Antarctic and Southern Ocean surface temperatures in CMIP5 models in the context of the surface energy budget

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CMIP5  Surface Temperature mean & bias

(a) Multi Model Mean Surface Temperature

(b) Multi Model Mean Bias

IPCC AR5, WG1 Chapter 9, 2014
CMIP5 cloud forcing biases

(a) Shortwave cloud radiative effect - MOD-OBS

(b) Longwave cloud radiative effect - MOD-OBS

(c) Net cloud radiative effect - MOD-OBS

(d) Zonal average of shortwave CRE

(e) Zonal average of longwave CRE

(f) Zonal average of net CRE

IPCC AR5, WG1 Chapter 9, 2014
Why study Antarctic & Southern ocean SAT & radiation biases?

**Southern Ocean:**
- most extensive region of positive surface temperature biases in CMIP5 ensemble mean
- problems with sea ice simulations
- global implication of biases
  - double ITCZ problem (Hwang and Frierson, 2013)
  - ocean heat transport (e.g. Trenberth and Fasullo, 2010)

**Antarctic ice sheet:**
- very little is known about model biases in the surface climate
- coupled ice sheet models – what biases in the atmospheric forcing?
- global implications of biases
  - (sea level rise; heat sink)
This Study

⇒ 26 CMIP5 models; Historical Run, late 20C (1981-2000)

⇒ Observations: CERES-EBAF, ERA-Interim, MERRA, Matsuura & Wilmott (UDEL) surface temperatures

⇒ 2 domains: Southern Ocean (40°S-60°S); Antarctica (60°S-90°S)

1. ACCESS 1-0
2. ACCESS 1-3
3. BCC-CSM 1.1
4. BNU-ESM
5. CanESM2
6. CCSM4
7. CESM1-CAM5
8. CESM1-CAM5-FV2
9. CNRM-CM5
10. CSIRO-MK3.0
11. GFDL-CM3
12. GFDL-ESM2G
13. GFDL-ESM2M
14. GISS-E2-H
15. GISS-E2-R
16. HAD-CM3
17. HadGEM2-ES
18. INMCM4
19. IPSL-CM5A-LR
20. IPSL-CM5A-MR
21. IPSL-CM5B-LR
22. MIROC5
23. MIROC-ESM
24. MPI-ESM-LR
25. MRI-CGCM3
26. NorESM1-M
Ensemble mean, monthly mean surface air temperature (SAT) and insolation
Ensemble mean bias, inter-model range, and inter-model spread in SAT

Bias

Range (max-min)

Spread

- ensemble-mean bias
- inter-model range
- January model spread vs. spread in each month
Surface energy fluxes

\[ \text{SEF}_{\text{net}} = R_{\text{net}} + \text{HF}_{\text{net}} \]

\[ \text{SEF}_{\text{net}} = \text{SW}_{\text{net}} + \text{LW}_{\text{net}} + \text{HF}_{\text{net}} \]

\[ \text{SEF}_{\text{net}} = (\text{SW}_d - \text{SW}_u) + (\text{LW}_d - \text{LW}_u) + (\text{SHF}_{\text{net}} + \text{LHF}_{\text{net}}). \]

Ensemble mean
Surface energy fluxes

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surface albedo (DJF, clear-sky)
Inter-model spread (DJF)

- Temperature
- ASR (Air-Surface Radiation)
- Surface Albedo
- SWCF (Solar Weighted Cloud Fraction)
Inter-model spread (DJF): \( \text{SEF}_{\text{net}} = (\text{SW}_{\text{net}} + \text{LW}_{\text{net}}) + \text{HF}_{\text{net}} \)
Inter-model spread (JJA):

\[ SEF_{net} = (SW_{net} + LW_{net}) + HF_{net} \]
$R_{net}$ (JJA)
Longwave cloud radiative effect at surface (JJA): $\text{CRE}_{\text{LW}} = (\text{LW}_d^{\text{all-sky}} - \text{LW}_d^{\text{clear-sky}})^*$

*e.g. Stephens et al., 2012, J. Climate*
Inter-model spread (ANN): $\text{SEF}_{\text{net}} = R_{\text{net}} + \text{HF}_{\text{net}}$
Ensemble mean (ANN): \( \text{SEF}_{\text{net}} = R_{\text{net}} + H F_{\text{net}} \)

- a) CERES-EBAF: \( R_{\text{net}} \) (W M\(^{-2}\))
- b) EM: \( R_{\text{net}} \) (W M\(^{-2}\))
- c) EM: \( H F_{\text{net}} \) (W M\(^{-2}\))
- d) EM: \( \text{SEF}_{\text{net}} \) (W M\(^{-2}\))

_Marshall and Speer, 2012_
Summary

1. In summer: Warm bias over Southern Ocean in majority of models and ensemble mean
   - lags biases in $SW_{net}$ and SWCF in late spring thru mid summer
   - SWCF explains model spread in SAT, ASR, $R_{net}$, etc. and model spread in SAT persists throughout year
   - however, annual $R_{net}$ bias on ocean is negative in ensemble mean

2. In winter: Strong negative $R_{net}$ and $LW_{net}$ bias on the Antarctic ice sheet in all models (!)
   - largely accounted for by $LW_d$
   - suggests lower atmosphere too stable (strong inversion)
   - associated with longwave CRE
   - compensated by large sensible heat flux
   - leads to annual $R_{net}$ negative bias on ice sheet

3. Models exhibit a relatively wide range of surface albedo on the ice sheet
   - regulates amount of shortwave radiation absorbed and contributes to model spread in SAT
   - some models have uniform albedo and some have complex spatial structure

4. Several biases are difficult to quantify
   - SAT bias on the Antarctic Ice Sheet? Reanalyses are very problematic for addressing this.
   - heat fluxes on both the ocean and ice sheet
     * turbulent heat fluxes (sensible + latent) are probably too large in most models on the ice sheet
     * ensemble mean net annual air-surface heat flux (radiation + sensible + latent) pattern looks reasonable over ocean but too uniform over land