

# Improving Tropical Cyclone Forecasts by Assimilating Microwave Sounder Cloud-Screened Radiances and GPM precipitation measurements

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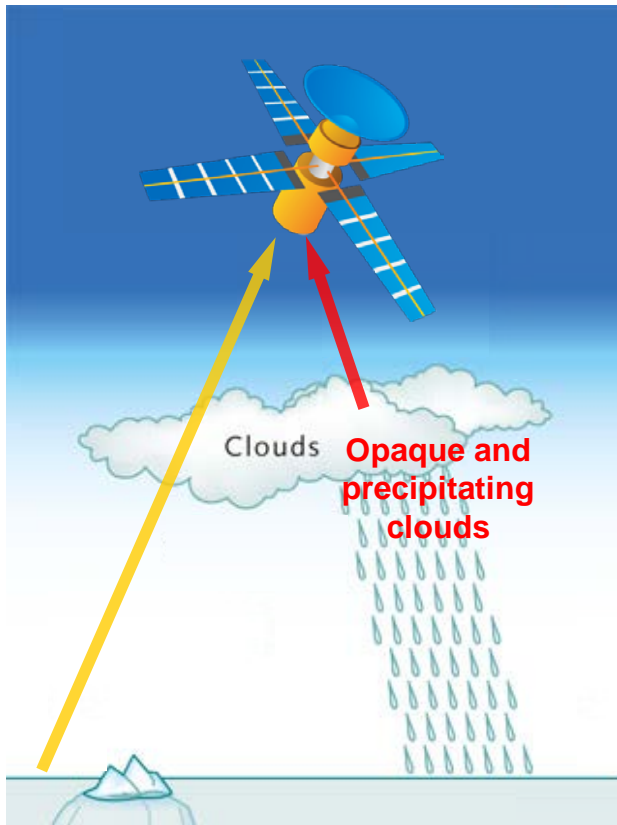
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<sup>d</sup>School of Earth and Environmental Sciences, Seoul National University



# Motivation

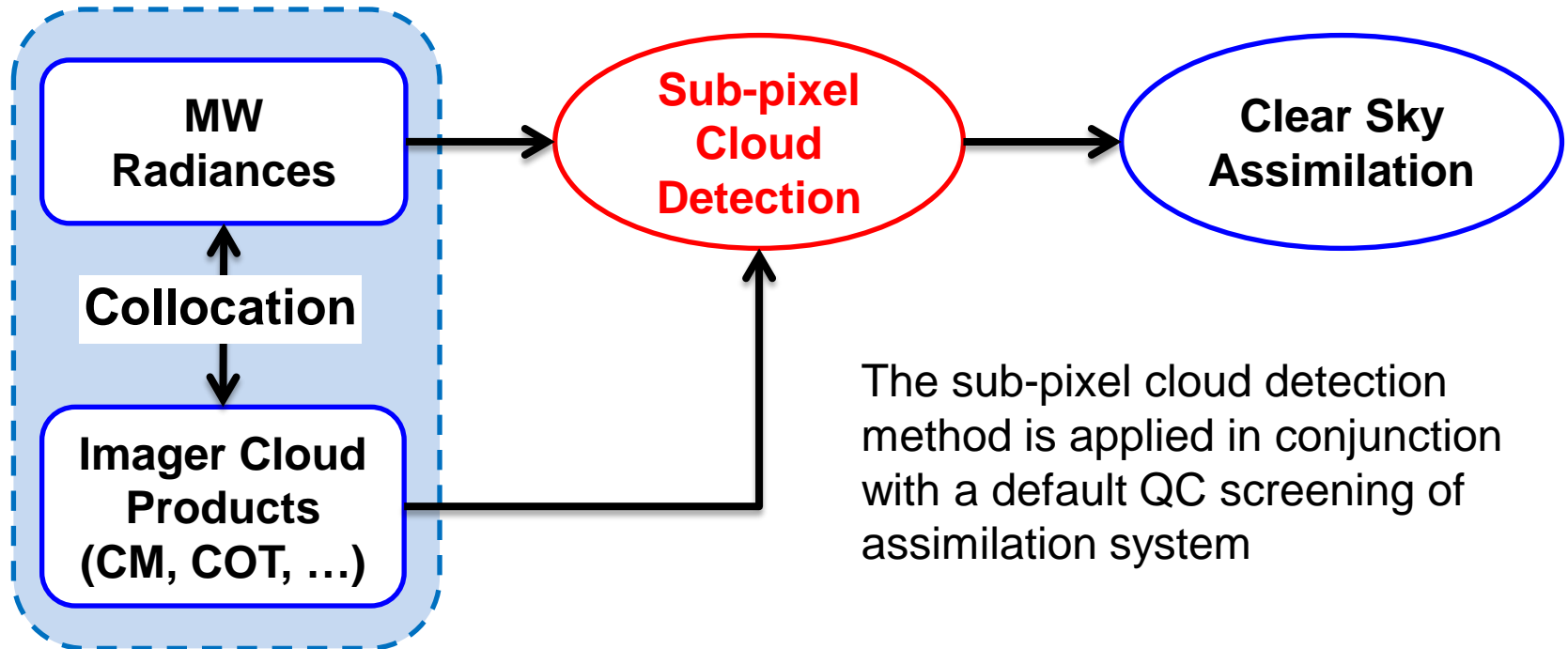
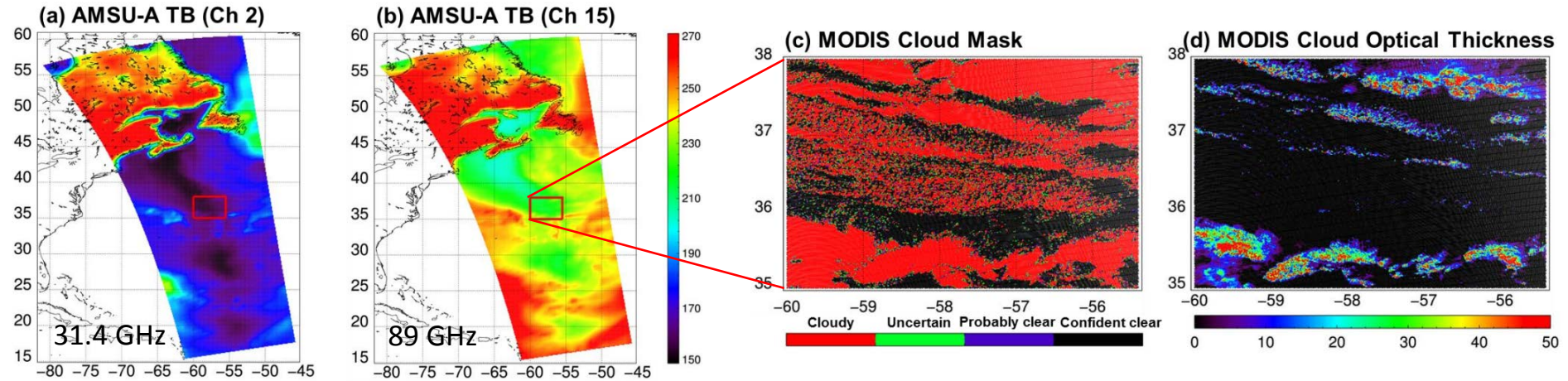


Improve the assimilation of thermodynamic information from MW sounder radiances in cloudy regions

- Using pixels not affected by clouds
- Direct assimilation of cloudy radiances using RTM
- Alternative approach for assimilating thermodynamic information

# Sub-Pixel Cloud Detection Method

Microwave Sounders: about 48 km spatial resolution at nadir



The sub-pixel cloud detection method is applied in conjunction with a default QC screening of assimilation system

# Assimilation System and NWP Model

## Gridpoint Statistical Interpolation (GSI) v3.3:

- Unified variational data assimilation system for both global and regional applications
- Developed by NOAA NCEP based on the operational Spectral Statistical Interpolation analysis system.
- The core of the NDAS for NAM, GDAS for GFS at NOAA, and various operational systems.

## Weather Research and Forecasting Model (WRF) v3.6:

- Next-generation mesoscale numerical weather prediction system
- Developed by NCAR, NOAA, AFWA, NRL, OU, and FAA.
- Applicable for both meteorological research and numerical weather prediction.

## Community Radiative Transfer Model (CRTM):

- Fast radiative transfer model for calculation of radiances for satellite IR or MW radiometers.
- Developed by JCSDA as an important component in the NOAA/NCEP data analysis system.
- Implemented into GSI system as its radiative transfer model.

# Dataset for Assimilation System

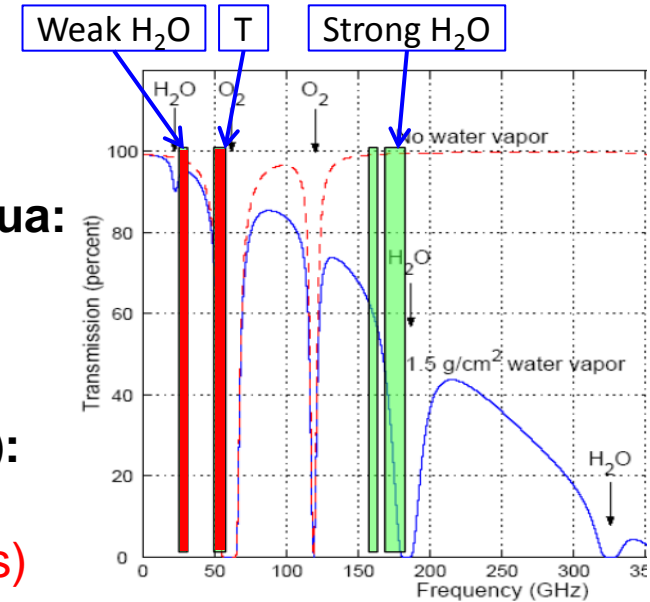
## Microwave Sounders:

### 1. Advanced Microwave Sounding Unit (AMSU)-A/Aqua:

- Microwave radiometer installed on Aqua platform
- 15 channels from 23.8 GHz to 89.0 GHz (T bands)
- 48 km spatial resolution at nadir

### 2. Advanced Technology Microwave Sounder (ATMS):

- Microwave radiometer installed on NPP platform
- 22 channels from 23.8 GHz to 183 GHz (T & q bands)
- 48 km spatial resolution at nadir



Green: ATMS

Red: AMSU-A & ATMS

## Visible/Infrared Imagers:

### 1. Moderate Resolution Imaging Spectroradiometer (MODIS)/Aqua:

- Cloud mask at 1 km spatial resolution

### 2. Visible Infrared Imaging Radiometer Suite (VIIRS)/NPP:

- Cloud mask and cloud optical thickness (COT) at 750 m spatial resolution

## WMO Global Telecommunication System (GTS) Data:

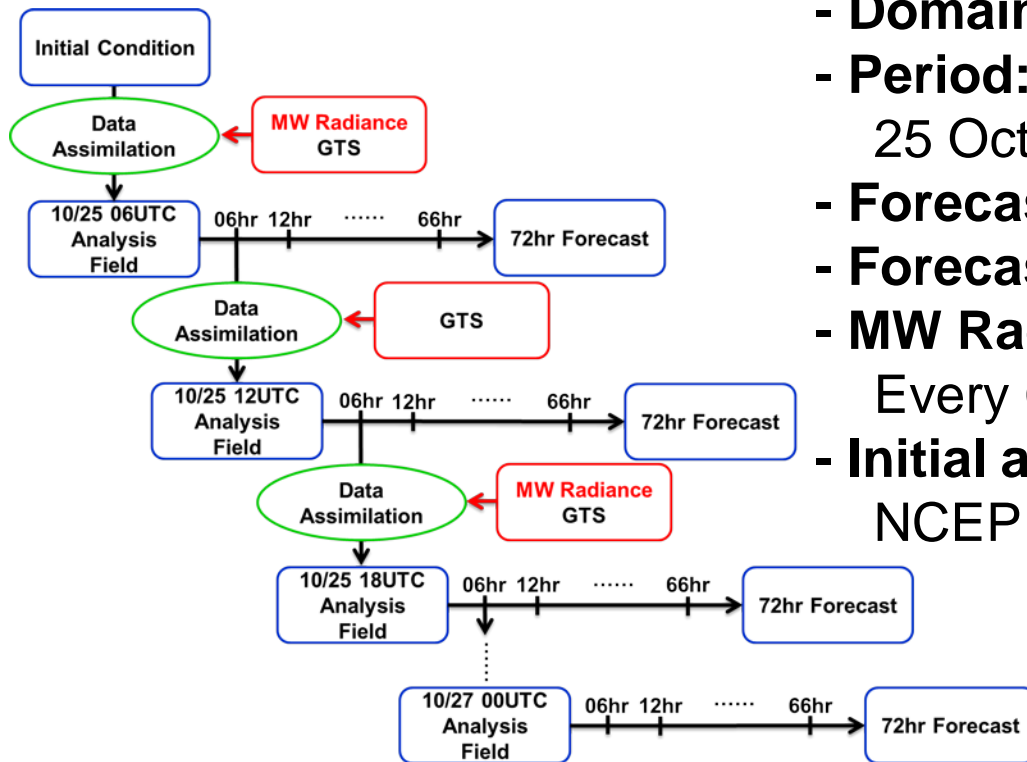
- Composed of surface observations, radiosondes, wind profiles, and aircraft data.

# Experiments for Hurricane Sandy

- Formed in the western Caribbean Sea on Oct. 24, 2012 and dissipated over Eastern Canada on Nov. 2, 2012.
- 147 direct deaths recorded across the Atlantic basin
- Preliminary U.S. damage estimates are near \$50 billion.



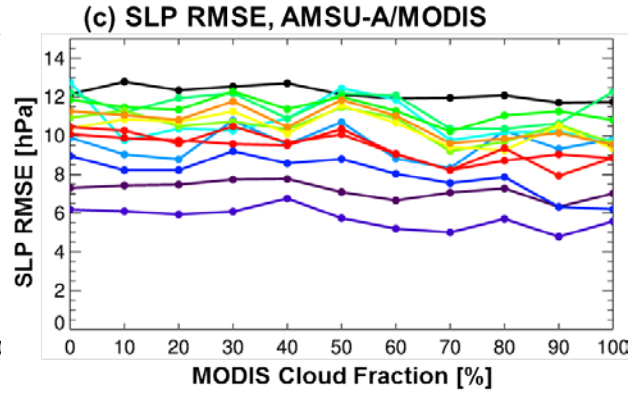
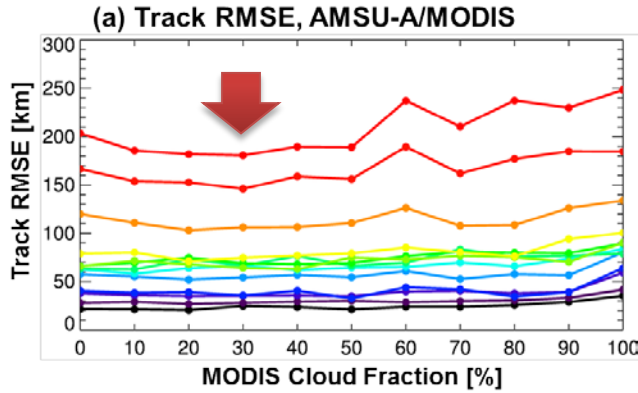
## Assimilation System Design



- **Domain:** 5N ~ 50N, 40W ~ 100W
- **Period:**  
25 Oct, 2012 06UTC ~ 30 Oct 00 UTC
- **Forecast Running Time:** 72 hr (3 days)
- **Forecast Cycle:** 6 hr
- **MW Radiance Assimilation:**  
Every 06 and 18 UTC
- **Initial and Boundary Conditions:**  
NCEP Final Operational Global Analysis

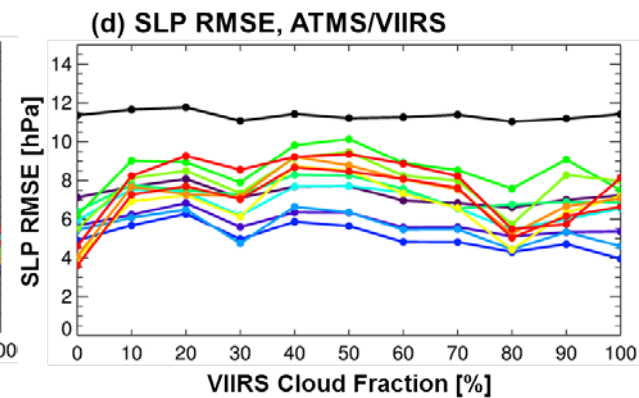
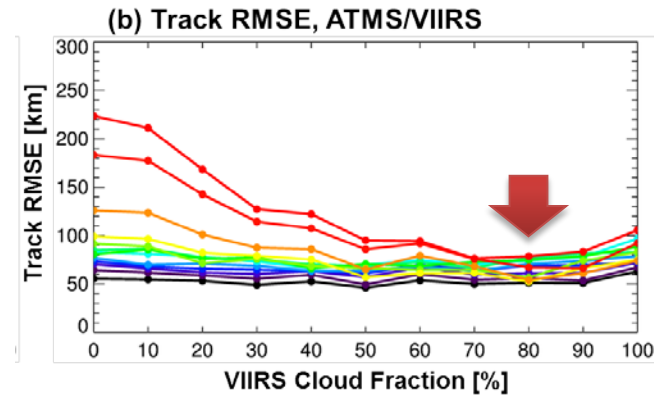
# Forecast Results for Various Cloud Fractions

AMSU-A  
MODIS



- 0 hr
- 6 hr
- 12 hr
- 18 hr
- 24 hr
- 30 hr
- 36 hr
- 42 hr
- 48 hr
- 54 hr
- 60 hr
- 66 hr
- 72 hr

ATMS  
VIIRS

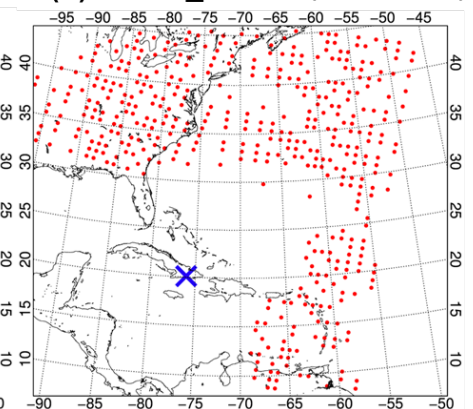
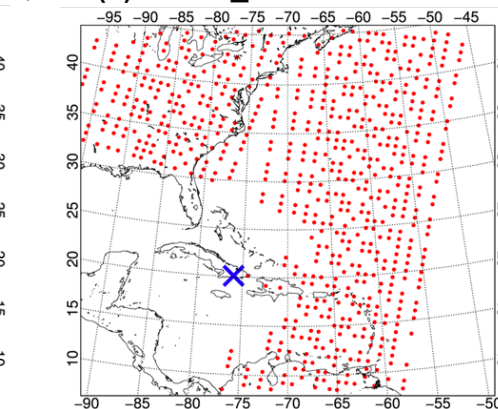
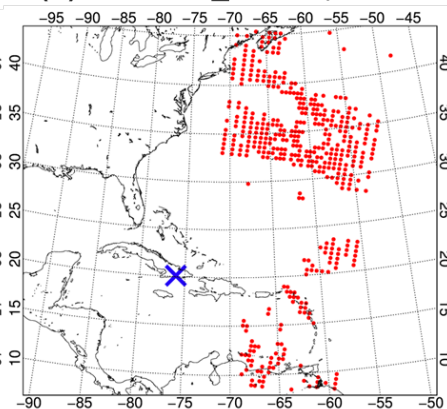
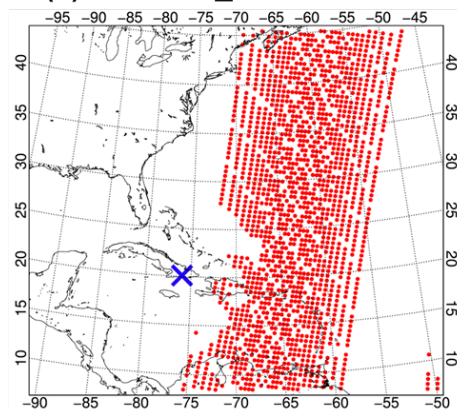


(a) AMSU-A\_GSI

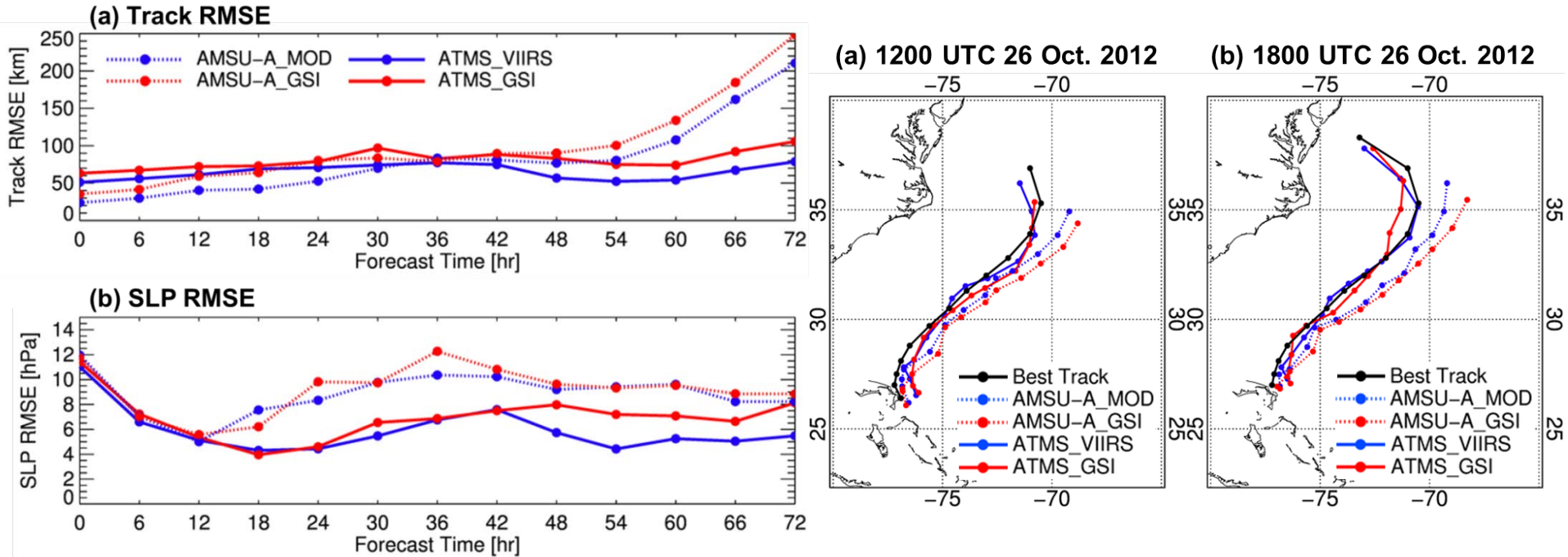
(b) AMSU-A\_MOD (CF<70%)

(c) ATMS\_GSI

(d) ATMS\_VIIRS (CF<80%)



# Hurricane Track and SLP RMSE Improvement

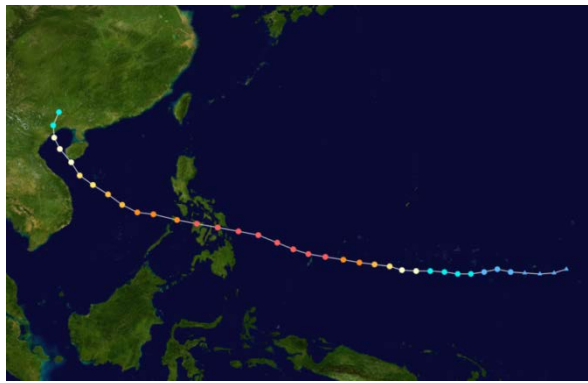


- The track and SLP RMSEs are reduced for the entire forecast times when the cloud-contaminated radiances are rejected with the collocated high spatial resolution CF.
- Forecasting using ATMS radiances generally outperforms that of AMSU-A radiances.
- The tracks of the ATMS\_VIIRS show the closest approaching to the best tracks while the AMSU-A\_GSI tracks are far from the turning point.



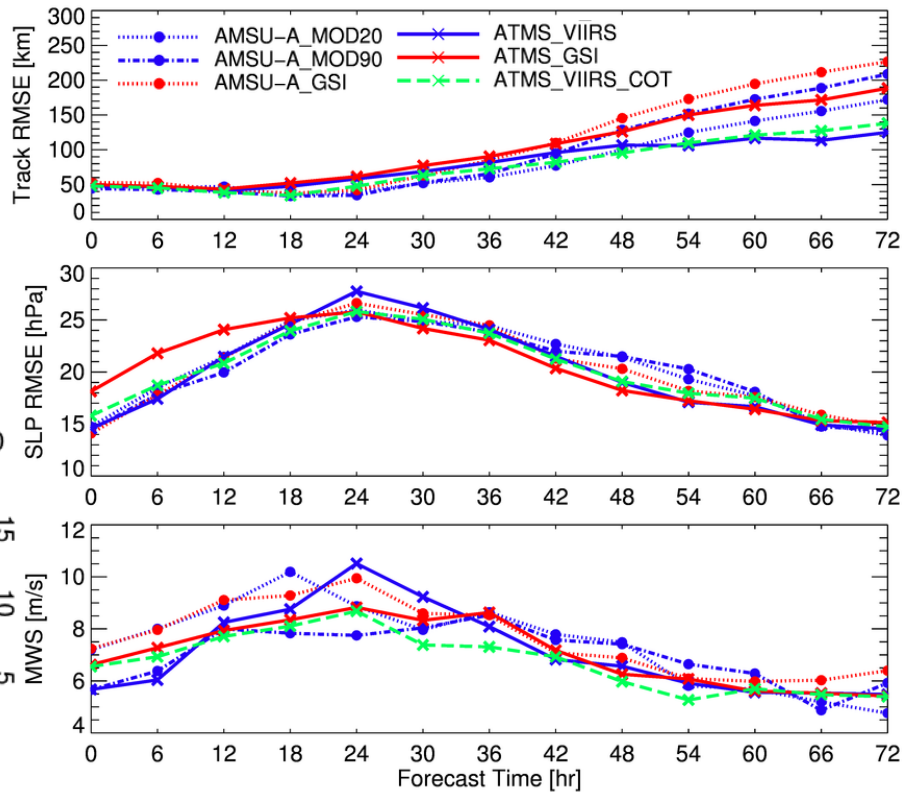
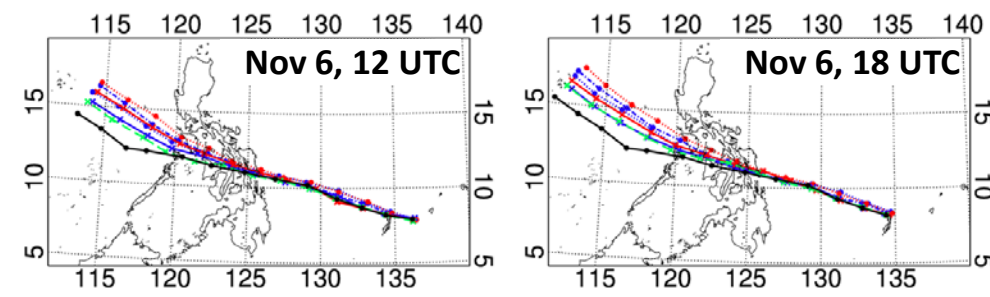
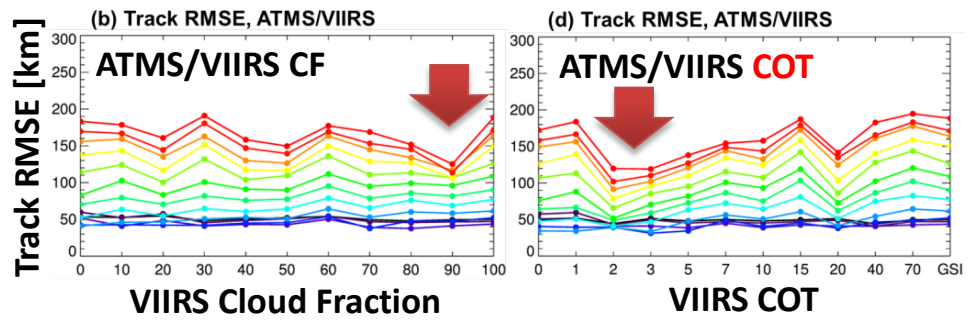
# Experiments for Typhoon Haiyan

- Formed over east-southeast of Micronesia on Nov. 3, 2013 and dissipated over Northern Vietnam on Nov. 11, 2013.
- The strongest typhoon recorded at landfall and 1-min sustained wind speed
- 6,300 deaths recorded in Philippines, and damage estimates are near \$2.86 billion.

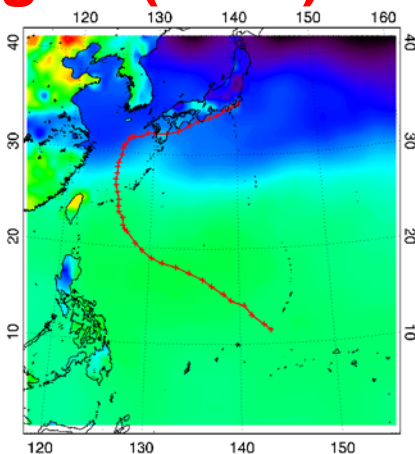
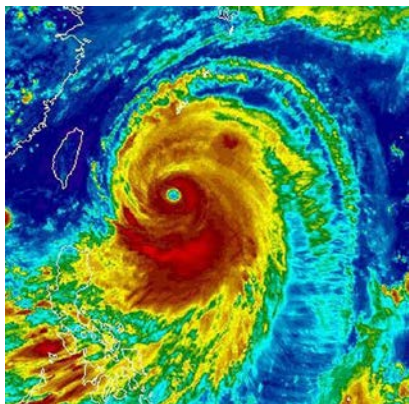


## Forecast Results for Various CF & COT

- Domain: 5S ~ 30N, 100E ~ 160E
- Period: 04 Nov, 2013 06UTC ~ 09 Nov, 2013 00 UTC



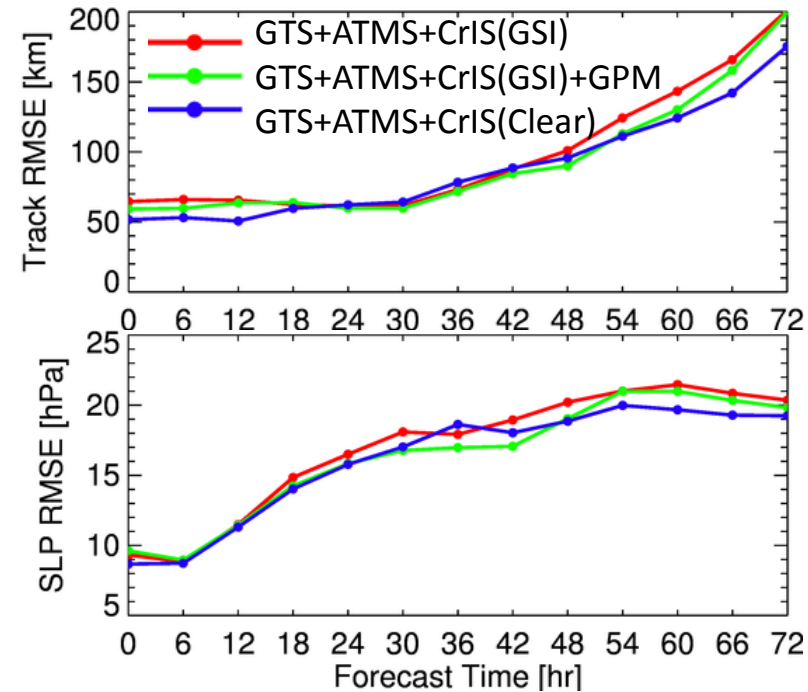
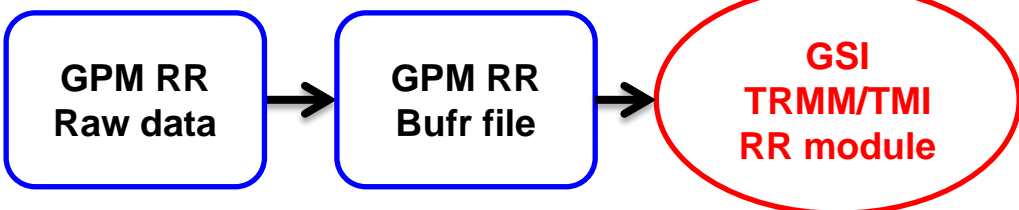
# Typhoon Neoguri (2014)



- **Domain:** 0N ~ 45N, 110E ~ 165E
- **Period:** 04 Jul, 2014 06UTC ~ 10 Jul 00UTC
- **Data assimilated**  
 MW sounder: ATMS/NPP radiance  
 IR hyperspectral: CrIS/NPP radiance  
**RR: GMI/GPM rain rate**

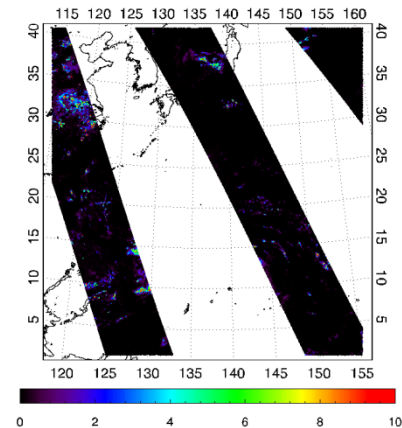
MTSAT IR Jul 07 0432UTC

Model Domain & Best Track (RSMC)

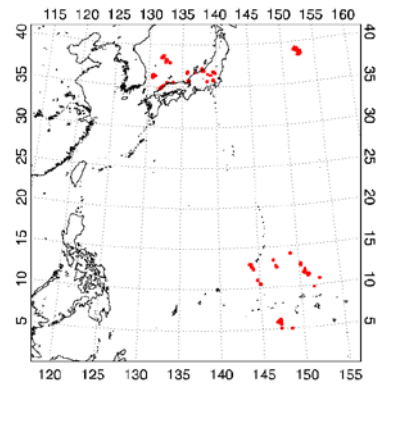


ATMS005\_CrIS05: ATMS (COT<5) + CrIS (CF<5%)

GPM/GMI RR [mm/hr]

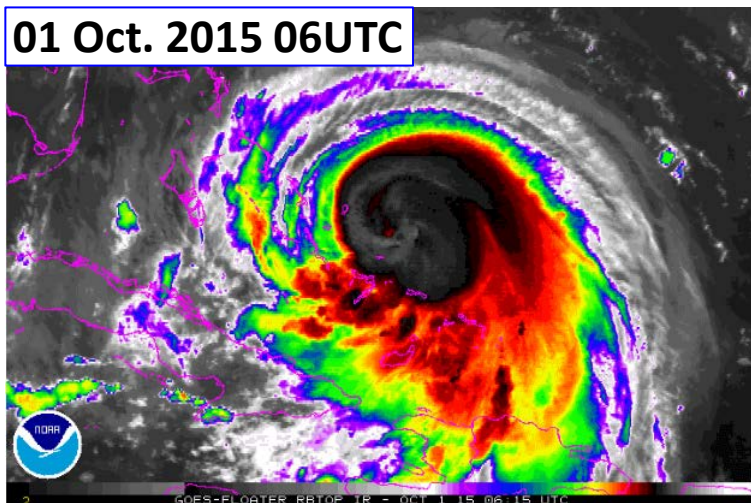


Assimilation Coverage

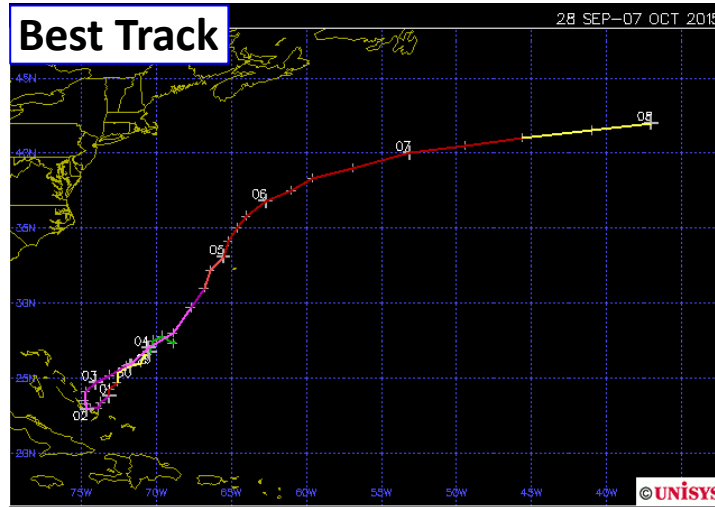


# Hurricane Joaquin (2015)

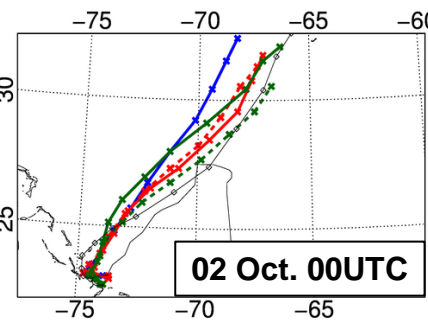
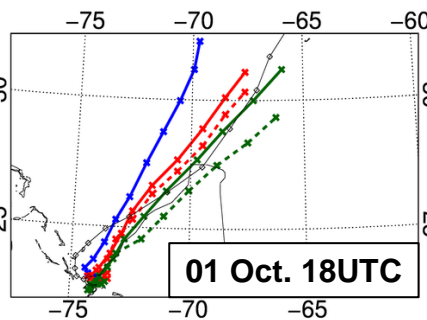
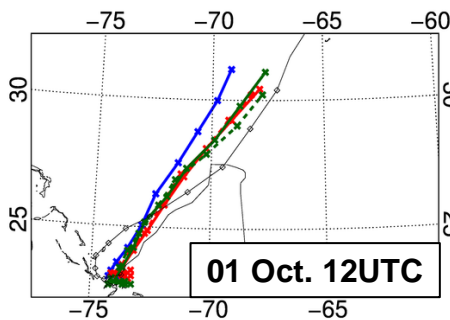
01 Oct. 2015 06UTC



Best Track

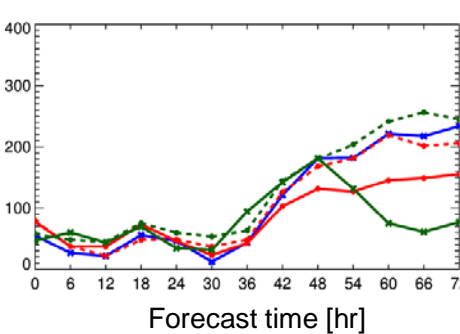
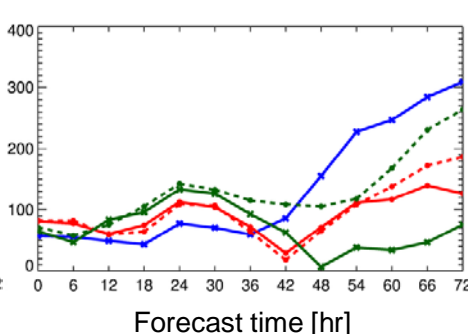
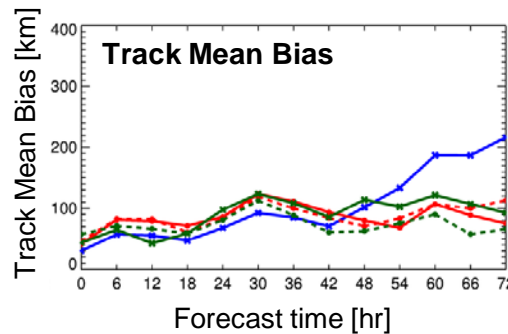


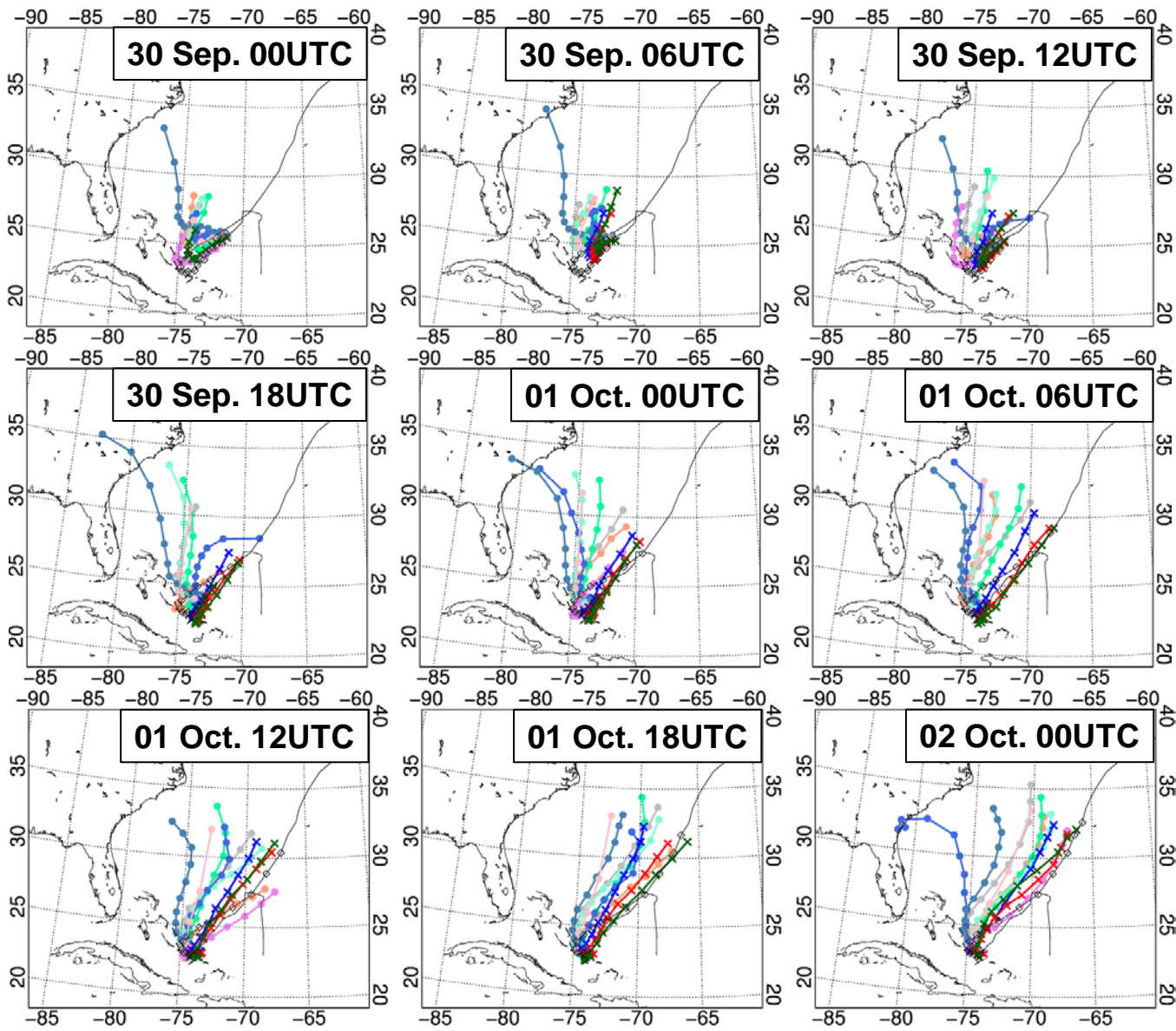
- Domain: 7N ~ 50N, 30W ~ 105W
- Period: 29 Sep, 2015 00UTC ~ 02 Oct 00 UTC



- ◆ Best Track
- ★ GTS
- ★ GTS + ATMS (GSI)
- × GTS + ATMS (COT<4)
- ★ GTS + JPSS (GSI)
- × GTS + JPSS (clear)

JPSS (clear):  
ATMS (COT<4) + CrIS (CF<5%)





- GSI/WRF Exp.**
- ✕ GTS
  - ✕ GTS+ATMS(COT<4)
  - ✕ GTS+JPSS(clear)
- Real-Time Guidance**
- AVNO
  - COTC
  - GFDL
  - HWRF
  - NAM
  - NVGM
  - OFCL
  - UKM

**AVNO:** GFS Model  
**COTC:** NRL COAMPS-TC model  
**GFDL:** Geophysical Fluid Dynamics Laboratory Model  
**HWRF:** Hurricane Weather Research and Forecast

**NAM:** North American Mesoscale Forecast System  
**NVGM:** Navy Global Environmental Model  
**OFCL:** NHC Official Forecast  
**UKM:** UK Metoffice Model

# Summary and Conclusions

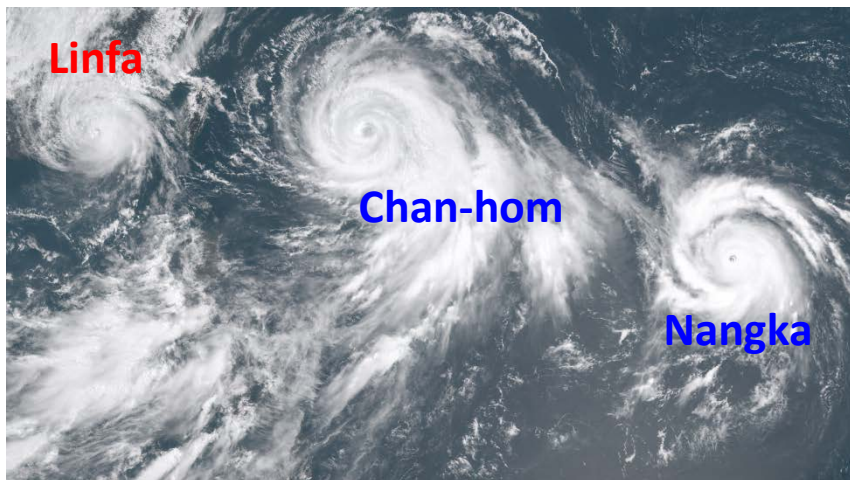
## Sub-pixel cloud detection method

- A methodology for **MW sub-pixel cloud detection with collocated high spatial resolution cloud product** has been developed.
- MODIS and VIIRS cloud products (cloud mask, COT) was used for AMSU-A and ATMS sub-pixel cloud characterization for radiance assimilation, respectively.
- To access to the impact of the methodology on radiance assimilation, several tropical cyclones have been studied with WRF/GSI.

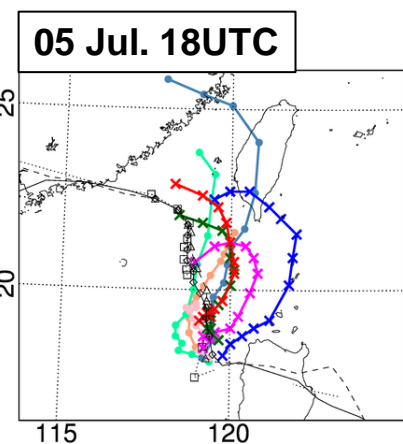
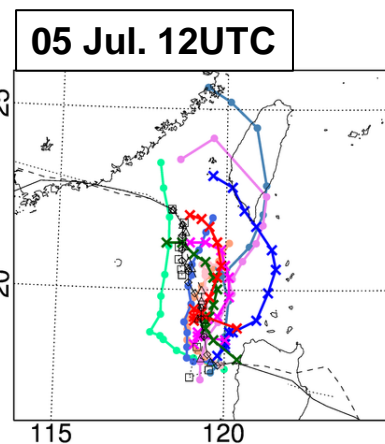
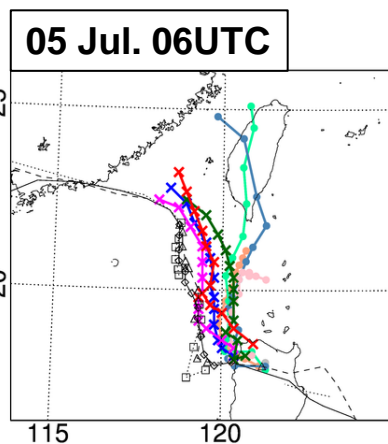
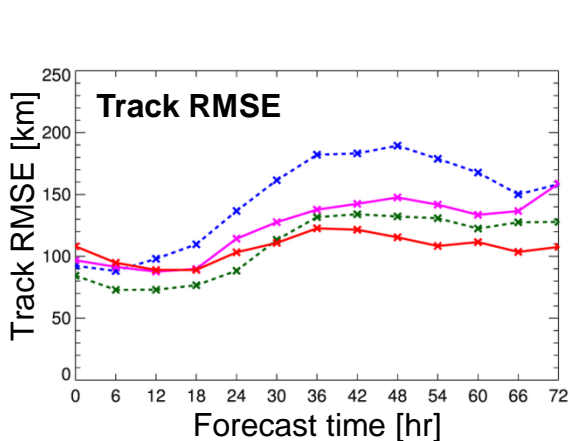
## Tropical cyclone forecasts

- After cloud detection with imagers, MW radiance assimilation **generally improves track and SLP forecasts**.
- The preliminary results shows a capability of **combination with other satellite data (ex GPM RR, CrIS, TPW)** in data assimilation for TC forecasts.
- The sub-pixel cloud detection method used here can also be applied to process measurements from other pairs of MW sounder and imager cloud products.

# Severe Tropical Storm Linfa



- **Domain:** 2N ~ 31N, 104E ~ 142E
- **Period:** 02 Jul 2015 06UTC ~ 09 Jul 00 UTC
- **Data assimilated**  
 MW sounder: ATMS/NPP radiance  
 IR hyperspectral: CrIS/NPP radiance  
**TPW: Himawari-8 AHI TPW**



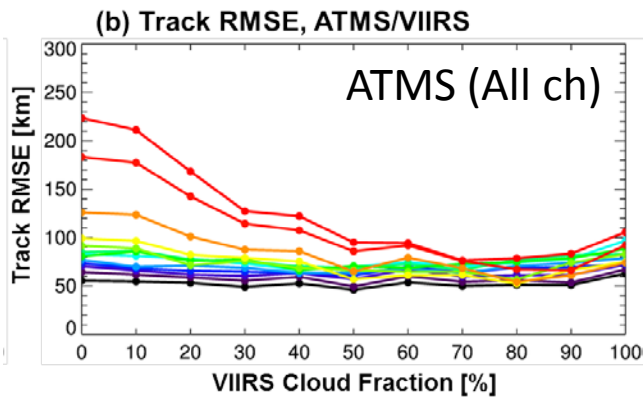
## GSI/WRF Exp.

- x— GTS
- x— GTS+TPW
- x— GTS+JPSS
- x— GTS+JPSS (clear)

## Real-Time Guidance

- CARQ
- CHIP
- COTC
- GFDN
- GFSO
- NVGM
- UKM

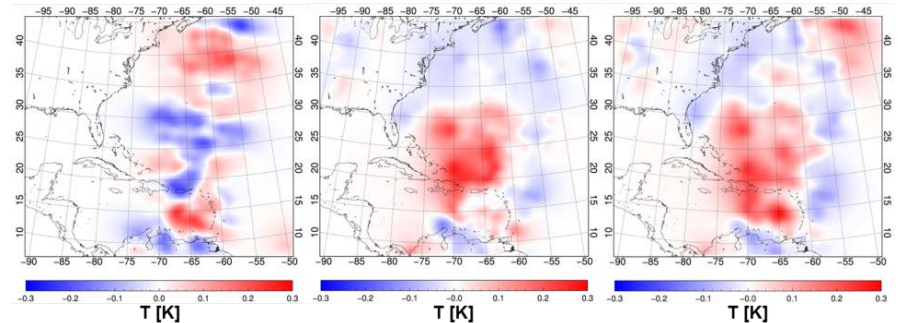
Use of JPSS radiances, sub-pixel cloud detection, geostationary satellite TPW improves the track forecast of Linfa.



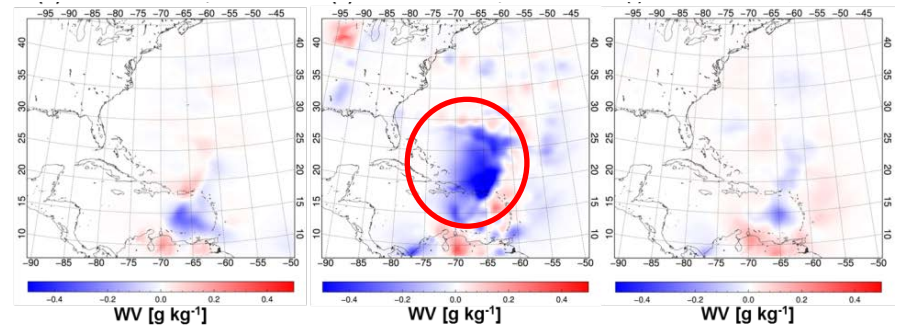
## Analysis Field Diff (Subpixel – GSI)

AMSU-A      ATMS      ATMS (sub)

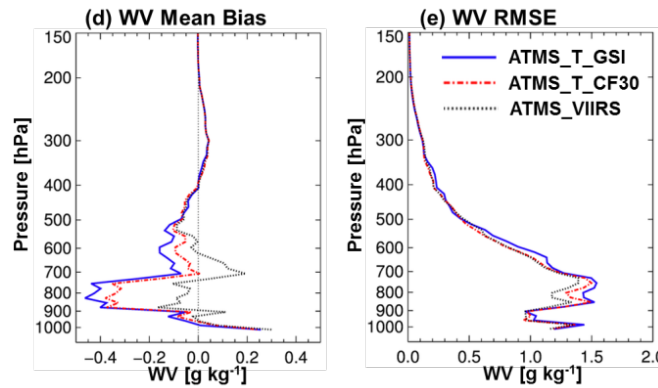
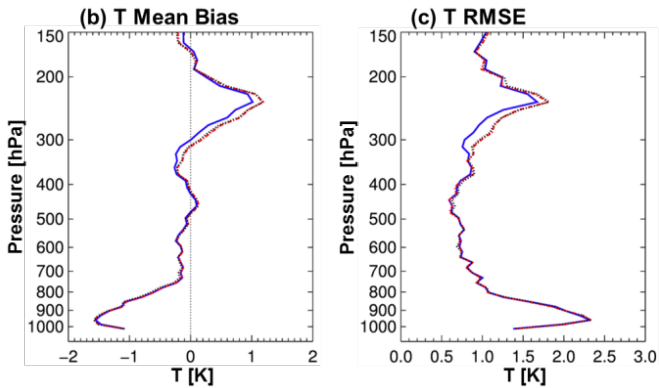
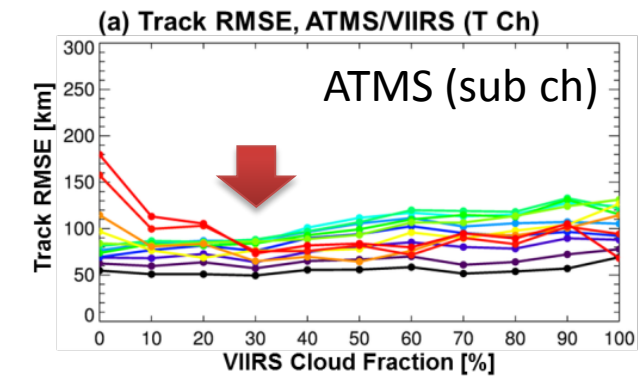
T500



q500



H<sub>2</sub>O channels have a strong influence on the assimilation

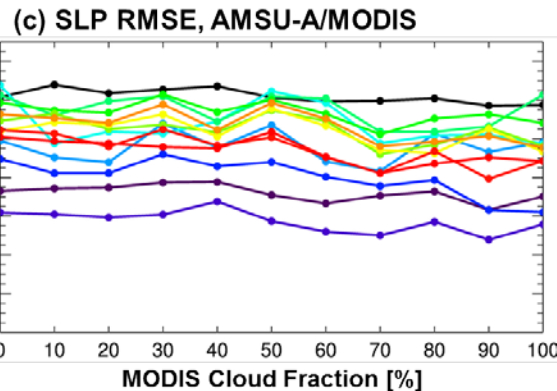
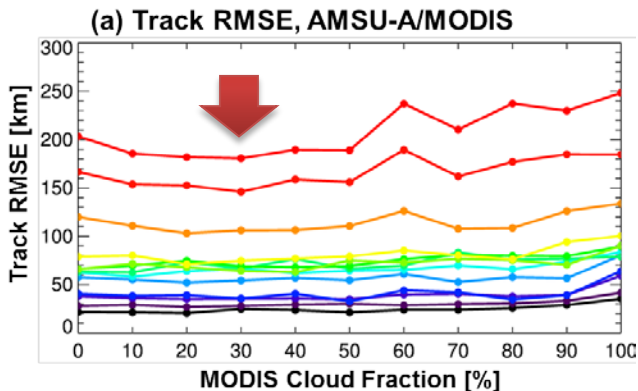


The sub-pixel cloud detection primarily effects on WV field even though the strong H<sub>2</sub>O band (183 GHz) is not used.

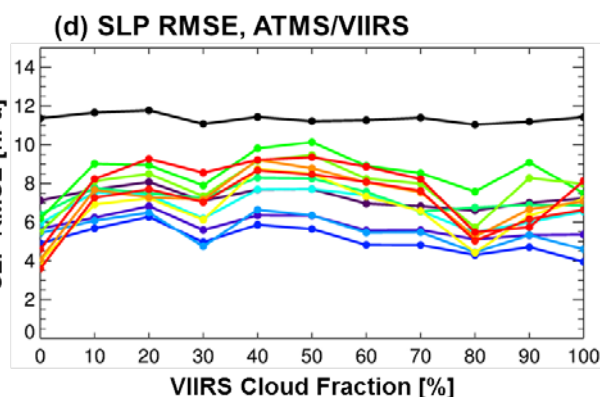
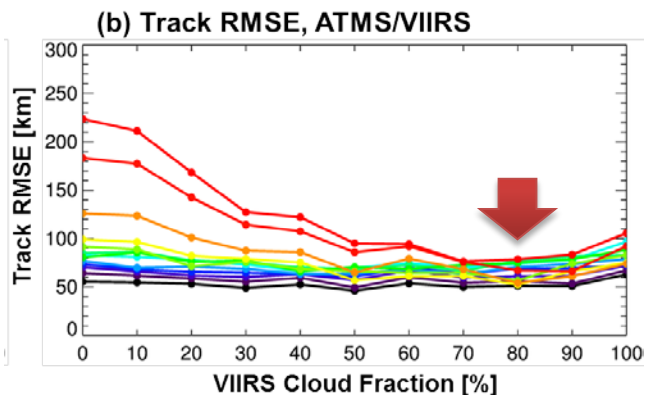
Since signal of the WV around 50.3 – 58.3 GHz is relatively small, **more strict cloud screening thresholds are required (lower CF numbers)** without the strong absorption by WV at 183 GHz.

# Forecast Results for Various Cloud Fractions

**AMSU-A  
MODIS**

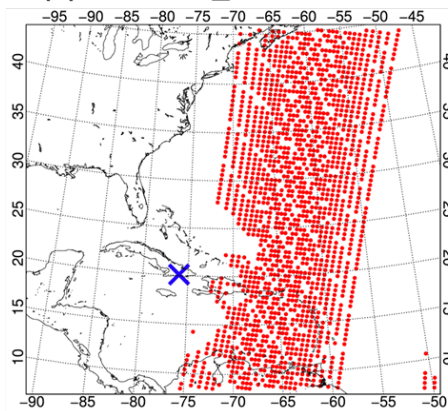


**ATMS  
VIIRS**

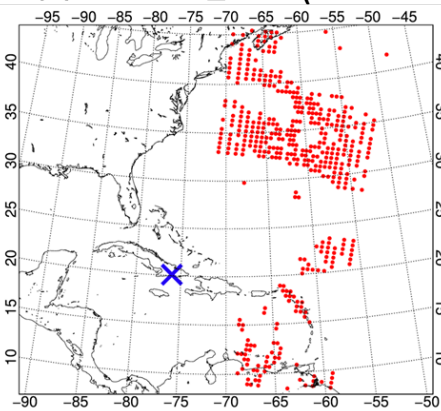


- 0 hr
- 6 hr
- 12 hr
- 18 hr
- 24 hr
- 30 hr
- 36 hr
- 42 hr
- 48 hr
- 54 hr
- 60 hr
- 66 hr
- 72 hr

(a) AMSU-A\_GSI



(b) AMSU-A\_MOD(CF<70%)



Analysis Q500 Diff (Subpixel – GSI)

