Assimilating Cloudy Radiances with MLEF using NCEP Operational HWRF System: A case study

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OUTLINE

- Objectives
- Methodology
- Experiments
- Preliminary results
- Summary
- Future work

MOTIVATION

- Evaluate the impact of cloudy radiance observations in regional hurricane analysis and forecast.
- Use a prototype hybrid variational-ensemble data assimilation system (HVEDAS) developed at Colorado State University to have an early assessment of the future operational HVEDAS.
- Use NOAA operational environment for evaluation: HWRF, GSI, CRTM, scripting.
- Prepare for merging current satellite measurements with the future GOES-R measurements (Advanced Baseline Imager and Geostationary Lightning Mapper).

HVEDAS components

- Ensemble DA algorithm
  - Maximum Likelihood Ensemble Filter (MLEF)
- NWP model
  - NCEP operational Hurricane WRF system (HWRF)
- Observation operators
  - Gridpoint Statistical Interpolation (GSI)
  - Community Radiative Transfer Model (CRTM)

DATA ASSIMILATION APPROACH

Maximum Likelihood Ensemble Filter

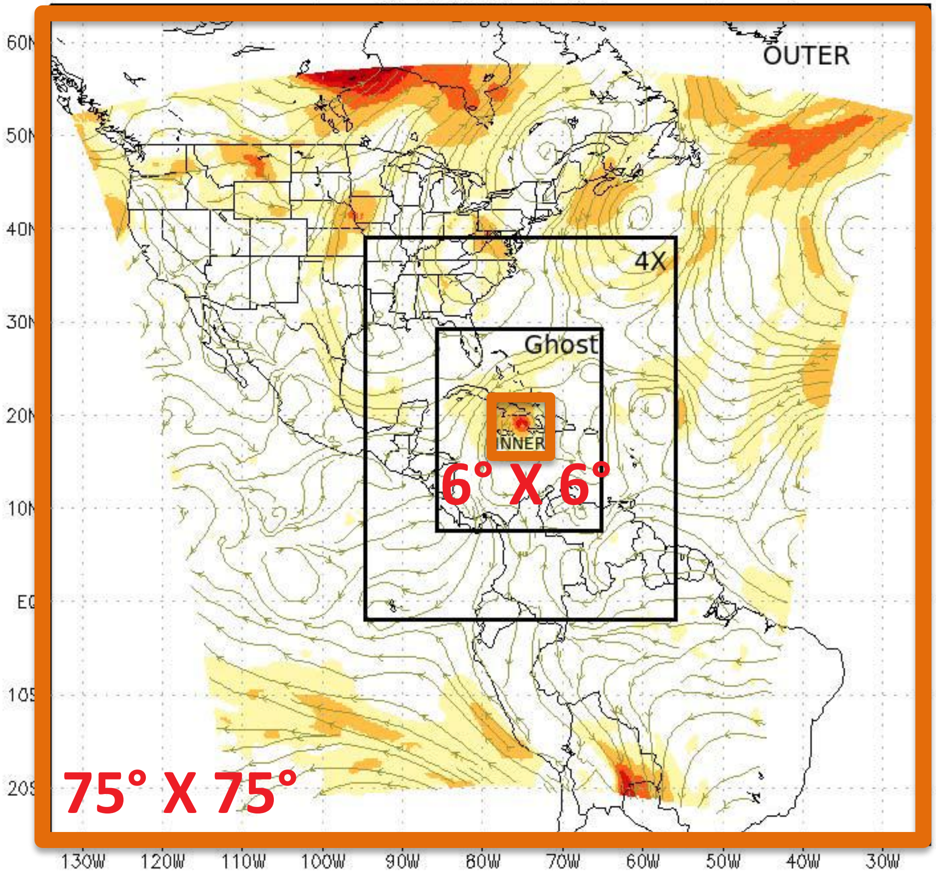
*(**MLEF**; Zupanski 2005; Zupanski et al. 2008)*

- A hybrid variational-ensemble DA method;
- Based on control theory;
- Suitable for nonlinear and discontinuous problems (e.g., involving atmospheric models with cloud microphysical variables);
- Flow-dependent forecast covariance;
- Assimilation of highly nonlinear observations;
- Computationally efficiency and robustness;

… … …

Zupanski, M., 2005: Maximum Likelihood Ensemble Filter: Theoretical Aspects. *Mon. Wea. Rev*., **133**, 1710-1726.
Zupanski, M., I. M. Navon, and D. Zupanski, 2008: The Maximum Likelihood Ensemble Filter as a non-differentiable minimization algorithm. *Q. J. R. Meteorol. Soc*., **134**, 1039-1050

NCEP operational HWRF system



The four domains used in HWRF vortex initialization

- ***Model Physics in HWRF***
  - Simplified Arakawa-Schubert scheme
  - Ferrier cloud microphysics scheme
  - Troen-Mahrt's non-local vertical diffusion scheme
  - Monin-Obukhov surface flux scheme
  - GFDL radiation scheme

- ***HWRF model with two nests***
  - Atmos OUTER domain
    - 75°×75°
    - ~ 27 km
    - 42 levels
  - Atmos INNER domain
    - 6°×6°
    - ~ 9 km
    - 42 levels

Skip HWRF vortex initialization in current MLEF-HWRF

Observation operators

- GSI forward model and basic quality control
  - NCEP operational observation type: include conventional data, radar data, and satellite observations (such as AMSU-A, AMSU-B/MHS, AIRS, IASI, GPSRO, …)

- Community Radiative Transfer Model (CRTM)
  - developed by the Joint Center for Satellite Data Assimilation (JCSDA)
  - Use forward component of the CRTM to get the all-sky radiances

Wu, W.-S., R. J. Purser and D. F. Parrish, 2002: Three-Dimensional Variational Analysis with Spatially Inhomogeneous Covariances. Mon. Wea. Rev., 130, 2905-2906.
DTC GSI documentation (http://www.dtcenter.org/com-GSI/users/index.php)
JCSDA-CRTM website (http://www.star.nesdis.noaa.gov/smcd/spb/CRTM/)

MLEF APPLICATIONS TO HWRF

MLEF-HWRF flowchart

•***Forecast step***:

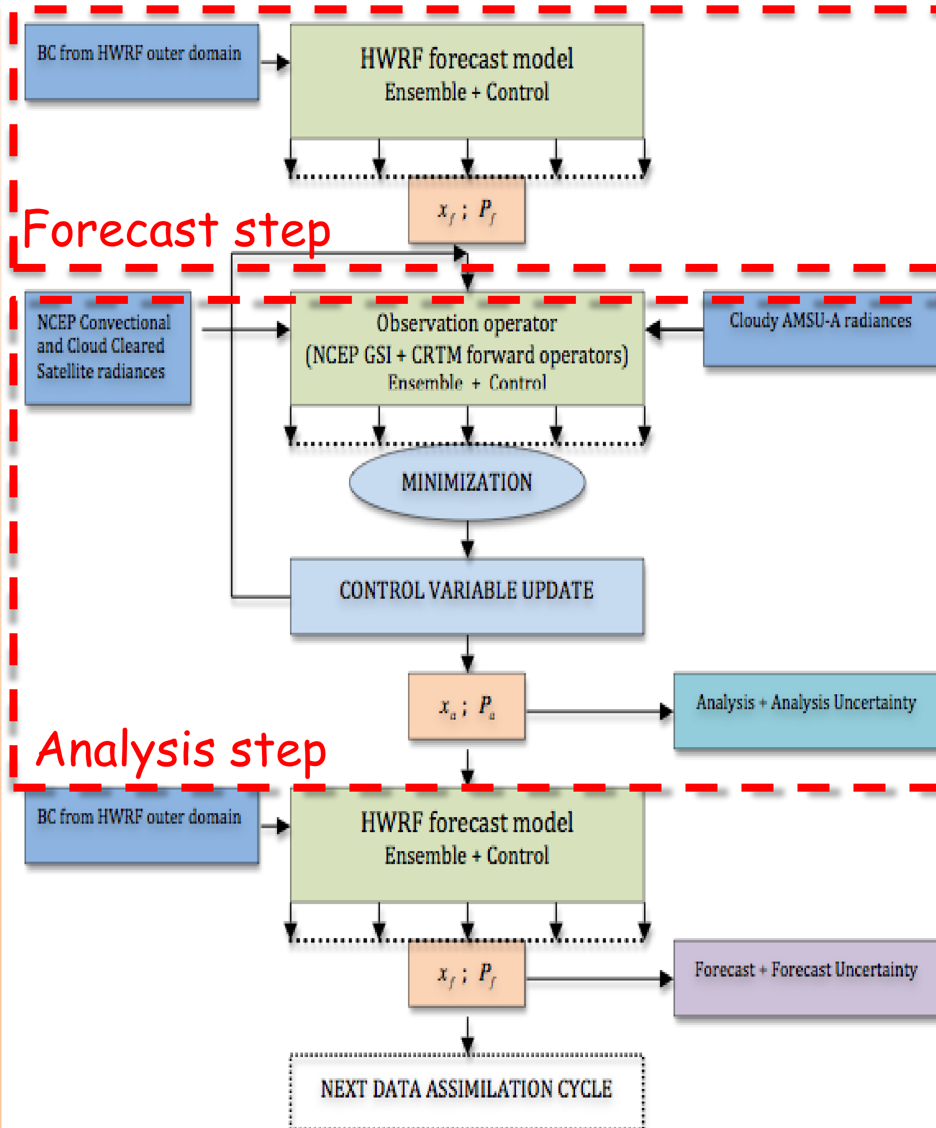
- MLEF calls subroutines to make HWRF ensemble forecasts to next analysis time
- each ensemble LBCs is interpolated from HWRF outer domain
- ensemble forecasts are transformed to MLEF state vectors

•***Analysis step***:

- Forward model computed for all obs, all members
- Observation operator includes forward component of the GSI and CRTM
- Added processing of cloudy radiances from GDAS (e.g., M-J Kim)

•***Provide: optimal state + uncertainty***

- Optimal state: Maximum a posteriori PDF estimate
  - as function of obs and forecast
  - optimal state = analysis = ICs for next fcsts
- Uncertainty: Ensemble-based uncertainty estimate



http://www.cira.colostate.edu/projects/ensemble/

EXPERIMENTS

- **CASE**: Hurricane Danielle (21-30 August 2010)

- **START DATE**: 1200 UTC 24 Aug 2010

- **MLEF-HWRF cycling system**:

- produce 9-km analysis in the HWRF inner domain every 6-hr; the outer domain provides the LBCs to the inner domain;

- **Control variables** include the following 5 components: wind components (**U, V**); specific humidity (**Q**); temperature (**T**); hydrostatic pressure depth (**PD**)

- ENSEMBLE SIZE is 32 members

TWO EXPERIMENTS

- Exp.1 (CLR): cloud cleared AMSU-A radiance assimilation
  - assimilate conventional observations and cloud cleared AMSU-A radiances;
  - standard simplification used in current NCEP operations.

- Exp.2 (ALL): all-sky AMSU-A radiance assimilation
  - same as CLR, but using the approach in GDAS (e.g., M-J Kim) to include cloudy AMSU-A radiance.

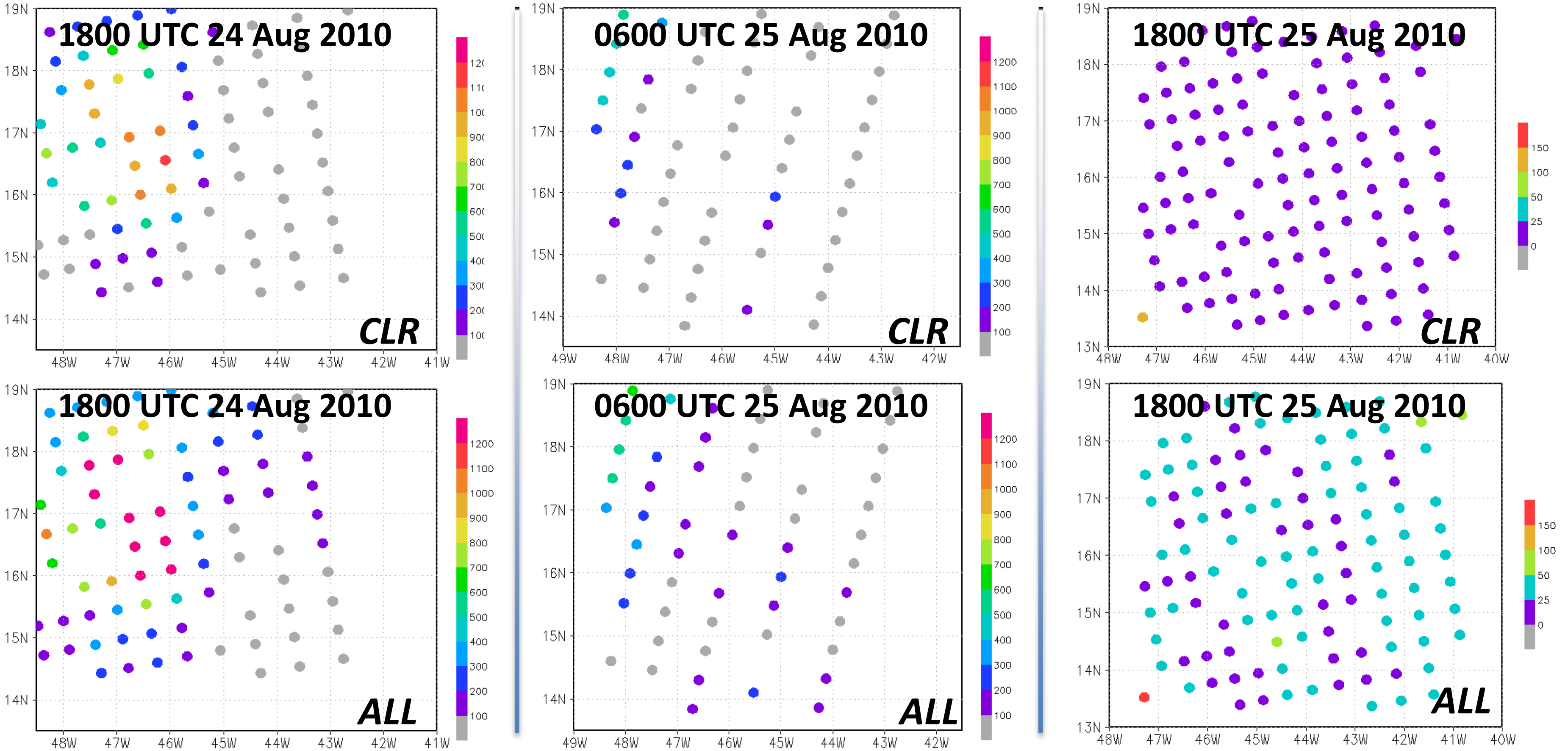
Kim M.-J. et al. Status on Cloudy Radiance Data Assimilation in NCEP GSI (http://www.jcsda.noaa.gov/documents/meetings/wkshp2011/dayOne/Kim_MJ.pdf)

Preliminary Results

- Inclusion of cloudy radiances
- Improvements in TC initial vortex analyses
- Forecasts

AMSU-A n18 CLW diagnostic analyses after QC and data thinning in GSI for HWRF inner domains

(g m^{-2}; thinning in a 60-km grid; time_window_max = ± 1.5 hr)



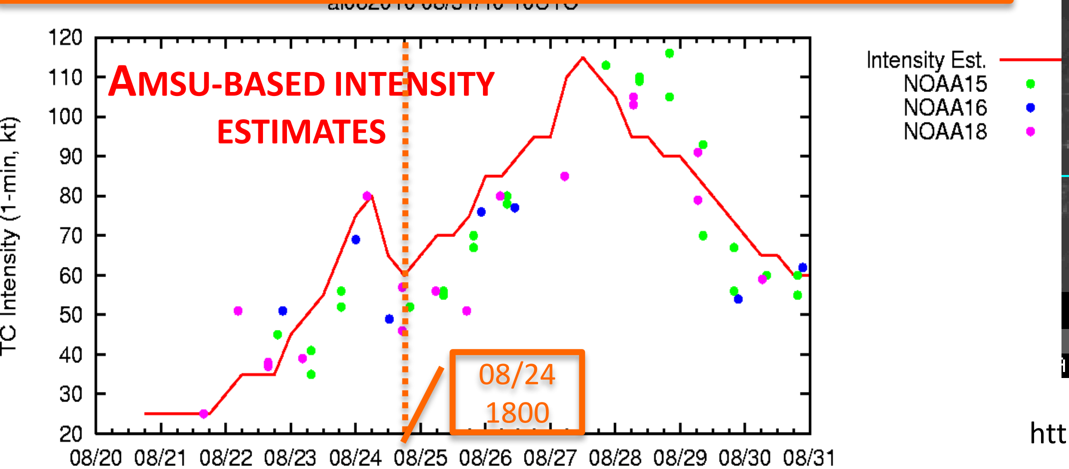
Positive impact for CLW diagnostic analyses when adding cloudy AMSU-A radiances

HURRICANE DANIELLE (2010)

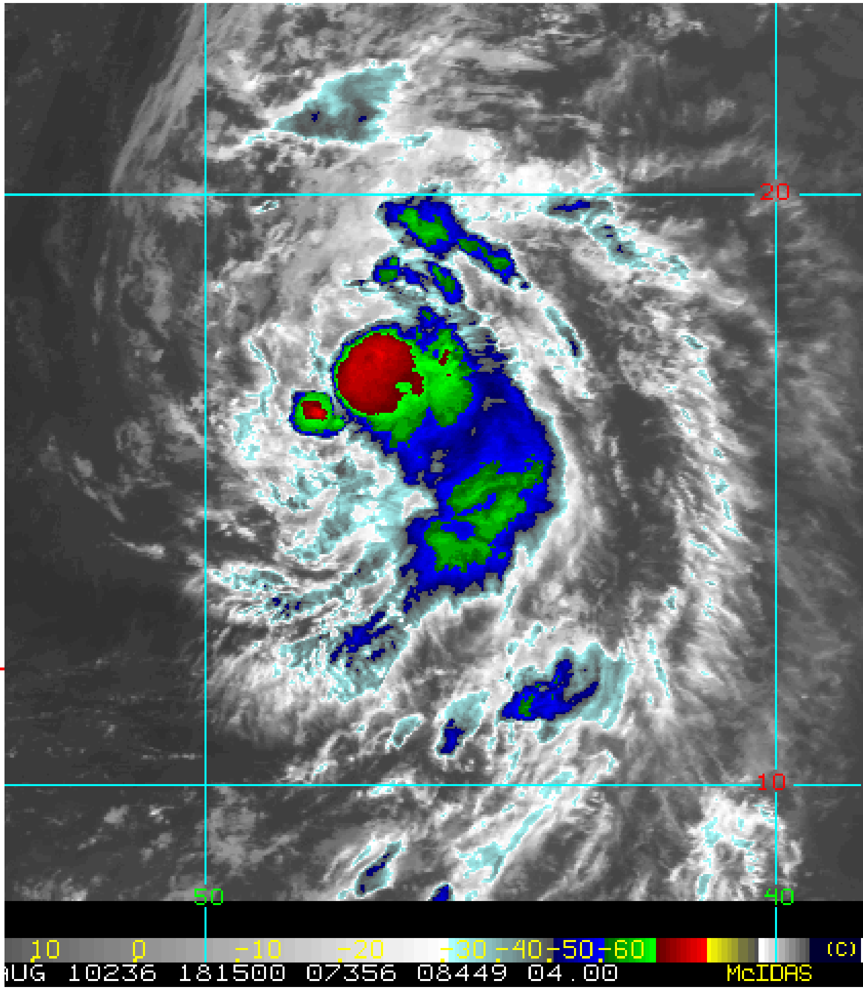
1800 UTC 24 Aug 2010

Table 1. Best track for Hurricane Danielle, 21-30 August 2010. (NHC-TC report)

Date/Time (UTC)	Latitude (°N)	Longitude (°W)	Pressure (mb)	Wind Speed (kt)	Stage
21 / 1200	10.7	31.1	1009	25	low
21 / 1800	11.0	31.7	1008	25	tropical depression
22 / 0000	11.4	32.4	1007	30	"
22 / 0600	11.8	33.1	1005	35	tropical storm
22 / 1200	12.4	33.9	1005	35	"
22 / 1800	13.2	34.8	1004	35	"
23 / 0000	13.8	35.9	1000	45	"
23 / 0600	14.2	37.4	997	50	"
23 / 1200	14.7	39.1	994	55	"
23 / 1800	15.2	40.9	987	65	hurricane
24 / 0000	15.4	42.6	982	75	"
24 / 0600	15.6	44.2	977	80	"
24 / 1200	16.2	45.8	984	70	"
24 / 1800	17.0	47.5	987	65	"



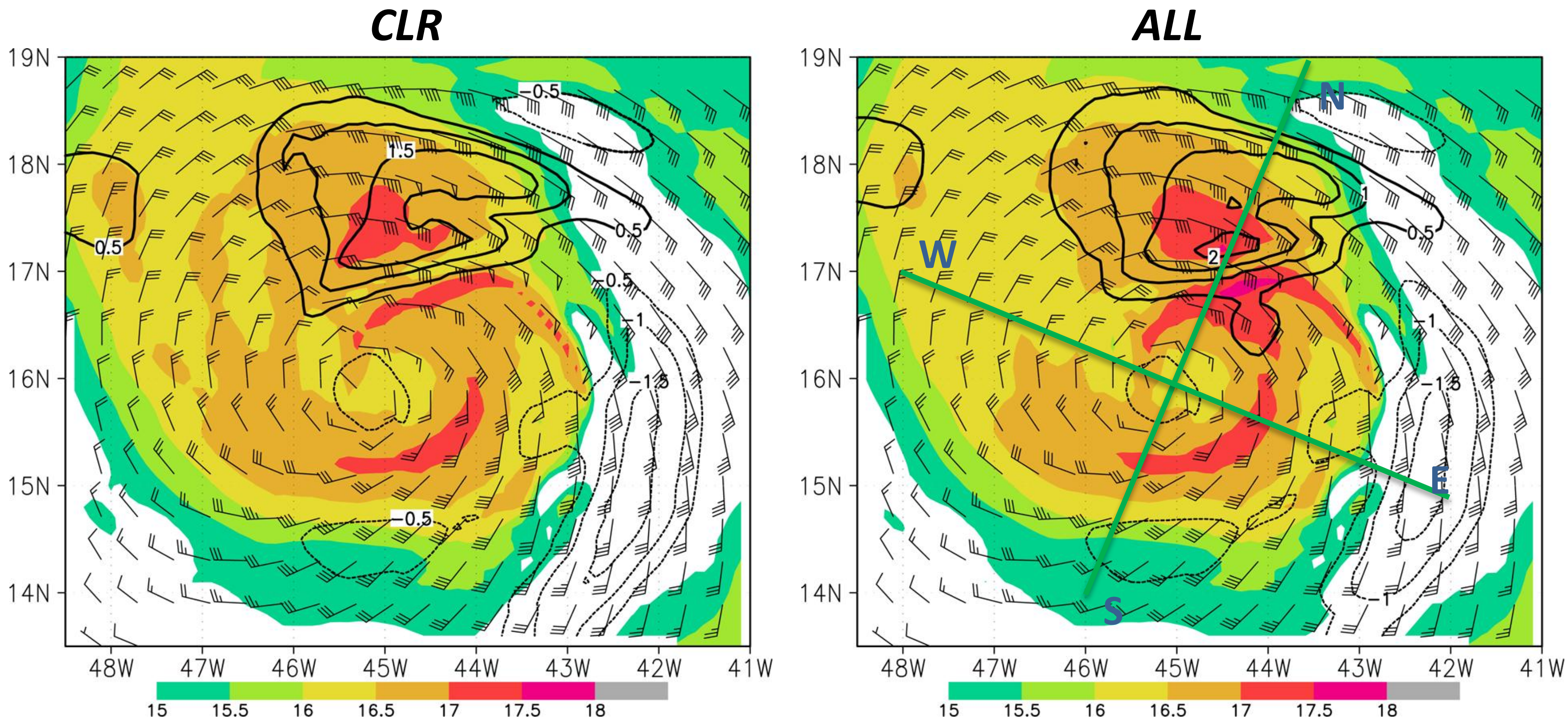
Enhanced Infrared (IR) Imagery
1815 UTC 24 Aug 2010



http://rammb.cira.colostate.edu/products/tc_realtime/index.asp

Analysis (X^a, shaded) and Analysis increments (X^a-X^b, contours) for Q ($g\ kg^{-1}$) at 900 hPa; A full barb is $5m\ s^{-1}$

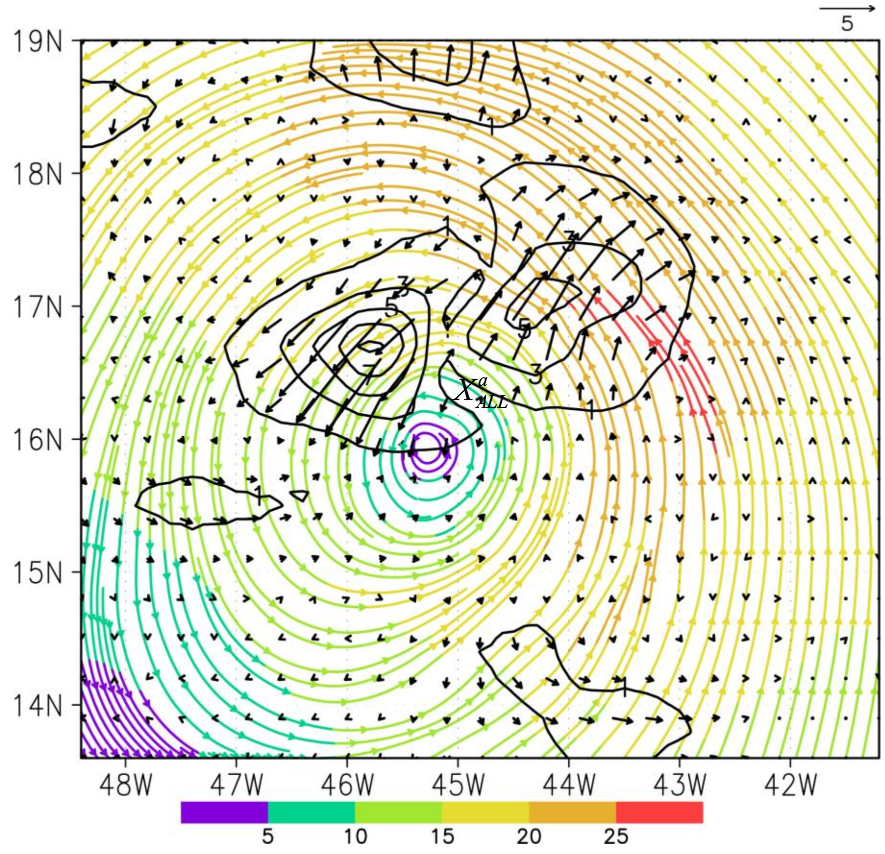
1800 UTC 24 Aug 2010



Increased humidity in the TC eyewall for cloudy DA

Analysis (X_{ALL}^a; shaded streamlines) and Analysis difference (X_{ALL}^a-X_{CLR}^a; black contoured) for wind vectors (ms^{-1}) at 850 hPa; The wind vectors indicates the vectors of X_{ALL}^a-X_{CLR}^a of winds

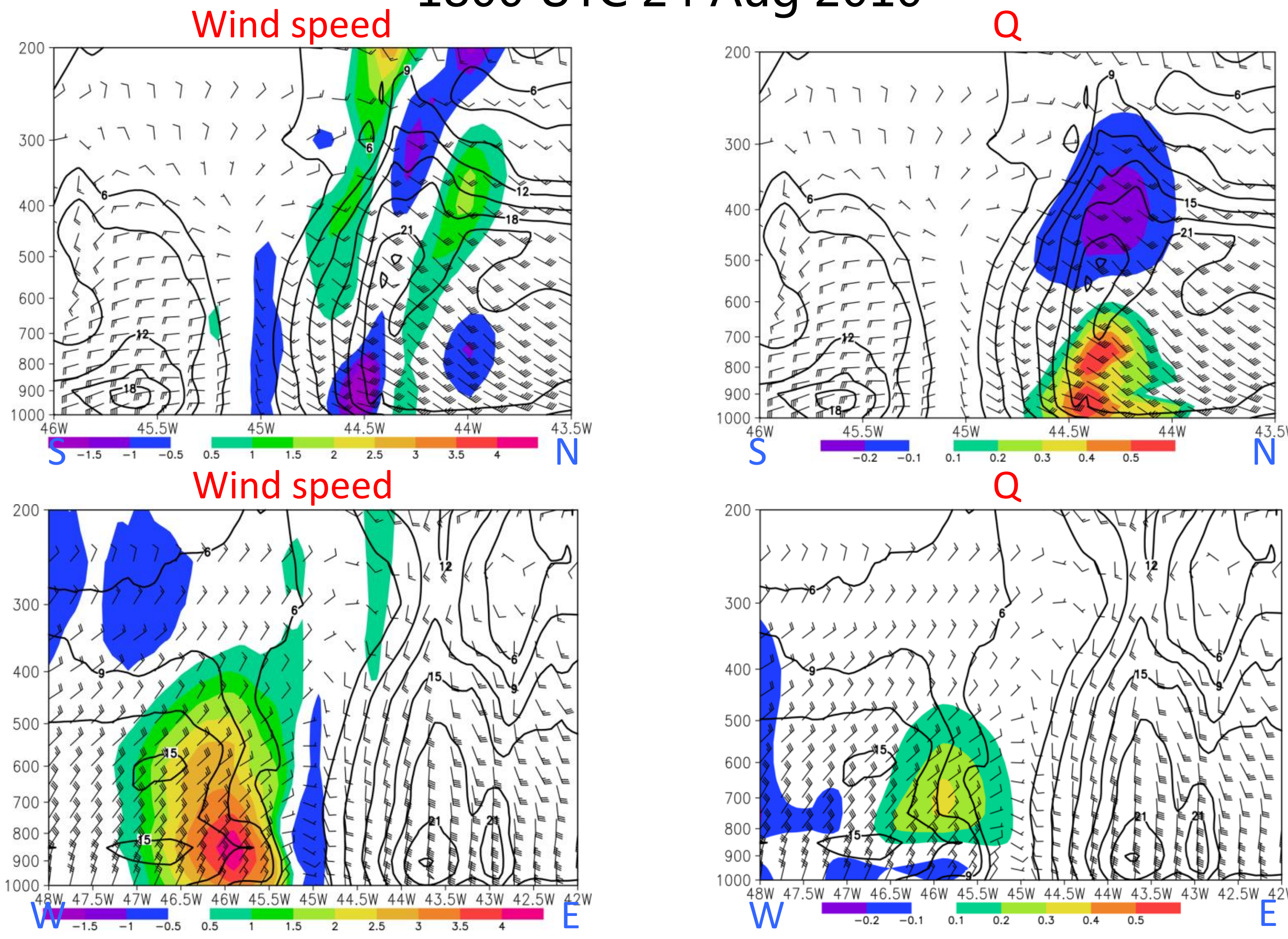
1800 UTC 24 Aug 2010



Both the tangential winds and radial winds are increased

$X_{ALL}^a - X_{CLR}^a$ for wind speed (m s^{-1}) and Q (g kg^{-1}) is shaded, the contours are X_{ALL}^a for wind speed (m s^{-1})

1800 UTC 24 Aug 2010

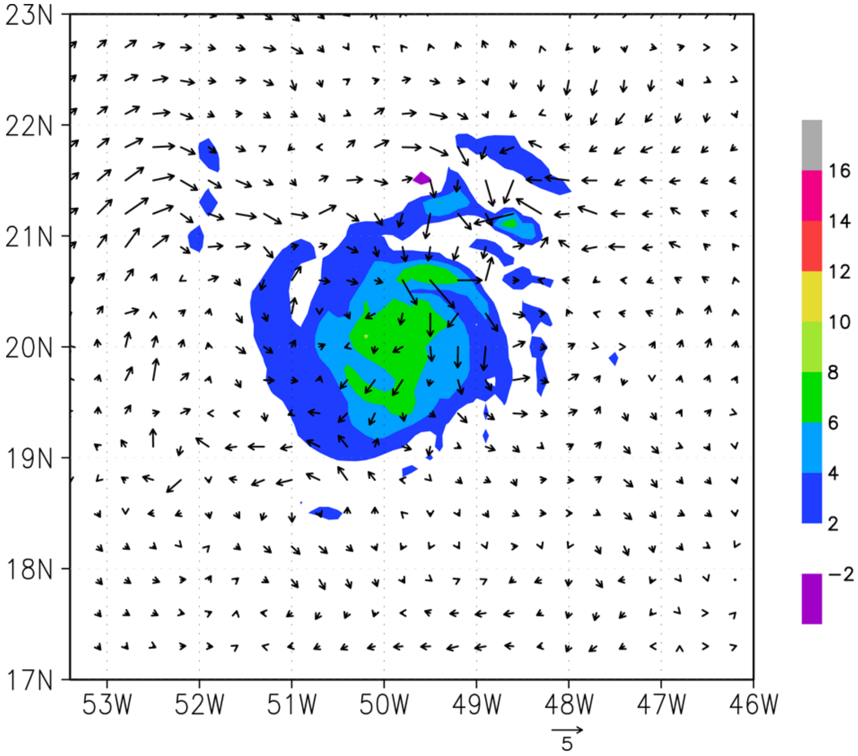


Both of low-level wind speed and humidity in the TC eyewall are enhanced with reasonable asymmetric structure

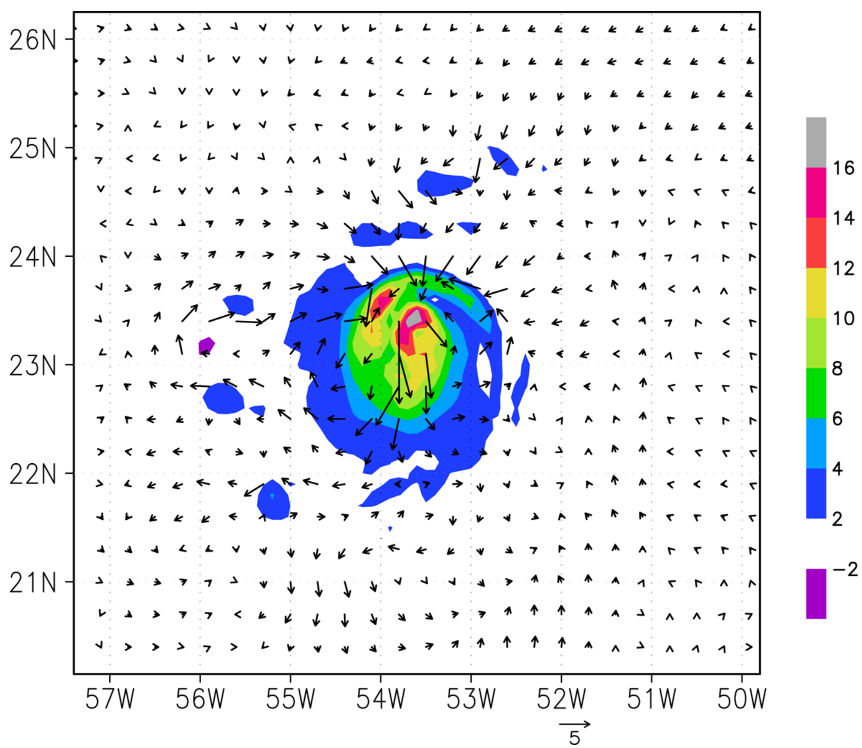
Forecasts

The 24- and 48- hr forecasting difference of absolute vorticity (shaded; 10^{-4} ms^{-2}) and wind vectors ($m\ s^{-1}$)at 700 hPa

24-hr fcsts : X_{ALL}-X_{CLR}



48-hr fcsts : X_{ALL}-X_{CLR}

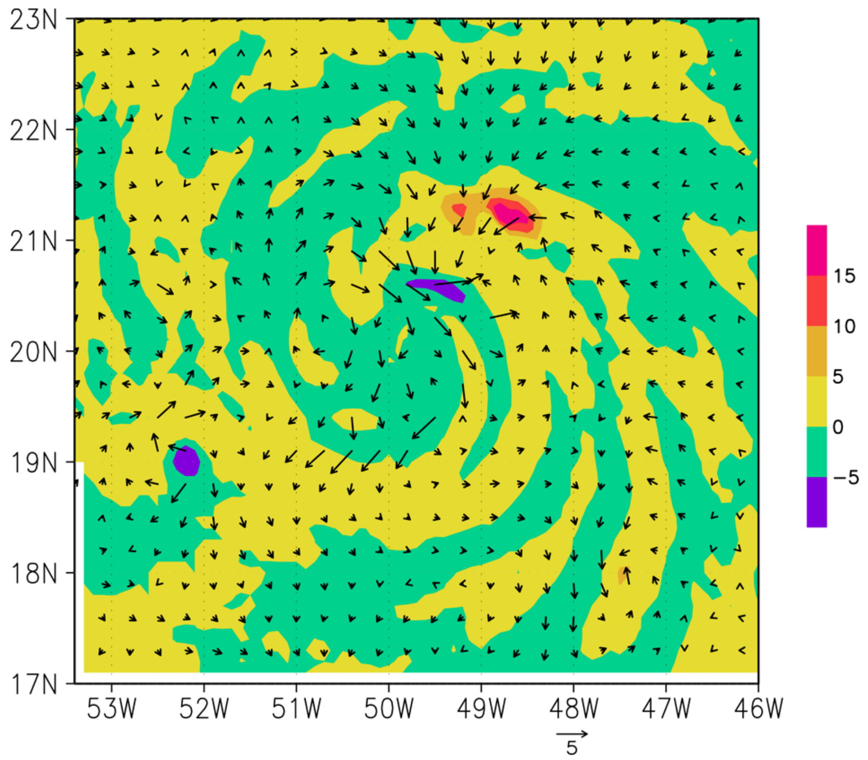


Increased positive absolute vorticity in the TC inner-core

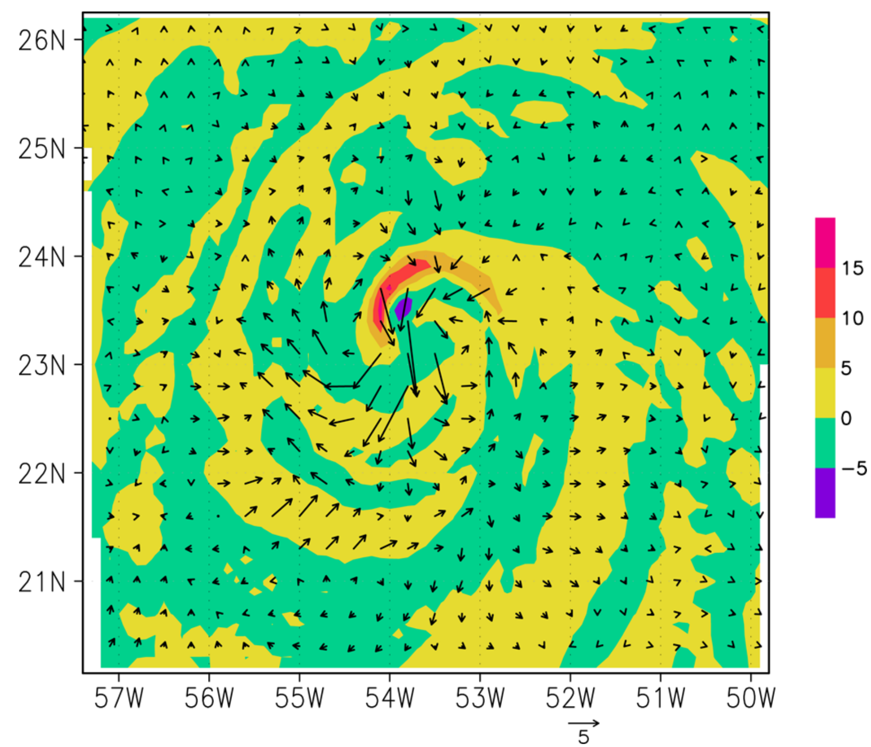
Forecasts

The 24- and 48- hr forecasting difference of total condensate (shaded; kg m^{-2}) and wind vectors (m s^{-1})at 900 hPa

24-hr fcsts : X_{ALL}-X_{CLR}



48-hr fcsts : X_{ALL}-X_{CLR}



More condensation occurring in the spiral rainband

Little indication of quick loss of cloudy observation information with time

Summary

- MLEF-HWRF has been evaluated in realistic assimilation/ forecasting environment;
- The system is generally applicable at variable stages of storm development;
- Cloudy AMSU-A EnsDA approach indicates more realistic adjustment of 3D structures of standard control variables;
- The forecasts do no show rapid falloff of cloudy observation information gained in the analysis, which indicates a good balance in the analysis itself;
- Encouraging for the future operational HVEDAS.

✎ Our expensive experiments were conducted on NCEP IBM

Work in progress

- Include the microphysical control variables (e.g., total condensate) to link with radiance observations;
- Examine flow-dependent background covariances beneficial for hurricane inner-core radiance assimilation;
- Revisit the observation error estimation, QC procedure, and bias correction for cloudy AMSU-A observations;
- Combined assimilation of GOES-R ABI, GLM proxies (MSG SEVIRI, NLDN, WWLLN), AIRS SFOV and current microwave radiances.

✎ MSG SEVIRI: Spinning Enhanced Visible and InfraRed Imager
✎ NLDN: National Lightning Detection Network
✎ WWLLN: World Wide Lightning Location Network

Further Reference

Zupanski D, S. Q. Zhang, M. Zupanski, A. Y. Hou and S. H. Cheung, 2010: A prototype WRF-based ensemble data assimilation system for dynamically downscaling satellite precipitation observations. *J. Hydrometeorology*, **12**, 118-134.

Zupanski D, M. Zupanski, L. D. Grasso, R. Brummer, I. Jankov, D. Lindsey and M. Sengupta, and M. DeMaria, 2011: Assimilating synthetic GOES-R radiances in cloudy conditions using an ensemble-based method. *Int. J. Remote Sensing*, (in print).

Zupanski M, 2005: Maximum Likelihood ensemble filter. *Mon. Wea. Rev.*, **133**, 1710-1726.

Zupanski M, S. J. Fletcher, I. M. Navon, et al., 2006: Initiation of ensemble data assimilation. *Tellus*, **58A**, 159-170.

Zupanski M, I. M. Navon, and D. Zupanski, 2008: The maximum likelihood ensemble filter as a non-differentiable minimization algorithm. *Q. J. R. Meteorol Soc*, **134**, 1039-1050.