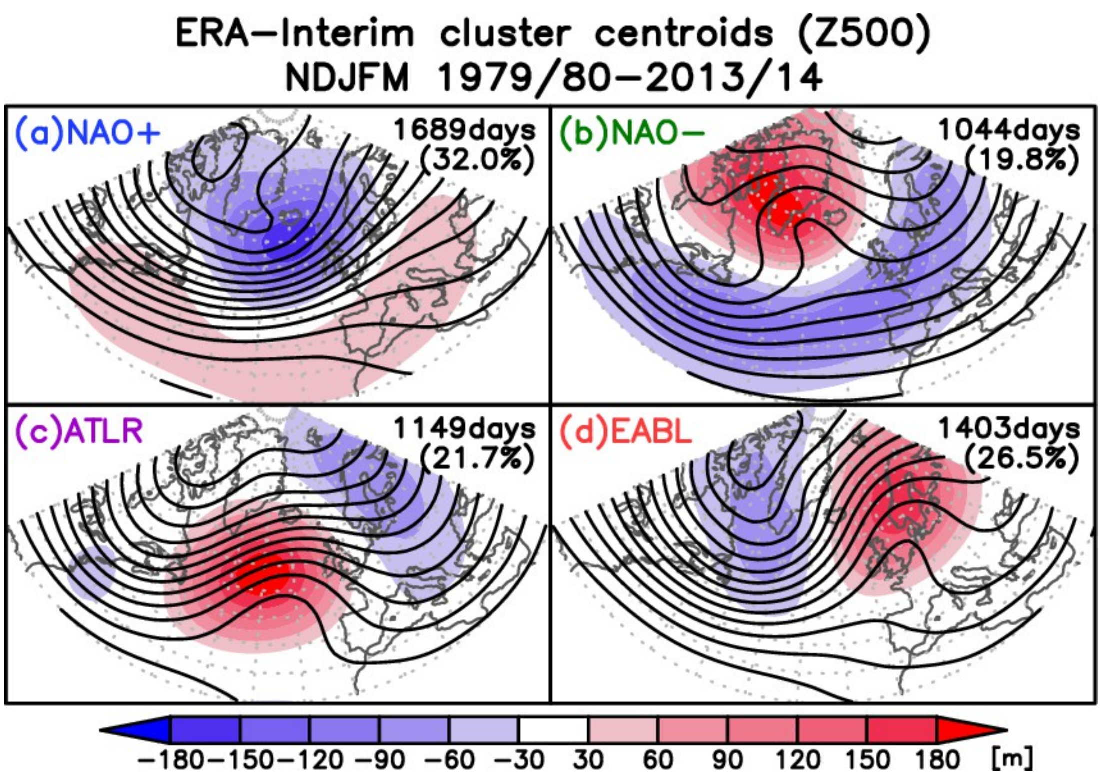
Flow-dependent predictability of wintertime Euro-Atlantic weather regimes in medium-range forecasts

Mio Matsueda (University Tsukuba)



Outlines of my talk

1. my work for TIGGE and S2S
   - The TIGGE an S2S Museum

   - early warning product of severe weather events (TIGGE)

2. Predictability of Euro-Atlantic weather regime (NDJFM)
   - reanalysis (ERA-Interim)
     - ・ pattern, frequency, duration & transition matrix

   - model performance (TIGGE models)
     - ・ bias in regime persistence and transition
     - ・ probabilistic verification of regime forecast

   - summary

My work for TIGGE and S2S

- Verification of grand ensemble: Matsueda & Tanaka (2009)
- NH Blocking: Matsueda (2009)
- Russian heatwave in 2010: Matsueda (2011)
- Madden-Julian Oscillation (MJO): Matsueda & Endo (2011)
- Early warning product for severe weather events: Matsueda & Nakazawa (2015)

  → poster on Tuesday

  high/low T, heavy rainfall & strong winds
- Weather regimes: Matsueda & Kyouda (2016), Matsueda & Palmer (2018)
- Forecast verification in the Polar region: Jung & Matsueda (2016)
- Arctic cyclones: Yamagami et al., (2018a,b, 2019)
- TIGGE project summary: Swinbank et al. (2016)
- The TIGGE and S2S Museums → poster on Wednesday

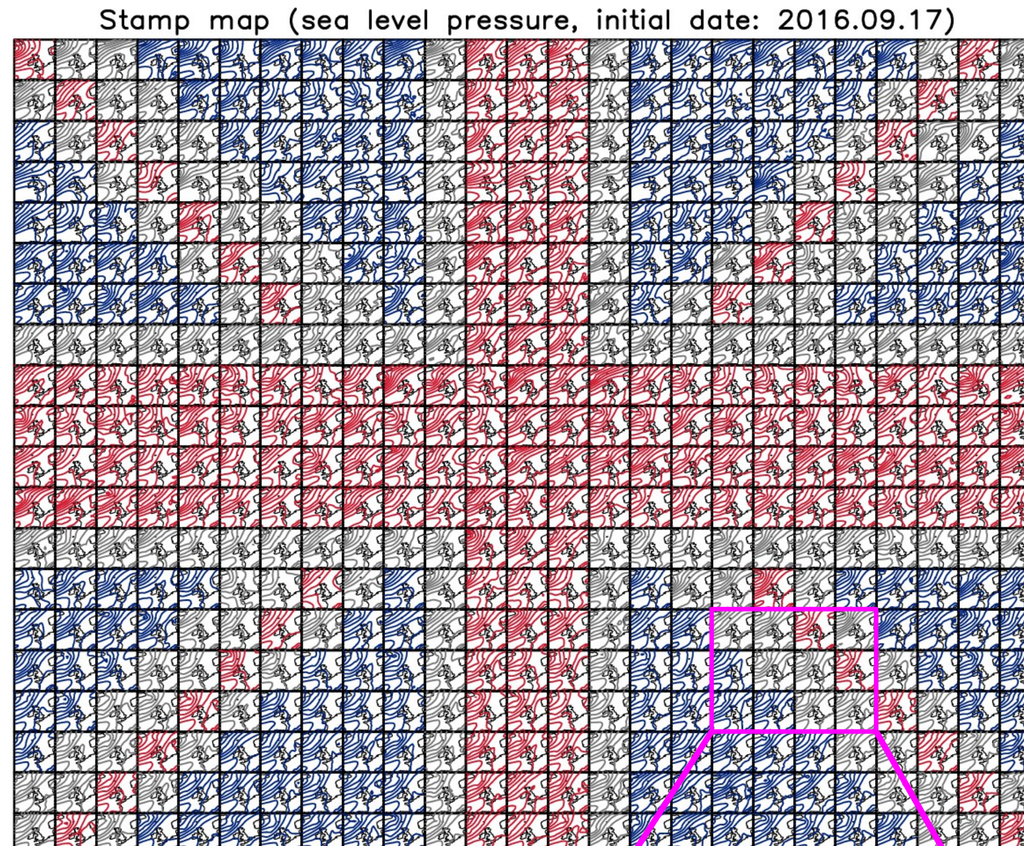
My work for TIGGE and S2S

Real spaghetti plot..

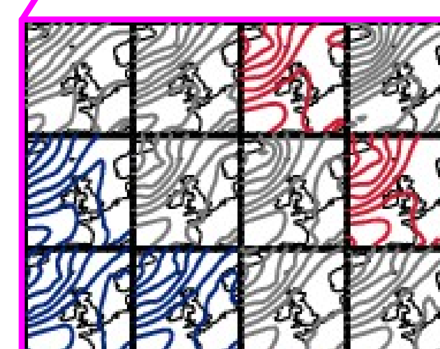
(**analysis**, CMC, JMA, NCEP)

Special thanks to Dr. Subramanian

Please see Matsueda et al. (2011, MWR)
for the blocking event.



Union Jack made with TIGGE data..



The TIGGE Museum (google "TIGGE Museum")

Poster on Wednesday

http://gpvjma.ccs.hpcc.jp/TIGGE/

TIGGE Museum - Welc

gpvjma.ccs.hpcc.jp/TIGGE

THORPEX

A World Weather Research Programme

Welcome to the TIGGE Museum

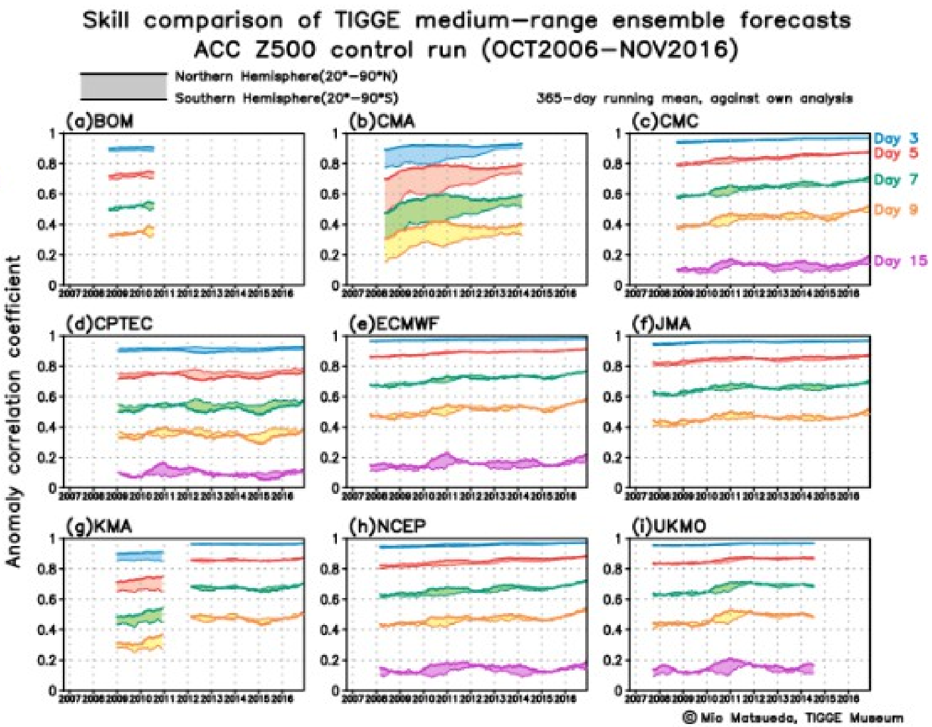
@University of Tsukuba, Japan

The THORPEX Interactive Grand Global Ensemble (TIGGE) is a key component of the THORPEX project, which provides operational global ensemble forecast data quasi-operationally (2-day delay). The TIGGE portals provide the TIGGE data freely only for research and education purposes. For details, visit the WMO THORPEX website or the TIGGE website.

The TIGGE Museum is operated for a promotion of utilization of the TIGGE data by Dr. Mio Matsueda (University of Tsukuba and University of Oxford). Forecast products in the TIGGE Museum are updated every day with a 2- or 3-day delay, and are available for non-commercial use.

If you want to use the TIGGE data, sample scripts (tar.gz, 48MB) (readme) would be helpful!

The S2S Museum has been just open! New!



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The TIGGE Museum (google “TIGGE Museum”)

The products are available for past forecast cases during the TIGGE period (from October 2006).

- Z500 Spaghetti & stamp maps
- **MJO (Madden-Julian Oscillation)**
- Atmospheric blocking
- Teleconnection indices
- EPS meteograms (UK&Europe)
- **Severe weather events (poster on Tuesday)**
  (high/low T, heavy **rainfall** & strong winds)
- Forecast verifications
  (daily and seasonal scores, MJO & blocking)
- Model biases

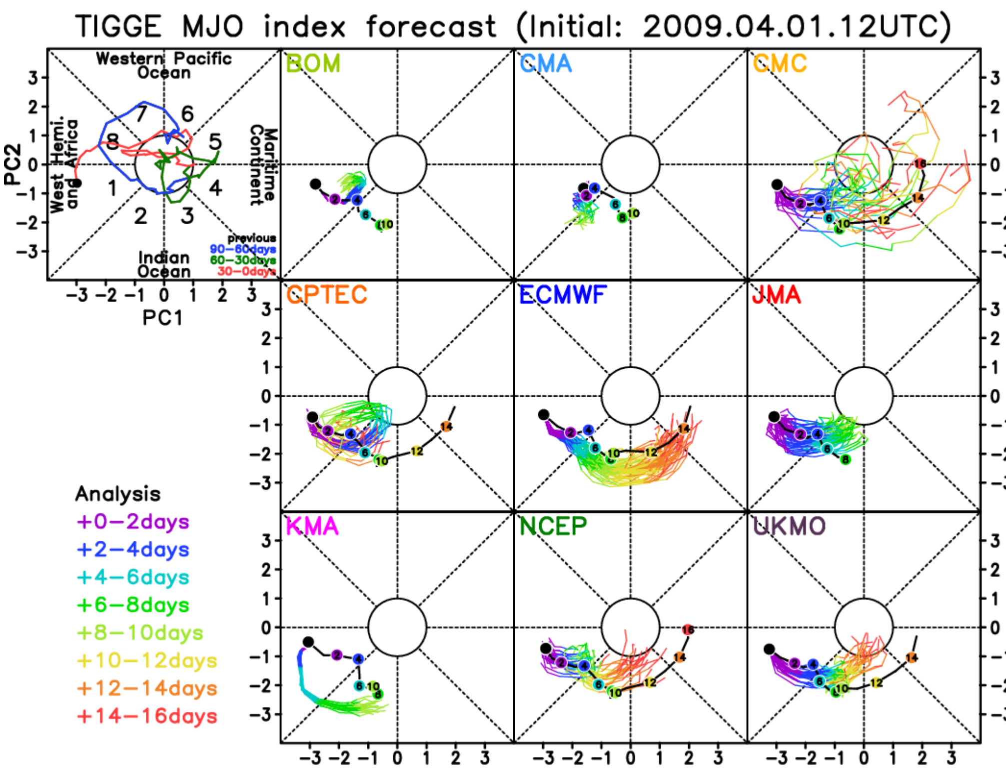


Fig. *(top left) Observed and (right 9panels) predicted* ***MJO indices*** *by BoM, CMA, CMC, CPTEC, ECMWF, JMA, KMA, NCEP, and UKMO, initialised on 1 April 2009 (Coloured line: individual members, black line: analysis).*

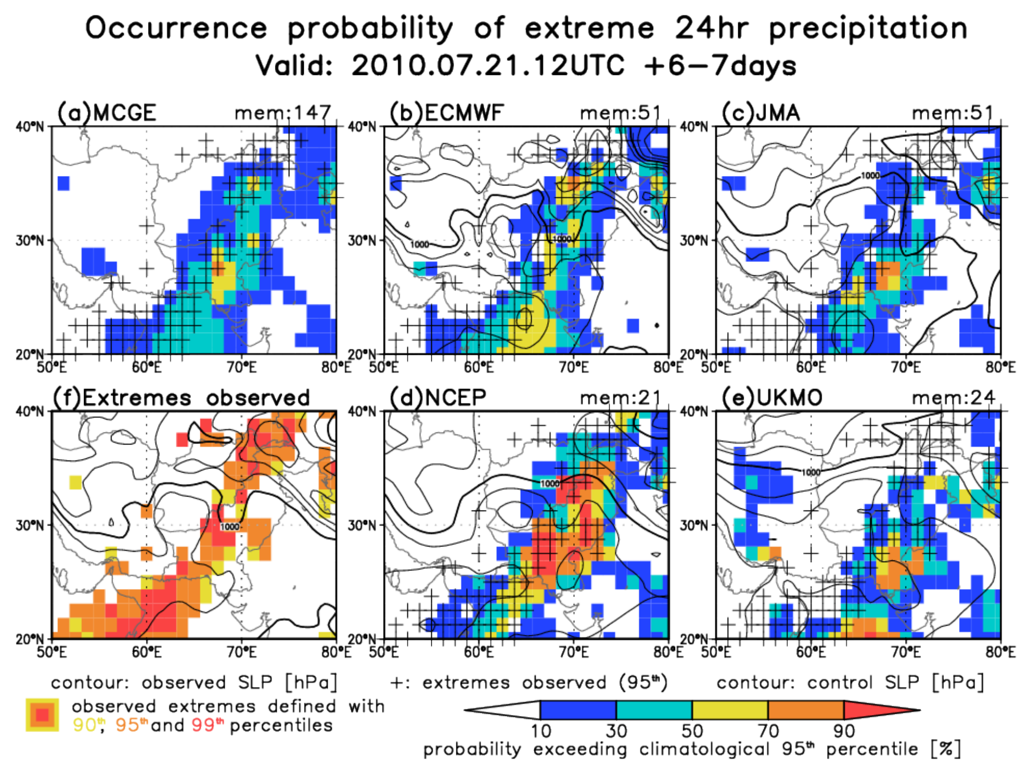
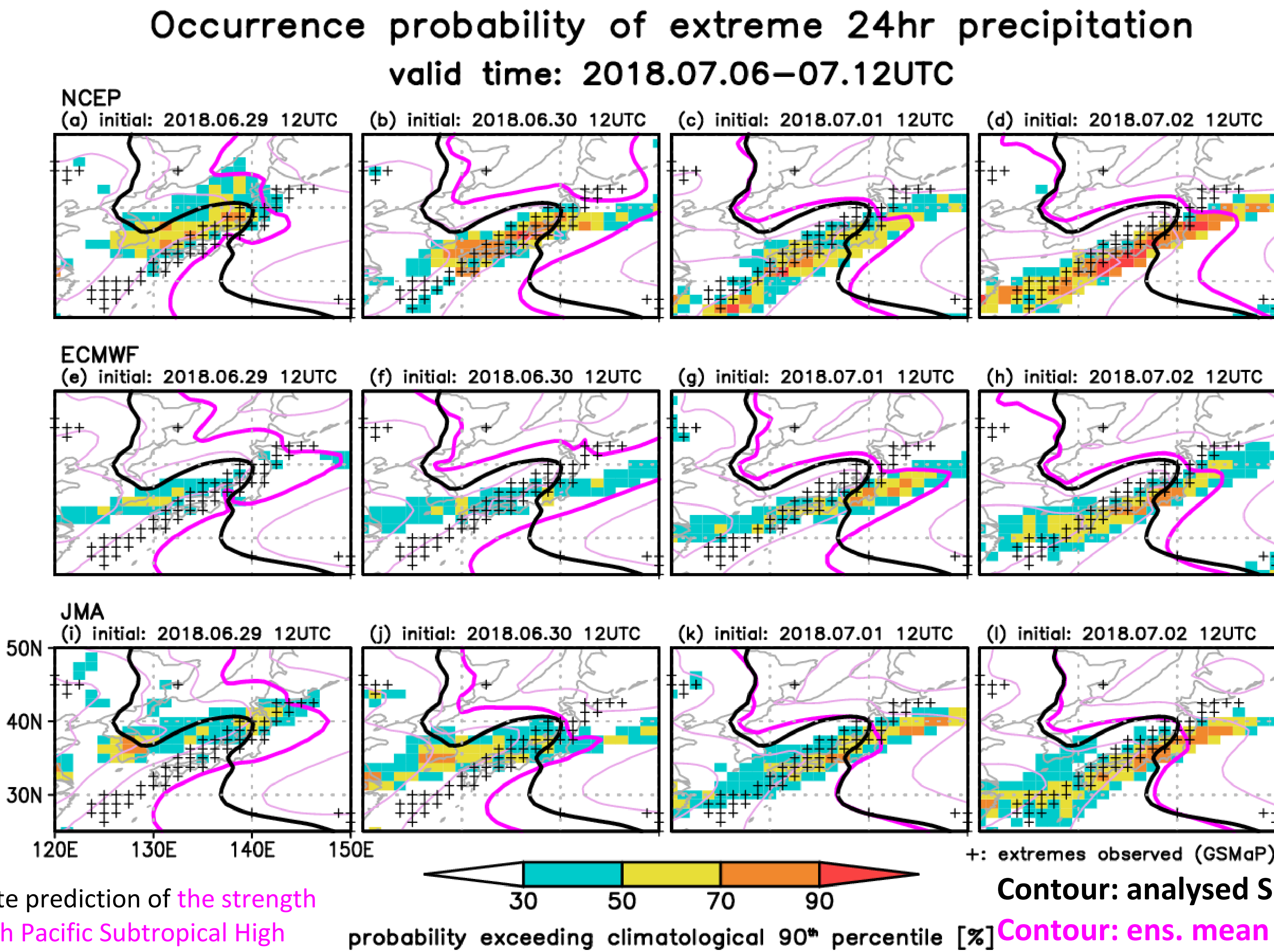


Fig. *Occurrence probabilities (shading) of extreme 24-hr rainfall for* ***the 2010 Pakistan floods****, by the (a) multicentre grand ensemble, (b) ECMWF, (c) JMA, (d) NCEP, and (e) UKMO, initialized at 1200UTC 21 July 2010, and valid at 1200UTC 27 – 28 July 2010. (f) Observed extremes.*

Matsunobu & Matsueda (submitted)

Heavy rainfall in Japan (7 July 2018)



Contour: analysed SLP

Contour: ens. mean SLP

Accurate prediction of the strength of North Pacific Subtropical High was important.

The TIGGE Museum (google “TIGGE Museum”)

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- Z500 Spaghetti & stamp maps
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- **Forecast verifications** (**daily and seasonal scores**, MJO & blocking)
- Model biases

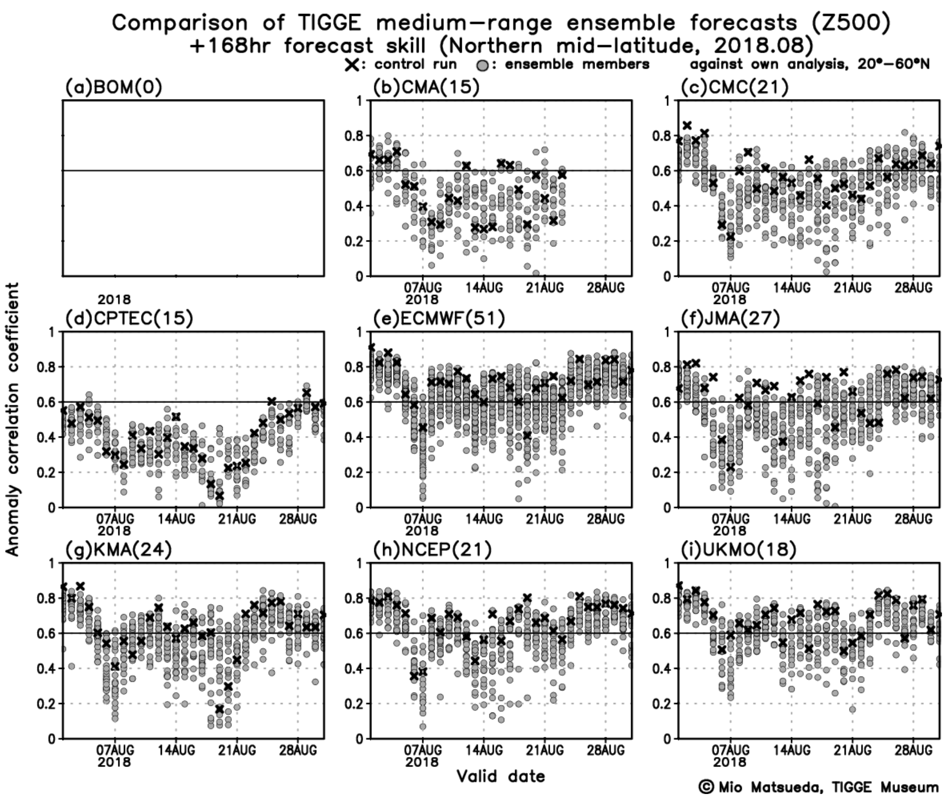

Fig. *Anomaly correlation coefficient for 7-day forecasts of Z500 over the Northern mid-latitude (20-60N), valid in August 2018.*

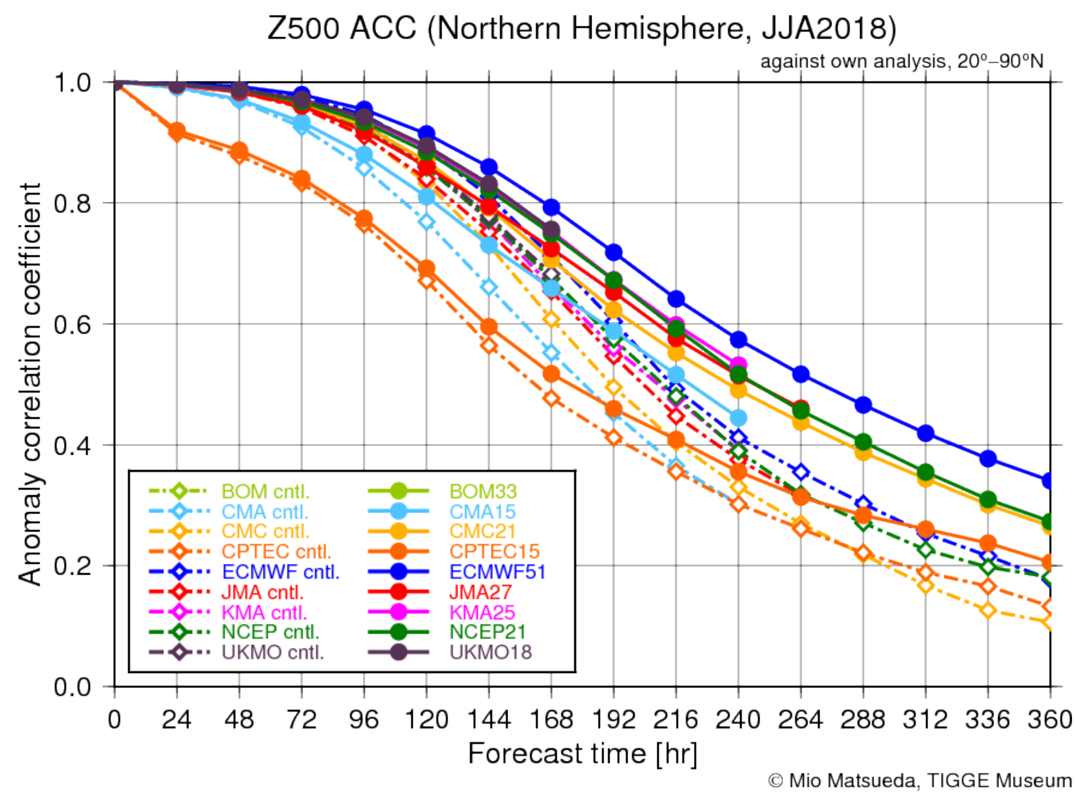

Fig. *Seasonal-mean anomaly correlation coefficient for control and ensemble mean forecasts of Z500 over NH in JJA 2018.*

The S2S Museum (google “S2S Museum”)

Poster on Wednesday

S2S Museum - Welcon

gpvjma.ccs.hpcc.jp/S2S/

http://gpvjma.ccs.hpcc.jp/S2S/

Subseasonal-to-Seasonal S2S Prediction Project

Welcome to the S2S Museum

@University of Tsukuba, Japan

WCRP World Climate Research Programme

WWRP

The Subseasonal to Seasonal Prediction (S2S) Project is a proposed WWRP/THORPEX/ WCRP joint research project.

The main goal of the S2S project is to improve forecast skill and understanding on the subseasonal to seasonal timescale, and promote its uptake by operational centres and exploitation by the applications community. Specific attention will be paid to the risk of extreme weather, including tropical cyclones, droughts, floods, heat waves and the waxing and waning of monsoon precipitation.

The S2S data portals provide the S2S data freely with a 3-week delay only for research and education purposes. For details, visit the S2S Project Office website or the ECMWF S2S website. Forecast products in the S2S Museum are updated everyday, with a 3-week delay, and are available for non-commercial use.

Supported by

ArCS Arctic Challenge for Sustainability

The S2S Museum (google "S2S Museum")

The products are available for past forecast cases during the S2S period (from January 2015).

- AO/AAO (Arctic/Antarctic Oscillations) index
- **NAO (North Atlantic Oscillation) index**
- Teleconnection indices (EA, PNA, WP & EU)
- SLP & Z500 anomalies (stamp maps)
- SSW (Sudden Stratospheric Warming)
- Stream function&Velocity Potential
- Wave Activity Flux at 200 hPa
- MJO (Madden-Julian Oscillation)
- **SST (Sea Surface Temperature)**
- **Sea-ice cover**

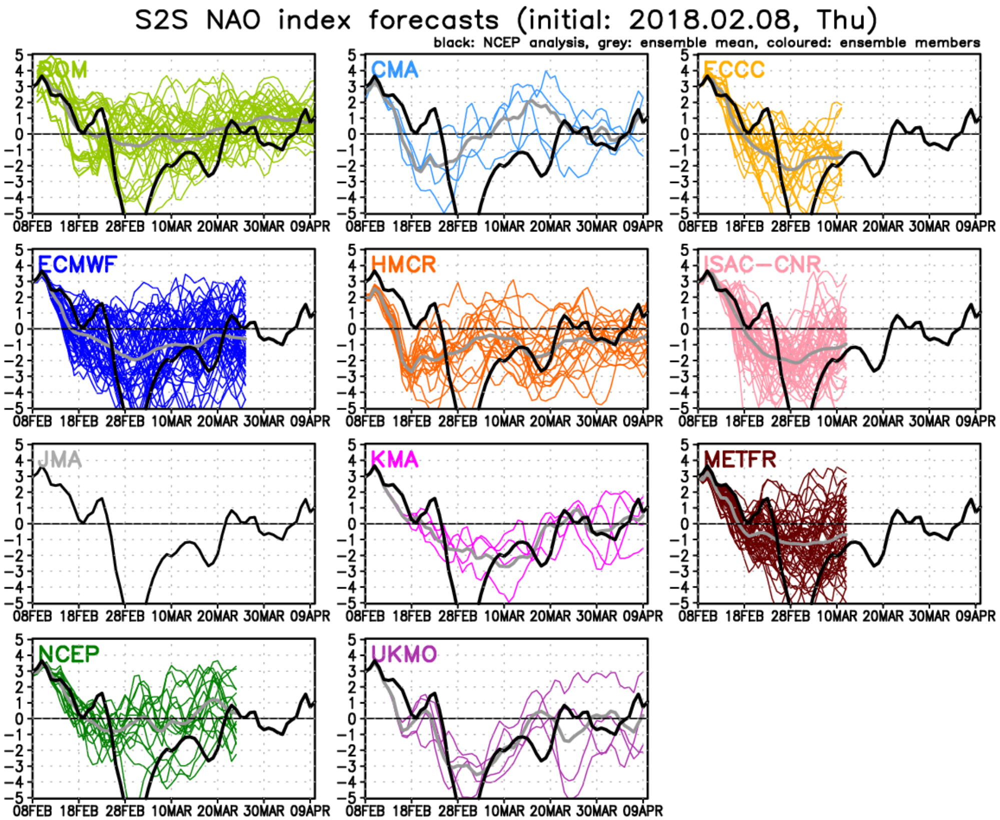

Fig. ***NAO index*** *forecasts by BoM, CMA, ECCC, ECMWF, HMCR, ISAC-CNR, KMA, METFR, NCEP and UKMO, initialised on 8 February 2018 (Coloured line: individual members, grey line: ensemble mean, black line: analysis).*

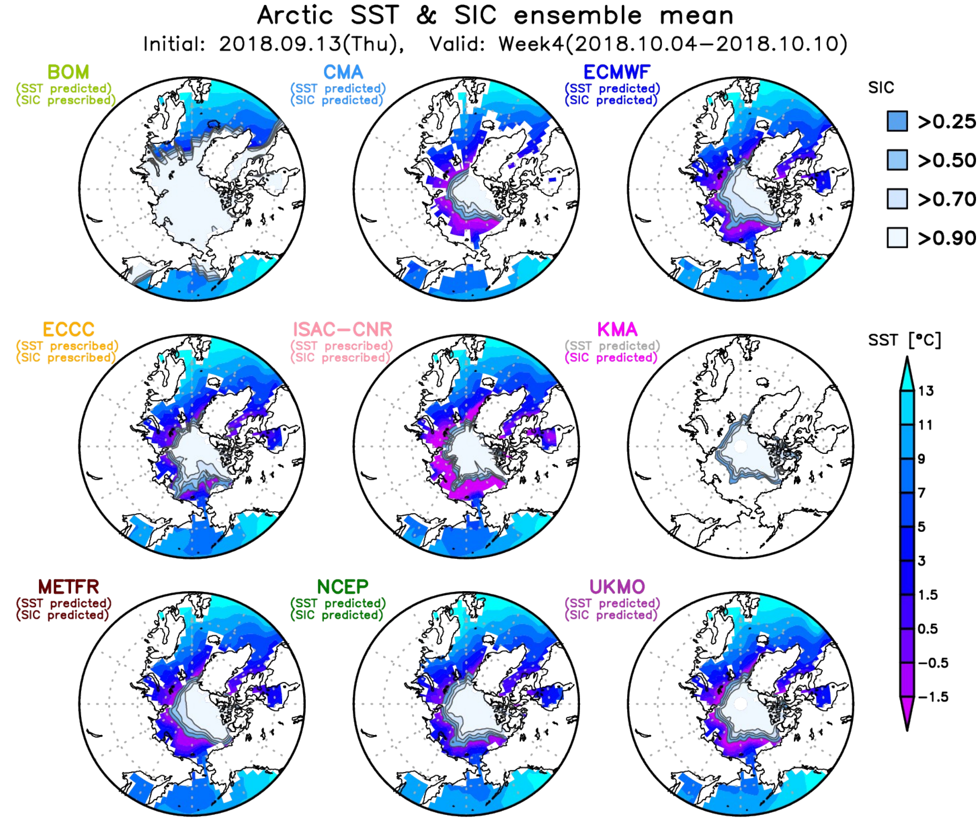

Fig. *Ensemble mean forecasts of* ***sea surface temperature*** *(colour bar at the lower-right corner) and* ***sea ice cover*** *(colour bar at the upper-right corner), initialised on 13 September 2018, valid on 4 – 10 October 2018 (Week 4).*

The S2S Museum (google "S2S Museum")

The products are available for past forecast cases during the S2S period (from January 2015).

- AO/AAO (Arctic/Antarctic Oscillations) index
- **NAO (North Atlantic Oscillation) index**
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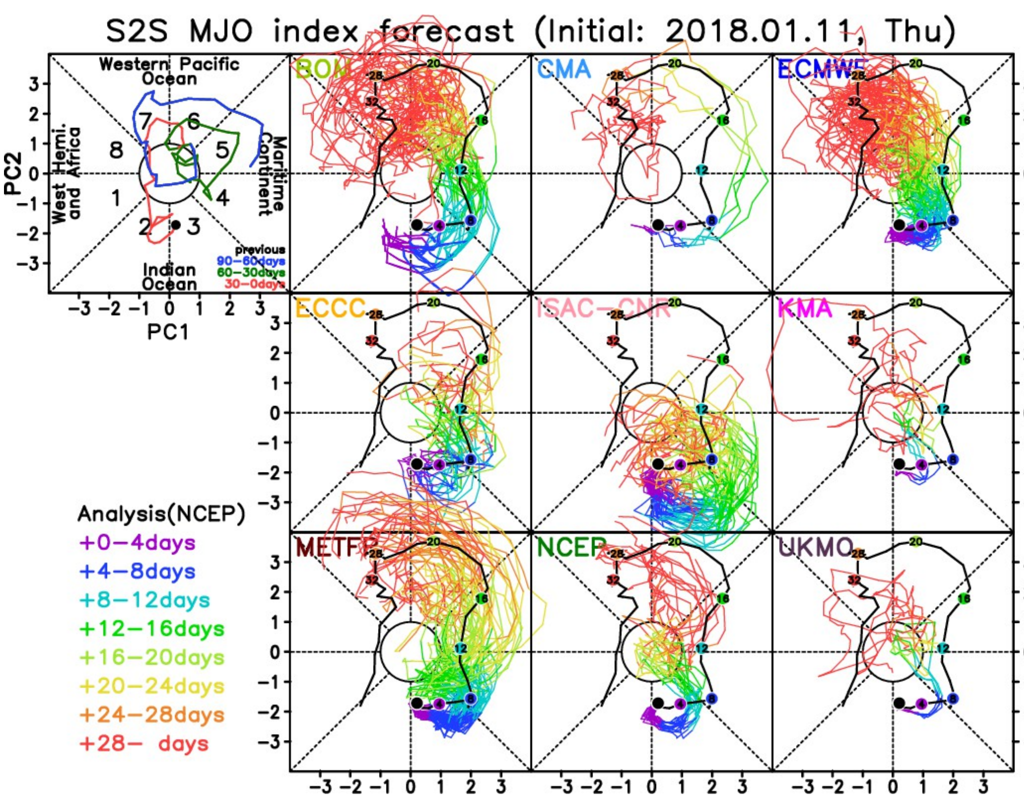

*Fig. (top left) NCEP control analysis for real-time multivariate **MJO index** for the 90 days prior to the initial date of the forecast. (right 9 panels) Real-time multivariate MJO index forecasts, initialised on 11 January 2018. The black line correspond to the NCEP control analysis. The coloured lines indicate ensemble members. The colour changes reflect the lead-time of the forecasts.*

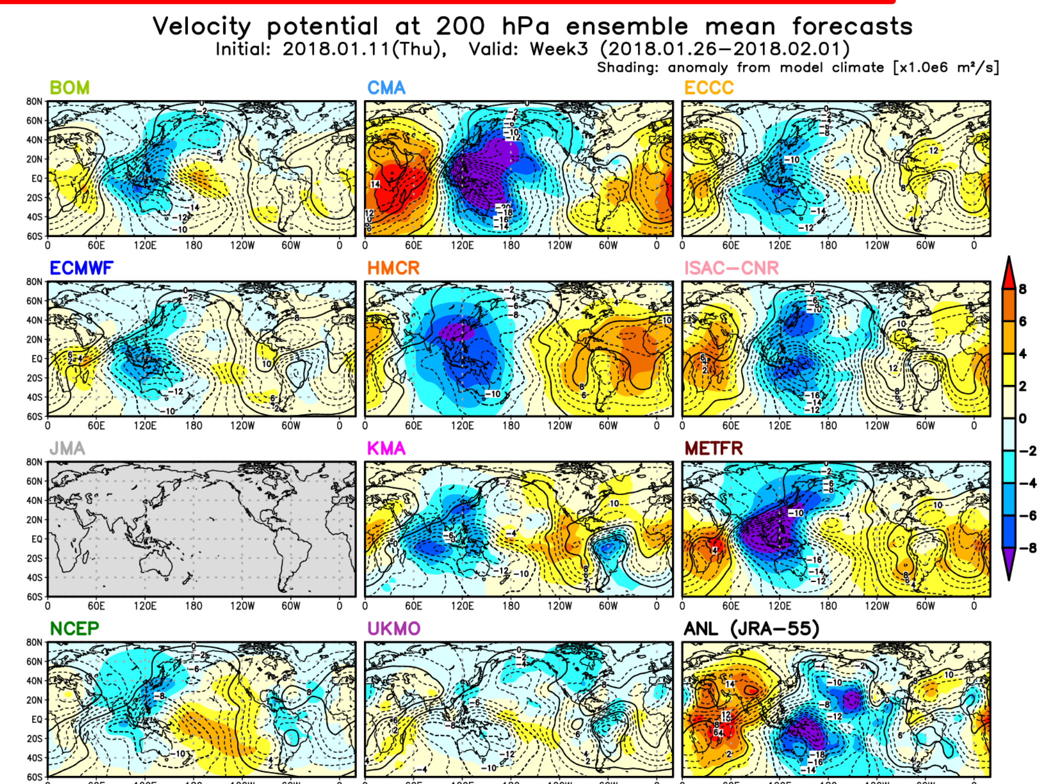

*Fig. Ensemble mean forecasts of **200hPa velocity potential** by 10 S2S models, initialised on 11 January 2018, valid on 26 January – 1 February 2018 (Week 3). Observed 200hPa velocity potential (JRA55, bottom right) is also added when it becomes available. The contour and shading indicate full and anomaly fields, respectively.*

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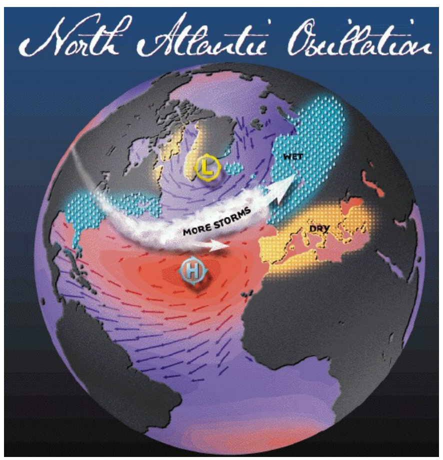
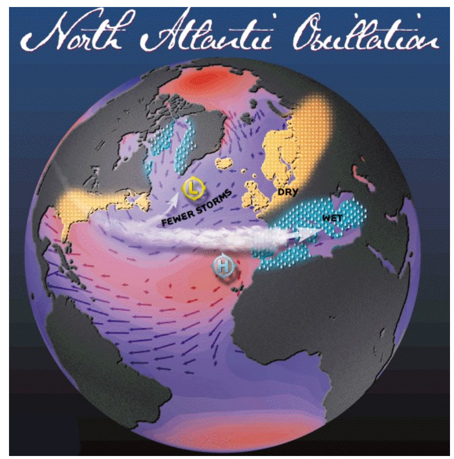
Introduction — weather regimes—

Weather regimes are persistent and/or recurrent large-scale flow patterns and are associated severe weather events. Accurate predictions of weather regimes are important in weather and climate.

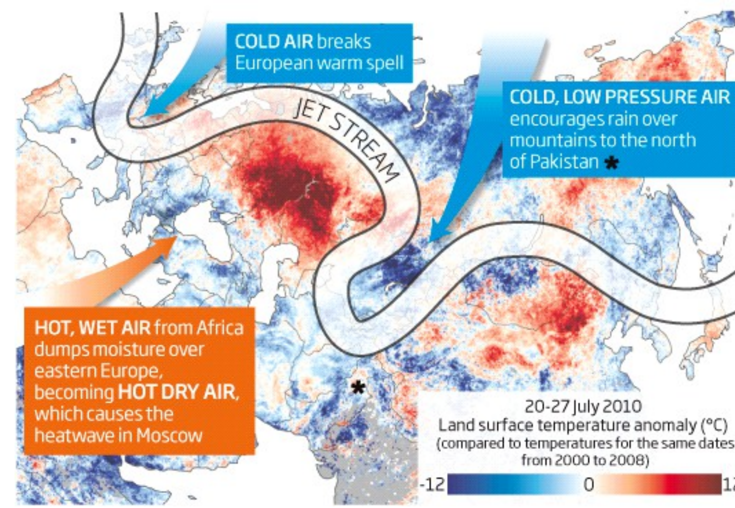
NAO+



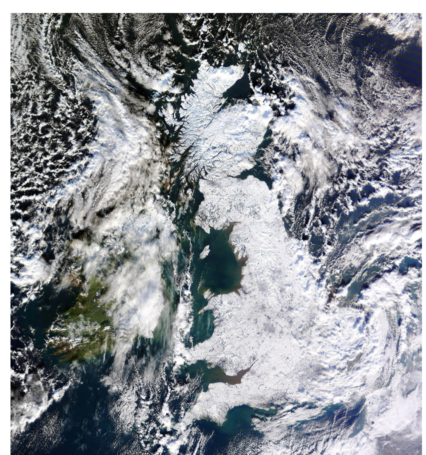
NAO-



blocking



flooding (Oxford, 2014)



Heavy snow (UK, 2010)

heatwave (Moscow, 2010)

Introduction — previous studies about weather regimes—

Weather regimes in reanalysis

Legras and Ghil (1985), Molteni et al. (1990), Molteni and Tibaldi (1990), Vautard (1990), Cheng and Wallace (1993), Kimoto and Ghil (1993a,b), Michelangeli et al. (1995), Mukougawa and Sato (1999), Robertson and Ghil (1999), Smyth et al. (1999), Moron and Plaut (2003), Straus and Molteni (2004), Casola and Wallace (2007), Cassou et al. (2007), Straus et al. (2007), Fereday et al. (2008), SanchezGomez et al. (2008), Straus (2010), Franzke et al. (2011), Michel and Riviere (2011), Luo et al (2012a,b), Roller et al. (2016), Fereday (2017), Madonna et al. (2017)

Weather regimes in weather and climate models

Corti et al. (1999), Kageyama et al. (1999), Monahan et al. (2000), Hsu and Zwiers (2001), Corti et al. (2003), Jung et al. (2005), Hannachi and Turner (2008), Sanchez-Gomez et al. (2009), Dawson et al. (2012), Peters et al. (2012), Frame et al. (2011, 2013), Inatsu et al. (2013), Rojas et al. (2013), Ferranti et al. (2014), Hertig and Jacobeit (2014), Weisheimer et al. (2014), Dawson and Palmer (2015), Ferranti et al. (2015), Matsueda and Kyouda (2016), Neal et al. (2016), Ferranti et al. (2018), Matsueda and Palmer (2018), Vigaud et al. (2018), Strommem and Palmer (2019)

Weather regimes and extreme events

Yiou and Nogaj (2004), Cassou and Terray (2005), Cassou (2008), Yiou et al. (2008), Vitart and Molteni (2010), Cattiaux et al. (2013), Franzke (2013), Riddle et al. (2013), Grams et al. (2017), Amini and Straus (2018), Paprltz and Grams (2018), Pasquier et al. (2019)

Medium-range ensemble forecasts and reforecast

Centres : TIGGE (CMC, ECMWF, JMA, NCEP, and UKMO)
NOAA's GEFS reforecast v2 (fixed model & DA system)

Area : Euro-Atlantic sector: 30°-87.5°N, 90°W-40°E)

Period : NDJFM (TIGGE: 2006/07-2013/14, GEFS: 1985/86-2013/14)
initialised on every day

Data availability

NDJFM	2006/07	2007/08	2008/09	2009/10	2010/11	2011/12	2012/13	2013/14
CMC								
ECMWF				8 years				
JMA								
NCEP								
UKMO								

NDJFM	1985/86	1986/87	—	2012/13	2013/14
GEFS			29 years		

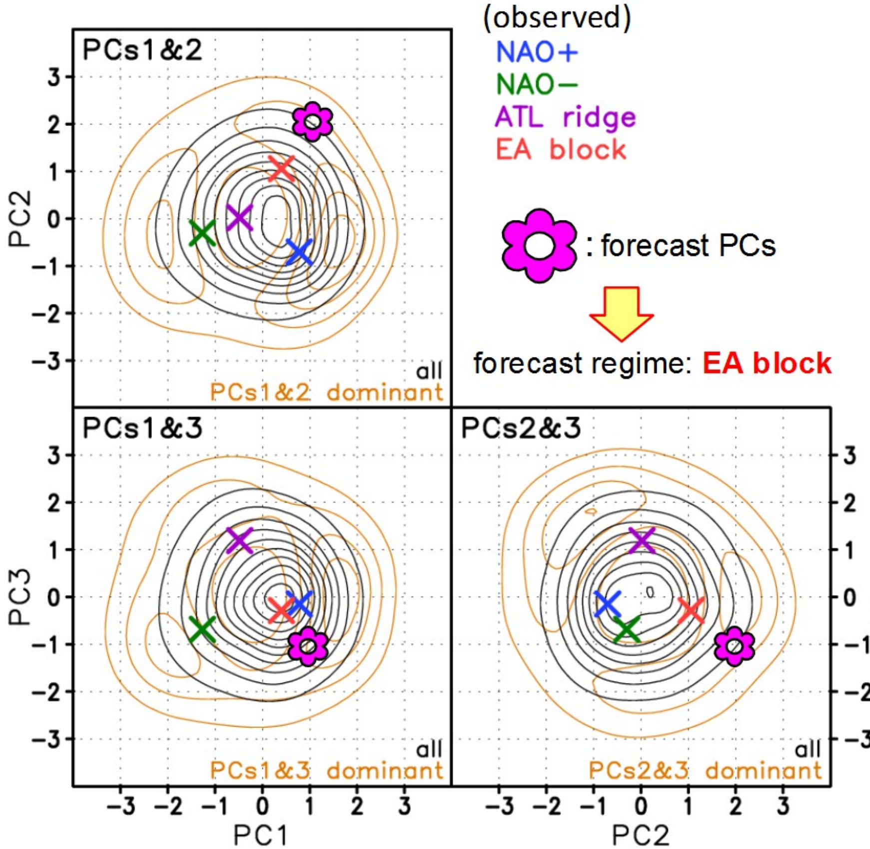
A k-means clustering

Observed regimes:

To define weather regimes in ERA-Interim (GEFS analysis), a k-means clustering (Jung *et al.,* 2005; Dawson *et al.*, 2012) has been applied to the leading 20 non-normalised principal components of Z500 anomalies (PCs, explained variance: 91.8%) over Euro-Atlantic sector in extended winters of 1979-2014 (1985-2014).

Forecast regimes:

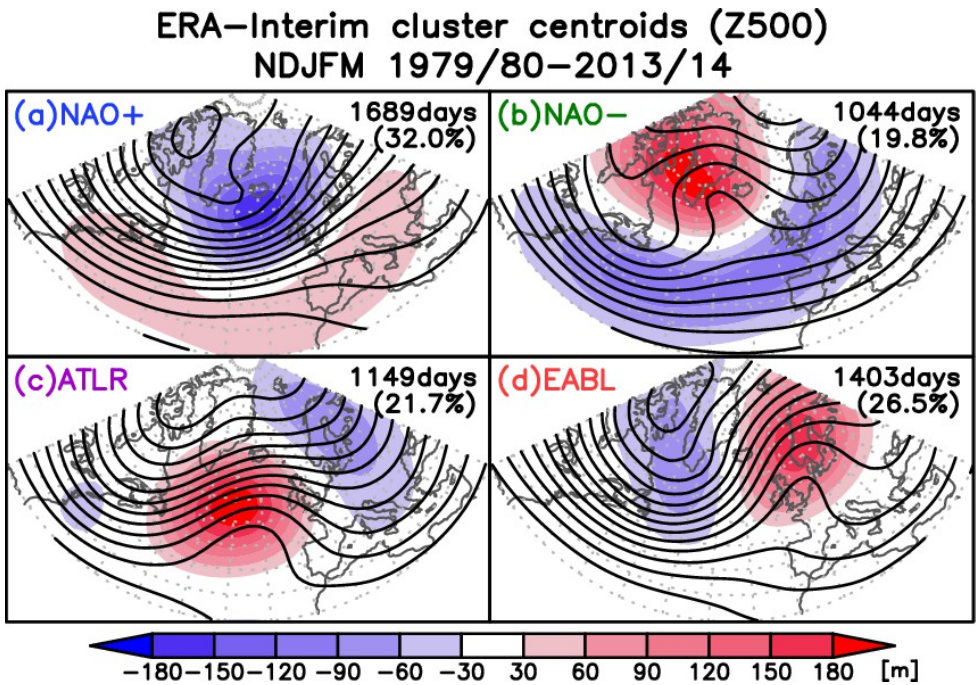
Z500 forecast anomaly is defined as a departure from the observed climatology (ERA-Interim or GEFS analysis). Non-normalised forecast PCs are calculated by projecting the forecast anomaly onto the first 20 observed EOFs (ERA-Interim or GEFS analysis). Then, **the observed cluster centroid closest** to **the forecast PC** is regarded as a forecast regime.

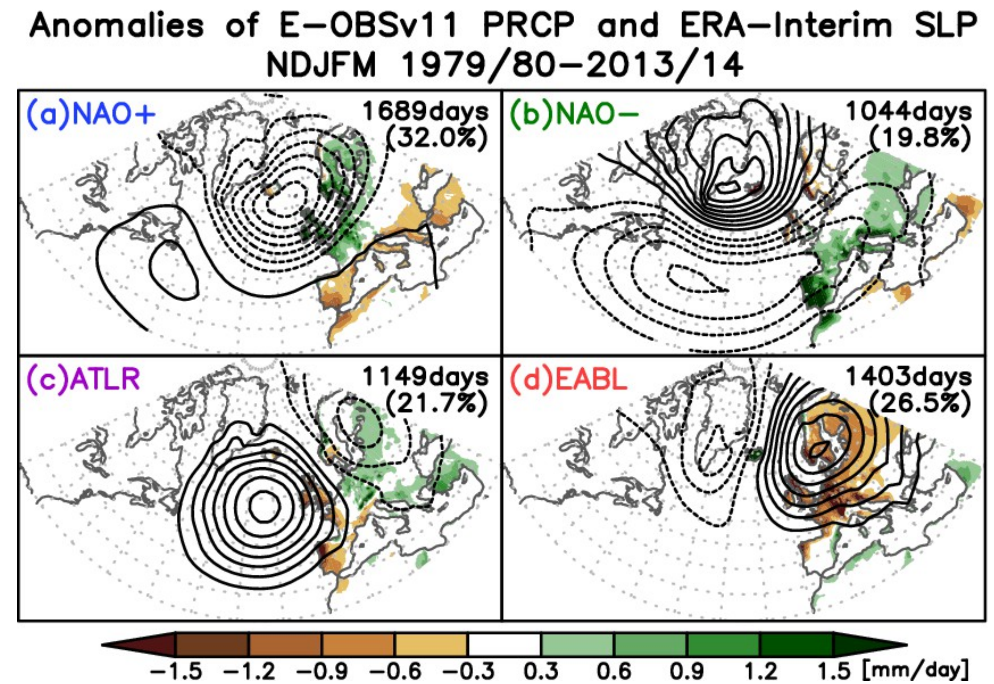


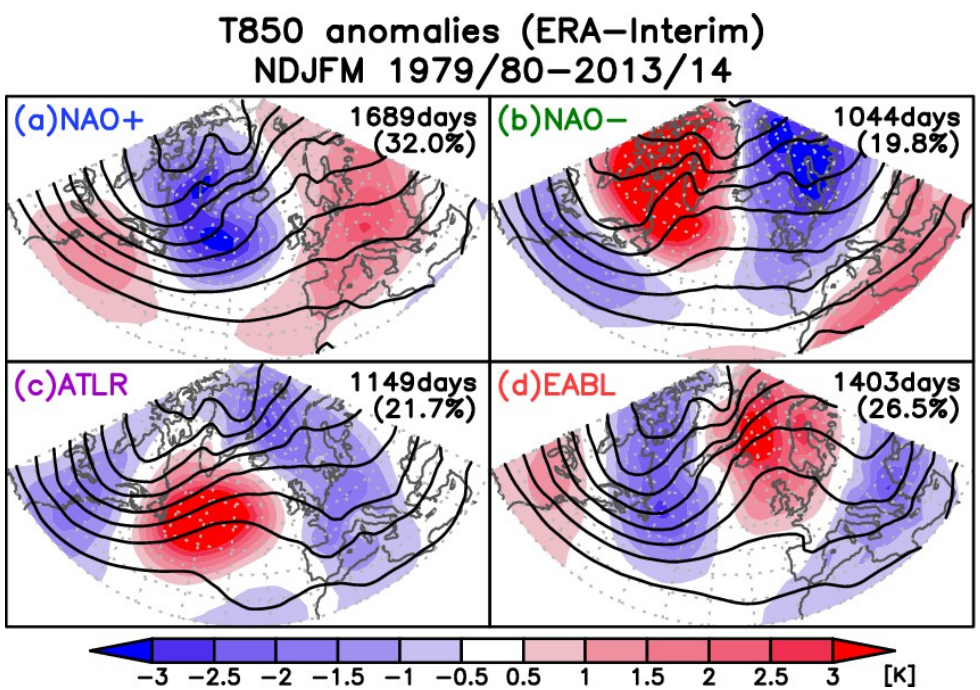
Each calendar day is classified as a specific regime (i.e. no "no-regime" days).

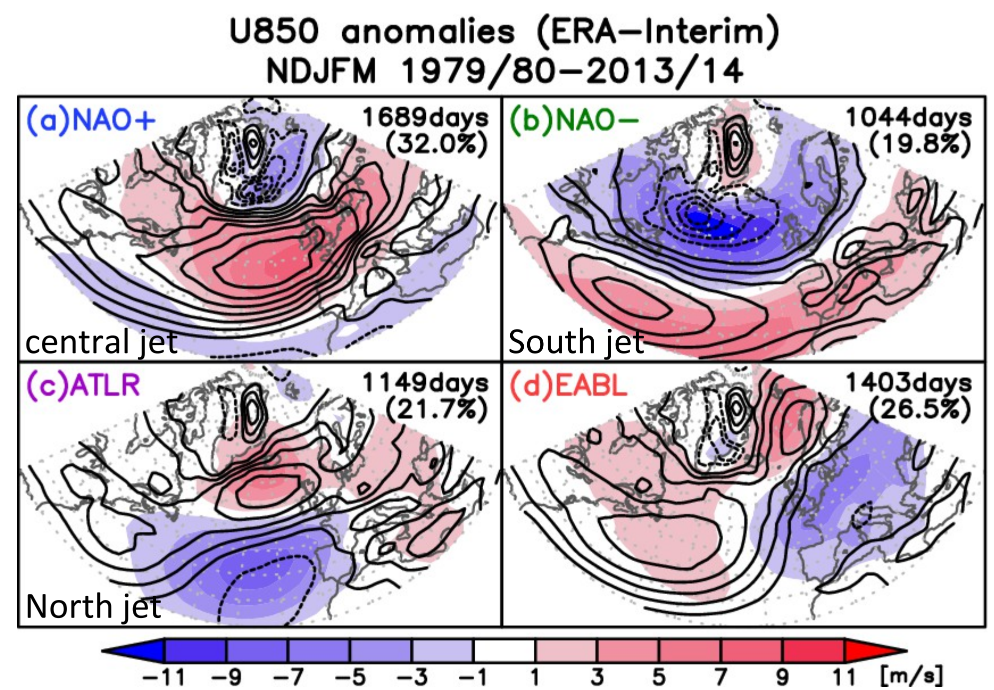
Weather regimes (ERA-Interim, NDJFM)

99.8% significant, consistent with other studies
(e.g. Ferranti et al. 2015, Dawson et al. 2012)

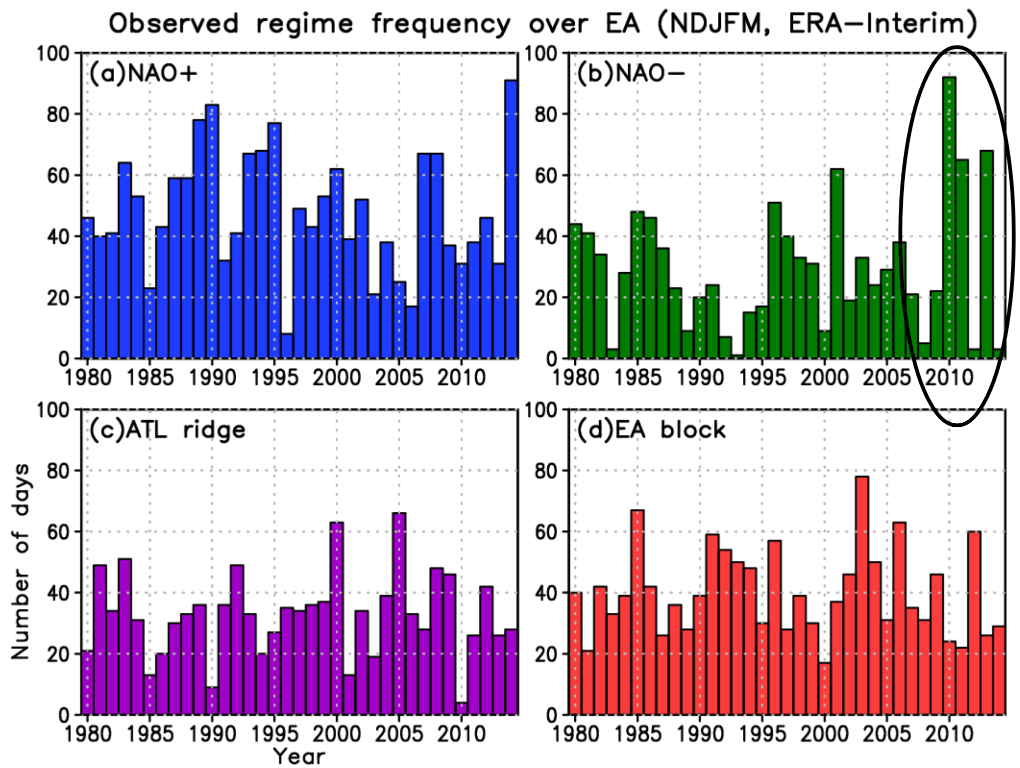


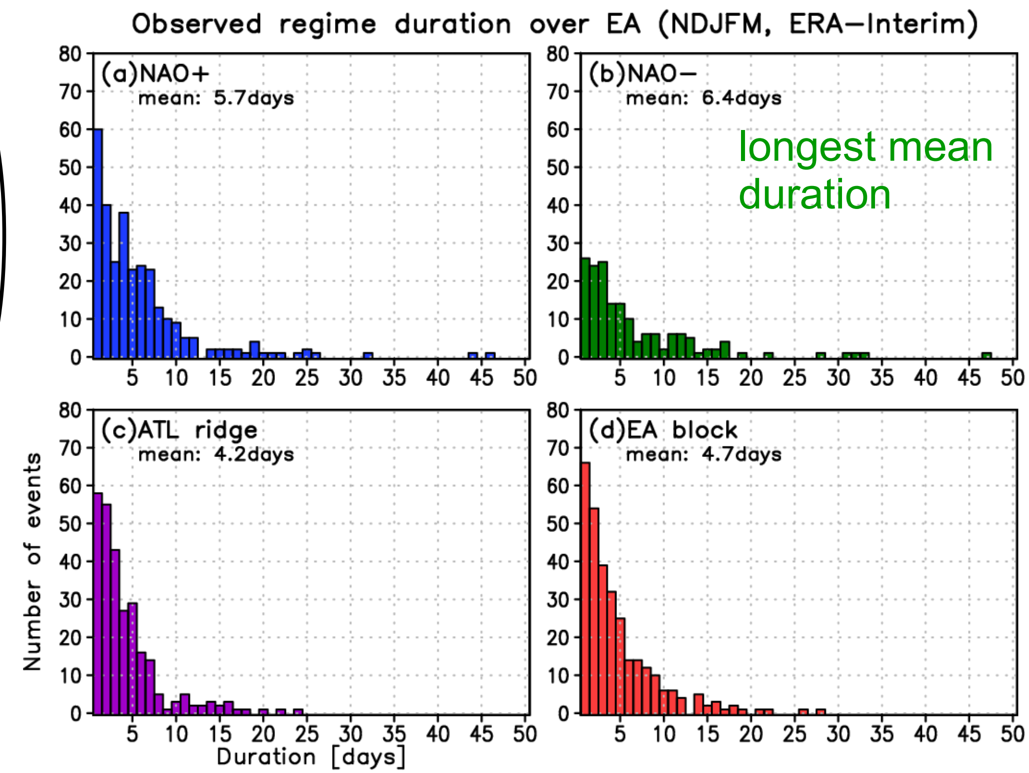






Weather regimes (ERA-Interim, NDJFM 1979/80-20013/14)





After 2009/10, many long-lasting NAO- events occurred:

28 days: Jan. - Feb. 1980

32 days: Dec. 2009 - Jan. 2010

47 days: Jan. - Mar. 2010

33 days: Dec. 2010 – Jan. 2011

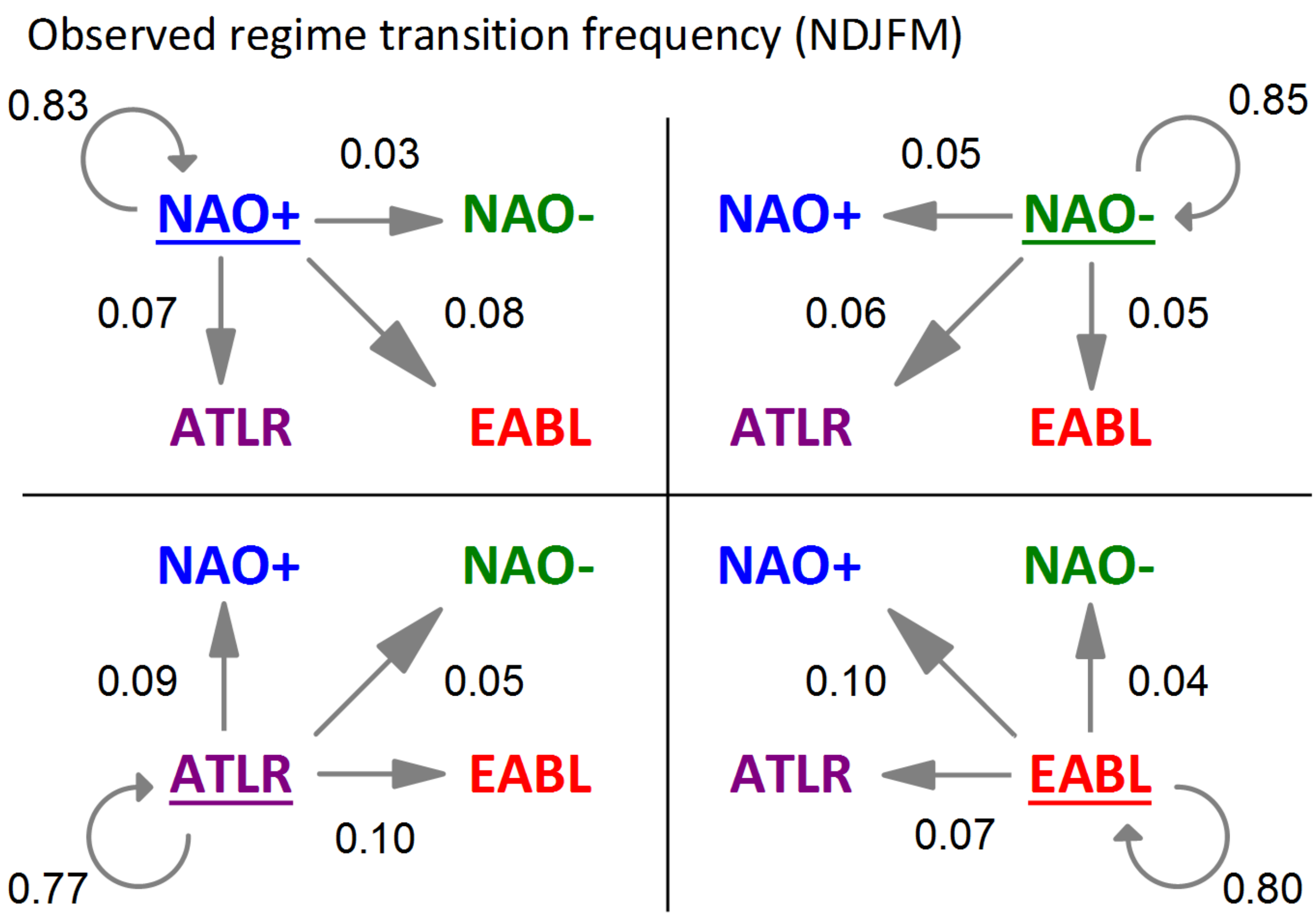
31 days: Mar. 2013

transition matrix

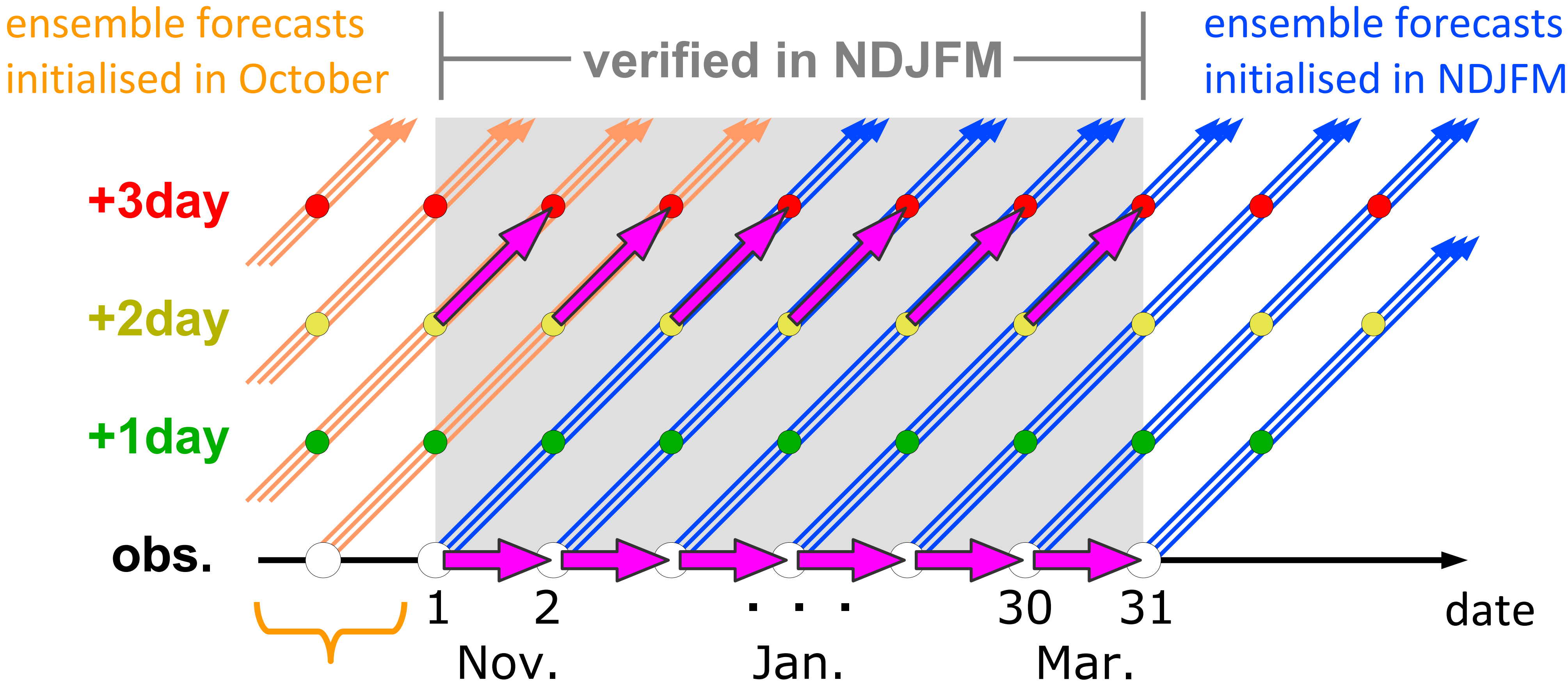
regime tomorrow

from \ to (regime today)	NAO+	NAO-	ATLR	EABL
NAO+	0.83	0.03	0.07	0.08
NAO-	0.05	**0.85**	0.06	0.05
ATLR	0.09	0.05	0.77	0.10
EABL	0.10	0.04	0.07	0.80

Frequencies of regime transition & regime in NWP models



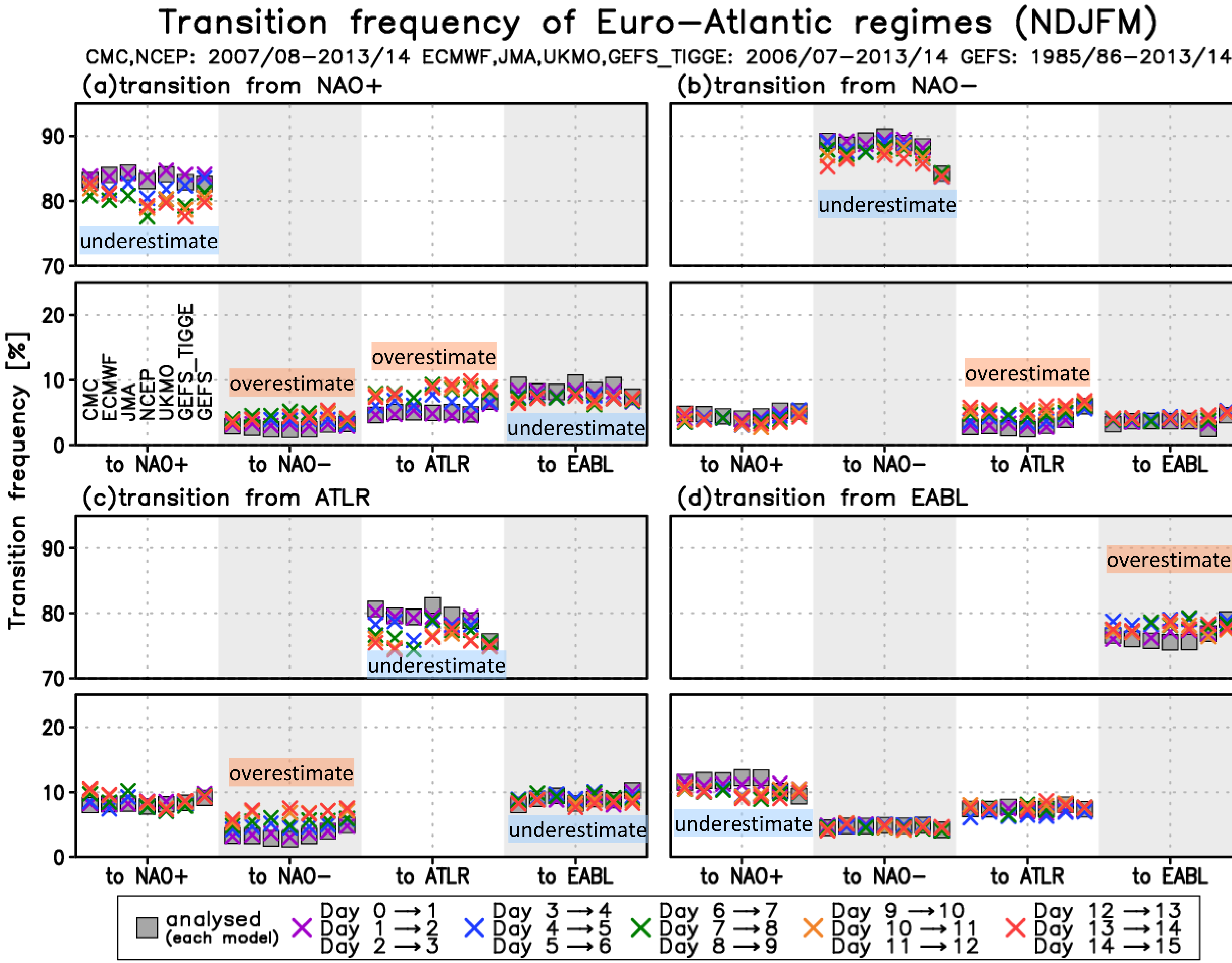
Regime transition frequency

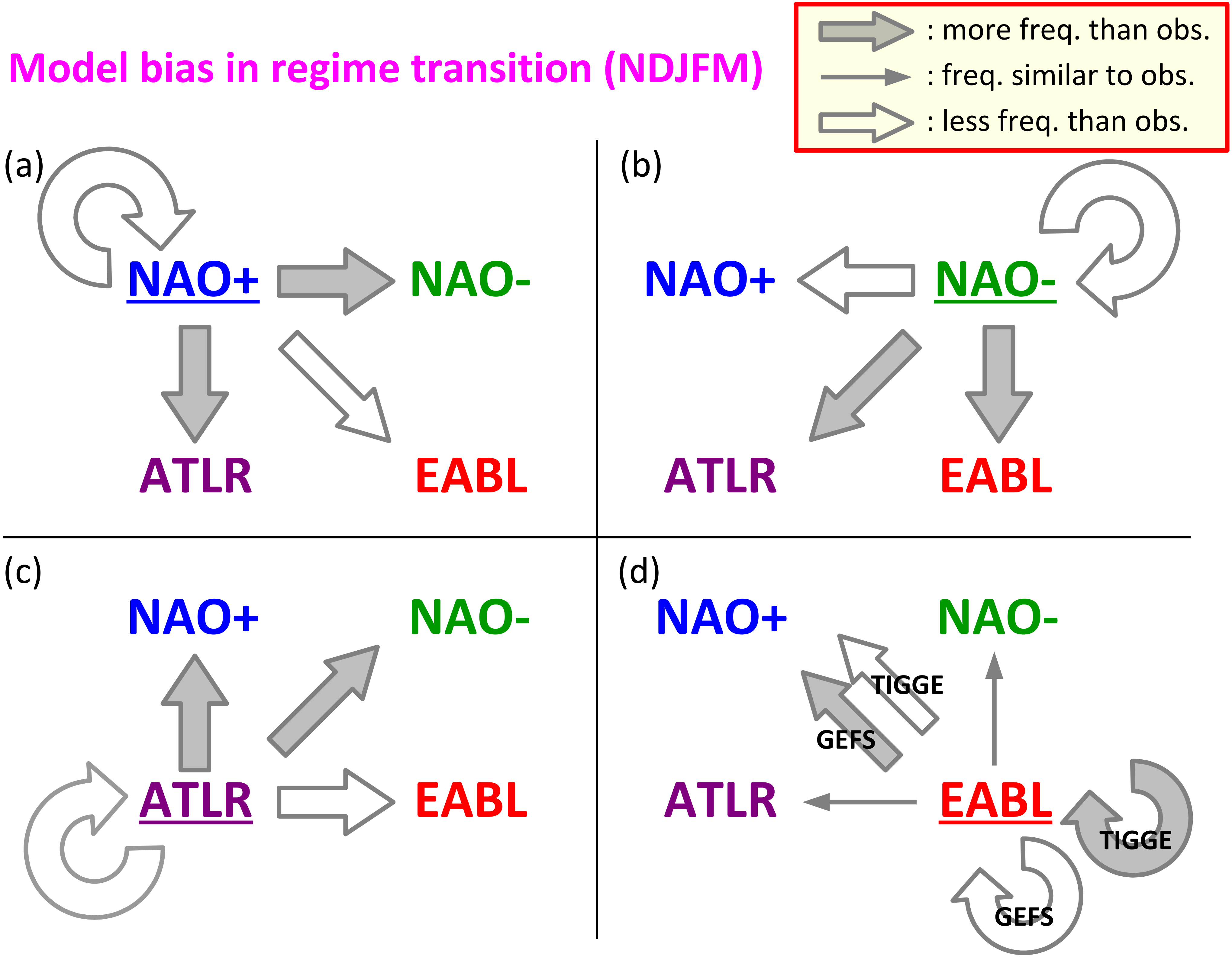


Forecast data verified in NDJFM are anslysed.

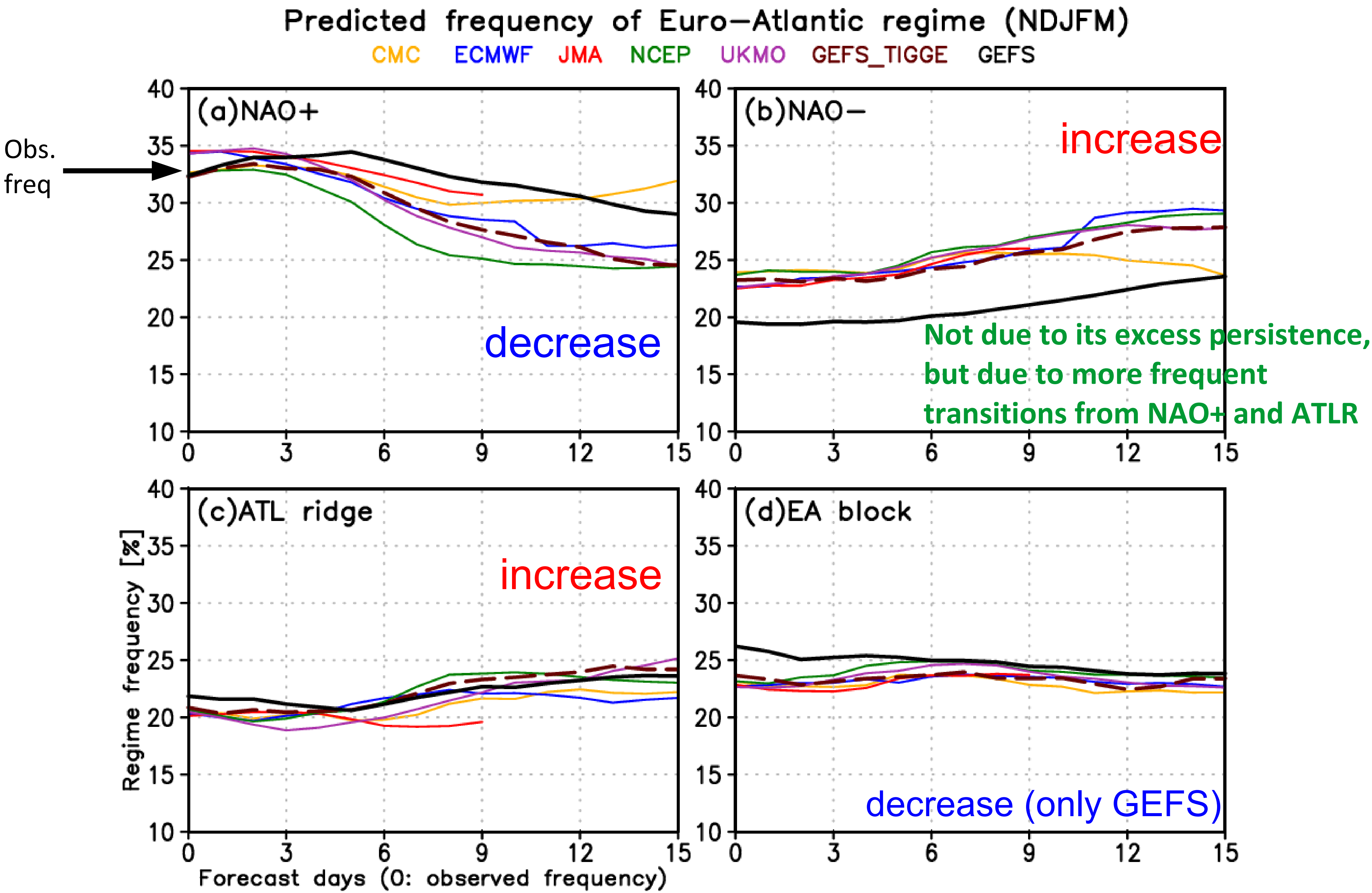
Some data are initialised in October.

Regime transition frequency in NWP models (NDJFM)



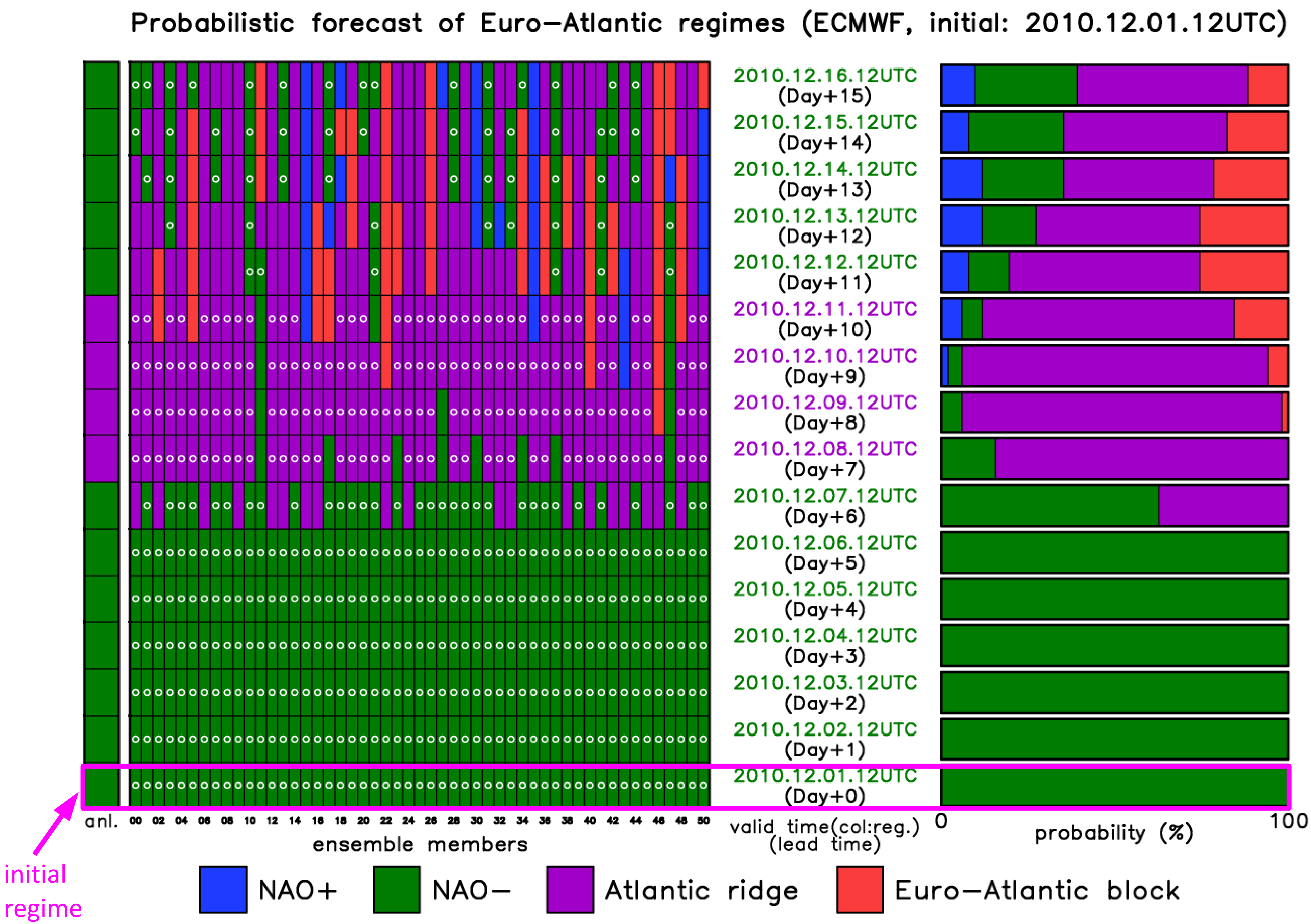

Model bias in regime transition (NDJFM)
: more freq. than obs.
: freq. similar to obs.
: less freq. than obs.
(a)
NAO+
NAO-
ATLR
EABL
(b)
NAO+
NAO-
ATLR
EABL
(c)
NAO+
NAO-
ATLR
EABL
(d)
NAO+
NAO-
TIGGE
GEFS
ATLR
EABL
TIGGE
GEFS

Regime frequency in NWP models (NDJFM)



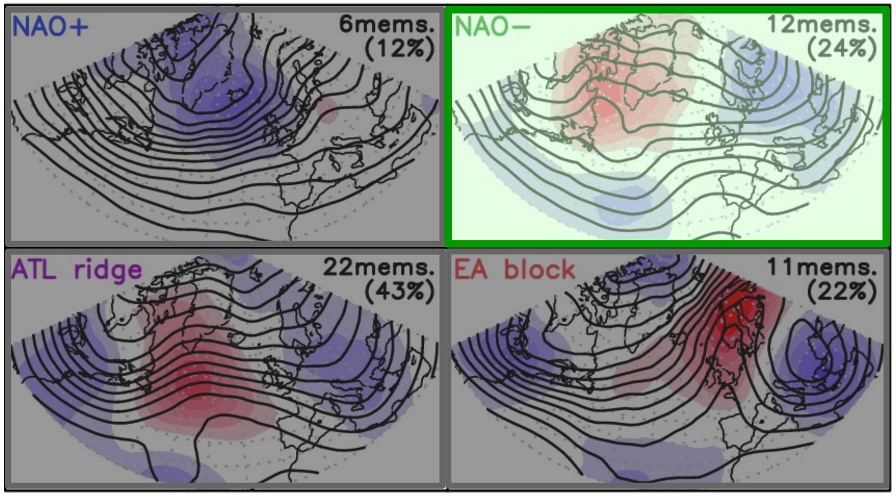
Models tend to prefer **NAO-** and ATLR to NAO+ with lead time.

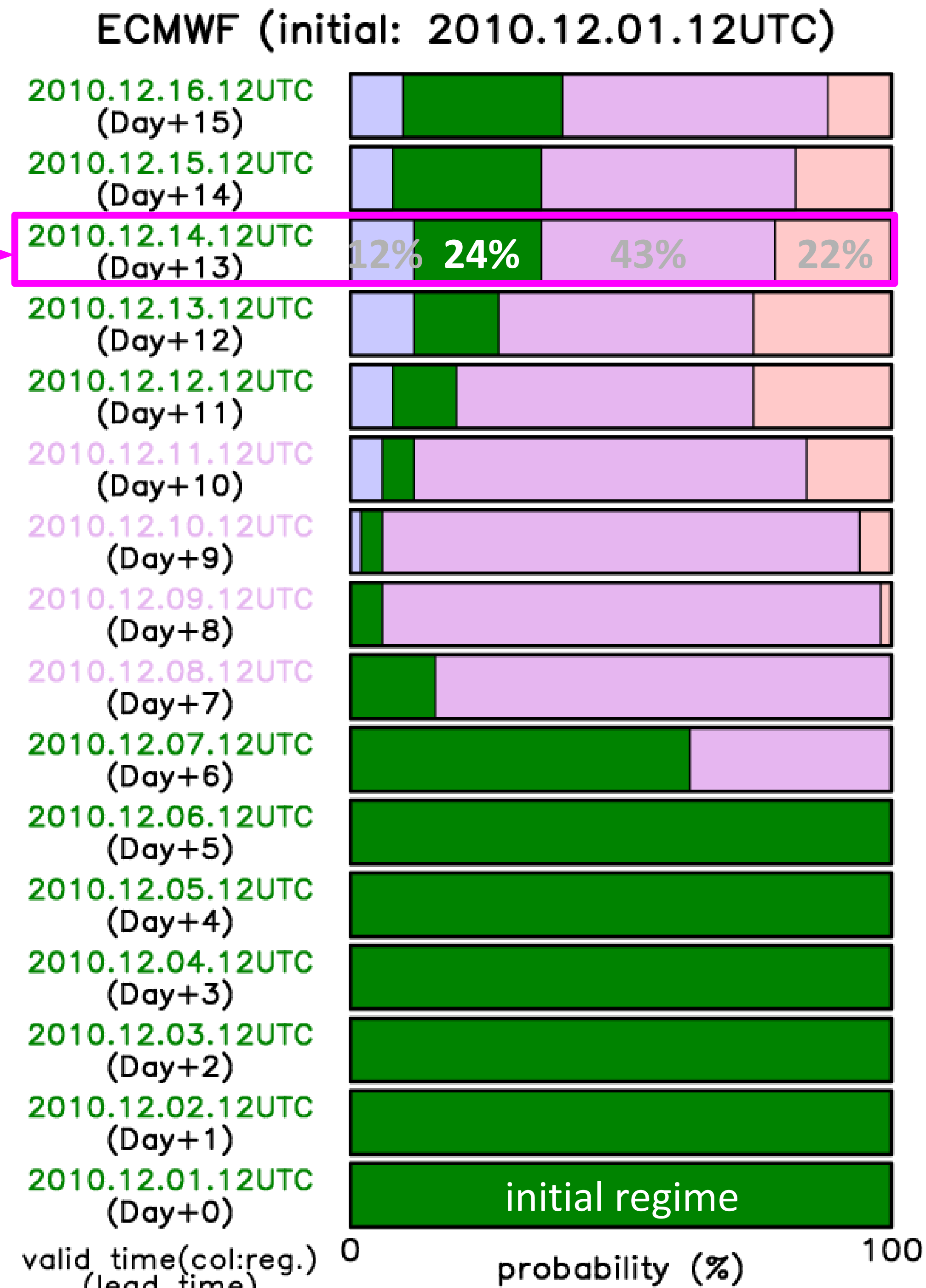
Verification of probabilistic regime forecast



Verification of probabilistic regime forecast

Forecast regime (Day 13, 51 members)





Brier Score (BS) is calculated for

1. **single-category probabilistic forecast**
   (probabilistic forecast of each regime)

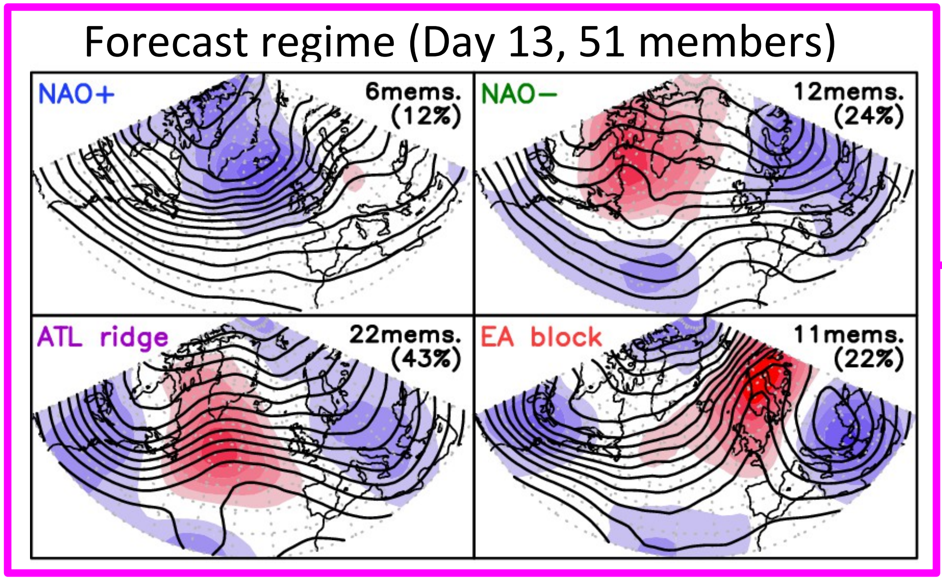
$$BS_r = \frac{1}{N}\sum_{i}^{N}(p_i^r - o_i^r)^2$$

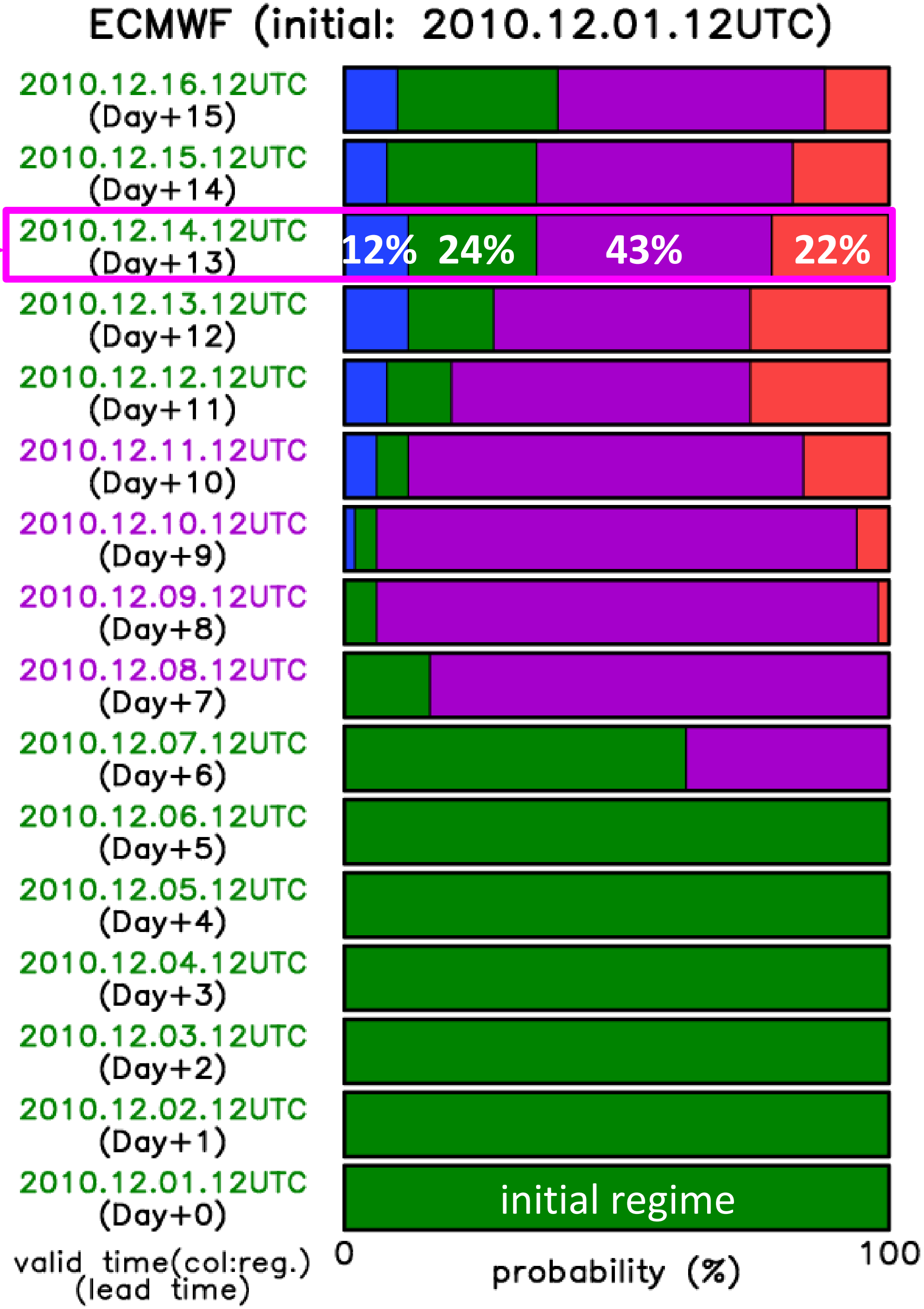
2. **multi-category probabilistic forecast**
   (probabilistic forecast of all regimes)

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

p^r: fcst prob. of regime r (0-1), N: No. of forecasts
o^r: obs prob. of regime r (0 or 1), R: No. of regimes

Verification of probabilistic regime forecast





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o^r: obs prob. of regime r (0 or 1), R: No. of regimes

Verification of probabilistic regime forecast

Brier Skill Score (BSS)

$$BSS = 1 - \frac{BS_{fcst}}{BS_{ref}}$$

BSS=1: a perfect skill
BSS=0: a comparable skill to reference forecast
BSS<0: poorer skill than reference forecast

BSS is conventionally defined as the relative probability score compared with the probability score of a reference forecast. Here, a reference forecast is produced by considering a Markov chain with the initial regime (we know today's regime!) and the observed transition matrix (i.e. multiplying initial regime probability vector by the transition matrix). Therefore, the reference forecast has a higher skill than the climatological forecast, especially in the short forecast range.

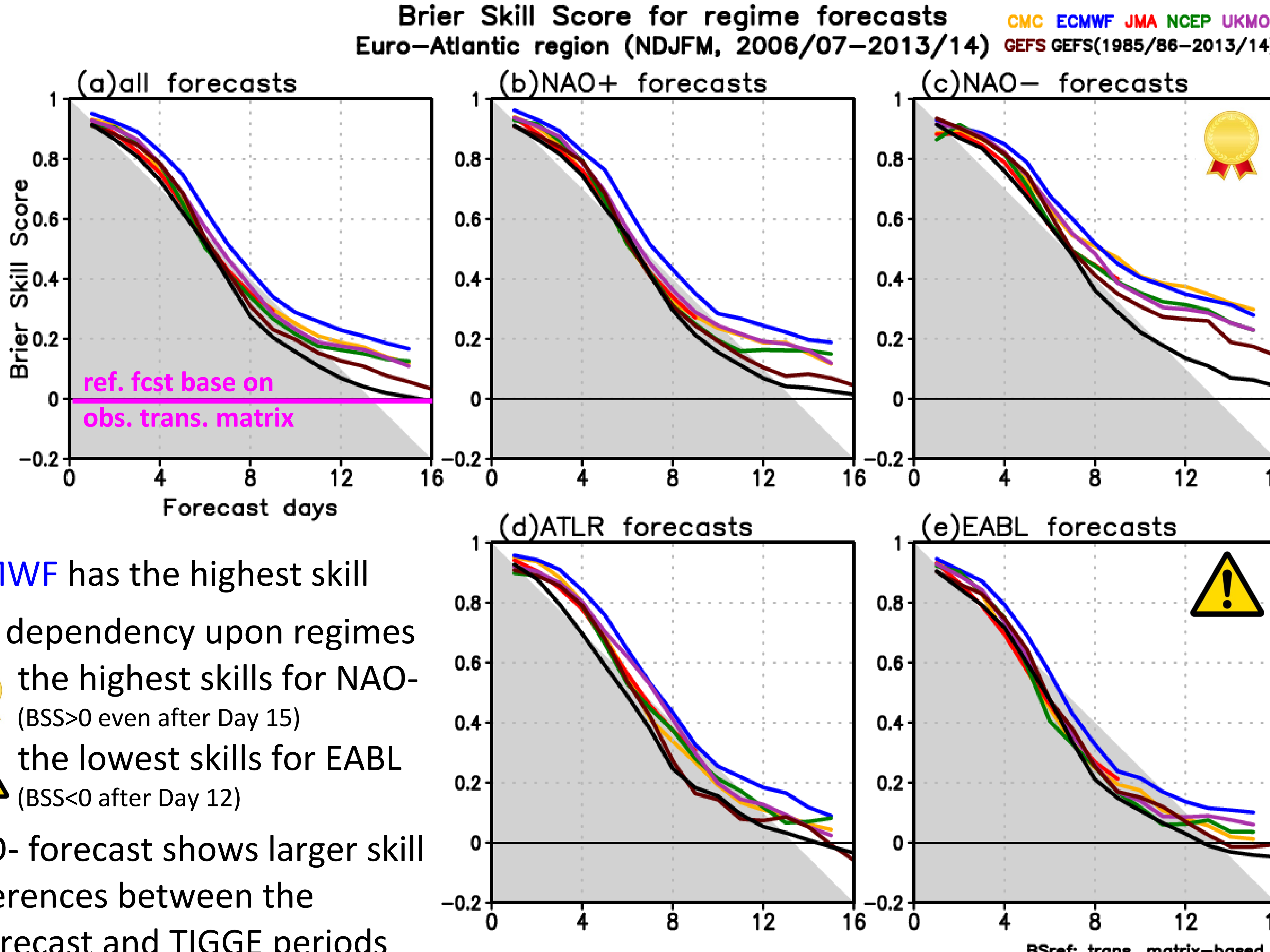
If initial regime is NAO- (i.e. R_0=(0 1 0 0)), reference forecast R_X for Day X become

$R_1=R_0T=(0.05\ \ 0.85\ \ 0.06\ \ 0.05)$,
$R_2=R_1T=(0.09\ \ 0.73\ \ 0.10\ \ 0.09)$,
$R_3=R_2T=(0.12\ \ 0.63\ \ 0.13\ \ 0.12)$,
:
$R_{15}=R_{14}T=(0.30\ \ 0.23\ \ 0.21\ \ 0.26)$. close to clim. Freq.

$$\begin{array}{c|c}
 & \text{regime tomorrow} \\
\text{from} \backslash \text{to} & \begin{array}{cccc} \text{NAO+} & \text{NAO-} & \text{ATLR} & \text{EABL} \end{array} \\
\text{regime today} \begin{array}{c} \text{NAO+} \\ \text{NAO-} \\ \text{ATLR} \\ \text{EABL} \end{array} & \begin{pmatrix} 0.83 & 0.03 & 0.07 & 0.08 \\ \underline{0.05} & \underline{0.85} & \underline{0.06} & \underline{0.05} \\ 0.09 & 0.05 & 0.77 & 0.10 \\ 0.10 & 0.04 & 0.07 & 0.80 \end{pmatrix}
\end{array}$$

Skill dependency upon forecast regime (all models)

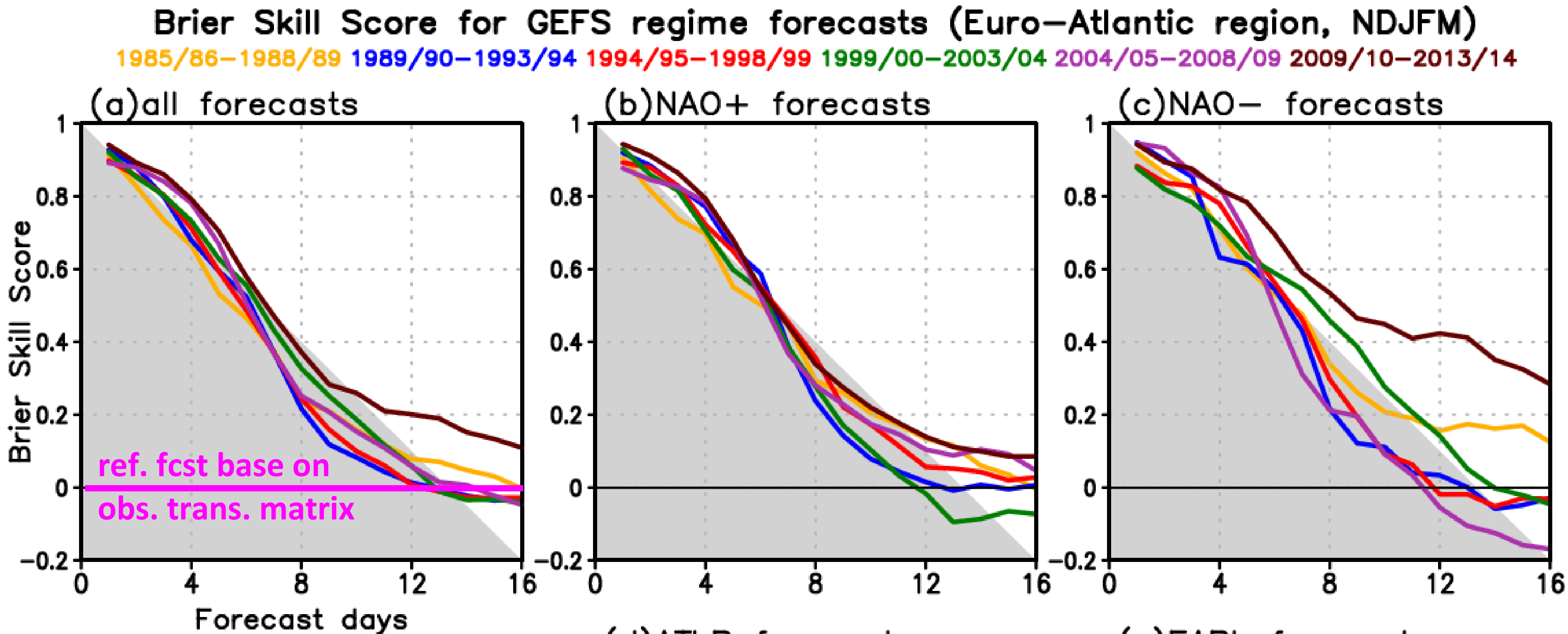
single-category probabilistic forecast

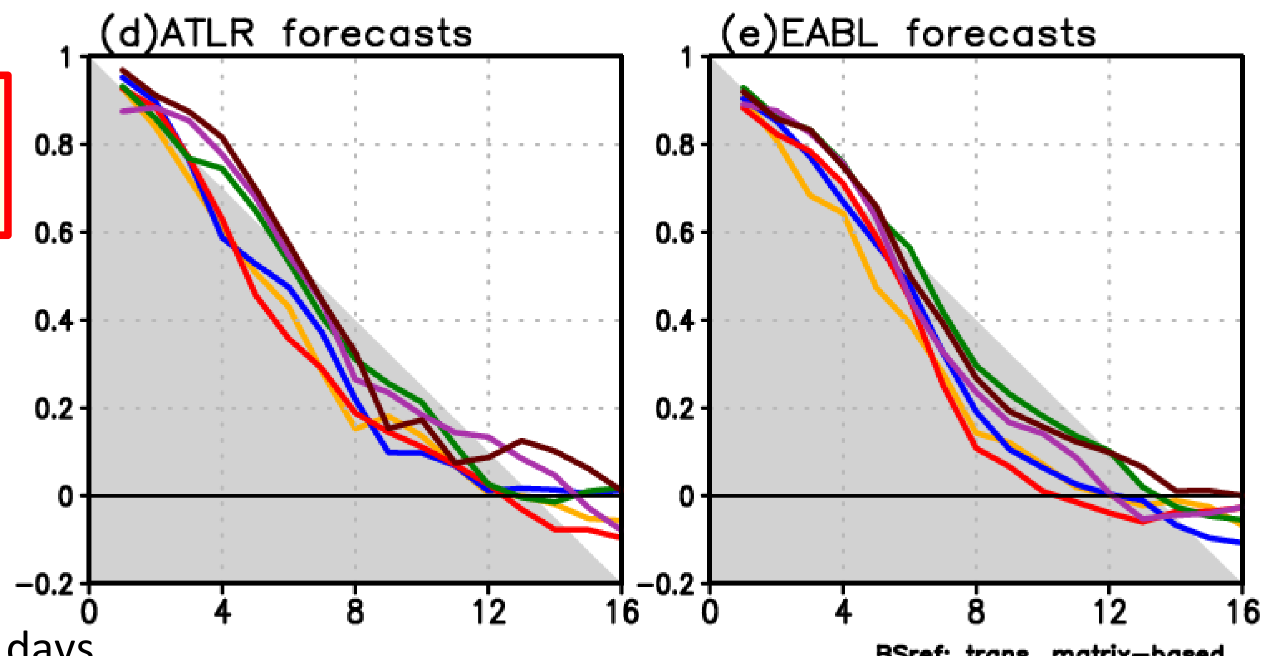


- ECMWF has the highest skill
- Skill dependency upon regimes
  - the highest skills for NAO- (BSS>0 even after Day 15)
  - the lowest skills for EABL (BSS<0 after Day 12)
- NAO- forecast shows larger skill differences between the reforecast and TIGGE periods

Skill dependency upon forecast regime (GEFS)

single-category
probabilistic forecast





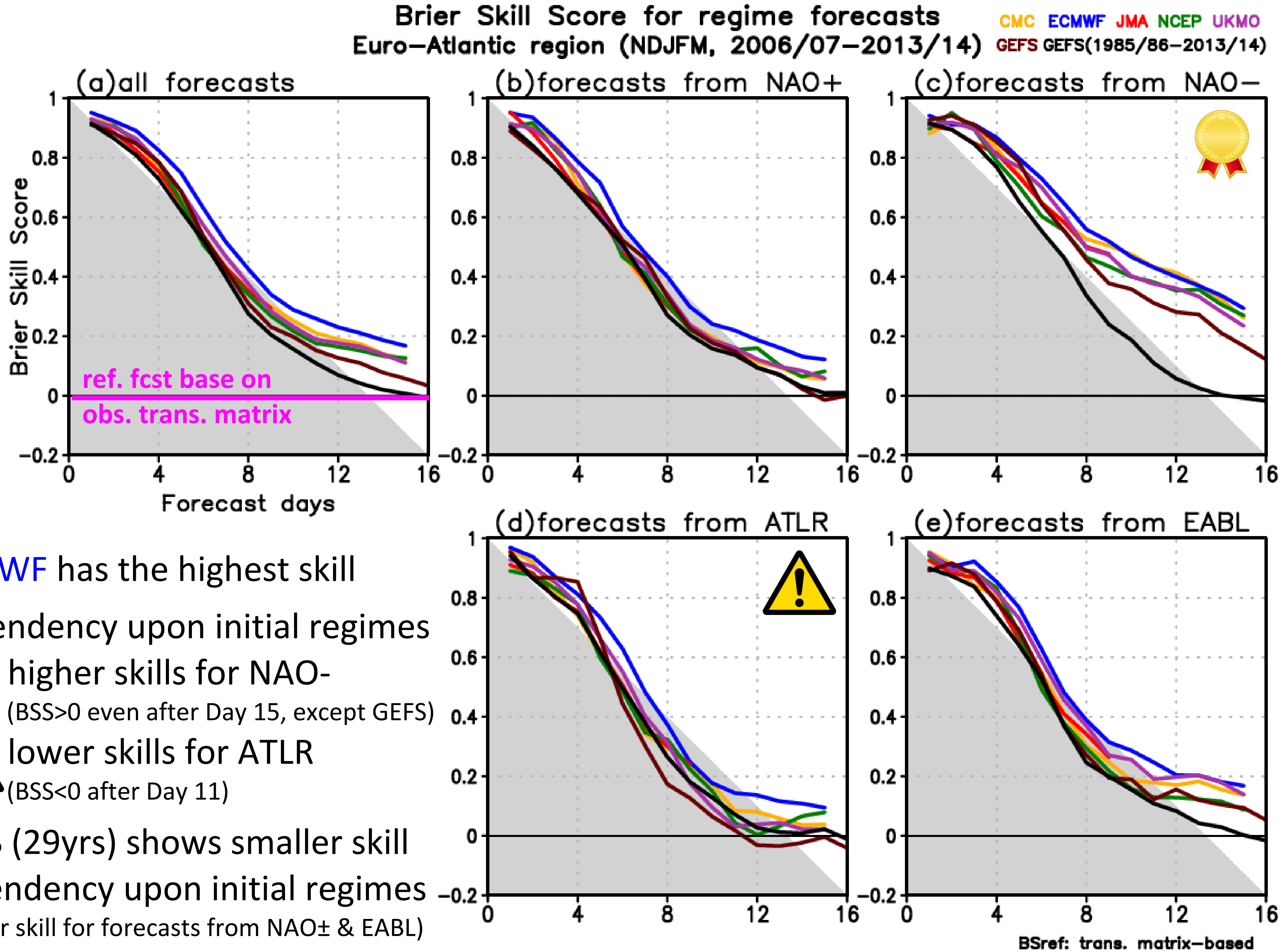
Higher skill for the NAO- forecasts during the active NAO- periods

Long-lived (≧14 days) NAO- events

- 1985/86-88/89: 16, 16, 16, 14 days
- 1989/90-93/94: N/A
- 1994/95-98/99: 22 days
- 1999/00-03/04: 16, 15, 14, 14 days
- 2004/05-08/09: 16, 15 days
- 2009/10-13/14: 47, 33, 32, 31, 19, 14 days

Skill dependency upon initial regime (all models)

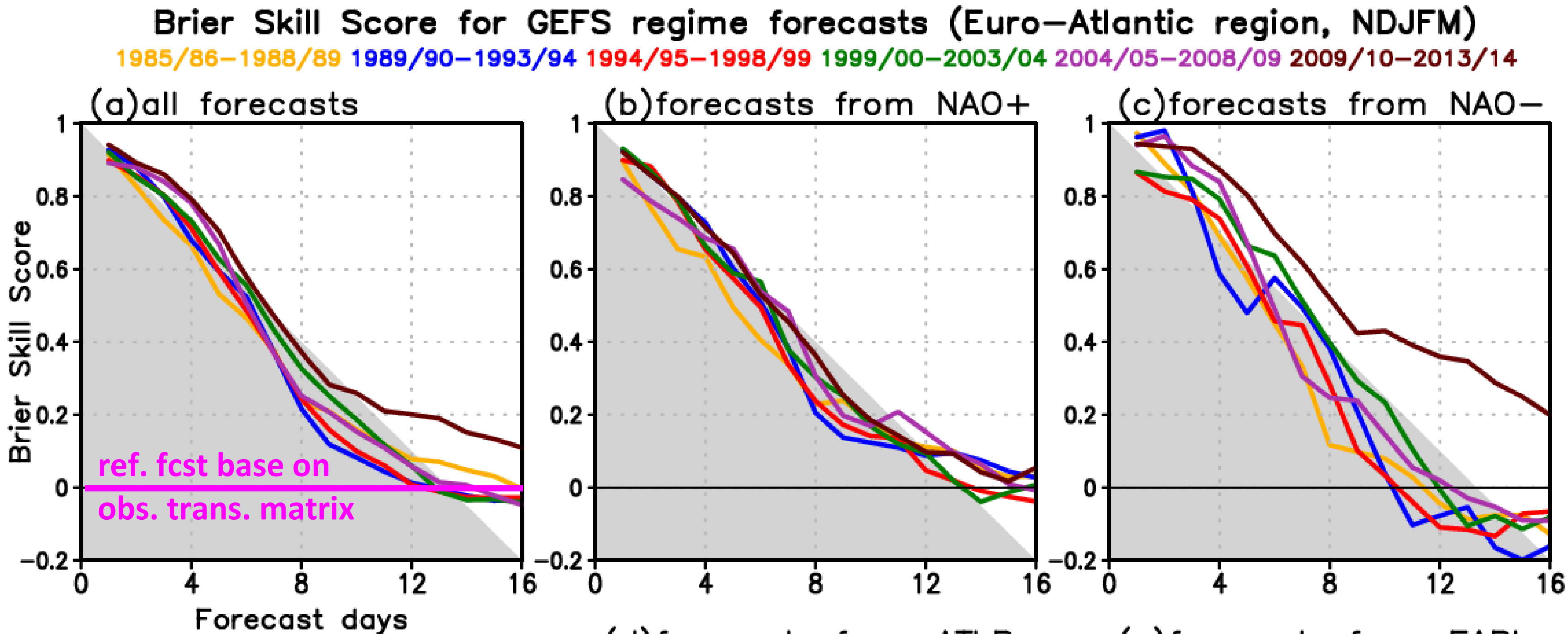
multi-category probabilistic forecast

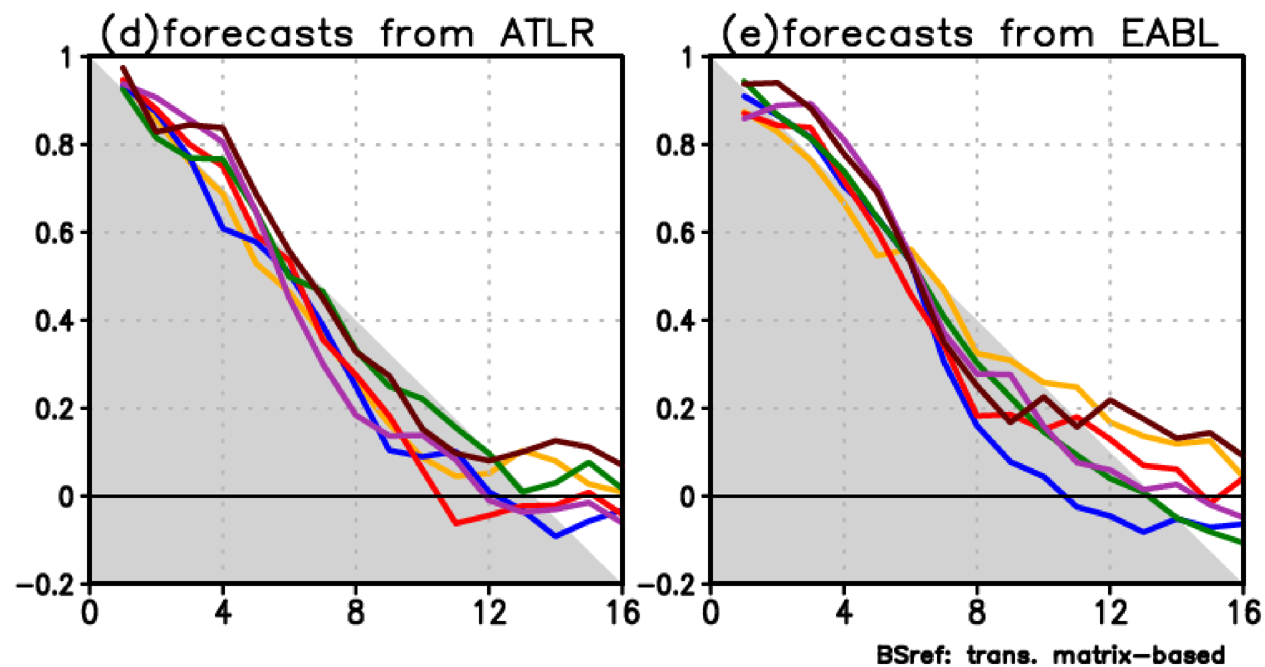


- ECMWF has the highest skill
- Dependency upon initial regimes
  - higher skills for NAO-
    (BSS>0 even after Day 15, except GEFS)
  - lower skills for ATLR
    (BSS<0 after Day 11)
- GEFS (29yrs) shows smaller skill dependency upon initial regimes
  (similar skill for forecasts from NAO± & EABL)

Skill dependency upon initial regime (GEFS)

multi-category
probabilistic forecast

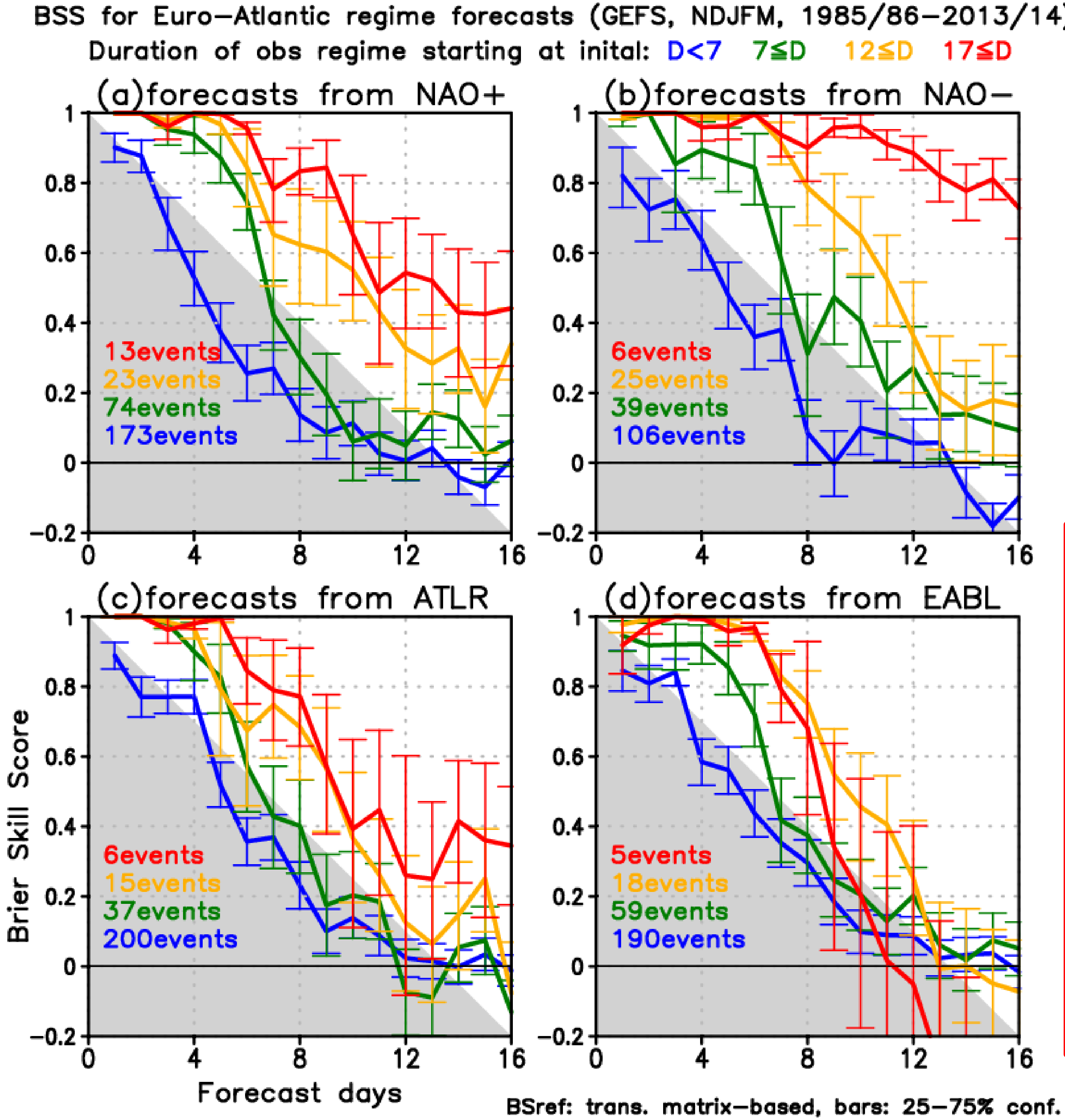




- Regarding forecasts from NAO-, **forecasts after 2009/10** show a much higher skill, compared with before 2009/10. **Forecasts before 2009/10** become useless at Day 10-12 and show the lowest skill.
- Forecasts from the other regimes shows small skill dependency on verification periods.

Skill dependency upon regime duration (GEFS)

multi-category probabilistic forecast



BBS for forecasts initialised on the start day of each regime event.

Long-lived (≧17 days) NAO- events
1994/95-98/99: **22** days
2009/10-13/14: **47**, **33**, **32**, **31**, **19** days

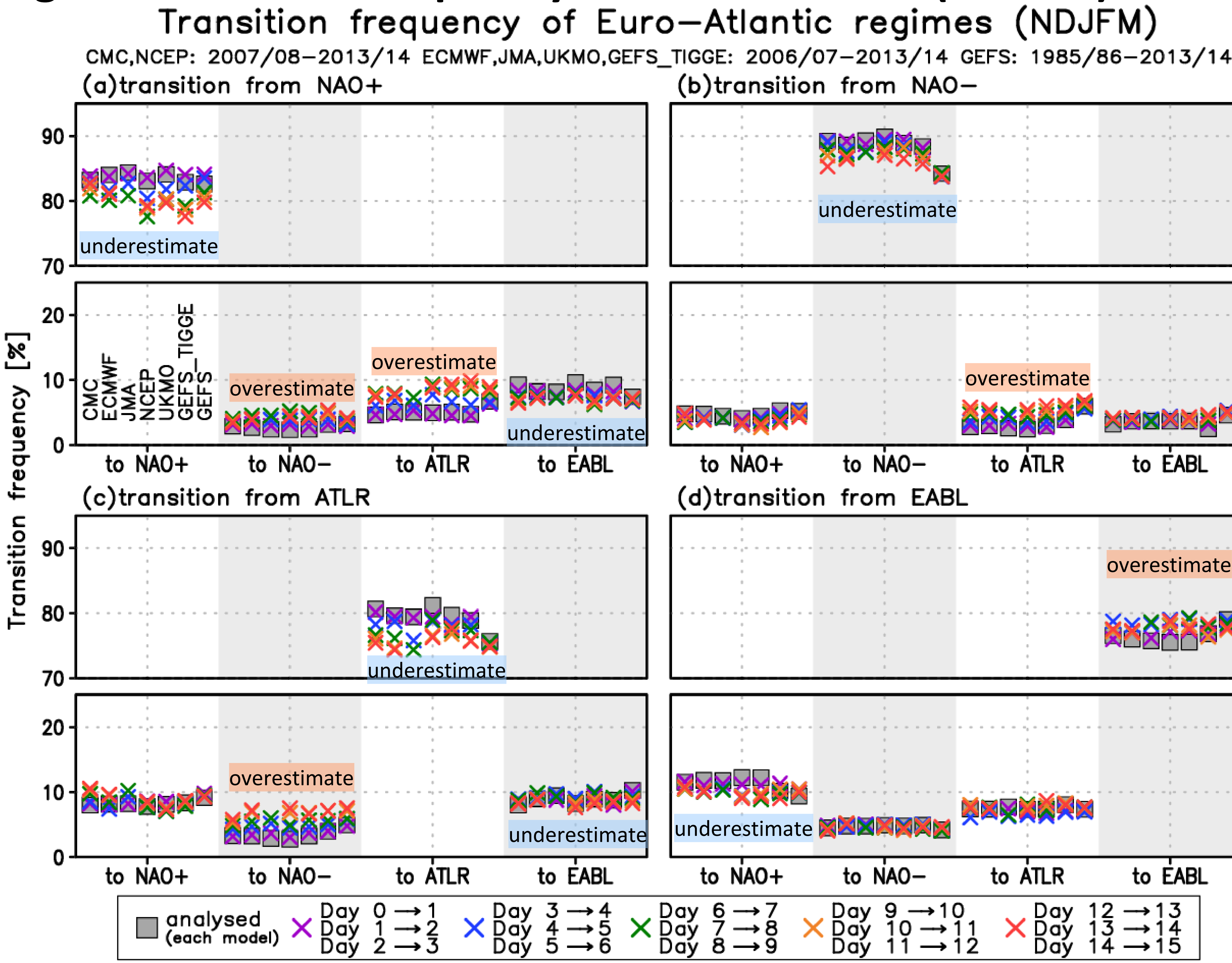
- The longer the NAO– events persist, the higher the skill of forecasts initialised on NAO–.
- The skill dependency on regime duration is less clearly observed for the other regimes.

Summary

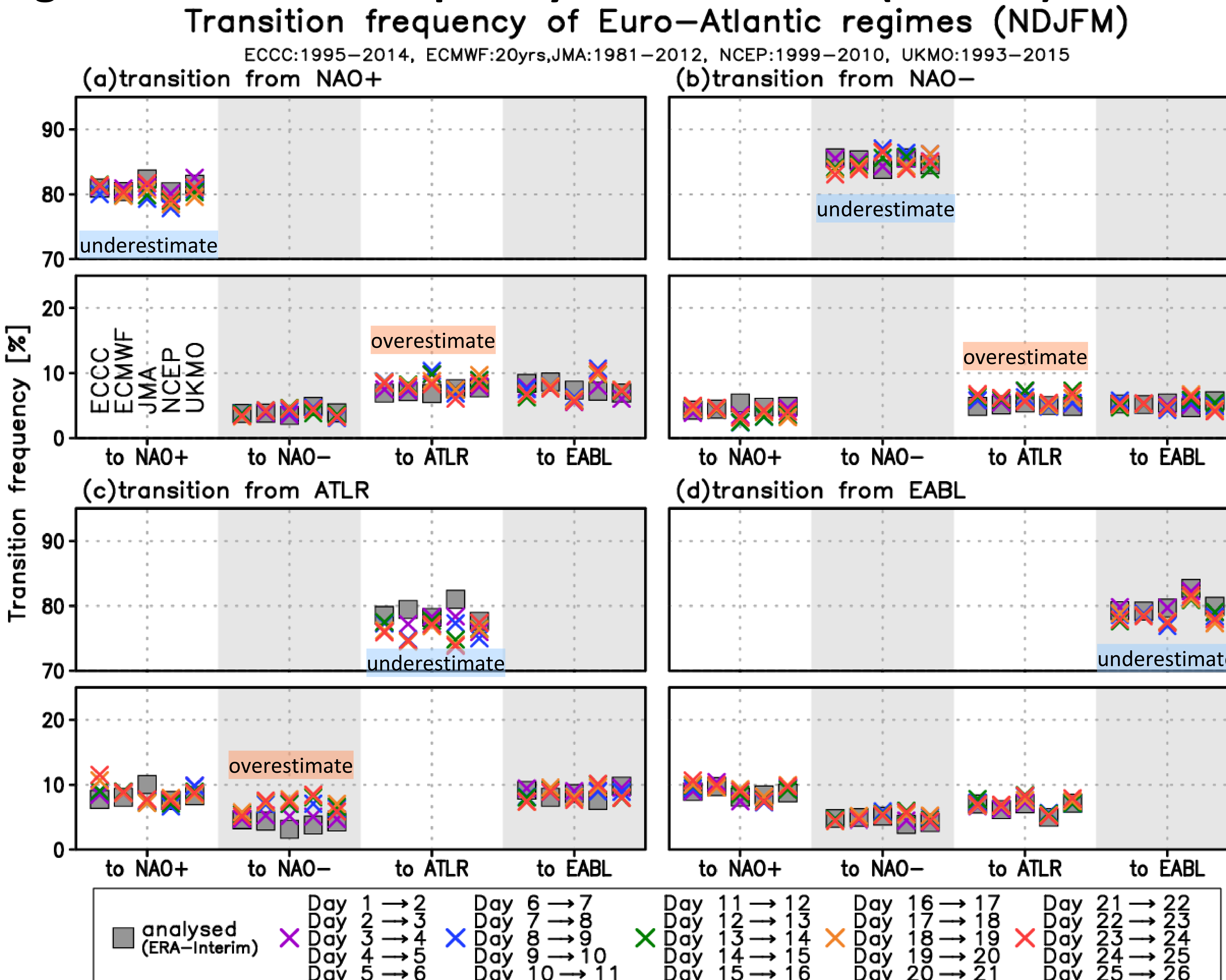
- Models have common biases in regime persistence and transition, leading to more (less) frequent NAO- and ATLR (NAO+) with lead time.
- The increased frequency of NAO– is not due to its excess persistence but due to more frequent transitions mainly from NAO+ and ATLR. In turn, NAO+ is under-persistent. A typical model bias is to underestimate regime persistence, as Strommen and Palmer (QJRMS) independently pointed out.
- Probabilistic NAO- (EABL) forecasts show the highest (lowest) skill. In particular, NAO- forecasts show a higher skill during active NAO- years.
- The models show the highest (lowest) probabilistic skill for forecasts from NAO- (ATLR) during the TIGGE period (NAO- was active) and the lowest skill for forecasts from NAO- before 2009/10 (NAO- was inactive).
- The longer the NAO– events persist, the higher the skill of forecasts initialised on NAO–. The skill dependency on regime duration is less clearly observed for the other regimes.

Matsueda, M. and T. N. Palmer, 2018: Estimates of flow-dependent predictability of wintertime Euro-Atlantic weather regimes in medium-range forecasts. *Quart. J. Roy. Meteor. Soc.,* 144, 1012-1027. doi:10.1002/qj.3265.

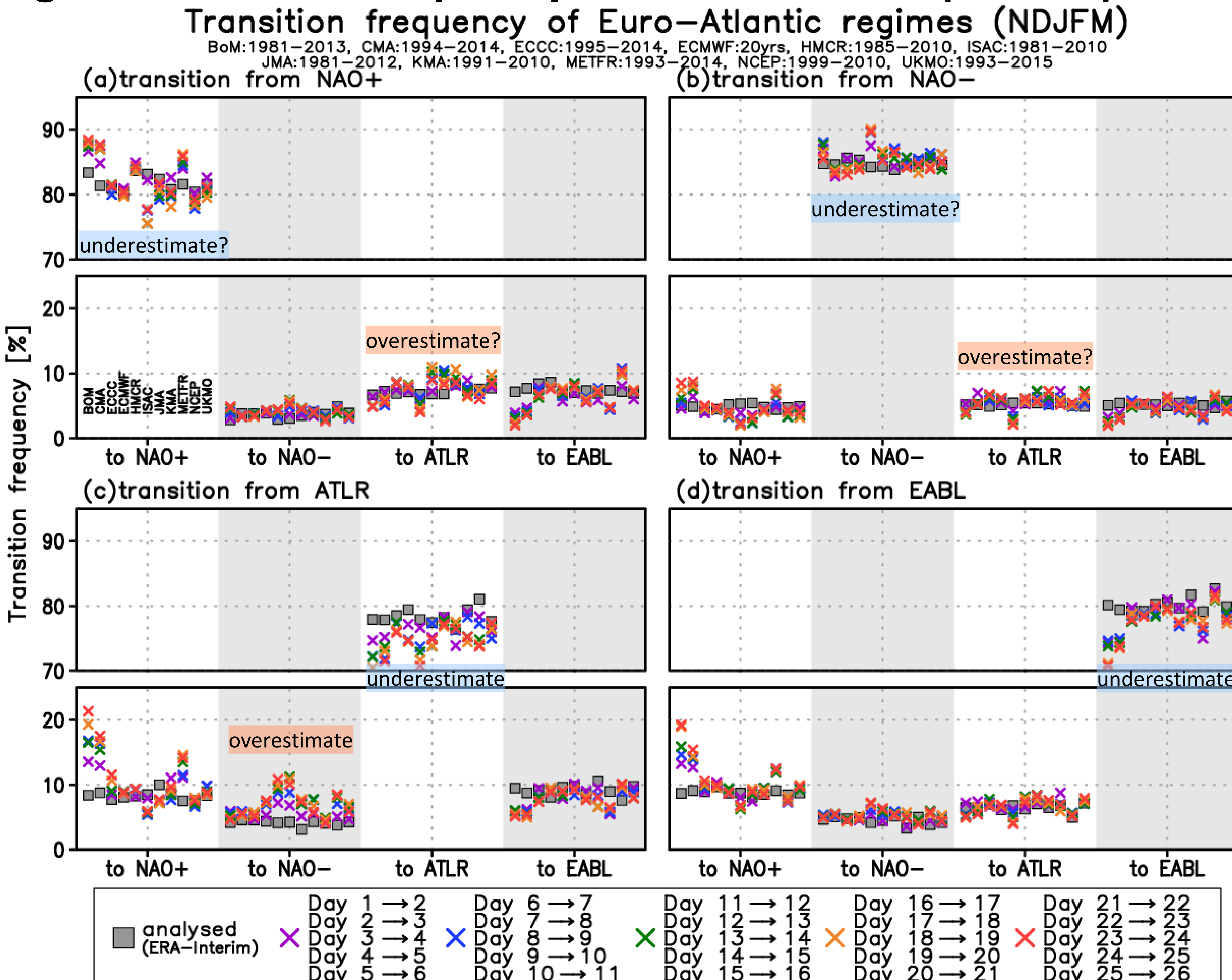
Regime transition frequency in TIGGE models (NDJFM)



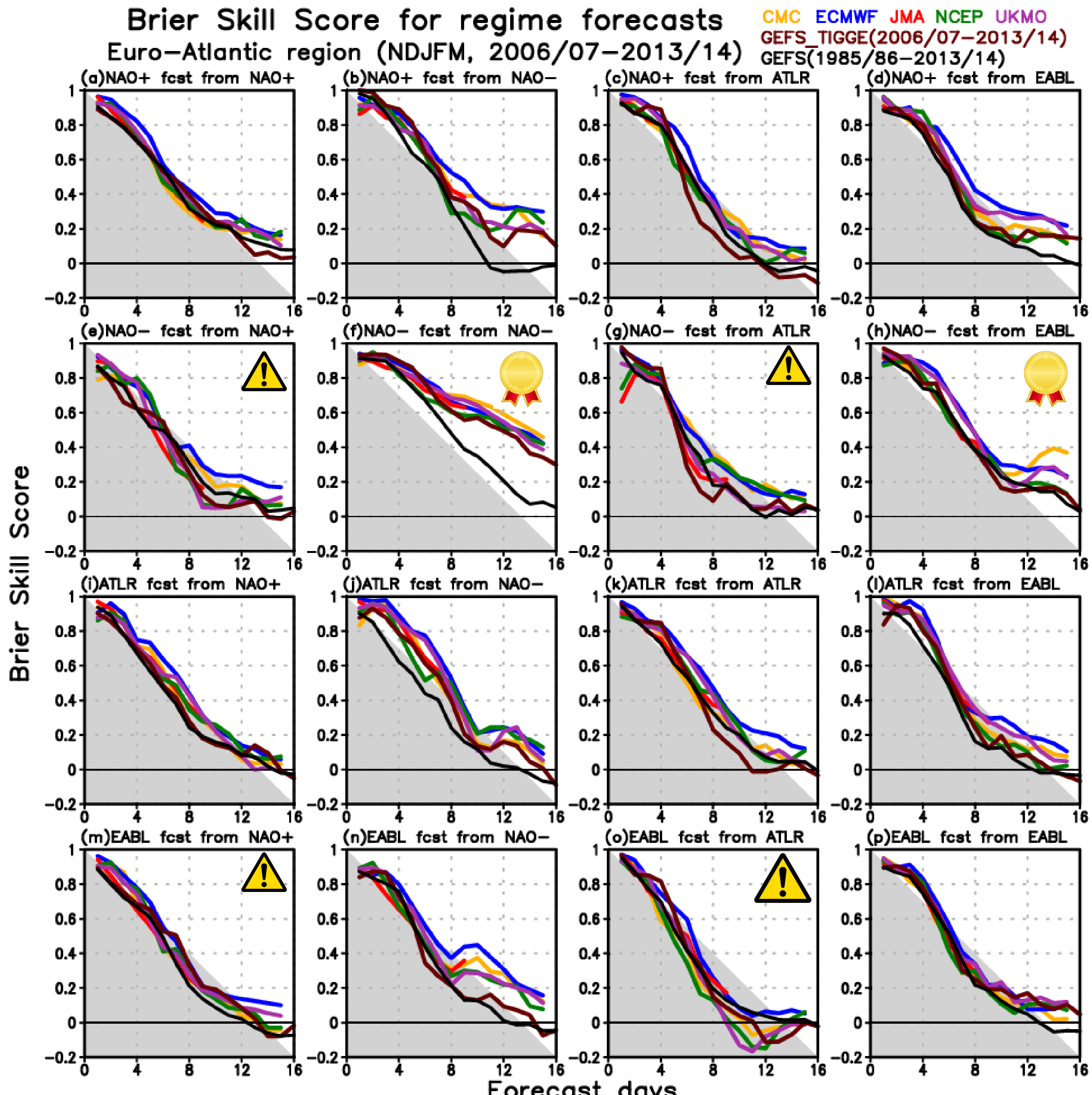
Regime transition frequency in S2S models (NDJFM)



Regime transition frequency in all S2S models (NDJFM)



Thank you for your attentions.



NAO+ fcst

NAO- fcst

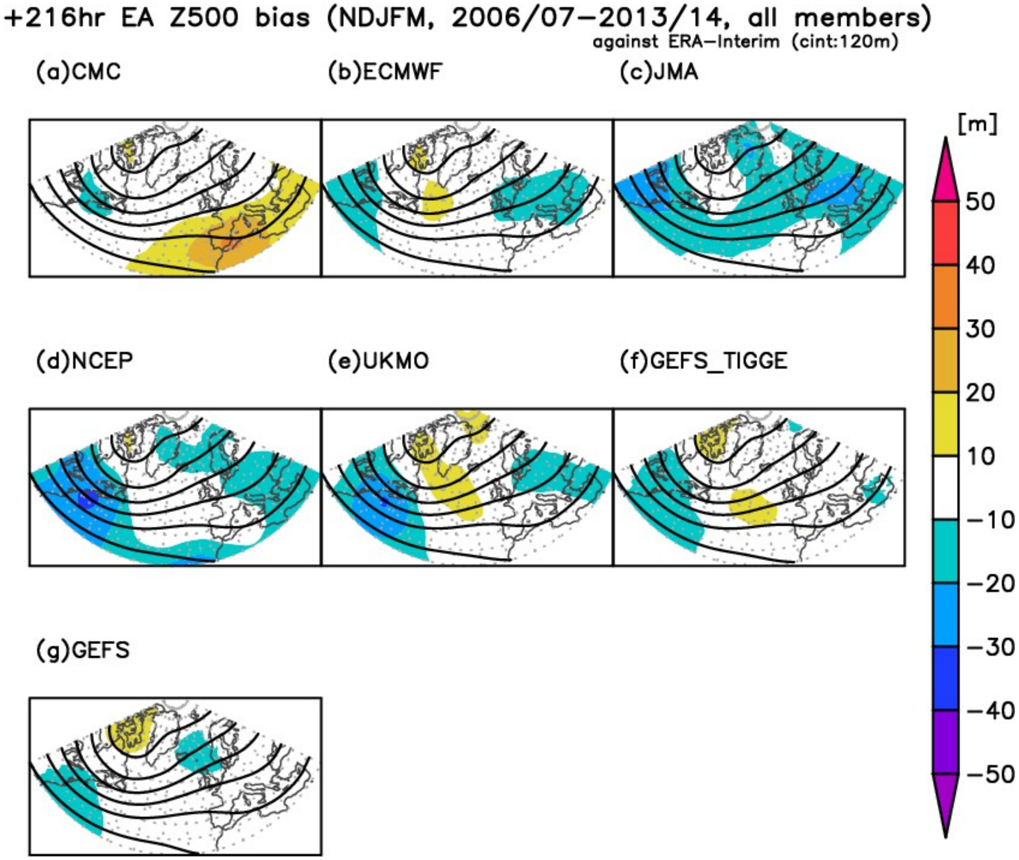
ATLR fcst

EABL fcst

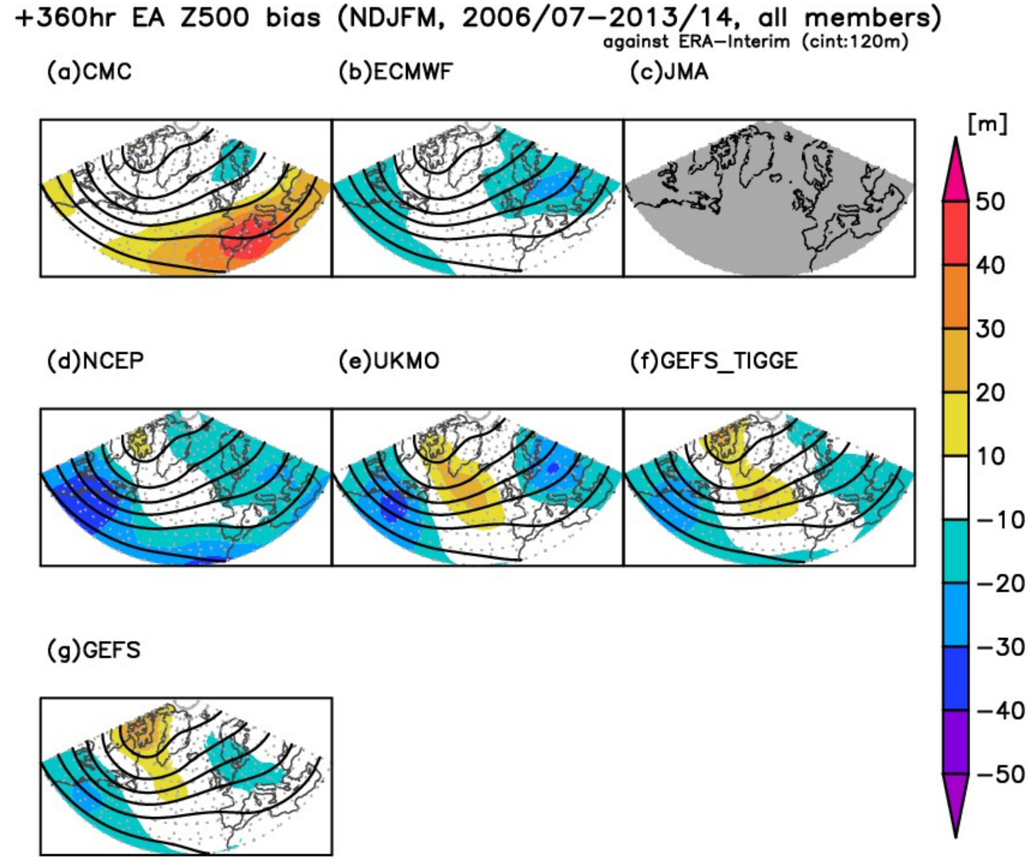
Initial regime NAO+ NAO- ATLR EABL

Model bias in Z500 (against ERA-Interim/GEFS analysis)

Day 9



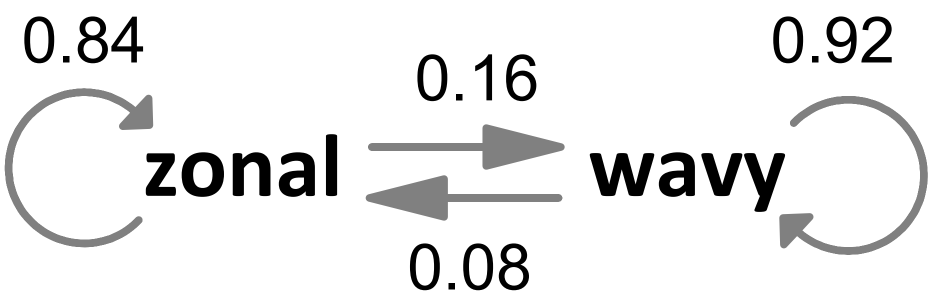
Day 15



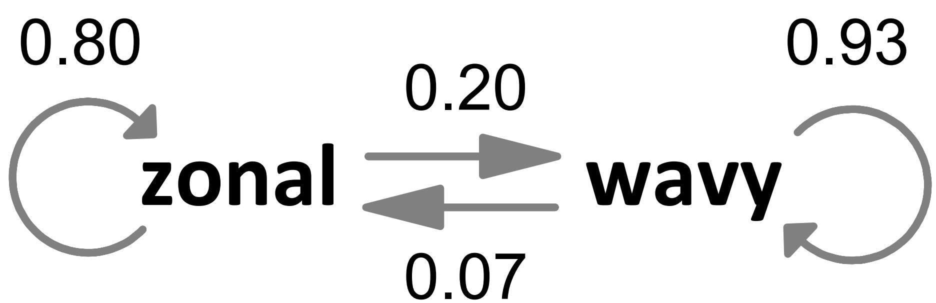
“super” regimes – zonal vs wavy regimes -

zonal regime: NAO+, **wavy regime**: NAO-, ATLR&EABL

(a) regime transition (analysis)



(b) regime transition
(5 models' mean, +13-15days)



(c) potential well for regimes