Predictability of wintertime Euro-Atlantic weather regimes in medium-range forecasts

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A weather regime is a persistent and/or recurrent large-scale atmospheric circulation pattern which is associated with specific weather conditions on a regional scale (e.g. zonal flow, NAO, PNA and blocking). Accurate simulations of weather regimes are important in weather and climate.

**Goal**

To know in advance whether today’s forecast is reliable (forecast of forecast skill)
Method — data —

Data type: medium-range ensemble forecast
- **TIGGE** (CMC, ECMWF, JMA, NCEP, and UKMO)
- NOAA's GEFS reforecast v2 (Hamill et al. 2013, BAMS)

Data grid: 2.5×2.5 (TIGGE) and 1.0×1.0 (GEFS)
(Euro-Atlantic region: 30-87.5N, 90W-40E)

Period: **NDJFM** (TIGGE: 2006/07-2013/14, GEFS: 1985/86-2013/14)

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### Data availability

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<td>CMC</td>
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<tr>
<td>ECMWF</td>
<td></td>
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<td></td>
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<td>8 years</td>
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<tr>
<td>JMA</td>
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<table>
<thead>
<tr>
<th>NDJFM</th>
<th>1985/86</th>
<th>1986/87</th>
<th></th>
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<tr>
<td>GEFS</td>
<td>29 years</td>
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</table>

<table>
<thead>
<tr>
<th>NDJFM</th>
<th>2012/13</th>
<th>2013/14</th>
</tr>
</thead>
<tbody>
<tr>
<td>GEFS</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
GEFS reforecast version 2 details

- Past forecasts using the currently operational GEFS, NOAA’s global ensemble forecast system. **fixed model (2012 version)**

- Each 00Z, 11-member forecast, 1 control + 10 perturbed.

- Reforecasts produced **every day, for 1984120100 to current** (actually, working on finishing late 2012 now). **30 years**

- CFSR (NCEP’s Climate Forecast System Reanalysis) initial conditions (3D-Var) + ETR perturbations (cycled with 10 perturbed members). After ~ 22 May 2012, initial conditions from hybrid EnKF/3D-Var. **fixed DA and perturbation method**

- Resolution: T254L42 to day 8, T190L42 from days 7.5 to day 16.

from Dr. Tom Hamill's slide@Workshop on ensemble method

A reforecast with a fixed system is expected to show consistent skills throughout the verification period (at least much better than operational forecasts).
Methods — clustering to detect weather regimes —

- Z500 in extended winter (November-March) is used.

- For TIGGE, ERA-Interim (1979-2014) is used as observation. For GEFS, control forecasts at FT=0 are regarded as observation (1985-2014).

- EOF analysis is performed for ERA-Interim and GEFS analysis over the Euro-Atlantic region (30-87.5N, 90W-40E) to reduce the dimensionality of the Z500 anomaly.

- A K-means clustering (Jung et al. 2005, GRL) has been applied to the leading 20 non-normalised principal components (PCs) of Z500 anomalies over the Euro-Atlantic region to identify weather regimes in ERA-Interim and GEFS analysis.
Weather regimes (NDJFM)

ERA–Interim cluster centroids (Z500)
NDJFM 1979/80–2013/14

- Regime 1: NAO+ (32.0%)
  - Activity: 56.9 m
- Regime 2: NAO− (19.8%)
  - Activity: 81.5 m
- Regime 3: ATL ridge (21.7%)
  - Activity: 61.5 m
- Regime 4: EA block (26.5%)
  - Activity: 57.5 m

Consistent with other studies (e.g. Dawson et al. 2012, GRL)

No significant trends
For forecast data, Z500 forecast anomaly is defined as a departure from the observed climatology (ERA-Interim or GEFS analysis). Non-normalised forecast PCs are calculated by a projection of the forecast anomaly onto the first 20 observed EOFs (ERA-Interim or GEFS analysis). Then, the closest cluster centroid to the forecast PCs is regarded as a forecast regime.
Regime transition frequency & Regime frequency

How well do models simulate the frequency of regime transitions and the frequency of regime?
Regime transition frequency

Forecast data verified in NDJFM are analysed.
Some data are initialised in October.
Transition probability matrix

NDJFM 1979/80–2013/14

<table>
<thead>
<tr>
<th>Regime</th>
<th>Activity</th>
<th>Days</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>NAO+</td>
<td>56.9m</td>
<td>1689</td>
<td>32.0%</td>
</tr>
<tr>
<td>NAO-</td>
<td>61.5m</td>
<td>1149</td>
<td>21.7%</td>
</tr>
<tr>
<td>ATLR</td>
<td>57.5m</td>
<td>1403</td>
<td>26.5%</td>
</tr>
<tr>
<td>EABL</td>
<td>81.5m</td>
<td>1044</td>
<td>19.8%</td>
</tr>
</tbody>
</table>

Diagonal elements: freq. of persistence
Non-diagonal elements: freq. of transition

Markov chain: \( R_{t+1} = R_t T \)

\[
R_{clm} = \begin{pmatrix}
0.32 & 0.20 & 0.22 & 0.27 \\
0.05 & 0.85 & 0.05 & 0.05 \\
0.08 & 0.05 & 0.77 & 0.10 \\
0.10 & 0.04 & 0.06 & 0.80 \\
\end{pmatrix}
\]
Regime transition frequency (NDJFM)

Small differences among centres.

Transition frequency of Euro–Atlantic regimes (NDJFM)


(a) transition from NAO+ to NAO+, NAO−, and EABL

(b) transition from NAO− to NAO+, NAO−, and EABL

(c) transition from ATLR to NAO+, NAO−, and EABL

(d) transition from EABL to NAO+, NAO−, and EABL

Small differences among centres.
Regime transition frequency in models (NDJFM)

- **NAO+**: more freq. than obs.
- **NAO-**: freq. similar to obs.
- **NAO+**: less freq. than obs.

Diagram:

- **NAO+** to **NAO-**
- **NAO-** to **NAO+**

- **ATLR** to **EABL**
- **EABL** to **ATLR**

- **NAO+** to **ATLR**
- **ATLR** to **NAO-**

- **NAO-** to **EABL**
- **EABL** to **NAO+**
Models tend to prefer NAO- and ATLR to NAO+ and with lead time. (The Markov chain of regime transition also shows the same results.)
Skill dependency upon initial and forecast regimes
(deterministic verification)

We want to know IN ADVANCE whether today's forecast is reliable or not (forecast of forecast skill).

Here, initial and forecast regimes are focused on (when today's forecast has been done, we can know both of them, but cannot know future (verifying) regime).
Skill dependency upon initial regimes (ACC averaged over all members)

For the TIGGE period (2006-2014), forecasts from NAO- (ATL ridge) show higher (lower) skills. (consistent with Ferranti et al. 2014, QJ)

GEFS (29yrs) shows no significant skill differences among initial regimes.
Skill dependency upon forecast regimes (initial regime: NAO-)

For both TIGGE and GEFS, NAO- forecasts from NAO- show much higher skills. Lower skills for NAO+ and ATLR forecast from NAO-.
Skill dependency upon forecast regimes (initial regime: EA block)

Higher skills for NAO- forecast from EABL.

Lower skills for ATLR (EABL) forecast from EABL.
Skill dependency upon forecast regimes (initial regime: ATL ridge)

For the TIGGE period, lower skills for ATLR, EABL, NAO- forecast from ATLR. GEFS (29yrs) shows no significant skill differences.
Probabilistic verification of regime forecast
Probabilistic regime forecast

Today's forecast

Ensemble forecast over Euro–Atlantic region

Initial regime: NAO-

Forecast regimes (Day 9)

51 members

6/51 = 12(%)  
12/51 = 24(%)  
22/51 = 43(%)  
11/51 = 22(%)  

Forecast probability: 12% 24% 43% 22%
Verification of probabilistic forecast

**Brier Score (BS, Brier 1950)**

The most common verification score for probabilistic forecasts.

\[ BS = \frac{1}{N} \sum_{i} \sum_{r} (p_i^r - o_i^r)^2 \]

- \( p_i^r \): forecast prob. of regime \( r \) (0-1)
- \( o_i^r \): observed prob. of regime \( r \) (0 or 1)
- \( N \): No. of forecasts
- \( R \): No. of regimes

BS measures the difference between the forecast probability of an event (p) and its occurrence (o). BS=0 for a perfect forecast. The lower, the “better”.

Forecast regimes (Day 9, 51 members)

<table>
<thead>
<tr>
<th>Forecast prob.</th>
<th>12%</th>
<th>24%</th>
<th>43%</th>
<th>22%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observed prob.</td>
<td>0%</td>
<td>100%</td>
<td>0%</td>
<td>0%</td>
</tr>
</tbody>
</table>

verifying regime: NAO-
Verification of probabilistic forecast

**Brier Score (BS, Brier 1950)**

The most common verification score for probabilistic forecasts.

\[
BS = \frac{1}{N} \sum_i \sum_r \left( p_i^r - o_i^r \right)^2
\]

- \( p_i^r \): forecast prob. of regime \( r \) (0-1)
- \( o_i^r \): observed prob. of regime \( r \) (0 or 1)
- \( N \): No. of forecasts
- \( R \): No. of regimes

BS measures the difference between the forecast probability of an event (p) and its occurrence (o). BS=0 for a perfect forecast. The lower, the “better”.

**Brier Skill Score (BSS)**

\[
BSS = 1 - \frac{BS_{fcst}}{BS_{clm}}
\]

- BSS=1: a perfect skill
- BSS=0: comparable skill to climatological fcst.
- BSS<0: poorer skill than climatological fcst.

BSS is conventionally defined as the relative probability score compared with the probability score of a climatological forecast.
• ECMWF has the highest skill.

• Dependency upon initial regimes higher skills for NAO- lower skills for ATLR

• GEFS (29yrs) shows smaller skill dependency upon initial regimes.
Brier Skill Score for regime forecasts
Euro-Atlantic region (NDJFM, 2006/07-2013/14)

- NAO+ fcst.
- NAO- fcst.
- ATLR fcst.
- EABL fcst.

Initial regime fcst regime
EPS reliability diagram for regime forecasts

+7,8,9 day forecasts (Euro–Atlantic region, NDJFM, 2006/07–2013/14)

- NAO+ fcst.
- NAO- fcst.
- ATLR fcst.
- EABL fcst.

Good reliability
Models have some biases in regime transition, leading to more (less) frequent NAO- and ATLR (NAO+) with lead time.

Forecast skills strongly depend on weather regimes (small differences among NWP centres).

Dependencies of skill upon initial and forecast regimes:

- higher skills for forecasts from NAO-
- higher skills when predicting NAO±

In particular,

- highest skills: NAO- → NAO-
- higher skills: EABL → NAO-, NAO- or EABL → NAO+
- lowest skills: ATLR → EABL
- lower skills: NAO+ or ATLR → NAO-, NAO+ → EABL
Supplements
3 data archive centres: ECMWF, NCAR, and CMA
data period: October 2006-current (2-day delay)
ensemble size: 497 members/day
data size: 500GB/day (350GB from ECMWF EPS!)

Table: Operational global ensemble prediction systems (April 2013).

<table>
<thead>
<tr>
<th></th>
<th>BoM (Australia)</th>
<th>CMA (China)</th>
<th>CMC (Canada)</th>
<th>CPTEC (Brazil)</th>
<th>ECMWF (Europe)</th>
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</thead>
<tbody>
<tr>
<td>Init perturb</td>
<td>SV</td>
<td>SV</td>
<td>EnKF</td>
<td>EOF-based</td>
<td>Svs&amp;EDA</td>
</tr>
<tr>
<td>Model Uncert.</td>
<td>N/A</td>
<td>N/A</td>
<td>SP,MP,SKEB</td>
<td>N/A</td>
<td>SP</td>
</tr>
<tr>
<td>Resolution</td>
<td>TL119L19</td>
<td>TL213L31</td>
<td>66kmL74</td>
<td>T126L28</td>
<td>TL639L62(0-10d)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>TL319L62(11-15d)</td>
</tr>
<tr>
<td>Frct length</td>
<td>10</td>
<td>10</td>
<td>16</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Init UTC</td>
<td>00,12</td>
<td>00,12</td>
<td>00,12</td>
<td>00,12</td>
<td>00,12</td>
</tr>
<tr>
<td>Mem/day</td>
<td>33*2</td>
<td>15*2</td>
<td>17*2</td>
<td>15*2</td>
<td>51*2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>JMA (Japan)</td>
<td>KMA (Korea)</td>
<td>Meteo France (France)</td>
<td>NCEP (US)</td>
</tr>
<tr>
<td>Init perturb</td>
<td>SV</td>
<td>ETKF</td>
<td>SV</td>
<td>ETR</td>
<td>ETKF</td>
</tr>
<tr>
<td>Model Uncert.</td>
<td>N/A</td>
<td>SP, SKEB</td>
<td>MP</td>
<td>SP</td>
<td>SP, SKEB</td>
</tr>
<tr>
<td>Resolution</td>
<td>TL319L60</td>
<td>0.5555(lat)x</td>
<td>TL538L65</td>
<td>T254L42(0-192h)</td>
<td>T190L42(192-300h)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.8333(lon)L70?</td>
<td></td>
<td></td>
<td>16</td>
</tr>
<tr>
<td>Frct length</td>
<td>9</td>
<td>10.5</td>
<td>3, 4.5</td>
<td>16</td>
<td>15</td>
</tr>
<tr>
<td>Init UTC</td>
<td>12</td>
<td>00,12</td>
<td>06, 18</td>
<td>00,06,12,18</td>
<td>00,12</td>
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<tr>
<td>Mem/day</td>
<td>51*1</td>
<td>24*2</td>
<td>35*2</td>
<td>21*4</td>
<td>24*2</td>
</tr>
</tbody>
</table>

SP: Stochastic perturbation of physics tendency
MP: Multi parameterizations  SKEB: Stochastic Kinetic Energy Backscatter
EOFs

ERA–Interim EOFs (1979/80–2013/14, NDJFM)

EOF1 (18.1%)
EOF2 (12.4%)
EOF3 (11.4%)
EOF4 (8.4%)
EOF5 (7.8%)
EOF6 (5.4%)

GEFS analysis EOFs (1985/86–2013/14, NDJFM)

EOF1 (18.4%)
EOF2 (12.8%)
EOF3 (11.2%)
EOF4 (8.3%)
EOF5 (7.6%)
EOF6 (5.5%)

ERA–Interim EOF spectrum (Z500)

NDJFM 1979/80–2013/14

Variances [%]

Mode

GEFS analysis EOF spectrum (Z500)

NDJFM 1985/86–2013/14

Variances [%]

Mode
Methods —K-means clustering—

The outcome of K-means clustering depends to some degree on the choice of initial clusters used. In order to reduce the sensitivity to initialisation, cluster analyses has been carried out 500 times with different initial clusters. A member (○) which is most similar to all other 499 members has been chosen. The similarity is measured in terms of root mean square differences.

Cluster centroids on a phase space spanned by PCs

regime 3

regime 1

regime 2

regime 4

□ : member 1
○ : member 2
△ : member 3
× : member 500
Models prefer NAO- and ATLR to NAO+ with lead time.
Regime frequency (DJF, GEFS, 1984/85-2012/13)

NOAA GEFS reforecast regime frequency over EA (NDJFM)

NAO+  NAO−  ATL ridge  EA block

Forecasts from X days ago (0: observed frequency)
Regime frequency (DJF, 2006/07-2012/13)
### Transition probability matrix (transposed)

<table>
<thead>
<tr>
<th>From</th>
<th>Regime today</th>
<th>Probability Matrix</th>
</tr>
</thead>
<tbody>
<tr>
<td>NAO+</td>
<td>NAO+</td>
<td>0.83 0.05 0.08 0.10</td>
</tr>
<tr>
<td>NAO-</td>
<td>NAO-</td>
<td>0.03 0.85 0.05 0.04</td>
</tr>
<tr>
<td>ATL R</td>
<td>ATL R</td>
<td>0.07 0.05 0.77 0.06</td>
</tr>
<tr>
<td>EABL</td>
<td>EABL</td>
<td>0.07 0.05 0.10 0.80</td>
</tr>
</tbody>
</table>

**Markov chain:** \( R_{t+1} = TR_t \)

\[
R_t = T^{t-1} R_1 = \left( V A^{t-1} \right) R_1 \quad \text{(} T = V \Lambda V^{-1} \text{)}
\]

\[
\begin{pmatrix}
1 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0
\end{pmatrix}
\rightarrow
\begin{pmatrix}
1 & 1 & 1 & 1 \\
a & b & c & d \\
e & f & g & h \\
i & j & k & l
\end{pmatrix}
\]

\[
R_1 = \mathbf{v}_1, \quad (t \rightarrow \infty)
\]

\[
\sum \mathbf{v}_{i,1} = 1 \rightarrow V_{1,j}^{-1} = 1, \quad \lambda_1 = 1, \quad 0 < \lambda_2, \lambda_3, \lambda_4 < 1
\]
Transition probability matrix
(GEFS reforecast, NDJFM 1986-2014)

<table>
<thead>
<tr>
<th>from</th>
<th>to</th>
<th>NAO+</th>
<th>NAO-</th>
<th>ATLR</th>
<th>EABL</th>
</tr>
</thead>
<tbody>
<tr>
<td>NAO+</td>
<td>0.83</td>
<td>0.03</td>
<td>0.07</td>
<td>0.08</td>
<td></td>
</tr>
<tr>
<td>NAO-</td>
<td>0.05</td>
<td>0.86</td>
<td>0.07</td>
<td>0.05</td>
<td></td>
</tr>
<tr>
<td>ATLR</td>
<td>0.09</td>
<td>0.05</td>
<td>0.75</td>
<td>0.10</td>
<td></td>
</tr>
<tr>
<td>EABL</td>
<td>0.10</td>
<td>0.04</td>
<td>0.07</td>
<td>0.79</td>
<td></td>
</tr>
</tbody>
</table>

\[ R_\infty = (0.32 \ 0.20 \ 0.22 \ 0.26) \]

<table>
<thead>
<tr>
<th>from</th>
<th>to</th>
<th>NAO+</th>
<th>NAO-</th>
<th>ATLR</th>
<th>EABL</th>
</tr>
</thead>
<tbody>
<tr>
<td>NAO+</td>
<td>0.84</td>
<td>0.03</td>
<td>0.06</td>
<td>0.07</td>
<td></td>
</tr>
<tr>
<td>NAO-</td>
<td>0.05</td>
<td>0.84</td>
<td>0.06</td>
<td>0.05</td>
<td></td>
</tr>
<tr>
<td>ATLR</td>
<td>0.10</td>
<td>0.05</td>
<td>0.75</td>
<td>0.10</td>
<td></td>
</tr>
<tr>
<td>EABL</td>
<td>0.10</td>
<td>0.04</td>
<td>0.07</td>
<td>0.78</td>
<td></td>
</tr>
</tbody>
</table>

\[ R_\infty = (0.35 \ 0.20 \ 0.21 \ 0.25) \]

Day 0→1, 1→2, 2→3

\[ R_{clm} = (0.32 \ 0.20 \ 0.22 \ 0.26) \]

Day 6→7, 7→8, 8→9

\[ R_\infty = (0.30 \ 0.22 \ 0.23 \ 0.24) \]

Day 12→13, 13→14, 14→15

\[ R_\infty = (0.28 \ 0.25 \ 0.24 \ 0.24) \]
Regime frequency expected from transition matrix (NDJFM)

Expected frequency of Euro-Atlantic regimes (NDJFM)

Expected frequency of regimes [%]

<table>
<thead>
<tr>
<th>Regimes</th>
<th>NAO+</th>
<th>NAO−</th>
<th>ATL RF</th>
<th>EABL</th>
</tr>
</thead>
<tbody>
<tr>
<td>(matrix used)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>observed</td>
<td>Day 0</td>
<td>Day 1</td>
<td>Day 9</td>
<td>Day 12</td>
</tr>
<tr>
<td></td>
<td>Day 1</td>
<td>Day 2</td>
<td>Day 10</td>
<td>Day 13</td>
</tr>
<tr>
<td></td>
<td>Day 2</td>
<td>Day 3</td>
<td>Day 11</td>
<td>Day 14</td>
</tr>
<tr>
<td></td>
<td>Day 3</td>
<td>Day 4</td>
<td>Day 12</td>
<td>Day 15</td>
</tr>
</tbody>
</table>
### Expected regime frequency from transition matrix (NDJFM)

<table>
<thead>
<tr>
<th></th>
<th>GEFS (1985/86-2013/14)</th>
<th>JMA (2006/07-2013/14)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(matrix used)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Observed:</td>
<td>$R_\infty = (0.32, 0.20, 0.22, 0.26)$</td>
<td>$R_\infty = (0.34, 0.23, 0.20, 0.23)$</td>
</tr>
<tr>
<td>Day0→1, 1→2, 2→3:</td>
<td>$R_\infty = (0.35, 0.20, 0.21, 0.25)$</td>
<td>$R_\infty = (0.32, 0.26, 0.20, 0.22)$</td>
</tr>
<tr>
<td>Day6→7, 7→8, 8→9:</td>
<td>$R_\infty = (0.30, 0.22, 0.23, 0.24)$</td>
<td>$R_\infty = (0.29, 0.28, 0.19, 0.23)$</td>
</tr>
<tr>
<td>Day12→13, 13→14, 14→15:</td>
<td>$R_\infty = (0.28, 0.25, 0.24, 0.24)$</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>CMC (2007/08-2013/14)</th>
<th>NCEP (2007/08-2013/14)</th>
</tr>
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<tbody>
<tr>
<td>(matrix used)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Observed:</td>
<td>$R_\infty = (0.32, 0.25, 0.20, 0.23)$</td>
<td>$R_\infty = (0.34, 0.23, 0.20, 0.23)$</td>
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<tr>
<td>Day0→1, 1→2, 2→3:</td>
<td>$R_\infty = (0.32, 0.26, 0.19, 0.22)$</td>
<td>$R_\infty = (0.32, 0.26, 0.19, 0.23)$</td>
</tr>
<tr>
<td>Day6→7, 7→8, 8→9:</td>
<td>$R_\infty = (0.28, 0.27, 0.22, 0.22)$</td>
<td>$R_\infty = (0.23, 0.30, 0.25, 0.23)$</td>
</tr>
<tr>
<td>Day12→13, 13→14, 14→15:</td>
<td>$R_\infty = (0.34, 0.23, 0.22, 0.22)$</td>
<td>$R_\infty = (0.24, 0.30, 0.23, 0.23)$</td>
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</table>

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<th>ECMWF (2006/07-2013/14)</th>
<th>UKMO (2006/07-2013/14)</th>
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<tr>
<td>(matrix used)</td>
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<tr>
<td>Observed:</td>
<td>$R_\infty = (0.34, 0.23, 0.20, 0.23)$</td>
<td>$R_\infty = (0.34, 0.23, 0.20, 0.23)$</td>
</tr>
<tr>
<td>Day0→1, 1→2, 2→3:</td>
<td>$R_\infty = (0.32, 0.26, 0.19, 0.23)$</td>
<td>$R_\infty = (0.33, 0.27, 0.17, 0.23)$</td>
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<tr>
<td>Day6→7, 7→8, 8→9:</td>
<td>$R_\infty = (0.27, 0.28, 0.22, 0.23)$</td>
<td>$R_\infty = (0.24, 0.30, 0.23, 0.24)$</td>
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<tr>
<td>Day12→13, 13→14, 14→15:</td>
<td>$R_\infty = (0.28, 0.28, 0.21, 0.22)$</td>
<td>$R_\infty = (0.24, 0.28, 0.26, 0.22)$</td>
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</tbody>
</table>
Some trends in forecast skills due to the number of observation
Skill dependency upon forecast regimes (initial regime: NAO+)

Z500 ACC over EA (NDJFM, fcsts from NAO+, all members)

- CMC
- ECMWF
- JMA
- NCEP
- UKMO
- GEFS_TIGGE
- GEFS

all
  - to NAO+
  - to NAO-
  - to ATL ridge
  - to EA block
  - (fcast regime)
Skill dependency upon forecast regimes (initial regime: NAO-)

For both TIGGE and GEFS, NAO- forecasts from NAO- show much higher skills. Lower skills for NAO+ and ATLR forecast from NAO-. 
Skill dependency upon forecast regimes (initial regime: ATL ridge)

For the TIGGE period, lower skills for ATLR, EABL, NAO- forecast from ATLR.
GEFS (29yrs) shows no significant skill differences.
Skill dependency upon forecast regimes (initial regime: EA block)

Higher skills for NAO- forecast from EABL.
Lower skills for ATLR (EABL) forecast from EABL.
Skill dependency upon initial regimes

Z500 ACC over Euro-Atlantic region
(NDJFM, 2006/07–2013/14, all members)

- (a) all forecasts
- (b) forecasts from NAO+
- (c) forecasts from NAO−
- (d) forecasts from ATLR
- (e) forecasts from EABL

Anomaly Correlation Coefficient
Forecast days
Skill dependency upon forecast regimes

Z500 ACC over Euro-Atlantic region
(NDJFM, 2006/07—2013/14, all members)

- NAO+ fcst.
- NAO- fcst.
- ATLR fcst.
- EABL fcst.
Probabilistic regime forecast

Today's 8-day forecast

Forecast regimes

51member

<table>
<thead>
<tr>
<th>Regime</th>
<th>Forecast</th>
<th>Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>NAO+</td>
<td>8%</td>
</tr>
<tr>
<td>2</td>
<td>NAO−</td>
<td>14%</td>
</tr>
<tr>
<td>3</td>
<td>ATL ridge</td>
<td>59%</td>
</tr>
<tr>
<td>4</td>
<td>EA block</td>
<td>20%</td>
</tr>
</tbody>
</table>

Forecast Probability (4 regimes)

Forecast Probability (focus on only ATLR)

8% 14% 59% 20%

59% 41%
NOAA GEFS reforecast v2 reliability diagram for regime forecasts
+7,8,9day forecasts (Euro–Atlantic region, NDJFM, 1985/86–2013/14)

(a) all $\rightarrow$ NAO+
BSS:0.33
BSSrel:0.97
BSSres:0.36

(b) NAO$^+$ $\rightarrow$ NAO$^+$
BSS:0.33
BSSrel:0.98
BSSres:0.36

(c) NAO$^-$ $\rightarrow$ NAO$^+$
BSS:0.34
BSSrel:0.97
BSSres:0.37

(d) ATLR $\rightarrow$ NAO$^+$
BSS:0.29
BSSrel:0.96
BSSres:0.33

(e) EABL $\rightarrow$ NAO$^+$
BSS:0.23
BSSrel:0.94
BSSres:0.29

(f) all $\rightarrow$ NAO$^-$
BSS:0.41
BSSrel:0.98
BSSres:0.43

(g) NAO$^+$ $\rightarrow$ NAO$^-$
BSS:0.29
BSSrel:0.96
BSSres:0.32

(h) NAO$^-$ $\rightarrow$ NAO$^-$
BSS:0.48
BSSrel:0.96
BSSres:0.43

(i) ATLR $\rightarrow$ NAO$^-$
BSS:0.23
BSSrel:0.93
BSSres:0.29

(j) EABL $\rightarrow$ NAO$^-$
BSS:0.39
BSSrel:0.93
BSSres:0.41

(k) all $\rightarrow$ ATLR
BSS:0.28
BSSrel:0.97
BSSres:0.31

(l) NAO$^+$ $\rightarrow$ ATLR
BSS:0.27
BSSrel:0.97
BSSres:0.31

(m) NAO$^-$ $\rightarrow$ ATLR
BSS:0.25
BSSrel:0.96
BSSres:0.29

(n) ATLR $\rightarrow$ ATLR
BSS:0.32
BSSrel:0.97
BSSres:0.35

(o) EABL $\rightarrow$ ATLR
BSS:0.2
BSSrel:0.93
BSSres:0.27

(p) all $\rightarrow$ EABL
BSS:0.24
BSSrel:0.96
BSSres:0.27

(q) NAO$^+$ $\rightarrow$ EABL
BSS:0.23
BSSrel:0.95
BSSres:0.27

(r) NAO$^-$ $\rightarrow$ EABL
BSS:0.22
BSSrel:0.95
BSSres:0.27

(s) ATLR $\rightarrow$ EABL
BSS:0.2
BSSrel:0.97
BSSres:0.29

(t) EABL $\rightarrow$ EABL
BSS:0.26
BSSrel:0.97
BSSres:0.29

Initial regime
Fcst regime

NAO+$^+$ fcst.

NAO$^-$ fcst.

ATLR fcst.

EABL fcst.
NOAA GEFS reforecast v2 reliability diagram for regime forecasts
+7,8,9 day forecasts (Euro-Atlantic region, NDJFM, 2006/07-2013/14)
ECMWF EPS reliability diagram for regime forecasts
+7, 8, 9 day forecasts (Euro–Atlantic region, NDJFM, 2006/07–2013/14)

Initial regime
Fct regime

NAO+ fct.
NAO- fct.
ATLR fct.
EABL fct.
JMA EPS reliability diagram for regime forecasts
+7,8,9 day forecasts (Euro-Atlantic region, NDJFM, 2006/07–2013/14)

- NAO+ fcst.
- NAO- fcst.
- ATLR fcst.
- EABL fcst.

Initial regime Fcst regime
NCEP EPS reliability diagram for regime forecasts
+7,8,9day forecasts (Euro–Atlantic region, NDJFM, 2007/08–2013/14)

(a) all → NAO+
(b) NAO+ → NAO+
(c) NAO+ → NAO-
(d) ATLR → NAO+
(e) EABL → NAO+

(f) all → NAO-
(g) NAO+ → NAO-
(h) NAO- → NAO-
(i) ATLR → NAO-
(j) EABL → NAO-

(k) all → ATLR
(l) NAO+ → ATLR
(m) NAO- → ATLR
(n) ATLR → ATLR
(o) EABL → ATLR

(p) all → EABL
(q) NAO+ → EABL
(r) NAO- → EABL
(s) ATLR → EABL
(t) EABL → EABL

Initial regime Fct regime

NAO+ fcst.
NAO- fcst.
ATLR fcst.
EABL fcst.
UKMO EPS reliability diagram for regime forecasts
+7,8,9day forecasts (Euro–Atlantic region, NDFM, 2006/07–2013/14)
EPS reliability diagram for regime forecasts
+1, 2, 3 day forecasts (Euro-Atlantic region, NDJFM, 2006/07–2013/14)

- NAO+ fcst.
- NAO- fcst.
- ATLR fcst.
- EABL fcst.
EPS reliability diagram for regime forecasts
+4,5,6 day forecasts (Euro-Atlantic region, NDJFM, 2006/07–2013/14)
EPS reliability diagram for regime forecasts
+7,8,9 day forecasts (Euro–Atlantic region, NDJFM, 2006/07–2013/14)

(a) all $\rightarrow$ NAO+
(b) NAO+ $\rightarrow$ NAO+
(c) NAO- $\rightarrow$ NAO+
(d) ATLR $\rightarrow$ NAO+
(e) EABL $\rightarrow$ NAO+
(f) all $\rightarrow$ NAO-
(g) NAO+ $\rightarrow$ NAO-
(h) NAO- $\rightarrow$ NAO-
(i) ATLR $\rightarrow$ NAO-
(j) EABL $\rightarrow$ NAO-
(k) all $\rightarrow$ ATLR
(l) NAO+ $\rightarrow$ ATLR
(m) NAO- $\rightarrow$ ATLR
(n) ATLR $\rightarrow$ ATLR
(o) EABL $\rightarrow$ ATLR
(p) all $\rightarrow$ EABL
(q) NAO+ $\rightarrow$ EABL
(r) NAO- $\rightarrow$ EABL
(s) ATLR $\rightarrow$ EABL
(t) EABL $\rightarrow$ EABL

Observed frequency (%)

Forecast probability (%)

NAO+ fcst.
NAO- fcst.
ATLR fcst.
EABL fcst.
EPS reliability diagram for regime forecasts
+10,11,12 day forecasts (Euro–Atlantic region, NDJFM, 2006/07–2013/14)

(a) all → NAO+
(b) NAO+ → NAO+
(c) NAO− → NAO+
(d) ATLR → NAO+
(e) EABL → NAO+

(f) all → NAO−
(g) NAO+ → NAO−
(h) NAO− → NAO−
(i) ATLR → NAO−
(j) EABL → NAO−

(k) all → ATLR
(l) NAO+ → ATLR
(m) NAO− → ATLR
(n) ATLR → ATLR
(o) EABL → ATLR

(p) all → EABL
(q) NAO+ → EABL
(r) NAO− → EABL
(s) ATLR → EABL
(t) EABL → EABL

Observed frequency (%)
Forecast probability (%)

NAO+ fcst.
NAO− fcst.
ATLR fcst.
EABL fcst.
+13,14,15 day forecasts (Euro-Atlantic region, NDJFM, 2006/07–2013/14)

EPS reliability diagram for regime forecasts

(a) all → NAO+
(b) NAO+ → NAO+
(c) NAO- → NAO+
(d) ATLR → NAO+
(e) EABL → NAO+

(f) all → NAO-
(g) NAO+ → NAO-
(h) NAO- → NAO-
(i) ATLR → NAO-
(j) EABL → NAO-

(k) all → ATLR
(l) NAO+ → ATLR
(m) NAO- → ATLR
(n) ATLR → ATLR
(o) EABL → ATLR

(p) all → EABL
(q) NAO+ → EABL
(r) NAO- → EABL
(s) ATLR → EABL
(t) EABL → EABL

Forecast probability (%)

Observed frequency (%)