NASA ADVANCED SATELLITE AVIATION–WEATHER PRODUCTS (ASAP) STUDY REPORT

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For the National Aeronautic and Space Administration (NASA) and the
Federal Aviation Administration (FAA) Aviation Weather Research Program (AWRP)

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EXECUTIVE SUMMARY

This Report outlines a roadmap for the National Aeronautic and Space Administration (NASA) and the Federal Aviation Administration (FAA) Aviation Weather Research Program (AWRP) to enhance and extend the use of satellite data sets for applications in aviation weather.

In recent years, satellite remote sensing capabilities have advanced so rapidly that the AWRP's Product Development Teams (PDTs) are not always using all available satellite data sets to an optimum level. At the same time, a new generation of advanced meteorological satellites is being developed that promises vastly enhanced capability that will have a major impact on future aviation weather products. This Report suggests that there is an opportunity, through NASA sponsorship, to assist the AWRP PDTs in making better use of existing satellite data sets and to prepare the teams to be ready to make effective use of the next generation of satellite instrumentation.

The Report envisions collaboration between NASA and the FAA AWRP utilizing the University of Wisconsin Cooperative Institute for Meteorological Satellite Studies (UW-CIMSS) and the AWRP Product Development Teams. This collaboration would involve assistance in testing and evaluation of existing satellite algorithms that have been developed or are proposed by AWRP team members, the introduction of new techniques and data sets to the PDTs from the satellite community, and providing PDT access to satellite data sets available through CIMSS for research and development purposes. The goal of this collaboration would be to enhance the usage of satellite data sets within the existing PDT structure and to transfer satellite expertise to the PDTs. New satellite information would be integrated into the PDT's suite of weather products that undergo standard FAA procedures for testing and transition to operational use, including implementation in official aviation weather providers such as the National Weather Service.

The collaborative effort can also be used to facilitate an early involvement of the AWRP PDTs in the development process for the next generation of satellite sensors and speed the use and incorporation of these new technologies into the Nation's aviation safety programs.

1 INTRODUCTION

Aviation safety is everybody's concern. In February 1997 the White Commission on Aviation Safety and Security set a goal of reducing the rate of aviation accidents by 80% before the year 2006 (Keel et al., 2000). In response to this goal the National Aeronautic and Space Administration (NASA) initiated the Aviation Safety Program (AvSP) as a means by which NASA can contribute to meeting this goal. Since weather has been identified as a contributing factor in 30% of all aviation accidents a major portion of the AvSP program is focused on weather-related accident prevention.

The FAA's Aviation Weather Research Program (AWRP) formed Product Development Teams (PDTs) that have the responsibility to develop, test, and transfer into operational use new weather products to improve the safety and efficiency of the Nation's aviation system. The existing PDTs already make use of satellite data, in combination with other data resources such as radars, surface observing systems, numerical weather prediction models, and pilot reports to produce integrated, comprehensive products for the aviation community. Satellite remote sensing capabilities, however, have advanced so rapidly that the PDTs are not always using all available satellite data sets to an optimum level. At the same time, a new generation of advanced meteorological satellites is currently being developed that promise vastly enhanced capabilities which have the potential to have a major impact on future aviation weather products. This Report suggests that there is an opportunity, through NASA sponsorship, to assist the AWRP teams to make better use of existing satellite data sets and to prepare the teams to be ready to make use of the next generation of satellite instrumentation. The Report envisions collaboration between NASA and the FAA AWRP through involvement of the University of Wisconsin Cooperative Institute for Meteorological Satellite Studies (UW-CIMSS) and the AWRP Product Development Teams. This collaboration would involve assistance in testing and evaluation of existing satellite algorithms that have been developed or are proposed by AWRP team members, the introduction of new techniques and data sets to the PDTs from the satellite community, and giving PDT access to satellite data sets for research and development available through CIMSS. The goal of this collaboration would be to increase and optimize the usage of satellite data sets within the existing PDT structure and to transfer satellite expertise to the PDTs. New satellite products or data sets would be integrated into the PDT's suite of weather products and undergo the normal FAA procedures for testing and transition to operational use.

The proposed collaboration would occur in two phases. The first ("Phase I") will focus on enhancing the AWRP Product Development Teams use of *current* satellite data and processing techniques to address various aviation problems (current includes new platforms to be launched in the next year or two). These instrument systems fall into two categories: geostationary-Earth orbiting ("GEO") and low-Earth orbiting ("LEO"). The geostationary satellite observations include those from the Geostationary Operational Environmental Satellite (GOES) East and West instruments (currently GOES-8 and GOES-10, respectively), the European Meteorological Satellites (the current METEOSAT and future Meteosat Second Generation, MSG), and the Japanese Geostationary Meteorological Satellites (current GMS and future Multi-functional Transport Satellite, MTSAT). The polar orbiting observations include those in the current series of National Oceanic and Atmospheric Administration (NOAA) Polar Operational Environmental Satellite (POES) platforms and the NASA Earth Observing System (EOS) Terra and Aqua research platforms. The second phase, which will overlap with Phase I, will focus on exploiting the dramatic improvements in remote sensing technologies that will be possible with the next generation of satellites and identifying the opportunities that these satellites will provide for improving aviation weather products. These new satellite technologies will include the hyperspectral sounding capabilities of the Geosyncronous Imaging Fourier Transform Spectroradiometer (GIFTS) and the vastly enhanced capabilities of the GOES Advanced Baseline Imager (GOES-ABI) the Advanced Baseline Sounder (GOES-ABS) instruments. Similar capabilities will also be introduced on the next generation of polar orbiting satellites (NPOESS) through the NOAA Visible/Infrared Imager/Radiometer Suite (VIIRS) and Crosstrack Infrared Sounder (CrIS). Phase I activities would be conducted from late 2002 through 2005, while Phase II would identify research to be conducted from late 2005 through 2012 as these new technologies become available.

This Report reviews the opportunities for enhanced use of state-of-the-art in satellite remote sensing techniques for aviation applications and outlines an approach for a collaborative effort to broaden and enhance the use of current generation of satellite sensors within the AWRP PDTs. The collaborative effort can also be used to facilitate an early involvement of the AWRP PDTs in the development process for the next generation of satellite sensors and speed the use and incorporation of these new technologies into the Nation's aviation safety programs. This Report has been developed jointly by UW–CIMSS and NCAR, as directed by the NASA AvSP. The collaboration, however, would involve the entire AWRP community and is intended to represent a broad-based collaboration between the satellite and aviation weather communities.

This Report provides details on specific satellite-based methods and applications for increasing aviation weather-related safety. Section 2 highlights particularly desirable applications of satellite observations and describes how these applications can be utilized to address aviation issues. Section 3 summarizes how CIMSS would work in conjunction with the AWRP PDTs. Section 4 identifies how field experiments can be used to validate and best employ current and upcoming (hyperspectral) measurements and the role that the AWRP PDTs could play in bringing an aviation perspective to the testing and validation of the new remote sensing technologies. Section 5 provides an overview of the recommended timeline for implementing the enhancements in satellite utilization. Finally, Section 6 overviews the NCAR and UW–CIMSS scientific teams. Appendix A is included to provide an overview of satellite data availability and latency as critical issues that must be addressed if this information is to be applied to aviation interests. In particular, the UW Space Science and Engineering Center's (SSEC) Data Center will be described as an R&D resource for infusing new techniques and new capabilities into the existing FAA AWRP Product Development Team structure. Successful new technology would be implemented operationally within the appropriate operational organization (e.g. NOAA). Appendix B provides an overview the research facilities at UW–CIMSS and NCAR. Appendix C lists and defines the many acronyms used throughout this study.

2 APPLICATION OF SATELLITE INFORMATION TO ADDRESS PROBLEMS FOR AVIATION SAFETY

The following sections detail some of the scientific methods that can be employed to enhance the use of satellite information for addressing various meteorological problems related to aviation safety. Highlighted are seven specific aviation hazards for which satellite information can add value. These hazards are discussed in no particular order.

The techniques for processing satellite information are presented as they fall into the two phases of this ASAP initiative. Specifically, for all Phase I development, the methods focus on utilization of data from the current generation GOES satellites (GOES-8 and GOES-10) and the MODerate Resolution Imaging Spectroradiometer (MODIS; one each on Terra and Aqua). For Phase II, the focus is on hyperspectral data collected by AIRS (on the Aqua platform), and the CrIS, VIIRS, GIFTS, GOES-ABI, and -ABS instruments. In many cases, the following discussion will not be satellite-specific but instead will concentrate on techniques for using a particular form of spectral data (i.e., selected bands versus hyperspectral radiances).

2.1 In-Flight Icing

For some aviation applications knowledge of the detailed microphysical state of the clouds is critical. In particular, knowledge of conditions in which "super-cooled" (liquid water below 0° C) water drops may be present within clouds is of high interest. Aircraft encountering super-cooled clouds can experience a rapid accumulation of ice on exposed aircraft surfaces leading to a rapid loss in aircraft performance. During Phase I and Phase II of this effort, progress can be made in the area of cloud phase evaluation. Immediate progress is foreseen during Phase I using existing techniques, with improvements during Phase II occurring as methods are enhanced and new hyperspectral sensors become available.

Icing hazards are fundamentally dependent on the size and phase (ice or water) of hydrometeors (including water drops and ice crystals) throughout the depth of the cloud. There is a similar dependence on precipitation type and amount for predicting the impact of winter storms on aircraft operations in the airport terminal area. While infrared-emission remote sensing techniques may limit sensing through clouds, multi-spectral processing techniques have already shown skill in monitoring hydrometeor size and phase information at cloud top. Figure 1 is an example of cloud phase as determined by the MODIS sensor. This cloud top information can be valuable, but has to be used with caution since the particles at cloud top may not be typical of the particles below. For example, air motions at cloud top may produce liquid drops, while underlying layers might be totally glaciated. Techniques of this sort, however, may well be used for classifying clouds and in the identification of convective cores (see section 2.4).

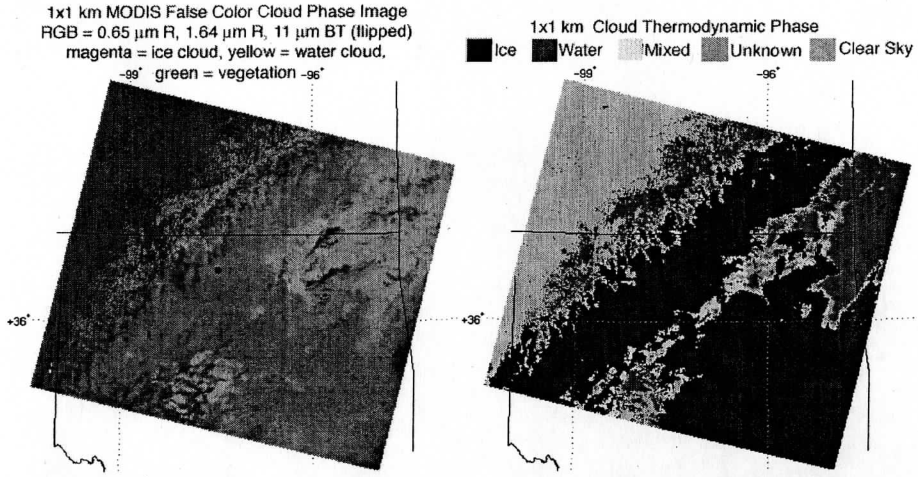


Figure 1: The MODIS scene is from 1745 UTC, 21 April 2001 over the ARM SGP CART site. It includes multilayered clouds, with a cirrus shield overlying a stratocumulus cloud deck. In the false color image on the left, the ice clouds appear as magenta while the low clouds are white/yellow. Cloud-free land appears as green. The blue dot in the left-hand image denotes the location of the ARM SGP CART site central facility near Lamont, Oklahoma, which provides independent cloud property information for validation. The right hand image shows the cloud phase classification, where the majority of the low cloud is correctly classified as being water phase, and the cirrus is typed as being ice phase. Around the boundaries of the cirrus deck, the classification may be either mixed or uncertain phase. Often, thin cirrus over lower-level clouds are classified as being mixed phase.

The MODIS cloud phase algorithm (Strabala et al. 1994; Menzel and Strabala 1997; Baum et al. 2000) differentiates between ice, water, and mixed phase clouds using infrared tests involving the 8.5-µm and 11-µm bands. This methodology has advantages over those that use "split window" data. As the approach involves only infrared bands, it has the flexibility to be applied to data regardless of solar illumination. The MODIS infrared cloud thermodynamic phase algorithm has been applied routinely to all operational data with considerable success but several issues are outstanding. For example, phase discrimination for optically-thin cirrus remains problematic. The challenge of inferring the cloud phase of thin cirrus near the cirrus shield boundaries can be seen in Figure 1. Considerable effort is underway to improve the performance of the infrared phase algorithm when optically-thin ice clouds are present regardless of surface type or solar illumination conditions. Another issue is the determination of the most prevalent cloud phase when the cloud-top temperature resides in the range 250-270 K. In this temperature range, a mixture of both liquid drops and ice crystals are likely present. As supercooled water drops are typically prevalent over large areas in both hemispheres at high latitudes (~60°-90°), this is a significant issue that needs further investigation. An effort is underway to supplement the infrared-based method with visible and near-infrared bands during daytime viewing conditions to improve the phase classification under the conditions listed above.

The methods of Smith et al. (2000a,b), similar to those developed for use with MODIS data but which evaluate supercooled liquid water using the current generation GOES instruments, can be also be implemented. The Smith et al. techniques also provide cloud optical depths, hydrometeor size, phase and total water path in near real time, and therefore can be applied during Phase I of the ASAP initiative. These methods take advantage of GOES abilities to measure conditions within the top several hundred meters of clouds over large geographical regions. In addition, this ASAP project will seek to work in conjunction with the Forecast Products Development Team (FPDT), Office of Research and Applications (ORA NOAA/National Environmental Satellite Data and Information Service (NESDIS), see http://orbit-net.nesdis.noaa.gov/arad/fpdt/), as well as other AWRP PDTs, to improve satellite-based in-flight icing safety products currently in existence.

2.2 Turbulence

Turbulence, in particular clear-air turbulence (CAT) and convection-induced turbulence (CIT) are among the most important, but least understood, of the outstanding problems in aviation weather. Turbulence studies are still at a fundamental stage; exploring the basic physics of the energy transfer and trying to understand what forces have to combine to produce aircraft-threatening severe turbulence. These are very active areas of research for the AWRP. A fundamental problem for turbulence is the difference in scale between the turbulent motions that affect aircraft (scales of 10's to 100's of meters) and the larger scale atmospheric properties that can be observed by satellites or resolved by numerical weather models. Researchers hope to discover connections between larger scale structures that can be observed and the small-scale turbulent events that affect the aircraft.

Vertical wind shear is frequently thought to be a likely source of turbulence. High resolution monitoring of the vertical gradients in wind patterns may be possible with satellite derived winds. For this application it may be necessary to resolve wind gradients on a vertical scale of much less than a kilometer. It may not, however, be necessary to completely resolve the horizontal winds at this scale, so long as the analysis can identify areas with strong gradients. Some initial studies can be done with current wind products, but real progress may have to wait for the improved wind products expected from hyperspectral instruments.

At present, the most useful approach may be to undertake a series of exploratory investigations of turbulence incidents, examining all the available satellite imagery and sounding information in areas of reported turbulence in order to define the limits of satellite monitoring of turbulent events. Another approach would be to use three-dimensional numerical models (e.g. Clark 1977; Clark et al. 2000) to simulate turbulent events and then use the high-resolution gridded output fields as input for computer simulations of satellite instrument behavior and capabilities. This approach would not only document the detection potential for an existing instrument, but could also be used to define the levels of performance needed to detect the turbulent events. Finally, work already in progress at UW–CIMSS using hyperspectral instrumentation [from the NPOESS Airborne Interferometer Test-bed (NAST-I) and Atmospheric Emitted Radiance Interferometer (AERI) instruments] to detect the signals of organized turbulent structures within and above the convective boundary layer may be able to be extended to flight level altitudes. Field experiments such as the International H_2O Project 2002 (IHOP_2002), and THe Observations Research and Predictability experiment (THORpex), may be of great use for performing some of the necessary exploratory turbulence research.

Another area of potential importance for turbulence research is in the monitoring of abnormal ozone concentrations resulting from the folding of the tropopause and wave structures identified by distinctive patterns in visible or water vapor geostationary satellite imagery. This research would focus on flight-level turbulence near the tropopause.

Current geostationary satellite technologies may be able to be used for turbulence detection in combination with other data sets. For example, satellite-derived winds may be able to be integrated with model output and satellite imagery to identify conditions supportive of the occurrence of turbulence. In particular, jet streams, jet streaks and/or mesoscale "jetlets" are easily identifiable using high-density cloud motion and water vapor winds in combination with high-resolution imagery. An additional use of satellite-derived winds could be to explore how "low-quality indicator" winds may be used to infer regions of highly divergent/convergent flows at flight level.

Figure 2: An example of mountain waves as viewed in clear air from GOES-8 over Colorado at 10:15 UTC 8 October 1997. Moderate to severe turbulence was reported in AIREP reports in association with the "standing wave" features.

Figure 2 demonstrates how GOES imagery alone may be used to detect mountain waves that may cause turbulence. In this example, moderate to severe turbulence was reported in AIREP reports associated with the "standing wave" cloud features. The difficulty, of course, is that waves do not necessarily produce turbulence. Such observations, however, may play an important role as one of a number of "interest fields" that are used in a mature turbulence detection algorithm. Figure 3 shows the improved resolution of the MODIS instrument that can be used to make higher precision detection of the wave structures. In combination with the Turbulence PDT, it should be possible to explore whether the wave signatures for mountain-induced turbulence in GOES and MODIS imagery may be used to infer the severity and spatial extent of turbulence.

As satellite-derived winds give us an improved description of the kinetic state of the atmosphere, derived variables such as lower tropospheric equivalent potential temperature (θ_e), and convective available potential energy (CAPE) similarly describe the thermodynamic state over large regions. With hourly or sub-hourly updates, satellite-derived stability fields can be used to assess the general synoptic scale environmental stability across large regions, especially over data void oceans (Eyre 1990; Smith et al. 1990; Feltz et al. 1998; Menzel et al. 1998; Li and Huang 1999; Ma et al. 1999; Li et al. 2000; Schmit et al. 2001). Experience gained through this past research will be immediately applied during Phase I to current-generation instruments and later in Phase II to hyperspectral datasets.

The combination of thermodynamic retrivals, high-density winds, and high-resolution imagery can be applied to explorative studies of turbulence incidents to evaluate the potential for satellite-based methodologies for real-time turbulence detection. With the introduction of GIFTS (during Phase II), and other hyper spectral sounding instruments, there should be a significant leap in observational capabilities that will permit better measurement of the vertical temperature structure and improved vertical resolution in wind analyses leading to improved identification of strong wind shear environments and elevated inversions.

Phase II turbulence research with hyperspectral data will follow immediately the Phase I work, as new methods are developed and tested using GIFTS-like data sets. The goal of this portion of the ASAP will be to demonstrate a number of turbulence-specific interest fields so that they can be examined and tested within the AWRP Turbulence PDT. In summary, while initial efforts in understanding and diagnosing turbulence hazardous to aircraft can be made using current instrumentation, true progress may have to wait for the future generation of sounding and imaging instruments. In the meantime, remote sensing data sets can be studied in concert with high-resolution numerical modeling and observations (e.g. PIREPs) to better understand turbulent structures hazardous to aircraft.

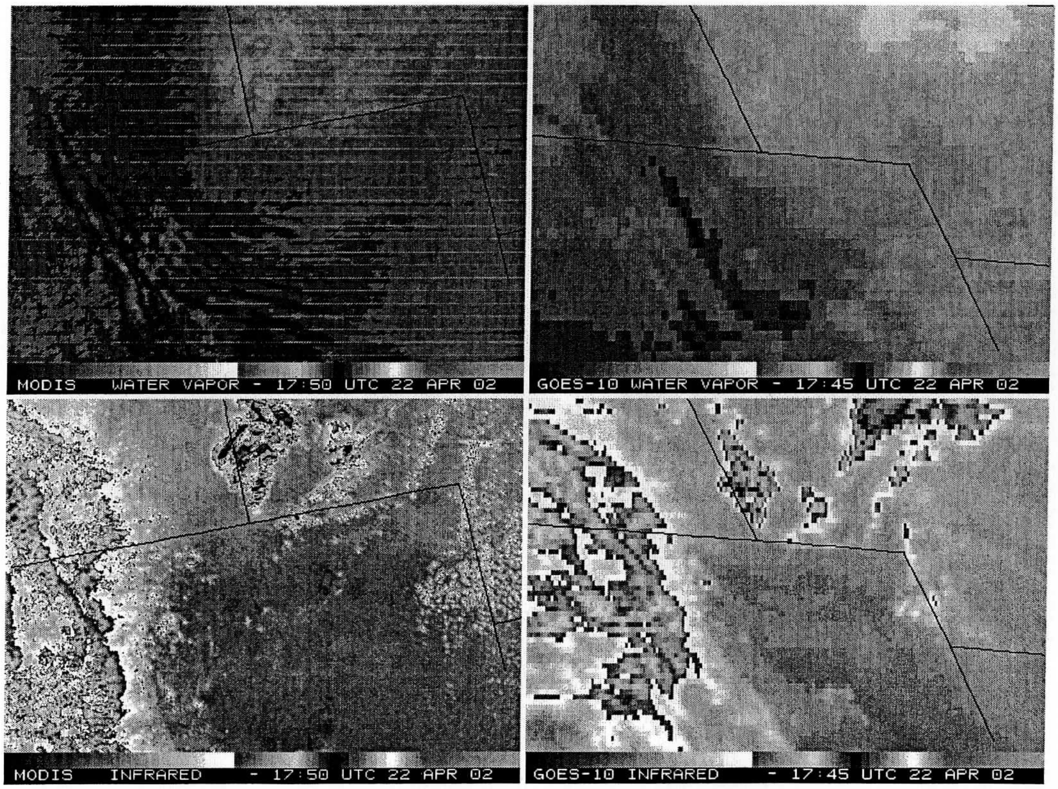


Figure 3: An example of mountain waves as viewed from GOES-10 (right two images) and MODIS (left images) for 17:45-17:50 UTC 22 April 2002. Note that the wave features are seen in clear air, associated with signals in the water vapor field.

2.3 Dust, Aerosols and Visibility

Airborne dust and anthropogenic aerosols such as those resulting from large-scale biomass burning are global phenomena that pose serious threats to aviation safety and airspace efficiency. Reduction in visibility due to dust and smoke can produce hazardous conditions for aircraft arrival and departure. Large dust outbreaks originating in Asia and Africa travel thousands of kilometers impacting regions far from the source. In South America, airports are closed for weeks at a time each year during the biomass burning season due to large smoke palls that can extend over several million square kilometers. During 1997, drought conditions associated with El Nino resulted in unprecedented wildfires in Southeast Asia. Dense haze disrupted air traffic and may have played a role in the crash of an Indonesian jetliner carrying over 230 passengers. Remote sensing offers the only cost-effective means to monitor aerosols on a global basis.

Volcanic ash emissions also yield a major hazard to aviation–impacting both the safety of flight at all altitudes and the efficiency of air traffic routing and control. Volcanic ash hazards are discussed separately in Section 2.7 below.

To date, operational aerosol detection and characterization has primarily been based on applications of the NOAA POES and the GOES, METEOSAT, and GMS geostationary platforms. Single and multi-band techniques incorporating visible, near-infrared, and thermal infrared information are used to delineate aerosol from cloud and to estimate the aerosol properties (Ackerman 1989; 1997; LeGrand et al. 1989; Prata 1989; Stowe et al. 1997; Wald et al. 1998; Prins et al. 1998; 2001a; 2001b). Geostationary and POES Advanced Very High Resolution Radiometer (AVHRR) visible data have been used successfully for many years to locate aerosols over water, although the lack of on-board visible calibration on NOAA operational platforms has been a limiting factor in providing highly accurate quantitative products on aerosol optical depth and characteristics. For over 10 years the NOAA Office of Research and Applications (ORA) has produced an operational global Aerosol Optical Thickness (AOT) product using the POES AVHRR 0.63 μm band. Efforts are underway to implement a multi-channel algorithm to retrieve aerosol size parameters and more accurate assessment of aerosol properties and AOT by using the AVHRR 0.83 μm band and/or the 1.6-μm band available on the NOAA POES-KLM series (Stowe et al. 1997).

The biomass burning monitoring team at UW-CIMSS has been using multi-spectral GOES Imager data to locate fires and identify and map the transport of associated aerosols for nearly 15 years. The NOAA/NESDIS/ORA Advanced Satellite Products Team (ASPT) and CIMSS developed two algorithms to identify fires, smoke, and cloud types using GOES data. The GOES Wildfire Automated Biomass Burning Algorithm (WF_ABBA) identifies and characterizes sub-pixel burning in half-hourly GOES imagery throughout the Western Hemisphere (Prins and Menzel, 1994; Prins et al., 1998, Prins et al., 2001b). The WF_ABBA is a dynamic multispectral contextual algorithm that uses the visible, shortwave infrared window (3.9 μm) and longwave infrared window (10.7 μm) bands and ancillary data to locate fires as small as a few acres in size. Once a fire is found, numerical techniques are used to estimate sub-pixel fire size and temperature. As part of a NASA funded Earth Science Enterprise (ESE) study, the half-hourly Wildfire ABBA product is assimilated into the Navy Aerosol Analysis and Prediction System (NAAPS) in real-time to analyze and predict aerosol loading and transport. Aerosol products are posted on the web at http://www.nrlmry.navy.mil/aerosol/. A global geostationary fire network will be possible with the launch of the European Meteosat Second Generation (MSG) satellite in 2002 and the replacement Japanese Multi-functional Transport Satellite (MTSAT-1R) in 2003. Although no funding is currently available, CIMSS plans to adapt the GOES Wildfire ABBA for application with MSG and MTSAT-1R. This will enable global automated diurnal fire detection and monitoring using a common algorithm. Global fire products will be made available to the user community for real-time fire monitoring and for assimilation into numerical aerosol transport models.

The Merged Automated Cloud/Aerosol Detection Algorithm (MACADA) was developed by the ASPT and CIMSS to distinguish clear sky from smoke and various cloud types (cumulus, stratus, thick cirrus, thin cirrus, multi-level clouds) and catalogue smoke and cloud extent in South America. The MACADA is a merged spectral/textural algorithm which uses multispectral GOES data (visible, 3.9, 10.7, 12.0 μm) to map smoke, aerosols, and clouds (Prins et al. 1998; Prins et al. 2001b). Applications of the MACADA in South America has provided valuable insight regarding smoke coverage and trends in smoke and cloud coverage over the continent and the Atlantic Ocean for the past 7 years. Initial applications of the MACADA in North America indicate that additional effort is needed to re-train the algorithm for this region. An experimental GOES AOT product is also under development and has been applied to several case studies in North and South America (Feltz et al. 2002). Comparisons of the GOES AOT with ground truth Aeronet sun photometer derived AOT show good correlation. Further work is needed to improve the product resolution of the GOES AOT.

The next generation GOES ABI instrument will have bands similar to those currently available from the GOES Imager and POES AVHRR/3 instruments. It will also have an 8.5 μm band, and possibly bands centered at 0.47 μm, 2.26 μm and 7.4 μm. These channels will offer improvements in diurnal aerosol detection and improved characterization of aerosol properties. The preliminary work by Sokolik et al. (2002) indicates that high spectral information available from GIFTS and ABS will enable quantitative characterization of aerosol properties not possible with current sensors (GOES, AVHRR, and MODIS) by allowing in-depth analyses of the unique spectral signatures associated with individual aerosols in relation to other atmospheric constituents.

Because GIFTS will retrieve pollutant type/density and wind profiles at high temporal and spatial resolutions it will be able to closely monitor the spread of a pollutant from a source region. This monitoring will include an assessment of the pollutant's height, depth (thickness) and general dispersion trends.

2.4 Convective Weather

Convective activity presents both a direct hazard to aircraft and an impediment to efficient use of airspace. In general, there are two different aspects of convection that need to be studied: monitoring intensification, dissipation and movement of existing convection, and monitoring the initiation of new convection. Thus our objectives within this ASAP initiative will be to: 1) identify which convective clouds (across a region) are likely to produce significant precipitation, 2) predict the geographical location to be affected by convective initiation (CI), and 3) validate the characteristics of the observed convection versus the characteristics of the forecasted convection.

The Convective Weather PDT produces time and space specific forecasts for the location and intensity of convective storms within the continental United States. Expert system techniques that employ "fuzzy logic" (see Kartalopoulos 1996) are used and designed to mimic the deductive and inductive reasoning of a human expert for forecasting CI. When assessing patterns from data, as well as relationships between various components of a dataset, non-binary logic, or fuzzy logic, is advantageous. These expert systems have exhibited greater skill for estimating the occurrence of CI as compared to numerical weather prediction models (Wilson et al. 1998).

Forecasts are produced for a variety of spatial scales that range from the synoptic-scale, to the regional scale and finally to the mesoscale. Temporal coverage is from 0-2 hours. Systems currently supported by the FAA include the "National Convective Weather Forecast" (NCWF), the "Regional Convective Weather Forecast" (RCWF), the Terminal Convective Weather Forecasting (TCWF), and the mesoscale system called the "AutoNowCaster" (ANC). The Oceanic Weather PDT forecasting system will produce synoptic-scale convection forecasts over oceanic regions and is called the "Oceanic Convective Weather Forecasting" (OCWF).

The Convective Weather PDT currently uses a variety of techniques and data sources to forecast the occurrence, intensity and duration of convective storms. The data sets include Doppler radar, satellite visible and infrared imagery, surface meteorological data, upper air soundings and numerical model output, among others. The synthesis of multiple data sets into a coherent system designed to anticipate convective development is a key component of the success of the Convective Weather PDT. Using various instrument systems from the IHOP_2002 field experiment (occurring during May-June 2002 in

Oklahoma and Kansas) and GOES to infer quantities such as atmospheric stability will be important for improving the quality of the forecasting products. The Oceanic Weather PDT will use similar techniques as the Convective Weather PDT but will have more limited data sets (for example, Doppler radar is not generally available).

Improving the current and future uses of satellite information within the Convective and Oceanic Weather PDTs will be a particularly important focus for ASAP. These improvements will be used in conjunction with other current and future techniques and with other data sets. For this reason, only satellite applications relevant to convective weather forecasting are discussed in this section. Research done at UW–CIMSS will be done in collaboration with FAA PDT scientists such that new findings can be incorporated into the forecasting methodologies.

A general diagnosis or detection of convective activity is immediately available from geostationary imagery in both visible and infrared channels. These data are widely available and are already being used effectively by the PDTs. With the current generation of GOES instrumentation there are opportunities to enhance the PDTs' use of satellite data through more advanced techniques, some of which are already being investigated by the PDTs, but which are not yet used operationally. In particular, there are a number of multi-spectral techniques that can be used to identify the active convective cloud cores such as split window brightness temperature differences or differences between the brightness temperatures in the water vapor channel and the thermal infrared channel. Temporal variations in the size, height, and location of these convective cores provide an indication of their future evolution and development of the systems.

For existing convection, evaluating the height of the cloud tops is one important Phase I activity. The current generation GOES sounder instrument routinely produces cloud top pressure estimates (Schriener et al. 2001). An important ASAP investigation will be to compare GOES sounder cloud top information against current techniques in use by the PDT's to estimate cloud top height using infrared brightness temperatures from the imaging instrument in conjunction with model-derived soundings. Seeking the best, cloud top estimation method from GOES data could allow some improvement in the cloud top height product.

Monitoring the initiation of convection is much more difficult than observation of existing clouds and storms using satellite imagery only. The critical parameters for convective initiation include the low-level convergence patterns and moisture fields. At present, satellite imagery can be used to infer the presence of low-level convergence by observing the formation of small convective bands. Use of satellite imagery in conjunction with radar detection of convective boundary layer convergence (CBL) boundaries further differentiates benign cumulus cloud with clouds undergoing vigorous growth (Roberts and Rutledge, 2002). Moisture fields and stability indices can be derived from the current generation of sounding instruments on an hourly update cycle, and will have greatly enhanced temporal and spatial capabilities as improved hyperspectral instruments become available between 2006 and 2012. One goal for this CI research is to be able to monitor and track stability and moisture fields throughout the troposphere and particularly in the CBL. Further enhancement of the geostationary infrared sounding instruments can be obtained by integrating the geostationary soundings with microwave soundings from existing and future polar orbiting meteorological satellites. A combined sounding product would feature the high resolution and precision of a hyperspectral product along with the all weather capability of the microwave soundings.

The main developments in satellite analysis to be undertaken during Phase I include development of new algorithms and modification of existing algorithms to 1) characterize cloud types across an image; 2) advection of cumulus clouds for accurate calculation of cloud growth rate to a 4 km grid resolution, 3) evaluate conditions supportive of convective clouds and their growth across a geographical region from a given set of satellite data such as sounder derived product imagery (DPI) of convective available potential energy (CAPE), convective inhibition (CIN), lifted index (LI), precipitable water (PW) and CBL moisture convergence; and4) assess patterns within satellite scenes of convective clouds (e.g., cloud lines, cloud-line orientations, convective cloud patterns, cumulus cloud streets). Figure 4 is a schematic image that illustrates many of the important cloud features that can be identified within geostationary imagery to nowcast CI. The plan early during Phase I of ASAP is to routinely infuse satellite-derived information as value-weighted inputs within the Convective Weather and Oceanic Weather forecasting systems; late in Phase I, new methods will be developed for assessing the characteristics of the newly developed convection, as well as to employ existing techniques.

Considerable effort will occur toward organizing all necessary data sets for performing CI analysis and eventual nowcasting, and to efficiently exchange information with all PDT collaborators. During Phase I, work will continue between CIMSS and NCAR scientists to identify case-study events of CI in which additional satellite interest fields (i.e., derived products based on the 1 km and 4 km GOES imager data) will be input into the ANC and the CI performance skill will be assessed. Initial collaboration has already begun on two case study events: 8-11 September 1999 for evaluating CI over the oceans and 2 June 2000 for CI analysis over land. Additional collaboration will occur during IHOP_2002 and during the THunderstorm Operational Research (THOR) experiments in the northeastern US during summer 2002.

GOES-8 1 km visible imagery: 17:45 UTC 10 September 1999

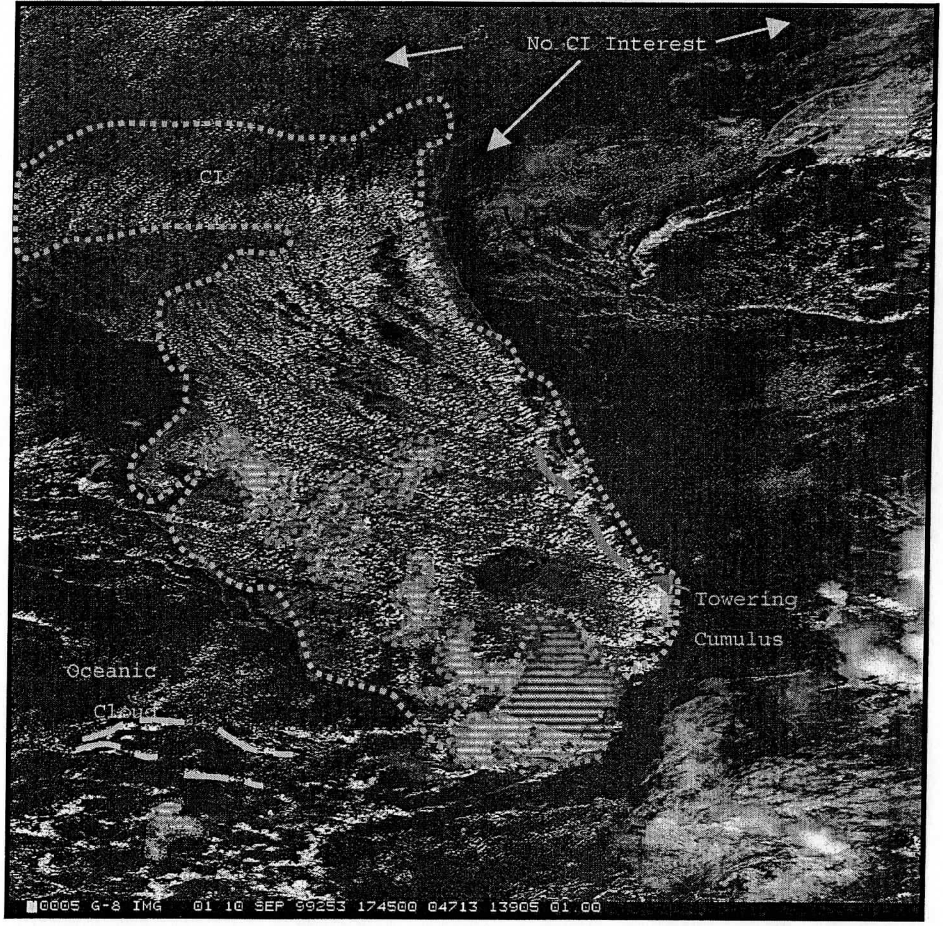


Figure 4: Schematic representation showing the potential use of GOES visible satellite to detect various interest fields for convective initiation (CI). Cloud features and patterns of interest would be automatically identified through the processing of GOES images. In the example above, differentiation is made between various types of cumulus clouds; this is important for nowcasting storm intensification. This example is for 17:45 UTC 10 September 1999.

Phase I research will build on the work already completed. Convective initiation research demands access to geostationary satellite data with a low-latency of collection (2-10 minutes). The combination of readily available data within several existing satellite data algorithms at both CIMSS and those already developed by the Convective Weather PDT will allow us to more fully exploit their potential. For example, cloud identification algorithms such as CIMSS's MACADA, NCAR's CloudClass, Naval Research Laboratory's (NRL) neural network Cloud Classification, and MIT Lincoln Labs' multispectral cloud classifier algorithms have been trained to appropriately identify specific aspects of convective clouds across North America and adjoining oceanic areas to isolate convective clouds within 4 km-resolution imagery. Both the CIMSS and Convective Weather PDT facilities have developed software tools that can be modified for the manipulation of satellite data for the ASAP project. For example, these include software that may apply various first- and second-order algorithms to satellite data (e.g. low-pass filters, gradient computations).

Although sophisticated pattern recognition techniques for clouds can be employed for this work (e.g., Bezdek and Pal 1992) simple pattern detection methods that provide an accurate cloud-typing algorithm can also be employed to isolate convective clouds from non-convective clouds. For the pattern recognition development, methods involving the comparison of geometric measurements of convective cloud patterns with cloud features known to be related to important precursors of CI (e.g., lines, oblong ellipses, pentagons) have been initially formulated, but need to be more fully developed. These geometric shapes are those most often identified with three-dimensional turbulence phenomena within deepening ABLs, such as "closed" and "open-celled" convection, ABL convective roll patterns, wave structures atop a growing ABL, and linear convergence. Analysis of 1 km satellite data in this manner has led (and will evolve) to the definition of "CI interest fields" (as noted above), or larger geographic regions that generally are supportive of CI, or possess actively growing convective clouds. Flagging areas as possessing little potential for CI ("non-CI interest areas") will be done in a similar manner. Figure 5 demonstrates an example from IHOP_2002 for identifying only small cumulus clouds across a region.

GOES 1 km visible imagery will play a key role in this work during Phase I, and has already been used to identify and analyze important precursive cloud features of CI, such as surface convergence-induced cloud lines, surface fronts such as those caused by lake- or sea-breeze circulations, and old convective outflows. Accurate, *automated* detection of these cloud patterns will be a key task during Phase I and a crucial component for the 0-3 hr nowcasting of thunderstorms. This is particularly important for nowcasting convection over oceanic regions. Ongoing research to date using the GOES visible and infrared data has been focused on: 1) convective cloud identification and detection, 2) cloud pattern recognition, and 3) the evaluation and tracking of cloud growth using GOES visible and 4 km infrared (Roberts and Rutledge 2002) and 10 km sounder imagery.

Methods for evaluating convective cloud patterns, growth, deepening and expansion have already been formulated by CIMSS for GOES (4 km) imager and (10 km) sounder data, and will be fully demonstrated during Phase I of ASAP. These include 1) nowcasting of the *initiation* of thunderstorms by automated detection of the very early growth of cumulus clouds over time using multispectral satellite information. This requires accurate tracking of cumulus clouds to compute the change in cloud top brightness temperature and has been shown to provide an additional 15-30 min lead-time for CI nowcasts (Roberts and Rutledge 2002). 2) Employing the procedures of Schmetz et al. (1997) and those implemented at NOAA's Aviation Weather Center (AWC, see http://aviationweather.noaa.gov/gcd/gcdinfo.html; Mosher 2002) to identify active "overshooting" cumulus development. These methods reveal cloud-top height changes through simple brightness temperature differencing somewhere in the infrared window between 10.5 and 12.5-μm and by differencing the brightness temperatures between water vapor (5.7-7.1 μm) and infrared, at the same time. The technique of Schmetz et al. is especially useful for identifying new regions of cloud-top glaciation as convective clouds near the tropopause or their equilibrium level and important for nowcasting storm duration and intensification. 3) Differencing cloud-top height estimates from hourly GOES sounder data using the methods of Schreiner et al. (2001), and other real-time satellite-derived products. 4) Evaluate the expansion, growth (deepening), and growth rates of convective clouds; initial cloud-top glaciation. 5) Using the 3.9-μm GOES imager channel to identify low-level liquid-water clouds at night, as done in Dunion (1999) over oceans. 6) Evaluate low clouds by means of the 11.0-μm infrared channel, and determining cloud-water or -ice by radiance differencing the 3.9 and 11.0-μm channels. GOES sounder data will also be invaluable for obtaining information throughout a cloud's depth, and can be used to measure cumulus cloud growth rates and supplement other information obtained from the imager.

Another Phase I effort will be to utilize GOES infrared and water vapor (4 km) cloud-motion winds, available in real-time (e.g., Velden et al. 1997), to assess the motion of pre-thunderstorm convective cloud forms. One basis for our nowcasting procedures is that observed trends in the relevant atmospheric phenomena maintain their integrity for short distances (~10-50 km) and time periods (0.5-6 hours) within real-time geostationary satellite data. In essence, clouds can be tracked within satellite data. One method to explore involves the linear tracking of radiance/brightness features based on observed trends and past motions. Although well proven by cloud-motion and cloud-derived wind algorithms (see Velden et al. 1997; Dunion 1999), this assumption has yet to be tested for CI applications as a viable method for nowcasting CI.

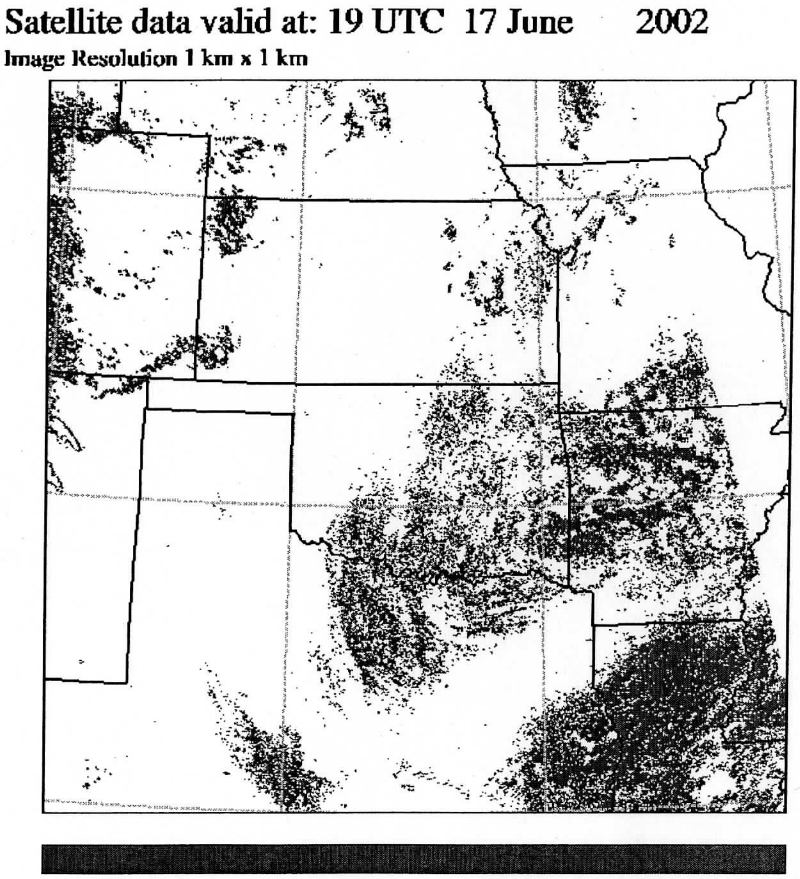


Figure 5: Identification within GOES visible satellite of only small, non-precipitating cumulus clouds across the IHOP_2002 domain on 17 June 2002 at 19:00 UTC. Computation of the vertical and horizontal brightness gradients leads to the identification of sharp cloud edges associated with cumulus clouds in this 1-km imagery.

At UW–CIMSS, routinely available satellite-derived products, including CAPE, lifted index, precipitable water, vertical temperature and moisture soundings, and cloud-top heights and cloud amounts

(Menzel et al. 1998; Ma et al. 1999; Schmit et al. 2001), will be incorporated into the Phase I CI research activities. The GOES sounder-derived products will be used to evaluate favorable environmental conditions for CI and the monitoring of subsequent convective activity and potential intensification of storms. To date, few of these environmental products have been employed in the FAA convective forecasting systems to evaluate conditions favorable to CI. Collaboration between CIMSS and the Convective Weather and Oceanic Weather PDTs will facilitate the transfer and use of these products into the FAA convective forecasting systems.

With the introduction of the new generation of sounding instruments during late Phase I and Phase II of ASAP there will be better earth coverage, higher resolution, and more frequent updates that will make sounders the instruments of choice for many convective applications. The combination of pressure surface data, coupled with the multi-spectral capabilities will be particularly attractive for advanced aviation products. With the introduction of the Advanced Baseline Imager on GOES-R, satellite imagery will, for the first time, be able to match meteorological radars in terms of spatial resolution (sub kilometer) and temporal update cycles (5 min). This advance will further enhance the attractiveness and usefulness of satellite data as a primary data source for convection studies that are not restricted to the (worldwide) limited geographical coverage provided by meteorological radars.

Several important components of this CI analysis system will undergo significant expansion during Phase I into Phase II of ASAP, especially with the incorporation of hyperspectral measurements. The items listed below represent key tasks toward improving the CI nowcasting on the 0-3 hr time frame as determined through initial CIMSS-NCAR collaborative research. They include: 1) a more comprehensive development of GOES image processing techniques for evaluating CI that combines visible, infrared, and the (hyperspectral) sounder data with other multi-sensor instrumentation when available, 2) the application of pattern recognition algorithms for convective clouds and convective cloud types, 3) the evaluation of how certain convective cloud patterns relate to or are associated with storm intensification, duration and heavy precipitation that are hazardous to aircraft and cause aviation delays, 4) the formation of robust data/information conduits between the CIMSS collaborators and the PDT members' 5) the development of a "confidence indicator" for estimates of convective cloud growth/expansion or dissipation rates and trends, 6) the evaluation of the usefulness of surface weather (from derived product imagery) and model forecasts for improving CI nowcasting research, 7) and the first-time development of algorithms using simulated GIFTS and GIFTS-quality data to prepare for the rapid utilization of the GOES-ABS and GOES-ABI instruments for aviation weather support.

2.5 Flight-Level Winds

One of the major success stories in modern meteorology is the development of satellite-based monitoring of atmospheric winds through high-resolution tracking of water vapor patterns and cloud drift winds. The UW–CIMSS has played a leading role in this development and now routinely generates global satellite-based atmospheric wind measurements using all current operational geostationary satellite platforms. By using imagery from different wavelengths, it is possible to estimate atmospheric motions throughout the depth of the atmosphere. In particular, water vapor (WV), infrared window (IRW), and visible (VIS) channel winds are normally available from each operational geostationary satellite. Wind estimates can also be obtained from the two shortwave infrared and sounder imagers (SNDR), providing additional low and mid-level atmospheric motion measurements within their fields-of-view. These motions are calculated using state-of-the-art computer algorithms that track water vapor gradients and cloud edges over successive images. Multiple quality control tests are employed to yield high-quality and accurate atmospheric wind vector data sets. A number of derived analysis fields are then derived from the basic motion data sets, providing additional motion information to users worldwide. Application of these wind measurements and analysis products can easily be transitioned for aviation needs and additional aviation-specific analysis products can be developed using current and future satellite technologies.

Wind vector information is currently assimilated into several different regional and global numerical weather prediction models. The assimilation and use of the satellite derived wind data sets in these models has led to significant accuracy improvements that have been documented in numerous studies, such as those investigating tropical cyclone motion (Velden et al. 1998, Goerss et al. 1998; Soden et al. 2001) and severe weather/mesoscale prediction (Rabin et al. 2001). In addition, several derived products from these wind sets have been developed to provide forecasters with atmospheric analyses products, such as atmospheric relative and absolute vorticity, wind shear, wind shear tendency, divergence, and inertial available kinetic energy analysis. These products have proved to be very valuable to both researchers and forecasters.

Motion vector and analyses products are now derived routinely on various atmospheric scales, from global to mesoscale, at varying time resolutions. Global wind vectors are currently being produced operationally every three hours for all of the operational geostationary satellites except for the GMS-5 imagery, which only allows for wind vector derivation every six hours (see Fig. 6). The fully automatic satellite wind system developed at UW–CIMSS (Velden et al. 1997, 1998) has been operational at the NOAA/NESDIS for several years and also provides wind products for Fleet Numerical Meteorology and Oceanography Center (FNMOC) and international users.

The current state-of-the-art wind-tracking algorithm allows for site-specific wind processing for the Man-computer Interactive Data Access System (McIDAS) and non-McIDAS users at locations outside of UW–CIMSS (Olander et al. 2000). This availability enhancement is significant since it allows for processing of satellite-derived wind fields at each individual location for site-specific needs. The algorithm includes the capability to automatically navigate a set of images used to derive wind vector fields, eliminating erroneous shifts in the satellite navigation that can affect the accuracy of the measurement. Multiple quality control routines, including a recursive filter (RF) editing routine (Hayden and Pursor 1988; Hayden and Nieman 1996), a European Organization for the Exploitation of Meteorological Satellites (EUMETSAT) quality indicator (QI) routine (Holmlund 1998), and various situation-specific routines checks are performed during the analysis to ensure a stable and accurate wind vector determination. The resultant wind vectors have a typical wind vector root mean square (RMS) errors of between five and eight meters/second for upper-level water vapor derived wind vectors (above 70 kPa), and between three and seven meters/second for cloud drift winds between 10 and 95 kPa (Velden et al. 1997).

The most common way for users to access the wind information is through the use of model output data from models such as the National Center for Environmental Prediction's global Aviation Model (AVN) model which are initialized using the satellite derived winds. Use of the model, however, restricts the timeliness of the wind information since the model is only run four times per day. For aviation applications it could be more useful to produce a separate gridded wind product through a stand-alone data assimilation program of the sort use for model input. The gridded product could provide a more timely and higher resolution description of flight level winds. In this case the improved wind information could be used predicting storm movement, identifying gradient regions that may be likely to generate turbulence, or predicting the dispersion and advection of dust or volcanic ash. A separate wind product could also be used for planning efficient flight routes, but the benefit in this area is still limited by current air traffic procedures. With the development of FANS (Future Air Navigation System), improved knowledge of the winds will be more useful and may be essential to allow the closer spacing of aircraft and higher capacities that are desired under FANS.

In addition to a gridded flight level winds product, it is also possible to generate custom data sets as needed for specific AWRP PDTs. In particular, analysis products, such as wind shear, wind shear tendency, and jet stream analysis, could easily be produced. It may also be possible to generate special product windows for tracking smoke or volcanic ash. For example, studies investigating a layer of air over the Atlantic Ocean containing trapped dust silicates from the Sahara desert has successfully identified and tracked this these dust particles using multiple satellite channels and derived wind vectors

(Dunion and Velden 2001). It may also be possible to extend the routine satellite-based wind analysis coverage areas to polar regions through the use of imagery from polar orbiting satellites.

With the introduction of new satellite technology as Phase II of ASAP begins, the production of satellite-derived wind fields will drastically improve and increase. Improved horizontal resolutions with the GOES-N, GOES-R, MSG, and MTSAT series of geostationary satellites will allow for a greater number of winds and higher accuracy in tracking cloud/moisture gradients. Water vapor, in particular, plays a very important role in determining the stability and the chemistry of the atmosphere. One of the key features of the vertical distribution of water vapor is that it decreases exponentially with height. About 60% of the total precipitable water in the atmosphere is concentrated between sea level and 85 kPa (the typical extent of the boundary layer). Less than 10% is generally found above 50 kPa. Therefore, an accurate determination of the lower tropospheric moisture profile is important for analyzing stability. Obtaining accurate moisture profiles can also be used to derive measurements of the lower-tropospheric wind field. The wind field can be generated from successive high spatial and temporal resolution moisture analyses obtained by radiative measurements from geostationary satellite platforms.

Added satellite channels will introduce wind vectors at different atmospheric levels than currently derived, and will allow for the development of additional wind vector height assignments. The new capabilities in producing satellite track winds through the combination of cloud tracking techniques and the tracking of moisture patterns visible in the water vapor absorption bands has been a revolution in observing atmospheric wind patterns. In the future there should be a great improvement in wind monitoring from geostationary satellites.

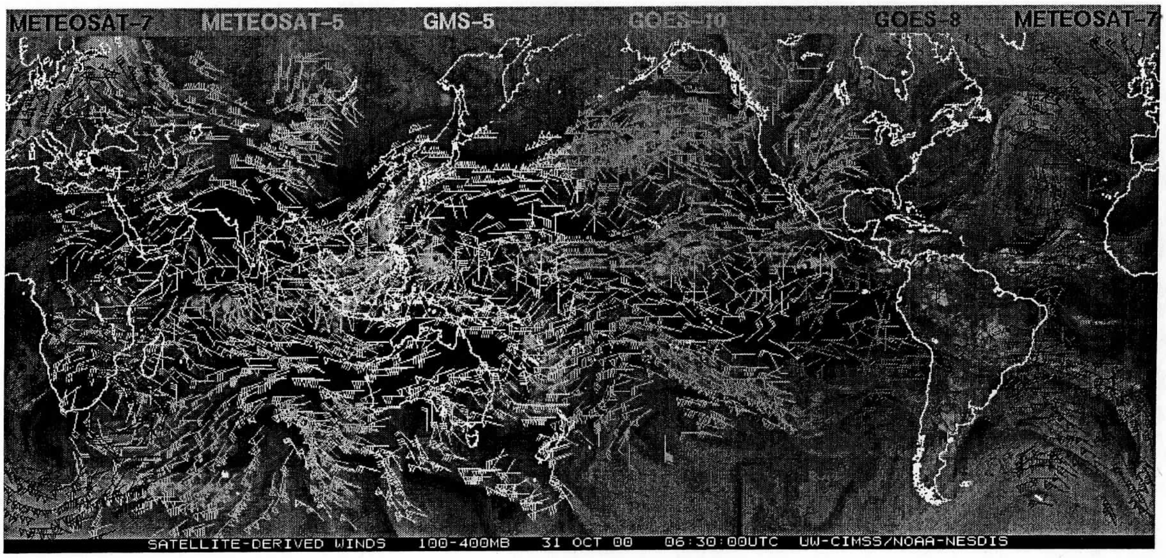


Figure 6: UW–CIMSS global water vapor wind vectors (thinned) for 100–400 hPa layer, derived automatically in real time from METEOSAT-5 (cyan color), METEOSAT-7 (blue color), GMS-5 (yellow color), GOES-8 (red color), and GOES-10 (green color) water vapor data.

The greatest technological impact will be obtained via the interferometer-class of sounding instruments, such as the GOES-ABS and GIFTS. These instruments will allow for wind vector derivation at thousands of potential atmospheric levels. Not only will this type of instrument produce a more complete vertical structure of atmospheric motion, but they will improve the accuracy of the derived heights at which the wind vector are assigned via the increased measurement precision of atmospheric radiation. Drastic improvements realized by these future satellite platforms will also result in finer-scale analyses products, due to the increased spatial and temporal resolutions at which satellite winds can be derived. These improvements result in more accurate and more comprehensive current and theoretical analysis products for aviation interests.

Using the hyperspectral sounding capabilities of GIFTS, it should be possible to extend the routine monitoring of atmospheric winds down to the boundary layer. Initial tests of this capability will be made through the use of simulated GIFTS radiances. Through simulation, the retrieved boundary layer moisture can be evaluated against "truth." The simulation of GIFTS radiances will be able to account for the effects of surface emissivity, contrast between surface skin temperature and surface air temperature, clouds and surface height. The boundary layer moisture imagery from successive time steps over cloud-free regions can then be used as input to the UW–CIMSS automated feature-tracking algorithm to evaluate the potential for monitoring low-level wind shear and low-level convergence/divergence fields (Velden et al. 1997, 1998).

GIFTS moisture analyses at high temporal frequency will provide targets of opportunity to track over time to infer winds. Experiments will include examining the ability to retrieve lower tropospheric wind profiles by tracking moisture features vertically collocated in GIFTS analyses. The full potential of this altitude resolved moisture imagery sequence (retrieved moisture profile imagery at different time steps) within the mature feature-tracking wind technique would be reached when the future geostationary hyperspectral data are also used to provide mass field information for numerical weather prediction models and real time local environmental monitoring.

2.6 Cloud Layers and Boundaries

This section focuses on the use of cloud information by the AWRP PDTs, in particular, cloud boundaries (i.e. tops, bases) and the layering of clouds. While knowledge of the multi-layer structure of clouds would be important to many of the AWRP PDTs, visible and infrared satellite observations have traditionally been limited to cloud tops. In some cases, however, it is possible to see lower clouds through thin cirrus and recent studies suggest that it may be possible to make quantitative observations of the lower cloud properties.

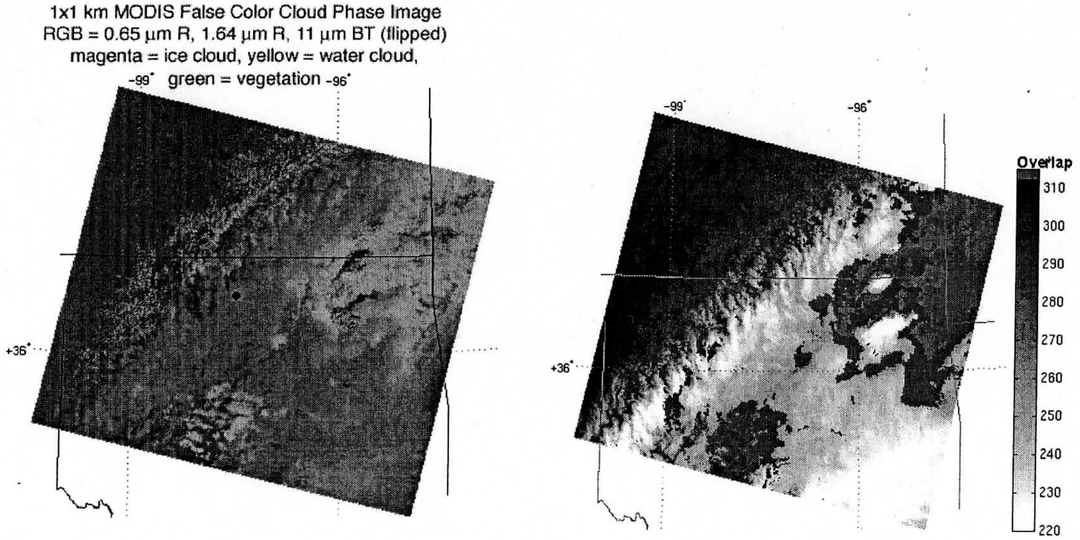


Figure 7: (left) MODIS false color image (RGB = 0.65, 1.64, and 11 µm) over the ARM SGP CART site (indicated by a blue dot) on 21 April 2001 at 1745 UTC. Ice clouds appear as magenta, low clouds are white/yellow, and cloud-free land appears as green. The scene is one of multi-layered clouds, with a cirrus shield overlying a stratocumulus cloud deck. The right hand image shows in red the MODIS pixels that potentially contain multiple cloud layers.

The evaluation of complex cloud structures can make use of current generation GOES instrumentation, perhaps supplemented by data sets from AVHRR and MODIS. Using current GOES imagery, researchers at CIMSS have had some success in making quantitative observations of multiple cloud layers by using the occasional breaks in the upper layer clouds to see the underlying cloud deck below. These successes can be used, on a test basis, in support of AWRP PDT algorithm development and validation testing.

The high-resolution MODIS instrument offers much-improved capabilities for monitoring complex cloud structures and points the way toward the enhanced capabilities of the next generation of geostationary instruments. With MODIS it may be possible to develop a routine, operational capability for monitoring multi-layer clouds. This capability can be investigated during the ASAP Phase I studies.

Studies of layered cloud structures began as an attempt to improve estimates of cloud top properties by removing the "contamination" of thin upper level clouds and multiple cloud decks. Initially, cloud retrieval efforts made the assumption that only one cloud layer could occupy any individual field of view. Unfortunately, surface observations have shown that perhaps half of all cloud observations are multi-layered. The presence of more than one cloud layer in an observation introduces errors into the cloud retrievals (e.g., Baum and Wielicki 1994). The MODIS imager, with its improved spectral and spatial resolution, is well suited to address this problem. Algorithms have been developed and applied to several case studies for both daytime and nighttime conditions to infer whether thin cirrus overlies a lower-level water cloud. While these approaches show promise, further improvements will stem from operational testing using MODIS direct broadcast data.

The approach for daytime overlapping cloud detection by MODIS is presented in Baum and Spinhirne (2000). The daytime algorithm involves a bispectral approach involving a near infrared (NIR) and IR band. Progress in inferring where daytime cloud overlap occurs is demonstrated in Fig. 7 recorded over the Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) program Southern Great Plains (SGP) site on 21 April 2001 at 1745 UTC. The scene is one of multi-layered clouds, with a cirrus shield overlying a stratocumulus cloud deck. In the false color image on the left, the ice clouds appear as magenta while the low clouds are white/yellow. Cloud-free land appears as green. The blue dot in the left-hand image denotes the location of the ARM SGP site, which provides independent cloud property information for comparison purposes. The right hand image shows in red the MODIS pixels that potentially contain multiple cloud layers.

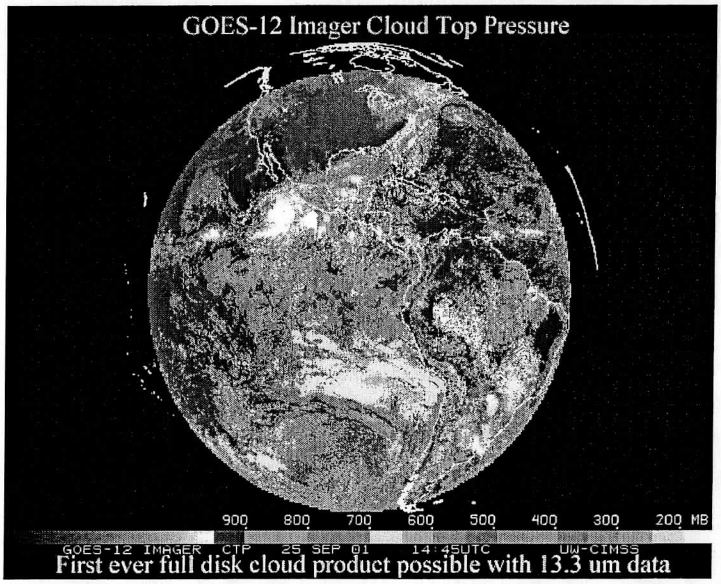


Figure 8: An example of full disk cloud top height coverage using GOES-12 sounder data for 25 September 2001.

For nighttime cloud overlap detection, an approach was originally developed for use with merged data from the AVHRR and High Resolution Infrared Radiometer Sounder (HIRS) data (Baum et al. 1994). This work has been further refined (Baum et al. 2002) to take advantage of the higher spatial and spectral resolution of the MODIS instrument. This work is in its initial stages but looks promising. The goal is to move from case studies, where MODIS-derived cloud properties are compared to those obtained from ground-based sites, to an operational algorithm. This entails the incorporation of all the inputs necessary for a detailed analysis, such as the cloud-clearing product, cloud top height and phase analyses, and Global Data Assimilation System (GDAS) gridded fields for temperature and humidity.

Better treatment of the multi-layer structures will also result in better measurements of cloud top properties. Building on these new MODIS-based algorithms, Phase II activities can make better use of the high-resolution and multi-spectral capabilities using GIFTS, GOES-ABI and -ABS. For example, with the future generation of instrumentation we should have a significantly greater capacity to monitor cloud top pressures (see Section 2.4) using sounding instruments. The faster scan rates of GIFTS, and especially GOES-ABI and -ABS, will allow for a nearly five-fold increasing in scanning rate with a concurrent increase in coverage compared to the GOES current generation sounder. Figure 8 exemplifies the expected coverage for GOES-12 sounder for monitoring cloud top pressure.

Using other frequency bands, it should be possible to retrieve estimates of the type, quantity and density of various kinds of atmospheric pollutants. This sort of information may also be used to quantify visibilities, gaseous effluent and gas clouds (type and area coverage), smoke layers, and dust and sand storms.

2.7 Volcanic Ash

The particulate content of volcanic ash plumes is comprised of materials that, in general, can be characterized as a mixture of silicate glasses and other mineral shards. The hazards for aircraft that encounter significant ash plumes is extreme, and result from (*i*) loss of engine function due to the obstruction of small internal passages by the melting and re-crystalization of ash material, (*ii*) severe "frosting" of the pilots' windscreen by abrasion from ash particles and chemical etching associated with acidic plume contents, and (*iii*) interference with flight instrumentation and pilot-based sensors.

Not all ash plumes pose comparable threats to aviation, so the challenge for any detection methodology is the proper diagnosis of ash cloud material, as well as the proper assessment of the hazard in space and time. Both tasks are the subject of ongoing research. Ideally, satellite detection and diagnosis of volcanic ash will assist pilots in choosing flight paths that realistically designate the operationally critical hazard zones, rather than the extremely broad regions that are (or may be) influenced by the plume in a non-critical way.

The importance of volcanic ash impacts on aviation and other activities has led to the international organization of a number of Volcanic Ash Advisory Centers (VAAC) which monitor volcanic eruptions, usually through a team of scientists working at a laboratory at or near prominent volcanoes. The VAAC warnings, however, are of limited application since they have limited ability to monitor the ash cloud after its creation and not all volcanoes are monitored.

From an aviation perspective, the critical issues are to detect the presence of the ash cloud, even thousands of miles downwind, and to determine its height. It is also important to estimate the mass density of the ash cloud and determine the degree of hazard that the cloud presents to aircraft. While it is often easy to detect volcanic ash in imagery that is known to include an erupting volcano, developing an automated, operational detection scheme has proven to be a very difficult task. One of the problems has been the variability in the ash clouds of different volcanoes and even between different eruptions of the same volcano.

Applications of GOES and POES infrared information to detect and monitor volcanic aerosol and dust are primarily based on utilization of the shortwave infrared window (near 3.9 µm), the longwave infrared window (10-11 µm) and the split window (near 12 µm). For a number of years a daytime visible signature and a negative 11 minus 12-µm brightness temperature difference were the primary tools used to identify volcanic ash (Prata 1989). Volcanic ash clouds provide a signal similar to that of sand and dust; the volcanic ash plumes often generate negative brightness temperature (BT) differences between $BT_{11\mu m}$–$BT_{12\mu m}$. This so-called "split window" infrared technique has primarily been applied to detecting and quantifying volcanic aerosols using GOES, particularly those from sulfur-rich eruptions (e.g., Barton et al. 1992). [Unfortunately, this technique will be degraded by the move of the 12 µm infrared channel to 13 µm on the imagers of GOES-12/N/O/P.] Several aerosol remote sensing techniques have been developed using observations from the AVHRR. Other approaches have used short wavelength visible measurements, such as used in a smoke or haze algorithm with some success (see Fig. 9). Infrared channels in the ozone absorption band (9.6 µm) may be of some benefit for ash cloud detection, as would other channels that are sensitive to other trace gasses such as sulfates and nitrates. Sulfuric acid, a common component in stratospheric aerosols resulting from volcanic eruptions, also exhibits strong absorption in this spectral region and demonstrates a spectral signature quite different from that of cirrus and water vapor. Modeling is important for understanding the physics behind the algorithms, but observations are required to truly test and verify the techniques.

Figure 9 is an image of the 11-12 µm BT differences from GOES-8 taken during an eruption of Mt. Popocatepetl in Mexico on 4 December 1998. Sometimes negative differences occur in cold, convective clouds that can be screened with a simple threshold on the magnitude of $BT_{11\mu m}$ (e.g. must be warmer than 270 K).

Figure 9: GOES-8 imager split window temperature difference demonstrating the negative $BT_{11\mu m}$–$BT_{12\mu m}$ values in the presence of volcanic ash plume from Popocatepetl eruption. Colored regions are flagged as containing suspended matter.

For a robust automated algorithm with an acceptably low level of false alarms, it is likely that there will be a need to develop a series of multi-spectral algorithms that would be combined into an integrated product that would have wide scale applicability. Height measurements of the ash cloud may be able to be obtained using the future generation of hyper-spectral sounding instruments, or through the inversion of the ash cloud's advection in response to the winds aloft. In the short term, however, the most fruitful avenue for investigation may be through the analysis of MODIS imagery from volcanic eruptions.

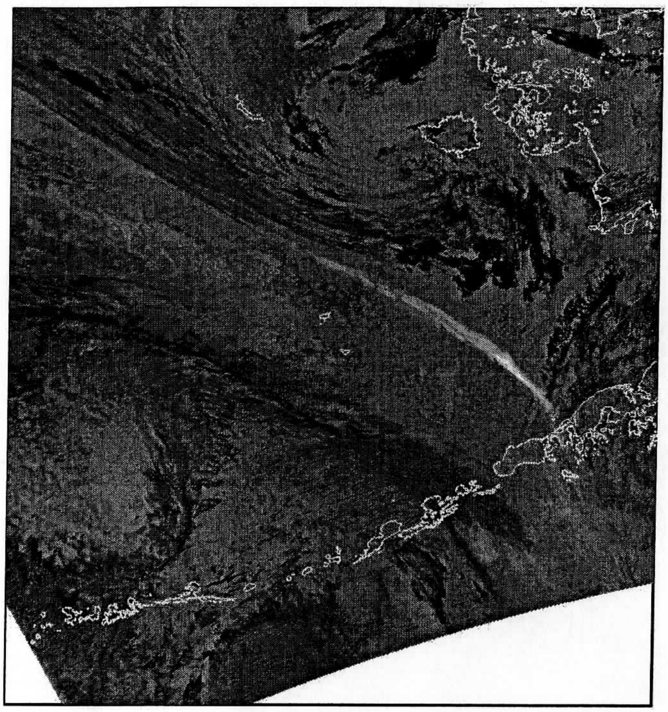


Figure 10. MODIS brightness temperature difference between the 11 μm and 12 μm bands 31 and 32 on February 19, 2001 2310 UTC. The white feature extending from one island near the middle of the Aleutian Islands of Alaska is a plume of volcanic ash from the eruption of Mt. Cleveland earlier in the day.

Recently NOAA NESDIS ORA has experimented with a three-channel approach by also incorporating a 3.9 minus 11-μm brightness temperature difference product (Ellrod and Connell 1999). Similar techniques have also been used to detect dust, especially over land. Ackerman (1989, 1997) demonstrated how the 3.7 minus 11-μm brightness temperature difference can be used to track dust outbreaks and how a negative 11 minus 12 μm difference can be used to identify and monitor dust transport over desert due to emissivity considerations. Many aerosols also exhibit strong spectral variation in the 8 to 10 μm regions. Recall that the 8.5-μm band available on the MODIS instrument has been shown to be particularly useful in volcanic ash detection and monitoring. (Ackerman, 1997). Recent studies have also suggested that the correlation between MODIS visible reflectance at 0.49 μm (blue), 0.66 μm (red) and 2.1 μm can aid in improved remote sensing of aerosol over land using the dark surface target technique (Kaufman et al., 1997a; 1997b; Remer et al. 2001). The MODIS onboard NASA's EOS Terra and Aqua satellites has wide spectral range, high spatial resolution, and near-daily coverage that equips it to detect and track volcanic ash plumes. Brightness temperature differences between various MODIS infrared bands can provide a daily or twice daily snapshot of the location of an ash plume. One such approach, the two-band split window (Prata 1989, Davies and Rose 1998) uses the brightness temperature difference between infrared bands at 11 μm and 12 μm. Because ash radiates at a different intensity in these two bands and water vapor does not, the difference between the 11-μm and 12-μm brightness temperature highlights the ash over clouds. Figure 10 shows an example of this technique where the difference between MODIS bands 31 and 32 clearly highlights the plume created by the eruption of Mt. Cleveland on February 19, 2001. Mt. Cleveland is located on an uninhabited island near the middle of the chain of Aleutian islands off the southwestern coast of Alaska.

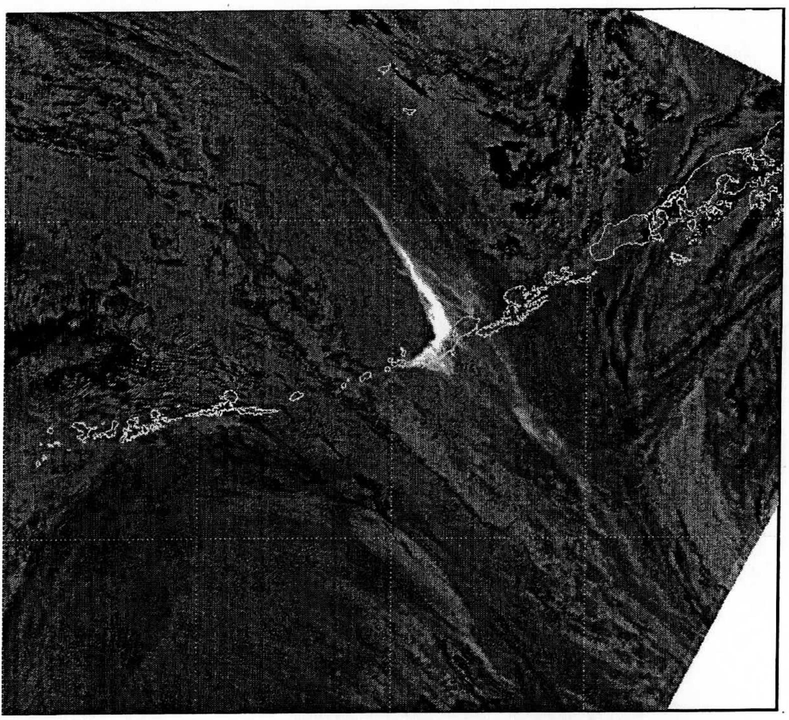


Figure 11. Same as in Figure 10 except for February 20, 2001 at 0845 UTC.

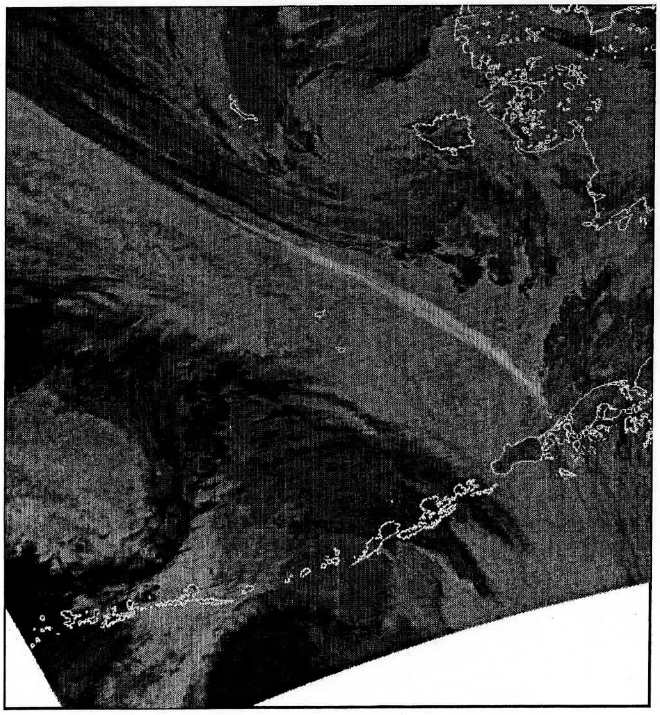


Figure 12. Same as in Figure 11 except for MODIS brightness temperature difference between the 8.5 μm and 11 μm bands on February 20, 2001 at 0845 UTC.

Although MODIS is a polar orbiting satellite and does not provide continuous coverage of an area, coupling daily or twice-daily MODIS images (but more frequent at the poles) with information about the atmospheric winds can information during the time periods between Terra and Aqua passes. When a second MODIS snapshot becomes available, the estimated location based on winds can be updated. Figure 11 shows a MODIS image from the next Terra pass following the pass from the image in Fig. 10. Because the volcano was located fairly far north, there are more frequent Terra passes and the two images in Figs. 10 and 11 are less than 10 hours apart. A comparison of the two figures indicates that the ash plume has moved to the northeast and become further elongated into a narrow filament oriented northwest-southeast over the Bering Sea.

In addition to the bands required for the two-band split window test, MODIS has other bands that can assist in the detection and location of volcanic ash. For example, the 8.5-μm and 3.9 μm bands are useful either individually or in combination with other bands. The 8.5-11 μm infrared difference product (Fig. 12) shows better ash plume continuity along the extreme northwestern portion of the plume filament. Figure 13 shows an example of the 3.9-μm image from the same time as in Figure 12. This band is sensitive to heat and the scattering of light by ash particles and detects very warm pixels (around 310 K, brown enhancement) over the southwestern end of the island where the volcano itself is located.

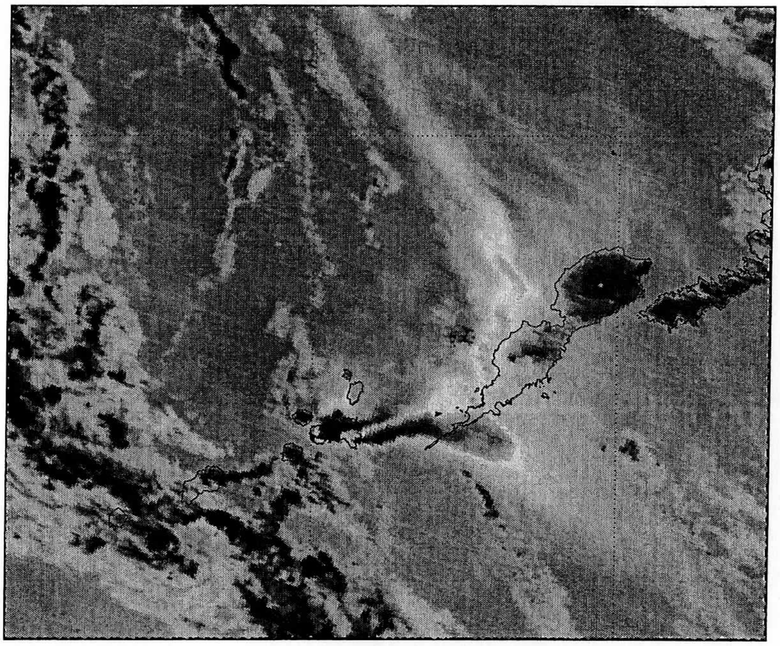


Figure 13. MODIS brightness temperature from the 3.9 μm band 22 at 2310 UTC on February 29, 2001. The red-brown color is the warmest temperature, approximately 310 K and the dark blue are the coolest, approximately 265 K.

With the recent addition of a second MODIS instrument (and AIRS) on the Aqua platform, the sharing of "direct broadcast" MODIS data from several ground-based receiving stations, in view of the nature of volcanic ash cloud detection and movements (on synoptic time and space scales), the development of a global volcanic ash detection procedure is warranted and highly feasible. Beginning during Phase I, application of the scientific procedures noted above toward regionally focussed near-operational volcanic ash cloud detection and monitoring could be performed through collaboration between CIMSS and the AWRP teams. With dedicated researchers and computer processing capabilities, methods to automatically retrieve MODIS imagery over ongoing erupting volcanoes, process these data for ash cloud characteristics and movements (upward through the wind-sheared troposphere into the lower stratosphere), and realtime dissemination of important products can be accomplished. Direction from AWRP teams will help steer CIMSS scientists to develop an optimal system.

Many of these channels should be accessible with data from hyperspectral sounding instruments such as GIFTS and the GOES-R ABS. In addition, the GOES-ABI is likely to include most of the wavelengths of interest. GIFTS longwave hyperspectral measurements will greatly enhance the detection and identification of volcanic materials. Beginning immediately in 2005, GIFTS measurements can be applied into algorithms already developed for MODIS.

3 METHODS FOR INFUSING SATELLITE INFORMATION TO THE AWRP TEAMS

Key to a successful ASAP research effort will be how efficiently UW–CIMSS and the AWRP PDTs collaborate toward the common goal enhancing the use of satellite information. Several important issues will need to be addressed within this collaboration. They include:

- Issues related to the sharing of scientific knowledge;
- Issues for sharing value-added satellite-derived information and the promotion of feedback mechanisms that are needed to continuously improve the research;
- Data formatting and sharing via computer facilities;
- Developing means for assessing confidence, quality and validity of satellite-based information as determined to be important within the FAA PDTs.

An initial roadmap for collaborating with the AWRP teams will be to adapt and expand upon the work already ongoing between CIMSS and NCAR's Convective Weather and Oceanic Weather PDTs on issues of convective initiation. Specifically, Dr. John Mecikalski of CIMSS, Rita Roberts of NCAR (Convective Weather PDT) and Cathy Kessinger (Oceanic Weather PDT) have already identified several optimal procedures by which satellite information can be infused to the their nowcasting and forecasting systems (e.g., the AutoNowcaster). The procedures developed to date would provide a logical starting point for the Phase I efforts.

In terms of the evaluating of quality and confidence of all satellite-based products that will be infused into the AWRP teams, all team members will need to work together toward developing methods for estimating: 1) how these satellite data should be used, 2) how useful are these data for addressing particular issues of aviation safety, and 3) quality indicators of satellite-derived information and how these indicators should be used within the AWRP team systems.

3.1 Goals and Objectives of the AWRP Teams

The Federal Aviation Administration's AWRP is designed to address specific requirements for weather support to aviation by providing the capability to generate more accurate and accessible weather observations, warnings, and forecasts and also by increasing the scientific understanding of atmospheric processes that spawn aviation weather hazards. The goal of the AWRP is to provide meteorological research that leads to the satisfaction of specific and focused aviation weather requirements.

The FAA's AWRP has been successful in developing new technology and in bringing that technology to operational users. The program utilizes a disciplined planning approach to research with an operational focus on outcomes and accomplishments. A key aspect of this approach is a phased introduction and testing of all potential products. The AWRP includes extensive efforts to coordinate across other agencies, industry, and institutions involved in aviation weather research. This has resulted in the program gaining broad support within the agency, throughout the aviation community, and in Congress.

Table 1: FAA AWRP Partner Organizations (see *http://www.faa.gov/aua/awr/partners.htm*).

National Center for Atmospheric Research (NCAR)
Research Applications Program (RAP)
- Boulder, Colorado
- Point of Contact: Bruce Carmichael

NOAA Forecast Systems Laboratory (FSL)
- Aviation Division
- Forecast Division
- Boulder, Colorado
- Point of Contact: Mike Kraus

NOAA National Severe Storms Laboratory (NSSL)
- Norman, Oklahoma
- Point of Contact: Kim Elmore

NOAA NWS National Centers for Environmental Prediction (NCEP)
- Participates through two of its Centers:
  - *Environmental Modeling Center (EMC)*
    - Camp Springs, Maryland
    - Point of Contact: Geoff DiMego
  - *Aviation Weather Center (AWC)*
    - Kansas City, Missouri
    - Point of Contact: Jim Henderson

Massachusetts Institute of Technology, Lincoln Laboratories
- Weather Sensing Group
- Lexington, Massachusetts
- Point of Contact: Jim Evans

Naval Research Laboratory Monterey (NRL)
- Marine Meteorology Division
- Monterey, California
- Point of Contact: John McCarthy

In designing the structure of the AWRP teams, the Weather Sensors and Aviation Weather Research Product Team (AUA-430, the FAA manager of the AWRP) has intentionally developed broad-based teams that represent the full spectrum of interests and capabilities. The full listing of AWRP team members includes 55 separate laboratories, offices, and agencies. The primary lead laboratories are listed in Table 1. These laboratories possess a considerable range of expertise and supporting facilities that can be brought to bear on PDT efforts.

The major areas of expertise include Doppler radar processing, field experimentation and testing, applied product development, and years of experience with FAA procedures for testing and evaluating products from research to operational use.

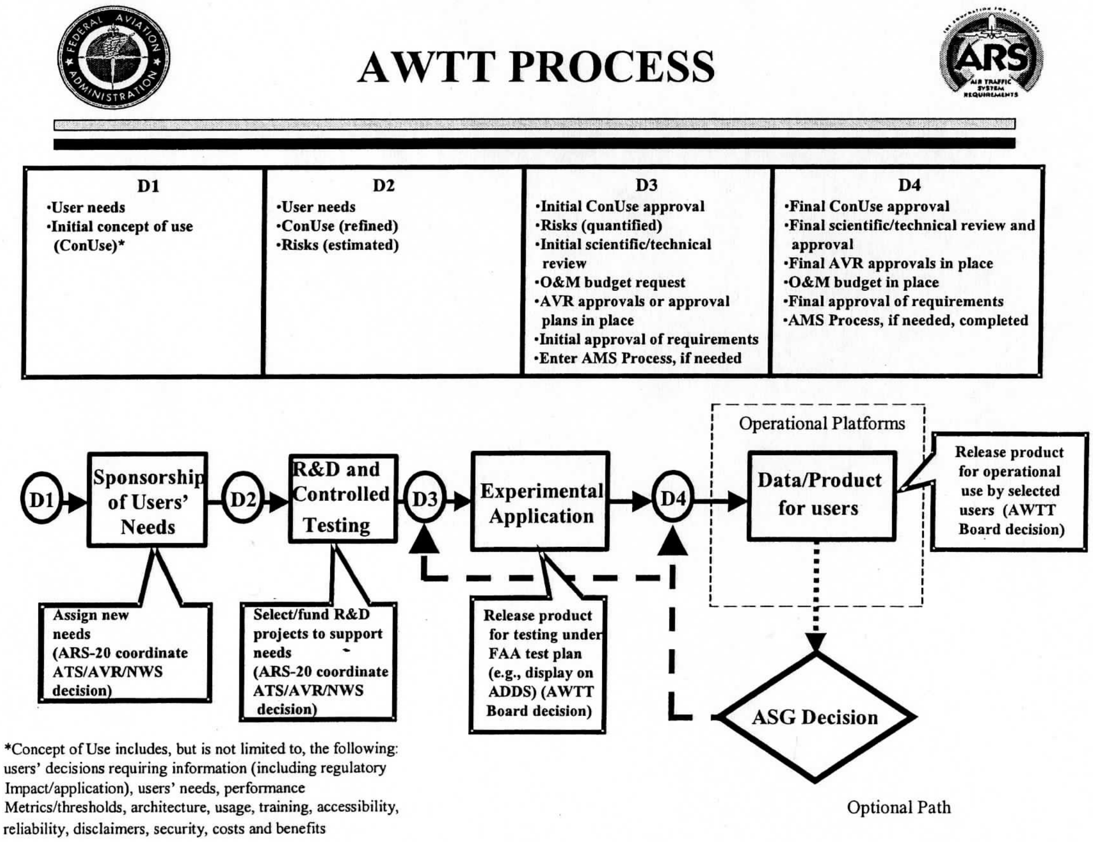
At present, the AWRP teams do not have any center of expertise and infrastructure to support the development and dissemination of satellite expertise comparable to UW–CIMSS. The Navy Research Laboratory-Monterey has an active and respected applied research program in satellite meteorology. NRL, however, is the Navy's primary applied meteorological research organization and has broader operational requirements than satellite meteorology. The other AWRP laboratories have smaller groups and individuals supporting satellite activities that can be thought of as isolated pockets of excellence. UW–CIMSS, by virtue of its staffing, capability, pioneering leadership in satellite meteorology and its relationship with NOAA, is best suited to serve as the lead research facility for the implementation of ASAP.

3.2 The Aviation Weather Technology Transfer (AWTT) Process

The Federal Aviation Administration (FAA) spends over $20M a year on weather research and development and will have many new products coming online in the near future. In order to ensure the scientific and operational readiness of these products, the FAA has established a formal review and approval process called the Aviation Weather Technology Transfer (AWTT) process. This process is administered by the AWTT Board, which represents all major FAA and National Weather Service (NWS) stakeholders. One of the distinguishing features of the AWTT process is the early development of a "concept of use" for a potential product to define a specific path to implementation as well as its operational utility.

The goal of AWTT is to facilitate the transition of research and development products into full operational use by proactive budget planning, early identification of infrastructure and training needs, and timely resolution of management and labor issues. The AWTT Board has the responsibility to monitor the overall R&D process and to approve weather products for experimental use by selected meteorologists or end-users, for operational use by meteorologists, or for operational use by end-users.

The overall process is depicted in Figure 14. The process involves the application of a set of decision criteria successively at various stages of the technology transfer life cycle. The decision criteria are applied in an incrementally increasing level of precision as the technology matures and is readied for implementation into operation. In addition, the process incorporates advance budget planning to ensure that the needed operational funds are available at the time the technology is ready to become operational.



D1	D2	D3	D4
•User needs •Initial concept of use (ConUse)*	•User needs •ConUse (refined) •Risks (estimated)	•Initial ConUse approval •Risks (quantified) •Initial scientific/technical review •O&M budget request •AVR approvals or approval plans in place •Initial approval of requirements •Enter AMS Process, if needed	•Final ConUse approval •Final scientific/technical review and approval •Final AVR approvals in place •O&M budget in place •Final approval of requirements •AMS Process, if needed, completed

*Concept of Use includes, but is not limited to, the following: users' decisions requiring information (including regulatory Impact/application), users' needs, performance Metrics/thresholds, architecture, usage, training, accessibility, reliability, disclaimers, security, costs and benefits

Figure 14. A schematic illustration of the FAA Aviation Weather Technology Transfer (AWTT) process.

A key part of the AWTT process is a series of decision points (labeled D1 through D5 on the diagram). It is important to note that even the earliest steps in the development of a new aviation weather product are driven by operational user needs and not just the availability of a technology. In the end, a product may be approved for use by meteorologists (a D4 decision) or for direct use by end-users such as pilots or controllers (a D5 decision).

Depending on the product, there can be many different paths to implementation. Most of the AWRP PDTs have at least part of their technologies implemented through the forecaster tools or the ADDS gridded database at the AWC in Kansas City. Other products can be implemented through commercial vendors, by the airlines themselves, or through coordination with other federal agencies. Figure 15 illustrates some of the possible implementation tracks for current or anticipated products from the AWRP's ten Product Development Teams. The PDTs are shown at the left. Octagons are intermediate systems and implementation platforms are depicted as rectangles. The AWC is represented as a "keystone" shape in the middle of the diagram.

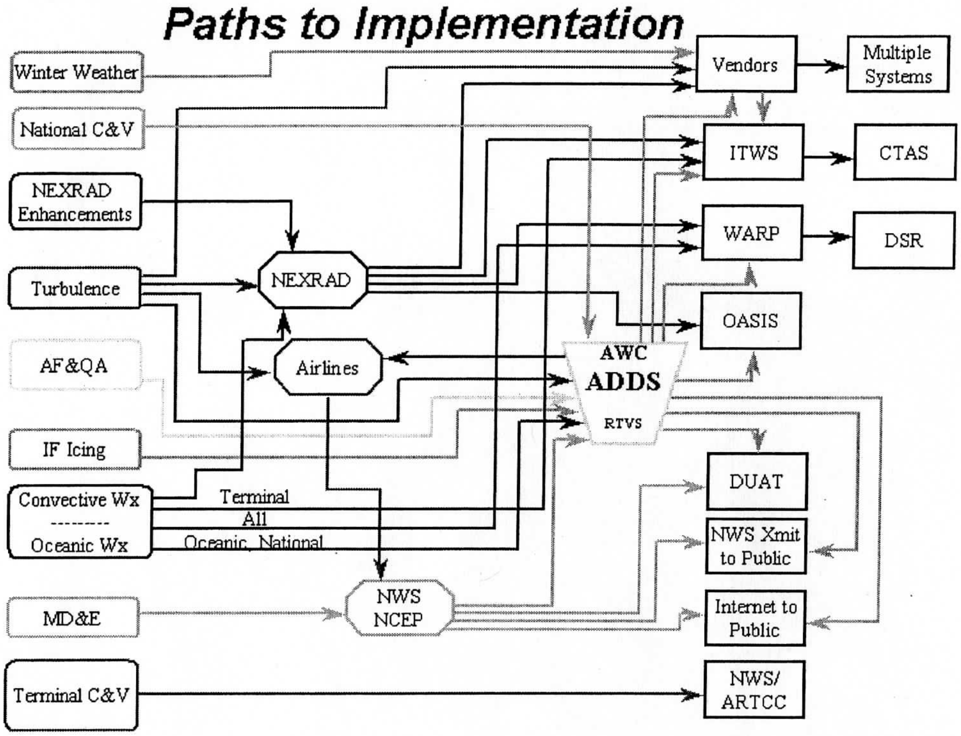


Figure 15. A schematic diagram outlining the variety of paths that an AWRP product might take for operational implementation.

Abbreviation	Explanation
ADDS	Aviation Digital Data Service
ARTCC	FAA Air Route Traffic Control Center
CTAS	Center/TRACON Automation System
DSR	Display System Replacement
DUAT	Direct User Access Terminal
IF	Inflight
ITWS	Integrated Terminal Weather System
MD&E	Model Development and Enhancement
NCEP	National Centers for Environmental Prediction
NEXRAD	Next Generation Weather Radar (WSR-88D)
NWS	National Weather Service
OASIS	Operational and Supportability Implementation System
PDT	Product Development Team
TRACON	Terminal Radar Approach Control Facility
WARP	Weather and Radar Processor
WSDDM	Weather Support to De-icing Decision Making
Wx	Weather
Xmit	Transmit

3.3 ASAP Implementation

ASAP is implemented by the NASA Langley Research Center's Atmospheric Science Competency for its sponsors, the NASA Aviation Safety Program and the NASA ESE's Applications Division (Code YO, NASA Headquarters). The effort began with hyperspectral data collection in 2002 during IHOP_2002 and the Cirrus Regional Study of Tropical Anvils and Cirrus Layers Florida Area Cirrus Experiment (CRYSTAL-FACE). The Product development phase of the effort will begin in 2003 and will continue until 2012 when GOES-R is launched. The details of ASAP's implementation are delineated in a separate, dual-purpose document. That document is the NASA Aviation Safety Program's Weather Accident Prevention Project (WxAP) Level IV ASAP Plan, which is managed directly by a NASA Langley Research Center, Atmospheric Science Competency researcher assigned to the WxAP Aviation Weather INformation (AWIN) element. It also serves as the NASA ESE, Code YO ASAP Plan. The following elements were recommended to serve as significant directions within the ASAP Plan. These recommendations emphasize the infusion of research talent and expertise directly into the AWRP, specifically into the AWRP PDTs to ensure that they will efficiently utilize the data of current and future satellite remote sensing systems over the duration of ASAP. They include:

1. In order to integrate the existing satellite expertise at CIMSS into the PDTs, it is recommended that new staff (working level expert, satellite-trained staff) would be detailed for a minimum of one year at a time to NCAR/RAP to directly work with the AWRP PDT's. This researcher would act as the main, day-to-day point of contact between CIMSS and the PDTs. For optimal results, this new staff would be a CIMSS researcher located at NCAR. Dedicated office and computer resources would be required at NCAR to facilitate the new full-time employee, as well as other visiting UW–CIMSS staff as periodic visits to NCAR occur. It is feasible that other UW–CIMSS scientists might spend from 3-9 month periods at NCAR as specific FAA PDTs work closely to develop satellite-based algorithms for the benefit of the AWRP. Similarly, two-way exchange would occur as AWRP researchers might visit UW–CIMSS, for short-term or longer intervals. Frequent coordination between ASAP and the FAA AWRP management is recommended to ensure that optimal exchange assignments, visits and detailed tasking occurs.
2. Scientific exchange and collaboration with all PDT team members, not only those at NCAR or UW–CIMSS. NASA scientists will also play a direct investigative role in ASAP research.
3. Exchange of satellite data and analyses between participants. GOES-East and West imagery is generally already available to AWRP teams. Additional data sets [e.g. GOES-11, MODIS, Tropical Rainfall Measuring Mission (TRMM), etc.] should be exchanged or made available, as appropriate and as needed for this collaboration. This gives each PDT member a stake and potential benefit from this collaboration. It is suggested that if both UW–CIMSS and the AWRP have access to the same data sets, a viable ASAP is more likely to occur.
4. It is recommended that ASAP researchers meet semi-annually with ASAP and AWRP managers for ASAP Periodic Management Reviews (PMR's) to refine, implement and manage ASAP research requirements, goals and schedules.

4 DATA COLLECTION AND SATELLITE PRODUCT VALIDATION

Extensive verification of basic satellite-derived products (i.e. total precipitable water, cloud top heights, temperature and moisture retrievals) has already been conducted using ground-based and aircraft instrument measurements (Smith et al. 1996, Schmit et al. 2002). Collaborations with the DOE ARM project have allowed climatological verification of satellite radiances and value-added information. A best-estimate product for temperature and moisture derived from DOE SGP site Raman Lidar, AERI, microwave radiometer, and radiosonde information is currently providing a way to evaluate EOS Terra (and soon EOS Aqua) overpass radiance calibration. NASA EOS-sponsored field program verification has provided the opportunity to collect data sets from a variety of atmospheric conditions to provide direct radiance verification of both POES and GOES satellite instrumentation.

The ASAP initiative will be an important forum for performing very specific remote sensing system verification and evaluation that will profoundly impact the production of aviation weather products. In particular, before a given value-added satellite-based technique can be implemented with the FAA PDTs, ground-based and aircraft data sets (radiances and atmospheric state measurements) will be used to verify the new information. Coordination (and participation by AWRP team members, as appropriate) in instrument verification and algorithm development, as well as structuring test flights and test data from research satellites

Table 2: Anticipated AWRP Field Project Involvement.

In Flight Icing *Winter 2002-2004*	**NASA Glenn Research Center Icing Flights** Location: Ohio (and surrounding states) Dates: December–March (each year scheduled) Facilities: NASA Instrumented Twin Otter A/C Ground-based remote sensing system (K-band radar plus profiling radiometer)
In Flight Icing *Winter 2003*	**Alliance Icing Research Study** (AIRS-2) Location: Montreal, Quebec, Canada Dates: November 2003–March 2004 Facilities: Two (or 3) instrumented research A/C, Surface radars, radiometers, and lidars
Convective Weather *Spring/Summer 2002*	**International H2O Project** (IHOP) Location: Southern Great Plains Dates: May–June 2002 Facilities: Instrumented aircraft, surface radars, radiometers, and lidars
Convective Weather *Summer 2002-2004*	**Regional Convective Weather Forecast** (RCWF) Location: Northeast Corridor Dates: May–September Regional 1-2 hour convective weather forecast demonstration
Convective Weather *Summers 2003-2005*	**Thunderstorm Operational Research** (THOR) Location: NE Corridor (Chicago-New York) Dates: May–September (anticipated)
Ceiling/Visibility and Winter Weather *Beginning Winter 2002*	**Northeast Ceiling and Visibility Program** Location: Rutgers Field Site, New Jersey Dates: Long term installation Facilities: Concentration of ground-based ceiling and visibility instrumentation, fog spectrometer, IR and Visible radiative flux sensors, fog spectrometer.
Convective Weather *Summer 2003*	**Short-Term Prediction Research and Transition** (SPoRT Center) [similar to THOR] (proposed)

Several methods for organized verification strategies may be performed over the duration of the ASAP. This exercise will also provide data sets required for the production of new products or the enhancement of aviation weather products currently in production or development. ASAP data collection will focus on current and future satellites as discussed earlier, but will also require airborne field campaigns to ensure that hyperspectral data and ground truth are readily available for the research that will support the production or enhancement of aviation weather products by ASAP. Data already collected by the NAST-I instrument, such as that obtained by ASAP during the IHOP_2002 and CRYSTAL-FACE field campaigns, will be an initial element of this effort. Future ASAP participation in dedicated field experiments such as THORpex will provide hyperspectral and other measurements that will be needed to fully address the development of convection, turbulence, icing, volcanic ash and flight-level winds products. These NAST-I field campaigns will also provide the opportunity to leverage existing NASA satellite validation studies and to collaborate with NOAA to obtain in situ dropsonde data which will be important for airborne and satellite remote sensing data validation and ground truth for required simulations, product development and verification studies. ASAP has already positioned itself to be a major participant in THORpex and has been selected by the THORpex International Science Steering Committee to coordinate its first Pacific field experiment. THORpex is considered a unique opportunity to leverage many complimentary experiments to maximize the efforts of multiple researchers and to synergize the effect of multiple funding sources that alone could not accomplish the individual science objectives as effectively. This and future multi-aircraft THORpex field campaigns represent opportunities to collect the full spectrum of remote sensing and in situ required to support a viable ASAP program.

Specific methods of verification for the ASAP team would also take advantage of future AWRP field projects (Table 2), intensive investigation periods through the incorporation of overpasses by the Proteus and ER-2 aircraft with the NAST-I instrument for GIFTS data validation and product development. The collection of supporting data from research satellites such as EOS (MODIS) or TRMM will also be employed. Most importantly however, the multiple sub-experiments performed by THORpex will provide invaluable, multi-source data for verification studies. The analysis of field-experiment data will be done by the participating institutions of ASAP, in particular the UW–CIMSS and AWRP teams. The verification of current and new remote sensing technologies will set the stage for rapid incorporation of new capabilities into the PDT product stream.

5 RESPONSIBILITIES AND TIMELINE OF TASKS

The general responsibilities per collaborating institution are outlined. These responsibilities are left general as the scientific procedures dictate how the ASAP projects are completed will be formulated in detail in the NASA Aviation Safety Program and NASA ESE ASAP plan.

5.1 NASA ASAP Phase I: Current Satellite Technologies

Phase I of ASAP is scheduled to begin in October 2002 and last through September 2005. This time period will signify the end of the non-hyperspectral era in geostationary satellite instruments. As GIFTS is planned to be launched by late 2005 and become operational in early 2006, the goal of Phase I activities will be to develop new, working research collaborations between UW–CIMSS and many of the AWRP PDTs. These new collaborations will assist in the proper and most efficient means of infusing satellite remote sensing information into the existing efforts structures of the AWRP PDTs, as detailed above. As importantly, Phase I efforts will also focus on prototyping and benchmarking several methods and procedures for using hyperspectral (GIFTS) data within the FAA PDTs. Although actual GIFTS data will not be available until after Phase I, the goal will be to develop the data pipelines for using and processing hyperspectral information from airborne, ground-based and NPOESS interferometers so they may be immediately used once GIFTS data become available.

5.2 NASA ASAP Phase II: Future and Advanced Satellite Technologies

Phase II of the ASAP initiative is scheduled to last from October 2005 through late 2012. The timing of Phase II corresponds to the launch of GIFTS in late 2005 through to the successful implementation of the GOES-ABI and -ABS instruments in 2012. As stated above, the GOES-ABI and -ABS instruments will be the operational next generation hyperspectral instruments prototyped after the GIFTS instrument. Exciting new research on the use of hyperspectral remote sensing, as initiated during Phase I, will become operational components of the AWRP PDTs during Phase II. Much of the software, data sharing and research initiatives started during Phase I will become the infrastructure that Phase II will expand and grow. Similarly, as Phase I and II span a decade in time, it is anticipated that a continual infusion of new knowledge and expertise will occur during Phase II as the AWRP–UW collaboration is maintained.

Table 3: Timeline of tasks over the duration of the ASAP initiative.

Research Tasks	Phase I	Phase II
Initiate Collaboration through the definition of Scientist-to-Scientist collaborations: AWRP–UW	**2002-2003**	
Establish information pipelines between UW–CIMSS and the AWRP PDTs	**2002-2003**	
Identify how and where within the AWRP PDTs specific satellite data products will be used	**2002-2003**	
Define and perform initial research toward enhancing PDT use of GOES imagery and soundings	**2003**	
Establish UW Scientist at NCAR, or elsewhere within the PDT structure, to foster a robust UW–AWRP relationship	**2003**	
Participate in dedicated ASAP data collection campaigns such as THORpex and other NAST instrument flight experiments.	**2003-2005**	**2005-2012**
Establish robust procedures for infusing additional GOES data usage into PDTs	**2003-2004**	
Prototype and benchmark first hyperspectral (GIFTS) fields for evaluating critical issues in aviation safety	**2003-2005**	
Initiate Phase II: Focus on the using of hyperspectral in place of non-hyperspectral data within existing ASAP UW–AWRP collaboration		**2005**
New research in the use of hyperspectral measurements for assessing the meteorological issues of aviation safety		**2005-2010**
Prepare for operational processing for GOES-ABI and -ABS		**2011-2012**

5.3 Timeline of Tasks and Delivery Schedule

The NASA Aviation Safety Program and NASA ESE ASAP plan will expand upon the elements contained in Table 3 and elsewhere in this report to provide individual definitions of ASAP tasks and their delivery schedule. Beyond the mechanics of implementing ASAP as outlined in Table 3, ASAP efforts will focus initially on the full utilization of real and simulated satellite data to address the most readily accessible, critical aviation weather issues of convection, icing, turbulence, volcanic ash and flight-level winds. This decision is based on a consensus opinion held by all the parties who have contributed to the study including its NASA Aviation Safety Program and FAA AWRP customers. The specific ASAP science elements that will first be pursued, therefore, are as follows:

1. Dedicated data collection campaigns such as THORpex to collect data on convection, icing, turbulence, volcanic ash and flight level winds. ASAP will also leverage ad hoc NAST-I data collection experiments whenever possible.
2. Infusion of satellite-derived convection data and precursors as value-weighted inputs within the Convective Weather and Oceanic Weather expert forecasting systems such as the Convective AutoNowCaster.
3. Exploratory investigations of turbulence incidents. This will involve examining all the available satellite imagery and sounding information in areas of reported turbulence in order to define the limits of satellite monitoring of turbulent events and then to use three-dimensional numerical models (e.g., Clark 1977; Clark et al. 2000) to simulate turbulent events and to employ the high-resolution gridded output fields as input for computer simulations of satellite instrument behavior and capabilities.
4. Evaluation of icing parameters such as supercooled liquid water using the current generation GOES instruments for the enhancement of nationwide icing products. This will also involve the exploration of cloud optical depths, hydrometeor size, phase and total water path in near real time. The ASAP icing effort will also seek to leverage common objectives between the Forecast Products Development Team (FPDT) of the Office of Research and Applications (ORA NOAA/NESDIS) and the AWRP PDTs in its efforts to improve satellite-based in-flight icing safety products currently in existence. These efforts will then be expanded to realize the full potential of hyperspectral satellite data.
5. Numerical weather prediction model enhancement using hyperspectral data to facilitate the development of "digital atmosphere" concept as expounded by the NASA Aeronautics Blueprint, (e.g., Lewis et al 2001; Murray 2002).

While convection, icing and turbulence provide the most accessible avenues of research as ASAP product enhancement and development begins, laboratory research in the other critical aviation weather phenomena discussed in this study will be evaluated for initiation beginning in 2003. Due to the intrinsic nature of passive infrared retrievals of remotely sensed satellite data such as those obtained via GIFTS, the more difficult areas of ASAP research involve the enhancement and development of products for ceiling and visibility.

6 THE SCIENCE TEAMS

Section 2 of this report outlined the specific meteorological problems for aviation safety that ASAP will seek to address by demonstrating and validating methods for infusing satellite information into the AWRP PDTs using current-day satellite technologies (Phase I) through 2005, and next generation, hyperspectral remote sensing technologies beginning in 2005 (Phase II). The feasibility of this effort is bolstered by the collaboration formed by ASAP between UW–CIMSS and the AWRPs PDTs. The value of the long-term commitment by these institutions to the aviation community will be the substantial increase in aviation safety and efficiency that is expected to occur as a result of the accomplished research. The following sections highlight the science teams that will lead the work as overviewed above.

Section 6.1 summarizes the UW–CIMSS science team that will be heading this ASAP effort. Section 6.2 gives an overview of the AWRP PDTs.

6.1 UW–CIMSS

6.1.1. Research

The University of Wisconsin-Madison SSEC/CIMSS has pioneered the development of satellite-derived applications and visualization of satellite sounder and imager data. Bill Smith Sr. and Kit Hayden conducted early work in sounding science from several research instruments in polar orbit and the VISSR (Visible and Infrared Spin-Scan Radiometer) Atmospheric Sounder (VAS) in geostationary orbit (Smith 1983; Hayden 1988). Success in this early work and a desire to transfer successful research ideas into operations led to the formation of the CIMSS in 1980. This transfer of technology objective is strongly enabled by the co-location of the NOAA NESDIS ORA (Office of Research and Applications) Advanced Satellite Products Team (ASPT) in Madison. UW and NESDIS scientists work side by side at CIMSS seeking optimal use of GOES and POES data in weather analysis and forecasting.

To support NOAA operations, CIMSS scientists research retrieval methods from the GOES Sounder and Imager in several areas, including retrieval of temperature and moisture profiles, total ozone, cloud amount and cloud top pressure/altitude, sea surface temperature, surface biomass burning, atmospheric aerosol amount, and cloud and water vapor motion derived winds. For many of these retrieval methods, the products are also transformed to an image format, referred to as Derived Product Imagery (DPI). DPI products include total precipitable water, lifted index and convective available potential energy (CAPE; stability), cloud top pressure, ozone and sea surface temperature. Successfully developed techniques and products are transferred into NOAA operations through collaboration with the NESDIS Forecast Development Products Team (FPDT). While FPDT tests and implements the software into NESDIS operations, CIMSS continues its research work on improvements to the algorithms and developing new techniques. This research to operations collaboration has been ongoing for over 20 years and continues to serve as the foundation of a strong research partnership between the UW and NOAA.

UW-Madison investigators also have extensive basic research expertise in modeling and deriving meteorological products from geostationary and polar orbiting satellites. Examples include fast radiative transfer modeling, sea surface temperature estimate (Wu et al. 1999), atmospheric aerosol and dust loading (Ackerman and Strabala 1994), atmospheric temperature and water vapor profiles (Eyre 1990; Feltz et al. 1998; Menzel et al. 1998; Li and Huang 1999; Ma et al. 1999; Li et al. 2000; Schmit et al. 2000) and real time wind products (Velden et al. 1997).

SSEC/CIMSS also has demonstrated a strong presence in the development, deployment and validation of advanced technology instrumentation to observe the atmosphere from the ground, onboard aircraft and in space. The UW–CIMSS has been involved in both the hardware design and fabrication and data modeling/processing for such hyperspectral instruments as: (1) ER-2 aircraft prototype High-resolution Interferometer Sounder (HIS); (2) Aircraft Scanning HIS and NAST-I for NASA/NOAA; (3) AERI for the Department of Energy; and (4) Marine AERI for University of Miami (Revercomb et al. 1988; Smith et al. 1990; Revercomb et al. 1993; Minnett et al. 2001).

SSEC/CIMSS has successfully processed these ground-based, airborne and spaceborne Fourier Transform Spectrometer (FTS) hyperspectral data since early 1980. SSEC/CIMSS scientists have extensive experience with thermal infrared hyperspectral data processing. UW-Madison investigators have more than a decade of experience with hyperspectral modeling, algorithm, and product development from such satellite instruments as: (1) AIRS of NASA EOS; (2) Interferometric Monitor for Greenhouse Gases (IMG) of the Advanced Earth Observing Satellite (ADEOS) of the National Space Development Agency of Japan (NASDA); (3) NPOESS Cross-Track Infrared Sounder (CrIS) of the Integrated Program Office (IPO), and especially, (4) GOES High-resolution Interferometer Sounder (Smith et al. 1990; Huang et al. 1992; Huang and Purser 1996; Huang and Antonelli 2001).

UW is currently responsible for GIFTS, sounding and imaging hyperspectral data calibration, and GIFTS data compression and processing algorithm development. UW will also validate GIFTS hyperspectral measurements and retrieved geophysical products through the use of a GIFTS ground data processing facility funded by the GIFTS project. The GIFTS receiving and processing facility will allow UW to access hyperspectral data freely for this proposal. The ASAP research activities will parallel the involvement in the hyperspectral modeling and development of atmospheric product retrieval algorithms for the NASA NMP (New Millennium Program) GIFTS project. The breadth of research skills and expertise of the proposed science team, as outlined above, will provide a very complete description of the marine environment using GIFTS hyperspectral modeling techniques.

6.1.2 Personnel

SSEC/CIMSS is a scientist led research organization, with leadership derived from its Director and Principal Investigators. Strong technical support is provided from a diverse group of scientists, engineers, computer scientists, students and support staff. Science teams are formed based on program needs. A major strength of this infrastructure is its flexibility to adapt quickly to new projects and to provide expertise across many programs.

Table 4: FAA AWRP Product Development Teams (PDT's) (for additional information see *http://www.faa.gov/aua/awr/prodprog.htm*).

In-Flight Icing PDT
  Program Lead: Marcia Politovich, NCAR/RAP
  Alternate Lead: Ben Bernstein, NCAR/RAP
Aviation Forecasts and Quality assessment PDT (AF&QA)
  Program Lead: Lynn Sherretz, FSL
  Alternate Lead: Jim Henderson, AWC
  QA Leads: Jennifer Mahoney, FSL, and Barb Brown, NCAR
Turbulence PDT
  Program Lead: Bob Sharman, NCAR/RAP
  Alternate Lead: Steve Koch, FSL
Winter Weather Research PDT
  Program Lead: Roy Rasmussen, NCAR/RAP
  Alternate Lead: Chuck Wade, NCAR/RAP
Convective Weather PDT
  Program Lead: Marilyn Wolfson, MIT LL
  Alternate Lead: Cindy Mueller, NCAR
Terminal Ceiling and Visibility PDT
  Program Lead: Dave Clark, MIT LL
  Alternate Lead: Wes Wilson, NCAR
Model Development and Enhancement PDT
  Program Lead: Tom Schlatter, FSL
  Alternate Lead: Geoff DiMego, EMC
NEXRAD Enhancement PDT
  Program Lead: Kim Elmore, NSSL
  Alternate Lead: Don Burgess, NSSL
National Ceiling and Visibility PDT
  Program Lead: Paul Herzegh, NCAR/RAP
  Alternate Lead: Stan Benjamin, FSL
Oceanic Weather PDT
  Program Lead: Tenny Lindholm, NCAR/RAP
  Alternate Lead: Ted Tsui, NRL

At UW–CIMSS the ASAP project will be directed by Dr. John Mecikalski, a senior researcher at CIMSS. Program management of ASAP will be performed by Thomas Achtor, the Deputy Director of CIMSS and Wayne Feltz, a CIMSS project scientist. The expertise of the CIMSS investigators will determine what portion of the ASAP initiative they will be most involved. Specifically, the research on *in-flight icing*, *volcanic ash* and *multi-layer clouds* at UW–CIMSS will be organized by Suzanne Wetzel-Seemann, the research on *turbulence* will be organized by John Mecikalski and Wayne Feltz, the research on *ceiling, visibility and dust* will be organized by NOAA/NESDIS staff at CIMSS, the *convective weather* research will be organized by John Mecikalski, and the *flight-level winds* research will be organized by Timothy Olander. Several of the above UW–CIMSS scientists will actively work to support the *oceanic weather* efforts of ASAP.

Finally, in addition to the people listed above, a support staff of up to 10 additional CIMSS employees will contribute to the research conducted for this project. Researchers as part of NOAA/NESDIS, and the NOAA Advanced Products Team will provide scientific assistance on this effort. Graduate student involvement at UW–CIMSS is expected to become a significant method for linking the UW and AWRP PDTs on the ASAP initiative as these students contribute to research ongoing at both facilities. In some cases, it is expected that these students will be shared between members of the AWRP PDTs and UW as they complete their studies on topics that fall under the ASAP goals as discussed above.

6.2 The AWRP Teams

The AWRP PDTs consist of teams of scientists who work together across organizational lines on order to solve aviation problems associated with particular weather phenomena or specific weather hazards. At present there are ten separate product development teams, Table 4.

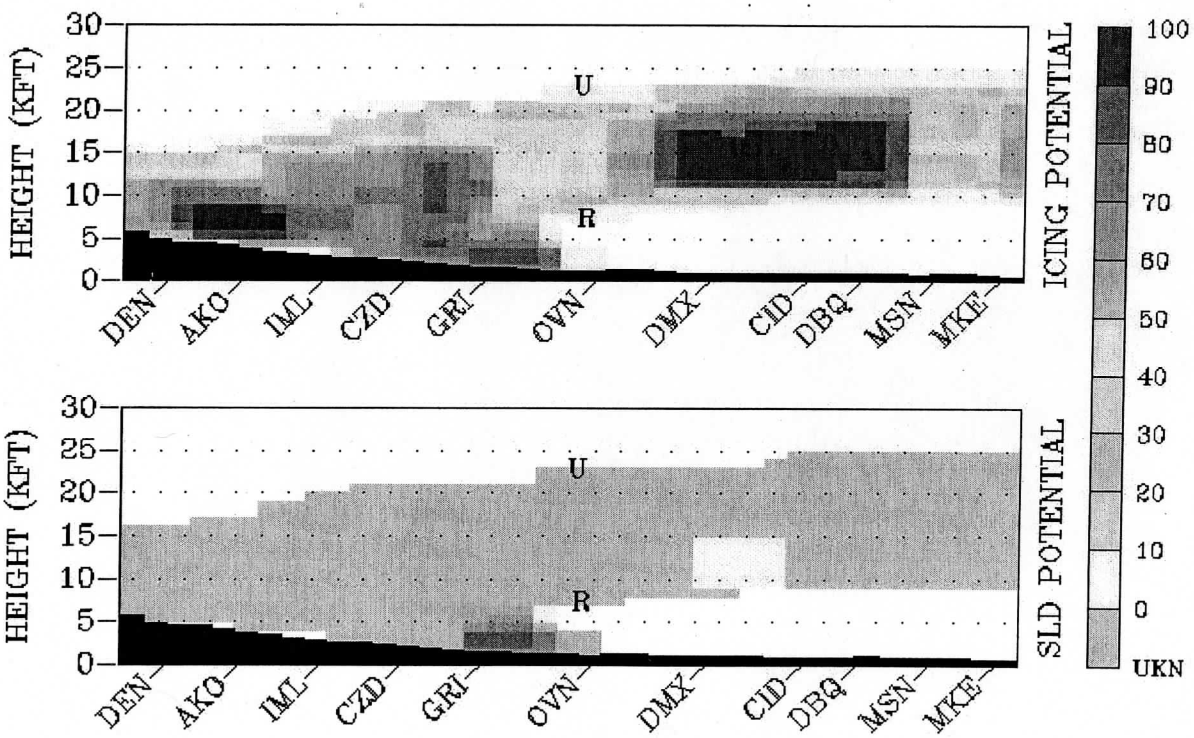


Figure 16. Experimental Forecast Icing Product vertical cross-section from Denver, CO (DEN) to Milwaukee, WI (MKE). Altitudes in 1000's of ft are shown at the left. Top panel is inflight icing potential from 0 (no icing) to 100 (certain icing); bottom panel is same for SLD icing potential. Grey shading shows where condition is not known due to insufficient information.

6.2.1 In-Flight Icing PDT

Icing has been a critical factor in numerous fatal aircraft accidents, and can disrupt domestic flight operations. Current weather products do not adequately address these dangerous and disruptive events.

Avoidance of these events requires accurate, high-resolution, operational forecasts of atmospheric icing conditions. The goal is an hourly gridded depiction or forecast of in-flight icing based on operational model output combined with real-time sensor and remote sensing data, including icing characteristics (severity and type). The philosophy is to minimize volume warned while not compromising the probability of detection.

The first In-Flight Icing PDT product to go into operational use was the Current Icing Potential (CIP). A subsequent product, the Forecast Icing Potential (FIP) has also been developed and is in an experimental status. The CIP and FIP algorithms apply fuzzy logic techniques to combine up to 56 interest fields into one fused product. CIP presently combines data from five sources–multispectral GOES imagery, model output from the RUC model, surface observations, NEXRAD radar data, and pilot reports. The CIP and FIP are available on the ADDS web page at: http://adds.aviationweather.noaa.gov/projects/adds/icing/. Figure 16 presents an example.

The In-Flight Icing PDT also conducts research into supercooled large drop (SLD) conditions, an environment conducive to severe icing. Their SLD work is leveraged with NASA and Canadian teams. They are also involved with remote sensing, using Ka-band radars and radiometers developed by NOAA and NCAR. Their extended radar research is expected to lead to techniques suitable for implementation in the national NEXRAD network, or as stand-alone units deployed in affected terminal areas. The In-Flight Icing PDT also contributes to model improvements through development of microphysical parameterizations, as recently implemented in the RUC and Eta numerical weather prediction models.

6.2.2 Convective Weather PDT

Thunderstorms account for most of the US air traffic delays and are responsible for many aircraft accidents and incidents. By some estimates, more than half of all turbulence incidents are the direct result of aircraft encounters with convection.

The Convective Weather PDT is working to develop a reliable 0-6hr forecast of convective weather. Initial operational products include the Terminal Convective Weather Forecast (TWCF), that is implemented at the Integrated Terminal Weather System (ITWS) test-sites, and the National Convective Weather Forecast (NCWF), which is implemented at the AWC. These products provide high-resolution 1-hr extrapolation forecasts. Filters are used to ensure that propagation motions and nowcast skills are optimized for long-lived linear storm systems. Subsequent development has focused on 0-2 hr nowcasts of thunderstorm evolution. A 2-hr nowcast demonstration is being conducted in collaboration with the Corridor Integrated Weather System (CIWS) and provides probabilistic nowcasts to users. In addition to the operational nowcasts, various experimental systems are being run in real-time for evaluation.

Historically, the Convective Weather PDT has based its forecasts on the availability of high-resolution Doppler radar data. Recent advances in the convective forecasts, however, have required technological enhancements such as the incorporation of wind and stability forecasts from high resolution numerical models such as the RUC, satellite-based cloud and convergence line detections, radar characteristic analysis to predict storm longevity, and boundary layer wind retrieval techniques.

Data from the National Convective Weather Forecast can be viewed on the web at: http://adds.aviationweather.noaa.gov/projects/adds/convection/.

6.2.3 Oceanic Weather PDT

The Oceanic Weather PDT is concerned with weather hazards over remote, data sparse regions of the world. Long-range oceanic flights by commercial aircraft, for example, frequently receive little weather guidance during their flights of ten hours or longer.

The initial focus of the Oceanic Weather PDT is on oceanic convection and its resulting turbulence. The PDT is already testing a real-time product showing the locations and cloud top heights of convective elements over several areas of the Pacific and over the Gulf of Mexico and Caribbean (see http://www.rap.ucar.edu/projects/owpdt/realtime_systems.htm.). An example of the current cloud-top height product is shown in Figure 17. Other critical weather phenomena of interest include volcanic ash, clear air turbulence, in-flight icing, and improved flight level winds.

While the Oceanic Weather PDT shares many of its areas of concern with other PDTs, the oceanic problem is unique in that it requires data on a global scale, well out of the range of many of the observing systems used over the continental United States. In general, the only available sources of data for the Oceanic Weather PDT are satellite observations and global weather forecast models such as NCEP's AVN model. Perhaps the most difficult task of the PDT is to develop reliable products that are primarily based on satellite imagery and soundings. Product dissemination is also a critical issue for the Oceanic Weather PDT, making sure that air traffic controllers, airline dispatchers, and the flight crews of the en route aircraft receive timely weather updates and warnings over their entire route.

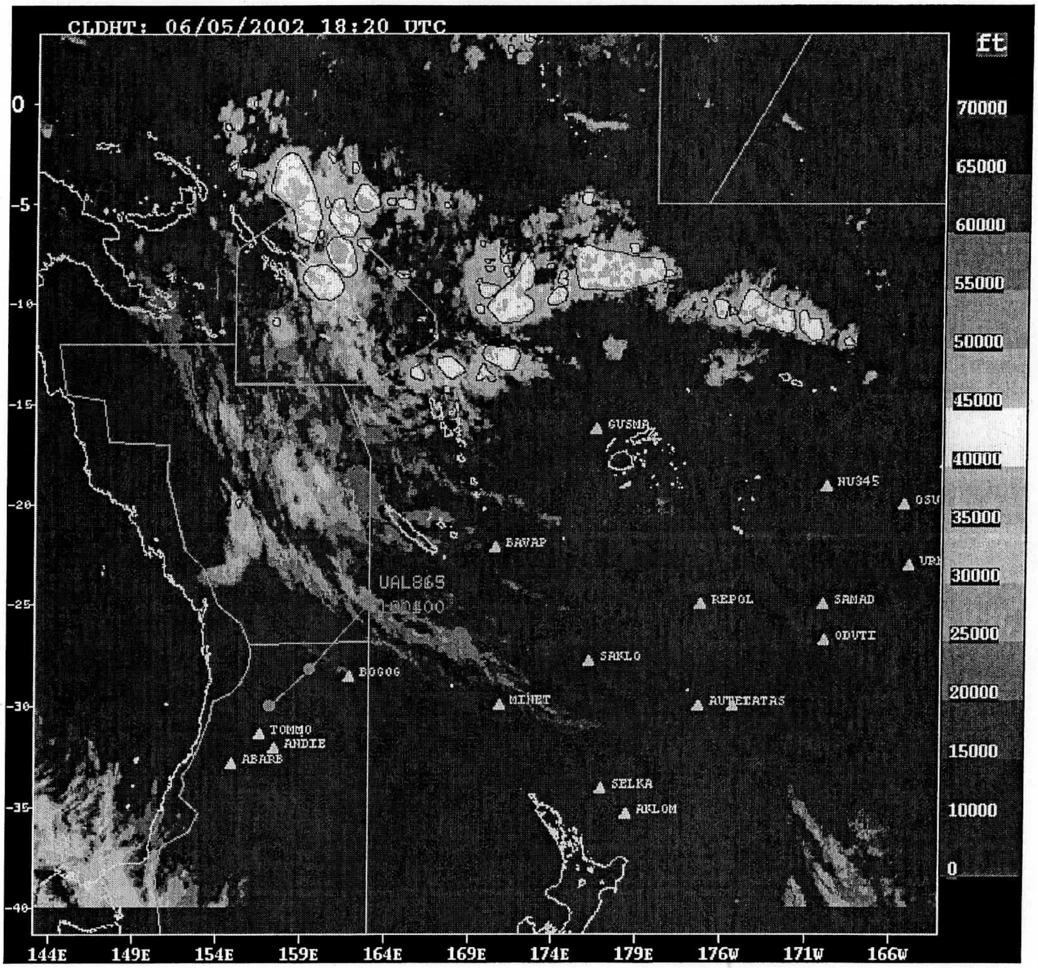


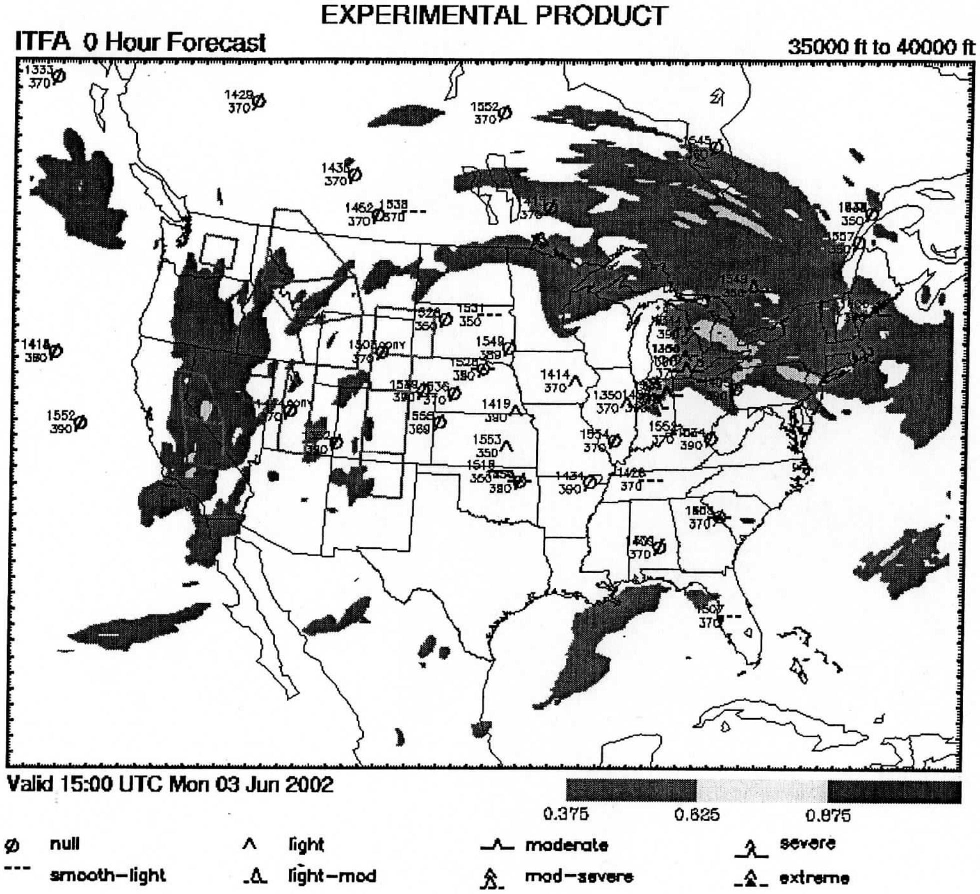
Figure 17. A detail from the Oceanic Weather PDT's real-time cloud-top height product page. The cloud top heights are given in standard feet above sea level (as displayed on an aircraft altimeter). This page also plots the real-time positions and projected flight track of commercial aircraft cooperating with the PDT to validate the product.

6.2.4 Turbulence PDT

Commercial and general aviation aircraft continue to encounter unexpected turbulence that can be a serious hazard to the aircraft and passengers. Current information (i.e., PIREPS) is not accurate enough to identify the location, timeliness and intensity of turbulence. The mission of the Turbulence PDT is threefold:

- Develop a quantitative, automated, *in-situ* measurement program to replace qualitative PIREPS.
- Develop timely and accurate analyses and forecasts of turbulence and present these in user-friendly formats.
- Develop turbulence remote sensing techniques using any viable method (e.g. Doppler radar, lidar, or satellite).

The Turbulence PDT has developed an algorithm to provide objective, aircraft-type independent turbulence data that can be downlinked from commercial air carriers in real time. Its sensor is the accelerometer suite already resident on the aircraft, and the software is an addition to the Aircraft Condition Monitoring System. This algorithm was approved by the International Civil Aviation Organization (ICAO) as an international standard.



Note: For pireps, time of pirep is in upper left corner in the format HHMM (GMT).
Altitude is in lower left corner in 100's of feet

Figure 18. Graphical output from the Integrated Turbulence Forecasting Algorithm (ITFA).

The Turbulence PDT has also developed an algorithm to forecast turbulence, the Integrated Turbulence Forecast Algorithm (ITFA). The turbulence diagnostic is a combination of some 12 common turbulence diagnostics or turbulence indices (e.g., wind shear, Richardson's number, Ellrod Indices, etc.) optimized to give the best agreement with available observations. These indices are most useful in forecasting upper level CAT associated with upper level fronts and jet streams. Some of the more common diagnostics that were used in the ITFA combination are displayed as contour maps of the maximum value of that index anywhere above 20,000 ft. The resulting ITFA combination is shown as contour maps of predicted CAT intensity at flight levels 22,000 to 41,000 ft at 4,000 foot intevals. ITFA automatically and continuously ingests weather observational and forecast data—and in the future in-situ data—and then fuses these data to produce turbulence forecasts. ITFA is currently available in an experimental mode via ADDS at: http://adds.aviationweather.noaa.gov/projects/adds/turbulence/. Figure 18 demonstrates an experimental turbulence product.

6.2.5 Aviation Forecasts and Quality Assessment (AF&QA) PDT

The Aviation Forecasts and Quality Assessment (AF&QA) team seeks to provide weather data to pilots that is in a useful format and that can be easily understood. The AF&QA team has four objectives:

- Build a meteorological database for aviation decision-makers (e.g., pilots, dispatchers and air traffic controllers) and FAA automation systems.
- Develop product generation, grid editing and verification tools to ensure that the weather impact information provided to aviation interests is accurate and timely.
- Build dissemination tools to ensure that the weather impact information is easily accessible and in a usable format.
- Provide a conduit for continuous NWS dissemination of meteorological information.

This PDT achieved a major success with implementation of the initial operating capability in the form of the Aviation Digital Data Service (ADDS), at the AWC. ADDS provides aviation data with a user-friendly interface and easy to understand formats. ADDS is based on gridded databases, both as a forecasters' tool with which they can interact, and as a computer readable database for use by automation systems. The most recent innovation is a flight path tool that displays turbulence, icing, thunderstorms, and other aviation weather hazards for specific flight altitudes and flight paths selected by the user.

A key component of the AF&QA PDT is the Quality Assessment Group (QAG). QAG represents a partnership between FSL and NCAR and is responsible for product verification for the AWRP. QAG works with the PDTs and AWC, advising them on verification approaches and developing verification methods appropriate for a particular product. The goal is to devise verification systems for experimental algorithms and operational products that are objective, independent, and statistically valid. QAG ultimately provides the FAA with quality assessment plans and reports that are used to decide whether products can become operational.

A noteworthy accomplishment of the PDT's QAG is the implementation of a Real-Time Verification System (RTVS). The RTVS is an online tool that includes a relational database for storage and provides forecasters and researchers the opportunity to compare forecast products with the subsequent verification datasets. This near real-time processing of the data gives the forecasters immediate feedback on the accuracy of their guidance products and rapid evaluation of new products. It also provides a long-term baseline evaluation of operational and experimental products.

The RTVS can be viewed on the web at: http://www-ad.fsl.noaa.gov/fvb/rtvs/.

6.2.6 Winter Weather PDT

The primary focus of the Winter Weather Research PDT is a product called the Weather Support to De-icing Decision-Making (WSDDM) system. The objective of WSDDM is to produce real time, short-term forecasts in the terminal area to support ground deicing and terminal management during winter storm conditions. Inadequate aircraft deicing before take off is a safety hazard that has resulted in a number of accidents.

WSDDM is dependent on a three-dimensional knowledge of the winter storm structure. At present, the system is based on Doppler radar, surface weather data, and snow gauges to determine precipitation type, temperature, wind speed and direction, and the liquid water equivalent of snow. This information provides airline and airport decision makers such as pilots, controllers, dispatchers, and maintenance personnel with valuable weather information needed to make more accurate and timely aircraft deicing/anti-icing and runway plowing decisions. The WSDDM technology was technology-transferred to a private vendor who operationally implemented it at JFK, LaGuardia and Newark airports. The PDT's plans for the future include developing forecasts out to 12 hours, an improved and less expensive gauge that measures the liquid water equivalent of frozen precipitation, and the inclusion of Terminal Doppler Weather Radar (TDWR) data.

The PDT is also beginning research on the low ceiling and visibility conditions that are prevalent during the winter season, in conjunction with the Terminal Ceiling and Visibility PDT. The goal of this work is a winter storm ceiling and visibility product that can be integrated with WSDDM and the FAA's Integrated Terminal Weather System.

6.2.7 National Ceiling and Visibility PDT

National-scale ceiling and visibility (C&V) research seeks to develop methodologies for automated analysis, forecasting and display of C&V conditions critical to aviation safety. Within the team's (initial) CONUS domain, the key phenomena are low ceiling, fog and visibility reductions due to snow and rain. The visibility impacts of haze and dust can play important but generally secondary roles as related to safety impacts in the CONUS. The PDT's current methodology utilizes surface-based observational data, GOES satellite observations, numerical and statistical forecast models, pilot reports, and expert system techniques to produce first-generation warning products displayed in real time at www.rap.ucar.edu/projects/cvis/. Within the next two years the PDT expects to begin work toward a forecast system focused on the Alaska domain and its unique difficulties associated with limited surface observations and strong terrain influences.

Satellite observations are critical to recognition of current meteorological conditions and to guidance of extrapolation procedures needed to estimate C&V conditions in regions between surface observation stations. Key objectives of satellite use include day and night-time detection of fog, discrimination between low cloud and snow-covered surfaces, determination of cloud height, profiling of temperature, winds and humidity, and estimation of the optical depth of obscurants such as cloud, fog, haze and dust. While the GOES satellites serve as primary data sources over the CONUS domain, polar-orbiting satellites can provide less frequent but useful data there. Within the planned Alaska domain, polar-orbiting satellite data will play a critical role.

6.2.8 Terminal Ceiling and Visibility PDT

Terminal C&V research is aimed at providing next-generation tools for real-time analysis and short-term prediction in the immediate terminal area as needed to best manage traffic flow and airport operations in degraded C&V conditions. Especially in the larger terminal areas, C&V impacts yield runway closures and flight delays that produce extensive regional and national-scale traffic disruptions. To date the Terminal Ceiling and Visibility PDT has worked extensively on the forecasting problems associated with summertime stratus at San Francisco Airport. Here, the difficulty in accurate forecasting of the time of burn-off of marine stratus decks causes significant and repeated disruptions and delays in airport operations and regional traffic flow. Emerging PDT work further focuses on the C&V impacts of winter weather on the major airports in the northeast U.S.

Satellite measurements that support detailed regional physical and statistical weather models, improved detail in terminal-area winds, improved recognition of fog/stratus formation and extent, and improved real-time understanding of regional cloud structure on the macro- and microscales represent important needs of the Terminal C&V PDT.

6.2.9 Model Development and Enhancement PDT

The objective of the Model Development and Enhancement (MD&E) PDT is to improve the numerical models on which aviation weather forecasts are based, using three approaches:

- Improve the model's internal representation of cloud development, including thunderstorms.
- Define the detailed wind and cloud features that need to be simulated in order to forecast turbulence, icing, convection, and cloud ceiling.
- Exploit all available observations as model initialization fields in order to improve the analyses of wind, cloud, and moisture fields.

The primary accomplishments of this PDT have been the introduction of the high resolution, rapid update cycle (RUC) model as an operational model and a higher resolution mesoscale version of the Eta model.

Current work by this PDT includes assimilating and integrating cloud and precipitation observations for model initialization, based on data from satellites and radars. The data assimilation aspects of this effort will be conducted in conjunction with the new Joint Center for Satellite Data Assimilation (JCSDA), a cooperative effort of NOAA, NASA, and NSF. The PDT is also working on the development of a next-generation mesoscale model that will be suitable for use by both researchers and operational forecasters. This is the high-resolution, non-hydrostatic Weather Research and Forecast model (WRF), a cooperative effort among NOAA, FAA, NCAR, and the University Community.

6.2.10 NEXRAD Enhancement PDT

The NEXRAD Enhancement PDT is a highly focused PDT that seeks to maximize the utility of the existing NEXRAD weather radar network for the aviation community as well as developing new products based on planned upgrades. This combination of short and long-term objectives is similar to those described in this ASAP document. The team strategy to accomplish this is by developing applications to allow nationwide detection and prediction of weather phenomena that are hazardous to aviation and assisting in the transfer of those applications to the NEXRAD network.

To date, the PDT has developed a storm cell identification and tracking algorithm (SCIT), a hail detection algorithm, and a tornado detection algorithm. Other areas of ongoing investigation include anomalous propagation and clutter identification and mitigation, bright band identification, network mosaic products, and hydrometeor classification algorithms using polarimetric radar data.

APPENDIX A: SATELLITE DATA AVAILABILITY AND LATENCY

Critical issues that must be seriously considered when evaluating the use of weather satellite information for improving aviation safety is the availability and latency of acquiring and processing satellite radiances from the spacecraft. Acquiring the Level 0 (raw data) or Level 1 data (calibrated, navigated radiances) as soon as possible after observation time is one important step. The time to process derived meteorological quantities (referred to as Level 2 data sets) from these data must also be considered. With the knowledge that even the most robust Level 2 products designed to address aviation safety-related problems will lose value with age, the following section addresses the capabilities of SSEC's Data Center as an example of a modern, state-of-the-art facility to receive, quality control and store meteorological data in real-time, and the capabilities at CIMSS to apply scientific algorithms to the data to create the required data sets.

It is important to note that although this section emphasizes the satellite capabilities at UW–CIMSS, it is important to note that several of the current AWRP PDT team members possess similar satellite data availability and processing capabilities. The discussion below is intended to provide an overview of current and future satellite remote sensing data requirements as relevant to addressing issues of aviation-weather safety. These satellite data and capabilities are likely available at other institutions [e.g., NASA, Jet Propulsions Laboratory, NRL, the Lincoln Laboratory at the Massachusetts Institute of Technology (MIT–LL), NOAA/NESDIS].

Throughout the following discussion, issues of data latency are reviewed. As stated previously, satellite data can only be useful for addressing issues of aviation safety if these data become available on time scales appropriate to the problems being addressed (e.g., short-fuse nowcasting). For example, data latencies of 1-2 minutes from space craft to processing calibrated radiances for GOES is the current direct broadcast capability.

Section A.1 discusses the current weather satellite instrumentation. In particular, the "direct broadcast" of MODIS data at UW–CIMSS will be highlighted for its much-enhanced capabilities compared to GOES for addressing several unique problems relevant to aviation, including the measurement of cloud layers and cloud microphysical properties. Sections A.2–A.6 overview the UW SSEC Data Center along with the coming hyperspectral instruments that will be relied upon as this project proceeds into Phase II during 2005. The current and planned activities at UW–CIMSS in preparing for these advanced instrument measurement capabilities will also be highlighted in these sections.

A.1 Current Space-based Weather Satellite Instrumentation

Table A1 provides a summary of current geostationary and polar weather satellites. There are currently five geostationary and three polar operational weather satellites that provide continuous, real-time data. The geostationary systems (and their operators) are GOES (U.S.), Meteosat (Europe) and GMS (Japan). These satellites provide continuous coverage over the globe from 60 N to 60 S. The GOES system currently is the only geostationary instrument that possesses a multi-spectral sounding capability. Polar data are made available by the NOAA POES satellite series, currently NOAA–14, –15 and –16, which provide data in real time to direct broadcast reception facilities, and at reduced resolution over the entire globe to NOAA ground stations in Wallops Is., VA and Gilmore Creek, AK. Other geostationary and polar satellites operated by China (the "FY" series) provide data when available. India and Russia also have weather satellite programs, but their data are not readily available.

Real time data is also available from research satellites. The NASA EOS Terra and Aqua satellites transmit MODIS and Advanced Infrared Sounder (AIRS) data to direct broadcast reception facilities. The AIRS instrument on Aqua is the first U.S. direct broadcast hyperspectral-sounding instrument.

Table A1: Satellite Data Characteristics

Geostationary Orbit Satellite	**Spectral Bands**
GOES 8/10	5 band Imager: Visible, Shortwave window, longwave window, "dirty" window, Water Vapor 19 band Sounder
MeteoSat 5/7	3 band Imager: Visible, Infrared, Water Vapor
GMS	3 band Imager: Visible, Infrared, Water Vapor
FY-2B	3 band Imager: Visible, Infrared, Water Vapor
Polar Orbiting Satellite	
POES/NOAA	6 band Imager: Visible, Infrared, Water Vapor Sounder: 19 band Infrared, 10 band Microwave
EOS Terra/Aqua	MODIS: 36 band Imager: Visible, Infrared AIRS: 3000+ band Sounder: Infrared
FY-1C	10 band Imager: Visible, Infrared, Water Vapor

A.1.1 GOES and other Geostationary Weather Satellites

The GOES imager has five channels. The visible channel has a 1-km spatial resolution, while the four infrared channels have a 4-km nominal resolution (the water vapor band resolution was 8 km prior to GOES-12). GOES-12 supports a 13.3-μm band in place of the 12-μm band (Schmit et al 2001). The Imager covers 3/5th of the Western Hemisphere full disk every 15 minutes, but can also be put into "Rapid Scan" mode, achieving up to one-minute temporal resolution.

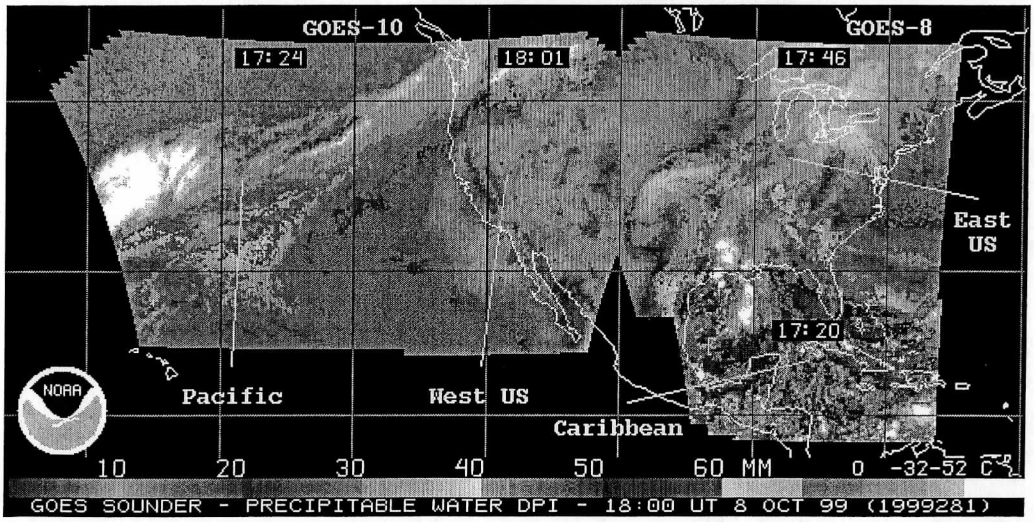


Figure A1: Hourly coverage of derived GOES 8/10 sounder total precipitable water.

The GOES sounder contains 18 infrared bands and a visible band. The infrared spectral coverage extends from 3.7 to 14.7-μm (2700 to 700 cm^{-1}) and provides information on vertical characteristics of the atmosphere. The 10-km spatial resolution currently provides coverage each hour over a domain that includes the continental U.S. and near offshore regions. That coverage is adjusted during the Atlantic hurricane season to expand south and east into the Caribbean. Figure A1 shows the GOES sounder hourly coverage of total precipitable water. Color enhanced precipitable water values are displayed where GOES sounder retrievals exist; where no retrieval is made, the gray scale infrared window brightness temperatures are shown.

Meteosat–5 and –7 are currently operated by the by EUMETSAT. Meteosat–7 is located at 0 degrees longitude and Meteosat–5 is at 50 degrees east longitude. Both satellites contain an image with three channels: a visible, water vapor and infrared window. GMS is operated by the Japanese Meteorological Agency and is located at 145 degrees east longitude. GMS also has a 3-channel imager, covering the same spectral regions as Meteosat. It is important to note that since the GOES East and West imager also contains these bands, global coverage from geostationary altitude is achieved in these bands.

A wide range of products that were developed at UW–CIMSS from GOES measurements is now operationally produced by NOAA/NESDIS in Washington, D.C. This includes information on atmospheric motions, sea surface temperature, atmospheric moisture/stability and clouds.

A.1.2 POES and other Polar Weather Satellites

The NOAA series of polar orbiting satellites (POES) has an instrument configuration similar to GOES, and includes an Advanced Microwave Sounding Unit (AMSU). The imager, the AVHRR is a 6-band instrument with 1-km resolution in all channels. On recent platforms (NOAA –15 and –16) the 3.9 µm channel operates on the daytime coverage and a 1.6 um channel on the nighttime coverage. The HIRS/3 IR Sounder has a spectral configuration like the GOES Sounder, but has a 20 km field of view, compared to 10 km for GOES. The AMSU has windows channels at 23.8, 89, and 150 GHz, temperature sounding channels in the 50 GHz O_2 band, and moisture sounding channels in the 183 GHz band, providing all weather sounding capability at a reduced spatial resolution.

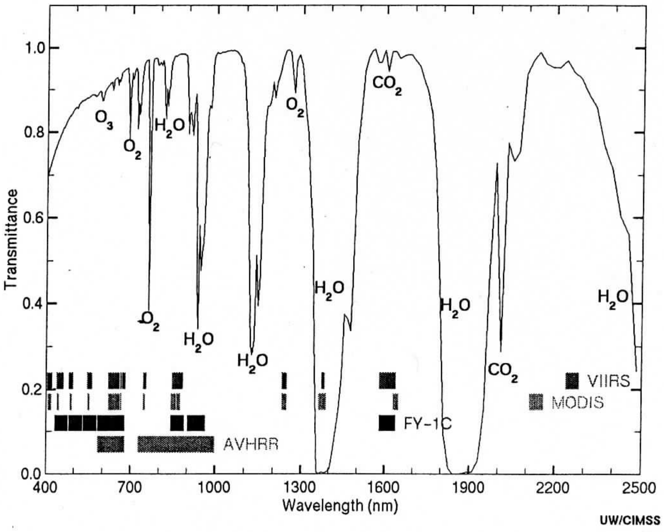


Figure A2: Spectral comparison of MODIS, VIIRS, FY-1C, and NOAA AVHRR polar orbiting instrumentation.

The NASA EOS platforms, Terra and Aqua, carry several instruments. Only certain instruments transmit for direct broadcast and are thus available in real time. The MODIS imager provides direct broadcast data from both EOS platforms. MODIS is a 36-band imager with resolution up to 0.25 km in the visible and 1 km in all bands. Figure A2 presents a comparison of spectral bands of several polar orbiting instruments, including MODIS and AVHRR. The EOS Aqua platform contains the first high spectral resolution atmospheric sounder in space. AIRS is a high spectral resolution spectrometer with coverage in nearly 2300 bands in the infrared and visible. The infrared spectral range is 3.7 to 15 μm and the visible range is 0.4-1.0 μm. AIRS has a spatial resolution of 10 km and represents a hyperspectral instrument.

A.2 SSEC Data Center

The University of Wisconsin-Madison Space Science and Engineering Center (SSEC) Data Center facility has evolved over the past three decades to support the science and computing activities of its scientific investigators and their collaborators. The growth and evolution of the SSEC Data Center has been driven by science opportunities in the atmospheric and earth sciences, primarily in support of NASA and NOAA objectives.

The SSEC Data Center mission is to create and maintain the facilities, human expertise and technology necessary to provide SSEC scientists and their collaborators with the highest quality geophysical data in a timely fashion, and to provide data storage, archive and retrieval services as necessary to support Center scientific programs.

The SSEC Data Center began as a support service to the McIDAS in the mid-1970's. As the McIDAS data processing and visualization capabilities grew, so did the desire for expanded data types to support McIDAS science studies and visualization needs. More recently, as data manipulation and visualization tools have expanded and data formats have changed, the SSEC Data Center has also expanded its ability to serve geophysical data in a variety of formats to serve multiple data systems.

Since the start of the NOAA GOES program in 1978, SSEC has served as the national archive for all GOES imager and sounder data. The data is ingested through rooftop antennas, quality controlled and written to IBM 3590 tape. The tape archive includes over 2,500 tapes and is 270 Terabytes in size. One copy of the tape archive resides with the National Climate Data Center (NCDC) and one copy remains with SSEC. The SSEC Data Center also archives Meteosat, GMS and direct broadcast MODIS data.

The remaining part of this section details the capabilities of the SSEC Data Center in terms of data ingest, distribution and archiving. Again, these capabilities, although specific to the SSEC Data Center, are an important prerequisite of any institution performing intensive satellite data processing in support of aviation-weather safety.

A.3 Hardware Configuration

The current SSEC Data Center uses a distributed data acquisition and distribution system. The current configuration utilizes both Unix and PC based computers for product generation, tape processing, quality control (QC), and serving data. SSEC Desktop Ingestors (SDI) are used for all data except MODIS. The GOES Satellite Archive System (GSAS) system hardware is 100% redundant. Primary and backup systems ingest data from the GOES 8 (East) and 10 (West) satellites simultaneously, thus a hot backup is always online. Sun E4000 servers support data archiving and serving to users in SSEC and across the world via the Internet. Over 100 GB of real-time online archive provide several days of the most recent data to our users via ADDE. The GSAS system has successfully recorded 99.9% of all the data sent from the GOES Variable Format (GVAR) satellites since it became operational in October 1997.

In the fall of 2000, a 4.2-meter dish was installed in a radome on the roof of the SSEC building. The SSEC Data Center monitors the ingestion of the direct readout system (SeaSpace X-band ingestor), archives the Level-0 data, quality controls the data and provides the data to users via Advanced Data Distribution Environment (ADDE) and File Transfer Protocol (FTP). SSEC keeps seven days of direct broadcast MODIS data online. Work is also underway to enable the reception of the EOS Aqua AIRS data from the SSEC X-band direct broadcast facility. The first space-based sounding instrument with high spectral resolution, AIRS direct broadcast data will maintained an online archive.

A.4 Data Center Activities

The SSEC Data Center is currently staffed by three full time employees, four staff members who devote part of their work schedule to Data Center activities, and one student. The Data Center manager oversees a team leader/programmer, full and part time programmers, two operations experts, and an archivist (whose role is to verify and maintain the automatically generated online inventories of all archived data). The Data Center operates 16 hour per day, 5 days per week, and can run 24/7 during field programs or other times needing such support.

Table A2: SSEC Direct Ingest Data with On-line storage

Satellite	**Gbytes Available**	**Days Available Online**
Meteosat-7	0.9 Gb	1.1 days
Indoex (Met 5)	2.0 Gb	2.23 days
GMS-5	7.8 Gb	3.0 days
GOES-8	57.0 Gb	3.6 days
GOES-10	57.0 Gb	3.6 days
FY-2B	8.4 Gb	3.0 days
POES N16	4.3 Gb	2.2 days
POES N15	4.3 Gb	2.2 days
POES N14	4.3 Gb	2.2 days
POES N12	4.3 Gb	2.2 days
FY-1C	1.76 Gb	.57 days
Terra-MODIS	750.0 Gb	7.0 days
Radar		
NEXRAD	800 Mb	1.0 days
Conventional and Model Data		
NOAAPORT	5.8 Gb	3.0 days

Data Center activities include design, fabrication and maintenance of support facilities to receive, archive, and serve real-time geophysical data. Data Center staff provides typical data processing support, including tape read-write and copying. During field programs (normally several per year) the Data Center provides special archiving and other requests and can provide extended staff hours or on-call services. Additional responsibilities of staff include:

- Assisting the NOAA Satellite Operational Controls Center (SOCC) and other agencies in satellite checkout and troubleshooting of satellite and data related problems.
- Providing support to the National Climate Data Center (NCDC) with their GOES archive system operations.
- Processing data requests (and product generation) for archived data.

- Generating and maintaining real-time data products for the SSEC Web site.

A.5 Data Availability, Usage and Archive

All data are provided to users via ADDE over the internet. A large real-time, on-line data base is maintained for all data types (Table A2), and most data is archived on IBM 3590 tape and other formats.

A.6 Future Infrared Hyperspectral Datasets

SSEC has pioneered the design and development of new remote-sensing approaches and analysis techniques, including the design of infrared high spectral resolution instruments and techniques for sounding and imaging from both geostationary and polar orbits. These research and development efforts resulted in aircraft and ground-based instrumentation (High-resolution Interferometer Sounder, HIS; Scanning HIS, and the AERI), which led the way for future spacecraft instruments (CrIS, GIFTS and GOES-ABS). Along with instrument advances are data processing techniques to produce robust analysis techniques. CIMSS has developed numerous derived product algorithms for current NOAA GOES (imager and sounder) and Advanced Television Infrared Observation Satellite (TIROS) Operational Vertical Sounder (ATOVS; with HIRS and AMSU) data, and the NASA MODIS data on the EOS Terra Platform. CIMSS is currently planning similar activities for exploiting AIRS data from the Aqua Platform.

The University of Wisconsin also has a long history of collaborating with other organizations, nationally and internationally, to fulfill the goals of improving space-based measurements of Earth's surface and atmosphere. An example of this collaboration, one that has high relevance to this ASAP initiative (especially during ASAP's Phase II) is the involvement of UW–CIMSS in the GIFTS program.

In December 1999, NASA made a New Millennium Project (NMP) Award for the GIFTS instrument technology demonstration and observing system data validation. With NASA Langley, Utah State Systems Dynamics Lab and others, SSEC/CIMSS has been working toward the successful development of the GIFTS instrument. In May 2001, UW–CIMSS was awarded a grant from the Department of Defense (DoD), Office of Naval Research's (ONR) Multidisciplinary University Research Initiative (MURI) for: "*Physical Modeling for Processing of Hyperspectral Data*." Within this grant, UW–CIMSS is working with several partners to understand and develop capabilities for utilizing GIFTS data for characterizing atmospheric and land surface properties, well in advance of the GIFTS launch. Specifically, the UW MURI addresses the following research areas: 1) to translate optimally, as well as efficiently, the physical principles of a hyperspectral data retrieval problem to the mathematical algorithms that try to solve it, 2) quantifying mathematically where the useful information to complete a physically-driven application resides in the electromagnetic spectrum, and 3) applications of physics-based processing of hyperspectral data for surface material detection, classification and identification; atmospheric parameter retrieval including visibility and stability, and coastal water quality.

The combined GIFTS-IOMI (Geostationary Imaging Fourier Transform Spectrometer-Indian Ocean METOC Imager) mission, jointly funded by the NASA NMP and ONR, is truly a revolutionary step in hyperspectral imaging from geostationary orbit. GIFTS has been selected for flight demonstration on NASA's NMP Earth Observing–3 (EO–3) Satellite Mission, and combines new and emerging sensor and data processing technologies to acquire geophysical measurements that will lead to revolutionary improvements in meteorological observations and forecasting. While the EO–3 satellite will be located over North America for 18 months after launch to facilitate instrument technology and measurement validation the satellite will be relocated over the Indian Ocean in 2006. The Indian Ocean is an important strategic Navy mission area, and is currently one of the world's largest meteorological data void areas. The impact of GIFTS to the evaluation of aviation hazards to meet the FAA objectives for increasing safety are therefore likely to be significant.

The GIFTS uses a Large area format Focal Plane detector Array (LFPA; 128 × 128 grid) in a Fourier Transform Spectrometer (FTS) to enable the simultaneous gathering of high spectral resolution (0.6 cm^{-1} in the regional sounding mode) and high spatial resolution (4-km pixel) Earth infrared radiance spectra over a large geographical area (512 km × 512 km). An additional visible low-light level camera provides quasi-continuous imaging of clouds at 1-km spatial resolution down to quarter Moon lighting of Earth. Extended Earth coverage is achieved by step scanning the instrument field of view in a contiguous fashion across any desired portion of the visible Earth (Fig. A3). GIFTS is designed to provide quantitative soundings of water vapor, temperature, and atmospheric pollutants, and has broad-based applicability for atmospheric chemistry measurements, natural disaster assessment, and exploratory observations.

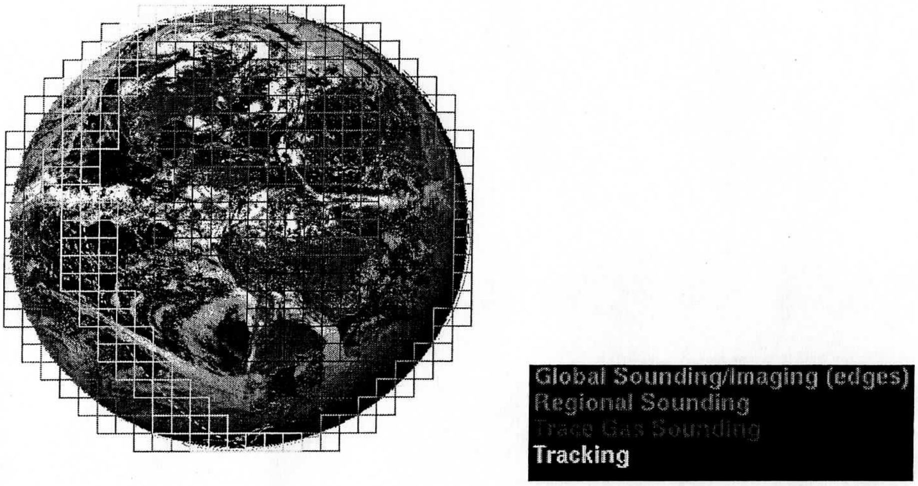


Figure A3: A selection of GIFTS measurement modes. Each box represents the area sampled by the 128 × 128 Large area format Focal Plane detector Array (LFPA).

Table A3 lists the area coverage, measurement frequency, spectral resolution, and geophysical measurement for example modes of operation for GIFTS. Quasi-continuous imagery of localized areas and minute-interval imagery of large-scale areas can be achieved. Full disk sounding coverage will be obtained every 7 minutes at contemporary sounder spectral resolutions (e.g., 18 cm^{-1}). High vertical resolution soundings and atmospheric chemistry measurements of GIFTS require 0.6 cm^{-1} spectral resolution and a longer stare time, thereby reducing the area coverage and/or frequency of observation relative to the imagery mode of operation. Nevertheless, GIFTS will cover a major portion of the visible disk with high vertical resolution soundings in less than 30 minutes. This feature is important for obtaining wind profiles from geostationary temperature and moisture sounding data. A relatively long dwell time and more limited area coverage "self validation mode" will enable 0.3 cm^{-1} spectral resolution radiances to be achieved.

GIFTS uses two detector arrays to cover the spectral bands 685 to 1130 cm^{-1} (longwave) and 1650 to 2250 cm^{-1} (midwave). Although dependent on the choice of operating mode—GIFTS' Michelson interferometer design allows spectral resolution to be traded for greater area coverage or higher temporal resolution—radiance data can be obtained in up to ~4000 spectral channels. The current Geostationary Operational Environmental Satellite (GOES) Sounder, by way of comparison, measures a total of 18 thermal bands and one visible light band.

Table A3: Five example GIFTS operating modes.

Mode	Resolution		Coverage	
	Spectral	OPD	Area	Time*
Stare Mode	0.3–36cm^{-1}	0.014–1.744 cm	512 km	<1–20 sec
Regional Imaging	36 cm^{-1}	0.014 cm	6000 km	3 min
Global Sounding	18 cm^{-1}	0.027 cm	10,000 km	7 min
Regional Sounding and Chemistry	0.6 cm^{-1}	0.872 km	6000 km	25 min
Self Validation**	0.3 cm^{-1}	1.744 cm	1000 km	60 min

*Assumes a constant data rate associated with Michelson mirror scan velocity of 0.17 cm/sec and 1 sec telescope pointing step time.

** Provides radiometric precision better than 0.1K over all wavelengths.

The GIFTS longwave window region from 850–950 cm^{-1} possesses the surface temperature and emissivity signal that will be used for surface characterization and identification. The GIFTS shortwave band from 1650–2250 cm^{-1} includes the shortwave half of the 6.3-μm water vapor band and will be used for water vapor profile retrievals. Carbon dioxide absorption throughout the longwave band is used for atmospheric temperature profile retrievals. These spectral characteristics achieve all technology and scientific validation objectives of GIFTS, as well as the sounding accuracy desired for a future operational sounding system.

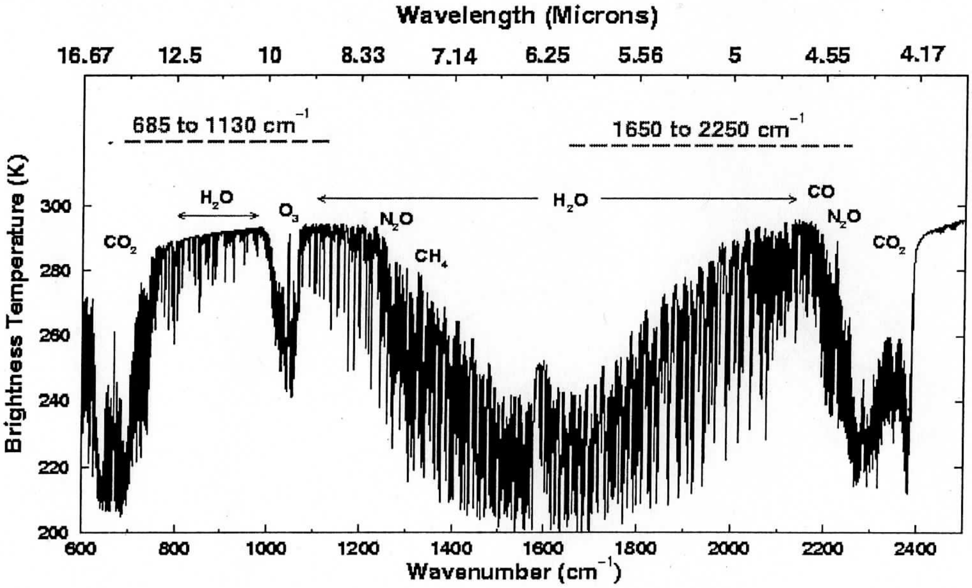


Figure A4: GIFTS spectral coverage with two detector arrays, showing spectral features of key radiatively active atmospheric trace gases.

The radiance spectra observed at each time step are transformed to high vertical resolution (1–2 km) temperature and water vapor mixing ratio profiles using rapid profile retrieval algorithms. These profiles are obtained on a 4-km resolution grid and then converted to relative humidity profiles. Images of the horizontal distribution of relative humidity for each atmospheric level, vertically separated by approximately 2 km, are constructed for each spatial scan. The sampling period will range from minutes to an hour, depending upon the spectral resolution and the area coverage selected for the measurement. Successive images of clouds and the relative humidity for each atmospheric level can be animated to reveal the motion of small-scale features, providing an estimate of the wind velocity distribution as a function of altitude. Feature tracking can be performed for mixing ratio profiles of ozone and carbon monoxide, derived from their spectral radiance features observed by the FTS instrument (see Fig. A4), providing a direct measure of the transport of these pollutant and greenhouse gases.

The net result of GIFTS profiling will be a dense grid of temperature, moisture, and wind profiles that can be used for atmospheric analyses and operational weather prediction. Especially over the oceans, this will serve as a vast wealth of information for aviation-weather analysis and forecasting.

GIFTS will be a technology demonstration that will help design the next generation of operational NOAA geostationary satellites. The Advanced Baseline Imager (ABI) is being designed for future GOES (starting with GOES-R in 2012). As with the current GOES imager, this instrument will be used for a wide range of qualitative and quantitative weather and environmental applications. The ABI will improve over the existing GOES imager with more spectral bands (Fig. A5), higher spatial resolution, faster imaging, and broader spectral coverage. The ABI will improve the spatial resolution from nominally 4 to 2 km for the infrared bands and 1 to 0.5 km for at least one visible band. There will be a five-fold increase of the coverage rate. The ABI expands the spectral band number to at least 12; five are similar to the 4, 11, and 12 μm infrared windows and the 6.5 μm water vapor band on the current GOES-8/11 Imagers (see Table A4). The additional bands are planned to be a visible band at 0.86 μm for the detection of aerosols and vegetation; a near-infrared band at 1.38 μm to detect very thin cirrus clouds; a snow/cloud-discriminating 1.6-μm band; a mid-tropospheric 7.0-μm water vapor band to track atmospheric motions; a 8.5-μm band to detect volcanic dust clouds containing sulfuric acid aerosols and cloud phase; the 10.35-μm band to derive low-level moisture and cloud particle size; and a 13.3-μm band useful for determining cloud top heights and effective cloud amounts. There is also interest in adding bands centered at 0.47 μm for aerosol detection and visibility estimation, at 7.4 μm for low/mid-level flow and sulfuric acid aerosols, and at 9.6 μm for monitoring atmospheric total column ozone on space and time scales never before possible. ABI will not only allow new satellite products to be created, but due to the improved spatial, temporal and additional bands, the existing products will be improved.

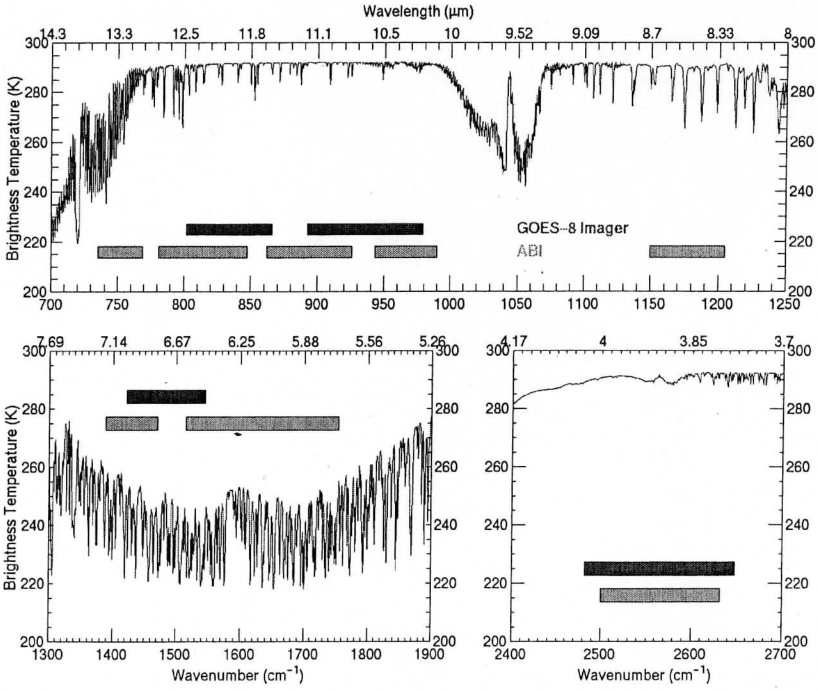


Figure A5: The GOES-8 IR spectral bands (top bars) and the ABI IR spectral bands (lower bars). A high-spectral resolution earth-emitted spectrum is also plotted.

The Advanced Baseline Sounder (ABS) (or HES–Hyperspectral Environmental Sounder) is being designed for future GOES (starting with GOES-R in 2012). ABS will have thousands of channels with spectral bandwidths on the order of single wavenumber, while the current GOES Sounder has only 18 bands with widths on the order of tens of wavenumbers. The coverage rate of the ABS will be approximately five times faster than the current GOES sounder. This will allow large oceanic areas to be covered by the ABS that are not scanned by GOES sounder instrumentation currently. With high temporal resolution (better than one hour), high spatial resolution (better than 10 km), high-spectral-resolution (better than single wavenumber), and broad coverage (hemispheric), ABS measurements will enable monitoring the evolution of detailed temperature and moisture structures in clear skies with high accuracy (better than 1 C root mean square differences) and improved vertical resolution (about 1 km). The current GOES sounder yields roughly 3-km vertical resolution. Temperature and moisture retrievals from current GOES radiance measurements and simulated future ABS radiances have been compared with time/space co-located radiosonde observations and numerical weather prediction (NWP) forecasts; results show the large improvement of ABS moisture retrievals over both the current GOES sounder and the NWP/forecasts. Due to the ABS spectral resolutions, significant atmospheric temperature inversions can be better detected. Of course inversion strength is important for convective initiation or fog formation. In addition, cloud top pressure retrievals from simulated ABS cloudy radiances in thin high clouds are improved over those achieved by GOES.

Table A4: ABI channel selection. The four shaded bands denote the proposed additional bands.

Wavelength (μm)	Description
0.64 +/- 0.05	Visible
0.86 +/- 0.05	Visible
1.375 +/- 0.015	Near Infrared
1.61 +/- 0.03	Near Infrared
3.9 +/- 0.1	Shortwave Infrared
6.15 +/- 0.45	Water Vapor 1
7.0 +/- 0.2	Water Vapor 2
8.5 +/- 0.2	Infrared Window 1
10.35 +/- 0.25	Infrared Window 2
11.2 +/- 0.4	Infrared Window 3
12.3 +/- 0.5	Infrared Window 4
13.3 +/- 0.3	Carbon Dioxide

Other forthcoming satellite data to be available will be from the VIIRS, CrIS and AIRS.

The VIIRS will combine the radiometric accuracy of the AVHRR currently flown on the NOAA polar orbiters with the high (0.65 kilometer) spatial resolution of the Operational Linescan System (OLS) flown on the DMSP. The VIIRS will provide imagery of clouds under sunlit conditions in about a dozen visible channels (or frequency bands), as well as provide coverage in a number of infrared channels for night and day cloud imaging applications.

VIIRS will have multi-channel imaging capabilities to support the acquisition of high-resolution atmospheric imagery and generation of a variety of applied products including visible and infrared imaging of hurricanes and detection of fires, smoke, and atmospheric aerosols. VIIRS will also provide capabilities to produce higher resolution and more accurate measurements of sea surface temperature than currently available from the heritage AVHRR instrument on POES, as well as an operational capability for ocean color observations and a variety of derived ocean color products.

The CrIS provides improved measurements of the temperature and moisture profiles in the atmosphere. The current HIRS instrument on POES provides about 20 infrared channels of information and is able to characterize atmospheric temperature profiles to an accuracy of 2 to 3 degrees Kelvin. The CrIS will provide over one thousand spectral channels of information in the infrared at an improved horizontal spatial resolution and will be able to measure temperature profiles with improved vertical resolution to an accuracy approaching one degree Kelvin.

The AIRS is a key facility instrument on Aqua, the first afternoon ("PM"—1:30 pm Equatorial crossing time) EOS platform. The AIRS instrument is the first high-spectral resolution infrared sounder developed by NASA in support of operational weather forecasting by NOAA. Radiosonde accuracy is equivalent to profiles with 1-K RMS accuracy in 1-km thick layers and humidity profiles with 10% accuracy in the troposphere. To meet these WMO requirements, an extensive data simulation and retrieval algorithm development effort was required to establish AIRS instrument-measurement requirements in the areas of spectral coverage, resolution, calibration, stability, and spatial response characteristics, including alignment, uniformity, and measurement simultaneity, radiometric and photometric calibration and sensitivity. AIRS, with 2378 spectral channels, possesses spectral coverage from 3.7 to 15.4 μm, the AMSU (27 to 89 GHz), and the Microwave Humidity Sounder (HSB, 150 to 187 GHz), form a complementary sounding system for NASA's Aqua spacecraft.

APPENDIX B: RESEARCH FACILITIES

B.1 UW–CIMSS

The Space Science and Engineering Center (SSEC) is housed in a 15 story building on the University of Wisconsin–Madison campus. The facilities at SSEC include: a) interactive shared computing systems designed primarily for the analysis and display of weather and climate data [e.g. the McIDAS, and Vis5D and VisAD], b) a Center-wide network of UNIX (RISC, SGI and Sun) and IBM PC workstations, including a subset of systems focused on the calibration, retrieval and display of high spectral resolution data sets (e.g. Scanning HIS, NAST-I, AERI), c) fully equipped electronic design, fabrication, and maintenance facilities, and d) a mechanical workshop suitable for the design and manufacture of high quality products compatible with space qualification standards. Numerous UNIX-based workstations, as well as an evolving "Linux PC Cluster," linked to the McIDAS facility, provide a powerful computational capability for running atmospheric models, data assimilation algorithms, and atmospheric data retrievals.

Currently, this cluster computer is comprised of 18 processors; plans into 2002 are for an increase to near 256 processors, with the installation of a 64-bit architecture Symmetric Multi-Processor (SMP) computer workstation. This 64-bit SMP system will enable UW CIMSS Scientist to solve massive problems in atmospheric modeling (e.g., very high-resolution simulations).

Within SSEC, CIMSS was established in 1980 to formalize and support cooperative research between the National Oceanic and Atmospheric Administration's (NOAA) National Environmental Satellite, Data, and Information Service (NESDIS), and SSEC at the University of Wisconsin–Madison. Sponsorship and membership of CIMSS was expanded to include the National Aeronautics and Space Administration (NASA) in 1988. As of November 2001, CIMSS employs approximately 80 fulltime scientists and about 20 graduate and undergraduate students.

CIMSS and SSEC offer a unique combination of resources available to investigators, especially for the processing of a wide variety of remotely-sensed satellite data, and is also ideally-suited for the efficient analysis of the suite of GOES, MODIS and hyperspectral GIFTS data to be used in the proposed work. CIMSS scientists support the MODIS direct data broadcast from antenna location on the roof of the SSEC building, while SSEC support the GOES Data Center and GOES Data Archive. In addition, the infrastructure to optimally process and use the large satellite data sets from GIFTS will be constructed within SSEC and CIMSS over the next three years. CIMSS is currently designing the software and computer facilities needed to ingest and processes GIFTS data for meteorological purposes.

A complete regional scale analysis and prediction system is available at CIMSS that has evolved around the incorporation of satellite-derived products to ultimately improve numerical weather prediction. In particular, the CIMSS Regional Analysis System (CRAS), RUC2 (and 3DVAR system), NCEP Eta (the Eta Data Assimilation System, EDAS), the Weather Research and Forecasting (WRF) model, the NCAR/Penn State MM5, and the UW-Nonhydrostatic Modeling System (UW-NMS) model, are available and run in-house at CIMSS. These systems, and the expertise (in CIMSS and UW AOS) to operate them, are available to the data processing and verification components of this project. Information in the form of global forecast and analysis products [from the NCEP Medium Range Forecast (MRF) model, the NCEP Aviation (AVN) model, and European Centre for Medium range Weather Forecasting (ECMWF) analysis systems] are also readily available.

Finally, the SSEC staff consists of scientists, engineers, computer programmers, and support staff who provide the highest level of expertise and professionalism. The NESDIS Advanced Satellite Products Team (ASPT) resides within CIMSS. Their collaboration is available to this project. Access to the NCEP, the National Severe Storm Laboratory (NSSL), and NCAR are available via both computer links and in-house personnel. In addition, members of the faculty and staff of the UW Department of Atmospheric and Oceanic Sciences are available for consultation on this project, as detailed above.

B.2 NCAR

The National Center for Atmospheric Research (NCAR) is a federally funded research and development center under the primary sponsorship of the National Science Foundation (NSF). NCAR's mission is to conduct research into the atmospheric and related sciences, provide state-of-the-art tools and facilities to the atmospheric research community, and facilitate the transfer of technology and information to the public and private sectors. Over 800 people are employed at NCAR's two main campuses in Boulder, Colorado. NCAR is operated by the University Corporation for Atmospheric Research (UCAR), a nonprofit corporation formed in 1959 by research institutions with doctoral programs in the atmospheric and related sciences. UCAR was formed to enhance the computing and observational capabilities of the universities, and to focus on scientific problems that are beyond the scale of a single university.

Since its beginnings, NCAR has been the primary NSF-funded supercomputer center for the atmospheric sciences. Through its Scientific Computing Division (SCD), NCAR supports climate modelers and atmospheric scientists with a state-of-the-art, high-performance computing infrastructure. NCAR scientists, in collaboration with university researchers, have developed and a variety of research models, including the NCAR/Penn State MM5 mesoscale model, the Clark-Hall high-resolution model, and the Community Climate System Model (CCSM). In addition to its supercomputer center, NCAR makes extensive use of multiple clusters of high-performance workstations linked by high-speed ethernet networks. NCAR was one of the original nodes on the NSF internet backbone and is participating in the new Internet2 advanced internet development program, allowing for high speed data distribution and remote computing.

Through its Atmospheric Technology Division (ATD), NCAR supports the research community with advanced observational capabilities. NCAR develops and deploys a variety of remote and in-situ atmospheric instruments and platforms. NCAR radars, lidars, aircraft, surface stations, and sounding systems have been used in field programs designed to improve aviation safety and the efficiency of terminal area operations for the past 25 years. NCAR engineers and scientists have developed state-of-the-art radar antennas and signal processing technology for dual wavelength systems, polarimetric radars for improved accuracy in precipitation estimation, distributed real time digital signal processing for Doppler radar and lidar systems, and scanning and fixed phased array antennas for ground-based and airborne remote sensing.

NCAR's Research Applications Program (RAP) has the mission of facilitating the transfer of technology developed in the atmospheric sciences to the public and private sectors. Through a program of directed research aimed at solving practical problems, RAP contributes to the depth of fundamental understanding in atmospheric science and develops new sources of support for such research. Subsequently, through a program of technology transfer, RAP expands the reach of atmospheric science into weather-sensitive human endeavors that are not currently making practical use of weather information or are using such information in naïve or inefficient ways. Through RAP, NCAR is a lead organization in the FAA's Aviation Weather Research Program (AWRP) and plays a leading role in many of the ten AWRP Product Development Teams.

The Research Applications Program began as a small effort within the Atmospheric Technology Division to investigate, and later detect, the intense, small-scale downdrafts known as microbursts. The program became a separate NCAR division in 1989 and has expanded dramatically, both in scientific focus and size, since then. RAP currently has a staff of 120, with 48 scientists, 45 software engineers, 16 managers/administrative staff, and 11 student assistants. RAP is unique within NCAR for its emphases on directed research and technology transfer, its near-total reliance on non-NSF funding, and its matrix organization that blends scientific and engineering expertise to accomplish programmatic objectives. The division's research and development emphases are: in-flight icing; snowfall and freezing precipitation; convective weather forecasting; ceiling and visibility; atmospheric turbulence; numerical weather prediction; land-surface modeling; remote sensing of precipitation; precipitation physics; hybrid automated forecast systems; and algorithm development/enhancement. Since 1996, RAP has developed considerable experience in the operational use of high-resolution modeling and real-time four-dimensional data assimilation (RT-FDDA). RAP scientists, dating back to the division's origins within the Atmospheric Technology Division, have extensive experience in designing and conducting field experiments and real world operational tests of new technology.

For the past 20 years NCAR has worked to develop state-of-the-art tools, products, displays, and systems to improve aviation safety, efficiency and capacity. Working with industry and other government and university laboratories, they developed a method to provide pilots timely warnings of the presence of low-altitude wind shear utilizing surface anemometers and Doppler radar. With this work and associated training aids, the number of aircraft accidents attributed to windshear dropped dramatically in the mid-1980s.

Through continued support from the FAA's Aviation Weather Research Program (AWRP), NCAR has developed advanced, user-friendly aviation weather products to improve aviation safety and efficiency. Aviation products developed at NCAR include microburst detection and prediction; local, regional and national icing detection; quantitative detection and forecasts of snowfall and freezing drizzle affecting aircraft operations on the ground at airports; short-term forecasting of thunderstorm formation and movement; regional and national turbulence detection and forecasting; and ceiling and visibility forecasting. The work generally involves the integration of automated hazard-detection techniques (particularly involving remote sensing methods), automated nowcasting techniques, mesoscale modeling (including variational data assimilation schemes), and the rapid prototyping and development of systems (including innovative display techniques). This NCAR work emphasizes strong interactions with the weather product end-users throughout the whole process, starting with needs assessment and continuing through product demonstration and scientific and operational evaluation of capability.

NCAR/RAP maintains an Aviation Weather Development Laboratory (AWDL) which concentrates many of the real-time data feeds and prototype analysis and display systems in a single computer center and operations room. The AWDL has also been used as a control center for local field experiments and observational system tests. Within the AWDL, NCAR maintains direct downlink receivers for both the GOES-EAST and GOES-WEST geostationary meteorological satellites.

APPENDIX C: ACRONYM LIST

ABI	Advanced Baseline Imager
ABS	Advanced Baseline Sounder
ADDS	Aviation Digital Data Service
ADEOS	Advanced Earth Observing Satellite
AERI	Atmospheric Emitted Radiance Interferometer
AF&QA	Aviation Forecast and Quality Assessment
AIREP	Aircraft Report
AIRS	Aeronautic Information Retrieval System
AMSU	Advanced Microwave Sounding Unit
ANC	AutoNowCaster
AOT	Aerosol Optical Thickness
ARM SGP CART	Atmospheric Radiation Measurement Southern Great Plains Cloud and Radiation Testbed
ASAP	Advanced Satellite Aviation-Weather Products
ASPT	Advanced Satellite Products Team
ATD	Atmospheric Technology Division
ATOVS	Advanced TIROS Operational Vertical Sounder
AVHRR	Advanced Very High Resolution Radiometer
AVN	Aviation Model
AWC	Aviation Weather Center
AWDL	Aviation Weather Development Laboratory
AWRP	Aviation Weather Research Program
AWTT	Aviation Weather Technology Transfers
BT	Brightness Temperature
C&V	Ceiling and Visibility
CAPE	Convective Available Potential Energy
CAT	Clear Air Turbulence
CBL	Convective Boundary Layer
CCSM	Community Climate System Model
CI	Convective Initiation
CIMSS	Cooperative Institute for Meteorological Satellite Studies
CIN	Convective Inhibition
CIP	Current Icing Potential
CIT	Convective Initiated Turbulence
CIWS	Corridor Integrated Weather Systems
CONUS	Continental United States
CRAS	CIMSS Regional Analysis System
CrIS	Crosstrack Infrared Sounder
CRYSTAL-FACE	Cirrus Regional Study of Tropical Anvils and Cirrus Layers Florida Area Cirrus Experiment.
DOE	Department of Energy
DPI	Derived Product Imagery
ECMWF	European Centre for Medium range Weather Forecasting
EDAS	Eta Data Assimilation System
EOS	Earth Observing System
ESE	Earth Science Enterprise
EUMETSAT	European Organization for the Exploitation of Meteorological Satellites
FAA	Federal Aviation Administration
FANS	Future Air Navigation System
FIP	Forecast Icing Potential
FNMOC	Fleet Numerical Meteorology and Oceanography Center
FPDT	Forecast Products Development Team
FSL	Forecast Systems Laboratory
FTP	File Transfer Protocol
FTS	Fourier Transform Spectrometer
GDAS	Global Data Assimilation System
GEO	Geostationary Earth Orbiting

GIFTS	Geosynchronous Imaging Fourier Transform Spectroradiometer
GIFTS-IOMI	GIFTS-Indian Ocean METOC Imager
GMS	Geostationary Meteorological Satellites
GOES	Geostationary Operational Environmental Satellite
GSAS	GOES Satellite Archive System
GVAR	GOES Variable Format
HES	Hyperspectral Environmental Sounder
HIRS	High Resolution Infrared Radiometer Sounder
HIS	High-resolution Interferometer Sounder
ICAO	International Civil Aviation Organization
IHOP_2002	International H2O Project 2002
IMG	Interferometer Monitor for Greenhouse Gasses
IPO	Integrated Program Office
IRW	Infrared Window
ITWS	Integrated Terminal Weather System
ITFA	Integrated Turbulence Forecast Algorithm
JCSDA	Joint Center for Satellite Data Assimilation
KLM	NOAA-K-NOAA-M polar Orbiter Satellites
LEO	Low Earth Orbiting
LFPA	Large area format Focal Plane detector Array
LI	Lifted Index
MACADA	Merged Automated Cloud/Aerosol Detection Algorithm
McIDAS	Man Computer Interactive Data Access System
MD&E	Model Development and Enhancement
MIT	Massachusetts Institute of Technology
MIT-LL	MIT Lincoln Laboratories
METEOSAT	European Meteorological Satellites
MODIS	Moderate Resolution Imaging Spectroradiometer
MRF	Medium Range Forecast
MSG	Meteosat Second Generation
MTSAT	Multi-functional Transport Satellite
MURI	Multidisciplinary University Research Initiative
NAAPS	Navy Aerosol Analysis and Prediction System
NASA	National Aeronautic and Space Administration
NASDA	National Space Development Agency of Japan
NAST-I	NPOESS Aircraft Sounder Testbed-Interferometer
NCAR	National Center for Atmospheric Research
NCDC	National Climate Data Center
NCEP	National Centers for Environmental Prediction
NCWF	National Convective Weather Forecast
NESDIS	National Environmental Satellite, Data, and Information Service
NEXRAD	Next Generation Weather Radar System
NIR	Near Infrared
NMP	New Millennium Project
NOAA	National Oceanic and Atmospheric Administration
NPOESS	Next generation Polar Orbiting Satellites
NRL	Naval Research Lab
NSF	National Science Foundation
NSSL	National Severe Storms Laboratory
NWP	Numerical Weather Prediction
NWS	National Weather Service
ONR	Office of Naval Research
ORA	Office of Research and Applications
OCWF	Oceanic Convective Weather Forecast
PDT	Product Development Team
PIREP	Pilot Report
POES	Polar Orbiting Environmental Satellites
PW	Precipitable Water
QC	Quality Control
QI	Quality Indicator
RAP	Research Applications Program
RCWF	Regional Convective Weather Forecast

RF	Recursive Filter
RMS	Root Mean Square
RT-FDDA	Real Time Four Dimensional Data Assimilation
RTVS	Real Time Verification System
RUC	Rapid Update Cycle Model
SCD	Scientific Computing Division
SCIT	Storm Cell Identification and Tracking algorithm
SDI	SSEC Desktop Images
SLD	Supercooled Large Drop
SMP	Symmetric Multi-Processor
SNDR	Sounder
SOCC	Satellite Operational Controls Center
SSEC	Space Science and Engineering Center
TCWF	Terminal Convective Weather Forecast
TDWR	Terminal Doppler Weather Radar
THOR	Thunderstorm Operational Research
TIROS	Television Infrared Observation Satellite
THORpex	The Observing System Research and Predictability Experiment
TRMM	Tropical Rainfall Measuring Mission
UCAR	University Corporation for Atmospheric Research
UW	University of Wisconsin-Madison
UW-NMS	UW-Nonhydrostatic Modeling System
VAAC	Volcanic Ash Advisory Centers
VAS	VISSR Atmospheric Sounder
VIIRS	Visible/Infrared Imager/Radiometer Suite
VIS	Visible
VISSR	Visible and Infrared Spin-Scan Radiometer
WF_ABBA	Wildfire Automated Biomass Burning Algorithm
WRF	Weather Research and Forecast Model
WSDDM	Weather Support De-icing Decision Making
WV	Water Vapor

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