CROSS TRACK INFRARED SOUNDER (CrIS)

Product Validation Plan

for the

NATIONAL POLAR-ORBITING OPERATIONAL
ENVIRONMENTAL SATELLITE SYSTEM (NPOESS)

Prepared by

H. E. Revercomb[1], R. O. Knuteson[1], D. C. Tobin[1],
W. P. Menzel[2], A. M. Larar[3], W. L. Smith[3]

[1] Space Science and Engineering Center, University of Wisconsin-Madison
[2] NOAA NESDIS ORA, University of Wisconsin-Madison
[3] NASA Langley Research Center

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1 EXECUTIVE SUMMARY

The product validation for CrIS focuses on (1) operational algorithm assessment, and (2) validation of system performance. The NAST and Scanning HIS aircraft instruments are two of the primary tools for performing a product validation; another is the MODIS Airborne Simulator. The Sounder-Operational Algorithm Team is preparing the plan to conduct these activities. With the support of the IPO, the Sounder-OAT provides expertise to assure that performance options and algorithm approaches get reviewed and thoroughly tested with real atmospheric data. The Sounder-OAT will efficiently combine the government and university community experience base with the expertise of the selected vendor for algorithm development.

Aircraft data is important to the program both before and after launch. Before launch, it will provide the means to demonstrate expected EDR performance and to establish algorithm approaches that will work in the presence of actual atmospheric cloud conditions. After launch, it will form the basis for system validation. In addition other remote sensing systems and in situ systems will be incorporated into the validation activities. Early work to validate MODIS, AIRS, and IASI will establish some of the CrIS validation procedures detailed in this plan.

Part of the program can be established on the basis of shared costs. While expenses associated with maintaining and fielding aircraft instruments can be significant, the requirements for IPO are compatible with those of ongoing NASA scientific programs, NOAA Calibration and Validation of its operational observing capabilities, NASA plans for EOS validation, and DOE field programs for climate studies. Plans are already in place from these other organizations to support a substantial number of field programs that can be used to leverage IPO support. Some of the relevant planning documents (including the MODIS Validation Plan, the AIRS Validation Plan, and the NOAA Polar Products Assurance Plan (POPAP)) are available on the web. More specifically, NASA has plans to conduct missions with these instruments in 2000, including the SAFARI mission in South Africa, and a joint water vapor experiment with the DOE centered around the Atmospheric Radiation Measurement (ARM) site in Oklahoma. NOAA will be conducting calibration / validation of the operational polar orbiting infrared and microwave sounders in 2001; intercalibration of the ongoing series of POES sensors and the associated sounding products is a high priority for these efforts.

However, it is important for the IPO to plan with the SOAT the necessary data gathering and data analysis that can suggest instrument processing adjustments and algorithm evolution that will foster the maximum utilization of CrIS data. This will be an intenseive effort after CrIS launch on NPP and continue annually for some time after that.

2 INTRODUCTION

The National Polar-orbiting Operational Environmental Satellite System (NPOESS) is a joint NASA, NOAA, and DOD program merging the current POES & DMSP systems into a common system (i.e. NPOESS) of polar satellites with the goal of providing meteorological and other environmental data products operationally. In order to achieve these goals, these programs must produce accurate and precise long-time series of radiometric measurement data from multiple instruments on multiple platforms. Understanding and correctly interpreting these data require the ability to separate geophysical variability from instrument response changes in the observed signal during the missions. This requires a detailed instrument system-level characterization pre-launch, as well as extensive in-flight calibration and validation activities.

Validation is the process of assessing by independent means the uncertainties of derived geophysical data products from instrument system outputs. This is generally approached by direct comparison with independent correlative measurements from ground-based networks, comprehensive test sites, and field campaigns; along with comparisons with independent satellite retrieval products from instruments on the same and different platforms. Pre-launch activities usually focus on algorithm development and characterization of instrument uncertainties, while post-launch emphasis is on algorithm refinement and measured/retrieved data product assessments. It is essential to have an integrated strategy for validation, including contributions from airborne field campaigns, surface networks, as well as satellites.

2.1 SCOPE

2.1.1 IDENTIFICATION

This Product Validation Plan document provides a roadmap for the validation of Level I Products (calibrated/navigated radiances), Level II Primary Products (temperature and water vapor vertical profiles), and selected Level II Secondary Products (including sea and land surface temperature and selected cloud products) from the Cross-track Infrared Sounder (CrIS) which is part of the National Polar-orbiting Operational Environmental Satellite System (NPOESS) series of polar-orbiting spacecraft. The CrIS instrument forms a key component of the larger Cross-track Infrared/Microwave Sounding Suite (CrIMSS) and is intended to operate within the context of the CrIMSS architecture. For each validation area, the general validation strategy and specific implementation plans are presented. For this DRAFT version, the implementation approaches are not meant to be comprehensive. Emphasis is placed on validation of the fundamental CrIS radiance observations.

The validation of CrIS algorithms, including calibration, forward model, and retrieval, is (to be) presented in a separate document, the *CrIS Operational Algorithm Assessment Plan*.

2.1.2 SENSOR OVERVIEW

The CrIS provides cross-track measurements of scene radiance to permit the calculation of the vertical distribution of temperature and moisture in the Earth's atmosphere. It also provides supporting measurements for a variety of other geophysical parameters as listed in the Integrated Operational Requirements Document (IORD) (Paragraph 3.2.1.1). The CrIS shall consist of a Michelson interferometer infrared sounder covering the spectral range of approximately 3.5 to 16 microns. It will be operated together with a co-registered microwave cross-track sounder suite of instrument(s). Note: The current notional baseline performance level assumed for this microwave suite specification will be no less than that currently projected for the Advanced Microwave Sounder Unit-A (AMSU-A) and the Advanced Microwave Sounder Unit-B/Microwave Humidity Sounder (AMSU-B/MHS) microwave sounders, as scheduled to fly on the National Oceanic and Atmospheric Administration (NOAA) K-N' series spacecraft. One CrIS flight unit is intended to be provided to meet an early flight opportunity on the NOAA N' satellite to be available for launch in 2004. The NOAA N' microwave sounding sensor channels will be provided by the AMSU-A and MHS instruments. Three additional CrIS flight units are needed for the NPOESS C1, C3, and C5 spacecraft which will be available for launch in 2007, 2009, and 2010. The microwave sensors to be used with the CrIS as part of the larger CrIMSS sounding suite are TBS. The purpose of a possible early flight opportunity on NOAA N' is to meet user requirements in advance of the first NPOESS launch and to provide early improved IR sounder capability. These data are processed and delivered to the users in the form of Raw Data Records (RDRs), Sensor Data Records (SDRs), and Environmental Data Records (EDRs).

2.1.3 RELATION TO OTHER VALIDATION EFFORTS

The CrIS product validation plans and efforts benefit greatly from the validation efforts and infrastucture of several existing programs. These include the EOS AIRS and MODIS programs, NPOESS Atmospheric Sounder Testbed (NAST) program, the Atmospheric Radiation Measurement (ARM) Program, the NASA NMP EO-3 Geostationary Imaging Fourier Transfrom Spectrometer (GIFTS), NOAA GOES, and the EUMETSAT IASI program. Where applicable and possible, the CrIS validation efforts will draw from these existing programs. Specific examples include:

1. Radiance and atmospheric state validation using ARM site observations
2. SST and radiance validation using ship cruise observations (MAERI)
3. NAST-Interferometer (NAST-I) and Scanning High Resolution Infrared Sounder (S-HIS) aircraft facilities
4. Radiance and land surface temperature validation using Polar AERI observations
5. Water vapor validation using airborne LASE observations
6. Intercomparison with other high resolution satellite borne sensors including AIRS, GIFTS, and IASI.

While the infrastructure for many of these approaches is, or will be, in place for CrIS product validation, additional resources may be required for implementation and analysis of CrIS validation. Specifically, arrangement and funding of aircraft campaigns involving the NASTI, SHIS, and/or LASE and other special field campaigns (Polar AERI and ship cruises) are required.

2.1.4 DOCUMENT OVERVIEW

This document contains a general overview and a list of specific implementation plans for the validation of each of the Level I and Level II data products from the CrIS sensor. Section 4 is a brief summary of the CrIS primary products. The validation approaches listed in section 5 follow a common format. Each implementation plan defines the following; product name, primary validation source, ancillary data source, techniques to be used, scope and schedule, comparison and accuracy, supporting documents, cost sharing, and the plan author. The term "(TBD)" applies to an element of the draft validation plan that remains "to be determined".

Appendix A presents a more detailed description of the use of aircraft based radiance measurements for satellite validation. Appendix B contains a definition of the terms used throughout the document.

2.2 UTILIZATION OF AIRCRAFT DATA

Aircraft data is important to the NPOESS program both before and after launch. Before launch, it will provide the means to demonstrate expected performance and to establish algorithm approaches that will work in the presence of actual atmospheric cloud conditions. After launch, it will form the basis for system validation.

Product validation for the NPOESS program can be established on the basis of shared costs. While expenses associated with maintaining and fielding aircraft instruments can be significant, the requirements for IPO are compatible with those of ongoing NASA scientific programs, NOAA Calibration and Validation of its operational observing capabilities, NASA plans for EOS validation, and DOE field programs for climate studies. Plans are already in place from these other organizations to support a substantial number of field programs that can be used to leverage IPO support. More specifically, NASA has plans to conduct missions with these instruments in 2000, including the SAFARI mission in South Africa, and a joint water vapor experiment with the DOE centered around the Atmospheric Radiation Measurement (ARM) site in Oklahoma. NOAA will be conducting calibration / validation of the operational polar orbiting infrared and microwave sounders in 2000; intercalibration of the ongoing series of POES sensors and the associated sounding products is a high priority for these efforts.

See Appendix A for a more detailed, self-contained report on the utility of NAST-I and S-HIS for CrIS validation.

3 APPLICABLE DOCUMENTS

- Sensor Requirements Document (SRD) Cross Track Infrared Sounder (CrIS), Version Two, 8 March 1999

- CrIS Operational Algorithm Assessment Document, Draft Version, 5 June 2000
- ITT Calibration / Validation Plan, Version submitted with CrIS Proposal

4 CRIS PRODUCTS SUMMARY

The CrIS products summary presented here is derived from information found in the CrIS Sensor Requirements Document (SRD).

4.1 LEVEL I PRODUCT

Sensor Data Records (SDRs) are full resolution sensor data that are time referenced, Earth located, and calibrated by applying the ancillary information, including radiometric and geometric calibration coefficients and georeferencing parameters such as platform ephemeris. These data are processed to sensor units (e.g., radiance). Calibration, ephemeris, and any other ancillary data necessary to convert the sensor data back to sensor raw data (counts) are included.

The operational SDR should, at a minimum, consist of the following information:

- Spacecraft ID tag
- CrIS sensor ID or serial number
- Flight software version number
- Orbit number
- Beginning Julian day and time tag
- Ending Julian day and time tag
- Ascending Node Julian day and time tag
- Spectral radiance in all channels
- Signal levels from all visible detectors.
- Geolocation: geodetic latitude and longitude for each sample
- Time tag information - beginning of scan time
- Scan index

4.2 LEVEL II PRODUCTS (PRIMARY)

Environmental Data Record (EDR) requirements are broken into two categories: primary and secondary. Primary EDRs are those EDR attributes for which a sensor contractor has been assigned primary sensor and algorithm development responsibility. The algorithm may or may not require the use of additional data from other than the primary sensor. Secondary EDRs are those EDR attributes for which the sensor may provide data as a secondary input to an EDR algorithm assigned as a primary EDR to another NPOESS sensor contractor.

Atmospheric Vertical Moisture Profile

An atmospheric vertical moisture profile is a set of estimates of average mixing ratio in three-dimensional cells centered on specified points along a local vertical. For this EDR, horizontal cell size is specified at nadir only. The mixing ratio of a sample of air is the ratio of the mass of water vapor in the sample to the mass of dry air in the sample. Clear refers to cases in which the average fractional cloudiness in the array of CrIS spots falling within an "AMSU-A like" footprint is up to 50%. The instrument shall be capable of meeting sounding requirements in situations where none of the individual spots **is cloud-free**. The sounding requirements represent errors in a given layer. There is no requirement that errors in adjacent layers be uncorrelated.

Units: g/kg

Para. No.		Thresholds	Objectives
K40.2.1-1	a. Horizontal Cell Size	15 km @ nadir	2 km @ nadir
K40.2.1-2	b. Horizontal Reporting Interval	(TBD)	(TBD)
K40.2.1-3	c. Vertical Cell Size	2 km	2 km
	d. Vertical Reporting Interval		
K40.2.1-4	1. surface to 850 mb	20 mb	5 mb
K40.2.1-5	2. 850 mb to 100 mb	50 mb	15 mb
K40.2.1-6	e. Horizontal Coverage	N/A*	N/A*
K40.2.1-7	f. Vertical Coverage	Surface to 100 mb	Surface to 100 mb
K40.2.1-8	g. Measurement Range	0 - 30 g/kg	0 – 30 g/kg
	h. Measurement Uncertainty (expressed as a percent of average mixing ratio in 2 km layers)		
	Clear (≤ 50% cloudy)		
K40.2.1-9	1. surface to 600 mb	15% or 0.2g/kg (TBR)	10%
K40.2.1-10	2. 600 mb to 300 mb	20% or 0.1g/kg (TBR)	10%
K40.2.1-11	3. 300 mb to 100 mb	25% or 0.1g/kg (TBR)	10%
	Cloudy		
K40.2.1-12	4. surface to 600 mb	20% or 0.2g/kg (TBR)	10%
K40.2.1-13	5. 600 mb to 300 mb	40% or 0.1g/kg (TBR)	10%
K40.2.1-14	6. 300 mb to 100 mb	40% or 0.1g/kg (TBR)	10%
K40.2.1-15	i. Mapping Uncertainty		
	j. Deleted		
	k. Deleted		
K40.2.1-16	l. Minimum Ground Swath-width (833 km, circular, polar-orbit altitude)	2,200 km (TBR) See*	(TBD)

* Horizontal Coverage is a system level specification determined by the number of satellites, orbitology, and sensor swath width. Thus, only "Minimum Ground Swath-width" is specified at the sensor level.

Atmospheric Vertical Temperature Profile

An atmospheric temperature profile is a set of estimates of the average atmospheric temperature in three-dimensional cells centered on specified points along a local vertical. Clear refers to cases in which the average fractional cloudiness in the array of CrIS spots falling within an "AMSU-A like" footprint is up to 50%. The instrument shall be capable of meeting sounding requirements in situations where none of the individual spots **is cloud-free**. The sounding requirements represent errors in a given layer. There is no requirement that errors in adjacent layers be uncorrelated.

Units: K

Para. No.		Thresholds	Objectives
	a. Horizontal Cell Size		

Para. No.		Thresholds	Objectives
K40.2.2-1	1. Clear, nadir	18.5 km	5 km
K40.2.2-2	2. Clear, worst case	100 km	(TBD)
K40.2.2-3	3. Cloudy, nadir	48 km (TBR)	5 km
K40.2.2-4	4. Cloudy, worst case	160 km (TBR)	(TBD)
K40.2.2-5	b. Horizontal Reporting Interval	(TBD)	(TBD)
	c. Vertical Cell Size		
	Clear (≤ 50% cloudy)		
K40.2.2-6	1. Surface to 300 mb	1 km	(TBD)
K40.2.2-7	2. 300 mb to 30 mb	3 km	(TBD)
K40.2.2-8	3. 30 mb to 1 mb	5 km	(TBD)
K40.2.2-9	4. 1 mb to 0.01 mb	5 km (TBR)	(TBD)
	Cloudy		
K40.2.2-10	5. Surface to 700 mb	1 km	(TBD)
K40.2.2-11	6. 700 mb to 300mb	1 km	(TBD)
K40.2.2-12	7. 300 mb to 30 mb	3 km	(TBD)
K40.2.2-13	8. 30 mb to 1 mb	5 km	(TBD)
K40.2.2-14	9. 1 mb to 0.01 mb	5 km (TBR)	(TBD)
	d. Vertical Reporting Interval		
K40.2.2-15	1. Surface to 850 mb	20 mb	15 mb
K40.2.2-16	2. 850 mb to 300 mb	50 mb	15 mb
K40.2.2-17	3. 300 mb to 100 mb	25 mb	15 mb
K40.2.2-18	4. 100 mb to 10 mb	20 mb	10 mb
K40.2.2-19	5. 10 mb to 1 mb	2 mb	1 mb
K40.2.2-20	6. 1 mb to 0.1 mb	0.2 mb	0.1 mb
K40.2.2-21	7. 0.1 mb to 0.01 mb	0.02 mb (TBR)	0.01 mb (TBR)
K40.2.2-22	e. Horizontal Coverage	N/A**	N/A**
K40.2.2-23	f. Vertical Coverage	Surface to 0.01 mb (TBR)	Surface to 0.01 mb (TBR)
K40.2.2-24	g. Measurement Range	180 - 335 K (TBR)	(TBD)
K40.2.2-25	Not used		
	h. Measurement Uncertainty		
	Clear (≤ 50% cloudy)		
K40.2.2-26	1. Surface to 300 mb	1.0 K / 1 km layers	0.5K / 1km
K40.2.2-27	2. 300 mb to 30 mb	1.0 K / 3 km layers	0.5K / 1km
K40.2.2-28	3. 30 mb to 1 mb	1.5 K / 5 km layers	0.5K / 1km
K40.2.2-29	4. 1 mb to 0.01 mb*	3.5 K / 5 km layers (TBR)	0.5K / 1km (TBR)
	Cloudy		
K40.2.2-30	5. Surface to 700 mb	2.5 K / 1 km layers	0.5K / 1km
K40.2.2-31	6. 700 mb to 300 mb	1.5 K / 1 km layers	0.5K / 1km
K40.2.2-32	7. 300 mb to 30 mb	1.5 K / 3 km layers	0.5K / 1km
K40.2.2-33	8. 30 mb to 1 mb	1.5 K / 5 km layer	0.5K / 1km
K40.2.2-34	9. 1 mb to 0.01 mb	3.5 K / 5 km layers (TBR)	0.5K / 1km (TBR)
K40.2.2-35	i. Mapping Uncertainty	5 km	1 km
	j./k. Deleted		
K40.2.2-36	l. Minimum Ground Swath-width (833 km, circular, polar-orbit altitude)	2,200 km (TBR) See**	(TBD)

Measurement Uncertainty as specified in K40.2.2-29 shall be referenced to the Cloudy Horizontal Cell Size thresholds and objectives as listed under K40.2.2-3 and K40.2.2-4.

** Horizontal Coverage is a system level specification determined by the number of satellites, orbitology, and sensor swath width. Thus, only "Minimum Ground Swath-width" is specified at the sensor level.

Pressure (Surface/Profile)
A pressure profile is a set of estimates of the atmospheric pressure at specified altitudes above the Earth's surface. The requirements below apply under both clear and cloudy conditions. Pressure is assumed to be a derived quantity. The pressure profile is derived from the temperature and moisture profile as well as an external estimate of pressure at some level in the atmosphere.

Units: mb

Para. No.		Thresholds	Objectives
K40.3.5-1	a. Horizontal Cell Size	55 km (TBR)	5 km
K40.3.5-2	b. Horizontal Reporting Interval	(TBD)	(TBD)
K40.3.5-3	c. Vertical Cell Size	1 km	0 km
	d. Vertical Reporting Interval		
K40.3.5-4	1. 0 - 2 km	1 km	0.25 km
K40.3.5-5	2. 2 - 5 km	1 km	0.5 km
K40.3.5-6	3. > 5 km	1 km	1 km
K40.3.5-7	e. Horizontal Coverage	N/A*	N/A*
K40.3.5-8	f. Vertical Coverage	0 – 30 km	0 - 30 km
K40.3.5-9	g. Measurement Range	10 – 1050 mb	10 - 1050 mb
	h. Measurement Accuracy		
K40.3.5-10	1. 0 - 2 km	1 % (TBR)	(TBD)
K40.3.5-11	2. 2 - 10 km	1 % or or 10 mb (TBR)	0.5 % (TBR)
K40.3.5-12	3. 10 - 30 km	1 % or or 1 mb (TBR)	0.5 % (TBR)
K40.3.5-13	i. Measurement Precision	4 mb	2 mb
K40.3.5-14	j. Mapping Uncertainty	7 km	1 km
	k. Deleted		
	l. Deleted		
K40.3.5-15	m. Minimum Ground Swath-width (833 km, circular, polar-orbit altitude)	2,200 km (TBR) See*	(TBD)

* Horizontal Coverage is a system level specification determined by the number of satellites, orbitology, and sensor swath width. Thus, only "Minimum Ground Swath-width" is specified at the sensor level.

5 PRODUCT VALIDATION IMPLEMENTATION PLANS

5.1 LEVEL 1 PRODUCTS

5.1.1 RADIANCE

Radiance validation consists of independent assessment of the spectral, spatial, and radiometric accuracy of the calibrated CrIS radiances. For spectral validation, the efforts are focussed on top-of-atmopshere calculations using known spectral features. For radiometric calibration, the primary validation is done with coincident observations from the NPOESS aircraft instruments, NASTI and SHIS, with top-of-atmosphere calculations using validation site atmospheric profiles and surface characterization, and with intercomparison with other satellite sensors.

5.1.1.1 Approach 1: Aircraft Radiance Observations

Product: High Resolution Spectral Radiance

Primary Validation Source: Aircraft Radiances from NAST-I and Scanning HIS

Ancillary Data Sources:
1. Image data from Aircraft-based Imager (MAS) to assess spatial variations over the CRIS field-of-view.
2. Atmospheric state (from radiosondes supplemented by other high altitude data sources, even including CRIS retrievals above the aircraft altitude) for input to model used to simplify spectral comparisons.

Techniques:
1. Coincident Observing: Conduct an aircraft field campaign in which NPOESS under-flights are made with aircraft flight tracks arranged parallel to the sub-satellite track. Adjust the aircraft view-angle to match the appropriate CRIS cross-track angle.
2. Target Selection: Select reasonably uniform targets with a range of radiance levels (e.g. uniform ocean for a range of latitudes, deserts, and uniform cloud decks).
3. Spectral Weighting: Basically, the approach is to compare both CRIS and aircraft spectral radiances at a common spectral resolution. This is possible since the NAST-I and S-HIS are both Fourier Transform Spectrometers as is the CrIS sensor.
4. Spatial Weighting: The higher resolution aircraft pixels are summed with appropriate weights to represent the larger CRIS Spatial Response Function. Unsampled regions are represented by using imager data to assign spectra from similar sampled regions.

Scope and Schedule:
At least 40 flight hours per year from field campaigns of opportunity will be supported by CRIS throughout the instrument lifetime to perform this type of validation. If necessary, CRIS will organize a special campaign during the second half of its first year in orbit to insure that a timely comparison is achieved. The radiometric characteristic of NAST-I and Scanning HIS will be documented before CRIS launch, in preparation for estimating errors.

Comparison and Accuracy:
The spectral comparison of CRIS to aircraft spectrometers is based on comparing the direct comparison of radiances. If the calibration of both instruments were perfect and the scene were uniform, the difference between residual spectra would be noise. It would be nearly uncorrelated with wavelength and dominated by the CRIS single sample noise (many aircraft samples are averaged to match CRIS spatial sampling). We are really looking for differences that are correlated with wavelength that represent consistent radiometric or spectral calibration differences. For reasonably uniform scenes, we expect to be able to detect differences that are on the order of the peak calibration uncertainties for both instruments (less than 1 K brightness temperature for the critical spectral

regions). By achieving a number of comparisons, it will be possible to separate consistent, significant differences from differences attributable to spatial sampling errors.

Supporting Documents: (TBD)

Funding: IPO support is required for dedicated aircraft flight hours.

5.1.1.2 Approach 2: Calculations of TOA radiance, ARM sites

Product: High Resolution Spectral Radiance (Cloud Cleared)

Primary Validation Source: Calculated clear sky upwelling TOA radiance spectra

Ancillary Data Sources:

1. Atmospheric state from ARM (SGP, NSA, and TWP) site temperature and water vapor best estimates.
2. Surface skin emissivity from the following sources: USGS land type maps, temporal and spatial collocated ground-based SAERI measurements, calculated sea-surface values.
3. Surface skin temperature from broadband infrared measurements at the ARM sites or fitted to the CRIS observations.
4. Imager Data for assessing spatial variability of surface characteristics.

Technique:
The basic approach is to compare CRIS cloud cleared radiance spectra to calculations of the upwelling clear sky radiance for NPOESS overpasses of the ARM sites. The calculations will be performed using input from the ARM site temperature and water vapor best estimate products from the Southern Great Plains (central facility), North Slope of Alaska (Barrow site), and the Tropical Western Pacific (Nauru site) sites. The CRIS fast model and line-by-line radiative transfer codes will be used to perform these clear sky calculations. The differences between the observed and calculated radiances are then analyzed with respect to the calculation uncertainties (spectroscopic accuracy, fast model parameterization, atmospheric state uncertainty, and surface emissivity and temperature characterization) to assess the accuracy of the observed radiances. The AER Optimal Spectral Sampling will be compared to other fast transmittance models (including a PFAAST-based model for CrIS). These comparisons will be done for all-sky conditions and will therefore serve not only to assess the accuracy of the clear sky CRIS radiances but also the accuracy of the cloud-clearing algorithm and resulting radiances under cloudy and partly cloudy conditions.

Scope and Schedule:
The calculations will be performed following the ARM site T/q best estimate production for NPOESS overpasses of the ARM sites. This includes periods using the on-going routine ARM observations as well as periods with dedicated NPOESS overpass radiosonde launches.

Comparison and Accuracy:
The accuracy of the calculated radiances will depend largely on the specification of the surface temperature and emissivity, as well as the atmospheric state. The surface emissivity and temperature used in the calculations will likely be determined by fitting a linear combination of the known pure scene type emissivities and the effective, area weighted surface temperature such that window region residuals (CRIS – calculation) are

minimized. In this sense, this validation activity does not address absolute calibration accuracy, but rather has an emphasis on spectral and relative radiometric accuracy. That is, the technique of fitting the surface characteristics to the observed radiances sets the residuals to zero in specific spectral regions in the 10 micron region, but allows for meaningful comparisons of the observed and calculated radiances in spectral regions which do not see the surface. The spectral performance of the CRIS will be assessed by taking differences between the observed and calculated spectra. Using a large number of comparisons, radiometric differences between the observed (or cloud cleared) and calculated radiances will be analyzed statistically using, for example, scatter plots of radiance differences, or distributions of radiances for selected, limited wavenumber regions.

Funding: (TBD)

5.1.1.3 Approach 3: Satellite Sensor Intercomparisons

Product: High to Moderate Spectral Resolution Radiance
Primary Validation Data Source: AIRS, IASI, MODIS, GIFTS, VIIRS, GOES, POES radiances
Ancillary Data Sources:
Technique:
The general technique is to reduce the CrIS and the validation sensor radiances to the same spectral resolution and to spatially average the data in a consistent manner. Comparisons to the validation sensor radiances are then made for selected scene types of varying homogenaity and signal level. Thee intercomparisons can be conducted for climate applications (leo/leo is available daily in the polar regions and geo/leo is available hourly in the equatorial regions).

Collocation in space and time (within thirty minutes) is required. Data is selected within 10 degrees from nadir for each instrument in order to minimize viewing angle differences. Measured means of brightness temperatures of similar spectral channels from the two sensors are compared. Data collection is restricted to mostly clear scenes with mean IRW radiances greater than 80 $mW/m^2/ster/cm^{-1}$, and no effort is made to screen out clouds from the study area. Data from each sensor is averaged to 100 km resolution to mitigate the effects of different field of view (fov) sizes and sampling densities. Mean radiances are computed within the study area. Clear sky forward calculations (using a global model for estimation of the atmospheric state) are performed to account for differences in the spectral response functions (when comparing to broad band radiometers). The observed radiance difference minus the forward-calculated clear sky radiance difference is then attributed to calibration differences.

$$\Delta R_{cal} = \Delta R_{mean} - \Delta R_{calc}$$

Scope and Schedule: will depend on the individual sensor lifetimes and observation geometries and times.
Comparison and Accuracy:
Supporting Documents:
Funding:

5.1.1.4 Approach 4: Calculations of TOA Radiance, Polar Validation Site

Product: High Spectral Resolution Radiance

Primary Validation Data Source: PAERI observations of ground-based high spectral resolution radiance, and overpass coincident radiosondes

Ancillary Data Sources:
1. GPS and/or tethersonde profiles of water vapor
2. Broadband radiometer measurements of surface temperature to characterize gradients within the CrIS footprints
3. Cloud Lidar or ceiliometer for cloud detection

Technique: This approach uses accurate sensors (PAERI and broadband radiometers) to derive the land surface temperature and spectral emissivity of a homogeneous polar site. Using these surface parameters and temperature and water vapor profiles from overpass coincident soundings, line-by-line calculations of the TOA upwelling radiances will be performed and compared to the CrIS observations. This approach is advantageous due to the very homogeneous polar targets that are available (e.g. Dome Concordia in Antarctica), the large number of satellite overpasses, the accurate surface measurements, and the small atmospheric effects due to very low water vapor amounts (and the resultingly small errors in the line-by-line radiance calculations). These comparisons will provide a very stringent test of the CrIS radiances at low values.

Scope and Schedule: The field measurements should consist of several two-week long campaigns, preferably at Dome Concordia in Antarctica. These should occur after an initial CrIS check-out period and following other less stringent radiometric validation efforts. Observations during austral winter are preferred, although austral summer conditions are sufficient. Clear-sky satellite overpass conditions are required for the comparisons to the clear-sky line-by-line calculations.

Comparison and Accuracy: The radiance validation will consist of comparisons of the CrIS radiances to calculations performed with the PAERI observations of surface temperature and emissivity and sonde measurements of temperature and water vapor profiles. Due to the very low water vapor amounts (~0.3 mm in winter), and the relatively high accuracy of research grade temperature profile measurements, errors in the sonde profiles will not contribute significantly to errors in the calculated radiances. Similarly, due to the very low water vapor amounts, uncertainties in the line-by-line models associated with water vapor absorption (which scale with water vapor amount) will be insignificant. The main source of error in the calculations are expected to arise from uncharacterized gradients in the surface temperature within the CrIS footprints. Comparisons are expected to be made on the 0.1K to 0.2K level.

Funding: (TBD)

5.1.1.5 Approach 5: Calculations of TOA Radiance, Ocean Ship Cruise

Product: High Spectral Resolution Radiance
Primary Validation Data Source: MAERI SST, overpass coincident sondes
Ancillary Data Sources: MWR
Technique: The general technique is the same as that of the ARM site and Polar site radiance calculations, but is implemented using a ocean (or appropriately large sea or lake) ship cruise equipped with accurate skin surface temperature and atmospheric profile measurements.
Scope and Schedule:
Comparison and Accuracy:
Supporting Documents:
Funding:

5.1.2 NAVIGATION

The goal of navigation validation is to ensure that the CrIS radiances and atmospheric profiles are navigated to Earth located footprints to the required accuracy. Candidate approaches include the comparison of CrIS images to calculated images for well defined, high contrast coastlines and similar surface features, and the comparison of CrIS images with VIRS and other high spatial resolution image data.

5.1.2.1 Approach 1: Coastline Crossings

Product: Navigated CrIS Radiances

Primary Validation Data Source: Coastline location database

Technique:
The basic approach is to compare the navigated CrIS radiances with high IR contrast coastlines. This will be done by comparing images of CrIS radiances obtained over well-defined coastlines for clear sky conditions to coastline locations from the database. This can be done manually or automated given the scope of the effort. Potential coastline databases include ETOPO-5 and GLOBE.

Scope and Schedule:
This effort should be conducted during initial instrument check-out periods and continued throughout the mission. It should include views from a range of satellite scan angles and for a number of TBD earth locations.

Comparison and Accuracy:
The coastline databases available for this purpose report elevation maps to an accuracy of 1 km (e.g. GLOBE). The analysis should include nighttime and daytime comparisons and also address infrared (versus visible) effects.

Funding: TBD

5.2 LEVEL 2 PRODUCTS, PRIMARY

5.2.1 WATER VAPOR

Water vapor is highly variable in space and time and is difficult to measure in the atmosphere, especially over the dynamic range required for atmospheric applications. Many observing platforms are however making significant improvements in our ability to measure atmospheric water vapor with the accuracy required for satellite validation. A recent workshop held to discuss the current observation capabilities and to define the future needs concluded that (a) moisture demonstrates considerable variability in the horizontal and vertical, (b) measurements of total precipitable water (TPW) from different systems agree within 5 – 10%, (c) ground based profile measurements offer new opportunities to depict rapid small scale boundary layer moisture changes, (d) remote sensing at high spectral IR resolution offers the promise of depicting vertical H2O layer patterns, (e) assimilation of moisture information is challenging as all observations are interdependent and influence H2O balance (forecasts are accurate to within 15 – 20% for TPW), (f) moisture profiles are especially useful in NWS Forecast Offices and centers and geo-soundings are very timely for subjective forecasting because pre-storm environments initiate in moist clear skies often near outflow boundaries (which present good opportunities for IR systems), and (g) there is a need for a coherent national program for moisture measurements and NWP utilization.

5.2.1.1 Approach 1: ARM Sites Observations

Product: Water Vapor profiles (and integrated column water vapor)

Primary Validation Source: Routine ARM site observations and dedicated NPOESS overpass radiosondes. (ARM site T/q best estimate).

Ancillary Data Sources:
1. GOES and Oklahoma Mesonet data for assessing spatial variability.

Technique:
The basic technique is to use the routine ARM site observations (at the Southern Great Plains site in central Oklahoma, at the North Slope of Alaska site in Barrow, Alaska, and the Tropical Western Pacific site in Nauru) along with dedicated NPOESS overpass radiosondes to measure the temperature and water vapor profiles for validation of the CRIS retrievals. Temporally continuous profiling at the ARM sites will be used to assess small scale spatial variability. GOES, surface networks, and the relative variability of the single-FOV CRIS retrievals will be used to address larger scale spatial gradients. Best estimate profiles and quantitative error estimates will be provided and compared with the coincident CRIS retrieved profiles which have been interpolated in space (using single-FOV CRIS retrievals) to the validation profile locations. Additional information on the technique and estimated uncertainties are given in the supporting document.

Scope and Schedule:
The best estimate products produced from the routine ARM observations will be available for validation purposes from the launch of NPOESS onward. During yearly three month long periods, dedicated NPOESS overpass sondes will be launched and incorporated into the best estimate products. During these periods, sondes will be launched ~90 minutes and ~5 minutes prior to overpass time to provide improved collocation with the satellite overpasses, for the lowest view angle (closest to nadir) overpass of the ARM site each day (e.g. 1 overpass per day, 2 sondes per overpass). Estimates of the number of clear and cloudy overpasses of each site are given in the supporting document.

Comparison and Accuracy:
Rough estimates of the validation profiles show that their accuracies surpass the validation needs of CRIS. Supporting information is given in the supporting document.

Supporting Documents: "Position Paper on ARM T/q Best Estimate Profiles for AIRS Validation", D. Tobin et al., March 1, 2000.

Funding: (TBD)

5.2.1.2 Approach 2: International Validation Sites

Product: Water Vapor profiles (and integrated column water vapor)

Primary Validation Source: International Validation sites

Ancillary Data Sources:
1. Overpass coordinated Vaisala radiosondes with GPS or Microwave Radiometer (MWR) or a high quality surface met station for independent radiosonde water vapor calibration. Imager data (GOES, GMS, MODIS, etc) data for assessing cloud cover and spatial and temporal variability

Techniques:
The basic approach is to make measurements of temperature and water vapor profiles coincident with CRIS retrievals via overpass coordinated radiosonde launches. Sonde water vapor calibration errors will be addressed by scaling the sonde integrated column water vapor to values measured by a GPS or MWR, or alternatively by scaling to point measurements made with a high quality met station coincident with the sonde measurements just prior to launch. Imager data will be used to assess cloud cover and spatial and temporal variability.

Scope and Schedule:
Potential sites include UW-Madison, U. Hawaii, INPE/Brazil, BOM/Australia, Perth/Australia, Lannion/Meteo France, KMA/Korea, and SMC/China. Depending on site resources and funding, overpass coordinated launches will be conducted for three month periods every year for the life of CRIS.

Comparison and Accuracy:
Expected accuracies are comparable to those from DOE ARM sites, although they will be slightly degraded due to the lack of continuous profiling to assess small scale spatial variability. Upper level water vapor measurements will lack the benefit of Raman Lidar observations, although it is expected that Raman Lidar/sonde comparisons from the Southern Great Plains ARM site can be used to assess the accuracy of global upper level radiosonde measurements.

Supporting Documents:
AIRS Validation Plan input: AIRS_inorbit_validation_corrected.doc, A.Huang, Dec, '99.

Funding: (TBD)

5.2.1.3 Approach 3: Retrievals from NASTI and SHIS aircraft observations

Product: Water Vapor Profiles

Primary Validation Data Source: NAST-I and S-HIS retrievals

Ancillary Data Sources: NAST-M, MAS, CLS

Technique:
For high altitude NAST-I and/or S-HIS underflights of the CrIS overpasses, retrievals of atmospheric water vapor profiles derived from the NAST-I and/or S-HIS observations will be compared to the CrIS products. Cross-track scanning will allow the aircraft observations to be averaged to match the CrIS footprint. As with radiance validation approaches with S-HIS and NAST-I (5.1.1.1), the flight paths and sensor scan angles can be tailored to match the CrIS viewing angles. These flights should be performed at maximum aircraft altitude.

A complimentary technique is to perform slow ascents with the aircraft sensors to derive profiles from NAST-I and/or S-HIS data using opaque spectral channels which represent the local temperature and gas concentrations. Such experiments have recently been performed with NAST-I on the Proteus aircraft during the ARM WVIOP 2000 experiment. Due to the slow ascents, these comparisons would be performed on a limited scope for stable, homogeneous meteorological conditions in order to provide meaningful comparisons to the CrIS product.

Scope and Schedule:
A large number of overpass underflights should be performed in order to sample a range of conditions. Initial comparisons should focus on clear sky underflights over water (e.g. ocean , Great Lakes, Gulf of Mexico). Following underflights would involve more diverse meteorological (including clouds) and surface conditions. In particular, the higher spatial resolution aircraft data can be used to determine the effects of partially cloudy scenes on the CrIS retrieval performance. Aircraft-based Cloud Lidar (CLS) and/or high spatial resolution imagery (MAS) can be used to further assess the cloudiness of the scenes. Several aircraft field campaigns per year, each targeting on the order of 10 CrIS overpasses, for the duration of the mission are desired.

Funding: TBD

5.2.1.4 Approach 4: Active and In-situ Aircraft-based observations

Product: Low to upper level water vapor profiles
Primary Validation Data Source: LASE and frost-point and/or Diode Laser water vapor in-situ sensors
Ancillary Data Sources:
Technique:
Scope and Schedule:
Comparison and Accuracy:
Supporting Documents:
Funding:

5.2.1.5 Approach 5: Comparison to Other Satellite Retrievals

Product: Water Vapor profiles
Primary Validation Data Source: AIRS, GIFTS, IASI, HIRS, MODIS, …
Ancillary Data Sources:
Technique:
Scope and Schedule:
Comparison and Accuracy:
Supporting Documents:
Funding:

5.2.1.6 Approach 6: WVSS (ACARS water vapor observations)

Water vapor (and temperature) measurements provided from Water Vapor Sensor System (WVSS) units mounted on United Parcel Service (UPS) aircraft offer another source of water vapor information complementing radiosondes, an Atmospheric Emitted Radiance Interferometer (AERI), global positioning system, Vaisala ceilometer, and surface meteorological stations. Preliminary results from prior intercomparions indicate WVSS water vapor measurements are of reasonable quality above the boundary layer, however they exhibit a moist bias occur during ascent and descent through the boundary layer. This problem has been remedied with the WVSS-II which shows improved performance in accuracy due to a single mode diode laser, probe placement on aircraft, and longer maintenance intervals. Ascending and descending aircraft WVSS-II data will be intercompared to CrIS moisture profiles.

Product: Water Vapor level and profile measurements

Primary Validation Data Source: commercial aircraft based water vapor in-situ sensors

Ancillary Data Sources: Radiosondes, an Atmospheric Emitted Radiance Interferometer (AERI), global positioning system, Vaisala ceilometer, and surface meteorological stations.

Technique: A suite of meteorological instruments including radiosondes, an Atmospheric Emitted Radiance Interferometer (AERI), global positioning system, Vaisala ceilometer, and surface meteorological stations will be deployed at a site to be selected. Ascending and descending UPS aircraft WVSS data will be intercompared to research grade radiosonde data as well as CrIS moisture profile retrievals.

Scope and Schedule:
Comparison and Accuracy:
Supporting Documents:
Funding:

5.2.2 TEMPERATURE

Obtaining temperature profile information similar to radiosonde quality soundings, both in absolute accuracy and vertical structure, is a primary goal of advanced sounders. The stated accuracy objective for the CrIS temperature profiles is 1K in 1km layers for clear (<= 50% cloudy) scenes. The combination of high spectral (to resolve the temperature sounding CO_2 spectral lines) and spatial resolution from CrIS measurements is capable of reaching these goals. Opposed to water vapor measurements, temperature measurements of this accuracy (and better) are widely available for validation purposes, although complications due to spatial inhomogeneaity and cloudiness need to be taken into account in any validation effort. Candidate validation efforts include comparisons to national radiosonde network observations, observations from validation sites such as the ARM sites, retrievals from aircraft based measurements (remotely-sensed, active, and in-situ), and other satellite retrievals.

5.2.2.1 Approach 1: ARM Site Observations

Product: Temperature profiles

Primary Validation Source: Routine ARM site observations and dedicated NPOESS overpass radiosondes. (ARM site T/q best estimate).

Ancillary Data Sources:

2. GOES and Oklahoma Mesonet data for assessing spatial variability.

Technique:
The basic technique is to use the routine ARM site observations (at the Southern Great Plains site in central Oklahoma, at the North Slope of Alaska site in Barrow, Alaska, and the Tropical Western Pacific site in Nauru) along with dedicated NPOESS overpass radiosondes to measure the temperature and water vapor profiles for validation of the CRIS retrievals. Temporally continuous profiling at the ARM sites will be used to assess small scale spatial variability. GOES, surface networks, and the relative variability of the single-FOV CRIS retrievals will be used to address larger scale spatial gradients. Best estimate profiles and quantitative error estimates will be provided and compared with the coincident CRIS retrieved profiles which have been interpolated in space (using single-FOV CRIS retrievals) to the validation profile locations. Additional information on the technique and estimated uncertainties are given in the supporting document.

Scope and Schedule:
The best estimate products produced from the routine ARM observations will be available for validation purposes from the launch of NPOESS onward. During yearly three month long periods, dedicated NPOESS overpass sondes will be launched and incorporated into the best estimate products. During these periods, sondes will be launched ~90 minutes and ~5 minutes prior to overpass time to provide improved collocation with the satellite overpasses, for the lowest view angle (closest to nadir) overpass of the ARM site each day (e.g. 1 overpass per day, 2 sondes per overpass). Estimates of the number of clear and cloudy overpasses of each site are given in the supporting document.

Comparison and Accuracy:
Rough estimates of the validation profiles show that their accuracies surpass the validation needs of CRIS. Supporting information is given in the supporting document.

Supporting Documents: "Position Paper on ARM T/q Best Estimate Profiles for AIRS Validation", D. Tobin et al., March 1, 2000.

Funding: (TBD)

5.2.2.2 Approach 2: Retrievals from NASTI and SHIS aircraft observations

Product: Temperature Profiles

Primary Validation Data Source: NAST-I and S-HIS retrievals

Ancillary Data Sources: NAST-M, MAS, CLS

Technique:
For high altitude NAST-I and/or S-HIS underflights of the CrIS overpasses, retrievals of atmospheric water vapor profiles derived from the NAST-I and/or S-HIS observations will be compared to the CrIS products. Cross-track scanning will allow the aircraft observations to be averaged to match the CrIS footprint. As with radiance validation approaches with S-HIS and NAST-I (5.1.1.1), the flight paths and sensor scan angles can be tailored to match the CrIS viewing angles. These flights should be performed at maximum aircraft altitude.

A complimentary technique is to perform slow ascents with the aircraft sensors to derive profiles from NAST-I and/or S-HIS data using opaque spectral channels which represent the local temperature and gas concentrations. Such experiments have recently been performed with NAST-I on the Proteus aircraft during the ARM WVIOP 2000 experiment. Due to the slow ascents, these comparisons would be performed on a limited scope for stable, homogeneous meteorological conditions in order to provide meaningful comparisons to the CrIS product.

Scope and Schedule:
A large number of overpass underflights should be performed in order to sample a range of conditions. Initial comparisons should focus on clear sky underflights over water (e.g. ocean , Great Lakes, Gulf of Mexico). Following underflights would involve more diverse meteorological (including clouds) and surface conditions. In particular, the higher spatial resolution aircraft data can be used to determine the effects of partially cloudy scenes on the CrIS retrieval performance. Aircraft-based Cloud Lidar (CLS) and/or high spatial resolution imagery (MAS) can be used to further assess the cloudiness of the scenes. Several aircraft field campaigns per year, each targeting on the order of 10 CrIS overpasses, for the duration of the mission are desired.

Funding: TBD

5.2.2.3 Approach 3: Comparison to Other Satellite Retrievals

Product: Temperature profiles
Primary Validation Data Source: AIRS, GIFTS, IASI, HIRS, MODIS, …
Ancillary Data Sources:
Technique:
Scope and Schedule:
Comparison and Accuracy:
Supporting Documents:
Funding:

5.2.2.4 Approach 4: Comparison to ACARS Data

Product: CRIS Temperature Profile

Primary Validation Source: ACARS ascent/descent temperature profiles at UPS hub in Louisville, Kentucky, USA.

Ancillary Data Sources:
None

Techniques:
1. Coincident Observing: ACARS ascent and descent profiles from the United Parcel Service Louisville hub will be collected coincident with the NPOESS overpasses (nightly).
2. Target Selection: Fixed target. Louisville airport.
3. Spatial Weighting: The numerous takeoffs and landings will map out a spatial volume in three dimensions which can be weighted appropriate to the CRIS sounding.

Scope and Schedule:
At least 10 days per month will be analyzed for the year following the CRIS checkout period. The data analyzed will be restricted to the ascent and descent profiles from the Louisville airport location.

Comparison and Accuracy:
The ACARS temperature measurements have been validated to an accuracy of better than 1 K in 0.5 km vertical layers (Feltz, et al., 1999) using a combination of radiosonde and groundbased remote sensing data. An uncertainty in the validation product can be obtained from computing the variance of temperature measurements within the measured data volume from many different aircraft observations. This estimate will include both the ACARS reproducibility error and the natural variability of the atmosphere over the measurement volume.

Supporting Documents: ACARS WebPage: http://acweb.fsl.noaa.gov/

Funding: (TBD)

5.2.2.5 Approach 5: International Radiosonde Network

Product: Temperature Profiles

Primary Validation Data Source: International radiosonde network

Ancillary Data Sources:

Technique:

Scope and Schedule:

Comparison and Accuracy:

Supporting Documents:

Funding:

5.2.3 PRESSURE

Introduction

5.3 LEVEL 2 PRODUCTS, SECONDARY

Surface temperature and cloud parameters are discussed in this section.

5.3.1 SURFACE TEMPERATURE

Introduction

5.3.1.1 Sea Surface Temperature (SST)

Primary Validation Source: Marine-Atmospheric Emitted Radiance Interferometer (M-AERI) from University of Miami.

Ancillary Data Sources:

1. Imager data from NPOESS platform
2. GOES SST product for temporal stability from NOAA
3. Buoy data from NOAA

Techniques:

1. Coincident Observing: Collect CRIS SST product data along M-AERI cruise tracks within a predefined time window.
2. Target Selection: Select reasonably uniform and temporally stable targets with a range of radiance levels encompassing the range of surface temperatures observed by M-AERI and atmospheric water column amounts measured by CRIS.
3. Spatial Characterization: The imagery will be used to characterize the area for which the CRIS SST is considered valid. The M-AERI SST value coincident in time with the NPOESS overpass will be weighted by the ratio of the sum of image data window channel radiance over the entire CRIS field of view to the sum of image data window channel radiances over the portion of the ship track within the CRIS field of view. Error bars will be assigned to the comparison to characterize the variability of the scene. When available, high resolution GOES products will be used to characterize temporal change of the scene during the comparison period. A comparison of CRIS SST, M-AERI SST, and buoy SST measurements will be made wherever possible to assist in the interpretation of CRIS SST and buoy comparisons made elsewhere.

Scope and Schedule:

Validation of the CRIS SST product will begin when the M-AERI SST data is available. Between one and five sets of cruise data is anticipated during the year following the CRIS checkout period. This effort assumes that MAERI data from a MODIS validation cruise will be available from existing funding.

Comparison and Accuracy:

The comparison of CRIS SST and M-AERI SST products is simplified by the high absolute accuracy of the M-AERI (order 0.1 K) but complicated by the large mismatch between the CRIS SST domain (order 45 km) and the point M-AERI measurements. The largest source of uncertainty in the SST product comparison is expected to be the spatial variability within the CRIS scene. Uncertainty estimates will be developed to allow error bars to be attributed to each CRIS/M-AERI comparison. The goal of this activity will be to validate the CRIS SST product to within about 0.5 degree Kelvin over as wide a range of atmospheric column water vapor amounts as possible.

Funding: (TBD)

5.3.1.2 Land Surface measurements

Primary Validation Source: University of Wisconsin S-AERI measurements of land surface temperature and emissivity

Ancillary Data Sources:
Land surface/Land cover maps.
Imager data from NPOESS platform.
Broadband measurements (KT-19) of surface emitted radiance.

Techniques:
The focus of this activity is to provide a limited number of case studies for the validation of the CRIS land surface temperature product which take advantage of the accurate point measurements from the University of Wisconsin S-AERI system. Examples of both uniform and mixed scenes will be chosen. For a mixed surface scene, the CRIS land surface temperature product is actually an emissivity-weighted temperature.
1. Coincident Observations: Collect surface temperature and emissivity from the S-AERI system co-incident with NPOESS overpasses on a limited campaign basis. Coincident imager data from the NPOESS platform are also required.
2. Target Selection: The DOE SGP ARM site will be used for one of the case studies. Uniform non-vegetated scenes (e.g. desert) will be used in additional case studies.
3. Spatial Characterization: In order to properly handle the relatively large CRIS footprint (15 km), SAERI measurements of the surface emissivity and temperature of one to three pure scene types within an CRIS footprint are made. KT-19 radiometers are used to monitor surface temperature changes at the sites while the SAERI measurements are made during the overpass. Land surface maps and satellite imagery are then used to create area-weighted emissivities and emissivity-weighted temperatures for direct comparison with CRIS products.

Scope and Schedule:
The S-AERI measurements of land surface temperature and emissivity at the SGP site will be performed once during each season (Spring, Summer, Fall, and Winter) beginning about 120 days after launch in order to capture the sensitivity of the product to changing land cover. The S-AERI measurements at the uniform non-vegetated sight(s) will be performed within one year of launch but timed to coordinate with any supporting measurements.

Comparison and Accuracy:
The standard CRIS surface emissivity and temperature products (derived for individual 15 km CRIS footprints) will be validated in this effort. The point measurement accuracy of land surface temperature from the S-AERI is high (order 0.2 K), so the largest anticipated error is expected from the extrapolation to the land surface temperature for the CRIS footprint based on satellite imagery and a detailed surface emissivity map. The

goal of this project is to validate the CRIS land surface temperature and emissivity products to better than 2 K and 2% over a range of atmospheric conditions.

Funding: (TBD)

5.3.2 CLOUD PARAMETERS

CrIS will provide greatly enhanced remote sensing capability for the characterization of atmospheric clouds. Current low spectral resolution sounders such as HIRS are limited in their ability to provide information on multi-layer clouds (Menzel et al. 1992), while AIRS, CrIS, IASI, GIFTS, and ABS will overcome this limitation with their high spectral longwave cloudy radiance measurements.

Algorithms will be developed for retrieving cloud-top pressure (CTP) and effective cloud amount (ECA; which is defined as the product of the cloud emissivity and the fractional cloud coverage) from the longwave advanced sounder radiances. Advanced sounder radiances (CrIS) and co-located imaging radiances (VIIRS) will be directly used to retrieve cloud properties from a single CrIS FOV. The algorithms can be tested with AIRS and MODIS data, and usd operationally in future with CrIS and VIIRS data.

Algorithms will be developed for high spectral resolution sounder radiances and co-located high spatial resolution multi-spectral imaging radiances which retrieve the multi-layer atmospheric CTPs and ECAs from a single FOV. A simulation study will be carried out to evaluate quantitatively the multi-layer cloud retrieval capability of CrIS/VIIRS.

Algorithms will be refined to (a) combine CO_2-slicing plus 1DVAR with high spectral resolution data, and (b) high spectral resolution sounder radiances (CrIS/) with co-located high spatial resolution multi-spectral imaging data (VIIRS).

5.3.2.1 Cover/Layers

Primary Validation Data Source:
Ancillary Data Sources:
Technique:
Scope and Schedule:
Comparison and Accuracy:
Supporting Documents:
Funding:

5.3.2.2 Cloud Effective particle size

Primary Validation Data Source: Aircraft replicator profiles from Cloud Particle Imager (CPI)

Ancillary Data Sources: Imagers with three or four broad band (spectral resolution around 10 - 20 cm^{-1}) measurements in the infrared window region between 800 to 1000 cm^{-1} are likely to be able to distinguish large from small particle size cirrus and to provide IWP estimates.

Technique: Calculations of high-spectral resolution infrared radiances in cirrus cloud situations indicate that cloud forcing (clear minus cloudy) spectra are sensitive to ice particle size, ice water path, and cloud altitude. A numerical procedure based on the DISORT algorithm is used to retrieve the effective radius and ice water path of cloud layers with known optical depths and cloud boundaries and with nearby clear sky atmospheric conditions also known. The reasonable reproduction in a rather wide window region suggests that the DISORT based algorithm can distinguish small from large particle clouds as well as provide a fair estimate of IWP.
Cirrus clouds with small ice particles ($r_{eff} < 10$ μm) exhibit a non-linear *S*-shaped cloud forcing in 800 - 1000 cm^{-1} that gradually disappears as the particle size is increased. Clouds with ice water path (IWP) greater than 50 gm^{-2} (130 gm^{-2}) and small (large) particles of $r_{eff} = 7.5$ μm ($r_{eff} = 30$μm) are found to be opaque (upwelling radiance is unchanged within 1 K).

Scope and Schedule:

Comparison and Accuracy: Ice particle size and ice water path are estimated with 20% variation in the inferred values. The best sets of effective radius and ice water path can reproduce the observed HIS cloud forcing within 2 K in 800-1000 cm^{-1} and within 4.5 K in 1150-1250 cm^{-1} for both small ($r_{eff} < 10$ μm) and large ($r_{eff} > 10$ μm) particle clouds.

Supporting Documents: Chung, S., S. A. Ackerman, P. F. van Delst, and W. P. Menzel, 2000: Calculations and Interferometer Measurements of Ice Cloud Characteristics. Jour Appl. Meteor., 39, 634-644.

Funding:

5.3.2.3 Cloud ice water path

Primary Validation Data Source: Aircraft data

Ancillary Data Sources: VIIRS with three or four broad band (spectral resolution around 10 - 20 cm^{-1}) measurements in the infrared window region between 800 to 1000 cm^{-1} will likely be able to provide complementary IWP estimates.

Technique: Calculations of high-spectral resolution infrared radiances in cirrus cloud situations indicate that cloud forcing (clear minus cloudy) spectra are sensitive to ice particle size, ice water path, and cloud altitude. A numerical procedure based on the DISORT algorithm is used to retrieve the effective radius and ice water path of cloud layers with known optical depths and cloud boundaries and with nearby clear sky atmospheric conditions also known. The reasonable reproduction in a rather wide window region suggests that the DISORT based algorithm can distinguish small from large particle clouds as well as provide a fair estimate of IWP. Ice particle size and ice water path are estimated with 20% variation in the inferred values.

Cirrus clouds with small ice particles (r_{eff} < 10 μm) exhibit a non-linear *S*-shaped cloud forcing in 800 - 1000 cm^{-1} that gradually disappears as the particle size is increased. Clouds with ice water path (IWP) greater than 50 gm^{-2} (130 gm^{-2}) and small (large) particles of r_{eff} = 7.5 μm (r_{eff} = 30μm) are found to be opaque (upwelling radiance is unchanged within 1 K).

Scope and Schedule:

Comparison and Accuracy: Ice particle size and ice water path are estimated with 20% variation in the inferred values. Measured spectra from the HIS have been used to infer a range of ice particle sizes between 7.5 and 40 μm with ice water paths between 10 and 600 gm^{-2}.

Supporting Documents: Chung, S., S. A. Ackerman, P. F. van Delst, and W. P. Menzel, 2000: Calculations and Interferometer Measurements of Ice Cloud Characteristics. Jour Appl. Meteor., 39, 634-644.

Funding:

5.3.2.4 Cloud liquid water

Primary Validation Data Source:
Ancillary Data Sources:
Technique:
Scope and Schedule:
Comparison and Accuracy:
Supporting Documents:
Funding:

5.3.2.5 Cloud optical thickness

Primary Validation Data Source:
Ancillary Data Sources:
Technique:
Scope and Schedule:
Comparison and Accuracy:
Supporting Documents:
Funding:

5.3.2.6 Cloud top height / pressure / temperature

5.3.2.6.1 **Approach 1:** Aircraft Cloud Lidar Sensor

Ancillary Data Sources: geometric stereo determinations from leo / geo high spatial resolution imagers viewing the same cloud at the same time from different view angles

Technique: CO_2-slicing will be followed by 1DVAR algorithms for high spectral resolution sounder (e.g., CrIS or AIRS or IASI) radiances and co-located high spatial resolution multi-spectral imaging radiances (e.g., VIIRS or MODIS) which retrieve the single layer atmospheric CTP and ECA from a single field-of-view (FOV) with higher accuracy than the current operational sounders (HIRS).

Scope and Schedule:

Comparison and Accuracy: Cloud pressure will be determined within 30 hPa.

Supporting Documents: Wylie, D. P. and W. P. Menzel, 1999: Eight years of global high cloud statistics using HIRS. Jour. Clim., 12, 170-184.

Funding: TBD

5.3.2.6.2 Approach 2: ARM site ARSCL product

Product: Cloud top height (and base)

Primary Validation Data Source: ARM site Micropulse Lidar (MPL) and Cloud Radar (MMCR), combined with the Active Remotely Sensed Cloud Layers (ARSCL) algorithm (Clothiax et al., 2000)

Ancillary Data Sources:
1. Vaisala ceiliometer
2. Winds from Wind Profiler, model output, or radiosondes

Technique: This approach uses the ARM site ARSCL product to validate the CrIS cloud top heights. ARSCL combines the MPL and MMCR measurements into a single product of cloud layers (base, top, thickness) versus time at each of the primary ARM sites (Southern Great Plains (SGP), Tropical Western Pacific (TWP), and North Slope of Alaska (NSA)). The technique then is to perform temporal averaging of the ARSCL product that produces an equivalent spatial averaging to match the extent of the CrIS footprint at that ARM site overpass time and compare the averaged product to the CrIS product. Winds data from the Wind Profiler network (for SGP), model data, and/or sondes can be used to determine the averaging times.

Scope and Schedule:
These comparisons can be preformed regularly for CrIS overpasses of each ARM site (SGP, TWP, and NSA) for the duration of the mission. Initial analysis should focus on cases of single layer clouds, followed by cases of overlapping clouds. A large number of cases of different types of clouds from each site should be compiled in order to perform statistically meaningful comparisons.

Comparison and Accuracy:
The ARSCL cloud top height product should be considered a lower bound on the cloud top height. In general, the MMCR has trouble detecting very high clouds, and the MPL will miss high clouds if low, thick clouds are present. The most accurate comparisons and analysis should therefore focus on single layer clouds at any altitude of optical depths <=1. For these cases, the ARSCL product is expected to be accurate to better than ~100m.

Supporting Documents: Clothiax et al., JAM, **39**, pp 645-665, 2000.

Funding: TBD

6 SCHEDULE OVERVIEW

6.1 CRIS SCHEDULE

6.2 PLANNED FIELD CAMPAIGNS

6.3 OTHER SATELLITE SCHEDULES

6.3.1 NASA AQUA

6.3.2 IASI

6.3.3 NASA EO-3 (GIFTS)

6.3.4 NOAA GOES

6.3.5 NOAA POES

Appendix A: Space-based instrument validation using the npoess Aircraft sounder testbed (NAST) and scanning high resolution interferometer sounder (SHIS) airborne sensors

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1.0 Introduction

1.1 The need for validation

The National Polar-orbiting Operational Environmental Satellite System (NPOESS) is a joint NASA, NOAA, and DOD program merging the current POES & DMSP systems into a common system (i.e. NPOESS) of polar satellites with the goal of providing meteorological and other environmental data products operationally. The Earth Observing System (EOS) is an international multi-satellite program for global remote sensing of the Earth, with a mission goal to advance the scientific understanding of the Earth system (i.e., including land, oceans, and atmosphere) as well as the influences of natural and anthropogenic processes on this system. In order to achieve these goals, these programs must produce accurate and precise long-time series of radiometric measurement data from multiple instruments on multiple platforms. Understanding and correctly interpreting these data require the ability to separate geophysical variability from instrument response changes in the observed signal during the missions. This requires a detailed instrument system-level characterization pre-launch, as well as extensive in-flight calibration and validation activities. Validation is the process of specifying the transformations required to extract estimates of high-level geophysical quantities from calibrated basic instrument measurables (i.e. radiances) and specification of the uncertainties in the high-level geophysical quantities. It requires detailed knowledge of the relationship between measurables and geophysical quantities of interest over the full range of possible observable conditions.

1.2 Advantage of airborne observations

Field validation measurements from high-altitude airborne sensors are critical for successful space-based instrument validation, since only observations from such platforms can provide the proper spatial & temporal context needed as well as be used to simulate expected satellite measurements for the instrument being validated. The higher spectral and spatial resolution aircraft sensor data can be spectrally and spatially convolved, respectively, to simulate what should be measured by the concurrent satellite observations during overpass events. The much higher spatial resolution of the aircraft sensor data can play an important role in validating satellite-derived data products under the conditions of variable surface and atmospheric radiance (e.g., due to clouds) within the satellite sensor footprint.

1.3 Overview and purpose of NAST & SHIS sounding sensor suite

The National Polar-orbiting Operational Environmental Satellite System (NPOESS) Atmospheric Sounding Testbed (NAST) is a suite of airborne infrared and microwave spectrometers, developed for the Integrated Program Office (IPO), that has been flying on the NASA high altitude ER-2 aircraft as part of the risk reduction effort for NPOESS. In addition to their stand alone scientific value, data from these airborne instruments have been used to simulate possible satellite-based radiance measurements, therefore enabling experimental validation of instrument system specifications and data processing techniques for future advanced atmospheric remote sensors (e.g., CrIS, the proposed sounder component for NPOESS). The NAST-I is a high resolution Michelson interferometer that derives its heritage from the nonscanning High resolution Interferometer Sounder (HIS) developed by researchers at the University of Wisconsin and serves as one important component of the NAST instrument suite. It scans the Earth beneath the ER-2 with a nominal spatial resolution of approximately 2.5 km within a cross-track swath width of about 46 km; its unapodized spectral resolution of 0.25 cm-1 within the 3.6 - 16.1 micron spectral range will enable experimental simulation of future infrared sounding instruments. NAST-M is the microwave component of NAST, currently with channels covering the 54 & 118 GHz oxygen bands; this microwave component enables atmospheric sounding in the presence of clouds. The Scanning High –resolution Interferometer Sounder (S-HIS) is an angular scanning Michelson interferometer also deriving its heritage from the non-scanning HIS instrument. While initially developed for operation on an unpiloted aircraft, S-HIS has flown on both the NASA DC-8 & ER-2 platforms. NAST-I & -M have both participated in the Wallops98, CAMEX-3, and WINTEX field measurement campaigns, and S-HIS served as an integral part of both CAMEX-3 & WINTEX. The NAST & SHIS are validated airborne sensors that are available to: support NPOESS sounding instrument (i.e., CrIS & ATMS) development & validation activities; serve as an EOS Validation Tool (e.g., AIRS, CERES, MODIS, MOPITT, & TES); provide mesoscale Earth science observations (from field experiment campaigns, e.g. CAMEX-3, WINTEX, and other flights of opportunity, e.g. Wallops98/99); as well as to serve as an engineering testbed for infusion of new technology (i.e., to explore enhancing airborne sounding; optimizing space-based sounding performance; and applicability toward other measurements, e.g. chemistry).

2.0 Validation approach

2.1 Overview & goals

Validation is the process of assessing by independent means the uncertainties of derived geophysical data products from instrument system outputs. This is generally approached by direct comparison with independent correlative measurements from ground-based networks, comprehensive test sites, and field campaigns; along with comparisons with independent satellite retrieval products from instruments on the same and different platforms. Pre-launch activities usually focus on algorithm development and characterization of instrument uncertainties, while post-launch emphasis is on algorithm refinement and measured/retrieved data product assessments. It is essential to have an integrated strategy for validation, including contributions from airborne field campaigns, surface networks, as well as satellites. LEO satellites provide measurements within a spatial context, while surface networks bring in the temporal context; airborne field measurements, however, provide both spatially & temporally registered observations from a configuration geometry (i.e. nadir viewing) similar to the space-based sensor being validated. Multi-platform observation campaigns can provide simultaneous radiometric and geophysical parameter measurements over spatially and spectrally homogeneous Earth scenes enabling validation of the on-orbit satellite radiometric calibration as well as geophysical parameter retrieval validations. The overall goal is to enable a timely assessment of data product uncertainty for the new space-based sensor being validated.

2.2 NAST-I, NAST-M, & SHIS airborne sensors

2.2.1 Measurement & science objectives

The primary focus of the combined NAST & SHIS payload will be to provide upwelling infrared and microwave radiance measurements and retrieved geophysical parameters to assist with or enable the following:

- ✓ accurate, spatially & temporally registered infrared & microwave calibrated radiance spectra for observed Earth scenes
- ✓ detailed characterization of atmospheric thermal and moisture structure, under clear to cloudy conditions
- ✓ radiative trace gas detection & transport (e.g. O3, CO, CH4, N2O, CO2)
- ✓ biomass burning studies: atmospheric radiative impact; radiative temperatures of fires; and Earth scene type classification

- ✓ NPOESS IPO instrument and forward model pre-launch specification optimization and post-launch calibration/validation (e.g. CrIS & ATMS)
- ✓ EOS instrument and forward model calibration/validation (e.g. CERES, MODIS, MOPITT, AIRS, TES)
- ✓ NAST-I, NAST-M, & S-HIS instrument performance verification/calibration/validation
- ✓ synergistic retrieval studies (e.g., NAST-I + NAST-M, MAS + S-HIS), including other platform measurements,etc.)
- ✓ EOS & NPOESS follow-on sensors for T, H2O, & chemistry: instrument concept definition and optimization studies
- ✓ advanced geostationary Earth orbit (GEO) sounding & chemistry applications: instrument concept definition and optimization studies

2.2.2 Data products

The following radiance and geophysical data products may be obtained from field implementation of the NAST-I, NAST-M, and S-HIS instrument suite:

<u>Direct Products</u>

- ✓ calibrated radiances (IR & U-wave)

<u>Derived Products</u>

- ✓ atmospheric temperature profiles
- ✓ atmospheric water vapor profiles
- ✓ surface temperature & emissivity
- ✓ cloud properties (altitude, temp. & emiss., LWP, effective particle size)
- ✓ tropospheric species column concentrations & some profiling (e.g. ozone, carbon monoxide, methane, & water vapor)
- ✓ atmospheric transport via H2O winds
- ✓ aerosol IR optical depth

2.2.3 Observation platforms

Up until this point, NAST-I & NAST-M have flown exclusively on NASA's high-altitude ER-2 aircraft. SHIS has flown the bulk of its time on the NASA DC-8 (i.e. during the CAMEX-3 field mission), while also having several flights on the ER-2 (i.e., during WINTEX). Plans are currently underway to enable accommodation of NAST-I & NAST-M on the new high-altitude Proteus aircraft. In addition to enabling flight opportunities when the ER-2 is booked, the Proteus has several beneficial flight attributes making it very attractive stand-alone or for flying combined sorties with the ER-2 during field deployments. The Proteus-unique platform attributes include:

- Ultra-fine and variable spatial resolution by not being constrained with a minimum flight altitude
- Improved geophysical data product quality with increased sample averaging afforded by slower ground speed
- Extended time observation capability of pollution episode evolution and transport processes with long duration flight capability
- Measurement altitude profiling capability using platform cruise altitude variations

Further complementary benefits may be achieved by combining Proteus flights with ER-2 field deployments, including:

- Inter-platform validation capability
- Radiation Divergence (cooling rate) measurements via formation flying at different levels
- Enhanced total measurement set through combined instrument diversity
- Extend effective swath width of airborne remote sensing observations through offset formation flying
- Broader spatial scale coverage through varying simultaneous flight patterns

2.2.4 Data archive and dissemination

The NASA LaRC DAAC will be used as a focal point for data archiving and dissemination. Other data products, such as experimental retrieved quantities, and miscellaneous instrument information will be available from the official NAST web page residing at NASA LaRC. The LaRC NAST-I page will also provide virtual links to the

SHIS and NAST-M home pages at the University of Wisconsin and MIT LL, respectively, for access to data products and/or information pertaining to those sensors.

2.3 Other complementary measurements

While the NAST/S-HIS airborne package can play a critical role in future space-based sensor validation, other complementary measurement components (i.e., other measurements from the same or different platforms) may be required depending on the particular validation task being addressed. Additionally, in-situ and ground based remote sensing data (e.g., from the DOE ARM CART sites) can provide independent validation of the airborne data products used to validate the space-based sensors.

Useful contributing measurements may include some of the following:

Ground-based Instruments

1) Surface observations of temperature, humidity, winds, and pressure
2) Radiosondes, for T & H_2O profiles
3) Ozonesondes for direct measurement of Ozone profiles.
4) LIDAR for high vertical resolution H_2O and aerosol profiles in the lower to middle troposphere.
5) Up-looking microwave radiometer for total column H_2O.
6) Up-looking IR interferometer (e.g. AERI) for high resolution spectral measurements and PBL thermodynamic profiles
7) Cloud LIDAR for cloud altitude and thickness.

Airborne Instruments

1) Aircraft in situ spectrometer for IR active trace gases at platform altitude
2) Airborne LIDAR (i.e. LASE) for upper tropospheric H_2O and aerosol profiles; co-incident observations with NAST-I/S-HIS would be invaluable to addressing H_2O spectroscopic issues, particularly in the hard to measure upper troposphere.
3) MAS for much higher spatial resolution to address small-scale scene variability
4) FIRSC for far-IR measurements and cirrus cloud characterization
5) MicroMAPS for measurements of layer integrated CO amounts
6) MIR for microwave measurements of water vapor profiles

2.4 Objectives for data usage

Space-based instrument validation tasks can be divided into two categories, pre-launch and post-launch activities. For both of these categories, multi-instrument field experiment data are needed to address validation goals such as the following:

Pre-launch activities

1) Spectroscopic validation
2) Forward model test & development

3) Catalogue spectral information about clouds/homogeneous land surfaces
4) Investigate land surface inhomogeneity effects
5) Algorithm/data system verification and error analysis

Post-launch activities

1) Absolute calibration for and validation of radiance products
2) Spectroscopic validation
3) Forward Model Validation and refinement
4) Validation of retrieved geophysical parameters under varying surface types and atmospheric conditions

3 Planned experiments

3.1 Space-based missions

Figure 1 summarizes the transition of the POES & DMSP sensors into the NPOESS operational fleet. It also shows the EOS AM-1 & PM-1 platforms and how the NPOESS Preparatory Platform (NPP) to be launched in 2005 will "bridge" sounding observations between the PM-1 AIRS/AMSU (scheduled for launch in 2001) and NPOESS CrIS/ATMS (scheduled for launch in 2008) sensors.

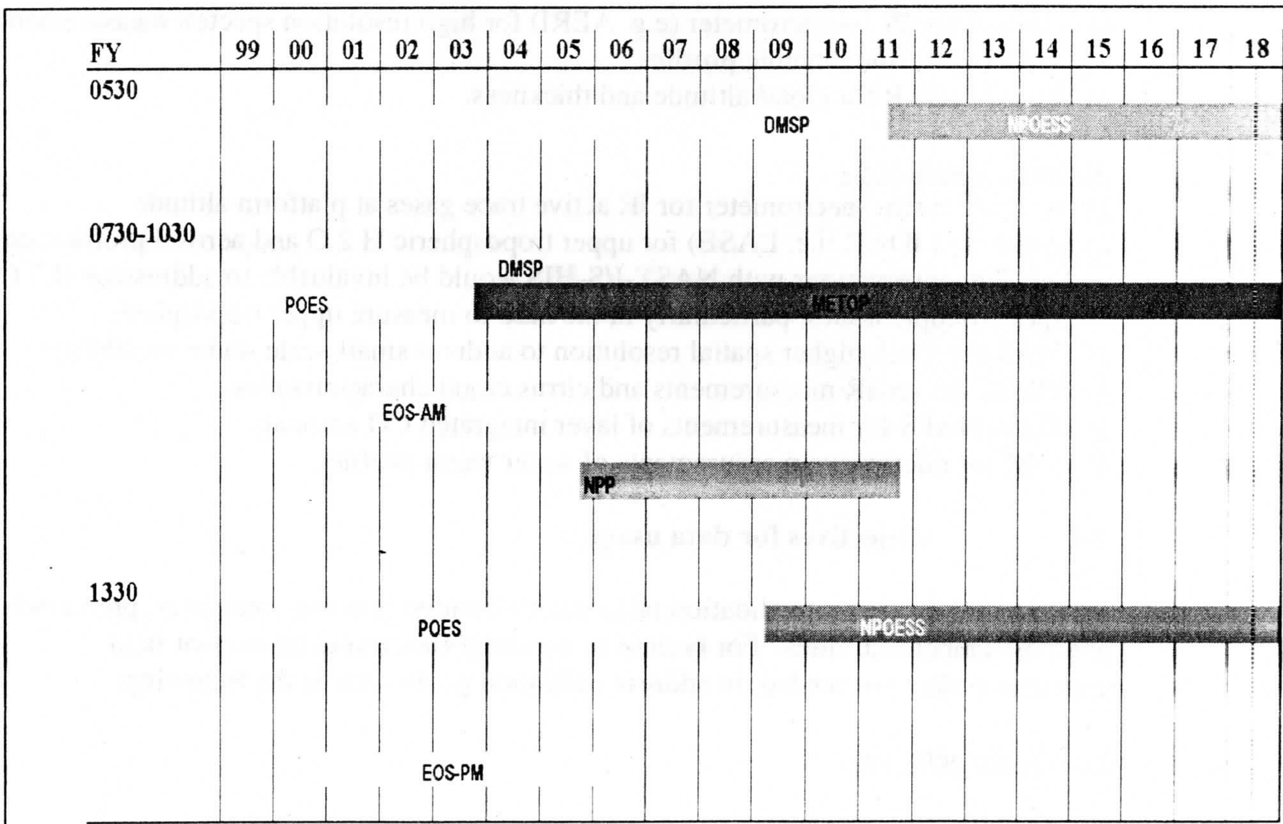

Figure 1: Polar Orbiting Earth Remote Sensing Mission Profile

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Space-based missions which would greatly benefit from including the NAST & S-HIS airborne sounding suite in their field validation programs include:

Terra (a.k.a. EOS AM-1, 08/1999) CERES, MODIS, MOPITT
The Terra satellite is the flagship of EOS. It will provide global data on the state of the atmosphere, land, and oceans, as well as their interactions with solar radiation and with one another.

METEOR 3M-1 (SAGE III - 12/1999)
The SAGE III mission on the Russian Meteor 3M-1 spacecraft seeks to enhance our understanding of natural and human-derived atmospheric processes by providing high latitude long-term measurements of the vertical structure of aerosols, ozone, water vapor, and other important trace gases in the upper troposphere and stratosphere.

EOS PM (12/2000) AIRS, AMSU, CERES, MODIS
The focus for the EOS PM satellite is the multidisciplinary study of the Earth's interrelated processes (atmosphere, oceans, and land-surface) and their relationship to Earth system changes.

ADEOS II (12/2000) ILAS-2
The Advanced Earth Observing Satellite II (ADEOS II), the successor to the Advanced Earth Observing Satellite (ADEOS) mission, is a joint mission with the National Space Development Agency (NASDA) of Japan. The mission will take an active part in the research of global climate changes and their effect on weather phenomena.

SAGE III (2001 Flight of Opportunity - 2001)
SAGE III (Stratospheric Aerosol & Gas Experiment) is the fifth in a series of spaceborne remote sensing instruments developed by NASA's Langley Research Center for monitoring global distribution of aerosols and gaseous consitiuents using the solar occultation approach.

International Space Station (SAGE III - 10/2002)
The SAGE III mission on the Space Station seeks to enhance our understanding of natural and human-derived atmospheric processes by providing high latitude long-term measurements of the vertical structure of aerosols, ozone, water vapor, and other important trace gases in the upper troposphere and stratosphere.

EOS Chemistry (12/2002) TES, MLS, HIRDLS
The EOS Chemistry-1 satellite will focus on measurements of atmospheric trace gases and their transformations. The objective of the mission is to study the chemistry and dynamics of the Earth's atmosphere from the ground through the mesosphere.

Earth System Science Pathfinders (2003+) PICASSO-CENA, CloudSat
The Earth System Science Pathfinder (ESSP) Project is a component of the Earth Science Enterprise (ESE) that addresses unique, specific, highly-focused mission requirements in Earth science research.

NMP EO-3 (2004) GIFTS
Geostationary sounding and/or chemistry mission currently under study. GIFTS would provide first high spectral resolution mesoscale meteorological profiles and cloud optical and geometric property observations with high temporal frequency.

NOAA polar series HIRS, AMSU, AVHRR
polar-orbiting meteorological operational satellites; K (launched 5/13/98), L (12/99), M (5/2001), N (12/2003), N' (1/2008)

METOP polar series IASI, MHS, AVHRR
polar-orbiting operational meteorological satellites; 1 (6/2003), 2 (SPR/2008)

NPOESS platforms NPP (2005), NPOESS (2008 & 2011) CrIS/ATMS/VIIRS

GOES platforms ABS, ABI
geostationary operational meteorological satellites; L – Q, 1999 – 2008

3.1 Field deployments

Figure 2 shows the current NASA ER-2 flight schedules for FY99-FY03. Specific field deployments for which the NAST/S-HIS package could significantly contribute toward both field mission science goals and EOS instrument validation include:

Wallops-99	East Coast USA	NAST, AVIRIS, INTESA	Aug/99
SCAR-99	Pacific NW	MOPITT, MAS	Oct/99
CALVEX-M	CART/GMEX	MAS, CLS, SHIS MOPITT-A (ER-2) NAST, FIRSC (Proteus)	Mar-Apr/00
SAFARI-2000	South Africa	MAS, CLS, SHIS MOPITT-A (ER-2) NAST, FIRSC, Micro-maps (Proteus)	Aug-Sep/00
CRYSTAL	Guam	NAST, MAS, CLS, LASE, S-HIS	Jul-Aug/01 or 02
CAMEX-4	PAFB, FL	NAST, MAS, CLS, SHIS	Aug-Sep/01 or 02

We propose to fly NAST/S-HIS on the Proteus aircraft to participate in the above field deployments as well as for new campaigns (TBD) focusing specifically on NPOESS sensor underflight validation activities. Flying NAST-I + S-HIS on same platform provides inter-sensor validation, enabling an independent check of infrared radiance spectra quality. However, the maximum benefit from implementing this airborne sounding suite as a space-based instrument validation tool can be achieved by simultaneously flying S-HIS & NAST on two independent high-altitude platforms (e.g. using both the ER-2 & Proteus, as mentioned earlier).

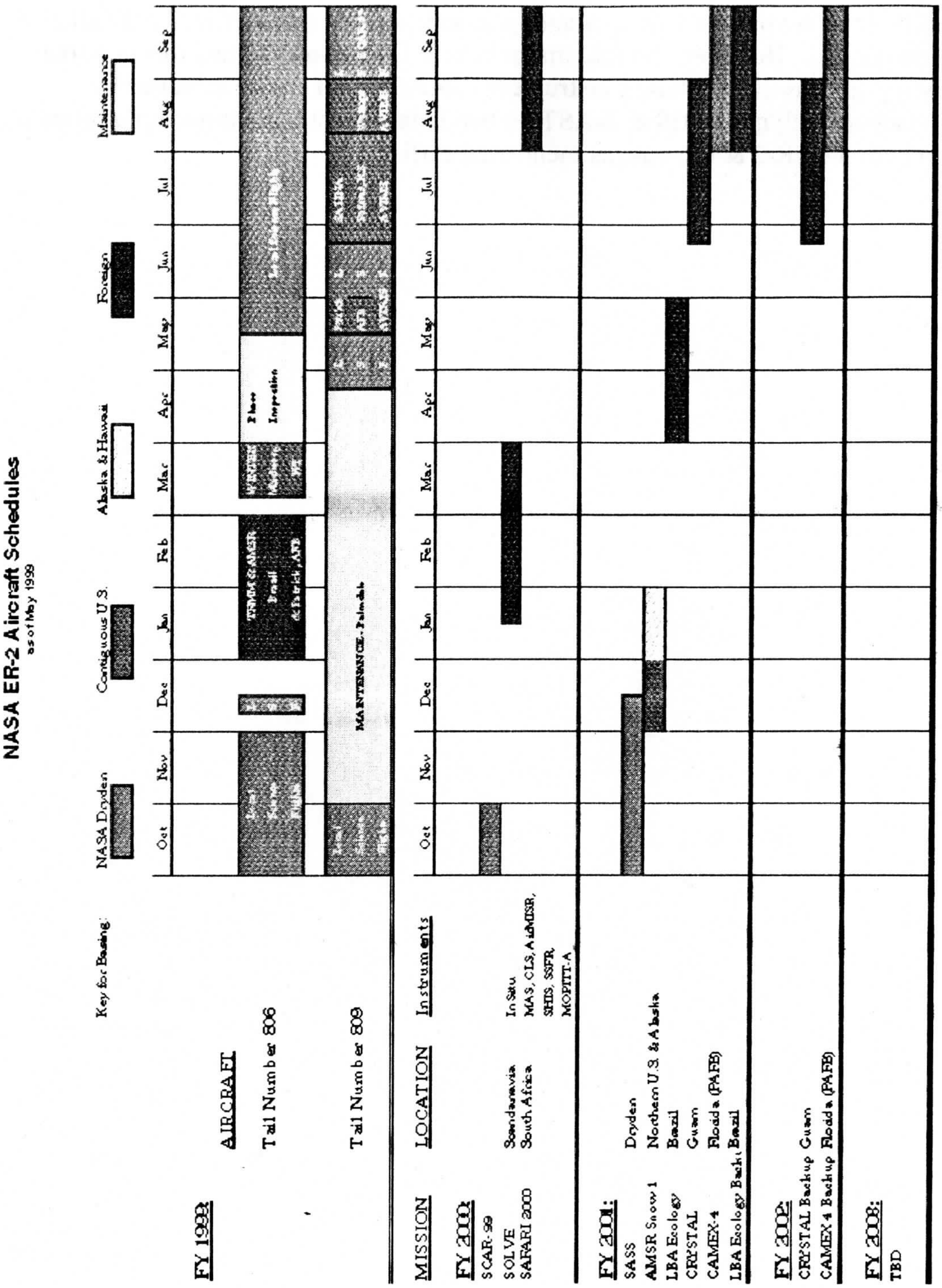

Figure 2: Deployment schedule for NASA's high-altitude ER-2 aircraft.

7 APPENDIX B WATER VAPOR WORKSHOP SUMMARY AND CONCLUSIONS

On November 22-23, 1999, National Environment Satellite and Data Information Service (NESDIS) and the National Weather Service (NWS) hosted A Workshop on "Improving Observation and Analysis of Atmospheric Moisture for Operational Weather Forecasting" at the Space Science and Engineering Center, Madison, Wisconsin. The workshop was intended to start activities toward determining the necessary moisture sensing components of national mesoscale observing system of the future and to improve utilization of those measurements for weather analyses, nowcasting and forecasting.

The workshop had presentations on moisture measurements, assimilation of moisture measurements, impact on numerical weather prediction, utilization at forecast offices, and needs for the future. The agenda can be found in Attachment A; attendees are in Attachment B. The major points from the workshop were (a) moisture demonstrates considerable variability in the horizontal and vertical, (b) measurements of total precipitable water (TPW) from different systems agree within 5 – 10%, (c) ground based profile measurements offer new opportunities to depict rapid small scale boundary layer moisture changes, (d) remote sensing at high spectral IR resolution offers the promise of depicting vertical H2O layer patterns, (e) assimilation of moisture information is challenging as all observations are interdependent and influence H2O balance (forecasts are accurate to within 15 – 20% for TPW), (f) moisture profiles are especially useful in NWS Forecast Offices and centers and geo-soundings are very timely for subjective forecasting because pre-storm environments initiate in moist clear skies often near outflow boundaries (which present good opportunities for IR systems), and (g) there is a need for a coherent national program for moisture measurements and NWP utilization.

Relevant parts of the conclusions from the workshop are appended.

1. Moisture measurements of TPW from different systems agree within 5 – 10%
   Differences are beginning to be understood

2. AERI boundary layer temperature / moisture profiles every ten minutes are providing good mesoscale data sets from CART deployment
   2a. A network of AERIs along the coast of the Gulf of Mexico could provide valuable information on moisture intrusions into the continent and possible return flow

3. Bias from sonde to sonde is being characterized (e.g. Viz sondes have moist bias)

   3a. More accurate sondes, even at only selected sites, are needed for validation of many moisture measurements
   3b. There is an evolution to better definition of sonde performance from more intercomparisons with other profile measurements (more colocations with GPS were encouraged)

4. Water vapor lidar measures boundary layer H2O profiles within 5%
   4a. A low cost DIAL version is under development

5. WVSS are producing about 1500 moisture profiles per day from six aircraft
   5a. Sep-Oct 99 Louisville field experiment showed WVSS data comparing well with raobs

5b. The number of units installed are expected to increase rapidly in 2000 on UPS and American Airlines

5c. A second generation WVSS will be ready for testing in 2000

5d. The concept of an atmospheric sounding system (including WVSS, AERI, DIAL, sondes, GOES, POES,...) covering the Eastern US is under consideration

6. Ground based GPS are measuring total column moisture (there is good potential for use as stable reference)

6a. Biases with respect to other measurements are under investigation

6b. A GPS network of 18 units provided small positive impact in the RUC during a test period (the RUC already included GOES TPW)

6c. GPS offers geometric validation of other measurements

6d. 59 GPS are operating in (a demonstration network of more than 200 is planned in 3 to 5 years)

6e. There is some progress being made in reducing the data delay

6f. The combination of GPS and GOES PW is largely untapped

6g. Explore BUFR distribution in real time to NWP centers via GTS (action)

7. Remote sensing at high spectral IR resolution is revealing vertical H2O patterns

7a. Information content is approaching radiosonde-like

7b. Surface emissivity can be separated from Ts (with an on line off line analysis) assisting use of radiances over land

7c. Determination of cloud heights are improved

7d. Advent of AIRS, IASI, CrIS requires preparations for successful assimilation

8. GOES moisture measurements in NWP are providing positive impact

8a. Three layers of moisture from GOES-8/10 are going in to the Eta

8b. Modest but consistent positive impact has been realized (5% improvement in equitable threat score during wet season)

9. Assimilation of moisture information is challenging

9a. Forecasts are within 15 – 20%

9b. all observations (wind, temperature, moisture,...) are interdependent and influence the H2O balance

9c. Discriminating moisture flux from motion and static H2O is important

9d. There is a need for moisture observation impact tests

9e. The combination of IR and microwave measurements is more powerful than either by itself

9f. Each new measurement system (or existing ones not being used) requires at least one person two years for introduction to NWP operations, plus ther are ongoing maintenance considerations

10. EDAS testing suggests positive impact from all sensing systems in ops

10a. Removal of remote sensing assets would have negative impact of the forecast

11. Physics in the forecast model is most important part of moisture assimilation

11a. Assimilation of new systems often requires improved physics in model

12. A Composite Moisture Observing System is necessary (components complement but don't replace one another)

12a. Adequate horizontal, vertical, and temporal sampling necessitates a composite system

12b. Remote sensing from ground, satellite radiances, and in situ aircraft all play an important role

12c. Placement of continuous between intermittent observation systems should be considered (e.g. AERI between airports)

12d. Geographical complementarity must also be considered

13. NWS-Forecast Offices are deriving benefit from geo-soundings in subjective forecasting

13a. Pre-storm environments initiate in moist clear skies often near outflow boundaries (thus presenting good opportunities for IR systems)

13b. More meso-scale data assimilation efforts are needed for forecasters in the field

14. Better initialization of clouds in NWP is showing promise

14a. This merits more attention but is complicated by cloud-moisture physics interactions

14b. Soundings above clouds need to be generated in operations and their utility needs to be explored further

15. A matrix of observing systems is needed to effectively summarize current and future opportunities

15a. It must include hor res, vert res, cycle time, delay time, accuracy, bias, profile domain, cost, maturity, financial status, external collaboration

15b. Oct 99 BAMS article by T. Weckworth provides background information

16. There is no coherent program for moisture measurements and NWP utilization

16a. There is a need for NESDIS & OAR & NWS coordination

16b. Proven observing systems need to be posted in a demonstration area (phased demonstration would occur as new observing systems become available)

16c. A Moisture Program in phases would look something like the following (including forecast office assessment, 4DDA development, and model physics investigations)

16c1. 2000 CART Site Campaign with mesoscale model studies

16c2. 2002 start of Eastern US Network line of observations along Gulf of Mexico with regional scale model studies

16c3. Therafter establish an observing network over the Eastern US (maximizing use of newly launched satellite assets)

8 APPENDIX C: GLOSSARY OF TERMS

ABBA - Automated Biomass Burning Algorithm

ABI – Advanced Baseline Imager
ABS – Advanced Baseline Sounder
ACARS - Aeronautical Radio Incorporated Communications Addressing and Reporting System
AERI - Atmospheric Emitted Radiance Interferometer
AIREP - AIRcraft REPort
AIRS - Atmospheric Infrared Sounder
AMDAR - Aircraft Meteorological Data Relay
AMSU – Advanced Microwave Sounding Unit
ARAD – Atmospheric Research and Applications Division
ARM - Atmospheric Radiation Measurement (DOE)
ASOS - Automated Surface Observing Stations
ASPT – Advanced Satellite Products Team (ORA)
ATS - Applications Technology Satellites
AVHRR - Advanced Very High Resolution Radiometer
AWC – Aviation Weather Center
AWIPS - Advanced Weather Interactive Processing System
CART – Clouds and Radiation Testbed
CICS – Cooperative Institute for Climate Studies
CIMMS – Cooperative Institute for Mesoscale Meteorological Studies
CIMSS - Cooperative Institute for Meteorological Satellite Studies
CIPSU - Cooperative Institute at Pennsylvania State University
CIRA - Cooperative Institute for Research in the Atmosphere
COMET - Cooperative Program for Operational Meteorology, Education and Training
CONUS - Continental United States
CRAD – Climate Research and Applications Division
CrIS - Cross track Infrared Sounder
CST - Convective Stratiform Technique
DMSP - Defense Military Satellite Program
DPI – Derived Product Image
EDAS – Eta Data Assimilation System
EMC - Environmental Modeling Center
EOS – Earth Observing System
ERBE - Earth Radiation Budget Experiment
ERB - Earth Radiation Budget Satellite
ERL - Environmental Research Laboratory
ESA - European Space Agency
EUMETSAT - EUropean organization for the exploitation for METeorological SATellites
FAA - Federal Aviation Administration
FPA - Focal Plane Arrays
FPDT – Forecast Products Development Team (ORA)
FSL - Forecast Systems Laboratory of ERL
FTS – Fourier Transform Spectrometer
FOV - field of view
GCIP – GWEX Continental scale International Project

GDAS - Global Data Assimilation System
GFDL – Geophysical Fluid Dynamics Laboratory
GHCC - Global Hydrology and Climate Center
GIFTS – Geostationary Imaging Fourier Transform Spectrometer
GMS - Geoststionary Meteorological Satellite (Japan)
GOES - Geostationary Operational Environmental Satellite
GPS – Global Positioning System
GSFC - Goddard Space Flight Center
GWEX – Global Energy and Water Cycle Experiment
HIRS - High resolution Infrared Radiation Sounder
HIS - High spectral resolution Interferometer Sounder
HT – Hydrology Team (ORA)
IASI - Infrared Atmospheric Sounding Interferometer
IFFA - Interactive Flash Flood Analyzer
INR - Image Navigation and Registration
IRIS - Infrared Radiation Interferometer Spectrometer
ISCCP - International Satellite Cloud Climatology Project
LAPS - Local Area Prediction System
M-AERI - Marine AERI
METEOSAT - METEOrological SATellite
METOP - Meteorological Operational Platform
MIMR - Multifrequency Imaging Microwave Radiometer
MISR - Multi-angle Imaging Spectro-Radiometer
MODIS – Moderate resolution Imaging Spectroradiometer
MSFC - Marshall Space Flight Center
MTF - modulation transfer function
MTSAT - Multi-functional Transport Satellite
NASA - National Aeronautics and Space Administration
NCAR – National Center for Atmospheric Research
NCDC - National Climate Data Center
NCEP - National Center for Environmental Prediction
NEDT - noise equivalent temperature
NESDIS - National Environmental Satellite Data and Information Service
NMC - National Meteorological Center
NOAA - National Oceanic and Atmospheric Administration
NORPEX – Northern Pacific Experiment
NOVA - NOAA Operational VAS Assessment
NPOESS - National Polar-orbiting Operational Environmental Satellite System
NWS - National Weather Service
NWSTC - National Weather Service Training Center
OAR - Office of Oceanic and Atmospheric Research
OGE - Operational Ground Equipment
ORA - Office of Research and Applications
ORAD – Ocean Research and Development Division
OSD – Office of Systems Development
OSDPD - Office of Satellite Data Processing and Distribution

POP - Product Oversight Panel
QI - Quality Indicator
QPF – Quantitative Precipitation Forecast
RAMMT - Regional and Mesoscale Meteorology Team (ORA)
RAMSDIS - Regional and Mesoscale Meteorology Branch Advanced Meteorological Satellite Demonstration and Interpretation System
RDAS - Regional Data Assimilation System
RFF – Recursive Filter Flag
RUC – Rapid Update Cycle
SAB – Synoptic Analysis Branch (OSDPD)
SAO - Systems Acquisition Office
SCP – Satellite Cloud Product
SOCC - Satellite Operations Control Center
SOO - Science Operations Officers
SPC - Storm Prediction Center
SPOP - Sounding Product Oversight Panel
SPOT - Systeme Probatoire d'Observation de la Terre satellite
SPSRB - Satellite Products and Services Review Board
SSMI - Special Sensor Microwave/Imager
SSMT - Special Sensor Microwave/Temperature
SST - Sea Surface Temperature
SSU - Stratospheric Sounding Unit
TAC – Technical Advisory Committee
TIROS - Television InfraRed Operational Satellite
TOA - Top of the Atmosphere
TOMS - Total Ozone Mapping Spectrometer
TOVS - TIROS Operational Vertical Sounder
TPC - Tropical Prediction Center
TRMM - Tropical Rainfall Measuring Mission
VAS - VISSR Atmospheric Sounder
VDUC - VAS Data Utilization Center
VIIRS - Visible Infrared Imager Radiometer Suite
VISSR - Visible and Infrared Spin Scan Radiometer
VORTEX - Verifications of the Origins of Rotation in Tornadoes Experiment
WSFO - Weather Service Forecast Office

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6. AUTHOR(S)
H.E. Revercomb, R.O. Knuteson, D.C. Tobin, W.P.Menzel, A.M.Larar, W.L.Smith

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Space Science and Engineering Center, U. of Wisconsin
1225 W. Dayton Street
Madison, WI 53706
NOAA/NESDIS/ORA, University of Wisconsin-Madison

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The product validation for CrIS focuses on (1) operational algorithm assessment, and (2) validation of system performance. The NAST and Scanning HIS aircraft instruments are two of the primary tools for performing a product validation; another is the MODIS Airborne Simulator. The Sounder-Operational Algorithm Team is preparing the plan to conduct these activities. With the support of the IPO, the Sounder-OAT provides expertise to assure that performance options and algorithm approaches get reviewed and thoroughly tested with real atmospheric data. The Sounder-OAT will efficiently combine the government and university community ex-perience base with the expertise of the selected vendor for algorithm development.

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