STORM SURGE ENSEMBLE MODELING USING A SUITE OF HURRICANE WIND MODELS

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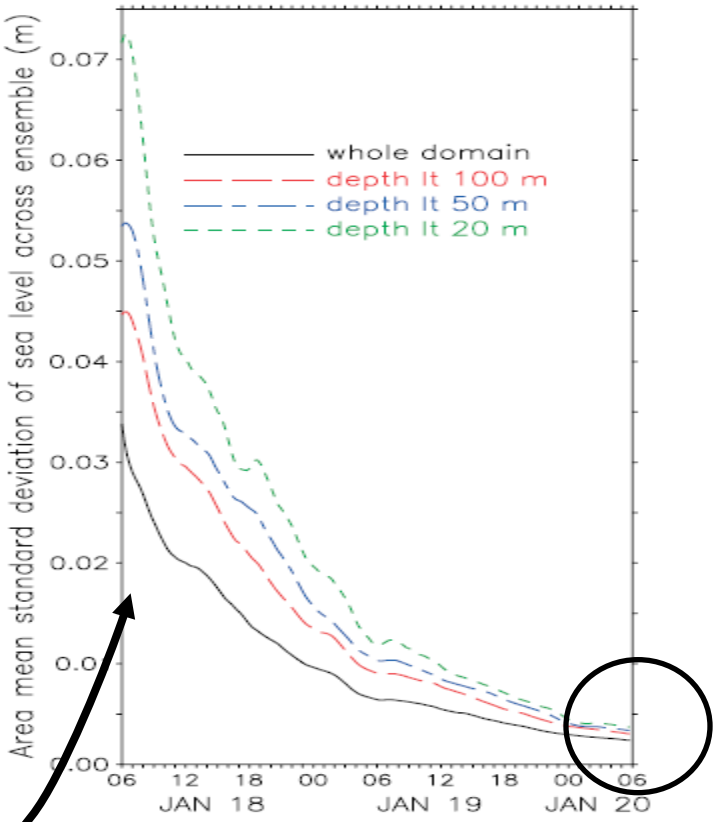
Outline of the talk

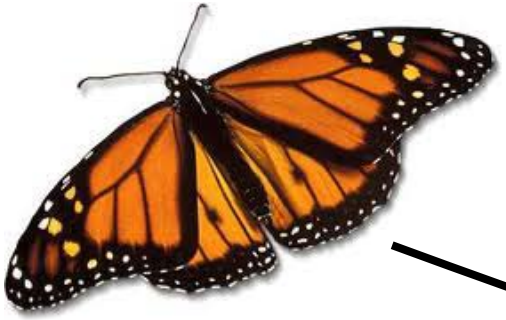
- Value of ensemble modeling
  - Wind forcing from hurricane models
- Importance of accurate Rmax in surge prediction
- Evaluation of ensemble predictions

Why do ensemble modeling?

- Uncertainty in initial conditions
- Model uncertainty: dynamics
- Model uncertainty: physics
- Uncertainty in forcing
- Probability forecasts can help address these uncertainties

Effect of Initial Conditions can be ignored compared with wind forcing (Flowerdew 2010)

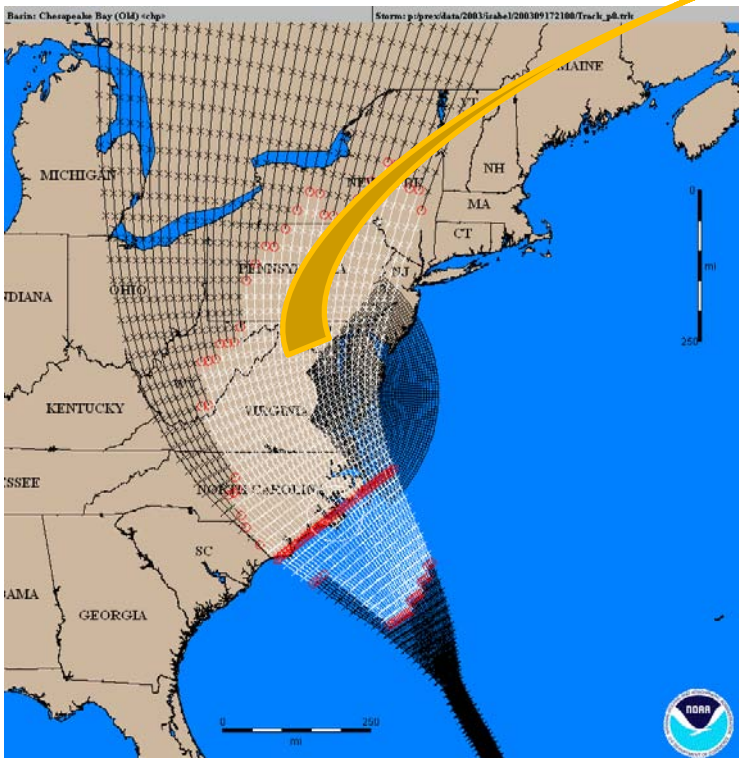


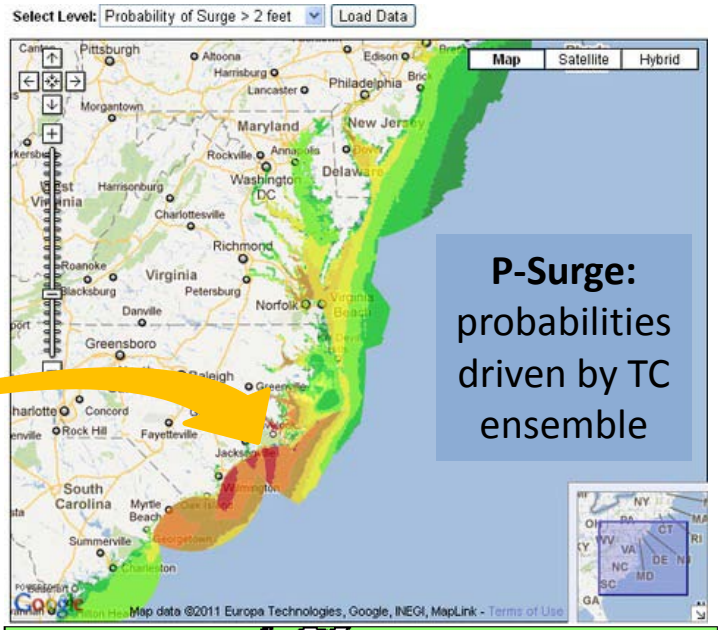


Uncertainty in initial conditions…

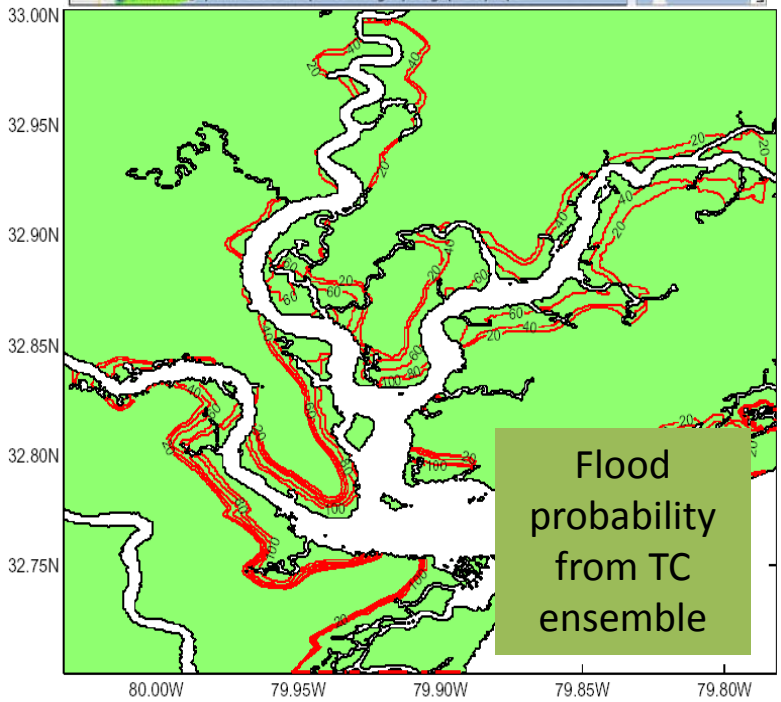
fades over time when predicting water level

Wind forcing is the major uncertainty source for TC track and intensity forecast and the resulting storm surge and inundation prediction





P-Surge: probabilities driven by TC ensemble



Flood probability from TC ensemble

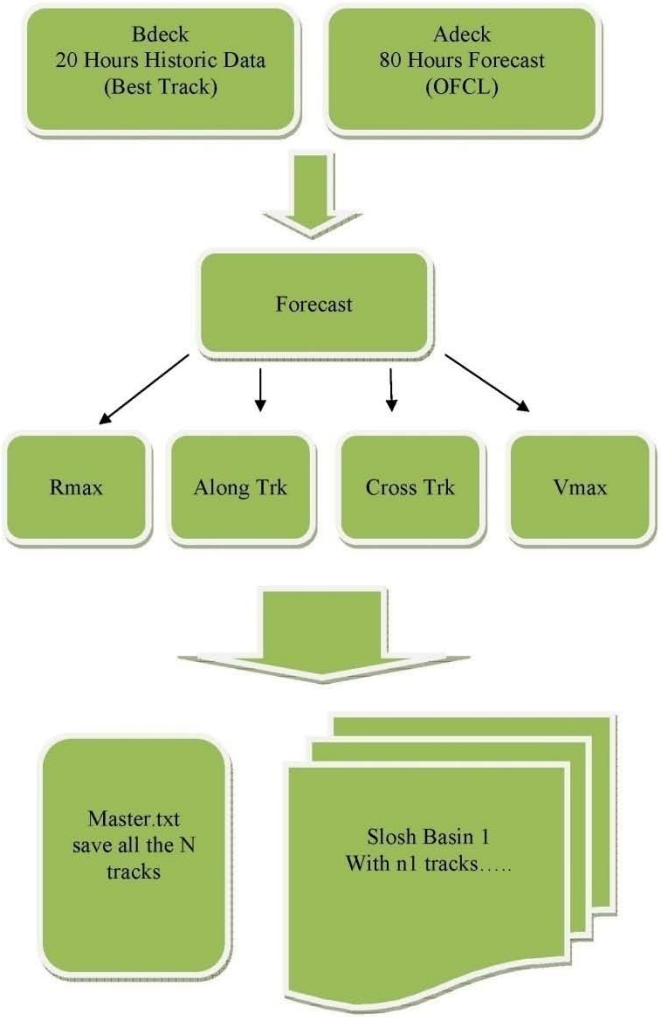
Initial testing of ensemble methods

- Possible ensemble members
  - Wind forcing can be based on parametric or dynamic models
  - Surge models can be 2-D or 3-D, structured or unstructured, …
- As a first step we employ SLOSH surge model
  - Contains parametric wind model driven by track, R_{max} and central pressure
  - Efficient 2D finite difference
  - Used in P-Surge to determine probabilities

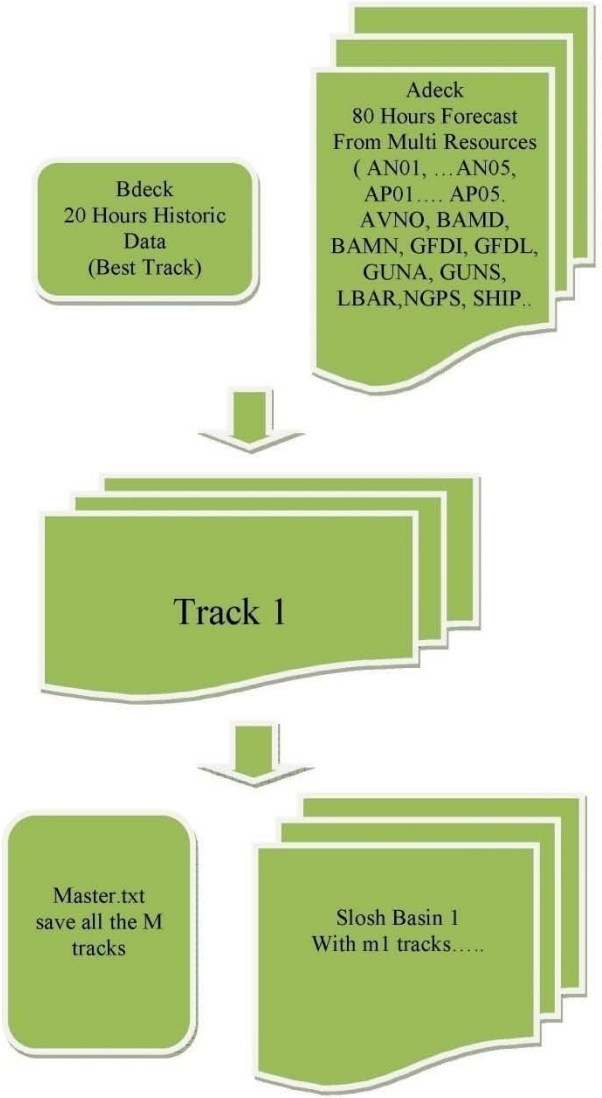
- NHC track and intensity predictions in set of 2 files
  - *Bdeck* track data based upon recent observations
  - *Adeck* contains 70+ predictions based upon models and forecasts

OFCL (Official NHC forecast)
Geophysical Fluid Dynamics Lab (GFDL)
HWRF (Hurricane WRF)
Global Forecast System (GFS)
U.K. Met Office (UKMET)
Navy Operational Global Atmospheric Prediction System (NOGAPS)
European Center for Medium Range Weather Forecasting (ECMWF)
…

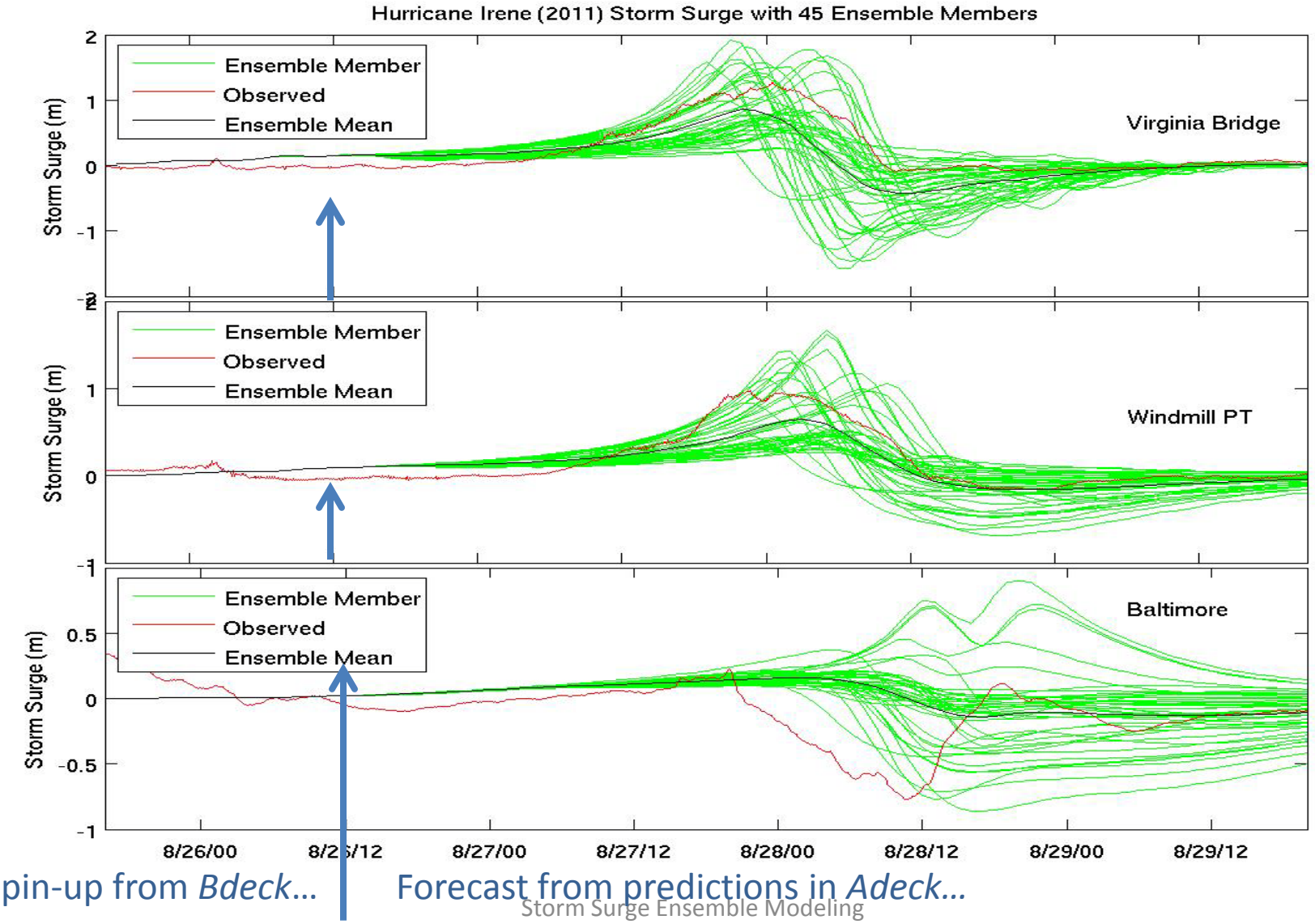
P-Surge Set-up based on Official Forecast Track



Ensemble Set-up using Multiple Track Predictions



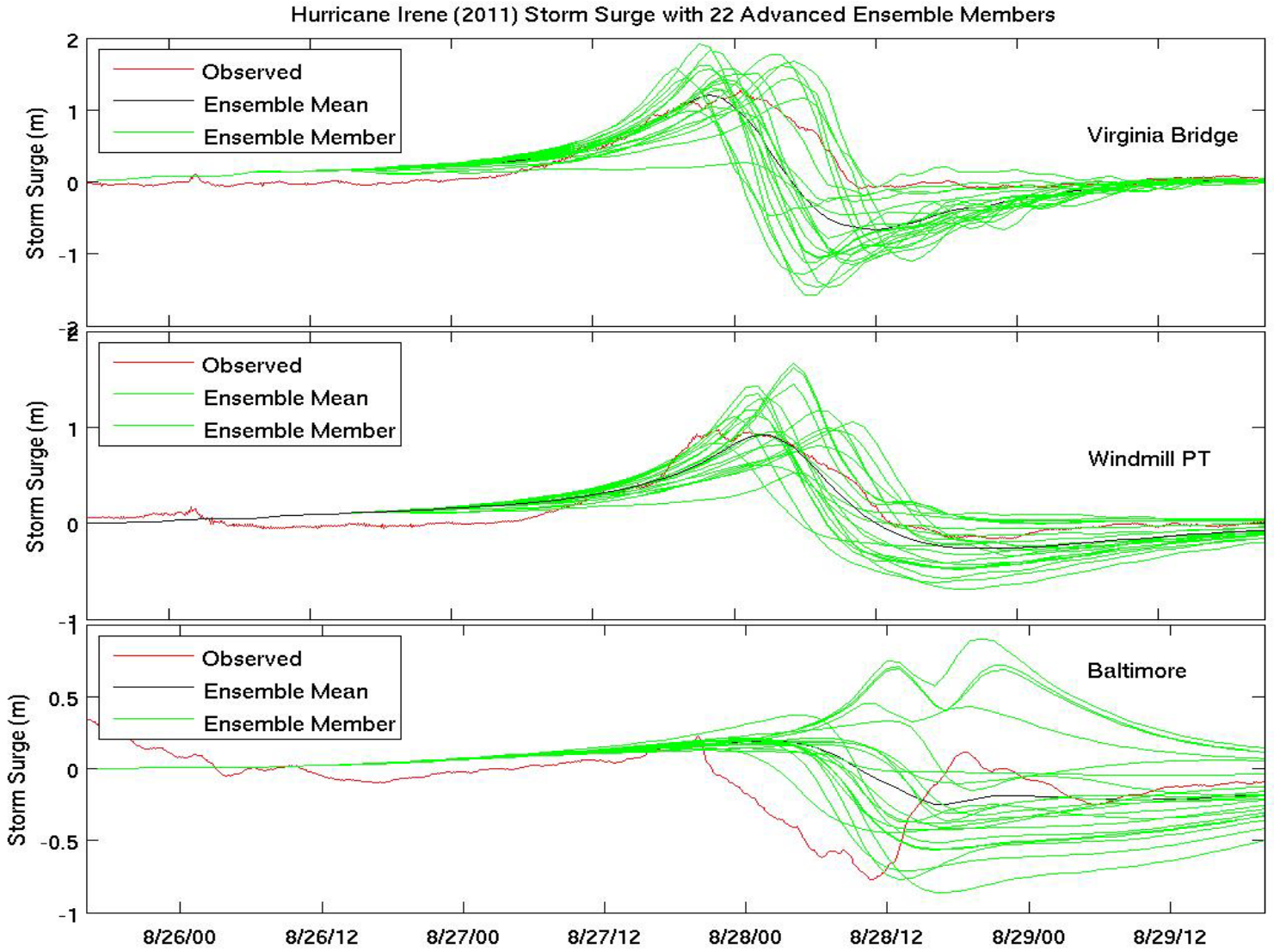
Hurricane Irene (2011) storm surge with 45 *Adeck* ensemble members for Chesapeake Bay



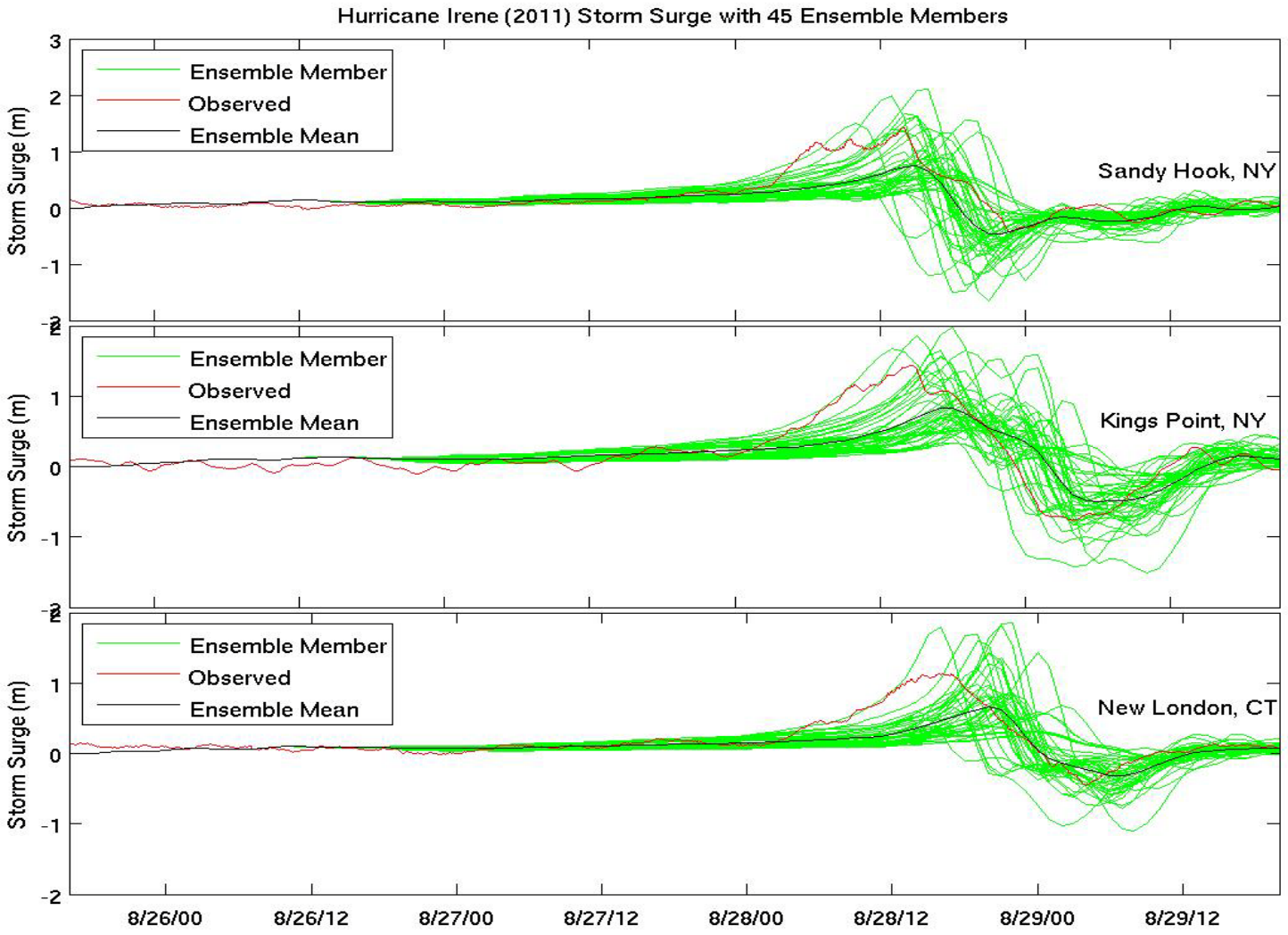
Spin-up from *Bdeck*…

Forecast from predictions in *Adeck*…

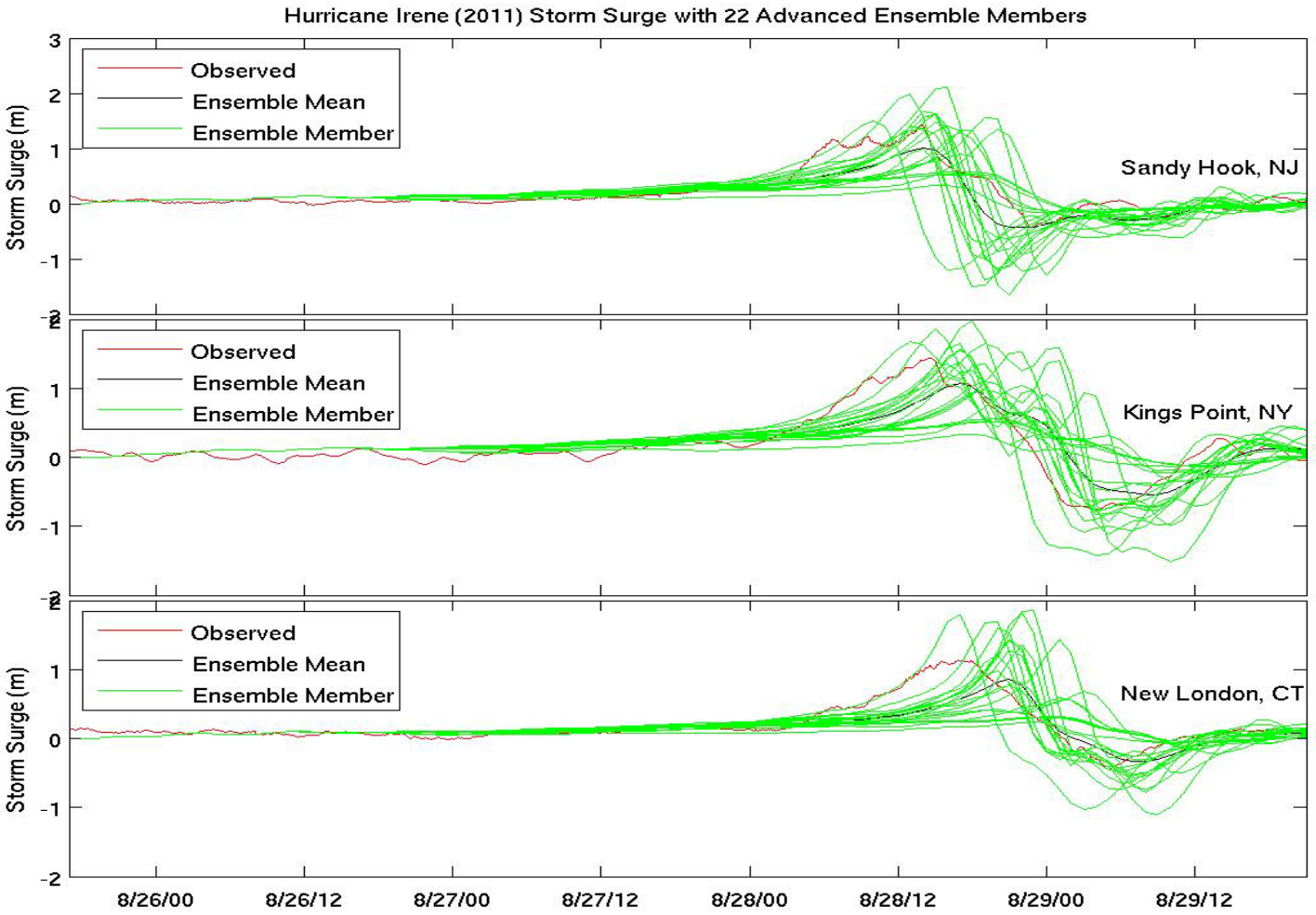
Hurricane Irene (2011) storm surge with 22 historically accurate *Adeck* ensemble members for Chesapeake Bay



Hurricane Irene (2011) storm surge with 45 *Adeck* ensemble members for Northeast



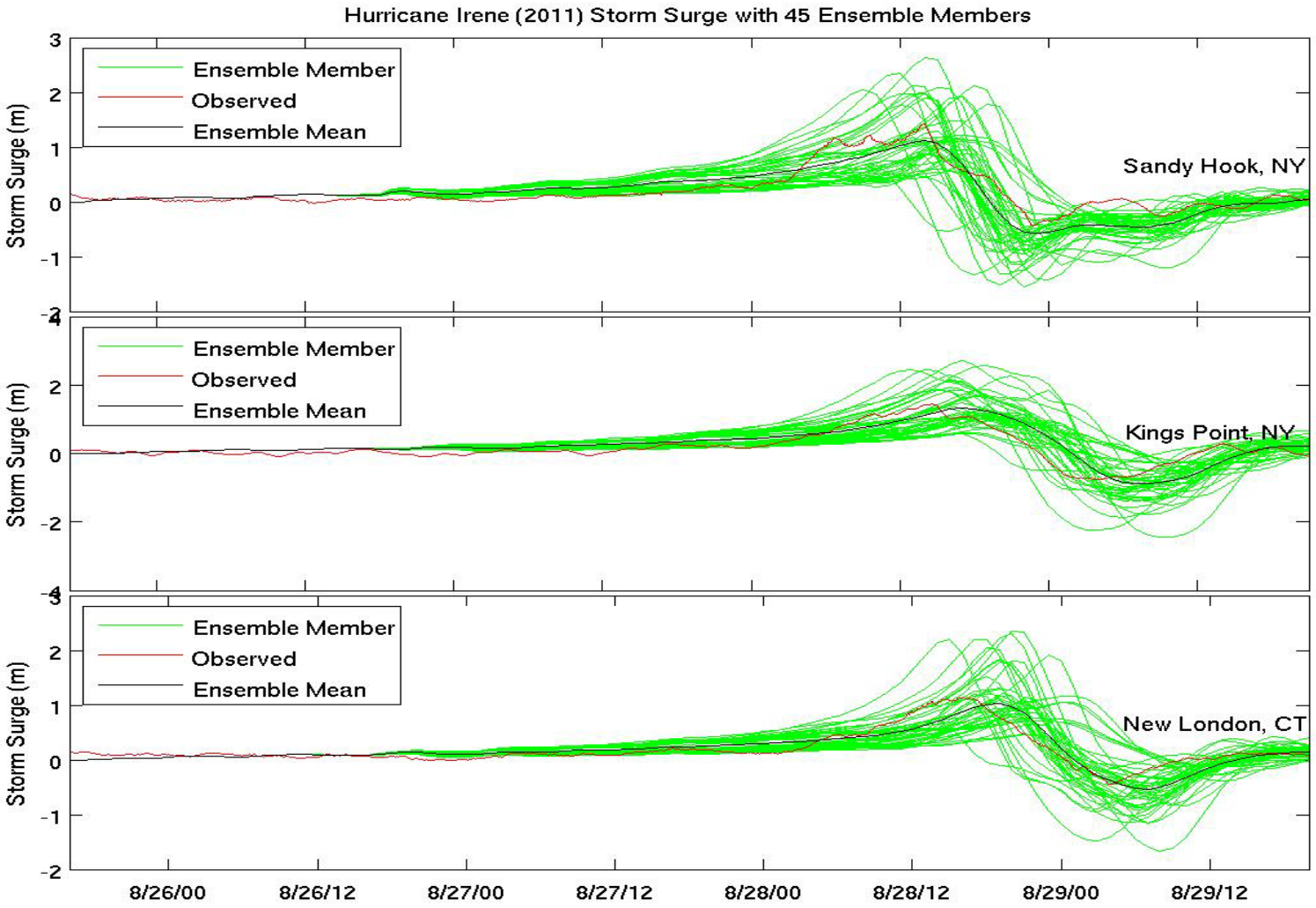
Hurricane Irene (2011) storm surge with 22 historically accurate *Adeck* ensemble members for Northeast



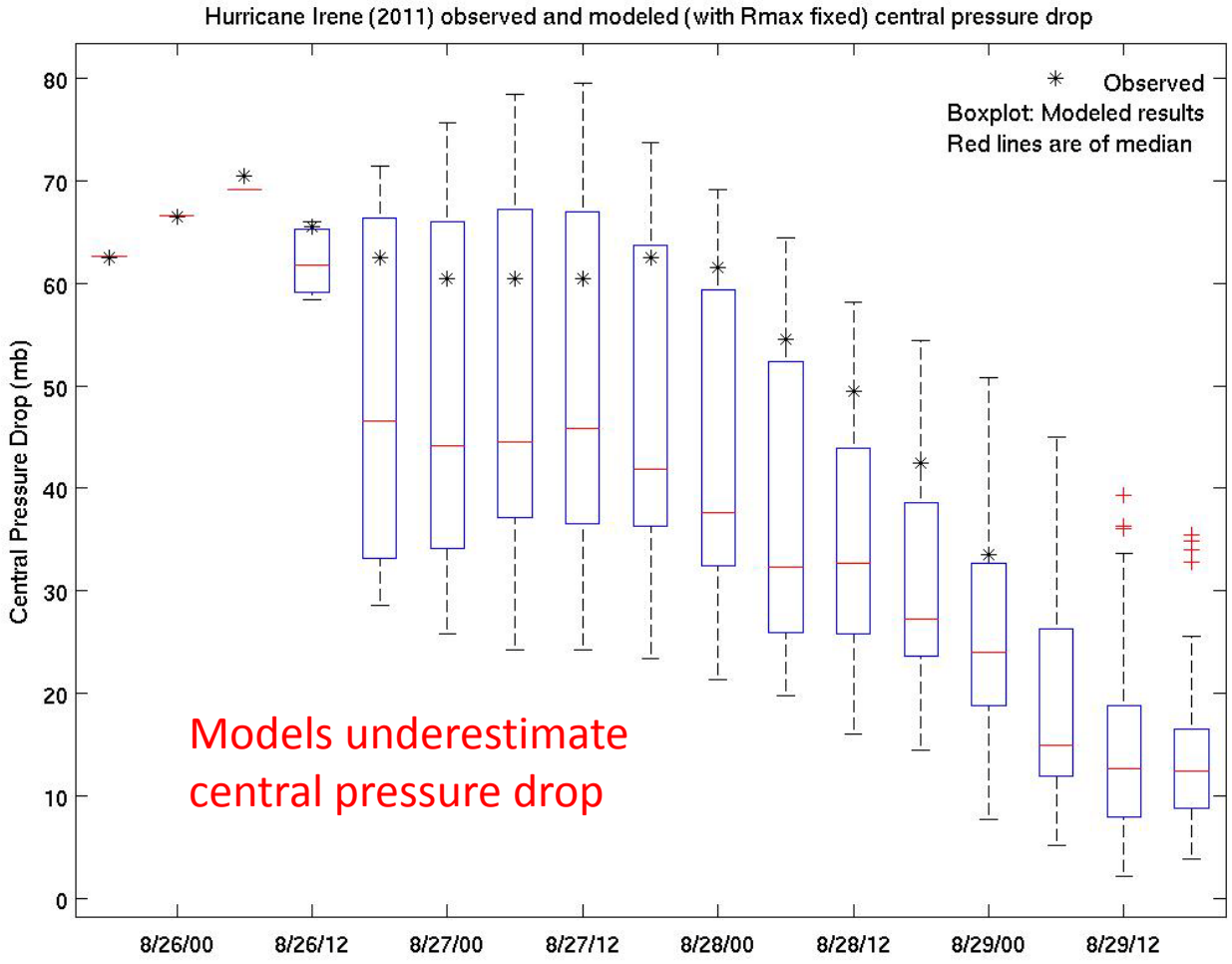
Size of storm not predicted

- R_{max} is not predicted in either *Adeck* or *Bdeck* files but is an important factor in determining wind forcing and storm surge
- Use SLOSH parametric hurricane model equation to calculate R_{max} based on maximum wind and central pressure predictions
- Can be determined from *Bdeck* then keep as a constant for whole forecast time
- Can be updated at each time step from *Adeck*

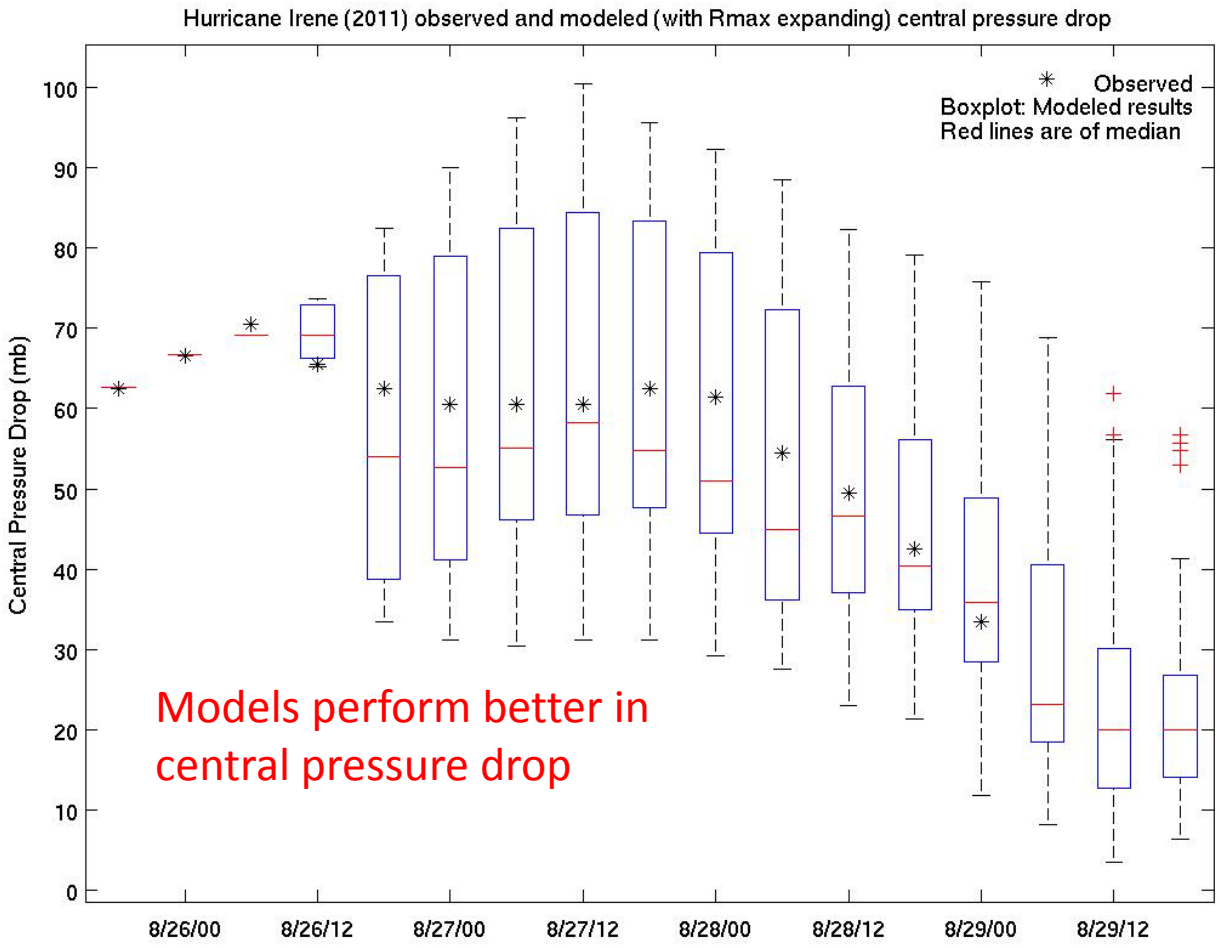
Hurricane Irene (2011) surge hindcast with 45 ensemble members by using observed R_{max}



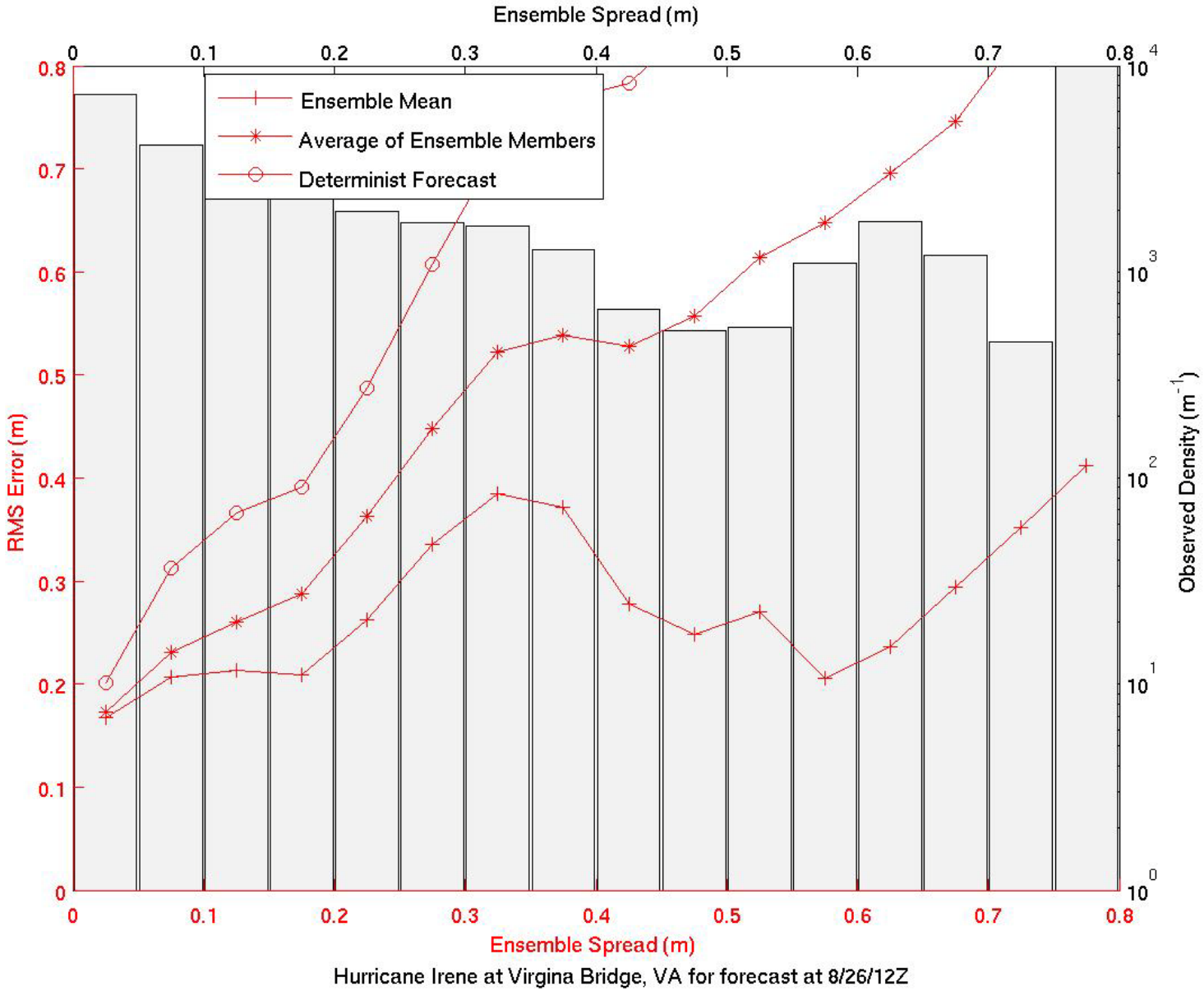
Modeled central pressure drop from *Adeck* tracks' maximum winds, assuming constant R_{max}



Modeled central pressure drop from *Adeck* tracks' maximum winds, by using observed R_{max}



Storm Surge Prediction Error as a Function of Ensemble Spread



Evaluating skill of a ensemble prediction

- **Ranked Probability Score (RPS)**

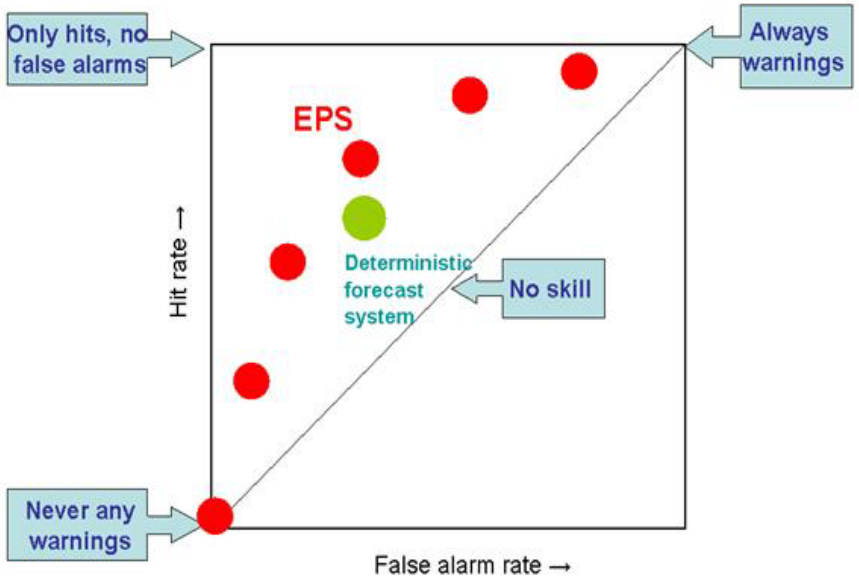
Let K be the number of forecast categories to be considered. For a given probabilistic forecast–observation pair, the ranked probability score is defined as

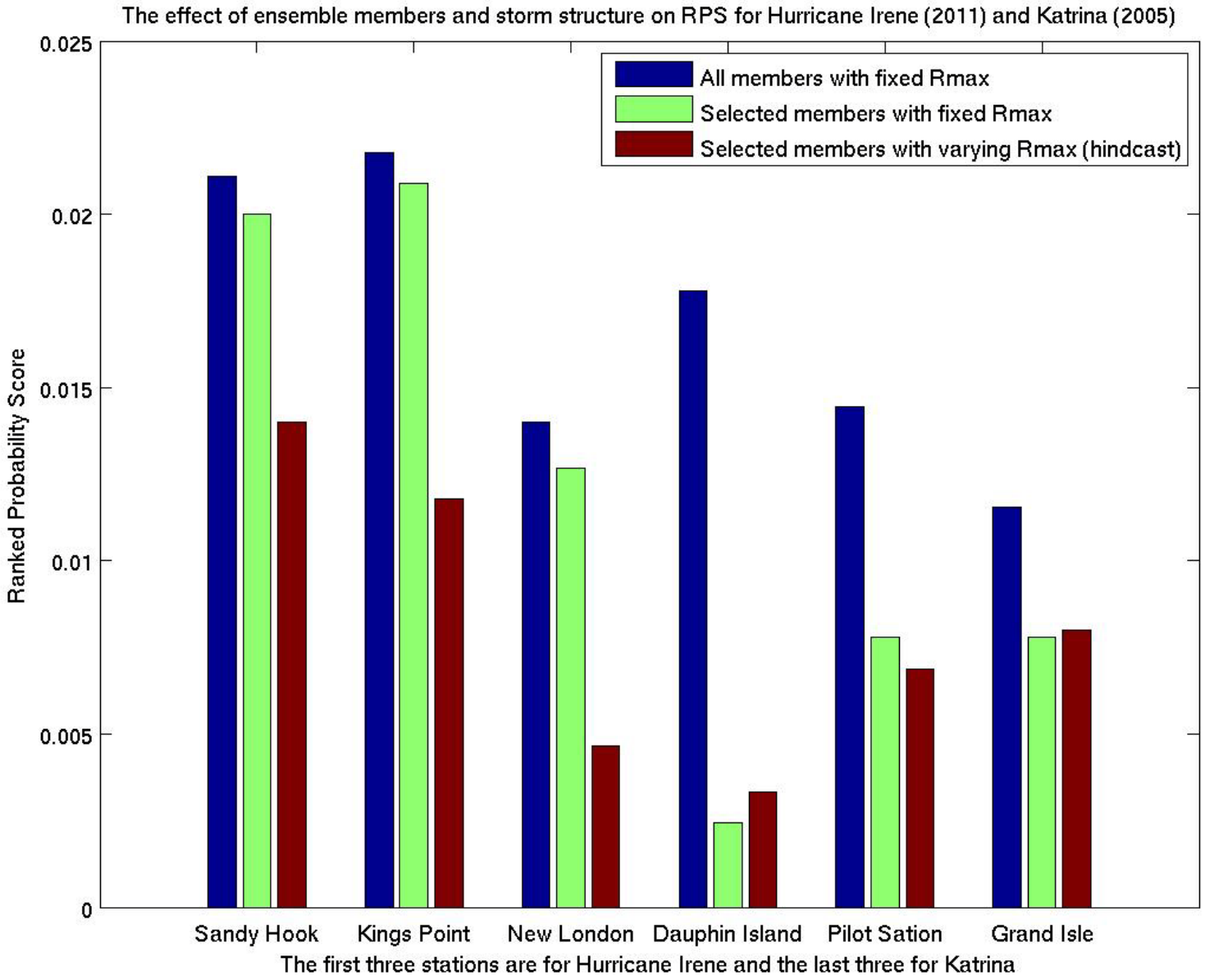
$$\mathrm{RPS} = \sum_{k=1}^{K} (Y_k - O_k)^2 = (\mathbf{Y} - \mathbf{O})^2. \qquad (1)$$

Here, Y_k and O_k denote the kth component of the cumulative forecast and observation vectors $\mathbf{Y}$ and $\mathbf{O}$, respectively. That is, $Y_k = \Sigma_{i=1}^{k} y_i$, with y_i being the probabilistic forecast for the event to happen in category i, and $O_k = \Sigma_{i=1}^{k} o_i$ with $o_i = 1$ if the observation is in category i and $o_i = 0$ if the observation falls into a category $j \neq i$. Note that the RPS is zero for a perfect forecast and positive otherwise.

- smaller value is more accurate

- **Relative Operating Characteristics (ROC)**
- Calculates ensemble members' ability to match ("hit") observation versus overpredicting




The effect of ensemble members and storm structure on RPS for Hurricane Irene (2011) and Katrina (2005)
All members with fixed Rmax
Selected members with fixed Rmax
Selected members with varying Rmax (hindcast)
Ranked Probability Score
0.025
0.02
0.015
0.01
0.005
0
Sandy Hook
Kings Point
New London
Dauphin Island
Pilot Sation
Grand Isle
The first three stations are for Hurricane Irene and the last three for Katrina

Future work

- Choose the best *Adeck* TC track and intensity predictions as ensemble members
  - Accurately estimate R_{max} and C_p where needed
  - Apply weighting based upon historical performance
- Develop and apply ensemble evaluation techniques
  - Statistically evaluate ensemble groups
- Use of gridded wind forcing from dynamic models rather than the parametric wind model
- Develop and evaluate super ensemble with multiple storm surge models