The Long Road to CESM2

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AMWG liaison

CESM 2 development at a glance

- **Huge team effort started in Mid November 2015**
- **2 co-chair meetings/week**

Land
CLM5

Atmosphere
CAM6

Sea-ice
CICE5

Land Ice
CISM2

River Model
MOSART

Ocean
POP2

CESM 2 development simulations

http://www.cesm.ucar.edu/working_groups/Atmosphere/development/cesm1_5/

Nov 2015: First coupled

- First coupled simulation

Feb 2016: Winter Working Group Meeting

- 34 experiments ("cases")
- 1300+ years of simulations + diagnostics

June 2016: Breckenridge workshop

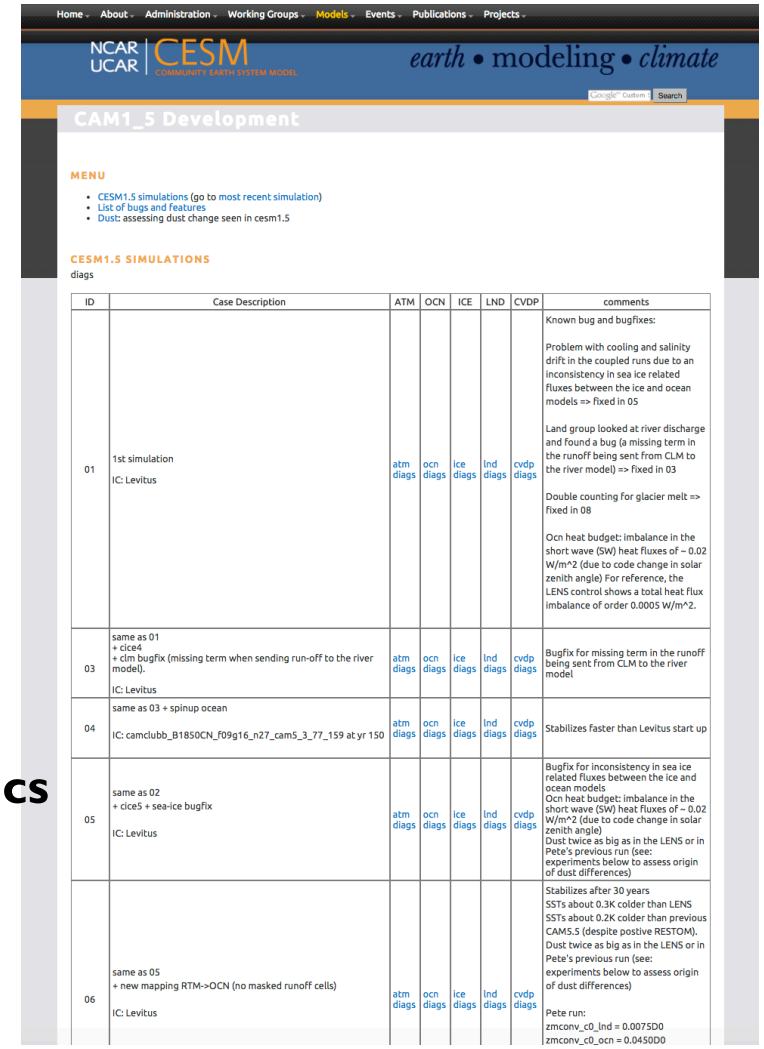
- 94 experiments ("cases")
- 2900+ years of simulations + diagnostics

Feb 2017: Winter Working Group Meeting

- 150 experiments ("cases")
- Thousands of simulated years + diagnostics

And also

- Many standalone simulations in individual working groups



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NCAR UCAR | CESM COMMUNITY EARTH SYSTEM MODEL — *earth • modeling • climate*

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CAM1_5 Development

MENU

- CESM1.5 simulations (go to most recent simulation)
- List of bugs and features
- Dust: assessing dust change seen in cesm1.5

CESM1.5 SIMULATIONS

diags

ID	Case Description	ATM	OCN	ICE	LND	CVDP	comments
01	1st simulation IC: Levitus	atm diags	ocn diags	ice diags	lnd diags	cvdp diags	Known bug and bugfixes: Problem with cooling and salinity drift in the coupled runs due to an inconsistency in sea ice related fluxes between the ice and ocean models => fixed in 05 Land group looked at river discharge and found a bug (a missing term in the runoff being sent from CLM to the river model) => fixed in 03 Double counting for glacier melt => fixed in 08 Ocn heat budget: imbalance in the short wave (SW) heat fluxes of ~ 0.02 W/m^2 (due to code change in solar zenith angle) For reference, the LENS control shows a total heat flux imbalance of order 0.000S W/m^2.
03	same as 01 + cice4 + clm bugfix (missing term when sending run-off to the river model). IC: Levitus	atm diags	ocn diags	ice diags	lnd diags	cvdp diags	Bugfix for missing term in the runoff being sent from CLM to the river model
04	same as 03 + spinup ocean IC: camclubb_B1850CN_f09g16_n27_cam5_3_77_159 at yr 150	atm diags	ocn diags	ice diags	lnd diags	cvdp diags	Stabilizes faster than Levitus start up
05	same as 02 + cice5 + sea-ice bugfix IC: Levitus	atm diags	ocn diags	ice diags	lnd diags	cvdp diags	Bugfix for inconsistency in sea ice related fluxes between the ice and ocean models Ocn heat budget: imbalance in the short wave (SW) heat fluxes of ~ 0.02 W/m^2 (due to code change in solar zenith angle) Dust twice as big as in the LENS or in Pete's previous run (see: experiments below to assess origin of dust differences)
06	same as 05 + new mapping RTM->OCN (no masked runoff cells) IC: Levitus	atm diags	ocn diags	ice diags	lnd diags	cvdp diags	Stabilizes after 30 years SSTs about 0.3K colder than LENS SSTs about 0.2K colder than previous CAM5.5 (despite postive RESTOM). Dust twice as big as in the LENS or in Pete's previous run (see: experiments below to assess origin of dust differences) Pete run: zmconv_c0_lnd = 0.0075D0 zmconv_c0_ocn = 0.0450D0

What happened since Breckenridge ?

At Breckenridge: we had a preliminary version of CESM2

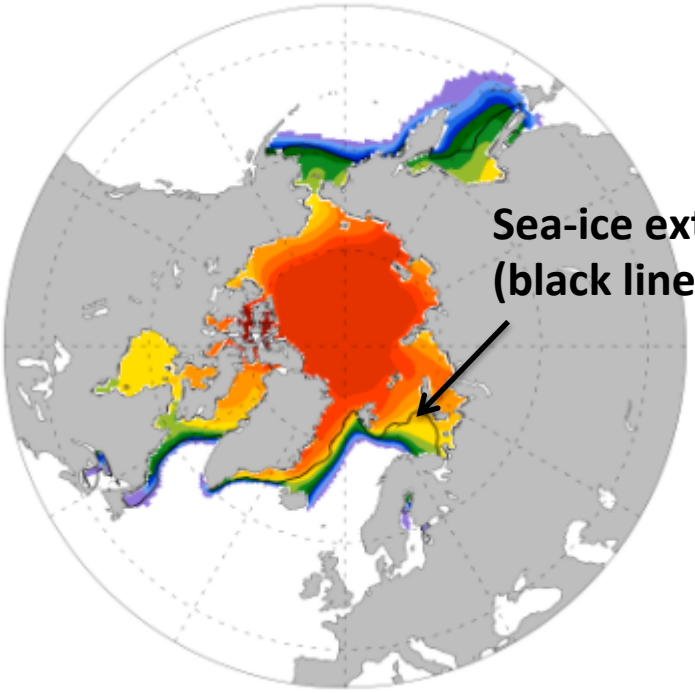
FAQ: "I thought CESM2 was almost ready at Breckenridge, what happened since then ? "

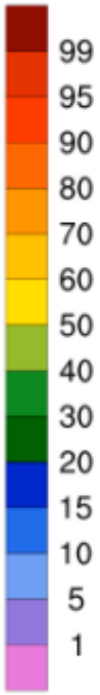
Can you spot the difference ? **The word "Almost"**

Houston, we have a problem: The Labrador Sea is freezing

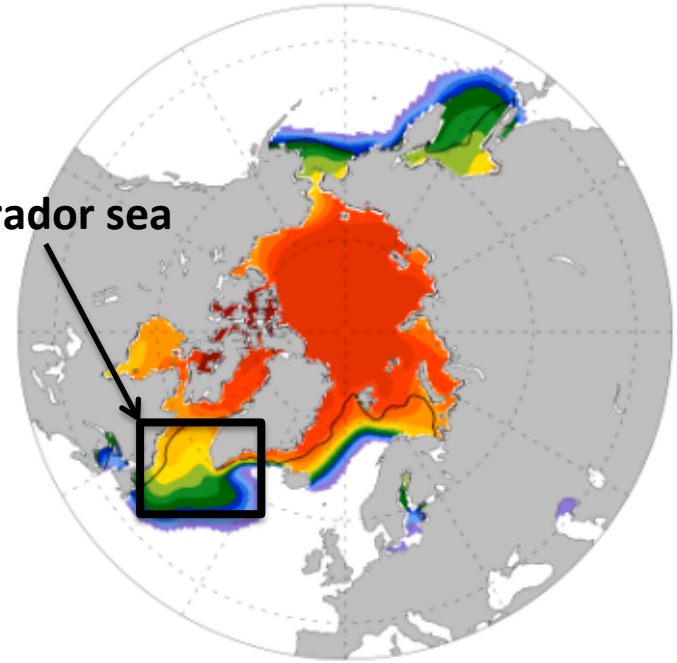
Sea-ice extent (ANN)

Typical CESM1





CESM2_dev (Breckenridge)

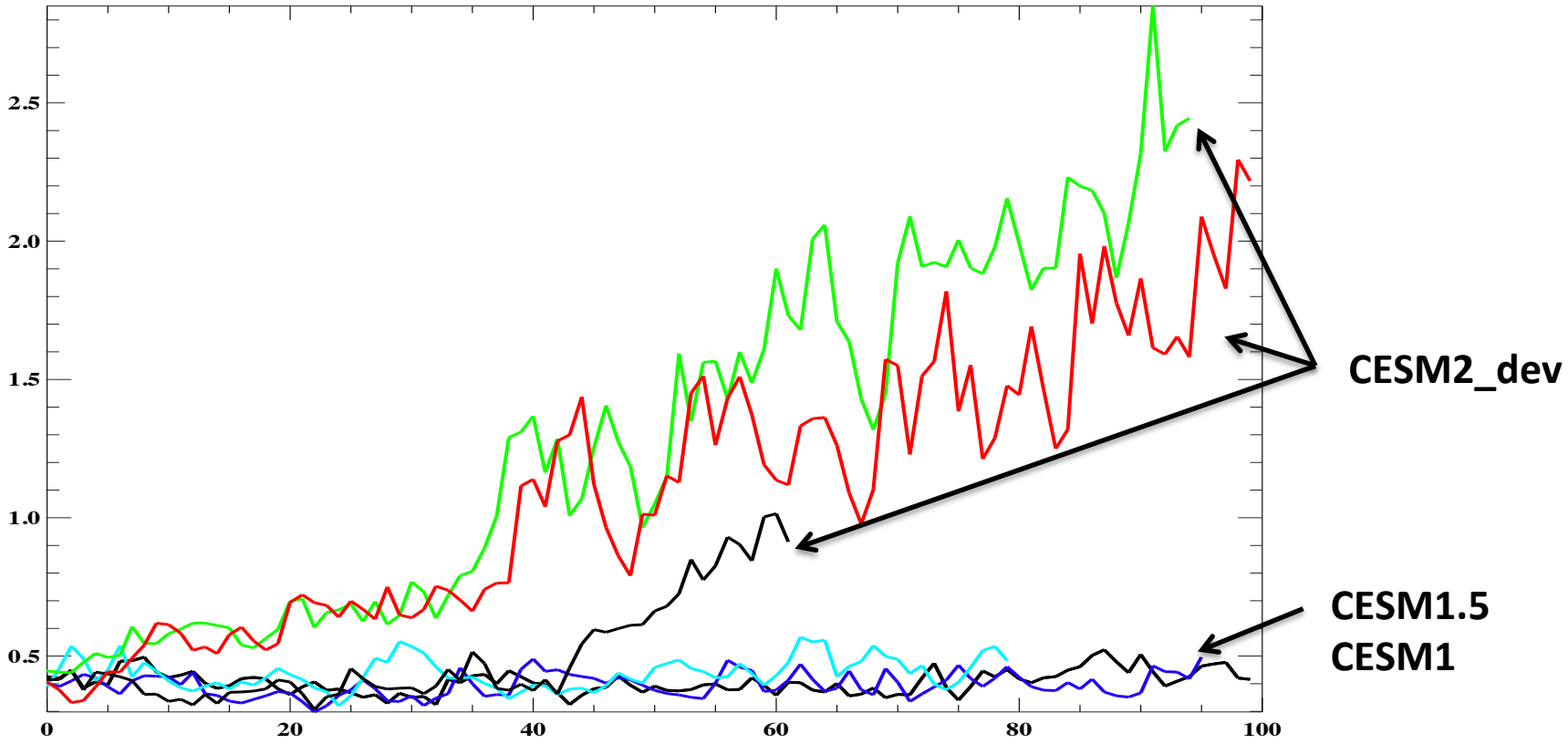


Sea-ice extent is close to obs
Labrador sea is ice free

Extensive sea-ice cover
Labrador sea is ice covered

We're in trouble in the Labrador Sea

Timeseries of sea ice thickness in Labrador sea



Sea ice is building up in Labrador sea

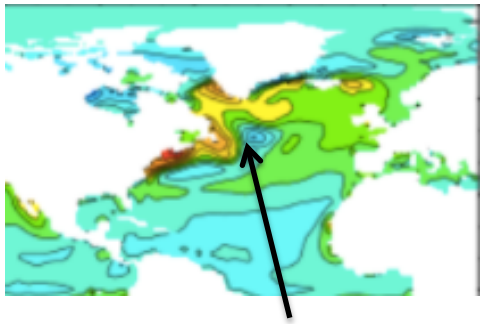
This can happen after 1 yr, 40 yr, 100^{+} yr

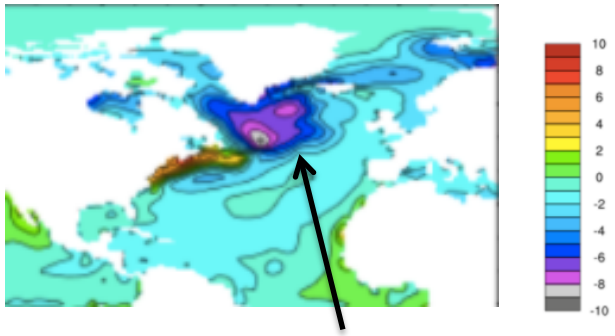
SST and salinity bias

Typical CESM1

CESM2_dev (Breckenridge)

SST

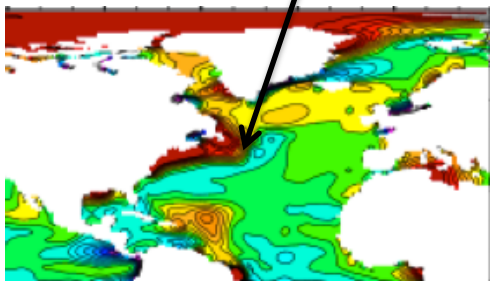


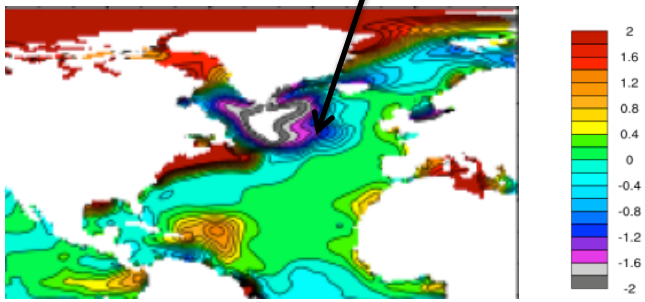


Too warm and salty

Too cold and too fresh

Salinity

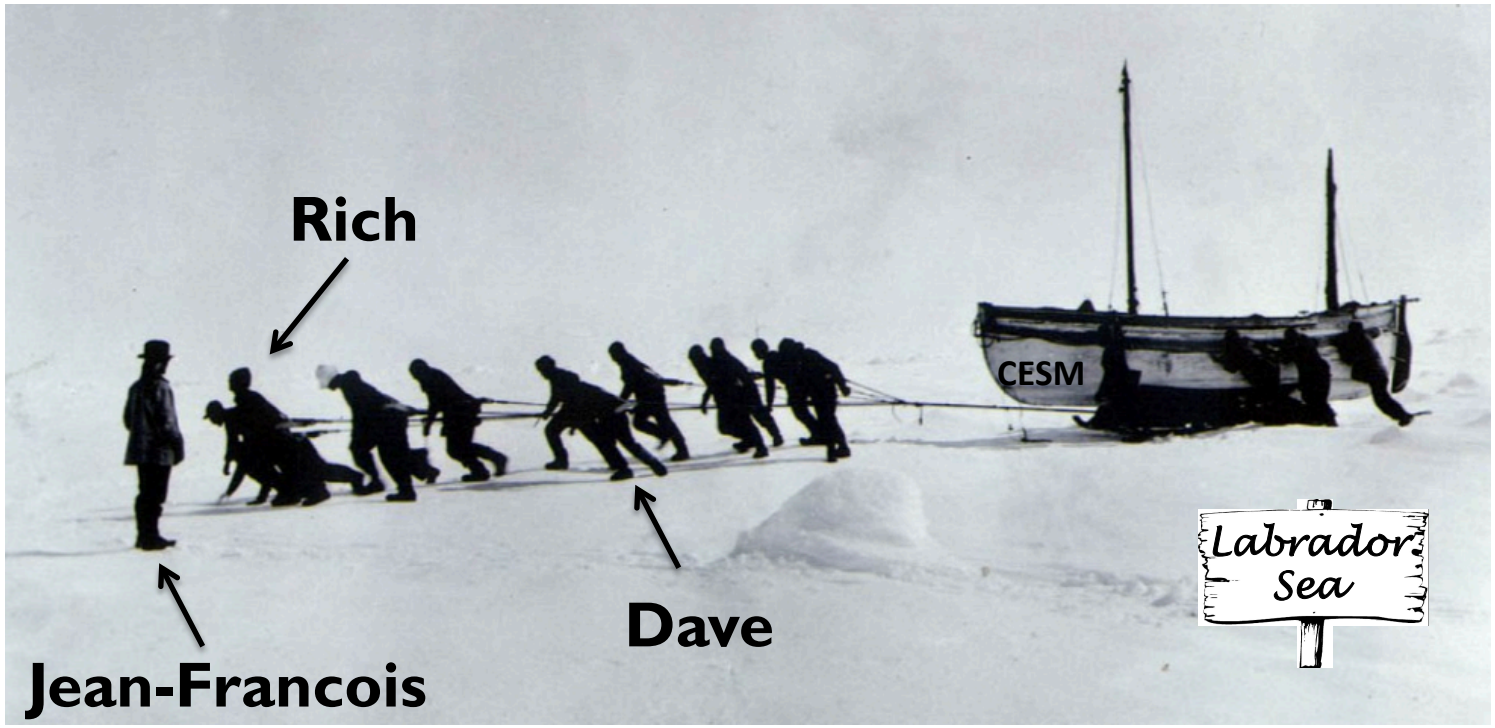




CESM2_dev: Too cold and too fresh South of Greenland.
Fresh water pool prevent further mixing

Solving the Labrador Sea problem

After Breckenridge, multiple attempts to solve the issue



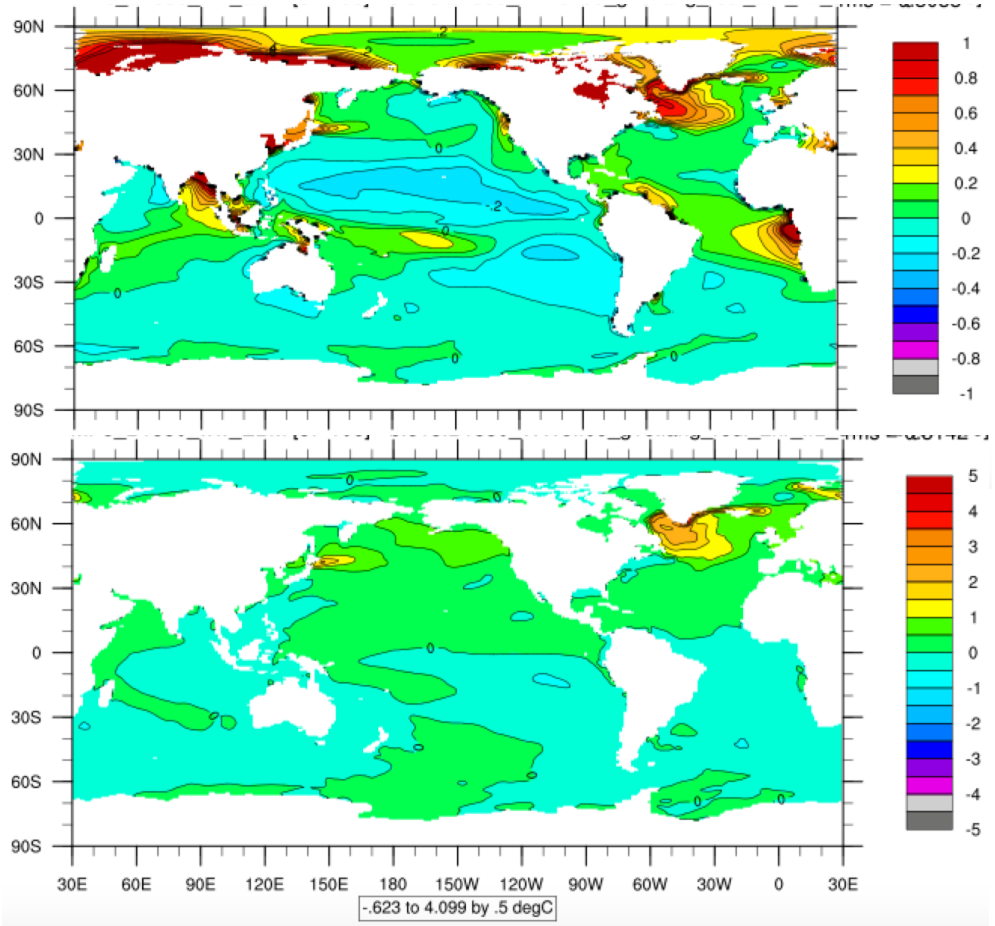
We found out it is a very robust feature in CESM2_dev

Estuary Box Model to the rescue!

Sea surface salinity

Sea surface temperature

EBM – CONTROL (COUPLED)



=> Increased salinity and SST prevent Labrador sea freezing

Courtesy: Gokhan Danabasoglu

What happened since Breckenridge ?

It was not only fixing the Labrador Sea

CMIP6 emission

Nitrogen cycle

crop

Caspian Sea

Robert Filter

CESM2

CLUBB bugfix

Tuning

GW tuning

1 hour coupling

Climate sensitivity

Angular momentum

Greenland precipitation

Volcanos

Quick glance at two CESM milestones

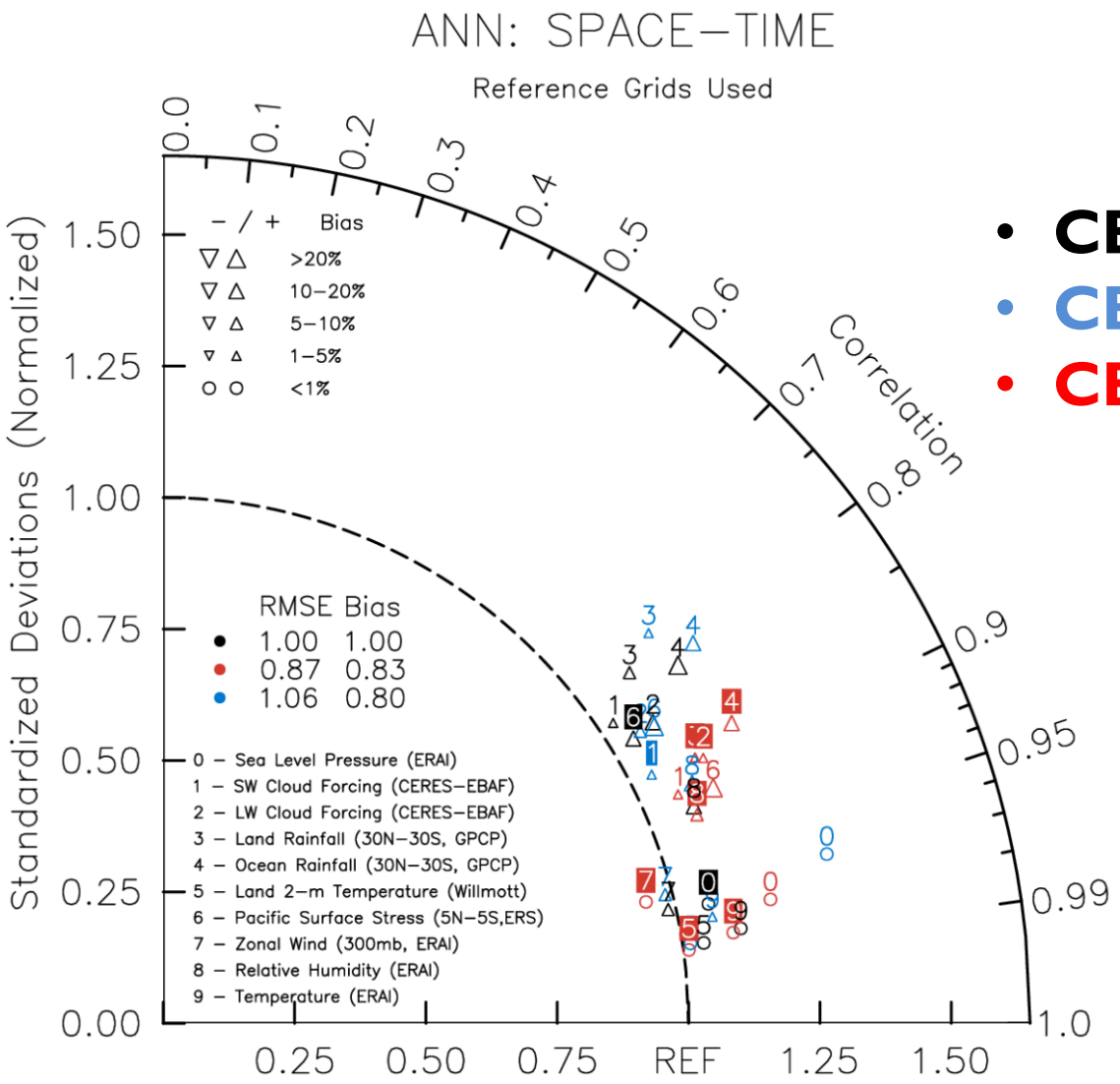
CESM1

"LENS"

CESM2

"125"

Taylor Diagram

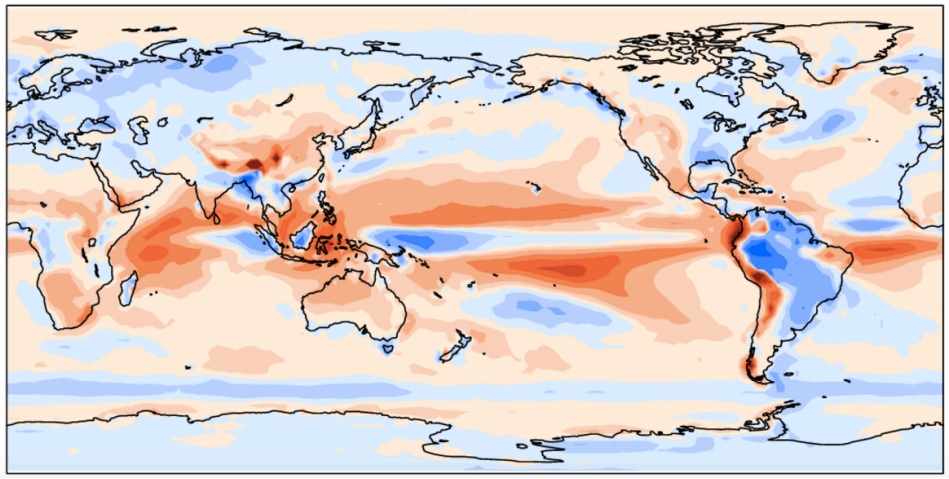


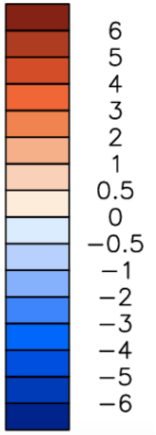
	RMSE	Bias
• CESM1	1.00	1.00
• CESM1.5	1.06	0.80
• CESM2	0.87	0.83

Taylor score was degraded in CESM1.5
CESM2 is better than LENS

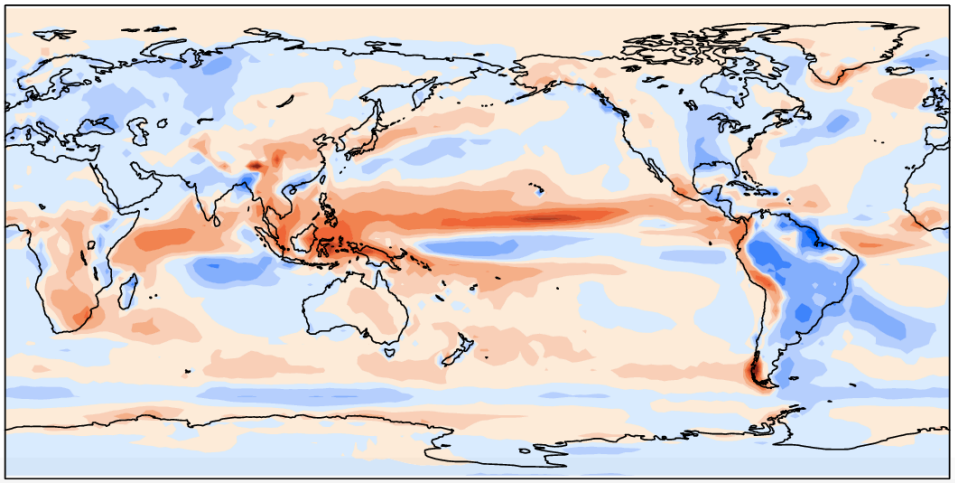
Precipitation bias versus GPCP (ANN)

CESM1
Bias = 0.37
RMSE = 1.13
(mm/day)





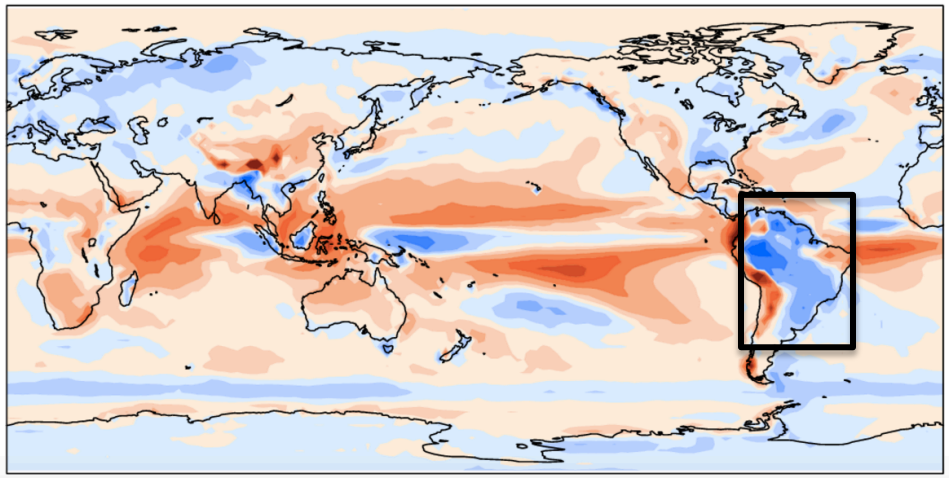
CESM2
Bias = 0.18
RMSE = 0.89
(mm/day)

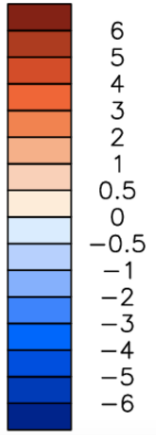


Improved RMSE

Precipitation bias versus GPCP (ANN)

CESM1
Bias = 0.37
RMSE = 1.13
(mm/day)





CESM2
Bias = 0.18
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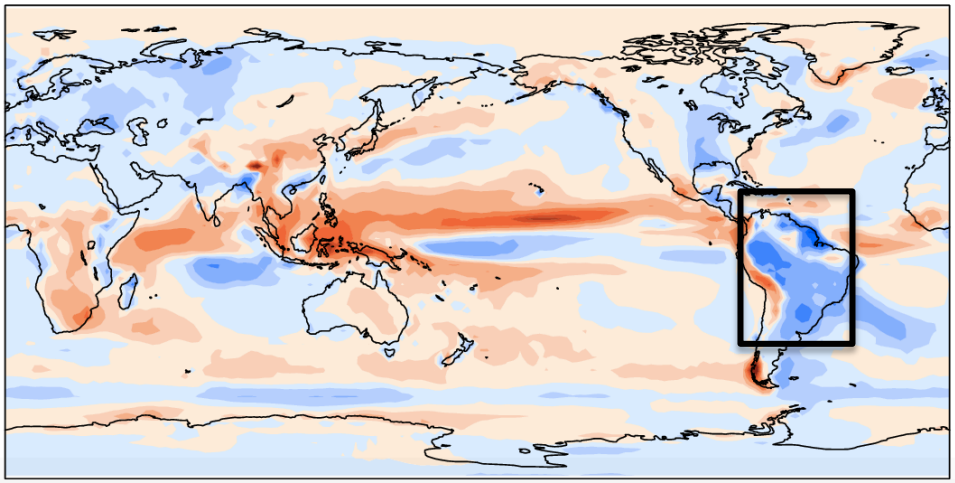
(mm/day)

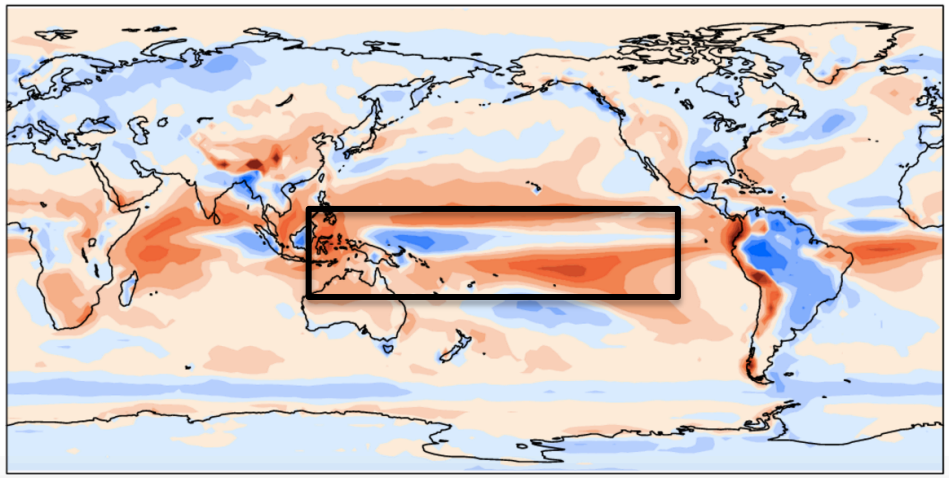


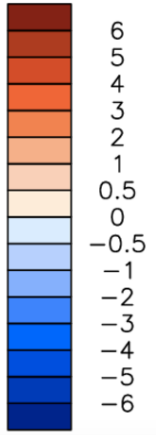
Improved RMSE

Better Amazon precip

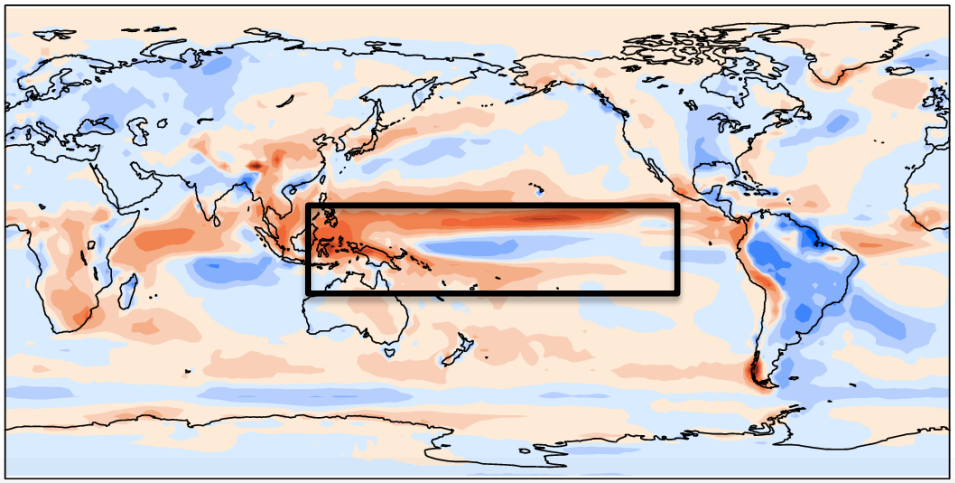
Precipitation bias versus GPCP (ANN)

CESM1
Bias = 0.37
RMSE = 1.13
(mm/day)





CESM2
Bias = 0.18
RMSE = 0.89
(mm/day)



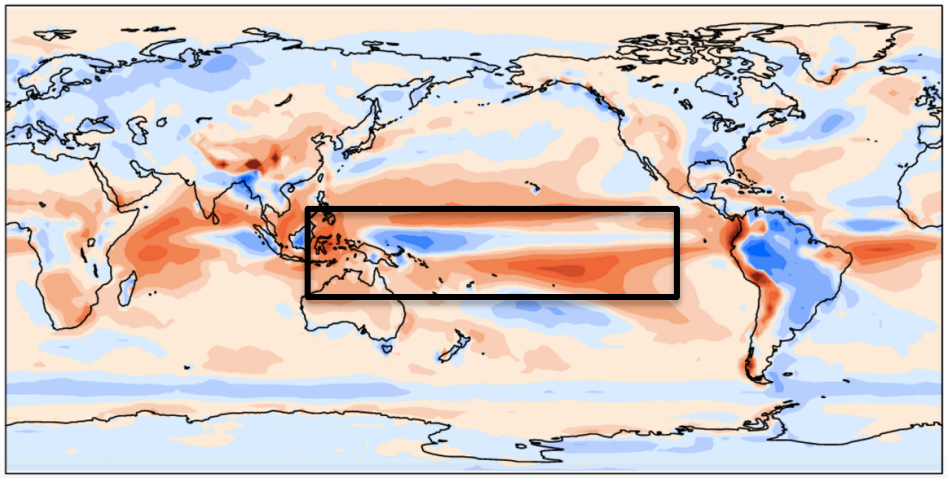
Improved RMSE

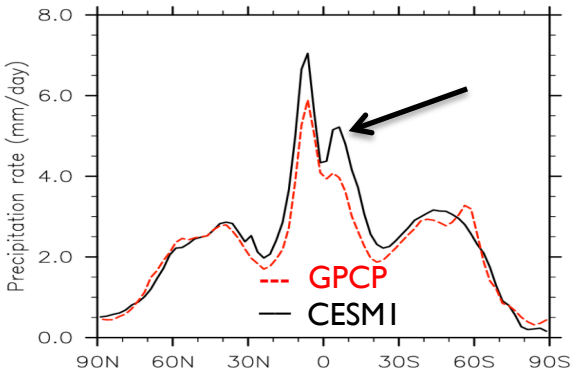
Better Amazon precip

Improved tropical precip

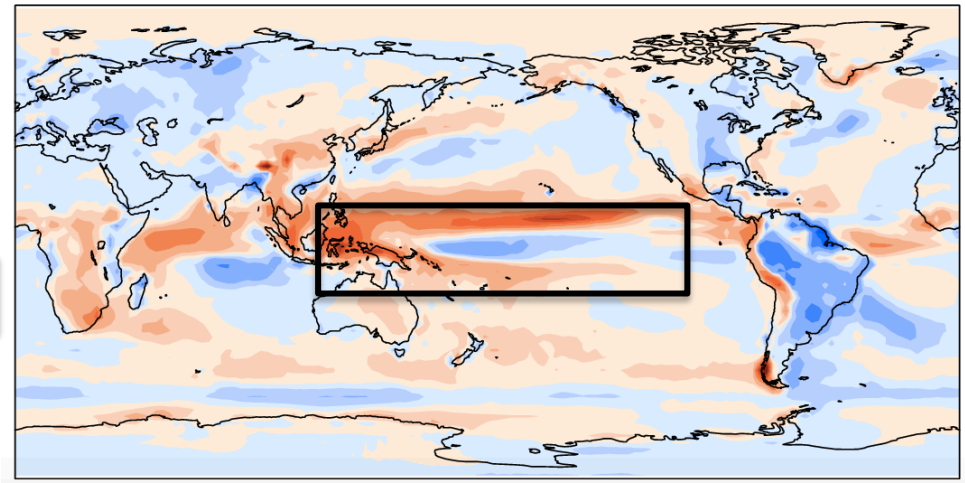
Precipitation bias versus GPCP (ANN)

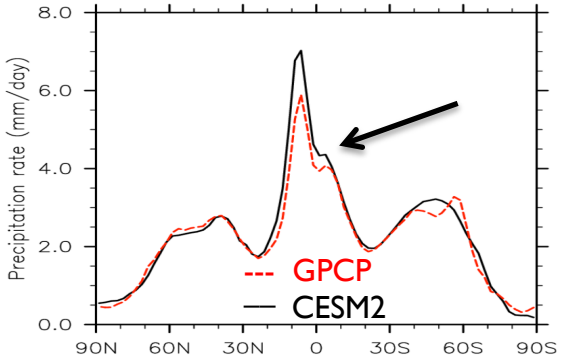
CESM1
Bias = 0.37
RMSE = 1.13
(mm/day)



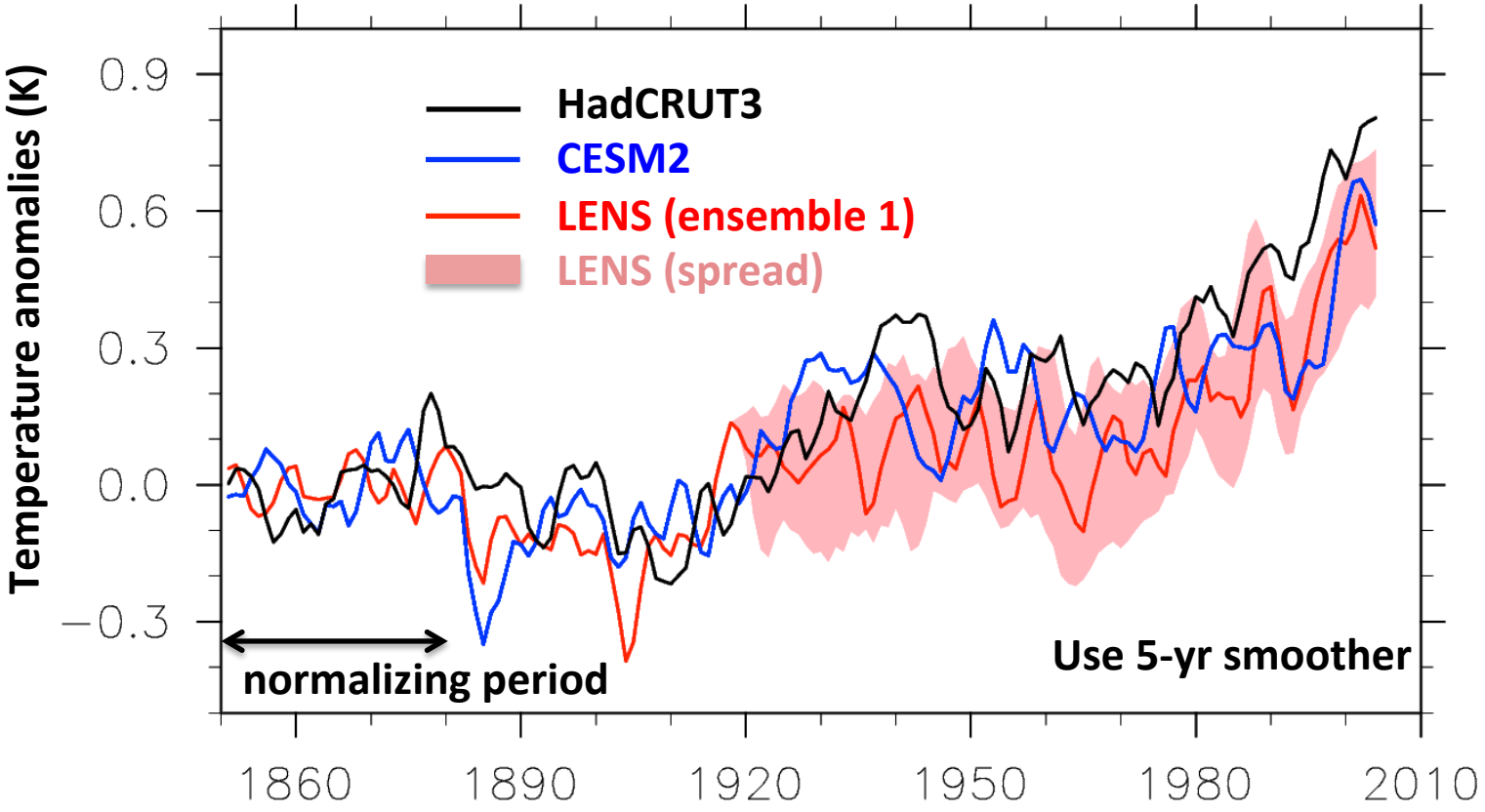


CESM2
Bias = 0.18
RMSE = 0.89
(mm/day)





20th century warming



	Climate Sensitivity (K)	Aerosol Indirect Effect (W/m2)
LENS	3.9	-1.4
CESM2	4.2	-1.6

It has been a long road to CESM2

Are we there yet ? Yes, we are

Rich Neale	AMWG co-chair
Julio Bacmeister	AMWG co-chair
Cecile Hannay	AMWG liaison
Pete Bogenschutz	CLUBB developer
Andrew Gettelman	WACCM co-chair
Mike Mills	WACCM liaison
Simone Tilmes	Chemistry Liaison
David Bailey	Sea-ice liaison
Marika Holland	Sea-ice expert
Gokhan Danabasoglu	Ocean co-chair
Keith Lindsay	Biogeochemistry co-chair
Mariana Vertenstein	SEWG co-chair
Jim Edwards	CSEG software engineer
David Lawrence	Land co-chair
Keith Oleson	Land liaison
Bill Sacks	Land ice
Joe Tribbia	AMP spy
John Truesdale	Ocean Liaison
and gazillions of others.	The forgotten men

This has been 15 months of intense work

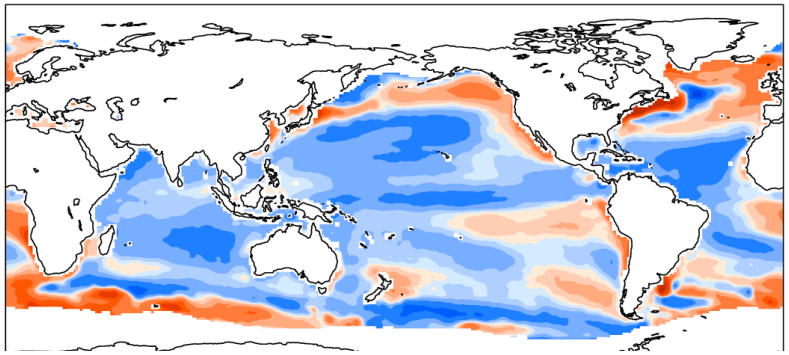
We had good days

We had bad days

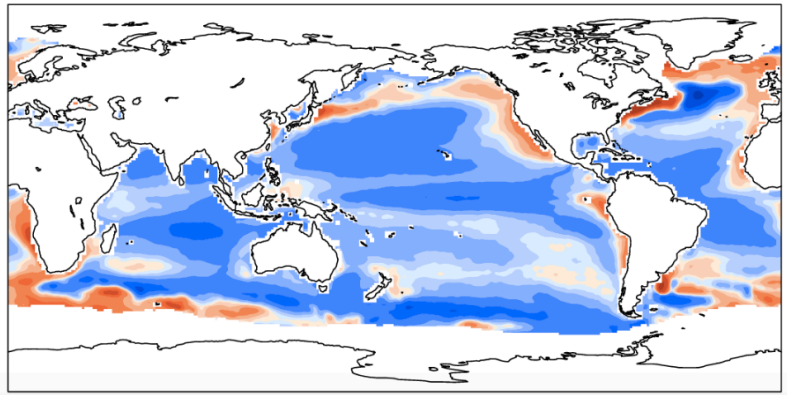
We always found the cause of our problems

Sea Surface Temperature (SST) bias (ANN)

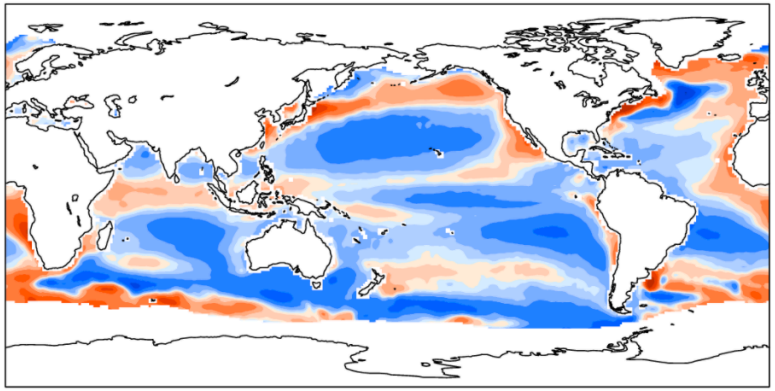
LENS
Bias = -0.24K
RMSE = 0.91

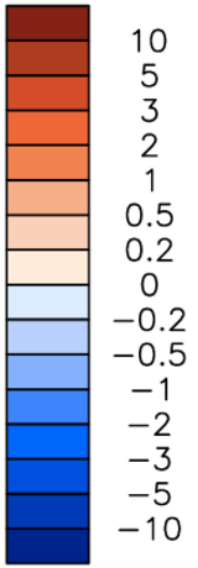


CESM1.5
Bias = -0.62K
RMSE = 1.12



CESM2
Bias = -0.32K
RMSE = 0.98





RMSE improves in CESM2 compared to CESM1.5 but not as good as in LENS

Beyond 125

Changes for final version:

- **Subgrid-scale topography representation around Greenland (different scale due to very strong winds)**
- **Caspian sea: from ocean model to land model (lake)**
- **Update to land vegetation parameters (little climate impact, mostly for carbon-cycle improvements)**
- **Crop improvement**
- **CMIP6 emissions**
- **Robert Filter**
- **1 hour coupling atm ⇔ ocn**
- **Ocean initial conditions from LENS**
- **Dust tuning**
- **Ocean biogeochemisty**

CESM 2 development simulations

Are you lost in translation ?

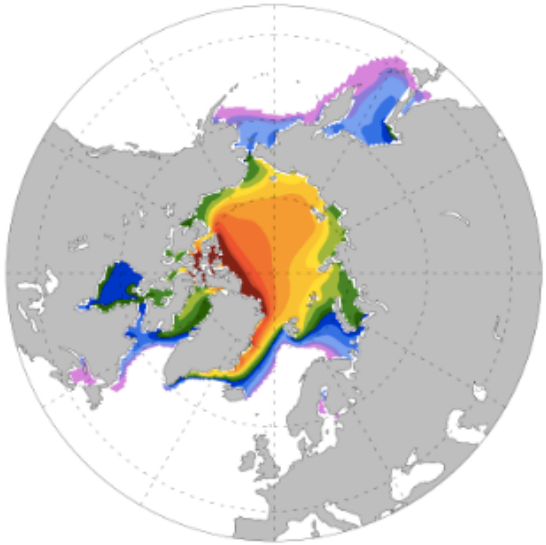
Simplified terminology for this talk

CESM1	Large Ensemble (2013)	LENS
CESM1.5	Winter Working Group (Feb 2016)	28 or 36
CESM2_dev	Breckenridge (June 2016)	63, 64, 66, 79
CESM2	Winter Working Group (Feb 2017)	125

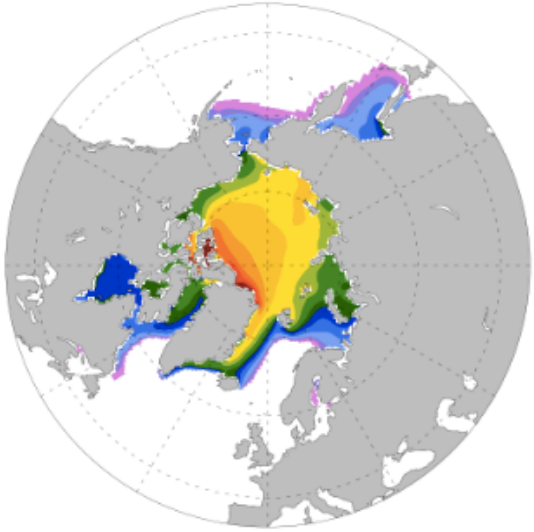
Caveat: 125 is not the "final" version of CESM2 but no major change in climate.

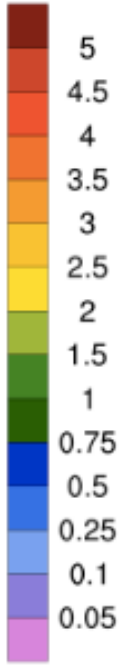
Sea ice thickness (ANN)

LENS (yrs 475-499)

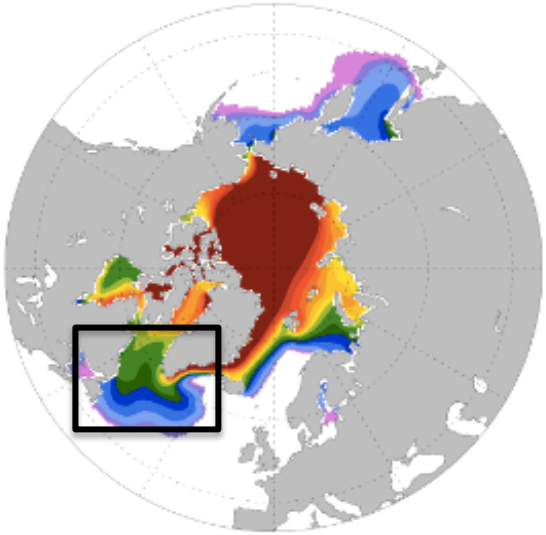


Mini-Breck (yrs 75-99)





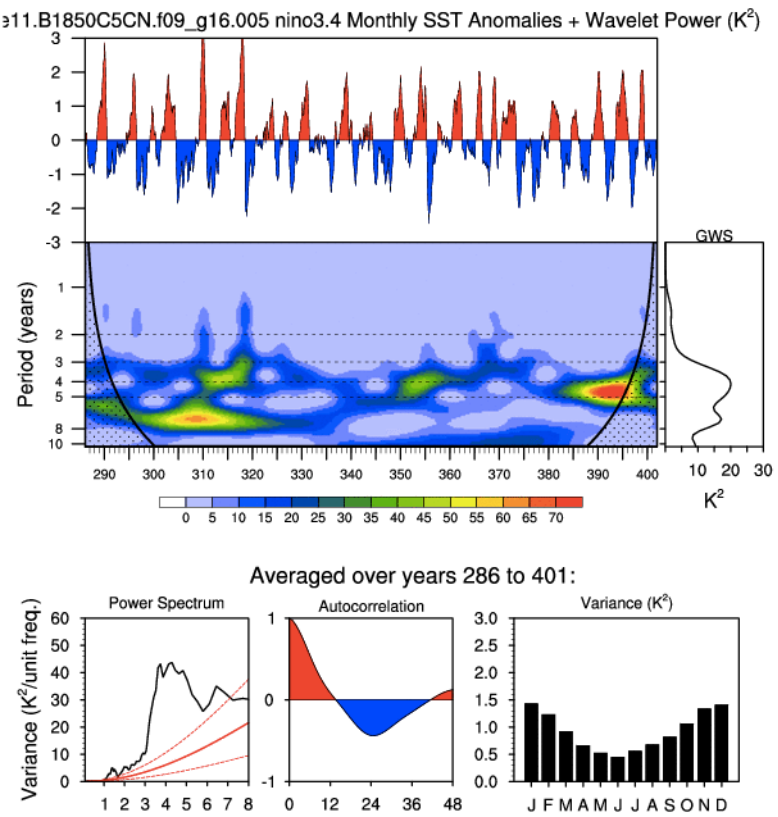
Now (yrs 72-91)

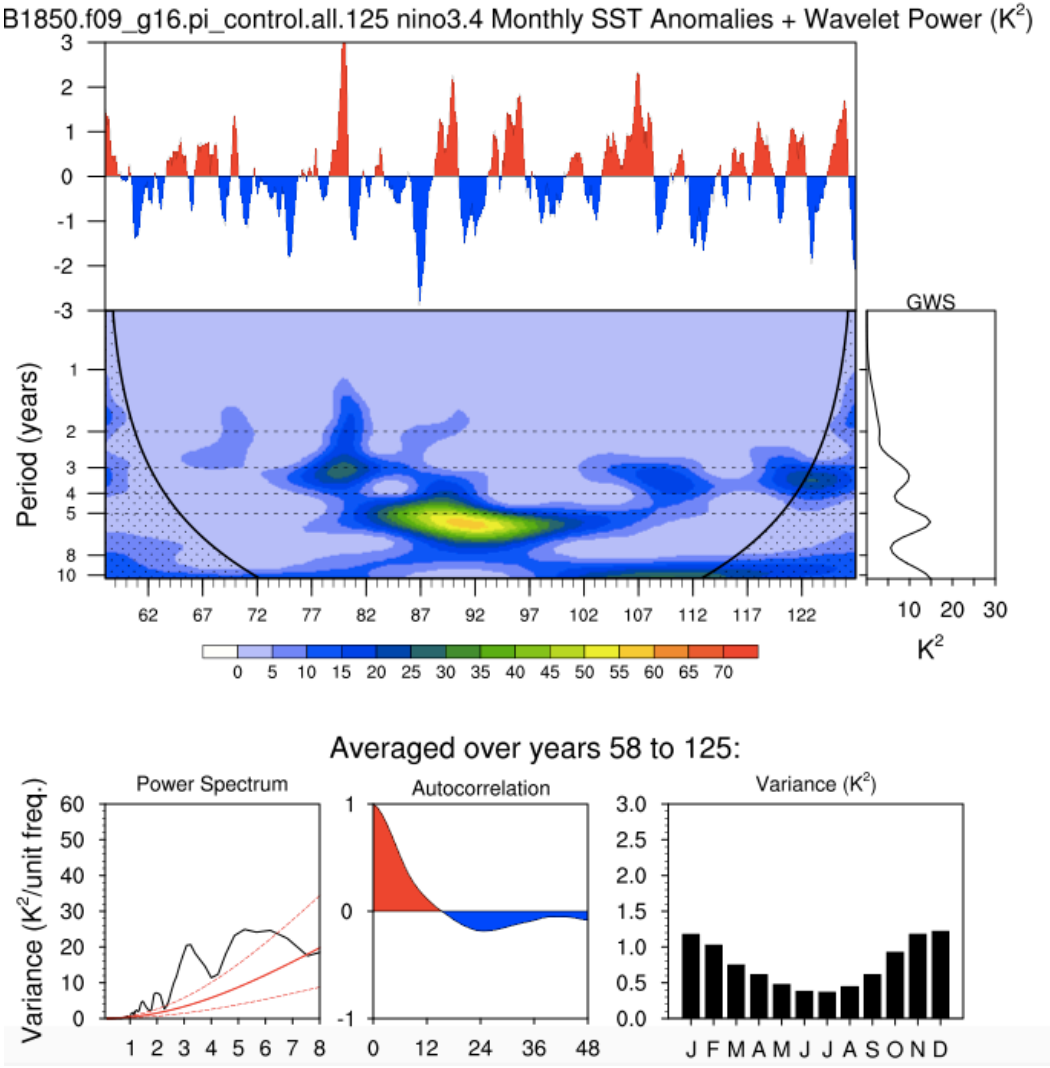


Sea-ice thicker over Central Arctic

Ice-covered Labrador sea

Nino3.4


e11.B1850C5CN.f09_g16.005 nino3.4 Monthly SST Anomalies + Wavelet Power (K²)
Period (years)
GWS
K²
Averaged over years 286 to 401:
Power Spectrum
Autocorrelation
Variance (K²)
Variance (K²/unit freq.)
J F M A M J J A S O N D


B1850.f09_g16.pi_control.all.125 nino3.4 Monthly SST Anomalies + Wavelet Power (K²)
Period (years)
GWS
K²
Averaged over years 58 to 125:
Power Spectrum
Autocorrelation
Variance (K²)
Variance (K²/unit freq.)
J F M A M J J A S O N D

AMWG homework

Following mini-Breck, we identified biases to be targeted

- **Taylor score lower than in LENS**
- **Cold SSTs** => Adjust tuning to reduce SWCF
- **Underestimated Amazon precipitation** => ZM changes
- **Insufficient Tropical Sub-Seasonal Variability** => ZM changes
- **Weak Surface winds** => Beljaars and ridge scheme (TMS off)
- **Strong indirect effects** => New autoconversion
- **Excessive humidity (RHliq > 105%)** => Fix in CLUBB
- **Poor polar stratospheric clouds** => New ice microphysics

How did we do on our homework ?

How did we do on our homework ?

Following mini-Breck, we identified biases to be targeted

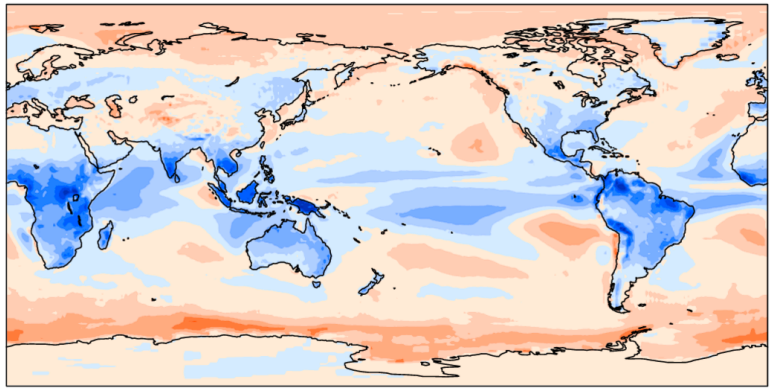
- Taylor score lower than in LENS => Improved
- Cold SSTs => Not improved (degraded Labrador sea)
- Underestimated Amazon precipitation => Improved
- Insufficient Tropical Sub-Seasonal Variability => Improved
- Weak Surface winds => Improved
- Strong indirect effects => Improved
- Excessive humidity (RHliq > 105%) in CLUBB => Improved
- Poor representation of polar stratospheric clouds => Improved

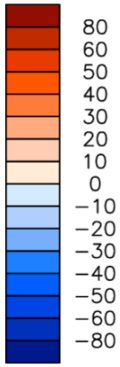
Remaining issues in current simulations

- Ice too thick over central Arctic and ice-covered labrador sea

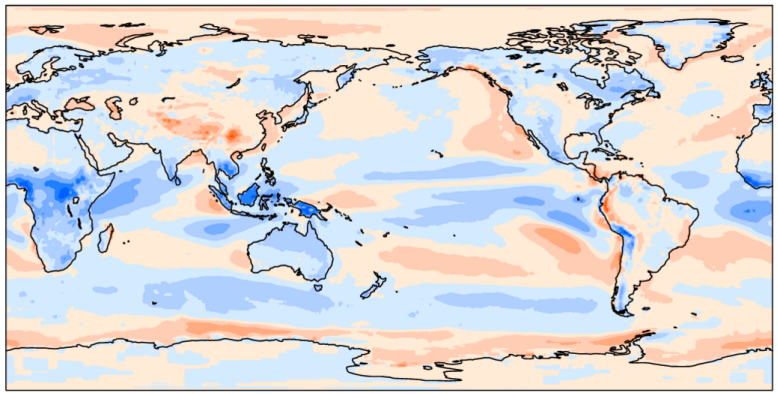
SWCF bias versus CERES-EBAF (ANN)

LENS
Bias = -1.18
RMSE = 13.7
(W/m2)



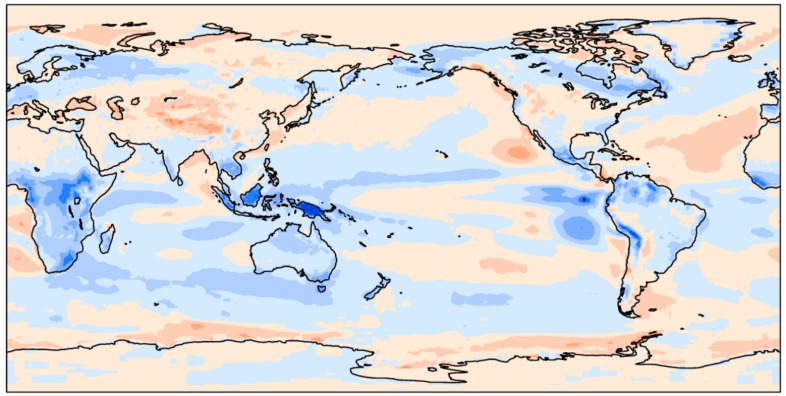


CESM1.5
Bias = -0.98
RMSE = 10.9
(W/m2)



CESM1.5: improved SWCF

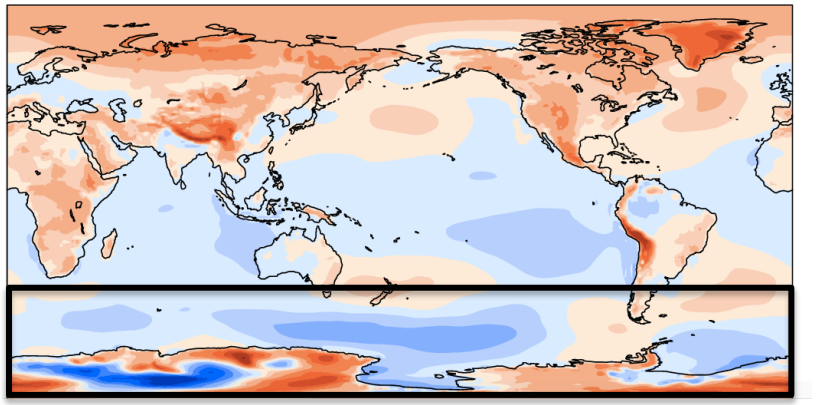
CESM2
Bias = -1.43
RMSE = 8.97
(W/m2)



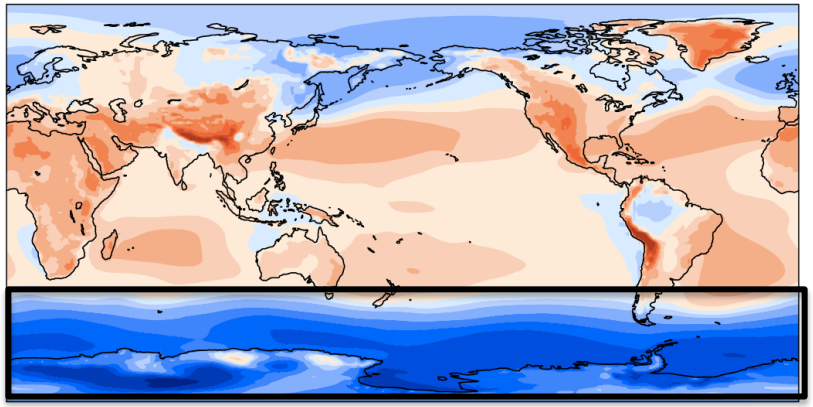
CESM2: even better

Sea-level pressure versus MERRA (ANN)

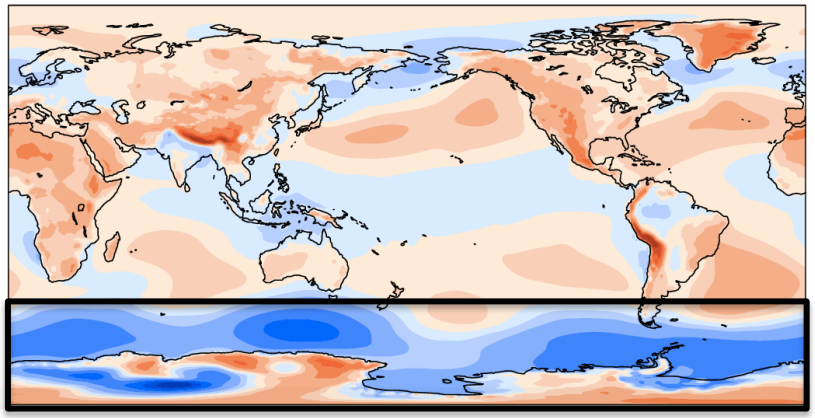
LENS
Bias = 0.29
RMSE = 1.61
(mbar)

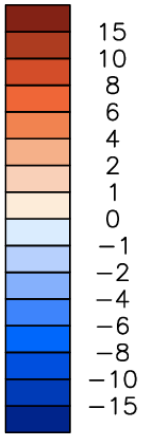


CESM1.5
Bias = 0.09
RMSE = 3.02
(mbar)



CESM2
Bias = 0.29
RMSE = 1.86
(mbar)





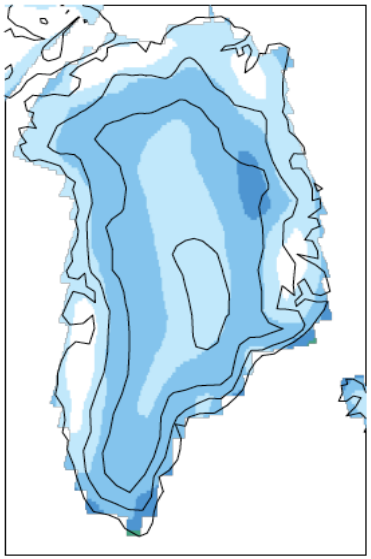
Improved SLP in Southern Ocean

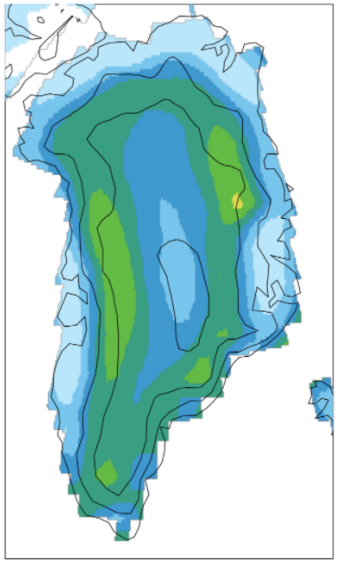
RMSE improves in CESM2 compared to CESM1.5 but not as good as in LENS

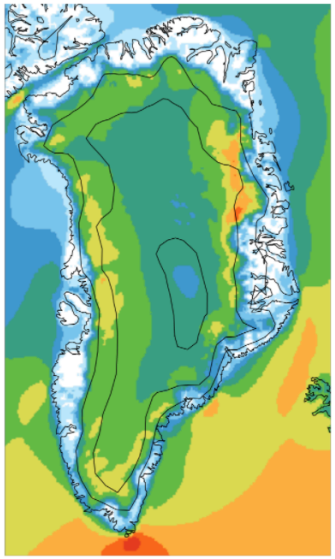
Greenland and Antarctica surface winds

CESM1.5 CESM2 Obs (RACMO2.3)

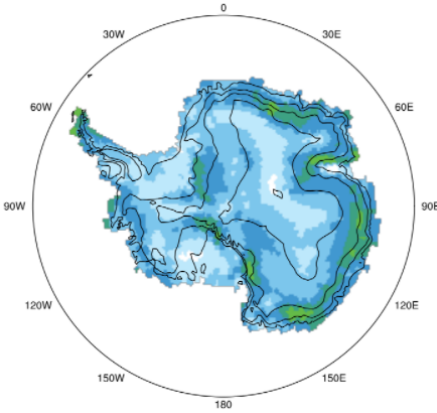
Greenland

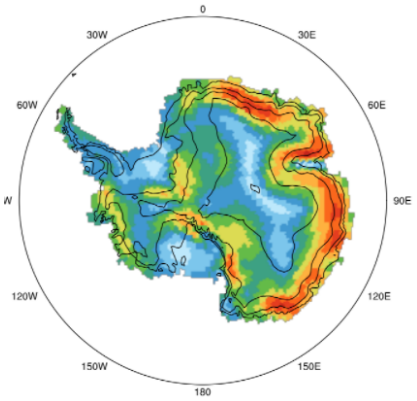


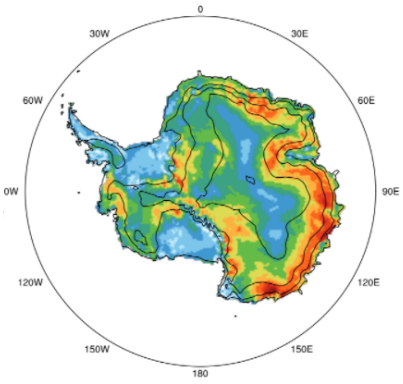




Antarctica







Courtesy Lenaerts