A Cirrus-Cloud Experiment: Intensive Field Observations Planned[1] for FIRE

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Abstract

Plans for an intensive cirrus-cloud field experiment are described. The Cirrus Intensive Field Observations (Cirrus IFO) is a major component of the First ISCCP[3] (International Satellite Cloud Climatology Project) Regional Experiment (FIRE). The field campaign was conducted in Wisconsin during October 1986. Observing systems include satellites, "cloud" lidars, a very high-altitude, satellite-simulator aircraft platform, two research aircraft instrumented for detailed in situ microphysical and radiometric observations, a Doppler lidar, numerous passive surface-radiation sites, and a rawinsonde network. This is the first cirrus experiment involving such a comprehensive observing system.

1. Introduction

The program of intensive field observations of cirrus clouds (Cirrus IFO) is a major component of the First ISCCP Regional Experiment (FIRE) originally described by Bretherton and Suomi (1983). Cox et al. (1987) give an overview of FIRE outlining the various research components, objectives, and methodologies. With respect to cirrus, FIRE seeks to improve our knowledge of cirrus-cloud properties and our understanding of the interactions of physical processes in determining these properties.

FIRE focuses on cirrus clouds because of their importance in the climate system and the consequent need to properly represent their effects in general-circulation models (GCMs), e.g., Ramanathan et al. (1983). Also, since ambiguities in retrievals of cloud properties from satellite observations are particularly acute for cirrus (e.g., Rossow et al., 1985), emphasis is given to this issue, especially with respect to the characteristics of the ISCCP algorithm. FIRE takes advantage of recent advances in theory and instrumentation (see review by Liou, 1986) to address these problems by investigating relationships between representations of cloud properties and processes over a suitable range of spatial and temporal scales. The observational activities are strongly coupled to modeling activities, including work on retrieval algorithms, radiative-transfer models, GCM cloud and radiative parameterizations, and detailed cloud models. In each case, model evaluation and improvement is a central theme. The design of the field program reflects this purpose.

Numerical model studies of cirrus clouds may be used to illustrate the interaction of modeling activities and observational efforts within FIRE. Large-scale forcing is a dominant factor in determining cirrus-cloud properties. However, using a two-dimensional model including representations of microphysical, radiative, and dynamic processes at a grid scale of 100 m, Starr and Cox (1985b) have shown that cloud-scale processes strongly modulate the result for convective cirrus. In particular, the rapid growth of relatively large ice crystals and their subsequent fallout greatly reduce the amount of cloud water that is typically maintained. For example, the rapid adjustment in the ice-water–content (IWC) profile seen during a simulation of the formation of a cirrus layer (Fig. 1) is primarily forced by this process. Note that net generation of ice occurs only in the upper 0.6 km of the cloud layer that is being maintained by large-scale ascent ($w_0 = 2\,cm \cdot s^{-1}$). The precipitation process continues to be important as the cloud layer evolves further and is equally significant in nonconvective cases (Starr, 1986 and 1987). The effects of this process are also quite apparent in observations, e.g., Heymsfield (1975 and 1977). Although Heymsfield and Platt (1984) and Starr and Cox (1985a) have attempted to parametrically represent cirrus-particle size distributions, further evaluation of such schemes is required because of the strength of the resultant effect on the cloud-water budget and, therefore, also on the cloud's radiative properties. The FIRE Cirrus IFO will provide data sets appropriate for this purpose.

As seen in Liou (1986), significant uncertainties also exist in our knowledge of relationships between the microphysical properties and radiative properties of cirrus. This linkage is important both from GCM and cloud modeling perspectives. For example, Starr and Cox (1985b) have shown the importance of radiative processes in convective cirrus (approximately 25 percent of all cases). Because of the nonblack character of these clouds, strong horizontal and strong vertical gradients of radiative heating occur within the cloud in conjunction with the cellular structure of cloud water. In this way, radiative processes are comparable in importance to latent-heat release in driving the cloud circulations that regulate the water budget, e.g., approximately 25 percent greater vertically integrated ice-water path (IWP) at night when compared to midday conditions. In turn, the ice-water contents maintained in the cloud largely determine the radiative

[1] Readers should note that the field campaign will have already been conducted by the time this article appears. An overall summary and assessment of the experiment based on preliminary analyses of the data obtained will be presented in a suitable forum in the near future.

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[3] See Schiffer and Rossow (1983) for a description of the parent International Satellite Cloud Climatology Project.

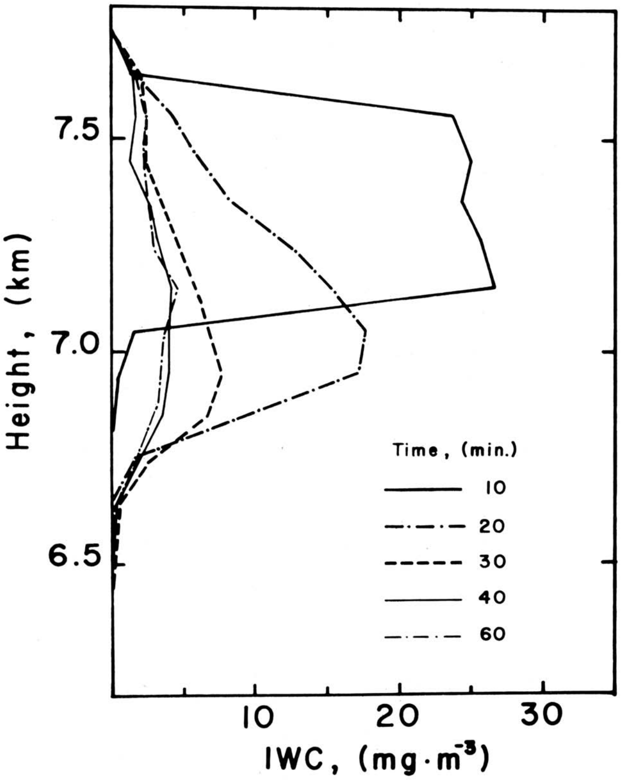

FIG. 1. Vertical profile of horizontally averaged ice-water content (IWC) at various times during a 2-D model simulation of the formation of a convective cirrus-cloud layer (after Starr and Cox, 1985a).

properties and, therefore, the pattern of radiative heating.

Obtaining coincident measurements of microphysical and radiative properties is a high priority for the Cirrus IFO. The Cirrus IFO data sets will also be sufficiently comprehensive for detailed comparison to the results of model simulations with respect to the observed structure and dynamics of cirrus cloud layers, e.g., in terms of vertical structure as in Fig. 1 or horizontal structure as in Starr (1987). Similar comparative studies are planned for the other modeling efforts.

Many of the modeling activities are also interrelated. For example, results of cloud-model studies may be used to develop an improved GCM cirrus-cloud parameterization, which might also be tested by comparison to observations. Starr (1986) demonstrates the potential of this approach. A reasonably systematic relationship is found (Fig. 2) between the accumulation rate (A) of IWP determined from cloud simulations and the large-scale generation rate (G) that would be diagnosed in a nonparametric GCM treatment. The strong dependence of G on large-scale vertical motion (w_0) and available water vapor (thin-versus-thick cirrus-generating layers at high [cold] and low [warm] levels) is evident as is the effect of the precipitation fallout process ($A \neq G$). Within each hatched area, variations are due to initial static stability (neutral to 1°C/km more stable) and time of day (midday to nighttime).

Similar links exist among many of the modeling efforts in which the Cirrus IFO data serves as a common bridge. Plans for the FIRE Cirrus IFO are described in the following sections.

2. The field experiment

Two periods of intensive field observations of cirrus-cloud systems are planned; each period is to last from three to four weeks. The first will be conducted in Wisconsin (Fig. 3) beginning in mid-October 1986 and is described here. The second will most likely be conducted in 1988 in the central United States. Details of the plans for the second Cirrus IFO campaign are contingent on the findings of the first. Selection of the site and time for the first IFO period was based upon considerations of maximizing the probability of cirrus occurrence, satellite coverage, and effective deployment of research aircraft (altitude capabilities), and minimizing complications arising from the effects of orography and deep convection. Proximity to a large uniform-background region (Lakes Michigan and Superior) was also desired as an experimental control. The primary target systems are pre- warm-frontal and jet-stream cirrus.

a. Objectives

The Cirrus IFO will provide data to support high-spatial-resolution and high-temporal-resolution studies of cirrus-cloud fields. Two new and unique aspects of the Cirrus IFO are first, the inclusion of simultaneous "cloud-truth" observations (primarily lidar) to validate retrievals of cloud properties from satellite observations, and second, observations of upwelling and downwelling radiation at the surface and near the cloud boundaries and at other levels in conjunction with simultaneous satellite radiance observations.

Analysis of the data obtained will seek to satisfy three specific observational objectives:

1) To characterize the bulk physical structure of cirrus-cloud fields, the associated radiative fields and the corresponding large-scale meteorological environment. The cloud properties of interest are the vertically inte-

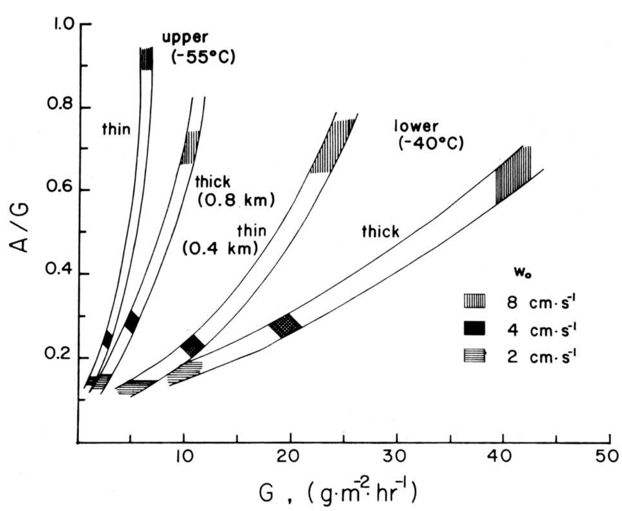

FIG. 2. Comparison of the rate of accumulation (A) of horizontally averaged, vertically integrated ice water path (IWP) computed with a 2-D cirrus-cloud model to the rate of generation (G) of IWP computed with a simple 1-D large-scale diagnostic model for the same conditions (average rates over a two-hour period). See text for explanation (after Starr, 1986).

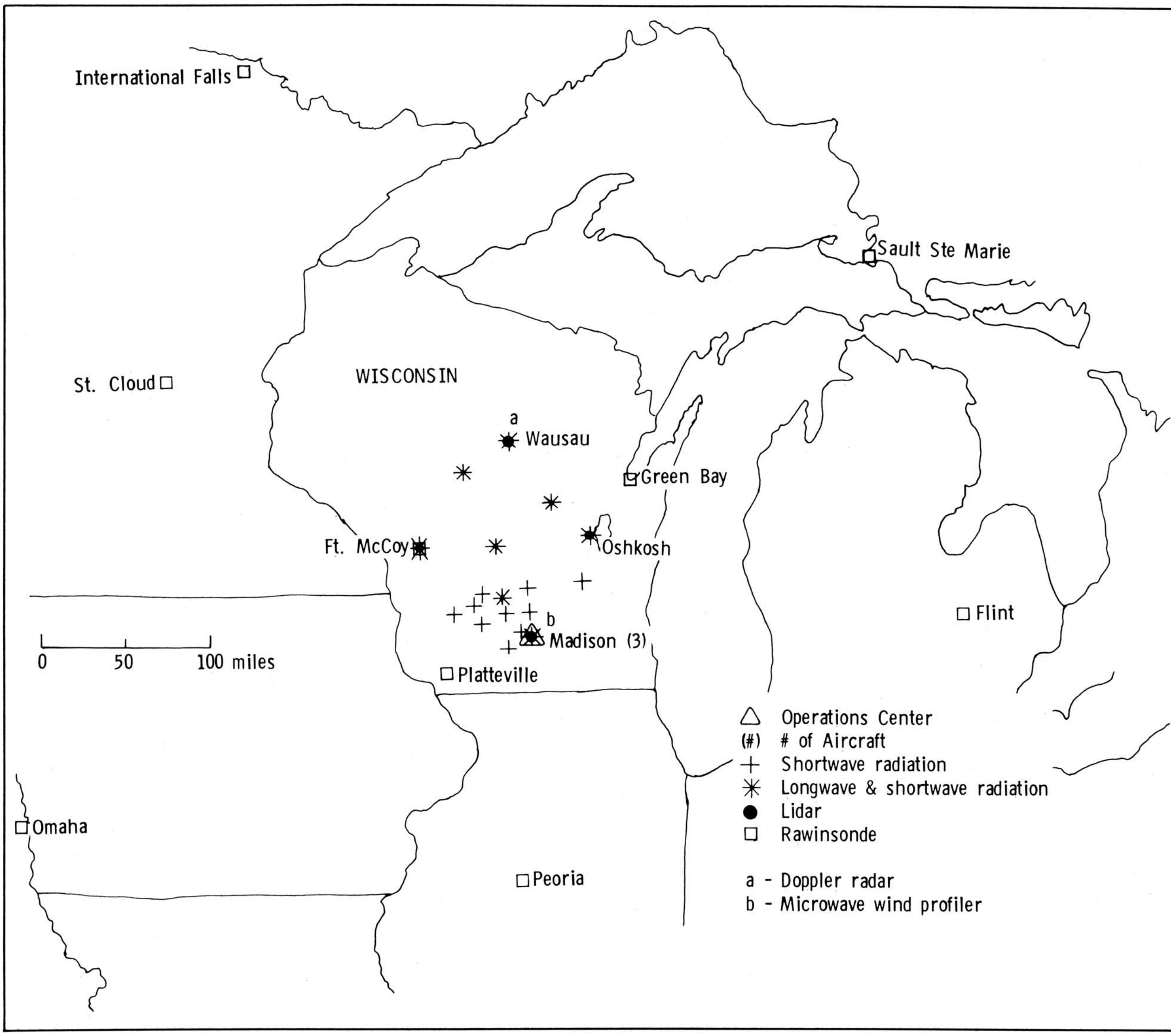

FIG. 3. Observational network for the FIRE Cirrus Intensive Field Observations (October 1986).

grated IWP, and broadband and "window" radiative properties. Description of the radiative fields will include the broadband radiative fluxes as well as the directionally and spectrally dependent radiance fields;

2) To characterize the fine-scale microphysical, radiative, thermodynamic, and dynamic structure of cirrus clouds at various stages of their life cycles and the concomitant environmental conditions. Here, the cloud properties of interest also specifically include the IWC, (and liquid if present), cloud-particle size distribution and ice-crystal habit;

3) To characterize relationships between cloud properties inferred from satellite observations at various scales to those obtained directly or inferred from very high-resolution measurements[4].

Achievement of the first objective will enable detailed evaluations of current and future GCM cirrus-cloud and radiative parameterizations in a diagnostic mode. Issues of special concern are the representation of spatial structure and relationships between them, and the variability of fundamental cloud properties. The second objective supports efforts to evaluate and improve current cloud-process models and radiative models. Each of these objectives requires high-resolution observations, though somewhat different sampling strategies are involved. It must be emphasized that the results of the detailed individual case studies and fine-scale modeling efforts will likely be crucial for proper interpretation of the more-statistical studies of the cloud fields and for generalizing those results to the full range of naturally occurring situations.

b. Observations

Measurements will be made from a diverse set of observing platforms including satellites, research aircraft, surface sites, and weather balloons (Table 1). The intent is to obtain a rela-

[4] Using a variety of techniques, especially the ISCCP algorithm.

tively comprehensive set of observations at the greatest level of coincidence possible.

1. Satellites

There are two primary satellite platforms: *NOAA-9* and *GOES-6*. During the experiment, all measurements will be archived for the region within 37.5°N to 47.5°N and 80°W to 102.5°W. Aircraft operations will typically coincide with the *NOAA-9* afternoon overpass (approximately 1430 local time). A few missions are also planned in conjunction with the nighttime overpass. Data will also be obtained from the *ERBS, Landsat-5,* and DMSP satellites.

Specifically, data from the *NOAA-9* polar-orbiting satellite will include, Advanced Very High Resolution Radiometer (AVHRR) data—5 channels (imaging) with approximately 1-km resolution, TIROS Operational Vertical Sounder (TOVS) data—20 channels (sounding) with approximately 15-km resolution, and Earth Radiation Budget Experiment (ERBE) data—30-km-resolution scanner data and medium and wide field-of-view data. The AVHHR data will be obtained in the direct readout high-resolution picture transmission (HRPT) mode as well as the usual global area coverage (GAC) mode (approximately 4 km). Data from the *GOES-6* geostationary satellite will include Visible and Infrared Spin-Scan Radiometer (VISSR) data—2 channels (imaging) at approximately 1-km (visible) and 4-km (infrared) nominal resolution, and VISSR Atmospheric Sounder (VAS) data—12 channels (sounding) at approximately 8-km resolution. The VISSR data will be collected every 30 minutes except when the instrument is operated in sounding mode. Up to seven 3-hour periods coincident with aircraft operations are planned for VAS sounding, during which the mode of operation will alternate between imaging and sounding at 30-minute intervals.

Eight Landsat Thematic Mapper scenes will be collected; each will cover a 180-km square area (approximately 30-m resolution). During the experiment, two adjacent along-orbit scenes will be obtained on each of the four days when the satellite overflies the experiment region (approximately 0945 local time). All ERBS/ERBE data for times when the satellite views the experiment region will be archived. In addition, Stratospheric Aerosol and Gas Experiment (SAGE II) data will be obtained whenever the ERBS tangent point (solar occultation) occurs over the region. DMSP satellite observations of visible and infrared radiances (0.5-km digital data) will be collected as available.

Obtaining multispectral radiance observations from multiple viewing angles is a high priority, e.g., *GOES-6* and *NOAA-9*, ERBS, or Landsat. Times when two or more satellites simultaneously sample the same region are specifically targeted for intense sampling from other platforms.

2. Aircraft

Three research aircraft will be deployed for the experiment: the NASA ER-2, the NCAR Sabreliner, and the NCAR King Air. They will be based at Truax Field in Madison, Wisconsin. The ER-2 is a very high-altitude (approximately 20 km) aircraft and will serve as an areal cloud-mapping and satellite-simulator platform. The Sabreliner and King Air are equipped to make detailed microphysical and radiometric measurements as well as observations of atmospheric state variables. They will serve primarily as in situ cloud-sampling platforms. However, they also will be occasionally deployed in profiling and mapping modes below the target cloud layers.

Each aircraft carries its own standard complement of instrumentation including temperature and pressure probes, INS (inertial navigation system) wind systems, and upward- and downward-pointing, hemispheric, broadband infrared

TABLE 1. Instruments for Cirrus IFO, October 1986.

Platform/Instruments	Measurement	Institution
Aircraft		
NASA ER-2		
Lidar	Cloud height, etc.	GSFC
MCR	Up radiances	GSFC
TMS	Up radiances	GSFC
HIS	Up radiances	U. Wis.
Radiation sensors	Up and down radiances	ARC
NCAR Sabreliner		
Radiation sensors	Up and down radiances	CSU
Microphysics	Cloud microphysics	NCAR/CSU
Met	Met	NCAR
NCAR King Air		
Radiation sensors	Up and down radiances	NCAR
Microphysics	Cloud microphysics	NCAR
Met	Met	NCAR
Satellite		
Polar Orbiters (2)	1- and 4-km	
AVHRR	1-km radiances	NOAA
GAC	4-km radiances	NOAA
TOVS	20-channel radiances	NOAA
GOES		
VISSR	1-km radiances	CSU/U. Wis.
VAS	12-channel radiances	U. Wis.
ERBS		
ERBE	Large-scale radiances	NASA
SAGE II	Cloud-top height	LaRC
LANDSAT-TM	30-m radiances	NOAA
DMSP	0.5-km radiances	AFGL
ISCCP	B3, Cloud parameters	ISCCP
Surface		
Madison		
Lidar	Cloud height, etc.	U. Wisconsin
Radiation sensors	Down radiances	Purdue U./CSU
Microwave profiler	Vertical winds, etc.	Astronautics
HIS	Down radiances	U. Wisconsin
Oshkosh		
Doppler lidar	Cloud height, etc.	NOAA/ERL
Radiation sensors	Down radiances	CSU
Wausau		
Lidar	Cloud height, etc.	U. Utah
Radiation sensors	Down radiances	Columbia U.
Ft. McCoy		
Lidar	Cloud height, etc.	LaRC
Radiation sensors	Down radiances	LaRC
Rawinsondes	Met profile	LaRC
Platteville		
Rawinsondes	Met profile	NCAR
NWS Sites (7)		
Rawinsondes	Met profile	NWS
Surface radiation budget		
Radiation sensors	Down radiation	LaRC

and solar radiometers. In addition the NASA ER-2[5] will be equipped with a *cloud lidar system* (*CLS*)—a downward pointing Nd and doubled Nd dual-polarization lidar with 7.5-m vertical resolution and 50-m horizontal-sampling interval; a *multispectral cloud radiometer*—a scanning (45° from nadir) seven-channel radiometer with resolution of 100 m at nadir (synchronized with CLS); a *thematic mapper simulator*—a scanning (84°) eleven-channel radiometer with 50-m resolution at nadir (also serves as an AVHRR simulator); a *high-resolution interferometer sounder* (*HIS*)—a prototype multichannel scanning interferometer with high vertical resolution; a downward pointing, narrow bandpass, narrow field-of-view, two-channel (split window), infrared radiometer; and downward looking photography. The NCAR Sabreliner[6] will be equipped with microphysical spectrometer probes (PMS)—a 2-D cloud-particle probe (50 μm–1.6-mm size range) and a 2-D precipitation probe (100 μm–3.4-mm size range); a frost-point indicator, a Rosemont icing-rate detector, a Johnson-Williams liquid-water probe, and a spectrally and angularly narrow-field-of-view radiometer (zenith to nadir), a bugeye radiometer, and front- and side-viewing cameras. The NCAR King Air[6] will be equipped with gust probes, microphysical spectrometer probes (PMS, Inc.)—ASASP aerosol probe (0.12–3.12-μm size range), a 2-D cloud-particle probe (50 μm–1.6-mm size range), and a 2-D precipitation probe (100 μm–3.4-mm size range), a decelerator impactor (ice-crystal morphology), a Lyman-alpha hygrometer, a Johnson-Williams liquid-water probe, front-and side-viewing cameras, and a downward-pointing, narrow-field-of-view, infrared-window radiometer.

3. *Surface Sites*

Four prime surface observing sites will be operated through the experiment. They will be located at Oshkosh, Wausau, Fort McCoy, and Madison, Wisconsin (Fig. 3). Each includes a cloud lidar system. Madison will also be the location of the operations center (Truax Field) with direct nearly real-time access to GOES data and the standard meteorological data base through a link to McIDAS, which is located at the Space Science and Engineering Center of the University of Wisconsin at Madison.

Fourteen passive surface-radiation sites will also be deployed (Fig. 3). At each lidar site and at four of the other sites, upwelling and downwelling, broadband infrared and solar fluxes will be observed; while at the remainder of the sites, only the solar components will be measured.

Besides the flux measurements and cloud photography, the following instrumentation will be operated at the respective prime surface sites: At Oshkosh, measurements will be made with a scanning, CO_2 doppler lidar and a multiple-field-of-view radiometer/pyrheliometer. Wausau will operate with ruby lidar (dual polarization), a narrow-field-of-view, "infrared-window" radiometer; a pyrheliometer and stereo cloud photography. The Fort McCoy site will be equipped with scanning ruby lidar, scanning, narrow-field-of-view (fov) multichannel radiometers; and a multiple-fov radiometer/pyrheliometer. At the Madison site, instrumentation includes raster-scanning ruby lidar, high-resolution interferometer sounder (HIS); narrow-field-of-view, multichannel radiometers; spectral photometer and polarimeter, and multiple-field-of-view radiometer/pyrheliometer. In addition, a 218.5-MHz wind-profiling system being built in Madison by Astronautics, Inc. may be operational during the experiment.

Passive radiometric instrumentation will be operated in a continuous mode, while the active cloud sensing systems will sample as cloud conditions, satellite overpasses, and aircraft operations warrant. Calibration and intercomparison of the various systems will be conducted prior to full deployment.

4. *Weather Balloons*

In addition to the routine rawinsondes at 0000 and 1200 UTC, coordinated special launches will be made from a network of National Weather Service (NWS) stations (Fig. 3) including Green Bay, Wisconsin; St. Cloud and International Falls, Minnesota; Omaha, Nebraska; Peoria, Illinois; and Flint and Sault Ste. Marie, Michigan. Up to three special launches at three-hour intervals will be made on days when cloud conditions are favorable and the aircraft are deployed. In addition, a special rawinsonde site (NCAR CLASS), located in Platteville, Wisconsin (Fig. 3), will be operated in conjunction with the NWS sites. Additional sondes will also be launched from the Ft. McCoy site.

c. *Data analysis*

It is important to note that full achievement of the observational objectives for the Cirrus IFO involves substantially more than data collection and reduction by individual investigators. Although much will be learned from this approach as a required initial step, integration of the various derived characterizations will be necessary to produce internally consistent descriptions and to maximize the utility and information content of the data for users, especially modelers. For example, important scientific questions that will be addressed during the data-analysis phase include, can lidar data be used directly to infer vertically integrated IWP (Liou, 1986), what is the level of uncertainty involved, and what ancilliary data would allow this level of uncertainty to be reduced to acceptable levels? The coincident in situ micro-

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[5] As noted previously, the ER-2 will be deployed primarily in a mapping mode. Two basic flight patterns will be used. The first is a rectangular sampling pattern involving successively offset straight legs (approximately 200 km in length). The second is an oval or triangular pattern, which is either flown repeatedly over the same scene or successively flown over the same cloud mass as it advects in the horizontal.

[6] The NCAR aircraft will be used mostly for vertical profiling in the cloud layer. Typical patterns will involve oval (racetrack) patterns or straight-line samples flown at successive levels, including just above and below the cloud (30–100 km in length). These patterns may be vertically stacked or float with the mean wind. Because of altitude limitations, the King Air will be responsible for levels below 30 000 feet with the Sabreliner usually above. The King Air will also fly low-level mapping patterns during a few missions (surface radiative properties).

Aircraft flight patterns will be coordinated with each other and with satellite overpasses to the extent possible. Selection of locations will also attempt to maximize coincidence with surface site observations; however, the meteorology of a specific case will be a dominant factor influencing decisions. When cirrus conditions are not favorable over the prime target area, alternate targets and target areas will be considered, e.g., over Lake Michigan.

physical observations will be crucial for this purpose. Similar questions may be raised with respect to the other remote-sensing systems when considering comparable levels of data reduction. Resolution of such issues will greatly enhance the value of this experiment and the data obtained.

The mechanism by which these issues will be addressed is through the generation of value-added case-study data sets. Specific cases will be selected by the FIRE Science Team (FST) for detailed comparative analysis. The added value of these data sets will result both from the merging of individual data sets obained from a variety of observing sensors and platforms, and from the level of data reduction. For example, cloud optical depths inferred from lidar and satellite observations will be compared, as will the more-elementary properties of cloud height and cloud fraction. This is envisioned as an iterative process involving collaboration among multiple investigators. This strategy is fundamental to FIRE and is also highly appropriate for resolving basic scientific issues involving some of the relatively new remote-sensing systems and techniques used in the experiment.

Reduced data, including calibration and navigation information, and the "value-added" data sets will be formally archived in the Pilot Climate Data System (a prototype, interactive data-management system) at the NASA Goddard Space Flight Center. Selection of these data sets, including formats, will be made by the FST Cirrus Working Group. The data will be made available to the general community once the reduced products are validated (approximately 18 months after the field experiment). Raw data will generally be archived at the home institution of the responsible investigator.

3. Final Comments

The FIRE Cirrus IFO is the first comprehensive cirrus-cloud field experiment. It is unique with respect to the diversity and scope of instrumentation, and the coordination between sampling platforms, i.e., coincident observations by multiple lidars, multiple satellites, in situ and remote-sensing aircraft, Doppler lidar, passive surface systems, and rawinsondes.

It should be noted that a program of extended time observations (climatological) of cirrus is also being conducted as part of FIRE (Cox, et al., 1987). This effort involves most of the surface-based systems deployed for the IFO in coordination with satellite observations. It is hoped that the acquisition and analysis of these and the IFO data sets will lead to rapid progress in observing, understanding, and modeling cirrus clouds.

More information about FIRE, the Cirrus IFO, the participating investigators, and the data may be obtained from the FIRE Project Office located at NASA Langley Research Center in Hampton, Virginia (see Cox, et al., 1987 for a list of FIRE documents).

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