ACCESS AGREPS
Ensemble Prediction System

Michael Naughton
CAWCR Earth System Modelling

Model Data Fusion Workshop
10-12 May 2010

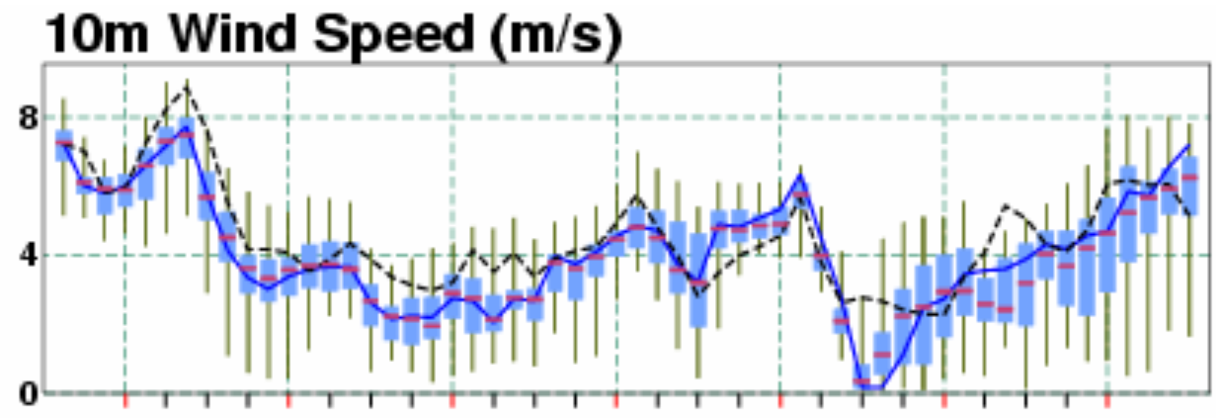
Australian Government
Bureau of Meteorology

The Centre for Australian Weather and Climate Research
A partnership between CSIRO and the Bureau of Meteorology

CSIRO

Motivation for Ensemble Prediction

- NWP forecasts greatly improved but are still uncertain
- Internal and external users can make better decisions when uncertainty information is provided
- Ensemble prediction is a good way to estimate forecast uncertainty



Service requirements for probability forecasts

- **Thunderstorms –** probability of conditions favourable to severe weather

- **Heat wave warnings –** probability of exceeding critical heat stress index based on temperature, humidity, and wind speed

- **Precipitation –** probabilities of exceeding critical accumulation thresholds

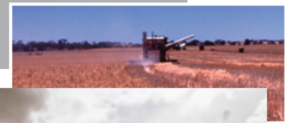
- **Wind –** probability of gales – crucial for tropical regions

- **Waves –** probabilities of exceeding critical wave heights

- **Tropical cyclones –** strike probability

NWP Ensemble Prediction Methodologies






Multi-model ensemble (Poor Man's Ensemble) – form ensemble from deterministic forecasts from available local and overseas models

- PME precip forecasts on BoM WATL site
- GOCF forecasts used operationally in BoM public weather forecasts

Single-centre EPS systems – run by almost all major international Met Centres

Global:

- BoM: GASP-EPS (2002-present)
- ECEPS (1993-present), US-EPS (1993-present), CMC-EPS (1998-present), JMA-EPS (2001-present), KMA-EPS (2001-present), UK-MOGREPS (2005-present; oper 2008)


Australian Region:

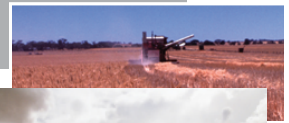
- LAPS-EPS: research system (2002-2005)
- ACCESS-AGREPS: research system (in progress)

Multi-EPS systems – form ensemble from ensemble forecasts from multiple centres

- TIGGE – Thorpex Interactive Grand Global Ensemble (research)
- GIFS – Global Integrated Forecast System (research)
- NAEFS – North American Ensemble Forecast System (operational)

Ensemble Prediction System Techniques






EPS systems typically run 10-50 ensemble members at about ½ resolution of centre's deterministic systems

Initial conditions perturbations

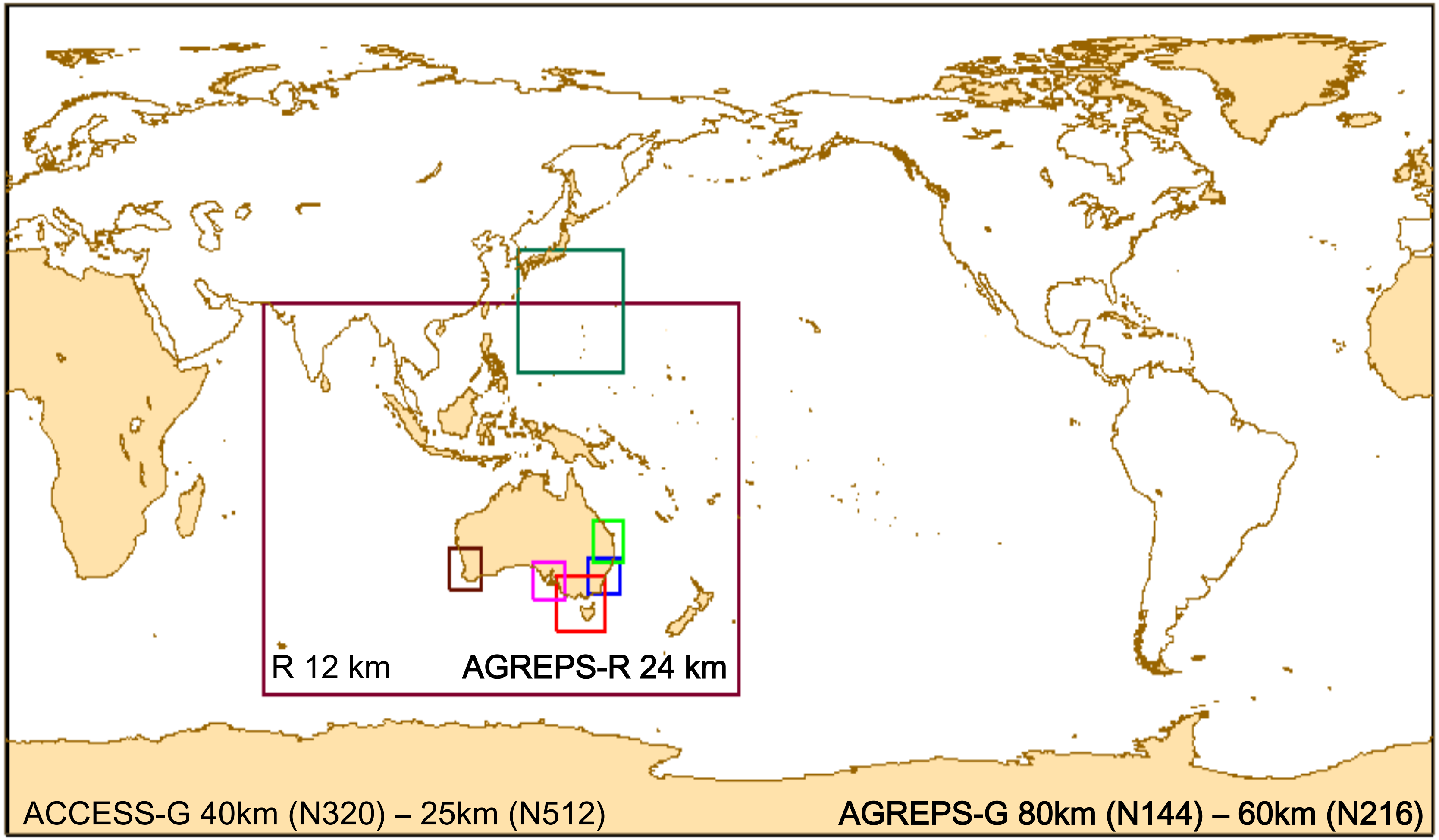
- **Singular Vectors –** EC / BoM (GASP) / JMA
- **Breeding / EKF / ETKF –** US-NCEP / KMA / UK
- **Ensemble DA –** CMC

  Research: BoM (LAPS), EC, Meteo-Fr


Model Perturbations

- **Stochastic physics schemes –** EC, BoM (LAPS), UK
- **Multiple physics schemes –** CMC, BoM (LAPS)

AGREPS – ACCESS Global and Regional Ensemble Prediction System



Ensemble teams

UK Met Office – MOGREPS

- Richard Swinbank – Research
  - Neill Bowler
  - Sarah Beare
  - Jonathan Flowerdew
  - Warren Tennant
  - Christine Johnson
  - Kelvyn Robertson
  - Simon Thomson

CAWCR – AGREPS

- Michael Naughton (0.5)
- *Beth Ebert*
- *Kamal Puri*
- Terence O'Kane (2007-2009)
- David Smith (from May 2010)
- Asri Sulaiman (0.5)
- *business case proposal to increase effort*

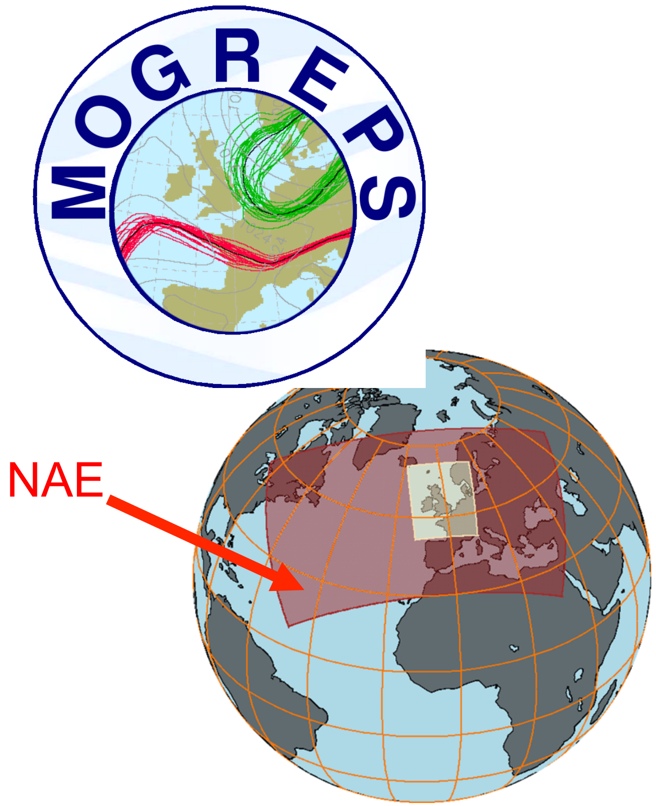
- Ken Mylne – Products and consulting
  - Caroline Woolcock
  - Piers Buchanan
  - Rob Neal
  - Lisa Murray
  - Martin Sharpe
  - Helen Titley (maternity leave)

- Dale Barker – Hybrid DA
  - Adam Selwood

MOGREPS – The Met Office short-range ensemble

24-member ensemble designed for short-range forecasting

- Regional ensemble over N. Atlantic and Europe (NAE) (24km resolution, 38 levels) to T+54
- Global ensemble (~90km resolution, 38 levels) to T+72
  - Also runs to 15 days at ECMWF for THORPEX
- ETKF for initial condition perts (global only)
- Stochastic model perturbations
- Global run at 0Z and 12Z. Regional run at 6Z & 18Z



Fully operational system since 2008

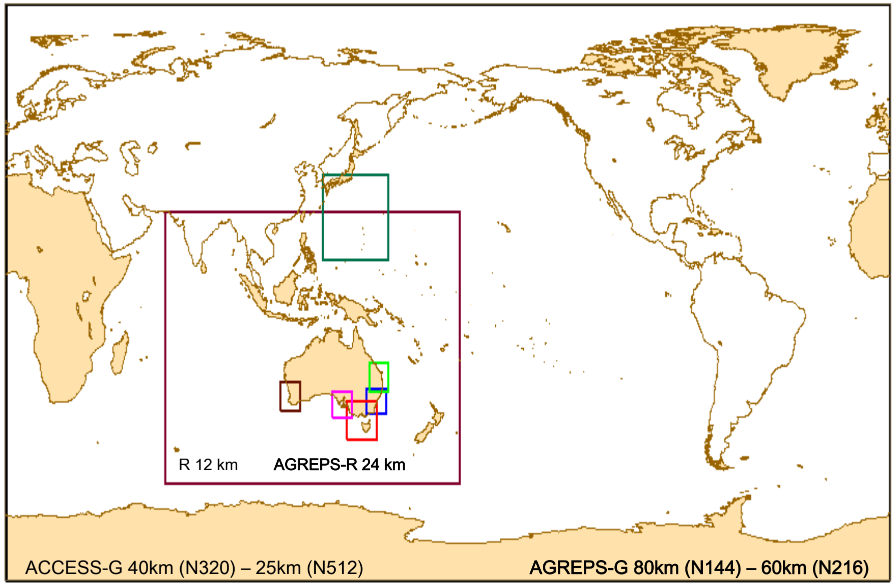
AGREPS – The ACCESS short-range ensemble

ACCESS
The Australian Community Climate and Earth-System Simulator

MOGREPS

24-member ensemble designed for short-range forecasting

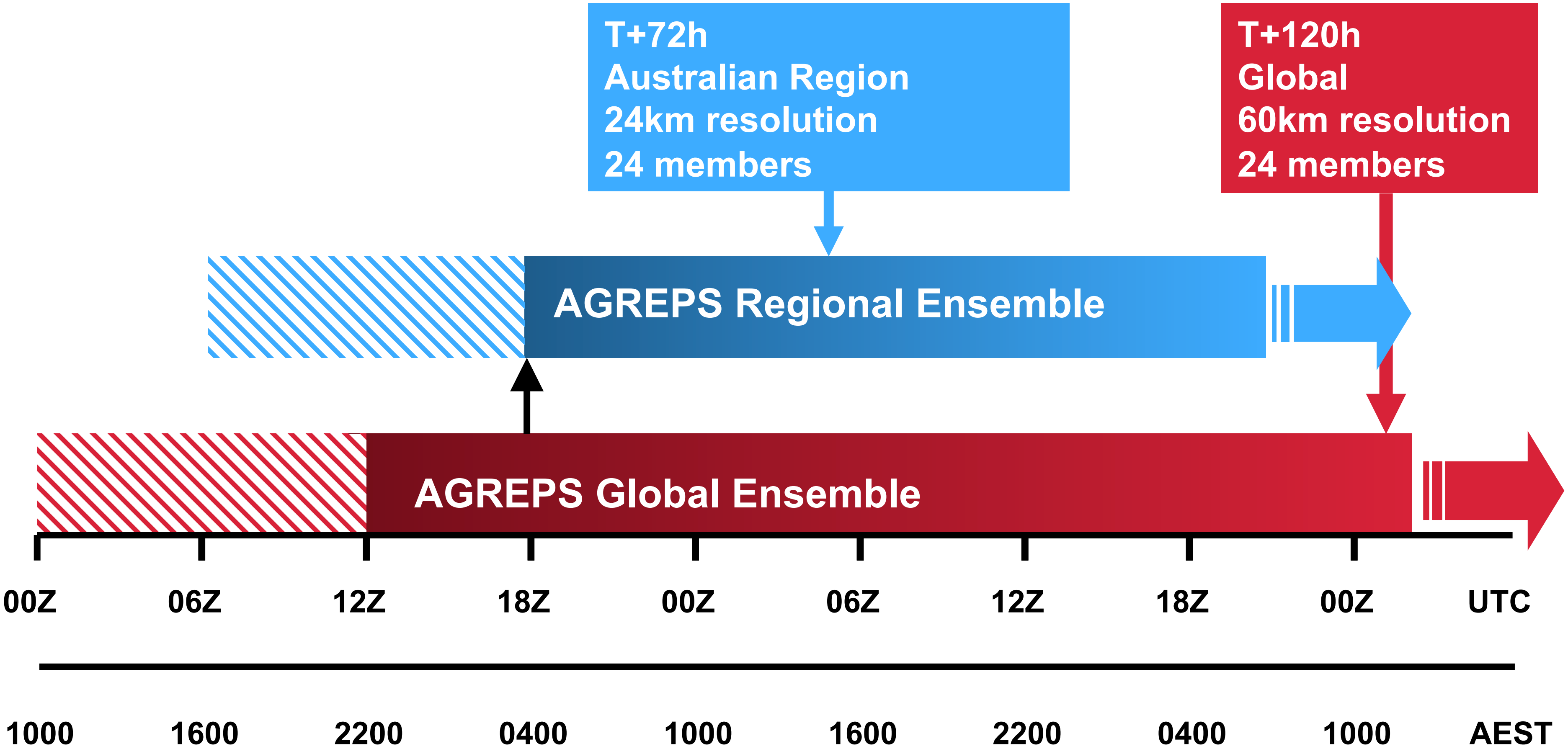
- Regional ensemble over Australian Region (24km resolution, 70 levels) to T +72
- Global ensemble (60km resolution, 70 levels) to T+120
- ETKF for initial condition perts (global only)
- Stochastic model perturbations
- Global run at 0Z and 12Z. Regional run at 6Z & 18Z



Currently running on NEC-SX6 at 37.5 & 80 km

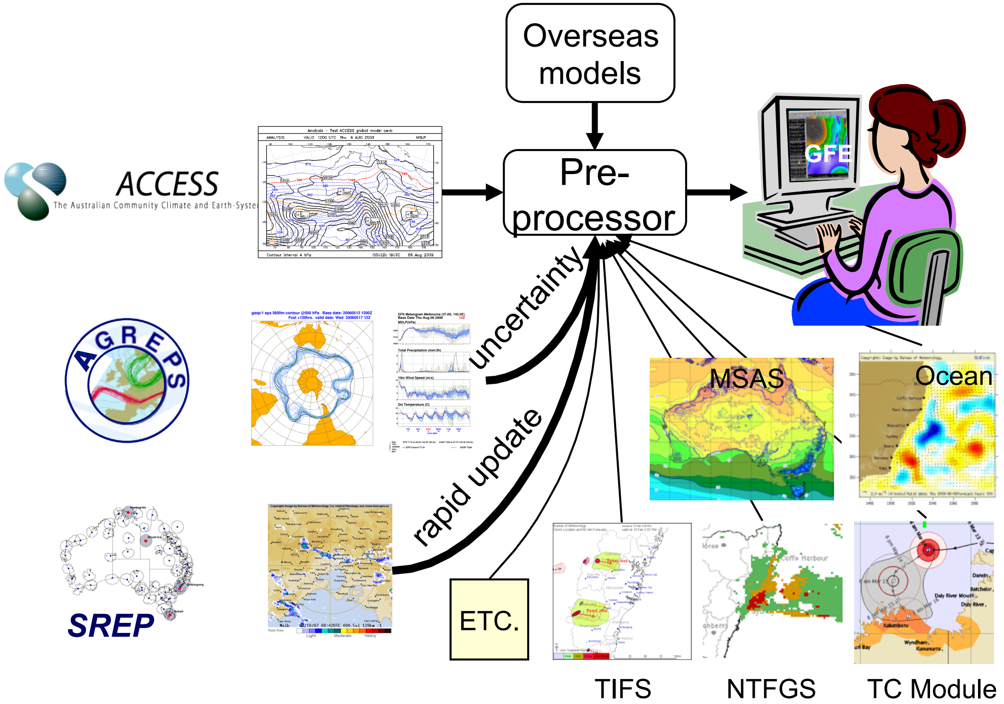
Aiming for research system on Sun later in 2010

Forecast Systems



CAWCR Ensemble Development activities (proposed)

- Scientific
  - Getting appropriate ensemble spread: initial conditions, physics
  - Optimal NWP data assimilation
    - 4D variational + ensemble → hybrid approach
  - Calibration and verification
- Forecast process
  - Use of ensembles in NexGenFWS
- Services
  - Probabilistic forecasts available to the public and other users
  - User liaison required



Benefits for the Bureau

- **Uncertainty information** for forecasters
- **More reliable and accurate forecasts**
- **Hybrid data assimilation**
- **Probabilistic predictions** for a wide range of meteorological parameters
- Inclusion of uncertainty / probability information in automated forecasts **enhances efficiency of end-to-end forecasting service**
- Provision of ensemble-based uncertainty information to **customers**
- Extension to **downstream applications** such as flood forecasting, continuous streamflow, transport (dust, smoke, volcanic ash, etc.), fire spread, and storm surge

Ensemble Transform Kalman Filter (ETKF)

- Simplified version of EnKF
- Do not try to update ensemble mean, only to chose appropriate perturbations
- Accounts for the observations in choosing a method for re-scaling the perturbations
- New analysis perturbations are transformed as

$$\mathbf{X}^a = \mathbf{X}^f \mathbf{T}$$

- Perturbations are applied to U, V, T, P, q (no perturbations to q_{cl}, q_{cf}, SST or land-surface)

Ensemble Transform Kalman Filter (ETKF)

- Calculate the matrix of forecast ensemble perturbations in normalised observation space

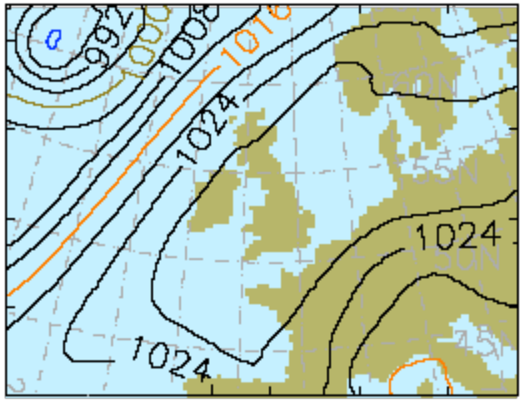
$$E = \left(R^{-1/2} H X^{f}\right)^{T} R^{-1/2} H X^{f}$$

- Find the eigenvectors and eigenvalues of this matrix (one will be zero).
- C is the kx$(k\text{-}1)$ matrix of non-zero eigenvectors, Γ is a $(k\text{-}1)$x$(k\text{-}1)$ diagonal matrix with non-zero eigenvalues

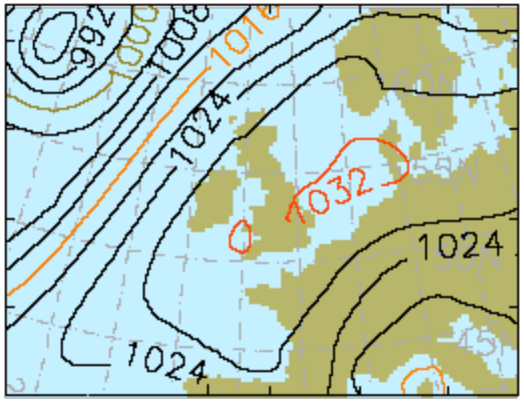
$$T = C\left(\Gamma + I\right)^{-\frac{1}{2}} C^{T}$$

- Transform matrix tells how to mix perturbations from different members – doesn't directly hold any spatial information

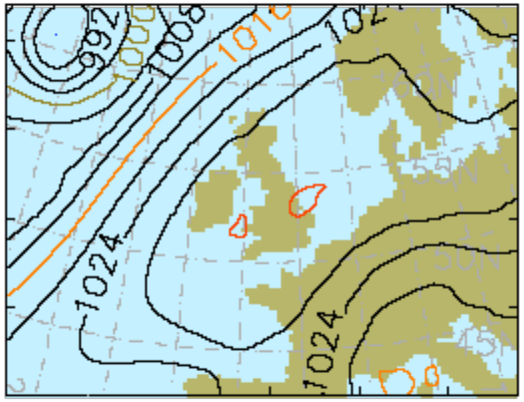
Error breeding

(

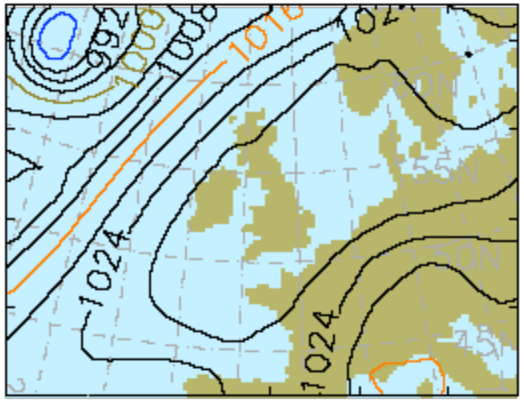
T+12 perturbed forecast

\- 

T+12 control forecast)

\+ 

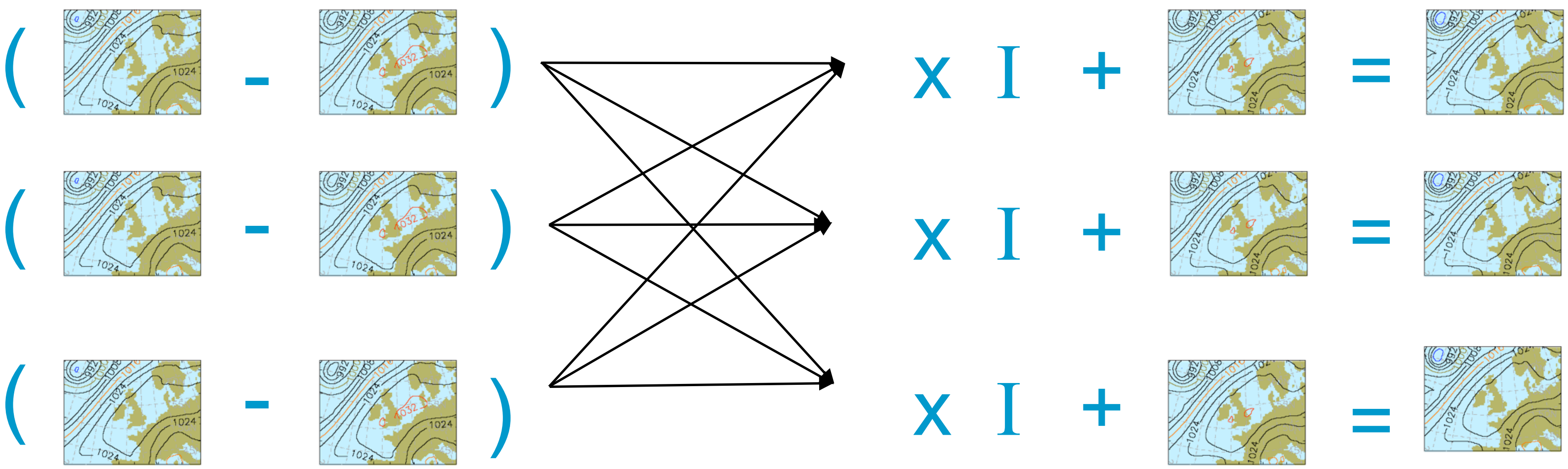
Control analysis

= 

Perturbed analysis

Ensemble Transform Kalman Filter (ETKF)

$$X^a = X^f T \Pi_n$$



T+12 perturbed forecast

T+12 ensemble mean forecast

Transform matrix

Inflation factor

Control analysis

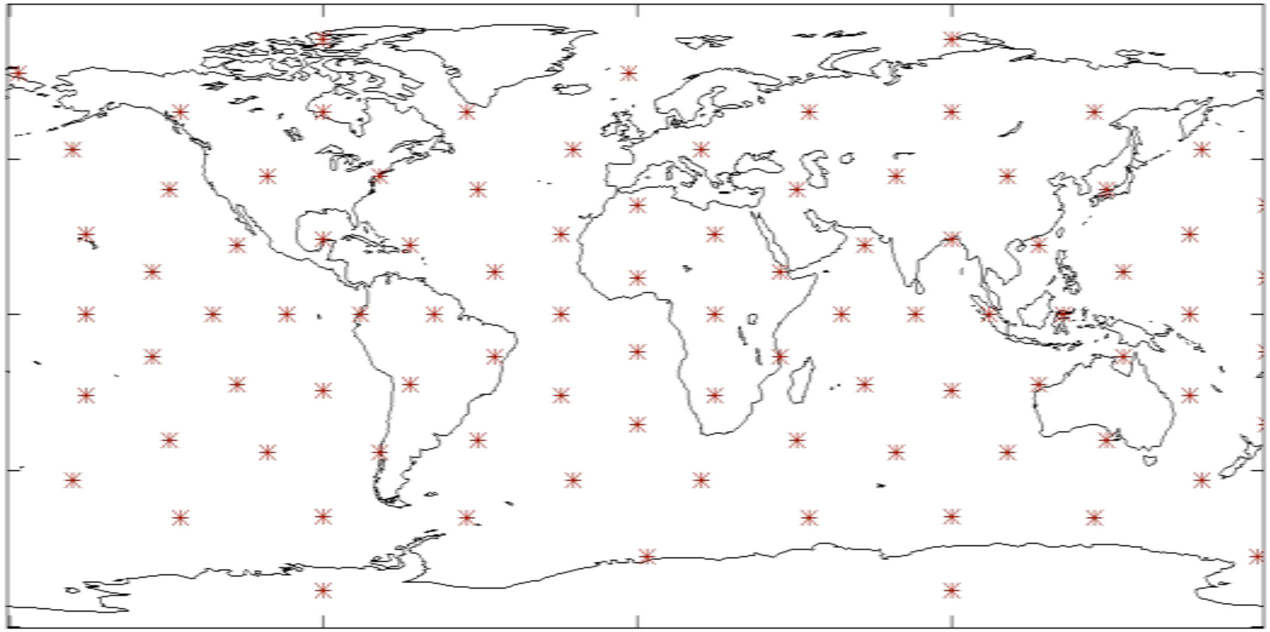
Perturbed analysis

Local ETKF – why we have to localise

Neill Bowler

- Only have 23 perturbed members (would ideally want 10,000+)
- Small sample will have spurious long-range correlations
- Growth of spread in tropics is slow (since the perturbation methods are not producing the right structures)
- Continual re-scaling will mean that the IC spread is too small where growth is slow

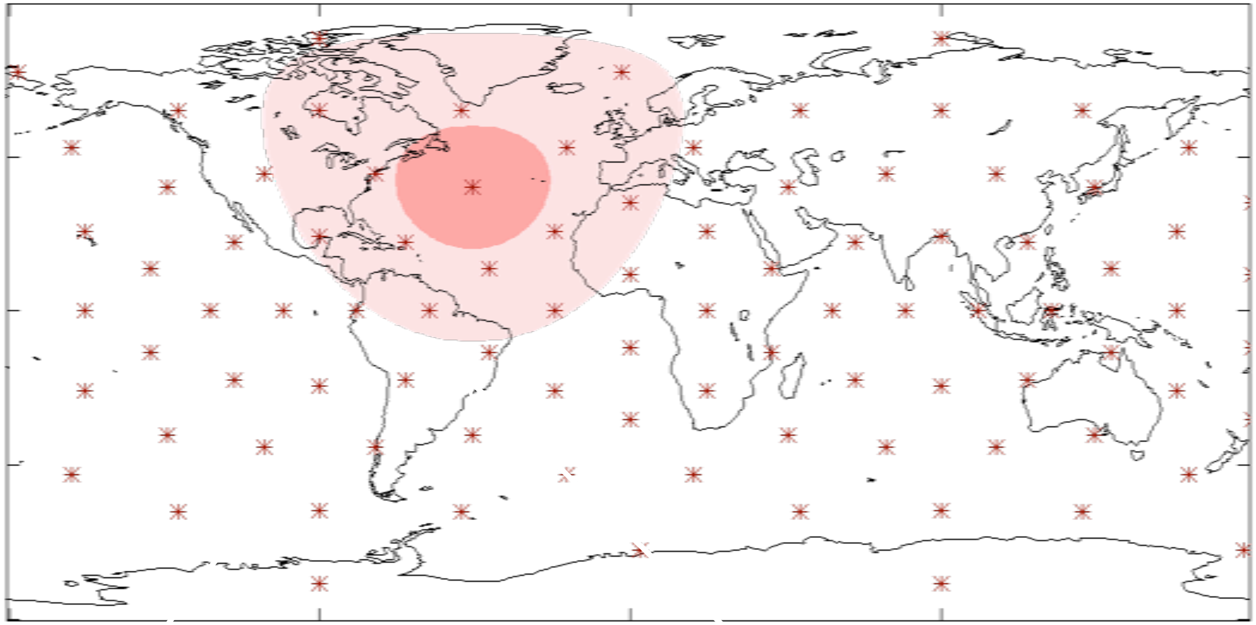
Local ETKF



Calculate transform matrix using observations local to a limited set of points, approximately evenly distributed around globe

Interpolate transform matrix to intermediate grid points

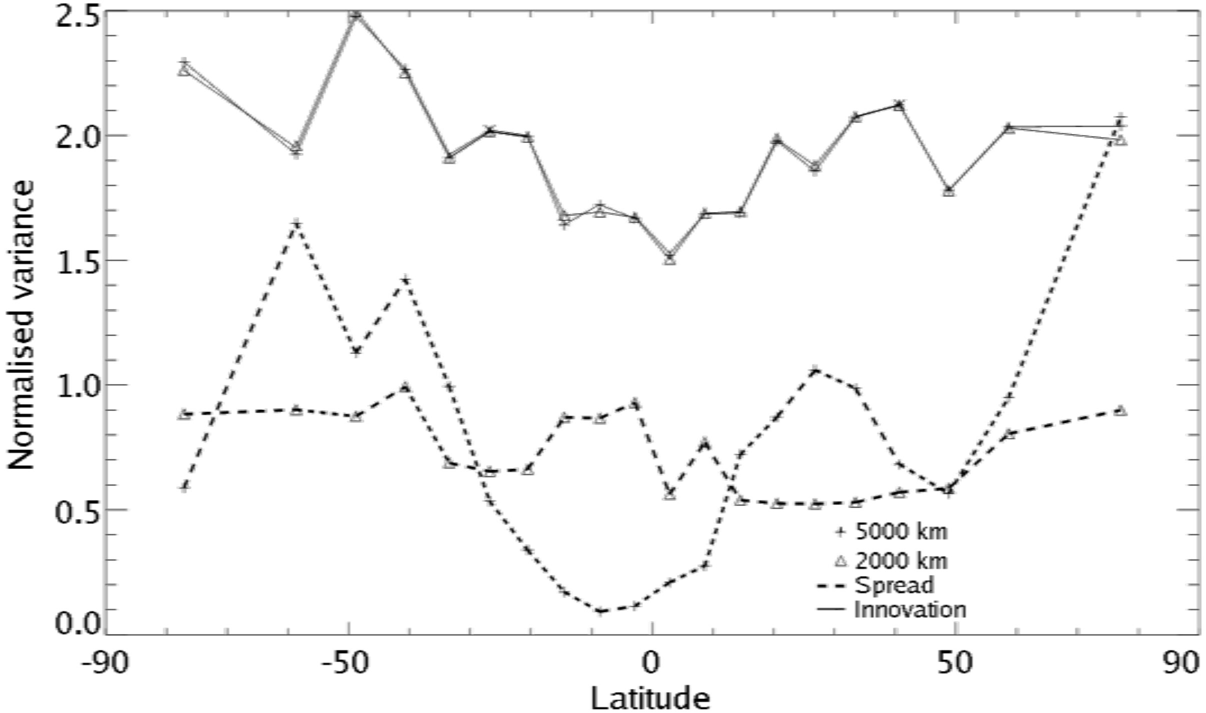
Revised localisation – 5000km -> 2000km



Large localisation used when only radio-sonde observation errors known (caused problems in tropics)

Tighter localisation possible with sonde and ATOVS observations available

Spread and Error Variance at T+12h (measured against radiosondes)

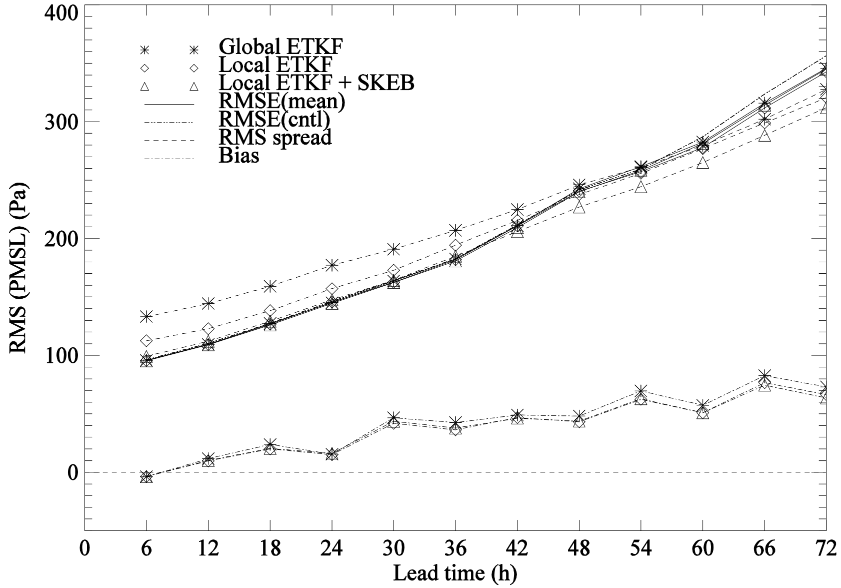


With larger localisation radius spread still too small in tropics

With small localisation radius, spread in tropics much larger, and spread in extra-tropics smaller

Results normalised by observation error, so ideally error=spread+1

Pressure at Mean Sea-Level – Spread and Error



Spread with global ETKF too large

Spread with local ETKF (and SKEB) in good agreement with error

Observation errors have been accounted for in error of ensemble mean

Stochastic Parameterizations: SKEB2

Alberto Arribas, Glenn Shutts & Warren Tennant

Rationale for Stocastic Kinetic Energy Backscatter

- Models have an excessive dissipation of kinetic energy; due to
  - Interpolation in semi-Lagrangian advection scheme
  - Limitations in the parameterisation scheme (e.g. Kinetic energy detrainment)
- Stochastic Kinetic Energy Backscatter – scheme to replenish excessively dissipated energy

Stochastic Physics: SKEB2

- SKEB2 = Stochastic Kinetic Energy Backscatter version 2
- A randomly initialised stream-function forcing field (Ψ) is created with specified spatial and temporal characteristics
- Calculate energy dissipation as a result of:
    - Numerical schemes: Smagorinsky-Lilly
    - Convection buoyancy: Mass-flux change * CAPE
- Modulate the random Ψ-field with the energy dissipation
- Calculate wind components from the Ψ-field and add to other wind increments from model physics at each time-step

AGREPS current status and near-term plans

- Initial AGREPS global and Australian regional systems at 80km & 37.5km have been implemented on NEC-SX-6
- AGREPS has been daily running in near-real-time since mid-2009, ceased now with changeover to Sun
- Porting to BoM Sun system now commencing, will allow more timely running and resolution increase
- GASP-EPS ensemble web displays have been enabled for AGREPS (and ECEPS)
- ECMWF Verify ensemble verification package has been installed, will be used for detailed quantitative probabilistic forecast validation
- Comparison of singular vector perturbations with ETKF perturbations in MOGREPS is being considered
- GOCF-type bias correction can be applied to AGREPS and ECEPS
- Investigation of approaches to combining deterministic and EPS forecasts in GOCF/GFE is planned

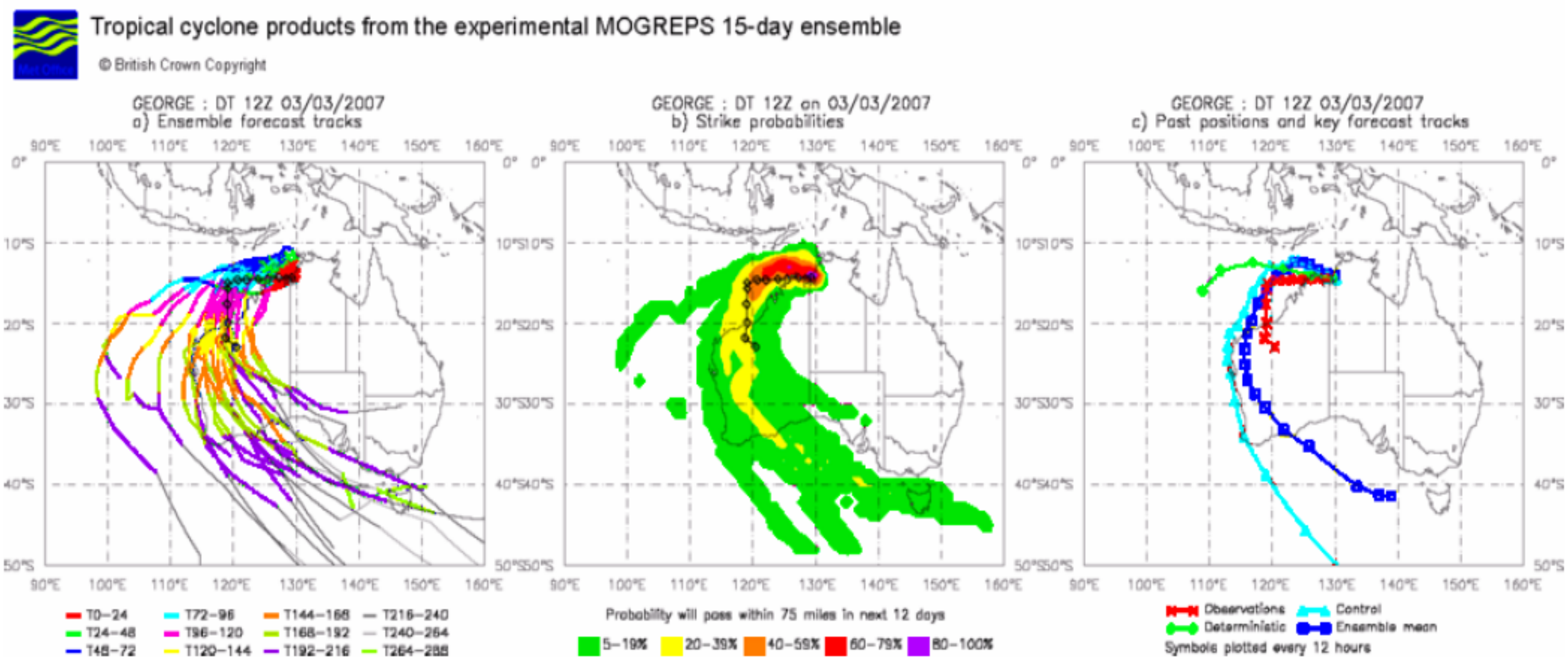
Collaboration opportunities

Obvious research collaboration potential for using EPS forecasts to drive downstream models for hydrological, oceanographic, severe weather impacts

Tropical cyclone ensemble charts

- Tropical cyclones are identified and tracked using 850hPa relative vorticity maxima
- Identifies new storms out to T+144

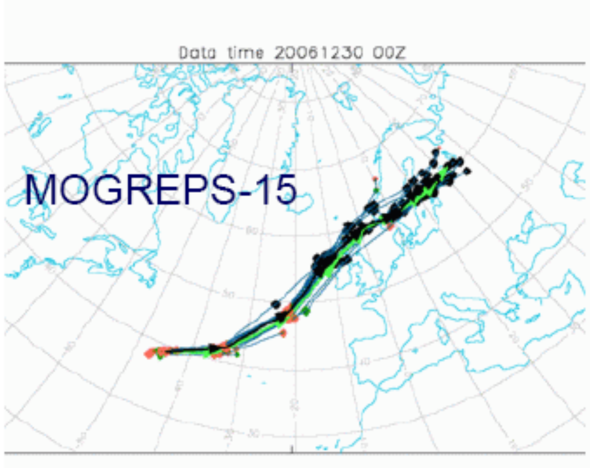
- Cyclone George: Landfall near Port Headland, winds 195km/hr, 3 deaths

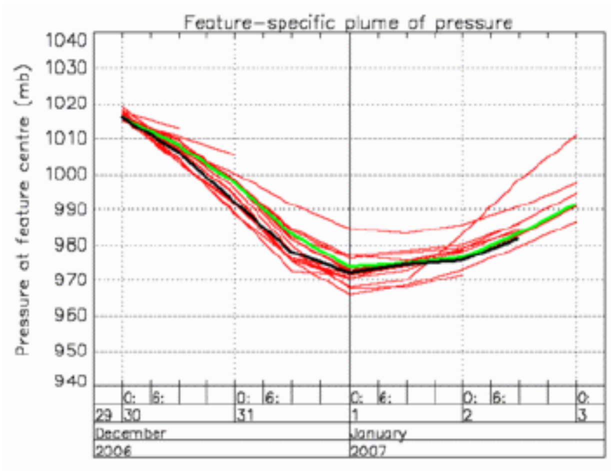


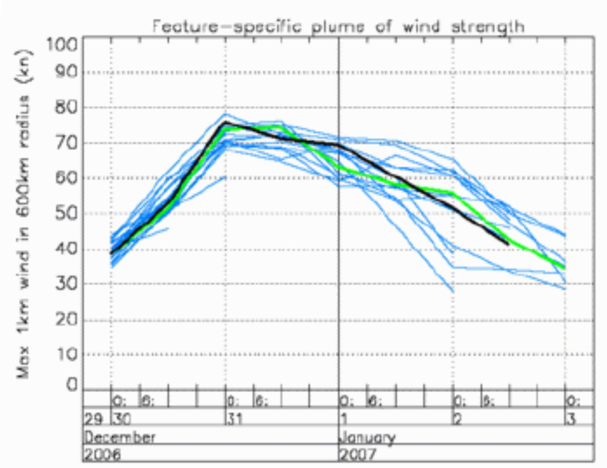
- Mean reduction in forecast errors for ensemble mean compared to deterministic:
- Similar up to T+72 • 12% at T+96 • 23% at T+120 (7 months data)

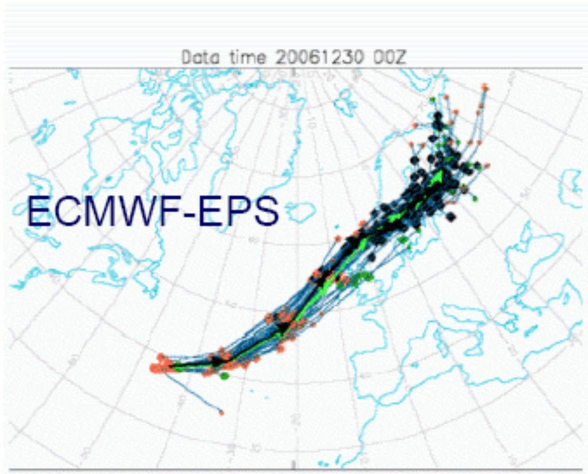
Cyclone database: 31/12/2006 example

- Clicking on a feature brings up feature-specific tracks from each ensemble member and matching plumes of intensity measures to identify the potential for high-impact weather

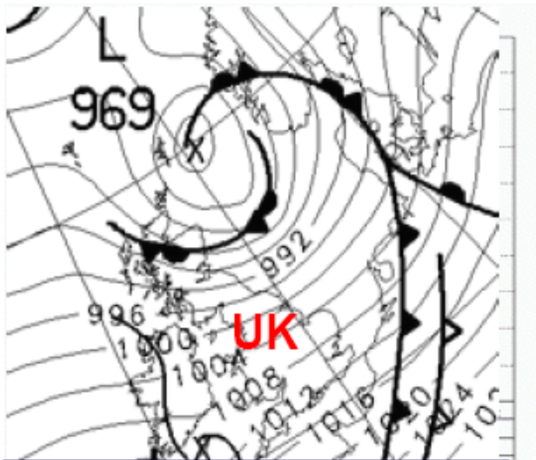








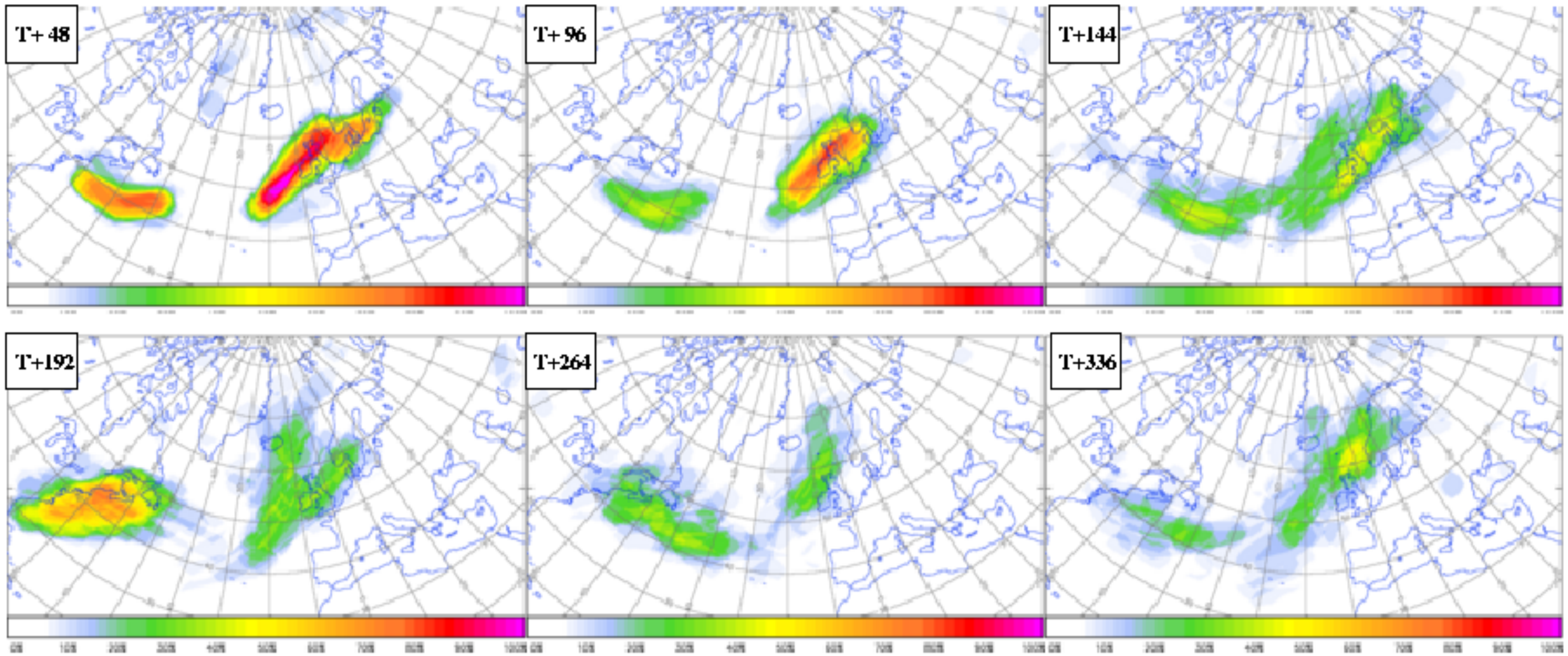
This storm tracked across Scotland, with gusts up to 100mph, leading to the high-profile cancellation of New Year's Eve celebrations and loss of power to 1000s of homes



Analysis 00Z 01/01/2007

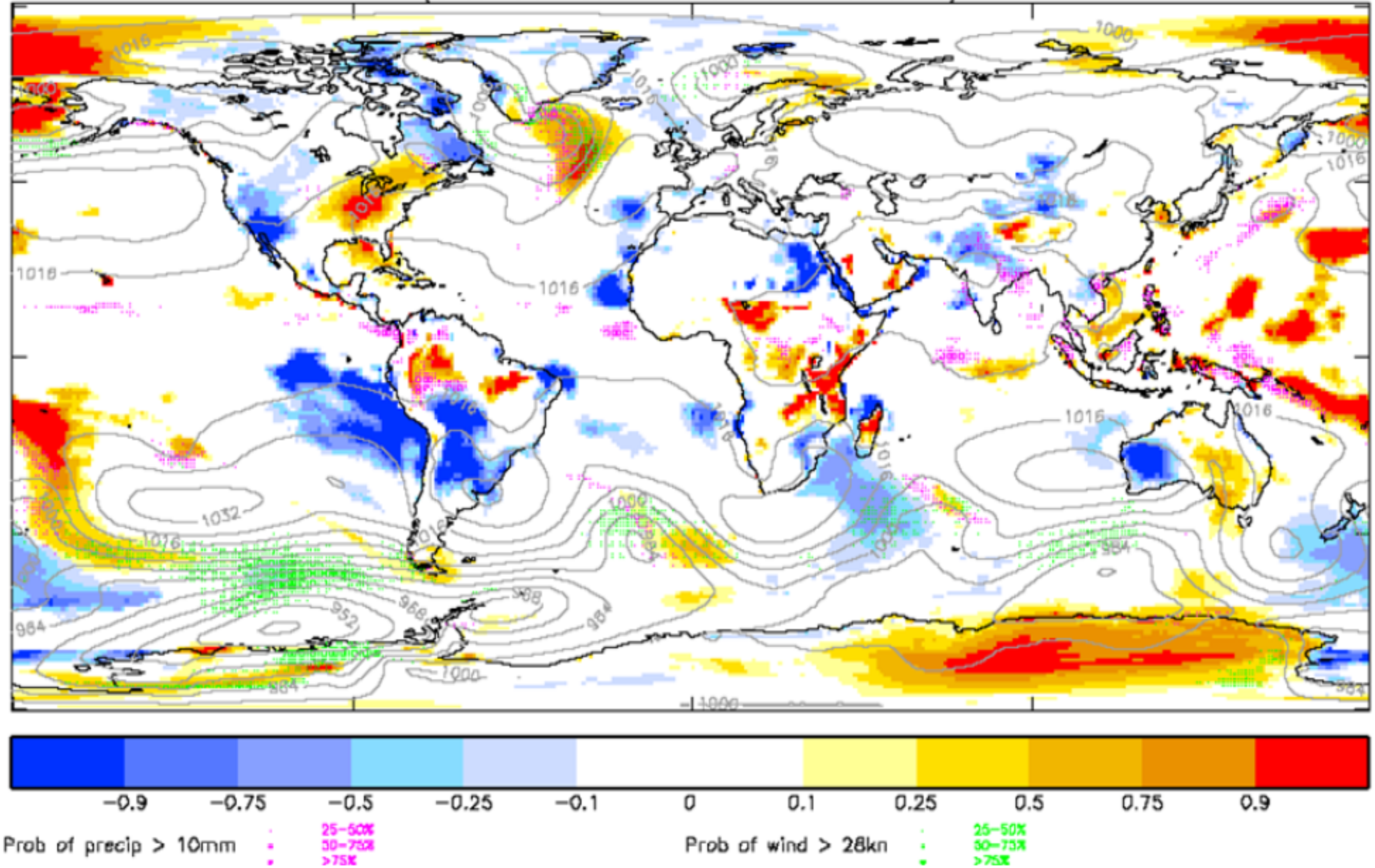
Strike probability plots

- At longer lead times, the uncertainty in tracking individual features increases (they may well not exist in the initial analysis).
- The strike probability plots give a broader indication of risk of storms, based on cyclone database data.
- Plots show number of MOGREPS-15 ensemble members with potential for surface gusts> 60 kt in each 24-hour period.

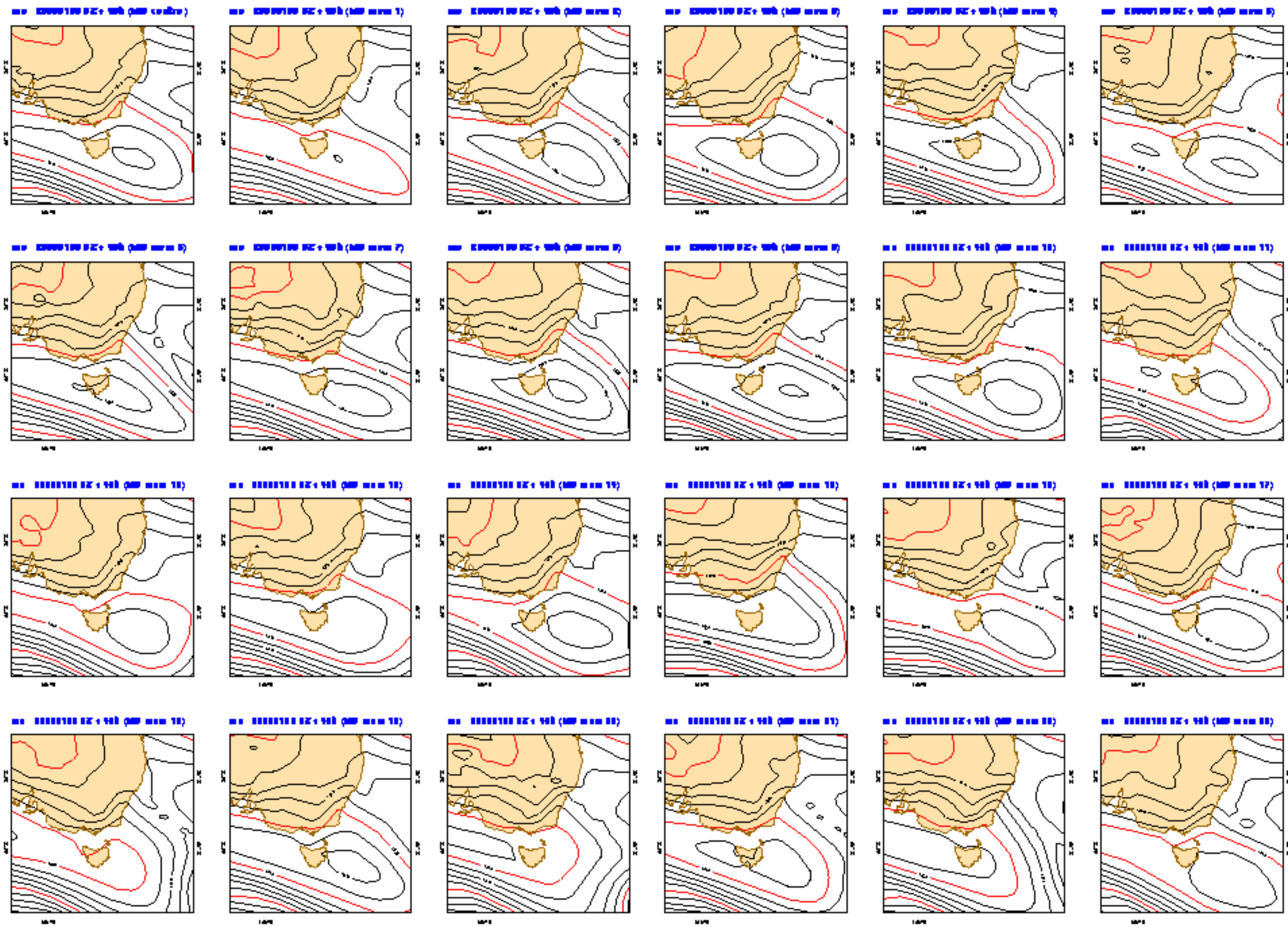


Combined high-impact weather risk map

MOGREPS-15 Probability map for 2m temp <5/>95th percentile,
12hr precip > 10mm, and 10m wind speed > 28kn
DT: 00Z Fri 21/09/2007 VT: 12Z Tue 25/09/2007 lead time 108h
(Ensemble mean PMSL overlain in contours)

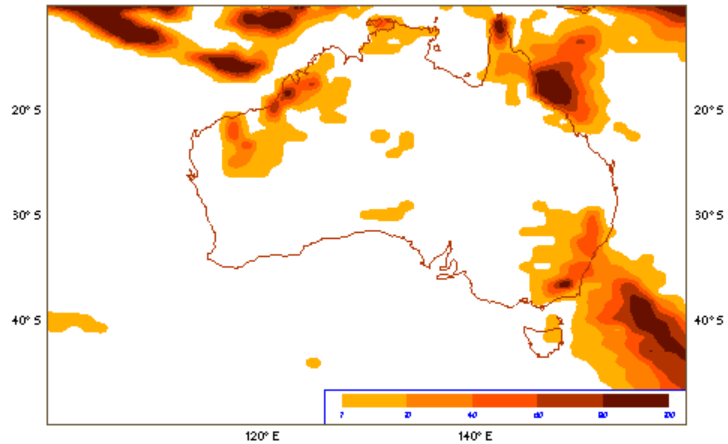


Example of experimental AGREPS run



Example of experimental AGREPS run

MOGREPS precip probabilities from 0Z 20080130
valid from +24h to +48h
thresholds:min 10 max 1000



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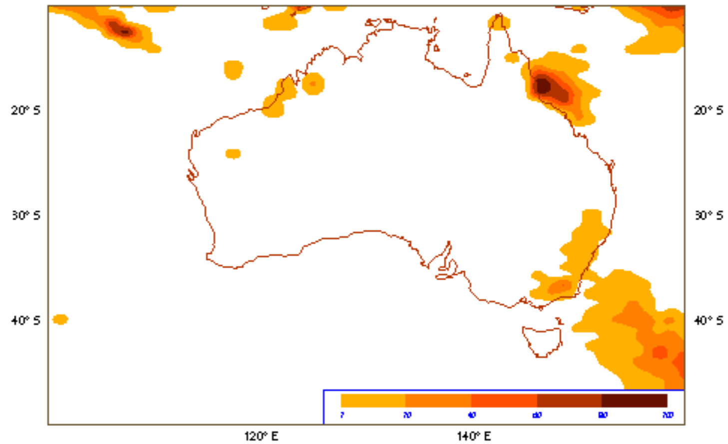
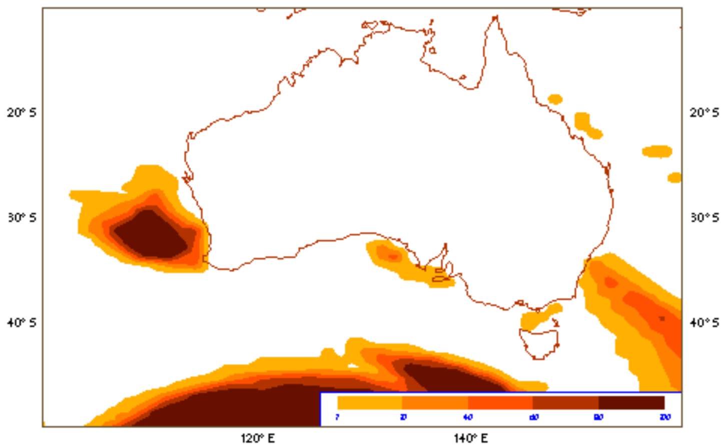
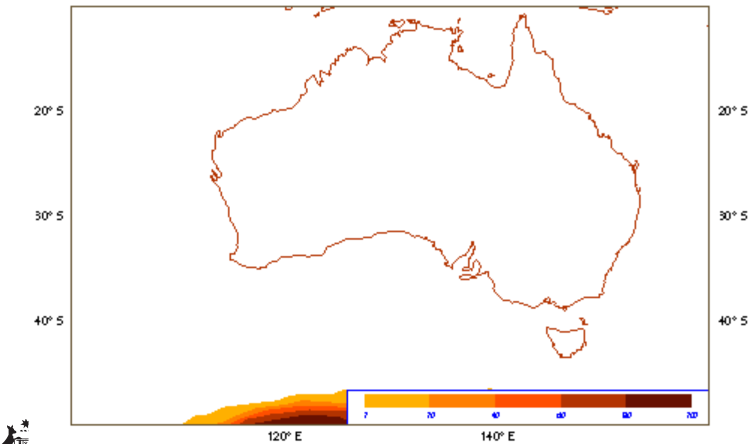


MOGREPS w10m probabilities from 0Z 20080130
valid for 48h
thresholds:min 10 max 1000



MOGREPS w10m probabilities from 0Z 20080130
valid for 48h
thresholds:min 15 max 1000



Questions & answers

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