National Polar-orbiting Operational Environmental Satellite System
(NPOESS)

2005 CEOS WGCV 24

NPOESS/NPP Calibration/Validation/Verification Program:

Its Role in Emerging Global Remote Sensing Systems and Its Potential for Improved Numerical Weather Prediction and Climate Monitoring

European Space Research Institute - ESRIN
Frascati, Italy, November 8-11, 2005

Stephen A. Mango
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NPOESS is a Tri-agency Effort to Combine Operational Environmental Polar Satellite Activities

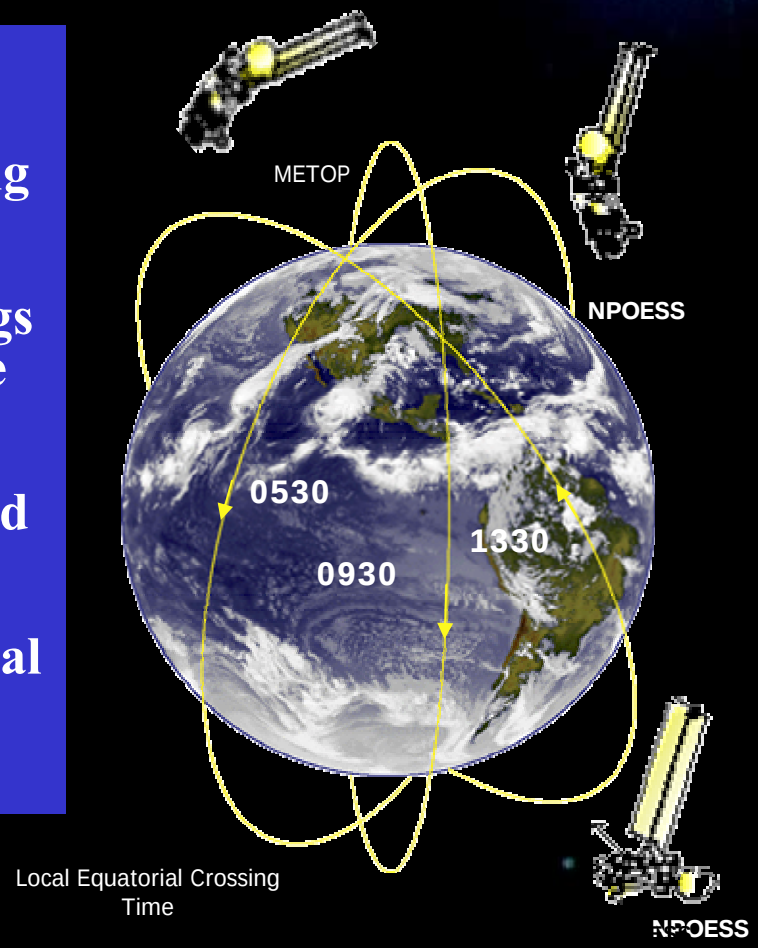
Mission

Provide a national, operational, polar-orbiting environmental capability

Achieve National Performance Review savings by converging DoD and NOAA polar satellite programs

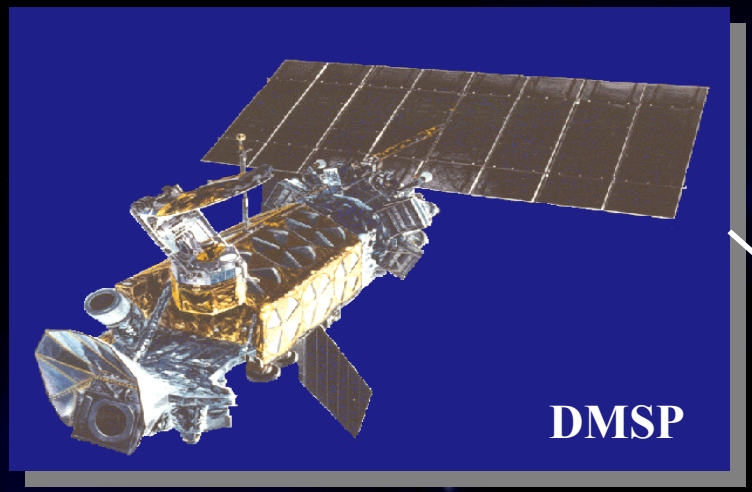
Incorporate new technologies from NASA and others

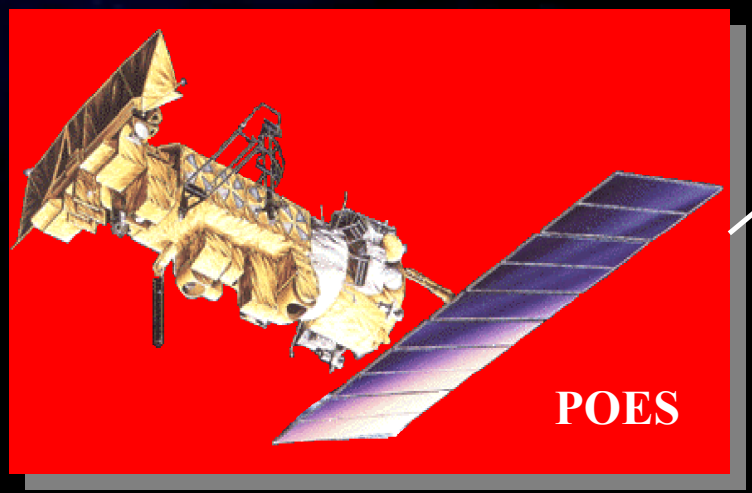
Incorporate, where appropriate, International Cooperation (EUMETSAT)

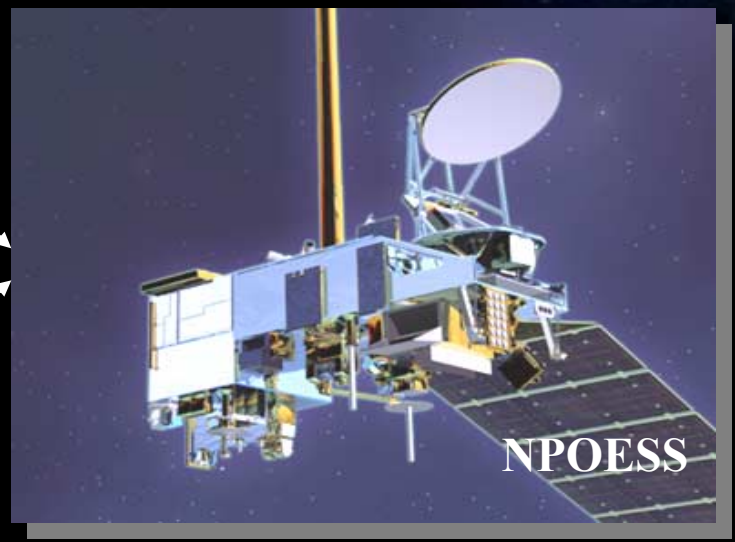


Local Equatorial Crossing Time

DMSP/POES to NPOESS
Convergence / Evolution of Satellite Systems







DMSP/POES to NPOESS
Convergence / Evolution of Missions/Sensors

DMSP

OLS
SSM/I, SSM/T-1, SSM/T-2 or SSMIS
SES

-Imaging
-Sounding
-Space Environment

POES

AVHRR
HIRS
AMSU-A, AMSU-B, MHS
SBUV
SEM
DCS
SARSAT

-Imaging
-Sounding
-Climate
-Ozone
-Space Environment

NPOESS

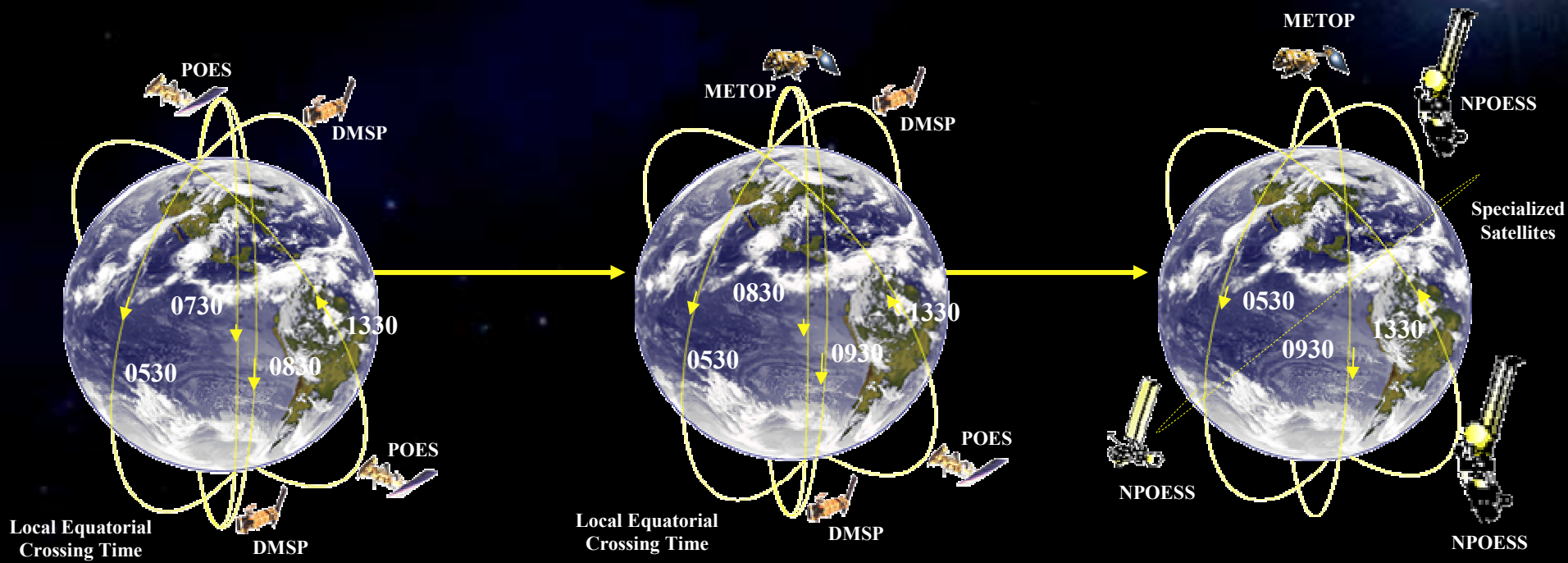
VIIRS
CMIS
CrIS, ATMS
OMPS
SESS
CERES
TSIS
ALT
DCS
SARSAT

-Imaging
-Sounding
-Climate
-Ozone
-Space Environment

Corollary ---- Convergence of Requirements

Operational Satellite System Evolution

U.S. civil and defense programs, working in partnership with EUMETSAT, will ensure improved global coverage and long-term continuity of observations at less cost!



Today

- 2 US Military
- 2 US Civilian

Tomorrow (~2006)

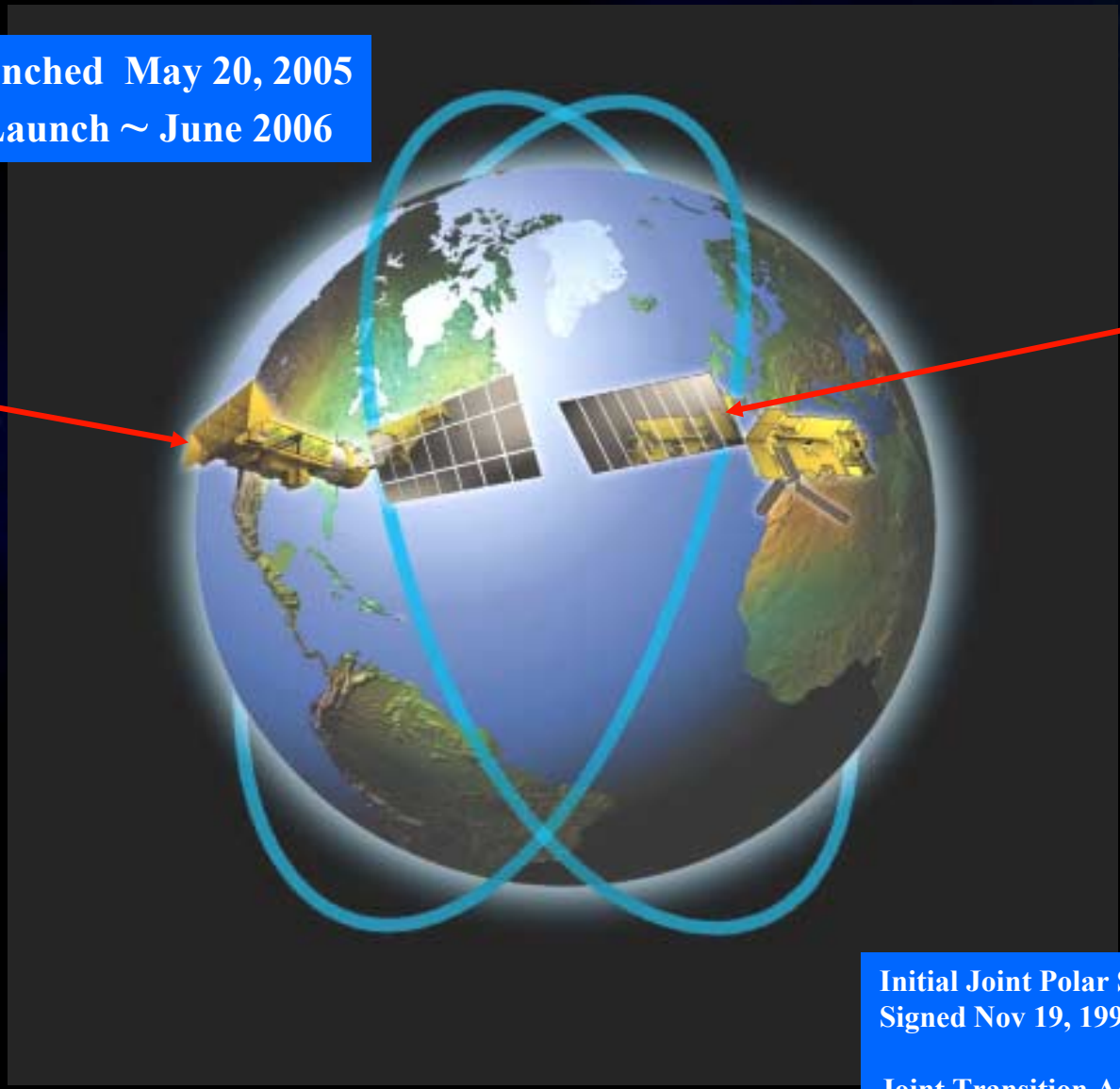
- 2 US Military
- 1 US Civilian and
- 1 European METOP

Future (~2014)

- 3 US Converged
- 1 (or 2)European METOP
- Specialized satellites?

The Initial Joint Polar System [IJPS]

POES N – Launched May 20, 2005
METOP 1 - Launch ~ June 2006



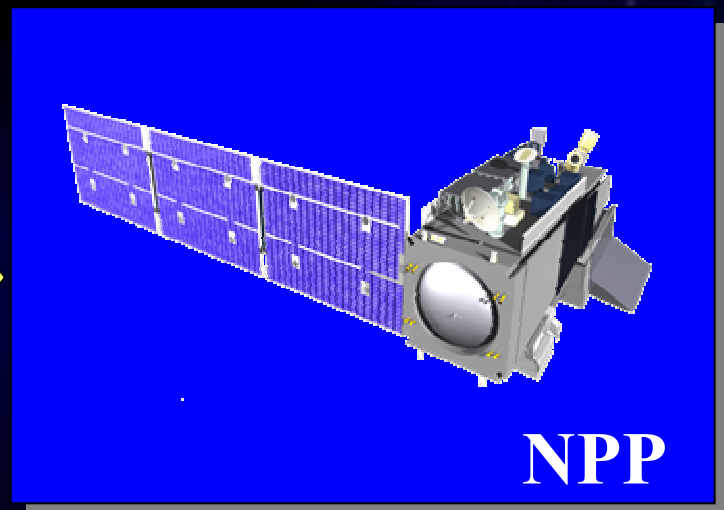
POES N/N'
[NOAA]
HIRS/AMSU/MHS

Metop 1/2
[EUMETSAT]
IASI/AMSU/MHS

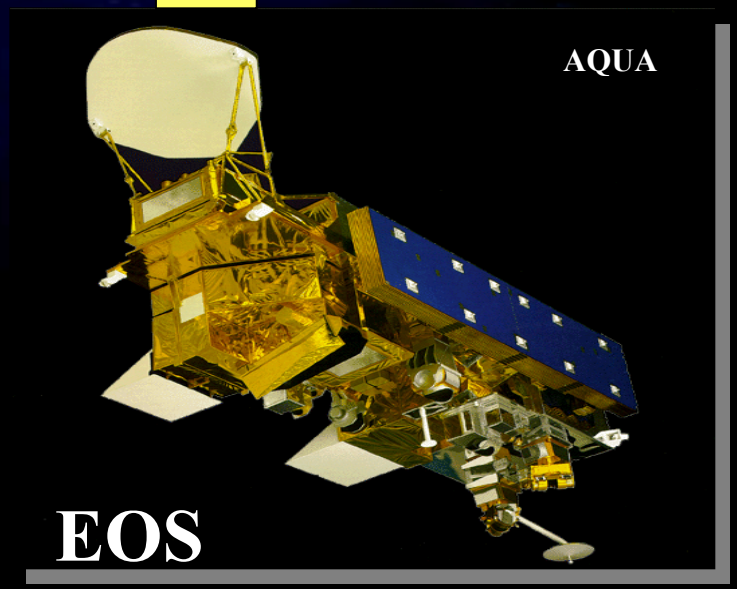
Initial Joint Polar System [IJPS]
Signed Nov 19, 1998 NOAA & EUMETSAT

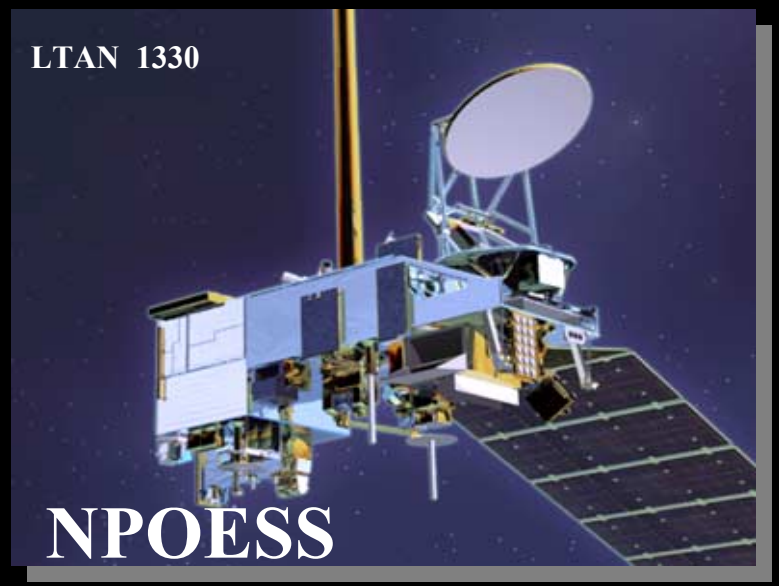
Joint Transition Activities [JTA] Agreement
Signed Jun 24, 2003 NOAA & EUTMETSAT

NPOESS Preparatory Project [NPP]
"Bridge from EOS to NPOESS"



"Bridges EOS & NPOESS Climate Measurement Missions"





NPOESS Preparatory Project (NPP)

NPP Contributions to NPOESS

- **Instrument Risk Reduction** - Early delivery/ instrument level test/system-level integration and test Provides lessons learned and allows for any required modifications in time to Support NPOESS first launch readiness
- **Ground System Risk Reduction**
  - Early delivery and test of a subset of NPOESS-like ground system elements
- **Early User Evaluation of NPOESS Data Products**
  - Provides algorithms/instrument verification and opportunities for instrument calibration/validation
  - Allows for algorithm modification prior to NPOESS first launch

Mission Characteristics

Instruments:
- Visible Infrared Imaging Radiometer Suite (VIIRS)
- Cross-track Infrared Sounder (CrIS)
- Advanced Technology Microwave Sounder (ATMS)
- Ozone Mapper and Profiler Suite (OMPS)

Launch:	October 2006 [FY07]
Orbit:	824 km polar sun-synch, 10:30 am descending node
Launch Site:	Western Test Range
Mission Duration:	5 year/7.5 year consumables

Responsibility Sharing*

IPO	NASA
Joint Program Management	Joint Program Management
VIIRS Instrument/Algorithms	Mission Systems Engineering, Integration, & Test
CrIS Instrument/Algorithms	ATMS Instrument/Algorithms
OMPS Instrument/Algorithms	Spacecraft and Subsystem Integration to the S/C
Command, Communications, Control Segment (C3S)	Launch Vehicle and Associated Activities
Interface Data Processing Segment (IDPS)	Science Data Segment (SDS)
Mission Management and Satellite Operations	Manage NPP Cal/Val for Level 1B and CDRs
Manage NPP Cal/Val [EDRs, SDRs, and EDRs]	Science Support (NRA)
Science Support (IGS,NIP)	

Note: NOAA/NCDC is supporting formulation of Archive and Distribution Segment (ADS).
* As documented in NASA/NOAA/DoD Initial Implementation Agreement, November 27, 1999

Role of NPOESS in the World Scenario

- **NPOESS – Represents**
  - The U.S. next generation, polar-orbiting, Low-Earth-Orbit [LEO] operational, satellite constellation
  - A major portion of the LEO component of a "Future National Operational Environmental Satellite System" for the U.S.
  - Whereas, the GOES-R series represents a major portion of the GEO component of a "Future National Operational Environmental Satellite System" for the U.S.
  - A significant contributing component moving towards an international Global Earth Observation System of Systems [GEOSS].
  - An end-to-end system for Environmental Remote Sensing Observations to contribute to the " Nine Societal Benefits Areas " that are the foundation challenge areas identified for GEOSS

The Global Framework
Global Earth Observation System of Systems (GEOSS)

- A historic series of events have taken place for establishing a global, integrated Earth observing system

- Nations and international agencies of the world have met and agreed to cooperate on developing a cooperative strategy for understanding the Earth's environment and its interaction with the peoples of the planet [Earth Summits]

- Frameworks, plans, and ideas are being drafted in preparation for the next round of meetings in 2006.

"Potential U.S. Contributions to the GEOSS"

What is in the US Plan? - Focus on 9 Societal Benefits Areas

Natural & Human Induced Disasters

Water Resources

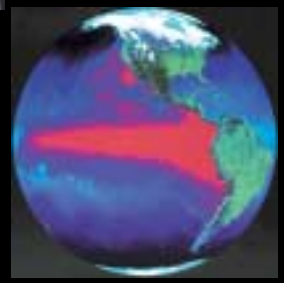
Ecosystems

Human Health & Well-Being

Energy Resources

Sustainable Agriculture & Desertification

Weather Information, Forecasting & Warning

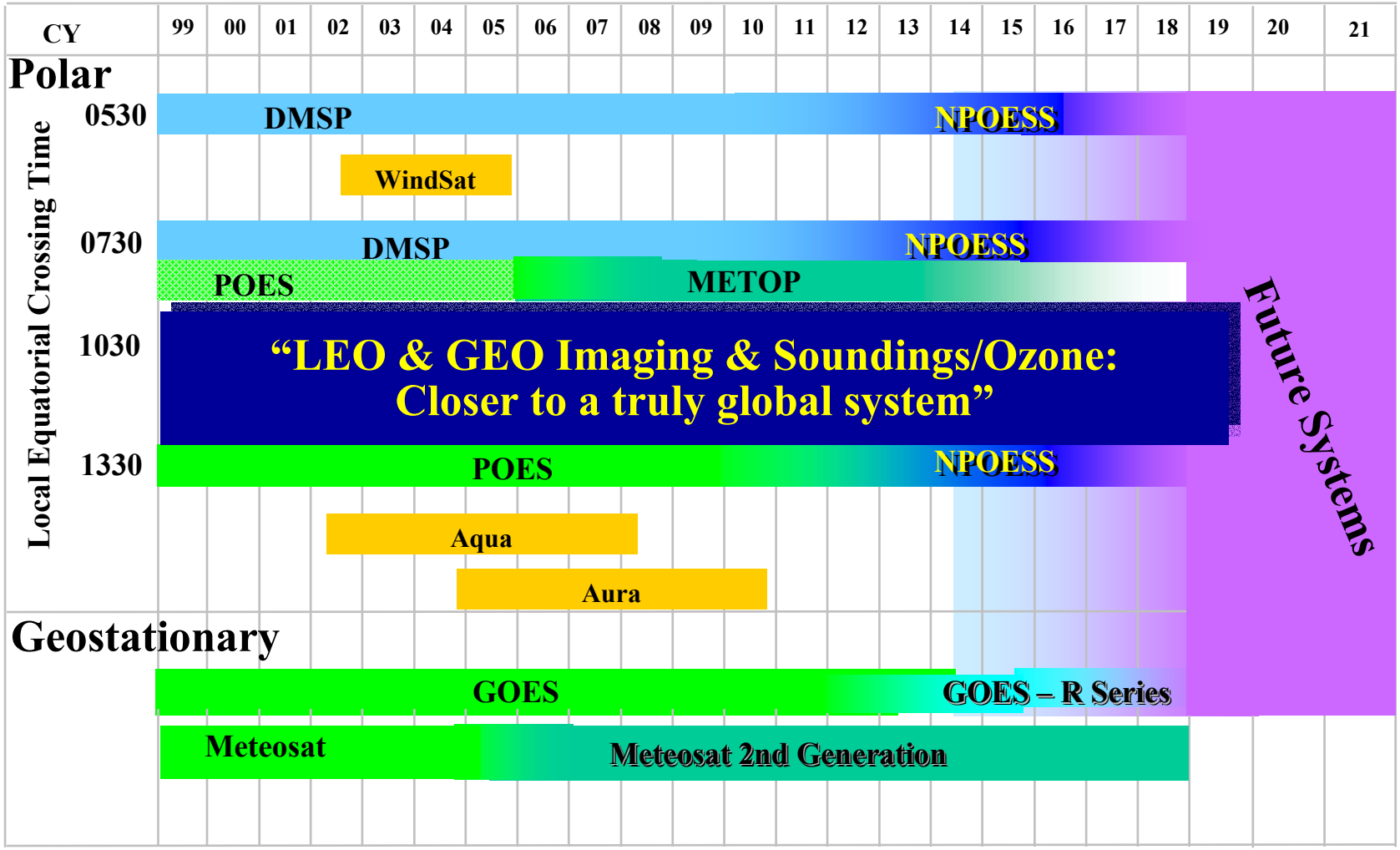


Climate Variability & Change

Oceans

NATIONAL POLAR-ORBITING OPERATIONAL ENVIRONMENTAL SATELLITE SYSTEM

Long-Range Integrated USA/European Satellite Transition



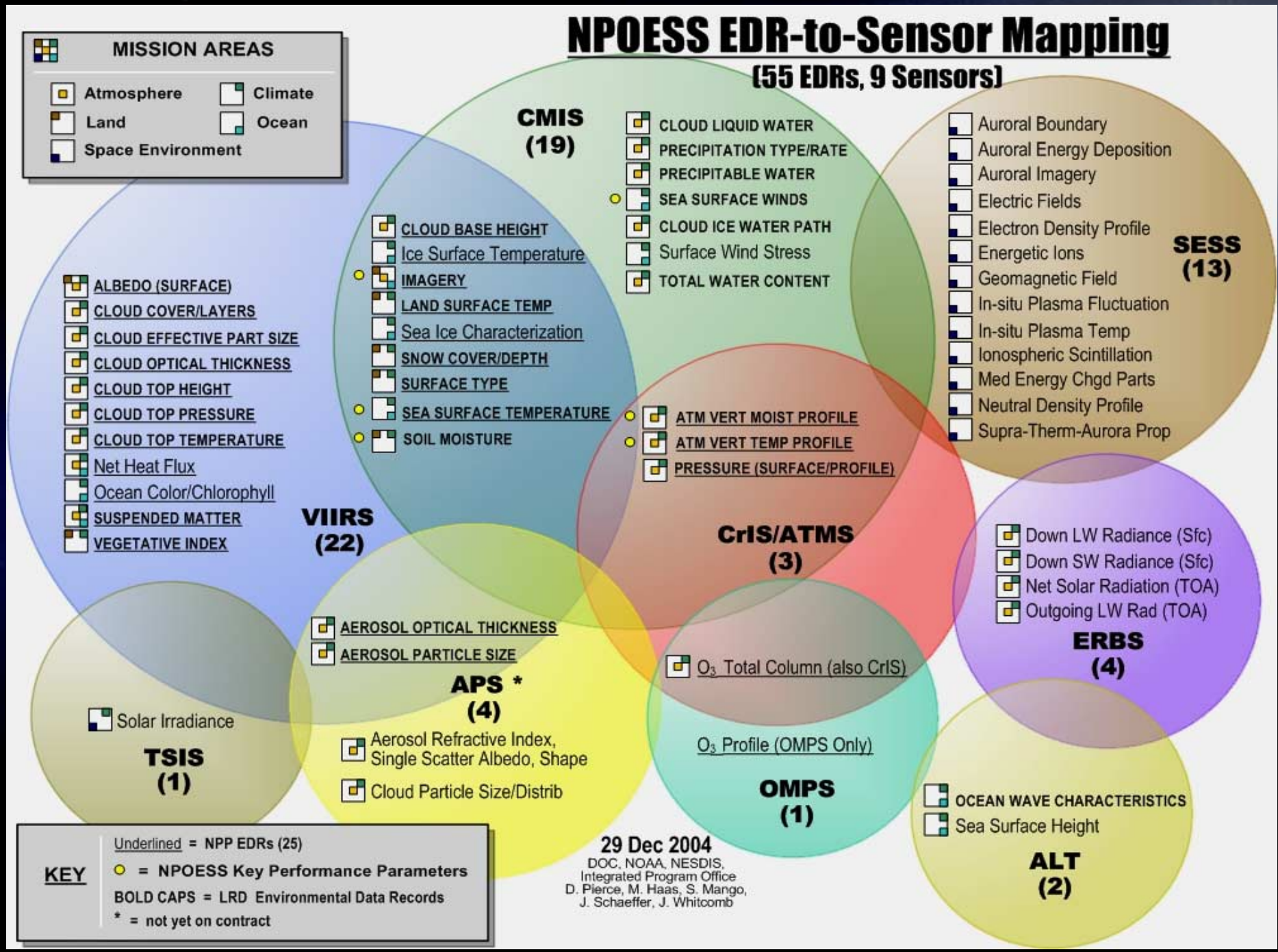
Climate Monitoring & NWP Systems Several Major Components

- Ground/ocean/ice based Systems
- In-situ Systems [radiosondes, rawinsondes]
- Airborne Remote Sensing & In-situ Systems
- Satellite Remote Sensing Systems & In-situ Systems
  - Polar
  - Geostationary
  - Other
- Modeling/Simulation/Assimilation Systems
- Calibration/Validation Campaigns
  Post-Launch Intensive, Intermittent &
  Sustaining Efforts/Campaigns

NPOESS is only one part of one major component of the Satellite Systems that can, should and will contribute to the overall " Climate Mission " & to the "NWP/Weather Forecasting Mission" and hence, to "GEOSS" !!!

NPOESS EDR-to-Sensor Mapping

(55 EDRs, 9 Sensors)



29 Dec 2004

DOC, NOAA, NESDIS,
Integrated Program Office
D. Pierce, M. Haas, S. Mango,
J. Schaeffer, J. Whitcomb

NPOESS Requirements

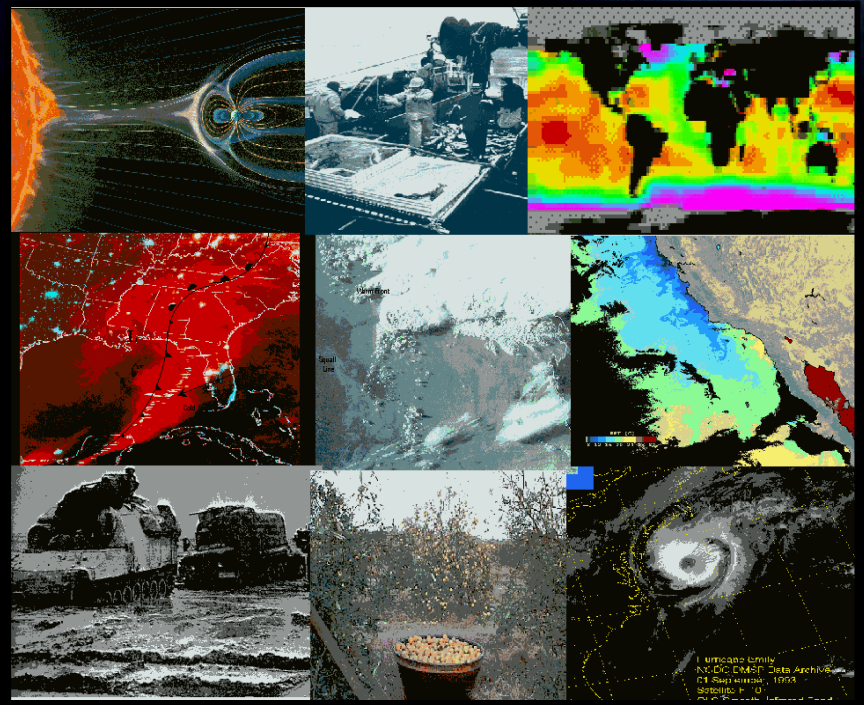
Convergence of Alternatives

- **Integrated Operational Requirements Document (IORD-I)**
  - 59 Data Products
  - 9 Enhancement Products
  - 1 System Characteristic KPP

  Validated by JARC 1996

- **IORD-II**
  - 55 Data Products
  - 21 Enhancement Products
  - 2 System Characteristic KPPs

  Validated by JARC Dec 2001

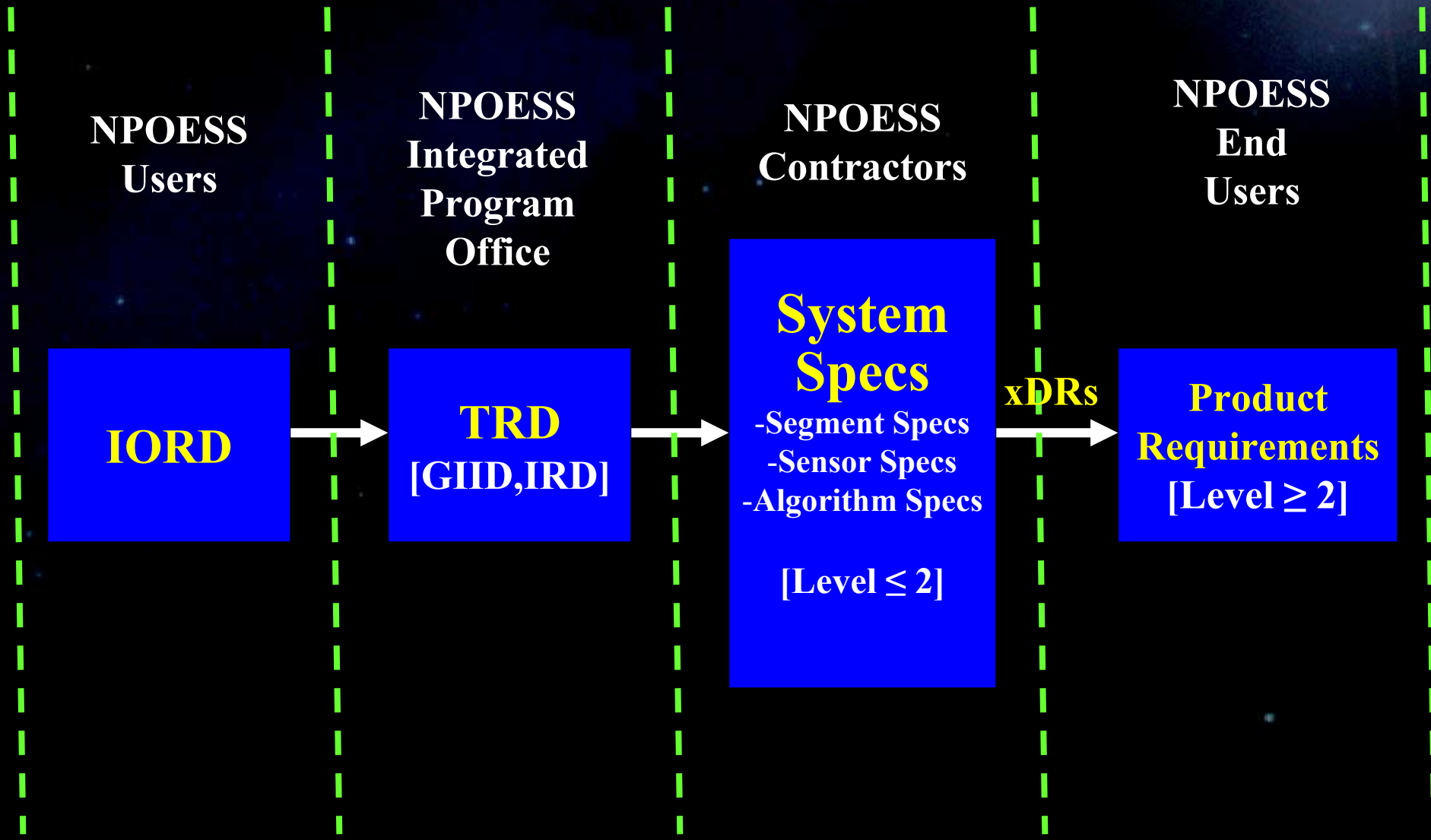


Convergence of Requirements

Converged requirements provide foundation for combined program

First success after eight previous attempts

NPOESS
Requirements, Specifications, Performance
"A New Way of Doing Business"



NPOESS / NPP Data Products

Raw Data Records (RDRs)

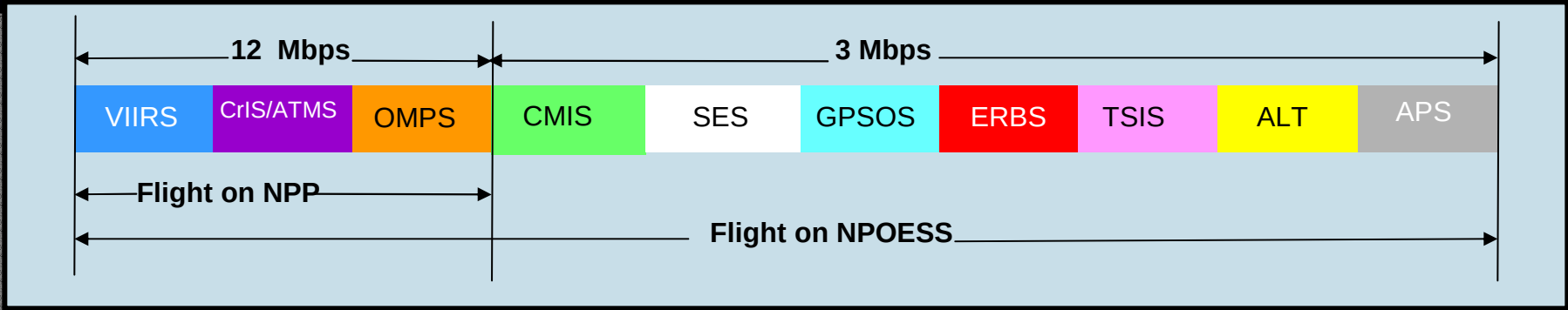
- Similar to Level 0/1A for CEOS/NASA.
- ~ 150 giga bytes per day (similar to Terra or Aqua).

Environmental Data Records (EDRs)

- Similar to CEOS/NASA Level 2.
- *NPP Provides 25 of 55 NPOESS EDRs.*

Sensor Data Records (SDRs)

- Similar to CEOS/NASA Level 1B



NATIONAL POLAR-ORBITING OPERATIONAL ENVIRONMENTAL SATELLITE SYSTEM

NPOESS/NPP Data Products

Raw Data Records (RDRs - Similar to Level 1A for CEOS/NASA.
~ 150 giga bytes per day (similar to Terra or Aqua).
Sensor Data Records (SDRs) - Similar to CEOS/NASA Level 1B

Environmental Data Records (EDRs)
Similar to CEOS/NASA Level 2.
NPP Provides 25 of 55 NPOESS EDRs.

★ Atmospheric Vertical Moisture Profile	Cloud Top Pressure	Precipitable Water
★ Atmospheric Vertical Temp Profile	Cloud Top Temperature	Precipitation Type/Rate
★ Imagery	Downward Longwave Radiance (Sfc)	Pressure (Surface/Profile)
★ Sea Surface Temperature	Downward Shortwave Radiance(Sfc)	Sea Ice Characterization
★ Sea Surface Winds	Electric Field	Sea Surface Height/Topography
★ Soil Moisture	Electron Density Profile	Snow Cover/Depth
Aerosol Optical Thickness	Energetic Ions	Solar Irradiance
Aerosol Particle Size	Geomagnetic Field	Supra-Thermal-Auroral Particles
Aerosol Refractive Index	Ice Surface Temperature	Surface Type
Albedo (Surface)	In-*situ* Plasma Fluctuations	Wind Stress
Auroral Boundary	In-*situ* Plasma Temperature	Suspended Matter
Auroral Energy Deposition	Ionospheric Scintillation	Total Water Content
Auroral Imagery	Medium Energy Charged Particles	Vegetation Index
Cloud Base Height	Land Surface Temperature	
Cloud Cover/Layers	Net Heat Flux	
Cloud Effective Particle Size	Net Solar Radiation (TOA)	
Cloud Ice Water Path	Neutral Density Profile	
Cloud Liquid Water	Color/Chlorophyll	
Cloud Optical Thickness	Ocean Wave Characteristics	
Cloud Particle Size/Distribution	Outgoing Longwave Radiation (TOA)	
Cloud Top Height	Ozone - Total Column/Profile	

VIIRS (23)
CMIS (19)
CrIS/ATMS (3)
OMPS (1)
SES (13)
GPSOS (2)
ERBS (5)
TSIS (1)
ALTIMETER (3)
APS (4)

★ **Environmental Data Records (EDRs) with Key Performance Parameters**

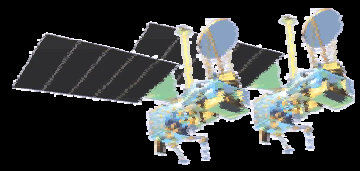
U.S. NPOESS Mission Capability Timeline

Baseline Program – As of 10/1/2005 – Under Major Re-Plan

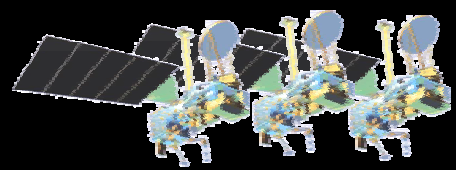
- **PROOF OF CONCEPT: 1998 - 2007**
  - NPOESS Airborne Sounder Testbed (NAST)
  - Operational Utilization of EOS data (Terra, Aqua, Quikscat, Jason-1….)
  - Windsat Coriolis Experiment
  - Shuttle Ozone Limb Sounding Experiment (SOLSE)
  - Solar Research and Climate Experiment (SORCE)

- **ON-ORBIT DEMONSTRATION: 2008 - 2013**
  - NPOESS Preparatory Project [NPP]
    - *Combined Test & Evaluation-VIIRS,CrIS,ATMS,OMPS*
    - *Users develop data exploitation applications & systems*
    - *Incorporate improvements into Operational System*

- **INITIAL OPERATIONAL CAPABILITY: 2012**
  - Two US Operational Orbits - Most KPPs met



- **FULL OPERATIONAL CAPABILITY: 2014**
  - Three US Operational Orbits - All KPPs met



NAST WINDSAT NPP NPOESS-C1 NPOESS-C2 NPOESS-C3

IOC FOC

NATIONAL POLAR-ORBITING OPERATIONAL ENVIRONMENTAL SATELLITE SYSTEM

NPOESS Program Schedule

[Baseline Planned Program – Under Review for Major Replan!!!]

2002 A&O Contract Award

2003 NPP Delta Critical Design Review

2005 NPOESS Δ Preliminary Design Review

2006 NPOESS Critical Design Review
NPP Ground Readiness

2008 NPP Launch

2009 NPOESS Ground Readiness

2010 NPOESS C1 Launch

2011 NPOESS C2 Launch
Field Terminal Segment Readiness

2012 Initial Operational Capability

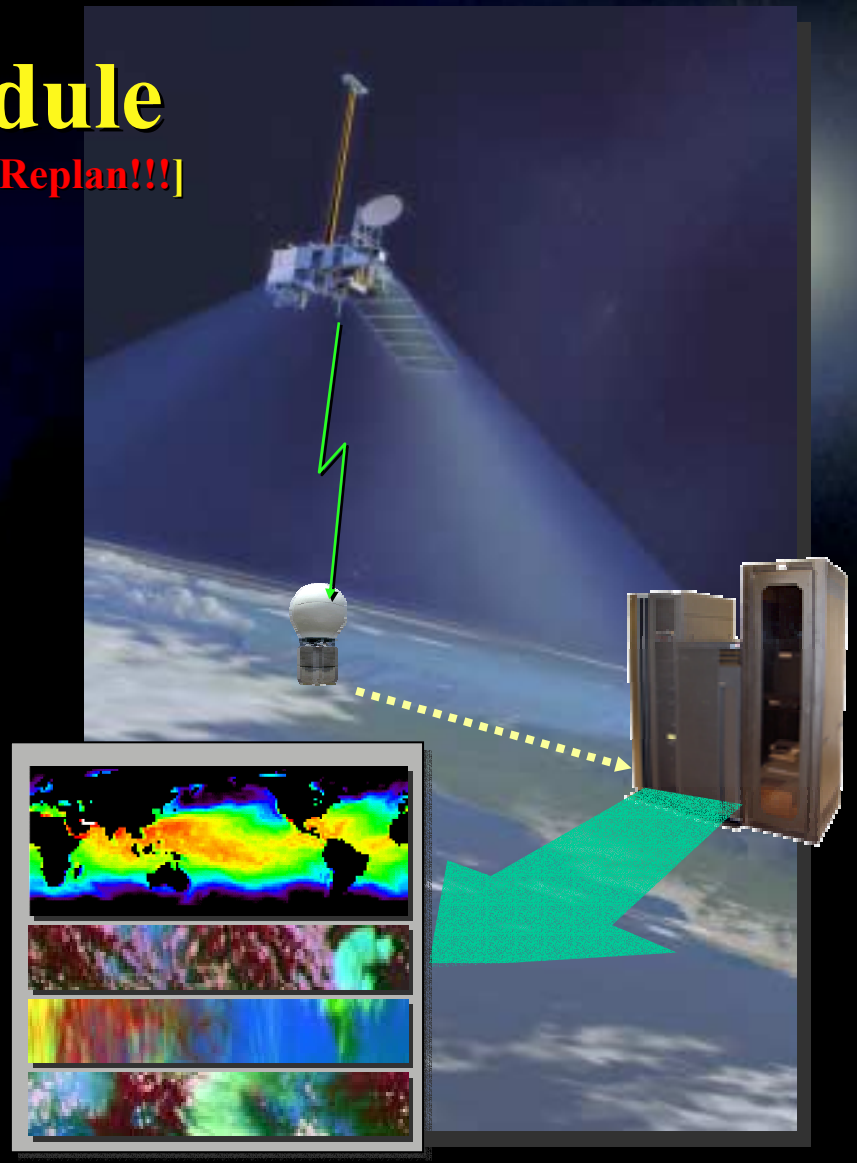
2013 NPOESS C3 Launch

2015 NPOESS C4 Launch

2017 NPOESS C5 Launch

2019 NPOESS C6 Launch
End of Phased Program Launches

~2026 OPS of Flying Systems



Reliable and timely collection, delivery, and processing of quality environmental data

NPOESS/NPP/METOP Payloads

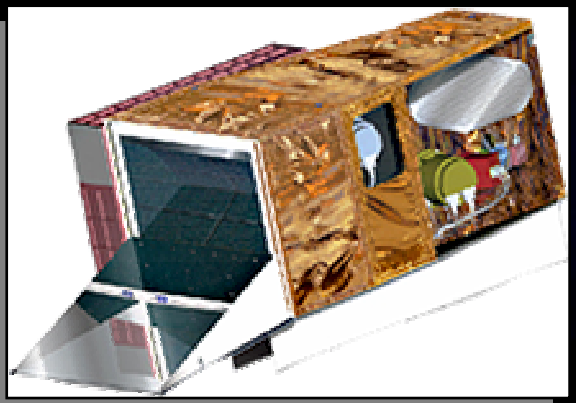
Baseline as of 10/1/2005-Under Review

NPOESS Instruments	C3,C6 LAN 1730	C1,C4 LAN 2130	C2,C5 LAN 1330	METOP 1,2,3 [~2006,2011,2015] LAN 2130	NPP LAN 2230**
IPO Developed					
Visible/IR Imager Radiometer Suite (VIIRS)*	X	X	X	X (AVHRR/3)	X
Cross-track IR Sounder (CrIS)*	X		X	X (IASI&HIRS/4)	X
Conical MW Imager/Sounder (CMIS)*	X	X	X		
Ozone Mapper/Profiler Suite (OMPS)			X	X (GOME-2)	X
GPS Occultation Sensor (GPSOS)				X (GRAS)	
Space Environmental Sensor Suite (SESS)			X	X (SEM)	
Aerosol Polarimetry Sensor (APS)		X			
Leveraged					
Advanced Technology MW Sounder (ATMS)*	X		X	X (AMSU/MHS)	X
ARGOS-Data Collection System (ADCS)	X		X	X	
Search and Rescue (SARSAT)	X	X	X	X	
Earth Radiation Budget Sensor (ERBS)			X		
Total Solar Irradiance Sensor (TSIS)	X				
Radar altimeter (ALT)	X				
Advanced Scatterometer (ASCAT)				X	

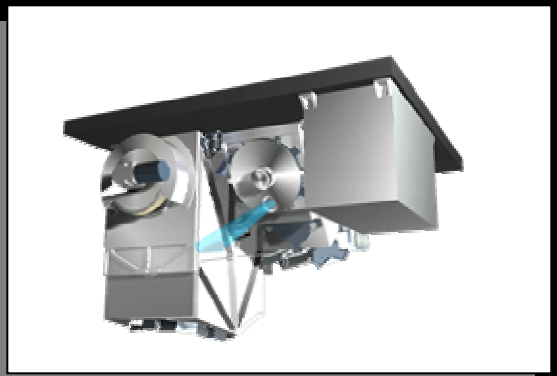
*Critical instrument - Failure constitutes need to replace satellite

** Change under Consideration (~LAN 1330 Synch with "A-Train")

NPOESS/NPP Risk Reduction Instruments



Visible/IR Imaging Radiometer Suite (VIIRS)
Raytheon SBRS



Ozone Mapping & Profiler Suite (OMPS)
Ball Aerospace

Conical-scanning Microwave Imager/Sounder (CMIS)
Boeing

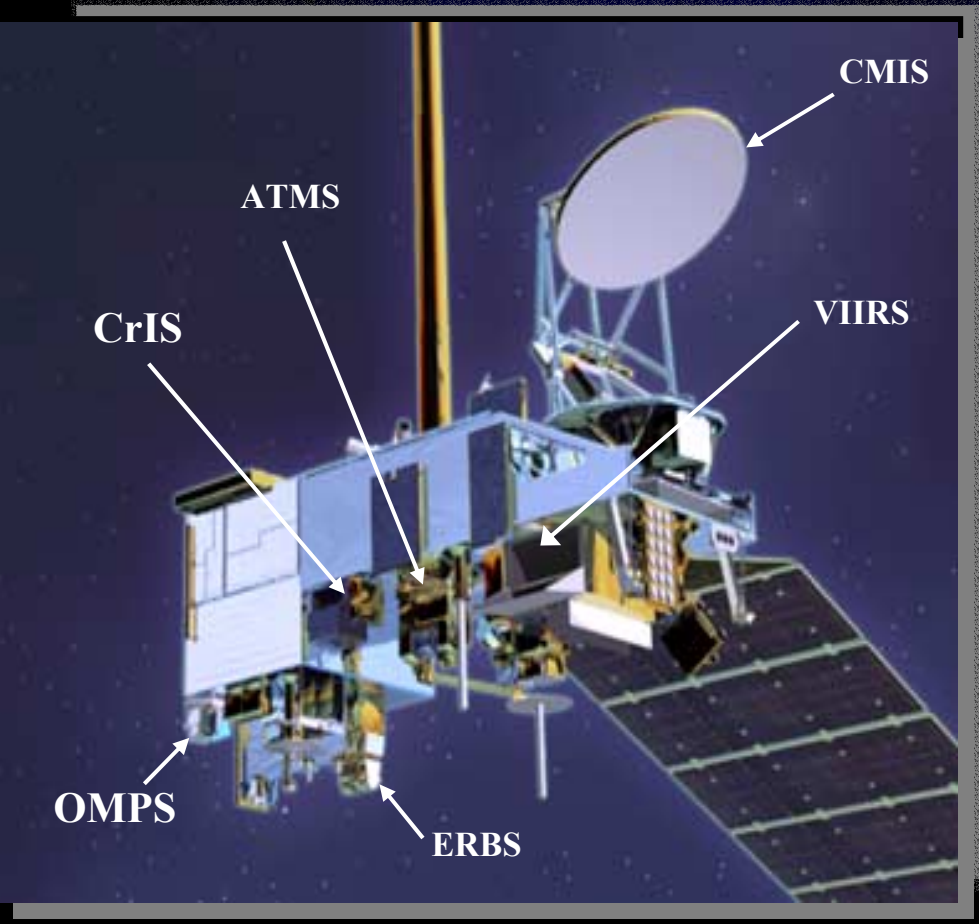
[*NPOESS only*]

Cross-track IR Sounder (CrIS)
ITT Industries

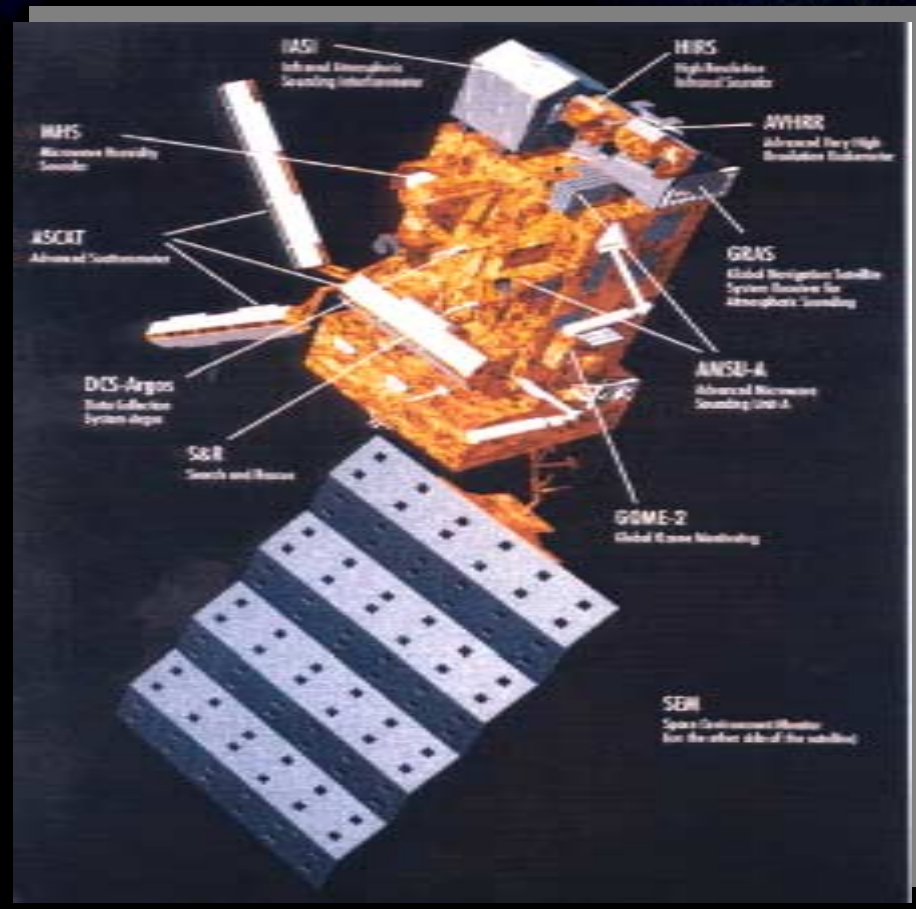
Advanced Technology Microwave Sounder (ATMS)
Northrop Grumman

NPOESS/METOP Sensors

NPOESS 1330 Satellite

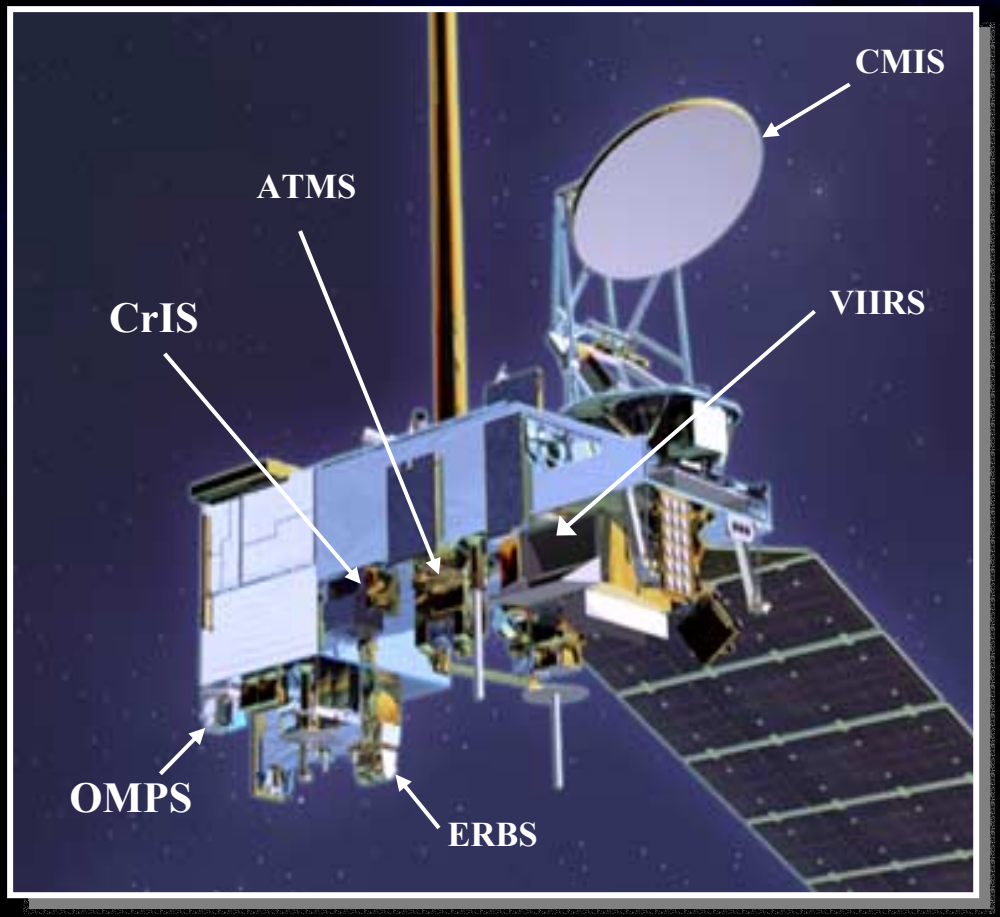


METOP 0930 (2130) Satellite

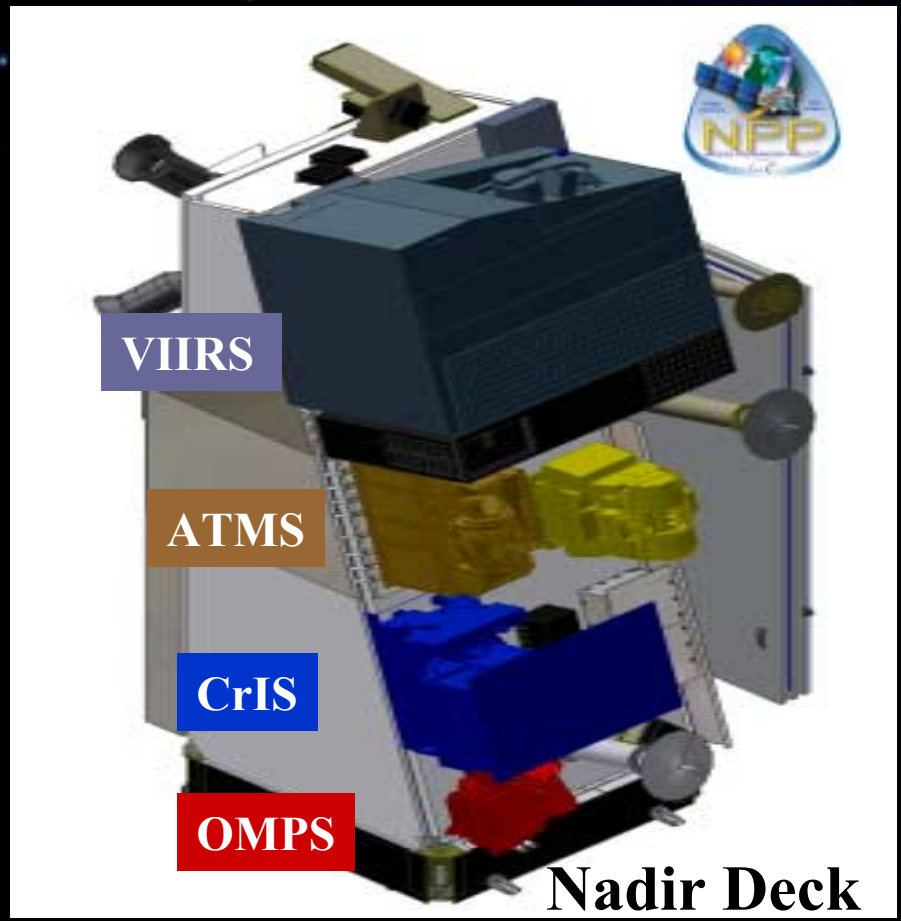


NPOESS/NPP CrIS/ATMS/OMPS/VIIRS Sensors

NPOESS 1330 Satellite



NPP 1030 (2230) Satellite



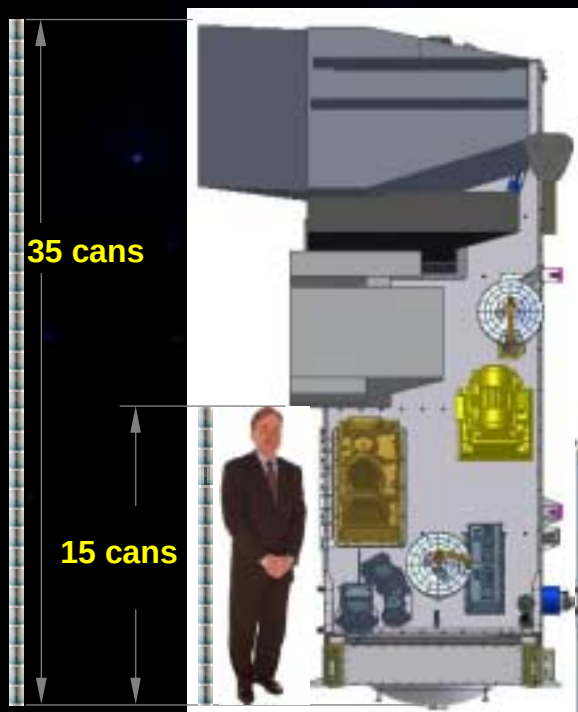
METOP-1,-2, -3 Sensors

INSTRUMENT	FULL NAME	PRIMARY FUNCTION
AVHRR/3*	Advanced Very High Resolution Radiometer	Global imagery of clouds, the ocean and land surface
HIRS/4	High Resolution Infrared Radiation Sounder	Temperature and humidity of the global atmosphere in cloud-free conditions
AMSU-A*	Advanced Microwave Sounding Unit-A	Temperature of the global atmosphere in all weather conditions
MHS	Microwave Humidity Sounder	Humidity of the global atmosphere
IASI	Infrared Atmospheric Sounding Interferometer	Enhanced atmospheric soundings
GRAS	Global Navigation Satellite System Receiver for Atmospheric Sounding	Temperature of the upper troposphere and in the stratosphere with high vertical resolution
ASCAT	Advanced Scatterometer	Near-surface wind speeds over the global oceans
GOME-2*	Global Ozone Experiment-2	Monitoring Profiles of ozone and other atmospheric constituents

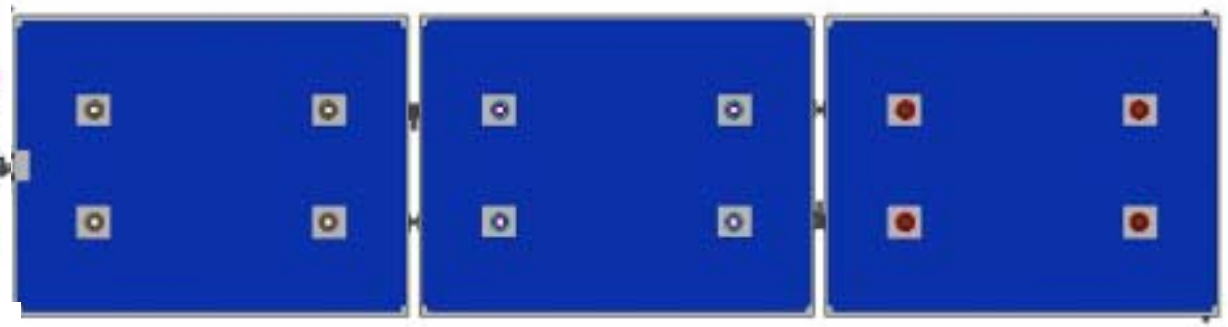
NPP Satellite – By Ball Aerospace "Bridge from EOS to NPOESS"

Weight: 137,100 cans (dry)
247 cases of your favorite beverage (wet)

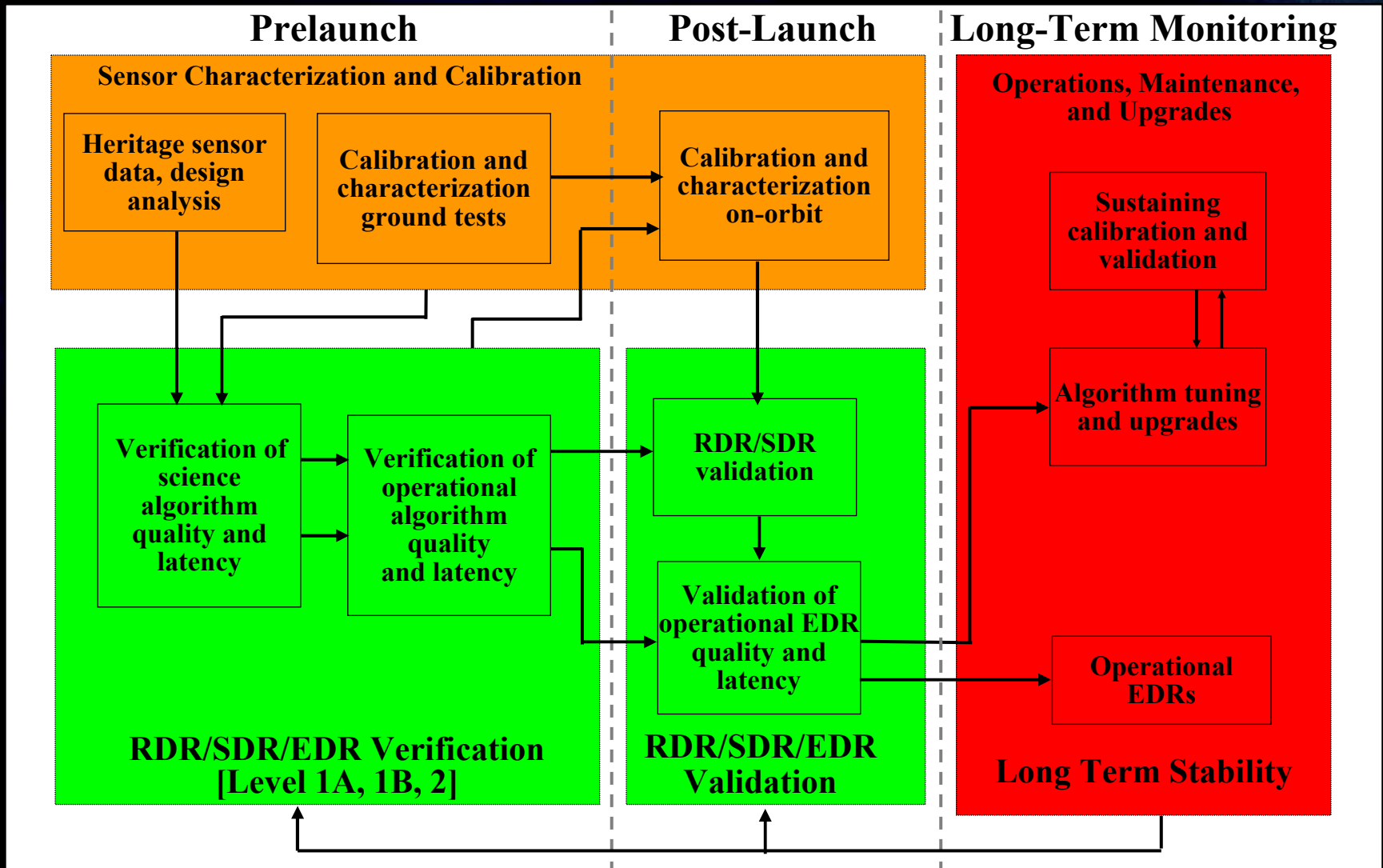
Note: Units in 202/211 X 413 aluminum cans (can, end & tab)



- Mass: 2150 kg (nearly 5000 lbs)
- Power: 2200 watts
- Volume: 14 ft x 6 ft x 5 ft
- 40" diameter oblate tank holds 400 kg of propellant
- 1553 and 1394 data buses for the Instrument C&DH interface
- Solar Array - Single wing deployed length ~ 25 feet
- Orbit: 824 km, sun-synchronous, 98° inclination, descending 10:30AM ± 10 minute local mean time
- Dimensions: ~1.35 m x 1.35 m x 4.03 m



NPOESS/NPP Calibration/Verification/Validation Program System Perspective



NPP/NPOESS Calibration Validation Plan

NPP/NPOESS Cal/Val Plan includes 3 phases

- **Pre-launch phase:**
  - — Verification of instrument characterization and calibration, and sources NIST traceability
  - — Algorithm performance assessment/characterization/verification
  - — Definition of validation approaches and validation data sets for each product

    Methods, priorities & timetable, work with all appropriate government organizations (including those not directly affiliated with NPOESS) to ensure availability of required truth data.
- **Post-launch phase:**
  - — Sensor functionality, on-orbit calibration, performance verification and validation
  - — Acquisition of validation data (ground, airborne and space borne data)

    Coordination with other validation programs (EOS, DMSP, POES), and planning and execution of field experiments.
  - — Execution of NPP algorithm and product validation
- **Long-term monitoring phase:**
  - — Conducting long term monitoring of NPP product quality and performing re-calibration/re-validation as required.

Fundamental Definitions

- **Characterization**
  - The measurement, over a range of sensor and environmental operating conditions, of all relevant sensor parameters; used to understand quantitatively the operation of an instrument and its response as a function of the range of operating and viewing conditions experienced by the instrument on-orbit.
- **Verification**
  - The process of ensuring that sensor, algorithm and/or mission requirements are satisfied.
- **Calibration**
  - The process of quantitatively defining the system response to known, controlled signal inputs.
  - Vicarious calibration techniques make use of natural or artificial sites typically on the surface of the Earth for post-launch sensor calibration/product validation.
- **Validation**
  - The process of assessing by independent means the quality of the direct and derived system output data products.

Accuracy, Precision, Uncertainty

[Adapted for NPOESS]

- **Measurement Accuracy**

  The systematic error, as specified by the difference between a measured or derived parameter and its true value, in the absence of random errors.

- **Measurement Precision**

  The uncertainty in a measured or derived parameter due only to random errors, specified as the standard deviation of a parameter.

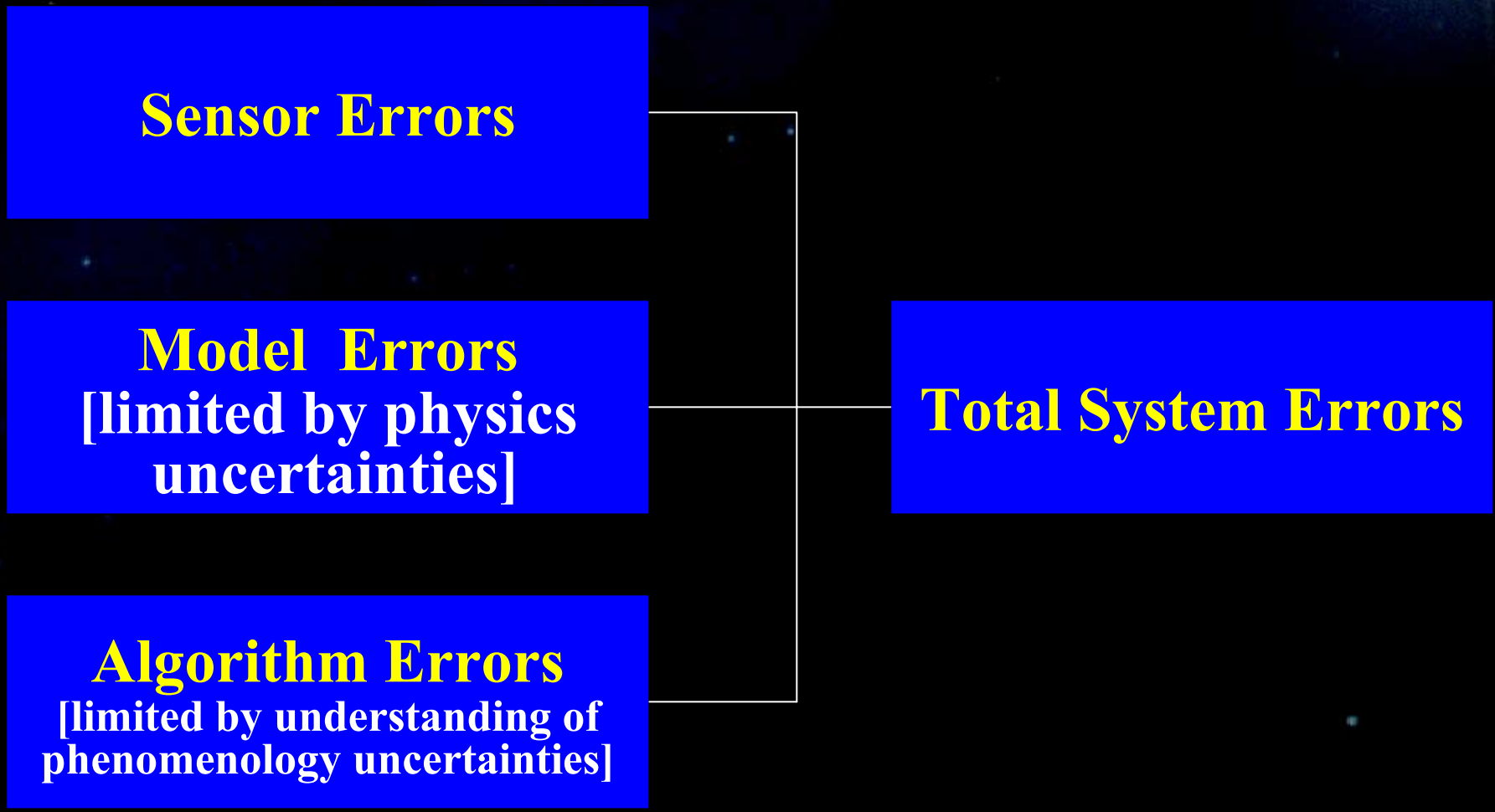
- **Measurement Uncertainty**

  The root-mean-square (RMS) of the measurement errors for an estimated parameter (assuming large statistical ensembles of measurements).

Importance of Definitions Used

Avoidance of Unnecessary Ambiguities & Incorrect Intercomparisons

Importance of Characterization & Calibration



Resources (People, Facilities, Finances) for Calibration/Verification/Validation

- Availability
- Capability
- Reliability
- Continuity
- Sustainability

N.B. A Satellite Remote Sensing System, such as NPOESS, has multiple satellites each with multiple sensors in different orbits in the constellation and replacement satellite/sensors for each orbit and with an operational lifetime expected to last through 2025 = A Cal/Ver/Val CHALLANGE

Sensor Calibration & Characterization

- Radiometric
- Spectral
- Polarization
- Temporal
- Geometric/Spatial
- Goniometric

Typical Challenge for C&C to "Do Its Part"

- **Measuring the small changes associated with long-term global climate change from space is a daunting task. The satellite instruments must be capable of observing atmospheric temperature trends as small as 0.10 C per decade, ozone changes as little as 1% per decade, and variations in the sun's output as tiny as 0.1% per decade.**
-

Satellite Instrument Calibration for Measuring Global Climate Change Workshop, November 2002, NISTIR 7047 [2003]

NPOESS Long-Term Stability [LTS] Requirements [IORD II, Dec 2001]

Climate Variable	LTS Threshold	LTS Objective
Solar Irradiance [Total]	0.002 %/yr	0.0005 %/yr
Earth Radiation Budget [Albedo]	0.02	0.01
Atmospheric Temperature [Profile]	0.05K Trop, 0.10 Strat	0.03K Trop, 0.05 Strat
Sea Surface Temperature [Range 271-313K]	0.1K	0.05K
Ocean Color/WLR[max,min,NIR wave]	0.5,0.25,0.08	0.25,0.125,0.04
Cloudiness [Coverage]	0.1	0.002
Precipitation [Rate]	1.0 mm/hr or 10%	0.1 mm/hr or 1%
Water Vapor [Profile]	2%	1%
Ozone [Tot Col, Profile]	1%,2% over 7 yrs	0.5%,1% over 7 yrs
CO_2 & Other Trace Gases	----	----
Aerosols [AOT]	0.01	0.005
Snow Cover	10 %	1 % Continental
Sea Ice [Concentration]	1 %	----
Vegetation	0.04 NDVI units	0.04 NDVI units

* If not otherwise stated, stability is over the 7 year sensor/satellite system lifetime at minimum

NPOESS Future "Scorecard"
GCOS Satellite Climate Monitoring Principles

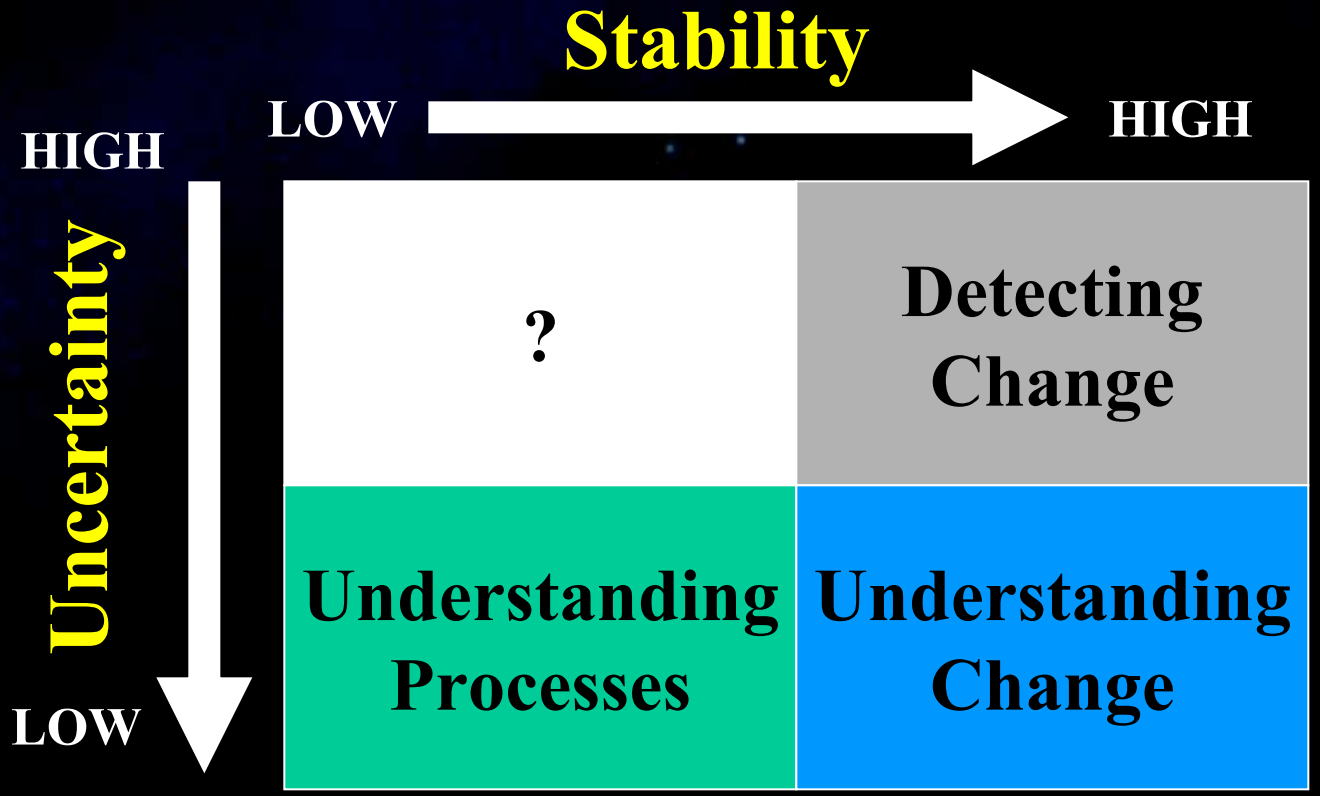
✓ 1	Minimize orbit drift	✓ 6	Operational production of priority climate products
P 2	Ensure sufficient overlap	✓ 7	Facilitate access to products, metadata, and raw data
P 3	Replace prior to failure	✓ 8	Continue baseline instrument observations on decommissioned satellites
✓ 4	Rigorous pre-launch calibration	✓ 9	Need in situ baseline observations
✓ 5	Adequate on-board calibration	✓ 10	Real-time monitoring of network performance

P = Partial Fulfillment

[Principles only Adapted from T. Karl]

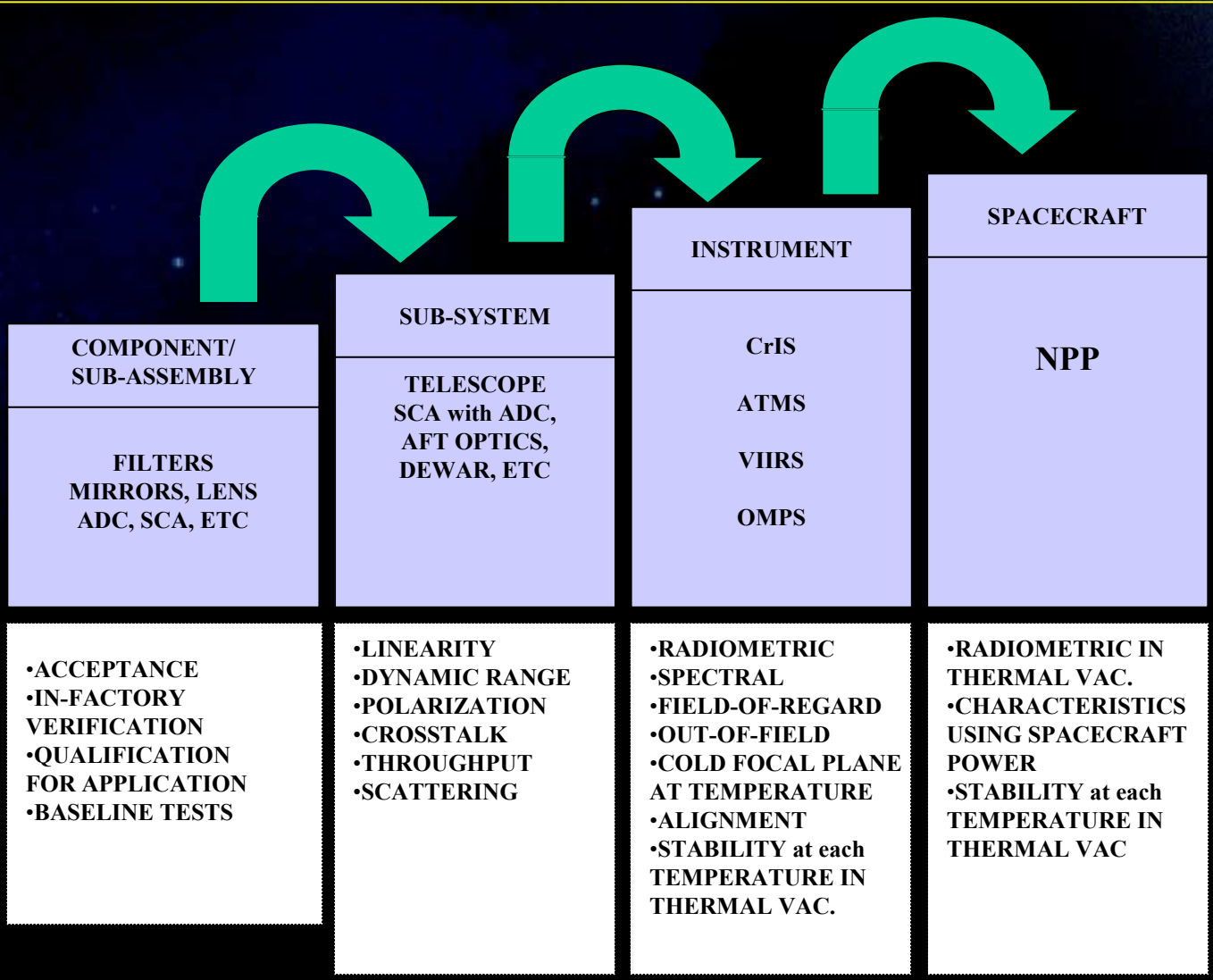
Desired Characteristics of a Climate Observing System

[Adapted from G. Stephens, 2003]



- Low Uncertainty (Accuracy & Precision components) vital for understanding climate processes & climate changes
- High Stability vital to detecting long-term changes and/or trends

NPP Pre-Launch Instrument Characterization and Calibration



Developed NPOESS Cal Val Plans

Starting Point

Draft

National Polar-orbiting Operational Environmental Satellite System [NPOESS]
Preparatory Project [NPP]

NPP
Calibration and Product Validation Plan

December 30, 2001
Updates for OMPS: May 2003

NATIONAL POLAR-ORBITING OPERATIONAL ENVIRONMENTAL SATELLITE SYSTEM (NPOESS) INTEGRATED PROGRAM OFFICE

and the

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Best Practices System Support

Northrop Grumman Space Technology

Raytheon

Engineering and Manufacturing Development (EMD) number

National Polar-Orbiting Operational Environmental Satellite System (NPOESS)

NPOESS Calibration and Validation Plan Volume 12: NPP Plan

DRAFT VERSION 2.0.5
Date: February 05, 2004

Prepared by
Northrop Grumman Space Technology
One Space Park
Redondo Beach, CA 90278

Under
Contract No. F04701-02-C-0502

Prepared for
Department of the Air Force
NPOESS Integrated Program Office
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DISTRIBUTION STATEMENT F: Distribution statement "F" signifies that further dissemination should only be made as directed by the controlling DoD Office (NPOESS IPO). Ref DODD 5230.24D.

Joint NPP Platform

Northrop Grumman Space & Mission Systems Corp.
Space Technology
One Space Park
Redondo Beach, CA 90278

Raytheon

Engineering & Manufacturing Development (EMD) Phase
Acquisitions & Operations Contract

CAGE NO. 11982

NPOESS Calibration and Validation Plan Volume 2: Visible/Infrared Imager/Radiometer Suite (VIIRS)

DATE: 03 November 2003 **NO.** D31409-02
CDRL A030 **REV.** A

PREPARED BY: L. B. Liao, ST&E

ELECTRONIC APPROVAL SIGNATURES:

Roy Tsugawa SE&I IPT Lead	Date	Keith Reinke Ground Segments IPT Lead	Date
Terry Larson Space Segment IPT Lead	Date	Ben James Operations and Support IPT Lead	Date
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Brian Lottman Cal Val Lead	Date	Michael Mussetto Project Scientist	Date

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- **Leveraging Science Community**
- **Describing Best Practices and Implementation Strategy**

NPP/NPOESS Product Validation Objectives

Pre-Launch Objectives

1. Validation of data acquisition and quality control
2. Forward Model Validation
3. Algorithm/data system verification
4. Validation using ground, airborne and space based observations

Post-Launch Objectives

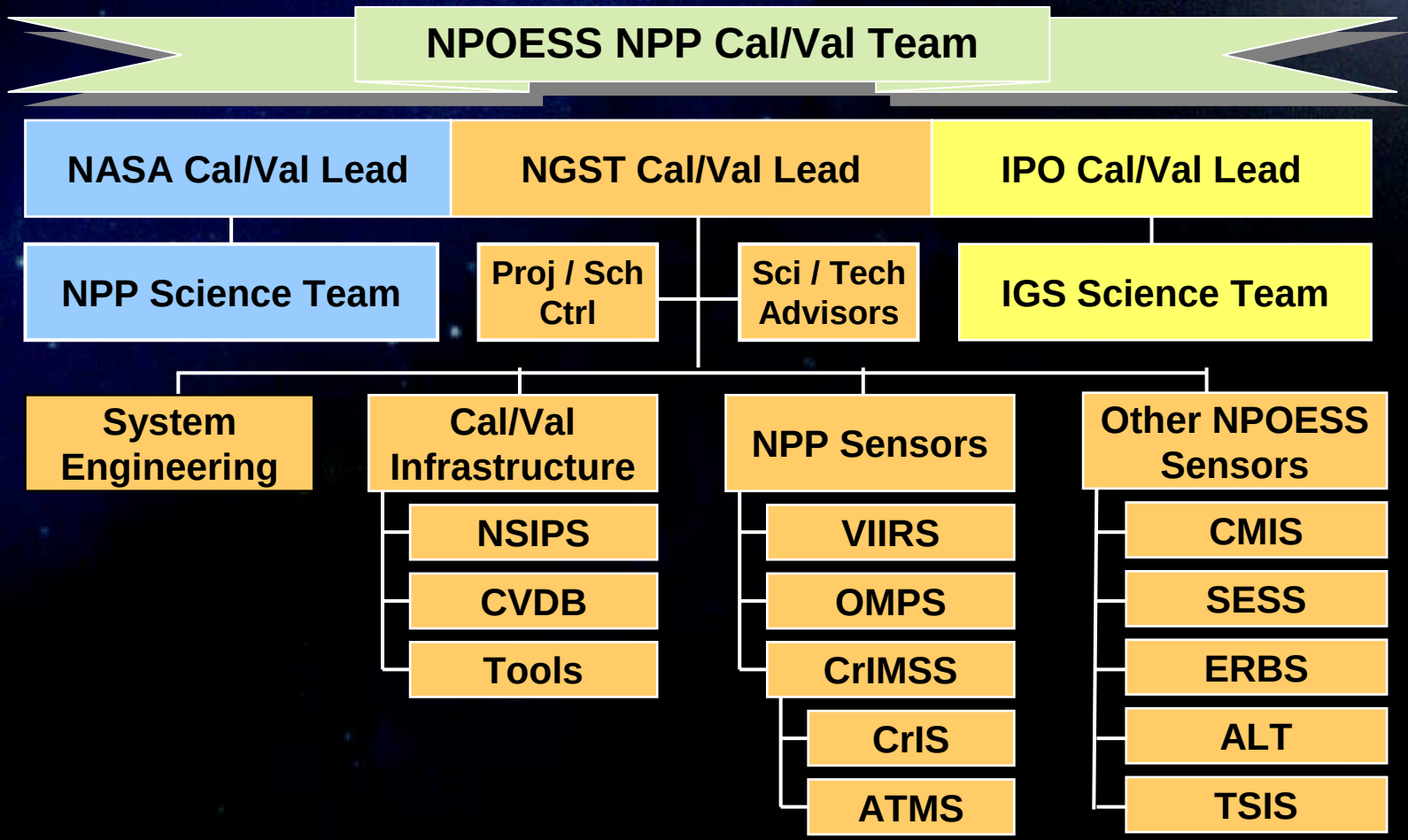
1. Validation of data acquisition and quality control
2. Vicarious calibration using stable targets
3. Validation of NPP products using ground, airborne and space based observations
4. Forward Model and algorithm refinement

Validation Tools and Assets to Achieve our Goals

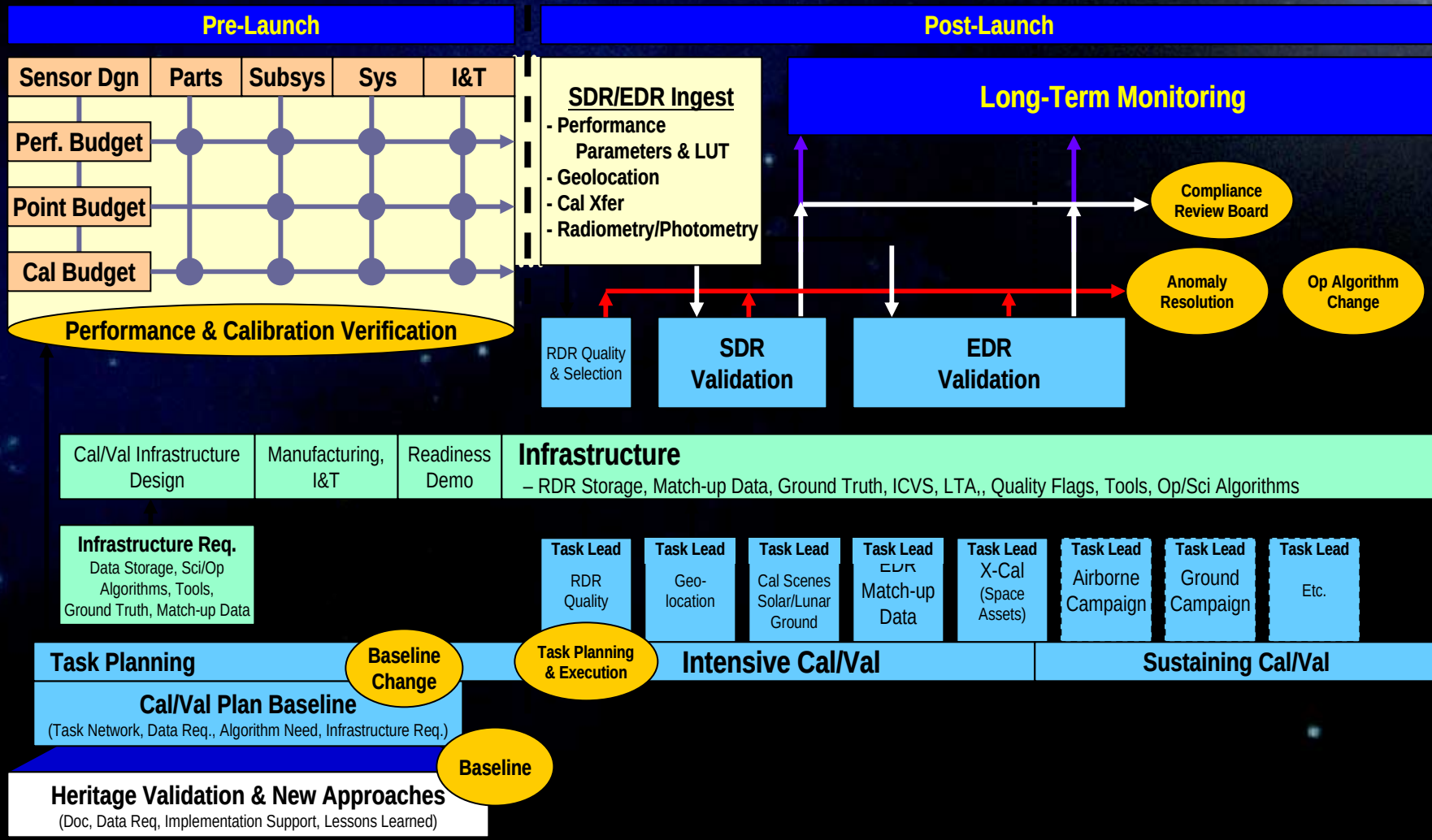
- Global ground networks
- Coordinated national and international field campaigns
- Cross-instrument validation data
- Match-up tools
- Comparison of assimilation and analysis products with NPP products

NPP/NPOESS calibration validation plan will interact with CEOS-WGCV to incorporate evolving Protocols and Standards, and global validation networks and field campaigns, for land, oceanic and atmospheric products.

Joint Cal/Val Team



NPOESS/NPP Cal/Val Approach



Adapted from IPO/NASA/NGST (Paul S. Lee)

VIIRS Instrument Checkout RDR, and SDR Tasks (sample)

ID	Task I	Task Name
11		**Sensor Characterization**
12		**Common**
13	1464	Operability
14	747	VIIRS Aggregation Method Verification
15	1041	VIIRS dual gain transition verification
16	1020	VIIRS on-board bow-tie deletion verification
17	752	VIIRS DC Restore Functionality and Performance Check
18	1386	High contrast scene analysis --- change to Structured Scene analysis
19	958	VIIRS Electronic Gain
20	1002	VIIRS band-to-band registration
21	755	VIIRS DC Restore LUT Recalculate and Upload
22	1043	VIIRS RDR Histogram Analysis of EV data - Digitization Error / Noise evaluation
23	957	VIIRS spectral validation with hyperspectral aircraft underflight
24	756	VIIRS Thermal Analysis for Maneuvers
25		**SRB-only**
26	1105	VIIRS VisNir noise prior to RTA scanning
27	1036	VIIRS SRB RDR Histogram Analysis, dark level
28	1053	VIIRS SRB (VisNir) SDR In-Band/band-to-band Cross Talk (Echoes and ghosts)
29	1054	VIIRS SRB SDR Band to Band Cross Talk (Ghosts)
30	1467	Collect day-time bands at night to look for electronic cross talk from night-time ba
31	1056	VIIRS SRB SDR Noise and SNR evaluation
32	1165	VIIRS SRB RDR statistical analysis of calibrator views
33	1039	VIIRS SRB dynamic range and linearity
34	1049	VIIRS SRB (VisNir only) Polarization
35	1000	VIIRS SRB MTF validation
36		**TEB-only**
37	718	VIIRS M/T RDR Histogram Analysis 1 - Door Closed
38	746	VIIRS M/T RDR Histogram Analysis 2 - Door Open
39	753	VIIRS M/T Initial Electronic Cross-Talk Verification
40	762	VIIRS M/T DN Space View - Make Image and Visual Inspection
41	`757	VIIRS M/T Dynamic Range and Linearity Check
42	763	VIIRS M/T SDR Moon Echo and Ghost Check
43	766	VIIRS M/T SDR In-Band/Band-to-band Cross Talk (Echoes and Ghosts)
44	767	VIIRS M/T SDR out of band Spectral Leak
45	759	VIIRS M/T SDR Noise Evaluation
46	760	VIIRS M/T SDR Glint Evaluation
47	774	VIIRS M/T SDR Band-to-Band Radiometric Comparison
48	1001	VIIRS M/T MTF
49		**Calibration Initialization**
50	1015	VIIRS SD and SDSM characterization
51	1048	VIIRS SRB SDR RVS Analysis - Cross Track Profile
52	1042	VIIRS SRB Solar Diffuser Straylight - Analysis of non-polar SD data
53	1166	Temporal Analysis of SD signal over polar region
54	1167	Temporal analysis of SDSM data
55	756	VIIRS Thermal Analysis for Maneuvers
56	1046	VIIRS SRB Yaw Maneuver Analysis - Screen Transmission
57	1388	Evaluate updated SRB calibration approach
58	1169	Submit updated VIIRS SRB calibration approach to CVCCB
59	1017	VIIRS OBCBB Uniformity Verification
60	765	VIIRS M/T SDR RVS Analysis
61	1019	VIIR OBCBB heat-up and cool down
62	769	VIIRS M/T SDR LUT Calculate and Update
63	775	VIIRS Yaw Maneuver
64	776	VIIRS Roll Maneuver
65	779	VIIRS Yaw Maneuver Analysis - Screen Transmission
66	780	VIIRS Roll Maneuver Analysis
67	778	VIIRS Begin Pitch Maneuver
68	997	VIIRS End Pitch Maneuver
69	781	VIIRS SDR Pitch Maneuver Analysis
70		**SDR- radiance/reflectance validation**
71	1055	VIIRS SRB detector and mirror side striping
72	1050	VIIRS SRB SDR Earth Scene - Visual inspection of images from all Bands
73	955	VIIRS Spectral Validation - Lunar Spectral Radiance
74	954	VIIRS Spectral Validation - Solar Spectral Radiance
75	1433	VIIRS SRB analysis of lunar calibration data from roll maneuver
76	1044	VIIRS SRB radiance/reflectance comparison with model
77	1051	VIIRS SRB SDR Comparison with MODIS
78	1052	VIIRS SRB SDR Comparison with AVHRR
79	1040	VIIRS SRB radiance/reflectance validation-Radiometric Sites
80		Evaluate VIIRS SRB SDR accuracy- Level 1 (TBR)
81	1045	VIIRS SRB radiance/reflectance validation-Underflight
82		Evaluate VIIRS SRB SDR accuracy- Level 2 (TBR)
83	764	VIIRS M/T SDR Earth Scene - Make Images All Bands
84	768	VIIRS M/T SDR Striping Analysis
85	773	VIIRS M/T SDR Model Comparison
86	772	VIIRS M/T SDR Comparison with MODIS
87	1466	VIIRS M/T SDR Comparison with AVHRR
88	1243	VIIRS SDR (MWIR and TIR) VALIDATION USING LAKE TAHOE SITE
89	956	VIIRS in-band spectral radiance comparison with CrIs
90	782	VIIRS M/T SDR Accuracy Evaluation -Level 1 (TBR)
91	1465	VIIRS M/T Radiance Validation with NAST-I underflight
92		VIIRS M/T Radiance Validation with MAS underflight
93		VIIRS M/T SDR Accuracy Evaluation- Level 2 (TBR)
94		**SDR- geolocation validation and training**
95	946	Initial validation of S/C Auxiliary Ephemeris and Attitude Data
96	945	Initial validation of VIIRS encoder data & scan rate stability
97	944	Initial validation of VIIRS scan time and scan period
98	947	Assess reasonableness of 1st period VIIRS SDR geolocation
99	949	Build 1st period simulated VIIRS images from GCP chips
100	948	Build 1st period VIIRS image chips from selected SDR pixels
101	950	Perform 1st period VIIRS-simulated VIIRS image match-up
102	951	Analyze 1st period VIIRS-GCP residuals
103	1110	Analyze initial intra-orbit thermal effects on VIIRS geolocation
104	952	Initial update to VIIRS geolocation parameters & thermal LUTs
105	1109	Test initial VIIRS geolocation parameter & thermal LUT updates
106	953	Deliver initial VIIRS geo parameter & thermal LUT updates to CCB

CrIMSS – CrIS Instrument Checkout RDR, and SDR Tasks (sample)

ID	Task Name
49	**Sensor/RDR/SDR Checkout**
50	Start CrIS SDR Checkout
51	CrIS Sensor Health and Status Monitoring and Fault Detection - Sensor/RDR/SDR Checkc
52	**CrIS Sensor Health Check - Sensor/RDR/SDR Checkout**
53	Begin CrIS Sensor Health Check - Sensor/RDR/SDR Checkout
54	CrIS Telemetry Parameter and RDR Trending - Sensor/RDR/SDR Checkout
55	CrIS RDR Trending Using Interferrograms - Sensor/RDR/SDR Checkout
56	CrIS SDR Trending - Sensor/RDR/SDR Checkout
57	CrIS SDR Data Quality Cross Comparison w/ AIRS and IASI - Sensor/RDR/SDR Che
58	End CrIS Sensor Health Check - Sensor/RDR/SDR Checkout
59	CrIS Sensor Thermal Balance Check - Sensor/RDR/SDR Checkout
60	CrIS Metrology Laser Temperature and Stabilize - Sensor Checkout
61	CrIS Neon Lamp (Calibration) - Sensor Checkout
62	CrIS Optimize Electronic Gains - Sensor Checkout
63	CrIS Correlated/Uncorrelated Noise (Diagnostic) Characterization - Sensor Checkout
64	CrIS DA Tilt Offset Determination - Sensor Checkout
65	CrIS Interferometer ZPD Shift and Magnitude Characterization - Sensor Checkout
66	CrIS Instrument Line Shape (ILS) Correction Validation - Sensor Checkout
67	CrIS ICT Stability Assessment - Sensor Checkout
68	CrIS Responsivity and Sensivity Characterization - Sensor Checkout
69	CrIS Self Emission and Background Radiance - Sensor Checkout
70	CrIS Operational Mode Checkout - Sensor Checkout
71	CrIS Bit Trim and Impulse Mask - Sensor Checkout
72	CrIS Laser and Neon Lamp Performance - Sensor Checkout
73	CrIS NEdN - Sensor Checkout
74	CrIS Radiometric Linearity Characterization - Sensor Checkout
75	CrIS Check FOV Response and Spectral Uniformity - Sensor Checkout
76	CrIS FOV Coregistration - Sensor Checkout
77	CrIS Data Review - Sensor checkout
78	CrIS Calibration Parameter Initial Trending Process - SDR Checkout
79	SST Early Calibrated and Geolocated Radiance Performance Evaluation - SDR Checkout
80	CrIS Early Spectral Calibration Evaluation - SDR Checkout
81	CrIS Geolocation Initial Performance Evaluation - SDR Checkout
82	CrIS off-axis calibration maneuver - SDR Checkout
83	CrIS Cal/Val Data Review - SDR Checkout
84	End CrIS Checkout
85	**SDR Cal/Val - Baseline**
86	Begin SDR Baseline
87	CrIS Radiometric Calibration Validation - SDR Baseline
88	CrIS Laser and Neon Lamp Stability - SDR Baseline
89	CrIS Spectral Calibration Validation- SDR Baseline
90	CrIS Calibration Data Trending: Initiated for Long-Term Monitoring (LTM) - SDR Baseline
91	CrIS Geolocation - SDR Baseline
92	Validation of CrIS SDR Input Parameters (Look-Up Tables) - SDR Baseline
93	CrIS Residual Analyses - SDR Baseline
94	CrIS Cross Calibration with VIIRS - SDR Baseline
95	CrIS External Cross Calibration - SDR Baseline
96	CrIS Cal Val Data Trending: Augment and refine the data parameter trending process and table - S
97	CrIS Data Review - SDR Baseline
98	End SDR Baseline
99	CrIS Cal Val RDR and SDR Error Analysis / Quality Assessment

CrIMSS – ATMS Instrument Checkout RDR, and SDR Tasks (sample)

ID	Task Name
1	882 (ATMS 1) - NPP launch
2	1322 - CrIS Survival heaters enabled
3	987 - OMPS Operational Power On
4	993 - VIIRS Power On and Initialize
5	976 (ATMS 1)- ATMS survival heater Monitoring
6	977 (ATMS 2) - ATMS pwr on and initialize
7	999 (ATMS 3) - ATMS functional test
8	978 (ATMS 4) ATMS cold soal
9	984 (ATMS 5) ATMS functional test after cold soak
10	979 (ATMS 6)- 983 space view (#1-#4, #1)
11	719 (ATMS 7) ATMS cold space view analysis
12	(ATMS 8) - Scanner Accuracy and Stability
13	720 (ATMS 9)- Blackbody PRT quality analysis
14	721 (ATMS 10)- Blackbody analysis
15	727 (ATMS 11) - ATMS dwell test
16	725A(ATMS 12 A) - RFI check with CrIS
17	725B (ATMS12B)- RFI check with OMPS
18	725C(ATMS 12C) - RFI check with VIIRS
19	725D(ATMS 12D) - RFI on board transmitter
20	740 (ATSM 13) RFI correction (if needed)
21	726 (ATMS 14) - ATMS Geolocation check
22	(ATMS 15) - Geolocation in stare mode
23	743 (ATMS 16) - Geolocation surface-based transmitter
24	(ATMS 17) ATMS radiometric Environmental Characterization
25	(ATMS 18) - Ascending & descending brightness temperature comparison
26	735 (ATMS 19) - SDR comparison with model fields
27	723 (ATMS 20) - ATMS RDR statistical analysis
28	734 (ATMS 21) - ATMS Scan uniformity analysis
29	724 (ATMS 22)- ATMS NWP scan bias evaluation
30	742 (ATMS 23)- ATMS Intermediate product verification
31	738 (ATMS 24) - ATMS resampling to AMSU FOV verification
32	(ATMS 25) ATMS NWP radiance validation
33	736 (ATMS 26)-Parameters trending
34	737 (ATMS 27) - ATMS Trending of blackbody and cold space count
35	741(ATMS 28) - ATMS SDR Center Frequency Stability
36	745 (ATMS 29) - ATMS resampling to CrIS verification
37	(ATMS 30) - ATMS High altitude aircraft underflights
38	(ATMS 31)- SDR comparison with RAOB
39	(ATMS 32) ATMS Lunar contiamination in space view
40	(ATMS 33) ATMS/NPP roll maneuver 1: Deep space analysis
41	744 (ATMS 34) - ATMS roll maneuver 2: Imaging of moon
42	733 (ATMS 35) - ATMS/NPP roll maneuver 3: Imaging of earth limb
43	731(ATMS 36) -ATMS/NPP pitch maneuver Image deep space (NPP pitch maneuver)

OMPS Instrument Checkout RDR, and SDR Tasks (sample)

ID	Task	Task Name
2	988	OMPS Operational Power On
3	989	OMPS System Functional Tests
4	790	OMPS Physical Temperatures in Range
5	789	OMPS RDR Digital Numbers in Range Check
6	791	OMPS Bad Pixel Check
7	792	OMPS Light Leak Check
8	1216	OMPS External EMI/EMC Check
9	793	OMPS SDR Functional Data Flow Check
10	1197	OMPS Bias Check
11	794	OMPS Self EMI/EMC Check
12	795	OMPS Charge Transfer Efficiency (CTE) Check
13	796	OMPS Dark Current Check
14	797	OMPS Bad Pixel Baseline
15	804	OMPS SDR Dark Current Histogram and Time Correlation
16	798	OMPS Dark Current Baseline
17	799	OMPS LED Cross Check and Bright Pixel Defects Check
18	800	OMPS LP Filter Characterization
19	801	OMPS Linearity Check
20	806	OMPS Characterization of Pixel Outliers
21	802	OMPS Linearity Baseline
22	1215	OMPS Calculate Lunar LP Slit Crossing Times
23	803	OMPS SDR Dark Current Characterization
24	807	OMPS Trending Dark Current, Linearity, Bad Pixels and Temperature
25	809	OMPS Trending Dark Current, Linearity, Bad Pixels and Temperature
26	810	OMPS Solar Diffuser Wheel Check
27	813	OMPS Diffuser Position Check via detector
28	814	OMPS Dichroic Check of TC and NP Solar SDRs
29	815	OMPS Jitter and Smear Solar SDR Check
30	816	OMPS Solar Measurement Parameter Tuning and Calibration SNR
31	818	OMPS SDR Wavelength Registration and Solar Reference Baseline
32	823	OMPS LP Stray Light Characterization
33	811	OMPS LP Solar Diffuser Cross Check with VIIRS
34	819	OMPS Goniometry Checks
35	820	OMPS Spectral Features in Solar View
36	824	OMPS SDR Wavelength Calibration
37	826	OMPS Solar Diffuser Crosscheck
38	817	OMPS SDR Flat Field Verification
39	821	OMPS Yaw Maneuver Goniometry Check
40	822	OMPS Solar Characterization
41	829	OMPS SDR Earth View Signals in Range
42	1248	OMPS Nadir Solar Irradiances Compared to SORCE Irradiances
43	830	OMPS LP Image Overlap Aperture Size
44	831	OMPS Earth Scene Sensor and SDR Parameter Check/Tune
45	842	OMPS LP Orbital Thermal Impact on 6 Focal Plane Images
46	827	OMPS NP Solar Magnesium II Index
47	832	OMPS Attitude Check - Equatorial Ozone
48	838	OMPS LP Integration Time and Sequence Verification
49	840	OMPS Earth SDR Radiometric Noise Analysis
50	843	OMPS TC and NP Retrieval Residuals Analysis
51	1249	OMPS Pixel Binning Earth RDR Counts Check
52	833	OMPS Make SDR Maps
53	845	OMPS LP Stray Light Height Dependence
54	848	OMPS LP Lunar Measurements for Altitude Check
55	1251	OMPS NP and LP Earth Ozone EDR Intercomparison
56	846	OMPS LP Pointing Determination Method Cross Check
57	834	OMPS Make Ozone EDR Maps
58	835	OMPS Geolocation Verification
59	844	OMPS NP Empirical Characterization of Stray Light
60	849	OMPS Mapper and NP SDR Cross-Check Earth Radiances
61	836	OMPS Co-Location with VIIRS
62	841	OMPS Smear/Scene Motion
63	847	OMPS Radiance vs. SBUV Cross Check
64	853	OMPS Ozone Consistency Checks for Satellite Ascending/Descen
65	850	OMPS LP and RTM Radiance Profiles Intercomparision
66	1250	OMPS LP and NP Radiance Comparison
67	851	OMPS Histogram Analysis of Reflectivities
68	852	OMPS Histogram Analysis of Reflectivities
69	837	OMPS LP Albedo Spectra Ratio Cross-Check with VIIRS
70	854	OMPS LP Altitude Registration - LIDAR
71	839	OMPS Earth Wavelength Fraunhofer Registration versus Temperature
72	797	OMPS Bad Pixel Baseline
73	798	OMPS Dark Current Baseline
74	802	OMPS Linearity Baseline
75	818	OMPS SDR Wavelength Registration and Solar Reference Baseline
76	824	OMPS SDR Wavelength Calibration
77	817	OMPS SDR Flat Field Verification
78	831	OMPS Earth Scene Sensor and SDR Parameter Check/Tune

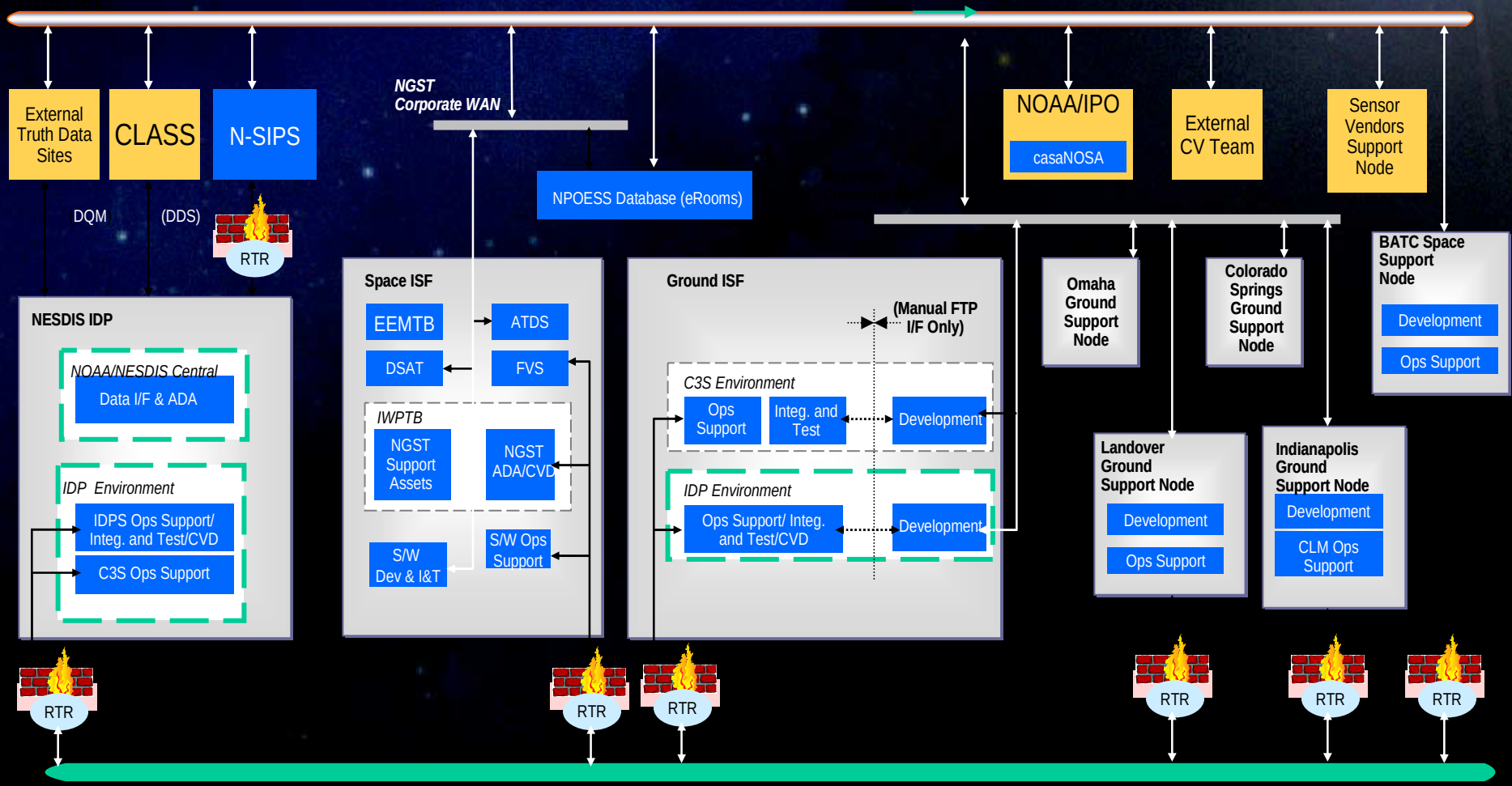
NPOESS

Preliminary Off-line Infrastructure Architecture

NORTHROP GRUMMAN

Raytheon

EEMTB	Electrical Engineering Model Test Bed	ADA	Algorithm Development Area
DSAT	Dynamic Systems Analysis Tool	CVDB	Cal Val Database
ATDS	Algorithm Timing and Dependency Simulation	ICVS	Interim Cal Val Storage
IWPTB	Integrated Weather Products Test Bed		

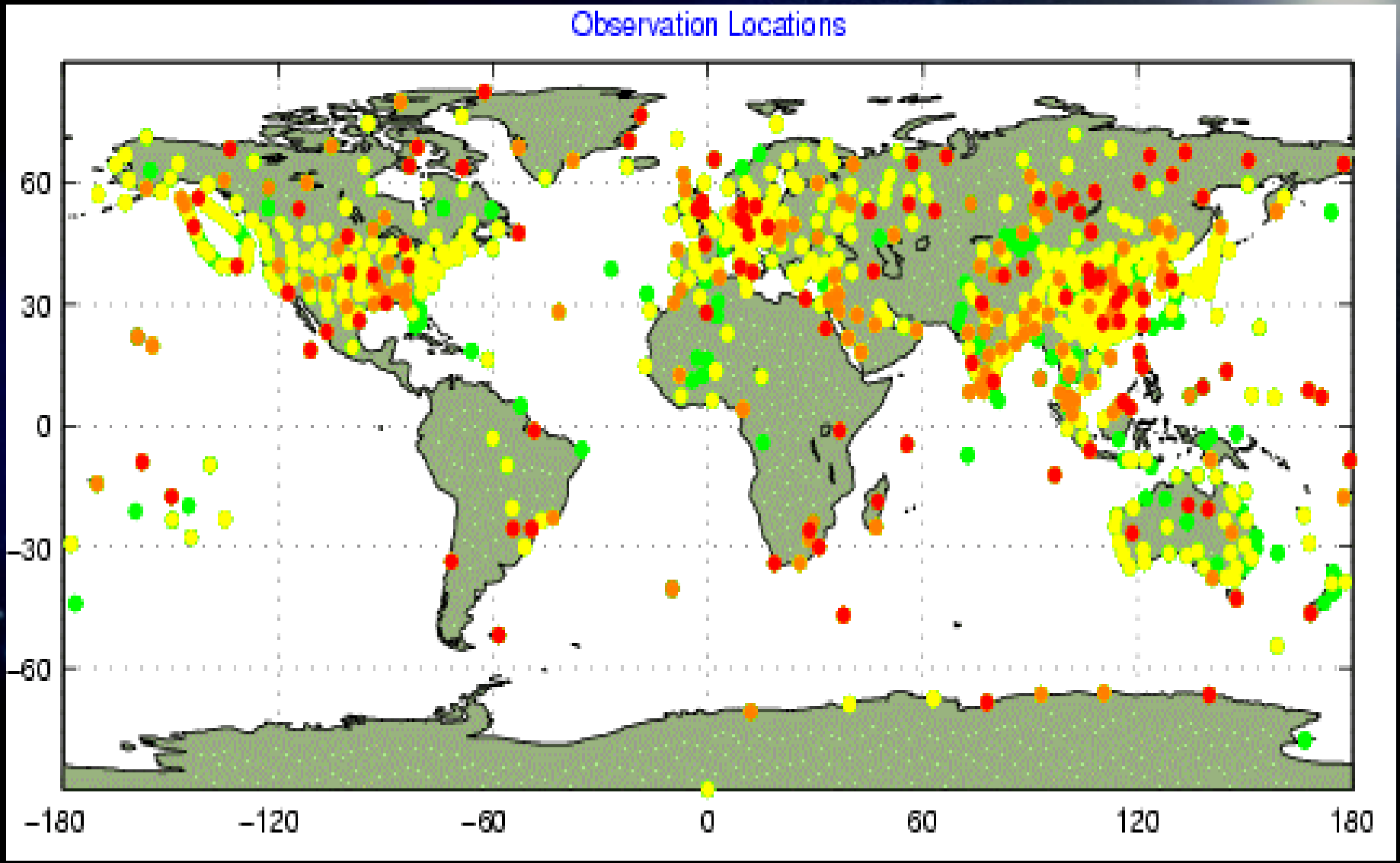


Adapted from IPO/NGST (Paul S. Lee)

NPP Cal/Val Tools Development

- **Develop tools to**
  - Format Products (RDR, SDR, EDR) to match up with ground truth
  - Acquire match-up data for Cal/Val
  - Process match-up data to needed physical unit for Cal/Val
  - Format match-up data for comparison
  - Perform match-up data analysis, statistics, and display of results

Typical Radiosonde Data Coverage



Radiosonde Match-up Process

Global Raw Radiosonde Data (prev 24 hours) NCEP PRODUCTION (~2000 per day)

Read NCEP prebufr Files & Reformat

QC & Interpolation

CVDB

Centrals/Extended CalVal team have to/from access

Processed Raobs (10 day archive)

Archived every 5 days

Read/extract EDRs, SDRs, and Ancillary data

FTPed from NESDIS

NOAA-16 Mission Data (prev 24 hours) (~ 14 orbits)

Radiosonde Matchup

Radiosonde Matchup Database

Cal Val Team workstations

Raob Match File

Java format

Matlab Daily Matchfile Monitor

MDB Update

VSTAT - automated stratified vertical accuracy stats

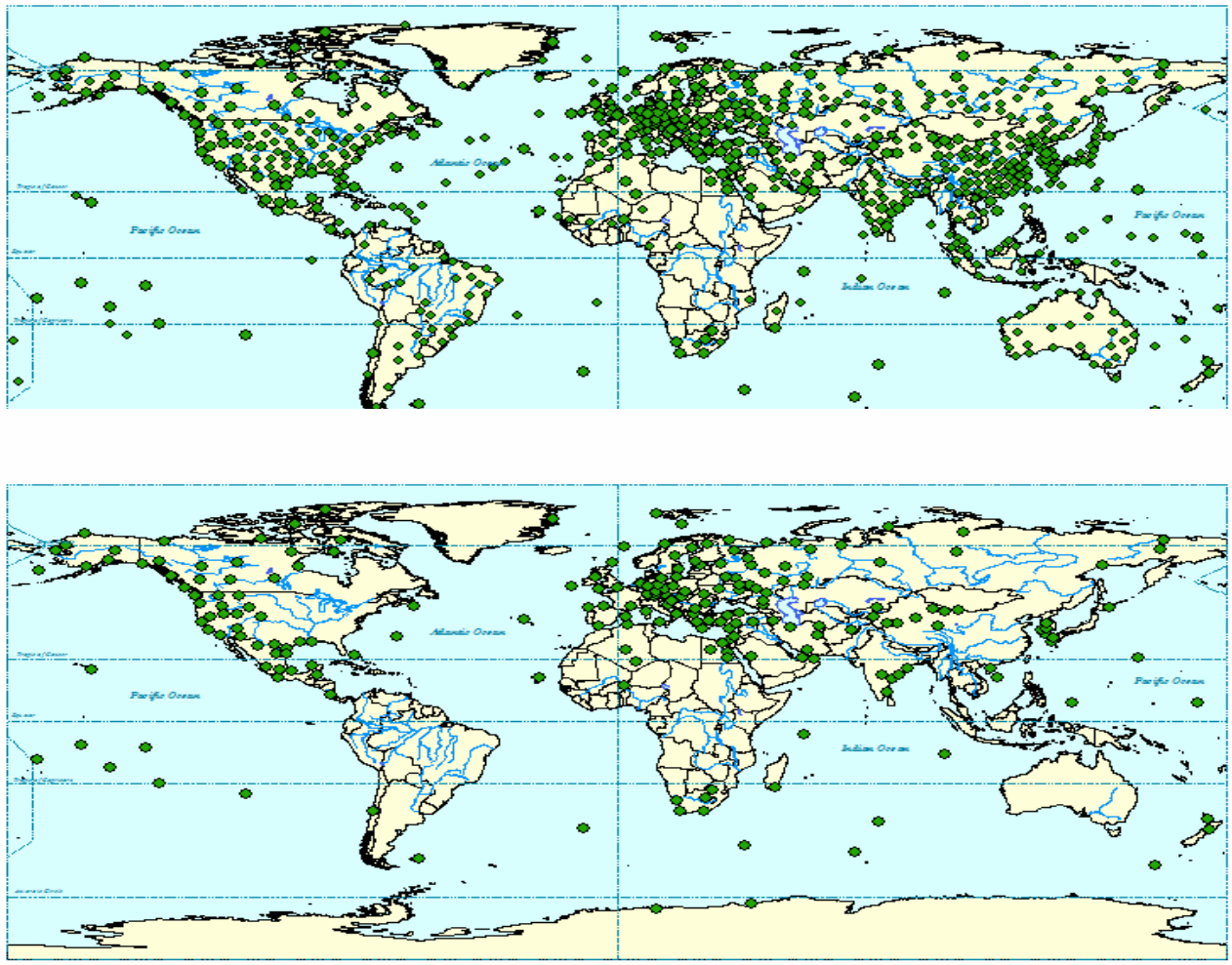
PDISP - retrieval /raob profile display

NESDIS P.O.C. - Mike Chalfant

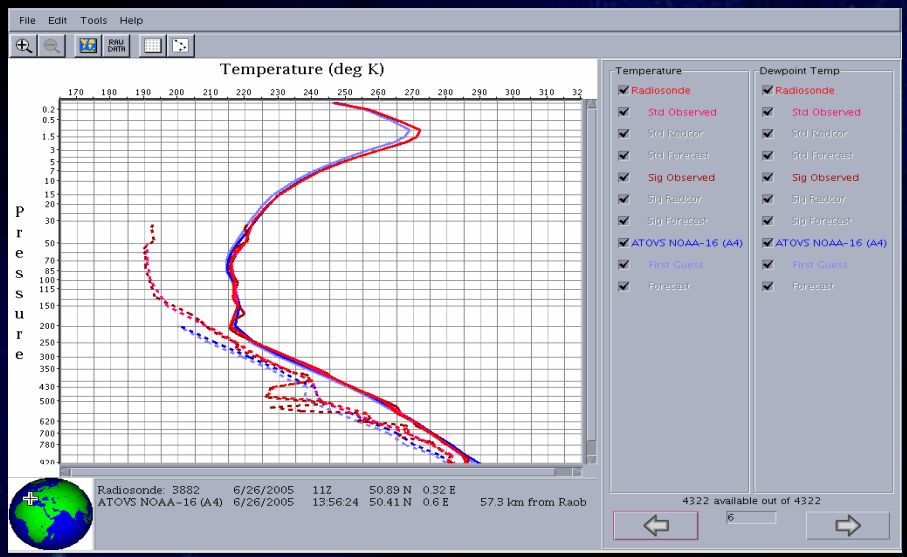
Daily Radiosonde Match-up using NOAA-16 data (7/5/2005)

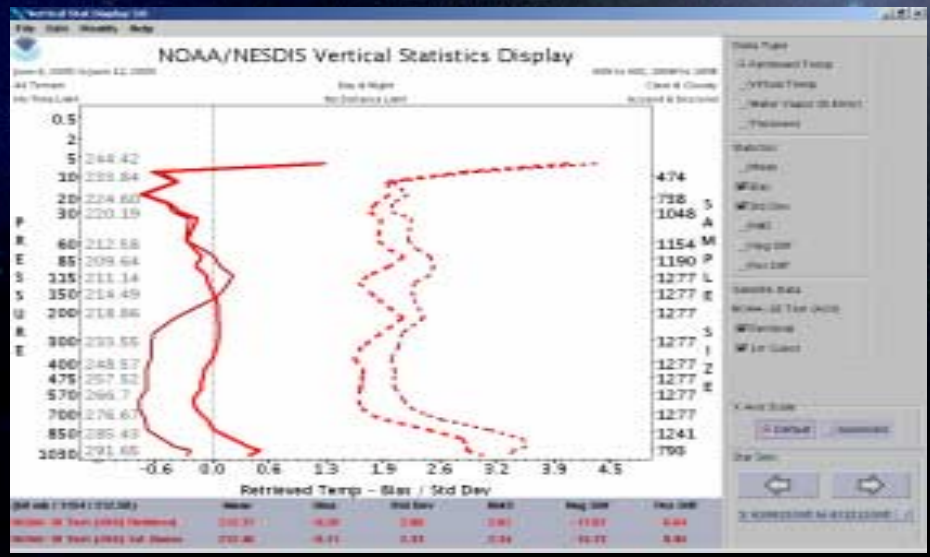
1943 Radiosondes Available From NCEP

308 Radiosondes matched with NOAA16



Radiosonde Match-up Process Display & Analysis Tools





Profile Display Tool (PDISP)

- Graphical representation of match-ups as well as the raw radiosonde data in tabular form

Vertical Accuracy Tool (VSTATS)

- Statistical assessment of the AVTP and AVMP EDRs
- bias and uncertainty statistics
- user defined stratifications

Adapted from IPO/NGST (Paul S. Lee)

NCEP Model Data Match-up Process

FTPed from NCEP

GFS Forecast Model
GRIB files: 4x/day

NCEP production suite

GRIB
De-coder

CVDB

Centrals/ Extended
CalVal team have
to/from access

Extract parameter
files & Reformat

FTPed from NESDIS

NOAA-16 Mission
Data (prev 24 hours)
(~ 14 orbits)
AIRS Level 2 (DAAC)

Model T, q, and Ts
Forecast fields

Reformat and subset
Interpolated fields

Cal Val Team
workstations

Read/extract
EDRs, SDRs,
and Ancillary
data

Interpolate model
data to Instrument
FOVs in Time and
Space

Forward model/
vicarious SDR
CalVal tools

EDGEIS/GIS -
SDR and EDR
Visualization/
analysis tools

SST/Buoy/Ship Data Match-up Process

Raw Buoy/Ship Data

<RTDHS>

Independent SST File

CVDB

Centrals / Extended CalVal team have to/from access

FTPed from NESDIS

NOAA-16, 17 Mission Data (prev 24 hours) (~ 14 orbits) GOES East/West

Buoy/Ship Extraction

SST Match-up Database

Mission Data Matchup w/ Buoy/Ship

Read/extract EDRs, SDRs, and Ancillary data

Cal Val Team workstations

Automated Generation of Statistics

EDGEIS - SDR and EDR Visualization/ analysis tools Extract Tools

Mission Data SST Data Storage

NESDIS P.O.C. - John Sapper

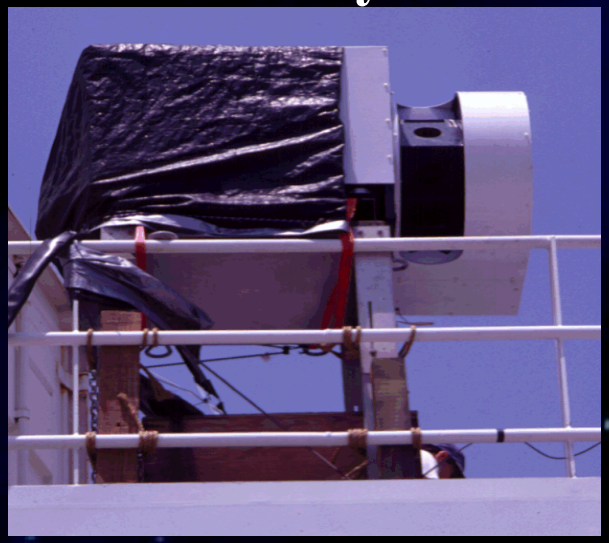
SST Validation

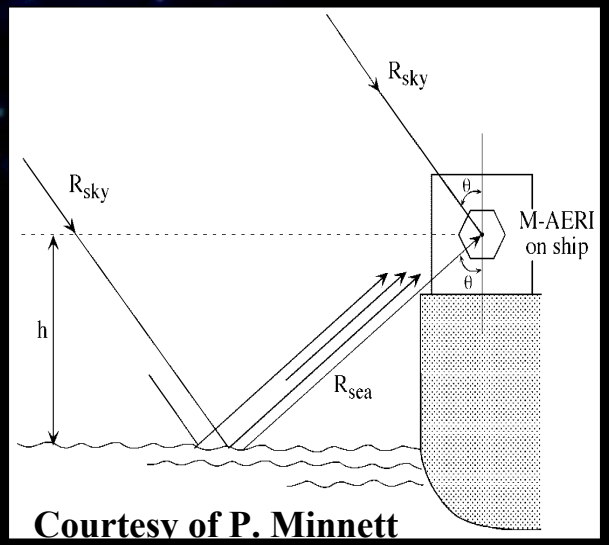
- Sources of uncertainties in SST are
  - a) instrumental imperfections
  - b) imperfect correction for the effects of intervening atmosphere
- Primary validation must be radiometric – skin SSTs; M-AERI & filter radiometers.
- Use more numerous buoys to 'fill in parameter space' of atmospheric and oceanic variability.

Courtesy of P. Minnett

SST Validation using Marine-Atmospheric Emitted Radiance Interferometer (M-AERI)

Shipboard measurement of Skin SST by M-AERI





Courtesy of P. Minnett

Specifications

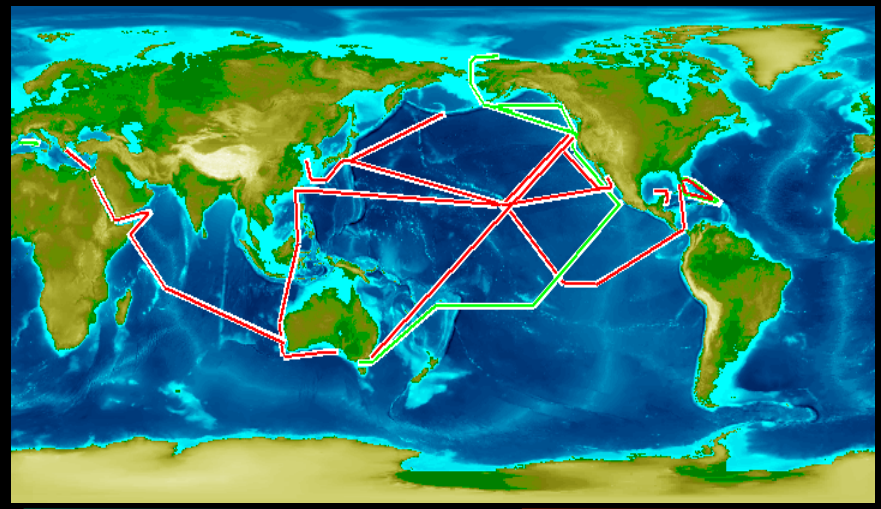
Spectral interval	~3 to ~18μm
Spectral resolution	0.5 cm^{-1}
Interferogram rate	1Hz
Aperture	2.5 cm
Detectors	InSb, HgCdTe
Detector temperature	78°K
Calibration	Two black-body cavities
SST retrieval uncertainty	<< 0.1K (absolute)

Laboratory tests of M-AERI accuracy

Target Temp.	LW (980-985 cm^{-1})	SW (2510-2515 cm^{-1})
20°C	+0.013 K	+0.010 K
30°C	0.024 K	-0.050 K
60°C	0.122 K	-0.086 K

The main discrepancies in the M-AERI 02 measurements of the NIST water bath blackbody calibration target in two spectral intervals where the atmosphere absorption and emission are low. Discrepancies are M-AERI minus NIST temperatures.

M-AERI Cruises Since launch of *Terra* MODIS



In 2000 In 2001

NPOESS/NPP Pre- & Post-Launch Instrument Calibration, Characterization & NIST Traceability

•**Integrating sphere** intercomparison heritage from EOS. Shown here is a NIST Visible Transfer Radiometer (VXR) viewing a NIST portable integrating sphere at NASA Ames during an intercomparison of several radiometers and integrating spheres, the purpose of which was to verify the uncertainty of airborne validation instruments such as those aboard MAS. Heritage example for the NPP Cal/Val Plan Type B activity.

•**NOAA/NASA Marine Optical Buoy (MOBY).** This NOAA program provides validation of ocean color data by maintaining buoy measurements off the coast of Hawaii that are compared to overflying satellites. NIST's role has been to to perform system level radiometric calibrations of the spectrographs used for down-welling and up-welling spectral radiance measurements on the buoy, ensuring a more direct tie of satellite ocean color data to the NIST radiance scale, using a portable tunable laser-illuminated integrating sphere approach. Heritage example for the NPP Cal/Val Plan Type E activity.

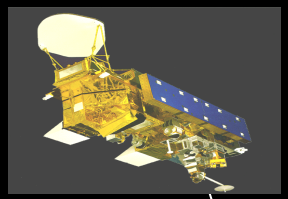
MOBY

Courtesy of J. Rice-NIST

NATIONAL POLAR-ORBITING OPERATIONAL ENVIRONMENTAL SATELLITE SYSTEM

Near Real-Time Operational Demonstrations of Utilization of Advanced Sounder & Ozone Data for Improved NWP, Ozone Forecasting & Climate

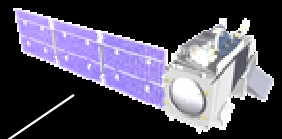
"Aqua" [EOS-PM] (2002)
AIRS/AMSU/HSB & MODIS



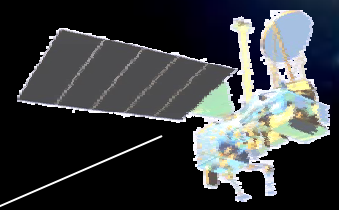
WindSat (2003)

METOP (2006)
IASI/AMSU/MHS, GOME-2 & AVHRR

NPP (2008)
CrIS/ATMS, OMPS & VIIRS



NPOESS (2010, 2012, 2014)
CrIS/ATMS, VIIRS, CMIS, OMPS, ERBS, APS



NOAA Near Real-Time Data Delivery Ground Station Scenario

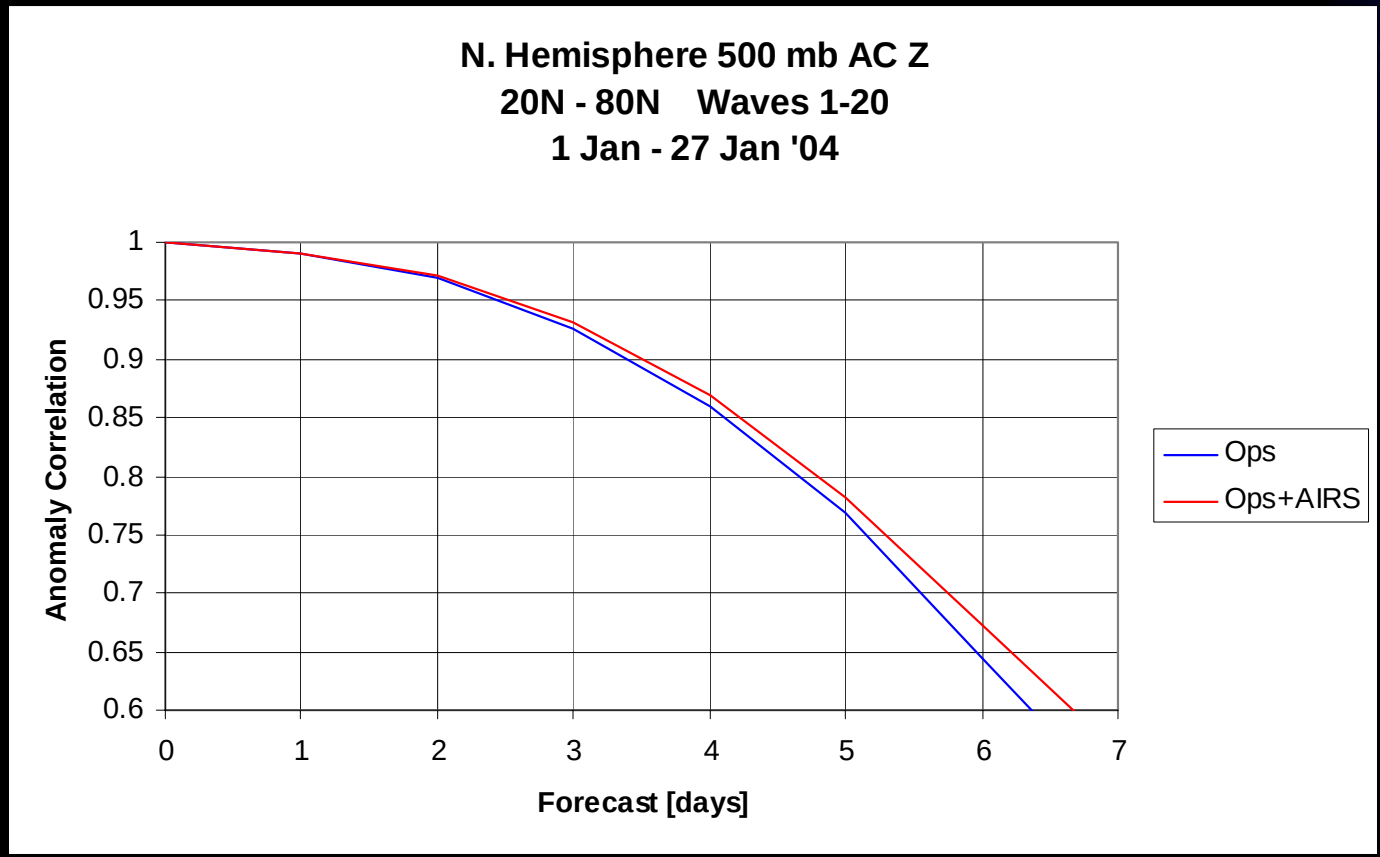
C3S → IDPS → NOAA Realtime User

Joint Center for Satellite Data Assimilation

→ NWS/NCEP
GSFC/DAO
ECMWF
UKMO
FNMOC
Meteo-France
BMRC-Australia
Met Serv Canada

→ NWP Forecasts

Data from AIRS is showing valuable NWP improvements over the Northern Hemisphere – the forerunner to CrIS

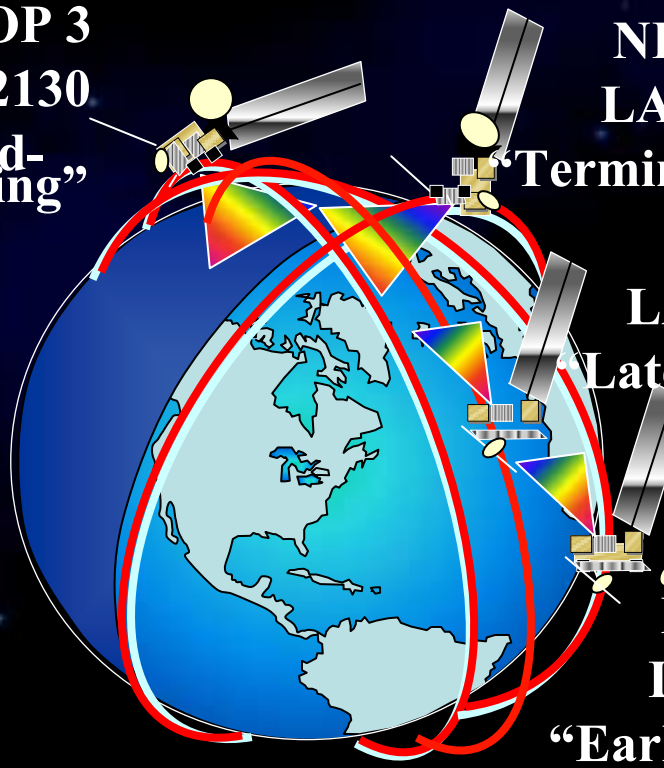


500hPa Z Anomaly Correlations with (Ops.+AIRS) and without (Ops.) AIRS data Northern hemisphere, January 2004

Atmospheric InfraRed Sounder (AIRS) Observations: Impact on Weather Forecasts
J. Le Marshall, J. Jung, J. Derber, R. Treadon, S.J. Lord,
M. Goldberg, W. Wolf, H.C. Liu, J. Joiner, J. Woollen and R. Todling.
NOAA/NASA/NAVY/Air Force Joint Center for Satellite Data Assimilation

Cal/Val & The NAST
[NPOESS Airborne Sounder Testbed]

Joint Transition Activities [JTA] Agreement Notional Concept – "Towards a JPS" + NPP E.G.



	Launches	Lifetime	Ozone Sensors	Atmos Sounders
METOP [2130]	~2006, 2011, 2015	5 yr	GOME-2/IASI	IASI/AMSU/MHS
NPP [2230]	~2008	5 yr	OMPS/CrIS	CrIS/ATMS
NPOESS [1330]	~ 2010, 2016	7 yr	OMPS/CrIS	CrIS/ATMS
NPOESS [1730]	~2012, 2018	7 yr	CrIS	CrIS/ATMS

"Continuity of GLOBAL and/or Quasi-GLOBAL Products from 2005 – 2025"

NPOESS/NPP Sounding Instruments

- **CrIS**
  - 1301 IR (3.92 to 15.38 μm) channels
  - 3x3 detector array with 15 km ground center-to-center
  - 2200 km swath width
  - EDU built and ready for integration testing with NPP Spacecraft in 10/05
  - Flight model in assembly
- **ATMS**
  - CrIS companion cross track scan with 22 microwave channels
  - 1.1, 2.2, and 5.2 deg (SDRs resampled to CrIS 3.3-deg FORs)
  - 2300 km swath width
  - EDU built and ready for integration testing with NPP Spacecraft
  - Flight model in testing
- **CMIS**
  - 2.2 m antenna imaging/profiling/polarimetry in microwave channels
  - 15-40 km resolution
  - 1700 km swath width
  - Preliminary design complete

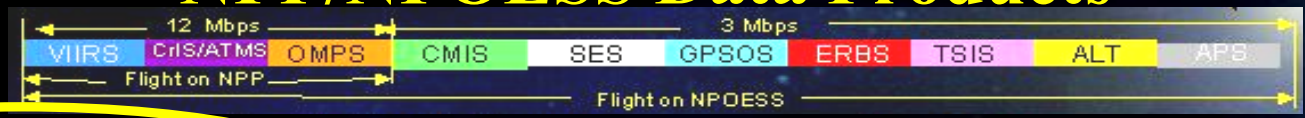
Conical-scanning Microwave Imager/Sounder (CMIS) Boeing

[NPOESS only]

Cross-track IR Sounder (CrIS) ITT Industries

Advanced Technology Microwave Sounder (ATMS) Northrop Grumman

CrIS Contributes to Sixteen (16) NPP/NPOESS Data Products



★ Atmospheric Vertical Moisture Profile	Cloud Top Pressure	Precipitable Water
★ Atmospheric Vertical Temp Profile	Cloud Top Temperature	Precipitation Type/Rate
★ Imagery	Downward Longwave Radiance (Sfc)	Pressure (Surface/Profile)
★ Sea Surface Temperature	Downward Shortwave Radiance(Sfc)	Sea Ice Characterization
★ Sea Surface Winds	Electric Field	Sea Surface Height/Topography
★ Soil Moisture	Electron Density Profile	Snow Cover/Depth
Aerosol Optical Thickness	Energetic Ions	Solar Irradiance
Aerosol Particle Size	Geomagnetic Field	Supra-Thermal-Auroral Particles
Aerosol Refractive Index	Ice Surface Temperature	Surface Type
Albedo (Surface)	In-situ Plasma Fluctuations	Wind Stress
Auroral Boundary	In-situ Plasma Temperature	Suspended Matter
Auroral Energy Deposition	Ionospheric Scintillation	Total Water Content
Auroral Imagery	Medium Energy Charged Particles	Vegetation Index
Cloud Base Height	Land Surface Temperature	
Cloud Cover/Layers	Net Heat Flux	
Cloud Effective Particle Size	Net Solar Radiation (TOA)	
Cloud Ice Water Path	Neutral Density Profile	
Cloud Liquid Water	Color/Chlorophyll	
Cloud Optical Thickness	Ocean Wave Characteristics	
Cloud Particle Size/Distribution	Outgoing Longwave Radiation (TOA)	
Cloud Top Height	Ozone - Total Column/Profile	

VIIRS (23)
CMIS (19)
CrIS/ATMS (3)
OMPS (1)
SES (13)
GPSOS (2)
ERBS (5)
TSIS (1)
ALTIMETER (3)
APS (4)

CrIS (16)

★ Environmental Data Records (EDRs) with Key Performance Parameters

Evolution of High Resolution IR Atmospheric Soundings

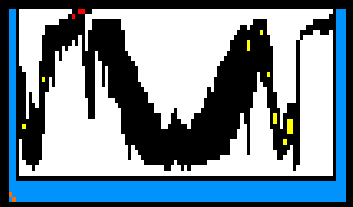
Nimbus 3 & 4 *IRIS/SIRS* (1969-1972)

First Satellite Sounders

Nimbus 5/*ITPR* *ITOS/VTPR* Nimbus 6/NOAA *HIRS* *GOES/VAS & HIRS* (1972-2009)

High Horizontal Resolution

High Resolution Interferometer Sounder (*HIS*) (1985-)

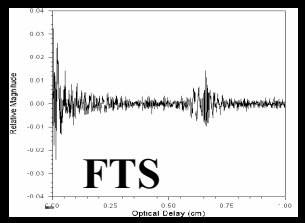


High Vertical Resolution

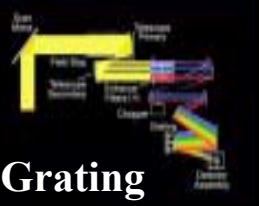
Aircraft *NAST-I / SHIS* (1995 -)

High Vertical Resolution Imagery

ADEOS *IMG* *(1996-1997)*

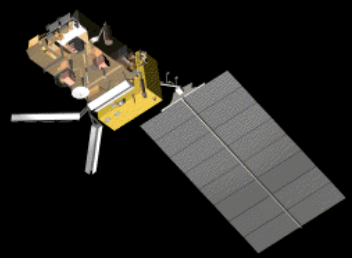


Aqua *AIRS* (2002-)



First Satellite High Vertical Resolution Sounding Spectrometers

METOP-*IASI* (2006 -)

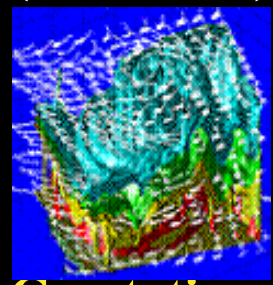


European High Vertical Resolution Sounder

NPP/NPOESS/*CrIS* (2009 -)

US High Vertical Resolution Sounder

GIFTS GOES-*HES* (2008,2012)



Geostationary Imaging 4-d T,q,"V" Sounder

Courtesy of Bill Smith

CrIS is Combined with ATMS to Satisfy NPOESS Atmospheric Sounding EDRs

(CrIMSS ➔ Profiles of Temperature, Moisture, and Pressure)

- CrIS
- ATMS

RDR = Raw Data Record
SDR = Sensor Data Record
EDR = Environmental Data Record

RDRs

Central or Regional Ground Stations

CrIS Swath 2200km

ATMS Swath 2500km

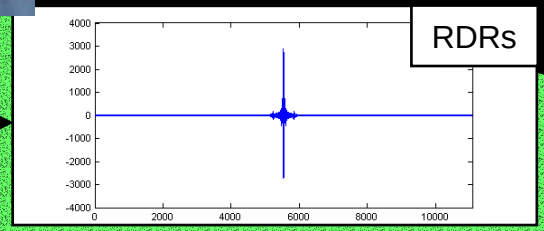
3x3 Array of CrIS FOVs (Each at 14-km Diameter)

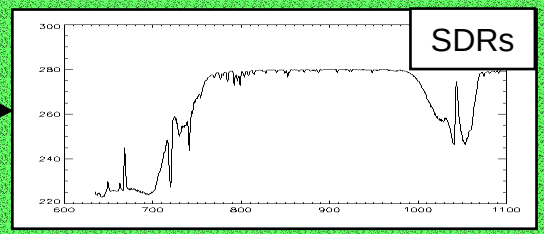
Co-located ATMS SDRs

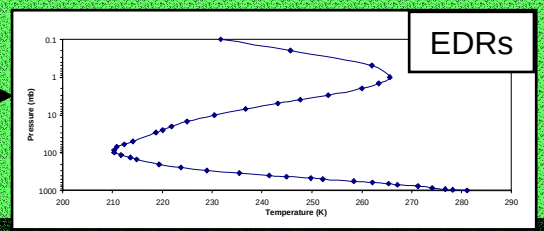
Decode Spacecraft Data

SDR Algorithms

EDR Algorithms







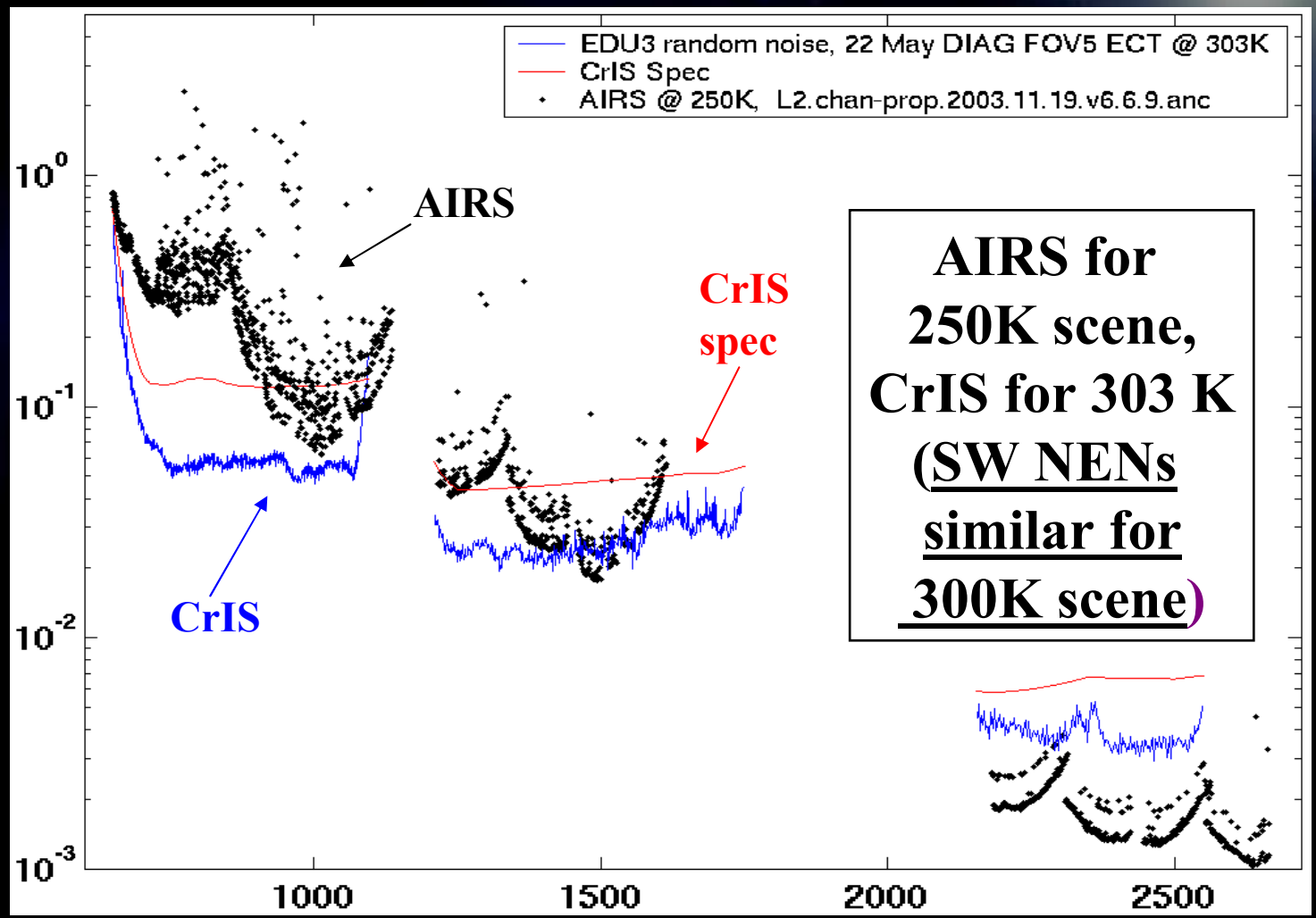
Courtesy of ITT

CrIS vs. AIRS Noise Comparison

(Lower Noise => Higher Vertical Resolution)

CrIS EDU 3 NEdN Was Measured in Thermal Vacuum Testing At Mission Nominal Temperature To Verify Performance

CrIS FM1 will have improved SWIR and MWIR Performance with Flight Detectors and Signal Processors



Courtesy of Bill Smith, Allen Larar, Henry Revercomb et al.

Radiometric Calibration

e.g. CrIS Michaelson Interferometer Spectrometer

Noise Factors

- Gain, offset, phase errors;Non-linearity
- ICT Temperature, emissivity & other CrIS state errorsa
- On-orbit radiation
- Photon, detector and amplifier noise
- Background radiance changes

Signal Factors

- Interferograms for Scene, Deep Space [DS] & Internal Calibration Target [ICT]
- CrIS Telemetry

OBJECTIVE
Minimize Intensity (Radiance) Uncertainty

Response

- Radiometrically Calibrated SDRs [Level 1B]

Control Factors

- Correct Gain offset & phase errors
- Correct non-linearity
- Remove Spikes
- Compute moving averages

Adapted from ABB Bomem, CrIS ATBD

NATIONAL POLAR-ORBITING OPERATIONAL ENVIRONMENTAL SATELLITE SYSTEM

NPOESS Airborne Sounder Testbed - [NAST]

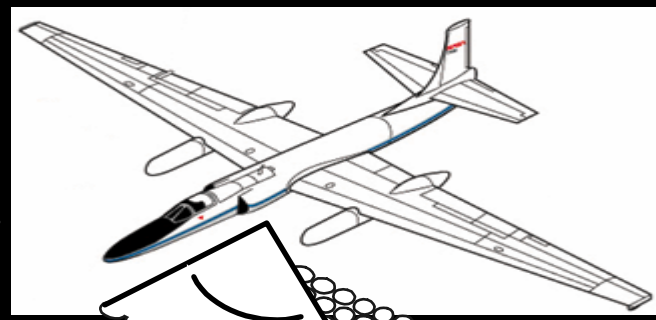
[NASA/LaRC, U. Wisconsin, MIT Lincoln Laboratory, MIT]

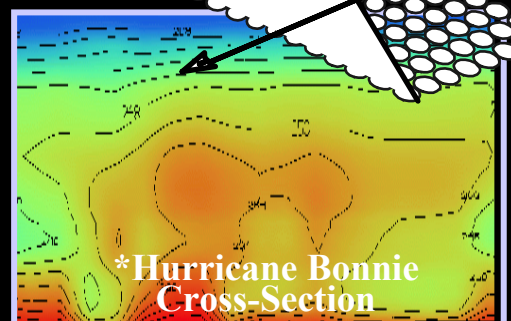
OBJECTIVES

- Developed by IPO to Simulate Candidate Spaceborne Instruments - CrIS, ATMS, IASI, AIRS, AMSU, HSB
- Science Issue & Risk ReductionTestbed
- Evaluate Key EDR Algorithms
- Preview High Resolution Products (Spectral & Spatial)
- Under Flight Calibration/Validation [AIRS,IASI,CrIS, AMSU, HSB, ATMS]

INSTRUMENTS [NAST-I & NAST-M]

- NAST-I: IR Michelson Interferometer [FTS] Sounder
- NAST-M: Microwave Sounder
- Co-Boresighted IR and Microwave
- IR Interferometer [FTS] Sounder 3.5 – 16 µm, 9000 Chan.
  - High Spectral Resolution 0.25 cm^{-1}
  - Calibrated Radiances-0.5K Abs. Accuracy, 0.1K Prec.
  - High Sensitivity in a cold scene
    - 0.10 K NEDT @ 14.9 µm (250K)
    - 0.15 K NEDT @ 8.2 µm (250K)
    - 0.20 K NEDT @ 4.7 µm (250K)
- Microwave Sounder
  [4 Bands, 29 Chan.] 50-56, 118.7±4, 183±11, 425±4 GHz





NAST Program Overview

NPOESS Airborne Sounder Testbed (NAST)

NAST

IR Interferometer (NAST-I)

Spectral Range: 3.5 - 16 microns
Spectral Res.: 0.25 cm-1 ($\nu/\nu\delta > 2000$)
Spatial res.: 130m/km flight alt.
A/C platforms: ER-2, Proteus, WB-57 (soon)

Microwave Radiometer (NAST-M)

Spectral Regions: 50 - 60 GHz,
113 - 119 GHz, 183 GHz, 425GHz
A/C platforms: ER-2, Proteus, WB-57 (soon)

- **NAST Program Objectives**
  - **Pre-launch Testbed for Risk Reduction**
    - sensor concepts, algorithms, product specifications
  - **Cal/Val System for Heritage Sounders**
    - e.g. Aqua AIRS, Aura TES, Metop IASI, & NPP/NPOESS CrIS
    - measurement system (instrument, algorithms, direct/derived products)
  - **Data for Algorithm Development**
    - radiative transfer spectroscopy
    - retrieval methods and products
  - **Field Mission Geophysical State Characterization**
    - atmosphere, clouds, surface

A Fundamental Purpose of NAST

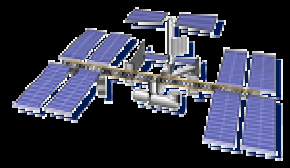
- The National Polar-orbiting Operational Environmental Satellite System (NPOESS) Airborne Sounder Testbed (NAST) program was established to provide ***real, experimental data needed to validate:***

(1) the design of the satellite sensors
(2) the data processing algorithms, and
(3) the scientific observations (i.e., SDRs and EDRs) obtained from their space deployment

Motivation for Satellite Sensor Cal/Val and Benefit from Using Airborne Sensors

- ***Post-launch validation activities are critical to verify quality of satellite measurement system (i.e., sensor, algorithms, and direct/derived data products)***

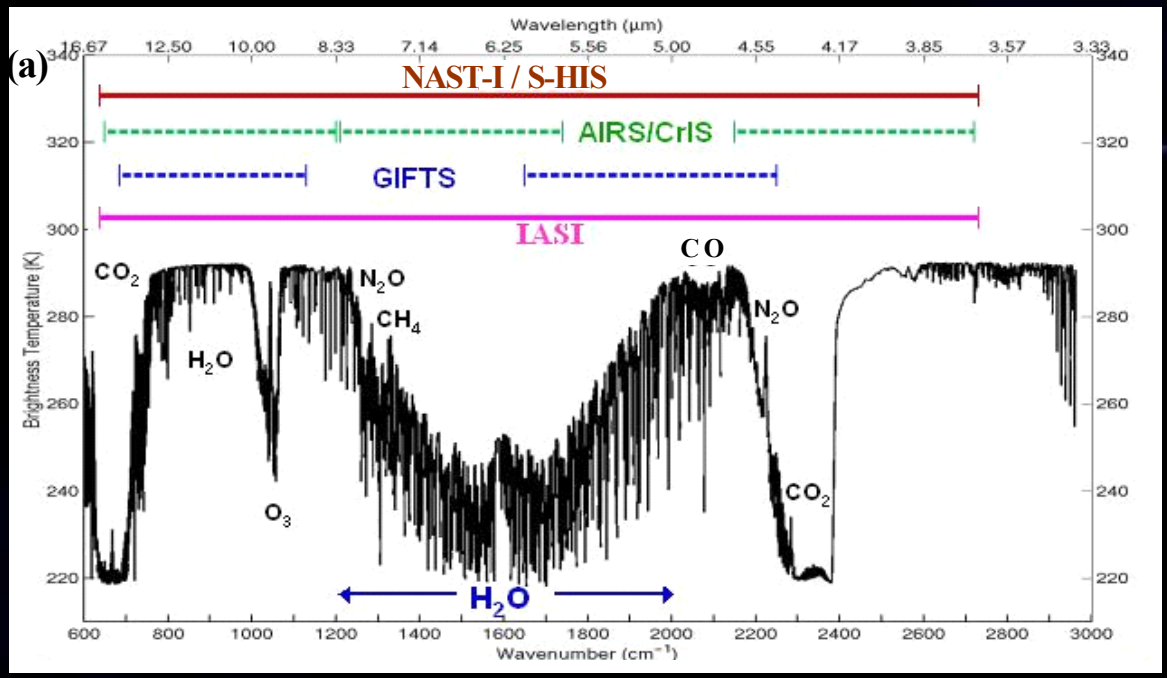
- ***Resulting data contribute toward essential cal/val activities***
  - On-orbit sensor performance verification
  - On-orbit sensor calibration validation
  - Validate algorithms
  - Direct and derived data product validation
  - Long-term monitoring of sensor performance (radiance & geophysical)

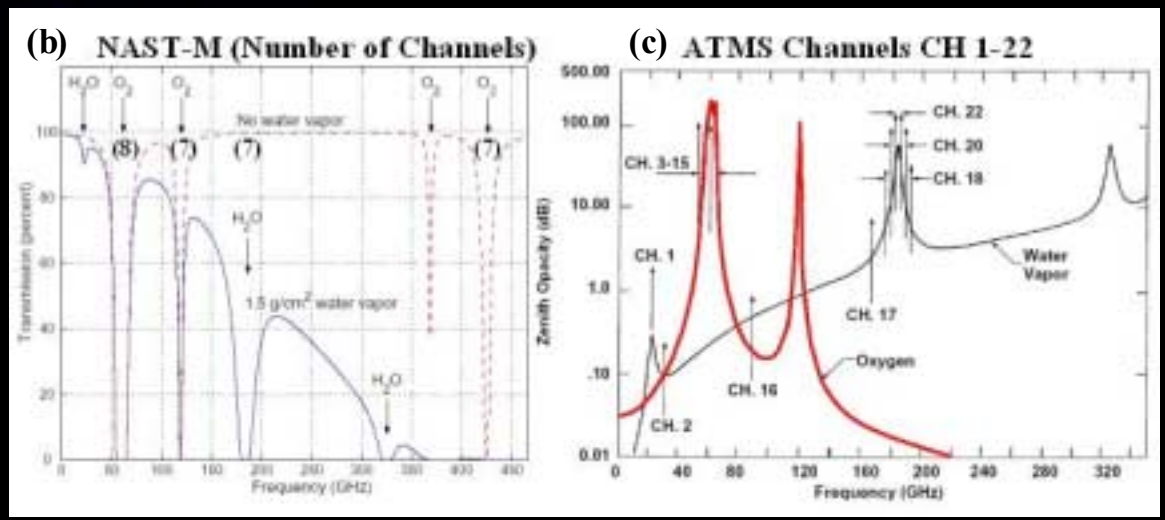


- ***Aircraft underflights fundamental to space-based sensor validation***
  - High-altitude aircraft platforms (Proteus, ER-2, DC-8, WB-57, P-3, BAE-146-300, etc.) instrumented with validation sensors (NAST-I, S-HIS, ARIES, INTESA, NAST-M, LASE, MAS, etc.) provide validation data by obtaining spatially & temporally coincident observations with satellite platforms of interest (e.g. Terra (Modis), Aqua (Modis & AIRS), Aura (TES), and future Metop (IASI), NPP/NPOESS (CrIS), and ~~EO-3~~ (GIFTS).

Adapted from Allen M. Larar et al

NPOESS Airborne Sounder Testbed - [NAST]



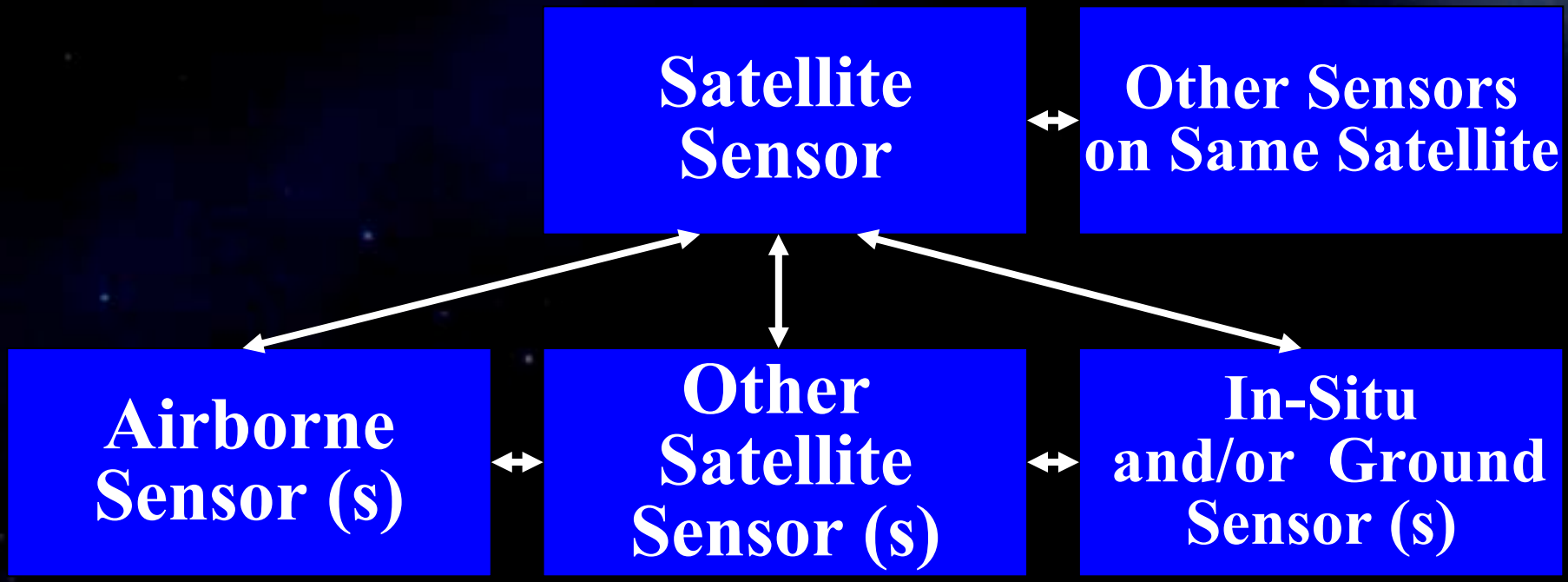


NAST on ER-2

At 20 km ALTITUDE
NADIR 2.6 km IFOV
± 23 km GROUND COVERAGE
± 48 º Scan

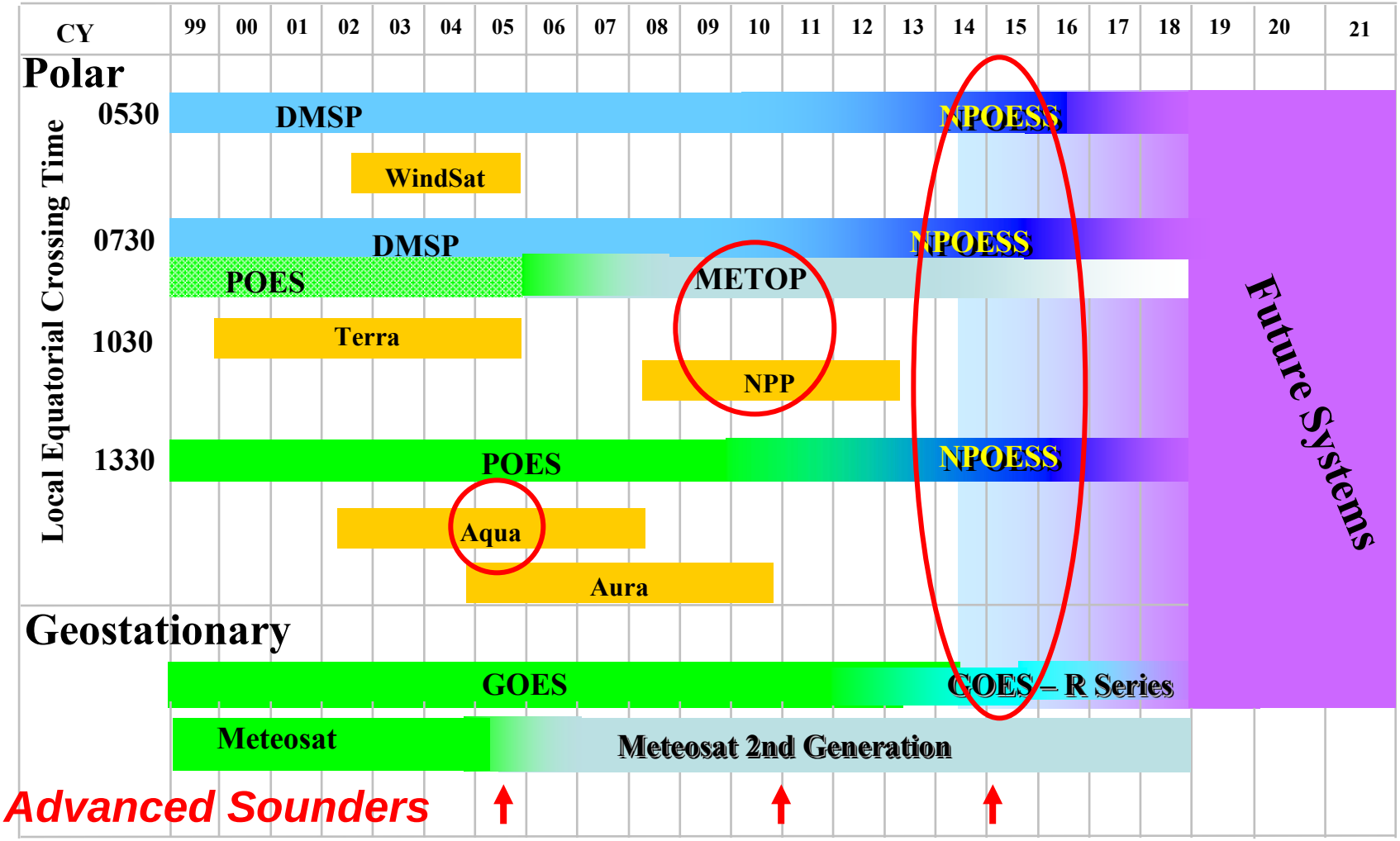
NAST on Proteus

Satellite Sensor Cross-Calibration/Validation



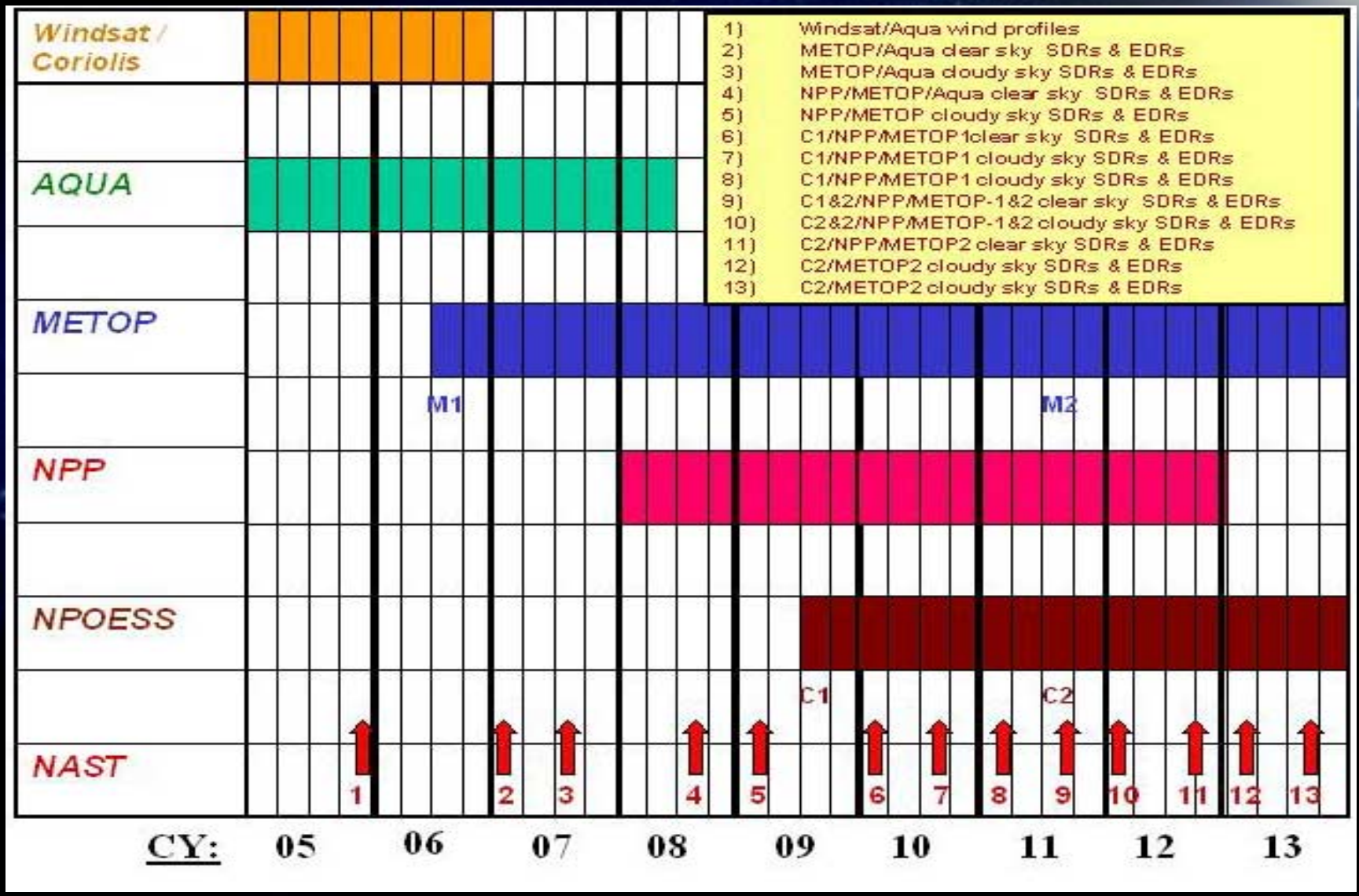
Both Cross-Calibration of Sensors & Cross-Validation of Products Should be planned & executed

Long-Range Integrated USA/European Satellite Transition



NPOESS/NPP Airborne Calibration and Science Validation Planned Program

NPOESS/NPP Cal/Val Agency Participants [IPO,NASA, NOAA, DOE, DoD, NSF]



IPO NAST Science Team*

- Prof. William L. Smith [Hampton U; NASA/LaRC;U Wisc]
- Prof. David H. Staelin [MIT & MIT/LL]
- Dr. Henry E. Revercomb [U. Wisc/SSEC]
- Dr. Daniel Mooney {MIT/LL]
- Dr. Allen M. Larar [NASA/LaRC]
- Dr. Stephen A. Mango [NPOESS IPO]
- Dr. W. Paul Menzel [NOAA/NESDIS]
- Dr. Daniel K. Zhou [NASA/LaRC]
- Dr. Michael Gazarik [NASA/LaRC]
- Dr. Xu Liu [NASA/LaRC; AER]
- Dr. Robert O. Knuteson [U Wisc/SSEC]
- Dr. David C. Tobin [U. Wisc/CIMSS]
- Prof. Allen H. Huang [U. Wisc]
- Dr. H.L. Huang [U. Wisc]
- Prof. Steven A. Ackerman [U. Wisc]
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- Dr. Michael Griffin [MIT/LL]
- Dr. Daniel Cousins [MIT/LL]
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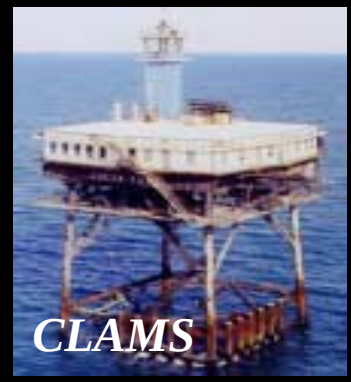
- Dr. Christopher Barnett [NOAA/NESDIS]

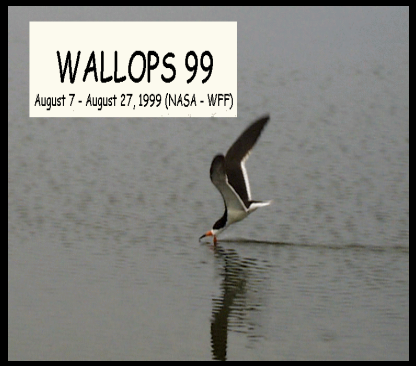
•Partial Listing of NAST Team and Collaborators; see also Related IGS Sounding ScienceTeam

NPOESS/NPP Airborne Calibration and Science Validation Program

NPOESS/NPP Cal/Val Agency Participants [IPO,NASA, NOAA, DOE, DoD, NSF]

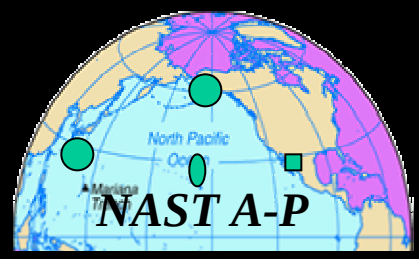


WALLOPS-98 & 99

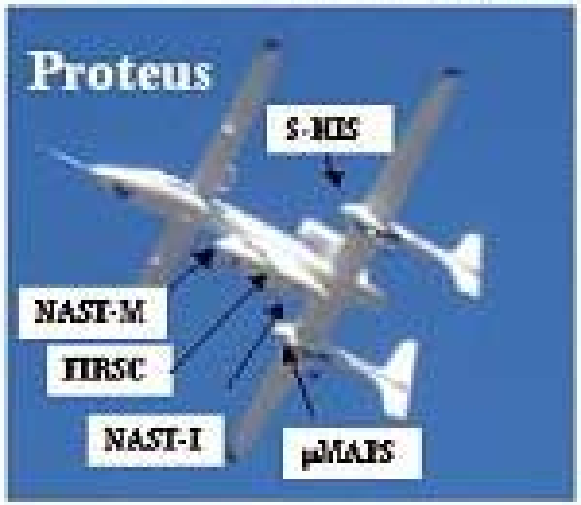


NAST has flown ~ 152 mission sorties accumulating over 850 hours of flight data in 17 field experiments:

Wallops98 (June-July, 1998); CAMEX-3 (Aug-Sep, 1998); WINTEX (Mar, 1999); Wallops99 (Aug, 1999); C-IOP (Mar, 2000), WV-IOP (Sep-Oct, 2000); AFWEX (Nov-Dec, 2000); Asian-Pacific (Feb-Mar, 2001); CLAMS (Jul-Aug, 2001); IHOP (May-Jun, 2002), CRYSTAL-FACE (Jul, 2002),TX2002 (2002), TOST (Feb-Mar, 2003), THORPEX 2003, INTEX (2004), EAQUATE-1 (2004), EAQUATE-2 (2004)



NAST Flight History



1998-2004

17 Missions; 152 Sorties; 850 Flight hours

Mission	Location	Platform	Year
Wallops 98	Virginia	ER-2	1998
Camex-3	Florida	ER-2	1998
WINTEX	Wisconsin	ER-2	1999
Wallops 99	Virginia	ER-2	1999
C-IOP	Oklahoma	Proteus	2000
WV-IOP	Oklahoma	Proteus	2000
AFWEX	Oklahoma	Proteus	2000
A-P	CA/HI/Japan/AK	Proteus	2001
CLAMS	Virginia	Proteus	2001
IHOP	Oklahoma	Proteus	2002
CRYSTAL-FACE	Florida	Proteus	2002
TX2002	Texas	ER-2	2002
THORPEX	Hawaii	ER-2	2003
ATOST	Maine	ER-2	2003
INTEX	Virginia	Proteus	2004
EAQUATE-1	Italy	Proteus	2004
EAQUATE-2	United Kingdom	Proteus	2004

Courtesy of NAST Team

PTOST

PTOST (February 18 - March 13, 2003, HAFB, Hawaii). The 2003 Pacific ***THORPEX Observing System Test (TOST)*** was the first in a series of Pacific and Atlantic observation campaigns in support of the WWRP/USRP THORPEX Program. THORPEX - a Global Atmospheric Research Program aimed at improving short range (up to 3 days), medium range (3-7 days) and extended range (two week) weather predictions. Flights targeted frontal boundaries and storm systems, as well as satellite sensor validation underflights (TERRA, AQUA, and ICESat)

Aircraft Sensors Included:

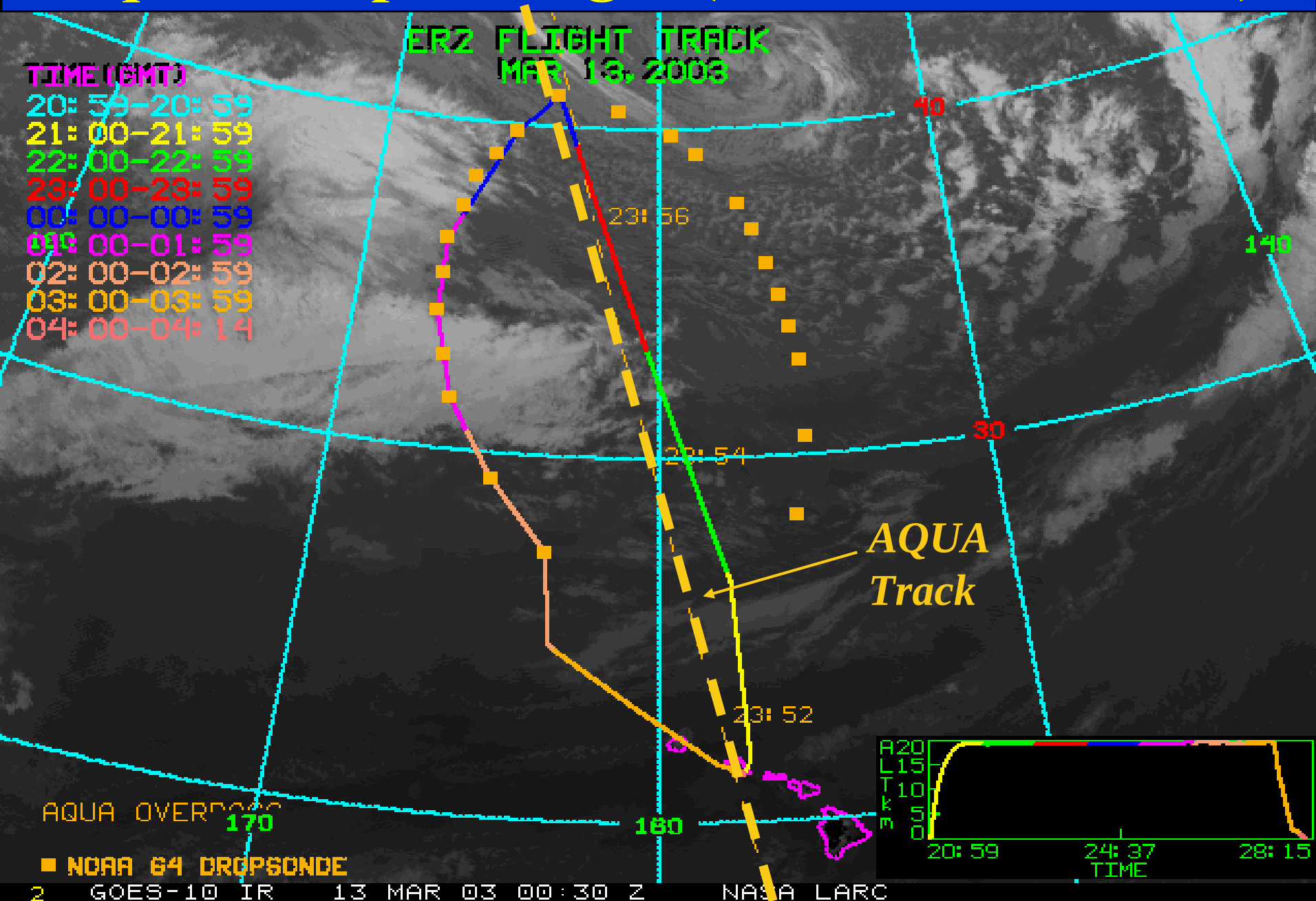
ER-2 (NAST-I, NAST-M, S-HIS, MAS, CPL); **G-IV** (Dropsondes, in-situ O_3)

Satellite Platforms Included:

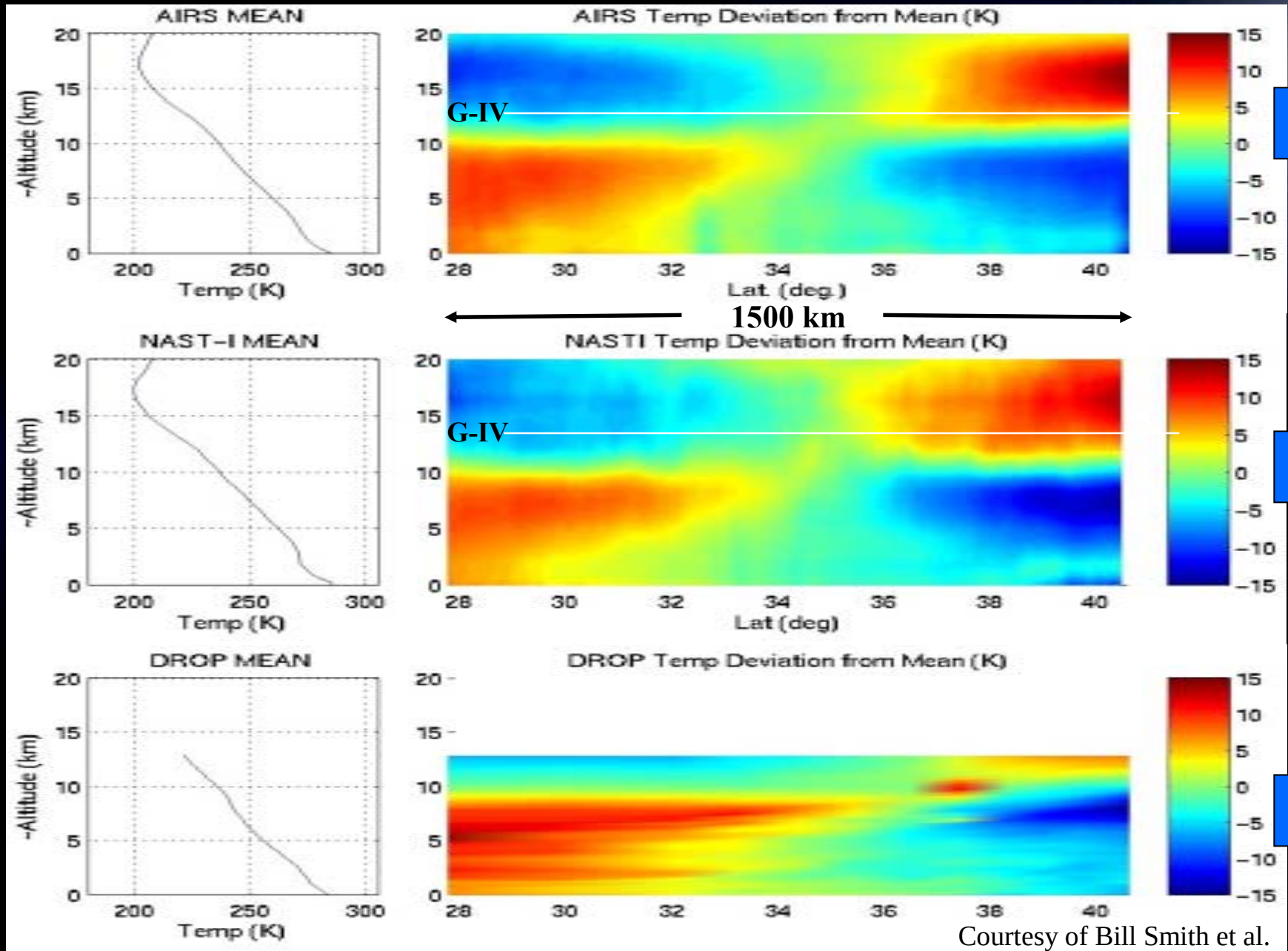
Terra & Aqua

Adapted from NAST Team

Aqua Overpass Flight (March 12/13, 2003)



Cross-Sensor Cal/Val Retrieval Comparisons



Courtesy of Bill Smith et al.

Case Study: *EAQUATE*

Continued NPP/NPOESS risk mitigation with pre-Metop (IASI , AMSU, MHS, HIRS) collaborations focusing on Aqua satellite cal/val and chemistry product validation

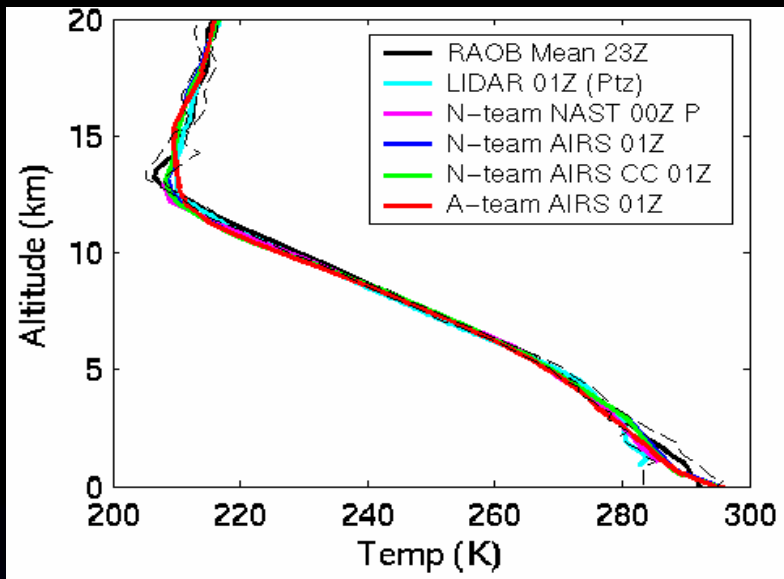
- **European AQUA Thermodynamic Experiment (EAQUATE)**
  - Naples, Italy; 3 – 11 Sep; Proteus, Potenza/Naples ground sites, AQUA
  - Cranfield, UK; 11 – 19 Sep; Proteus, BAE 146-300, & AQUA

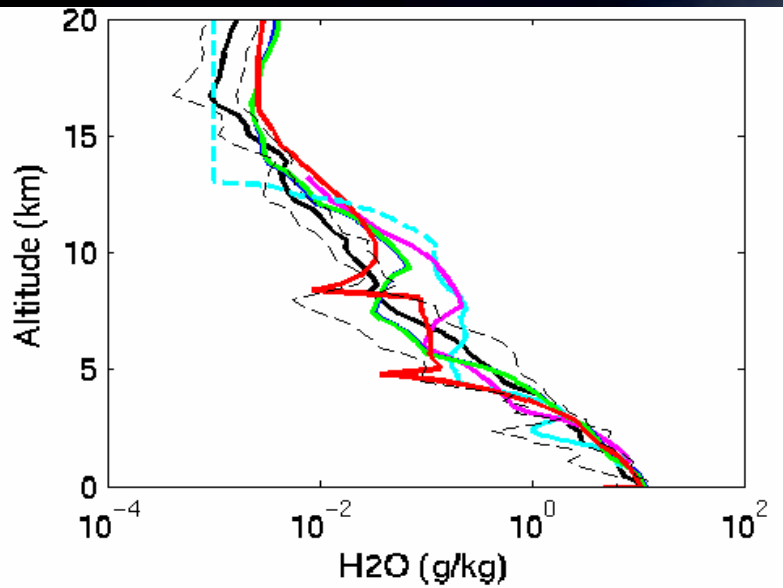
Measurements Included:

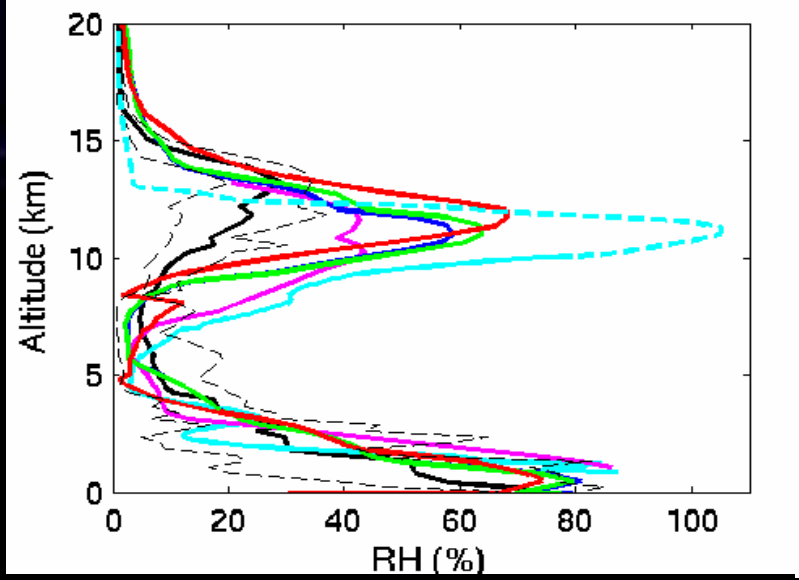
NG Proteus (NAST-I, NAST-M, S-HIS, FIRSC, MicroMAPS)
UK BAE146-300 (ARIES, TAFTS, SWS, MARSS & Deimos; dropsondes; in-situ cloud phys. & trace species)
Ground sites: Potenza/Naples (lidar, radiosondes, aeri, m-wave)
Satellite: AQUA (AIRS & MODIS); MSG (Seviri)

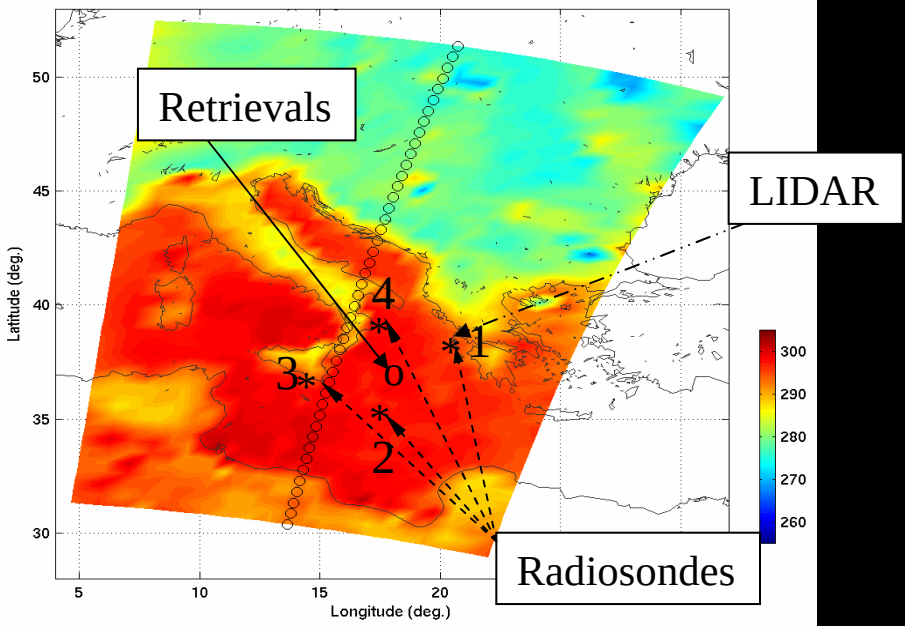
Adapted from NAST Team

NAST-I retrieval inter-comparison (Sept. 09/10, 04)



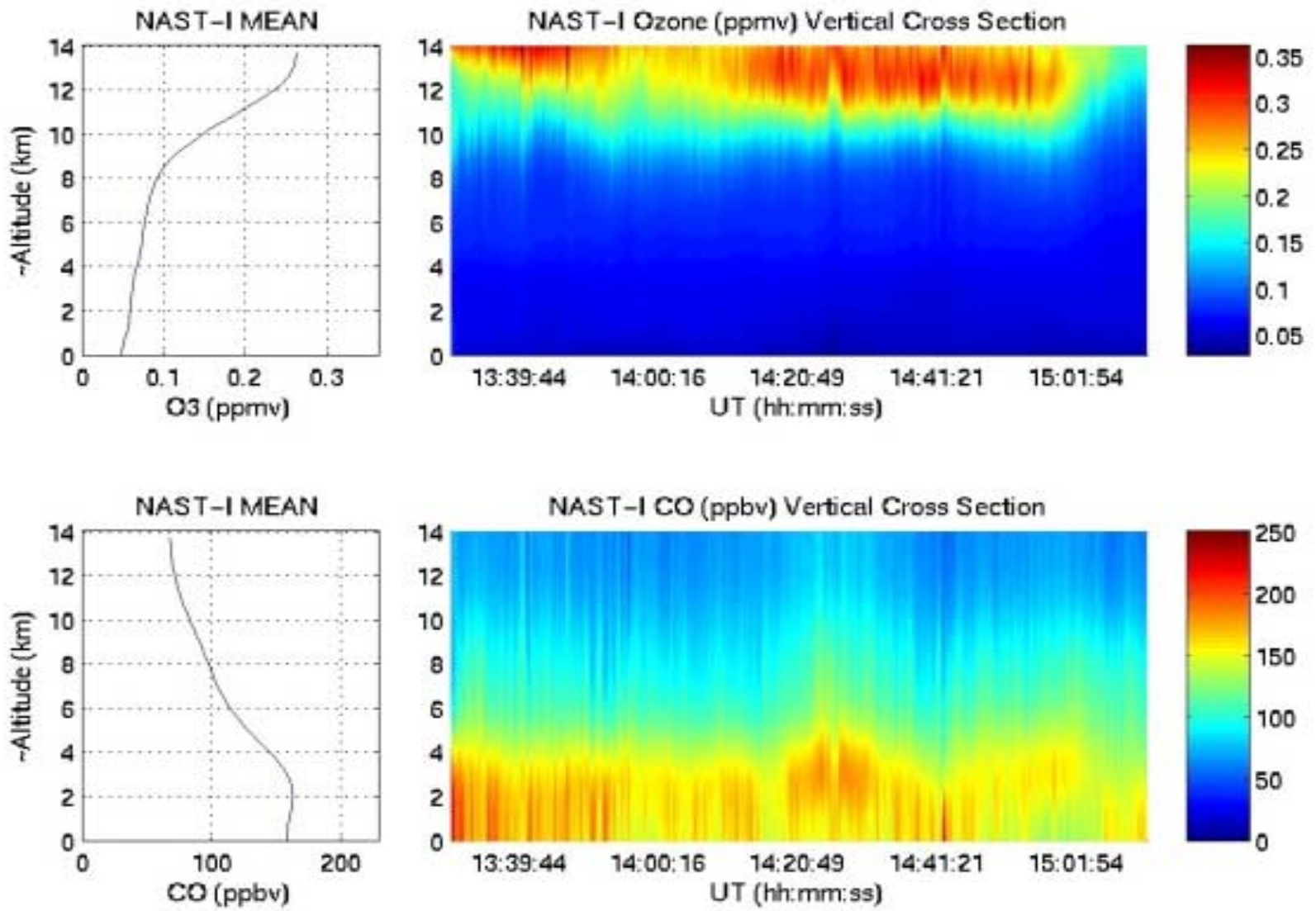






Adapted from NAST Team

NAST-I Cross sections of Ozone [O_3] & Carbon Monoxide [CO] Retrieved along the Proteus INTEX flight track for July 22, 2004



Adapted from NAST Team

Radiance Calibration Validation Approach*

- **Spatial**
  - **Landmark navigation**
    - compare observations to databases for time invariant distinct features of known spatial characterization (e.g., coastlines)
  - **Comparison with coincident observations**
    - compare measurements with other temporally-coincident same-scene view observations containing spatial feature variability (coastlines, thermal gradients, clouds, hot lava, fires, etc.)
- **Spectral**
  - **Comparison with simulations**
    - compare clear sky measured radiance to LBL radiative transfer model calculations for spectral regions where FM parameters are well-known (e.g. spectroscopy, temperature and CO_2 profiles for 15 μ band); vary simulated instrument spectral response to minimize residuals (e.g., effective metrology laser wavenumber for FTS or channel SRFs for grating)
  - **Comparison with coincident observations**
    - compare measured radiance with other temporally-coincident same-scene view high-spectral resolution measurements (i.e., a/c- or s/c-based FTS)
- **Radiometric**
  - **Comparison with other coincident observations and simulations**
    - compare measured radiances in window and opaque regions across spectral extent, for varying uniform clear sky over ocean and overcast scene temperatures, with other observations/calculations
      - High-spectral resolution measurements (aircraft, e.g. NAST-I, SHIS, & ARIES; s/c, e.g. AIRS, IASI, CrIS)
      - Broadband radiance measurements (e.g., GOES, SEVERI, MODIS, VIIRS)
      - Radiative transfer calculations (using, e.g., lidar, radiosondes, dropsondes, a/c in-situ, NWP analysis fields, e.g., ECMWF)

* ***Applied to each detector, i.e. FTS band, grating channel, etc.***

Adapted from Allen M. Larar

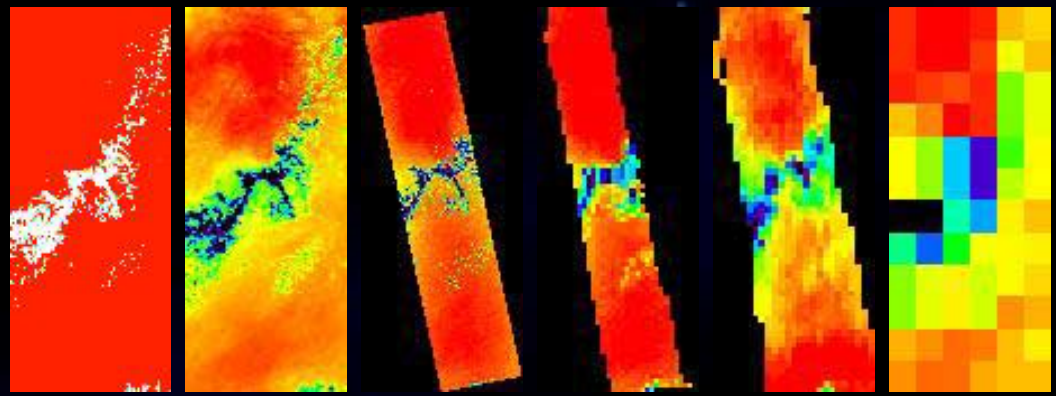
Radiance Inter-Comparison Summary

EAQUATE (090904)

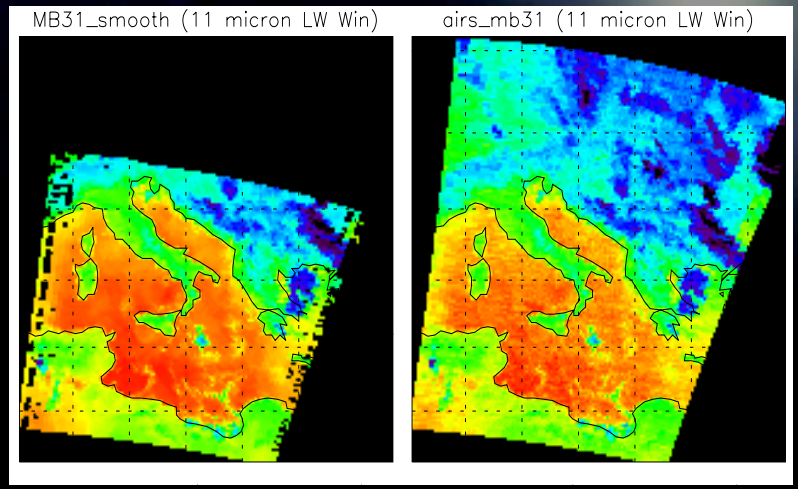
Geo-reference verification using like spatial features; shows clear regions used for spectra inter-comparison

Window region (MB31; 11μ)

PTOST (030303)

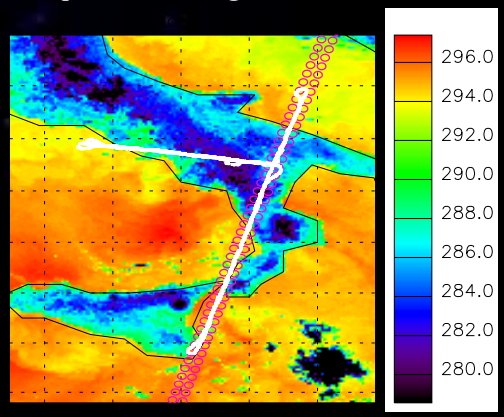


MODIS (Cld msk) | MODIS | MAS (B45) | S-HIS | NAST-I | AIRS

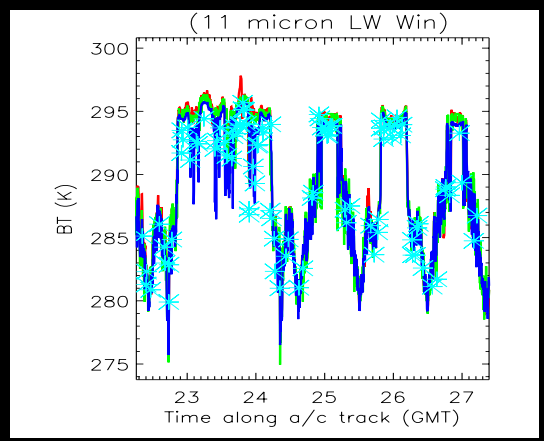


MODIS vs AIRS
(MB31 srf/ AIRS IFOVs)

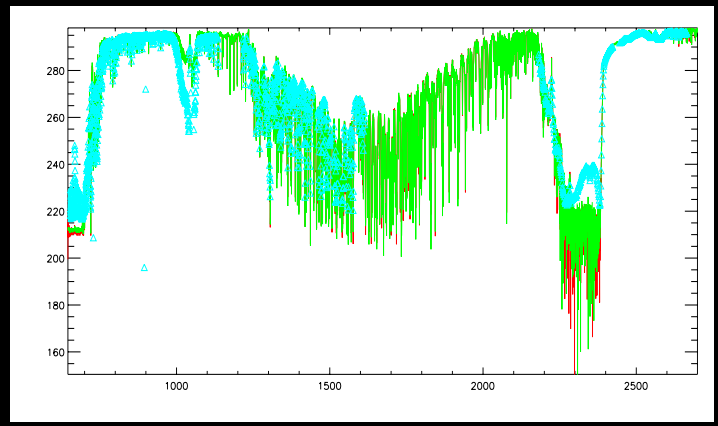
Aqua & Proteus ground tracks



Broadband radiometric time series



NAST-I, S-HIS, & AIRS spectra

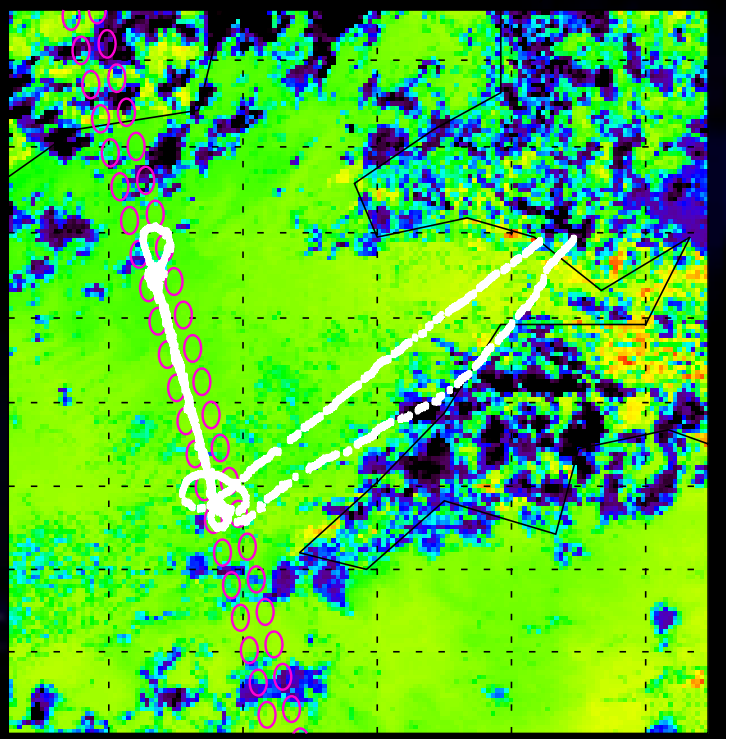


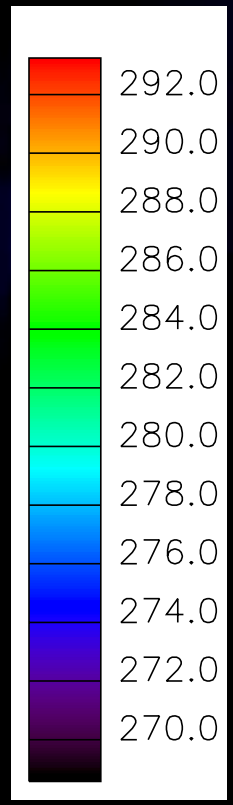
Adapted from NAST Team

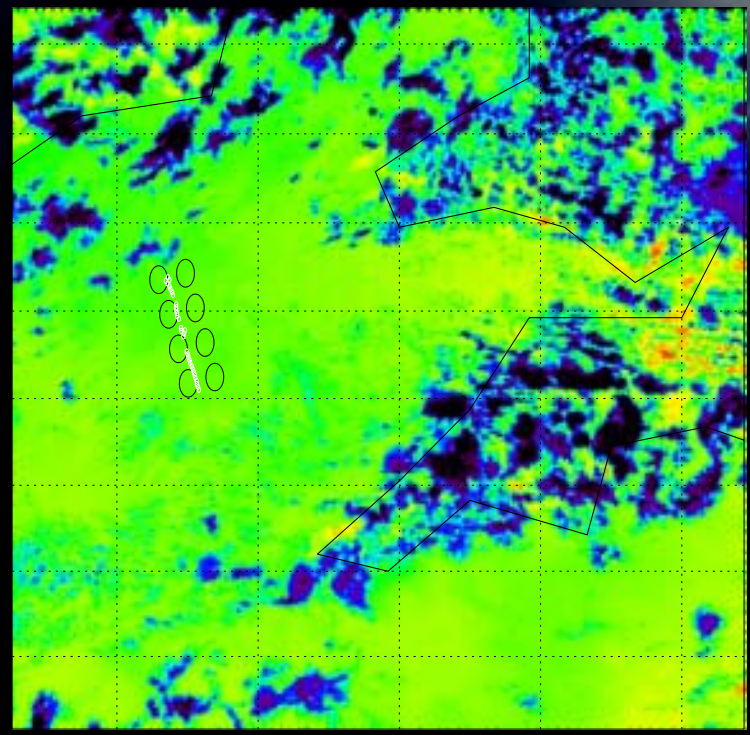
EAQUATE 091404

Spectra Comparison: NAST-I, S-HIS, AIRS

MB31







MB31 stddev (AIRS IFOVs)

max = 0.23 K

min = 0.07 K

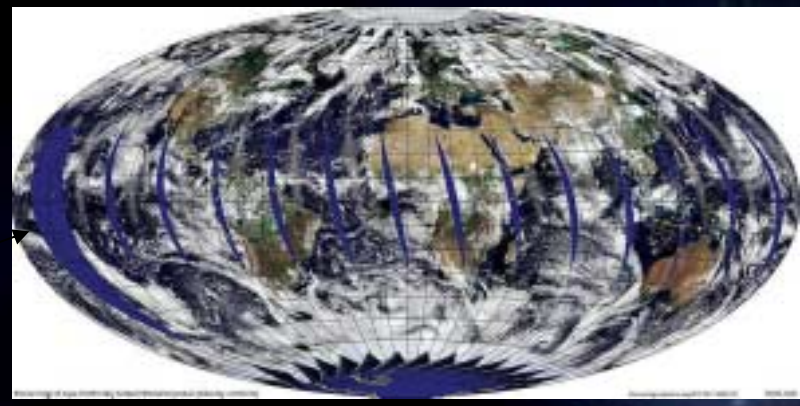
mean = 0.16 K

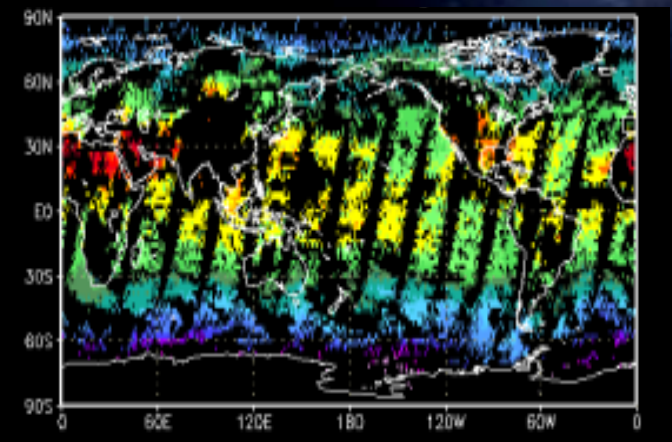
stdev = 0.05 K

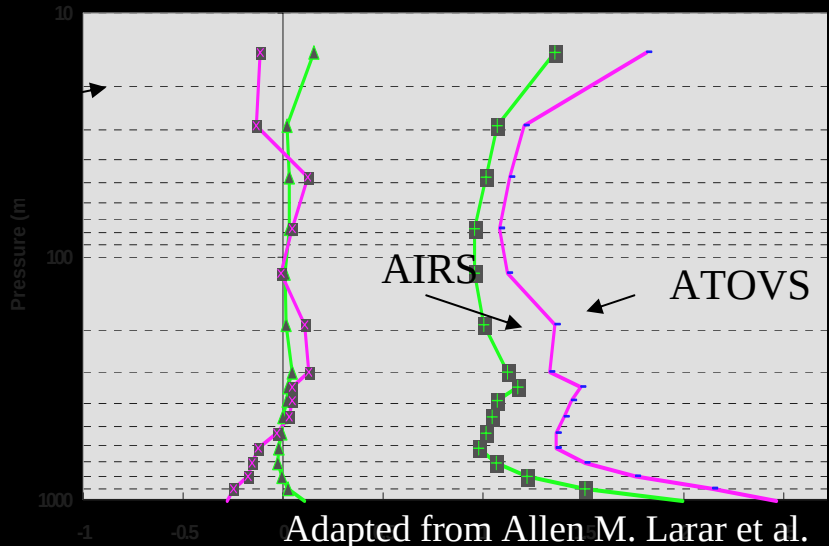
Adapted from NAST Team

Advanced Sounder Lessons-Learned from AIRS

- AIRS instrument is extremely stable and accurate
- Only 5% of the globe is clear at a 14 km fov
- AIRS has resulted in positive impacts in NWP, however only clear channels are assimilated and larger impacts are still expected.
- Cloud-clearing radiances increases yield to about 50%
- Retrievals from cloud-cleared radiances are significantly more accurate than AMSU-only.
- Demonstrated 1 K/km precision
- Algorithm evolution collaborative effort among science community (NASA, NOAA, universities)
- Science improvements continue throughout program (e.g., Modis to improve CC; trace species retrieval)

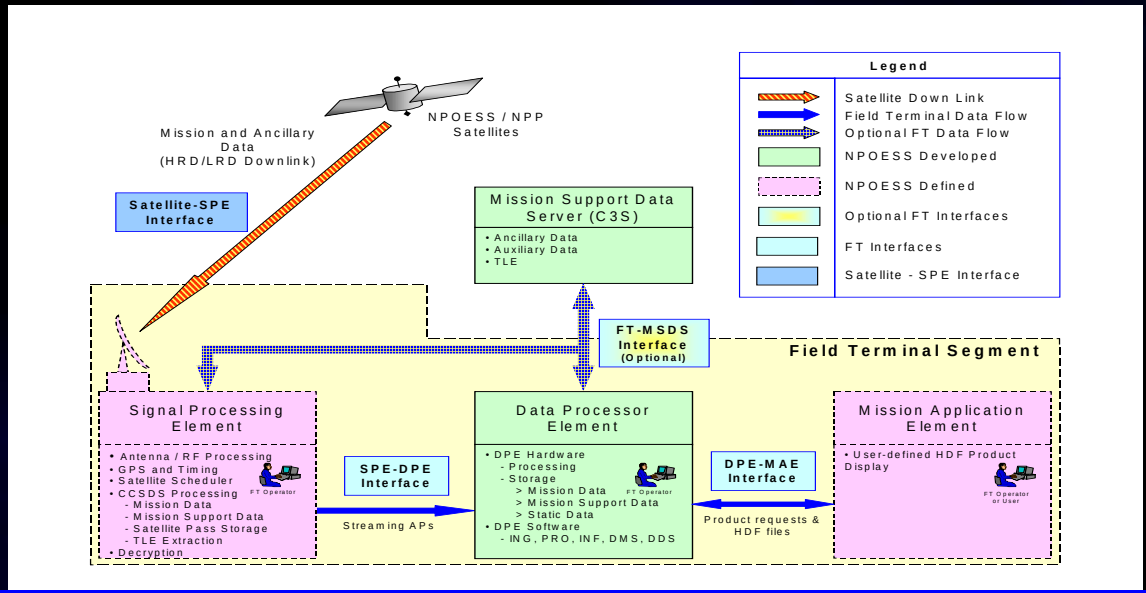






Adapted from Allen M. Larar et al.

NPOESS/NPP Field Terminal Segment [FTS] Direct Broadcast [DB] /Direct Readout



NPOESS/NPP Field Terminal Link Parameters

Parameter	High Rate Data [HRD]	Low Rate Data [LRD]
Carrier Frequency	7834 MHz (NPP 7812 MHz)	1707 MHz
Modulation	SQPSK (NPP QPSK)	SQPSK
Data Rate*	20 Mbps (NPP 15 Mbps)	3.88 Mbps
Ground Aperture Size <=	2.0 meters	1.0 meters
Minimum Elevation Angle	5.0 degrees	5.0 degrees

- Includes all CCSDS overhead, Reed-Solomon forward error correction, and convolutional encoding