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NEW CLOUD PHYSICS INSTRUMENTATION REQUIREMENTS,(U)
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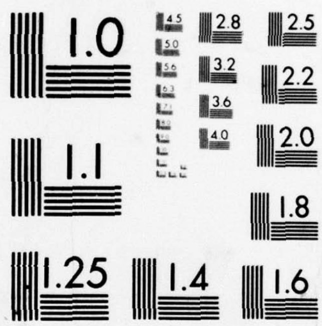
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NEW CLOUD PHYSICS INSTRUMENTATION REQUIREMENTS

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1. INTRODUCTION

The purpose of this paper is to review Air Force requirements for in situ cloud physics measurements, specifically those supported by the Air Force Geophysics Laboratory (AFGL), and to point out areas where present instrumentation is lacking. The areas of cloud dynamics, turbulence, atmospheric electricity, lightning and cloud nuclei are specifically excluded.

2. PROGRAMS AND REQUIREMENTS

There are a number of areas of Air Force testing, research and development which require measurements of cloud and precipitation particles. In the following subsections the problems with which AFGL is concerned are delineated and the requirements are translated into the types of cloud physics data which are needed.

2.1 Hydrometeor Erosion of Hypersonic Vehicles

Hypersonic vehicles penetrating regions of clouds and precipitation undergo erosion of the surfaces as the hydrometeors impact on the forward surfaces. The damage to the surface of the vehicle is a direct function of the relative momentum of the particle. For this reason the interest lies in measuring the mass of the hydrometeors which the vehicle intercepts.

2.1.1 Heavy Weather Testing

These tests are conducted through areas where the water content values are large. The tests are conducted to insure that the vehicle will survive the erosion and be able to successfully complete its mission. The primary information required is the total mass intercepted by the vehicle as a function of time. Information on mass spectra and crystal habit is also needed.

2.1.2 Light Weather Testing

In some tests it is desired to maintain laminar flow around the vehicle for as long as possible. Roughening of the surface by collision with a particle above a certain mass causes premature transition from laminar to turbulent flow altering the ablation and flight characteristics. The cloud physics requirements are for measurements of particle mass spectra and crystal habit in relatively thin cirrus clouds.

2.2 Microwave Propagation

Hydrometeors cause reflection, scattering and attenuation of microwave beams. This property causes problems for some Air Force applications, but has been useful for other applications such as weather radar.

2.2.1 Communications

Microwave communication links have been used since the fifties starting with point-to-point surface systems and now using satellite relay systems. The surface systems are subject to disruption caused by heavy precipitation between the terminals. Some of the links are fairly long so that the amount of attenuation reduces the signal below the level at which the link can reliably operate. The usual way to circumvent this problem is to increase the transmitted power, to use other series of links in the system, or wait until the precipitation area has moved beyond the link.

Satellite links are power-limited from the satellite end, but, because of the nearly vertical beam path, the amount of precipitation between the satellite and the ground station is significantly less than between ground stations.

Attenuation is not a simple function and is dependent on the total hydrometeor mass, the wavelength of the radar, crystal habit and particle size spectrum.

2.2.2 Energy Transmission

Since microwave beams can be made very directional, it has been proposed to transmit energy by microwave beams to power airborne vehicles or to transfer solar energy collected in space to ground terminal distribution stations. The problems are the same as for microwave communication, namely attenuation and scattering, but probably would not be as severe because of the vertical path through the storm and the areal extent of the receiving array. Again we find requirements for crystal habit and particle size spectrum data.

2.2.3 Weather Radar Utilization

Weather radars operate in the microwave region of the electromagnetic spectrum. The returns from hydrometeors become stronger at shorter wavelengths but the attenuation also becomes larger. In some cases the returns from distant storms are completely masked by the attenuation due to intervening storms. Hence attenuation is a problem, and the hydrometeor data requirements are the same as in subsection 2.2.2. In order to obtain values of liquid water content, M, from the radar reflectivity values obtained from the weather radars for use in erosion testing (see section 2.1.1), rainfall rate measurements or cloud physics research studies, it is necessary to know the crystal habit and the particle size spectrum or the particle mass spectrum.

2.3 Laser Propagation

Lasers cover a different section of the electromagnetic spectrum than that covered by microwaves. Laser wavelengths are small compared to the hydrometeor particles and, therefore, the interactions are more complex and are not as well understood.

2.3.1 Communications

Voice and data transmissions over laser beams are degraded or wiped out by intervening hydrometeors. Target designation systems are similarly affected but possess the additional hazard of inadvertently designating clouds as targets.

Transmissions can take place under some degraded conditions, but studies of these conditions require knowledge of the crystal habit, size distribution and cloud type.

2.3.2 Weapon Systems

High power laser weapon systems are designed to concentrate laser energy on a target. Problems are to (1) minimize the dispersion of the beam, (2) minimize attenuation, and (3) operate through intervening clouds. The scattering and attenuation problems are similar to those in 2.3.1 but extend to higher power levels. Operations through clouds will vaporize some or all hydrometeors thereby altering the environment along the transmission path. Such studies would require cloud physics data such as cloud types, crystal habit, particle size distributions, mass distributions, temperature and humidity.

2.4 Stratus/Fog Clearing

Previous work has shown that supercooled stratus clouds can be cleared by seeding. The optimum seeding particle size, material and dispensing rates are not known. If measurements of the hydrometeors were taken before and after the controlled seedings so as to provide the ambient hydrometeor size and crystal habit distributions, then the variables in the seeding operations could be altered to optimize the areal extent or persistence of the cleared area.

Data requirements are for temperature, humidity, cloud type, crystal habit, particle size distribution and mass spectrum.

2.5 Numerical Prediction

This topic is divided into two parts. The first concerns the numerical modeling of severe storms and convective clouds, and the second concerns the utilization of hydrometeor data in large scale numerical weather prediction models.

2.5.1 Convective Clouds and Severe Storms

This work is primarily supported by NOAA, NSF and the Bureau of Reclamation. Because of flight restriction on the AFGL aircraft, the interest of other agencies in these areas and AFGL emphasis on other areas of cloud physics, we have not extended our instrumentation investigations into these areas. The rapidly changing nature of these storms, both in space and time, requires fast response instruments capable of operating in extreme weather conditions, capable of collecting hail data and capable of measuring large values of liquid water content.

2.5.2 NWP Large Area Models

Large area numerical weather prediction models have had difficulties incorporating clouds and precipitation. Clouds and precipitation are usually parameterized because of the lack of measurements of the 3-dimensional distribution of ice/water content in the atmosphere. Recently satellite data have been utilized to obtain some information on the vertical as well as horizontal distribution of clouds and ice/water content values, but actual in-situ measurements are needed to improve the interpretation of the satellite indirect sensor data.

The quantities desired for this work are ice/water content values, crystal habit, cloud type, location, temperature and dewpoint. Future research into the cloud formation and precipitation mechanism for large scale NWP models will require more detailed data such as contained in size and mass spectra.

2.6 Aircraft Discharge Test

In order to test the response of aircraft to actual inflight icing, the Air Force is using a KC-135 tanker to create a spray of demineralized water for the test aircraft to fly through. The tests are conducted in clear air for safety and at altitudes high enough above the freezing level to produce icing on the test aircraft. AFGL has provided measurements of the particle size spectra across the spray at various distances behind the KC-135. Similar measurements have been made of aircraft fuel dumps and also of contrails.

2.7 Cloud Truth Measurements

Remote sensors such as weather radars, lidars, acoustic sounders and instruments mounted on satellites provide data which are correlated with the physical properties of the clouds. In order to obtain maximum use of these remote sensors it is necessary to make in situ measurements of the physical properties to obtain the optimum transfer functions. Since the remote sensors, both passive and active, usually have non-linear relationships to the meteorological parameters measured in situ or to the operational parameter desired, it is prudent to make as many kinds of in situ measurements as possible.

3. CONSOLIDATED MEASUREMENT REQUIREMENTS

In this section we discuss the requirements delineated in section 2 and discuss the instrumentation used on the AFGL instrumented C-130E and Learjet 36.

Due to the variable nature of cloud physics data, it is obvious that many data must be obtained and these data must be handled by high speed computers. For this reason in recent years we have changed over to instruments which provide digital outputs and have moved away from analogue data wherever possible. Both airplanes have on-board computers which process some of the data to provide real-time information for operational decisions.

3.1 Cloud Types

Data on cloud types are still recorded in analogue format. During daylight, 16mm time lapse movies are taken through the windshield. Time is recorded on each frame, and the frame rate is set at one every second or one every ten seconds. Pictures are also taken with hand held 35mm and Polaroid cameras, and the exact times and conditions are recorded in notes and/or on the voice tape. High quality satellite pictures provide data on cloud types and areal extent which were not available in such detail in the past.

3.2 Crystal Habit

Crystal habit is an extremely important piece of information for a number of diverse applications such as in supercooled seeding, conversion of size measurements to mass and selection of the proper dielectric constant. Real-time determinations of crystal habit are made visually and are supplemented by data from the PMS 2D instruments. To aid visual observations, a snowstick is mounted out in the free air away from the aircraft boundary layer. It has a black, one square centimeter, graduated area upon which the cloud drops, rain drops, snow or ice crystals impinge. The detection area is held perpendicular to the air flow and can be viewed from inside the aircraft. The snowstick on the C-130 can be pulled inside for microscopic inspection of snow and ice crystals.

The PMS 2D instruments use laser beams to obtain shadows of particles as they pass through the sampling area. The shadow passes over an array of diodes which provide digital information that is recorded on tape for further processing and that is also displayed on CRTs for real-time use. The minimum size detected is about 20 μm and the maximum sampling width is 6.4 mm.

Visual observations of ice or water on the windshield or of snow passing in front of dark areas on the wings are recorded in notes or on voice tape.

Decelerators, glass slides, cat's fur and other devices have been used successfully in the past to obtain crystal habit data.

The fomvar replicator captures the particles, embedding them in plastic which then hardens to leave a replica of the original shape. The opening limits the maximum size of pristine crystals to roughly one millimeter. The collection efficiency begins to decrease for sizes below 20 μm, is down to 50% at 10 μm and is 20% at 5 μm. We considered 5 μm as the lower limit for this instrument.

Soft aluminum foil is used to obtain imprints of the particles as they impinge on the foil. Maximum size is limited by the opening which is 38 mm by 38 mm square. The ridges of the grid behind the foil are 250 μm apart which limits the definition of the particle shapes.

The foil sampler has the largest sampling area and hence provides us with information on particles larger than those recorded by the PMS Precipitation Probes. On the other hand, particles larger than the opening of the foil sampler break on the edge of the opening and are not adequately recorded. The major problem with the foil sampler is the amount of time and manpower required to abstract the data.

Real-time determinations of crystal habit are made by the on-board meteorologist and are entered into the computer manually. Post flight determinations are similarly made by a meteorologist for manual entry into the data processing. Advances in pattern recognition and miniaturized computers may allow this function to be automated for both real-time and post flight applications in the future.

3.3 Size Spectra

Real-time measurements of particle sizes are being made by the 1D PMS instruments. The 1D Precipitation Probe uses an array of diodes to measure the maximum dimension normal to the flight path of the magnified particle image. The 1D Cloud Probe uses a larger magnification to measure smaller particles. These two instruments cover the size range from 20 μm to 4.5 mm. Below 20 μm diffraction effects, small sampling volumes and other optical problems limit this approach. Below 20 μm we are using the PMS Axially Scattering Probe (ASP) for sizes down to 2 μm. This technique uses laser light scattered from particles in a small sampling volume and classifies the strength of the scattered light. The ASP is designed for use in water clouds where the drops are spherical and there is a good relationship between drop size and scattered signal strength. In practice we have found that the ASP (1) counts all water drops above 2 μm which pass through the sampling volume and (2) has limited use as a size discriminator in ice clouds because of the poor or unknown relationships between amount of scattered energy and the size or mass of the ice particle.

The PMS 2D-Precipitation and Cloud Probes are advanced versions of the 1D Precipitation and Cloud Probes, and they provide two dimensional, quantified shadows of the particles which are used to size the particles.

Particles larger than those which are detected by the 1D and 2D Precipitation Probes are recorded by the foil sampler. Particles at the small end of the spectrum can be captured by the replicator under optimum conditions. Improved counting and sizing techniques are needed for both ends of the particle size spectrum.

3.4 Mass Spectra

Spectral distributions of particle mass are obtained from the size spectra by using density (actually length to equivalent mass) functions which depend on the crystal habit. Devices for measuring the mass from the momentum have been used by other investigators.

3.5 Total Ice/Water Mass

Currently we obtain total hydrometeor mass from the mass spectrum which in turn is obtained from crystal habit and size spectrum, and the size spectrum is obtained from the PMS data. We are also currently flying two research instruments to obtain total ice/water mass directly.

The Total Water Content Indicator (TWCI) is essentially a cyclone separator which mixes the water and melted snow with a fluid and then obtains the water content as the mixture passes through a dielectric measuring chamber. This instrument was built by Meteorology Research Incorporated.

A second instrument, the EWER, was built by Aerospace Inc., exploiting the evaporator technique while increasing the sampling area by an order of magnitude over the sampling areas of previously used evaporators. A Lyman-alpha detector is used to measure first the ambient water vapor and second the water vapor of an air sample which has had all of the hydrometeors vaporized. The difference between the two measurements gives the total ice/water content.

Both of these instruments are still in the research and development phase but show promising results.

3.6 Standard Meteorological Instruments

3.6.1 Temperature

Rosemont thermometers are used on both aircraft and are currently meeting our data requirements.

3.6.2 Humidity

Commercially available humidity instruments are used on both aircraft. The dew-point is difficult to measure at high altitudes or under other conditions where the humidity is very low. Our present requirements do not call for rapid response instruments or low value measurements.

3.6.3 Atmospheric Pressure

This quantity is easily measured aboard the aircraft and is used in combination with other measurements to obtain meteorological and flight parameters.

3.7 Other Requirements

In order to support some missions, it has been necessary to install special equipment aboard the aircraft or to utilize existing aircraft systems.

3.7.1 True Altitude

The difference between true altitude and pressure altitude has exceeded one kilometer on some flights. Since most tests use true altitude, radar altimeters, tracking radars or computed D values are used depending on the mission accuracy requirements.

3.7.2 Location

As with measurements of true altitude, the equipment or systems used depend on the accuracy requirements. There is an inertial navigation system (INS) in the C-130E and a global navigation system (GNS) in the Lear. Both aircraft have TACAN and DME, and both carry beacons for tracking by radars.

3.7.3 Communications

Both aircraft have UHF, VHF and HF radios for voice communication with the AFGL Weather Team and with the aircraft controllers. Recently a downlink was installed in the Lear to transmit data from the on-board computer to the Weather Team thereby freeing the Lear meteorologist for other tasks. A similar downlink is currently being installed in the C-130E.

4. DEFICIENCIES BY HYDROMETEOR LEVEL

In section 2 we reviewed program requirements. In section 3 we reviewed the cloud physics data requirements and pointed out some of the areas where the information supplied by current instrumentation is lacking. In this section we will review these deficiencies by considering the different hydrometeor zones which an aircraft has to sample.

4.1 Rain

Because the rain drops and cloud water drops are almost spherical and their density is essentially constant at 1.0 g cm^{-3}, the PMS 1D and 2D Cloud and Precipitation Probes provide good measurements of size spectra, mass spectra and total mass. The PMS ASP was designed to measure spherical drops hence it works better in this zone than in others.

4.2 Melting Zone/Bright Band Layer

This is the most difficult but most important region. Its importance lies in the fact that this region contains very large values of ice/water content. It contains large clusters of snow which give large radar returns, and as these clusters melt on the outside, the dielectric constant changes and they appear to the radar like extremely large water drops. Besides being a layer of strong radar returns, it is also a layer of maximum attenuation for microwaves. So far we have not found a way to obtain useful M values from the radar signals returned from the bright band.

Primarily because of the inadequacy of M measurements in this region, and secondarily to improve M measurements in the snow region, the Air Force has funded construction of the TWCI and EWER (see section 3.5). Both instruments are experiencing problems in the transition from theory to application. Other techniques have been investigated but these two seemed the most promising. We will continue the review and testing of other promising techniques until we are satisfied that we have an instrument in operation which meets our needs.

4.3 Snow Region

Above the bright band the snow particles do not coagulate into clusters. Snow particles with dimensions between 100 and 6400 μm are quite well measured by the PMS equipment, and the particle density is fairly stable so that useful mass spectra may be obtained. We intend to use the total ice mass values obtained by the TWCI or the EWER to adjust the particle mass spectra and particle density values.

Upper cutoffs of the particle spectra are required for some applications. Presently we use the foil sampler to obtain this information, but we need an instrument which (1) has a larger sampling area, (2) measures the largest clusters of snow and (3) provides digital outputs for ease of data reduction.

4.4 Ice Crystal Region

As mentioned in section 2 there are a number of requirements for particle spectra measurements in cirrus clouds. Present measurements in thin cirrus have two deficiencies. First, existing instrumentation does not provide reliable mass spectra for ice crystals in the size range from 1 to 100 μm. Second, the sampling areas of the instruments are small and must be increased so that representative size and/or mass spectra may be obtained over paths of ten kilometers or less.

5. SUMMARY

Air Force requirements for in situ cloud physics measurements, specifically those germane to AFGL endeavors, have been reviewed. Three main areas of deficiency are noted. The first is in the melting zone where present instrumentation fails to provide good total ice/water content values. The TWCI and EWER have been built to measure total ice/water content values in this zone, and these instruments are being test flown. The second is the measurement of particles in thin cirrus clouds where the particle numbers are generally smaller than we have previously had a requirement to measure, and the smaller size particles are not adequately sampled for some of our requirements. The third main area, in order of priority, is the measurement of the largest size particles or clusters in the melting and large snow levels. This information is needed to determine upper cutoff values for size spectra.

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Air Force requirements for in situ cloud physics measurements of crystal habit, particle size distribution and ice/water content values are reviewed. These areas of deficiency are noted. The first is in and just above the melting zone where there are large clusters of snow and mixed ice and snow. Two instruments developed for the Air Force are being tested to obtain total ice/water measurements through this region. The second deficiency exists in automatic instrumentation for the detection of the largest size particles. These data are needed for determining size spectra cut off. The third

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deficiency is in the area of measurements in tenuous clouds, and is essentially a sampling volume problem.