Comparing Flood-producing Catastrophic Hurricanes in GEOS: A Study of Juan 1985 and Harvey 2017

Tropical Cyclones and Extreme Monsoon Precipitation: Prediction, Impacts, and Communication

January 9, 2019

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NASA GEOS System

- GEOS is the Goddard Earth Observing System model
- GEOS is maintained by the NASA Global Modeling and Assimilation Office
- Primary GEOS functions:
  - ✓ Earth system model for studying climate variability and change;
  - ✓ Provide research quality reanalyses for supporting NASA instrument teams and scientific community;
  - ✓ Provide near-real time forecasts of meteorology, aerosols, and other atmospheric constituents to support NASA airborne campaigns;
  - ✓ The GEOS atmospheric data assimilation system is used to generate near real-time analyses every six hours;
  - ✓ These analyses provide the initial conditions for the GEOS forecasts taking into account the effects that aerosols and trace gases have on atmospheric circulations.

GEOS Forward Processing (FP) – 12km

- GMAO's Flagship high resolution state-of-the-art global Data Assimilation System
- Near real time
- Short and medium range forecasts of meteorology & aerology out to 10 Days
- Upgraded about once per year to bring in the latest modeling and assimilation developments

Reanalyses – 50km

- Historic satellite-era retrospective analysis (MERRA-2)
- Employs multiple observations incl. radiance assimilation (e.g**. AIRS**)
- Interactive aerosols; uses **NASA MODIS** input data
- Stratospheric ozone and temperature assimilates **NASA MLS**
- In the planning stages for the next generation earth-system reanalysis
- TC relocation

Seasonal and Sub-Seasonal Prediction – 50km

- Uses an initialized state of the ocean-atmosphere-land-ice to predict phenomena that evolve on longer time scales
- A recent GMAO upgrade includes new developments in physics,
- core dynamics, and the cryopshere
- Forecasts provided to the NOAA National Multi-Member Ensemble which compares and distributes seasonal forecasts of El Nino/La Nina events
- Makes sea-ice predictions

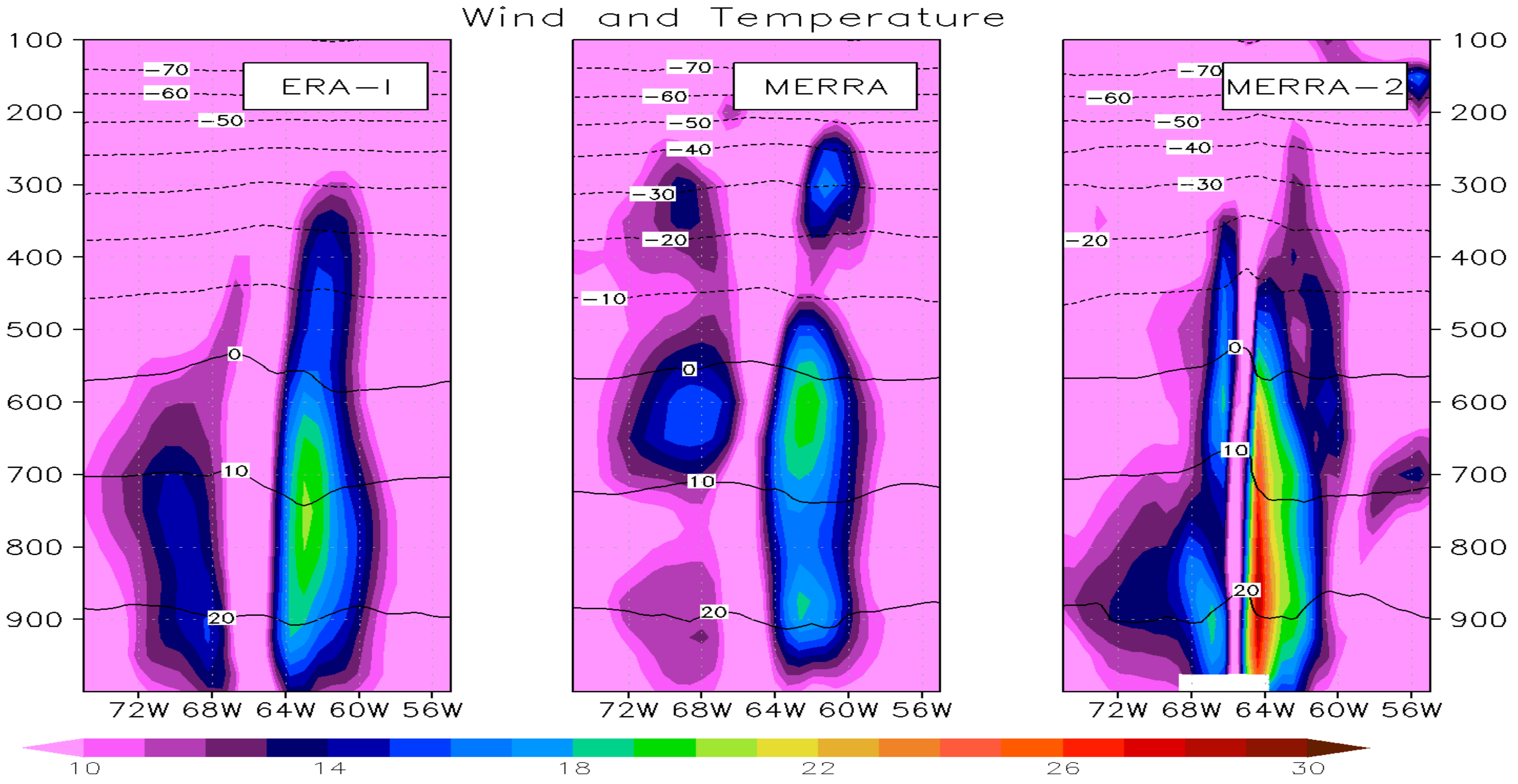
- Highly reliable depictions of synoptic-scale weather systems.
- Continued improvements in forecast and analyses of extreme events (hurricanes, sudden stratospheric warming)

- Can be used to investigate historical hurricanes by creating higher resolution hindcasting experiments with state-of-the-art forecasting systems.
- The MERRA-2 fields can be used as analyses to initialize the current GMAO `operational' model, which is more recent than the one used to produce MERRA-2. In these experiments, the GEOS model is run with a cubed-sphere geometry at a horizontal resolution of a quarter or an eight of a degree approximately, with vertical resolution of 72 hybrid-eta layers.

- Forecast the pattern conducive to an extreme Eastern Pacific hurricane season and above normal Atlantic season
- Correctly identified this autumn's ENSO anomaly and associated atmospheric anomalies.

National Aeronautics and Space Administration

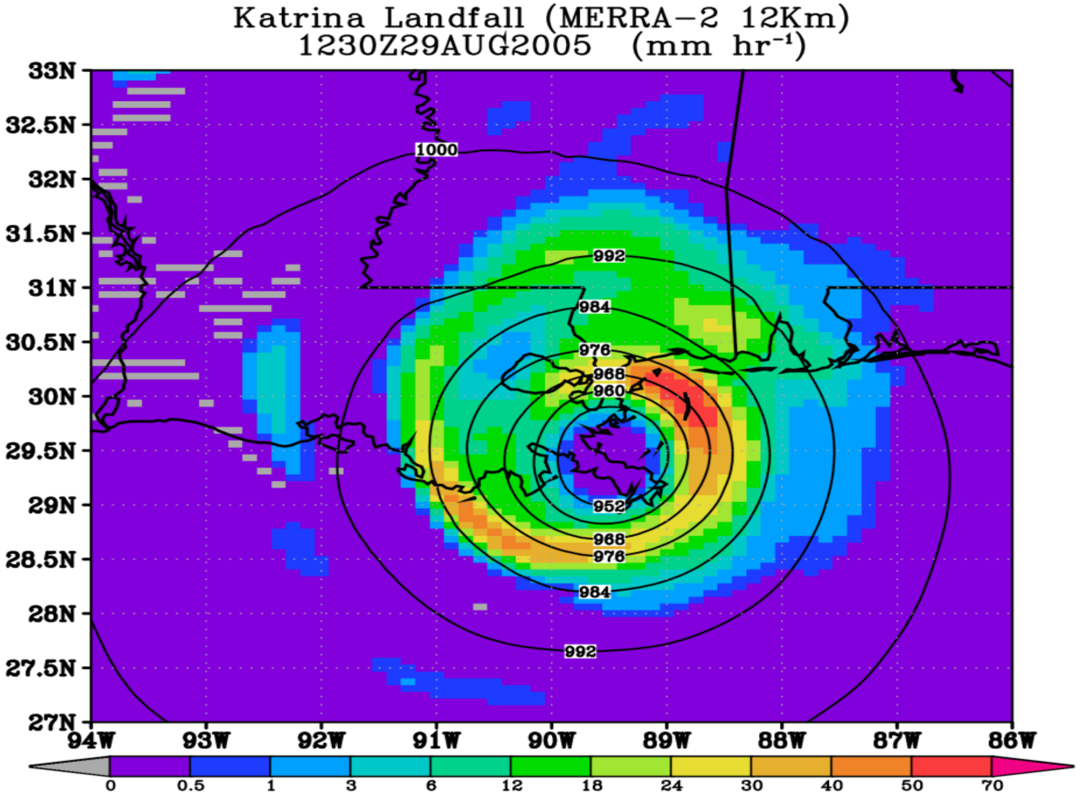
Hurricane David (1979): Vertical Structure

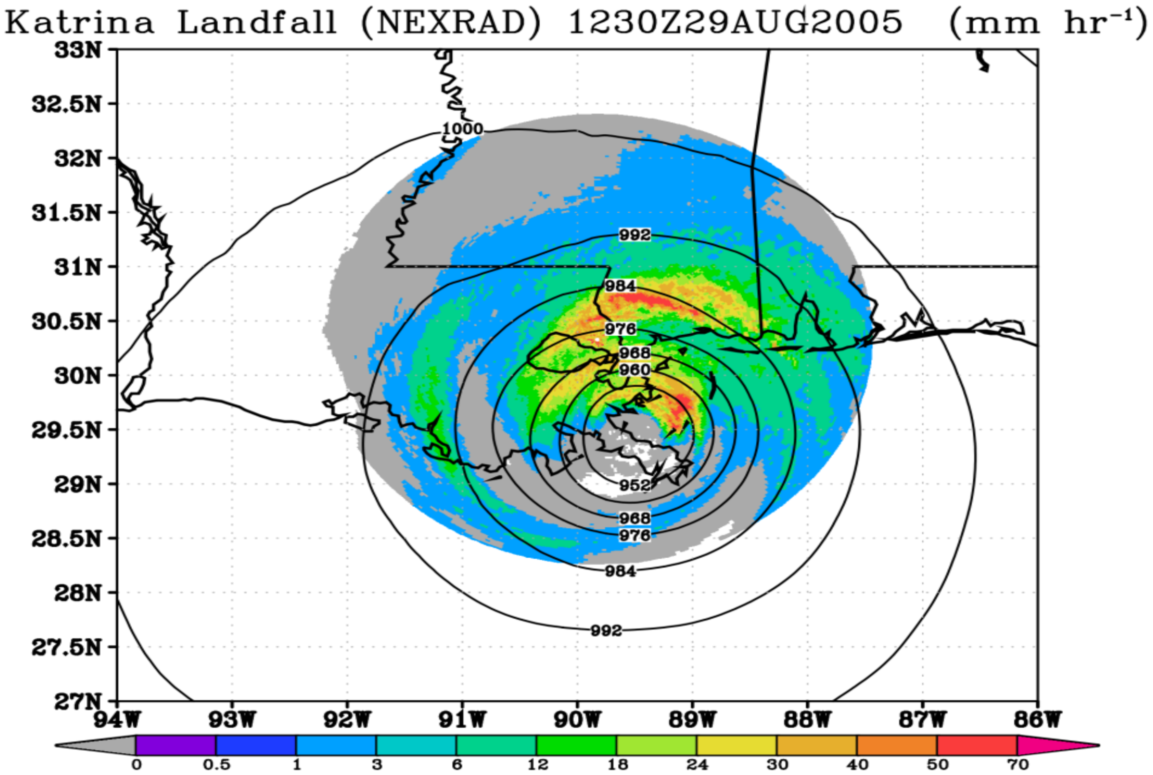


Recent Hurricanes: Downscaling from MERRA-2

Example of 12.5 km `replay' by Bill Putman (NASA/GMAO) for
Hurricane **Katrina (2006),** compared against observations

The observed eye scale and
a rainband to the southwest of the eye are correctly resolved





Hurricane Juan (1985)

- Hurricane Juan (26 October – 1 November 1985) was responsible of the largest life and financial losses of the US 1985 season (*);
- Difficult tropical cyclone from a forecasting perspective;
- Originated from an open wave which had gale-force winds –before- a close circulation was formed. It was hard to provide a dynamically consistent explanation of its genesis;
- Had an extremely erratic track with 3 loops and 2 landfalls;
- Moved less than 200 km in 48 hours being locked slightly S of Louisiana producing catastrophic rainfall (250-450 mm)

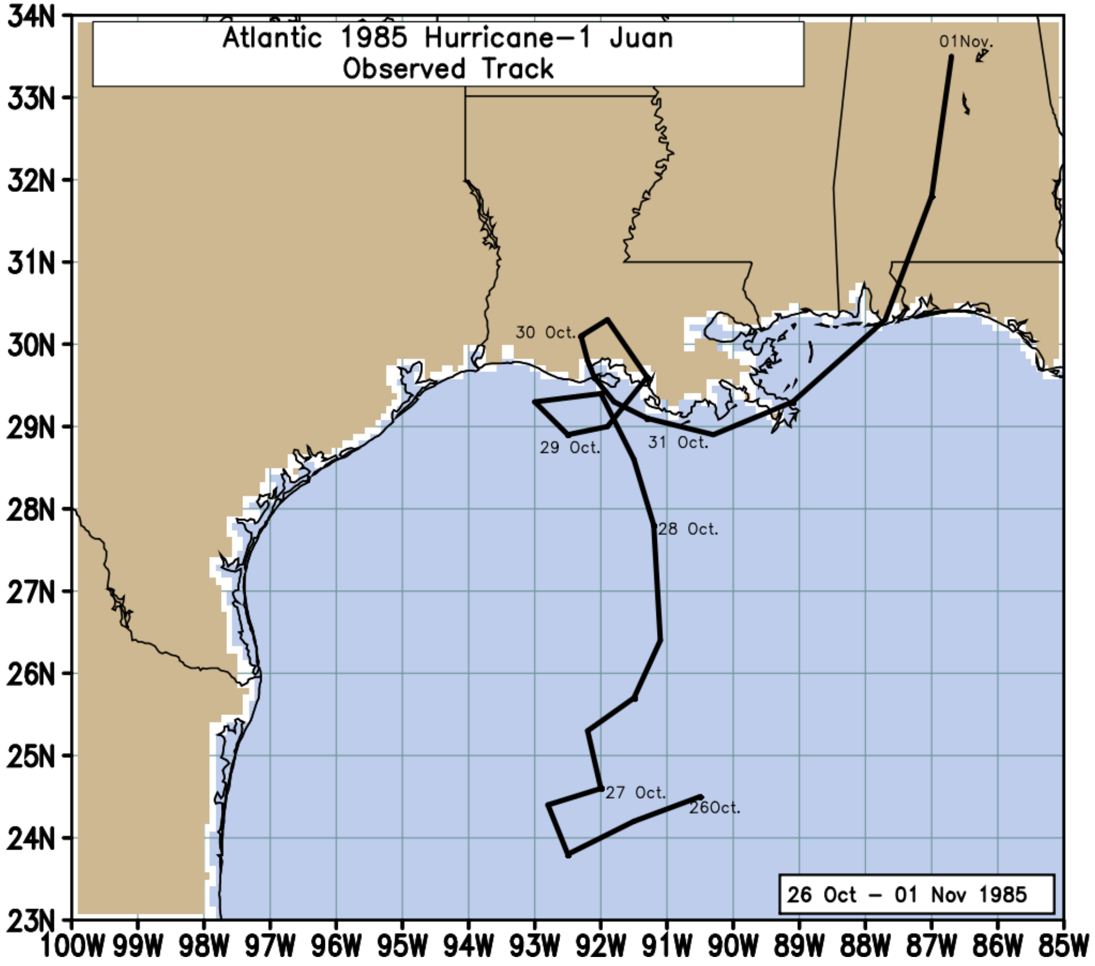
Hurricane Harvey (2017)

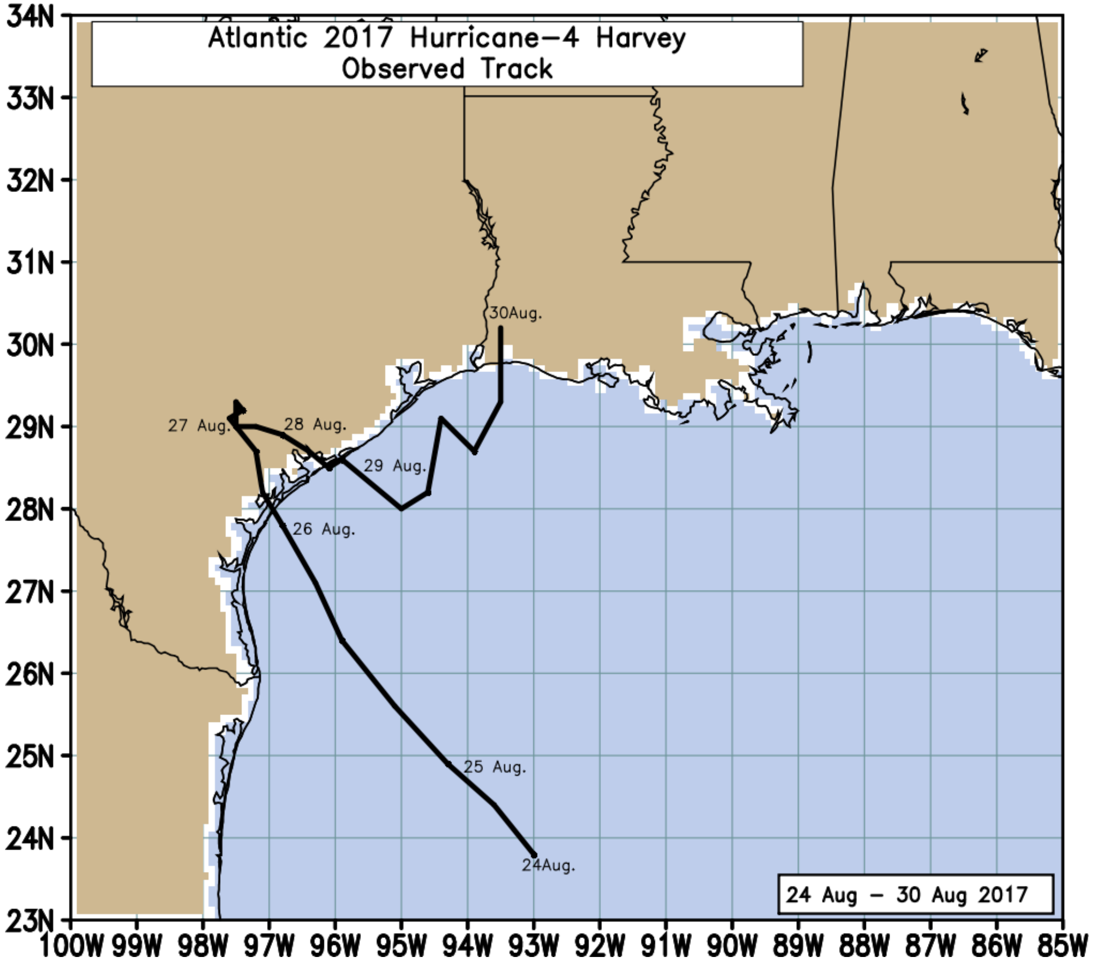
- Hurricane Harvey (17-30 August 2017) tied with 2005's Hurricane Katrina as the costliest tropical cyclone on record, primarily from catastrophic rainfall-triggered flooding in Southeast Texas;
- While the computer models accurately predicted the large amounts of rainfall from Harvey, intensity forecast and placement of heaviest rainfall lacked predictability;
- Originated from a westward-moving tropical wave that emerged from Africa over the eastern Atlantic Ocean, on August 12, 2017. After weakening, the remnants of Harvey regenerated on August 23rd, undergoing rapid intensification soon after;
- Had 2 landfalls;
- Moved less than 200 km in 48 hours producing catastrophic rainfall to the S of Texas (254-1270 mm)

(*) Case, R., 1986: Annual Summary, Atlantic Hurricane Season of 1985. Mon. Wea. Rev., 114,1390-1405.

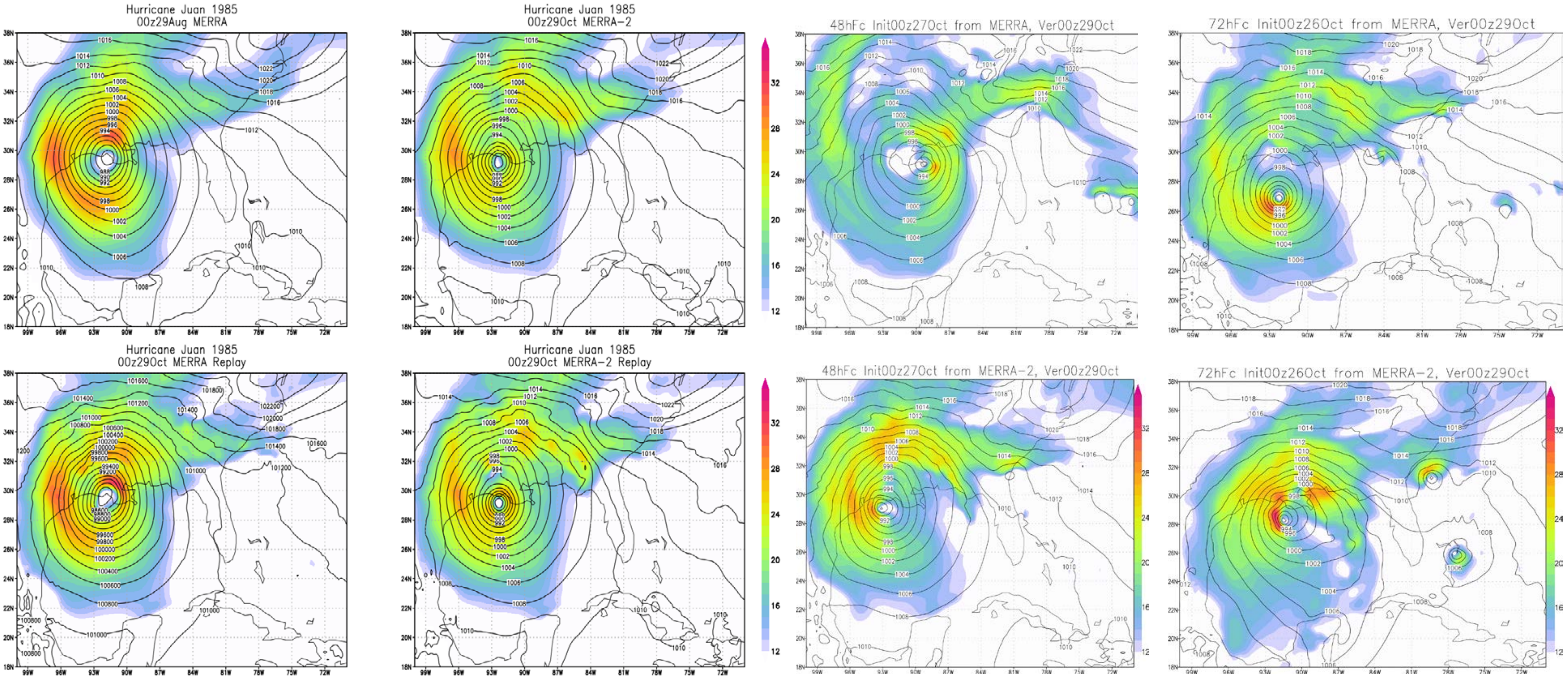
Juan 1985 and Harvey 2017 Observed Track

Observed tracks of Hurricane Juan (left) and Harvey (right) both showing double landfall and progress of **less than 200 km in 2 days** (29-31 October 1985 for Juan, and 26-28 August 2017 for Harvey).



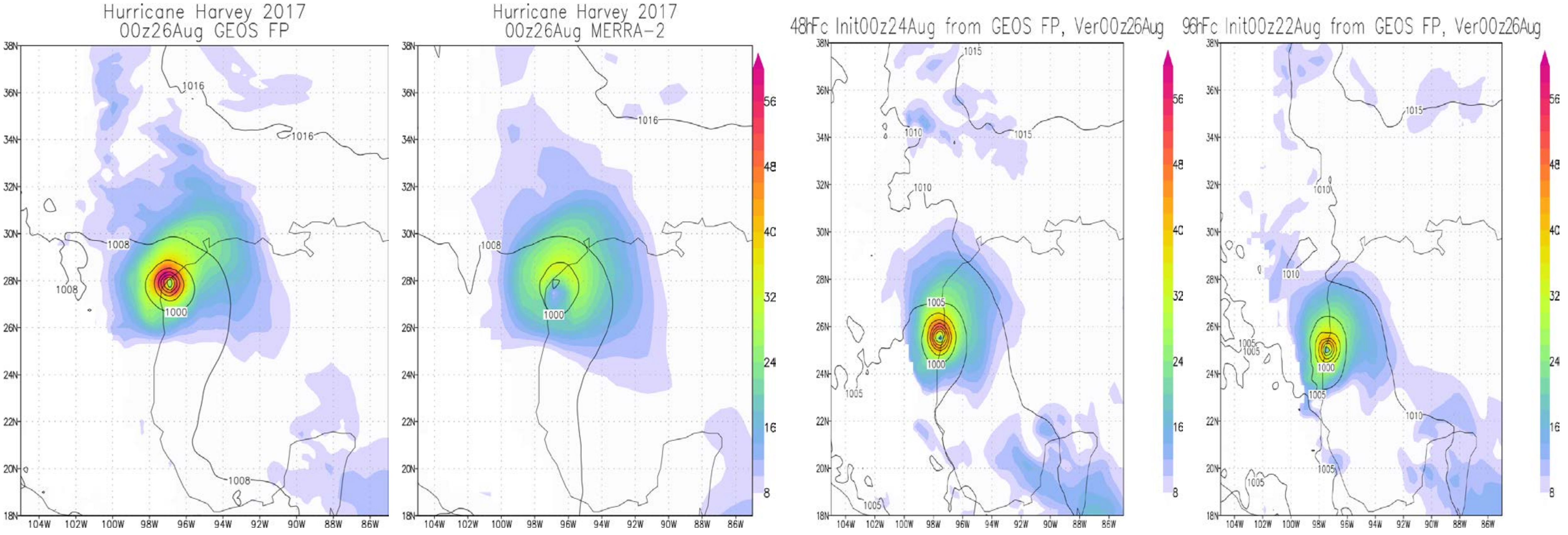


Juan 1985 Landfall Analysis and Forecast in the GEOS Systems



First Landfall Analysis **48-hr Forecast** **72-hr Forecast**

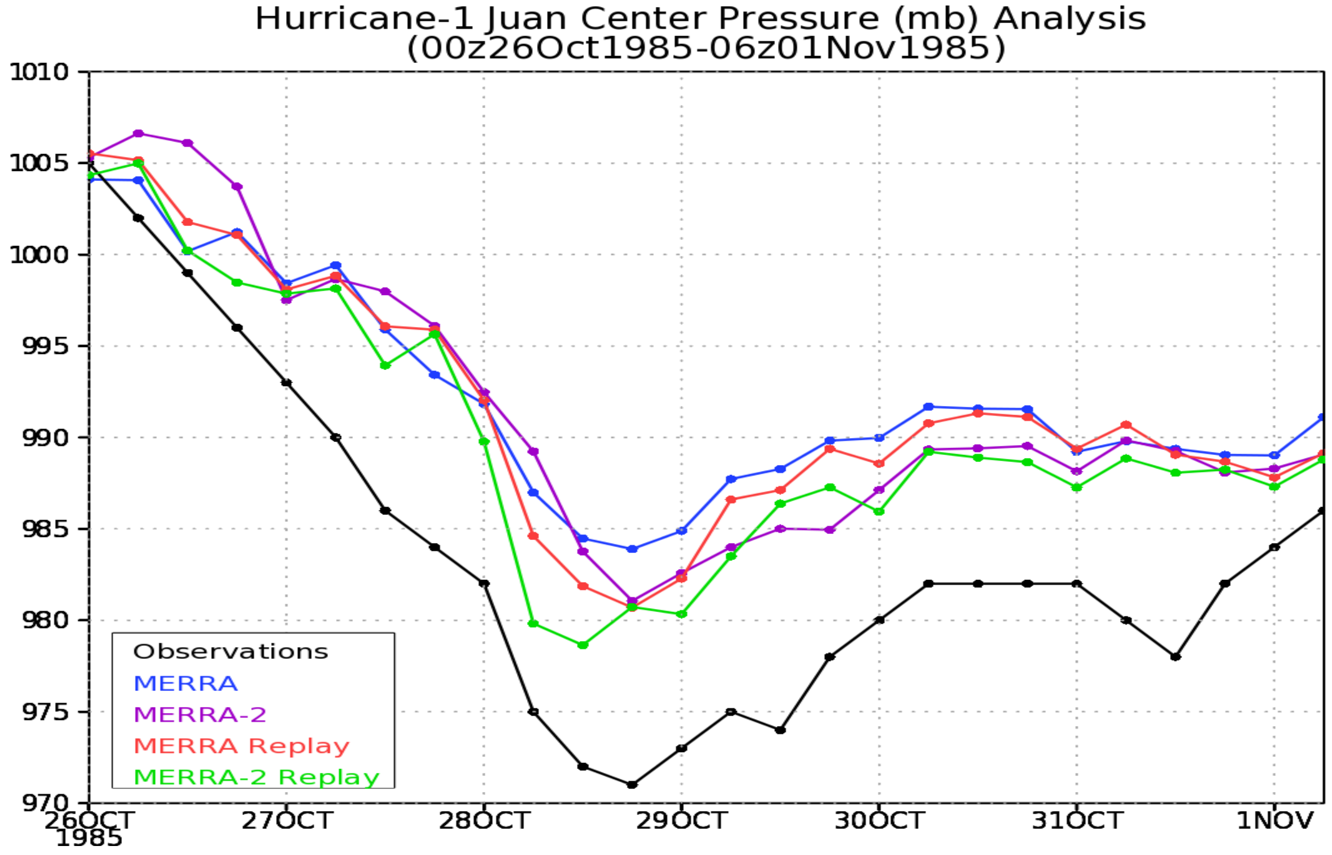
Harvey 2017 Landfall Analysis and Forecast in the GEOS Systems

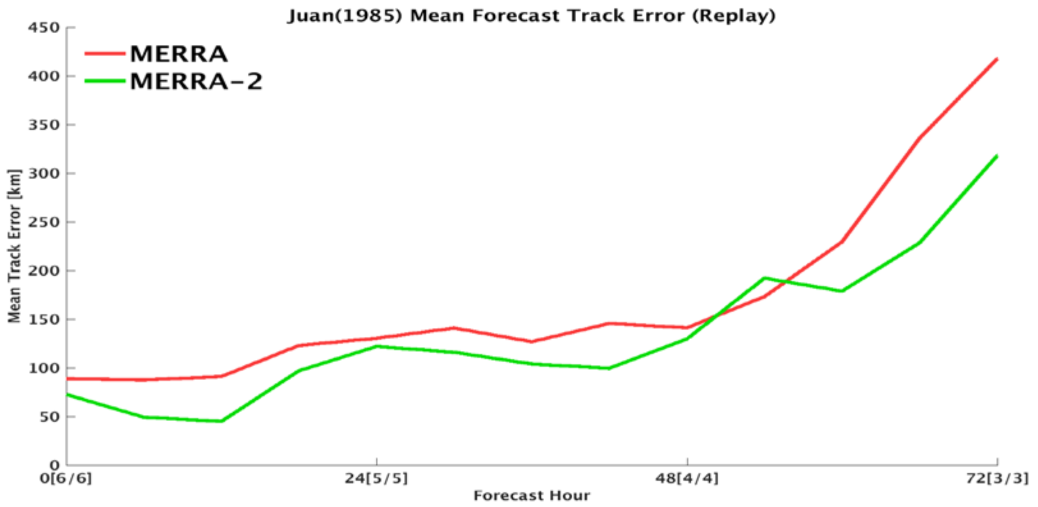


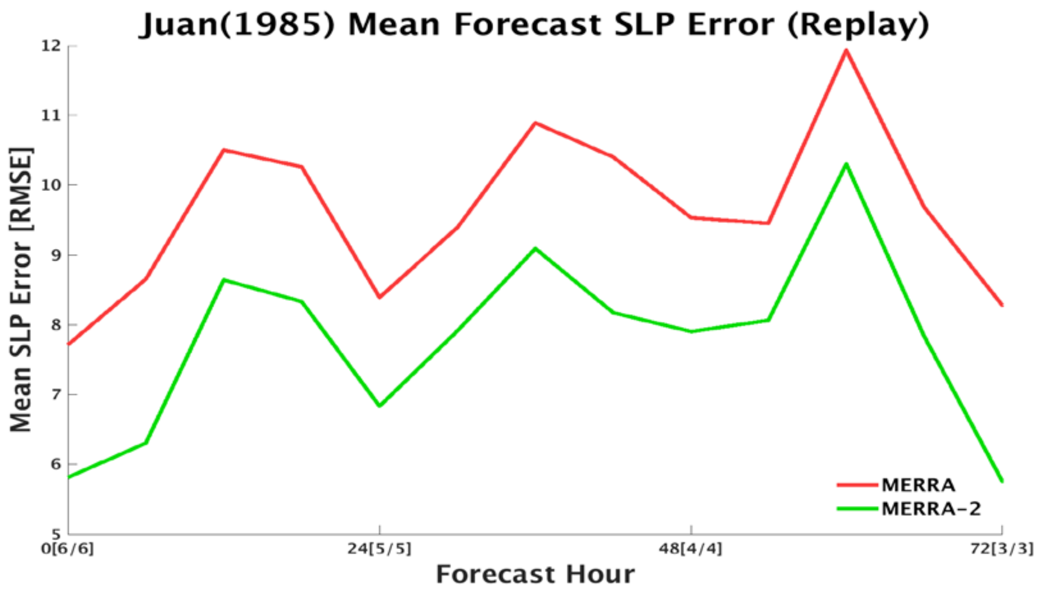
First Landfall Analysis **48-hr Forecast** **96-hr Forecast**

48 hour and 96 hour forecasts from the GEOS FP (near-real time, operational version) of the 00z26Aug landfall have errors of less than 50km and 250 km, respectively. The average of all forecasts for intensity, measured as SLP error at the center, is less than 15 hPa in the 48-hour range, which is a very good result . However, because of Harvey's slow and erratic motion after landfall, the critical forecasting aspect for this storm is accumulated precipitation, not mere intensity or position at landfall.

Juan 1985 Analyzed Intensity, Track Error and Intensity Error in GEOS

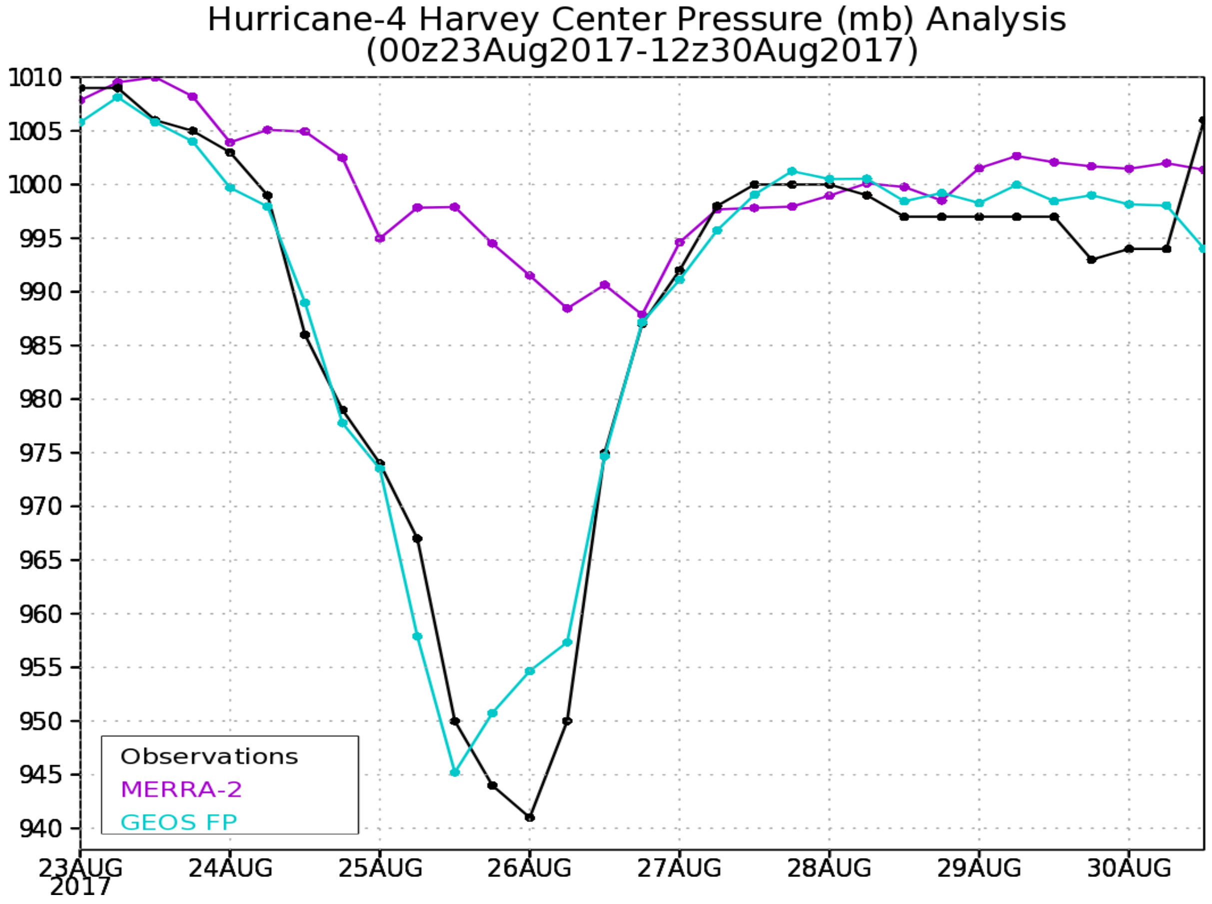


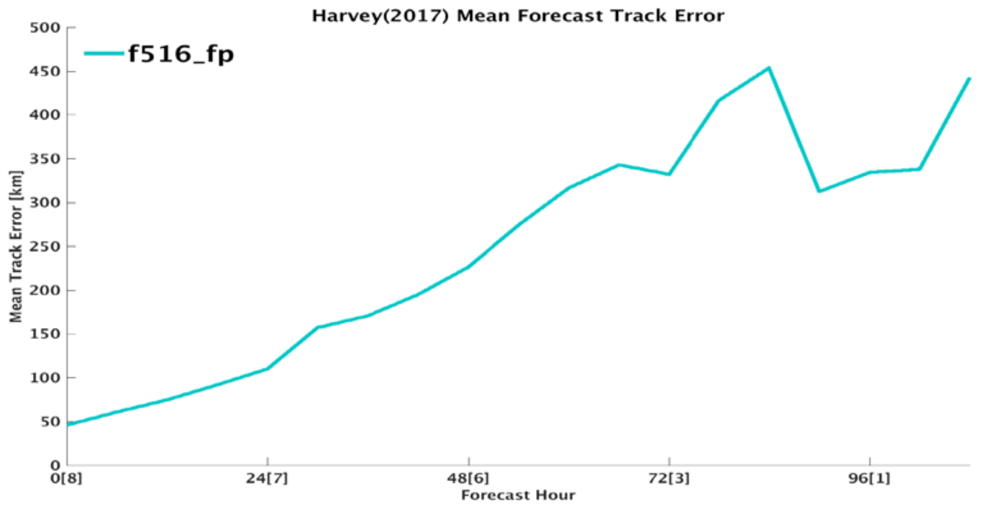


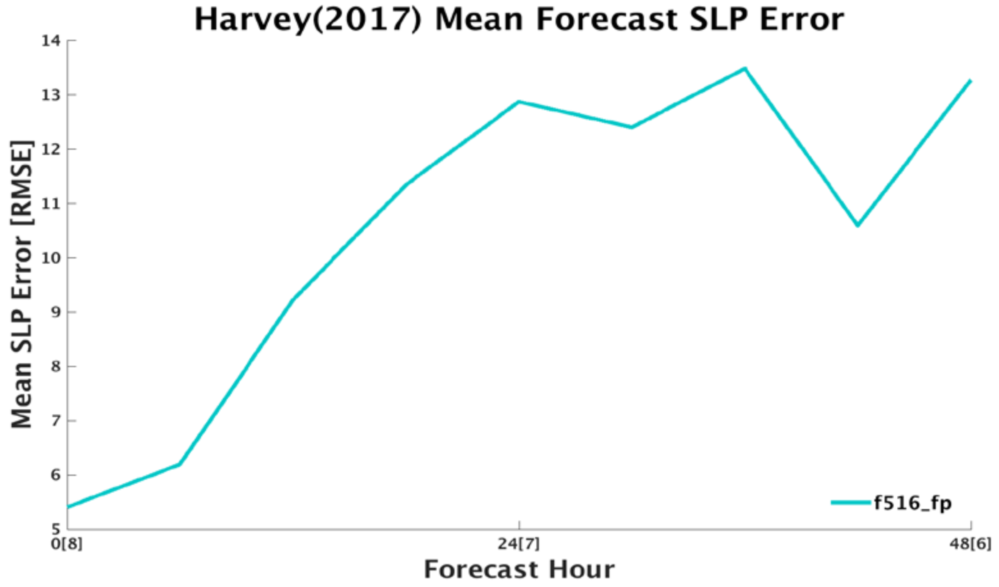


While Juan was considered impossible to predict at that time, the replay capability allows to revisit the storm 30 years later, obtaining a state-of-the-art analysis, track forecast and intensity forecast. In particular, intensity errors of less than 10 hPa for the storm center in the 72-hour range are remarkable. Furthermore, the improvement from MERRA to MERRA-2-driven hindcast showcases the continuous progress.

Harvey 2017 Analyzed Intensity, Track Error and Intensity Error in GEOS

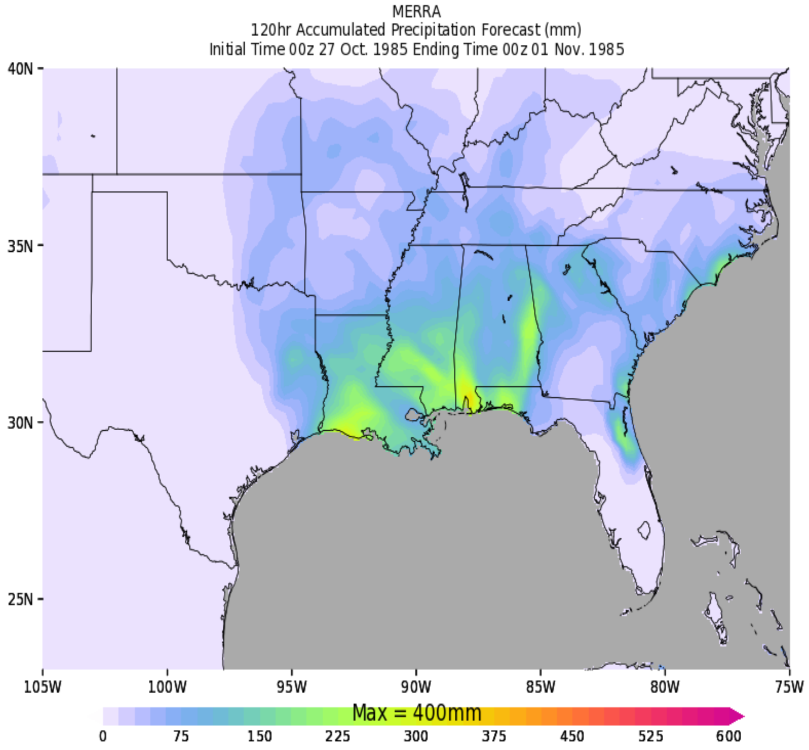


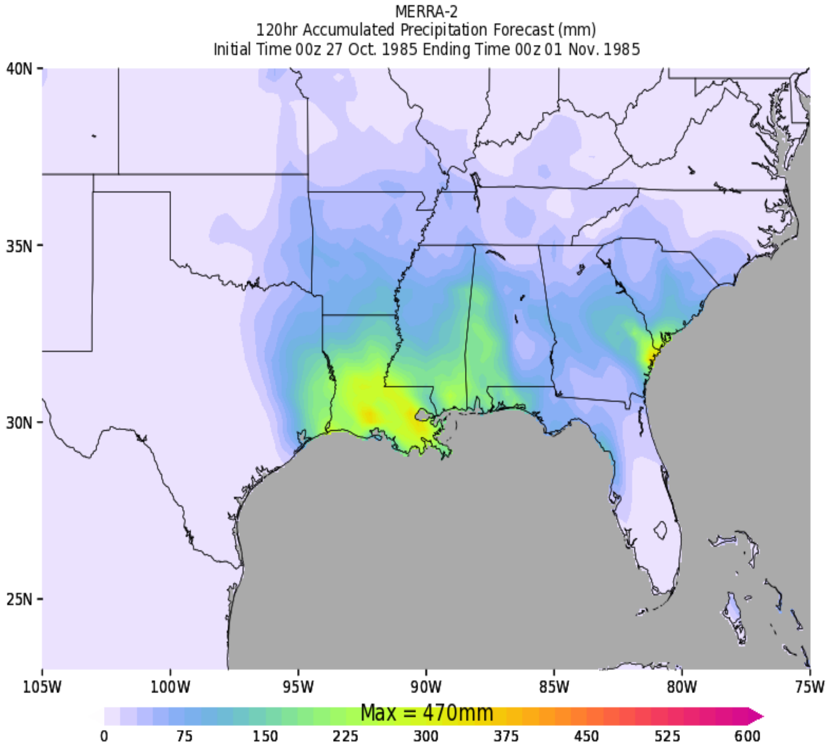


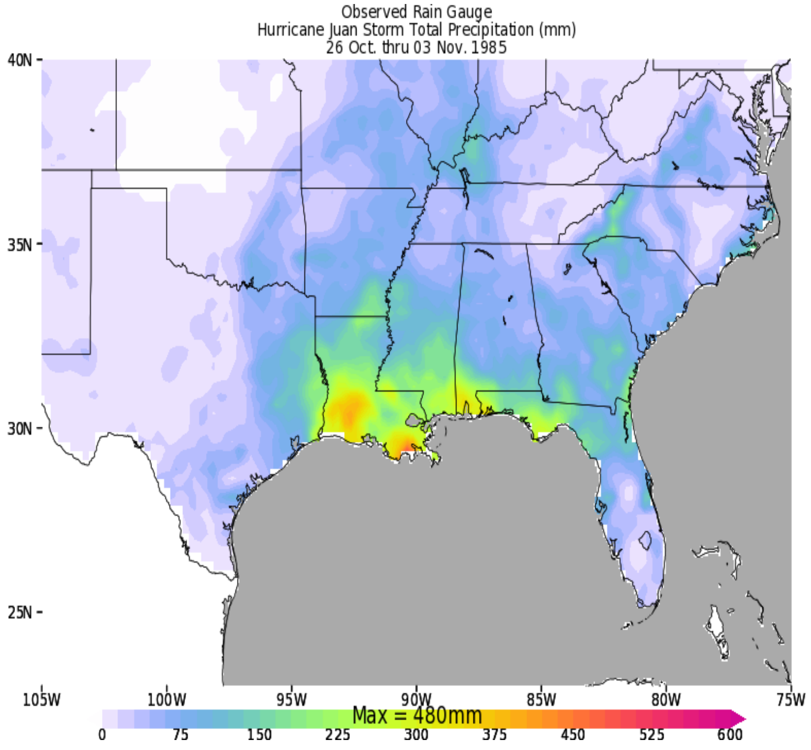


The analyzed minimum center pressure differs from the observed one by 5 hPa. Forecast track errors are larger than the official NHC forecast, but the predicted center pressure is remarkably accurate (less than 15 hPa in the 48-hour range).

Hindcast of 120-hr Accumulated Precipitation in GEOS: Juan 1985

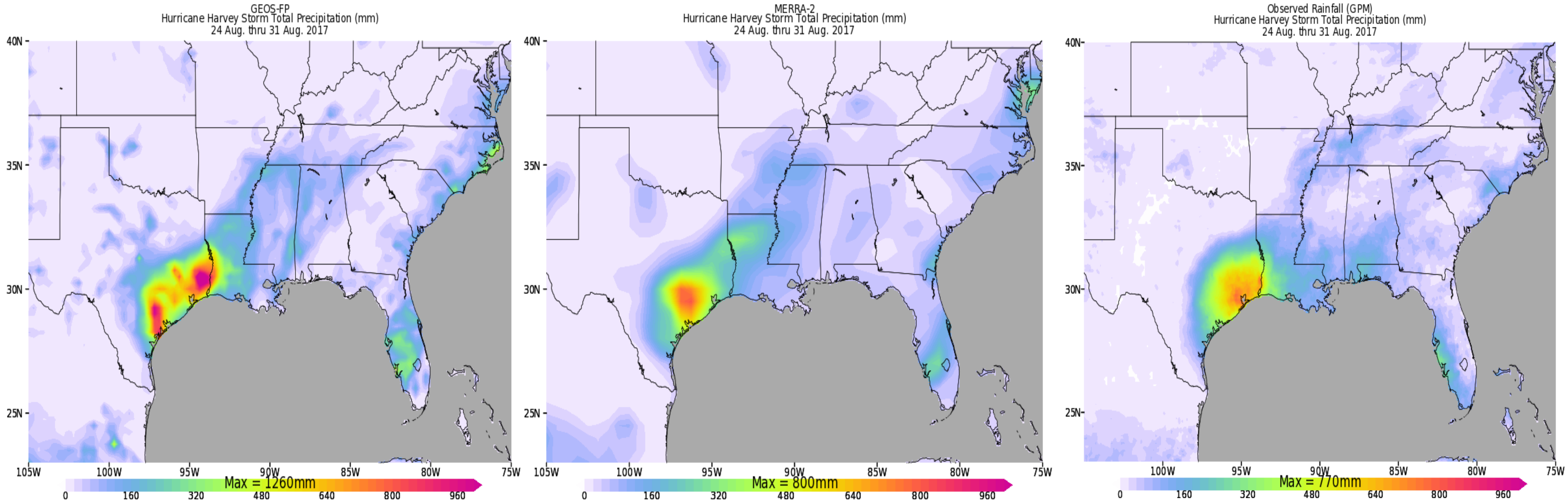






5-day accumulated precipitation obtained from replay forecasts initialized from MERRA and MERRA-2 on 00z27Oct1985. Precipitation distribution is extremely sensitive and responds abruptly to the inherent instability of Juan’s track . Nevertheless, the 5-day forecast from MERRA-2 captures the maximum precipitation very accurately and produces precipitation above 300mm over Louisiana, coastal Mississippi and Alabama, in agreement with observations.

Harvey 2017 Analyzed Precipitation in GEOS



Surprisingly, Harvey's precipitation field appears even more difficult to predict because of the storm's greater intensity and smaller size.

Conclusions

- The track and intensity of Hurricane Juan is captured by MERRA-2 better than MERRA.
- Forecasts initialized from MERRA-2 show excellent results (TC track skill comparable to the *current operational skill*) WHEN AN INITIAL VORTEX IS PRESENT (after the 26th). Prediction of TC genesis is not successful.
- Forecasts initialized from MERRA show slightly larger track error after the 26th, and substantially inferior structure and intensity.
- The MERRA-2 modern reanalyses can be used to investigate historical hurricanes by initializing higher resolution hindcasting experiments with state-of-the-art forecasting systems.
- By studying the performance of a modern forecast system with respects of TCs of the past, we can broaden the range of scenarios and expand our understanding of predictability on various spatial and temporal scales.

Backup Slide

The MERRA-2 data assimilation system

2014 GEOS-5 system (GEOS-5.12.4 AGCM/GSI 3D-Var)

Interpolated to 0.5° x 0.625° x 72 hybrid-eta levels to 0.01 hPa

MERRA → MERRA-2 Evolution

- ❑ **Updates to the AGCM and GSI**
  - AGCM
  - *Cubed-sphere dynamics*
  - *Updated physics: limited deep convection, re-evap of rain, snow sublimation*
  - *Improved glacier model and cryosphere albedos*
  - GSI
  - *Modern observations: GPSRO, NOAA-19, MetOp-A/B, S-NPP, SEVIRI, Aura OMI and MLS, capable for JPSS, MetOp-C*
  - Reprocessed satellite data (e.g. Wentz SSMI v7, SBUV v8.6)
  - *Updated moisture control variable and background errors*
  - *Bias correction for aircraft temperature observations*
  - *TC Relocation*
- ❑ **Aerosol assimilation** and Aerosol-model interaction (AVHRR pre-EOS, MODIS post-EOS)
- ❑ **Constraints on dry mass and globally integrated water** (balanced Precip/Evaportation)
- ❑ **Corrected precipitation for land surface forcing and aerosol deposition**
- ❑ **Climate validation and other docs at: http://gmao.gsfc.nasa.gov/reanalysis/MERRA-2/docs/**