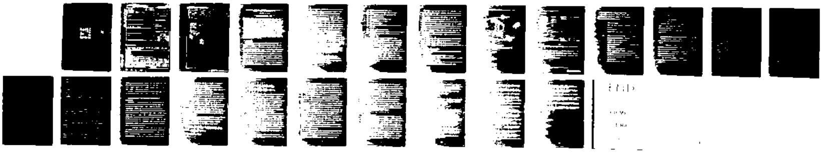
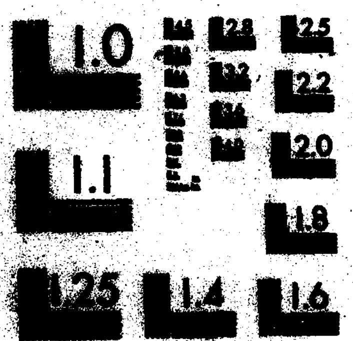
AD-A135 844 ON GENERATION ESTIMATION UTILIZATION AVAILABILITY AND COMPATIBILITY ASPEC..(U) ARMY ENGINEER TOPOGRAPHIC LABS FORT BELVOIR VA H B LUETZOW AUG 83 ETL-R053 1/1

UNCLASSIFIED F/G 22/2 NL




1.0
2.8
2.5
3.2
2.2
3.6
4.0
2.0
1.1
1.8
1.25
1.4
1.6

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: ETL R-053
2. GOVT ACCESSION NO.: AD-A135844
3. RECIPIENT'S CATALOG NUMBER:
4. TITLE (and Subtitle): On Generation, Estimation, Utilization, Availability and Compatibility Aspects of Geodetic and Meteorological Data
5. TYPE OF REPORT & PERIOD COVERED:
6. PERFORMING ORG. REPORT NUMBER:
7. AUTHOR(s): Dr. H. Baussus von Luetzow
8. CONTRACT OR GRANT NUMBER(s):
9. PERFORMING ORGANIZATION NAME AND ADDRESS:
10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS:
11. CONTROLLING OFFICE NAME AND ADDRESS: US Army Engineer Topographic Laboratories, Fort Belvoir, VA 22060
12. REPORT DATE: August 1983
13. NUMBER OF PAGES:
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office):
15. SECURITY CLASS. (of this report):
15a. DECLASSIFICATION/DOWNGRADING SCHEDULE:
16. DISTRIBUTION STATEMENT (of this Report): Approved for public release; distribution unlimited

DTIC SELECTE DEC 15 1983 D

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report):

D

18. SUPPLEMENTARY NOTES: Presented at the Interdisciplinary Symposium "Data Management," International Union of Geodesey and Geophysics (IUGG) XVIII General Assembly, Hamburg, West Germany, 15-27 August 1983

19. KEY WORDS (Continue on reverse side if necessary and identify by block number):
Generation
Estimation
Utilization
Geodetic
Meteorological

20. ABSTRACT (Continue on reverse side if necessary and identify by block number):
Following an introduction, the paper discusses in section 2 the collection or generation of final geodetic data from conventional surveys, satellite observations, satellite altimetry, the Global Positioning System, and moving base gravity gradiometers. Section 3 covers data utilization and accuracy aspects including gravity programmed inertial positioning and subterraneous mass detection. Section 4 addresses the usefulness and limitation of the collocation method of physical geodesy. Section 5 is concerned with the computation of classical climatological data. In section 6, meteorological data assimilation is considered. Section 7

DD FORM 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

83 12 14 048

deals with correlated aspects of initial data generation with emphasis on initi wind field determination, parameterized and classical hydrostatic prediction models, non-hydrostatic prediction, computational networks and computer capacit The paper concludes that geodetic and meteorrological data are expected to become increasingly more diversified and voluminous both regionally and globally, that its general availability will be more or less restricted for some time to come, that its quality and quantiy are subject to change and that meteorologica generation, accuracy and density have to be considered in conjunction with advanced as well as cost-effective numerical weather prediction models and associated computational efforts.

ON GENERATION, ESTIMATION, UTILIZATION, AVAILABILITY AND COMPATIBILITY ASPECTS OF GEODETIC AND METEOROLOGICAL DATA

H. Baussus von Luetzow

US Army Engineer Topographic Laboratories
Fort Belvoir, Virginia 22060

Following an introduction, the paper discusses in section 2 the collection or generation of final geodetic data from conventional surveys, satellite observations, satellite altimetry, the Global Positioning System, and moving base gravity gradiometers. Section 3 covers data utilization and accuracy aspects including gravity programmed inertial positioning and subterranean mass detection. Section 4 addresses the usefulness and limitation of the collocation method of physical geodesy. Section 5 is concerned with the computation of classical climatological data. In section 6, meteorological data assimilation is considered. Section 7 deals with correlated aspects of initial data generation with emphasis on initial wind field determination, parameterized and classical hydrostatic prediction models, non-hydrostatic prediction, computational networks, and computer capacity. The paper concludes that geodetic and meteorological data are expected to become increasingly more specialized and voluminous both regionally and globally, that its general availability will be more or less restricted for some time to come, that its quality and quantity are subject to change, and that meteorological data generation, accuracy and density have to be considered in conjunction with advanced as well as cost-effective numerical weather prediction models and [illegible].

1. Introduction

Fundamental aspects of geodetic data management were addressed at the Symposium on Management of Geodetic Data, Copenhagen, August, 1981, and a number of pertinent articles are published in Bulletin Geodesique, Volume 56. While management of geodetic data is not restricted to gravity measurements and their coordinate identifications, they are playing a fundamental role because of the relative simplicity of their determination, accuracy, [illegible] density, and geodetic applications, sometimes in combination with satellite and satellite altimetry data. In contrast to essentially static geodetic data and the absence of a critical time constraint as to applications, meteorological data for operational numerical weather prediction has to be rapidly acquired and processed for use in dynamic prediction models with [illegible] speedy dissemination. The data base has to be preferably world-[illegible] and the output extends to several variables and a number of discrete [illegible] For this reason, all organizations concerned with operational [illegible] have developed extensive data management systems. [illegible] and meteorological data management have in common the predominant [illegible] or public organizations. There is, however, a much [illegible] data exchange in meteorology, dictated by necessity, [illegible] military considerations impose certain restrictions at [illegible] proprietary rights are also claimed by private [illegible] from the abstract, this paper is not concerned with [illegible] technical sense, including consideration of [illegible] It emphasizes the influence of [illegible] and identifies some geodetic and [illegible] systems. In the field [illegible] of gravity gradiometers and its [illegible] In meteorology, it emphasizes [illegible] and a denser network of [illegible] on the problem of data [illegible] with improved dynamic models. [illegible] limitations of necessity not [illegible] and contextual in nature.

[illegible] of [illegible] and [illegible] Data.

[illegible] purposes consist, under deletion of [illegible] of geodetic networks and the conventional [illegible] positions, essentially of:

(1) Satellite Doppler and Related Measurements

(2) Satellite Altimetry Measurements, GEOS 3 and SEASAT

(3) Global Positioning System (GPS) Measurements (New)

(4) Point Gravity Measurements

(5) Elevation Measurements (Topographic Maps)

(6) Astrogeodetic Vertical Deflections

(7) Polar Motion Measurements

(8) Height Anomaly or Geoid Representations (Including Combined Solutions)

(9) Satellite Altimetry Representations

(10) Astrogeodetic - Inertially Determined Gravity Vector Components

(11) Astrogeodetic - Gradiometrically Derived Gravity Vector Components (New)

(12) Satellite - Based Gradiometric Measurements (Future)

The primary data center pertaining to satellites is the National Space Science Data Center, Greenbelt, Maryland (World Data Center - A for Rockets and Satellites) which also performs data management studies. Gravimetric information is provided by the National Geodetic Service Data Center in Boulder, Colorado (World Data Center - A for Solid Earth Geophysics). It is obtained primarily from the International Gravimetric Bureau, Paris, France, as the central agency of the International Gravity Commission whose data management has been described by Isaac [1982]. Height anomaly or geoid representations may be obtained from Goddard Space Flight Center, Greenbelt, Maryland and from the Department of Geodetic Sciences and Surveying, The Ohio State University, Columbus, Ohio.

While geodetic data generation, except for point measurements, has been potentially facilitated by satellite technology combined with new instrumentation, dense, uniform, and highly accurate regional gravity vector determination is expected to be performed in the United States after 1987. The anticipated accuracies of 0.2 arcsec rms and 1 mgal rms in the context of constant elevation networks of considerable size and a grid length of about 5 km will revolutionize physical geodesy in many respects and will ultimately, together with interpolation techniques, simplify many aspects of geodetic data management. Technical details of the Bell gravity gradiometer have been addressed by Metzger and Jurcitano [1981], Heller [1981], and Jordan [1982]. For astrogeodetic-inertial and astrogeodetic-gradiometric gravity vector determination and a combination thereof, reference is made to Bausseus von Luetzow [illegible].

b. Meteorological measurements generated for both conventional weather forecasts and for numerical prediction are performed by balloon soundings, global satellite soundings, and surface pressure measurements in fixed stations [illegible]. The measurements are supplemented by data from aircraft and ships.

Two polar satellites provide:

Atmospheric soundings, sea surface temperatures, snow and ice mapping, ocean monitoring.

Geostationary satellites generate information concerning:

Atmospheric soundings, cloud motion (wind in about 2 layers), sea surface temperature, precipitation estimates.

A polar orbiting satellite equipped with a scatterometer may also provide [illegible] of ocean surface winds according to Pierson [1983].

[illegible] environmental satellites are depicted in Figure 1 below.

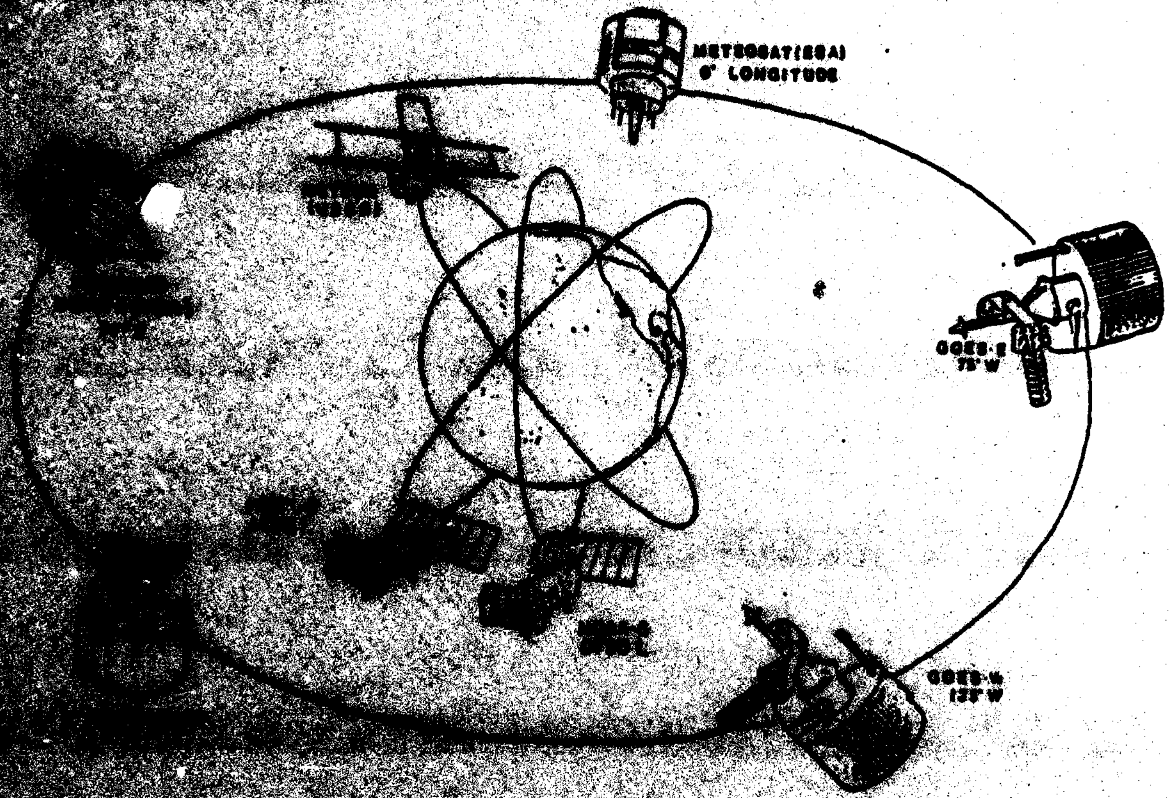


FIGURE 1

[illegible] ENVIRONMENTAL SATELLITES, 1982.

[illegible] Polar Environmental Satellite Products List is shown in the [illegible] table.

[illegible]	ACCURACY GOALS	SPATIAL RESOLUTION/ GEOGRAPHICAL COVERAGE	SCHEDULE	APRIL 1980 USERS (Output Media)
[illegible]	SFC-500 mb ± 2.5°K [illegible] ± 3.25°K [illegible] ± 3°K [illegible] ± 2.5°K ± 30% of the true value (or 1 mm whichever is larger) Pressure ± 50 mb Temperature ± 2.5° ± 10% tropical, ± 50% polar ± 2°K ± 20%	250 km near the sub-satellite track, increasing with scan angle/ global.	Orbit-by-orbit	NMC (Disk) EDIS (CCT)
[illegible]	In [illegible] of single layer cloud [illegible], ± 2°K [illegible] [illegible] ± [illegible] Pressure ± 50 mb Temperature ± 2.5°K ± [illegible]	500 km near the sub-satellite track, increasing with scan angle global.	Orbit-by-orbit	All customers served by GTS (teletype)
[illegible]	± [illegible]	Same as above	Orbit-by-orbit	GTS (teletype)
[illegible]	[illegible]	[illegible] reduced to [illegible] resolution.	Orbit-by-orbit	British Meteorological Office, Bracknell, UK (Telecommunication line)

TABLE

[illegible] SATELLITE PRODUCTS LIST, SOUNDING PRODUCTS

[illegible] Data Services Division of the National Climate Center, Ashville, [illegible] with the operations center of NOAA's National [illegible] Satellite Service, Suitland, Maryland is the United States [illegible] environmental satellite data.

[illegible] Oceanic and Atmospheric Administration.

[illegible] Utilization and Accuracy Aspects of Geodetic Data.

The geodetic data generated by different means enumerated in section 2a [illegible], sometimes in combination, the establishment and utilization of the following with associated accuracies:

(1) . Improved Geopotential, Non-uniform Accuracy, Equal to or Better than Spherical Harmonics Representation of Degree and Order 360.

. Height Anomaly RMS Error of the Order 1 m.

. Improved Space Vehicle Trajectories and Orbits

(2) . Determination of the First Derivatives of the Geopotential in Regions Covered by Gradiometric Traverses and Cross Traverses, RMS Error 1 mgal or Better.

. Geodetic Azimuth Determination.

. Coordinate Transformation from Local to Global System (Mean Earth Ellipsoid).

. Improved Space Vehicle Trajectories.

. Gravity Programmed Inertial System with Reduction of Accumulated RMS Position Error and Position Error Due to Accelerometer Scale Factors and Gyro Bias Errors, Accuracy of the Order 5.10^{-6} for 60 km Traverse with Initial and Terminal Position Control.

. Improved Geodetic Network Adjustment.

(3) . Rapid GPS Positioning, RMS Error Dependent on Acquisition Time, Reducible to 1 m or Better.

(4) . Subterraneous Mass Detection and Geophysical Prospecting (Oil, Water, Cavities)

The greatest impact on geodetic data management, heretofore strongly concerned with gravity data, has the regional, uniform and accurate determination of gravity vector components by astrogeodetic-gradiometric means in the foreseeable future and the application of suitable interpolation methods addressed in section 4.

4. <u>Usefulness and Limitation of the Collocation Method of Physical Geodesy.</u>

The collocation method of physical geodesy is indispensable for many geodetic applications, its usefulness and limitations characterized by the following:

(1) Interpolation of high accuracy gravity vector components determined by astrogeodetic-gradiometric means in level surface about 500 m above ground and analytical downward continuation to the earth's surface and combined use of point gravity anomalies in semi-flat terrain as an integral part of data management favored by the uniform distribution of vector component data in covered regions.

(2) Post-mission adjustment of gradiometric data or optimal gravity vector determination under consideration of initial and terminal vector component data.

5. Climatological Data, Univariate and Multivariate Analysis.

Of immediate interest to climate data management are the Guidelines on Climate Data Organization and Formats, published by the World Meteorological Organization in 1982 (WPC-31). It addresses climate data types, data management principles, management of data bases, and advanced techniques. Associated with the generation of climate data is the establishment of a multivariate statistical interpolation scheme. Such schemes have been discussed by Lorenc [1980] and Gustavsson [1981]. Although climatological means are subtracted from measured or model-generated random variables to be used in the regression estimation, the assumption of homogeneity and isotropy is often made for simplification. Significant in this respect is that the statistical estimation corresponds to the generation of meteorological variables by a simpler model. For the same reason, means, variances and covariances are subject to variations, i.e., do not behave in accordance with an ergodic generation process. In the context of the use of climatological data for estimation purposes the following should be noted:

(1) Stationary statistics involving first and second order moments compatible with an ergodic generation process is applied for the estimation using variables generated by a non-stationary process.

(2) Winds utilized for interpolation and extrapolation of geopotentials are associated with a-geostrophic estimation structure and tend to cause imbalances in multivariate analysis, ascertained by Williamson, Daley and Schlatter [1981].

(3) Univariate geopotential estimation does not appear to introduce significant errors if the data points are not widely separated.

(4) For improved univariate estimation, winds require a decomposition in non-divergent and divergent components.

(5) The utilization of measured winds for the estimation of geopotentials should preferably be accomplished in the context of 4-dimensional data assimilation, by univariate analysis, and employment of an improved balance equation addressed in section 7. The ultimate estimation of the geopotential would then be a weighted univariate solution.

(6) The existence of measurement errors and correlated noise can be considered in univariate and multivariate estimation.

6. Meteorological Data Assimilation.

An overview of meteorological data assimilation has been presented by Morel [1981] under inclusion of grid point analysis by multivariate techniques, dynamics of adjustment, normal mode initialization, and 4-dimensional data assimilation. He emphasizes the development of filtering techniques and the consideration of artificial damping pertaining to the generation of meteorological noise during dynamic prediction because of the generation of divergent winds and stated that the mathematical basis for understanding the continous or discontinuous adjustment process involved in 4-dimensional data assimilation is not well established as yet.

Bengtsson, Kanamitsu, Kallberg, and Uppala [1982] discuss the FGGE[2] 4-dimensional data assimilation at ECMWF.[3] The respective scheme is evident from figure 2 below.

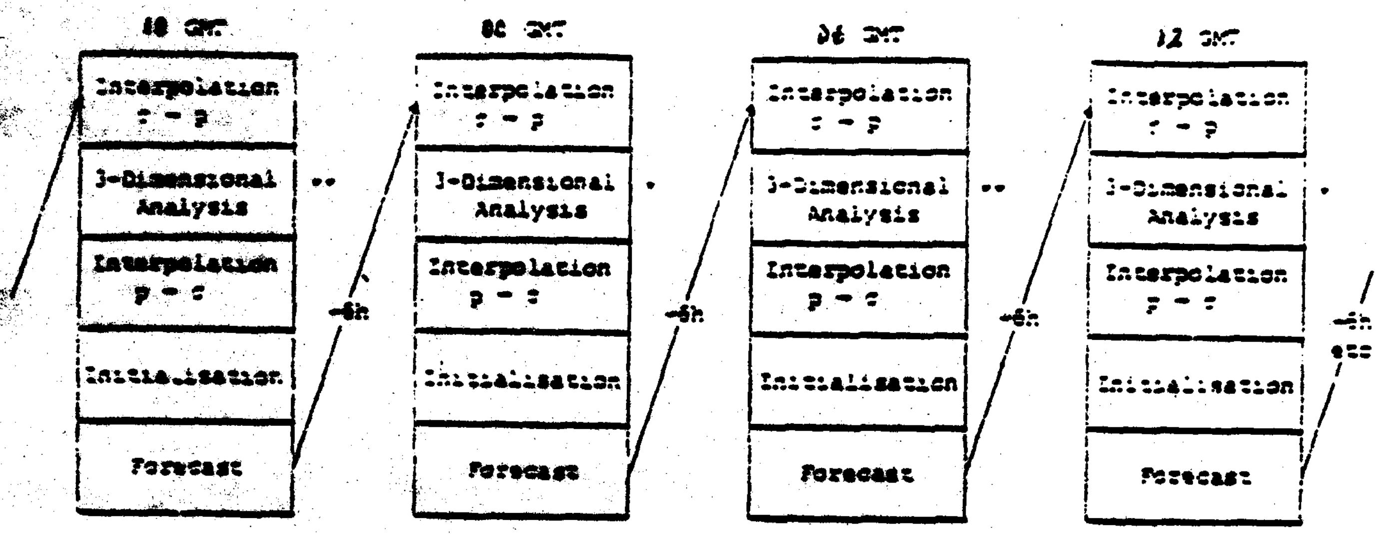


FIGURE 2

The different stages in 4-dimensional data-assimilation at ECMWF (*archived through the whole FGGE year, **archived during the Synopses).

In this scheme, the scalar field variables at a specific time are estimated from their values generated from fields established 6 hours prior to time t_0. This approach presupposes the existence of errors pertaining to the generated and observed fields and their covariances and requires a considerable empirical effort. Nonlinear mode initialization was applied for the

---

[2]FGGE: First GARP Global Experiment (GARP: Global Atmospheric Research Project).

[3]ECMWF: European Center for Medium Range Forecasts (Reading, United Kingdom)

computation of quasi-balanced wind and mass fields. The significance is that this approach does not only lead to reduced scalar field errors at time t_o but also to a partial influence of the respective observed fields. For this reason, accurate initialization is important.

The global data assimilation system at the National Meteorological Center has been described by Ward, Kistler, Tracton and Gordon [1981].

7. <u>Initialization, Dynamic Model Improvement, Predictability and Compatibility</u>.

Initialization for determination of the wind field from the mass field under no or limited consideration of diabatic processes and dynamic model improvement and correlated computer capacity impose data management considerations. Although they ceteris paribus increase predictability, purposes have also to be compatible with the generation of denser and more accurate data primarily by satellites and a greater number of surface pressure sensors, particularly in oceanic areas. A marginal utility analysis would further have to assign weights to short and long range forecasts under consideration of the spectrum of applications. There are already implications that relatively accurate and correspondingly expensive long range predictions for non-military purposes should be centralized in the future. Of specific interest here are the following topics.

(1) Normal Mode Initialization (NMI): Nonlinear NMI along the lines of Williamson and Temperton [1980] is the presently preferred and practiced method to derive mutually balanced mass and wind fields. As shown by Phillips [1982], multivariate optimum interpolation analysis is consistent with NMI if the model-generated first guess data contain only slow modes with correspond-

[illegible] and [illegible] observations are used. As indicated in [illegible] data assimilation and the univariate [illegible] at grid points from computed and sufficiently [illegible] with the existence of higher modes and the [illegible] initialization method.

[illegible] of [illegible] and the Classical Balance Equations: Leith [illegible] of these methods. The truncated balance [illegible] the stream function ψ and the geopotential ϕ has been [illegible] [illegible] in his study of elliptic regions in balanced [illegible] in which he [illegible] the need for a [illegible] balance equation. The inadequacy of [illegible] and [illegible] has further been established by [illegible] equation and the omega equation [illegible] by [illegible], [illegible] and [illegible] [illegible] [illegible] in a mesoscale numerical [illegible]

[illegible] Equations: These are obtained [illegible] of the second order total time [illegible] velocity vector in the (x,y,p,t)-system. In [illegible] filter equation

$$[illegible] \qquad (1.)$$

[illegible]

$$\text{[illegible]} \frac{\partial\Omega}{\partial p} - \left(\frac{\partial\Omega}{\partial x}\frac{\partial^2\phi}{\partial x\,\partial p} + \frac{\partial\Omega}{\partial y}\frac{\partial^2\phi}{\partial y\,\partial p}\right) +$$

$$+ \text{[illegible]} \left(\text{[illegible]}\right)\frac{\partial^2\phi}{\partial x\,\partial y} + \frac{\partial\Omega}{\partial x}\frac{\partial^2\phi}{\partial y^2} + \beta\left(\frac{\partial\phi}{\partial x} - 2f\nabla\right) \qquad (2)$$

In equations (1) and (2) the symbol ^ indicating a filtered variable has been [illegible] since actual φ-data are employed for initialization. Equation (2) [illegible] to the thermodynamic equation with 3 ellipticity conditions including a new Richardson criterion. The new diagnostic equations are [illegible] superior to the classical balance equation, particularly under [illegible] conditions. They were derived by [illegible] (1966) and [illegible] in a broader context including non-hydrostatic [illegible] (1979). As is well known, the solution of the [illegible] requires a considerable computational effort.

(4) [illegible] Signal Generation Process: The vorticity equation, the [illegible] equation, the continuity equation, the diagnostic equation (1), and the [illegible] balance equation comprise a hydrodynamic signal generation process which is [illegible] or elliptic, respectively, and which parameterizes [illegible] influences [illegible] considered to the extent [illegible]. The prognostic equations are only subject to small subgrid scale [illegible]. The signal generation process has a definite prognostic capability because of the [illegible], the demonstrated success of spectral dynamic [illegible] number of expansion terms, and shortcomings of the [illegible] equation system.

(5) [illegible] Hydrodynamic Prediction (Primitive Equations): The [illegible] implicitly incorporate convection down to the

[illegible], thus requiring adjustment schemes, and thus cannot not fully [illegible] with the continuity equation for water vapor. Prognostically, this deficiency has an increasingly degrading effect, also with respect to the determination of radiation which has not been well accomplished yet at the National Meteorological Center as reported by Pacey, Gerrity and Sela [1981].

(6) Nonhydrostatic Prediction: The use of the prognostic equation for the vertical velocity component is generally prohibited because of uncertainties in the initial fields, the lack of time-varying boundary conditions at the bottom and the top of the atmosphere, and the computational effort required. For a limited area, for the purpose of research, and with some simplifications, Tapp and White [1976] have considered a non-hydrostatic mesoscale model. Leaving the structure of the continuity equation in the [illegible]-system invariant, [illegible] von Lustzow [1971] derived a higher order [illegible] equation for the vertical velocity component, modified in 1980. The [illegible] system, free of internal sound waves, is compatible with a horizontal grid length down to about 10 km and allows for an essentially full exploitation of the continuity equation for water vapor. The system simultaneously allows for more vertical levels. As a consequence of computational network densification, it requires an enlarged computer capacity. In accordance with findings by Gordon and Stern [1982], the spectral method is expected to be less suitable in this system, tantamount to the requirement of higher order difference schemes.

(7) Predictability and Compatibility Aspects: Sophisticated models are the necessary prerequisite for long range weather prediction under full exploitation of the geopotential, humidity and cloud observations, and [illegible] and derived equatorial winds. However, these models cannot

[illegible] for the lack of dense and accurate data. From the standpoint of [illegible], a grid length of 100 km appears to be fully adequate. At the present, [illegible] length must be relaxed. In view of the availabilty of effective [illegible] methods, in particular equation 1 and the associated omega [illegible], the initial data problem is the most crucial, calling for more and [illegible] meteorological satellites, considerably more surface pressure sensors in [illegible] areas, and an improvement in wind measurements in equatorial regions. Presently, the density and accuracy of available data are not compatible with sophisticated models and also not with initialization methods. This is in agreement with results summarized by Reuter [1982] at the Symposium on [illegible] Problems of Weather Prediction, Vienna, Austria, June 1982. Therefore, meteorological data management has to reconcile scientific-[illegible] considerations with cost-benefit analyses.

[illegible]

Because of the availability of new and powerful technology in the near future, geodetic and meteorological data are expected to become increasingly more diversified and voluminous both regionally and globally, and its quantity and quality are subject to change. Primarily in the field of geodesy, its availability will be restricted because of military considerations. Gravity [illegible] surveys are expected to have a profound effect on geodetic data management. Meteorological data generation, accuracy and density have to be considered in conjunction with advanced as well as cost-effective numerical weather prediction models and associated computational efforts. For the initialization of wind fields, diagnostic equations superior to the classical [illegible] equation are available. Long range numerical weather [illegible] for the full exploitation of available observations, for [illegible] of convection instabilities, and for correlated extension to a [illegible] a non-hydrostatic generation model with an invariant [illegible] in the (x,y,z,t)-system and an already established [illegible] for the vertical wind velocity.

[illegible]

[illegible] "[illegible] Environmental Satellites Product List" [illegible] Satellite Service, Suitland, Maryland. Figure 2 is [illegible] included in the references.

[illegible]

[illegible] 1971. [illegible] and Potential of New Filter [illegible] Research Note [illegible]-71-3, U.S. [illegible]

[illegible] 27709.

[illegible] Gravity Anomalies and [illegible] International [illegible] Republic of Germany.

[illegible] and Utilization of [illegible] Gravity Vector [illegible] Sofia, Bulgaria, [illegible]

[illegible], and [illegible] Uppala, 1982. FGGE [illegible] Data Assimilation at ECMWF. Bull. Am. Meteor. Soc., 69, No. 1.

[illegible] 1981. Radiation in Global Atmospheric Modeling. [illegible] Report, pp. 4-5, National Oceanic and [illegible] Administration, Washington, DC.

[illegible] and [illegible], 1982. A Description of the GFDL Global [illegible] Mo. Weather Rev., 110, No. 7.

[illegible] A Review of Methods for Objective Analyses. Dynamic [illegible] Assimilation Methods, 17-76. Springer Verlag, New York, [illegible]

[illegible] Proposals for Gradiometer Aiding of Inertial Survey [illegible] International Symposium on Inertial Technology, Banff, [illegible]

[illegible] Data Management at [illegible]. Bull. Geodesique, [illegible]

[illegible] Gravity Gradiometer Survey Accuracy. TR-34-1, [illegible] Wellesley Office Park, Wellesley, MA 02181.

[illegible] of Non-Elliptic Regions in Balanced Flows of [illegible] Rev., 110, [illegible]-1967.

[illegible] Normal Mode Initialization and Quasi-Geostrophic [illegible]

[illegible] Multivariate Statistical [illegible]

[illegible] Application of Ball Rotating [illegible] to Airborne or Land [illegible] Symposium on Inertial Technology, [illegible]

[illegible] Data Assimilation. Dynamic [illegible] Springer Verlag, New York, [illegible]

[illegible] Gravity Gradiometer. Proc. Second [illegible] Technology, Banff, Canada.

[illegible] Multi-Variate Optimum [illegible] Analysis. Mo. Weather Rev., 110, [illegible]

[illegible] of the Synoptic Scale Wind over [illegible] II: Scientific Results, 1683-1708. Am. [illegible]

[illegible] on Current Problems of Weather Prediction, 23-26 [illegible] Bull. Am. Meteor. Soc., Vol. 63, No. 1.

[illegible] 1982. Mixed Collocation: A Proposal. [illegible] (Reports from Topography and Higher Geodesy [illegible] Engineering, Univ. of Thessaloniki, Greece).

[illegible] A Non-Hydrostatic Mesoscale Model. Quart. [illegible] 277-294.

[illegible] Wind Component in a Mesoscale Numerical [illegible] Model. Mo. Weather Rev., 109, 77-95.

[illegible] G. Hollier, 1976. Efficient Estimation Techniques for [illegible] Data Processing. Report AFGL-TR-76-0232. Air Force [illegible] Laboratory, Hanscom Air Force Base, MA 01731.

[illegible] Nonlinear Normal Mode Balancing and the Ellipticity [illegible] Rev., 109, 1751-1761.

[illegible] M. S. Tracton, and D. S. Gordon, 1981. The Global [illegible] System at the National Meteorological Center. Fifth [illegible] Weather Prediction, pp. 27-30. Am. Meteorological [illegible]

[illegible] and C. [illegible], 1980. Normal Mode Initialization for a [illegible] Model. Part II: Nonlinear Aspects. Mo. Weather Rev., [illegible]

[illegible] 1981. The Balance Between [illegible] Optimal Interpolation. Mo. [illegible]