Improving Hurricane/Typhoon Prediction through Assimilation of Suomi NPP Data in HWRF

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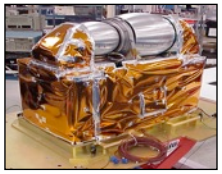
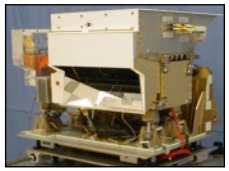
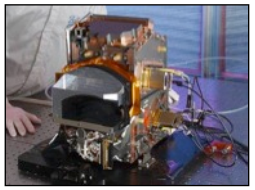
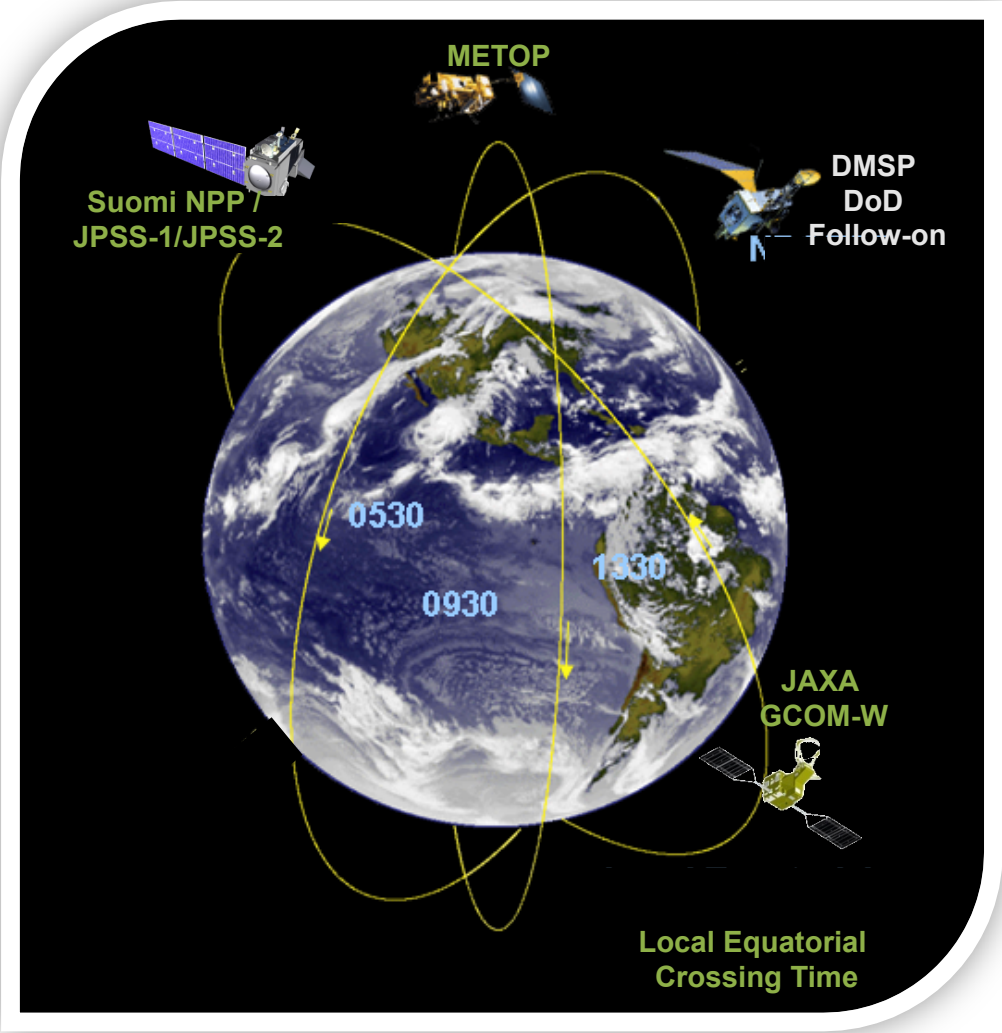
1. NOAA Center for Satellite Applications and Research
2. Florida State University
3. ERT. Inc
4. IMSG. Inc
5. Colorado State University
6. NOAA Environmental Modeling Center
7. NOAA Joint Polar Satellite System Program Office

Suomi NPP Instruments

JPSS Instrument		Measurement
	**ATMS** - Advanced Technology Microwave Sounder	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
	**CrIS** - Cross-track Infrared Sounder	
	**VIIRS** – Visible Infrared Imager Radiometer Suite	VIIRS provides many **critical imagery products** including snow/ice cover, clouds, fog, aerosols, fire, smoke plumes, vegetation health, phytoplankton abundance/chlorophyll
	**OMPS** - Ozone Mapping and Profiler Suite	Ozone spectrometers for **monitoring ozone** hole and recovery of stratospheric ozone and for UV index forecasts
	**CERES** - Clouds and the Earth's Radiant Energy System	Scanning radiometer which supports studies of Earth Radiation Budget

JPSS Integral to 3-Orbit Global Polar Coverage

JPSS implements US civil commitment, interagency and international agreements to afford 3-orbit global coverage.



JPSS ENVIRONMENTAL PRODUCT PRODUCTION

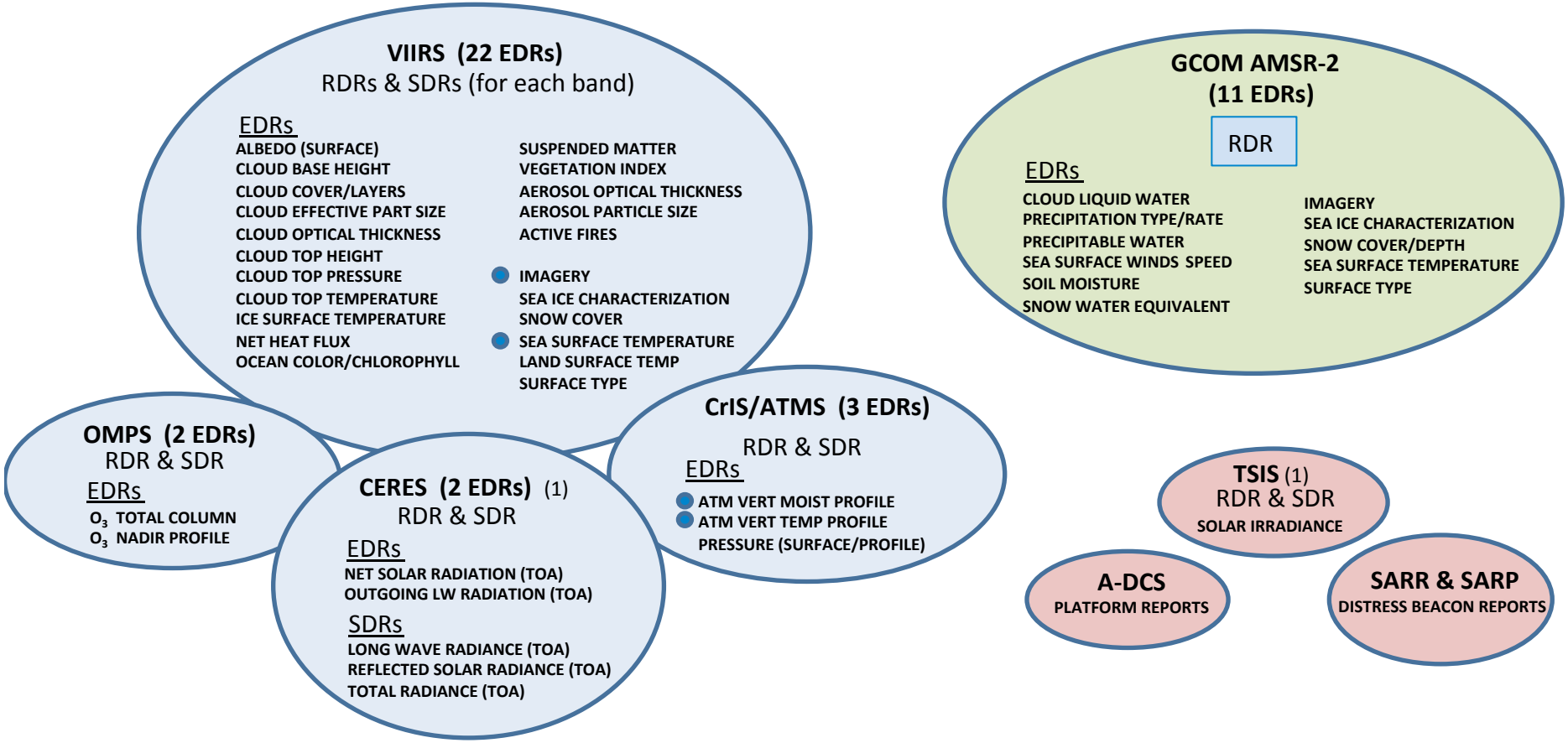
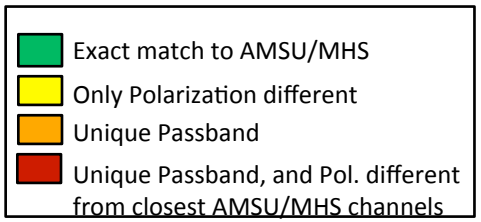


Figure 3-4, Rev B, 4/5/12

ATMS and AMSU Spectral Differences

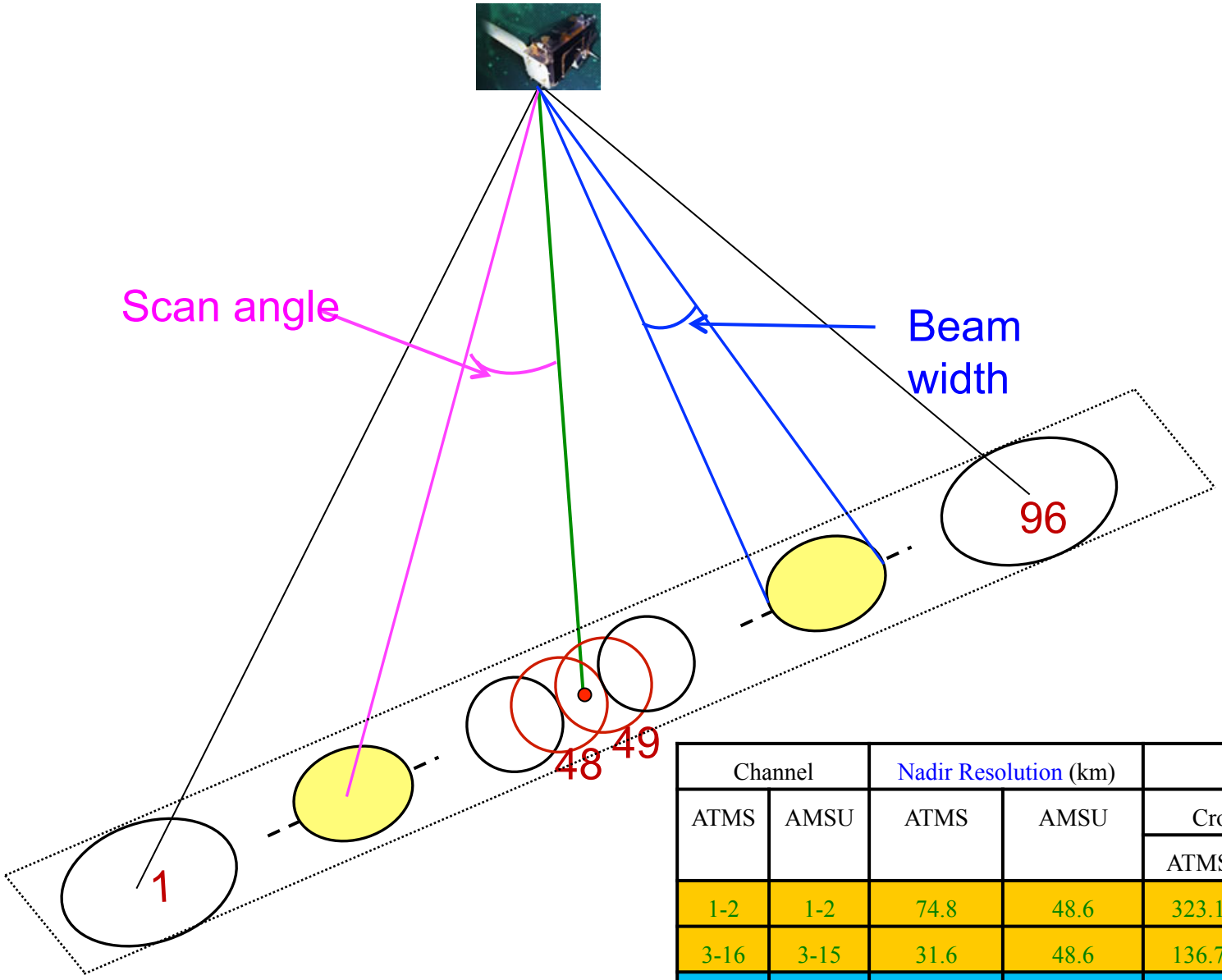
ATMS has 22 channels and AMSU/MHS have 20, with polarization differences between some channels

- QV = Quasi-vertical *polarization vector is parallel to the scan plane at nadir*
- QH = Quasi-horizontal *polarization vector is perpendicular to the scan plane at nadir*



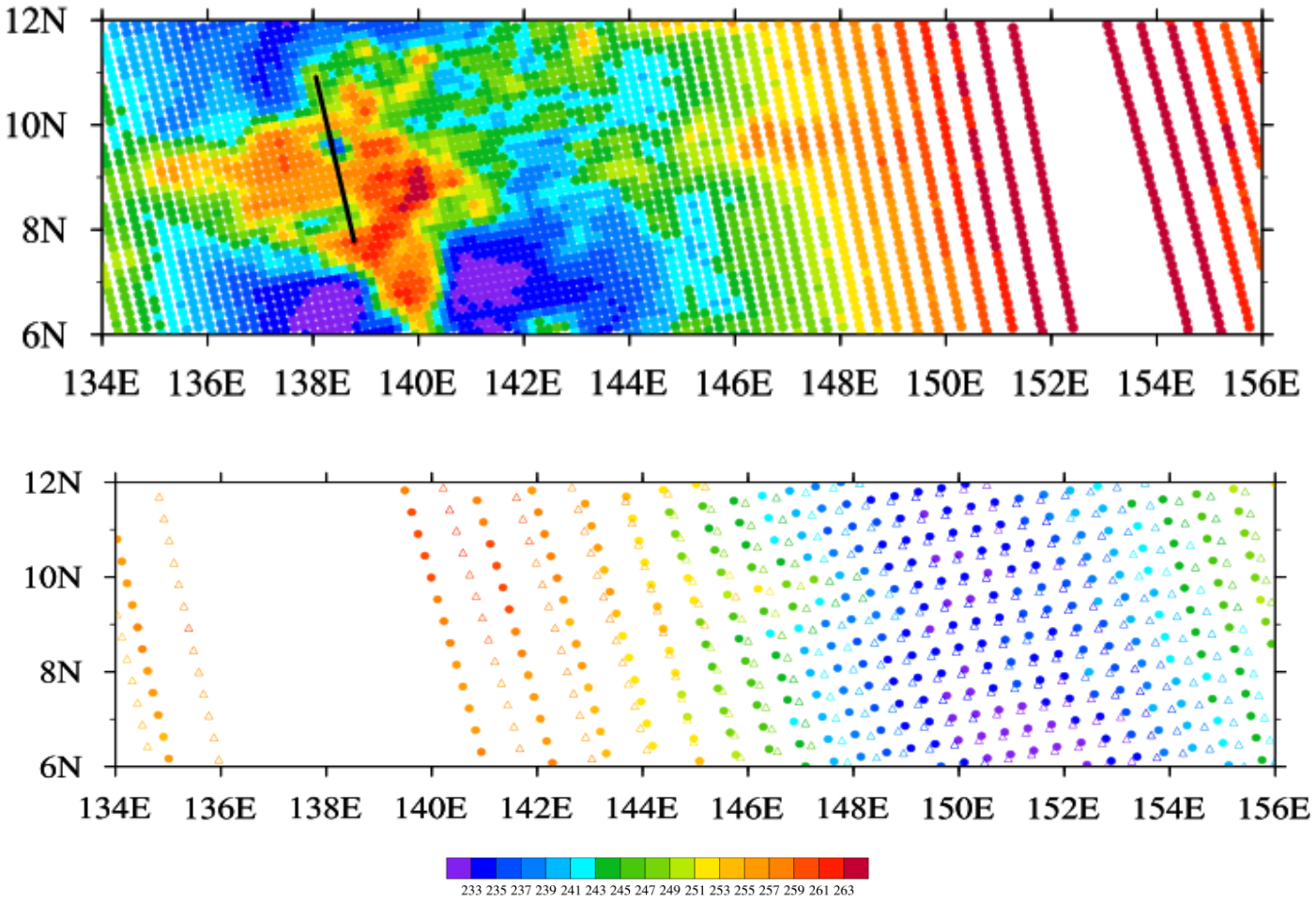
	AMSU/MHS			ATMS		
	Ch	GHz	Pol	Ch	GHz	Pol
AMSU-A	1	23.8	QV	1	23.8	QV
	2	31.399	QV	2	31.4	QV
	3	50.299	QV	3	50.3	QH
				4	51.76	QH
	4	52.8	QV	5	52.8	QH
	5	53.595 ± 0.115	QH	6	53.596 ± 0.115	QH
	6	54.4	QH	7	54.4	QH
	7	54.94	QV	8	54.94	QH
	8	55.5	QH	9	55.5	QH
	9	fo = 57.29	QH	10	fo = 57.29	QH
	10	fo ± 0.217	QH	11	fo±0.3222±0.217	QH
	11	fo±0.3222±0.048	QH	12	fo± 0.3222±0.048	QH
	12	fo ±0.3222±0.022	QH	13	fo±0.3222±0.022	QH
	13	fo± 0.3222±0.010	QH	14	fo±0.3222 ±0.010	QH
	14	fo±0.3222±0.0045	QH	15	fo± 0.3222±0.0045	QH
	15	89.0	QV			
MHS	16	89.0	QV	16	88.2	QV
	17	157.0	QV	17	165.5	QH
	18	183.31 ± 1	QH	18	183.31 ± 7	QH
	19	183.31 ± 3	QH	19	183.31 ± 4.5	QH
	20	191.31	QV	20	183.31 ± 3	QH
				21	183.31 ± 1.8	QH
				22	183.31 ± 1	QH

ATMS Scan Angle and Beam Width



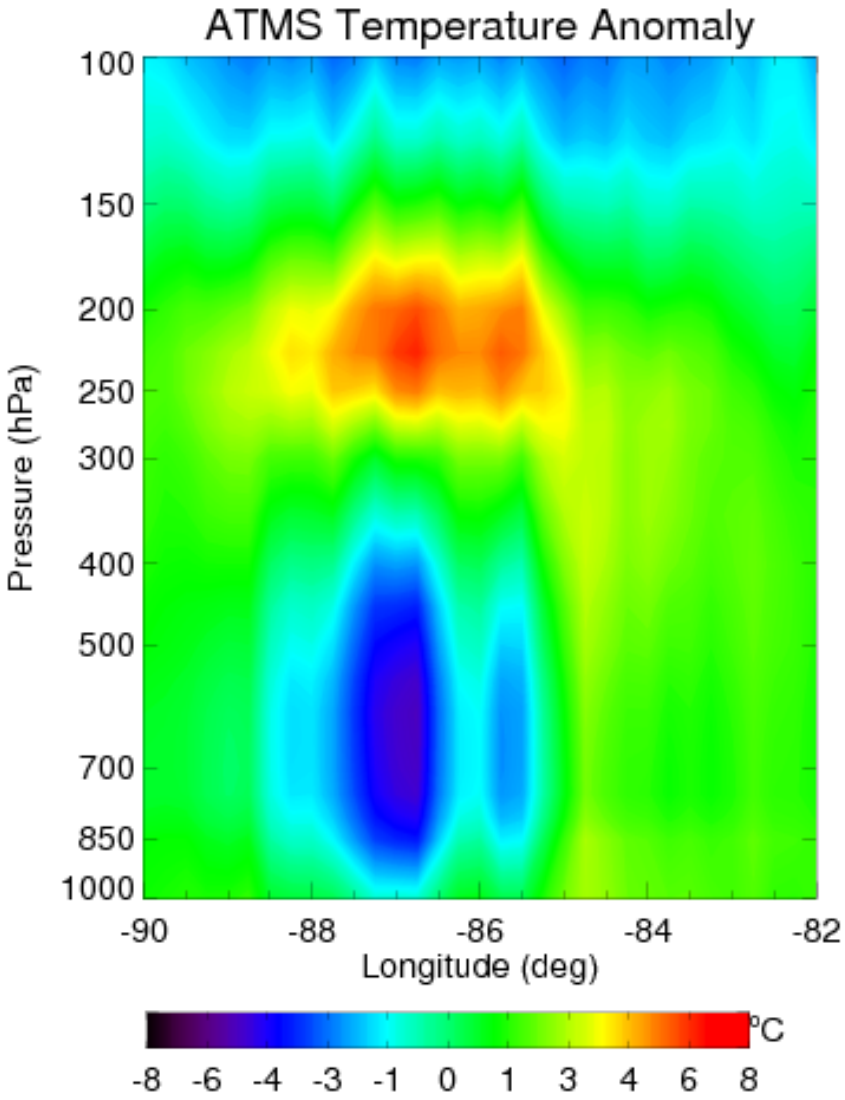
Channel		Nadir Resolution (km)		Outmost FOV size (km)			
ATMS	AMSU	ATMS	AMSU	Cross-track		Along-track	
				ATMS	AMSU	ATMS	AMSU
1-2	1-2	74.8	48.6	323.1	155.2	141.8	85.6
3-16	3-15	31.6	48.6	136.7	155.2	60.0	85.6
17-22	16-20	15.8	16.2	68.4	58.9	30.0	6666

Comparison of Spatial Temperature Structure between ATMS and AMSU-A (CH2)

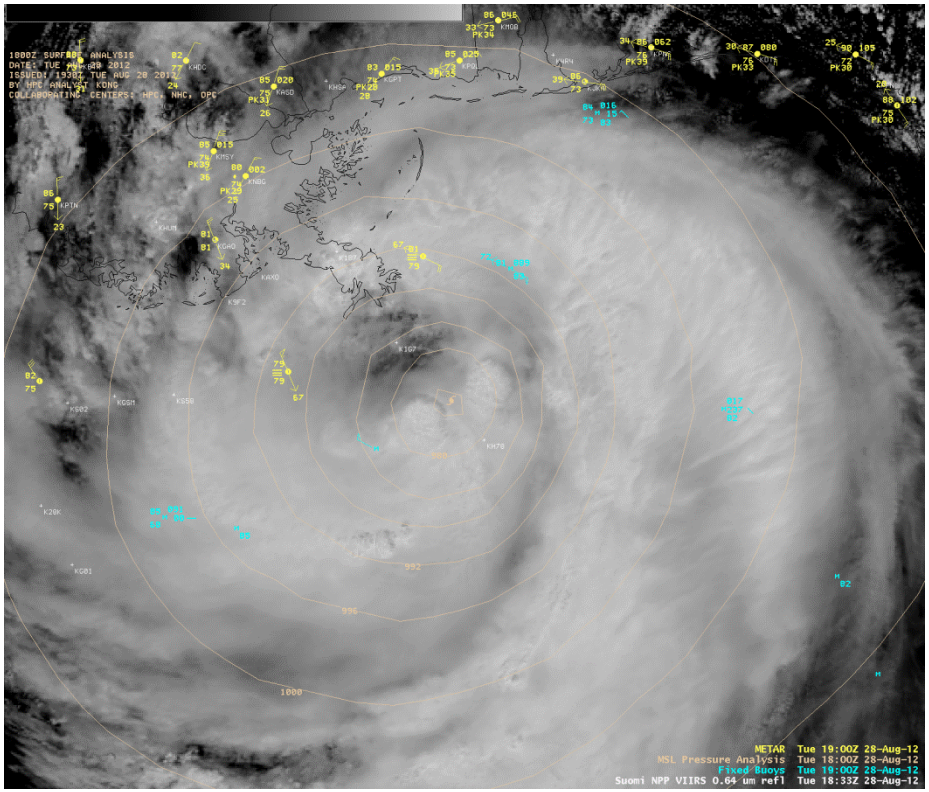


NPP ATMS and VIIRS Imager and Products

Warm Core Cross section along 26.0 N



VIIRS 0.64 μm visible and 11.45 μm IR images at 18:33 UTC, 28 Aug 2012

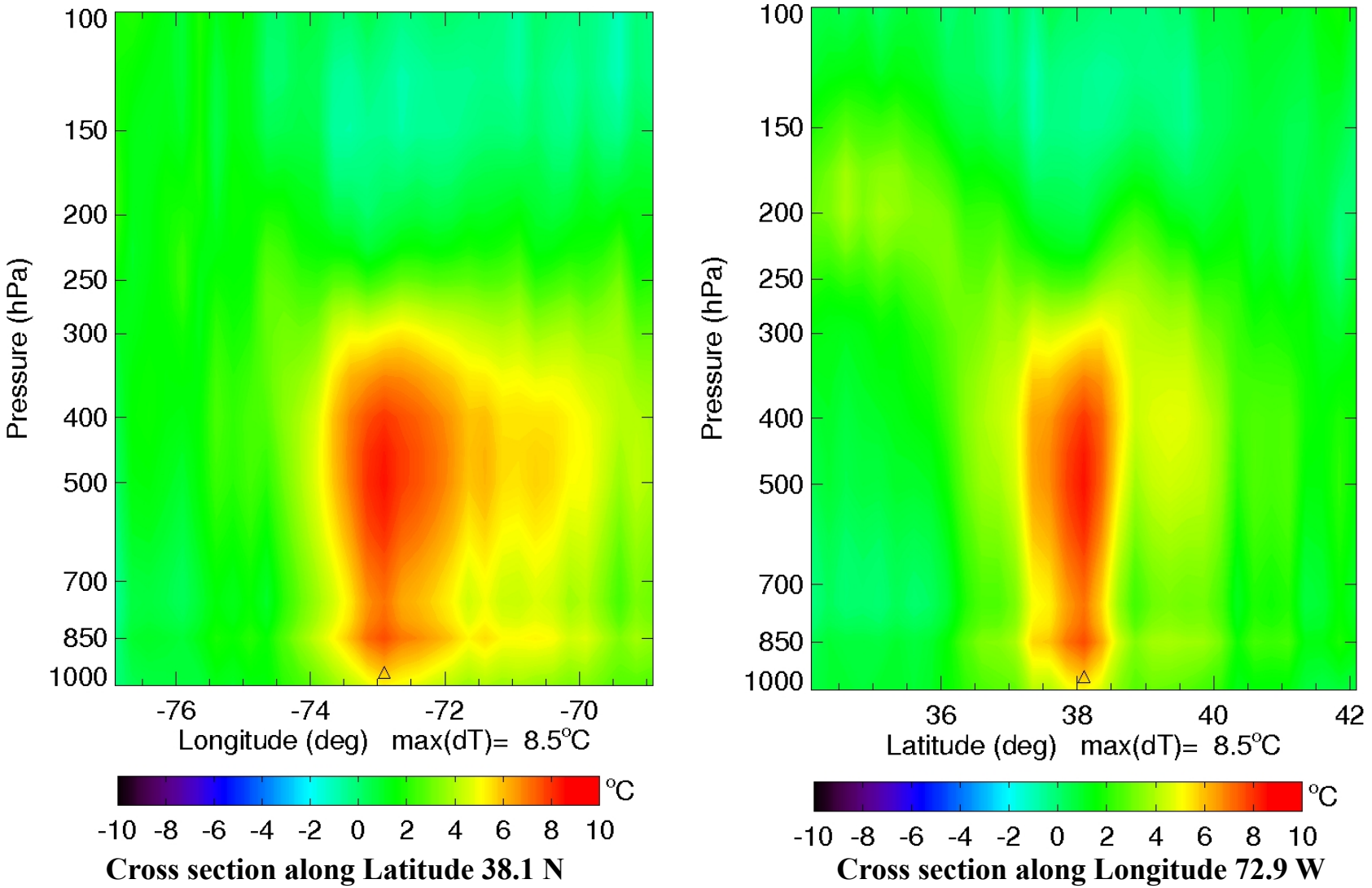


METAR, MSL Pressure, and Buoys information included

Zhu and Weng, 2013, GRL

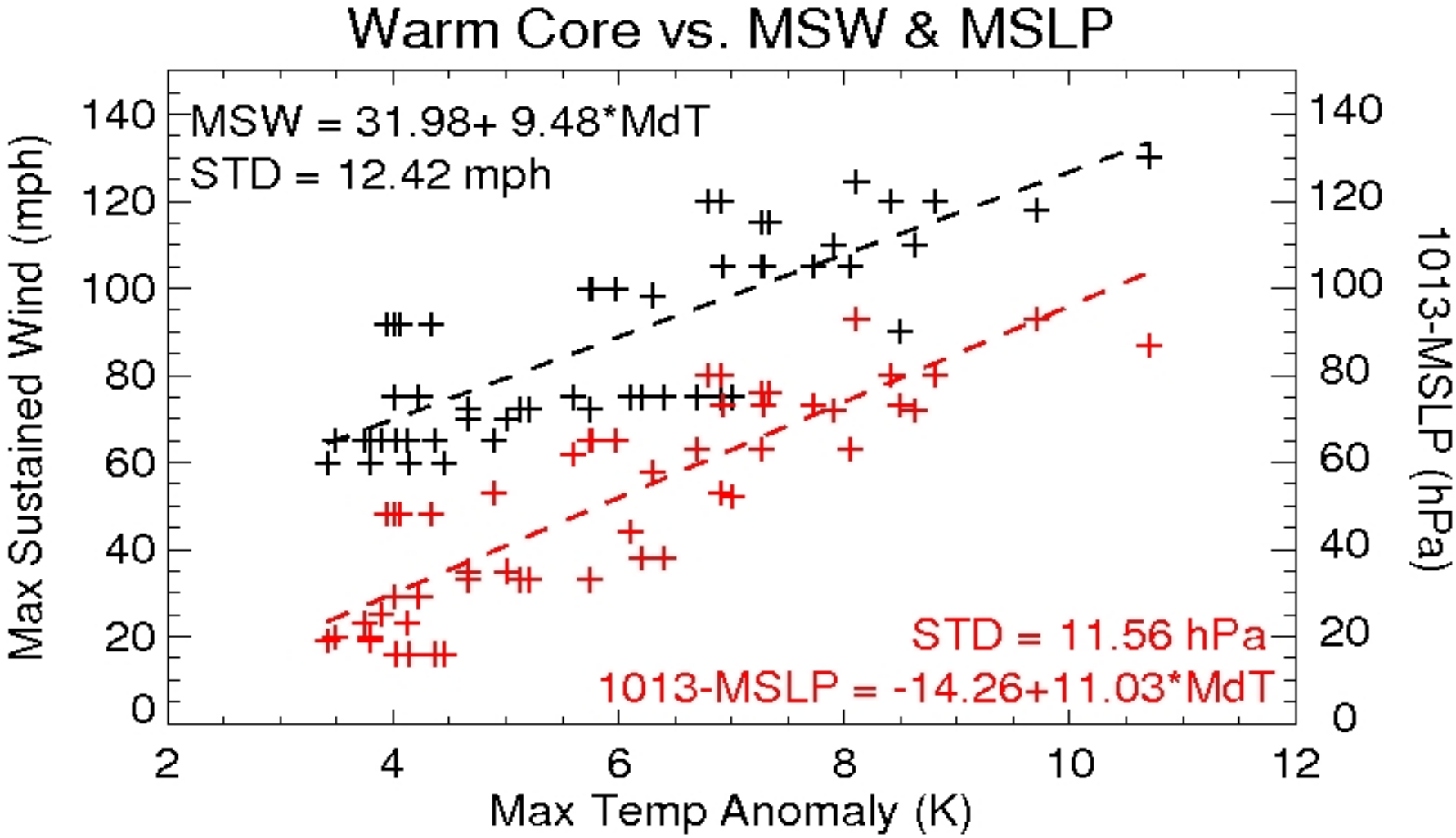
Hurricane Sandy Warm Core Anomaly
Ascending 1730 UTC, 29 October 2012

At 1800 UTC Oct 29 Max Wind: 90 MPH, Min Pressure: 940 hPa



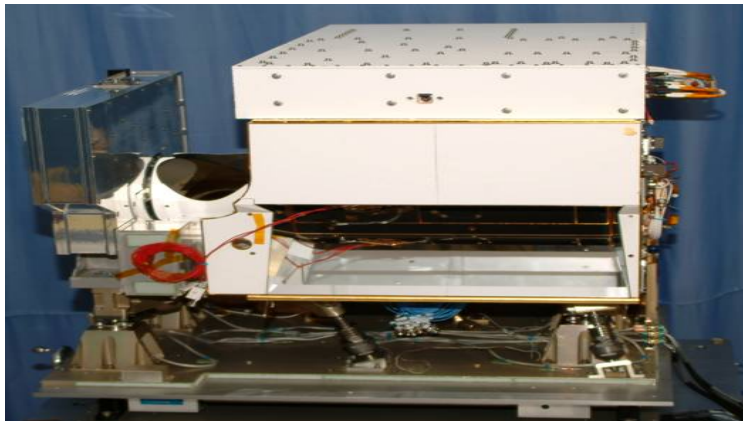
Zhu and Weng, 2013, GRL

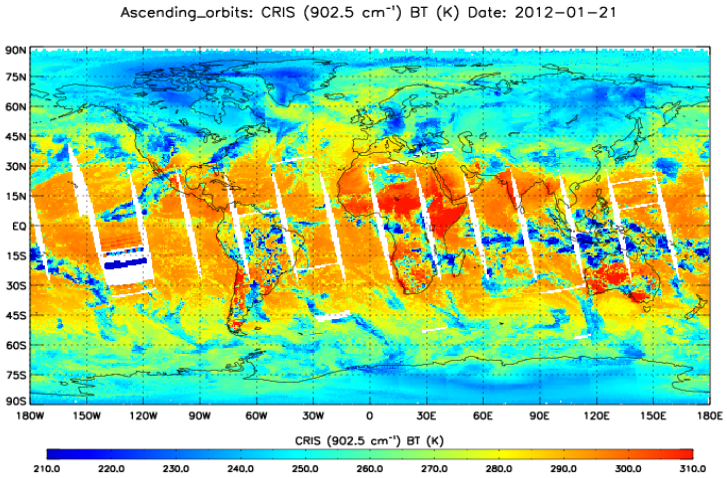
Sandy Max Wind, Warm Core and MSLP



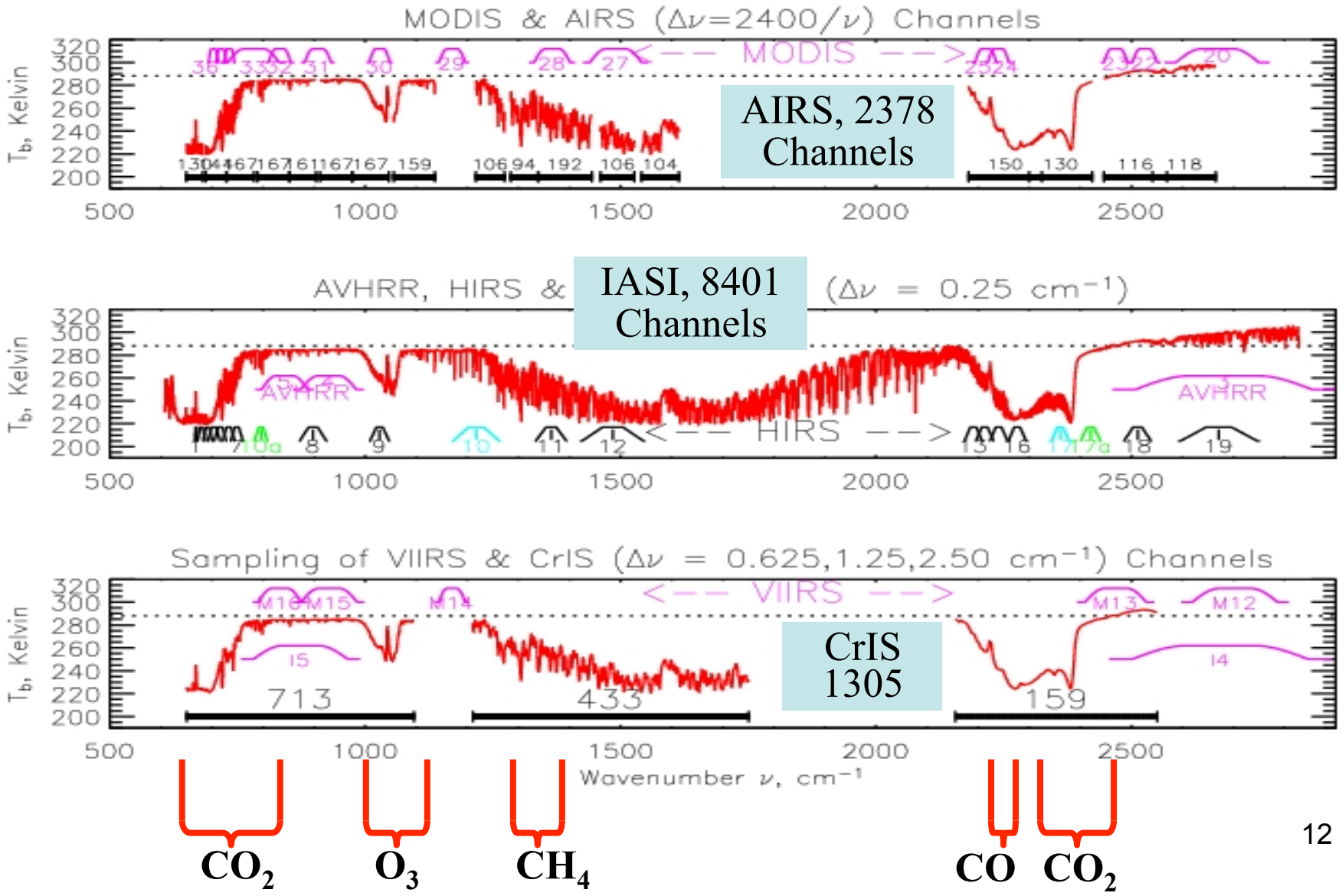
Cross-Track Infrared Sounder (CrIS) SDR Status

- CRIS SDR provisional product review was held on October 23-24, 2012 and the panel recommended its provisional Maturity level which is now being approval by AERB
- SDR provisional product:
  - NEdNs are well below specifications
  - Spectral uncertainty: < 2 ppm, well below specification
  - Radiometric uncertainty: ~0.1K, well below specification
  - Geolocation error: < 1.0 km below specification





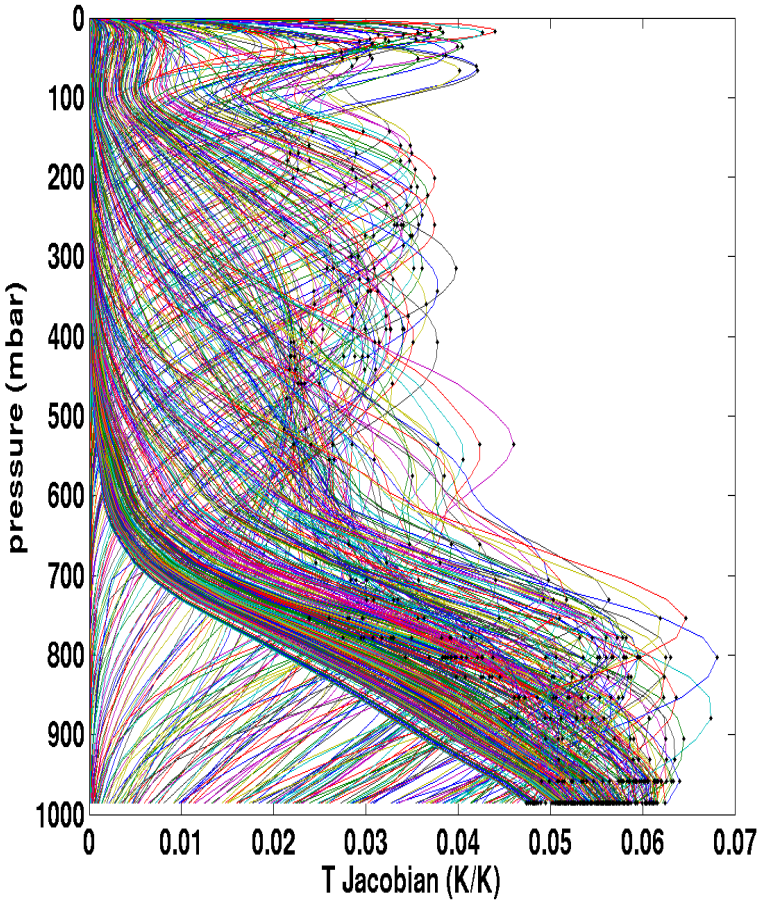
Spectral Coverage of AIRS, IASI, & CrIS



Example of T(p) & q(p) Channel Kernel Functions

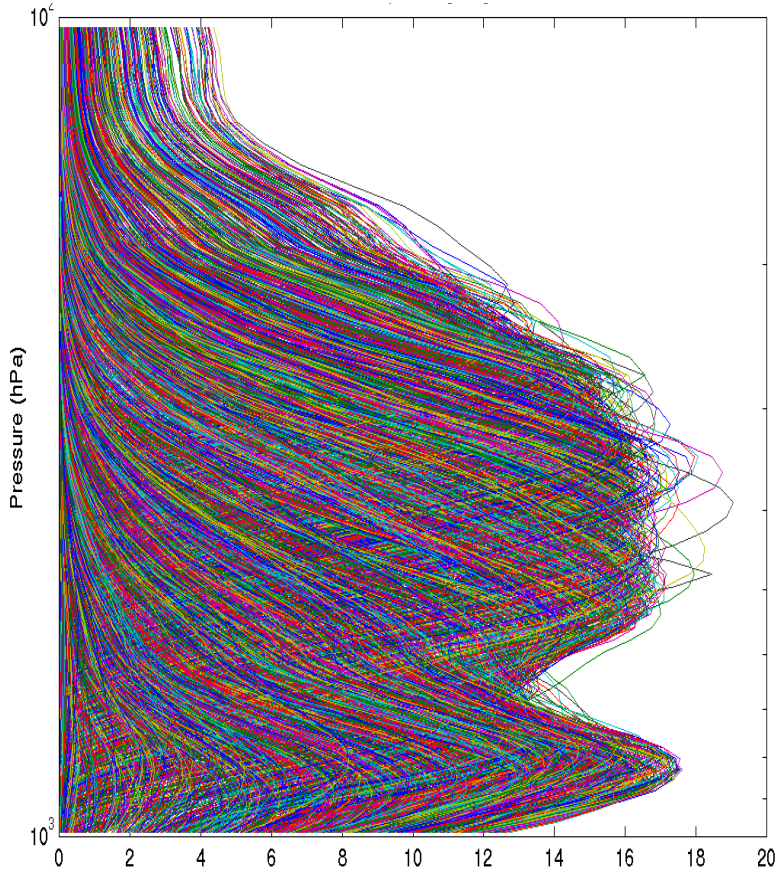
AIRS 15 μm (650-800 cm-1) band

K = dTb/dT



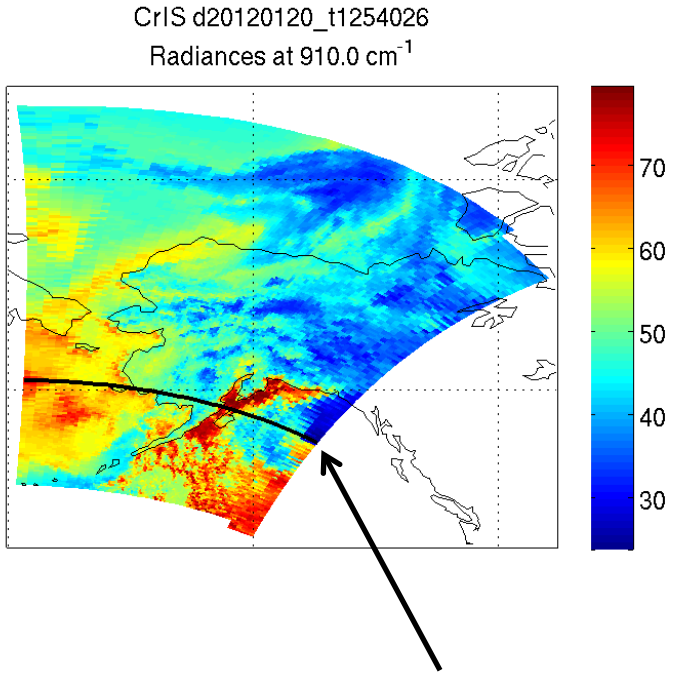
AIRS 6.7 μm (1200-1600 cm^{-1}) band

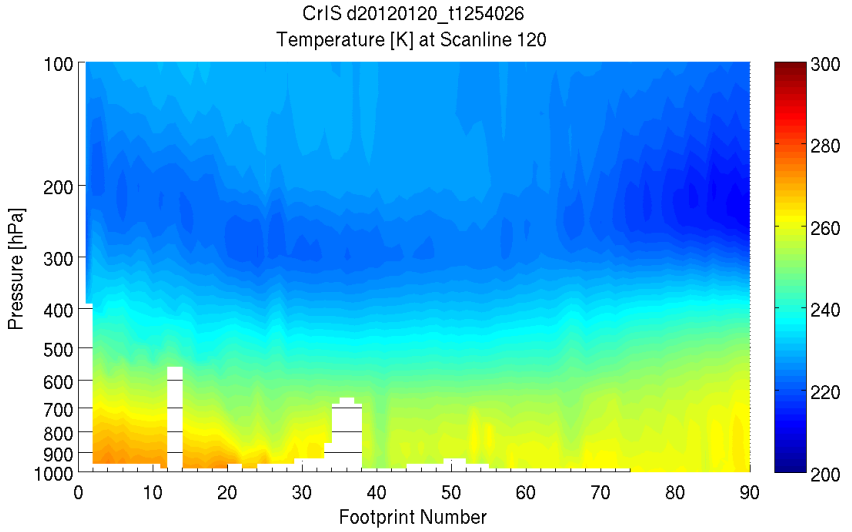
K = dTb/dq

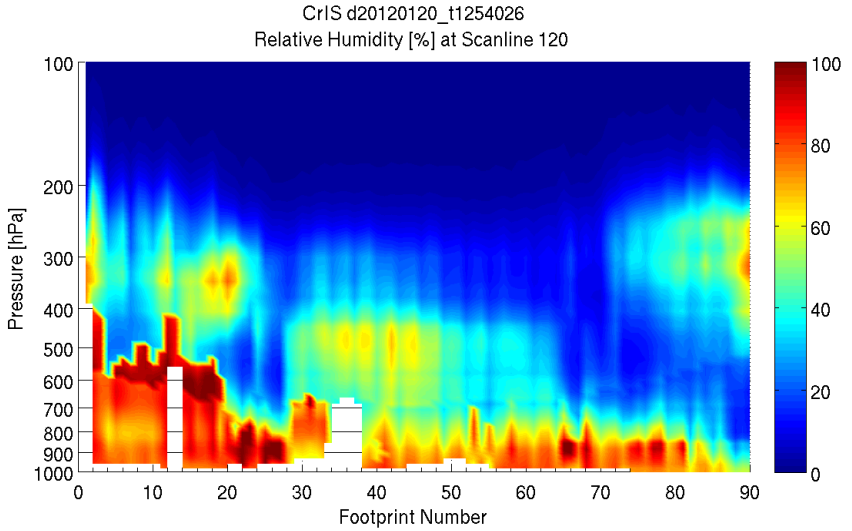


CrIS RTV for 20 Jan 2012, t1254026

Temperature and Relative Humidity Cross-sections







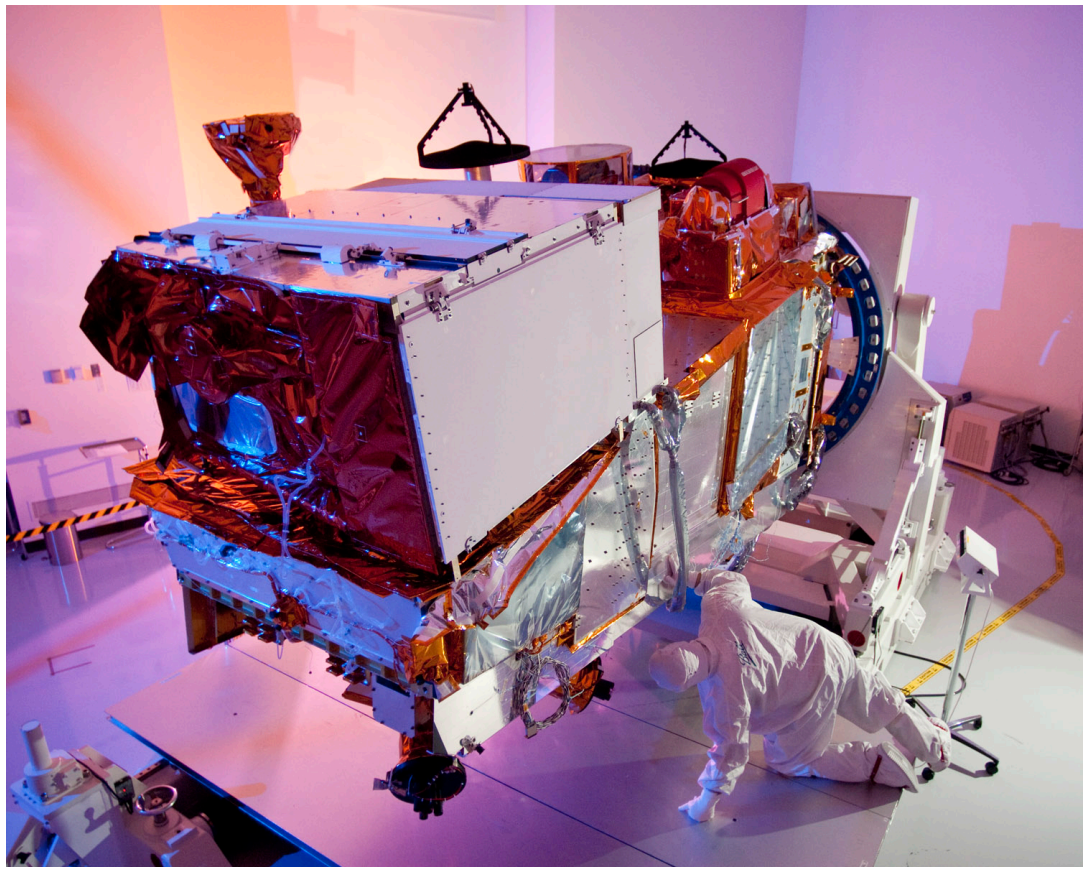
Visible Infrared Imaging Radiometer Suite
Raytheon SAS El Segundo

Description

- **Purpose:** Global observations of land, ocean, & atmosphere parameters at high temporal resolution (~ daily)
- **Predecessor Instruments:** AVHRR, OLS, MODIS, SeaWiFS
- **Approach:** Multi-spectral scanning radiometer (22 bands between 0.4 µm and 12 µm) 12-bit quantization
- **Swath width:** 3000 km

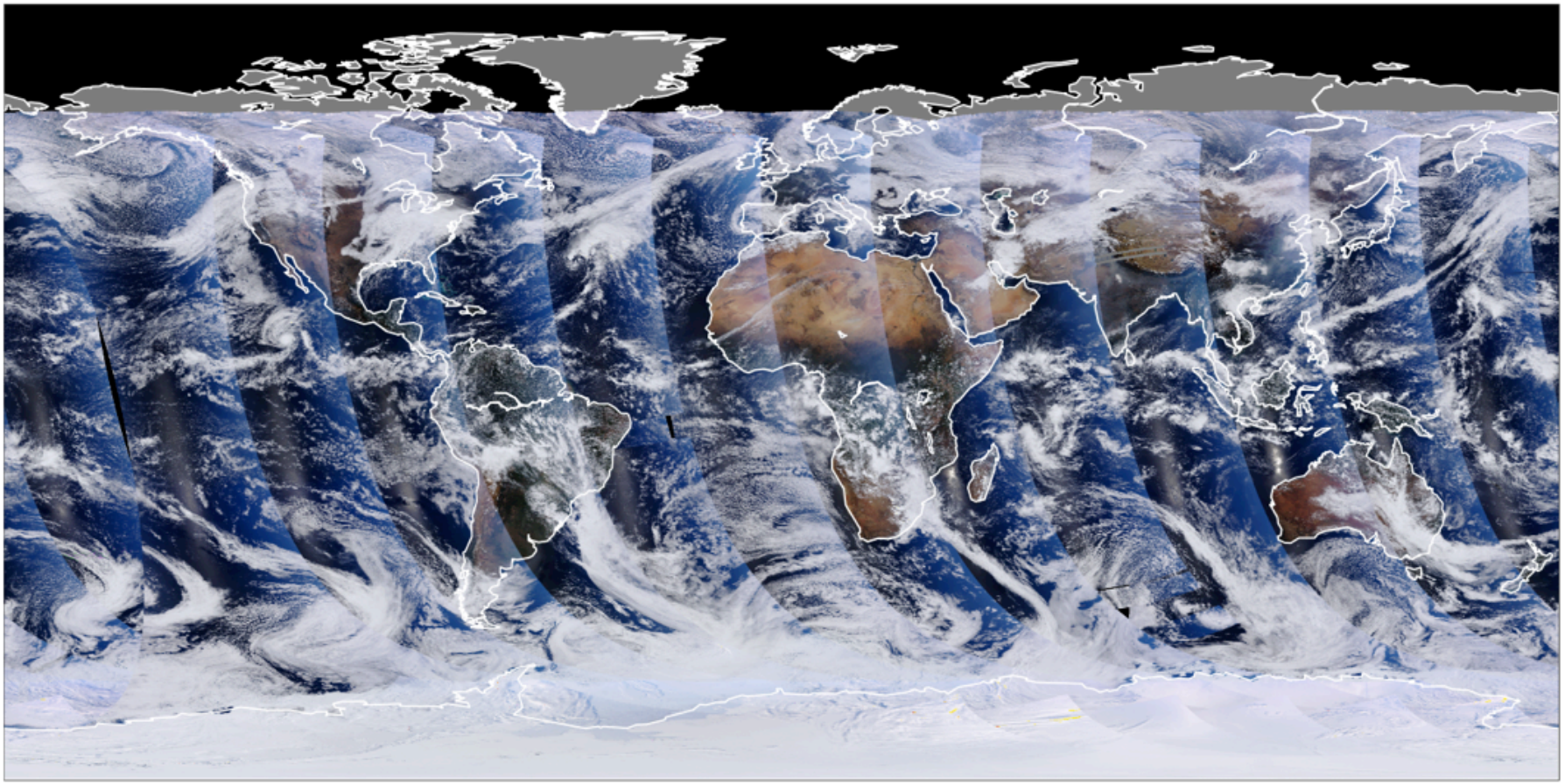
Spatial Resolution

- 16 bands at 750m
- 5 bands at 370m
- DNB



VIIRS on NPP

First Global VIIRS Image

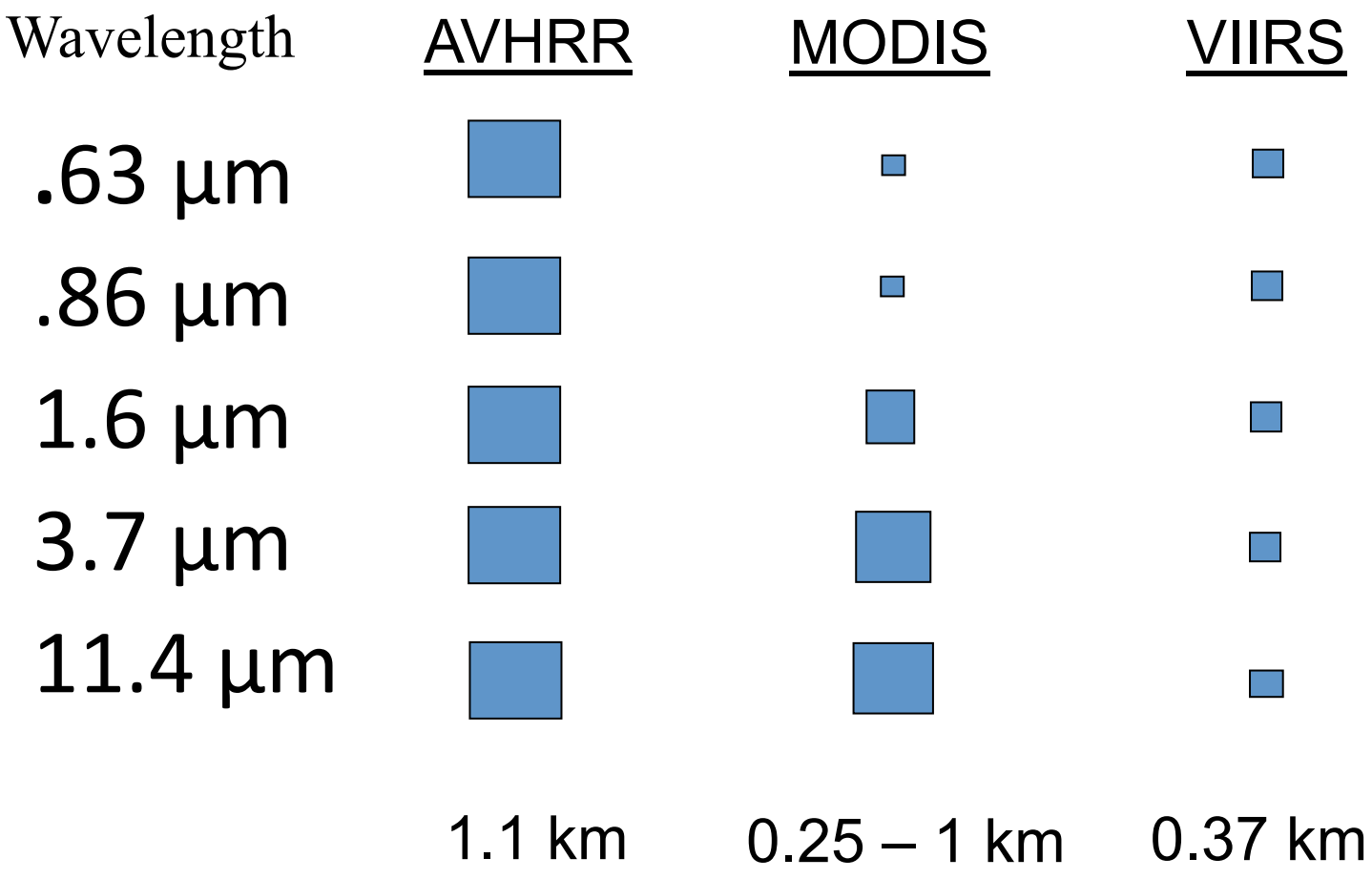


VIIRS RGB (True Color), 20111122

R : M05 (0.672 μm); G : M04 (0.555 μm); B : M02 (0.445 μm)

Creation date: 2011-11-26 07:19:26 Z

Comparison of "Imagery" Bands at Nadir

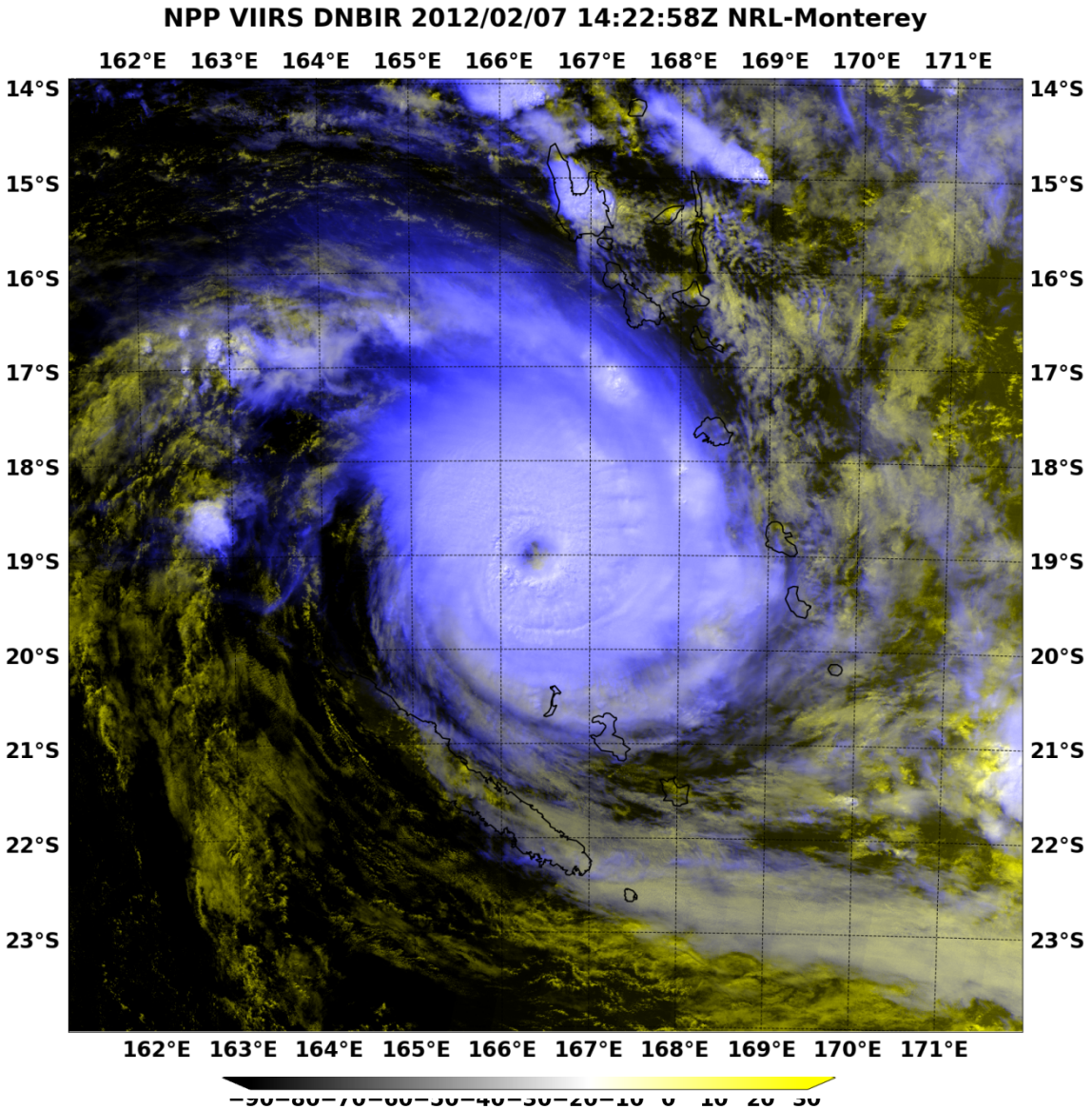


VIIRS Day Night Band Views TC

Tropical
Cyclone
10P Jasmine

02-07-12 1422Z
0122 (Local)

Infrared
Day Night
IR-DNB
Band
Multi-spectral

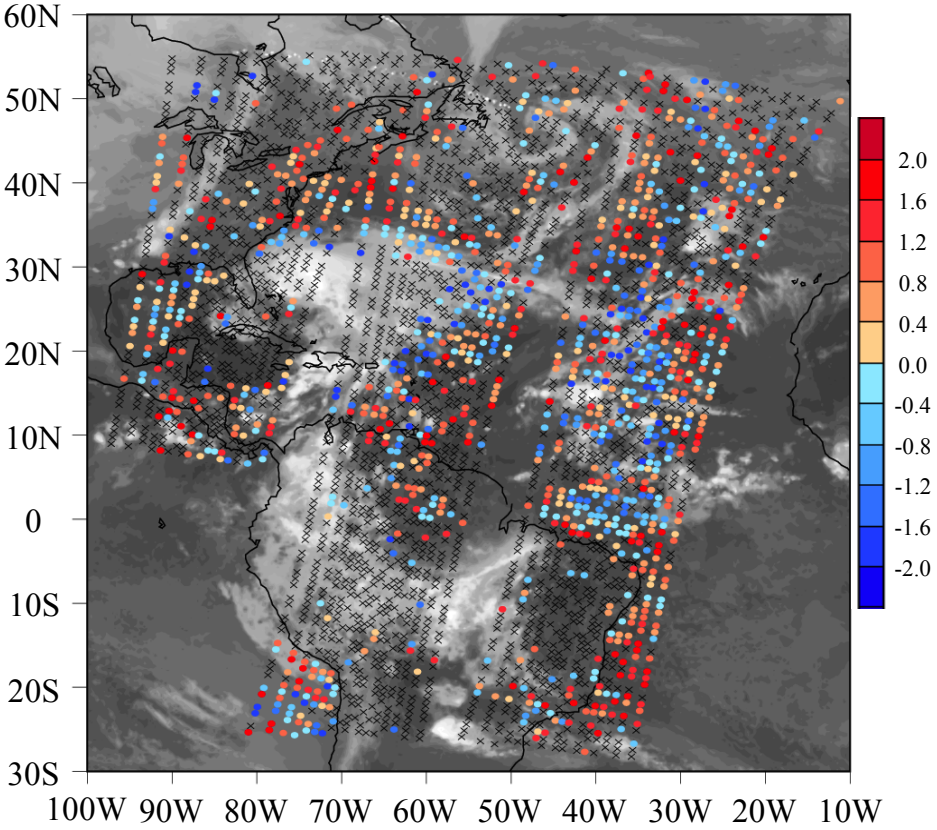


Improvements to HWRF Data Assimilation

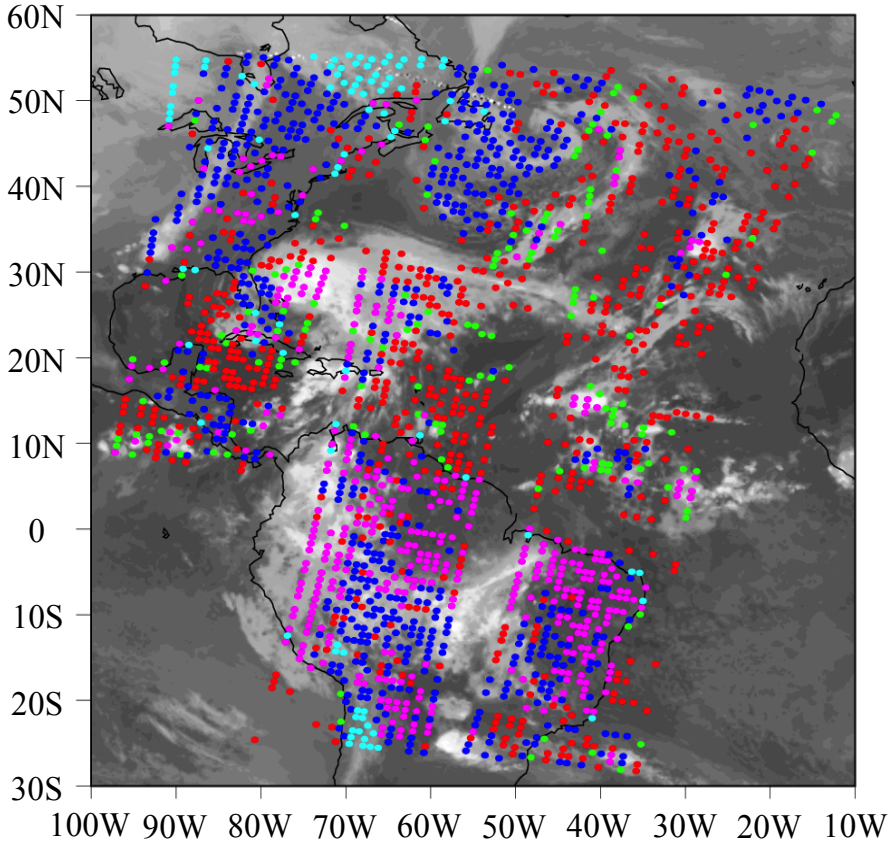
- Work out an optimal configuration of HWRF modeling domains and its data assimilation system
- Examine the quality control procedures for all ingested data and implement the additional criteria for removing all clouds-affected radiances from microwave humidity sounder
- Improve the radiative transfer modeling processes for effectively assimilating cloud-affected radiances in HWRF and characterize the error covariances within each of HWRF domains
- Refine the bias correction algorithms at various domains and according to cloud and precipitation type.

Quality Control of ATMS Data

ATMS ch 19 passing QC



ATMS ch 19 data rejected by various QC indices



Zou, X., F. Weng, B. Zhang, L Lin, V. Talapragada,, 2013, JGR (revised)

HWRF Model and Data Assimilation System

HWRF Model:

- 2012 NCEP-Trunk version 934
- Three telescoping domains:

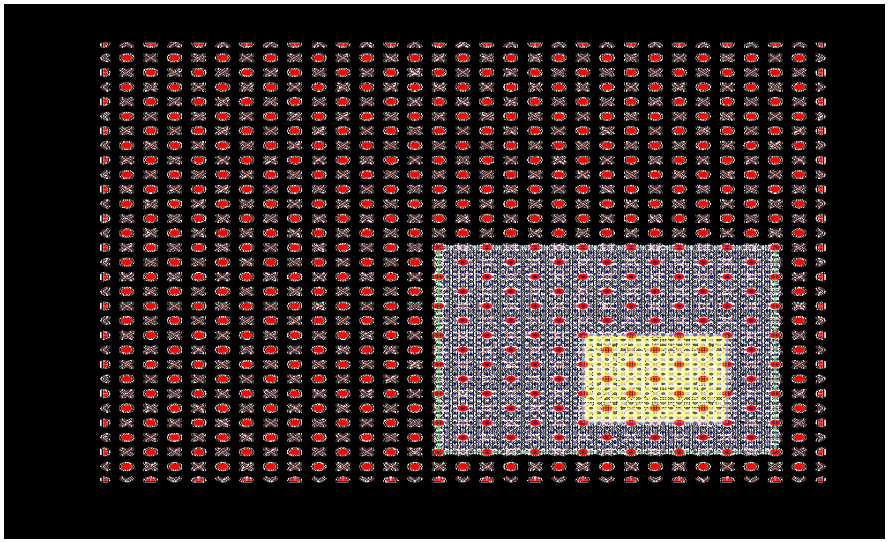
Outer domain: 27km: 75x75^o;
Inner domain: 9km ~11x10^o
Inner-most domain: 3km inner-most nest ~6x6^o

Revised Model Level and Top:

- Vertical levels: 61
- Model top: 0.5 hPa

Data Assimilation System:

- HWRF 6 hour forecasts
- GSI (3DVAR)



•The Hurricane Weather Research and Forecasting (HWRF) Model dynamical core is designed based on the WRF model using NCEP Non-Hydrostatic Mesoscale Model (NMM) core with a movable high-resolution nested grid (telescopic)

•Regional-Scale, Moving Nest, Ocean-Atmosphere Coupled Modeling System. Horizontal resolution: 27 km outer grid, 9 km inner grid, 42 vertical levels

•Non-Hydrostaticsystem of equations formulated on a rotated latitude-longitude, Arakawa E-grid and a vertical, pressure hybrid (sigma_p-P) coordinate.

•Advanced HWRF 3D Variational analysis that includes vortex relocation, correction to winds, MSLP, temperature and moisture in the hurricane region and adjustment to actual storm intensity.

•Uses SAS convection scheme, GFS/GFDL surface, boundary layer physics, GFDL/GFS radiation and Ferrier Microphysical Scheme.

•Ocean coupled modeling system (POM/HYCOM).

Control Experiment – L61

Conventional Data:

Radiosondes, aircraft reports (AIREP/PIREP, RECCO, MDCRS-ACARS, TAMDAR, AMDAR), Surface ship and buoy observations , Surface observations over land, Pibal winds,Wind profilers, VAD wind, Dropsondes

Satellite Instrument Data:

- AMSU-A (channel 5-14) from NOAA-18, NOAA-19 and METOP-A
- HIRS from NOAA-19 and METOP-A
- AIRS from EOS Aqua
- ASCAT from METOP-A
- GPSRO from GRAS/COSMIC

Hurricane Sandy Forecasts

Control : L61 (conventional data only)

Sensitivity Experiments

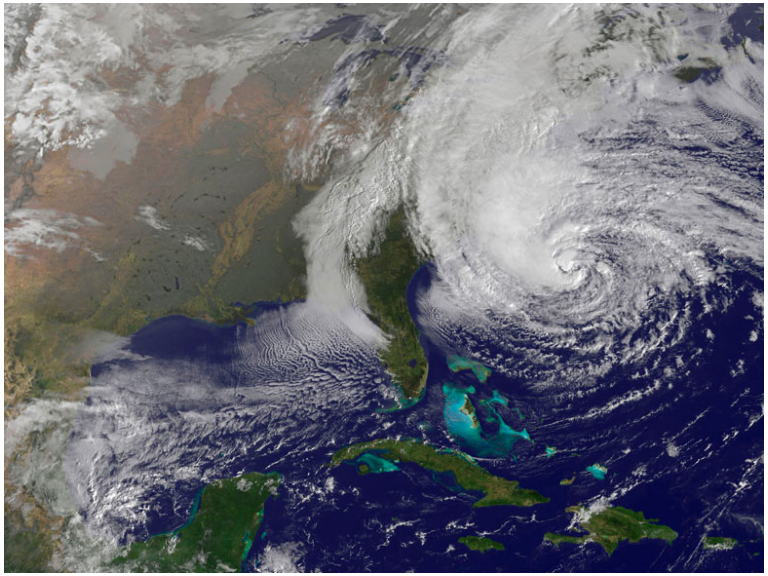
ATMS: L61+ATMS

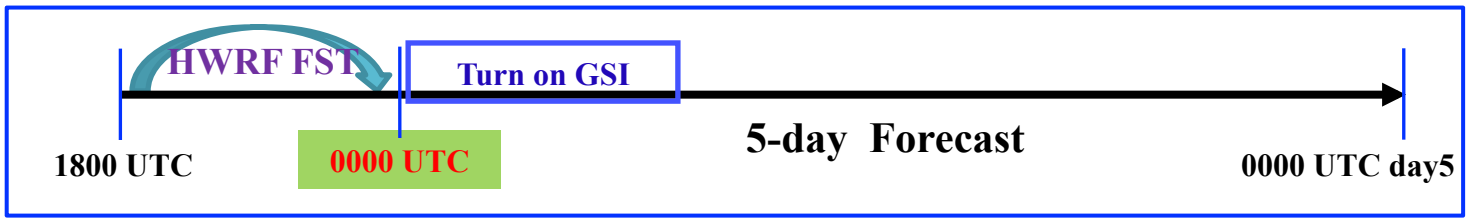
IASI: L61+IASI

CrIS: L61+CrIS

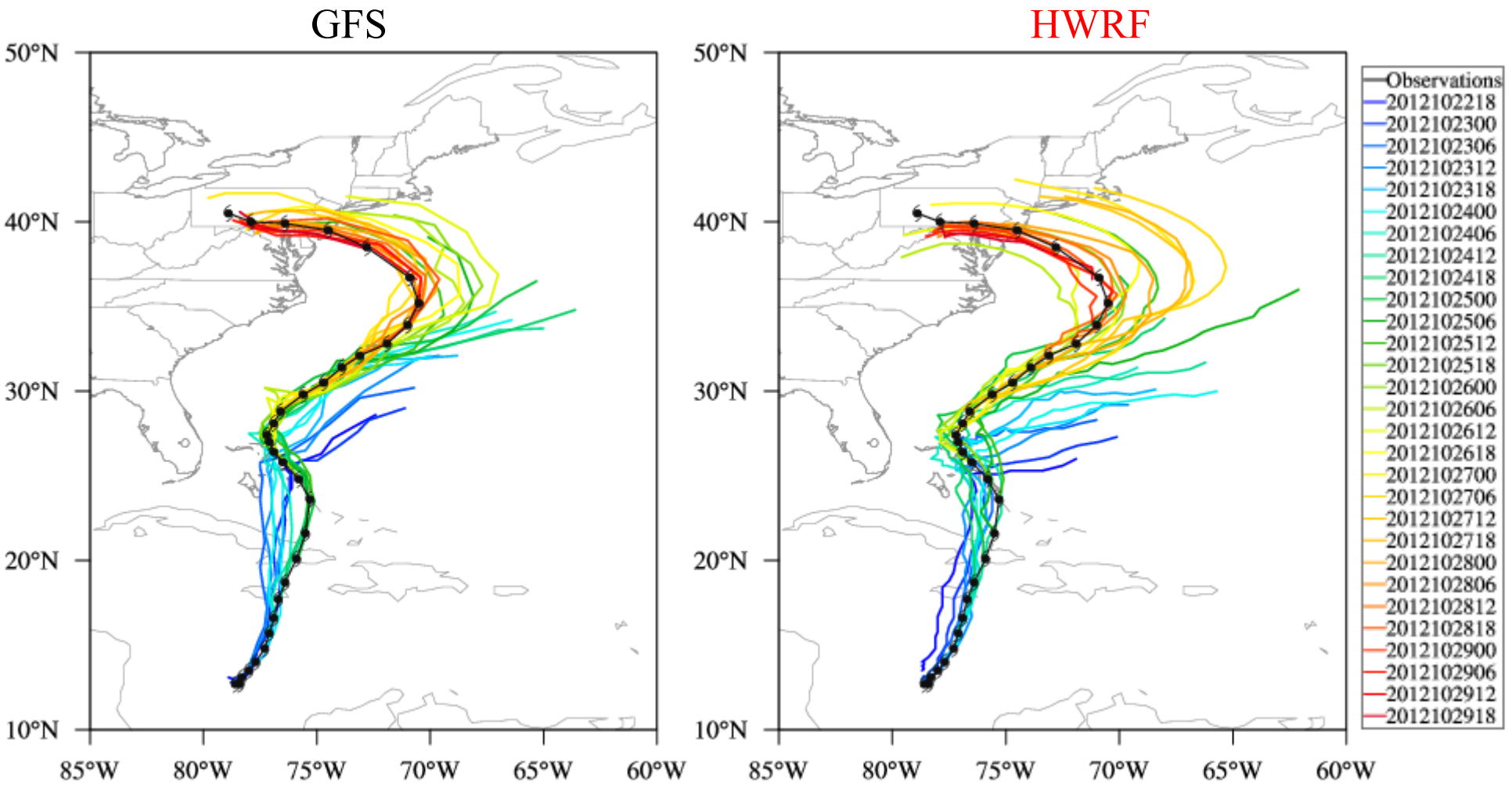
Forecast Period: 1800 UTC Oct 22, 2012 - 1800 UTC Oct 29, 2012

Total Cycles: 29

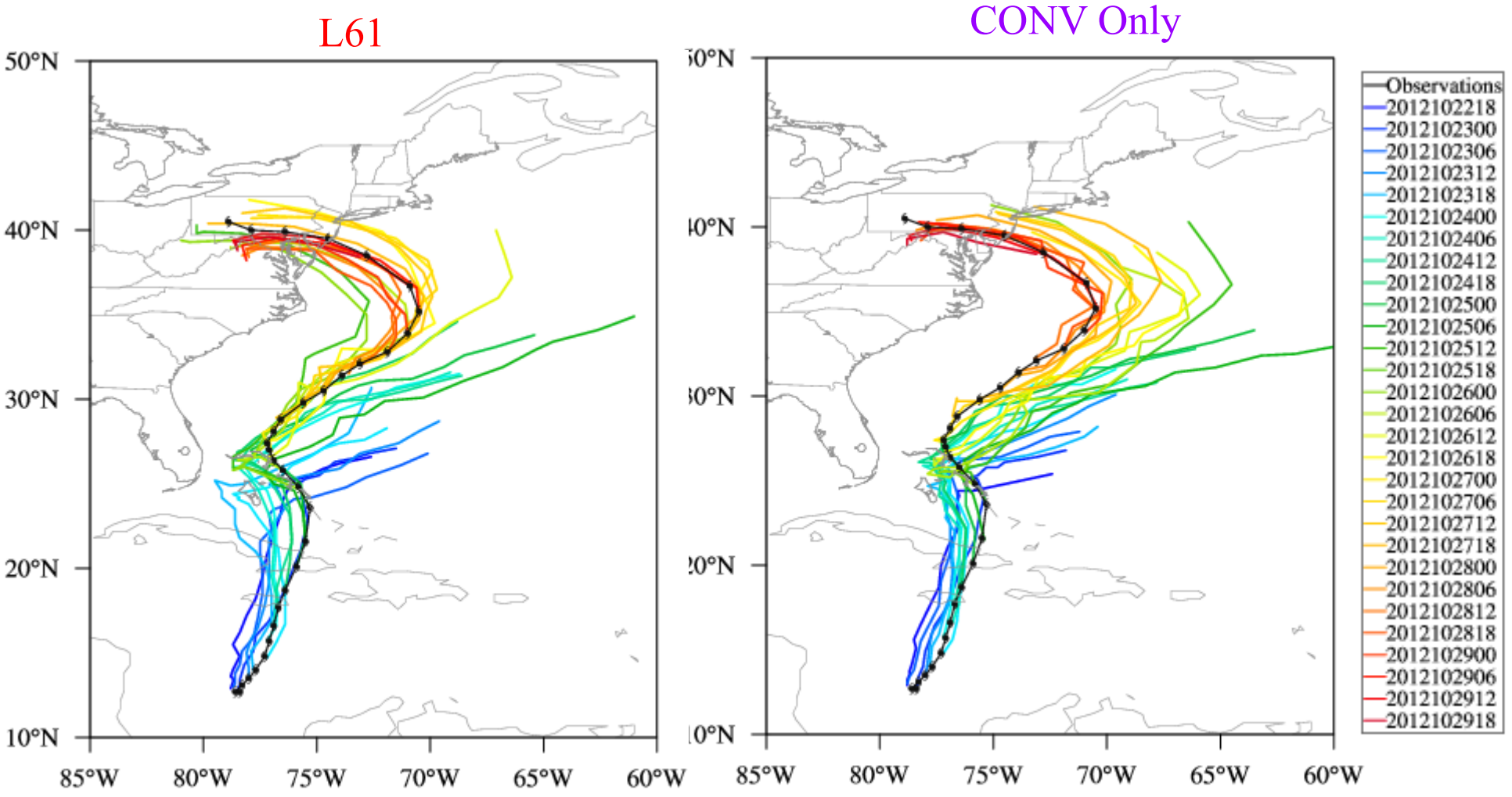




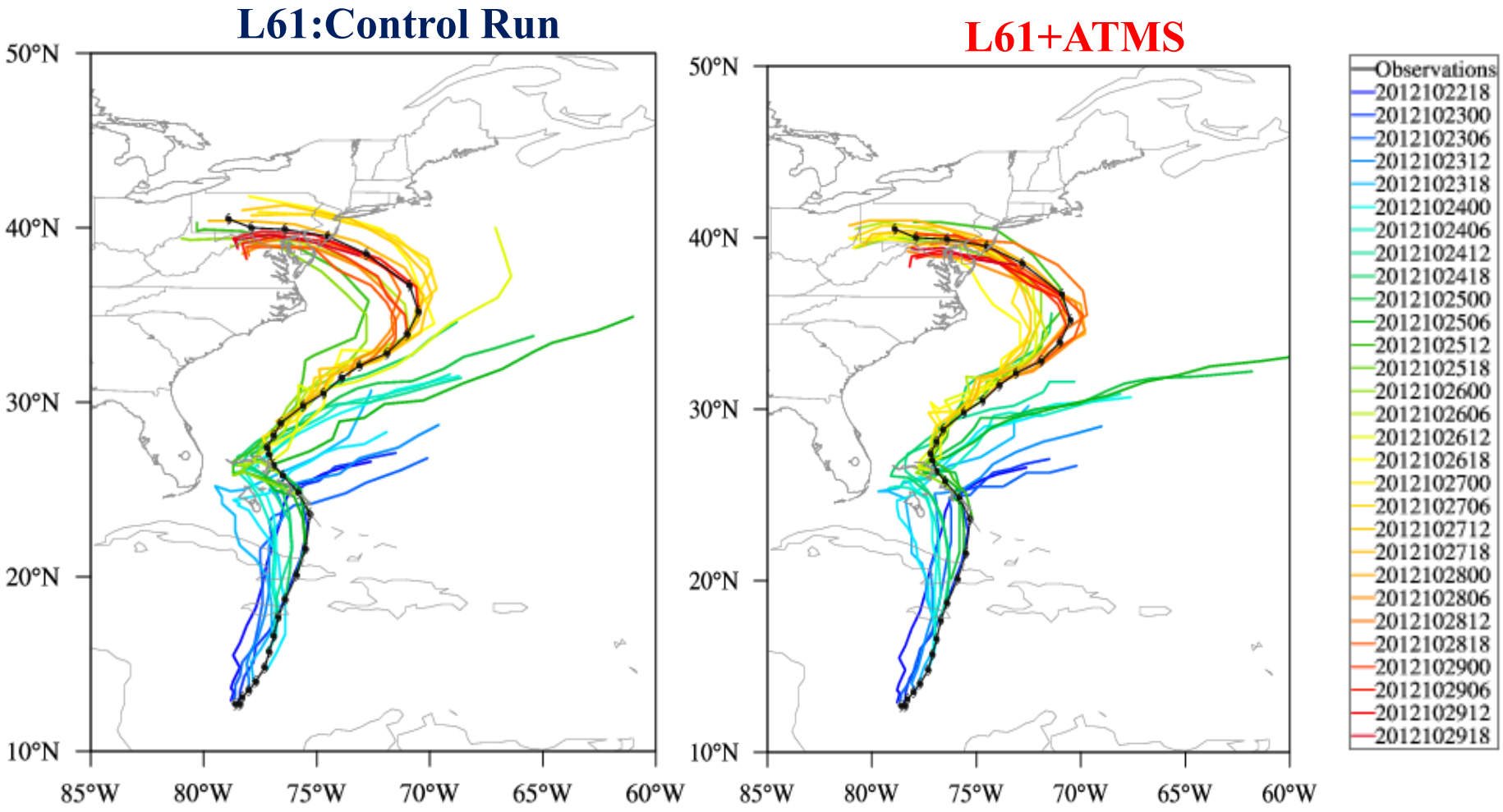
Hurricane Sandy Tracks from NCEP GFS and HWRF Operational Forecasts



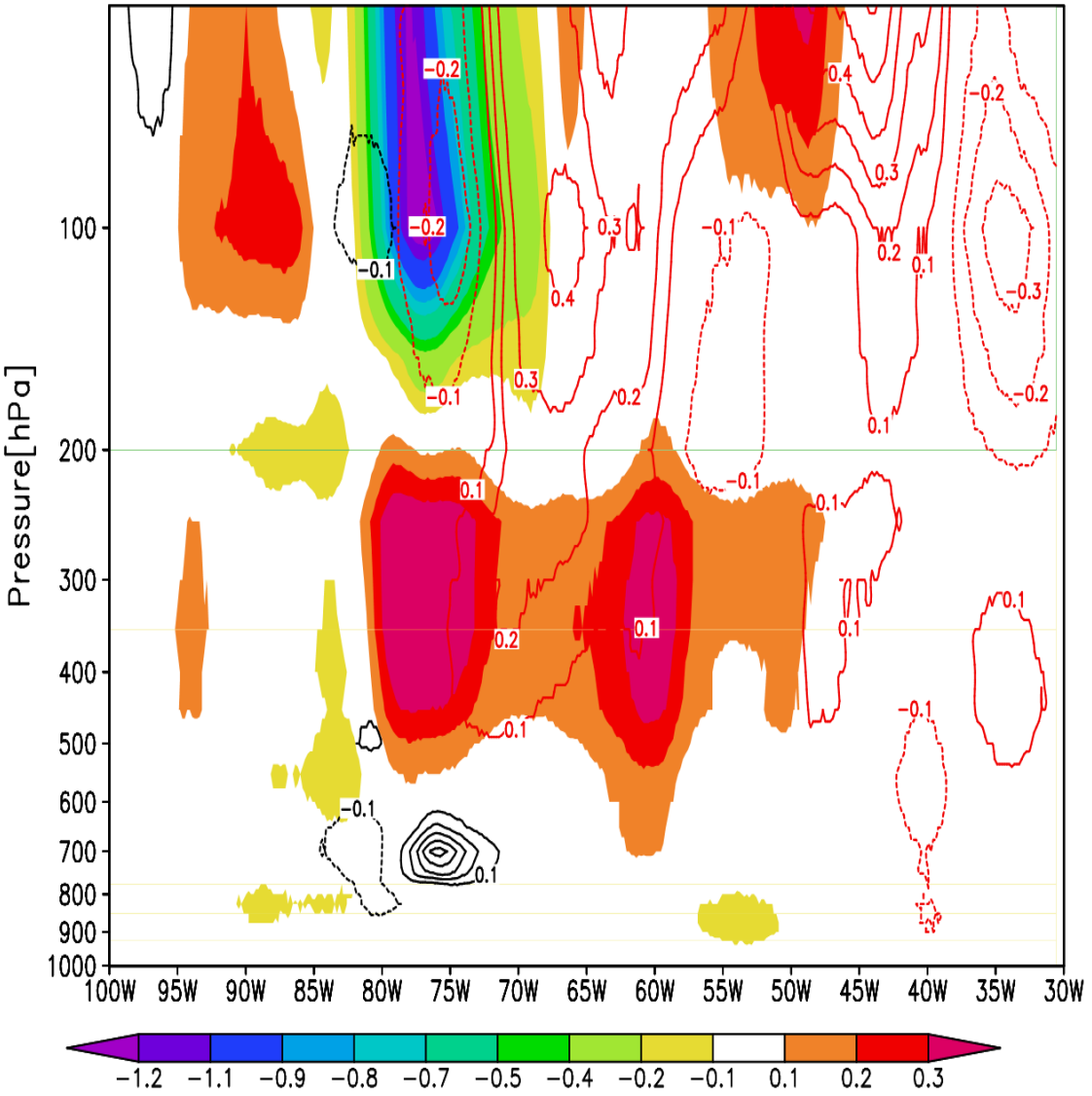
Impacts of Assimilation of NOAA/METOP data on Hurricane Sandy's Track



Impacts of Direct Assimilation of Suomi NPP ATMS Radiances on Hurricane Sandy's Track



Comparison of Temperature Increments from ATMS and AMSU-A



Shaded: ATMS
Red contour: AMSU-A
Black contour: Conventional

ATMS and AMSU-A (NOAA-19) produce largest temperature innovation in storm regions in similar magnitudes and complementary in spatial coverage

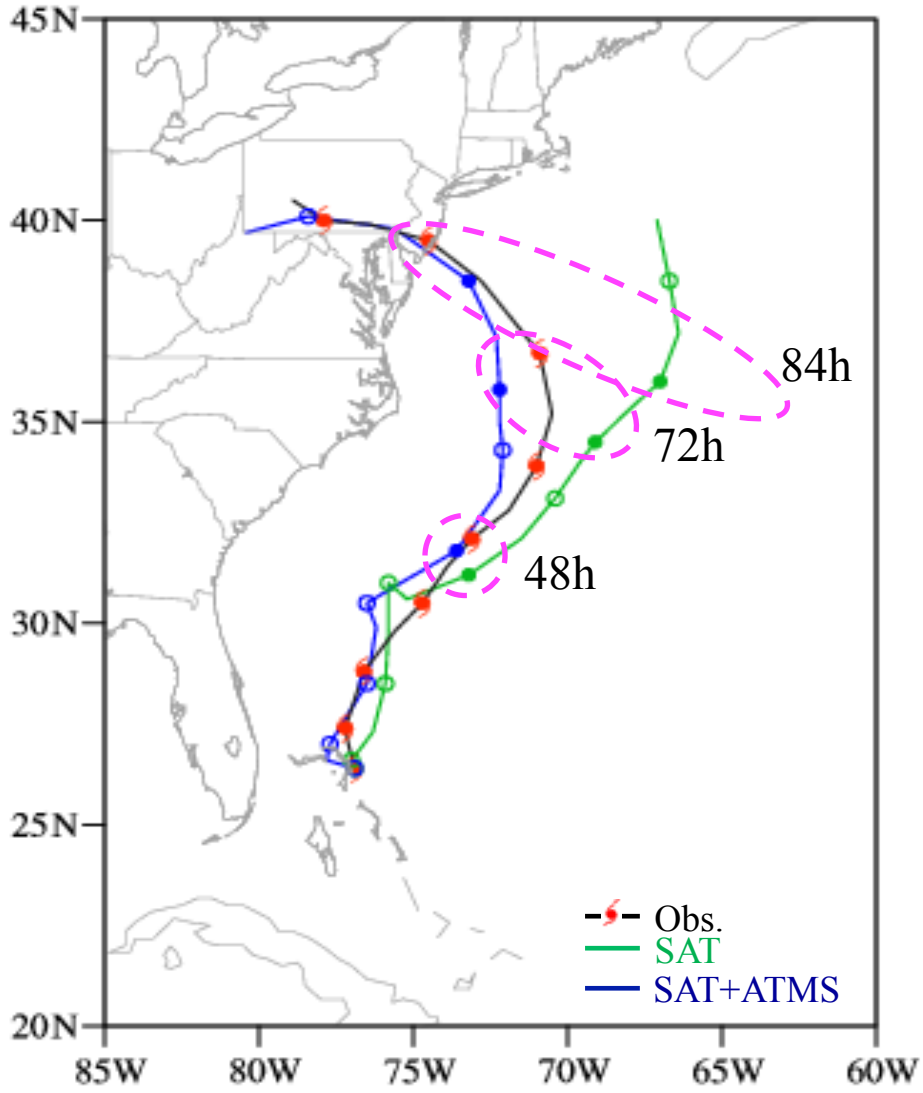
Sandy Track Forecast starting at 1200 UTC Oct. 26

• SAT:
Conventional data + GPS + channels 5-14 AMSU-A (N18, N19, and Metop-A); AIRS (Aqua) and HIRS (N19, Metop-A)

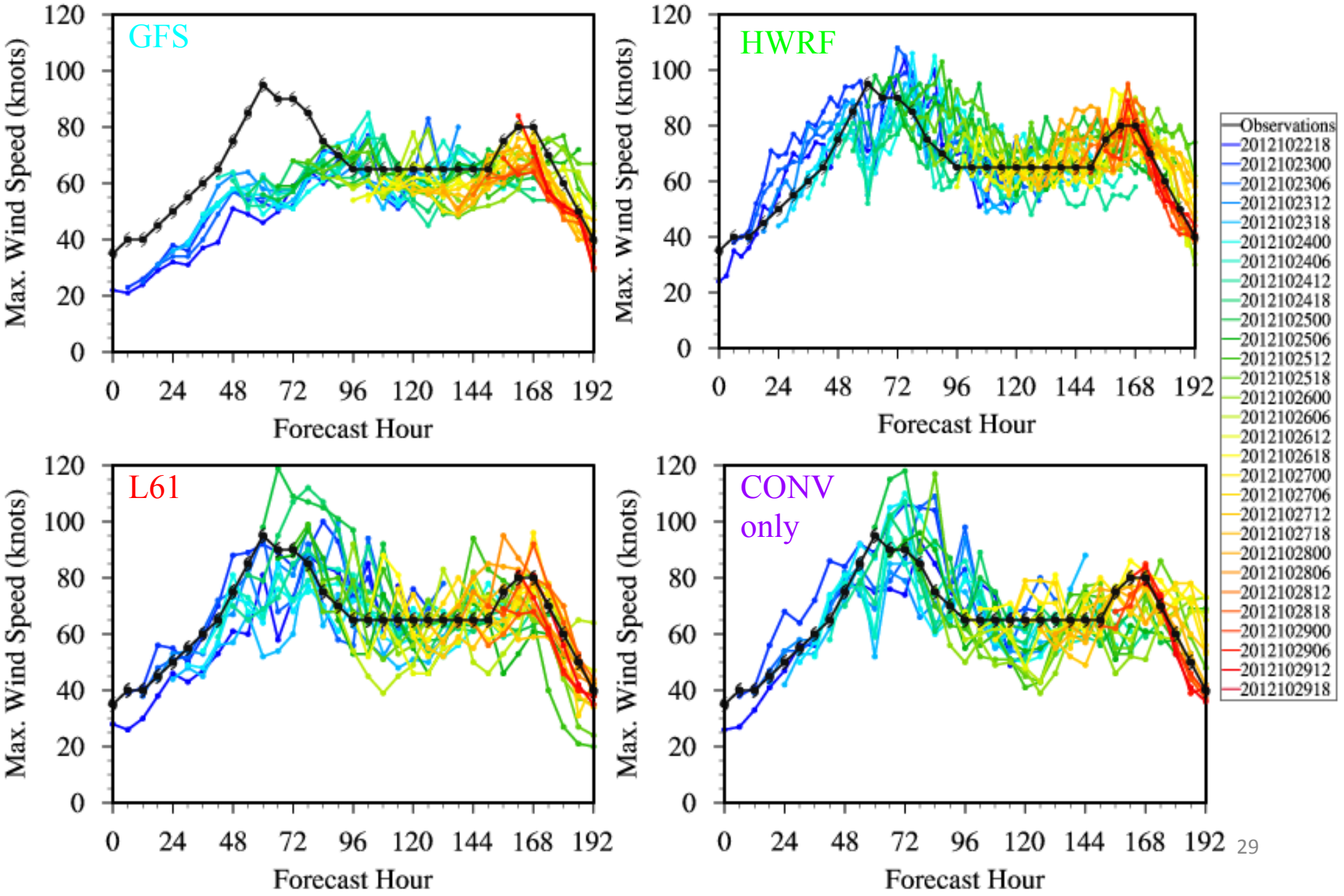
• SAT+ATMS:

SAT + ATMS (all channels except for 15)

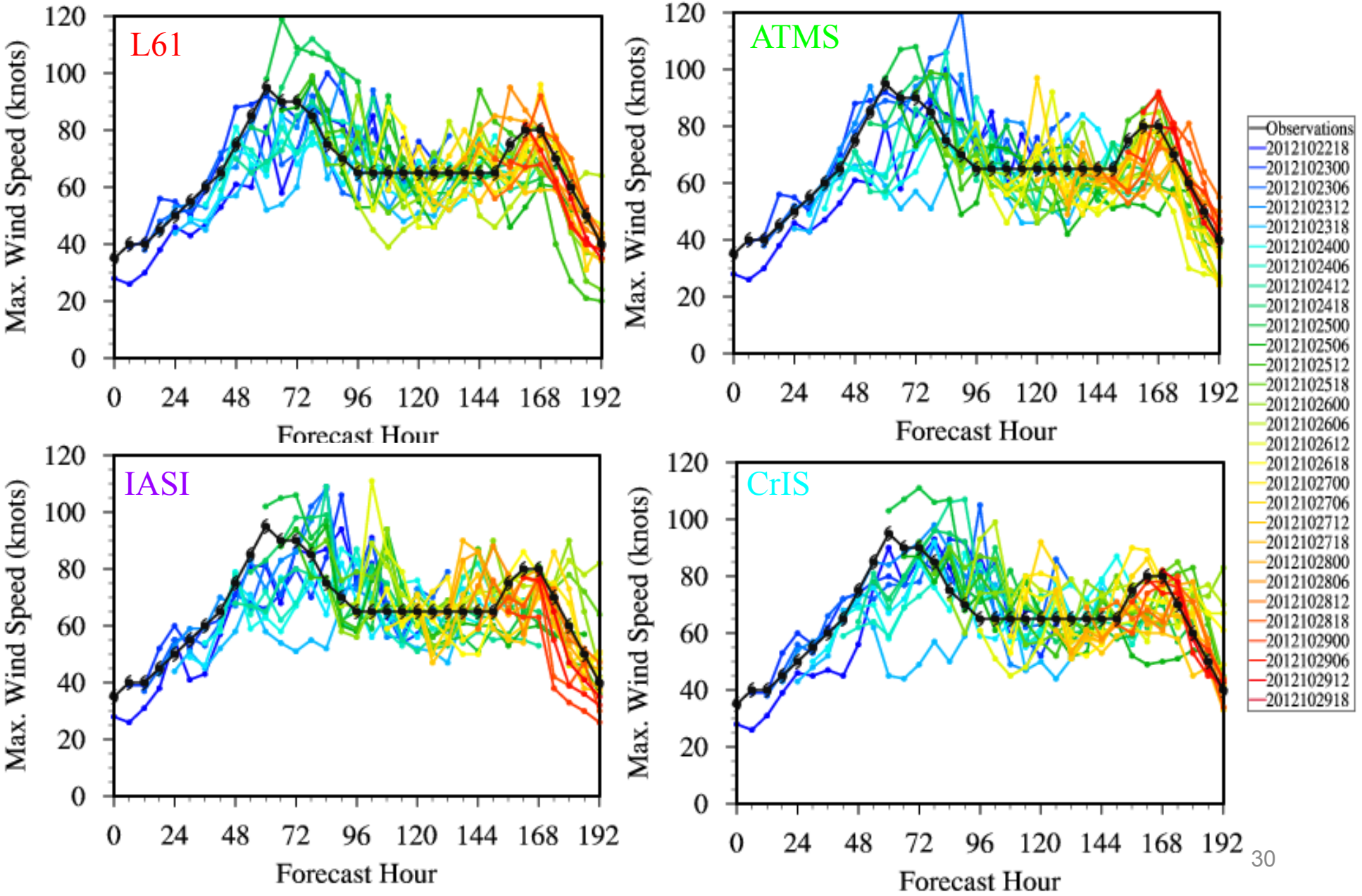
Zou, X., F. Weng, B. Zhang, L Lin, and V. Talapragada, 2013, JGR (revised)



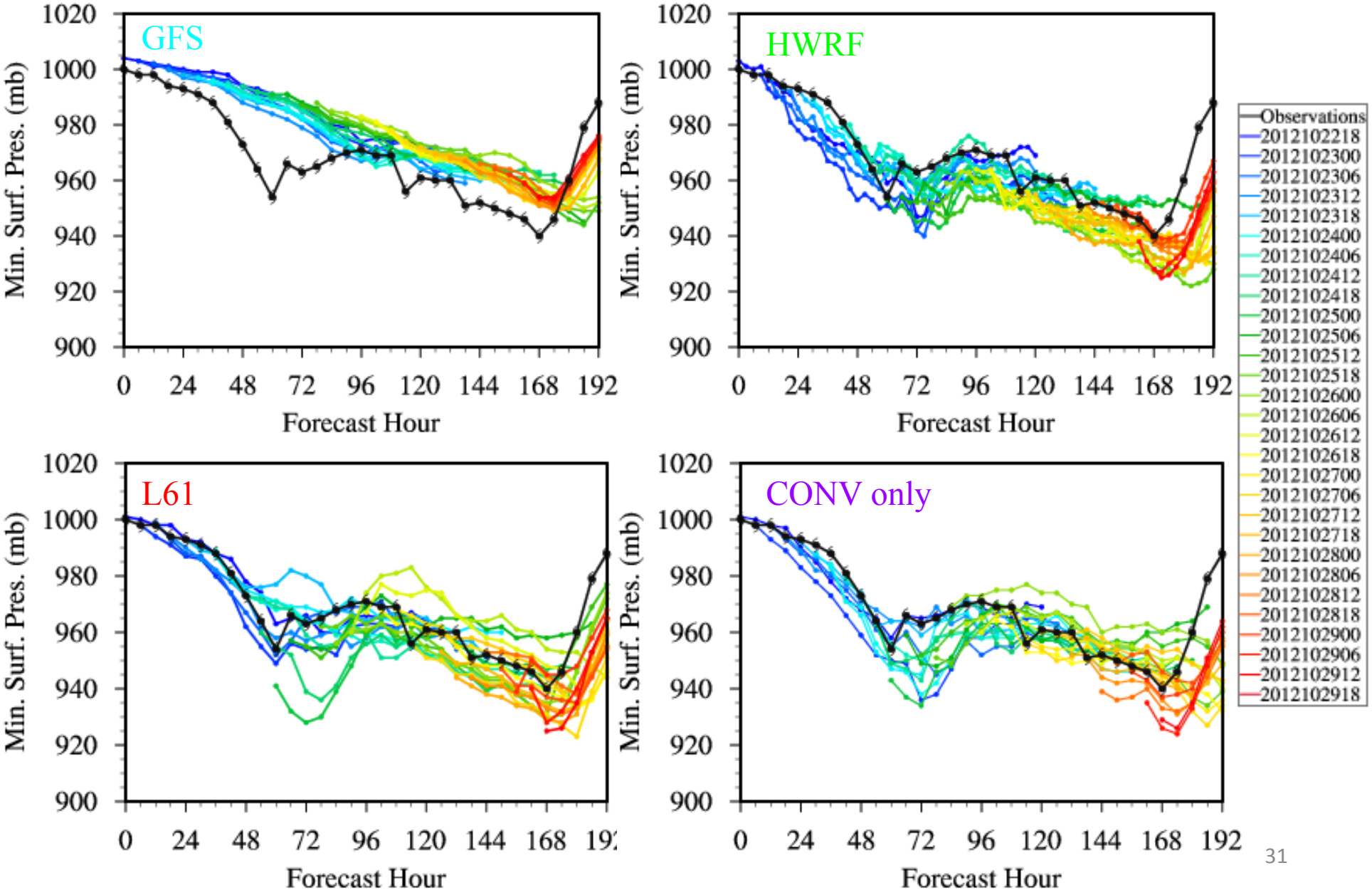
Multiple Forecasts of Max. Wind Speed for Hurricane Sandy



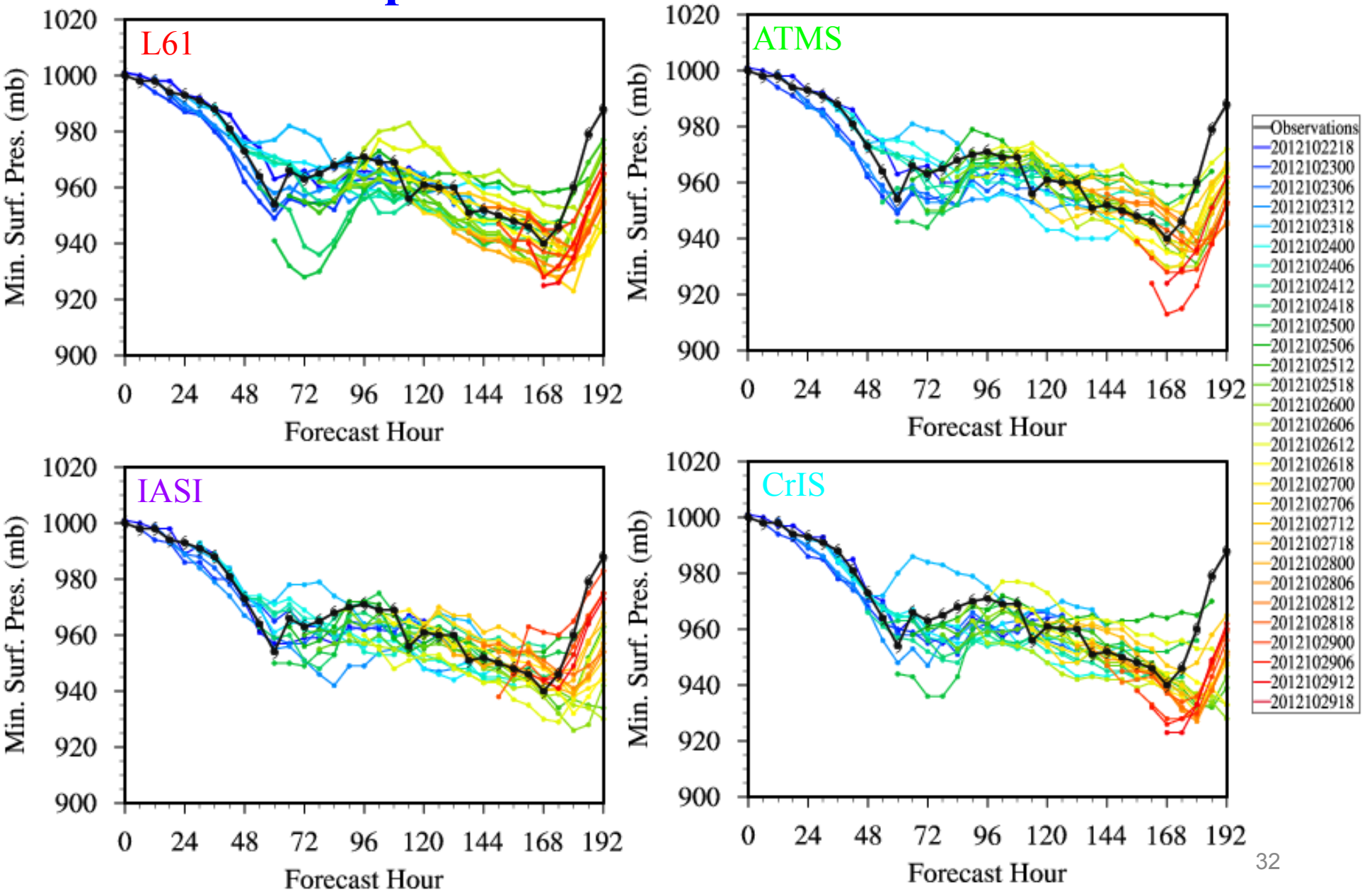
Multiple Forecasts of Max. Wind Speed for Hurricane Sandy



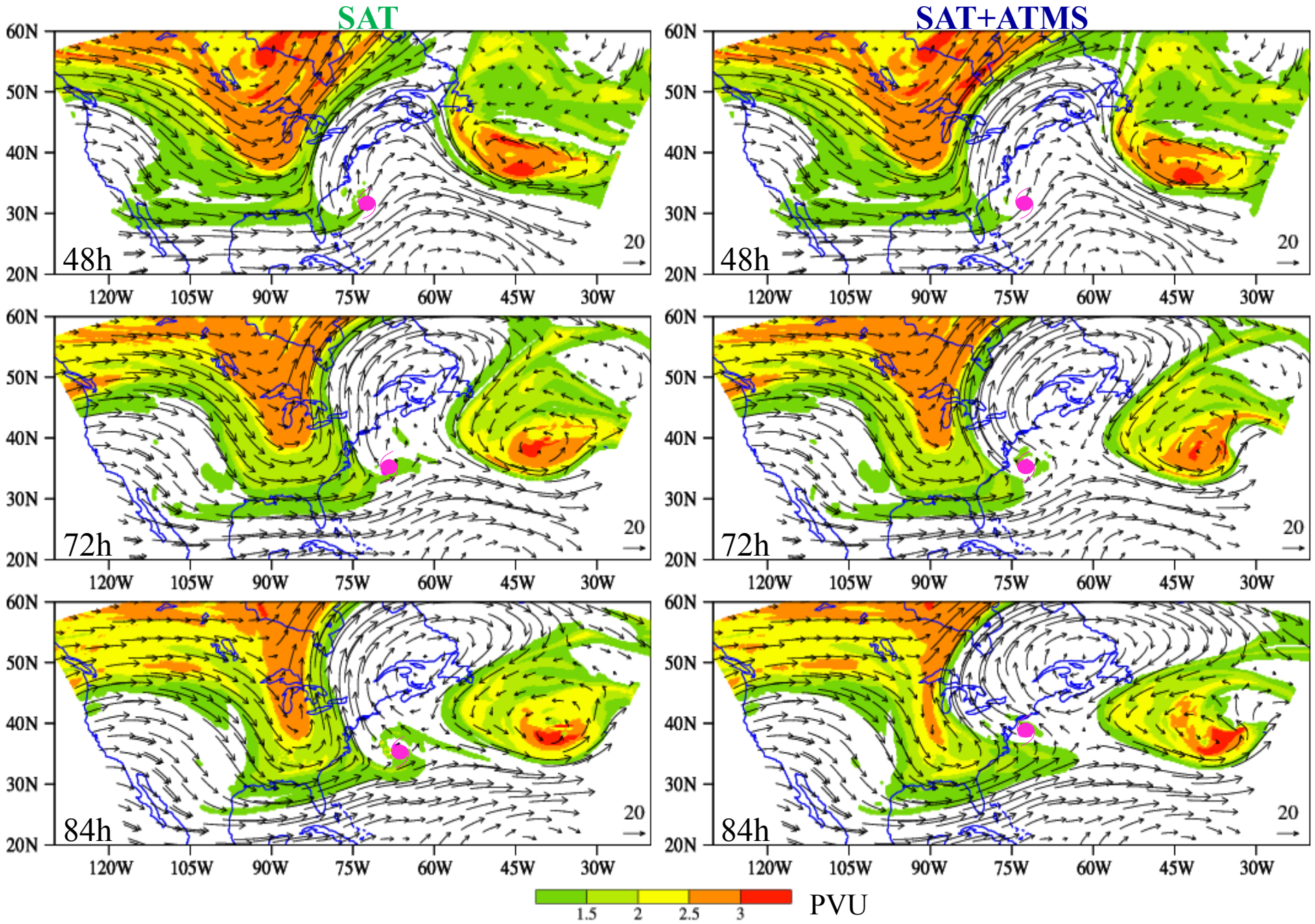
Multiple Forecasts of Min. Surf. Pressure for Hurricane Sandy



Multiple Forecasts of Min. Surf. Pres.

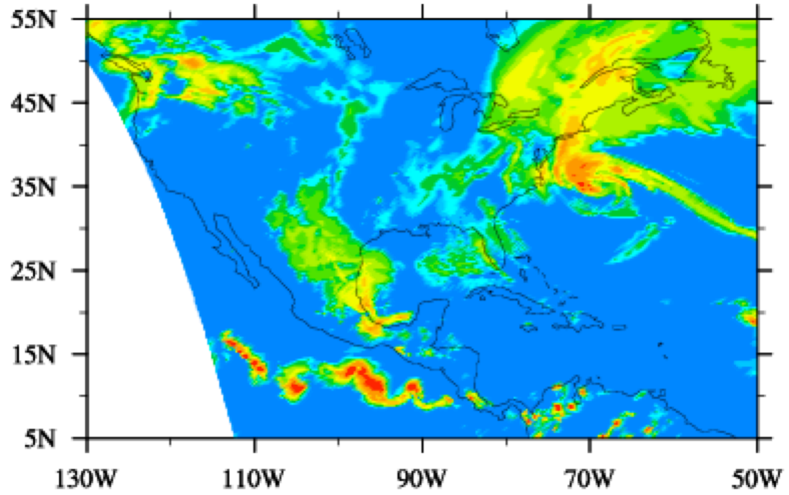


200 mb PV and wind for 48h, 72h and 84h forecast

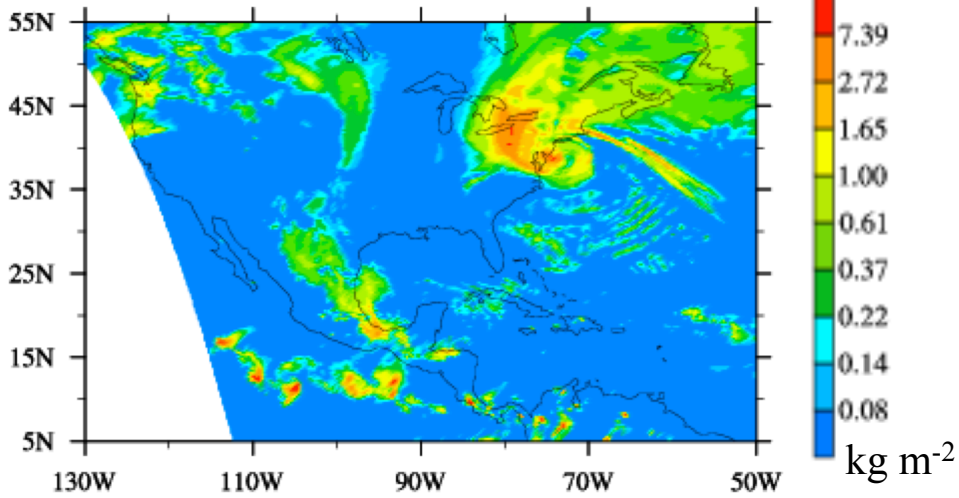


84-h Forecasts of Cloud Liquid Water Valid at 0000 UTC 30 October 2012

Without ATMS

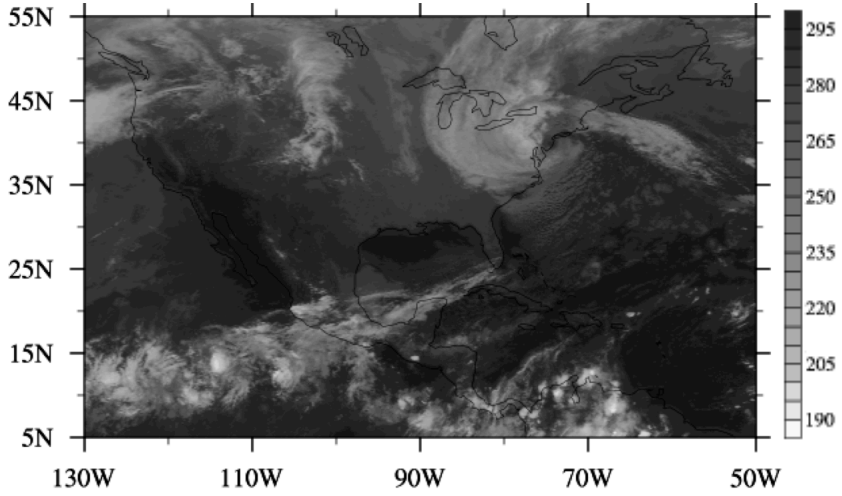


With ATMS

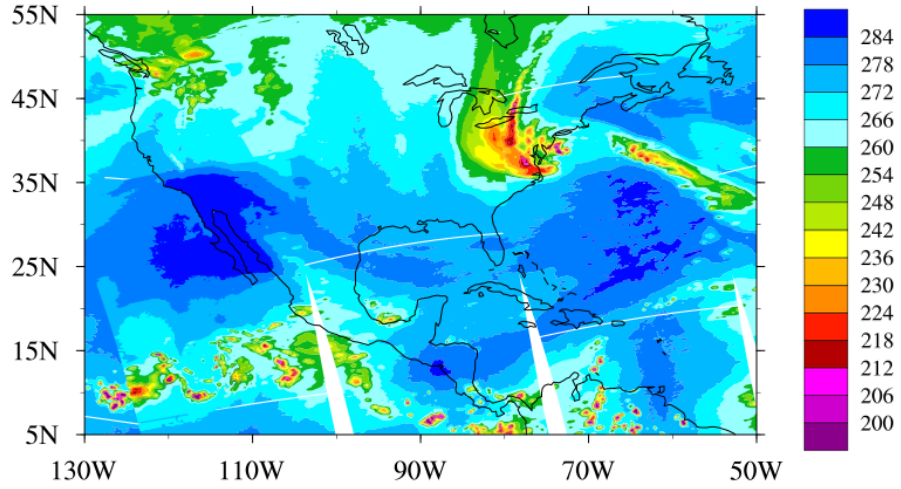


kg m^{-2}

GOES-13 $T_{b,4}$ for Verification



ATMS $T_{b,18}$ at 1727 UTC 10/29/12



Summary

- Suomi NPP mission provides the unique data for NOAA operations (e.g. resolving hurricane warm core features, CrIS all FOVs in NWP, VIIRS ocean color).
- 2012 HWRF/GSI is re-configured with more vertical layers and higher model top for direct satellite radiance assimilation. In general, control and sensitivity experiments show uses of ATMS/CrIS data in HWRF improve the hurricane forecasts in both intensity and track.
- VIIRS day and night band (DNB) is used from monitoring weather in polar winter dark period and night-time hurricane monitoring
- Some advanced applications are being planned, including revising the data assimilation experiments with better quality controls and bias corrections
- Suomi NPP mission is a very successful mission in both research and operation!