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Sea ice in the Weddell Sea: use of moderate resolution imagery to summarize inter-annual variation in conditions and support operational ship survey

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The distribution and concentration of sea ice presents a significant challenge to shipping and scientific expeditions in high-latitude regions. In addition to achieving safe navigation, information about likely sea ice conditions is needed for expedition planning, and the deployment and retrieval of scientific instruments and their data. In areas where time series of passive microwave data exist, broad-scale analysis of sea ice concentration can be readily achieved. However, the spatial resolution of these data does not permit detailed investigations of sea ice conditions, including near-shore lead development.

Here we present a new methodology for processing moderate resolution multispectral and thermal satellite imagery to summarise inter-annual differences in the probability of sea ice observation. By using multiple daily imagery sources (Terra and Aqua MODIS; Suomi-NPP VIIRS), and averaging resultant concentration maps over longer time periods, we reduce the impediment of cloud cover to characterising sea ice using this type of imagery. Our processing provides a higher-resolution depiction of sea ice conditions and their variability than that afforded by passive microwave data. By estimating a sub-pixel concentration for all pixels identified as 'Ice', we capture further nuances of narrower water/thin ice inclusions within the ice cover.

The utility of this new methodology to support operational ship survey in polar regions is demonstrated using examples from the Weddell Sea, Antarctica. Our description of sea ice cover agrees well with that derived from very high-resolution imagery from the Operation Ice Bridge DMS camera system, and with experience of the actual sea ice conditions encountered during the Weddell Sea Expedition (https://weddellseaexpedition.org/) in early 2019.

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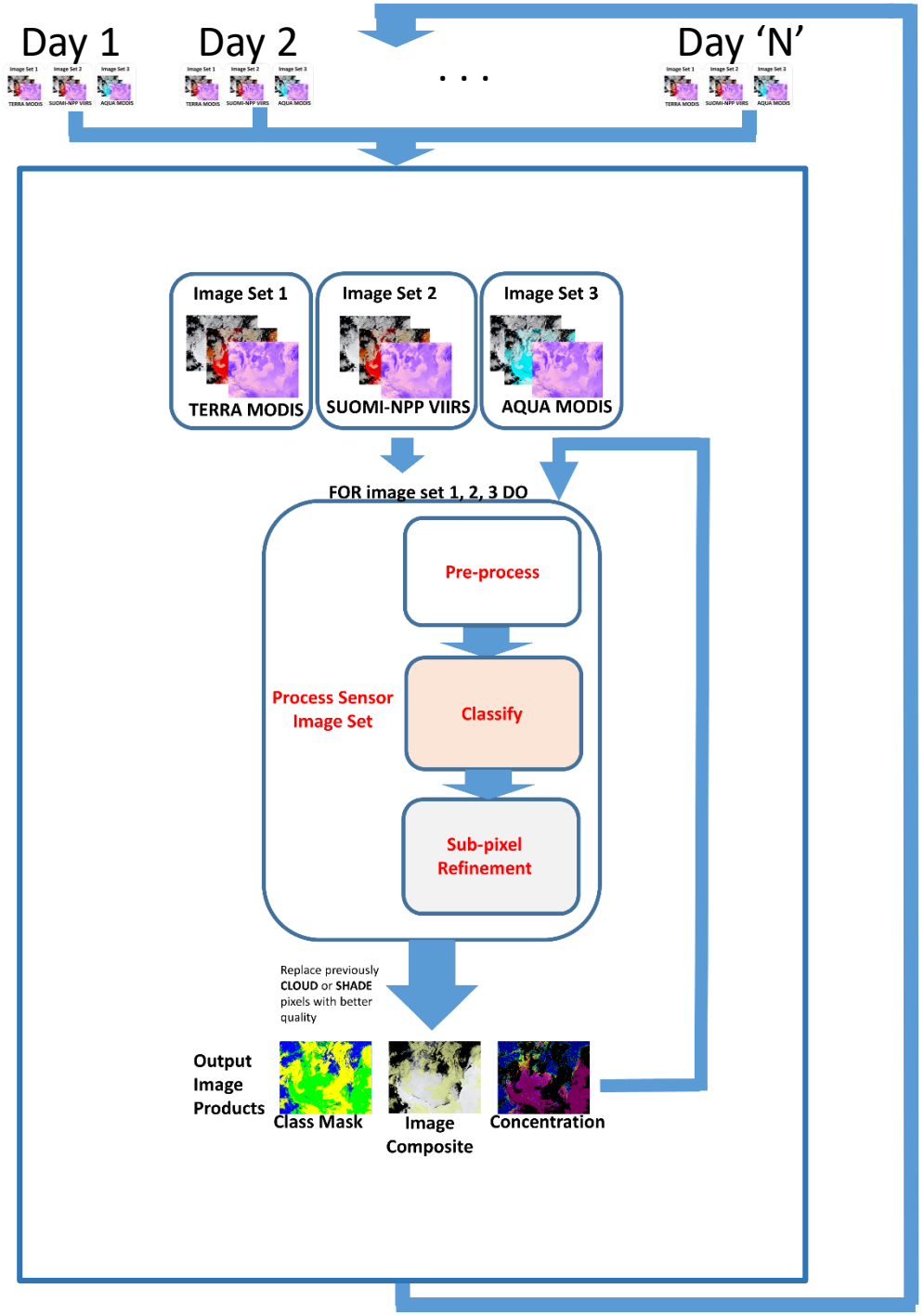

- Our algorithm uses daily WorldView mosaics of MODIS (Aqua, Terra) & VIIRS (Suomi-NPP) True Colour, False Colour (256m) and Thermal (~1km) imagery.
- Pixels are firstly classified as Ice, Water or Cloud, with pixel value statistics gathered for Ice and Water classes. A second pass refines the concentration estimate for Ice pixels, with reference to class statistics.
- The output images are progressively filled with non-cloud results from each sensor in turn. The progressive compositing process may be repeated over a number of days to produce a more complete result.
- Yellow tinting of the cloud-flagged output true colour image allows underlying detail to be manually interpreted.

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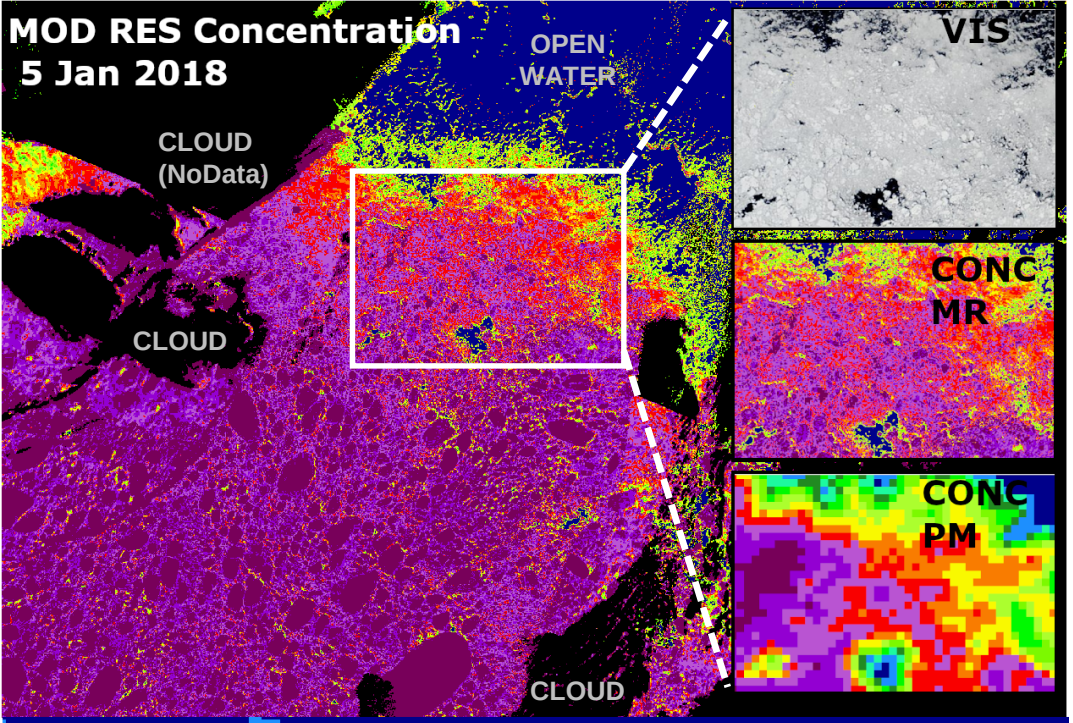

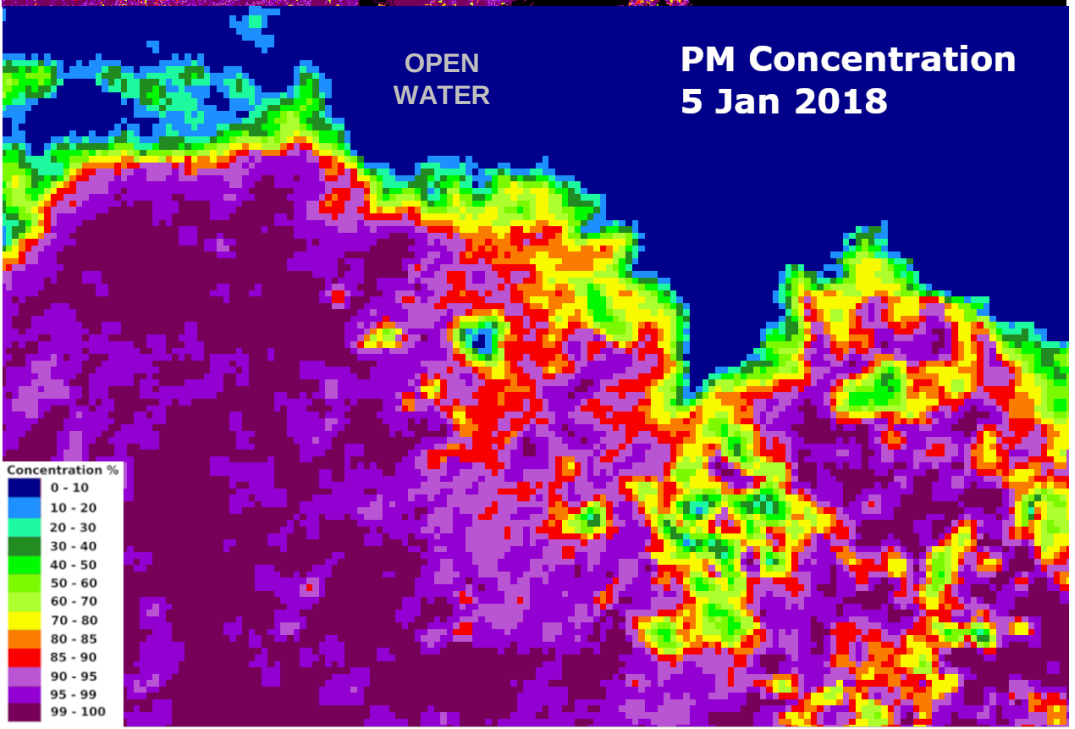

- Our method shows similar patterns in sea ice cover to that recorded by traditional Passive Microwave (PM) observations (~3-25 km spatial resolution), but at a ***much higher resolution*** (250 m).
- Since 2019, the Uni of Bremen have produced a 1 km merged MODIS/PM concentration product (Ludwig et al., 2019). Our use of finer resolution visible imagery yields a ***four-fold resolution increase*** using only self-consistent image band data, and not requiring any assumptions as to consistency of sea ice at PM and MODRES imaging times.
- Allowing for dynamic sea ice drift between imaging times, we find good agreement between our MODIS/VIIRS-based observations and near-contemporaneous, high-resolution (best resolution circa 10cm) Operation Ice Bridge aerial photography (Dominguez, 2010), highlighting the potential utility of our method for sea ice monitoring (see next slide) and operational use.

Process limitations and future opportunities

- At present, cloud shadow incorrectly categorised as open water constitutes the largest source of error in our outputs, although further development and processing – using e.g. cloud computing-based full spectral-resolution MODIS/VIIRS data repositories – may reduce this error.
- Cloud cover is the major impediment to achieving daily coverage, and visible imagery will be unavailable in times of polar region winter darkness. Future inclusion of other sources of Moderate Resolution imagery (e.g. Sentinel 3a/b) is a possible extension to enhance coverage.

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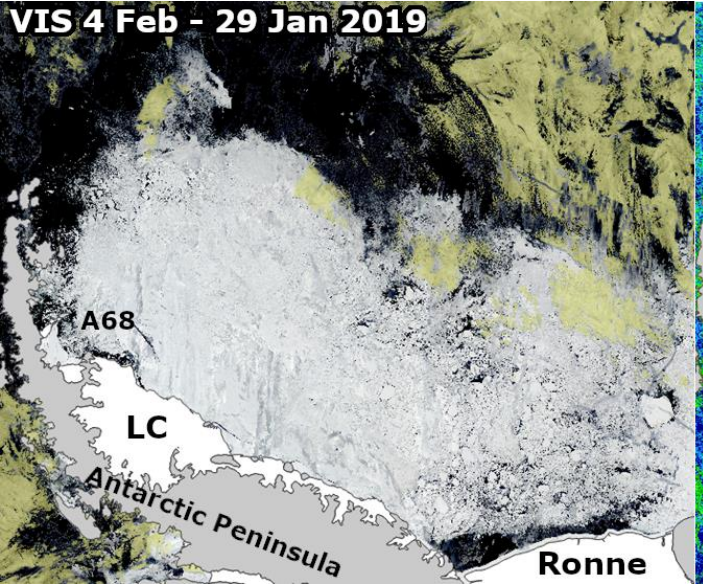
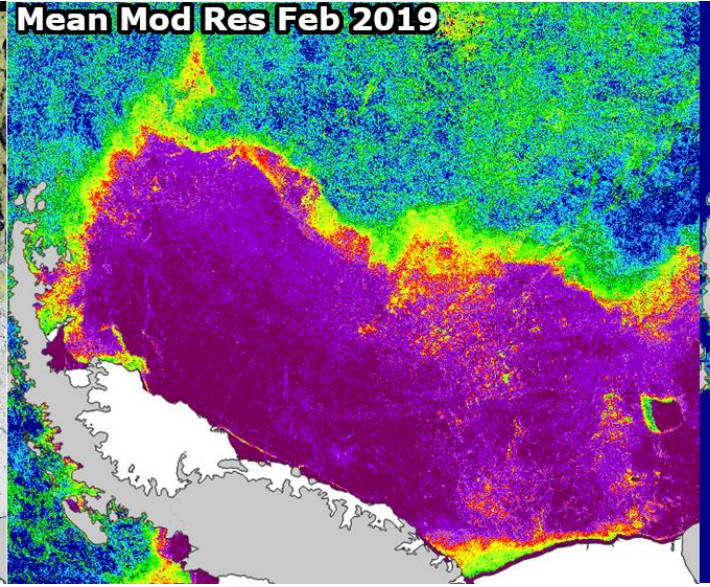
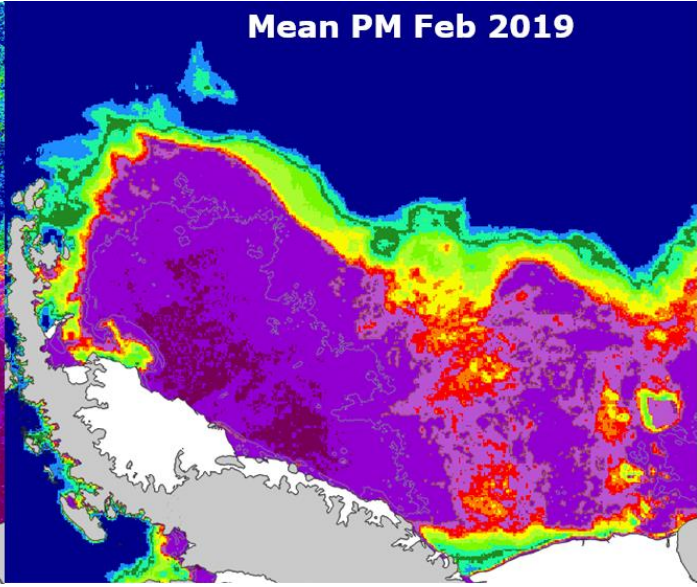


Composite of Visible Moderate Resolution imagery (256m) over Weddell Sea for period 29 Jan – 4 Feb 2019. Yellow shade marks persistent cloud. LC = Larsen C Ice Shelf.



Average sea ice concentration derived from MODIS/VIIRS imagery in February 2019 using our algorithm



Average sea ice concentration derived from daily Passive Microwave (AMSR/2, Uni Bremen) imagery in February 2019

- Compositing over a longer timescale allows for the reduction of cloud effects (upper left), at the expense of temporal resolution.
- The upper central and right panels show a comparison between average February 2019 MODIS/VIIRS and PM concentrations, respectively, illustrating the ***much improved, cloud-free detail afforded by our algorithm***.
- By averaging over individual summer months, our method can also be used to yield high resolution insights into ***seasonal and inter-annual sea ice cover changes*** (bottom and bottom-right panels, plus following slide) in an ***automated*** way.

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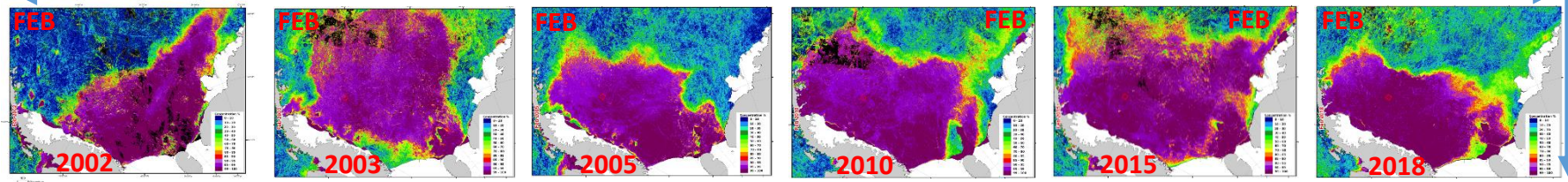

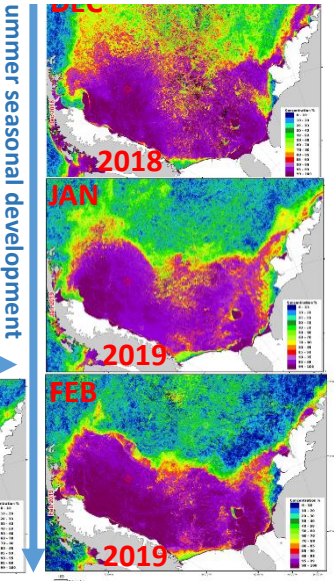

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Sea-floor and sea-ice conditions in the western Weddell Sea, Antarctica, around the wreck of Sir Ernest Shackleton's *Endurance*

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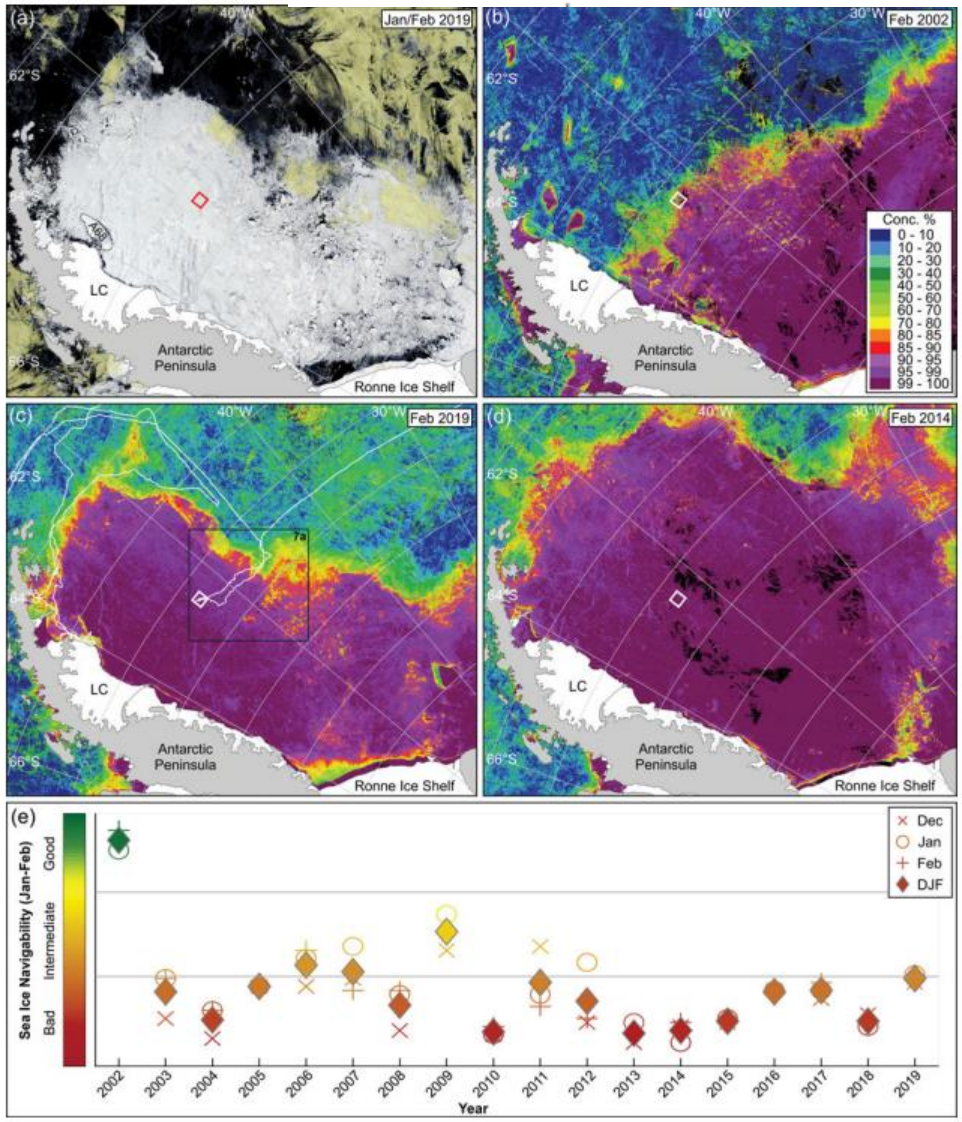

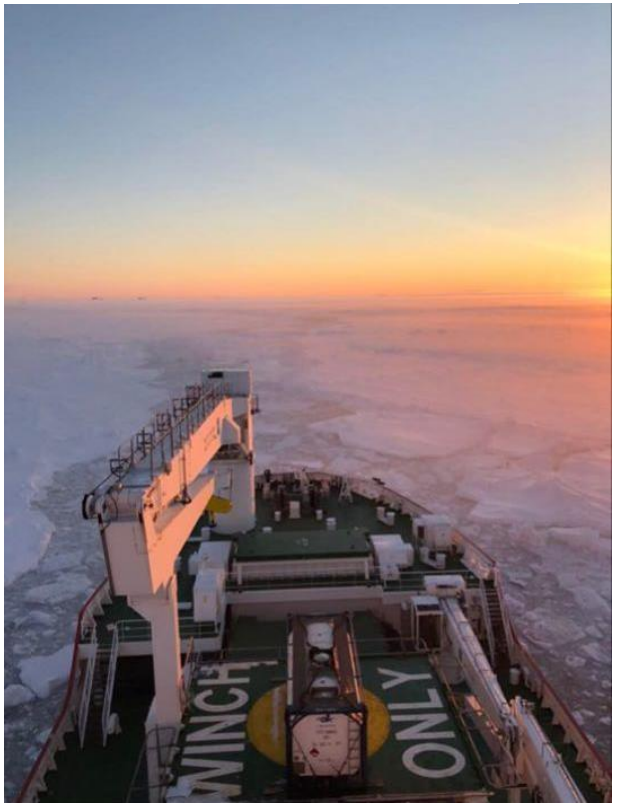

- Our maps were used to infer December-January-February (DJF) sea ice cover probability in the Weddell Sea, and were used in the day-to-day navigation of the S.A. Agulhas II en route to the Endurance wreck site in Feb 2019.

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