Future Opportunities of Using Microwave Data from Small Satellites for Monitoring and Predicting Severe Storms

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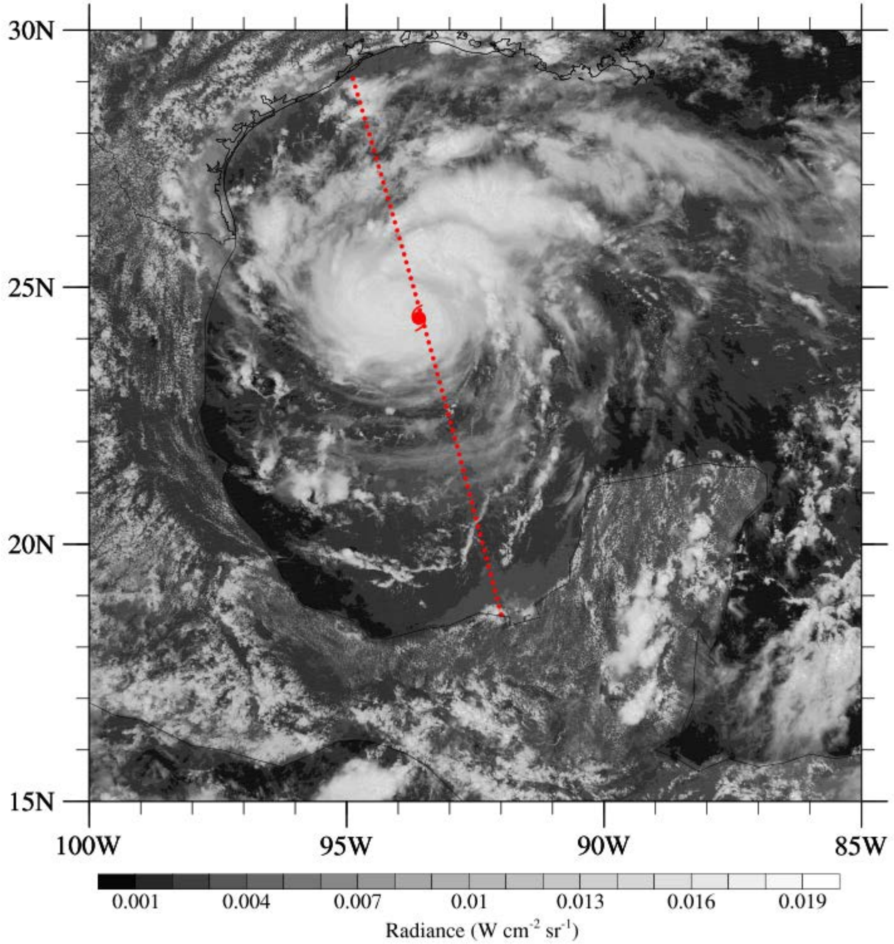
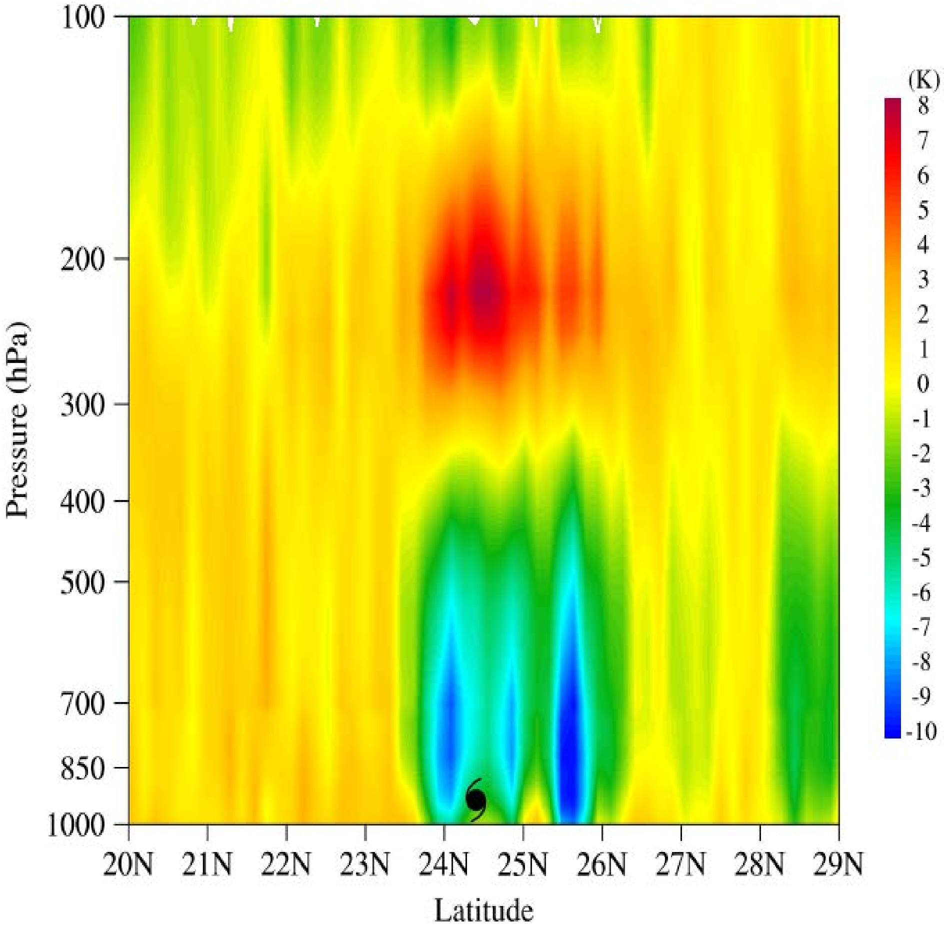
21st International TOV Study Conference, Darmstadt, Germany

ATMS-Derived Warm Core Structure of Hurricane Harvey

VIIRS DNB Radiance

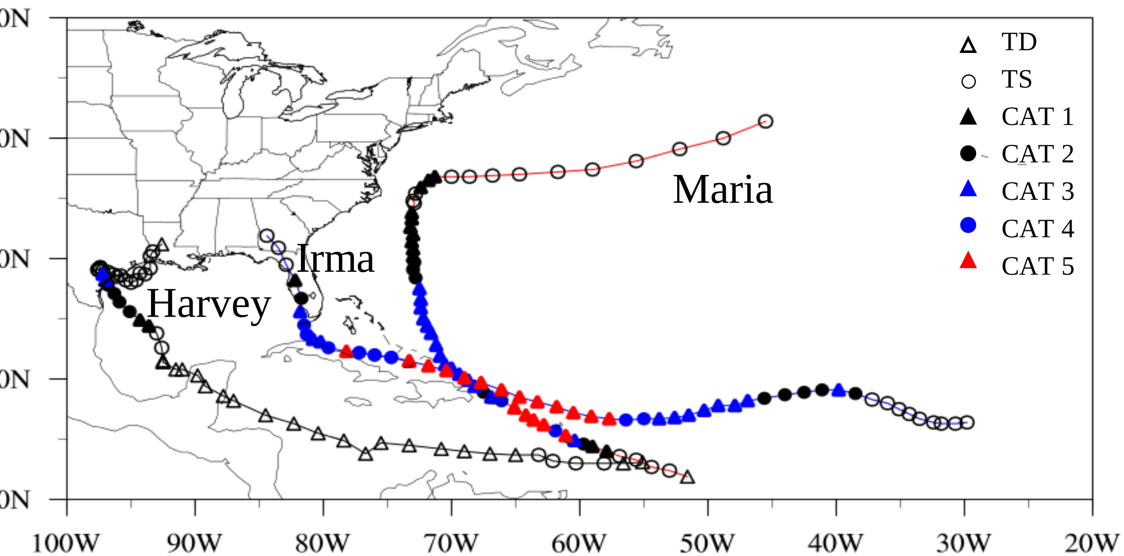


Vertical Cross Section of TA



Estimation of Hurricane Maximum Wind Speed (MWS) using Temperature Anomaly

Tracks of Hurricane Harvey, Irma and Maria



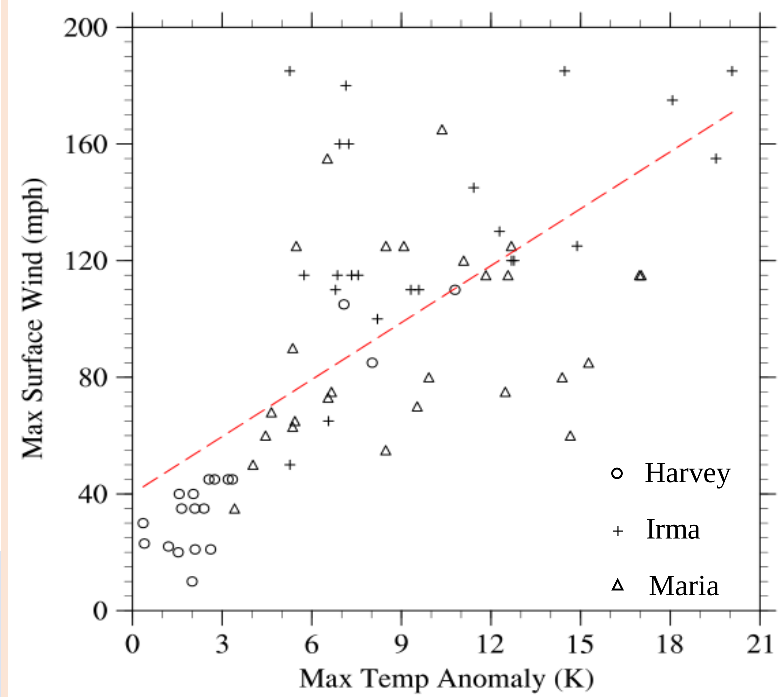
Harvey: 1800UTC 17 August – 0000UTC 31 August

Irma: 1200UTC 30 August – 0000UTC 12 September

Maria: 1800UTC 16 September – 1800UTC 30 September

69 pairs of ATMS-retrieved TA and observed MWS

Relationship between MWS and MTA



MWS = 6.51*MTA+40.12

STD = 35.27 mph

r = 0.67

Uses ATMS Derived Temperature to Monitor Hurricane Warm Core Evolution and Intensification Process

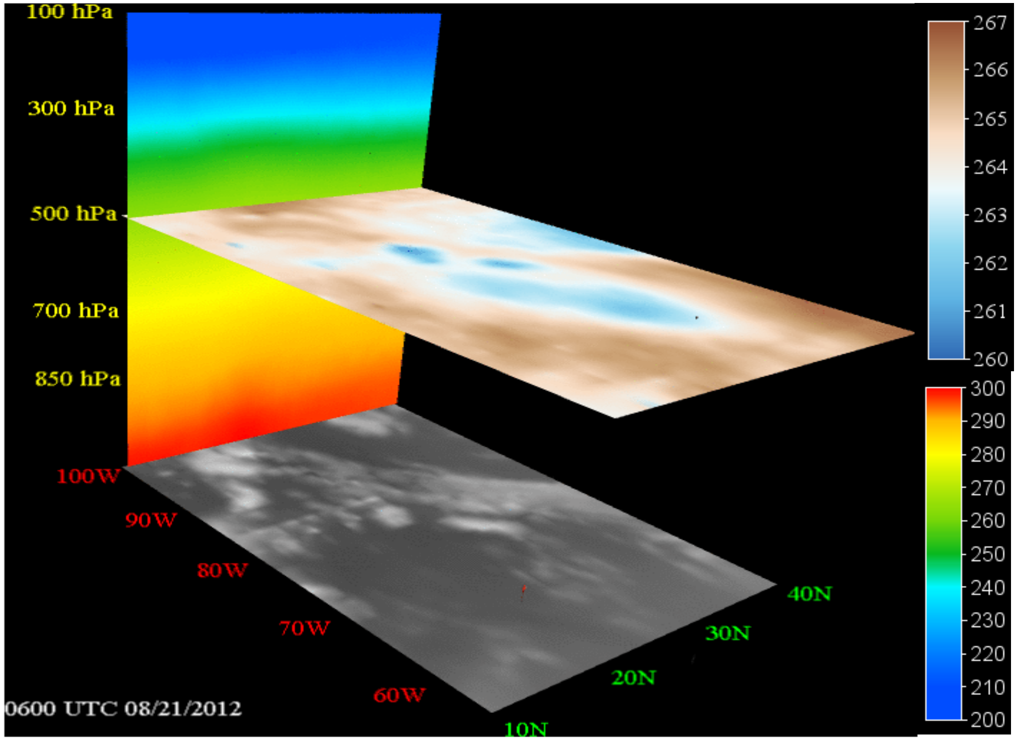
Isaac's warm core characterized by 2 K anomalous temperature (3D isosurface in red)

500 hPa temperature

GOES imager radiance

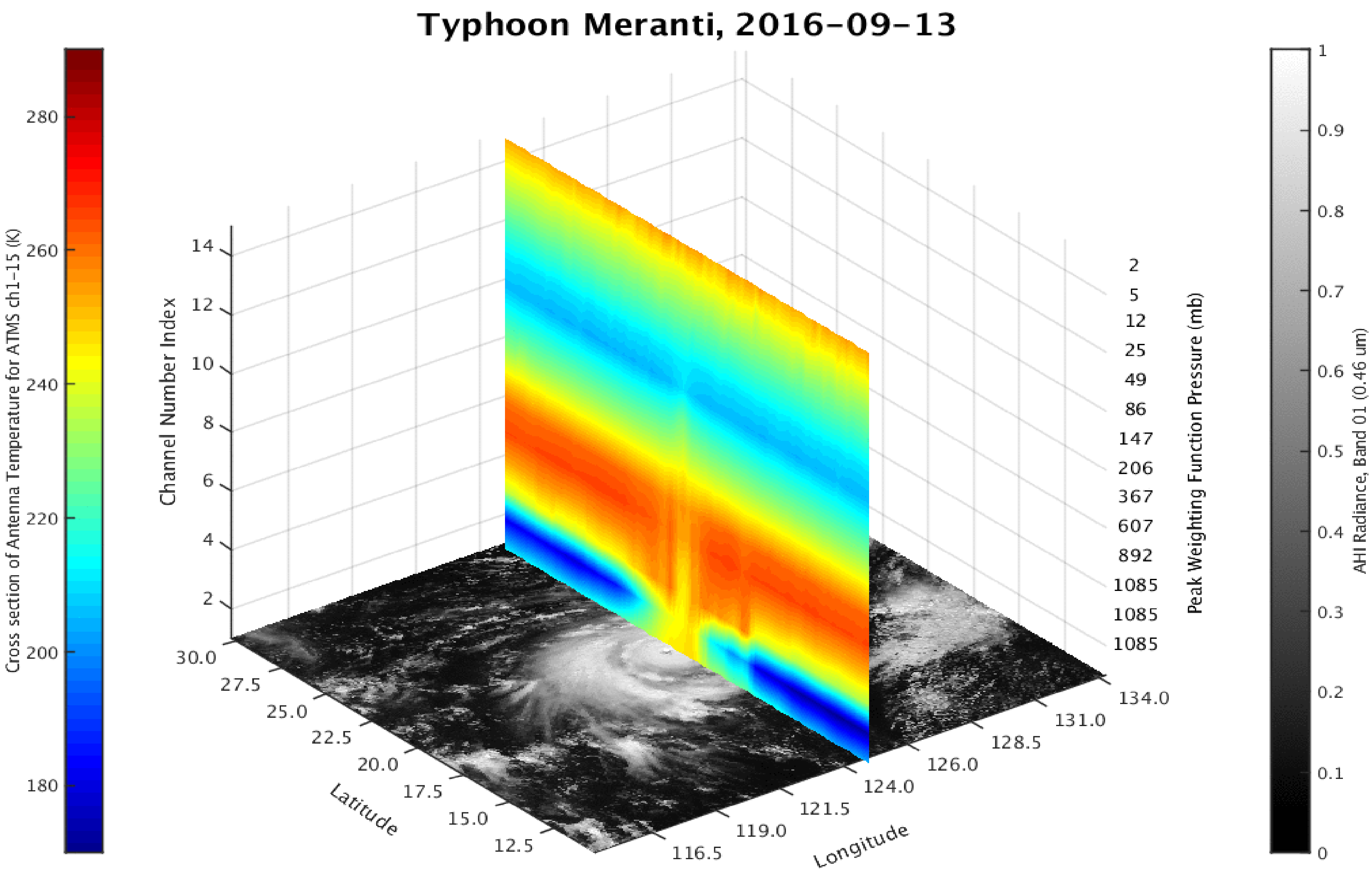
Vertical temperature

Hurricane symbols represent the best track at 12-h interval from 0600 UTC 21 August to 1800 UTC 30 August 2012.

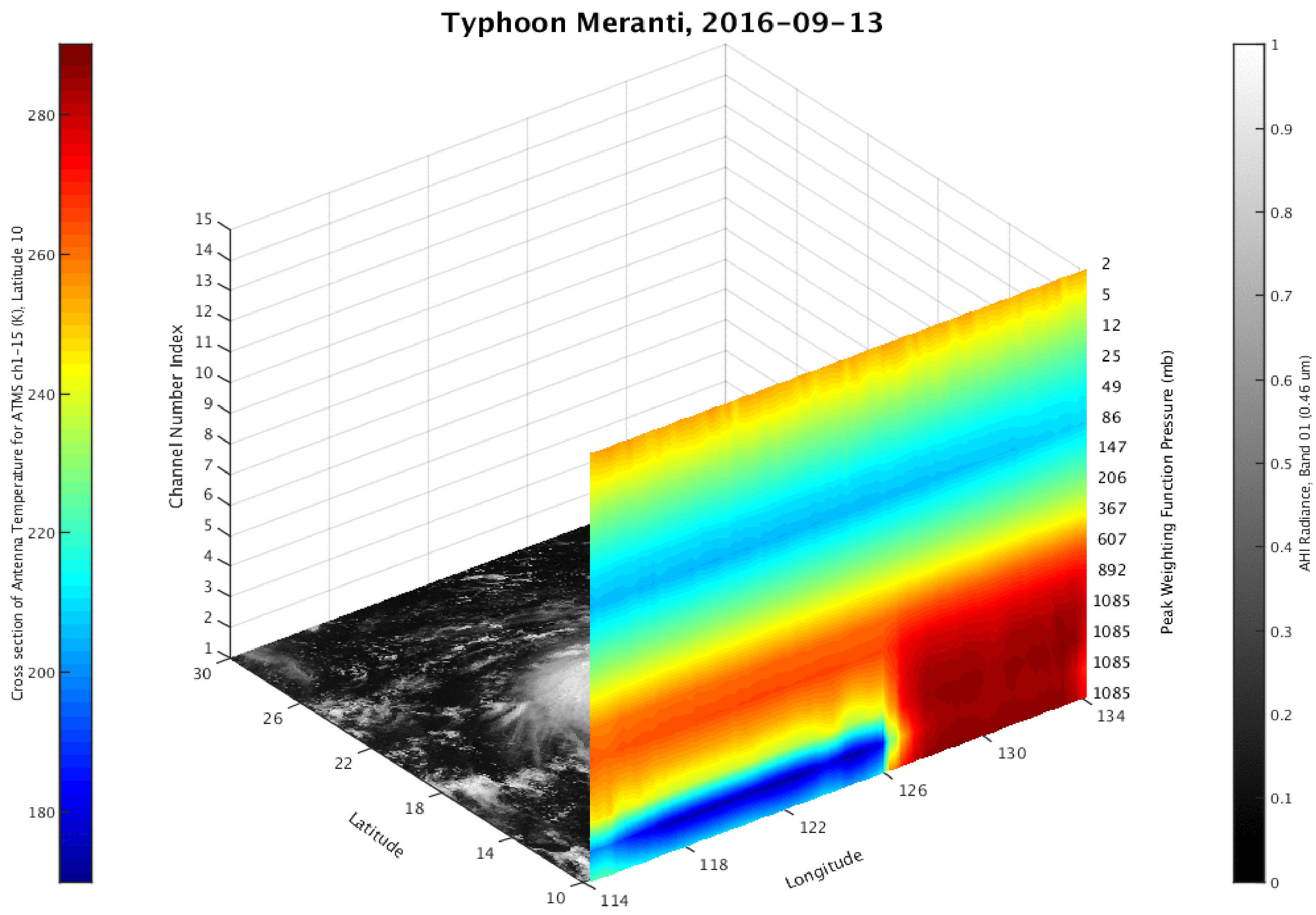


Observations from POES microwave sounders have proved to be invaluable to NWP, but four observations/day do not resolve the fast-evolving weather events. Visible and infrared observations from GOES imagers and sounders offer higher temporal resolution but cannot resolve the hurricane warm core structure and therefore are of limited applications.

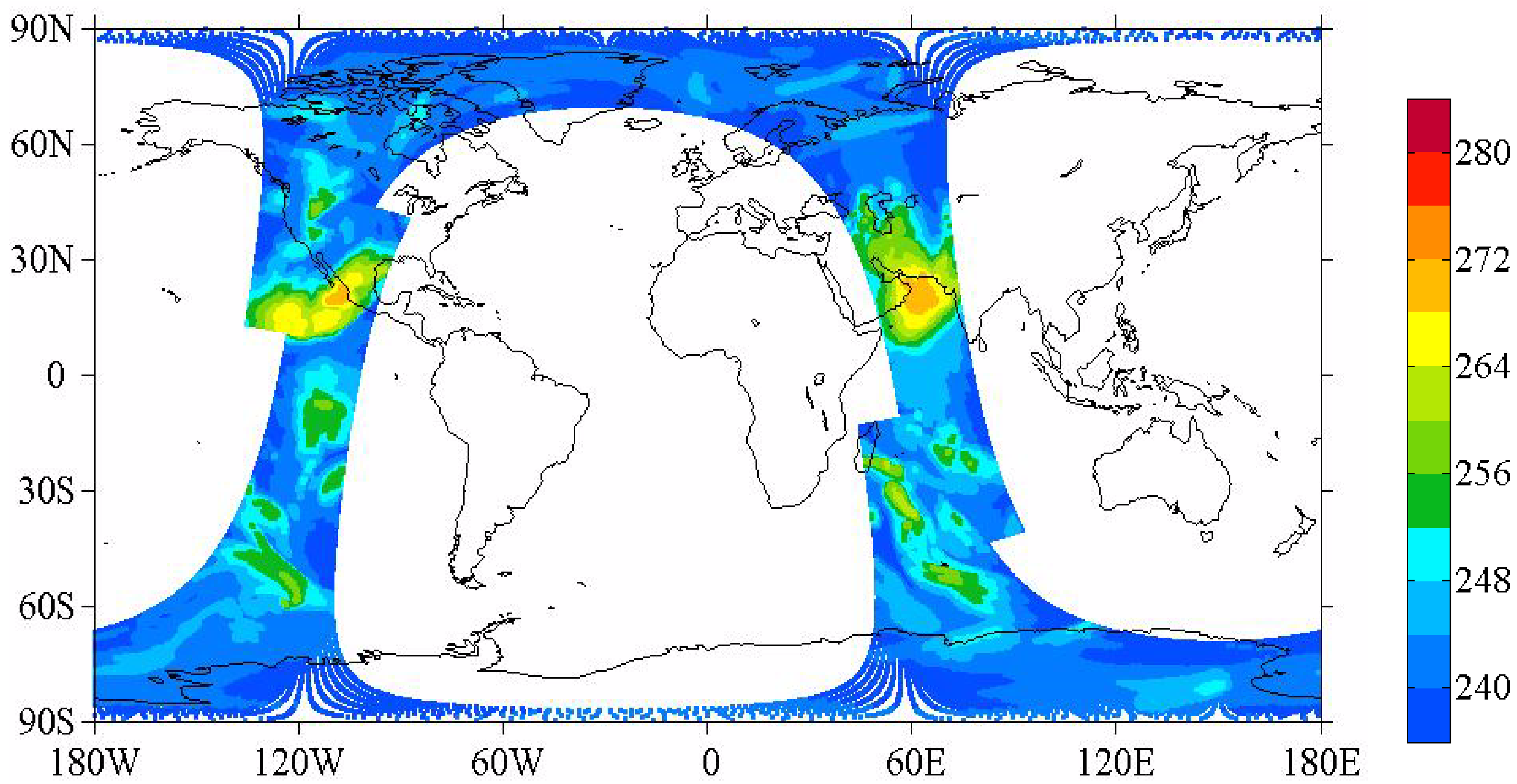
ATMS Monitoring of Typhoon Meranti



ATMS Monitoring of Typhoon Meranti



Data Coverage from Single Polar-Orbiter within Two Hours



In a two-hour observation window, a single sun synchronous polar orbiting satellite observes limited areas and leaves most of the earth uncovered.

Examples of US Small Satellite Missions

- COSMIC — A constellation with six smallsats in low-inclination orbits carrying GPS RO receivers
- COSMIC-2 — Two constellations carrying GPS RO receivers:

  1) Six low-inclination smallsats

  2) Six high inclination smallsats
- CYGNSS — A constellation of eight smallsats receive both direct and reflected GPS signals
  - ✓ The direct signals pinpoint CYGNSS observatory positions
  - ✓ The reflected signals respond to ocean surface roughness
- TROPICS: A constellation with 12 CubeSats carrying microwave radiometers (12 channels) to provide measurements of Temperature by 7 channels near the 118.75 GHz oxygen absorption line; Water vapor by 3 channels near the 183 GHz water vapor absorption line; Precipitation by a single channel near 90 GHz; and cloud ice by a single channel at 206 GHz.

COSMIC: Constellation Observing System for Meteorology, Ionosphere, and Climate
TROPICS: Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats

Scientific and Technological Challenges of Smallsat Data Processing and Applications – MW mission

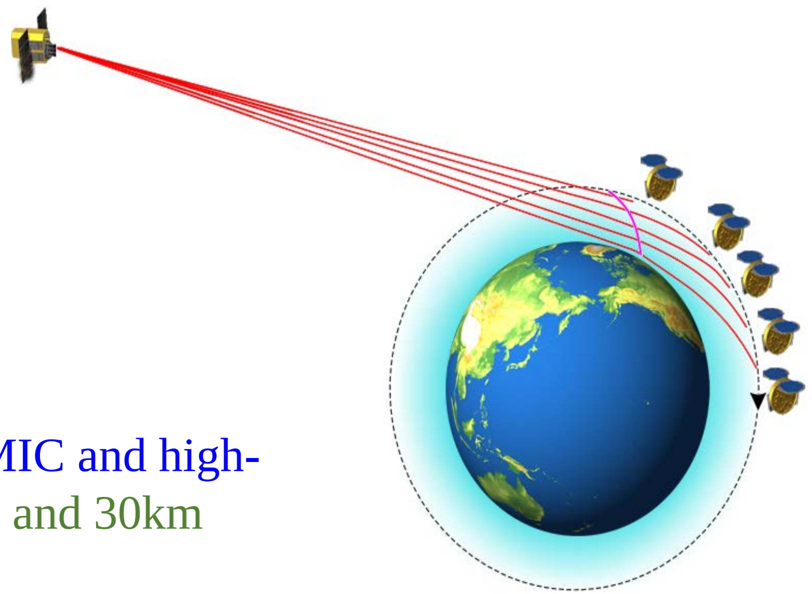
- Calibration: RDR to SDR data conversion may require some innovative procedures to accommodate the unique design in its electronical and antenna subsystems
- NWP observational forward operators: Spectral response functions and antenna pattern function must be fully characterized for NWP radiance assimilation.
- Quality control of satellite data in NWP systems: Detection of clouds and precipitation from smallsat data may require new developments. If K/Ka bands are not included in the baseline smallsat design, other channels near 60/118 GHz need to be fully explored for quality control process.
- Temporal and spatial composite for storm monitoring: Uses of smallsat data for storm monitoring require that all data in constellation be cross-calibrated. The same storm location may be viewed from multiple angles of smallsat instruments and therefore the radiances should be projected to the same viewing angle

Smallsat MW Sounder Calibration Strategy

- Develop an absolute calibration standard through collocated GPSRO data
- Periodically conduct a pitch maneuver operation for observing the cold space
- Cross-calibrate smallsat MW sounders to the baseline mission such as JPSS/METOP
- Derive relative calibration errors between smallsats using the double difference of NWP simulated radiances

Establish an in-orbit Calibration for Smallsat MW Sounder

1. High vertical resolution
2. No contamination from clouds
3. No system calibration required
4. High accuracy and precision:



The global mean differences between COSMIC and high-quality reanalyses is ~0.65K between 8 and 30km (Kishore et al. 2008)

The precision of COSMIC GPS RO soundings is ~0.05K in the upper troposphere and lower stratosphere (Anthes et al. 2008)

COSMIC Collocation with ATMS Data

- **Time period of data search:**

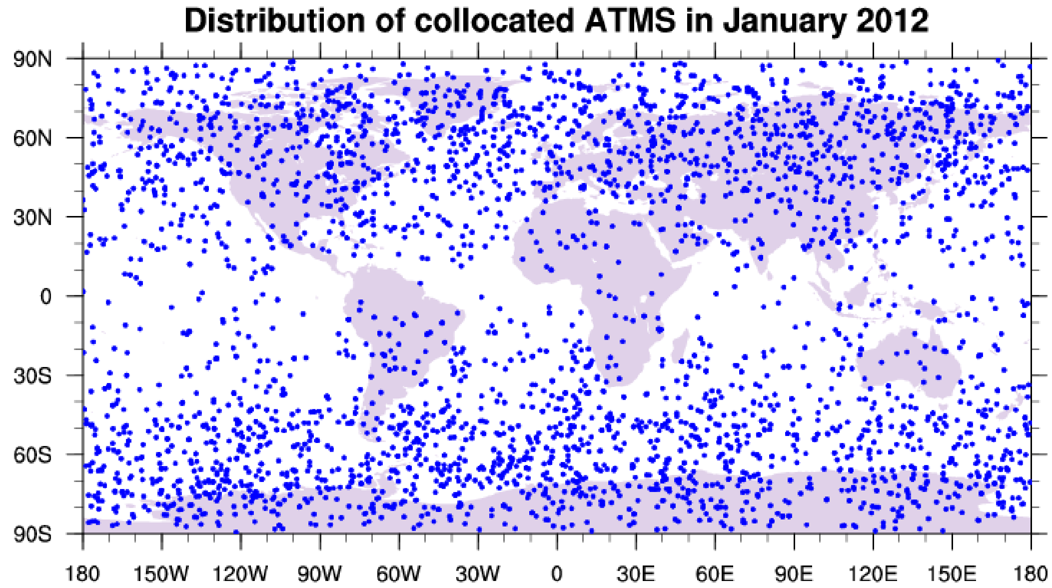
  January, 2012

- **Collocation with COSMIC data:**

  Time difference < 0.5 hour

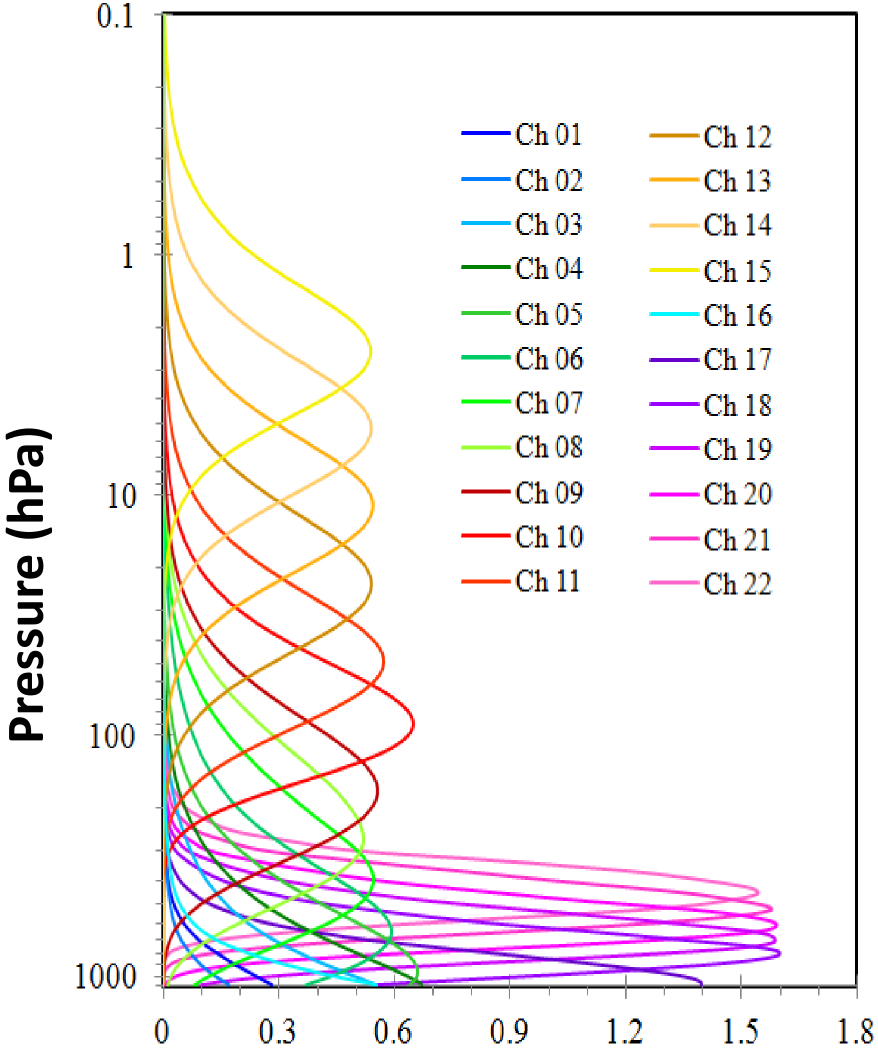
  Spatial distance < 30 km

(GPS geolocation at 10km altitude is used for spatial collocation)

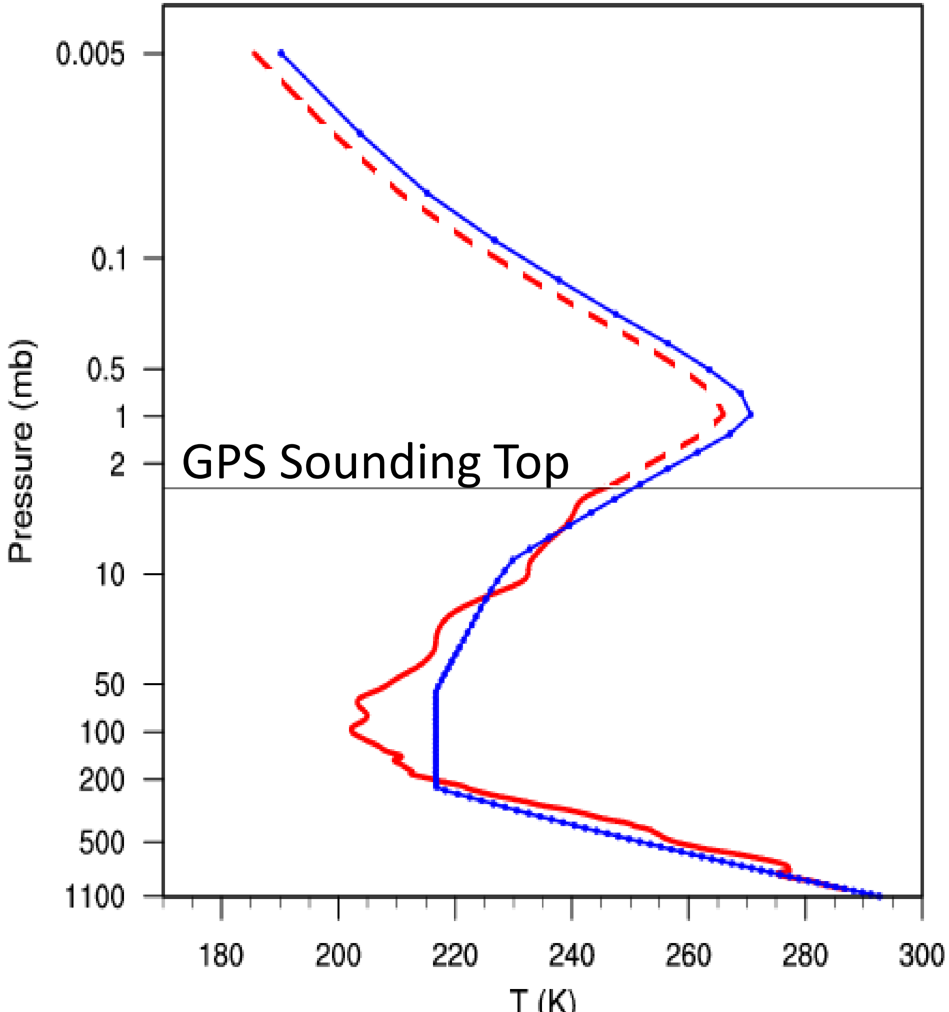


3056 collocated measurements

ATMS WF
(U.S. Standard Atmosphere)



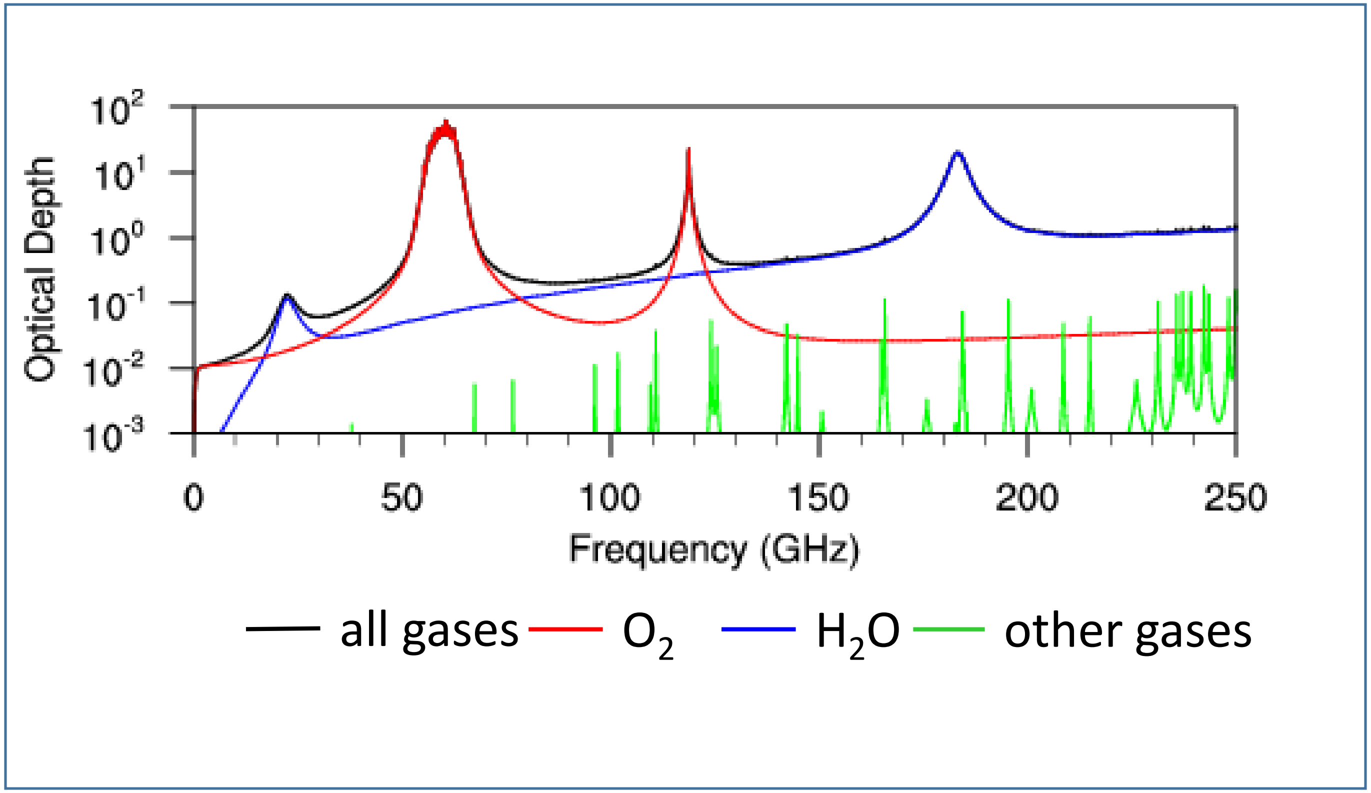
Add 1976 U.S. Standard Atmosphere State to GPS Soundings



1051 UTC on January 1, 2012

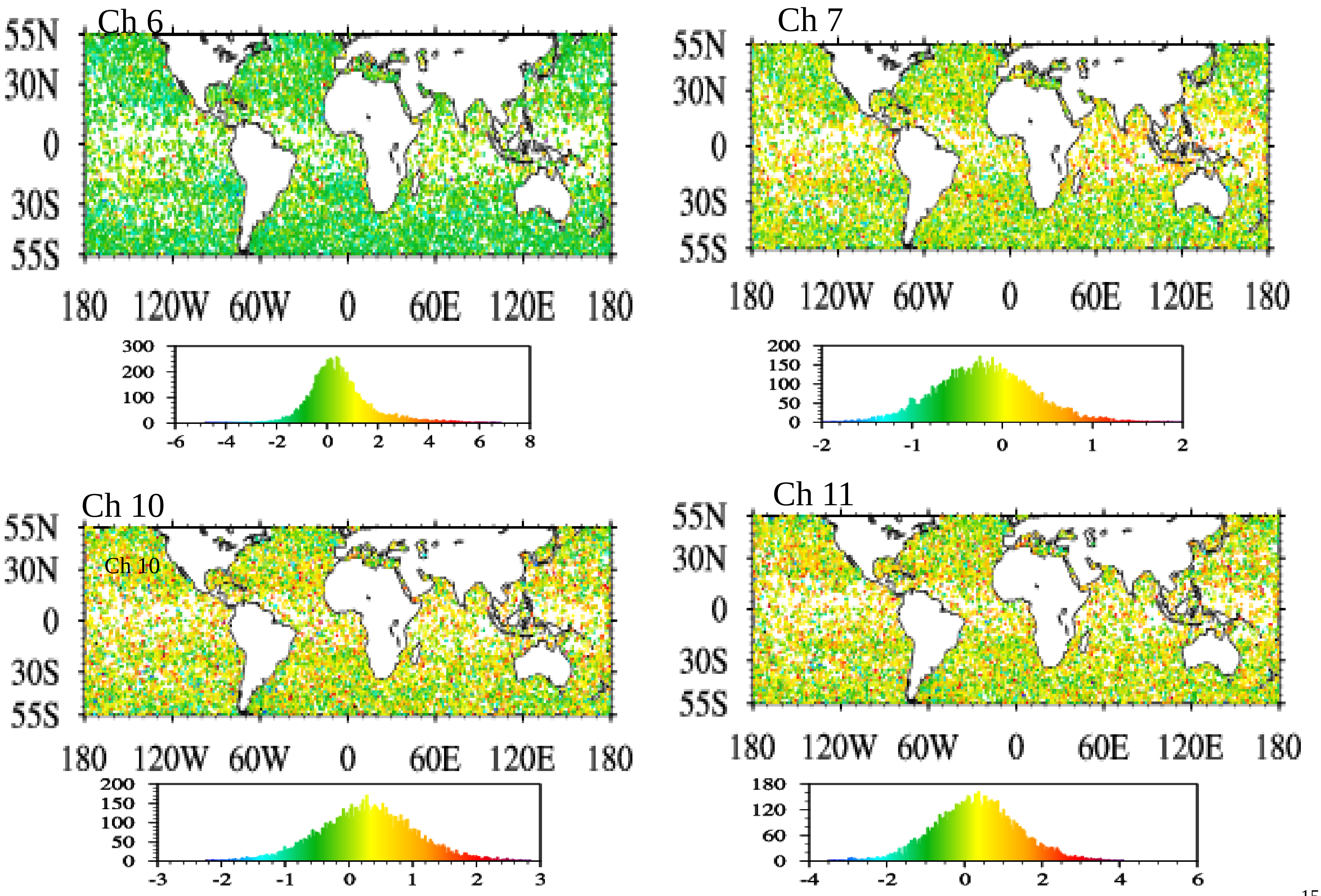
MonoRTM – Line by Line Radiance Computations

- Perform a line by line radiative transfer calculation
- Accurate atmospheric spectroscopy data base
- Only gaseous absorption
- Vertical stratification

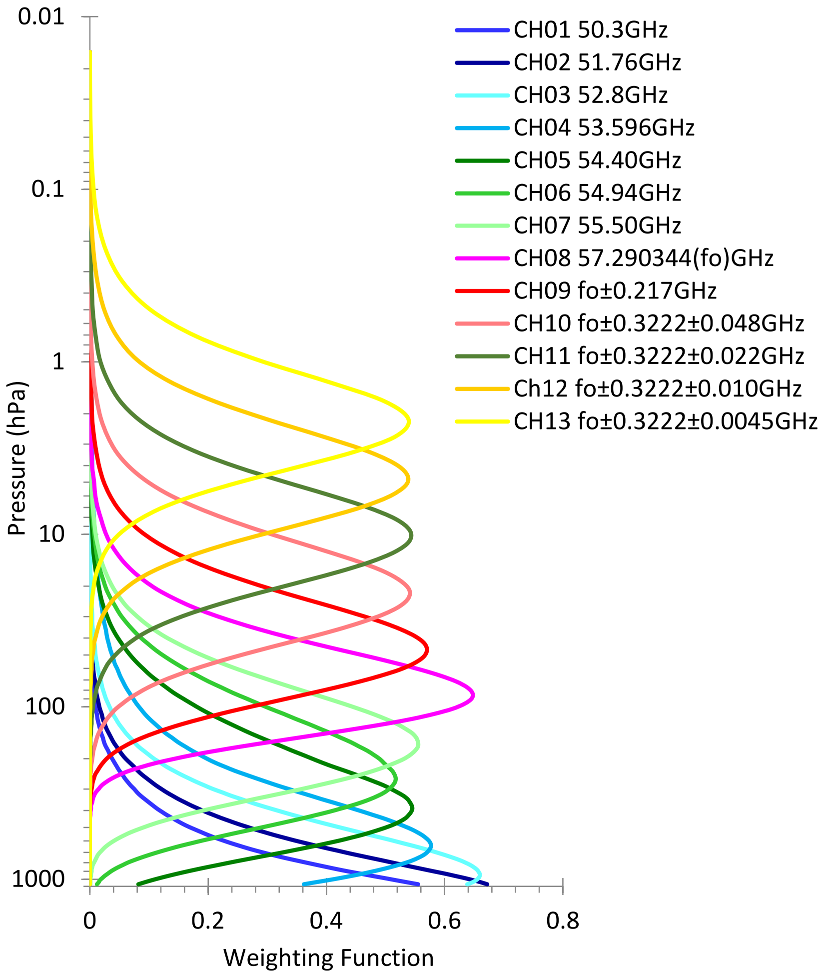


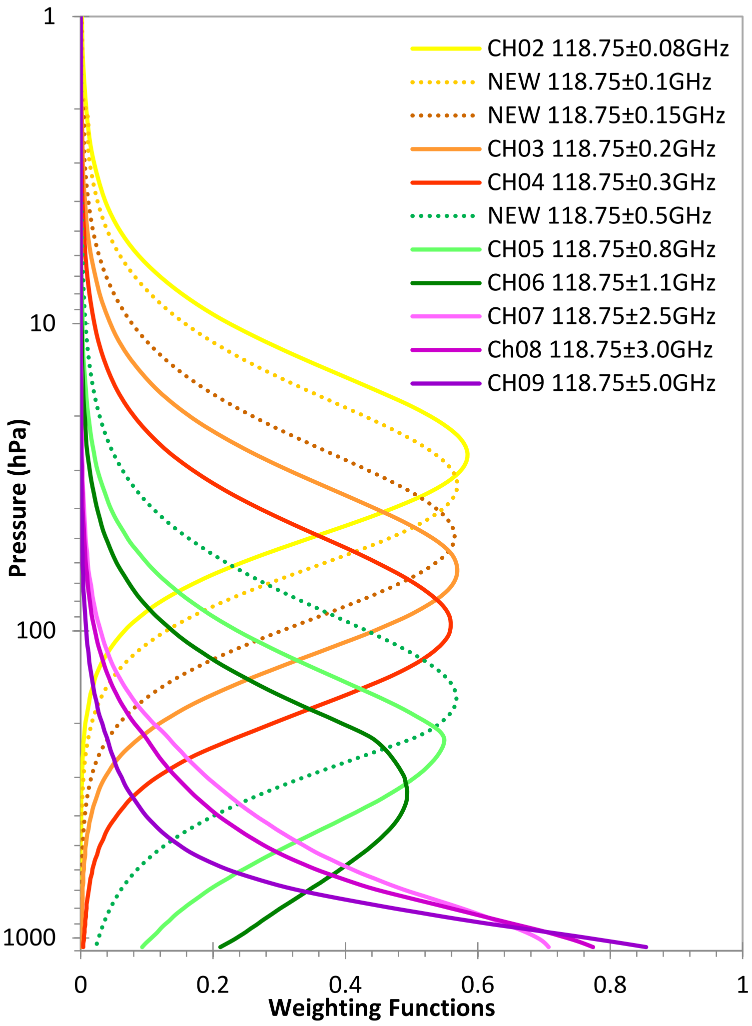
Microwave sounding channels at 50-60 GHz O_2 absorption band can be best simulated under a cloud-free atmosphere using line by line calculation

ATMS Bias Obs (TDR) - GPS RO Simulated

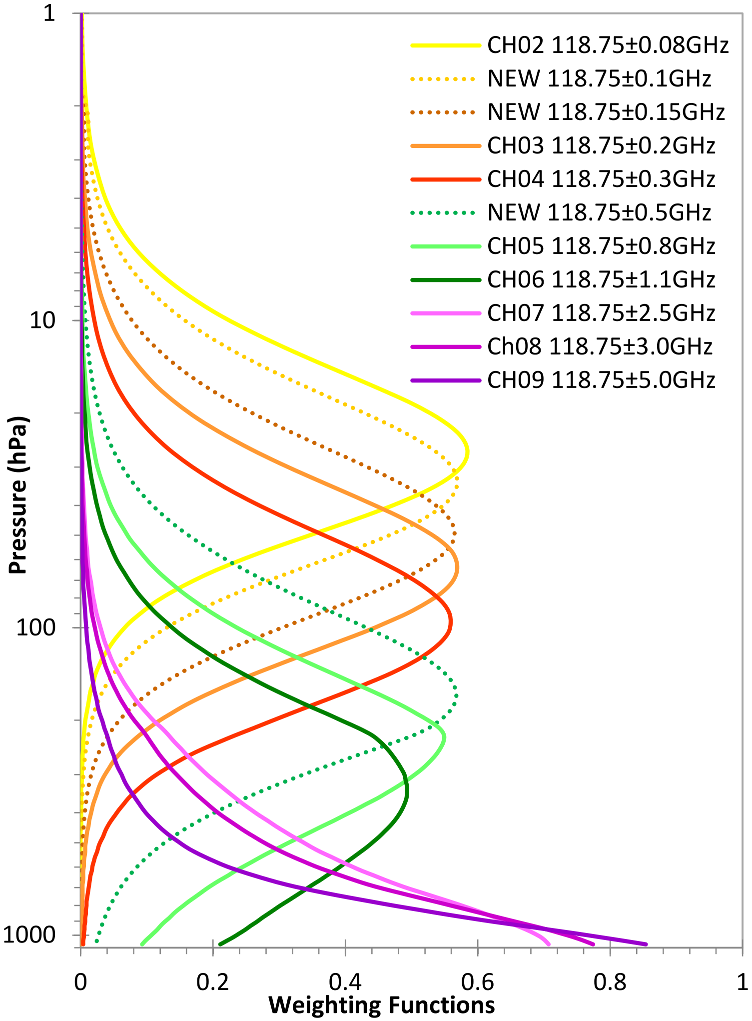


Uses of Double O2 Bands for Cloud Detection





Idealized 118 Channels and Weighting Functions

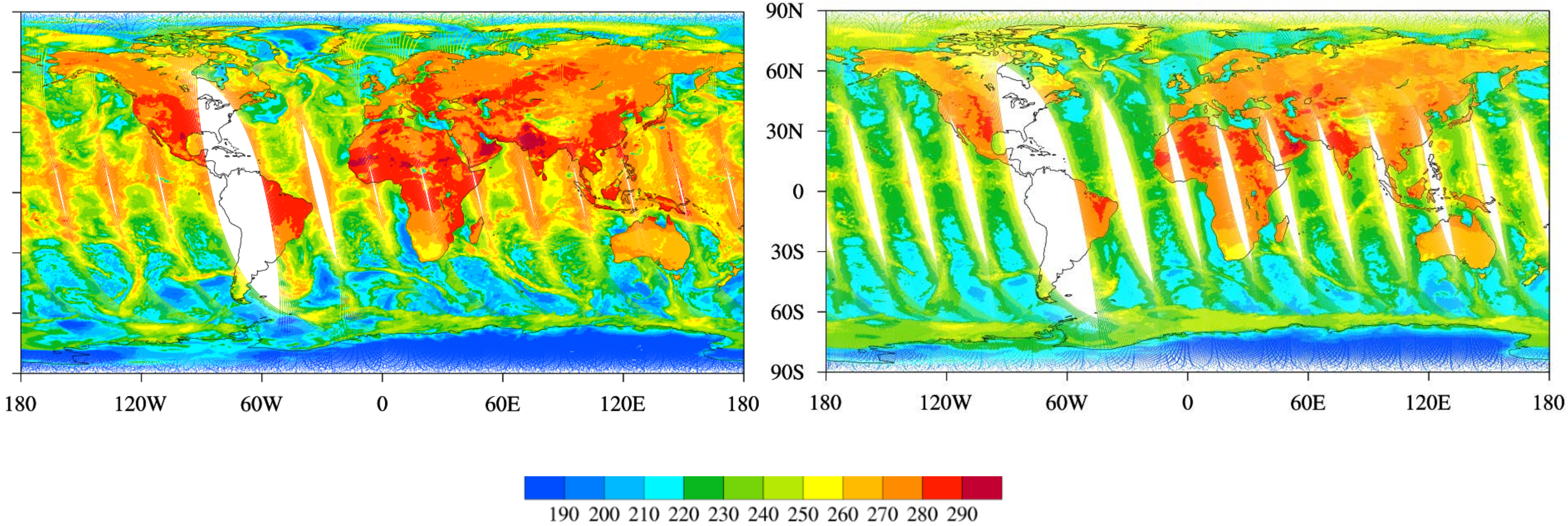


NO.	Central Frequency (GHz)	Band Width (MHz)
2	118.75±0.08	20
NEW	118.75±0.1	60
NEW	118.75±0.15	100
3	118.75±0.2	100
4	118.75±0.3	165
NEW	118.75±0.5	200
5	118.75±0.8	200
6	118.75±1.1	200
7	118.75±2.5	200
8	118.75±3.0	1000
9	118.75±5.0	2000

The figure shows the weighting functions of FY-3C MWHS channels with frequencies at 118.75GHz, also some new channels are added, the weighting functions are calculated by the MonoRTM V5.0 (AER) using the U.S. standard atmosphere profiles.

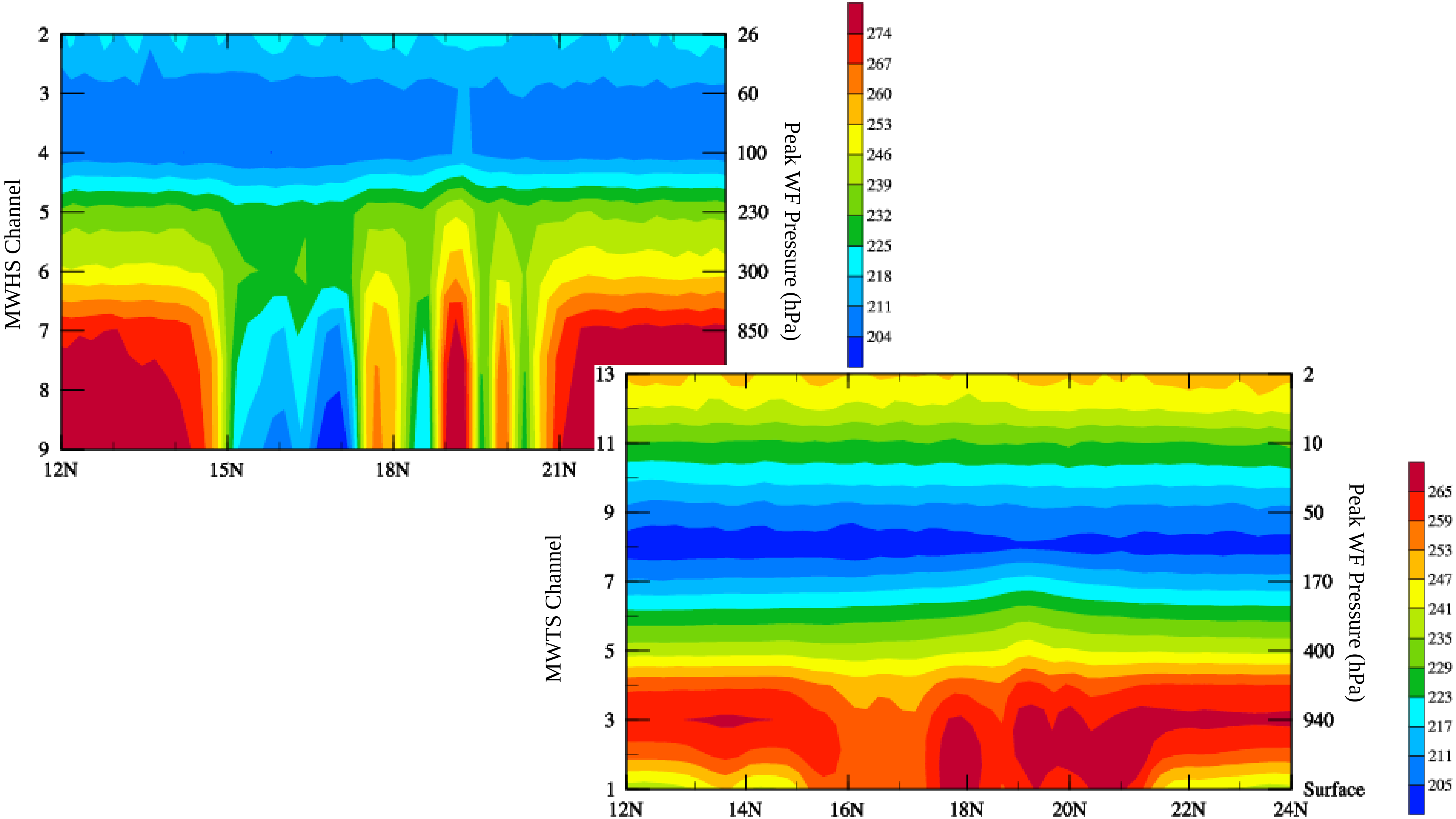
FY-3C MWHS & MWTS Observations

MWHS: 118.75±0.08 GHz **MWTS:50.3 GHz**



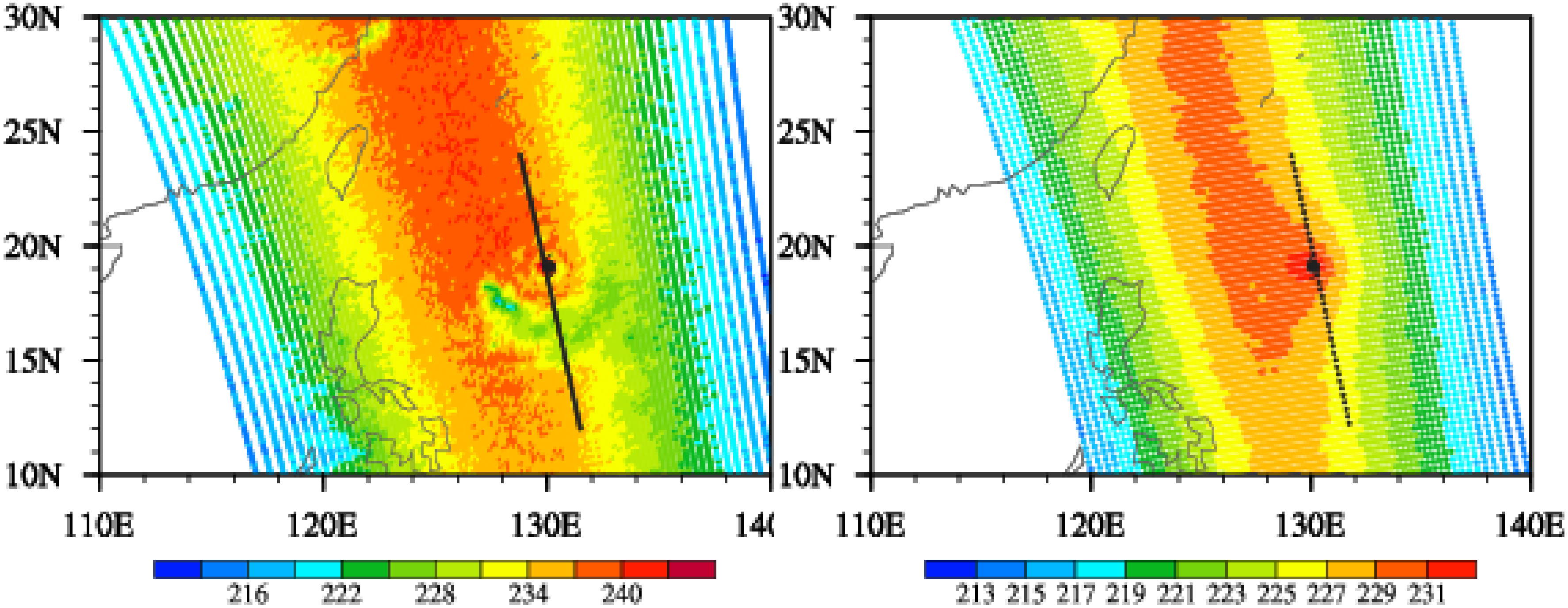
FY-3C MWHS (left panel) & MWTS (right panel) global observations on July 7, with super typhoon Neoguri centered at (20.4N, 128.3E).

Super Typhoon Neoguri Structures Observed from MWTS and MWHS (July 6, 2014)



MWHS CH5(118.75±1.1GHz) vs MWTS CH6(54.4GHz) (230 hPa)

Super Typhoon Neoguri, 1236 UTC July 6, 2014

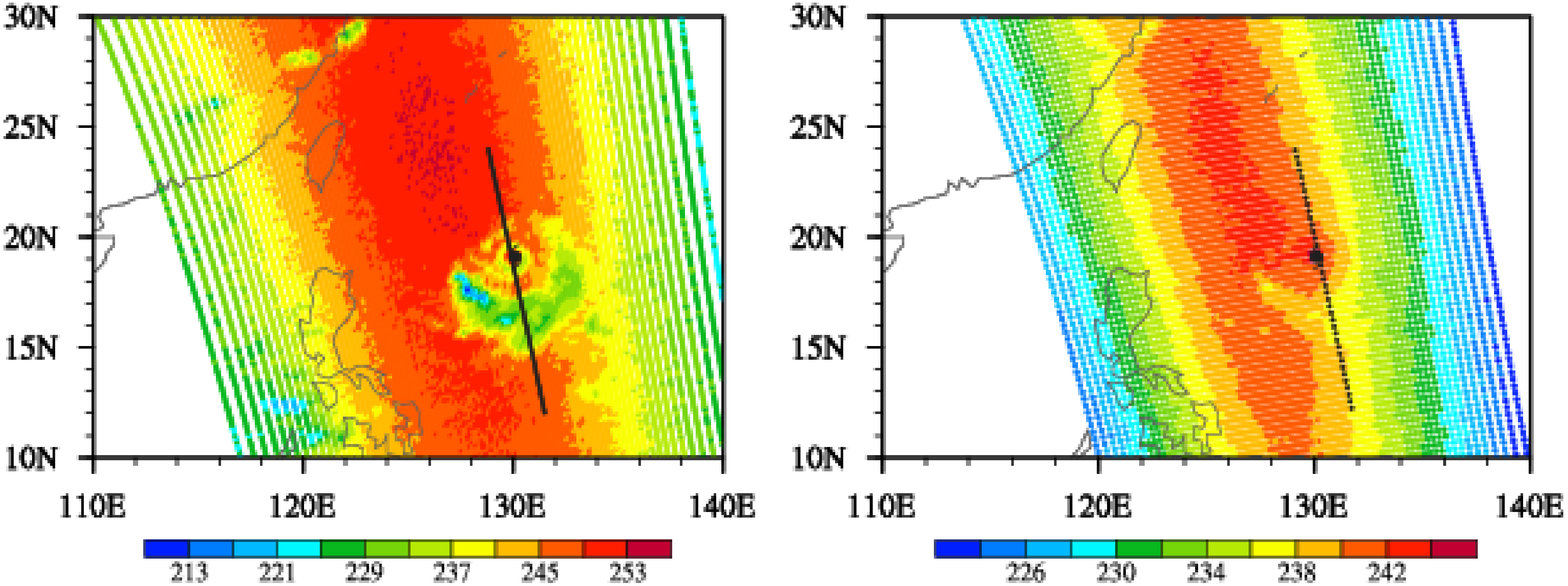


FY-3C MWHS (left panel) and MWTS (right panel) observations with weighting function peak near 230 hPa.

(Han et al., 2015 GRL)

MWHS CH6(118.75±0.8GHz) vs. MWTS CH5(54.94GHz) (300 hPa)

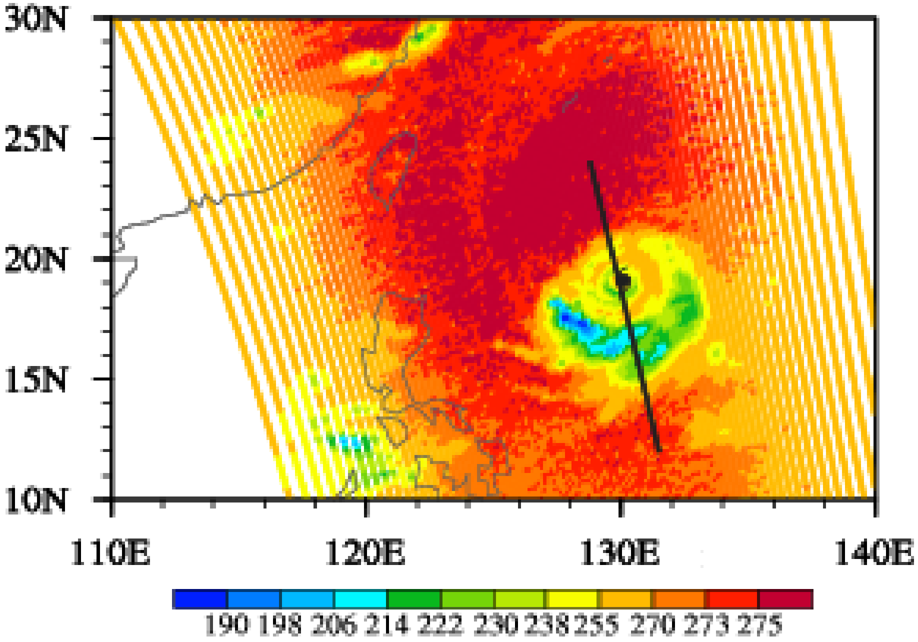
Super Typhoon Neoguri, 1236 UTC July 6, 2014

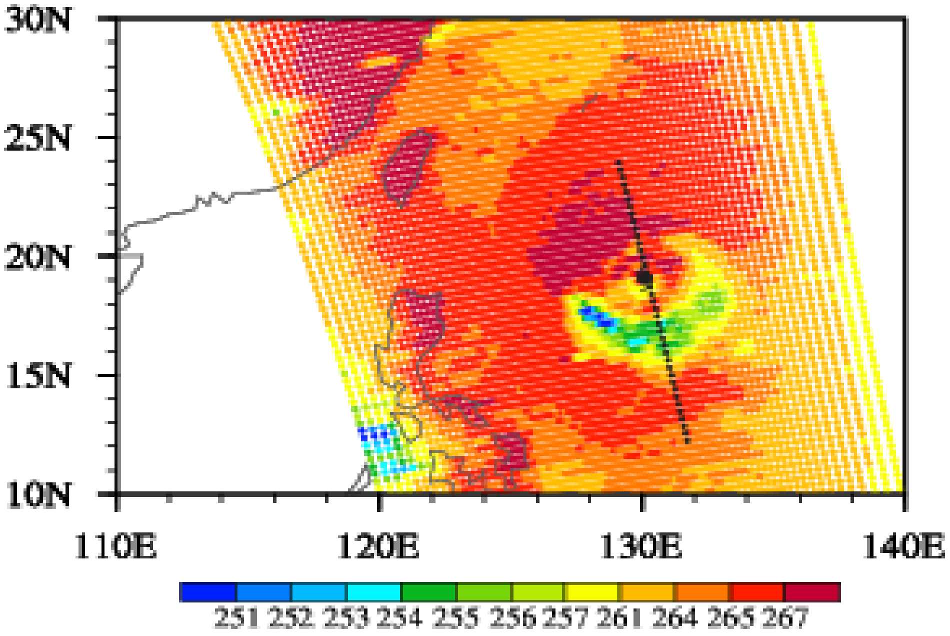


FY-3C MWHS (left panel) and MWTS (right panel) observations with weighting function peak at 300 hPa.

MWHS CH7(118.75±2.5GHz) vs. MWTS CH3(52.8GHz) (940 hPa)

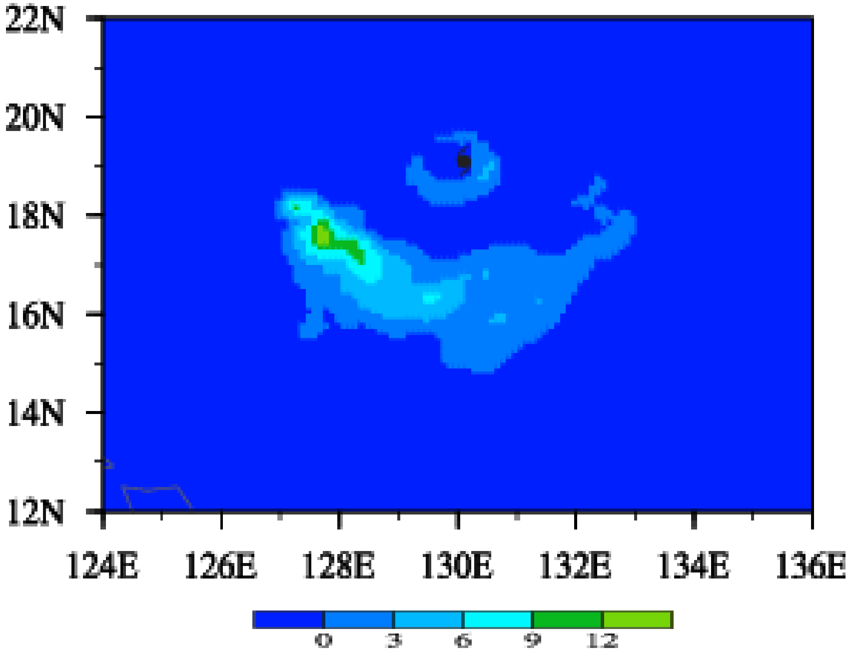
Super Typhoon Neoguri, 1236 UTC July 6, 2014



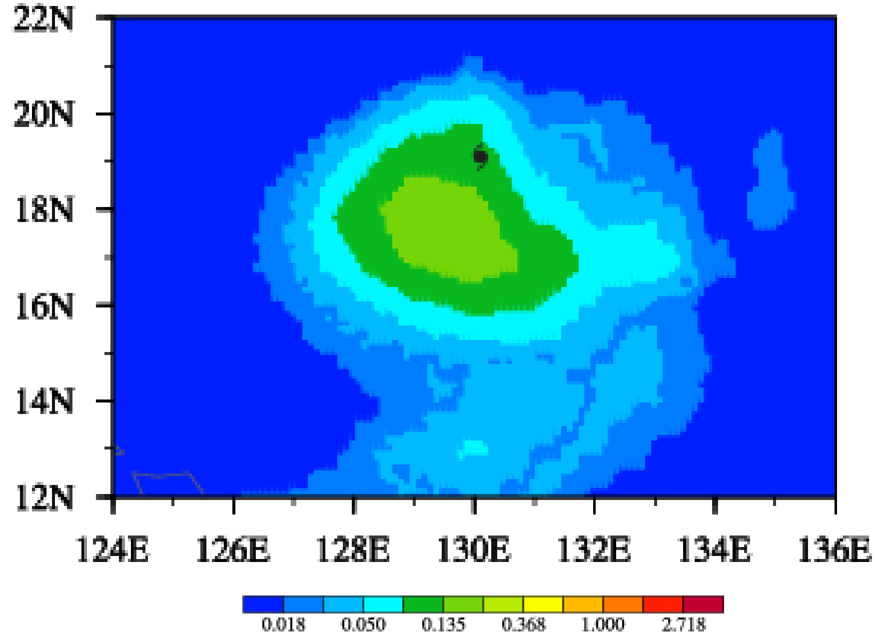


FY-3C MWHS (left panel) and MWTS (right panel) observations with weighting function peak at 940 hPa.

Cloud Scattering and Emission Index (CESI) vs. ECMWF Total Water Path (200 hPa)



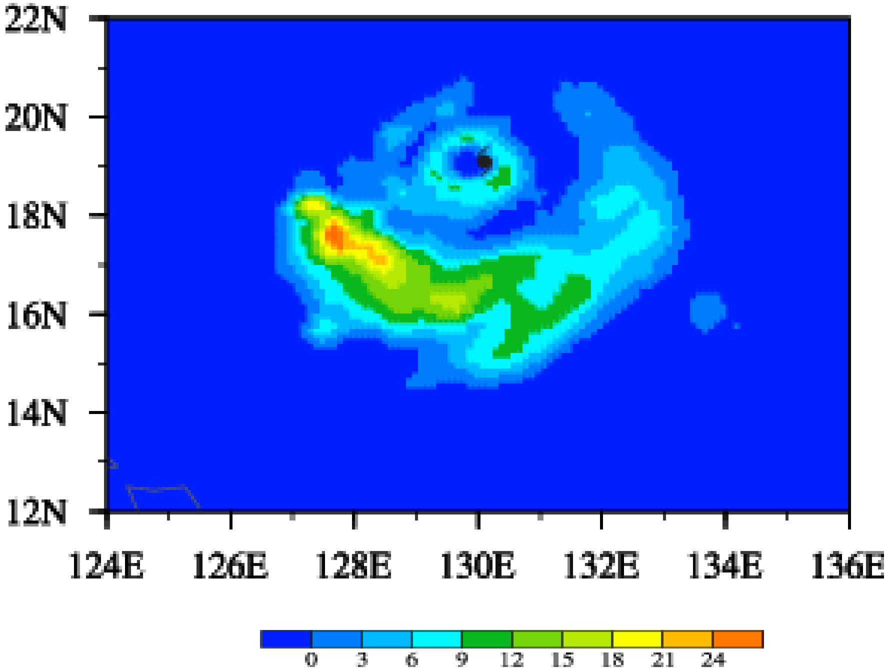
CESI



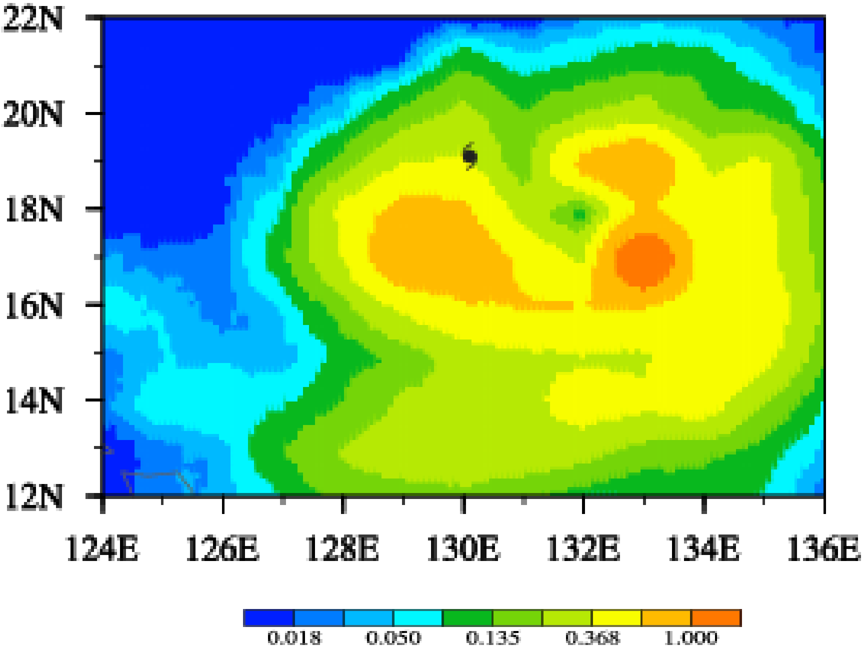
TWP (kg/m^2)

ECMWF total water path (ice+liquid) is derived by integrated all the hydrometeor mixing ratio above 200 hPa

Cloud Scattering and Emission Index (CESI) vs. ECMWF Total Water Path (500 hPa)



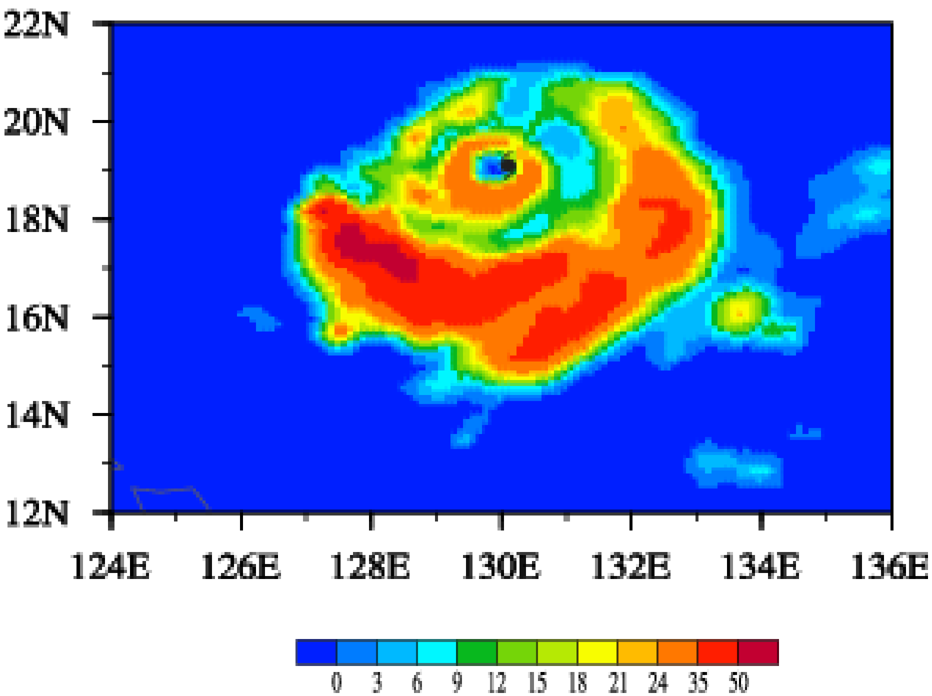
CESI



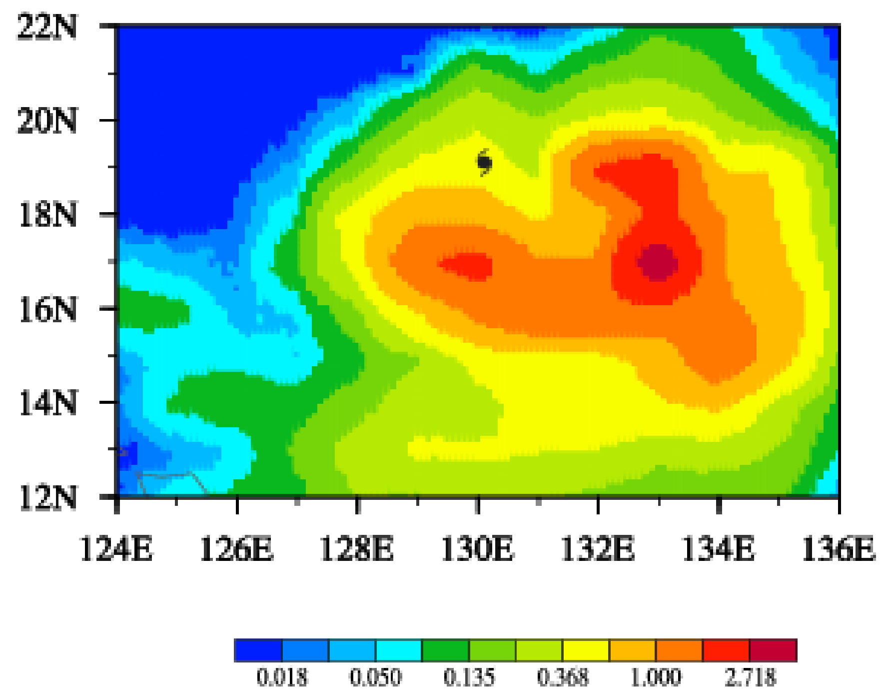
TWP (kg/m^2)

ECMWF total water path is derived by integrated all the hydrometeor mixing ratio above 500 hPa

Cloud Scattering and Emission Index (CESI) vs. ECMWF Total Water Path (850 hPa)



CESI



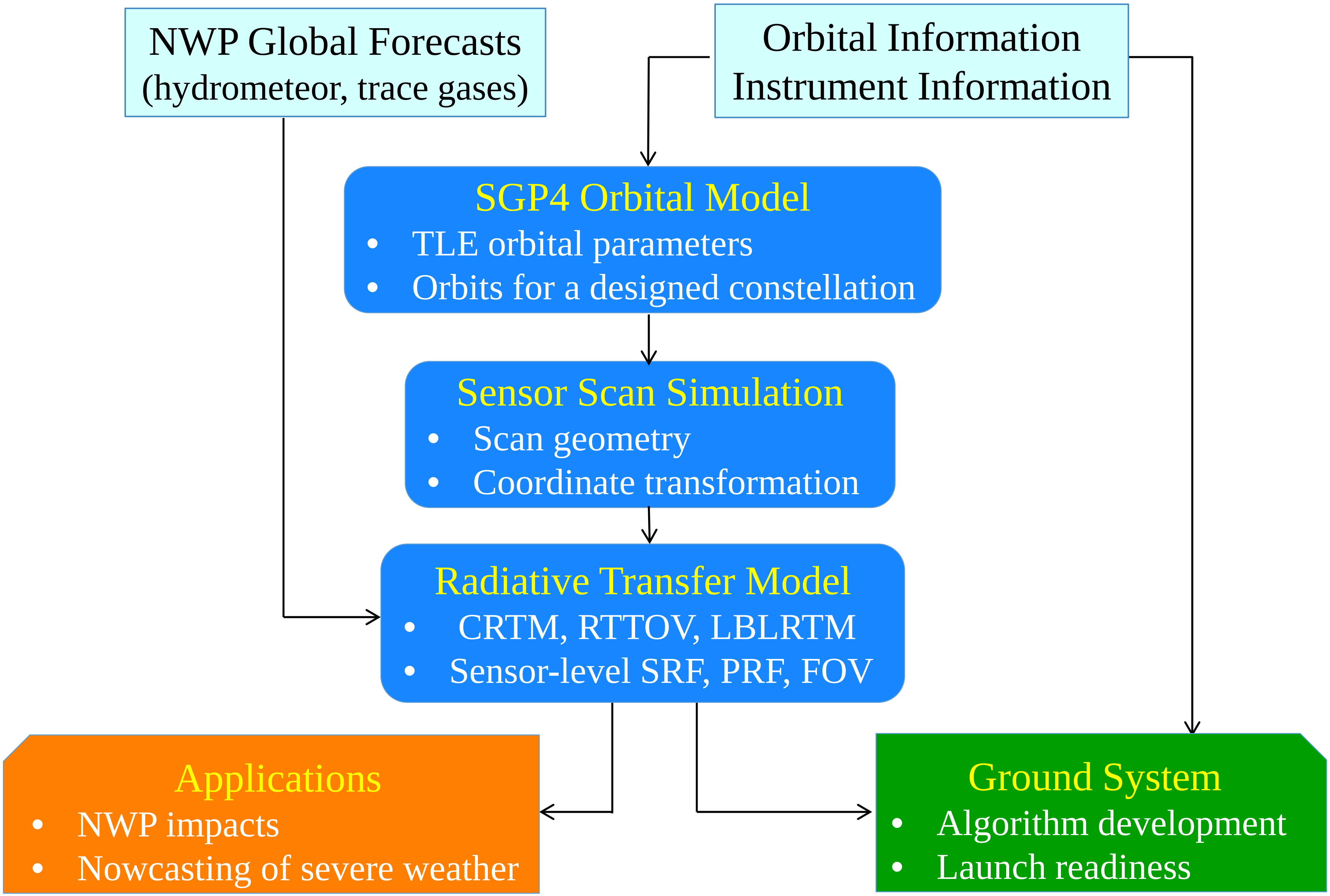
TWP (kg/m^2)

ECMWF Total Water Path is derived by integrated all the hydrometeor mixing ratio above 850 hPa

Space Sensor Simulator for Smallsat Mission

- Space Sensor Simulator (S^3) is developed for small satellite missions that have passive (e.g. microwave sounder) to active sensors
- Smallsat proxy data sets are produced for testing the instrument calibration, products and algorithms
- The proxy data are also converted to the formats required in the numerical weather prediction models and forecasting applications

Space Sensor Simulator (S^3)



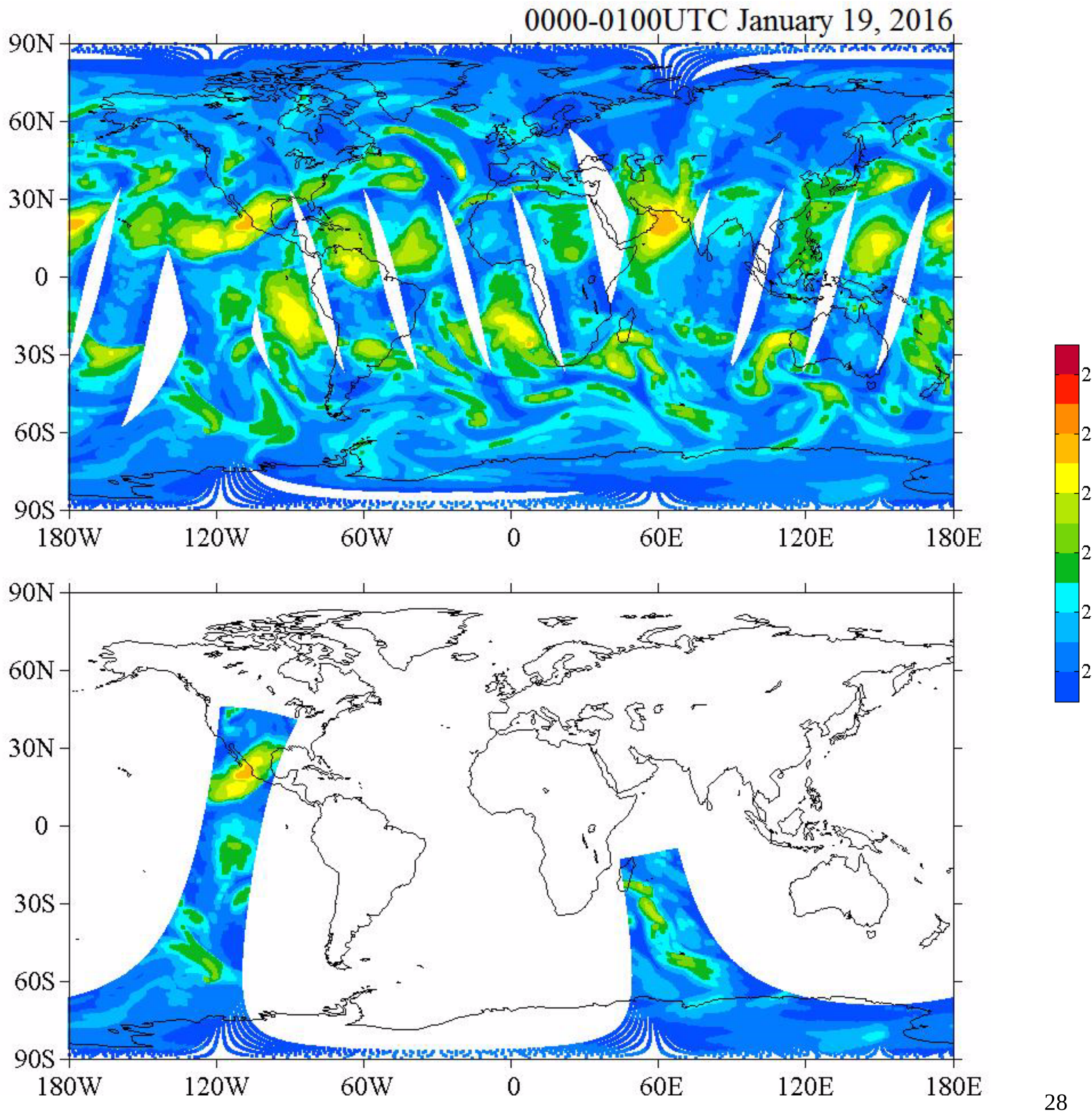
Comparison of Hourly Coverage between 14 Smallsat and Suomi NPP Satellite

Smallsat Simulation

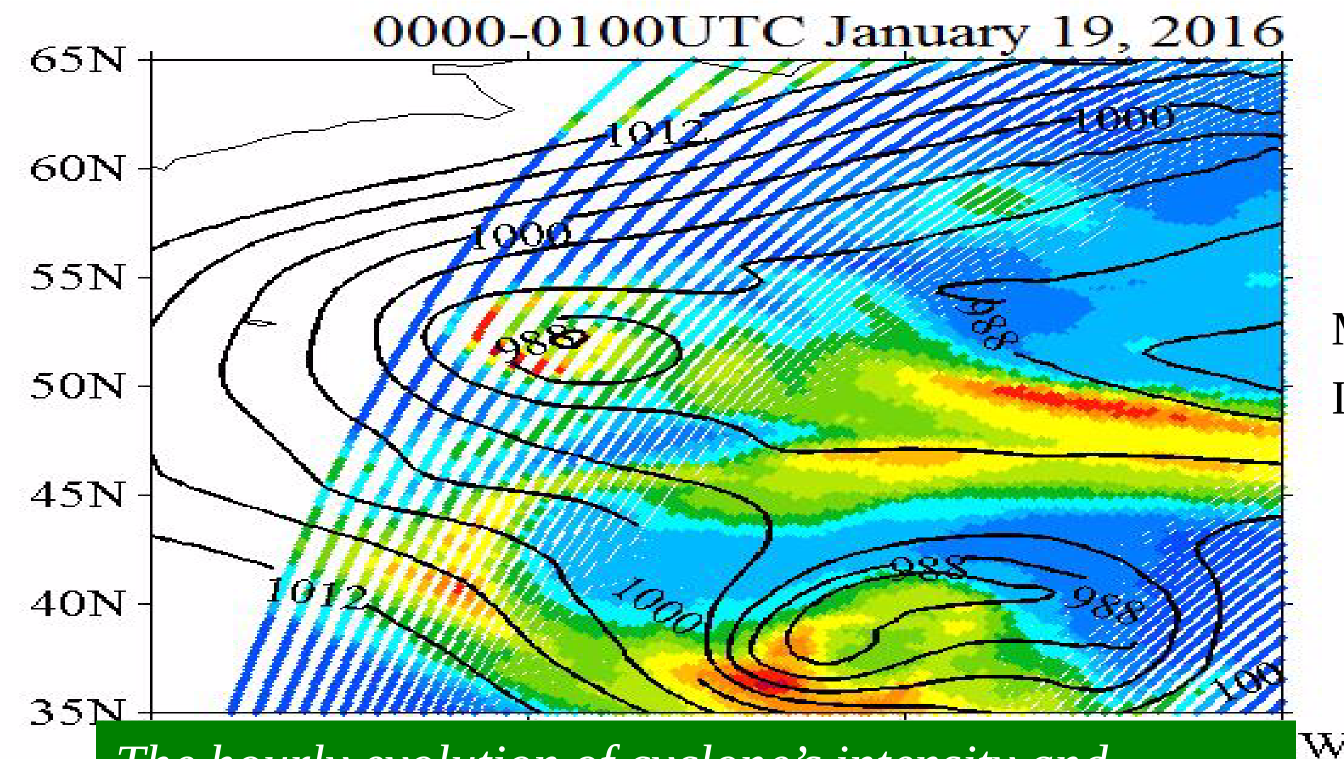
POES Observations

- NCEP operational forecast ouputs are used as input to CRTM simulation
- ATMS channel 22 and its scan geometry

Ma et al., 2017, IEEE J-STARS



Small Satellite MW Sounder Simulations for a Mid-latitude Cyclone



Ma et al., 2017, IEEE J-STARS

The hourly evolution of cyclone's intensity and structural change are captured by smallsat observations. Thus, A smallsat constellation with microwave sensors onboard can be designed optimally at high spatial and temporal resolutions for both NWP and severe storm monitoring/nowcasting

Summary and Conclusions

- Microwave sounder such as ATMS is very capable of monitoring hurricanes and can define the storm intensity through its warm core products.
- Assimilation of MW sounder data in hurricane models can improve forecasts of hurricane track and intensity.
- Establishing a calibration standard is critical for characterizing smallsat MW sounder performance in orbit
- 12 smallsats in combination with FY3/NOAA/METOP satellites can offer hourly refreshing of global coverage
- MW sounders with double O_2 bands (e.g. FY3 MWTS/MWHS) are of high values and are recommended as the major smallsat payloads