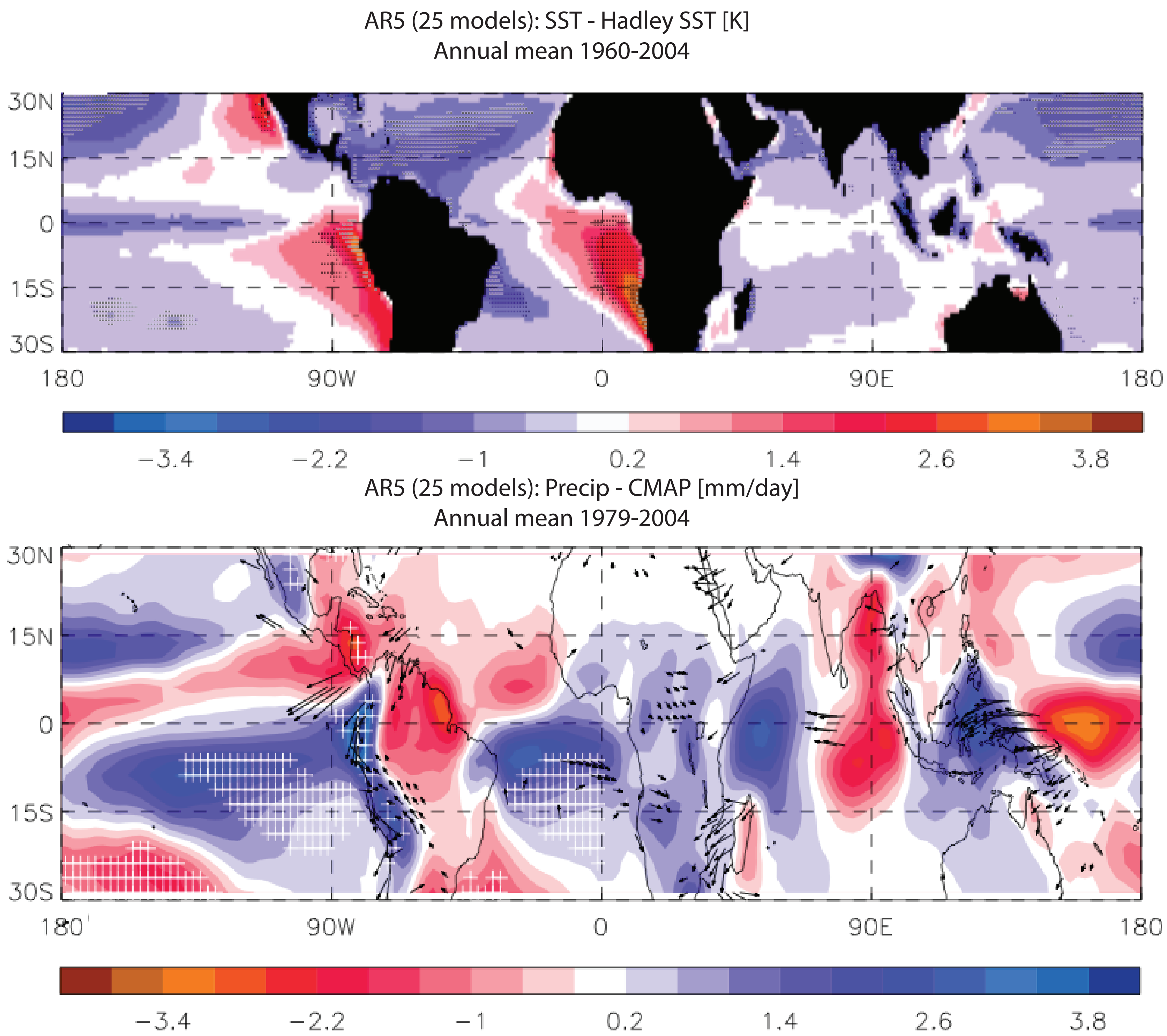
Challenges and Future Prospects for Reducing Coupled Climate Model SST Biases in the Eastern Tropical Atlantic and Pacific Oceans

US CLIVAR Eastern Tropical Oceans Synthesis Working Group

Coupled models typically possess a climate with too-warm sea surface temperatures (SSTs) in the eastern Atlantic and Pacific basins, and too symmetric a climate about the equator. The US CLIVAR Working Group on Eastern Tropical Ocean Synthesis provides herein its assessment of the current state of knowledge about the SST biases, with the aim of identifying promising areas for future work.



adapted from Toniazzo and Woolnough, 2014

Most of this presentation based on a white paper currently under preparation

Main Contributors:

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History:

- Working Group established under US CLIVAR in 2012, following up on two independent but related activities
- Workshop in March 2011 on tropical Atlantic SST biases @ U of Miami recommending a continuing working group
- Emerging hypotheses on importance of oceanic eddy-mixing processes to SST cooling in the southeast Pacific

WG Objectives

- Promote collaboration between observationalists and modelers, atmospheric scientists and oceanographers, actively researching the southeast oceanic basins.
- Coordinate a model assessment of surface flux errors for the equatorial Atlantic, mining all available observations.
- Identify recent model improvements and common and persistent model errors in both CMIP5 and higher-resolution coupled models.
- Provide recommendations of cases for community simulation and evaluation using eddy-permitting ocean models, sharing specified model conditions and output datasets.

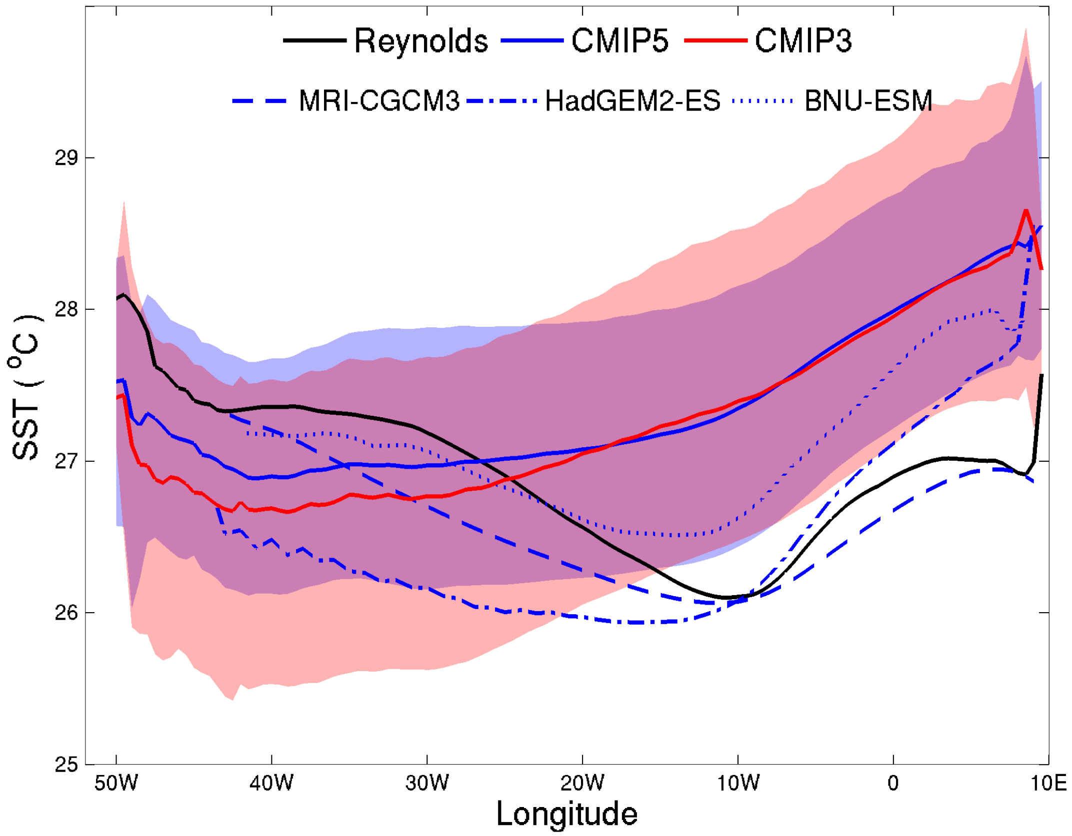
WG Activities

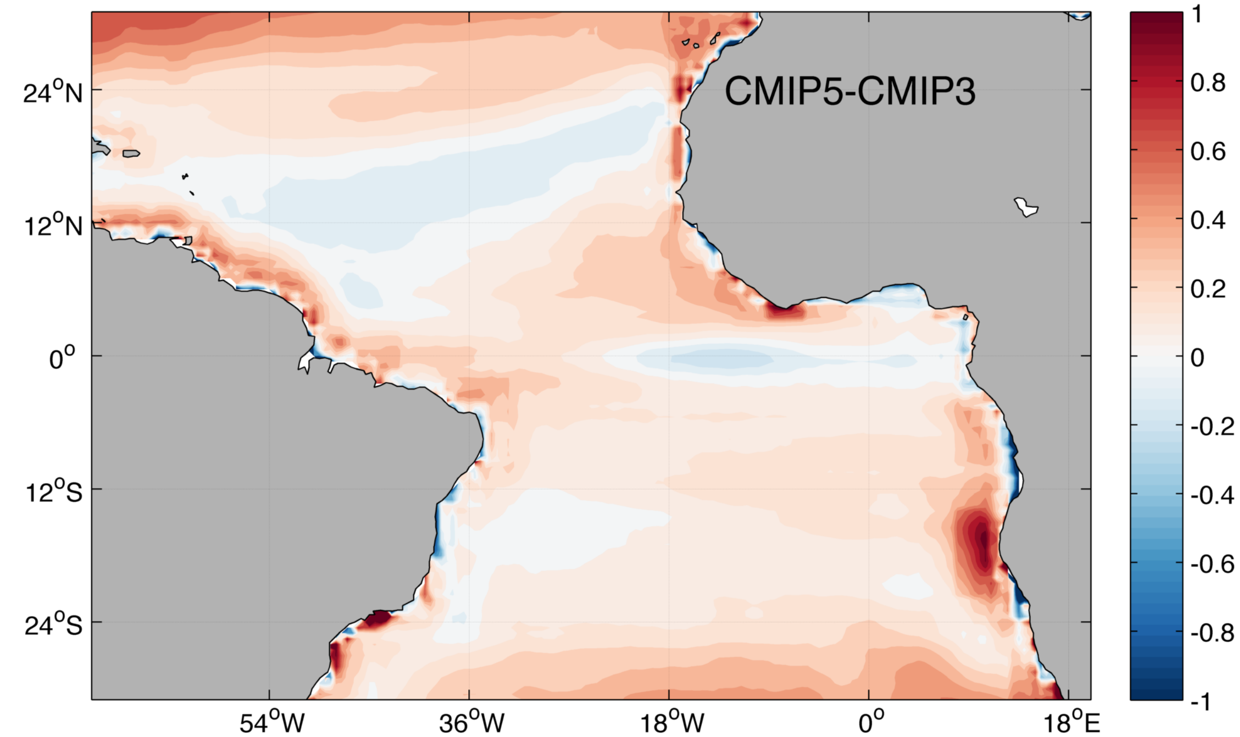
telecons, AGU fall 2012 session + appended meeting
Google site &US CLIVAR site for collecting materials

smaller meeting spring 2014 in Miami
culminating in a US CLIVAR white paper currently being finalized, with plans for a journal article

Summary

•The most pronounced SST model biases occur in the southeast Atlantic, with the connection to the equatorial biases not yet well well-understood.
•The processes responsible for cooler eastern basin sea surface temperatures differ between the Pacific and Atlantic, with oceanic processes appearing to be more important for the southeast Atlantic.
• Remote bias experiments suggest the southeast Atlantic SST biases deliver a larger global impact than those of the southeast Pacific.
• Hindcast experimentation indicates that the dominant processes establishing the eastern basin SST biases are model-dependent.
• The importance of oceanic eddy-mixing processes to the offshore SST cooling in the southeast Pacific still lacks a robust consensus.
• The oceanic processes maintaining the southeast Atlantic SST distribution include the shallow oceanic Angola Dome thermocline at 10S and southward Angola Current meeting the northward Benguela Current at the Angola-Benguela Front at 18S. These coastal features affect offshore SSTs through low-level atmospheric temperature and moisture advection, with the contribution to cooling by oceanic eddies unknown.
• The southern hemisphere stratocumulus decks' cloud fraction remains underestimated in most CMIP5 models, and even the decks' seasonal cloudiness cycle is inadequately captured by many models.
• The stratocumulus decks' cloud fractions are underestimated even when the SST field is unbiased, implicating the atmospheric model component as the origin of the cloud error.
• The gridded surface flux datasets used to assess coupled climate models can themselves overestimate the leading term - the amount of shortwave radiation entering the ocean - by ~ 10 W m^{-2} in the stratocumulus regions.
• Improvements in atmospheric spatial resolution improve model topography, and thereby better capture the coastal atmospheric jets and the equatorial cold tongue. For this reason, causes for coastal and offshore SST and cloud cover biases may differ.
• Fieldwork is elucidating causes for SST and cloud errors in the southeast Pacific, not yet so for the Atlantic.
• Ongoing European-funded Atlantic fieldwork is focusing on oceanic processes hypthesized to affect the SST distribution, while upcoming US-funded efforts will examine biomass-burning aerosol direct radiative effects and the low cloud response to the shortwave-absorbing aerosol.



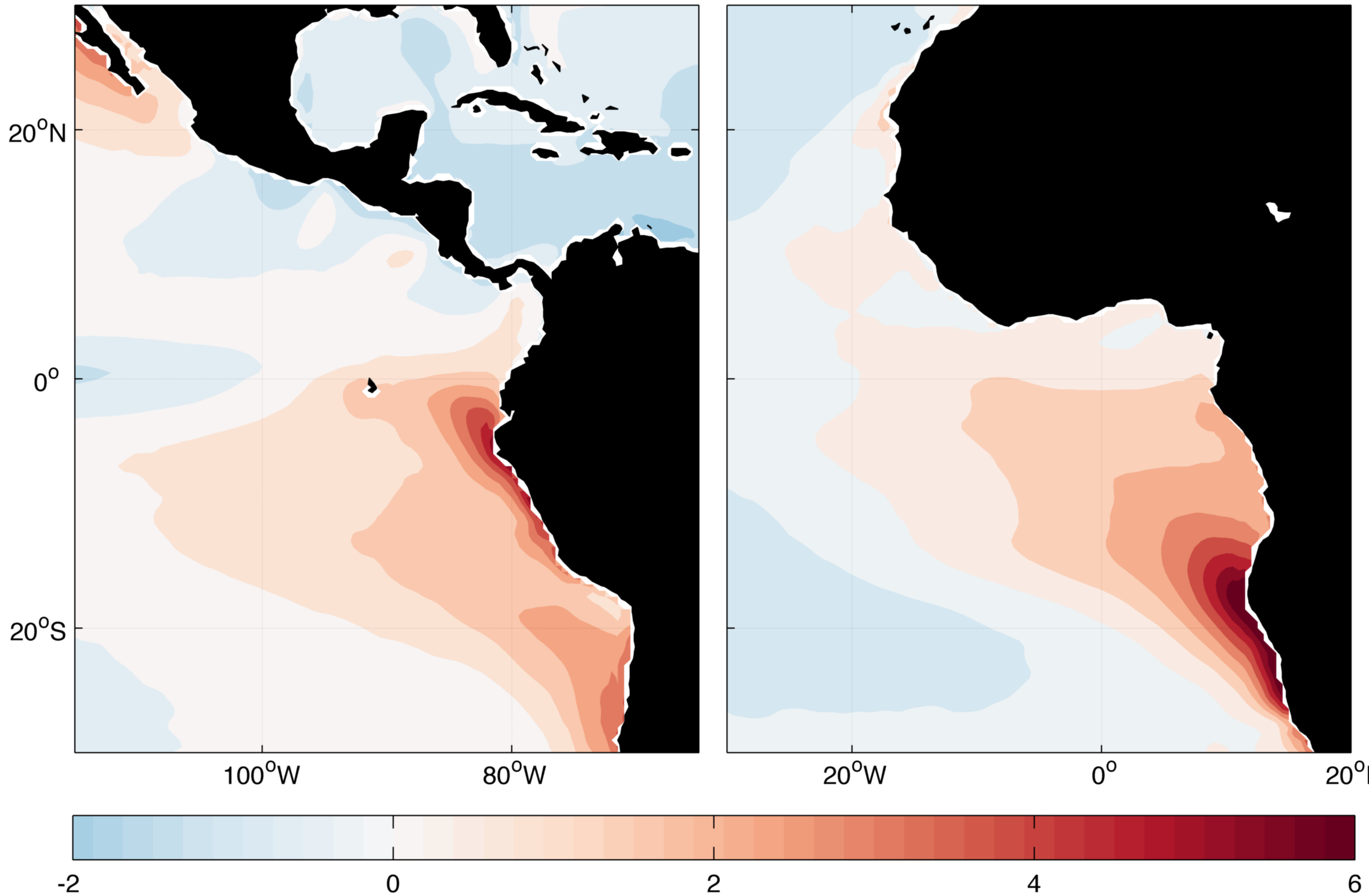


Ingo Richter

Ping Chang

Fundamental feature of Atlantic equatorial climate - warmer SSTs in west, cooler in east - not captured by almost all models

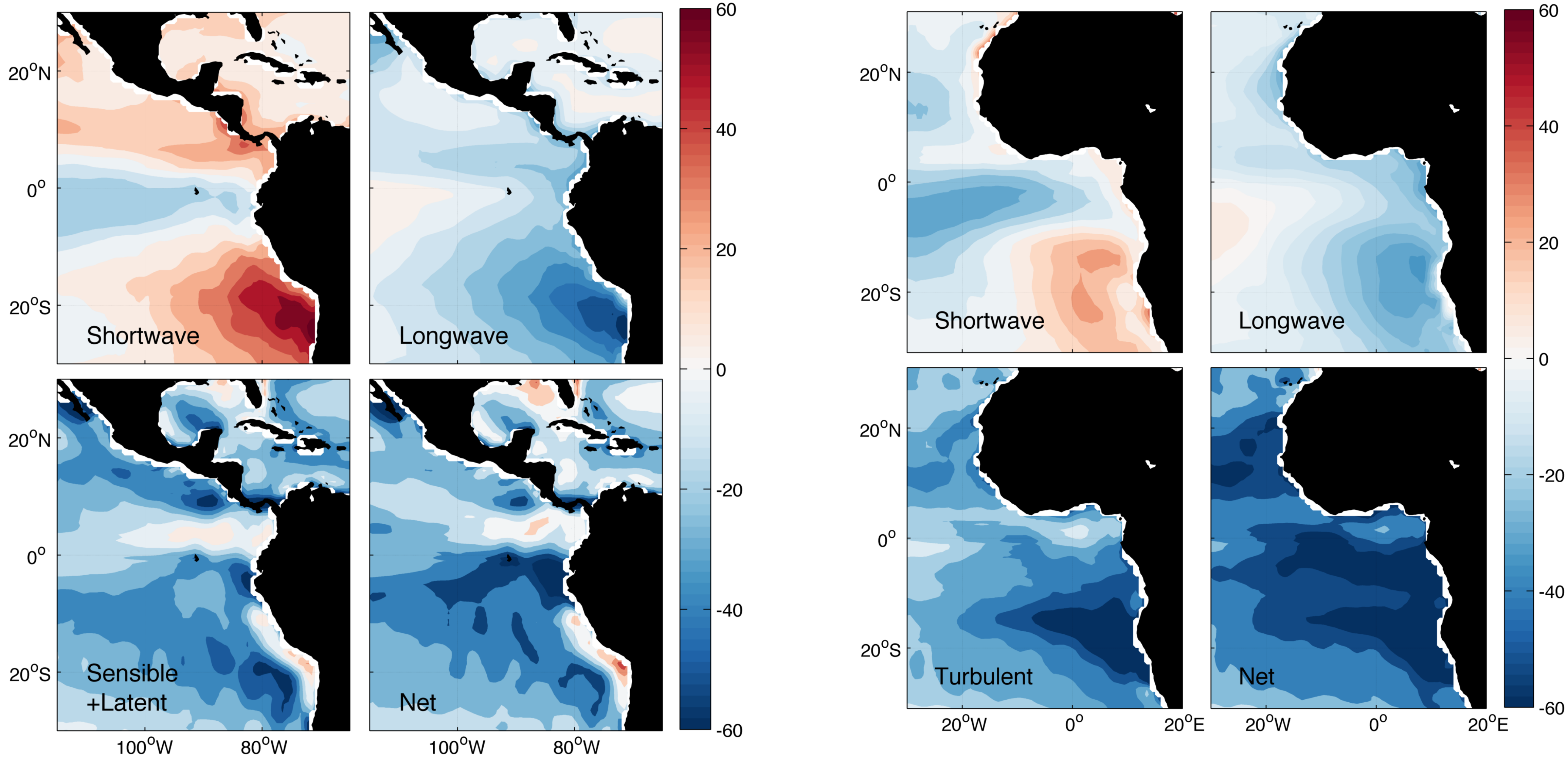
CMIP5 model-mean shows little improvement over CMIP3 model-mean



CMIP5 model-mean SST biases relative to Reynolds climatology

SST biases most pronounced in the southeast Atlantic, away from the equator

What are the sources for the bias?

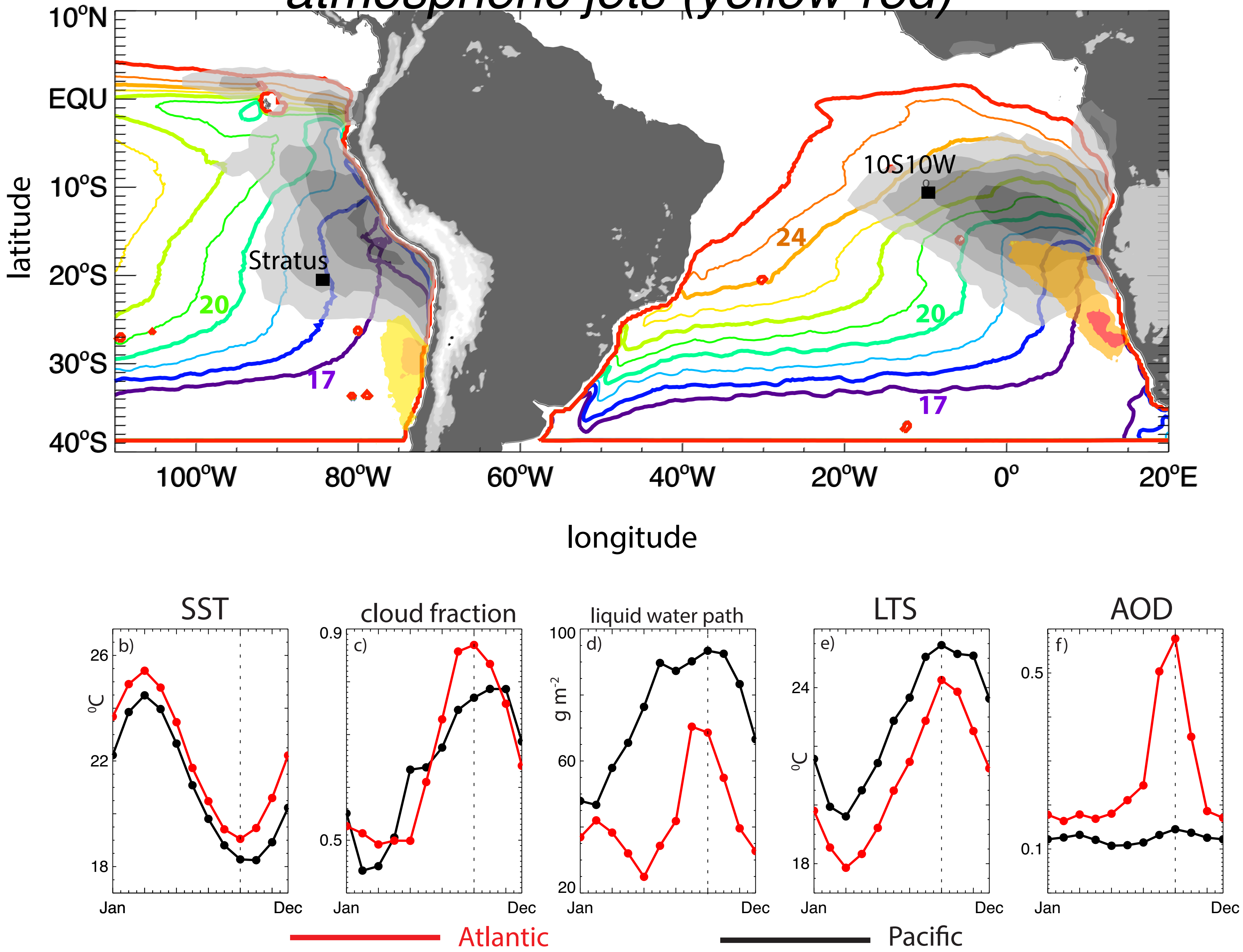


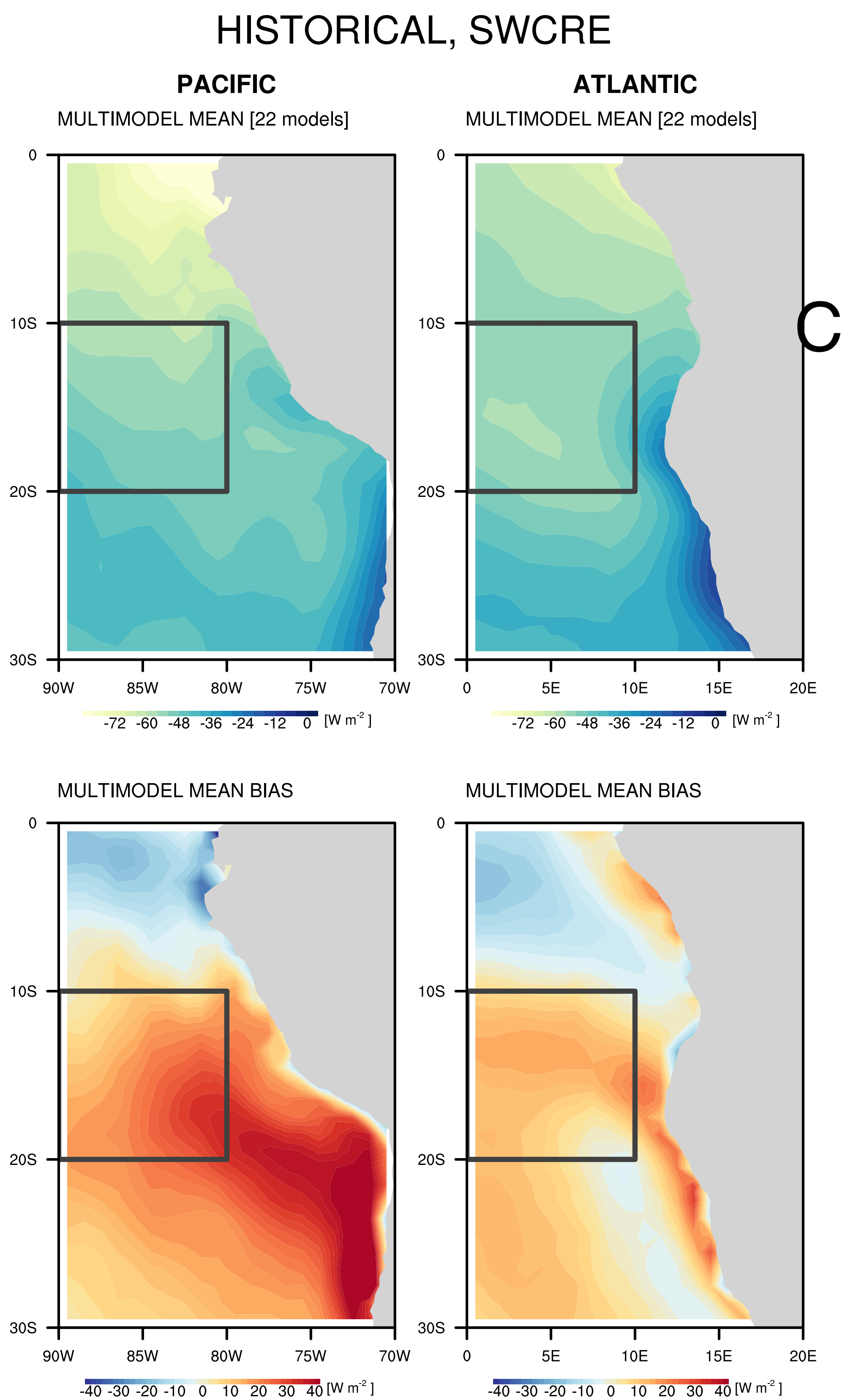
CMIP5 surface flux biases relative to OAFLUX

a breakdown by surface energy budget component reveals shortwave errors dominate in Pacific, but turbulent fluxes appear to overcompensate in Atlantic

The southern hemisphere stratocumulus cloud decks have long been implicated

September-mean cloud fraction (grey), SST (color contours), coastal atmospheric jets (yellow-red)





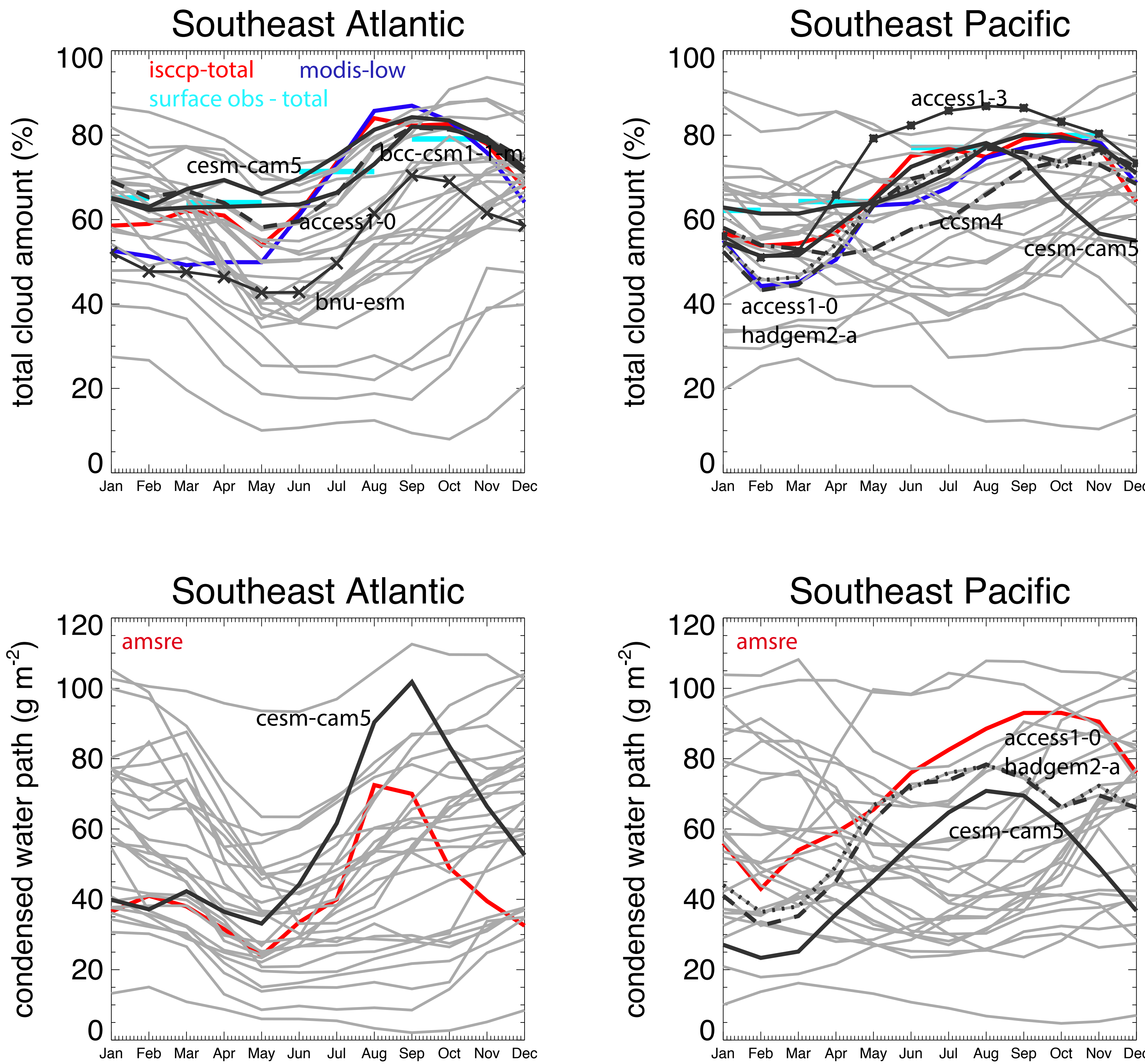
CGCMs do not typically have enough stratus

cloud radiative biases reach 40 Wm^{-2} in annual mean, particularly pronounced in Pacific

but clouds cannot (fully) explain southeast Atlantic bias

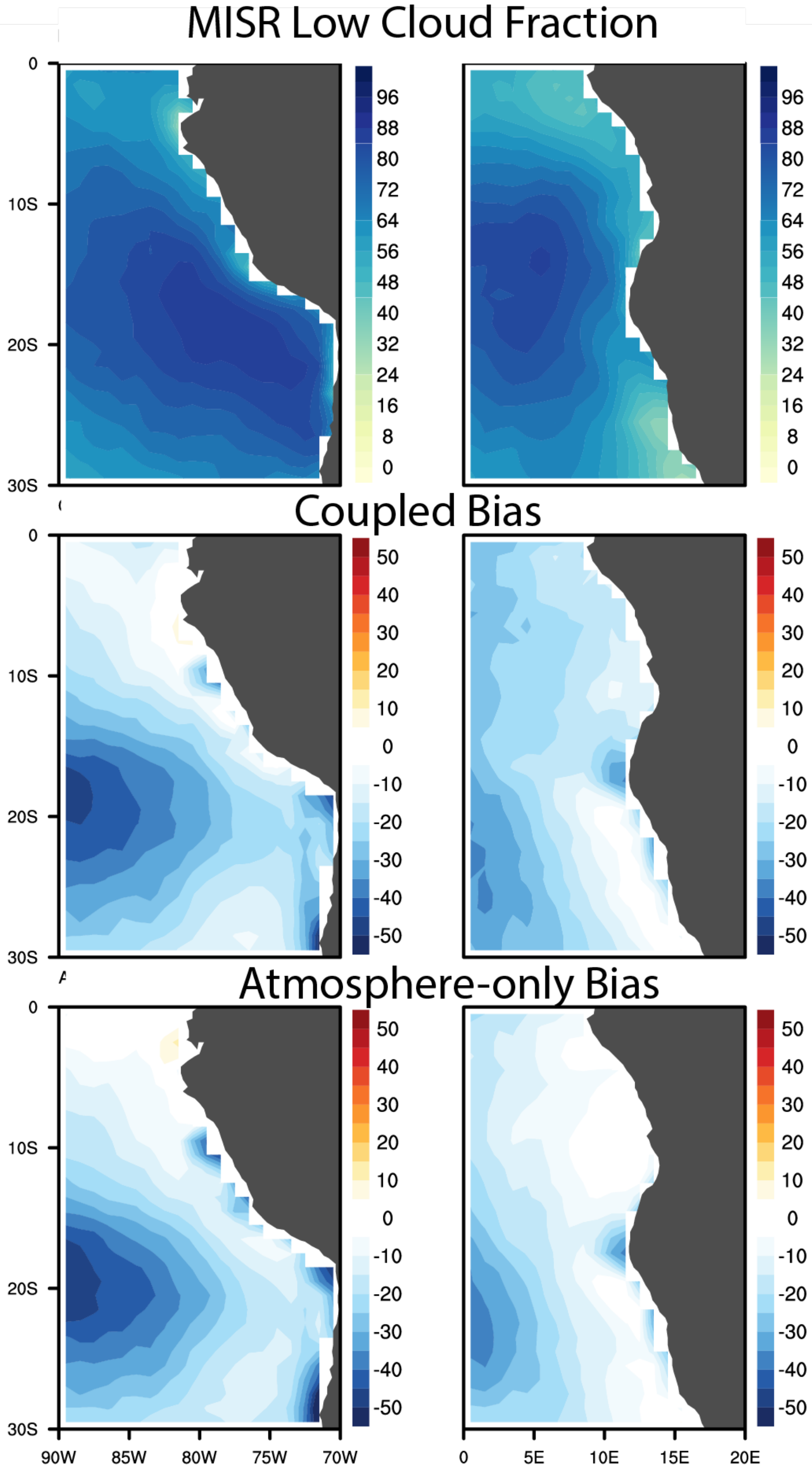
CMIP5 1950-1999, all months, net shortwave cloud radiative effect (top panels) & bias with respect to CERES EBAF (bottom panels)

Brian Medeiros



most CMIP5 models possess an unrealistic seasonal cycle in the SH stratocumulus decks

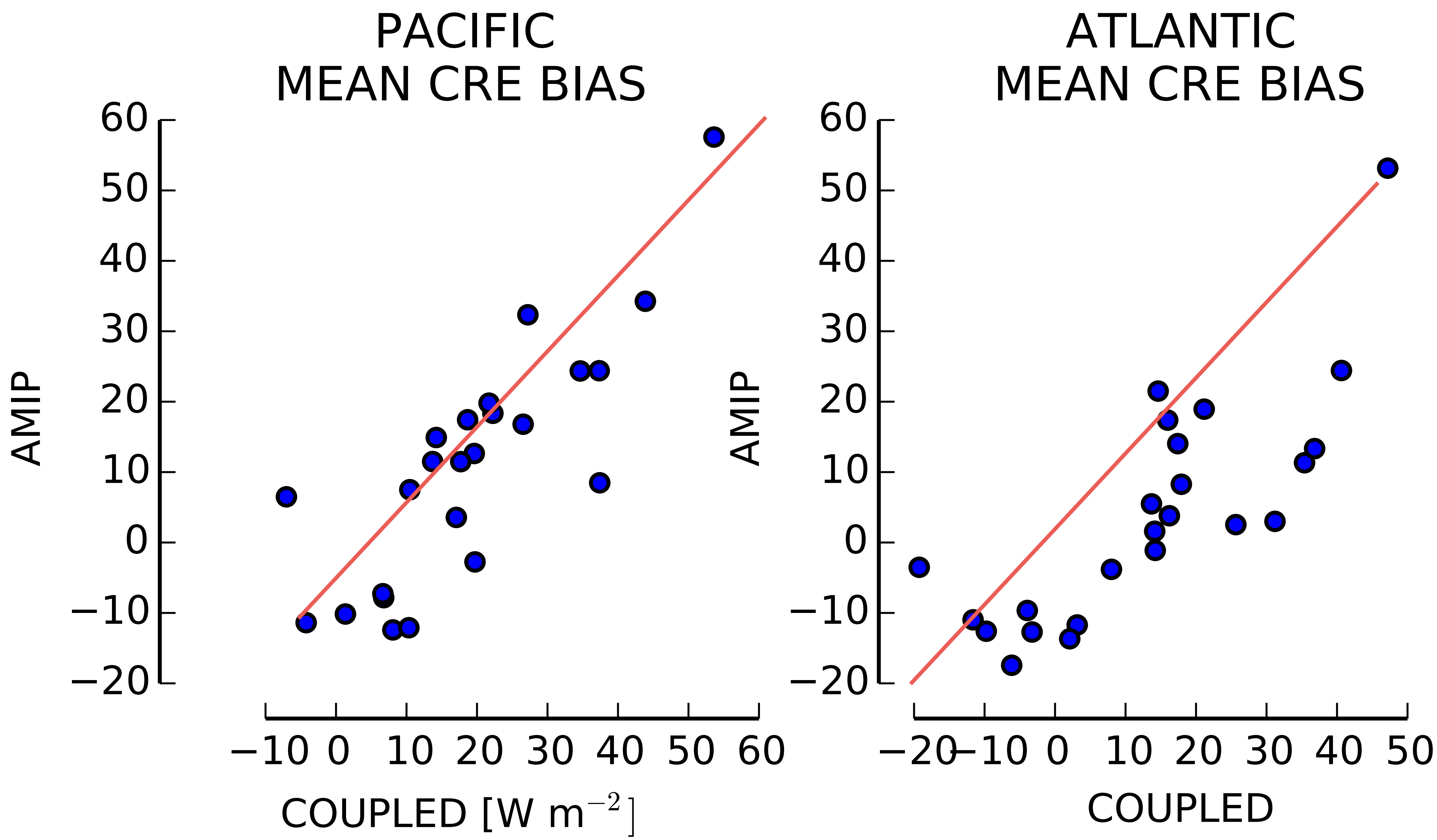
when the SSTs are specified, the cloud biases remain, suggesting a problem with the internal model representation, rather than large-scale conditions



Multiangle Imaging SpectroRadiometer (MISR) 2000-2009 Pacific and Atlantic low cloud amount (top panels), bias in CESM1/CAM5 with respect to the MISR cloud fractions when coupled to the ocean (middle panels) and atmosphere-only (panels).

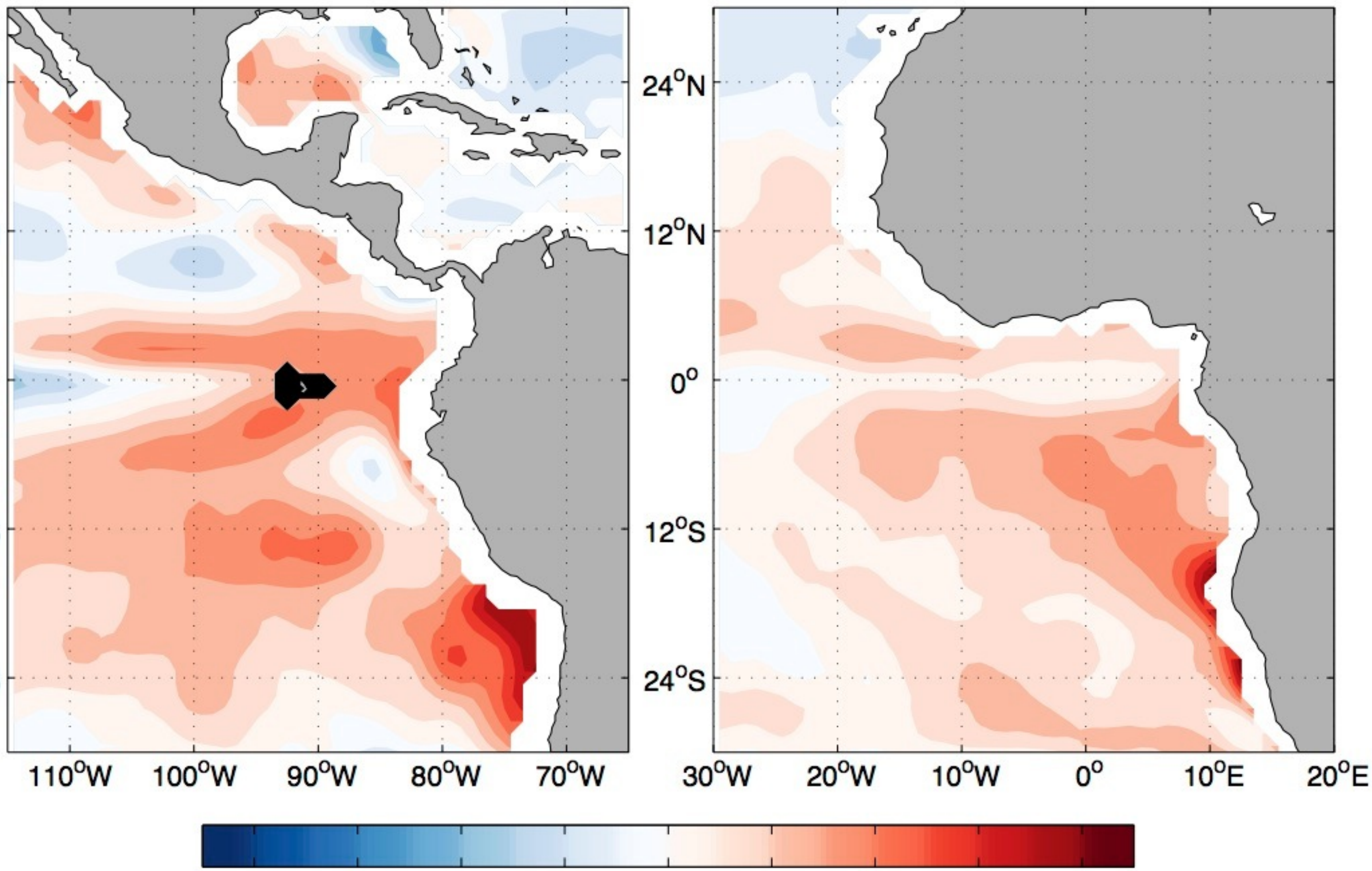
Brian Medeiros

some overcorrection when SSTs are specified (more negative AMIP cloud biases) but overall CMIP5 biases>AMIP5 biases



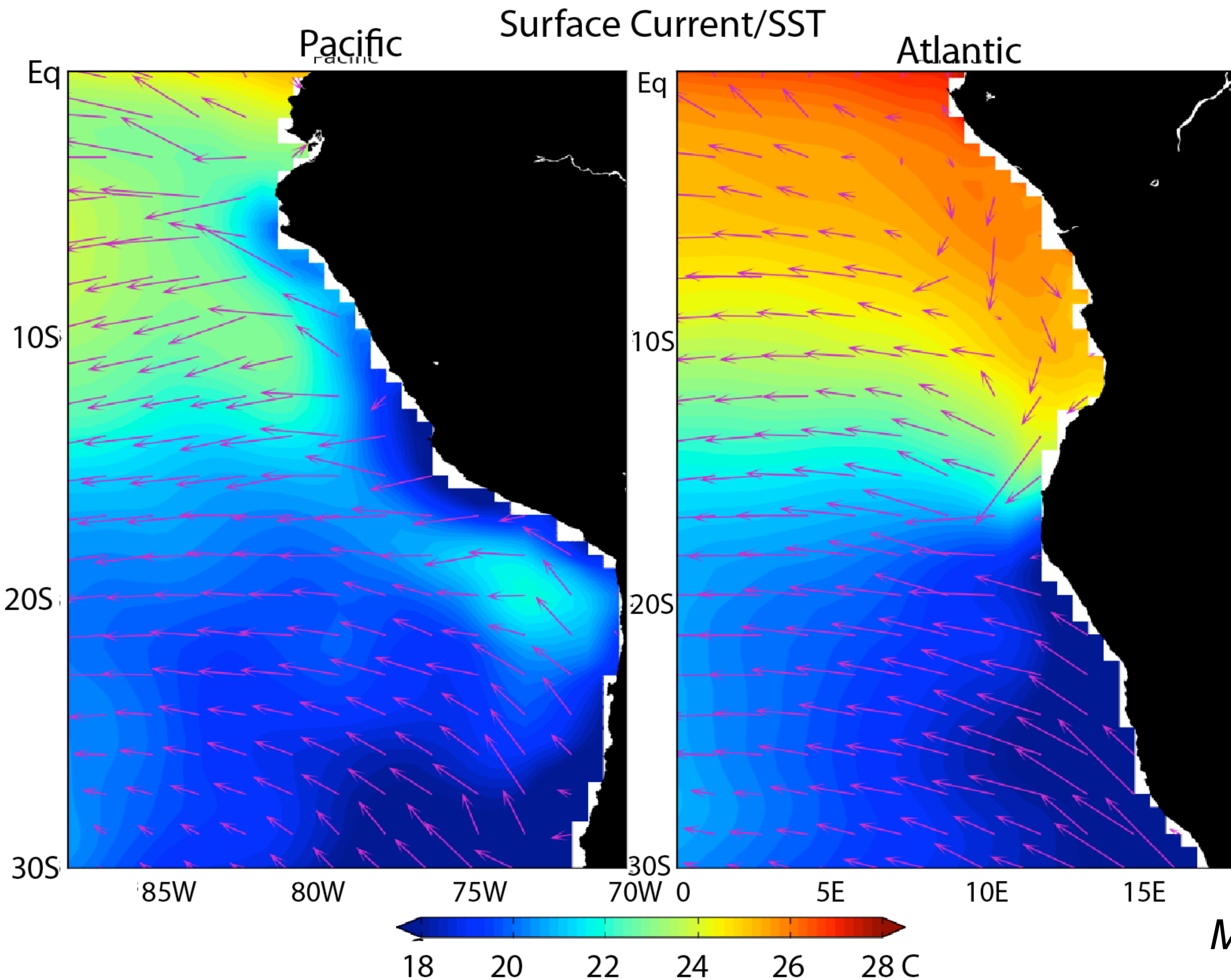
Average cloud radiative effect bias in the Pacific (10^0S-20^0S, 80^0W-90^0W) and Atlantic (10^0S-20^0S, 0-10^0W) from atmosphere-only versus coupled simulations of the same model, The domains are those used within Klein and Hartmann (1993).

both regions also show SST biases even when forced with a realistic atmosphere - indicating at least part of the SST bias has an oceanic origin



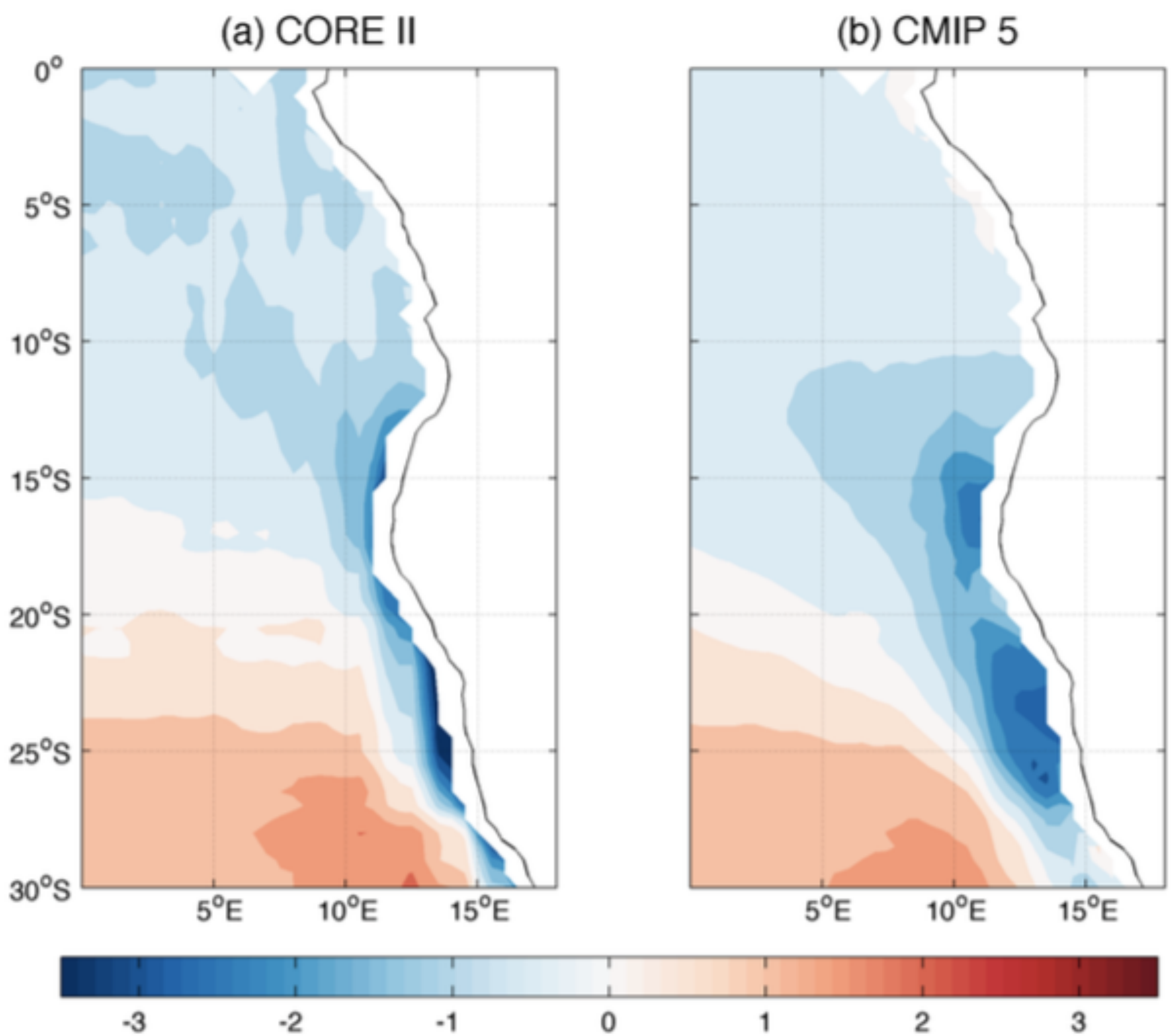
22-ensemble OMIP SST bias relative to CORE2 (Danabasoglu et al., 2014)

oceanography differs significantly between the two basins



Mingkui Li

annual-mean SST and currents, from SODA one issue may be inadequate (weak) winds generating too much surface wind stress curl. this is related to the atmospheric resolution, with land topography inadequately realized & land cells intruding where the ocean should be.



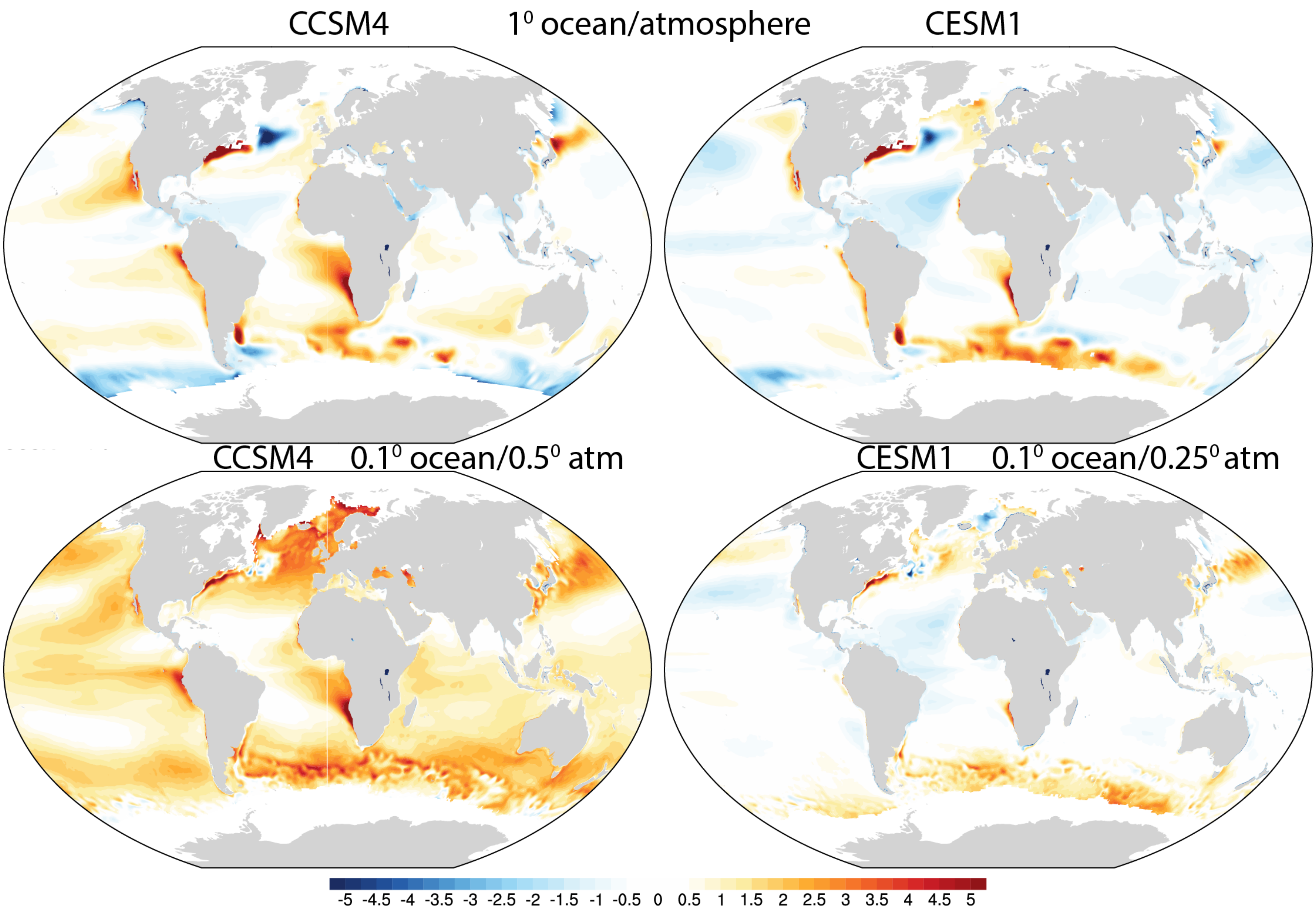
surface wind stress curl

reproduced from Xu et al., (2014)

too much surface wind stress curl -> too much upwelling

in this case of warmer Angola current water

impact of resolution changes



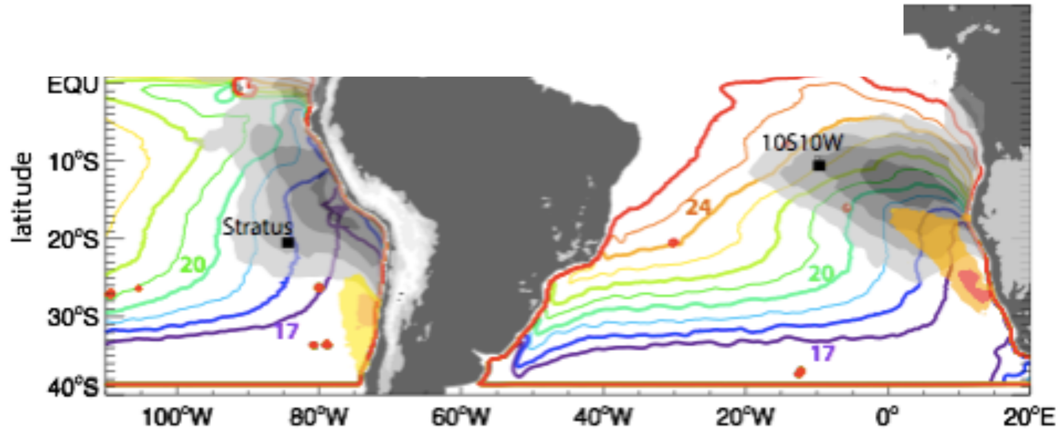
Kirtman et al. 2012

other work is assessing the surface flux gridded products

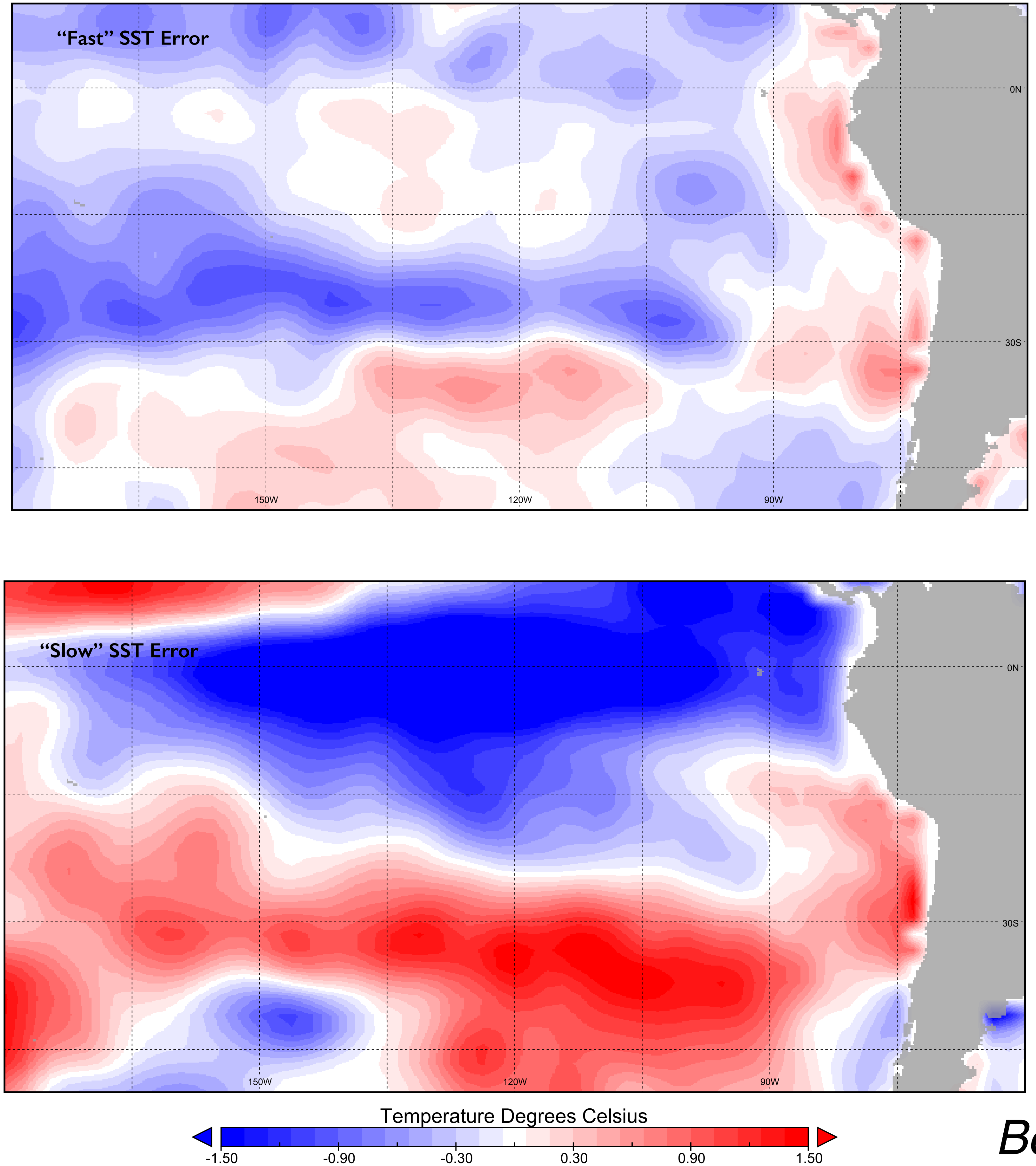
these tend to put too much sunlight into the ocean in the cloudy regions

	STRATUS (85°W, 20°S)[1]					PIRATA (10°E, 10°S)[2]				
	net SW W m-2	net LW W m-2	SH+LH W m-2	SH W m-2	net	net SW W m-2	net LW W m-2	SH+LH W m-2	SH W m-2	net
buoy	191.0	-42.6	-111.9	-7.4	36.5	219.8	-48.7	-150.5	-5.4	20.6
CERES	201.1	-39.4			(52.4)	224.7	-49.5			(38.0)
OAFLUX (ISCCP)	195.3	-30.0	-109.3		56	223.0	-42.3	-137.2		43.5
ERA-Interim	207.0	-47.3	-137.8	-15.4	21.8	229.1	-51.0	-170.7	-15.0	7.7

[1] January 1, 2001-December 31, 2009 [2] January 1, 2009-December 31, 2009. SH= sensible heat; LH=latent heat. net CERES fluxes in parentheses are calculated using the OAFLUX turbulent fluxes.



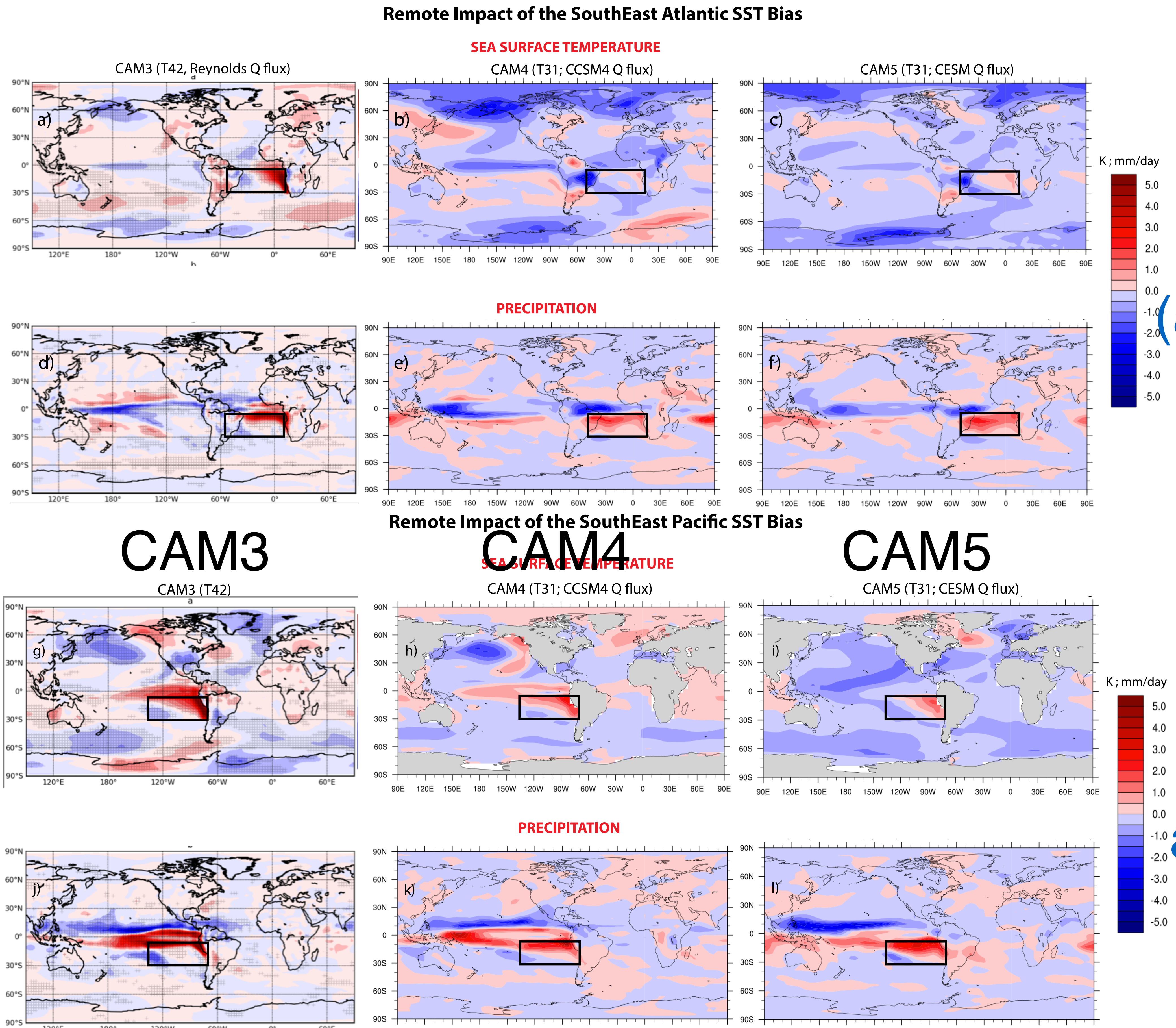
how do we attribute the SST bias?



SST error of10-member CCSM4 ensemble forecasts averaged over first 5 days (top) and days 361-365 (bottom). December initialization

Ben Kirtman

do these local SST biases matter to the global climate?



Atlantic
(affects Pacific)

Pacific
(does not
affect Atlantic)

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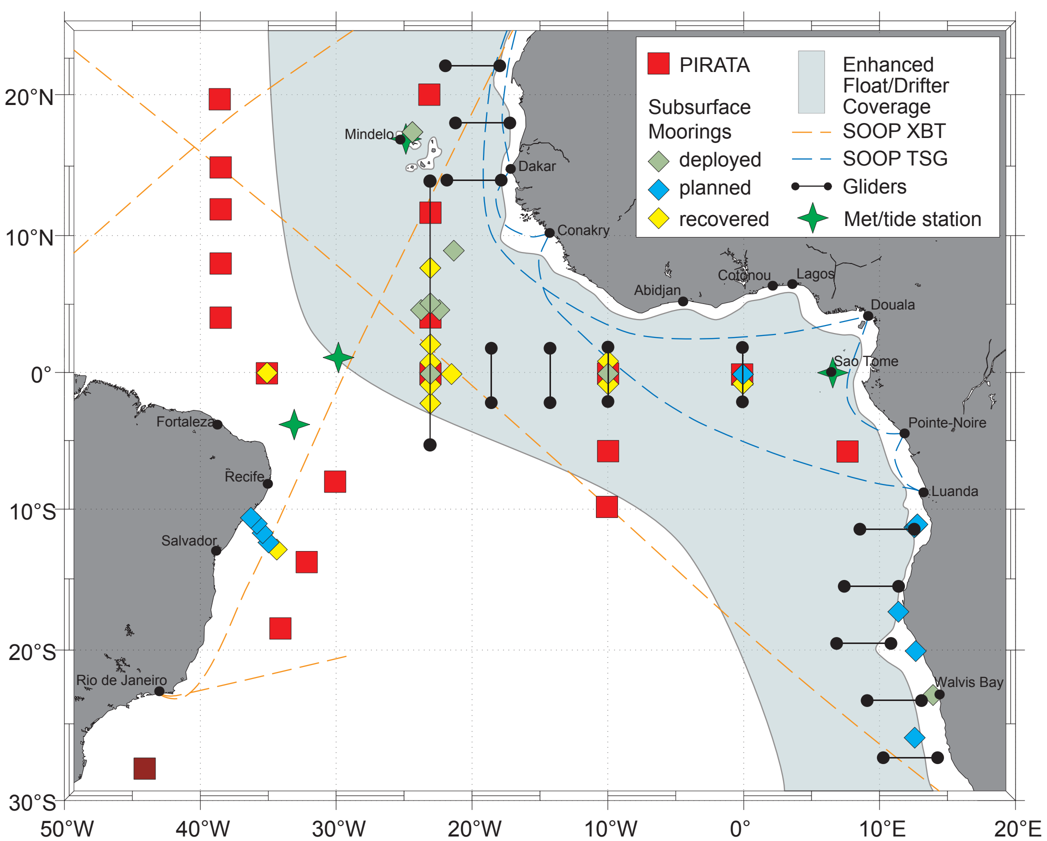
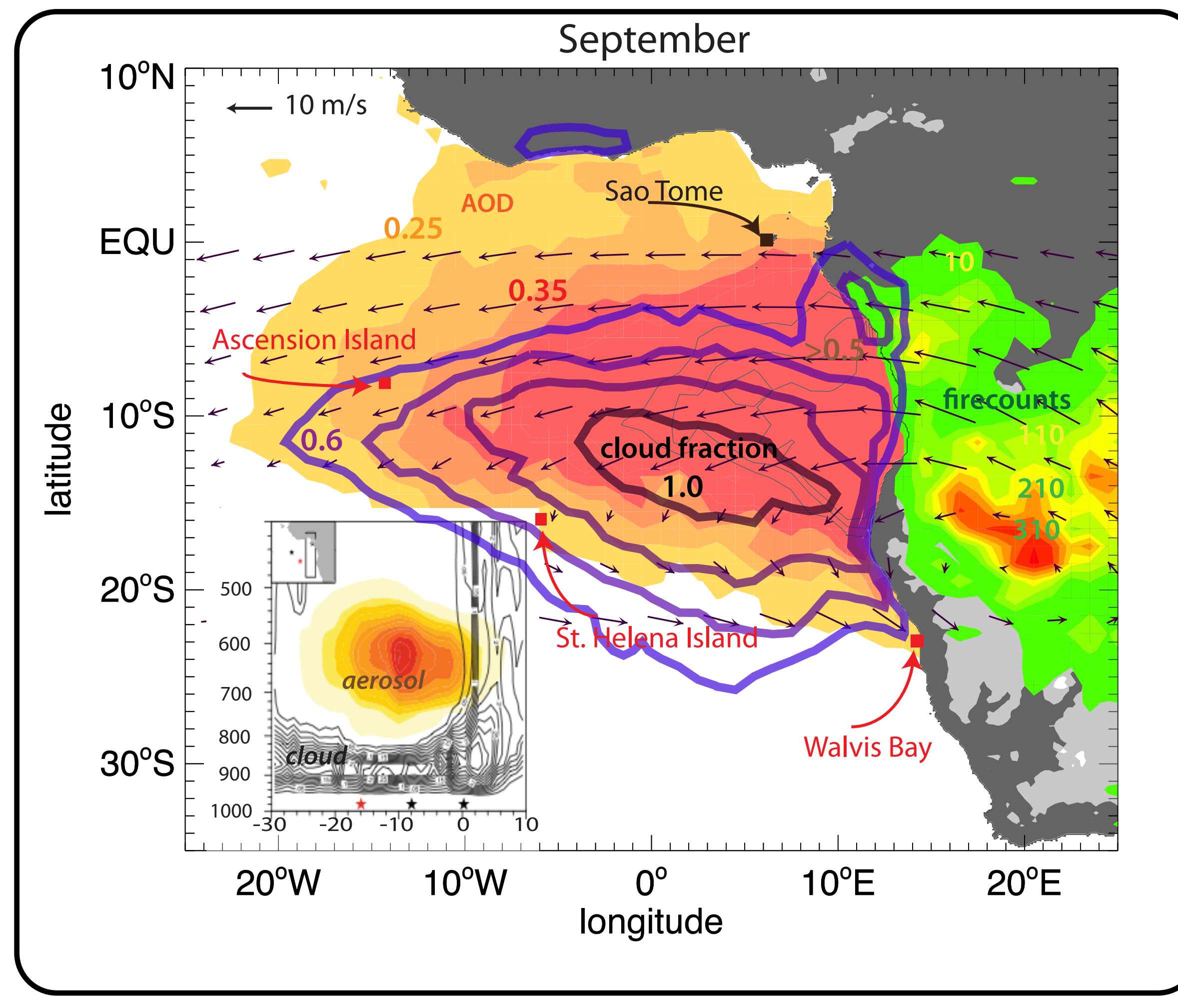
EU-funded PREFACE focusing on oceanographic sources for Atlantic SST biases

Upcoming (2016-2018) NASA, DOE, UK (&NSF?) fieldwork will focus on biomass burning aerosols over the remote Atlantic & the low cloud response



oceanographic data sources



September-mean MODIS cloud fraction (blue contours) aerosol optical depth (yellow-red) & fire counts (green-red, over land)

Recommendations

- Individual modeling centers should be encouraged to identify and improve their model's bias origins as these may be model-dependent.
- The development of high resolution coupled models with a concurrent emphasis on parameterization development for vertical mixing and finer-scale oceanic and atmospheric dynamics.
- A focus on the model representation of the spatially-confined but climatically-influential eastern basin coastal oceanic upwelling regions, including perhaps through a coupled Climate Process Team.
- Further model improvement incorporating data from recent and upcoming field campaigns.
- Fuller data quality control and assessment of available buoy measurements and gridded surface flux products towards improving both's use as climate model validation datasets.