Alliance Icing Research Study II
(AIRS II)

Science Plan Appendix E
NASA Langley Research Center Addendum

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Executive Summary of the NASA LaRC Addendum for AIRS II

NASA Langley Research Center is conducting research in three areas that are highly complimentary to the Second Alliance Icing Research Study (AIRS II). Langley participation was incorporated into this year's AIRS II campaign during the late summer of 2003. The NASA Langley effort will involve measurements taken from mid levels (FL250-410) using the University of North Dakota Cessna Citation II aircraft and high levels (FL650-720) using the NASA Dryden Flight Research Center ER-2 aircraft. These measurements are being closely coordinated with previously scheduled AIRS II operations. The maneuvers and procedures pursuant to these measurements have been incorporated into the AIRS II ATC planning documents and the AIRS II Operations Plan. The purpose of this Addendum is to describe the NASA Langley participants, to outline the objectives of their affiliated NASA programs and/or projects, and to formally ascribe to the data protocols as outlined in the AIRS II Science Plan.

1. Introduction

The NASA Langley Research Center is participating in AIRS II to support data collection requirements related to the research activities of the NASA Aviation Safety Program (AvSP) and the NASA/NOAA/DOD Integrated Program Office (IPO). The Aviation Safety Program was created in 1997. Its charter is to develop and demonstrate technologies that contribute to a reduction in the aviation fatal accident rate by a factor of 5 by year 2007. The program is a partnership that includes NASA, the Federal Aviation Administration (FAA), the aviation industry and the Department of Defense. The NPOESS IPO was established on 3 October 1994 to develop, acquire, manage, and operate the next generation of polar-orbiting operational environmental satellites. The IPO organizationally resides within the Department of Commerce, NOAA National Environmental Satellite, Data and Information Service (NESDIS) and is staffed with personnel from the Department of Defense, Department of Commerce, and the National Aeronautics and Space Administration (NASA).

In addition to directly supporting in-flight icing research activities at the NASA Glenn Research Center that comprise elements of the original research of the AIRS II campaign, the AvSP directs the research of a separate Weather Accident Prevention Project (WxAP) at NASA GRC. The WxAP manages several broad-based weather research initiatives having focused in-flight icing research components. These activities include an Advanced Satellite Aviation-weather Product (ASAP) development element and a Tropospheric Airborne Meteorological Data and Reporting (TAMDAR) instrument development element. ASAP is a partnership with the FAA Aviation Weather Research Program (AWRP) to infuse current and next-generation satellite data and applications into FAA AWRP nowcasting products for aviation weather hazards including in-flight icing, convective weather, ceiling & visibility, turbulence and volcanic ash. The TAMDAR instrument was developed by NASA for commercial and private general aviation (GA) to extensively augment the MDCRS and AMDAR data stream in the lower troposphere and to increase ambient weather situational awareness in the cockpit of GA aircraft.

To develop the next generation of atmospheric sounders that will fly on operational polar orbiting weather satellites, the IPO supports the research activities of the NPOESS Atmospheric Sounder Testbed (both infrared and microwave) conducted by Dr. William L. Smith at NASA Langley Research Center. This research is also used to support the development of GIFTS (the Geosynchronous Imaging Fourier Transform Spectrometer). GIFTS is a demonstration project for the development of the next generation of GOES (Geostationary Operational Environmental Satellite) hyperspectral infrared sounders.

2. Objectives

ASAP, TAMDAR and NAST will conduct complimentary measurements during AIRS II to support their respective research, development and validation requirements.

ASAP Objectives:

A1) Test and evaluate GOES-based cloud microphysical property algorithms for their incorporation into the FAA AWRP In-Flight Icing Product Development Team's Current Icing Product (CIP) and Forecast Icing Product (FIP);

A2) To collect atmospheric state variables used in the development, simulation and validation activities for ASAP satellite algorithms being developed or evaluated as potential discriminators in other FAA AWRP expert systems, I.e., nowcasting and forecasting products; and

A3) To collect atmospheric state variables to be used to support the FAA/NOAA/NASA/DOD Joint Planning Office requirement to develop a high spatial and temporal resolution Aviation Weather Digital Database; and

A4) To provide continuous, web-based, real-time, satellite cloud microphysics experimental products to assist the AIRS II science team in daily operational planning.

TAMDAR Objectives:

T1) Collect ambient and remotely sensed aircraft measurements of temperature, humidity, wind velocity, icing and turbulence to validate the ambient measurements of the TAMDAR sensor.

NAST Objectives:

N1) Collect ambient and remotely sensed aircraft measurements to develop the measurement concept for future NPOESS and GOES sounders; and

N2) To collect ambient and remotely sensed aircraft data during Terra and AQUA satellite over-flights to validate and advance the utility of the Moderate Resolution Imaging Spectroradiometer (MODIS) and the Atmospheric Infrared Sounder (AIRS) instruments.

3. Aircraft and instrumentation.

A. NASA ER-2

The ER-2 is a civilian version of the Air Force's U2-S reconnaissance platform. These high-altitude aircraft are used as platforms for many investigations that cannot be accomplished by sensor platforms of the private sector. Aircraft and spacecraft have proven to be excellent platforms for remote and *in situ* sensing. The ER-2, flying at the edge of space, can profile the atmosphere very much the same way as a satellite.

The Lockheed ER-2 was developed for the National Aeronautics and Space Administration (NASA), to serve as a high altitude scientific research aircraft. The ER-2 designation was first applied to NASA's version of the U-2C model. NASA has since acquired and used the U2-R or TR-1 model, but has retained the ER-2 descriptor. The ER-2 differs from the U.S. Air Force's U-2 in the lack of defensive systems, absence of classified electronics, completely different electrical wiring to support NASA sensors, and, of course, a different paint scheme.

The ER-2 is an extremely versatile aircraft well suited to multiple mission tasks. The ER-2 is thirty percent larger than the original U-2 with a twenty-foot longer wingspan and a considerably increased payload over the older airframe. The aircraft has four large pressurized experiment compartments and a high capacity AC/DC electrical system, permitting a variety of payloads to be carried on a single mission. The modular design of the aircraft permits rapid installation or removal of payloads to meet changing mission requirements. The ER-2 has a range beyond 3,000 miles (4800 km); is capable of long flight duration and can operate at altitudes above 70,000 feet (21.3 km) if required. A summary of the aircrafts operating characteristics follows in table 1.1.

Crew:	One Pilot
Length:	62 feet, 1 inch
Wingspan:	103 feet, 4 inches
Engine:	One Pratt & Whitney J75-P-13B
Altitude:	70,000 feet
Range:	2200 nautical miles, 3000 on exception
Duration:	6.5 hours, 8 hours on exception
Cruise Speed:	~400 knots above 65,000 feet altitude ~210 meters/sec

Table 1. ER-2 Characteristics

During THORPEX, the ER-2 payload will consist of the MODIS Airborne Simulator (MAS), the Scanning High-resolution Interferometer Sounder (S-HIS), the NPOESS Atmospheric Sounder Testbed – Interferometer (NAST-I) and – Microwave Temperature Sounder (NAST-MTS), the Cloud Physics LIDAR (CPL) and a fast in situ ozone probe.

The NASA ER-2 Mission Manager is Michael Kapitzke of the NASA Dryden Flight Research Center (mike.s.kapitzke@nasa.gov, (661) 276-2575.

A.1 MODIS Airborne Simulator

The MODIS Airborne Simulator (MAS) is a 50 channel (VNIR – TIR) airborne scanning spectrometer that acquires high spatial resolution imagery of cloud and surface features from its vantage point on-board a NASA ER-2 high-altitude research aircraft. MAS collects 50 m (nadir) spatial resolution data across a 37 km swath (+/- 43° view angle) from the nominal ER-2 20 km altitude. MAS uses dichroics and four gratings to separate upwelling earth scene radiance into VNIR (9 channels: 0.47 – 0.96 μm), SWIR (16 channels: 1.6 – 2.4 μm), MWIR (16 channels: 3.1 – 5.3 μm) and LWIR (9 channels: 8.5 – 14.2 μm) spectral regions.

MAS reflectance channels (VNIR, SWIR) are calibrated using laboratory measurements collected from a calibrated integrating sphere at NASA Ames Research Center (ARC) both before and after aircraft deployments. These measurements are supplemented by ground-based measurements collected during pre-flight of each ER-2 mission. Thermal IR channels (MWIR, LWIR) are calibrated using two flat plate onboard blackbody sources, one of which is typically heated to about 20°C, the other being allowed to settle to ambient conditions at altitude in the scan cavity of the MAS scan assembly. Blackbody emissivity is characterized periodically in a laboratory setting to maintain performance. The onboard blackbodies are viewed on each scan line; an additional view upward into the MAS scan head is used to characterize background radiance in the scan cavity for use in the L1B calibration algorithm. MAS TIR band radiometric calibration accuracy is about 0.5 to 1.0°C depending on channel (best in window bands); however, MAS accuracy can be improved to within 0.5°C through comparisons to co-incident S-HIS and NAST-I observations. MAS reflectance channel calibration accuracy is conservatively estimated to be within 10%.

MAS is spectrally calibrated before deployments at the NASA ARC facility using both monochromator-based and FTIR-based measurements. The four gratings are each aligned to specific spectral positions. These measurements are repeated at ARC after the ER-2 deployment to confirm that the spectral characterization has not changed during the deployment.

Data acquired by the MAS have been a key element in defining, developing, and testing science product algorithms for the Moderate Resolution Imaging Spectroradiometer (MODIS), a key sensor of NASA's Earth Observing System (EOS). MAS continues to function as a validation tool in complement with the S-HIS, NAST-I, and CPL instruments for MODIS and AIRS L1B and L2 science products. The MODIS and AIRS programs emphasize the use of remotely sensed data to monitor variation in environmental conditions for assessing both natural and human-induced global change.

MAS is managed by Jeff Myers of NASA Ames Research Center (jmyers@mail.arc.nasa.gov, (650) 604-6252).

A.2 Scanning High-resolution Interferometer Sounder

The Scanning High-resolution Interferometer Sounder (S-HIS) is a scanning interferometer which measures emitted thermal radiation at high (0.5 cm^{-1}) spectral resolution between 3.3 and 18 microns (specifications). The measured emitted radiance is used to obtain temperature and water vapor profiles of the Earth's atmosphere. S-HIS produces sounding data with 2 kilometer resolution (at nadir) across a 30 kilometer ground swath (+/- 35° view angle) from a nominal altitude of 20 kilometers onboard a NASA ER-2 aircraft or 15 kilometer ground swath from a nominal altitude of 10 kilometers aboard the NASA DC-8 aircraft.

The S-HIS radiometric accuracy is a key component of its usage in validating science products from MODIS and AIRS. S-HIS is calibrated in flight using two onboard high emissivity (.996, known to within .001) cavities with temperature knowledge to better than 0.1 K. The S-HIS in-flight reference cavities have been characterized using National Institute of Standards and Technology (NIST) traceable standards. The S-HIS scene mirror surface is gold coated to minimize reflectance variation and polarization as a function of scan angle. The performance of S-HIS has been routinely tested in the laboratory environment to ensure ongoing high accuracy radiances during in-flight data collection. These tests include component characterization as well as system testing such as data collection over ice baths, and side-by-side comparisons with other interferometers. A typical radiometric uncertainty of the S-HIS observations using the estimated uncertainty of S-HIS cavity performance (i.e. 0.1 K for cavity temperature, 0.001 for cavity emissivity) during in-flight data collection conditions is less than 0.2 K for atmospheric window regions and less than 0.3 K for atmospheric absorption regions (some exceptions for saturation on strong absorption lines).

The Scanning HIS Instrument PI and manager is Hank Revercomb of the University of Wisconsin (hankr@ssec.wisc.edu, 608-263-6758).

A.3 NPOESS Atmospheric Sounder Testbed

The National Polar-orbiting Operational Environmental Satellite System (NPOESS) Aircraft Sounder Testbed – Interferometer (NAST-I) is a high resolution Michelson interferometer, developed at MIT Lincoln Laboratory that derives its heritage from the non-scanning High resolution Interferometer Sounder (HIS) developed by researchers at the University of Wisconsin. The NAST-I instrument scans the earth from beneath the ER-2 with a nominal spatial resolution of approximately 2.5 km with a total of 13 earth views in the cross-track direction (the resultant swath width covers about 45 km). The unapodized spectral resolution of NAST-I is 0.25 1/cm within a 590-2810 1/cm (3.6-17 micron) spectral range. The instrument flies in the right superpod of NASA's high altitude ER-2 research aircraft. The infrared radiance measurements obtained from the NAST-I instrument will provide detailed spectral characteristics of the atmosphere and land surface along with providing detailed atmospheric temperature and water vapor profiles derived from either physical or regression based retrieval algorithms.

The National Polar-orbiting Operational Environmental Satellite System (NPOESS) Aircraft Sounder Testbed- Microwave Temperature Sounder (NAST-MTS) is an aircraft-mounted Microwave Temperature Sounder. The instrument, built by Massachusetts Institute of Technology's Research Laboratory of Electronics (RLE), is about the size of a footlocker, and is mounted inside the forward section of one of the wing-mounted superpods of the NASA ER-2 aircraft. NAST-MTS is a scanning radiometer that sweeps from side to side viewing a path that is sixty-five degrees either side of nadir. MTS covers 16 microwave frequencies in the vicinity of 54 gigahertz and 118 gigahertz in each of its scans. This results in an image that is approximately 80 kilometers wide measured from the aircraft altitude (~20km). The radiometer 'sees' in the microwave portion of the electromagnetic spectrum. Images produced by the instrument represent the thermal radiation emitted by the environment at these microwave frequencies. Each microwave frequency responds differently to temperatures at different altitudes as well as to the different constituents such as water vapor, precipitation and ice. By combining the information gathered from MTS with information derived from the sensors in both the visible and infrared regions of the spectrum, the structure and composition of the atmosphere in the field of view as well as surface characteristics may be determined. Since microwave frequencies penetrate clouds much more readily than do infrared or visible, internal structure becomes apparent.

The NAST Instrument PI is Bill Smith of the NASA Langley Research Center (william.l.smith@larc.nasa.gov, (757) 897-9597. The NAST Manager is Allen Royal (A.C.Royal@larc.nasa.gov, (757) 864-7927).

A.4 Cloud Physics LIDAR

The Cloud Physics LIDAR is an airborne LIDAR system designed specifically for studying clouds and aerosols using the NASA ER-2 aircraft. Because the ER-2 typically flies at 65,000 feet (20 km), its instruments are above 94% of the earth's atmosphere, thereby allowing ER-2 instruments to function as spaceborne instrument simulators. The Cloud Physics LIDAR provides a unique tool for atmospheric profiling and is sufficiently small and low cost to include in multiple instrument missions.

The Cloud Physics LIDAR provides a complete battery of cloud physics information. Data products include:

Cloud profiling with 30 m vertical and 200 m horizontal resolution at 1064 nm, 532 nm, and 355 nm, providing cloud location and internal backscatter structure.

Aerosol, boundary layer, and smoke plume profiling at all three wavelengths.

Depolarization ratio to determine the phase (e.g., ice or water) of clouds using the 1064 nm output.

Cloud particle size determined from a multiple field-of-view measurement using the 532 nm output (off-nadir multiple scattering detection).

Direct determination of the optical depth of cirrus clouds (up to ~OD 3) using the 355 nm output.

The CPL provides information to permit a comprehensive analysis of radiative and optical properties of optically thin clouds. To determine the effects of particulate layers on the radiative budget of the earth-atmosphere system certain information about the details of the layer and its constituents is required.

The Cloud Physics LIDAR Instrument PI is Matthew McGill of the NASA Goddard Space Flight Center (Matthew.J.McGill@nasa.gov, (301) 614-6281).

A.5 Langley In Situ Fast-Response Ozone Measurements

The In Situ Fast-Response Ozone sensor is capable of fast, sensitive ozone measurements over a large dynamic range and a wide variety of atmospheric conditions. The measurements are performed by combining pure reagent nitric oxide (NO) with incoming sample air in a small volume reaction chamber, and by measuring the resulting chemiluminescence. This chemiluminescence is light emitted in the near-infrared spectral region by relaxation of nitrogen dioxide (NO2) that has been excited by the chemical reaction of NO and ozone (O_3) in the sample. The chemical equations for this set of reactions are:

$$NO + O_3 \text{ ® } O_2 + NO_2^*$$
$$NO_2^* \text{ ® } NO_2 + hn$$

This technique is very well established [Pearson and Stedman, 1980, Gregory et al., 1987, Eastman and Stedman, 1997] and is a reverse application of a standard nitric oxide (NO) detection technique [Clough and Thrush, 1967]. The near-infrared light emitted by relaxation of the excited NO_2 (chemiluminescense) is measured with a sensitive photocathode and photomultiplier tube (PMT). The amplified signal from the PMT is proportional to the amount of O_3 in the sampled air.

The reaction chamber is maintained at constant temperature and pressure (17 Torr) and sampled air enters the aircraft through a forward-facing, J-shaped probe. Sample flow from the prechamber into the reaction chamber is 500 cm^3/minute. We maintain a laboratory reference O_3 photometer that is regularly taken to NIST for intercomparison with their standard O_3 photometer. The residual between the NIST-referenced linear regression and our O_3 measurements in the laboratory is 1 ppbv or less over the range of our measurements.

Technique	Chemiluminescent Reaction of Ozone with Nitric Oxide
Dynamic Range	0.5 – 3500 ppbv
Accuracy	5 percent or 5 ppbv
Precision	3 percent pr 2.5 ppbv
Response Time	2-3 Hz
Data Rate	1 Hz
Spatial Resolution	~200 m horizontal (vertical – depends on ascent rate)
Weight	260 lbs
Power Required	Less than 10 A 110V/60 Hz

Table 2. Ozone Instrument Specifications

The In Situ Fast Ozone Detector Instrument PI is Melody Avery of the NASA Langley Research Center (m.a.avery@larc.nasa.gov, (757) 864-5522).

B. University of North Dakota Citation II

The University of North Dakota owns and operates a Cessna Citation II aircraft (N77ND) for the purpose of atmospheric research. This aircraft type has a number of design and performance characteristics that make it an ideal platform for a wide range of atmospheric studies. The Citation II is a twin-engine fanjet with an operating ceiling of 43,000 feet (13.1 km). The turbofan engines provide sufficient power to cruise at speed of up to 340 knots (175 m/s) or climb at 3300 feet per minute (16.8 m/s). These high performance capabilities are accompanied by a relatively low fuel consumption at all altitudes, giving an on-station time of up to 4 hours or more, depending on mission type. Long wings allow it to be operated out of relatively short airstrips and to be flown at the slower speeds necessary for many types of measurements. The Citation is certified for flight into known icing conditions.

The cabin measures approximately five feet in diameter and more than 16 feet in length. The minimum flight crew is pilot, co-pilot, and data system operator. Two additional seats are available for scientific observers.

A series of structural modifications have been made to the basic airplane. These include the following: pylons under the wing tips for a variety of probes in the undisturbed air flow away from the fuselage; a heated, 5-port radome for wind measurement; and an air inlet port and manifold for air sampling inside the pressurized cabin.

B.1 Instrumentation: The research instrumentation available on the Citation is listed in the Summary of Measurement Capabilities. Typically, the equipment carried on any given research project will be a subset of this list. The installation of instruments provided by other investigators can be accommodated, subject to space, weight and electrical requirements. A variety of 19-inch racks are available to accommodate standard instruments.

Click here for a chart of Citation II's Instrumentation Specifications.

The basic instrumentation package measures temperature, dew point temperature, pressure, wind and cloud microphysical characteristics along with aircraft position, attitude and performance parameters. The three-dimensional wind field is derived from measurements of acceleration, pitch, roll and yaw combined with angles of attack and sideslip and indicated airspeed. The aircraft parameters are supplied by an Applanix POS-AV strap-down gyro system with integrated global positioning system (GPS). Strap-down accelerometers provide lateral and longitudinal aircraft accelerations. Turbulence intensity can be derived from differential pressure transducers and accelerometer outputs. Cloud microphysical measurements are made with an array of Particle Measuring Systems probes (FSSP, 1D-C, 2D-C) mounted on the wing-tip pylons. These probes measure both liquid water content and icing rate.

The NCAR AVAPS GPS dropsonde system is also installed on the UND Citation II for real-time temperature, water vapor and wind profiling which will be provided directly to the GTS via satellite data link. AVAPS (Airborne Vertical Atmospheric Profiling System) debuted in 1997. It has flown on numerous missions in support of operational weather forecasting and atmospheric research. AVAPS uses dropwindsonde and Global Positioning System (GPS) receivers to measure the atmospheric state parameters during the its descent. Dropwindsondes measure vertical profiles of pressure, temperature, humidity, and wind during their descent through the atmosphere.

A number of gas and aerosol sampling instruments are also installed. These include fast response O3, CO2/H2O and NO/NO2 monitors, and monitors for SO2, CO and SF6. Aerosol sampling equipment includes PMS passive cavity scattering and Royco light scattering probes, a condensation nuclei counter and a MEE-type cloud condensation nuclei counter.

A forward or side-looking video camera is used to provide a visual record of flight conditions. A Bendix-King vertical profiling forward-looking weather radar can be viewed in the cockpit and recorded on videotape.

Data onboard the Citation II are sampled at various rates from 4 to 100 Hz. The sampling is controlled by the onboard computer system that also displays the data in real time in graphic and alphanumeric formats while recording them on magnetic tape. The data can also be telemetered to a ground station and displayed in real time, or data may be telemetered from the ground to the aircraft. The data system is based on a project-customized windows system to allow flexibility in data acquisition and instrumentation in order to accommodate specific research demands.

4. NASA Langley Cloud Products

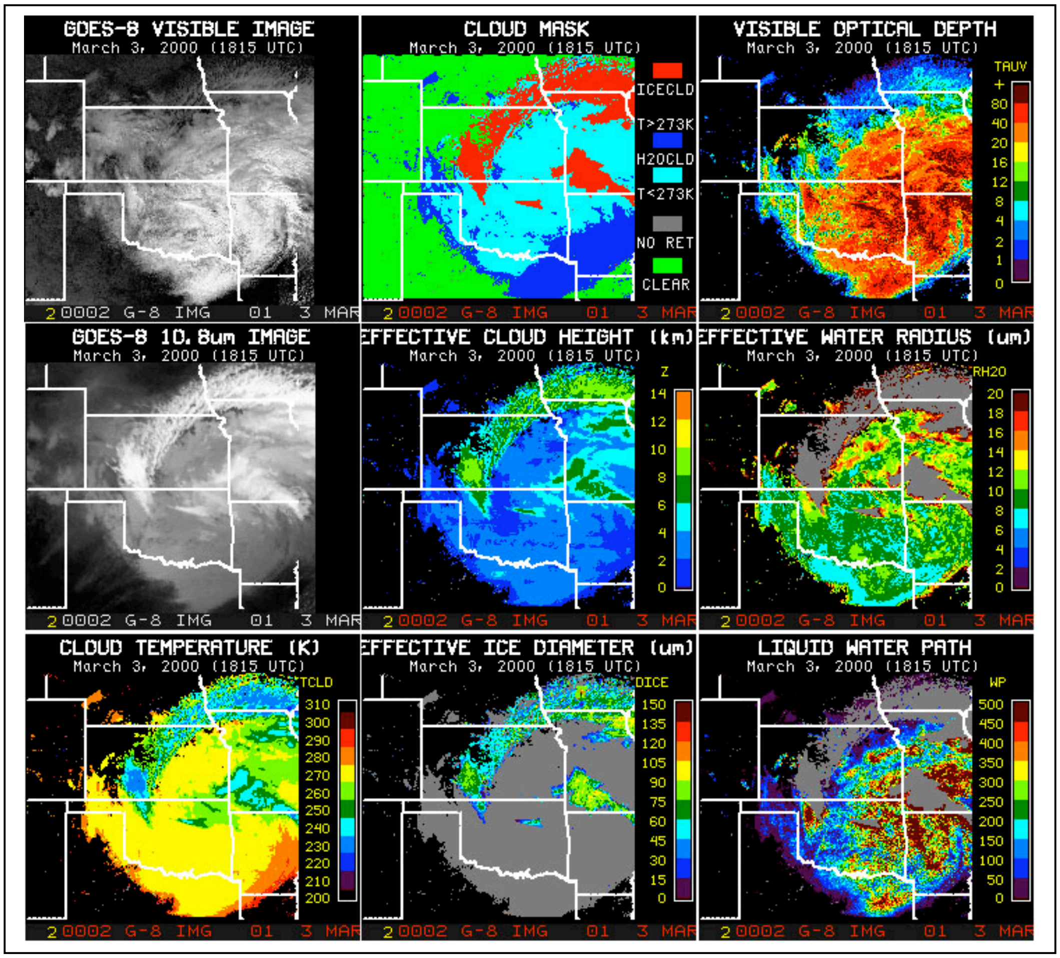

Figure 1. NASA Langley Cloud Products to be validated in AIRS II.

Details on NASA Langley cloud products being developed and evaluated during AIRS II can be found at ftp://angler.nasa.gov/public/ .

4. TAMDAR Instrument Specifications

Patented Ice Optical Sensing Technology	Microprocessor based pulse modulation, utilizing high power LED's emitting in the infrared range
Operating Limits	-70C to +65C, Altitude 50,000 feet, Humidity 0-100%
Probe Mechanical Specifications	Airfoil Type: 3.865" height, 2.521" chord, 0.752" thickness, 0.32" pitot extension, 0.188" base flange thickness. 6061 T6 anodized aluminum. Quartz optical filters. Drag: 0.5 lb at 200 knots
Electronics Module (SPU) Mechanical Specifications	W5.15" X L4.13" X H3.1" (not including connectors)
Power Requirements	12 to 35 VDC (>26VDC nominal for proper deicing), 6 Watts average electrical load de-icing heaters not engaged; 300 Watts electrical load de-icing heaters engaged @ 28VDC input.
Measurement Sampling Rate	10.7 Hz for sensors, 0.333 Hz for turbulence. Data (except that used for the turbulence calculation) is filtered with a 10 sec response IIR digital filter.
Data Output Observation Period	See "Observation and Reporting Intervals" section
Serial Ports	3 RS-232
Weight	Probe and electronics module approx. 1.5 lb
Design Life	Probe: 20,000 hours. Electronics Module: 50,000 hour MTBF
Warranty	2 years

Table 3 – TAMDAR General Specifications

Parameter	Range	Accuracy	Resolution	Latency (See Note 1)	Comments
Pressure	10 -101 kPa	3 hPa	0.05 hPa	10 sec	See Note2.
Temperature	-70 to +65°C	±1°C	0.1°C	10 sec	
Humidity	0 to 100%RH	±5% (typical) ±10% (typical)	1% (RH > 10%) 0.1% (RH < 10%)	10 sec	Below Mach 0.4 Mach 0.4 - 0.6 (RH from 2 separate sensors is reported)
Heading	0-360°	±3°	0.1°	10 sec	@ < 30° pitch & roll
Ice Detection		0.020 inch			

Table 4 - Measured Parameters; Aircraft Altitudes to 50,000 Feet

Parameter	Range	Accuracy	Resolution	Latency	Comments
Pressure Altitude	0 – 25,000 ft.	±150 feet	10 feet	10 sec	See Note 2
Pressure Altitude	25,000 – 50,000 ft.	±250 feet	10 feet	10 sec	See Note 2
Indicated Airspeed	70-270 knots	±3 knots	1 knot	10 sec	See Note 2
True Airspeed	70-450 knots	±4 knots	1 knot	10 sec	See Note 2
Turbulence (eddy dissipation rate--$\in^{1/3}$); Peak and Median	0-20 $cm^{2/3}$ sec^{-1}			3 sec	See Note 3. Reported as single encoded character (see TAMDAR Downlink Data Format).
Winds Aloft		± 4 to 6 knots vector magnitude error	1 knot, 1 deg	10 sec	See Note 4. Accuracy depends on relative magnitude and direction of vectors.

Table 5 - Derived Parameters; Aircraft Altitudes to 50,000 Feet

Notes:

1. 10-second latency is caused by digital filtering of the data as recommended in the AMDAR reference manual.
2. Accuracy specified for angles of attack less than 30° except for winds aloft whose accuracy depends on the heading sensor used.
3. Turbulence determination: calculation of eddy dissipation rate in accordance with MacReady.[1] Atmospheric Calculated from 32-point DFT of TAS (3 sec block).
4. Winds aloft calculation will require use of GPS and magnetic heading.

[1] Paul B. MacReady, Jr., "Standardization of Gustiness Values from Aircraft," Journal of Applied Meteorology, August 1964, Vol. 3, pp. 439-449.v