Impact of snow and sea ice on sub-seasonal to seasonal forecasts

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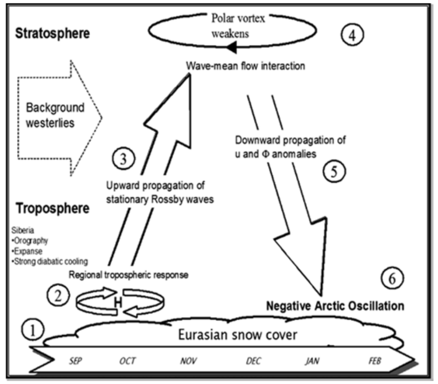
Snowpack impact on autumn/winter circulation

- **Snow-covered land : key role in climate system due to snow unique radiative and thermodynamical properties: high albedo, high thermal emissivity, strong insulating properties**

- **Snowpack may impact not only local meteorological conditions but also global circulation patterns**

- **Eurasian autumn snow cover influences wave trains propagating downstream over the North Pacific and vertically into the stratosphere, with a lagged impact in the Arctic**
  (e.g. Ross and Walsh, 1988; Cohen et al., 2007; Orsolini and Kvamstø, JGR 2009; Jeong et al., 2011)



”stratospheric bridge”

- **Does snow initialisation have a quantitative impact on monthly to seasonal prediction skill ?**

Snowpack impact on autumn/winter circulation

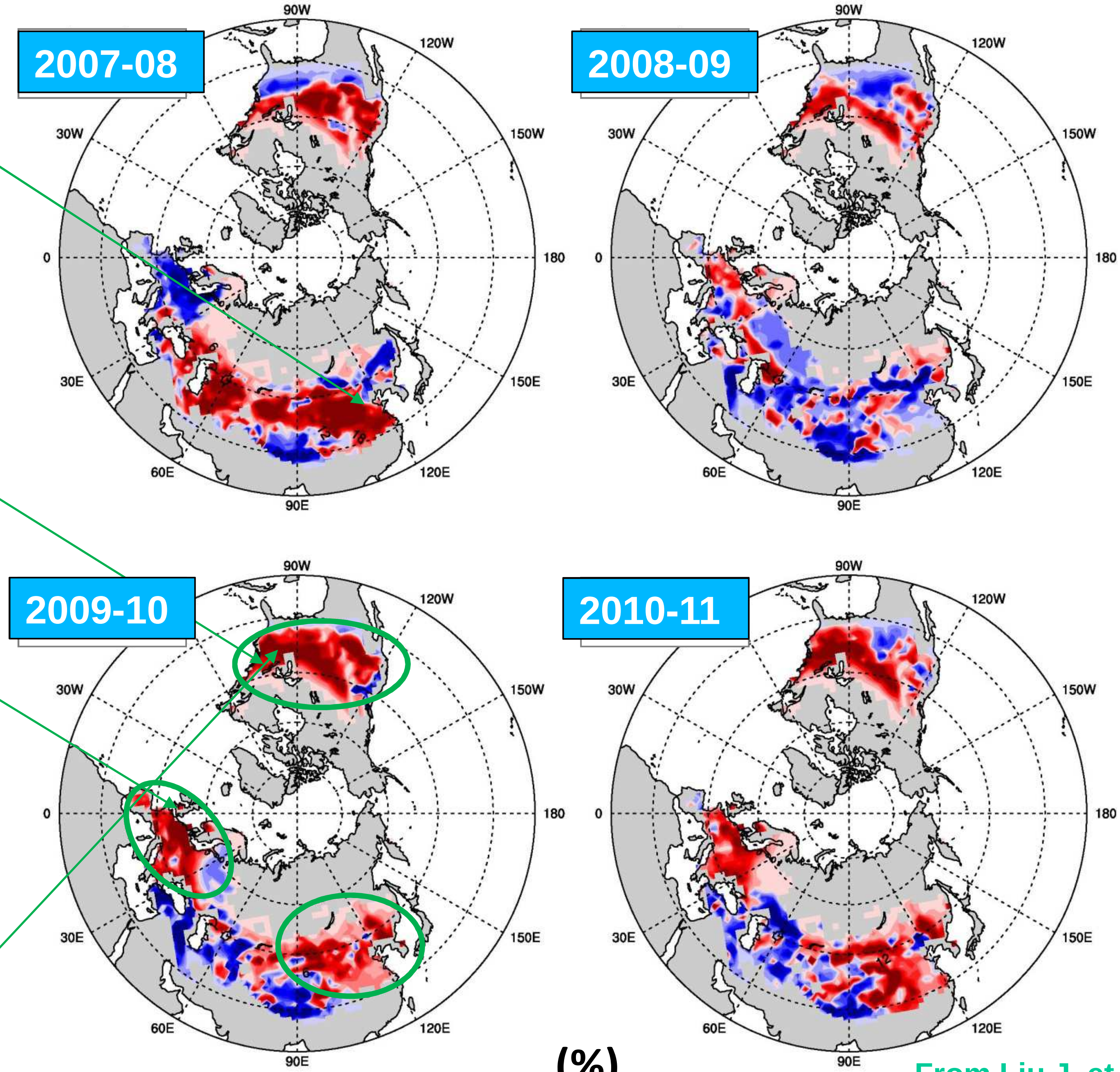
- State of the snowpack itself depends on atmospheric circulation patterns (e.g. negative NAO leads to snowy precipitation over Europe and North America, like in the recent winter 2009/10)

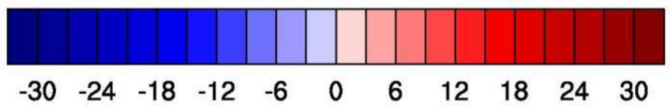
- But does snowpack itself feedback onto the atmospheric circulation ?

→Weak coupling is difficult to ascertain from standard model simulations, or observation-based correlative studies

→ Need for dedicated model experiments

Winter snow cover anomalies





From Liu J. et al. (PNAS, 2012)

SNOWGLACE simulations

- We made simulations using a modelling strategy similar to the one used for looking at soil moisture impact in the warm season (Koster et al. 2004; 2010) in the GLACE international modeling project

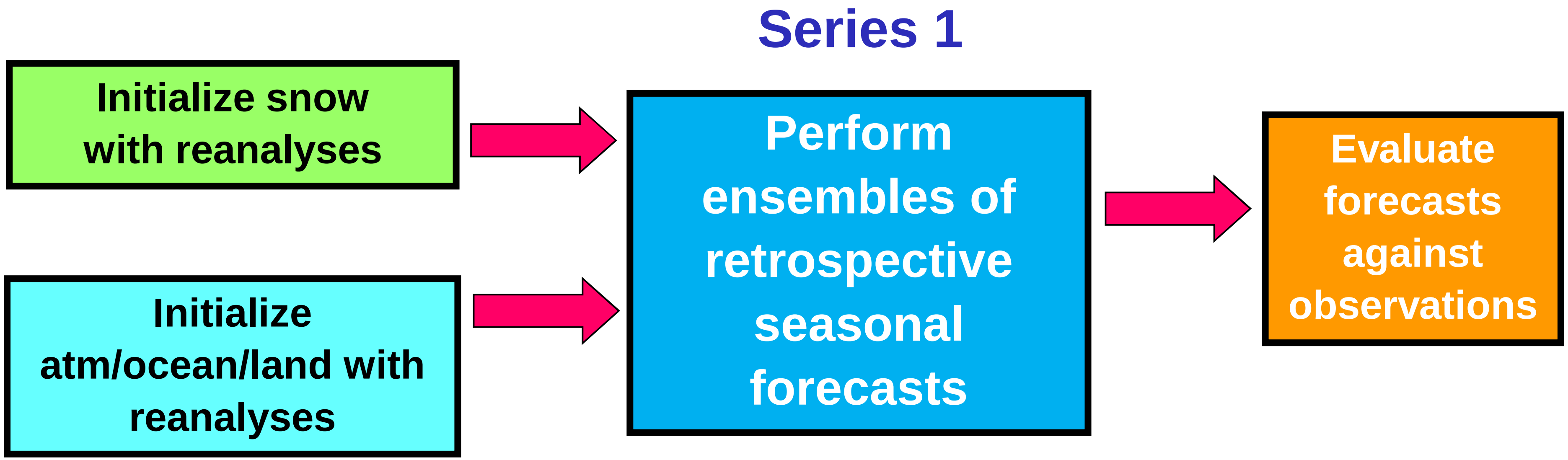
- actual predictability experiments : coupled ocean-atmosphere forecasts at high resolution, with realistic initialisation

- twin forecast ensembles, only differing in snow initialisation

→ attribute difference to snow initialisation

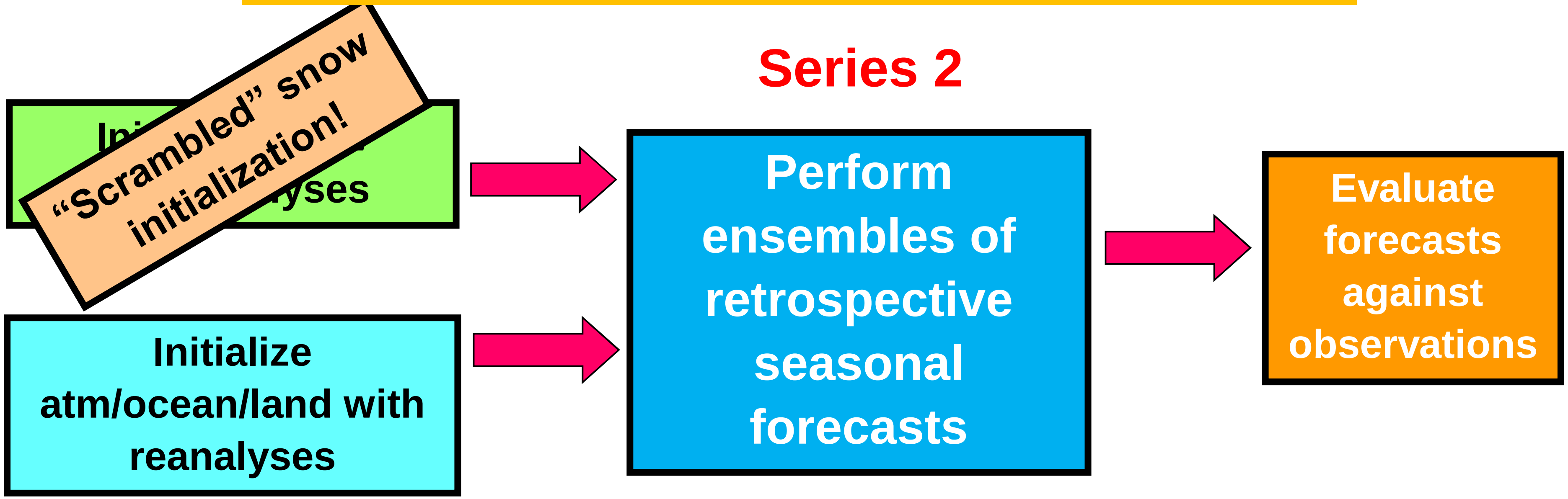
→comparison with observations: skill difference

A first ensemble of seasonal forecasts with accurate snow initialisation



Following GLACE soil moisture approach (Koster et al. 2004; 2010)

A second ensemble of seasonal forecasts with ”scrambled” snow initialisation



“Scramble” snow variables in a consistent way: snow T, density, albedo, SWE

Following GLACE soil moisture approach (Koster et al. 2004; 2010)

”SNOWGLACE” coupled experiments at ECMWF (not operational system S4)

Two-month forecasts with ECMWF model

- **High horizontal resolution (T255;l62) coupled ocean-atmosphere model (IFS HOPE V4)**
- **State-of-the-art ensemble prediction system atmospheric model:** 36R1, 62L, (low) top at 5hPa
- **land surface module is HTESSEL improved hydrology**
- **improved 1-layer snow scheme Dutra (2011)**
- **<u>High horizontal</u> resolution is same as ERAINT re-analyses**

Orsolini, Y.J., Senan, R., Balsamo, G., Doblas-Reyes, F., Vitart, D., Weisheimer, A., Carrasco, A., Benestad, R. (2013), Impact of snow initialization on sub-seasonal forecasts , Clim. Dyn., DOI: 10.1007/s00382-013-1782-0

Series 1:

- **12-member ensemble**
- **atmospheric / oceanic / land initialisation**
- **forecast length : 2-month**
- **4 Start dates:**

OCT 15, NOV 1, NOV 15, DEC 1

- **6 Years 2004-2010**

•**realistic snow initialisation *(ERAINT)***

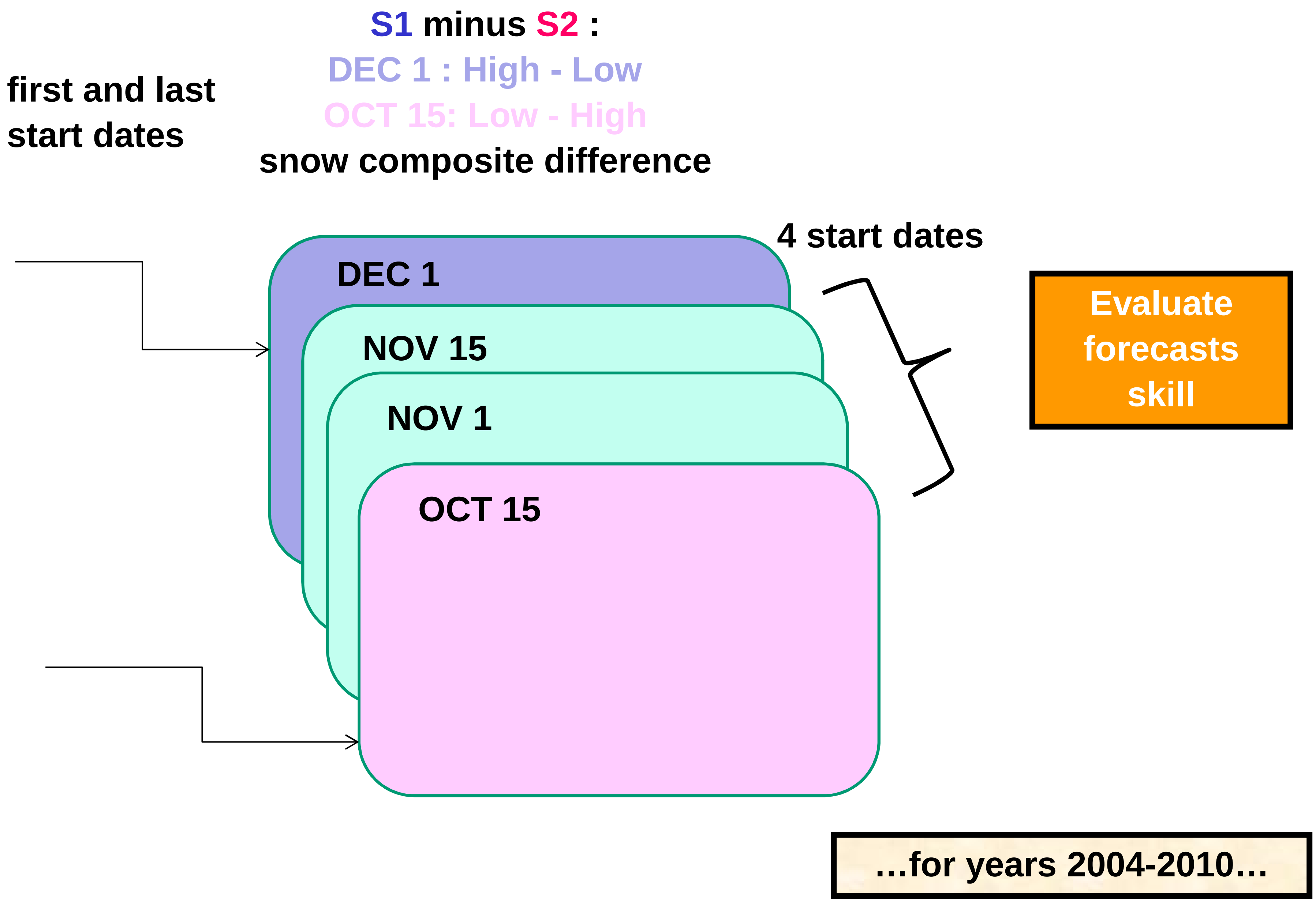
Series 2:

identical , but

• **globally "scrambled snow": taken from other start dates or years**

Anomaly field : ensemble-mean difference (Series 1 – Series 2) in 15-day averaged sub-periods (day 1-15, day 16-30, …)

2004-2010: assimilation of satellite-derived snow cover from NOAA/NESDIS in ERAINT since 2003 → better inter-annual variability

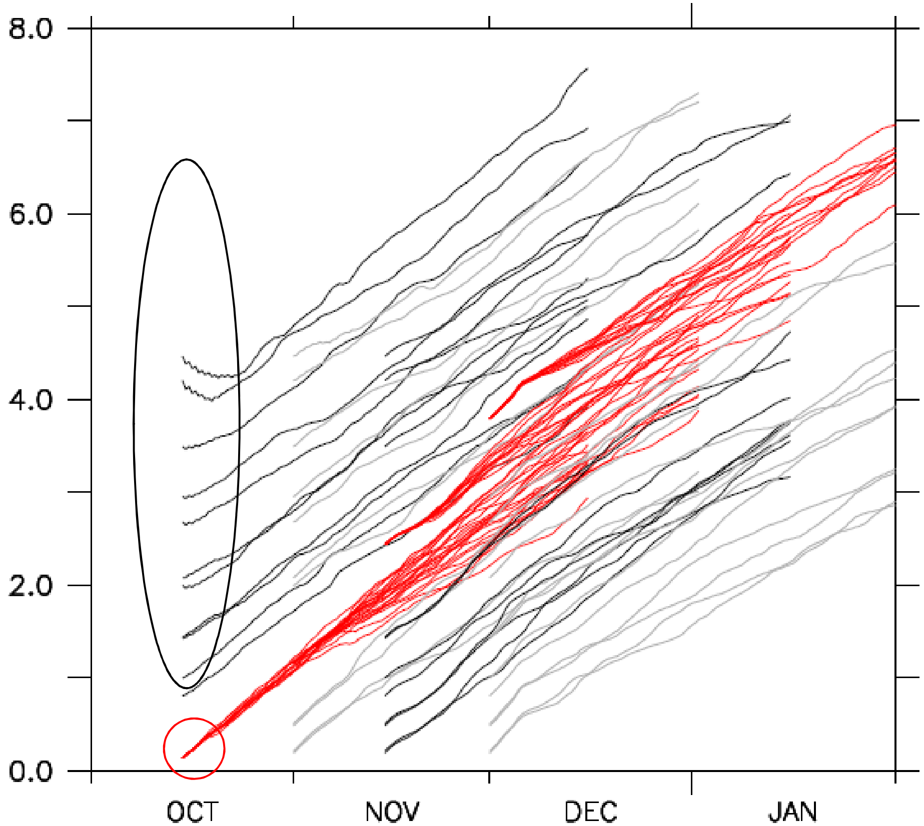

S1 minus S2 :
DEC 1 : High - Low
OCT 15: Low - High
snow composite difference
first and last
start dates
4 start dates
DEC 1
NOV 15
NOV 1
OCT 15
Evaluate
forecasts
skill
…for years 2004-2010…

Evolution of the snow depth over Eurasia

Snow Depth (cm of water equivalent) 40–140°E 40–70°N

- **first and last start date (OCT 15, DEC 1) : snow perturbations are one-sided (Series 2 with “scrambled” snow has always more snow (OCT 15) or less snow (DEC1)**

Year 2009



Series 1

Series 2

4 start dates

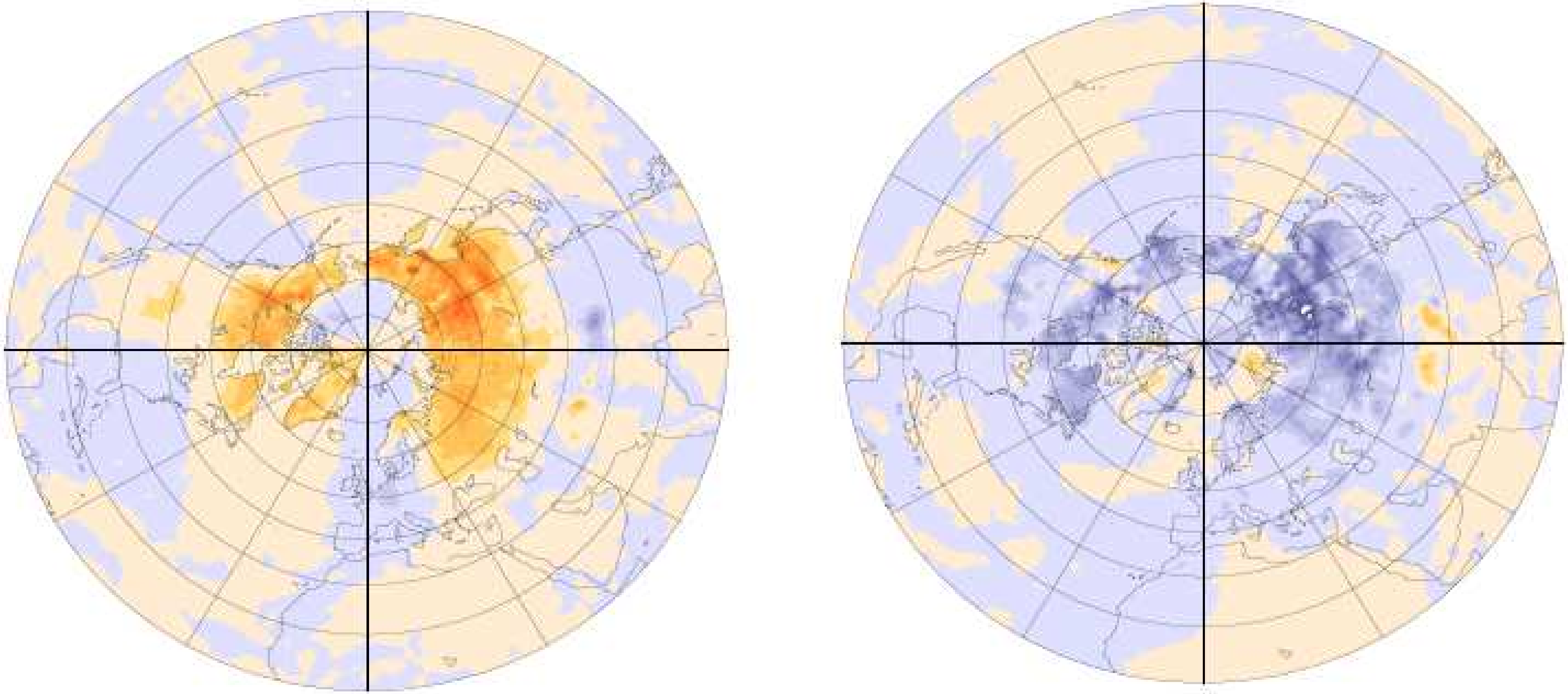
Surface Temperature differences (0-lead)

OCT 15 (first start date)

Low-High snow composite difference

DEC 1 (last start date)

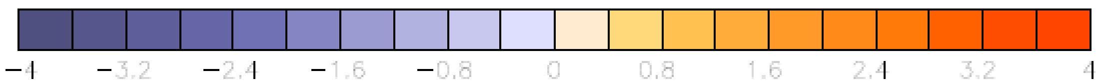
High-Low snow composite difference



ensemble-mean

Series 1 – Series 2
Zero lead (1-15 days)

First sub-period



-4

Presence of thick snow pack → colder lower atmosphere (4K)

snowpack is decoupling atmosphere from the soil layer below (Dutra et al., 2010; 2011) ***(despite low short-wave snow albedo feedback in autumn).***

Forecast skill increment in surface temperature : evaluation against re-analyses

Forecast skill obtain in experiment using realistic snow initialization (SERIES 1)

–

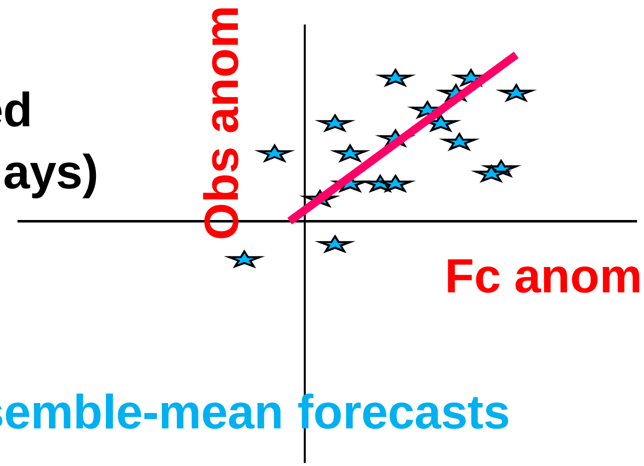
Forecast skill obtained in identical experiment, except that snow is not initialized to realistic values (SERIES 2)

=

Forecast skill due to snow initialization

Skill measure : **r^2 (correlation coefficient sqr)**

Lead fixed (e.g. 30 days)

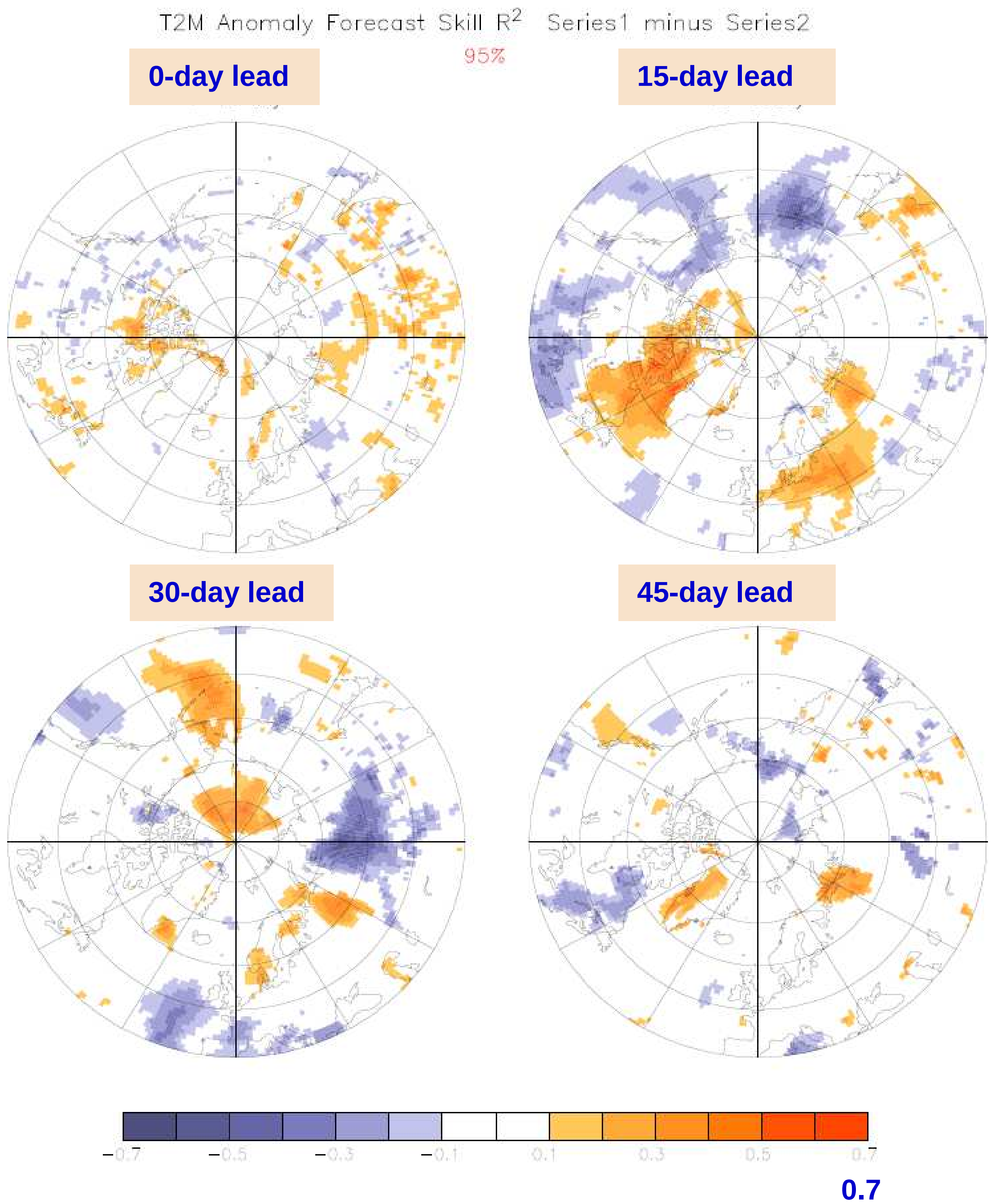


☆ **Ensemble-mean forecasts**

Following GLACE approach (Koster et al. 2004; 2010)

Forecast skill difference vs. lead time

T2m



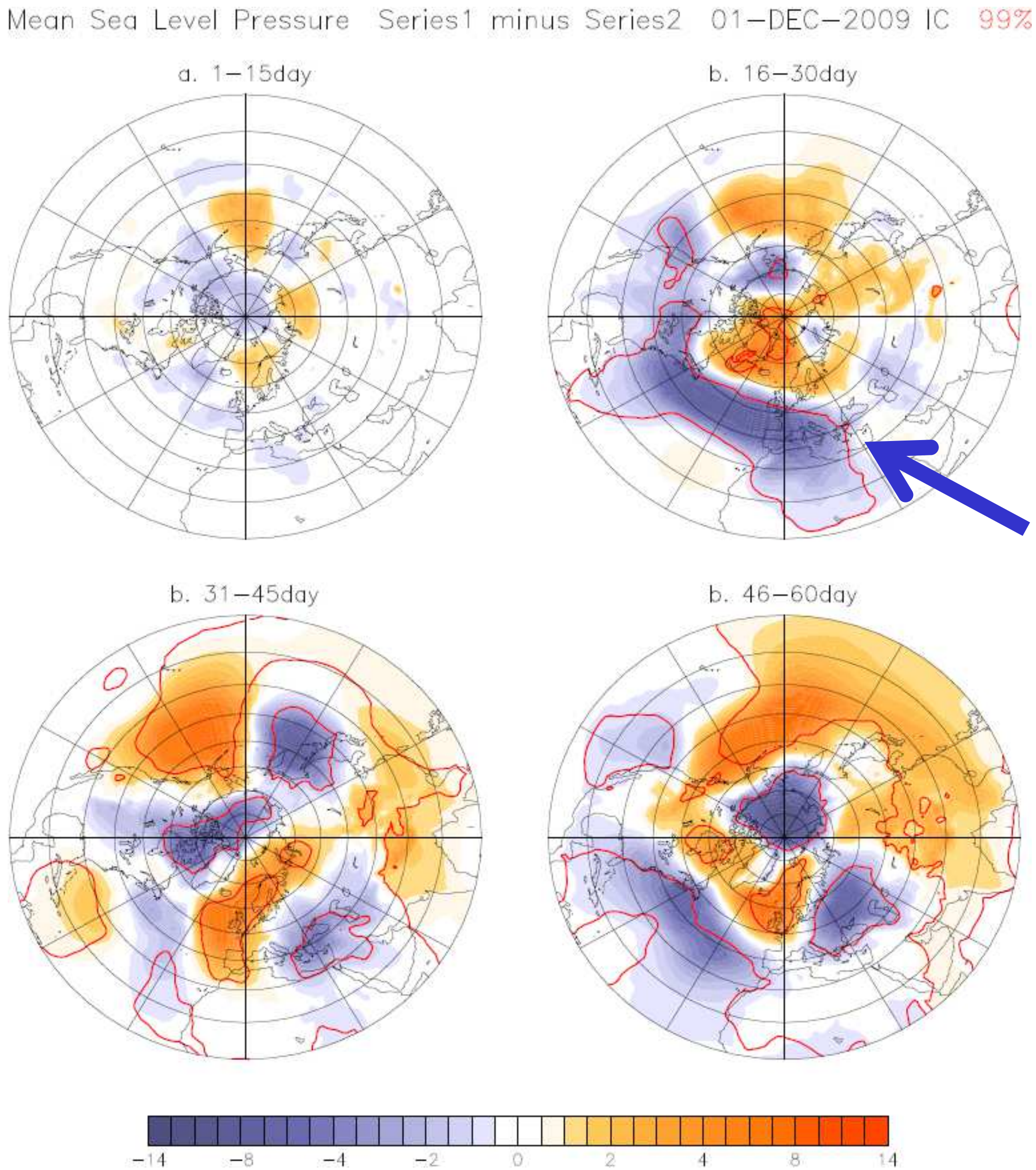
- Initial (0 lead) weak positive difference over snow-covered land
- Very large difference (~0.7) even at 30-day lead (e.g. parts of Arctic, North Pacific)
- Teleconnection influence : 30-day lag qualitatively consistent with snow forcing of Siberian High and planetary wave propagation (Jeong et al, 2012; Cohen et al. 2007; Smith et al., 2012)
- High skill difference not necessarily realised in operational context (first guess would be better than Series2)

Snow impact on the negative NAO phase in winter 2009/10

- ❑2009/10 : very cold winter in Europe and US, and over Far East : cold air outbreaks
- ❑2009/10: Most negative winter (DJF) NAO in 145-Year Record
- ❑Numerous studies look different factors influencing NAO (Jung et al., 2011; Fereday et al., 2012; Wang L. et al., 2011; Cohen et al, 2010...)

We use only DEC 1 start date: (high minus low) snow composite difference


Sea level pressure differences



ensemble-mean

Series 1 – Series 2

0-day lead (1-15 days)

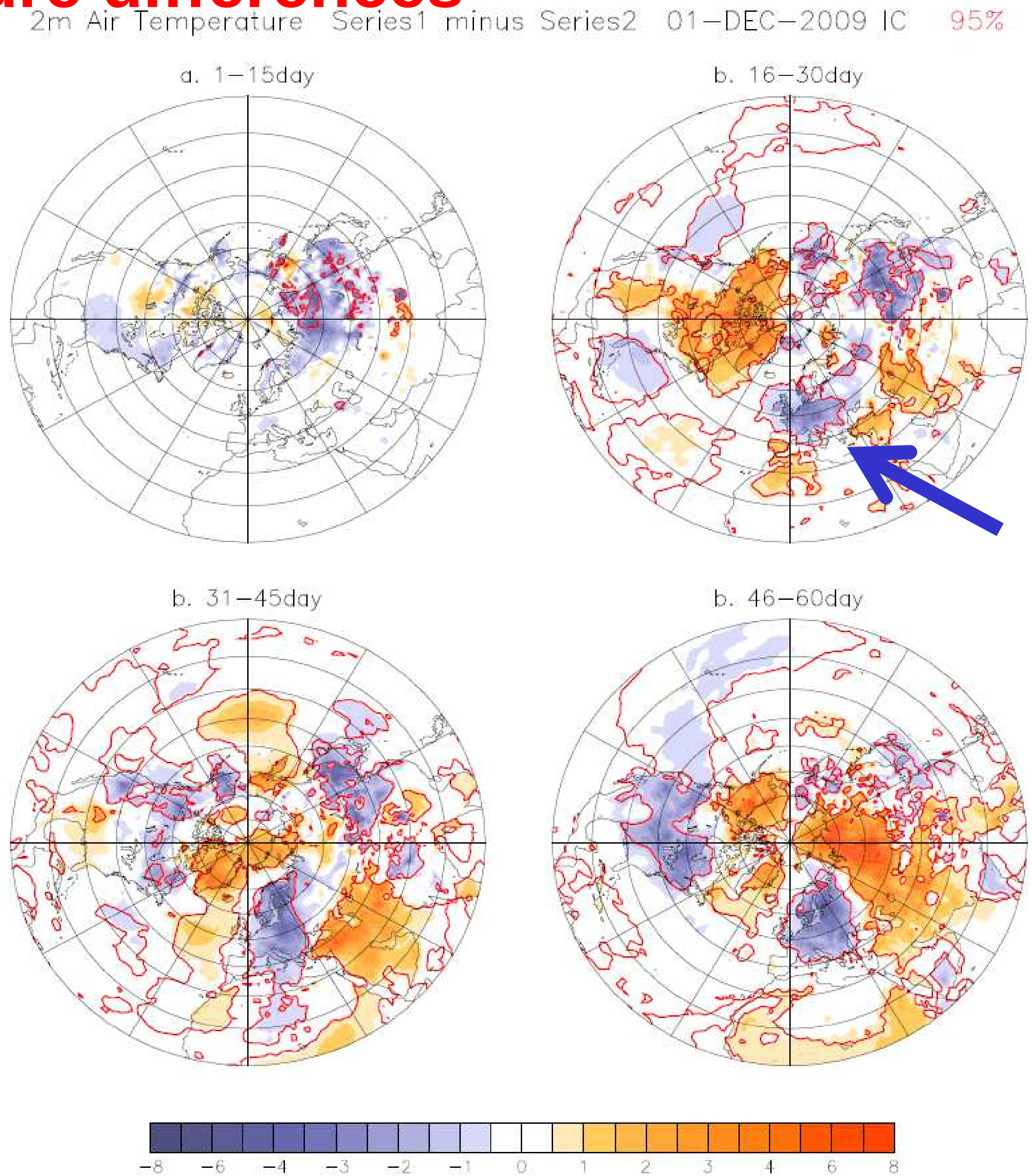
15-day lead (16-30 days)

30-day lead (31-45 days)

45-day lead (46-60 days)

SLP changes after 15-day lead: Series1 → negative NAO anomaly compared to Series2, also at 45-day lead

Surface Temperature differences



ensemble-mean

Series 1 – Series 2

0-day lead (1-15 days)

15-day lead (16-30 days)

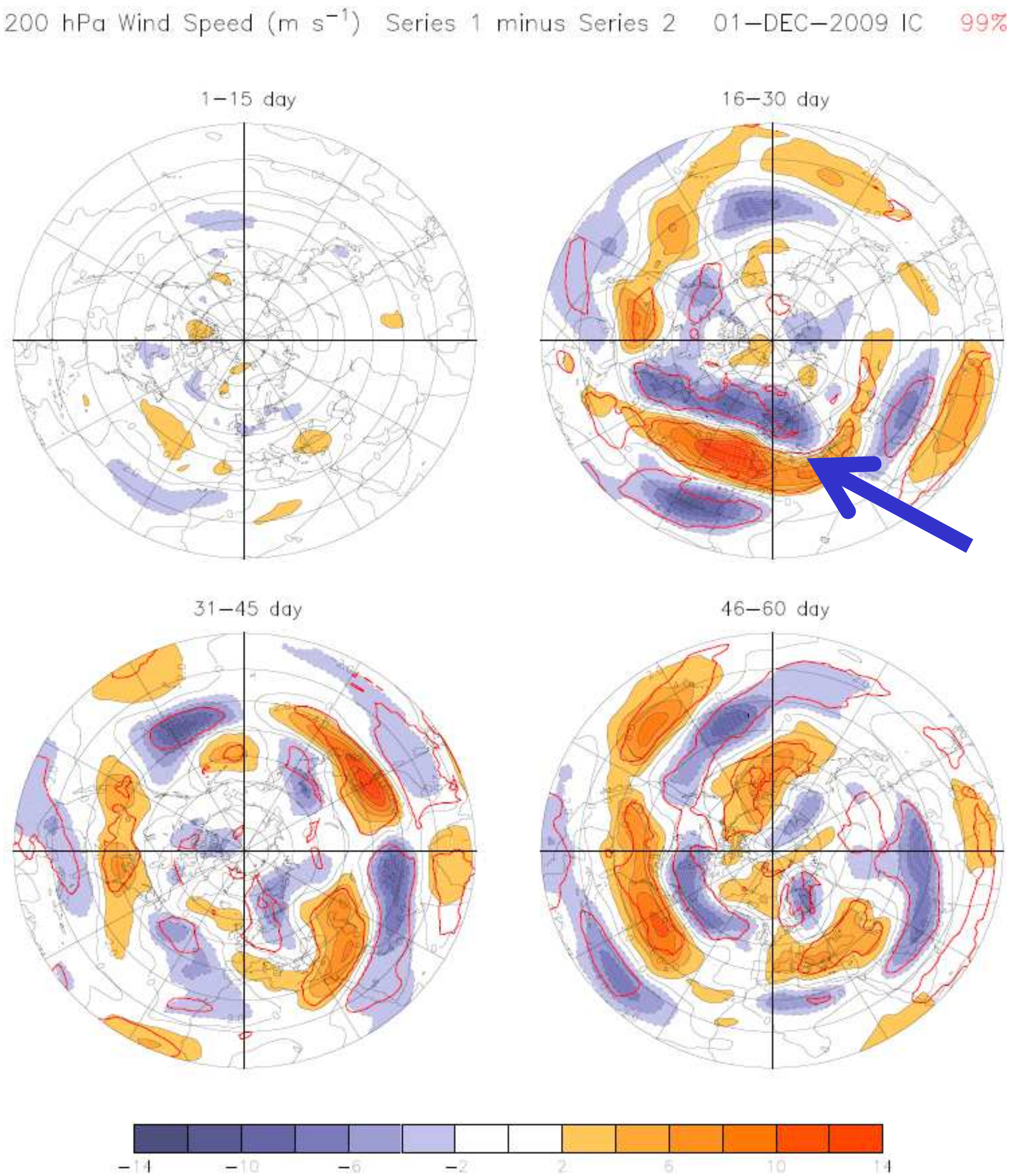
30-day lead (31-45 days)

45-day lead (46-60 days)

Presence of thick snow pack → colder lower atmosphere (up to 6K) over Eurasia initially.

Afterwards, quadrupole pattern typical of negative NAO → cold Europe and NE America

Wind speed differences (200 hPa)



ensemble-mean

Series 1 – Series 2

0-day lead (1-15 days)

15-day lead (16-30 days)

30-day lead (31-45 days)

45-day lead (46-60 days)

Wind speed differences largest at 15-day lead over the Atlantic: Series1 → jet stream further south as in negative NAO phase compared to Series2

Normalised NAO index

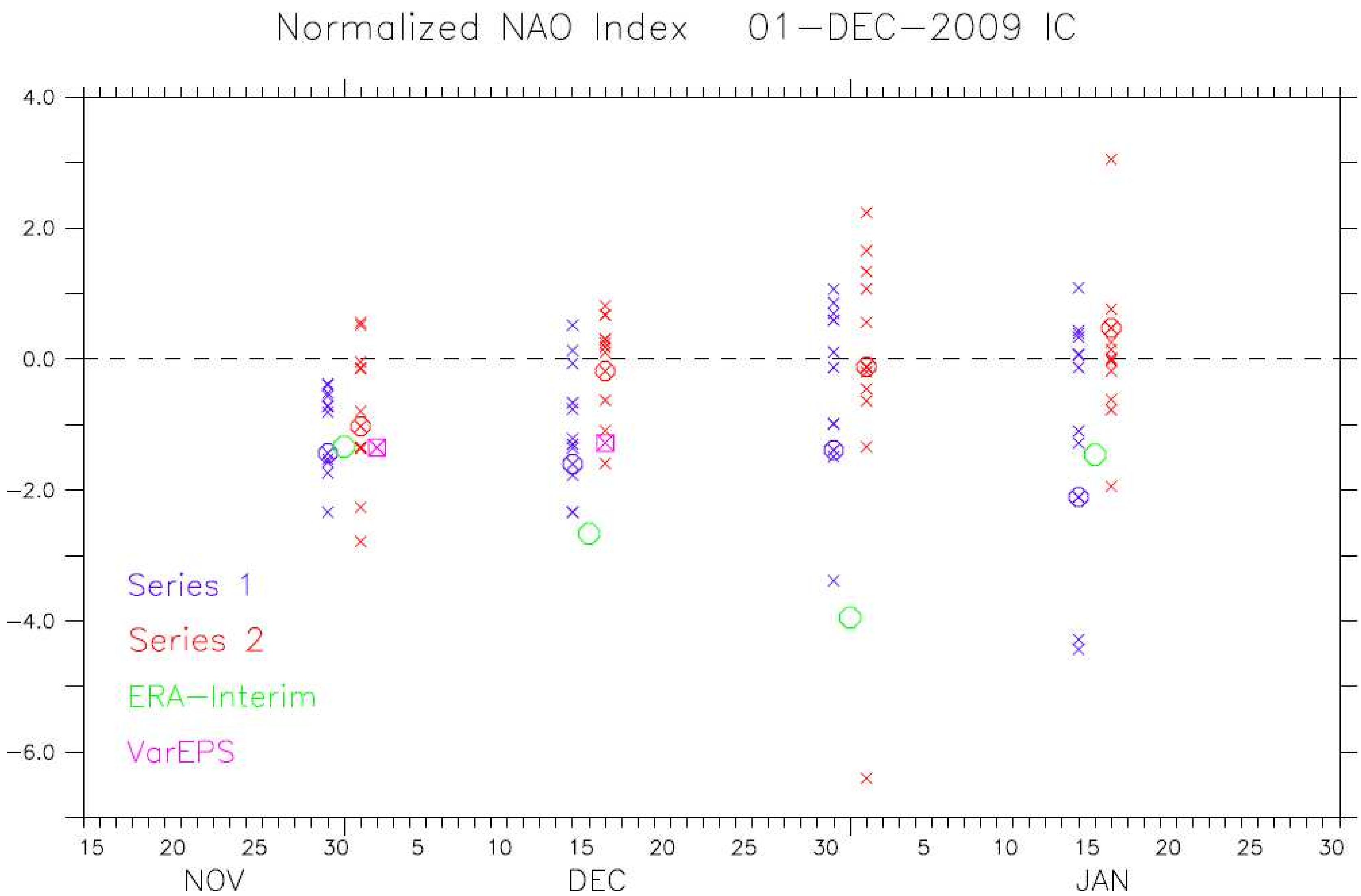
(based on anomaly of SLP difference; years *2004-2010*)

- **Series1 has more negative NAO index than Series2, closer to re-analyses.**

  (in ensemble-mean)

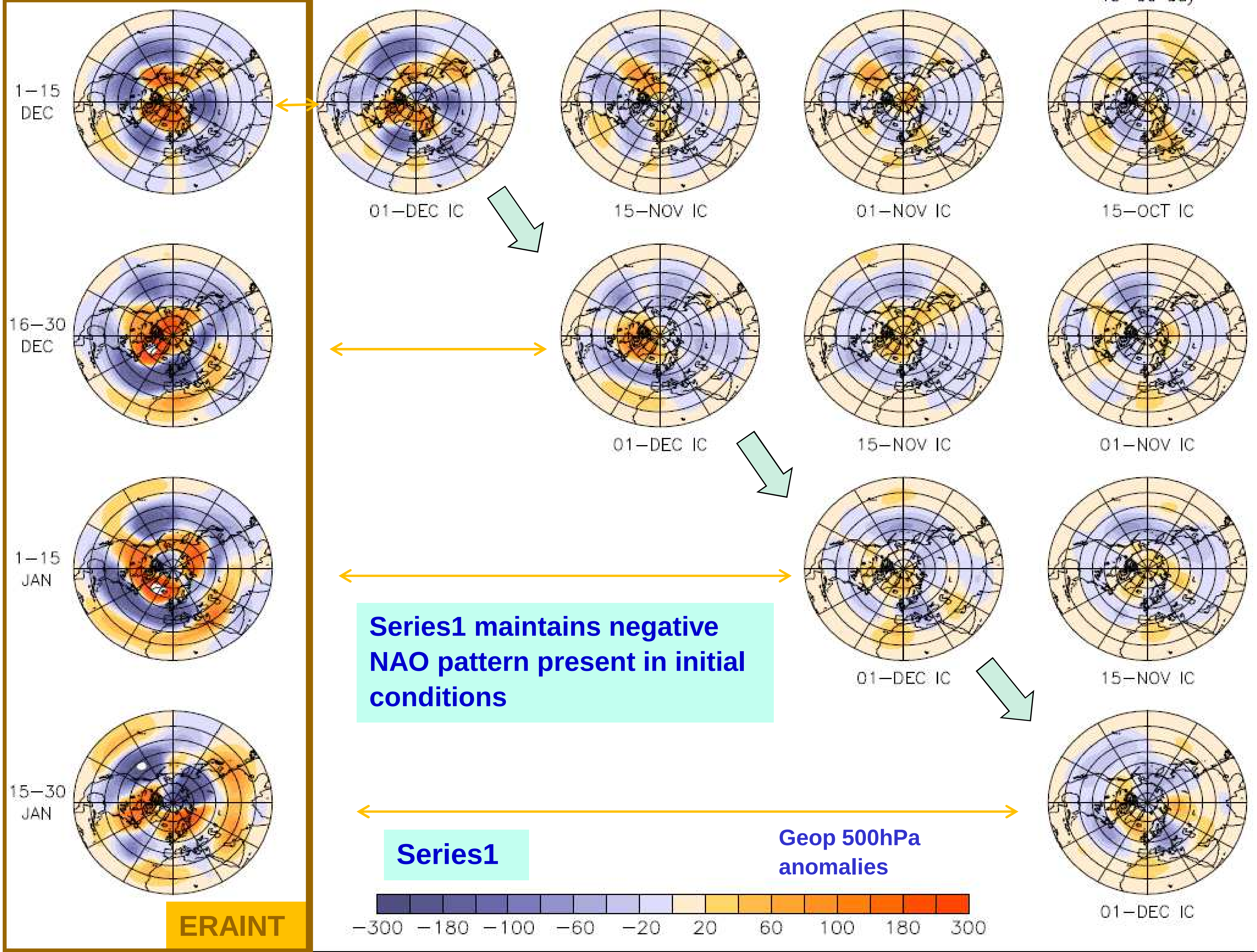
- **VAREPS: oper. monthly forecasts, at variable resolution**

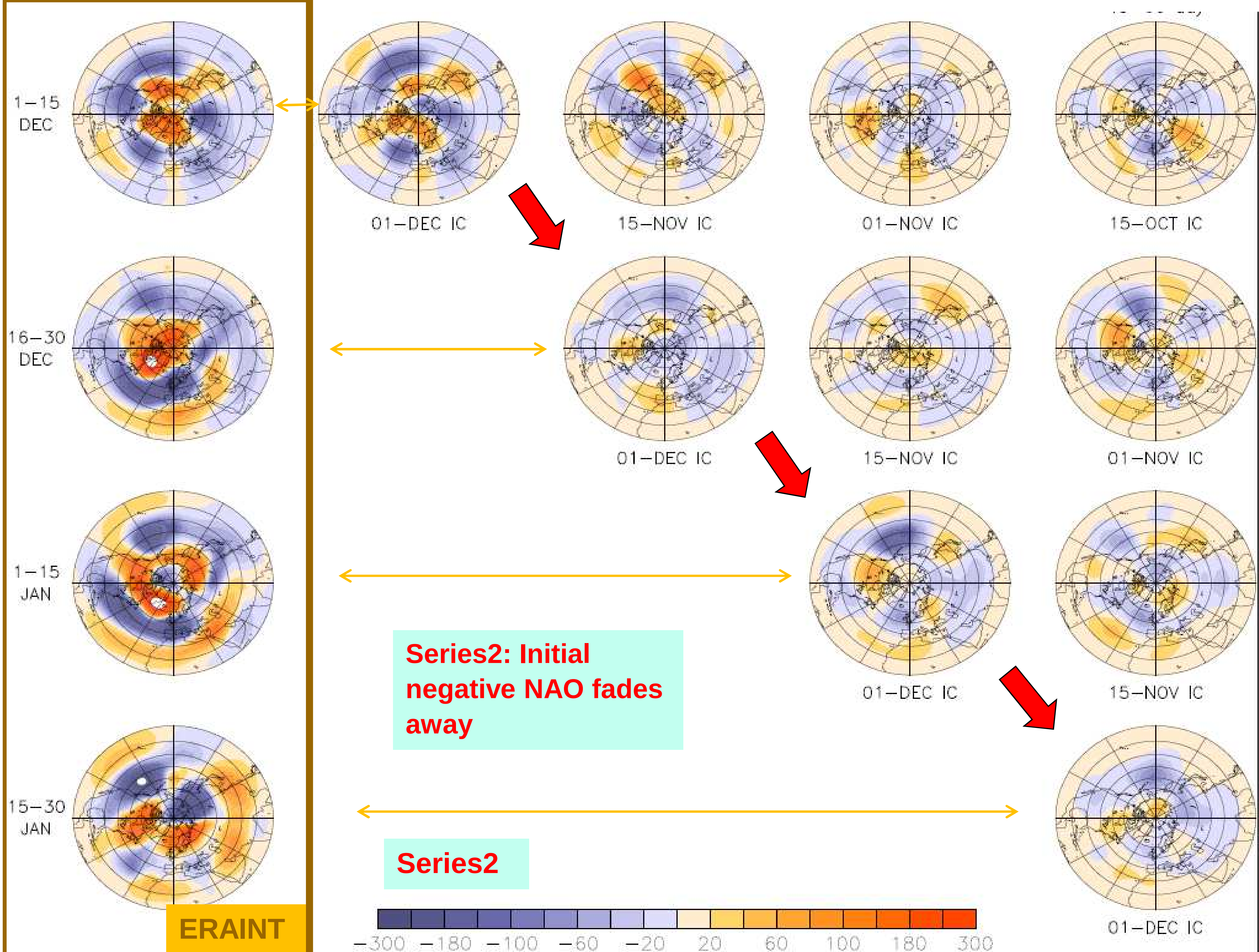
  (nearly identical to our SNOWGLACE runs)



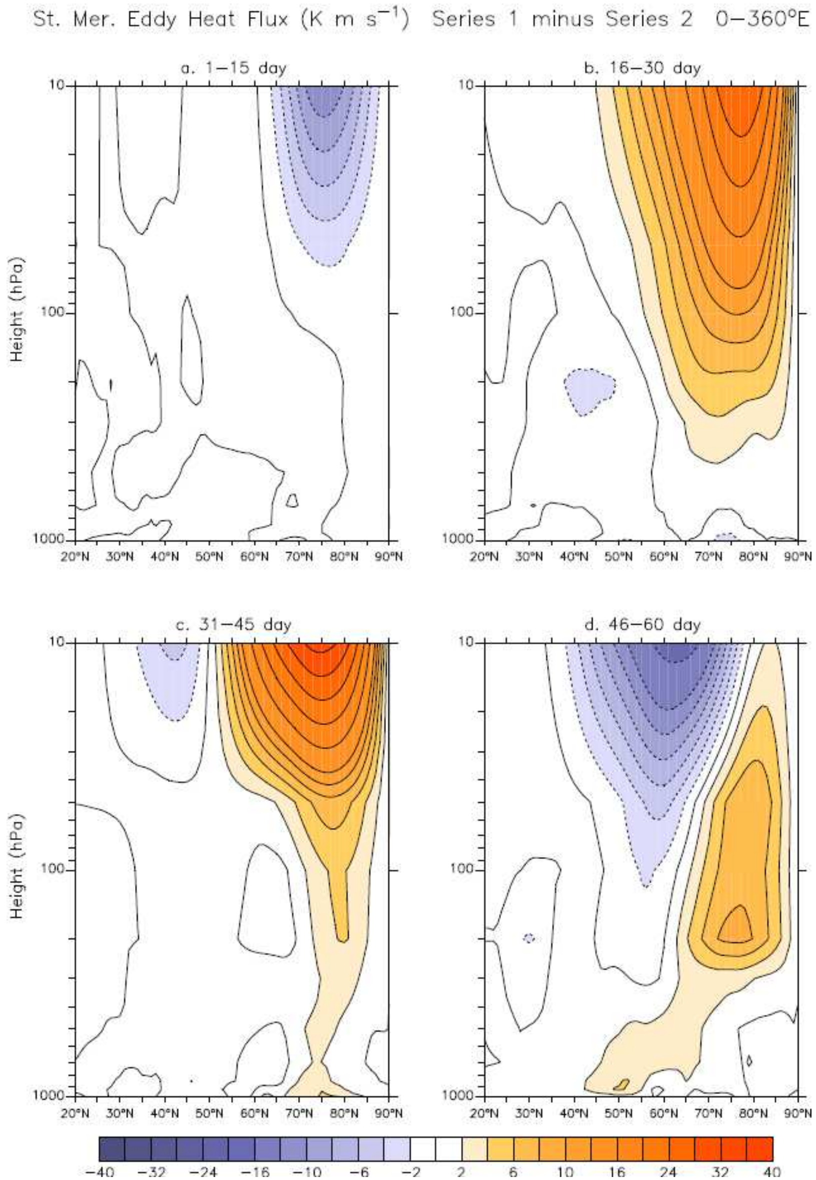
-> Snow contributes to maintaining negative NAO

-> one of the factors influencing negative NAO phase, not main driver


1–15
DEC
16–30
DEC
1–15
JAN
15–30
JAN
ERAINT
01–DEC IC
15–NOV IC
01–NOV IC
15–OCT IC
01–DEC IC
15–NOV IC
01–NOV IC
01–DEC IC
15–NOV IC
01–DEC IC
Series1 maintains negative NAO pattern present in initial conditions
Series1
Geop 500hPa anomalies
−300
−180
−100
−60
−20
20
60
100
180
300


1–15
DEC
16–30
DEC
1–15
JAN
15–30
JAN
ERAINT
01–DEC IC
15–NOV IC
01–NOV IC
15–OCT IC
01–DEC IC
15–NOV IC
01–NOV IC
01–DEC IC
15–NOV IC
01–DEC IC
Series2: Initial negative NAO fades away
Series2
−300 −180 −100 −60 −20 20 60 100 180 300

(Quasi-stationary) zonal-mean meridional eddy heat flux differences (v’T’)



ensemble-mean

Series 1 – Series 2

0-day lead (1-15 days)

15-day lead (16-30 days)

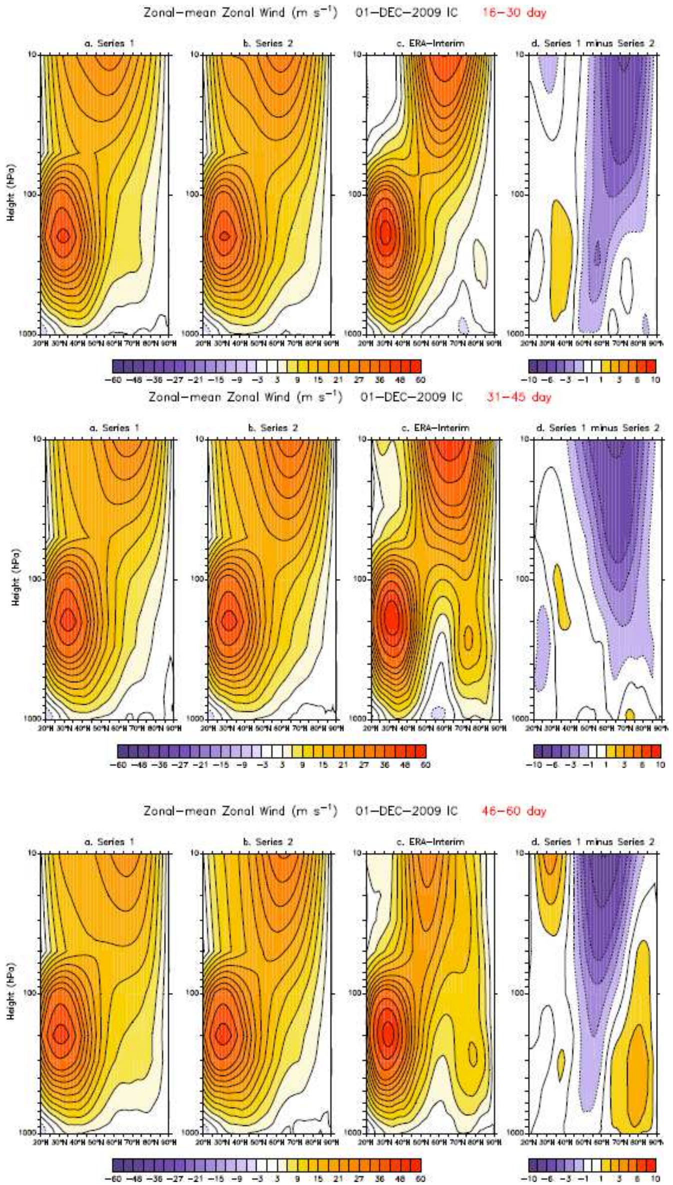
30-day lead (31-45 days)

45-day lead (46-60 days)

Enhanced pulse of heat flux at 15- and 30-day lead times: Series1 → stronger fluxes into the lower stratosphere, compared to Series2.

Zonal-mean U

S1 S2 Eraint S1-S2



15-day lead (16-30 days)

30-day lead (31-45 days)

45-day lead (46-60 days)

Enhanced pulse of heat flux at 15- and 30-day lead times associated with jet decceleration (Series1 → weaker jet, compared to Series2)

Snow / Stratosphere upward coupling

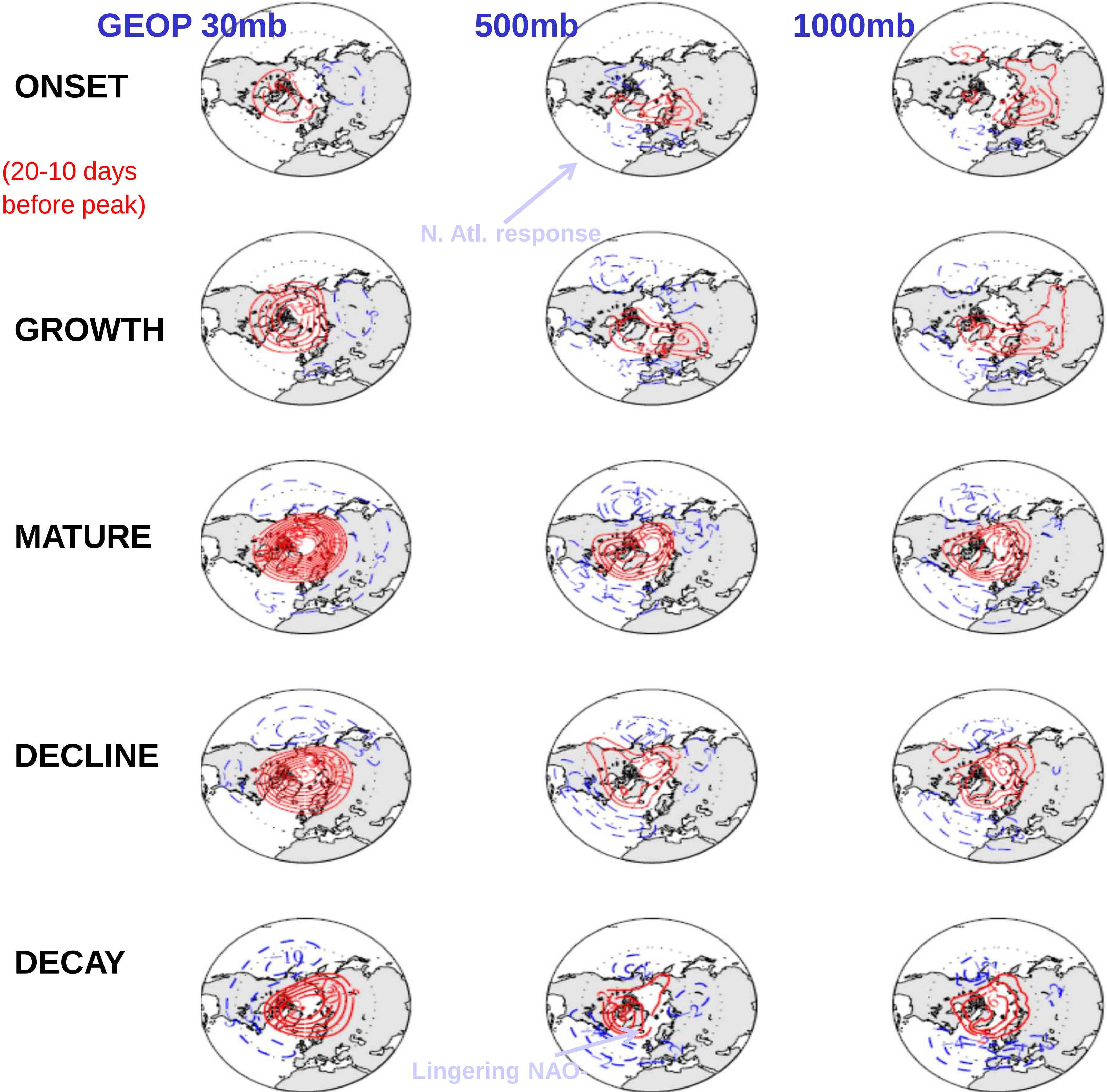
(time scale of 2 weeks)

Life-cycle of stratospheric sudden warmings: composites

- Strong N. Atlantic response to weakening jet

Orsolini, Y. J., Kindem, I.T ., N.G. Kvamstø, On the potential impact of the stratosphere upon seasonal dynamical hindcasts of the North Atlantic Oscillation: a pilot study, Clim. Dyn., doi: 10.1007/s00382-009-0705-6, Vol 36, 3, p579,2011.

- Similar conclusion on rapid response to high heat flux events in Shaw et al. (JGR, 2014)



Conclusions

- **Heavy snow pack has initial cooling effect on lower atmosphere, decoupling atmosphere from the soil layer below (Dutra et al., 2010; 2011)** ***(despite low short-wave albedo feedback in autumn)***

- **Accurate snow initialisation has potential to improve forecast skill in surface temperature over the Arctic and Pacific sectors, even at monthly lead time.**

- **The 2009/10 winter case study:**

  - **Presence of thick snow over Eurasia maintains the initial negative NAO pattern, which is consistently seen in SLP, jet stream, geopotential at 500hPa**

  - **Increased heat flux into stratosphere (upward coupling)**

  - **Rapid tropospheric adjustment to stratospheric vortex weakening (downward coupling), like proposed by Cohen et al (2001), but acting on faster time scale**

  - **It appears that high horizontal resolution is important to capture snow-stratosphere feedback**

➢*Orsolini, Y.J., Senan, R., Balsamo, G., Doblas-Reyes, F., Vitart, D., Weisheimer, A., Carrasco, A., Benestad, R. (2013), Impact of snow initialization on sub-seasonal forecasts , Clim. Dyn., DOI: 10.1007/s00382-013-1782-0*

➢*Orsolini, Y.J., Senan, R., Balsamo, G., Doblas-Reyes, F., Vitart, D., Weisheimer, A., (2014), Influence of the Eurasian snow on the negative North Atlantic Oscillation in seasonal forecasts of the cold winter 2009/10, to be submitted.*

Conclusions

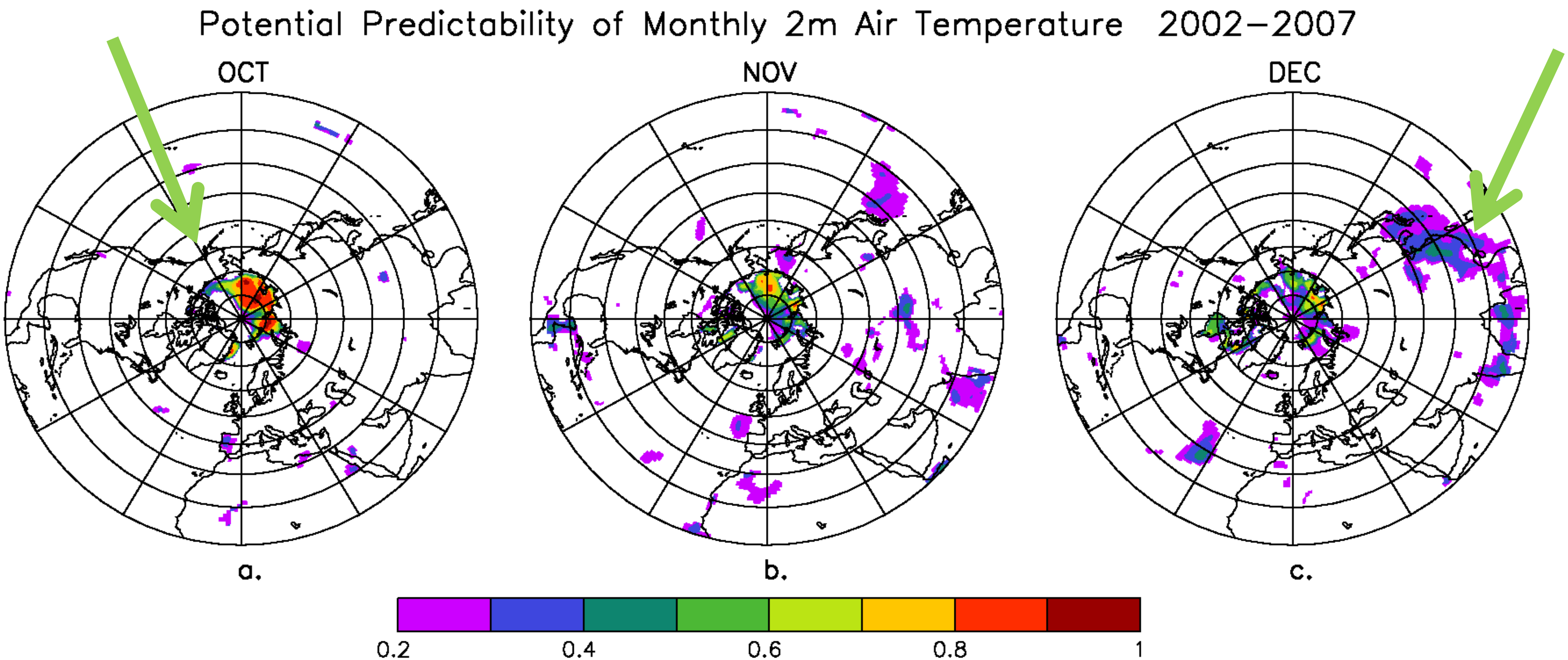
- Snow depth is an important variable to initialise in prediction models!

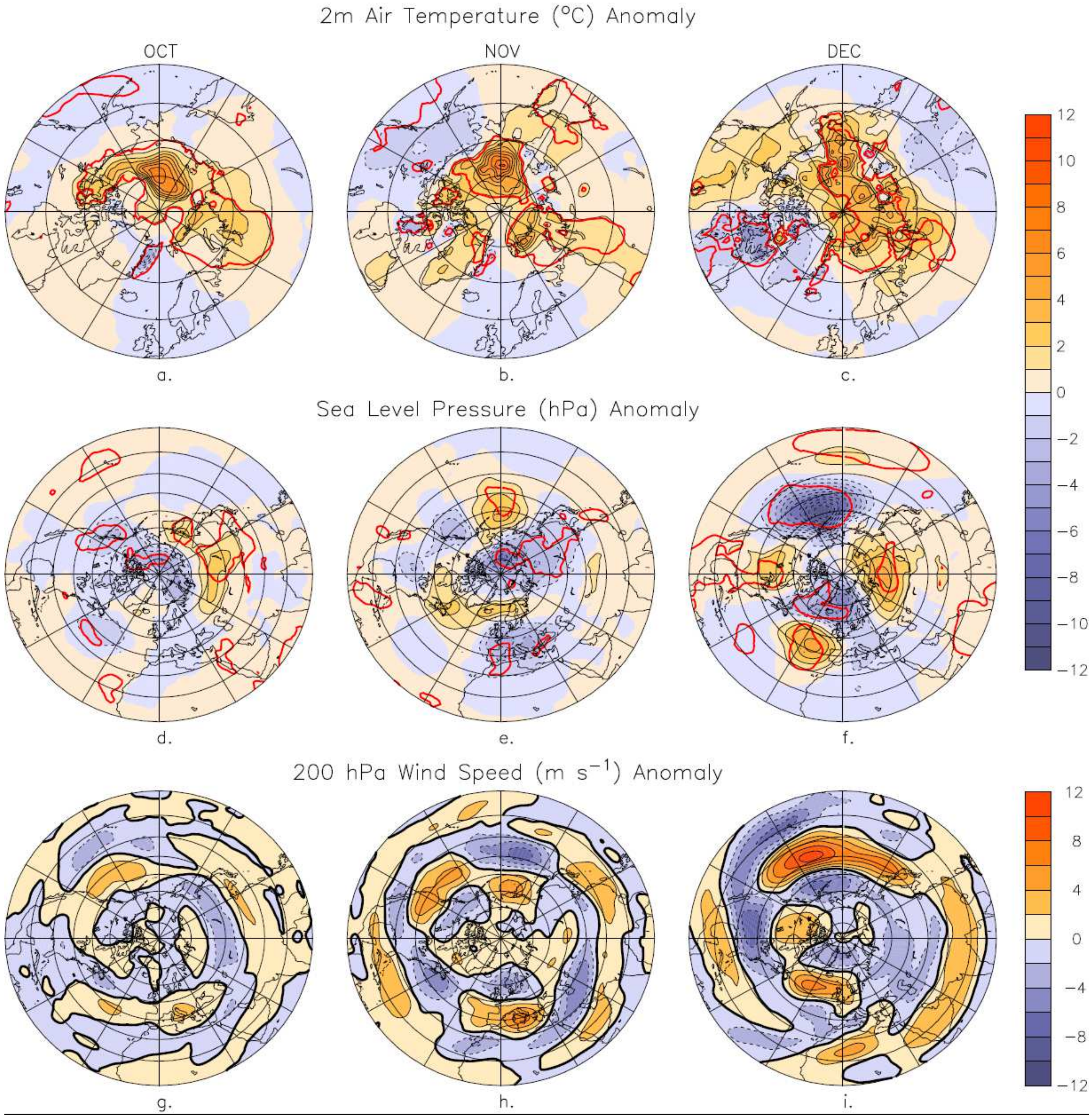
"SNOWGLACE" initiative promoted by WMO Working Group on Seasonal-to-Interannual Predictability (WGSIP), coordinated by Y.J. Orsolini (Norway) and J.-H. Jeong (Korea)

- Define and carry out experiments to investigate the impact of snow initialisation on seasonal forecasts

Potential predictability in T_{2m}

- High values, close to 1, over the Arctic: strong local influence of sea ice
- Enhanced values (0.4) over Pacific coast of Asia in DEC
  - ➢Strongest remote influence of sea ice
  - ➢Cooler T_{2m}(1-2 K) related to cold air advection, consistent with SLP anomalies
  - ➢Similar calculation using SST as external forcing shows no such enhancement





Note change of latitude range, here!

Intensified Highs over continents of Asia and North America

Intensification of jet over oceans, jet shifted south over continents:

more meandering jet

RESERVE SLIDES

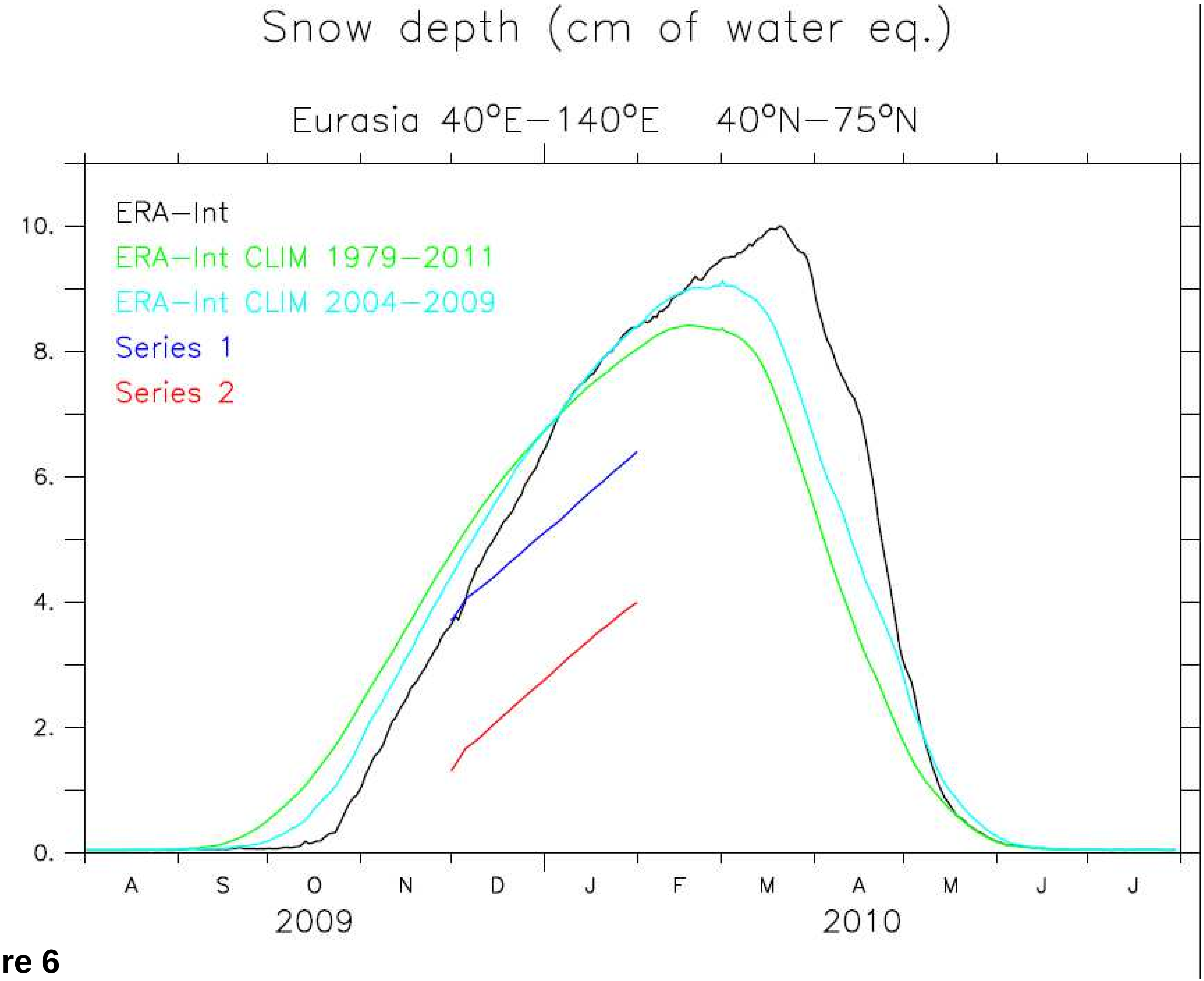
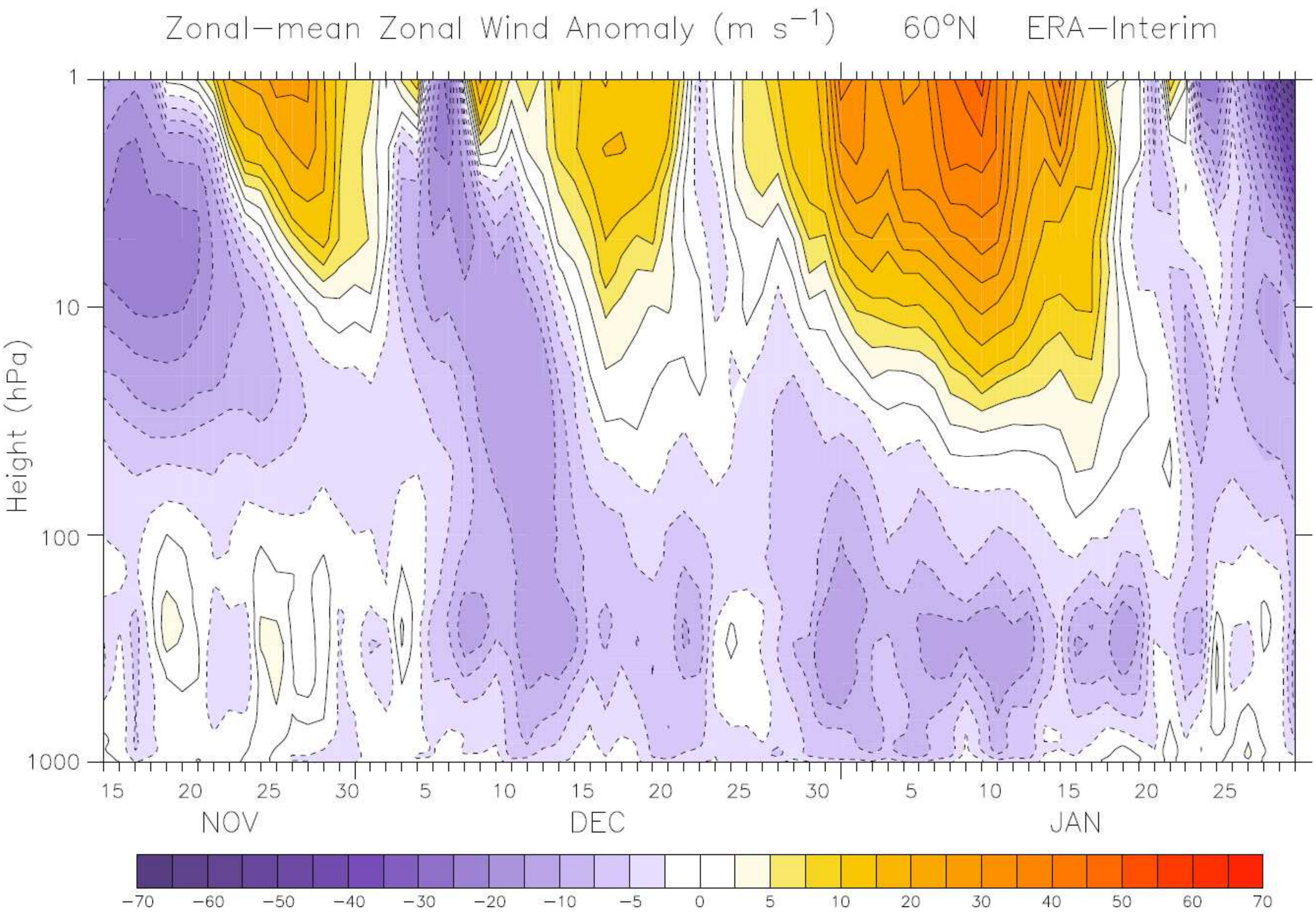

Snow depth (cm of water eq.)
Eurasia 40°E–140°E 40°N–75°N
ERA–Int
ERA–Int CLIM 1979–2011
ERA–Int CLIM 2004–2009
Series 1
Series 2
10.
8.
6.
4.
2.
0.
A S O N D J F M A M J J
2009
2010

Figure 6

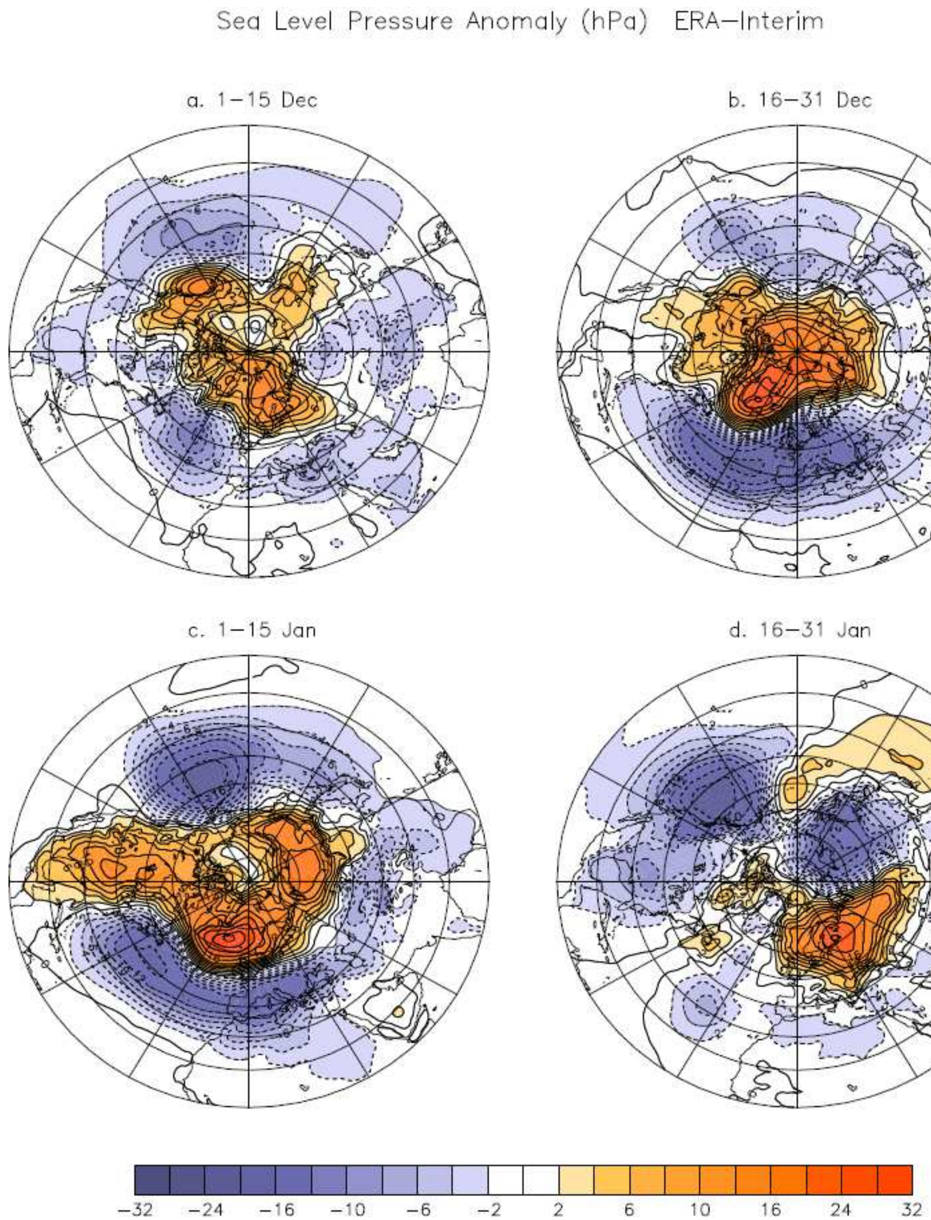


Zonal-mean Zonal Wind Anomaly (m s^{-1}) 60°N ERA-Interim
Height (hPa)
1
10
100
1000
15
20
25
30
5
10
15
20
25
30
5
10
15
20
25
NOV
DEC
JAN
−70
−60
−50
−40
−30
−20
−10
−5
0
5
10
20
30
40
50
60
70

Sea level pressure anomalies (ERAINT)

DEC 2009

JAN 2010



Anomaly wrt same period in 2004-2009

SST differences

ensemble-mean

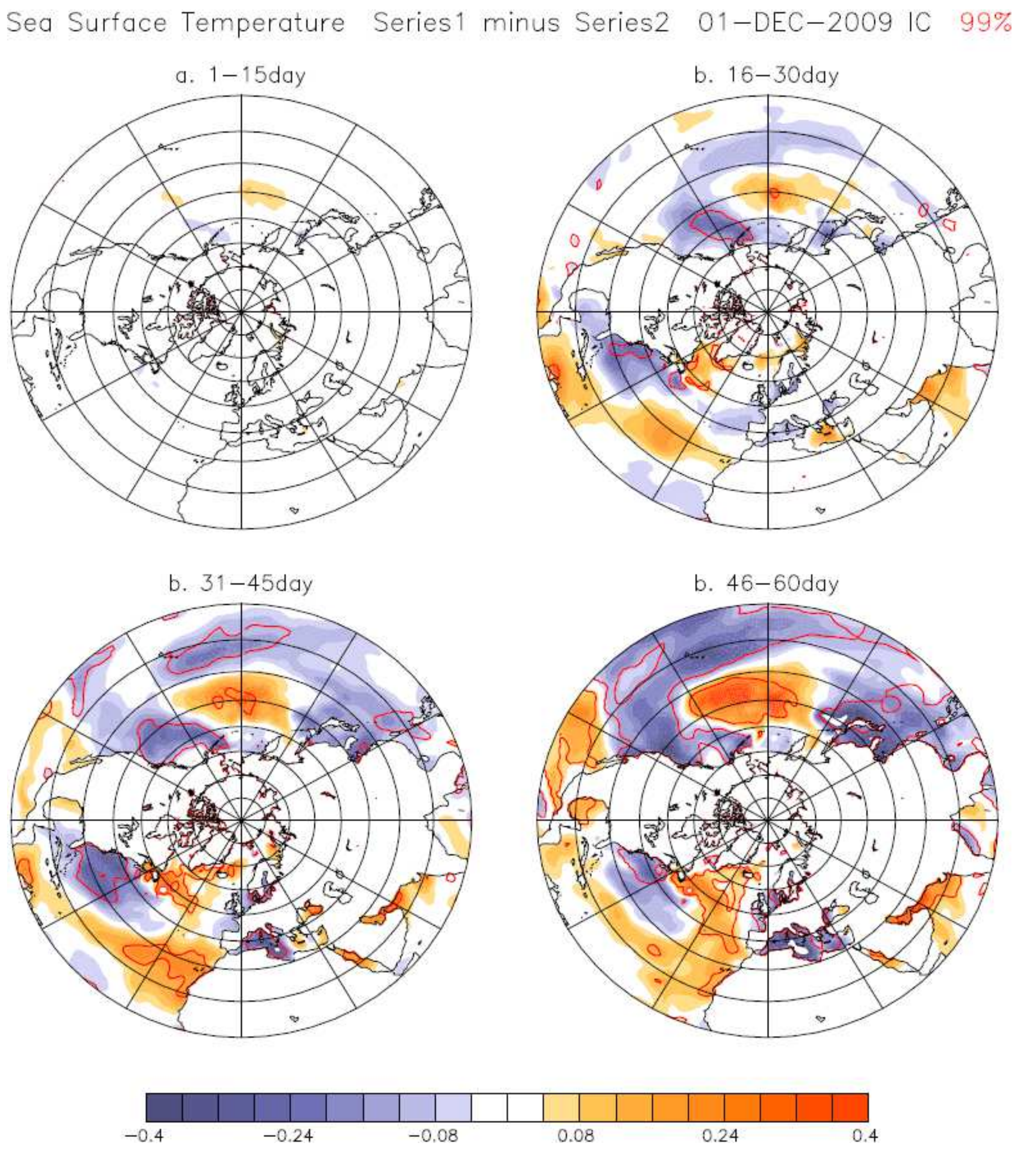
Series 1 – Series 2

0-day lead (1-15 days)

15-day lead (16-30 days)

30-day lead (31-45 days)

45-day lead (46-60 days)



SST changes : Series1 → tripole SST anomaly over ATL, compared to Series2, also characteristic of the negative NAO

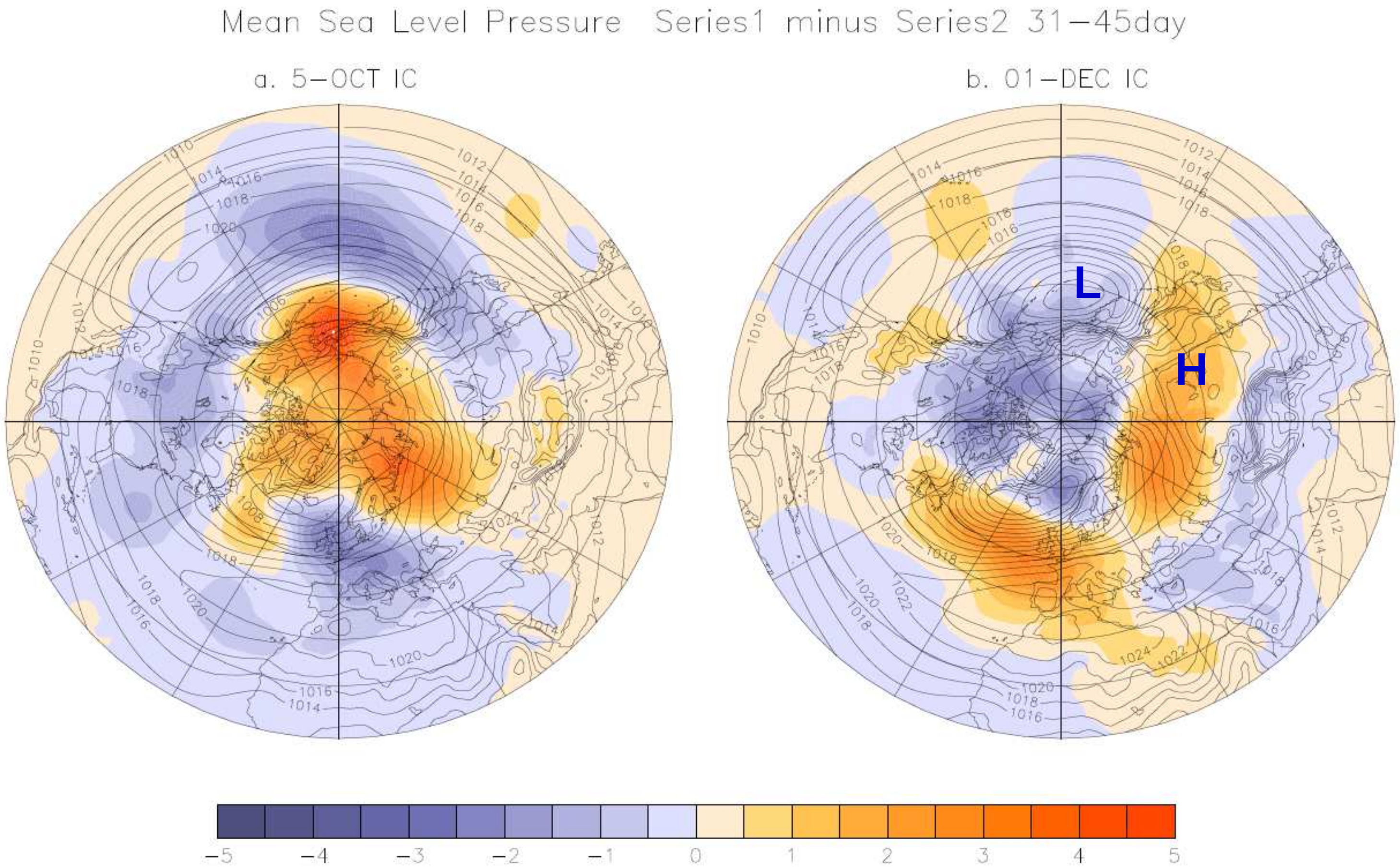
Sea level pressure differences: 30-day lead

OCT 15

Low-High snow composite

DEC 1

High-Low snow composite



Series 1 – Series 2

30-day lead (31-45 days)

Circulation changes :

high snow → intensification & westward expansion of Siberian High, lower SLP over Arctic