

# Regional links between atmospheric variability and the sea-ice – ocean system in the Southern Ocean area

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## Motivation

- The **sea-ice area (SIA) in the Southern Hemisphere (SH)** has shown a significant **increase** during recent decades (e.g. *Stammerjohn and Smith, 2008*).
  - The **Southern Annular Mode (SAM)** has exhibited a **positive trend** during this period, possibly due to ozone depletion or increases in Greenhouse gasses (*Thompson and Solomon, 2002, Kushner et al., 2001*).
  - However, **no clear link** between SIA and the SAM index **on a hemispheric scale** could be found so far (*Lefebvre et al., 2004*).
- We analyze regional changes in both SLP and SIA.
- The main SIA variability takes place in a dipole pattern, the so-called **Antarctic dipole**, with opposite poles in the Bellingshausen-Weddell Sea and in the Amundsen-Ross Sea (*Lefebvre et al., 2004*).
  - Amundsen low (AML)** has an important **influence on the state of the dipole**. Recently, a trend to **more cyclonic** circulation has been observed due to **stratospheric ozone depletion** (Turner et al., 2009).

## Questions

- ? **Where does the sea-ice increase** take place?
- ? **Where do the trends in the SAM** occur?
- ? How does the **dipole pattern** relate to the **hemispheric trend**?
- ? How does the **state of the Amundsen low** influence **sea-ice trends**?
- ? Can a comprehensive climate **model confirm the findings** in the observations?

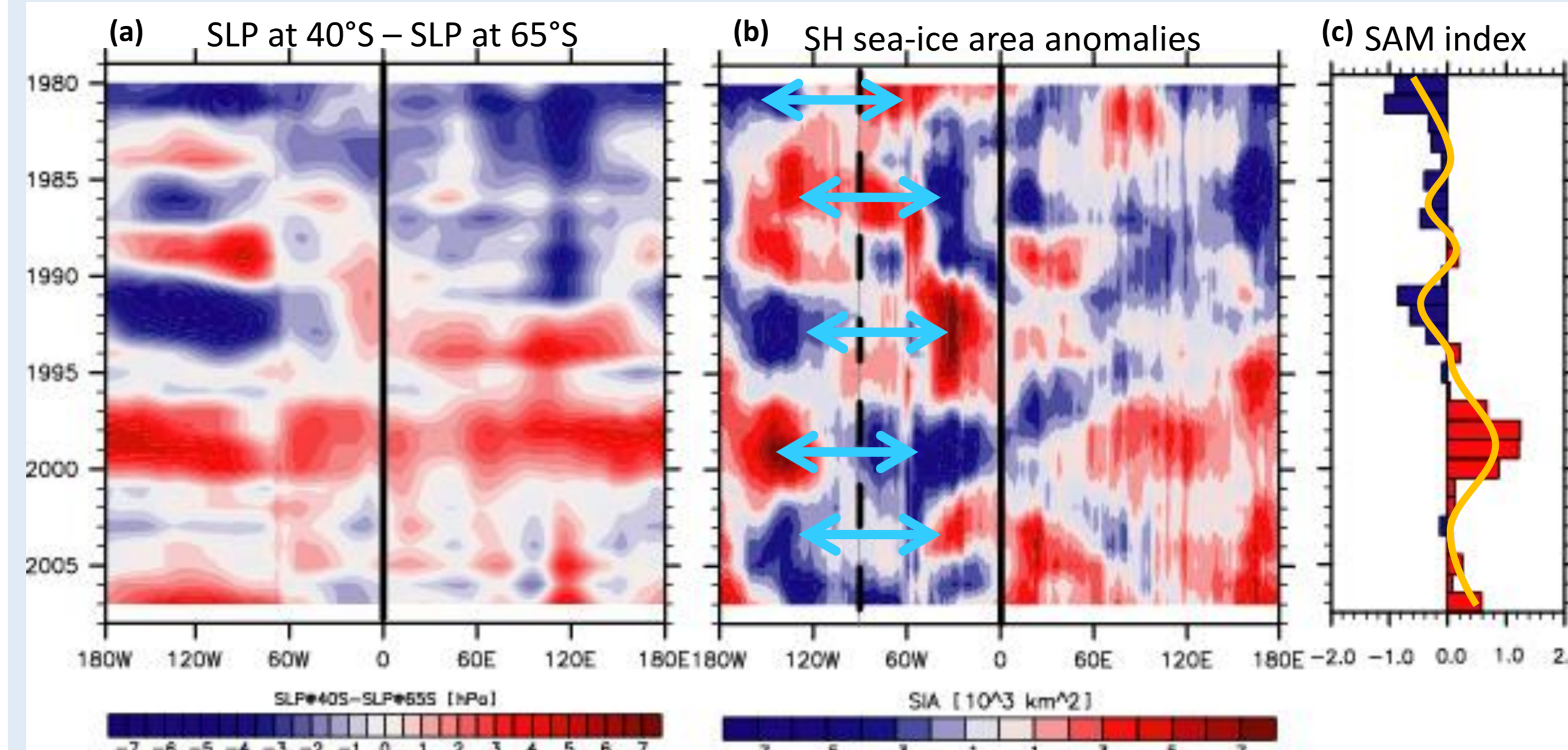
## Data and Methods

- Sea-surface pressure (SLP)**: monthly **NCEP Reanalysis** data from 1979 – 2008 with a spatial resolution of 2.5° x 2.5°.
- Sea-ice area (SIA)**: monthly **HadISST1 SIA** data with horizontal resolution of 1° x 1° from 1979 – 2008.
- Present day control simulation** (with perpetual 1990AD forcing) from the Community Climate System Model 3 (**CCSM3**) with T85 resolution (1.4° x 1.4° horizontal resolution and 26 vertical levels).
- The **SAM index** is calculated according to *Gong and Wang* (1999) as the normalized difference between the zonal mean of SLP at 40°S and 65°S.

## References

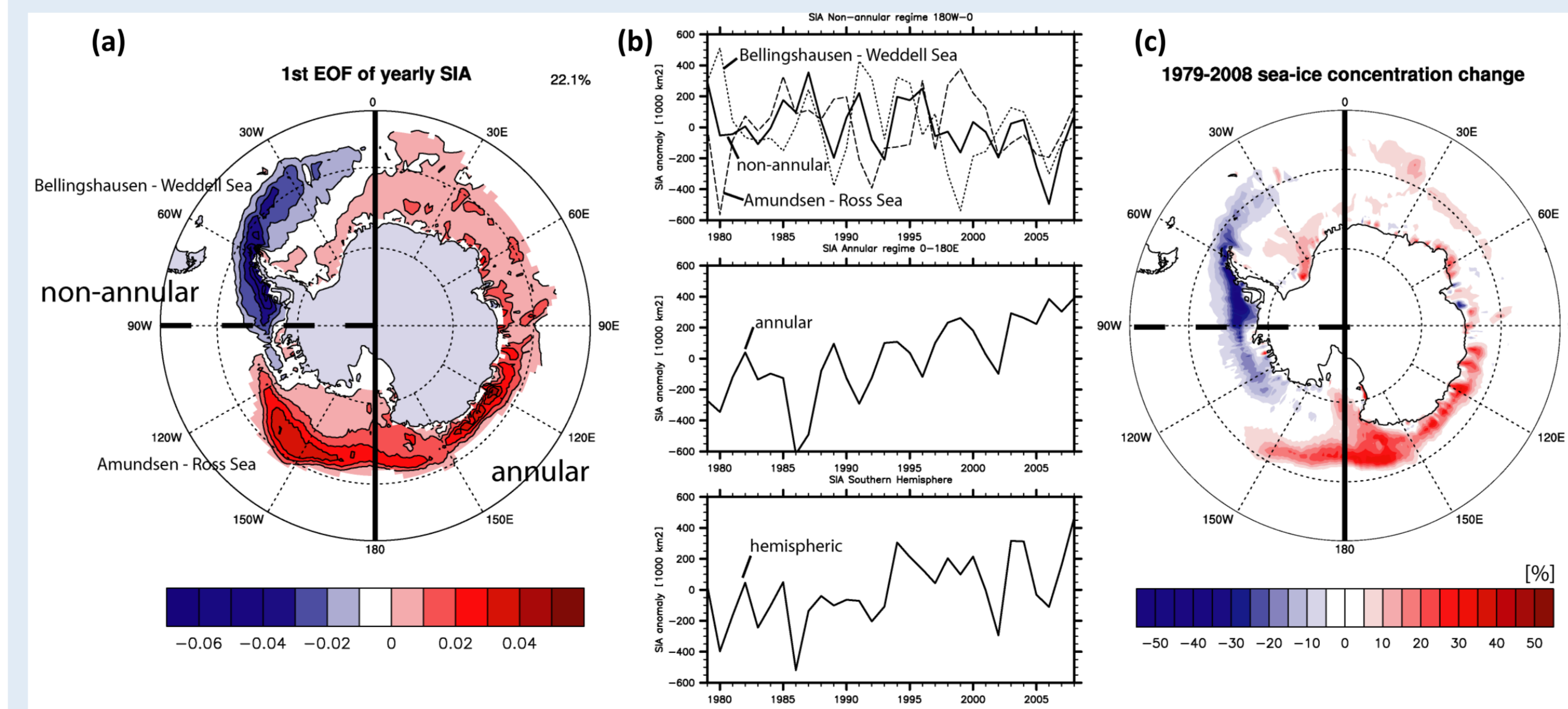
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## Regional changes in SLP and SIA from 1979 to 2008



**Figure 1.** Hovmöller diagram of (a) NCEP SLP difference between 40°S and 65°S and, (b) meridionally averaged HadISST1 SIA anomalies, (c) corresponding SAM index calculated according to *Gong and Wang* (1999). The black thick line shows the separation between the non-annular and the annular regime, the blue arrows indicate the dipole pattern. For (a) and (b) a 3-year running mean was applied.

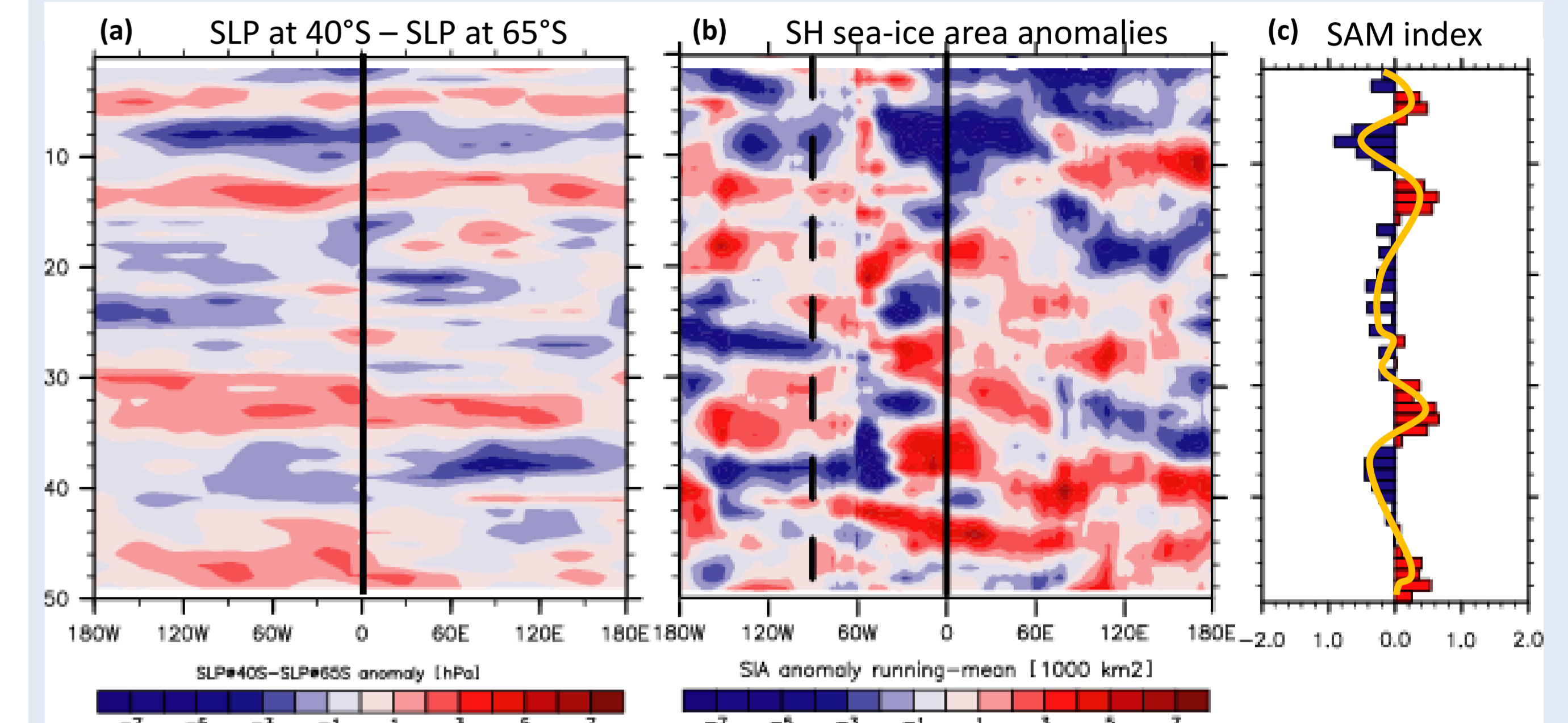
- > **Synchronous variability** between the **Amundsen low and SIA** in the western half of Antarctica in form of a **dipole pattern**: a switch in sign of the AML anomaly leads to a change in sign of the dipole (Fig. 1a and b).
  - > SLP changes in the eastern half of Antarctica show similar behavior as SIA in this area.
  - > The **Amundsen low** changes **independently of the remaining zonal SLP** variations and determines the high frequency behavior of the SAM index (Figure 1a and c).
- Hence, we postulate a **two regime approach**: an **annular regime** in the eastern half of Antarctica, and a **non-annular regime** in the western half of Antarctica which is validated by the calculation of the 1<sup>st</sup> EOF of SIA (Fig. 2a).



**Figure 2.** (a) EOF1 of HadISST1 SIA and the corresponding two-regime approach. Area weighting was applied prior to calculation. (b) Time series of HadISST1 SIA anomalies for the non-annular regime (top), annular regime (middle) and hemispheric SIA anomalies. (c) 1979-2008 change in SH sea-ice concentration calculated with a linear regression.

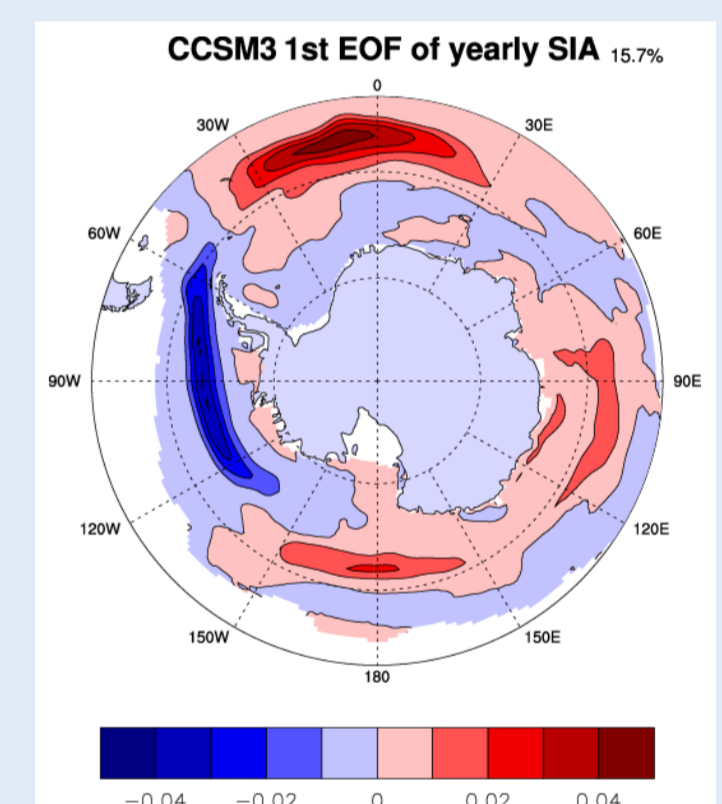
- The positive hemispheric trend in SIA originates in the annular regime, (Fig. 2b and c).
  - Anomalies in the dipole region cancel each other out; thus they are not contributing to the hemispheric trend. In the non-annular regime a slightly negative trend can be seen (Fig 2b and c).
  - > Limitations: only 30 years of data → are the patterns found robust?
- Use model to check the two-regime approach and the suggested role of the Amundsen low pressure system.

## Comparison of the results with T85 CCSM3



**Figure 3.** Hovmöller diagram of (a) SLP difference between 40°S and 65°S and, (b) meridionally averaged SIA anomalies, (c) corresponding SAM index calculated according to *Gong and Wang* (1999) from the CCSM3 CTRL1990 simulation. The black thick line shows the separation between the non-annular and the annular regime. For (a) and (b) a 3-year running mean was applied.

- > The **Amundsen low** does **not** behave **independently** of the remaining **zonal SLP** field (Fig. 3a and b).  
→ **too zonal** behavior of the model
  - > **No consistent dipole pattern** can be seen in the **SIA anomalies** in the non-annular regime (Fig. 3b).
  - > The EOF1 pattern (Fig. 4) does **not** display a **similar variability** pattern as the observational data.
  - > Again a dipole pattern can be seen, however it is **shifted** to the East by approximately 45°E.
- The model is **neither able to represent** the changes of SLP, nor of SIA.



**Figure 4.** EOF1 of SIA for 50 years of CCSM3 CTRL1990. Area weighting was applied prior to EOF calculation.

## Conclusions

### Observations

- Positive **Southern Hemisphere SIA** trend originates in the **annular regime**.
- The Antarctic sea-ice dipole cancels out the trend in the non-annular regime.
- State of **Amundsen low** explains **high frequency variability** of SAM and affects the **state of the sea-ice dipole** but not the hemispheric SIA trend.
- Therefore, **processes influencing the strength of the Amundsen low** (e.g., polar ozone chemistry (*Turner et al., 2009*)), **should not influence** Southern Hemisphere sea-ice trends.

### Model

- **CCSM3** does **not** display the **same regional patterns** in SIA and SLP; thus, not conforming with the **two-regime pattern** found in the observations.
- Although **Amundsen low** exists, it does **not** show the **independent behaviour** in comparison to the main SLP variations in the Southern Ocean. CCSM3 shows a too zonal behaviour.
- **The SIA dipole is shifted** and **no clear link to Amundsen low** exists.