NILU - Norwegian Institute for Air Research

Bjerknes Centre for Climate Research

Impact of snow initialisation in coupled ocean-atmosphere seasonal forecasts

Yvan J. ORSOLINI

NILU - Norwegian Institute for Air Research,

and Bjerknes Centre for Climate Research (Bergen)

R. Senan, (U. of Oslo), R. E. Benestad, A. Carrasco (Norwegian Met. Inst.)

G. Balsamo, F. Vitart, A. Weisheimer (ECMWF, England)

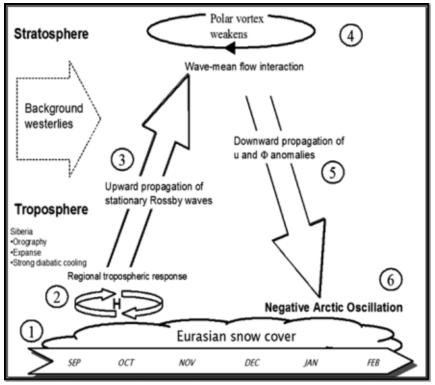
F. Doblas-Reyes (ICREA, Spain)

Eurasian snowpack impact on climate

- **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**
(Ross and Walsh, 1988; Saito et al., 2001; Cohen et al., 2007; Orsolini and Kvamstø, JGR 2009; Allen and Zender, 2011)



”stratospheric bridge”

Eurasian snowpack impact on climate

- 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

Here, we address the impact of the (Eurasian) snowpack on sub-seasonal forecasts during autumn/early winter

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

→ Strong interest in tapping the memory effect of such surface conditions for improving atmospheric predictability

In autumn/early winter at high latitudes → influence of snow mediated by long-wave cooling, thermal insulation, and not short-wave albedo. ***(e.g. Dutra et al., 2010; 2011)***

Eurasian snowpack impact on autumn/winter circulation

- We further assess the impact of the Eurasian snowpack on autumn/winter climate using a coupled ocean-atmosphere seasonal forecast model at high resolution

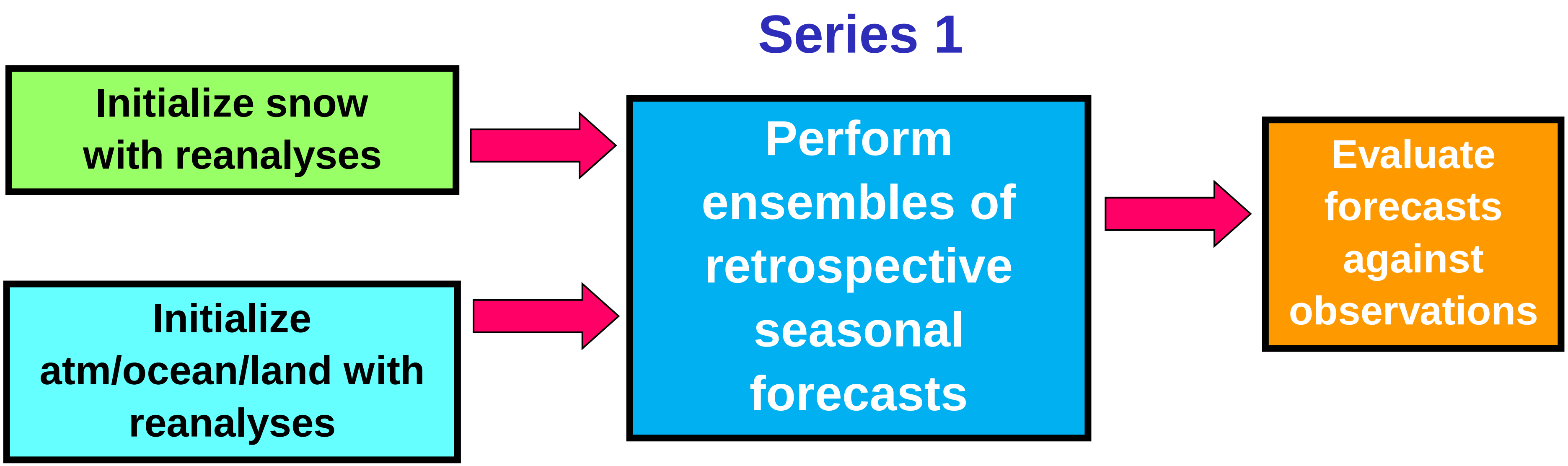
- We made simulations using a modelling strategy similar to the one used for looking at soil moisture impact in the warm season (Koster et al. 2004; 2010) in the GLACE international modeling project

- twin forecast ensembles, only differing in snow initialisation
→ attribution of differences to snow initialisation

- Realistic initialisation + comparison with observations → looking at actual predictability

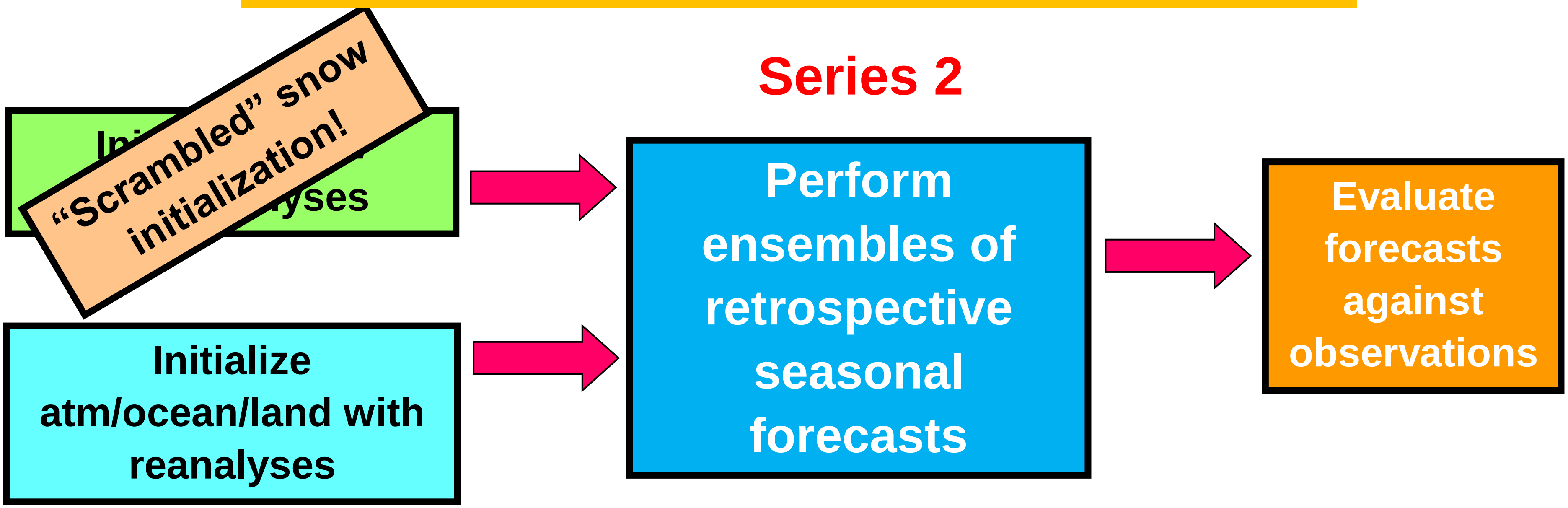
- Pilot study: only one model, limited number of years

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” experiments:

Seasonal forecast model from ECMWF

- High horizontal resolution (T255;l62) coupled ocean-atmosphere model (IFS HOPE V4)
- State-of-the-art ensemble prediction system: most recent version of atmospheric model
- land surface module is HTESSEL improved hydrology
- improved 1-layer snow scheme Dutra (2011)
- High horizontal resolution is same as ERAINT re-analyses

Orsolini, Y.J., Senan, R., Balsamo, G., Doblas-Reyes, F.J., Vitart, F, Weisheimer, A., Carrasco, A., and Benestad, R.E. **Impact of snow initialization on sub-seasonal forecasts, Climate Dynamics,** online May1, 2013.

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

•"scrambled snow": other dates or years from the same set

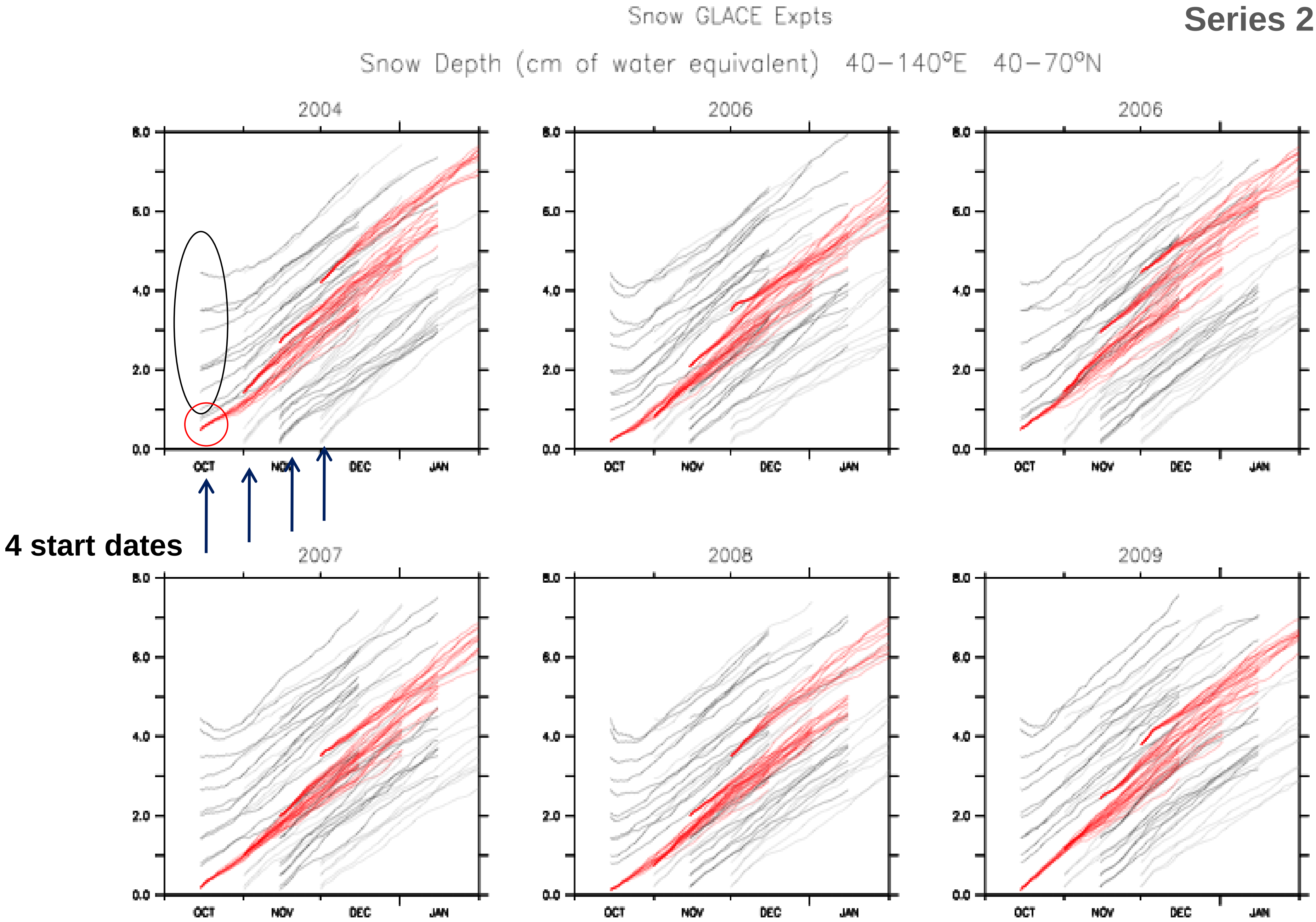
Anomaly field : ensemble-mean difference (Series 1 – Series 2) in 15-day averaged sub-periods (day 1-15, day 16-30, …)

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

Evolution of the snow depth over Eurasia

Series 1

Series 2



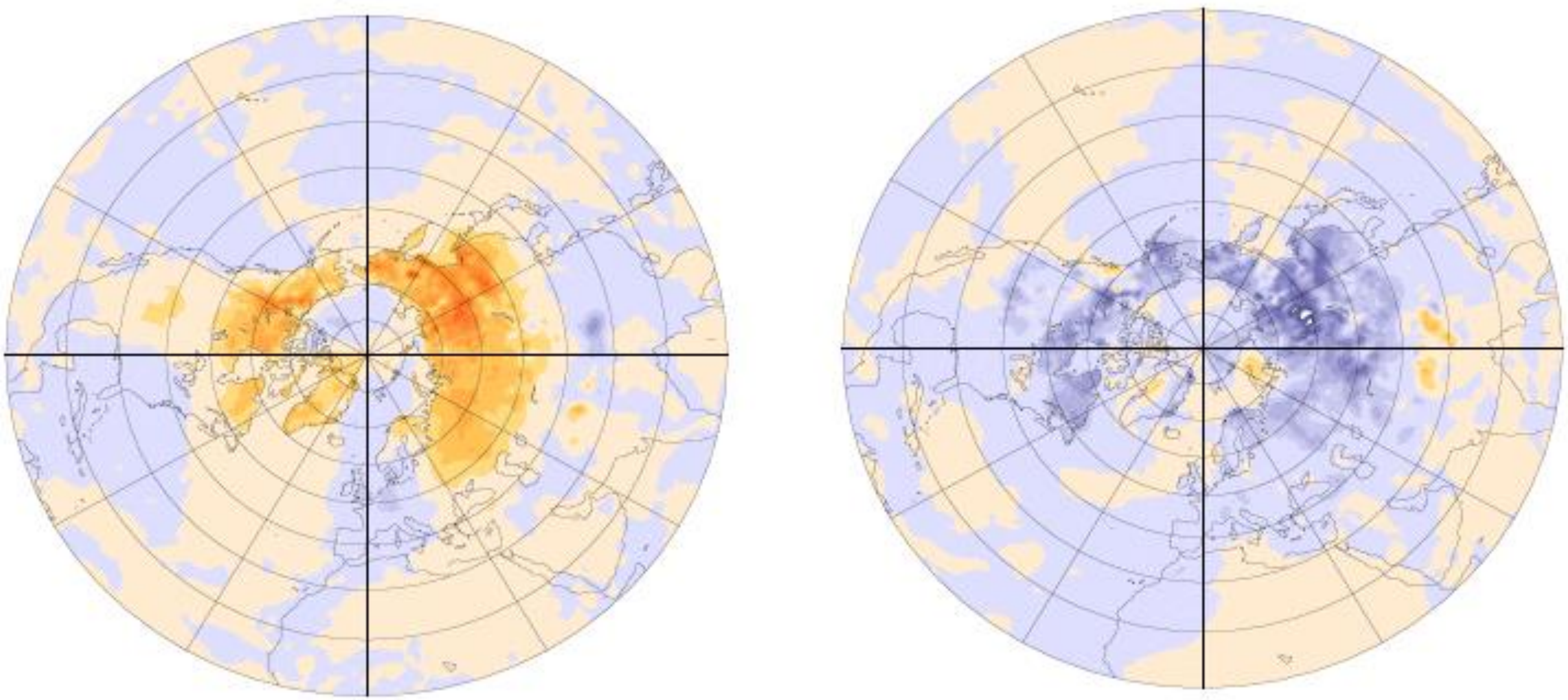
Surface Temperature differences (0-lead)

OCT 15 (first start date)

Low-High snow composite difference

DEC 1 (last start date)

High-Low snow composite difference

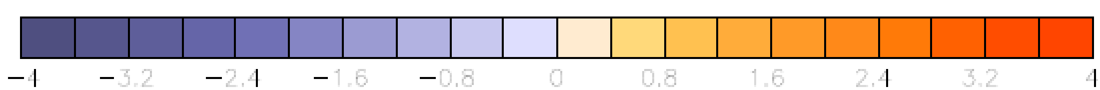


ensemble-mean

Series 1 – Series 2

Zero lead (1-15 days)

First sub-period



4

-4

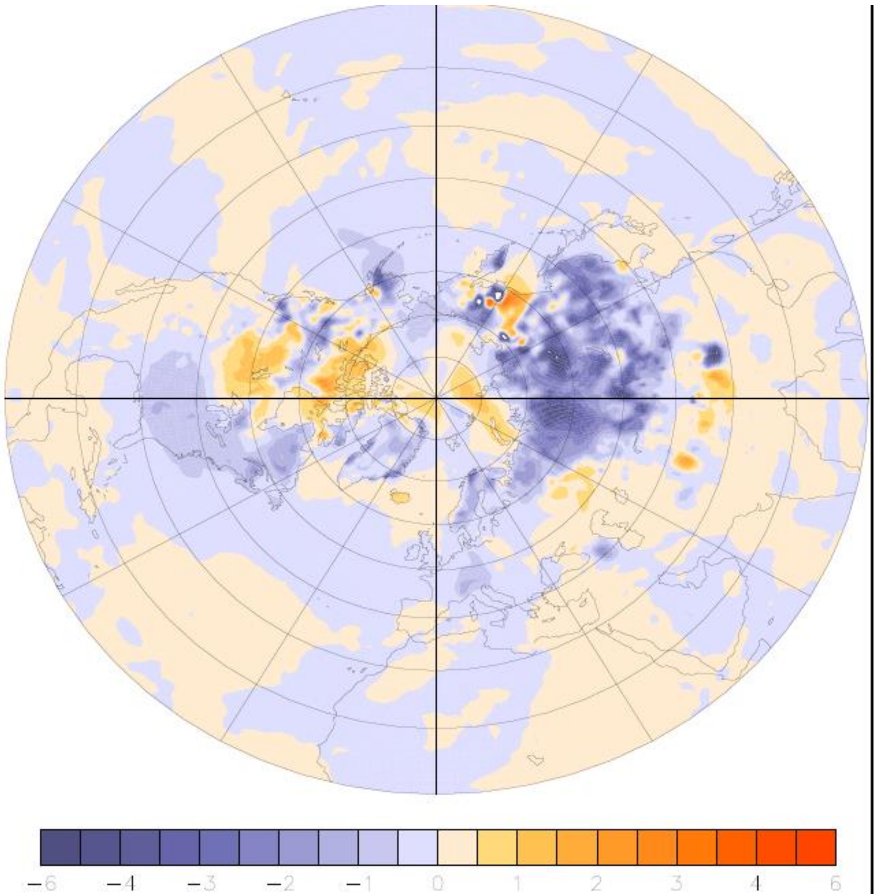
Presence of thick snow pack → colder lower atmosphere (4K)

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

Surface Temperature differences (0-lead): winter 2009/10

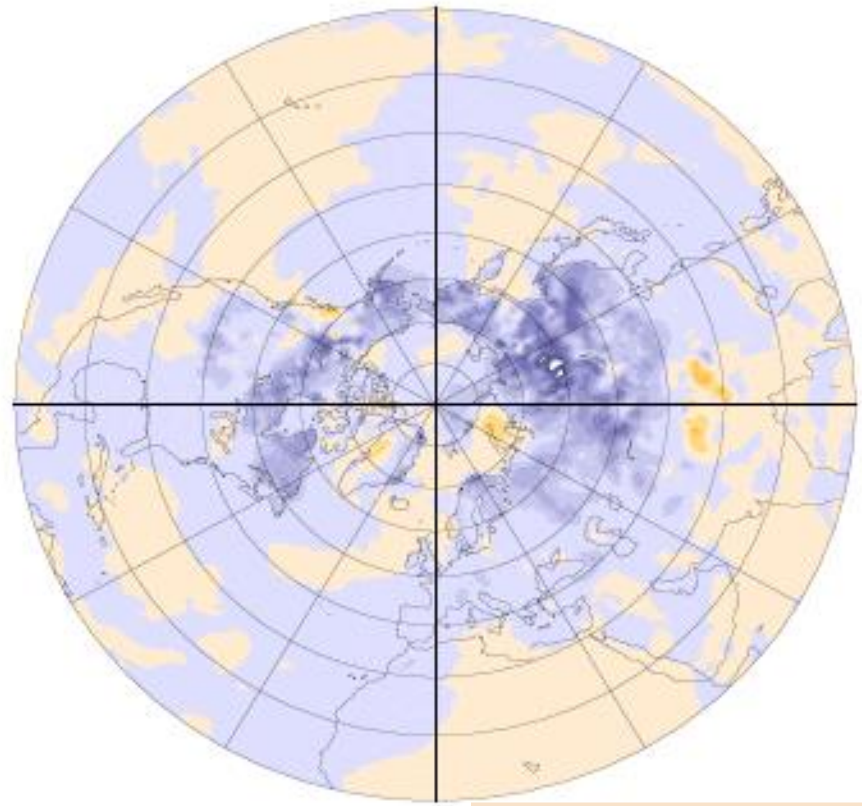
DEC 1 (last start date)

2009



DEC 1 (last start date)

6-year composite difference



ensemble-mean

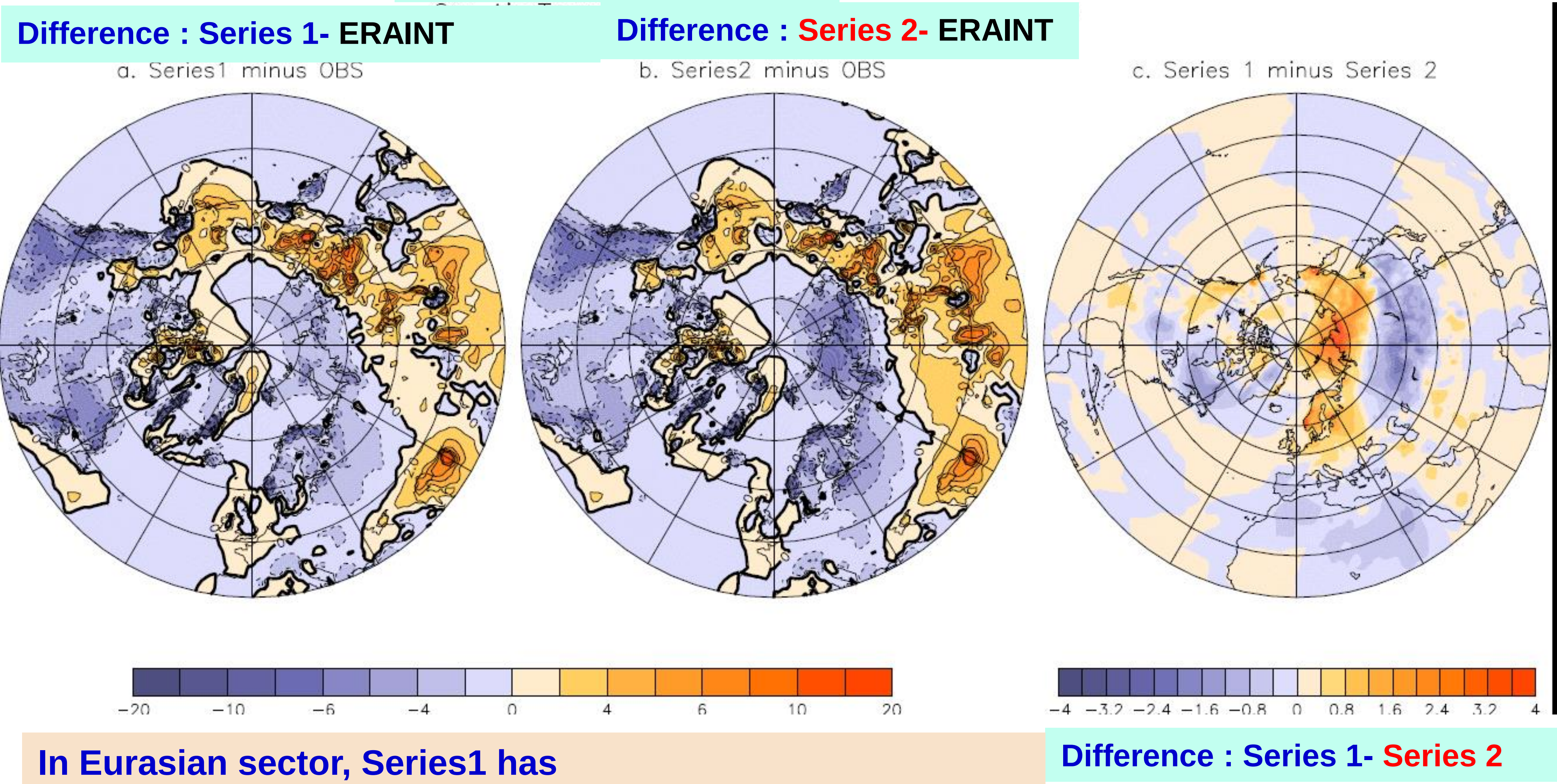
Series 1 – Series 2
Zero lead (1-15 days)

First sub-period

Presence of snow pack → colder lower atmosphere : 2009/2010 Had Most Negative Winter(DJF) NAO Climate Pattern in 145 Year Record

Surface Temperature in Series 1 and Series 2 (30-day lead)

DEC 1 (High snow)



In Eurasian sector, Series1 has

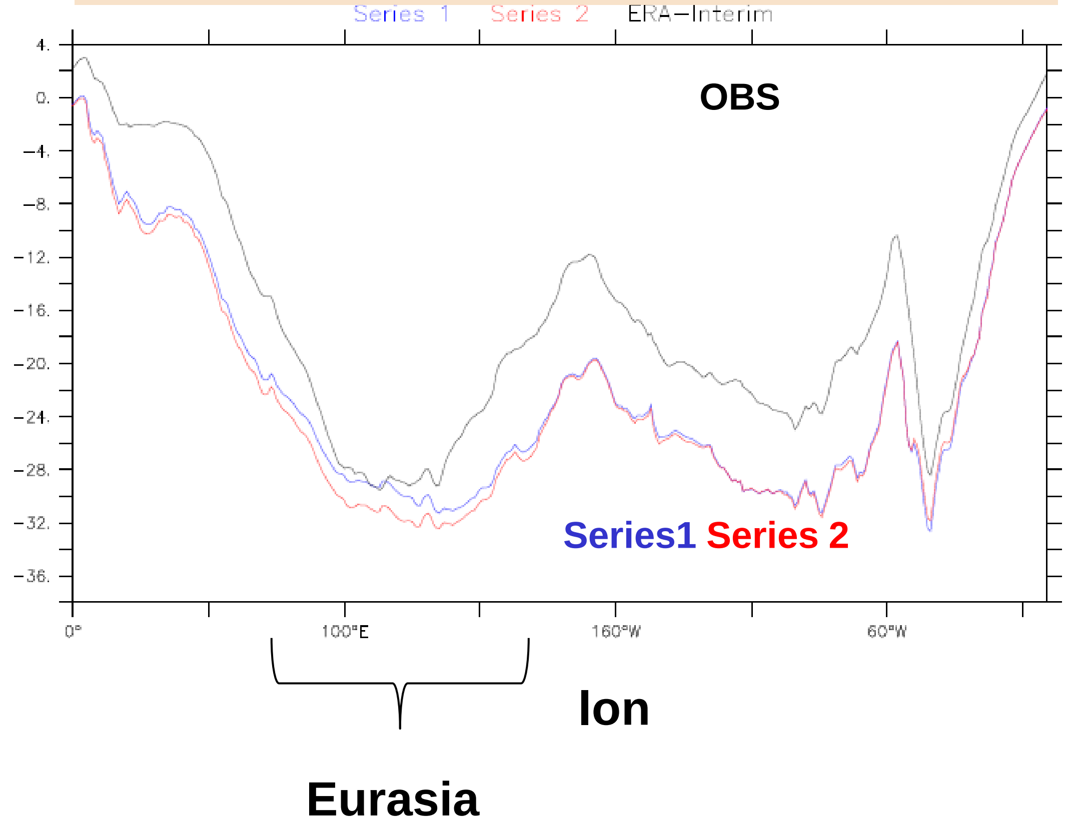
- warmer Arctic than Series2 : alleviates a cold bias
- colder mid-latitudes than Series2 : alleviates a warm bias

Surface Temperature in Series 1 and Series 2 (30-day lead)

DEC 1 (High-Low snow composite)

30-day lead

Longitudinal variation at [60N-80N]

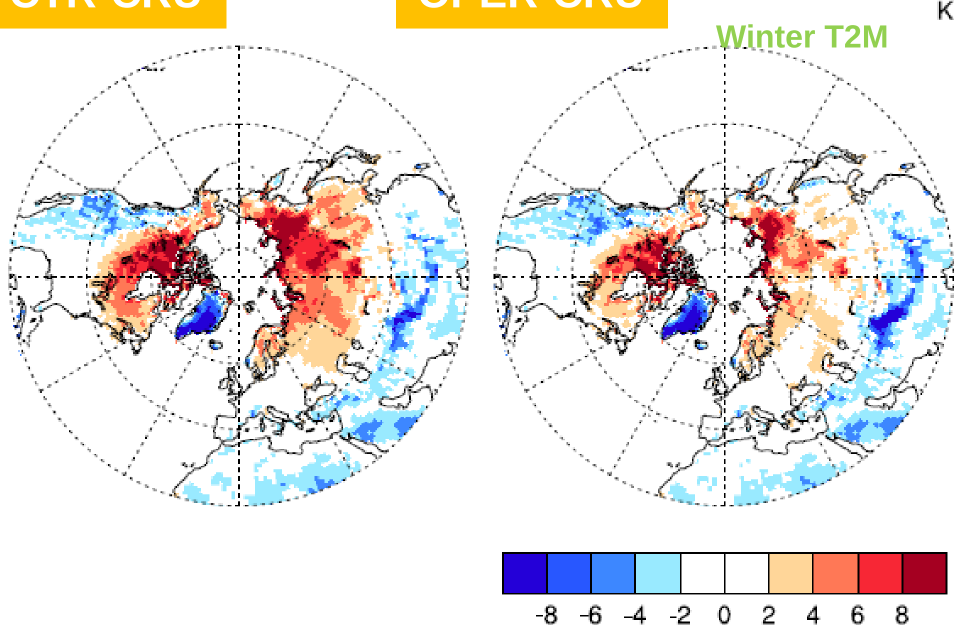


Series1 has warmer high-latitudes in Eurasian sector, closer to observations. It alleviates a cold bias wrt ERAINT in Series2

Snowpack in climate models

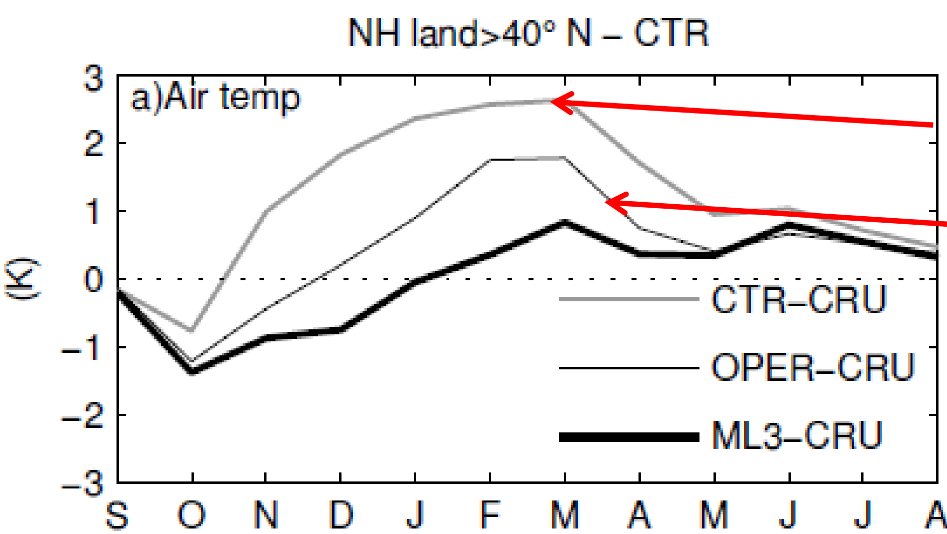
CTR-CRU

OPER-CRU



Recent studies with ECMWF EC-Earth climate model: Improving snow schemes reduces the warm bias against OBS (CRU) at high latitudes

→need better snow schemes in land modules



CTR-CRU

OPER-CRU

-Adding complexity:

CTR → OPER (new 1-layer scheme)

→ML3 (new multi-level scheme)

From DUTRA, E., (J Hydromet 2011; JGR, 2011)

CRU air temperature 1979-2006.

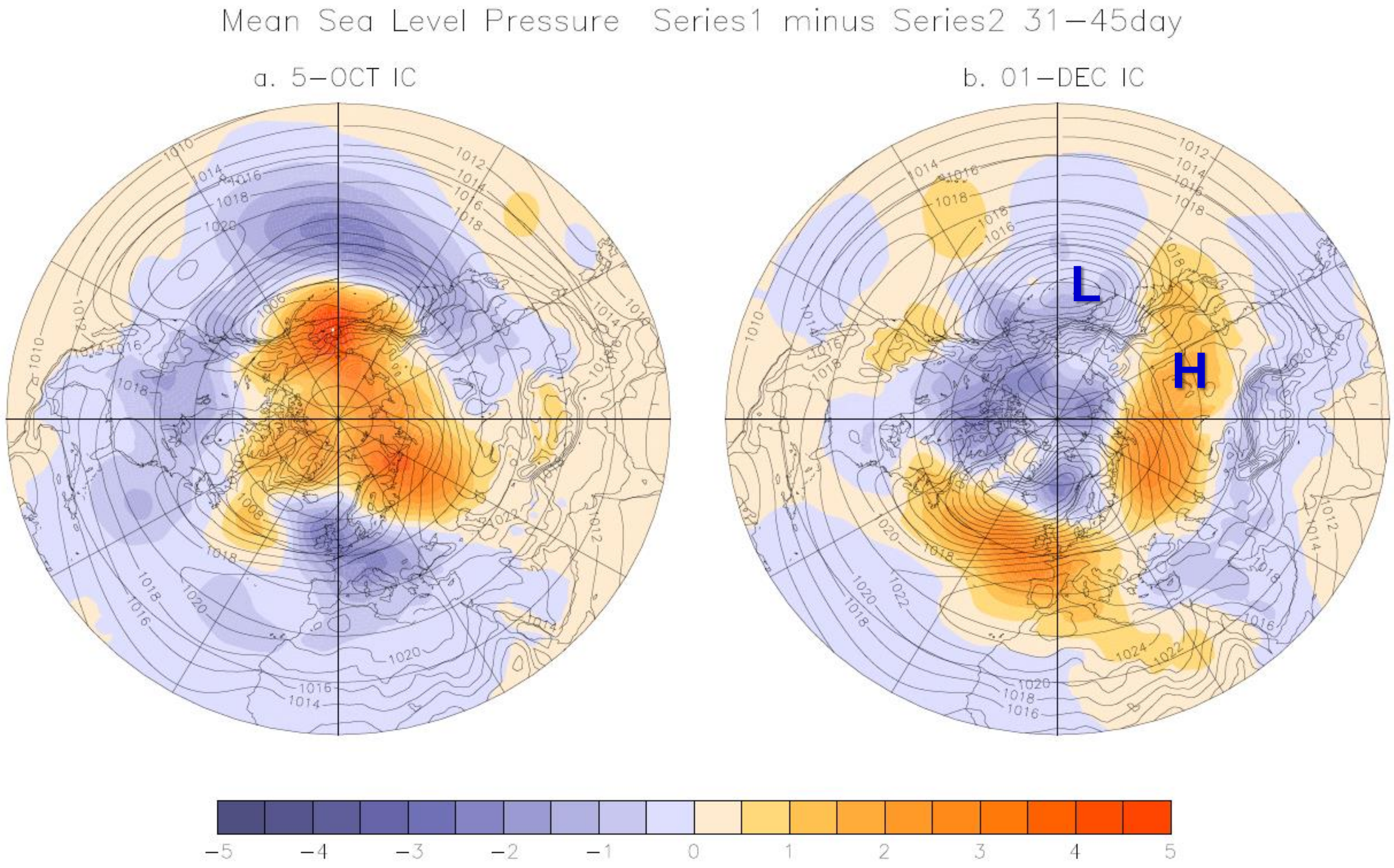
Sea level pressure differences: 30-day lead

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

Implication for Arctic Oscillation

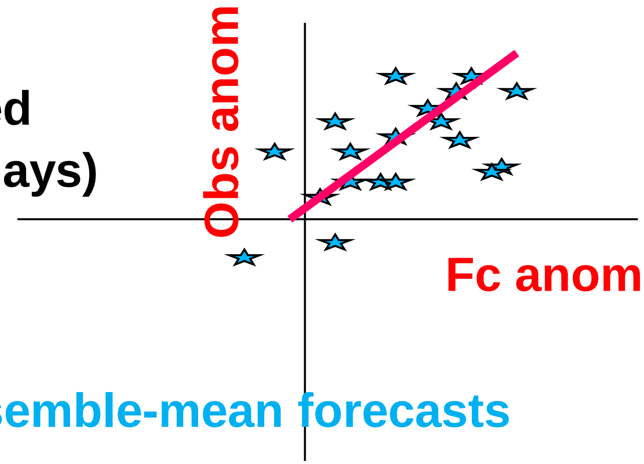
- Wintertime variability of SLP in Arctic is dominated by AO
- Implication of our snow analysis→ snowpack modulates AO amplitude (5 hPa)
- Several papers also suggest influence of snowpack on AO variability or trend : Saito et al. (2001), Cohen (2007); Allen and Zender (2011), Peings et al. (2012)
- However, lagged downward stratospheric influence as in Cohen et al. can’t be seen in our (short) 2-month forecasts: we see the initial high snow / positive AO association.

Forecast skill difference 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)**

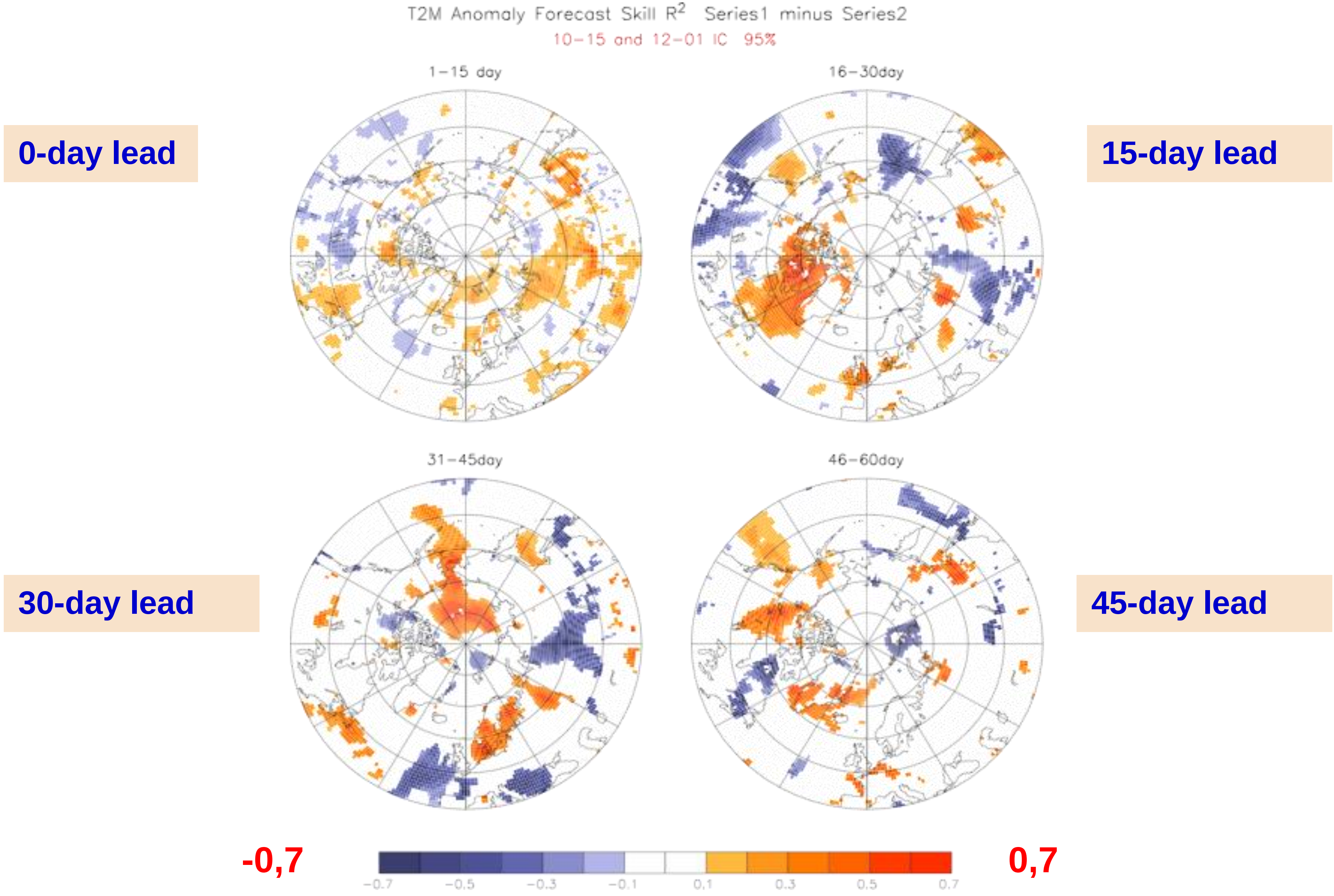
Lead fixed (e.g. 30 days)



Ensemble-mean forecasts

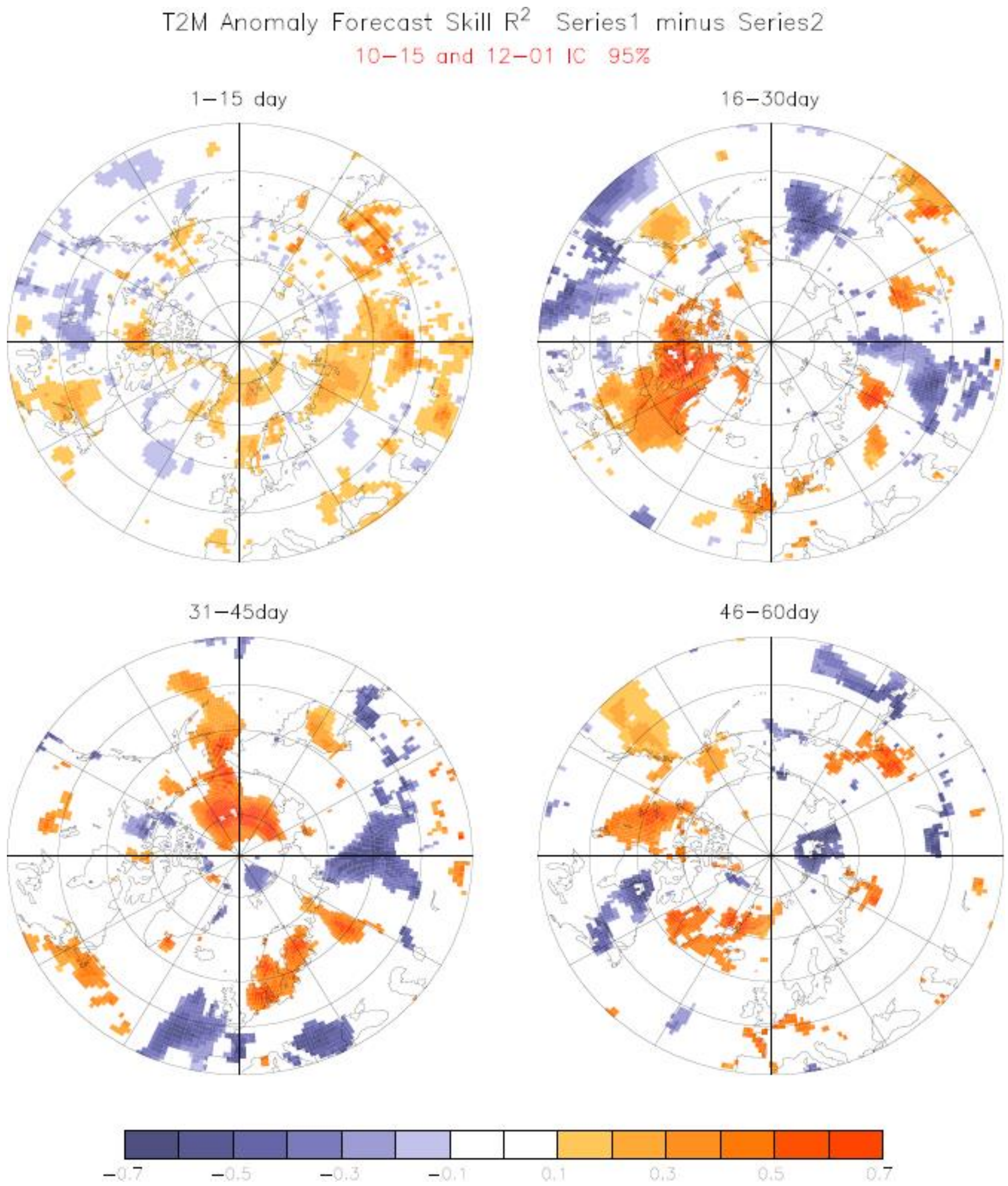
Following GLACE approach (Koster et al. 2004; 2010)

Forecast skill difference in T_{2m} vs. Lead time (stat signi. 95%)



Forecast skill difference vs. lead time

T2m

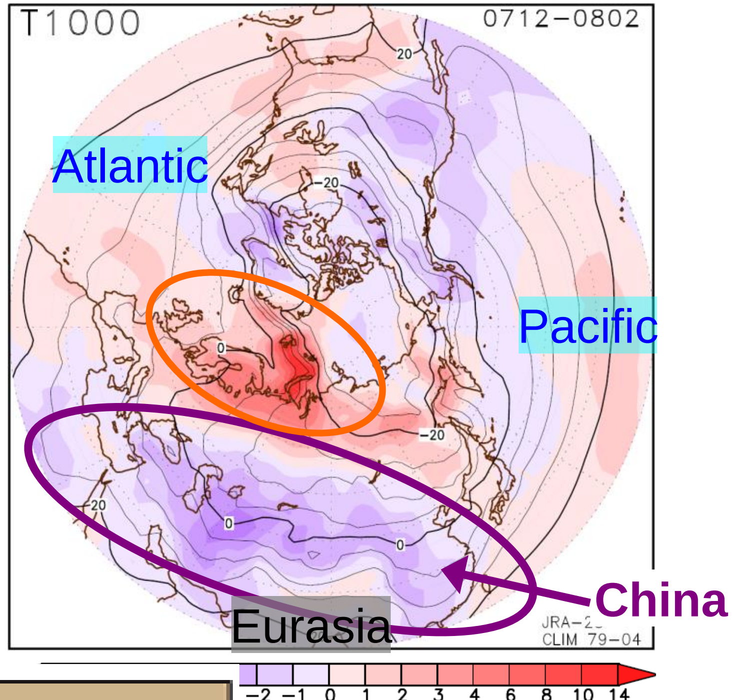


- **Initial (0 lead) weak positive difference over snow-covered land**
- **Very large difference (~0.7) at 30-day lead (e.g. parts of Arctic, North Pacific)**
- **Teleconnection influence : 30-day lag qualitatively consistent with snow forcing of planetary wave propagation (Fletcher et al., 2008; Cohen 2007), and quasi-linear interference (Smith et al., 2012)**

“Warm Arctic-Cold continent” paradigm (Overland et al., 2010)

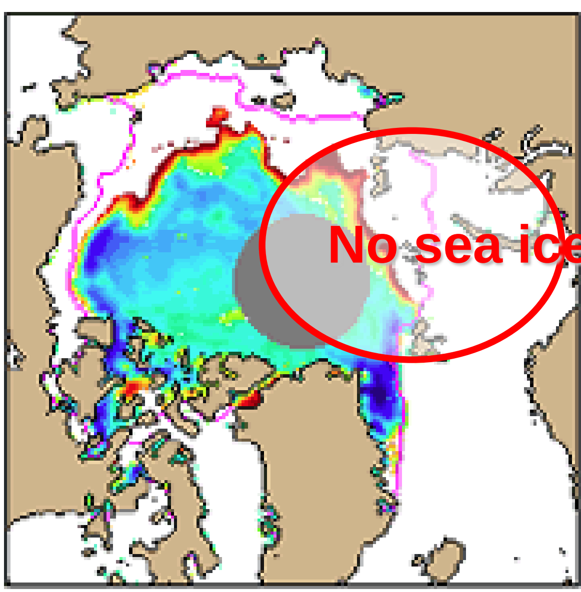
Surface Temp

~(DEC-JAN)



- **Could be partly mediated by snow anomalies over Eurasia (?)**
- **Potential link with Arctic sea ice retreat in late summer→ snow anomalies in autumn, is subject of active research**

(e.g. Orsolini et al., Clim Dyn, 2012; Ghattak et al., JGR 2011; Liu et al., 2012)



Sea ice reduction
In the Barents Sea

Asia

Summer to winter connection

Anomalous cold winters in Asia, with heavy snow over Japan, China

(from Honda et al., 2009; Hori and Inoue, 2011)

Cold winter climate
in Asia

Conclusions

❑ **Heavy snow pack has initial cooling effect on lower atmosphere: consistent with role of snowpack in 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.**

❑**Snow depth is an important variable to measure and initialise in prediction models!**

Conclusions

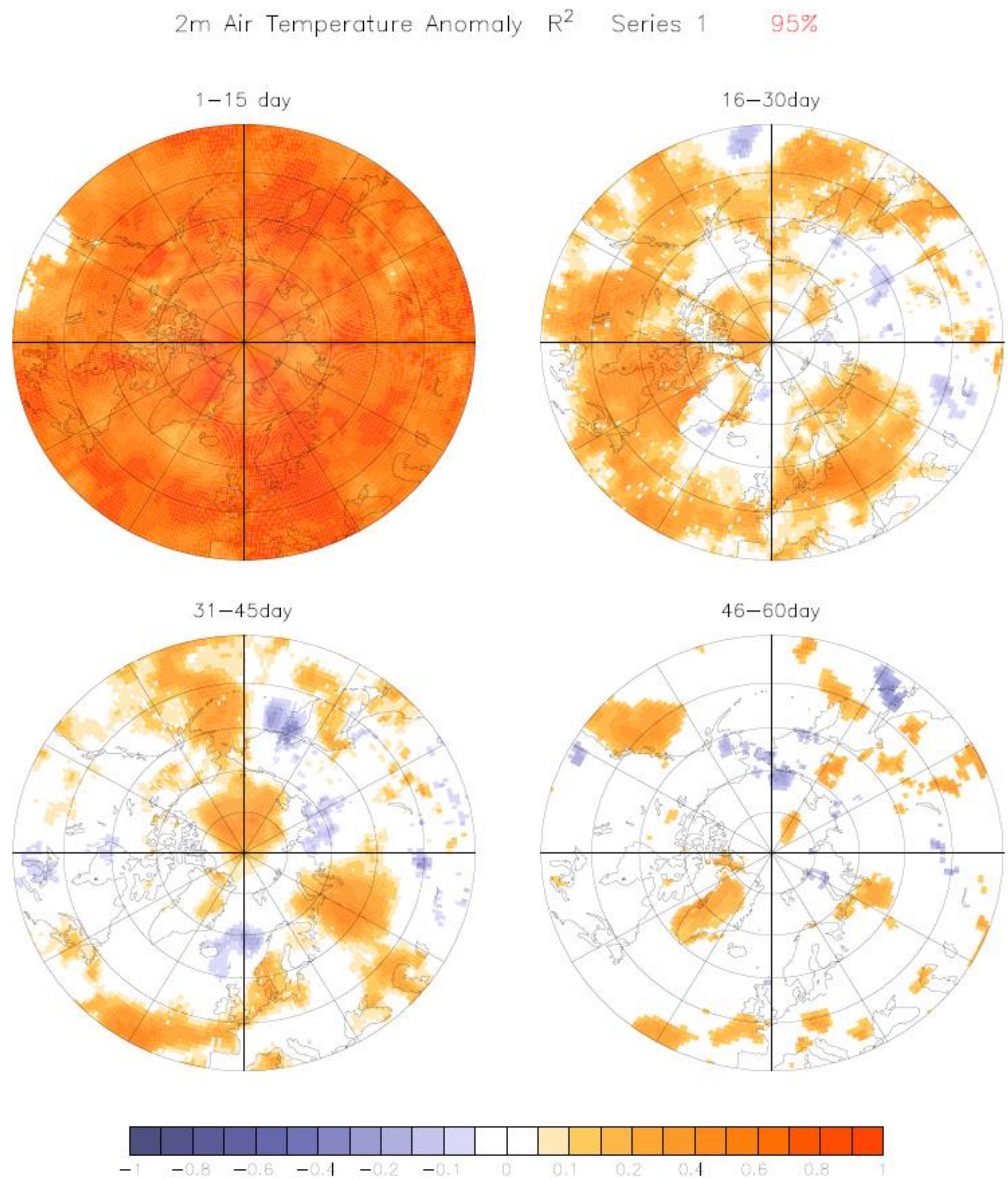
❑ **Key mechanism: intensification and westward expansion of the Siberian High, leading to a warm Arctic/cold Eurasia pattern**

Our high-resolution coupled forecasts partly confirm results from earlier studies *(e.g. Cohen et al., 2007; Orsolini and Kvamstø, JGR 2009; Allen and Zender, 2011; Jeong et al., JGR, 2011)*

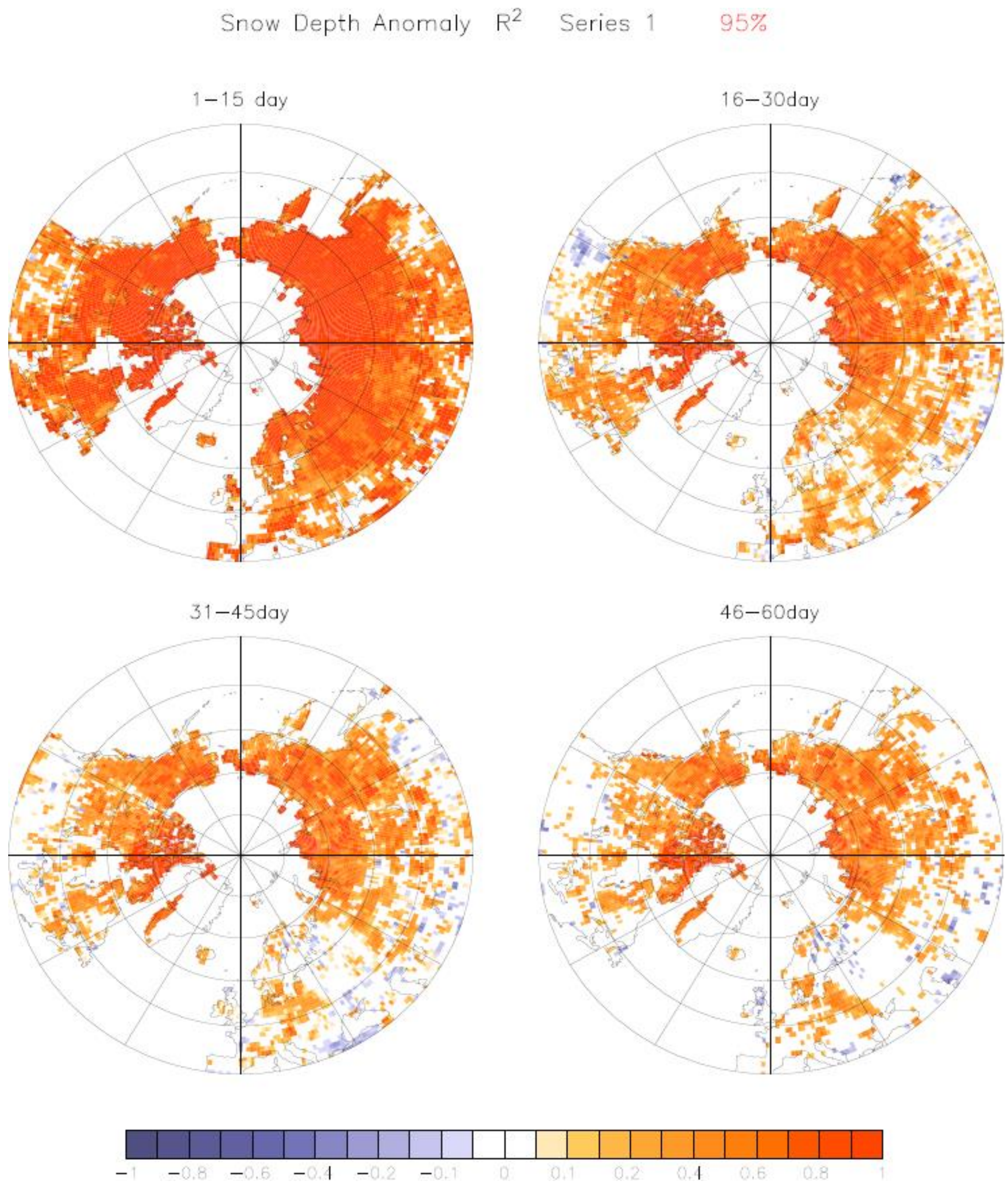
- ✓ **Eurasian autumn snow and Siberian High co-variability**
- ✓ **Eurasian autumn snow influence on Arctic heights (AO)**

Orsolini, Y.J., Senan, R., Balsamo, G., Doblas-Reyes, F.J., Vitart, F, Weisheimer, A., Carrasco, A., and Benestad, R.E. Impact of snow initialization on sub-seasonal forecasts, Climate Dynamics, online, May 2013.

Reserve slides

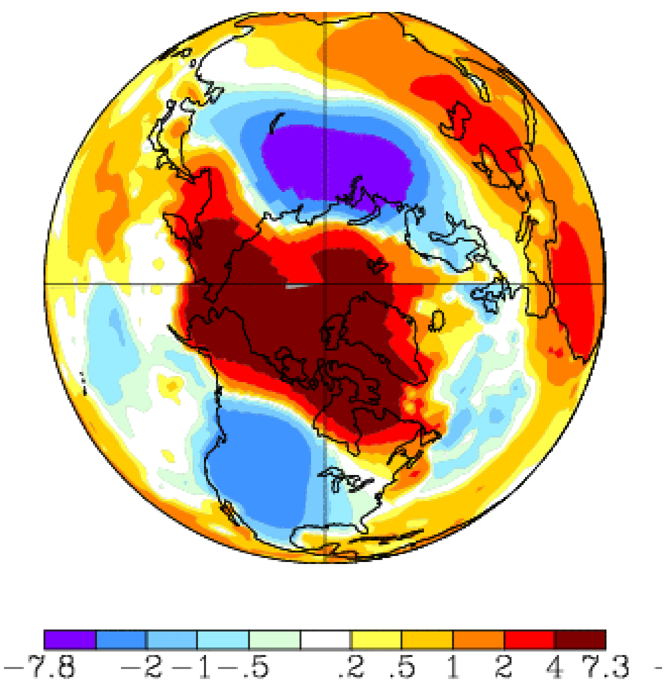


2m Air Temperature Anomaly R2 Series 1 95%
1–15 day
16–30day
31–45day
46–60day
−1 −0.8 −0.6 −0.4 −0.2 −0.1 0 0.1 0.2 0.4 0.6 0.8 1

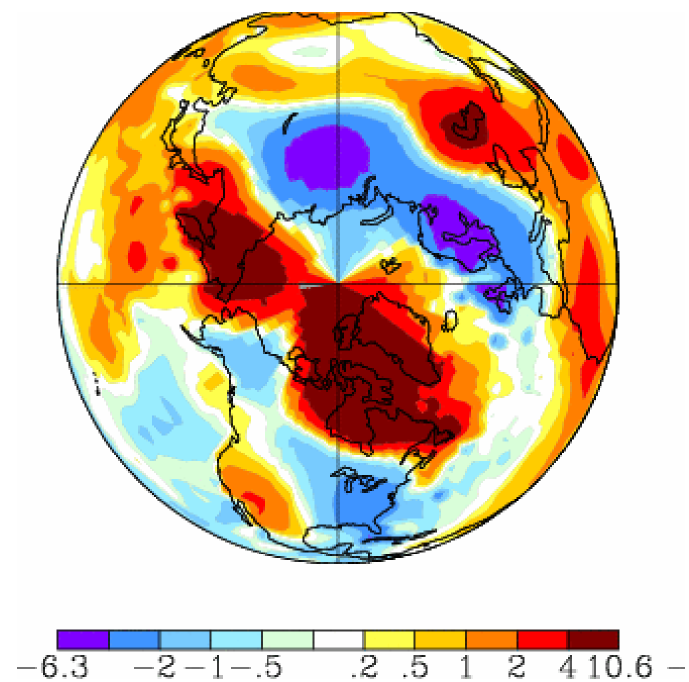

Snow Depth Anomaly R2 Series 1 95%
1-15 day
16-30day
31-45day
46-60day
-1 -0.8 -0.6 -0.4 -0.2 -0.1 0 0.1 0.2 0.4 0.6 0.8 1

Warm high-latitudes / cold mid-latitudes pattern observed in early winter in recent years

December 2009



December 2010



Warm Arctic-Cold Continents pattern has been linked to sea-ice decrease (Overland and Wang, 2010)

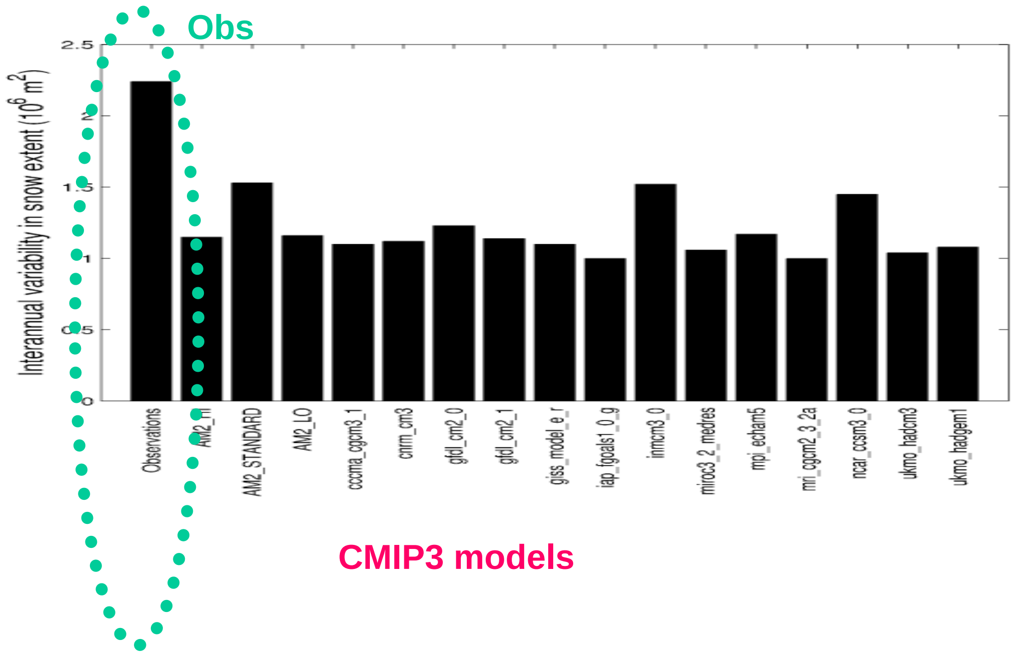
NASA – GISS land-ocean temp.

Snowpack in climate models

- **Hardiman et al. (JGR, 2008) and Peings et al. (JClim 2012) examined why climate models do not replicate the observed NAO/snow cover linkage**

They found a series of reasons:

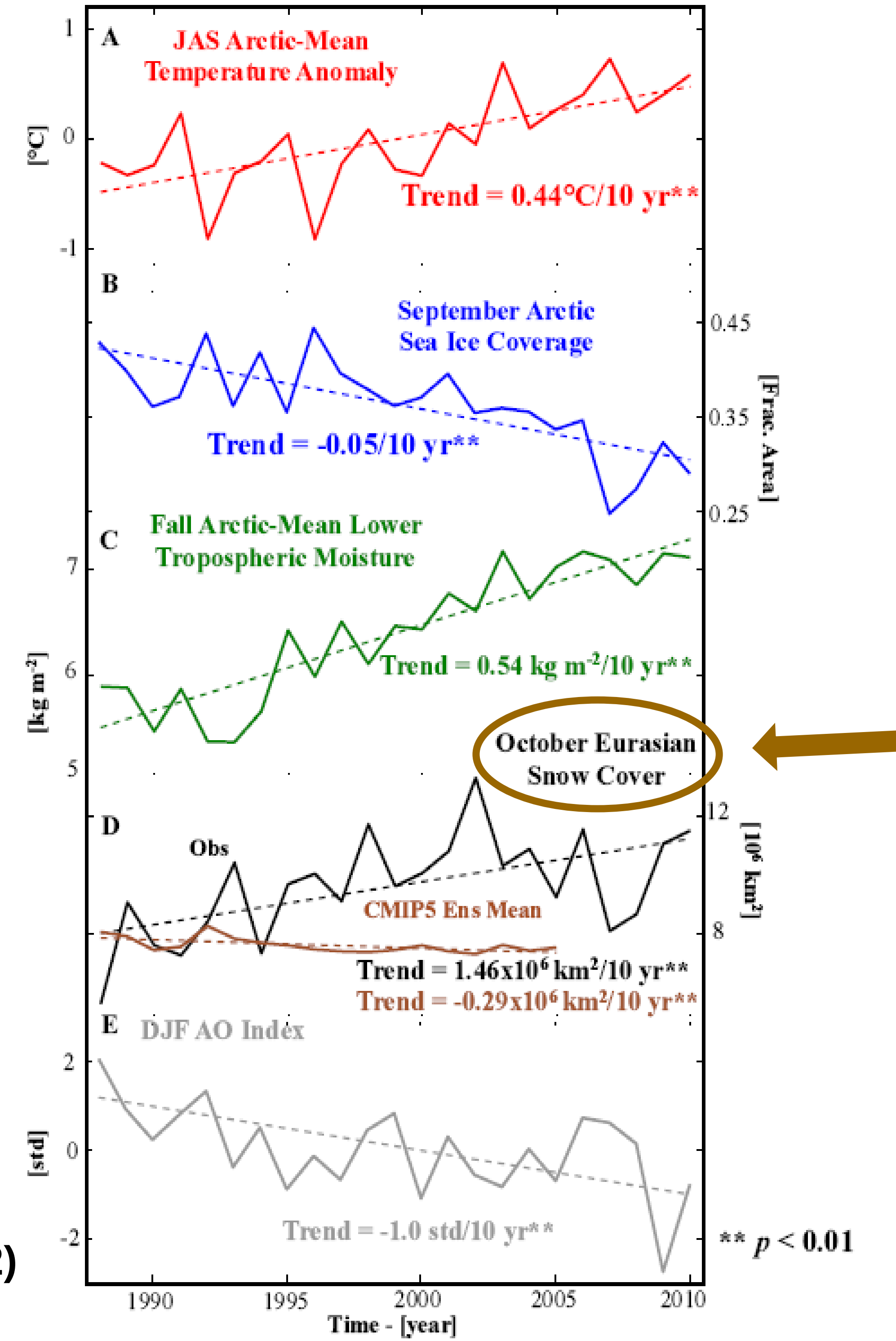
inter-annual variability in Eurasian snow extent (St Dev)



- **Models underestimate year-to-year variability in autumn Eurasian snow cover**

- **Models do not reproduce the wave response and vertical propagation**

Snowpack in climate models



- Additional difficulty in reproducing the observed positive trend in Eurasian snow cover over the last decades
- Cohen links this trend to the Arctic sea decline, moisture increase in Arctic LT

From Cohen, J., et al., Env. Res. Lett. (2012)