



High Spectral and Temporal Resolution Imaging Sounders for GOES



Hank Revercomb, Director

**University of Wisconsin - Madison
Space Science and Engineering Center (SSEC)**

**5th GOES Users Conference
AMS Annual Meeting, New Orleans, LA
23 January 2008**



Verner E. Suomi: Father of Satellite Meteorology and Sounding from GEO

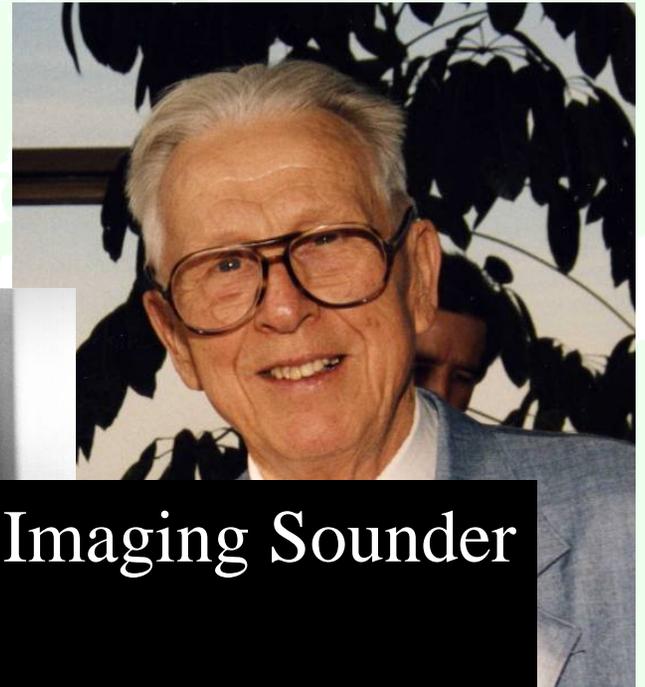
I know his message would be:
What's the Problem?



**We know
What we need,
Why we need it, and
How to get there, so
Take your Bravery Pills
and ...**

Verner E. Suomi: Father of Satellite Meteorology and Sounding from GEO

I know his message



- ◆ **What:** High spectral resolution IR Imaging Sounder from GEO
- ◆ **Why:** Vertical distribution and transport of water vapor, stability from lapse rates and inversions for hurricane and severe storm prediction
- ◆ **How:** Recent technological advances- key elements demonstrated in polar orbit

Take your Bravery Pills
and ...



Topics



- 1. Message Summary**
- 2. Advanced Sounder Endorsements**
- 3. Key Sounder Capability**
- 4. Advanced Sounder Instrument Status**
- 5. Plan Needed!**

1. Sounder Message Summary



- ◆ **GOES-R is now defined and offers key advances over the current GOES Imager** [ABI offers 20 times more horizontal & temporal detail ($x \times 2$; $y \times 2$; $t \times 5$) and three times more spectral channels ($5 \Rightarrow 16$)]
- ◆ **However, GOES-R will lack sensitivity to the vertical dimension**, long recognized as a key property for predicting the onset of dangerous storms
- ◆ **Advanced Sounder needed to meet User Requirements for profiling**
- ◆ **Cost-benefit studies ascribe about half of the benefit of a new GOES system to the advanced sounder** (Centrec Consulting Group LLC effort led by NCDC)
- ◆ **Instrument development efforts have succeeded in showing how to make a revolutionary advance with low technical risk**
- ◆ **A new start is needed to provide this “advanced sounding” capability as soon as possible** via demonstration/prototype instrument programs on a parallel path to GOES-R

2. Advanced Sounder Endorsements



- ◆ **The best and brightest in our field have clearly stated that the sounder is urgently needed** —I can't pretend to improve on that

We have heard the vision from many key individuals, often here at the GUC



Bill Smith, Paul Menzel, Jim Purdom, Louis Uccellini,
John LeMarshall, John Eyre, Mitch Goldberg,...

High Level Group Endorsements

- ◆ **National Research Council of the National Academy of Sciences**
 - “Decadal Survey”, October 2007, final
 - Follow-up on Climate and GOES Sounder
- ◆ **AMS Satellite Meteorology and Oceanography Committee-**
3 October 2007
- ◆ **National Weather Association-**
5 October 2007

NOAA Project Endorsements

- ◆ **GOES-R Algorithm Working Group**
- ◆ **GOES-R Technical Advisory Committee**
- ◆ **Analysis of Alternatives for Advanced Sounding and Coastal Waters Imaging**
 - John J. Pereira, 23 April 2007
 - NESDIS Office of Systems Development

Analysis of Alternative (AoA) Finding

- ◆ **Broad range of options considered, including**
 - **Several high spectral resolution imaging sounders**
 - **GEO microwave**
 - **Polar advanced sounders**
 - **COSMIC GPS**
 - **Ground-based RAOBS and NEXRAD**
- ◆ **Conclusion: Advanced GEO Sounder needed to meet requirements**
- ◆ **Early Demonstration Options Recommended**

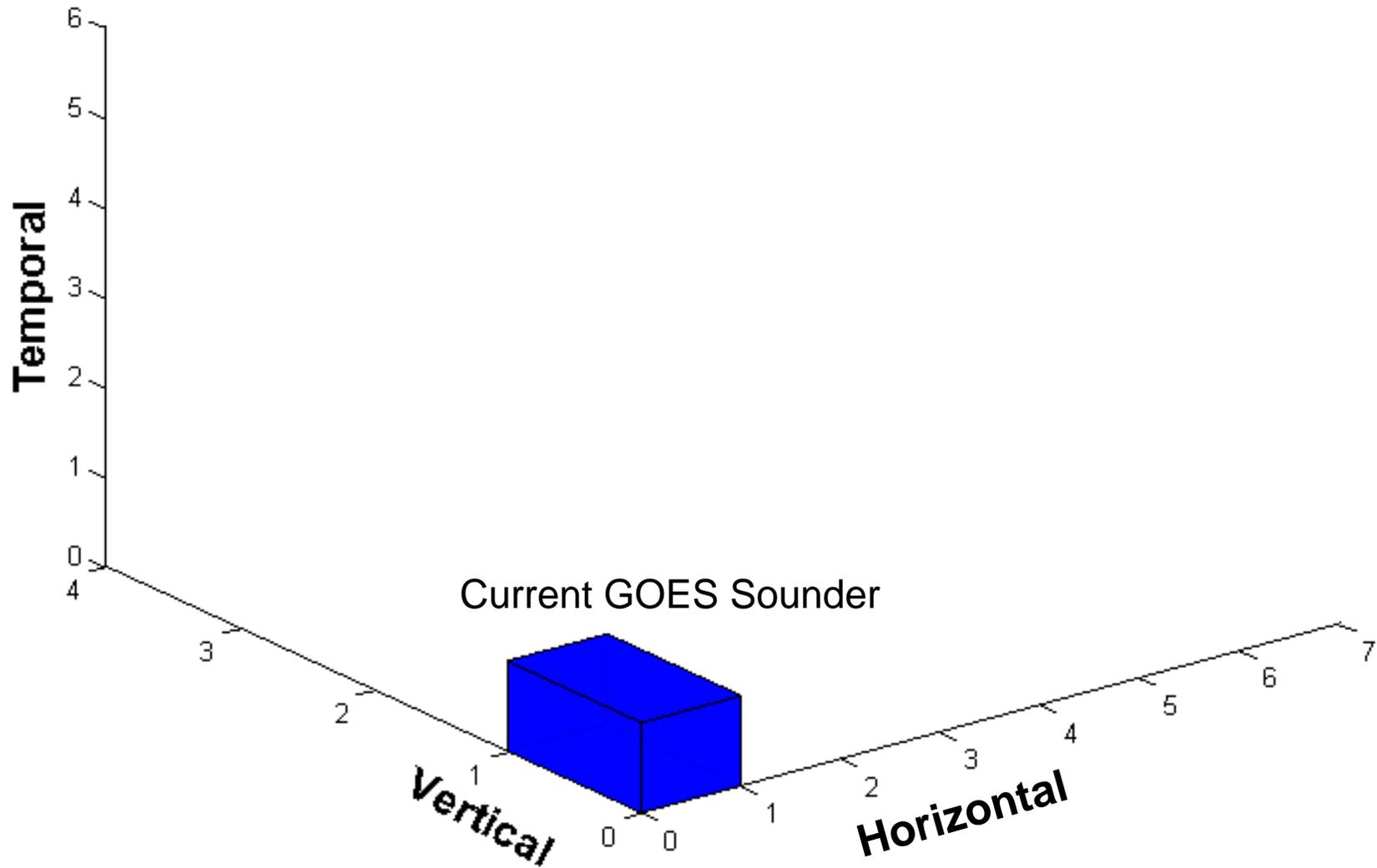
3. Key Imaging Sounder Capability



- ◆ **Spectral Coverage & resolution:**
broad contiguous coverage,
resolving power >1000
- ◆ **Vertical Resolution:** increased by $\times 3$
- ◆ **Horizontal Image Sampling:**
increased from 10 km to 4-5 km
- ◆ **Temporal Sampling Rate:**
increased up to $\times 5.5$

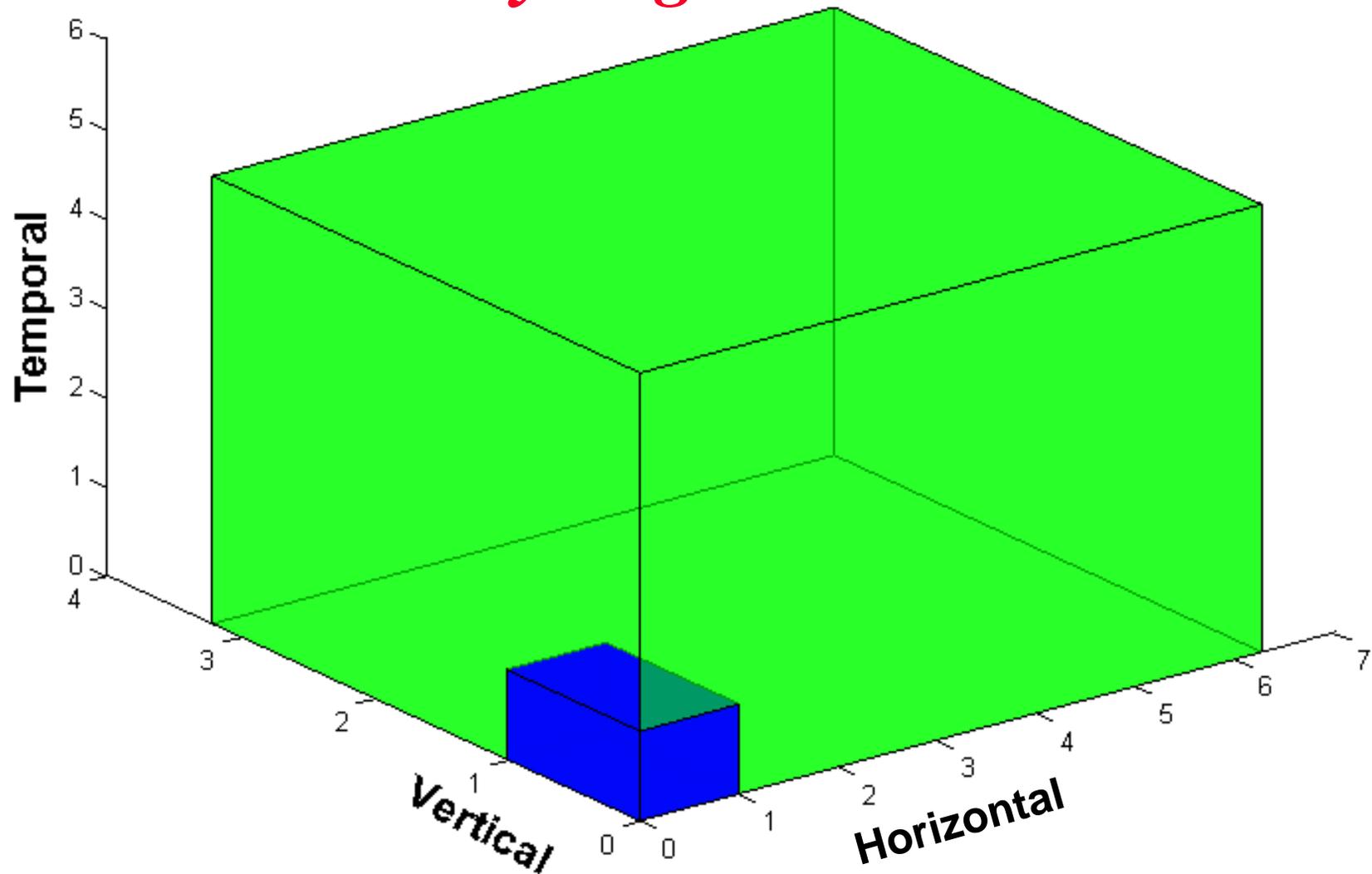
Factor of 100 improvement in spatial/temporal detail

Current Sounder Information Volume



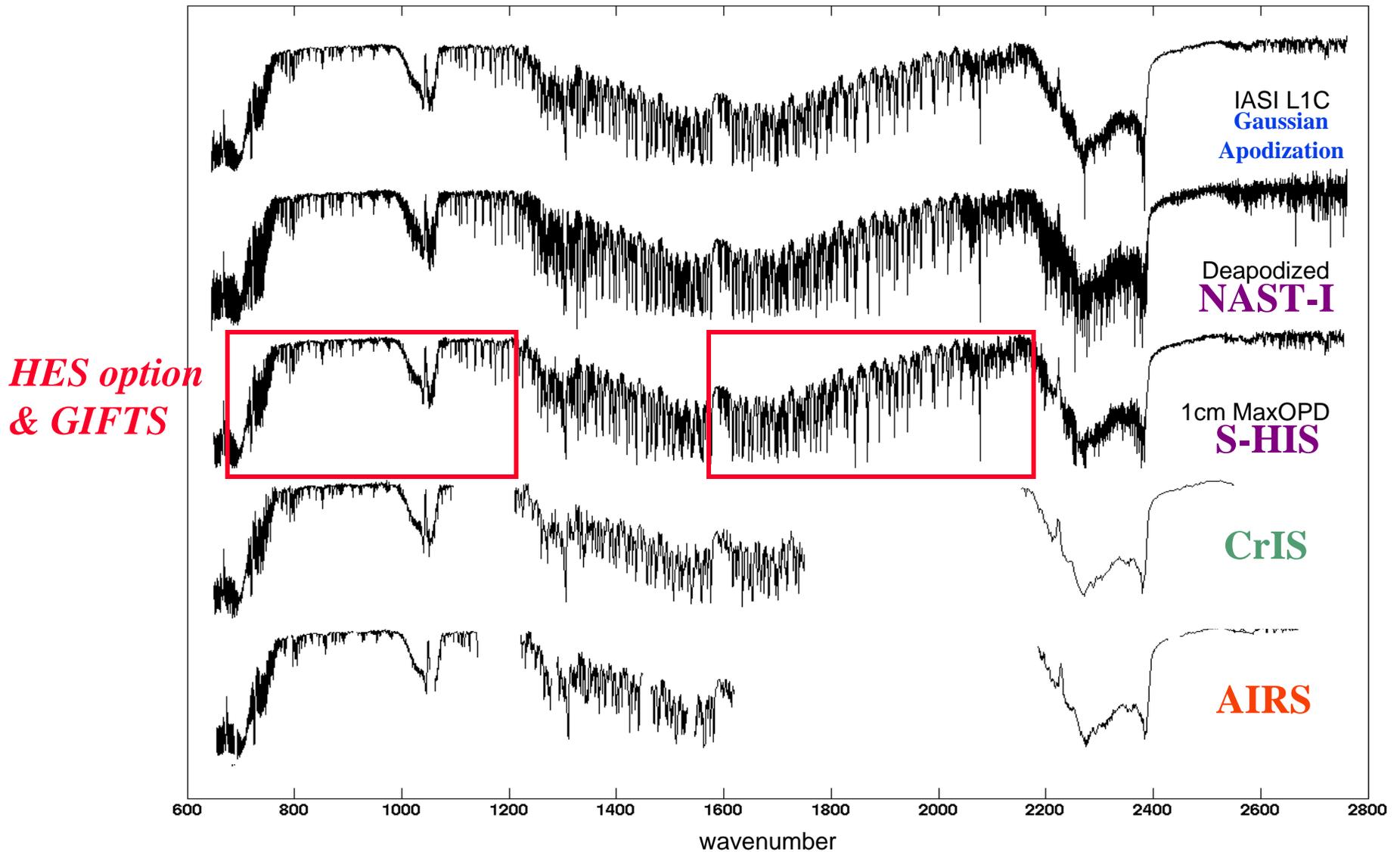
Advanced Sounder (GIFTS example)

A truly huge advance



Example T_b Spectrum from IASI:

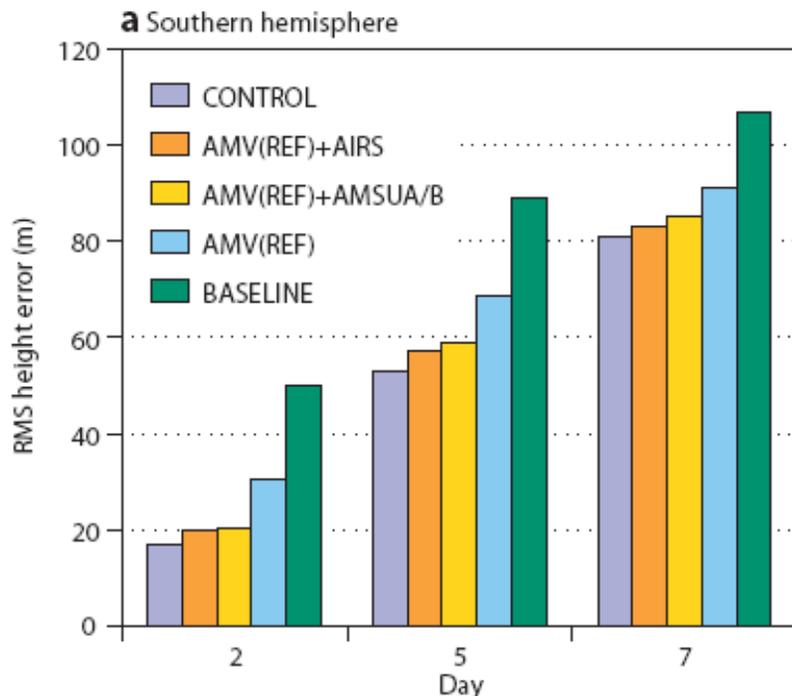
Processed to represent **S-HIS** & **NAST-I**, **AIRS** & **CrIS**



Expect high impact on regional numerical prediction models

- ◆ Vertical resolution of atmospheric state and water vapor winds on compatible space and time scales
- ◆ Analogy from existing obs: Impact of high resolution IR on global NWP according to Graeme Kelly:

500-hPa Geopotential height



OSEs show that AIRS is the sensor that has the most impact on mass and wind forecasts in the ECMWF system

Similar conclusions shown by LeMarshall, McNally, Collard

4. Advanced Sounder Instrument Status



- ◆ Development under Hyperspectral Environmental Suite (**HES**) Program successfully yielded low risk designs
- ◆ **GIFTS** Program with joint NASA and NOAA support yielded an Engineering Demonstration Unit that underwent very successful thermal vacuum and uplooking atmospheric tests



NOAA Analysis of Alternatives Final Advanced Sounder Results

Alternative versus Risk



Alternative/Risk	HES on GOES	HES on GEO free flyer	FPCCR on GOES	FPCCR on GEO free flyer	RCSC on GOES	RCSC on GEO free flyer	GIFTS on GEO free flyer	GEO Microwave on free flyer
Cost	High	High	(Demo mode)	High	(Demo mode)	High	High	High
Performance	Meets	Meets (1 sat)	Meets	Meets (1 sat)	Medium Accuracy and spatial resolution	Medium Accuracy and spatial resolution	Meets	Does not meet
Space Development / Implementation Risk	High	High	Low	Low	Medium	Medium	Medium	High
Schedule Risk for GOES-T (2019) or Free flyer (2014)	Medium	High	Low	Low	Low	Low	Low	Low
Ground System Development / Implementation Risk	Medium	Medium	Low for Demo Mode	Low for Demo Mode	Low for Demo Mode	Low for Demo Mode	Low for Demo Mode	Medium
	Case 1	Case 3	Case 4 (b)	Case 6	Case 5 (b)	Case 7	Case 8	Case 9



NOAA Analysis of Alternatives Final Advanced Sounder Results

Alternative versus Risk



Alternative/Risk	HES on GOES	HES on GEO free flyer	FPCCR on GOES	FPCCR on GEO free flyer	RCSC on GOES	RCSC on GEO free flyer	GIFTS on GEO free flyer	GEO Microwave on free flyer
Cost	High	High	(Demo)	High	(Demo)	High	High	High
Performance	Meets	Meets (1 s)						
Space Development / Implementation Risk	High	High	Low	Low	Medium	Medium	Medium	High
Schedule Risk for GOES-T (2019) or Free flyer (2014)	Medium	High	Low	Low	Low	Low	Low	Low
Ground System Development / Implementation Risk	Medium	Medium	Low for Demo Mode	Low for Demo Mode	Low for Demo Mode	Low for Demo Mode	Low for Demo Mode	Medium
	Case 1	Case 3	Case 4 (b)	Case 6	Case 5 (b)	Case 7	Case 8	Case 9

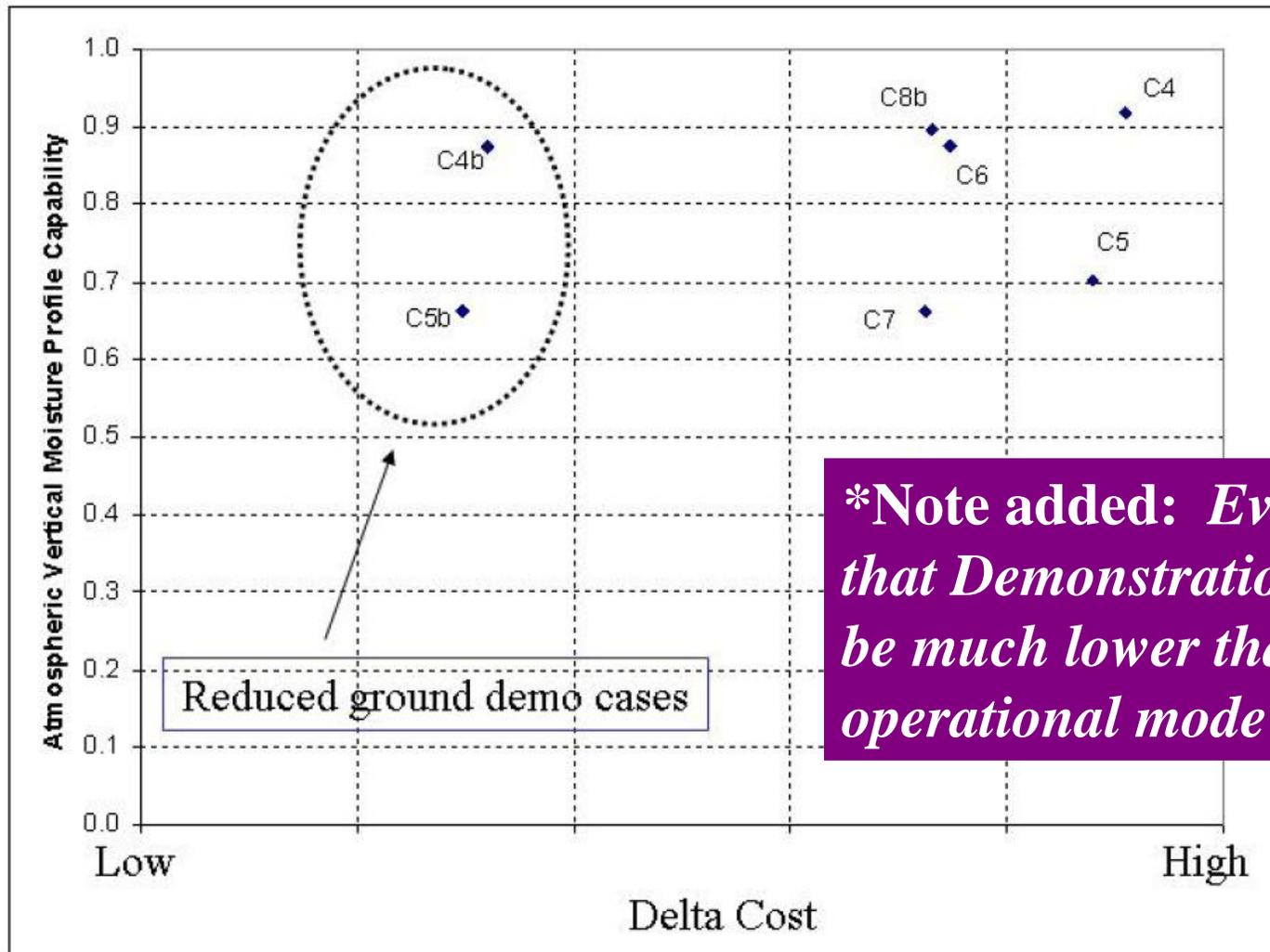
**Full blown HES Sounder
(without Coastal Waters)
is Low Risk in demo mode!**



NOAA Analysis of Alternatives

Sounder Capability vs. Cost

Atmospheric Vertical Moisture Profile



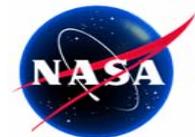
- C4: FPCCR on GOES-T
- C4b: FPCCR demo on GOES-T
- C5: RCSC on GOES-T
- C5b: RCSC demo on GOES-T
- C6: FPCCR Free flyer
- C7: RCSC Free flyer
- C8: GIFTS Free flyer

**Note added: Evidence given that Demonstration costs can be much lower than full operational mode costs*

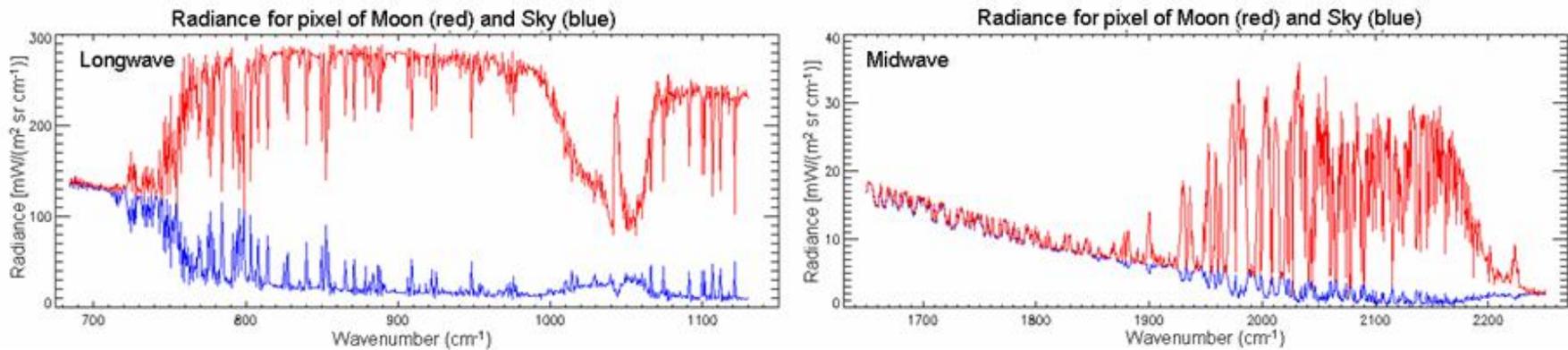
The GIFTS EDU



- ◆ **GIFTS Proof of Concept has been successfully demonstrated with the Engineering Development Unit Thermal/Vacuum & Sky Viewing Tests**
(expected long-poles are working well: LW detector with good sensitivity and operability, Long-lived stable laser, mechanical cooler and cryogenic thermal design, imaging FTS radiometric integrity, plus many others)
- ◆ **Results Demonstrate that NOAA Requirements for a Successful GOES Imaging Spectrometer are achievable with a GIFTS Flight Model**
(spatial coverage and resolution, spectral coverage, spectral calibration and Instrument line shape knowledge, and spectral scale standardization)



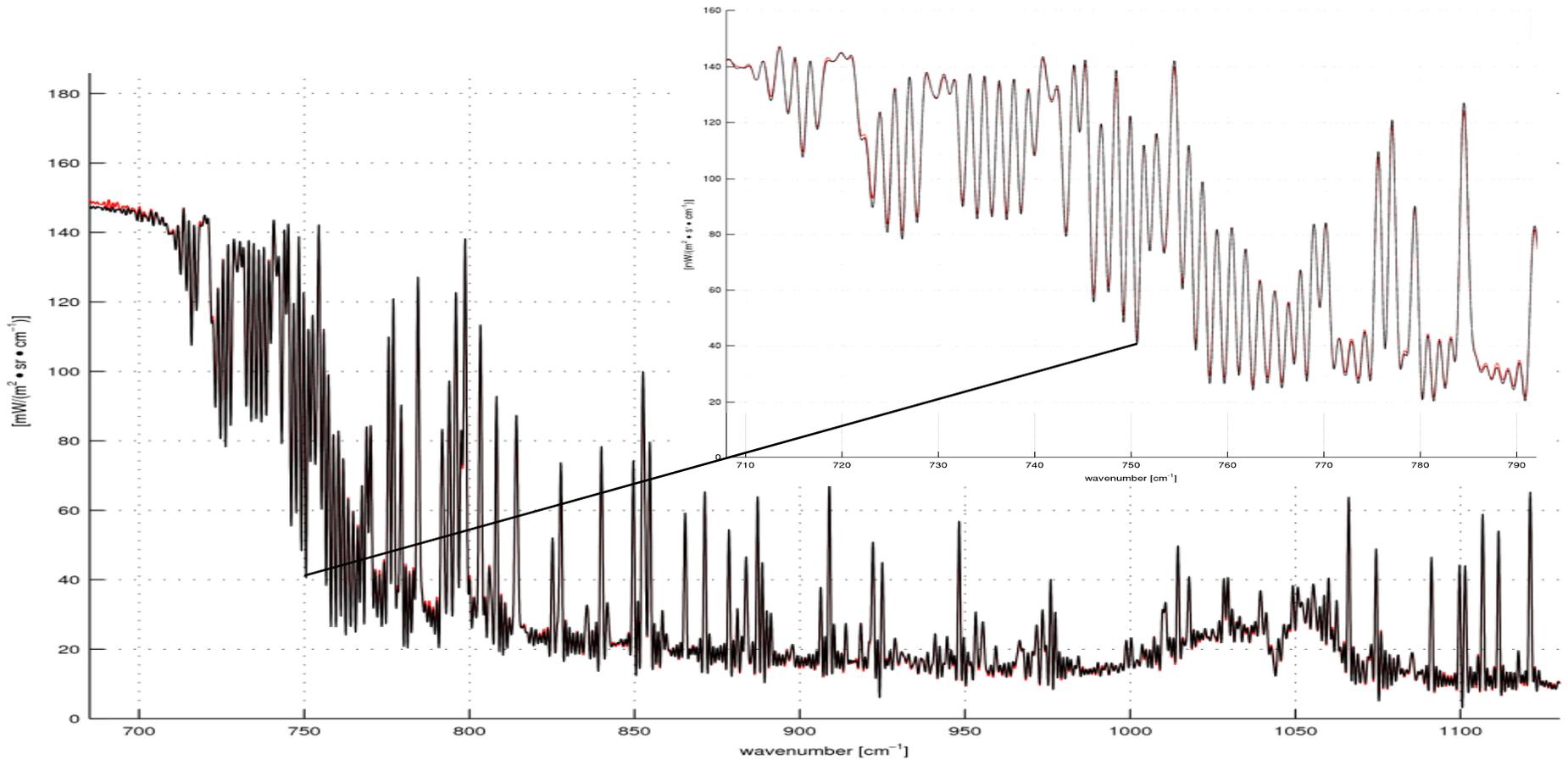
Lunar Views Demonstrate GIFTS Imaging Capability



Results from a single interferometer scan of the moon, viewed in the visible, mid-wave IR, and long-wave IR. Also the spectral intensities of two selected pixels from the IR images, one viewing the moon, the other the clear sky background.

GIFTS Atmospheric Views prove Radiometric & Spectral Integrity

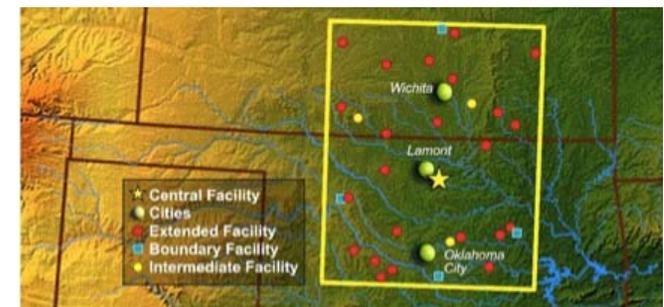
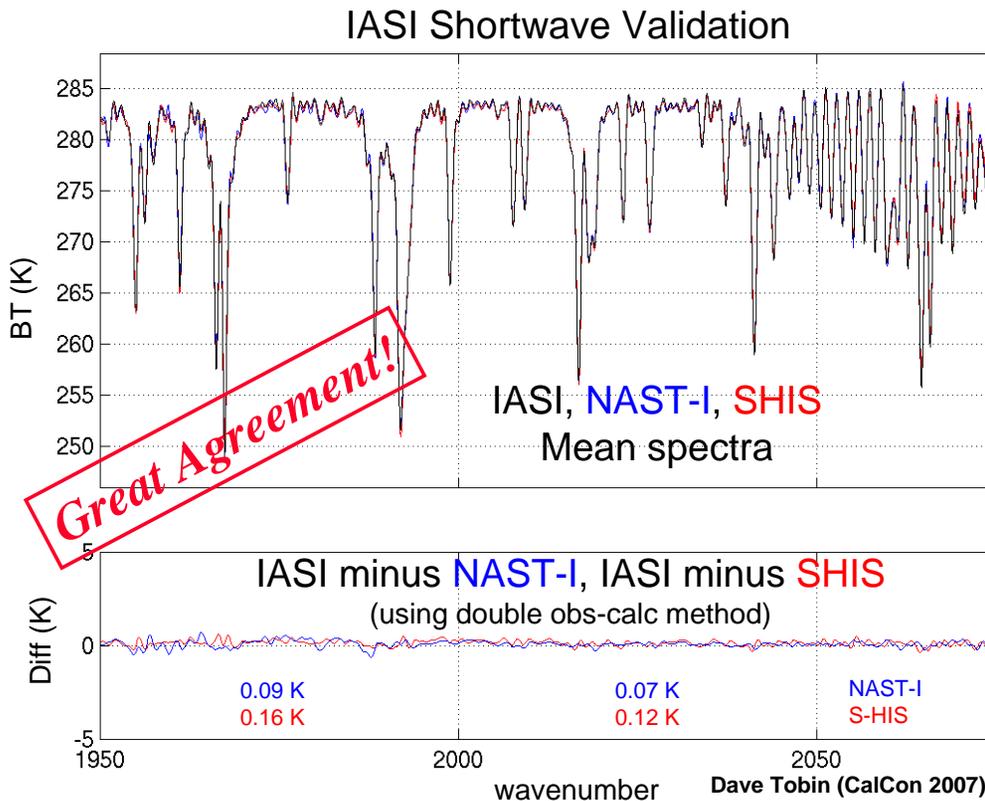
GIFTS LW uplooking spectrum compared to AERI



GIFTS LW Band shows good agreement,

Joint Airborne IASI Validation Experiment (JAIVEx)

- ◆ *IASI on MetOp-A: 1st advanced sounder in the US/European Joint Polar System*
- ◆ *JAIVEx: 1st US-European collaboration in US focusing on validation of radiance and geophysical products from MetOp-A*



5. Plan Needed!



- ◆ Now that GOES-R is established, we need a **new start** to develop and implement a compatible **Sounder Demonstration**
- ◆ **Sounder Demonstrations** are critical to
 - Realize societal benefits as soon as possible and as cost effectively as possible, and
 - Optimize future operational approaches
- ◆ **International efforts consistent with GEOSS objectives should be sought as one path**
 - e.g. joint GEO system with Europe analogous to current joint polar system
 - European IR Sounder (IRS) planned for MTG

Backup Slides



NRC Decadal Survey Recommendation for Advanced Sounding (January 2007)

- ◆ **“The National Research Council committee ... recommends that NOAA, working with NASA, develop a strategy to restore the previously planned capability to make high temporal- and vertical-resolution measurements of temperature and water vapor from geo orbit.”**
- ◆ **“Recognizing the technological challenges and accompanying potential for growth in acquisition costs for HES, the committee recommends consideration of the following approaches:**
 - **1. Complete the GIFTS instrument, deliver it to orbit via a cost-effective launch and spacecraft opportunity, and evaluate its potential to be a prototype for the HES instrument, and/or**
 - **2. Extend the HES study contracts focusing on cost-effective approaches to achieving essential sounding capabilities to be flown in the GOES-R time frame.”**

Follow-on NRC recommendations are being formulated based on discussions held 7 June 2007 to discuss climate and GOES-R capabilities lost during the original NRC study period

GOES-R Algorithm Working Group Guidance

13 September 2006

- **A GIFTS Demonstration should be pursued in coordination with NASA** – *This prototype mission would provide experience with a large volume of high temporal and spectral resolution data*
- **A pre-operational Sounder should be pursued for 2016 on GOES-S** – *This prototype instrument would introduce the technology that will be used operationally and provide a testbed for operational data processing and utilization*
- **Advanced sounder operations should be planned to begin in 2021 on GOES-T** – *This allows adequate time for all phases of preparation – (algorithm development, technology testing, and user familiarization)*

GOES-R Technical Advisory Committee

16-18 May 2007

- ◆ **The TAC felt that as a matter of urgency that hyperspectral atmospheric sounding from the GOES-R series of spacecraft should be reinstated as soon as possible**

It felt that use of the current, although lower temporal and spatial resolution, AIRS and IASI data should be processed in real time with nowcasting products developed for demonstration would be a valuable step toward reinvigorating that dialogue

On the Importance of Deploying a GEO Advanced Sounder Without Delay

Satellite Meteorology and Oceanography Committee AMS Scientific Activities and Activities Commission Consensus Statement, October 3, 2007

The satellite meteorology and oceanography community recognizes that there are unmet needs for a variety of satellite observing systems—each would provide important measurements that would permit research and operational advances in their respective fields. This statement of support focuses on one such unmet need: the deployment of a GEO advanced sounder.

The members of the American Meteorology Society's Satellite Meteorology and Oceanography Committee encourage NOAA and NASA to partner together to demonstrate and complete development of an important observing capability. More than two decades ago, NASA and NOAA partnered to fly a critical demonstration mission—the Visible and Infrared Spin Scan Radiometer (VISSR) Atmospheric Sounder (VAS) on the first GOES series. There has not been a U.S. demonstration mission in the geostationary orbit since then. In this coming decade, a renewed partnership could deliver early hyperspectral demonstration sounders on the GOES-R series, which could include the technology-proven Geosynchronous Imaging Fourier Transform Spectrometer (GIFTS) on an experimental GEO platform, and/or an early flight of a new sounder prototype for the GOES-R series. This would then be followed by an operational sensor, allowing the United States, within our generation, to advance and achieve the atmospheric profiling capabilities necessary for rapid-refresh observations ranging from mesoscale weather nowcasting applications to improving tropical cyclone forecasts.

Geostationary sounders provide unique, rapidly-updated temperature and moisture profile measurements. The ability to vertically resolve water vapor in the atmosphere—the “basic fuel” for severe thunderstorms—is crucial for monitoring and predicting hazardous weather conditions. Large variations in atmospheric water vapor occur over fine scales of ten kilometers in the horizontal, one kilometer in the vertical, and over tens of minutes. Continuous monitoring is essential. Hyperspectral infrared measurements from GEO would continuously describe the clear-sky vertical moisture structure, more than double the temperature profile information content from today's sounders, and permit new wind profiling capabilities by constantly tracking retrieved water vapor profile features at many discrete levels. Assimilated into the next generation of numerical weather prediction models and used for “nowcasts,” observations from the GEO advanced sounder could enable improved analyses of severe weather and hurricanes, with the potential to save lives while also providing important new climate observations. Other applications include the areas of aviation and air quality. We recommend that NASA and NOAA proceed with these missions.

National Weather Association Support for Advanced IR Sounder on GOES-R



NATIONAL WEATHER ASSOCIATION

228 West Millbrook Road
Raleigh, North Carolina 27609-4304
Tel/Fax: (919) 845-1546
exdir@nwas.org
www.nwas.org

October 5, 2007

2007 NWA Council

President

Alan E. Gerard
President@nwas.org

President-Elect

John R. Scala

Vice-President

Lans P. Rothfus

Secretary

Elizabeth M. Page

Treasurer

Steven M. Zubrick

Councilors

Ruth Aiken
Janice Bunting
Gregory D. Boyd

Dr. Gerald Dittberner

Chief, Advanced Systems Planning Division, E/OSD1

National Environmental Satellite, Data, and Information Service, NOAA

1335 East-West Highway

SSMC1 Room 8338

Silver Spring, MD 20910-3226

Dear Colleague:

The National Weather Association (NWA) respectfully requests your support and advocacy for the inclusion of a capable high spectral resolution atmospheric infrared Sounder on the next generation GOES-R series of spacecraft. This letter was authored and unanimously supported by a broad cross-section of remote sensing experts representing research and operational scientists and forecasters from the public, private and academic sectors.

“The NWA strongly supports flying a hyperspectral infrared sounder on a GOES satellite at the earliest opportunity”, Gerald Dittberner, NOAA

Summary of AoA Findings

- ◆ **Broad range of options considered, including**
 - Several high spectral resolution imaging sounders
 - GEO microwave
 - Polar advanced sounders
 - COSMIC GPS
 - Ground-based RAOBS and NEXRAD

⇒ Advanced GEO Sounder needed to meet requirements
- ◆ **Advanced high spectral resolution sounder trade included**
 - **HES:** Original Hyperspectral Environmental Suite
 - **FPCCR:** High spectral resolution sounder with 5-km, rapid-coverage mesoscale mode
 - **RCSC:** High spectral resolution sounder specified with current GOES spatial (10 km) and temporal (70 min CONUS) capability
 - **GIFTS:** High spectral resolution sounder with 4 km imaging and rapid mesoscale coverage (12 minute CONUS)

⇒ FPCCR is lowest risk option for GOES-T operational sounder

⇒ GIFTS cost ranked high because of assumed cost of free-flyer spacecraft, but considered option for Demonstration

⇒ Path forward involves an earlier Demonstration
- ◆ **Ground Processing Costs: Greatly reduced from original estimates!**
(Based on NOAA STAR and Cooperative Institutes playing major role)



NOAA Analysis of Alternatives Recommended Path Forward for Advanced Geostationary Sounding



- High temporal operational advanced sounding measurements are needed
 - FPCCR (Design of HES w/o coastal waters at the GOES-R Formulation Phase Concept and Cost Review) is low risk for GOES –T
- A path forward for GOES-T involves an earlier demonstration
 - Allows time for algorithm development and testing and user familiarization
 - Provides risk reduction in the product generation, product distribution, and user readiness
- Two potential paths
 - An early copy of the FPCCR planned for GOES-T but available sooner
 - Not on the critical path – only flies if available
 - Could provide risk reduction as a demo for GOES-S
 - A GIFTS demo hosted on a one instrument satellite (free flyer) anytime prior to GOES-T (as early as 2012)
 - Should be pursued in coordination with NASA
 - Could provide the earliest data and ground processing risk reduction
- Pursuit of GIFTS Demonstration should not interfere with the early advent of advanced sounding measurements on the GOES series

** Underline added*