Can Solar cyclic Variability modulate Winter Arctic Climate?

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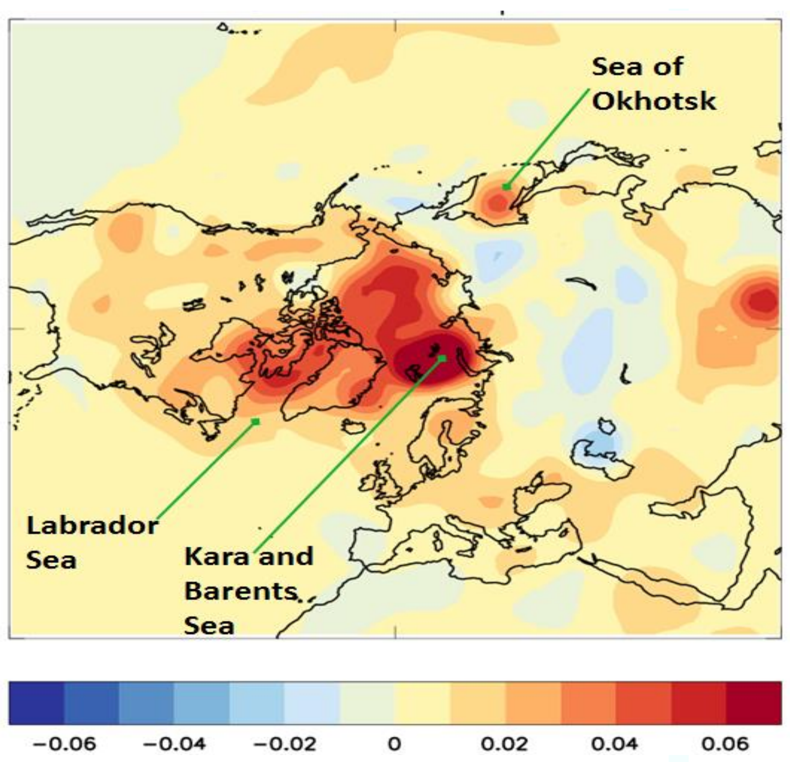
Abstract. This study investigates the role of the eleven-year solar cycle on the Arctic climate during 1979–2016. It reveals that during those years, when the winter solar sunspot number (SSN) falls below 1.35 standard deviations (or mean value), the Arctic warming extends from the lower troposphere to high up in the upper stratosphere and vice versa when SSN is above. The warming in the atmospheric column reflects an easterly zonal wind anomaly consistent with warm air and positive geopotential height anomalies for years with minimum SSN and vice versa for the maximum. Despite the inherent limitations of statistical techniques, three different methods – Compositing, Multiple Linear Regression and Correlation – all point to a similar modulating influence of the sun on winter Arctic climate via the pathway of Arctic Oscillation. Presenting schematics, it discusses the mechanisms of how solar cycle variability influences the Arctic climate involving the stratospheric route. Compositing also detects an opposite solar signature on Eurasian snow-cover, which is a cooling during Minimum years, while warming in maximum. It is hypothesized that the reduction of ice in the Arctic and a growth in Eurasia, in recent winters, may in part, be a result of the current weaker solar cycle.

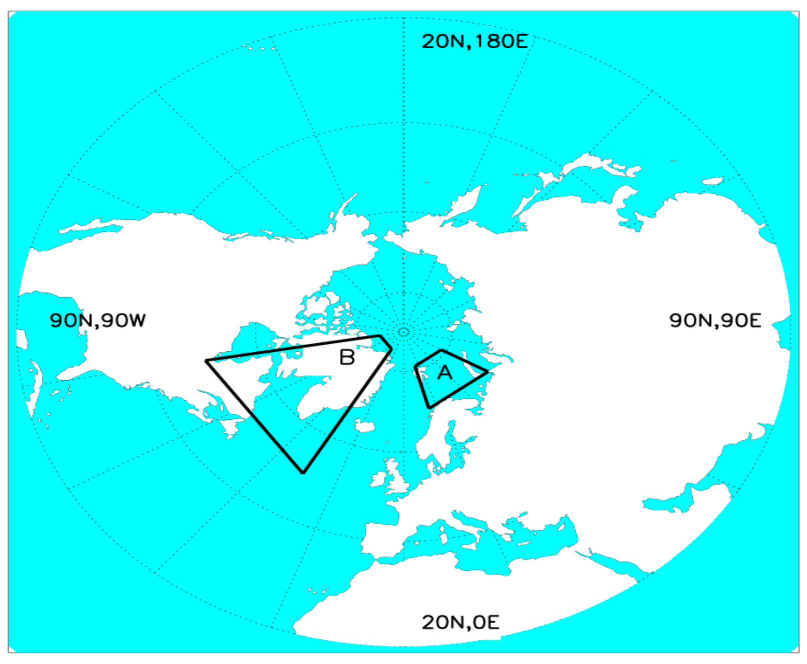
1. Background: Trend

Trend: 1000mb Air Temperature (DJF, 1979-2016)



- Warming in Arctic, cooling in Eurasian sector.

Map of Arctic



- More warming in Kara and Barents Sea- Marked by 'A'.
- Lesser warming in Greenland and Labrador Sea area- Marked by 'B'.

2. Method & Results

We employ monthly datasets of Sun Spot Number (SSN), Sea Level Pressure (SLP), Sea Surface Temperature (SST), Air temperature, Geopotential Height, Zonal Wind, Arctic Sea Ice Extent (SIE), Arctic Oscillation (AO) and Atlantic Multidecadal Oscillation (AMO). We use three different techniques: Compositing technique, Correlation method and a Multiple Linear Regression (MLR) Analysis, incorporating an AR(1) noise model. In MLR, dependent parameters are: a linear trend, stratospheric aerosol optical depth (AOD, to represent volcanic effects), QBO (30 hPa) and ENSO. [See at the end for data sources.]

2.1. Method of Compositing : Years of Solar Max and Min

Solar Cycle No	Cycle Year	Solar Minimum (Min) Years (SSN <100 or mean)	Solar Maximum (Max) Years (SSN >100)
21	1976 –1986	1984,1985,1986	1979,1980,1981,1982,1983
22	1986 –1996	1987,1988,1994,1995,1996	1989,1990,1991,1992,1993
23	1996 –2007	1997,1998,2004, 2005,2006, 2007	1999, 2000,2001,2002,2003
24	2008 –2016	2008,2009, 2010,2011, 2012, 2013, 2015, 2016	2014
Total	38	22	16

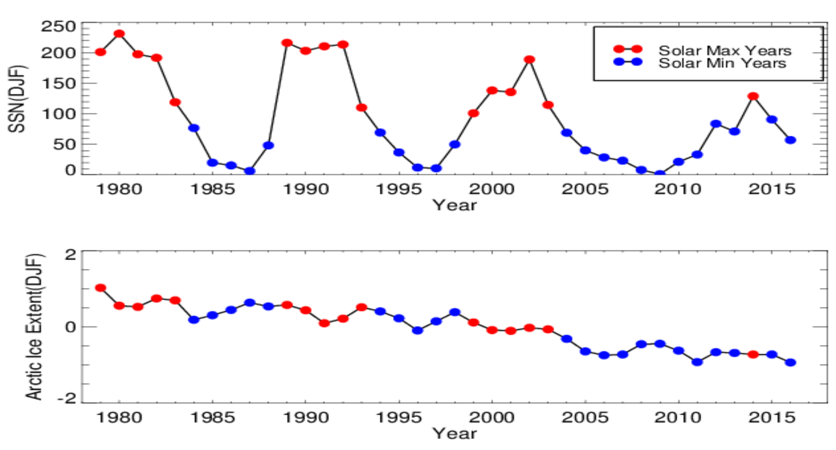


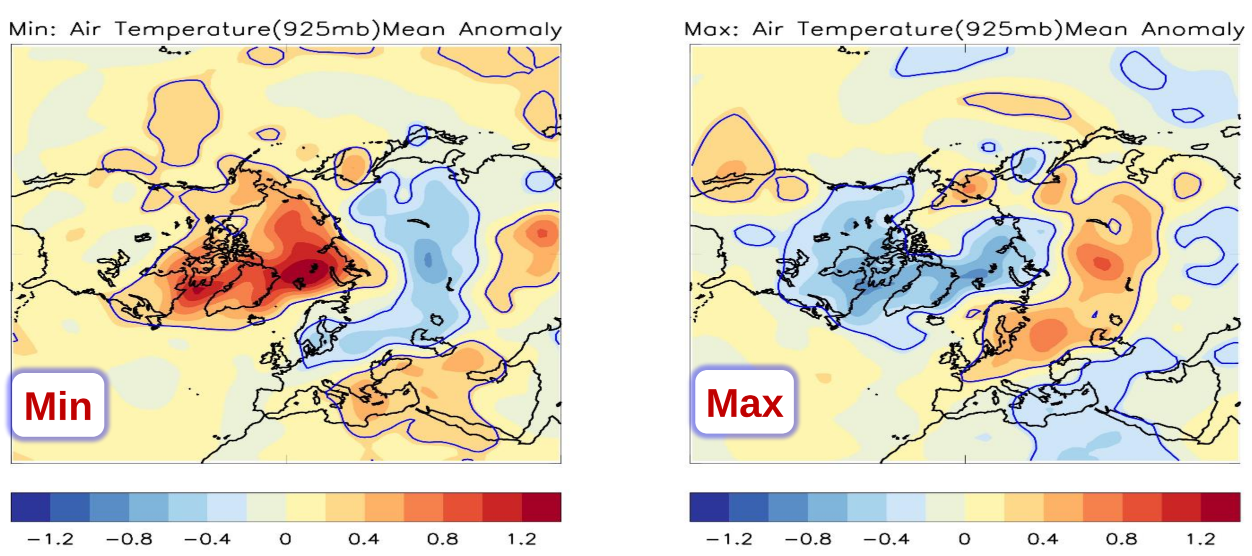
Figure. Time Series (**DJF**): Solar cycle (top) and Arctic Sea Ice Extent (bottom).

Top: Equal number of Max and Min points. Exception **last solar cycle**- only **one Max** of 2014.

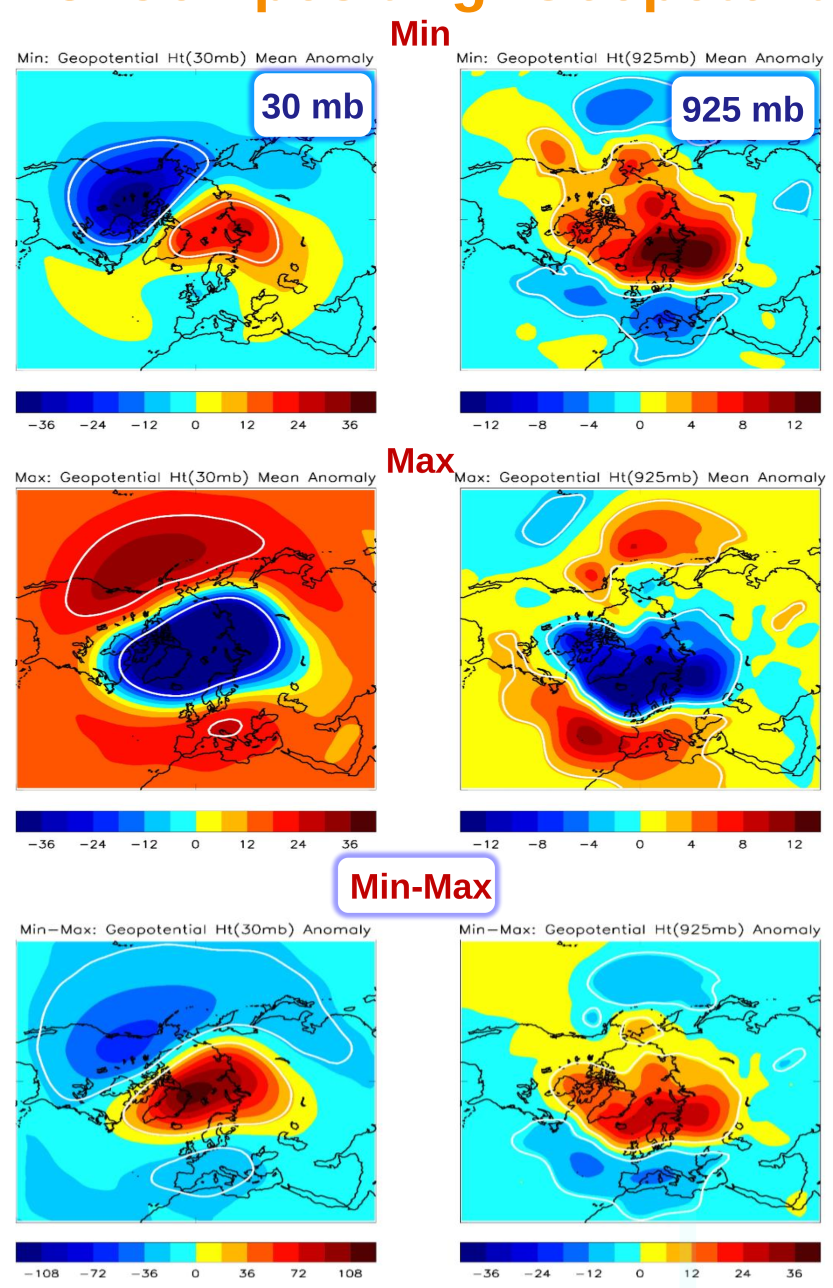
Bottom: Last four years after 2014 is unprecedented Ice loss.

2.2. Results: Compositing Air Temperature (Min vs Max)

- **Min**: Warming in Arctic, but cooling in Eurasian Sector.
- **Max**: Cooling in Arctic, but warming in Eurasian Sector.
- Even detrending data before, nature of signal does not change.

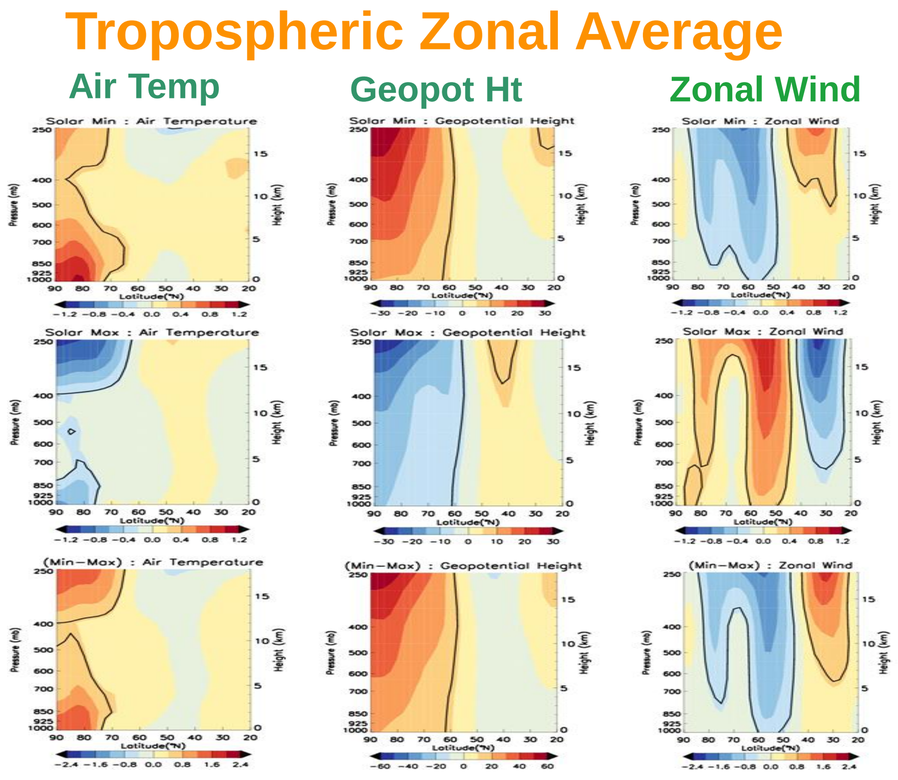


2.3. Compositing: Geopotential Height (Solar Min vs. Max)



- **Min**: +ve Geo.pot. Height (gph) in Arctic for 30mb and 925 mb. **Max**: -ve gph. Signal similar with or without the trend.
- **Min-Max**: gph diff. 30 mb -108m; 925 mb - 24m.

Tropospheric Zonal Average

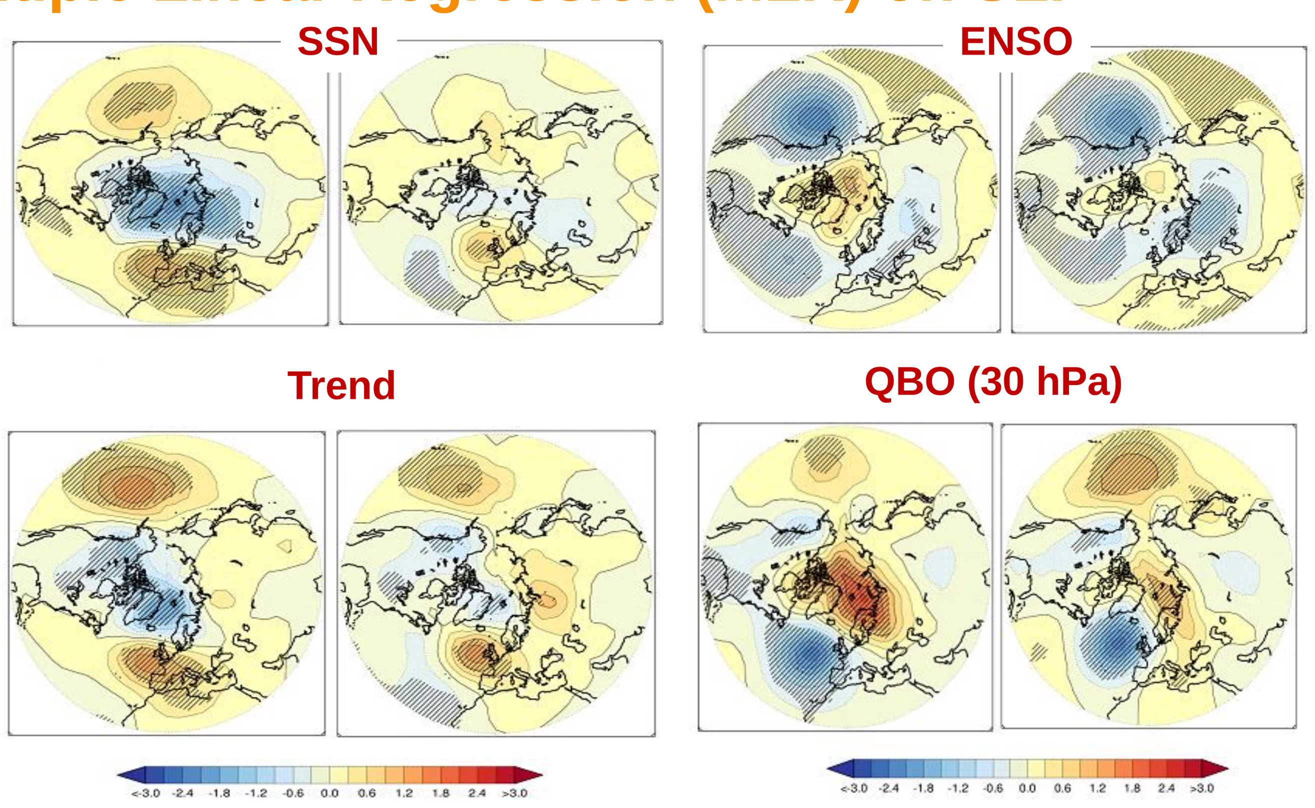


- **Min: Warming** in Arctic, **+ve** Geopotential Ht., **-ve** zonal wind (Top).
- **Max: Cooling** in Arctic, **-ve** Geopotential Ht., **+ve** zonal wind (Middle). **Min-Max**: Bottom.

2.4. Multiple Linear Regression (MLR) on SLP

Figure. Without AO (left); including AO (right) for all cases.

- Strongest signal due to **Sun** followed by **QBO**.
- **Including AO,** signal in Arctic reduces; **major reduction** for **solar** signal.
- Solar signal in Arctic is via **AO**.



2.5 Proposed Mechanism

UV 205 nm increases ~6% Solar Min to Max

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More ozone heating in upper stratosphere(DJF), SH causes stronger jet (U) in NH– follows Thermal Wind Balance Relationship

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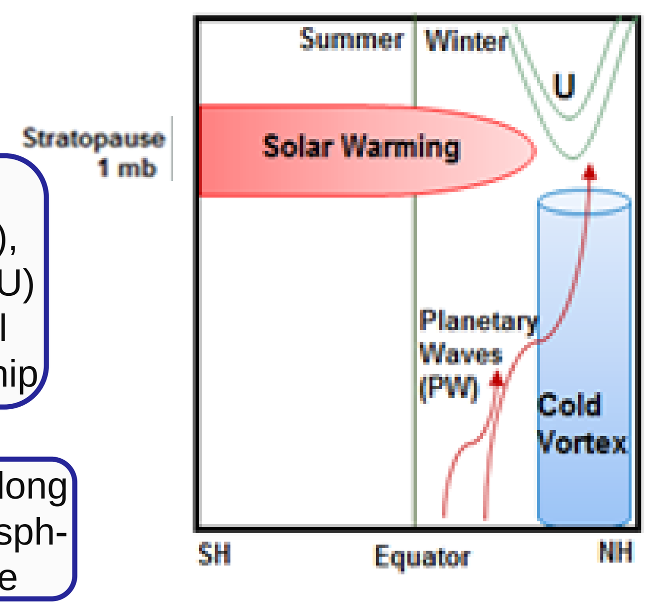
Planetary waves (PW) (long say no ~1-3) from troposph--ere reach stratopause



Charney Drazin Criteria: PW cannot break strong U. Hence, in Max, vortex stronger, constricted, colder. In Min, it breaks, mixes with airs, causes warm vortex.

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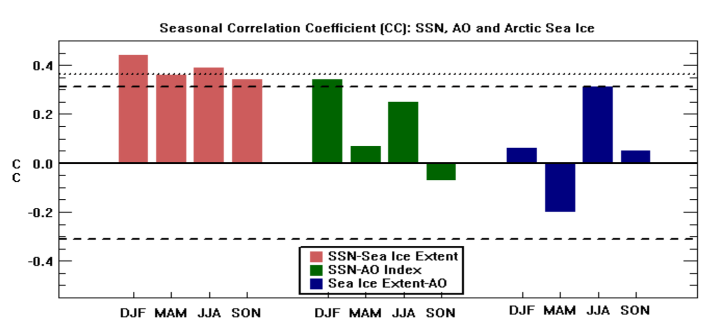
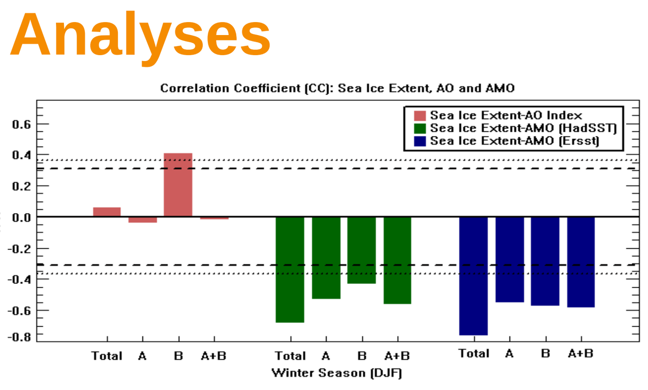
Perturbation of stratospheric vortex are transported down to surface via NAM (Baldwin et al. 1999). **Thus, Cold (Warm) Arctic for Solar Max (Min).**

2.6 Results: Correlation Analyses



Significant upto **95%** by **dash line**, 99% by dotted line.



- **SSN** has significant +ve correlation with **SIE and AO** in DJF. **SIE** does **not** show significant correlation with **AO** in DJF (left). Only **Region B** shows connection for **AO** and **SIE** (right).
- **AMO** has a strong -ve **correlation** with **SIE** for **all regions. True for HadSST, Ersst** (right).

3. Conclusions

- During years, when winter SSN falls below mean (termed as solar **Min**), **warming** in **Arctic** extends from **lower troposphere** to high up in the upper stratosphere and **vice versa** when SSN is above (**Max**).
- **Warming** in atmospheric column reflects **easterly zonal wind** anomaly consistent with warm air, **positive geopotential height** anomalies for **Min** and vice versa for Max.
- Despite inherent limitations of statistical techniques, three different methods – **Compositing, MLR and Correlation** – all point to similar modulating influence of sun on winter Arctic climate via pathway of **Arctic Oscillation**.
- Presenting schematics, it discusses **mechanisms** how **solar cycle** variability influences **Arctic** climate involving **stratospheric route**.
- Compositing also detects **opposite** solar signature on **Eurasian** snow-cover, which is **cooling** during **Min** years, while **warming** in **Max**.
- Hypothesized that **reduction** of ice in **Arctic** and **growth** in **Eurasia**, in recent winters, may in part, be result of current **weaker solar cycle**.
- Greenland region shows strong connection between AO and Arctic Sea Ice Extent (SIE) in winter.
- In winter, AMO has strong significant negative correlation with SIE for all regions in Arctic.
- Strong connection between AMO and SIE is seen even using different data sources HadSST or Ersst.

For further details see: Roy, (2018). Scientific Repoers, 8, 4864.

Data

SLP: HadSLP2. http://www.metoffice.gov.uk/hadobs/hadslp2. Updated up to 2012 using HadSLP2r_lowvar data52 (http://www.metoffice.gov.uk/hadobs/ hadslp2/data /down load.html); **SSN**: http://www.sidc.be/silso/versionarchive ;
SST: NOAA extended SST v4 (ERSST). http://www.esrl.noaa.gov/psd/ ; **Air temperature, geopotential height, zonal wind**: NCEP/NCAR reanalysis product. http://www.esrl.noaa. gov/psd/.
ENSO, AO, AMO, AOD: KNMI Climate Explorer (http://climexp.knmi.nl) ; **QBO**: http://www .cpc.ncep.noaa.gov/data/indices/qbo.u30.index; **Arctic Sea Ice Extent (SIE)**: http://nsidc.org/data/seaice_index/