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Seasonal Predictability over the Arctic Region – exploring the role of boundary conditions

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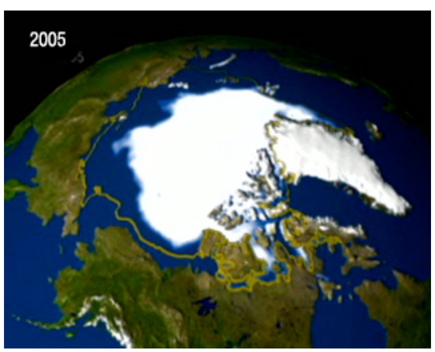
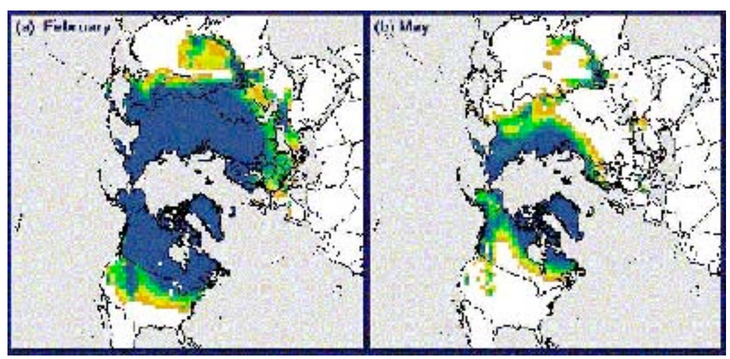
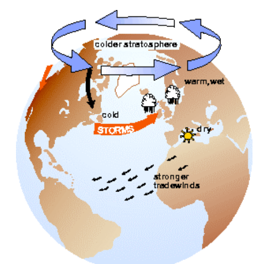
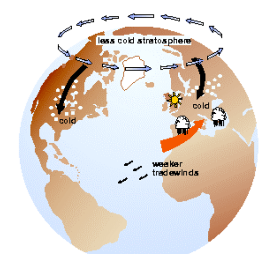
Variety of factors influencing Arctic seasonal predictability :

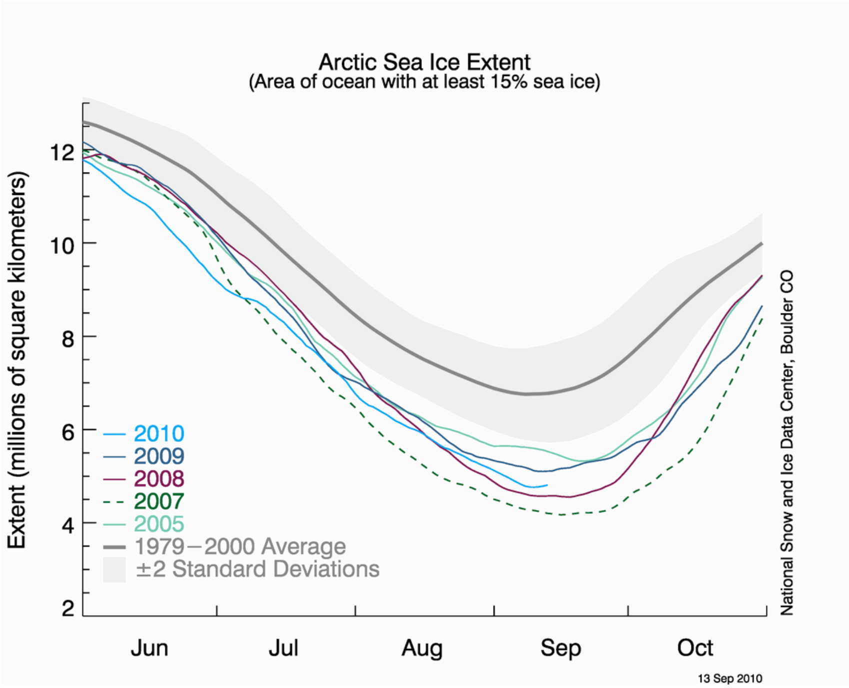
- ✓ Sea-ice
- ➢ Eurasian Snow cover
- ➢ Stratosphere







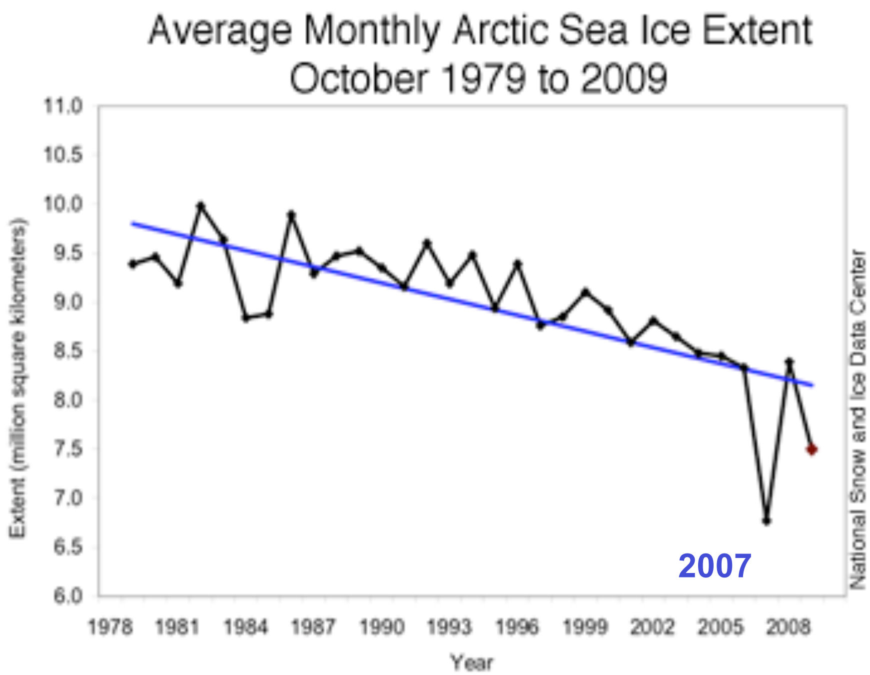


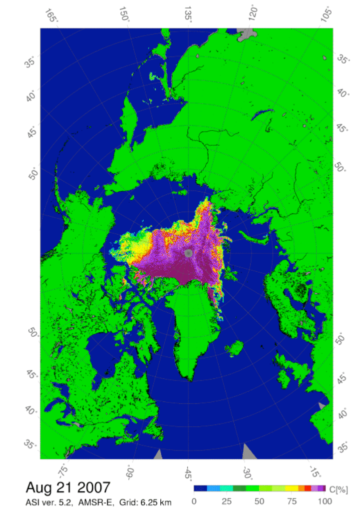


Arctic sea-ice extent

- Does the reduced sea-ice at end of summer impact the weather and climate in following autumn and early winter months ?
- Does this influence extend beyond boundaries of Arctic Ocean ?
- Prediction experiment

Record for minimum Arctic sea-ice extent is still 2007





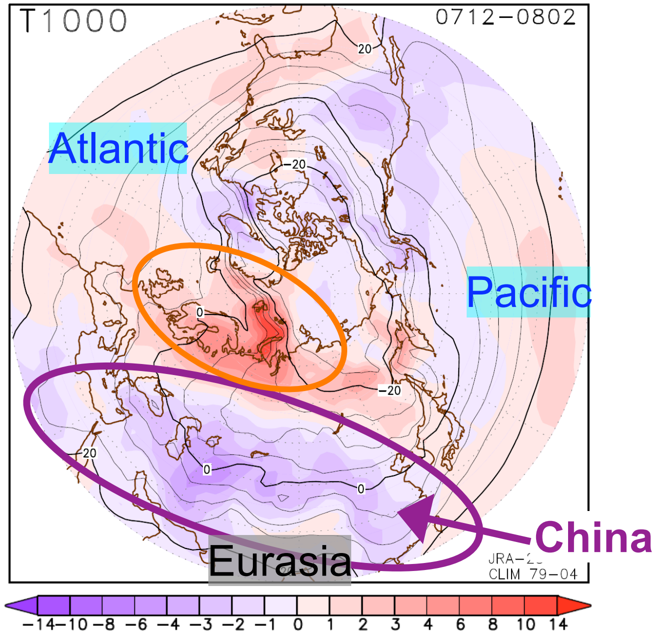
- Focus on year 2007, lowest summer extent
- Autumn is key period when ocean heat is released to the atmosphere

(Benestad, Senan, Balmaseda,Ferranti, Orsolini, Melsom, in press, Tellus, 2010 shows little influence beyond the Arctic in summer)

- High-resolution model to resolve regional aspects of the forcings
- Most of previous studies of sea-ice/climate coupling used coarse resolution climate models (and had winter focus) with the exception of Strey et al (JGR, 2010) who used high-resolution mesoscale (WRF) model on hemispheric scale

Motivation from observational studies

Surface Temp



~(DEC-JAN)

Anomalous cold winter in 2007/08 in Asia, with heavy snow over China

(from Honda et al., 2009)

- **Meiji Honda (GRL 2009) proposed a link between Arctic sea-ice reduction and cold Asian winter, through Rossby wave train triggered by anomalous heating over Eastern Arctic**

- **Observational study based on NCEP data by Francis et al. (GRL, 2009) : weakened jets, negative NAO (lasting 6 months) in winters following reduced summer sea-ice**

Seasonal (5-month) hindcasts for 2007

- Operational Seasonal forecast model from ECMWF
  - High horizontal resolution (T159;l62) coupled ocean-atmosphere model (IFS HOPE V3 – cy31r1)
  - State-of-the-art ensemble prediction system
  - Contains no dynamic sea-ice module
  - Sea ice realistically initialised from ocean analyses (SST -1.7 deg), but persisted for ~10 days, then relaxed to seasonal climatology
  - Adapted the model to use <u>presribed, observed sea-ice throughout the simulation</u>
  - Ensemble runs with <u>prescribed sea-ice</u> from 2007, and additional sensitivity ensembles with “erroneous” sea-ice from 6 previous years

Our Basic Experiment:

- 5-month hindcasts
- 5-member ensemble (perturbed SST)
- initialized on 2007-10-01 (atm, ocean, sea-ice)
- Prescribed, observed sea ice throughout the period (2007)

Sensitivity Experiment :

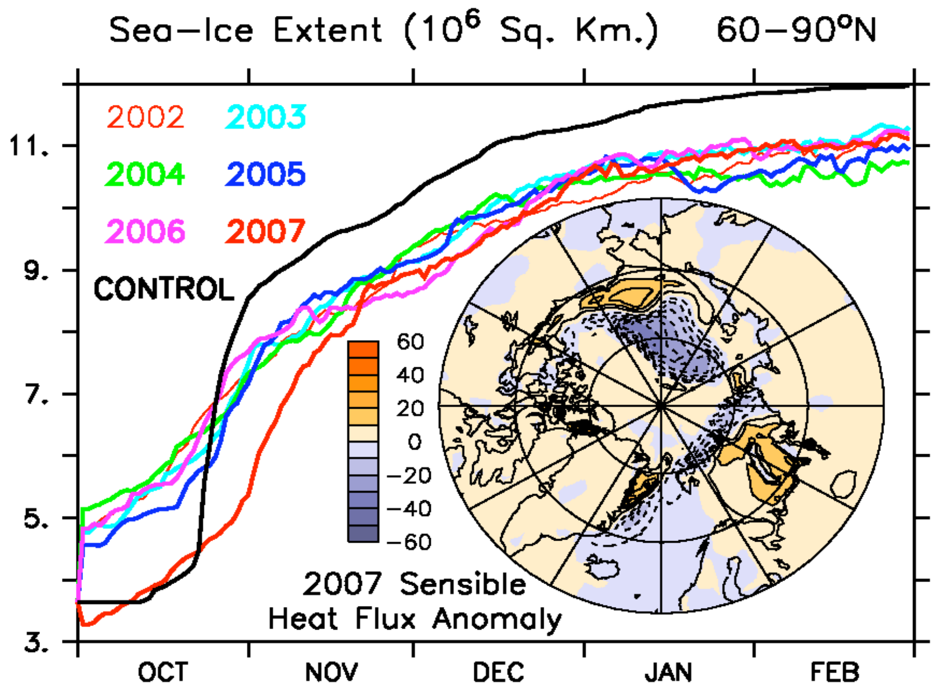
- (same)
- Prescribed "erroneous" sea ice from 2002 to 2006 (5 additional ensembles)

Grand ensemble of 30 hindcasts for OCT-FEB 2007, 5 of which had actual observed 2007 sea-ice

2007 anomalies : departures of the 2007 ensemble mean from the grand ensemble mean

Prescribed sea-ice extent: seasonal evolution

- **2007 stands out with negative anomaly (~40-day) in SIE**

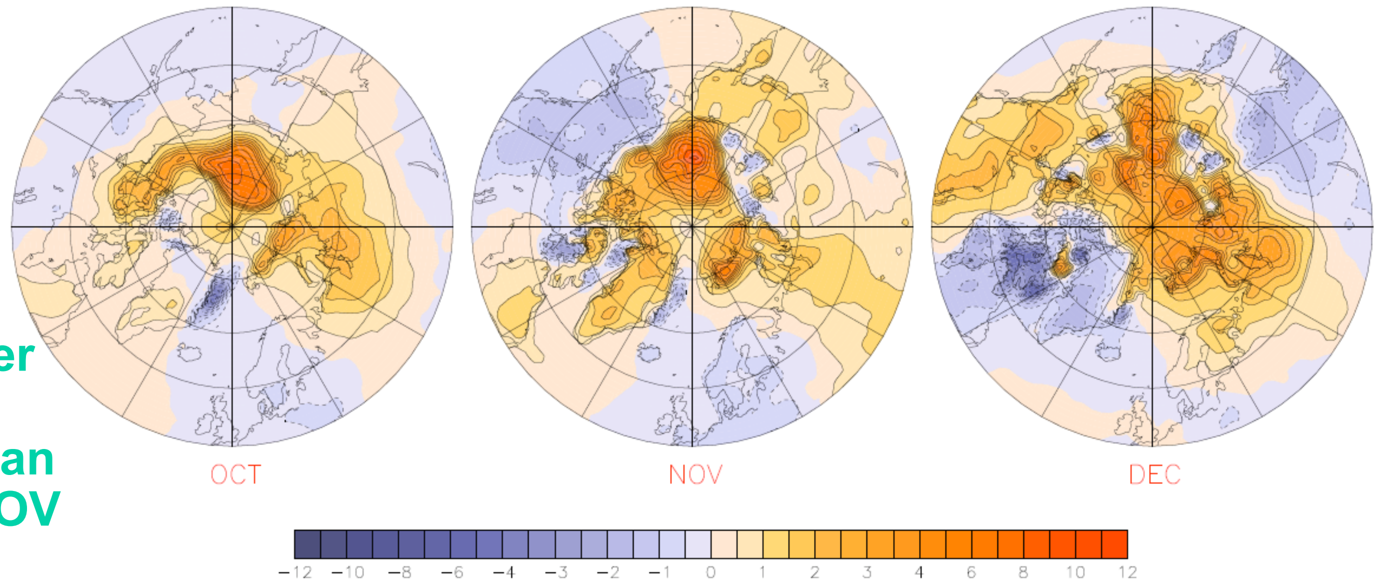


2007 anomalies in T_{2m}

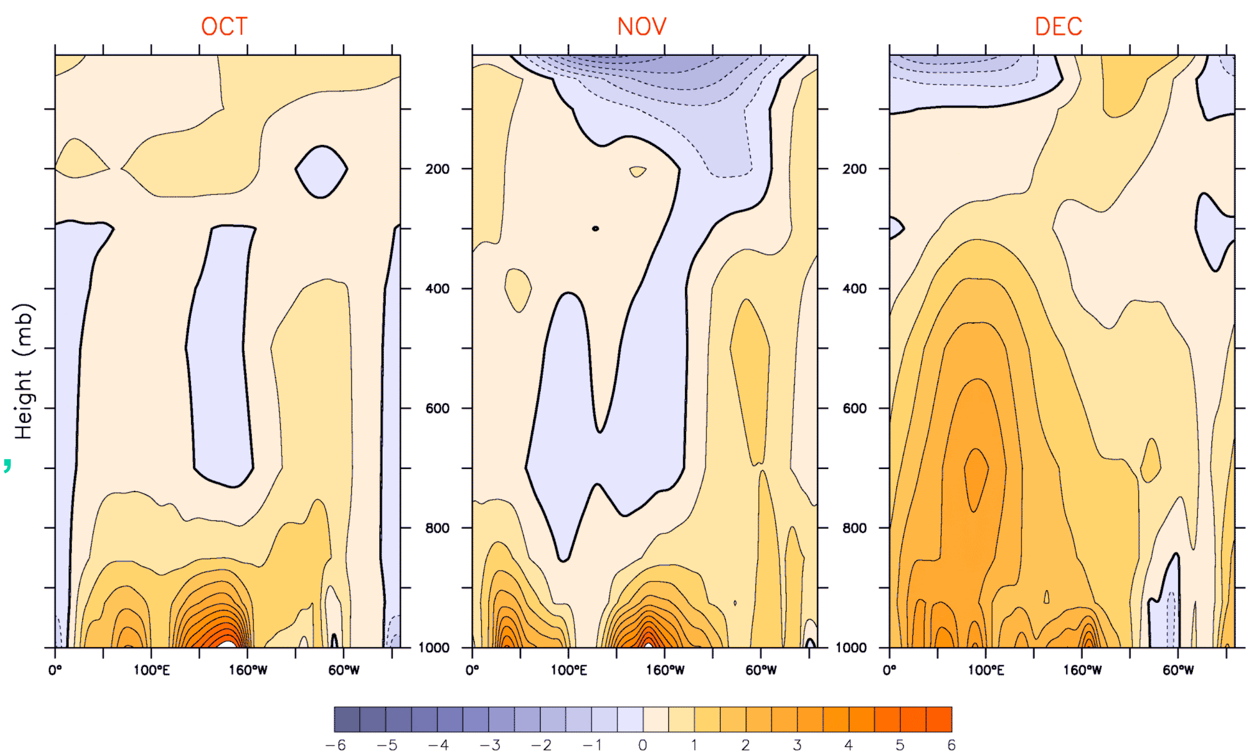
- **Warming of lower atmosphere over Pacific and Siberian sectors in OCT-NOV**

- **Magnitude (10K) of surface maximum in agreement with recent observational studies**
  (e.g. Serreze et al.,2009; Overland and Wang, 2010)

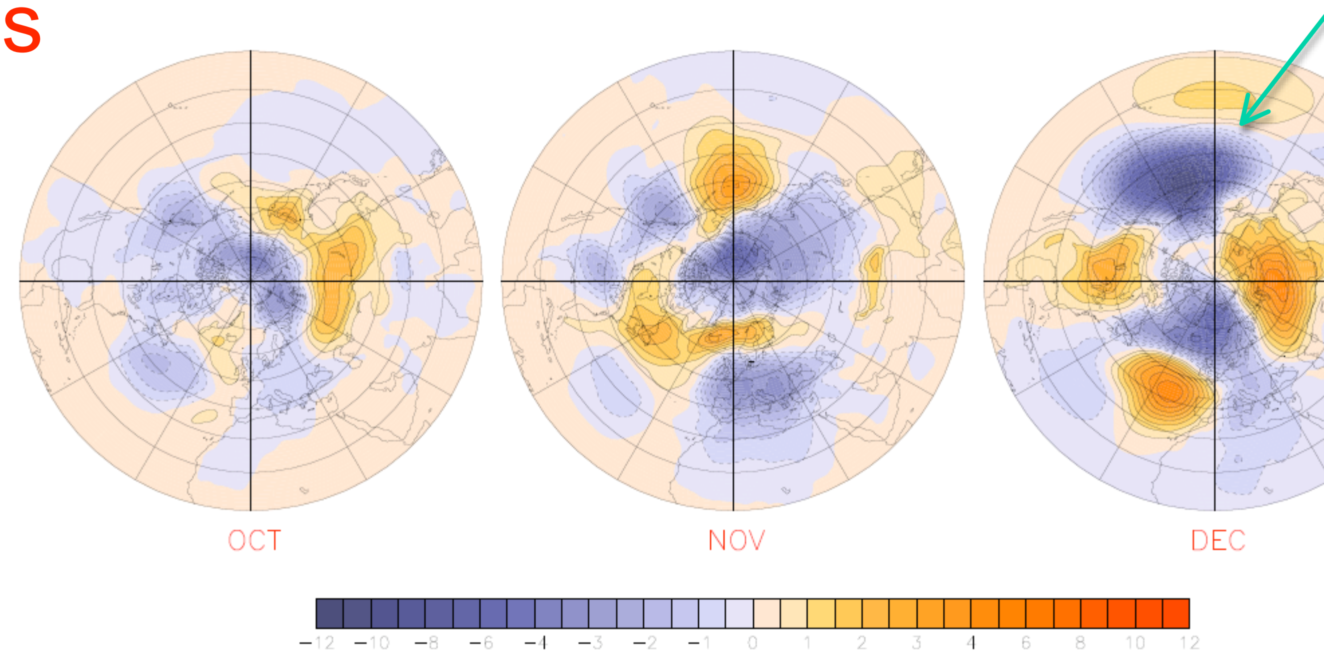
➢ **a regime change in DEC: spread Pan-Arctic and continental Eurasia, also deeper structure**



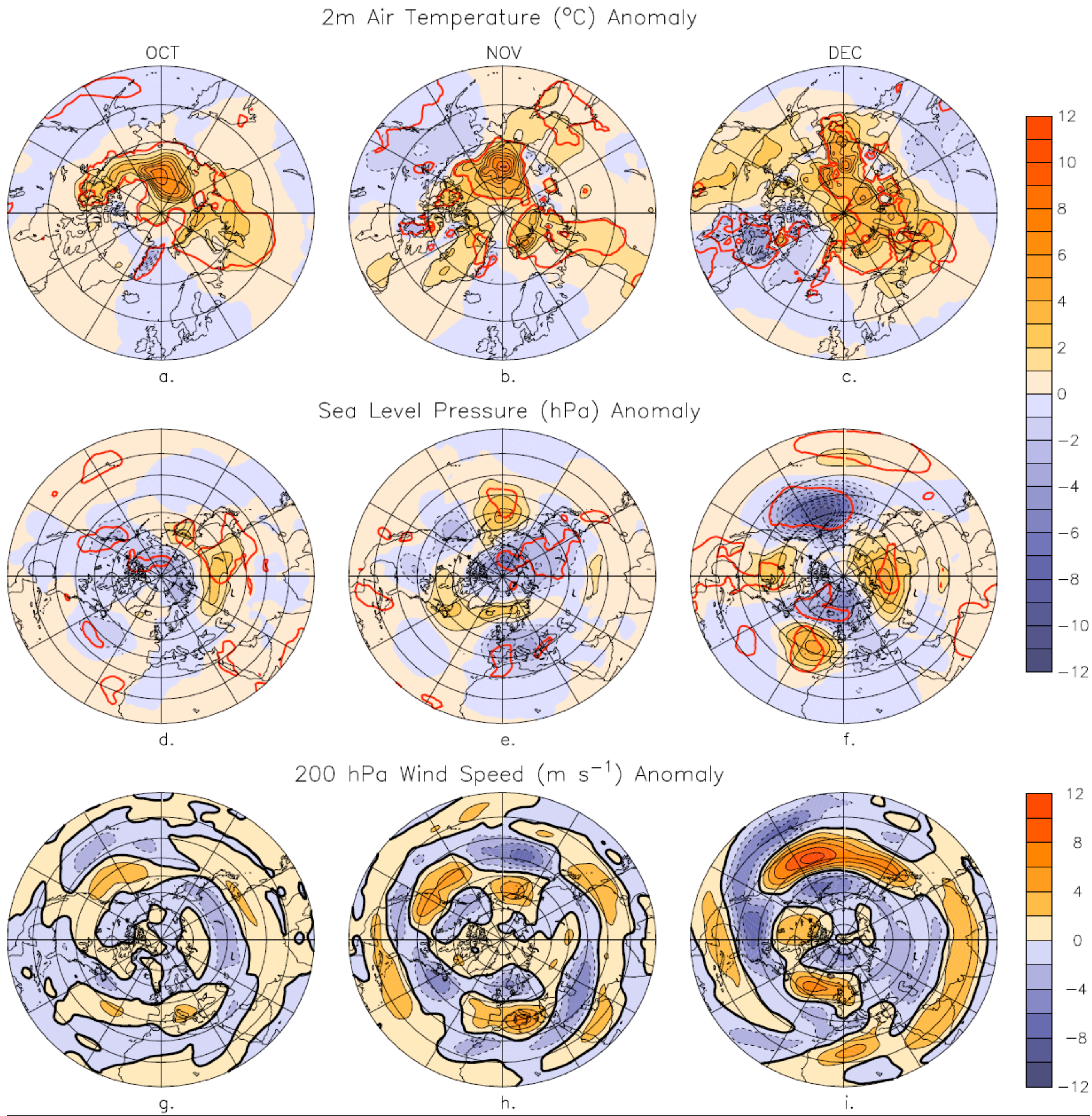
2007 2m Air Temperature (°C) Anomaly w.r.t Super Ens Mean 80°N



2007 anomalies in SLP



- OCT-NOV : lower SLP over Arctic
- DEC : regime change
  - Strongest SLP signal over Pacific: deepened Aleutian Low
  - Intensified Highs over continents of Asia and North America
  - Enhanced positive NAO phase over the Atlantic



Note change of latitude range!

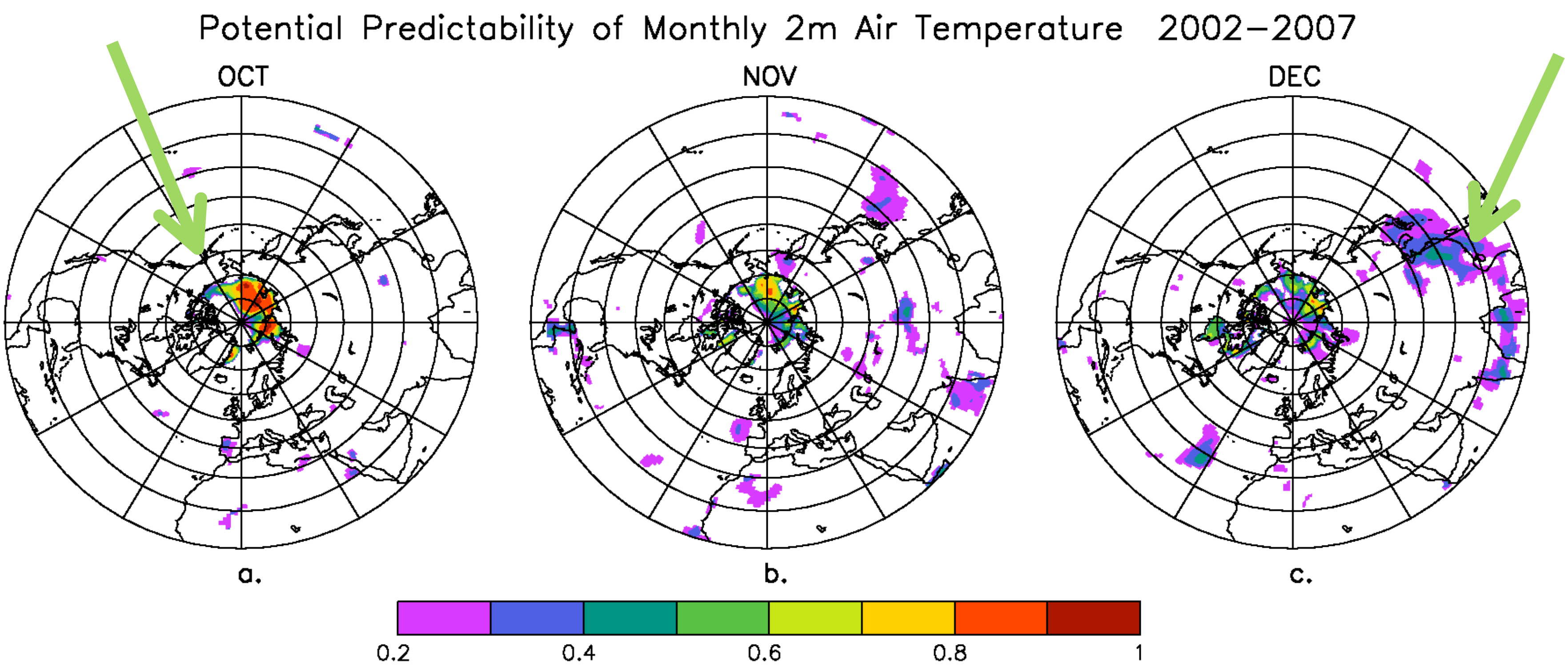
Eastward extension and intensification of Pacific jet

Potential predictability in T_{2m}

- High values potential predictability over the Arctic: strong local influence of sea-ice

- Enhanced potential predictability over Pacific coast of Asia in DEC

- Cooler T_{2m} (1-2 K) might be related to cold air advection, consistent with SLP anomalies.

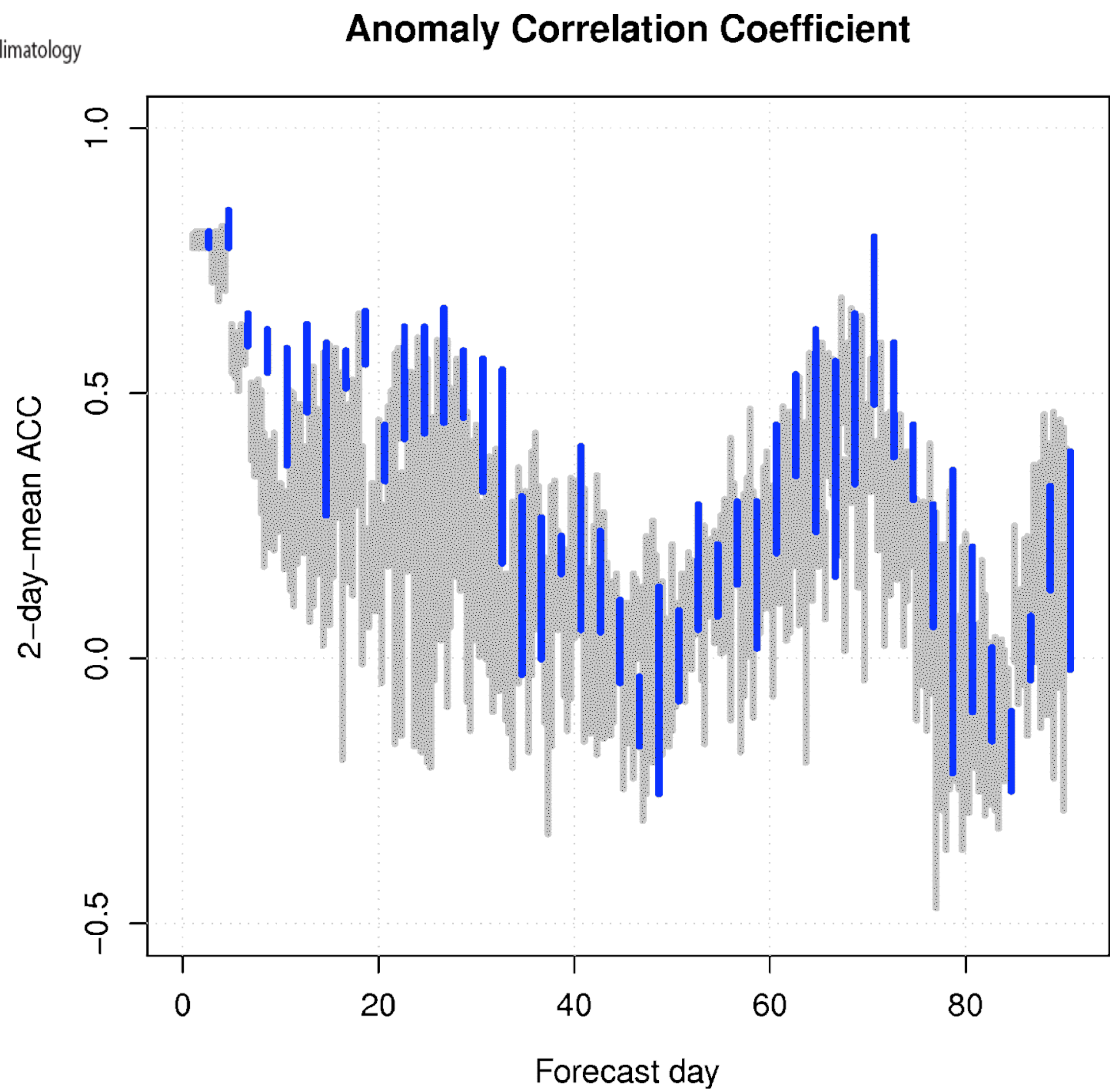


Improved Hindcasts of T_{2m} at high latitudes

$$ACC = \frac{\sum(f-c)(a-c)}{\sqrt{\sum(f-c)^2}\sqrt{\sum(a-c)^2}}$$

f is the forecast, a is the ERA-Interim analysis, and c is the ERA-Interim 1989-2009 climatology

- **Correlation of all hindcasts with ERAINT over polar regions (60N-90N)**
- **ACCs higher for about one month when using 2007 sea-ice (blue envelope) than sea ice from 2002-2006 (grey envelopes)**



Summary of autumn response

Ensemble of hindcasts for 2007 with coupled ocean-atmosphere ECMWF seasonal foreceast model at high horizontal resolution

- **Warm anomalies (10K), max at surface in OCT and NOV (consistent with high-resolution WRF study by Strey 2010, and obs.)**

- **In DEC, weaker but deeper T anomalies through the troposphere, deeper Aleutian Low (Overland and Wang,2010), NAO positive phase, and extended upper-level jet esp. across the Pacific ocean**

- **Intensified Highs over continents over Asia and North America leading to cold (warm) air advection on their eastern (western) sides**

Implications for seasonal prediction

- **Improved correlation of T_{2m} wrt re-analyses over high latitudes through October from sea-ice being realistically prescribed**

- **Potential predictability: strong influence of sea ice on T_{2m} over the Arctic Ocean but also over Pacific coast of Asia in DEC**

Remaining issues

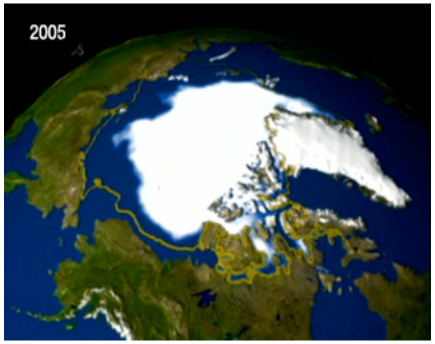
- **Large-ensemble simulation needed to investigate the winter response, esp. whether there is a significant winter cooling over Asia**
- **Understand the mechanisms governing the DEC regime change**
- **To establish improved predictability skill by prescribing sea ice: we need decadal simulations**

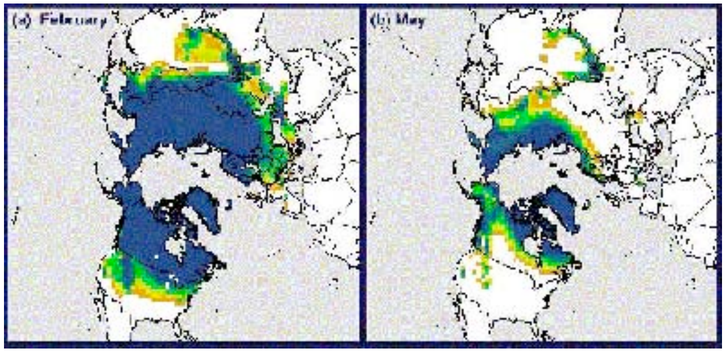
Orsolini, Y.J., R.Senan, R. Benestad and A. Melsom, Autumn atmospheric response to the 2007 low Arctic sea ice extent in coupled ocean-atmosphere hindcasts, to be submitted, 2010

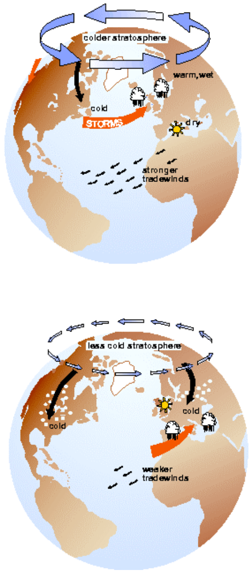
• SPAR

Variety of factors influencing Arctic seasonal predictability :

✓ Sea-ice
✓ Eurasian Snow cover
➢ Stratosphere







Eurasian snow cover impact on predictability

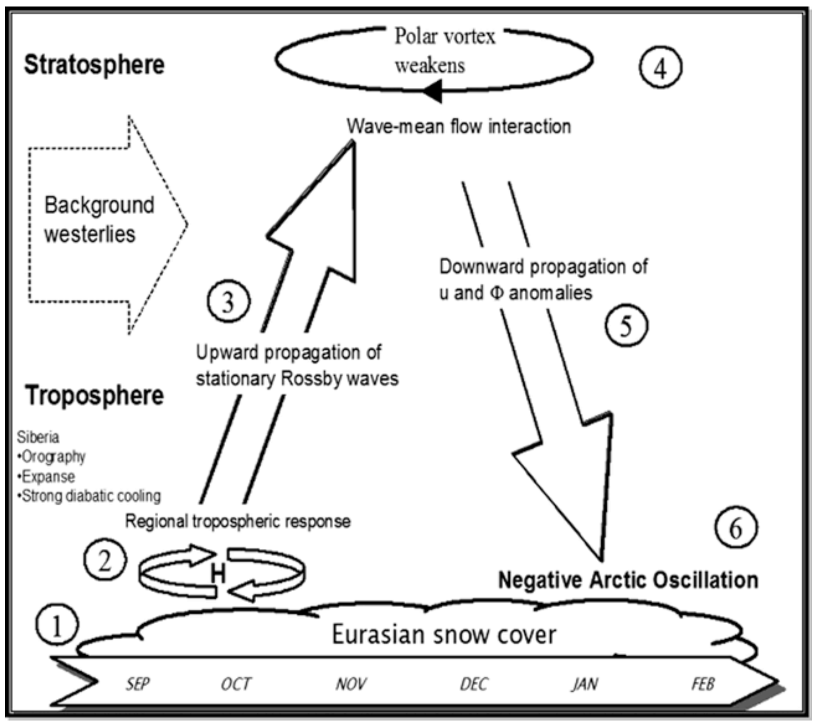
- Snow-covered land : key role in climate system due to snow unique radiative and thermodynamical properties:
high albedo, high thermal emissivity, insulating properties

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

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

Eurasian snow cover impact upon atmospheric circulation patterns

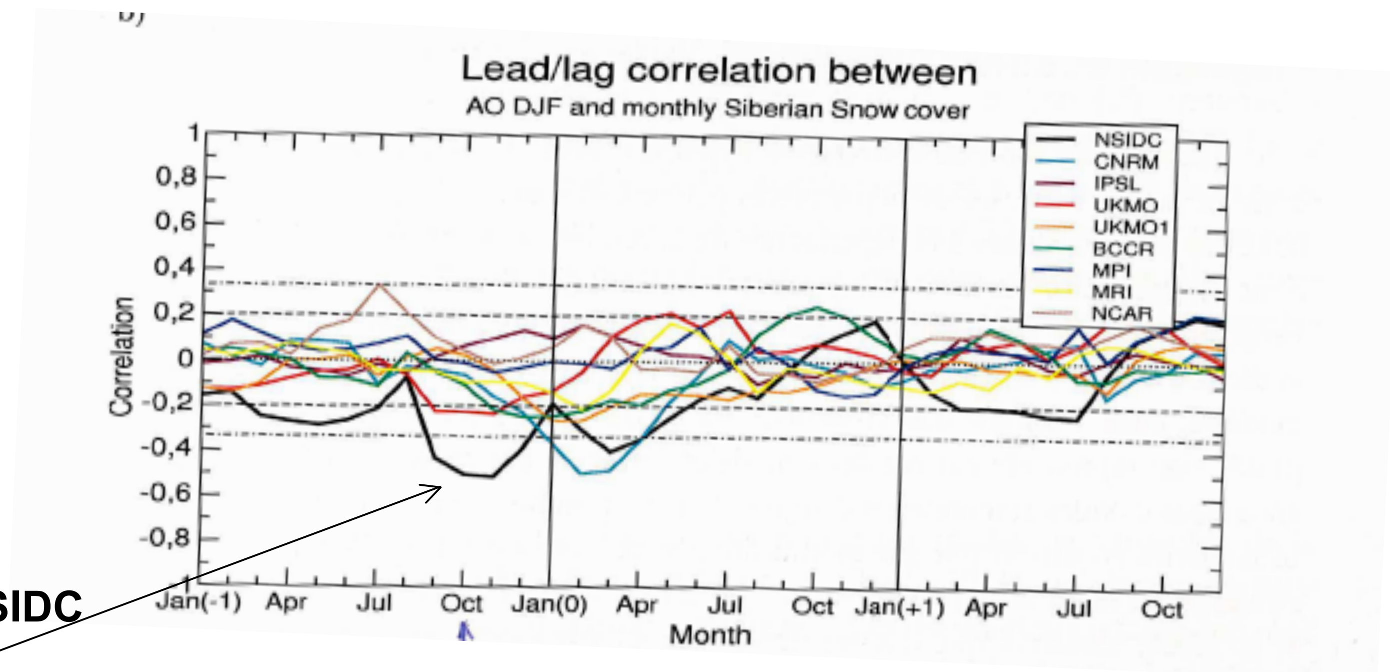
- ***Eurasian snow cover influences wave trains propagating downstream over the North Pacific (Walsh and Ross, 1988; Yasunari, 1991; Clark and Serreze, 2000)***
- ***Eurasian* Autumn *snow cover influences propagation of planetary waves and NAO (AO) in following winter (Cohen, Saito , Fletcher, Kushner and Gong...)***



- **"stratospheric bridge" (hence not a shallow influence)**

(from Cohen et al 2007)

- ***Eurasian Autumn snow cover influences NAO phase in following winter (Cohen et al.)***
- ***Many climate models fail to reproduce that relation (extensive Eurasian snow cover → NAO (or AO) negative)***

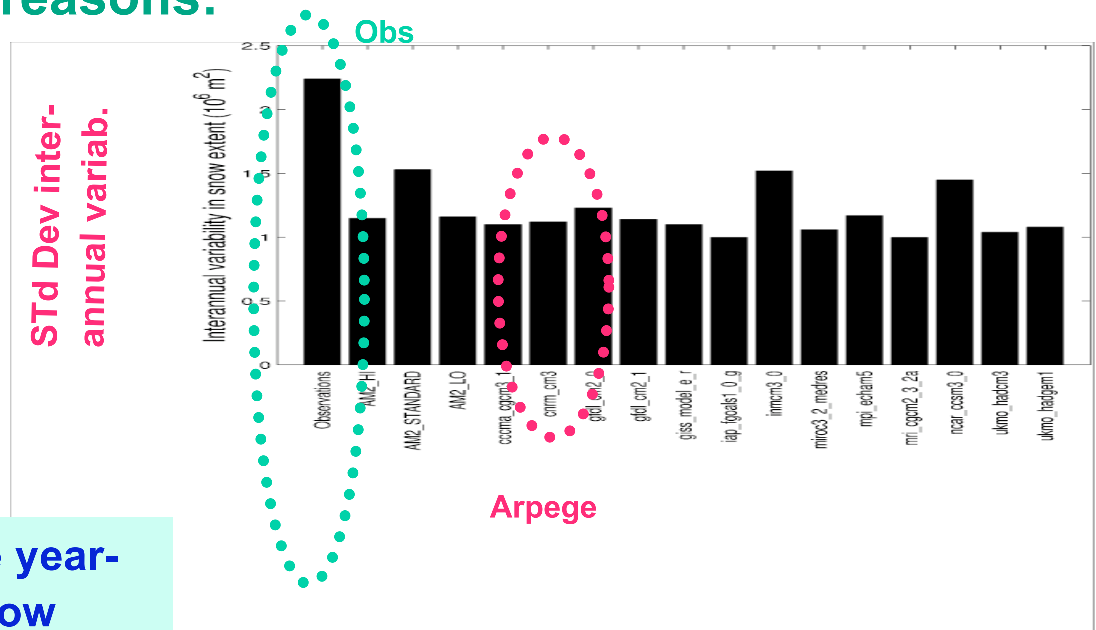


SCA from NSIDC

From : Y. Peings and H. Douville (Meteo-France, CNRM)

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:



▪Models underestimate year-to-year variability in snow cover

▪Model response too zonally confined→ detrimental to upward vertical propagation

AGCM simulations with the ”ARPEGE Climat” (V3.0) model

- **Developed at METEO-FRANCE**

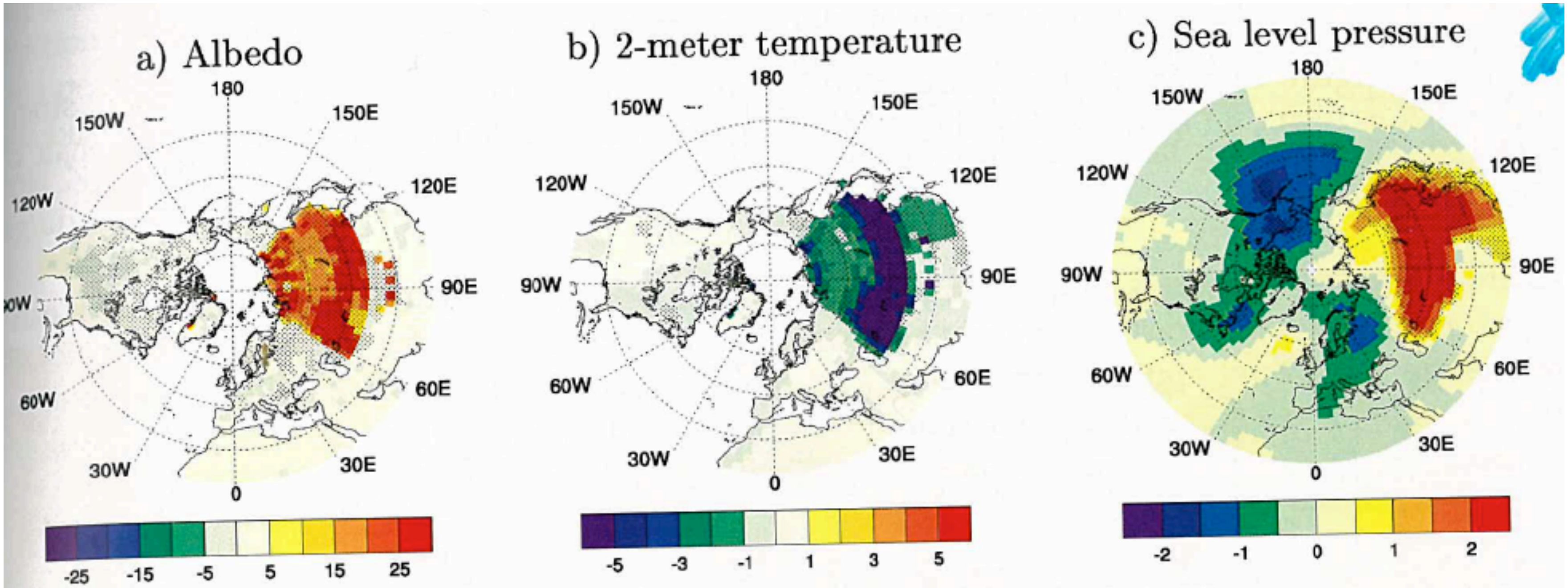
(Deque et al., 1994; Orsolini, Deque and Cariolle, 1995)

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

(*Douville et al., 1995)*

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

METEO FRANCE
Toujours un temps d'avance



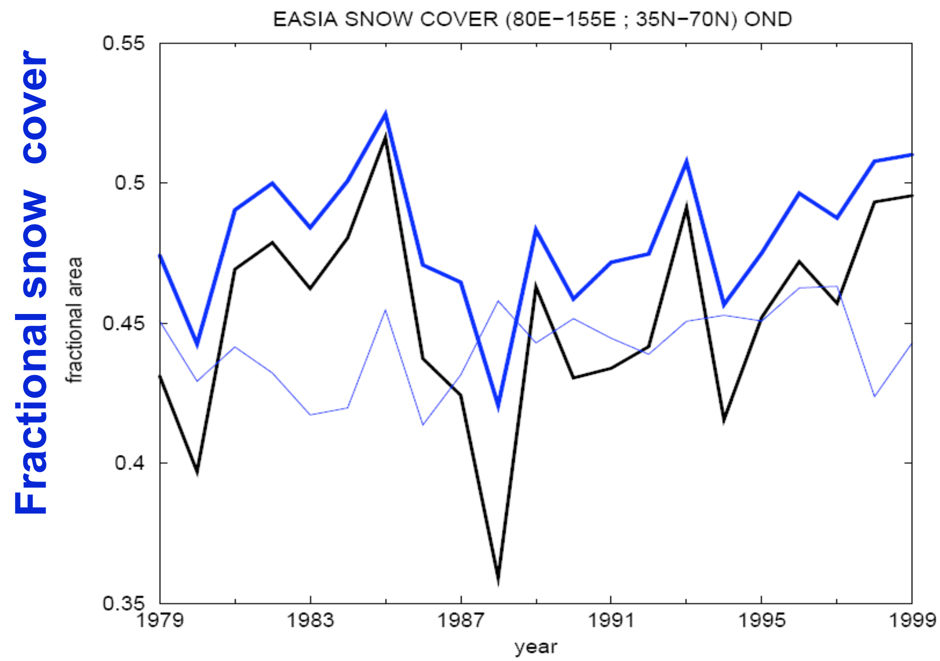
- Prescribed initial snow depth anomaly (10cm) over Siberia in the model in October
- It leads to anomaly (wrt control ensemble simulations) in albedo, surface temperature, SLP, and geop upper troposphere

From : Y. Peings and H. Douville (Meteo-France, CNRM)

Satellite snow cover observations nudged in decadal simulations with Meteo-France ”Arpege” climate model

- **Remedy is to ”nudge” (in fact data insertion)**

model snow variables to satellite SCA observations



❑**Satellite-derived snow (NSIDC data)**

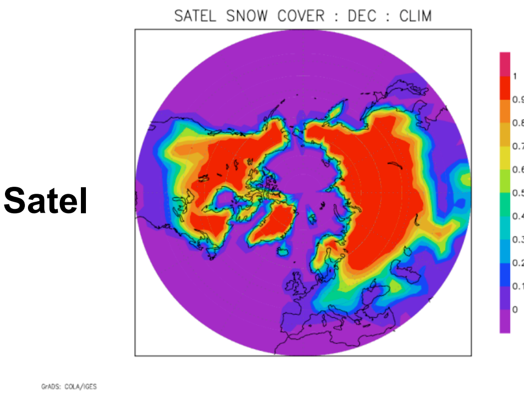
❑Meteo-France Arpege Model prognostic snow

❑**Meteo-France Arpege nudged snow**

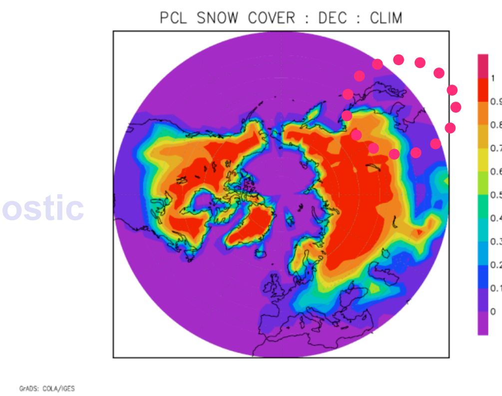
- **Autumn (OND)**
- **Eastern Eurasia**

December

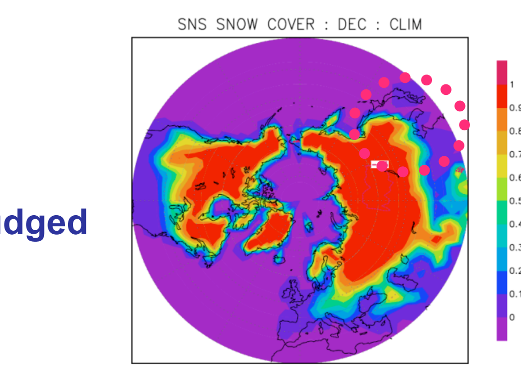
Satel



prognostic



nudged



Potential impact of Eurasian snow cover on teleconnections: the Aleutian-Icelandic Low seesaw (AIS)

- ❑We still lack the NAO response
- ❑However, we find that the AIS teleconnection responds strongly to snow cover enhanced variability
- ❑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

Honda et al., J Clim 2001

- ❑Our underlying hypothesis is that snow cover anomalies over Eastern Eurasia influence the North Pacific sector in autumn-early winter, and the North Atlantic in late winter

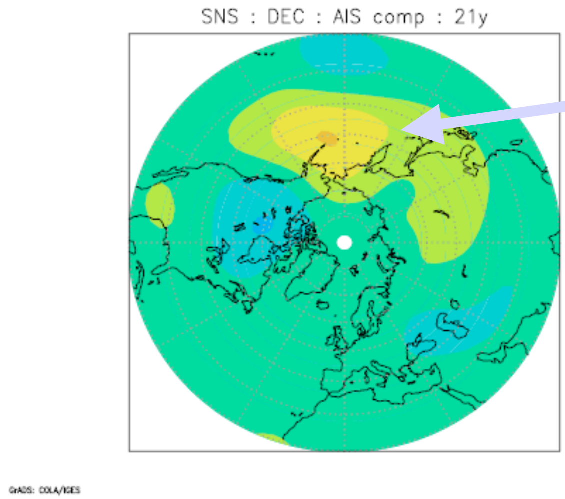
Extensive Eurasian snow cover in autumn (SNOW+) → Aleutian Low deeper in early winter → Icelandic Low weaker in late winter

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.

geop 250mb

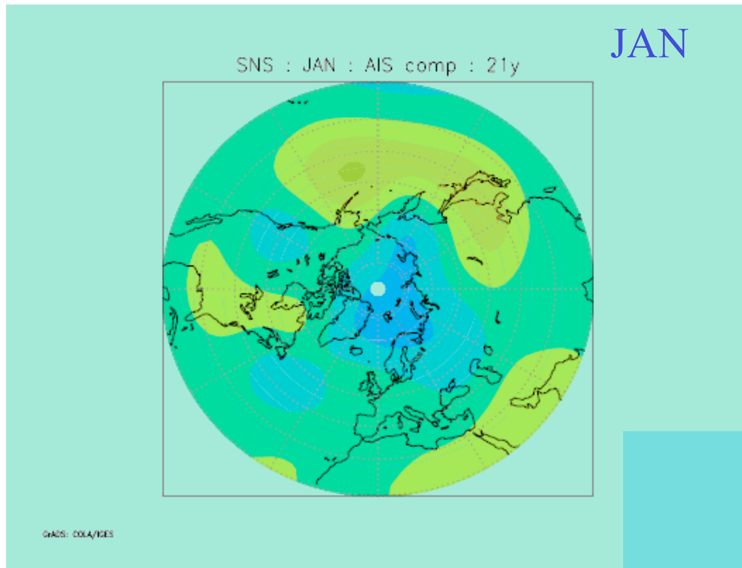
ENSO + Snow ?

DEC



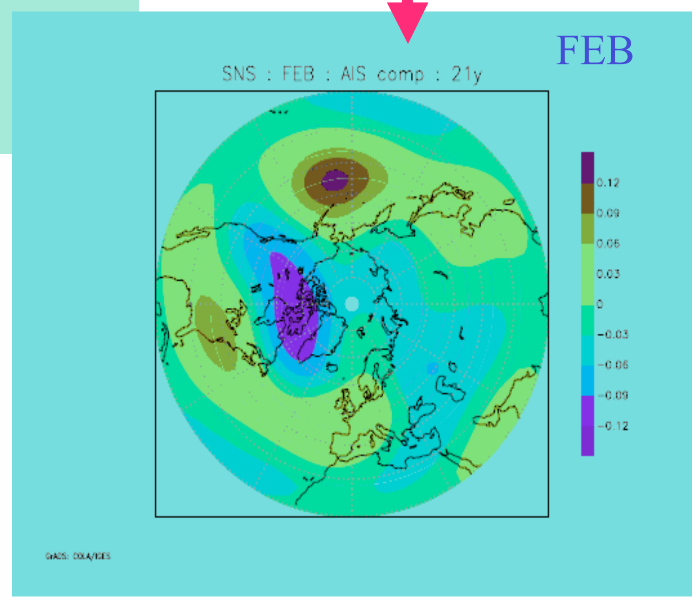
The AIS lifecycle
Aleutian Low Index AL (based on SLP)
Icelandic Low Index IL (based on SLP)
→ AIS index (AL-IL)

JAN



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

FEB



Difference of composite of (high– low) AIS index, based on February when anticorrelation is strongest

Snow nudged run

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

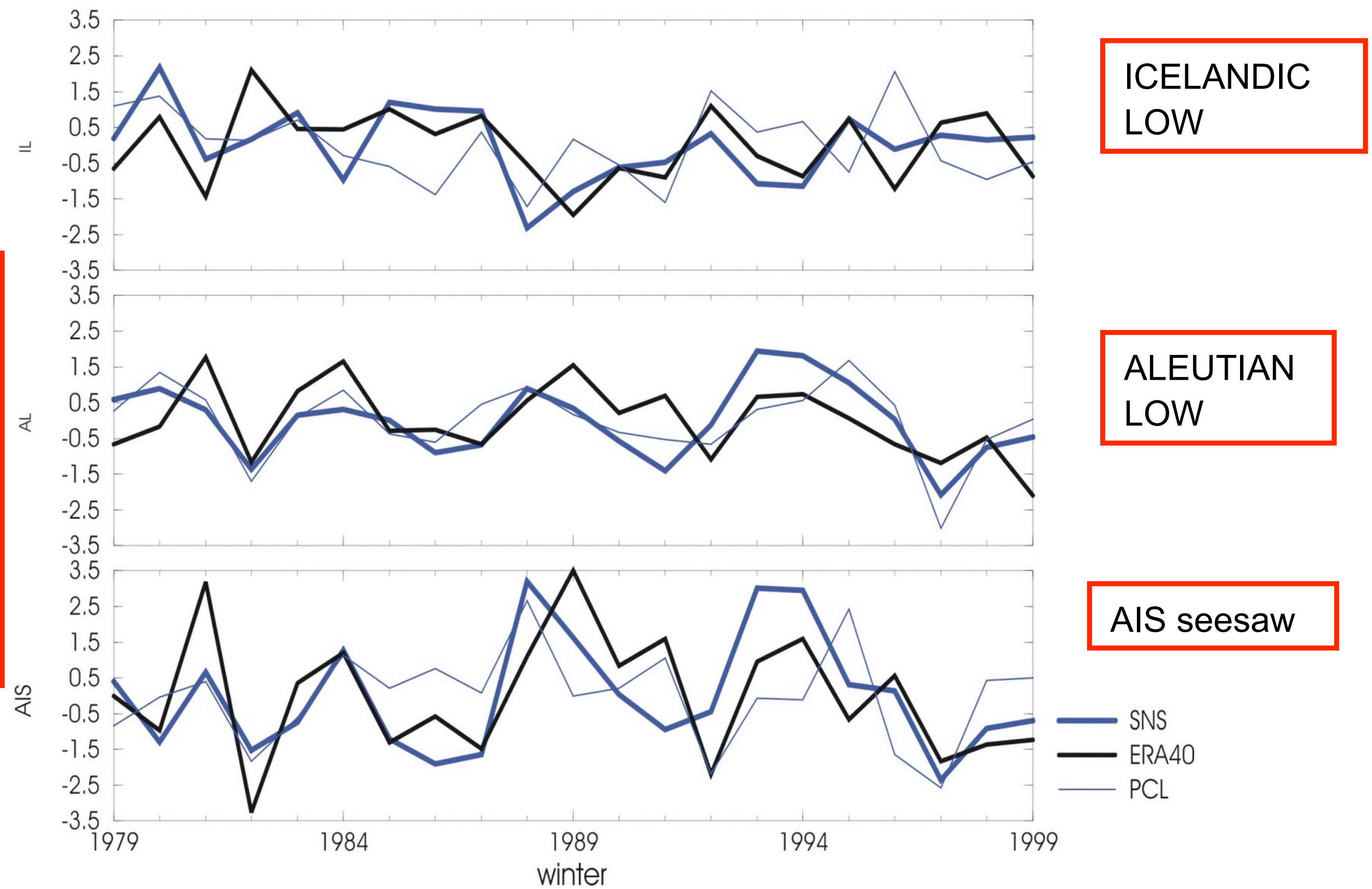
OBS (ERA-40)
nudged (thick)

prognostic (thin)

❑AIS is in better agreement with observations in nudged than prognostic

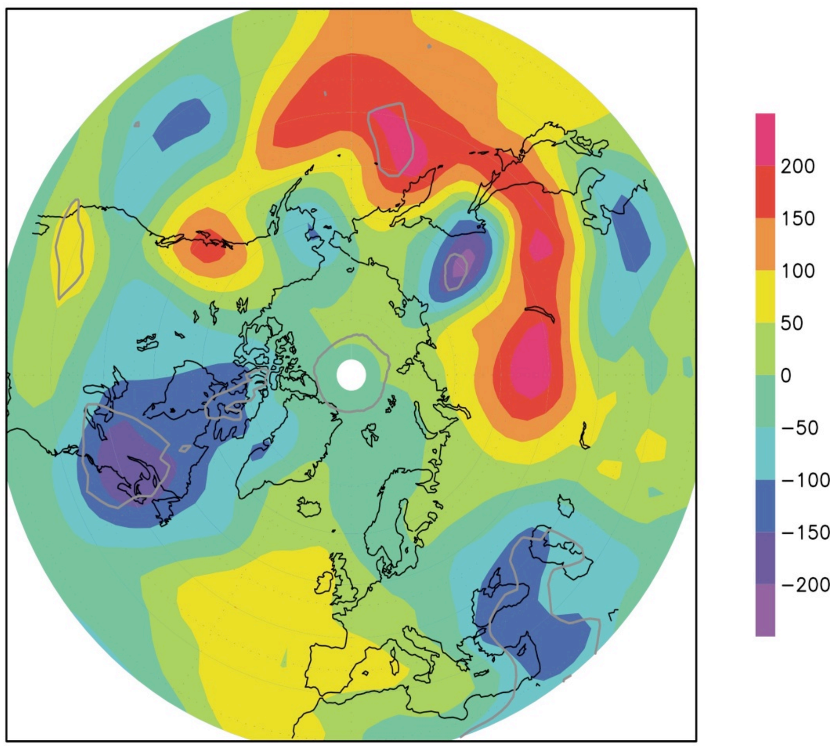
❑ Skill score of hindcast of the AIS

Cor: 0.66 vs 0.38



Wave activity flux (upward component)

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



GrADS: COLA/IGES

- Snow index composite difference of WAFz

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

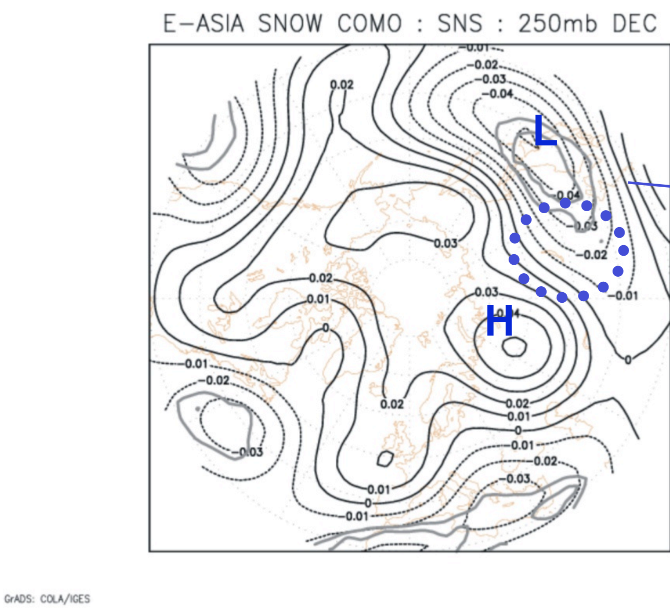
(Saito et al., 2001; Fletcher et al., 2008)

- Eurasian snow cover modulates WAF over North Pacific region

250mb
DEC
Plumb vector (z)

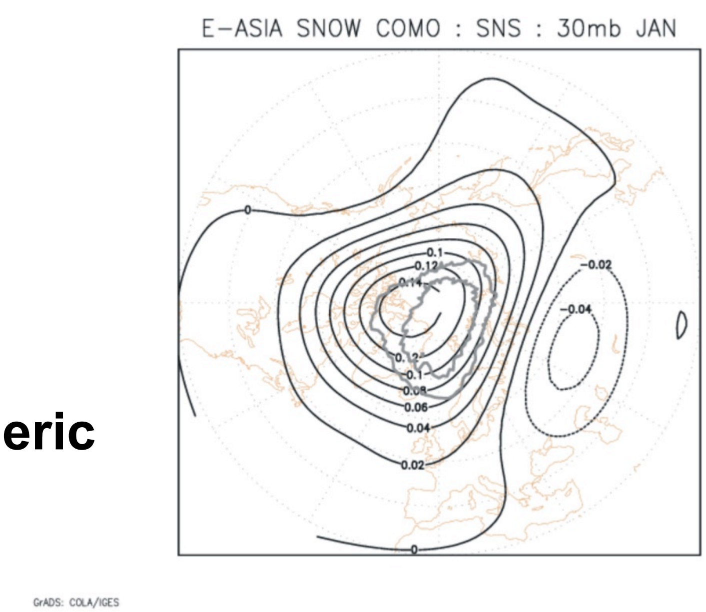
Snow cover geop composites in nudged run

Upper troposphere 250mb
DEC



Surface cooling (1.5-2K)

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



Displaced stratospheric
vortex at 30mb

Conclusions

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

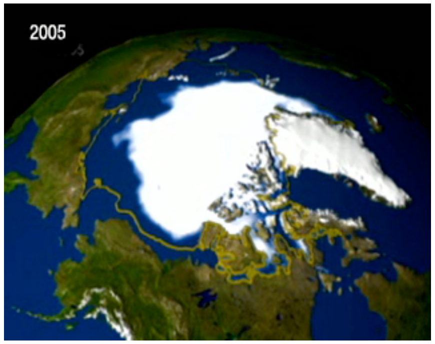
- **Through late-winter influence on the Icelandic Low, our model results partly confirm those of Cohen et al. linking Eurasian autumn snow cover and Pacific and North Atlantic in following winter.**

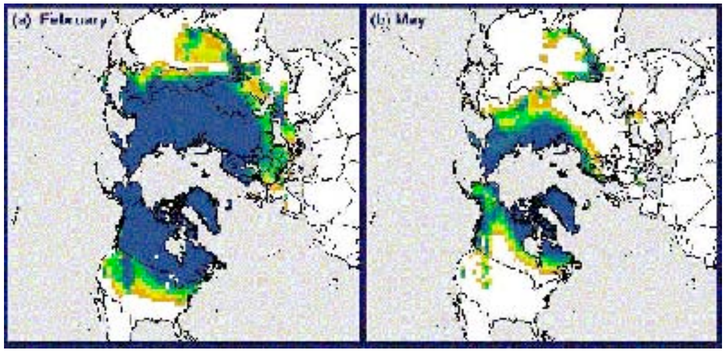
- **We emphasize that horizontal propagation also plays a role (AIS seesaw), in addition to the "stratospheric bridge".**

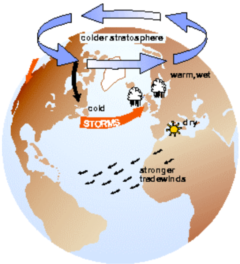
Orsolini, Y. J., and N. Kvamstø, The role of the Eurasian snow cover upon the wintertime circulation: decadal simulations forced with satellite observations, J. Geophys. Res.,114, D19108, doi:10.1029/2009JD012253, 2009.

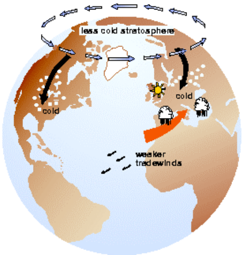
Variety of factors influencing Arctic seasonal predictability :

- ✓ **Sea-ice**
- ✓ **Snow cover**
- ✓ **Stratosphere**





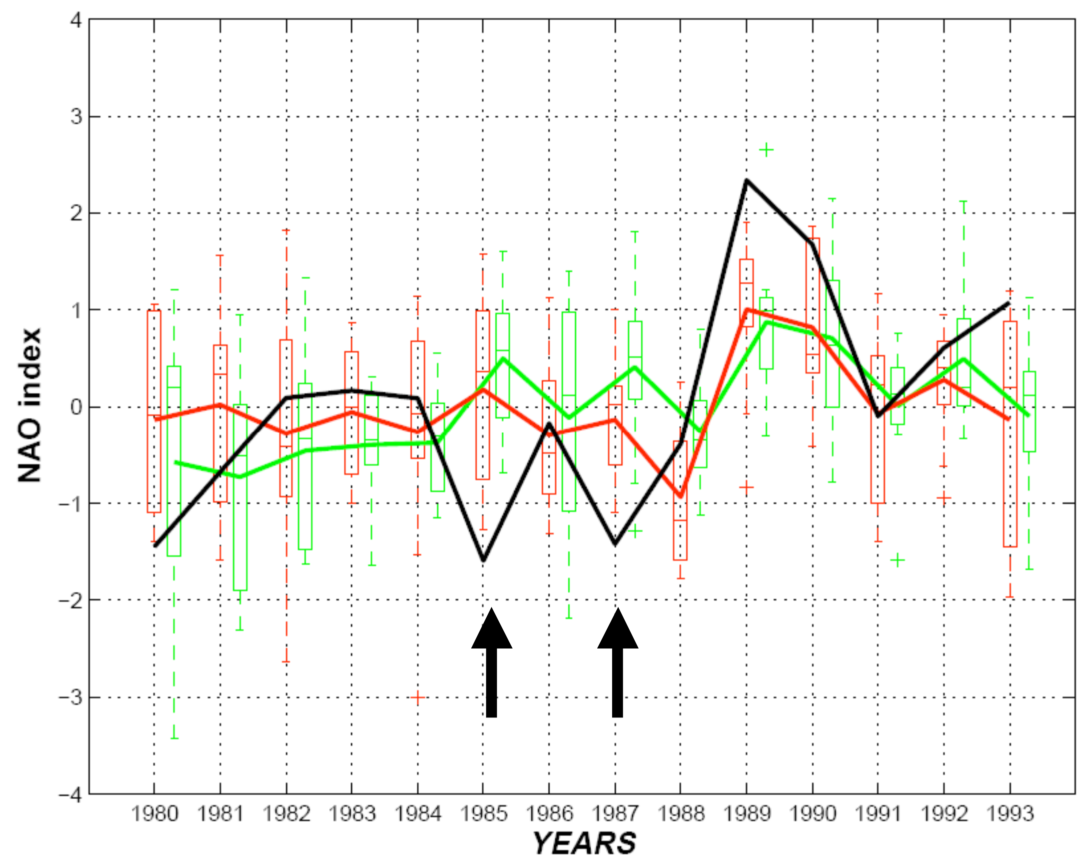




Ensemble seasonal hindcast of the NAO with an AGCM: impact of high top vs low top

Deterministic Skill Score

- ERA-40 is verification (BLACK)
- skill = correlation (ENS MEAN, VERIF)
- (JFM) 0.59 vs 0.44
- Skill of 0.59 is comparable to PROVOST multi-model mean (0,57) (Reyes et al., 2005)
- Increment arises from 2 winters with negative NAO (arrows)



Box plot : spread of model

Strat-trop Arpege model Low-top ECMWF

ROLE OF STRATOSPHERE IN SEASONAL PREDICTABILITY : CONCLUSION

- Model extreme (weak or strong) stratospheric vortex events are shown to influence the troposphere over several weeks, in particular the phase of NAO

- However, their occurrences are generally not predictable on seasonal time scale, so they provide only modest yet positive skill increment
- To tap the stratosphere coupling in seasonal predictability, it is not sufficient to increase the vertical resolution in the stratosphere (also model tuning issue)
- Models have to be improved in terms of predictability of such events, which means, ultimately, their tropospheric precursors and subsequent non-linear evolutions.

Article : Orsolini, Y.J., I. T. Kindem, N. G. Kvamstø, On the potential impact of the stratosphere upon seasonal, dynamical hindcasts of the NAO: a pilot study, Climate Dynamics, 2009

Thank you!

Seasonal forecast of the NAO: impact of stratosphere

Winter hindcasting with AGCM “Arpege”

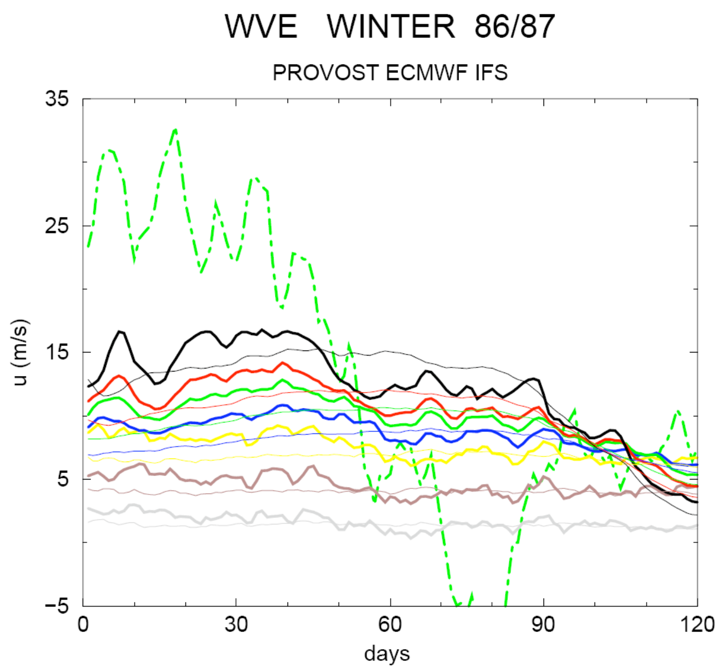
- **SEASONAL** : 4-month integration (DJFM), 14 winters : 1979/80 to 1992/93
- **ENSEMBLE** : 9-member ensemble, time-shifted initial conditions from ERA40
- **HIGH RESOLUTION** : 60 levels up to stratopause (near 50km), high horizontal resolution (T106, or 1.5 degree)
- **INITIALISATION** : ERA-40
- **VERIFICATION** : NAO defined using model Atlantic sector EOF-1

Comparison with PROVOST

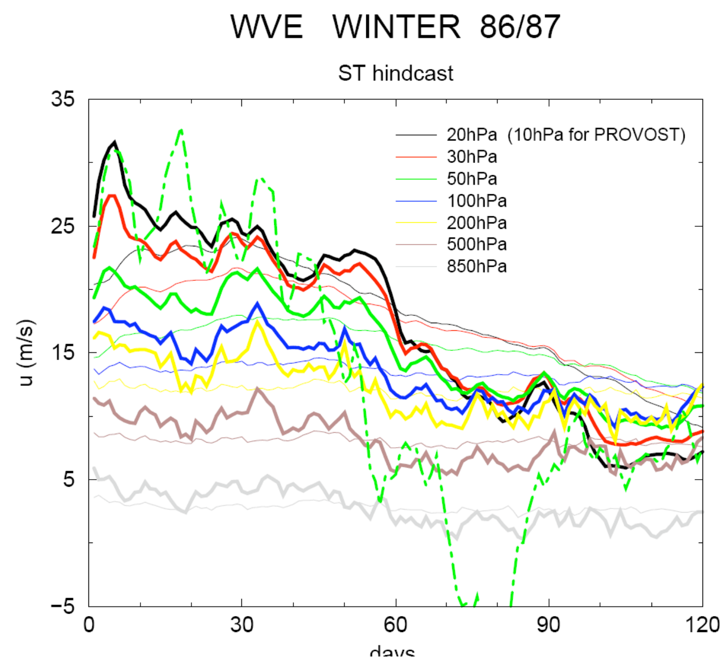
PROVOST ECMWF IFS T42 model run (only one storing strat. data)

Caveat :

- Not merely extending up the PROVOST T42 runs!
- Series of changes : resolved stratosphere, but also model version, increased horizontal resolution, initial conditions (ERA40)
- Only a rough comparison is possible



Days since DEC 1



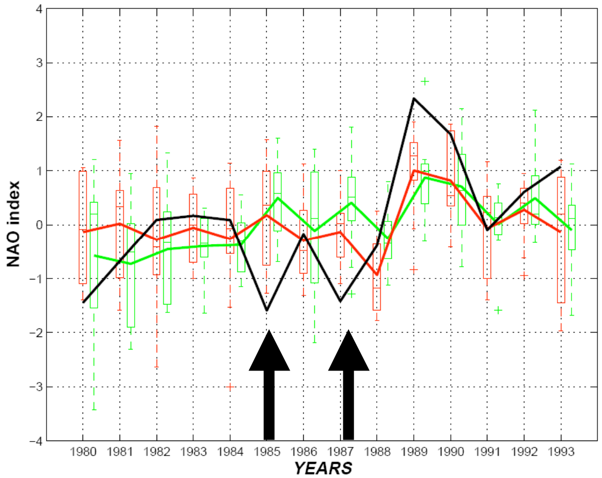
Days since DEC 1

Polar night jet (60N) : zonal-mean zonal wind

ERA-40 (dashed green; 50hPa) compared to ensemble-mean hindcasts

Strat hindcasts :

- **more realistic winds**
- **stronger deceleration, albeit not full SSW (see 50hPa in green)**
- **Persistent weakening of winds, below climatology, even at trop levels**



Skill score

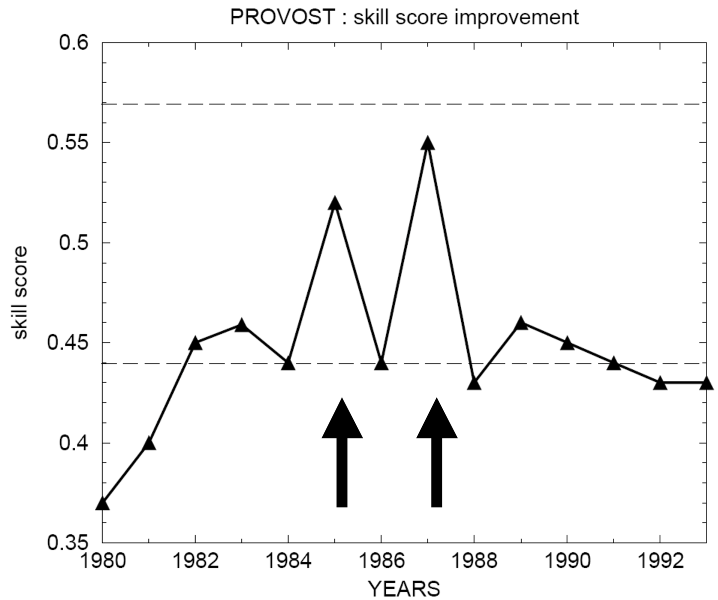
- Substitute the "predicted" NAO index from stratospheric hindcast, into PROVOST predicted time serie (one at a time)

→Determine which winter led to a strong improvement

0.57 : Skill from PROVOST multi-model hindcasts (Reyes et al.,2005)

0.44 : Skill from PROVOST ECMWF IFS hindcasts :

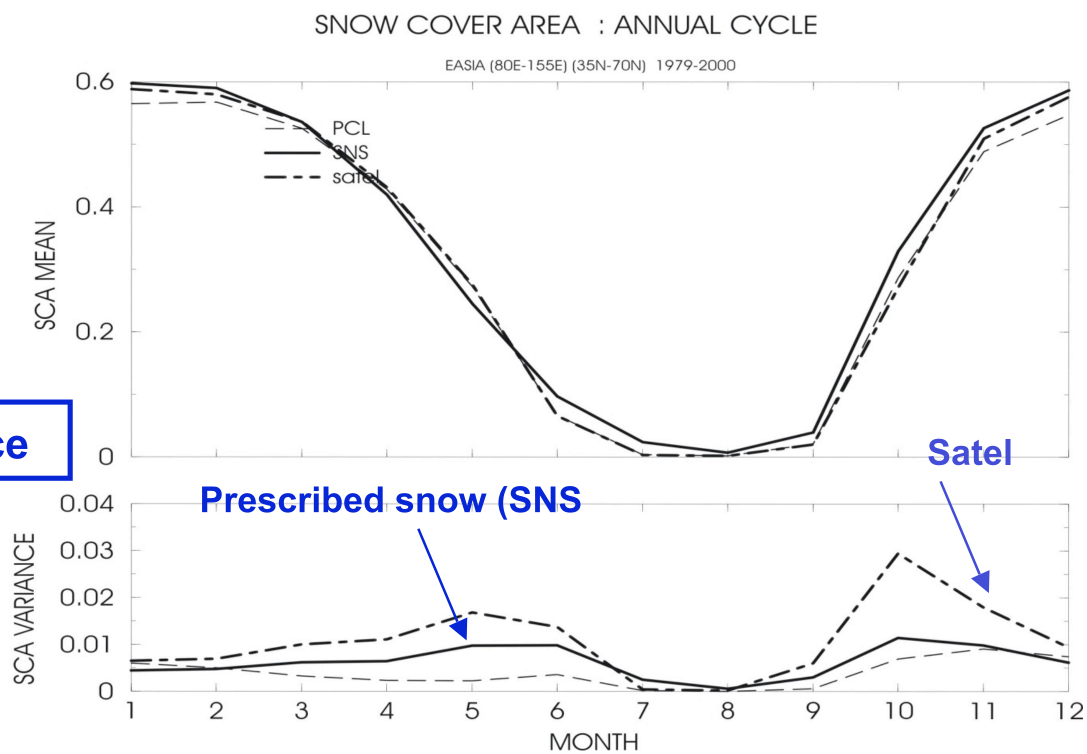
Winter 1984/85 and 1986/87 : strat warmings



Snow cover annual cycle over Eastern Eurasia

mean clim

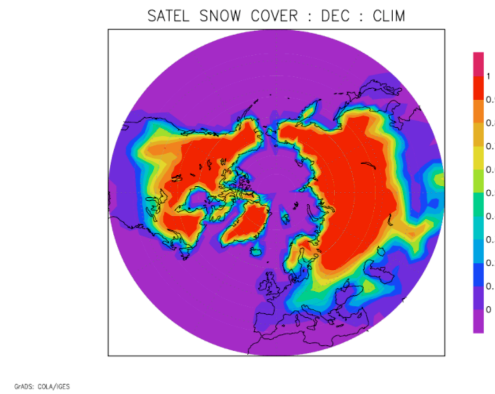
variance



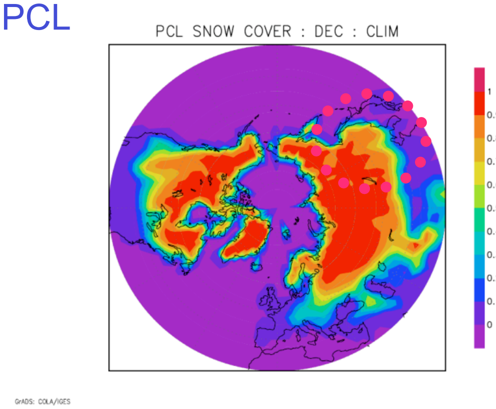
Prescribed snow (SNS): full lines
Prognostic snow (PCL): dash
Satellite (Satel) : dot-dash

December

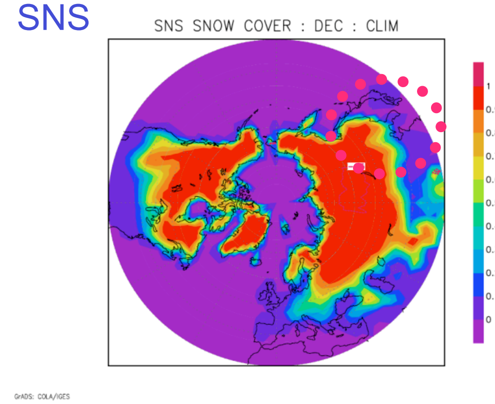
Satel

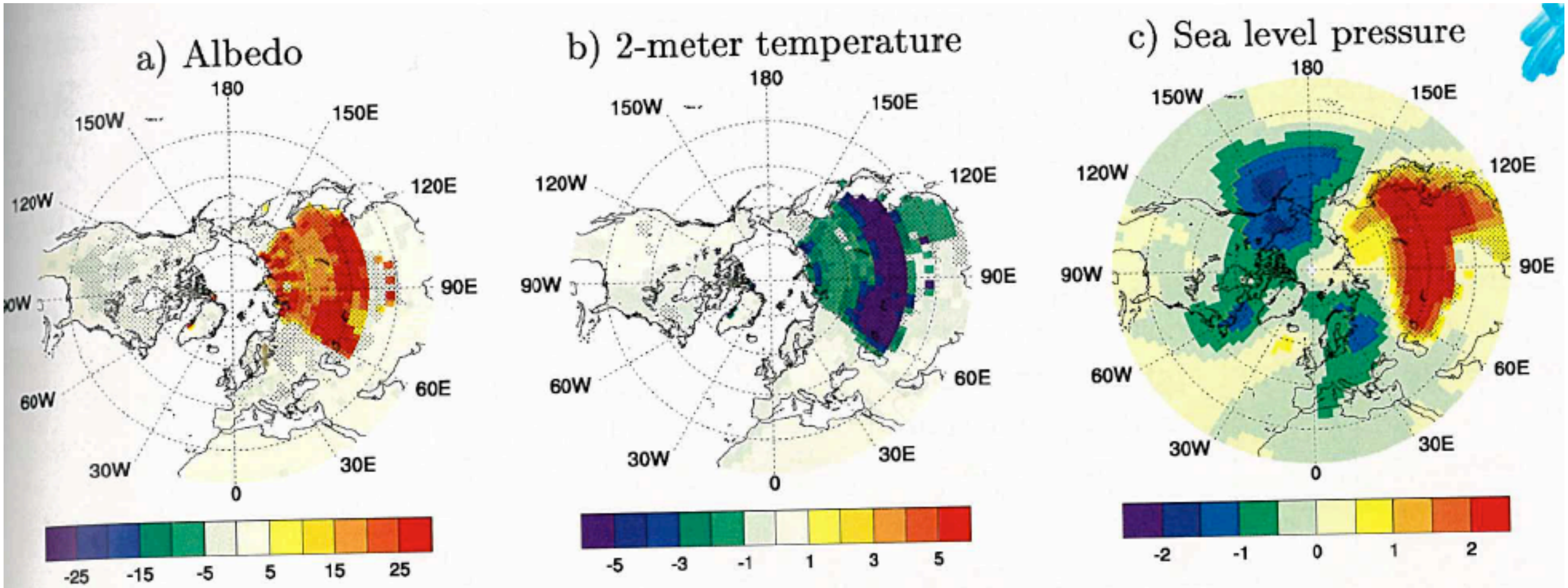


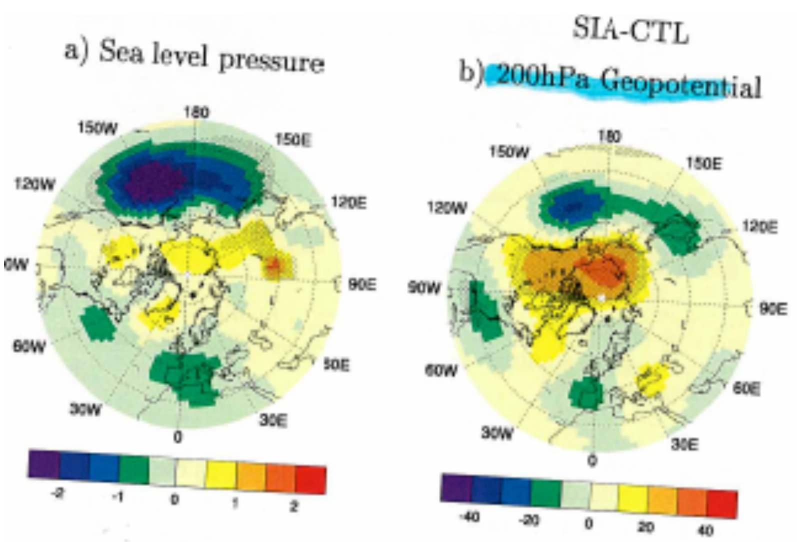
PCL



SNS







- Prescribed initial snow depth anomaly in the model in October
- It leads to anomaly in albedo, surface temperature, SLP, and geop upper troposphere

From : Y. Peings and H. Douville (Meteo-France, CNRM)