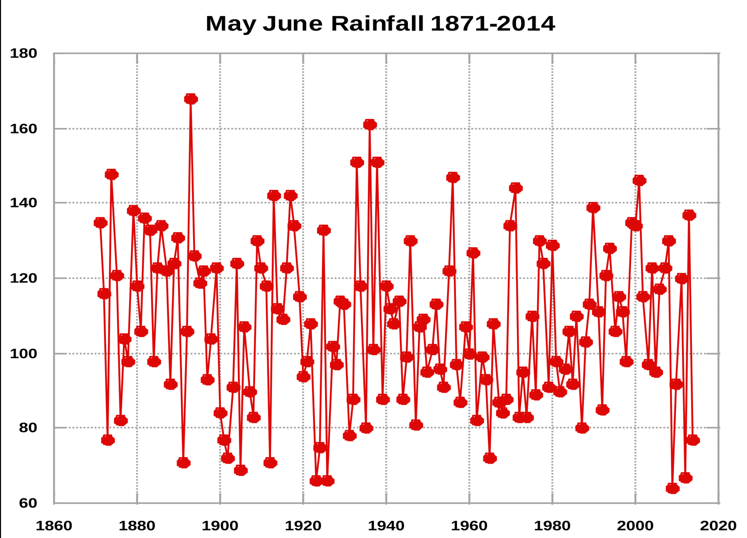

Time series for May-June rainfall
All India area weighted mean rainfall data set of 306 rain gauges in India (1871-2014)

Changing Seasonality of Indian Monsoon

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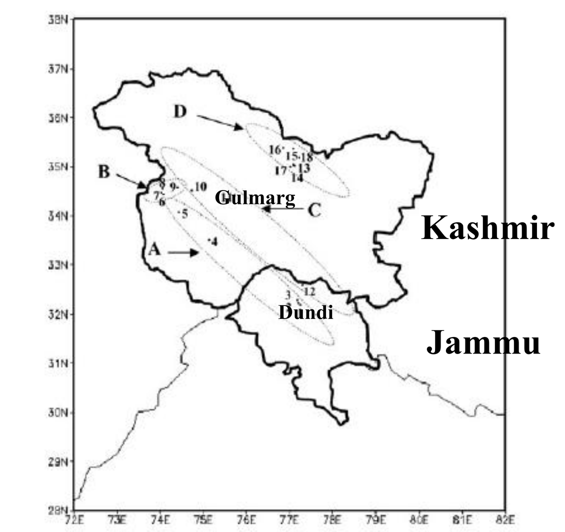
Arctic Change and its influence on Mid-latitude Climate & Weather, Feb 1-2, Washington D.C.

Western Himalaya



Main Results

- Increase in May-June rainfall. Is the shift in seasonality driven by a decline in Himalayan snow depth?
- Correlation between M-J rainfall and SWE is positive in northern Eurasia and negative in southern Eurasia.
- Research shows that sea ice is one of the drivers for higher northern Eurasian snow depth.
- A link between the Arctic and the tropics is plausible!

Motivation

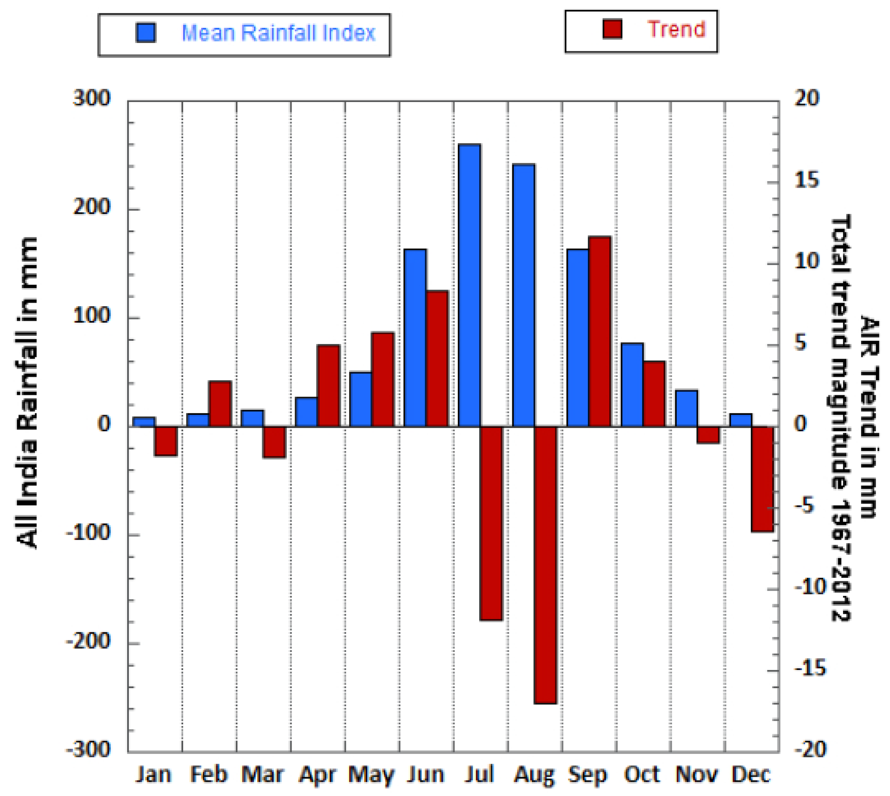


Figure 1. All India Rainfall mean (red) and trend (blue) from 1967-2014.

- Monthly mean All India Rainfall (Blue)
- Monthly trends of AIR (Red)
- Positive trends in early rainy season and negative trends during peak monsoon season

What is causing the early season precipitation increase?

Overview

We hypothesize that snow depth changes are driving the strengthening of May-June rainfall.

Snow observations in Western Himalaya

- Less snow in the Himalaya leads to a more vigorous monsoon Blanford [1884].
- Himalayan snow is melting earlier [Shekhar et al. 2010].
- Less snow is falling in winter. Snow is gone by May in Dundhi and Gulmarg (Indian Himalayan stations).
- Northward shift in storm tracks could be reducing the snow in Himalaya. (Conjecture).
- One possible explanation is that a warmer climate and/or black carbon can lead to earlier snow melt [Ramanathan et al. 2008].

Synthesis of past work for snow in Eurasia

- Less snow in Himalaya leads to a more vigorous monsoon Blanford [1884].
- Snow fall/depth is increasing in Eurasia.
- Declining sea ice is linked to an increase in snow depth in Siberia in autumn and winter. [Ghatak et al. 2010, Vihma 2014].
- A warmer, more moisture laden Arctic in autumn leads to an increase in Eurasian snow cover during that season. [Cohen et al. 2012].

Less Snow in March is associated with increased May rainfall (agrees with Blanford hypothesis)

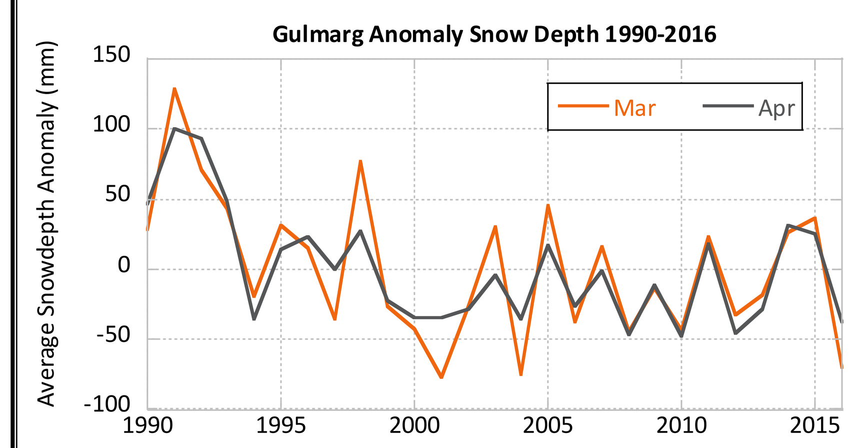


Figure 2. Snow depth measurement for Gulmarg (1990-2016)

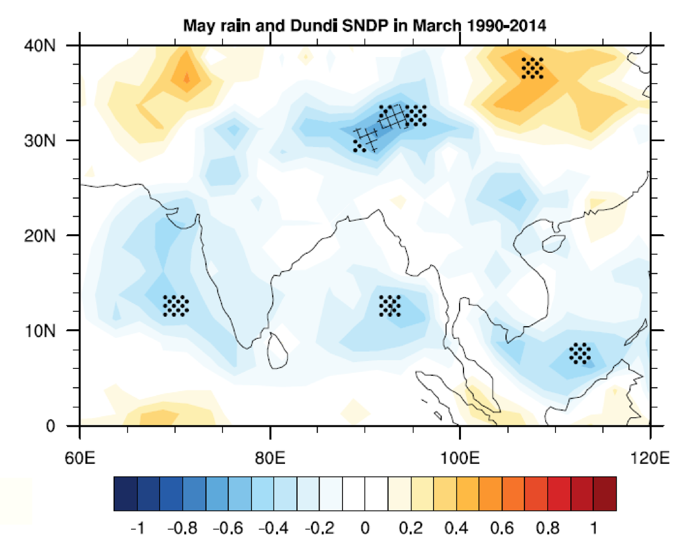


Figure 3. Correlation between May Rain and Dundi Snow depth in March (1990-2014).

- Declining snow depth in Gulmarg (Figure 2) for March (orange) and April (black).
- Snow depth and May rainfall (Figure 3) are negatively correlated (blue) (significant at >95%) over the Arabian sea and northeastern Himalayas.

Is the changing snow pattern in Eurasia linked to the Indian Monsoon?

Composites of SWE based on high rainfall minus low rainfall May-June periods

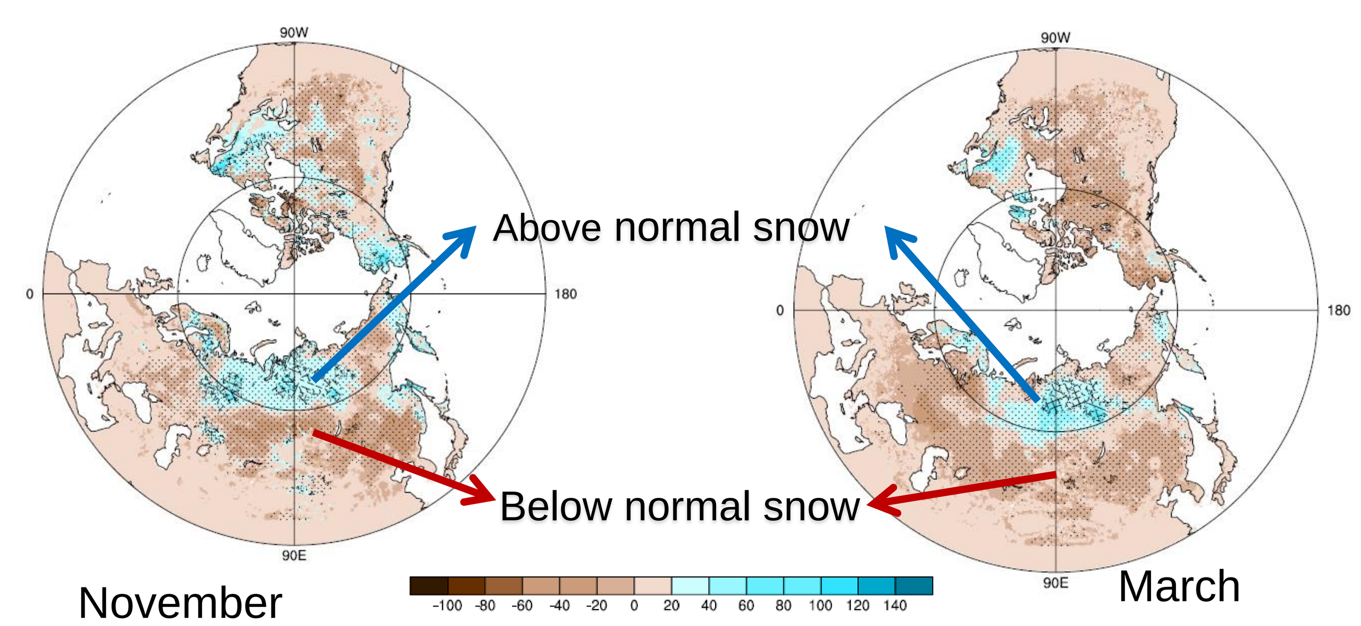


Figure 4. SWE composites for November and March (1990-2014)

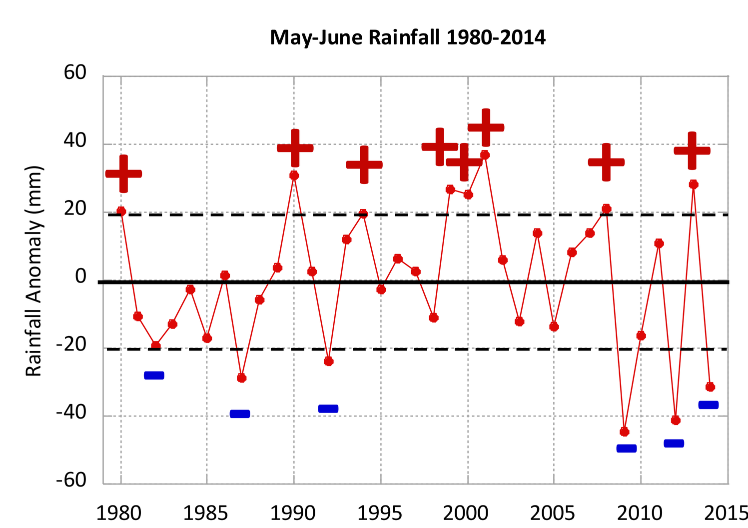


Figure 5. May-June AIR cases chosen for composite analysis.

- Both November and March composites (Figure 4) show significantly (95%) higher SWE (Blue) in northern Eurasia and lower in Southern Eurasia (Brown) .
- All India rainfall index for May-June (Figure 5) is used to construct composites. Plus signs identify positive (>1 std) cases while minus signs identify the negative cases.

High (positive) Years: 1990, 1994, 1999, 2001, 2008, 2013
Low (negative) Years: 1987,1991, 2009, 2012, 2014

Is sea ice connected to Indian Monsoon?

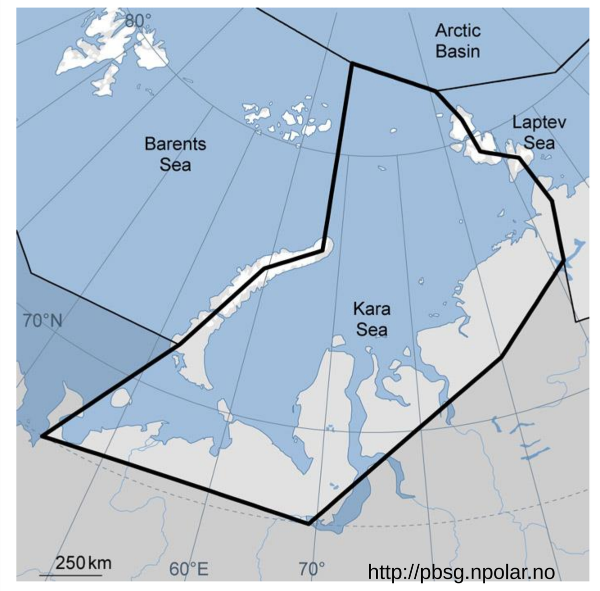


Figure 5. Map of Kara sea ice.

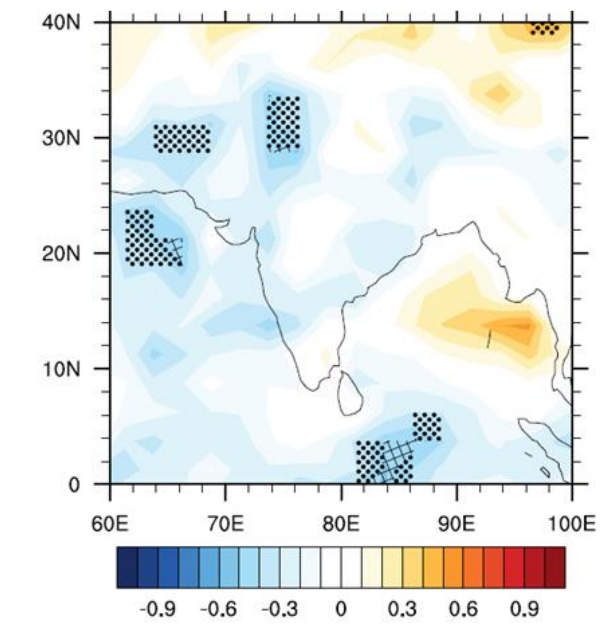


Figure 7. Correlation between May Rain and December Kara sea ice index (1990-2014).

Less sea ice in December in W Kara sea is correlated with higher June rainfall

Hypothesized sequence of Events

Sea ice decline

Increase in snowfall in Eurasia and reduction over Himalayas (Possibly due to shift in storm tracks) [Kidston et al. 2015; Yin 2005]

Earlier snowmelt leads to increase in May-June rainfall [Blanford 1884]

Changing seasonality of Monsoon

Next Steps

- Use all India gridded data to understand spatial correlations with snow in the Himalayas and Eurasia.
- Investigate land surface temperature over India and Eurasia to understand how it is modified by snow depth.
- Document variations in meridional circulation.
- Perform storm track analysis and examine how western disturbances have changed over the Himalayas.

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