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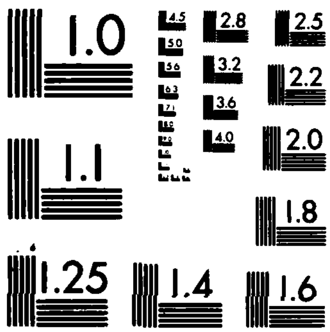

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A HIGH FREQUENCY RADIO TECHNIQUE FOR MEASURING PLASMA DRIFTS IN THE IONOSPHERE

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A technique is developed for investigating the dynamics of the auroral ionosphere through the interpretation of high-frequency radio-wave observations made at Goose Bay, Labrador. Spectral analysis of ionospheric reflections received at four spaced antennas identifies each echo by its Doppler shift, making it possible to locate several simultaneous reflection points with a limited antenna array. The radial velocity components of

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20. ABSTRACT (Continued)

the reflection areas are determined from the Doppler shifts, and a resultant plasma-drift velocity is calculated from these components. The analysis technique is first tested with computer-simulated drift data; then calculations using Goose Bay data from night observations of the F region verify the technique by showing a westerly drift in late evening, shifting to an easterly drift around midnight, in agreement with F-region drift measurements made by other observational techniques.

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1.0 INTRODUCTION

1.1 Thesis Topic

The subject of this thesis is the measurement of "drift" (i.e. plasma motion)[1] in the F region of the auroral (polar) ionosphere. In order to justify the role of drift measurements in the context of a scientific study of the ionosphere, a brief review of the history and present status of ionospheric investigation will be presented first. Since the method of observation used for gathering the data for this thesis is radio sounding (via radio waves reflected coherently off the ionosphere), emphasis will be placed on this method of investigation and what it reveals about the ionosphere.

[1]In this thesis, when we speak of "drift" without qualification, we are referring to plasma drift, as opposed to current. (Some authors, in the context of fading measurements (see section 1.7.1), speak of drift velocity in reference to the "drifting" of the interference pattern on the ground.) When charged particles are accelerated by an applied force but are also continuously subject to collisions with neutral particles, the resulting motion of the charged particles is random, but there is also a net component of motion at some angle to the applied force (see section 1.6.2.1); the average speed of this net motion is called the drift speed. In this sense, electrons and positive ions each drift in some particular direction. If the electron and ion drifts are in the same direction, the plasma moves bodily: this is what we call plasma drift or simply drift. If the electron and ion drifts are in opposite directions, we speak of plasma currents. We also use the expression "Doppler drift" in reference to measurements of plasma drift using ULCAR's method of measuring the Doppler-frequency of the reflected echoes.

1.2 Summary

The discovery and scientific study of the ionosphere is relatively recent in the history of physics. Guglielmo Marconi's successful trans-Atlantic radio transmission in 1901 initiated speculation as to how radio waves which travel in nearly straight lines could be received at great distances beyond the horizon. The presence of ionized gases in the upper atmosphere had been postulated earlier as an explanation of the aurora ("northern lights") and of variations in the earth's magnetic field; belief in the existence of an ionized layer now gained further impetus as the possible explanation of electromagnetic-wave reflection. Scientific curiosity and the growing commercial use of radio for long-distance communications stimulated the development of methods for investigating various theories about the nature and structure of the ionized layer. A milestone was achieved in 1924 when vertical reflection of high-frequency radio waves was first used to study directly the electron content of the upper atmosphere; after that, knowledge of the ionosphere developed rapidly, although radio sounding was limited to heights of about 300 km. The study of the chemical structure of the entire atmosphere by various techniques added further to man's knowledge of the ionosphere, in particular after rockets and satellites came into use in the 1950's. The successful development in 1958 of Thomson scatter sounding with VHF and UHF radio waves (which measures the weak incoherent signals scattered back by the free-electron clusters in the ionosphere)[2] and the use of topside sounding by satellite (using HF radio waves transmitted from a satellite)[3] since 1962, have made it possible to explore

[2] Hargreaves (1979), section 3.7.4.

[3] Hargreaves (1979), section 3.7.1.

the ionosphere above 300 km; satellites have also added important knowledge about the geomagnetic field (which extends much beyond the ionosphere) and solar radiation, and the influence of both on the ionosphere.

The various observation techniques employed in studying the ionosphere have measured continual changes in ionospheric structure. Knowledge of the dynamics behind the structure variations is a prerequisite for a more thorough understanding of ionospheric phenomena. Attempts have been made to measure ionospheric movements by analyzing the fading of radio signals (fading is due to the interference of multi-path signals reflecting off moving ionospheric irregularities), but interpretation of the resulting interference patterns has proven difficult. Another method, which determines plasma drift by measuring the Doppler shift of each reflected signal, has been under development since the late 1960's by the University of Lowell Center for Atmospheric Research (ULCAR) in cooperation with the Air Force Geophysics Laboratory (AFGL).

The purpose of "Doppler-drift" measurements is to determine general plasma motion from direct measurements of the moving irregularities. Some results have been obtained with this approach; but in order to take advantage of the full potential of drift measurements, it is necessary to develop the capacity to do 24-hour observations, leading to knowledge about the diurnal and seasonal variations in drift motion. With the recent advances in computer technology (in particular the development of microchips with greater memory capabilities), it has been possible for ULCAR to incorporate Doppler-drift measurements as a standard feature in its Digisonde.[4] The raw drift data is stored on magnetic tape, to be interpreted later by computer analysis. This thesis is a report on the development of computer algorithms by the author for

[4]The Digisonde is a digital ionospheric sounder developed by ULCAR. See section 1.5.2.

calculating the speed and direction of drift motion. In view of the future goal of making 24-hour drift observations, it was necessary to develop a method of computing drift-velocity vectors in a completely automatic fashion, eliminating the need for separate visual inspection of the raw drift data, or hand-plotting of the calculated vectors. This was achieved by the reduction of systematic errors and by appropriate averaging and smoothing techniques; and by incorporating into the drift-calculation program an output format which plots the drift direction and the drift speed as a function of time on two side-by-side graphs. Doppler-drift measurements from a period of several hours at night were used to calculate the F-layer drift in fifteen-minute intervals over Goose Bay, Labrador; the results compared favorably with drift measurements made by other observational techniques.

1.3 Discovery and Early Investigations of the Ionosphere[5]

1.3.1 Early History

Until the early 1900's observations of the atmosphere were limited to measurements (chemical composition, pressure, temperature, geomagnetic field) of the region below 30 km (the highest that balloons could ascend to) and to a few observations of natural phenomena occurring at higher heights. Theoretical investigations of the air friction required for meteors to burn up gave an indication of the density of gases in the region of 100 km; spectral analysis of auroral light revealed some information about the chemical composition in the same region. From the temperature dependence of the velocity of sound, the temperatures at heights above 30 km were deduced from experiments with sky-wave sound transmissions. From the gas laws and principles of photochemistry, and what

[5]Ratcliffe (1970), Chapters 1 and 2.

was known of the lower atmosphere, some estimates about the physical structure and chemical composition of the upper atmosphere were extrapolated, but the conclusions were limited and not very accurate.

Early investigations also led to the suspicion of the presence of charged particles in the higher regions, to account for the aurora and for the minute diurnal variations in the earth's magnetic field. It was thought that the aurora was caused by electrons from the sun, which were deflected by the geomagnetic field to the polar regions, where they produced an effect similar to the electric discharge in a neon lamp. Gauss proposed, in 1839, that the fluctuations in the geomagnetic field could be explained by electric currents in the atmosphere, and Stewart developed this idea further in 1882. Stewart postulated a dynamo effect due to tidal motions of the atmosphere across the earth's magnetic field, resulting in currents at those heights where the gas pressure is low enough for the gas to conduct. When it was later realized from laboratory experiments that a gas at low pressure conducts only if first ionized by some external agent, it was postulated that the ionization was probably brought about during the day by particles or radiation from the sun, and persisted through the night, although with diminished strength.

1.3.2 Discovery of the Heaviside Layer

In 1901, Marconi transmitted a radio signal beyond the curvature of the earth. MacDonald's revision of the diffraction theory to account for this phenomenon was disproved by Lord Rayleigh. Heaviside and Kennelly independently invoked the notion of a layer of ionized gases acting as a reflector of electromagnetic waves. The reflecting layer was named the Heaviside layer by Eccles in 1912, in a paper on the effect of an ionized layer on radio transmission.

After the development of commercial radio communications across the Atlantic following Marconi's experiment, repeated measurements of the strength of long-distance radio transmissions manifested diurnal and seasonal variations in the attenuation of the signals. This was seen as evidence that the sun probably ionizes the upper atmosphere: the changes in signal strength could be explained by the ionization level varying with the inclination of the sun's rays. A statistical correspondence was also observed between solar sunspot activity on the one hand, and on the other hand, magnetic "storms" (stronger-than-usual variations in the geomagnetic field), intensified auroral activity, and unusually strong radio reception during magnetic storms, possibly resulting from intensified ionization at the reflection level. Furthermore, long-distance communications weakened considerably at sunrise and disappeared completely after a few hours, returning only at night. It was suggested that this might be due to increased ionization in the presence of solar radiation, ionization which penetrated to levels below the reflecting layer, where the high frequency of collisions between charged and neutral particles (due to greater particle density) would account for the increased absorption.[6] Scientists became increasingly convinced that the sun plays a key role in the production of an ionized layer which determines radio-propagation conditions, and that a detailed study of radio waves reflected off this layer could reveal much about the charged-particle distribution and about the sun itself.

The phenomenon of fading (fluctuations in signal strength over short periods -- a few minutes or less) seemed to indicate the possibility of reflecting radio waves ver-

[6]Later, long-distance communications during the day became possible with the use of higher radio frequencies, since there is less absorption at higher frequencies.

tically off the Heaviside layer. If trans-Atlantic communication was due to the reflection of radio waves off an ionized layer (not everyone accepted this explanation in the early 1920's), these waves were reflected at very large oblique angles. However, fading was observed even at short distances that were within reach of the ground wave, so it seemed to result from the interference of a sky wave with the ground wave;[7] this sky wave would have to be reflected at a sharp angle of incidence, suggesting that even vertical reflections might be possible. In 1924, Breit and Tuve in America tested this hypothesis by transmitting pulses vertically, and succeeded in picking up the echoes reflected from directly overhead. By timing the return time of each pulse, they calculated the height of reflection to be about 100 km. In the same year, Appleton and Barnett achieved the same result in England by varying the frequency of a continuous wave and timing the return time of the echo at a given frequency. These two achievements not only proved the existence of the Heaviside layer, but also opened the door to a systematic and quantitative study of the "ionosphere," as it later came to be known.

1.3.2.1 Virtual vs. Real Height

The height of reflection calculated by Breit and Tuve from the return time of the echo is called the "virtual" height. The difference between virtual height and the real height is explained as follows. The height at which a radio wave of a given frequency is reflected depends on the density N_e (number density, or concentration) of free electrons. The wave is reflected at the level where its frequency f is equal

[7] Fading can also result from the interference between sky waves. See section 1.7.1.

to the so-called "plasma frequency," ($f_p \sim \sqrt{N_e}$).[8] The density of ionization in the upper atmosphere increases with height up to the level of the peak electron density. Higher frequencies penetrate deeper into the ionosphere before reaching the level where the density is sufficient for reflection; if the wave frequency is greater than the plasma frequency of the peak electron density, the wave is not reflected but radiates into space. As a wave travels through the ionization below the reflection level, its group velocity v_g decreases. The denser the ionization, the more the pulse is slowed down. (In fact, vertical reflection occurs because at the level of reflection, v_g becomes zero: the wave cannot propagate any further, so the energy carried by the radio wave is reflected back toward the earth.) Since the speed of light (in vacuum) is used for the group velocity of the waves in calculating the reflection height of the pulses, the calculated or virtual height h' is greater than the real height h.[9]

1.3.3 Discovery of the Appleton Layer

By using successively higher radio frequencies, Appleton attempted to measure the highest frequency reflected by the Heaviside layer, from which he could calculate the peak electron density of the layer. He expected that frequencies above the "penetration frequency" would radiate into space, but instead he discovered that they were reflected higher up from a denser layer of ionization. This layer was at first called the Appleton layer; later, the Heaviside and

[8] See the discussion of the magneto-ionic theory in section 1.5.1, and in particular, equation (14).

[9] The real-height profile can be calculated from the virtual heights using an appropriate inversion algorithm.

Appleton layers were renamed the E and F layers, respectively.[10] The region below the E layer where absorption occurs during the day was called the D region.[11] At about the same time, the term "ionosphere" came into use to refer to the entire ionized region of the atmosphere.

1.3.4 Scientific Investigation of the Ionosphere: The Ionosonde

Subsequently, Breit and Tuve originated a systematic technique for investigating the ionosphere by developing the "ionosonde" (ionospheric sounder), an apparatus which plots the virtual height of the reflected echoes vs. the frequency of the transmitted signal, as the frequency is increased. The resulting plot is called an "ionogram."[12] From the plasma frequencies, the electron densities can be calculated as a function of height up to the level of the F-layer peak, which is typically at about 300 km (real height) but can vary by ±100 km or so. The electron-density profile above that can be estimated from theoretical considerations. From

[10] The letters E and F were chosen because the electric field reflecting off the Heaviside layer had originally been labeled E, and subsequently the field reflecting off the Appleton layer had been labeled F. This choice also conveniently left room for labeling other layers in alphabetical order, if any were later discovered.

[11] D region rather than D layer, because the ionization in that region does not form a layer but merges into the bottom of the E layer. At times, however, the E layer also merges into the F layer, so that the distinction between "layer" and "region" is not strictly adhered to. We can also speak of the E and F regions in the sense of the height ranges at which the E and F layers are found.

[12] See Figure 2 and section 1.5.2.1.

records of the time variations in the peak densities and in the heights of the layers, knowledge about the diurnal and seasonal variations in ionospheric structure can be acquired.

Soon other scientists in different parts of the world began using ionosondes for continuous monitoring of the ionosphere. The ionosonde became the most widely used instrument for continuous investigation of the ionosphere. "Although complemented by many newer methods, the ionosonde has not been supplanted as the basic tool for ionospheric monitoring, and does not seem likely to be."[13] It is relatively inexpensive to set up, and can be kept in operation 24 hours a day with little maintenance. Other observational techniques measure parameters which the ionosonde cannot measure (and as such the importance of these other techniques for the study of the ionosphere should not be underestimated), but their use is limited because of much higher cost (some of them require the use of rockets or satellites), or because they depend on the sporadic occurrence of natural phenomena (e.g. the observation of meteor trails). Even Thomson scatter sounding, which can measure the electron density at all heights and a variety of other plasma parameters, is much more expensive than ionosonde sounding because it requires very powerful transmitters and large sensitive antennas.

1.4 Vertical Structure of the Upper Atmosphere

1.4.1 The Ionosphere

The ionosphere is a "shell" of naturally occurring plasma (ionized gas) which surrounds the earth in the upper regions of the atmosphere, where the atmospheric density is sufficiently low that a significant number of positive ions

[13] Hargreaves (1979), p. 39.

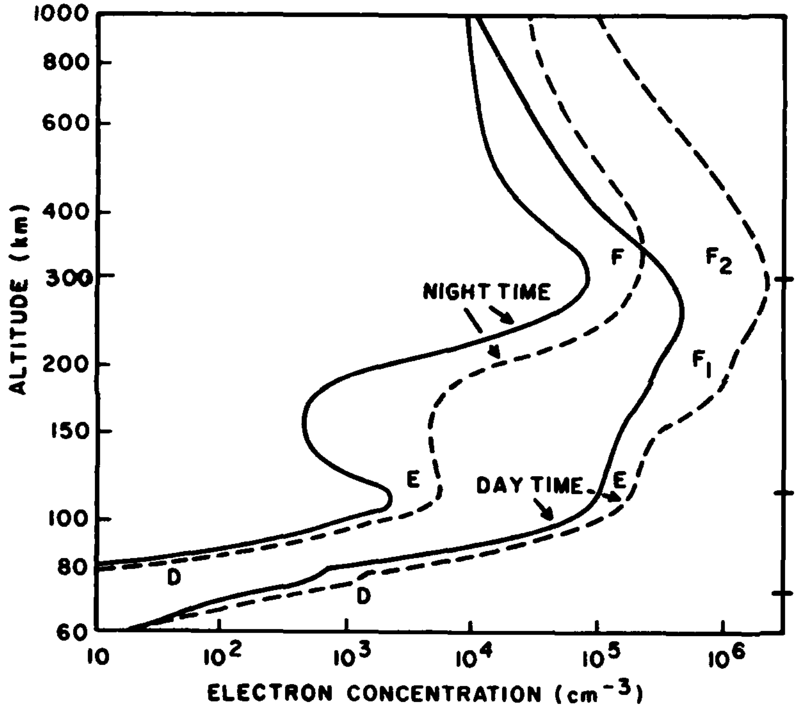
and free electrons (separated under the influence of the sun's energy) do not recombine but remain only loosely associated by electrostatic forces, giving the ionosphere the electrical nature characteristic of a plasma. Figure 1[14] shows typical electron-density profiles in the mid-latitude ionosphere. Actual profiles are characterized by many temporal and geographical variations.[15] The overlapping E and F layers approximate the shape of the so-called "Chapman layers" as predicted by Chapman in 1931.[16] The nose of a Chapman layer (the region near the height of maximum electron density) approaches the shape of a parabola; at increasing heights, the profile decays into an exponential tail. (These tails are not shown in Figure 1: the E-layer tail merges into the F layer; the F-layer tail extends into the magnetosphere, beyond the range of the figure.) Despite several simplifying assumptions made by Chapman in his deductions, the electron-density profiles behave approximately as predicted. Historically, observed profiles have been compared to Chapman layers, and major departures from Chapman theory were called "anomalies."

The lower border of the ionosphere is considered to be the height at which the density of free electrons is sufficient to affect radio propagation; this height is somewhere

[14] Taken from a wall chart prepared by A. L. Carrigan and R. A. Skrivanek, Aerospace Environment (Hanscom Air Force Base, Mass.: Air Force Geophysics Laboratory, 1974), Figure 13, by W. Swider. The ratios of free-electron to neutral-particle concentrations were added by the present author. We speak of electron-density profiles because, even though the ionosphere is essentially neutral on a macroscopic scale (containing approximately equal numbers of free electrons and positive ions), it is the electrons that affect HF radio propagation.

[15] See Hargreaves (1979), Chapter 5.

[16] Davies (1965), section 1.4 and references therein.



Typical midlatitude daytime and nighttime electron profiles for sunspot maximum --- and minimum ——.

$$\frac{N_{el}}{N_{neutral}} \left[cm^{-3}\right]$$

$$\frac{10^6}{10^9} = 10^{-3} = .1\% \quad \text{VERY HIGHLY IONIZED}$$

$$\frac{10^5}{10^{13}} = 10^{-8} \quad \text{VERY SIGNIFICANT}$$

$$\frac{10^3}{10^{16}} = 10^{-13} \quad \text{DIFFICULT TO MEASURE}$$

DAY/NIGHTTIME ELECTRON CONCENTRATIONS

Figure 1

between 50 and 80 km (depending when and where it is measured). In the D and E regions, recombination of electrons and ions occurs more quickly because of the greater density of gases; the ionization in those regions is more closely dependent on the inclination of the sun's rays, and practically disappears at night. In the E region, a narrow layer of dense ionization called the sporadic E layer (Es) develops occasionally. The F layer can differentiate into two sub-layers called the F1 and F2 layers (see the two daytime profiles in Figure 1). This differentiation, which is sometimes pronounced, sometimes barely noticeable, occurs during the days of the summer season. In the F region also, a phenomenon called Spread-F can occur in the evening and at night. Spread-F manifests itself on ionograms as a widening of the trace, indicating reflections from many height ranges for the same wave frequency; this effect is probably due to patches of ionization covering a large height range.

1.4.2 The Magnetosphere[17]

Beyond the F layer, the electron density decreases exponentially with height. (The ratio of free electrons to neutral particles actually increases, but the total atmospheric density decreases exponentially.) In a broad sense, the ionosphere (the ionized region of the atmosphere) extends to tens of earth radii;[18] however, the region above 800 or 1000 km is sometimes referred to as the magnetosphere, because there the geomagnetic field dominates plasma phenomena in determining the motion of charged particles: i.e., the energy density of the geomagnetic field exceeds the plasma energy density.

[17]Hargreaves (1979), section 7.1.

[18]The earth's radius is approximately 6370 km.

1.4.3 The Solar Wind[19]

Prior to the advent of artificial satellites, what was known of the atmospheric region beyond the peak of the F layer was limited to what could be inferred about the upper ionosphere and the magnetosphere from ground-based measurements and theoretical considerations. It was thought that beyond the magnetosphere and up to the sun's corona (outer atmosphere), there existed a vast region of "empty space," and that the influence of the sun on the earth's atmosphere was limited to photon radiation and occasional streams of plasma. In the early 1950's, it was suspected from observations of meteor trails and later from spectroscopic measurements of the sun's corona that the sun emits a steady stream of particles. Satellite measurements since then have shown that the sun's corona is not confined to a limited region near the sun but flows continuously outward to distances far beyond the earth; the earth is immersed in a sea of coronal plasma, which has been named the solar wind. The solar wind is pure plasma, which has the peculiar property of "freezing-in" the sun's magnetic field[20] and thus extending its influence to the regions of the earth. Since it is much easier for the charged particles from the solar wind to propagate along the earth's magnetic field lines than across them, and because of the nearly-vertical incidence of the geomagnetic field lines at the poles, the auroral ionosphere and magnetosphere are especially prone to the influence of the complex interactions between the solar wind (and the solar magnetic field) and the earth's upper atmosphere. The exact mechanism of how the solar wind particles enter into the magnetotail of the magnetosphere and from there into the polar ionosphere is the

[19] Ratcliffe (1970), Chapter 7.

[20] Hargreaves (1979), section 2.3.6.

subject of current research and goes beyond the scope of this thesis.

1.4.4 The Dynamics of the Ionosphere

Variations in ionospheric structure are a function of the rate of change of plasma density, which in turn depends on the ionization rate, the recombination rate, and the loss (or gain) of plasma through movement.[21] When Chapman calculated the theoretical shape of the ionospheric layers, he considered only the ionization and recombination rates, and he made simplifying assumptions about the nature of the ionizing radiation, the gas distribution in the atmosphere, and the photochemical processes involved in the ionization of the various gases.[22] The anomalous behavior of the ionosphere can be explained in part by correcting these simplifications; but a complete picture of ionospheric variations requires knowledge of plasma motion, from which the scientist attempts to understand the forces governing the large-scale behavior of the ionosphere, as well as the origins of these forces. In particular, it is hoped that future drift measurements at Goose Bay, Labrador[23] will provide valuable information about the effects of the solar wind on the earth's atmosphere.

1.5 The Ionosonde

As mentioned above, a large part of our knowledge of the ionosphere before 1960 was acquired by remote sensing with

[21] Hargreaves (1979), section 4.2.

[22] Davies (1965), sections 1.4.3 and 1.4.4.

[23] Goose Bay is located about 25° south of the north geomagnetic pole.

ionosondes; and even in this age of artificial satellites, the ionosonde continues to play an indispensable role for continuous ionospheric monitoring.

1.5.1 The Magneto-Ionic Theory[24]

The principles of ionosonde operation are based on the reflection properties of the plasma. Since the first suggestion of the existence of an ionized atmospheric layer by Heaviside and Kennelly, attempts were made to understand how radio waves are propagated by charged particles in the presence of the earth's magnetic field. Appleton and Lassen both developed the form of the magneto-ionic theory in common use today.

1.5.1.1 Radio Propagation in the Ionosphere

According to the magneto-ionic theory, electrons in the ionosphere oscillate under the influence of the electric field of the transmitted wave and then re-radiate wavelets of energy. The influence of the geomagnetic field causes the oscillating particles to gyrate around the magnetic field lines under the influence of the Lorentz force (see equation (24)), so that the electrons oscillate in a curve rather than in a straight line. As a result the re-radiated wavelets acquire a rotating polarization. The magneto-ionic theory shows that only waves with two particular polarizations, called "characteristic" polarizations, can propagate in the ionosphere: for the major part of the globe these polarizations are right-handed and left-handed circular. (Very close to the magnetic equator, where the field is horizontal, the characteristic modes for vertical propagation are linearly polarized

[24]Davies (1965), section 2.3.

waves, parallel and perpendicular to the magnetic field.) A linearly polarized wave impinging on the ionosphere is split into these two characteristic waves, which propagate with different velocities. The two waves are called the ordinary (O) and extraordinary (X) waves.

1.5.1.2 The Appleton Formula

The speed of wave propagation in the ionosphere is expressed by the complex index of refraction

$$n = \frac{c}{v} = \mu - i\chi \tag{1}$$

where c is the speed of light in free space, v is the phase velocity of the transmitted wave, and μ and χ are respectively the real and imaginary parts of n. The effect of χ can be seen by expressing the wave equation for vertical propagation (along the z axis) in the following form (since $v = \omega/k$; here $e \equiv \exp$):

$$\begin{aligned} E &= E_o\, e^{i(\omega t - kz)} \\ &= E_o\, e^{i[\omega t - (\mu - i\chi)\frac{\omega}{c} z]} \\ &= E_o\, e^{-\chi \frac{\omega}{c} z}\, e^{i(\omega t - \mu \frac{\omega}{c} z)} \end{aligned} \tag{2}$$

The term $e^{-\chi \frac{\omega}{c} z}$ represents a decay in the wave amplitude. In the ionosphere, the index of refraction takes the form of the so-called Appleton formula

$$n^2 = 1 - \frac{X}{1 - iZ - \frac{Y_T^2}{2(1-X-iZ)} \pm \left(\frac{Y_T^4}{4(1-X-iZ)^2} + Y_L^2\right)^{1/2}} \tag{3}$$

where the upper sign is for the O wave, and the lower sign, for the X wave; and

$$X = \frac{Ne^2}{\varepsilon_o \, m \, \omega^2} = \frac{\omega_p^{\;2}}{\omega^2} = \frac{f_p^{\;2}}{f^2} \tag{4}$$

$$Y_{L,T} = \frac{|e| B_{L,T}}{m \, \omega} = \frac{\omega_{L,T}}{\omega} \tag{5}$$

$$Z = \nu/\omega \tag{6}$$

where: N is the electron density,

e is the electron charge,[25]

ε_o is the permittivity of free space,

m is the electron mass,

$\omega = 2\pi f$ where f is the radio frequency and ω is the corresponding angular frequency,

$\omega_p = 2\pi f_p$ where f_p is the plasma frequency (to be explained later),

$B_{L,T}$ are the components of the geomagnetic field $\vec{B}$ longitudinal to (along), and transverse to, the direction of wave propagation, i.e. $B_L = B \cos\theta$, $B_T = B \sin\theta$, θ being the angle between the geomagnetic field and the direction of propagation.

$\omega_{L,T}$ are the longitudinal and transverse components of the angular gyrofrequency $\omega_B = |e| \, B/m$,

ν is the frequency of electron collisions with other particles.

[25]There is a confusion in the literature in the usage of the symbol e for denoting charge. Throughout this thesis, $e = \pm\ 1.6 \times 10^{-19}$ coul, i.e. $e = |e|$ for positive ions (neutrals stripped of one electron) and $e = -\ |e|$ for electrons.

The absorption due to collisions results in a decrease of the wave amplitude, as expressed in equation (2). Collisions are significant in the D region; but since D-region absorption is inversely proportional to the square of the radio frequency, waves of frequency above 1 or 2 MHz can penetrate into the E and F regions, where collisions can be neglected, so we will consider only the real part of n:

$$\mu^2 = 1 - \frac{2X\ (1-X)}{2(1-X) - Y_T{}^2 \pm \sqrt{Y_T{}^4 + 4(1-X)^2\ Y_L{}^2}} \tag{7}$$

Just below the ionosphere, N = 0 so X = 0 and $\mu^2 = 1$. As N increases with height, μ^2 decreases. When μ^2 becomes negative, the index of refraction becomes a purely imaginary number; the wave does not propagate any further but becomes an evanescent wave, whose amplitude decays rapidly. For wave propagation in the ionosphere then, μ takes values between 1 and 0. At $\mu = 0$, the wave cannot propagate further but is reflected back towards the earth. If the direction of propagation of the incident wave is perpendicular to an iso-density surface (a surface of equal plasma density), the wave returns to the transmitter/receiver site and its virtual height or range is defined by the travel time of the signal.

1.5.1.3 Conditions of Reflection

Setting $\mu^2 = 0$ in equation (7) and solving for X, we get, with the + sign,

$$X = 1 \tag{8}$$

and with the - sign,

$$X = 1 - Y \tag{9}$$

$$X = 1 + Y \tag{10}$$

$$Y^2 = Y_T{}^2 + Y_L{}^2 \tag{11}$$

Note that, in the absence of the magnetic field ($Y_T = Y_L = 0$), equation (7) becomes, for all heights,

$$\mu^2 = 1 - X \tag{12}$$

which also yields $X = 1$ for $\mu = 0$ at the reflection height. Thus, one of the magneto-ionic waves is reflected as in the absence of the magnetic field; this is the ordinary wave. From (4) and (8), at the level of reflection,

$$\frac{Ne^2}{\varepsilon_o m} = \omega^2 \text{ or } \frac{Ne^2}{4\pi^2 \varepsilon_o m} = f^2 \tag{13}$$

$$\sqrt{\frac{Ne^2}{4\pi^2 \varepsilon_o m}} = \sqrt{80.5 N} \approx 9\sqrt{N} = f_p \tag{14}$$

i.e. reflection of the ordinary wave occurs at the level where the electron concentration is such that $f = 9\sqrt{N}$, which is why the quantity $9\sqrt{N}$ is called the plasma frequency f_p. Therefore we rewrite (8) as

$$f_p^2 = f^2 \text{ (reflection condition for the 0 wave)} \tag{15}$$

The reflection condition for the X wave is expressed by equation (9),[26] which can be written, using the definitions of X (equation (4)) and Y (equations (5) and (11)), and the gyrofrequency $f_B = \omega_B/2\pi$,

$$f_p^2 = f^2 \left(1 - \frac{f_B}{f}\right) \text{ (reflection condition for the X wave)} \tag{16}$$

To compare the densities at which the 0 and X waves are reflected, consider (using the definition (14) of f_p): from (15), the 0 wave is reflected at density

[26]Equation (10) expresses the reflection condition for another type of wave, the so-called Z wave, which is rarely seen, so we will ignore it.

$$N = \frac{f^2}{80.5} \tag{17}$$

and from (16), and noting that $f_B < f$, the X wave is reflected at density

$$N = \frac{f^2 \left(1 - \frac{f_B}{f}\right)}{80.5} < \frac{f^2}{80.5} \tag{18}$$

For a given radio frequency, the density required for reflection of the X wave is less than for reflection of the O wave; or, for a given N, the reflection frequency is higher for the X wave than for the O wave. For both ionograms and Doppler-drift measurements, it is the O wave that is normally used for analysis.

1.5.1.4 Phase Velocity vs. Group Velocity

From equation (1), as μ decreases, the phase velocity v increases and exceeds the speed of light. This does not contradict the special theory of relativity, since no energy is propagated by phase motion; it only means that in the ionosphere the wavelength is greater than in free space. Energy transport occurs at the group velocity of the pulses; in a dispersive medium (where each frequency component of the pulse travels at a different speed: $n = n(\omega)$, which is the case in the ionosphere; see equation (3)), the group velocity is different from the phase velocity. We can define a group index of refraction

$$\mu' = \frac{c}{v_g} \tag{19}$$

where v_g is the component of the group velocity in the direction of phase propagation; in the absence of a magnetic field or at the level of reflection of the O wave,

$$\mu' = \frac{c}{v_g} = \frac{1}{\mu} \tag{20}$$

or

$$\mu = \frac{v_g}{c} \tag{21}$$

so that as μ approaches zero the group velocity approaches zero. With the magnetic field and below the level of reflection of the O wave, the expression for μ' is much more complicated,[27] but v_g is less than c at all heights.

1.5.2 The Digisonde 128PS

ULCAR has developed its own model of the ionosonde, the Digisonde, which is an advanced digital ionosonde[28] capable of measuring and recording all the important wave parameters of the reflected echo: amplitude, phase, transmitted frequency, Doppler offset due to the motion of reflection areas, incidence angle and wave polarization (O, X). The Digisonde model presently in operation in Goose Bay, Labrador (where the drift measurements discussed later were made) is the DGS 128PS,[29] which implements many ideas suggested by experience with previous models. The DGS 128PS operates in two complementary modes: the ionogram and drift modes. In either mode, digital preprocessing and multiplexed output formatting reduces the data to manageable size, so that information about all the wave parameters can be stored on digital magnetic tapes, from which particular parameters can later be extracted for special research studies.

[27] See Davies (1965), equation 2.119.

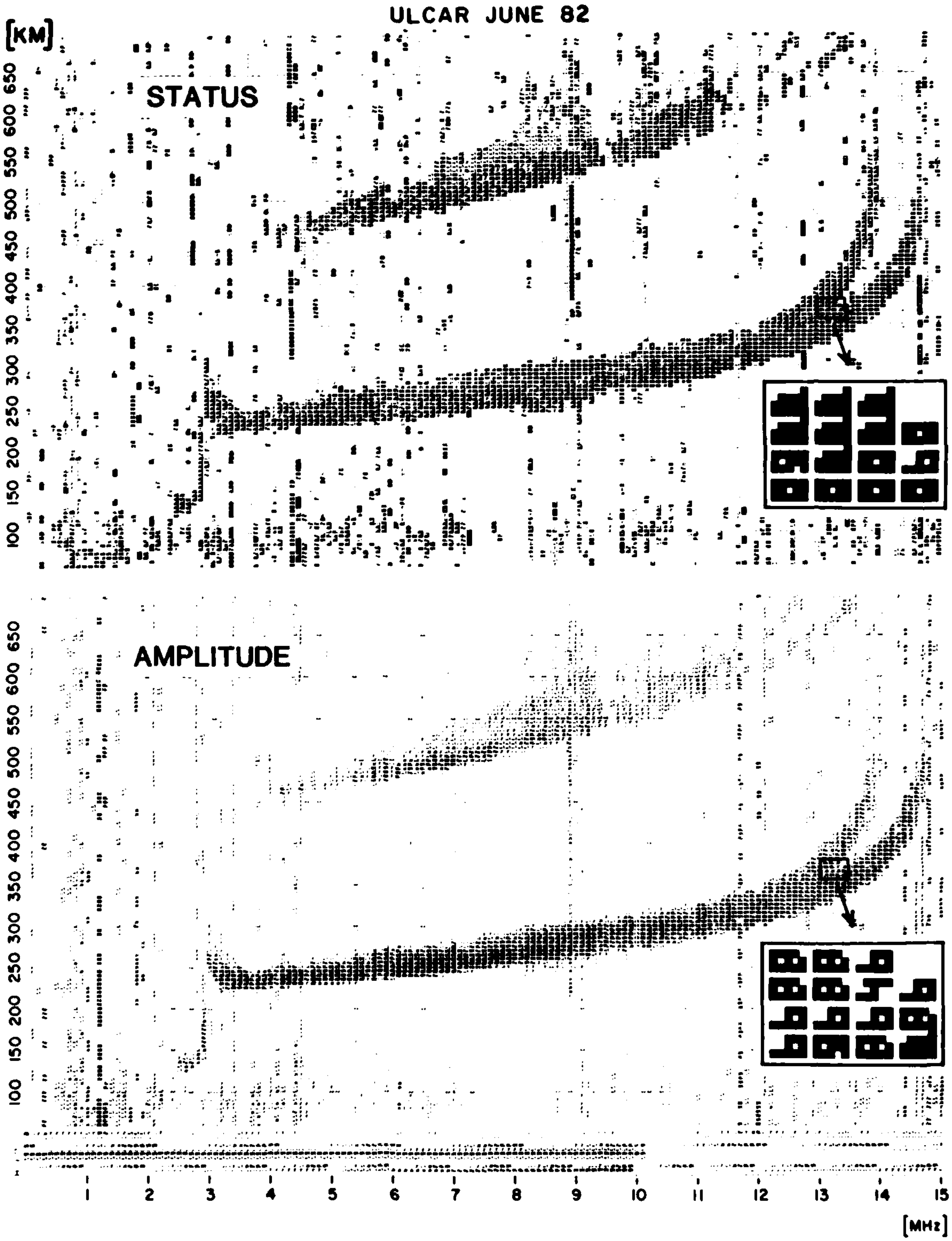
[28] Bibl and Reinisch (1978b).

[29] Bibl and Reinisch (1978a).

1.5.2.1 The Ionogram Mode

Figure 2 is a typical ionogram generated at Goose Bay in December of 1981. The height-vs-frequency trace is enhanced by the use of a special printing format[30] called the "Opti-Font" (optical font) in which the hexadecimal numbers of larger value are more prominent, as illustrated in the two inserts where some of the numbers are enlarged: the enlarged numbers 4, 6, 8 and 9 are easily recognizable; the thick 0 represents 10; and the other enlarged symbol represents 11. Similarly, recognizable symbols represent all numbers from 0 to 15, permitting the printing of all numbers representable by a 4 bit binary code by a single character presentation. The horizontal scale is the sounding frequency $f = f_p$ in 100 kHz steps for the selected band of frequencies; the vertical scale is the virtual height in increments of 5 km, starting at 60 km. The lower ionogram contains the amplitudes corresponding to each frequency-range bin (FRB); in order to improve the signal-to-noise ratio, the amplitudes are calculated by integrating, for each FRB, the echoes of several pulses (typically 64 pulses; the number is varied according to the encountered level of radio interference). The upper amplitude trace is due to the second echo: energy returning to earth from the ionosphere is reflected by the earth back to the ionosphere, from which it returns to the transmitter/receiver site; since the travel time of a double echo is twice that of a single echo, the lower trace is partially reproduced on the ionogram at twice the virtual height. For each FRB in the amplitude ionogram there is a corresponding status number in the upper ionogram, which provides information about the

[30] Patenaude, Bibl and Reinisch (1973).



DIGISONDE IONOGRAM

GOOSE BAY 3 DEC 1981 11:00 AST

Figure 2

incidence angle,[31] the Doppler shift and the polarization (O, X) of the strongest echo for each FRB. In this ionogram the major part of the trace is from the F layer; only a small section of the E layer shows up, the E-layer cusp, from 2.5 to 3 MHz (other numbers are due to noise; energy transmitted at the lower frequencies was absorbed in the D region). A cusp is formed near the critical frequency (penetration frequency) of each layer because near the peak of the layer the pulse stays longer in a region where μ is close to, though not quite, zero,[32] i.e. the pulse travels very slowly for a relatively long time, so the time delay of the echo is increased much more. Of the two F-layer cusps, the one at the higher frequencies is from the extraordinary wave. This particular ionogram is a vertical ionogram; oblique ionograms (for which the transmitting and receiving antenna arrays are phased for maximum radiation at an oblique angle of incidence) are also made at Goose Bay to collect more specific information about the horizontal electron-density distribution.

1.5.2.2 The Drift Mode

Ionograms provide amplitude information for all FRB's within the selected limits of frequency and range, but only limited information about the incidence angles and Doppler frequencies of each FRB. In the drift mode, on the other hand, only 3 or 6 FRB's are chosen (FRB's with echo signals, as determined from an ionogram made immediately prior to the drift measurement); integration time is increased (providing

[31] Vertical sounding does not yield only vertical but also off-vertical echoes because of irregularities in the ionosphere. See section 1.6.1.

[32] See the electron-density profiles in Figure 1: near the peaks of each layer the slope increases sharply, indicating that N changes much more slowly with height.

better Doppler resolution) and the complete discrete complex Fourier transform (amplitude and phase) of each signal from the four receiving antennas is recorded on magnetic tape. Each antenna signal is, in general, a composite of echoes received from different reflection points that are likely to move with a different radial velocity component. We will elaborate on this in later sections below.

1.6 Horizontal Structure of the Ionosphere

1.6.1 Horizontal Density Gradients[33]

If the ionosphere were spherically symmetric about the earth, isodensity surfaces above a given site would be essentially horizontal; only radio waves that are propagated vertically would be reflected back to the site, and the study of horizontal movement in the ionosphere by the analysis of fading records or the measurement of Doppler frequencies would be impossible. There would be no fading of radio waves, since all echoes would come from the same area (directly overhead) and would therefore all be in phase; and since the Doppler-frequency shift imposed on reflected waves is proportional to the component of velocity along the direction of wave propagation, the Doppler-drift method would measure only vertical motion.

In fact, horizontal density gradients do exist in the ionosphere, so that off-vertical radio waves can be reflected back to the transmitter/receiver site by isodensity surfaces that are perpendicular to their direction of propagation. The density gradients are due to small-scale irregularities (in the order of 100's of meters) and large-scale travelling-wave disturbances (10's or 100's of kilometers). The fading of radio waves and the preliminary results obtained

[33]Hargreaves (1979), Chapter 6.

from ULCAR's Doppler-drift measurements (see section 1.7.2.1) give evidence of the existence of the small and the large irregularities in both the E and F regions. F-region irregularities have been studied with ionosondes and by observing the fluctuations ("scintillations") imposed on signals from radio stars and satellites; they have also been measured directly by plasma probes placed on satellites. The large-scale density gradients fall in the category of acoustic-gravity waves, in which the restoring force is a combination of compressional and gravitational forces acting on the neutral air particles; the resulting motion is imparted to the charged particles through collisions. These waves or "travelling ionospheric disturbances" (TID's) have been observed in the distortion of meteor trails; they have been measured by ionosondes (for example, by continuous observations of virtual height at a fixed frequency),[34a] by incoherent scatter, and by the Doppler-drift measurements made by ULCAR.

1.6.2 Movement of Irregularities[34]

The small-scale irregularities move under the influence of neutral winds and electric fields. The movement of irregularities implies that the plasma is moving as a body, i.e. both electrons and positive ions[35] are moving in the

[34] Risbeth and Garriott (1969), section 4.2; Ratcliffe (1972), sections 7.1 and 7.2; Hargreaves (1979), section 4.4.

[34a] Techniques for the Study of TID's with Multi-Station Rapid-Run Ionosondes by M. G. Morgan, C. H. J. Calderon and K. A. Ballard, Radio Sci. 13, 4, 729-741, July 1978.

[35] The concentration of negative ions (neutral particles to which free electrons have attached themselves) is generally negligible in the E and F regions. See Rishbeth and Garriott (1969), p. 127.

same direction; motion in opposite directions constitutes a current, but does not result in any net movement of the plasma. The mechanical force $\vec{F}^U$ due to the wind, which transfers momentum to the charged particles through collisions, is

$$\vec{F}^U = m \nu \vec{U} \tag{22}$$

where m is the particle mass, ν is the collision frequency at which charged particles collide with neutrals and $\vec{U}$ is the wind velocity. The electrical force $\vec{F}^E$ is

$$\vec{F}^E = e \vec{E} \tag{23}$$

where e is the particle charge[36] and $\vec{E}$ is the electric field vector.

1.6.2.1 Charged-Particle Motion in the Geomagnetic Field

To determine under what conditions these forces result in plasma drift, we must include the effects of collisions and of the earth's magnetic field. We consider first the Lorentz force $\vec{F}^B$ exerted by the magnetic field $\vec{B}$, where $\vec{V}$

$$\vec{F}^B = e \vec{V} \times \vec{B} \tag{24}$$

is the velocity of the charged particle. For our considerations, we choose the z axis along the field, so that $|\vec{B}| = B_z$ and there is no Lorentz force in the z direction. A charged particle moving in the x-y plane and accelerated only by the Lorentz force rotates or gyrates around an axis parallel to the z axis with (angular) gyrofrequency ω,

$$\omega = \frac{|e| B_z}{m} \tag{25}$$

[36] See footnote 25 in section 1.5.1.2.

(particles of opposite charge rotating in opposite directions). To illustrate the resulting motion when there is also an applied force, consider a particle at rest at the origin of the coordinate system, to which is applied a force perpendicular to the magnetic field, say along the x axis. We consider both the electrical force $\vec{F}^E$ ($|\vec{E}| = E_x$) and the mechanical force $\vec{F}^U$ ($|\vec{U}| = U_x$) and neglect collisions for the moment.[37] The mechanical force F_x^U is in the direction of +x for both positive and negative particles, but the Lorentz force is $|e| \vec{V} \times \vec{B}$ for ions and $- |e| \vec{V} \times \vec{B}$ for electrons. Both particles will start off in the +x direction;[38] the positive ion will curve clockwise into an arc, coming to rest at some point down the -y axis; the electron will curve counterclockwise and come to rest on the +y axis; F_x impedes any further motion of either particle in the -x direction. The motion of each particle then starts over again with an identical travel path. With the electrical force, F_x^E is $|e| E_x$ for ions, $- |e| E_x$ for electrons. Assuming that $|F_x^E| = |F_x^U|$, positive particles follow the same path as with the mechanical force; negative particles start off in the -x direction and curve counterclockwise toward the -y axis. The result is that under the influence of either force, both positive and negative particles drift with speed $F_x/|e|B_z$ in a direction perpendicular to the applied force and to the magnetic field.

[37] Strictly speaking, for the mechanical force we must consider the limit as ν approaches zero, since $\vec{F}^U = m\nu\vec{U}$ is zero if $\nu = 0$; as will be shown later, the result is the same as for $\nu << \omega$.

[38] See Figure 3, adapted from Risbeth and Garriott (1969), Figure 31, p. 133. The subscripts i and e refer to ions and electrons respectively; the heights in parentheses are the approximate heights at which the stated conditions apply. For simplicity of illustration, it is assumed in the drawing that $|F_x^U| = |F_x^E|$, $\nu_i = \nu_e$ and $\omega_e/\omega_i = m_i/m_e = 3$ instead of 10^4.

The influence of collisions on the above motions is also illustrated in Figure 3; it is assumed that the charged particles collide with neutral particles with an average collision frequency ν,[39] and start from rest after each collision. A component of particle drift is introduced in the direction of the applied force, at the expense of the drift perpendicular to that force, as expressed in the following equations (where we include the effect of an applied force along the magnetic field):

$$V_x = k_1 F_x \tag{26}$$

$$V_y = \mp k_2 F_x \tag{27}$$

$$V_z = k_0 F_z \tag{28}$$

$$k_1 = \frac{1}{|e|B_z} \frac{\omega\nu}{\nu^2+\omega^2} \tag{29}$$

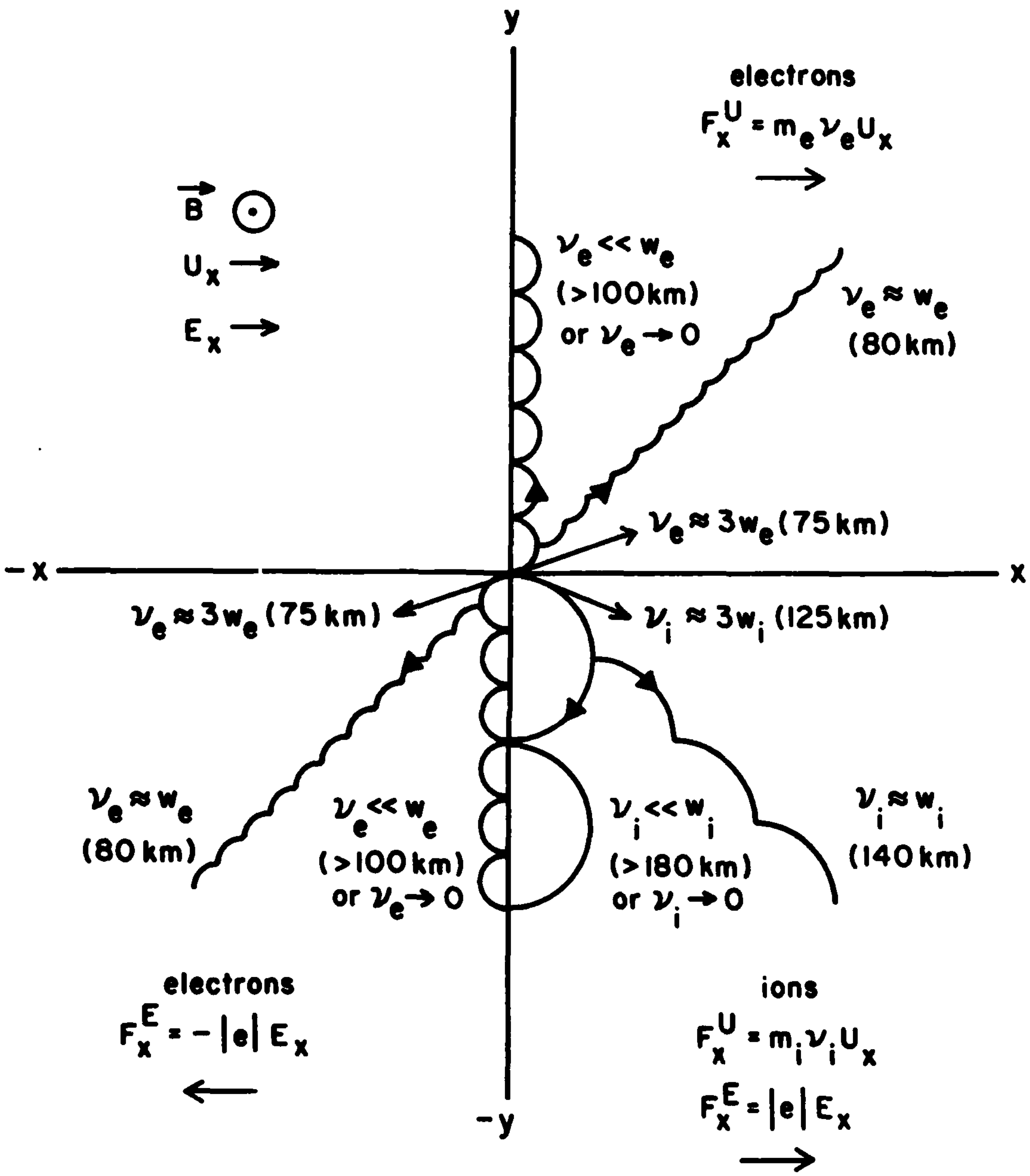
$$k_2 = \frac{1}{|e|B_z} \frac{\omega^2}{\nu^2+\omega^2} \tag{30}$$

$$k_0 = \frac{1}{m\nu} = \frac{1}{|e|B_z} \frac{\omega}{\nu} \tag{31}$$

where the quantities ω, ν and m are, of course, different for positive ions and electrons. The signs in equation (27) indicate opposite results for positive and negative particles: here and below, the upper sign refers to positive ions; the lower sign, to electrons. Along the magnetic field, the wind causes the plasma to drift at velocity U_z:

$$V_z = \frac{m\nu U_z}{m\nu} = U_z \tag{32}$$

[39] Or "effective" collision frequency; see Risbeth and Garriott (1969), section 4.12.



CHARGED – PARTICLE MOTIONS IN A $\vec{B}$ FIELD UNDER THE INFLUENCE OF ELECTRICAL AND MECHANICAL FORCES

Figure 3

whereas the electric field causes a current:

$$V_z = \frac{\pm|e|E_z}{m\nu} \tag{33}$$

For the component of the applied force perpendicular to the magnetic field, we consider two special cases. Below about 70-75 km, $\nu \gg \omega$ for both positive ions and electrons; to a first approximation, $k_1 = k_0 \gg k_2$, so that $V_y \simeq 0$ and

$$V_x = \frac{F_x}{m\nu} \tag{34}$$

The effect of the magnetic field is negligible: the wind carries the plasma along at its own velocity,

$$V_x^U = \frac{m\nu U_x}{m\nu} = U_x \tag{35}$$

and the electric field produces a current parallel to itself,

$$V_x^E = \frac{\pm|e|E_x}{m\nu} \tag{36}$$

i.e. the results are the same as along the magnetic field. At heights above 180-200 km, $\nu \ll \omega$ for both types of particles: $k_1 \ll k_2 \simeq 1/|e|B_z$ so $V_x \simeq 0$; here, the wind produces a current perpendicular to itself and to the magnetic field,

$$V_y^U = \mp \frac{1}{|e|B_z} m\nu U_x = \mp \frac{\nu}{\omega} U_x \tag{37}$$

and the electric field causes plasma drift perpendicular to $\vec{E}$ and to $\vec{B}$,

$$V_y^E = (\mp)(\pm) \frac{1}{|e|B_z} |e|E_x = \frac{-E_x}{B_z} \tag{38}$$

1.6.2.2 Summary

Generally, the applied force can be in any direction. In the D region of the ionosphere, drift is due to the wind, with drift velocity given by

$$\vec{V}^U = \vec{U} \tag{39}$$

In the F region, the field-aligned component of drift is due to the neutral wind, with velocity

$$\vec{V}^U = \frac{(\vec{U}\cdot\vec{B})\vec{B}}{B^2} \tag{40}$$

whereas the non-aligned drift is caused by an electric field, and its velocity is

$$\vec{V}^E = \frac{\vec{E} \times \vec{B}}{B^2} \tag{41}$$

with direction perpendicular to the plane containing $\vec{E}$ and $\vec{B}$. In the E region ($\nu_e < \omega_e$ but $\nu_i > \omega_i$) the situation is more complex; in general both winds and electric fields can produce drift velocities inclined to themselves, electron currents perpendicular to themselves, and ion currents parallel to themselves.

1.6.3 Plasma Drift in the F Region[40]

The mechanical forces on charged particles in the ionosphere are divided into two classes: prevailing winds, and tides (which oscillate with a period related to the 24-hour daily cycle), both of which are primarily horizontal. The mechanism of prevailing winds is that of pressure gradients coming from the variation of solar heating with latitude, balanced by the Coriolis effect (as in the lower atmosphere); tides (which also exist in the lower atmosphere) are due primarily to the gravitational effects of the moon (as in the oceans--gravitational tides) and to the temperature differ-

[40]Hargreaves (1979), section 6.4; Rishbeth and Garriott (1969), section 7.4; Ratcliffe (1972), section 5.1.

ences between the day and night sides of the earth (thermal tides), because of solar heating on the day side through absorption of solar radiation. The magnitude of the currents which can flow in any region of the ionosphere is dependent on the conductivity σ, which in turn is a function of the charged-particle density N and of the ratio ν/ω. The conductivity is highest in the E region, so that an appreciable current flows at heights of about 110 km, under the influence of neutral winds; the separation of charges due to the different ion and electron drift directions ($\nu_e < \omega_e$ but $\nu_i > \omega_i$) results in an electric field, which further modifies the charged-particle motions. Since conductivity is greatest along magnetic field lines, which are oblique over most of the earth, the lines act as conductors between the E and F regions; thus (at low and middle latitudes) the electric field pattern of the E region is reproduced in the F region, which results in F-region plasma drift. The E region is referred to as the dynamo region, and the F region is compared to a motor driven by the dynamo. In the polar regions, F-region plasma drift[41] is believed to arise from magnetospheric effects rather than from the neutral winds of lower altitudes. Several theories have been proposed to explain the interaction of the polar magnetosphere with the ionosphere.[42] It is believed that interaction of the interplanetary field and the solar wind with the magnetosphere is the source of a large scale electric field across the magnetosphere, which maps down to F region heights across the polar cap, driving a large plasma convection system.[42a] Satellite and UHF incoherent

[41]See Weber and Buchau (1981).

[42]Stern (1977) gives an extensive review of the various theories.

[42a]Evans et al, 1980 and references therein.

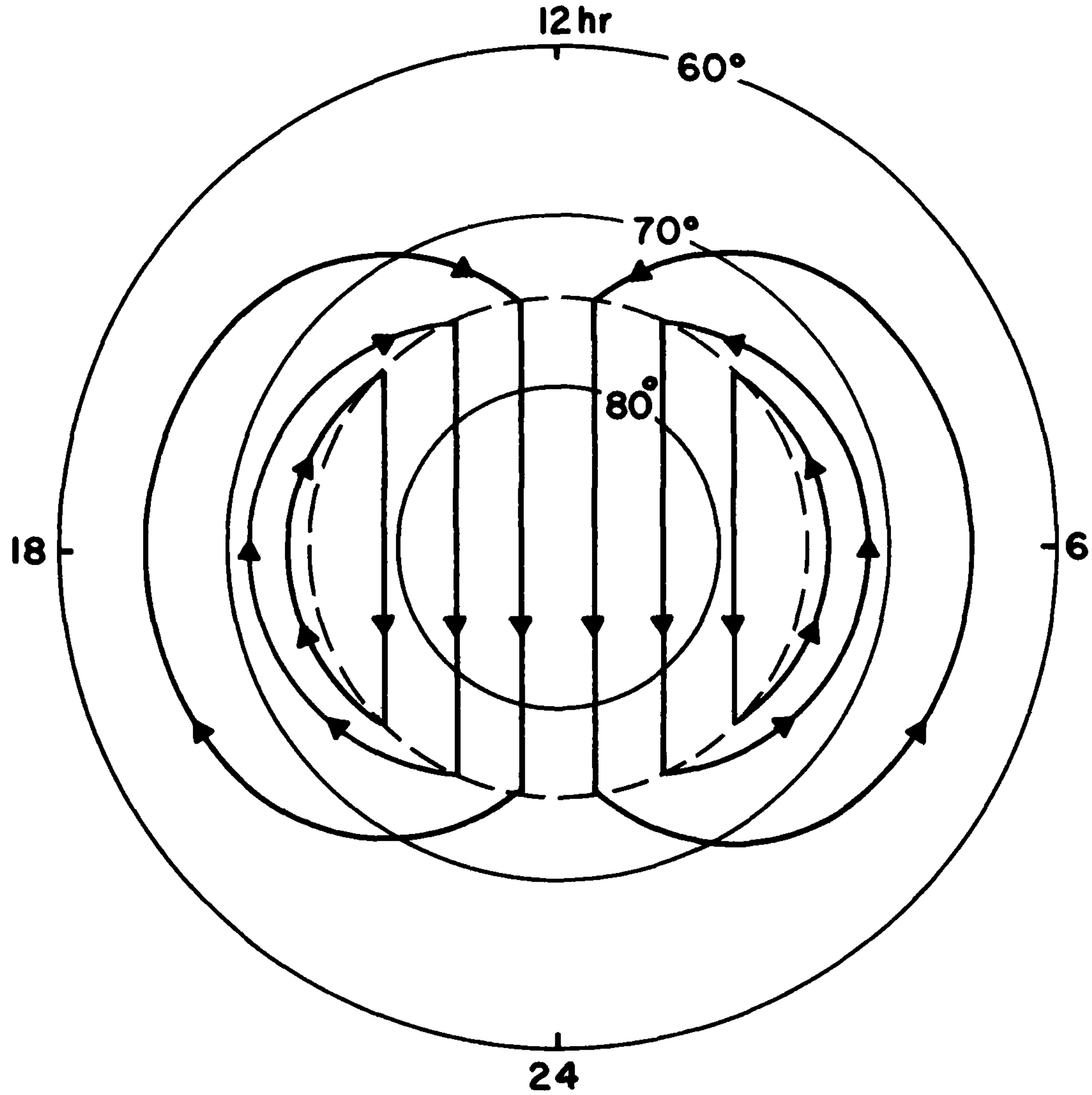
scatter (Thomson) radar measurements suggest a pattern of plasma drift motion over the polar cap from the day side to the night side, with sunward return flow at the lower latitudes, as shown in Figure 4.[44] Recent measurements made at Thule, Greenland (86° Corrected Geomagnetic Latitude) with the Digisonde and optical systems substantiate this flow pattern.[43] Measuring this convection from the ground at Goose Bay, one would expect a westerly flow of plasma prior to midnight, changing to an easterly flow after midnight. As will be shown below, the drift velocities calculated from the Doppler-drift data collected by ULCAR at Goose Bay are in agreement with these predictions.

1.6.4 Effects of TID's on Plasma Motion

The oscillating movement of plasma under the influence of acoustic-gravity waves reflects the phase velocity of a disturbance propagating through the ionosphere and not the true convection motion of the plasma as a whole, somewhat like ripples from a local disturbance in the current of a smoothly flowing stream of water. We do not know at present the precise effects of this ripple motion on the Doppler-drift measurements. As is typical of many scientific measurements, we make first a simple model, based on the assumption that our measurements reflect predominantly the true plasma drift, and we use a statistical approach for calculating the drift velocities, in order to smooth out the errors due to waves and to other factors discussed later. In this thesis, we are attempting only to prove that the results of ULCAR's Doppler-

[43]Buchau et al. (1982).

[44]From Spiro et al. (1978), Fig. 1a. See also Evans et al. (1982), section 5.3.



HIGH-LATITUDE PLASMA CONVECTION PATTERN

Figure 4

drift measurements are a step in the right direction, so that we may proceed with further drift measurements and thus collect a data base for more extensive analysis.

1.7 Measurement of Plasma Drift in the Ionosphere

1.7.1 Fading Measurements[45]

The first attempts to measure ionospheric plasma drift were made by studying the fading of radio waves reflected off irregularities in the ionosphere. The study of fading is not to be confused with the incoherent scatter technique, where the radio waves are scattered off electron clusters smaller than the wavelength of the transmitted wave; since the electrons are in random motion, the resulting total echo is incoherent. Fading involves specular reflection of coherent waves off ionospheric irregularities larger than their wavelength. The difference in the path lengths of the coherent echoes from various directions results in phase interference and therefore a change in the amplitude of the signal received at a fixed site. As the irregularities move, the phase differences vary, causing the amplitude to fluctuate. At a different site "downwind" from the movement of the irregularities, the corresponding fluctuations should appear at a time t later, where t depends on the distance between the two receiving sites and the speed (on the ground) of the diffraction pattern produced by the interference of the several echoes. To measure drift in any direction, a minimum of three receivers is required (usually placed at the corners of the right triangle) in order to measure both components of the horizontal drift motion.

In a paper which is considered a classic in the

[45]Hargreaves (1979), sections 6.2.1 and 6.3.1.

study of fading, Briggs et al.[46] pointed out that the changes in the diffraction pattern are due not only to the motion of the irregularities as a whole (so that the same fading pattern would be measured, at different times, at several spaced receivers -- "similar fade") but also to random motions of the irregularities relative to each other (so that the shape of the fading pattern would vary between sites). They also discuss how to calculate the rate at which the pattern is changing and the velocity with which the pattern moves over the ground. These calculations involve a statistical correlation analysis of the fading records measured by three (or more) spaced receivers; several techniques of correlation analysis were subsequently developed in the 1950's and 60's by various authors.[47]

1.7.2 Doppler-Drift Measurements

1.7.2.1 History

By the late 1960's, the insufficiency of the fading technique was becoming apparent. W. Pfister of AFGL published a paper in 1971[48] in which he introduced the concept of adding phase measurements to HF radio sounding and using Doppler analysis to distinguish several signals reflected simultaneously off a moving ionosphere, an approach which "allows to look at the distribution of rays as they emerge from the ionosphere and not merely at the diffraction pattern on the

[46] Briggs, Phillips and Shinn (1950).

[47] For a summary of the four major techniques developed before 1960, see Sales (1960), Appendices A, B, C, D. For further references, see Pfister (1971), p. 999.

[48] Pfister (1971).

ground."[49] The paper is a report on results obtained for E-layer measurements made in 1967 and 1969 in Billerica, Mass., in cooperation with ULCAR personnel and using phase-recording instrumentation developed by ULCAR. Analysis of the data showed evidence of both wave motion and motion of irregularities in the ionosphere. Also, a limited number of discrete reflected signals were measured, disproving the assumption of Briggs et al. that the diffraction pattern on the ground is produced by a random distribution of many irregularities in the ionosphere.

In succeeding years, personnel from ULCAR and AFGL continued the collaborative work of improving the Doppler method for measuring drift. The bibliography lists several publications which describe the progress in the development of the instrumentation and measurement techniques. We note in particular the measurements of E-layer ionospheric motion made at Eglin, Florida, and of F-layer motion at Goose Bay, Labrador, in the early 1970's.[50] Narrow reflection regions were observed, which changed position at a different rate than indicated by the Doppler shifts. This change in position seemed to be controlled by medium- and large-scale TID's: as the wavelike structures moved over the observation site, the portion of the ionosphere satisfying the perpendicularity condition changed position. The Doppler shifts, on the other hand, indicated a movement of the reflecting irregularities independent of the wave motion, and probably due to a large-scale convection of the plasma.

The method of analysis used in interpreting the data from the Doppler-drift measurements involves a Fourier trans-

[49]Ibid., p. 999.

[50]Bibl et al. (1975).

form from the time domain into the frequency domain to determine the Doppler spectrum. Calculation of the transform consumed too much computer time, so in order to develop the capability for the rapid analysis required for 24-hour observations, a hardware transform had to be designed which could perform the spectral analysis as the drift data was collected. This has become possible in recent years due to the advancement of hardware memory technology.

1.7.2.2 The Present

The on-line Fourier transform and other improvements based on past experience[51] have been incorporated into the DGS 128PS, which is in operation at Goose Bay. The primary function of the Digisonde at present is to monitor the diurnal and seasonal variations in ionospheric structure, but it is also equipped with the capability for Doppler-drift measurements. This capability is not yet fully automatic, but requires the presence of a skilled operator. ULCAR personnel occasionally travel to Goose Bay for specialized scientific experiments, and during the past few years they have on those occasions made drift measurements from which to calculate the drift velocity. After considerable efforts, which revealed technical problems in the data and led to their correction, a limited data base of correct data was collected; analysis of these data is discussed below.

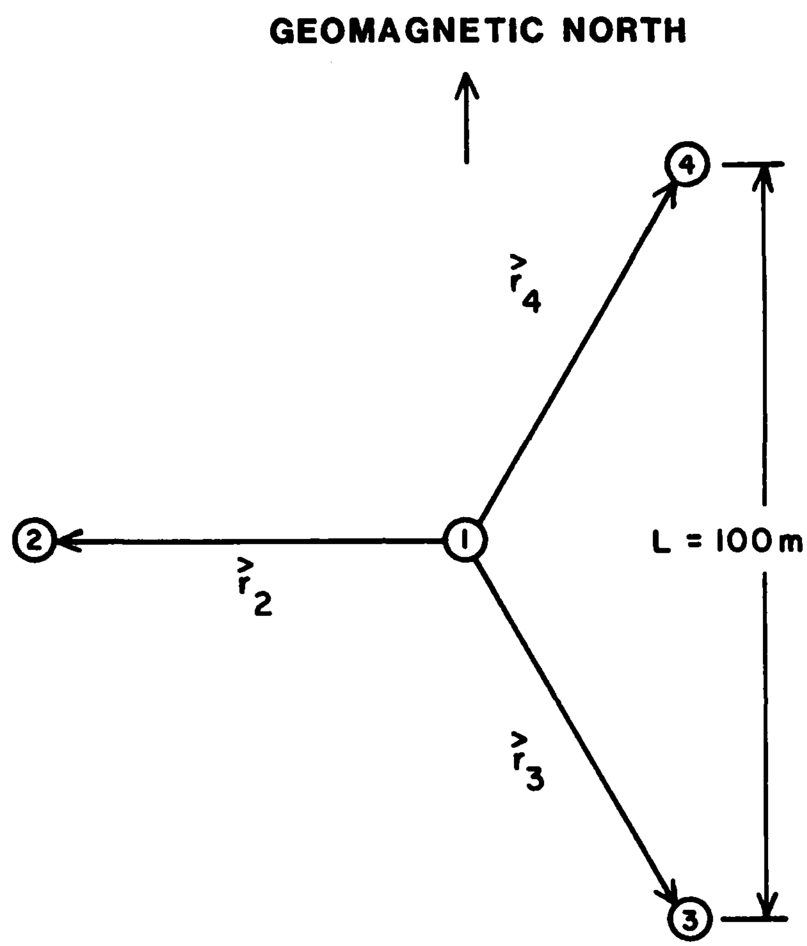
[51] Including the addition of a fourth (center) antenna to the triangular receiving array, so as to be able to distinguish signals reflected from two distinct areas with the same Doppler-frequency shift. See section 2.4.3.

2.0 EXPERIMENTAL PROCEDURE

2.1 Summary

For Doppler-drift measurements at Goose Bay, Digisonde operation is alternated between the ionogram and drift modes (see section 1.5.2). The ionograms scan the relevant frequency range from 1 to 16 MHz and sample the virtual height from 60 to 700 km. Three or six frequencies and corresponding echo ranges are selected from the ionograms for the drift measurements.[52] Doppler-shifted echoes from moving isodensity areas that are perpendicular to the direction of wave propagation are received at four antennas (see Figure 5). Spectral analysis of the composite signal received by each antenna yields the amplitude and phase of each echo; from the amplitudes and phases the frequency-wavenumber power density (FWPD) calculation determines the incidence angle of each echo. Since the range R is known, the angles of incidence of the echoes determine the positions of the various reflection areas. The coordinates of the reflection areas are displayed on a sky map; they are also used, together with the corresponding Doppler frequencies, to determine the radial component of motion of each reflection area, from which a resultant plasma-drift velocity is calculated.

[52]There are five drift programs available in the drift mode of the DGS 128PS. The number of sounding frequencies (and ranges) used for drift measurements, as well as other parameters defined below such as the number N of quadrature samples, the time δt between quadrature samples, etc., vary according to the program used. The values of these parameters for each drift program will be specified in section 2.2.1.



RECEIVING - ANTENNA ARRAY

GOOSE BAY, LABRADOR

(53.3° GEOGRAPHIC N, 60.5°W)

Figure 5

2.1.1 The Time Sequence

Each reflection area is considered the source of a separate radio signal with propagation vector $\vec{k}$. Because the distance from the antenna array to the sources is much greater than the antenna separation, the wave at the antenna array can be considered a plane wave, so that the incidence angle of $\vec{k}$ is the same at all antennas. The instantaneous voltage at each antenna due to a given source is

$$V_{a,s}(t) = V_0(s) \cos [(\omega + \Delta\omega_s)t + \phi_{a,s}] \tag{42}$$

$$\phi_{a,s} = \vec{k}_s \cdot \vec{R}_{a,s} + \delta_s \tag{43}$$

$$a = 1, 2, 3, 4 \tag{44}$$

$$\omega = 2\pi f \tag{45}$$

$$\Delta\omega_s = 2\pi \ \Delta f_s \tag{46}$$

$$|\vec{k}_s| = k = \frac{2\pi}{\lambda}, \text{ all sources} \tag{47}$$

$$\lambda = \frac{c}{f} \tag{48}$$

where:

a is the antenna index;

s is the source index;

$V_0(s)$ is the amplitude or maximum voltage of the signal from source s;

the argument of the cosine is the phase of the signal from source s received at antenna a, $\phi_{a,s}$ being the time-independent component of the phase;

f is the frequency of the transmitted wave (carrier frequency);

Δf_s is the Doppler shift or change in carrier frequency due to the motion of source s;

t is the time;

$\vec{k}_s$ is the wave propagation vector for the signal from source s;

λ is the wavelength of the carrier;[53]

c is the speed of light in vacuum;

$\vec{R}_{a,s}$ is the position vector of source s relative to antenna a;

δ_s is the initial phase of the signal at source s.

The phase term $\vec{k}_s \cdot \vec{R}_{a,s}$ is different at each antenna (see Figure 6):

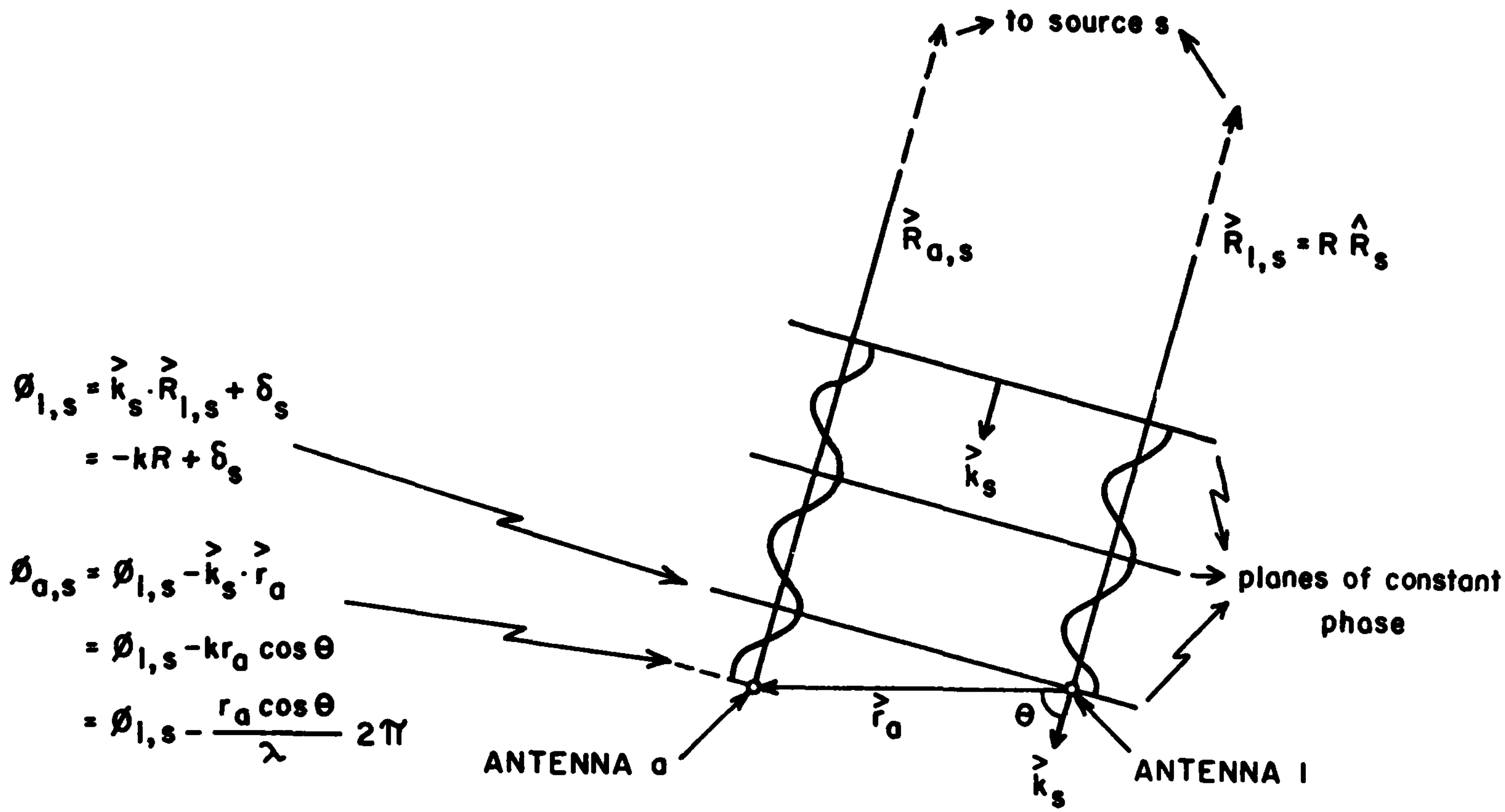
$$\vec{k}_s \cdot \vec{R}_{a,s} = \vec{k}_s \cdot \vec{R}_{1,s} - \vec{k}_s \cdot \vec{r}_a \tag{49}$$

$$\vec{R}_{1,s} = R \hat{R}_s \tag{50}$$

$$\phi_{a,s} = \vec{k}_s \cdot \vec{R}_{1,s} - \vec{k}_s \cdot \vec{r}_a + \delta_s \tag{51}$$

where the magnitude of $\vec{R}_{1,s}$ is the range R and its direction is given by the unit source position vector $\hat{R}_s$; $\vec{r}_a$ is the position vector of antenna a relative to antenna 1 ($\vec{r}_1 \equiv 0$; see Figure 5). $V_{a,s}(t)$ differs from $V_{a',s}(t)$ only in the terms $\vec{k}_s \cdot \vec{r}_a$, $\vec{k}_s \cdot \vec{r}_{a'}$ $(a \neq a')$: the signal from a given source is the same at all antennas except for a constant phase difference, which is a function of the wavelength of the signal ($|\vec{k}_s| = 2\pi/\lambda$), the antenna separation $\vec{r}_a - \vec{r}_{a'}$, and the incidence angle of the source represented by $\hat{R}_s$. Since the wavelength and the antenna separation are known, the incidence angle can be calculated if $\phi_{a,s}$ is known for all antennas, as will be shown later.

[53]Using $\lambda = c/f$ instead of $c/(f+\Delta f_s)$ results in an error of about 10^{-4} m, which can be neglected.



TIME – INDEPENDENT PHASES AT ANTENNAS 1 AND a AND SOURCE - POSITION VECTORS $\vec{R}_{1,s}$ AND $\vec{R}_{a,s}$

Figure 6

With several sources, the total signal $V_a(t)$ at antenna a is the sum (superposition) of the reflected signals,

$$V_a(t) = \sum_s V_{a,s}(t) = \sum_s V_0(s) \cos [(\omega+\Delta\omega_s)t + \phi_{a,s}] \tag{52}$$

$$s = s', s'', s''', \ldots \tag{53}$$

$$V_a(t) = V(M_a(t), \Phi_a(t)) \tag{54}$$

where the sum is over all sources; $M_a(t)$ is the magnitude (time-varying amplitude) of the composite signal at time t, and $\Phi_a(t)$ is its phase.

At each antenna the composite analog signal $V_a(t)$ is sampled N times at intervals δt, i.e. at

$$t_n = n\,\delta t,\ n = -\frac{N}{2}, -\frac{N}{2}+1, -\frac{N}{2}+2, \ldots, \frac{N}{2}-1. \tag{55}$$

Each sample consists of two measurements X and Y obtained by quadrature sampling,[54]

$$X_a(t_n) = V_a(t_n) = \sum_s V_0(s) \cos[(\omega + \Delta\omega_s)\, t_n + \phi_{a,s}] \tag{56}$$

$$Y_a(t_n) = -V_a(t_n + \frac{\pi}{2\omega}) = \sum_s V_0(s) \sin[(\omega + \Delta\omega_s)\, t_n + \phi_{a,s}] \tag{57}$$

$$\frac{\pi}{2\omega} = \frac{\tau}{4} \tag{58}$$

$$\tau = \frac{1}{f} = \frac{2\pi}{\omega} \tag{59}$$

where τ is the period of the carrier wave. X and Y are related to the amplitude M and phase Φ of equation (54) by

$$M = \sqrt{X^2 + Y^2} \tag{60}$$

$$\Phi = \arctan \frac{Y}{X} \tag{61}$$

[54]In the phase of $Y_a(t_n)$, we are neglecting the term $\pi\, \Delta\omega_s/2\omega \simeq 10^{-6}\, \pi/2$.

The quadrature samples are measured in phase with the carrier, i.e.

$$\delta t = m\tau = \frac{2m\pi}{\omega} \tag{62}$$

(where m is an integer), which effectively filters out the carrier frequency: remembering that $t_n = n\ \delta t$ (equation (55)),

$$\cos[(\omega + \Delta\omega_s)\ t_n] = \cos[(\omega + \Delta\omega_s)\ \frac{2nm\pi}{\omega}] \tag{63}$$

$$= \cos \Delta\omega_s\ t_n \tag{64}$$

and similarly for $\sin[(\omega + \Delta\omega_s)\ t_n]$; therefore

$$X_a(t_n) = \sum_s V_0(s) \cos(\Delta\omega_s\ t_n + \phi_{a,s}) \tag{65}$$

$$Y_a(t_n) = \sum_s V_0(s) \sin(\Delta\omega_s\ t_n + \phi_{a,s}) \tag{66}$$

The result is a digital time sequence which represents a signal whose frequency components are the frequencies of the Doppler shifts only.

2.1.2 The Frequency Spectrum

As the quadrature samples are measured, they are inputted in real time into a hardware processor which performs a direct discrete Fourier transform[55] with Hanning weighting by spectral averaging,[56] to reduce the sin x/x ringing and noise. For each spectral line of frequency ω_d,

$$\omega_d = d\ \delta\omega \tag{67}$$

[55] Bibl and Reinisch (1978b), p. 527.

[56] See section 2.2.3 for references.

$$d = d', d'', d''', \ldots \tag{68}$$

(where $\delta\omega$ is the angular Doppler-frequency resolution of the transform, and d is an integer, whose numerical values will be specified in section 2.2.1), the Fourier transform is defined as[57]

$$F_a(d) = \sum_{n=-N/2}^{N/2-1} f_a(n)\, e^{-i \frac{2\pi}{N} dn} \tag{69}$$

$$f_a(n) = X_a(t_n) + i\, Y_a(t_n) = \sum_s V_0(s)\, e^{i\,(D_s\, \delta\omega\, n\, \delta t + \phi_{a,s})} \tag{70}$$

$$D_s\, \delta\omega = \Delta\omega_s \tag{71}$$

where we have formed a complex time sequence from the quadrature measurements (X,Y); in the time sequence (70) the Doppler shift $\Delta\omega_s$ due to the motion of source s is written in terms of the Doppler-frequency resolution.

To illustrate the result of equation (69), consider two sources s' and s''. If $D_{s'}$ and $D_{s''}$ are integers,

$$D_{s'} = d' \tag{72}$$

$$D_{s''} = d'' \tag{73}$$

then

$$\Delta\omega_{s'} = D_{s'}\, \delta\omega = \omega_{d'} = d'\, \delta\omega \tag{74}$$

$$\Delta\omega_{s''} = D_{s''}\, \delta\omega = \omega_{d''} = d''\, \delta\omega \tag{75}$$

where d' and d'' are two different Doppler numbers, and[58]

[57] See section 2.2.2 for references.

[58] See section 2.2.2 for the derivation of these results.

$$F_a(d') = N\, V_0(s')\, e^{i\,\phi_{a,s'}} \tag{76}$$

$$F_a(d'') = N\, V_0(s'')\, e^{i\,\phi_{a,s''}} \tag{77}$$

yielding the amplitude and the time-independent phase of the signal from each source. In general the Doppler shifts are not integral multiples of $\delta\omega$, and $F_a(d')$ and $F_a(d'')$ are modulated by the sin x/x ringing due to the limited sample length of the time sequence; Hanning weighting is applied to the frequency spectrum to reduce both the ringing and extraneous noise. Note that if

$$D_{s'} = - D_{s''} \tag{78}$$

equations (76) and (77) still hold (for integer D_s): the complex Fourier transform distinguishes positive and negative frequencies. In the present context, negative frequencies have a physical significance; they follow mathematically from the discrete quadrature sampling, which filters out the carrier frequency (see equations (65) and (66)). Negative Doppler frequencies correspond to a decrease in carrier frequency due to motion of the source away from the observation site; positive Doppler frequencies correspond to an increase in carrier frequency due to motion toward the observation site.

2.1.3 Sky-Map Calculations

A scanning method is used to determine the incidence angle of each echo. The area of the sky above the observation site is represented by a square sky map, with the corners of the map area at range R and with the maximum zenith angle ζ_{max} (at the corners) defined so as to exclude from the sky map the major side lobes which follow from the periodicity of the FWPD calculation (the major side lobes have the same strength as the main lobe). In section 2.4.2 we will show that

$$\sin \zeta_{max} = \frac{\lambda}{L} \tag{79}$$

where λ is the wavelength of the sounding frequency and L is the maximum antenna separation in the receiving array (see Figure 5); ζ_{max} is limited to a maximum of 45°. The map is divided into 1681 locations defined by a 41 × 41 array of coordinates $(x_m, y_{m'})$,

$$x_m = m\ \delta x \tag{80}$$

$$y_{m'} = m'\ \delta y \tag{81}$$

$$\delta x = \delta y \tag{82}$$

$$m, m' = 0, \pm 1, \pm 2, \ldots, \pm 20 \tag{83}$$

where δx is a function of R and ζ_{max}. Each coordinate $(x_m, y_{m'})$ defines the angle of incidence of the scanning vector $\vec{k}(x_m, y_{m'})$ whose magnitude is the same as that of $\vec{k}_s$ (equation (47)). For each Doppler number d, the frequency-wave-number power density P is calculated 1681 times, once for each map coordinate $(x_m, y_{m'})$:

$$P(d, x_m, y_{m'}) = \sum_{a=1}^{4} \sum_{a'=1}^{4} F_a(d)\, F^*_{a'}(d)\, e^{i \vec{k}(x_m, y_{m'}) \cdot (\vec{r}_a - \vec{r}_{a'})} \tag{84}$$

where * denotes the complex conjugate; $F_a(d)$, $F_{a'}(d)$ are the frequency spectra (after spectral averaging) of antennas a and a'; and $\vec{r}_a$, $\vec{r}_{a'}$ are the antenna position vectors relative to antenna 1. The factor $e^{i\vec{k}(x_m, y_{m'})\cdot\vec{r}_a}$ introduces a computational phase "delay" in the signal spectrum from antenna a. When $\vec{k}(x_m, y_{m'})$ looks in the direction of the echo whose Doppler frequency is ω_d, the delayed phases of that echo are equal at all antennas, which makes $P(d, x_m, y_{m'})$ a maximum; thus the map coordinates $(x_m, y_{m'})$ for which P is a maximum indicate the direction $\hat{k}_s$ of the corresponding source.[59] We re-write these map coordinates as the source coordinates

$$(x_s, y_s) = (x_m, y_{m'})^{60} \tag{85}$$

and define

$$P_s \equiv P(d, x_s, y_s) \tag{86}$$

as the power density of source s.

Two parallel sky maps are used to display the positions of the sources calculated in this manner: one map displays the power densities P_s at the corresponding source coordinates (x_s, y_s); the other map displays the Doppler numbers d at the same coordinates (see Figure 17).

2.1.4 Drift-Velocity Calculations

The sky map data (x_s, y_s, d, P_s) for all sources calculated from a given measurement are then used to determine the velocity of the plasma drift. The Doppler shift Δf_s due to the velocity $\vec{V}_s$ of source s is [61]

$$\Delta f_s = -2 \frac{\vec{V}_s \cdot \hat{R}_s}{c} f \tag{87}$$

[59]If there are two or more sources whose motion results in the same Doppler shift, the FWPD does not in general yield the correct source positions. See section 2.4.3.

[60]In general, since the sky map is defined by a set of discrete coordinates, x_s is only approximately equal to x_m and y_s is only approximately equal to $y_{m'}$; we use the equal sign with the understanding that the equality is within the limits of the errors due to the digitizing of continuous functions.

[61]See section 2.5.1 for the derivation of (87).

where $\hat{R}_s$ is the unit source-position vector, f is the sounding frequency, and c is the speed of light in vacuum. Thus the radial component W_s of the source velocity is

$$W_s \equiv \vec{V}_s \cdot \hat{R}_s = -\frac{1}{2}\frac{\Delta f_s}{f} c \tag{88}$$

It is assumed that

$$\vec{V}_s \equiv \vec{V}, \text{ all } s \tag{89}$$

that is, all sources for a given measurement or case (a case is typically a measurement of 10 or 18 seconds; see Table 1) are moving at the same velocity $\vec{V}$. This velocity is calculated using a least-square fit procedure: the average square error ε^2 is defined as

$$\varepsilon^2 = \frac{\sum_s w_s (\vec{V} \cdot \hat{R}_s - W_s)^2}{\sum_s w_s} \tag{90}$$

where w_s is a weighting factor proportional to P_s but normalized so that $\sum_s w_s$ is equal to the total number of sources. By setting the derivatives $\partial\varepsilon^2/\partial V_x$, $\partial\varepsilon^2/\partial V_y$ and $\partial\varepsilon^2/\partial V_z$ equal to zero, three simultaneous equations are obtained from which V_x, V_y and V_z are calculated; plugging $\vec{V}$ back into equation (90) yields the least square error.

The sources for a given case are sorted in descending order of the magnitude of P_s, then equation (90) is calculated several times: the first calculation uses only the first five sources; the second calculation, the first six sources; and so on. Each calculation of equation (90) is called an individual velocity calculation. A case velocity is calculated as the median of the individual velocities; the median of the case velocities from a group of four to six con-

P	N_f	δt [msec]	T [sec]	CASE SPACING [sec]	N	δf [Hz]	AFTER SPECTRAL AVERAGING			
							N'	$\delta f'$ [Hz]	DOPPLER SPECTRUM [Hz]	DOPPLER RANGE [Hz]
5	6	127.5	8.16	10	64	$\frac{1}{8}$	64	$\frac{1}{8}$	$\pm(0, \frac{1}{8}, \frac{1}{4}, \ldots, \frac{31}{8})$	$\pm(0 \text{ to } 3\frac{7}{8})$
6	6	127.5	16.32	18	128	$\frac{1}{16}$	64	$\frac{1}{8}$	$\pm(\frac{1}{16}, \frac{3}{15}, \frac{5}{16}, \ldots, \frac{63}{16})$	$\pm(\frac{1}{16} \text{ to } 3\frac{15}{16})$
7	6	127.5	32.64	34	256	$\frac{1}{32}$	128	$\frac{1}{16}$	$\pm(\frac{1}{32}, \frac{3}{32}, \frac{5}{32}, \ldots, \frac{127}{32})$	$\pm(\frac{1}{32} \text{ to } 3\frac{31}{32})$
8	3	63.75	8.16	10	128	$\frac{1}{8}$	128	$\frac{1}{8}$	$\pm(0, \frac{1}{8}, \frac{1}{4}, \ldots, \frac{63}{8})$	$\pm(0 \text{ to } 7\frac{7}{8})$
9	3	63.75	16.32	18	256	$\frac{1}{16}$	128	$\frac{1}{8}$	$\pm(\frac{1}{16}, \frac{3}{16}, \frac{5}{16}, \ldots, \frac{127}{16})$	$\pm(\frac{1}{16} \text{ to } 7\frac{15}{16})$

P = Program number

N_f = # of sounding frequencies

δt = sample spacing

T = total sampling time/case

Case spacing = T + dead time

N = # of quadrature samples or Fourier components

N' = # of spectral lines after spectral averaging

δf = Doppler-frequency resolution in transform

$\delta f'$ = Doppler resolution after averaging

δf, $\delta f'$, Doppler spectrum and range are rounded out to convenient fractions (for example, δf = .122549 Hz is rounded out to 1/8 = .125 Hz)

DRIFT-MEASUREMENT PARAMETERS IN THE DGS 128PS

Table 1

secutive cases yields the group-norm velocity.[62] Each case comprises simultaneous drift measurements at three or six sounding frequencies (and corresponding ranges); a velocity called the all-frequency velocity is also calculated as the median of the group-norm velocities which correspond to the three or six sounding frequencies.

The calculated drift velocities are displayed on two parallel graphs, one with a plot of the horizontal direction (azimuth graph) of a time sequence of drift velocities, the other with a plot of the magnitude of the horizontal drift, the vertical-drift magnitude being indicated by a + or - symbol (see Figure 22). Graphs of the individual, case and group-norm velocities were used for analyzing the effects of various weighting and smoothing techniques. After the best approach for calculating the drift velocities had been determined, a time sequence of all the group-norm and all-frequency velocities for a given time sequence of measurements was plotted on one pair of graphs, the direction and horizontal speed of the group-norm velocities being indicated by a number or letter specifying the range R of each measurement, and the direction and horizontal speed of the all-frequency velocities being indicated by a solid line drawn through the corresponding graph coordinates (see, for example, Figure 24).

2.2 Drift Measurements with the Digisonde 128PS

2.2.1 Drift-Measurement Parameters

Five drift programs are provided in the DGS 128PS, identified by the program number P,

[62] The expression is awkward but was coined, for want of a better term, to avoid possible confusion with the "group velocity" of a wave.

$$P = 5,\ 6,\ 7,\ 8,\ 9 \tag{91}$$

with different drift parameters for each P (see Table 1). Drift measurements are made at three or six sounding frequencies as follows. The Digisonde transmits four 100 μsec pulses 5 msec apart at the first frequency (see Figure 7) and receives with each of the four antennas successively, measuring the quadrature samples X and Y. The process is then repeated for the other sounding frequencies. After the measurements at the last frequency, the process starts over again at the first frequency. N such measurements are made, yielding a time sequence of N quadrature pairs (X, Y) for each sounding frequency at each antenna. The set of N quadrature measurements for all frequencies and antennas comprises one drift measurement or case.

The sample spacing δt (the time between successive samples at a given antenna and given frequency) is

$$\delta t = (1.25 \text{ msec} + 5 \text{ msec} \times N_a)\, N_f \tag{92}$$

where N_a is the number of antennas (four at Goose Bay; but the DGS 128PS provides for the possibility of up to 24 antennas for drift measurements) and N_f is the number of sounding frequencies. At Goose Bay,

$$\delta t = 21.25 \text{ msec} \times N_f \tag{93}$$

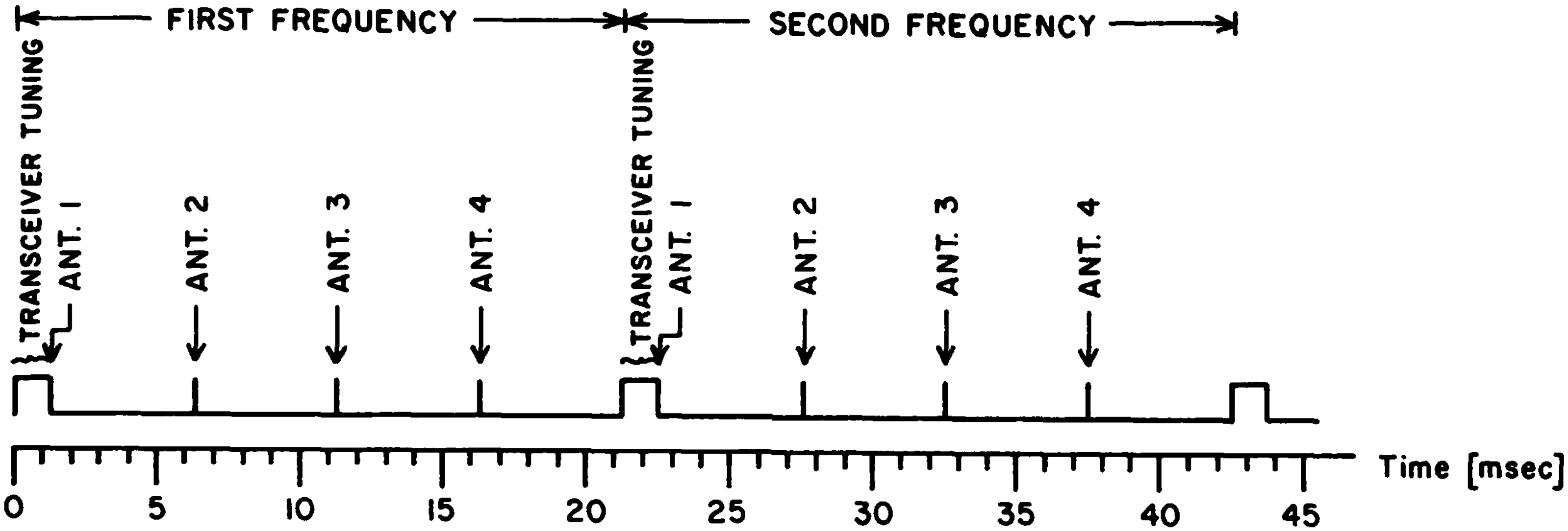
which gives the results shown in Table 1.

The Fourier transform yields a spectrum of N Doppler lines (see section 2.2.2) of frequency

$$f_d = d\ \delta f \tag{94}$$

$$-\frac{N}{2} \le d \le \frac{N}{2} - 1 \tag{95}$$

$$\delta f = \frac{1}{N\delta t} \tag{96}$$



1.25 msec is required for transceiver tuning.

Pulses are 100 μsec long, spaced 5 msec apart.

The time indicated for each pulse is the time of transmission; the antenna number above each pulse indicates which antenna is used for receiving that pulse a few msec or less after transmission.

SEQUENCE OF QUADRATURE MEASUREMENTS

Figure 7

where N is the number of quadrature samples. Hanning weighting (see section 2.2.3) is applied to the frequency spectrum in either of two ways. For drift programs 5 and 8, all spectral lines are kept (the antenna index is omitted in the following equations):

$$F'(+0) = 2\ F(0) + F(1) \tag{97}$$

$$F'(-0) = 2\ F(0) + F(-1) \tag{98}$$

$$F'(d) = F(d-1) + 2\ F(d) + F(d+1) \tag{99}$$

$$d = \pm 1,\ \pm 2,\ \pm 3,\ \ldots,\ \pm(\frac{N}{2} - 1) \tag{100}$$

where F is the spectrum before spectral averaging and F' is the spectrum after averaging.[63] Equations (97) and (98) do not follow strictly from the definition of Hanning weighting, which would yield

$$F(+0) = F(-0) = F(-1) + 2F(0) + F(1). \tag{101}$$

Equations (97) and (98) were adopted in order to distinguish between positive and negative frequencies which are close to zero. For drift programs 6, 7 and 9, only the odd spectral lines are kept, the even spectral lines being used only in the average,

$$F'(d) = F(d-1) + 2F(d) + F(d+1)^{64} \tag{102}$$

[63]See footnote 70 in section 2.2.3.

[64]Note that in

$$F'(\frac{N}{2} - 1) = F(\frac{N}{2} - 2) + 2F(\frac{N}{2} - 1) + F(\frac{N}{2}) \tag{103}$$

the third term, $F(\frac{N}{2})$, is not within the transform spectrum (equation (95)); but from equation (140),

$$F(\frac{N}{2}) = F(-\ \frac{N}{2}) \tag{104}$$

$$d = \pm 1, \pm 3, \pm 5, \ldots, \pm(\frac{N}{2} - 1) \tag{105}$$

The result is that for these three drift programs the spectral spacing is doubled, the number of spectral lines is halved, and the lowest Doppler frequency is $\pm\delta f$ instead of ± 0. The spectrum for all five drift programs can be summarized as

$$f_d = \pm [f_0 + (|d| - 1)\, \delta f'] \tag{106}$$

$$d = \pm 1, \pm 2, \pm 3, \ldots, \pm \frac{N'}{2} \tag{107}$$

where, for programs 5 and 8,

$$f_0 = 0 \tag{108}$$

$$N' = N \tag{109}$$

$$\delta f' = \delta f \tag{110}$$

and for programs 6, 7 and 9,

$$f_0 = \delta f \tag{111}$$

$$N' = \frac{N}{2} \tag{112}$$

$$\delta f' = 2\delta f \tag{113}$$

N and δf are as defined before spectral averaging, but note that d (equation (107)) is defined differently than in previous equations. The parameters defined in this section are summarized in Table 1.

2.2.2 The Fourier Transform[65]

The definition of the Fourier transform used in the DGS 128PS has been given in Equation (69); with the time sequence (70) the transform becomes

[65] Peled and Liu (1976), section 1.7.

$$F_a(d) = \sum_{n=-N/2}^{N/2-1} [\sum_s V_0(s)\, e^{i(D_s\, \delta\omega\, n\, \delta t\, +\, \phi_{a,s})}]\, e^{-\, i\, \frac{2\pi}{N}\, dn}$$

(114)

$$F_a(d) = \sum_s V_0(s)\, e^{i\, \phi_{a,s}} \sum_{n=-N/2}^{N/2-1} e^{i[(D_s\, -\, d)\, \frac{2\pi}{N}]\, n} \tag{115}$$

$$D_s\ \delta\omega = \Delta\omega_s \tag{116}$$

$$s = s',\ s'',\ s''',\ \ldots \tag{117}$$

$$\delta\omega\ \delta t = \frac{2\pi}{N} \tag{118}$$

$$F_a(d) = \sum_s V_0(s)\, e^{i\, \phi_{a,s}}\, S(s,\, d) \tag{119}$$

$$S(s,\, d) = \sum_{n=-N/2}^{N/2-1} e^{i[(D_s - d)\, \frac{2\pi}{N}]\, n} \tag{120}$$

$$= e^{-i[(D_s - d)\pi]} \sum_{n=0}^{N-1} e^{i[(D_s - d)\, \frac{2\pi}{N}]\, n} \tag{121}$$

where (121) is a geometric progression of the form

$$r^{-N/2} \sum_{n=0}^{N-1} r^n = r^{-N/2}\, \frac{r^N - 1}{r-1} = \frac{(r^{N/2} - r^{-N/2})}{r^{1/2}(r^{1/2} - r^{-1/2})} \tag{122}$$

so that

$$S(s,\, d) = \frac{\sin\ (D_s - d)\ \pi}{\sin\ (D_s - d)\ \pi/N}\, e^{-i(D_s - d)\pi/N} \tag{123}$$

$$\simeq N\, \frac{\sin\ (D_s - d)\ \pi}{(D_s - d)\ \pi}\, e^{-i\ (D_s - d)\ \pi/N} \tag{124}$$

where (125) follows from the approximation for small angles,

$$\sin\ (D_s - d)\ \pi/N \simeq (D_s - d)\ \pi/N \tag{125}$$

The Fourier transform must be evaluated for each value of d, so that (114) represents a sequence of N equations. To illustrate the result of calculating the transform, we write it for one of the values of d, say d',

$$
\begin{aligned}
F_a(d') = {} & V_0(s')\, e^{i\,\phi_{a,s'}}\, S(s', d') \\
& + V_0(s'')\, e^{i\,\phi_{a,s''}}\, S(s'', d') \\
& + V_0(s''')\, e^{i\,\phi_{a,s'''}}\, S(s''', d') \\
& + \ldots
\end{aligned}
\tag{126}
$$

If $\Delta\omega_s$ is an integral multiple of $\delta\omega$ for all sources, that is,

$$D_{s'} = d' \tag{127}$$

$$D_{s''} = d'' \tag{128}$$

etc.,[66] we use ℓ'Hôpital's rule to evaluate S(s', d'), getting

$$\lim_{b \to 0} \frac{\sin b\pi}{\sin b\pi/N}\, e^{-ib\pi/N} = N \tag{129}$$

$$b = D_{s'} - d' \tag{130}$$

A straightforward evaluation of all other terms shows that they are all zero, since $(D_{s''}-d')$, $(D_{s'''}-d')$, etc. are all

[66] In this section, we further assume that each echo has a different Doppler shift, i.e. that d', d'', etc. are all different Doppler numbers. Since the Doppler shift is proportional to the radial component of the velocity of the source (the component of velocity along $\hat{R}_s$), sources at different incidence angles will, in general, result in different Doppler shifts even if all sources move at the same velocity. There can, however, exist echoes with the same Doppler shift; this situation will be treated as a special case in section 2.4.3.

non-zero integers. Therefore

$$F_a(d') = N\ V_0(s')\ e^{i\ \phi_{a,s'}} \tag{131}$$

For $F_a(d'')$, only the second term is non-zero, so

$$F_a(d'') = N\ V_0(s'')\ e^{i\ \phi_{a,s''}} \tag{132}$$

and similarly for $F_a(d''')$, etc. Thus the Fourier transforms of the time sequence yield for each source the amplitude and time-independent phase at each antenna a, from which the location of each source can be calculated using the FWPD.

Returning to $F_a(d')$: if $D_{s'}$ is not an integer, then $S(s', d')$ is not equal to N: the amplitude is less than $N\ V_0(s')$, and the phase $\phi_{a,s}$ is shifted by $-(D_{s'}-d')\ \frac{\pi}{N}$, although the first term is still the only non-zero term. If in addition $D_{s''}$ (and/or $D_{s'''}$, etc.) is not an integer, the second (and/or third, etc.) term is non-zero: the first term dominates, but is modulated by the effect of the other term(s). The ringing effect of $D_s = 6.25$ on F(0) to F(12) is illustrated in the next section in Figure 8, which shows a comparison between unweighted and weighted Fourier transforms.

The spectral spacing or Doppler-frequency resolution δf of the N-term transform follows from equation (118),

$$\delta f = \frac{\delta\omega}{2\pi} = \frac{1}{N\delta t} \tag{133}$$

The frequency of each spectral line is

$$f_d = d\ \delta f \tag{134}$$

$$d = 0,\ \pm 1,\ \pm 2,\ \ldots,\ \pm(\frac{N}{2} - 1),\ -\frac{N}{2} \tag{135}$$

so that the unambiguous frequency range is $-\frac{N}{2}\ \delta f$ to

$(\frac{N}{2} - 1)\ \delta f$.[67] The discrete Fourier transform is periodic, so that other frequencies are "aliased"[68] (folded in) and appear in the same frequency range; that is,

$$F(d + mN) = F(d) \tag{136}$$

$$m = 0, \pm 1, \pm 2, \ldots \tag{137}$$

This can be seen from equation (120),

$$S(s,\ d + mN) = \sum_{n=-N/2}^{N/2-1} e^{i[(D_s-(d+mN))\frac{2\pi}{N}]\,n} \tag{138}$$

$$= \sum_{n=-N/2}^{N/2-1} e^{i[(D_s-d)\frac{2\pi}{N}]\,n}\ e^{-i(m2\pi n)} \tag{139}$$

$$= S(s,d) \tag{140}$$

where the last step follows from the fact that both m and n are integers.

2.2.3 Hanning Weighting: Spectral Averaging[69]

Defining the Fourier transform as a finite series has the effect of multiplying it by the box function, which results in the sin x/x ringing described in the previous section. This effect can be reduced significantly by weighting each term of the transform by [.5 + .5 cos ($2\pi n/N$)], which is called the von Hann (or Hanning) window or the raised cosine window. The weighted transform $F'_a(d)$ is therefore

[67] Note that the above results are modified by the way spectral averaging is applied. See section 2.2.1.

[68] Hamming (1977), section 2.2.

[69] Hamming (1977), section 5.9.

$$F'_a(d) = \sum_s V_0(s)\, e^{i\phi_{a,s}} \sum_{n=-N/2}^{N/2-1} e^{i[(D_s-d)\frac{2\pi}{N}]n}$$

$$\times \left[\frac{1}{2} + \frac{1}{4}\left(e^{i\frac{2\pi}{N}n} + e^{-i\frac{2\pi}{N}n}\right)\right] \tag{141}$$

Since

$$e^{i[(D_s-d)\frac{2\pi}{N}]n}\, e^{\pm i\frac{2\pi}{N}n} = e^{i\{[D_s - (d\mp 1)]\frac{2\pi}{N}\}n} \tag{142}$$

the weighted transform is

$$F'_a(d) = \sum_s V_0(s)\, e^{i\phi_{a,s}} \left[\frac{1}{2} S(s,d) + \frac{1}{4} S(s,d-1) + \frac{1}{4} S(s,d+1)\right] \tag{143}$$

$$= \frac{1}{4}\left[F_a(d-1) + 2\, F_a(d) + F_a(d+1)\right] \tag{144}$$

Hanning weighting can therefore be applied in the frequency domain by averaging three adjacent spectral lines with weights (1), (2), (1).[70]

To evaluate the result of spectral averaging, we write equation (123) as

$$S(s,\, d) = \frac{\sin b}{\sin c}\, e^{-ic} = \sin b\, (\cot c - i) \tag{145}$$

$$b = (D_s - d)\,\pi \tag{146}$$

$$c = (D_s - d)\,\pi/N \tag{147}$$

$$S(s,\, d\mp 1) = \sin\,(b\pm\pi)\,[\cot\,(c \pm \pi/N) - i] \tag{148}$$

$$= -\sin b\,[\cot\,(c \pm \pi/N) - i] \tag{149}$$

Then the bracket in equation (143) becomes

[70]The scaling factor 1/4 is ignored since it makes no difference in the FWPD calculation of the source positions.

$$\sin b \, \{\frac{\cot c}{2} - \frac{1}{4} [\cot (c+\pi/N) + \cot (c-\pi/N)]\}$$

$$= \sin b \, \{\frac{\cot c}{2} - \frac{1}{4} \frac{2 \sin c \cos c}{\sin^2 c - \sin^2 \pi/N}\} \tag{150}$$

$$= \frac{1}{2} \frac{\sin b}{\sin c} \cos c\{1 - \frac{\sin^2 c}{\sin^2 c - \sin^2 \pi/N}\} \tag{151}$$

where the right side of (150) follows from the identity[71]

$$\cot (\alpha + \beta) + \cot (\alpha - \beta) = \frac{2 \sin \alpha \cos \alpha}{\sin^2 \alpha - \sin^2 \beta} \tag{152}$$

Therefore,

$$F_a'(d) = \frac{1}{2} \sum_s V_0(s) \, e^{i \phi_{a,s}} \frac{\sin (D_s-d) \pi}{\sin (D_s-d) \pi/N}$$

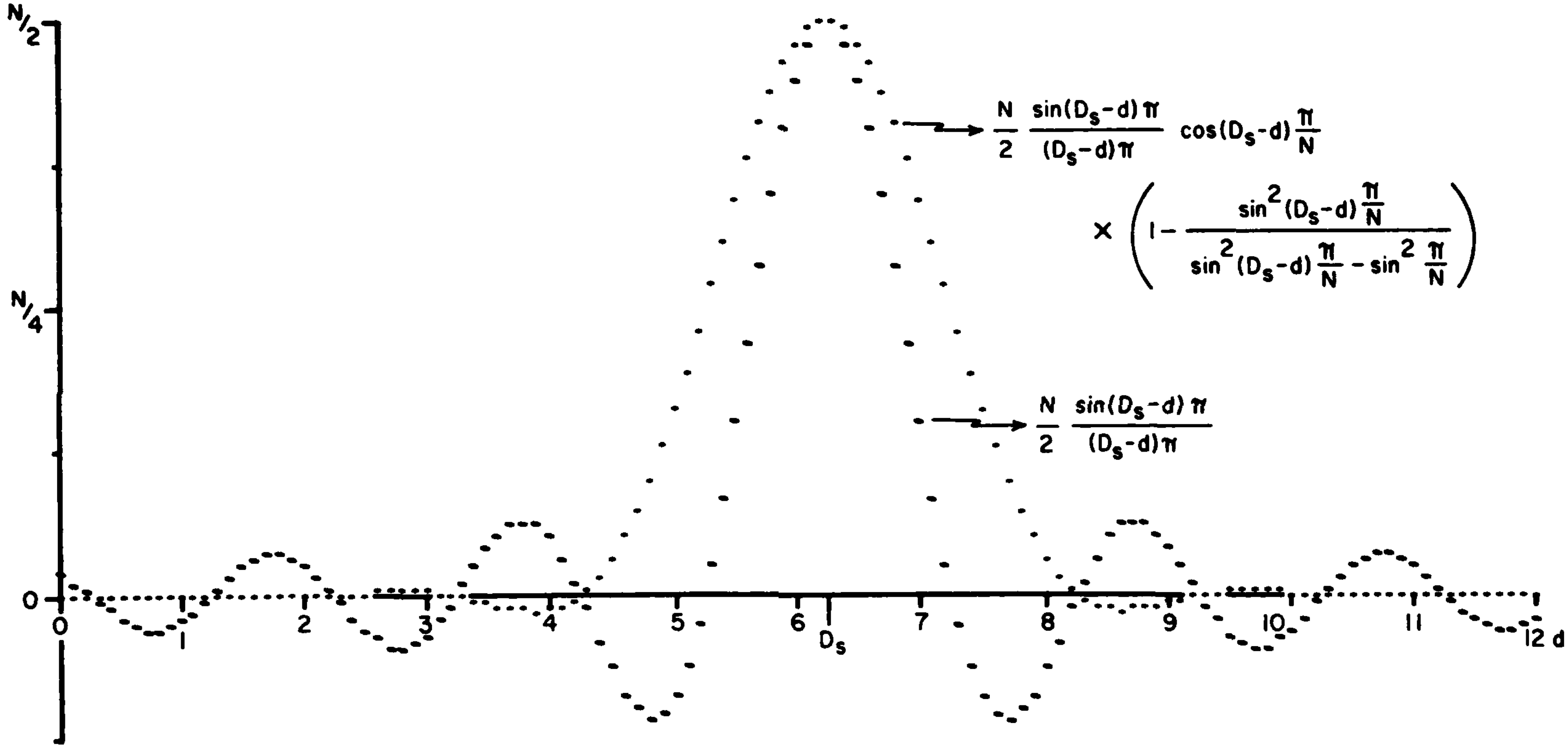
$$\times \cos (D_s-d) \frac{\pi}{N} (1 - \frac{\sin^2 (D_s-d) \pi/N}{\sin^2 (D_s-d) \pi/N - \sin^2 \pi/N}) \tag{153}$$

Figure 8 compares $\frac{1}{2} F_a(d)$ and $F_a'(d)$ for one source with $D_s = 6.25$, $V_0(s) = 1$, and $\phi_{a,s} = 0$. The widening of the spectral line $F_a'(6)$ -- i.e. $F_a'(5)$, $F_a'(7)$ are amplified -- is compensated by the significant reduction of the side lobes $F_a'(0)$ to $F_a'(4)$ and $F_a'(8)$ to $F_a'(12)$.

2.2.4 Data Recording

The data from each case of drift measurements is stored on digital tape in two or four records (see Table 2), the first record (the first two records for drift program

[71] Hamming (1977), section 5.9.



DOPPLER SHIFT $\Delta\omega_s = 6.25\,\delta\omega$

EFFECT OF HANNING WEIGHTING

Figure 6

<table>
<tr><th>PROGRAM
N</th><th>RECORD
#</th><th colspan="3">CONTENTS</th></tr>
<tr><td rowspan="2">5, 6, 8, 9</td><td>1</td><td colspan="3">Negative Dopplers</td></tr>
<tr><td>2</td><td colspan="3">Positive Dopplers</td></tr>
<tr><td rowspan="4">7</td><td>1</td><td colspan="3">Negative Dopplers, Frequency #'s 1-3</td></tr>
<tr><td>2</td><td colspan="3">Negative Dopplers, Frequency #'s 4-6</td></tr>
<tr><td>3</td><td colspan="3">Positive Dopplers, Frequency #'s 1-3</td></tr>
<tr><td>4</td><td colspan="3">Positive Dopplers, Frequency #'s 4-6</td></tr>
<tr><th></th><th># OF
CHARACTERS</th><th colspan="3">FORMAT OF EACH RECORD</th></tr>
<tr><td rowspan="2">5, 6, 7,
8, 9</td><td>80</td><td colspan="3">Preface*</td></tr>
<tr><td>160</td><td colspan="3">Dummies</td></tr>
<tr><th></th><th></th><th>ANTENNA
#</th><th># OF SPECTRAL
LINES**</th><th></th></tr>
<tr><td rowspan="4">5, 6</td><td>80</td><td>1</td><td>32</td><td rowspan="4">Same for each
of six
sounding
frequencies</td></tr>
<tr><td>80</td><td>2</td><td>32</td></tr>
<tr><td>80</td><td>3</td><td>32</td></tr>
<tr><td>80</td><td>4</td><td>32</td></tr>
<tr><td rowspan="4">7, 8, 9</td><td>160</td><td>1</td><td>64</td><td rowspan="4">Same for each
of three
sounding
frequencies</td></tr>
<tr><td>160</td><td>2</td><td>64</td></tr>
<tr><td>160</td><td>3</td><td>64</td></tr>
<tr><td>160</td><td>4</td><td>64</td></tr>
</table>

*See Table 3.

**Two spectral lines coded into five six-bit characters. See Table 4.

DRIFT-DATA RECORDING FORMAT

Table 2

7)[72] including a preface and the negative-Doppler data; the second (third and fourth for program 7), a preface and the positive-Doppler data. The preface includes the identification number of the Digisonde station, the date and time of the measurement, and other relevant drift-measurement parameters (see Table 3). Each of the 80 digits of preface information is coded separately into 80 six-bit characters. (The station identification may contain two digits, but in this case the entire number is coded into one character.) The logarithmic amplitudes (maximum 63 dB) are also coded into six-bit characters. The phase accuracy of the data is more critical: negative phases are shifted by 2π to make them positive, and all phases are converted to nine-bit numbers,

$$\phi_{new} = \frac{\phi_{old}}{2\pi} \times 511 \tag{154}$$

(giving a phase resolution of $2\pi/511$), then two nine-bit phases are coded into three six-bit characters (see Table 4).

With all the information coded into six-bit characters, ten characters can be packed into one 60-bit computer word. Thus each record, which includes 2160 characters, is recorded on digital tape in only 216 computer words, so that one tape of Digisonde data can hold over a thousand cases (2000 records) of drift data and a comparable number of ionograms. (All data is recorded as it is measured, so the ionogram and drift data are inter-mixed on the tape.) Since no digit of preface information exceeds four bits, the fifth bit (the second MSB) is set to one in the preface of the drift data, in order to distinguish it from the ionogram data.

[72] The program number, which was called P above to avoid confusion with the number N of quadrature samples, is called N in the following tables to conform with existing Digisonde documentation; see for example Bibl and Reinisch (1978a), p. 68.

CHARACTER #	SYMBOL	MEANING	
1	V	Station Identification	
2 - 6	YyΔDd	Calendar Year, Julian Day	
7 - 12	HhMmSs	Hour, Minute, Second	
21	R	Pulse Repetition Rate	
22	W	Pulse Width	
23, 24	Tt	Task # (Tt $\equiv$ 0 for Goose Bay)	
26	N	Program # (called P in text)	
		FREQ. #	
33 - 36	ΓFfg	1	Frequency in 10 kHz units, for each of the three or six sounding frequencies
37 - 40		2	
41 - 44		3	
45 - 48		4	
49 - 52		5	
53 - 56		6	
		RANGE #	
57 - 60	RrρG	1	Range [km] and Receiver Gain G in -10 dB units
61 - 64		2	
65 - 68		3	
69 - 72		4	
73 - 76		5	
77 - 80		6	

Parameters not listed are ionogram parameters.

DRIFT PREFACE

Table 3

CHARACTER #	1	2	3	4	5	6	7	.
6-BIT DATA	M_6^1	ϕ_9^1	ϕ_3^1	M_6^2	ϕ_9^2	M_6^3	ϕ_9^3	.
	M_5^1	ϕ_8^1	ϕ_2^1	M_5^2	ϕ_8^2	M_5^3	.	.
	M_4^1	ϕ_7^1	ϕ_1^1	M_4^2	ϕ_7^2	M_4^3	.	.
	M_3^1	ϕ_6^1	ϕ_3^2	M_3^2	ϕ_6^2	M_3^3	.	.
	M_2^1	ϕ_5^1	ϕ_2^2	M_2^2	ϕ_5^2	M_2^3	.	.
	M_1^1	ϕ_4^1	ϕ_1^2	M_1^2	ϕ_4^2	M_1^3	.	.

M_i^d is the i'th bit of the magnitude of F(d).

ϕ_i^d is the i'th bit of the phase of F(d).

CODING OF TWO SPECTRAL LINES INTO FIVE SIX-BIT CHARACTERS

Table 4

2.3 Digisonde-Data Simulation: Program TESTSKY

TESTSKY[73] is a Fortran-coded program which simulates the drift data outputted from the Digisonde. The program was started some years ago by AFGL and ULCAR, and was further developed by ULCAR for use in testing sky maps. The author has adapted TESTSKY to the University of Lowell's Cyber 71 computer system, and has modified and updated the program for use with the latest drift measurements. The program generates a simulated digital time sequence, transforms the time sequence into the frequency domain (with or without spectral averaging), and packs the data into two records in the same format as the Digisonde drift data.

The digital time sequence is calculated from sources of known incidence angles. The source information (azimuth, zenith, amplitude and Doppler frequency of the echo from each source; see Figure 12 in section 2.4.2 for the definition of the coordinate system) is specified on the input file TAPE1, which also includes the coordinates of the receiving antennas, the drift program number,[74] the sounding frequency, the task number (see Table 3), and the amplitude and seed (see below) of the noise to be added to each antenna. Arbitrary values for the Doppler frequencies can be inputted via TAPE1, or the frequencies can be calculated from the incidence angles of the sources and an assumed drift-velocity vector. The former choice is sufficient for testing the SKYMAP program (see section 2.4.4) in order to determine that SKYMAP calculates the correct source positions; the latter choice is necessary when it is desired to test program DRIFVEL (see section 2.5.3)

[73] See program listing in Appendix A.

[74] TESTSKY is coded only for drift programs 5, 6, 8 and 9.

which calculates the drift velocity on the assumption that all sources are moving at the same velocity. A binary-coded variable KPRINT (also inputted via TAPE1) determines whether to calculate the Doppler frequencies; it also determines whether to do the spectral averaging, whether to add noise to the time sequence, and which values (the time sequence, the frequency sequence, etc.) are to be printed (see comment statements in the program listing in Appendix A).

TESTSKY calculates for each antenna the digital time sequence

$$X_a(t_n) = \sum_s V_0(s) \cos (\Delta\omega_s t_n - \vec{k}_s \cdot \vec{r}_a) \tag{155}$$

$$Y_a(t_n) = \sum_s V_0(s) \sin (\Delta\omega_s t_n - \vec{k}_s \cdot \vec{r}_a) \tag{156}$$

$$|\vec{k}_s| = 2\pi/\lambda_s \tag{157}$$

$$\lambda_s = c/(f + \Delta f_s) \tag{158}$$

$$n = 0, 1, 2, \ldots, N-1 \tag{159}$$

(The parameters not defined here are the same as in section 2.1.1.) The time-independent phase $-\vec{k}_s \cdot \vec{r}_a$ in (155) and (156) is different from $\phi_{a,s}$ of equations (65) and (66), which has the additional phase term $\vec{k}_s \cdot \vec{R}_{1,s} + \delta_s$ (see equation (51)); since this term cancels out in the FWPD calculation (see equation (179)), it can be omitted in the time-sequence simulation.[75] Also, compare the definition of $|\vec{k}_s|$ in (157) to equation (47): the latter is an approximation that we use in our calculations; TESTSKY uses the exact definition of $|\vec{k}_s|$.

[75]Except that δ_s is included when simulating drift data from more than one source at the same Doppler frequency. See section 2.4.3.

Note also that in (159), n starts at zero instead of -N/2 (compare equation (55)): adding N/2 to each of the values of n is equivalent to replacing $\Delta\omega_s \, t_n$ of equations (65) and (66) by (using equations (55), (116) and (118)):

$$\Delta\omega_s \, (n + N/2) \, \delta t = \Delta\omega_s \, t_n + D_s \, \pi \tag{160}$$

The phase constant $D_s \, \pi$ can be considered to be absorbed by δ_s.

If desired, noise can be added to the time sequence. For each of the simulated quadrature samples $X_a(t_n)$ and $Y_a(t_n)$, subroutine GAUSS1 calls a Fortran intrinsic function RANF, which is a random number generator, and uses the random numbers to generate a Gaussian noise sequence. The random number sequence can be varied by varying the seed of RANF. The noise is then added to the sequence of quadrature samples. Different noise sequences are added to the real parts $X_a(t_n)$ and to the imaginary parts $Y_a(t_n)$ of the time sequence. The result is not a Gaussian distribution of noise, but then neither is the noise in the real data. With an I.F. bandwidth of ±10 kHz in the Digisonde receiver and a Doppler bandwidth of ±4 Hz or ±8 Hz (see Table 1), noise outside the Doppler range folds over and shows up within the Doppler range.

Subroutine FORER transforms the time sequence of each antenna into the frequency domain. The transform is defined as in equation (114), except that again n runs from 0 to N-1. The Doppler-frequency resolution and the Doppler range are the same as in section 2.2.1; $F_a(d)$ is the same as in section 2.2.2 except for a phase shift $(D_s\text{-}d)\pi$: S(s,d) becomes (compare equation (124))

$$S(s,d) = N \, \frac{\sin\,(D_s-d)\pi}{(D_s-d)\pi} \, e^{i[(D_s-d)\pi \, - \, (D_s-d)\pi/N]} \tag{161}$$

The Fourier algorithm used in subroutine FORER is the Radix 2 Decimation-in-Frequency Fast Fourier Transform

(FFT),[76] taken from a program written by Michael Forman. The FFT is a discrete Fourier transform algorithm which calculates a transform of N points (for $N = 2^L$, with L an integer) by a suitable combination of two transforms, each of length N/2. An N-point transform is calculated from two (N/2)-point transforms, each of which is computed using two (N/4)-point transforms, and so on; in the final analysis, the N-point transform is calculated from N/2 two-point transforms. Whereas the direct transform employs N^2 complex multiplications to compute all N points, the FFT needs only $N \times L = N \log_2 N$ multiplications. For 64 and 128 points, this is a ratio of 4096/384 (over 10/1) and 16384/128 (over 18/1) respectively, resulting in a significant saving of computer time. With the FFT, the order of the sequence of points is shuffled and must be rearranged to produce the correct results. The Radix 2 Decimation-in-Time algorithm shuffles the input sequence, and the output is obtained in natural order. The algorithm used in TESTSKY takes the input in natural sequence so that the output must be reshuffled. The function IBRSH in TESTSKY determines the indices for the calculation of the N/2 two-point transforms, the combinations of half-length to full-length transforms, and the re-shuffling of the output into the correct order.

Spectral averaging is applied to the complex frequency spectrum by averaging three adjacent spectral lines with weights (-1), (2), (-1) instead of (1), (2), (1), since for the Fourier transform defined with n starting at zero, the Hanning window is $[.5 - .5 \cos (2\pi n/N)]$.[77] The resulting weighted spectrum $F_a'(d)$ is the same as in equation (153), except for an added phase factor $(D_s - d)\pi$: i.e. $\phi_{a,s}$ of (153)

[76] Peled and Liu (1976), sections 3.2 and 3.3.

[77] Peled and Liu (1976), p. 99, exercise 2.6(c).

is replaced by $\phi_{a,s} + (D_s - d)\pi$.

After spectral averaging, the frequency spectrum is converted from (real, imaginary) to (amplitude, phase). Subroutine C720 then converts the amplitudes to $\log_{10}$ values and scales them to a maximum log value of 63 (six bits); the phases are converted as described in section 2.2.4 to nine-bit values. The preface and data for each case are then packed in the same format as in the Digisonde, and outputted on file TAPE9 by subroutine C2160 in two records (negative and positive Dopplers, in that order), with the 2160 six-bit characters for each record packed in 216 60-bit words. Program TESTSKY produces data for only one sounding frequency per case, but its output is otherwise identical to that of the Digisonde.

2.4 Analysis of the Drift Data: Locating the Sources

2.4.1 The Frequency-Wavenumber Power Density

The FWPD is a transform from the amplitude/phase domain into the spatial domain, using the cross-spectra between antennas to determine the angle of incidence of each spectral component.

The FWPD is defined as in equation (84), which is repeated here,

$$P(d, \vec{k}) = \sum_{a=1}^{4} \sum_{a'=1}^{4} F_a(d)\, F^*_{a'}(d)\, e^{i\vec{k}\cdot(\vec{r}_a - \vec{r}_{a'})} \tag{162}$$

$$\vec{k} \equiv \vec{k}\,(x_m, y_{m'}) \tag{163}$$

$$P(d, \vec{k}) \equiv P\,(d, x_m, y_{m'}) \tag{164}$$

$$P(d, \vec{k}) = \sum_{a=1}^{4} F_a(d)\, e^{i\vec{k}\cdot\vec{r}_a} \sum_{a'=1}^{4} [F_{a'}(d)\, e^{i\vec{k}\cdot\vec{r}_{a'}}]^* \tag{165}$$

$$= \left| \sum_{a=1}^{4} F_a(d)\, e^{i\vec{k}\cdot\vec{r}_a} \right|^2 \tag{166}$$

where * denotes the complex conjugate; $F_a(d)$ and $F_{a'}(d)$ are the Fourier spectra at antennas a and a' respectively; and $\vec{k}$ is a scanning vector of constant magnitude $2\pi/\lambda$ but varying direction, as explained in section 2.1.3. $F_a(d) \times F^*_{a'}(d)$ is the cross-spectrum between a and a', and $e^{i\vec{k}\cdot\vec{r}_a}$, $e^{i\vec{k}\cdot\vec{r}_{a'}}$ are computational phase delays.

If no two Doppler shifts fall on the same spectral line, then equation (153) yields (the prime has been dropped):

$$F_a(d) = V_{a,s}\, e^{i\phi_{a,s}} \tag{167}$$

$$F_{a'}(d) = V_{a',s}\, e^{i\phi_{a',s}} \tag{168}$$

$$V_{a,s} = V_{a',s} = \frac{N}{2} V_0(s) \frac{\sin b}{b} \cos c \left(1 - \frac{\sin^2 c}{\sin^2 c - \sin^2 \pi/N}\right) \tag{169}$$

$$b = (D_s - d)\,\pi \tag{170}$$

$$c = (D_s - d)\,\pi/N \tag{171}$$

We are neglecting the ringing contributions of neighboring Doppler lines, since spectral averaging has reduced their significance (see Figure 8). For each source whose Doppler shift $\Delta\omega_s$ is an integral multiple of $\delta\omega$, equation (169) becomes

$$V_{a,s} = V_{a',s} = \frac{N}{2} V_0(s) \tag{172}$$

Using (167) and (168), the FWPD becomes

$$P(d, \vec{k}) = \sum_{a=1}^{4} \sum_{a'=1}^{4} V_{a,s}^2 \, e^{i(\psi_{a,s} - \psi_{a',s})} \tag{173}$$

$$= \sum_{a=1}^{4} V_{a,s}^2$$

$$+ \sum_{a=1}^{3} \sum_{a'=a+1}^{4} V_{a,s}^2 \, [e^{i(\psi_{a,s}-\psi_{a',s})} + e^{-i(\psi_{a,s}-\psi_{a',s})}] \tag{174}$$

$$= \sum_{a=1}^{4} V_{a,s}^2 + 2 \sum_{a=1}^{3} \sum_{a'=a+1}^{4} V_{a,s}^2 \cos(\psi_{a,s}-\psi_{a',s}) \tag{175}$$

$$\psi_{a,s} = \phi_{a,s} + \vec{k}\cdot\vec{r}_a \tag{176}$$

$$\psi_{a',s} = \phi_{a',s} + \vec{k}\cdot\vec{r}_{a'} \tag{177}$$

where the first term of (175) is the auto-correlation term. From the definition of $\phi_{a,s}$ in equation (51),

$$\psi_{a,s} - \psi_{a',s} = \vec{k}_s\cdot\vec{R}_{1,s} - \vec{k}_s\cdot\vec{r}_a + \delta_s + \vec{k}\cdot\vec{r}_a$$

$$- \vec{k}_s\cdot\vec{R}_{1,s} + \vec{k}_s\cdot\vec{r}_{a'} - \delta_s - \vec{k}\cdot\vec{r}_{a'} \tag{178}$$

$$= (\vec{k} - \vec{k}_s)\cdot(\vec{r}_a - \vec{r}_{a'}) \tag{179}$$

so that in the phase of the echo only the phase component which depends on the antenna separation matters. From (179), equation (175) is clearly a maximum when

$$\vec{k} = \vec{k}_s \tag{180}$$

that is, when the scanning vector $\vec{k}$ looks in the direction of the wave-propagation vector $\vec{k}_s$.

2.4.2 The Sky Map

As mentioned in section 2.1.3, the direction of the scanning vector $\vec{k}$ is defined by the Cartesian coordinates $(x_m, y_{m'})$, which vary in steps of equal increments on both horizontal axes of a square map. The north-west quadrant of the map area is sketched in Figure 9 and illustrated in more detail in Figure 10. Imagine a spherical cap formed by the set of all points at range R, zenith angle ζ and azimuth α,

$$\zeta \leq \zeta_{max} \tag{181}$$

$$0 \leq \alpha < 360° \tag{182}$$

The sky map represents that area of the sky which is on the curved surface of the cap, and whose vertical projection onto a horizontal plane forms a square whose corners are at (R, ζ_{max}) and azimuth 45° (NE), 135° (SE), 225° (SW) and 315° (NW). (The azimuth α is defined as zero on the x axis, which points north, and increases towards the -y axis, or east.)

The incremental steps δx and δy for the x- and y-axis coordinates are defined by R and ζ_{max}, as illustrated in Figure 11. The range vector at the corner of the map has x and y components both equal to $.707 \, R \sin \zeta_{max}$. These components are divided into 20 equal increments so that

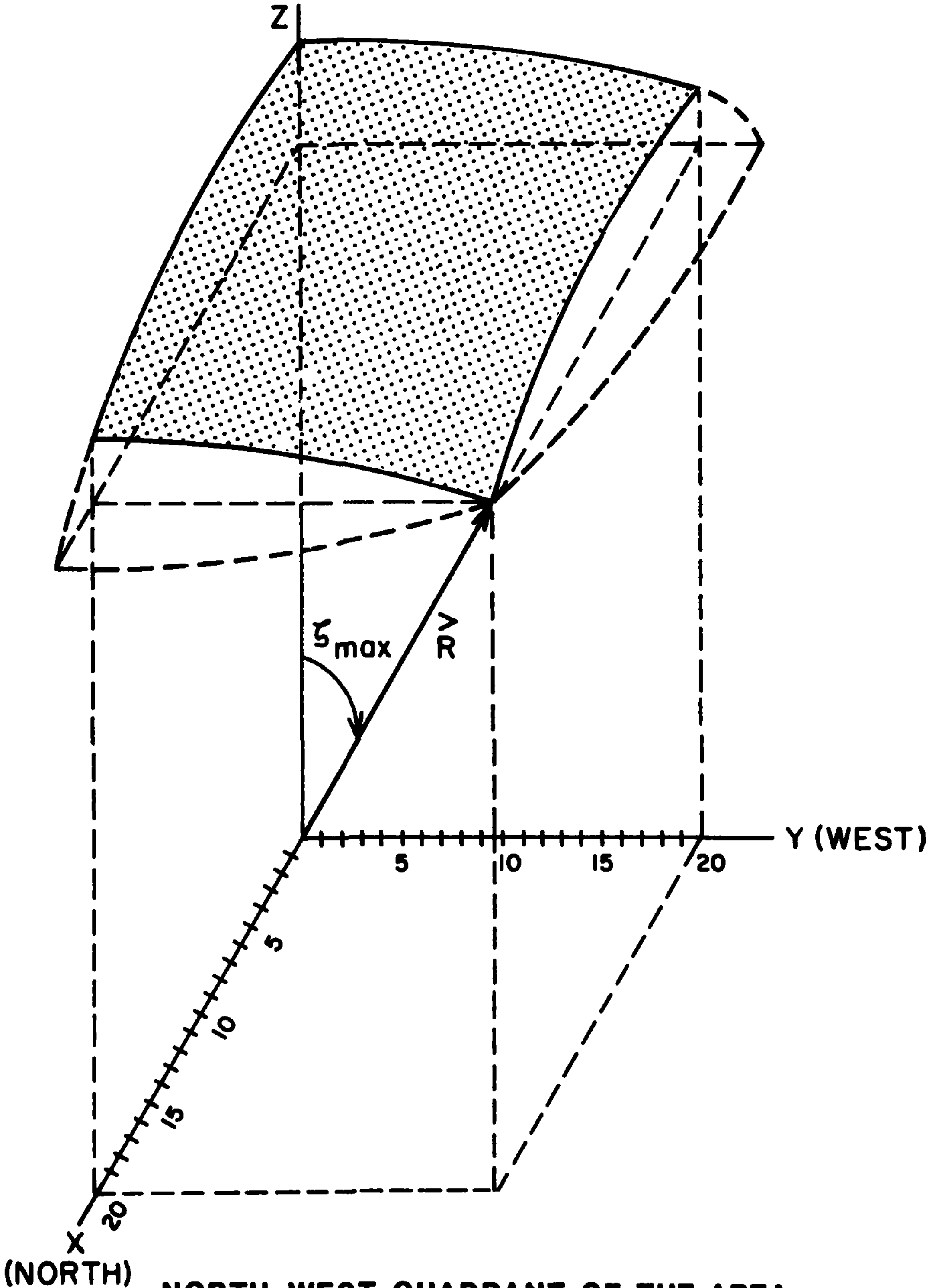
$$\delta x = \delta y = (.707 \, R \sin \zeta_{max})/20 \tag{183}$$

Each of the sky map coordinates then corresponds to a point in the sky whose position vector $\vec{R}$ has components x_m, $y_{m'}$, z:

$$x_m = m \, \delta x = (.707 \, R \sin \zeta_{max}) \frac{m}{20} \tag{184}$$

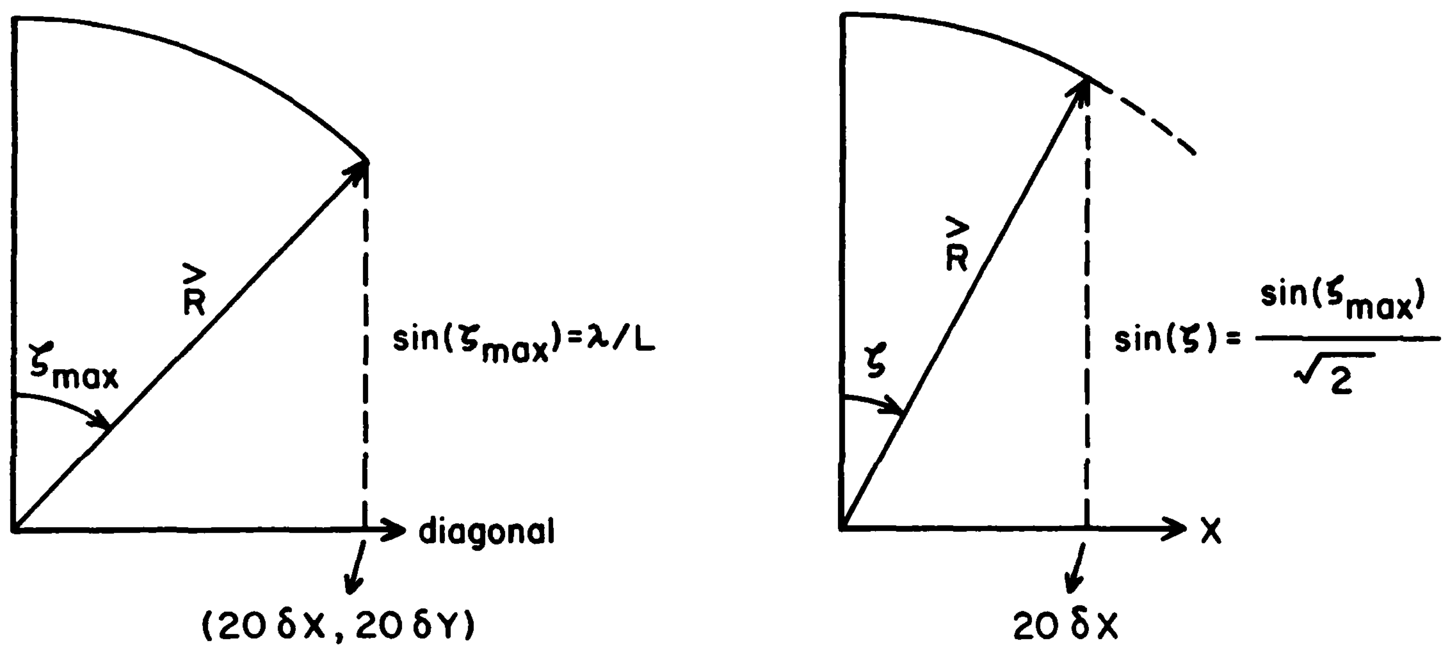
$$y_{m'} = m' \, \delta y = (.707 \, R \sin \zeta_{max}) \frac{m'}{20} \tag{185}$$

$$z = (R^2 - x_m{}^2 - y_{m'}^2)^{1/2} \tag{186}$$



NORTH-WEST QUADRANT OF THE AREA REPRESENTED BY THE SKY MAP

Figure 9

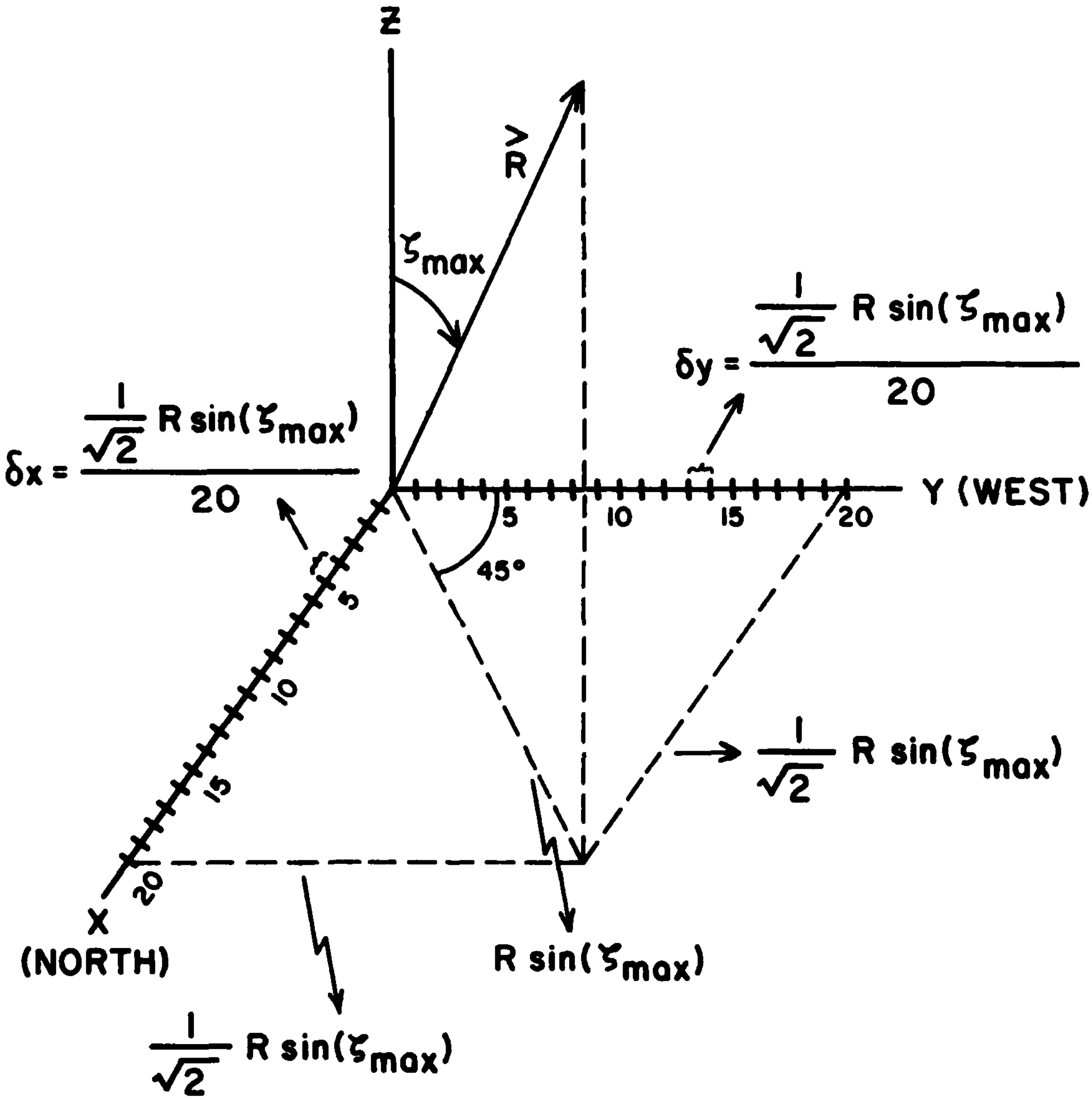


CROSS-SECTION ALONG DIAGONAL OF SKY MAP
(a)

CROSS-SECTION ALONG X AXIS OF SKY MAP
(b)

CROSS-SECTIONS OF SKY AREA REPRESENTED BY SKY MAP

Figure 10



MAP INCREMENTS δx AND δy IN TERMS OF R AND ζ_{max}

Figure 11

For drift-data simulation in program TESTSKY (see section 2.3), the source positions are inputted in terms of the angles α and ζ, which are related to x, y and z as follows (see Figure 12):

$$x = R \sin \zeta \sin (\alpha - 3\pi/2) \tag{187}$$

$$= R \sin \zeta \cos \alpha \tag{188}$$

$$y = R \sin \zeta \cos (\alpha - 3\pi/2) \tag{189}$$

$$= - R \sin \zeta \sin \alpha \tag{190}$$

$$z = R \cos \zeta \tag{191}$$

For a given Doppler number d, $P(d, \vec{k})$ is calculated for each of 1681 angles of $\vec{k}$ $(x_m, y_{m'})$; since $\vec{k}$ and $\vec{R}$ are anti-parallel,

$$\vec{k} = k_x \hat{x} + k_y \hat{y} + k_z \hat{z} \tag{192}$$

$$\vec{R} = x \hat{x} + y \hat{y} + z \hat{z} \tag{193}$$

$$\vec{k} = k (-\hat{R}) = - \frac{k}{R} \vec{R} \tag{194}$$

$$= - \frac{k}{R} (x \hat{x} + y \hat{y} + z \hat{z}) \tag{195}$$

$$\vec{k}(x_m, y_{m'}) = - \frac{k}{R} x_m \hat{x} - \frac{k}{R} y_{m'} \hat{y} - \frac{k}{R} z \hat{z} \tag{196}$$

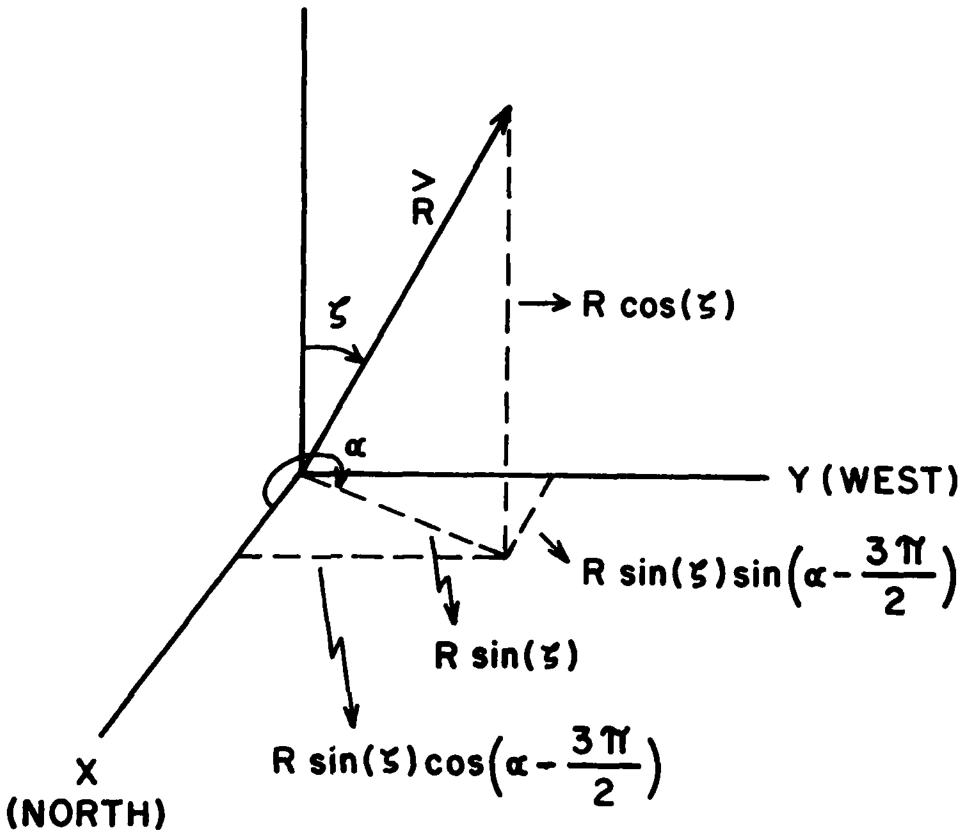
so that

$$k_x(m) = - (.707 k \sin \zeta_{max}) \frac{m}{20} \tag{197}$$

$$k_y(m') = - (.707 k \sin \zeta_{max}) \frac{m'}{20} \tag{198}$$

The z component of $\vec{k}$ $(x_m, y_{m'})$ is not needed since in $P(d,\vec{k})$, $\vec{k}$ appears in the term $\vec{k} \cdot \vec{r}_a$, and the antenna position vector $\vec{r}_a$ has no z component.

The antenna pattern produced by the variations of $P(d, \vec{k})$ as $\vec{k}$ $(x_m, y_{m'})$ scans the sky contains not only the



COMPONENTS OF THE RANGE VECTOR $\vec{R}$

Figure 12

main lobe (whose values increase to a maximum as $\vec{k}$ approaches the source vector $\vec{k}_s$ from any direction) but also two types of side lobes, which we call the major and minor side lobes: the major side lobes have a peak value equal to the peak of the main lobe; the minor side lobes have a maximum 6 dB below that of the main lobe. Both types of lobes are illustrated in Figure 13, which is the antenna pattern for a source directly overhead (the main lobe is in the center), at a sounding frequency of 10 MHz. The numbers labeled IX and IY to the right of and below the map respectively are the indices of the map coordinates; the other indices IXMAX and IYMAX will be explained in section 2.4.4. IX and IY are more properly array indices as defined in program SKYMAP but we consider them as map indices corresponding to m and m' as follows:

$$m = 21 - IX \tag{199}$$

$$m' = 21 - IY \tag{200}$$

$$IX, IY = 1, 2, 3, \ldots, 41 \tag{201}$$

$$m, m' = 20, 19, 18, \ldots, 0, \ldots, -18, -19, -20 \tag{202}$$

For example,

$$\vec{k}(IX = 1, IY = 1) = \vec{k}(x_{20}, y_{20}) \tag{203}$$

$$\vec{k}(IX = 41, IY = 41) = \vec{k}(x_{-20}, y_{-20}) \tag{204}$$

(Note that the positive quadrant (+x, +y) is the NW quadrant of the sky map; see Figure 9). At each coordinate of the antenna pattern, $P(d, \vec{k})$ for each $\vec{k}(IX, IY)$ and any given d (the result is the same no matter which Doppler number is used) is indicated in dB. Note the six minor side lobes of peak density 67 dB around the main lobe, and the six major side lobes further out, of the same peak density (73 dB) as the main lobe. The angles shown are the zenith angles; the reason for their uneven spacing will be explained below.

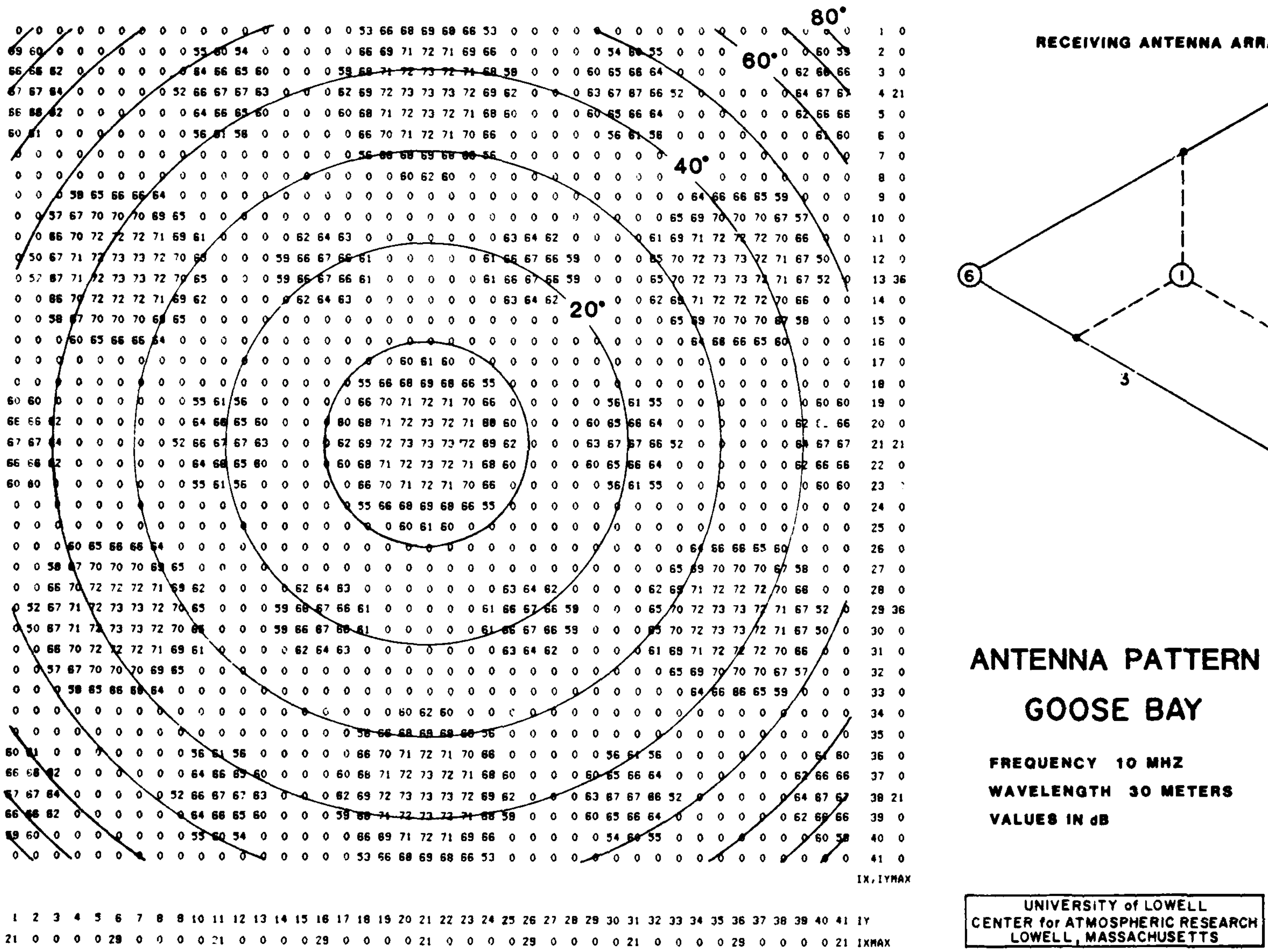
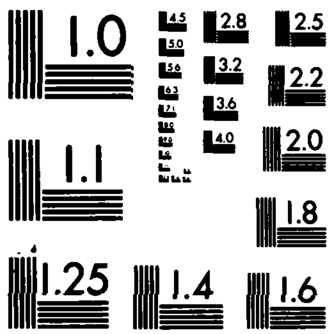

RECEIVING ANTENNA ARRAY
100 [m]
3
ANTENNA PATTERN
GOOSE BAY
FREQUENCY 10 MHZ
WAVELENGTH 30 METERS
VALUES IN dB
UNIVERSITY of LOWELL
CENTER for ATMOSPHERIC RESEARCH
LOWELL, MASSACHUSETTS
20°
40°
60°
80°
IX, IYMAX
IY
IXMAX

Figure 13

AD-A140 509 A HIGH FREQUENCY RADIO TECHNIQUE FOR MEASURING PLASMA DRIFTS IN THE IONOS..(U) LOWELL UNIV MA CENTER FOR ATMOSPHERIC RESEARCH C G DOZOIS JUL 83 ULRF-424/CAR 2/3

UNCLASSIFIED AFGL-TR-83-0202 F19628-80-C-0064 F/G 4/1 NL



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

With a proper choice of ζ_{max}, the map area can be limited so as to exclude the center (peak value) of the first major side lobe. A coarse approximation for ζ_{max} can be derived by considering two antennas 1 and 2. The term in the FWPD (equation 175) which includes $\psi_{1,s}$ and $\psi_{2,s}$ is (ignoring the constants):

$$\cos\,(\psi_{1,s} - \psi_{2,s}) = \cos\,(\vec{k}_s \cdot \vec{r}_2 - \vec{k} \cdot \vec{r}_2) \tag{205}$$

where the right side follows from equation (179) with $\vec{r}_1 = 0$. The maxima of (205) are at

$$\vec{k}_s \cdot \vec{r}_2 - \vec{k} \cdot \vec{r}_2 = 0,\ \pm 2\pi,\ \pm 4\pi,\ \ldots \tag{206}$$

Figure 14 illustrates the relationship between the zenith angle ζ and the angle θ (where θ is between $\vec{k}$ and $\vec{r}$) for $\vec{k}$ in the same vertical plane as $\vec{r}$, the antenna-position vector. In quadrant I,

$$\vec{k} \cdot \vec{r} = \frac{2\pi}{\lambda} |\vec{r}| \cos\,(90° - \zeta) \tag{207}$$

$$= \frac{2\pi}{\lambda} r \sin \zeta \tag{208}$$

and in quadrant II,

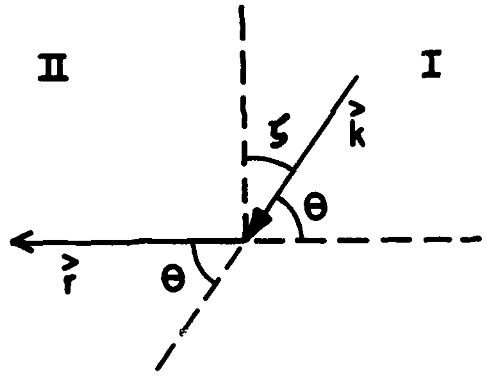
$$\vec{k} \cdot \vec{r} = \frac{2\pi}{\lambda} |\vec{r}| \cos\,(90° + \zeta) \tag{209}$$

$$= -\frac{2\pi}{\lambda} r \sin \zeta \tag{210}$$

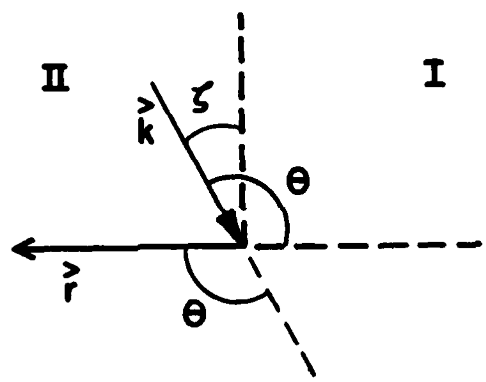
Now suppose that ζ_s (the zenith angle of $\vec{k}_s$) is in quadrant I, and

$$\sin \zeta_s = \lambda/2r \tag{211}$$

and ζ_k (the zenith angle of the scanning vector) is at the same zenith but in quadrant II, then from (208) and (210), equation (206) yields in this example



(a) $\vec{k}$ IN QUADRANT I



(b) $\vec{k}$ IN QUADRANT II

RELATIONSHIP BETWEEN ZENITH ANGLE ζ, AND ANGLE θ BETWEEN $\vec{k}$ AND $\vec{r}$, FOR $\vec{k}$ AND $\vec{r}$ IN THE SAME PLANE

Figure 14

$$\vec{k}_s \cdot \vec{r}_2 - \vec{k} \cdot \vec{r}_2 = \frac{2\pi}{\lambda} r \sin \zeta_s - (- \frac{2\pi}{\lambda} r \sin \zeta_k) \tag{212}$$

$$= \frac{2\pi}{\lambda} r \left(\frac{\lambda}{2r} + \frac{\lambda}{2r}\right) \tag{213}$$

$$= 2\pi \tag{214}$$

so that the FWPD (for two antennas) is a maximum in the direction of the source (main lobe) and at the same zenith angle but diametrically opposite in azimuth (side lobe). To exclude this side lobe, the searching angle (with only two antennas) must be limited to

$$\sin \zeta_{max} < \lambda/2r \tag{215}$$

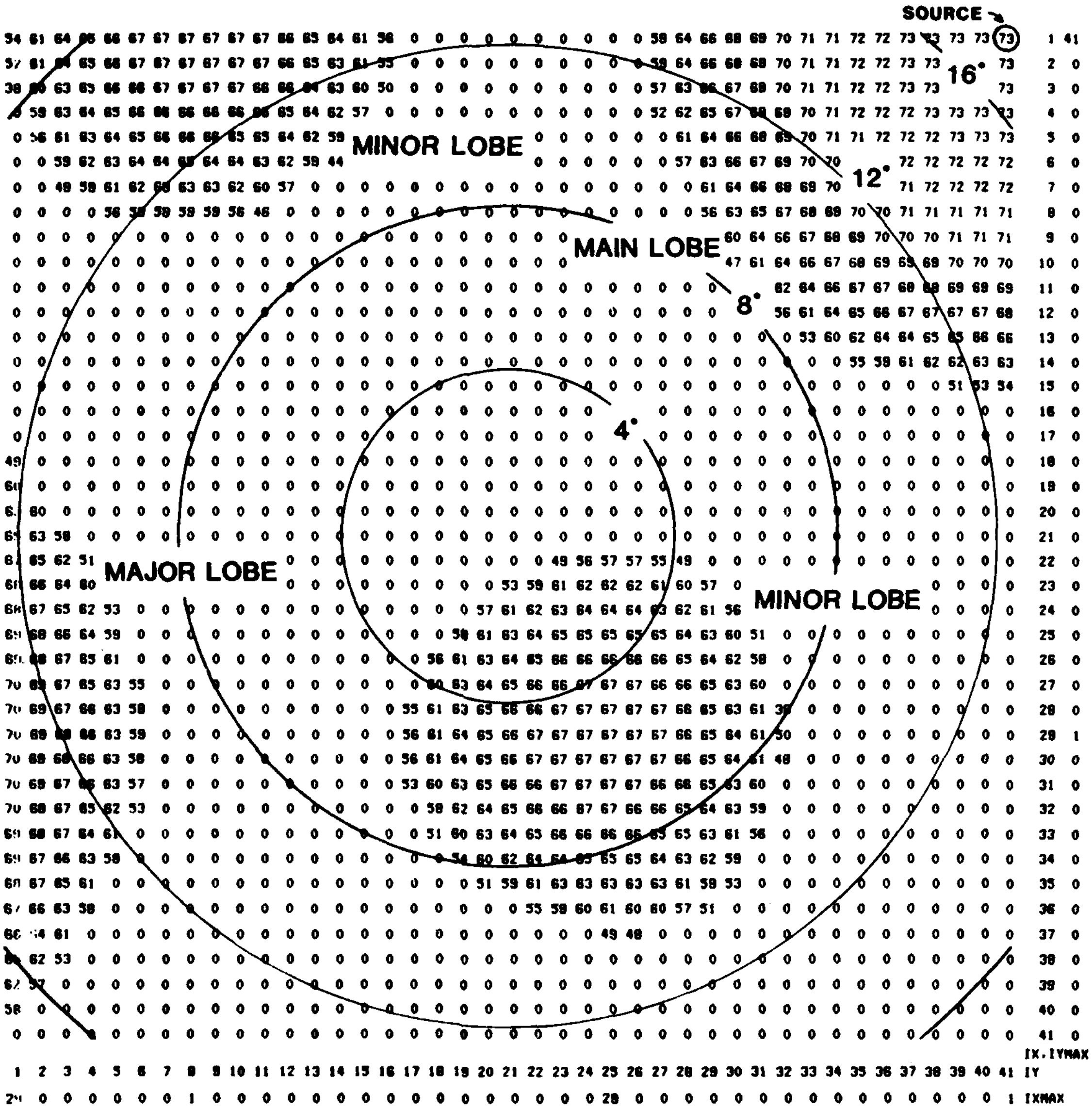
The determination of ζ_{max} with four antennas was done numerically, and it was found that setting

$$\sin \zeta_{max} = \lambda/L \tag{216}$$

(where L is the maximum antenna separation -- see Figure 5) eliminates the peak of the first major side lobe. This is illustrated in Figure 15 which shows the antenna pattern at a sounding frequency of 10 MHz, for a source placed at the extreme upper right-hand corner of the map, at zenith angle

$$\zeta_{max} = 17.42° \tag{217}$$

Part of the major side lobe appears near the bottom, on the left. Its maximum value at (IX = 29, IY = 1) is 3 dB below the peak of the main lobe; its own peak value is outside the map, which justifies the value of ζ_{max} in (217) calculated according to (216). Two minor side lobes show up with peaks at (1, 8) and at (29, 25); these are 6 dB below the peak of the main lobe. Thus it is possible to determine the actual source position from the maximum value of P(IX, IY). Note, however, that if a source is outside ζ_{max}, the peak of one of its major side lobes may appear on the map.



FREQUENCY 10 MHZ

WAVELENGTH 30 METERS

ζ_{max} = 17.42°

SIDE LOBES WITH $\sin(\zeta_{max}) - \lambda/L$,

SOURCE AT ZENITH ANGLE ζ_{max}

Figure 15

ζ_{max} is a function of λ; at lower sounding frequencies, the lobes are spread further apart, so ζ_{max} is larger. Up to about 4 MHz, ζ_{max} as defined in (216) is greater than 45°, but the program SKYMAP sets it to 45° since it is not expected that the receiving pattern of the antenna array at Goose Bay will pick up sources beyond a zenith angle of 45°.

With the sky map coordinates as defined above, the angular increments for the zenith angles at a given azimuth are not equally spaced (as can be seen in the antenna pattern of Figure 13), which explains the apparent asymmetry of some of the side lobes in the antenna pattern. This uneven spacing of the zenith angles is illustrated in Figure 16, which shows a vertical cross-section of the sky along the map diagonal ξ, for ζ_{max} at 45° (the maximum for the sky maps) and at 90° (the maximum for the antenna pattern of Figure 13). From equation (183), the diagonal map increment $\delta\xi$ is

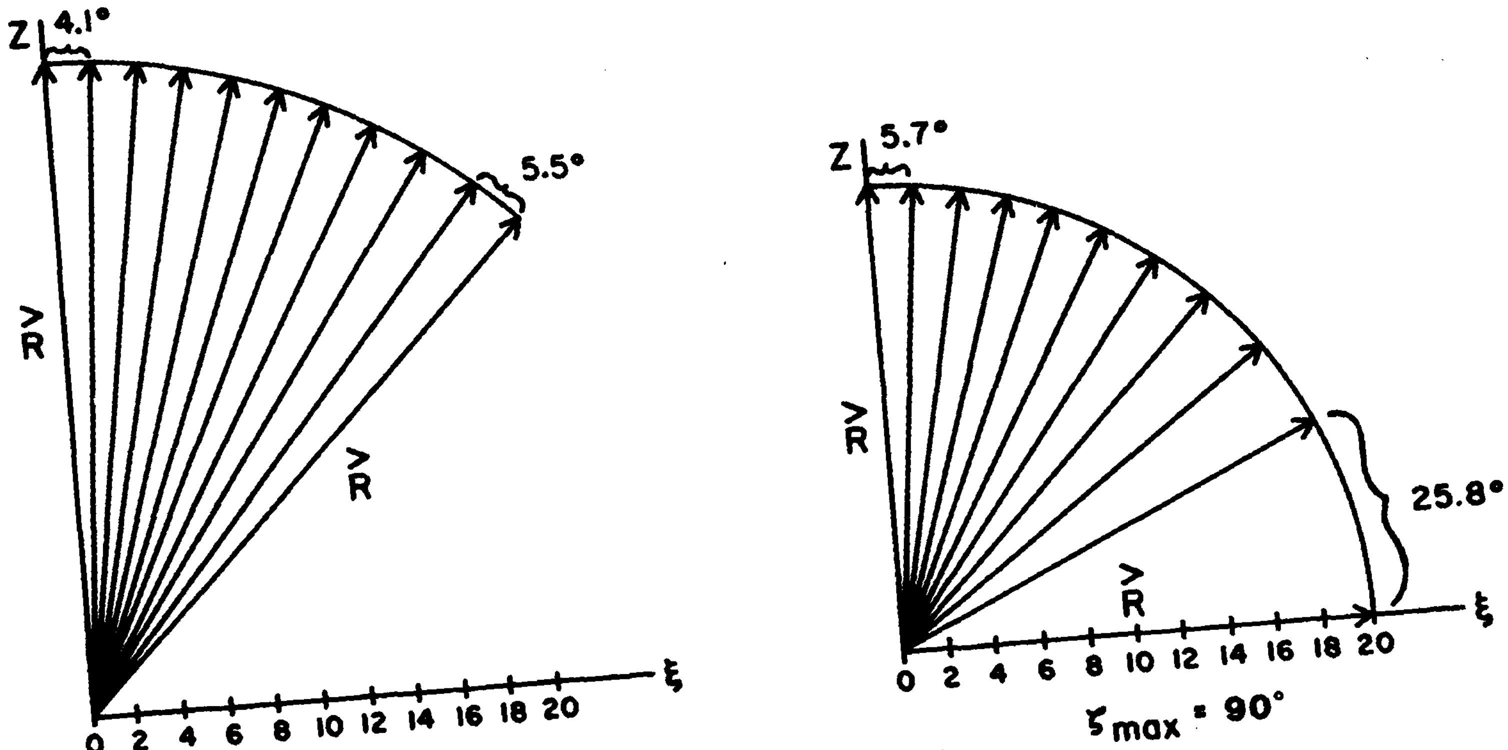
$$\delta\xi = (\delta x^2 + \delta y^2)^{1/2} \tag{218}$$

$$= \delta x \sqrt{2} \tag{219}$$

$$= (R \sin \zeta_{max})/20 \tag{220}$$

which yields the scale values given in the figure.

The range vectors $\vec{R}$ are drawn for the values of m (= m') which are multiples of 2. Since the increments of arc length are proportional to the increments in zenith angle, a comparison of the arc-length increments near the center of the map with those near the edge gives a qualitative picture of the variations in zenith. The distortion near the edge is much less for the sky maps than for the antenna pattern in Figure 13. A few specific values of angular increments are indicated in Figure 16; these were calculated from



(a) $\zeta_{max} = 45°$
SCALE: $\delta\xi = .035R$

(b) $\zeta_{max} = 90°$
SCALE: $\delta\xi = .05R$

ZENITH-ANGLE INCREMENTS ALONG THE MAP DIAGONAL ξ

Figure 16

$$\sin \zeta(\vec{R}) = \xi/R \tag{221}$$

$$= m\ \delta\xi/R \tag{222}$$

$$= (m \sin \zeta_{max})/20 \tag{223}$$

where $\zeta(\vec{R})$ is the zenith angle of the range vector $\vec{R}$.

2.4.3 More Than One Echo at the Same Doppler Line

To illustrate the result of the FWPD calculation when more than one source has the same Doppler shift, let us assume two sources s' and s" with

$$\Delta\omega_{s'} = \Delta\omega_{s''} = d'\ \delta\omega \tag{224}$$

$$\Delta\omega_{s'} = D_{s'}\ \delta\omega \tag{225}$$

$$\Delta\omega_{s''} = D_{s''}\ \delta\omega \tag{226}$$

$$D_{s'} = D_{s''} = d' \tag{227}$$

where d' is one of the Doppler numbers d. In the more general case, $D_{s'}$ and $D_{s''}$ may not be integers (i.e. may not be exactly equal to d') and may not even be equal to each other; if they are both approximately equal to d', then they fall on the same Doppler line d'. The principle to be illustrated below is the same with or without assumption (224); but this assumption makes the algebra considerably simpler.

With $D_{s'}$ (= $D_{s''}$) an integer, the spectrum is the same before and after spectral averaging except for a scaling factor, so let us consider first equation (126), which is the spectrum before averaging: in (126), only the first two terms are non-zero, since it is assumed that there are only two sources; and from equation (129),

$$S(s', d') = S(s'', d') = N \tag{228}$$

$$D_{s'} = D_{s''} = d' \tag{229}$$

so that

$$F_a(d') = N\, V_0(s')\, e^{i\phi_{a,s'}} + N\, V_0(s'')\, e^{i\phi_{a,s''}} \tag{230}$$

A comparison of equations (119) and (143) shows that spectral averaging replaces S(s,d) by the bracket in (143), which yields equation (151); it can be shown that with D_s an integer, (151) becomes N/2, so that (after averaging),

$$F_a(d') = \frac{N}{2} \left[V_0(s')\, e^{i\phi_{a,s'}} + V_0(s'')\, e^{i\phi_{a,s''}}\right] \tag{231}$$

To make the FWPD analytically tractable, we make the simplifying assumption that the amplitude V_0 of both sources is the same, and write

$$F_a(d') = \frac{N}{2} V_0 \left[e^{i\phi_{a,s'}} + e^{i\phi_{a,s''}}\right] \tag{232}$$

$$V_0 = V_0(s') = V_0(s'') \tag{233}$$

$$e^{i\phi_{a,s'}} + e^{i\phi_{a,s''}} = 2 \cos\left[(\phi_{a,s'} - \phi_{a,s''})/2\right] \times e^{i(\phi_{a,s'} + \phi_{a,s''})/2} \tag{234}$$

$$F_a(d') = V_a\, e^{i(\phi_{a,s'} + \phi_{a,s''})/2} \tag{235}$$

$$V_a \equiv V_a(s',s'') = N\, V_0 \cos\left[(\phi_{a,s'} - \phi_{a,s''})/2\right] \tag{236}$$

The last equation expresses the fact that with two (or more) echoes on the same Doppler line, the amplitude of that Doppler is in general different at each antenna. We write also $F_{a'}(d')$ as

$$F_{a'}(d') = V_{a'}\, e^{i(\phi_{a',s'} + \phi_{a',s''})/2} \tag{237}$$

$$V_{a'} = N\, V_0 \cos\left[(\phi_{a',s'} - \phi_{a',s''})/2\right] \tag{238}$$

(To avoid confusion, remember that as defined consistently above,

$$a,\ a' = 1,\ 2,\ 3,\ 4 \tag{239}$$

$$s = s',\ s'',\ s''',\ \ldots \tag{240}$$

$$d = d',\ d'',\ d''',\ \ldots \tag{241}$$

that is, the antenna index a' is a running index and not a specific value of a.) Then the FWPD (equation (162) evaluated for d = d') becomes

$$P \equiv P(d', \vec{k}) = \sum_{a=1}^{4} \sum_{a'=1}^{4} V_a\, V_{a'}\, e^{i(\Psi_a - \Psi_{a'})} \tag{242}$$

$$\Psi_a \equiv \Psi_a(s', s'') = (\phi_{a,s'} + \phi_{a,s''})/2 + \vec{k}\cdot\vec{r}_a \tag{243}$$

$$\Psi_{a'} \equiv \Psi_{a'}(s',s'') = (\phi_{a',s'} + \phi_{a',s''})/2 + \vec{k}\cdot\vec{r}_{a'} \tag{244}$$

$$P = \sum_{a=1}^{4} V_a^{\,2} + \sum_{a=1}^{3} \sum_{a'=a+1}^{4} \{V_a\, V_{a'}[e^{i(\Psi_a-\Psi_{a'})} + e^{-i(\Psi_a-\Psi_{a'})}]\} \tag{245}$$

$$P = \sum_{a=1}^{4} V_a^{\,2} + \sum_{a=1}^{3} \sum_{a'=a+1}^{4} 2\, V_a\, V_{a'} \cos\,(\Psi_a - \Psi_{a'}) \tag{246}$$

Using (236), (238), (243), (244) and the definition (51) of $\phi_{a,s}$, equation (245) becomes:

$$\begin{aligned} P = {} & N^2\, V_0^{\,2} \sum_{a=1}^{4} \cos^2 \left[\frac{\vec{k}_{s''}-\vec{k}_{s'}}{2} \cdot \vec{r}_a + \delta\right] \\ & + 2\, N^2\, V_0^{\,2} \left\{ \sum_{a=1}^{3} \sum_{a'=a+1}^{4} \cos \left[\frac{\vec{k}_{s''}-\vec{k}_{s'}}{2} \cdot \vec{r}_a + \delta\right] \right. \\ & \times \cos \left[\frac{\vec{k}_{s''}-\vec{k}_{s'}}{2} \cdot \vec{r}_{a'} + \delta\right] \\ & \left. \times \cos \left[\left(\vec{k} - \frac{\vec{k}_{s'}+\vec{k}_{s''}}{2}\right)\cdot(\vec{r}_a - \vec{r}_{a'})\right] \right\} \end{aligned} \tag{247}$$

$$\delta = \frac{\delta_{s'} - \delta_{s''}}{2} \tag{248}$$

Thus with two (or more) echoes at the same Doppler frequency, the initial phase of each echo does not cancel out. Examples of the effects of various values of δ will be shown in section 3.1.

2.4.4 Program SKYMAP

The SKYMAP program[78] is used to calculate sky maps using Doppler-drift data from either the Digisonde or program TESTSKY. The original SKYMAP program was developed a few years ago by ULCAR. In its present form, it retains the original routines for unpacking and decoding the data; but the rest of the program has been modified and expanded extensively by the present author.

The drift data is inputted via file TAPE1. At the beginning of each run, the program requests the value of KPRINT, the record number, the frequency number(s), and whether negative, positive or both Dopplers are to be processed. KPRINT is, as in program TESTSKY, a binary-coded variable which determines the functions to be performed (see below). The record number determines whether to start processing the data with the first record found on input file TAPE1 or with a later record. The frequency number (or numbers) indicates whether the data for all three or six sounding frequencies is to be processed, or only the data from one of the sounding frequencies.

The functions performed by the SKYMAP program are of three types:[79] data checks; separating the drift data from

[78] See listing in Appendix B.

[79] See program comments at the beginning of the program listing for more details.

the ionogram data; and calculating or printing sky maps or antenna patterns. The data checks include printing the drift data in its various forms (raw data, unpacked data, amplitudes, phases); these checks were used in the early testing stages to verify the format of the simulated data from TESTSKY, and for a preliminary examination of the measured drift data from Goose Bay. The second type of function is used to separate the drift data from the ionogram data on a physical tape and store it in a computer file, in order to use the allotted computer-memory space more efficiently. Of the four sky-map functions, three include the calculation of the sky maps (i.e. calculating the FWPD of each map coordinate, for each Doppler line), with options for printing the sky maps (via subroutine PRIN) as they are calculated, printing the antenna patterns for each Doppler line, and/or saving the map data (the map indices IX and IY of each source, the source density P_s(IX, IY), and the Doppler number d of each source) on file TAPE50. This last function is performed by subroutine MAPDATA. The fourth function involves printing the sky maps from the data on TAPE50. If the value of KPRINT indicates this function, the FWPD calculation is skipped and subroutine MAPSEQ is called. The subroutine requests information as to the starting time (the time of the first case to be printed; or "zero", to start at the beginning of TAPE50), whether negative, positive or both Dopplers are to be printed; the minimum density in dB of the sources to be included on the map (with the option of setting the minimum density at a fixed value for all maps, or at a fixed number of dB below the maximum density of each map); and whether to print each case on a separate map or to compress several consecutive cases onto one map ("time sequence"). With the latter choice, the densities P_s are replaced on the map by the numbers 0, 1, 2, ... to indicate the time sequence of the cases.

When calculating sky maps, the program buffers in one record of drift data from TAPE1 and unpacks the 216 characters into 2160 computer words (see section 2.2.4). Then the next record is buffered in and unpacked, and the date and time in the preface of both records are compared to determine whether both records belong to the same case. If the date and time are not identical, the next record is buffered in; if they are identical, both records are stored temporarily on TAPE99, so that processing can continue with each record separately.

Next the preface parameters that are relevant to drift measurements (see Table 3) are decoded: the appropriate preface characters are combined to form the station number, the year, etc.; and the decoded sounding frequencies, ranges and receiver gains are assigned an index number for identification. The frequencies are incremented by 12.5 kHz, because the sounding frequencies in the DGS 128PS are offset by 12.5 kHz from the indicated frequencies in order to diminish possible interference with commercial short-wave stations, which generally broadcast at multiples of 100 kHz. It was found that for technical reasons the data transfer from the Digisonde to digital tape is not done correctly for drift measurements at ranges greater than 510 km, so the program skips to the next case if the range is too high.

Subroutine ANT is then called to determine, from the task number, the number of antennas used, and to define the indices for identifying the antenna sequence. For drift data from the Goose Bay station, the task number is always zero and the four-antenna array is used for all measurements; but the DGS 128PS is designed for processing drift data from receiving arrays of up to twenty-four antennas (using all antennas in the array or submultiples of 24 in various combinations). Subroutine ANT also determines from the drift program number the parameters of Table 1, and calculates the components of $\vec{k}\cdot\vec{r}/m$ for each antenna-position vector $\vec{r}_a$,

$$\frac{k_x r_x}{m} = \frac{-.707 \; k \sin (\zeta_{max}) \; r_x}{20} \qquad (249)$$

$$\frac{k_y r_y}{m'} = \frac{-.707 \; k \sin (\zeta_{max}) \; r_y}{20} \qquad (250)$$

$$\vec{r} = r_x \hat{x} + r_y \hat{y} \qquad (251)$$

where k_x and k_y were defined in equations (197) and (198).

Subroutine SPLIT sorts out the two six-bit amplitudes and two nine-bit phases from each group of five six-bit characters (see Table 4), converting the log amplitudes to linear amplitudes.

Next, subroutine FOU is called to calculate the FWPD of each Doppler line. In order to save computing time, we define an estimated power density $P'(d)$ for each Doppler,

$$P'(d) = [\sum_{a=1}^{4} |V_a(d)|]^2 \qquad (252)$$

where $|V_a(d)|$ is the measured amplitude of spectral line d ($V_a(d) \equiv V_{a,s}$ if all sources are at different Dopplers); and we skip the calculation of the FWPD for all Dopplers for which $P'(d)$ is more than 20 dB below the maximum $P'(d)$. Also, no FWPD is calculated when $P'(d)$ is less than 6 dB or when $|V_a(d)|$ is less than 1 at any antenna.

The FWPD is calculated from equation (166). $F_a(d)$ and $e^{i\vec{k}\cdot\vec{r}_a}$ are calculated separately and then combined: $e^{i\vec{k}(x_m,y_{m'})\cdot\vec{r}_a}$ is first calculated for each of the 1681 (41 × 41) coordinates, for antennas 2 to 4 ($\vec{r}_1 \equiv 0$); then at each Doppler, the measured amplitudes $V_a(d)$ and phases $\phi_a(d)$ ($\equiv \phi_{a,s}$ if all sources are at different Dopplers) are used to calculate $F_a(d)$ as $V_a(d)\, e^{i\phi_a(d)}$ for each antenna. $F_a(d)$ and $e^{i\vec{k}\cdot\vec{r}_a}$ are then combined as in (166) to yield the FWPD for each $(x_m, y_{m'})$. The FWPD algorithm in the original SKYMAP program combined the two exponentials as $e^{i[\phi_a(d) + \vec{k}\cdot\vec{r}_a]}$ and calculated this term 1681 times for each of the four antennas at each Doppler number, which used more computing time. Also, in the current SKYMAP program, the cosine and sine values for the exponentials are determined by the program function COSINE, from a table (calculated at the beginning of the main program) of the values of cos(0) to cos(π/2), in angular increments of 2π/1024. The original program calculated the trigonometric values with a Fortran library subroutine, which yields more exact values but takes more time. A comparison was made of the two algorithms, using a drift measurement with 64 Doppler lines (2 records: 32 positive and 32 negative Dopplers). The CPU time used for all 107,584 (64 × 1681) FWPD calculations with the original algorithm was 180 seconds. This was cut down to 40 seconds by using the cosine table and calculating the $e^{i\vec{k}\cdot\vec{r}_a}$ array only once. Skipping the FWPD calculations of the weaker Doppler lines as explained earlier further reduces the CPU time in varying amounts, depending how many strong sources there are; for the data used in the comparison, the time was reduced to 16 seconds.

Subroutine FOU subtracts from each value of $P(d, \vec{k})$ the constant auto-correlation term (the first sum in equations (175) and (246)) and sets the negative values to zero. As a result, when the antenna patterns are printed, only the values within a limited radius of the local peaks are non-zero, which makes it easier to identify the lobes.

For each Doppler, the map coordinates of the source(s) are determined from the maximum linear values of $P(d, \vec{k})$ of each row IX and the maximum of each column IY; these indices are stored as (IX, IYMAX) and (IXMAX, IY). (See Figure 13, to the right of and below the antenna pattern.) The densities $P_s(d)$ and the Doppler numbers d of those peaks whose row and column indices are equal ($IX_{row} = IXMAX_{column}$, $IYMAX_{row} = IY_{column}$) are stored for the final sky map, unless the densities are more than 3 dB below the maximum density for that Doppler (thus eliminating the minor side lobes). The final sky map consists of two parallel maps, one with the logarithmic densities at the coordinates of the sources, the other with the corresponding Doppler numbers at the same coordinates.

As mentioned above, if subroutine MAPDATA is called, the map data is stored on TAPE50. The data on TAPE50 can be used either for printing sky maps or for calculating the drift velocities; the latter will be discussed in the next section.

2.5 Determining the Drift Velocity

2.5.1 Relationship between the Source Velocity and the Doppler Shift

The Doppler shift Δf_s of source s is proportional to the radial component (the component parallel to the source-position vector $\vec{R}_s$) of the velocity of the source, and is determined as follows. Consider first a radio signal of frequency f impinging on a reflector which is moving at a non-relativistic speed W towards or away from the transmitter; the signal is observed by the reflector as though it were at frequency f'[80]

$$f' = f \frac{1 \pm W/c}{[1 - (W/c)^2]^{1/2}} \tag{253}$$

$$f' \simeq f\ (1 \pm W/c),\ W << c \tag{254}$$

where c is the speed of light in vacuum, the upper sign is for approaching motion, and the lower sign is for receding motion. The reflected signal is then observed at the transmitting site at frequency f"

$$f'' = f'\ (1 \pm W/c) \tag{255}$$

$$= f\ (1 \pm W/c)^2 \tag{256}$$

[80]Halliday and Resnick (1966), section 40-5.

$$f'' \simeq f\,(1 \pm 2\,\frac{W}{c}),\ W << c \tag{257}$$

with Doppler shift

$$\Delta f = f'' - f = \pm\, 2\,\frac{W}{c}\,f \tag{258}$$

We consider the reflector as the source of a signal with Doppler shift Δf; since the source motion can be in any direction, W is the radial component of the source velocity $\vec{V}$,

$$\vec{V}\cdot\hat{R} = \mp\, W \tag{259}$$

where with our choice of coordinate system, $\vec{V}\cdot\hat{R}$ is negative for motion towards the transmitter/receiver site (motion along $-\hat{R}$) and positive for motion away from the site (along $+\hat{R}$). Adding the source index s and combining (258) and (259) yields equation (87) given in section 2.1.4,

$$\Delta f_s = -\,2\,\frac{\vec{V}_s\cdot\hat{R}_s}{c}\,f \tag{260}$$

2.5.2 Calculation of the Median and Average Drift Velocities

It was stated in section 2.1.4 that the so-called case velocity is determined as the median of the individual velocities of the case; the group-norm velocity is the median of several case velocities; etc. For testing purposes, two other types of central-tendency calculations were also used: the weighted median and the weighted average.

All central tendencies are calculated separately for the velocity components V_x, V_y and V_z. The weighted average $\bar{V}_x$ (and similarly for $\bar{V}_y$ and $\bar{V}_z$) is defined as[81]

[81]Selby (1971).

$$\bar{V}_x = \frac{\sum_{j=1}^{n} \tilde{w}_j \; V_x(j)}{n} \tag{261}$$

$$n = \sum_j \tilde{w}_j \tag{262}$$

$$w_j = \mathrm{MIN}\;[(1/\varepsilon_j^2),\; 1] \tag{263}$$

where the index j refers to the velocities being averaged; w_j is the jth weighting factor, defined in (263) where MIN means the minimum of the values in the bracket; $\tilde{w}_j$ is the same weight but normalized such that the sum of the normalized weights equals the total number of velocities n. When the case velocity is being calculated, the least square error ε_j^2 is calculated for each individual velocity as in equation (90). For the calculation of the group-norm velocity, ε_j^2 of the jth case velocity is the average of the least square errors of the individual velocities of case j; the group-norm velocities are not weighted when calculating the all-frequency velocities ($w_j \equiv 1$). With the average, the variance (the square of the standard deviation)

$$\sigma_x^2 = \frac{\sum_j \tilde{w}_j \; [V_x(j) - \bar{V}_x]^2}{n - 1} \tag{264}$$

is calculated using the faster computational form

$$\sigma_x^2 = \frac{\sum_j \tilde{w}_j \; V_x(j)^2 - \dfrac{\sum_j [\tilde{w}_j \; V_x(j)]^2}{n}}{n - 1} \tag{265}$$

Program DRIFVEL provides the option of calculating the weighted average once or twice: if the average is calculated twice, the second calculation bypasses those velocity vectors that are outside the standard deviation, according to the following definition:

$$V_j > \sigma \tag{266}$$

$$V_j = [V_x^2(j) + V_y^2(j) + V_z^2(j)]^{1/2} \tag{267}$$

$$\sigma = (\sigma_x^2 + \sigma_y^2 + \sigma_z^2)^{1/2} \tag{268}$$

The weighted median is determined as follows. The un-normalized weight w_j is rounded out to an integer after being multiplied by 10^4, and is then treated as the frequency-of-occurrence of $V_x(j)$. The $V_x(j)$ for all j are sorted into descending order of magnitude; each occurrence of $V_x(j)$ is considered a separate value, and the median is defined as the center value if there is an odd number of values, or as the average of the two center values if the number of values is even. A variance for the weighted median is also calculated as

$$\sigma_x^2 = \frac{\sum_{j=1}^{n} \tilde{w}_j \, [V_x(j) - V_x^{med}]^2}{n - 1} \tag{269}$$

where V_x^{med} is the x component of the median velocity. The above procedure is also used to determine the y and z components of the median velocity. For the unweighted median, the weights w_j are all set to 1.

2.5.3 Program DRIFVEL

Program DRIFVEL[82] was developed by the author to calculate the drift velocities from the sky-map data on file TAPE50. Some of the program options (calculations and output formats) indicated in the comments of the program listing will not be discussed here because they are not directly relevant to the presentation of the results in section III; they in-

[82]See Appendix C.

volve preliminary efforts which were later supplanted by the calculations and data-presentation formats discussed below.

At the beginning of a run, DRIFVEL requests information about the program options desired. The value inputted for KPRINT determines which velocites are to be outputted. Since TAPE50 can include several files of map data (calculated by program SKYMAP) merged into a single file for storage, the starting date, time and frequency number determine which portion of the data on TAPE50 is to be used for velocity calculations. The program starts the calculations with the data of the indicated date, time and frequency number, and continues until the frequency number changes, unless zero is inputted, in which case all the data on TAPE50 is processed. The choice of central-tendency calculation for determining the case, group-norm and all-frequency velocities is also inputted, as well as the variable parameters for the least-square-error calculation.

The least-square-error calculation can be varied in several ways. It was indicated in section 2.1.4 that the source density is used as the weighting factor w_s in equation (90), and that the sources for a given case are sorted in descending order of the magnitude of P_s before the individual velocities are calculated; other weights and sorting orders can also be used. The least-square-error calculation can also be limited to sources with $|d|$ between chosen minimum and maximum values; and the result of the calculation is ignored if the least-square-error and/or the absolute value of V_z is greater than the inputted values for those parameters. These options will be discussed in section 3.2.

The main program calculates the individual velocity vectors, using function DET to calculate the determinants for solving for V_x, V_y and V_z. If further calculations are called for, subroutines MED, WHTMED or AVE calculate the central tendencies, using the sorting subroutine VSORT for the median calculations. Subroutine VEL calculates from V_x, V_y and V_z the magnitude V of the drift vector, the horizontal component V_h and the azimuth and elevation. Subroutine GRAPH prints the two parallel graphs (azimuth and speed graphs) of the individual, case, group-norm or all-frequency velocities. All-frequency velocities need one run per frequency number; the group-norm velocities are calculated for each frequency number separately and stored by subroutine ALLFREQ on file TAPE49; during the run at the last frequency number, ALLFREQ calculates the all-frequency velocities from the group-norm velocities. The output then consists of two sets of graphs: one set with the all-frequency velocity results; the other with the group-norm velocities of all frequency numbers printed together. For the latter set of graphs, subroutine IDENT is called to "spread out" values that are at the same graph coordinates, so that none of the values will be lost: for example, if the azimuth of three group-norm velocities is 90°, IDENT will spread them out to 85°, 90° and 95° (the azimuth axis is in 5° increments).

3.0 RESULTS AND DISCUSSION

3.1 Simulated Data: Two Sources at the Same Doppler Frequency

In this section, we present some examples of sky-map and drift-velocity calculations with simulated drift data calculated from pairs of sources at the same Doppler number, with various initial phase differences δ (see equation 248). These examples serve the double purpose of verifying the validity of the sky maps and of the calculated drift velocities, and of illustrating the effects of multiple sources falling on the same Doppler line.

A horizontal drift velocity of 200 m/s due south is assumed. The correct source positions are shown in Figure 17 with an identifying source number (circled) next to the Doppler number of each source. The Doppler frequencies f_d are indicated by the Doppler number d as (see Table 1, for drift program number 9)

$$f_d = \pm 1/16,\ \pm 3/16,\ \pm 5/16,\ \ldots\ [\mathrm{Hz}] \tag{270}$$

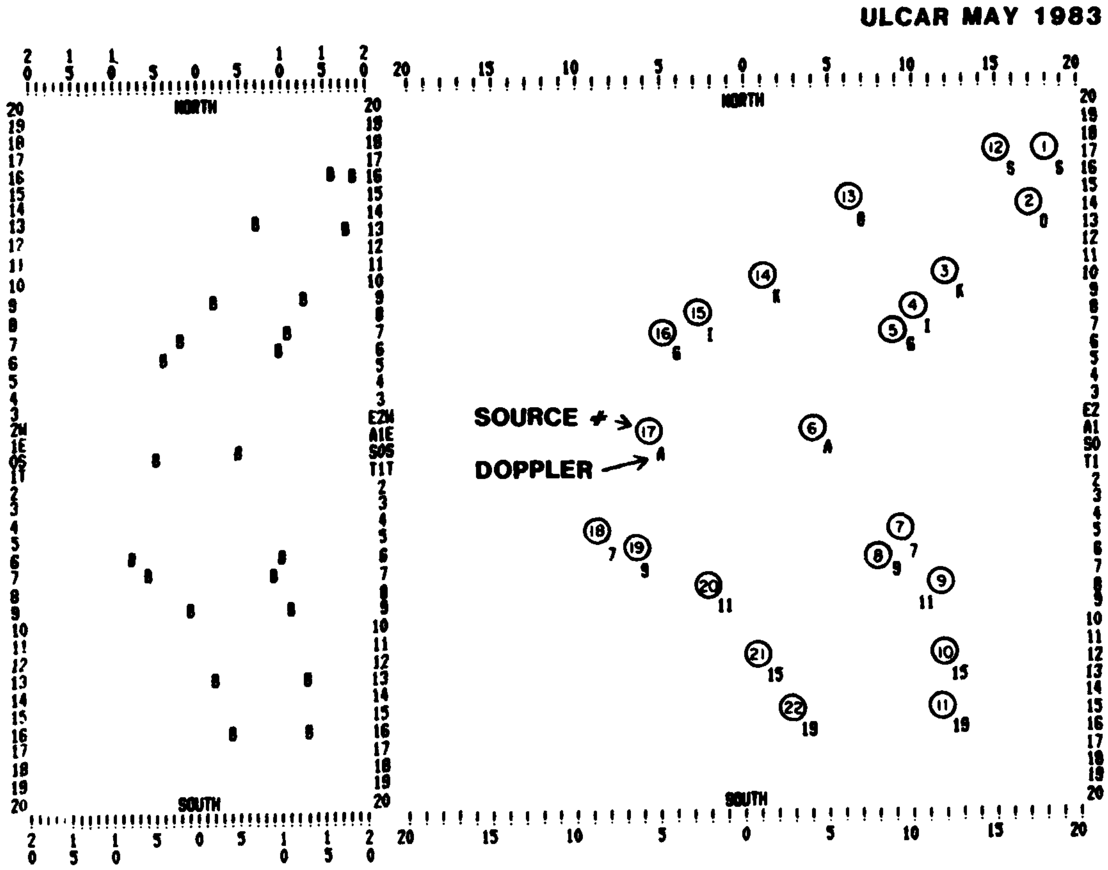
$$d = 1, 2, 3, \ldots \text{ for negative frequencies} \tag{271}$$

$$d = A, B, C, \ldots \text{ for positive frequencies} \tag{272}$$

The hexadecimal numbers in the map on the left indicate the density P_s of each source in 6 dB increments, at the same coordinates as the corresponding Doppler numbers on the right. Note that the densities are single-digit numbers, whereas the Doppler numbers may be double-digit, which is why the map on the right is twice as wide. The absolute value of the map indices m and m' are indicated around the periphery of each map. The map scale and maximum zenith angle are

$$\delta x = \delta y = 7.3 \text{ km} \tag{273}$$

$$\zeta_{max} = 29.9° \tag{274}$$



RANGE: 412 KM SCALE: 7.3 KM/DIVISION
FREQ: 6.0 MHZ $\zeta_{max} = 29.9°$
LEFT MAP: DENSITIES (6 dB INCREMENTS)
RIGHT MAP: DOPPLER NUMBERS
NEG DOPP: NUMERIC POS DOPP: ALPHA
DOPPLER RESOLUTION: .1225 HZ

SIMULATED DATA: SOURCE POSITIONS FOR TESTS OF EQUAL-DOPPLER ECHOES

Figure 17

where δx follows from the value of ζ_{max} and an (arbitrary) range of 412 km (see equation 183) and ζ_{max} follows from the sounding frequency of 6 MHz (see equation 216).

Table 5 lists the source parameters for all 22 sources. Each of the source pairs (1, 12), (2, 13), (3, 14), ... (11, 22) is at the same Doppler frequency. The Doppler frequencies were chosen to be integral multiples of $\delta\omega$. The source coordinates X and Y are not integers; the sky map calculation places them at the closest integral multiples of m and m' (remember that +X is north, +Y is west). Fourteen cases of data were calculated; the map in Figure 17 is a superposition of the maps from the first two cases, each calculated from sources that are all at different Doppler frequencies: the first map was calculated from sources 1 to 11, the second from sources 12 to 22.

Sky maps calculated from all 22 sources together (cases 3 to 14) show the effects of double sources at the same Doppler number. Since δ is the difference in phase between the two sources at the same Doppler, the first set of sources (1 to 11) were given an initial phase of zero for all cases, and the phases were varied in the second set (12 to 22). The values of δ in Table 5 ("INIT PH") are those of case 3: all pairs of sources have a phase difference of 30°. In the succeeding cases, δ was incremented by 30° for each new case,

$$\delta = 30°, 60°, 90°, \ldots, 330° \text{ all source pairs} \tag{275}$$

$$\text{case} = 3, 4, 5, \ldots, 13 \tag{276}$$

except that for the last case (case 14), each source pair has a different δ,

$$\delta = 0°, 30°, 60°, \ldots, 330° \tag{277}$$

$$\text{sources} = (1, 12), (2, 13), (3, 14), \ldots, (11, 22) \tag{278}$$

Case 3 is shown in Figure 18: with a 30° phase difference, each pair of identical-Doppler sources is seen as one source

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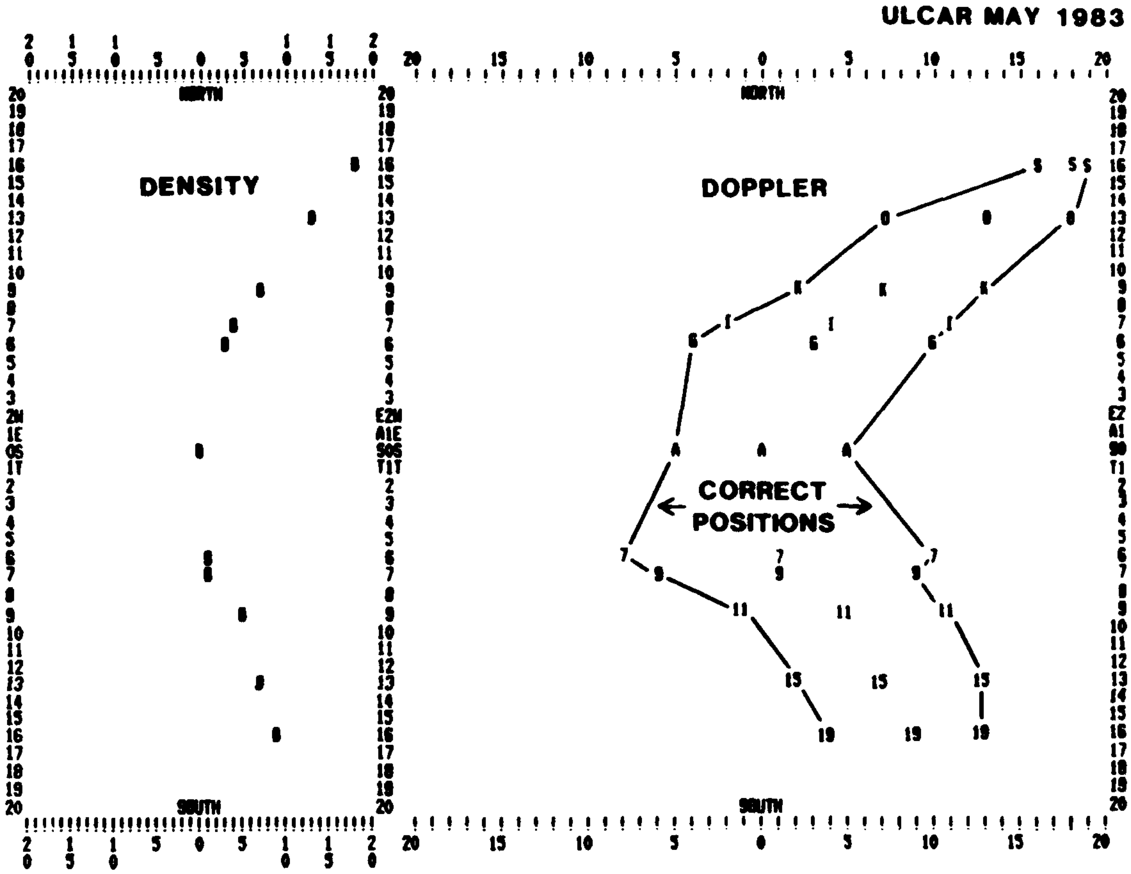
SOURCE	VX	VY	VZ	AZIM	ZEN	X	Y	AMPL	DOPFREQ	INIT PH	DOPP. NO.
		[m/sec]		[deg]					[Hz]	[deg]	
1	-200.00	0.00	0.00	50.00	26.08	16.0	-19.1	1.00	2.2670	0.00	19.00
2	-200.00	0.00	0.00	55.00	22.72	12.6	-17.9	1.00	1.7772	0.00	15.00
3	-200.00	0.00	0.00	55.00	16.24	9.1	-13.0	1.00	1.2868	0.00	11.00
4	-200.00	0.00	0.00	55.00	13.08	7.4	-10.5	1.00	1.0413	0.00	9.00
5	-200.00	0.00	0.00	60.00	11.45	5.6	-9.8	1.00	.7963	0.00	7.00
6	-200.00	0.00	0.00	85.00	5.03	.4	-5.0	1.00	.0613	0.00	1.00
7	-200.00	0.00	0.00	120.00	11.45	-5.6	-9.8	1.00	-.7963	0.00	-7.00
8	-200.00	0.00	0.00	130.00	11.65	-7.4	-8.8	1.00	-1.0413	0.00	-9.00
9	-200.00	0.00	0.00	130.00	14.45	-9.1	-10.8	1.00	-1.2867	0.00	-11.00
10	-200.00	0.00	0.00	135.00	18.26	-12.6	-12.6	1.00	-1.7774	0.00	-15.00
11	-200.00	0.00	0.00	140.00	21.65	-16.0	-13.5	1.00	-2.2672	0.00	-19.00
12	-200.00	0.00	0.00	45.00	23.56	16.0	-16.0	1.00	2.2674	30.00	19.00
13	-200.00	0.00	0.00	30.00	14.82	12.6	-7.3	1.00	1.7770	30.00	15.00
14	-200.00	0.00	0.00	10.00	9.37	9.1	-1.6	1.00	1.2862	30.00	11.00
15	-200.00	0.00	0.00	345.00	7.73	7.4	2.0	1.00	1.0423	30.00	9.00
16	-200.00	0.00	0.00	325.00	6.96	5.6	3.9	1.00	.7963	30.00	7.00
17	-200.00	0.00	0.00	275.00	5.03	.4	5.0	1.00	.0613	30.00	1.00
18	-200.00	0.00	0.00	235.00	9.97	-5.6	8.0	1.00	-.7966	30.00	-7.00
19	-200.00	0.00	0.00	220.00	9.76	-7.4	6.2	1.00	-1.0418	30.00	-9.00
20	-200.00	0.00	0.00	185.00	9.27	-9.1	.8	1.00	-1.2874	30.00	-11.00
21	-200.00	0.00	0.00	170.00	13.00	-12.6	-2.2	1.00	-1.7772	30.00	-15.00
22	-200.00	0.00	0.00	165.00	17.01	-16.0	-4.3	1.00	-2.2668	30.00	-19.00

SOURCE PARAMETERS FOR TESTS OF EQUAL-DOPPLER ECHOES

Table 5



NEGATIVE DOPP = NUMERIC   POSITIVE DOPP = ALPHA
DOPPLER RESOLUTION = .1225 HZ

POSITIONS OF SOURCES CALCULATED FROM EQUAL-DOPPLER ECHOES, WITH δ = 30°

Figure 18

near the center of the correct positions. Some values of δ give the same results as others except for a difference in the densities; for example, the positions for 60° and 90° are the same as for 30°. Higher initial-phase differences shift the source positions. Figure 19 is an extreme example of what can happen: with a δ of 150°, most of the calculated or "apparent" sources are shifted outside the sky map; we suspect that those sources which appear on the map are probably side lobes rather than the main lobe. This suspicion is based on a comparison of Figures 20 and 21. Figure 20 is a composite map of the results of all 14 cases; the map on the left now contains the case numbers in hexadecimal notation, starting at zero for case 1. The sources for some of the cases are lost, since they fall at the same coordinates as those of previous cases. Figure 21 shows the Doppler numbers that result at each map coordinate with the assumed velocity of 200 m/s due south; those positions that are on a line perpendicular to the velocity vector are all at the same Doppler number. In Figure 20, we can see that most of the calculated source positions that are not correct have been shifted along a line perpendicular to the velocity vector; that is, most of the shifted sources are still at locations which result in the same Doppler number as do the correct source locations. The source positions indicated in Figure 19, on the other hand, seem to be due to the side lobes of sources whose positions have been shifted completely out of the map.

Those sources that appear on the same line (perpendicular to the velocity vector) as the correct source positions yield the correct velocities, as can be seen in Figure 22, which is a computer plot of the case velocities for all 14 cases. In the graph on the left, the "#" symbols indicate the azimuth of the velocity in 5° increments, the "+" signs indicate σ (see equation (268)) in 5 m/s increments. In the graph on the right, the horizontal speed is indicated by "#",

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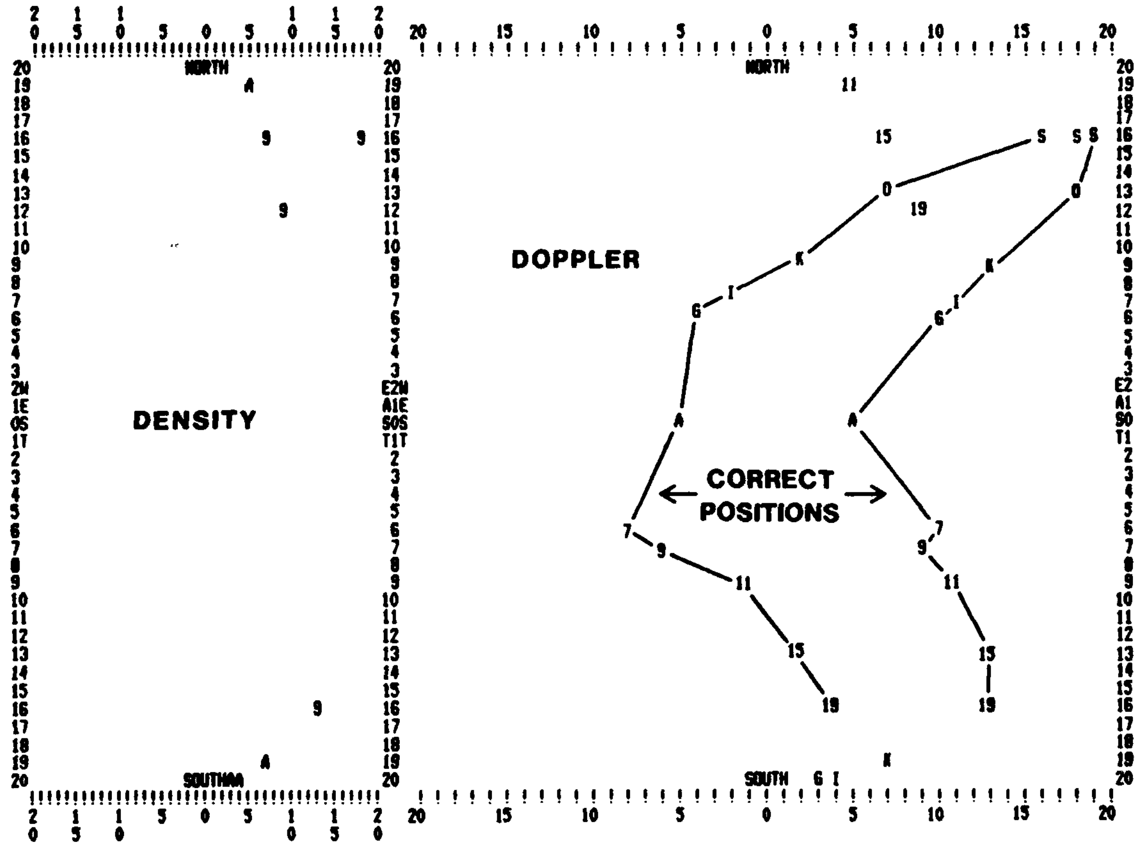
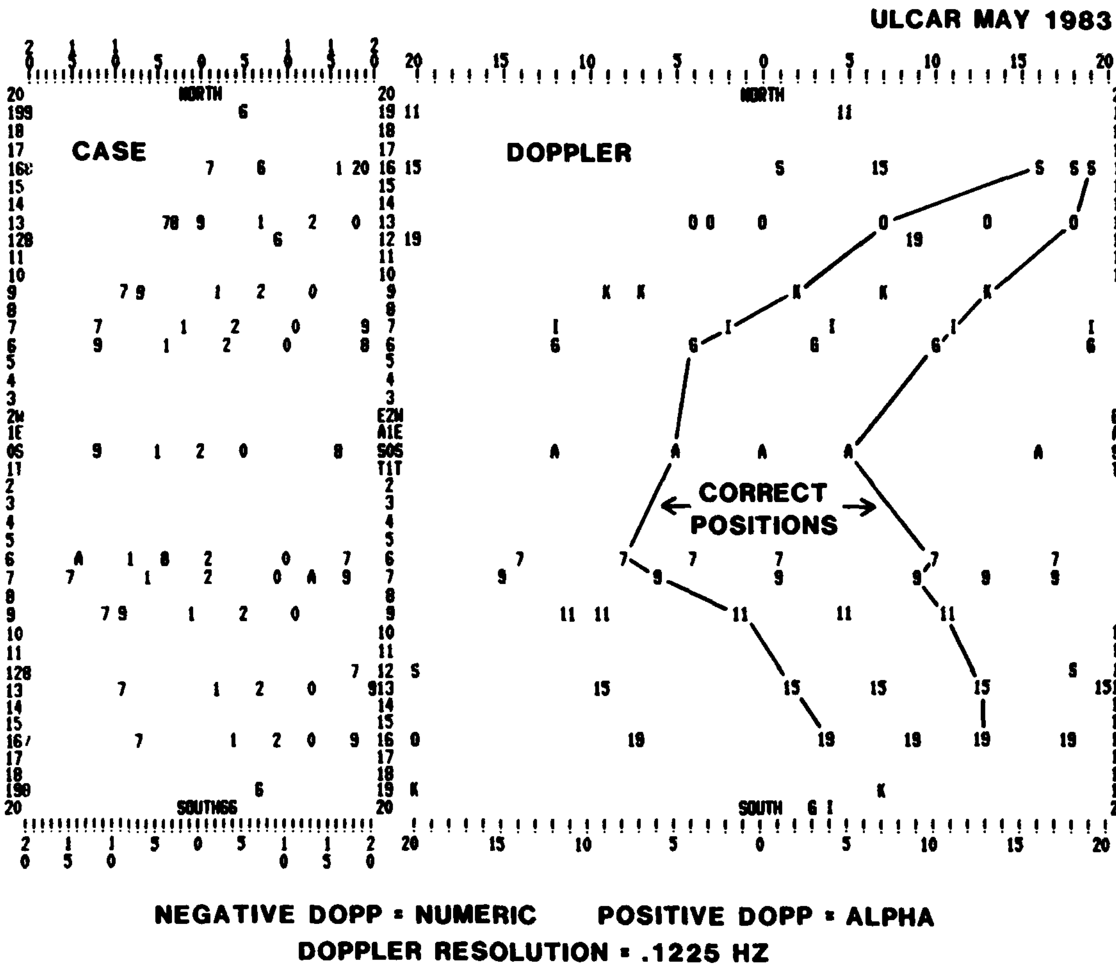


NEGATIVE DOPP = NUMERIC   POSITIVE DOPP = ALPHA
DOPPLER RESOLUTION = .1225 HZ

POSITIONS OF SOURCES CALCULATED FROM EQUAL-DOPPLER ECHOES, WITH δ =150°

Figure 19



POSITIONS OF SOURCES CALCULATED FROM EQUAL-DOPPLER ECHOES, $\delta = 30^\circ, 60^\circ, 90^\circ, \ldots, 330^\circ$

Figure 20

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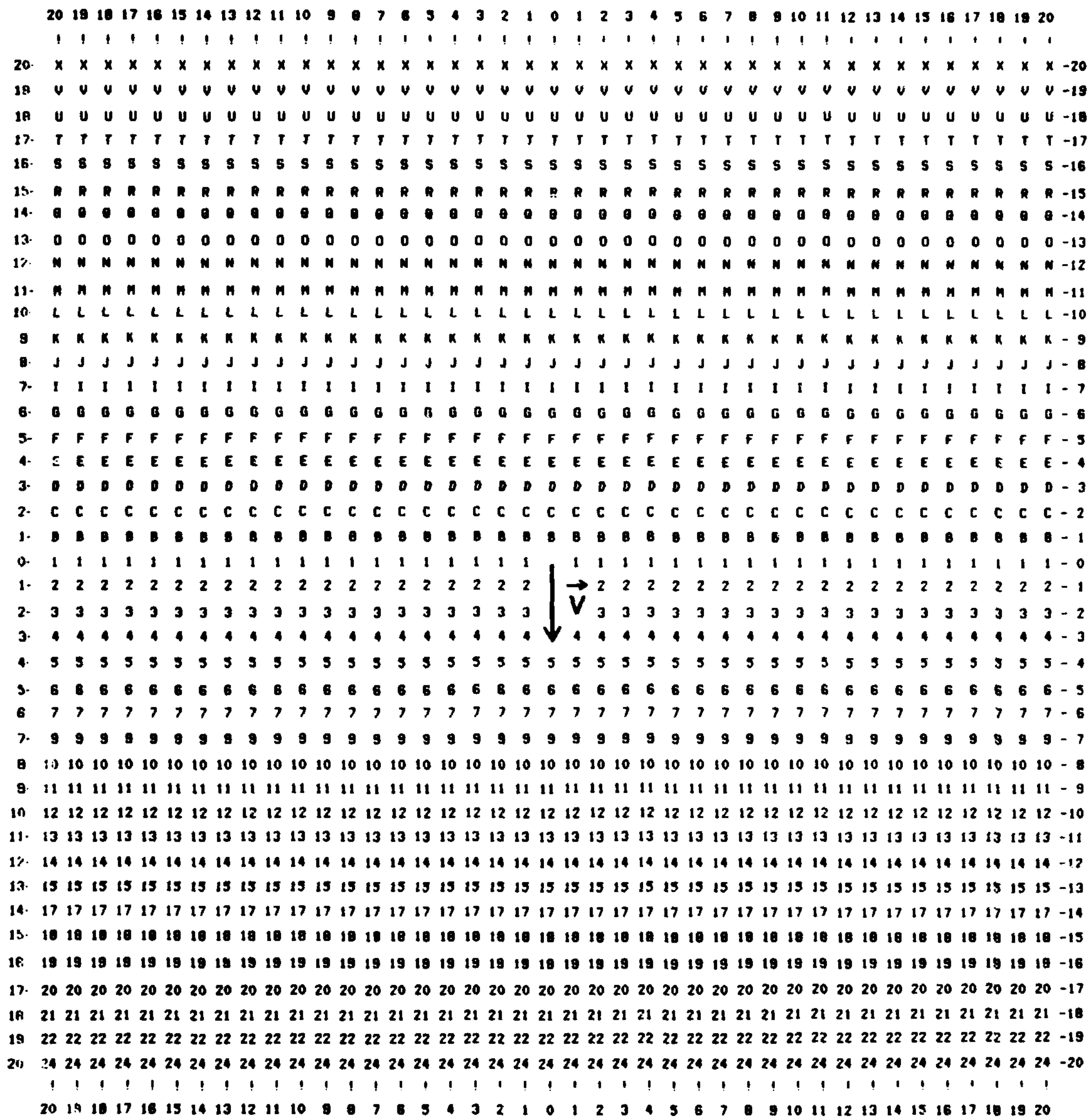


FREQUENCY = 6.0 MHZ
V_x = -200 V_y = 0 V_z = 0
NEGATIVE DOPP = NUMERIC
LOWEST DOPP FREQ = 1/16 HZ

MAX ZENITH ANGLE = 29.9°
PROGRAM NO. 9
POSITIVE DOPP = ALPHA
DOPP-FREQ RESOLUTION = 1/8 HZ

DOPPLER DISTRIBUTION FOR UNIFORM PLASMA DRIFT

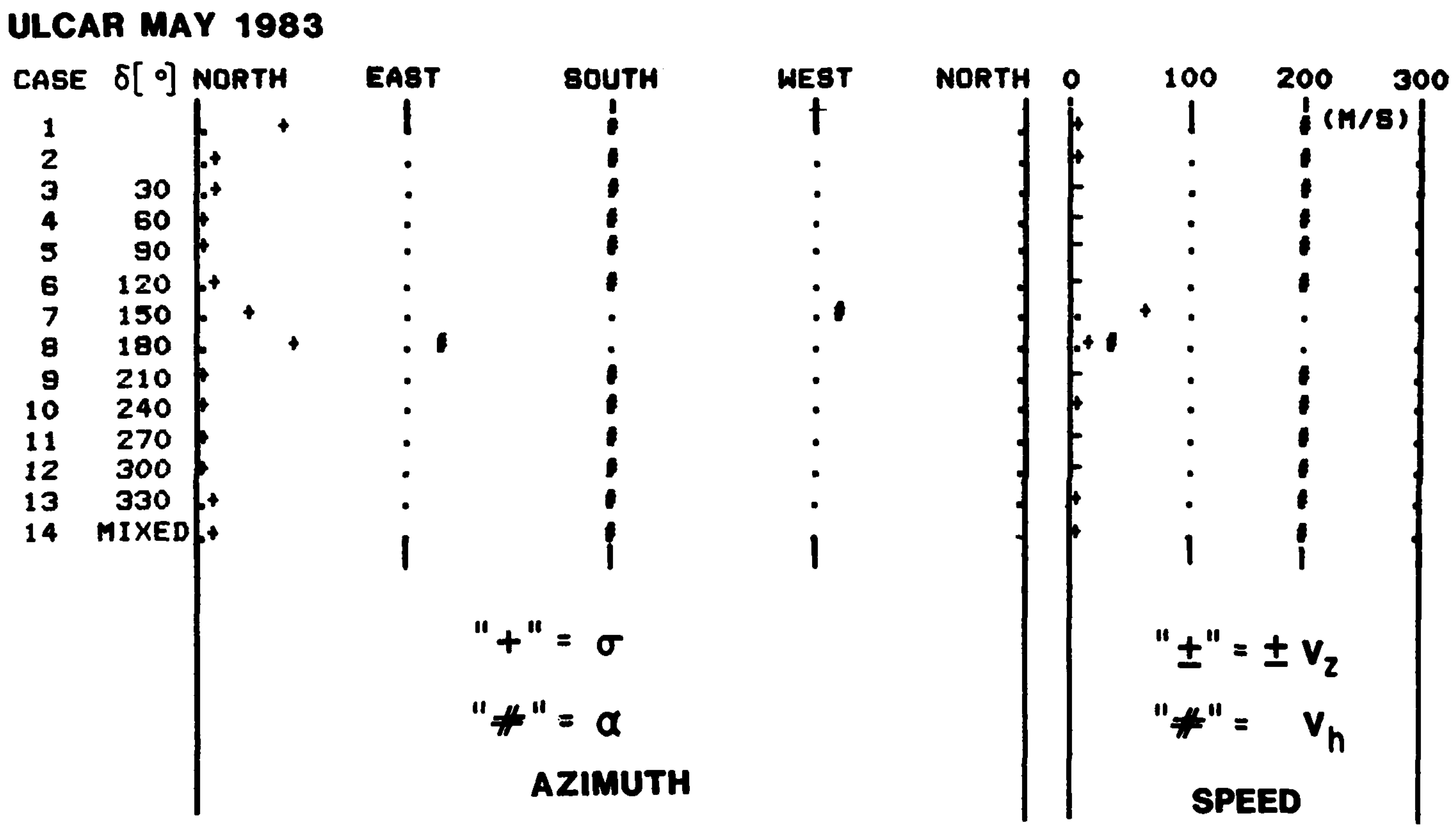
Figure 21

and the vertical speed by a "+" (V_z = up) or "-" (V_z = down) in increments of 10 m/s. As shown in Table 5, the velocity inputted into the test program was a horizontal velocity of 200 m/s south; so with the values of δ that were tested and with the chosen original source positions, only two cases yield velocities that are significantly incorrect. The initial phase difference in those two cases were 150° and 180°.

The most realistic case is number 14 where the phase differences δ vary from pair to pair. For a 6 MHz signal a range difference of 25 meters will cause a 2π shift in the phase of the echoes. It must therefore be assumed that the phase differences for a set of equal Doppler pairs are random. Figure 22 shows that for this situation, as simulated in case 14, the velocity is reproduced exactly.

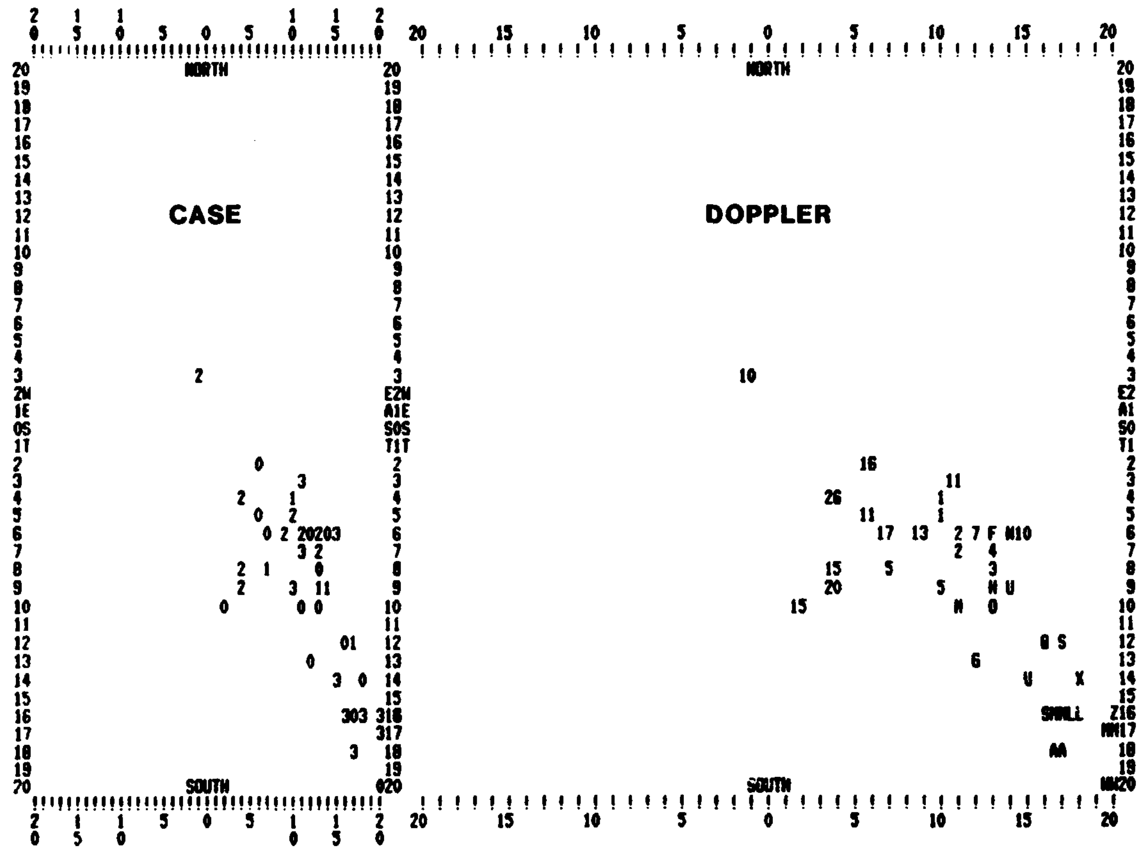
3.2 Tests of Measured Drift Data from Goose Bay

After the drift-measurement technical problems in the Digisonde had been corrected (see section 1.7.2.2), several sky maps were calculated with the available F-region drift data from Goose Bay. Efforts were made to determine from the information on the map, the general shape of the ionospheric iso-density surfaces above the measuring station as well as the direction of the drift motion. Analysis of maps with data from individual cases did not yield any satisfying results. A determination of the direction of the drift motion by analyzing successive cases was then attempted. This was done by composing "time sequence" maps of the sources with densities within 4 dB of the maximum density for each case, like the map in Figure 23, which compresses four successive cases (covering 72 seconds) of data. (The map legend is explained in the previous section; here the positive Doppler numbers run higher than 26, so the symbols AA, BB, CC, ... are used for Dopplers +27, +28, +29, ...) The resulting map displays a good consistency in the locations of the sources;



DRIFT VELOCITIES CALCULATED FROM EQUAL-DOPPLER ECHOES

Figure 22



NEGATIVE DOPP = NUMERIC　　**POSITIVE DOPP = ALPHA**

DOPPLER RESOLUTION = .1225 HZ

SCALE: 9.4 KM/DIVISION　　$\zeta_{max} = 45°$

DOPPLER SKY MAP

26 JAN 1982　GOOSE BAY, LABRADOR

20:18 AST　3 MHZ　375 KM

Figure 23

however, the sequence of cases (indicated by the numbers 0 to 3 in the map on the left) do not show a very clear progression of the reflection areas with time. This map is typical of most maps that were generated. Even if the movement of the reflection areas could be determined from the maps, this movement may be due to medium- and large-scale TID's and may not reflect the large-scale convection of the plasma. Analysis of earlier drift measurements made in the early 1970's supported this distinction of the two types of motions (see section 1.7.2.1). It was then decided to calculate the drift velocities directly from the map data, using the least-square-error method described earlier.

Program DRIFVEL was then written to calculate several drift velocities for each case. Calculating only one velocity per case using all the map data from that case could lead to large errors, since the map data are probably not all equally reliable. It is expected that the measured Doppler frequencies and calculated positions of the strongest sources are probably more accurate (this assumption is evaluated below); the weakest calculated sources may actually be due to noise rather than to echoes from real sources. On the other hand, since all map data have some error (for example, the digitizing error), using only a few sources to calculate the velocity can also lead to large errors; with more sources (provided they are reliable), the errors smooth out somewhat. Therefore, the procedure used was to calculate the first so-called individual drift velocity with the five strongest sources of a given case, then the second velocity with the six strongest sources, etc. By starting with the strongest sources (using a minimum of five sources in order to eliminate excessively large errors) and adding one more source to each calculation, we hoped that each succeeding velocity would be relatively consistent with the previous one until we hit unreliable map data. The last "good" velocity would then probably be the most accurate one. Several cases of data were calculated in this way, but some of the results were not as simple to interpret as had been expected. An effort was made to evaluate each velocity by its least-square-error ε^2; this was also difficult to do since ε^2 increases as more sources are added, even if they are reliable sources. That is, with more sources the errors smooth out (the positive errors are compensated by negative errors), but ε^2 is a sum of the squares of the errors. A weighting factor was added to the least-square-error calculation (several different factors were tried, as explained below), but there were still cases whose individual velocities varied too drastically (in speed and/or direction) to be considered valid. Also, the velocities from case to case sometimes varied more than would be expected over periods of 10 or 18 seconds.

It was then decided to determine the case velocity by a weighted average of the individual velocities, in an effort to smooth out the effects of the bad data; and to apply further smoothing by averaging the velocities of four to six consecutive cases, yielding the group-norm velocity. The number of cases per group was restricted by the choice to use only groups for which the frequencies and ranges remained constant for all cases of the group (frequencies and/or ranges were changed during drift measurements as ionospheric conditions changed). Later results have shown that this restriction can be removed in the future. Both types of averages (averaging once or twice; see section 2.5.2) were calculated. Later, the same calculations were also tried with a median, and with a weighted median, instead of the average. The output of DRIFVEL at the time was in the form of a list of the velocity components (both Cartesian and spherical), and it was difficult to draw definite conclusions about the differences among the results of the four central-tendency calculations. The different smoothing methods did not affect the trend of the velocities, but showed in the standard deviation of the values; all calculations showed some cases and groups whose velocities varied drastically from the general trend.

Meanwhile, drift measurements covering longer time periods than the previous measurements did became available, so a larger amount of data could be calculated to see if a trend in the velocities would be observed over several hours. Groups of drift measurements made about every fifteen minutes from 18:00 to 05:00 AST (217 18-second cases; drift program number 9 had been used) on 26/27 January 1982, were chosen for analysis. The case and group-norm velocities were calculated; an average source position was also calculated from the source positions (negative- and positive-Doppler sources separately) of each case, as well as an average position for each group of cases. The results of both the position and velocity calculations were hand-plotted to permit easier analysis. Each group position and velocity was plotted on a separate graph, with vectors indicating the drift direction and speed, and plus and minus signs indicating the positive- and negative-Doppler average source positions. The velocity results were very promising, showing the expected westward drift in the late evening, shifting towards the east around midnight; and the results were very similar for all three ranges (heights) and the different sounding frequencies. The effects of the velocities with large discrepancies were not smoothed out satisfactorily by any of the central-tendency calculations, but at least we could tell which groups were departures from the general trend.

No general trend could be determined in the averaged source positions. This may be due in part to the shift in the virtual position of the sources due to the interaction of the sources whose Doppler shifts fall on the same Doppler line, as discussed in the previous section. Note that sources close to each other but far enough apart to be at slightly different Doppler frequencies may still fall on the same Doppler line and therefore still affect each other's calculated positions.

This is especially true since the Doppler line is widened by spectral averaging. Spectral averaging helps the determination of the drift velocity by diminishing side lobes and noise; but its effect on the determination of the positions of reflection areas in the ionosphere is less clear.

Program DRIFVEL was then modified to print the drift-calculation results in the form of an azimuth graph and a speed graph, and to print a separate graph of the root-mean-square error ε,

$$\varepsilon = (\varepsilon^2)^{1/2} \tag{279}$$

where ε^2 is the least-square error for the individual velocity calculations. This concise format made it much easier to compare the results of various calculations using different statistical weighting and smoothing; it also cut down drastically the time involved in plotting the calculated velocity vectors since this step is done by the computer.

Drift data from F-region measurements made in Goose Bay on 20/21 January 1982, from 20:30 to 12:00 AST, were used for the following test. Groups of four to six successive 18-second cases from measurements made approximately 15 minutes apart were chosen from the available data, for a total of 280 cases. The data of the first frequency number was used. Four separate graphs of the individual velocities were calculated, with the sources sorted in decreasing order of P_s, increasing order of P_s, decreasing $|d|$ and increasing $|d|$. In each run, the first individual velocity for each case was calculated using the first four sources instead of the first five, in order to re-evaluate our choice of the minimum number of sources to be used. All least-square-error calculations were done without weighting. The purpose of this test was to determine if there was any relationship between the error ε (we call it error from now on, but we mean RMS error) and the density of the sources, or between the error and the Doppler number, in order to determine the validity of using the density and/or the absolute value of the Doppler number as a weighting factor in the least-square-error calculation. Also, if it turned out that the weaker sources caused large errors, we would set a higher minimum density threshold for the FWPD calculation in program SKYMAP (where the threshold is set to 20 dB below the strongest source, as explained in section 2.4.4).

Examination of the error graphs of the above four runs showed that when we started with the strongest sources or the lowest $|d|$, the error increased as more sources were added (which is to be expected, as explained above), but also there were occasionally some sudden jumps in the increase. In the error graphs from the calculations starting with the weakest sources or with the highest $|d|$, some cases had errors starting quite high and decreasing as more sources were added. Closer examination showed that the large errors were caused by sources with $|d|$ around 25 or higher. (These sources have generally small amplitudes.) Typical errors for cases without any Dopplers higher than 20 were between 5 to 20 m/s; with higher Doppler numbers, the errors jumped to 100-150 m/s. The cases with high Dopplers were relatively few in this group of data, so we tested a two-hour portion of the 26/27 January data, which included about 55 cases, most of which had high Dopplers. Velocity calculations were made using only those sources with $|d|$ above 20; most of these cases yielded errors in the order of 90 to 100 m/s. It seems that the calculated sources with these high Doppler numbers are due to noise and/or to reflection areas whose motion is not the same as the large-scale plasma drift that we are trying to measure. Velocities were also calculated with the sources limited to $|d|$ from 11 to 20. Some of these results had errors of the order of 40 to 70 m/s; but many cases had much lower errors. Later calculations of the group-norm velocities with a weighted

ε^2 calculation, and using the median as the central-tendency determination of the case and group-norm velocities, showed that velocities calculated with $|d|$ from 1 to 20 or with $|d|$ from 1 to 10 were not significantly different. Therefore, it was decided to use sources with $|d|$ up to 20 for all future calculations.

Once the large errors were removed by eliminating the higher Doppler numbers, there was no conclusive evidence that the minimum density threshold should be changed for the FWPD calculation in program SKYMAP; nor was it clear which weighting factor should be used in the ε^2 calculation. Originally, six different factors had been tried for the least-square-error weights:

1. log density P_s;
2. log density $\times$ $|d|$;
3. linear P_s;
4. linear $P_s \times |d|$;
5. $|d|$;
6. no weighting.

It had already become clear from the handplotted graphs of the 26/27 January data that the linear density was superior to the log density. The last four weights were compared using the 20/21 January data by printing together on the same set of graphs the individual velocities calculated with each weight, with the resulting errors. (Program DRIFVEL was modified temporarily for this purpose; the version of the program listed in Appendix C does not have this option.) The calculated velocities were more consistent with each other within each case, and the errors were smaller, with the linear density alone used as the weighting factor. In most cases, the results with the other three weights were not drastically different; but there were several cases where the difference was significant enough to justify preferring the linear-density weight.

With the cause of the large errors removed, the minimum number of sources for the first individual velocity calculation could be set higher; but setting the minimum too high eliminates many cases which yield only a few sources. It was finally decided after examination of the data that a minimum of five sources appeared to be a good compromise.

Before the discovery that the large discrepancies in some of the velocities were due to high Doppler numbers, it had been observed that some of these velocities had a vertical component V_z of several hundred meters per second. It is known from various experiments that the vertical drift in the ionosphere is generally more of the order of tens of m/s; even under the most disturbed conditions, vertical velocities cannot be expected to be greater than 150-200 m/s. Therefore, sources which yielded velocities with $|V_z|$ greater than 200 m/s were ignored. The tests discussed above were done without this limitation; and with the data tested, the vertical velocities have reasonable values when the sources are limited to those with lower Dopplers. However, in the final results shown in the next section (as well as in future drift calculations), this limitation is kept since it can do no harm.

Once we were satisfied with the results of the individual velocity calculations, we proceeded to evaluate the weighted average (calculated once or twice), the median and the weighted median in determining the case velocities and the group-norm velocities. All resulting group-norm graphs were essentially the same, so it was decided to use the median in future calculations.

The last variation that we tried in the drift calculations was ignoring those sources which result in values of ε^2 greater than a chosen maximum. The group-norm velocities were calculated for all three sounding frequencies with the data from 26/27 January, with a maximum ε^2 of 250 m^2/s^2 (i.e. a RMS error of about 16 m/s) and compared to the same calculations without any limit on ε^2; the resulting graphs did not show any significant differences. Apparently, velocities with larger errors are filtered out by the median calculation.

3.3 Final Results

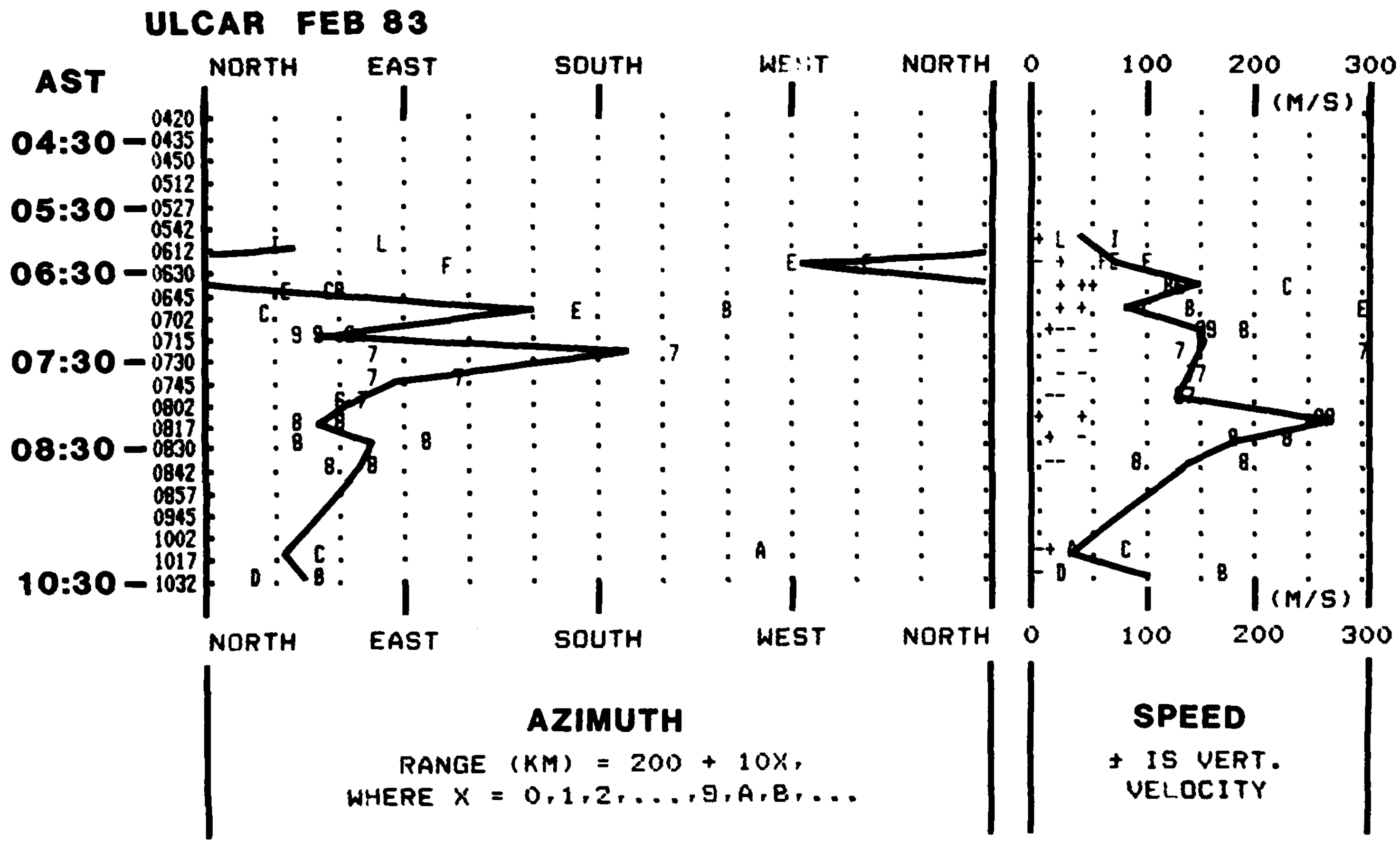
Drift velocities were calculated from measurements of four different days: 29 August 1981, 20/21 January 1982, 23 January 1982 and 26/27 January 1982 (see Figures 24 to 27). As explained in the previous section, the map data were first sorted in order of decreasing source density, and the individual velocities were calculated with a minimum of five sources, using only sources with Doppler numbers between -20 and +20. The linear density was used as a weighting factor in the least-square-error calculation. Any map data yielding $|V_z|$ greater than 200 m/s, if there were any, were ignored.

The graphs in this section display the group-norm velocities for the three simultaneous drift measurements (at three different sounding frequencies and ranges; drift program number 9 had been used for these drift measurements), in terms of the ranges:

$$R = 200 + 10X \text{ [km]} \tag{280}$$

$$X = 0, 1, 2, \ldots, 9, A, B, \ldots \tag{281}$$

where the letters A to V are used for the numbers 10 to 31; as explained in section 2.4.4, measurements at ranges above 510 km (200 + 10•31) are not calculated in program SKYMAP. Each group-norm velocity is the median of the case velocities of the group, and the case velocity is the median of the individual velocities of the case. The solid line in the graphs indicates the all-frequency velocities, each of which is the median of the three corresponding group-norm velocities.

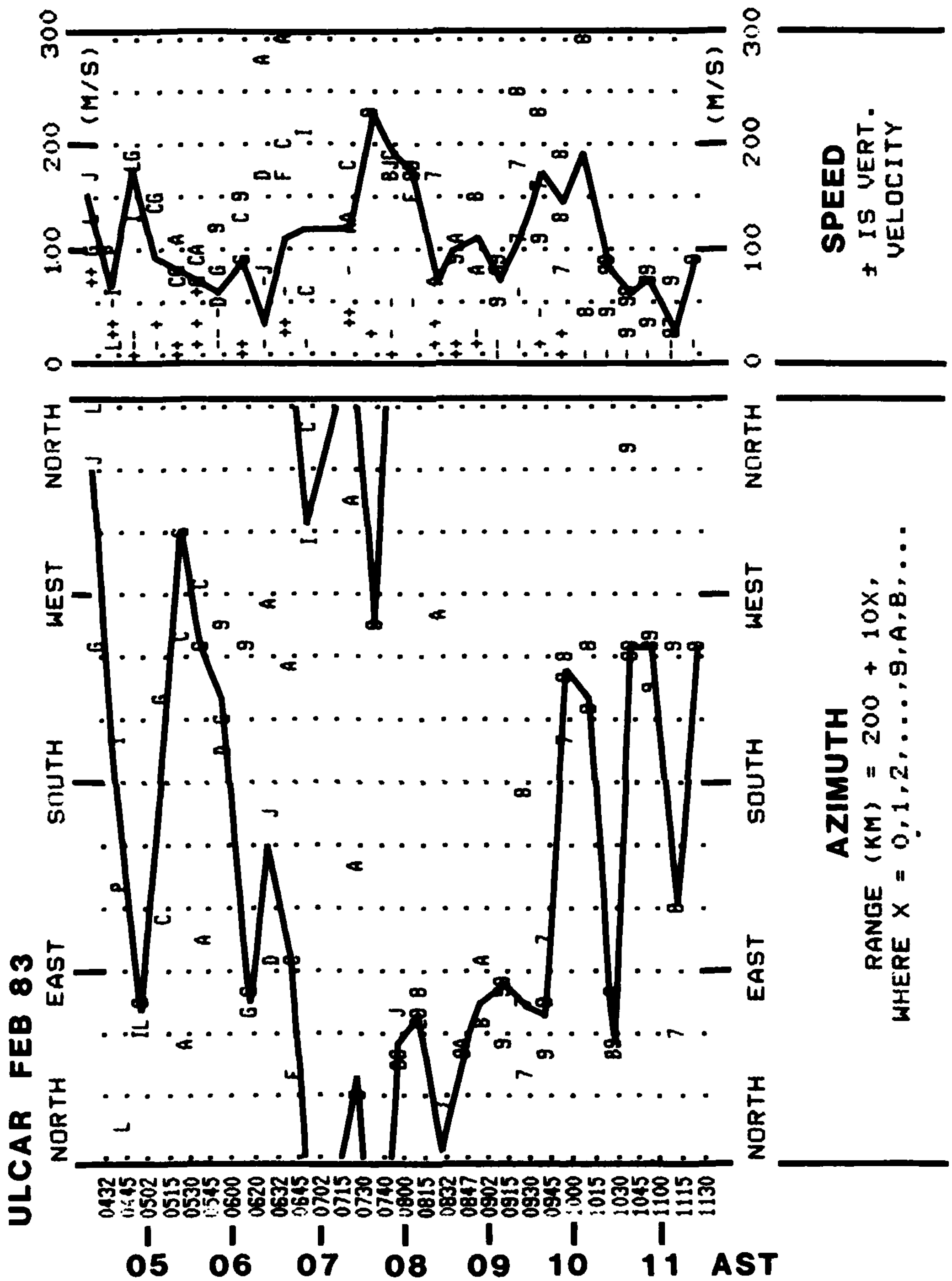


F - REGION DRIFT

DIGISONDE OBSERVATIONS AT GOOSE BAY, LABRADOR

29 AUG 81 04:20 TO 10:30 AST

Figure 6

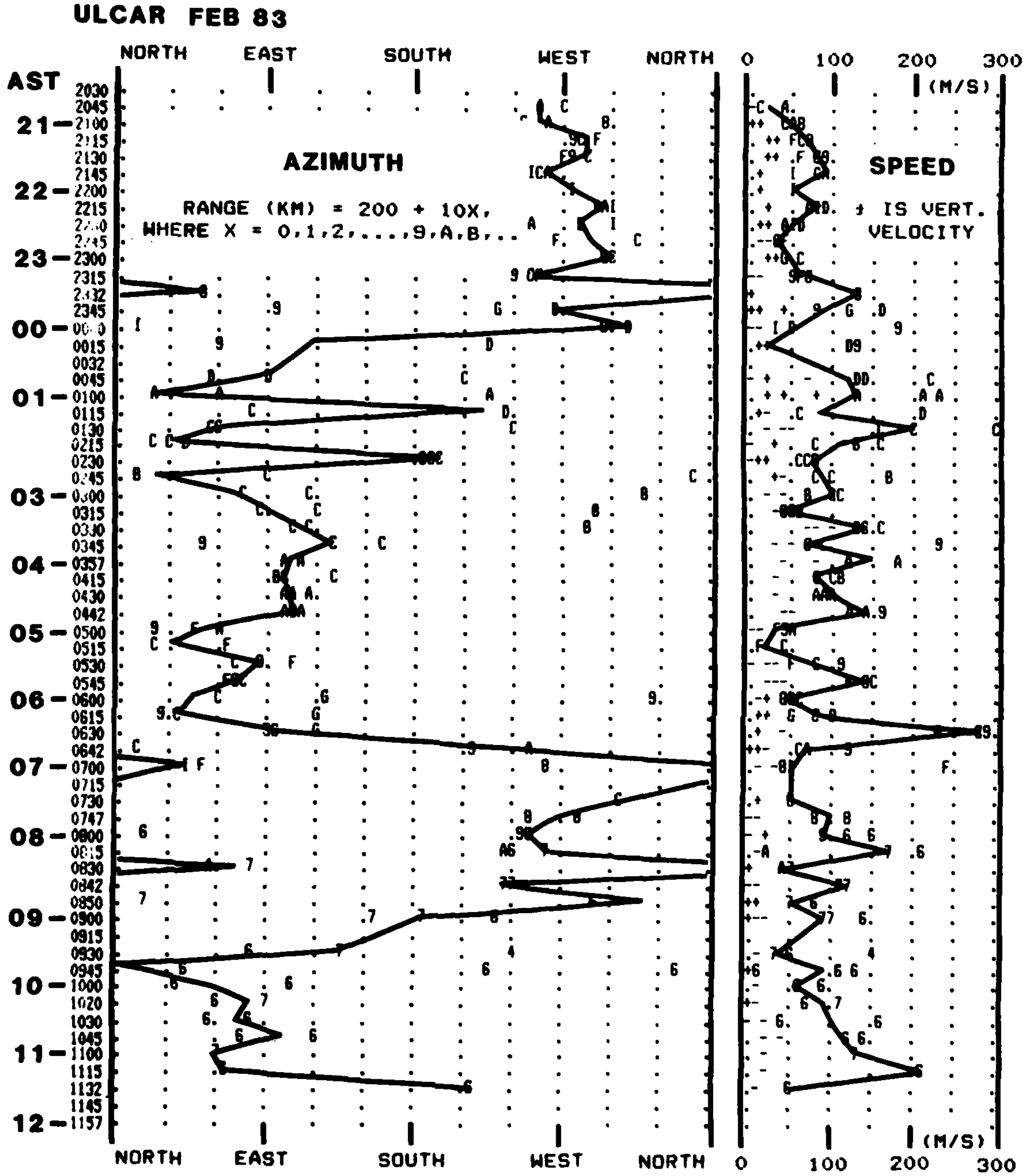


F - REGION DRIFT

DIGISONDE OBSERVATIONS AT GOOSE BAY, LABRADOR

23 JAN 82 04:30 TO 11:30 AST

Figure 25

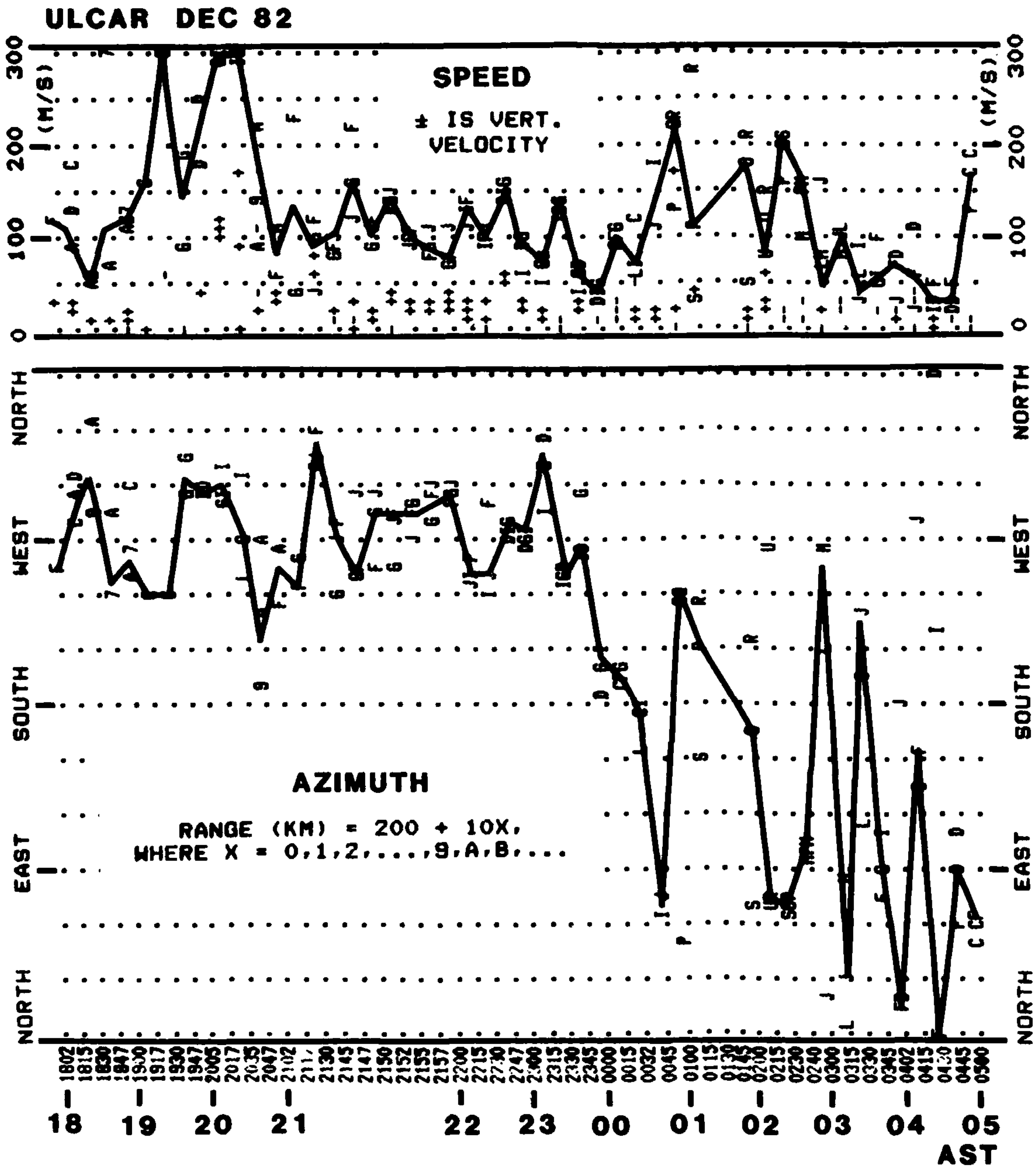


F - REGION DRIFT

DIGISONDE OBSERVATIONS AT GOOSE BAY, LABRADOR

20/21 JAN 82 20:30 TO 12 AST

Figure 26



F - REGION DRIFT
DIGISONDE OBSERVATIONS AT GOOSE BAY, LABRADOR
26/27 JAN 82 18 TO 05 AST

Figure 27

We consider first the results in Figures 26 and 27, where the drift observations start before midnight. The plasma drifts in a generally westward direction until midnight, then shifts towards the east; this is what we would expect (see section 1.6.3 and references therein).[82A] Before midnight, both the direction and speed are similar for all three ranges of each group, although after midnight there are groups where the velocities are not as consistent for all ranges. Most measurements are fifteen minutes apart, so it is quite possible that the calculated-velocity variations as a function of time reflect true variations. Because of a fortunate typing mistake in punching computer cards when choosing the drift data to be calculated, a series of seven drift measurements only two or three minutes apart were also calculated (see Figure 27, 21:45 to 22:00); these velocities show relatively little variation during the fifteen-minute period.

The first three graphs include drift velocities calculated from data measured after sunrise. The first graph starts at 04:20 because no earlier drift measurements were made that day. The blanks from 04:20 to 05:42 indicate that the sky map calculation yielded less than five sources for each case of drift measurements during that time period. (The data from cases yielding less than five sources are not used to calculate drift velocities; see section 3.2.) On this and the other graphs, some times have less than three velocities for the same reason. The second graph starts at 04:32 because even though drift measurements were started the previous evening, all F-region echoes before 04:32 were blanketed by a strong Es layer. The median of the three velocities is more

[82A]The results of 20/21 and 26/27 January 1982 also compare favorably with drift direction and velocity shown for averaged data from the Millstone Hill Incoherent Scatter Radar (Oliver et. al., 1983).

jagged during this time period. At sunrise, there is a sudden surge of ionizing energy in the ionosphere; the changes in electron concentration along the wave propagation path causes the high-frequency phase to change. This apparent Doppler shift is interpreted as motion of the reflecting ionization.

4.0 CONCLUSIONS

The Doppler method of measuring plasma drift seems to be valid if we evaluate the results in the light of statements by Hargreaves and by Rawer and Suchy (the latter is in the context of fading measurements):

> The small-scale structure of the atmosphere tends to be irregular and unpredictable in detail -- though predictions of a statistical kind may be possible. The distinction can be illustrated by reference to meteorology, in which the forecaster might predict the average wind speed and direction, but it would be a hopeless task to attempt a prediction of the precise wind vector for a stated place and instant of time.[83]

> ... individual determinations with neighbouring antennae triangles may give considerable differences. So the fluctuations in time and space are another reason to disregard individual observations and accept only the median of several of these as a reasonable determination.[84]

[83]Hargreaves (1979), p. 107.

[84]Rawer and Suchy (1967), p. 407.

5.0 RECOMMENDATIONS

The next step in the study of high-latitude ionospheric plasma motion is to analyze the drift measurements of a large number of days in order to determine if there are typical features which are repeated from day to day in the drift-movement pattern, and to distinguish the diurnal and seasonal variations in these features. Also, by analyzing all drift measurements made instead of small groups of measurements fifteen minutes apart, it should be possible to evaluate the validity of the data for those time periods (for example, the morning measurements) which yielded large variations in the velocities, by determining whether the calculated velocity changes with time in a steady or random manner.

The drift convection pattern (discussed in section 1.6.3) characteristic of the polar cap[85] has been observed in the F region with ionograms and optical techniques from the AFGL Airborne Ionospheric Observatory (AIO)[86] during flights from Thule, Greenland (which is about 23° of latitude north of Goose Bay) and while the AIO was on the ground at Thule. During periods of high magnetic activity the auroral oval, which bounds the polar cap, extends down to mid-latitudes and, at night, Goose Bay may be directly below or poleward to the oval. During more quiet periods Goose Bay is south of the equatorward edge of the oval. In order to determine if and when the plasma drift at Goose Bay forms part of the polar cap convection pattern, it would be extremely useful if another

[85] The polar cap is the region where the geomagnetic-field lines are vertical or nearly vertical. It is along these magnetic lines that energetic solar particles penetrate deep into the atmosphere. See Hargreaves (1979), section 8.2.2.

[86] See Buchau et al (1982).

Digisonde station with the capability of making multi-antennae drift measurements were put into operation at Thule, so that the drift measurements from Goose Bay could be correlated with those from Thule.

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APPENDIX A

PROGRAM TESTSKY

TESTSKY (ULCAR)

```
      PROGRAM TESTSKY(INPUT,OUTPUT,TAPE1,TAPE3,TAPE8,TAPE9)
C
C======================================================================
C
C  THIS PROGRAM GENERATES A TIME SEQUENCE OF DATA POINTS WHICH
C SIMULATES DRIFT DATA RECEIVED FROM ONE OR MORE SOURCES BY A SET OF
C ANTENNAS IN THE COMPLEX PLANE, IN THE SAME FORMAT AS THE DGS 128PS
C IN GOOSE BAY, LABRADOR.  THE TIME SEQUENCE IS TRANSFORMED INTO THE
C FREQUENCY DOMAIN BY SUBROUTINE FORER.  SPECTRAL AVERAGING (HANNING
C WEIGHTING APPLIED TO THE FREQUENCY DOMAIN) IS DONE IN THE COMPLEX
C DOMAIN: FROM EACH SPECTRAL LINE WEIGHTED BY A FACTOR OF TWO, THE
C ADJACENT SPECTRAL LINES ARE SUBTRACTED.  FOR PROGRAM NUMBERS IN=5
C OR 8, ALL SPECTRAL LINES ARE KEPT; THE FIRST SPECTRAL LINE (OF
C DOPPLER FREQ. ZERO) IS DOUBLED, BUT ONLY THE SECOND SPECTRAL LINE
C IS SUBTRACTED. FOR IN=6,7,9, ONLY THE ODD-FREQUENCY (E.G.: 1/16,3/16
C HZ,ETC.) SPECTRAL LINES ARE KEPT, THE INFORMATION FROM THE EVEN-FREQ.
C LINES (0 HZ,2/16 HZ, ETC.) BEING INCLUDED ONLY IN THE AVERAGING. THE
C RESULT IS TRANSFORMED FROM (REAL,IMAG) TO (AMPLITUDE,PHASE), AND IS
C THEN PACKED AND BUFFERED OUT ONTO TAPE9 BY SUBROUTINES C720 AND
C C2160, IN THE SAME FORMAT AS THE DATA ON TAPES GENERATED BY THE
C DIGISONDE, EXCEPT THAT DATA IS GENERATED FOR ONLY ONE FREQUENCY AND
C RANGE.  (THE DGS 128PS MEASURES DRIFT AT THREE FREQUENCIES AND RANGES
C FOR IN=8,9 AND AT SIX FOR IN=5,6,7.)  ALSO, TESTSKY IS NOT FULLY
C CODED FOR PROGRAM IN=7, WHICH REQUIRES FOUR OUTPUT RECORDS PER
C CASE INSTEAD OF TWO.
C
C  FR,FI,HAMPLTD,HPHASE, MUST BE DIMENSIONED AT LEAST TO NMAX, NMAX=
C =NPTS IF NPTS IS A POWER OF 2, NMAX=NEXT HIGHER POWER OF 2 OTHERWISE.
C FOR DGS 128PS, NMAX=NPTS.  DIM OF SINS AT LEAST ((DIM OF FI)/4)+1.
C HFR,HFI, DIMENSIONED AT LEAST TO NSL.  THESE ARRAYS, AND ARRAYS
C FM TO IBUF1 IN SUBROUTINE C720, AND ARRAY IBUF IN C2160, ARE
C DIMENSIONED TO THE MAXIMUM PRESENTLY REQUIRED, BUT MAY NEED LARGER
C DIMENSIONS IF DIGISONDE PARAMETERS ARE CHANGED.
C (DIMENSION REQUIREMENTS ARE DEFINED IN C720 AND C2160 COMMENTS).
C
C  FOR DGS 128PS DATA, NPTS=NO. OF POINTS IN THE TIME SEQUENCE=NMAX
C =NO. OF SPECTRAL LINES BEFORE SPECTRAL AVE'G=64 FOR IN=5; 128 FOR
C IN=6,8; 256 FOR IN=7,9.  AFTER SPECTRAL AVE'G, NSL=NO. OF SPECTRAL
C LINES=64 FOR IN=5,6; 128 FOR IN=7,8,9.
C
C  BEFORE SPECTRAL AVERAGING, FREQ. SPECTRUM IS APPROXIMATELY:
C IN             DOPFREQ [HZ]                        I=1 TO NMAX DF
C  5  0,-1/8,-2/8,...,-31/8,32/8,31/8,...,1/8.          1 TO 64   1/8
C  6  0,-1/16,-2/16,...,-63/16,64/16,63/16,...,1/16.    1 TO 128  1/16
C  7  0,-1/32,-2/32,...,-127/32,128/32,127/32,...,1/32. 1 TO 256  1/32
C  8  0,-1/8,-2/8,...,-63/8,64/8,63/8,...,1/8.          1 TO 128  1/8
C  9  0,-1/16,-2/16,...,-127/16,128/16,127/16,...,1/16. 1 TO 256  1/16
C WHERE DF=DOPP-FREQ RESOLUTION [HZ] BEFORE SPECTRAL AVERAGING.
C
C  AFTER SPECTRAL AVE'G, AND AFTER AFTER NEG & POS DOPPLERS HAVE
C BEEN SEPARATED AND ORDER OF POS DOPPLERS HAS BEEN REVERSED (IN
```

```
C SUBROUTINE C720),THE ABSOLUTE VALUE OF THE NEG AND POS DOPPLER
C FREQUENCIES ARE APPROXIMATELY:
C     IN      DOPFREQ [HZ]      I=1 TO NSL/2 DFR[HZ]
C      5  0,1/8,2/8,....,31/8     1 TO 32      1/8
C      6  1/16,3/16,....,63/16    1 TO 32      1/8
C      7  1/32,3/32,....,127/32   1 TO 64      1/16
C      8  0,1/8,2/8,....,63/8     1 TO 64      1/8
C      9  1/16,3/16,....,127/16   1 TO 64      1/8
C WHERE DFR=DOPP-FREQ RESOLUTION AFTER SPECTRAL AVERAGING.
C
C EXPLANATION OF KPRINT USAGE:
C   (FUNCTIONS CAN BE CALLED SIMULTANEOUSLY BT SETTING KPRINT EQUAL
C   TO THE SUM OF THE INDIVIDUAL KPRINTS)
C
C KPRINT:  PROGRAM FUNCTION:
C    1      CALCULATE DOPPLER FREQUENCIES FROM DRIFT VELOCITY
C             SPECIFIED ON TAPE1.  (OTHERWISE, DOPP. FREQ'S
C             MUST BE DEFINED ON TAPE1: SEE FREQ. SPECTRUM ABOVE;
C             REPLACE 1/8 BY .12254902, AND MULTIPLES OR SUB-
C             MULTIPLES OF 1/8 BY MULT. OR SUB-MULT. OF .12254902)
C    2      PRINT VALUES (TAPE1)
C    4      PRINT ANTENNA NO., LOCATION, NOISE PARAMETERS
C    8      PRINT SOURCE NO., ANT. PHASE, TOTAL PHASE
C             (TOT. PH.=ANT. PH. + PHINIT, WHERE PHINIT IS
C             INITIAL PHASE AT THE SOURCE)
C   16      PRINT TIME SEQUENCE (REAL, IMAG)
C   32      PRINT FREQ. SEQUENCE (REAL, IMAG)
C 2048      SKIP SPECTRAL AVE'G
C             (THE SAME DOPPLER LINES APPEAR AT THE OUTPUT,
C             BUT THE ADJACENT SPECTRAL LINES ARE NOT SUBTRACTED)
C   64      PRINT AVERAGED SPECTRAL LINES (REAL,IMAG)
C  128      PRINT AVE'D SPECTRAL LINES (AMPLITUDE, PHASE)
C  256      PRINT NEG & POS DOPPLERS AFTER THEY ARE SEPARATED
C              AND ORDER OF POS DOPP HAS BEEN REVERSED
C  512      PRINT NEG & POS DOPPLERS AFTER SCALING
C 1024      PRINT DATA AFTER PACKED INTO TWO RECORDS
C=========================================================================
C
        COMMON KPRINT,RADIAN
        COMMON FR(256),FI(256),SINS(65)
        DIMENSION HAMPLTD(256),HPHASE(256),HFR(128),HFI(128)
        COMPLEX ANT2
        DIMENSION ANT3(3)  $  EQUIVALENCE(ANT3,ANT2)
        DIMENSION S3(3)
C
C=========================================================================
C SOURCE INFORMATION.
C DIRECTION AND INITIAL PHASE AT THE SOURCE IN DEGREES.
C=========================================================================
C
        DIMENSION VX(32),VY(32),VZ(32),VXYZ(3)
```

```
      DIMENSION SAZMTH(32),SZENITH(32),AMPLTDE(32),DOPFREQ(32)
+       ,PHINIT(32)
      DIMENSION RX(32),RY(32),RZ(32)
C
C=========================================================================
C ANTENNA INFORMATION.
C ANTENNA LOCATION IN METERS.
C RADIAN=RADIANS/DEGREE.
C=========================================================================
C
      COMPLEX ANT(10)
      REAL NOISE(10)
      DIMENSION TINIT(10),TINCR(10)
      COMMON /BLK/FMAXMAG,TWOPI
C
      NAMELIST/VALUES/CASE,KPRINT,IN,KSOURCE,VX,VY,VZ,
+      SAZMTH,SZENITH,AMPLTDE,DOPFREQ,PHINIT,FREQ,
+      NANT,ITT,ANT,NOISE,SEED
      DATA TINIT/10*0.0/
      DATA C/2.997925E8/
      DATA TWOPI/6.2831853071795B6/
      DATA ANT3/3*0.0/,NSWTCH/0/
      REWIND 1
      REWIND 3
      REWIND 8
      REWIND 9
C
C=========================================================================
C READ VALUES.
C DETERMINE:
C   ITIME=TIME OF EACH MEASUREMENT (CASE);
C   TINCR=DELTA-T FOR TIME SAMPLES;
C   NPTS=NO. OF DATA POINTS IN TIME SEQUENCE,
C       =NO. OF SPEC. LINES BEFORE SPEC. AVE'G;
C   NSL=NO. OF SPEC. LINES AFTER SPEC. AVE'G;
C   DFR=DOPP-FREQ RESOLUTION AFTER SPECTRAL AVERAGING;
C   DF2=DOPP. FREQ. OF FIRST SPECTRAL LINE;
C   USCALE=.707*SINZMAX/20
C         =COORD.-SYSTEM SCALE FOR THE UNIT VECTORS;
C   RX,RY,RZ=X,Y,Z COMPONENTS OF THE UNIT SOURCE-POSITION
C                 VECTOR R;
C   DOPPLER FREQUENCIES.
C OUTPUT OF DOT=VR=DOT PRODUCT OF VELOCITY VECTOR V
C   AND UNIT SOURCE-POSITION VECTOR R.
C PRINT VALUES.
C=========================================================================
C
      ITIME=KT=0
      RADIAN=.0174532925199433
    1 CONTINUE
      NPTS0=0
```

```
      READ (1,VALUES)
      IF(CASE.LT.0) GO TO 28
      KT=KT+1  $ IF(KT.EQ.7)KT=1
      ITIME=ITIME+10+((KT/6)*40)
      DO 17 I=1,NANT
   17 TINCR(I)=.1275/(1+IN/8)
      NPTS=64+((IN/6)*64)  $ IF(IN.EQ.7.OR.IN.EQ.9)NPTS=256
      NSL=64+64*(IN/7)
      DFR=.12254902  $ IF(IN.EQ.7) DFR=DFR/2
      DF2=DFR/2  $ IF(IN.EQ.5.OR.IN.EQ.8) DF2=0
      USCALE=(.707/20)*AMIN1(.707,(C/(FREQ*100)))
C
      DO 4 IS=1,KSOURCE
      ZENRAD=SZENITH(IS)*RADIAN  $ AZIMRAD=SAZMTH(IS)*RADIAN
      RX(IS)=SIN(ZENRAD)*COS(AZIMRAD)
      RY(IS)=-SIN(ZENRAD)*SIN(AZIMRAD)
    4 RZ(IS)=COS(ZENRAD)
C
      IF((KPRINT.AND.1).EQ.0) GO TO 14
C
      DO 16 IS=1,KSOURCE
      VXYZ(1)=VX(IS) $ VXYZ(2)=VY(IS) $ VXYZ(3)=VZ(IS)
      S3(1)=RX(IS)  $ S3(2)=RY(IS)  $ S3(3)=RZ(IS)
      CALL DOT(VXYZ,S3,VR)
   16 DOPFREQ(IS)=-2*(VR/C)*FREQ
C
   14 IF((KPRINT.AND.2).EQ.0) GO TO 15
C
      PRINT 105, CASE,KPRINT,IN,KSOURCE
  105 FORMAT(" CASE=",F3.0,",  KPRINT=",I5,",  IN=",I1,
+        ",  NO. OF SOURCES=",I3)
C
      IF((KPRINT.AND.1).EQ.0) GO TO 100
      PRINT 110
  110 FORMAT(/," SOURCE",6X,"VX",7X,"VY",7X,"VZ",6X,"AZIM",5X," ZEN",5X,
+        "X",6X,"Y",4X,"AMPL",3X,"DOPFREQ",1X," INIT PH",2X,"DOPP. NO.")
C
      DO 120 IS=1,KSOURCE
  120 PRINT 130,IS,VX(IS),VY(IS),VZ(IS),SAZMTH(IS),SZENITH(IS),
+        (RX(IS)/USCALE),(RY(IS)/USCALE),AMPLTDE(IS),
+        DOPFREQ(IS),PHINIT(IS),(((ABS(DOPFREQ(IS))-DF2)/DFR+1)*
+         ((DOPFREQ(IS)+.0000001)/ABS((DOPFREQ(IS)+.0000001))))
  130 FORMAT(I5,2X,5F9.2,2F7.1,F7.2,F10.4,2F9.2)
      GO TO 140
C
  100 PRINT 150
  150 FORMAT(/" SOURCE",5X,"AZIM",6X,"ZEN",5X,"X",6X,"Y",4X,"AMPL",3X,
+        "DOPFREQ",1X," INIT PH",2X,"DOPP. NO.")
C
      DO 160 IS=1,KSOURCE
  160 PRINT 170,IS,SAZMTH(IS),SZENITH(IS),(RX(IS)/USCALE),
```

```
+       (RY(IS)/USCALE),AMPLTDE(IS),DOPFREQ(IS),
+       PHINIT(IS),(((ABS(DOPFREQ(IS))-DF2)/DFR+1)*((DOPFREQ(IS)+
+        .0000001)/ABS((DOPFREQ(IS)+.0000001))))
  170 FORMAT(I5,2X,2F9.2,2F7.1,F7.2,F10.4,2F9.2)
C
  140 PRINT 180,(FREQ/(1E+6)),NANT,ITT
  180 FORMAT(/" SOUNDING FREQ=",F8.4," MHZ,  NO. OF ANT=",I2,",  ITT="
+     ,I2/)
C
      PRINT*,"ANT. COORD.(X,Y)= ",(ANT(IA),IA=1,NANT)
      PRINT*,"  "
      PRINT*,"NOISE= ",(NOISE(IA),IA=1,NANT)
      PRINT*,"  "
      PRINT*,"T-INIT= ",(TINIT(IA),IA=1,NANT)
      PRINT*,"  "
      PRINT*,"DELTA-T= ",(TINCR(IA),IA=1,NANT)
      PRINT*,"  "
      PRINT*,"TIME= ",ITIME,",  SEED= ",SEED
C
C=========================================================================
C SET INITIAL PARAMETERS
C=========================================================================
C
   15 IF(NPTS.EQ.NPTSO) GO TO 2  $  NPTSO=NPTS  $  NMAX=0
      FMAXMAG=1.E-6
    2 IA=0
      W=TWOPI*FREQ
      IF(SEED.NE.0.) CALL RANSET(SEED)
C
C=========================================================================
C INITIALIZE ANTENNA PARAMETERS.
C PRINT ANTENNA PARAMETERS.
C=========================================================================
C
    3 IA=IA+1  $  IS=0
      ANT2=ANT(IA)  $  SDN=NOISE(IA)  $  TI=TINIT(IA)  $  DT=TINCR(IA)
C
      IF((KPRINT.AND.4).EQ.0) GO TO 5
      PRINT*,"  "  $ PRINT*,"  "  $ PRINT*,"  "
      PRINT *,"ANTENNA NO.=",IA,",  LOCATION=",ANT2,",  NOISE=",SDN
      PRINT *," "
C
C=========================================================================
C INITIALIZE SOURCE PARAMETERS.
C=========================================================================
C
    5 IS=IS+1
      AMP=AMPLTDE(IS)  $  DFREQ=DOPFREQ(IS)
      DELTA=PHINIT(IS)*RADIAN
      WD=TWOPI*DFREQ
C
```

```
C========================================================================
C COMPUTE ARRIVAL PHASE DIFFERENCE DUE TO ANTENNA LOCATION.
C OUTPUT OF DOT=Q=DOT PRODUCT OF UNIT PROPAGATION VECTOR K
C   AND ANTENNA-POSITION VECTOR A.
C PRINT SOURCE PARAMETERS.
C========================================================================
C
       S3(1)=-RX(IS)  $ S3(2)=-RY(IS)  $ S3(3)=-RZ(IS)
       CALL DOT(ANT3,S3,Q)
       PHI=(W+WD)*Q/C
C
       IF((KPRINT.AND.8).EQ.0) GO TO 7
       IF(IS.EQ.1) PRINT*," SOURCE ANT.PHASE TOT.PHASE(DEG)"
       PRINT 6,IS,(PHI/RADIAN),((PHI+DELTA)/RADIAN)
     6 FORMAT(I5,F11.2,F10.2)
C
C========================================================================
C COMPUTE TIME SEQUENCE FOR THIS SOURCE.
C========================================================================
C
     7 T=TI  $  I=1
     8 IF(IS.EQ.1) FR(I)=FI(I)=0.
CCC       Q=PHI+WD*T+DELTA
       Q=WD*T-PHI-DELTA
       FR(I)=FR(I)+AMP*COS(Q)  $  FI(I)=FI(I)+AMP*SIN(Q)
       IF(I.EQ.NPTS) GO TO 9  $  I=I+1  $  T=T+DT  $  GO TO 8
     9 IF(IS.LT.KSOURCE) GO TO 5
       IF(SDN.EQ.0.) GO TO 20
C
C========================================================================
C ADD NOISE TO THE TIME SEQUENCE.
C PRINT TIME SEQUENCE.
C========================================================================
C
       DO 10 I=1,NPTS
       CALL GAUSS1(0.,SDN,Q)
       FR(I)=FR(I)+Q
       CALL GAUSS1(0.,SDN,Q)
    10 FI(I)=FI(I)+Q
C
    20 IF(KPRINT.AND.16)21,22
    21 PRINT 32,TI,DT
    32 FORMAT(/," TIME SEQUENCE:  T-INIT=",F6.5,",  DELTA-T=",
+         F6.5,/,6(4X,"I",3X,"REAL",4X,"IMAG",2X))
       PRINT 13,(I,FR(I),FI(I),I=1,NPTS)
    13 FORMAT(25(I5,2F8.2,,5(I6,2F8.2)/))
C
C========================================================================
C COMPUTE THE FOURIER SPECTRUM.
C PRINT FREQ. SPECTRUM (REAL,IMAG).
C========================================================================
```

```
C
 22 CALL FORER(NPTS,FR,FI,SINS,NSWTCH,NMAX)
C
    IF((KPRINT.AND.32).EQ.0) GO TO 31
    PRINT 30
 30 FORMAT(/," FREQUENCY SEQUENCE (REAL,IMAG)",/,
+      6(4X,"I",3X,"REAL",4X,"IMAG",2X))
    PRINT 13,(I,FR(I),FI(I),I=1,NMAX)
C
C=========================================================================
C DO SPECTRAL AVERAGING.
C IF SKIPPING SPECTRAL AVE'G, ADJACENT SPECTRAL LINES ARE NOT
C SUBTRACTED.  MULTIPLYING SPECTRAL LINES BY 2 CHANGES NOTHING
C SINCE SPECTRAL LINES ARE SCALED LATER TO SIX BITS.
C
C PRINT AVERAGED SPECTRAL LINES (REAL,IMAG).
C=========================================================================
C
 31 O1=1.
    IF((KPRINT.AND.2048).NE.0) O1=0.
    IF(IN.NE.5.AND.IN.NE.8) GO TO 25
C
    HFR(1)=2*FR(1)-O1*FR(2)
    HFI(1)=2*FI(1)-O1*FI(2)
C
    NS2=NSL/2  $ NS3=NS2+1  $ NS4=NSL-2
    DO 40 I=2,NS2
    HFR(I)=-O1*FR(I-1)+2*FR(I)-O1*FR(I+1)
 40 HFI(I)=-O1*FI(I-1)+2*FI(I)-O1*FI(I+1)
C
    DO 50 I=NS3,NS4
    HFR(I)=-O1*FR(I)+2*FR(I+1)-O1*FR(I+2)
 50 HFI(I)=-O1*FI(I)+2*FI(I+1)-O1*FI(I+2)
C
    HFR(NSL-1)=-O1*FR(1)+2*FR(NSL)-O1*FR(NSL-1)
    HFI(NSL-1)=-O1*FI(1)+2*FI(NSL)-O1*FI(NSL-1)
    HFR(NSL)=2*FR(1)-O1*FR(NSL)
    HFI(NSL)=2*FI(1)-O1*FI(NSL)
    GO TO 60
C
 25 NS1=NSL-1
    DO 70 I=1,NS1
    J=2*I
    HFR(I)=-O1*FR(J-1)+2*FR(J)-O1*FR(J+1)
 70 HFI(I)=-O1*FI(J-1)+2*FI(J)-O1*FI(J+1)
    HFR(NSL)=-O1*FR(1)+2*FR(2*NSL)-O1*FR(2*NSL-1)
    HFI(NSL)=-O1*FI(1)+2*FI(2*NSL)-O1*FI(2*NSL-1)
C
 60 IF((KPRINT.AND.64).EQ.0) GO TO 24
    IF((KPRINT.AND.2048).NE.0) PRINT*," "
    IF((KPRINT.AND.2048).NE.0) PRINT*," NO SPECTRAL AVE'G: ",
```

```
+       "WHAT FOLLOWS IS FREQ. SEQ."
        PRINT 61
     61 FORMAT(/," AVERAGED SPECTRAL LINES (REAL,IMAG)
+       ",/,6(4X,"I",3X,"REAL",4X,"IMAG",2X))
        PRINT 13,(I,HFR(I),HFI(I),I=1,NSL)
C
C=====================================================================
C CONVERT TO AMPLITUDE AND PHASE.
C PRINT AVERAGED SPECTRAL LINES (AMPL & PHASE).
C=====================================================================
C
     24 DO 26 I=1,NSL
        TEMP=(HFR(I)*HFR(I)+HFI(I)*HFI(I))
        IF(TEMP.EQ.0.0)GO TO 27
        HAMPLTD(I)=SQRT(TEMP)
        HPHASE(I)=ATAN2(HFI(I),HFR(I))
        GO TO 26
     27 HAMPLTD(I)=0.0
        HPHASE(I)=0.0
     26 CONTINUE
C
        DO  55 I=1,NSL
     55 IF(HAMPLTD(I).GT.FMAXMAG) FMAXMAG=HAMPLTD(I)
C
        IF((KPRINT.AND.128).EQ.0) GO TO 62
        IF((KPRINT.AND.2048).NE.0) PRINT*," "
        IF((KPRINT.AND.2048).NE.0) PRINT*," NO SPECTRAL AVE'G; ",
+         "WHAT FOLLOWS IS FREQ. SEQ."
        PRINT 23
     23 FORMAT(/," AMPLITUDE & PHASE(DEG) OF AVERAGED SPECTRAL LINES ",/,
+         6(4X,"I",3X,"AMPL",3X,"PHASE",2X))
        PRINT 13,(I,HAMPLTD(I),(HPHASE(I)/RADIAN),I=1,NMAX)
C
C=====================================================================
C WRITE THE SPECTRAL AMPLITUDES & PHASES ON TAPE3.
C=====================================================================
C
     62 WRITE(3) NSL,(HAMPLTD(I),HPHASE(I),I=1,NSL)
        IF(IA.LT.NANT) GO TO 3
C
        PRINT*," "
        PRINT*,"MAX HAMPLTD=",FMAXMAG
        PRINT*," "
C
        IF((KPRINT.AND.2048).NE.0)PRINT*," ***** NO SPECTRAL AVE'G *****"
C
C=====================================================================
C THIS CASE IS COMPLETED.
C
C SCALE DATA AND PACK PREFACE AND DATA INTO 2 RECORDS IN SAME FORMAT
C AS DIGISONDE OUTPUT.
```

```
C======================================================================
C
      CALL C720(FREQ,IN,ITT,ITIME,NSL,NANT,NWORD,IOUT)
C
      CALL C2160(NWORD,IOUT)
C
      GO TO 1
   28 STOP
      END
C
C
C
C
C
C
C
C======================================================================
C SUBROUTINE FORER
C======================================================================
C
      SUBROUTINE FORER (NPTS,FR,FI,SINS,NSWTCH,NMAX)
C
C======================================================================
C COMPUTE FOURIER COEFFICIENTS OF ARRAY OF DATA
C
C TAKEN FROM A PROGRAM WRITTEN BY MICHAEL FORMAN
C
C NPTS IS THE NUMBER OF INPUT POINTS
C
C FR IS INPUTED AS THE REAL PART OF THE INPUT DATA ARRAY
C (FOR SIMPLE OPERATION INPUT DATA ARRAY)
C FR IS OUTPUTED AS THE ARRAY OF COSINE COEFFICIENTS
C
C FI IS INPUTED AS THE IMAGINARY PART OF THE INPUT DATA ARRAY
C (FOR SIMPLE OPERATION ARRAY OF ZEROS)
C FI IS OUPUTED AS THE ARRAY OF SINE COEFFICIENTS
C
C GIVEN THE ORIGINAL TIME SEQUENCE ( FR(I),FI(I) ) FOR I=1,...,NPTS,
C THE RESULTING FREQUENCY SEQUENCE ( FR(J),FI(J) ) FOR J=1,...,NMAX
C IS DEFINED:
C                           NMAX
C      ( FR(J),FI(J) ) = SUM ( FR(I),FI(I) ) ( COS(K),SIN(K) )
C                           I=1
C WHERE K = (J-1)(TWOPI/NMAX)(I-1).
C
C SINS IS AN ERASABLE ARRAY (MUST BE DIMENSIONED AT LEAST M/4+1
C      WHERE M IS THE DIMENSION OF FI)
C
C NSWTCH=0  FORWARD TRANSFORM
C NSWTCH=1  BACKWARDS TRANSFORM
C
```

```
C NMAX (ON INPUT) SET NMAX=0 ONLY WHEN NECESSARY TO COMPUTE
C                     A NEW NMAX OR SINS ARRAY
C      (ON OUTPUT) THE NUMBER OF POINTS IN THE EXTENDED FUNCTION
C                      (EXTENDED WITH ZEROS TO THE NEXT POWER OF 2)
C======================================================================
C
            COMMON KPRINT,RADIAN
            DIMENSION FR(1),FI(1),SINS(1)
            DATA TWOPI/6.283185307179586/
C            PRINT 10,(I,FR(I),FI(I),I=1,NPTS)
            IF(NMAX.NE.0) GO TO 650
C
C======================================================================
C COMPUTE NEXT HIGHER POWER OF 2 ABOVE NPTS
C======================================================================
C
            NBIT = ALOG(FLOAT(NPTS))/.693147180559945
            NMAX = 2**NBIT
            IF (NMAX.GE.NPTS) GO TO 200
            NBIT = NBIT+1
            NMAX = 2*NMAX
        200 FNMAX = NMAX
            NP = NPTS+1
            KR = NMAX/4+1
C
C======================================================================
C COMPUTE 1/4 CYCLE SINE FUNCTION
C======================================================================
C
            DO 600 I=1,KR
            XI = I-1
        600 SINS(I) = SIN(TWOPI*XI/FNMAX)
        650 IF(NMAX.LE.NPTS) GO TO 675
C
C======================================================================
C CLEAR REMAINDER OF REAL AND IMAGINARY PARTS
C======================================================================
C
            DO 300 I=NP,NMAX
            FR(I) = 0.
        300 FI(I) = 0.
        675 JMAX = NMAX
            JHALF = NMAX/2
            LXY = 2*KR
C
C======================================================================
C COMPUTE FOURIER COEFFICIENTS
C======================================================================
C
            DO 1300 K=1,NBIT
            JP = NBIT-K
```

```
      DO 1200 J=1,NMAX,JMAX
      JT = J+JHALF-1
      JJ = IBRSH(J-1,NBIT,JP)
      KK = KR-JJ-1
      IF (KK) 900,800,700
  700 WI = SINS(JJ+1)
      WR = SINS(KK+1)
      GO TO 1000
  800 WI = 1.0
      WR = 0.0
      GO TO 1000
  900 JB = LXY-(JJ+1)
      WI = SINS(JB)
      KK = -KK
      WR = -SINS(KK+1)
 1000 CONTINUE
      IF(NSWTCH.NE.0) WI=-WI
      DO 1100 L=J,JT
      LK = L+JHALF
      AR = FR(L)
      AI = FI(L)
      BR = FR(LK)*WR-FI(LK)*WI
      BI = FR(LK)*WI+FI(LK)*WR
      FR(L) = AR+BR
      FI(L) = AI+BI
      FR(LK) = AR-BR
 1100 FI(LK) = AI-BI
 1200 CONTINUE
      JMAX = JMAX/2
 1300 JHALF = JHALF/2
C
C========================================================================
C SWAP COEFFICIENTS INTO CORRECT ORDER
C========================================================================
C
      DO 1400 I=1,NMAX
      JJ = IBRSH(I-1,NBIT,0)
      IF (JJ.LE.I-1) GO TO 1400
      FX = FR(I)
      FR(I) = FR(JJ+1)
      FR(JJ+1) = FX
      FX = FI(I)
      FI(I) = FI(JJ+1)
      FI(JJ+1) = FX
 1400 CONTINUE
C      PRINT 10,(I,FR(I),FI(I),I=1,NMAX)
   10 FORMAT(3(2X,*SUB*4X*I*7X*FR*13X*FI*6X)/3(I10,1P2E15.7))
      IF(NSWTCH.EQ.0) RETURN
      TMAX=1.0/FLOAT(NMAX)
      DO 2 I=1,NMAX
      FR(I)=FR(I)*TMAX
```

```
      FI(I)=FI(I)*TMAX
    2 CONTINUE
      RETURN
      END
C
C
C
C
C
C
C
C=========================================================================
C FUNCTION IBRSH
C=========================================================================
C
      FUNCTION IBRSH (K,NP,JP)
      NS=2**(NP-1)
      NM=2**JP
      JC=2+JP
      KST=K
      KV=0
      DO 1 I=JC,NP
      KIN=KST/NS
      KV=KV+KIN*NM
      KST=KST-NS*KIN
      NS=NS/2
      NM=NM*2
    1 CONTINUE
      IBRSH=KV+KST*NM
      RETURN
      END
C
C
C
C
C
C
C
C=========================================================================
C SUBROUTINE GAUSS1
C THIS SUBROUTINE COMPUTES A NORMALLY DISTRIBUTED
C RANDOM VARIABLE V WITH GIVEN MEAN AND STANDARD
C DEVIATION
C=========================================================================
C
      SUBROUTINE GAUSS1(AM,S,V)
C
    1 P=RANF(DUM)
      IF(P) 1,1,2
    2 D=P
      IF(P.GT.0.5) D=1.0-D
```

```
      T2=ALOG(1.0/(D*D))
      T=SQRT(T2)
      V=T-(2.515517+0.802853*T+0.010328*T2)/(1.0+1.432788*T+0.189269*T2
+     +0.001308*T*T2)
      IF(P.LE.0.5) 3,4
    3 V=-V
    4 V=V*S+AM
      RETURN
      END
C
C
C
C
C
C
C
C=======================================================================
C SUBROUTINE VECTORS
C=======================================================================
C
      SUBROUTINE VECTORS(A,B,C)
      DIMENSION A(3),B(3),C(3)
C
      ENTRY CROSS
      C(1)=A(2)*B(3)-A(3)*B(2)
      C(2)=A(3)*B(1)-A(1)*B(3)
      C(3)=A(1)*B(2)-A(2)*B(1)   $  RETURN
C
      ENTRY DOT
      C(1)=A(1)*B(1)+A(2)*B(2)+A(3)*B(3)   $  RETURN
C
      ENTRY LENGTHV
      C(1)=SQRT(A(1)**2+A(2)**2+A(3)**2)   $  RETURN
      END
C
C
C
C
C
C
C
C=======================================================================
C SUBROUTINE C720
C=======================================================================
C
      SUBROUTINE C720(FREQ,IN,ITT,ITIME,NSL,NANT,NWORD,IOUT)
C
C=======================================================================
C TO SCALE AND PACK THE OUTPUT (AMPLITUDE, PHASE) FROM THE TEST
C FUNCTION SUCH THAT EACH DATUM WILL APPEAR AS STORED IN THE
C 6-BIT WORD WITH AMPLITUDE RANGE (0-63) AND PHASE RANGE
```

```
C (0-511). THE MAX AMPLITUDE HAS BEEN SORTED OUT IN MAIN PROGRAM.
C
C NSL=NO. OF SPECTRAL LINES
C    =NO. OF DOPPLER FREQUENCIES
C NANT=NO.OF ANTENNAS
C NHALF=NO. OF NEGATIVE DOPPLERS
C      =NO. OF POSITIVE DOPPLERS
C NTOT=NANT*NHALF
C     =TOTAL NO. OF NEG-DOPP VALUES OVER ALL ANTENNAS
C     =TOTAL NO. OF POS-DOPP VALUES OVER ALL ANTENNAS
C NCHAR=NO. OF  6-BIT CHARACTERS INTO WHICH THE NEG (OR POS) DATA IS
C        CODED: 2 AMPLITUDES AND 2 PHASES ARE CODED INTO 5 CHARACTERS
C NWORD=NO.OF COMPUTER WORDS CONTAINING THE NEG (OR POS) PACKED DATA:
C        10 6-BIT CHARACTERS ARE PACKED INTO EACH 60-BIT COMPUTER WORD
C IOUT=TOTAL NO. OF PACKED COMPUTER WORDS: 8 PREFACE, NWORD-NUMBER OF
C        NEG-DOPP, NWORD-NUMBER OF POS-DOPP
C
C FM,PHI,FMN,PHIN MUST BE DIMENSIONED AT LEAST TO NTOT; TM,TPHI, TO NSL;
C   IBUF, TO NCHAR; IBUF2, TO NWORD; IBUF1, TO IOUT.
C=========================================================================
       DIMENSION FM(256),PHI(256),FMN(256),PHIN(256),TM(128),
+       TPHI(128)
       DIMENSION IBUF(640),IBUF2(64),IBUF1(136),IPREF(80)
       COMMON /BLK/FMAXMAG,TWOPI
       COMMON KPRINT,RADIAN
C
       NHALF=NSL/2  $ NTOT=NANT*NHALF  $ NCHAR=(NTOT/2)*5
       NWORD=NCHAR/10  $ IOUT=2*NWORD+8
C
C======================== P R E F A C E =================================
C
C STATION IDENT,YR,DAY,HR,MIN,SEC; LAST 4 DIGITS NOT USED
C  (IDENT=0 IDENTIFIES THIS DATA AS TEST DATA IN SKYMAP)
       DATA IPREF /0, 7,8, 0,8,2, 0,0, 0,0, 0,0, 0,0,0,0,
C FOR MICROCOMPUTER ONLY
+      0,0,0,0,
C FIRST DIGIT=IREP; 2ND,IDB; 3RD & 4TH,ITT
+      4,3,0,0,
C IG,IN; NEXT 6 DIGITS NOT USED
+      1,0,0,0,0,0,0,0,
C SOUNDING FREQUENCIES 1 TO 6, IN 10-KHZ UNITS
+      0,0,0,0, 0,0,0,0, 0,0,0,0, 0,0,0,0, 0,0,0,0, 0,0,0,0,
C FIRST 3 DIGITS: CORRESPONDING RANGES (1.5-KM UNITS); 4TH DIGIT: IGAIN
+      2,7,5,4, 0,0,0,0, 0,0,0,0, 0,0,0,0, 0,0,0,0, 0,0,0,0/
C
C=========================================================================
C DETERMINE IN, ITT AND HR,MIN,SEC FROM NAMELIST VALUES
C=========================================================================
C
       IPREF(26)=IN
       IPREF(23)=ITT/10
```

```
      IPREF(24)=ITT-IPREF(23)*10
      IPREF(7)=ITIME/100000
      IPREF(8)=MOD(ITIME,100000)/10000
      IPREF(9)=MOD(ITIME,10000)/1000
      IPREF(10)=MOD(ITIME,1000)/100
      IPREF(11)=MOD(ITIME,100)/10
      IPREF(12)=MOD(ITIME,10)
C
C======================================================================
C SET SOUNDING FREQ EQUAL TO FREQ FROM NAMELIST VALUES
C
C TEST FUNCTION USES ONLY FIRST FREQ, WHEREAS DIGISONDE DATA
C   CAN INCLUDE DRIFT DATA FOR UP TO 6 FREQUENCIES
C======================================================================
C
      IFREQ=FREQ-12.5E+3
      IFREQ=IFREQ/10000
      IPREF(33)=MOD(IFREQ,10000)/1000
      IPREF(34)=MOD(IFREQ,1000)/100
      IPREF(35)=MOD(IFREQ,100)/10
      IPREF(36)=MOD(IFREQ,10)
C
      DO 11 I=1,80
   11 IPREF(I)=IPREF(I).OR.16
C
C============= F R E Q U E N C Y   S E Q U E N C E ======================
C
C READ FREQUENCY SEQUENCE FROM TAPE3
C
C PUT FIRST HALF OF THE DOPPLERS (NEG. DOPPLERS) FROM ALL ANTENNAS
C  INTO FM,PHI; 2ND HALF (POS. DOPPLERS) IN REVERSE ORDER INTO FMN,PHIN.
C PRINT NEGATIVE AND POSITIVE DOPPLERS, ALL ANTENNAS
C======================================================================
C
      DO 66 I=1,NANT
      BACKSPACE 3
   66 CONTINUE
C
      DO 15 IA=1,NANT
      READ (3) NPT64,(TM(I),TPHI(I),I=1,NPT64)
      IF(EOF(3))100,10
   10 II=IA-1
C
      DO 15 K=1,NHALF
      KK=II*NHALF+K
      FM(KK)=TM(K)
      PHI(KK)=TPHI(K)
      FMN(KK)=TM(NSL+1-K)
      PHIN(KK)=TPHI(NSL+1-K)
   15 CONTINUE
C
```

```
      IF((KPRINT.AND.256).EQ.0) GO TO 26
      PRINT 27
   27 FORMAT(/," NEGATIVE DOPPLERS, ALL ANTENNAS (PHASE IN DEGREES)",/,
+       6(5X,"I",3X,"AMPL",2X,"PHASE"))
      PRINT 28,(I,FM(I),(PHI(I)/RADIAN),I=1,NTOT)
   28 FORMAT(6(I6,2F7.1))
      PRINT 29
   29 FORMAT(/," POSITIVE DOPPLERS, ALL ANTENNAS (PHASE IN DEGREES)",/,
+       6(5X,"I",3X,"AMPL",2X,"PHASE"))
      PRINT 28,(I,FMN(I),(PHIN(I)/RADIAN),I=1,NTOT)
C
C========================================================================
C PACK PREFACE AND STORE RESULT IN IBUF1
C========================================================================
C
   26 CALL COMPACT(IPREF,80,IBUF1,8)
C
C========================================================================
C SCALE THE AMPLITUDES AND PHASES AND STORE IN IBUF1 WITH PREFACE:
C   ICOUNT=1:
C     CALL SCAST TO SCALE NEG-DOPPLER AMPL. & PHASES; AND TO STORE
C       SETS OF 2 6-BIT AMPLITUDES AND 2 9-BIT PHASES INTO ARRAY
C       IBUF IN SETS OF 5 6-BIT CHARACTERS.
C     CALL COMPACT TO PACK GROUPS OF 10 6-BIT CHARACTERS FROM IBUF INTO
C       60-BIT COMPUTER WORDS IN IBUF2.
C     APPEND NEG. DOPPLERS TO PREFACE IN IBUF1.
C   ICOUNT=2:
C     DO SAME FOR POS. DOPPLERS, APPENDING THEM TO PREFACE AND NEG.
C       DOPPLERS IN IBUF1.
C========================================================================
C
      DO 45 ICOUNT=1,2
C
      CALL SCAST(FM,PHI,NTOT,IBUF,NCHAR,ICOUNT)
C
      CALL COMPACT(IBUF,NCHAR,IBUF2,NWORD)
C
      K=8
      IF(ICOUNT.EQ.2) K=8+NWORD
      DO 35 I=1,NWORD
   35 IBUF1(K+I)=IBUF2(I)
      IF(ICOUNT.EQ.2) GO TO 45
      DO 40 J=1,NTOT
      FM(J)=FMN(J)
      PHI(J)=PHIN(J)
   40 CONTINUE
   45 CONTINUE
C
C========================================================================
C OUTPUT DATA WITH BUFFEROUT TO TAPE8
C========================================================================
```

```
C
   70 BUFFEROUT(8,1)(IBUF1(1),IBUF1(IOUT))
      IF(UNIT(8))95,80,70
   80 STOP 2
   95 CONTINUE
      GO TO 100
    4 PRINT 3,(IBUF1(I),I=1,IOUT)
    3 FORMAT (6(1X,O20))
  100 RETURN  $ END
C
C
C
C
C
C
C
C=====================================================================
C SUBROUTINE COMPACT
C PACK NN 6-BIT CHARACTERS FROM IBUFIN INTO N=NN/10 60-BIT COMPUTER
C   WORDS IN IBUFOUT
C=====================================================================
C
      SUBROUTINE COMPACT(IBUFIN,NN,IBUFOUT,N)
      DIMENSION IBUFIN(NN),IBUFOUT(N)
      DO 65 IM=1,N
      IBUFOUT(IM)=IBUFOUT(IM).AND.0
      DO 65 IBY=1,10
      IB=10*IM+IBY-10 $ IBB=60-IBY*6
      IBUFOUT(IM)=(IBUFIN(IB).AND.77B).OR.
+     (SHIFT(IBUFOUT(IM),6).AND.(.NOT.77B))
   65 CONTINUE
      RETURN $ END
C
C
C
C
C
C
C
C=====================================================================
C SUBROUTINE SCAST
C=====================================================================
C
      SUBROUTINE SCAST(FM,PHI,NTOT,IBUF,NCHAR,ICOUNT)
C
C=====================================================================
C INPUT      FM: AMPLITUDES
C            PHI: PHASES
C            NTOT: NUMBER OF POINTS TO BE SCALED
C OUTPUT:    IBUF: SCALED FM,PHI STORED IN ARRAY IBUF
C=====================================================================
```

```
C
      DIMENSION FM(NTOT),PHI(NTOT),IBUF(NCHAR)
      COMMON /BLK/FMAXMAG,TWOPI
      COMMON KPRINT,RADIAN
C
C=========================================================================
C SCALE THE AMPLITUDES TO A MAXIMUM OF 63.999 DB, SETTING NEGATIVE
C   AMPLITUDES TO ZERO
C SHIFT NEG. PHASES(RAD) BY +TWOPI AND SCALE PHASES TO MAX OF 511.999
C PRINT NEG. & POS. DOPPLERS, ALL ANT., AFTER SCALING
C=========================================================================
C
      CONST=FMAXMAG/10**(63.999/20.)
      DO 45 I=1,NTOT
      IF(FM(I).EQ.0.0)GO TO 20
      FM(I)=20*ALOG10(FM(I)/CONST)
      IF (FM(I).LT.0) FM(I)=0
   20 IF(PHI(I).EQ.0.0) GO TO 45
      IF(PHI(I).GT.0.0) GO TO 30
      PHI(I)=(TWOPI+PHI(I))/TWOPI*511.999
      GO TO 45
   30 PHI(I)=PHI(I)/TWOPI*511.999
C
   45 CONTINUE
C
      IF((KPRINT.AND.512).EQ.0) GO TO 31
      IF(ICOUNT.EQ.1) PRINT 27
   27 FORMAT(/," NEGATIVE DOPPLERS, ALL ANTENNAS, AFTER SCALING",
+         "; RADIANS SCALED TO 511",/,
+        6(4X,"I",3X,"AMPL",3X,"PHASE",2X))
      IF(ICOUNT.EQ.2) PRINT 29
   29 FORMAT(/," POSITIVE DOPPLERS, ALL ANTENNAS, AFTER SCALING",
+        "; RADIANS SCALED TO 511",/,
+        6(4X,"I",3X,"AMPL",3X,"PHASE",2X))
      PRINT 28,(I,FM(I),PHI(I),I=1,NTOT)
   28 FORMAT(25(I5,2F8.2,5(I6,2F8.2)/))
C
C=========================================================================
C STORE THE AMPLITUDES AND PHASES IN ARRAY IBUF, PUTTING 2 AMPL. & 2
C   PHASES INTO 5 ELEMENTS OF ARRAY IBUF:
C     FM(I);  6 MSB OF PHI(I);  3 LSB OF PHI(I) AND 3 LSB OF PHI(I+1);
C     FM(I+1);  6 MSB OF PHI(I+1)
C=========================================================================
C
   31 NN=NTOT/2
      DO 55 I=1,NN
      I5=I*5 $ I2=I*2
      IBUF(I5-4)=FM(I2-1)
      IBUF(I5-3)=PHI(I2-1)/8
      IBUF(I5-2)=(IFIX(PHI(I2)).AND.7)+SHIFT(IFIX(PHI(I2-1)).
+     AND.7,3)
```

```
      IBUF(I5-1)=FM(I2)
      IBUF(I5)=PHI(I2)/8
   55 CONTINUE
      RETURN  $  END
C
C
C
C
C
C
C
C=======================================================================
C SUBROUTINE C2160
C=======================================================================
C
      SUBROUTINE C2160(NWORD,IOUT)
C
C=======================================================================
C OUTPUT DATA WITH 2160 6-BIT CHARACTERS PER RECORD
C   IN 216 10-CHARACTER WORDS
C DIMENSION OF IBUF MUST BE AT LEAST IOUT
C=======================================================================
C
      COMMON KPRINT,RADIAN
      DIMENSION IOUTPT2(216),IBUF(136)
C
C=======================================================================
C READ DATA FROM TAPE8
C=======================================================================
C
      BACKSPACE 8
      IRECRD=2
    4 BUFFERIN (8,1)(IBUF(1),IBUF(IOUT))
      IF(UNIT(8))10,5,4
    5 STOP 1
C
C=======================================================================
C INITIALIZE IOUTPT2 TO 0
C=======================================================================
C
   10 DO 15 I=1,216
   15 IOUTPT2(I)=IOUTPT2(I).AND.0
C
C=======================================================================
C OUTPUT 2 RECORDS OF 216 WORDS:
C   REC 1: 8 PREFACE, 16 DUMMIES, NWORD-NUMBER OF NEG DOPPLERS, REST 0
C   REC 2: 8 PREFACE, 16 DUMMIES, NWORD-NUMBER OF POS DOPPLERS, REST 0
C PRINT DATA AFTER PACKED INTO 2 RECORDS
C=======================================================================
C
      DO 45 IR=1,IRECRD
```

TESTSKY (ULCAR)

```
C
      DO 25 II=1,8
   25 IOUTPT2(II)=IBUF(II)
C
      K=8 $  KK=24
      IF(IR.EQ.2)K=8+NWORD
      DO 35 J=1,NWORD
   35 IOUTPT2(KK+J)=IBUF(K+J)
   39 BUFFEROUT(9,1)(IOUTPT2(1),IOUTPT2(216))
      IF(UNIT(9))46,40,39
   40 STOP 2
   46 IF ((KPRINT.AND.1024).EQ.0) GO TO 45
      PRINT*," "
      IF(IR.EQ.1)PRINT*," PACKED DATA: 1ST RECORD"
      IF(IR.EQ.2)PRINT*," PACKED DATA: 2ND RECORD"
      IJ=24+NWORD
      PRINT 1,(IOUTPT2(I),I=1,IJ)
      PRINT*," "
   45 CONTINUE
    1 FORMAT(6(1X,O20))
      RETURN $  END
```

A P P E N D I X   B

PROGRAM SKYMAP

SKYMAP (ULCAR)

```
      PROGRAM SKYMAP(INPUT,TAPE1,OUTPUT,TAPE30
+     ,TAPE50,TAPE90,TAPE91,TAPE97,TAPE98,TAPE99)
C
C====================================================================================
C GOOSE BAY
C CALCULATES SKYMAP FROM DRIFT TAPE DATA, USING THE FREQUENCY-WAVENUMBER
C   POWER DENSITY (FWPD).
C
C
C TAPE1: INPUT FOR ALL FUNCTIONS EXCEPT MAPSEQUENCE (KPRINT=128)
C TAPE30: OUTPUT FOR KPRINT=4
C TAPE50: OUTPUT OF MAPDATA (KPRINT=64)
C         INPUT FOR MAPSEQUENCE (KPRINT=128)
C TAPE90,91: SCRATCH FILES FOR TEMPORARY STORAGE OF FWMAX(I),
C            FM(I,J),PHI(I,J); SEE SUBROUTINE SPLIT
C TAPE97,98: OUTPUT OF MAXIMUM AMPLITUDE (KPRINT=8192) OF NEGATIVE
C              AND POSITIVE DOPPLERS RESPECTIVELY
C            MAX AMPL OF BOTH NEG AND POS DOPPLERS ARE PRINTED OUT
C              TOGETHER AT THE SAME TIME AS THEY ARE WRITTEN SEPARATELY
C              ON TAPE
C TAPE99: SCRATCH FILES FOR TEMPORARY STORAGE OF ARRAYS IB216 AND
C           IB216T WHILE SORTING OUT NEG- AND POS-DOPPLER DRIFT DATA
C
C
C EXPLANATION OF KPRINT USAGE (SEE FURTHER COMMENTS WITH EXPLANATION
C                               OF INPUT PARAMETERS BELOW):
C  (COMPATIBLE FUNCTIONS CAN BE CALLED SIMULTANEOUSLY BY SETTING KPRINT
C   EQUAL TO THE SUM OF THE INDIVIDUAL KPRINTS)
C
C  KPRINT   PROGRAM FUNCTION:
C
C           DATA CHECKS
C
C     1     PRINTS OCTAL DUMP OF RAW DATA.
C     8     PRINTS UNPACKED DUMP (IN DECIMAL), WITH MASKED PREFACE.
C   256     PRINTS RECORD NUMBER AND MASKED PREFACE.
C  1024     PRINTS COMPARISON OF THE PHASES (0 TO 2*PI) AT THE FOUR
C             ANTENNAS FOR EACH OF THE FIRST 32 DOPPLERS.
C  4096     PRINTS THE AVERAGE OF THE LOG AMPLITUDES OF THE FOUR
C             ANTENNAS FOR EACH OF THE FIRST 32 DOPPLERS
C    16     PRINTS COMPARISON OF THE LOG AMPLITUDES AT THE FOUR
C             ANTENNAS FOR EACH OF THE FIRST 32 DOPPLERS.
C           (ALL DATA CHECKS ABOVE ARE COMPATIBLE)
C
C  8192     PRINTS A GRAPH OF THE MAXIMUM LOG AMPLITUDE AT EACH
C              FREQUENCY. (NOT COMPATIBLE WITH ANY OTHER FUNCTION)
C   512     ANTENNA CORRELATION THROUGH COMPARISON OF PHASE
C             DIFFERENCES. (NOT COMPATIBLE WITH ANY OTHER FUNCTION)
C
C
C           SORTING DRIFT DATA
```

SKYMAP (ULCAR)

```
C
C      4     USING INPUT TAPE CONTAINING BOTH IONOGRAM AND DRIFT
C            DATA, SORTS OUT 252 RECORDS OF DRIFT AND BUFFERS THEM
C            ONTO TAPE30, WHICH CAN BE SAVED ON FILE.  ALSO PRINTS
C            RECORD NUMBER AND PREFACE.
C            (NOT COMPATIBLE WITH ANY OTHER FUNCTION)
C
C
C
C            SKYMAP CALCULATIONS AND PRINTOUTS
C
C      2     PRINTS SINGLE SKYMAPS, ONE RECORD AT A TIME (NEG OR
C               POS DOPPLERS), AS THEY ARE CALCULATED.  IF BOTH NEG
C               AND POS DOPPLERS ARE REQUESTED, PRINTS NEG- AND
C               POS-DOPPLER MAPS SEPARATELY; DOPPLER NUMBERS ARE
C               REPRESENTED BY NUMERALS ON BOTH MAPS.
C     32     PRINTS ANTENNA PATTERNS, FOR THOSE DOPPLERS WHERE THE
C               ANT. PATTERN CONTAINS NON-ZERO VALUES.
C     64     MAPDATA: WRITES FWPD'S, THEIR COORDINATES, AND THEIR CORRES-
C              PONDING DOPPLER NUMBERS ON TAPE FOR LATER USE IN  PRINTING
C              SKYMAPS (SEE KPRINT 128 BELOW).
C 16384      AVERAGE THE RAW DRIFT DATA (IN COMPLEX DOMAIN)
C               OVER SEVERAL CASES (ADD TO 2,32 OR 64).
C               (16384 NEEDS TO BE MODIFIED IF TO BE RUN IN BATCH
C               MODE.  PRESENTLY STOPS WHEN TIME CONTINUITY OF CASES
C               IS BROKEN.)
C            (ABOVE 4 CALCULATIONS ARE COMPATIBLE; 2 AND/OR 32 CAN BE RUN
C              FOR A SINGLE FREQUENCY NUMBER AND/OR FOR ONLY NEG OR ONLY
C              POS DOPPLERS.  IF 64 IS RUN, WITH OR WITHOUT 2 AND/OR 32,
C              ALL FREQUENCY NUMBERS AND BOTH NEG AND POS DOPPLERS
C              ARE CALCULATED).
C
C    128     MAPSEQUENCE:
C             IF REQUEST "FWPD", EACH CASE IS PRINTED ON A SEPARATE
C               SKY MAP.
C             IF REQUEST "TIME", COMPRESSES A TIME SEQUENCE OF UP TO
C               16 CASES ON ONE MAP (SEE COMMENTS IN SUBROUTINE
C               MAPSEQ FOR DETERMINATION OF NUMBER OF CASES IN EACH
C               SEQUENCE); THE FWPD'S ARE REPLACED BY NUMBERS 0 TO 15,
C               INDICATING THE SEQUENCE OF CASES.
C             IF REQUEST "BOTH" (BOTH NEG AND POS DOPPLERS),
C               BOTH ARE PRINTED ON THE SAME MAP, WITH NEG DOPPLERS
C               REPRESENTED BY NUMERALS, POS DOPPLERS BY LETTERS.
C             IF REQUEST "NEG" (OR "POS"), ONLY NEG (OR POS)
C               DOPPLERS ARE PRINTED; POS DOPPLERS ARE STILL
C               REPRESENTED BY LETTERS.
C            (INCOMPATIBLE WITH ANY OTHER FUNCTION)
C
C
C EXPLANATION OF INPUT PARAMETERS REQUIRED:
C   (ALL "QUOTED" PARAMETERS ARE TO BE INPUTTED WITHOUT QUOTES)
```

SKYMAP (ULCAR)

```
C
C   A: KPRINT (SEE ABOVE).
C      IF KPRINT=128, IGNORE INPUT PARAMETERS LISTED BELOW; BUT
C      SEE SUBROUTINE MAPSEQ FOR OTHER INPUT PARAMETERS.
C
C   B: STARTING RECORD NO.:
C      INPUT "1" TO START AT BEGINNING OF TAPE1.  TO START AT
C      A SPECIFIC DRIFT RECORD, FIRST RUN KPRINT=256 TO FIND THE
C      RECORD NO. OF THE DRIFT RECORD WANTED.
C      WITH KPRINT 64, IF ONE RUN IS NOT SUFFICIENT TO PROCESS
C      ALL DRIFT DATA ON TAPE1, CHECK THE END OF THE OUTPUT TO
C      DETERMINE THE RECORD NUMBER AT WHICH TO START THE NEXT RUN.
C      SKYMAP ONLY PROCESSES DRIFT DATA FOR WHICH IT FINDS BOTH
C      RECORDS OF A CASE, SO STARTING RECORD NUMBER MUST BE THAT
C      OF THE FIRST RECORD OF THE FIRST CASE WANTED.
C
C   C: CPU TIME LIMIT (IN DECIMAL SECONDS):
C      USED WITH KPRINT 64. THE TIME IS CHECKED AFTER EACH CASE
C      (2 RECORDS, ALL FREQUENCIES).  IF THERE ARE 300 OR LESS
C      SECONDS LEFT, SKYMAP CALCULATIONS ARE STOPPED AND THE
C      RECORD NO. (DECIMAL) AND THE FIRST TWO WORDS (OCTAL) ARE
C      PRINTED FOR EACH DRIFT RECORD ON TAPE1 NOT YET PROCESSED,
C      UNTIL END OF TAPE OR ONLY 5 CPU SECONDS ARE LEFT.
C
C   D: FIRST FREQ. NO., LAST FREQ. NO.:
C      E.G. "1,3" FOR FREQUENCIES 1,2,3;
C      E.G. "2,2" FOR FREQ. 2;
C      E.G. "0" (ZERO) FOR ALL FREQ. NOS., EVEN IF THE NUMBER OF
C           FREQUENCIES CHANGES DURING THE RUN.
C
C   E: "NEG", "POS", OR "BOTH" DOPPLERS.
C      RECORDS NOT CHOSEN ARE IGNORED;  EXCEPT THAT FOR KPRINT 2
C      OR 32, BOTH RECORDS OF A CASE ARE UNPACKED FOR DETERMINING
C      FWMAXX (=THE MAXIMUM ESTIMATED FWPD FOR A CASE; SEE SUB-
C      ROUTINES SPLIT AND FOU), BUT THE SKYMAPS OR ANTENNA PATTERNS
C      ARE CALCULATED ONLY FOR THE DESIRED RECORDS.
C
C   F: NO. OF CASES TO BE AVERAGED (ODD NO.); WEIGHT FACTORS:
C      USED WITH KPRINT 16384.  E.G. "3,1,2,1": EACH CASE IS
C      DOUBLED AND AVERAGED WITH ITS NEIGHBORS.  FIRST CASE
C      (DETERMINED BY "STARTING RECORD NO.") IS NOT CALCULATED;
C      CASE 2 WILL BE AVERAGED WITH CASES 1 AND 3; CASE 3 AVE'D
C      WITH 2 AND 4; ETC.
C
C   G: MINIMUM SOURCE (LOG) AMPLITUDE TO BE USED:
C      USED WITH KPRINT=512.  PURPOSE: TO CHOOSE ONLY HIGH-
C      AMPLITUDE SIGNALS (SOURCES, AS OPPOSED TO NOISE) IN
C      DOING ANTENNA CORRELATION.
C
C
C IF RUNNING SKYMAP ON A TERMINAL, THE REQUIRED INPUT PARAMETERS
```

```
C   WILL BE REQUESTED BY THE TERMINAL.
C
C IF A BATCH RUN:
C     IF KPRINT INCLUDES       BUT DOES NOT INCLUDE     INPUT
C    ONE OR MORE OF THESE          ANY OF THESE
C          1,8,256                 16,1024,4096          A,B,E
C          1024,4096,16                                  A,B,D,E
C          8192                                          A,B,D,E
C          512                                           A,B,D,E,G
C          4                                             A,B
C          2,32                    64,16384              A,B,D,E
C          64                      16384                 A,B,C
C          16384                   64                    A,B,D,E,F
C       16384 WITH 64                                    A,B,C,F
C          128                                           A
C  (SEE ALSO SUBROUTINE MAPSEQ FOR KPRINT 128 INPUT PARAMETERS)
C
C
C ARRAYS X,Y DIMENSIONED FOR ONLY 4 ANTENNAS
C
C VARIABLE FORMATS (REDEFINED AS NEEDED IN THE PROGRAM) IFORMAT,
C   JFORMAT, KFORMAT USED WITH KPRINT 512; LFORMAT, WITH KPRINT 8192
C=======================================================================
C
       DIMENSION IFORMAT(20),JFORMAT(28),KFORMAT(3),LFORMAT(36)
       DIMENSION SUM(6),NUMBR(6,18),AVE(32)
       DIMENSION FACT(11),X(64,4,2),IBTEMP(12),Y(64,4,2)
       DIMENSION KPTEST(6)
       COMMON/PIE/NPI,N2PI,N3PI2,NPI2,TWOPI,PI2,PI512,CSN(257)
       COMMON IB2160(2160),JSEQ(7),RJX(7,6),RJY(7,6)
+      ,IB216(216),IB216T(216),NANTNO(7),MAXFWPD(41,41),IMAX(41,41)
+      ,FWPD(41,41),PHI(64,7),FWMAX(64),FM(64,7),PI,RADIAN,KPRINT
+      ,FREQ(6),RANG(6),IGAIN(6),FWMAXX(6)
C
       INTEGER SHIFT
C
       DATA KPTEST/4,128,512,8192,5401,16482/
       DATA IFORMAT/4H(T2,,4H*0*,,7HT5,*-*,,3HT6,,4H*0*,,
+         8HT10,*+*,,0,4H*1*,,0,4H*2*,,0,4H*3*,,0,4H*4*,,0,4H*5*,,
+         0,4H*6*,,7H3(/T10,,5H*!*))/
       DATA JFORMAT/4H(T3,,8H*NUMBER*,8HT10,*0*,,4HT19,,0,4HT29,,0,
+          4HT39,,0,4HT49,,0,4HT59,,0,4HT69,,0,4HT79,,0,4HT89,,0,
+          4HT99,,0,5HT109,,0,5HT119,,0,5HT129,,0,1H)/
       DATA KFORMAT/8H(9X,*+*,,9H12(*----*,10H*-----+*))/
       DATA LFORMAT/9H(T22,*!*,,8HT32,*!*,,8HT42,*!*,,8HT52,*!*,,
+            8HT62,*!*,,8HT72,*!*,,8HT82,*!*,,8HT92,*!*,,
+            9HT102,*!*,,9HT112,*!*,,9HT122,*!*,,3HT2,,0,4H,T7,,
+            0,5H,T13,,0,6*(2H,T,1H1,1H ),1H)/
       REWIND 1
       REWIND 30
       REWIND 50
```

```
        REWIND 97
        REWIND 98
        REWIND 99
C
        CALL SECOND (START)
        PRINT 10
     10 FORMAT(*1*)
        PRINT*," START TIME (SECONDS)=",START
        PRINT*,"  "
C
        PI=2.*ASIN(1.)
        RADIAN=.0174532925199433
C
C==========================================================================
C RADIAN=RADIANS/DEGREE
C
C READ INPUT PARAMETERS
C KPRINT 30258=2+16+32+512+1024+4096+8192+16384
C KPRINT 30523=1+2+8+16+32+256+512+1024+4096+8192+16384
C==========================================================================
C
        MDTFLAG=0
        IALL=0
        NSIGN=3
C
        PRINT*," KPRINT?"
        READ*,KPRINT
C
        DO 15 I=1,5
        JI=I+1
        DO 15 J=JI,6
        IF(((KPRINT.AND.KPTEST(I)).EQ.0).OR.
+          ((KPRINT.AND.KPTEST(J)).EQ.0)) GO TO 15
        PRINT*," INCOMPATIBLE KPRINTS"
        STOP
     15 CONTINUE
C
        IF(KPRINT.EQ.128) CALL MAPSEQ
C
C============== REST OF MAIN PROGRAM NOT USED IF KPRINT=128 ===============
C
        PRINT*," STARTING RECORD NO.?"
        READ*,IREC
C
        IF((KPRINT.AND.64).EQ.0) GO TO 20
        PRINT*," CPU TIME LIMIT (DECIMAL SECONDS)?"
        READ*,TOTAL
        PRINT 18
     18 FORMAT(*1*//1X,78("*")/1X,78("*")//1X,"PREFACE FORMAT:"/
+           3X,"REC STAT",39X,"FREQ"/3X,"NO.",2X,"NO.",
+           " DATE  TIME  UUUS UUUU RWTT GNXZ UUUU   NO.",
```

```
+          "   FREQ    RANGE GAIN"//1X,"U: UNUSED"/
+          1X,"S: 1 FOR NEG. DOPPLERS, 2 FOR POS. DOPPLERS"/
+          1X,"(S IS NOT IN ORIGINAL PREFACE; DEFINED BY SKYMAP",
+          " PROGRAM)"//1X,78("*")/1X,78("*")////)
C
      20 IF((KPRINT.AND.68).NE.0) GO TO 50
C
         IF((KPRINT.AND.30258).EQ.0) GO TO 30
         PRINT*," FIRST FREQ. NO., LAST FREQ. NO.?"
         PRINT*,"     (OR 0 (ZERO) FOR ALL FREQ. NOS.)"
         READ*,IALL
         IF(IALL.EQ.0) GO TO 30
         IBEGIN=IALL
         READ*,IEND
C
      30 IF((KPRINT.AND.30523).EQ.0) GO TO 50
         PRINT*," NEG, POS, OR BOTH DOPPLERS?"
         READ 40,NSIGN
      40 FORMAT(A4)
         IF(NSIGN.EQ."NEG")NSIGN=1
         IF(NSIGN.EQ."POS")NSIGN=2
         IF(NSIGN.EQ."BOTH")NSIGN=3
         IF((KPRINT.AND.34).EQ.0) GO TO 50
         NSIG=NSIGN
         NSIGN=3
C
      50 IF((KPRINT.AND.16384).EQ.0) GO TO 55
         PRINT*," NO. OF CASES TO BE AVERAGED (ODD NO.);",
+            " WEIGHT FACTORS?"
         READ*,NCASES,(FACT(I),I=1,NCASES)
         MDL=FLOAT(NCASES)/2.+.5
         NCASE=0
C
      55 IF((KPRINT.AND.8192).EQ.0) GO TO 70
         PRINT 60  $ WRITE(97,60)  $ WRITE(98,60)
      60 FORMAT(//T22,*0*,T41,*10*,T61,*20*,T81,*30*,T101,*40*,
+              T121,*50*)
C
      70 IF((KPRINT.AND.512).EQ.0) GO TO 80
         PRINT*," MINIMUM SOURCE (LOG) AMPLITUDE TO BE USED?"
         READ*,FMIN
         DO 75 M=1,6
         DO 75 N=1,18
      75 NUMBR(M,N)=0
         MAXNUM=0
C
      80 IR=0
         DO 100 K=1,6
     100 SUM(K)=0
C
C==========================================================================
```

```
C CALCULATE COSINE TABLE FOR 0 TO PI/2, IN INCREMENTS OF 2PI/1024
C KPRINT 98=2+32+64
C=========================================================================
C
        IF((KPRINT.AND.98).EQ.0) GO TO 120
        NPI=512 $ N2PI=2*NPI $ N3PI2=3*NPI/2 $ NPI2=NPI/2
        TWOPI=2.*PI $ PI2=PI/2. $ PI512=PI/512.
        CSN(1)=1.  $ CSN(257)=0.
        DO 110 MN=2,256
    110 CSN(MN)=COS(FLOAT(MN-1)*PI512)
C
C=========================================================================
C INPUT DRIFT DATA WITH BUFFERIN FROM TAPE 1
C
C IF "16" BIT NOT ON IN PREFACE, DATA IS NOT DRIFT DATA;
C   BUFFERIN NEXT RECORD
C
C IF BUFFERING OUT DATA ONTO TAPE30 (KPRINT=4), STOP AFTER 252
C   RECORDS TO AVOID EXCEEDING PRU LIMIT
C=========================================================================
C
    120 IF(IREC.EQ.1) GO TO 135
        LSKIP=IREC-1
        DO 130 ISKIP=1,LSKIP
        BUFFERIN(1,1)(IB216(1),IB216(1))
        IF(UNIT(1)) 130,135,130
    130 CONTINUE
C
    135 DO 1290 NMAP=IREC,10000
        IF((IR.GT.252).AND.((KPRINT.AND.4).NE.0)) STOP
    140 BUFFERIN (1,1)(IB216(1),IB216(216))
        IF (UNIT(1))    280,150,140
    150 IF(KPRINT.AND.512)160,270
C
C=========================================================================
C STOP AT END OF DRIFT DATA TAPE, UNLESS DOING ANTENNA CORRELATION
C   (KPRINT=512), IN WHICH CASE PRINT OUT THE RESULTS
C=========================================================================
C
    160 K=0
CCC        NMINUS1=NANT-1
CCC        DO 180 J=1,NMINUS1
CCC        JPLUS1=J+1
CCC        DO 180 JJ=JPLUS1,NANT
CCC        K=K+1
CCC        PRINT 170,(J,JJ,(NUMBR(K,IDELPHI),IDELPHI=1,18))
CCC    170 FORMAT(/1X,*PHI(*,I1,*,*,I1,*)*,2X,18I6)
CCC    180 CONTINUE
C
        PRINT 185
    185 FORMAT(////* SUM OF THE SQUARE OF THE PHASE DIFFERENCES*,
```

```
+        * (RADIANS) BETWEEN ANTENNA PAIRS*/)
C
        PRINT 190,(SUM(K),K=1,6)
    190 FORMAT(*     1-2       1-3       1-4       2-3       *,
+       *2-4       3-4*/6(F9.1)////)
C
        MAXNUM=((MAXNUM/12)+1)*12
        JVF=3
        DO 230 M=10,120,10
        JVF=JVF+2
        MM=IFIX(FLOAT(MAXNUM*M)/120.)
        IF(MM.GT.99) GO TO 210
        ENCODE(5,200,JFORMAT(JVF))MM
    200 FORMAT(1H*,I2,2H*,)
        GO TO 230
C
    210 ENCODE(6,220,JFORMAT(JVF))MM
    220 FORMAT(1H*,I3,2H*,)
    230 CONTINUE
C
        PRINT 235
    235 FORMAT(* NUMBER OF OCCURRENCES OF INDICATED PHASE *,
+         *DIFFERENCES AT ANTENNA PAIRS 1-2,...,3-4,*,
+         *REPRESENTED BY 1,...,6*/)
        PRINT JFORMAT
        PRINT KFORMAT
        PRINT*," DEGREES!"
        PRINT*,"  PHASE !"
        ND=-10
        DO 260 IDELPHI=1,18
        IVF=5
        ND=ND+10   $ NT=ND+10
        ENCODE(10,220,IFORMAT(2))ND
        ENCODE(10,220,IFORMAT(5))NT
        DO 250 K=1,6
        IVF=IVF+2
        FRCTN=FLOAT(NUMBR(K,IDELPHI))/FLOAT(MAXNUM)
        NN=FRCTN*120.+10.5
        ENCODE(10,240,IFORMAT(IVF))NN
    240 FORMAT(1HT,I3,1H,)
    250 CONTINUE
C     PRINT*,(IFORMAT(KJK),KJK=1,18)
        PRINT IFORMAT
    260 CONTINUE
C
    270 PRINT*,"  "
        IF((KPRINT.AND.8192).NE.0)PRINT*," NEG. DOPP. ON TAPE 97;",
+                                  " POS. DOPP. ON TAPE 98."
        PRINT*," "
        PRINT*," STOPPED AT END OF TAPE1."
        STOP
```

```
C
   280 IF((IB216(1).AND.16).EQ.0) GO TO 1290
C
C=========================================================================
C TEMPORARILY SORT OUT NEG DOPPLERS INTO IB216T AND POS
C    DOPPLERS INTO IB216
C=========================================================================
C
       IF((IB216(1).NE.IB216T(1)).OR.
+         (IB216(2).NE.IB216T(2))) GO TO 310
       IR=IR+2
       GO TO 320
   310 CALL MOVLEV (IB216,IB216T,216)
       GO TO 1290
C
   320 REWIND 99
C
   330 BUFFEROUT(99,1)(IB216T(1),IB216T(216))
       IF(UNIT(99)) 350,350,330
   350 BUFFEROUT (99,1)(IB216(1),IB216(216))
       IF(UNIT(99)) 360,360,350
   360 REWIND 99
C
C
C
       DO 1230 IJ=1,2
   390 BUFFERIN(99,1)(IB216(1),IB216(216))
       IF(UNIT(99)) 400,400,390
C
C=========================================================================
C UNPACK 2160 6-BIT CHARACTERS FROM 216 60-BIT WORDS;
C  PUT "1" FOR NEG, "2" FOR POS INTO PREFACE (IB2160(16))
C=========================================================================
C
   400 DO 410 IM=1,216
       DO 410 IBY=1,10
       IB=10*IM+IBY-10 $ IBB=IBY*6
   410 IB2160(IB)=63.AND.SHIFT(IB216(IM),IBB)
       ISIGN=IB2160(16)=IJ
C
       IF(NSIGN.EQ.3.AND.ISIGN.EQ.1) NCASE=NCASE+1
       IF(NSIGN.EQ.3) GO TO 420
       IF(ISIGN.NE.NSIGN) GO TO 1230
       NCASE=NCASE+1
   420 IF(NCASE.GT.NCASES) NCASE=1
C
C=========================================================================
C OCTAL DUMP
C=========================================================================
C
       IF((KPRINT.AND.1).EQ.0) GO TO 440
```

```
            PRINT 430,(IB216(I),I=1,216)
       430 FORMAT (6(1X,O20))
            PRINT*," "
C=======================================================================
C MASK PREFACE
C=======================================================================
C
       440 DO 450 K=1,80
            IB2160(K)=IB2160(K).AND.15
       450 CONTINUE
            IB2160(7)=IB2160(7).AND.3
            IB2160(8)=IB2160(8).AND.3
            IB2160(9)=IB2160(9).AND.7
            IB2160(11)=IB2160(11).AND.7
C
C=======================================================================
C BUFFER OUT DRIFT DATA ONTO TAPE 30 (KPRINT=4)
C   AND PRINT RECORD # AND PREFACE
C=======================================================================
C
            IF(KPRINT.NE.4) GO TO 480
            IRR=IR-1   $ NRR=NMAP-1
            IF(IJ.EQ.2)IRR=IRR+1   $ IF(IJ.EQ.2)NRR=NRR+1
            PRINT 460,IRR,NRR,(IB2160(M),M=1,80)
       460 FORMAT(1X,2I6,I3,1X,5I1,1X,6I1,17(1X,4I1))
       470 BUFFEROUT(30,1) (IB216(1),IB216(216))
            IF(UNIT(30))1230,1230,470
C
C=======================================================================
C PRINT RECORD NUMBER AND MASKED PREFACE
C=======================================================================
C
       480 IF(KPRINT.AND.256)490,510
       490 PRINT 500,(NMAP-2+IJ),(IB2160(I),I=1,80)
       500 FORMAT(1X,I6,1X,I3,1X,5(I1),1X,6(I1),17(1X,4(I1)))
C
C=======================================================================
C PRINT UNPACKED DUMP, WITH MASKED PREFACE
C=======================================================================
C
       510 IF(KPRINT.AND.8)520,540
       520 PRINT 530,(IB2160(I),I=1,2160)
       530 FORMAT(54(1X,40I3/))
C
       540 IF(KPRINT.EQ.1.OR.KPRINT.EQ.8.OR.KPRINT.EQ.256.OR.KPRINT.EQ.
+           4) GO TO 1230
C
C=======================================================================
C DECODE PREFACE IF NOT ALREADY DECODED FOR THIS CASE
C=======================================================================
C
```

```
      IF((NSIGN.EQ.3).AND.(ISIGN.EQ.2)) GO TO 698
C
      IVSTAT=IB2160(1)
      IYEAR=10*IB2160(2)+IB2160(3)
      LDAY=IDAY $ LHR=IHOUR $ LMIN=IMIN $ LSEC=ISEC
      IDAY=100*IB2160(4)+10*IB2160(5)+IB2160(6)
      IHOUR=10*IB2160(7)+IB2160(8)
      IMIN=10*IB2160(9)+IB2160(10)
      ISEC=10*IB2160(11)+IB2160(12)
      IREP=50+(IB2160(21).AND.2)*25+((IB2160(21).AND.4)*75)/2
+           +((IB2160(21).AND.2)*(IB2160(21).AND.4)*75)/4
C
C===========================================================================
C IDB=20 FOR 1 DB INCREMENTS
C IDB=40 FOR 1/2 DB INCREMENTS
C ITT=TASK (FOR ANTENNA SEQUENCE SPECIFICATION; SEE SUBROUTINE ANT)
C   GOOSE BAY: ITT=0
C IN: PROGRAM NUMBER
C===========================================================================
C
      IDB=(IB2160(22).AND.4)*5+20
      ITT=0
CCC      ITT=10*IB2160(23)+(IB2160(24).AND.3)
      IQ=IB2160(25)
      IN=IB2160(26)
C
C===========================================================================
C IF AVERAGING DATA OVER SEVERAL CASES(KPRINT=16384),
C   STOP IF TIME CONTINUITY OF CASES IS BROKEN; OTHERWISE,
C   STORE DATE AND TIME (BOTH DECODED AND NON-DECODED FORMS)
C     IF THIS IS THE MIDDLE CASE
C===========================================================================
C
      IF(((KPRINT.AND.16384).EQ.0).OR.
+        ((NMAP-IREC).LE.2)) GO TO 600
      KASESEQ=10
      IF(IN.EQ.6.OR.IN.EQ.9)KASESEQ=18 $ IF(IN.EQ.7)KASESEQ=34
      IF((IDAY-LDAY).GT.1) GO TO 570
      IIHR=IHOUR+24*(IDAY-LDAY)
      IF((IIHR-LHR).GT.1) GO TO 570
      IIMIN=IMIN+60*(IIHR-LHR)
      IF((IIMIN-LMIN).GT.1) GO TO 570
      IISEC=ISEC+60*(IIMIN-LMIN)
      IF((IISEC-LSEC).GT.KASESEQ) GO TO 570
      GO TO 580
  570 PRINT*,"SEQUENCE OF CASES NOT CONTINUOUS." $ STOP
  580 IF(NCASE.NE.MDL) GO TO 600
      MDLYR=IYEAR $MDLDAY=IDAY $MDLHR=IHOUR
      MDLMIN=IMIN $MDLSEC=ISEC
      DO 590 I=1,12
  590 IBTEMP(I)=IB2160(I)
```

```
C
C=========================================================================
C FREQUENCY IN PREFACE IN 10 KHZ UNITS; CONVERTED TO FREQ(K) IN KHZ
C RANGE IN KM
C
C IF KPRINT=16384, STOP IF FREQ, RANGE, OR GAIN CHANGES; OR IF RANGE
C   GREATER THAN 510 KM
C
C IF RANGE G.T. 510 AND KPRINT NOT 16384, SKIP THAT RECORD AND CONTINUE
C=========================================================================
C
  600 DO 595 K=1,6
      RANG(K)=0.
      FREQ(K)=0.
  595 IGAIN(K)=0
      KL=6
      IF(IN.GE.8) KL=3
C
      DO 670 K=1,KL
      RA=RANG(K)  $ IGA=IGAIN(K)  $ FRE=FREQ(K)
      FREQ(K)=12.5 $ RANG(K)=0.
      DO 620 KK=1,4
      KKK=4*K-KK+33 $ KK10=10**KK $ KKKK=4*K-KK+56
      IF(KK.EQ.1) IGAIN(K)=(-10)*IB2160(KKKK+1)
      FKK  =IB2160(KKK)*KK10
      FREQ(K)=FREQ(K)+FKK
      IF(KK.EQ.4)GO TO 620
      FKK=IB2160(KKKK)*KK10
      RANG(K)=RANG(K)+.15*FKK
  620 CONTINUE
      IF(IQ.EQ.5.AND.((K/2)*2).EQ.K)630,640
  630 FREQ(K)=FREQ(K-1)
      RANG(K)=RANG(K-1)
C
  640 IF(RANG(K).GT.510.)650,660
  650 PRINT*,"RANGE(",K,") IS TOO HIGH; RANGE=",RANG(K)
      IF((KPRINT.AND.16384).NE.0) STOP
      PRINT*,"RECORDS ",(NMAP-1)," AND ",(NMAP)," SKIPPED. "
      GO TO 1290
  660 IF((KPRINT.AND.16384).EQ.0.OR.(RA.EQ.RANG(K).AND.IGA.EQ.
     +IGAIN(K).AND.FRE.EQ.FREQ(K)).OR.(NMAP-IREC).LE.2) GO TO 670
      PRINT*," CHANGE OF FREQ, RANGE OR GAIN."  $ STOP
C
  670 CONTINUE
C
      CALL ANT(IFF,ITT,IN,NF,NANT,NDOPP,SINZMAX,1)
C
      IF(IVSTAT.EQ.0) NF=1
      DO 690 K=NF,6
      IF (K.EQ.NF.OR.NF.EQ.6) GO TO 680
      RANG(K)=0. $ FREQ(K)=0.
```

```
  690 CONTINUE
C
      IF(IALL.NE.0) GO TO 694
      IBEGIN=1
      IEND=NF
      GO TO 698
  694 IF((IBEGIN.NE.IEND).OR.
+        (IEND.LE.NF)) GO TO 696
      PRINT*," NO FREQ. NUMBER ",IEND," IN PROGRAM NUMBER ",IN
      STOP
  696 IF(IEND.LE.NF) GO TO 698
      PRINT*," 'LAST FREQ. NO.' ",IEND," IS TOO HIGH FOR "
      PRINT*," PROGRAM NO. ",IN,"; HAS BEEN RESET TO ",NF
      IEND=NF
C
  698 KX=16
      DO 1170 IFF=IBEGIN,IEND
      IF(FREQ(IFF).LE.12.5) GO TO 1170
C
C
      IF(((KPRINT.AND.98).EQ.0).OR.(ISIGN.EQ.1))
+       CALL ANT(IFF,ITT,IN,NF,NANT,NDOPP,SINZMAX,2)
C
      CALL SPLIT(NDOPP,NANT,IFF,IDB,ISIGN,IBEGIN)
      IF((KPRINT.AND.16384).EQ.0) GO TO 820
C
C=========================================================================
C AVERAGE THE RAW DRIFT DATA (IN COMPLEX DOMAIN) OVER SEVERAL CASES
C (KPRINT=16384). NO. OF CASES (MUST BE ODD NO.) AND THE WEIGHT FACTOR
C OF EACH IS ASKED FOR AT BEGINNING OF PROGRAM.
C=========================================================================
C
      IF((NCASE.NE.1).OR.(NSIGN.EQ.3.AND.ISIGN.NE.1))GO TO 750
C
      DO 740 I=1,NDOPP
      DO 740 J=1,NANT
      DO 740 K=1,2
  740 X(I,J,K)=Y(I,J,K)=0
C
  750 DO 760 I=1,NDOPP
      DO 760 J=1,NANT
      X(I,J,ISIGN)=FACT(NCASE)*FM(I,J)*COS(PHI(I,J))+X(I,J,ISIGN)
  760 Y(I,J,ISIGN)=FACT(NCASE)*FM(I,J)*SIN(PHI(I,J))+Y(I,J,ISIGN)
C
      IF(NCASE.LT.NCASES) GO TO 1170
C
      DIV=0
      DO 770 L=1,NCASES
  770 DIV=DIV+FACT(L)
C
      DO 790 I=1,NDOPP
```

```
      DO 790 J=1,NANT
      FM(I,J)=SQRT((X(I,J,ISIGN))**2+(Y(I,J,ISIGN))**2)/DIV
      IF(X(I,J,ISIGN).EQ.0.0) GO TO 780
      PHI(I,J)=ATAN2(Y(I,J,ISIGN),X(I,J,ISIGN))
      GO TO 790
  780 PHI(I,J)=0
  790 CONTINUE
C
      IYEAR=MDLYR $IDAY=MDLDAY $ IHOUR=MDLHR
      IMIN=MDLMIN $ISEC=MDLSEC
      DO 800 I=1,12
  800 IB2160(I)=IBTEMP(I)
C
      IF(NSIGN.EQ.3.AND.ISIGN.NE.2) GO TO 820
      NCAS=2*NCASES-2
      DO 810 I=1,NCAS
  810 BACKSPACE 1
C
C===========================================================================
C TO PRINT THE AVERAGE OF THE LOG AMPLITUDES ON THE 4 ANT.AT EACH
C DOPPLER (KPRINT=4096) AND/OR PRINT THE MAXIMUM LOG AMPLITUDE OF
C EACH FREQ. (KPRINT=8192) AND/OR COMPARE LOG AMPLITUDES (KPRINT=16)
C AND/OR PHASES IN DEG (KPRINT=1024) OF EACH DOPPLER ON THE 4 ANT.
C (FIRST 32 DOPP ONLY FOR 4096,16,1024; 8192 PRINTED AFTER "DO 1170" LOOP)
C
C KPRINT 13328=16+1024+4096+8192
C KPRINT 1040=16+1024
C===========================================================================
C
  820 IF((KPRINT.AND.13328).EQ.0) GO TO 950
      LSIGN="NEG"  $ IF(IJ.EQ.2) LSIGN="POS"
C
      IF((KPRINT.AND.4096).EQ.0) GO TO 850
      DO 830 I=1,32
      AVE(I)=0.
      DO 825 J=1,NANT
  825 AVE(I)=AVE(I)+FM(I,J)
  830 AVE(I)=AVE(I)/NANT
      PRINT 840,(IB2160(I),I=2,12),FREQ(IFF),RANG(IFF),LSIGN,
+                ((IFIX(AVE(I))),I=1,32)
  840 FORMAT(1X,5I1,1X,6I1,1X,2(F6.1),1X,A3,3X,32I3)
      IF((KPRINT.AND.1040).EQ.0.AND.IFF.EQ.IEND) PRINT*," "
C
  850 IF((KPRINT.AND.8192).EQ.0) GO TO 890
      XAM=0
      DO 860 I=1,NDOPP
      DO 860 J=1,NANT
  860 XAM=AMAX1(XAM,FM(I,J))
      KX=KX+3
      NXAM=2*IFIX(XAM)+22
      ENCODE(4,870,LFORMAT(KX))NXAM
```

```
  870 FORMAT(I3,1H,)
      ENCODE(3,880,LFORMAT(KX+1))IFF
  880 FORMAT(1H*,I1,1H*)
C
  890 IF(KPRINT.AND.16)900,920
  900 PRINT 910,(IB2160(I),I=2,12),FREQ(IFF),RANG(IFF),LSIGN,
+      ((IFIX(FM(I,J)),I=1,32),J=1,NANT)
  910 FORMAT(1X,5I1,1X,6I1,1X,2(F6.1),1X,A3,3X,32I3/,6(33X,32I3/))
C
  920 IF(KPRINT.AND.1024)930,1170
  930 IF((KPRINT.AND.16).EQ.0) PRINT 910,(IB2160(I),I=2,12),
+     FREQ(IFF),RANG(IFF),LSIGN
      PRINT 940,(((IFIX(PHI(I,J)/RADIAN)),I=1,32),J=1,NANT)
  940 FORMAT(7(1X,32I4/))
      GO TO 1170
C
C==========================================================================
C CHECK ANTENNA CORRELATION (KPRINT=512).
C K=1,...,6 REPRESENTS ANTENNA PAIRS 1-2,1-3,1-4,2-3,2-4,3-4.
C SUM(K) IS THE SUM OF THE SQUARE OF THE PHASE DIFFERENCES (IN RADIANS)
C   BETWEEN BOTH ANTENNAS OF A PAIR.
C NUMBR(K,IDELPHI) COUNTS FOR EACH ANTENNA PAIR THE NUMBER OF TIMES THE
C   PHASE DIFFERENCE IS THE ABSOLUTE VALUE OF 0-10,10-20,...,170-180
C   DEGREES (FOR -180 TO +180 DEGREES).
C THE PHASES ARE COMPARED AT ALL DOPPLER NUMBERS WHOSE AMPLITUDES ARE
C   AT LEAST FMIN ON ALL ANTENNAS, FOR POS, NEG, OR BOTH TYPES OF
C   DOPPLERS (ACCORDING TO THE CHOICE INDICATED AT THE BEGINNING OF
C   THE RUN) AND FOR THE FREQUENCY NUMBER(S) INPUTTED AT THE BEGINNING
C   OF THE RUN.
C THE RESULTS ARE PRINTED WHEN TAPE1 RUNS OUT OF DATA
C (SEE STATEMENT 160 ABOVE).
C==========================================================================
C
  950 IF((KPRINT.AND.512).EQ.0) GO TO 1010
C
      DO 990 I=1,NDOPP
      DO 970 II=1,NANT
  970 IF(FM(I,II).LT.FMIN) GO TO 990
      K=0
      NMINUS1=NANT-1
      DO 980 J=1,NMINUS1
      JPLUS1=J+1
      DO 980 JJ=JPLUS1,NANT
      K=K+1
      SUM(K)=SUM(K)+(PHI(I,J)-PHI(I,JJ))**2
      DELPHI=ABS((PHI(I,J)-PHI(I,JJ))/(RADIAN*10.))
      IF(DELPHI.GT.18.) DELPHI=ABS(DELPHI-36.)
      IDELPHI=IFIX(DELPHI+1.)  $ IF(IDELPHI.EQ.19)IDELPHI=18
      NUMBR(K,IDELPHI)=NUMBR(K,IDELPHI)+1
  980 MAXNUM=MAX0(MAXNUM,NUMBR(K,IDELPHI))
  990 CONTINUE
```

```
            GO TO 1170
     C
     C=========================================================================
     C CALL FOU TO CALCULATE FWPD
     C
     C KPRINT 98=2+32+64
     C=========================================================================
     C
      1010 IFOU2=1
           IF((KPRINT.AND.98).EQ.0) GO TO 1020
           IF(ISIGN.EQ.1) GO TO 1170
           IFOU2=2
     C
      1020 DO 1165 IFOU=1,IFOU2
           IF((KPRINT.AND.98).EQ.0) GO TO 1040
           IF(((KPRINT.AND.34).NE.0).AND.
     +        ((NSIG.AND.ISIGN).EQ.0)) GO TO 1040
     C
     CCC      DPTIM=SECOND(CO)
     CCC      PRINT*,"START FOU=",DPTIM
           CALL FOU(ISIGN,NDOPP,NANT,IFF,IBEGIN,IFOU)
     CCC      DPTIM=SECOND(CP)
     CCC      PRINT*,"END FOU=",DPTIM
           IF((KPRINT.AND.64).NE.0) CALL MAPDATA(IFF,MDTFLAG,IFOU,NMAP)
      1040 IF((KPRINT.AND.2).EQ.0) GO TO 1165
           IF(((KPRINT.AND.2).NE.0).AND.
     +        ((NSIG.AND.ISIGN).EQ.0)) GO TO 1165
     C
     C=========================================================================
     C OUTPUT SKYMAP
     C ZMAX=ZENITH ANGLE OF FURTHEST K VECTOR IN SKYMAP
     C   (AT THE CORNERS OF THE SQUARE MAP)
     C RADIAN=RADIANS/DEGREE)
     C SCALE=INCREMENT OF SKYMAP COORDINATES IN KM
     C=========================================================================
     C
     C
     C====================== MAP HEADING FOR KPRINT 2 =========================
      1050 PRINT 1110,(K,K=1,6),IVSTAT,IYEAR,IDAY,IHOUR,
     +          IMIN,ISEC,IREP,IDB,NDOPP,NANT,FREQ,IFF,
     +          FREQ(IFF),RANG(IFF),RANG,(NANTNO(K),K=1,NANT),IGAIN
     C
           CALL PRIN(IN,ISIGN,IFWPD,SINZMAX,IFF)
     C
      1110 FORMAT(1H1,10X*VSTAT YEAR DAY HOUR MIN SEC REP IDB NDOPP *,
     +     *NANT  NF*,4X,6(I4,4X)/8X,2I6,I5,3I4,I5,I4,2I5
     +     *  FREQ*6F8.1* KHZ*/11X*FREQ. NO. *
     +     I1*, AT*F8.1* KHZ; RANGE=*F7.1,* KM  *,*RANG*6F8.1
     +     * KM*/11X*ANTENNA SEQUENCE  *4I3,17X*GAIN*I6,5I8*   DB*)
     C
     C
```

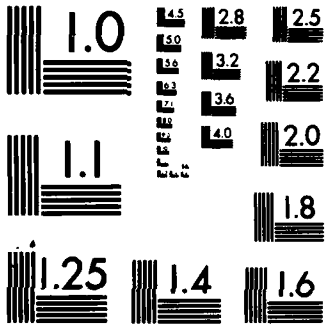
```
C
 1165 CONTINUE
 1170 CONTINUE
C
C==========================================================================
C PRINT THE MAXIMUM LOG AMPLITUDE FOR EACH FREQUENCY (KPRINT=8192)
C==========================================================================
C
      IF((KPRINT.AND.8192).EQ.0) GO TO 1230
      LSIGN="NEG"  $ IF(IJ.EQ.2) LSIGN="POS"
      ENCODE(6,1180,LFORMAT(13))LSIGN
 1180 FORMAT(1H*,A3,2H*,)
      ENCODE(7,1190,LFORMAT(15))(IB2160(K),K=2,6)
 1190 FORMAT(1H*,5I1,1H*)
      ENCODE(10,1200,LFORMAT(17))(IB2160(K),K=7,12)
 1200 FORMAT(1H*,2I1,I2,I1,I2,I1,1H*)
      IF(IB2160(16).EQ.2) GO TO 1210
      WRITE(97,LFORMAT)   $ GO TO 1220
 1210 WRITE(98,LFORMAT)
 1220 PRINT LFORMAT
      IF(IB2160(16).EQ.2) PRINT*,"   "
C
 1230 CONTINUE
C
      IF((KPRINT.AND.64).EQ.0) GO TO 1290
      CALL SECOND(ACTUAL)
      IF((TOTAL-(ACTUAL-START)).GT.300.0) GO TO 1290
C
      NREC=NMAP
      PRINT 1240
 1240 FORMAT(///1X,*RECORD NO. AND FIRST 2 WORDS OF EACH*,
+           * DRIFT RECORD NOT YET PROCESSED:*/)
 1250 BUFFERIN(1,1)(IB216(1),IB216(2))
      IF(UNIT(1)) 1260,270,1250
 1260 NREC=NREC+1
      IF((IB216(1).AND.16).NE.0)
+       PRINT 1270,NREC,IB216(1),IB216(2)
 1270 FORMAT(1X,I6,2(1X,O20))
      CALL SECOND(ACTUAL)
      IF((TOTAL-(ACTUAL-START)).GT.5.0) GO TO 1250
      PRINT 1280
 1280 FORMAT(//1X,*RAN OUT OF TIME; THERE MAY BE MORE*,
+             * DRIFT DATA ON TAPE1.*)
      STOP
C
 1290 CONTINUE
C
      STOP
      END
C
C
```

```
C
C
C
      SUBROUTINE ANT(IFF,ITT,IN,NF,NANT,NDOPP,SINZMAX,NUM)
C
      INTEGER AN
      DIMENSION ANTY(7),ANTX(7),AN(5,8)
      COMMON IB2160(2160),JSEQ(7),RJX(7,6),RJY(7,6)
+     ,IB216(216),IB216T(216),NANTNO(7),MAXFWPD(41,41),IMAX(41,41)
+     ,FWPD(41,41),PHI(64,7),FWMAX(64),FM(64,7),PI,RADIAN,KPRINT
+     ,FREQ(6),RANG(6),IGAIN(6),FWMAXX(6)
C
C=========================================================================
C ANTENNA COORD IN METERS
C   ANTY= Y COORD
C   ANTX= X COORD
C X AXIS=NORTH=AZIMUTH ZERO DEG
C (-Y) AXIS=EAST=AZIMUTH 90 DEG
C=========================================================================
C
      DATA ANTY /0.,57.73502,-28.86751,-28.86751,
+                0.,28.86751,-28.86751/
      DATA ANTX /0.,0.,-50.,50.,
+                33.3333,-16.6667,-16.6667/
C
C=========================================================================
C GENERATE JSEQ: ARRAY OF SEQUENCE NO'S FOR ANTENNAS
C
C   CAN USE UP TO 7 ANTENNAS
C   FOR EACH ANTENNA SEQUENCE, DEFINE:
C     DATA(AN(KT,J),J=1,8)/SEQUENCE-OF-ANTENNAS,99/
C     WHERE KT IS DETERMINED FROM ITT (SEE BELOW)
C   98 SIGNIFIES BLANK, 99 SIGNIFIES END OF SEQUENCE
C
C GOOSE BAY: ITT=0, KT=1, ALL 4 ANTENNAS USED
C=========================================================================
C
      DATA(AN( 1,J),J=1,8)/1,2,3,4,99/
      DATA(AN( 2,J),J=1,8)/1,2,3,4,5,6,7,99/
      DATA(AN( 3,J),J=1,8)/1,98,98,98,5,6,7,99/
C
      IF(NUM.EQ.2) GO TO 40
C
C=========================================================================
C DETERMINE KT
C=========================================================================
C
      KT=ITT/10
      KT=ITT-6*KT+1
C
C=========================================================================
```

```
C GENERATE JSEQ (ANTENNA SEQ.); DETERMINE NANT (NO. OF ANTENNAS)
C===========================================================================
           JS=0
           DO 20 J=1,8
           IF (AN(KT,J)-98)10,20,30
        10 JS=JS+1
           JSEQ(JS)=J
           NANT=JS
        20 CONTINUE
C
C===========================================================================
C DETERMINE:
C    NDOPP: NO.OF DOPPLERS
C    NF: NO. OF SOUNDING FREQ.
C    NC: NO.OF CHANNELS
C    SS: SAMPLE SPACING [SEC]=TIME BETWEEN SAMPLES AT ONE FREQ, ONE ANT
C    SW: SPECTRAL WIDTH [HZ]=RANGE OF NEG OR POS DOPPLER FREQUENCIES
C    DFR: SPECTRAL SPACING [HZ]=DOPPLER-FREQ RESOLUTION
C===========================================================================
C
        30 NDOPP=32+22*(IN/7)
           NC=24/((IN/8)+1)
           NF=NC/NANT
CCC           SS=.02125*NF
CCC           SW=.5/SS
CCC           DFR=SW/NDOPP
           RETURN
C
C===========================================================================
C TO LIMIT SKYMAP TO THE MAIN ANT. LOBE, DEFINE THE X AND Y
C COMPONENTS OF THE FURTHEST K VECTOR AS:
C
C  -.707*VK*SIN(MAXIMUM ZENITH)
C
C  WITH:  VK=ABS.VALUE OF WAVE PROPAGATION VECTOR K
C               =2*PI/WAVELENGTH
C    SIN(MAX. ZEN.)=WAVELENGTH/(MAXIMUM ANT. SPACING)
C      (BUT LIMIT THE MAX. ZENITH TO 45 DEGREES)
C
C THUS THE X COMPONENTS OF THE (41X41) ARRAY OF K VECTORS ARE:
C
C  -.707*VK*SIN(MAX. ZEN.(*(XIX/20)=RJ*XIX
C  WHERE XIX=+20,...,+1,0,-1,...,-20
C
C Y COORDINATES ARE: -.707*VK*SIN(MAX. ZEN.)*(YIY/20)=RJ*YIY
C  WHERE YIY=+20,...,+1,0,-1,...,-20
C
C AK= DOT PRODUCT (K,A)=(RJ*XIX*ANTX+RJ*YIY*ANTY)
C
C WAVELENGTH IN METERS
C===========================================================================
```

AD-A140 509 A HIGH FREQUENCY RADIO TECHNIQUE FOR MEASURING PLASMA DRIFTS IN THE IONOS..(U) LOWELL UNIV MA CENTER FOR ATMOSPHERIC RESEARCH C G DOZOIS JUL 83 ULRF-424/CAR 3/3

UNCLASSIFIED AFGL-TR-83-0202 F19628-80-C-0064 F/G 4/1 NL



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

```
C
   40 WAVELEN=299792.5/FREQ(IFF)
      VK=2.*PI/WAVELEN
      SINZMAX=WAVELEN/100.
      IF(KT.GT.2) SINZMAX=WAVELEN/200.
      IF(SINZMAX.GT.0.707) SINZMAX=.707
      RJ=-.707*VK*SINZMAX/20.
      DO 50 J=1,NANT
      JS=JSEQ(J)
      NANTNO(J)=AN(KT,JS)
      RJY(J,IFF)=RJ*ANTY(NANTNO(J))
   50 RJX(J,IFF)=RJ*ANTX(NANTNO(J))
      RETURN
      END
C
C
C
C
C
C
C
C
      SUBROUTINE SPLIT(NDOPP,NANT,IFF,IDB,ISIGN,IBEGIN)
C
C=============================================================================
C GOOSE BAY
C SPLITS IB2160 FROM BUFFERIN INTO PHASES AND MAGNITUDES
C INPUTS   IB2160   UNPACKED RAW DRIFT DATA
C          NDOPP    NO. OF DOPPLERS USED IN CALCULATION
C          NANT     NO. OF ANTENNA'S USED IN CALCULATION
C          IFF      FREQUENCY NO.
C          IDB      NO. OF LSB'S IN A BEL OF MAGNITUDE
C OUTPUTS  PHI      NDOPP X NANT ARRAY OF PHASES IN RADIANS
C          FM       NDOPP X NANT ARRAY OF LOG 10 MAGNITUDES
C                     CONVERTED TO LINEAR AMPLITUDES
C
C FOR KPRINT 16,512,4096 OR 8192, LEAVE AMPLITUDES AS LOG VALUES
C=============================================================================
C
      COMMON IB2160(2160),JSEQ(7),RJX(7,6),RJY(7,6)
+     ,IB216(216),IB216T(216),NANTNO(7),MAXFWPD(41,41),IMAX(41,41)
+     ,FWPD(41,41),PHI(64,7),FWMAX(64),FM(64,7),PI,RADIAN,KPRINT
+     ,FREQ(6),RANG(6),IGAIN(6),FWMAXX(6)
C
      DB=IDB
      NK=NDOPP*NANT/2
      DO 20 K=1,NK
      J=(2*K-2)/NDOPP+1
      I=2*K-(J-1)*NDOPP
      K5=5*(K+(IFF-1)*NK+(JSEQ(J)-J)*NDOPP/2)+240
      FM(I-1,J)=FLOAT(IB2160(K5-4))
```

```
      FM(I  ,J)=FLOAT(IB2160(K5-1))
      IF((KPRINT.AND.12816).NE.0) GO TO 10
      FM(I-1,J)=FM(I-1,J)/DB
      FM(I,J)=FM(I,J)/DB
      FM(I-1,J)=10.**FM(I-1,J)-1.
      FM(I,J)=10.**FM(I,J)-1.
   10 IPHI=8*IB2160(K5-3)+(IB2160(K5-2).AND.56)/8
      PHI(I-1,J)=2.*PI*FLOAT(IPHI)/512.
      IPHI=8*IB2160(K5)+(IB2160(K5-2).AND.7)
      PHI(I,J)=2.*PI*FLOAT(IPHI)/512.
   20 CONTINUE
      IF((KPRINT.AND.98).EQ.0) RETURN
C
C=======================================================================
C FOR KPRINT 2,32 OR 64, DEFINE:
C
C            NANT
C FWMAX(I)= SUM FM(I,J)
C             J=1
C
C AS THE SQRT OF THE ESTIMATED MAGNITUDE OF THE MAXIMUM FWPD(I).
C (FWMAX(I)**2 IS EXACTLY THE MAGNITUDE OF THE MAXIMUM FWPD(I)
C  IF THERE IS ONLY ONE SOURCE AT DOPPLER I).
C
C SET FWMAX(I)=0 IF FM(I,J).LT.1 FOR ANY ANTENNA J.
C FWMAXX(IFF)=MAXIMUM FWMAX(I) OVER ALL DOPPLERS I OF A CASE,
C               FOR A GIVEN FREQUENCY NUMBER IFF.
C FWMAX, FWMAXX USED IN SUBROUTINE FOU.
C
C STORE FWMAX(I), FM(I,J), PHI(I,J) FOR ALL FREQUENCY NUMBERS, IF
C   PROCESSING FIRST RECORD OF A CASE; IF SECOND RECORD, STORE ONLY
C   THOSE OF THE FREQUENCY BEING CALCULATED, AND MAIN PROGRAM CALLS FOU
C   TWICE, ONCE FOR THE NEGATIVE DOPPLERS, ONCE FOR THE POSITIVE
C   DOPPLERS, OF THE GIVEN FREQUENCY.
C=======================================================================
C
      IF(ISIGN.EQ.1) FWMAXX(IFF)=0.
      DO 50 I=1,NDOPP
      FWMAX(I)=0
      AMN=FM(I,1)
      DO 30 J=2,NANT
   30 AMN=AMIN1(AMN,FM(I,J))
      IF(AMN.LT.1.0) GO TO 50
      DO 40 J=1,NANT
   40 FWMAX(I)=FWMAX(I)+FM(I,J)
   50 FWMAXX(IFF)=AMAX1(FWMAXX(IFF),FWMAX(I))
C
      IF(ISIGN.EQ.2) GO TO 60
      IF(IFF.EQ.IBEGIN) REWIND 90
      WRITE (90) (FWMAX(I),I=1,NDOPP),
     +   ((FM(I,J),PHI(I,J),I=1,NDOPP),J=1,NANT)
```

```
      RETURN
   60 REWIND 91
      WRITE (91) (FWMAX(I),I=1,NDOPP),
+        ((FM(I,J),PHI(I,J),I=1,NDOPP),J=1,NANT)
      RETURN
      END
C
C
C
C
C
C
C
C
C
      SUBROUTINE MAPSEQ
C
C=========================================================================
C READS MAPDATA (IY,IX,FWPD,DOPP) FROM TAPE50 AND PUTS THE FWPD'S AND
C DOPPLERS WANTED (ACCORDING TO THE CHOICES INDICATED AT THE BEGINNING
C OF THE RUN) INTO ARRAYS MAXFWPD AND IMAX FOR PRINTING SINGLE SKY MAPS
C OR TIME-SEQUENCE SKY MAPS
C=========================================================================
C
      DIMENSION MAPDAT(4,80),MPDT(52),M1(64),M2(64),KOUNT(41,41)
      COMMON IB2160(2160),JSEQ(7),RJX(7,6),RJY(7,6)
+     ,IB216(216),IB216T(216),NANTNO(7),MAXFWPD(41,41),IMAX(41,41)
+     ,FWPD(41,41),PHI(64,7),FWMAX(64),FM(64,7),PI,RADIAN,KPRINT
+     ,FREQ(6),RANG(6),IGAIN(6),FWMAXX(6)
C
      INTEGER SHIFT
C
      DATA M1/" 1"," 2"," 3"," 4"," 5"," 6"," 7"," 8"," 9","10",
+     "11","12","13","14","15","16","17","18","19","20","21","22",
+     "23","24","25","26","27","28","29","30","31","32","33","34",
+     "35","36","37","38","39","40","41","42","43","44","45","46",
+     "47","48","49","50","51","52","53","54","55","56","57","58",
+     "59","60","61","62","63","64"/
      DATA M2/" A"," B"," C"," D"," E"," F"," G"," H"," I"," J",
+     " K"," L"," M"," N"," O"," P"," Q"," R"," S"," T"," U"," V",
+     " W"," X"," Y"," Z","AA","BB","CC","DD","EE","FF","GG","HH",
+     "II","JJ","KK","LL","MM","NN","OO","PP","QQ","RR","SS","TT",
+     "UU","VV","WW","XX","YY","ZZ","A+","B+","C+","D+","E+","F+",
+     "G+","H+","I+","J+","K+","L+"/
      DATA KBLANK1/1H /,KBLANK2/2H  /
C
C=========================================================================
C INPUTS REQUIRED: (ALL "QUOTED" PARAMETERS ARE TO BE INPUTTED
C                    WITHOUT QUOTES)
C --TIME (E.G."121832") OF THE FIRST CASE WANTED
C   OR "0" (ZERO) TO START AT THE BEGINNING OF TAPE50
```

```
C --FREQUENCY NUMBER (ONLY ONE FREQ. NO. CAN BE PROCESSED AT A TIME)
C --WHETHER WANT "NEG", "POS", OR "BOTH" DOPPLERS
C --"FWPD" IF WANT A SINGLE CASE ON EACH MAP; OR "TIME" IF WANT
C   SEVERAL SUCCESSIVE CASES (TIME SEQUENCE)
C --THE MINIMUM FWPD (IN DB) OF THE SOURCES TO BE INCLUDED IN THE
C   MAP:
C   --"0" (ZERO) IF WANT ONLY THE MAX FWPD OF EACH RECORD
C   --POSITIVE NO. (E.G."30") IF WANT THE SAME MINIMUM FOR ALL RECORDS
C   --NEG. NO. IF WANT THE MINIMUM FOR EACH RECORD TO BE A GIVEN
C     NUMBER OF DB BELOW THE MAX OF THAT RECORD: E.G. IF INPUT "-3",
C     MINIMUM OF EACH RECORD IS 3 DB BELOW THE MAX
C=======================================================================
C
        PRINT*," START TIME?"
        PRINT*," (OR 0 (ZERO) TO START AT THE BEGINNING)"
        READ*,ITIME
        PRINT*," FREQUENCY NUMBER?"
        READ*,IFREQ
        PRINT*," NEG, POS, OR BOTH DOPPLERS?"
        READ 10,ISIGN
     10 FORMAT(A4)
        PRINT*," FWPD OR TIME SEQUENCE?"
        READ 10,IFWPD
        IF(ISIGN.EQ."NEG")ISIGN=1  $ IF(ISIGN.EQ."POS")ISIGN=2
        IF(ISIGN.EQ."BOTH")ISIGN=3
        PRINT*," MINIMUM FWPD?"
        PRINT*," (POS. NO.: CONSTANT IDBMIN)"
        PRINT*," (0: IDBMIN=IDBMAX)"
        PRINT*," (NEG. NO.: AMOUNT BY WHICH IDBMIN IS L.T. IDBMAX)"
        READ*,MNN
C
C
C=======================================================================
C AT BEGINNING OF A RUN (NRUN=0) CHECK THE TIME UNTIL FIND FIRST
C   CASE WANTED, UNLESS ITIME ("START TIME") IS ZERO.
C FOR EACH RECORD, SKIP THE RECORD IF THAT FREQ. NO. IS NOT WANTED,
C   OR IF THAT SIGN ("1" FOR NEG DOPPLERS, "2" FOR POSITIVE) IS
C   NOT WANTED.
C KREC=1: FIRST RECORD OF A GIVEN SEQUENCE (OR GIVEN MAP).
C=======================================================================
C
        KREC=1
        NRUN=0
     20 DO 30 I=1,52
     30 MPDT(I)=MPDT(I).AND.0
C
        BUFFERIN(50,1)(MPDT(1),MPDT(52))
        IF(UNIT(50))50,40,20
     40 IF (KREC.EQ.1) STOP  $ GO TO 360
     50 IF(KREC.EQ.1.AND.NRUN.EQ.0.AND.MPDT(3).NE.ITIME
+         .AND.ITIME.NE.0) GO TO 20
```

```
      IF(IFREQ.NE.MPDT(9)) GO TO 20
      JSIGN=1  $ IF(((MPDT(4)/2)*2).EQ.MPDT(4)) JSIGN=2
      IF(ISIGN.NE.3.AND.JSIGN.NE.ISIGN) GO TO 20
      NRUN=1
C
      IF(KREC.EQ.2) GO TO 70
C
C============ INITIALIZE; PRINT FIRST PREFACE OF THIS SEQUENCE ============
C
      IHR=MPDT(3)/10000  $ IMIN=MPDT(3)/100-IHR*100
      ISEC=MPDT(3)-IHR*10000-IMIN*100
      ITOTSEC=LTOTSEC=IHR*3600+IMIN*60+ISEC
C
      NFREQ=MPDT(9)
      FREQ(NFREQ)=FLOAT(MPDT(10))/10.
      SINZMAX=AMIN1(.707,(2997.925/FREQ(NFREQ)))
      RANG(NFREQ)=FLOAT(MPDT(11))/10.
      IGAIN(NFREQ)=MPDT(12)
C
      NUMBER=-1
      IOVER=0
      DO 240 IX=1,41
      DO 240 IY=1,41
      MAXFWPD(IY,IX)=KBLANK1
      IMAX(IY,IX)=KBLANK2
  240 KOUNT(IY,IX)=0
C
      MSIGN="NEG"  $ IF(JSIGN.EQ.2) MSIGN="POS"
      PRINT 250
  250 FORMAT(1H1,31X,"SEQ DOPP VSTAT  DATE  TIME  RWTT GNXZ ",
+     "FREQ.NO. FREQ(KHZ) RANGE(KM) GAIN(DB)")
      PRINT 260,(NUMBER+1),MSIGN,(MPDT(I),I=1,3),MPDT(6),MPDT(7),
+             NFREQ,FREQ(NFREQ),RANG(NFREQ),IGAIN(NFREQ)
  260 FORMAT(22X,"BEGIN AT:  ",Z1,3X,A3,3X,I2,2X,I5.5,1X,
+       I6.6,2(1X,I4.4),4X,I1,6X,F7.1,3X,F6.1,6X,I3)
C
      KREC=2
      GO TO 270
C
C==========================================================================
C DETERMINE IF END OF THE SEQUENCE:
C IF TIME LAPSE SINCE FIRST PREFACE IS G.T. 5 MIN., OR TIME LAPSE
C   BETWEEN PREFACES IS G.T. 18 SEC. (INDICATING THE TIME SEQUENCE
C   OF CASES IS BROKEN), GO TO 360 TO PRINT THE MAP.
C IF, COMPARED TO THE FIRST PREFACE, FREQ. NO. CHANGES, OR RANGE
C   DIFFERENCE IS G.T. 10 KM, OR FREQ. DIFFERENCE IS G.T. 0.5 MHZ,
C   PRINT A MESSAGE AND PRINT THE MAP.
C IF GAIN IS DIFFERENT, PRINT A MESSAGE BUT CONTINUE READING DATA.
C==========================================================================
C
   70 JHR=MPDT(3)/10000  $ JMIN=MPDT(3)/100-JHR*100
```

```
      JSEC=MPDT(3)-JHR*10000-JMIN*100
      JTOTSEC=JHR*3600+JMIN*60+JSEC
      IF(JTOTSEC.LT.LTOTSEC) JTOTSEC=JTOTSEC+24*3600
      IF((JTOTSEC-LTOTSEC).GT.18) GO TO 170
      LTOTSEC=JTOTSEC
      IF((JTOTSEC-ITOTSEC).GT.300) GO TO 170
      IF(MPDT(9).NE.NFREQ) GO TO 80
      IF((ABS((FLOAT(MPDT(10))/10.)-FREQ(NFREQ))).GT.500.)GOTO 100
      IF((ABS((FLOAT(MPDT(11))/10.)-RANG(NFREQ))).GT.10.)GOTO 120
      IF(MPDT(12).NE.IGAIN(NFREQ))GO TO 140
      GO TO 270
   80 PRINT*," DIFFERENT FREQ. NO. ENCOUNTERED"
      GO TO 170
  100 PRINT*," FREQ. DIFFERENCE G.T. 0.5 MHZ"
      GO TO 170
  120 PRINT*," RANGE DIFFERENCE G.T. 10 KM"
      GO TO 170
  140 PRINT 150,IGAIN(NFREQ),MPDT(12)
      IGAIN(NFREQ)=MPDT(12)
  150 FORMAT(" NOTE GAIN CHANGE FROM ",I3," TO ",I3)
      GO TO 270
  170 BACKSPACE 50
      GO TO 360
C
C=========================================================================
C DETERMINE PARAMETERS OF LATEST PREFACE FOR PRINTING
C
C UNPACK IY,IX,FWPD,AND DOPPLER NO. INTO ARRAY MAPDAT
C=========================================================================
C
  270 IST=MPDT(1)
      MNUM=NUMBER  $ IF(ISIGN.LE.2) MNUM=NUMBER+1
      MSIGN="NEG"  $ IF(JSIGN.EQ.2) MSIGN="POS"
      MDATE=MPDT(2)
      MTIME=MPDT(3)
      MRW=MPDT(6)  $ MGN=MPDT(7)
      MFRQ=MPDT(9)  $ FRQ=FLOAT(MPDT(10))/10
      RNG=FLOAT(MPDT(11))/10
      IGN=MPDT(12)
C
      DO 280 NROW=1,4
      DO 280 NCOL=1,80
  280 MAPDAT(NROW,NCOL)=0
C
      DO 290 IM=13,52
      IBF=0
      DO 290 IBY=1,8
      IMM=8*IM+IBY-104  $ IBG=3+3*((IBY+1-4*(IBY/5))/2)
      IBF=IBF+IBG $ NCOL=(IMM+3)/4  $ NROW=IMM-(4*(NCOL-1))
  290 MAPDAT(NROW,NCOL)=(63+448*(IBG/9)).AND.SHIFT(MPDT(IM),IBF)
C
```

```
C========= IDBMAX=MAX. FWPD OF EACH RECORD (NEG OR POS DOPPLERS) =========
C
      IDBMAX=0
      DO 300 NCOL=1,80
  300 IDBMAX=MAX0(MAPDAT(3,NCOL),IDBMAX)
      IF(MNN.GT.0) IDBMIN=MNN
      IF(MNN.LT.0) IDBMIN=IDBMAX+MNN
      IF(MNN.EQ.0) IDBMIN=IDBMAX
      IF(IDBMIN.LT.3) IDBMIN=3
      IF((ISIGN.EQ.3.AND.JSIGN.EQ.1).OR.(ISIGN.LE.2))
+       NUMBER=NUMBER+1
C
C
C========================================================================
C SELECT THE CASES WITH FWPD .GE. IDBMIN.
C
C PUT THE DOPPLER NO. INTO ARRAY IMAX.
C IF IFWPD(INPUTTED AT BEGINNING OF RUN)="TIME",PUT A TIME SEQUENCE
C   NO. (0 TO 15) INTO ARRAY MAXFWPD.
C IF IFWPD="FWPD", PUT THE FWPD INTO ARRAY MAXFWPD.
C
C IF THE SAME COORDINATES HAVE MORE THAN ONE FWPD, KEEP THE FIRST ONE
C   IN THE MAP, AND PRINT THE INFORMATION ABOUT THE EXTRA ONES.
C (PRINTING THIS INFO NOT PRESENTLY OPERATIVE; ONLY COUNTING
C  THE NUMBER OF "OVERFLOWS")
C========================================================================
C
      DO 340 NCOL=1,80
      IF(MAPDAT(3,NCOL).LT.IDBMIN) GO TO 340
      IY=MAPDAT(1,NCOL)
      IX=MAPDAT(2,NCOL)
      IF(IMAX(IY,IX).NE.KBLANK2)310,330
  310 IOVER=IOVER+1
C
CCC        KOUNT(IY,IX)=KOUNT(IY,IX)+1
CCC        IYC="W"  $ IF(IY.GT.21) IYC="E"
CCC        IXC="N"  $ IF(IX.GT.21) IXC="S"
CCC        PRINT 320,NUMBER,KOUNT(IY,IX),IABS(21-IY),IYC,IABS(21-IX),IXC,
CCC+       (((-1)**JSIGN)*MAPDAT(4,NCOL)),MAPDAT(3,NCOL)
CCC   320 FORMAT(1X,Z1," OVERFLOW ("I2") AT ("I2,A1","I2,A1");  DOPPLER"I4,
CCC+       "  FWPD="I3" DB")
C
      GO TO 340
  330 MAXFWPD(IY,IX)=NUMBER
      IF(IFWPD.EQ."FWPD")MAXFWPD(IY,IX)=(MAPDAT(3,NCOL)-3)/6
      IMAX(IY,IX)=M1(MAPDAT(4,NCOL))
      IF(JSIGN.EQ.2) IMAX(IY,IX)=M2(MAPDAT(4,NCOL))
  340 CONTINUE
C
      IF(IFWPD.EQ."TIME") GO TO 350
      IF(ISIGN.EQ.3.AND.JSIGN.EQ.2.AND.NUMBER.EQ.0) GO TO 360
```

```
      IF(ISIGN.LE.2.AND.NUMBER.EQ.0) GO TO 360
C
  350 IF(ISIGN.EQ.3.AND.JSIGN.EQ.2.AND.NUMBER.EQ.15) GO TO 360
      IF(ISIGN.LE.2.AND.NUMBER.EQ.15) 360,20
C
C================= PRINT LAST PREFACE OF THIS SEQUENCE ==================
C                         AND CALL PRIN TO PRINT THE MAP
C
  360 PRINT 370,MNUM,MSIGN,IST,MDATE,MTIME,MRW,
+       MGN,MFRQ,FRQ,RNG,IGN
  370 FORMAT(22X,"END AT:     ",Z1,3X,A3,3X,I2,2X,I5.5,1X,
+       I6.6,2(1X,I4),4X,I1,6X,F7.1,3X,F6.1,6X,I3)
      PRINT*,"                              ",IOVER," OVERFLOW(S)"
C
      IF(NUMBER.GE.0) CALL PRIN(IN,ISIGN,IFWPD,SINZMAX,NFREQ)
C
      KREC=1
      GO TO 20
      END
C
C
C
C
C
C
      SUBROUTINE FOU(ISIGN,NDOPP,NANT,IFF,IBEGIN,IFOU)
C
C=======================================================================
C CALCULATES FOURIER TRANSFORMS FOR SKY MAP
C REQUIRED INPUTS ARE
C           NDOPP  NO.OF DOPPLERS USED IN CALCULATIONS
C           NANT   NO.OF ANTENNAS USED IN CALCULATION
C           RJY    NANT ARRAY SCALED Y ANTENNA COORDINATES
C           RJX    NANT ARRAY SCALED X ANTENNA COORDINATES
C           PHI    NDOPP X NANT ARRAY OF PHASES
C           FM     NDOPP X NANT ARRAY OF MAGNITUDES
C OUTPUTS ARE
C MAXFWPD   41X41 ARRAY SKYMAP W/FWPDS
C IMAX 41X41 ARRAY SKYMAP W/DOPPLERS
C=======================================================================
C
      COMPLEX FMEXP(4),EXPAK(41,41,3),FSUM
      DIMENSION IXMAX(41),IYMAX(41),FXMAX(41),FYMAX(41)
      DIMENSION LOGFWPD(41,41)
      COMMON IB2160(2160),JSEQ(7),RJX(7,6),RJY(7,6)
+     ,IB216(216),IB216T(216),NANTNO(7),MAXFWPD(41,41),IMAX(41,41)
+     ,FWPD(41,41),PHI(64,7),FWMAX(64),FM(64,7),PI,RADIAN,KPRINT
+     ,FREQ(6),RANG(6),IGAIN(6),FWMAXX(6)
C
C
      DO 10 IX=1,41
```

```
      DO 10 IY=1,41
      MAXFWPD(IY,IX)=0.
   10 IMAX(IY,IX)=0
C
C=========================================================================
C FWMAX(I) DETERMINED IN SUBROUTINE ANT.
C FWMAX(I)=0 IF FM(I,J).LT.1 FOR ANY ANTENNA J.
C FWMAXX=MAXIMUM FWMAX(I) OVER ALL I, FOR A GIVEN FREQUENCY.
C FWMIN=FWMAXX/10 (20 DB BELOW FWMAXX) BUT AT LEAST 2 (6 DB).
C=========================================================================
C
      IF(IFOU.EQ.2) GO TO 20
      IF(IFF.EQ.IBEGIN) REWIND 90
      READ (90) (FWMAX(I),I=1,NDOPP),
+        ((FM(I,J),PHI(I,J),I=1,NDOPP),J=1,NANT)
      FWMIN=AMAX1((FWMAXX(IFF)/10.),2.)
      GO TO 30
C
   20 REWIND 91
      READ (91) (FWMAX(I),I=1,NDOPP),
+        ((FM(I,J),PHI(I,J),I=1,NDOPP),J=1,NANT)
      GO TO 45
C
C=========================================================================
C ARRAY COORDINATES IY,IX=1,...,41 CORRESPOND TO MAP
C  COORDINATES YIY,XIX=+20,...,0,...,-20
C
C +YIY=WEST; +XIX=NORTH
C
C AK=K-DOT-A (SEE SUBROUTINE ANT).
C K=K(IY,IX)=WAVE PROPAGATION VECTOR (SCANNING VECTOR).
C A=A(J)=ANTENNA POSITION VECTOR; A=0 FOR ANTENNA J=1.
C EXPAK=EXPONENTIAL(II*AK); II=SQRT(-1)
C=========================================================================
C
   30 DO 40 IX=1,41
      XIX=21-IX
      DO 40 IY=1,41
      YIY=21-IY
      DO 40 J=2,NANT
      AK=(RJY(J,IFF)*YIY+RJX(J,IFF)*XIX)
   40 EXPAK(IY,IX,J-1)=CMPLX(COSINE(AK,SINE),SINE)
C
C=========================================================================
C SKIP DOPPLER I IF FWMAX(I).LT.FWMIN
C FMEXP(J)=FM(I,J)*EXP(II*PHI(I,J)); II=SQRT(-1)
C AUTOCOR=AUTOCORRELATION TERM
C=========================================================================
C
   45 DO 170 I=1,NDOPP
C
```

```
      IF(FWMAX(I).LT.FWMIN) GO TO 170
C
      DO 50 J=1,NANT
   50 FMEXP(J)=CMPLX((FM(I,J)*COSINE(PHI(I,J),SINE)),
+             (FM(I,J)*SINE))
C
      AUTOCOR=0
      DO 60 J=1,NANT
   60 AUTOCOR=AUTOCOR+FM(I,J)*FM(I,J)
C
C===========================================================================
C FOR A GIVEN DOPPLER (I), AT COORDINATES (IY,IX):
C
C        NANT
C   FSUM= SUM FM(I,J) * EXP(II*PHI(I,J)) * EXP(II*AK(IY,IX,J))
C          J=1
C                  WHERE II=SQRT(-1)
C
C   FWPD=ABS(FSUM)**2
C       =(REAL(FSUM))**2+(IMAGINARY(FSUM))**2
C
C SUBTRACT THE CONSTANT AUTO-CORRELATION TERM FROM THE FWPD
C===========================================================================
C
      DO 80 IX=1,41
      DO 80 IY=1,41
      FSUM=FMEXP(1)
      DO 70 J=2,NANT
   70 FSUM=FSUM+FMEXP(J)*EXPAK(IY,IX,J-1)
      FWPD(IY,IX)=REAL(FSUM)**2+AIMAG(FSUM)**2-AUTOCOR
   80 CONTINUE
C
C===========================================================================
C SEARCH FOR MAXIMA AT THIS DOPPLER I
C
C     SEARCH FOR MAXIMA ALONG EACH HORIZONTAL LINE IX:
C       FYMAX(IX)=MAX FWPD OF LINE IX
C       IYMAX(IX) IS ITS IY INDEX
C       FYMAX(IX)=FWPD(IYMAX(IX),IX)
C     SET INDEX IYMAX TO ZERO IF FYMAX OF LINE IX IS NOT GREATER
C     THAN FYMAX OF LINES IX-1 AND IX+1
C===========================================================================
C
      DO 100 IX=1,41
      FYMAX(IX)=FWPD(1,IX)  $ IYMAX(IX)=1
      DO 90 IY=2,41
      IF(FWPD(IY,IX).LT.FYMAX(IX)) GO TO 90
      FYMAX(IX)=FWPD(IY,IX)
      IYMAX(IX)=IY
   90 CONTINUE
      IF([illegible].EQ.1) GO TO 100
```

```
      IF(FYMAX(IX).GT.FYMAX(IX-1)) IYMAX(IX-1)=0
      IF(FYMAX(IX).LT.FYMAX(IX-1)) IYMAX(IX)=0
  100 CONTINUE
C
C===========================================================================
C     SEARCH FOR MAXIMA ALONG EACH VERTICAL LINE IY:
C       FXMAX(IY)=MAX FWPD OF LINE IY
C       IXMAX(IY) IS ITS IX INDEX
C       FXMAX(IY)=FWPD(IY,IXMAX(IY))
C     SET INDEX IXMAX TO ZERO IF FXMAX OF COLUMN IY IS NOT
C     GREATER THAN FXMAX OF COLUMNS IY-1 AND IY+1
C
C DETERMINE:
C   MAX=MAXIMUM LOGFWPD OF THE ARRAY FOR A GIVEN DOPPLER I
C===========================================================================
C
C
      DO 120 IY=1,41
      FXMAX(IY)=FWPD(IY,1)  $ IXMAX(IY)=1
      DO 110 IX=2,41
      IF(FWPD(IY,IX).LT.FXMAX(IY)) GO TO 110
      FXMAX(IY)=FWPD(IY,IX)
      IXMAX(IY)=IX
 110 CONTINUE
      IF(IY.EQ.1) GO TO 120
      IF(FXMAX(IY).GT.FXMAX(IY-1)) IXMAX(IY-1)=0
      IF(FXMAX(IY).LT.FXMAX(IY-1)) IXMAX(IY)=0
  120 CONTINUE
C
      BMAX=0
      DO 130 IY=1,41
      IF(IXMAX(IY).EQ.0) GO TO 130
      IF(IYMAX(IXMAX(IY)).NE.IY) GO TO 130
      BMAX=AMAX1(BMAX,FXMAX(IY))
  130 CONTINUE
      BMAX2=BMAX/2.
C
C===========================================================================
C DETERMINE MAXFWPD: ARRAY OF FWPD'S TO BE PRINTED ON THE SKYMAP:
C
C    FOR A GIVEN DOPPLER, SKIP FWPD'S LESS THAN OR EQUAL TO 1/2 THE
C MAX FWPD FOR THAT DOPPLER (TO SUPPRESS WEAK SIDELOBES; STRONG
C SIDELOBES ARE SUPPRESSED BY CHOICE OF MAX ZENITH ANGLE, AS
C DETERMINED IN SUBROUTINE ANT)
C
C    IF MULTIPLE SOURCES AT ONE LOCATION, KEEP THE DOPPLER WITH
C THE MAXIMUM INTEGER FWPD, OR KEEP THE LAST ONE IF TWO HAVE THE SAME
C INTEGER VALUE
C===========================================================================
C
      DO 140 IY=1,41
```

```
      IF(IXMAX(IY).EQ.0) GO TO 140
      IF(IYMAX(IXMAX(IY)).NE.IY) GO TO 140
      IF(FXMAX(IY).LE.BMAX2) GO TO 140
      IF(MAXFWPD(IY,IXMAX(IY)).GT.(IFIX(FXMAX(IY)))) GO TO 140
      MAXFWPD(IY,IXMAX(IY))=IFIX(FXMAX(IY))
      IMAX(IY,IXMAX(IY))=I
  140 CONTINUE
C
      IF((KPRINT.AND.32).EQ.0)GO TO 170
      IFPRINT=0
      DO 150 IXX=1,41
      DO 150 IYY=1,41
      FWPD(IYY,IXX)=AMAX1(1.,FWPD(IYY,IXX))
      LOGFWPD(IYY,IXX)=IFIX(10.*ALOG10(FWPD(IYY,IXX)))
      IF(LOGFWPD(IYY,IXX).LT.1) GO TO 150
      IFPRINT=1
  150 CONTINUE
      IF(IFPRINT.NE.1) GO TO 170
      PRINT 160, I,(((LOGFWPD(IYY,IXX),IYY=1,41),IXX,
+     IYMAX(IXX)),IXX=1,41),(IYY,IYY=1,41),(IXMAX(IYY),IYY=1,41)
  160 FORMAT(*1 DOPPLER=*,I3/////,41(41I3,3X,I2,1X,I2/),
+     T125,*IX,IYMAX*/,41I3,T125,*IY*/,41I3,T125,*IXMAX*,17(/))
  170 CONTINUE
C
C==========================================================================
C CONVERT FINAL MAP TO DB VALUES
C==========================================================================
C
      IF(KPRINT.EQ.32) RETURN
      DO 180 IX=1,41
      DO 180 IY=1,41
      MAXFWPD(IY,IX)=MAX0(1,MAXFWPD(IY,IX))
  180 MAXFWPD(IY,IX)=IFIX(10.*ALOG10(FLOAT(MAXFWPD(IY,IX))))
C
      RETURN
      END
C
C
C
C
      FUNCTION COSINE(ARG,SINE)
C
C==========================================================================
C DETERMINE COSINE=COS(ARG) AND SINE=SIN(ARG) FROM TABLE
C    CALCULATED AT BEGINNING OF MAIN PROGRAM
C==========================================================================
C
      COMMON/PIE/NPI,N2PI,N3PI2,NPI2,TWOPI,PI2,PI512,CSN(257)
      ARG=AMOD(ARG,TWOPI)
      IF(ARG.LT.0) ARG=ARG+TWOPI
      KUADRNT=IFIX(ARG/PI2)+1
```

```
      KARG=IFIX(ARG/PI512+.5)
      GO TO (1,2,3,4)KUADRNT
    1 COSINE=CSN(KARG+1) $ SINE=CSN(NPI2-KARG+1) $ RETURN
    2 COSINE=-CSN(NPI-KARG+1) $ SINE=CSN(KARG+1-NPI2) $ RETURN
    3 COSINE=-CSN(KARG+1-NPI) $ SINE=-CSN(N3PI2-KARG+1) $ RETURN
    4 COSINE=CSN(N2PI-KARG+1) $ SINE=-CSN(KARG+1-N3PI2)
      RETURN
      END
C
C
C
C
      SUBROUTINE MAPDATA(NFREQ,MDTFLAG,IFOU,NMAP)
C
C=======================================================================
C STORES THE FWPD'S, DOPPLER NUMBERS, AND THEIR COORDINATES
C FOR THE SKYMAPS
C=======================================================================
C
      DIMENSION MAPDAT(320),MPDT(52)
      COMMON IB2160(2160),JSEQ(7),RJX(7,6),RJY(7,6)
+     ,IB216(216),IB216T(216),NANTNO(7),MAXFWPD(41,41),IMAX(41,41)
+     ,FWPD(41,41),PHI(64,7),FWMAX(64),FM(64,7),PI,RADIAN,KPRINT
+     ,FREQ(6),RANG(6),IGAIN(6),FWMAXX(6)
C
      INTEGER SHIFT
C
C=======================================================================
C AT THE BEGINNING OF A RUN, READ TAPE50 UNTIL GET TO END OF DATA.  THUS
C  IF TAPE50 ALREADY CONTAINS DATA, THE NEW DATA WILL BE APPENDED TO IT.
C  IGNORE LAST RECORD IF MPDT(4) IS NOT AN EVEN NUMBER (SEE EXPLANATION
C  OF MPDT(4) BELOW); I.E., IF LAST RECORD IS NOT THE SECOND RECORD
C  OF A CASE.
C=======================================================================
C
      IF(MDTFLAG.EQ.1) GO TO 30
   10 BUFFERIN(50,1)(MPDT(1),MPDT(52))
      IF(UNIT(50)) 10,20,10
   20 MDTFLAG=1
      IF(((MPDT(4)/2)*2).NE.MPDT(4)) BACKSPACE 50
C
C=======================================================================
C CODE FIRST 32 PREFACE CHARACTERS INTO ARRAY MPDT:
C   CHARACTER(S)     1= VSTAT       INTO MPDT(1)
C                  2-6= DATE                 2
C                 7-12= TIME                 3
C                13-16: NOT USED; SEE NOTE   4
C                17-20: NOT USED             5
C                21-24= RWTT                 6
C                25-28= QNXZ                 7
C                29-32: NOT USED             8
```

```
C   NOTE: CHARACTER 16 SET TO 1 BY PROGRAM SKYMAP FOR
C         FIRST RECORD OF A CASE; SET TO 2 FOR SECOND RECORD.
C   ALSO: MPDT(9)=NFREQ=FREQUENCY NUMBER
C         MPDT(10)=FREQ(NFREQ), IN 100-HZ UNITS
C         MPDT(11)=RANG(NFREQ), IN 100-METER UNITS
C         MPDT(12)=IGAIN(NFREQ), IN DB
C   NOTE THAT PREFACE DOES NOT GET PACKED.
C
C PRINT PREFACE.
C==========================================================================
C
    30 DO 40 I=1,52
    40 MPDT(I)=MPDT(I).AND.0
       DO 50 I=1,320
    50 MAPDAT(I)=0
C
       IB2160(16)=IFOU
       MPDT(1)=IB2160(1)
C
       II=100000
       DO 60 I=2,6
       II=II/10
    60 MPDT(2)=MPDT(2)+IB2160(I)*II
C
       II=1000000
       DO 70 I=7,12
       II=II/10
    70 MPDT(3)=MPDT(3)+IB2160(I)*II
C
       II=10000
       DO 80 I=13,16
       II=II/10  $ JJ=-4
       DO 80 J=4,8
       JJ=JJ+4
    80 MPDT(J)=MPDT(J)+IB2160(I+JJ)*II
C
       MPDT(9)=NFREQ
       MPDT(10)=IFIX(FREQ(NFREQ)*10.)
       MPDT(11)=IFIX(RANG(NFREQ)*10.)
       MPDT(12)=IGAIN(NFREQ)
C
       PRINT 90,(NMAP-(MPDT(4)-(MPDT(4)/2)*2)),
+                (MPDT(I),I=1,9),(FLOAT(MPDT(10))/10.),
+         (FLOAT(MPDT(11))/10.),MPDT(12)
    90 FORMAT(1X,I5,1X,I3,1X,I5.5,1X,I6.6,5(1X,I4.4),3X,I3,2F8.1,I5)
C
C==========================================================================
C STORE DATA (IY, IX, FWPD, DOPPLER NO.) INTO MAPDAT.
C PRINT DATA.
C==========================================================================
C
```

SKYMAP (ULCAR)

```
      I=-3
      DO 110 IX=1,41
      DO 110 IY=1,41
      IF(MAXFWPD(IY,IX).LT.1) GO TO 110
      I=I+4  $ IF(I.LT.320) GO TO 100
      PRINT*,"WARNING: AMOUNT OF DATA EXCEEDS SIZE OF ARRAY ",
+     "MAPDAT,  AT (IY,IX)=(",IY,",",IX,"), WITH MAXFWPD=",
+     MAXFWPD(IY,IX)," IMAX=",IMAX(IY,IX)
      GO TO 110
  100 MAPDAT(I)=IY.AND.63  $ MAPDAT(I+1)=IX.AND.63
      MAPDAT(I+2)=MAXFWPD(IY,IX).AND.511
      MAPDAT(I+3)=IMAX(IY,IX).AND.511
  110 CONTINUE
      NPR=NPRR=I  $ IF(I.GT.157) NPR=157
      IF(I.GT.317) NPRR=317
      NPR1=NPR+1 $ NPR2=NPR+2 $ NPR3=NPR+3
      NPRR1=NPRR+1 $ NPRR2=NPRR+2 $ NPRR3=NPRR+3
C
      PRINT 120,(MAPDAT(I),I=1,NPR,4)
      PRINT 130,(MAPDAT(I),I=2,NPR1,4)
      PRINT 140,(MAPDAT(I),I=3,NPR2,4)
      PRINT 150,(MAPDAT(I),I=4,NPR3,4)
  120 FORMAT(1X,"  IY",40I3)
  130 FORMAT(1X,"  IX",40I3)
  140 FORMAT(1X,"FWPD",40I3)
  150 FORMAT(1X,"DOPP",40I3)
C
      IF(MAPDAT(161).EQ.0) GO TO 160
CCC      PRINT*,"  "
      PRINT 120,(MAPDAT(I),I=161,NPRR,4)
      PRINT 130,(MAPDAT(I),I=162,NPRR1,4)
      PRINT 140,(MAPDAT(I),I=163,NPRR2,4)
      PRINT 150,(MAPDAT(I),I=164,NPRR3,4)
C
C==========================================================================
C PACK DATA INTO MPDT(13) TO (52).
C BUFFEROUT PREFACE AND DATA.
C==========================================================================
C
  160 DO 170 IA=1,320
      ILS=3+3*((IA+1-4*((IA-1)/4))/2)
      IG=((IA-1)/8)+13
  170 MPDT(IG)=(SHIFT(MPDT(IG),ILS).OR.(MAPDAT(IA)))
C
  180 BUFFEROUT(50,1)(MPDT(1),MPDT(52))
      IF(UNIT(50)) 190,190,180
C
  190 RETURN
      END
C
C
```

```
C
C
C
C
C
      SUBROUTINE PRIN(IN,ISIGN,IFWPD,SINZMAX,IFF)
C
C==========================================================================
C TO PRINT SKY MAP.
C INPUTS ARE:
C    MAXFWPD=41X41 ARRAY OF MAXIMUM FWPD'S;
C    IMAX=41X41 ARRAY OF DOPPLER NO'S, EACH DOPPLER I AT THE COORDINATES
C         (IY,IX) OF FWPD(I,IY,IX).
C (SEE SUBROUTINES FOU AND MAPSEQ FOR MORE DETAILS.)
C==========================================================================
C
      DIMENSION IPR(94),IPRS(94)
      COMMON IB2160(2160),JSEQ(7),RJX(7,6),RJY(7,6)
+     ,IB216(216),IB216T(216),NANTNO(7),MAXFWPD(41,41),IMAX(41,41)
+     ,FWPD(41,41),PHI(64,7),FWMAX(64),FM(64,7),PI,RADIAN,KPRINT
+     ,FREQ(6),RANG(6),IGAIN(6),FWMAXX(6)
C
      DATA KBLANK1/1H /,KBLANK2/2H  /
C
C================ IPR,IPRA1,IPRA2, CONTAIN FORMAT STATEMENTS ==============
C
      DATA IPR/7H(1X,I2,,41*3HZ1,,6HI2,1X,,42*3HI2,,1H)/
      DATA IPRA1/3HA1,/,IPRA2/3HA2,/
C
C============================ PRINT MAP LEGEND ============================
C
      PRINT 150
C
      IF(ISIGN.EQ.3) GO TO 10
      DP1=DP4="          " $ DP3="RS        " $ DP2="NEG DOPPLE"
      IF(ISIGN.EQ.2) DP2="POS DOPPLE"
      GO TO 20
C
   10 DP1="NEG DOPP: " $ DP2="NUMERIC   "
      DP3="POS DOPP: " $ DP4="ALPHA     "
C
   20 IF(KPRINT.EQ.128.AND.IFWPD.EQ."TIME") GO TO 30
      PRINT*,"          FWPD    (6 DB INCREMENTS)"
      GO TO 40
C
   30 PRINT*,"                    TIME SEQUENCE"
C
   40 ZMAX=ASIN(SINZMAX)/RADIAN
      SCALE=(.707*RANG(IFF)*SINZMAX)/20.
      DFR=.12254902  $ IF(IN.EQ.7) DFR=DFR/2.
      DF2=DFR/2.  $ IF(IN.EQ.5.OR.IN.EQ.8) DF2=0.
```

```
      INVDFR=IFIX(1./DFR)
      INVDF2=0
      DP5="   "
      IF(DF2.EQ.0.) GO TO 50
      INVDF2=IFIX(1./DF2)
      DP5="1 /"
C
   50 PRINT 160, ZMAX,DP1,DP2,DP3,DP4,SCALE,DP5,INVDF2,INVDFR
C
C======================== PRINT MAP WITH BORDERS ========================
C
      PRINT 170
      PRINT 180
C
      DO 140 IX=1,41
      DO 60 IY=1,94
   60 IPRS(IY)=IPR(IY)
      DO 100 IY=1,41
      IF(KPRINT.EQ.128) GO TO 80
CCC     IF(IX.EQ.1.OR.IX.EQ.41.OR.IY.EQ.1.OR.IY.EQ.41)GO TO 70
      IF(MAXFWPD(IY,IX).NE.0.OR.IMAX(IY,IX).NE.0)GO TO 90
C
C=======================================================================
C PUT BLANKS INTO MAXFWPD,IMAX AND CHANGE CORRESPONDING
C       VARIABLE FORMAT (IPRS) TO HOLLERITH FORMAT
C=======================================================================
C
   70 MAXFWPD(IY,IX)=KBLANK1 $ IMAX(IY,IX)=KBLANK2
   80 IF(MAXFWPD(IY,IX).EQ.KBLANK1)IPRS(IY+1)=IPRA1
      IPRS(IY+43)=IPRA2
      GO TO 100
C
C=======================================================================
C EXPRESS MAXFWPD IN 6-DB INCREMENTS
C=======================================================================
C
   90 MAXFWPD(IY,IX)=(MAXFWPD(IY,IX)-3)/6
  100 CONTINUE
C
C=======================================================================
C FORMAT FOR BORDERS AND COMPASS DIRECTIONS
C=======================================================================
C
      IF(IX.NE.1) GO TO 110
      IPRS(86)=10HT22,*NORTH  $ IPRS(87)=2H*,
      IPRS(88)=10HT87,*NORTH  $ IPRS(89)=2H*)
  110 IF(IX.LT.19.OR.IX.GT.22) GO TO 120
      IPRS(86)=3HT3,  $ IPRS(88)=4HT45,
      IPRS(90)=4HT47, $ IPRS(92)=5HT130,
      IF(IX.EQ.19) IPRS(87)=IPRS(91)=4H*W*,
      IF(IX.EQ.19) IPRS(89)=IPRS(93)=4H*E*,
```

```
       IF(IX.EQ.20) IPRS(87)=IPRS(91)=4H*E*,
       IF(IX.EQ.20) IPRS(89)=IPRS(93)=4H*A*,
       IF(IX.EQ.21) IPRS(87)=IPRS(89)=IPRS(91)=IPRS(93)=4H*S*,
       IF(IX.EQ.22) IPRS(87)=IPRS(89)=IPRS(91)=IPRS(93)=4H*T*,
       IPRS(94)=1H)
   120 IF(IX.NE.41) GO TO 130
       IPRS(86)=10HT22,*SOUTH  $ IPRS(87)=2H*,
       IPRS(88)=10HT87,*SOUTH  $ IPRS(89)=2H*)
   130 IXI=IABS(21-IX)
       IF(IXI.LT.10) IPRS(1)=7H(I2,1X,
C
C=========================================================================
C PRINT LINE IX
C=========================================================================
C
       PRINT IPRS,
+       IXI,(MAXFWPD(IY,IX),IY=1,41),IXI,(IMAX(IY,IX),IY=1,41),IXI
C
   140 CONTINUE
       PRINT 180
       PRINT 190
C
C================================ FORMATS ================================
   150 FORMAT(//)
   160 FORMAT (11X*MAXIMUM ZENITH=*F5.1* DEG*,T72,A10,T82,A10,
+          T92,A10,T102,A10/11X,*SCALE:*,F5.1,* KM/DIVISION*,
+          T56,*LOWEST DOPP. FREQ.=  *,T77,A3,T80,I2,
+          T82,* HZ     DOPP.-FREQ. RESOLUTION=  1 /*,
+          T118,I2,T120,* HZ*)
   170 FORMAT (T4,*2*,T9,*1*,T14,*1*,T34,*1*,T39,*1*,T44,*2*/
+          3X,4(*0*,4X,*5*,4X),*0*,T48,*20*,T58,*15*,T68,*10*,T79,
+          *5*,T89,*0*,T99,*5*,T108,*10*,T118,*15*,T128,*20*)
   180 FORMAT(3X,41(1H!),3X,41(2H !))
   190 FORMAT (T4,*2*,T9,*1*,T14,*1*,T19,*5*,T24,*0*,T29,*5*,
+          T34,*1*,T39,*1*,T44,*2*,T48,*20*,T58,*15*,T68,*10*,T79,
+          *5*,T89,*0*,T99,*5*,T108,*10*,T118,*15*,T128,*20*/
+          T4,*0    5    0*,T34,*0    5    0*,8(/))
       RETURN
       END
```

A P P E N D I X   C

PROGRAM DRIFVEL

DRIFVEL (ULCAR)

```
      PROGRAM DRIFVEL(INPUT,OUTPUT,TAPE48,TAPE49,TAPE50,TAPE69,
+                    TAPE70,TAPE71,TAPE72)
C
C==========================================================================
C CALCULATION OF AVERAGE OR MEDIAN IONOSPHERIC-DRIFT VELOCITY VECTORS AND
C   SOURCE POSITIONS FROM SKYMAP DATA.
C
C INPUT=TAPE50, GENERATED BY SUBROUTINE MAPDATA OF PROGRAM SKYMAP.
C   MAPDATA OUTPUT IS STORED UNDER LABELS "YDDDHHN", WHERE Y=T,U,...FOR
C   YEARS 81,82,...; DDD=DAY; HH=STARTING HOUR; N=FREQUENCY NUMBER.
C   (E.G.: U026181=YEAR 82,DAY 26,HOUR 18,FREQ. NO. 1)
C   SEVERAL "SUB-FILES" (EACH SUB-FILE CONTAINING DATA AT ONE FREQUENCY
C     NUMBER) MAY HAVE BEEN MERGED INTO ONE FILE AND LABELLED IN CON-
C     SEQUENCE (E.G. U02618 IF ALL FREQ. NOS. ARE INCLUDED; OR U02618A
C     AND U02618B).  ALSO, DATA MAY BE ON PHYSICAL TAPES LABELLED MAPDAT.
C     SEE PROGRAM MAPDATA FOR FURTHER DETAILS.
C   (INPUT FILE MUST BE RENAMED TAPE50.)
C
C ONE SET OF BOTH NEGATIVE- AND POSITIVE-DOPPLER SOURCES (2 RECORDS)
C   CALCULATED BY PROGRAM SKYMAP COMPRISES ONE CASE.
C
C SEVERAL VELOCITY VECTORS ARE CALCULATED FROM THE DATA OF EACH CASE:
C   THE SOURCES ARE SORTED IN ORDER OF INCREASING OR DECREASING DENSITY
C   (I.E., FWPD; SEE PROGRAM SKYMAP) OR DOPPLER NUMBER (AS DETERMINED BY
C   "ISORT", INPUTTED AT BEGINNING OF THE RUN); THE FIRST VELOCITY
C   CALCULATION USES THE MINIMUM NUMBER OF SOURCES "MINSRC" (ALSO
C   INPUTTED AT BEGINNING), AND SUCCEEDING CALCULATIONS ADD ONE MORE
C   SOURCE. (SOME SOURCES ARE SKIPPED; SEE BELOW.) EACH VELOCITY IS
C   CALCULATED AS VX,VY,... AND STORED IN ARRAYS DBVX(NIVEL),DBVY(NIVEL),
C   ... WHERE NIVEL=NUMBER OF INDIVIDUAL VELOCITY CALCULATIONS.
C
C AN AVE OR MEDIAN VELOCITY IS CALCULATED FROM THE INDIVIDUAL VELOCITIES
C   FOR EACH CASE: CVX,CVY,...=CASEVX(KASE),CASEVY(KASE),...  AND IS
C   REFERRED TO AS CASE-NORM VELOCITY.
C
C AN AVERAGE NEG-DOPPLER SOURCE POSITION IS CALCULATED FOR EACH CASE:
C   CNX,CNY,...=CASENX(KASE),CASENY(KASE),...,
C AND AN AVERAGE POS-DOPPLER SOURCE POSITION: CPX,CPY,...=CASEPX(KASE),
C   CASEPY(KASE),...; THEY ARE REFERRED TO AS CASE-NORM POSITIONS.
C
C AN AVERAGE OR MEDIAN FOR GROUPS OF UP TO 6 CASES IS CALCULATED:
C     GVX,GVY,...=GROUP-NORM VELOCITIES, AND
C     GNX,GNY,...,GPX,GPY,...=GROUP-NORM NEG- AND POS-DOPP POSITIONS.
C
C THE DIGISONDE TAKES DRIFT MEASUREMENTS AT 3 OR 6 DIFFERENT FREQUENCIES
C   (AND RANGES) SIMULTANEOUSLY.  EACH MEASUREMENT IS LABELLED BY A
C   FREQUENCY NUMBER (1-3 OR 1-6).  AN AVE OR MEDIAN OF THE GROUP-NORM
C   VELOCITIES FROM ALL 3 OR 6 SIMULTANEOUS MEASUREMENTS IS CALCULATED
C   AND IS REFERRED TO AS ALL-FREQ VELOCITY.
C==========================================================================
C
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DRIFVEL (ULCAR)

```
C
       COMMON MPDT(52),MAPDAT(4,160)
       COMMON/IGA/NN(35)
       DIMENSION XX(160),YY(160),ZZ(160),ONE(160)
       DIMENSION DBVX(60),DBVY(60),DBVZ(60),DBESQ(60)
       DIMENSION CASENX(16),CASENY(16),CASENZ(16),CASENS(16)
       DIMENSION CASEPX(16),CASEPY(16),CASEPZ(16),CASEPS(16)
       DIMENSION CASEVX(16),CASEVY(16),CASEVZ(16),CASEESQ(16),CASESIG(16)
       DIMENSION MTEMP(4),KPTEST(15),KVW(3),KPT(3),IDT(5),NTAPE(5)
       DIMENSION IREAD(10)
       DATA NN/"1","2","3","4","5","6","7","8","9","A","B","C","D","E",
+       "F","G","H","I","J","K","L","M","N","O","P","Q","R","S","T","U",
+       "V","W","X","Y","Z"/
       DATA KPTEST/1,2,4,8,16,24,34,36,40,48,66,68,72,80,88/
       DATA KVW/"(22X,","*WEIGHT: *","R6,A5)"/
       DATA IDT/"(6X,*START","ING DATE A","ND TIME:*,","A9,","A1)"/
C
       REWIND 48
       REWIND 49
       REWIND 50  $ REWIND 69
       REWIND 70  $ REWIND 71  $ REWIND 72
C
       EOF50=0.
       IFLAG=IFHEAD=IFOUND=0
       DO 10 I=1,160
    10 ONE(I)=1.
C
C==================== I N P U T S   R E Q U I R E D ====================
C    K P R I N T :
C      1=SUMMARY OF CASE-NORM AND GROUP-NORM POSITION AND VELOCITY VECTORS
C      2=LIST OF INDIVIDUAL VELOCITY CALCULATIONS
C      4=LIST OF CASE-NORM VELOCITIES
C      8=LIST OF GROUP-NORM VELOCITIES
C      16=LIST OF ALL-FREQ VELOCITIES
C           (KPRINT 16 REQUIRES SEVERAL RUNS, ONE AT EACH FREQUENCY NUMBER.
C            AFTER EACH RUN, RENAME TAPE48=TAPE49 (SEE SUBROUTINE ALLFREQ).
C            AFTER LAST RUN, LIST TAPE49 FOR REQUIRED OUTPUT.)
C      32+(2,4,8 OR 16)=LIST AND POLAR MAP.
C      64+(2,4,8,16)=GRAPH, NO LIST.
C            FOR KPRINT 2, AZIM-SPEED GRAPH IS WRITTEN ON TAPE69,
C                          RMS ERROR GRAPH IS WRITTEN ON TAPE70.
C            FOR KPRINT 4,8, AZIM-SIGMA-SPEED GRAPH IS WRITTEN  ON TAPE69.
C            FOR KPRINT 16, AZIM-SIGMA-SPEED GRAPH IS WRITTEN ON TAPE71.
C                     ALSO,IF NO. OF FREQUENCIES IS .LE. 3, THE GROUP-NORM
C                    VELOCITIES OF ALL 3 FREQ. NOS. AND THE ALL-FREQ
C                    VEL. ARE WRITTEN ON ONE AZIM-SPEED GRAPH ON TAPE72.
C    NOTE: --32 OR 64 CANNOT BE USED ALONE BUT MUST BE ADDED TO 2,4,8 OR 16
C          --IF WANT BOTH GROUP-NORM AND ALL-FREQ OUTPUTS, SET KPRINT=8+16
C           FOR LIST ONLY, 8+16+64 FOR GRAPH.  IF WANT LIST AND POLAR
C           MAP, MUST USE SEPARATE RUNS: 8+32 OR 16+32.
C
```

```
C  D A T E , T I M E , F R E Q U E N C Y   N U M B E R :
C    OR, TO START AT BEGINNING OF INPUT DATA, INPUT ZERO
C        UNLESS KPRINT INCLUDES 16 AND/OR 64;
C    E.G.: 82026,185910,2; OR: 0
C    IF IDATE=0, ALL RECORDS FROM 1ST TO LAST ARE CALCULATED.
C    IF IDATE NOT ZERO, STARTS AT FREQ. NO., DATE, TIME INPUTTED, THEN
C      CONTINUES UNTIL FREQ. NO. CHANGES.
C
C  V E L - W E I G H T = VELOCITY-CALCULATION WEIGHT FACTOR
C       (USED IN LEAST SQUARE ERROR CALCULATIOM OF INDIVIDUAL VELOCITIES)
C     1=LOG DENSITY
C     2=LOG DENSITY*DOPPLER NO.
C     3=LINEAR DENSITY
C     4=LINEAR DENSITY*DOPPLER NO.
C     5=DOPPLER NO.
C     6=NO WEIGHTING
C
C  S O R T I N G   O R D E R :
C     "DECF": SOURCES ARE SORTED IN ORDER OF DECREASING FWPD
C             BEFORE CALCULATING THE SEVERAL INDIVIDUAL VELOCITIES,
C             THE FIRST CALCULATION USING "MINSRC" SOURCES, EACH
C             SUCCEEDING CALCULATIOM ADDING ONE MORE SOURCE.
C     "INCF": SOURCES SORTED IN ORDER OF INCREASING FWPD.
C     "DECD": SOURCES SORTED IN ORDER OF DECREASING DOPPLER NUMBER.
C     "INCD": SOURCES SORTED IN ORDER OF INCREASING DOPPLER NUMBER.
C
C  M I N - S O U R C E S = MINIMUM NUMBER OF SOURCES TO BE USED FOR
C     CALCULATING A VELOCITY (LEAST SQUARE ERROR CALCULATION)
C
C  M I N - D O P P : SOURCES WITH DOPPLER NUMBER LESS THAN
C     MIN-DOPP ARE BYPASSED IN VELOCITY CALCULATION
C
C  M A X - D O P P : SOURCES WITH DOPPLER NUMBER GREATER THAN
C     MAX-DOPP ARE BYPASSED IN VELOCITY CALCULATION
C
C  M A X - E S Q : CALCULATIONS WITH ESQ .GT. MAX-ESQ ARE BY-PASSED
C
C  M A X - V Z : CALCULATIONS WITH ABS(VZ) .GT.MAX-VZ ARE BY-PASSED
C
C NOTE: FOR MIN-DOPP,MAX-DOPP,MAX-ESQ,MAX-VZ, ENTER 0 (ZERO) IF WANT ALL
C
C  V E L - C H O I C E :
C     "MED": CASE-NORM VELOCITY=MEDIAN OF THE DBVX,... OF ONE CASE;
C            GROUP-NORM VEL=MEDIAN OF THE CASE-NORM VELOCITIES;
C            ALL-FREQ VELOCITY=MEDIAN OF THE GROUP-NORM VELOCITIES FROM
C                              ALL FREQUENCIES.
C     "WMED": WEIGHTED MEDIAN INSTEAD OF MEDIAN, EXCEPT ALL-FREQ
C             VELOCITY=NON-WEIGHTED MEDIAN.
C     "AVE"IJK: AVERAGE INSTEAD OF MEDIAN;
C               I,J,K=1 OR 2, AND INDICATE WHETHER CASE-NORM, GROUP-NORM
C               AND ALL-FREQ RESPECTIVELY ARE TO BE DETERMINED BY
```

```
C                    AVERAGING ONCE OR TWICE (IF TWICE, THE SECOND AVE'G
C                    BY-PASSES VELOCITIES OUTSIDE THE STANDARD DEVIATION
C                    OF THE FIRST AVERAGE)
C        "QUOTED" SYMBOLS ARE TO BE INPUTTED AS IS, BUT WITHOUT
C          QUOTE SIGNS  E.G. AVE211
C=========================================================================
C
         PRINT 20
      20 FORMAT(" KPRINT"/" DATE,TIME,FREQ-NO."/" VEL-WEIGHT,MIN-SOURCES"/
+              " MIN-DOPP,MAX-DOPP,MAX-ESQ,MAX-VZ?")
C
         READ*,KPRINT,IDATE
C
         DO 30 K=1,15
      30 IF(KPRINT.EQ.KPTEST(K)) GO TO 40
         PRINT 110
         PRINT*," INVALID KPRINT."  $ STOP
C
      40 IF((IDATE.NE.0).OR.((KPRINT.AND.80).EQ.0)) GO TO 50
         PRINT 110
         PRINT*," FOR THIS KPRINT, ENTER DATE,START TIME, FREQ. NO."
         STOP
C
      50 KD=0 $ KPT(1)=KPT(2)=KPT(3)=" "
         IF((KPRINT.AND.1).EQ.0) GO TO 55
         KD=1  $ KPT(1)=1
      55 DO 60 KB=1,6
         KC=2**KB
         IF((KPRINT.AND.KC).EQ.0) GO TO 60
         KD=KD+1  $ KPT(KD)=KC
      60 CONTINUE
C
         IF(IDATE.EQ.0) GO TO 70
         READ*,ITIME,IFREQNO
C
      70 READ*,IWT,MINSRC,MINDOPP,MAXDOPP,MAXESQ,MAXVZ
         GO TO (71,72,73,74,75,76) IWT
      71 MWT1="    LOG DE" $MWT2="NSITY"  $ GO TO 80
      72 MWT1=" LOG DENS." $MWT2="*DOPP. NO." $ KVW(3)="R9,A10)" $ GO TO 80
      73 MWT1="  LINEAR A" $MWT2="MPLITUDE" $ KVW(3)="R8,A8)" $ GO TO 80
      74 MWT1="LIN. DENS." $MWT2="*DOPP. NO." $ KVW(3)="2A10)" $ GO TO 80
      75 MWT1="   DOPPLER" $MWT2=" NUMBER" $ KVW(3)="R7,A7)" $ GO TO 80
      76 MWT1="    NO WEI" $MWT2="GHTING" $ KVW(3)="R6,A6)"
C
      80 PRINT*," SORTING ORDER?"
         READ 84,ISORT
      84 FORMAT(A4)
C
         IF((KPRINT.AND.29).EQ.0) GO TO 100
         PRINT*,"VELOCITY CHOICE?"
         READ 85,ICV
```

```
 85 FORMAT(A6)
    IF(ICV.EQ."MED".OR.ICV.EQ."WMED") GO TO 95
    DECODE(6,90,ICV)ICVTEMP,ICV1,ICV2,ICV3
 90 FORMAT(A3,3I1)
    ICV=ICVTEMP
 95 IF(ICV.EQ."MED") ICV=1
    IF(ICV.EQ."WMED") ICV=2
    IF(ICV.EQ."AVE") ICV=3
C
100 IDT1=" ALL DATA "  $ IDT2=" "
    IF(IDATE.EQ.0) GO TO 105
    IDT1=IDATE  $ IDT2=ITIME  $ IDT(4)="I6,"  $ IDT(5)="1X,I6.6)"
105 CONTINUE
    MINDO=MINDOPP  $ IF(MINDO.EQ.0) MINDO="ALL"
    MAXDO=MAXDOPP  $ IF(MAXDO.EQ.0) MAXDO="ALL"
    MAXES=MAXESQ  $ IF(MAXES.EQ.0) MAXES="ALL"
    MAXV=MAXVZ  $ IF(MAXV.EQ.0) MAXV="ALL"
    IF(ISORT.EQ."DECF") ISORT=1
    IF(ISORT.EQ."INCF") ISORT=2
    IF(ISORT.EQ."DECD") ISORT=3
    IF(ISORT.EQ."INCD") ISORT=4
C
C===== PRINT INPUT PARAMETERS CHOSEN, ON OUTPUT AND ON TAPES TO BE USED
C
C
    PRINT 110
110 FORMAT(////)
    PRINT*,"                         KPRINT: ",KPT
    PRINT IDT,IDT1,IDT2
    IF(IDATE.NE.0) PRINT*,"          FREQUENCY NUMBER: ",IFREQNO
    PRINT 111
111 FORMAT(/13X,"INDIVIDUAL VELOCITY CALCULATION")
    PRINT KVW,MWT1,MWT2
    GO TO (112,113,114,115) ISORT
112 PRINT*,"    ORDER OF SORTED SOURCES: DECREASING FWPD" $ GO TO 116
113 PRINT*,"    ORDER OF SORTED SOURCES: INCREASING FWPD" $ GO TO 116
114 PRINT*,"    ORDER OF SORTED SOURCES: DECREASING ABS(DOPPLER NUMBER)"
    GO TO 116
115 PRINT*,"    ORDER OF SORTED SOURCES: INCREASING ABS(DOPPLER NUMBER)"
116 PRINT*,"     MINIMUM NO. OF SOURCES: ",MINSRC
    PRINT*,"     MINIMUM DOPPLER NUMBER: ",MINDO
    PRINT*,"     MAXIMUM DOPPLER NUMBER: ",MAXDO
    PRINT*," MAXIMUM LEAST SQUARE ERROR: ",MAXES
    PRINT*,"            MAXIMUM ABS(VZ): ",MAXV
C
    DO 117 N=1,5
117 NTAPE(N)=0
C
    IF((KPRINT.AND.80).EQ.0) GO TO 135
    IF((KPRINT.AND.14).NE.0) NTAPE(1)=69
    IF(KPRINT.EQ.66) NTAPE(2)=70
```

DRIFVEL (ULCAR)

```
      IF((KPRINT.AND.16).EQ.0) GO TO 125
      NTAPE(3)=49
  118 FORMAT(10A10)
  119 READ(48,118)(IREAD(I),I=1,10)
      IF(EOF(48).EQ.1) GO TO 121
      WRITE(49,118)(IREAD(I),I=1,10)
      IF(IREAD(6).NE."OUP-NORM V") GO TO 119
      DO 120 I=1,9
  120 BACKSPACE 49
  121 IF((KPRINT.AND.64).EQ.0) GO TO 125
      NTAPE(4)=71
      NTAPE(5)=72
  122 READ(71,118)(IREAD(I),I=1,10)
      IF(EOF(71).EQ.1) GO TO 125
      IF(IREAD(6).NE." GRAPH OF ") GO TO 122
  123 READ(72,118)(IREAD(I),I=1,10)
      IF(EOF(72).EQ.1) GO TO 125
      IF(IREAD(6).NE."OF GROUP-N") GO TO 123
      DO 124 I=1,9
      BACKSPACE 71
  124 BACKSPACE 72
C
  125 DO 131 N=1,5
      IF(NTAPE(N).EQ.0) GO TO 131
      NTP=NTAPE(N)
      PRINT(NTP,110)
      PRINT(NTP,*)"                            KPRINT: ",KPT
      PRINT(NTP,IDT)IDT1,IDT2
      IF(IDATE.NE.0) PRINT(NTP,*)"          FREQUENCY NUMBER: ",
+                    IFREQNO
      PRINT(NTP,111)
      PRINT(NTP,KVW)MWT1,MWT2
      GO TO (126,127,128,129) ISORT
  126 PRINT(NTP,*)"   ORDER OF SORTED SOURCES: DECREASING FWPD" $GOTO130
  127 PRINT(NTP,*)"   ORDER OF SORTED SOURCES: INCREASING FWPD" $GOTO130
  128 PRINT(NTP,*)"   ORDER OF SORTED SOURCES: DECREASING DOPPLER NUMBER"
      GO TO 130
  129 PRINT(NTP,*)"   ORDER OF SORTED SOURCES: INCREASING DOPPLER NUMBER"
  130 PRINT(NTP,*)"    MINIMUM NO. OF SOURCES: ",MINSRC
      PRINT(NTP,*)"    MINIMUM DOPPLER NUMBER: ",MINDO
      PRINT(NTP,*)"    MAXIMUM DOPPLER NUMBER: ",MAXDO
      PRINT(NTP,*)" MAXIMUM LEAST SQUARE ERROR: ",MAXES
      PRINT(NTP,*)"           MAXIMUM ABS(VZ): ",MAXV
  131 CONTINUE
C
  135 IF((KPRINT.AND.29).EQ.0) GO TO 235
C
  140 FORMAT(/20X,"CHOICE OF VELOCITIES")
  145 FORMAT(8X,"CASE-NORM VELOCITIES: MEDIAN OF THE INDIVIDUAL",
+           " VELOCITIES")
  150 FORMAT(7X,"GROUP-NORM VELOCITIES: MEDIAN OF THE ",
```

```
                 "CASE-NORM VELOCITIES")
      155 FORMAT(9X,"ALL-FREQ VELOCITIES: MEDIAN OF THE GROUP-NORM ",
                 "VELOCITIES FOR ALL FREQUENCY NUMBERS")
      160 FORMAT(8X,"CASE-NORM VELOCITIES: WEIGHTED MEDIAN OF THE"
                 " INDIVIDUAL VELOCITIES")
      165 FORMAT(7X,"GROUP-NORM VELOCITIES: WEIGHTED MEDIAN OF THE ",
                 "CASE-NORM VELOCITIES")
      170 FORMAT(9X,"ALL-FREQ VELOCITIES: MEDIAN OF THE GROUP-NORM ",
                 "VELOCITIES FOR ALL FREQUENCY NUMBERS")
      175 FORMAT(8X,"CASE-NORM VELOCITIES: WEIGHTED AVE OF INDIVIDUAL ",
                 "VELOCITIES CALCULATED ",A5)
      180 FORMAT(7X,"GROUP-NORM VELOCITIES: ",
                 "WEIGHTED AVE OF THE CASE-NORM VELOCITIES CALCULATED ",A5)
      185 FORMAT(9X,"ALL-FREQ VELOCITIES: AVERAGE OF THE GROUP-NORM ",
                 "VELOCITIES FOR ALL FREQUENCY NUMBERS CALCULATED ",A5)
          PRINT 140
          GO TO (190,195,200) ICV
      190 PRINT 145
          IF((KPRINT.AND.25).NE.0) PRINT 150
          IF((KPRINT.AND.16).NE.0) PRINT 155
          GO TO 205
      195 PRINT 160
          IF((KPRINT.AND.25).NE.0) PRINT 165
          IF((KPRINT.AND.16).NE.0) PRINT 170
          GO TO 205
      200 IF(ICV1.EQ.1) ICVN1="ONCE"  $ IF(ICV1.EQ.2) ICVN1="TWICE"
          IF(ICV2.EQ.1) ICVN2="ONCE"  $ IF(ICV2.EQ.2) ICVN2="TWICE"
          IF(ICV3.EQ.1) ICVN3="ONCE"  $ IF(ICV3.EQ.2) ICVN3="TWICE"
          PRINT 175,ICVN1
          IF((KPRINT.AND.25).NE.0) PRINT 180,ICVN2
          IF((KPRINT.AND.16).NE.0) PRINT 185,ICVN3
      205 IF((KPRINT.AND.80).EQ.0) GO TO 235
C
          DO 230 N=1,5
          IF(NTAPE(N).EQ.0) GO TO 230
          NTP=NTAPE(N)
          PRINT(NTP,140)
          GO TO (210,215,220) ICV
      210 PRINT(NTP,145)
          IF((KPRINT.AND.25).NE.0) PRINT(NTP,150)
          IF((KPRINT.AND.16).NE.0) PRINT(NTP,155)
          GO TO 225
      215 PRINT(NTP,160)
          IF((KPRINT.AND.25).NE.0) PRINT(NTP,165)
          IF((KPRINT.AND.16).NE.0) PRINT(NTP,170)
          GO TO 225
      220 PRINT(NTP,175)ICVN1
          IF((KPRINT.AND.25).NE.0) PRINT(NTP,180)ICVN2
          IF((KPRINT.AND.16).NE.0) PRINT(NTP,185)ICVN3
      225 PRINT(NTP,110)
      230 CONTINUE
```

```
C
  235 PRINT 110
C
      IF((KPRINT.AND.64).EQ.0) GO TO 330
C
C====================== G R A P H   H E A D I N G ======================
C
  273 FORMAT(///44X,"GRAPH OF INDIVIDUAL VELOCITY CALCULATIONS")
  276 FORMAT(///50X,"GRAPH OF CASE-NORM VELOCITIES")
  279 FORMAT(///50X,"GRAPH OF GROUP-NORM VELOCITIES")
  282 FORMAT(///51X,"GRAPH OF ALL-FREQ VELOCITIES")
  283 FORMAT(///44X,"GRAPH OF GROUP-NORM VELOCITIES FOR ALL RANGES")
  285 FORMAT(/1X,"DATE:",I6/" AST: HOUR,MINUTE")
  288 FORMAT(1X,"MINUTE ROUNDED OUT TO NEAREST 2.5 MINUTE"/
+          3X,"(00,02,05,07,...=0, 2.5, 5, 7.5,... MIN.)")
  291 FORMAT(1X,"# = NUMBER OF SOURCES")
  294 FORMAT(1X,"# = NO. OF INDIVIDUAL VELOCITIES/CASE")
  297 FORMAT(1X,"# = NO. OF CASE-NORM VELOCITIES/GROUP")
  300 FORMAT(1X,"# = NO. OF FREQ. WITH NON-ZERO GROUP-NORM VELOCITY")
CCC   301 FORMAT(1X,"GROUP-NORM AZIM AND VH FOR FREQ. #1 = 1"
CCC+            /1X,"GROUP-NORM AZIM AND VH FOR FREQ. #2 = 2"
CCC+            /1X,"GROUP-NORM AZIM AND VH FOR FREQ. #3 = 4"
CCC+            /1X,"                 ALL-FREQ AZIM AND VH = 8")
  301 FORMAT(1X,"GRAPH SYMBOLS REPRESENT RANGE:"
+        /3X,"RANGE(KM)=(200+10X), WHERE X=0,1,2,...,9,A,B,...")
  302 FORMAT(" FREQ (100KHZ UNITS) = (MAX FREQ) - (MIN FREQ)"
+          /" RANGE (KM) = (MAX RANGE) - (MIN RANGE)")
  303 FORMAT(" FREQUENCY IN 100KHZ UNITS; RANGE IN KM")
  304 FORMAT(/1X,"SEQ",3X,"FREQ",5X,"#",35X,"AZIMUTH",50X,"SPEED"/
+          4X,"AST",3X,"RANGE",36X,"(DEGREES)",40X,
+          "VH=#  +VZ=+  -VZ=-  (M/S)"/
+          19X,I1,3(4X,I2),1X,9(3X,I3),3X,I1,3X,I2,1X,5(2X,I3)/
+          17X,"NORTH",13("."),"EAST",14("."),"SOUTH",13("."),
+          "WEST",14("."),"NORTH",2X,31("."),"X100")
 1304 FORMAT(/1X,"SEQ",3X,"FREQ",5X,"#",35X,"AZIMUTH",50X,"SPEED"/
+          4X,"AST",3X,"RANGE",36X,"(DEGREES)",40X,
+          "VH=#  +VZ=+  -VZ=-  (M/S)"/
+          19X,I1,3(4X,I2),1X,9(3X,I3),3X,I1,3X,I2,1X,5(2X,I3)/
+          17X,"NORTH",13("."),"EAST",14("."),"SOUTH",13("."),
+          "WEST",14("."),"NORTH",2X,31("."))
CCC   305 FORMAT(/49X,"SIGMA=+  (M/S)"/
CCC+         19X,I1,8(4X,I2),1X,4(3X,I3),16X,"SPEED"/
CCC+         1X,"SEQ",3X,"FREQ",5X,"#",30X,"AZIMUTH=# (DEGREES)",34X,
CCC+         "VH=#  +VZ=+  -VZ=-  (M/S)"/
CCC+         4X,"AST",3X,"RANGE",4X,I1,3(4X,I2),1X,9(3X,I3),3X,I1,3X,I2,1X,
CCC+         5(2X,I3)/17X,"NORTH",13("."),"EAST",14("."),"SOUTH",13("."),
CCC+         "WEST",14("."),"NORTH",2X,31("."),"X100")
  305 FORMAT(/109X,"SPEED"/
+        1X,"SEQ",3X,"FREQ",5X,"#",17X,"SIGMA=+ (M/S)",13X,"AZIMUTH",
+        "=# (DEGREES)",21X,"VH=#  +VZ=+  -VZ=-  (M/S)"/
+        4X,"AST",3X,"RANGE",4X,I1,3(4X,I2),1X,9(3X,I3),3X,I1,3X,I2,1X,
```

```
+         5(2X,I3)/17X,"NORTH",13("."),"EAST",14("."),"SOUTH",13("."),
+         "WEST",14("."),"NORTH",2X,31("."),"X100")
    308 FORMAT(/1X,"SEQ",3X,"FWPD",45X,"ROOT-MEAN-SQUARE ERROR ",
+              "(M/S)"/4X,"AST",3X,"DOPP")
    311 FORMAT(/3X,"SEQ  AST",45X,"ROOT-MEAN-SQUARE ERROR (M/S)"/)
    314 FORMAT(15X,I1,4X,I1,18(3X,I2),1X,3(2X,I3)/15X,111("."),"GT100")
C
        IF((KPRINT.AND.2).EQ.0) GO TO 317
        WRITE(69,273) $WRITE(70,273) $WRITE(69,285)IDATE $WRITE(70,285)IDATE
        WRITE(69,291)  $ WRITE(69,303)
        WRITE(69,304)((I-1),I=1,361,30),((I-1),I=1,301,50)
        WRITE(70,308)  $ WRITE(70,314)((I-1),I=1,111,5)
C
    317 IF((KPRINT.AND.4).EQ.0) GO TO 320
        WRITE(69,276) $WRITE(69,285)IDATE
        WRITE(69,294)  $ WRITE(69,303)
CCC       WRITE(69,305)((I-1),I=1,145,12),((I-1),I=1,361,30),
CCC+                    ((I-1),I=1,301,50)
        WRITE(69,305)((I-1),I=1,361,30),((I-1),I=1,301,50)
CCC       WRITE(70,276) $WRITE(70,285)IDATE
CCC       WRITE(70,311)  $ WRITE(70,314)((I-1),I=1,111,5)
C
    320 IF((KPRINT.AND.8).EQ.0) GO TO 323
        WRITE(69,279) $WRITE(69,285)IDATE
        WRITE(69,288)  $ WRITE(69,297)  $ WRITE(69,303)
CCC       WRITE(69,305)((I-1),I=1,145,12),((I-1),I=1,361,30),
CCC+                    ((I-1),I=1,301,50)
        WRITE(69,305)((I-1),I=1,361,30),((I-1),I=1,301,50)
CCC       WRITE(70,279) $WRITE(70,285)IDATE $WRITE(70,288)
CCC       WRITE(70,311)  $ WRITE(70,314)((I-1),I=1,111,5)
C
    323 IF((KPRINT.AND.16).EQ.0) GO TO 330
        WRITE(71,282)
        WRITE(71,285)IDATE
        WRITE(71,288)  $ WRITE(71,300)  $ WRITE(71,302)
CCC       WRITE(71,305)((I-1),I=1,145,12),((I-1),I=1,361,30),
CCC+                    ((I-1),I=1,301,50)
        WRITE(71,305)((I-1),I=1,361,30),((I-1),I=1,301,50)
        WRITE(72,283)  $ WRITE(72,285)IDATE  $ WRITE(72,288)
CCC       WRITE(72,311)  $ WRITE(72,314)((I-1),I=1,111,5)
        WRITE(72,300)  $ WRITE(72,301)  $ WRITE(72,302)
        WRITE(72,1304)((I-1),I=1,361,30),((I-1),I=1,301,50)
CG
CG=========================================================================
CG THERE ARE 3 PRINCIPAL BLOCKS IN THE MAIN PROGRAM:
CG   1: INDIVIDUAL-VELOCITY-CALCULATION LOOP,  WHICH IS INSIDE THE
CG   2: CASE LOOP,  WHICH IS INSIDE THE
CG   3: GROUP LOOP.
CG THE "COMMENT INDICATORS" (COLUMN 6) IDENTIFY THE BLOCKS:
CG   "CV" FOR INDIVIDUAL VELOCITY CALCULATIONS;
CG   "CK" FOR CASE CALCULATIONS;
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CG   "CG" FOR GROUP CALCULATIONS.
CG ALL-FREQ CALCULATIONS ARE DONE IN SUBROUTINE ALLFREQ.
CG========================  G R O U P  L O O P  ========================
CG INDEX NGRP=1 TO 35 COUNTS GROUPS,
CG   AND NN=1,2,...,9,A,...,Z IDENTIFIES GROUPS ON PRINTOUTS.
CG======================================================================
CG
    330 NGVEL=NFVEL=0
        DO 1420 NGRP=1,35
        IGSEQ=NN(NGRP)
C
    340 NFCNTOT=NFCPTOT=NKVEL=NGIVEL=0
CG
        DO 350 I=1,16
        CASENX(I)=CASENY(I)=CASENZ(I)=CASENS(I)=0
        CASEPX(I)=CASEPY(I)=CASEPZ(I)=CASEPS(I)=0
    350 CASEVX(I)=CASEVY(I)=CASEVZ(I)=CASEESQ(I)=CASESIG(I)=0
CG
CK
CK========================  C A S E  L O O P  ========================
CK INDEX KASE=1 TO 6 COUNTS CASES PER GROUP.
CK   (KASE CAN BE INCREASED FROM 1,6 TO 1,15 SINCE HEXADECIMAL DIGITS
CK   (1 TO F) ARE USED TO IDENTIFY CASES ON PRINTOUTS.)
CK
CK ARRAY MPDT CONTAINS ONE RECORD FROM TAPE 50:
CK     MPDT(1)=STATION IDENTIFICATION
CK         (2)=DATE
CK         (3)=TIME
CK         (6)=RWTT
CK         (7)=QNXZ
CK         (9)=FREQ. NO.
CK         (10)=FREQUENCY
CK         (11)=RANGE
CK         (12)=GAIN
CK         (4),(5),(8)=PREFACE PARAMETERS NOT USED HERE
CK         (13) TO (52)=PACKED SKYMAP DATA (IY,IX,FWPD,DOPPLER NO.--NEGATIVE
CK                      AND POSITIVE DOPPLERS IN SUCCESSIVE RECORDS)
CK
CK ARRAY MAPDAT CONTAINS UNPACKED SKYMAP DATA FOR A COMPLETE CASE
CK   (BOTH NEGATIVE AND POSITIVE DOPPLERS).
CK======================================================================
CK
        DO 1170 KASE=1,6
        NC=NR=0
        NICN=NFCN=NICP=NFCP=NICV=NFCV=0
CK
        IF(((KPRINT.AND.2).NE.0).AND.((KPRINT.AND.64).EQ.0)) PRINT*," "
CK
        DO 360 NRO=1,4
        DO 360 NCO=1,160
    360 MAPDAT(NRO,NCO)=0
```

```
CK
      370 DO 380 I=1,52
      380 MPDT(I)=MPDT(I).AND.0
CK
CK=====BUFFERIN SKYMAP DATA FROM TAPE50
CK
      390 BUFFERIN(50,1)(MPDT(1),MPDT(52))
          IF(UNIT(50)) 420,400,390
C
C===== IF NOT END OF TAPE50, GO TO 420
C
      400 EOF50=1.
          IF(IFOUND.EQ.1) GO TO 405
          PRINT*," NO DATA FOUND TO SATISFY THE INPUT PARAMETERS."
          PRINT*,"  "  $ PRINT*,"  "  $ STOP
C
C===== IF VELOCITIES HAVE BEEN CALCULATED FOR AT LEAST ONE CASE IN
C         THIS GROUP, EXIT CASE LOOP; IF NOT, PRINT INFO ABOUT WHERE
C         OUTPUTS ARE TO BE FOUND, THEN STOP.
C
      405 IF(KASE.NE.1) GO TO 1175
          PRINT 407
      407 FORMAT(///)
          IF(LASFREQ.EQ.0.AND.(KPRINT.AND.16).NE.0) PRINT 410
      410 FORMAT("  LIST OF GROUP-NORM VELOCITIES FOR THE FREQUENCY ",
+         "NUMBER(S) ALREADY RUN IS ON TAPE 49."/
+         "  PLEASE RENAME TAPE48=TAPE49, TO USE THE OUTPUT ",
+         "OF THIS RUN (TAPE49) AS INPUT (TAPE48) OF THE NEXT RUN."/
+         "  BE SURE THAT FOR THE NEXT RUN, TAPE50 HAS MAP DATA",
+         " OF A DIFFERENT FREQUENCY NUMBER.")
          IF(LASFREQ.EQ.1.AND.(KPRINT.AND.16).NE.0) PRINT 415
      415 FORMAT("  LIST OF GROUP-NORM-VELOCITIES-FOR-ALL-",
+            "FREQUENCY-NUMBERS AND OF ALL-FREQ-VELOCITIES IS ON TAPE 49.")
          IF((KPRINT.AND.64).EQ.0) GO TO 419
          IF((KPRINT.AND.2).NE.0) PRINT 416,NFREQ
      416 FORMAT("  AZIM-SPEED GRAPH OF INDIVIDUAL VELOCITIES FOR FREQ. NO. ",
+         I1," IS ON TAPE69, AND RMS-ERROR GRAPH IS ON TAPE70.")
          IF((KPRINT.AND.4).NE.0)
+            PRINT*," GRAPH OF CASE-NORM VELOCITIES FOR FREQ. NO. ",
+                   NFREQ," IS ON TAPE69."
          IF((KPRINT.AND.8).NE.0)
+            PRINT*," GRAPH OF GROUP-NORM VELOCITIES FOR FREQ. NO. ",
+                   NFREQ," IS ON TAPE69."
          IF(((KPRINT.AND.16).NE.0).AND.(LASFREQ.EQ.1))
+            PRINT*," GRAPH OF ALL-FREQ VELOCITIES IS ON TAPE 71."
          IF(((KPRINT.AND.16).NE.0).AND.(LASFREQ.EQ.1).AND.(NUMFREQ.LE.3))
+            PRINT 414
      414 FORMAT("  GRAPH OF GROUP-NORM VELOCITIES FOR ALL ",
+         "RANGES IS ON TAPE 72.")
          IF(((KPRINT.AND.16).NE.0).AND.(LASFREQ.NE.1).AND.(NUMFREQ.GT.3))
+            PRINT 417
```

```
  417 FORMAT("  IF SAVING RESULTS TO DO NEXT RUN LATER, SAVE TAPE48",
+     " AND TAPE71; GET BOTH TAPES, AS WELL AS TAPE50=(MAP DATA),",
+     /"     FOR THE NEXT RUN.")
      IF(((KPRINT.AND.16).NE.0).AND.(LASFREQ.NE.1).AND.(NUMFREQ.LE.3))
+        PRINT 418
  418 FORMAT("  IF SAVING RESULTS TO DO NEXT RUN LATER, SAVE TAPES 48,",
+     " 71, AND 72; GET THE 3 TAPES, AS WELL AS TAPE50=(MAP DATA),",
+     /"     FOR THE NEXT RUN.")
  419 PRINT 407
      STOP
CK
CK=====CHECK IF WANT THIS SKYMAP DATA
CK
  420 IF(IDATE.EQ.0) GO TO 440
      IF(IFLAG.NE.0) GO TO 430
      IF(MPDT(9).NE.IFREQNO) GO TO 370
      IF(MPDT(2).NE.IDATE) GO TO 370
      IF(MPDT(3).NE.ITIME) GO TO 370
      IFLAG=1
CK
  430 IF(MPDT(9).NE.IFREQNO) GO TO 400
CK
  440 ISIGN=MPDT(4).AND.3
      IFOUND=1
CK
CK=====UNPACK DATA
CK     IENDNEG=INDEX OF LAST NEG-DOPP SOURCE
CK            =NUMBER OF NEG-DOPP SOURCES
CK     IENDPOS=INDEX OF LAST POS-DOPP SOURCE
CK            =TOTAL NUMBER OF SOURCES
CK
      CALL UNPACK(ISIGN,NR,NC)
      IF(ISIGN.EQ.1) IENDNEG=NC
      IF(ISIGN.EQ.2) IENDPOS=NC
      IF(ISIGN.EQ.1) GO TO 370
CK
CK=============  C H E C K   F O R   E N D   O F   G R O U P  ===============
CK IF THIS CASE IS NOT THE FIRST ONE IN THE GROUP, CHECK IF IT SHOULD BE IN
CK   THIS GROUP;  IF NOT, BACKSPACE TAPE50 (2 RECORDS) SO THAT IT WILL BE
CK   BUFFERED IN AGAIN IN NEXT GROUP.
CK
CK END THE GROUP WITH THE PREVIOUS CASE (LAST CASE CALCULATED) IF:
CK   TIME LAPSE SINCE PREFACE OF FIRST CASE IN THE GROUP IS .GT. 5 MIN., OR
CK     TIME LAPSE SINCE PREVIOUS CASE IS .GT. 18 SEC. (INDICATING THE TIME
CK     SEQUENCE OF CASES IS BROKEN);
CK   OR IF, COMPARED TO PREFACE OF FIRST CASE, FREQ. NO. CHANGES, OR RANGE
CK     DIFFERENCE IS .GT. 10 KM, OR FREQ. DIFFERENCE IS .GT. 0.5 MHZ
CK     (FOR THE LAST THREE CONDITIONS, ALSO PRINT A MESSAGE; EXCEPT,
CK     MESSAGE IS SUPPRESSED FOR CERTAIN KPRINTS).
CK
CK OTHERWISE, CALCULATE THE LAST CASE BUFFERED IN.
```

```
CK   (PRINT MESSAGE IF GAIN CHANGES.)
CK
CK KIYR,ETC. REFER TO INITIAL (FIRST) CASE OF THE GROUP.
CK KLYR,ETC. REFER TO LAST CASE BUFFERED IN (NOT YET CALCULATED).
CK MYR,ETC. REFER TO CASE BEING CALCULATED.
CK KITIME,KLTIME,MTIME ARE HR-MIN-SEC IN SECONDS; ADD 24 HOURS TO KLTIME
CK   IF INITIAL AND LAST DAYS ARE DIFFERENT.
CK IN=DRIFT-MEASUREMENT PROGRAM NUMBER.
CK DF2=DOPPLER FREQUENCY (HZ) OF DOPPLER NUMBER D=1.
CK DFR=SPECTRAL WIDTH(HZ)=DOPPLER-FREQ RESOLUTION.
CK NFREQ=FREQUENCY NUMBER.
CK NUMFREQ=NUMBER OF FREQUENCIES.
CK FREQ IN 100-HZ UNITS, CONVERTED TO KHZ.
CK RANGE IN 100-METER UNITS, CONVERTED TO KM.
CK ZMAX=MAXIMUM ZENITH ANGLE FOR SKYMAP.
CK SCALE=METERS-PER-DIVISION SCALE IN SKYMAP.
CK=========================================================================
CK
        IF(KASE.NE.1) GO TO 460
        KIYR=MPDT(2)/1000  $ KIDY=MOD(MPDT(2),(KIYR*1000))
        KIHR=MPDT(3)/10000  $ KIMIN=MPDT(3)/100-KIHR*100
        KISEC=MPDT(3)-KIHR*10000-KIMIN*100
        KITIME=KIHR*3600+KIMIN*60+KISEC
        FREQKI=FLOAT(MPDT(10))/10 $ RANGKI=FLOAT(MPDT(11))/10
        KGAIN=MPDT(12)  $ NFREQKI=MPDT(9)
        GO TO 555
CK
    460 KLYR=MPDT(2)/1000  $ KLDY=MOD(MPDT(2),(KLYR*1000))
        KLHR=MPDT(3)/10000  $ KLMIN=MPDT(3)/100-KLHR*100
        KLSEC=MPDT(3)-KLHR*10000-KLMIN*100
        KLTIME=KLHR*3600+KLMIN*60+KLSEC
        IF(KLDY.NE.KIDY) KLTIME=KLTIME+86400
        IF((KLTIME-MTIME).GT.18) GO TO 550
        IF((KLTIME-KITIME).GT.300) GO TO 550
CK
        IF(MPDT(9).NE.NFREQKI) 470,480
    470 IF((KPRINT.AND.64).EQ.0) PRINT*," DIFFERENT FREQ-NO ENCOUNTERED"
        GO TO 550
CK
    480 IF((ABS((FLOAT(MPDT(10))/10)-FREQKI)).GT.500.) 490,500
    490 IF((KPRINT.AND.64).EQ.0) PRINT*," FREQ. DIFFERENCE G.T. 0.5 MHZ"
        GO TO 550
CK
    500 IF((ABS((FLOAT(MPDT(11))/10)-RANGKI)).GT.10.) 510,520
    510 IF((KPRINT.AND.64).EQ.0) PRINT*," RANGE DIFFERENCE G.T. 10 KM"
        GO TO 550
CK
    520 IF(MPDT(12).NE.KGAIN)530,555
    530 IF((KPRINT.AND.80).EQ.0) PRINT 540,KGAIN,MPDT(12)
        KGAIN=MPDT(12)
    540 FORMAT(" NOTE GAIN CHANGE FROM ",I3," TO ",I3)
```

```
      GO TO 555
CK
  550 BACKSPACE 50  $ BACKSPACE 50
      GO TO 1175
CK
CK===============  D E T E R M I N E   P A R A M E T E R S  ===============
CK                            OF THE CASE BEING CALCULATED
CK
  555 MSTAT=MPDT(1)  $ KSEG=NN(KASE)
      IF(KASE.NE.1) GO TO 560
      MYR=KIYR $MDY=KIDY $MHR=KIHR $MMIN=KIMIN $MSEC=KISEC $MTIME=KITIME
      GO TO 565
  560 MYR=KLYR $MDY=KLDY $MHR=KLHR $MMIN=KLMIN $MSEC=KLSEC $MTIME=KLTIME
  565 MRWTT=MPDT(6)  $ MGNXZ=MPDT(7)
CK
CK=====IN: DIGISONDE PROGRAM NUMBER
CK     DFR: DOPPLER-FREQ RESOLUTION (SPECTRAL SPACING)
CK     DF2: DOPP-FREQ OF DOPPLER NO. 1
CK     NFREQ: ACTUAL FREQ. NO.;  NUMFREQ: TOTAL NO. OF FREQUENCIES
CK     FREQ IN 100HZ UNITS CONVERTED TO KHZ
CK     RANGE IN 100M UNITS CONVERTED TO KM
CK
      IN=MGNXZ/100-(MGNXZ/1000)*10
      DFR=.12254902  $ IF(IN.EQ.7) DFR=DFR/2
      DF2=DFR/2  $ IF(IN.EQ.5.OR.IN.EQ.8) DF2=0
      NFREQ=MPDT(9)
      NUMFREQ=6-3*(IN/8)
      FREQ=FLOAT(MPDT(10))/10
      RANG=FLOAT(MPDT(11))/10
      SINZMAX=2997.925/FREQ
      IF(SINZMAX.GT.0.707) SINZMAX=.707
      SCALE=.707*RANG*SINZMAX/20
      R=RANG/SCALE
CK
CK=====================  P R I N T   H E A D I N G  =====================
CK
      IF((KASE.NE.1).OR.((KPRINT.AND.64).NE.0)) GO TO 630
CK
      IF(((KPRINT.AND.7).NE.0).OR.(((KPRINT.AND.8).NE.0).AND.(NGRP.EQ.1)))
+     PRINT 570,MSTAT,MYR,MDY,MRWTT,MGNXZ,NFREQ,FREQ,RANG,
+             SCALE,MWT1,MWT2
  570 FORMAT(////*1*/1X,*STAT  DATE  RWTT GNXZ FREQ.NO. FREQ(KHZ) *,
+         *RANGE(KM) SCALE  VEL WEIGHTING FACTOR  */,
+         1X,I3,2X,I2.2,1H-,I3.3,2(1X,I4.4),I5,F13.1,F9.1,F7.1,3X,2A10//)
CK
      IF(KPRINT.EQ.1) PRINT 580, SCALE
   580 FORMAT(22X,"(POSITION UNITS: X,Y,Z *",F4.[illegible] uX,
+         *+X,+VX=NORTH   +Y,+VY=WEST)*/
+         17X,*NEG-DOPP SOURCE POSITION    POS-DOPP SOURCE POSITION*,
+         *          VELOCITY(M/S)*/
+         1X,*CASE  TIME         X    Y    Z SIG NI NF        X    Y*,
```

```
+         *   Z SIG NI NF        VX     VY    VZ    VH  VEL AZIM ELEV*,
+         *  SIG    ESQ NI NF*)
CK
       IF((KPRINT.AND.2).NE.0) PRINT 590
   590 FORMAT(20X,*(MAP COORD)*,3X,*( +VX=NORTH  +VY=WEST )*,13X,*NO. OF*
+         /1X,*CASE  TIME   MIN DB  IVX IVY   VX(M/S) VY   VZ    VH*,
+         *  VEL  AZIM ELEV SOURCES   ESQ*)
CK
       IF((KPRINT.AND.4).NE.0) PRINT 600
   600 FORMAT(14X,*(MAP COORD)  ( +VX=NORTH  +VY=WEST )*/
+          1X,*CASE  TIME     IVX IVY  VX(M/S) VY   VZ   VH VEL*,
+          * AZIM ELEV  SIG    ESQ NI NF*)
CK
       IF(((KPRINT.AND.8).NE.0).AND.(NGRP.EQ.1)) PRINT 610
   610 FORMAT(36X,*(MAP COORD)*,3X,*( +VX=NORTH  +VY=WEST )*/
+         1X,*GROUP   TIME   FREQ(KHZ) RANGE(KM)*,
+         *   IVX IVY  VX(M/S) VY   VZ   VH VEL AZIM ELEV  SIG*,
+         *    ESQ NI NF*)
CK
CK=====IF NO SOURCES, PRINT MESSAGE (UNLESS KPRINT INCLUDES 8,16, OR 64).
CK     IF PRINTING CASE-NORM, GROUP-NORM OR ALL-FREQ GRAPHS, SKIP
CK     INDIVIDUAL-VELOCITY CALCULATION LOOP; OTHERWISE, GO TO END
CK     OF CASE LOOP.
CK
   630 IF(IENDPOS.NE.0) GO TO 645
       IF((KPRINT.AND.88).EQ.0) PRINT 640,KASE,MHR,MMIN,MSEC
   640 FORMAT(2X,Z1,2X,2(I2.2,1H:),I2.2,3X,*NO SOURCES*)
       IF(((KPRINT.AND.64).NE.0).AND.((KPRINT.AND.2).EQ.0)) GO TO 955
       GO TO 1170
CK
CK=====FIND MAX AND MIN FWPD (LOG DENSITY) OF NEG- AND POS-DOPPLER
CK     SOURCES COMBINED FOR THIS CASE.
CK
       645 CONTINUE
CKKK   645 IDBMAX=IDBMIN=0
CKKK       IF(IENDPOS.EQ.0) GO TO 660
CKKK       DO 650 MCOL=1,IENDPOS
CKKK       IDBMIN=MINO(MAPDAT(3,MCOL),IDBMIN)
CKKK   650 IDBMAX=MAXO(MAPDAT(3,MCOL),IDBMAX)
CKKK   660 CONTINUE
CK
CKKK       IDB6=MAXO((IDBMAX-5),0)
CK
       IF(KPRINT.NE.1) GO TO 760
CK
CK===== F I N D  C A S E - N O R M  S O U R C E  P O S I T I O N S  ======
CK                (NEG- AND POS-SOURCE POSITIONS SEPARATELY)
CK
       DO 750 J=1,2
       NC1=1  $ NC2=IENDNEG
       IF(J.EQ.1) GO TO 690
```

```
      NC1=IENDNEG+1  $ NC2=IENDPOS
  690 NS=0
      DO 700 I=1,160
  700 XX(I)=YY(I)=ZZ(I)=0
      IF(NC2.LT.NC1) GO TO 720
      DO 710 NCOL=NC1,NC2
CKKK      IF(MAPDAT(3,NCOL).LT.IDB6) GO TO 710
      NS=NS+1
      YY(NS)=21-MAPDAT(1,NCOL)
      XX(NS)=21-MAPDAT(2,NCOL)
      ZZ(NS)=SQRT(R*R-XX(NS)*XX(NS)-YY(NS)*YY(NS))
  710 CONTINUE
  720 GO TO (730,740) J
  730 KASENEG=1
      CALL AVE(1,2,XX,YY,ZZ,ONE,NS,CNX,CNY,CNZ,CNS,DUM,NICN,NFCN)
      IF(NFCN.EQ.0) KASENEG=0
      CASENX(KASE)=CNX
      CASENY(KASE)=CNY
      CASENZ(KASE)=CNZ
      CASENS(KASE)=CNS
      GO TO 750
  740 KASEPOS=2
      CALL AVE(1,2,XX,YY,ZZ,ONE,NS,CPX,CPY,CPZ,CPS,DUM,NICP,NFCP)
      IF(NFCP.EQ.0) KASEPOS=0
      CASEPX(KASE)=CPX
      CASEPY(KASE)=CPY
      CASEPZ(KASE)=CPZ
      CASEPS(KASE)=CPS
  750 CONTINUE
CV
CV===========  C A L C U L A T I O N   O F   V E L O C I T Y  =============
CV THE SOURCES FOR EACH CASE ARE SORTED IN ORDER OF DECREASING DENSITY,
CV   INCREASING DENSITY, DECREASING ABS(DOPP. NO.), OR INCREASING
CV   ABS(DOPP. NO.), AS REQUESTED IN INPUT PARAMETERS.
CV "MINSRC" (INPUTTED AT THE BEGINNING OF THE RUN) IS THE MINIMUM NUMBER
CV   OF SOURCES REQUIRED FOR THE FIRST VELOCITY CALCULATION (USING TOO FEW
CV   SOURCES CAN RESULT IN VERY LARGE ERRORS IN VELOCITY EVEN THOUGH ESQ
CV   APPROACHES ZERO).  EACH SUCCEEDING CALCULATION INCLUDES ONE MORE
CV   SOURCE.
CV
CV NSRC COUNTS THE NUMBER OF SOURCES USED. A SOURCE IS SKIPPED IF:
CV   --ITS DOPPLER NUMBER IS .LT. MINDOPP OR .GT. MAXDOPP
CV       (MINDOPP,MAXDOPP ARE INPUTTED AT BEGINNING OF RUN);
CV   --IT RESULTS IN A VELOCITY WHERE ABS(VZ).GT.MAXVZ, OR ESQ.GT.MAXESQ
CV        (UNLESS THE SOURCE IS ONE OF THE "MINSRC" SOURCES USED IN THE
CV        FIRST CALCULATION:  IN THAT CASE, THE VELOCITY IS IGNORED, BUT
CV        ALL MINSRC SOURCES ARE KEPT, SINCE THERE IS NO WAY IF KNOWING
CV        WHICH SOURCE IS BAD).
CV
CV NIVEL COUNTS THE INDIVIDUAL VELOCITY CALCULATIONS FOR THIS CASE.
CV
```

```
CV THE RESULTS ARE STORED IN ARRAYS DBVX(NIVEL), ETC.
CV
CV LEAST-SQUARE-ERROR CALCULATION:
CV
CV                                                          2
CV    ESQ= SUM A(I)*[(V,R(I))-(-C*DFREQ(I)/(2*FREQ))]
CV          I
CV         --------------------------------------
CV                        SUM A(I)
CV                         I
CV
CV    ESQ=LEAST SQUARE ERROR
CV    A(I)=WEIGHTING FACTOR
CV    (V,R(I))=DOT PRODUCT OF VELOCITY VECTOR V AND UNIT
CV                POSITION VECTOR R(I)
CV    C=SPEED OF LIGHT IN VAC
CV    DFREQ(I)=DOPPLER-FREQ COMPONENT IN DIRECTION OF R(I)
CV
CV SETTING DERIVATIVES (W.R.T. VX,VY,VZ) OF ESQ EACH EQUAL TO ZERO GIVES 3
CV   EQUATIONS WHICH ARE SOLVED FOR VX,VY,VZ VIA CRAMER'S RULE;
CV   ESQ IS THEN CALCULATED BY PLUGGING IN VX,VY,VZ.
CV=========================================================================
CV
      760 NIVEL=0
          IF(((KPRINT.EQ.66).AND.(IENDPOS.LT.4)).OR.
+            ((KPRINT.NE.66).AND.(IENDPOS.LT.MINSRC))) GO TO 955
CV
          DO 765 I=1,60
      765 DBVX(I)=DBVY(I)=DBVZ(I)=DBESQ(I)=0
CV
          IEND=IENDPOS-1
      770 IFAGAIN=0
          DO 790 KCOL=1,IEND
          GO TO (771,772,773,774) ISORT
      771 IF(MAPDAT(3,KCOL).GE.MAPDAT(3,KCOL+1)) 790,775
      772 IF(MAPDAT(3,KCOL).LE.MAPDAT(3,KCOL+1)) 790,775
      773 IF(IABS(MAPDAT(4,KCOL)).GE.IABS(MAPDAT(4,KCOL+1))) 790,775
      774 IF(IABS(MAPDAT(4,KCOL)).LE.IABS(MAPDAT(4,KCOL+1))) 790,775
      775 IFAGAIN=1
          DO 780 KROW=1,4
          MTEMP(KROW)=MAPDAT(KROW,KCOL)
          MAPDAT(KROW,KCOL)=MAPDAT(KROW,KCOL+1)
      780 MAPDAT(KROW,KCOL+1)=MTEMP(KROW)
      790 CONTINUE
          IF(IFAGAIN.EQ.1) GO TO 770
CV
          XSQ=YSQ=ZSQ=WSQ=XY=XZ=YZ=WX=WY=WZ=SUMA=NSRC=0
          VX=0.
          VY=0.
          VZ=0.
CV
```

DRIFVEL (ULCAR)

```
            DO 950 NCOL=1,IENDPOS
            IFWPD=MAPDAT(3,NCOL)
            IDOPP=MAPDAT(4,NCOL)
            FWPD=IFWPD
            DOPP=IDOPP
CV
CVVV            PRINT*," NCOL,FWPD,DOPP ",NCOL,FWPD,DOPP
CVVV            PRINT 800,XSQ,YSQ,ZSQ,WSQ,XY,XZ,YZ,WX,WY,WZ,SUMA
        800 FORMAT(" XSQ...",6F15.3/7X,6F15.3)
CV
            IF(IABS(IDOPP).LT.MINDOPP) GO TO 910
            IF(IABS(IDOPP).GT.MAXDOPP.AND.MAXDOPP.NE.0) GO TO 910
CV
            Y=(21-MAPDAT(1,NCOL))
            X=(21-MAPDAT(2,NCOL))
            Z=SQRT(R*R-X*X-Y*Y)
            GO TO (820,830,840,850,860,870) IWT
        820 A=FWPD $ GO TO 880
        830 A=FWPD*ABS(DOPP) $ GO TO 880
        840 A=10**(FWPD/10) $ GO TO 880
        850 A=(10**(FWPD/10))*ABS(DOPP) $ GO TO 880
        860 A=ABS(DOPP) $ GO TO 880
        870 A=1
        880 DFREQ=(DF2+(ABS(DOPP)-1)*DFR)*(DOPP/ABS(DOPP))
            W=-299792.5*DFREQ/(2*FREQ)
CV
            Y=SQRT(A)*Y/R
            X=SQRT(A)*X/R
            Z=SQRT(A)*Z/R
            W=SQRT(A)*W
CV
            XSQ=XSQ+X*X  $ YSQ=YSQ+Y*Y  $ ZSQ=ZSQ+Z*Z  $ WSQ=WSQ+W*W
            XY=XY+X*Y  $ XZ=XZ+X*Z  $ YZ=YZ+Y*Z
            WX=WX+W*X  $ WY=WY+W*Y  $ WZ=WZ+W*Z  $ SUMA=SUMA+A
CV
CVVV            PRINT 800,XSQ,YSQ,ZSQ,WSQ,XY,XZ,YZ,WX,WY,WZ,SUMA
CV
            NUMB=NSRC=NSRC+1
C
CVVV            IF(NCOL.EQ.IENDPOS) GO TO 895
CVVV            IF(IFWPD.EQ.MAPDAT(3,(NCOL+1))) GO TO 950
C
CVVV        895 IF(NSRC.GE.MINSRC) GO TO 897
            IF(NSRC.GE.MINSRC) GO TO 897
            IF((KPRINT.AND.64).NE.0) GO TO 920
            GO TO 950
CV
        897 DX=DET(WX,XY,XZ,WY,YSQ,YZ,WZ,YZ,ZSQ)
            DY=DET(XSQ,WX,XZ,XY,WY,YZ,XZ,WZ,ZSQ)
            DZ=DET(XSQ,XY,WX,XY,YSQ,WY,XZ,YZ,WZ)
            D=DET(XSQ,XY,XZ,XY,YSQ,YZ,XZ,YZ,ZSQ)
```

DRIFVEL (ULCAR)

```
CV
      VZ=DZ/D
      IF(IFIX(ABS(VZ)).GT.MAXVZ.AND.MAXVZ.NE.0) GO TO 900
CV
      VX=DX/D  $ VY=DY/D
      ESQ=VX*VX*XSQ+VY*VY*YSQ+VZ*VZ*ZSQ+WSQ+2*VX*(VY*XY+VZ*XZ
+     -WX)+2*VY*(VZ*YZ-WY)-2*VZ*WZ
      ESQ=ESQ/SUMA
      IF(IFIX(ESQ).GT.MAXESQ.AND.MAXESQ.NE.0) GO TO 900
C
      NIVEL=NIVEL+1
      DBVX(NIVEL)=VX
      DBVY(NIVEL)=VY
      DBVZ(NIVEL)=VZ
      DBESQ(NIVEL)=ESQ
      GO TO 920
CV
CVVV  900 CONTINUE
  900 XSQ=XSQ-X*X  $ YSQ=YSQ-Y*Y  $ ZSQ=ZSQ-Z*Z  $ WSQ=WSQ-W*W
      XY=XY-X*Y  $ XZ=XZ-X*Z  $ YZ=YZ-Y*Z
      WX=WX-W*X  $ WY=WY-W*Y  $ WZ=WZ-W*Z  $ SUMA=SUMA-A
      NSRC=NSRC-1
CV
CVVV        PRINT*,"  SKIPPED: NCOL,FWPD,DOPP ",NCOL,FWPD,DOPP
CV
  910 NUMB=" "
      IF((KPRINT.AND.64).EQ.0) GO TO 950
CV
  920 IF((KPRINT.AND.2).EQ.0) GO TO 950
CV
      CALL VEL(VX,VY,VZ,VH,V,AZIM,ELEV)
      IF((KPRINT.AND.64).EQ.0) GO TO 930
      CALL GRAPH(KSEQ,MHR,MMIN,FREQ,RANG,NUMB,FWPD,DOPP,NCOL,KASE,
+               NGRP,VH,VZ,AZIM,DUM,ESQ,KPRINT,IDUM,MINSRC)
      GO TO 950
  930 CALL POLMAP(IDUM,KPRINT,KASE,VY,VX,IVY,IVX,1)
CV
      PRINT 940,KASE,MHR,MMIN,MSEC,IFWPD,IVX,IVY,VX,VY,VZ,
+               (IFIX(VH+.5)),(IFIX(V+.5)),AZIM,ELEV,NSRC,
+               (IFIX(ESQ+.5))
  940 FORMAT(2X,Z1,2X,2(I2.2,1H:),I2.2,I5,I7,I4,F8,F6,F5,
+           2I5,F6,F5,I5,I9)
CV
      IF(KPRINT.EQ.34)
+        CALL POLMAP(NGRP,KPRINT,KASE,DUM,DUM1,IVY,IVX,2)
CV
  950 CONTINUE
CV
CV=====END OF INDIVIDUAL-VELOCITY LOOP
CV    NGIVEL COUNTS THE INDIV. VELOCITIES IN THIS GROUP
CV
```

```
           NGIVEL=NGIVEL+NIVEL
CV
CK
           IF(NIVEL.NE.0) GO TO 970
       955 IF((KPRINT.AND.89).EQ.0) PRINT 960,KASE,MHR,MMIN,MSEC
       960 FORMAT(2X,Z1,2X,2(I2.2,1H:),I2.2,3X,
+                *NOT ENOUGH SOURCES FOR VELOCITY CALCULATION*)
           KASEVEL=0  $ NIVEL=" "
           IF(KPRINT.EQ.68) GO TO 1000
           GO TO 1030
CK
       970 KASEVEL=4
CK
CK===========  F I N D  C A S E - N O R M  V E L O C I T I E S  ===========
CK           BY CALCULATING THE AVE OR MEDIAN OF THE INDIVIDUAL VELOCITIES.
CK         NKVEL COUNTS THE CASE-NORM VELOCITIES IN THIS GROUP.
CK
           IF((KPRINT.AND.2).NE.0) GO TO 1170
           GO TO (980,985,990) ICV
       980 CALL MEDIAN(DBVX,DBVY,DBVZ,ONE,NIVEL,CVX,CVY,CVZ,CVS,CVE,NFCV)
           GO TO 995
       985 CALL MEDIAN(DBVX,DBVY,DBVZ,DBESQ,NIVEL,CVX,CVY,CVZ,CVS,CVE,NFCV)
           GO TO 995
       990 CALL AVE(NFREQ,ICV1,DBVX,DBVY,DBVZ,DBESQ,NIVEL,CVX,CVY,CVZ,CVS,
+                   CVE,NICV,NFCV)
       995 NKVEL=NKVEL+1
           CASEVX(KASE)=CVX
           CASEVY(KASE)=CVY
           CASEVZ(KASE)=CVZ
           CASESIG(KASE)=CVS
           CASEESQ(KASE)=CVE
CK
           IF((KPRINT.AND.5).NE.0)
+             CALL VEL(CVX,CVY,CVZ,CVH,CV,CAZ,CEL)
           IF((KPRINT.AND.4).EQ.0) GO TO 1030
           IF((KPRINT.AND.64).EQ.0) GO TO 1010
CK
      1000 CALL GRAPH(KSEQ,MHR,MMIN,FREQ,RANG,NIVEL,DUM,DUM1,IDUM,KASE,
+                     NDUM,CVH,CVZ,CAZ,CVS,DUM2,KPRINT,IDUM2,IDUM3)
           GO TO 1030
      1010 CALL POLMAP(IDUM,KPRINT,KASE,CVY,CVX,IVY,IVX,1)
           PRINT 1020,KASE,MHR,MMIN,MSEC,
+                IVX,IVY,CVX,CVY,CVZ,(IFIX(CVH+.5)),(IFIX(CV+.5)),
+                CAZ,CEL,(IFIX(CVS+.5)),(IFIX(CVE+.5)),NICV,NFCV
      1020 FORMAT(2X,Z1,2X,2(I2.2,1H:),I2.2,I6,I4,F7,F6,F5,2I4,
+                 2F5,I5,I7,2I3)
           IF(KPRINT.EQ.36)
+             CALL POLMAP(NKVEL,KPRINT,KASE,DUM,DUM1,IVY,IVX,2)
CK
      1030 IF(KPRINT.NE.1) GO TO 1170
CK
```

DRIFVEL (ULCAR)

```
CK==========================================================================
CK PRINT CASE-NORM NEGATIVE- AND POSITIVE-DOPPLER SOURCE POSITIONS AND
CK   VELOCITIES FOR THIS CASE.  KASENEG, ETC., DETERMINE WHICH PRINT
CK   STATEMENT TO USE: ONLY THE "NON-ZERO" RESULTS ARE PRINTED.
CK (IF THERE ARE NO SOURCES, SEE COMMENT PRECEDING STATEMENT 630 ABOVE.)
CK==========================================================================
CK
           NFCNTOT=NFCNTOT+NFCN
           NFCPTOT=NFCPTOT+NFCP
           GO TO(1040,1060,1080,1100,1110,1130,1150)(KASENEG+KASEPOS+KASEVEL)
CK
      1040 PRINT 1050,KASE,MHR,MMIN,MSEC,
+               CNX,CNY,CNZ,(IFIX(CNS+.5)),NICN,NFCN,NICP,NFCP,
+               NICV,NFCV
      1050 FORMAT(2X,Z1,2X,2(I2.2,1H:),I2.2,4X,3F5,3I3,23X,2I3,55X,2I3)
           GO TO 1170
CK
      1060 PRINT 1070,KASE,MHR,MMIN,MSEC,
+               NICN,NFCN,CPX,CPY,CPZ,(IFIX(CPS+.5)),NICP,NFCP,
+               NICV,NFCV
      1070 FORMAT(2X,Z1,2X,2(I2.2,1H:),I2.2,22X,2I3,5X,3F5,3I3,55X,2I3)
           GO TO 1170
CK
      1080 PRINT 1090,KASE,MHR,MMIN,MSEC,
+               CNX,CNY,CNZ,(IFIX(CNS+.5)),NICN,NFCN,
+               CPX,CPY,CPZ,(IFIX(CPS+.5)),NICP,NFCP,NICV,NFCV
      1090 FORMAT(2X,Z1,2X,2(I2.2,1H:),I2.2,4X,3F5,3I3,5X,3F5,3I3,55X,2I3)
      1100 GO TO 1170
CK
CK
      1110 PRINT 1120,KASE,MHR,MMIN,MSEC,
+               CNX,CNY,CNZ,(IFIX(CNS+.5)),NICN,NFCN,NICP,NFCP,
+               CVX,CVY,CVZ,(IFIX(CVH+.5)),(IFIX(CV+.5)),CAZ,
+               CEL,(IFIX(CVS+.5)),(IFIX(CVE+.5)),NICV,NFCV
      1120 FORMAT(2X,Z1,2X,2(I2.2,1H:),I2.2,4X,3F5,3I3,23X,2I3,4X,2F7,F6,2I5,
+                 2F5,I5,I6,2I3)
           GO TO 1170
CK
      1130 PRINT 1140,KASE,MHR,MMIN,MSEC,
+               NICN,NFCN,CPX,CPY,CPZ,(IFIX(CPS+.5)),NICP,NFCP,
+               CVX,CVY,CVZ,(IFIX(CVH+.5)),(IFIX(CV+.5)),CAZ,
+               CEL,(IFIX(CVS+.5)),(IFIX(CVE+.5)),NICV,NFCV
      1140 FORMAT(2X,Z1,2X,2(I2.2,1H:),I2.2,22X,2I3,5X,3F5,3I3,4X,2F7,F6,2I5,
+                 2F5,I5,I6,2I3)
           GO TO 1170
CK
      1150 PRINT 1160,KASE,MHR,MMIN,MSEC,
+               CNX,CNY,CNZ,(IFIX(CNS+.5)),NICN,NFCN,
+               CPX,CPY,CPZ,(IFIX(CPS+.5)),NICP,NFCP,
+               CVX,CVY,CVZ,(IFIX(CVH+.5)),(IFIX(CV+.5)),CAZ,
+               CEL,(IFIX(CVS+.5)),(IFIX(CVE+.5)),NICV,NFCV
```

```
 1160 FORMAT(2X,Z1,2X,2(I2.2,1H:),I2.2,4X,3F5,3I3,5X,3F5,3I3,4X,2F7,F6,
+               2I5,2F5,I5,I6,2I3)
CK
 1170 CONTINUE
      GO TO 1180
CK
CK====================  E N D  O F  C A S E  L O O P  ===================
CK
 1175 KASE=KASE-1
CK
CK=====PRINT POLAR MAP OF INDIVIDUAL OR CASE-NORM VELOCITIES
CK
 1180 IF(((KPRINT.EQ.34).AND.(NGIVEL.NE.0)).OR.
+        ((KPRINT.EQ.36).AND.(NKVEL.NE.0)))
+        CALL POLMAP(NDUM,KPRINT,IDUM,DUM,DUM1,IDUM1,IDUM2,3)
CK
      IF((KPRINT.AND.6).NE.0) GO TO 1420
      IF(KPRINT.NE.1) GO TO 1182
CG
CG=====FIND GROUP-NORM NEG- AND POS-DOPP SOURCE POSITIONS
CG
      KGRPNEG=1  $ KGRPPOS=2
      CALL AVE(NFREQ,1,CASENX,CASENY,CASENZ,ONE,KASE,GNX,GNY,GNZ,
+              GNS,DUM,NIGN,NFGN)
      IF(NFGN.EQ.0) KGRPNEG=0
CG
      CALL AVE(NFREQ,1,CASEPX,CASEPY,CASEPZ,ONE,KASE,GPX,GPY,GPZ,
+              GPS,DUM,NIGP,NFGP)
      IF(NFGP.EQ.0) KGRPPOS=0
CG
CG=====FIND GROUP TIME ROUNDED OUT TO NEAREST 2.5 MINUTES
CG
 1182 IF((KPRINT.AND.24).EQ.0) GO TO 1185
      KFTIME=MTIME
      KIT=IFIX(FLOAT(KITIME)/150+.5)*150
      KFT=IFIX(FLOAT(KFTIME)/150+.5)*150
      IF((IABS(KIT-KITIME)).GT.(IABS(KFT-KFTIME))) GO TO 1183
      NGRPDAT=KIYR*1000+KIDY
      NGRPTIM=KIT
      GO TO 1184
 1183 NGRPDAT=MPDT(2)
      NGRPTIM=KFT
 1184 IF(NGRPTIM.GT.86400) NGRPTIM=NGRPTIM-86400
      NGRPHR=NGRPTIM/3600  $ NMINSEC=NGRPTIM-NGRPHR*3600
      NGRPMIN=NMINSEC/60  $ NGRPSEC=NMINSEC-NGRPMIN*60
CG
 1185 IF(NKVEL.NE.0) GO TO 1187
CG
      KGRPVEL=0  $ NKVEL=" "  $ GVX=GVY=GVZ=0  $ NIGV=NFGV=0
      IF(((KPRINT.AND.8).NE.0).AND.((KPRINT.AND.64).EQ.0))
+         PRINT 1186,NN(NGRP),NGRPHR,NGRPMIN,NGRPSEC,FREQ,RANG,NIGV,NFGV
```

```
 1186 FORMAT(3X,A1,3X,2(I2.2,1H:),I2.2,F8.1,F10.1,60X,2I3)
      GO TO 1196
CG
 1187 KGRPVEL=4
CG
CG=====FIND GROUP-NORM VELOCITY
CG    NGVEL COUNTS THE NUMBER OF GROUP-NORM VELOCITIES
CG
      GO TO(1191,1192,1193) ICV
 1191 CALL MEDIAN(CASEVX,CASEVY,CASEVZ,ONE,KASE,GVX,GVY,GVZ,GVS,GVE,NFGV)
      GO TO 1194
 1192 CALL MEDIAN(CASEVX,CASEVY,CASEVZ,CASEESQ,KASE,GVX,GVY,GVZ,GVS,GVE,
+     NFGV)
      GO TO 1194
 1193 CALL AVE(NFREQ,ICV2,CASEVX,CASEVY,CASEVZ,CASEESQ,KASE,GVX,GVY,
+                 GVZ,GVS,GVE,NIGV,NFGV)
 1194 NGVEL=NGVEL+1
CG
 1196 IF((KPRINT.AND.9).NE.0)
+        CALL VEL(GVX,GVY,GVZ,GVH,GV,GAZ,GEL)
CG
      IF(KPRINT.EQ.1) GO TO 1245
      IF((KPRINT.AND.8).EQ.0) GO TO 1230
      IF((KPRINT.AND.64).EQ.0) GO TO 1210
CG
 1200 CALL GRAPH(IGSEQ,NGRPHR,NGRPMIN,FREQ,RANG,NKVEL,DUM,DUM1,
+                 IDUM,IDUM1,NDUM,GVH,GVZ,GAZ,GVS,DUM2,KPRINT,IDUM2,8)
      GO TO 1230
CG
 1210 IF(NKVEL.EQ." ") GO TO 1230
      CALL POLMAP(IDUM,KPRINT,NGRP,GVY,GVX,IVY,IVX,1)
      PRINT 1220,(NN(NGRP)),NGRPHR,NGRPMIN,NGRPSEC,FREQ,RANG,IVX,IVY,
+                 GVX,GVY,GVZ,(IFIX(GVH+.5)),(IFIX(GV+.5)),GAZ,GEL,
+                 (IFIX(GVS+.5)),(IFIX(GVE+.5)),NIGV,NFGV
 1220 FORMAT(3X,A1,3X,2(I2.2,1H:),I2.2,F8.1,F10.1,I8,I4,1X,2F6,F5,
+        2I4,2F5,I5,I7,2I3)
      IF(KPRINT.EQ.40)
+        CALL POLMAP(NGVEL,KPRINT,NGRP,DUM,DUM1,IVY,IVX,2)
 1230 IF((KPRINT.AND.16).EQ.0) GO TO 1240
CG
      IF((RANG.LT.200.).OR.(RANG.GT.510.)) GVX=GVY=GVZ=0
      CALL ALLFREQ(KPRINT,NGRP,NGRPDAT,NGRPHR,NGRPMIN,NGRPSEC,GVX,
+     GVY,GVZ,FREQ,RANG,NUMFREQ,NFREQ,ONE,ICV,ICV3,IFHEAD,LASFREQ,NFVEL)
 1240 GO TO 1410
CG
CG==================  P R I N T   G R O U P - N O R M  ===================
CG=====  S O U R C E   P O S I T I O N S   A N D   V E L O C I T I E S  ======
CG    KG DETERMINES WHICH PRINT STATEMENT TO USE: ONLY THE "NON-ZERO"
CG    RESULTS ARE PRINTED.  IF THERE ARE NO SOURCES, NOTHING IS PRINTED.
CG
 1245 KG=KGRPNEG+KGRPPOS+KGRPVEL
```

```
      IF(KG.EQ.0) GO TO 1410
      IF((NFCNTOT+NFCPTOT).NE.0) PRINT 1250,NFCNTOT,NFCPTOT
 1250 FORMAT(6X,"(TOTAL)",25X,I3,26X,I3)
      GO TO(1260,1280,1300,1320,1330,1350,1370) KG
CG
 1260 PRINT 1270,"GROUP-NORM",":",
+            GNX,GNY,GNZ,(IFIX(GNS+.5)),NIGN,NFGN,NIGP,NFGP,
+            NIGV,NFGV
 1270 FORMAT(/1X,A10,A4,2X,3F5,3I3,23X,2I3,55X,2I3)
      GO TO 1390
CG
 1280 PRINT 1290,"GROUP-NORM",":",
+            NIGN,NFGN,GPX,GPY,GPZ,(IFIX(GPS+.5)),NIGP,NFGP,
+            NIGV,NFGV
 1290 FORMAT(/1X,A10,A4,20X,2I3,5X,3F5,3I3,55X,2I3)
      GO TO 1390
CG
 1300 PRINT 1310,"GROUP-NORM",":",
+            GNX,GNY,GNZ,(IFIX(GNS+.5)),NIGN,NFGN,
+            GPX,GPY,GPZ,(IFIX(GPS+.5)),NIGP,NFGP,NIGV,NFGV
 1310 FORMAT(/1X,A10,A4,2X,3F5,3I3,5X,3F5,3I3,55X,2I3)
 1320 GO TO 1390
CG
CG
 1330 PRINT 1340,"GROUP-NORM",":",
+            GNX,GNY,GNZ,(IFIX(GNS+.5)),NIGN,NFGN,NIGP,NFGP,
+            GVX,GVY,GVZ,(IFIX(GVH+.5)),(IFIX(GV+.5)),GAZ,
+            GEL,(IFIX(GVS+.5)),(IFIX(GVE+.5)),NIGV,NFGV
 1340 FORMAT(/1X,A10,A4,2X,3F5,3I3,23X,2I3,4X,2F7,F6,2I5,
+               2F5,I5,I6,2I3)
      GO TO 1390
CG
 1350 PRINT 1360,"GROUP-NORM",":",
+            NIGN,NFGN,GPX,GPY,GPZ,(IFIX(GPS+.5)),NIGP,NFGP,
+            GVX,GVY,GVZ,(IFIX(GVH+.5)),(IFIX(GV+.5)),GAZ,
+            GEL,(IFIX(GVS+.5)),(IFIX(GVE+.5)),NIGV,NFGV
 1360 FORMAT(/1X,A10,A4,20X,2I3,5X,3F5,3I3,4X,2F7,F6,2I5,
+               2F5,I5,I6,2I3)
      GO TO 1390
CG
 1370 PRINT 1380,"GROUP-NORM",":",
+            GNX,GNY,GNZ,(IFIX(GNS+.5)),NIGN,NFGN,
+            GPX,GPY,GPZ,(IFIX(GPS+.5)),NIGP,NFGP,
+            GVX,GVY,GVZ,(IFIX(GVH+.5)),(IFIX(GV+.5)),GAZ,
+            GEL,(IFIX(GVS+.5)),(IFIX(GVE+.5)),NIGV,NFGV
 1380 FORMAT(/1X,A10,A4,2X,3F5,3I3,5X,3F5,3I3,4X,2F7,F6,
+               2I5,2F5,I5,I6,2I3)
CG
 1390 CONTINUE
CGGG  1390 PRINT 1400,(GVX/20),(GVY/20),(GVZ/20)
 1400 FORMAT(1X,"(UNITS OF 20)",60X,2F7,F6)
```

```
CG
 1410 IF(EOF50.EQ.1.) GO TO 1430
CG
 1420 CONTINUE
CG
 1430 IF(((KPRINT.EQ.40).AND.(NGVEL.NE.0)).OR.
+          ((KPRINT.EQ.48).AND.(NFVEL.NE.0)))
+          CALL POLMAP(NDUM,KPRINT,IDUM,DUM,DUM1,IDUM1,IDUM2,3)
      IF((KPRINT.EQ.40).AND.(NGVEL.NE.0))  PRINT 110
      IF((KPRINT.EQ.48).AND.(NFVEL.NE.0)) WRITE(49,110)
      GO TO 330
      END
C
C
C
C==================  S U B R O U T I N E   U N P A C K  ==================
C EACH 60-BIT WORD IN MPDT(13) TO MPDT(52) CONTAINS 2 SETS OF
C   IY, IX, FWPD, DOPPLER NUMBER:
C     IY,IX: 6 BITS EACH;
C     FWPD,DOPP. NO.: 9 BITS EACH.
C STORE EACH SET IN MAPDAT(NROW,NCOLUMN),NROW=1 TO 4.
C STORE 2 RECORDS TOGETHER:
C   1ST RECORD: NEGATIVE DOPPLERS (MAPDAT(4,NCOL)=DOPP. NO. IS STORED
C               AS A NEGATIVE NUMBER).
C   2ND RECORD: POSITIVE DOPPLERS.
C
C         FOR: IBY=  1,  2,  3,  4,  5,  6,  7,  8:
C              IBG=  6,  6,  9,  9,  6,  6,  9,  9, AND
C              IBF=  6, 12, 21, 30, 36, 42, 51, 60, AND
C "63+448*(IBG/9)"= 63, 63,511,511, 63, 63,511,511.
C=========================================================================
C
      SUBROUTINE UNPACK(ISIGN,NROW,NCOL)
      COMMON MPDT(52),MAPDAT(4,160)
      INTEGER SHIFT
C
      DO 30 IM=13,52
      IBF=0
      DO 30 IBY=1,8
      NROW=NROW+1 $ IF(NROW.EQ.5)NROW=1 $ IF(NROW.EQ.1)NCOL=NCOL+1
      IBG=3+3*((IBY+1-4*(IBY/5))/2) $ IBF=IBF+IBG
      MAPDAT(NROW,NCOL)=(63+448*(IBG/9)).AND.SHIFT(MPDT(IM),IBF)
      IF((NROW.EQ.4).AND.(MAPDAT(1,NCOL).EQ.0)) GO TO 40
      IF((NROW.EQ.4).AND.(MAPDAT(1,NCOL).EQ.1.OR.MAPDAT(1,NCOL).EQ.41
+     .OR.MAPDAT(2,NCOL).EQ.1.OR.MAPDAT(2,NCOL).EQ.41)) 10,20
   10 NCOL=NCOL-1  $ GO TO 30
   20 IF((NROW.EQ.4).AND.(ISIGN.EQ.1))MAPDAT(NROW,NCOL)=
+       -MAPDAT(NROW,NCOL)
   30 CONTINUE
   40 NROW=0  $ NCOL=NCOL-1
      RETURN
```

```
      END
C
C
C
C======================= F U N C T I O N   D E T =======================
C=====CALCULATE DETERMINANT
C
      FUNCTION DET(A11,A12,A13,A21,A22,A23,A31,A32,A33)
      DET=A11*(A22*A33-A23*A32)-A12*(A21*A33-A23*A31)
+     +A13*(A21*A32-A22*A31)
      RETURN
      END
C
C
C
C===================== S U B R O U T I N E   A V E =====================
C CALCULATE AVERAGE VECTOR BY AVE'G X,Y,Z COMPONENTS SEPARATELY.
C
C INPUTS:
C    I2: EQUALS 1 OR 2, FOR AVERAGING ONCE OR TWICE. THE SECOND AVERAGING
C        BYPASSES VECTORS OUTSIDE THE STANDARD DEVIATION CALCULATED
C        WITH THE FIRST AVERAGE.
C    ARRAYS X,Y,Z: INPUTTED AS POSITION COORDINATES OR VELOCITY COMPONENTS.
C    ARRAY ESQ: VALUES FOR WEIGHTING FACTOR.  INPUTTED AS LEAST AVERAGE
C               SQUARE ERRORS FOR VELOCITIES, AS ARRAY ONE=1 FOR POSITIONS.
C          WEIGHT=1 FOR ESQ.LE.1,
C                =1/SQRT(ESQ) FOR ESQ.GT.1.
C    NVEC: NUMBER OF VECTORS INPUTTED, INCLUDING ZERO VECTORS IF ANY.
C
C OUTPUTS:
C    AVEX,AVEY,AVEZ.
C    SIG=STANDARD DEVIATION.
C    AVEESQ=AVE OF THE ESQ'S OF THE VECTORS USED IN FINDING AVEX,AVEY,AVEZ.
C    NI="NUMBER-INITIAL"=NUMBER OF VECTORS USED IN FIRST AVERAGING.
C       NI=NVEC IF NO INPUTTED VECTORS ARE IDENTICALLY 0.  IF ANY VECTORS
C       HAVE ALL 3 COMPONENTS ZERO, THEY ARE NOT INCLUDED IN THE AVERAGE.
C    NF="NUMBER-FINAL"=NUMBER OF VECTORS LEFT AFTER EXCLUDING THOSE
C       OUTSIDE THE STANDARD DEVIATION, I.E., NUMBER OF VECTORS USED
C       IN THE SECOND AVERAGING.  IF AVERAGE CALCULATED ONLY ONCE, NI=NF.
C=======================================================================
C
      SUBROUTINE AVE(NFREQ,I2,XX,YY,ZZ,EESQ,NVEC,AVEX,AVEY,AVEZ,SIG,
+                    AVEESQ,NI,NF)
      DIMENSION XX(1),YY(1),ZZ(1),EESQ(1)
      DIMENSION X(160),Y(160),Z(160),ESQ(160)
      DIMENSION WHTP(160)
CCC      PRINT*," "
CCC      PRINT*," "
C
      IF(NVEC.EQ.0) GO TO 120
C
```

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```
      CALL MOVLEV(XX(1),X(1),NVEC)
      CALL MOVLEV(YY(1),Y(1),NVEC)
      CALL MOVLEV(ZZ(1),Z(1),NVEC)
      CALL MOVLEV(EESQ(1),ESQ(1),NVEC)
C
      DO 110 I=1,I2
CCC      PRINT*,"I=",I
      IRETURN=1
      SUMWHTP=0
      NF=SUMWX=SUMWY=SUMWZ=SUMWXSQ=SUMWYSQ=SUMWZSQ=SUMWHT=SUMESQ=0
C
      DO 10 K=1,NVEC
   10 WHTP(K)=0.0
C
C=====COUNT NON-ZERO VECTORS; DETERMINE WHTP=UN-NORMALIZED WEIGHTS
C
      DO 30 J=1,NVEC
      IF(X(J).EQ.0.0.AND.Y(J).EQ.0.0.AND.Z(J).EQ.0.0) GO TO 30
      NF=NF+1
      IF(ESQ(J).LE.1.0) WHTP(J)=1.
      IF(ESQ(J).GT.1.0) WHTP(J)=1/SQRT(ESQ(J))
CCC      PRINT 20,J,WHTP(J)
   20 FORMAT("WHTP(",I2,")=",F7.4)
      SUMWHTP=SUMWHTP+WHTP(J)
   30 CONTINUE
C
      IF(I.EQ.1) NI=NF
C
C=====FIND FACTOR TO NORMALIZE WEIGHTS SO THEIR SUM IS NF
C
      IF(NF.EQ.0) GO TO 130
C
      ANORM=NF/SUMWHTP
CCC      PRINT 40,NF,SUMWHTP,ANORM
   40 FORMAT("NF,SUMWHTP,ANORM ",I3,2F9.3)
C
C=====DETERMINE NORMALIZED PARAMETERS FOR CALCULATION OF AVERAGE AND
C       SIGMA (STANDARD DEVIATION)
C
      DO 60 J=1,NVEC
      IF((X(J).EQ.0.0).AND.(Y(J).EQ.0.0).AND.(Z(J).EQ.0.0)) GO TO 60
      WHT=ANORM*WHTP(J)
CCC      PRINT 50,J,X(J),Y(J),Z(J),WHT
   50 FORMAT(3X,"J=",I2,2X,"X,Y,Z,WHT ",4F9.3)
      SUMWX=SUMWX+WHT*X(J)
      SUMWY=SUMWY+WHT*Y(J)
      SUMWZ=SUMWZ+WHT*Z(J)
      SUMWXSQ=SUMWXSQ+WHT*X(J)*X(J)
      SUMWYSQ=SUMWYSQ+WHT*Y(J)*Y(J)
      SUMWZSQ=SUMWZSQ+WHT*Z(J)*Z(J)
      SUMWHT=SUMWHT+WHT
```

```
      SUMESQ=SUMESQ+ESQ(J)
   60 CONTINUE
CCC      PRINT*,"SUMWHT,NF ",SUMWHT,NF
C
C=========================================================================
C                   SUM(W*X)      WHERE: W=NORMALIZED WEIGHT
C     AVERAGE-X = --------
C                    SUM(W)               SUM(W)=NF
C=========================================================================
C
      AVEX=SUMWX/SUMWHT  $ AVEY=SUMWY/SUMWHT  $ AVEZ=SUMWZ/SUMWHT
      AVEESQ=SUMESQ/NF
CCC      PRINT 80,AVEX,AVEY,AVEZ
   80 FORMAT(3X,"AVEX,AVEY,AVEZ   ",3F9.3)
C
      IF(NF.EQ.1) GO TO 140
C
C=========================================================================
C                                                            2
C                                             2      (SUM(W*X))
C                                      SUM(W*X )  -  ----------
C                                 2                      NF
C     X-VARIANCE = (SIGMA-X) = ----------------------
C                                          NF-1
C=========================================================================
C
      SIGXSQ=(SUMWXSQ-(SUMWX**2/SUMWHT))/(SUMWHT-1)
      SIGYSQ=(SUMWYSQ-(SUMWY**2/SUMWHT))/(SUMWHT-1)
      SIGZSQ=(SUMWZSQ-(SUMWZ**2/SUMWHT))/(SUMWHT-1)
      SIG=SQRT(SIGXSQ+SIGYSQ+SIGZSQ)
CCC      PRINT 90,SIGXSQ,SIGYSQ,SIGZSQ,SIG
   90 FORMAT(3X,"SIGXSQ,SIGYSQ,SIGZSQ,SIG ",4F9.3)
C
C=====RETURN AFTER 1ST AVE'G IF I2=1; AFTER 2ND,IF I2=2.
C
      IF(I.EQ.I2) RETURN
C
      DO 100 K=1,NVEC
CCC      PRINT*,"K,X,Y,Z FOR XD ",K,X(K),Y(K),Z(K)
      IF(X(K).EQ.0.0.AND.Y(K).EQ.0.0.AND.Z(K).EQ.0.0) GO TO 100
      XD=(X(K)-AVEX)**2
      YD=(Y(K)-AVEY)**2
      ZD=(Z(K)-AVEZ)**2
      IF((SQRT(XD+YD+ZD)).LE.SIG) GO TO 100
      X(K)=Y(K)=Z(K)=0
      IRETURN=0
CCC      PRINT*," ZERO VECTOR"
  100 CONTINUE
C
C=====IF I2=2, RETURN AFTER 1ST AVE'G IF ALL VECTORS ARE WITHIN SIGMA.
C
```

```
      IF(IRETURN.EQ.1) RETURN
C
  110 CONTINUE
  120 NI=NF=0
CCC       PRINT*,"NI=NF=0"
  130 AVEX=AVEY=AVEZ=AVEESQ=0
CCC       PRINT*," AVEX=AVEY=AVEZ=AVEESQ=0"
  140 SIG=0
CCC       PRINT*,"SIG=ZERO"
      RETURN
      END
C
C
C
C=====================  S U B R O U T I N E   V E L  =====================
C=====CALCULATE HORIZONTAL VELOCITY COMPONENT VH, MAGNITUDE V,
C     AZIMUTH AND ELEVATION.
C
      SUBROUTINE VEL(VX,VY,VZ,VH,V,AZIM,ELEV)
C
      VH=SQRT(VX*VX+VY*VY)
      V=SQRT(VH*VH+VZ*VZ)
      IF((VX.EQ.0.0).AND.(VY.EQ.0.0)) GO TO 10
      AZIM=ATAN2(VY,VX)/.0174532925199433
      IF(AZIM.GT.0.0) AZIM=360-AZIM
      IF(AZIM.LT.0.0) AZIM=-AZIM
      ELEV=ATAN(VZ/VH)/.0174532925199433
      RETURN
   10 IF(VZ.NE.0.0) GO TO 20
      AZIM=ELEV=0  $ RETURN
   20 AZIM=0
      ELEV=90  $ IF(VZ.LT.0.0) ELEV=-90
      RETURN
      END
C
C
C
C===================  S U B R O U T I N E   P O L M A P  ===================
C CALCULATE POLAR MAP OF HORIZONTAL COMPONENTS OF VELOCITY.
C
C IVY,IVX=Y AND X COMPONENTS OF VELOCITY IN UNITS OF 10.
C IY,IX=THE CORRESPONDING ADDRESSES OF ARRAY IMAP, INTO WHICH ARE STORED
C       THE SEQUENCE NUMBERS (HEXADECIMAL NUMBERS 1 TO F, IDENTIFYING
C       THE CASES;  OR NUMBERS 1 TO 9, LETTERS A TO Z, IDENTIFYING
C       THE GROUPS).  EACH SEQUENCE NUMBER IS AT THE POSITION OF
C       THE ARROWHEAD OF A VECTOR WITH ORIGIN AT THE CENTER OF THE
C       MAP. IF MORE THAN ONE VECTOR HEAD OCCUPIES ANY IMAP ADDRESS,
C       THE FIRST ONE IS KEPT IN THE MAP, THE OTHERS ARE INDICATED IN
C       AN "OVERFLOW" MESSAGE.
C=========================================================================
C
```

```
      SUBROUTINE POLMAP(KV,KPRINT,KG,VY,VX,IVY,IVX,NM)
      COMMON MPDT(52),MAPDAT(4,160)
      COMMON/IGA/NN(35)
      DIMENSION NNN(103),IMAP(103,103)
      DATA NNN/" ","500",9*" ","400",9*" ","300",9*" ","200",9*" ",
+     "100",9*" "," 0 ",9*" ","100",9*" ","200",9*" ","300",9*" ",
+     "400",9*" ","500"," "/
C
      IF(NM.EQ.3) GO TO 200
      IF(NM.EQ.2) GO TO 10
C
C=====  F I R S T  C A L L
C     DETERMINES IVY,IVX=VY/10,VX/10 ROUNDED TO INTEGERS, AND IY,IX=
C       THE CORRESPONDING COORDINATES FOR IMAP.
C     NEEDED IF PRINTING LIST ONLY, OR LIST AND POLAR MAP.
C
      SY=1  $ IF(VY.LT.0.0) SY=-1
      SX=1  $ IF(VX.LT.0.0) SX=-1
      IVY=IFIX(VY/10.+SY*.5)
      IVX=IFIX(VX/10.+SX*.5)
      IF(IABS(IVY).GT.50) IVY=50*SY
      IY=52-IVY
      IF(IABS(IVX).GT.50) IVX=50*SX
      IX=52-IVX
      RETURN
C
C=====  S E C O N D  C A L L
C
   10 IF(((KPRINT.EQ.34).AND.(KV.EQ.LASTKV)).OR.
+        ((KPRINT.NE.34).AND.(KV.NE.1))) GO TO 70
C
C=====INITIALIZE IMAP (BORDERS) IF FIRST CALCULATION.
C     NEEDED ONLY IF POLAR MAP TO BE PRINTED.
C
      DO 20 KY=1,103
      DO 20 KX=1,103
   20 IMAP(KY,KX)=" "
C
      DO 30 KY=2,102
   30 IMAP(KY,1)=IMAP(KY,52)=IMAP(KY,103)="-"
      DO 40 KY=2,102,10
   40 IMAP(KY,1)=IMAP(KY,52)=IMAP(KY,103)="+"
C
      DO 50 KX=2,102
   50 IMAP(1,KX)=IMAP(52,KX)=IMAP(103,KX)="-"
      DO 60 KX=2,102,10
   60 IMAP(1,KX)=IMAP(52,KX)=IMAP(103,KX)="+"
C
      IMAP(49,1)=IMAP(49,103)=IMAP(55,1)=IMAP(55,103)=" "
      IMAP(50,1)="N"  $ IMAP(50,103)="S"
      IMAP(51,1)=IMAP(51,103)="O"
```

```
          IMAP(52,1)="R"  $ IMAP(52,103)="U"
          IMAP(53,1)=IMAP(53,103)="T"
          IMAP(54,1)=IMAP(54,103)="H"
          IMAP(1,49)=IMAP(103,49)=IMAP(1,54)=IMAP(103,54)=" "
          IMAP(1,50)="W"  $ IMAP(103,51)="A"
          IMAP(1,51)=IMAP(103,50)="E"
          IMAP(1,52)=IMAP(103,52)="S"
          IMAP(1,53)=IMAP(103,53)="T"
C
C=====PUT SEQUENCE NUMBERS AT THE (IY,IX) COORDINATES OF IMAP,
C     OR PRINT OVERFLOW MESSAGE.
C
       70 LASTKV=KV
          IF(IMAP(IY,IX).EQ." ".OR.IMAP(IY,IX).EQ."-".OR.
+         IMAP(IY,IX).EQ."+") GO TO 90
          IF((KPRINT.AND.24).EQ.0) PRINT 80,NN(KG),IVX,IVY
          IF(KPRINT.EQ.40) PRINT 80,NN(KG),IVX,IVY
          IF(KPRINT.EQ.48) WRITE(49,81) IVX,IVY,NN(KG)
       80 FORMAT(2X,A1,37X,"OVERFLOW AT IVX=",I3,", IVY=",I3)
       81 FORMAT(97X,"OVERFLOW AT IVX=",I3,", IVY=",I3,5X,A1)
          RETURN
       90 IF((KPRINT.AND.24).EQ.0) IMAP(IY,IX)=NN(KG)
          IF((KPRINT.AND.24).NE.0) IMAP(IY,IX)=NN(KG)
          RETURN
C
C=====  T H I R D   C A L L
C      PRINT POLAR MAP
C
      110 FORMAT(///38X,*HORIZONTAL COMPONENTS OF IONOSPHERIC DRIFT*/)
      120 FORMAT(49X,*INDIVIDUAL VELOCITIES*/)
      130 FORMAT(49X,*CASE-NORM VELOCITIES*/)
      140 FORMAT(49X,*GROUP-NORM VELOCITIES*/)
      150 FORMAT(50X,*ALL-FREQ VELOCITIES*/)
      160 FORMAT(7X,9(A3,7X),A3,1X,"(M/S)",1X,A3)
      180 FORMAT(4X,A3,103A1,A3)
      200 IF(KPRINT.EQ.48) GO TO 220
          PRINT 110
          IF(KPRINT.EQ.34) PRINT 120
          IF(KPRINT.EQ.36) PRINT 130
          IF(KPRINT.EQ.40) PRINT 140
          PRINT 160,(NNN(I),I=2,102,10)
          INNN=0
          DO 210 IX=1,103
          INNN=INNN+1
      210 PRINT 180,NNN(INNN),(IMAP(IY,IX),IY=1,103),NNN(INNN)
          PRINT 160,(NNN(I),I=2,102,10)
          RETURN
C
      220 WRITE(49,110)  $ WRITE(49,150)
          WRITE(49,160)(NNN(I),I=2,102,10)
          INNN=0
```

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```
      DO 230 IX=1,103
      INNN=INNN+1
  230 WRITE(49,180) NNN(INNN),(IMAP(IY,IX),IY=1,103),NNN(INNN)
      WRITE(49,160)(NNN(I),I=2,102,10)
      RETURN
      END
C
C
C
C=================== S U B R O U T I N E   G R A P H ===================
C
      SUBROUTINE GRAPH(ISEQ,KHR,KMIN,FREQ,RANG,NUMB,DB,DOPP,
+                   NCOL,KASE,NGRP,VH,VZ,AZIM,SIG,ESQ,KPRINT,NUMFREQ,KP)
C
      COMMON/IR7/IRNG(7)
      COMMON/IGA/NN(35)
      COMMON/G/GVELZ(6),GVELH(6),GVELAZ(6)
      DIMENSION IAZMTH(73),ISPEED(32),IERR(112),KVV(8),KVE(6)
      DIMENSION IAZZ(6),IATMP(6),IAN(73),IVZZ(6),IVZTMP(6),IVHH(6),
+               IVHTMP(6),IVN(32)
C
C=====KVV IS FORMAT FOR AZIMUTH-SPEED GRAPH
C     KVE IS FORMAT FOR ROOT-MEAN-SQUARE-ERROR GRAPH
C
      DATA KVV/"(1X,A1,","I3.2,","I2.2,","I3,I4,","I3,","2X,73A1,",
+              "4X,31A1,","R3)"/
      DATA KVE/"(1X,A1,","I3.2,","I2.2,","I3,I4,","1X,111A1,","R4)"/
C
      IF(KPRINT.EQ.66) MINSRC=KP
      IF(IAZMTH(1).EQ.".") GO TO 40
C
      DO 10 I=2,72
   10 IAZMTH(I)=" "
      IAZMTH(1)=IAZMTH(73)="."
C
      DO 20 I=2,32
   20 ISPEED(I)=" "
      ISPEED(1)=ISPEED(31)="."
C
      DO 30 I=2,112
   30 IERR(I)=" "
      IERR(1)=IERR(111)="."
C
C======================================================================
C DEFINE VARIABLES AND GRID MARKERS FOR PRINTING (OR PUT BLANKS):
C
C  FOR KPRINT 4,8,16, PRINT:
C     SEQ.NO.,HOUR,MIN,FREQ,RANGE,NUMB ON AZIM-SPEED GRAPH,
C       WITH GRID MARKERS;
C     EXCEPT, FOR KPRINT 4, OMIT HOUR AND HALF OF THE GRID MARKERS IF NOT
C      FIRST CASE OF A GROUP (IF KASE.NE.1).
```

```
C     NUMB=
C      NIVEL: NO. OF INDIVIDUAL VEL. CALCULATIONS PER CASE FOR KPRINT 4;
C      NKVEL: NO. OF CASE-NORM VELOCITIES PER GROUP FOR KPRINT 8;
C      NFF: NO. OF FREQUENCIES WHICH HAVE NON-ZERO GROUP-NORM VELOCITIES
C          FOR KPRINT 16.
C  FOR KPRINT 16:
C     IFREQ,IRANG ARE THE DIFFERENCES BETWEEN THE HIGHEST AND LOWEST
C       FREQUENCIES AND RANGES;
C     MINUTES ARE ROUNDED OUT TO NEAREST 2.5 (BUT SECONDS ARE NOT
C       PRINTED, SO 2=2.5, 7=7.5, ETC.)
C
C  FOR KPRINT 2:
C    AT BEGINNING OF EACH GROUP OF CASES (NGRP.NE.LASTGRP),PRINT:
C     SEQ.NO.,HOUR,MIN,FREQ,RANGE,NUMB(NO.OF SOURCES) ON AZIM-SPEED GRAPH,
C     SEQ.NO.,HOUR,MIN,FWPD,DOPP.NO. ON ERROR GRAPH,
C       WITH GRID MARKERS ON BOTH GRAPHS.
C    IF BEGINNING A NEW CASE (NCOL=1)  BUT NOT A NEW GROUP,
C     OMIT THE HOUR AND HALF OF THE GRID MARKERS.
C    ELSEWHERE (NCOL.NE.1), PRINT ONLY:
C     SEQ.NO.,NUMB ON AZIM-SPEED GRAPH,
C     SEQ.NO.,FWPD,DOPP.NO. ON ERROR GRAPH.
C
C    NUMB COUNTS ONLY THOSE SOURCES USED FOR A VELOCITY CALCULATION,SO
C     WHEN THE SOURCE IS SKIPPED, NUMB IS OMITTED.
C=========================================================================
C
   40 IF((KPRINT.AND.2).NE.0) GO TO 70
      LHR=KHR $ LMIN=KMIN $ MGRID1=MGRID2="."
      IFREQ=IFIX(FREQ/100+.5) $ IRANG=IFIX(RANG+.5) $ KVV(4)="I3,I4,"
      IF((KP.NE.16.AND.KP.NE.99).OR.((NUMB.NE." ").AND.(NUMB.NE.1)))GOTO45
      IFREQ=IRANG=" "  $ KVV(4)="A3,A4,"
   45 KVV(5)="I3," $ IF(NUMB.EQ." ") KVV(5)="A3,"
CCC      IDB=IDOPP=" " $ KVE(1)="(5X,A1,1X,"  $  KVE(4)="2A1,"
      IF((KPRINT.AND.4).NE.0) GO TO 50
      IF(IAZMTH(19).EQ.".") GO TO 130  $ GO TO 90
C
   50 IF(KASE.EQ.1) GO TO 60
      LHR=" "  $ IF(KASE.GT.2) GO TO 130
CCC       KVE(2)="A3,"
      MGRID1=" "  $ KVV(2)="A3,"  $ GO TO 90
C
   60 KVV(2)="I3.2,"
CCC      KVE(2)="I3.2,"
      GO TO 90
C
   70 KVV(5)="I3," $ IF(NUMB.EQ." ") KVV(5)="A3,"
      IDOPP=DOPP  $ IDB=DB
      IF(NCOL.GT.2) GO TO 130
C
      IF(NCOL.EQ.2) GO TO 80
      IFREQ=IFIX(FREQ/100+.5)  $ IRANG=IFIX(RANG+.5)
```

```
      KVV(4)="I3,I4," $ LMIN=KMIN $ KVV(3)=KVE(3)="I2.2," $ MGRID2="."
      IF(NGRP.NE.LASTGRP) GO TO 75
      LHR=MGRID1=" "  $ KVV(2)=KVE(2)="A3,"  $ GO TO 90
C
   75 MGRID1="." $ LHR=KHR $ KVV(2)=KVE(2)="I3.2,"  $ GO TO 90
C
   80 IFREQ=IRANG=" " $ KVV(4)="A3,A4,"
      MGRID1=MGRID2=LHR=LMIN=" "
      KVV(2)=KVE(2)="A3,"
      KVV(3)=KVE(3)="A2,"
C
   90 DO 100 I=1,55,18
      IAZMTH(I)=MGRID2
  100 IAZMTH(I+6)=IAZMTH(I+12)=MGRID1
      IAZMTH(1)="."
C
      DO 110 I=1,21,10
      ISPEED(I)=MGRID2
  110 ISPEED(I+5)=MGRID1
      ISPEED(1)="."
C
      DO 120 I=1,101,10
      IERR(I)=MGRID2
  120 IERR(I+5)=MGRID1
      IERR(1)="."
C
C=====PUT SYMBOLS INTO THE GRAPH COORDINATES WHICH CORRESPOND TO THE
C     VALUES TO BE GRAPHED
C
  130 LASTGRP=NGRP
      IF((NUMB.EQ." ").OR.((KPRINT.EQ.66).AND.(NUMB.LT.MINSRC))) GO TO 310
C
      IF(KP.NE.99) GO TO 270
      DO 140 I=1,NUMFREQ
      IAZZ(I)=0
      IF(GVELZ(I).EQ." ") GO TO 140
      IAZZ(I)=IFIX(GVELAZ(I)/5+1.5)
  140 CONTINUE
      NFQ=NUMFREQ-1
      DO 150 I=1,NFQ
      I1=I+1
      DO 150 J=I1,NUMFREQ
      IF((IAZZ(I).EQ.0).OR.(IAZZ(J).EQ.0)) GO TO 150
      IF(IAZZ(I).EQ.IAZZ(J)) GO TO 160
  150 CONTINUE
      GO TO 170
  160 CALL IDENT(GVELAZ,IAZZ,NUMFREQ,1)
  170 DO 180 I=1,NUMFREQ
      IF(GVELZ(I).EQ." ") GO TO 180
      IATMP(I)=IAZMTH(IAZZ(I))
      IRG=IFIX((FLOAT(IRNG(I))-200)/10+.5)
```

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      IF(IRG.EQ.0) IAZMTH(IAZZ(I))="0"
      IF(IRG.NE.0) IAZMTH(IAZZ(I))=NN(IRG)
  180 CONTINUE
C
      DO 190 I=1,NUMFREQ
      IVZZ(I)=0
      IF(GVELZ(I).EQ." ") GO TO 190
      IF(GVELZ(I).LT.0) IVZZ(I)=MAXO(IFIX(GVELZ(I)/10-1.5),-31)
      IF(GVELZ(I).GE.0) IVZZ(I)=MINO(IFIX(GVELZ(I)/10+1.5),31)
      IVZTMP(I)=ISPEED(IABS(IVZZ(I)))
  190 CONTINUE
      DO 200 I=1,NUMFREQ
      IVHH(I)=0
      IF(GVELZ(I).EQ." ") GO TO 200
      IVHH(I)=MINO(IFIX(GVELH(I)/10+1.5),31)
  200 CONTINUE
      DO 210 I=1,NFQ
      I1=I+1
      DO 210 J=I1,NUMFREQ
      IF((IVHH(I).EQ.0).OR.(IVHH(J).EQ.0)) GO TO 210
      IF(IVHH(I).EQ.IVHH(J)) GO TO 220
  210 CONTINUE
      GO TO 230
  220 CALL IDENT(GVELH,IVHH,NUMFREQ,1)
  230 DO 240 I=1,NUMFREQ
      IF(GVELZ(I).EQ." ") GO TO 240
      IVHTMP(I)=ISPEED(IVHH(I))
  240 CONTINUE
      DO 250 I=1,NUMFREQ
      IF(GVELZ(I).EQ." ") GO TO 250
      IF(IVZZ(I).GT.0) ISPEED(IVZZ(I))="+"
      IF(IVZZ(I).LT.0) ISPEED(-IVZZ(I))="-"
  250 CONTINUE
      DO 260 I=1,NUMFREQ
      IF(GVELZ(I).EQ." ") GO TO 260
      IRG=IFIX((FLOAT(IRNG(I))-200)/10+.5)
      IF(IRG.EQ.0) ISPEED(IVHH(I))="0"
      IF(IRG.NE.0) ISPEED(IVHH(I))=NN(IRG)
  260 CONTINUE
      GO TO 310
C
  270 IF((KPRINT.EQ.66).OR.(NUMB.LT.2)) GO TO 280
      ISIG=MINO(IFIX(SIG/5+1.5),73)
      ISTEMP=IAZMTH(ISIG)  $ IAZMTH(ISIG)="+"
  280 IAZ=IFIX(AZIM/5+1.5)
      IATEMP=IAZMTH(IAZ)  $ IAZMTH(IAZ)="#"
C
      IF(VZ.LT.0) IVZ=MAXO(IFIX(VZ/10-1.5),-31)
      IF(VZ.GE.0) IVZ=MINO(IFIX(VZ/10+1.5),31)
      IVH=MINO(IFIX(VH/10+1.5),32)
      IVZTEMP=ISPEED(IABS(IVZ))  $ IVHTEMP=ISPEED(IVH)
```

```
      IF(IVZ.LT.0) ISPEED(-IVZ)="-"  $ IF(IVZ.GT.0) ISPEED(IVZ)="+"
      ISPEED(IVH)="#"
      IF(IVH.NE.32) GO TO 300
      IVH100=MINO((IFIX(VH/100+.5)),999)
      ENCODE(10,290,ISPEED(IVH)) IVH100
  290 FORMAT(I10)
C
  300 IF(KPRINT.NE.66) GO TO 310
      IE=MINO((IFIX(SQRT(ESQ)+1.5)),112)
      IETEMP=IERR(IE)  $ IERR(IE)="#"
      IF(IE.NE.112) GO TO 310
      IERR100=MINO((IFIX(ESQ+.5)),9999)
      ENCODE(10,290,IERR(IE)) IERR100
C
  310 IF(KP.EQ.16) GO TO 320
      IF(KP.EQ.99) GO TO 330
      WRITE(69,KVV) ISEQ,LHR,LMIN,IFREQ,IRANG,NUMB,IAZMTH,ISPEED
      IF(KPRINT.EQ.66) WRITE(70,KVE) ISEQ,LHR,LMIN,IDB,IDOPP,IERR
      GO TO 340
  320 WRITE(71,KVV) ISEQ,LHR,LMIN,IFREQ,IRANG,NUMB,IAZMTH,ISPEED
      GO TO 340
  330 WRITE(72,KVV) ISEQ,LHR,LMIN,IFREQ,IRANG,NUMB,IAZMTH,ISPEED
CCC       WRITE(72,KVE) ISEQ,LHR,LMIN,IDB,IDOPP,IERR
  340 IF((NUMB.EQ." ").OR.((KPRINT.EQ.66).AND.(NUMB.LT.MINSRC))) RETURN
      IF(KP.EQ.99) GO TO 350
C
      IAZMTH(IAZ)=IATEMP  $ ISPEED(IVH)=IVHTEMP
      IF(KPRINT.EQ.66)IERR(IE)=IETEMP  $ ISPEED(IABS(IVZ))=IVZTEMP
      IF((KPRINT.NE.66).AND.(NUMB.GT.1)) IAZMTH(ISIG)=ISTEMP
      RETURN
C
  350 DO 360 I=1,NUMFREQ
      IF(GVELZ(I).EQ." ") GO TO 360
      IAZMTH(IAZZ(I))=IATMP(I)
      ISPEED(IABS(IVZZ(I)))=IVZTMP(I)
      ISPEED(IVHH(I))=IVHTMP(I)
  360 CONTINUE
      RETURN  $ END
C
C
C
C=================  S U B R O U T I N E   A L L F R E Q  =================
C FINDS AVERAGE (OR MEDIAN) OF GROUP-NORM VELOCITIES FOR ALL FREQUENCY
C   NUMBERS.  EACH RUN WRITES ON TAPE49 THE GROUP-NORM VELOCITIES
C   CALCULATED FROM THE INPUT DATA ON TAPE50  (DATA FOR ONE FREQUENCY
C   NUMBER)  PLUS THE VELOCITIES FROM OTHER FREQUENCY NUMBERS ALREADY
C   STORED ON TAPE48, IF ANY. IN THE LAST RUN (WHEN DATA OF LAST FREQ. NO.
C   IS BEING RUN) THE SUBROUTINE CALCULATES THE AVE. OR MEDIAN OVER ALL
C   FREQ. NO.'S, AND WRITES THE RESULT ON TAPE49, WITH THE POLAR MAP IF
C   REQUESTED, AND  WRITES THE GRAPHS, IF REQUESTED, ON TAPES 71 AND 72.
C AT THE END OF A RUN, IF NOT ALL FREQUENCY NUMBERS HAVE BEEN RUN, BE SURE
```

```
C   TO RENAME TAPE48=TAPE49 TO USE TAPE48 (AS WELL AS TAPE50) AS INPUT FOR
C   THE RUN AT THE NEXT FREQUENCY NUMBER.  (FREQUENCY NUMBERS DON"T HAVE
C   TO BE RUN IN ORDER.)
C===========================================================================
C
          SUBROUTINE ALLFREQ(KPRINT,NGRP,NGRPDAT,NGRPHR,NGRPMIN,NGRPSEC,GVX,
+         GVY,GVZ,FREQ,RANG,NUMFREQ,NFREQ,ONE,ICV,ICV3,IFHEAD,LASFREQ,NFVEL)
C
C=====NUMFREQ=THE TOTAL NUMBER OF FREQUENCIES;
C        NFREQ=THE ACTUAL FREQ. NO. FOR THIS RUN.
C
          COMMON/IR7/IRANG(7)
          COMMON/IGA/NN(35)
          COMMON/G/GVELZZ(6),GVELH(6),GVELAZ(6)
          DIMENSION GVELX(6),GVELY(6),GVELZ(6),KVD(13),KVH(24)
          DIMENSION GFREQ(7),MHZ(7),KM(7),KFR(22)
C
C=====KVH=FORMAT FOR HEADING;  KVD: FOR DATA;  KFR: FOR FREQ AND RANGE.
C
          DATA KVH/"(/////44X,","4X,","*GROUP*,","     *-NORM ","VELOCITIES",
+         "*,34X,*/*,","  *    AVE ","OR MED OF ","ALL*/101X,","2X,",
+         "*/*,6X,","*FREQUENCI","ES*/9X,","2X,","6(","*   / FREQ.",
+         " NO.*,I2),","*   /*,25X","/2X,","*DATE   TIM","E*,7(* / V",
+         "X    VY    V","Z*),* SIGM","A NI NF*)"/
C
          NGTIME=NGRPHR*10000+NGRPMIN*100+NGRPSEC
          IF(KPRINT.EQ.48) KVH(19)=",*SEQ*/2X,"
C
          KVD(1)="(1X," $ KVD(2)="I5,1X," $ KVD(3)="I6.6,"
          DO 4 K=4,10
        4 KVD(K)="3F5,"
          KVD(11)="F5," $ KVD(12)="2I3," $ KVD(13)="1X,A1,1X)"
C
          KFR(1)="(7X,I6.6,"
          DO 6 K=2,20,3
          KFR(K)="F4.1,A3,"  $ KFR(K+1)="I5,A2,"
        6 KFR(K+2)="1X,"
          KFR(22)=")"
C
          LASFREQ=KDATE=KTIME=NIF=NFF=0
          DO 5 K=1,6
          MHZ(K)=KM(K)=" "
        5 GVELX(K)=GVELY(K)=GVELZ(K)=GFREQ(K)=IRANG(K)=0
          FVX=FVY=FVZ=FSIG=GFREQ(7)=IRANG(7)=0  $ MHZ(7)=KM(7)=" "
C
C=====ADVANCE TAPE48 BEYOND HEADING; WRITE HEADING ON TAPE49.
C
          IF(IFHEAD.EQ.1) GO TO 60
       20 FORMAT(A6)
       21 READ(48,20) IREAD
          IF(EOF(48))25,24
```

```
C
    24 IF(IREAD.NE."  DATE") 21,35
    25 EOF48=1.  $ GO TO 30
    35 EOF48=0.
    30 WRITE(49,KVH) (N,N=1,6)
       IFHEAD=1
C
    60 DO 61 K=1,NUMFREQ
    61 GVELZ(K)=999.
C
C=====READ DATE,TIME,AND DATA FROM TAPE48
C
    62 IF(EOF48.EQ.1.) GO TO 100
       READ(48,KVD) KDATE,KTIME,(GVELX(K),GVELY(K),
+                   GVELZ(K),K=1,6),FVX,FVY,FVZ,FSIG,NIF,NFF
       IF(EOF(48))65,65
    65 READ(48,KFR)KTIME,(GFREQ(M),MHZ(M),IRANG(M),KM(M),M=1,7)
       IF(EOF(48))68,70
C
    68 EOF48=1.
       GO TO 100
C
C=====IF DATE AND TIME FROM TAPE48 DON'T MATCH THOSE OF THIS GROUP,
C     READ NEXT RECORD.
C
    70 IF((NGRPDAT.NE.KDATE).OR.(NGTIME.NE.KTIME)) GO TO 62
C
CCC       PRINT 75,KDATE,KTIME,NGRPDAT,NGTIME
CCC    75 FORMAT(" DATE AND/OR TIME DO NOT MATCH.  TAPE48 IS AT ",
CCC+             I5,1X,I6.6,/" AND THIS RUN IS AT ",
CCC+             I5,1X,I6.6,".")
CCC       STOP
C
C=====PUT VELOCITIES CALCULATED IN THIS RUN INTO ARRAYS GVELX, ETC.
C
   100 SX=1.
       SY=1.
       IF(GVX.NE.0.) SX=GVX/ABS(GVX)
       IF(GVY.NE.0.) SY=GVY/ABS(GVY)
       GVELX(NFREQ)=AMIN1(999.,ABS(GVX))*SX
       GVELY(NFREQ)=AMIN1(999.,ABS(GVY))*SY  $ GVELZ(NFREQ)=GVZ
       IF(GVX.EQ.0.0.AND.GVY.EQ.0.0.AND.GVZ.EQ.0.0) GO TO 105
       GFREQ(NFREQ)=FREQ/1000  $ MHZ(NFREQ)="MHZ"
       IRANG(NFREQ)=IFIX(RANG+.5)  $ KM(NFREQ)="KM"
C
   105 DO 110 K=1,NUMFREQ
   110 IF(GVELZ(K).EQ.999.) GO TO 130
C
C=====IF ALL FREQUENCIES HAVE BEEN RUN, FIND MEDIAN OR AVERAGE.
C     NFVEL COUNTS THE NUMBER OF GROUPS THAT HAVE A GROUP-NORM VELOCITY
C       FOR AT LEAST ONE FREQUENCY NUMBER.
```

```
C
      LASFREQ=1
      GO TO (111,112,113) ICV
  111 CALL MEDIAN(GVELX,GVELY,GVELZ,ONE,NUMFREQ,FVX,FVY,FVZ,FSIG,DUM,NFF)
      GO TO 114
  112 CALL MEDIAN(GVELX,GVELY,GVELZ,ONE,NUMFREQ,FVX,FVY,FVZ,FSIG,DUM,NFF)
      GO TO 114
  113 CALL AVE(NFREQ,ICV3,GVELX,GVELY,GVELZ,ONE,NUMFREQ,FVX,FVY,FVZ,
+               FSIG,DUM,NIF,NFF)
C
  114 DELFREQ=DELRANG=0.
      IF(NFF.EQ.0) GO TO 120
      NFVEL=NFVEL+1  $ FREQMAX=MAXRANG=0  $ FREQMIN=MINRANG=9999
      DO 118 M=1,NUMFREQ
      IF(GFREQ(M).EQ.0.) GO TO 118
      FREQMAX=AMAX1(GFREQ(M),FREQMAX)
      FREQMIN=AMIN1(GFREQ(M),FREQMIN)
      MAXRANG=MAX0(IRANG(M),MAXRANG)
      MINRANG=MIN0(IRANG(M),MINRANG)
  118 CONTINUE
      DELFREQ=GFREQ(7)=FREQMAX-FREQMIN
      DELFREQ=DELFREQ*1000
      IRANG(7)=MAXRANG-MINRANG
      DELRANG=IRANG(7)
      MHZ(7)="MHZ"  $ KM(7)="KM"
C
      IF(KPRINT.EQ.48) CALL POLMAP(IDUM,KPRINT,NGRP,FVY,FVX,IVY,IVX,1)
C
  120 IF((KPRINT.AND.64).EQ.0) GO TO 130
      CALL VEL(FVX,FVY,FVZ,FVH,FV,FAZ,FEL)  $ IFSEQ=NN(NGRP)
      NFFF=NFF  $ IF(NFFF.EQ.0) NFFF=" "
      CALL GRAPH(IFSEQ,NGRPHR,NGRPMIN,DELFREQ,DELRANG,NFFF,DUM,DUM1,
+                 IDUM,IDUM1,NDUM,FVH,FVZ,FAZ,FSIG,DUM2,KPRINT,IDUM2,16)
CCC      IF(NUMFREQ.GT.3) GO TO 130
      IF(NFFF.EQ." ") GO TO 128
      DO 126 I=1,NUMFREQ
      GVELH(I)=SQRT(GVELX(I)**2+GVELY(I)**2)
      IF((GVELX(I).EQ.0.).AND.(GVELY(I).EQ.0.)) GO TO 125
      GVELAZ(I)=ATAN2(GVELY(I),GVELX(I))/.0174532925199433
      IF(GVELAZ(I).GT.0.0) GVELAZ(I)=360-GVELAZ(I)
      IF(GVELAZ(I).LT.0.0) GVELAZ(I)=-GVELAZ(I)
      GO TO 126
  125 GVELAZ(I)=0.
  126 CONTINUE
      DO 127 I=1,NUMFREQ
      GVELZZ(I)=GVELZ(I)
  127 IF((GVELX(I).EQ.0.).AND.(GVELY(I).EQ.0.).AND.(GVELZ(I).EQ.0.))
+        GVELZZ(I)=" "
CCC      GVELZZ(4)=FVZ  $ GVELH(4)=FVH  $ GVELAZ(4)=FAZ
  128 CALL GRAPH(IFSEQ,NGRPHR,NGRPMIN,DELFREQ,DELRANG,NFFF,DUM,DUM1,
+                 IDUM,IDUM1,NDUM,FVH,FVZ,FAZ,FSIG,DUM2,KPRINT,NUMFREQ,99)
```

```
C
C=====PREPARE VARIABLES FOR OUTPUT (PUT BLANKS IF APPROPRIATE,
C     AND RE-DEFINE FORMAT IN CONSEQUENCE; PUT BLANKS FOR SIGMA UNLESS
C     ALL-FREQ VEL IS AN AVE OR MEDIAN OF AT LEAST 2 GROUP-NORM VELOCITIES)
C
  130 DO 140 M=1,6
      IF((GVELX(M).NE.0.).OR.(GVELY(M).NE.0.).OR.(GVELZ(M).NE.0.))
+        GO TO 140
      GVELX(M)=GVELY(M)=GVELZ(M)=GFREQ(M)=" "
      MHZ(M)=IRANG(M)=KM(M)=" "
      KVD(M+3)="3A5,"  $ KFR(3*M-1)="A4,A3,"  $ KFR(3*M)="A5,A2,"
  140 CONTINUE
C
      IF(NFF.NE.0) GO TO 150
      FVX=FVY=FVZ=" "
      KVD(10)="3A5,"
  150 IF(NFF.GT.1) GO TO 160
      MHZ(7)=IRANG(7)=KM(7)=" "  $ GFREQ(7)=" "
      KFR(20)="A4,A3,"  $ KFR(21)="A5,A2,"
C
  160 IF(NFF.GT.1) GO TO 170
      FSIG=" "  $ KVD(11)="A5,"
C
C=====WRITE DATE, TIME, VELOCITIES, ETC ON TAPE49; ALSO SEQUENCE
C     NUMBERS (1-9,A-Z) IF WRITING POLAR MAP (KPRINT 32)
C
  170 ISEQ=" "
      IF((KPRINT.AND.32).NE.0) ISEQ=NN(NGRP)
      WRITE(49,KVD)NGRPDAT,NGTIME,(GVELX(M),GVELY(M),
+                   GVELZ(M),M=1,6),FVX,FVY,FVZ,FSIG,NIF,NFF,ISEQ
      WRITE(49,KFR)NGTIME,(GFREQ(M),MHZ(M),IRANG(M),KM(M),M=1,7)
      IF((NFF.NE.0).AND.(LASFREQ.EQ.1).AND.(KPRINT.EQ.48))
+        CALL POLMAP(NFVEL,KPRINT,NGRP,DUM,DUM1,IVY,IVX,2)
      IF(LASFREQ.EQ.1) WRITE(49,180)
  180 FORMAT("  ")
C
C
      RETURN
      END
C
C
C
C==================  S U B R O U T I N E   M E D I A N  ==================
C
      SUBROUTINE MEDIAN(VX,VY,VZ,ESQ,NC,VXMED,VYMED,VZMED,SIG,ESQOUT,
+                       KOUNT)
C
      DIMENSION VX(1),VY(1),VZ(1),ESQ(1)
      DIMENSION VXTEMP(60),VYTEMP(60),VZTEMP(60)
      DIMENSION IVXWHT(60),IVYWHT(60),IVZWHT(60)
      DIMENSION VXESQ(60),VYESQ(60),VZESQ(60)
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C
CCC        PRINT*," "
CCC        PRINT*,"VX,VY,VZ,ESQ"
CCC        PRINT 200,(VX(I),I=1,NC)
CCC        PRINT 200,(VY(I),I=1,NC)
CCC        PRINT 200,(VZ(I),I=1,NC)
CCC        PRINT 200,(ESQ(I),I=1,NC)
      200 FORMAT(16F8.1)
C
C=====NC INDICATES HOW MANY VECTORS (SOME OF WHICH MAY BE ZERO) ARE IN
C     ARRAYS VX,VY,VZ,ESQ
C
        IF(NC.LE.60) GO TO 10
        PRINT*," ARRAYS VXTEMP, ETC., NOT LARGE ENOUGH."  $ STOP
C
     10 IF(NC.EQ.0) GO TO 60
C
        DO 5 I=1,60
        IVXWHT(I)=IVYWHT(I)=IVZWHT(I)=0
      5 VXTEMP(I)=VYTEMP(I)=VZTEMP(I)=0.
C
C=====PUT NON-ZERO VECTORS (VX,VY,VZ) AND THEIR ESQ'S AND WEIGHTS INTO
C     ARRAYS VXTEMP,ETC. MAXIMUM WEIGHT WT IS 1, ALL WT'S BEING 1 IF ESQ
C     IS INPUTTED AS "ONE" WHEN SUBROUTINE IS CALLED; IVXWHT,ETC.=WEIGHTS
C     ROUNDED OUT TO INTEGER AFTER MULTIPLICATION BY 10000.
C
        KOUNT=ISUMWHT=0
        DO 20 I=1,NC
        IF((VX(I).EQ.0.).AND.(VY(I).EQ.0.).AND.(VZ(I).EQ.0.)) GO TO 20
        KOUNT=KOUNT+1
        VXTEMP(KOUNT)=VX(I)
        VYTEMP(KOUNT)=VY(I)
        VZTEMP(KOUNT)=VZ(I)
        VXESQ(KOUNT)=VYESQ(KOUNT)=VZESQ(KOUNT)=ESQ(I)
        WT=AMIN1(1.,(1/(SQRT(ESQ(I)+.00000001))))
        IVXWHT(KOUNT)=IVYWHT(KOUNT)=IVZWHT(KOUNT)=IFIX((WT*10000)+.5)
        ISUMWHT=ISUMWHT+IVXWHT(KOUNT)
     20 CONTINUE
C
CCC        PRINT*,"VXTEMP,VYTEMP,VZTEMP"
CCC        PRINT 200,(VXTEMP(I),I=1,NC)
CCC        PRINT 200,(VYTEMP(I),I=1,NC)
CCC        PRINT 200,(VZTEMP(I),I=1,NC)
CCC        PRINT 220,ISUMWHT,(IVXWHT(I),I=1,NC)
    220 FORMAT("ISUMWHT ",I8/"WEIGHTS"/16I8)
C
        IF(KOUNT.EQ.0) GO TO 60
        IF(KOUNT.EQ.1) GO TO 50
C
C=====SEPARATELY SORT VX,VY,VZ INTO DESCENDING ORDER, KEEPING TRACK
C     OF THEIR LEAST SQUARE ERRORS AND WEIGHTS.
```

```
C
      CALL VSORT(VXTEMP,VXESQ,IVXWHT,KOUNT)
      CALL VSORT(VYTEMP,VYESQ,IVYWHT,KOUNT)
      CALL VSORT(VZTEMP,VZESQ,IVZWHT,KOUNT)
C
CCC      PRINT*,"SORTED V*TEMP,V*ESQ,IV*WHT,  *=X,Y,Z"
CCC      PRINT 200,(VXTEMP(I),I=1,NC)
CCC      PRINT 200,(VXESQ(I),I=1,NC)
CCC      PRINT 230,(IVXWHT(I),I=1,NC)
CCC      PRINT 200,(VYTEMP(I),I=1,NC)
CCC      PRINT 200,(VYESQ(I),I=1,NC)
CCC      PRINT 230,(IVYWHT(I),I=1,NC)
CCC      PRINT 200,(VZTEMP(I),I=1,NC)
CCC      PRINT 200,(VZESQ(I),I=1,NC)
CCC      PRINT 230,(IVZWHT(I),I=1,NC)
  230 FORMAT(16I8)
CCC      PRINT*,"KOUNT=",KOUNT
C
C=====FIND THE MIDDLE VALUE OF THE SUM OF THE WEIGHTS.  FIND WEIGHTED
C     OR UNWEIGHTED MEDIANS FOR VX,VY,VZ SEPARATELY. (SEE COMMENTS IN
C     SUBROUTINE WHTMED)
C
      CENTER=FLOAT(ISUMWHT)/2+.5
      MID=MID1=IFIX(CENTER)
      IF(FLOAT(MID).NE.CENTER) MID1=MID1+1
C
      CALL WHTMED(VXTEMP,VXESQ,IVXWHT,MID,MID1,VXMED,ESQX,KOUNT)
      CALL WHTMED(VYTEMP,VYESQ,IVYWHT,MID,MID1,VYMED,ESQY,KOUNT)
      CALL WHTMED(VZTEMP,VZESQ,IVZWHT,MID,MID1,VZMED,ESQZ,KOUNT)
      ESQOUT=(ESQX+ESQY+ESQZ)/3
C
C=====                      2  KOUNT                          2
C     X-VARIANCE = (SIGMA-X) =  SUM WX(I)*(VX(I)-VXMEDIAN)
C                               I=1
C                               ---------------------------
C                                               KOUNT-1
C     WHERE WX(I) IS THE WEIGHT NORMALIZED SO THAT THE SUM OF THE
C       WEIGHTS EQUALS KOUNT.
C
      WX=WY=WZ=0
      ANORM=FLOAT(KOUNT)/FLOAT(ISUMWHT)
      SIG=SIGXSQ=SIGYSQ=SIGZSQ=0
      DO 70 I=1,KOUNT
CCC      PRINT*,"I=",I
      W=ANORM*FLOAT(IVXWHT(I))
      WX=WX+W
CCC      PRINT*,"W,VXTEMP(I) ",W,VXTEMP(I)
      SIGXSQ=SIGXSQ+W*((VXTEMP(I)-VXMED)**2)
      W=ANORM*FLOAT(IVYWHT(I))
      WY=WY+W
CCC      PRINT*,"W,VYTEMP(I) ",W,VYTEMP(I)
```

```
      SIGYSQ=SIGYSQ+W*((VYTEMP(I)-VYMED)**2)
      W=ANORM*FLOAT(IVZWHT(I))
      WZ=WZ+W
CCC      PRINT*,"W,VZTEMP(I) ",W,VZTEMP(I)
   70 SIGZSQ=SIGZSQ+W*((VZTEMP(I)-VZMED)**2)
CCC      PRINT*,"WX,WY,WZ,KOUNT ",WX,WY,WZ,KOUNT
      SIGXSQ=SIGXSQ/(KOUNT-1)
      SIGYSQ=SIGYSQ/(KOUNT-1)
      SIGZSQ=SIGZSQ/(KOUNT-1)
      SIG=SQRT(SIGXSQ+SIGYSQ+SIGZSQ)
CCC      PRINT*,"SIG:XSQ,YSQ,ZSQ; SIG "
CCC      PRINT*,SIGXSQ,SIGYSQ,SIGZSQ,SIG
C
CCC      PRINT 210,VXMED,VYMED,VZMED,ESQOUT,SIG,KOUNT
  210 FORMAT("VXMED,VYMED,VZMED,ESQOUT,SIG,KOUNT ",5F8.1,I4)
      RETURN
C
C=====IF ONLY ONE VECTOR, IT BECOMES THE MEDIAN.
C
   50 VXMED=VXTEMP(1) $VYMED=VYTEMP(1) $VZMED=VZTEMP(1) $ESQOUT=VXESQ(1)
      SIG=0
CCC      PRINT 210,VXMED,VYMED,VZMED,ESQOUT,SIG,KOUNT
      RETURN
C
   60 VXMED=VYMED=VZMED=ESQOUT=SIG=0
CCC      PRINT 210,VXMED,VYMED,VZMED,ESQOUT,SIG,KOUNT
      RETURN
      END
C
C
C
C===================  S U B R O U T I N E   V S O R T  ====================
C     SORT V,E,IWHT INTO DESCENDING ORDER OF V.
C
      SUBROUTINE VSORT(V,E,IWHT,ILAST)
C
      DIMENSION V(1),E(1),IWHT(1)
C
      IEND=ILAST-1
   10 IFAGAIN=0
      DO 20 I=1,IEND
      IF(V(I).GE.V(I+1)) GO TO 20
      IFAGAIN=1
      TEMP=V(I)   $ V(I)=V(I+1)   $ V(I+1)=TEMP
      TEMP=E(I)   $ E(I)=E(I+1)   $ E(I+1)=TEMP
      ITEMP=IWHT(I)   $ IWHT(I)=IWHT(I+1)   $ IWHT(I+1)=ITEMP
   20 CONTINUE
      IF(IFAGAIN.EQ.1) GO TO 10
C
      RETURN
      END
```

```
C
C
C
C=================== S U B R O U T I N E   W H T M E D ==================
C FIND WEIGHTED MEDIAN VMED (VMED=UNWEIGHTED MEDIAN IF ALL WEIGHTS ARE
C   EQUAL) AND ITS LEAST SQUARE ERROR ESQV.
C CONSIDER WEIGHT AS "FREQUENCY OF OCCURRENCE" OF A VALUE.  MID=MID1 IS
C   THE MIDDLE NUMBER OF THE SUM OF THE FREQUENCIES (WEIGHTS) IF THERE ARE
C   AN ODD NUMBER OF VALUES (EACH OCCURRENCE OF A VALUE BEING CONSIDERED A
C   DIFFERENT VALUE).  MID,MID1 ARE THE TWO MIDDLE NUMBERS IF THERE ARE AN
C   EVEN NUMBER OF VALUES.
C VMED=VMED(MID) IF MID=MID1; VMED=AVERAGE OF VMED(MID),VMED(MID1) IF NOT.
C   SIMILARLY FOR ESQV.
C=========================================================================
C
      SUBROUTINE WHTMED(V,ESQ,IWHT,MID,MID1,VMED,ESQV,KOUNT)
C
      DIMENSION V(1),ESQ(1),IWHT(1)
C
CCC      PRINT*,"MID,MID1 ",MID,MID1
      ISUMWHT=0  $ VMED1=99999.
      DO 10 I=1,KOUNT
      ISUMWHT=ISUMWHT+IWHT(I)
CCC      PRINT*,"ISUMWHT=",ISUMWHT
      IF(VMED1.NE.99999.) GO TO 5
      IF(ISUMWHT.LT.MID) GO TO 5
      VMED1=V(I)  $ ESQ1=ESQ(I)
    5 IF(ISUMWHT.LT.MID1) GO TO 10
      VMED2=V(I)  $ ESQ2=ESQ(I)
CCC      PRINT*,"VMED1,ESQ1,VMED2,ESQ2 ",VMED1,ESQ1,VMED2,ESQ2
      GO TO 20
   10 CONTINUE
C
   20 VMED=(VMED1+VMED2)/2
      ESQV=(ESQ1+ESQ2)/2
CCC      PRINT*,"VMED,ESQV ",VMED,ESQV
      RETURN
      END
C
C
C
C=================== S U B R O U T I N E   I D E N T ====================
C=====CALLED BY SUBROUTINE GRAPH: IF 2 OR MORE GRAPH COORDINATES ARE
C     IDENTICAL, IT "SPREADS" THEM OUT, KEEPING THEM AS CLOSE TO THE
C     ORIGINAL COORDINATE(S) AS POSSIBLE.
C       FOR EXAMPLE: COORDINATES 7,7,4,12 BECOME 6,7,4,12
C                    COORDINATES 10,10,10,10,10,10 BECOME 7,8,9,10,11,12
C
      SUBROUTINE IDENT(PARAM,INDEX,NUMFREQ,ICN)
C
      COMMON/G/GVELZ(6),GVELH(6),GVELAZ(6)
```

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```
      DIMENSION PARAM(6),INDEX(6),PAR(6),IND(6),IP(6)
C
      J=0
      DO 10 I=1,NUMFREQ
      PAR(I)=IND(I)=IP(I)=0
      IF(GVELZ(I).EQ." ") GO TO 10
      J=J+1
      PAR(J)=PARAM(I)  $ IND(J)=INDEX(I)  $ IP(J)=I
   10 CONTINUE
      JA=J  $ J1=J-1
C
      IF(ICN.EQ.2) GO TO 25
      DO 20 J=1,JA
      IF(IND(J).LE.(73-NUMFREQ)) GO TO 20
      IND(J)=IND(J)-72  $ PAR(J)=PAR(J)-360
   20 CONTINUE
C
   25 IFAGAIN=0
      DO 30 J=1,J1
      IF(PAR(J).LE.PAR(J+1)) GO TO 30
      IFAGAIN=1
      TEMP=PAR(J)  $ PAR(J)=PAR(J+1)  $ PAR(J+1)=TEMP
      ITEMP=IND(J)  $ IND(J)=IND(J+1)  $ IND(J+1)=ITEMP
      ITEMP=IP(J)  $ IP(J)=IP(J+1)  $ IP(J+1)=ITEMP
   30 CONTINUE
      IF(IFAGAIN.EQ.1) GO TO 25
C
      NT=IFIX(FLOAT(JA)/2+.5)
      JA1=JA-1  $ NTK=0
   40 IFAGAIN=0   $ NTK=NTK+1
      DO 50 J=1,JA1
      IF(IND(J).NE.IND(J+1)) GO TO 50
      IFAGAIN=1
      IND(J)=IND(J)-1
      GO TO 60
   50 CONTINUE
   60 IF(IFAGAIN.NE.1)GO TO 90
      IF(NTK.GT.NT) GO TO 80
      DO 70 J=1,JA1
      IBK=JA1+1-J
      IF(IND(IBK+1).NE.IND(IBK)) GO TO 70
      IFAGAIN=1
      IND(IBK+1)=IND(IBK+1)+1
      GO TO 80
   70 CONTINUE
   80 IF(IFAGAIN.EQ.1) GO TO 40
C
   90 IF(ICN.EQ.2) GO TO 110
      DO 120 J=1,JA
      IF(IND(J).LT.1) IND(J)=IND(J)+73
  120 IF(IND(J).GT.73) IND(J)=IND(J)-73
```

DRIFVEL (ULCAR)

```
C
  110 DO 100 J=1,JA
  100 INDEX(IP(J))=IND(J)
      RETURN
      END
```

BIOGRAPHICAL SKETCH

Claude G. Dozois was born on November 16, 194[illegible] in Lewiston, Maine, where he attended elementary school. He graduated from St. Joseph's High School Seminary in Bucksport, Maine in 1960, and obtained a Bachelor of Arts degree in Philosophy from the Oblate College and Seminary in Natick, Massachusetts in 1965. After completing his theological preparation at the Boston Theological Institute in Cambridge, Massachusetts, he was ordained to the priesthood and served in church ministry for several years. After making up undergraduate physics pre-requisites as a special student at the University of Lowell, he was admitted in the fall of 1979 as a matriculated graduate student in the Master of Science program in the Department of Physics of the University of Lowell. During his studies he worked part time under the supervision of Prof. Reinisch at the University of Lowell Center for Atmospheric Research, first as a technician and later as a research assistant.

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