Hurricane Data Assimilation Meeting

23 October 2008

1. News from HRD	Aberson
2. EnKF with the HRS	Aksoy
3. TACC runs	Aberson (for Marks/Zhang)
4. GSI withe WRF-NMM	Gopalakrishnan
5. EnKF with the GFS	Whitaker
6. LAPS update	Albers, et al.
7. H*Wind/vortex spec.	Winterbottom
8. Data warehouse	Xie, et al.
9. FAB	Kim, et al.

News from HRD

Successful 2008 Hurricane Field Program

- collected huge amounts of data for assimilation into models
- quick look at NOAA data available at ftp://ftp.aoml.noaa.gov/pub/hrd/aberson/hfp2008
- other data available from AFRES aircraft and T-PARC/TCS08
- http://www.aoml.noaa.gov/hrd, click on “Data”

Great progress made on Hurricane Research System model at HRD - running in real-time through much of 2008 season.

HRD to hire a data assimilation expert (ZP-IV position). I will forward announcement when it becomes available, hopefully by early November.

By Altuğ Aksoy
HRD/AOML/NOAA and CIMAS/U. of Miami

23 October 2008

The Implementation of the Ensemble Kalman Filter at HRD

Plans for Building an EnKF System at HRD

- Primary focus on assimilating high-density inner-core observations from flight missions:
  - Flight-level data
  - SFMR
  - Dropsondes
  - Radar
- The ensemble Kalman filter (EnKF) core is similar to Fuqing Zhang's PSU/TAMU EnKF system; an implementation of the square-root filter

Current Status of the EnKF Development at HRD

- A functional EnKF base system is already in place
- Operates on a single domain
- Distance-based covariance localization
- Initializes from GFS ensemble members, with 30 members
- Observation forward operators are implemented for:
  - Core model variables, SFMR (wind speed)
  - Interpolations from arbitrary locations to model grid possible
- Prior and posterior observation-space diagnostics

Near-Term Plans for EnKF Development

- Test run employing a perfect-model configuration:
  - 27-km resolution
  - "Simulate" observations from an independent HRS run
  - Assimilate simulated observations:
    - 1-hourly cycling for 6 or 12 hours
    - Ensemble forecast from the EnKF analysis
- Expand the system to assimilate into nested domains
- Test for more realistic perfect-model scenarios at higher resolutions
- Implement capability to assimilate radar

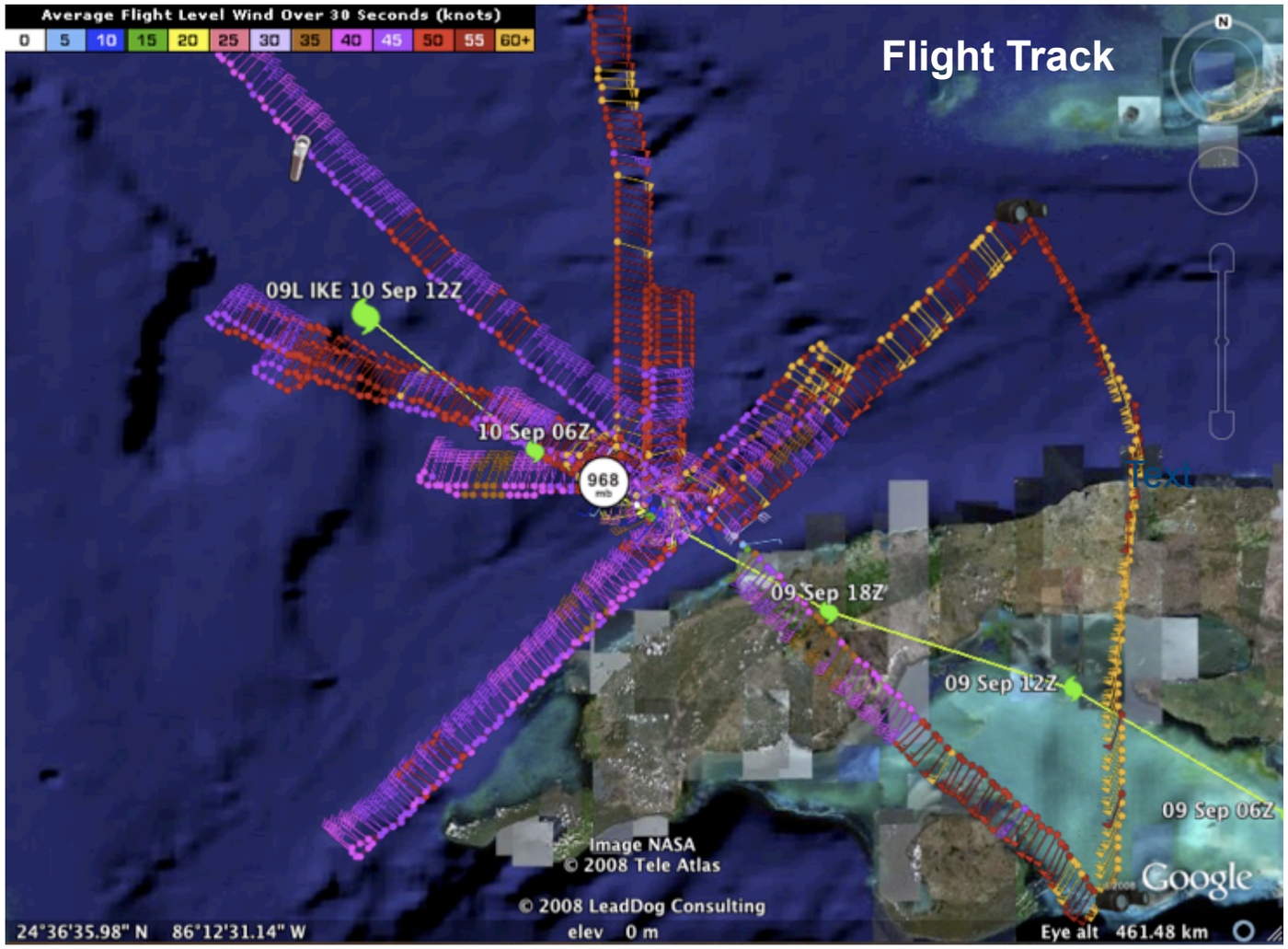
Scientific Challenges Regarding Hurricane Data Assimilation

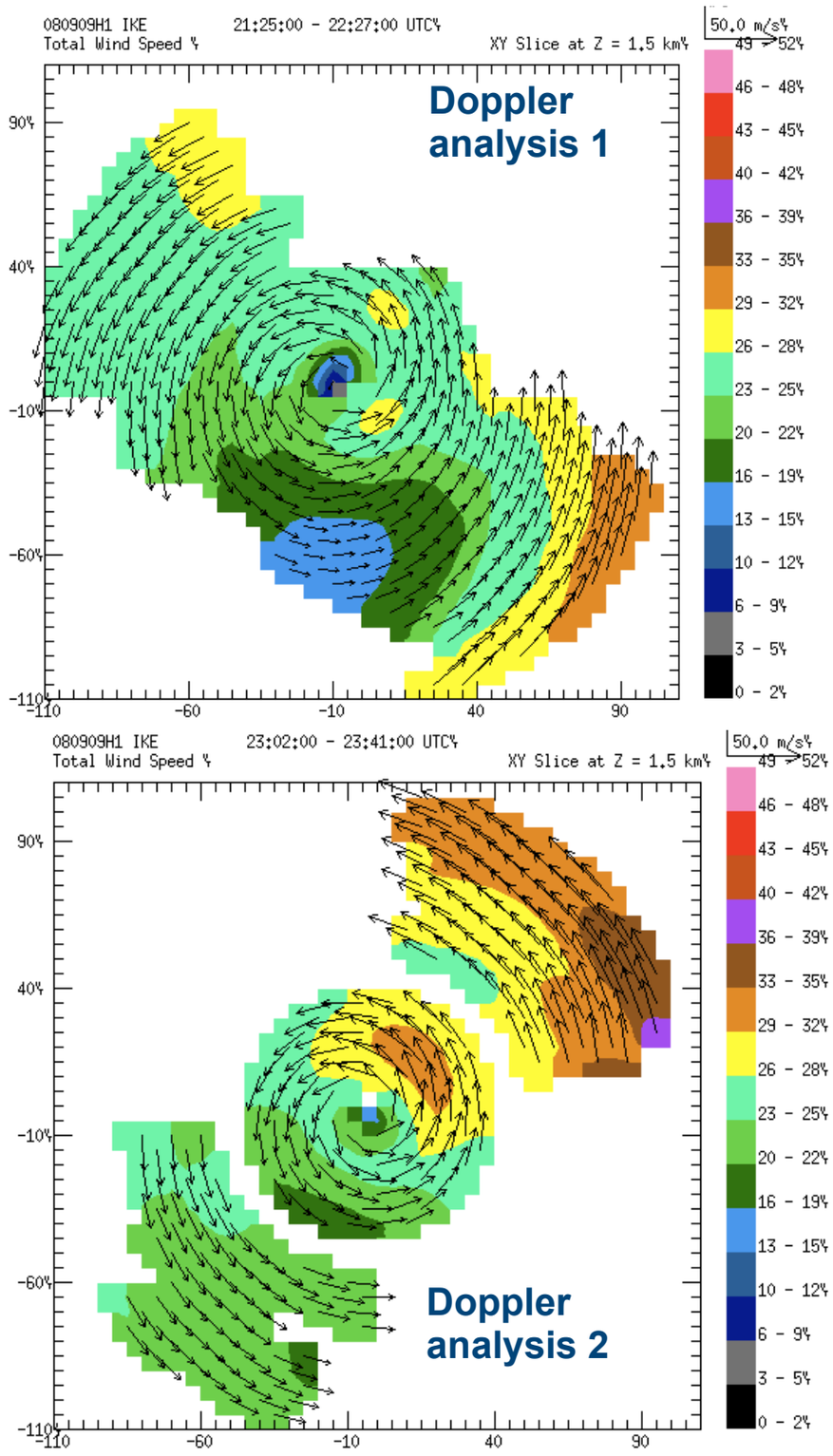
- How do we deal with assimilating observations into a system with distinct scales?
- What is the best way to initialize ensembles?
  - Large-scale initialization
  - Vortex-scale initialization
- How critical is the quality of the estimate of vortex position?
- How best to deal with covariance correlation?
  - How effective would be “traditional” distance-based methods in high-resolution inner-core data assimilation?
  - What alternative methods can be devised?

HFIP-TACC On-demand Test

- Diverse NOAA (HRD, ESRL, NCEP/NHC, NCO, EMC) and university (PSU, TAMU, TACC) team established on-demand capability to support operational hurricane forecasting.
- Built upon HFIP high-resolution test plan to use high resolution global (FIM at 15-km) and regional (ARW at 1.5-km using EnKF to assimilate Doppler radar superobs) models to demonstrate on-demand capability.
- NCEP model fields and Doppler radar superobs from NOAA P-3 aircraft flow automatically to TACC, research models run, output products generated for forecasters, and products transferred to NHC via NCO.
- Portions of process tested during Dolly and Fay, with a test of complete system during Gustav and Ike.

HFIP-TACC Real-time for Ike



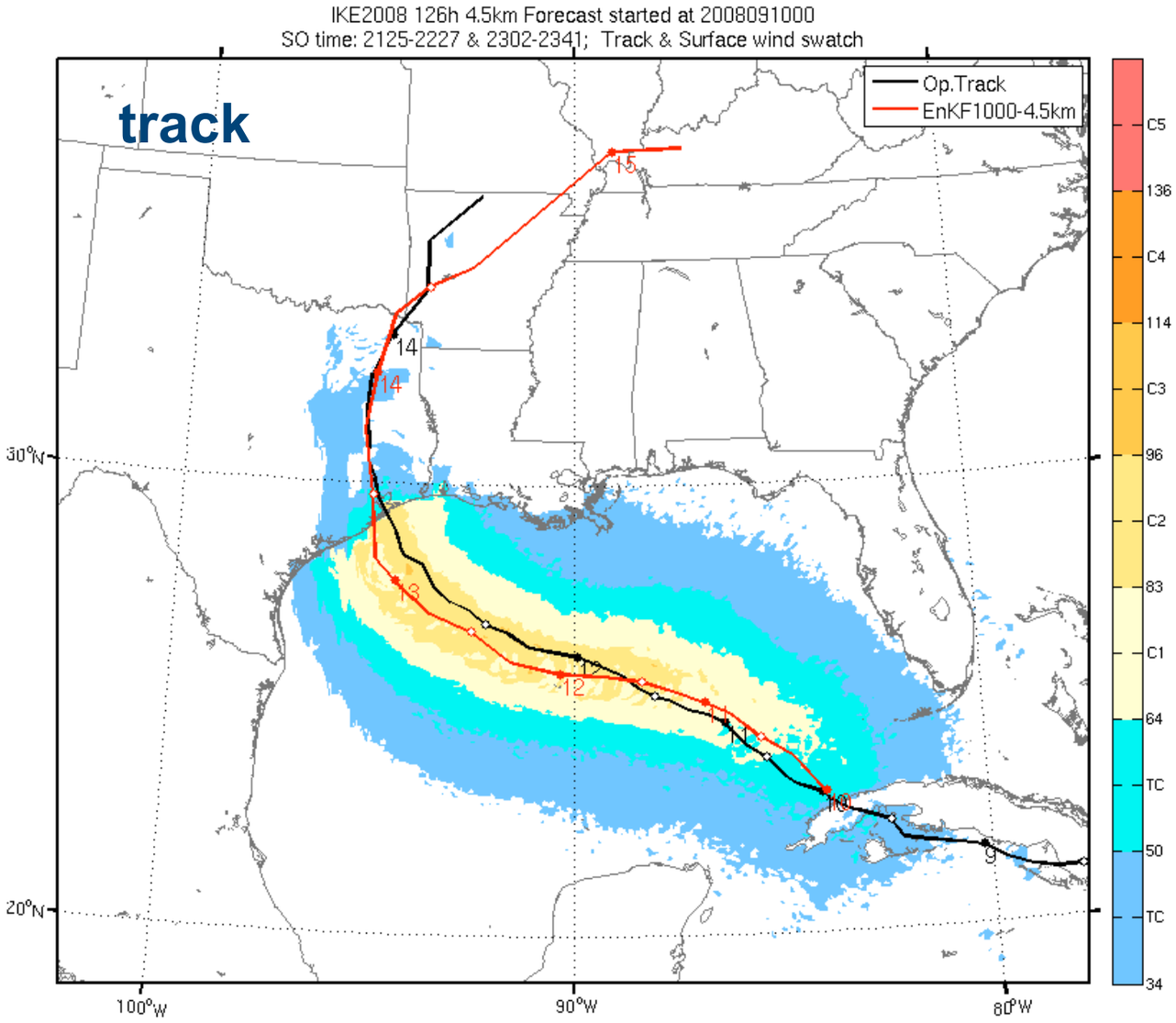


20080909H1 Doppler SO

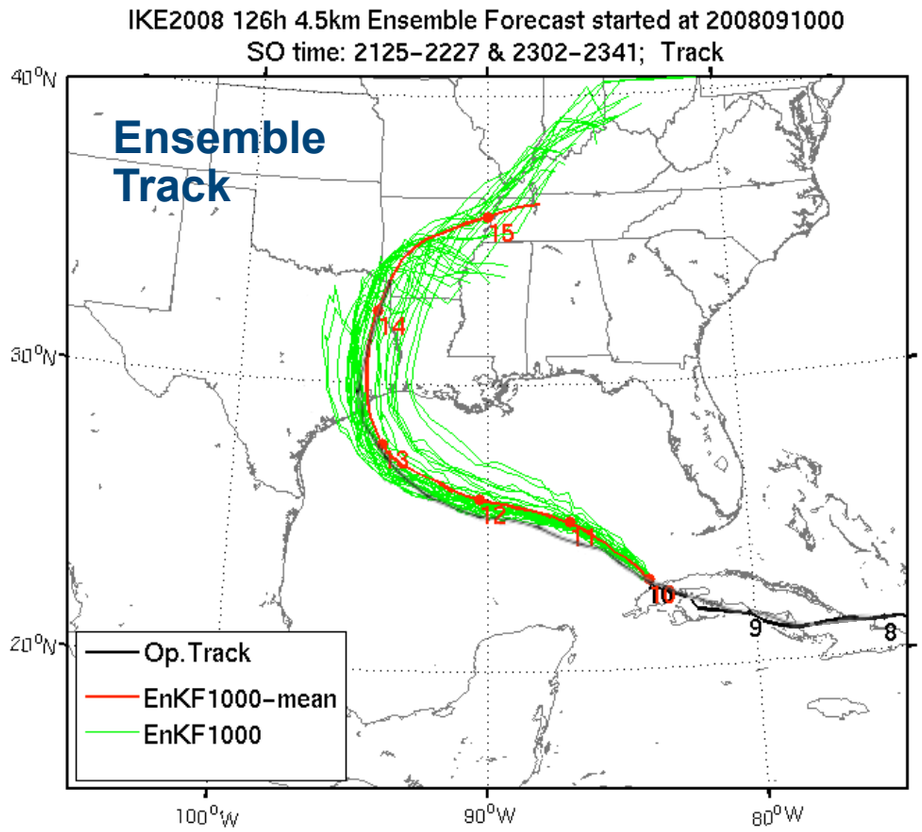
00Z, 10 September initialization with Doppler SO (EnKF)

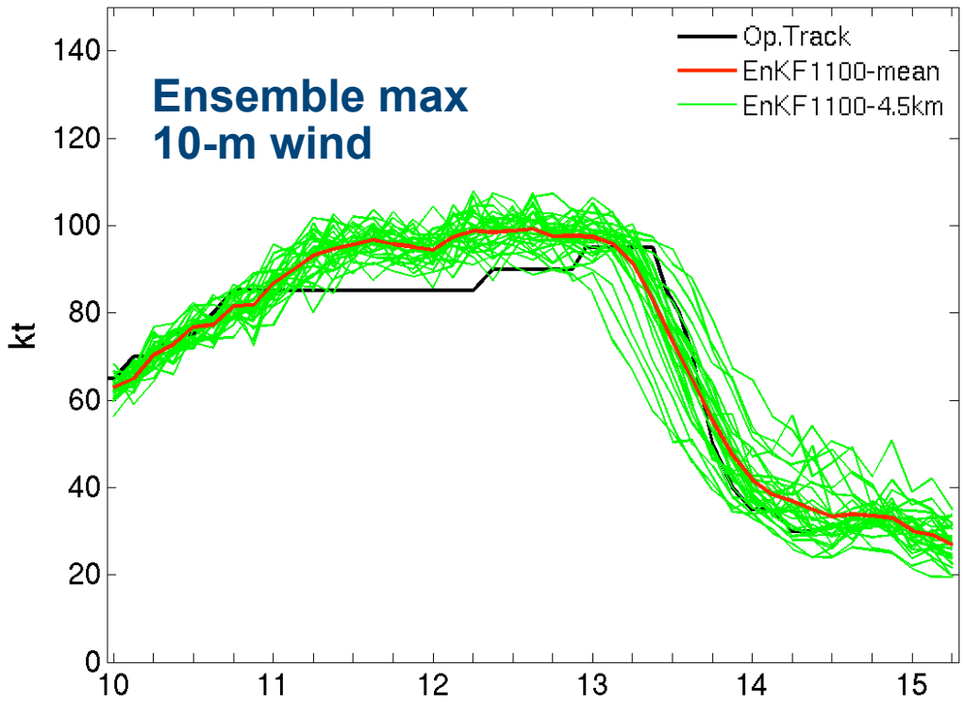
ARW

HFIP-TACC Real-time for Ike



Max 10-m wind swath





00Z, 10 September initialization with Doppler SO (EnKF) **ARW**

HRS: Hurricane Research System

Data Acquisition & Preparation

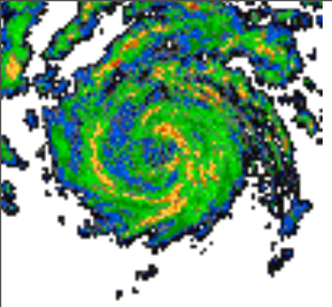
- Automatic Data Acquisition from NCEP
- Data Storage
- Automatic Model Operation

Hurricane Research System

- NMM Physics
- GFDL/ GFS Physics
- NCAR Physics
- Ocean Model
- WRF-NMM core with multiple moving nest
- EnKF
- Vortex Initialization & Assimilation
- WPS
- LAPS/ STMAS

Visualization & Diagnostics

- Global Hurricane Visualization System
- Post-Processing and Hurricane Diagnostic Tools



Objectives

- Improvement of data coverage close to the TC core environment using research aircraft and unmanned aerial vehicle (UAV) under the ongoing Forecast Demonstration Project (FDP)

- Quality control and data assimilation of conventional and non-conventional datasets

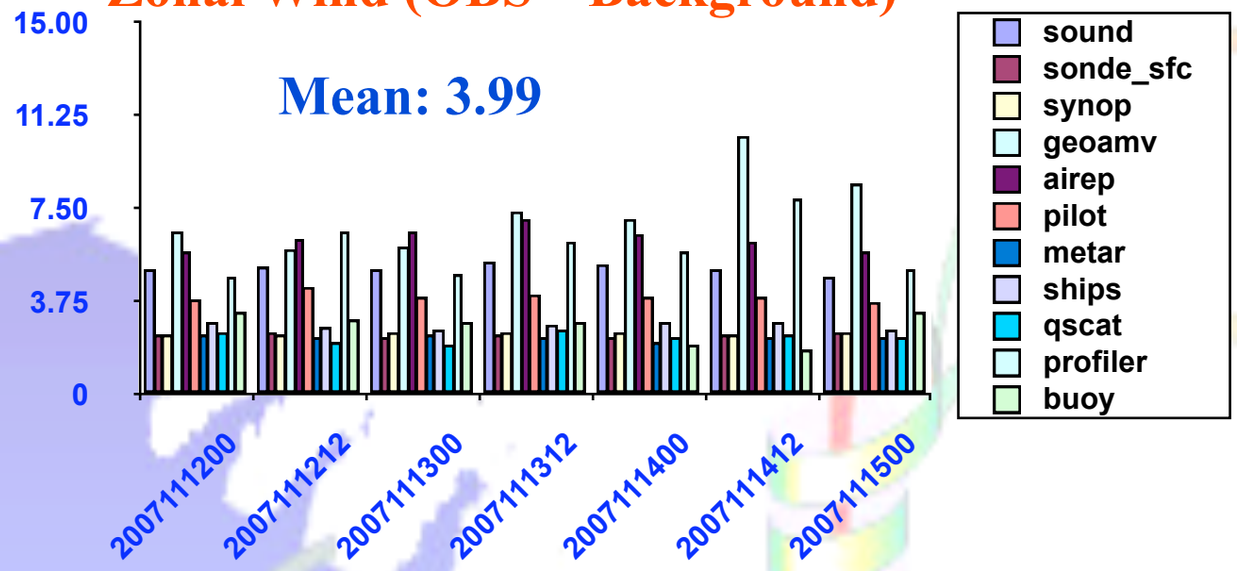
- Tropical cyclone vortex relocation and initialization.

- Improvement in the modeling approach for prediction of track and intensity of tropical cyclone, specifically with WRF-NMM system incorporating moving nest approach.

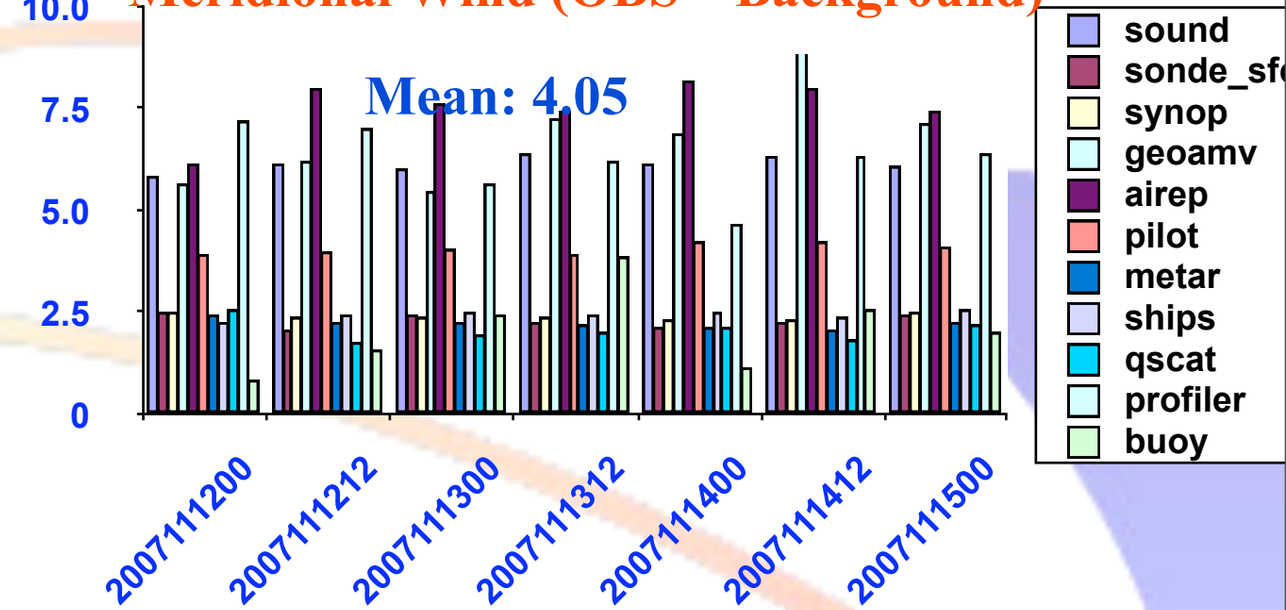
- Demonstrate the impact of additional data coverage though drop soundings and UAV observations in providing improved numerical prediction of the Bay of Bengal Tropical Cyclones

Root Mean Square Error

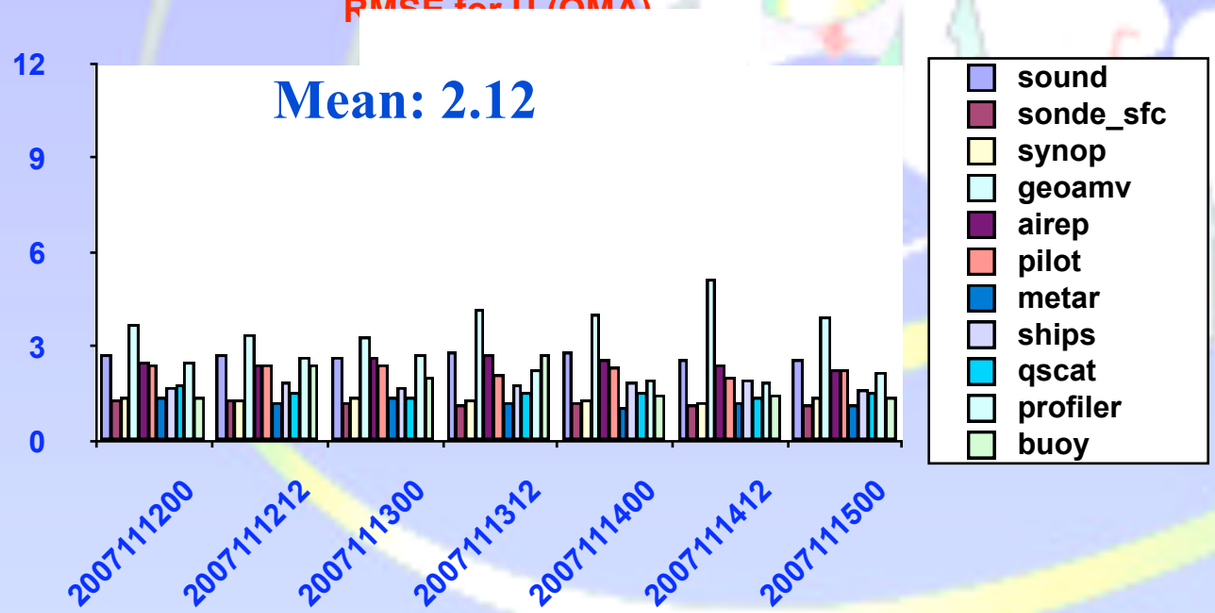
Zonal Wind (OBS – Background)



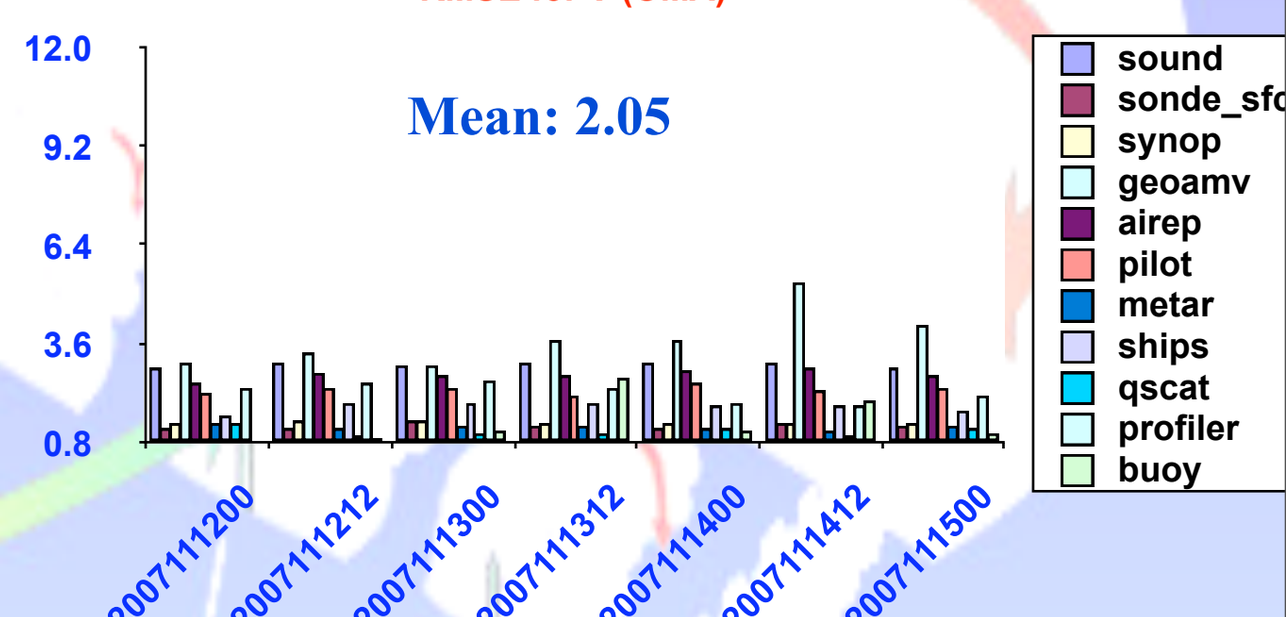
Meridional Wind (OBS – Background)



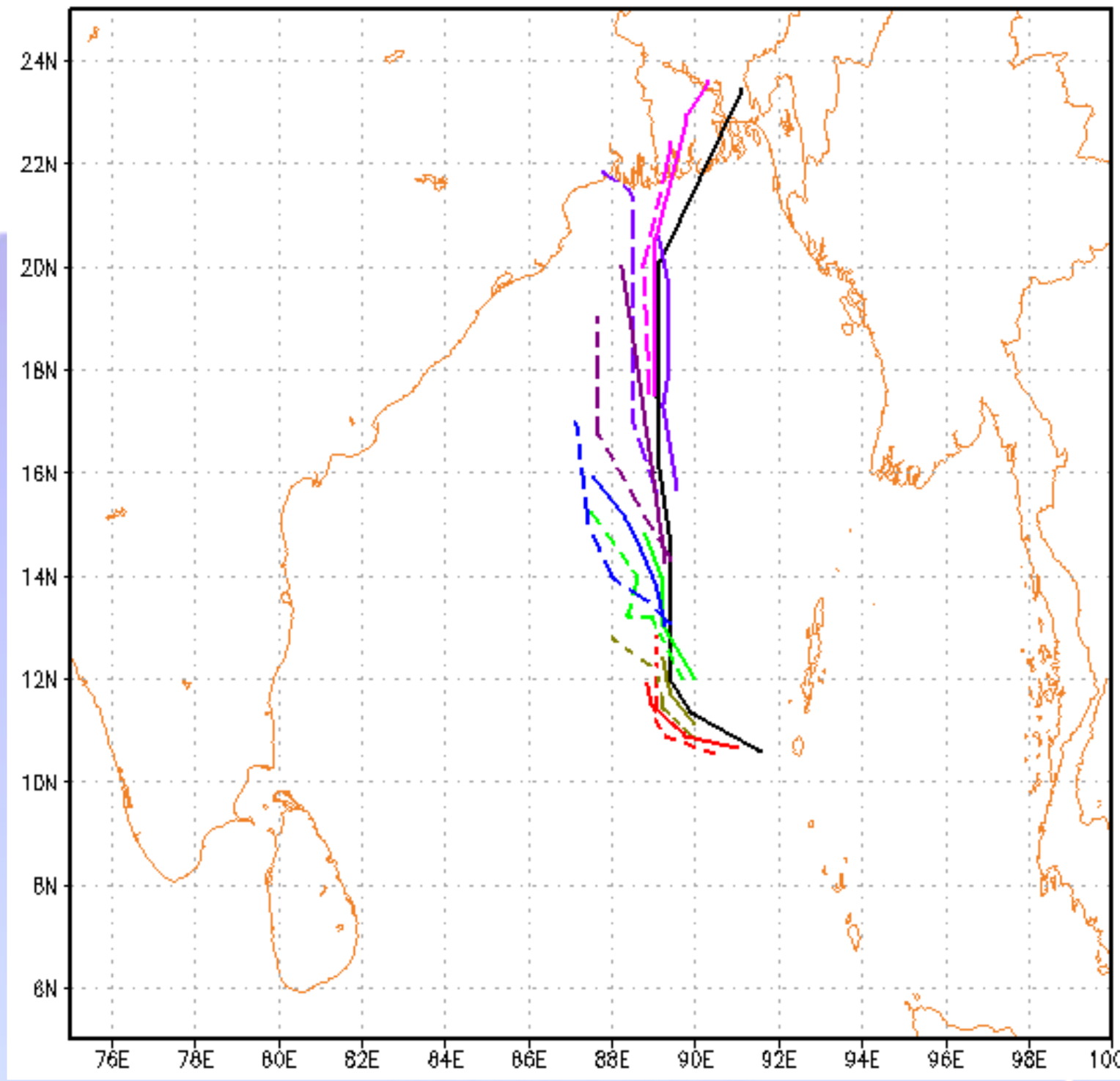
Zonal Wind (OBS – Analysis)



Meridional Wind (OBS – Analysis)



TRACK of the Cyclone “SIDR”



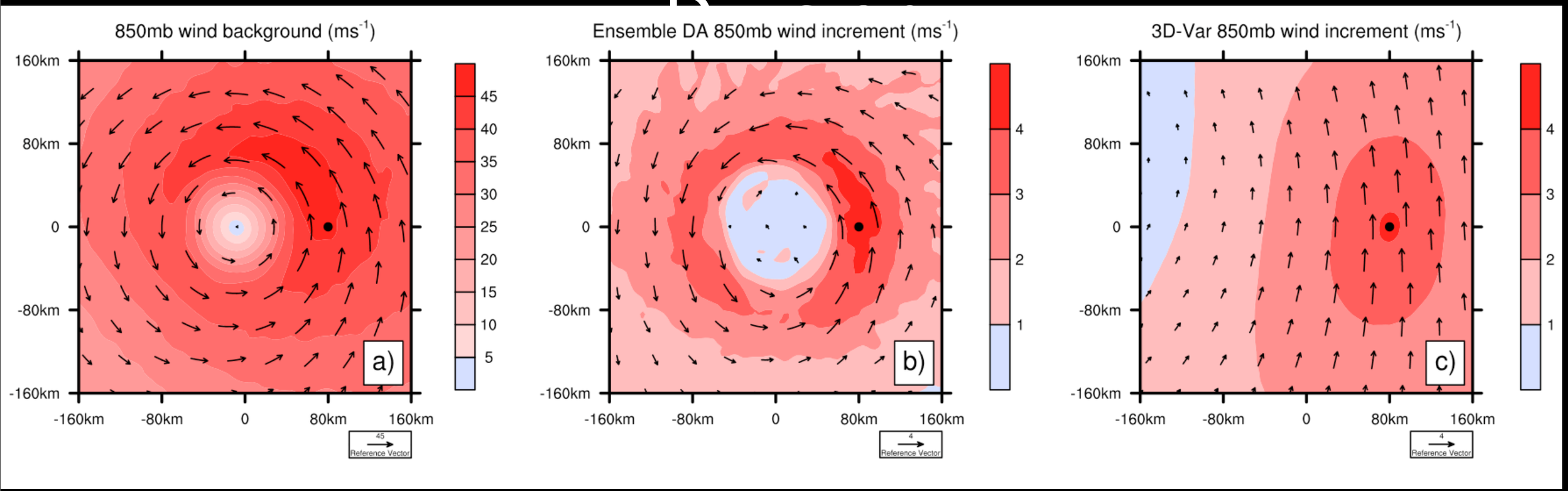
CONTROL	Initial Time	3DVAR
----	2007111200	———
----	2007111212	———
----	2007111300	———
----	2007111312	———
----	2007111400	———
----	2007111412	———
----	2007111500	———

BEST TRACK ———

A GFS-Based Ensemble Data Assimilation System for Hurricane Forecasts

Jeff Whitaker and Tom Hamill

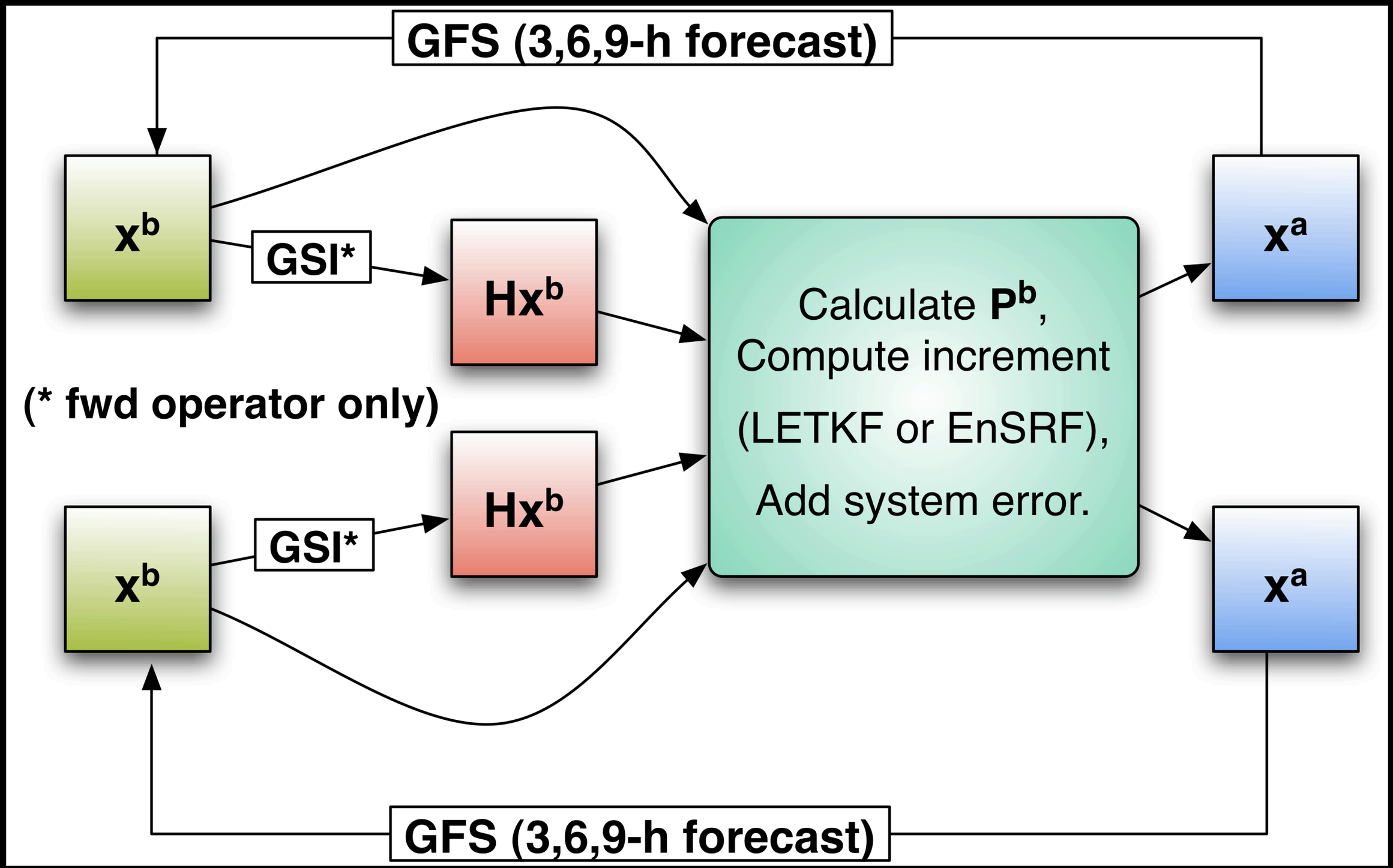
NOAA/ESRL Physical Sciences Division



EnKF for GFS

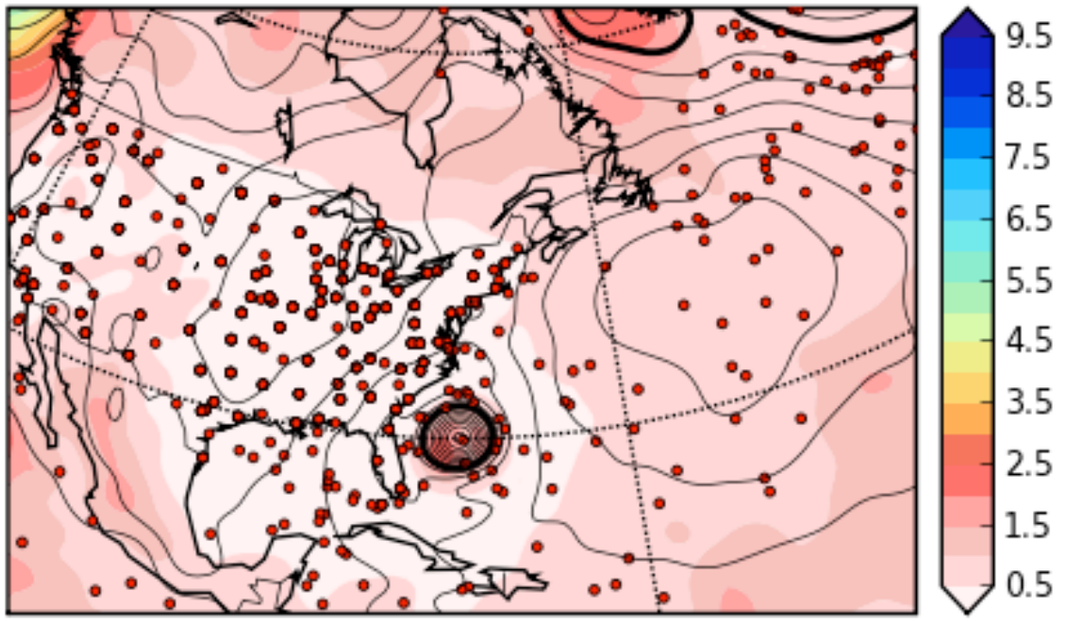
- Developed via a THORPEX funded collaboration.
  - U. of Maryland – LETKF
  - ESRL – serial EnSRF/system integration.
  - CSU – variational formulation
  - NRL – flow-adaptive localization
- Parallels 4D-Var development at NASA/GSFC.
- Spinoff system for historical reanalysis being used for 20th Century Reanalysis (1892-present) at ESRL.

EnKF for GFS

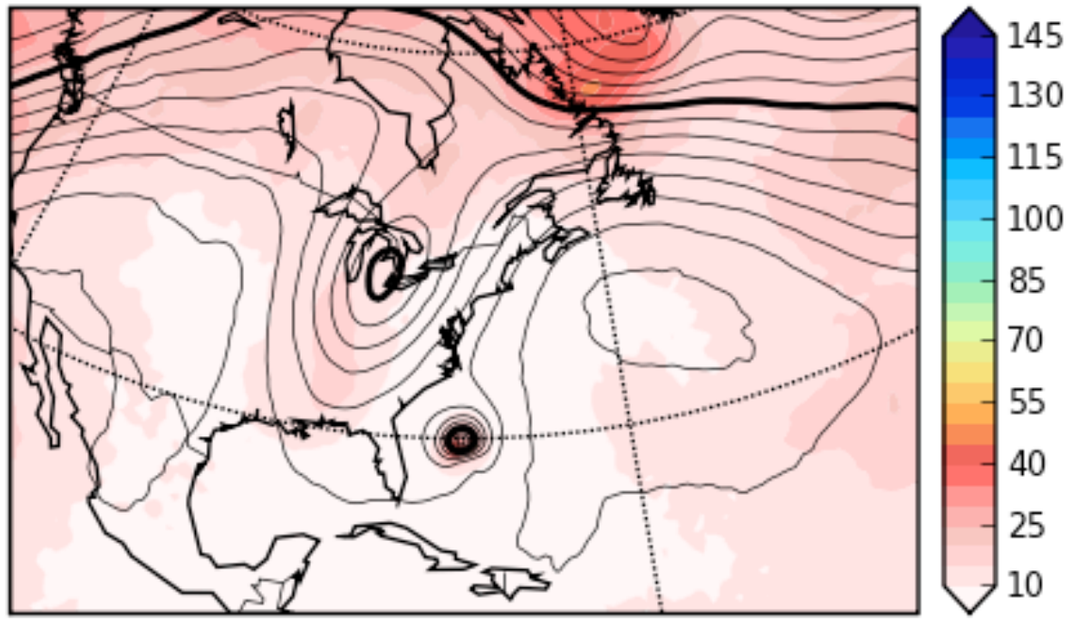

GFS (3,6,9-h forecast)
x^b
GSI*
Hx^b
Calculate P^b,
Compute increment
(LETKF or EnSRF),
Add system error.
x^a
(* fwd operator only)
Hx^b
x^b
GSI*
x^a
GFS (3,6,9-h forecast)

1938 New England

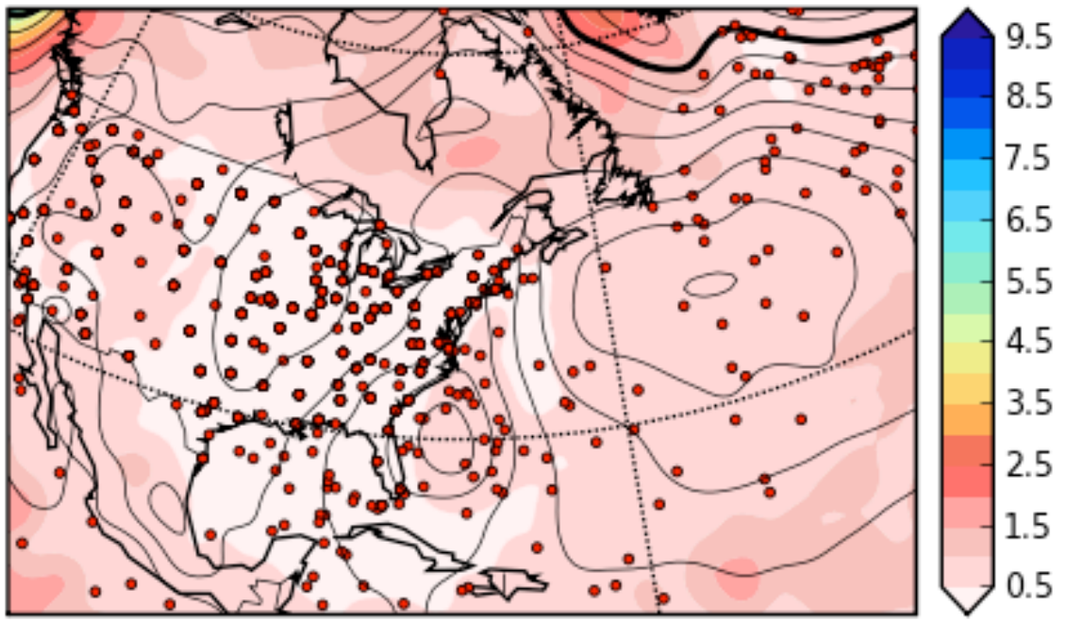
T254L64 Ens Mean SLP and Sprd (hPa - HURDAT 4mb) 1938092100



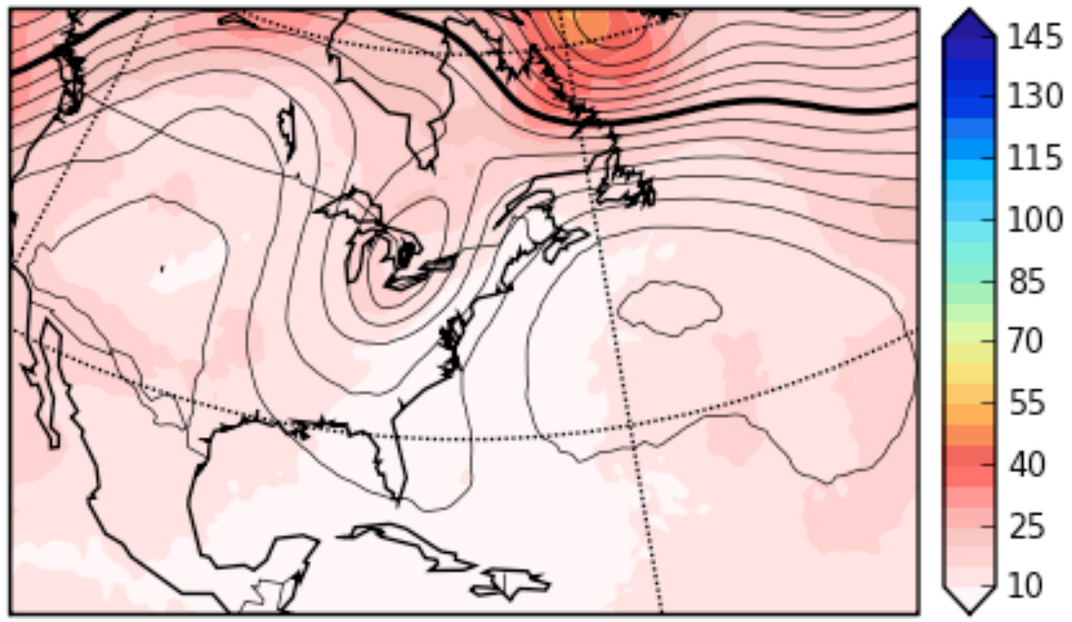
T254L64 Ens Mean Z500 and Sprd (m - HURDAT 4mb) 1938092100



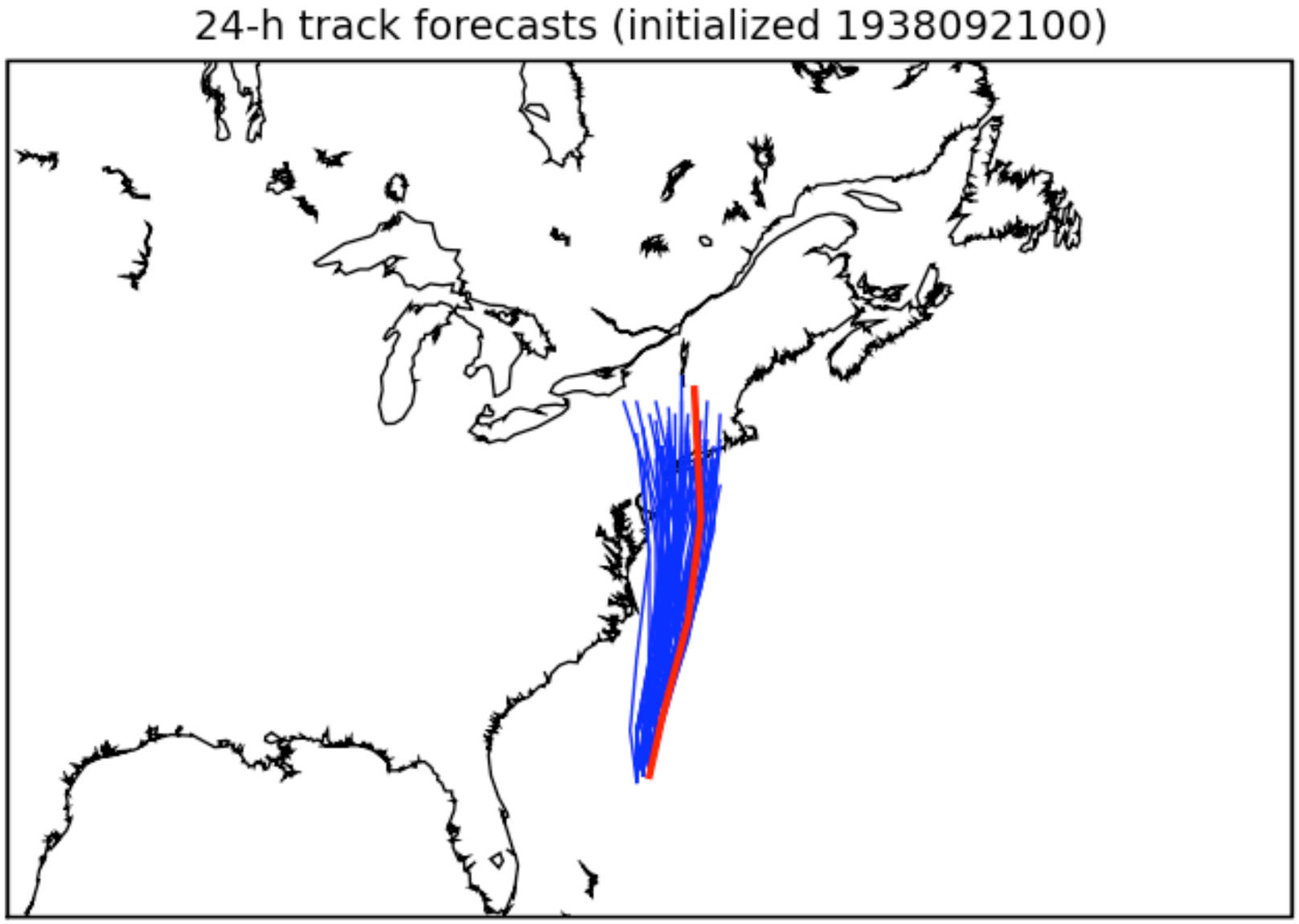
T254L64 Ens Mean SLP and Sprd (hPa - no HURDAT) 1938092100



T254L64 Ens Mean Z500 and Sprd (m - no HURDAT) 1938092100



1938 New England

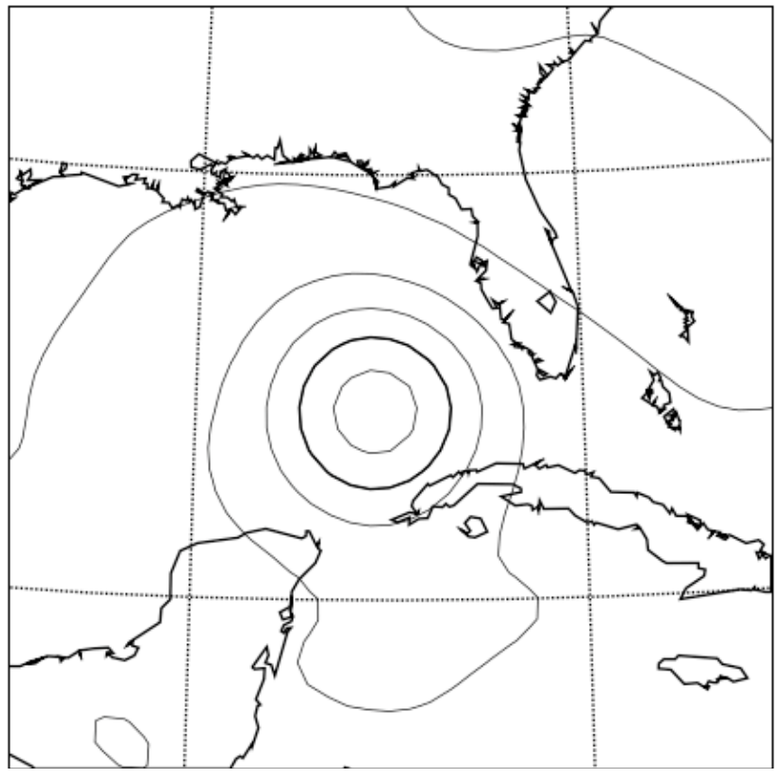


Hurricane Rita

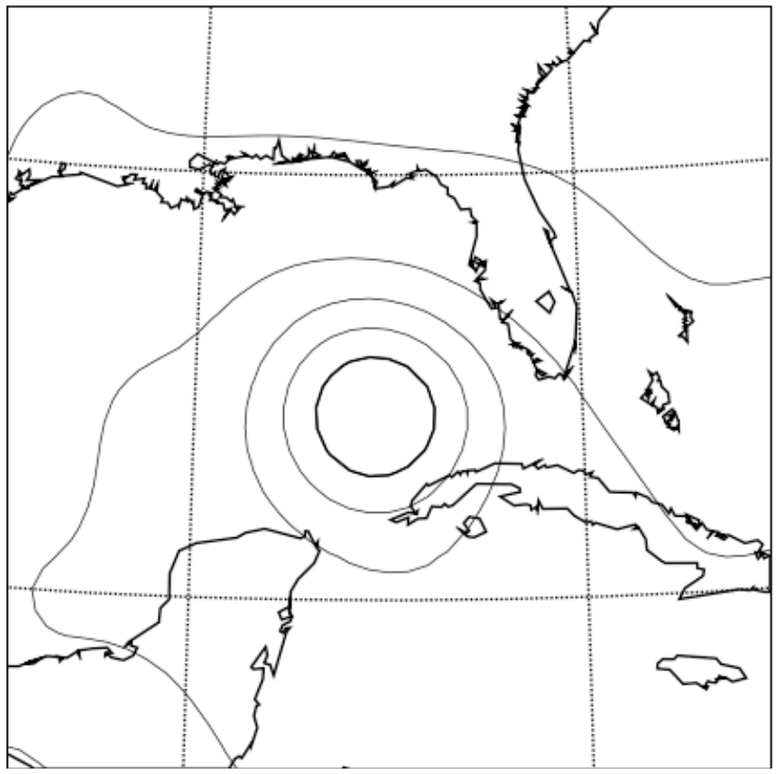
- Only “conventional” prepbufr obs assimilated, including reconnaisance obs.
- System started on Sept 1, 2005 run to Sept. 19 at T126 – then T254 to Sept 22.
- Comparison with then operational SSI (run at T382, recon obs excluded).

2005092112 (SLP, 4mb contours, 1000 mb thicker)

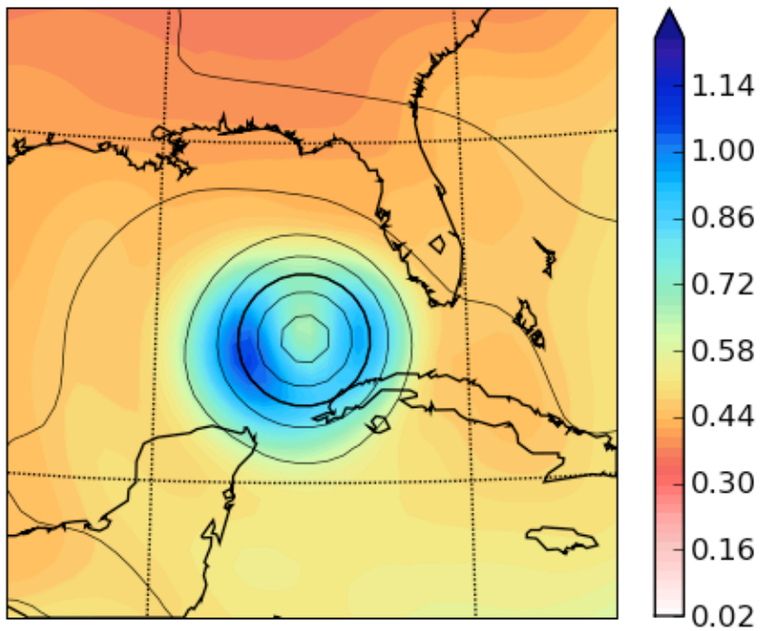
GDAS First-Guess 2005-09-21 12:00:00



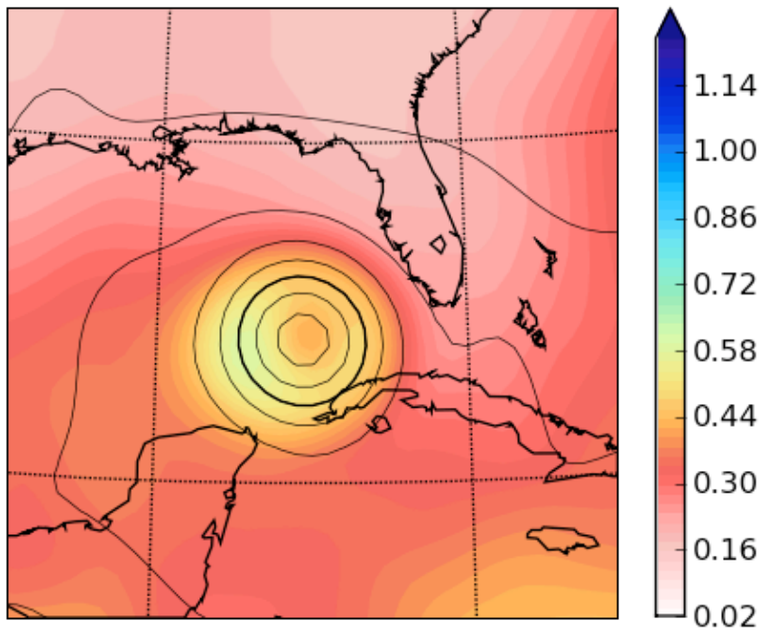
GDAS Analysis 2005-09-21 12:00:00



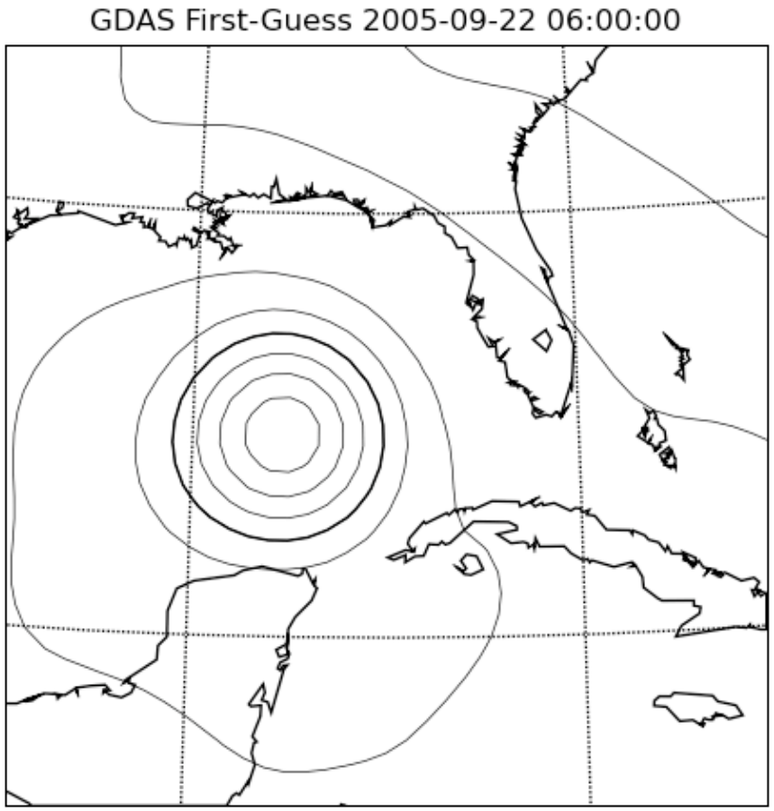
EnKF First-Guess with recon obs 2005-09-21 12:00:00

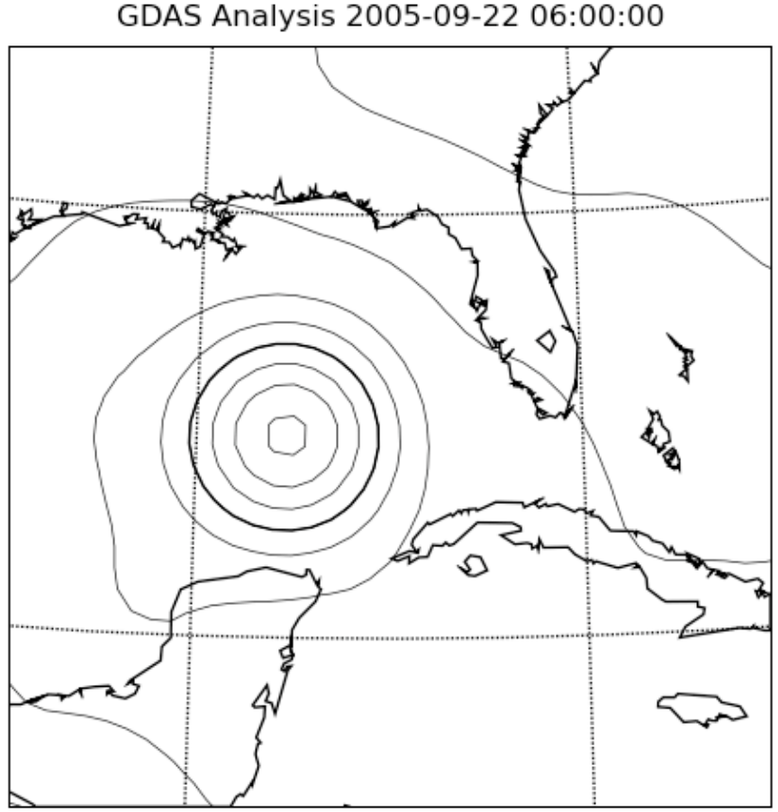


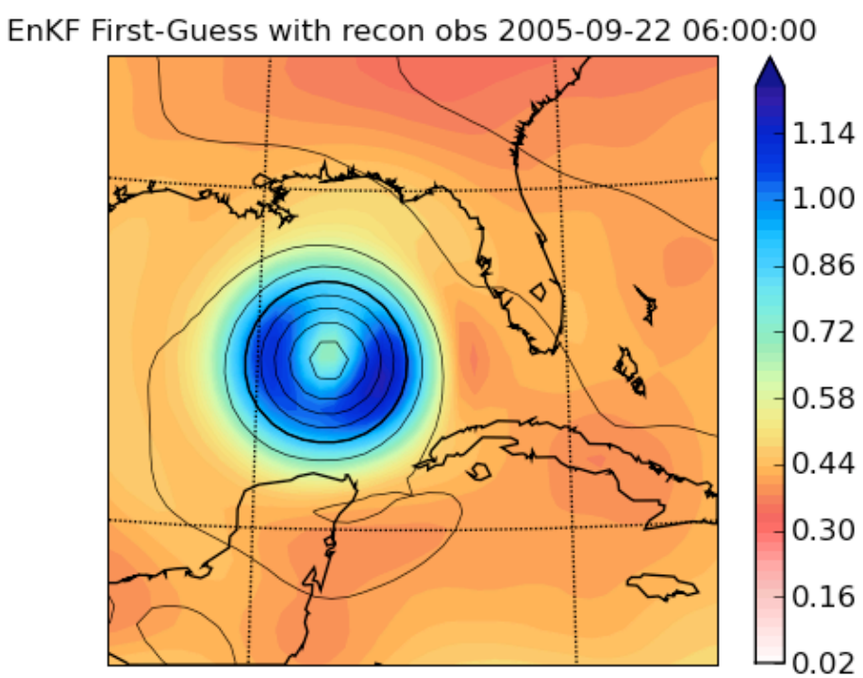
EnKF Analysis with recon obs 2005-09-21 12:00:00

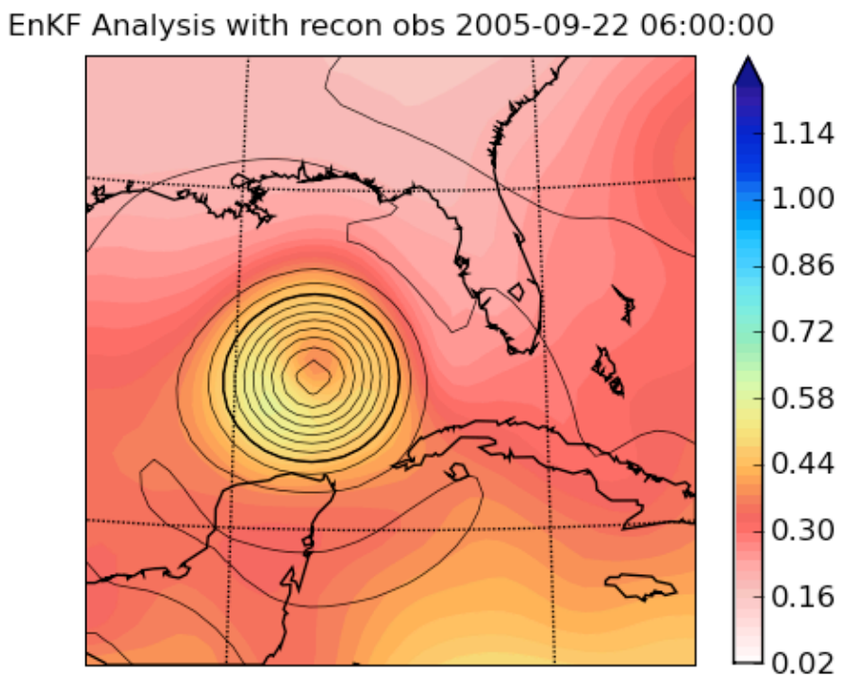


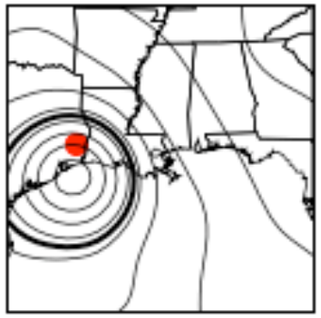
2005092206 (SLP, 4mb contours, 1000 mb thicker)





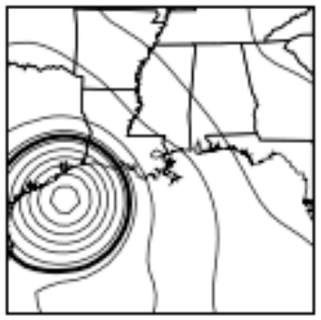
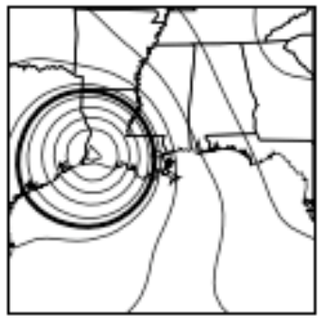
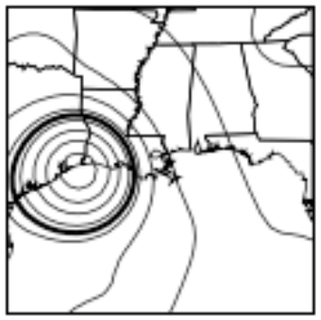
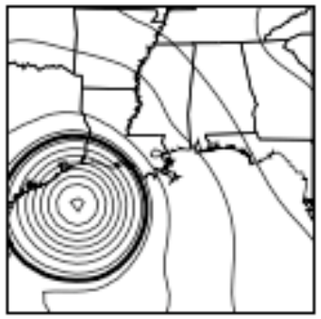
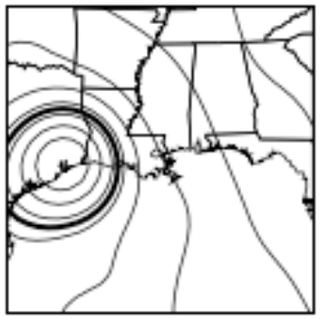
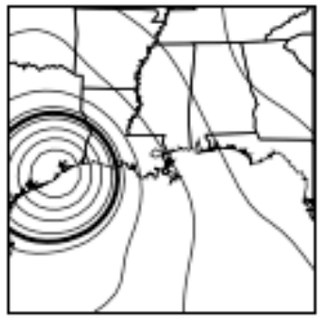
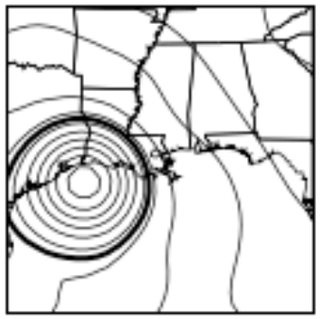
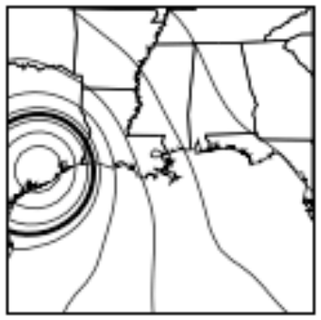
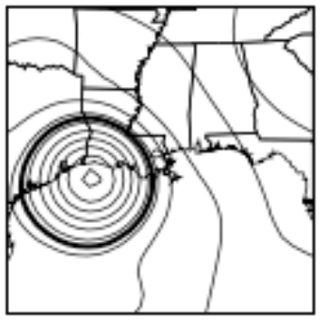
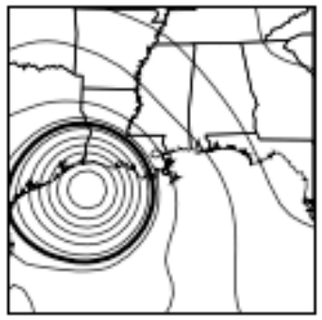
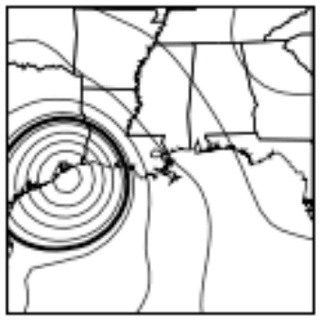
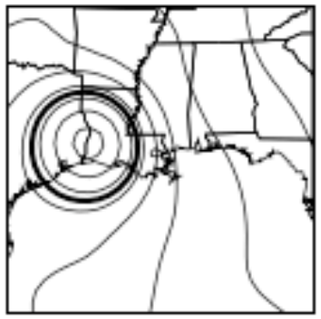
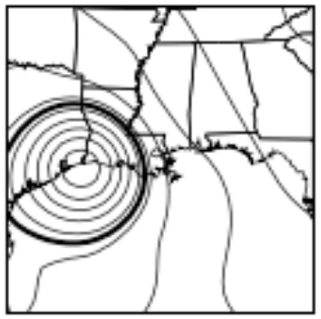
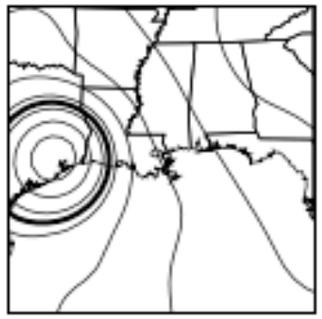
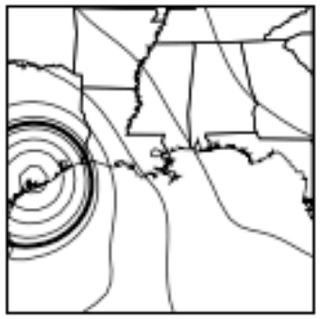


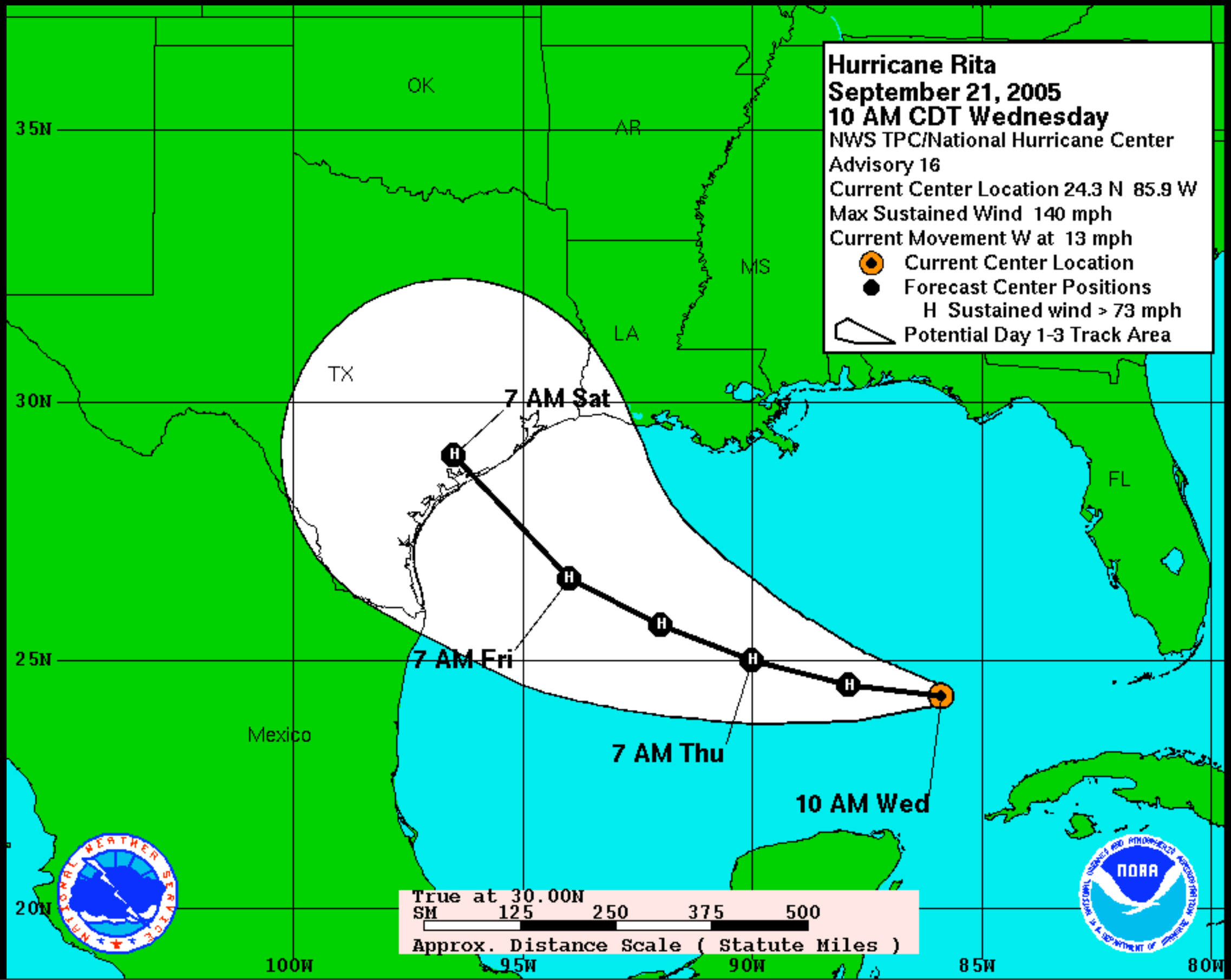




72-h 16 member ensemble from 2005092112

→ ens mean


Hurricane Rita
September 21, 2005
10 AM CDT Wednesday
NWS TPC/National Hurricane Center
Advisory 16
Current Center Location 24.3 N 85.9 W
Max Sustained Wind 140 mph
Current Movement W at 13 mph
Current Center Location
Forecast Center Positions
H Sustained wind > 73 mph
Potential Day 1-3 Track Area
OK
AR
MS
LA
TX
FL
Mexico
35N
30N
25N
20N
100W
95W
90W
85W
80W
7 AM Sat
7 AM Fri
7 AM Thu
10 AM Wed
H
True at 30.00N
SM 125 250 375 500
Approx. Distance Scale (Statute Miles)
NOAA

TODO

- More cases.
- Higher resolution?
- Model error?

Possible ESRL/AOML Collaborations

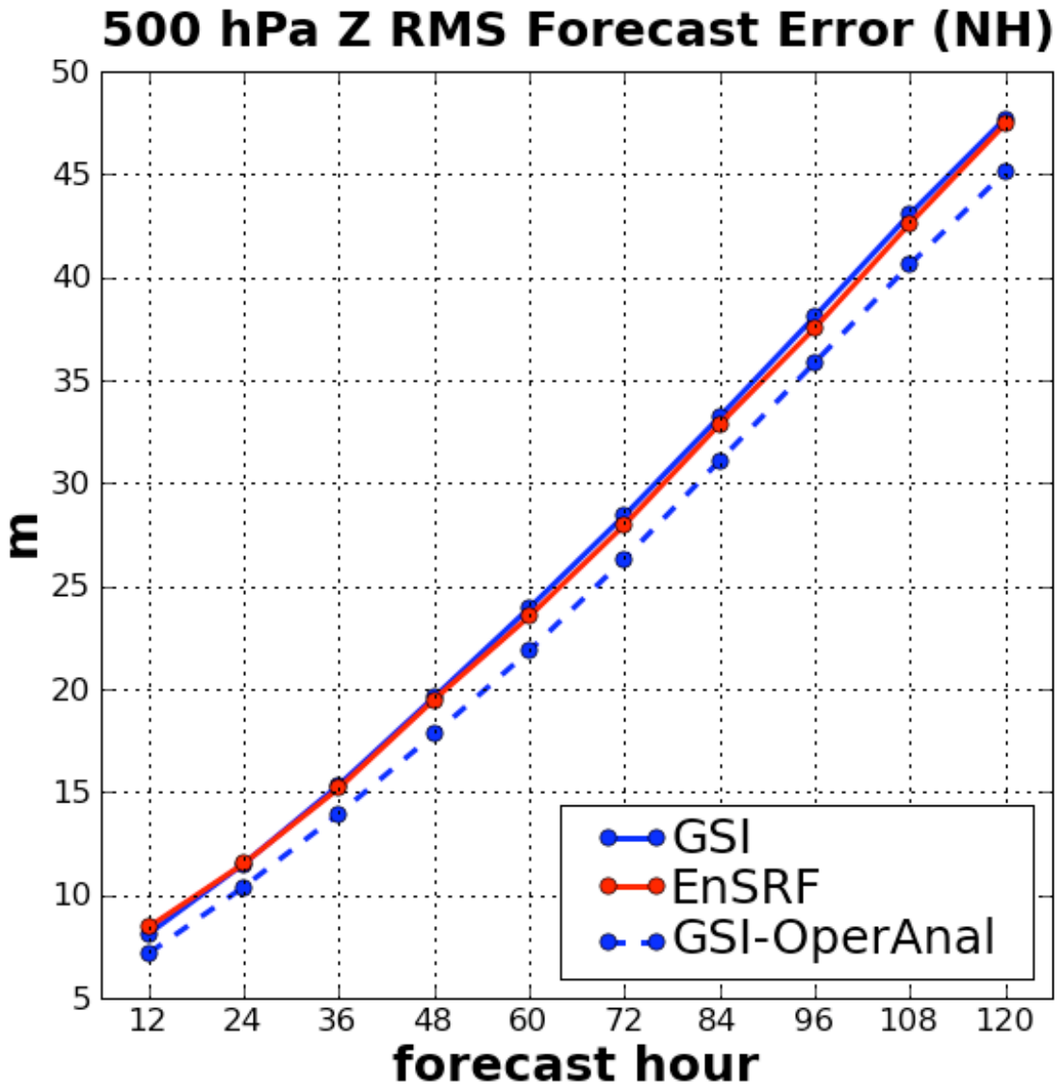
- Code sharing?
- Boundary conditions?
- Model error?

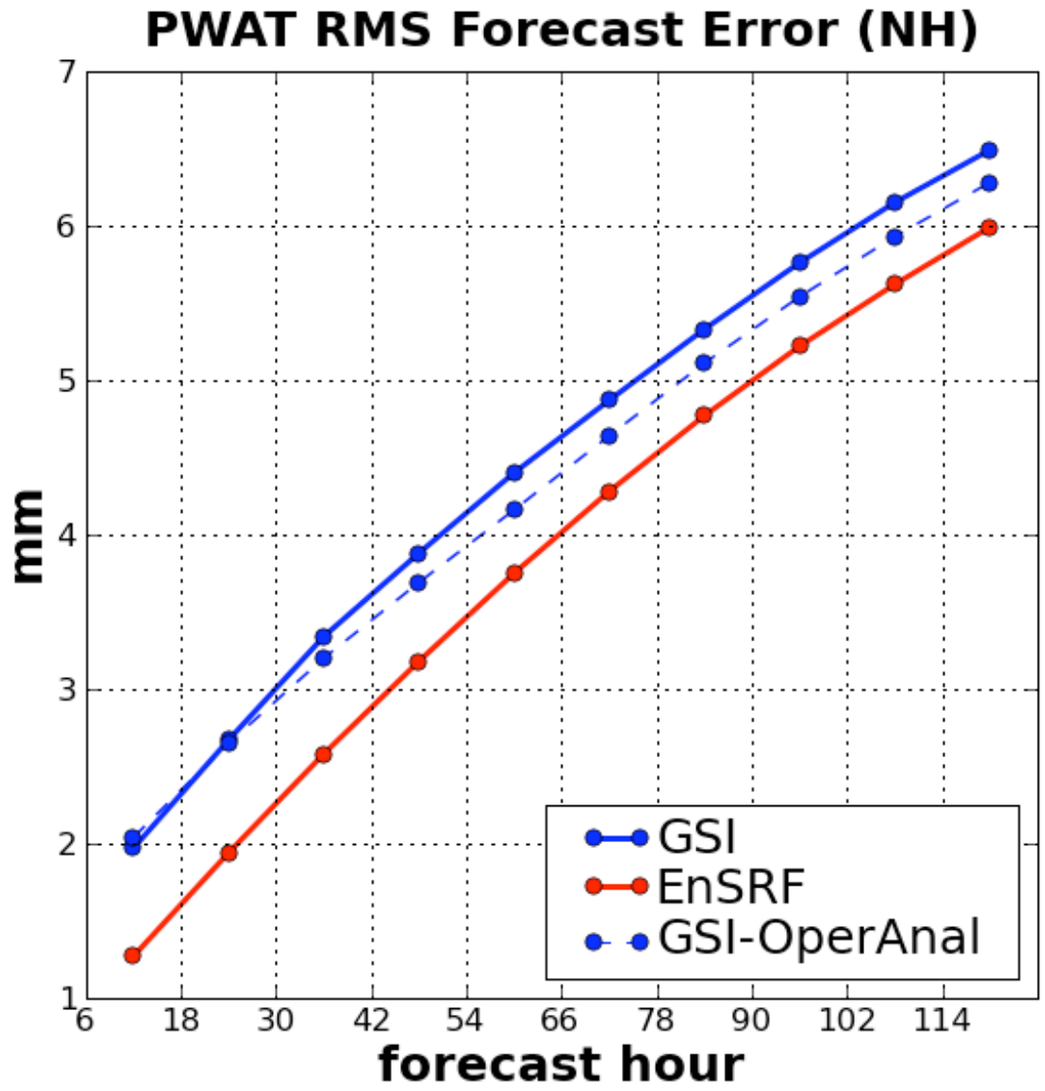
The End

Operational NWP: Comparison of EnKF with GSI

- GFS T126L64. May–June 2007.
- 'conventional' obs, GPSRO, AMSU radiances. GSI used for forward operator.
- GSI re-run at lower res to compare with EnKF.

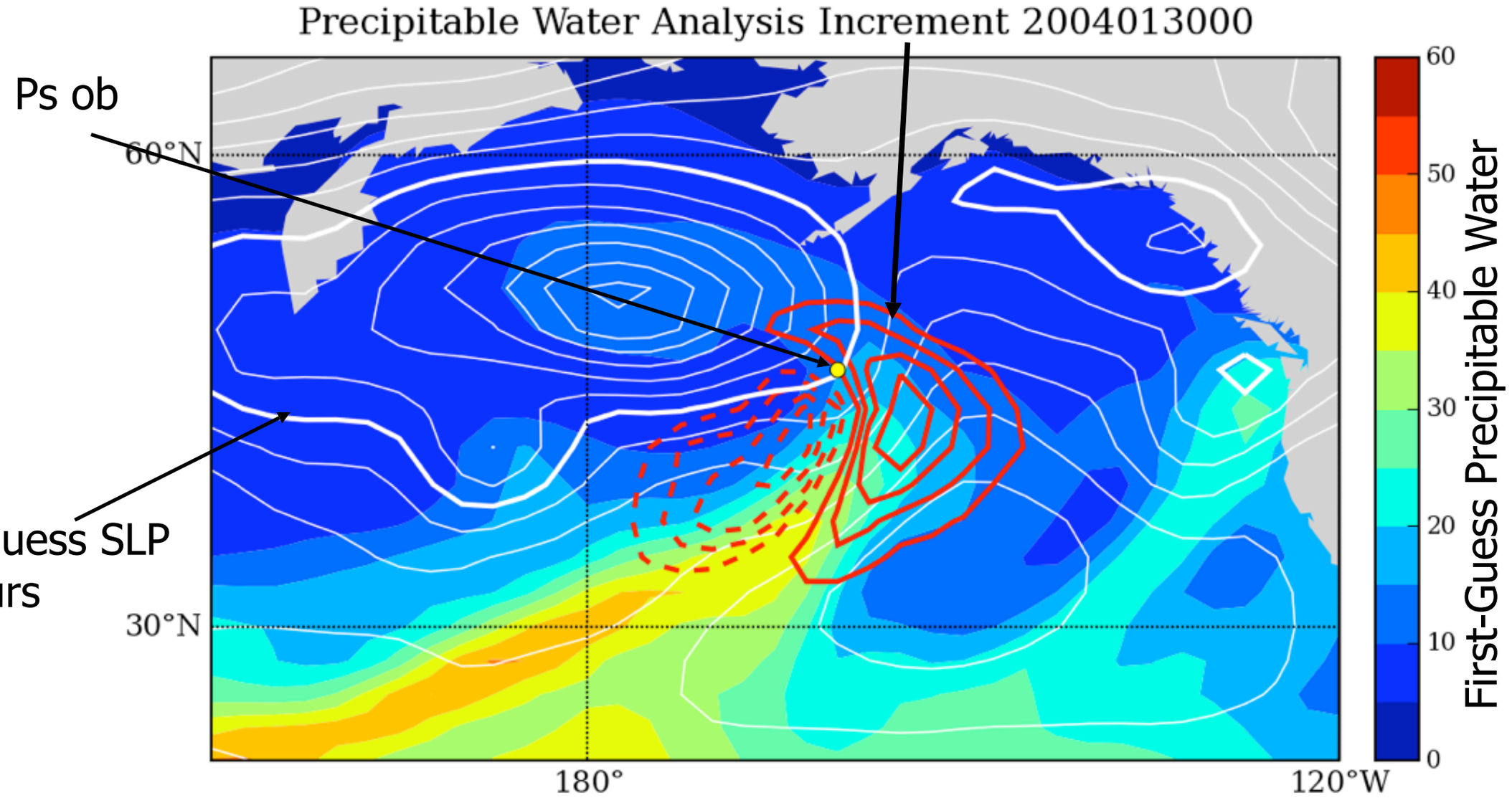
EnKF/GSI comparison





- GFS/EnKF similar for Z500, EnKF has a 12-h advantage for PWAT.
- T126L64 forecast from T382L64 operational GSI analysis is better than from EnKF analysis for Z500, but not for PWAT.

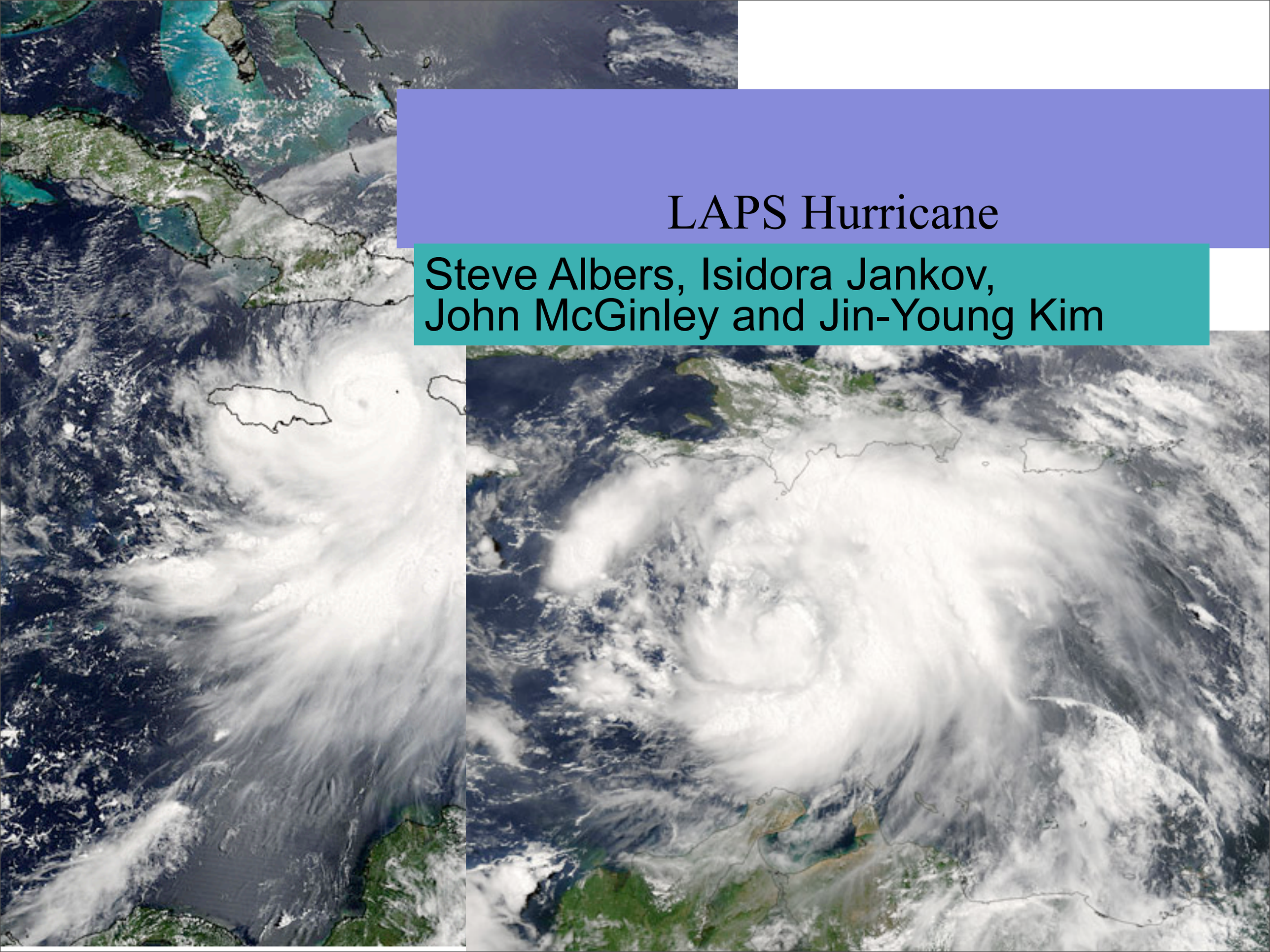
EnKF PWAT increment for a single p_s ob



p_s observation can improve analysis of precipitable water (cross-variable covariance in $\mathbf{P}^b$, not in GSI*).*

LAPS Hurricane

Steve Albers, Isidora Jankov,
John McGinley and Jin-Young Kim



CURRENT EFFORTS

Additional data sources being evaluated:

*** aircraft radar reflectivity

*** more complete use of dropsondes (including near surface pressure measurements)

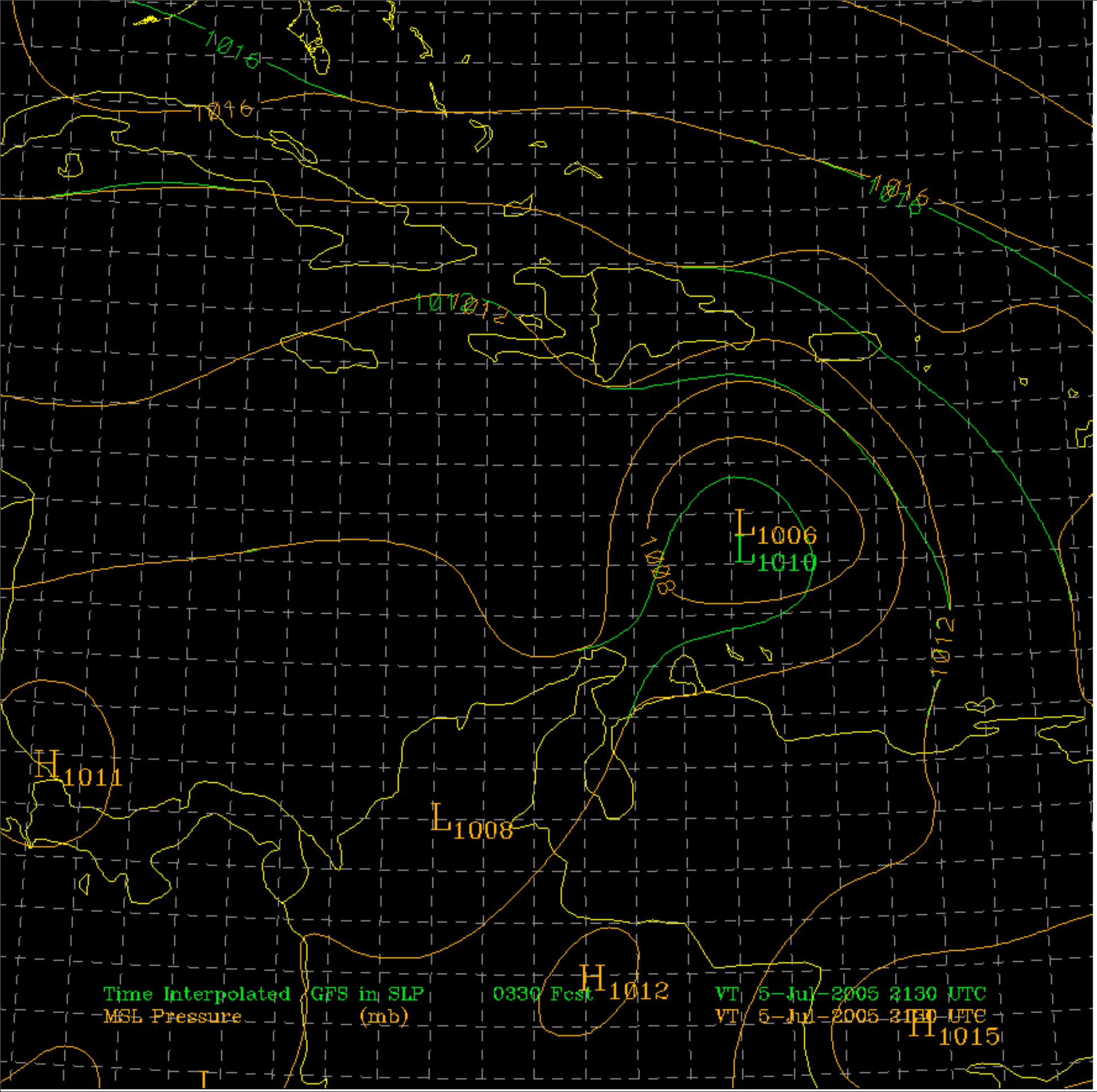
*** Goes satellite imagery for the cloud analysis.

ANALYSIS CONSIDERATIONS

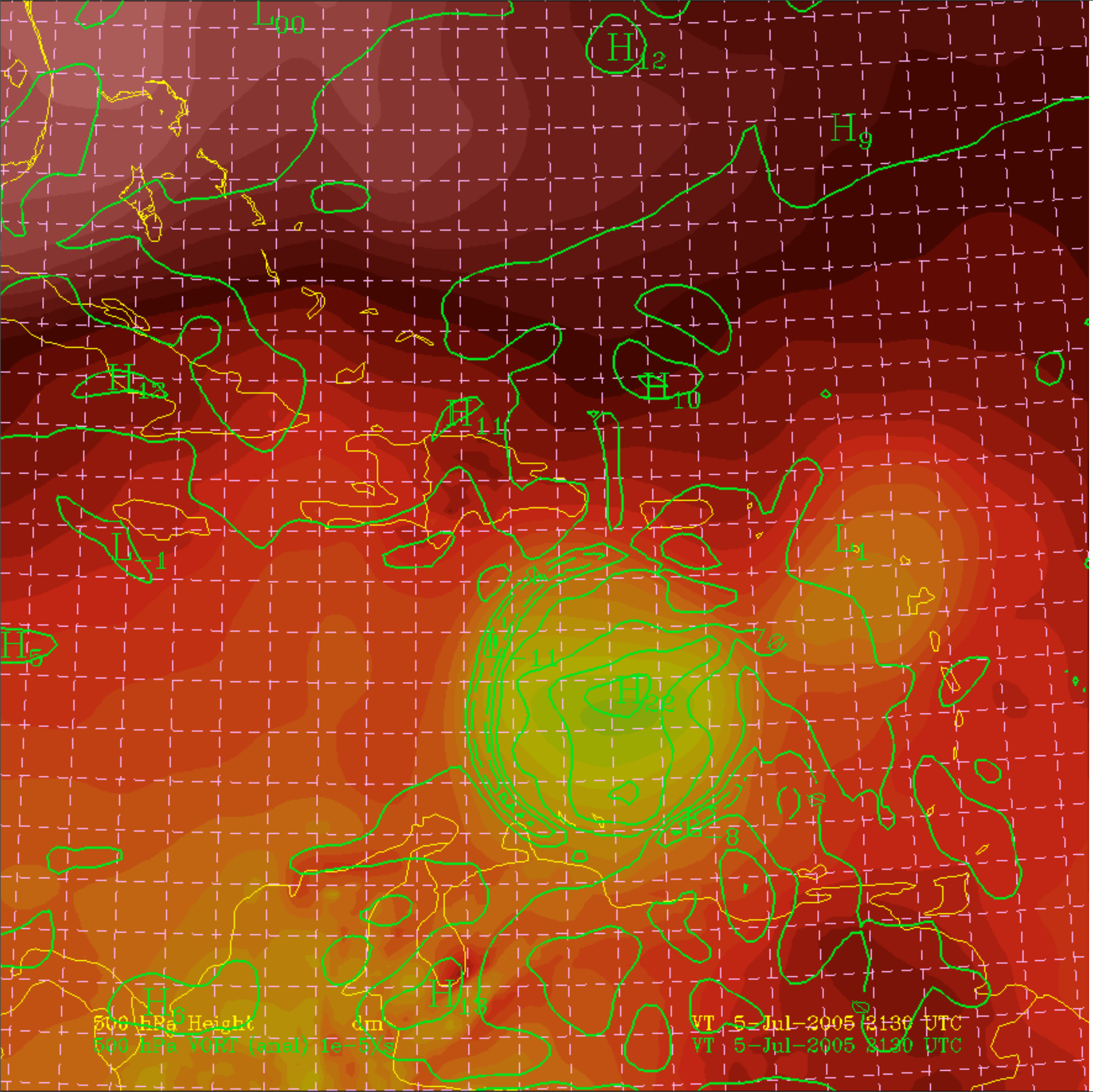
*** improved heights via hydrostatic integration using surface pressure boundary condition

*** wider time window to include more radar velocities

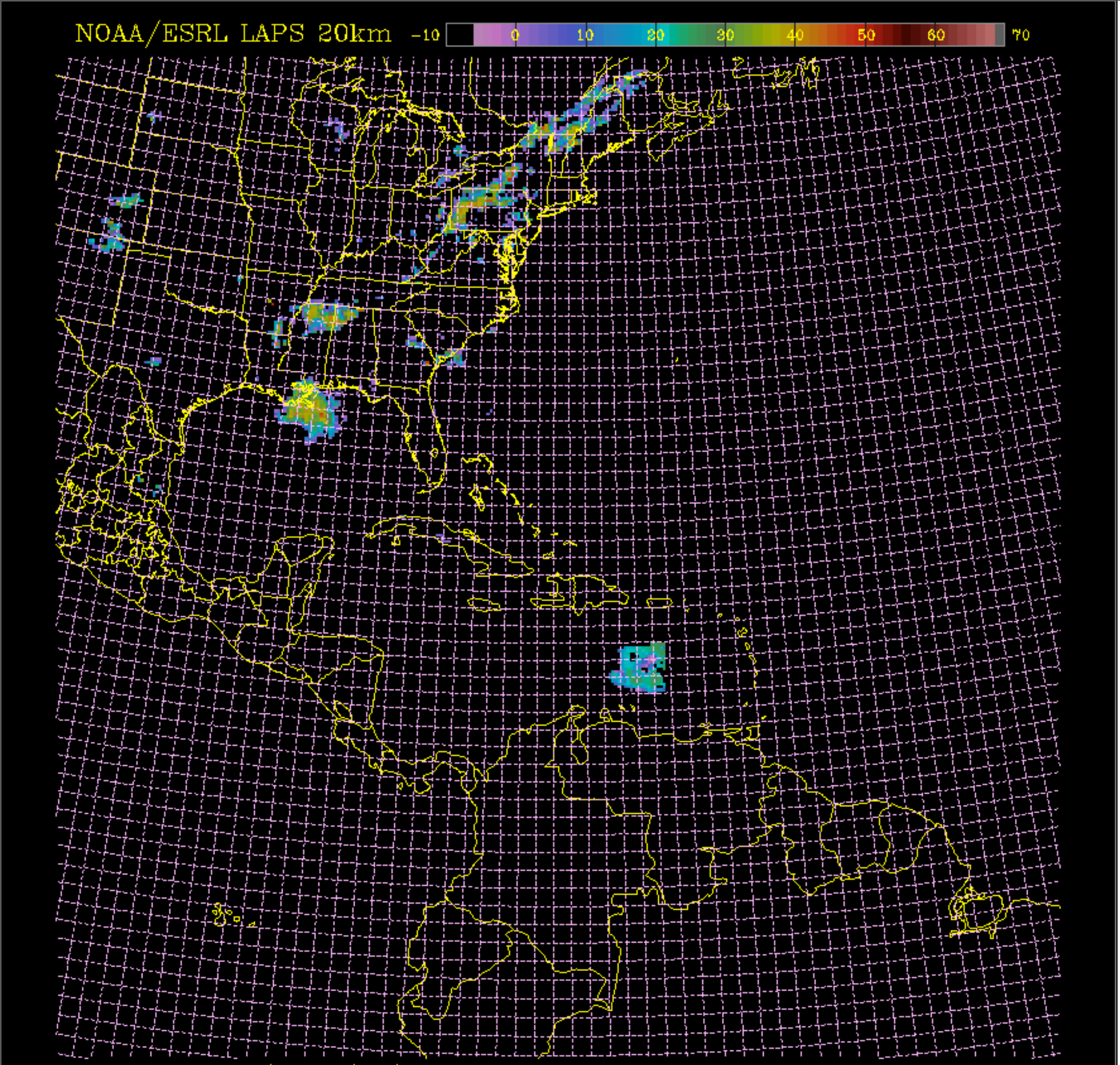
*** adjustable updraft strength in hot start



Surface mslp analysis from LAPS and GFS valid at 2130 05 July, 2005.



500 mb heights image and vorticity contours at 2130 UTC



AOML and NOWRAD observed radar reflectivity

NOAA/ESRL LAPS

0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1

100 150 200 250 300 350 400 450 500 550 600 650 700 750 800 850 900 950 1000 1050

16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0

11.28
-102.46 Gridded Cloud Cover X-Sect VT 5-Jul-2005 2130 UTC 11.28
-43.04
LAPS Reflectivity Vert X-Sect VT 5-Jul-2005 2130 UTC
Wind (Analyzed) (kt) VT 5-Jul-2005 2130 UTC

NOAA/ESRL LAPS

-40 -30 -20 -10 0 10 20 30 40

100 150 200 250 300 350 400 450 500 550 600 650 700 750 800 850 900 950 1000 1050

16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0

11:28
-102.46

LAPS Omega (cloud) ubar/s VT 5-Jul-2005 2130 UTC

LAPS Cloud Type VT 5-Jul-2005 2130 UTC

LAPS Reflectivity Vert X-Sect VT 5-Jul-2005 2130 UTC

11:28
-43.04

ONGOING WORK

* Real time Caribbean HLAPS analysis and HRS now implemented

* The analysis is nested in FIM

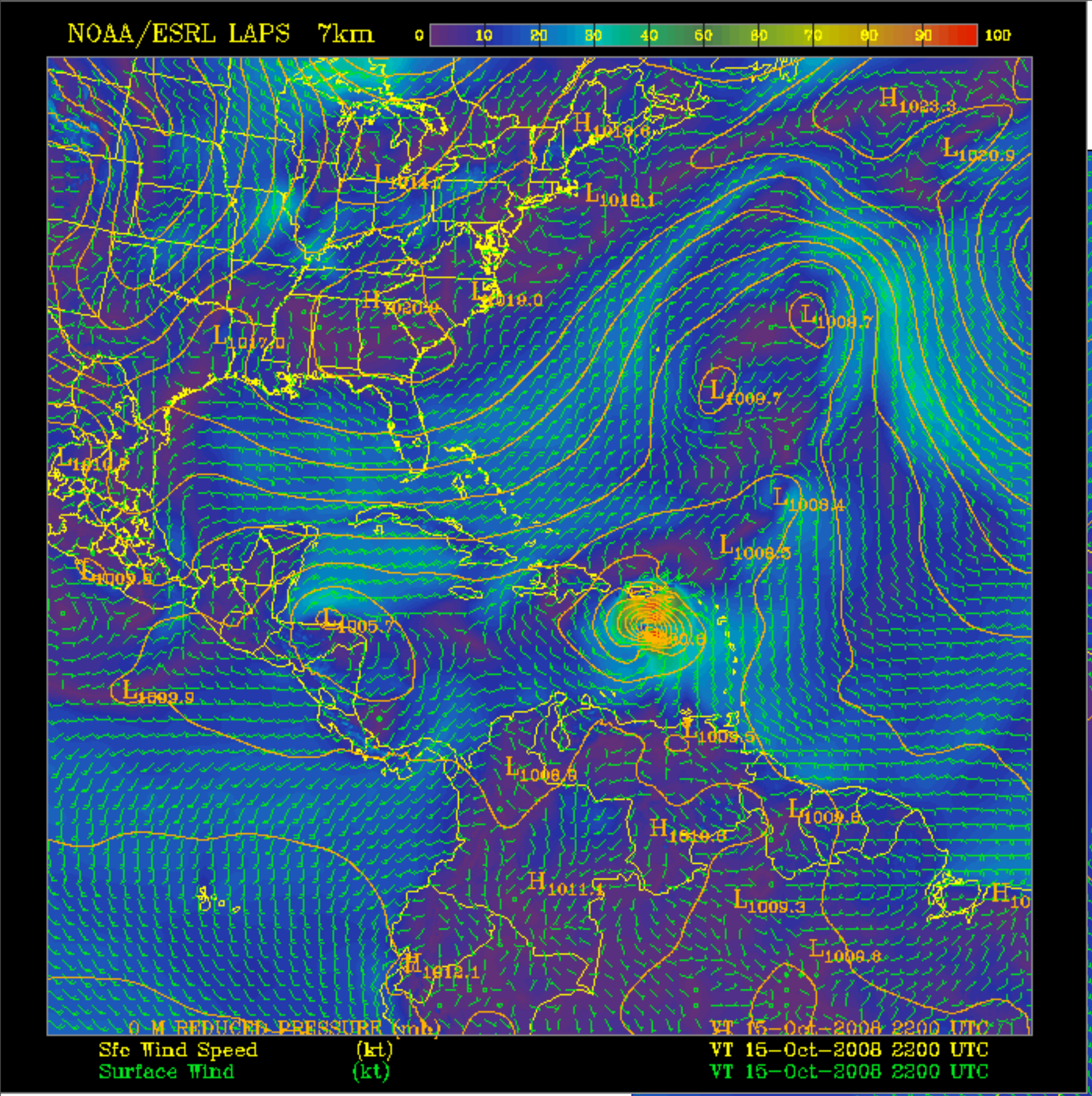
* GSD and AOML data sources

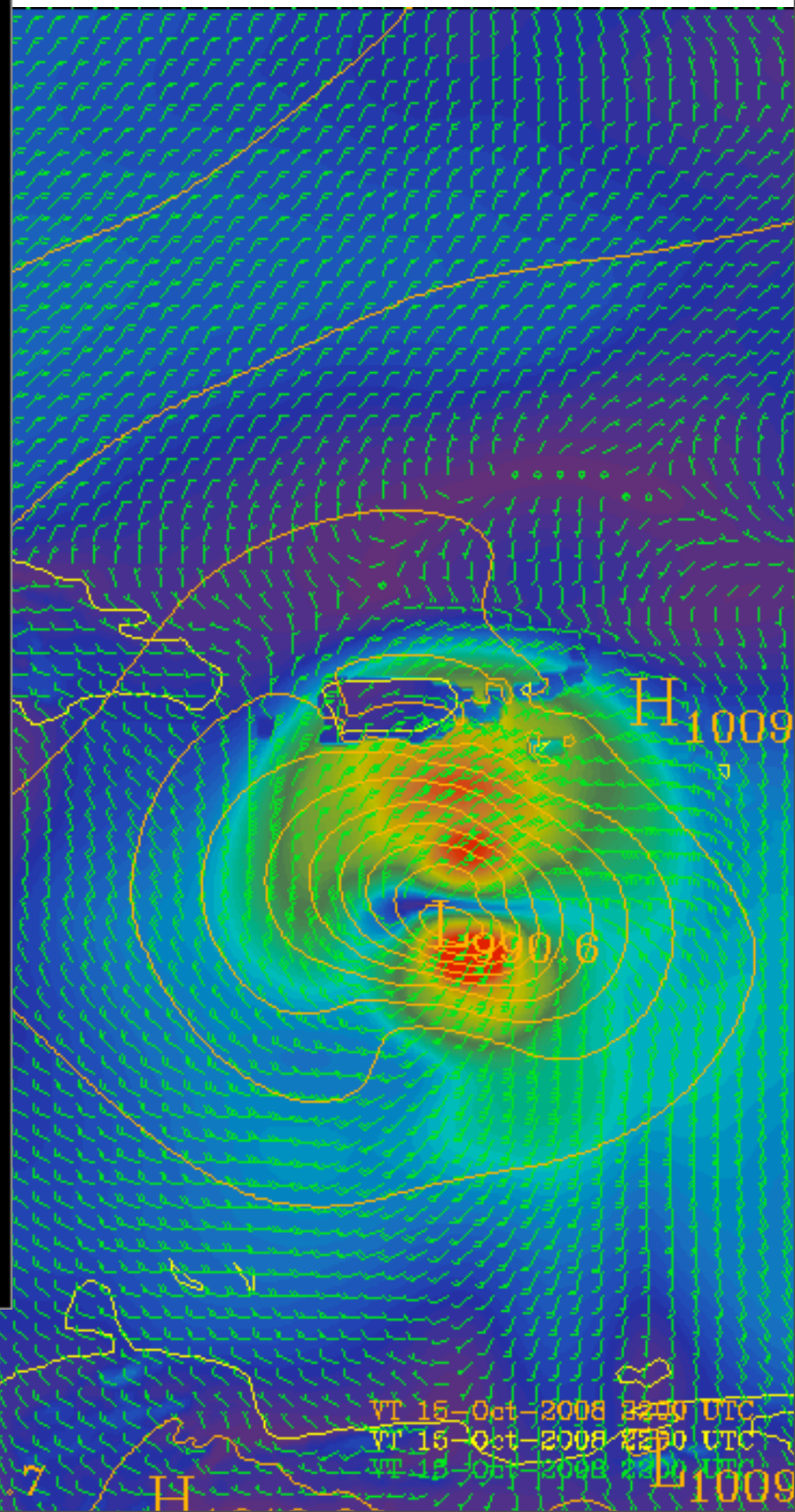
* The outer model domain matches HLAPS domain size and horizontal resolution of 9.9 km, and can run up to 19.8 km

* The nested grid horizontal resolution is 3.3 km , and can run up to 6.6 km

* Focus on hurricane track, intensity and QPF forecast

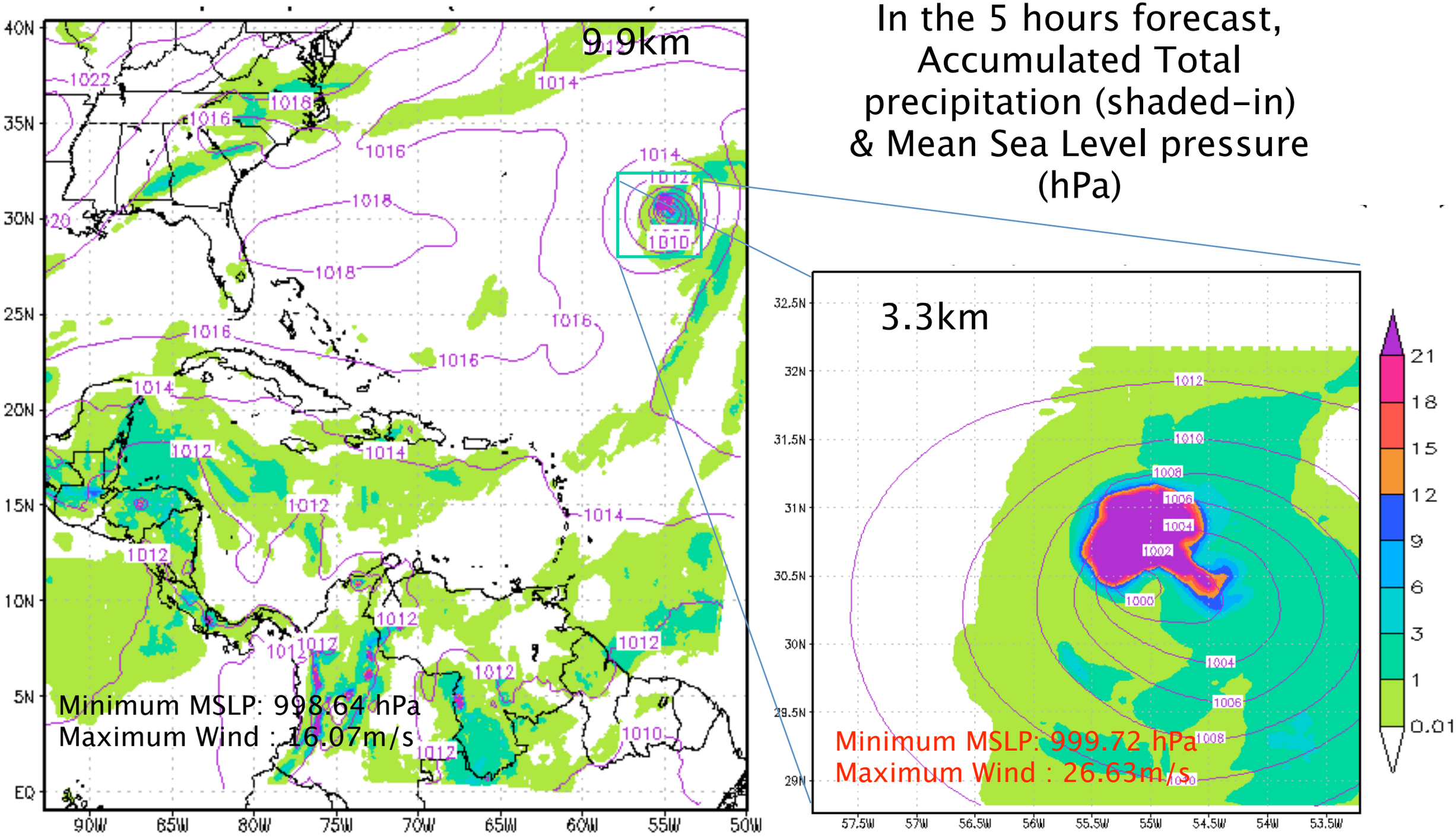
* Run Ike, Gustav and Katrina cases





http://laps.noaa.gov/aoml/aoml.html

In the 5 hours forecast,
Accumulated Total
precipitation (shaded-in)
& Mean Sea Level pressure
(hPa)



Another option: coarser grids - bigger nest

DESIRED REAL TIME DATA FROM AOML AIRCRAFT / SATELLITE

* flight level winds

* compacted radar reflectivity and velocity

* obtain SFMR data (for STMAS)

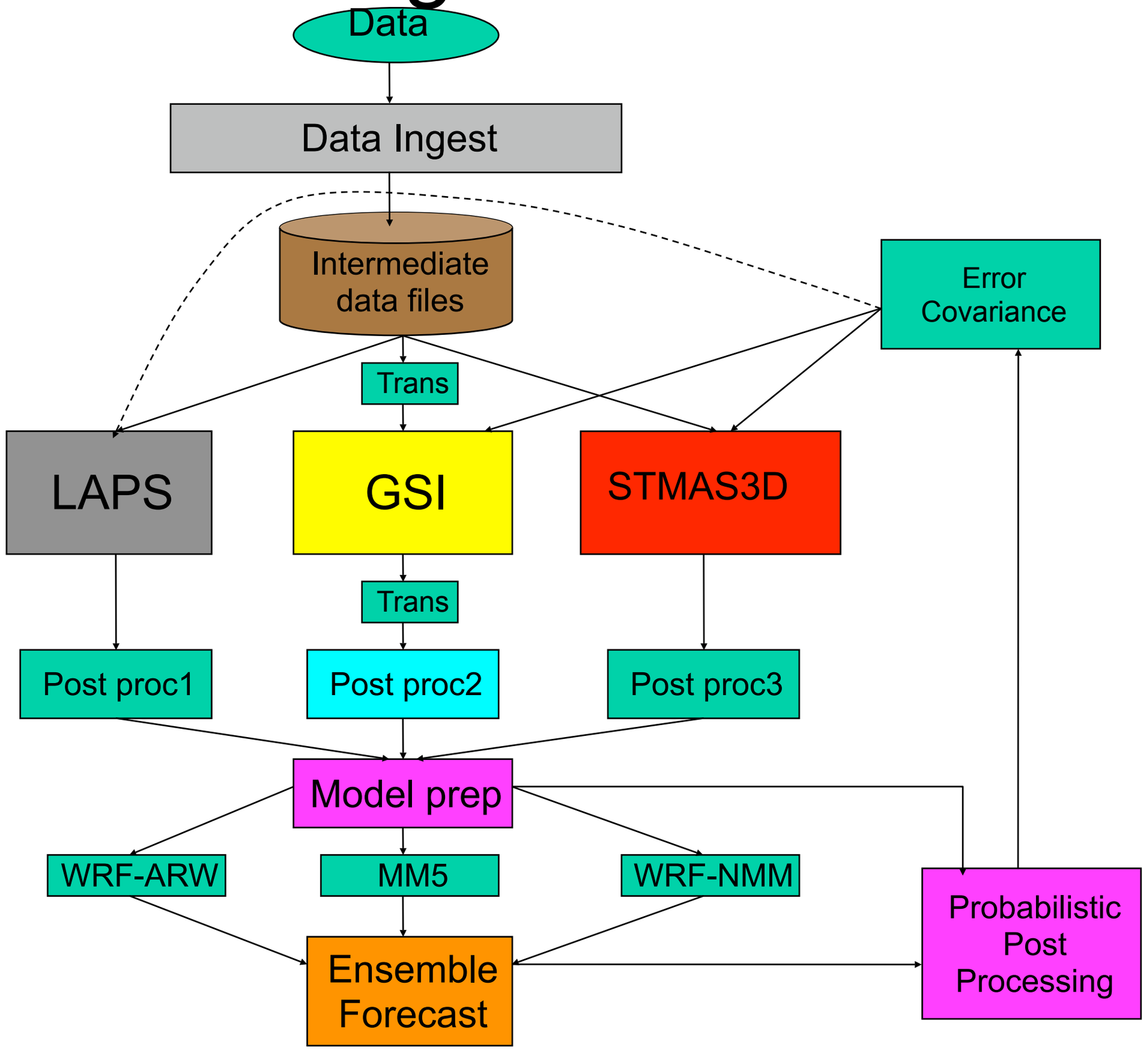
* part of data warehouse

COMING ATTRACTIONS

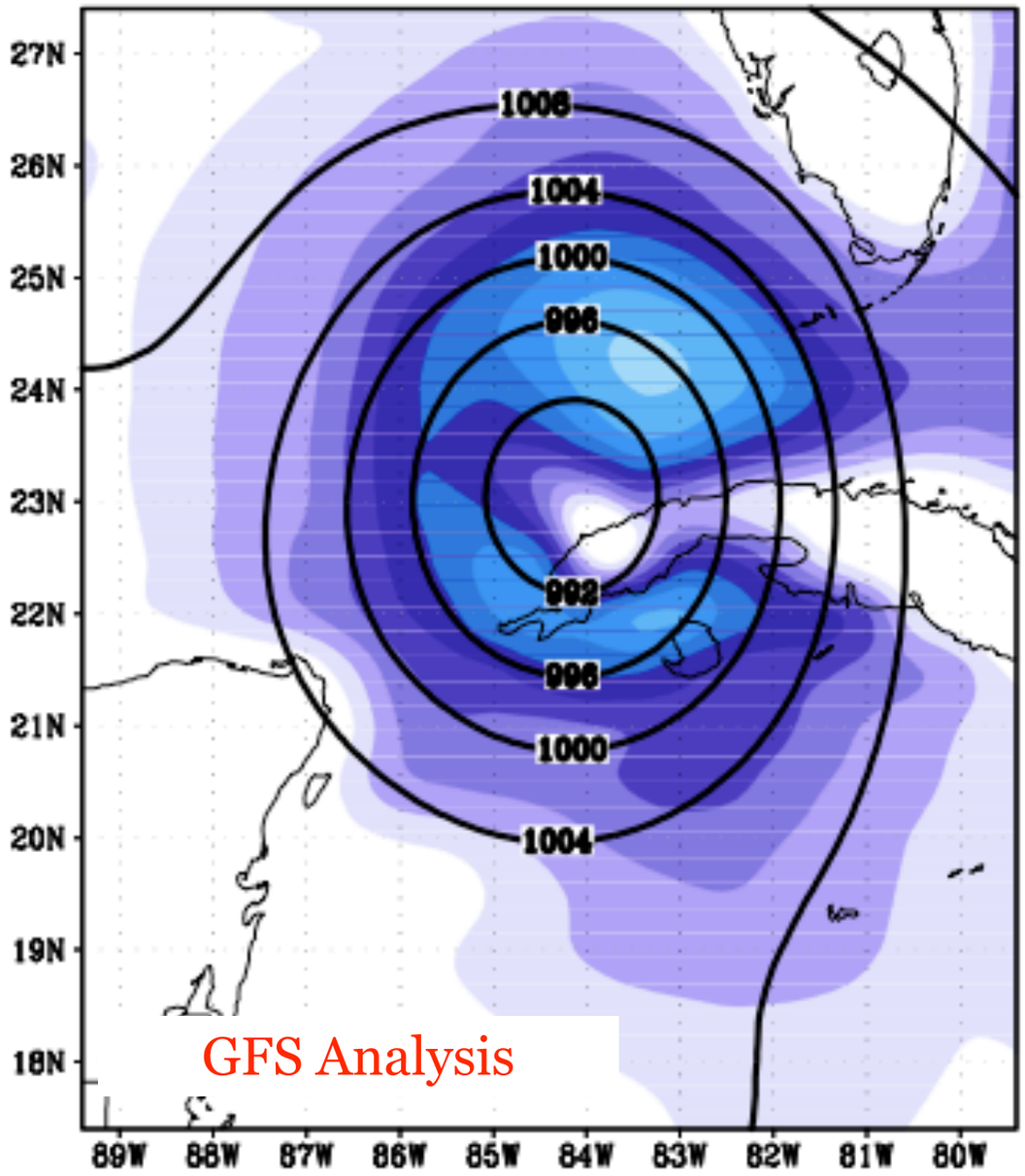
* Sensitivity tests to LAPS/GFS/GFDL model initializations and various Lateral Boundary Conditions will be presented at the next modeling meeting.

* Performance of two different post-processing track packages (NCEP tracker and HRS diapost) have been evaluated

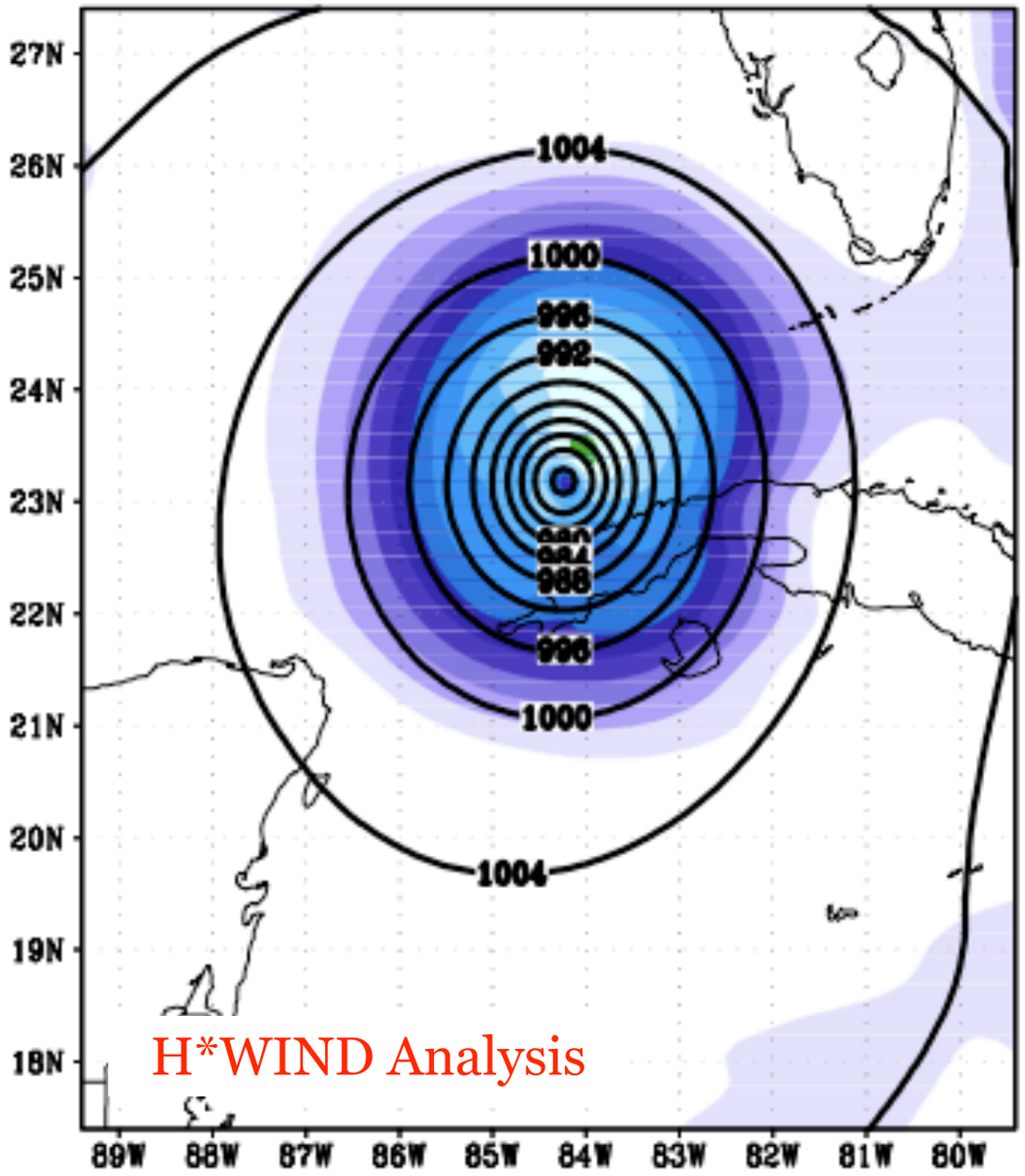
DA Configuration



Tropical Cyclone IKE – September 10 0000 UTC



GFS Analysis



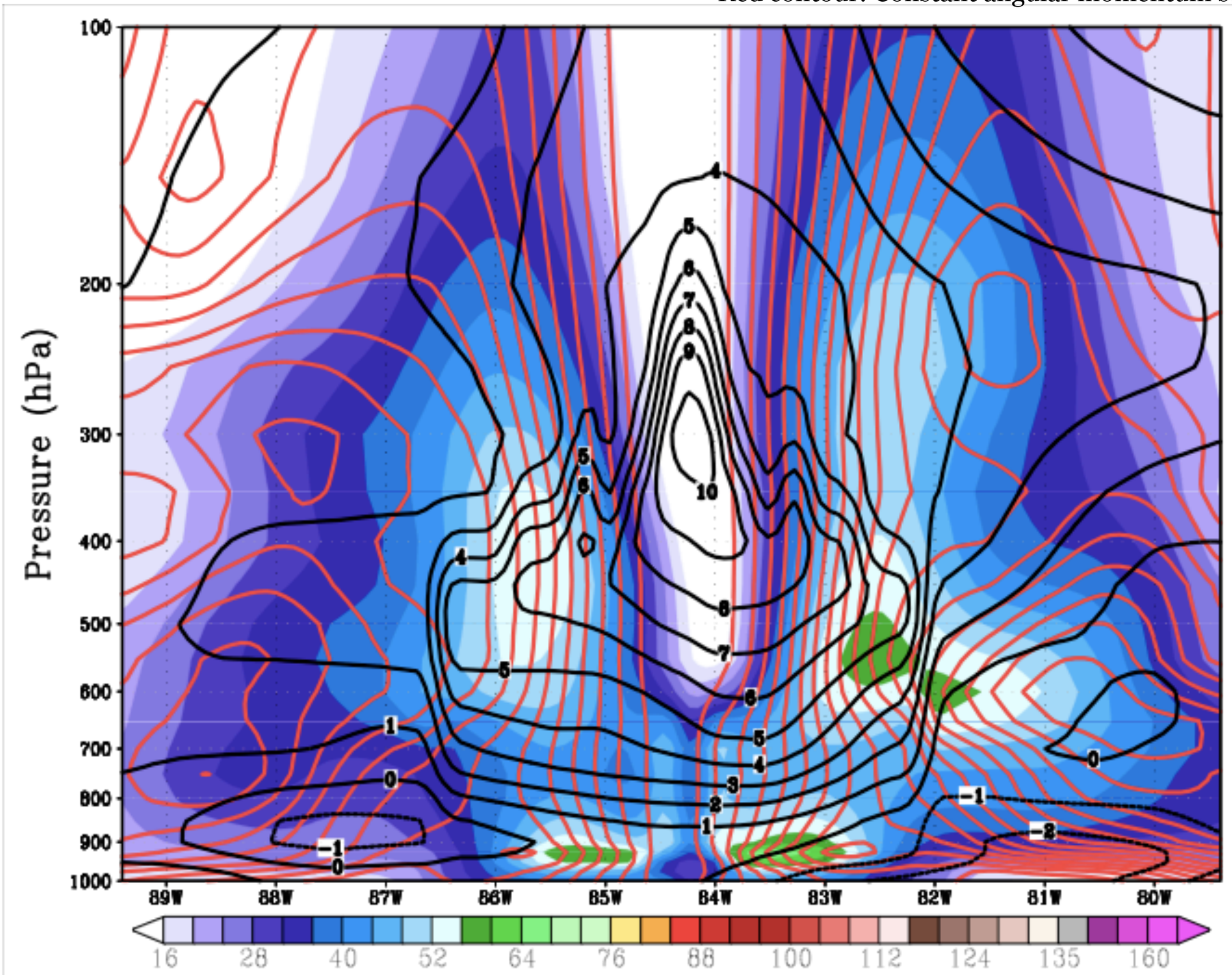
H*WIND Analysis

H.R. Winterbottom

Shading: Wind Speed Magnitude (kts)

Black Contour: Temperature anomaly (K)

Red contour: Constant angular momentum surfaces



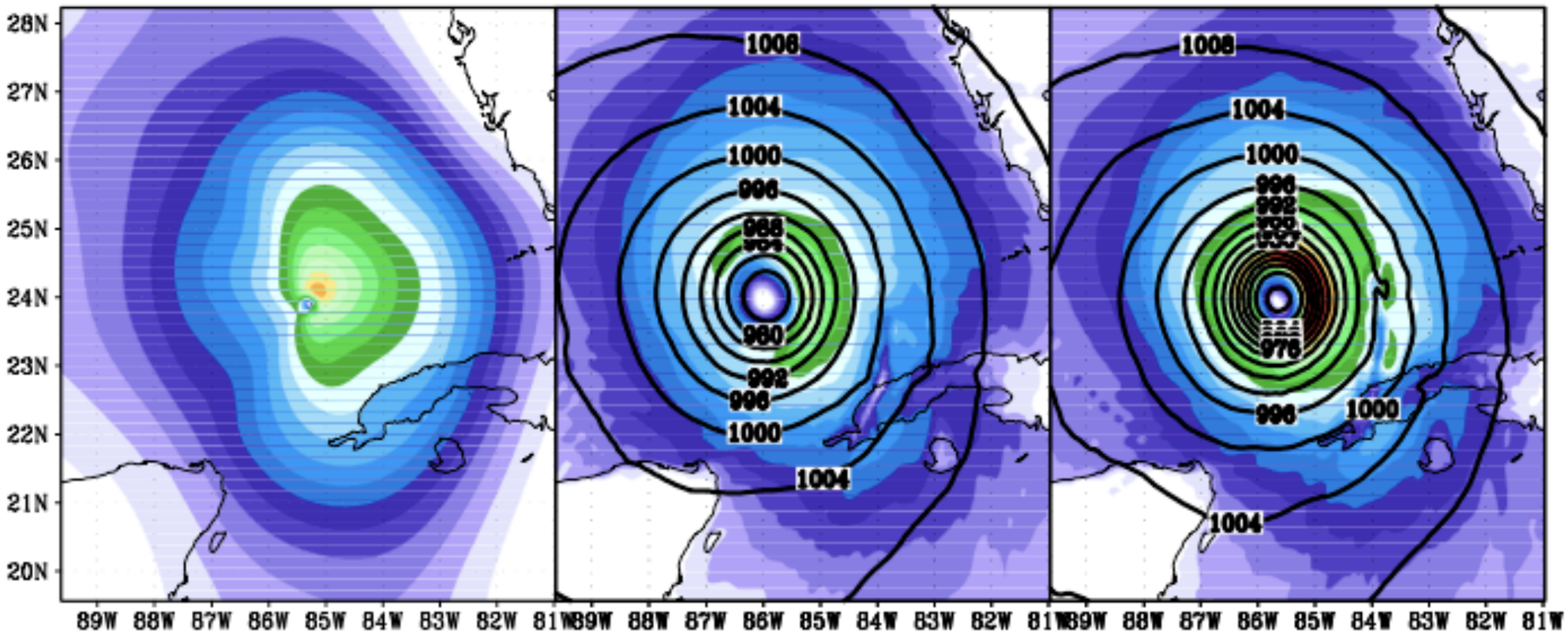
H.R. Winterbottom

Tropical Cyclone IKE Forecast – September 10 1200 UTC

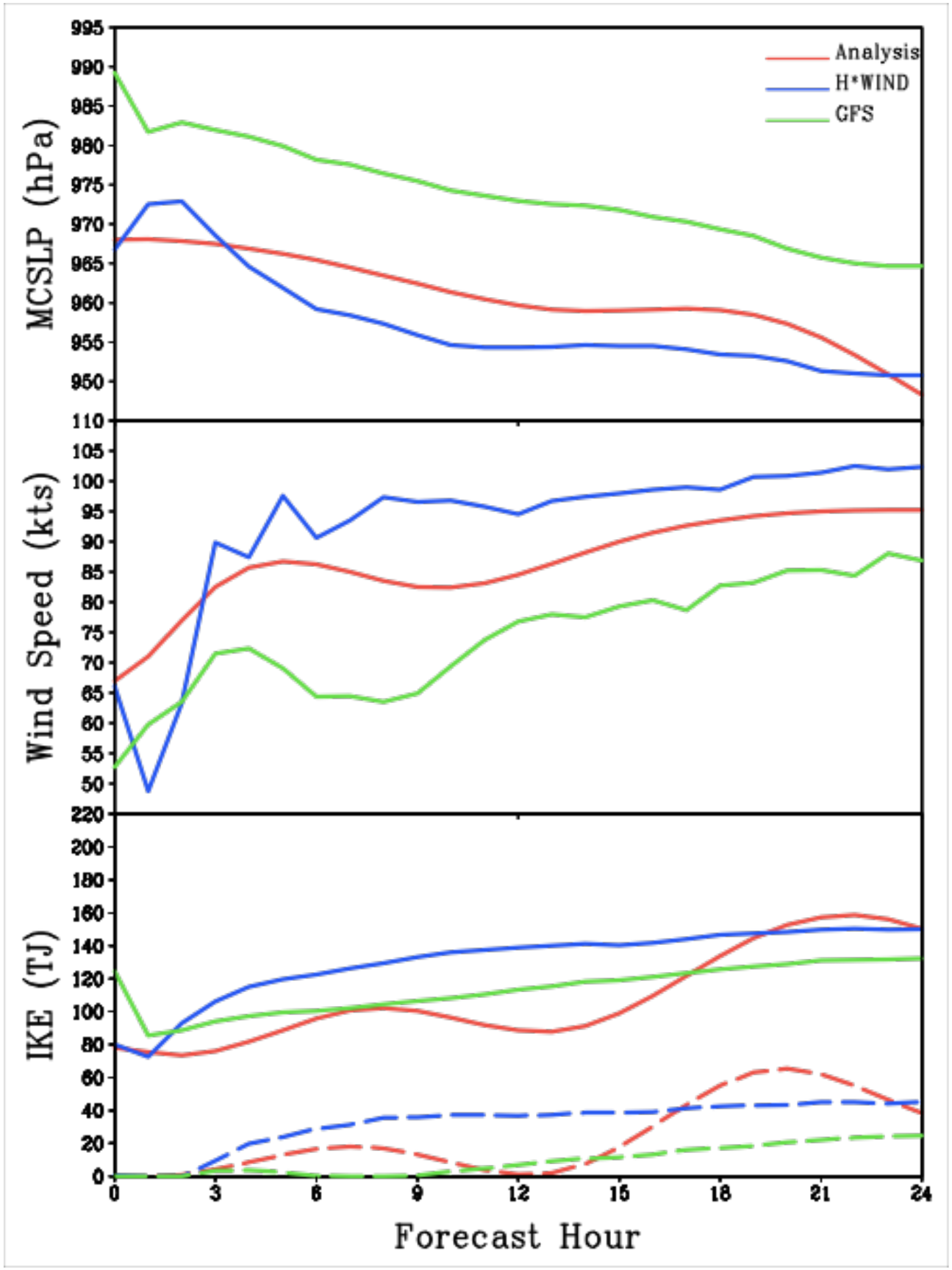
H*WIND Analysis

GFS Forecast

H*WIND Forecast



H.R. Winterbottom



Hurricane Data Warehouse

Yuanfu Xie, Sharan Majumdar, Sim Aberson,
Steve Albers, Sundararaman.G.Gopalakrishnan
and Nicholas Carrasco

We would like to propose a DA warehouse for hurricane data assimilation community.

- Controlled access the data
- Operational DA analyses
- Display capability
- Evaluation tools for hurricanes

Existing Facility

- AOML has started this warehouse:
  - http://www.aoml.noaa.gov/hrd/

    For all aircraft data and post-processed SFMR data.
    Real time aircraft data can be found at
  - http://www.nhc.noaa.gov/reconlist.html

    We may need to expand this for all data sources (raw and post-processed), a unified data ingest capability and DA analysis display and evaluation.
-

Existing Facility

- ESRL/GSD has also a warehouse hosting all types of data (obs and background in NetCDF) over the globe in archive and real time.
- MADIS (more easily accessible) has mainly point observations
- NIMBUS has additional observations from satellite and model grids
- AOML observations can potentially be added to MADIS and/or NIMBUS
- MADIS/NIMBUS data also available on Jet

Observations

- A unified observation data format for each observation data type (AOML).
- Possible near real time data update.
- Some basic data interface (Maybe ESRL/ LAPS or possible ESRL/MADIS).
- Basic QC criteria (LAPS and MADIS have various QCs).
- DA users' account management.

Datasets

- All in-situ observations;
- Raw radar and pre-analyzed radar data from AOML/HRD;
- Microwave observations;
- Satellite radiance data;
- Others…
- Model backgrounds.

Display and evaluation

- Display capability for all DA products in near real time, EnKF, GSI, LAPS, and STMAS.
- Evaluation tools for hurricane DA analyses and forecast impact.
- Discussion forum for improvement of all DA schemes.

Baby Steps toward the near real time warehouse

- Compile a list of observation instruments for hurricane DA;
- Define a unified data format, observations and model backgrounds;
- Setup servers with archive capability at AOML, GSD or both.

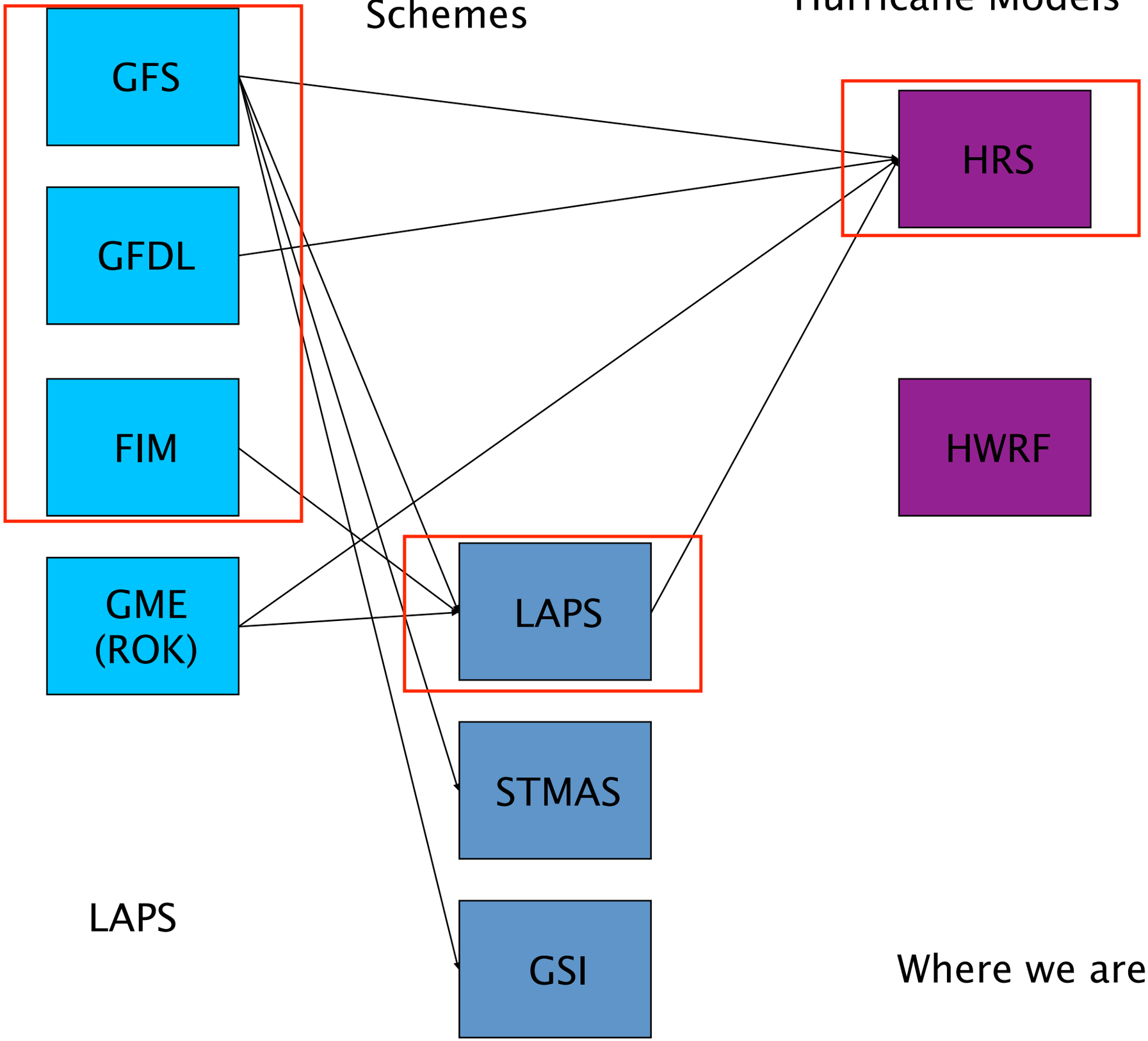
FAB MODELING ACTIVITIES

Jin-Young Kim, Isidora Jankov, Steve Albers
andJohn McGinley

BG, IC, TDBC

Initialization Schemes

Hurricane Models



LAPS

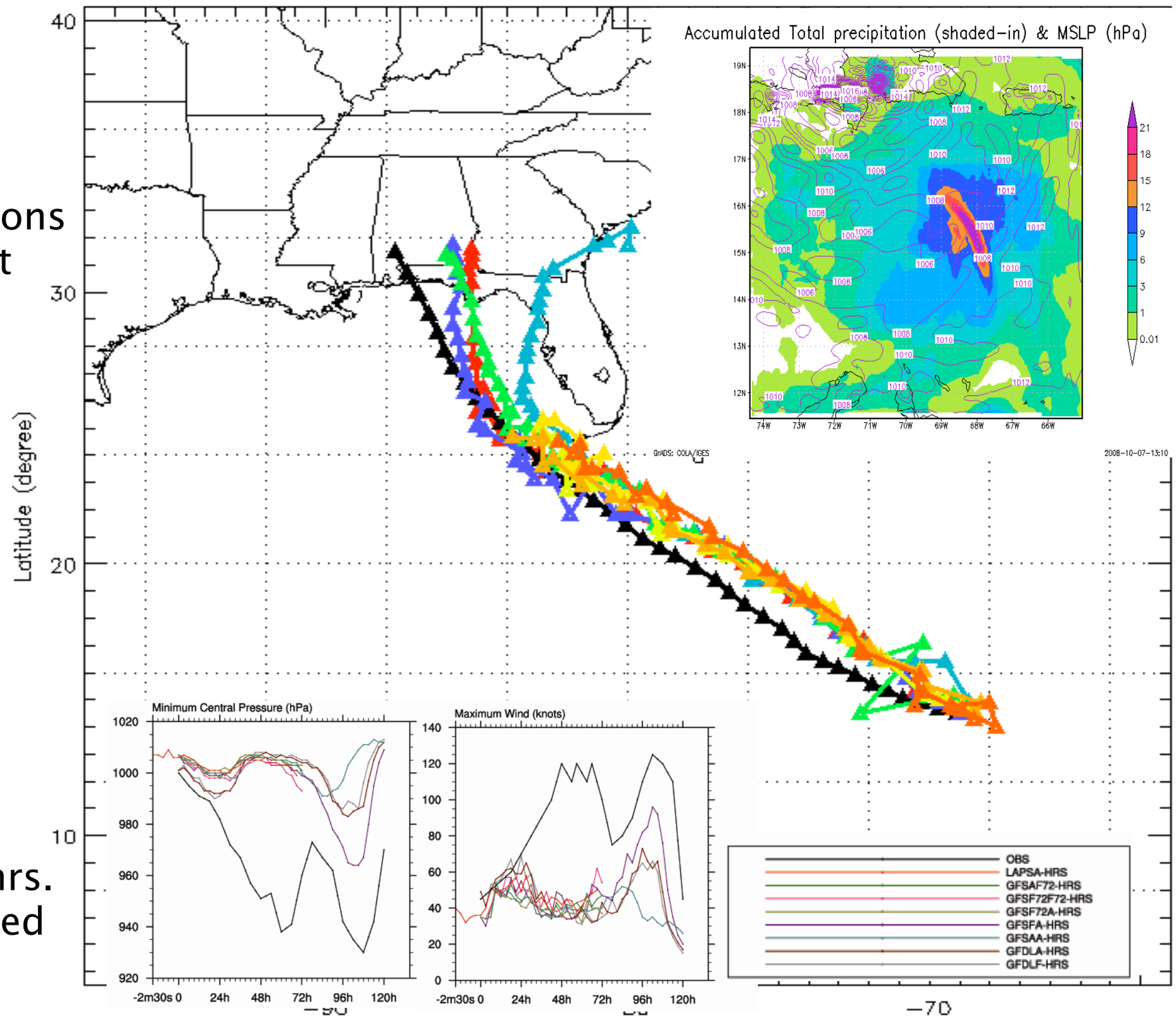
Where we are now

NOAA/ESRL/GSD/FAB

HURRICANE DENNIS04L(2005-07-06) TRACK

nsemble
track
edictions
ing GFDL,
FS, LAPS,
itial conditions
nd HRS. Best
ack…black

Lowest P
eft, and
peak wind
for Dennis
(black line)
out to 120hrs.
All runs failed
on early
deepening



Total
Precip
GFDL run

OBSERVATION

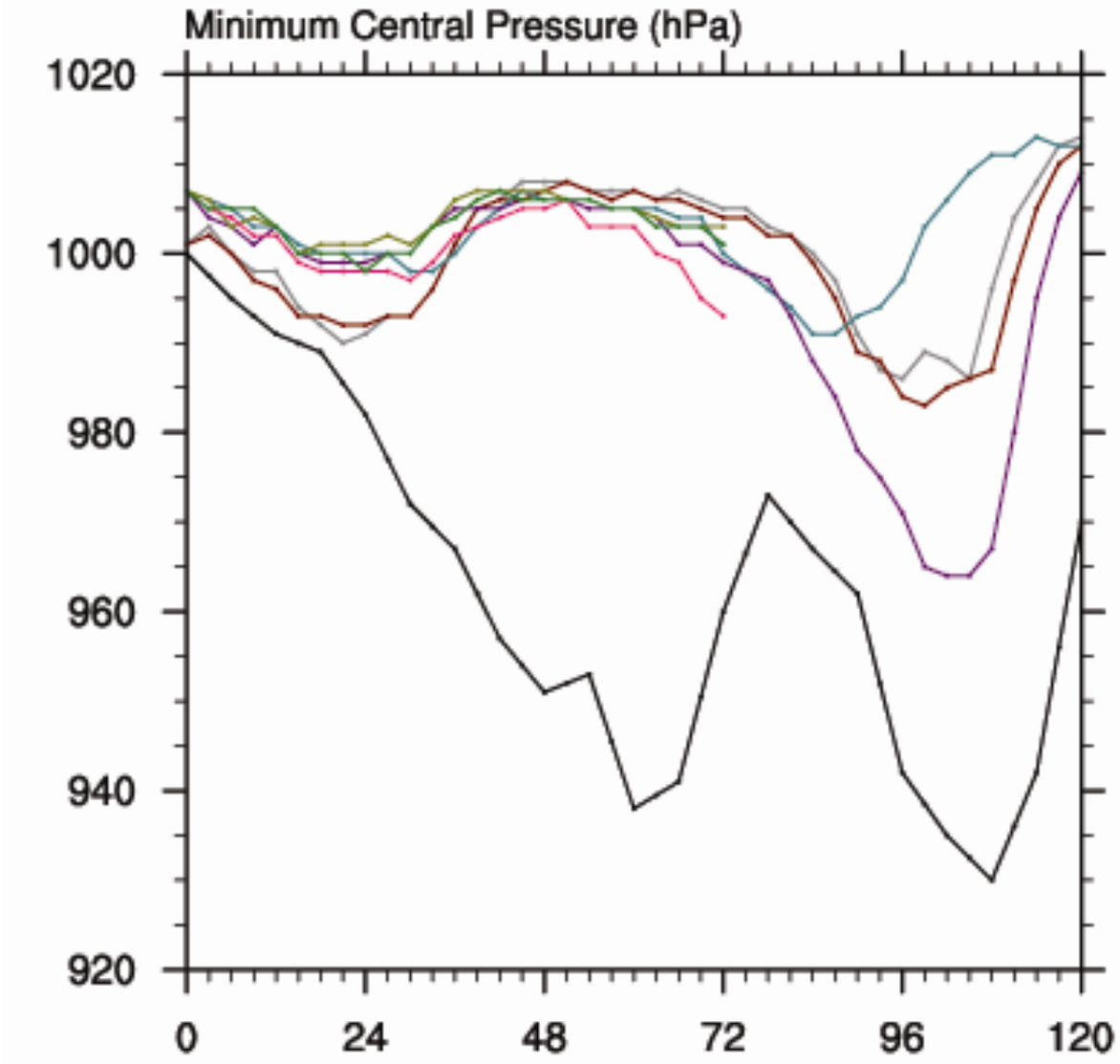
GFDL-GFSF-HRPS MODEL

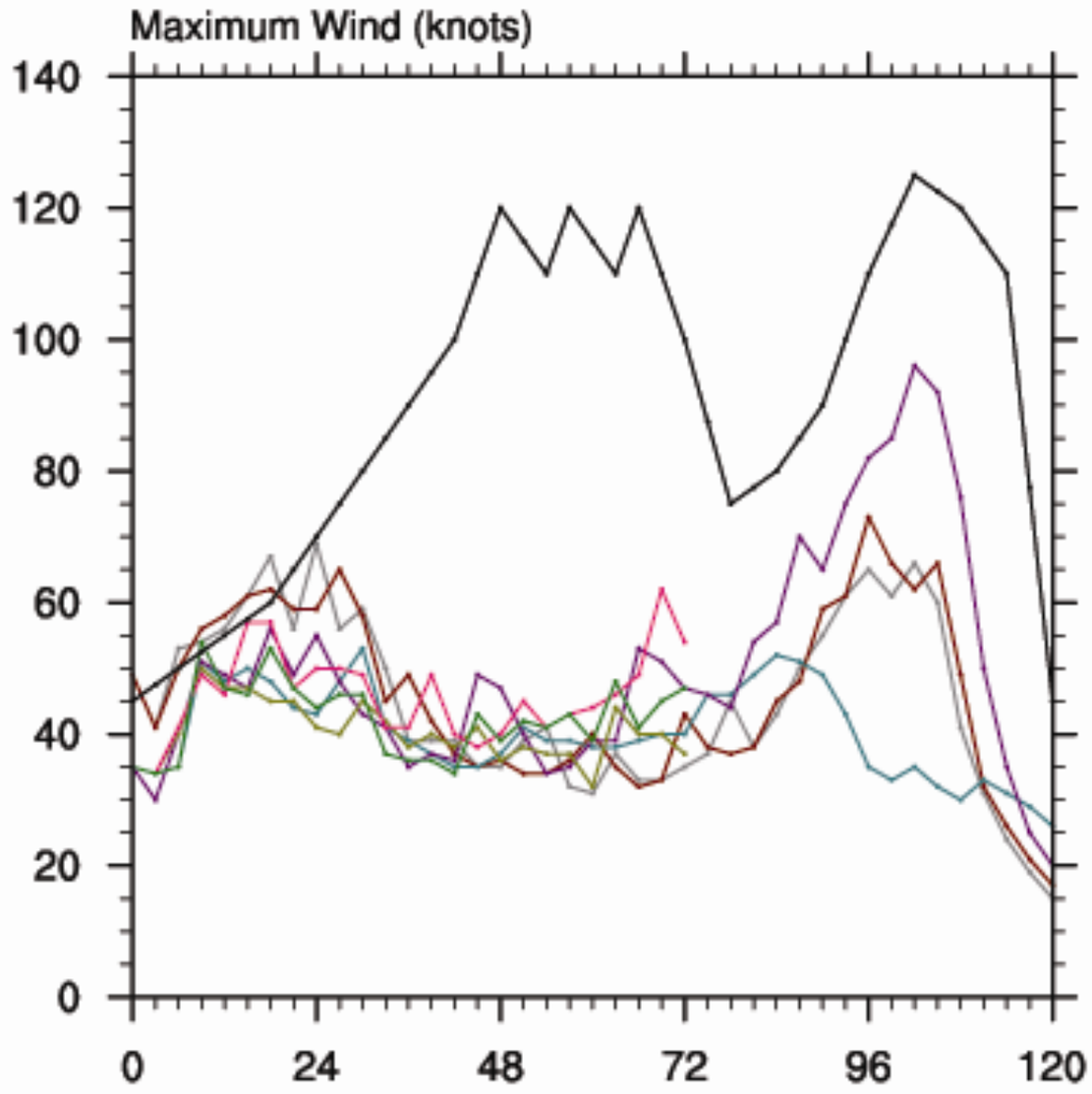
	GFDL	GFS (forecast 120)	GFS (analysis)	GFS (forecast 72)
H-Resolution	0.167 deg.	1 deg.	1 deg.	1 deg
T-Resolution	0-126hr, 6hr	0-180 hr, 3hr	0, 6hr	6-72 hr, 6hr
Scale	Regional	Global	Global	Global

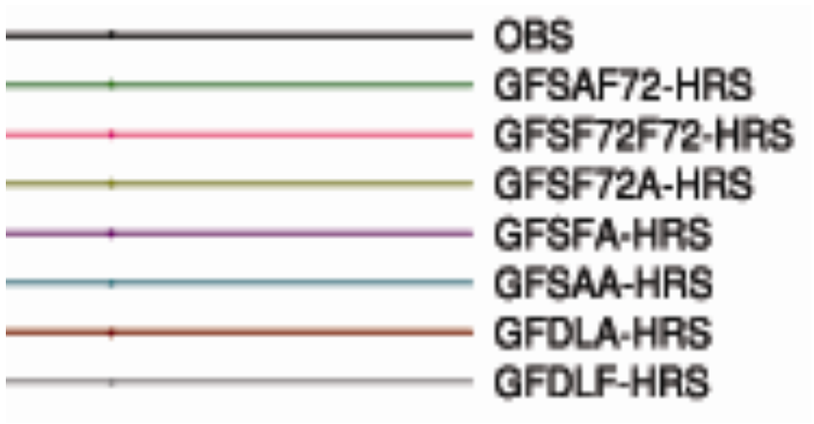
* GFDL: Geophysical Fluid Dynamics Laboratory model
* GFS : Global forecast System

Pressure	Surface	Experiment
GFDL	**GFS Forecast**	GFDLF (Operation of NHC, HRD)
GFDL	**GFS Analysis**	GFDLA
GFSA	GFS Analysis	GFSAA
GFSF	GFS Analysis	GFSFA
GFSF72	**GFS Analysis**	GFSF72A
GFSF72	**GFS Forecast 72**	GFSF72F72
GFSA	GFS Forecast 72	GFSAF72

DENNIS(2005-07-06)

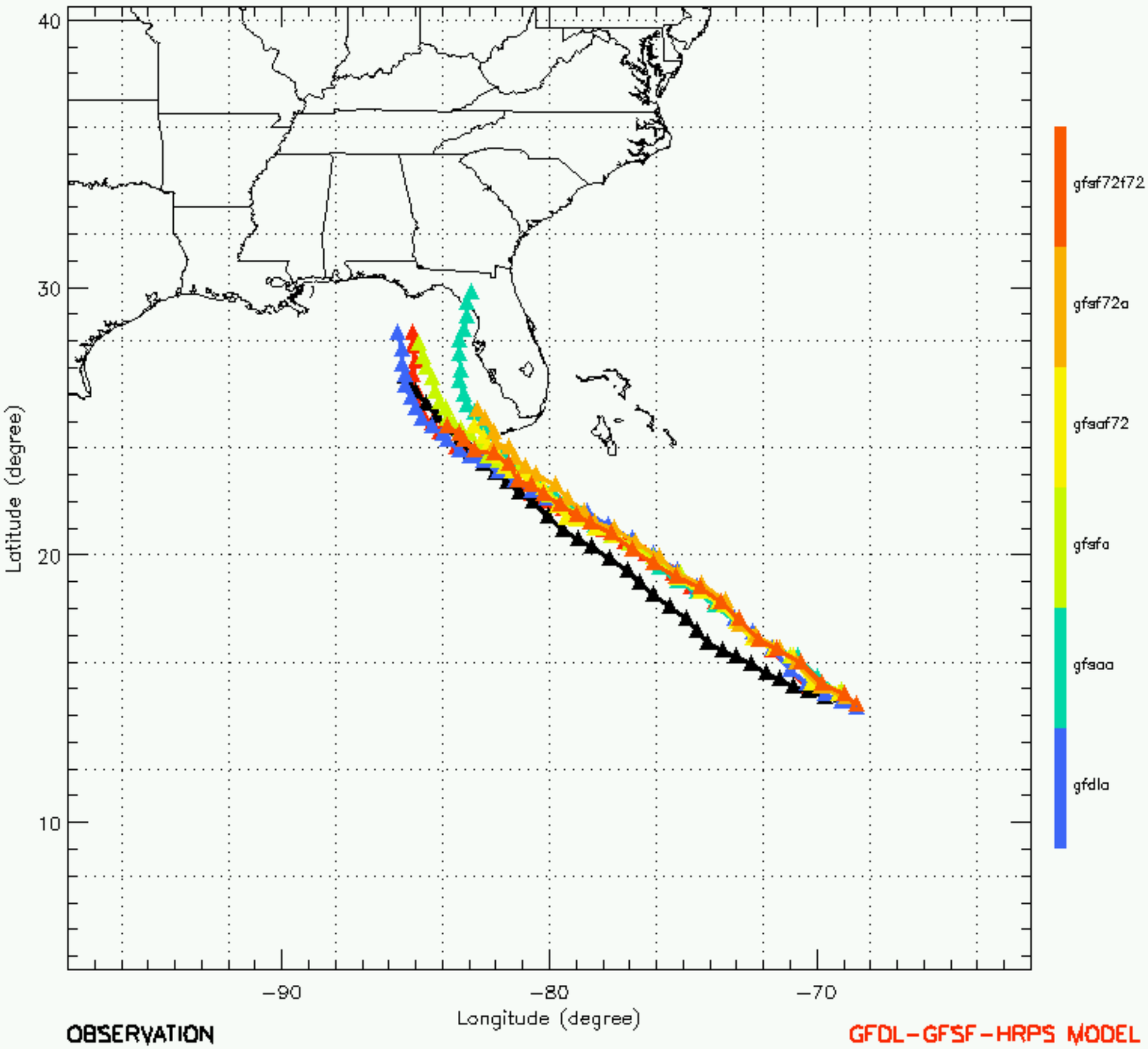






NOAA/ESRL/GSD/FAB

HURRICANE DENNIS04L(2005-07-06) TRACK



OBSERVATION

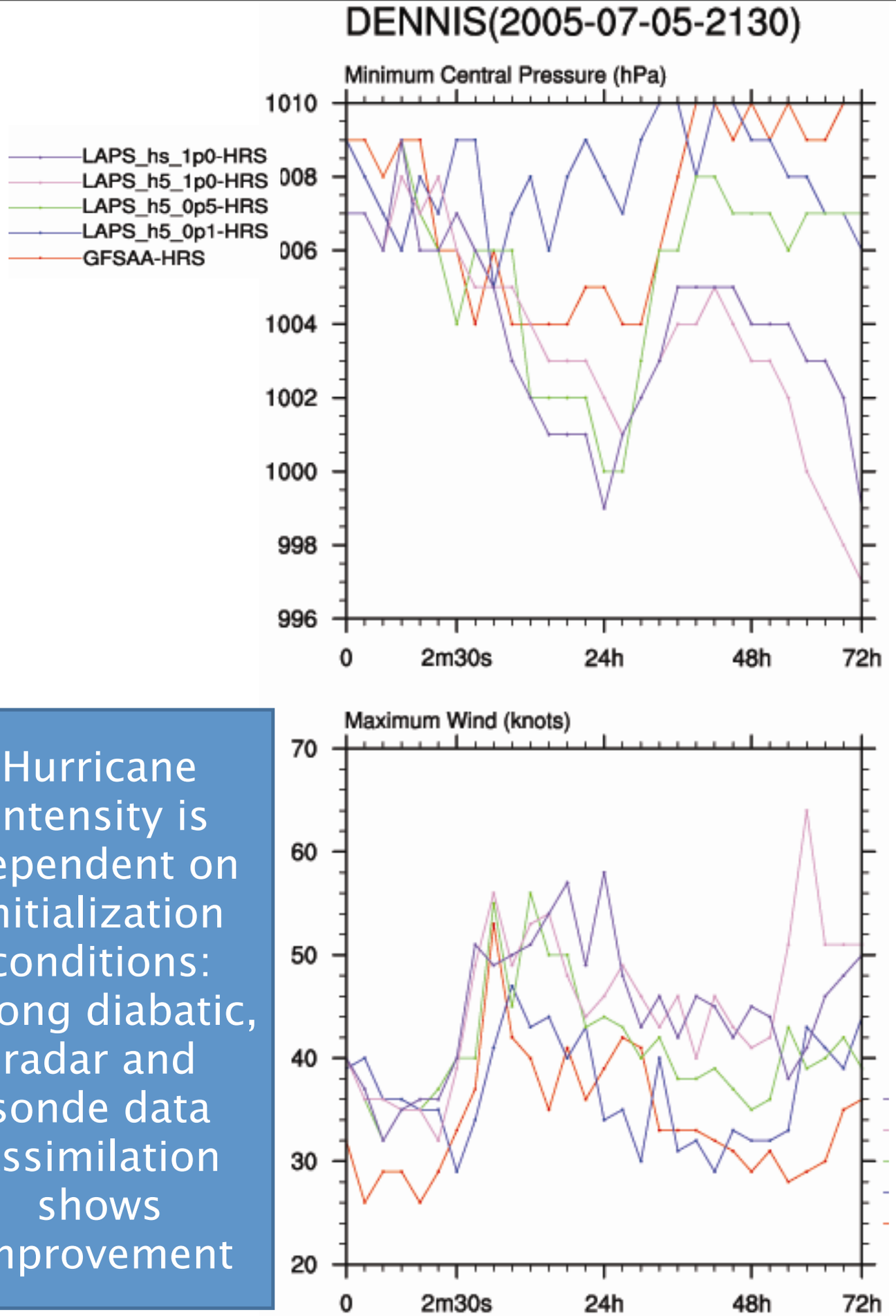
GFDL-GFSF-HRPS MODEL

Pressure	Surface	Experiment	Results
GFDL	GFS Forecast	GFDLF (Operation of NHR)	< 36hr fcst. (pres.), < 9hr fcst. (wind)
GFDL	GFS Analysis	GFDLA	``
GFSA	GFS Analysis	GFSAA	
GFSF	GFS Analysis	GFSFA	All the time, Rank=2
GFSF72	GFS Analysis	GFSF72A	
GFSF72	**GFS Forecast 72**	**GFSF72F72**	All the time, Rank=1
GFSA	GFS Forecast 72	GFSAF72	

1. GFDLF and GFDLA is good for the short forecast time
2. Analysis in not always good as IBCs for the hurricane forecast
   ex) For the initiation IBCs at 00, 06, 12, 18 UTC,
   GFS Forecast is good as IBCs during longer forecast.
3. Intensity is sensitive on various IBCs conditions, while it's similar on track forecasts.

To investigate the OBS sensitivity and Hot start in LAPS initialization based on GFSA LBCs ….

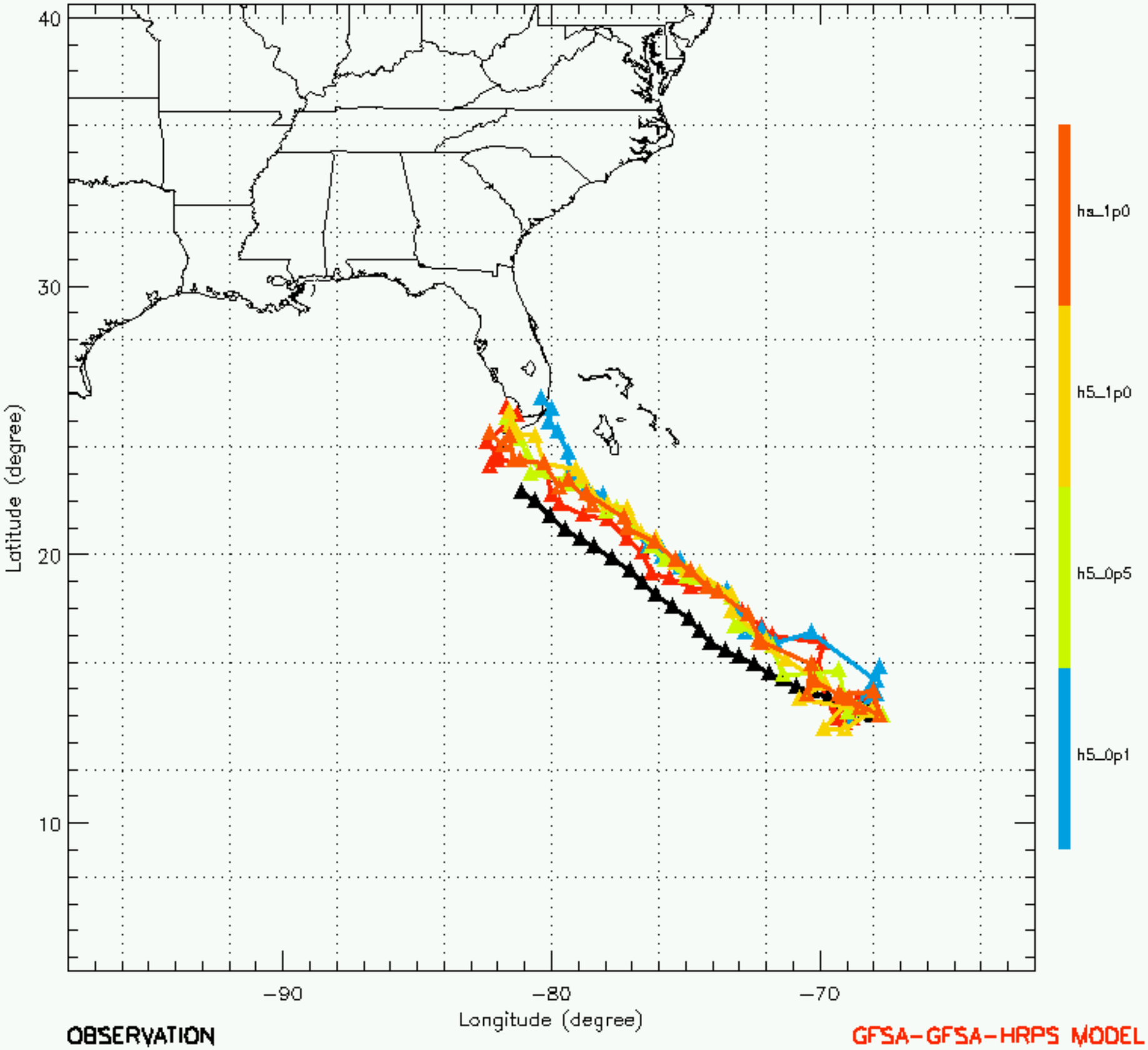
Experiment	Description
CNTL	No radar data assimilation, GFS Initial and lateral boundary conditions
Exp-h5_Wd_Vr	**Radar wind** only, **Groundsonde** upper level only, **surface pressure**, Hot start_**Weak** diabatic
Exp-h5_Md_VrRef	Radar wind and **reflectivity,** Groundsonde **full level**, surface pressure, Hot start_**Medium** diabatic
Exp-h5_Sd_VrRef	Radar wind and reflectivity, Groundsonde full level, surface pressure, Hot start_**Strong** diabatic
Exp-hs_Sd_VrRef	**Hydrostatic surface boundary condition**, Radar wind and reflectivity Groundsonde full level, Hot start_**Strong** diabatic



Hurricane Intensity is dependent on initialization conditions: Strong diabatic, radar and sonde data assimilation shows improvement

NOAA/ESRL/GSD/FAB

HURRICANE DENNIS04L(2005-07-05-2130) TRACK



OBSERVATION

GFSA-GFSA-HRPS MODEL

About tracker for the verification

	NCEP	HRS
	Tracker	Diapost
700 & 850 hPa	Relative vorticity (max), wind magnitude (min), and geopotential hegith (min)	
Sea level	MSLP (min)	MSLP (minval) over 20 x 40 box domain
		Point at minimum slp
→ Storm Center		
Surface level	Wind (max)	Wind Speed (maxval) over nested whole domain
→ Maximum wind speed near the storm center		

DENNIS(2005-07-06)

Minimum Central Pressure (hPa)

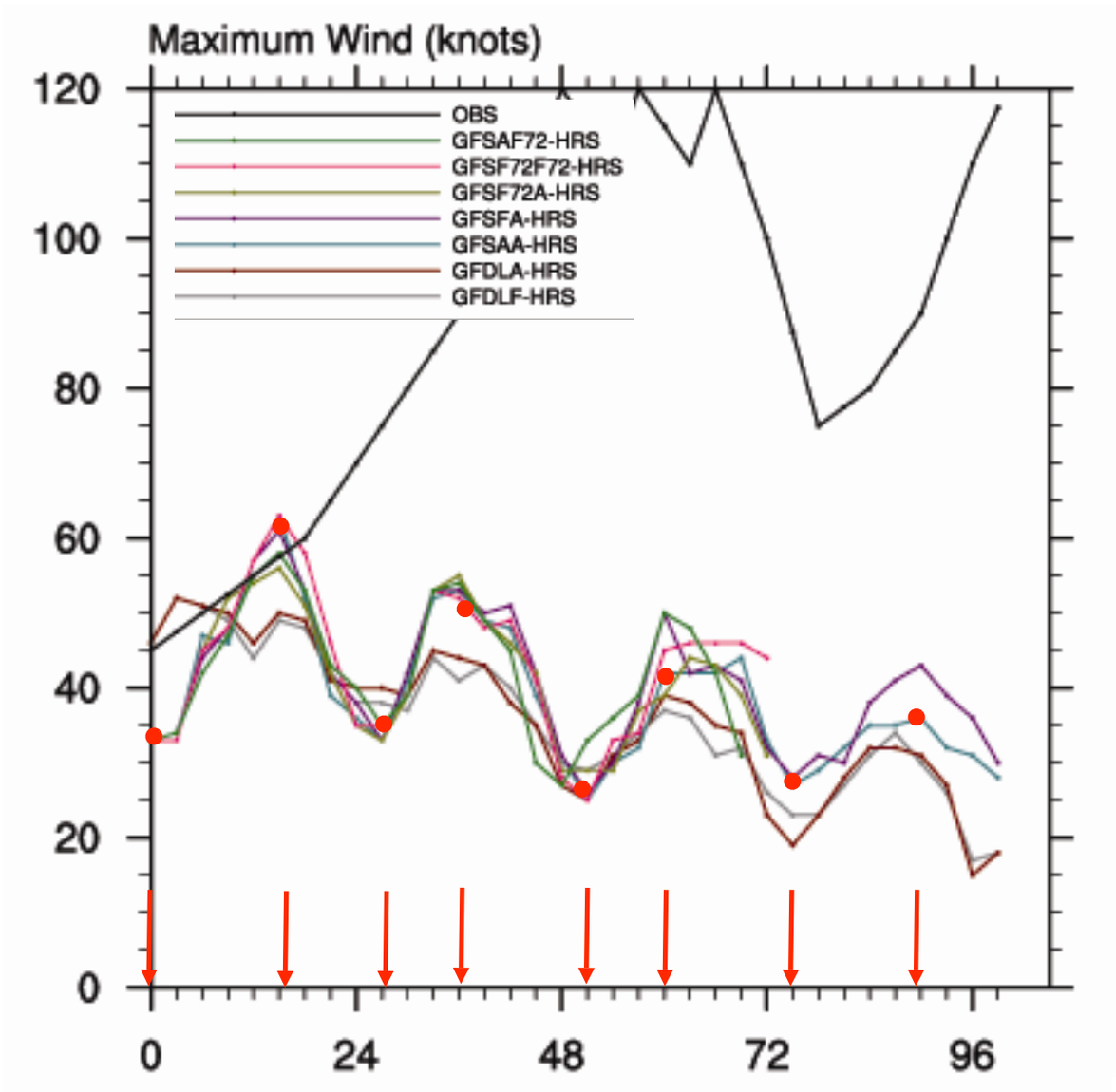
Maximum Wind (knots)

NCEP

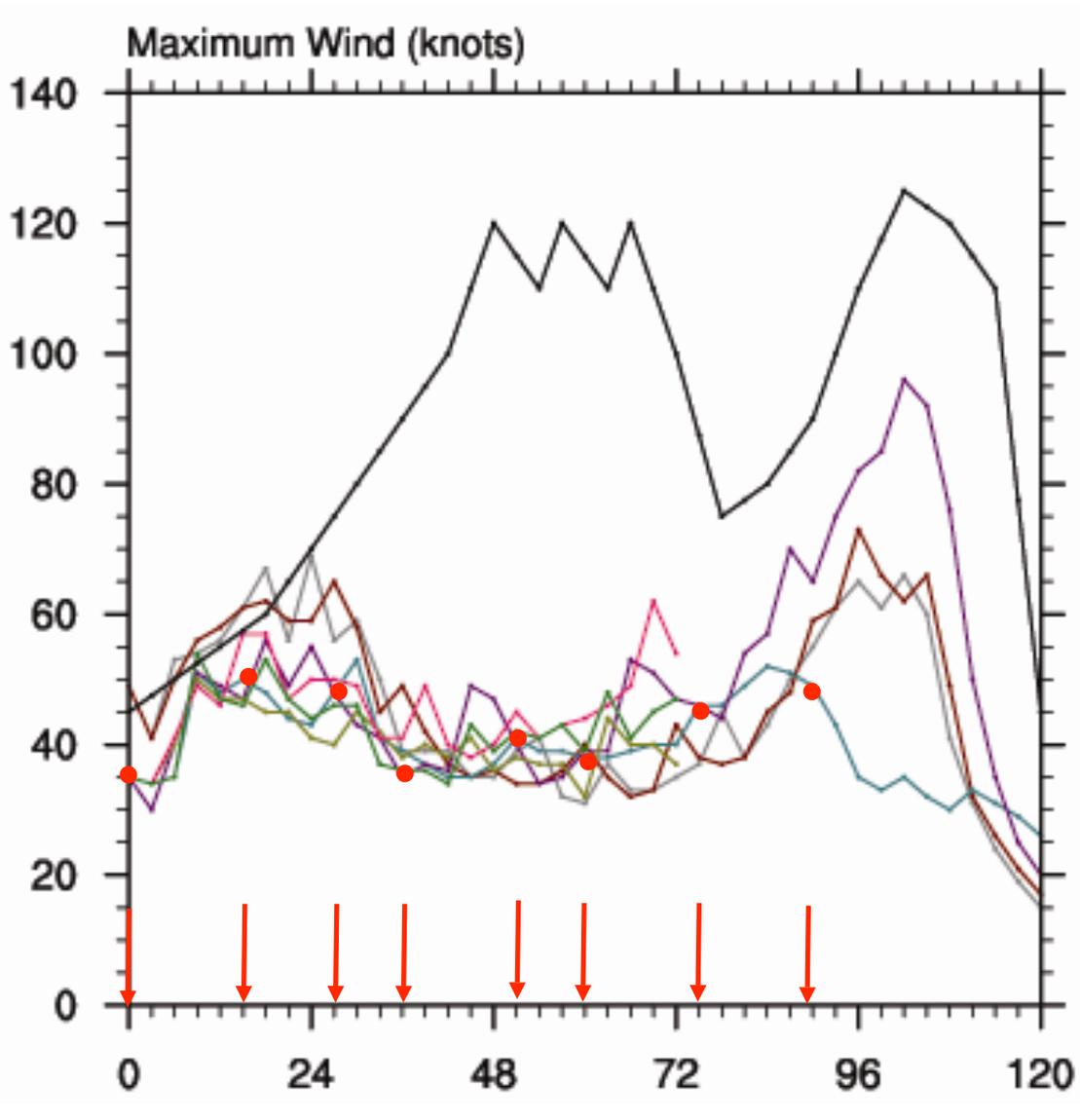
HRS

OBS
GFSAF72-HRS
GFSF72F72-HRS
GFSF72A-HRS
GFSFA-HRS
GFSAA-HRS
GFDLA-HRS
GFDLF-HRS

	0	15	27	36	51	60	75	90
Gettrk- Vmax	33	63	33	53	25	42	27	36
Diapost-Vmax	35	50	48	39	41	38	46	49



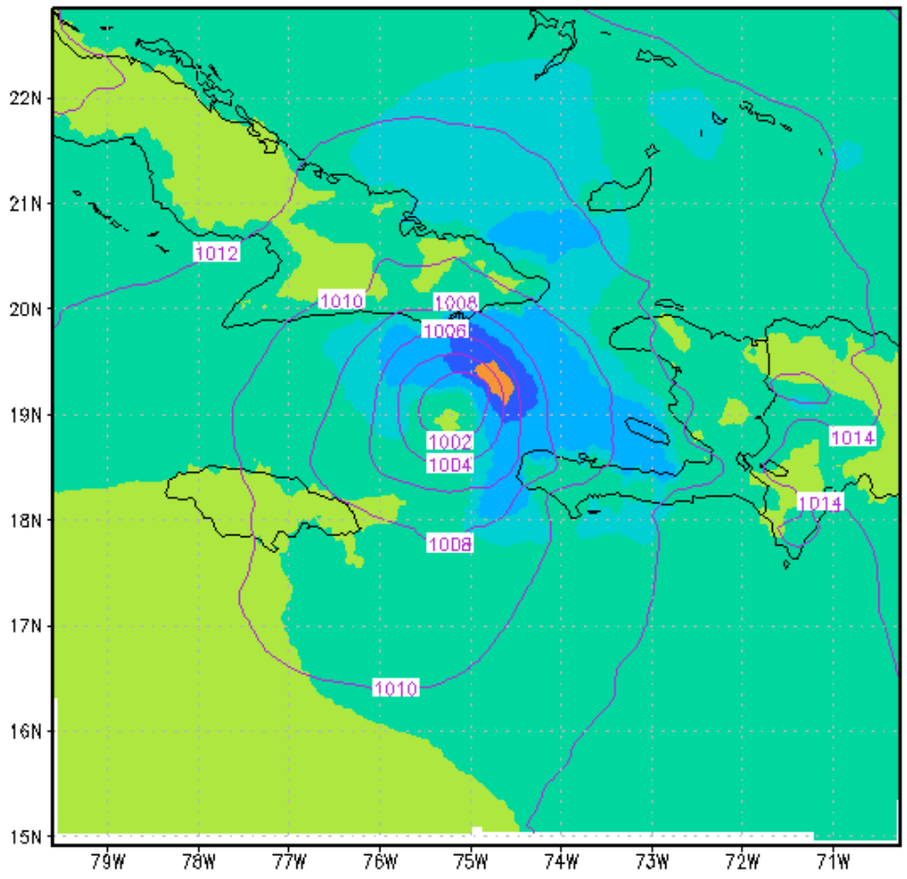
Tracker of NCEP



Tracker in HRPS

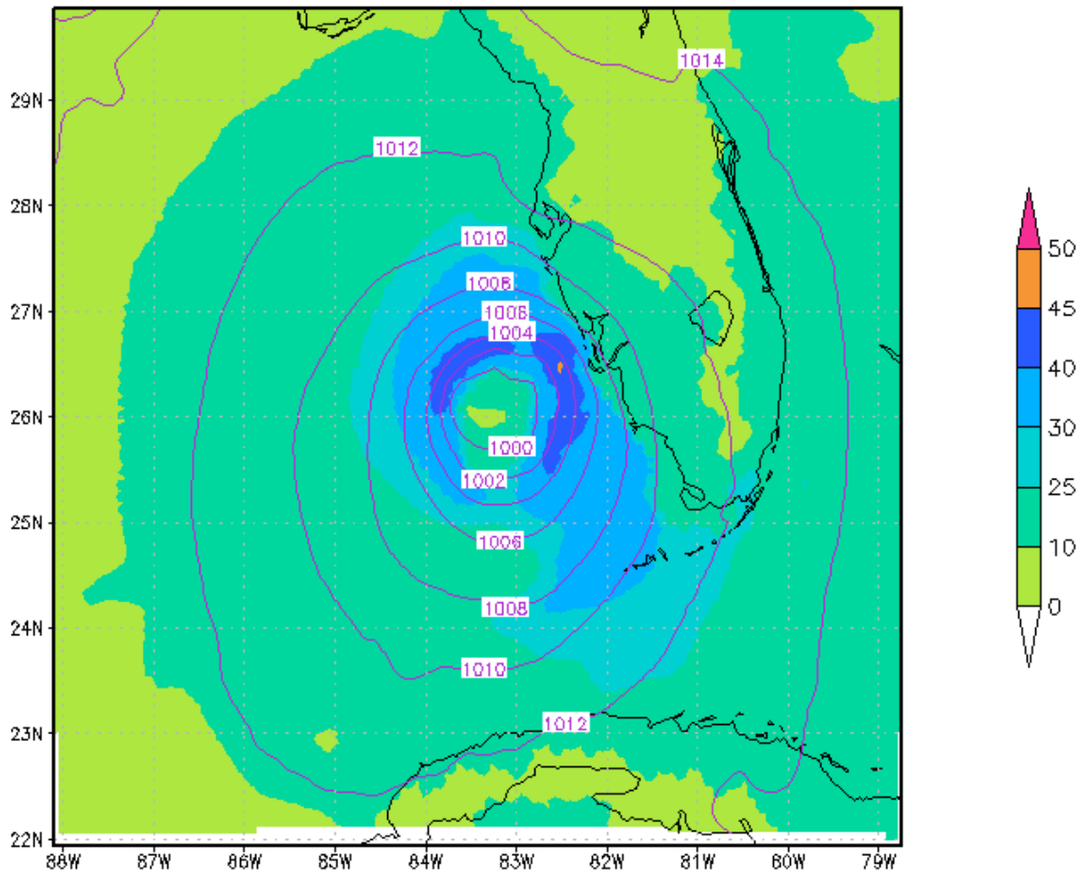
	0	15	27	36	51	60	75	90
Gettrk- Vmax	33	63	33	53	25	42	27	36
Diapost- Vmax	35	50	48	39	41	38	46	49

Surface wind speed at 10m (shaded-knots) & MSLP



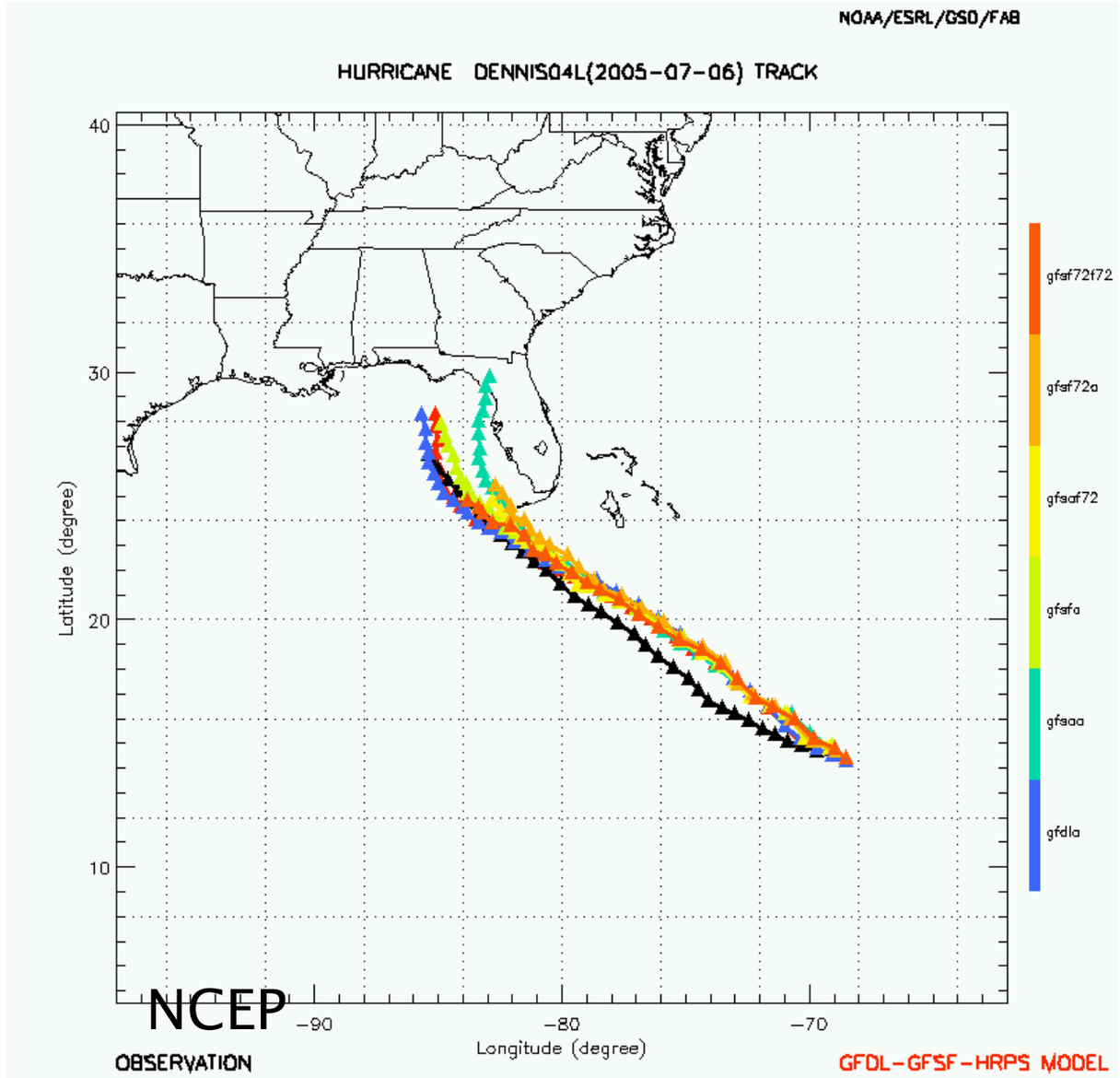
GrADS: COLA/IGES

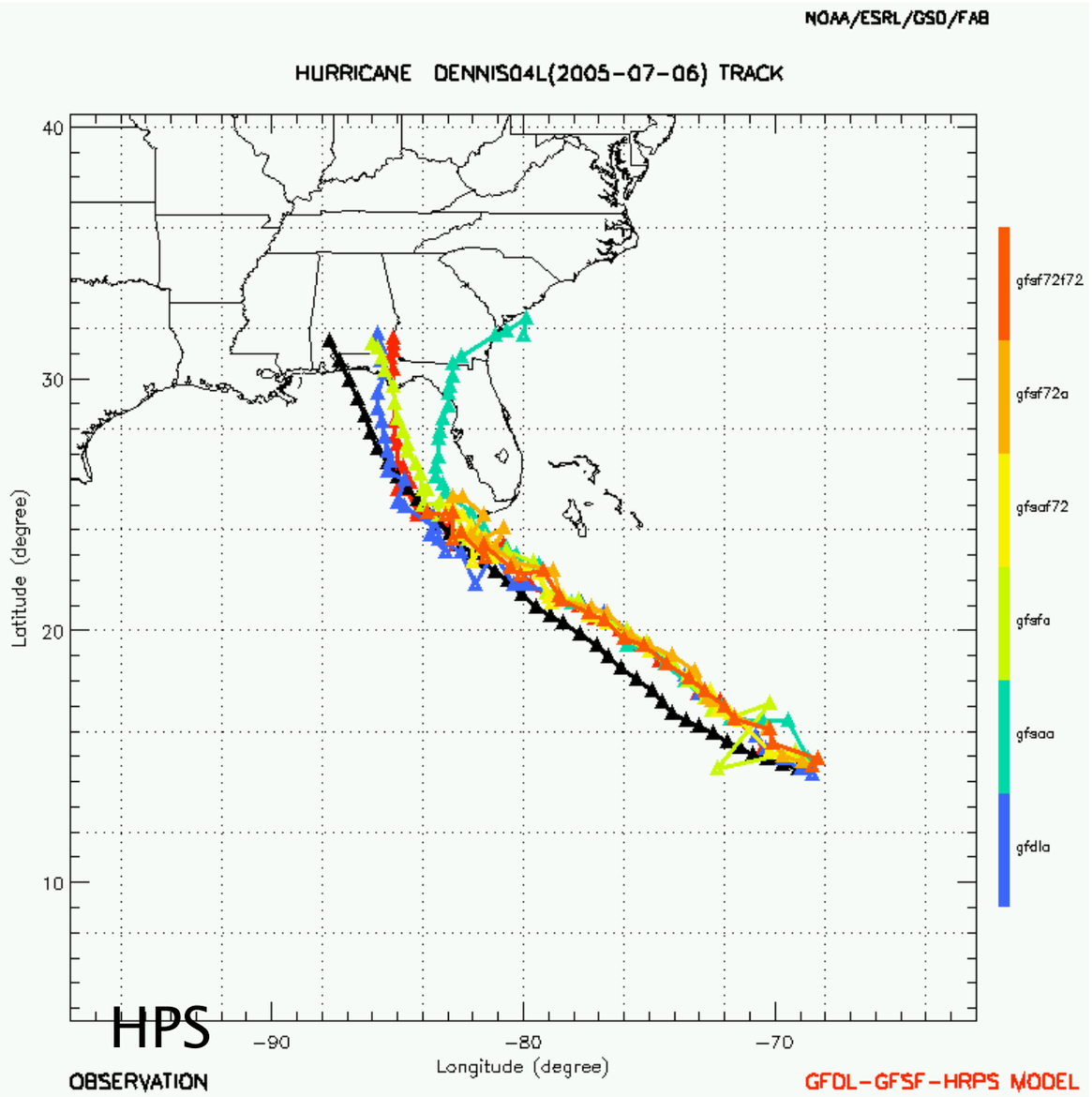
Surface wind speed at 10m (shaded-knots) & MSLP (hPa)



GrADS: COLA/IGES

2008-10-10-16:07





→ Track forecast : NCEP tracker > HRS tracker
Intensity forecast : HRS tracker > NCEP tracker

→ It means in the track forecasts it might be important on consideration deep environment (ex, vertical weighted NCEP tracker),
in the wind forecasts is might be reasonable to consider maximum wind valued within criteria in hurricane in the Dennis case study.

→ All of points should be considered various HURRICANE cases at least 40-50 cases…..