Analysis of Moisture Transport and its Impact on Mid-latitude Precipitation by Tropical Storm Hermine (2010) Using WRF

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Purpose

This work was designed to gain insight into Tropical Storm Hermine (2010) by investigating the meteorological factors responsible for the development of its predecessor rain event (PRE). As numerical weather models serve as a key component in developing precipitation forecasts, this case study will also evaluate the model performance of the Hermine-PRE event.

Background

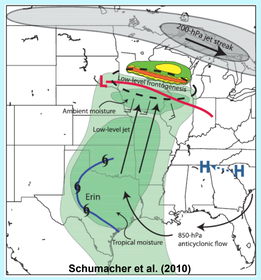


Figure 1. The main forcings responsible for TC Erin-PRE event.

A PRE is a region of heavy rainfall sustained by deep tropical cyclone (TC)-related moisture that is transported poleward, well in advance of the system. PREs are found to develop at the intersection of deep moisture and forced ascent associated with a low-level baroclinic zone situated beneath a jet-entrance region (Fig. 1).

PREs not only pose a large societal impact, but also a forecasting challenge as they act to enhance mid-latitude precipitation (Figs. 2, 3). Thus, it is important to assess model performance in simulating these events.

Models have trouble representing PREs due to their small-scale nature, and the multiple atmospheric features involved. Increased conceptual understanding of these events include identifying the factors most responsible for PRE development, and how well models simulate these processes.

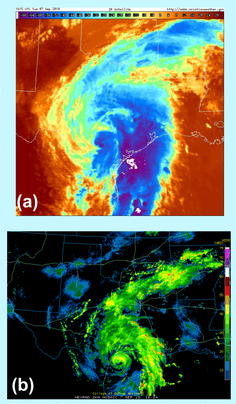


Figure 2. Hermine as it made landfall in (a) IR satellite imagery and (b) radar reflectivity.
Source: http://www.mmm.ucar.edu/imagearchive/

Hermine made landfall on the northeastern coast of Mexico, and moved northward through central Texas (TX). While most of the heavy rain fell in TX, there was another area of heavy rains to the northeast of the system in Oklahoma (OK) and Arkansas (AR). This is where the PRE occurred, which enhanced the total rainfall amounts across this region, as Hermine's main precipitation shield passed over these states.

This research attempted to study:
1. The physical mechanisms responsible for PRE initiation
2. How well models are able to simulate the Hermine-PRE precipitation

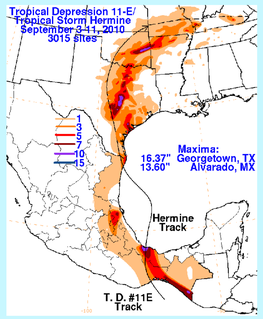


Figure 3. Observed track and precipitation of Hermine.
Source: http://www.hpc.ncep.noaa.gov/tropical/rain/hermine2010.html

Data and Methods

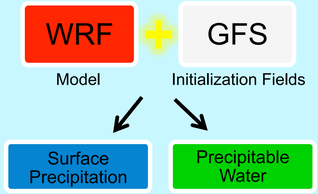
Figure 4. Domain of WRF-ARW model used to simulate Hermine-PRE event from 0000 UTC 7 through 0000 UTC 10 September. Model resolution was at 27 km.

Surface Analysis: Archived surface map analyses and precipitable water (PW) imagery were used to evaluate the synoptic and mesoscale environment surrounding Hermine.

Model Analysis: The WRF-ARW model with GFS initialization fields was used to produce a 72- hr. simulation of the Hermine-PRE event. Domain included nearly the entire continental U.S. (Fig. 4), and was centered over Lawton, OK. Initialization time was chosen to capture the precipitation of Hermine at landfall, and of its PRE.

Model simulation was compared to two sets of observational data:
1. The 6-hourly total accumulated surface precipitation
2. GPS-derived PW values

Characteristics such as the location, amount, spread, and structure of precipitation were used to score model performance.



Results : Environmental Set-Up

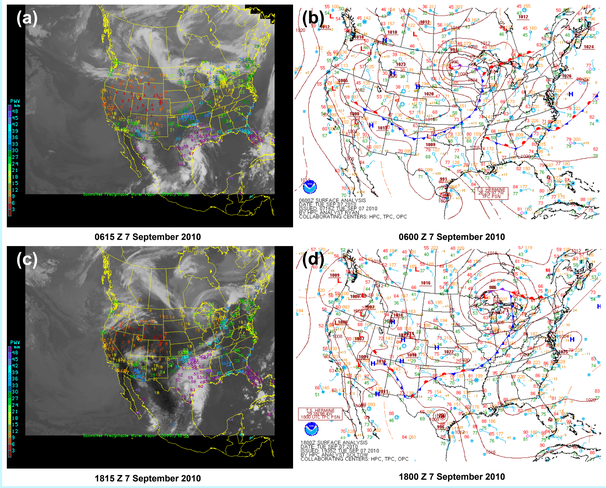


Figure 5. PW images (a, c) and surface map analysis (b, d) of the Hermine-PRE event.

Deep, rich moisture in southeast TX (Fig. 5a) was advected northward into OK and AR by the southerly surface winds of Hermine's circulation (Fig. 5b). The frontal boundary that was coming into place served as the primary lifting mechanism to precipitate the moisture, and led to the development of the PRE across this region. As the flux of moisture increased across AR and OK (Fig. 5c), and the frontal boundary continued to push southeastward, reports of heavy precipitation associated with the PRE were observed (Fig. 5d).

Results : Model Analysis

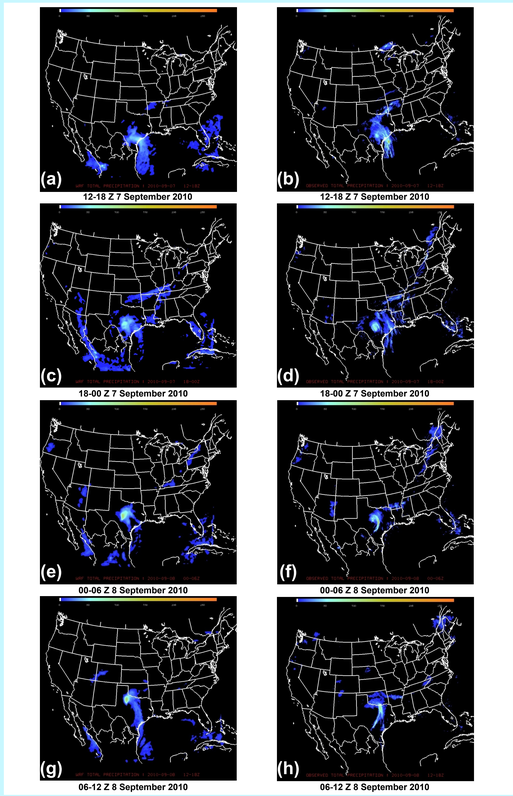


Figure 6a-h. A series of comparisons between model simulated precipitation (left column) and surface precipitation observations (right column) associated with the Hermine-PRE event.

The model displayed several discrepancies in its simulation of the Hermine- PRE precipitation. For example, the model missed the northward spread of precipitation into north central TX as Hermine moved inland (Fig. 6a, b). Although the model captured the PRE development across OK and AR, it was unable to simulate the local precipitation maxima in northern AR (Fig. 6c, d). The model preferentially simulated the Hermine-PRE precipitation in a smooth, less-defined fashion (Fig. 6e ,f). It also showed a clear western bias in the simulated precipitation for Hermine's remnants (Fig. 6g, h). These disagreements are attributed to coarse resolution, and lack of ocean-atmosphere coupling and hurricane vortex parameterization.

Conclusions

The findings considered most significant to the Hermine-PRE event…

- Favorable environment for PRE development:
  - Southerly winds advected rich moisture while frontal boundary served as lifting mechanism to precipitate moisture
- Model discrepancies with observations:
  - Simulated magnitude and spread of precipitation was inaccurate
  - Simulated track was consistently displaced to the west of the observed track
- This study emphasizes the need to:
  - Understand the physical interactions and role of TC moisture in PRE events in order to improve precipitation forecasts

Future work

- Improve model simulation of Hermine-PRE precipitation:
  - Initialize the simulation closer to the time of the event
  - Consider a coupled ocean-atmosphere model with finer resolution
  - Testing effectiveness of adding a vortex parameterization
- Develop a flood potential algorithm for societal benefit:
  - Warn emergency coastal managers of significant inland flooding due to PRE itself or from subsequent arrival of TC's main precipitation shield over soils already saturated by PRE
  - Develop flood potential algorithms for various regions in U.S.

Data Management

- WRF-ARW model configurations available through an online tutorial provided by the Mesoscale and Microscale Meteorology (MMM) division
- GFS initialization fields available online through the National Centers for Environmental Prediction Final (NCEP FNL) Operational Global Analyses data archive
- Surface precipitation observations available online through the Global Energy and Water Cycle Experiment Continental-scale International Project (GCIP)/Enhanced Observing Period (EOP) Surface: Precipitation NCEP/Environmental Modeling Center (EMC) 4KM Gridded Data (GRIB) Stage IV Data dataset archive
- Surface Map Analysis available online through the Hydrometeorological Prediction Center (HPC) archive database
- PW imagery available online through the SuomiNet Network archived database

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