Impact of Eurasian snow cover on the NH winter circulation

Yvan ORSOLINI

Norwegian Institute for Air Research, Kjeller (orsolini@nilu.no)

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

- albedo feedback (e.g on spring temperature)
- but hydrological and indirect dynamical feedbacks could be important too

➢At high latitudes, snow cover seasonal evolution is important for

- carbon cycle
- GHGs (methane) emissions
- Arctic river run-off

Brief Outline

- Linkage between snow cover and large-scale circulation patterns, focus on the winter

- Limitations in how models (AGCMs) represent these linkages

- Results from decadal simulations with prescribed snow cover from satellite obs., using Meteo-France Arpege model

- Perspective : new simulations planned in collaboration with ECMWF on impact of snow initialisation on forecast
(GLACE2 like)

Snow cover influences regional and global climate

- ***Snow cover may impact not only local conditions but also global circulation patterns***

- ***Snow cover itself depends on circulation patterns, hence weak indirect effects hard to detect***

(similar as for soil moisture local effects, see GLACE approach)

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

Snow cover influences regional and global climate

- Dedicated model experiments

Difficulties : length of simulations to assess skill or statistical significance, compared with relatively short record of satellite observations, need of control simulations

→sub-optimal experiment design

→ interpretation

- Strong interest in tapping on the memory effect of such surface conditions (SST, sea ice, snow cover) for improving atmospheric predictability from monthly to seasonal scales

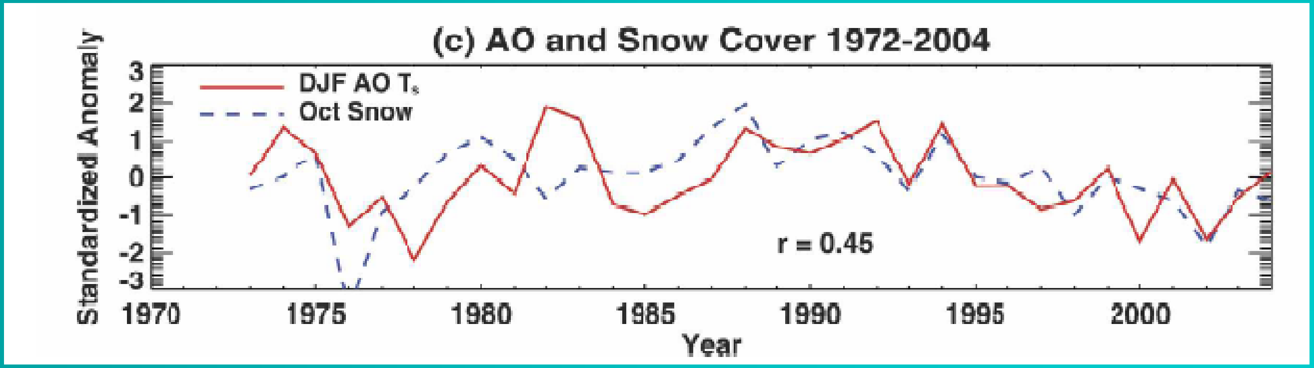
Eurasian snow cover impact upon atmospheric circulation patterns

- *Eurasian Spring snow cover influences the East-Asian Monsoon (Barnett et al. 1989, Douville and Royer, 1996)*

Linkage still being revisited !

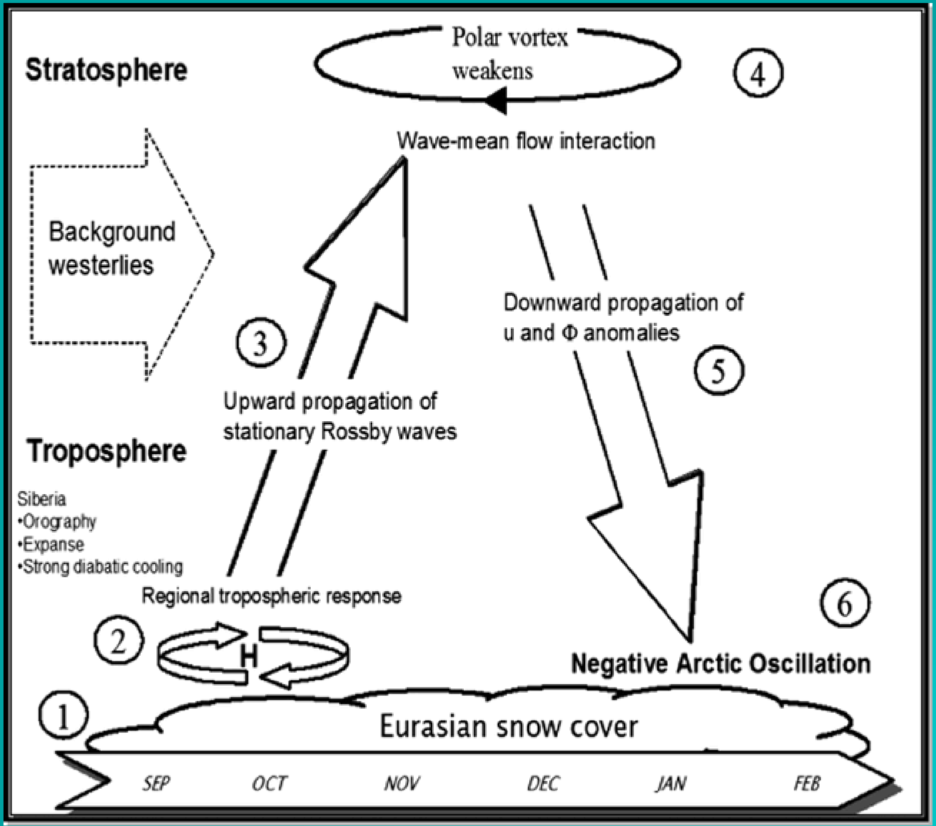
- *Eurasian snow cover influences wave trains propagating downstream over the North Pacific (Walsh and Ross, 1988; Yasunari, 1991; Clark and Serreze, 2000)*

- *Eurasian Autumn snow cover (Cohen, Saito , Fletcher, Kushner and Gong, 1999–2009) influences NAO in following winter*



Cohen and Fletcher, JClim 2007

Eurasian snow cover impact upon atmospheric circulation patterns



- **Snow Leading**
- **"stratospheric bridge" (hence not a shallow influence"**

(Cohen et al, JClim, 2007)

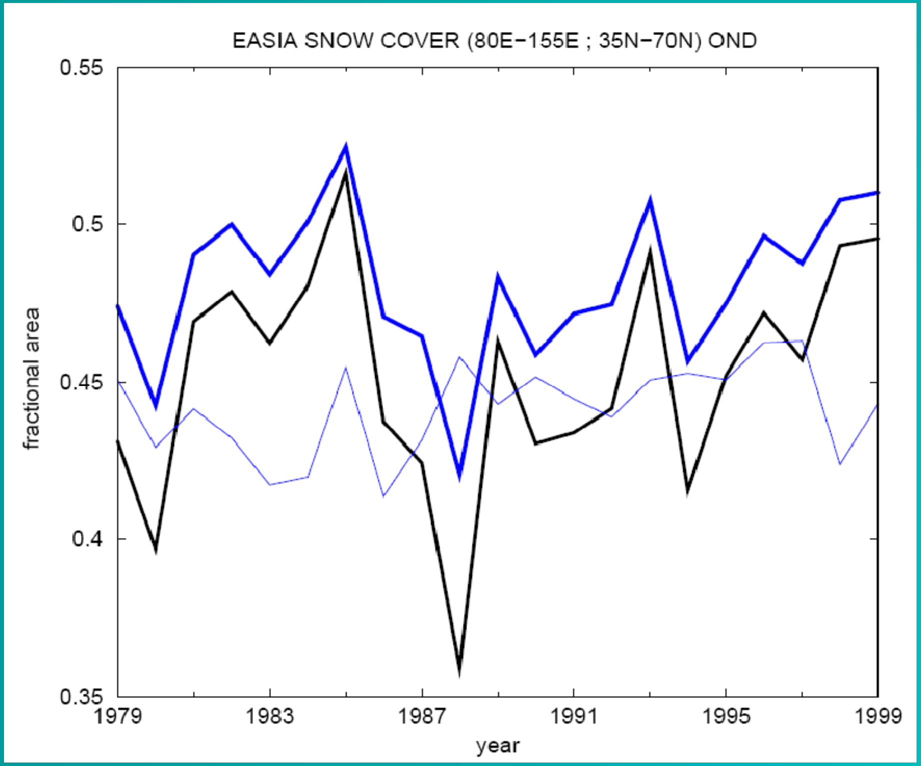
Extensive Eurasian snow cover in autumn **(SNOW+)**

NAO^{-} in winter

Snow cover in climate model simulations

- **GCMs tend to underestimate snow cover inter-annual variability, esp. in transition seasons**

Fractional snow cover



❑**Satellite-derived snow**

(NISDC data)

❑Meteo-France Arpege Model prognostic snow

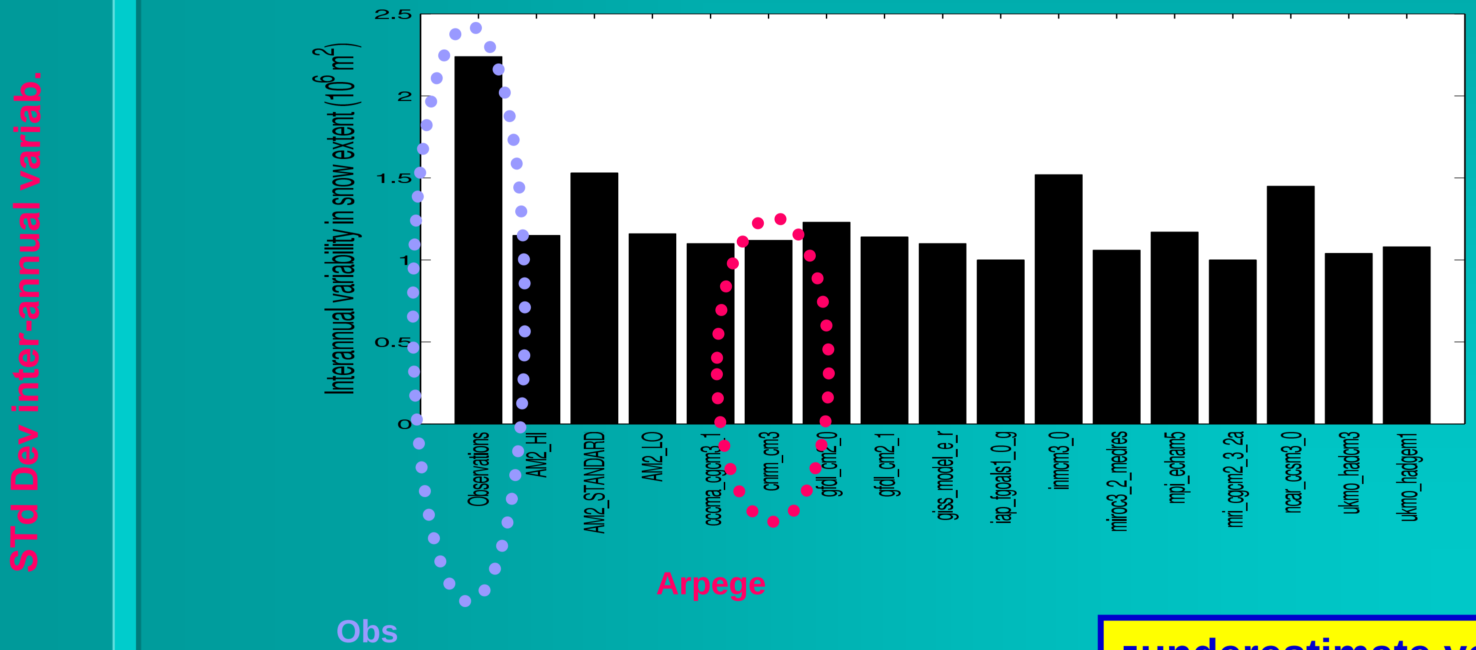
(thin blue)

nearly flat: not enough year-to-year variability

- **Autumn (OND)**
- **Eastern Eurasia (80E-155E ; 30N-70N)**

Snow cover in climate model simulations

- Hardiman et al. (JGR, 2008) examined why GCMs do not replicate the NAO/snow cover linkage, seen in observations. They found a series of reasons:



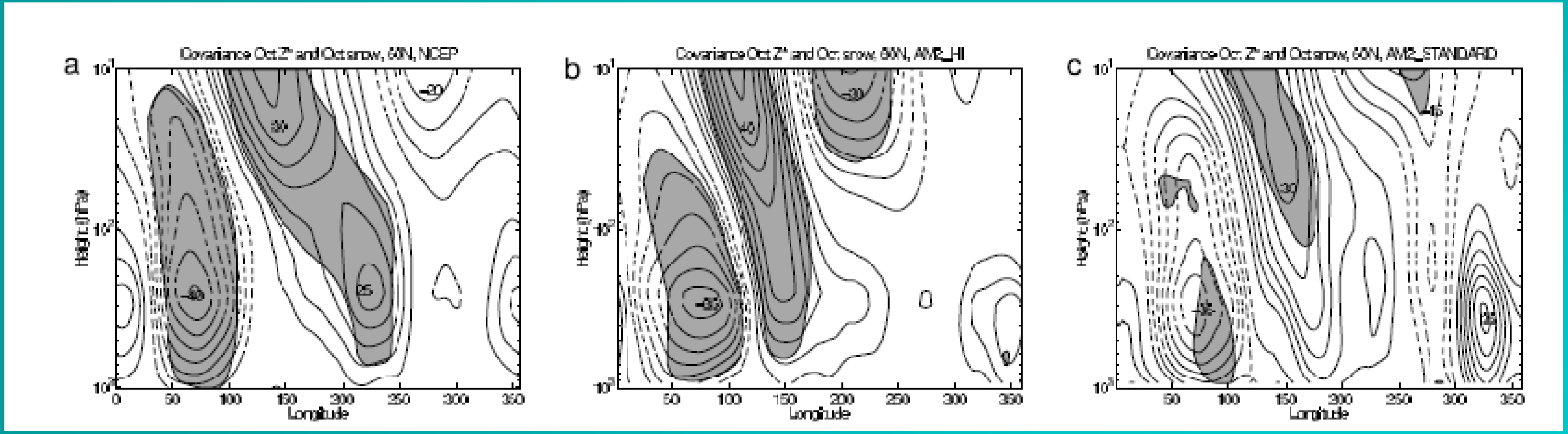
▪underestimate year-to-year variability in snow cover

Snow cover in climate model simulations

- Hardiman et al. (JGR, 2008) examined why GCMs do not replicate the NAO/snow cover linkage, seen in observations

60N geop

Longitude-Height Regression on October snow index



Obs

GFDL models

- **Model response more zonally confined→ detrimental to upward vertical propagation**

Prescribing Snow in climate model simulations

- **Can realistic, prescribed snow conditions lead to better modelled climate variability ?**

- **Several studies used prescribed or nudged snow cover or depth (Kumar and Fang, 2003, Schloesser and Mocko, 2003; Cohen et al.)**

- **Previous ”nudged” GCM seasonal simulations relied on modelling few, extreme years with exceptional snow conditions**

- **No decadal-scale simulations with realistic, observed snow cover extent, constrained by satellite observations**

(albeit, some decadal runs with prescribed snow cover from in-situ data)

→ **We have done new, dedicated simulations spanning two decades with prescribed snow cover from satellite observations**

GCM simulations with the ARPEGE Climat V3.0 model

- **Developed at METEO-FRANCE**

(Deque et al., 1994; Orsolini, Deque and Cariolle, 1995)

- **Land-surface scheme, physically-based snow hydrology model (ISBA)**

(*Douville et al., 1995)*

- **Observed SSTs, sea-ice (Reynolds dataset)**
- **21-year run (1979-2000)**
- **Ensemble approach (5 members)**
- **Resolution : T63, 31 levels**

GCM simulations with the ARPEGE Climat 3.0 model

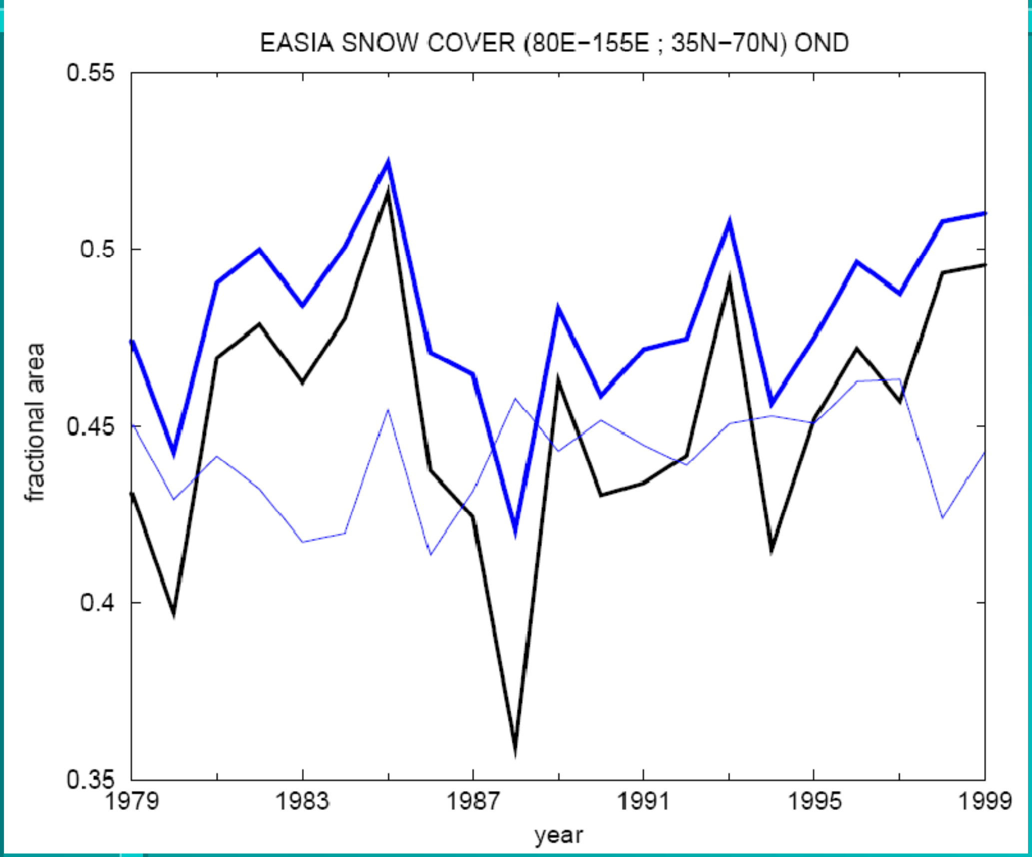
- We have a prescribed snow and a prognostic snow (control) simulations

(Note, I use the word prescribed. Approach is not truly nudging, neither data assimilation, but is akin to data insertion)

- <u>PRESCRIBED SNOW COVER simulation (SNS)</u>
  - Global, observed snow cover prescribed (over-written) onto model
  - Observations : NISDC EASE 25-km gridded weekly dataset based on visible/IR satellite imagery from NOAA

- <u>PROGNOSTIC SNOW COVER simulation (PCL)</u>
  - Freely-evolving

Prescribed snow cover



Snow cover variability is enhanced in SNS simulation

- ❑**Satellite-derived snow**
- ❑Model prognostic snow

(PCL, thin blue)

- ❑**Model prescribed snow**

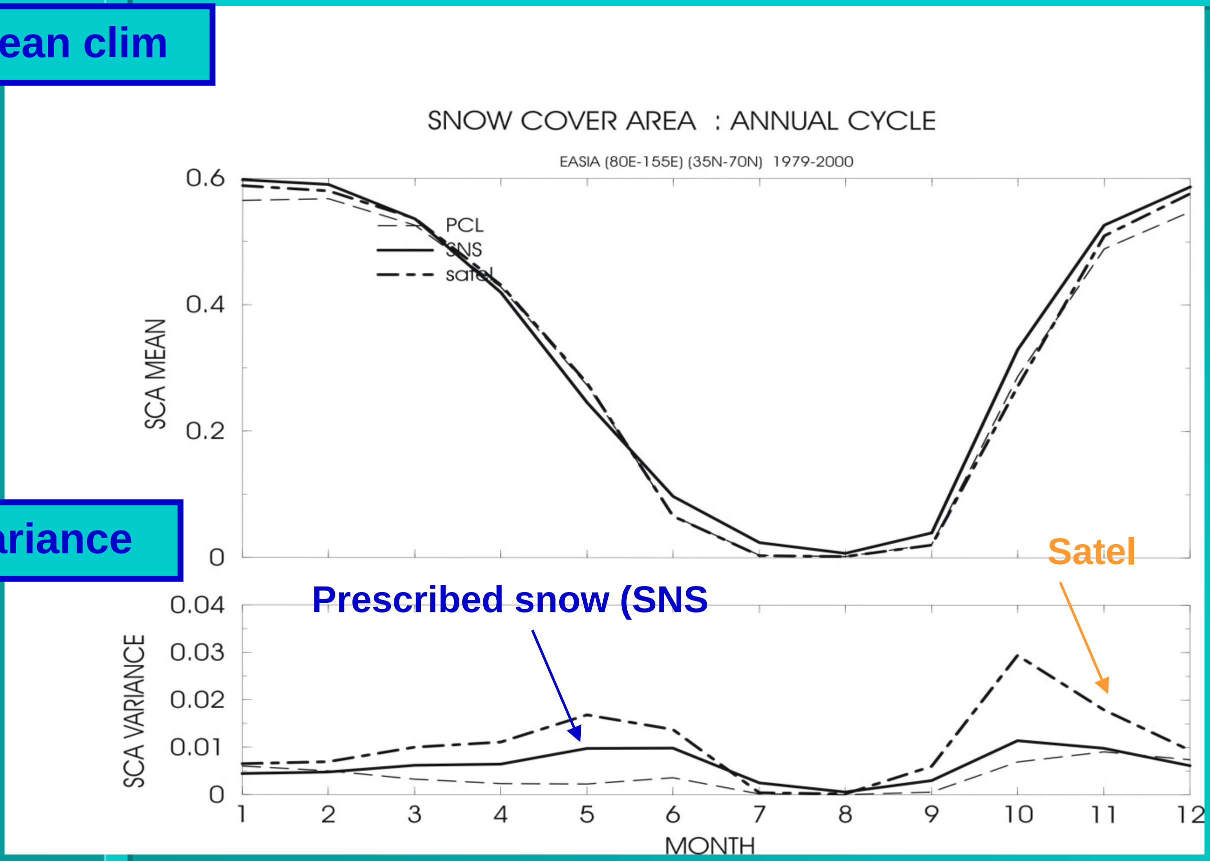
(SNS, thick blue)

- **Improved variability, closer to observations**
- **but slightly amplified in the mean, and not reproducing the years with smallest snow cover**

December

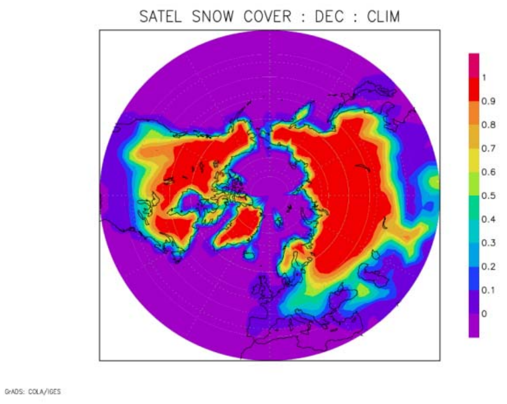
Snow cover annual cycle over Eastern Eurasia

mean clim

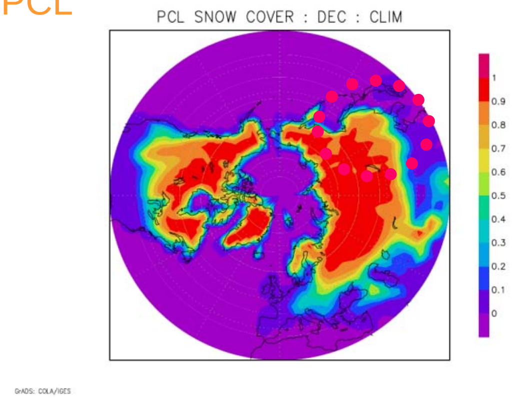


variance

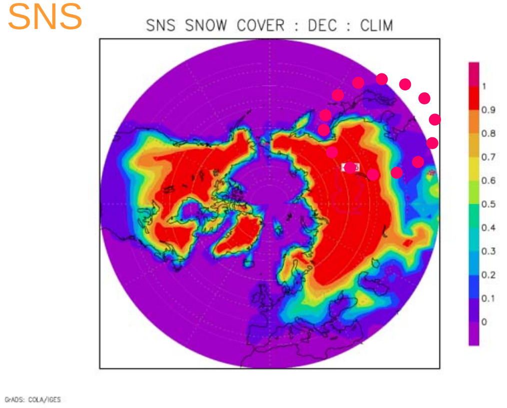
Satel



PCL



SNS



Prescribed snow (SNS): full lines
Prognostic snow (PCL): dash
Satellite (Satel) : dot-dash

Potential impact on teleconnection : the Aleutian-Icelandic Low seesaw (AIS)

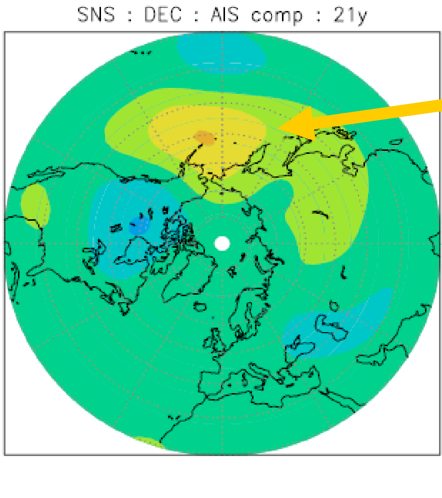
- **Our underlying hypothesis is that snow cover anomalies over Eastern Eurasia (esp. in autumn-early winter) influence the North Pacific sector, and the Aleutian Low**
- **There is recent evidence that climate variations over the North Pacific and Atlantic sectors are coupled in late winter, through an Aleutian (AL)-Icelandic (IL) Low Seesaw and.** **Honda et al., J Clim 2001**
- **Hence Eurasian snow cover variability, in addtition to ENSO (which is important forcing to the AIS, see Nakamura and Honda, 2002; Orsolini et al., JMSJ, 2004), could influence the Euro-Atlantic sector through the AIS in late winter**

Extensive Eurasian snow cover in autumn **(SNOW+)** → **Aleutian Low** (deeper)

The AIS lifecycle

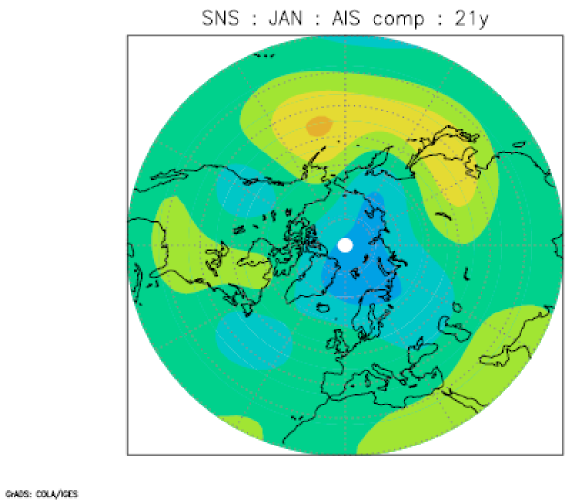
ENSO + Snow ?

DEC



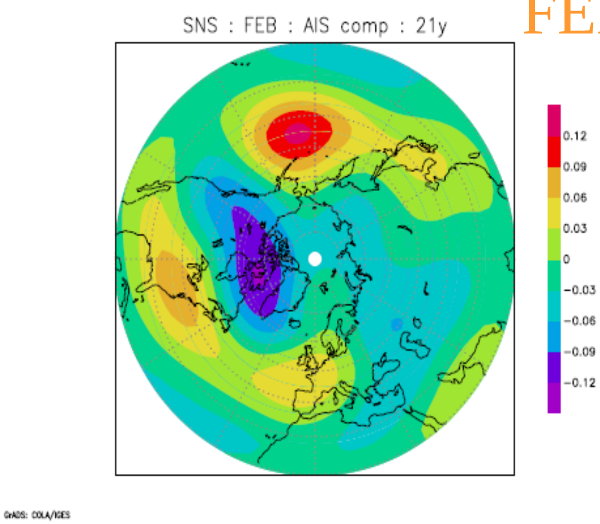
FEB

JAN



- ❑Anticyclonic anomalies over North Pacific in AIS+
- ❑Opposite anomalies over North Atlantic

FEB



- ❑Aleutian Low Index AL (based on SLP)
- ❑Icelandic Low Index IL (based on SLP)

→ AIS index (AL-IL)

Difference of composite of (high AIS index – low AIS index), based on February

SNS run

geop 250mb

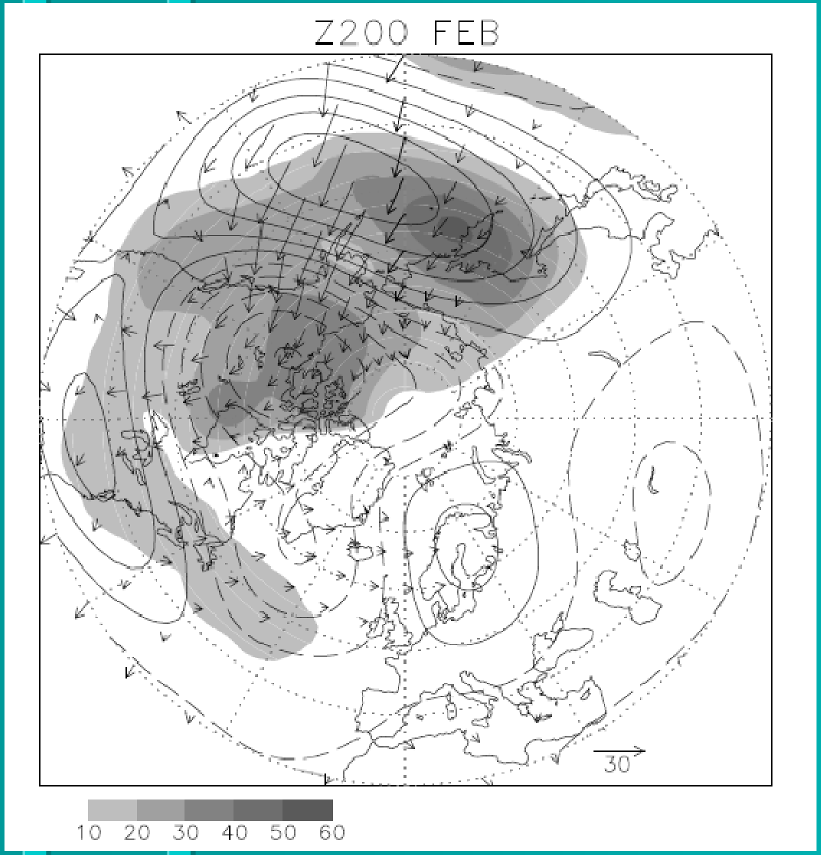
The AIS stratospheric connection

(Orsolini et al., JMS Japan, 2008)

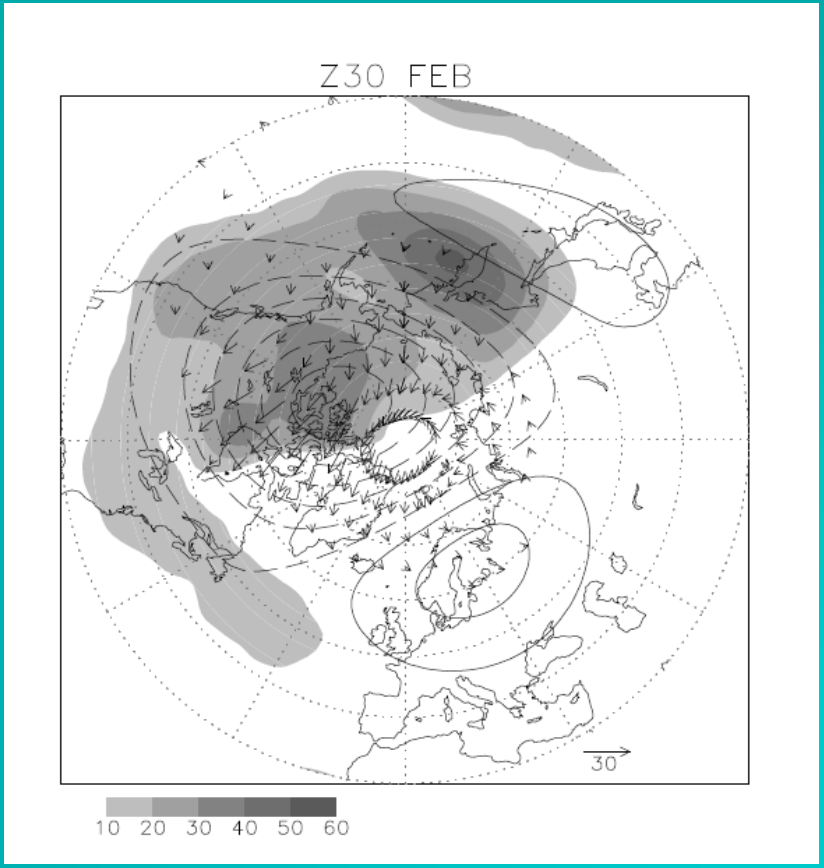
Difference of composite of (high AIS index – low AIS index)

AIS+ : weaker AL, less PW-1, stronger polar vortex

Geop 200mb



Geop 30mb

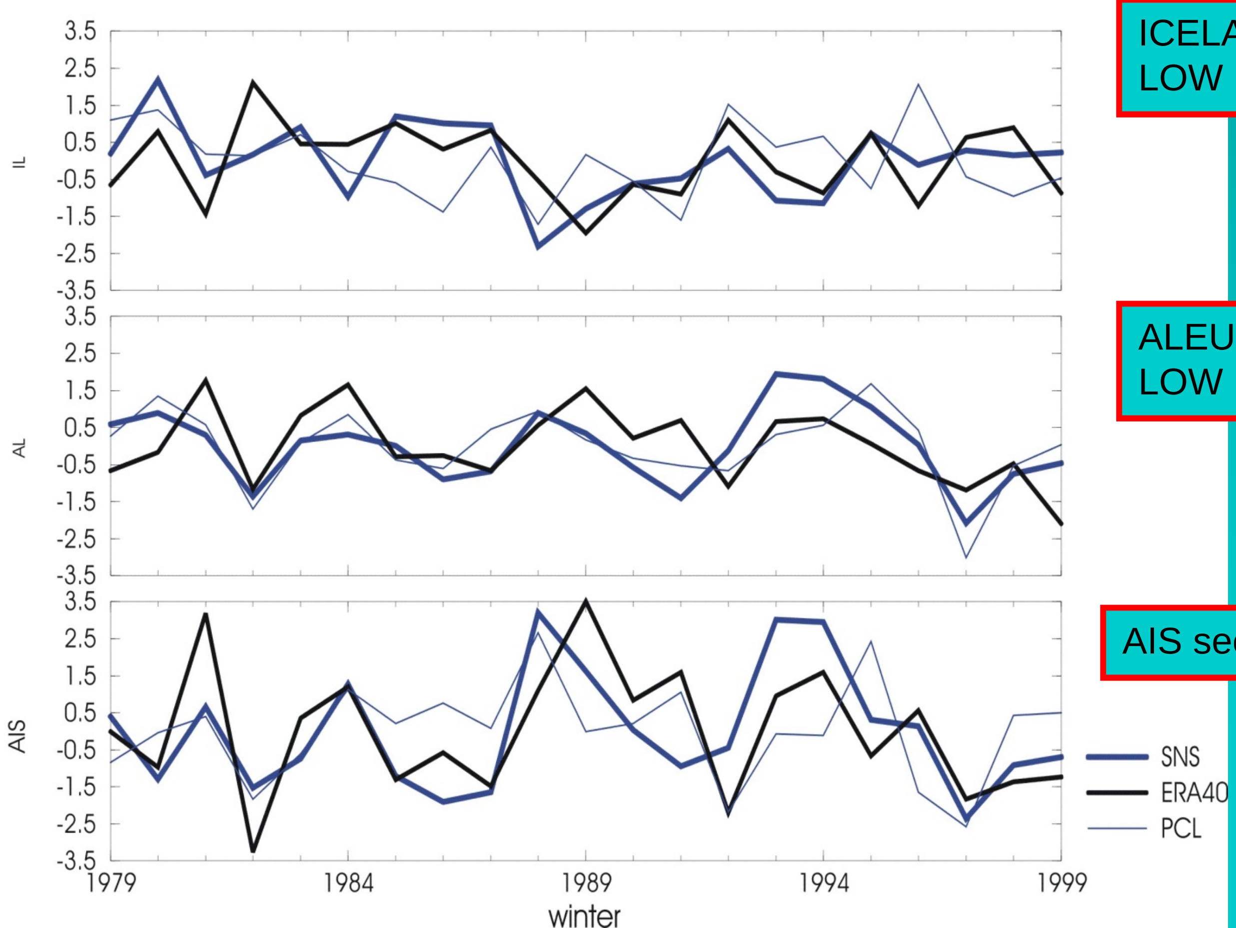


FEB

Hindcast of Aleutian Low, Icelandic Low and AIS for late winter

OBS (ERA-40)
SNS (thick)

PCL (thin)



ICELANDIC LOW

ALEUTIAN LOW

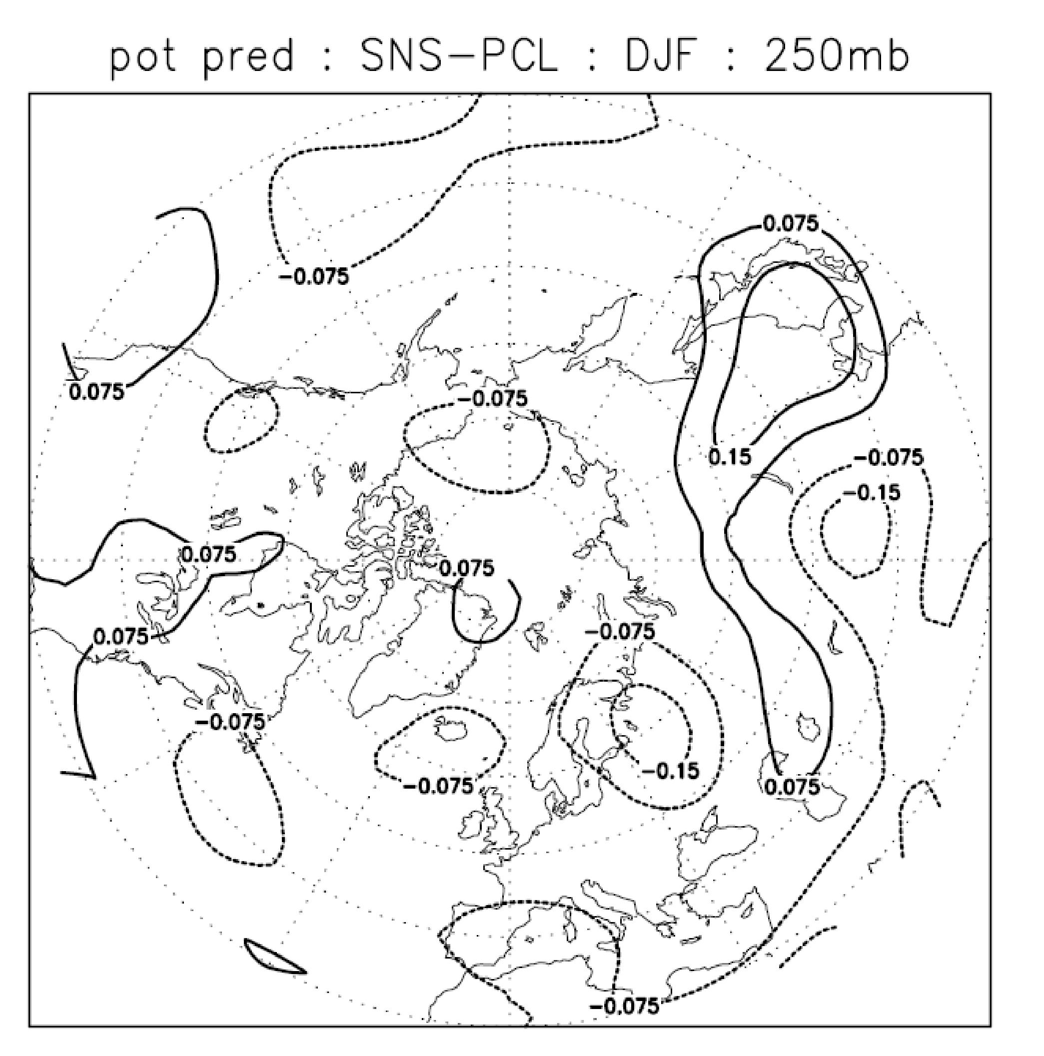
AIS seesaw

- **AIS is in better agreement with observations in SNS than PCL**

- **Skill score of hindcast of the AIS**

Cor: 0.66 vs 0.38

Potential predictability increment



ratio of external variance to total (internal + external) variance

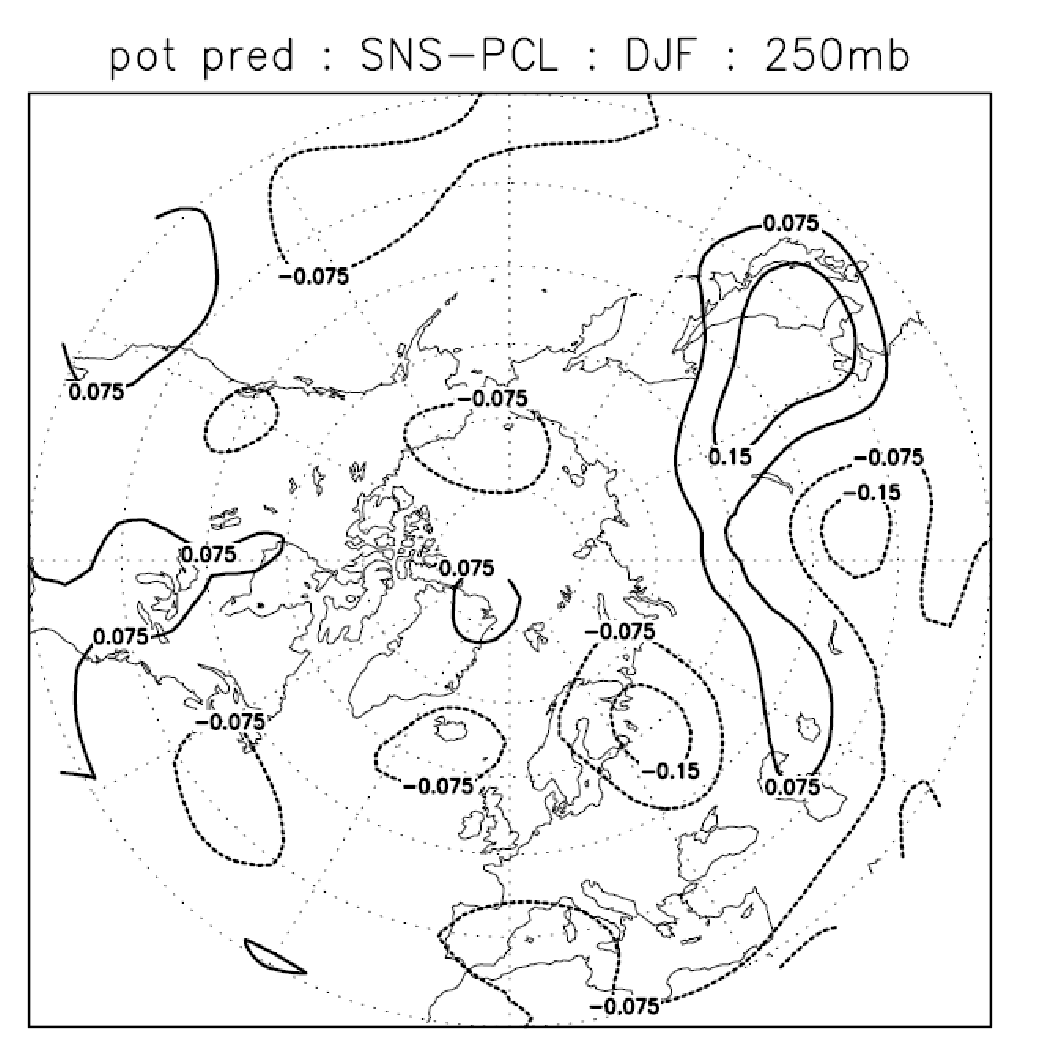
Tropical Pacific lead source of pot predictability

- **difference in potential predictability in DJF**

  (prescribed snow – prognostic snow)

  15% “gain” over Far East : more year-to-year variability in the ensemble-mean

Parallel with GLACE runs for soil moisture



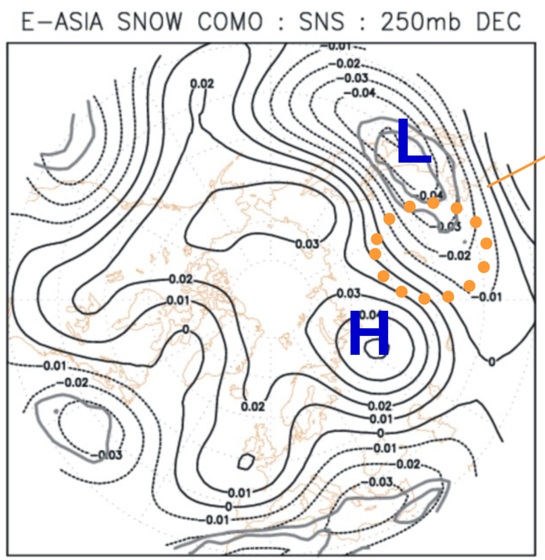
Koster et al. (2004; 2006)

15% "gain" over Far East : same order of magnitude as for soil moisture (local) impact (on temperature) (in summer)

In GLACE terminology

Realistic vs not realistic initial snow condtions

Snow cover composites



Surface cooling (1.5-2K)

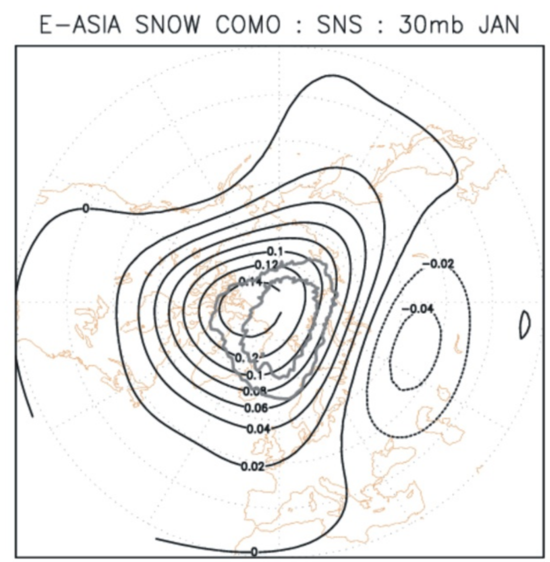
- Construct an "Eastern Eurasia snow index"
- Composite difference of geop for high minus low snow index

But weakly significant

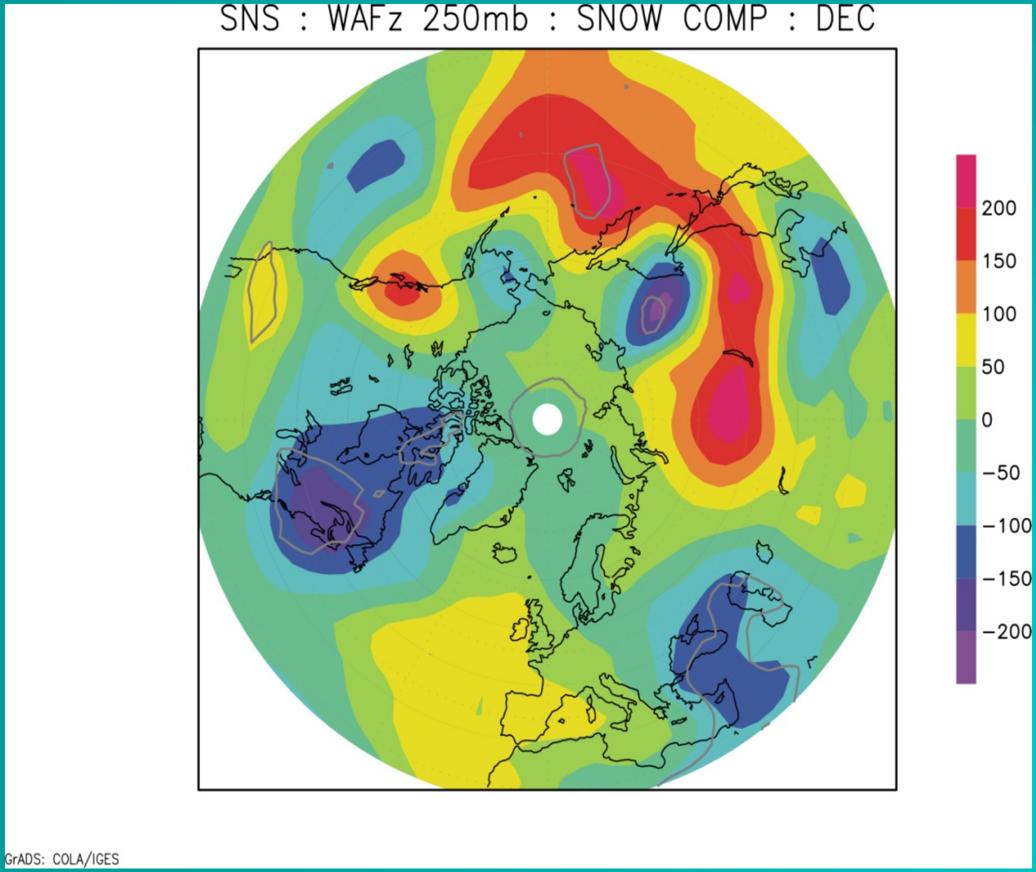
Wave-train over Eurasia/Pacific (also Fletcher et al, 2009)

Upper troposphere 250mb DEC

Stratosphere 30mb JAN



Wave activity flux (upward)



- Snow index composite difference of WAFz

→ high snow cover, deepening trough over Far East, more upward flux into stratosphere

- Eurasian snow cover modulates WAF over North Pacific region

250mb
DEC

Conclusions

Prescribing snow cover into a 20-year model run has allowed

- a gain in potential predictability over Eastern Asia of 15%, at 250mb (geop)

- a much improved hindcast of Aleutian-Icelandic Low Seesaw in late-winter, compared to earlier studies.

Conclusions

- The study leads credence to earlier model and observational studies linking anomalous Eurasian snow cover to wave trains over the North Pacific.

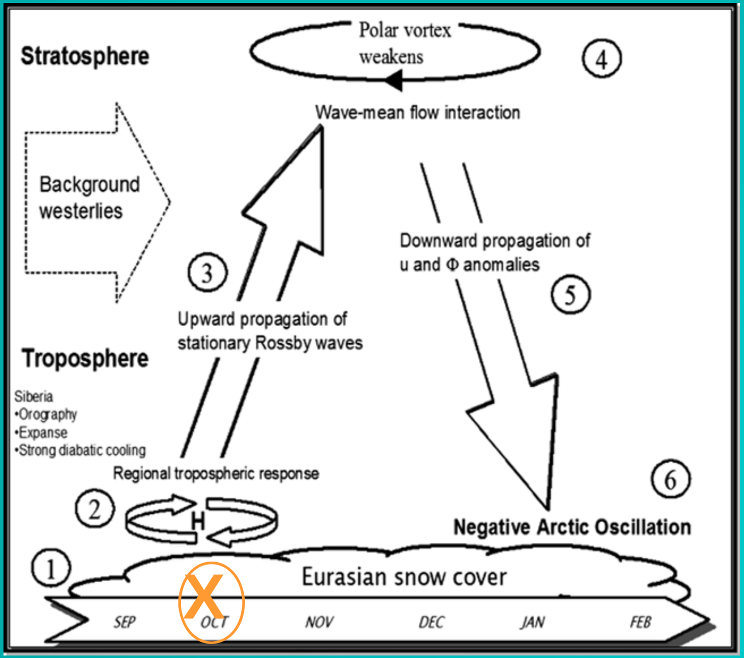
- Through late-winter influence on the Icelandic Low, our model results partly confirm those of Cohen et al. linking Eurasian autumn snow cover and negative NAO in following winter

Orsolini, Y. J., and N. Kvamstø, The role of the Eurasian snow cover upon the wintertime circulation: decadal simulations forced with satellite observations, J. Geophys. Res.,114, D19108, doi:10.1029/2009JD012253, 2009.

Conclusions

Caveat:

- **we emphasized that both horizontal propagation through AIS is important and in fact, consistent in phase, with stratospheric pathway.**
- **And we have not found a significant NAO link in our simulations (only IL, not Azores High?)**



New directions

Inspired by GLACE2, we now started to perform new experiments jointly with ECMWF

Balsamo G, Orsolini Y, Doblas-Reyes P

- ***Assess the role of autumn Eurasian snow cover/depth on seasonal forecast***
- ***Identify local "hot spots" (or "cool spots" ?) of coupling between snow cover and e.g. temperature***
- ***Identify teleconnection patterns linked to Eurasian snow cover***

New snow-dedicated simulations with ECMWF IFS

- *Either coupled AOGCM ensemble forecast system (V4), or with prescribed SST*
- *land surface module is HTESSEL, with improved snow scheme*

at first a few recent years after 2004, perhaps extended to 10 years later (2001-2010)

12-member ensemble

forecast length : 2-month

4 Start dates : OCT 15, NOV 1, NOV 15, DEC 1

resolution T255L62 (same horizontal resolution as ERAINT)

SERIES-1 with realistic snow initialisation

SERIES-2 with identical initialisation but for snow which is deterministically scrambled

Build a set of forecasts

	OCT 15	NOV 1	NOV 15	DEC 1	DEC 15
2004	X				
2005					
2006					
2007					
2008					
2009					

land surface : ERAINT

atmosphere/ocean : ERAINT atmospheric analyses and operational ocean analysis.

snow : ERAINT, with swapped years and dates for SERIES-2

The ERAINT snow analysis assimilates SYNOP depth and NOAA/NESDIS snow cover *(2004 onwards)*

Correlations

Correlations of the simulated AIS, IL and AL with ERA-40 as well as the ratio of the standard deviation of the model AIS to the standard deviation of the ERA-40 AIS, and the AL/IL anti-correlation, for the three simulations (SNS, CLI and PCL). The latter anti-correlation for the same period, based on ERA-40, is –0.43.

	AIS	IL	AL	AISdev	AL/IL corr
SNS	0.65	0.48	0.44	0.94	-0.32
CLI	0.23	0.07	0.37	0.83	-0.23
PCL	0.38	-0.02	0.44	0.77	-0.01