Ensemble Prediction Systems and Probabilistic Forecasting
"The Blame Game" or "The Passing of The Buck"

Atmosphere

Scientists

Computer models

Forecaster

Customer/Public

The atmosphere is "chaotic"

Errorneous observations misled the NWP

The NWP misled me

The forecaster misled me
Understanding chaos
Numerical Weather Prediction

The Atmosphere

Analysis Error

Data Assimilation

Forecast distribution

Forecast

Diagnostic Tools and Products

Model System

2012-11-28
Quantifying uncertainty with ensembles

Initial Condition Uncertainty → Analysis

Climatological uncertainty

Forecast uncertainty

Deterministic Forecast

CHAOS

time
The Effect of Chaos

- We can *usually* forecast the general pattern of the weather up to about 3 days ahead.
- Chaos then becomes a major factor

Tiny errors in our analysis of the current state of the atmosphere lead to large errors in the forecast – these are both equally valid 4-day forecasts.

- Fine details (eg rainfall) have shorter predictability
Ensembles

- In an ensemble forecast we run the model many times from slightly different initial conditions.
- This provides a range of likely forecast solutions which allows forecasters to:
  - assess possible outcomes;
  - estimate risks;
  - gauge confidence.
Reminder on scales and predictability
Temporal Resolution

<table>
<thead>
<tr>
<th>Space Scale</th>
<th>Lifetime</th>
<th>Predictability?</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 km</td>
<td>10 mins</td>
<td>30 mins</td>
</tr>
<tr>
<td>10 km</td>
<td>1 hr</td>
<td>3 hrs</td>
</tr>
<tr>
<td>100 km</td>
<td>12 hrs</td>
<td>36 hrs</td>
</tr>
<tr>
<td>1000 km</td>
<td>3 days</td>
<td>9 days</td>
</tr>
</tbody>
</table>

Tropical Cyclone

MCS Front

Thunderstorm

Hail shaft
MOGREPS
Short-range Ensembles

ECMWF EPS has transformed the way we do Medium-Range Forecasting

• Uncertainty also in short-range:
  – Rapid Cyclogenesis often poorly forecast deterministically
  – Uncertainty of sub-synoptic systems (eg thunderstorms)
  – Many customers most interested in short-range

• Assess ability to estimate uncertainty in local weather
  – QPF
  – Cloud Ceiling, Fog
  – Winds etc
Initial conditions perturbations

• Perturbations centred around 4D-Var analysis
• Transforms calculated using same set of observations as used in 4D-Var (including all satellite obs) within +/- 3 hours of data time
• Ensemble uses 12 hour cycle (data assimilation uses 6 hour cycle)
Initial conditions perturbations

Differences with ECWMF Singular Vectors:

- It focuses on errors growing during the assimilation period, not growing period:
  - Suitable for Short-range!

- Calculated using the same resolution than the forecast

- ETKF includes moist processes

- Running in conjunction with stochastic physics to propagate effect
Model error: parameterisations

Random parameters

- QUMP (Murphy et al., 2004)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Scheme</th>
<th>min/std/Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entrainment rate</td>
<td>CONVECTION</td>
<td>2 / 3 / 5</td>
</tr>
<tr>
<td>Cape timescale</td>
<td>CONVECTION</td>
<td>30 / 30 / 120</td>
</tr>
<tr>
<td>RH critical</td>
<td>LRG. S. CLOUD</td>
<td>0.6 / 0.8 / 0.9</td>
</tr>
<tr>
<td>Cloud to rain (land)</td>
<td>LRG. S. CLOUD</td>
<td>1E-4/8E-4/1E-3</td>
</tr>
<tr>
<td>Cloud to rain (sea)</td>
<td>LRG. S. CLOUD</td>
<td>5E-5/2E-4/5E-4</td>
</tr>
<tr>
<td>Ice fall</td>
<td>LRG. S. CLOUD</td>
<td>17 / 25.2 / 33</td>
</tr>
<tr>
<td>Flux profile param.</td>
<td>BOUNDARY L.</td>
<td>5 / 10 / 20</td>
</tr>
<tr>
<td>Neutral mixing length</td>
<td>BOUNDARY L.</td>
<td>0.05 / 0.15 / 0.5</td>
</tr>
<tr>
<td>Gravity wave const.</td>
<td>GRAVITY W.D.</td>
<td>1E-4/7E-4/7.5E-4</td>
</tr>
<tr>
<td>Froude number</td>
<td>GRAVITY W.D.</td>
<td>2 / 2 / 4</td>
</tr>
</tbody>
</table>
MOGREPS products

MOGREPS (Global)  Spaghetti chart for 1000-500hPa Thickness
DT 00Z on 04/07/2006  VT 18Z on 04/07/2006  lead time 18h
510/528/546/564/582 dam (Black lines represent Control member)
(Ensemble Mean PMSL plotted as faint background)

MOGREPS (Global)  Probability map for 10m Wind Speed > 34.0 knots
DT 00Z on 04/07/2006  VT 06Z on 06/07/2006  lead time 54h
(Ensemble Mean PMSL plotted as faint background)

MOGREPS (Global)  Probability map for 24 hour Precip > 10.0 mm
DT 00Z on 04/07/2006  VT 06Z on 06/07/2006  lead time 54h
(Ensemble Mean PMSL plotted as faint background)

MOGREPS (Global)  Probability map for 48 hour Precip > 0.9 mm
DT 00Z on 04/07/2006  VT 06Z on 06/07/2006  lead time 54h
(Ensemble Mean PMSL plotted as faint background)
Using probabilities
Using probabilities

• Recipients of forecasts & warnings are sensitive to different levels of risk: reflecting cost of mitigation vs expected loss
• An intelligent response to forecasts & warnings depends on risk analysis, requiring knowledge of impact probability
• Use of ensembles to estimate probability at longer lead times is well established in meteorology
Ensemble forecast products
Stamp maps and clusters
Products: Stamp maps

ECMWF ENSEMBLE FORECASTS
Monday 13 March 2006 00UTC ECMWF Forecast t+108 VT; Friday 17 March 2006 12UTC Surface: mean sea level pressure MSLP (contour every 5hPa) and Temperature at 850hPa (only 1 and 10 isolines are plotted)

All 50 EPS member
ECMWF Ensemble Forecast Clusters

Operational Forecast in cluster 2

Control Forecast in cluster 1

Cluster 1: 30 Forecast(s)
Cluster 2: 21 Forecast(s)
Cluster 3: 0 Forecast(s)
Cluster 4: 0 Forecast(s)
Cluster 5: 0 Forecast(s)
Cluster 6: 0 Forecast(s)
Probability maps
EC Total ppn prob > 20mm 12z Tue – 12z Wed
EPSgrammes
2012-11-28

- Total cloud cover
- 6 hourly precipitation
- 10m wind speed
- 2m temperature

**Deterministic**

- EPS control

**Median (50%)**

- Max
- Median
- 90%
- 75%
- 25%
- Min
- 10%

**EPS control**

- 2m temperature (°C)
- 14:54m (T709) 14:20m (T395)
The Extreme Forecast Index (EFI)
Extreme forecast index (EFI)

• EFI measures the distance between the EPS cumulative distribution and the model climate distribution

• Takes values from –1 (all members break climate minimum records) and +1 (all beyond model climate records)

• The main idea is to have an index that can be conveniently mapped – removing the effect from different climatologies – to use as an “alarm bell”
Advantages with probability density functions
Means and asymmetric variances are easily spotted

Climate mean

EPS mean

Climate distribution

EPS distribution

Temperature
Advantages with probability density functions
Means and asymmetric variances are easily spotted
The EFI generally does not take the probability into account.
For temperature the EFI can take values < 0

EFI ~ 50%

EFI ~ -50%
Weather anomalies predicted by EPS: Thursday 06 November 2008 at 00 UTC
1000 hPa Z ensemble mean (Thursday 06 November 2008 at 12 UTC)
and EFI values for 24h TP, 10m wind gust and 2m temperature
valid for 24 hours from Thursday 06 November 2008 at 00 UTC to Friday 07 November 2008 at 00 UTC
Weather anomalies predicted by EPS: Thursday 06 November 2008 at 00 UTC
1000 hPa Z ensemble mean (Monday 10 November 2008 at 12 UTC)
and EFI values for 24h TP, 10m wind gust and 2m temperature
valid for 24hours from Monday 10 November 2008 at 00 UTC to Tuesday 11 November 2008 at 00 UTC
Product under development

Thursday 6 November 2008 00UTC © ECMWF Extreme forecast index t+096-120 VT: Monday 10 November 2008 00UTC - Tuesday 11 November 2008 00UTC
Surface: 10 metre wind gust index
Product under development

Thursday 6 November 2008 00UTC. ECMWF Extreme forecast index t+000-120 VT: Thursday 6 November 2008 00UTC - Tuesday 11 November 2008 00UTC.

Surface: Total precipitation index.

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Working with the EPS

- Ensemble mean acts as a dynamic filter and removes normally unpredictable features
- The removed features are put back in a consistent way as probabilities
Would you guide the ships to go steer into Newcastle harbour??
Questions & Answers