Diagnostics 1

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Training course: Predictability & ocean-atmosphere ensemble forecasting

1 March 2019, ECMWF
Animation of a very poor medium-range single forecast

Potential Vorticity on the Potential Temperature = 320K surface. 20110410 0 UTC. Step (days, hours) = 0 00.0

**Observed**

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<table>
<thead>
<tr>
<th>PVU</th>
<th>-10</th>
<th>0</th>
<th>0.3</th>
<th>1</th>
<th>2.3</th>
<th>4</th>
<th>7</th>
<th>20</th>
</tr>
</thead>
</table>

**Forecast**

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<table>
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<th>PVU</th>
<th>-10</th>
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We see the mixing of air masses. The eventual block (high pressure) over Northern Europe is not well predicted. With a single forecast, it is easy to quantify the error (pointwise differences, pattern correlations etc.)
A bust is defined as when the day-6 Z500 forecast has European RMSE $>$ 60m \textit{and} ACC $<$ 40%.
Composite conditions during a bust

Using all 584 ERA Interim busts that occurred between the dates 1 January 1989 - 24 June 2012.

Rodwell et al, 2013, BAMS

European Centre for Medium-Range Weather Forecasts

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Average initial conditions of 584 single forecast “busts” over Europe at day 6

Rodwell et al, 2013, BAMS

**a** Z500 anomaly

Trough over the Rocky mountains, with high convective potential ahead
Conducive to the formation of mesoscale convection

Analysis highlights geographically-fixed factors. Other flow-features (extratropical transition of tropical cyclones and cyclogenesis) have also been shown to be important for some busts.

**b** CAPE anomaly

‘CAPE’ = Convective Available Potential Energy
PV budget at 330K for trough/CAPE composite

Contours: PV anomaly
Shading: PV tendency

Largely the wave is being advected downstream
But, by modifying the stratification, diabatic processes appear to oppose the advection term and slow the propagation of the wave
Not just a symptom of the wave, but an active ingredient in the downstream bust

Composite over 95 trough/CAPE events 25 June 2010 – 20 March 2012 (0 or 12UTC) where operational analysis has projection onto Rockies trough > 3 and onto CAPE > 1. Contours show Potential Vorticity (PV) anomaly, shading shows (a) local tendency, (b) adiabatic advection and (c) material PV tendency (due to diabatic & frictional processes; deduced as the residual in the PV budget) on the 330K surface (∼250hPa)

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Rodwell et al, 2013, BAMS
Distribution of RMSE Z500 over Europe

Shape of distribution is independent of lead-time
Limited by zero error, so inevitably a longer tail at large error
How important for the seasonal-mean score are cases where the error > 2SD?
Impact of frequency of poor forecasts on seasonal-mean Z500 RMSE over Europe

The impact of 1SD in poor forecast frequency equates to close to 1SD in seasonal-mean score.

![DJF scores versus busts. RMSE for Europe 2010–2018](image)

![MAM scores versus busts. RMSE for Europe 2010–2018](image)

![JJA scores versus busts. RMSE for Europe 2010–2018](image)

![SON scores versus busts. RMSE for Europe 2010–2018](image)
Back to the single bust case: All forecast centres suffered

Spatial Anomaly Correlation Coefficient for 500 hPa geopotential height in [12.5°W–42.5°E, 35°N–75°N]. Date is forecast start

All centres suffered
Suggests an issue of reduced “predictability”
Look at the ensemble
Potential Vorticity on the Potential Temperature = 320K surface. 20110410 0 UTC. Step (days, hours) = 0 00.0
Ensemble members start from very similar conditions. Differences account for our uncertainty in the truth and are almost imperceptible to the eye here.

Differences then grow with lead-time and the members become completely different beyond about day 4.

Member 32 agrees well with the observed outcome. Simply a case of low predictability? How do we make progress?
Potential Vorticity on the Potential Temperature = 320K surface. 20110404 0 UTC. Step (days, hours) = 0 00.0
For this start-date, there were many more good* forecasts
(*RMSE less than second best member in the bust case)
Motivation: Reliability and Sharpness

In a **reliable** forecast system, the truth should be statistically indistinguishable from the individual ensemble members. Reliability is very useful: an event predicted to occur with probability 12% will happen with frequency 12%.

An easily testable consequence of reliability is that

\[
\text{Error}^2 = \text{Spread}^2
\]

(averaged over many forecast start dates)

“The task of NWP research is to maintain/improve reliability while decreasing spread (improving refinement)”

Q. Can we develop diagnostics which efficiently (optimally?) guide us in this task?
Ensemble spread and error

500 hPa geopotential height (Z500). “Error” is RMS of ensemble-mean error
Spread = ensemble standard deviation (scaled to take account of finite ensemble size)

Overall Error and Spread have reduced and come into alignment; due to better observations, initial conditions, forecast model and better representation of uncertainty

…but we make ensemble forecasts to represent the day-to-day variations in predictability and uncertainty. Can we evaluate it in our forecasts?

Annual means N.Hem. (ECMWF)

Timeseries for Europe at D+6 (TIGGE)

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Rodwell et al. 2018, BAMS
Improving sharpness through ensemble data assimilation

Data: Temperature at 200 hPa from 10-member EDA, valid at 6UTC

Uncertainties in the prediction of mesoscale convection magnify first-guess spread.
Assimilation of new observations acts to sharpen the distribution.

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Animation of ECMWF ensemble forecast spread 20170305 12Z D+0 to 6: $\sigma_{Z_{500}}$

ECMWF ENS stdev $Z_{500}\text{hPa}$ (shaded).

20170305 12Z

Unit: m

Uncertainty growing from various sources, is itself advected, and becomes large over Europe by D+6
Ensemble forecast spread and the quasi-instantaneous growth of uncertainty

Look for sources of uncertainty growth about the truth trajectory.

‘Instantaneous’ (~12h) uncertainty growth. Use EDA background forecast ensemble.
“Lagrangian” growth-rate (following EnsMn horizontal flow) for EDA background $\sigma_{PV315}$

Much uncertainty growth associated with moist processes: Warm Conveyor-Belts, and Meso-Scale Convection

Interaction of uncertain features, large ENS spread & poor prediction of Euro blocking at D+6

Aim: Evaluate short-range synoptic flow-dependent representation of uncertainty

Q: Is sensitivity to moist processes real or due to deficiencies in model uncertainty representation? TIGGE?

20170307 05Z

Unit: 0.01h⁻¹

$PV_{315}=2 \& \nu_{950}$ from control forecast, precipitation is ensemble-mean. 1d running-mean gives 12h-integrated growth rate with any diurnal cycle removed. T21 smoothed
TIGGE 12h “Lagrangian” growth rate (following Ens-mean horizontal flow) for $Z_{250\text{hPa}}$ (shaded)

CF 850hPa winds (vectors), CF $Z_{250\text{hPa}}$ (green contour) and EM precip (dots). 1d running-mean applied.

ECMWF 20170305 12Z  \[ \frac{1}{\sigma_Z} \left( \frac{\partial \sigma_Z}{\partial t} + \mathbf{v}_p \cdot \mathbf{\nabla}_p \sigma_Z \right) \]  2 mm$h^{-1}$  30 ms$^{-1}$

Unit: 0.01h$^{-1}$  300 m

JMA 20170305 12Z

KMA 20170305 12Z

UKMO 20170305 12Z

EDA(PV$_{315K}$) ≈ ENS(Z$_{250\text{hPa}}$) ≈ JMA.

UKMO: MCS less, Europe more. KMA less everywhere(?) Which is best?
Ensembles start from a different initial uncertainties, but growth-rate (in linear regime) should be unaffected.

TIGGE 12h Standard deviation in $Z_{250\text{hPa}}$ (shaded) ~Initial uncertainty of ensemble
CF 850hPa winds (vectors), CF $Z_{250}$ (green contour) and EM precip (dots). 1d running-mean applied.
“Lagrangian” growth-rate for $\sigma_{PV_{315}}$: NAWDEX Vladiana & TC Karl

$PV_{315}$ and $\nu_{380}$ from control forecast, precipitation is ensemble-mean. 1d running-mean gives 12h-integrated growth rate with any diurnal cycle removed. T21 smoothed

$\frac{1}{\sigma_{PV}} \left( \frac{\partial \sigma_{PV}}{\partial t} + \bar{\nu}_\theta \cdot \nabla_\theta \sigma_{PV} \right)$

Heavy precipitation from AR associated with Karl 09/27-30

WCB ahead of Vladiana 09/22-24

Magnification of uncertainty during ET of TC Karl 09/25-27
"Lagrangian" growth-rate for $\sigma_{PV_{315}}$: NAWDEX Sanchez

$PV_{315}=2$ & $v_{500}$ from control forecast, precipitation is ensemble-mean. 1d running-mean gives 12h-integrated growth rate with any diurnal cycle removed. T21 smoothed

Heavy rainfall as TC Matthew makes landfall 10/08-10. ET leads to AR and heavy precipitation over Iceland 10/12-13

Interaction between low-level Sanchez & PV cut-off 10/08-09. Heavy precipitation over France & Italy 10/13-
Forecast for precipitation in Montpellier, southern France

Once uncertainties associated with the interaction between Sanchez and the upper-level PV cut-off are resolved, the probability for strong precipitation over southern France firms-up. Note the different y-axes.