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

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This poster participates in YSOPP
Young Scientists' Outstanding Poster Paper Contest

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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Lefebvre W., et al., 2004 : Influence of the Southern Annular Mode on the Antarctic sea ice-ocean system, *Journal of Geophysical Research.* C09005.

Stammerjohn, S. E., and R. C. Smith, 1997: Opposing Southern Ocean climate patterns as revealed by trends in regional sea ice coverage, *Climatic Change* **37**: 617-639.

Thompson, D.W.J., and S. Solomon, 2002: Interpretation of recent Southern Hemisphere climate change, *Science*, **296**: 895-899.

Turner, J., et al., 2009: Non-annular atmospheric circulation change induced by stratospheric ozone depletion and its role in the recent increase of Antarctic sea ice extent, *Geophysical Research Letters*, **36**, L08502.

Regional changes in SLP and SIA from 1979 to 2008

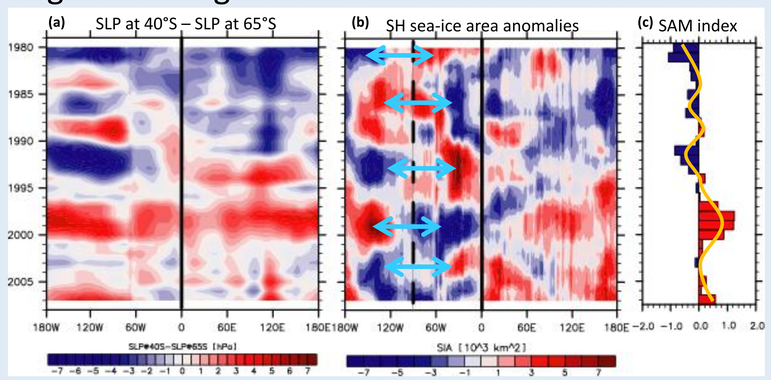

Figure 1. Hovmöller diagram of (a) NCEP SLP difference between 40°S and 65° and, (b) meridionally averaged HadISST1 SIA anomalies, (c) corresponding SAM index calculated according to *Gong and Wang* (1999). The black thick line shows the separation between the non-annular and the annular regime, the 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 1st EOF of SIA (Fig. 2a).

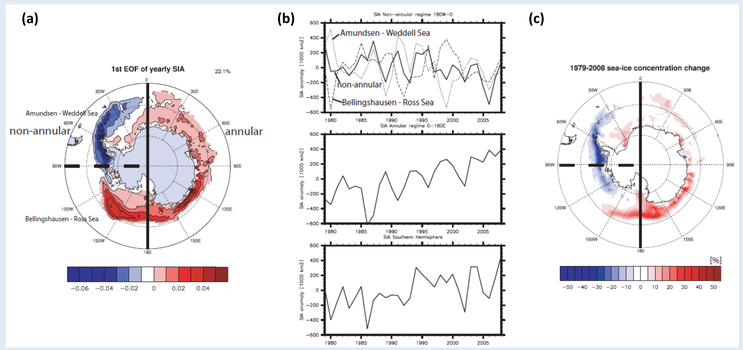

Figure 2. (a) EOF1 of HadISST1 SIA and the corresponding two-regime approach. Area weighting was applied prior to calculation. (b) Time series of HadISST1 SIA anomalies for the non-annular regime (top), annular regime (middle) and hemispheric SIA anomalies. (c) 1979-2008 change in SH sea-ice concentration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

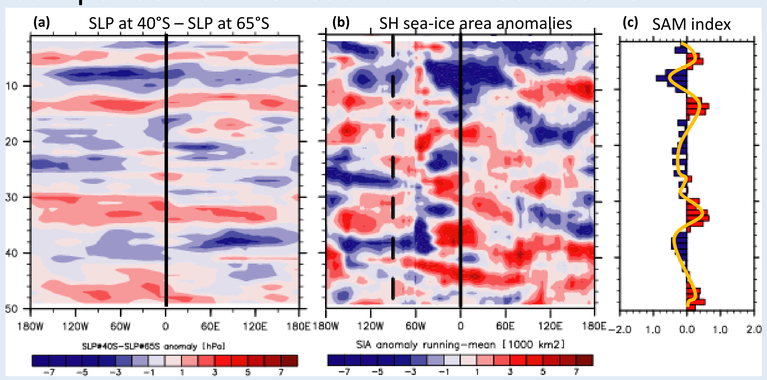

Figure 3. Hovmöller diagram of (a) SLP difference between 40°S and 65° and, (b) meridionally averaged SIA anomalies, (c) corresponding SAM index calculated according to *Gong and Wang* (1999) from the CCSM3 CTRL1990 simulation. The black thick line shows the separation between the non-annular and the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

> **The Amundsen low** does **not** behave **independent**ly 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.**

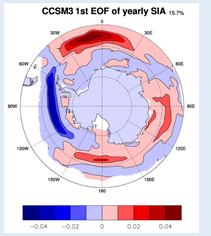

Figure 4. EOF1 of SIA for 50 years of CCSM3 CTRL1990. Area weighting was applied prior to EOF calculation.

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.**
- 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.**