Impacts of data assimilation of simulated rain rates from the NASA HIRAD instrument on tropical cyclone precipitation forecasts in a mesoscale model

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I. Introduction

One of the best ways to validate aircraft instrumentation with regard to hurricane forecasting is to utilize mesoscale model forecasting with simulated instrumentation data incorporated into its initialization schemes. A comparison of the enhanced forecast (made with the simulated or actual data incorporated) can be compared to a control run made before observations (or simulated observations) are included.

- Observing System Simulation Experiments (OSSE) can help make meaningful progress toward improving intensity prediction through data collection processes.
- New instruments under development such as the Hurricane Imaging Radiometer (HIRAD) being developed by NASA MSFC can stand to benefit from OSSE being run by mesoscale models.
  - Improve HIRAD while still in testing
  - Verify its usefulness in TCs and in various locations within a storm
  - Develop flight tracks
- This study seeks to utilize an OSSE approach to verify that NASA aircraft instrumentation will have profound usefulness in improving mesoscale model prediction of hurricane intensity via the inclusion of extremely high resolution aircraft data retrievals of rain rates and surface winds in a hurricane.

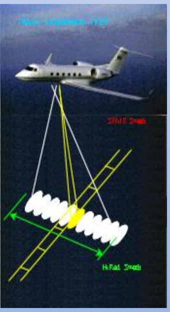
II. HIRAD and Data

HIRAD is a multi-frequency interferometric radiometer.

- The operating range is C-band and between 4 and 7 GHz.

HIRAD takes the basic measuring design of the Stepped Frequency Microwave Radiometer (SFMR) one step further by also combining it with the technology of the Lightweight Rainfall Radiometer (LRR) to make HIRAD a hybrid of the two technologies.

- Its geometry provides an excellent opportunity to image the high wind gradients and spiral rain bands surrounding the hurricane eye while flying the typical "butterfly" transects.
- Makes optimal observations across a huge swath in the heavy rain regions of a hurricane, available to be mounted on multiple platforms including research aircraft, and with a few modifications, even space-borne platform

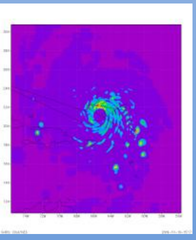


Example diagram depicting a NOAA Gulfstream IV aircraft with a mounted HIRAD instrument observing the surface below. The HIRAD instrument would observe in a wide-swath push-broom configuration capturing large areas of the surface below.

○This project uses simulated HIRAD, SFMR, and dropsonde data taken from a simulation of Hurricane Frances (2004). This simulated data is calculated from a Nature Run model. Synthetic observations used in OSSEs are usually extracted from long forecasts from high resolution, state-of-the art models, and are known as "nature runs", which acts as proxy atmospheres.

○Next, these simulated observations undergo data assimilation techniques to initialize a different model, a "fraternal twin" model of different resolution, physics, and dynamic core. In this study, the fraternal twin is the WRF-ARW model. Prof. Shuyi S. Chen has provided the nature run- Frances 2005, utlizing the MM5 model.

III. Data Assimilation



Sample Flight track adapted from an investigation of Hurricane Emily 2005 on July 17 during the NASA TCSP Field Campaign Overlain onto the Nature Run rain rate field.

○For the purposes of the OSSE, HIRAD observed rain rates are simulated from the nature run

○Developed a program specifically to take rain rates from within the model that are along a mock flight track through the nature run storm at a given time

○It is now assumed that for a given 3 hours of model space the HIRAD instrument would have observed along the track between points 1 and 2, 2 and 3, and 3 and 4

○There are two types of data assimilation utilized in this study:

○The Krishnamurti et al. 2007 technique of Rain Rate Initlizationin Mesoscale Models for the Rain Rates observed in this study

○3DVAR assimilation of winds in this study.

○These techniques are utilized to optimally inlcude the synthetic observations plus error into the model initialization, whereby a forecast can be made and error metrics determined to see the impacts on the hurricane intensity forecast.

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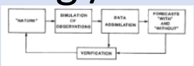
IV. Modeling /OSSE Approach



Schematic of the simulation system for OSSEs, from Atlas 1997.

○The simulated observations are taken from the nature model, as is done in this study.

○The simulated observations undergo data assimilation and are verified against the nature model, as is also done in this study.

○Finally, forecasts are made with and without the addition of the assimilated observations and all forecasts are compared against the nature model, which acts as the ultimate correct answer throughout the process.

○The forecasts must seek to achieve the results of the nature model by incorporating the observations simulated from that nature model and running it in a different model, or a fraternal twin, such is the strategy to be used in this study.

○This study proposes a suite of forecast experiments that include the following:

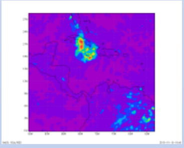
○A control run with no aircraft observations,

○An experiment, for the HIRAD example, that includes TRMM rain rates augmented by the heavy rain measured by HIRAD (this will be done similarly for other instrumentation studied),

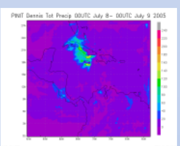
○ And to the previous experiment's initial state we will assimilate surface winds to a forecast run.

V. Preliminary Results

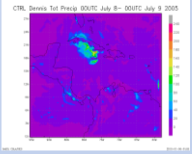
TRMM vs. Control vs. Physical Init For Hurricane Dennis 2005



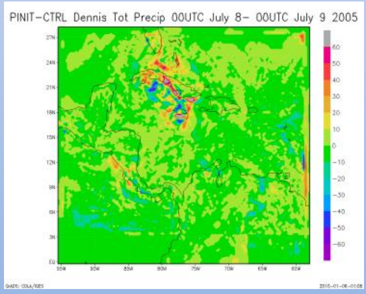
TRMM



Physical Initialization



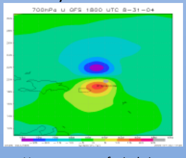
Control



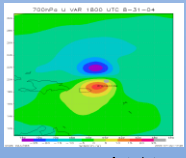
Quantifying the Difference- Both Positive and Negative values indicate areas where Physical Initialization has both added and subtracted from the total rain based on the techniques discussed herein.

Difference plot for Physical Initialization minus the Control Experiment when Physically Initialized with TRMM data

Preliminary Wind Obs Model Initialization Results- Just one Dropsonde can make a difference



U component of winds in Frances 2004 in the unaltered GFS at 700 hPA



U component of winds in Frances 2004 at 700 hPa AFTER initialization with just one dropsonde wind profile

Further work with 3DVAR is underway and more remains to be explored with Physical Initialization.

VI. Future Research

○To develop a systematic approach to, and evaluate the role of, the FSU physical initialization of rain rates technique in mesoscale modeling of hurricanes;

○To develop and/or utilize optimal methods of data assimilation of NASA aircraft instrumentation observations into mesoscale models;

○To use synthetic observations from existing and proposed observing systems to identify an optimal configuration for its use in the observation network aboard the research aircraft and bring to light any weaknesses in the processing or assimilation of the observations so they can be addressed.

○To make recommendations for flight track and optimal observing conditions for the NASA instrumentation in order to further the data's usefulness in mesoscale prediction of TC track and intensity.

○Also, multiple platforms are possible for HIRAD and the effects of one platform versus another may be explored if a significant impact on the data retrieved is noted.