The Use of Met Office Ensemble Model Data to Generate Severe Weather Forecasts

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- **Ensemble turbulence trial**
- Tropical Cyclones
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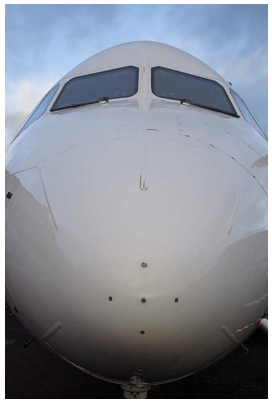
Introduction

- Turbulence - major cause of aviation incidents & active area of research
- Forecasts routinely produced by UK Met Office - World Area Forecast Centre (WAFC) service
- Operational forecasts currently derived from deterministic models
- There is always a degree of uncertainty in deterministic forecasts
- Ensembles are a way of communicating that uncertainty



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Ensembles

MOGREPS

Met Office Global and Regional Ensemble Prediction System

Operational from Sep 2008 after 3 years of trials

(March 2010 - March 2012)

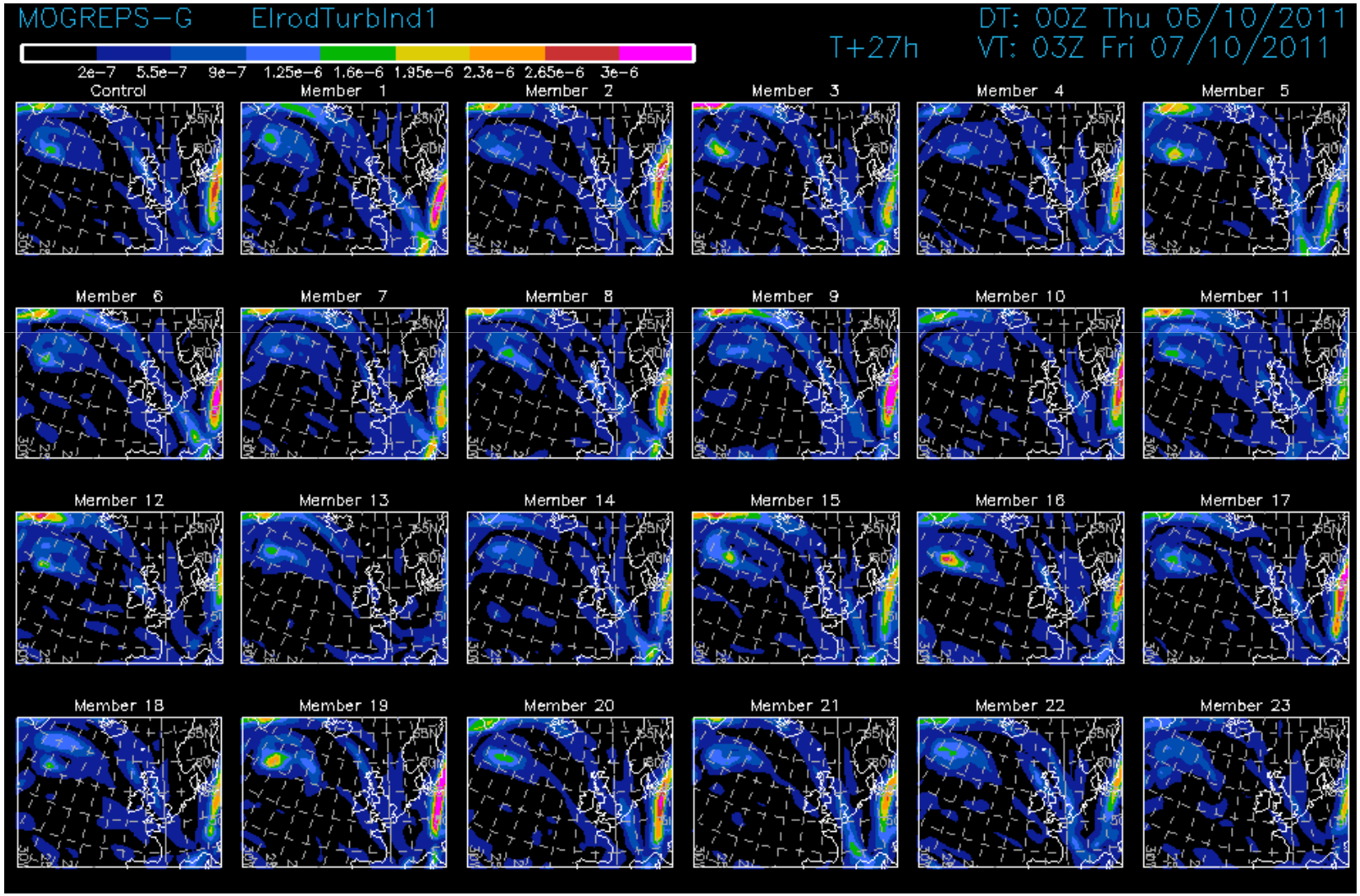
Global **Component (MOGREPS-G)**

- 60km, 70 Levels T+72h
- Run at 00Z, 12Z
- ETKF for initial condition perturbations
- Stochastic physics (SKEB2) and random parameters
- N.B **MOGREPS-15** run to 15 days at 00z and 12Z (at ECMWF)

Proposed resolution upgrade at the end of November 2012

- Horizontal resolution of approx. 33 km in mid latitudes and keeping 70 levels
- A *significant* res. increase – data volumes increase by factor 3.4!
- 12 members 4 times per day at 0Z,6,12 and 18 since March 2012

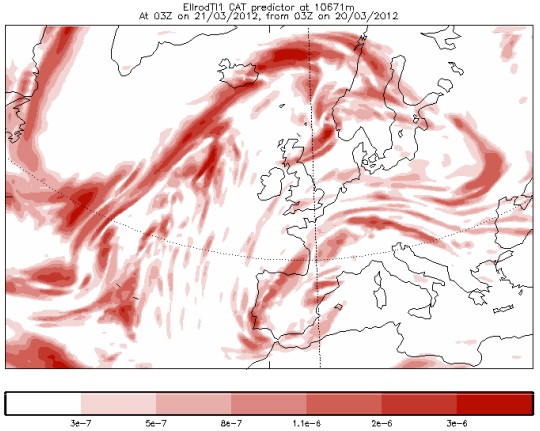
MOGREPS-G “postage stamp” plots



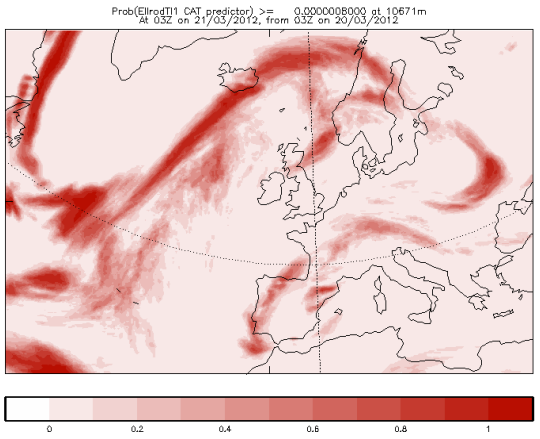
Ensemble Forecasts
Understanding Uncertainty

Ensemble: we run the model many times (e.g. 24 forecasts) from slightly different start conditions to account for chaos:

- take account of uncertainty
- assess confidence
- estimate probabilities and risks
  - 6 out of 24 members = 25%



Deterministic



Probabilistic

Turbulence forecasting

Turbulence predictors

Turbulence can come from different sources – wind shear, convection, (mountain-wave)

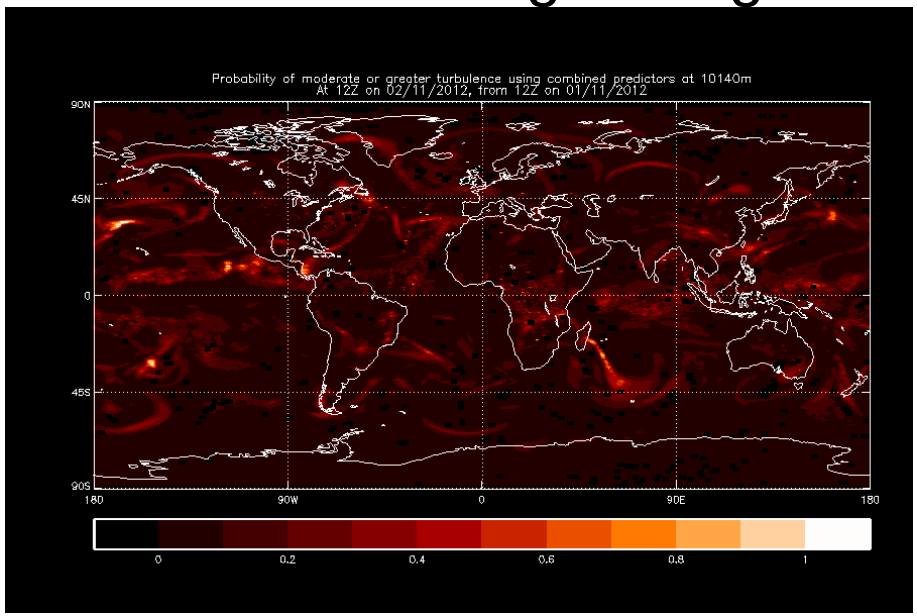
- **Windshear related:**
- Ellrod TI1, Ellrod TI2
- Brown
- Dutton
- Lunnon

- **Convection related:**
- Convective rainfall rate
- Convective rainfall accumulation
- Richardson number

- **Turbulence climatology**
  - Gridded field of observed turbulence frequency produced from aircraft observations from previous year

Combining predictors

- Combining turbulence predictors has been shown to increase forecast skill (**Sharman** *et al*, 2006)
- We use weights derived from verification using ROC area
- Predictors combined using a weighted sum



Combined probabilistic predictors

Ensemble turbulence trial

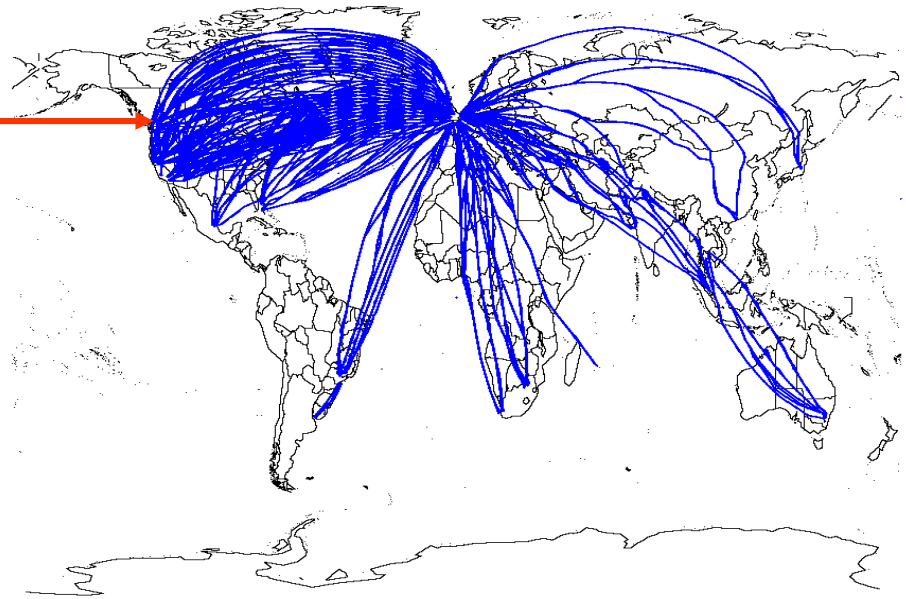
Ensemble turbulence trial

- **Objective** verification of deterministic and probabilistic model forecasts
- **Global** verification to assess T+24 hrs MOGREPS-G forecasts of turbulence
- Verification against **automated** aircraft observations from the Global Aircraft Data Set (GADS)
- **12-month** trial from November 2010-October 2011
- **Eight** numerical predictors and climatology verified
- **Five** thresholds used on each predictor to generate probability forecasts
  - Thresholds cover light to moderate to severe turbulence

Global Aircraft Data Set

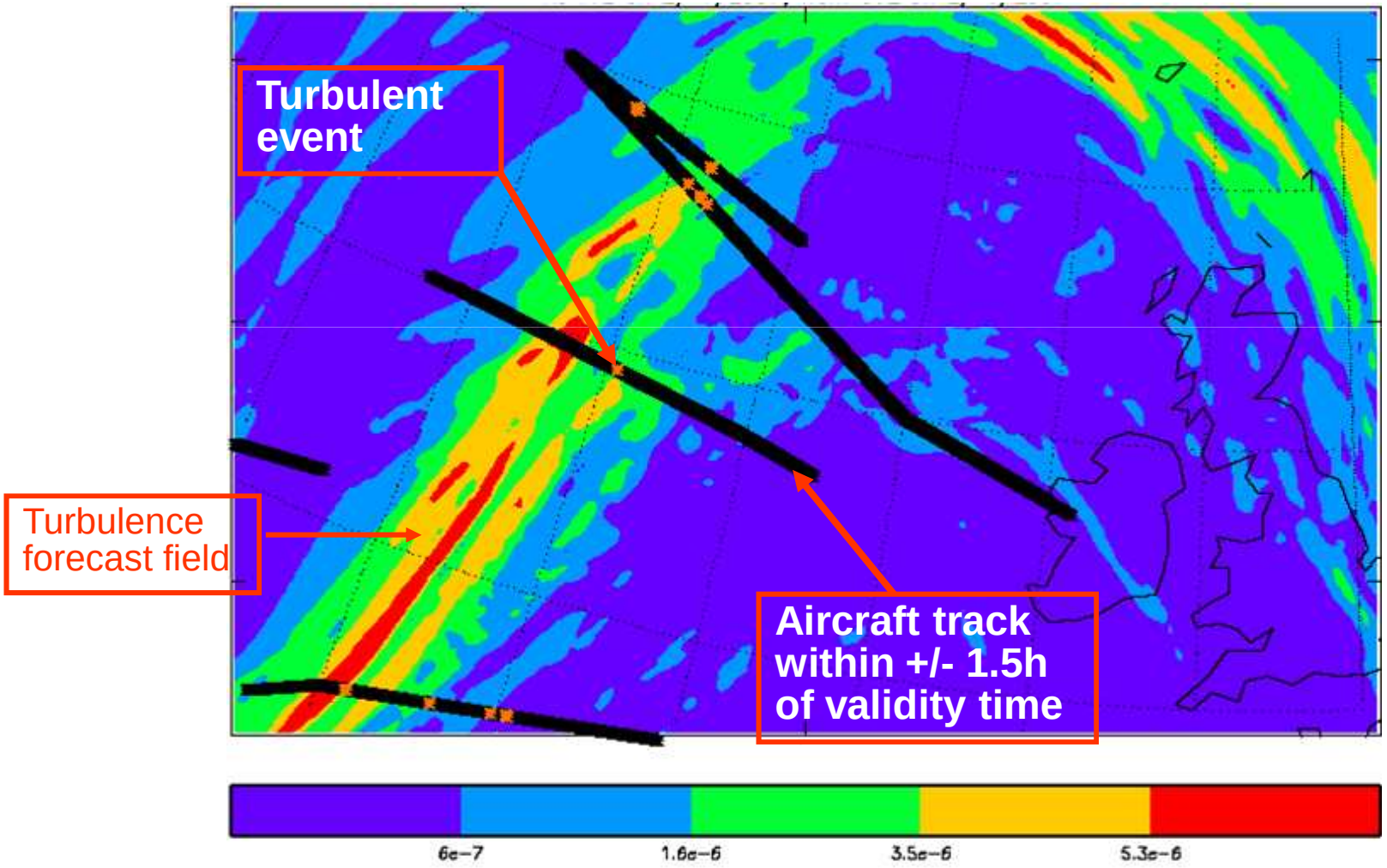
- Archive of aircraft data set up by Joel Tenenbaum (State University of New York)
- British Airways fleet of Boeing 747-400 aircraft
- **Global** coverage, but flights mainly over northern hemisphere
- **Automated** aircraft observations available every 4 seconds

Good coverage of N Atlantic, US and Europe



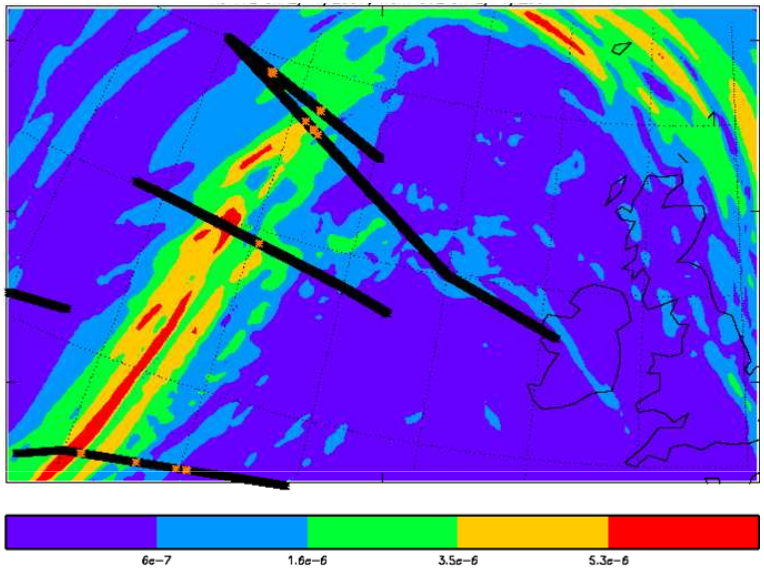
10-19 January 2009

Verification methodology



Forecast assessment

- Turbulent/non turbulent event defined on **10min aircraft track** ~120km - approx grid size
- Forecast turbulent event – CAT potential >= Threshold
- Observed (moderate or greater) turbulent event - **DEVG>=4.5m/s**
- Construct 2x2 contingency tables for each threshold
- Sum entries in contingency tables over the verification period



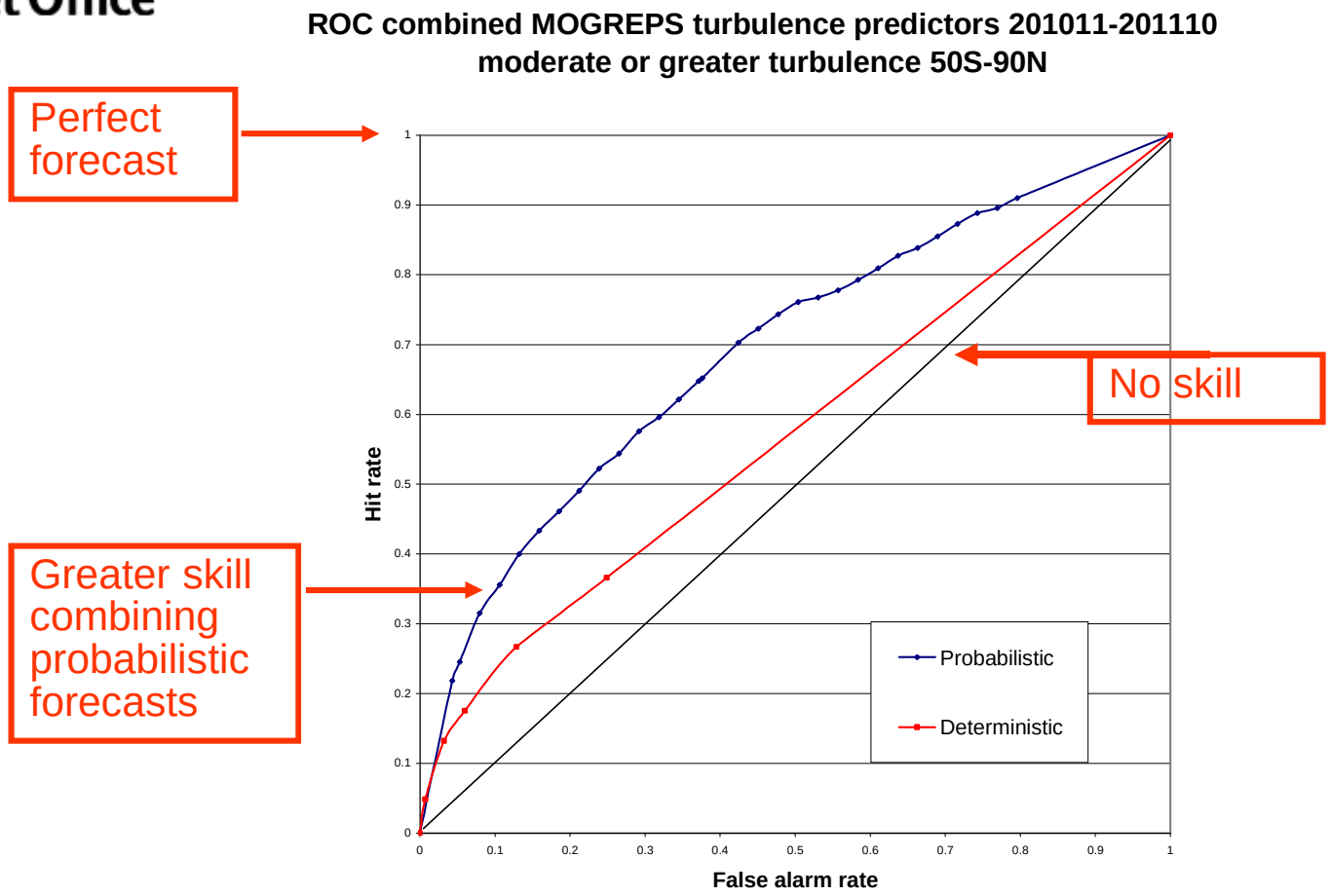
	Turbulence observed	No turbulence observed
Turbulence forecast	Hit	False alarm
No turbulence forecast	Miss	Correct rejection

2x2 contingency table

Verification measures

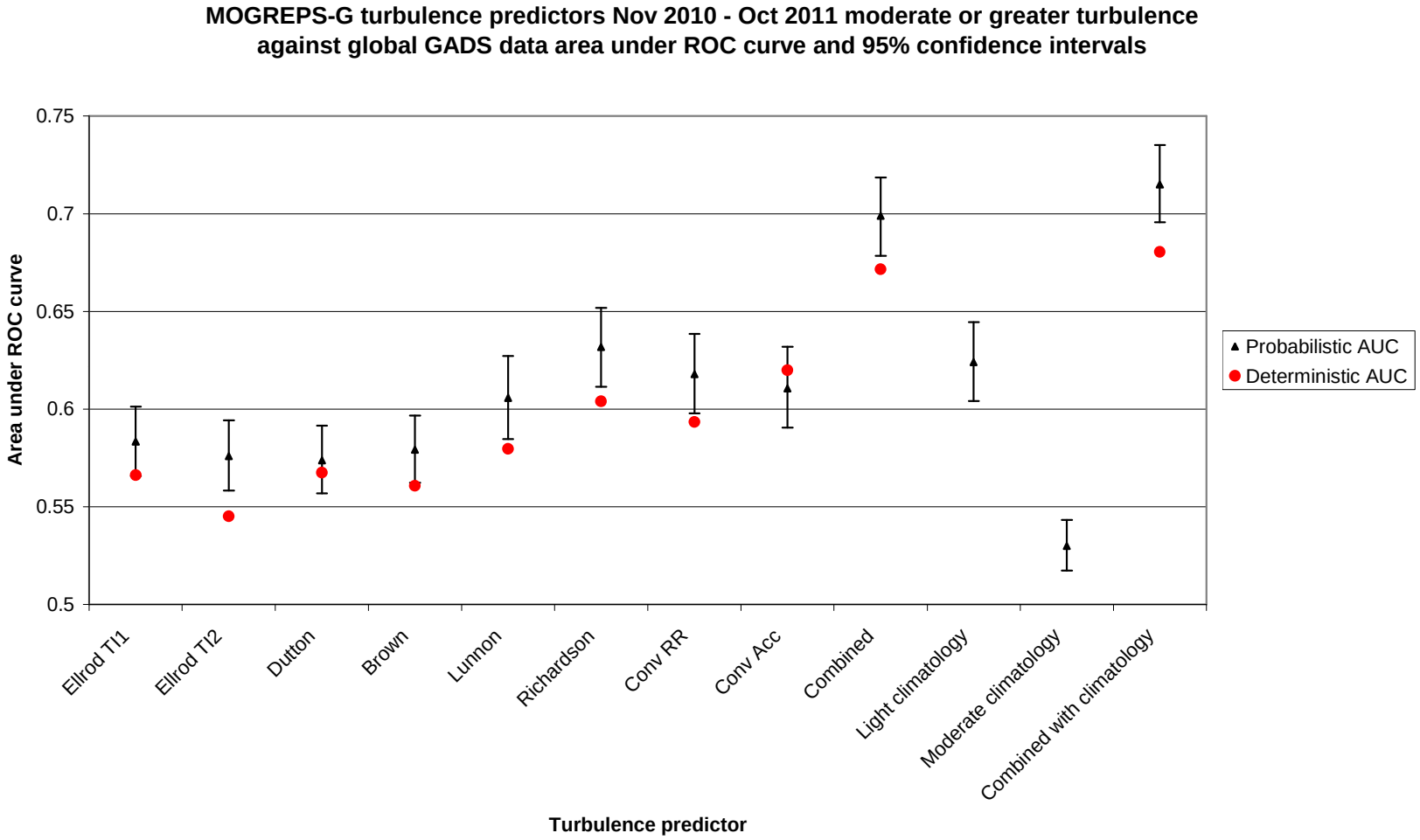
- **Relative Operating Characteristic** (ROC) curve by plotting the hit rate against false alarm rate for each threshold. The area under the ROC curve is a measure of skill. Useful for both **deterministic** and **probabilistic** forecasts
- **Reliability Diagram** by plotting the forecast probability against the frequency of occurrence
- **Relative economic value** (Richardson, 2000) by calculating the value for a range of cost/loss ratios. Useful for both **deterministic** and **probabilistic** forecasts.

Ensemble turbulence verification - ROC



Gill PG, Buchanan P. 2012. “An ensemble based turbulence forecasting system”, *Meteorological Applications (in press)*

ROC area for each predictor



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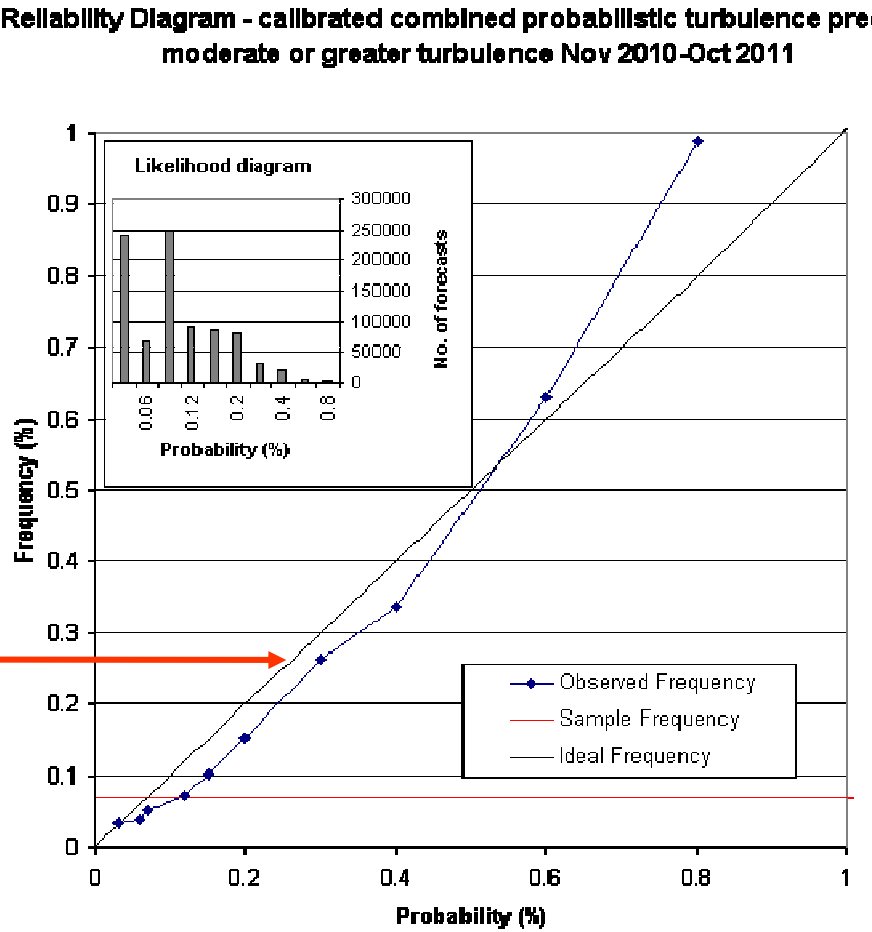
Ensemble turbulence verification - Reliability



Perfect reliability

Low probabilities but significant compared to background frequency

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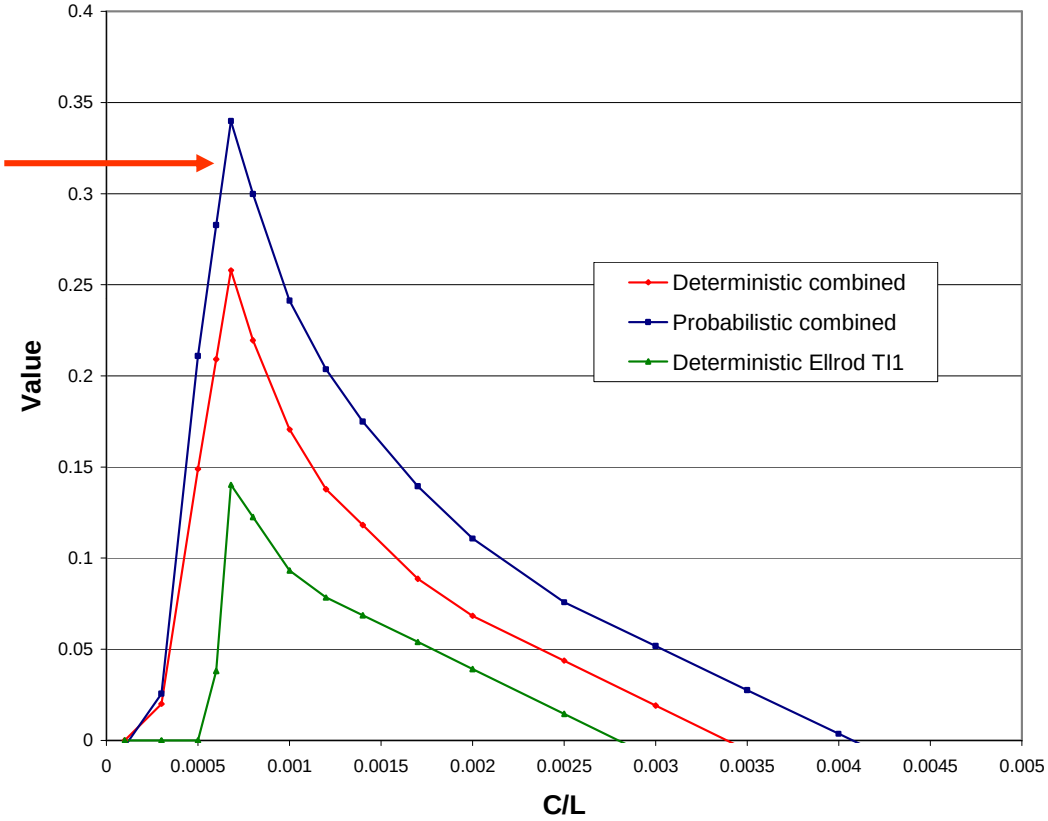
Ensemble turbulence verification – Relative economic value

Cost-loss relative economic value plot comparing MOGREPS-G probabilistic and deterministic global turbulence forecasts 201011-201110

Greater value combining probabilistic forecasts



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Summary

Benefits of using Ensemble turbulence forecasts

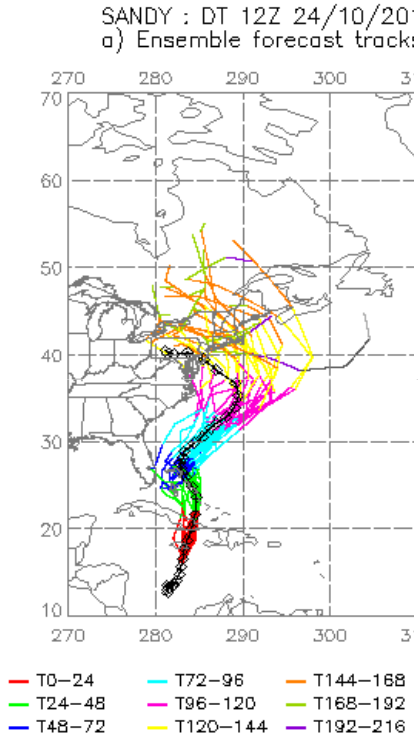
- Significant increase in skill
- Increased economic value of forecast
- Confidence can be communicated with every forecast
- Use of verification can help users to maximise the value of the forecast

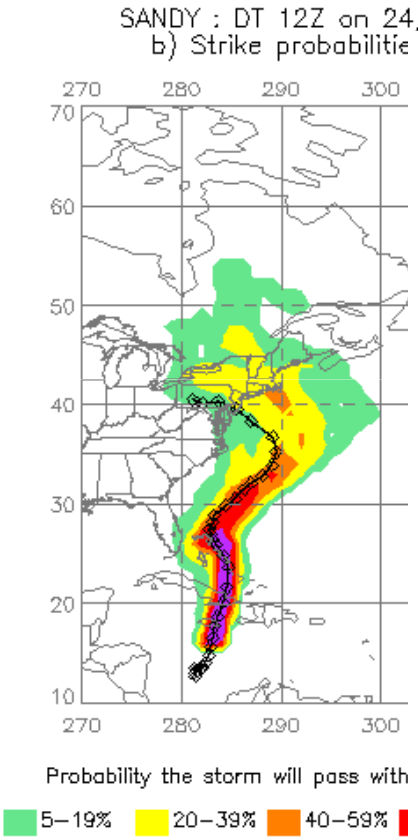
Future plans and challenges

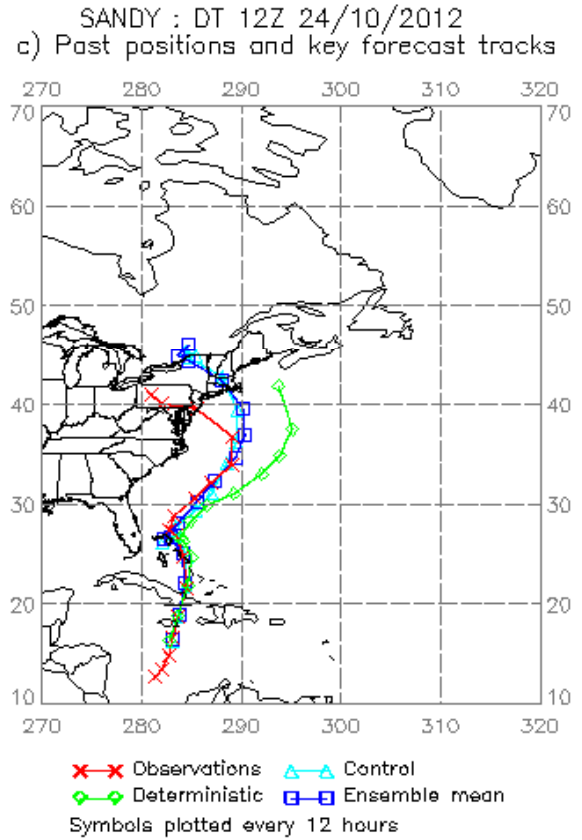
- Extend verification to cover 2011/12 and include additional predictors (CAPE, Mountain wave)
- Create operational probabilistic aviation hazard forecasts for **Turbulence, Cb** and **Icing**
- Investigate using a **multi-model ensemble** for WAFC turbulence forecasts
- Seek **additional observations** to give greater coverage to the verification.
- **Educating** users in interpretation of probabilistic forecasts and verification

Tropical Cyclones and Convective Diagnosis Products

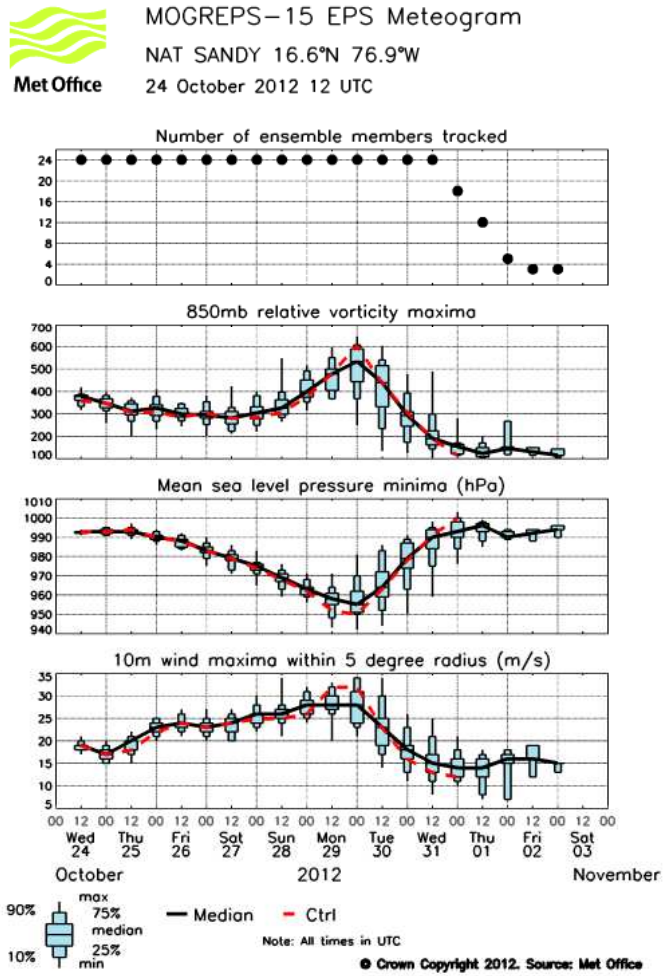
Tropical Cyclones –typical MOGREPS-15 products for Sandy, 12Z 24th October 2012





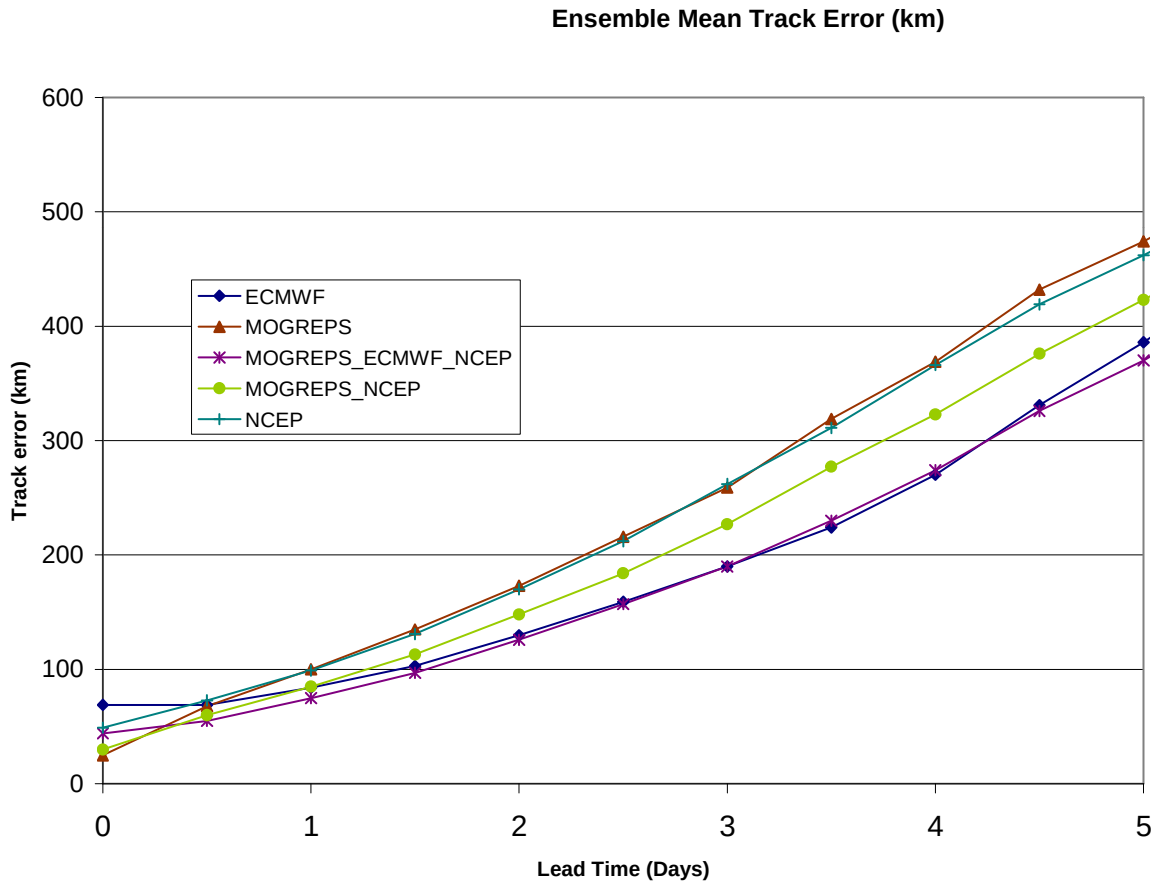


Tropical Cyclones –storm following Meteogram for MOGREPS for Sandy

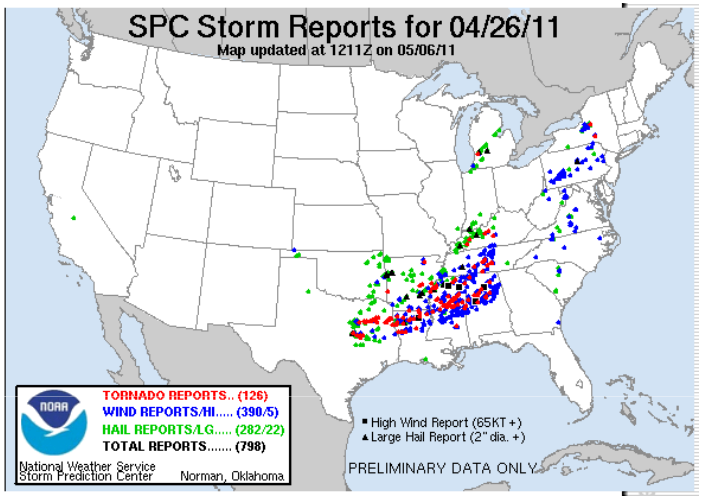


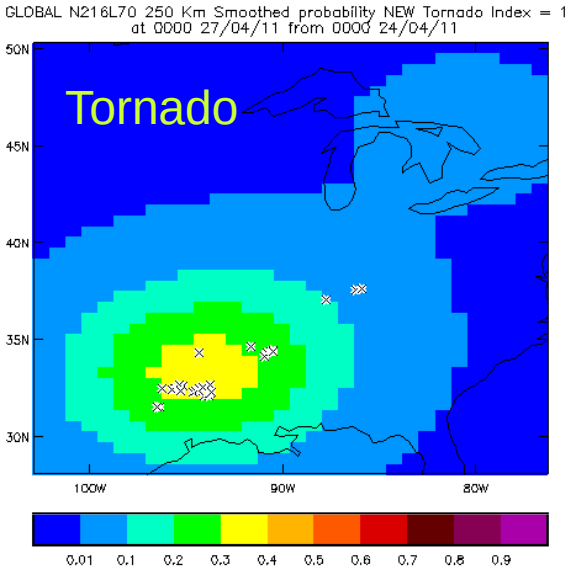
Tropical Cyclones (2)

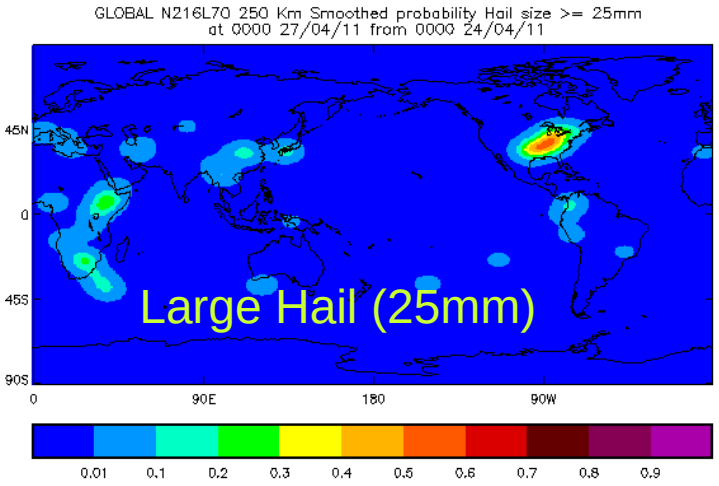
- Feb – Dec 2011. All named storms in all basins
- Met Office tracker run on ECMWF, NCEP and MOGREPS data

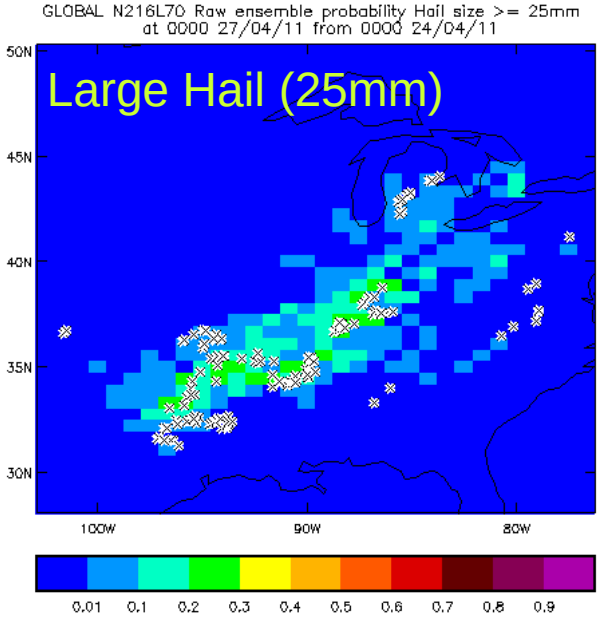


Global risk of Severe Convection









Acknowledgements

- Thanks to the UK **Civil Aviation Authority** for funding the aviation part of this project

- The aviation content of this presentation will shortly appear as a paper:

Gill PG, Buchanan P. 2012. “An ensemble based turbulence forecasting system”, *Meteorological Applications (in press)*

Questions?