Comparing Hurricane Earl's Structures Observed by Microwave Humidity Sounders with Radar Observations and HWRF Simulation

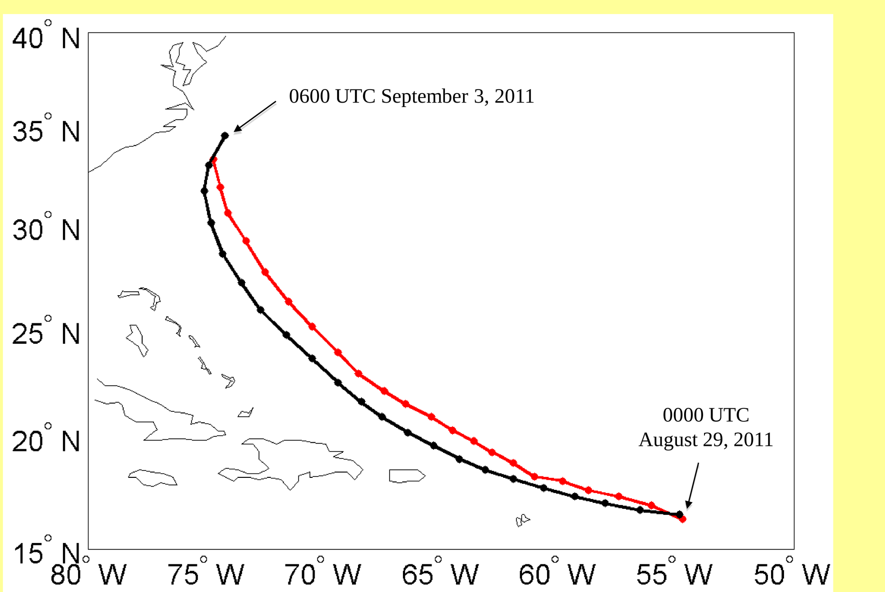
Q. Shi and X. Zou
Department of Earth, Ocean and Atmospheric Sciences, Florida State University, Tallahassee, Florida

Abstract

The potential applications of high-frequency microwave brightness temperature (TB) observations from polar-orbiting satellites to Hurricane Earl's rapid intensification forecasting is investigated. Comparisons are made in observation space. The HWRF outputs of temperature, water vapor, hydrometeor profiles and surface winds were then used as inputs to the Community Radiative Transfer Model (CRTM) to produce TB simulations at MHS and MWHS frequencies for Hurricane Earl. The track, intensity and size of model-simulated Hurricane Earl compared favorably with the best track data. By comparing the satellite TBs with radar reflectivity, liquid water content (LWC) and ice water content (IWC) from both models and observations, the ability for MHS/MWHS to see through hurricane clouds was assessed. This study calls for an effective use of high-frequency microwave cloudy radiances from multiple polar-orbiting satellites as highlighted.

Hurricane Earl and HWRF Description

Hurricane Earl originated from a tropical wave, and became a hurricane on 29 August 2010. It moved off the west coast of Africa and toward the northwest on 23 August 2011 (Fig. 1). Then, Earl intensified by 40-kt over 24 h and became a Category 4 hurricane by 1800 UTC 30 August (Fig. 2). Shortly after reaching that status, Earl began a concentric eyewall replacement cycle. This cycle halted the intensification process and Earl remained a 115-kt hurricane for the next 24 h. Southwesterly shear increased late on 31 August, which resulted in the weakening of Earl to a category 3 hurricane by 0000 UTC 1 September. Earl re-intensified to category 4 strength by 1800 UTC 1 September and reached its peak intensity of 125 kt at 0600 UTC 2 September. Earl then rapidly weakened as it turned northward and fell below major hurricane status by 0000 UTC 3 September 2010.



A 126-h model forecast initialized at 0000 UTC 29 August 2010 was made using the Hurricane Weather Research and Forecasting (HWRF) System (Community HWRF Users' Guide V3.3a, 2011). The model forecasted track is located to the east of the best track observation (Fig. 1). The maximum track error in the 126 h forecast is 239 km. The intensity and size of model-simulated Hurricane Earl compared reasonably well with the best track observation (Fig. 2).

Fig. 1: Forecast track of Hurricane Earl from HWRF forecast (red) and Best Track data (black).

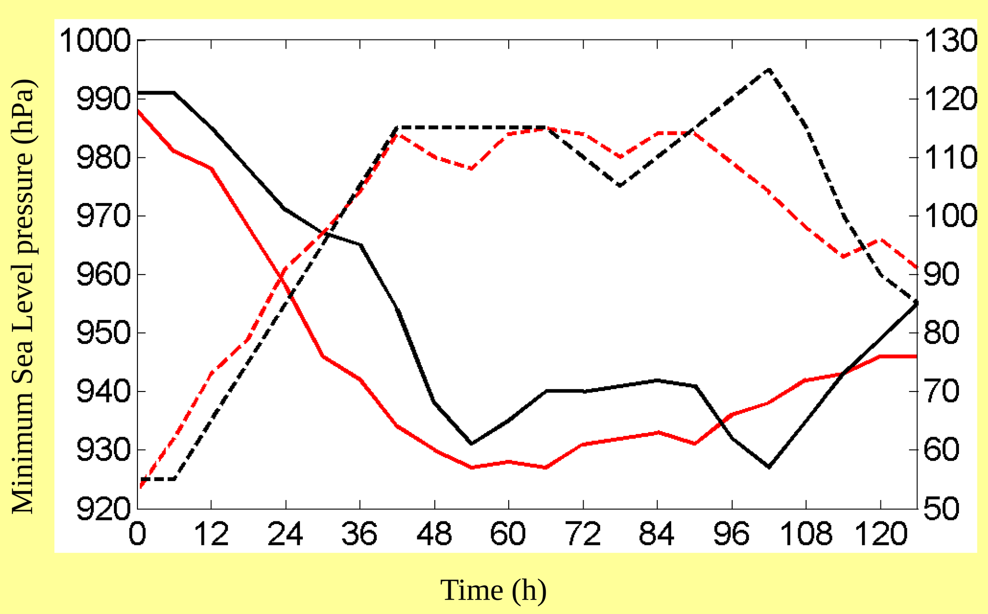


Fig. 2: Temporal evolution of the minimum sea-level pressure (hPa, solid) and the maximum 10-m level wind speed (kt, dashed) initialized at 0000 UTC August 29, 2010 for Hurricane Earl from the HWRF forecast (red) and Best Track data (black).

Surface-Sensitive Microwave Channels Capturing Hurricane Earl's Structures seen by Radar

In Fig. 4, TBs from surface-sensitive channels (157 GHz) are compared with radar reflectivity. It is found that the satellite observed hurricane structures sensitive to cloud and precipitation are quite similar to radar observations. The double eyewall seen in high-resolution radar observations is also resolved by the 15-km resolution satellite observations.

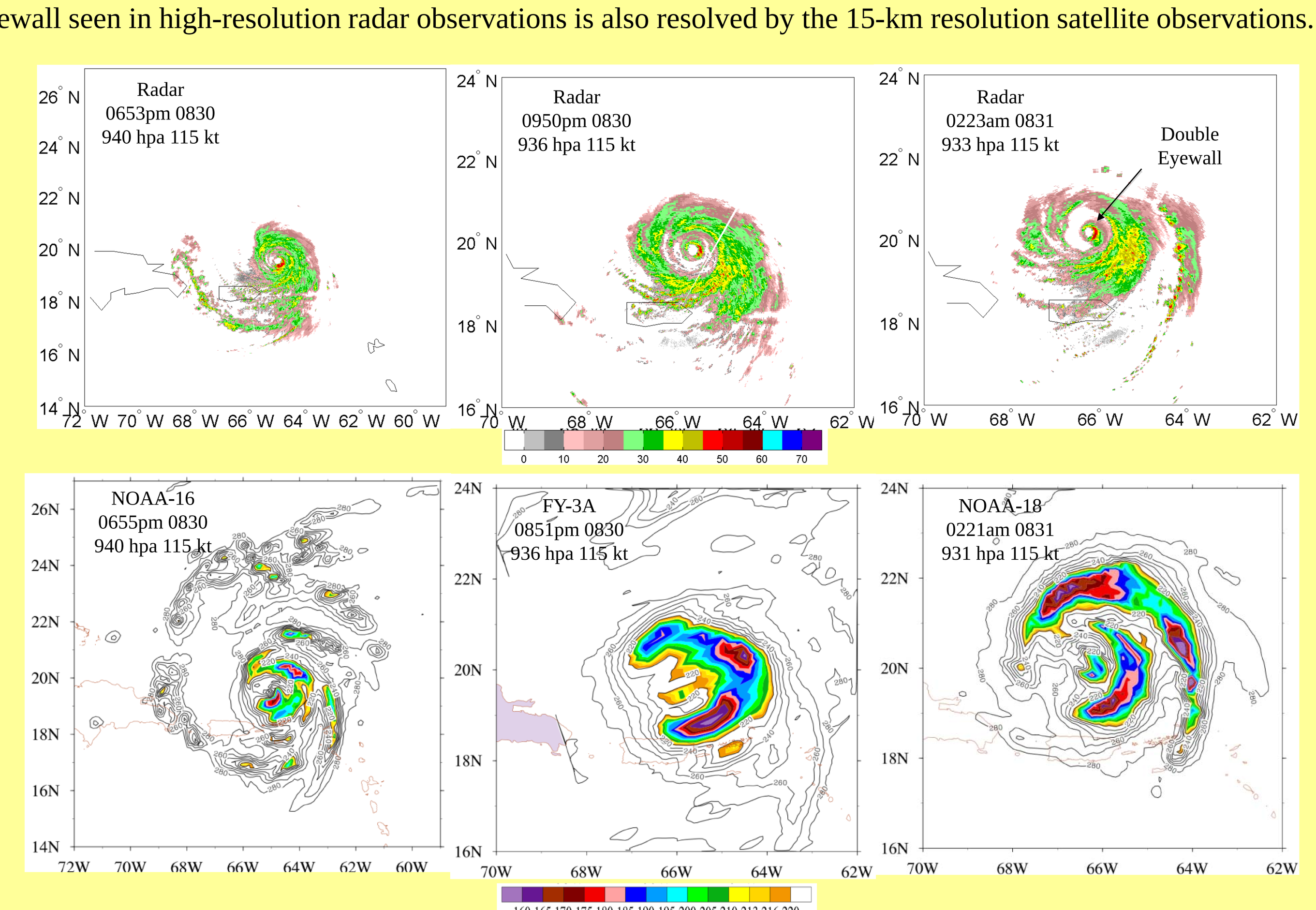


Fig. 4: Reflectivity distributions of Hurricane Earl observed by WSR-88D San Juan radar (upper panels) and brightness temperatures of channel 2 observed by MHS on board NOAA-16 and 18 and MWHS on board FY-3A (lower panels).

Polar-Orbiting Satellites Providing Hourly Evolutions of Hurricane Earl

Microwave temperature and humidity sounders onboard a polar-orbiting satellite provide twice daily the atmospheric and surface states in all-weather conditions (except for heavy precipitation). Figure 3 provides the microwave brightness temperature (TB) observations at 157 GHz from 1009pm August 29 to 0454pm August 30 from the Microwave Humidity Sounders (MHS) on board European MetOp-A, United States NOAA-15, 16, 18, 19 and Chinese FY-3 MicroWave Humidity Sounder (MWHS) during Earl's rapid Intensification process. The six polar-orbiting satellites provide an hourly evolution of a surface-sensitive channel observation of hurricane Earl. The development of multiple rainbands of Earl from early morning to noon is well depicted.

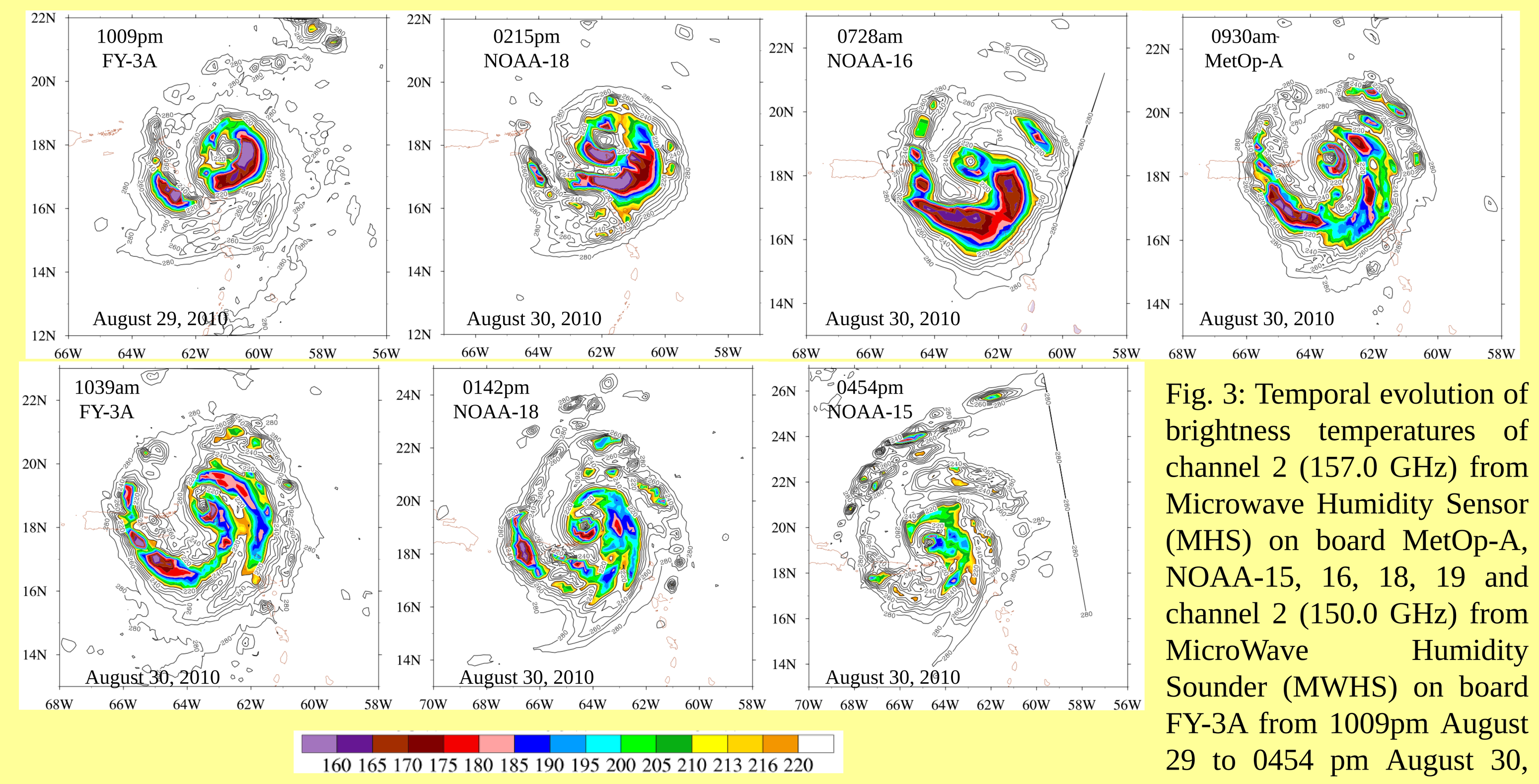
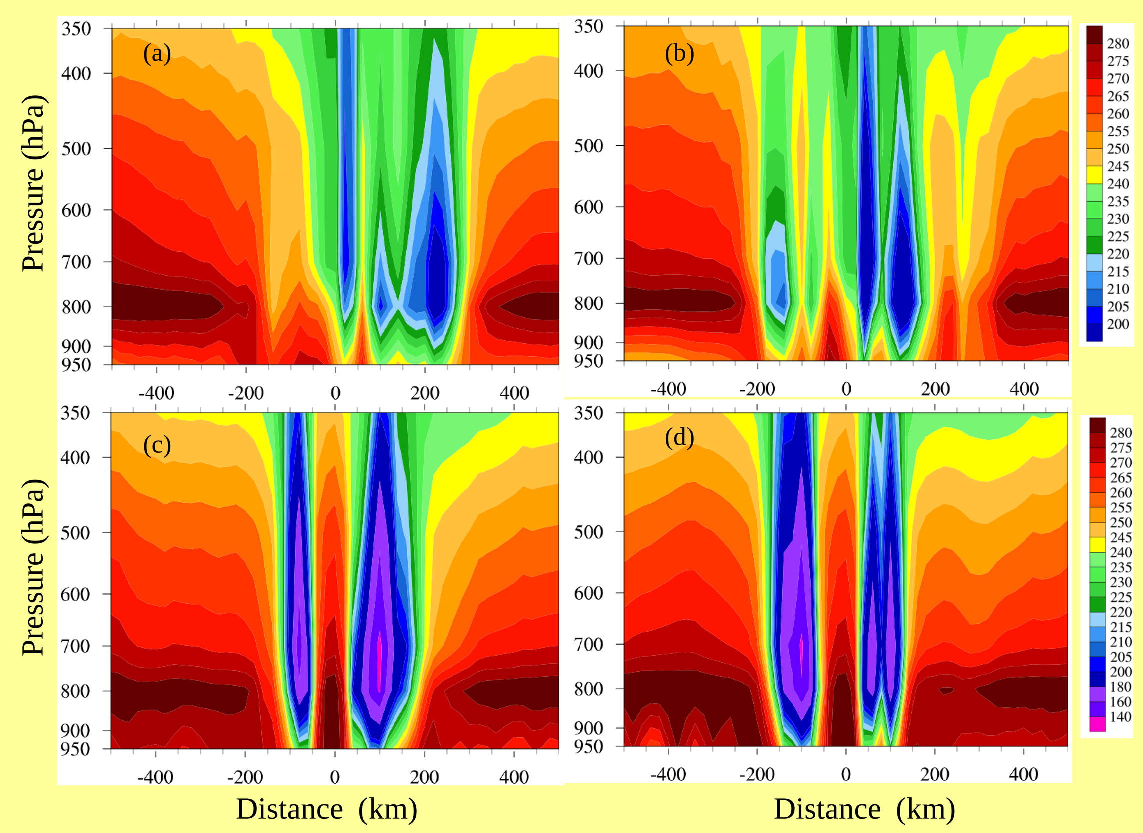


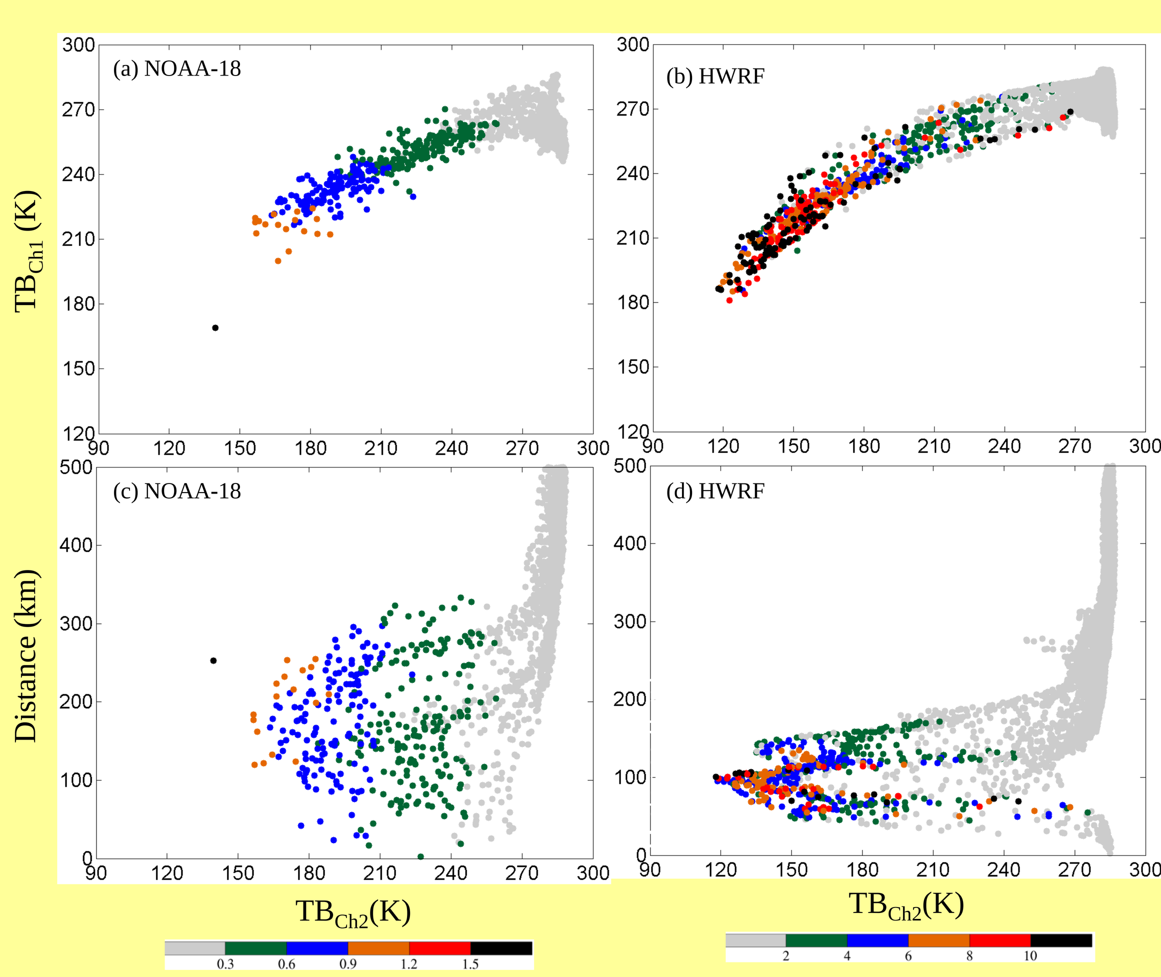
Fig. 3: Temporal evolution of brightness temperatures of channel 2 (157.0 GHz) from Microwave Humidity Sensor (MHS) on board MetOp-A, NOAA-15, 16, 18, 19 and channel 2 (150.0 GHz) from MicroWave Humidity Sounder (MWHS) on board FY-3A from 1009pm August 29 to 0454 pm August 30, 2010.

Satellite-Observed and HWRF-Simulated LWC and IWC



In order to compare HWRF model forecasts with satellite observations, we show in Fig. 7 cross-sections of quadrant averaged TBs from MHS (channel 1-5) on board NOAA-18 at 0600UTC August 31, 2010 (Fig. 7a-b) and HWRF 54-h forecast (Fig. 7c-d). Observations contain smaller-scale radial variations than observations. The modeled hurricane eye is clearer and larger in size than observations, but the size of the modeled hurricane is smaller than observations. The TB minimum values are 60K lower than observations. Outside the convective regions at radial distance greater than 300 km, the vertical TB structures compare well with model forecasts.

Fig. 7: Cross-sections of quadrant averaged TBs from (a)-(b) MHS (channel 1-5) on board NOAA-18 at 06 00UTC August 31, 2010 and (c)-(d) HWRF 54-h forecast.



A similar relationship between MHS channels 1 and 2 is modeled as observations (Fig. 8a-b), with the brightness temperature of MHS channel 1 increasing quadratically with that of channel 2. However, the model-predicted hurricane Earl is smaller than the observations (Fig. 8c-d)..

Fig. 8: Scatter plots of MHS channel 1 (89.0 GHz) TB against channel 2 (157.0 GHz) TB within 500-km hurricane region from (a) NOAA-18 observations and (b) 54-h HWRF forecast valid at 0600UTC August 31, 2010. (c) and (d) are same as (a)-(b) except for replacing TB channel 1 by the radial distance.

Characteristic Radial Structures of Tb

The averaged radial profile of TBs is calculated within each of the four quadrants of hurricane Earl (Fig. 5). It is seen that hurricane eye is characterized by a local TB maximum. Away from the eye, the TB radial profile shows a clear signature of rainband, with its local maxium and minimum corresponding to rainband and clear streak, respectively. In order to see if these features could be generalized, we plot in Fig. 6 the radial distances of the local minima and maxima during the five-day period from the six polar-orbiting satellites. We may conclude that there exists a relationship between the radial distances of local minimum/maximum TB points and the hurricane wind radii. The TB minimum closest to the hurricane eye is located outside the radius of maximum wind, but mostly inside of the radius of 50kt wind. The second TB minimum away from the hurricane eye is located between the radius of 50kt wind and 34kt wind. The TB maximum closest to the hurricane eye is located mostly inside the radius of maximum wind. The second TB maximum away from the hurricane eye is located between the radius of 50kt wind and 34kt wind.

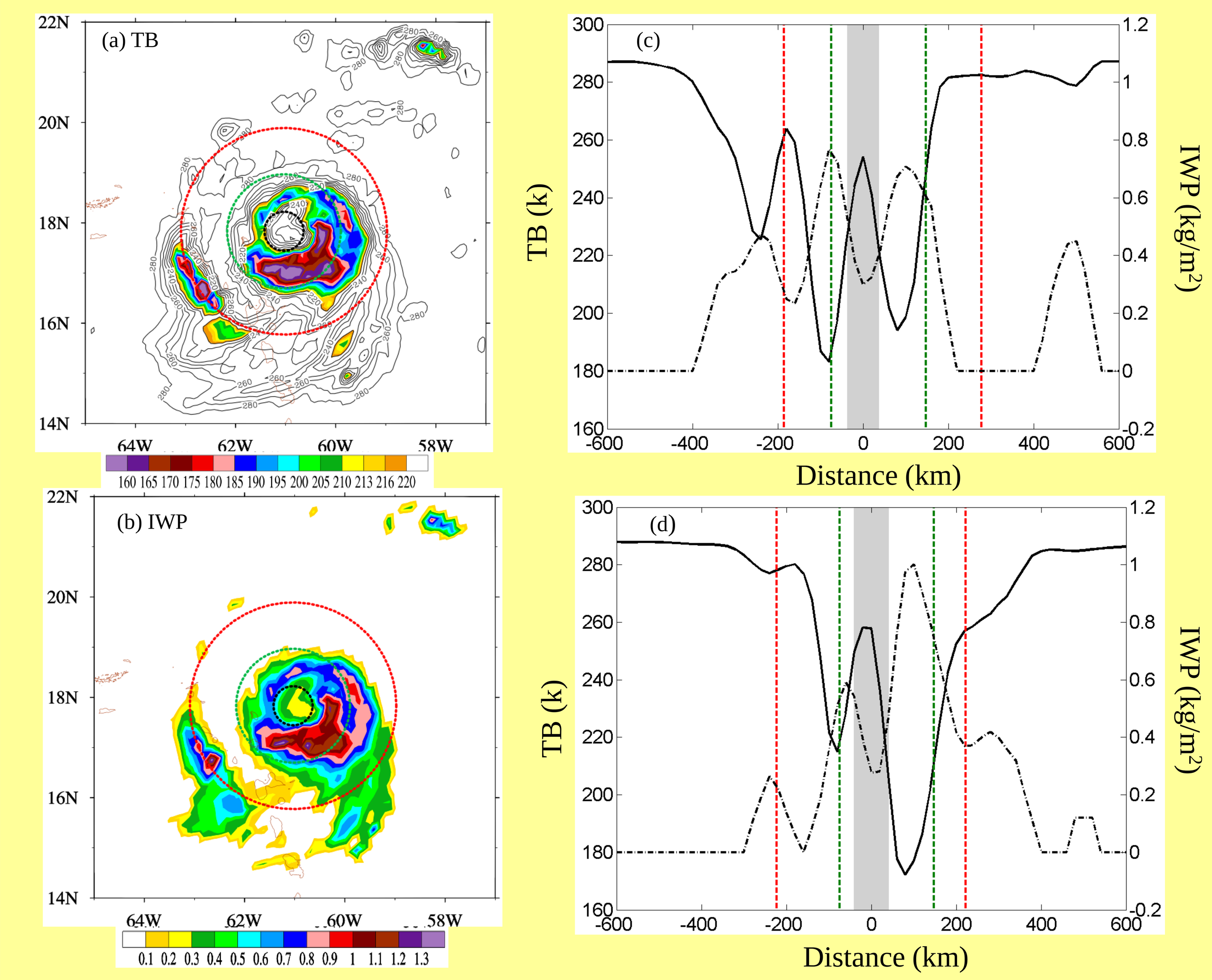


Fig. 5: (a) TB, (b) IWP. As well as radial profile of TB (solid) and IWP (dashed) plotted from (c) 0-90° (positive distance), 180°-270° (negative distance), (d) 90°-180° (positive distance), 270°-360° (negative distance) from MHS (channel 2) on board MetOp-A at 0100UTC August 30. The radius of 34-kt wind is indicated as red dashed, the radius of 50-kt wind is notated as green line, and the region inside the radius of maximum wind is shaded.

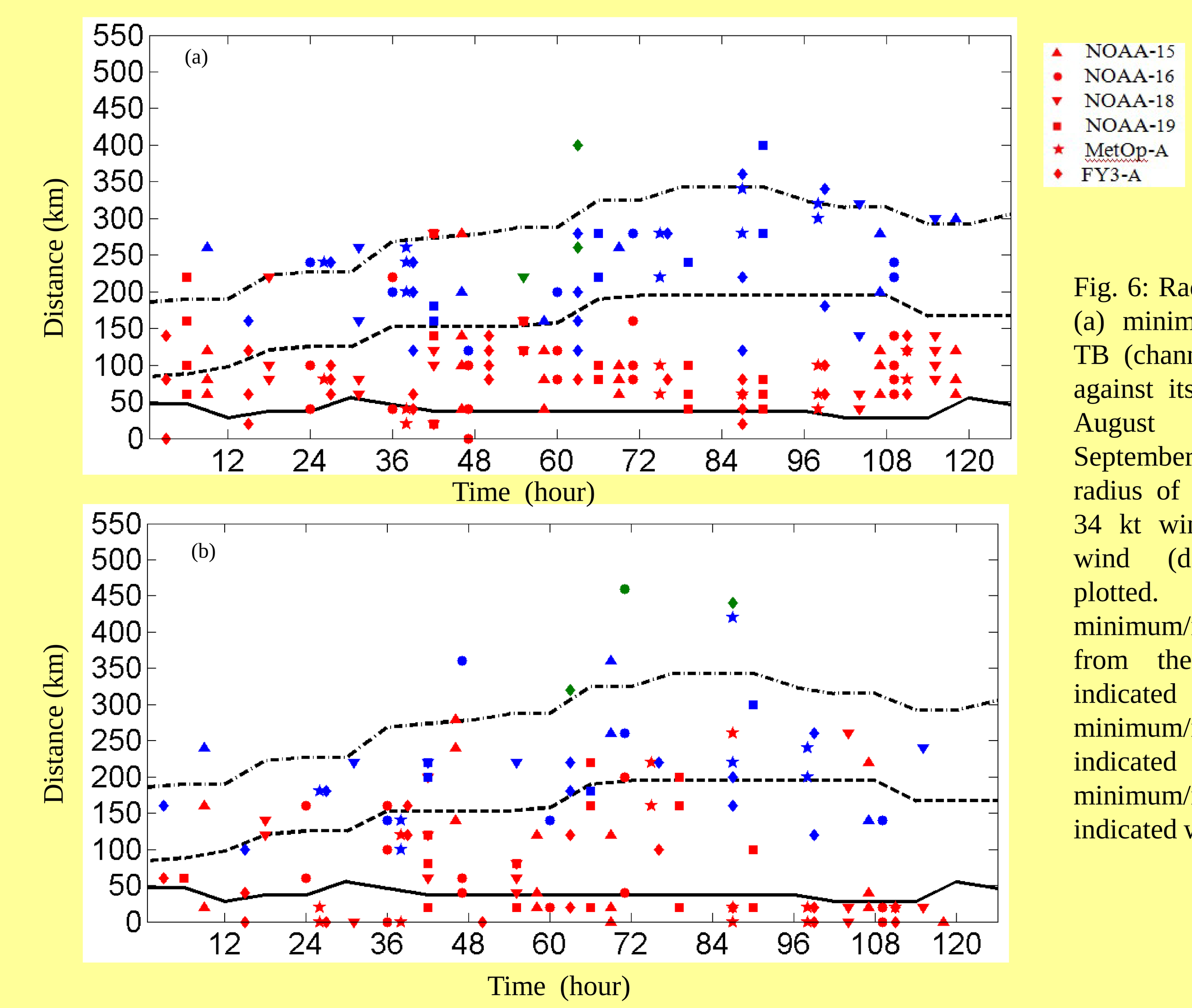


Fig. 6: Radial distance of the local (a) minimum and (b) maximum TB (channel 2, 157 GHz) points against its time from 0000 UTC August 29 to 0600 UTC September 3, 2010. The observed radius of maximum wind (solid), 34 kt wind (dashed) and 50 kt wind (dash-dotted) are also plotted. The first minimum/maximum TB point from the hurricane center is indicated as red, and the second minimum/maximum point is indicated as blue, and other minimum/maximum points are indicated with green color.

Summary

TB observations from the Microwave Humidity Sounders (MHS) on board European MetOp-A and United States NOAA-15, 16, 18, 19 and MicroWave Humidity Sounder (MWHS) on board Chinese FY-3A were analyzed during the rapid intensification period of Hurricane Earl from August 29 to September 3, 2010. A 126-h model forecast initialized at 0000 UTC 29 August 2010 was made using the Hurricane Weather Research and Forecasting (HWRF) System. The HWRF system is a coupled system composed of the non-hydrostatic, two-way interactive, moving nest model and the three-dimensional Princeton Ocean Model (POM). The weak vortex at the initial time in GFS analysis was replaced by a 2D axis-symmetric synthetic vortex. The cloud structures of Hurricane Earl are examined among MHS/MWHS TBs, airborne radar reflectivity and the HWRF model simulation. The availability of multiple polar-orbiting satellites provides high-frequency microwave observations offer great opportunity for an expected forecast improvement in hurricane intensity and size.

References:

Bao, S., R. Yablonsky, D. Stark, and L. Bernardet, 2011. HWRF Users' Guide V3.3a. Developmental Testbed Center, 101pp.

Acknowledgement: This research is supported by NSF project AGS-1037936.