



## The impact of Arctic warming on the timing of Indian monsoon and ice season in the Sea of Okhotsk

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In 2020, the Arctic Circle warming in Siberia was extraordinary. Strong anticyclones have been dominant over a large area in Northern Siberia through spring. It resulted in an all-time high-temperature record in the Arctic Circle - more than 6°C above the average (1981–2010). Thus, it accelerated the melting of snow, ice, permafrost and has gotten the wildfire in Siberia off to an unusually early and severe start. The Arctic warming has repercussions not only for Siberia but for the entire Eurasia and the Northern Hemisphere. Specifically, the Arctic conditions affect atmospheric circulation in the Pacific Ocean and the strength and direction of trade winds in the tropical zone.

Here, I show that Arctic Circle warming has impacted the timing of monsoon and sea ice seasons. First, I found the observational evidence of Arctic warming causing colder than average temperatures over the east of Eurasia, Central Europe, and Central Asia. Notably, North Pakistan and Northern India saw temperatures distinctly below the long-term average (1981–2010): 4°C below from March to December. Second, I took this evidence into account while developing a new method for forecasting the sea-ice timing and the recent long-range forecasting method of monsoon season [1]. Third, based on the forecast results for 2020, I found that utilizing only recent trends is an inadequate strategy for predictions. However, considering the current Arctic warming outcomes in specific regions overcomes this problem and results in successful forecasts for both sea-ice and monsoon seasons.

The results imply that when North Pakistan's temperature is cooler than usual: (i) it slows down an advance of monsoon, (ii) it accelerates the cooling of the entire Indian subcontinent during withdrawal from northern Pakistan to the east coast of central India. Hence, North Pakistan's cooling in 2020 caused a protracted offensive and early end of the Indian summer monsoon, thus, shortening its duration. As a result, it led to the early onset of the seasonal wind reversal in the eastern Pacific Ocean in the middle of October and, therefore, to the surprisingly early onset of the winter monsoon in South Asia and India [2]. The consequences of this change in monsoon timing strongly affected 70% of the Indian population directly related to farming.

In the Sea of Okhotsk in 2020, the sea ice retreated early due to heatwaves in Siberia. In

December, the onset date of ice season was around average, but ice grew faster than average, creating a hazard to navigation safety.

Hence, the proposed forecasting methodology applied to India and the Sea of Okhotsk opens new possibilities to forecasting monsoon and sea ice seasons around the globe.

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[1] Stolbova, V., E. Surovyatkina, B. Bookhagen, and J. Kurths (2016): Tipping elements of the Indian monsoon: Prediction of onset and withdrawal. GRL 43, 1–9 [doi:10.1002/2016GL068392]

[2] <https://www.pik-potsdam.de/en/output/infodesk/forecasting-indian-monsoon>