

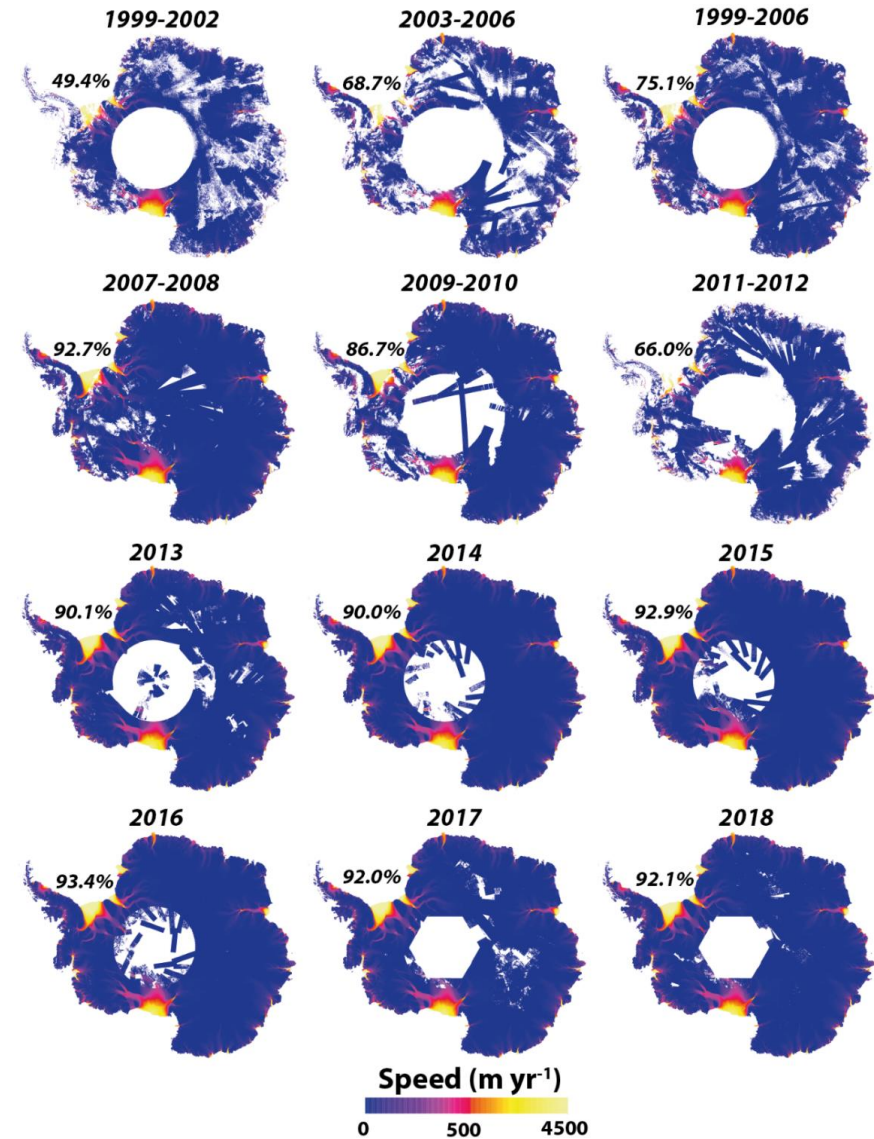
High spatial and temporal variability in Antarctic ice flux linked to ice shelf buttressing and bed geometry

Bertie Miles*, Chris Stokes, Stewart Jamieson, Hilmar Gudmundsson,
Jim Jordan and Adrian Jenkins

a.w.j.miles@durham.ac.uk

Time-stamped mosaics

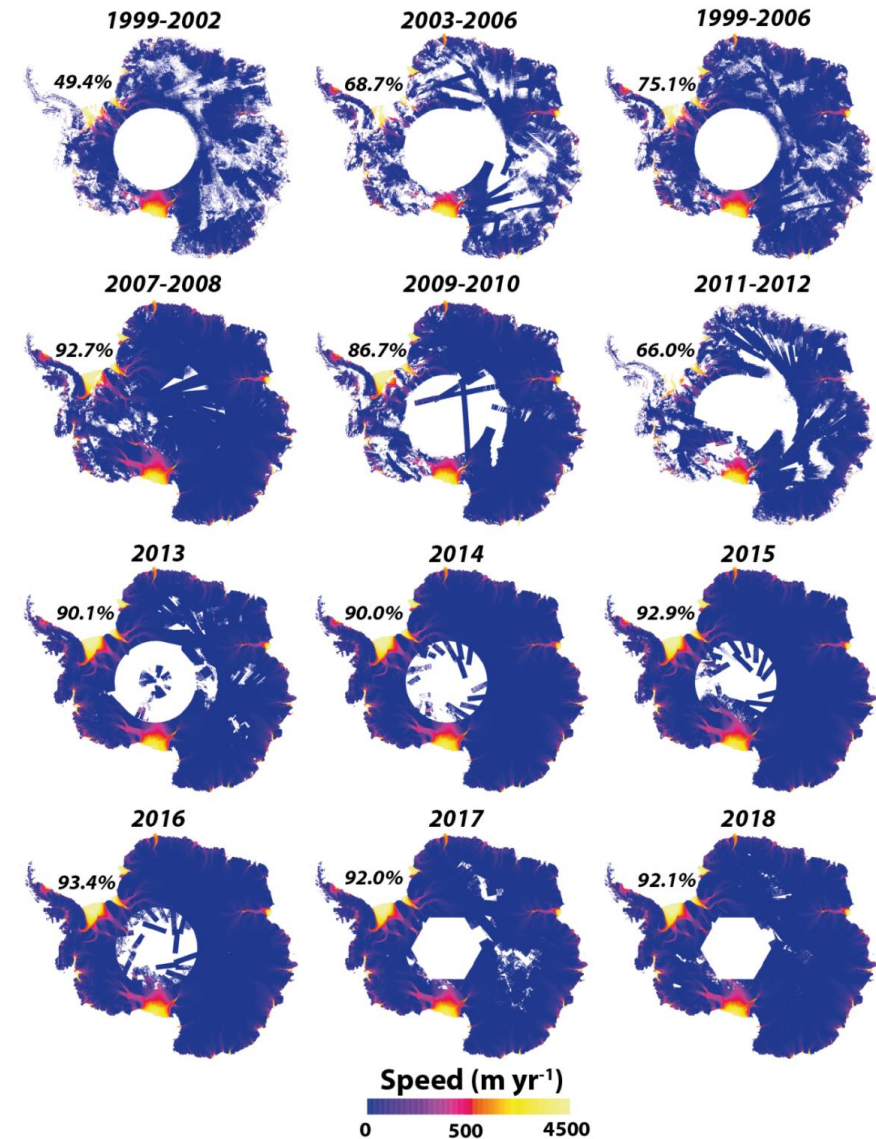
- Merged composites of the ITS_LIVE (Gardner et al., 2017) and MEaSUREs (Mouginot et al., 2017) annual velocity mosaics.
- Coverage improved between 1999 and 2012 by merging multiple years of data
- Percentage coverage in each year indicated on the top right of each mosaic
- The spatial resolution of the velocity products (1 km) struggle in some of the narrow fjords of the Peninsula, so we focus solely on West and East Antarctica



Composite velocity mosaics between 1999 and 2018. Percentage in top left represents the spatial coverage of total ice flux, relative to a reference dataset at each epoch.

Ice flux

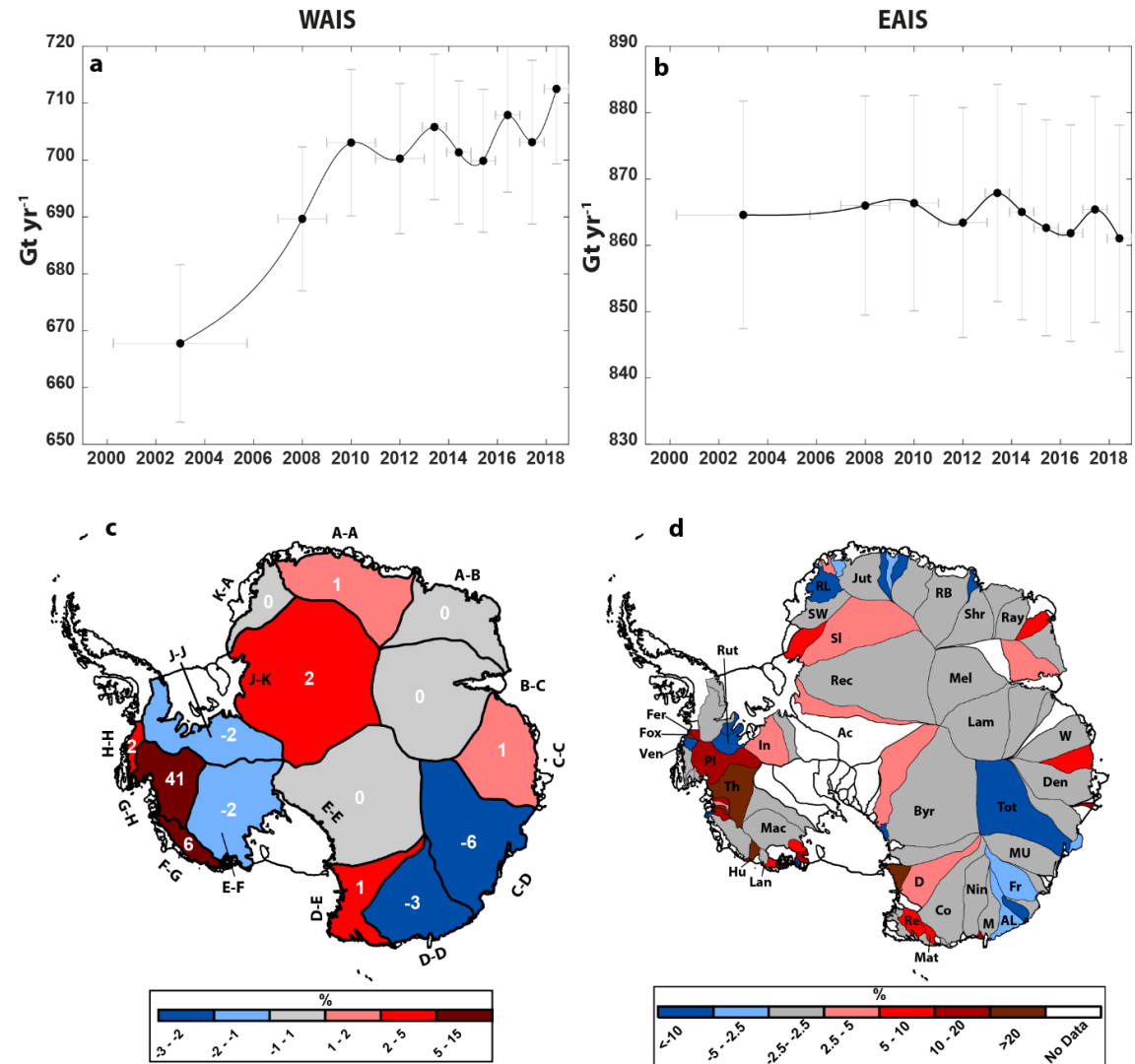
- Ice thickness taken from BedMachine
- Flux gate is fixed throughout and we use an amended version of the GLO product (Gardner et al., 2017), which is just behind the grounding line.
- No corrections for vertical velocity gradient or thinning
- For any node with missing data, the velocity values are taken from the corresponding node from the MEaSUREs reference product
- Time series produced at three different spatial scales: ice sheet; basin (e.g. Amundsen Sea; Wilkes Land etc) and catchment scale (e.g. Totten, Pine Island)



Composite velocity mosaics between 1999 and 2018. Percentage in top left represents the spatial coverage of total ice flux, relative to a reference dataset at each epoch.

Ice Sheet scale

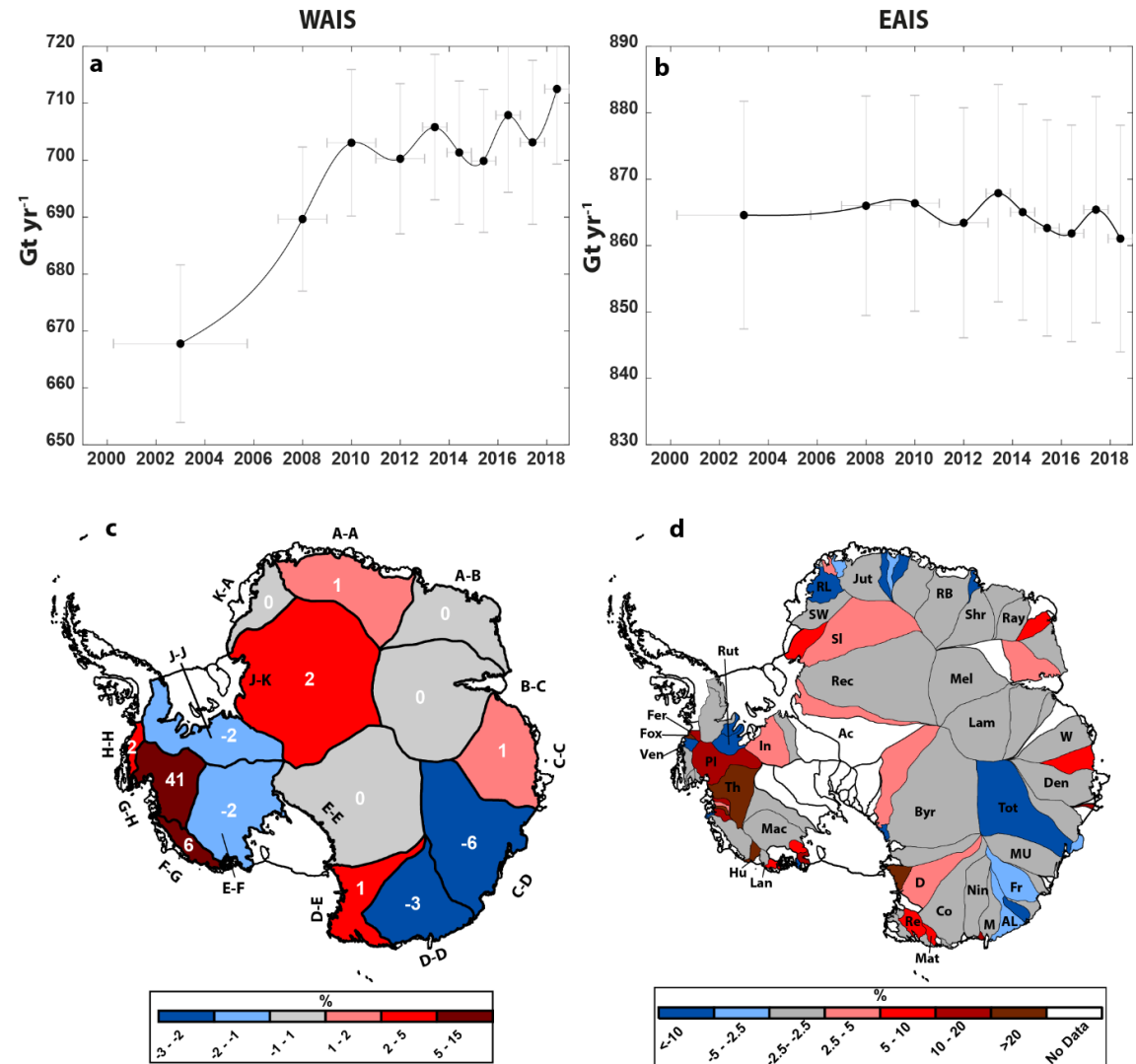
- $45 \pm 8 \text{ Gt yr}^{-1}$ increase in ice flux of the WAIS
- Small $4 \pm 7 \text{ Gt yr}^{-1}$ decrease in ice flux of the EAIS
- Large increase in flux from WAIS in the first half of the observational period, little change in the second half.
- Overall: $37 \pm 11 \text{ Gt yr}^{-1}$ increase from 1999-2010
- Overall: limited change between 2010 and 2018, with a $4 \pm 8 \text{ Gt yr}^{-1}$ increase



Time series of ice flux from the West Antarctic Ice Sheet (WAIS). **b)** East Antarctic Ice Sheet (EAIS) fitted with a gaussian best fit model in black. **c)** Percentage change in ice flux between 1999-2005 and 2018 for each IMBIE drainage basin (Rignot et al., 2019), the white numbers are the change in Gt. **d)** Percentage change in ice flux between 1999-2005 and 2018 for each individual catchemnt (Rignot et al., 2019)

Ice Sheet scale

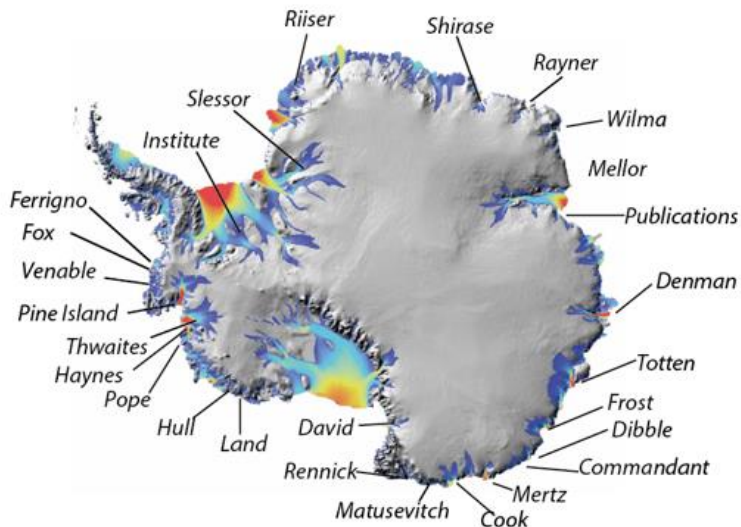
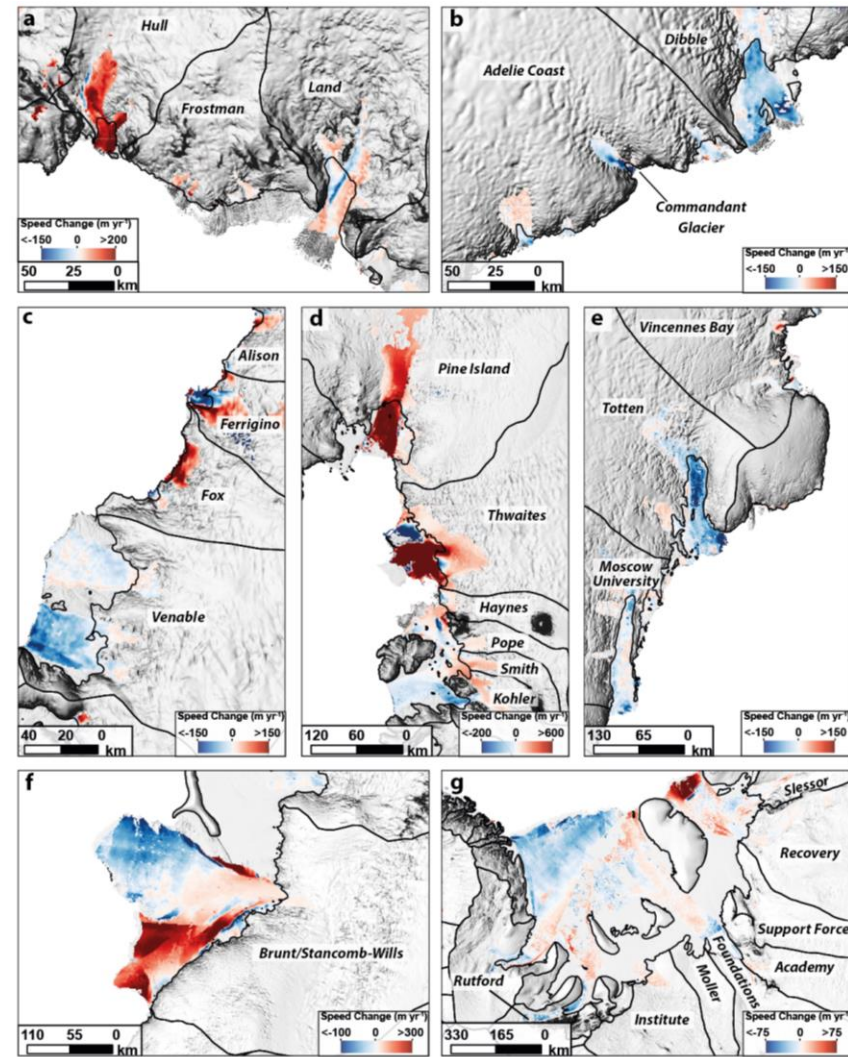
- Increase in ice flux has been dominated by the Amundsen Sea sector
- Decrease in ice flux in Wilkes Land, East Antarctica
- ~10 % decrease in ice flux in the Totten catchment
- Neighbouring catchments can simultaneously undergo opposing trends



Time series of ice flux from the West Antarctic Ice Sheet (WAIS). **b)** East Antarctic Ice Sheet (EAIS) fitted with a gaussian best fit model in black. **c)** Percentage change in ice flux between 1999-2005 and 2018 for each IMBIE drainage basin (Rignot et al., 2019), the white numbers are the change in Gt . **d)** Percentage change in ice flux between 1999-2005 and 2018 for each individual catchment (Rignot et al., 2019)

Spatial pattern

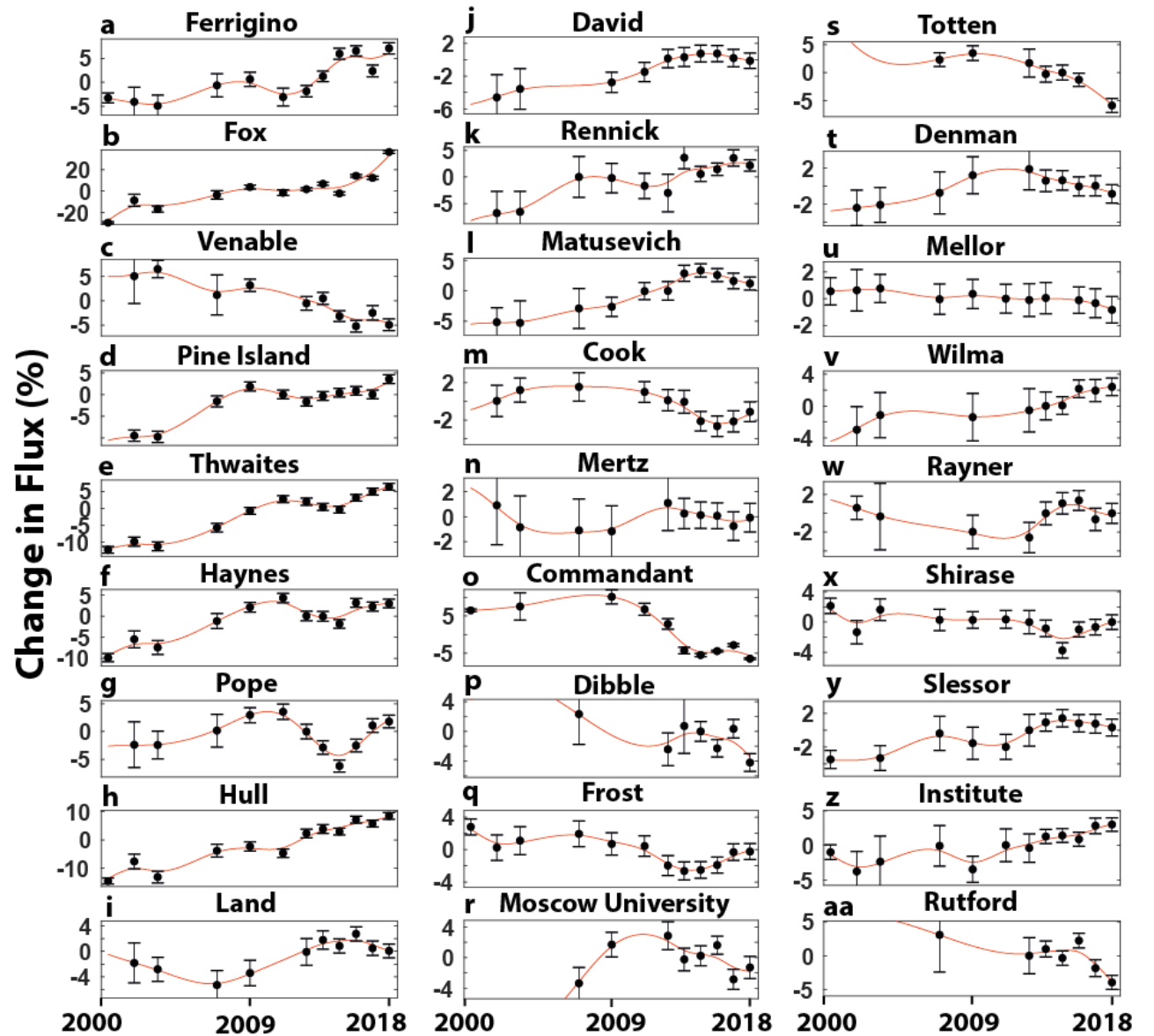
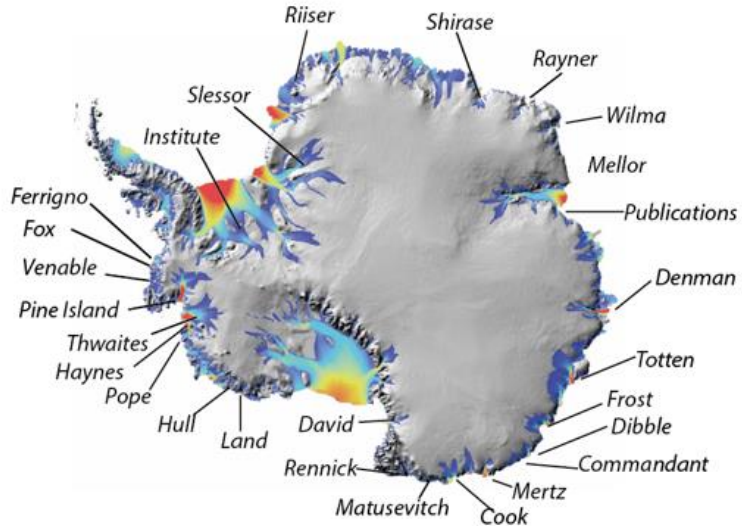
- Difference in ice speed between 2018 and 1999-2006 (red = increase; blue = decrease)
- Neighbouring catchments can simultaneously undergo opposing trends
- Complex spatial patterns



Spatial pattern of ice speed change between 1999-2006 and 2018 where ice flow speed is greater than 200 m yr⁻¹ for **a)** Land and Hull catchments **b)** Adelie Coast and Dibble catchments **c)** Venable, Fox and Ferrigno catchments **d)** the Amundsen Sea sector, **e)** Totten and Moscow University catchments **f)** Brunt/Stancomb-Wills catchment and **g)** The Filchner-Ronne Ice Shelf

Catchment scale

- Clear temporal variability in catchments in both WAIS and EAIS
- In the EAIS direct contrast to lack of temporal variability compared to ice sheet scale
- Some neighbouring catchments behave in-sync, others do not



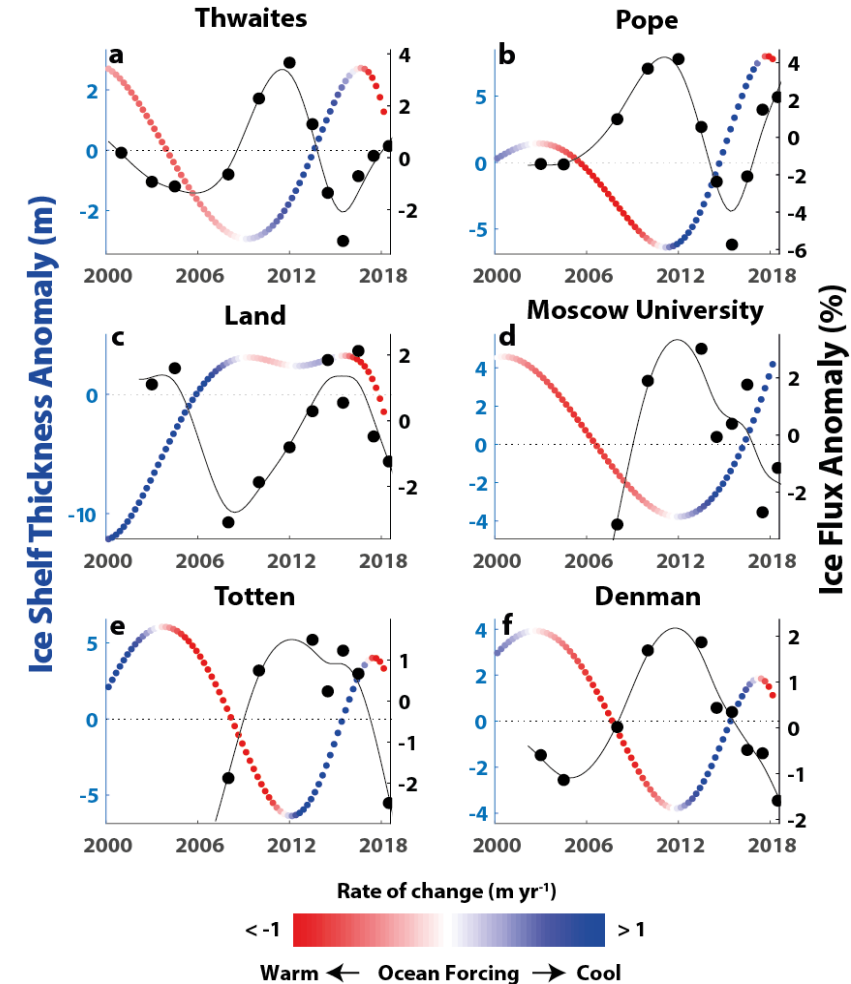
Time series of percentage change in ice flux rates relative to the mean for selected catchments in West and East Antarctica.

What is driving this temporal and spatial variability?

- Changes in ice shelf buttressing through either changes in ice shelf thickness or extent drive the interannual variability observed.
- The magnitude of response in ice flux to these perturbations in ice shelf buttressing is then determined by each glacier's unique geometry, explaining why some neighbouring catchments do not behave in-sync.

Ice shelf buttressing: ice shelf thickness

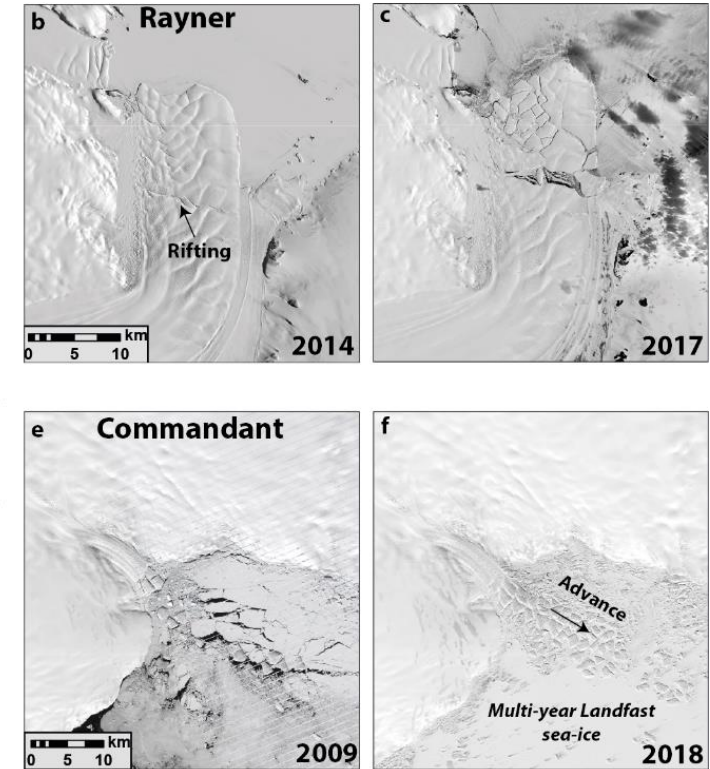
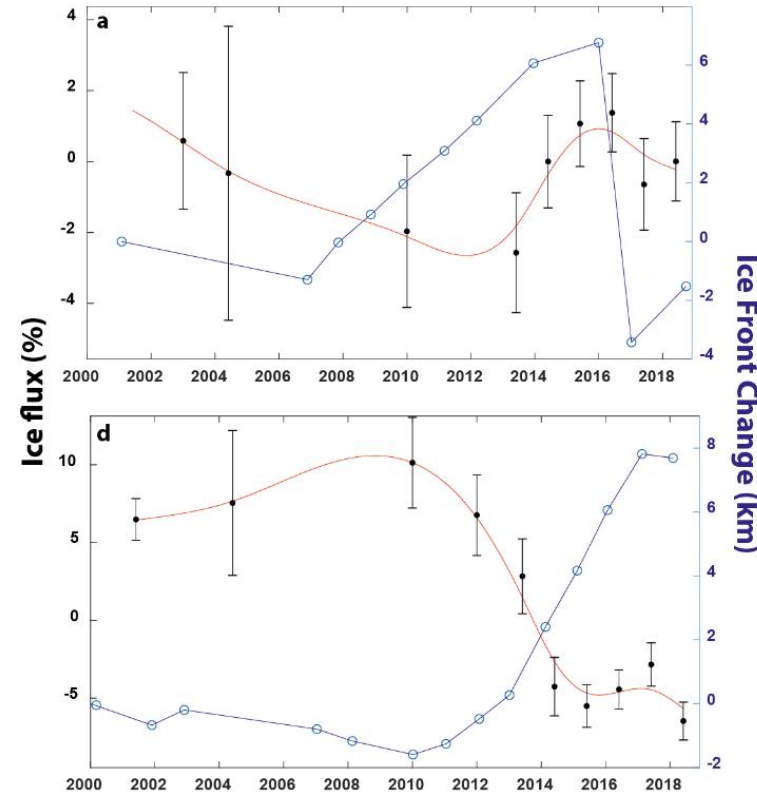
- Linearly de-trended Ice flux anomalies (1999-2018) vrs linearly de-trended ice shelf thickness change (1992-2018) anomalies.
- Ice shelf thickness anomalies derived from the time series in Adusumilli et al., 2020.
- Periods of anomalous thinning coincides with increases in ice flux; anomalous thickening coincides with decreases in ice flux
- Anomalous thinning indicative of relatively warm ocean forcing, anomalous thickening indicative of relatively cool ocean forcing



Linearly de-trended anomalies in ice shelf thickness (m) versus linearly de-trended anomalies in ice flux (%) for the **a)** Thwaites, **b)** Pope, **c)** Land, **d)** Moscow University, **e)** Totten, **f)** Denman catchments. Blue shading indicates thickening anomalies where the rate of ice shelf thickness change is greater than zero, which we interpret as relatively cooler oceanic conditions. Red shading indicates thinning anomalies where the rate of change is less than zero, which we interpret as relatively warm oceanic conditions.

Ice shelf buttressing: ice shelf extent

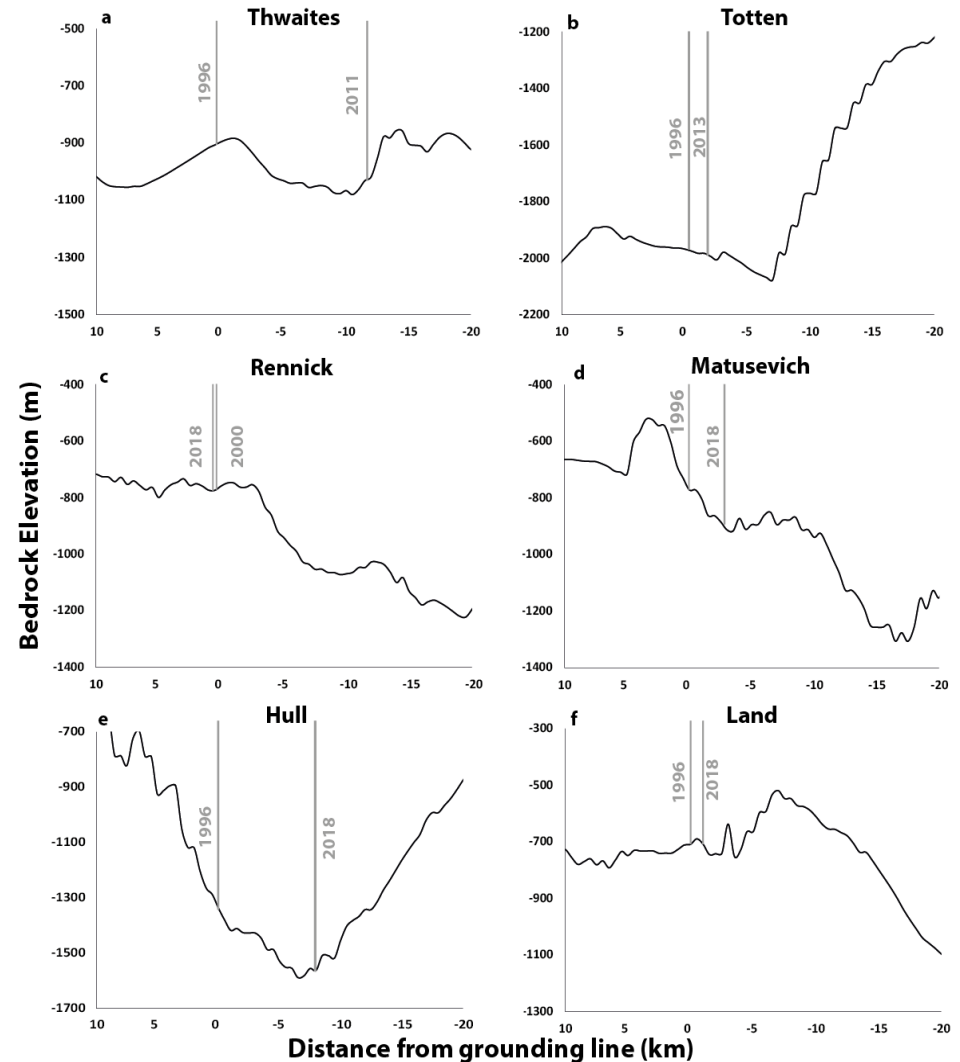
- The onset of calving and ice front retreat at Rayner coincides with an increase in ice flux
- The calving is part of a longer term cycle where the ice shelf calves at approximately the same position each time.
- The 15% decrease in ice flux at Commandant can be linked to the anomalous growth of an ice tongue
- At no stage in all satellite imagery stretching to 1962 is a comparable tongue present
- The anomalous growth of the tongue has been driven by a change in sea-ice conditions



a) Time-series of ice flux change (%) and ice-front position change between 2000 and 2018 for Rayner Glacier, **b)** and **c)** are Landsat-8 images showing the progression of a calving event at Rayner between 2014 and 2017. **d)** Time-Series of ice flux and ice-front position change for Commandant Glacier, **e)** and **f)** are Landsat-7 (2009) and Landsat-8 (2018) images showing the rapid growth of the Commandant ice tongue in response to persistent landfast sea-ice.

Bed Geometry

- Each glaciers unique geometry determines the absolute response in ice flux, following a perturbation in ice shelf buttressing. One important aspect of this is the local bedrock slope at the grounding line.
- For example, Hull and Land are neighbouring catchments, but have undergone opposing trends in ice flux. This can partly be explained by their differing bed topography



Bed topography profiles from BedMachine (Morlighem et al., 2020) extracted along the central flow line of the **a)** Thwaites, **b)** Totten, **c)** Rennick, **d)** Matusevich, **e)** Hull and **f)** Land Glaciers. The grey vertical lines are InSAR derived grounding line positions (Rignot et al., 2011; Mohajerani et al., 2021). On the x-axis, zero represents the earliest measured position of the grounding line, positive values are the bedrock elevations advanced of the grounding line and negative values are the bedrock elevation of grounded ice.