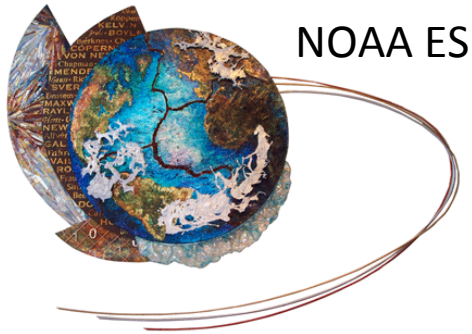


New ensemble-based products for tropical cyclones

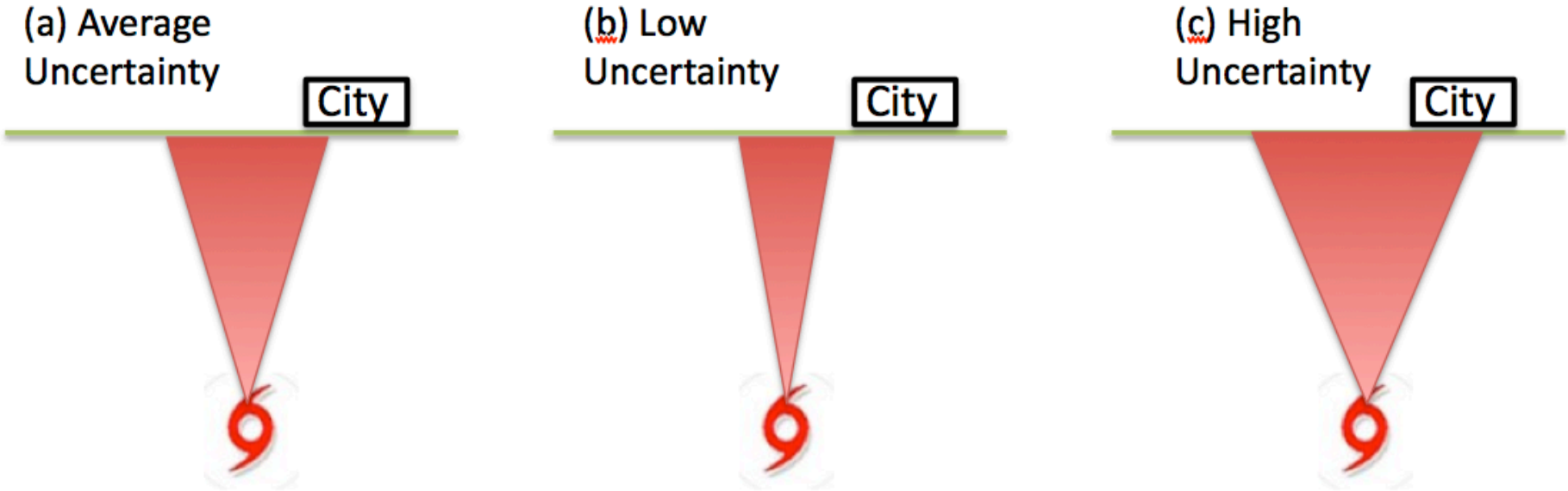
Tom Hamill

NOAA / ESRL, Physical Sciences Division

also: Ed Rappaport (NHC), Mark DeMaria (NESDIS), Zoltan Toth (ESRL), Barb Brown (RAL), Bob Gall (NWS/OST)

presentation at 91st Annual AMS, Seattle, WA in 24th WAF / 20th NWP, 24 January 2011

Why uncertainty products?



Paraphrasing Vice President Joe Biden:

*"Barack, if you lived in this city, then knowing the uncertainty would be a big *&^%ing deal."*

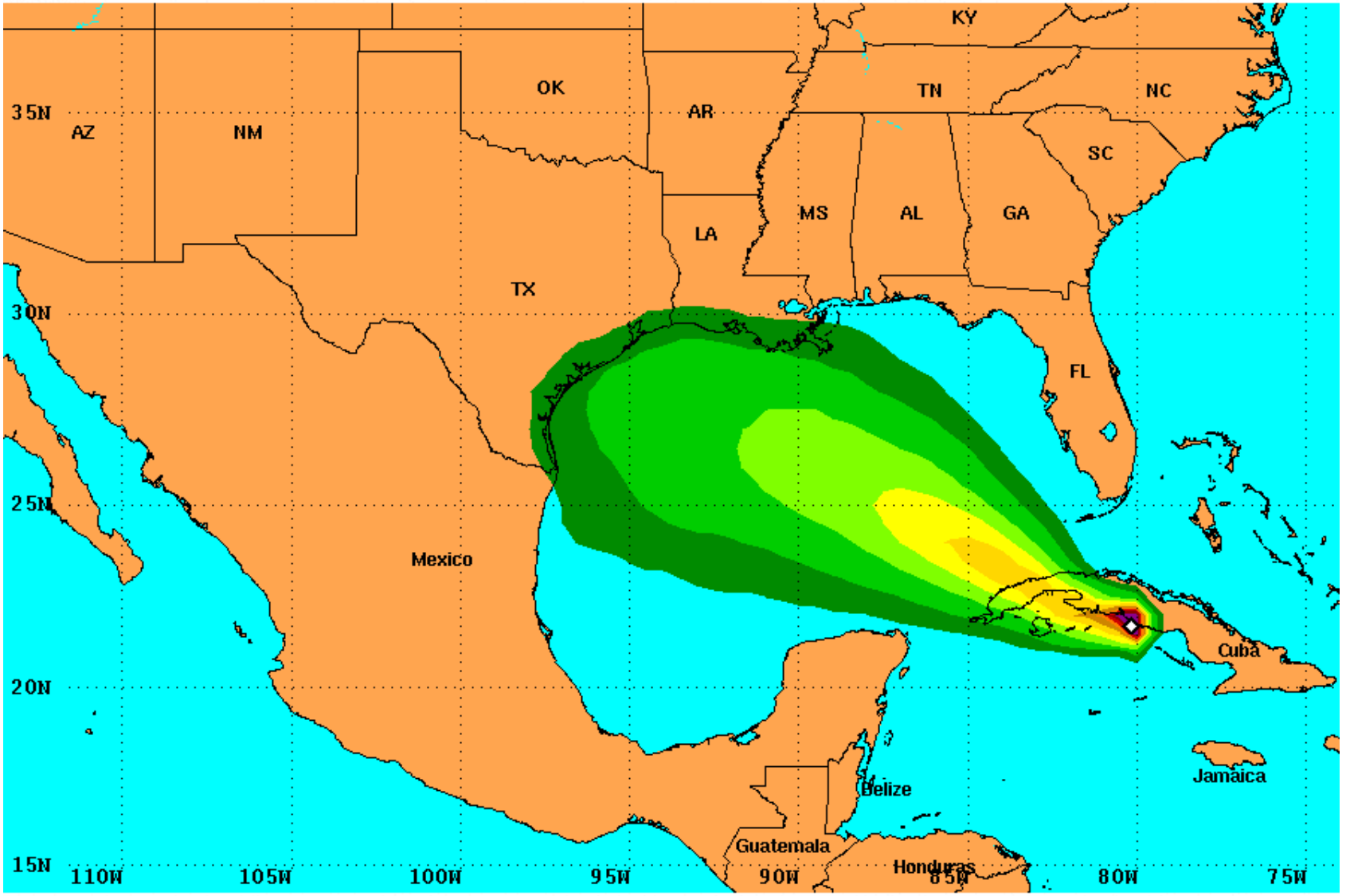
There **are** existing NHC uncertainty products, but they are primarily based on average statistics of past forecast errors

Intensity (Maximum Wind Speed) Probability Table
Hurricane Ike Advisory Number 31
5:00 PM EDT Sep 8 2008

Wind Range (mph)	Forecast Time						
	12 hour for 2 AM Tue	24 hour for 2 PM Tue	36 hour for 2 AM Wed	48 hour for 2 PM Wed	72 hour for 2 PM Thu	96 hour for 2 PM Fri	120 hour for 2 PM Sat
Dissipated	<1%	<1%	1%	1%	2%	11%	18%
Tropical Depression (<39)	1%	<1%	3%	2%	2%	9%	10%
Tropical Storm (39-73)	22%	15%	32%	19%	16%	17%	26%
Hurricane (all categories)	76%	84%	65%	79%	79%	63%	46%
-- Category 1 (74-95)	59%	59%	46%	40%	28%	19%	19%
-- Category 2 (96-110)	14%	19%	14%	23%	22%	16%	11%
-- Category 3 (111-130)	2%	5%	4%	13%	21%	18%	10%
-- Category 4 (131-155)	<1%	1%	1%	3%	7%	8%	5%
-- Category 5 (>155)	<1%	<1%	<1%	1%	1%	1%	1%
Forecast Maximum Wind	90 mph	90 mph	85 mph	100 mph	110 mph	115 mph	110 mph

Hurricane Force Wind Speed Probabilities

For the 120 hours (5 days) from 8 PM EDT Mon Sep 8 to 8 PM EDT Sat Sep 13

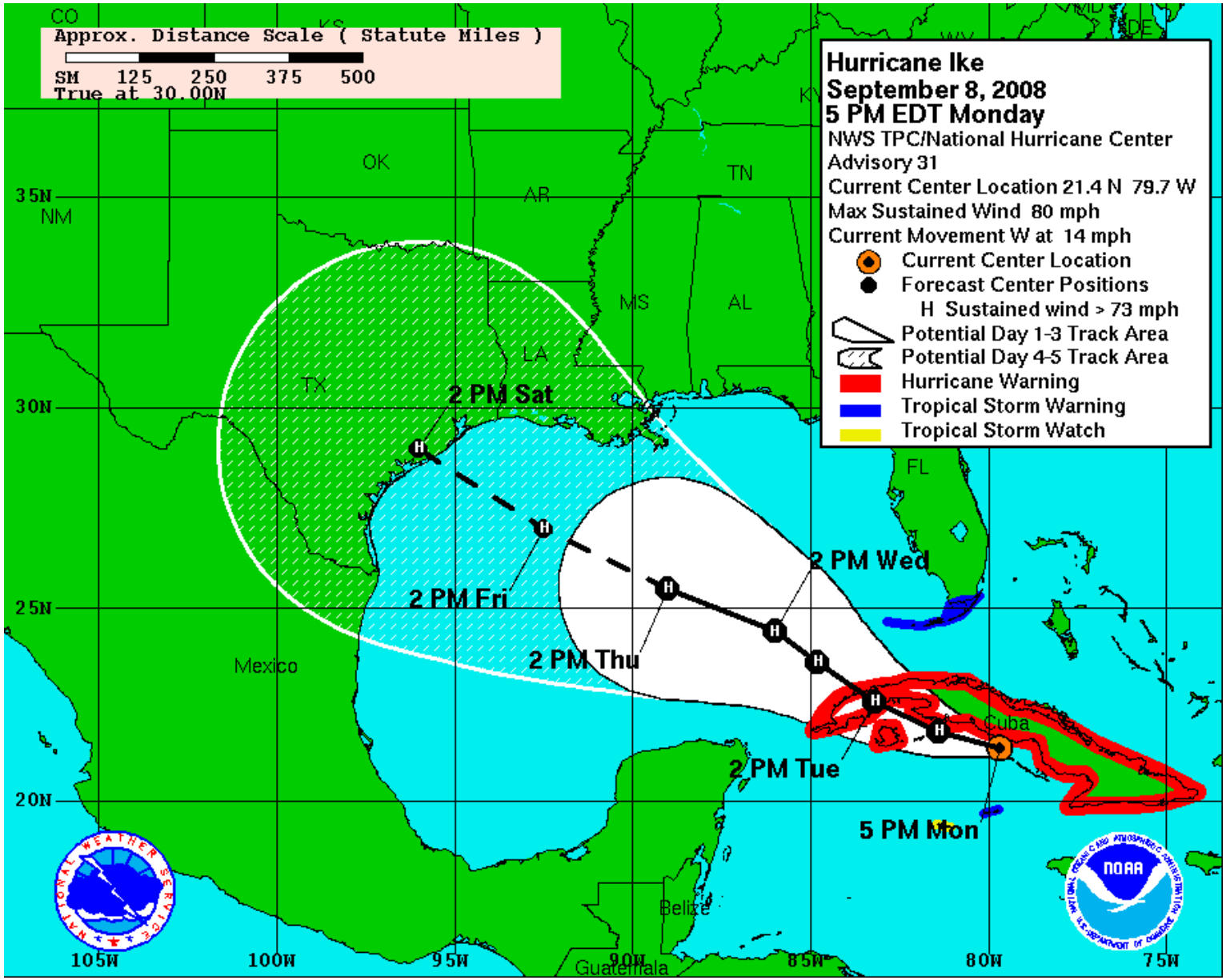


Probability of hurricane force surface winds (1-minute average >= 74 mph) from all tropical cyclones

◇ indicates HURRICANE IKE center location at 8 PM EDT Mon Sep 8 2008 (Forecast/Advisory #32)

5% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%

“Cone of uncertainty”

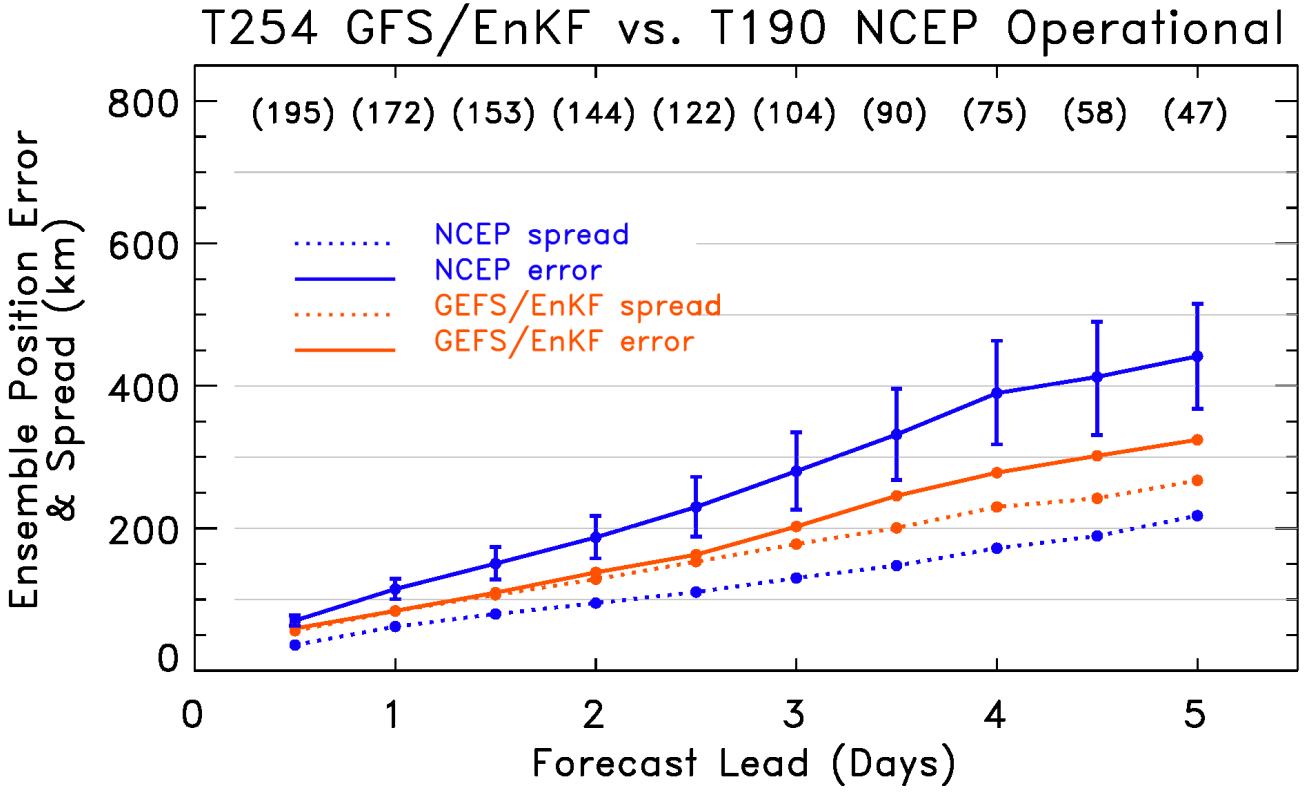


Are we ready for ensemble-based products?

- Ensembles still exhibit systematic errors
  - Global models under-forecast hurricane intensity
  - Ensemble spreads often too small – direct use may result in overconfidence in forecasts.
- Still…
  - There are methods such as statistical post-processing to ameliorate the errors.
  - Forecasters, media, emergency users want the products, even if imperfect.
  - It makes sense to start planning for a future with ensemble-based products.

And we are getting better.

As models and ensemble techniques improve, ensemble predictions will increasingly be used to improve hurricane forecasts.



Example: improvement to track forecasts from experimental EnKF-based GFS ensemble relative to operational NCEP ensemble.

Still, there are not that many tropical cyclone forecast products that leverage the uncertainty estimates produced by ensembles.

NCAR Research Applications Laboratory | RAL

You are here: NCAR • RAL • JNT • *TCMT - HFIP Ensemble Product Development Workshop*

HFIP-THORPEX Ensemble Product Development Workshop

About | **Schedule and Presentations** | **Logistics** | **Register**

Date

20 - 21 April 2010 (Two full days)

Location

National Center for Atmospheric Research (NCAR)
Foothills Lab Campus
Seminar Room 1001
3450 Mitchell Lane
Boulder, Colorado 80301

Co-hosted by the NOAA Hurricane Forecast Improvement Project (HFIP), NOAA THORPEX, and the NCAR Tropical Cyclone Modeling Testbed (TCMT)

Purpose

This workshop will bring together forecasters and ensemble system developers to: (1) review progress in ensemble prediction related to tropical cyclones (TCs) and the scientific issues in ensemble system development; (2a) discuss new methods for displaying ensemble information that will aid forecasters; and (2b) discuss what new uncertainty-based end products are a priority to develop. This workshop will produce recommendations for a 5-year agenda for related HFIP research and development in this area.

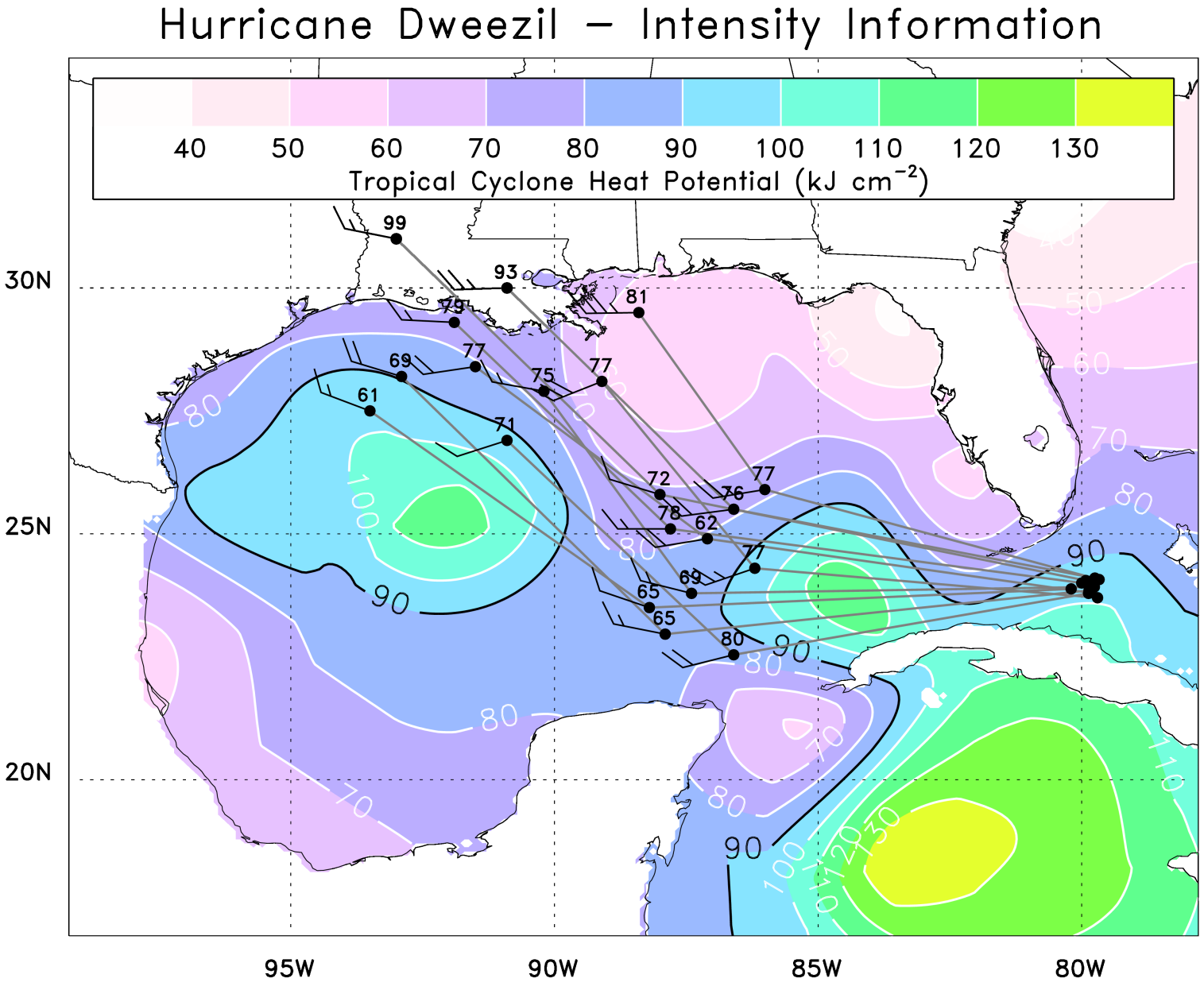
The remainder of the presentation will summarize recommendations from this workshop.

Recommendations for products oriented toward forecasters

- Intensity and intensity change
- Cyclogenesis
- Structure
- Track
- Associated phenomena (storm surge, winds, rainfall, tornadoes).
- Locations for supplemental adaptive observations.

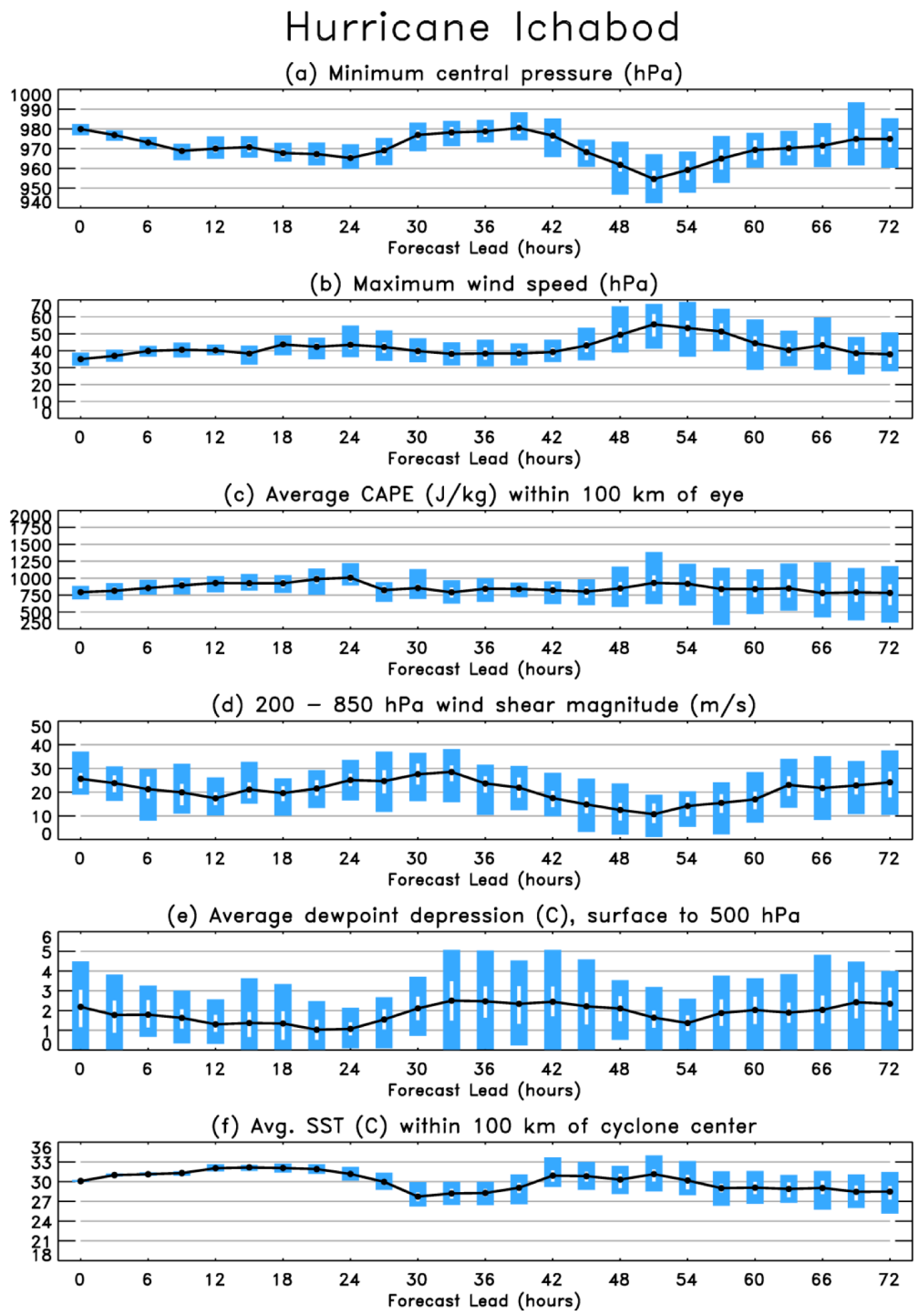
Non forecasters may be interested in the same products, but given early stage with these products, may be wise to put “experimental” disclaimer statement if made widely available.

Augment track products with intensity-related information



Analyzed ocean tropical cyclone heat potential (TCHP), forecast central pressure (mb-900) and vertical wind shear are shown.

Permits visualization of co-variations, e.g., central pressure's relation to TCHP, shear.



Time series of variables that may be related to intensity, displaying mean, 20th & 80th percentiles (white lines) and min/max from ensemble (blue).

In this case, the min in central pressure at 51 h appears to be related to a decrease in vertical shear.

Incorporate ensemble information into LGEM (Logistic Growth Eqn. Model)

$$\frac{dV}{dt} = \kappa V - \beta V \left(\frac{V}{V_{mpi}} \right)^n$$

$$\kappa = a_1 \bullet S + a_2 \bullet C + a_3 \bullet SC + b$$

V = forecast velocity

V_{mpi} = maximum potential intensity (a function of SST at forecast position)

S = 850-200 shear (normalized)

C = 0-15 km average vertical velocity from plume model using SST, temperatures and humidity in a 200 to 800 km ring around storm.

Red are parameters of the model, fit using reanalysis data, an adjoint algorithm, and steepest descent algorithm.

Ref: DeMaria, *MWR*, January 2009

LGEM intensity "forecast" (fit with dependent reanalysis data and observed track info)

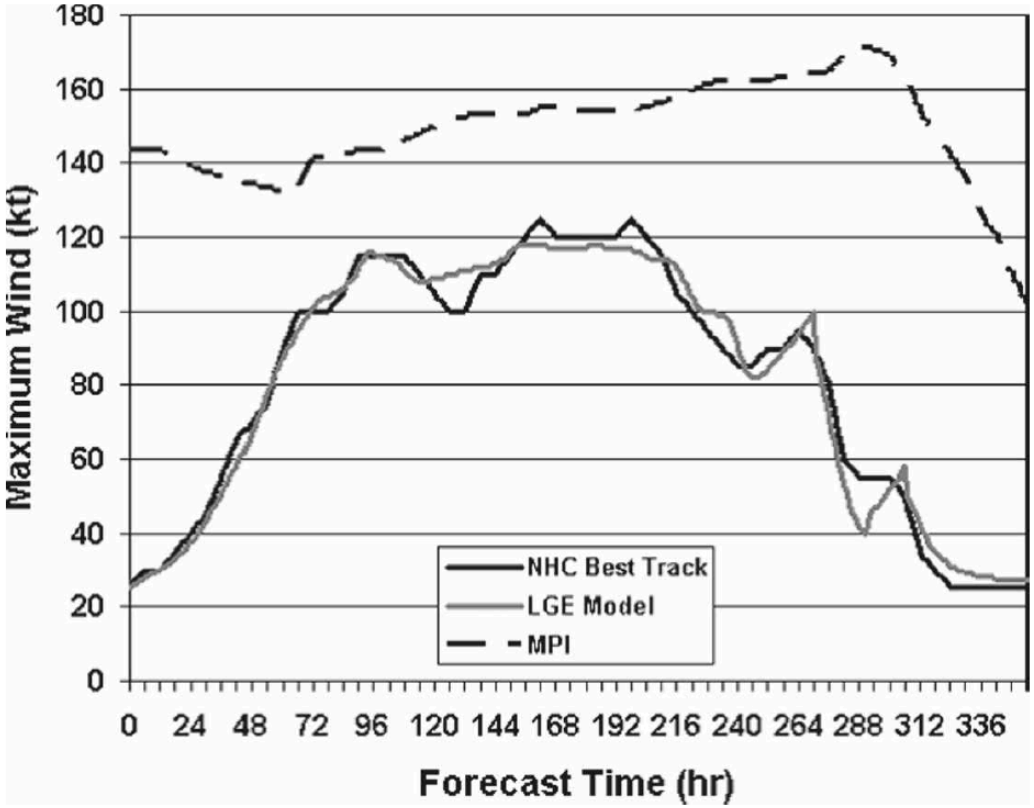


FIG. 6. The 14.75-day LGEM forecast of the intensity of Hurricane Frances (2004) and the corresponding NHC best-track intensity. The MPI estimated from the SST is also shown.

When trained after the fact on environmental analysis data from Frances, the reconstructed intensity is very accurate.

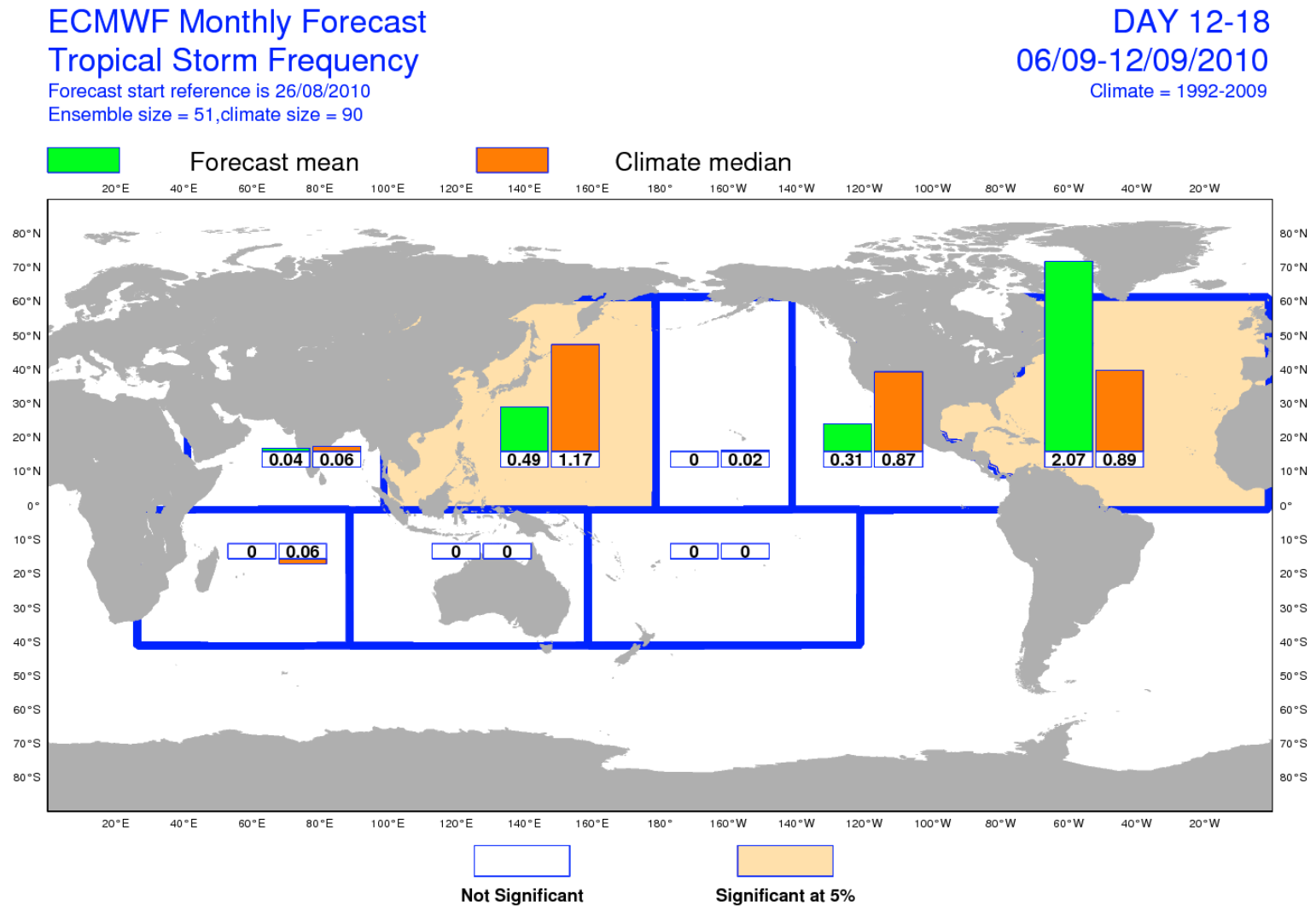
(But of course less accurate when trained on data across many storms and feeding real-time forecast information, with its biases).

Ref: ibid

Possible ensemble improvements to LGEM

- Provide ensemble of tracks and environmental forecasts to LGEM, resulting in ensemble of intensity forecasts.
- If large data set of past forecasts (reforecasts) are available from same model run operationally:
  - Statistically adjust forecasts for systematic errors (in position, in thermodynamic profiles, etc.)
  - Possibly train LGEM on forecast data as opposed to analysis data (i.e., MOS instead of perfect-prog).

Tropical cyclogenesis

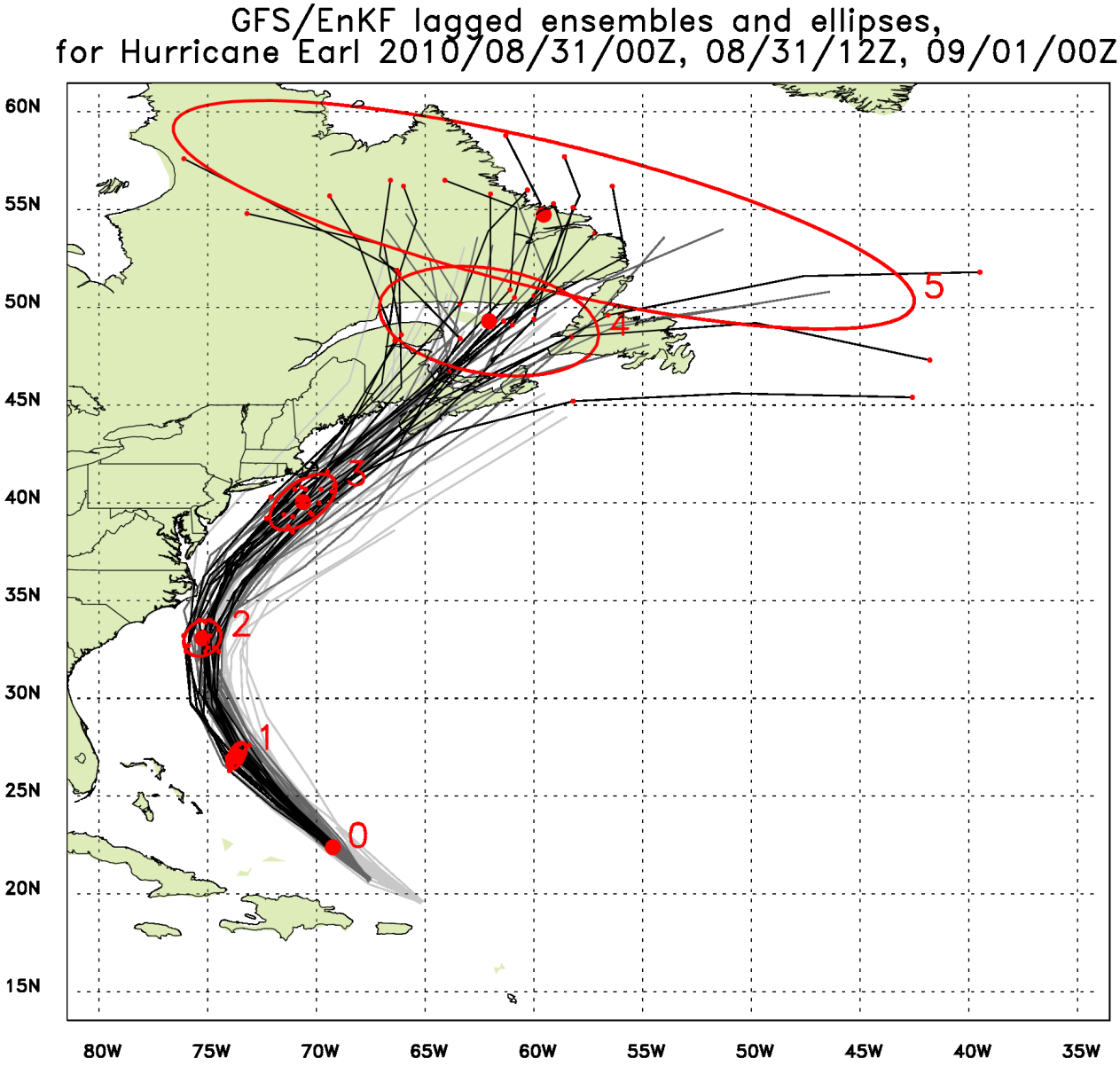


Uses TCgenesis from reforecasts to provide some calibration for possible biases.

Ref: D. Richardson, personal communication, ECMWF.

Other recommendations for new ensemble products for cyclogenesis, storm structure, storm surge, winds, rainfall, tornadoes in slides after conclusions.

Track products



Innovations here:

(1) Cone of uncertainty estimated directly from ensemble (contains 90% of probability).

(2) Lagged forecast track data shown in lighter grey colors, provides sense of trends in track.

Recommendations for/from media, emergency managers, end users.

- Keep it simple! Perhaps red/yellow/green confidence levels on deterministic forecasts.
- Desire some products similar to but simpler than those for forecasters.
- Associated explanatory web pages to accompany new graphics.
- Train product recipients, possibly by COMET.

Conclusions

- Several possible new ensemble-based graphics shown here.
- We welcome your input concerning other possible new graphics that will be useful to the community.
- BAMS draft article at **tinyurl.com/4t6onm4**

Other cyclogenesis recs.

- Include tracker output of model-generated storms and genesis probabilities estimated from the ensemble in geographical areas, especially at the 48-hour and 120-hour lead times.
- Examine whether a statistical model of genesis (Schumacher et al. 2009) incorporating ensemble genesis information might provide skillful guidance.

Storm structure products

- Ensemble averages of the radius of the outermost closed isobar (OCI), which provides one possible measure of overall storm size.
- Ensemble-mean predictions of 34, 50, and 64-kt (15.4, 25.7, and 32.9 ms^{-1}) wind radii in different quadrants, where the ensemble of storms is relocated to a common position.
- Probability distributions of the OCI and wind radii might also be useful.

Targeted observations

- Ensemble-based techniques may be useful for determining the most useful locations for supplemental observations.
- Typically, an ensemble-based targeting algorithm considers how much the forecast uncertainty (usually measured in this case as some function of the ensemble spread, i.e., the standard deviation about the mean) would be reduced as a result of the reduction in analysis-error variance in an ensemble due to the assimilation of extra data.
- Techniques are promising but are limited in their utility by the lack of calibration of the ensemble and the assumption of linear error growth (Majumdar et al. 2006; Reynolds et al. 2010).

Storm surge, winds, rainfall, tornadoes

- Storm surge probabilities might be generated by driving surge models like SLOSH (Sea, Lake, and Overland Surges from Hurricanes; Houston et al. 1999) with ensemble guidance.
- Post-processed ensemble guidance may provide improved estimates of precipitation from land-falling TCs.
- Statistical models may also make it possible to estimate tornado likelihood based on the environmental characteristics.
- Additional probabilistic forecasts could be generated for winds above critical thresholds such as tropical-storm or hurricane-strength and could provide information on the timing (onset, duration).