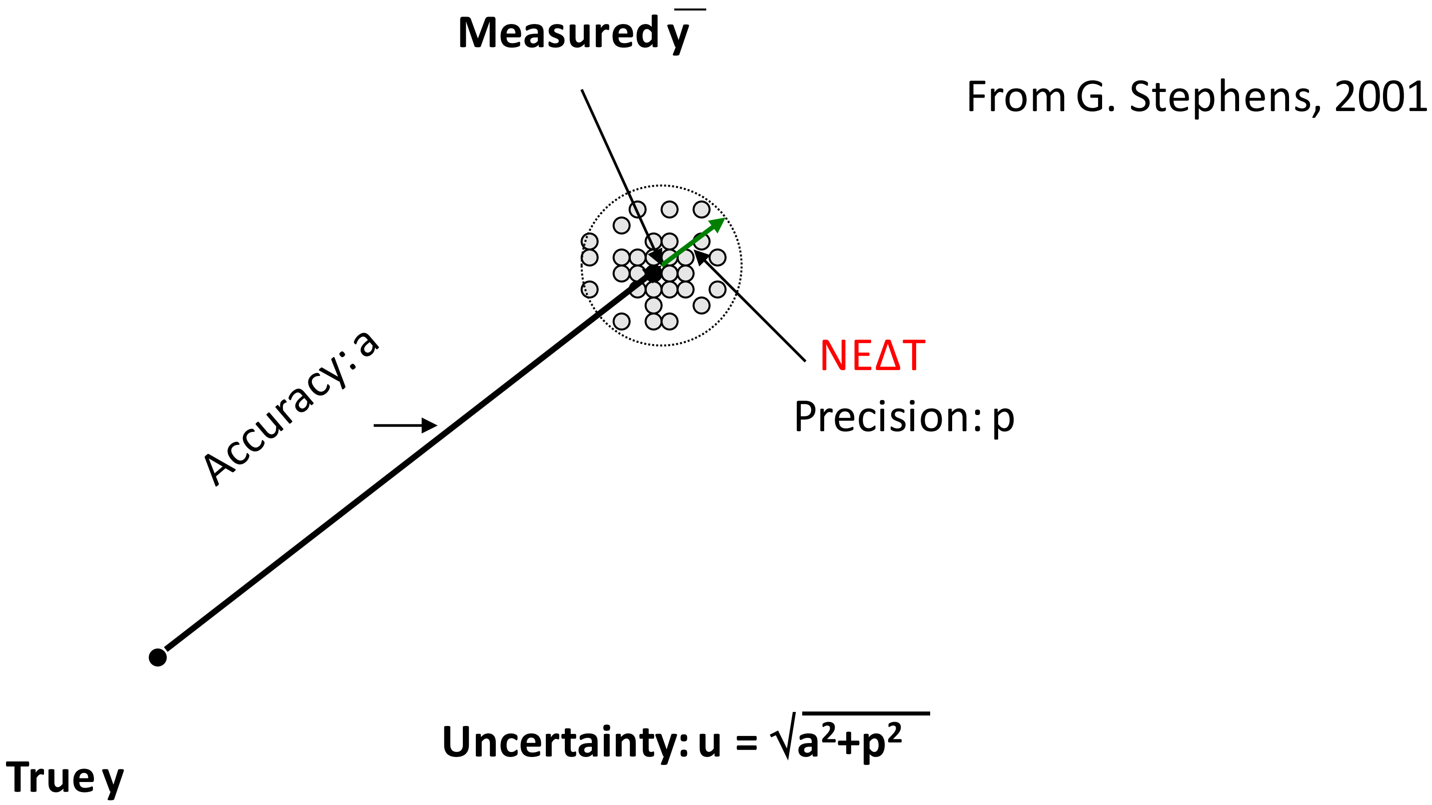
Well-Calibrated JPSS Instruments as GSICS References

Fuzhong Weng
Satellite Meteorology and Climatology Division (SMCD)
NOAA/NESDIS/Center for Satellite Applications and Research (STAR)

Key Satellite Calibration Parameters: Accuracy/Precision /Stability

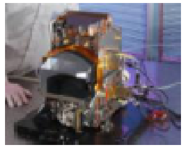


Accuracy: SDR measurement mean vs. truth
Precision: Noise Equivalent Delta Temperature or Radiance (NEΔT NEDN)
Stability: Change of calibration accuracy with time

Metrics for a Reference Instrument

- **The observations from the instrument are used in operations and research**
  - ✓ *Suomi NPP SDR data are widely distributed to the international community (e.g. CrIS/ATMS data are assimilated in both global and regional NWP models)*
  - ✓ *Suomi NPP data are used for environmental monitoring and climate studies*
- **The instrument calibration theory should be well established and documented**
  - ✓ *Peer reviewed publications*
  - ✓ *ATBD, OAD and user manual*
- **The instrument is well calibrated from the prelaunch tests and meets the specifications**
  - ✓ *Radiometric calibration (e.g. non-linearity)*
  - ✓ *Calibration accuracy from thermal vacuum data (TVAC)*
  - ✓ *Traceable methodology for instrument noise*
  - ✓ *Spectrum response function (SRF) measurement*
- **The instrument performance on orbit is well characterized and meets the specifications**
  - ✓ *Performance through trending noise is stable*
  - ✓ *On-orbit calibration accuracy is characterized*
  - ✓ *Inter-sensor bias with other similar instruments is also estimated*
  - ✓ *Geolocation accuracy is defined*
  - ✓ *Instrument has an error budget model*

Suomi NPP Instruments and Their Applications

NPP/JPSS Instrument		NOAA Mission Benefits
	**Advanced Technology Microwave Sounder (ATMS)**	ATMS and CrIS together provide high vertical resolution **temperature** and **water vapor information needed to maintain and improve forecast skill** out to 5 to 7 days in advance for extreme weather events, including hurricanes and severe weather outbreaks
	**Cross-track Infrared Sounder (CrIS)**	
	**Visible Infrared Imaging Radiometer Suite (VIIRS)**	VIIRS provides many **critical imagery products** including snow/ice cover, clouds, fog, aerosols, fire, smoke plumes, vegetation health, phytoplankton abundance/chlorophyll. All are required for environmental hazard monitoring and are useful for crucial economic sectors (transportation, fishing, energy, agriculture), all of which impact human health
	**Ozone Mapping and Profiler Suite (OMPS)**	Total ozone for **monitoring ozone** hole and recovery of stratospheric ozone and for UV index forecasts
	**Clouds and the Earth's Radiant Energy System (CERES)**	Provide **climate quality measurements** of the Earth's outgoing radiation budget- longwave infrared, reflected solar flux, and incoming solar radiation, all of which are vital to climate monitoring

Suomi NPP TDR/SDR Algorithm Schedule

Sensor	Beta	Provisional	Validated
CrIS	February 10, 2012	February 6, 2013	March 17, 2014
ATMS	May 2, 2012	February 12, 2013	March 17, 2014
OMPS	March 7, 2012	March 12, 2013	September 17, 2015
VIIRS	May 2, 2012	March 13,, 2013	April 17, 2014

Beta

- Early release product
- Initial calibration applied
- Minimally validated and may still contain significant errors (rapid changes can be expected. Version changes will not be identified as errors are corrected as on-orbit baseline is not established)
- Available to allow users to gain familiarity with data formats and parameters
- Product is not appropriate as the basis for quantitative scientific publications studies and applications

Provisional

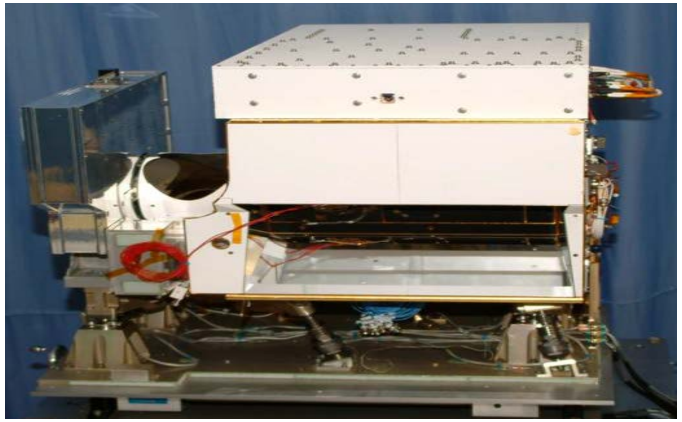
- Product quality may not be optimal
- Incremental product improvements are still occurring as calibration parameters are adjusted with sensor on-orbit characterization (versions will be tracked)
- General research community is encouraged to participate in the QA and validation of the product, but need to be aware that product validation and QA are ongoing
- Users are urged to consult the SDR product status document prior to use of the data in publications
- Ready for operational evaluation

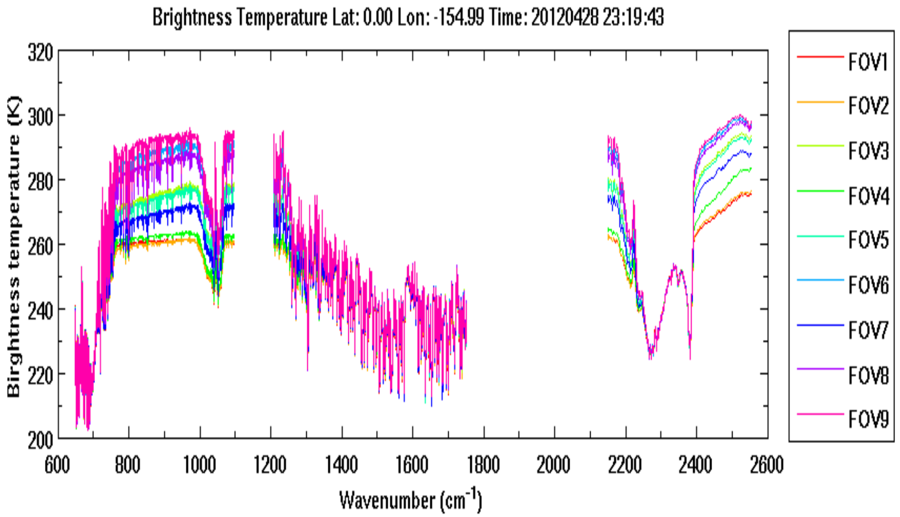
Validated

- On-orbit sensor performance characterized and calibration parameters adjusted accordingly
- Ready for use in applications and scientific publications
- There may be later improved versions
- There will be strong versioning with documentation

Cross-Track Infrared Sounder (CrIS)

- CrIS has 1305 channels (normal spectral resolution) and 2211 channels (full spectral resolution) located in 3 IR wavelength ranges: LWIR (9.14 - 15.38 µm); MWIR (5.71 - 8.26 µm); and SWIR (3.92 - 4.64 µm)
- CrIS is a cross-track scanning IR Fourier transform spectrometer with a scan swath width of 2200 km
- CrIS is radiometrically and spectrally calibrated well and its on-orbit performance (stability, noise and accuracy) all meet the specification
- CrIS SDR data are primarily used by NWP community to improve the global medium-range forecasts
- CrIS SDR data are also being tested in thee regional forecast models
- CrIS SDR data are used in NUCAPS for deriving a suite of atmospheric and surface products
- CrIS SDR data are used by WMO as a reference instrument for cross-calibrating other infrared imagers and sounders





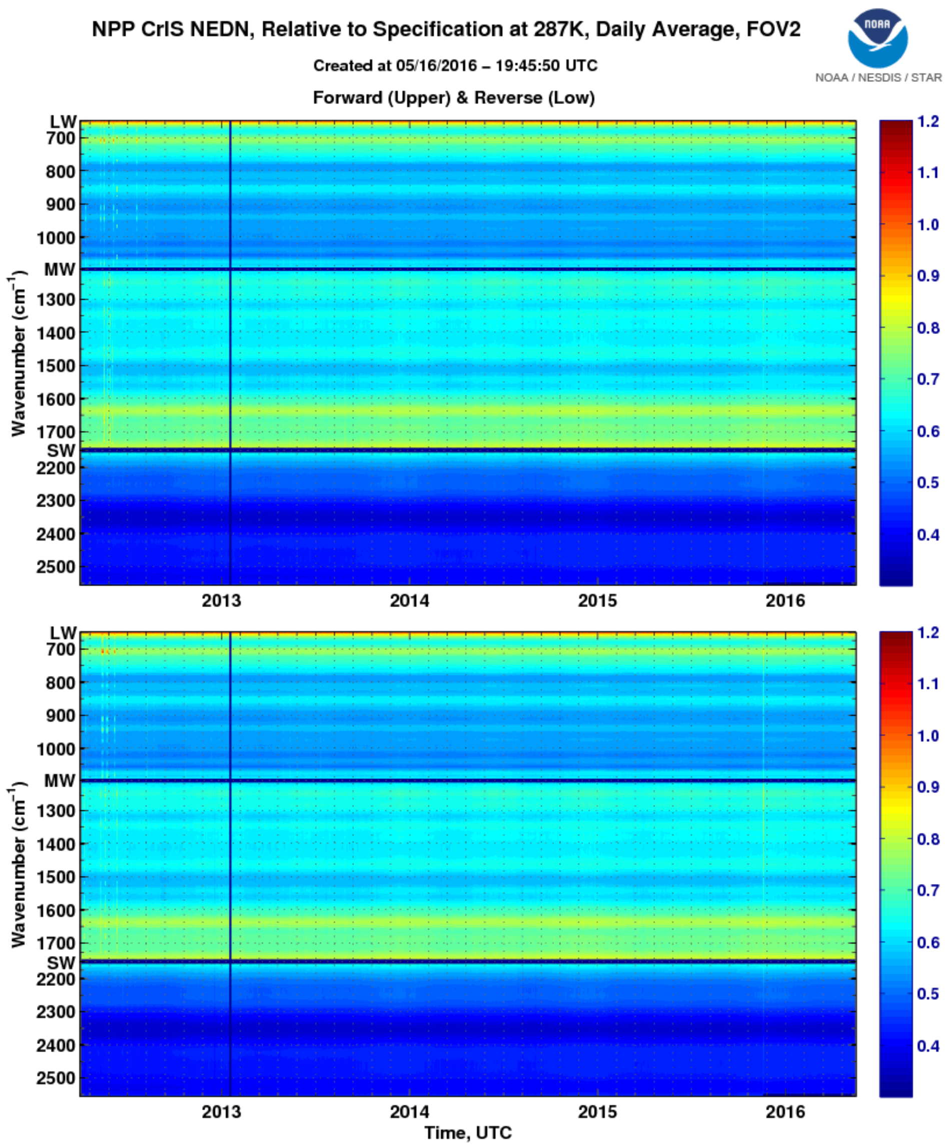
CrIS SDR Requirements vs. Performance

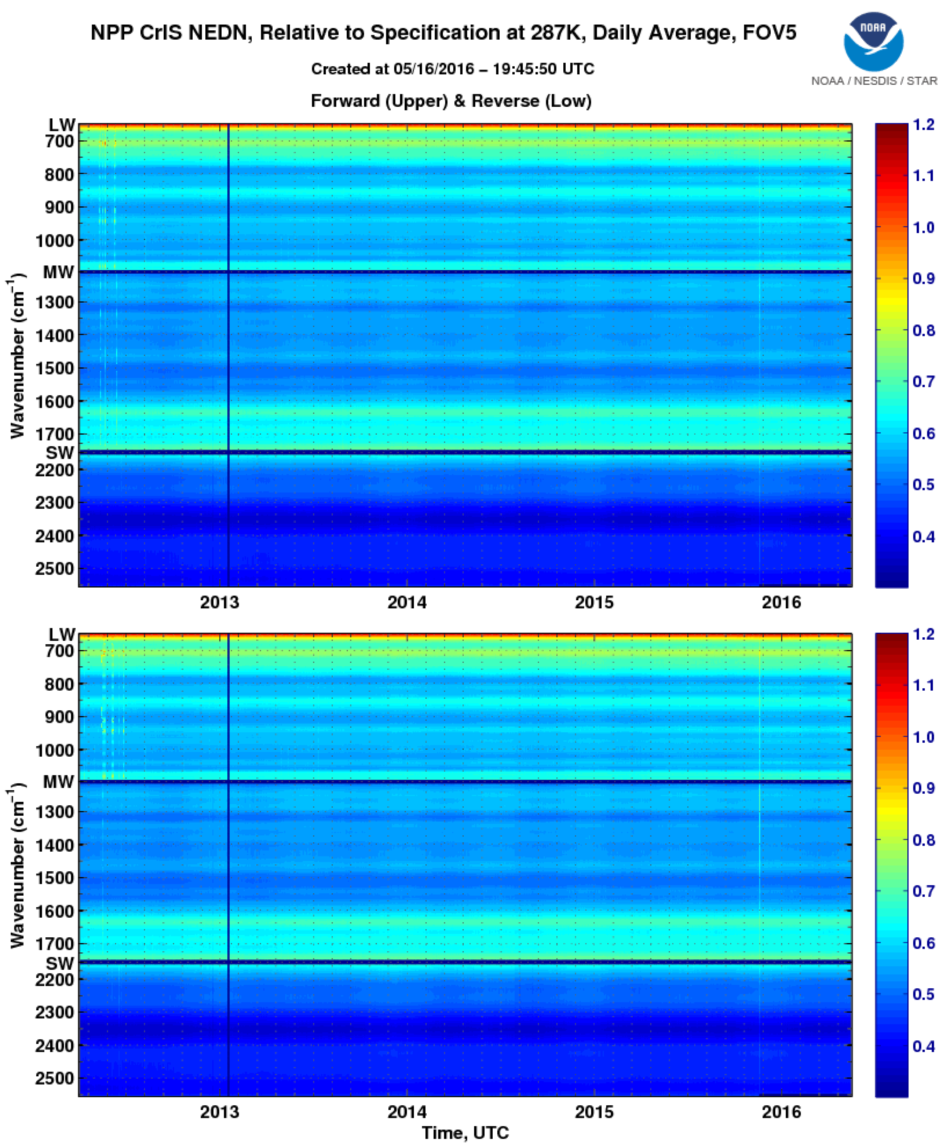
CrIS SDR uncertainties (**blue**) vs. specifications (black)

Band	NEdN @287K BB mW/m^2/sr/cm^{-1}	Radiometric Uncertainty @287K BB (%)	Frequency Uncertainty (ppm)	Geolocation Uncertainty (km) *
LW	**0.098** (0.14)	**0.12** (0.45)	**3** (10)	**1.2** (1.5)
MW	**0.036** (0.06)	**0.15**(0.58)	**3** (10)	**1.2** (1.5)
SW	**0.003** (0.007)	**0.2** (0.77)	**3** (10)	**1.2** (1.5)

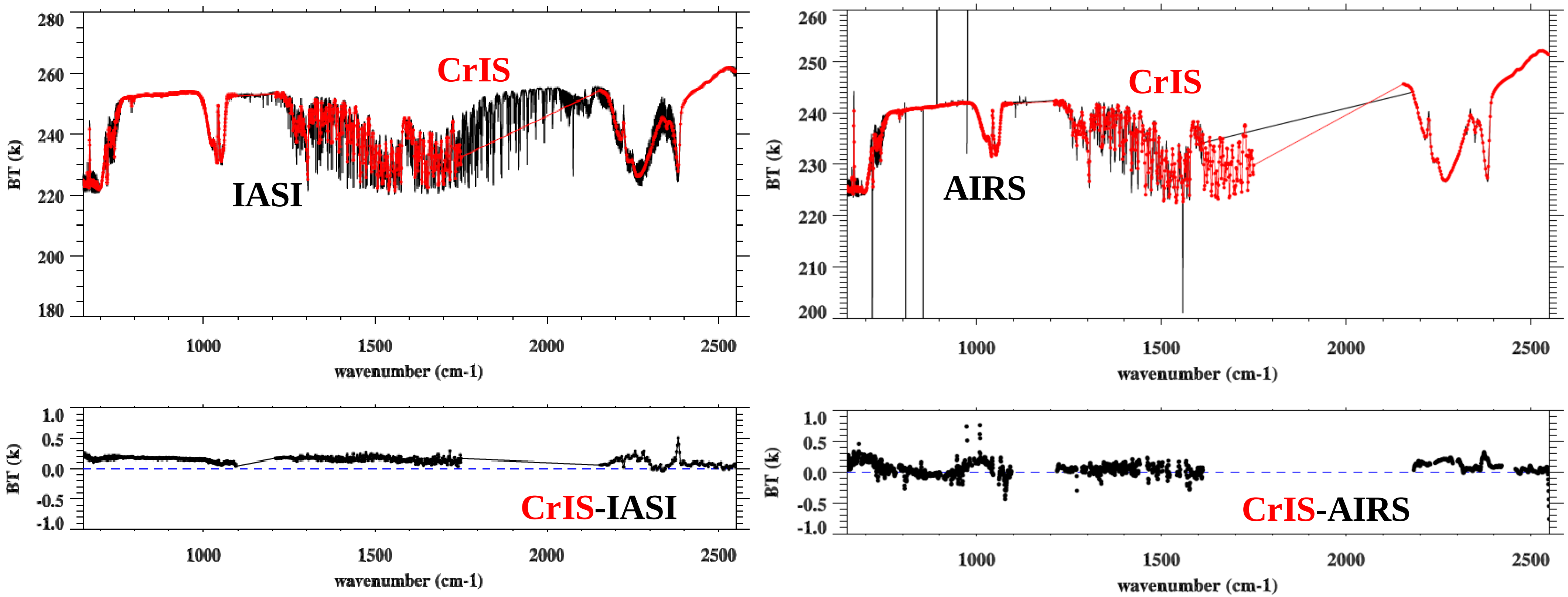
- Requirements
  - ✓ Instrument & SDR performances exceed requirements by large margins
- SDR software
  - ✓ Stable & free of errors that could impact data quality since 11/14/2013 (Mx8.0)

Long-Term Performance of Suomi NPP CrIS (NEDN)





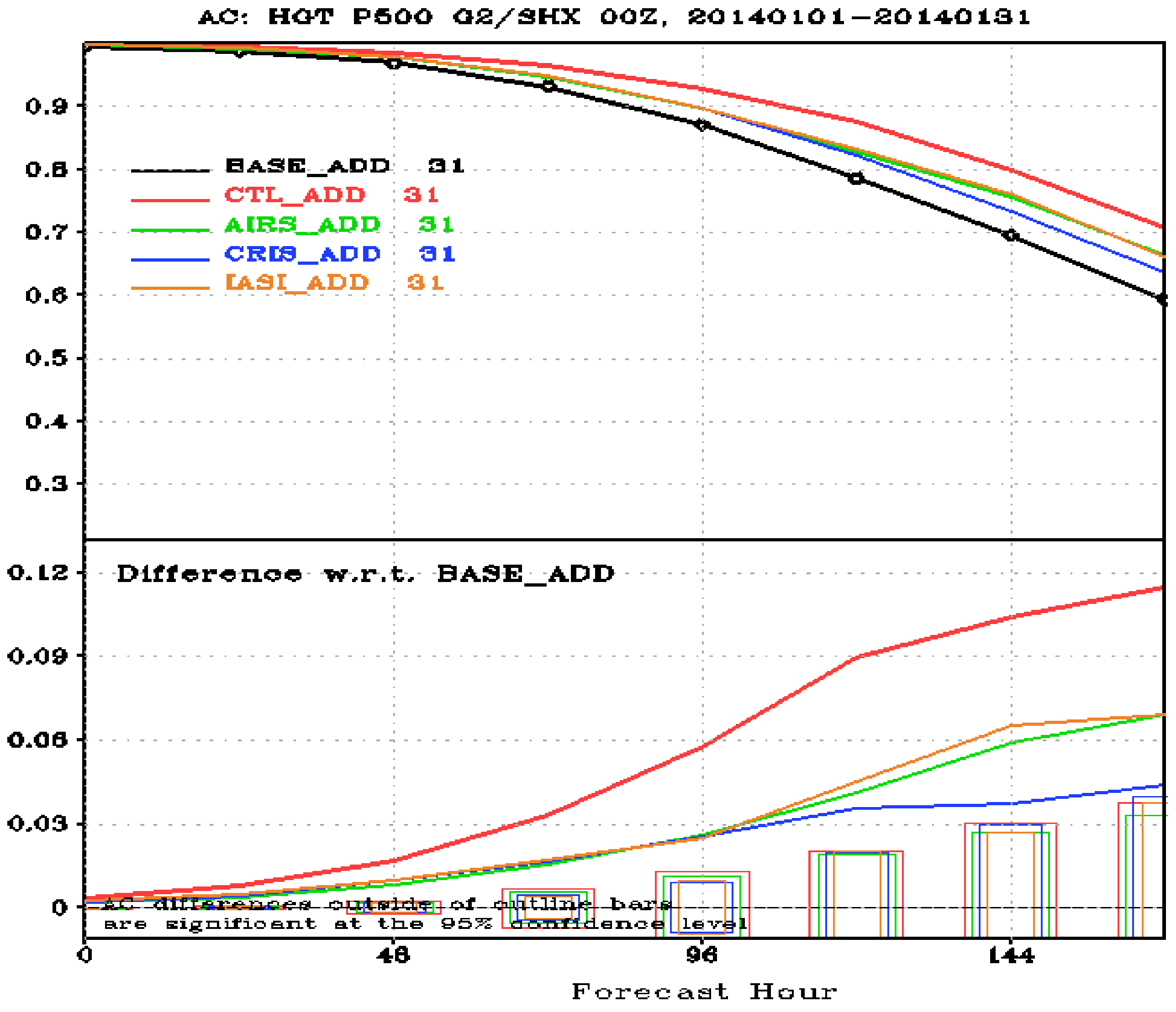
CrIS Radiometric Calibration: Compared to AIRS and IASI



- CrIS has about 0.2 K warm bias w.r.t. IASI and no bias w.r.t. AIRS from SNO collocated data sets.
- In the analysis, IASI data was de-apodized to obtain the original interferogram data and are then resampled using CrIS spectrum resolution, and FFTed back to CrIS-like radiances.

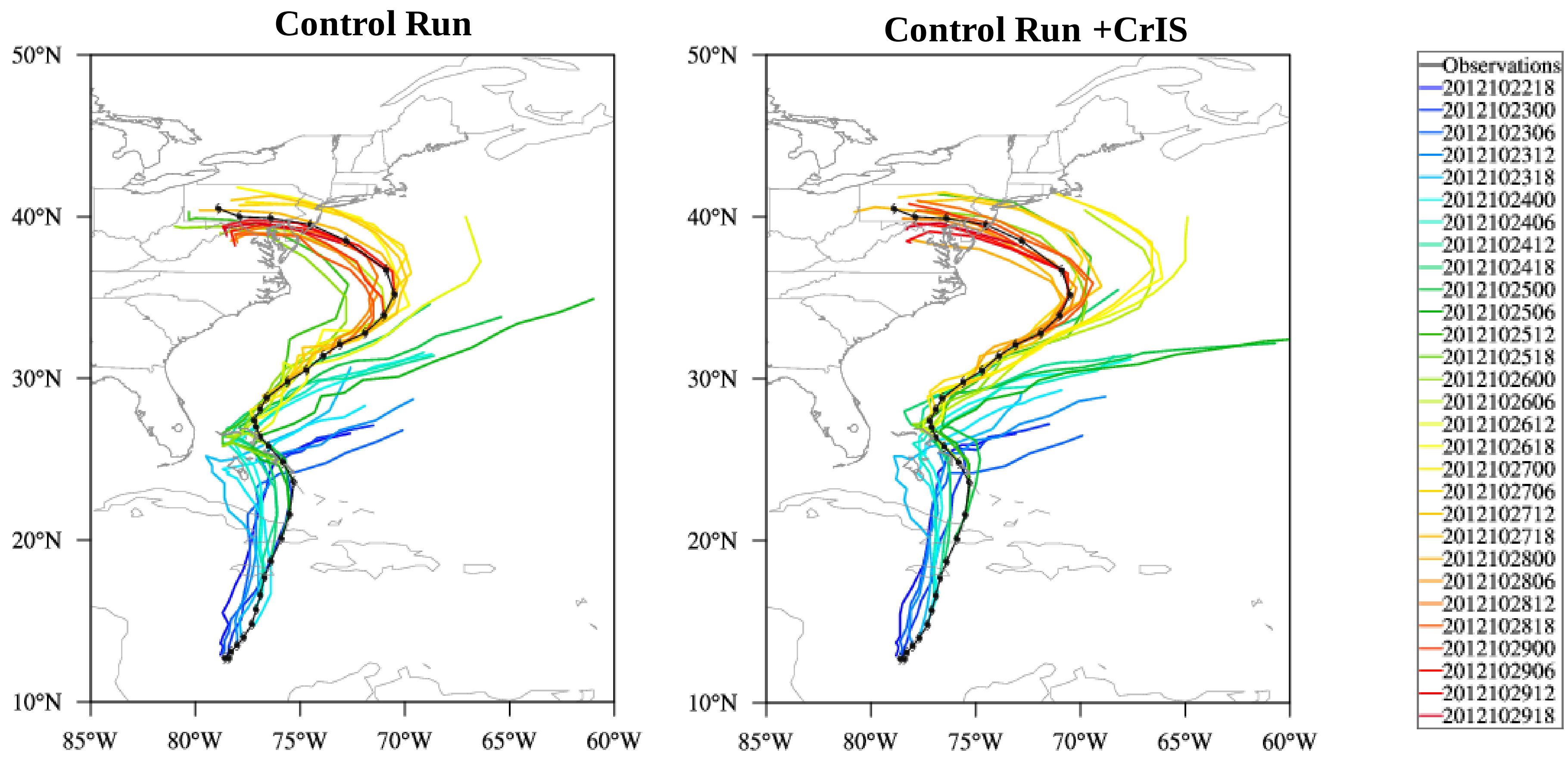
Impacts of CrIS in NCEP GFS

500 hPa Southern Hemisphere AC scores for 20140101 – 20140131 00Z



- The impact from assimilation of CrIS radiances in NCEP GFS is smaller, compared to that from AIRS and IASI.
- The baseline experiment includes the conventional and GPSRO data and the control experiment includes all the satellite instruments and conversional data.
- New quality control is required for better assimilation of CrIS radiances.

Impacts of CrIS DA on Hurricane Forecasts

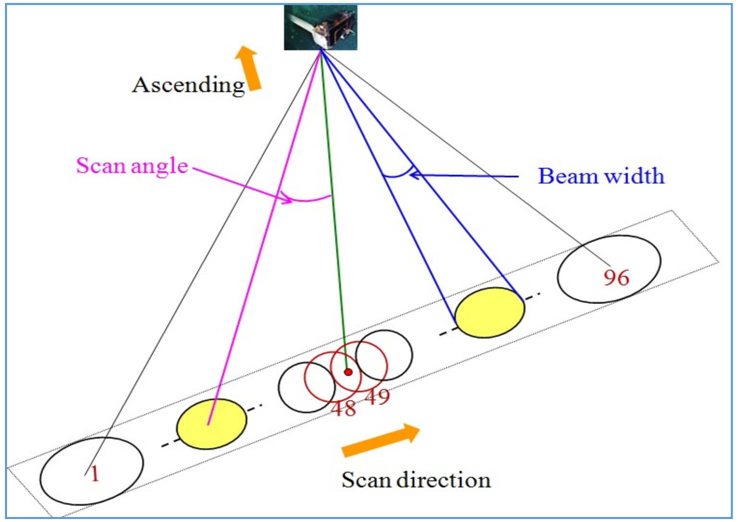


- Unlike ATMS data, assimilation of CrIS radiance observations in HWRF degraded the forecasts of Superstorm Sandy tracks.
- Some fundamental issues related to QC of CrIS data are yet to be resolved!

Advanced Technology Microwave Sounder (ATMS)

- ATMS has 22 channels located near microwave oxygen and water vapor absorption bands
- ATMS is a cross-track scanning microwave sounding instrument with a scan swath width of 2200 km
- ATMS's field of size at oxygen band is much smaller compared to its predecessor, AMSU-A
- ATMS is radiometrically calibrated well and its on-orbit performance (stability, noise and accuracy) all meet the specification
- ATMS SDR data are primarily used by NWP community to improve the global medium-range forecasts
- ATMS SDR data are also being tested in thee regional forecast models
- ATMS SDR data are used in microwave integrated retrieval system (MIRS) for deriving a suite of atmospheric and surface products
- ATMS SDR data are used for environmental monitoring such as hurricanes and severe storm events
- ATMS SDR data are used by WMO as a reference instrument for cross-calibrating other microwave sounders

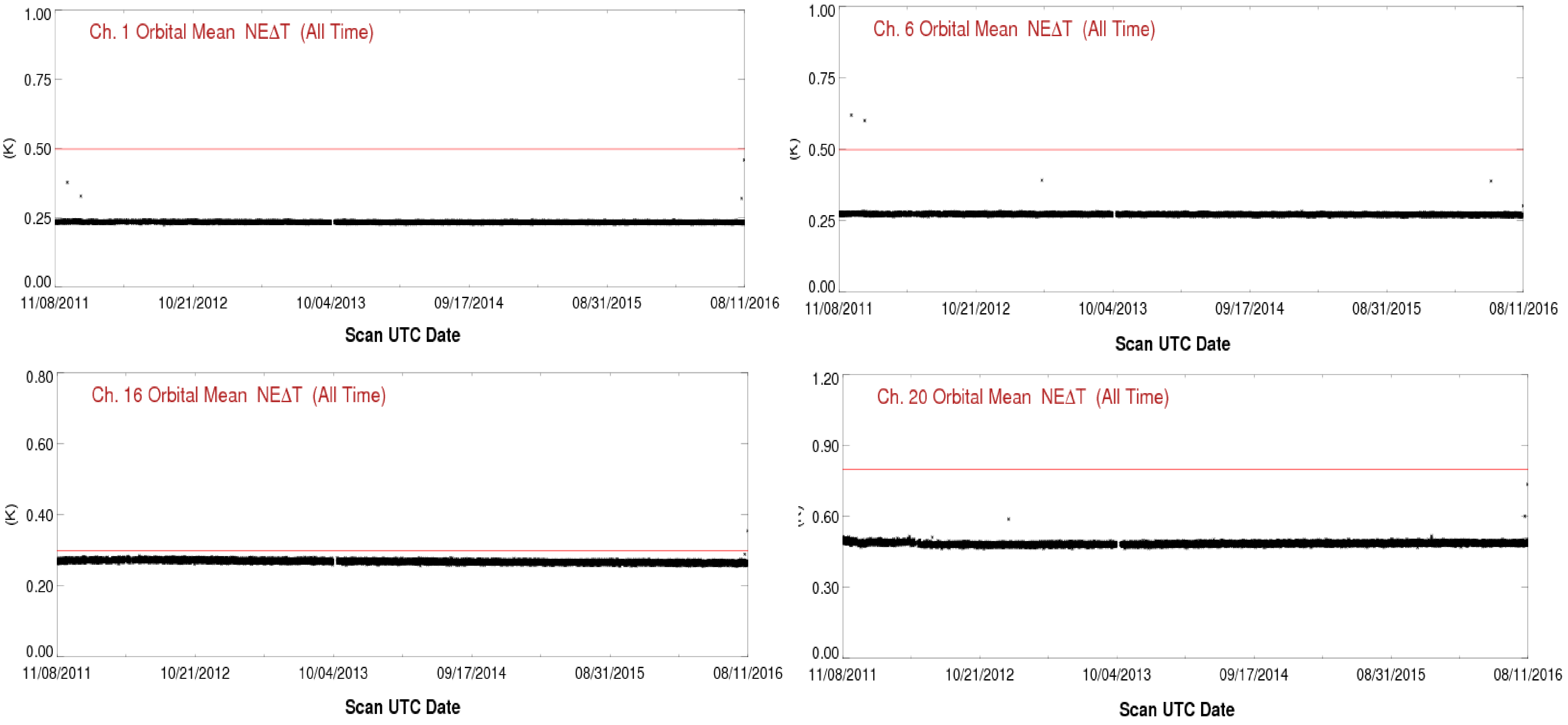
ATMS Integrated on NPP Spacecraft



ATMS SDR Requirements vs. Performance

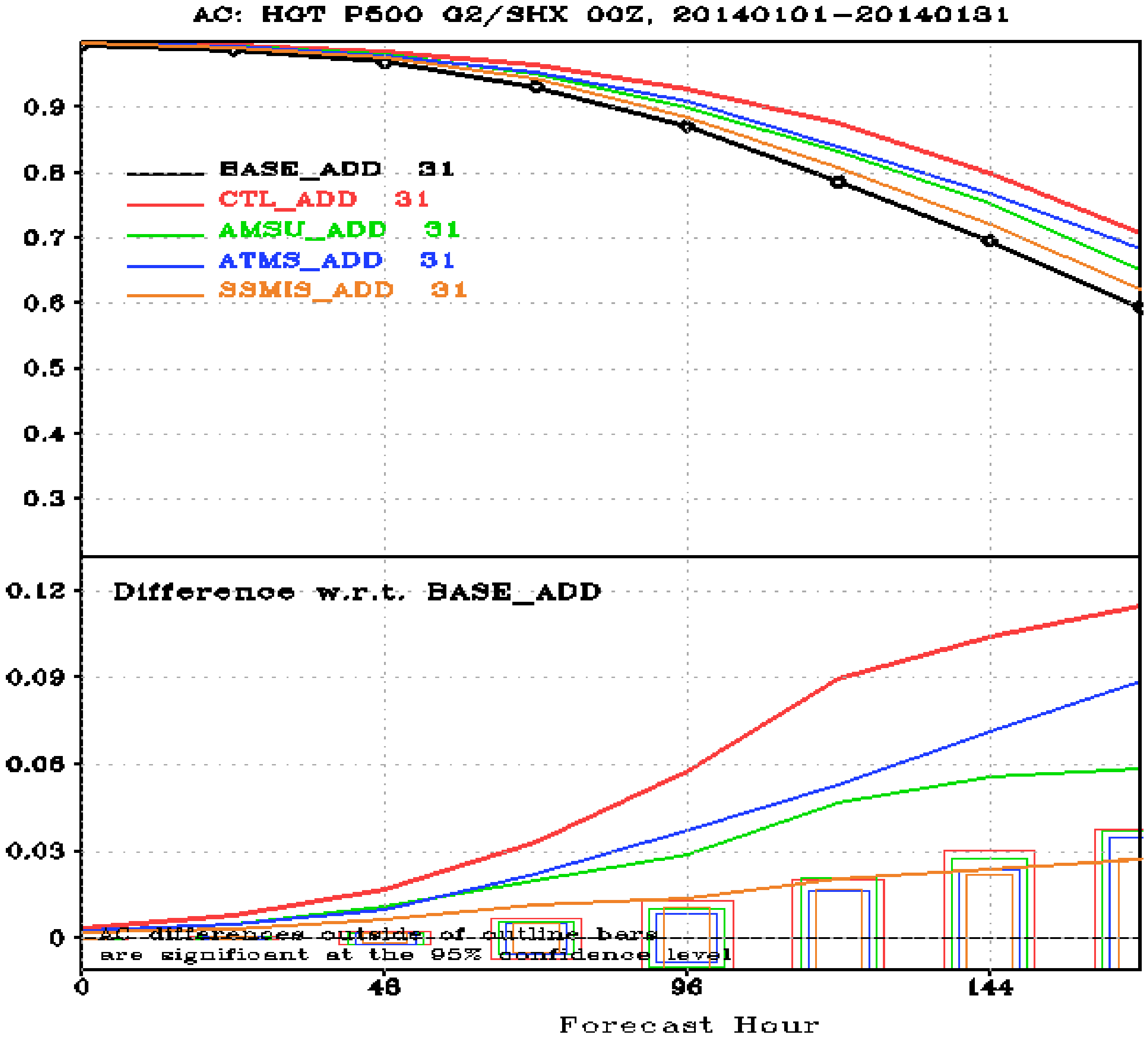
Channel	Accuracy (K) On-Orbit/Spec	NEΔT (K) On-Orbit/Spec	Channel	Calibration (K) On-Orbit/Spec	NEΔT (K) On-Orbit/Spec
1	/1.00	0.25/0.5	**12**	0.24/0.75	0.59/1.0
2	/1.00	0.31/0.6	**13**	0.13/0.75	0.86/1.5
3	/0.75	0.37/0.7	**14**	0.02/0.75	1.23/2.2
4	/0.75	0.28/0.5	**15**	0.09/0.75	1.95/3.6
5	0.18/0.75	0.28/0.5	**16**	/1.00	0.29/0.3
6	0.09/0.75	0.29/0.5	**17**	/1.00	0.46/0.6
7	0.02/0.75	0.27/0.5	**18**	0.50/1.00	0.38/0.8
8	0.06/0.75	0.27/0.5	**19**	0.36/1.00	0.46/0.8
9	0.06/0.75	0.29/0.5	**20**	0.31/1.00	0.54/0.8
10	0.18/0.75	0.43/0.75	**21**	0.13/1.00	0.59/0.8
11	0.22/0.75	0.56/1.0	**22**	0.40/1.00	0.73/0.9

Long-Term Performance of Suomi NPP ATMS (NEDT)



Impacts of US Microwave Sounders in NCEP GFS

500 hPa Southern Hemisphere AC scores for 20140101 – 20140131 00Z



- Assimilation of ATMS radiances in NCEP GFS produces a largest impact on global medium-range forecast, especially in southern hemisphere.
- The baseline experiment includes the conventional and GPSRO data and the control experiment includes all the satellite instruments and conversional data.

ATMS DA Research Highlighted in Nature

METEOROLOGY

Satellite improves storm forecasts

Data from a US Earth-observing satellite could help improve the accuracy of prediction of hurricane track and strength.

When generating hurricane forecasts the US National Weather Services does not use real-time information from weather satellites. But Xiaolei Zou at Florida State University in Tallahassee and her colleagues looked at the effect of including data from the Suomi NPP satellite, launched in 2011, on hurricane forecasts.

The satellite's microwave instrument measures air temperature and humidity.

Incorporating Suomi data into the government's hurricane model for four 2012 storms, including Sandy(pictured), made for more accurate forecasts of track and intensity. The work suggests a way to improve the notoriously difficult predictions of storm strength. J. *Geophys. Res. Atm*., 118, 11558-11576(2013)

ROBERT SIMMON/NASA/NOAA GOES

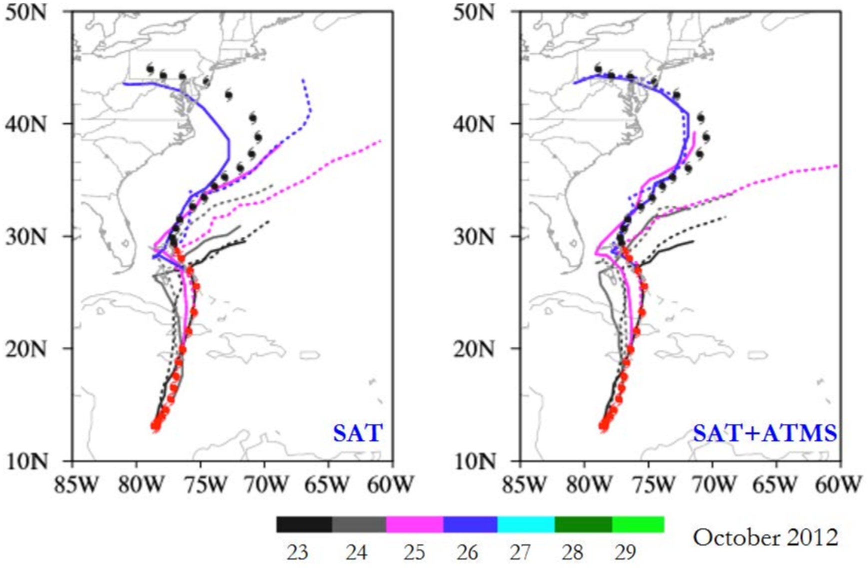
Suomi NPP launch date: October 28, 2011
ATMS into NCEP operational system: May 25, 2012
Impact test completed: Spring 2013
Results published: Fall 2013

12 DECEMBER 2013 VOL 504 NATURE [19]

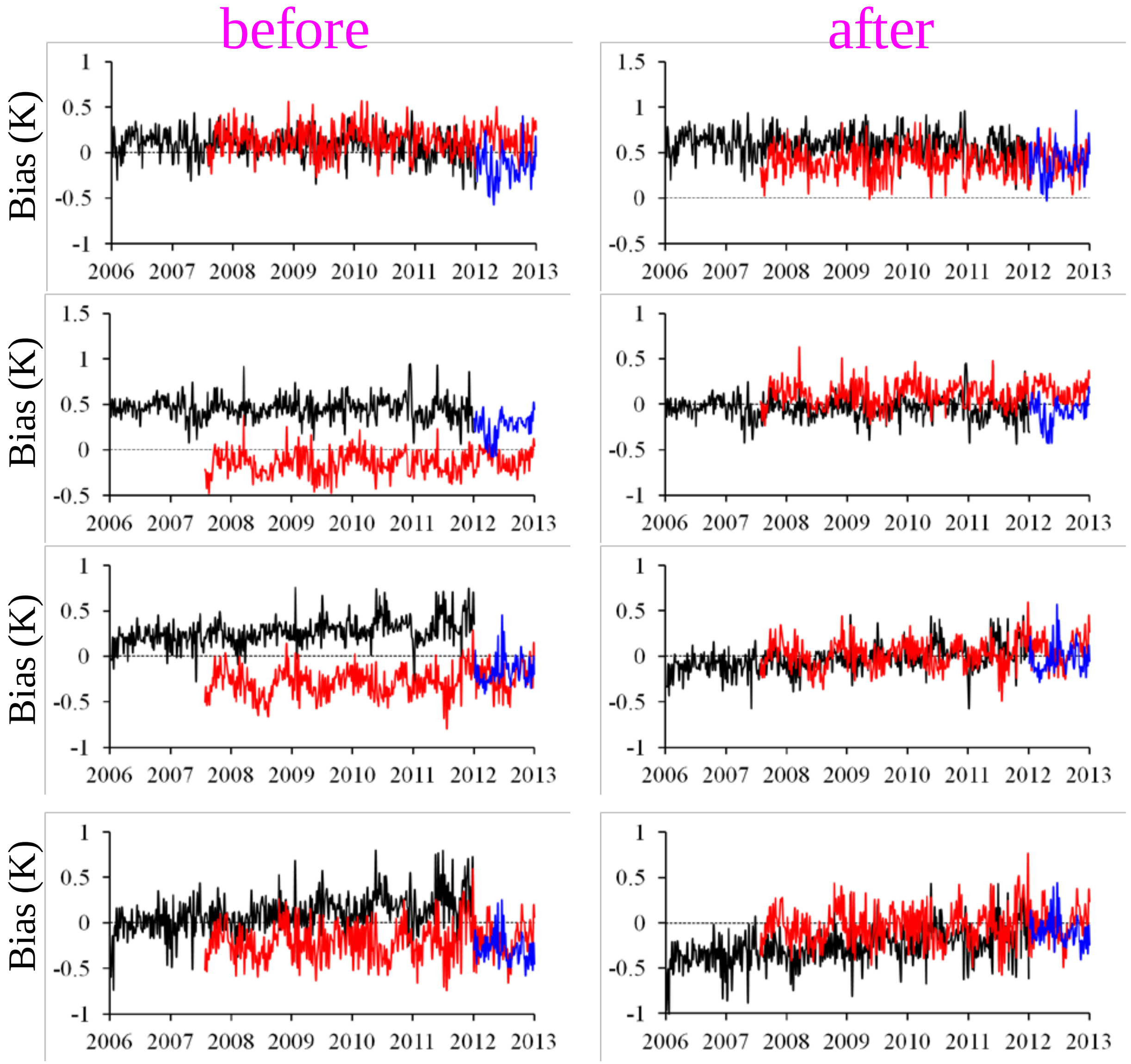
© 2013 Macmillan Publish

ATMS data assimilation in GSI/HWRF results in a consistent positive impact on the track and intensity forecasts of the four landfall hurricanes in 2012.

Impacts of ATMS Data Assimilation on Track Forecast of Hurricane Sandy



Biases in the Tropics (NOAA-15, MetOp-A, SNPP)



ATMS channel 10

ATMS channel 11

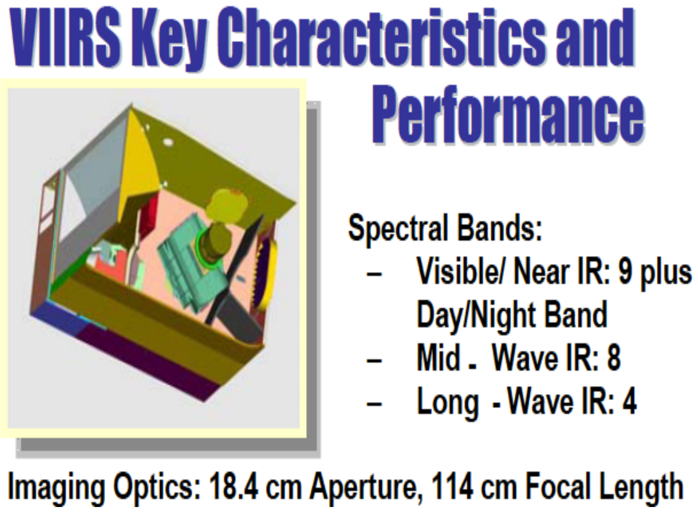
ATMS channel 13

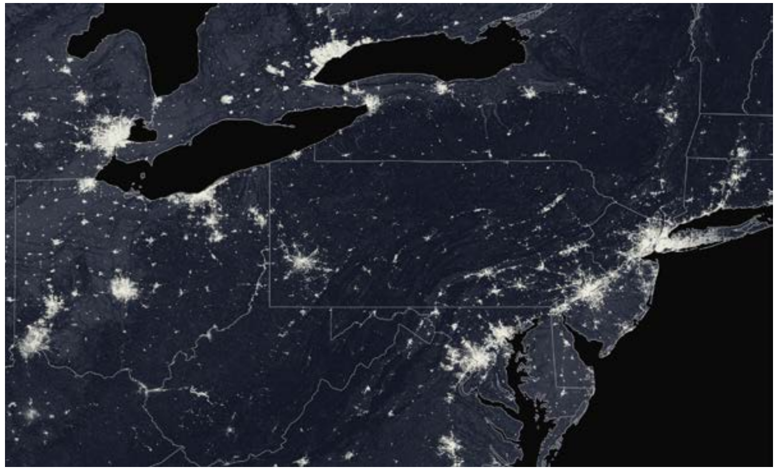
ATMS channel 14

NOAA-18 is subtracted. The pentad data set is within ±30^{o} latitudinal band.

Visible Infrared Imaging Radiometer Suite (VIIRS)

- VIIRS has 22 bands from visible/near IR, Day/Night Bands, mid-wave IR, and long-wave IR bands
- VIIRS is a scanning radiometer, collects visible and infrared imagery and radiometric measurements of the land, atmosphere, cryosphere and oceans
- VIIRS visible bands are calibrated with on-board solar diffuser
- VIIRS I bands have the highest resolution to 375 m
- VIIRS geolocation accuracy is about 80 m and can be used for validating other instrument geolocation
- VIIRS SDR data are used in measuring cloud and aerosol properties, ocean color, sea and land surface temperature, ice motion and temperature, fires and Earth's albedo.
- VIIRS SDR data are used by WMO as a reference instrument for cross-calibrating other infrared imagers and sounders





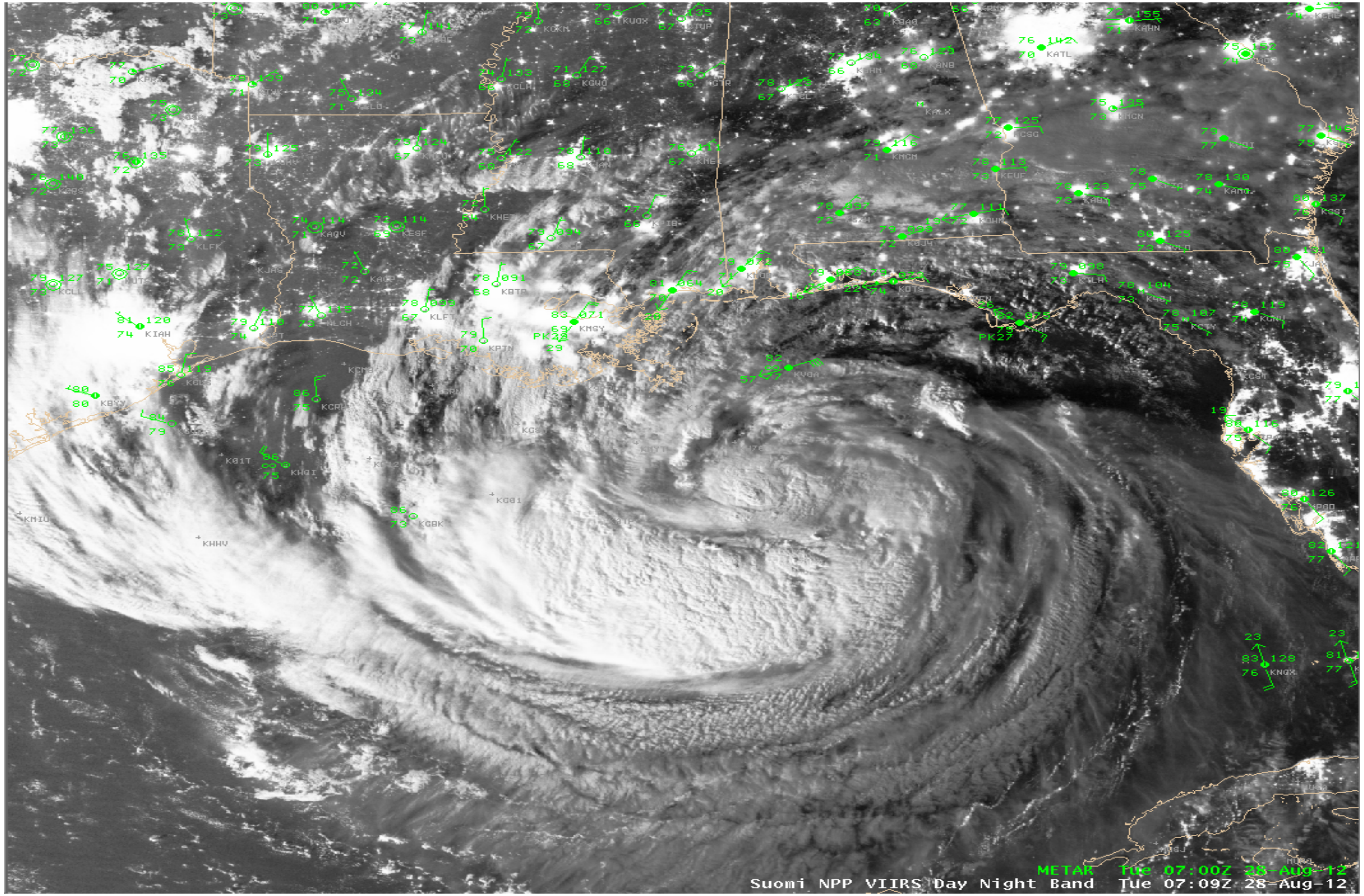
VIIRS DNB imagery

VIIRS SDR Requirements vs. Performance

	Requirement (absolute uncertainty for uniform scenes)	Prelaunch and onboard calibration	Validation: Relative to MODIS/CrIS/IASI/other thru Inter-comparisons	Note
VIIRS RSB	2% typical reflectance; 0.3% stability; 0.1% desirable for Ocean Color Applications	1.2% for M1-M7; 1.5% for M8&9 1.4% for M10 1.3% for I1&I2 1.6% for I3	2% (±1%) for matching bands	Except bands with very low signal (ex. M11) Geolocation error: expectation is half I-band pixel; achieved better than quarter I-band pixel (1-s)
VIIRS TEB	M12/M13: 0.7%(0.13K) @270K M14: 0.6% (0.26K) @ 270K M15/M16: 0.4% (0.22K/0.24K) @270K I4: 5% (0.97K) @270K I5: 2.5% (1.5K) @270K	Better than 0.13K for all M bands except M13 (0.14); 0.47K for I4; 0.23K for I5	0.1K based on statistical comparison with MODIS and CrIS ER-2/SHIS Aircraft underflight shows excellent agreement M15 0.4 K bias relative to CrIS at 200K (in spec.)	M15 at 190K requirement is 2.1% radiance or 0.56K Geolocation uncertainty: expectation was half I-band pixel; achieved better than quarter I-band pixel (1-s)
VIIRS DNB	5%, 10%,30% L_{min} (LGS,MGS,HGS)	3.5%, 7.8%, and 11% (LGS, MGS, HGS)	4%, 7.7%, 11.8% (LGS, MGS, HGS)	Geolocation error is a ~10th of a pixel (1-s) on the ellipsoid earth but can exceed 1km (up to 24 km at the edges of scan) without terrain correction

VIIRS SDR Data Used in AWIPS

Tropical Storm Isaac in AWIPS



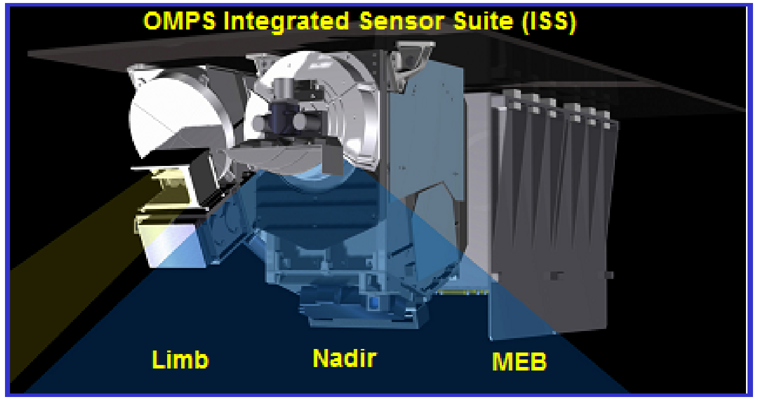
A unique visible look at a Tropical Storm at night

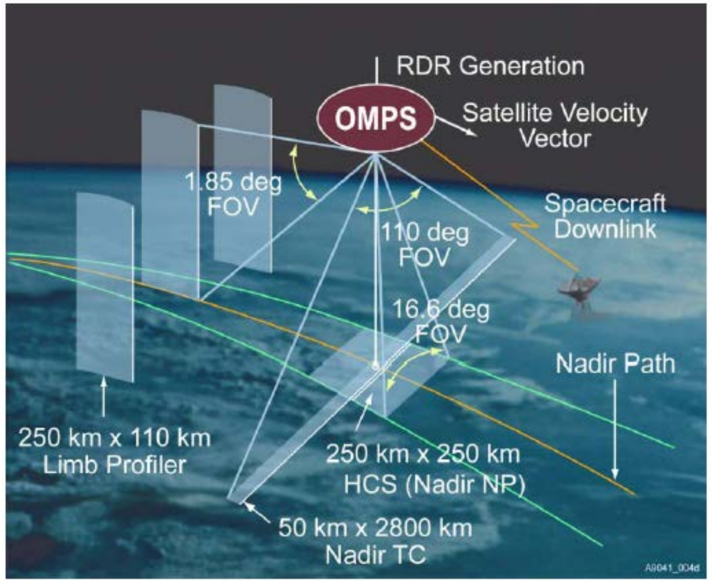
07:09 UTC
28 Aug 2012

Data captured and processed in real-time at the University of Wisconsin-Madison Space Science and Engineering Center using CSPP Software

Ozone Mapping and Profiling Suite (OMPS)

- OMPS is using an grating spectrometer with CCD (Charge-coupled device) optical detector
- OMPS consists of three spectrometers
  - Nadir Mapper Spectrometer covers a 50km x 2800km cross-track swath
  - Nadir Profile Spectrometer provides performance over $(250km)^2$ cell
  - Limb Sensor provides 1 km vertical sampling along three slits enabling ozone profile retrieval (Not on J1)
- OMPS Spectral coverage in UV regions
  - NM covers 300 nm to 380 nm
  - NP covers 250 nm to 310 nm
- OMPS has on-board calibrators
  - Light-emitting diode provides linearity calibration
  - Reflective solar diffusers maintain calibration stability

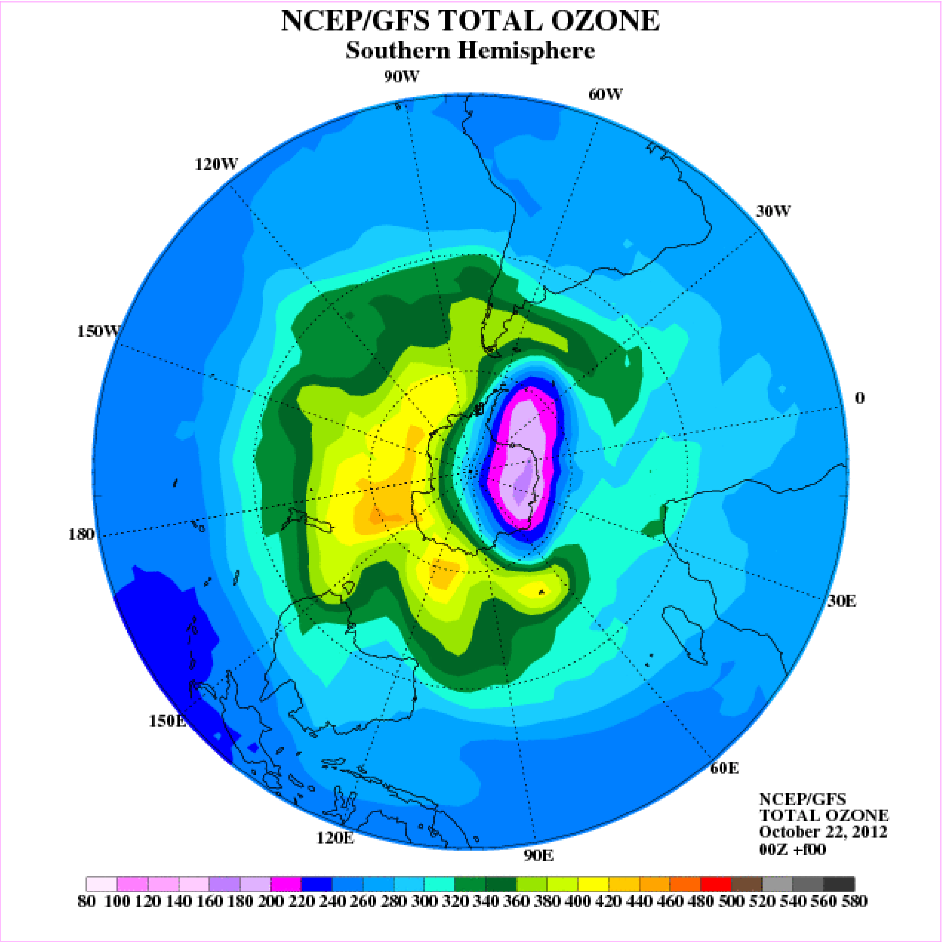


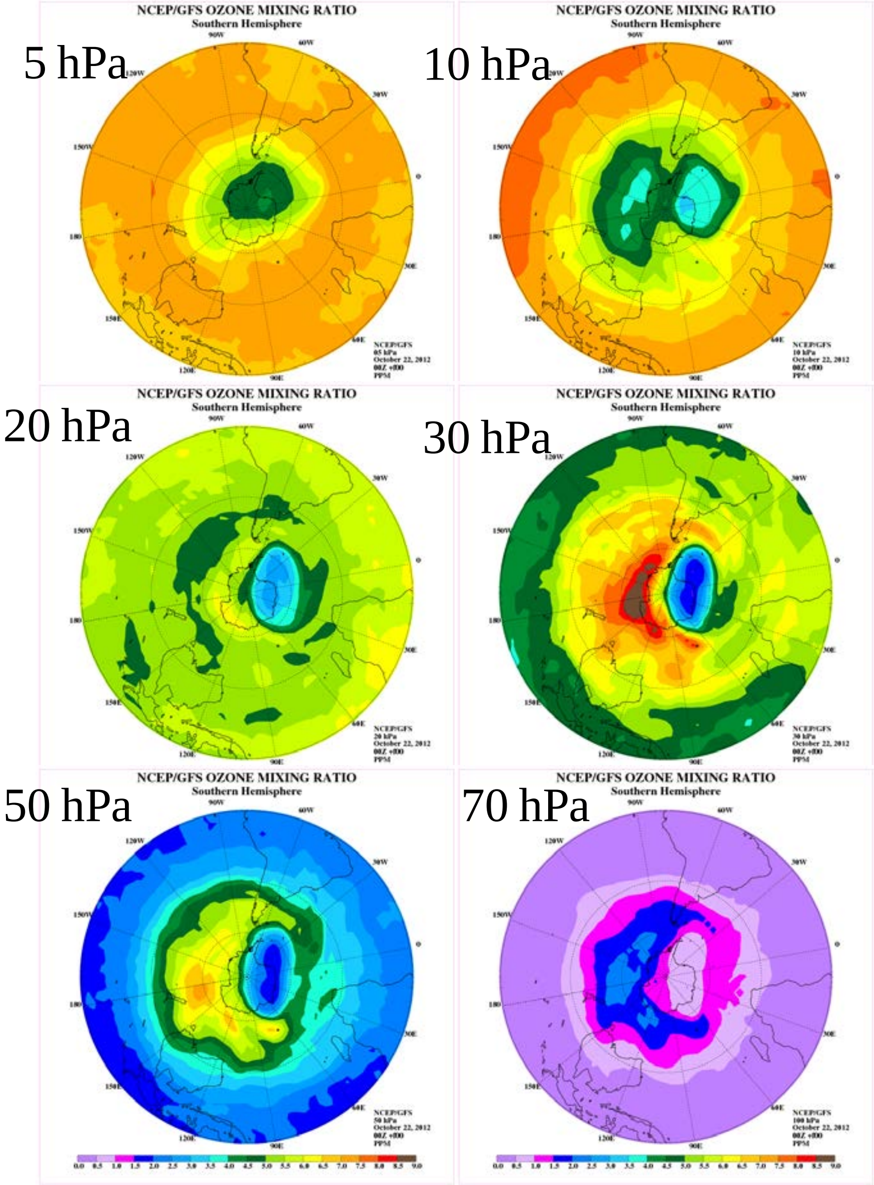


OMPS SDR Requirements and Performance

Budget Term	Requirement/Allocation	On-Orbit Performance
Non-linearity	< 2% full well	< 0.40%
Non-linearity Accuracy	< 0.2%	< 0.2%
On-orbit Wavelength Calibration	< 0.01 nm	<0.01 nm
Stray Light NM Out-of-Band + Out-of-Field Response	For NM ≤ 2	average < 2%
Intra-Orbit Wavelength Stability	Allocation (flow down from EDR error budget) = 0.02 nm	~ 0.006 nm
SNR	1000	> 1000
Inter-Orbital Thermal Wavelength Shift	Allocation (flow down from EDR error budget) = 0.02 nm	~0.006 nm
CCD Read Noise	60 –e RMS	< 25 –e RMS
Detector Gain	46	51
Absolute Irradiance Calibration Accuracy	< 7%	< 7% for majority channels
Absolute Radiance Calibration Accuracy	< 8%	< 8%
Normalized radiance Calibration Accuracy	< 1%	< 2%

Assimilation of Ozone Products in NCEP GFS

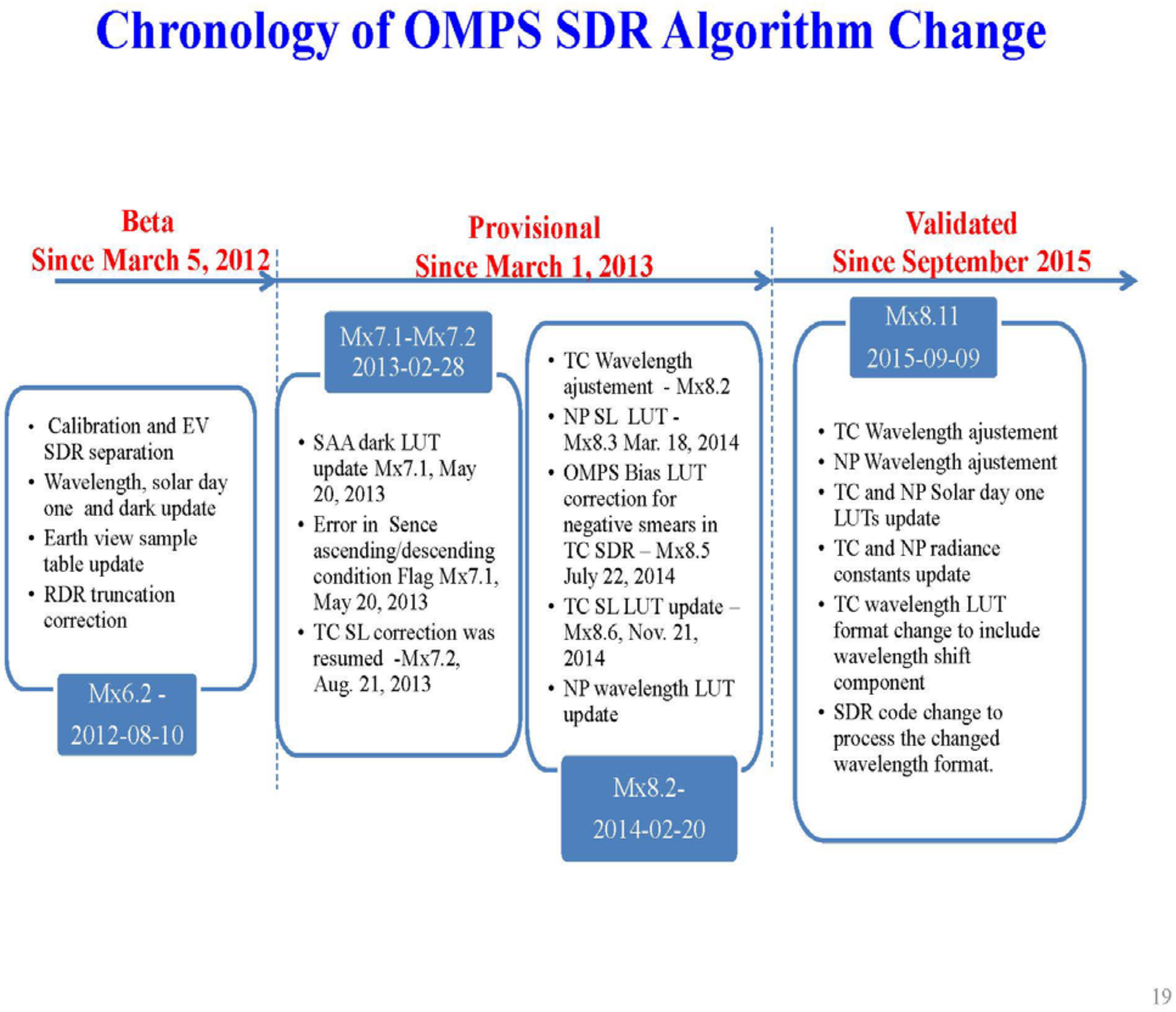




Current GFS Total and O3MR Ozone Analyses

Climate Quality SDR through JPSS Life-Cycle Data Reprocessing

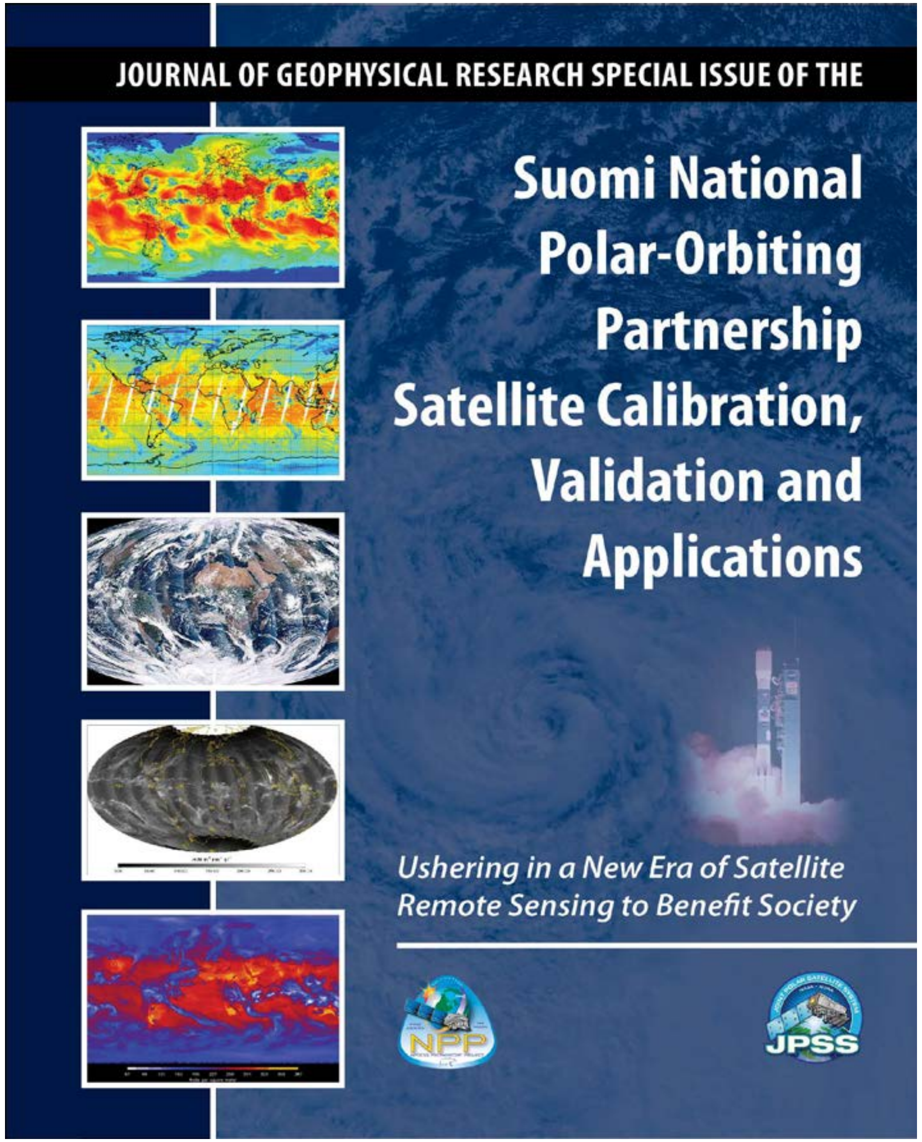
- Optimize the algorithms and processing systems to achieve the lowest JPSS data uncertainties
- Implement the mission-life consistent sciences to achieve a long-term stability of JPSS data accuracy
- Reduce the processing anomalies to the lowest level for preserving the highest integrity of the JPSS data stream
- Incorporate the user-oriented algorithm sciences into reprocessing to further augment the society impacts of JPSS datasets



American Geophysical Union (AGU) JGR Special Issue on Suomi NPP CalVal

35 papers have been published in AGU Journal Geophysical Research Special Issue on Suomi NPP satellite calibration, validation and applications.

Guest Editor: Fuzhong Weng



Summary and Conclusions

- Suomi NPP instruments are well calibrated and their performances on orbit meet the specifications
- Suomi NPP instruments have stable performance on orbit since its launch and all the SDR algorithms have been refined for future JPSS instruments
- Suomi NPP inter-sensor biases with other similar instruments are well characterized
- JPSS life-cycle reprocessing will deliver the climate-quality SDR for more advanced studies
- JPSS instrument calibration and SDR science advances have been published through special issues in JGR (2013) and Remote Sensing (2016), and many other journals