

### Takeaway message

The Ka Radar Interferometer (KaRIn) onboard SWOT opens new windows in the study of polar oceans and their sea ice covers, thanks to its large-scale topographic information. In particular, it allows us to perform a first global sea ice surface classification over the North and South poles ①. We find a general good agreement between the KaRIn classification and those derived from nadir laser (ICESat-2) and radar (Sentinel-3) observations ②. Based on this surface classification, we perform an extended analysis of the sea ice height distribution ③. Out of the four models tested, we find that the normal and lognormal are the least represented across the North and South poles, whereas the exponentially-modified normal and skewed-normal distributions seem to better describe the sea (primarily first-year) ice topography. These models could in principle be considered in the physical retracking of nadir radar waveforms.

① The first KaRIn topographic images over sea ice (c.f. background) revealed the contours of ice floes and leads (fractures within). Along with the backscatter information, Jestin et al. (in prep.) developed a sea ice classification using a K-means clustering method based on L3 v2 unsmoothed data (250 m). Identifying the type of surface (floes vs leads) is needed for the estimation of all sea ice related parameters, such as freeboard, thickness, and volume, but also in the analysis of nadir radar observations, which generally applies different processings to different surfaces.

② To validate KaRIn's surface classification we compare it with those from ICESat-2 and Sentinel-3 at crossover locations (56 for the first and 135 for the latter) during winter 2023/2024 with time-lags within 15'. Figures 1 and 2 illustrate the good agreement between the datasets for three selected cases. After computing the correspondance between the altimeter and the swath measurements<sup>a</sup>, we quantify the agreement using the Phi correlation coefficient  $\phi$  (-1 to +1, perfect disagreement to perfect agreement, 0 no relationship). We obtain  $\phi=0.17/0.34$  for ICESat-2 Arctic/Antarctic and  $\phi=0.24$  for Sentinel-3 (Arctic only), which shows an overall good agreement using this first KaRIn classification dataset.

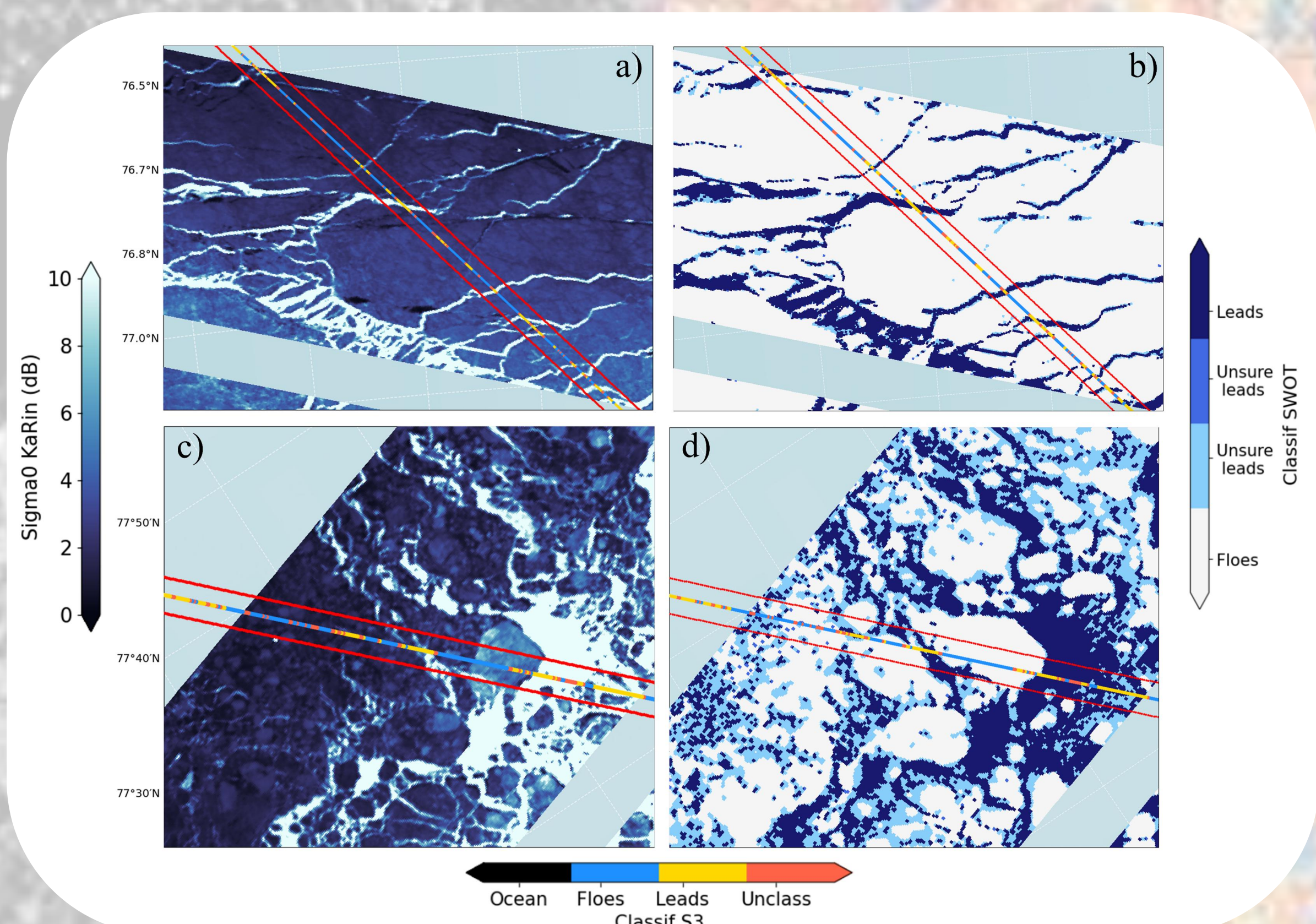


Figure 1: KaRIn backscatter (left) and classification (right) at two crossover points with Sentinel-3: SWOT c13 T496 time-lag 1'43'' (a,b) and SWOT c13 T87 time-lag 14'46'' (c,d). The tracks show Sentinel-3's classification (colour-coded) and cross-track resolution (red).  $\phi=0.35$  (a,b) and 0.58 (c,d).

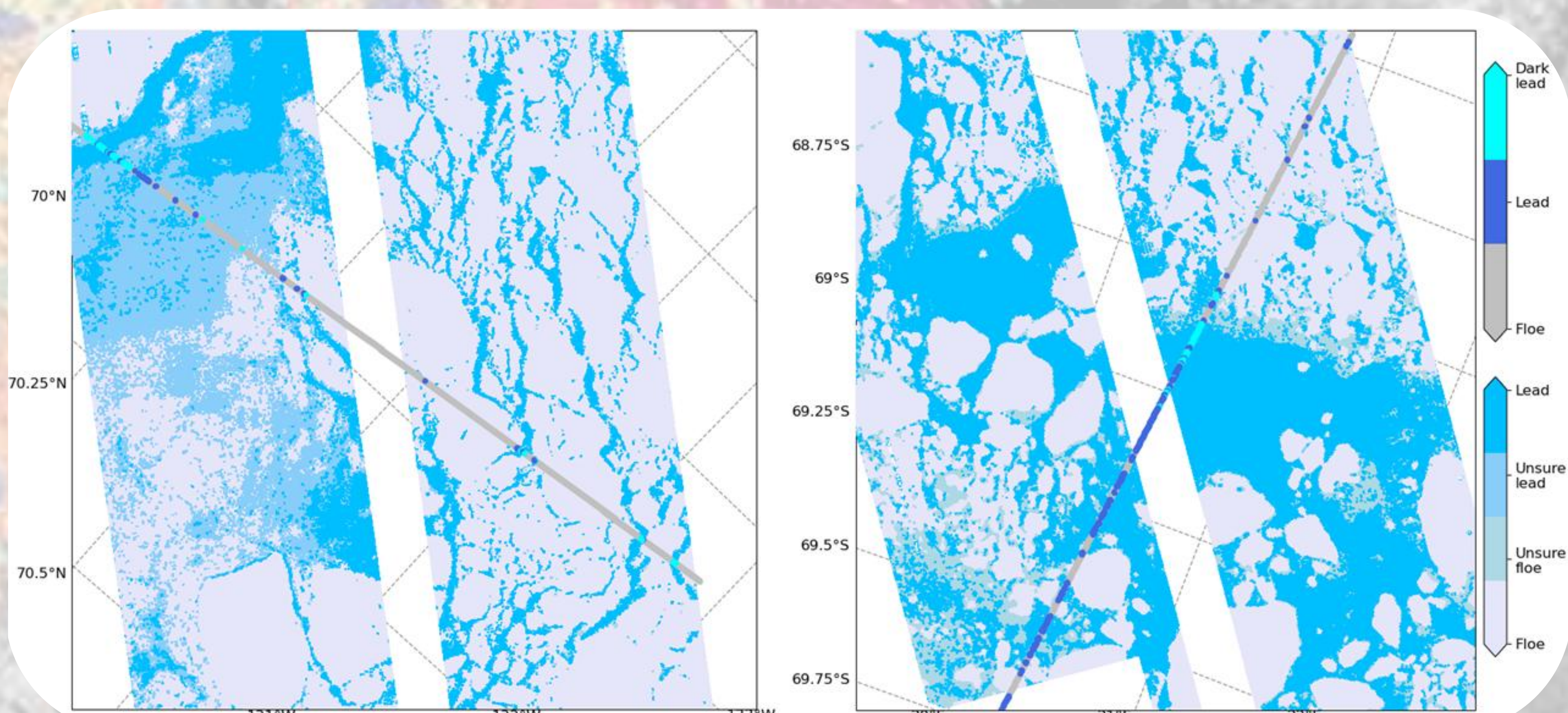


Figure 2: KaRIn classification at two ICESat-2 crossover points: SWOT c13 T431 time-lag 10'30'' (left, Arctic) and SWOT c2 T544 time-lag 7'12'' (right, Antarctic). The tracks show ICESat-2's classification. Note that only floes and leads classes are considered in the analyses, the others are shown (here and in Fig. 1) for completeness.  $\phi=0.50$  (left) and 0.57 (right).

③ Another great advantage of KaRIn data is that the height retrieval is independent of a classical retracking as used in nadir radar processing. Physical retracking models, originally designed to fit oceanic data, assume a normal surface height distribution, whereas several works indicate that the sea ice heights rather follow a lognormal or exponentially-modified normal (EMN). We use KaRIn and its surface classification ① to perform a large-scale study of the height distribution over floes, in 10 km-sided boxes defined along track. Such a kernel is chosen as it approximates the nadir altimeter's footprints and yields a reasonable sample given the 250 m/500 m posting/resolution. We tested the four distributions labelled in Figure 3: the skewed-normal, introduced in this work, and the EMN, provide the best fit (here given by the lowest Kolmogorov-Smirnov statistic) to the topography distributions across both poles, yielding interesting geographical patterns – to be studied.

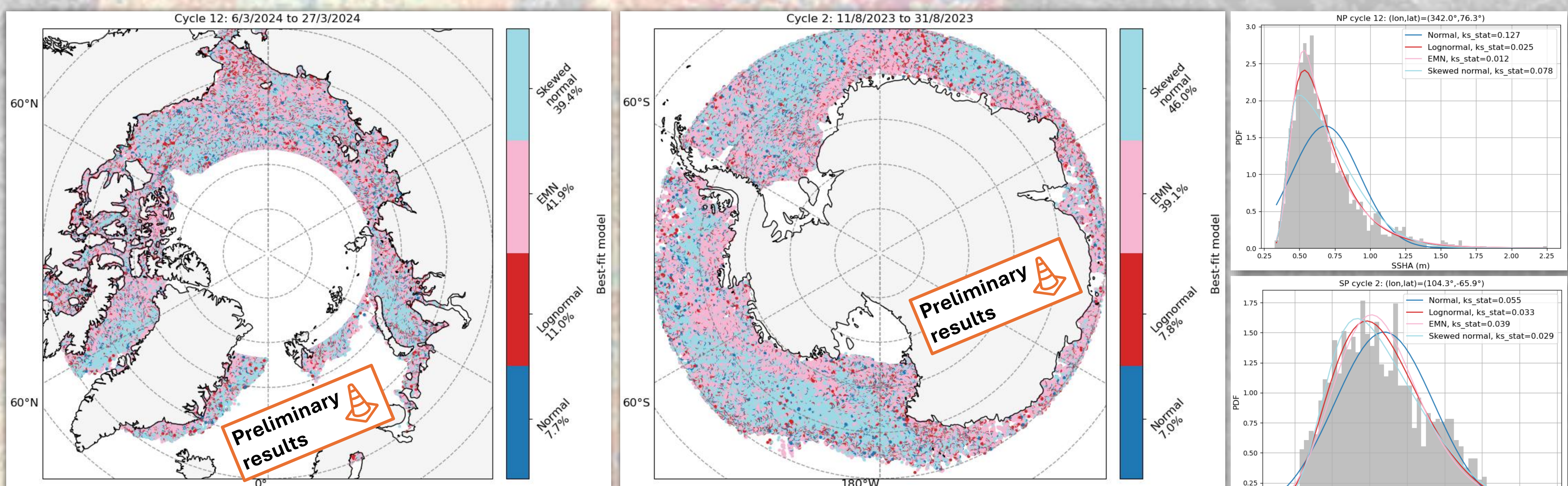


Figure 3: Left/middle panels: maps of the probability distribution that best fits KaRIn's sea ice surface height estimated in boxes of 10 km x 10 km (the fit is performed if at least 80% of the box's data points, i.e. 1280, are valid). The total proportion of each distribution is given below the corresponding name. Right panels: example of individual PDFs analysed with the corresponding fits and their Kolmogorov-Smirnov statistic.