Where did it come from, where did it go?

Regional and seasonal controls on airmass transport to the Ellsworth Mountains, Antarctica

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1 Ice cores play a vital role in our understanding of past climate. Atmospheric circulation patterns play a key role in influencing preserved chemical signals in ice cores - a role that is difficult to quantify.

2 To inform ice core analyses in the inner West Antarctic, we used an atmospheric trajectory model to simulate airmass transport to a contemporary ice coring site over a 15-year period.

3 Transport patterns were found to be strongly seasonal. Air parcels travel from further away in winter than summer and, critically, from different regions of the Southern Hemisphere.

4 These patterns may cause bias in chemical signals used as environmental proxies. More work is required for individual chemical species to determine source-vs-transport relationships.

1: Rationale

The West Antarctic is a critical region for the earth's climate. It is vulnerable, and contains enough ice to cause >3 m of sea level rise.[1,2] Understanding the past climate of this region is a vital component of our ability to anticipate future change. One of our greatest tools for documenting past climates comes in the form of ice cores, extracted from the earth's ice sheets.

- The chemical signals preserved in ice layers can tell us about past environmental conditions, acting as 'proxies'.
- When dated, these trapped signatures can provide us with time-resolved information about past temperature, wind strength, sea ice concentration and more.
- However, to understand these signals, we need to know how they came to be deposited on the ice sheet's surface. **Where do airmasses arriving in the West Antarctic (both 'dry' aerosols and precipitation) originate?**

2: The study site

In 2015, our team drilled a 16.6 metre core of dense snow from Patriot Hills in the Ellsworth Mountains, West Antarctica (**Fig. 1**).

- Meltwater samples in 2.5 cm increments were measured for isotopes, major chemistry, and fluorescence.
- By dating annual layers in stable water isotopes, we know the core extends back to 1975.
- This record overlaps with the satellite and instrumental records, providing a modern calibration tool for older ice cores.

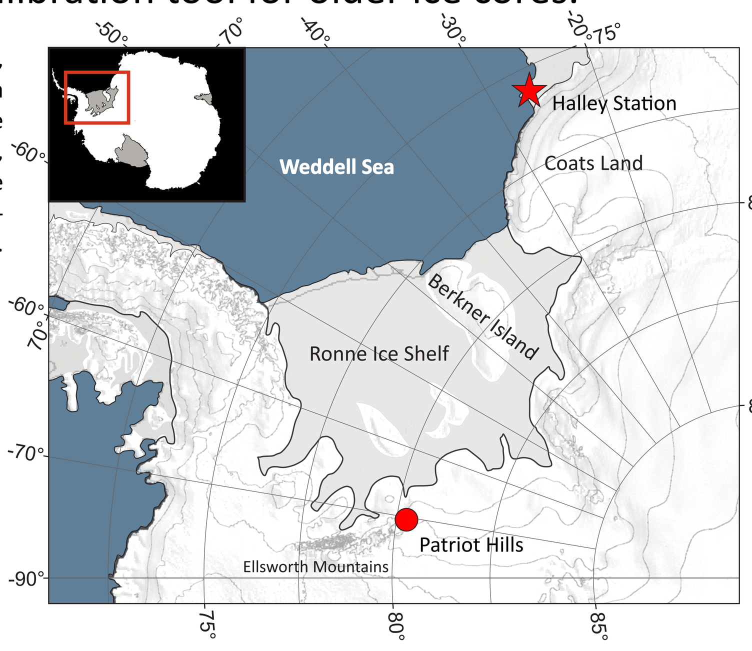

Fig. 1. The location of Patriot Hills, lying at the base of the Weddell Sea Embayment in West Antarctica. The Ellsworth Mountains run to the north, and to the south lies the Institute Ice Stream, feeding into the Ronne-Filchner ice shelf.

Scan the QR code to watch a video of our team coring at Patriot Hills.

3: Modelling airmass movements

We used the National Ocean and Atmospheres Administration's (NOAA) **HYSPLIT** model to analyse transport to Patriot Hills. HYSPLIT is freely available and widely used.[3]

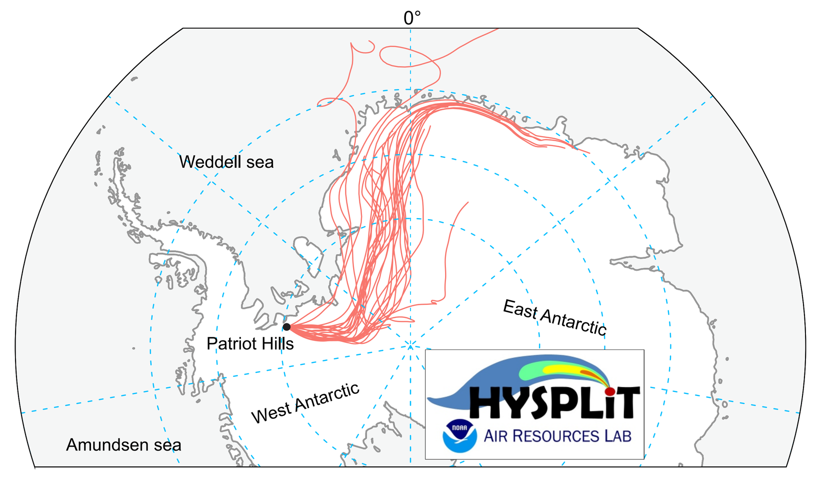

Fig. 2. Typical backwards trajectory 'spaghetti' paths generated by HYSPLIT. Each line is a single parcel of air, travelling backwards through time. Trajectories shown here are selected from days within a single week in January, 2009. Trajectories are three-dimensional, generating a range of variables including height and air pressure each hour as the parcel travels. Each trajectory produces 121 total data steps (0 to 120 hr).

The model was run **in reverse** from Patriot Hills on the hour, every hour, between 2005 and 2020 - the period covered by the highest-quality meteorological data supplied by NOAA. Trajectories were tracked for 120 hours in line with similar studies (**Fig. 2**).[4,5]

4: Broad spatial dynamics

Trajectory points-of-origin (the point 120 hours back in time for each trajectory) were grouped with density functions (**Fig. 3**).

- Trajectories in austral summer (Nov, D, J, F, M) are closely constrained to the continent.
- In winter (Apr, M, J, J, A, S) the trajectories travel further, more often originating beyond the continental margin.

This pattern is likely explained by the strengthening of the Southern Hemisphere westerlies during winter.

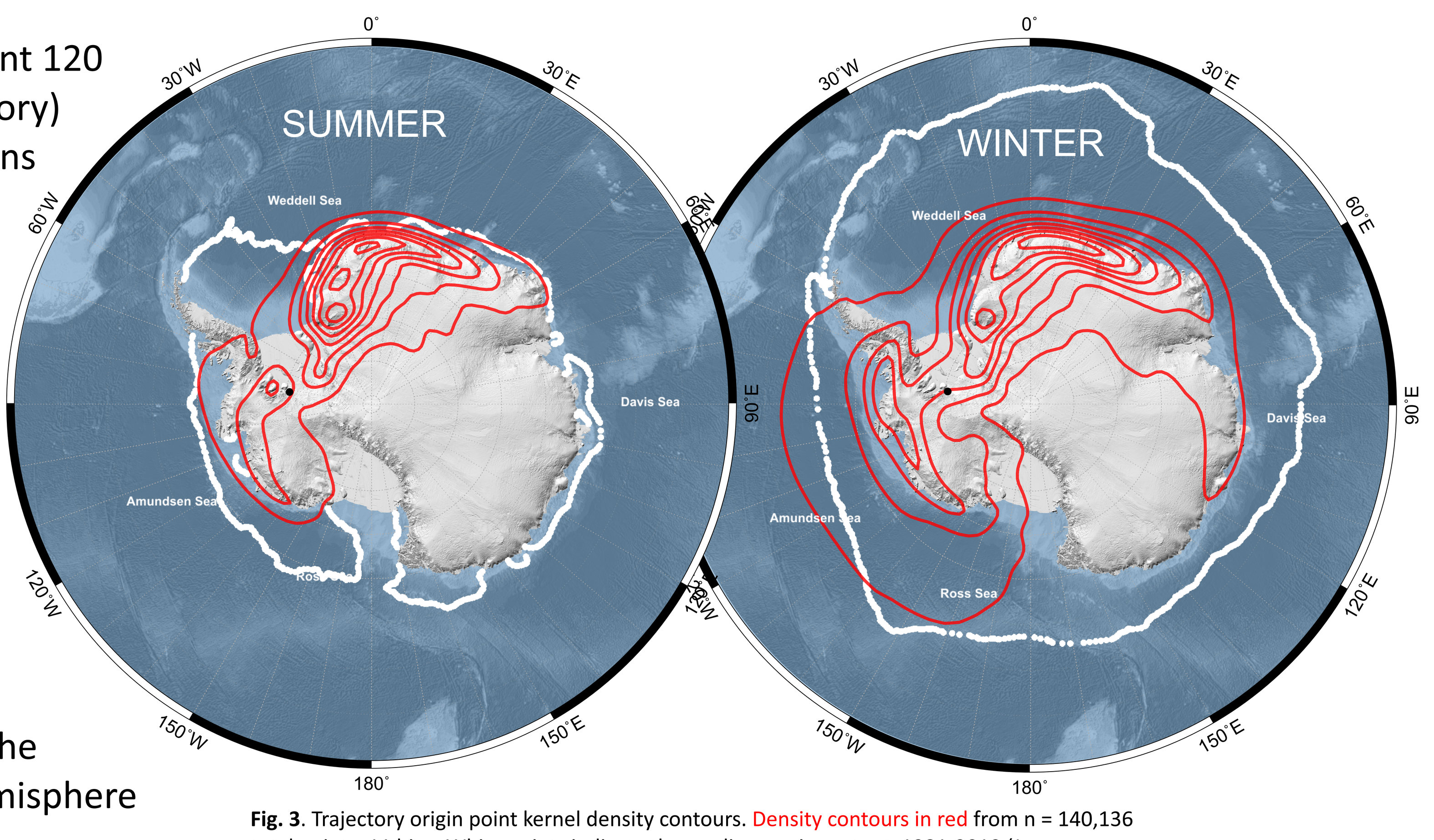

Fig. 3. Trajectory origin point kernel density contours. Density contours in red from n = 140,136 total points, 11 bins. White points indicate the median sea ice extent, 1981-2010 (January on summer plot, September on winter). Patriot Hills marked as a black dot.

5: Ocean sector contributions

Sea ice dynamics in the ocean sectors around Antarctica display conflicting relationships with key ice core proxies such as methanesulfonic acid.[6] Patriot Hills receives more than double the airmass volume from the Amundsen-Bellingshausen seas in winter relative to summer (**Fig. 4**).

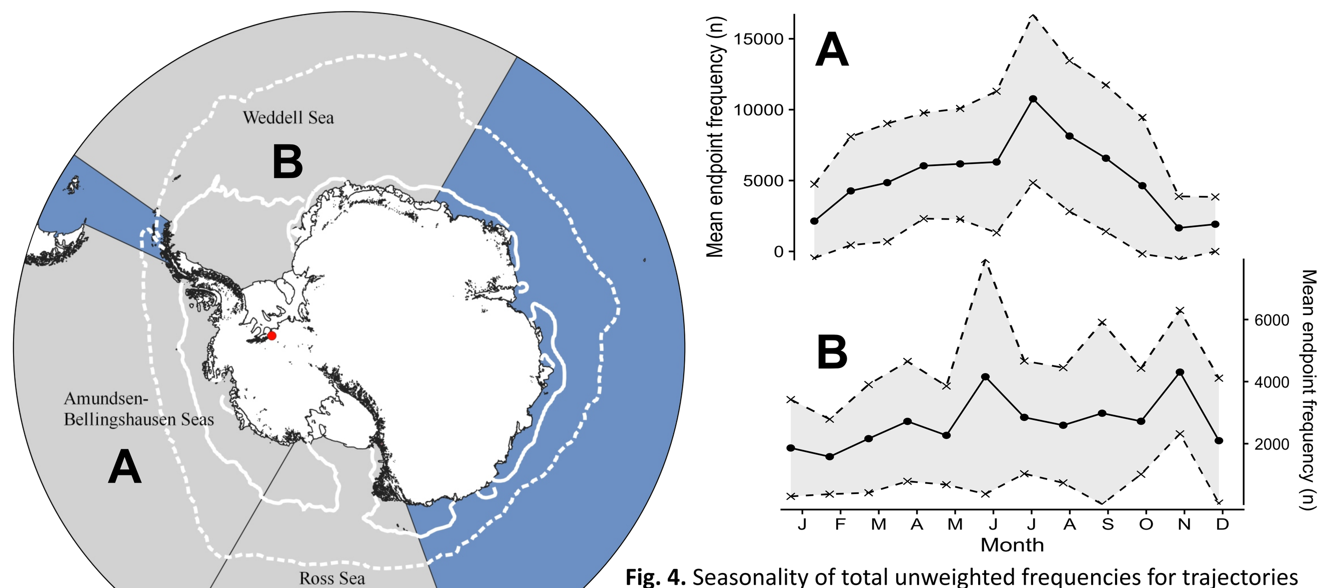

Fig. 4. Seasonality of total unweighted frequencies for trajectories reaching the Amundsen-Bellingshausen (A; top graph) and Weddell (B; lower graph) seas. Solid line for mean frequency, and dashed line for ± 1 standard deviation. All points included (total n = 16,956,456).

6: What about precipitation?

Bulk trajectory patterns are more representative of general trends in 'dry aerosol' transport. To investigate the paths of airmasses associated with snowfall, we used ERA5 reanalysis data to determine dates when the nearest half-gridpoint to Patriot Hills received >3 mm precipitation. In contrast to the bulk airmass patterns, identifying days associated with snowfall sees transport largely restricted to Queen Maud Land and the Weddell Sea (**Fig. 5**).

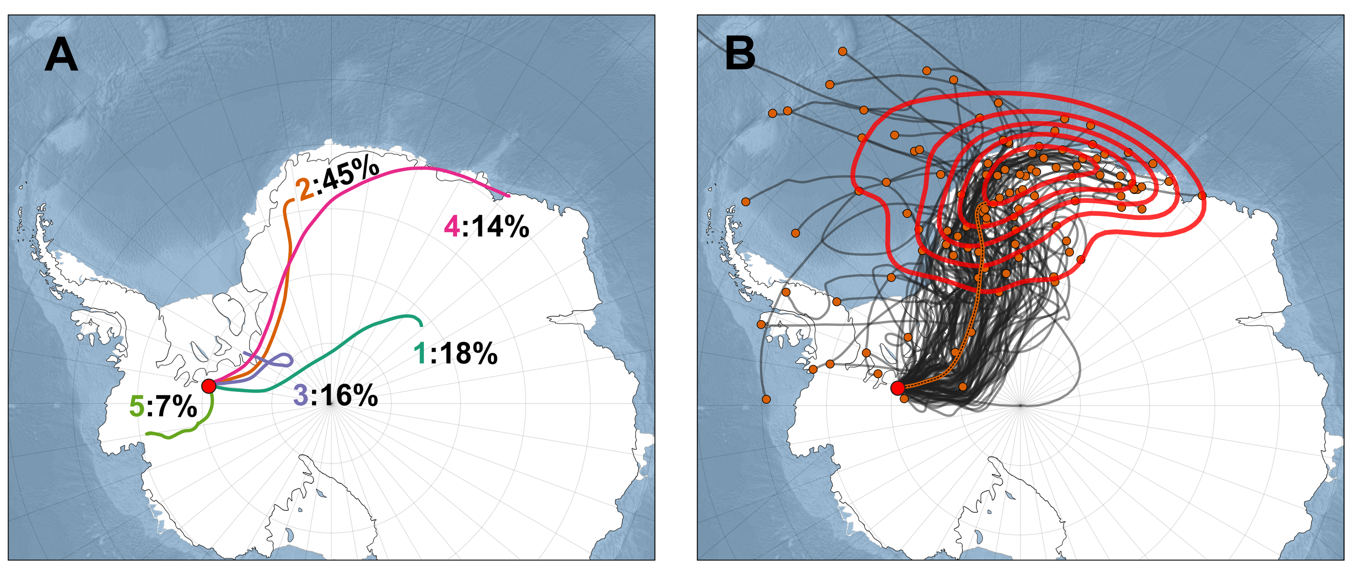

Fig. 5. A: 5-group cluster analysis of daily trajectories from Patriot Hills (2006 to 2020) on days exceeding 3 mm precipitation to the nearest ERA5 halfway gridpoint (n = 260). B: Points of origin and fetch areas of trajectories comprising cluster 2 (orange circles and grey lines respectively, n = 117). Red contours show kernel density of trajectory points of origin, binned into 6 tiers.

7: Conclusions

To inform ice core palaeoclimate analyses from the West Antarctic, we used an atmospheric trajectory model to analyse spatial patterns in airmass transport to Patriot Hills.

- Bulk aerosol patterns, representing 'dry' aerosol transport, show significant seasonal differences in back-trajectory origin. Trajectories travel from further away in winter.
- The Amundsen-Bellingshausen sea contributes a greater relative proportion of trajectories in winter, causing potential bias in ocean-originating chemistry.
- Precipitation-associated airmasses predominantly originate from the Weddell Sea and its continental margin.

Future work will unpack the precise interaction between these patterns and preserved chemistry concentrations. In addition, long-term airmass dynamics will be compared with major climate modes such as the Southern Annular Mode.

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Data and code availability

The code developed for trajectory spatial analysis used in this work is available as an R package on github at **https://github.com/MRPHarris/trajSpatial**