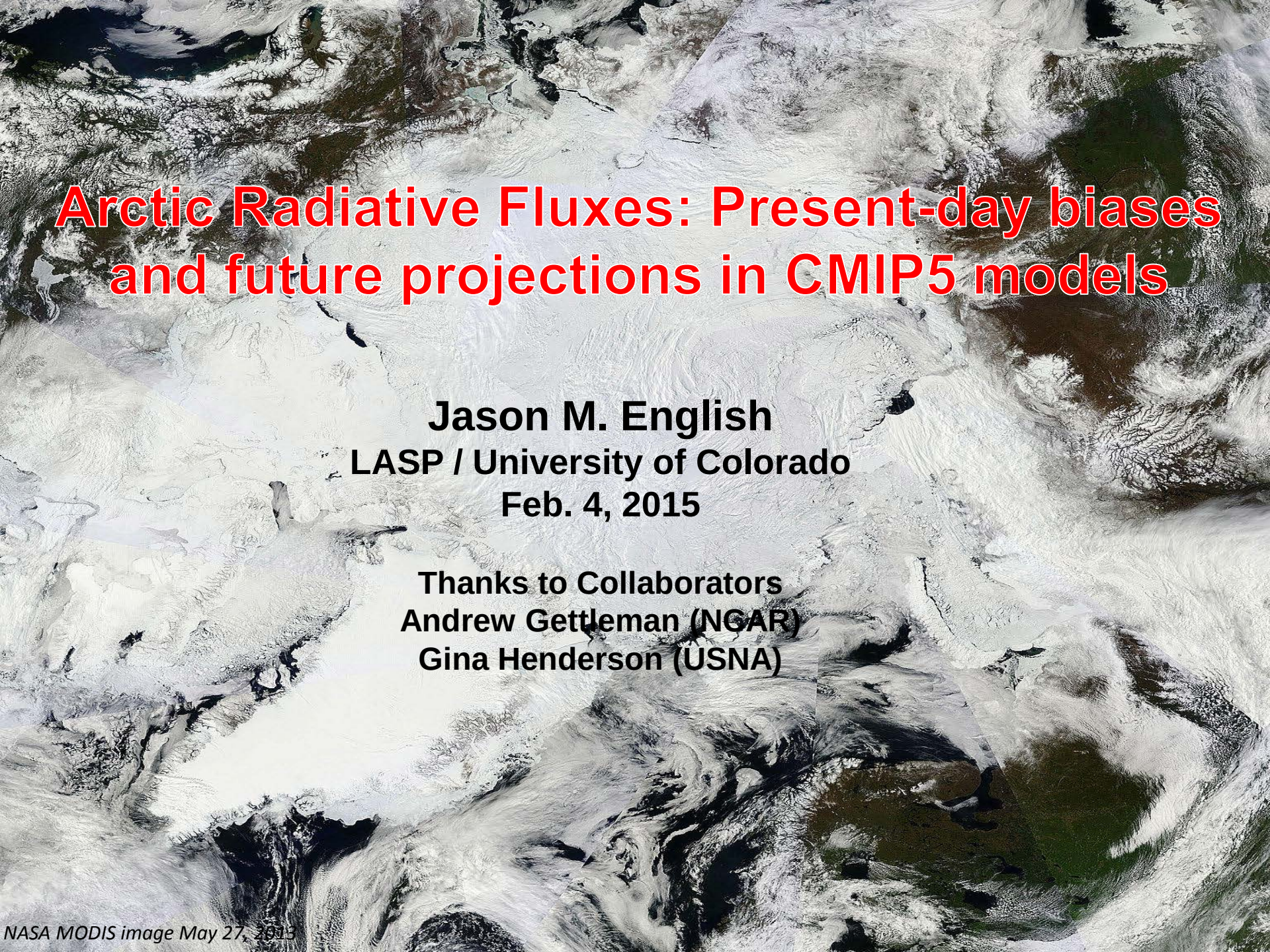

Arctic Radiative Fluxes: Present-day biases and future projections in CMIP5 models

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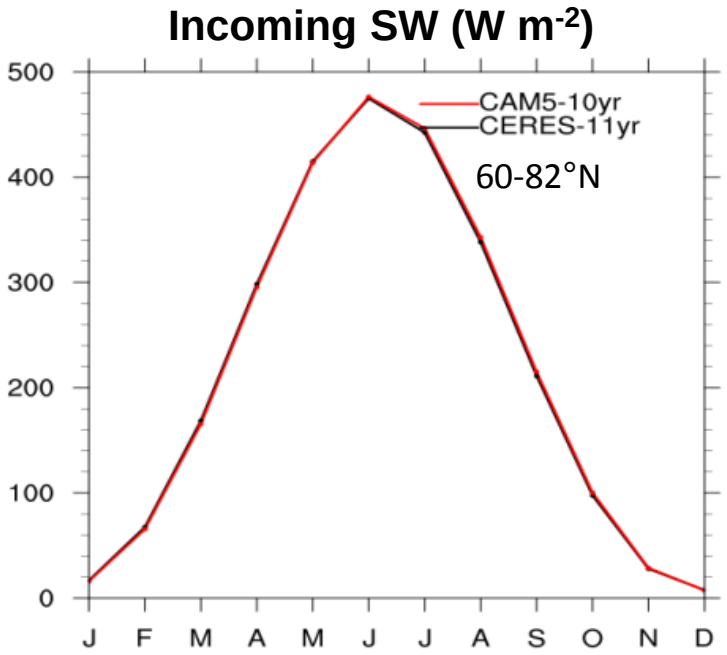
LASP / University of Colorado
Feb. 4, 2015

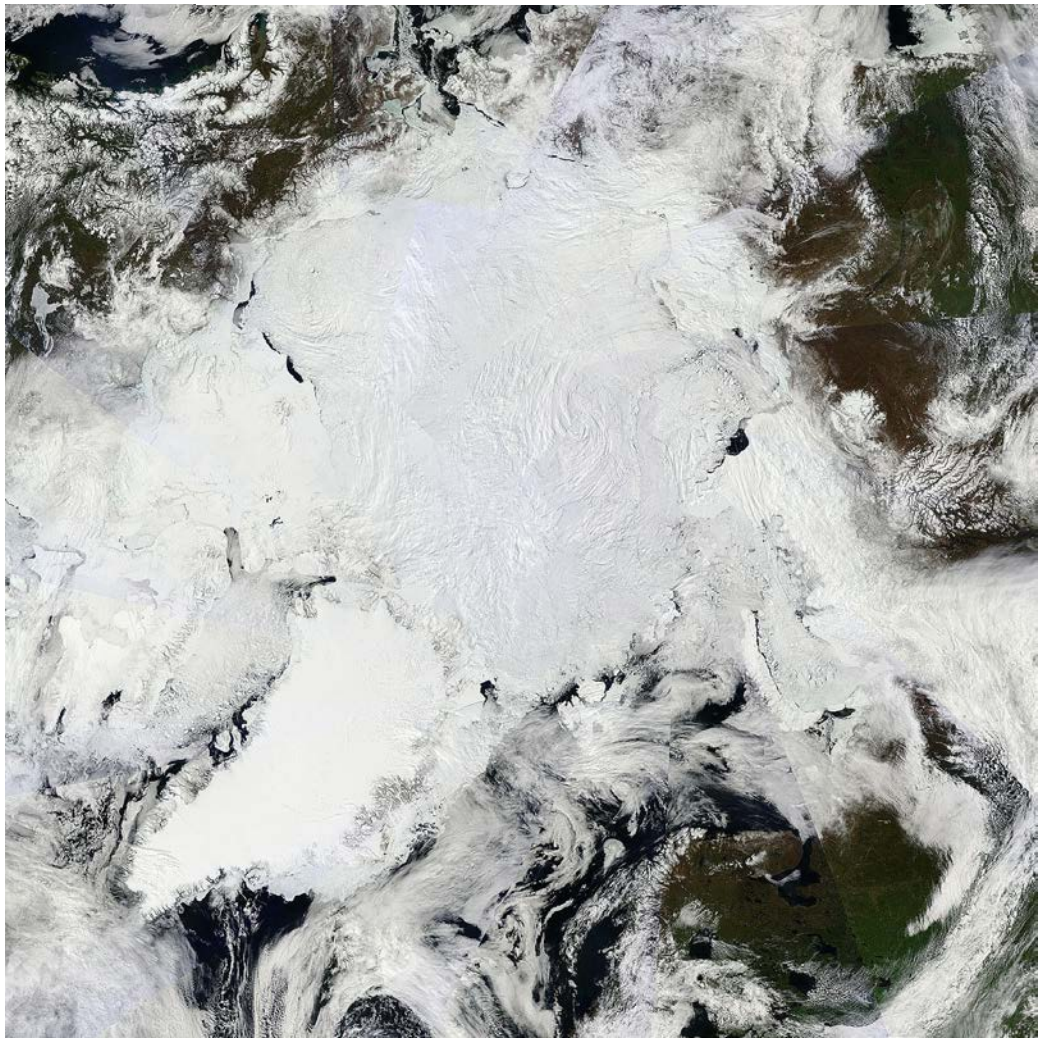
Thanks to Collaborators
Andrew Gettleman (NCAR)
Gina Henderson (USNA)

NASA MODIS image May 27, 2013

Arctic energy balance is strongly affected by clouds & surface albedo

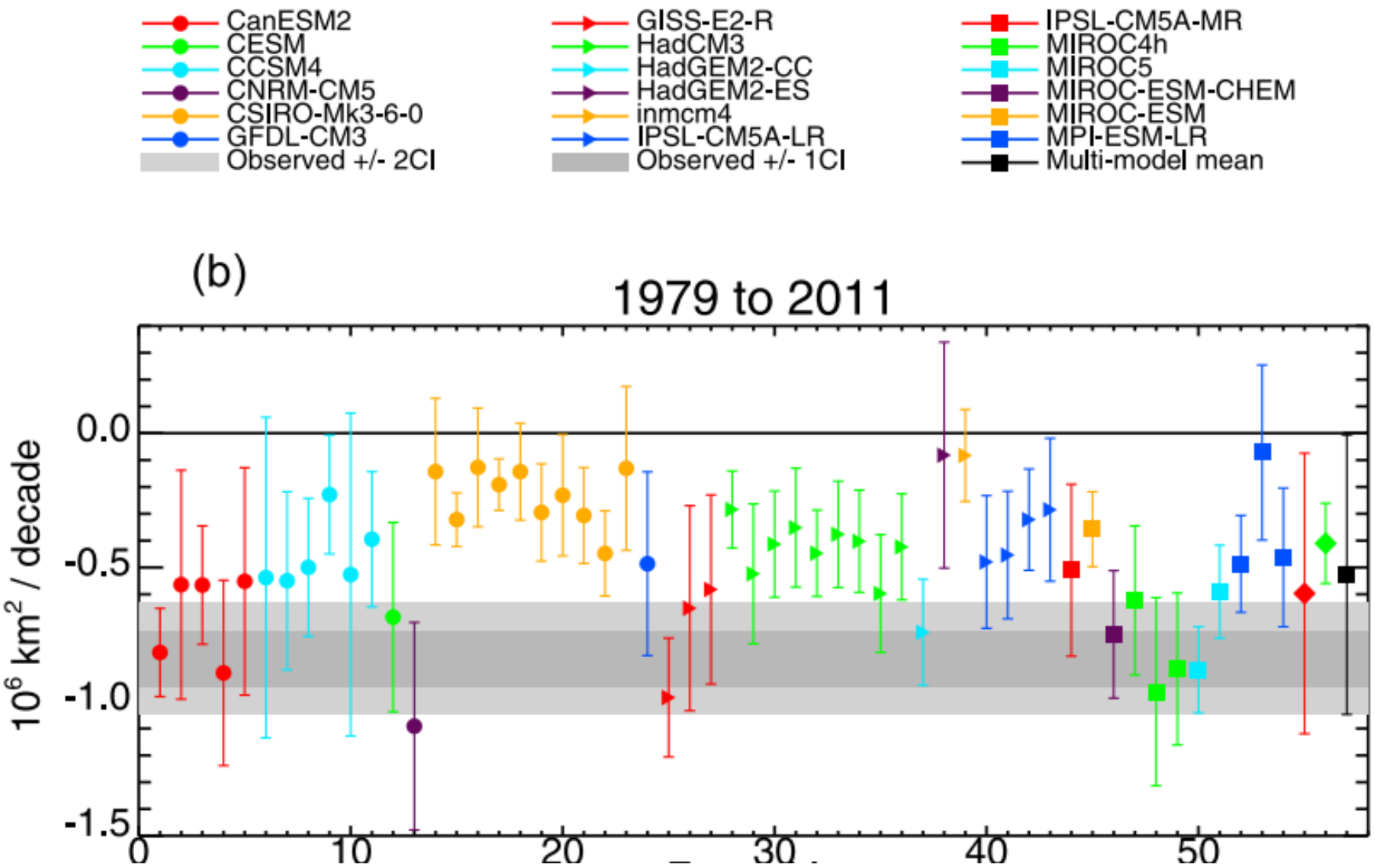


High albedo



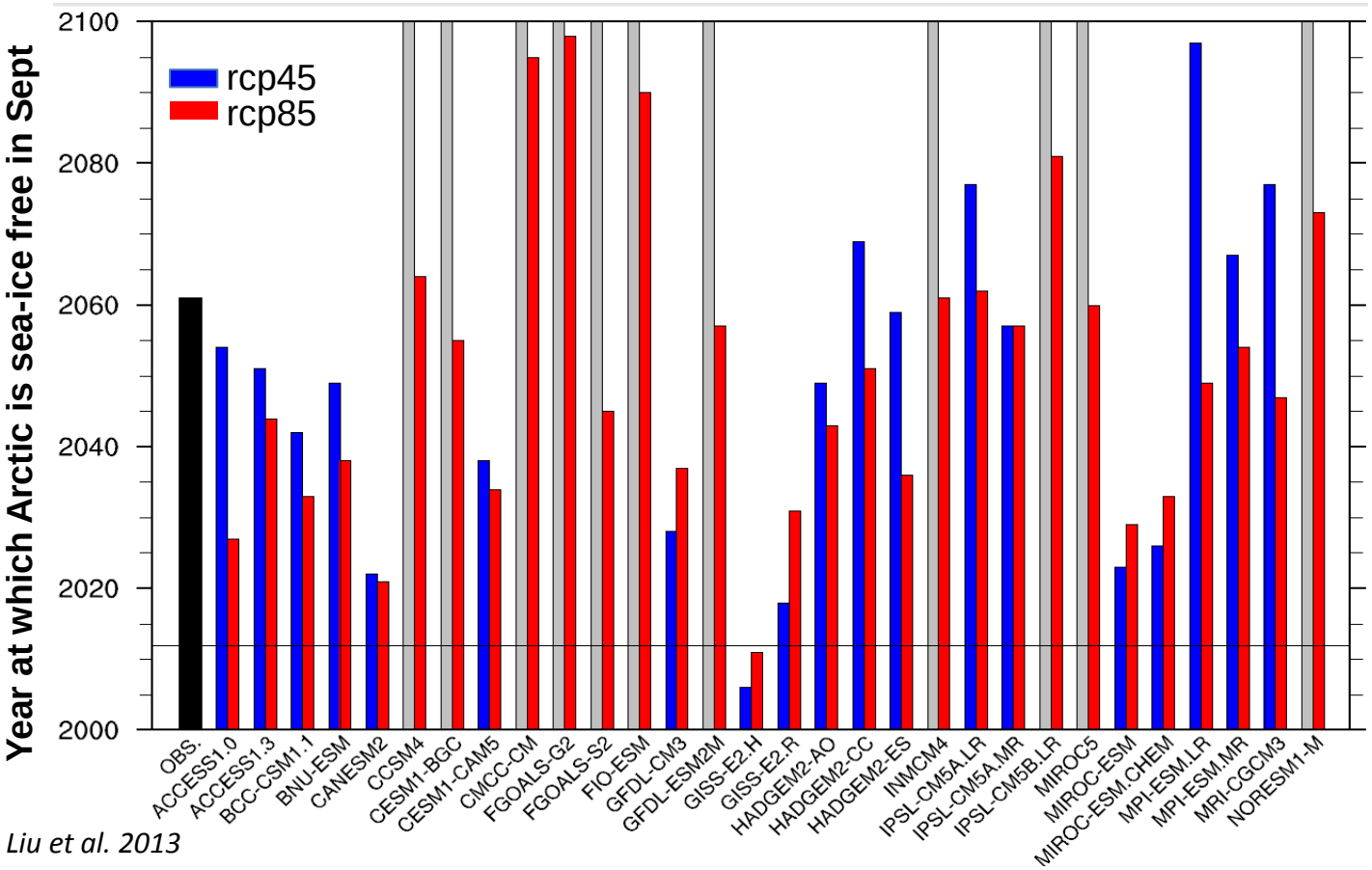
NASA MODIS image May 27, 2013

CMIP5 models underestimate observed recent sea ice loss



Stroeve et al 2012

CMIP5 models disagree on rate of future sea ice loss



Liu et al. 2013

What are the contributions of annual-average clouds, snow cover, surface albedos, & radiation?
(as opposed to NHT, atmospheric & oceanic circulation, internal variability)

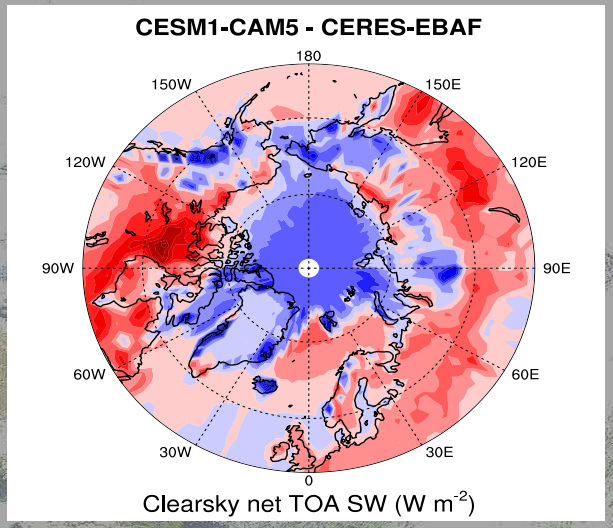
Science Questions

<u>Present climate (AMIP 2000-2008):</u> How do CMIP5 TOA radiative fluxes compare to CERES-EBAF? What are the contributions of cloud, snow cover, and surface albedo biases?

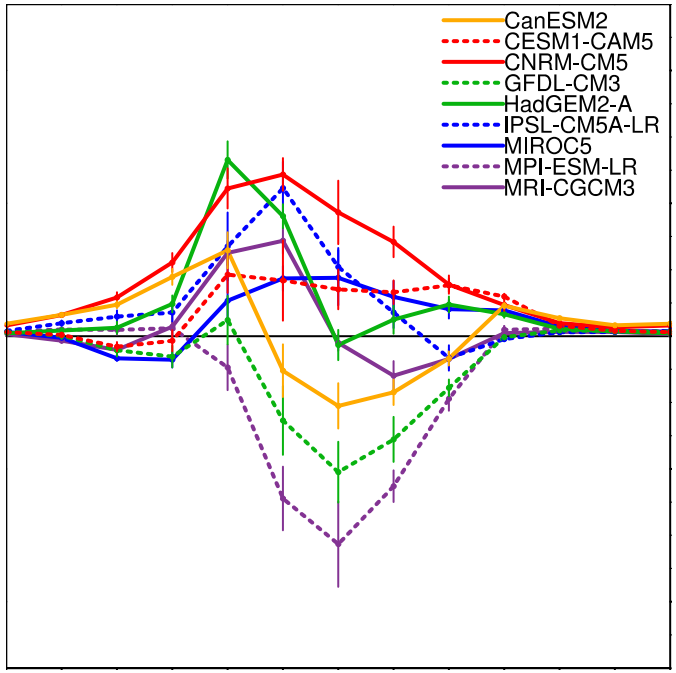
<u>Future climate (Fully coupled 2081-2090):</u> What are the projected changes to net TOA radiative fluxes in the CMIP5 models? What are the contributions of cloud, snow cover, and surface albedo changes?

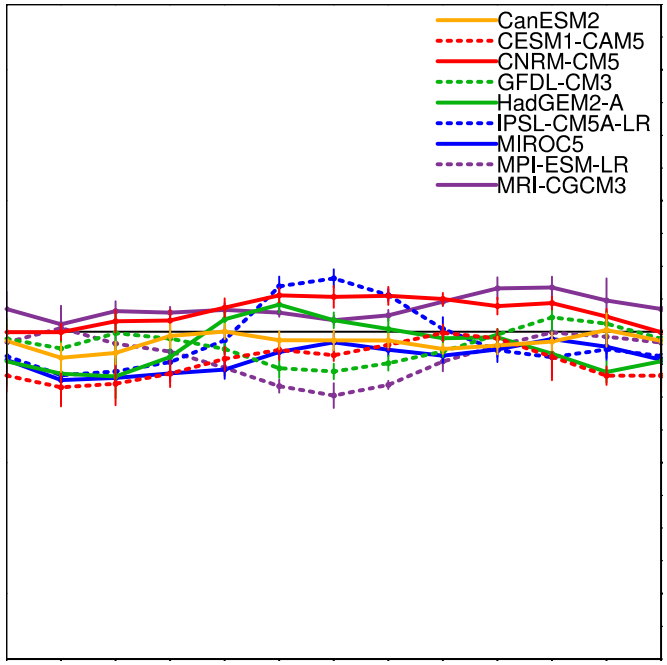
Approach

- **Analyze over different surface masks:**
  - **(all) Entire Arctic basin (60-82°N)**
  - **(cice) Sea ice *(AMIP: HadSST prescribed)***
  - **(ocn) Open ocean**
  - **(lnd) All land areas**
  - **(lnds) Land areas w/snow *(AMIP: NASA Measures prescribed)***
  - **(lndns) Land areas without snow *(AMIP: NASA Measures prescribed)***

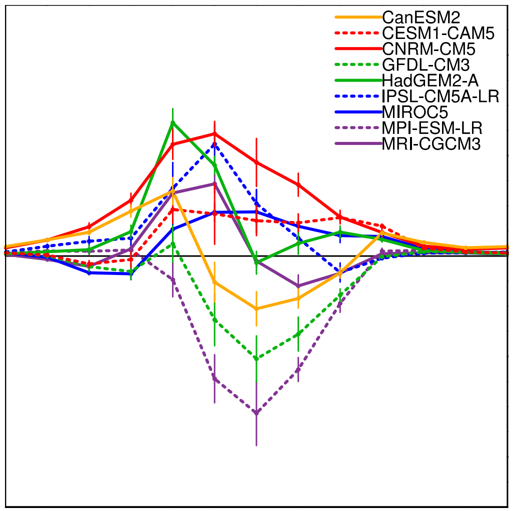


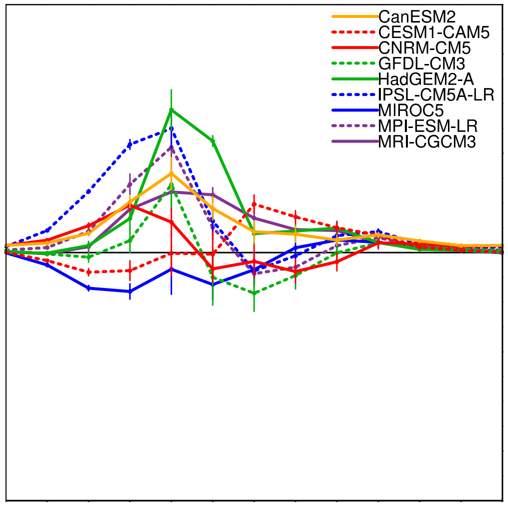
Current climate (AMIP 2000-2008):
SW biases in spring/summer are larger than OLR biases

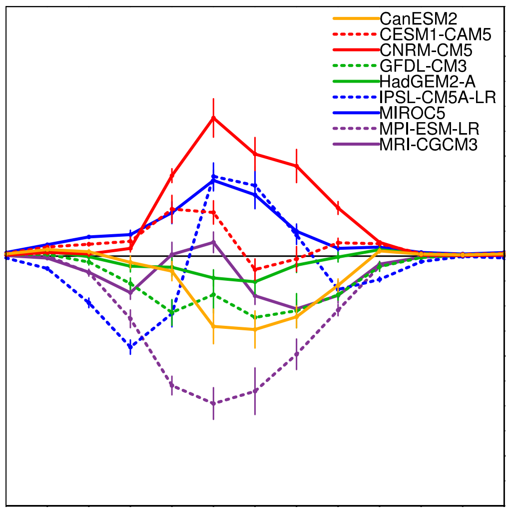


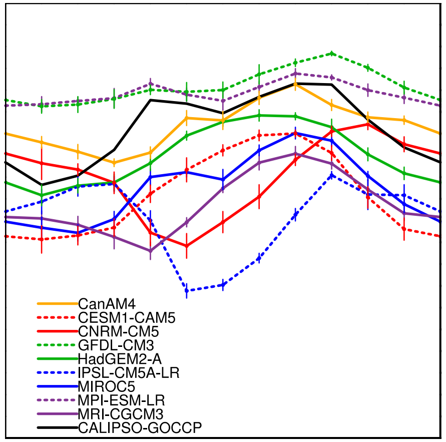


SW biases are present under both clear-sky and cloudy conditions

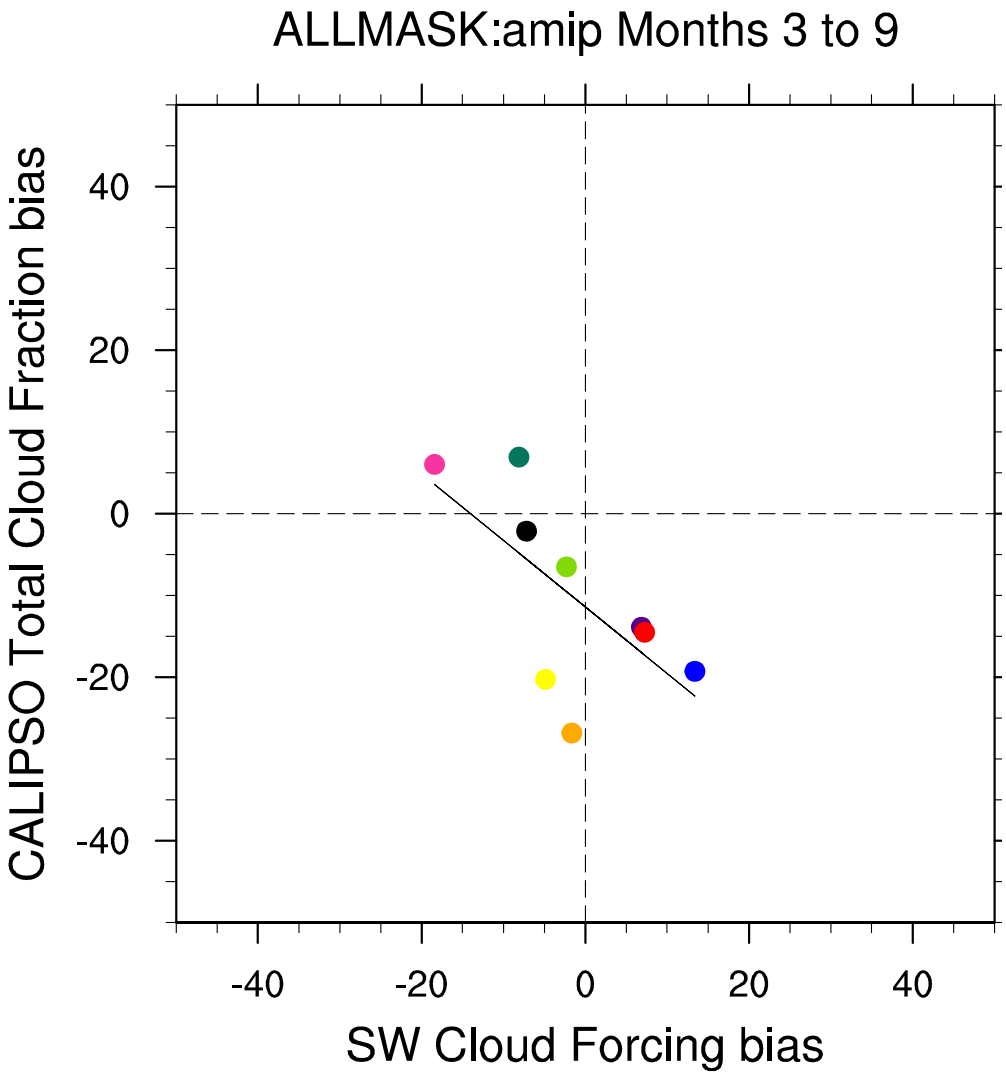






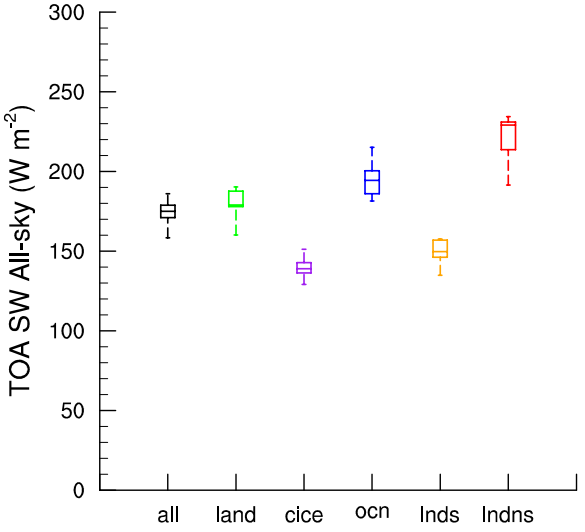


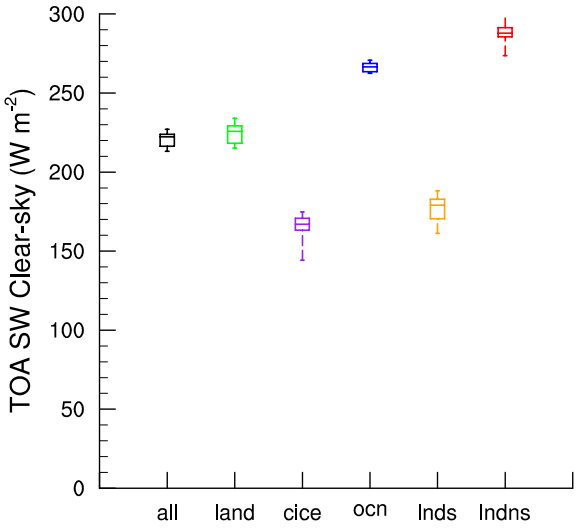
Cloud amount biases (CMIP5 - CALIPSO) correlate with SW cloud forcing biases (CMIP5 - CERES-EBAF), except 2 outliers.

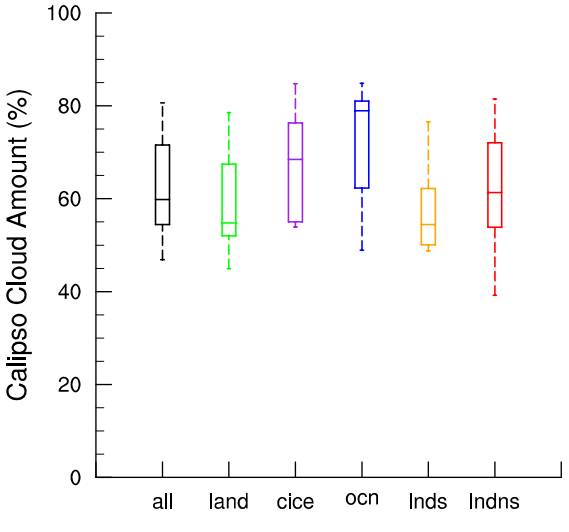


CMIP5 models span a broad range of biases, even over prescribed sea ice extent
SW clear-sky biases not correlated with snow depth, but possibly snow area extent
Most models have insufficient cloud amount

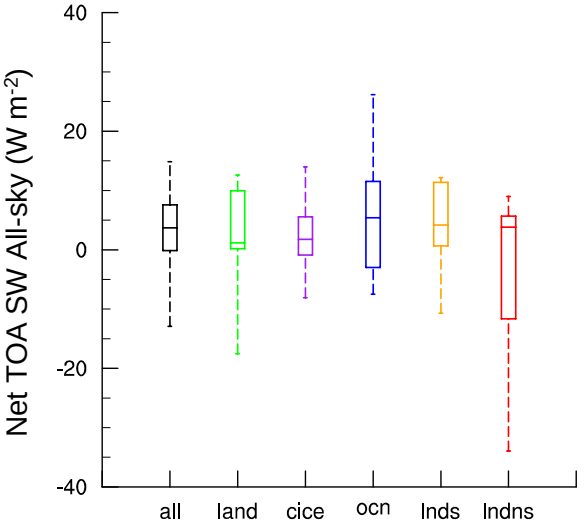
CMIP5 Models (2000-2008) (MAMJJAS avg)

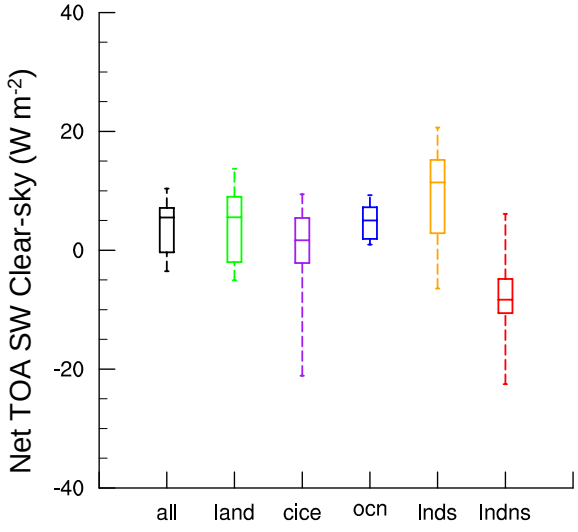


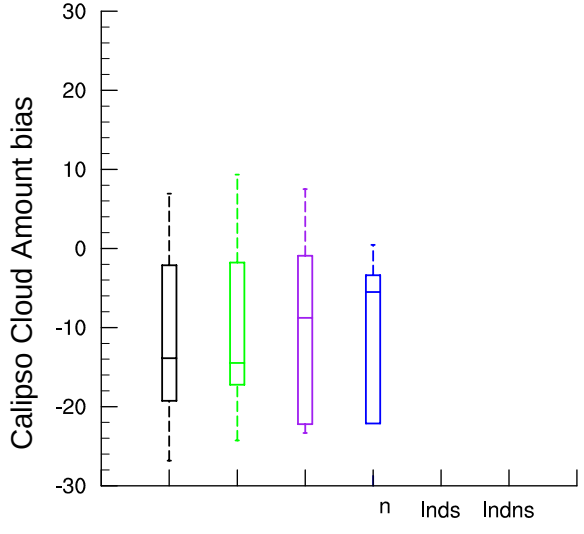




Bias (CMIP5 – Observations)







Projected increases in net TOA SW fluxes in summer; partially compensated by increases in OLR fluxes in winter

RCP8.5 All-sky Projection

RCP8.5 Clear-sky Projection

RCP8.5 Cloud Forcing Projection

a.

CanESM2
CESM1-CAM5
CNRM-CM5
GFDL-CM3
dGEM2-AO

b.

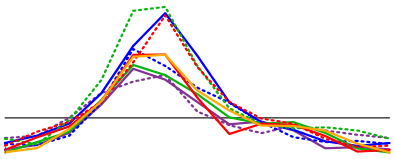
c.

d.

e.

f.

g.



h.

i.

Very little correlation between present-day biases and future projections in net TOA SW All-sky fluxes except over sea ice, where the extent was specified in present-day simulations.

all

a.

cice

b.

ocn

c.

CanESM2
CESM1-CAM5
CNRM-CM5
GFDL-CM3
HadGEM2-AO
IPSL-CM5A-LR
MIROC5
PI-ESM-LR

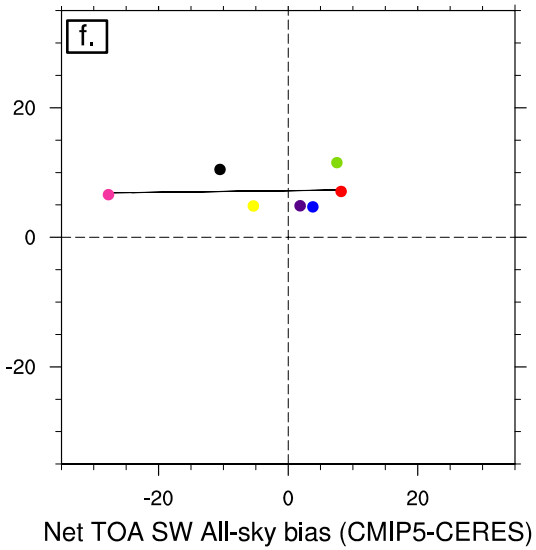
land

d.

Inds

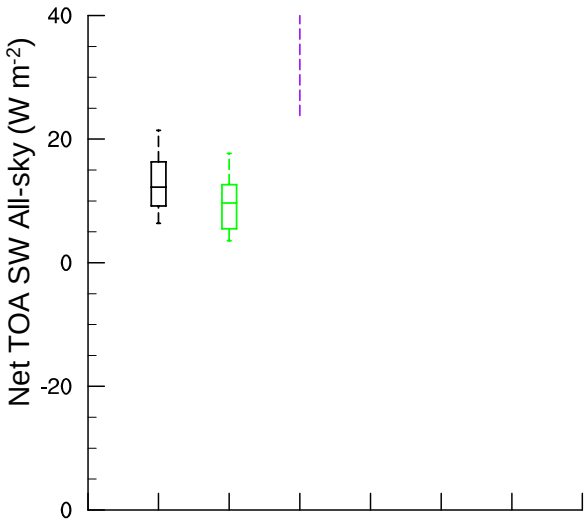
e.

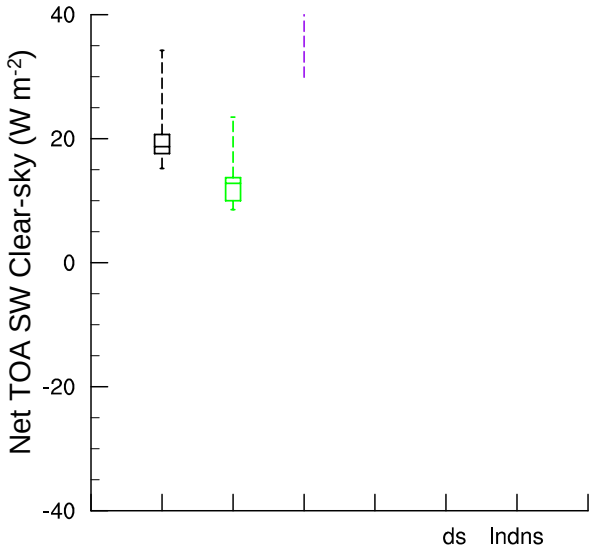
Indns

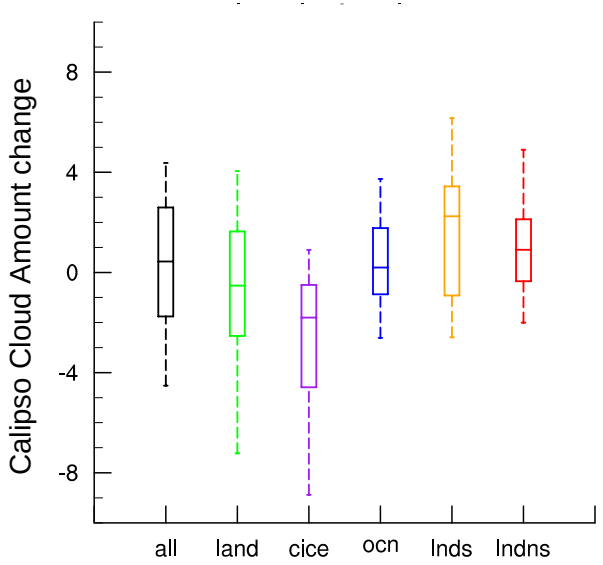


Increases in net TOA SW fluxes are projected over all areas except snow-on-land, suggesting decreasing albedos. Cloud amount not projected to change significantly

CMIP5 fully-coupled projected changes (2081-2090 minus 2006-2015) (MAMJJAS avg)

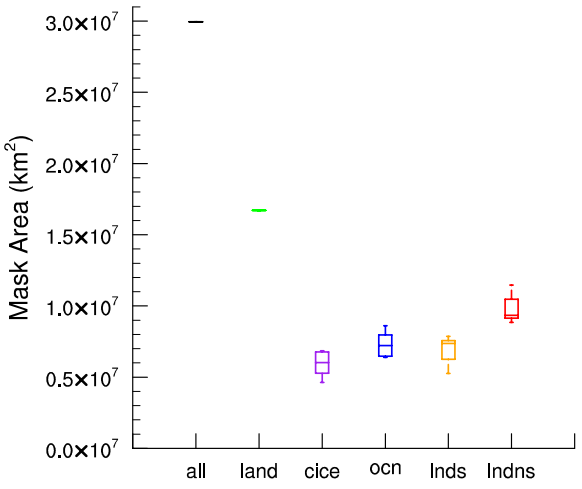


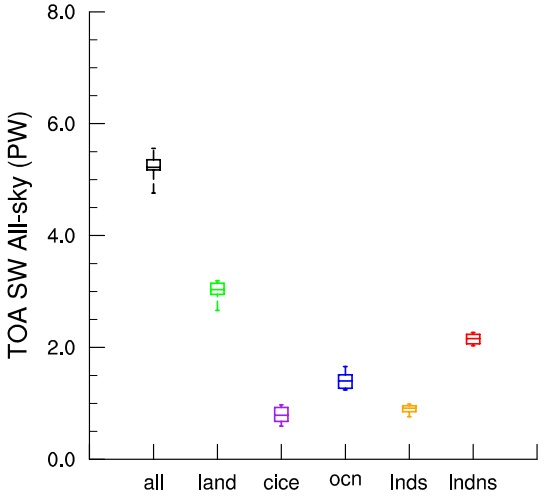


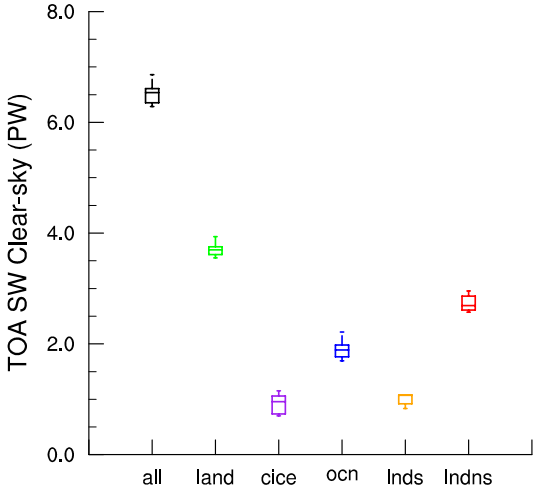


Significant reductions in sea ice (-3m km^2) and land snow cover (-1m km^2) and accompanied changes to net TOA SW fluxes

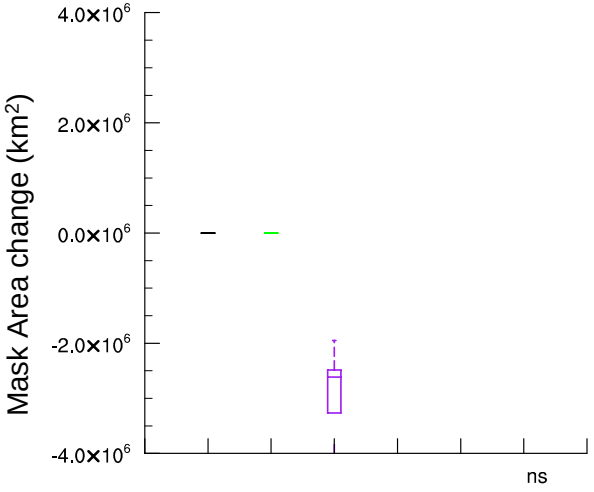
CMIP5 fully-coupled present-day (2006-2015) (MAMJJAS avg)

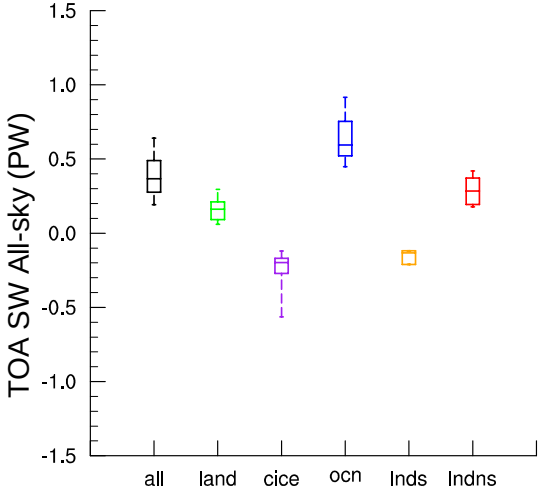


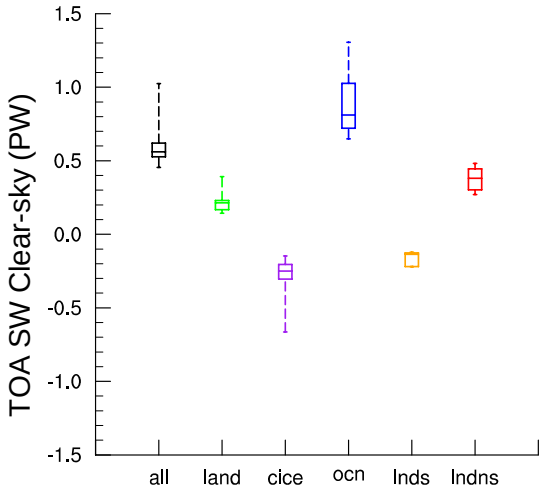




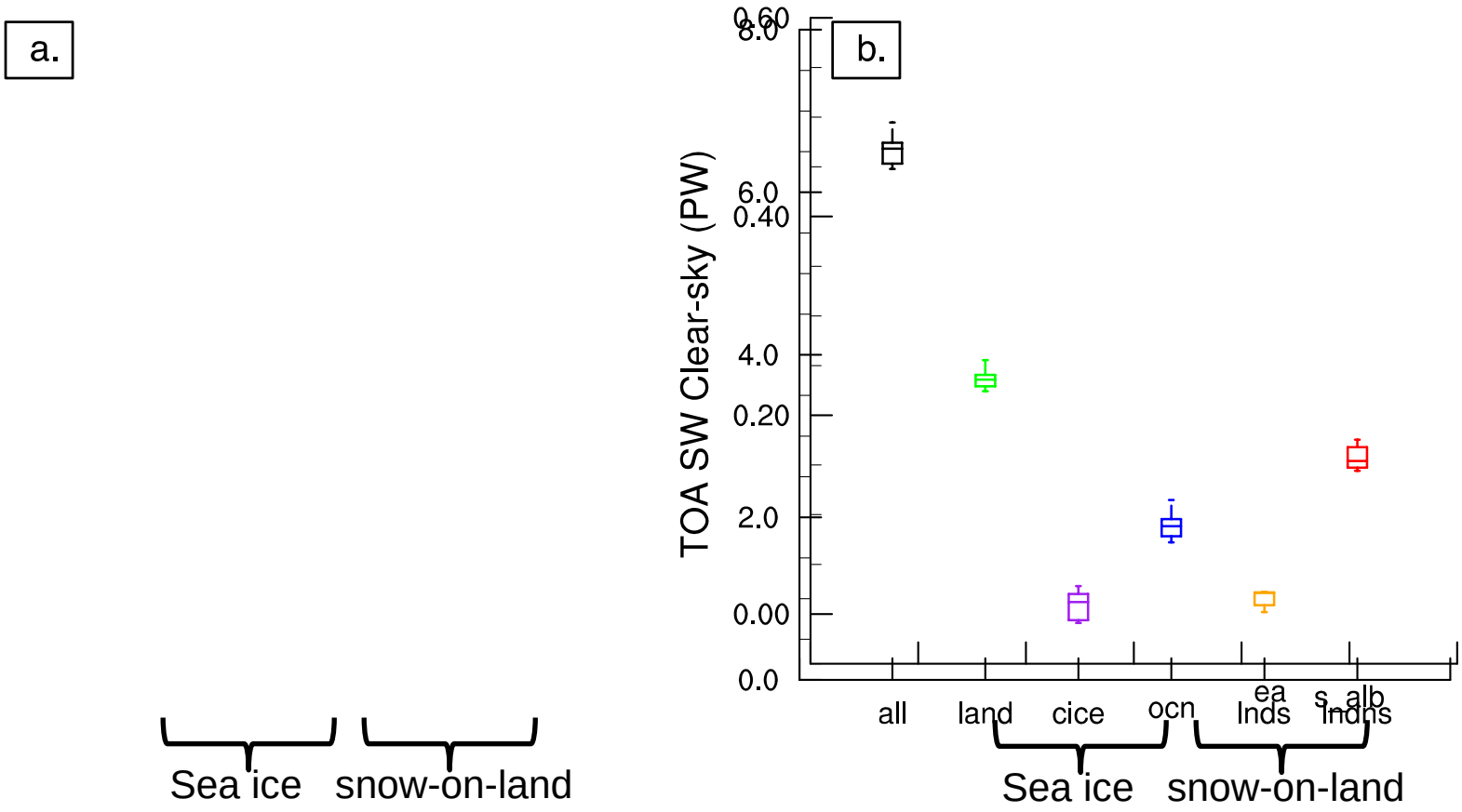
CMIP5 projected changes (2081-2090 minus 2006-2015) (MAMJJAS avg)







Loss of sea ice area responsible for ~50% of increase in Arctic net TOA SW all-sky and clear-sky fluxes. Changes to snow-on-land area and sea ice albedo also significant.



Summary: Present-day biases

- Net TOA SW biases are larger than OLR biases in spring/summer
- Primary contributions to spring/summer TOA SW biases:
  - Cloud amount vs CALIPSO-GOCCP (low bias common)
  - Snow-on-land extent vs MEASURES (low bias common)
  - Sea ice albedo (low & high biases)

Summary: RCP8.5 Projections

- Net TOA SW increases in spring/summer; OLR increases in winter
- Primary contributions to spring/summer TOA SW changes:
  - #1: loss of sea ice extent (~50% of total SW increase)
  - #2: loss of snow-on-land extent (~30% of total)
  - #3: reduced albedo of remaining sea ice (~20% of total)
- Changes to cloud amount and changes to snow-on-land albedo insignificant
- Important to get clouds, sea ice & snow extent, albedos correct

English, J.M., A. Gettelman, G.R. Henderson (2015): Arctic Radiative Fluxes: Present-day biases and future projections in CMIP5 models, J. Clim., under revision.

Surface Mask	Abbrev.	Gridbox requirements
Arctic basin	all	All gridboxes between 60 and 82°N
Arctic land	land	> 0.5 land fraction
Arctic sea ice	cice	≤ 0.5 land fraction and >0.5 sea ice fraction*
Arctic open ocean	ocn	≤ 0.5 land fraction and ≤ 0.5 sea ice fraction
Arctic land with snow cover	lnds	AMIP simulations (present-day with prescribed SSTs and sea ice extent): > 0.5 land fraction and > 0.5 MEaSUREs observed snow cover frequency* RCP8.5 simulations: >0.5 land fraction and >5 cm grid-box averaged snow depth
Arctic land without snow cover	lndns	> 0.5 land fraction and ≤ 5 cm grid-box averaged snow depth sea ice fraction

* CMIP5 present-day comparisons utilize consistent sea ice and snow cover surface masks for all models prescribed from Hadley center observed sea ice extent and MEaSUREs snow cover frequency data, regardless of predicted snow cover from individual models. RCP8.5 comparisons utilize projected sea ice and snow cover extent from each model to determine the surface mask designation.

Simulations	Mask	Cutoff criteria	Gridboxes that meet criteria	SW Clear-sky bias (CMIP5–CERES) (Wm^{-2})		
				min	med	max
Present-day	Land w/snow	>0.3	26%	-7.1	+10.4	+18.2
Present-day	Land w/snow	>0.5	24%	-6.5	+11.4	+20.6
Present-day	Land w/snow	>0.7	23%	-6.2	+11.9	+23.0
Present-day	Land w/snow	>0.95	21%	-5.1	+5.6	+13.7
Present-day	Sea ice	>0.3	60%	-20.0	+1.5	+8.2
Present-day	Sea ice	>0.5	52%	-21.1	+1.7	+9.4
Present-day	Sea ice	>0.7	43%	-22.5	+1.0	+10.1
Present-day	Sea ice	>0.95	17%	-21.5	+2.5	+14.3

Simulations	Mask	Cutoff criteria	Gridboxes that meet criteria	SW Clear-sky change (2081-2090 – 2006-2015) (Wm^{-2})		
				min	med	max
RCP8.5	Land w/snow	>0.3	26%	-3.9	13.9	18.8
RCP8.5	Land w/snow	>0.5	23%	-0.3	12.8	14.7
RCP8.5	Land w/snow	>0.7	21%	5.9	11.8	14.3
RCP8.5	Land w/snow	>0.95	16%	-12.3	1.6	4.3
RCP8.5	Sea ice	>0.3	15%	17.8	31.0	48.5
RCP8.5	Sea ice	>0.5	13%	8.0	28.8	44.8
RCP8.5	Sea ice	>0.7	12%	-13.7	24.6	28.8
RCP8.5	Sea ice	>0.95	6%	-35.2	-3.0	10.1