The 2014 high record of Antarctic sea ice extent

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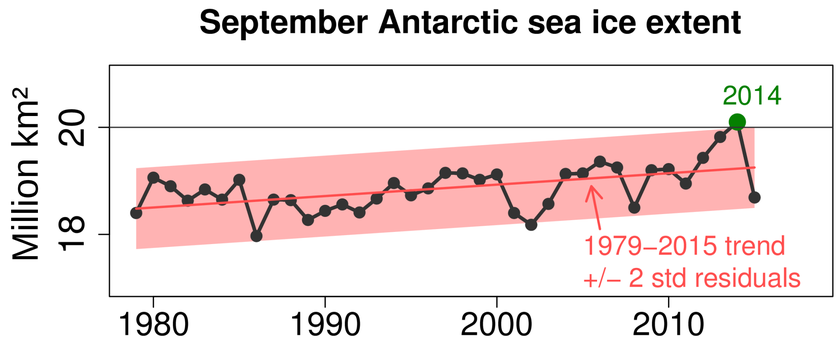
Antarctic sea ice extent is one of the few climate variables that has exhibited counterintuitive trends given the well-established global warming forcing. In particular, austral winter sea ice extent has peaked to unprecedented levels in September 2014, before returning to normal conditions in September 2015:



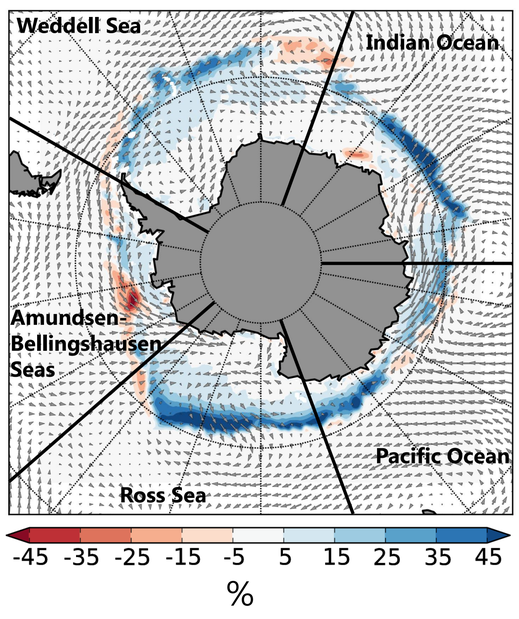
We address three questions:

1) What were the 2014 prevailing sea ice and atmospheric conditions?
2) What are the driving forces behind the 2014 record?
3) Is this high record attributable to anthropogenic climate change?

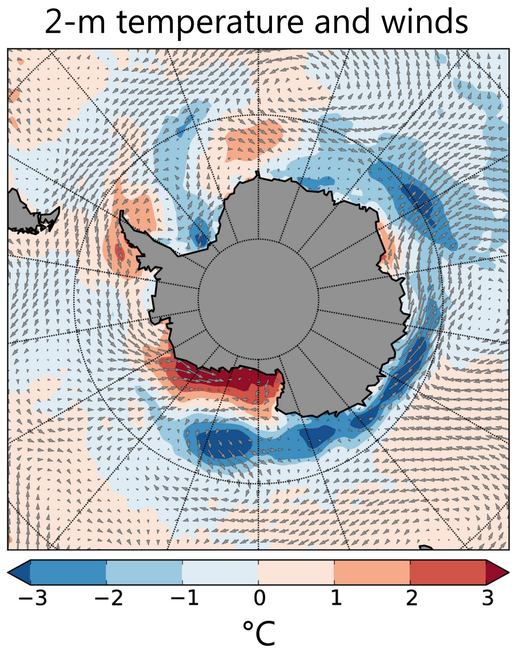
1) Characterizing the event

September 2014 anomalies (departure from the 1979-2013 mean)

Sea ice concentration and winds



2-m temperature and winds



The event is characterized by a circumpolar increase in sea ice concentration except in the Amundsen-Bellingshausen sector. Anomalous sea ice conditions in September 2015 could result from:

- **anomalous wind forcing** (mechanical effect: more sea ice is advected northwards),
- **anomalous temperature forcing** (thermal effect: colder conditions are prone to ice growth),
- **anomalous oceanic conditions** (pre-conditioning),
- **anomalous hydrological forcing** (stratification effect: larger snow/precipitation/ice-shelve meltwater make the oceanic column more stratified),
- **internal variability**.

2) Driving forces behind the record

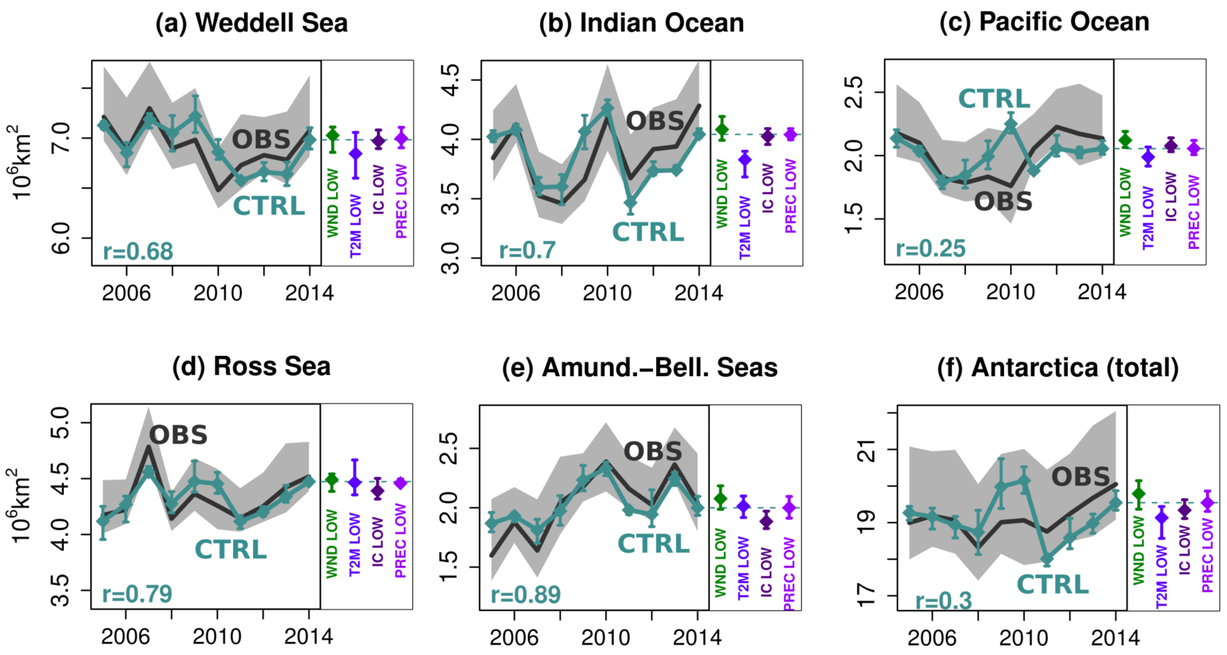
We run a series of sensitivity analyses with the oceanic general circulation model (OGCM) NEMO3.3 (Madec, 2008) forced by the ERA-Interim atmospheric reanalysis.

Control simulation: 10 retrospective seasonal predictions comprising each 5 ensemble members (« hindcasts ») are conducted over 2004-2014. Each simulation is initialized in March 1st and runs for 7 months (see Massonnet et al., 2015 for details).

Sensitivity experiments: to detect the individual roles of atmospheric forcing terms and initial conditions on the modeled September sea ice extent, we conduct several sensitivity experiments in 2014:

- **Winds** of 2014 are replaced by those of 2007, 2008, 2011, 2012 and 2013 (those years with low sea ice extent over the 2004-2014 period),
- **Temperature** of 2014 is replaced by those of 2007,8,11,12,
- **March oceanic and sea ice initial conditions** of 2014 is replaced by those of 2007,8,11,12,
- **Snow and precipitation** of 2014 is replaced by those of 2007,8,11,12.

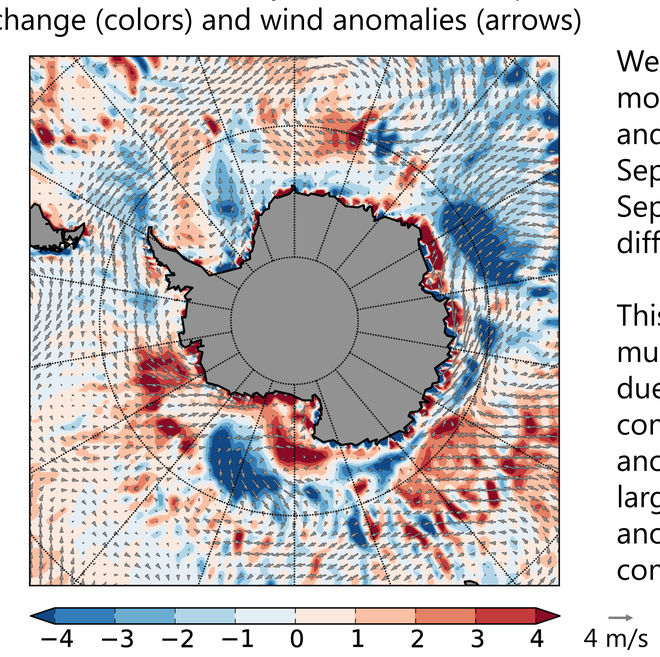
Sea ice extent in various sectors of the Southern Ocean



The model has a realistic behaviour in all sectors except the Pacific Ocean Sector. Because of that sector, Antarctic sea ice extent is not a high record in the model. Still, sea ice extent variability is well captured in the other sectors, and in particular in the Indian Ocean Sector where sea ice conditions were anomalous (see the maps in Section 1).

Sensitivity tests in 2014 suggest little mechanical impact of winds on the 2014 anomaly in the model. However, 2-m temperature has an impact on sea ice extent anomalies. To reconcile these two results, we compute the advective temperature change anomaly in 2014:

September 2014 anomaly of advective temperature change (colors) and wind anomalies (arrows)



We compute the quantity – $\mathbf{u} \bullet \nabla T$ from monthly means of surface temperature and winds of ERA-Interim, first over September 1979-2013 and then in September 2014. The map shows the difference (2014 – climatology).

This diagnostic is helpful to quantify how much surface temperature has changed due to the changes in prevailing wind conditions. It suggests that the 2014 anomaly in the Indian Ocean sector was largely driven by southerly wind anomalies, that transported more continental cold air masses offshore.

3) Is the record linked to man-made climate change?

The Antarctic sea ice extent high record appears to result from a combination of long-term linear positive trend and high-frequency interannual variability (first figure). Reasons behind the positive, long-term trend are still obscure. For instance, ozone depletion was found to have a negative (not positive) impact on winter sea ice extent in many recent studies.

The Southern Annular Mode (SAM) is thought to have a significant influence on shorter-term variability, but 2014 SAM conditions in September we close to neutral.

In addition, we conducted a last sensitivity experiment to emulate the effect of increased meltwater from ice shelves. We decreased the March initial ocean salinity by 0.1 PSU in a lens around Antarctica extending up to Cap Horn and 100m in depth. (This is an unrealistic perturbation! It is 4 orders of magnitude larger than the observed equivalent discharge). We see only a moderate effect of + 0.2 million km². We conclude that anomalous ice shelf melting cannot have caused the record.

It is therefore difficult to formulate a robust attribution statement linking anthropogenic climate change and the 2014 sea ice record.

References

- The study: Massonnet et al., contribution to the 2015 BAMS special issue on « Explaining Extreme events of 2014 from a climate perspective », doi:10.1175/BAMS-D-15-00093.1
- Madec, G., 2008: NEMO ocean engine. Note du Pôle de modélisation de l'Institut Pierre-Simon Laplace 27, 357 pp. [Available online at ww.nemo-ocean.eu/about-NEMO/Reference-manuals.]

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