Arctic moisture source for Eurasian snow cover variations in autumn

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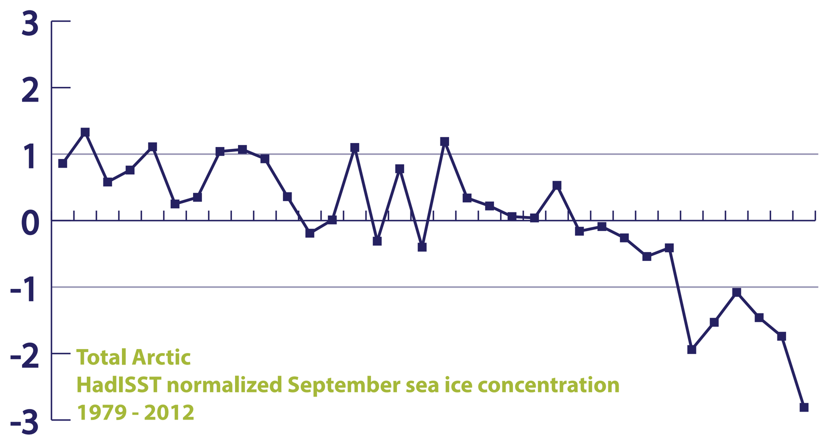
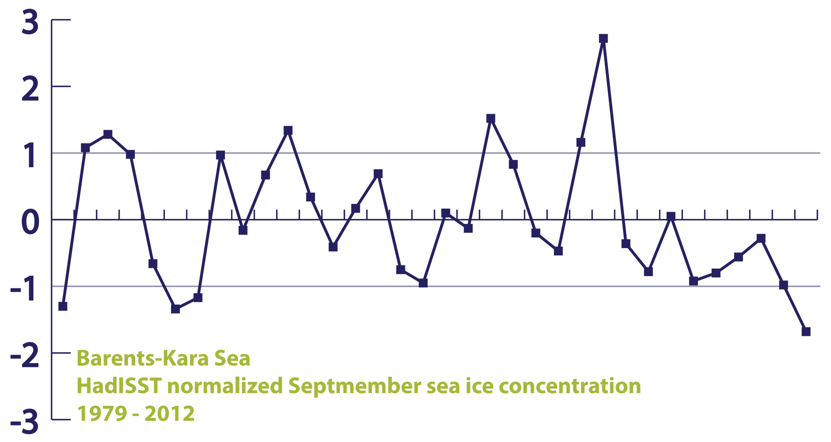
Background

Recent Arctic warming is one of the strongest effects of global change. Sea-ice decline is very prominent as well as the reduction in mass of the Greenland ice sheet.

Arctic summer sea-ice extent has declined by more than 10% per decade since the start of the satellite era (e.g. Stroeve et al., 2012), culminating in a **record low** in September 2012, with the long-term trend largely attributed to **anthropogenic global warming.**





Eurasian fall snow cover changes have been suggested as a driver for changes in the Arctic Oscillation and might provide a link between sea-ice decline in the Arctic during summer and atmospheric circulation in the following winter.

? *How consistent is the link between sea-ice variability in the Barents-Kara sea region and snow pack variability in Central Eurasia during early snow fall season?*

? *What are possible moisture sources for the snow depth anomalies?*

? *What are the atmospheric conditions and dynamics to sustain such a snow depth distribution?*

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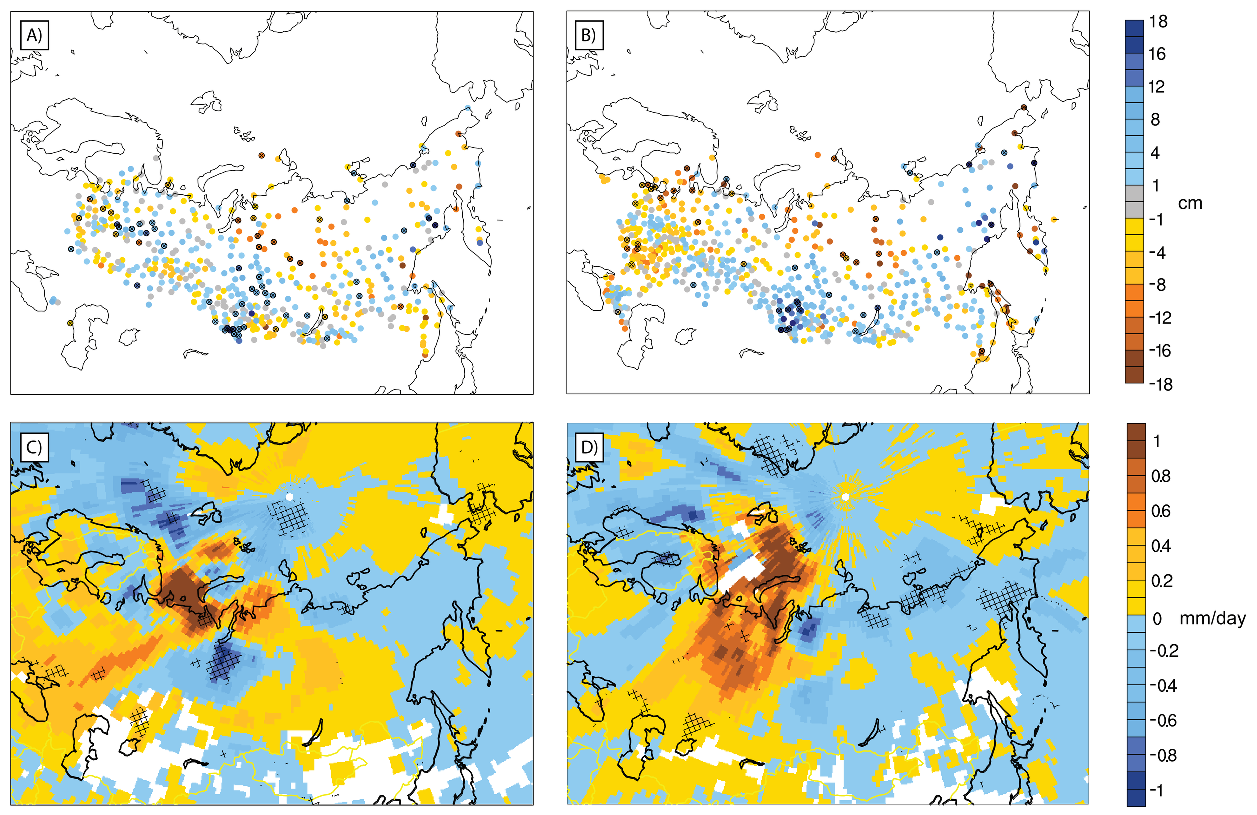
Results for October and November

Snow depth anomalies and Flexpart moisture distribution



Differences between low and high BKS September sea-ice in station snow depth [cm] for A) October and B) November. E-P [mm/day] from forward trajectories starting in the BKS region for C) October and D) November. Shaded areas and crossed stations represent 90% Student´s t-test significance level.

Octobers in years with low BKS sea-ice have significantly **higher snow depths in SW-Siberia** and in some coastal areas of the Far East and Northern Volga, with the first being the most striking region of positive anomalies.
Forward trajectories composite also indicates, that during low ice years, **air parcels which start over the BKS tend to lose more moisture over the Urals and the Far East.**

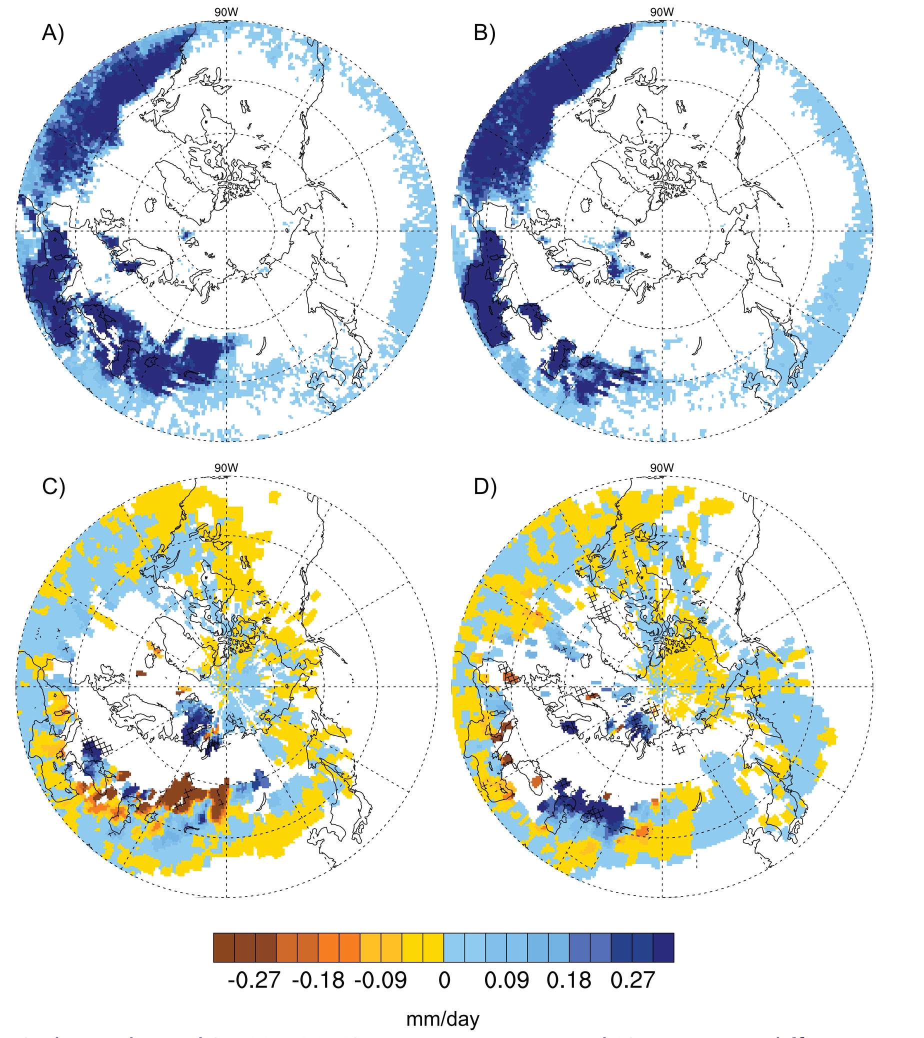
For **November**, we found **strong positive anomalies in Southern Siberia between Lake Balkash and Lake Baikal**, positive anomalies in the Far East, now more inland than in October, coexist with significant decrease of snow depth mainly between Lake Baikal and the Arctic coast as well as towards the western border of Russia.
Forward trajectories in FLEXPART indicate that air parcels starting over the Barents/Kara Seas tend to **loose less moisture over Western Russia** than during high ice years.

Moisture sources

The main **climatological moisture sources** for SW-Siberia in Oct. and Nov. are the Atlantic, the Mediterranean Sea and the Black Sea.

October composite: Air parcels arriving in SW-Siberia have **picked up more moisture over the BKS region** as opposed to high sea ice years, together with the Northern Balkans.

November shows two relatively enhanced moisture source regions: **The Kara Sea** and the northern surroundings of the Caspian Sea.



A) Climatological (1980 – 2012) moisture sources and C) composite differences in the moisture gain for backward trajectories starting in southwestern Siberia" (region of relatively high snow depth in low ice years) (left) for October. B and D show the same for November. Shaded areas represent 90% Student´s t-test significance level for anomaly plots.

Atmospheric conditions

Positive **snowfall anomalies** fit well with increased tropospheric uplift and **positive snow depth anomalies.** Another cause for higher snowfall are sea-land breezes.

SLP variance as a proxy for **storm activity** is showing increased activity over Central Siberia, with positive anomalies up to the Barents-Kara sea region.

The European high pressure center is an important trigger for **cold air advection to central Eurasia.**

A "**warm Arctic - cold continent**" pattern is found, with negative temperature anomalies over large parts of central Russia. Positive surface temperatures may reduce initial snowfall signal.

A pronounced **wave-number three** anomaly pattern is found for October and November for 500 hPa geopotential height.

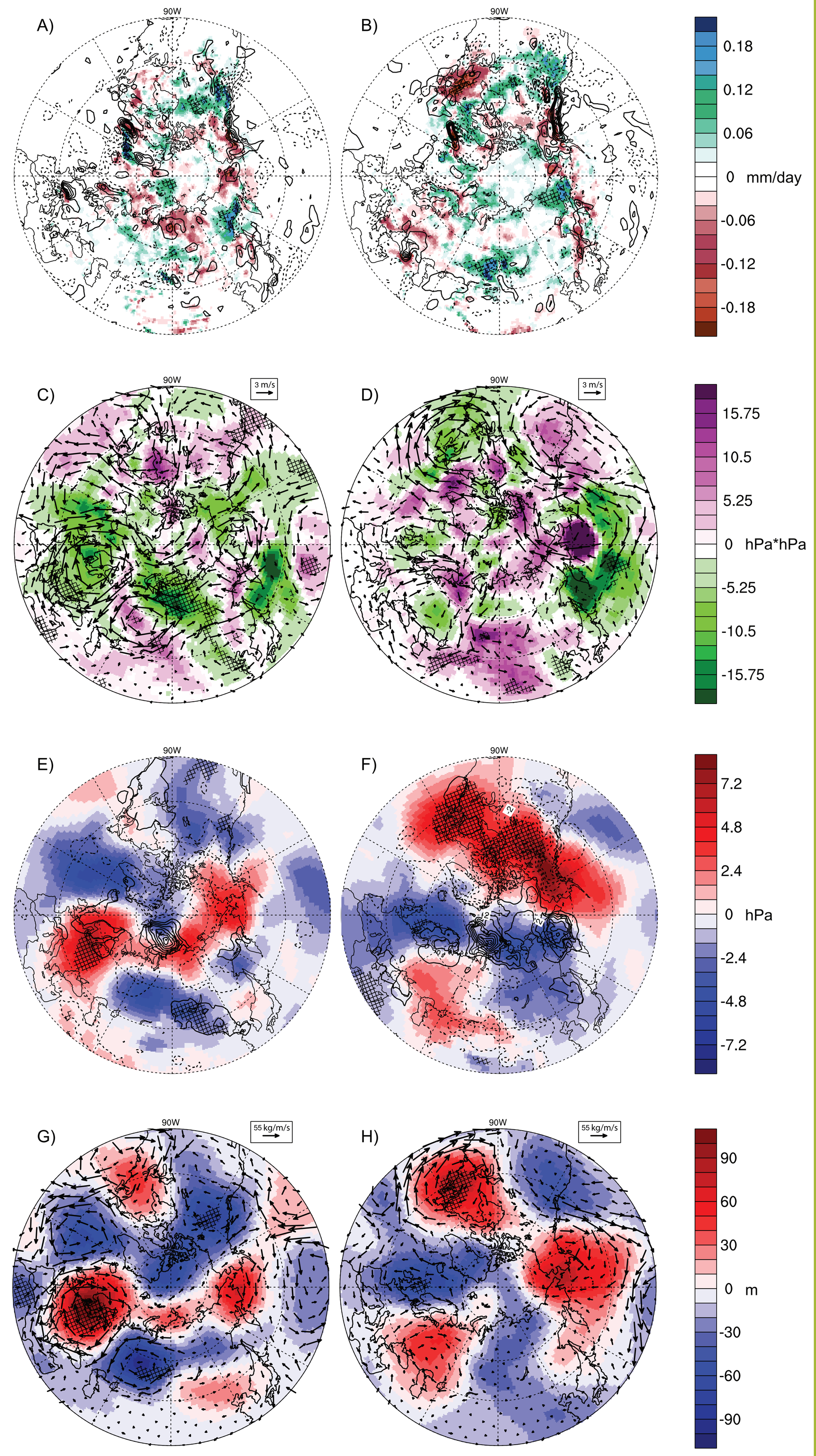


Fig. 3. Difference between low and high sea-ice years in the Barents Kara Sea region for A) 700 hPa Omega [Pa/s] (contours) and snow fall [mm/day] (colours), C) 700 hPa wind [m/s] (vectors) and 2-7 day band-passed SLP variance [hPa2] (colours), E) SLP [hPa] (colours) and 2m temperature [K] (contours), and G) geopotential height at 500 hPa [m] (colours) and integrated water vapour transport [kg/m/s] (vectors) for October. Positive/negative differences are plotted as solid/dashed contours. B,D,F,H show the same for November. Shaded areas represent 90% Student´s t-test ignificance level for colored variables.

Conclusions

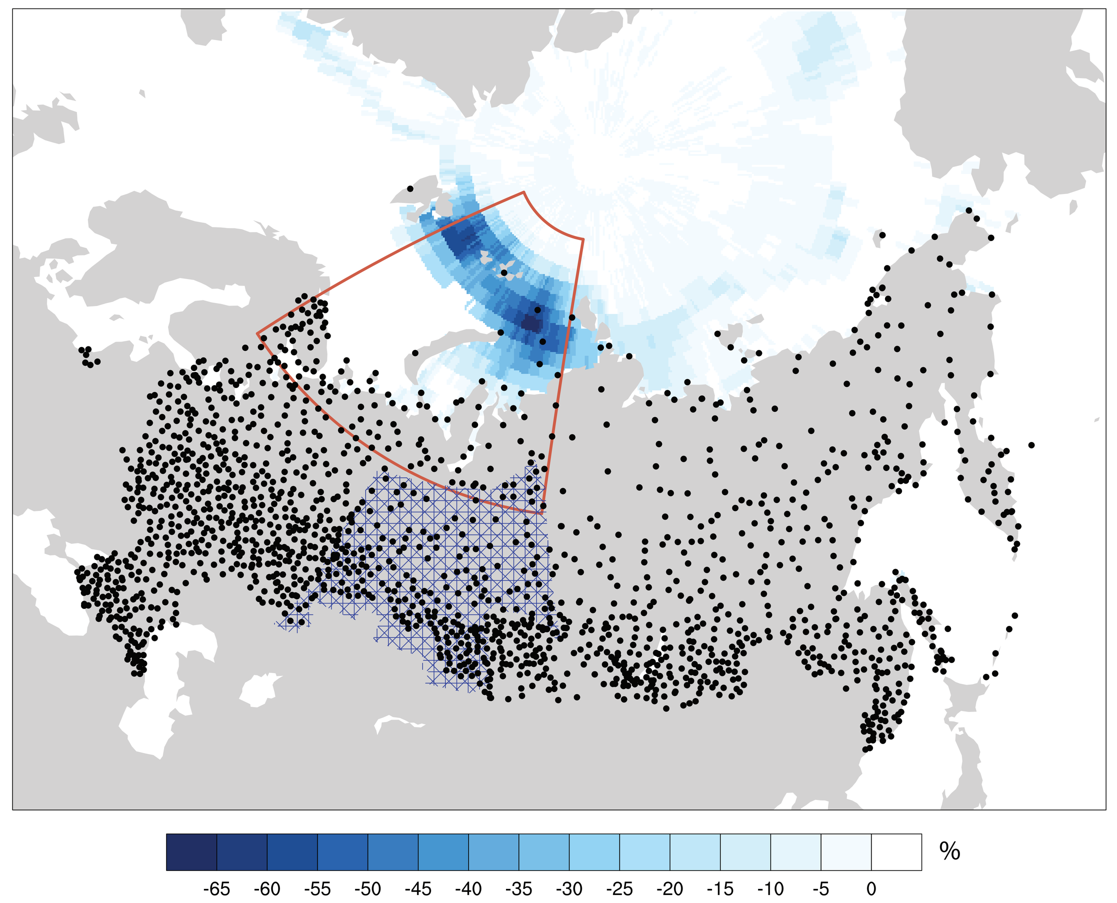
Evidence was found for an **increase of SW-Siberian snow depth in years of low sea-ice** in the BKS region. Backward trajectories from FLEXPART originating in that region indicate an **ice free BKS as a main moisture source** and an important factor for Siberian snow accumulation.

ERA-INTERIM shows an increased atmospheric wavenumber and meridional circulation during low sea-ice years. **Cold air advection from the Arctic sea** into the Eurasian continent is strenghend, accompanied by an **intensified storm track over and into SW-Siberia.**

Storms enter the continent through a small sector over the BKS, steered by a block to the West and a low to the East, extending to Central Russian land areas. In case of the strong snow depth increase during October, **enhanced frontal activity on the southeastern flank of the cyclonic anomaly** is a possible trigger for the increased vertical uplift.

Setting

Data



Map showing the positions of the 820 snow cover stations (black dots), with the BKS and the "southwestern Siberia" regions highlighted (red frame and blue crossing, respectively). Blue shading shows the composite of HadISST October and November sea-ice concentration anomalies of high minus low sea-ice years.

- **HadISST** sea ice coverage database
- **Daily snow depth observations** from 820 Russian meteorological stations
- **ERA-INTERIM** reanalysis dataset covering 1979 - 2013 (1 .5°x 1.5°)
- **Flexpart V9.0** forward and backward mode based on ERA-INTERIM input and domain

Methods

Based on HadISST sea-ice data (Rayner et al. 2003) we defined years with high or low sea-ice in the **Barents and Kara Seas** (BKS) region (65-85° N, 30-90° E) in September.

High and low ice years are defined by **exceeding one standard deviation** of the normalized sea-ice concentration (see Background Graph) which results in **six high sea-ice years and four low sea-ice years.**

We then analyse differences in **snow depth, moisture transport and atmospheric circulation** diagnostics for the selected high minus low sea ice years in **October and November:**

Flexpart forward analysis considers only particles starting in the BKS region and following the particles over a period of 3 days. Furthermore, a **backward trajectory analysis** is carried out where particles arriving over SW-Siberia are tracked backwards to their region of origin over a period of 3 days.