Supplementary figures

- **Figure S1:** Random forest classification confusion matrix.
- **Figure S2:** Random forest feature importance.
- **Figure S3:** Multi-year lake ice-free period distribution.
- **Figure S4:** Ice probability time series for various lake samples.
- **Figure S5:** Ice phenology interannual variability.
- **Figure S6:** Ice phenology vs. lake size.
- **Figure S7:** Ice free duration vs. lake morphometrics.
- **Figure S8:** Morphometry vs. ice phenology correlation matrix.
- **Figure S9:** RF vs ADD model offsets and distributions
- **Figure S10:** Residual Moran's I: OLS vs SEM filtered maps
- **Figure S11:** SDI vs. ice free duration.
- **Figure S12:** RF vs ADD model offsets with early/late/revisit statistics.
- **Figure S13:** Sentinel-1 flight direction timing and occurrence by year.
- **Figure S14:** ADDT and ADDF vs. RF and ADD model offsets by latitude.
- **Figure S15:** Ice-off date and ice-on date vs. Latitude
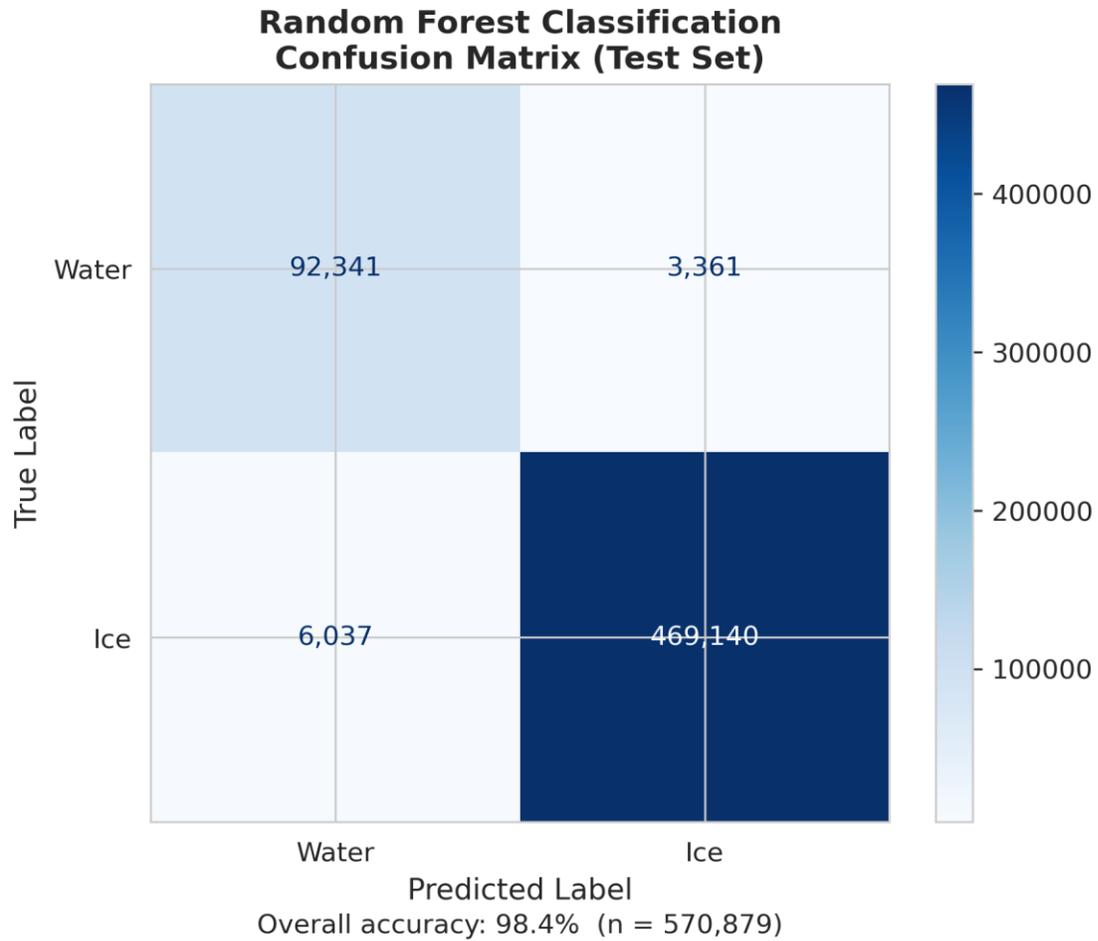- **Figure S16:** Morphometric distribution histograms for ALPOD and this study

Figure S1: Random forest classification confusion matrix, where numbers within each box represent number of samples falling within each category. The boxes with darker saturation indicate where the RF model predicted the correct label based on the true label, where correct water and ice predictions are represented by medium blue and dark blue, respectively. The light blue/gray boxes indicate where the RF model predicted incorrectly.
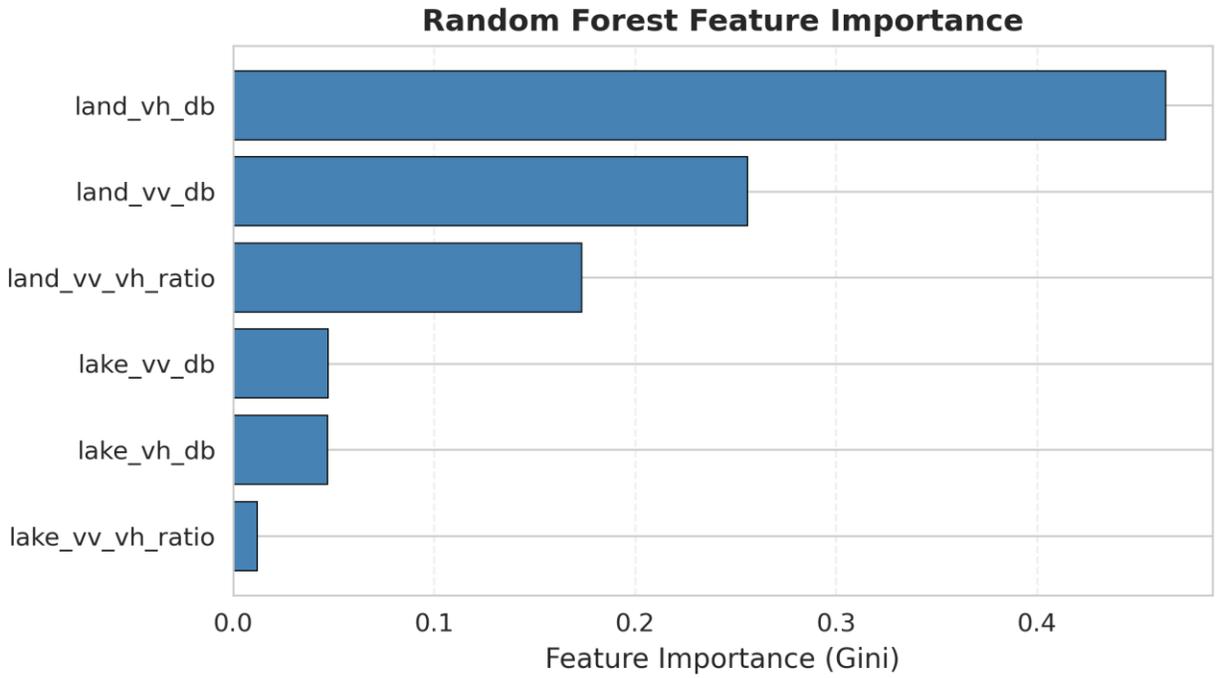
Figure S2: Random forest feature importance using Gini, where land and lake refer to the exterior and interior lake buffers, respectively. VV, VH, and VV/VH ratio refer to the polarimetric SAR band, and db represents decibels.
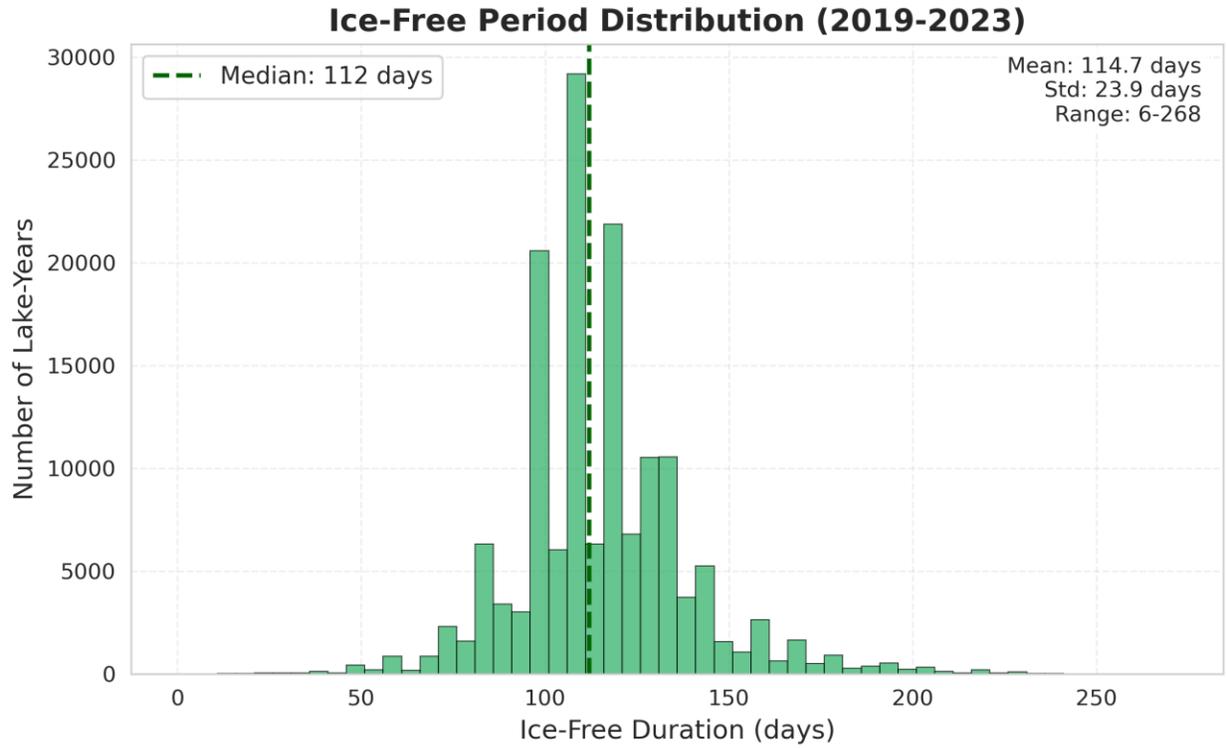
Figure S3: Ice-free period distribution for the entire 2019 – 2023 time range across all lake-year combinations, where the median (plotted), mean, standard deviation, and range are reported in days.
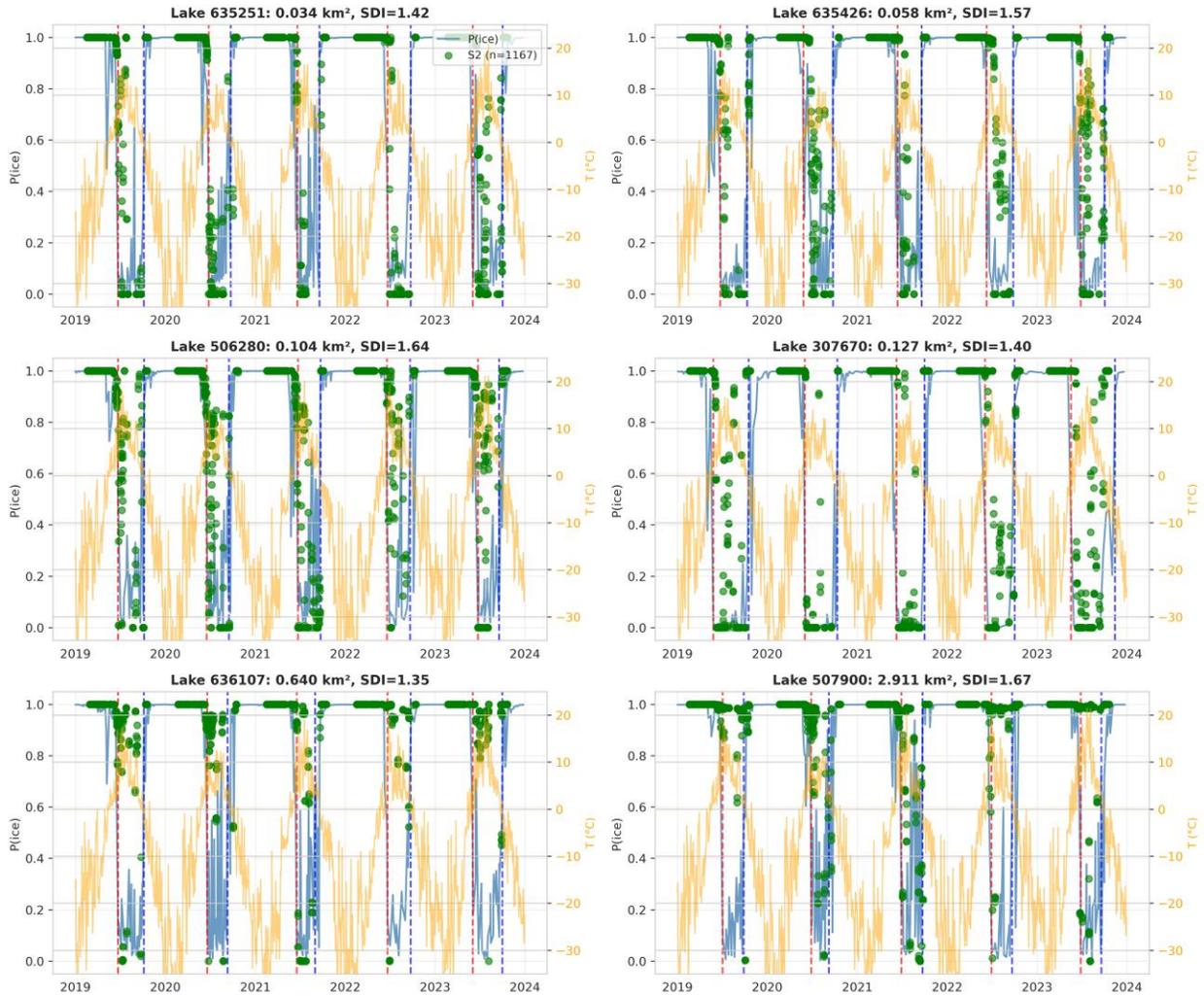
Figure S4: Example ice probability time series for six lakes spanning different size classes (Small: < 0.05 km², Medium: 0.05–0.5 km², Large: > 0.5 km²) and shoreline complexity (SDI). Blue line: Random Forest ice probability from Sentinel-1; orange line: ERA5 daily temperature; green dots: Sentinel-2 ice fraction. Vertical dashed lines mark detected ice-off (red) and ice-on (blue) dates.
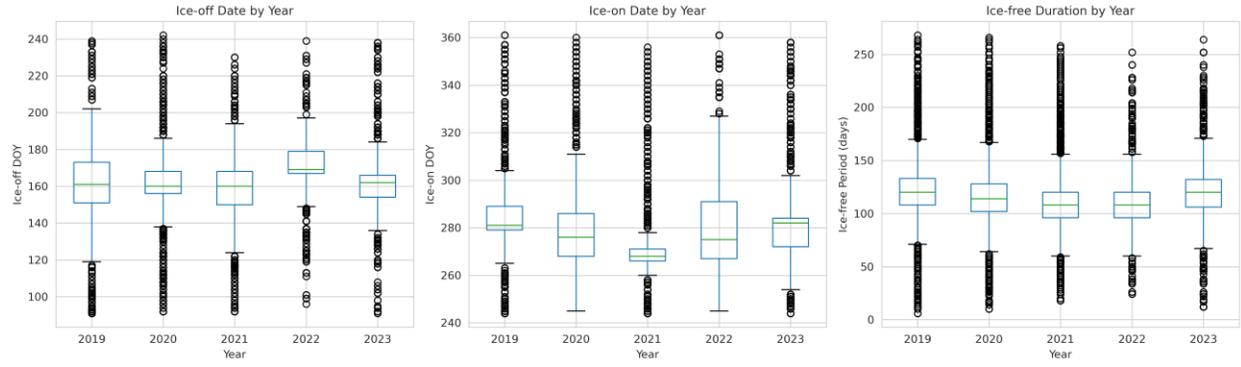
Figure S5: Box plots of ice-off dates for phenology-detected lakes each year **(left)**, ice-on dates for each year **(center)**, and ice-free duration (days) for each year **(right)**.
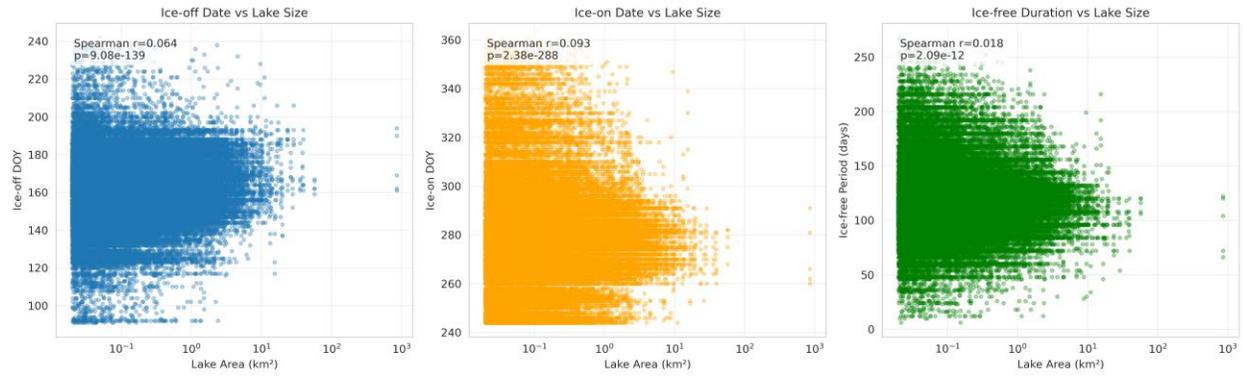
Figure S6: Ice-off dates vs lake area (km^2) for all lake-years **(left)**, ice-on dates vs lake area for all lake-years **(center)**, and ice-free duration vs lake area for all lake-years **(right)**.
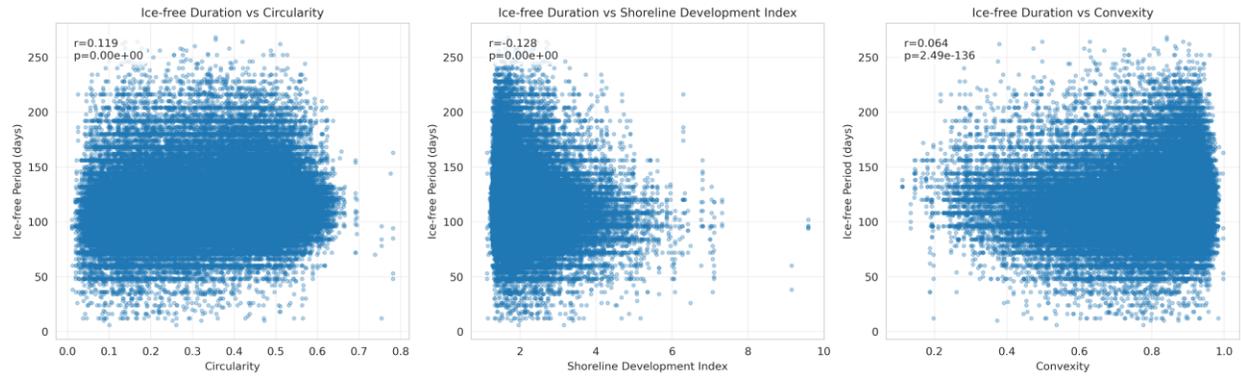
Figure S7: Ice-free period (days) vs lake circularity for all lake-years **(left)**, ice-free period vs lake SDI for all lake-years **(center)**, and ice-free period vs lake convexity for all lake-years **(right)**.
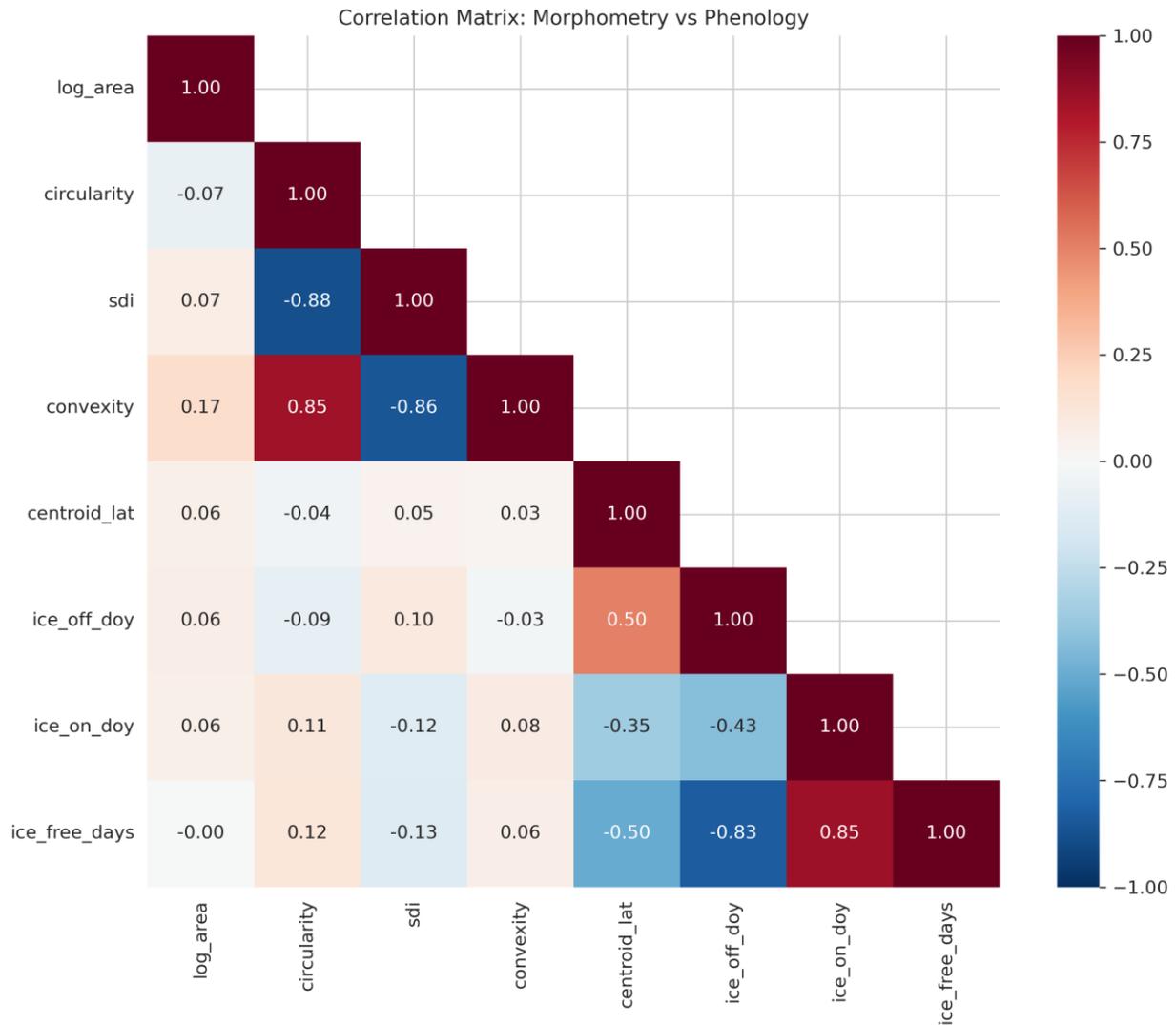
Figure S8: Correlation matrix between lake morphometric variables (log transformed area, circularity, SDI, convexity), latitude (centroid latitude), and ice phenology (ice-off dates, ice-on dates, ice-free days).
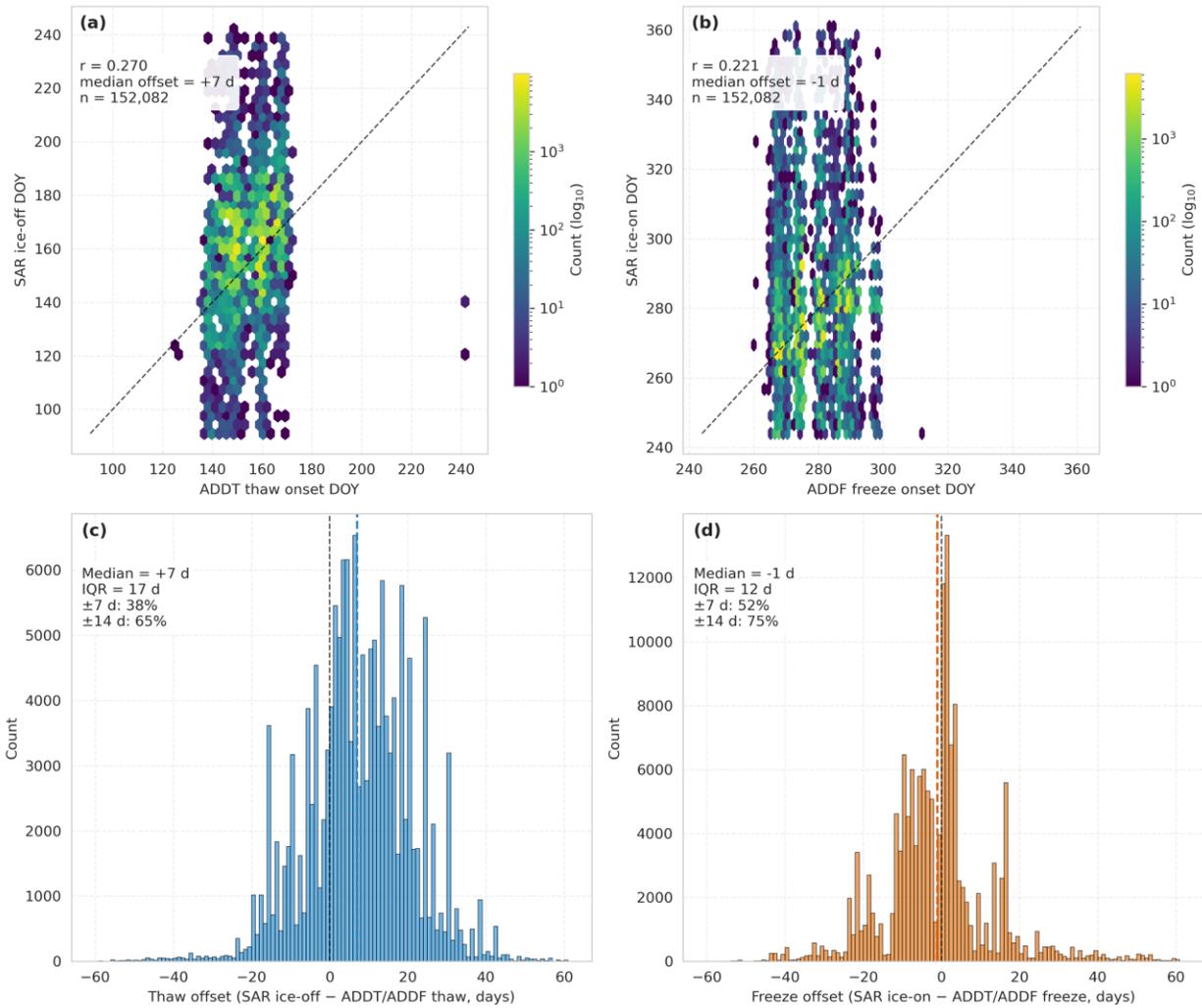
Figure S9: Day of year agreement and offset distribution plots. **(a)** ADDT thaw onset vs RF SAR model ice-off (day of year) colored by number of lake-year counts. **(b)** ADDF freeze onset vs RF SAR model ice-on, as in **(a)**. **(c)** Histogram distribution of the thaw offset between RF SAR model ice-off and ADDT thaw onset (days). **(d)** As in **(c)** instead for freeze offset between RF SAR model ice-on and ADDF freeze onset.
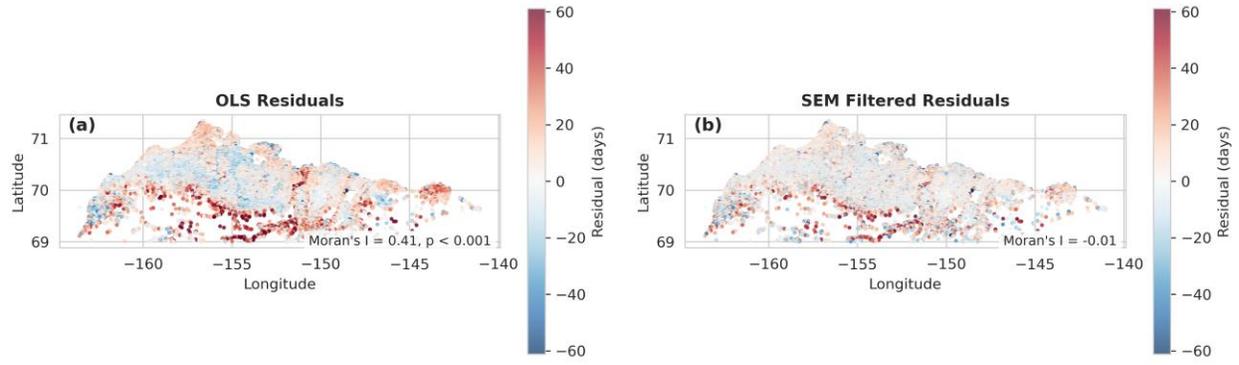
Figure S10: (a) OLS residual map and **(b)** SEM filtered residual map, both colored by days along with calculated Moran's I values.
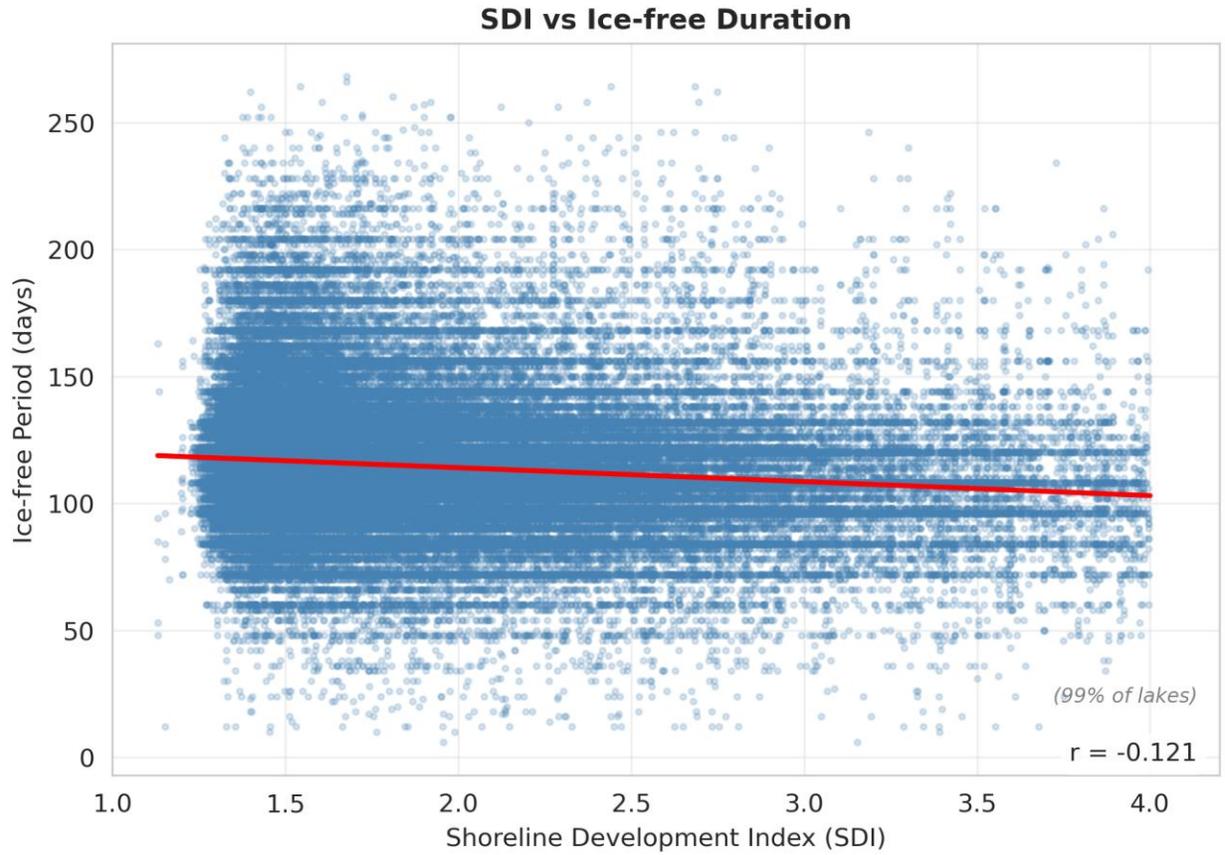
Figure S11: Ice-free period (days) vs shoreline development index (SDI). Red line shows best-ft regression.

(a) Thaw: SAR ice-off − ADDT onset

n = 152,082
Early (< 0): 25%
of which ≤6d: 45%
Late (> 0): 72%
of which ≤6d: 30%
Total within ±6d: 35%

(b) Freeze: SAR ice-on − ADDF onset

n = 152,082
Early (< 0): 51%
of which ≤6d: 36%
Late (> 0): 42%
of which ≤6d: 55%
Total within ±6d: 49%

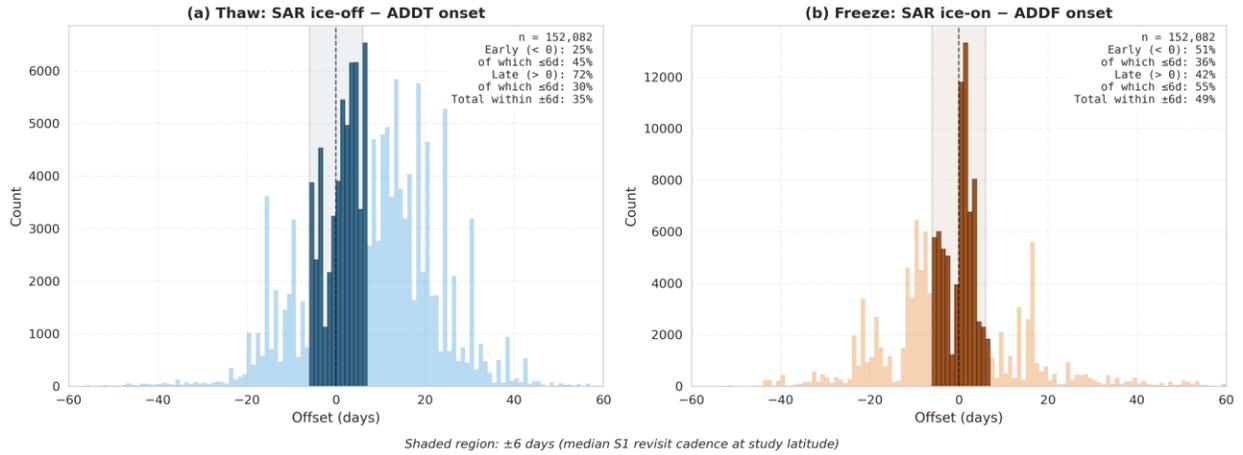*Shaded region: ±6 days (median S1 revisit cadence at study latitude)*

Figure S12: Histograms of offsets between RF model detected ice-off date and ADD model onset of thaw date **(a)** and offsets between RF model detected ice-on date and ADD model onset of freeze date **(b)**. Shaded regions indicate the subset of offsets that fall within the SAR revisit temporal resolution. Negative values are where the RF model detects ice-off **(a)** or ice-on **(b)** before the ADD model, and positive values occur where the RF model does so after the ADD model.
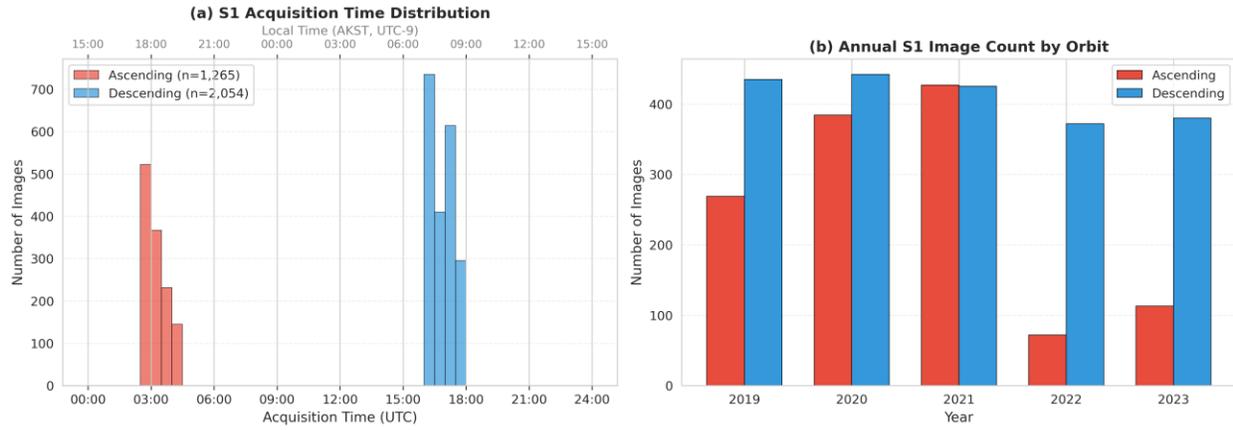
Figure S13: Number of Sentinel-1 image information with ascending and descending tracks in red and blue, respectively. **(a)** Acquisition time (in Alaska Standard Time and UTC) distribution for all years of data. **(b)** Number of Sentinel-1 scenes by year and flight direction.
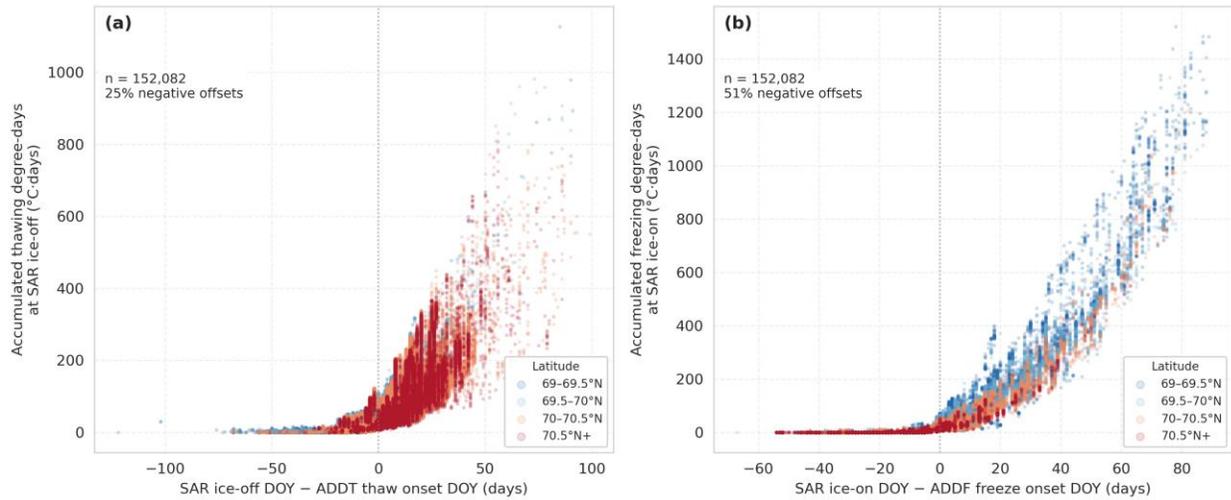
Figure S14: Accumulated thawing degree-days (ºC·days) from the ADD model by the time the RF model detected ice-off date occurs vs the timing offset between the RF and ADD models for ice-off date and thaw onset **(a)**. Accumulated freezing degree-days (ºC·days) from the ADD model by the time the RF model detected ice-on date occurs vs the timing offset between the RF and ADD models for ice-on date and freeze onset. Points are colored by latitude bins. Negative values are where the RF model detects ice-off **(a)** or ice-on **(b)** before the ADD model, and positive values occur where the RF model does so after the ADD model.
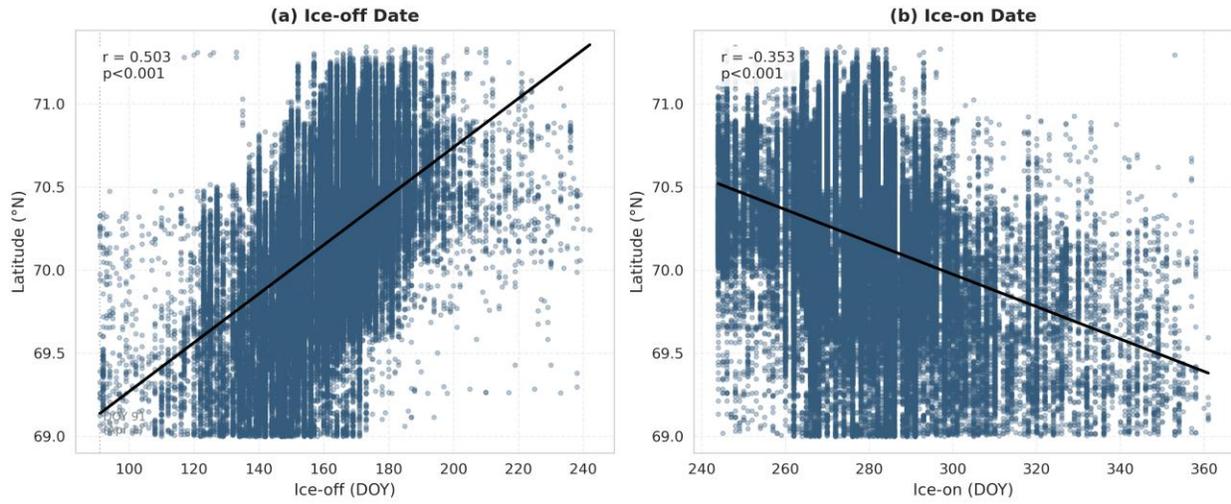
Figure S15: Relationship between latitude and ice-off date **(a)**, and latitude and ice-on date **(b)**. The black lines show the linear regression best-fit.
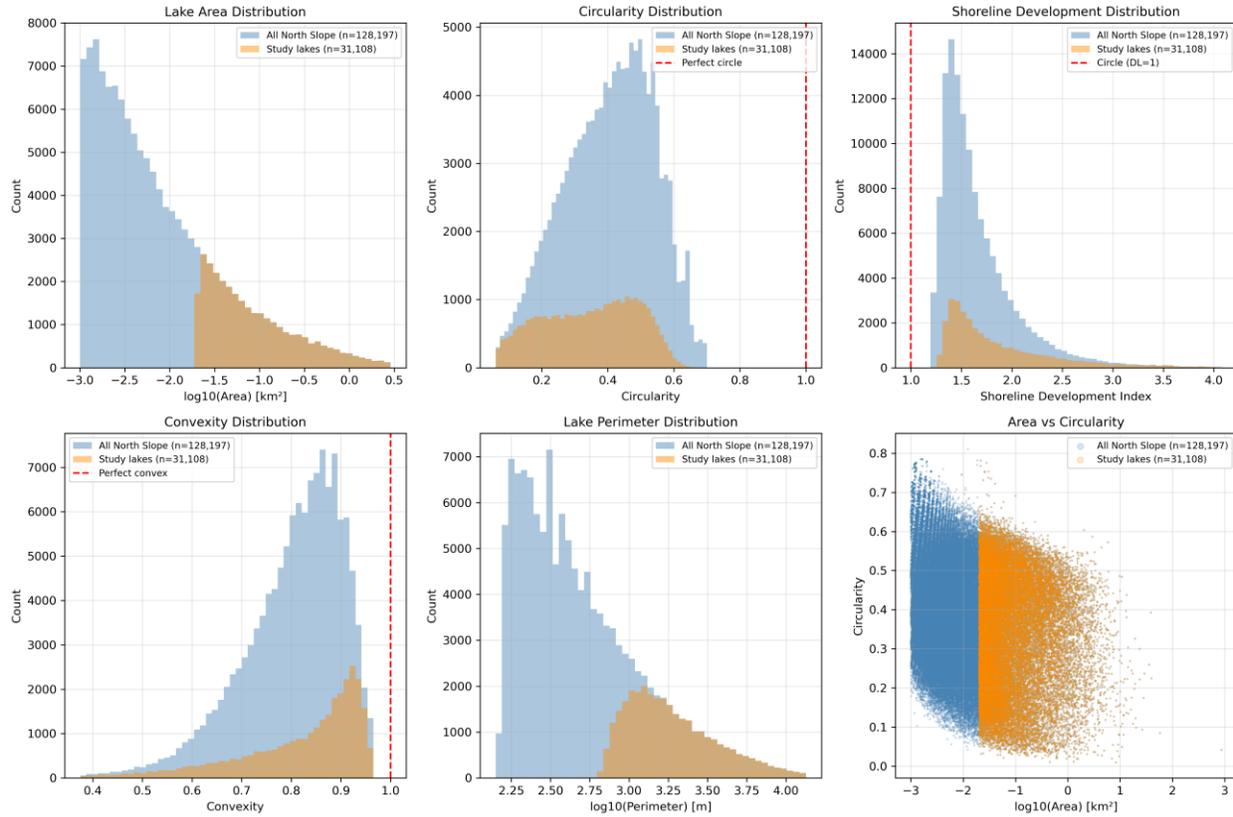
Figure S16: Histograms of lake area (km^2) for both lakes utilized in this study and all lakes in the study region in the ALPDOD dataset **(top-left)**, circularity **(top-center)**, SDI **(top-right)**, convexity **(bottom-left)**, perimeter **(bottom-center)**, and circularity vs lake area (km^2) **(bottom-right)**. Red dashed lines indicate a perfect circle **(top-center)**, a circle **(top-right)** and perfect convexity **(bottom-left)**.