Met Office post-processing of operational NWP forecasts

Andrew Bennett, Ian Pearman, Stephen Moseley, Caroline Jones, James Canvin, Simon Jackson, Bruce Wright (etc)

Post-Processing R&D, Met Office, UK
Contents

• Introduction & context
• Downscaling techniques
• Added value diagnostics
• Nowcasting techniques
• Bias correction
• Optimal blended forecasts
• Verification
• The future
• Summary
Context
Why post-processing?
Comprehensive NWP suite: deterministic

Global
- 17km 70 Levels
- 48 hour forecast twice/day
- 6 day forecast twice/day

Euro4
- 4.4km 70 Levels
- 60 hour forecast twice/day
- 5 day forecast twice/day

UKV
- 1.5km 70 Levels
- 36 hour forecast eight times/day

NAE retired
(our old regional model)
Comprehensive NWP suite: ensembles

MOGREPS-G
- 33km 70 Levels
- 7 day forecast 4 times/day
- 12 members

MOGREPS-R retired
(our regional ensemble)

MOGREPS-UK
- 2.2km 70 Levels
- 36 hour forecast four times/day
- 12 members
In this half hour, we focus on…

Post-Processing

1.1 billion
Pieces of forecast information at any one time
The role of post-processing: Adding value

- Quality Automated Forecasts
  - Up to 2 weeks ahead
  - Public, Government & Commercial customers

- Improve on model skill
  - Statistical correction
  - Adding detail
  - Observations and nowcasting
  - Never degrade model output

- Integration of ensemble and deterministic models
  - Ensembles essential for quantifying uncertainty

- Optimal, multi-model blending
Standard forecast information

model-independence

NWP model-specific forecast information

Standard forecast information

User-specific forecast information

Break the direct link between:

- NWP model
- Customer products & services

Provide a controlled bridge between producer and customer, to ensure:

- A change to one does not affect other (i.e. no costs incurred away from the change)
- Standardised, single source of data
Downscaling
Downscaling

Standard grids

Regular Arakawa-A grids

Standard Coordinate Reference Systems in common use

2 km

5 km

~17 km at mid-latitudes (0.2252 deg)
Downscaling techniques

Nearest point

- Unadjusted value from the nearest available UM grid-point
- Used for non-linear fields:
  - precipitation rate,
  - accumulation
  - cloud
  - SW and LW radiation fluxes
  - snow melt
  - soil evaporation
Downscaling techniques

Bilinear interpolation

- Spatially adjusted value from the four nearest available UM grid-points
- Used for slowly varying fields

Pressure at mean sea level
UV radiation flux
Aerosol and water-content (for visibility)
Boundary-layer depth
Snow depth
Wet-bulb freezing level

Weight proportional to $1/x$
Downscaling techniques

Trilinear interpolation

• 3D Spatially adjusted value from the four nearest available UM grid-points at the nearest levels

• Used for linear fields on vertical levels
  Temperature
  Relative Humidity

• With additional interpolation below lowest model level (using level 1-2 model lapse rate)
  Pressure
Downscaling techniques

Intelligent grid-point selection
- Uses model grid-point most closely matching target grid-point for land/sea status and orographic height.

Surface temperature
Soil diagnostics
Downscaling techniques:

Wind

- UM parameterisation employs high surface stress
  - Improves synoptic flow
  - Too slow for near-surface winds
- Correction in free atmosphere
  - Trilinear interpolation in free-atmosphere
- Correction in boundary layer
  - Near-surface points re-calculated by selecting lowest free-atmosphere point and applying log profile with more realistic drag-coefficient
  - Not required for the highest resolution models


© Crown copyright  Met Office
Wind downscaling

Before

After


© Crown copyright  Met Office
Downscaling techniques:

**Screen temperature**

Screen temperature

- Between two model levels: trilinear interpolation
- Below lowest model level (unresolved valley):
  - Lapse rate estimated from lowest model level variation of temperature with model orography
  - Prevention of super-adiabatic lapse rate (limited to dry adiabatic rate)
  - Apply lapse rate correction according to height difference to nearest model grid point
  - For inversion (lapse rate > 0) limit correction to 70m (prevents excessively cold valleys on stable nights)


© Crown copyright   Met Office
Added detail: 4km MetUM

Before downscaling

After downscaling

© Crown copyright Met Office
Added detail: 1.5km MetUM

Before downscaling

After downscaling
Site-specific downscaling

Model
levels

Coastal
Adjustment

Model
land
point

Wind

Model sea
point

Site-specific downscaling

© Crown copyright Met Office
Added value diagnostics
Derived diagnostics

- Precipitation type
- Visibility
- Cloud Diagnostics (height of base/top etc)
- Probabilities e.g.
  - Fog
  - Precipitation (with spatial and temporal neighbourhood)


© Crown copyright  Met Office
Severe Convective Weather

- Tornado probability
- Hail size
- Convective inhibition
- CAPE
- Low-level wind characteristics
- Lightning risk


© Crown copyright Met Office
Nowcasting
Exploiting the latest information

- Current forecast models do not have the update frequency to be reliable
- Use extrapolation techniques to ‘fill the gap’
Precipitation analysis
STEPS
Modelling framework

• Scale-decomposition framework
• Seamless combination of nowcast & NWP forecasts
• Noise used to generate ensembles & downscale NWP
• Accounts for radar error


© Crown copyright  Met Office
Other Nowcast Products

- Precipitation
  - accumulations
  - probability of snow

- Visibility
  - screen visibility
  - fog probabilities
  - screen temperature & dew point
  - cloud amount and base
Bias correction
Kalman Filtering

- Operationally used on sites
  - where observations available
  - ~30 day memory
  - Applied on all model inputs
  - Screen temperatures and 10m winds

12-24 hour gain in skill

Simon Jackson
James Canvin
Optimal blended forecasts
Combining Forecast Systems

Forecast system 1

Forecast system 2

Blend of system 1 + system 2

Error Reduction

Observation

Error

Error of Blend

Error Reduction
Optimal blended forecasts

- Blend of site-specific forecast data
  - Generic
  - Single source for downstream systems
- Updated every NWP model run and nowcast
- Includes deterministic and ensemble model data
  - Represented by PDF
  - Captures extremes as well as “most likely”
Lagging & blending

- Start with a single model
- Add a model with the same weighting
- Add another model with a lower weighting
- And another with a much higher weighting

- Includes multiple updates of same model (lagging)
- Weights depend on model and lead-time, optimised to reduce overall error
- Pragmatic approach
Blended diagnostics

- Temperature (hourly, day max, night min, surface)
- ‘Feels Like Temperature’
- Wind (speed, direction, gust)
- Visibility
- Relative Humidity
- Pressure
- UV Index
- Precipitation (amount, rate)
- Snow (amount, depth)
- Sunshine Duration
- Parameters for route based forecasting sites
- Dew Point Temperature
- Surface Temperature
- Cloud Base Height (3, 5, 7 Okta)
- Cloud Amount (<200ft, Low, Medium, High, Total)
- Short Wave Down Radiation (Instantaneous/Integrated, Direct/Diffuse)
- Freezing level (Wet Bulb & Dry Bulb)
- Probabilities (Precip, Snow, Heavy Snow, Rain, Heavy Rain, Hail, Lightning, Mist, Fog, Sunshine/Clear Sky)
Verification
Verification: gridded post-processed

NWP UK Index components for March 2010
Comparing UK gridded post-processing against UK 4km MetUM

<table>
<thead>
<tr>
<th>Skill Score Temperature</th>
<th>0.4483</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skill Score Vector Wind</td>
<td>0.2573</td>
</tr>
<tr>
<td>ETS – Visibility</td>
<td>0.1938</td>
</tr>
<tr>
<td>ETS – Total Cloud</td>
<td>-0.0442</td>
</tr>
<tr>
<td>ETS – Cloud Base Height</td>
<td>0.2180</td>
</tr>
<tr>
<td>ETS – 6hr Precipitation</td>
<td>-0.0200</td>
</tr>
<tr>
<td>Total Weighted Score</td>
<td>1.053</td>
</tr>
<tr>
<td>Total Weighted Score (%)</td>
<td>+2.2%</td>
</tr>
</tbody>
</table>
Public Performance

Site wind speed within 5 knots

Wind Speed within 5 kn (3 year mean)
Future work

- Ensemble calibration
- More extensive bias correction
  - use analysis as “truth”
  - extension to gridded fields
  - other variables
- Optimal blending of gridded forecasts
  - account for spatial relationships
  - consider consistency of diagnostics
- Software improvements
  - open source software
  - standard file formats
  - maintainable infrastructure
Summary

- **Post-processing at the Met Office:**
  - Adds value to the raw NWP models
  - Combines ensemble and deterministic models
  - Delivers single source of data

- **Future work**
  - extend to gridded blending
  - improve statistical corrections
  - Improve software
Thanks for listening!

Any questions?