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Spatial and temporal patterns in Arctic river ice breakup revealed by automated ice detection from MODIS imagery

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The annual spring breakup of river ice has important consequences for northern ecosystems and significant economic implications for Arctic industry and transportation. River ice breakup research is restricted by the sparse distribution of hydrological stations in the Arctic, where limited available data suggests a trend towards earlier ice breakup. The specific climatic mechanisms driving this trend, however, are complex and can vary both regionally and within river systems. Consequently, understanding the response of river ice processes to a warming Arctic requires simultaneous examination of spatial and temporal patterns in breakup timing.

Here we present an automated algorithm for river ice breakup detection using MODIS satellite imagery that enables identification of spatial and temporal breakup patterns at large scales. We examine breakup timing on the Mackenzie, Lena, Ob' and Yenisey rivers for the period 2000-2014. First, we split each river into 10 km segments. Next, for each day of the breakup season, we classify each river pixel as snow/ice, mixed ice/water or open water based on MODIS reflectance values and remove all cloud-covered segments using the MODIS cloud product. We then define the breakup date as the first day where the segment is 75% open water. Using this method, we are able to determine breakup dates with a mean uncertainty of +/-1.3 days. We find our remotely sensed breakup dates to be highly correlated to ground breakup dates and the timing of peak discharge.

All statistically significant temporal trends in breakup timing are negative, indicating an overall shift towards earlier breakup. Considerable variability in the statistical significance and magnitude of trends along each river suggests that different climatic and physiographic drivers are impacting spatial patterns in breakup. Trends detected on the lower Mackenzie corroborate recent studies indicating weakening ice resistance and earlier breakup timing near the Mackenzie Delta. In Siberia, the increased magnitude of trends upstream and strong correlation between the timing of breakup initiation and whole-river breakup patterns suggest that earlier onset of upstream discharge may play the dominant role in determining breakup timing. Exploratory analysis demonstrates that MODIS imagery may also be used to differentiate thermal and mechanical breakup events.