POLAR SCIENCE
FOR PLANET EARTH

The Impacts of El Niño on the Observed Sea Ice Budget of West Antarctica

James Pope

with

Paul Holland, Andrew Orr, Gareth Marshall & Tony Phillips

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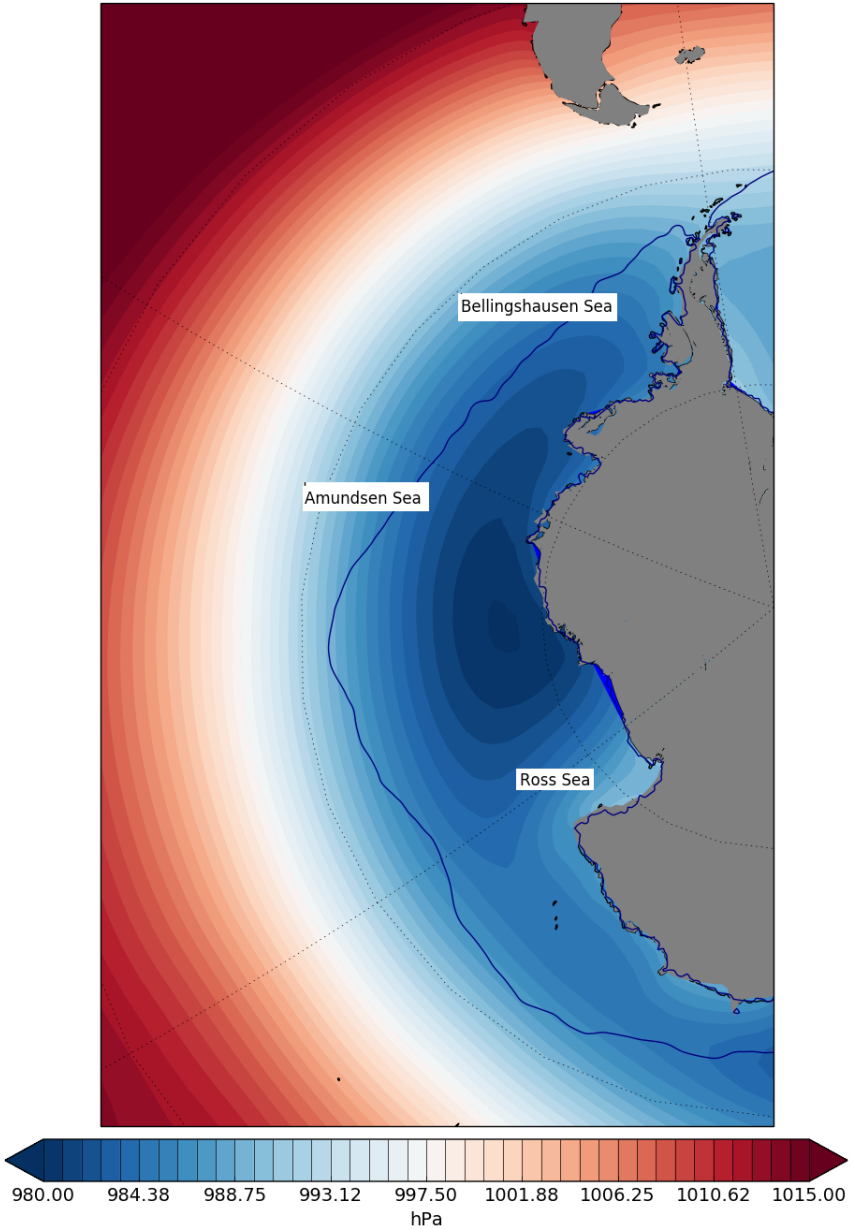


Focus Area

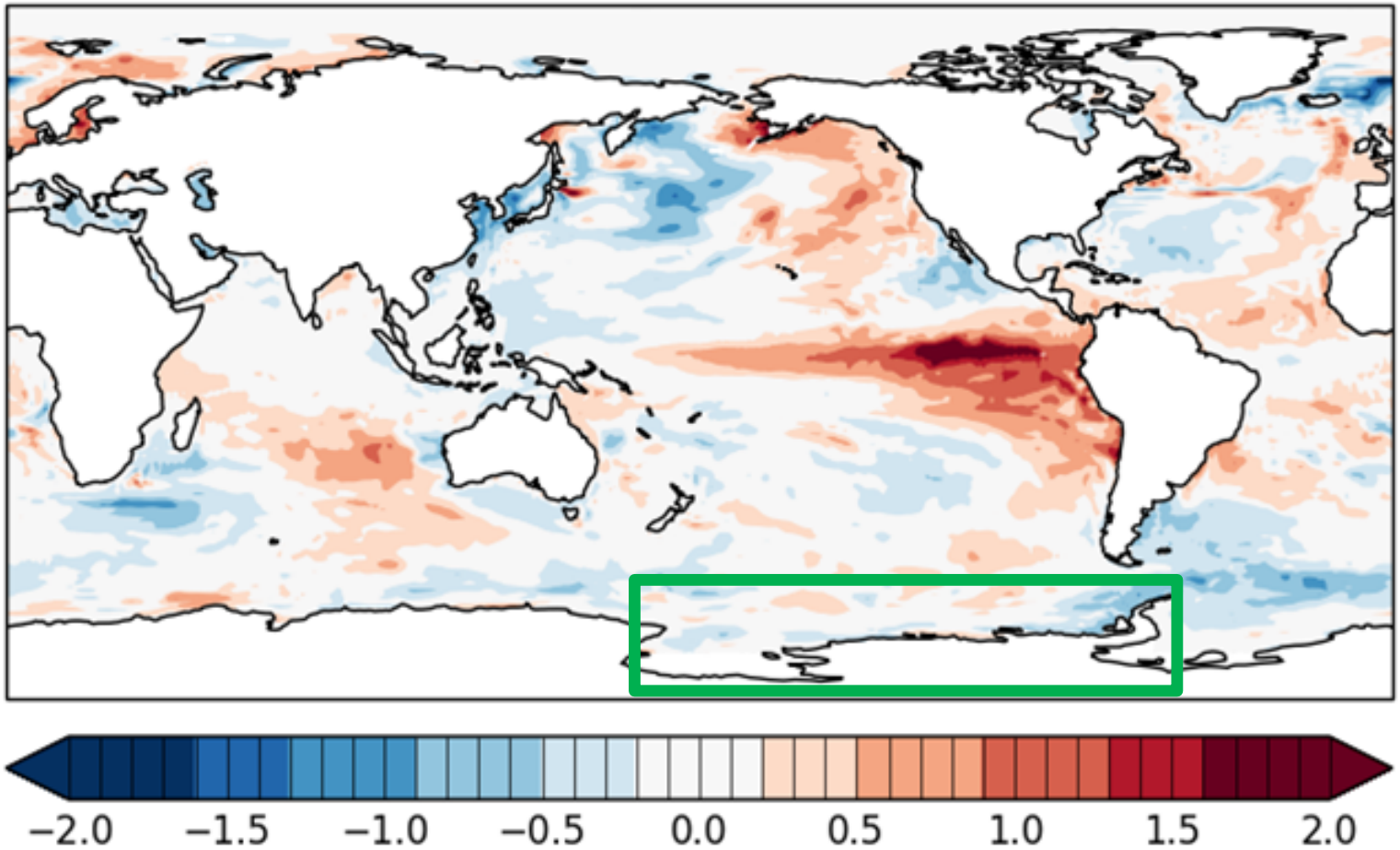
West Antarctica, specifically the Amundsen, Bellingshausen and Ross Seas.

Reason for this focus is:

1. This sector is also where the most robust teleconnections to tropical climate variability occur.
2. The El Niño Southern Oscillation (ENSO) has been strongly linked to changes in SIE in this region.
3. This sector demonstrates dynamic responses to changes in sea ice concentration.

We focus on El Niño because it directly opposes the long term trend in sea ice concentration (increases in Bellingshausen Sea and decreases in Ross Sea).

El Niño



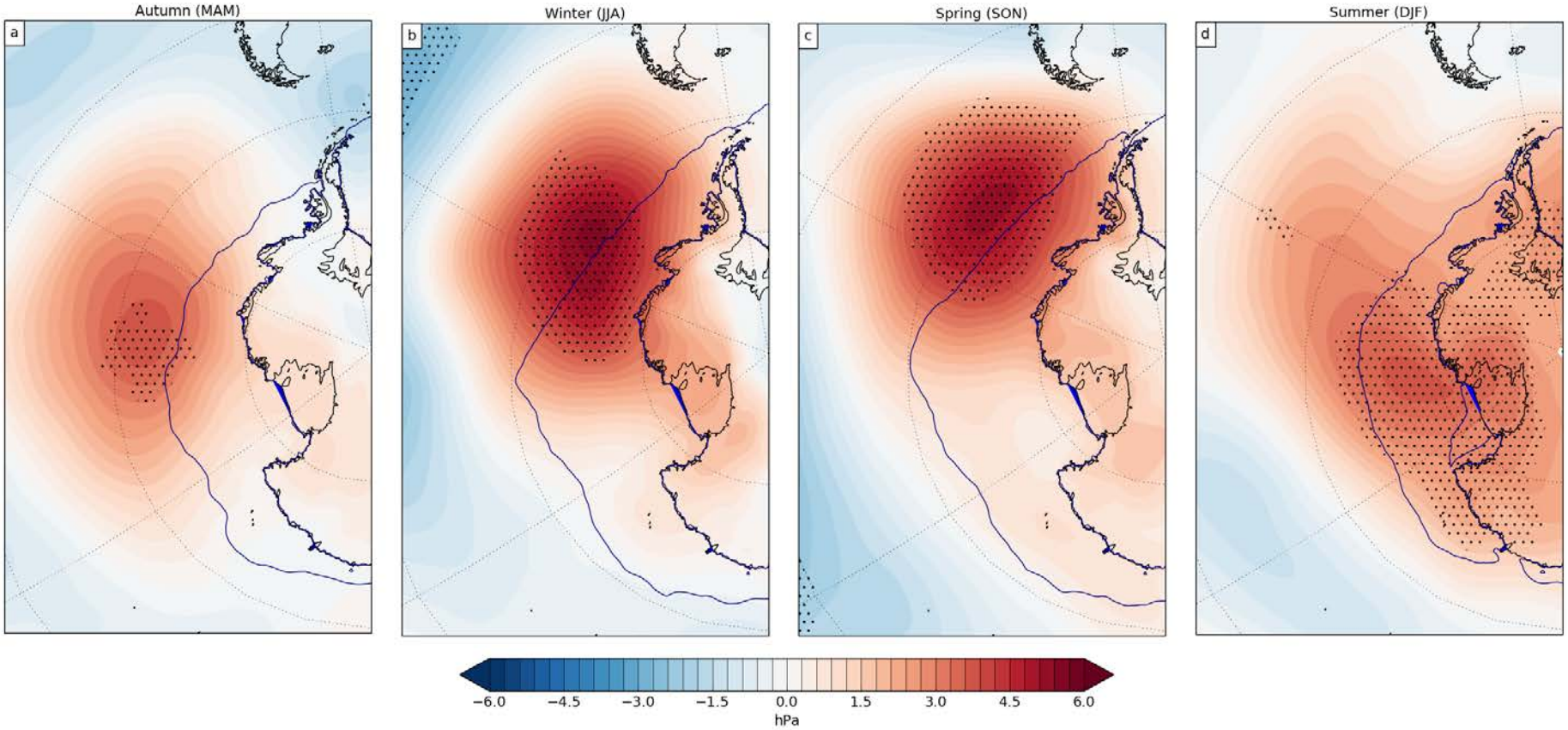
Assessing the El Niño Forcing

- *"Composite El Niño"* minus *"All"* ERA-Interim (January 1979-December 2014).
- Composite El Niño consists of 12 months of ERA-I data (March to February) for:
    - 1982/83
    - 1986/87
    - 1987/88
    - 1991/92
    - 1997/98
    - 2001/02
    - 2009/10
- Composites have been produced for ERA-Interim MSLP, 850 hPa temperature, 10 m wind components (U & V) and NSIDC Bootstrap2 sea ice concentration.

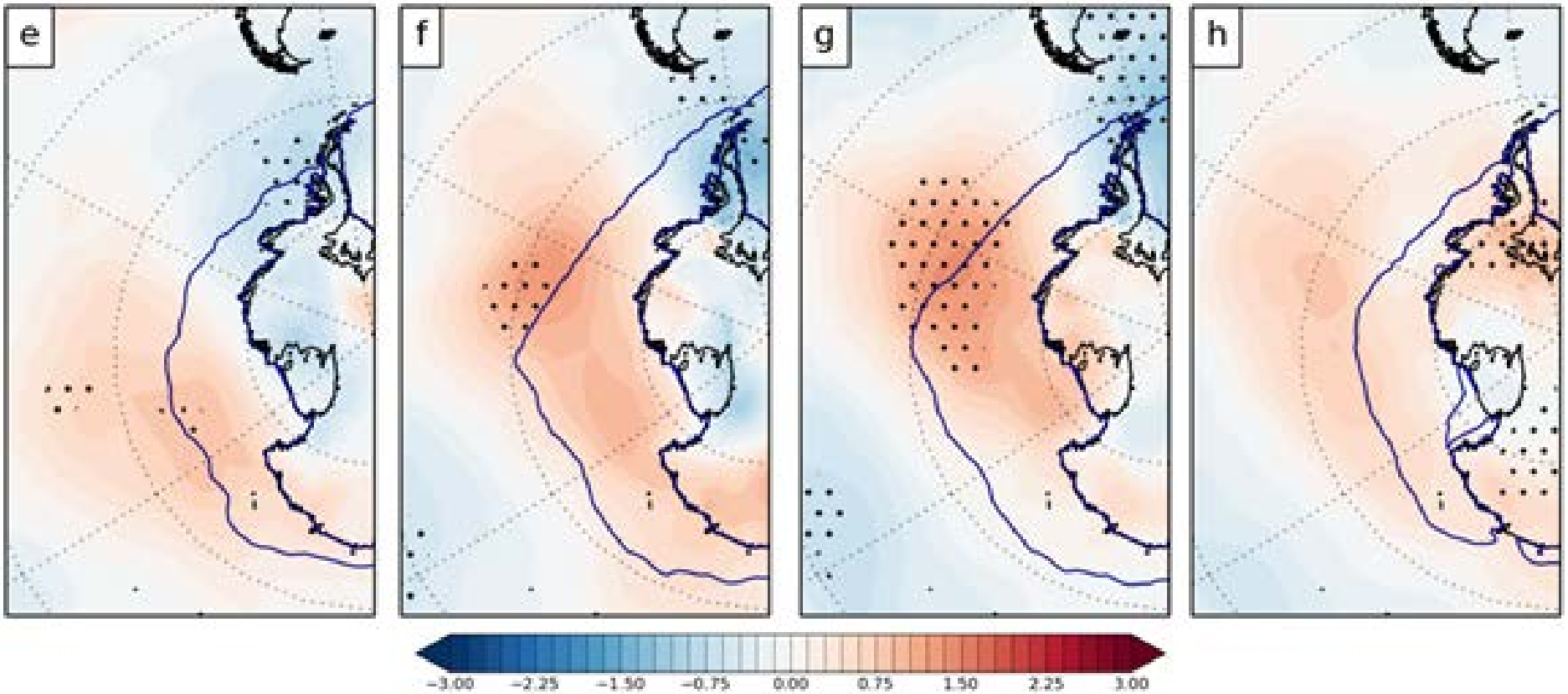
Observed MSLP Response to El Niño

El Niño Develops through the year

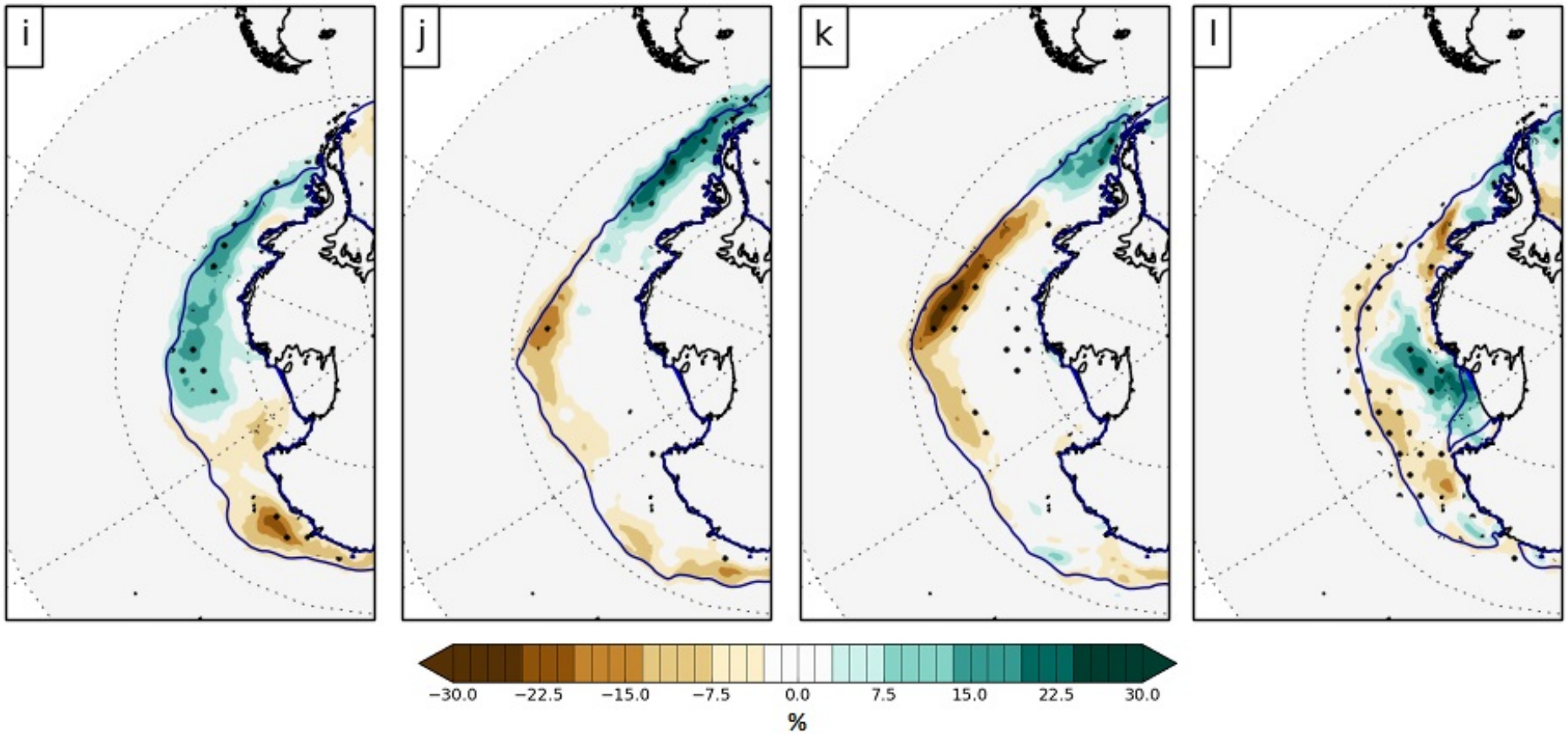
El Niño Initiates →



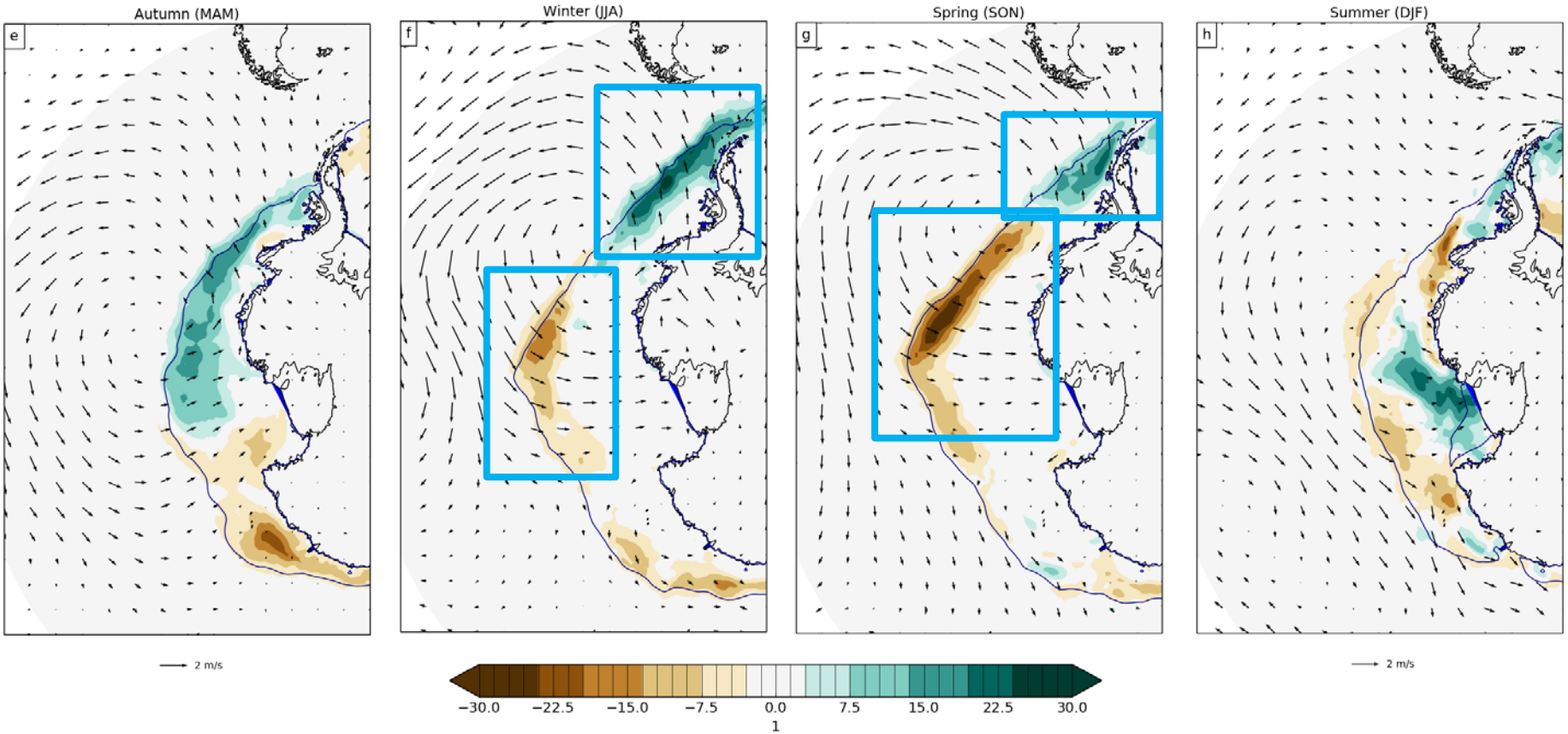
Observed 850 hPa Temperature Response to El Niño



Observed Sea Ice Response to El Niño



Observed Surface Winds Response to El Niño



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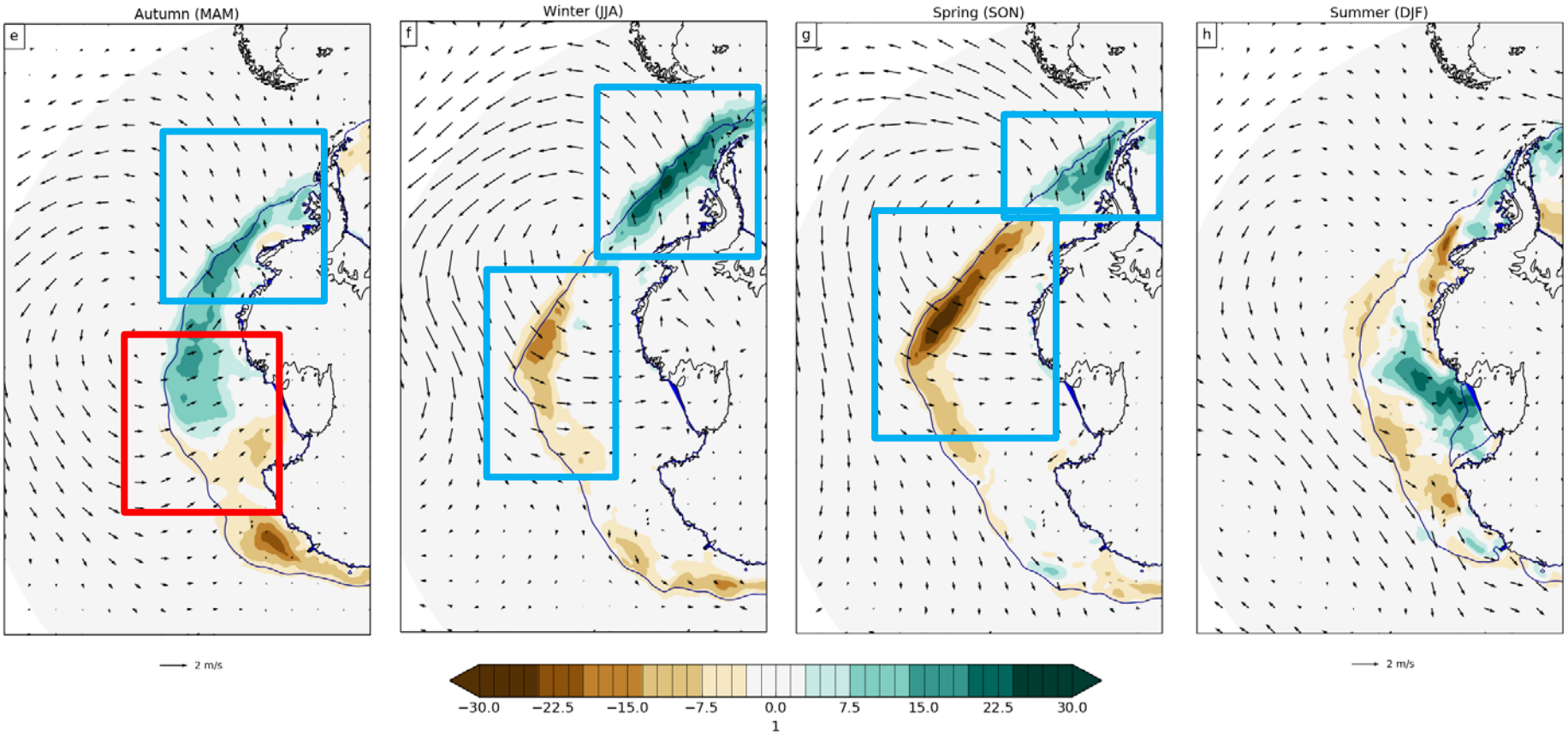


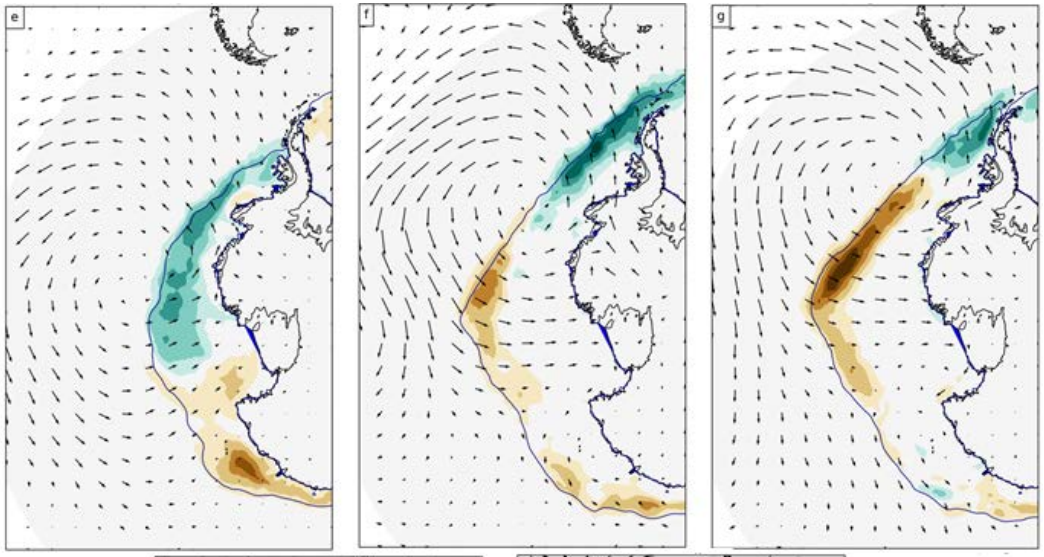
Is There A Better Metric Than Sea Ice Concentration Anomalies?

- Sea ice concentration anomalies work well in winter and spring, but perform poorly in autumn and summer.
- An alternative is too look at the anomalies in the intensification of sea ice.
- Sea ice intensification is calculated as:

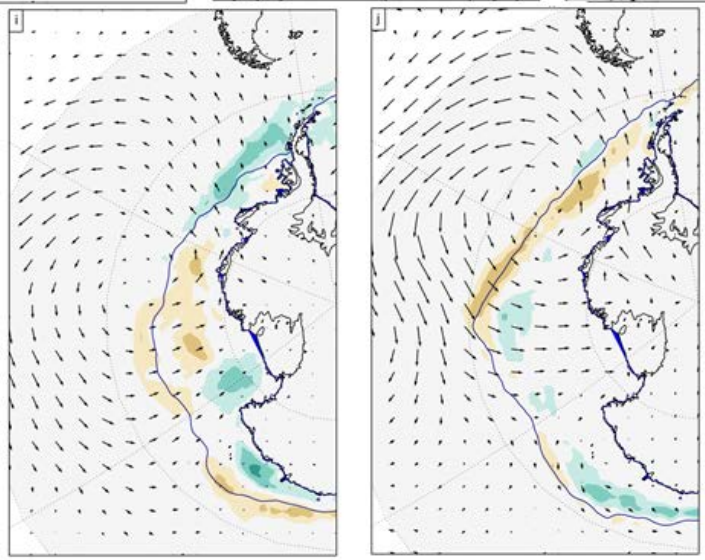
$$\frac{\partial C}{\partial t} = \frac{\text{Change in concentration}}{\text{Change in time}}$$

Holland & Kimura, 2016

Understanding Intensification

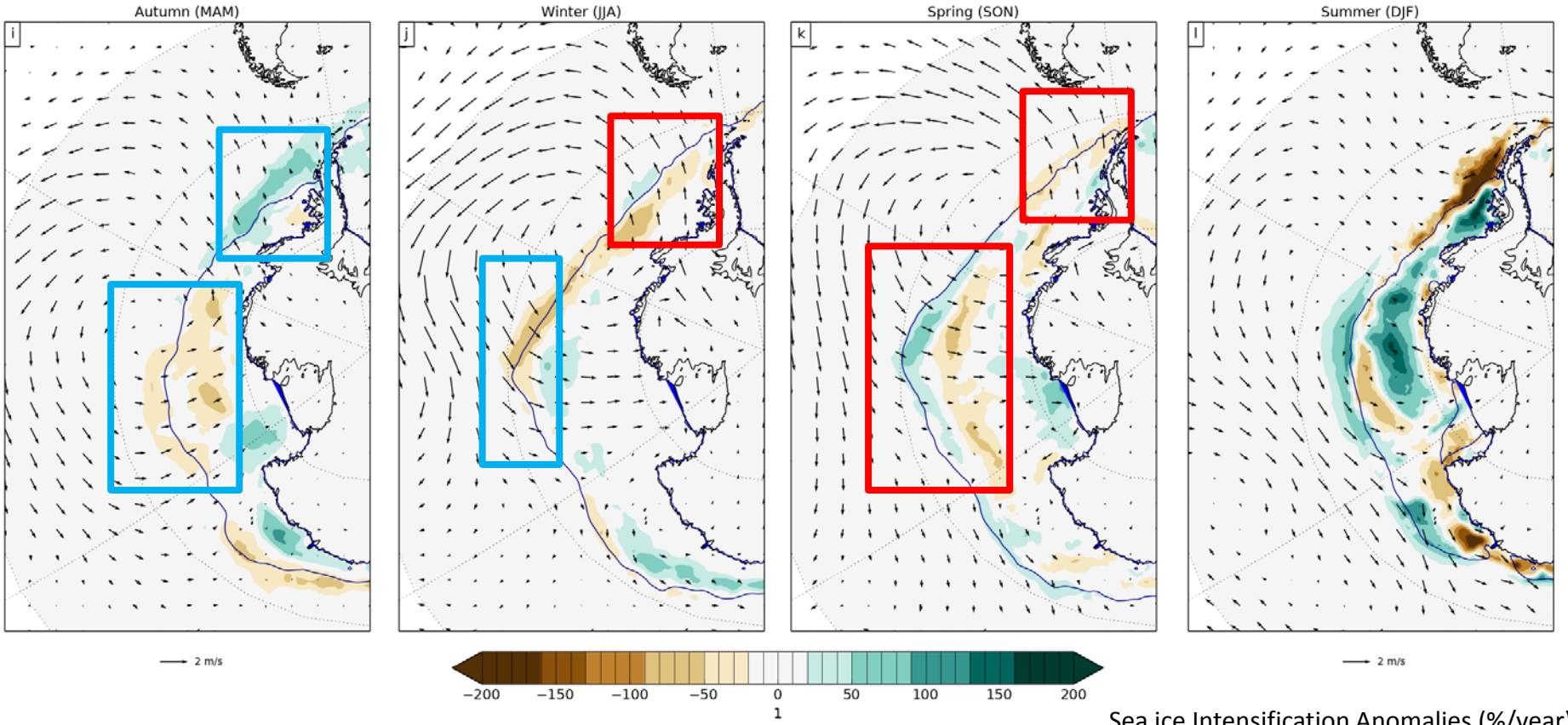


Sea ice Concentration



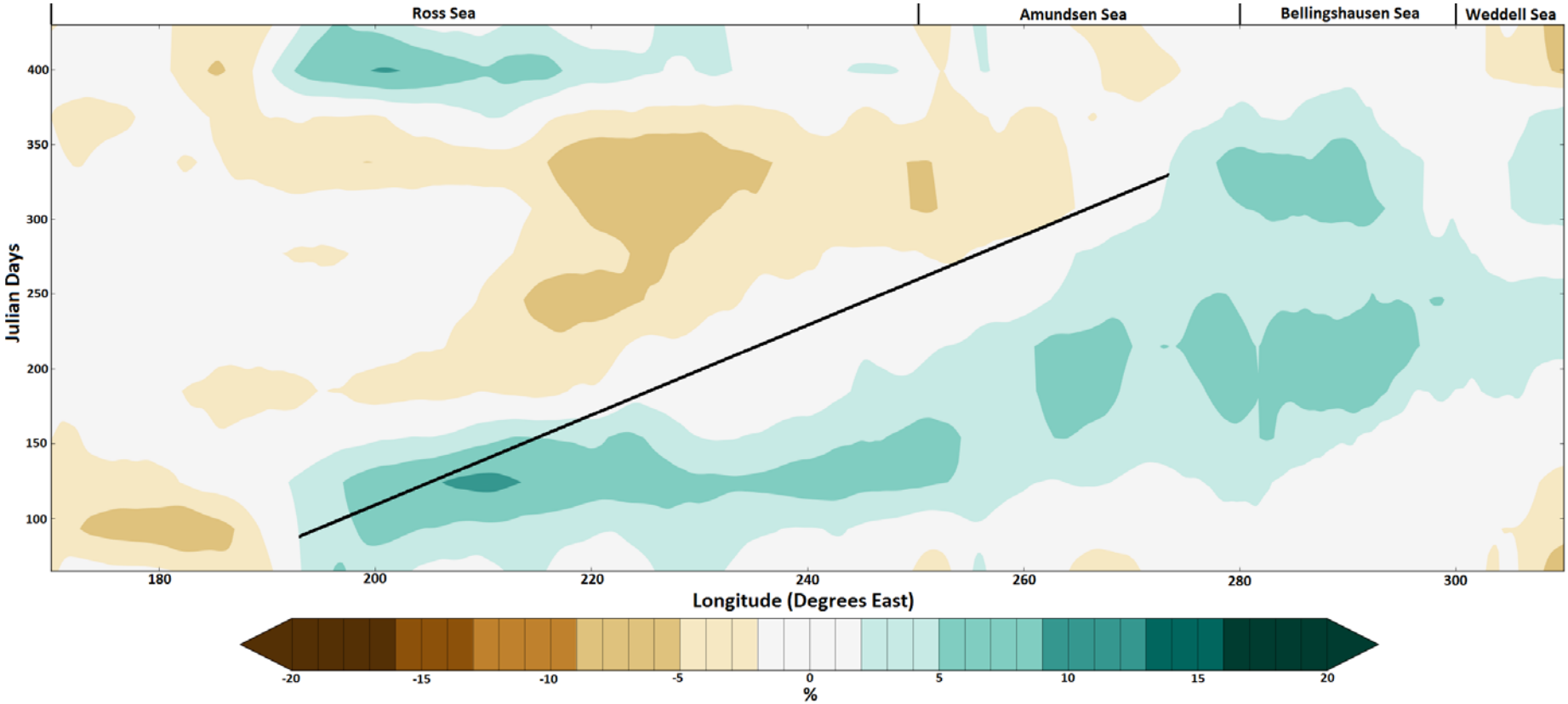
Sea ice Intensification

Observed Surface Winds Response to El Niño



Sea ice Intensification Anomalies (%/year)

Ice Drift – Rather Than Wind Response?



The ice drift speed (~15 cms^{-1}) consistent with observations (Kimura, 2004) was calculated based on the seasonal progression of the positive anomaly which was calculated between 195° to 275° over the course of 230 days, denoted by the solid black line.

Strong Observed Response

- Comparison of the anomalies in the ERA-Interim data shows a distinct climatological response in MSLP and surface winds in the region of the Amundsen Sea Low.
  - Additional studies (Kwok & Comiso, 2002; Kwok et al., 2016) using NCEP reanalysis indicates a similar response.
- Visual comparison to sea ice concentration and sea ice intensification anomalies indicates that there is a response to this forcing.
  - However, there are regions where this visual comparison breaks down.
- Additionally, are anomalies propagating due to wind forcing or climatological sea ice drift?
- **Can we have a more quantitative answer?**

Sea Ice Budget

- Our anomalies of sea ice intensification (displayed earlier) can be broken down into two further components:
  - Sea Ice Advection.
  - Sea Ice Divergence.
- We modify the work of Holland & Kimura (2016) to replace the *"U"* term. In their work *"U"* represented the sea ice drift from satellite data, for this work we modify ERA winds to be our *"U"* values.
- For all terms in the budget, a positive value represents an increase in sea ice concentration.

Intensification Advection Divergence

$$\frac{\partial C}{\partial t} = -\mathbf{u} \cdot \nabla C - C\nabla \cdot \mathbf{u} + \text{residual}$$

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Dynamic Component

Intensification — Advection — Divergence

$$\frac{\partial C}{\partial t} = -\mathbf{u} \cdot \nabla C - C \nabla \cdot \mathbf{u} + \text{residual}$$

Ice Dynamics: Expanded

- Within our analysis there are two key parts to the Dynamic Component.

$$\overline{\overline{\frac{\partial \Delta C}{\partial t}}} = -\overline{\overline{\nabla.(\overline{\boldsymbol{u}}\Delta C)}} - \overline{\overline{\nabla.(\Delta \boldsymbol{u}\overline{C})}} + \overline{\overline{\Delta f}}$$

Ice Dynamic (Anomalous Concentration)

This term reflects the role of the climatological winds on the anomalous ice concentration.

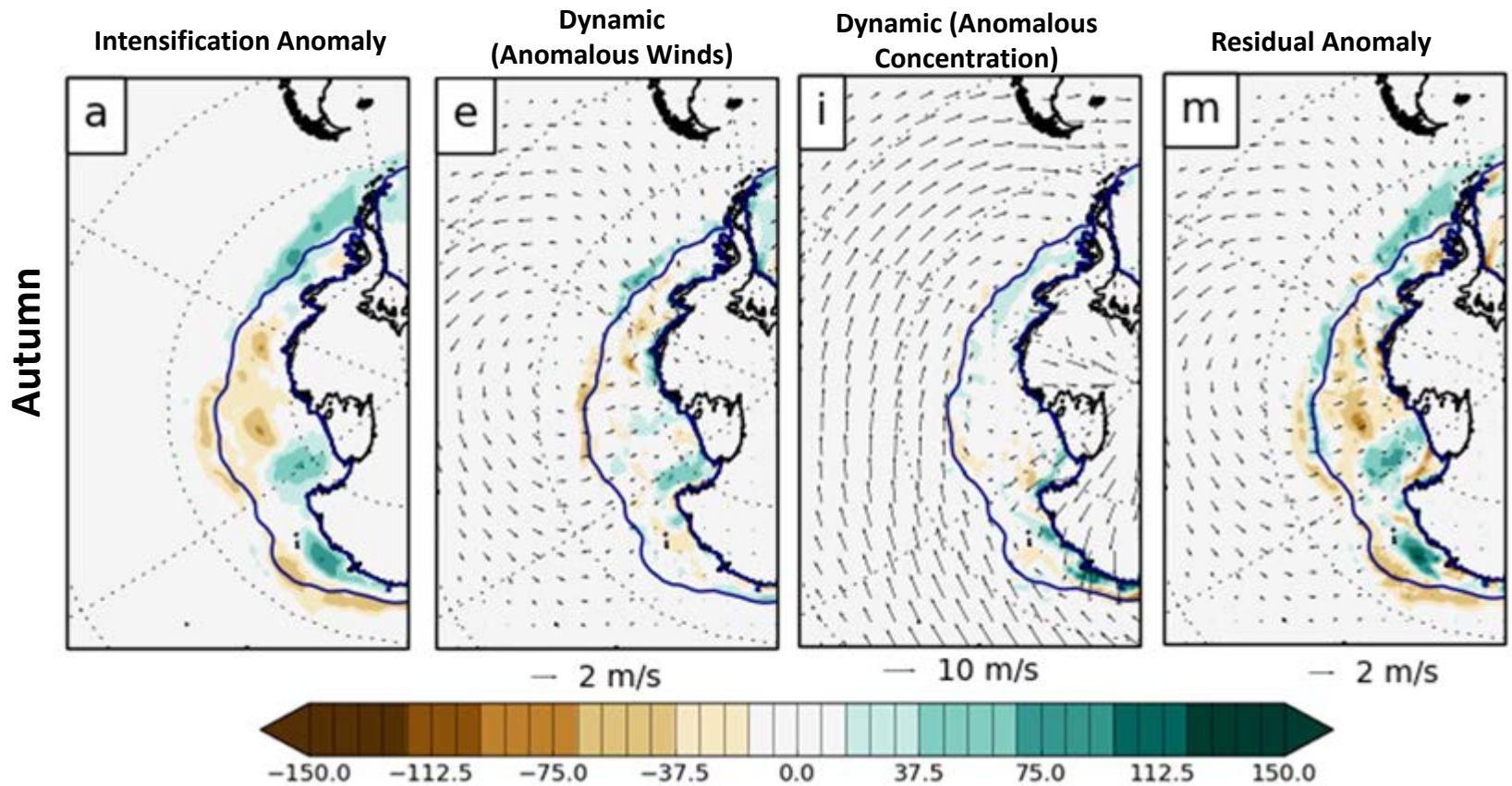
Represents ice drift.

Ice Dynamic (Anomalous Winds)

This terms reflects the role of the anomalous winds acting on the climatological sea ice concentration.

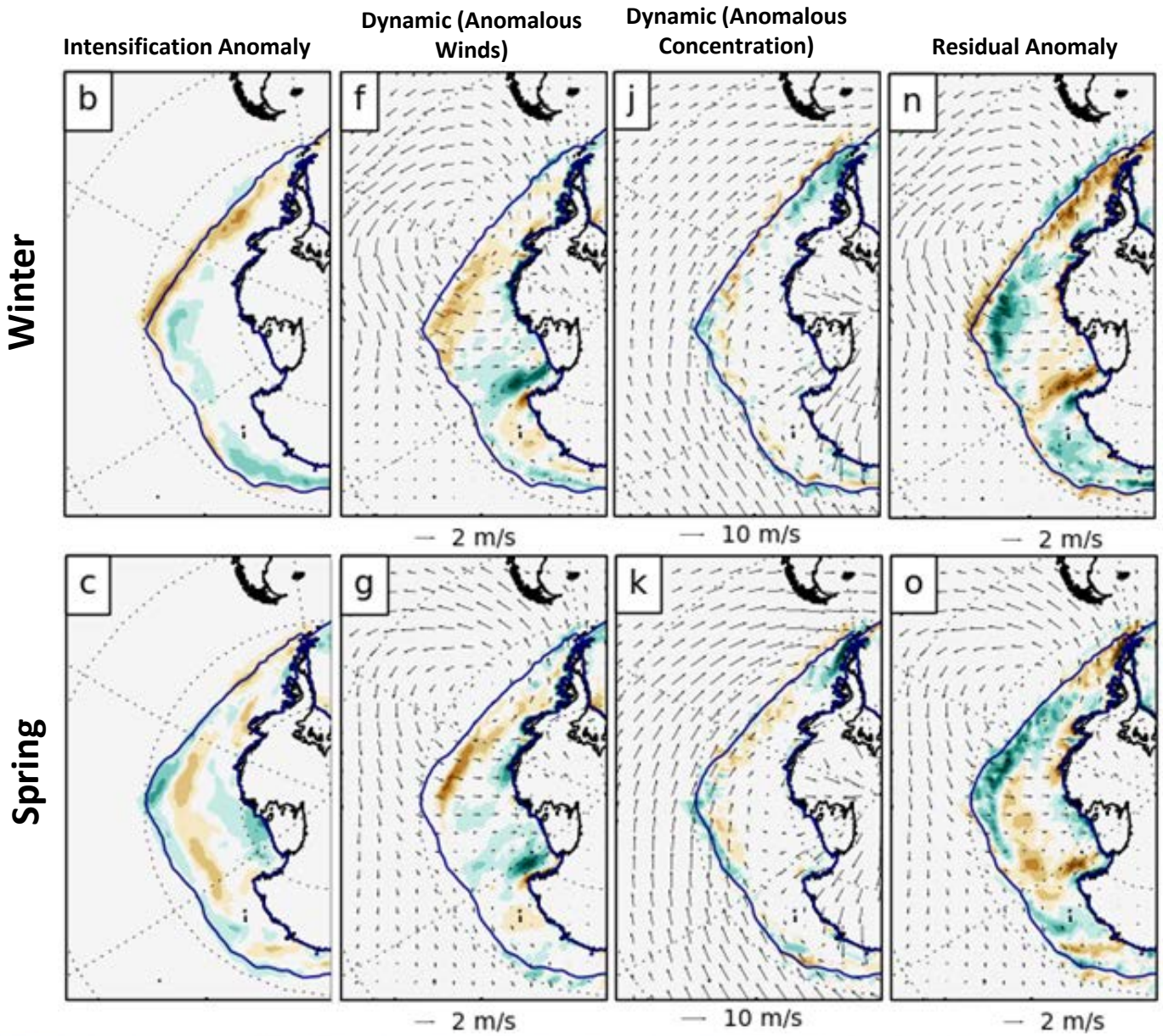
Represents effect of El Niño winds.

Sea Ice Budget:
Dynamic Formation of the Sea Ice Anomaly



- Intensification anomalies during autumn resemble the dynamic (anomalous winds) component, indicating ice anomalies are driven by anomalous changes in surface winds.
- A significant residual remains with a similar structure to the intensification and dynamic (anomalous winds) components. This is interpreted as a changes in freezing induced by the atmospheric anomalies.

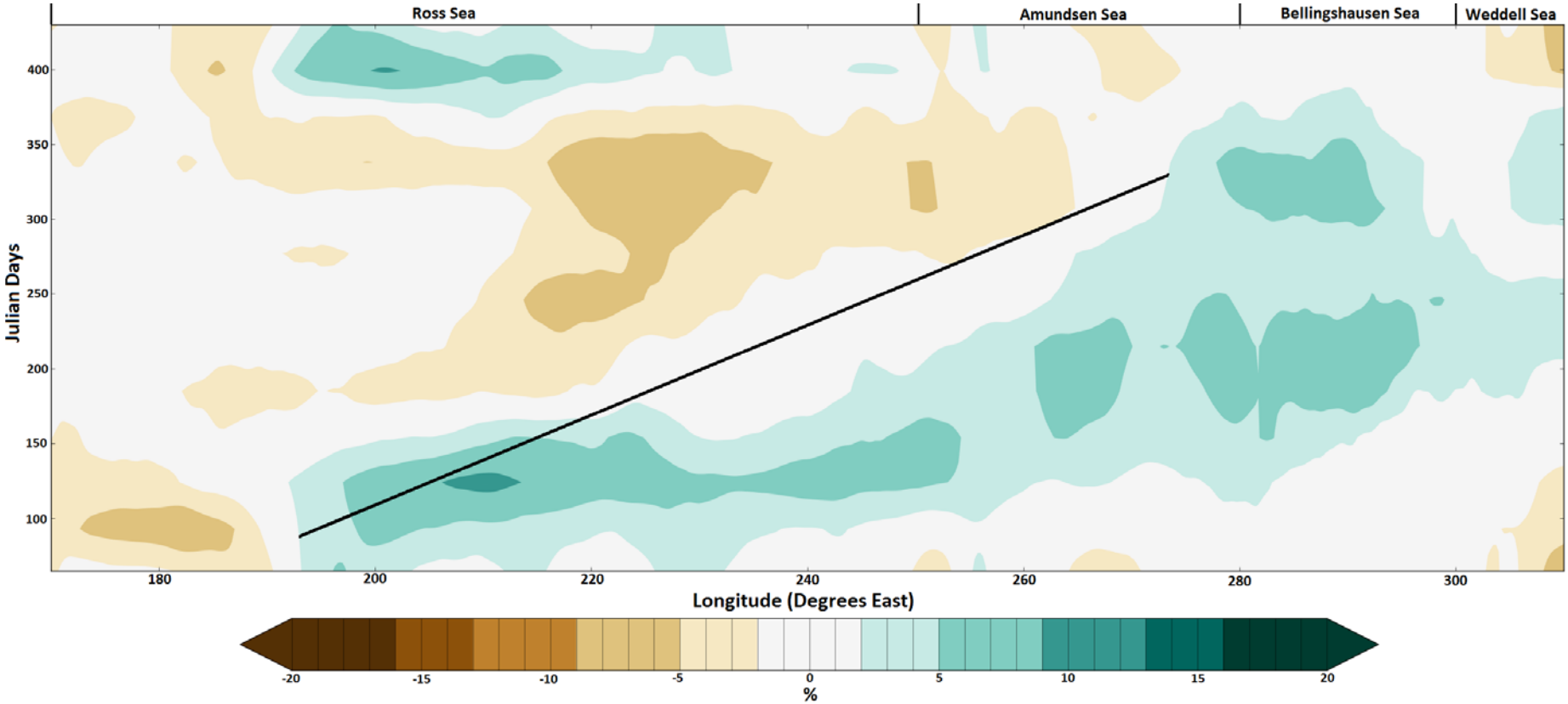
Sea Ice Budget: Development and Propagation of the Sea Ice Anomaly


Intensification Anomaly
Dynamic (Anomalous Winds)
Dynamic (Anomalous Concentration)
Residual Anomaly
Winter
Spring
b
f
j
n
c
g
k
o
2 m/s
10 m/s
2 m/s
2 m/s
10 m/s
2 m/s

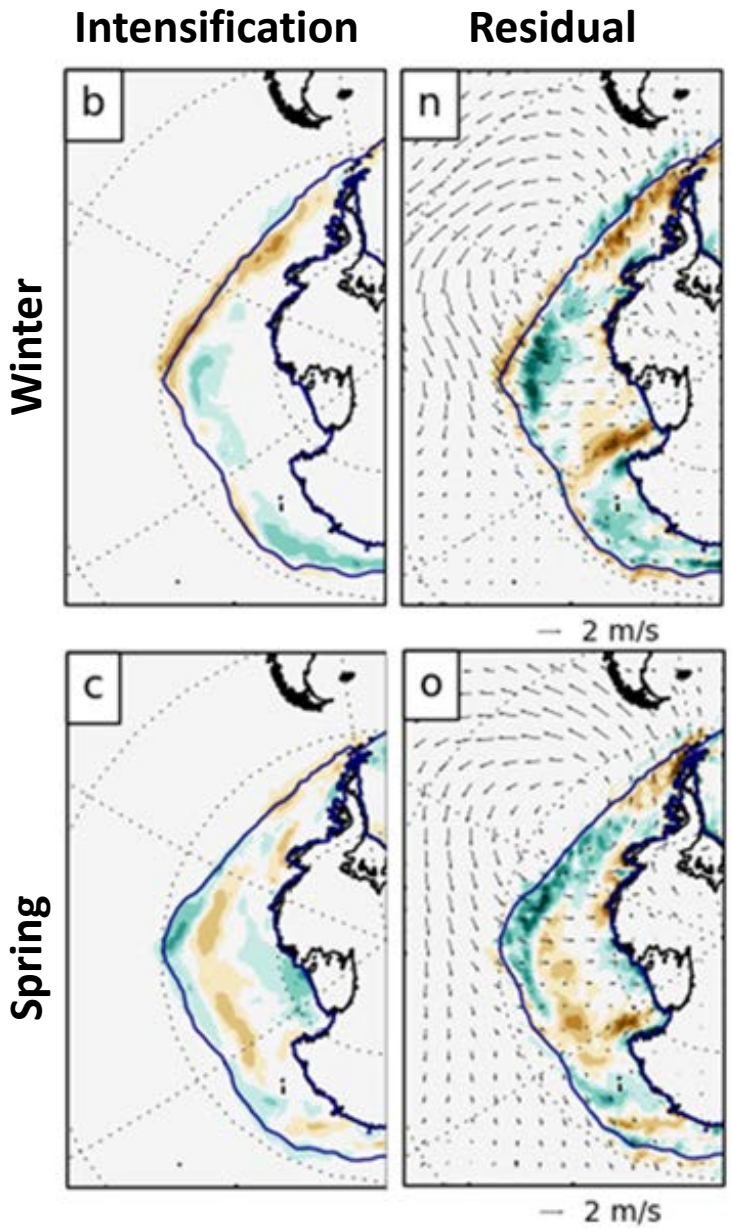
Sea Ice Budget: Development and Propagation of the Sea Ice Anomaly

- The dynamic (anomalous winds) component produces a similar pattern in winter and spring as it did in autumn. This is inconsistent with the intensification anomaly in both seasons.
- Through spring the dynamic (anomalous concentration) component resembles intensification anomalies at the sea ice edge.
- This indicates that the drift of anomalies formed in preceding seasons plays a role in the changing sea ice concentration.

Role of Ice Drift

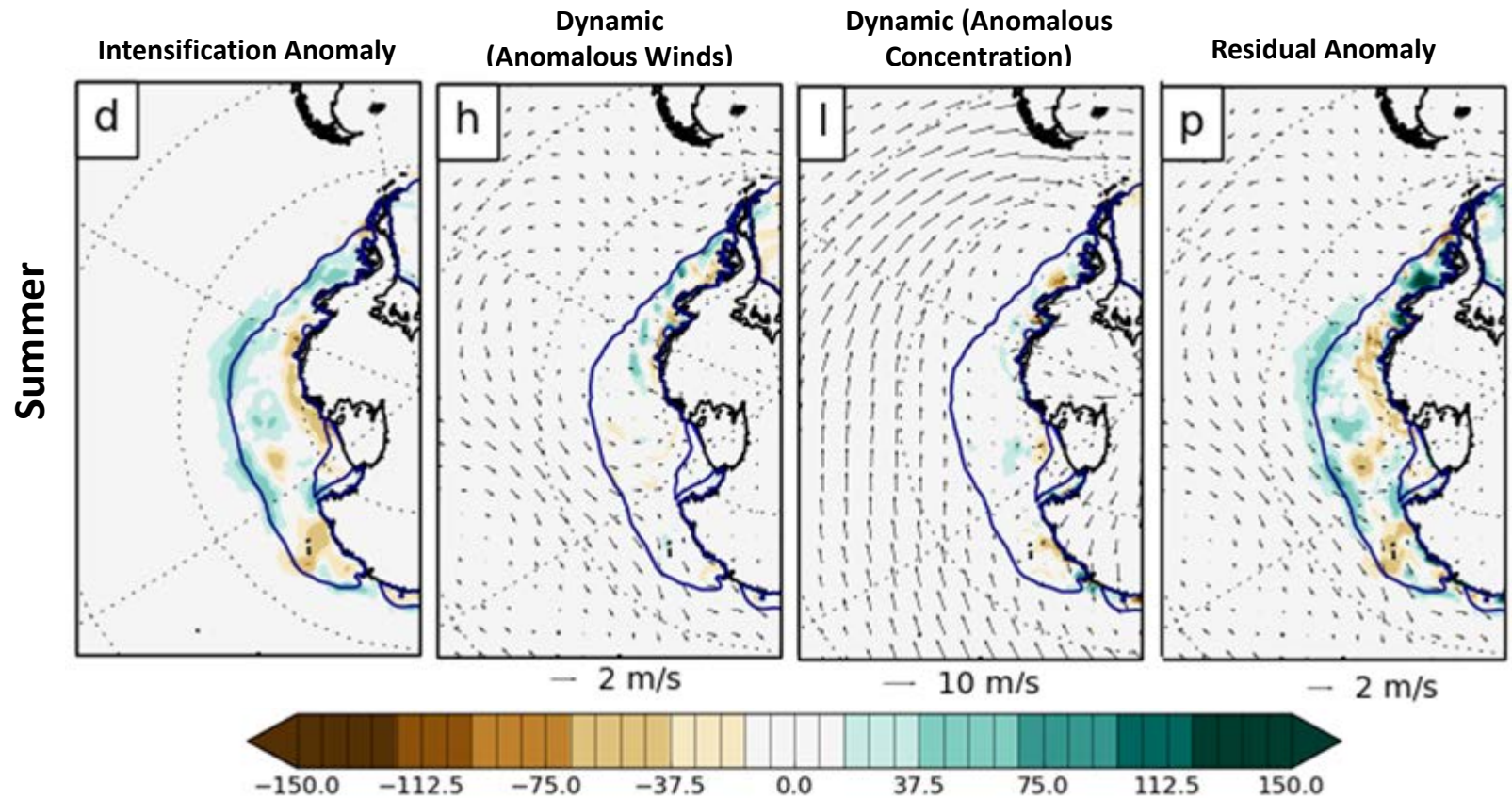


During autumn & winter (days 60-240) ice drift is slower than the mean speed, however during spring (days 240-310) the drift of the anomaly increases, consistent with the dynamic (anomalous concentration) component.



Residual

- The residual anomaly dominates the budget during winter and spring.
- The majority of our residual in these two seasons is a thermodynamic feedback.
- During winter residual anomalies are reflecting changes in sea ice growth rates, during spring they reflect melting rates.
- However, the nature of our budget calculation results in a slightly confusing residual image.
- For example, a positive intensification anomaly in autumn in the Bellingshausen Sea, indicates ice growth. Because this ice has already formed, it can not form during winter and therefore a negative anomaly occurs in intensification & the residual.
- During spring, positive residual's indicate the "melt" of ice that either retreated abnormally early or never grew, while negative residuals indicate the enhanced melt of sea ice concentration increased due to El Niño.



- During summer there is negligible contribution from either dynamic term and the residual anomaly dominates.
- This is consistent with the climatological sea ice budget which is dominated by thermodynamic processes during summer (Holland & Kimura, 2016).

Sea Ice Budget:
Remaining Residual Effects

Sea Ice Budget: Remaining Residual Effects

- The residual anomaly in our study contains four parts:
  - 1) thermodynamic anomalies directly induced by El Niño forcing;.
  - 2) thermodynamic feedbacks acting upon forced anomalies.
  - 3) mechanical processes.
  - 4) methodological error due to ice not being in a state of free drift.
- Terms 1 & 2 have already been discussed, while terms 3 & 4 act on our residual in all seasons.
- The role of mechanical processes is discussed in Holland & Kimura, 2016.
- The methodological error is largest close to the coastline, where the ice is not in a state of free drift and therefore wind becomes a poor approximation for ice drift.

Summary

- The previous identified sea ice concentration dipole forms in autumn due to wind driven processes supported by thermodynamic feedbacks.
- The propagation of this ice concentration anomaly is driven by the mean ice drift rather than the anomalous wind forcing.
- Our results demonstrate that linkages between sea ice anomalies and atmospheric variability are non-local in space and time.

Why Should You Care?

- There are two good reasons for this.

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- There are two good reasons for this.
- 1) It took us a **really long time** to work out exactly what was going on.
- 2) All previous studies have considered ice-climate linkages to be static in either space or time, or both.
  - For example, using our approach, it becomes clear that the ice anomaly in the Bellingshausen Sea in spring is affected by anomalous winds and air temperature in the Ross Sea in autumn.
- Point 2 (the important one) highlights the complexity of climate processes and asserts that **caution needs to be applied when trying to link sea ice concentration in any given region or season to local forcings.**