Connection between NAO/AO, surface climate over Northern Eurasia: snow cover force - possible mechanism.

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Focus is on:

Can autumn Siberian Snow Cover force response in Northern Hemisphere Winter Climate?

Is snow active in driving seasonal variability of the winter tropospheric circulation?

Can autumn snow drive upward propagating wave activity (WAF) from the surface into the stratosphere?

Does the stratospheric influence on winter surface climate actually originate in the troposphere?

Background

How local surface heating anomalies generate remote dynamical changes?

•The physical hypothesis (Cohen and Entekhabi, 1999) to explain their results is that extensive Eurasian snow cover in SON interval excites the dominant modes of Northern Hemisphere variability by its effects on the extension of Siberian high and on the latitudinal thermal gradient.

•Cohen et al. (2002) further develop the hypothesis of a NAO mechanism originating in the lower troposphere, in eastern Siberia, during late fall, when vertical wave activity flux due to the snow cover anomaly propagates vertically into the stratosphere and returns as zonal wind anomalies in early winter.

•Watanabe and Nitta (1998) hypothesis that snow cover anomalies interact with zonal asymmetries and transient eddies to produce height changes observed in the atmosphere and in their GCM experiment.

Size and extent of anomaly of a thermal source at a surface which is caused by anomaly of a snow cover in territory of Eurasia, in particular, in Siberia, can have influence both on local climatic conditions, and on a condition of a climate in the remote regions due to dynamic and thermodynamic mechanisms.

Achievement of last years is the establishment of connection between anomalies of a snow cover in territory of Eurasia with the main modes of troposheric circulation variations of Northern Hemisphere (Cohen et al, 2002; Cohen et al, 2007).

Analysis of the given observations and modelling has found out statistical connection between NAO/AO and anomalies of a snow cover in territory of Eurasia. (Cohen, 1994; Cohen, 1994 Cohen, Entekhabi, 1999; Cohen et al, 2002; Cohen et al, 2007; C. Fletcher et al, 2007; Fletcher et al, 2009; Krupchatnikov, etc. 2009)

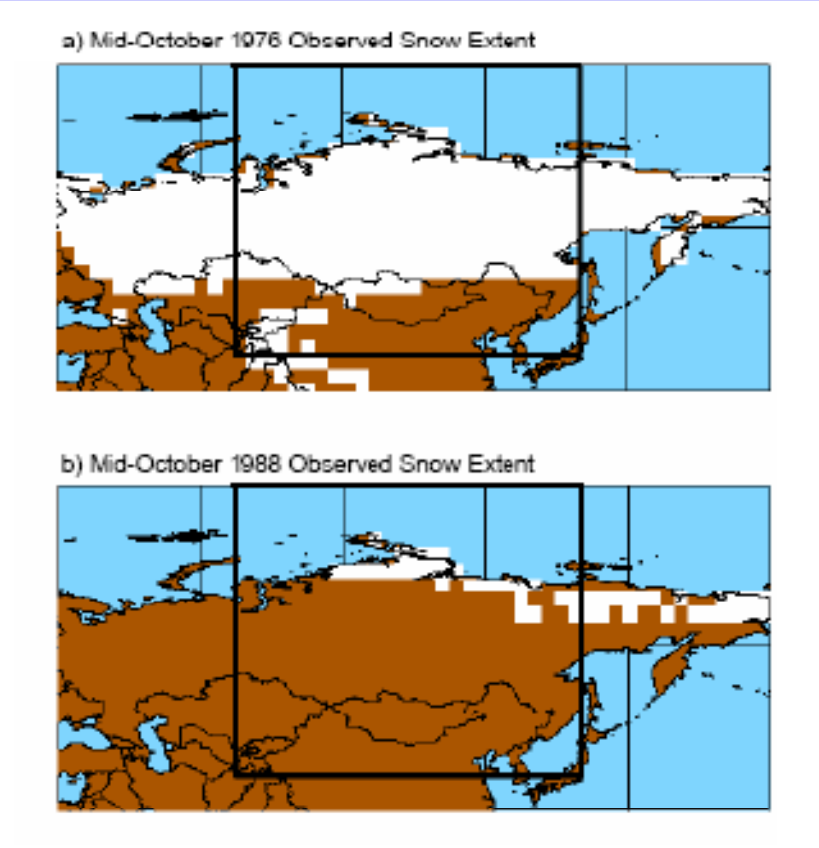
One of the major characteristics of a snow is albedo:

- the fresh snow on a homogeneous surface has albedo ~ 0.8.
- during ageing a snow albedo decreases up to 0.4.
- the snow on a surface covered by wood vegetation has albedo within the limits of from 0.2 up to 0.4, depending on type of vegetation.

The essence of a feedback mechanism albedo – a snow consists in reduction of a snow cover leads to reduction surface albedo and to the tendency of increase in temperature of a surface and on the contrary.

These changes influence on thermal balance, circulation and planetary albedo, and, in a consequence, on deposits and speed of thawing of a snow. The vegetation and age of a snow are played great role in this mechanism

Observational Evidence

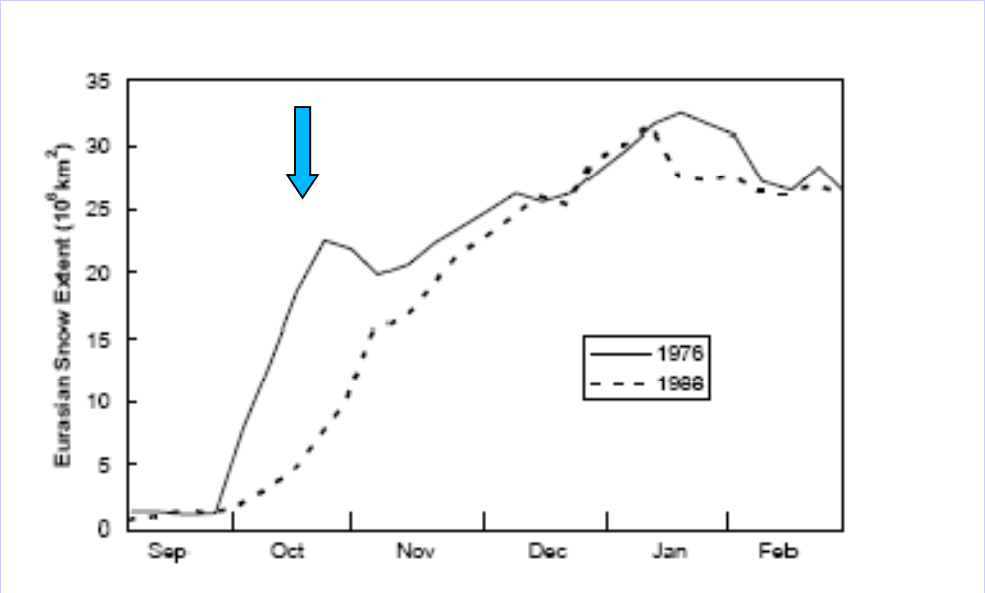


NOAA visible satellite observations of snow extent over Asia.

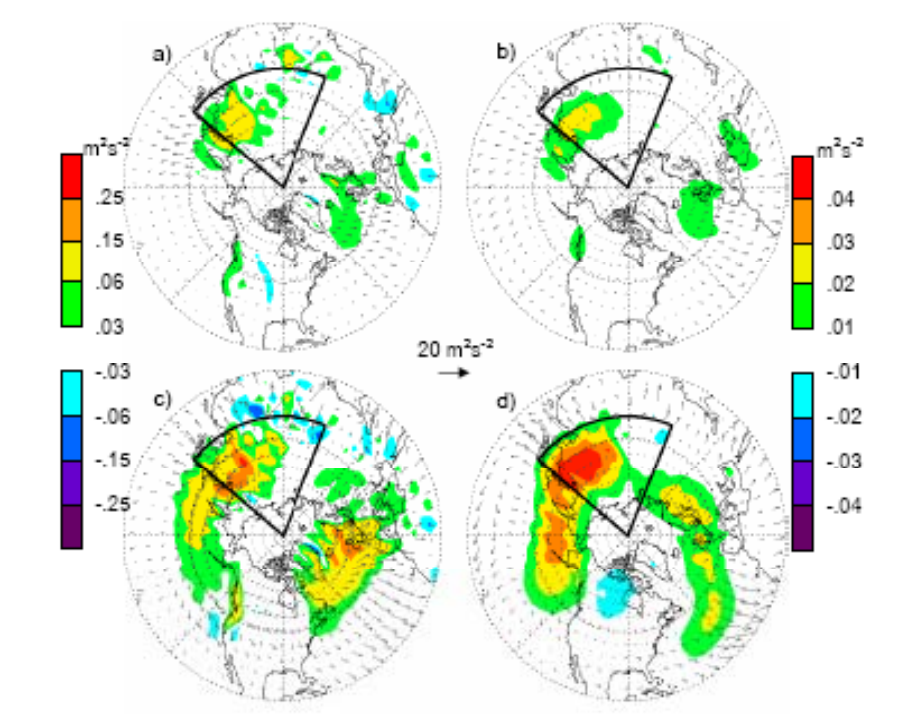
a) Mid-October 1976.

b) Mid-October 1988.

(G. Gong et al., 2005)

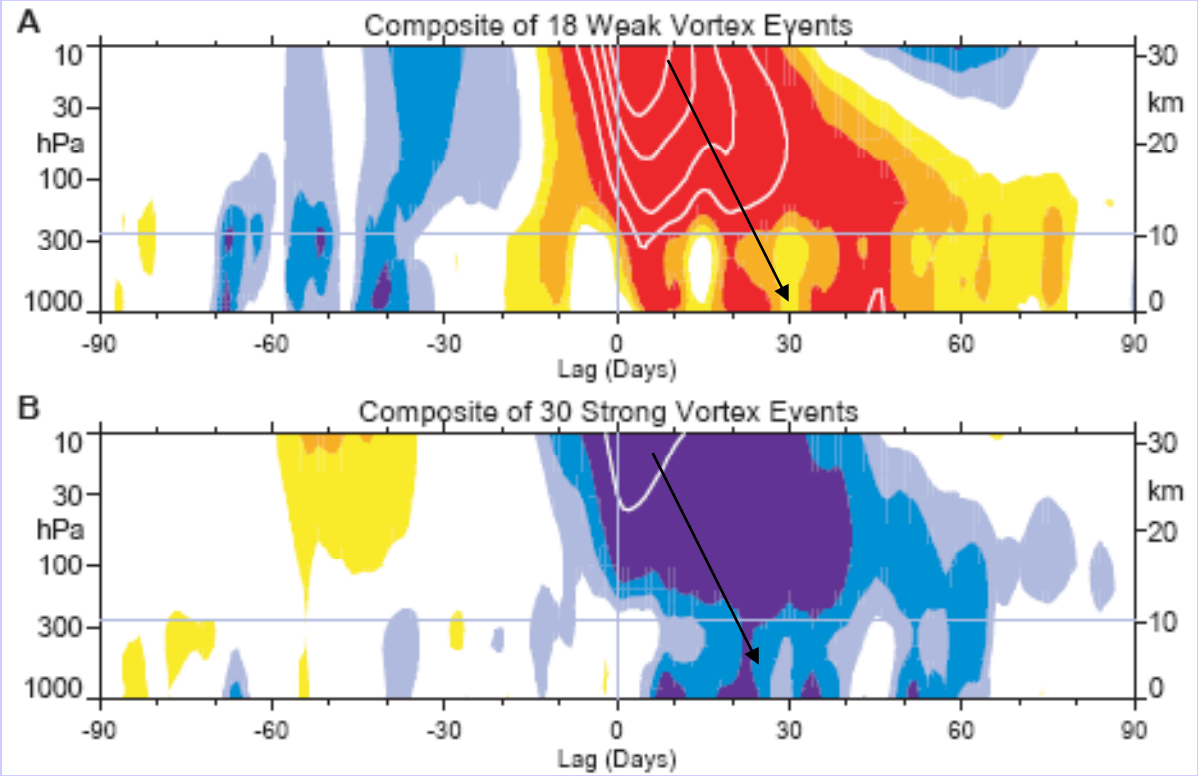


Weekly timeseries of NOAA satellite-observed snow cover extent over Eurasia, for the period September 1976 – February 1977 (solid line) and September 1988 – February 1989 (dashed line).



Three-dimensional wave activity flux (WAF) climatology over the extratropical Northern Hemisphere, from a twenty-year control simulation of the ECHAM3 GCM. Vectors denote horizontal fluxes and contours denote vertical fluxes. Dashed line denotes negative contour value.

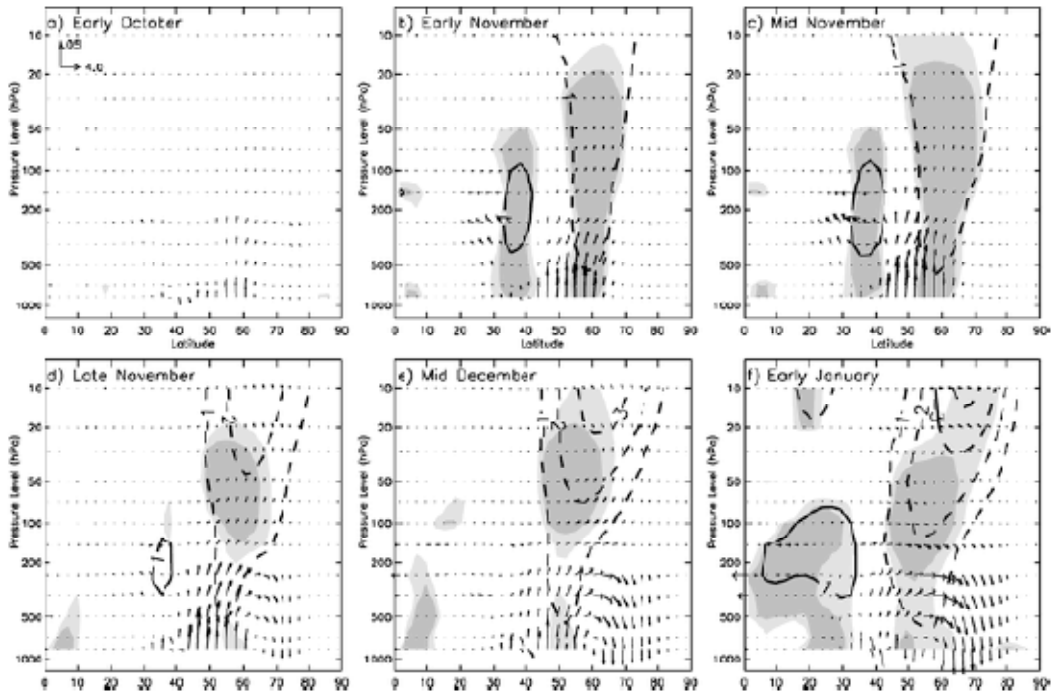
a) Autumn, 500 hPa elevation; b) Autumn, 150 hPa elevation; c) Winter, 500 hPa elevation; d) Winter, 150 hPa elevation.



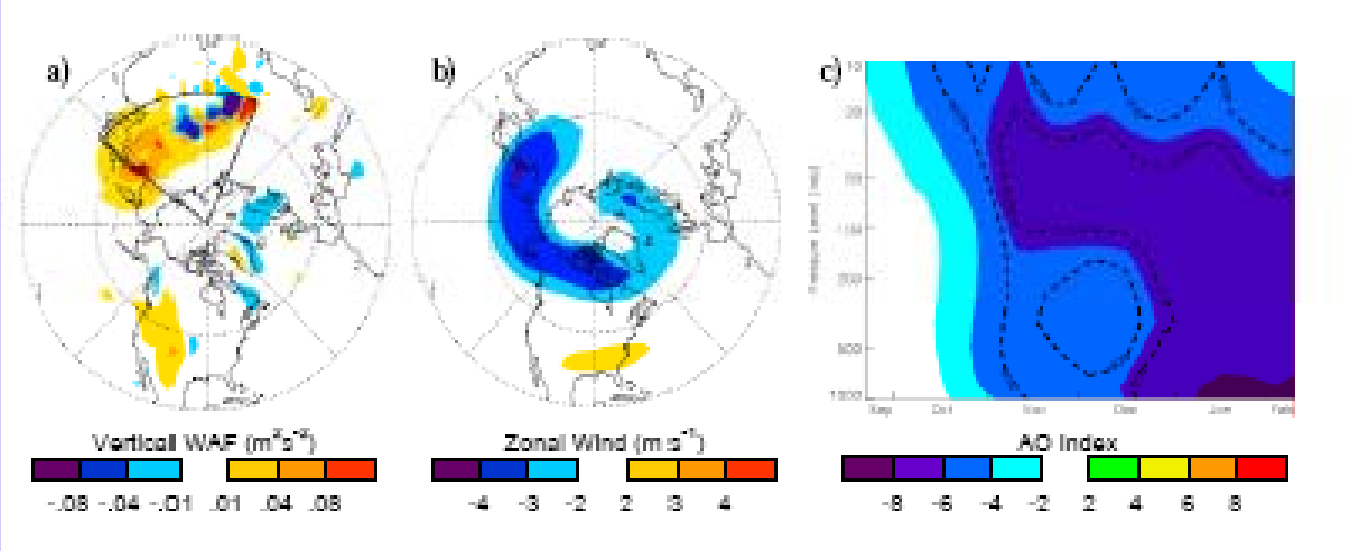
Latitude - time cross- section of development of leading mode NAO/AO in case of:

(a) Weak polar vortex

(b) Strong polar vortex.



Gong et al [2003]



Climatic response to a positive snow forcing, for the SIB experiment.

a) Vertical WAF at 850 hPa elevation during autumn (SON).

b) Zonal wind at 50 hPa elevation during winter (DJF).

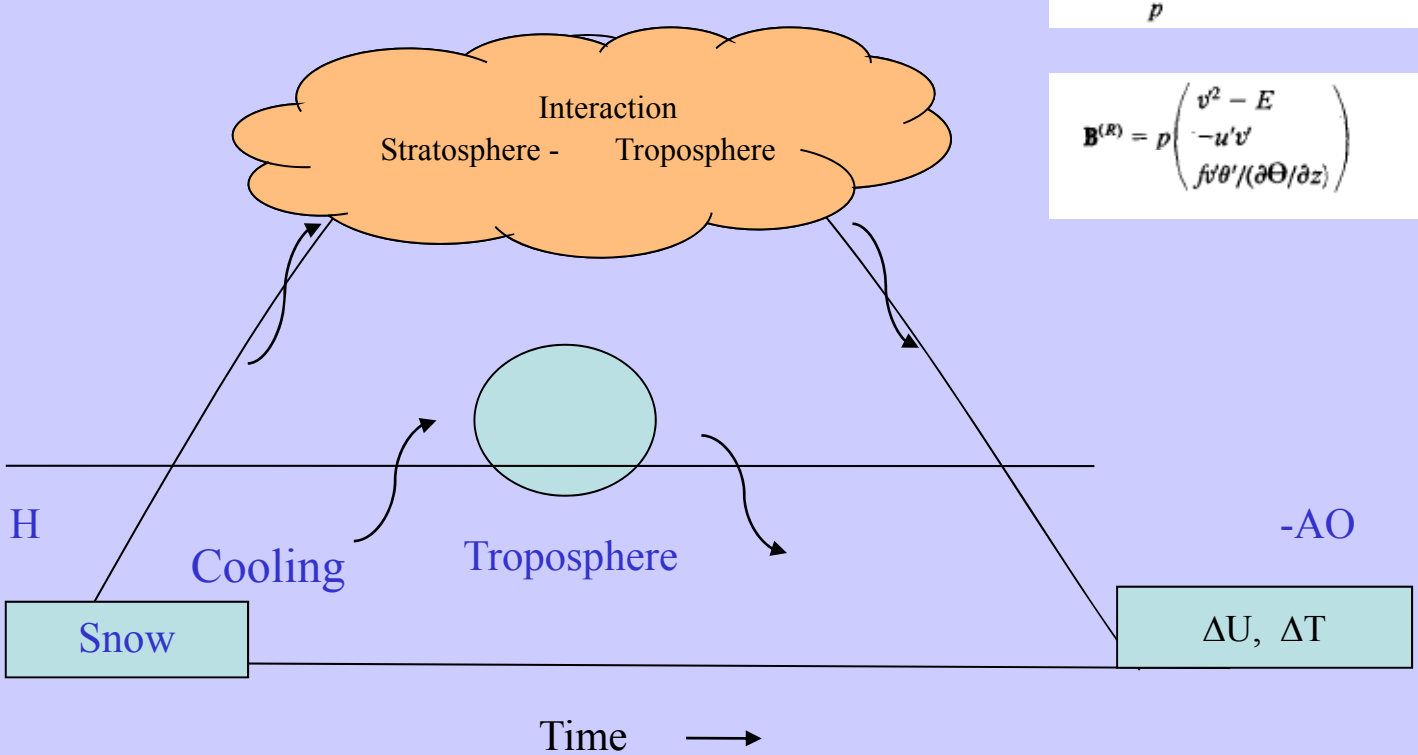
c) Weekly evolution over the atmospheric column of normalized 42-day running mean hemispheric NAO index.

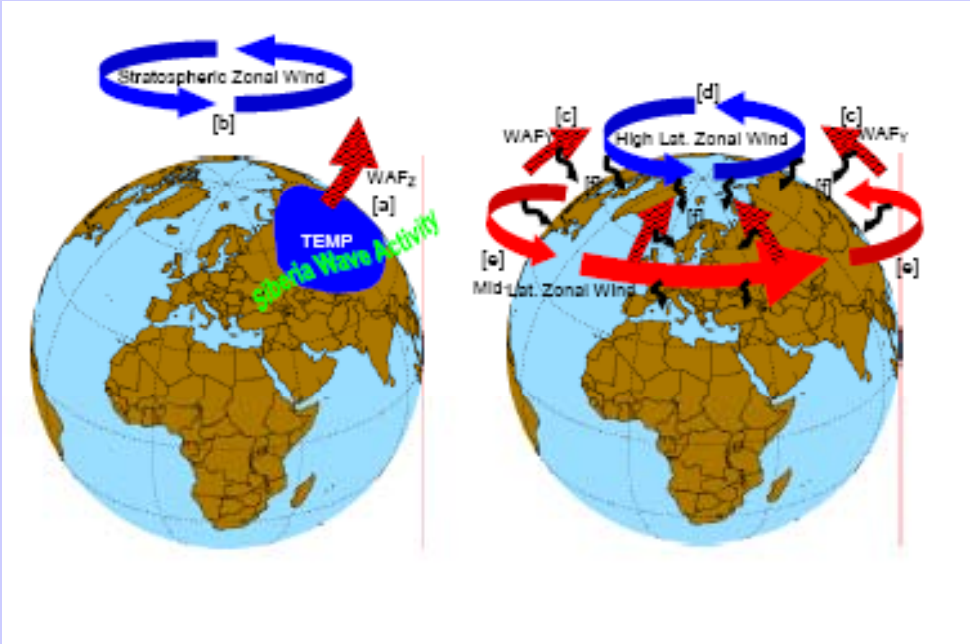
The mechanism of interaction of troposphere and stratosphere

$$q' = \frac{\partial^2\psi'}{\partial x^2} + \frac{\partial^2\psi'}{\partial y^2} + \frac{f^2}{p}\frac{\partial}{\partial z}\left(\frac{p}{N^2}\frac{\partial\psi'}{\partial z}\right)$$

$$v'q' = \frac{\partial\psi'}{\partial x}\left[\frac{\partial^2\psi'}{\partial x^2} + \frac{\partial^2\psi'}{\partial y^2} + \frac{f^2}{p}\frac{\partial}{\partial z}\left(\frac{p}{N^2}\frac{\partial\psi'}{\partial z}\right)\right] = \frac{1}{p}\nabla\cdot\mathbf{B}^{(R)}$$

$$\mathbf{B}^{(R)} = p\begin{pmatrix} v'^2 - E \\ -u'v' \\ fv'\theta'/(\partial\Theta/\partial z) \end{pmatrix}$$



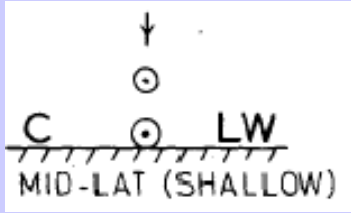


Remote teleconnection pathway in response to positive snow forcing over Siberia. Red (blue) denotes a positive anomaly.

(G. Gong et al., 2005)

Hoskins B., D. Karoly, 1981

$$v' \propto Q \cdot H_Q / \left(f\overline{U} \right)$$



$$v' \propto fQ / \left(\beta N^2 H_Q \right)$$

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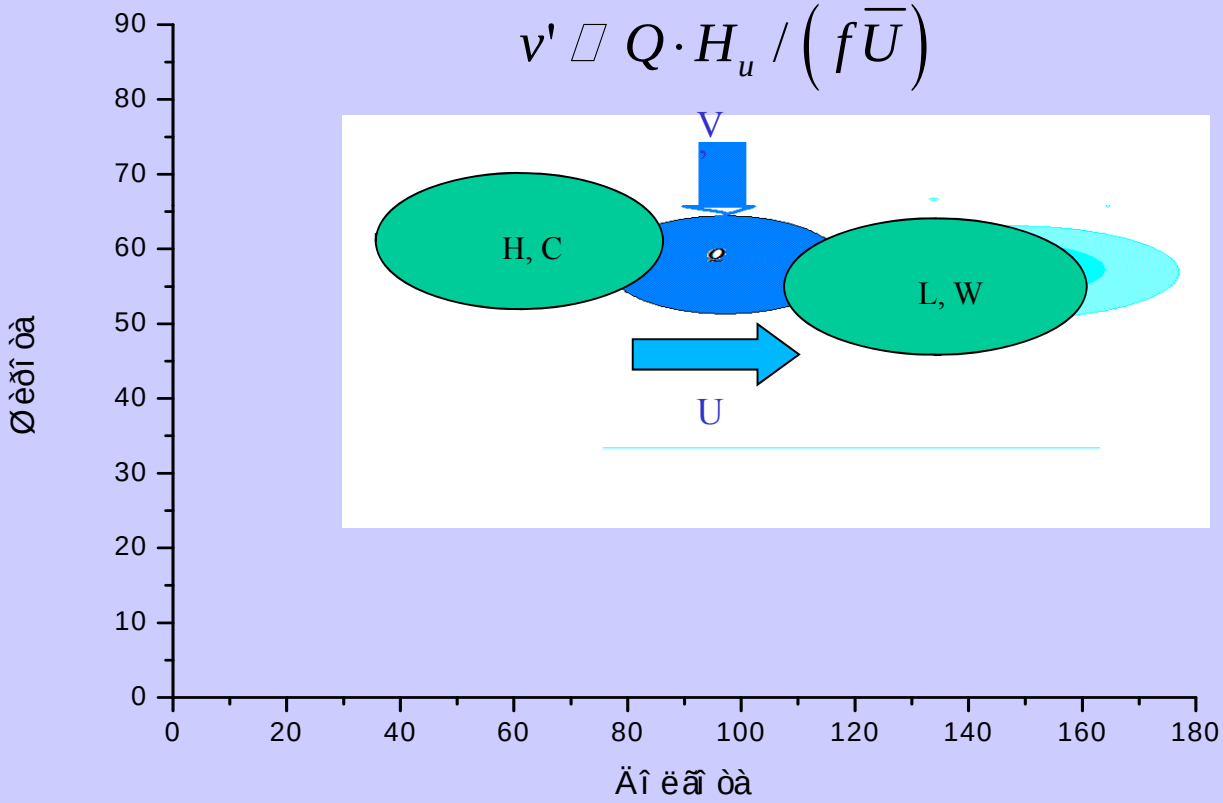
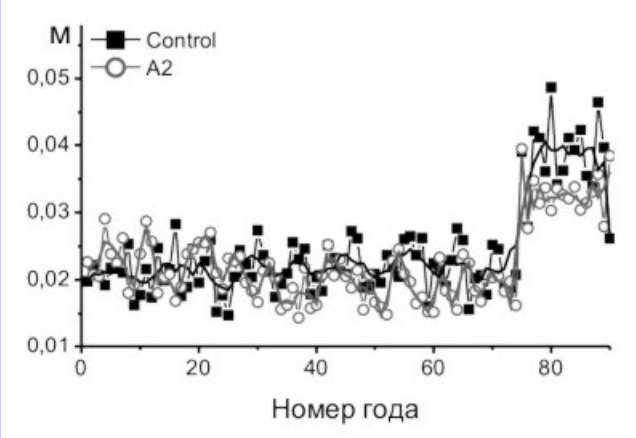
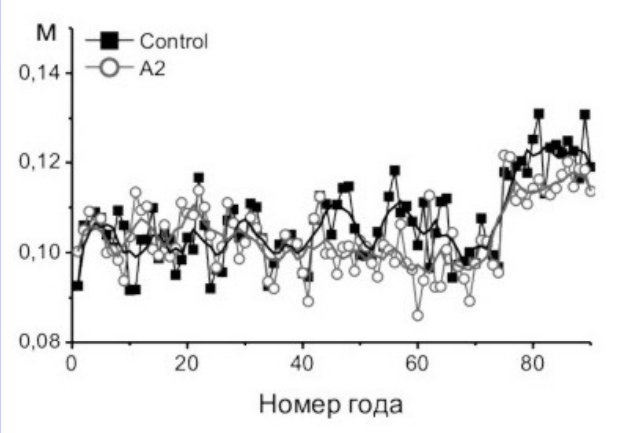
$$v' \propto Q \cdot H_u / \left(f\overline{U} \right)$$



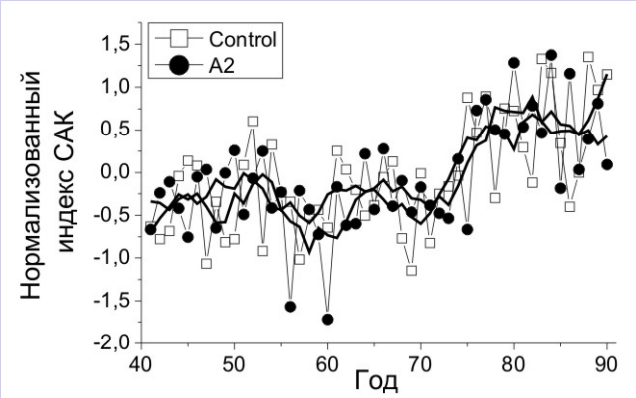
(а) (б)

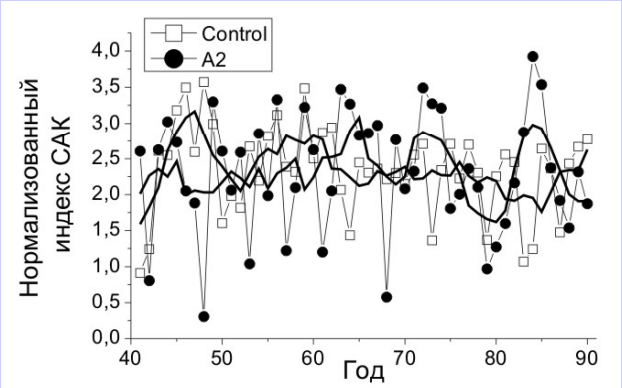




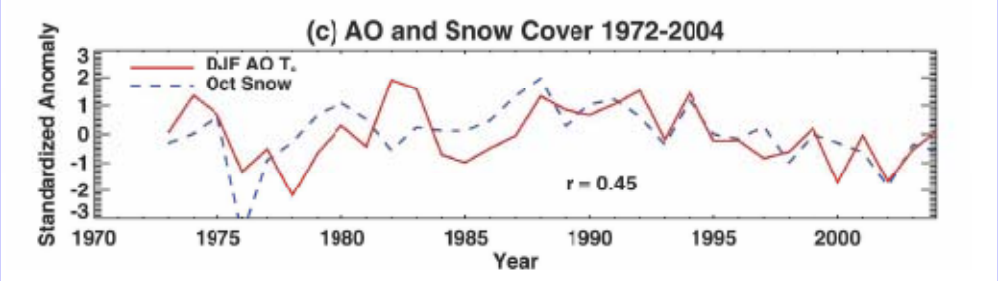
Average depth of a snow cover on territory of Siberia: (a) – autumn season; (b) – winter season

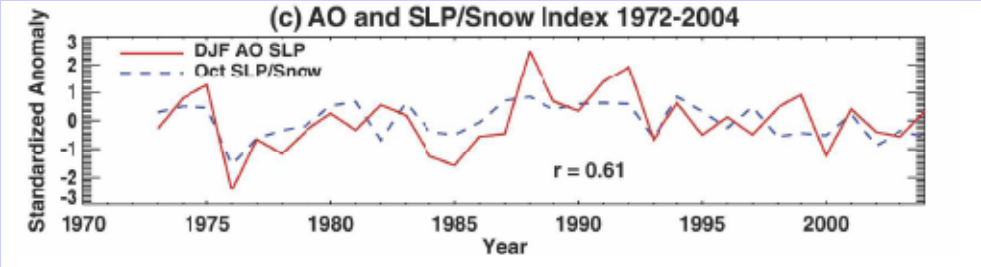
(а) (б)





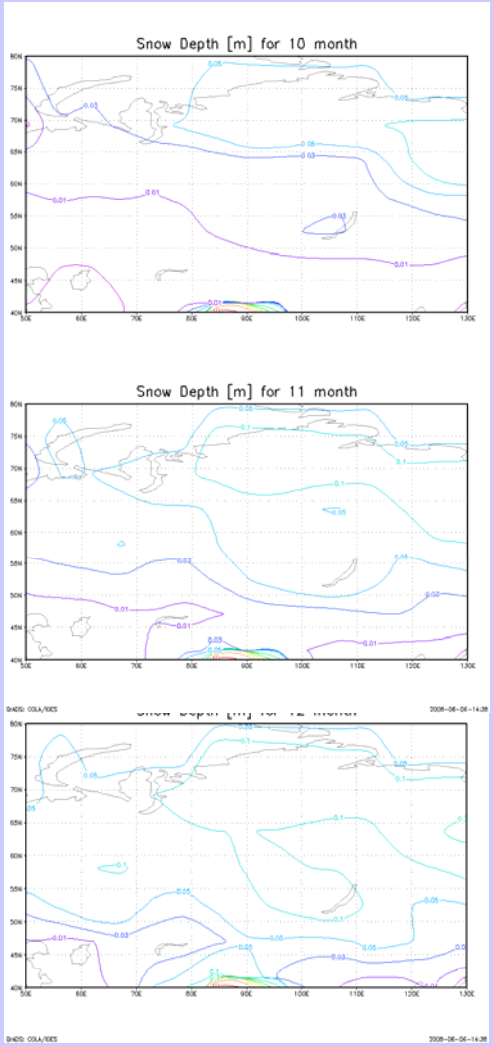
Normalized index NAO: (a) – autumn; (b) – winter

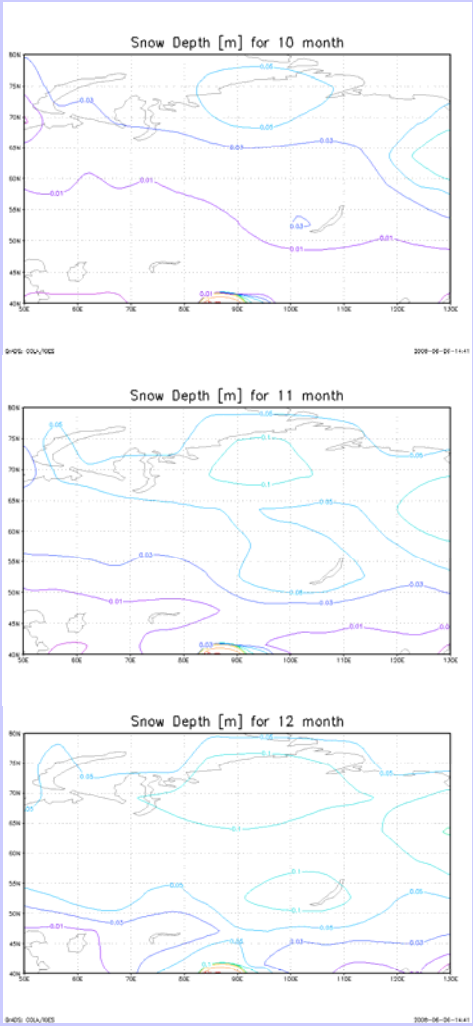




$$SS_i = \alpha \frac{SNOW_i}{\sigma_{sn}} + \beta \frac{SLP_i}{\sigma_{slp}} + \lambda,$$

Snow depth (oct. – dec.) in Siberia





Results from ensemble of transient simulations using a climate system model forced with anomalous Siberian snow extent…

- Planeta_Sim model: Grid=72*36*24

- Prescribed snow field:

Max = max over Siberia, October mean elsewhere.
Min = min over Siberia, October mean elsewhere.

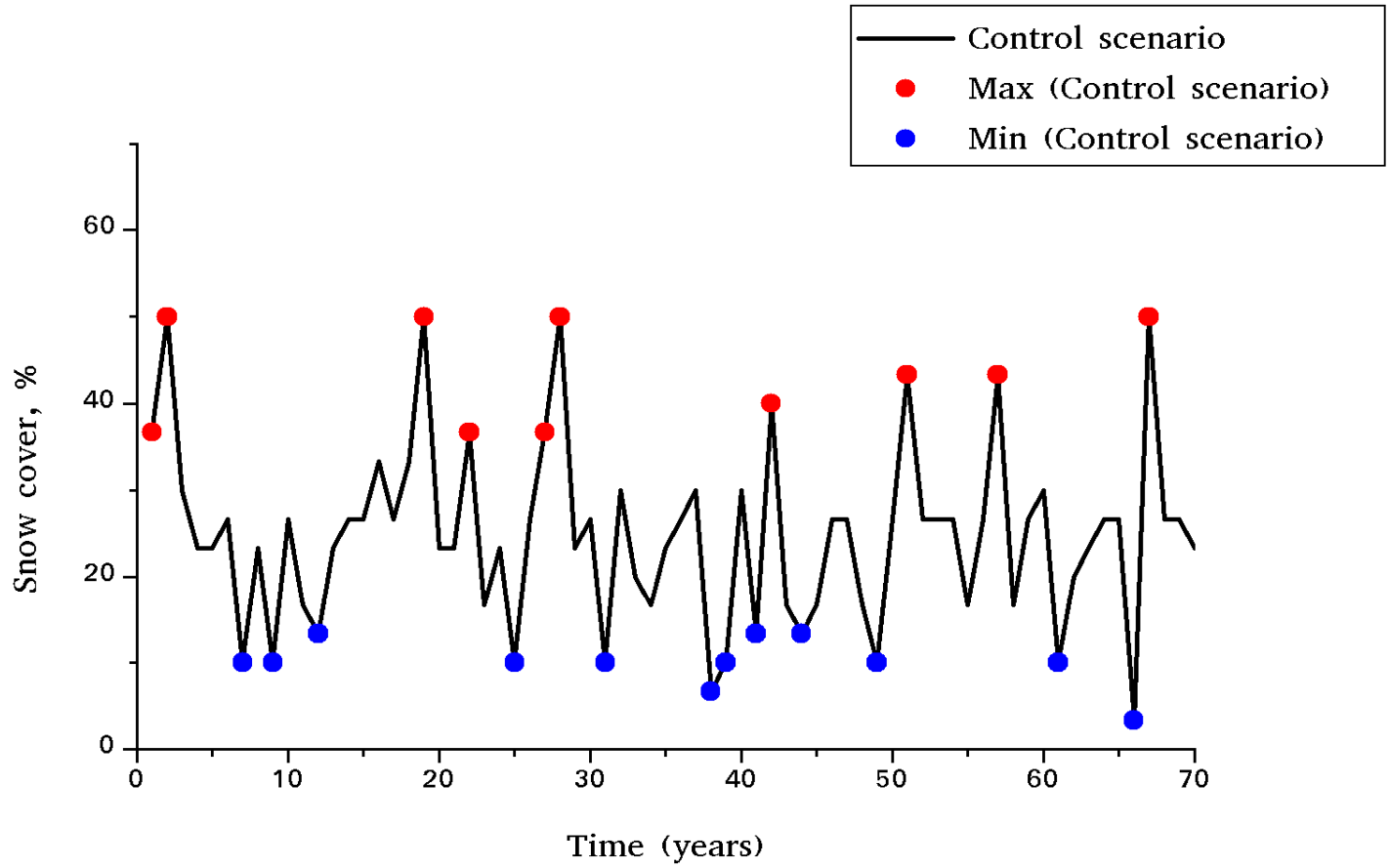
- Oct 1st - Jan 31st

- 2 x 10-member ensembles (paired independent initial conditions)

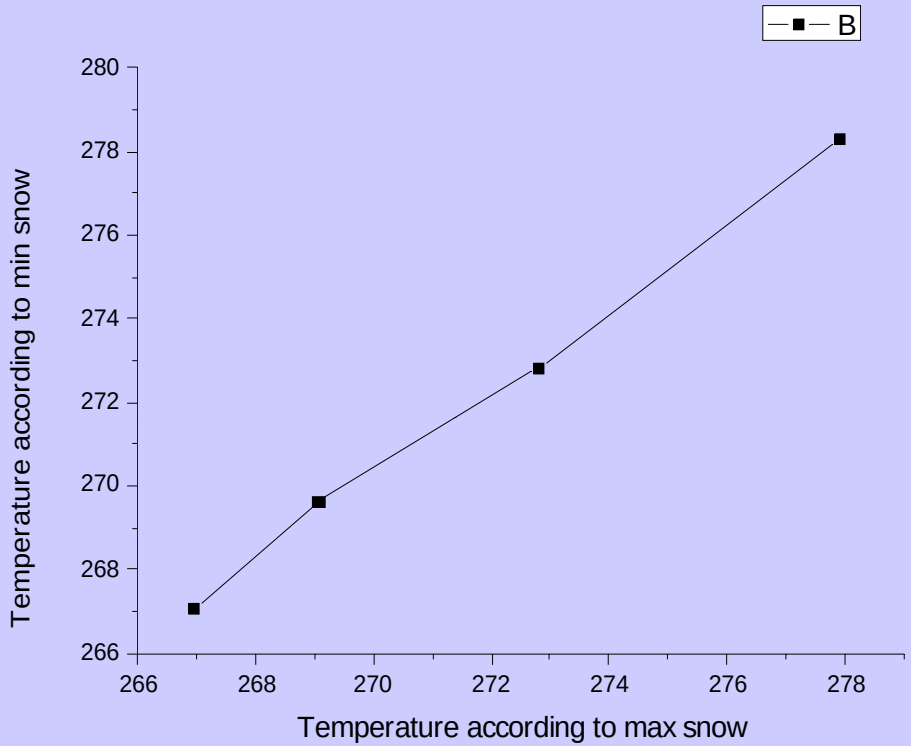
- Seasonally varying insolation

- Climatological SST

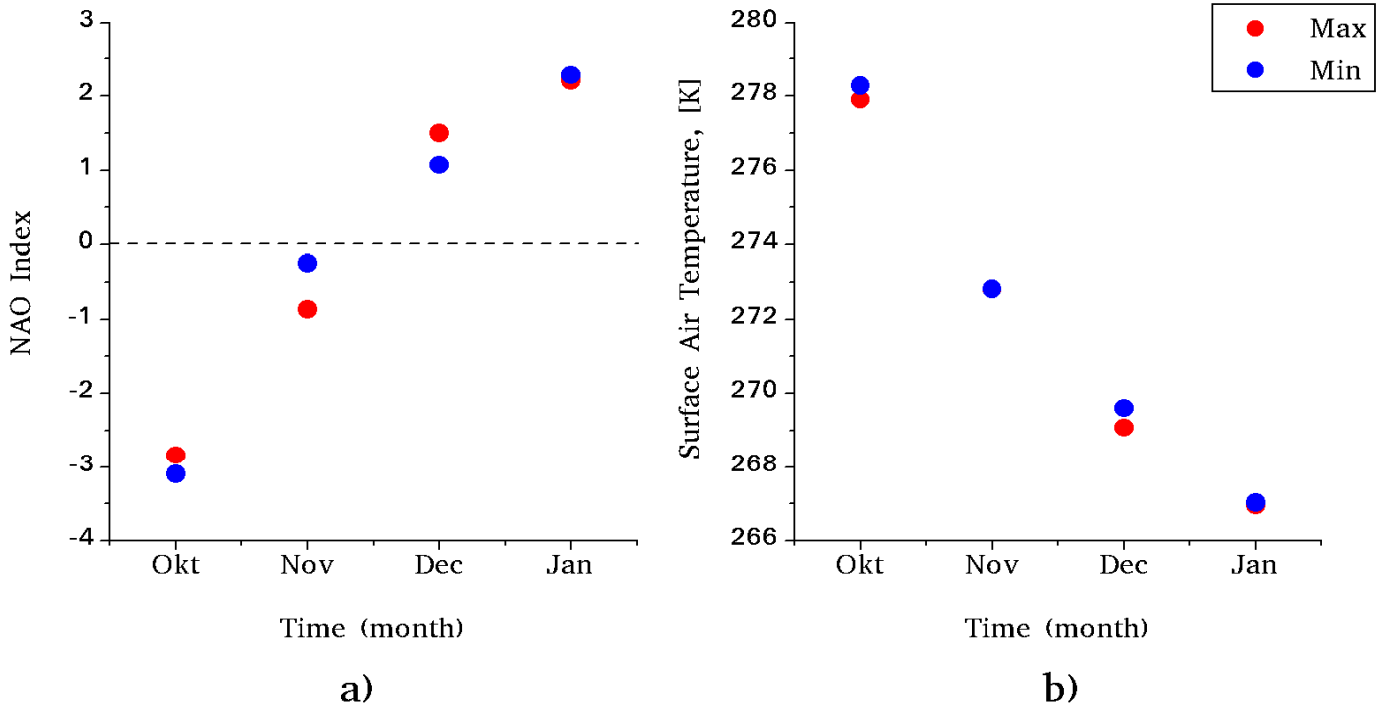
- ‘Response’ = Max minus Min ensemble mean.

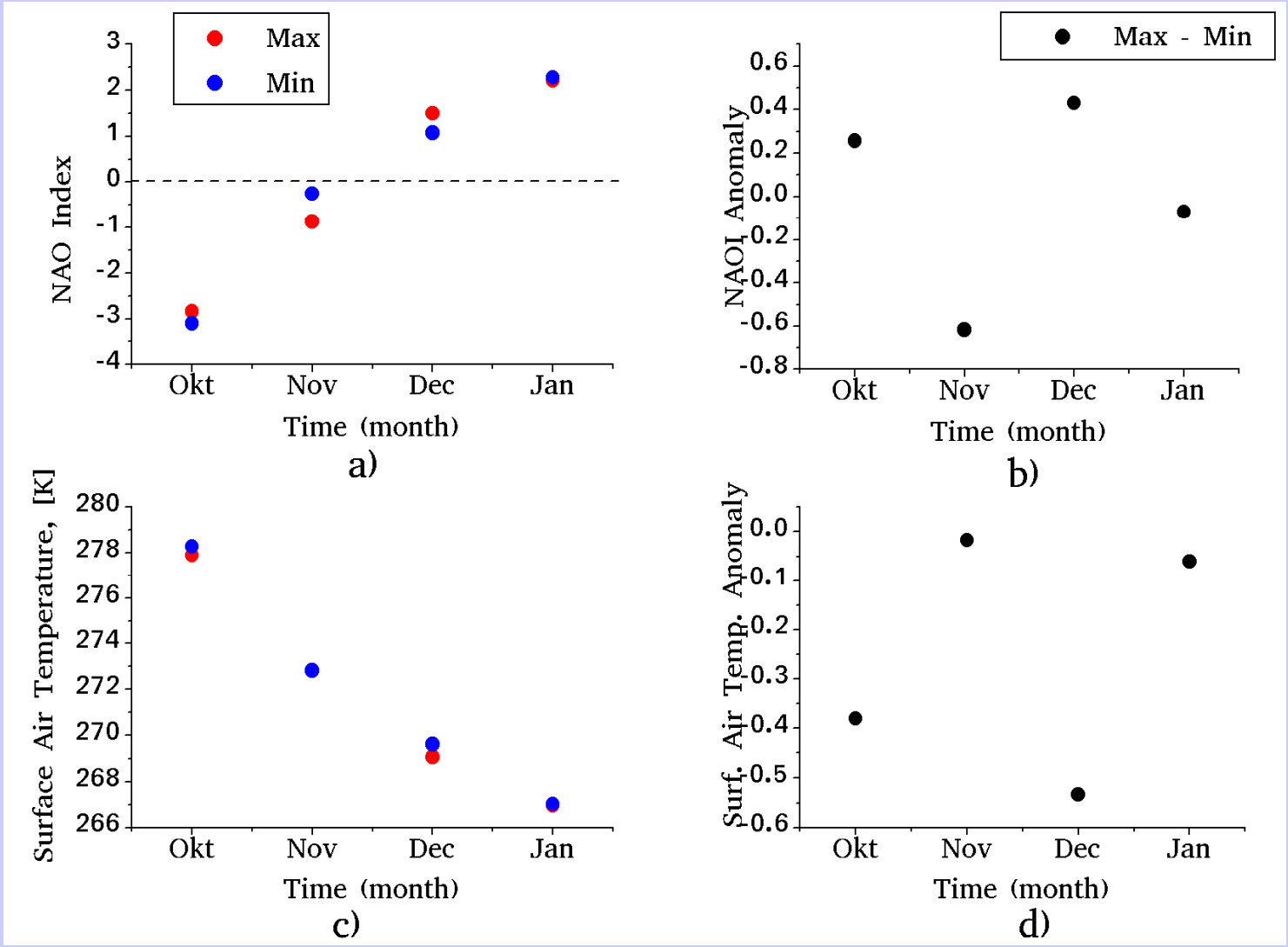


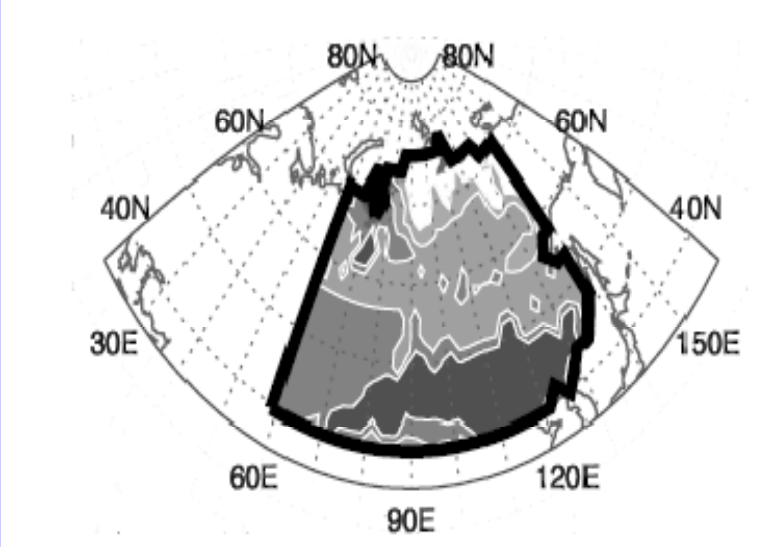
Territory under snow (%) for 1 Oktober at each year



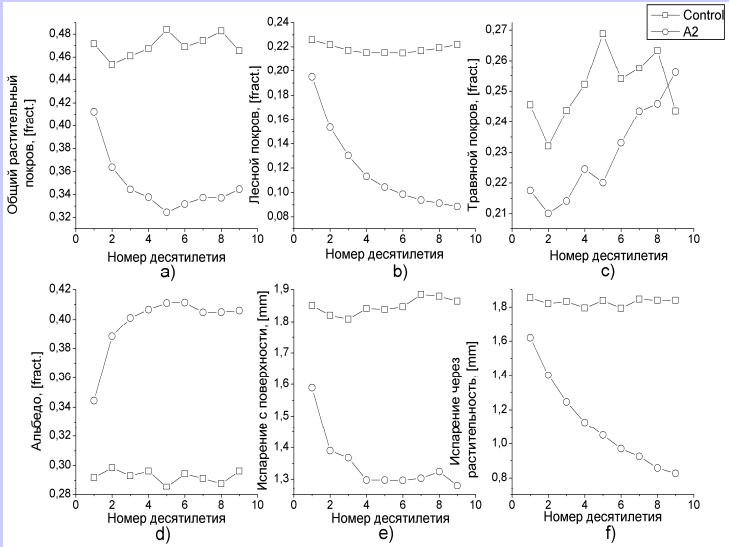
Max(snow)	Min(snow)	Max – Min
277,9033	278,2841	-0,3808
272,8008	272,8175	-0,0167
269,0754	269,6085	-0,5331
266,9662	267,0265	-0,0603


NAO Index
3
2
1
0
-1
-2
-3
-4
Okt
Nov
Dec
Jan
Time (month)
a)
Surface Air Temperature, [K]
280
278
276
274
272
270
268
266
Okt
Nov
Dec
Jan
Time (month)
b)
Max
Min


Max
Min
NAO Index
3
2
1
0
-1
-2
-3
-4
Okt
Nov
Dec
Jan
Time (month)
a)
Max - Min
NAOI Anomaly
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
Okt
Nov
Dec
Jan
Time (month)
b)
Surface Air Temperature, [K]
280
278
276
274
272
270
268
266
Okt
Nov
Dec
Jan
Time (month)
c)
Surf. Air Temp. Anomaly
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
Okt
Nov
Dec
Jan
Time (month)
d)



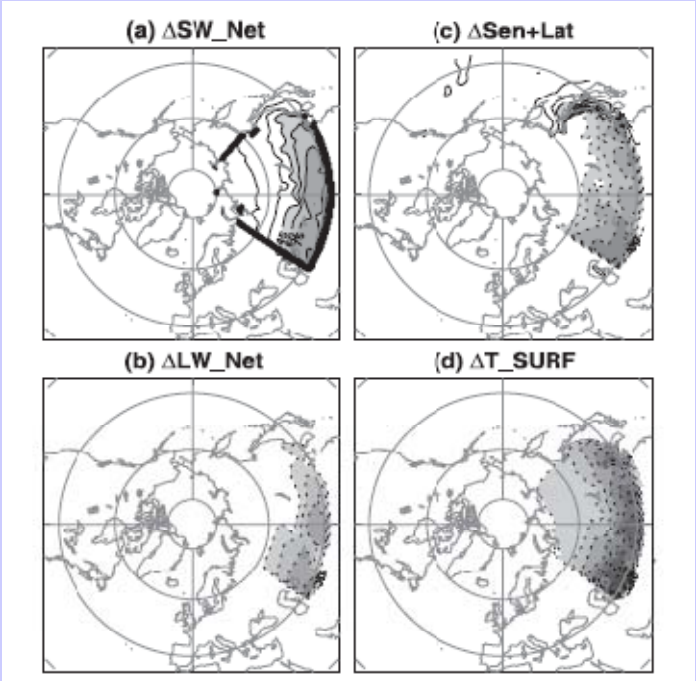
Basic mechanism of influence of anomaly of a snow cover of Eurasia this increase albedo surfaces from 0.15 to 0.66 (Fletcher et al. 2007).



Changes of parameters of surface for two scenario depending on number of decade of integration (0 – 2000, 10 - 2100) in Siberia (Krupchatnikov, etc., 2009)

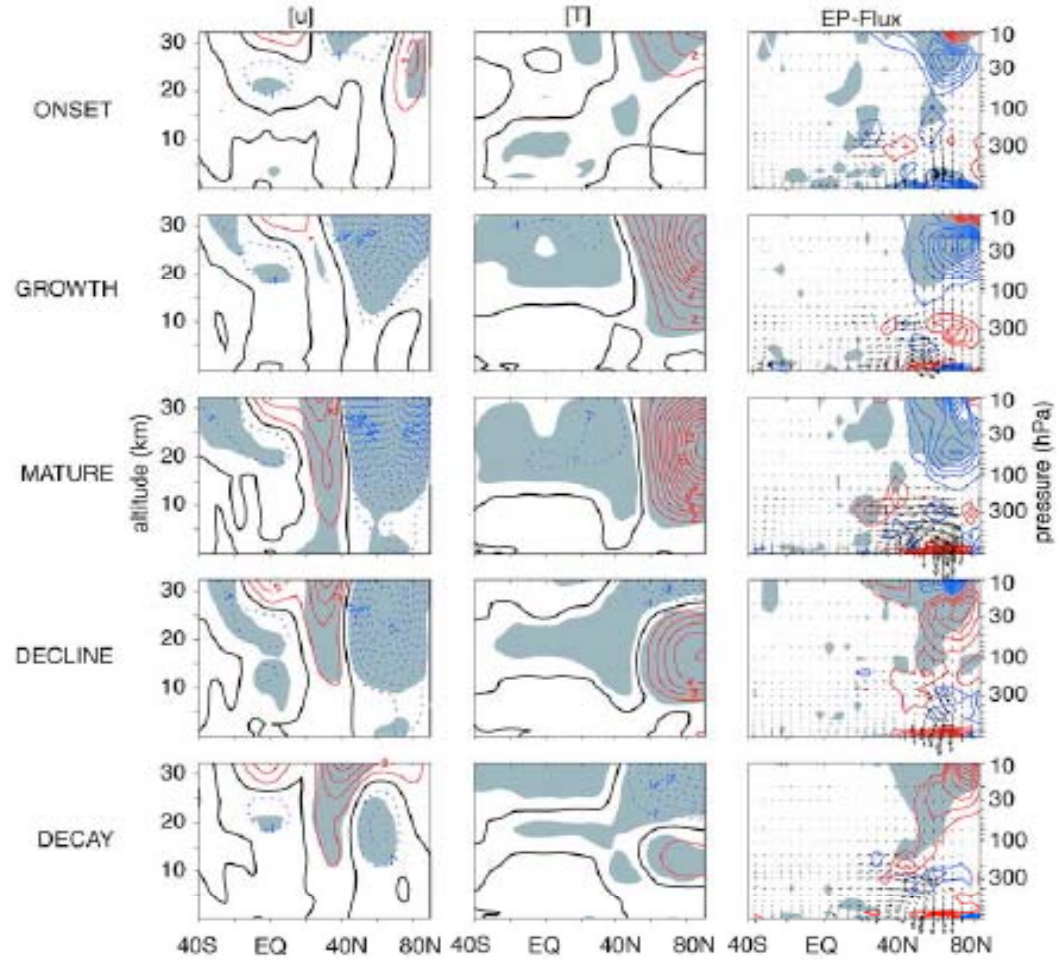
Responce of atmosphere to radiative cooling (36 W/m2), caused by increase albedo:

The temperature falls on ~ 3 K; The long-wave radiation flux decreases on 14 W/m2.



Time-averaged ensemble mean surface response to snow forcing for days 1–15 in (a) net shortwave radiation (W/m2), (b) net longwave radiation (W/m2), (c) sensible plus latent turbulent heat fluxes (W /m2), and (d) surface temperature (K). Contour interval and shading (a)–(c) is 15 W/m2 and in (d) is 2 K, and negative contours are dashed.

(Fletcher et al, 2009)



Limpasuvan et al [2004]

The phenomenon of descending influence of a variation of the main flow in a stratosphere on a variation of circulation in the low stratosphere and in a weather layer of troposphere is known – “downward control” .

Within the next two months after occurrence of anomaly in a stratosphere the structure of ground pressure becomes rather like structure of leading modes NAO/AO.

It means, that in a stratosphere there are harbingers which can be used as the precursor of weather conditions in troposphere (M. Baldwin, T. Dunkerton, 2001).

- Snow forces significant local cooling ⇨ intensification and eastward propagation of Siberian High.

- **Snow forcing in autumn is may be proposed as a source of seasonal predictability in the NH extratropics during winter**

Problems:

- weather noise, model sensitivity at midlatitudes.

- Idealised model experiments -- does snow force upward WAF in simplified model?

- Nonlinearity may be important -- does snow influence weak and strong vortex events differently?

Acknowledgements

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