Operational ensemble forecasting of coastal storm surges

Jonathan Flowerdew, NTSLF-Challenger Symposium, Tuesday 3 November 2009

Thanks to Kevin Horsburgh, Jane Williams, Chris Wilson (Proudman Oceanographic Laboratory) and Ken Mylne (Met Office)

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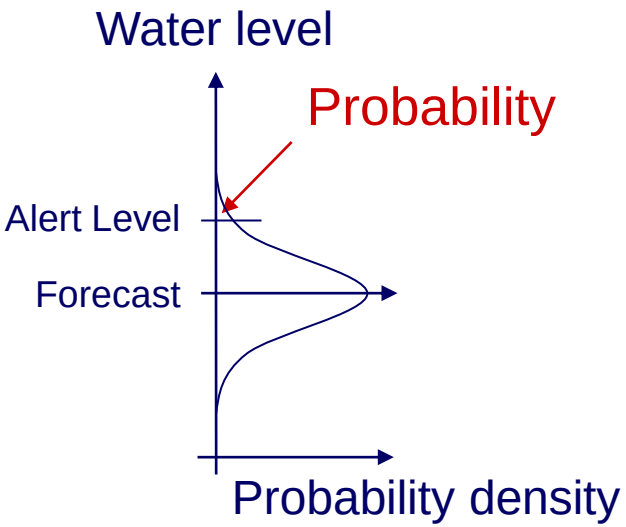
Talk outline

- Ensemble surge forecasting – why and how
- Forecast products
- Verification results

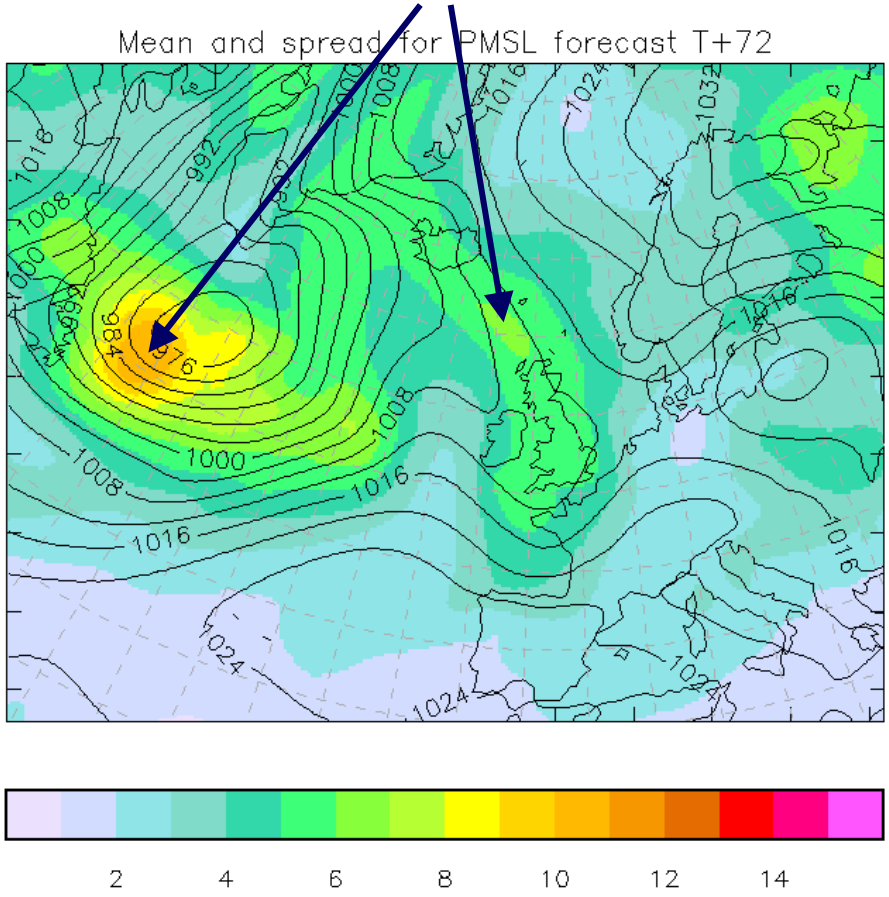
The problem with deterministic forecasts

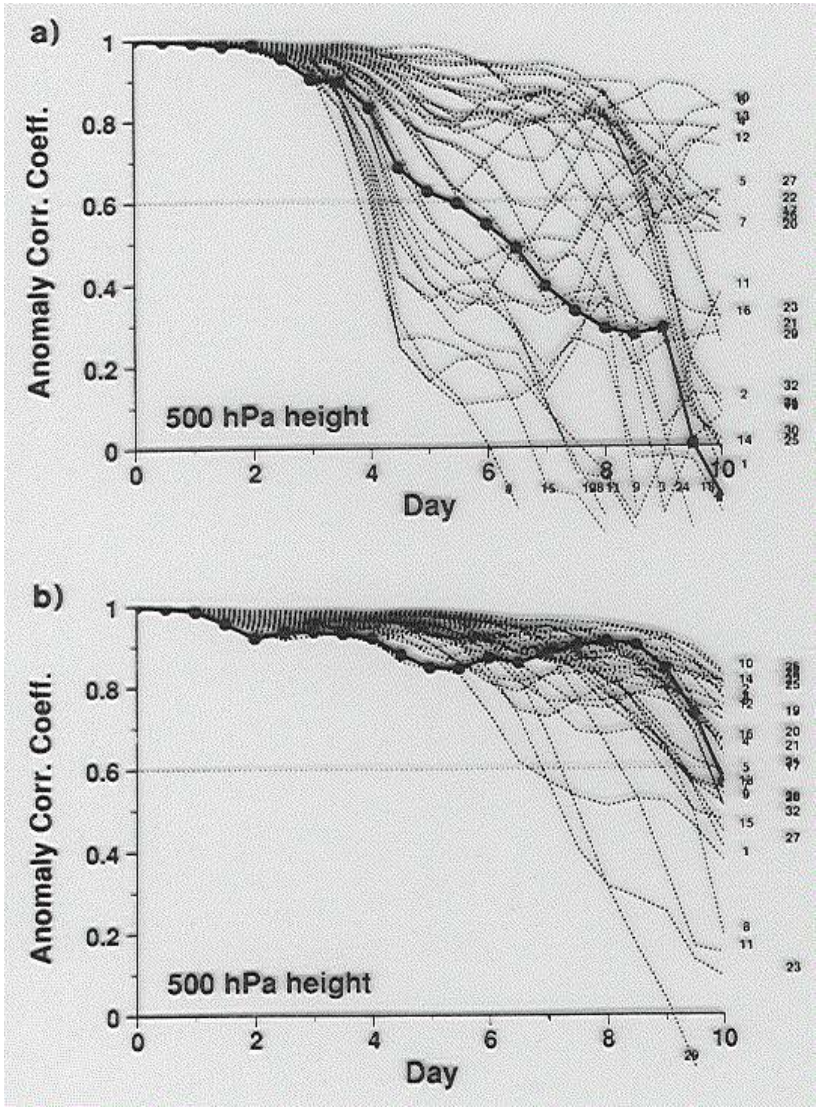


- Deterministic forecast is either above or below the alert level
- All forecasts have error, described by the PDF of truth given the forecast
- The fraction of the PDF above the alert level gives the probability of the event occurring
- The deterministic approach assumes this PDF does not change significantly

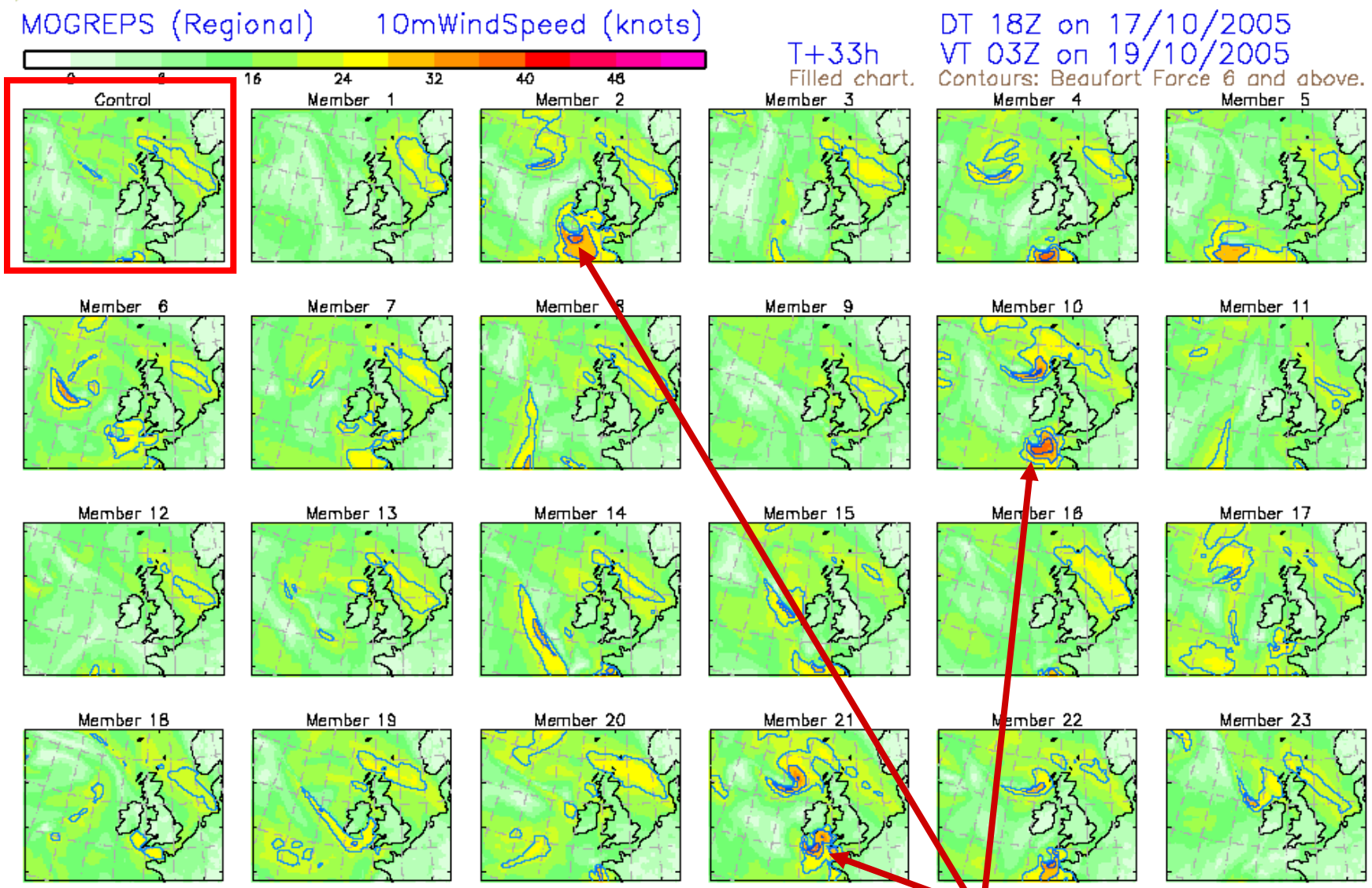
Flow-dependent uncertainty

Spread tends to be concentrated around fronts and sharp gradients



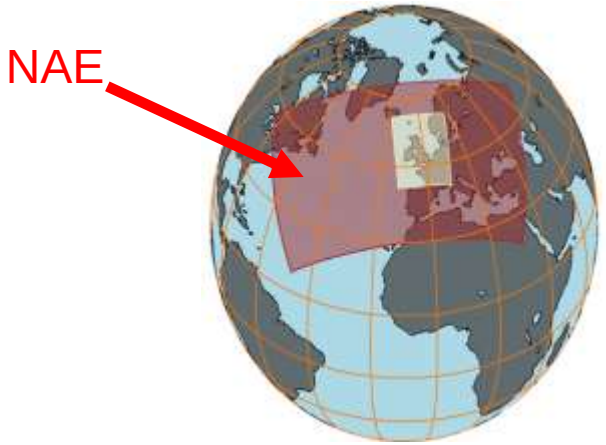


Extreme events



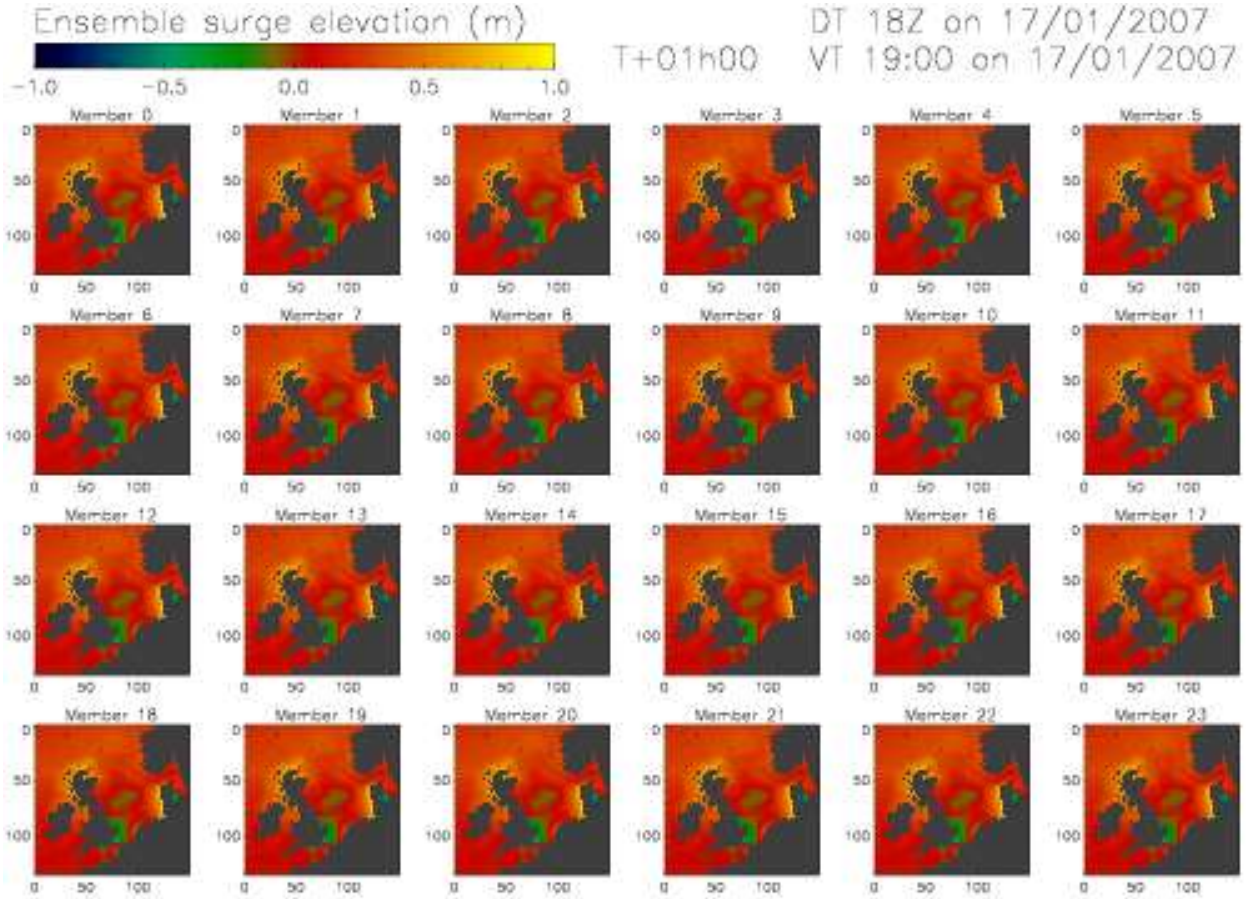
MOGREPS – The Met Office atmospheric ensemble

- 24-member ensemble designed for short-range forecasting
  - Regional ensemble over N. Atlantic and Europe (NAE) to T+54 at 06Z and 18Z (24km resolution, 38 levels)
  - Global ensemble to T+72 at 00Z and 12Z (~90km resolution, 38 levels)
    - Also runs to 15 days at ECMWF for multi-model ensemble research
  - ETKF for initial condition perturbations
  - Stochastic physics



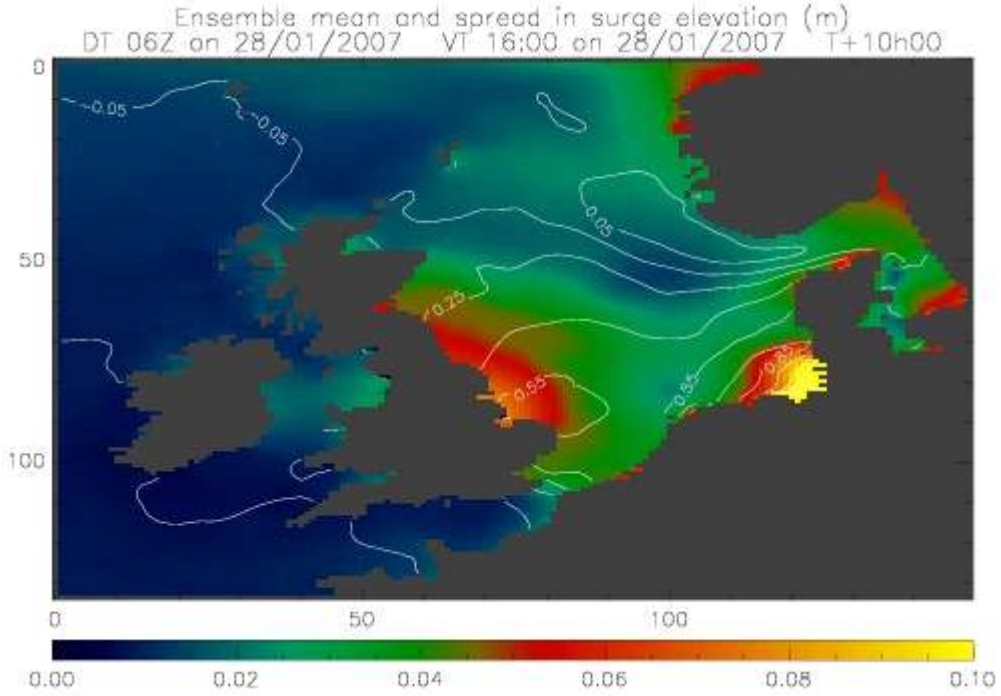
MOGREPS has been running since August 2005, and was made Operational in September 2008.

Postage stamps



- Shows the evolution of each member
- Highlights alternative or extreme events
- Does not summarise or quantify risk

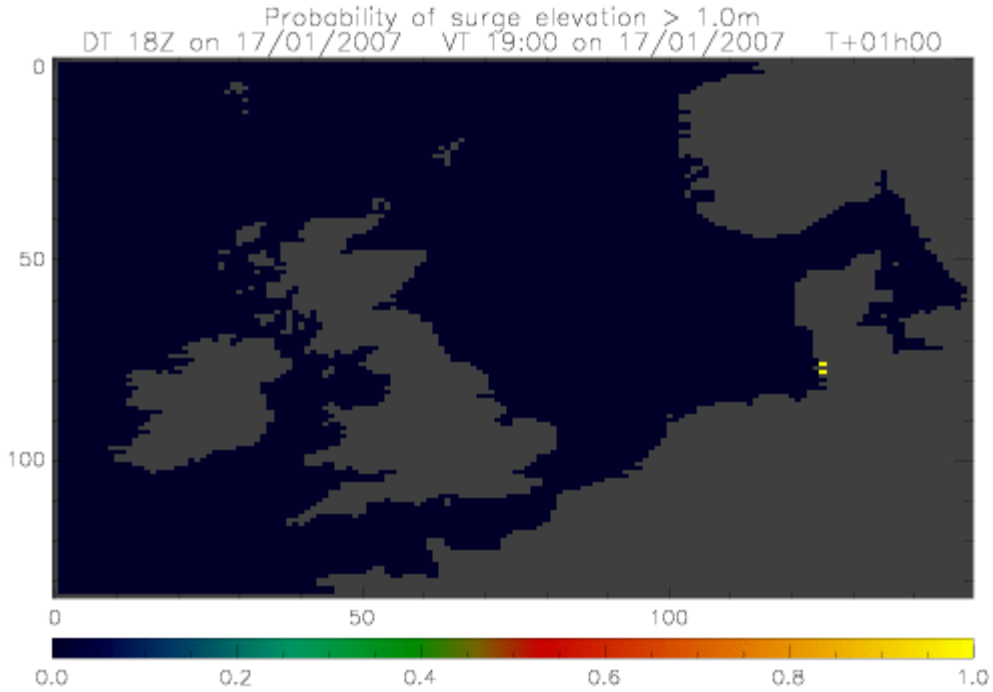
Mean and spread charts



- Shows where the forecast is uncertain, and how this relates to the mean prediction
- Animated as a function of time

- At each timestep, spread = $\sum(x - x_m)^2 / 23$ and mean $x_m = \sum x / 24$

Probability charts

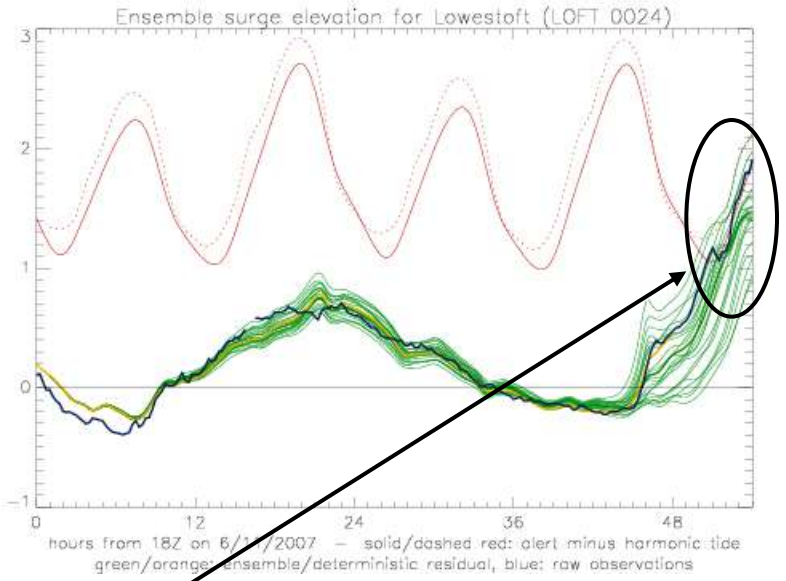


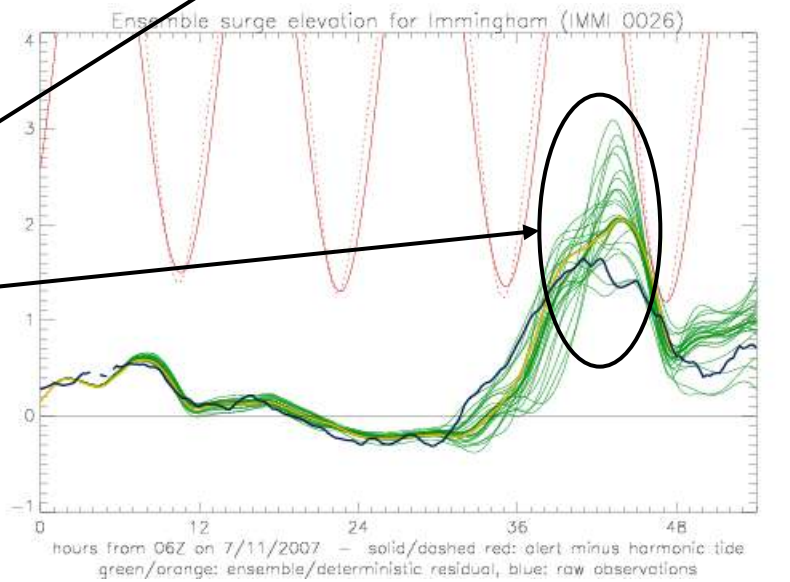
- Directly predicts risk of a significant event
- Animations produced for surge > 0.6m, 1.0m, 1.5m, 2.0m, and surge < -1.0m

- At each timestep, raw probability = (number of members forecasting surge beyond threshold) / 24

Port timeseries – 9 Nov 2007

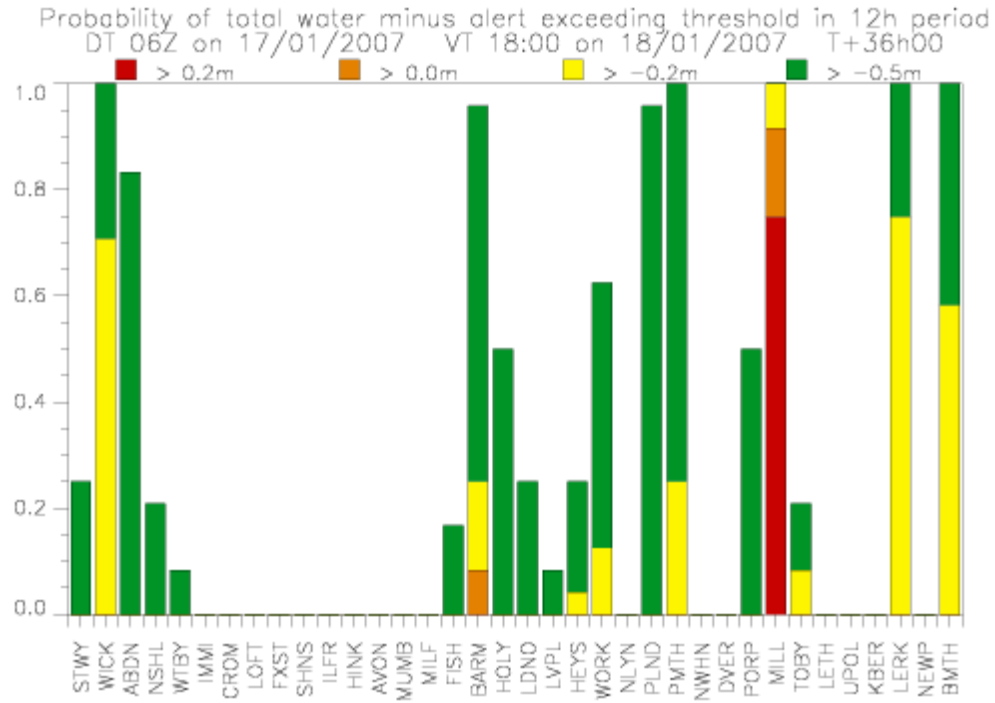
- Green: ensemble surge forecasts
- Orange: deterministic surge forecast
- Red: alert level minus harmonic tide (surge required to reach alert level)
- Blue: observations minus harmonic tide (observed surge)



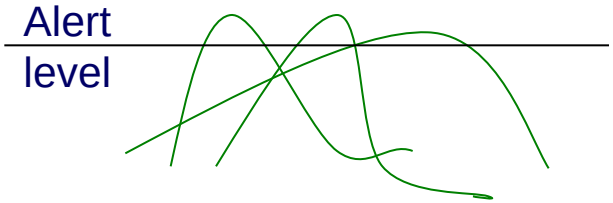


- Clear signal at longest lead
- Range of scenarios
- Good rejection 2 weeks later

Port risk charts



- Stacked probability for successively severe events
- Produced for positive surge, negative surge, and total water minus alert level
- Accumulated in 12 hour bins starting at 6 hour intervals

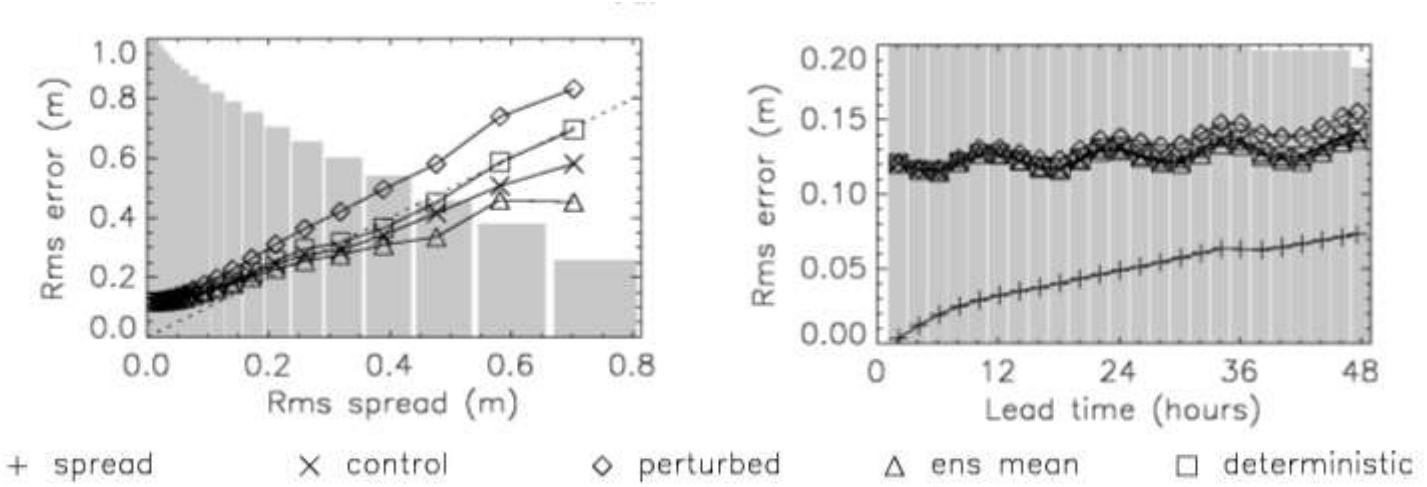


Time binning example: at any one time, only one member is above threshold, but three members exceed it at some point within the time window

Decision-making with probabilities

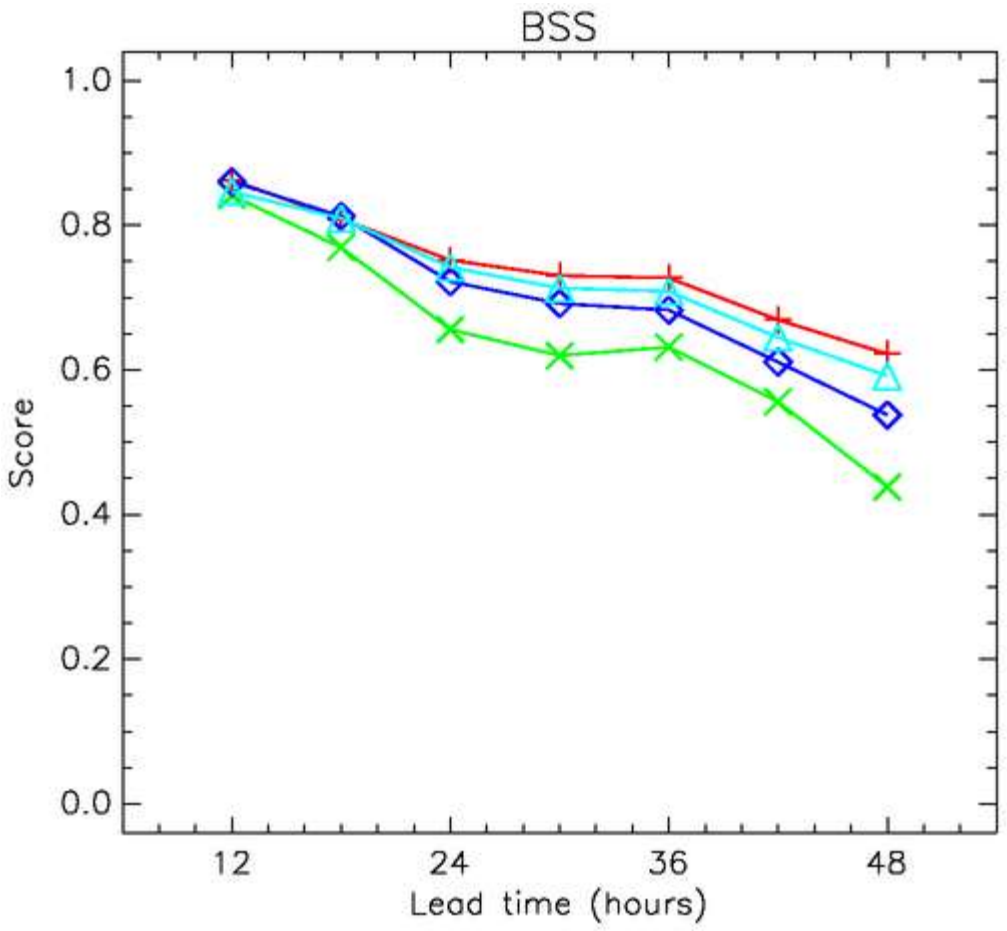
- I either close the Thames Barrier or I don't, surely probabilities only make this harder?
- Maybe, but they allow you to make better decisions, since they express real uncertainties that were previously hidden
- To turn a probability into a decision, you need to balance the cost, C, of taking action, against the loss, L, which that action would prevent if the event occurs
- Long-term benefit is maximised by acting if the probability of the event occurring exceeds C/L

Spread/error statistics



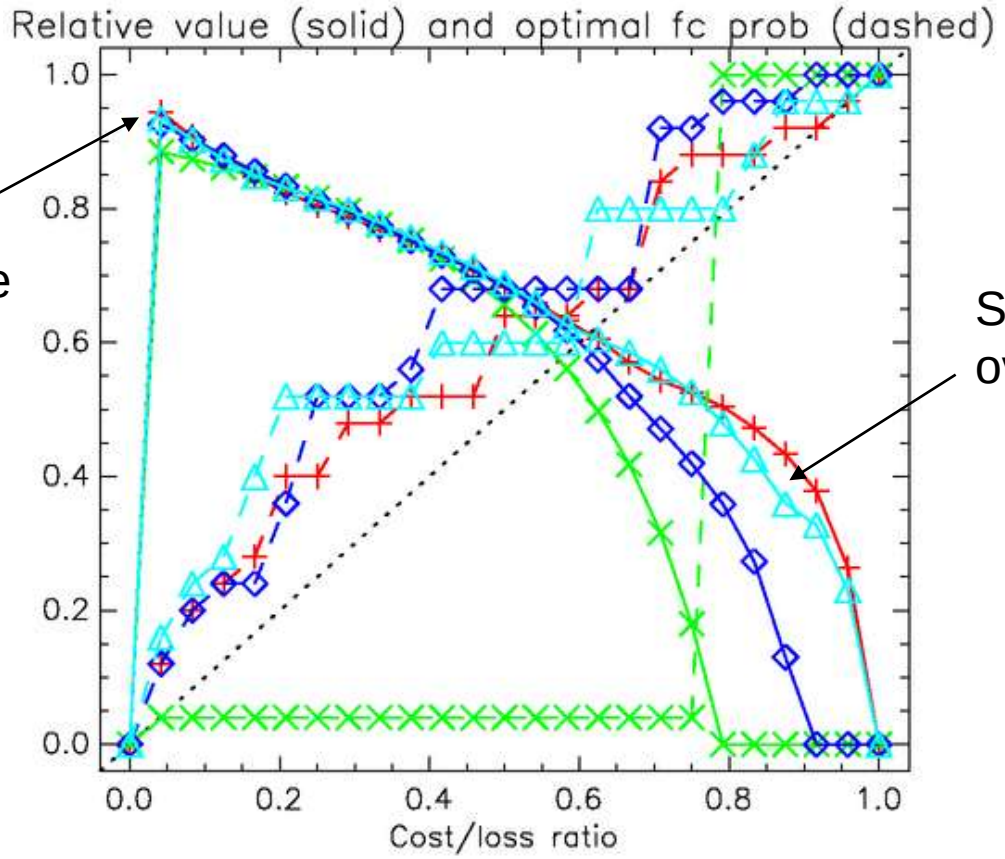
- Data from 36 ports from December 2006 to March 2008
- Spread predicts rms error of ensemble mean
- The ensemble mean provides the lowest rms error
- An unsimulated ~12cm error dominates in calm situations

Brier Skill Score



- Summarises overall skill of probabilistic forecast (reliability *and* resolution)
- Based on ‘rms error’ of probability, where truth is 0 or 1 in each case
- Ensemble beats dressed deterministic
- Greatest benefit at long lead times

Relative economic value



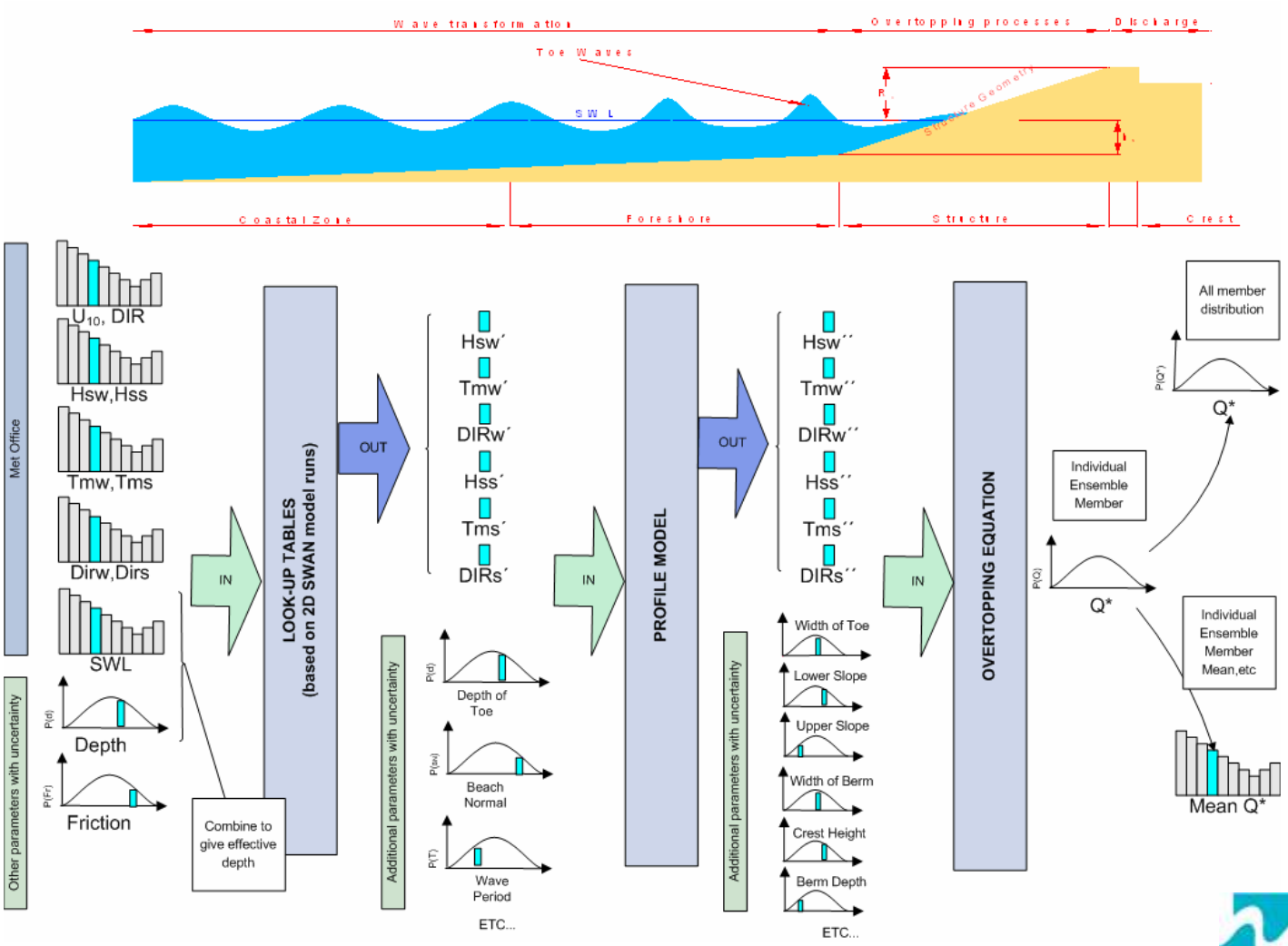
Some benefit from true ensemble

Significant benefit over simple methods

Preventable loss high compared to cost of protection

Cost of protection approaching preventable loss

Wider Coastal Flood Forecasting Project



Summary

- Deterministic forecasts ignore variations in skill and can miss extreme events
- The storm surge ensemble forecasts the range of possible outcomes, with particular advantage at larger thresholds and longer lead times
- Action should be taken when the forecast probability exceeds the ratio of the cost of taking action to the loss it would prevent

Suggestions for future work

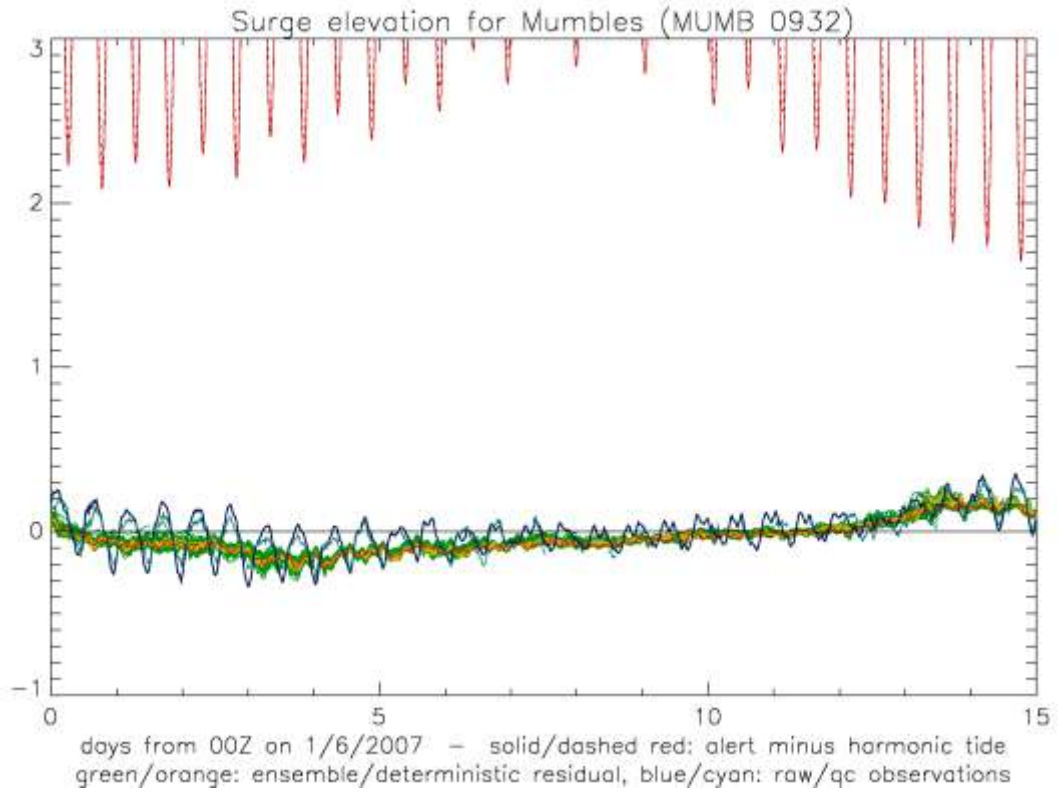
- Make operational by end of 2009
- Trial 5 days forecasts in 2010/11
- Reduce/sample harmonic tide error
- Define thresholds by vulnerability assessment
- Sample uncertainty in surge initial state
- Extend verification, multimodel study, …
- Other derived ensembles

References

- Surge ensemble papers:
  - Flowerdew, Horsburgh, Wilson, Mylne. 2009. *Development and evaluation of an ensemble forecasting system for coastal storm surges*. QJRMS submitted.
  - Flowerdew, Horsburgh, Mylne. 2009. Ensemble Forecasting of Storm Surges (JCOMM Conference paper). Marine Geodesy 32: 91-99.
  - Horsburgh, Williams, Flowerdew, Mylne. 2008. Aspects of operational forecast model skill during an extreme storm surge event. J Flood Risk Management 1: 213-221.
- Coastal Flood Forecasting Project reports:
  - Bocquet, Flowerdew, Hawkes, Pullen, Tozer. 2009. *Probabilistic Coastal Flood Forecasting: Forecast Demonstration and Evaluation*. Environment Agency Science Report SCO50069/SR2.
- MOGREPS papers:
  - Bowler, Arribas, Mylne, Robertson, Beare. 2008. The MOGREPS short-range ensemble prediction system. QJRMS 134: 703-722.
  - Bowler, Arribas, Beare, Mylne, Shutts. 2009. The local ETKF and SKEB: Upgrades to the MOGREPS short-range ensemble prediction system. QJRMS 135: 767-776.

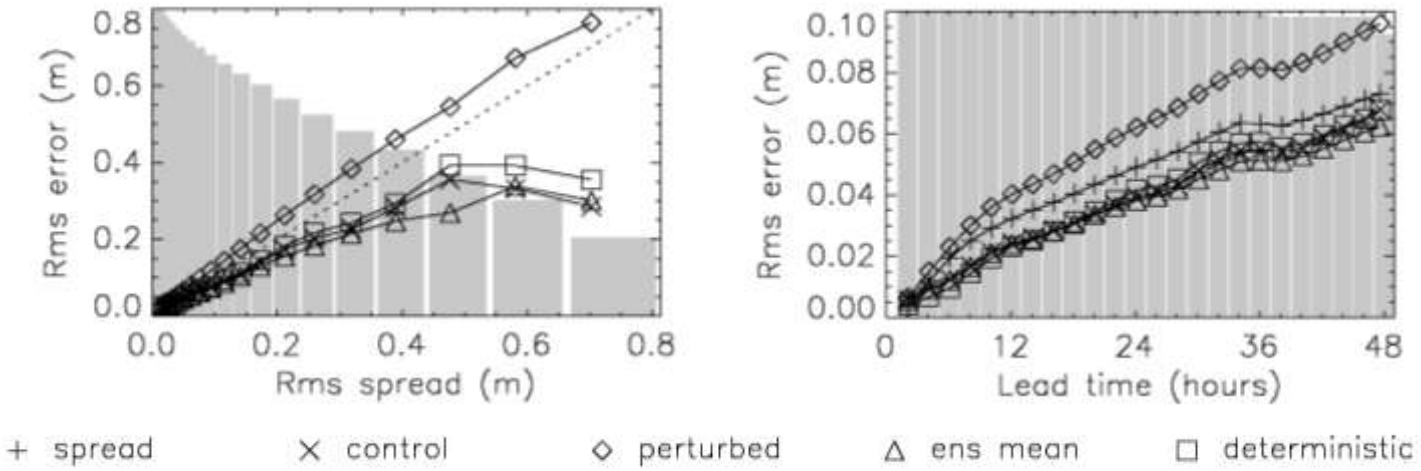
Questions & answers

Harmonic tide errors



- Residual oscillations on timescales of hours to months
- Twin experiment supports tide prediction error ~10 cm
- Not sampled by ensemble

Spread/error wrt hindcasts



- Eliminate harmonic tide by evaluating against surge model output for analysed meteorology
- The spread is a good predictor of this component of the error
- Ensemble mean remains the best forecast beyond the first 18 hours

Initial condition uncertainty

- The current surge ensemble neglects initial condition uncertainty
- Chris Wilson took 24 members from a T+12 forecast and forced them all with the same meteorology
- The spread *decays* with a half life of 6-12 hours
- The impact of model parameter (bottom friction) uncertainty was also found to be negligible