Antarctic Sea Ice: Mean state and variability in CCSM4 1850 control run

Laura Landrum, Marika Holland, Dave Schneider, Elizabeth Hunke
Overview

• Model years and variables
• Mean state and some comparisons with observations
• Variability in wintertime (JAS) Sea Ice Concentration (SIC)
• Sea ice advance/retreat data from daily output: mean, comparison with obs, and variability
• Thermodynamic vs. dynamic contributions: regional differences
• SIC variability and ENSO
• SIC variability and SAM
• Conclusions
Model years and variables

- 1850 control run: fully coupled land-ocean-ice-atmosphere forced at constant, 1850 conditions
- 500 yrs of monthly data: simulation years 701-1200
- 150 yrs of daily data
- Some comparisons with observations (Antarctic Sea Ice observations are very limited: ~30 yrs)
- Some 20th C ensemble run means (Dave Schneider’s talk will focus more on this)
Mean State: Sea Ice Concentration

- Mean SIC too extensive - austral summer (JFM) and winter (JAS)
- Anomalously high southern ocean zonal wind stress - too much ice transported equatorwards
Seasonal cycle of total Sea Ice Extent (SIE)

- Too extensive
- Large equatorward transport
- Timing of seasonal cycle – ok over entire Antarctic – however, not good in some regions, and specific latitudes (daily data)
Day of ice advance and retreat

- Regional and/or seasonal differences in ice anomalies?
- 150 yrs of daily data
- Ice year = Feb. 16 – Feb 15 following year (mid-February ~ time of minimum SH ice extent)
- Day of ice advance (each grid cell): 1st day SIC > 15% for 5 or more consecutive days
- Day of ice retreat: 1st day ice concentration < 15% and remains so until the end of the ice year
- Ice duration (days) = day of retreat – day of advance
Day of Ice Advance: mean

- Day of ice advance – up to 50 days early (compared to observations)
- Improved modestly in 20\textsuperscript{th} C runs
Mean Day of Ice Retreat

Day of ice retreat – 50+ days later in CCSM4 than obs (with modest improvement in 20th C runs)

Excessively long ice season – implications for 20C runs, simulation of SH water mass formations, biological models and biogeochemical cycles
JAS SIC variability: EOFs

- 500 yrs of monthly data: removed monthly climatology
- Calculated seasonal (e.g. JAS sea ice extent) and/or annual means
- EOF analysis: EOFs and accompanying PCs
- All maps are shown with original field regressed onto standardized PC time series to show units/standard deviation
JAS SIC variability: EOFs

Leading order EOF of JAS SIC, 701-1200 of 1850 control run:
- S. Pacific - S. Atlantic Dipole pattern
- Contours from 1979-2005 satellite data (SSMI)
- 1850 control run - similar pattern but further north than obs
- Spectral peak at 4 yrs - ENSO
• Max. centered in Drake Passage between 2 min. 180° apart

• Anomalies more equatorward than obs. EOF2 of obs. Doesn’t extend through Drake Passage

• 4 yr spectral peak

• Positively correlated with EOF1 at 1 year lag (EOF1 leading EOF2)

• propagating pattern?
Do anomalies propagate?

- Correlation of JAS SIC PC1 and Sea Ice Area (SIA = SIC * grid cell area then summed over each longitude)
- Wintertime anomalies travel eastward, ~7-8 cm/s (consistent with mean surface ocean currents)
- Decay by mid-eastern S. Indian ocean
- Anomaly propagates from year to year through sea surface temperature ("ocean memory")
Pacific vs. Atlantic: seasonality and thermodynamic vs dynamic contributions to JAS SIC variability

- Thermodynamic contributions (within a grid cell) to sea ice concentration: melt and growth (congelation)

- Dynamic contributions: advection of ice into/out of grid cell as well as ridging within a cell

- Computed area-weighted averages of thermodynamic and dynamic contribution variables in the Pacific and Atlantic regions of high wintertime SIC anomaly (SIC >10%/SD in EOF1)

- Correlated this time series with PC 1 of wintertime SIC anomaly
Correlations: PC1 of JAS SIC to:

Pacific

Atlantic

AMJ

OND

DJF
Day of advance/retreat and wintertime SIC anomaly

- Regressed day of ice advance/retreat and duration onto PC1 of wintertime SIC
JAS SIC variability and ENSO

- Wintertime SIC anomalies - PCs clear 4 yr peak (like CCSM4 ENSO)
- ENSO and teleconnections with SH SSTs, SLP (although observations are limited)
- Regressed CCSM4 control run monthly Nino3.4 with monthly surface temperature (TS), monthly sea level pressure (SLP) and DJF Nino3.4 with JAS SIC
ENSO and sea ice

**TS, SIC regressed onto Nino34.**

**JAS SIC EOF1**

**EOF 1**

**EOF 2**

**Period (years)**

**TS-JAS Alce**

**TS-DJF Nino3.4**
Day of ice advance and retreat regressed onto DJF Nino3.4

Dipole pattern present and stronger in Pacific sector

Equal influence on advance and retreat in S. Pacific – perhaps more on advance in S. Atlantic?
**ENSO and sea ice: SLP**

- SLP regressed onto Nino3.4: very similar to SAM (next!)

- Wintertime SIC anomaly strongly linked to ENSO in CCSM4
- Positive ENSO (El Nino): warm TS anomalies in Pacific sector, cold TS anomalies in Atlantic sector + decrease/increase in meridional winds lead to net decrease/increase in Pacific/Atlantic wintertime SIC
- Sea Ice anomaly propagates through surface temperatures and with Antarctic Circumpolar current
JAS SIC variability and Southern Annular Mode (SAM)

- **SAM**: leading order EOF of southern hemisphere (20°S-90°S) annual Sea Level Pressure
- **Annual**: all seasons of SAM have similar pattern
- **Annual SAM**: 41% of variability in SLP (only OND is higher at 53%)
- **Annual SAM** - highest correlation with wintertime JAS
SAM

- SAM: moderately (compared with ENSO) correlated with PC1 JAS SIC, ann TS
- Some ENSO-SAM influence
- Positive SAM: increase in zonal winds (+SAM and -ENSO reinforce one another)
SAM and advance/retreat

- Dipole pattern - opposite in sign to ENSO regression
- Equally strong in S. Atlantic and S. Pacific sectors
- Greater influence on day of retreat
Conclusions: Mean state

- CCSM4 Antarctic Sea Ice is too extensive compared to observations
- Large meridional transport of sea ice
- Seasonal cycle too far north – i.e. at a given latitude, ice advances early and retreats late compared to obs)
Conclusions: Variability

- Anomalies: dipole pattern between S. Pacific and S. Atlantic
- Anomalies propagate eastward at rates comparable to Antarctic Circumpolar Current
- Anomalies propagate from year to year through surface temperatures
- S. Pacific anomalies appear to be due primarily to thermodynamics in austral fall, dynamics in austral spring
- S. Atlantic anomalies: thermodynamics and dynamics in both fall and spring
- ENSO predominant - particularly in the S. Pacific (also present in S. Atlantic)
- SAM influence in both S. Pacific and S. Atlantic
- Some ENSO modulation of SAM
- +SAM -ENSO (La Nina) - reinforce ice response
- Patterns of anomalies, as well as relationships to TS, SLP, ENSO/SAM resemble those in [limited 20thC] observations - except too far north