Impact of snow on subseasonal-to-seasonal forecasts

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NILU Norsk institutt
for luftforskning

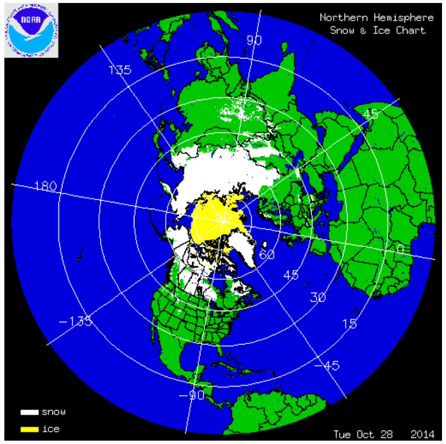
Impact of snow on subseasonal-to-seasonal forecast

- **AUTUMN EURASIAN SNOW influences wave trains propagating downstream over the North Pacific and vertically into the stratosphere, with a lagged downward impact the North Atlantic/Arctic**

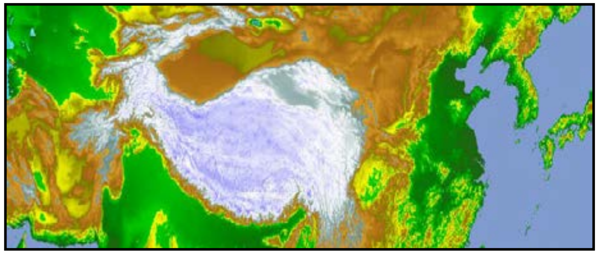
(e.g. Cohen et al., Nature Geos 2014; Orsolini and Kvamstø, JGR 2009,…)

- **SPRING EURASIAN/HIMALAYA-TIBET SNOW influences the Indian summer monsoon (ISM) onset (e.g. Turner and Slingo, 2011; Peings and Douville, 2010)**

(Blanford's Hypothesis (Blanford ,1884): Inverse relationship between spring Himalayan snowfall and subsequent summer rainfall over Indian sub-continent

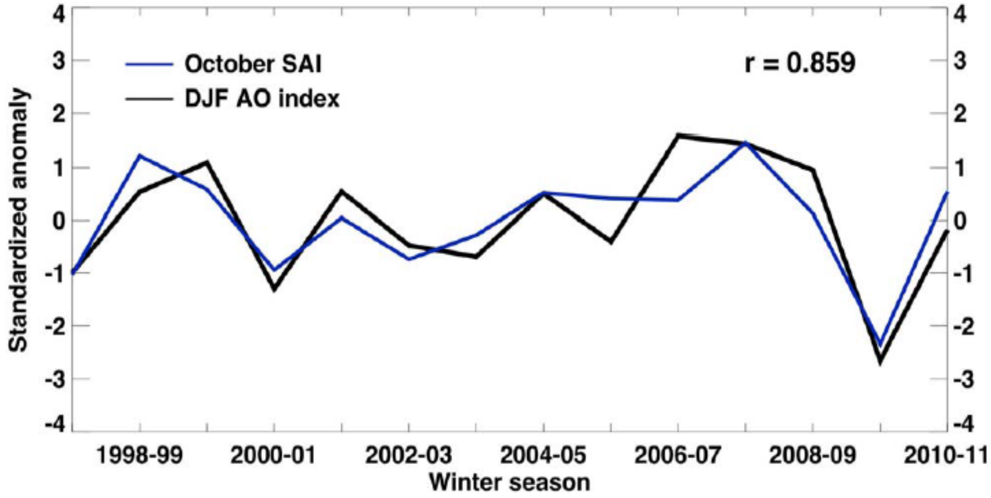


[high snowfall → weak, delayed monsoon]



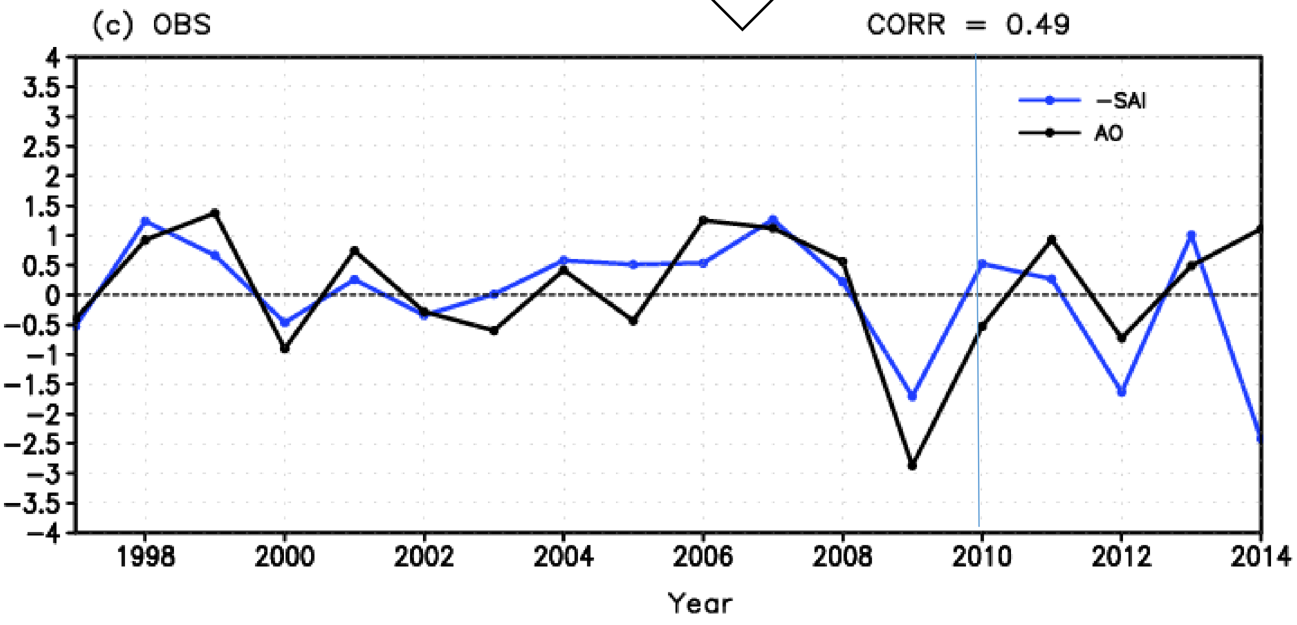
Impact of autumn Eurasian snow cover on NAO/AO

high correlation: 0.86



OCT snow advance index
vs winter (DJF) AO

e.g. Cohen (2011)



Extended to recent period: 0.49

→Need to better understand the sub-seasonal response of atmosphere to snow forcing

Figure courtesy of SH Kim and J-H Jeong, KOPRI

Impact of snow on subseasonal-to-seasonal forecast

- What is the impact of autumn Eurasian snow on s2s forecasts ?

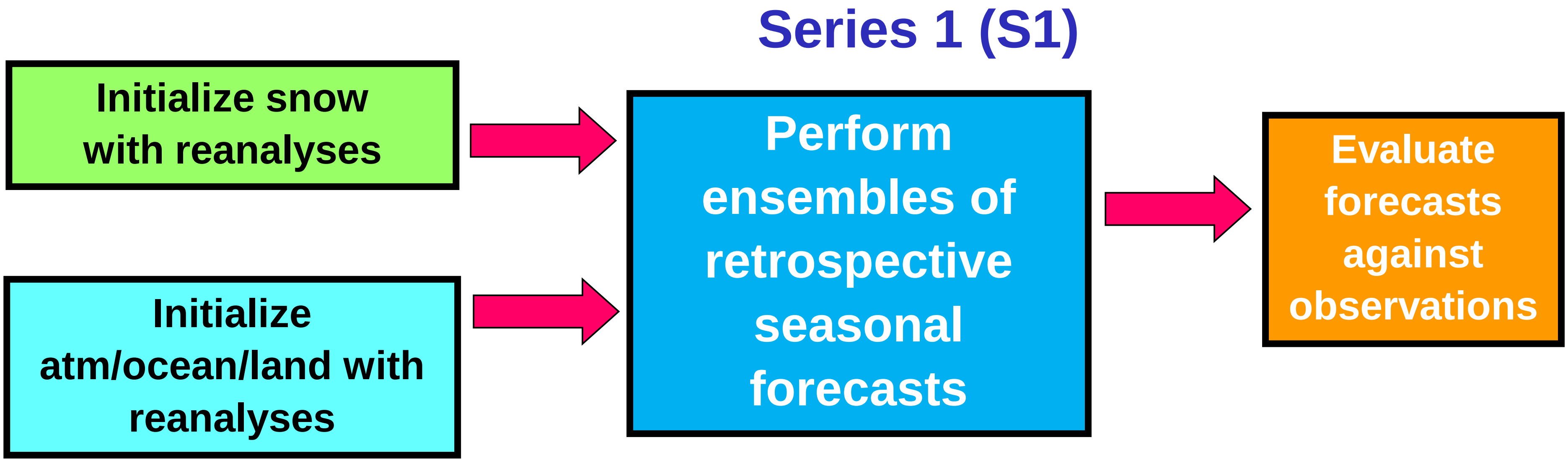
- modelling strategy similar to the one used for looking at soil moisture impact in the warm season (Koster et al. 2004; 2010) in the GLACE international modeling project

- twin forecast ensembles, only differing in snow initialisation

→ attribute difference to snow initialisation

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

A first ensemble of seasonal forecasts with accurate snow initialisation



Series 1 (S1)

Initialize snow with reanalyses

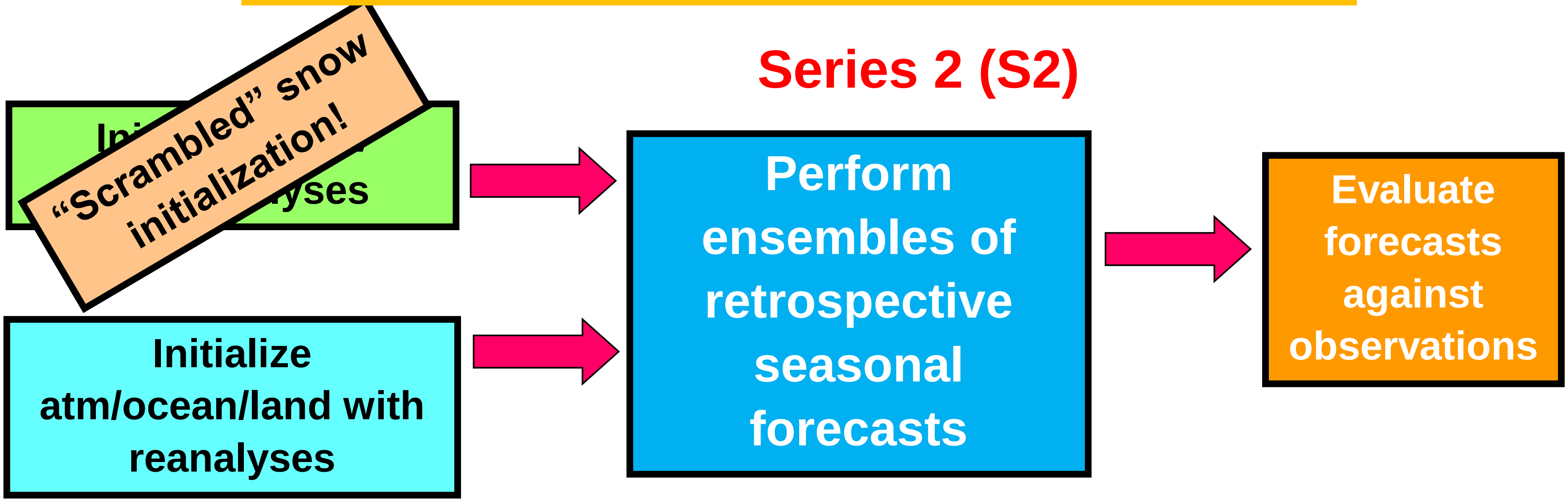
Initialize atm/ocean/land with reanalyses

Perform ensembles of retrospective seasonal forecasts

Evaluate forecasts against observations

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

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



Series 2 (S2)

Ini… …yses

“Scrambled” snow initialization!

Initialize atm/ocean/land with reanalyses

Perform ensembles of retrospective seasonal forecasts

Evaluate forecasts against observations

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

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

- **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)**
- **High horizontal resolution is same as ERAINT re-analyses**

Paper on skill increment over period (2004-2010) **: Orsolini, Y.J., Senan, R., Balsamo, G., Doblas-Reyes, F., Vitart, D., Weisheimer, A., Carrasco, A., Benestad, R., Impact of snow initialization on sub-seasonal forecasts , Clim. Dyn., 2013**

Impacts of snow initialisation on subseasonal-to-seasonal forecasts – single model cases

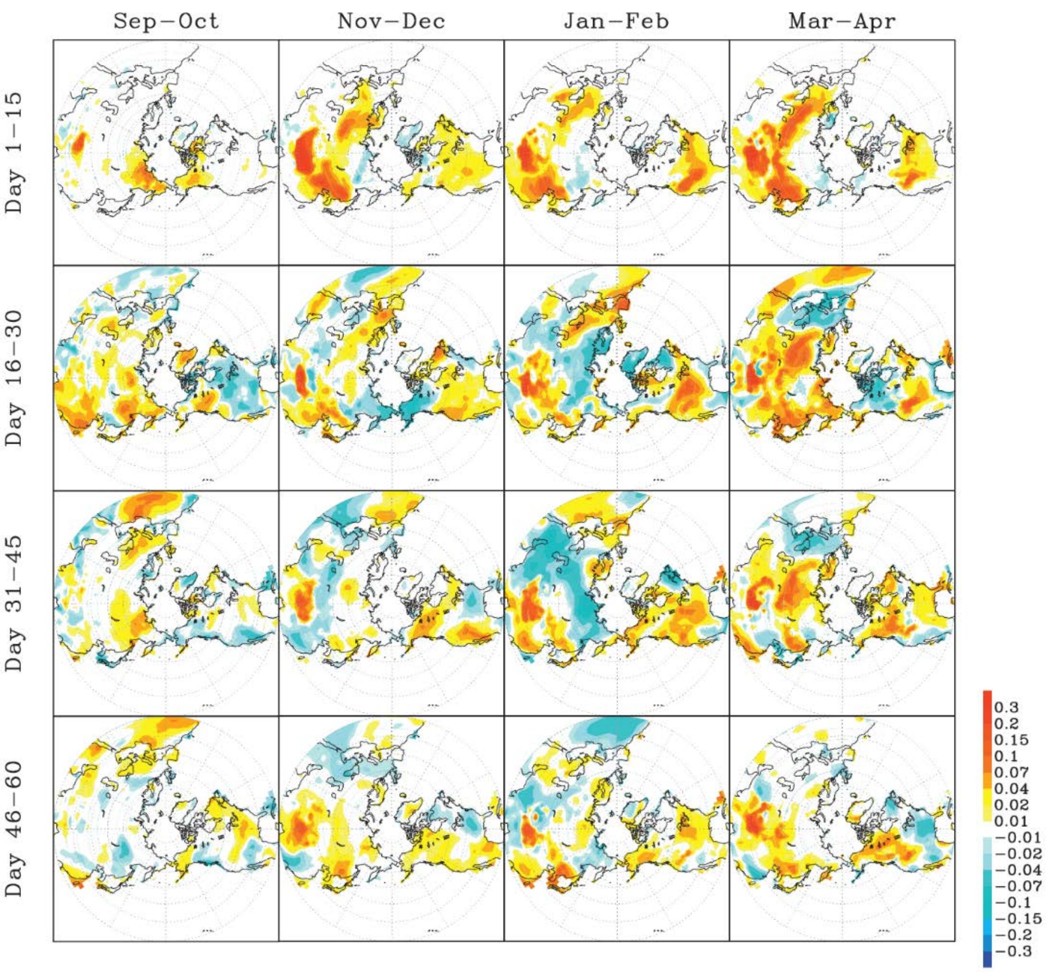


FIG. 4. Change in potential predictability (r^2; see text for details) of SAT hindcast using the snow depth initialization (S1 − S2): (left to right) Sep–Oct to Mar–Apr and (top to bottom) day 1–15 to 46–60.

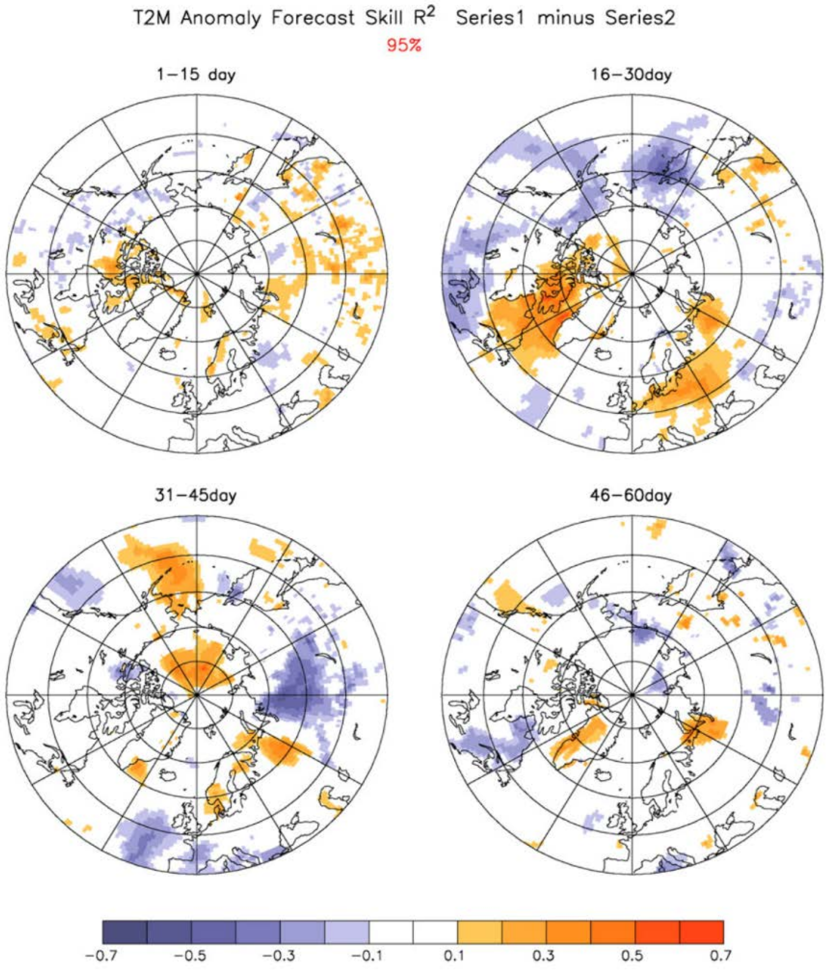


Fig. 11 Forecast skill difference for near-surface temperature. Forecast skill difference between Series 1 and Series 2 for near-surface temperature (as in Fig. 8)

Jeong et al. (2013), Change in potential predictability of T_{2m} due to snow initialisation (NCAR CAM3)

Orsolini et al. (2013), Change in T_{2m} forecast skill due to snow initialisation (ECMWF EPS)

Process studies : negative NAO phase in cold winter 2009/10

- Very cold winter in Europe and US, and over Far East : cold air outbreaks
- 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; Hori et al, 2010; Cohen et al, 2010...)
- Potential factors : sea-ice, solar top-down forcing, snow, stratosphere dynamics

Normalised NAO index

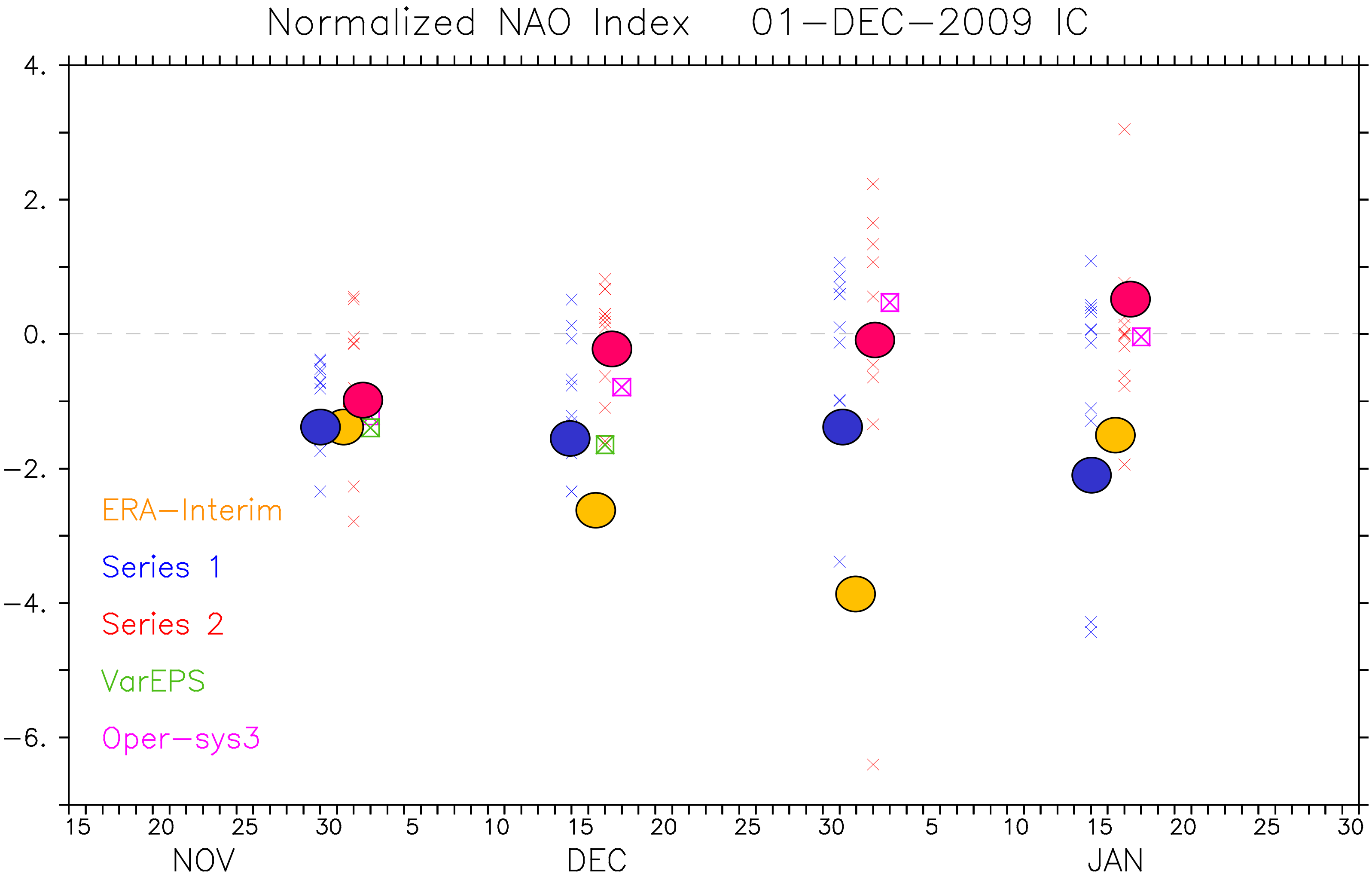
(based on anomaly of SLP difference; years *2004-2010*)

- ❑ **Series1 has more negative <ensemble> NAO index than Series2, closer to re-analyses. (T255)**
- ❑ **VAREPS: oper. monthly forecasts, at variable resolution**

(nearly identical to our SNOWGLACE runs) (T255)

- ❑ **Operational (S3) (T159)**

(As in Jung GRL 2011)

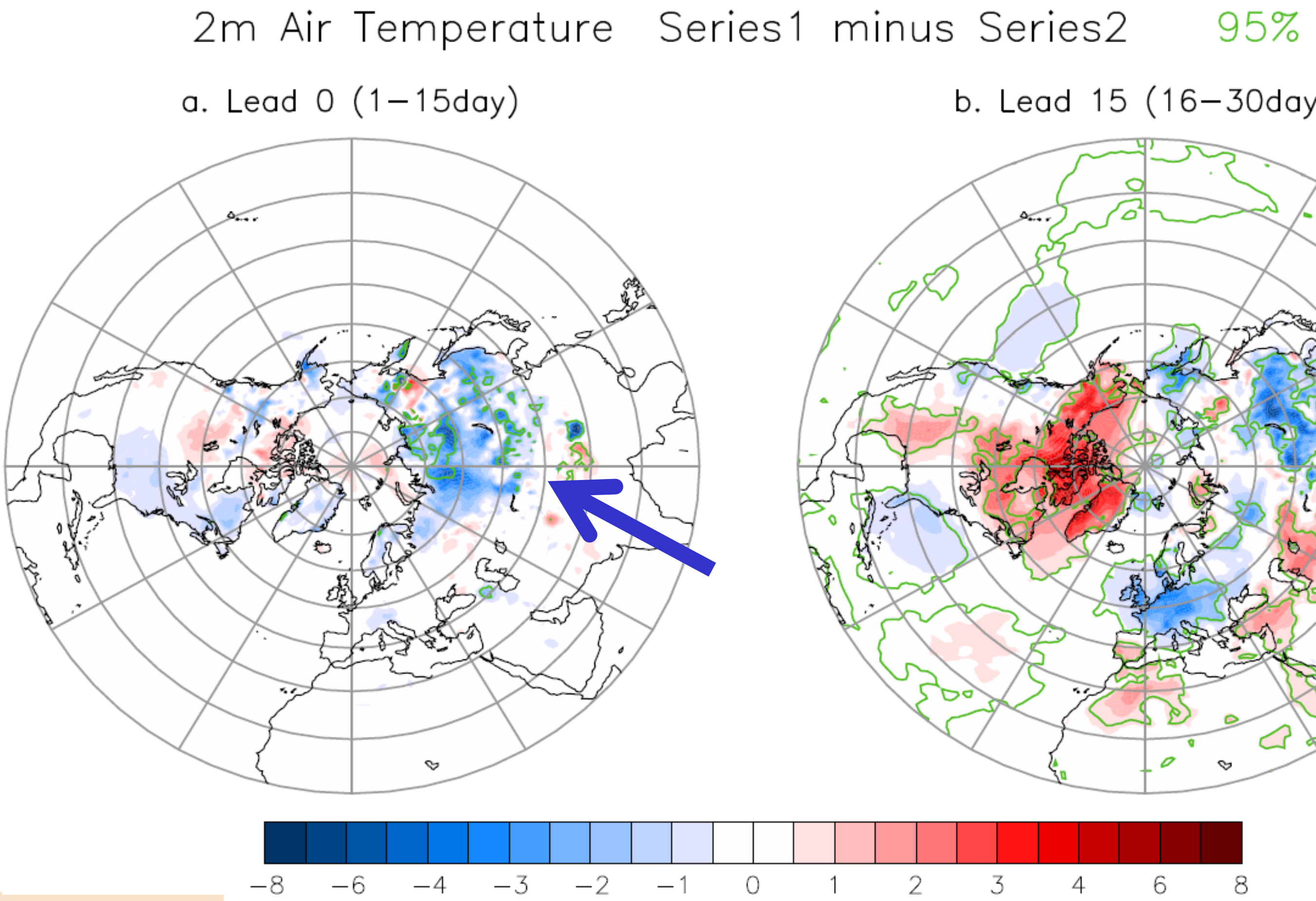


→ Snow initialisation (high snow) contributes to maintaining negative NAO

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

→ Realistic snow initialisation and horizontal resolution are both important

Surface Temperature differences



ensemble-mean

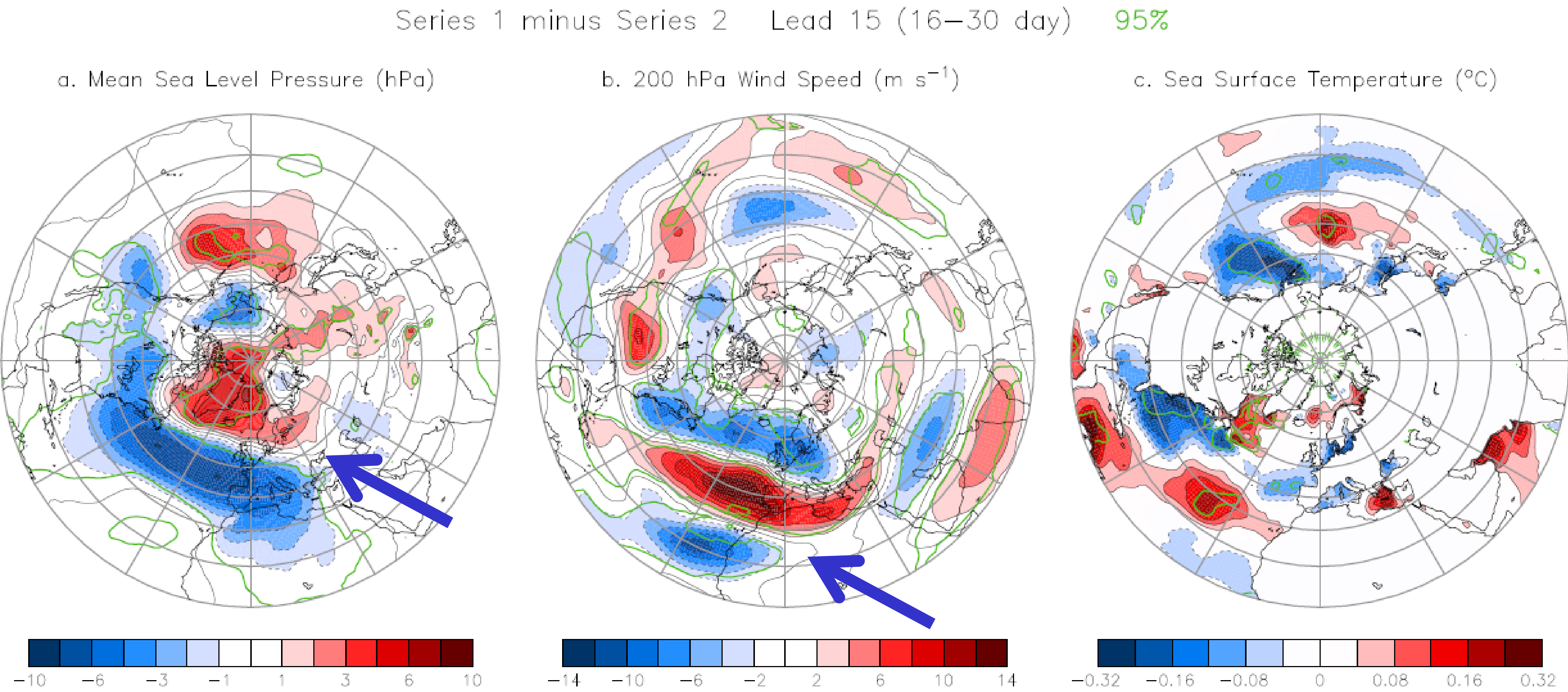
Series 1 – Series 2

<u>0-day lead</u> : Presence of thick snow pack → colder surface temperature (up to 6K) over Eurasia.

<u>15-day lead</u> :

- **quadrupole pattern across ATL, typical of negative NAO → cold Europe and NE America.**
- **cold anomaly over Far East**

Sea level pressure, wind speed (200 hPa), SST differences



ensemble-mean

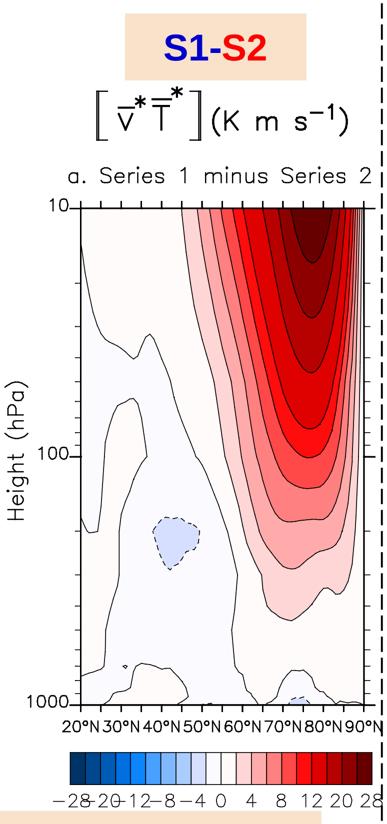
Series 1 – Series 2

15-day lead (16-30 days))

SLP meridional dipole, jet stream displaced further south, SST tripole across the Atlantic:

→ Series1 with realistic (high) snow initialisation : more negative NAO compared to Series2

Snow-stratosphere linkage

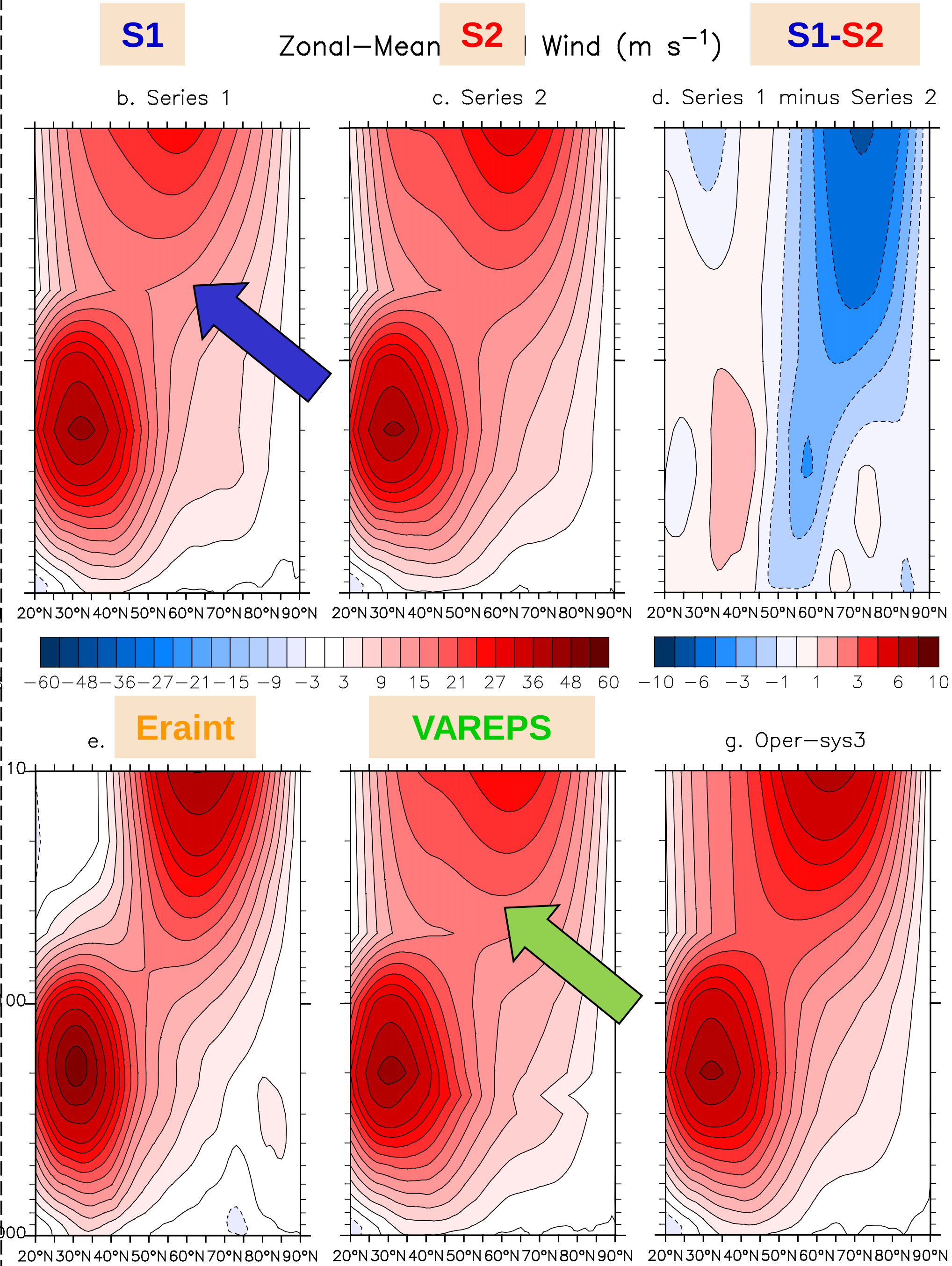


Quasi-stationary v-heat flux (v*T*)

Enhanced heat flux in S1 → PNJ decceleration: (Series1 weaker jet, compared to Series2)

Both forecasts at high resolution (S1 and Vareps) →decelerated PNJ

→ Fast response to stratospheric variability over N.ATL. (NAO neg)



Zonal-mean U cross section

ensemble-mean

15-day lead

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)***

- ☐ **Forecasts of the 2009/10 winter demonstrate snow initialisation impact:**

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

  - **Upward coupling into the stratosphere**

  - **Rapid tropospheric adjustment to stratospheric vortex weakening, focused over the N. Atlantic (e.g. Shaw et al., JGR, 2014; Orsolini et al, Clim Dyn, 2009)**

  - **It appears that only high-horizontal resolution models (SNOWGLACE, VAREPS) capture snow-NAO coupling (via stratosphere)**

  - **Resolving background circulation (Siberian High) over Eurasia might be key**

➢*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, in revision.*

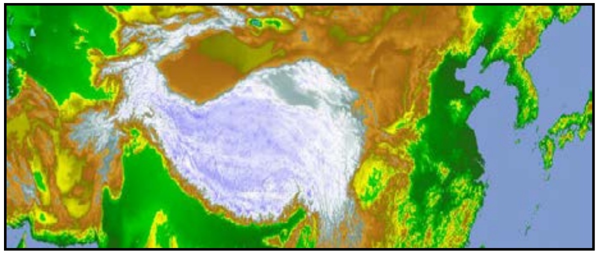
Spring snow and Indian monsoon

- The influence of the springtime Eurasian/Himalayan snow cover for modulating the Indian summer monsoon (ISM) is also known as **Blanford's Hypothesis** (Blanford ,1884):

- Inverse relationship between spring Himalayan snowfall and subsequent summer rainfall over Indian sub-continent

[high snowfall → weak, delayed monsoon]

- **Blanford's Hypothesis** remains controversial, despite having been the subject of many observational and model studies.
- **Issues** : in-situ vs satellite data, snow cover or depth, model differences, short observational record
- **Physical reasoning:** the snowpack over the Himalayan and Tibetan Plateau (HTP) region (often referred to as the 3rd pole) influences the seasonal land warming:



India Summer Monsoon: Large social and economical impacts

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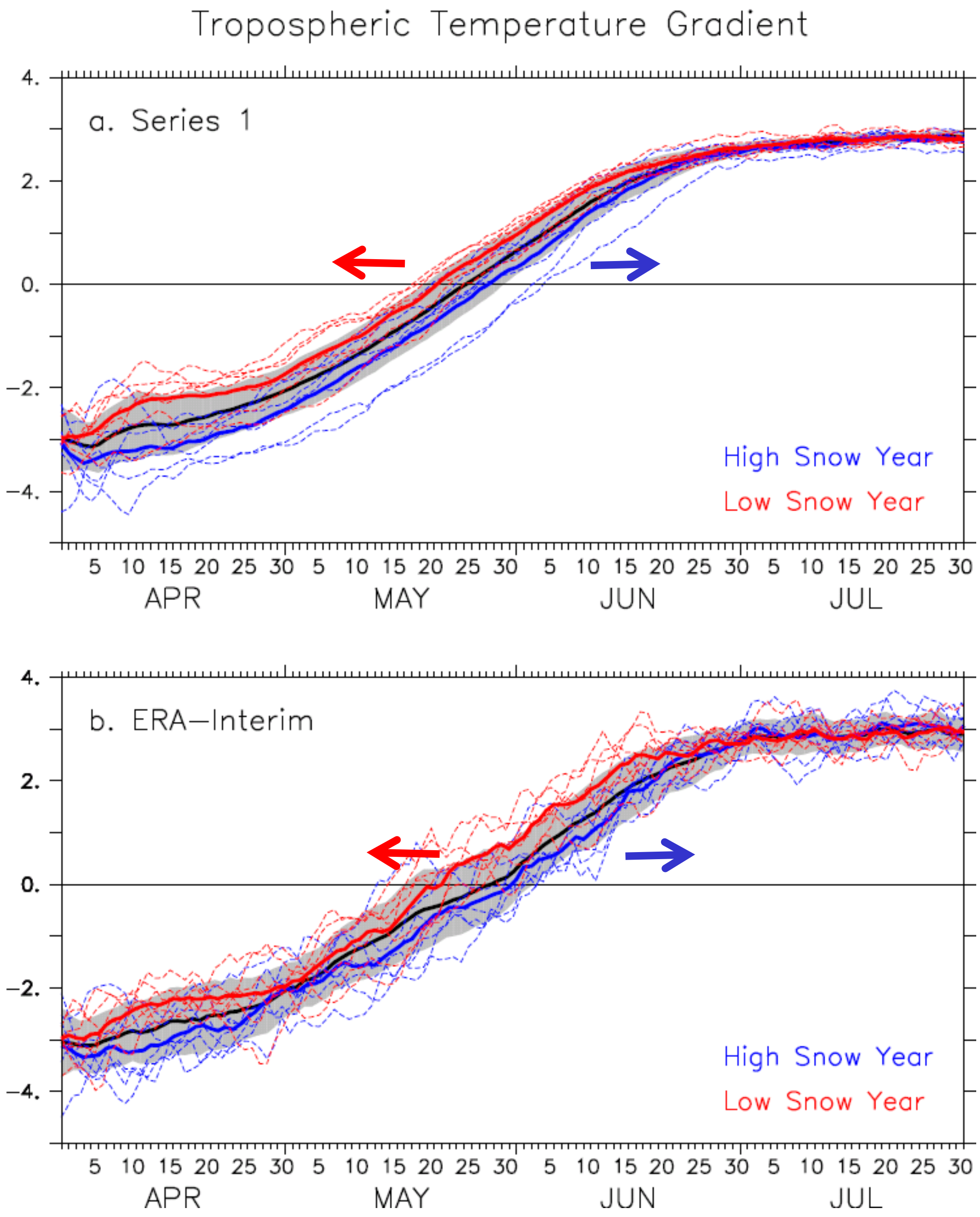
ISM ONSET as reversal of North/South tropospheric temp. gradient



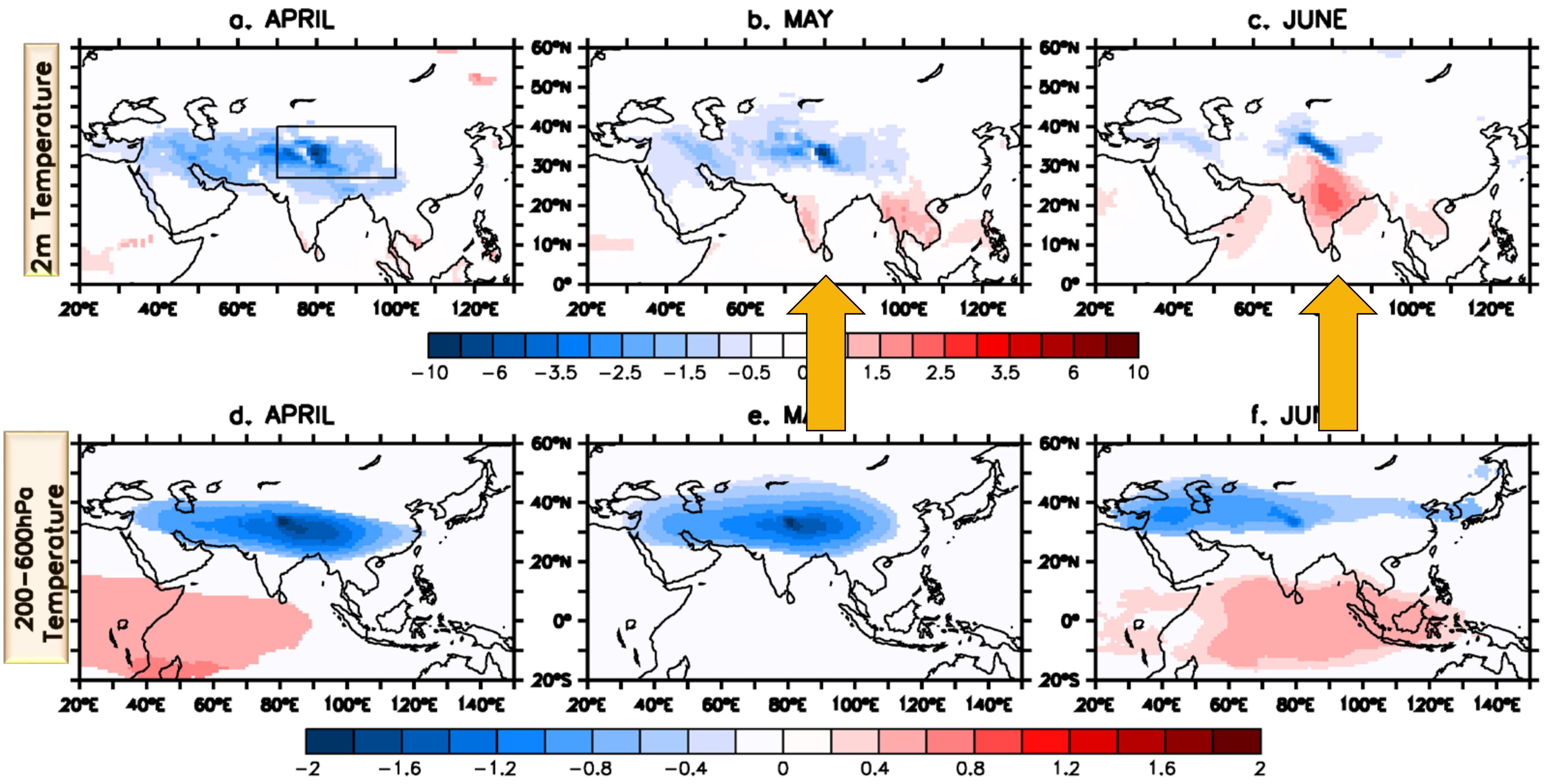
- **Reversal occurs earlier/later (← or →) or later in May in low/high April snow years over HTP region**
- **Average delay in onset is about 1 week**

Based on (Xavier et. al, 2007)

- **TTG : difference of the vertically integrated (200-600hPa) temperature, between a northern region (5°N-35°N) and southern region (15°S-5°N) over 40°E -100°E**
- **Onset of the monsoon: TTG zero-crossing (in late May)**

Snow composite differences: temperature

Composite High (7 yrs) minus Low (7 yrs) APRIL HTP Snow Depth Series 1 95%



- High APRIL HTP SNOW: warm anomaly in MAY-JUNE over India
- Consistent with delayed monsoon

Conclusion

- Revisit the influence of springtime Eurasian/Himalayan snow cover on Indian summer monsoon (ISM) onset using modern, dynamical prediction system

- ECWMF seasonal (coupled) ensemble prediction system (operational + dedicated, attribution experiments)

- High snow over HTP in April leads to a delay of monsoon onset (8 days)

- Half of the delay is attributable to the HTP snow initialisation, the rest comes from other factors (e.g. atmospheric preconditioning, SST or snow initialisation over Eurasia,…)

→more dedicated experiments needed to ascertain the role of these factors separately

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, 41:1969-1982, 2013.

Orsolini Y.J., Senan R., Weisheimer A., Balsamo G., Doblas-Reyes F.J., Vitart F, E. Dutra, Climate Dynamics, in revision, October 2015.

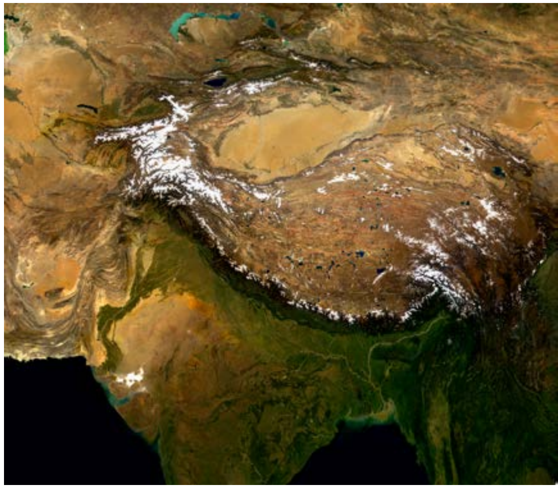
RESERVE SLIDES

Our focus: revisit the role of snowpack over the Himalaya-Tibet Plateau on ISM onset

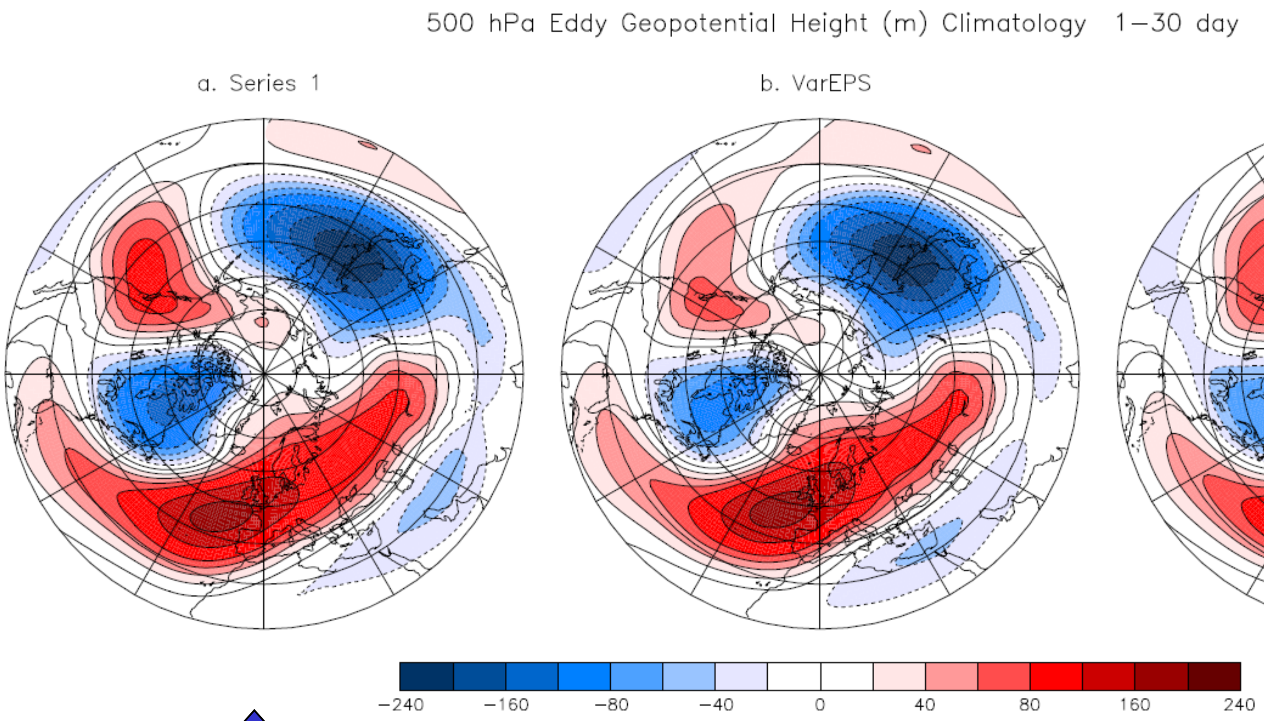
Attribute the impact of snow initialisation over the Himalaya-Tibet Plateau region (HTP) on the ISM onset in actual predictability experiments

- **Revisit the "Blanford hypothesis" with a state-of-the-art ensemble prediction system**
- **Coupled ECMWF seasonal forecasting system in operational mode, plus dedicated experiments**
- **Verification : ECWMF Atmospheric or Land Re-analyses**

HTP



Importance of horizontal resolution ?



Snow -> Stratosphere linkage : Series1, VarEPS high-resolution runs

Hypothesis: model climatology and drift

Background circulation over Eurasia (Siberian High)

→Pronounced ridge is important for (quasi-linear) interaction with snow-induced anomalies

Series 1 (S1)

- 12-member ensemble
- atmospheric / oceanic / land initialisation
- forecast length : 2-month
- Start date: DEC 1
- 2009

- realistic snow initialisation *(ERAINT)*

Series 2 (S2)

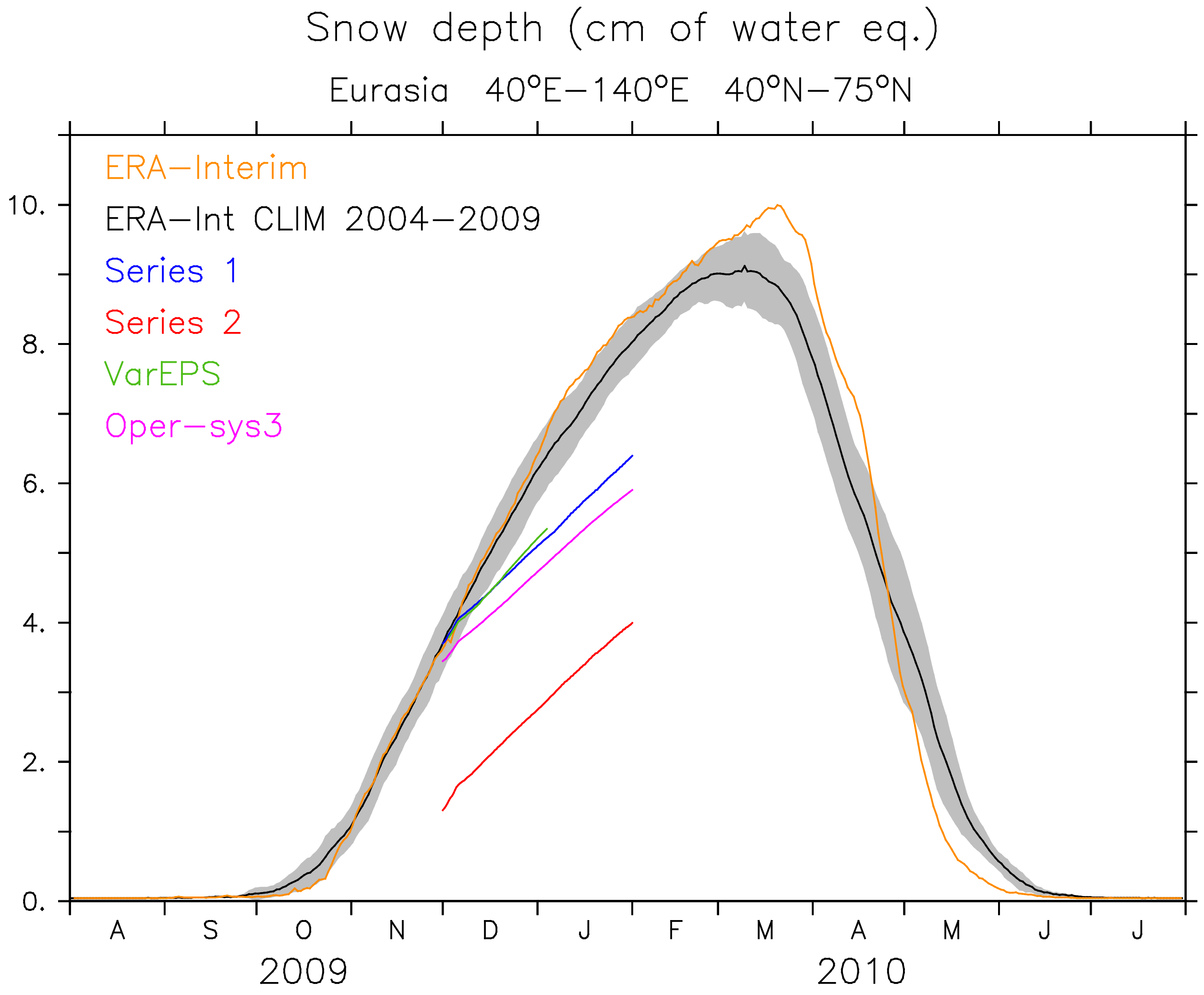
identical , but

- scrambled snow : "low snow" taken from earlier start dates in fall, and other years

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

(S1 – S2) is a (high minus low) snow composite difference

Snow depth over Eurasia in 2009/10 winter



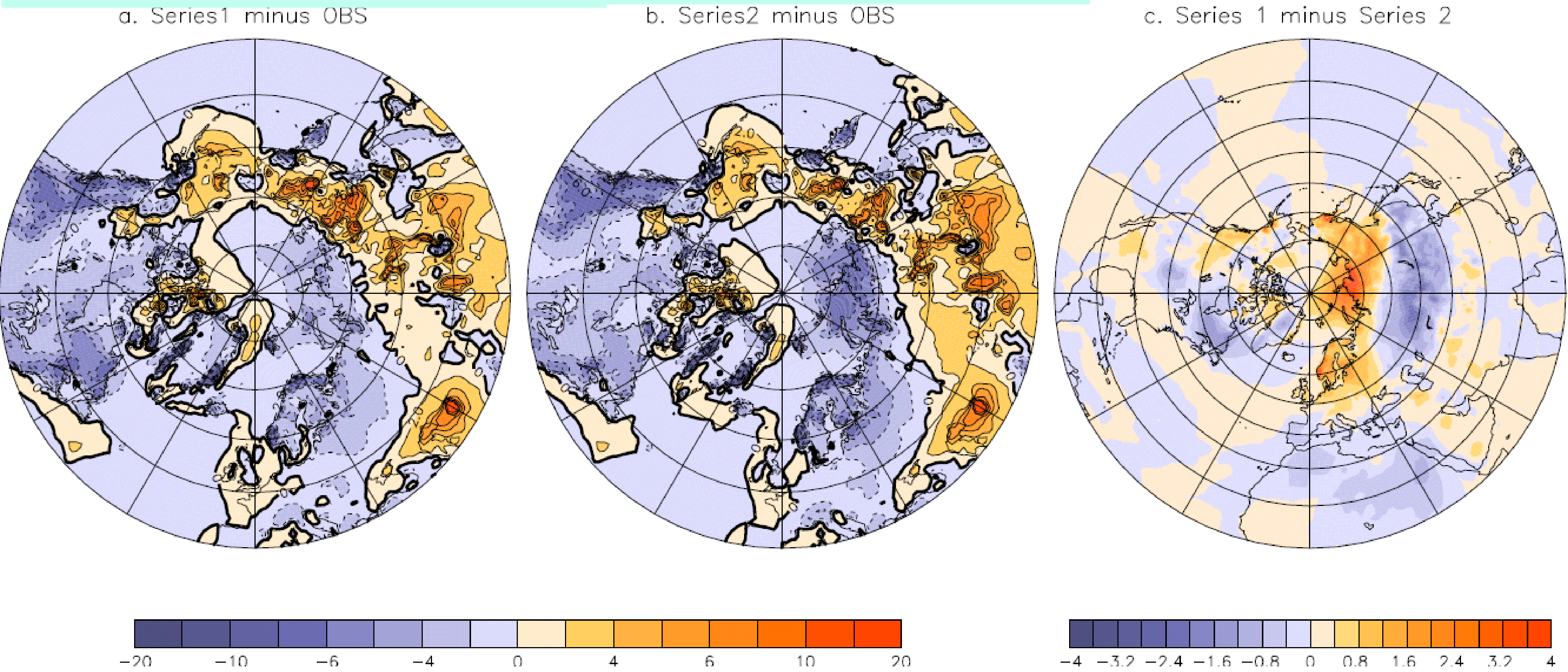
Series2 **has large snow perturbations**

T_{2m} difference : warm Arctic-cold continents

Difference : Series 1- ERAINT

Difference : Series 2- ERAINT

(2004-2010)



In Eurasian sector, Series1 has

- **warmer Arctic : alleviates a cold bias in Series2**
- **colder mid-latitudes: alleviates a warm bias in Series2**
- **Due to intensification of Siberian High**

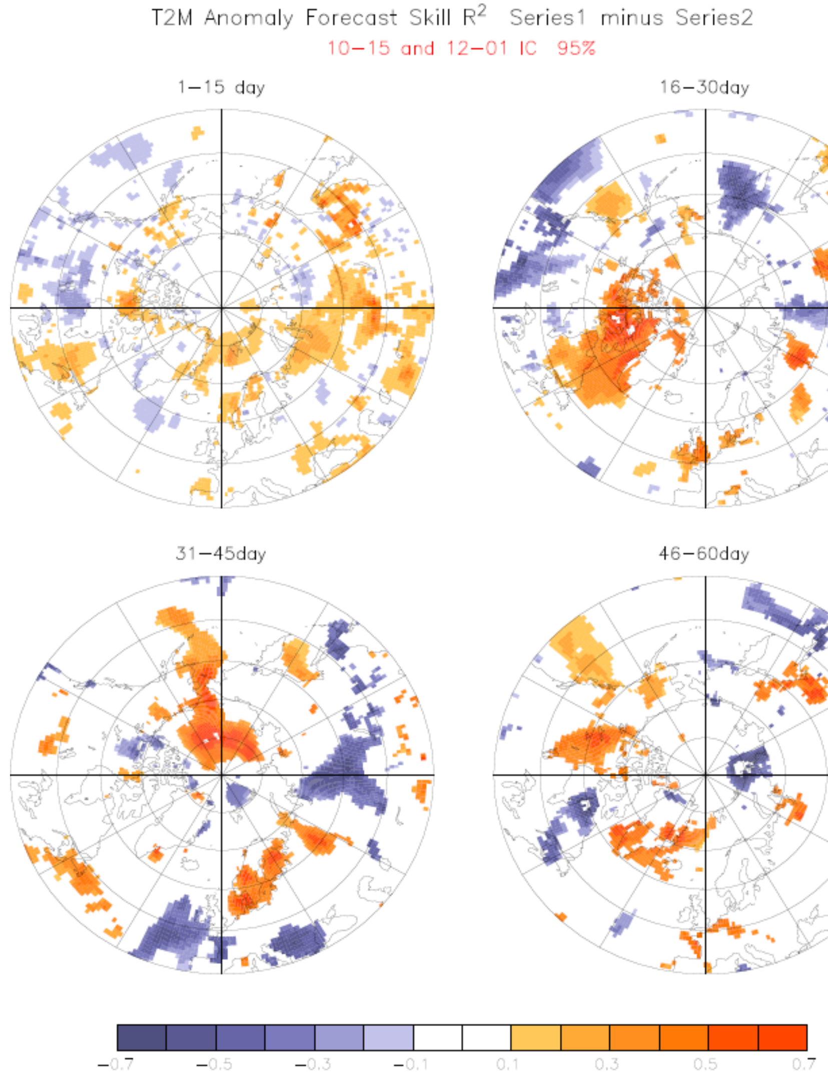
Difference : S1- S2 (30-day lead)

Warm Arctic-Cold Eurasia pattern

(analogous to sea-ice impact)

Forecast skill increment vs. lead time

T2m



- **Initial (0 lead) weak positive difference over snow-covered land**
- **Very large (~0.7) over Arctic at 30-day lead**

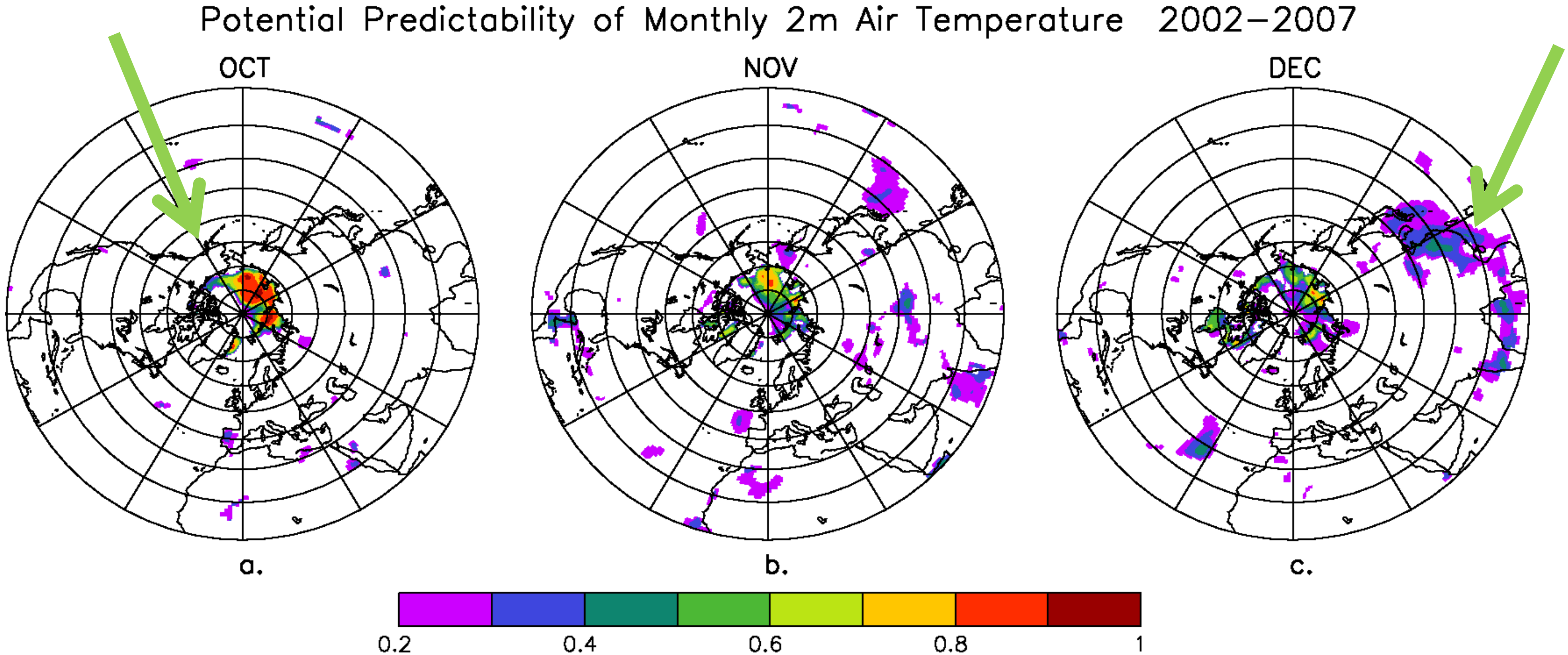
Note: GLACE2 →soil moisture skill increment ~0.2-0.3] (Koster et al, 2006]

- **Teleconnection influence : 30-day lag consistent with remote forcing through planetary wave propagation (Fletcher et al., 2008; Cohen 2007)**

Note: downward stratospheric influence comes into play after 2 months (cannot be seen in our 2-month forecasts)

Potential predictability in T_{2m}

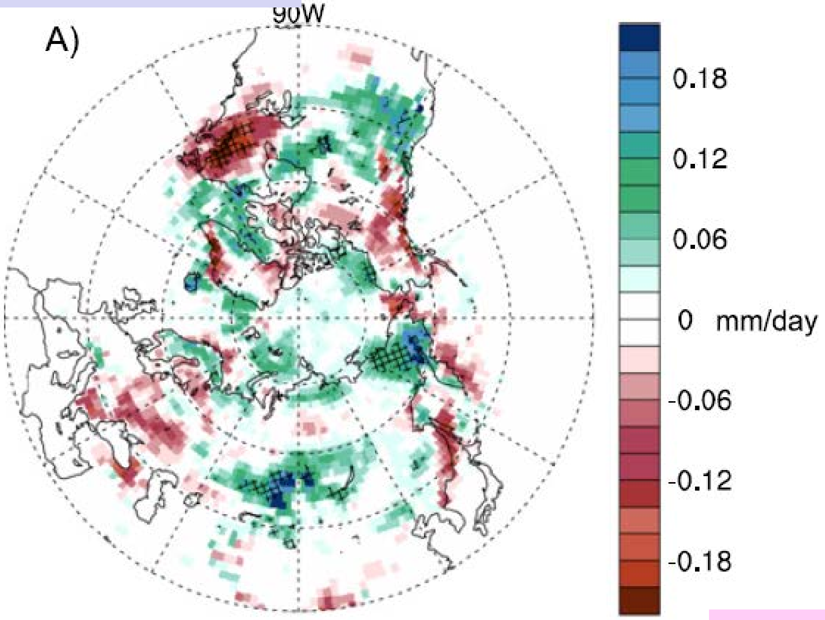
- **High values, close to 1, over the Arctic: strong local influence of sea ice**
- **Enhanced values (0.4) over Pacific coast of Asia in DEC**
  - **Strongest remote influence of sea ice**
  - **Cooler T_{2m}(1-2 K) related to cold air advection, consistent with SLP anomalies**
  - **Similar calculation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



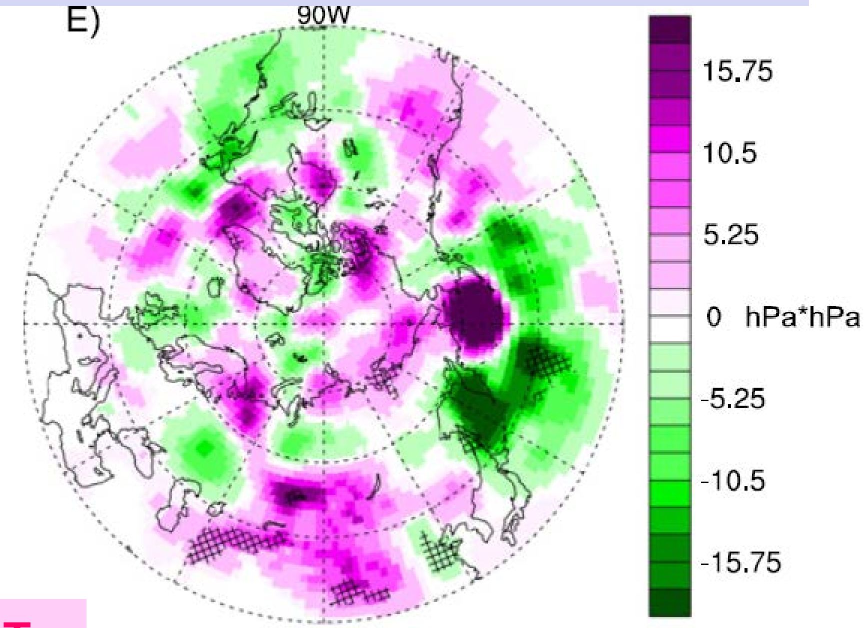
Arctic moisture source for Eurasian snow cover variations in autumn (Env. Res. Lett. - May 2015)

Martin Wegmann[1], Yvan Orsolini[2], Marta Vázquez[3], Luis Gimeno[3], Raquel Nieto[3], Olga Bulygina[4], Ralf Jaiser[5], Dörthe Handorf[5], Annette Rinke[5], Klaus Dethloff[5], Alexander Sterin[4] and Stefan Brönnimann[1]

Snow depth



Storm track activity (SLP variance)



ERAINT

September Barents-Kara Sea ice

Composite difference

Low – High Sea ice

November

Low Sea Ice Barents-Kara sea correspond to :

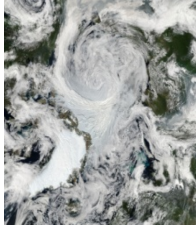
→ Enhanced snow depth over Southwestern Siberia (supported by in-situ Russian data)

→ «Corridor» of enhanced storm track activity

→ Source of moisture is ice-free Barents-Kara sea (lagrangian trajectories)

Summertime Arctic circulation and storm track

AUG 2012



Summer months with high sea ice melt rates (HMR) have

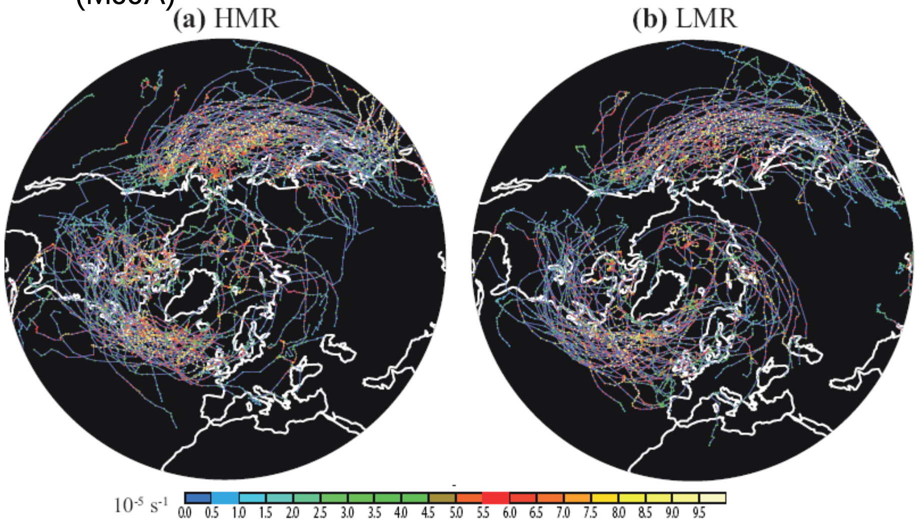
- ☐ fewer storms, less precipitation and snowfall over the Arctic.
- ☐ Enhanced precipitation over northern Europe (Great Britain, Scandivania)

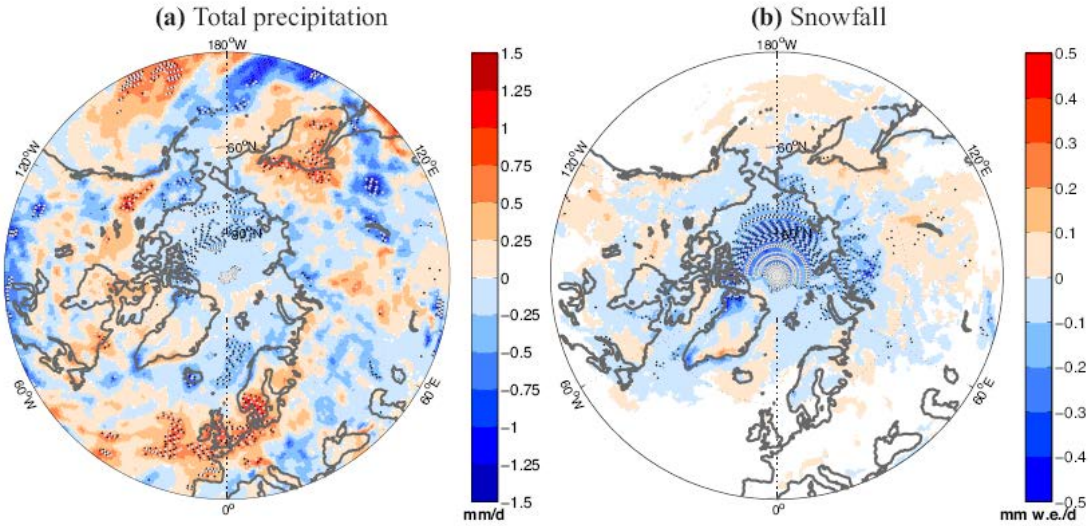
✓ *Previous work by Screen et al. (2011; 2013), Tang et al. (2013)*

➢ To investigate role of cryosphere in forecasts

Knudsen, E., Orsolini, Y.J., Furevik, T. and K. Hodges, Observed anomalous atmospheric patterns in summers of unusual Arctic sea ice melt, *J. Geophys. Res,*, 2015.

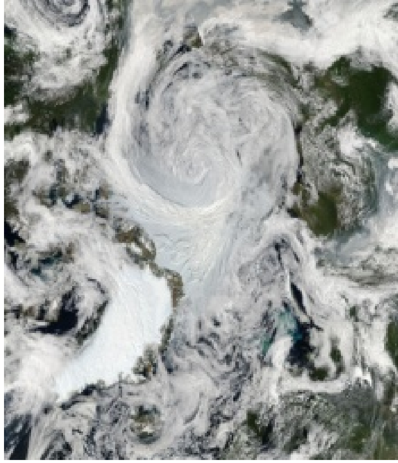
Paths of major summer storms in high and low sea-ice melt months (MJJA)



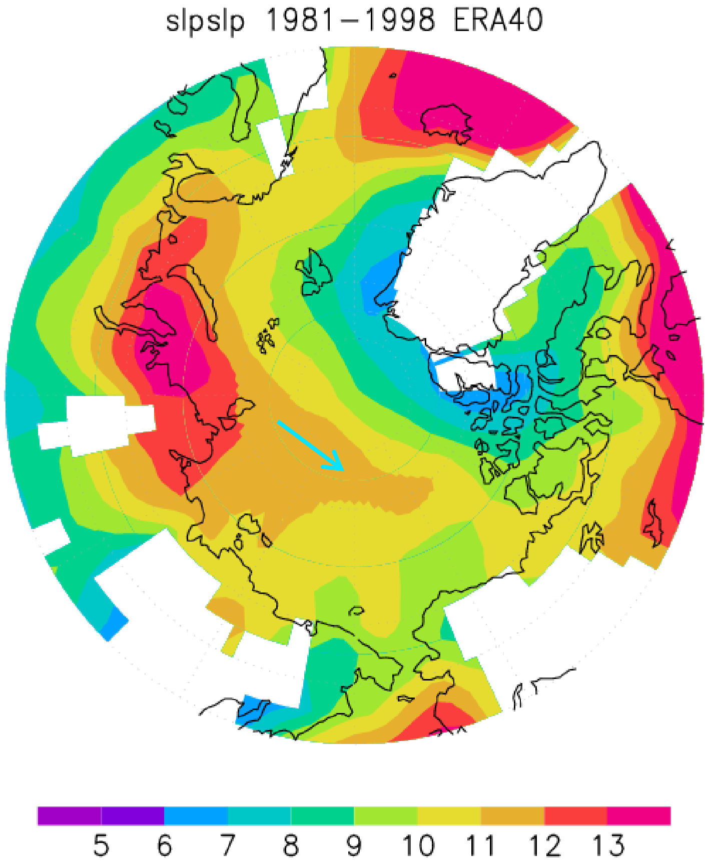


Anomalies of precipitation and snowfall (MJJA)

Summertime Arctic circulation and storm track



AUG 2012



Climatological Arctic summer storm track and Arctic Ocean Cyclone Maximum

Nishii, K., H. Nakamura, and Y.J. Orsolini (2014) Arctic summer storm track in CMIP3/5 climate models, Clim. Dyn.