Assimilation, Ensemble forecast and Adaptive strategies using CAMEX4 datasets

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Introduction

Numerical weather prediction depends on an accurate representation of the initial state of the atmosphere. An error in the analysis of the initial state can amplify through the modeling process and cause a drastic error in the predicted state. This is especially true in case of Hurricanes and tropical storms. If the location and intensity of the storm in the analysis do not match the observations (location and intensity), even the best model is likely to fail in predicting the future course of the storm. If the initial vortex is not well defined because of the lack of data, models may fail to predict the track and intensity of the storm.

In the past, various field experiments were conducted to enhance the observational database of hurricanes. CAMEX (The convection and Moisture Experiments) includes a series of field experiments sponsored by the National Aeronautics and Space Administration (NASA). The first two CAMEX field studies were conducted from Wallop's Island, Virginia, during 1993 and 1995 and third field study, specially designed for hurricane studies, was conducted during 3 August to 28 September 1998. Recently, a fourth field campaign in the CAMEX series (CAMEX-4) was held during 16 August - 24 September 2001 and was centered at Jacksonville Naval Air Station, Florida. CAMEX-4 is focused on the study of tropical cyclone (hurricane) development, tracking, intensification, and landfalling impacts using NASA-funded aircraft and surface remote sensing instrumentation. The overall objectives of CAMEX were to study the atmospheric water vapor and precipitation processes using an array of airborne, space and land-based remote sensors. Our previous studies showed promising impacts on hurricane forecast using several CAMEX campaign data sets (E. L. Bensman, 2000 and S. R. H. Rizvi et al, 2002) and also provided the opportunity to understand the reasons of model failures in hurricane predictions. Here we made an attempt to analyze the available CAMEX4 data sets using three dimensional variational analysis scheme and medium range predictions were carried out by integrating the NWP model out to 5 days with these new initial conditions.

Data & Experimental plan

NASA's ER-2 and DC-8 were the main research aircraft in addition to those the NOAA operational research aircraft, Gulfstream-4, WP-3D and WC-130 of the US Air Force were available for this study. The Airborne Vertical Atmospheric Profiling System (AVAPS) was used for monitoring the dropsondes from operational and research aircraft. All these were Global positioning satellite (GPS) based dropsondes consisting of four components, namely the pressure, temperature and humidity (PTH) sensor, the digital microprocessor circuitry, the GPS receiver and the 400 MHz transmitters. The LASE sensor was flown on the NASA DC-8 aircraft. This sensor was specifically designed to measure the moisture in the zenith and nadir positions. Further details on these data can be found on CAMEX website. Since we had access to the DC-8 and LASE data sets, these data sets were used for the following experiments, which were designed to study the impact on the analysis and forecasts of Atlantic hurricanes.

CTRL: Control analysis at T170L14 by using ECMWF analysis at 0.5º Resolution + FSU Physical Initialization.
CTRL1: CTRL + DC8 wind data. It served as background field for the following experiments.
EXP1: CTRL1 + DC8 moisture data
EXP2: CTRL1 + LASE data
EXP3: CTRL1 + DC8 moisture + LASE data

Analysis scheme and NWP model

CAMEX4 data were analyzed using three dimensional variational analysis scheme, which is mainly based on the Lorenc's (1986) concept of minimizing a generalized cost function using the Spectral Statistical Interpolation (SSI) technique (Parrish & Derber 1992). Since the analysis scheme works on the residuals (observations - background), it was essential to have a proper quality control of these residuals before used in the analysis. The background field was interpolated bilaterally in the horizontal and an Exner interpolation (Krishnamurti et al., 1998) was used in the vertical while computing the background field at the locations of observations. The background error statistics were used to weigh the background field. Statistical parameters, such as the background error covariance, Empirical Orthogonal Functions (EOF) for vorticity, divergence, temperature, moisture and various other statistical parameters were computed using the difference between the Day-1 forecasts of the FSU global spectral model (produced from the ECMWF reanalysis) and the corresponding verifying analysis for that date. One-month data sets (August, 1998) were used to compute these statistics.

The Numerical Weather Prediction (NWP) model used in this study is the FSU Global Spectral Model (FSUGSM), described in Krishnamurti et al (1998). The horizontal resolution of the model was triangularly truncated at wave number 170 (T170), which corresponds to a Gaussian grid of 512 x 256 longitude/latitude, and it had 14 σ-vertical levels. A semi-implicit time integration scheme is used with time step of 450 seconds to represent the time derivatives. The high frequency gravity wave oscillations are

controlled by using a semi-implicit time differencing scheme. The prognostic variables are Vorticity, divergence, dew point depression, surface pressure and a variable, which combines the height and the log of surface pressure. The model physics includes:
Modified Kuo scheme for cumulus parameterization (Krishnamurti et al. 1983)
Shallow convective adjustment (Tiedtke, 1983)
Dry convective adjustment
Large-scale condensation
Planetary boundary layer parameterization by similarity theory (Businger et al. 1971)
Parameterization of radiation for short wave by Lacis and Hansen (1979), and long wave by Harshvardhan and Corsetti (1984).

Numerical Results

We started with a ½ deg lat-lon resolution of ECMWF analysis and the microwave radiances provided by TRMM and DMSP satellites (F13, F14 and F15) and produce rain rate estimates using NASA Goddard algorithms. The FSU model at the resolution T170 makes use of these data to perform Physical Initialization. Control forecasts were next carried out at the resolution T170 that includes ECMWF + Rain rate estimates in its initial state. 3D VAR (Three Dimensional Variational data assimilation) is next carried out sequentially to add Dropsonde data and LASE data sets.

A number of experiments were carried out during CAMEX3 and CAMEX4 on the sensitivity of track forecasts from the inclusion of various data sets. Figure.1 shows the 120 hr forecast tracks of hurricane Erin from the outputs of various experiments mentioned as above. These results for hurricane Bonnie of 1998 and for hurricane Erin of 2001 essentially demonstrated that as more and more data were introduced (beyond those of the control experiment) the left bias of the control experiments was generally reduced for each addition of a newer data set. This left bias is largely related to the positive surface vorticity tendency that arises from the larger scale horizontal advection of vorticity. That feature is similar for all of the above experiments and occurs downwind for the wind maximum of the hurricane. As dropsonde and LASE data sets are sequentially introduced the hurricane is better resolved on a smaller scale. The model shows a pronounced center of rising motion, precipitation and positive vorticity tendency where this storm is now being resolved. This occurs to the right of the track of the control run; the control run's track appeared to the largely dictated by the larger scale vorticity advection. The local enhancement of the diabatic physics appears to bring a positive tendency for the storm's newer data sets. It is easy to see how that pushes the positive vorticity maxima to the east of the control experiment. In a related study, Krishnamurti et al (1997), noted that if several different analyses were deployed within the same model then either a left or a right bias developed depending on which ever analysis was used. This appeared to be related to the vorticity advection downwind for the velocity maxima of a hurricane that was differently placed in the different analysis. This suggests that a left or a right bias could be reduced somewhat simply from the addition of more initial data sets.

Also we examined the precipitation for every six hours of day-1 to day-4 forecasts with and without LASE data sets. Figure.2 shows the precipitation (shaded with colors) and Specific Humidity at 700 hPa (contours) of day-3 forecasts. The differences based on the data assimilation including LASE and the control show a marked positive anomaly centered around 850 hPa. However we do see a negative anomaly at the surface level. Over this region the FSU control was somewhat too moist. That arises from the physical initialization of the control where to match the observed rain estimates, the initialization place a more moisture over surface layer. This feature is however removed when the LASE data are incorporated. However we do observe an eventual increase of precipitation, over the storm area, when the LASE data are included. That feature is most likely related to the enhanced evaporation over the slightly drier surface layer.

Conclusions

It is still a little premature to make many conclusions from CAMEX4 since the data sets are still coming in and a rigorous evaluation is required to make any conclusions. However, we do find a positive impact from the assimilation of moisture profile data from LASE. Two things emerge over the region of the hurricanes and the TD over the domain. These regions show a more humid storm and slightly more rain in the analysis and in the short-range forecasts. Forecast tracks are somewhat improved in 3 day forecasts from the use of LASE data sets. The large left bias of the control is reduced in the track forecasts.

Future Plan

If we can work with the totality of CAMEX4 data sets (Flight level, Dropsonde, LASE) from all aircraft that participated, it may be possible to carry out:

a) High resolution NWP experiments using a regional spectral model at a resolution of around 25 km.
b) Deploy physical initialization using TRMM and DMSP microwave radiance data sets and derived rain rate estimates.
c) Assimilate the available totality of CAMEX4 data sets.
d) Carry out 3-day forecast experiments with various options on inclusion versus exclusion of data types.
e) Possible impact of CAMEX4 on intensity modeling for storms such as Erin, Humberto, Chantal and Gabrielle.
f) Adaptive strategies where data deployment area will be addressed.

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References

Bensman, E. L., 2000: The impact of aircraft digital weather data in an adaptive observation strategy to improve the ensemble prediction of hurricanes. Ph.D.

Dissertation, Dept. of Meteorology, FSU, Tallahassee, Fl - 32306. FSU Report No. 00-10, October, 2000.

Businger, J.A., L.C. Wyngard, Y. Izumi and E.F. Bradley, 1971: Flux profile relationship in the atmospheric surface layer. *Jour. of Atmos. Sci.*, 28, 181-189.

Harshvardhan and T.G. Corsetti, 1984: Long wave parameterization for the UCLA/GLAS GCM, NASA Technical Memo, 86072, Goddard Space Flight Center, Greenbelt, Maryland.

Krishnamurti, T. N., S. Low-Nam and R. Pash, 1983: Cumulus parameterization and rainfall rates II. *Mon. Wea. Rev.*, 111, 816-828.

Krishnamurti, T. N., Correa Torres R., Rohaly G., et al 1997: Physical initialization and hurricane ensemble forecasts. *Weather Forecast*, 12 (3), 503-514 part 1.

Krishnamurti, T. N., H. S. Bedi and D.V.M. Hardiker, 1998: An Introduction to Global Spectral Modeling. Oxford University Press, 253 pp.

Lacis A. A. and J.E. Hansen, 1974: A parameterization for the absorption of solar radiation in the earth's atmosphere. *Jour. of Atmos. Sci.*, 31, 118-133.

Lorenc, A.C., 1986: Analysis methods for Numerical Weather prediction. *Quart. J. Roy. Meteor. Soc.*, 112, pp. 1177-1194.

Parrish D.F. and J. C. Derber, 1992: The National Meteorological Center's Spectral Statistical Interpolation analysis scheme. *Mon. Wea. Rev.*, 120, 1747-1763.

Rizvi SRH, EL Bensman, TSV Vijay Kumar, A Chakraborty and TN Krishnamurti (2002): Impact of CAMEX3 data on the analysis and forecasts of Atlantic hurricanes, *Meteo. Atmos. Phy.*, 79, 13-32.

Tiedtke, M., 1984: The sensitivity of the time-mean large-scale flow to cumulus convection in the ECMWF model. Workshop on convection in large-scale numerical models., Reading, UK. UCMWF, 297-316.

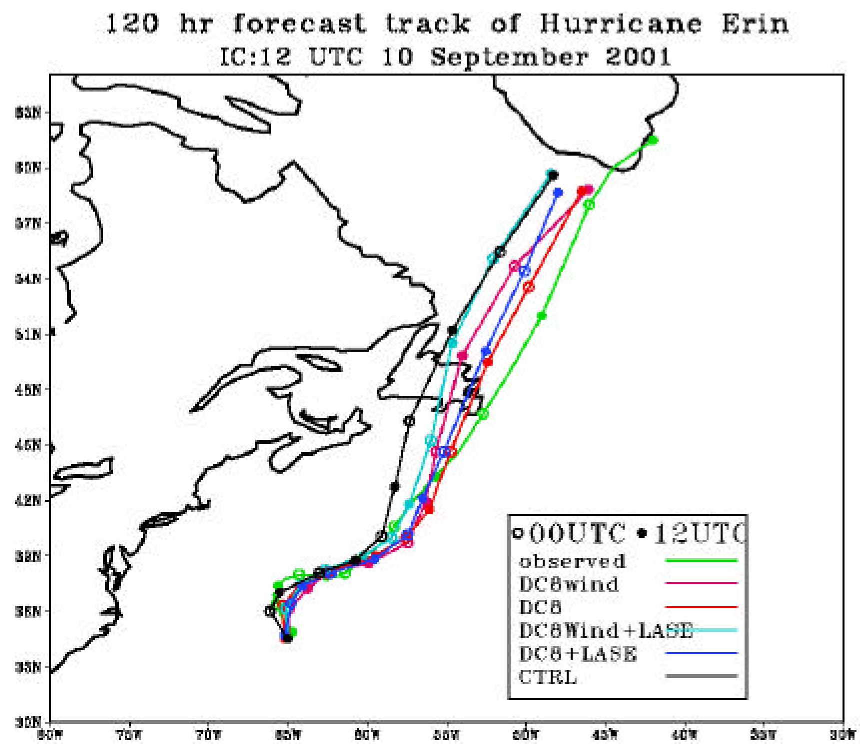
120 hr forecast track of Hurricane Erin
IC:12 UTC 10 September 2001
00UTC
12UTC
observed
DC8wind
DC8
DC8Wind+LASE
DC8+LASE
CTRL

Figure.1

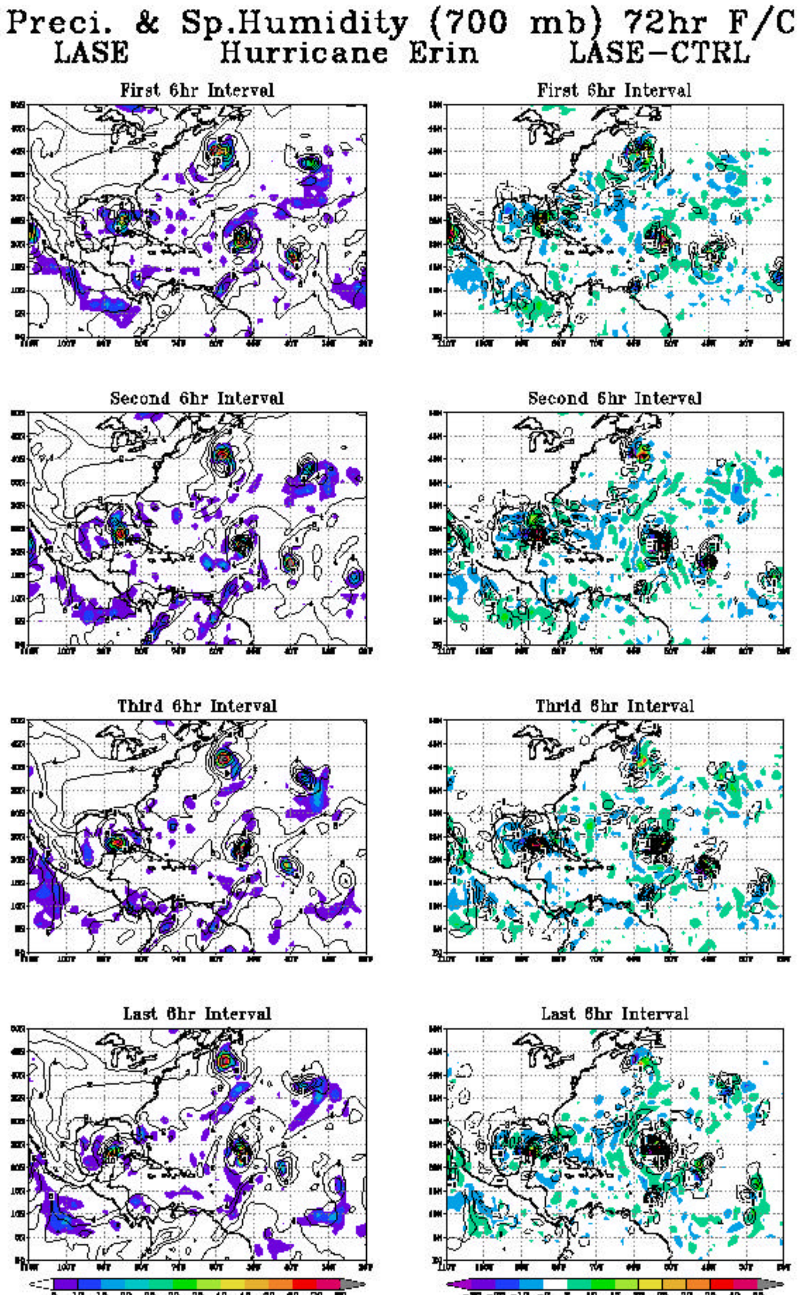
Preci. & Sp.Humidity (700 mb) 72hr F/C
LASE
Hurricane Erin
LASE-CTRL
First 6hr Interval
First 6hr Interval
Second 6hr Interval
Second 6hr Interval
Third 6hr Interval
Third 6hr Interval
Last 6hr Interval
Last 6hr Interval

Figure.2