The CLIVAR Eastern Boundary Upwelling Systems (EBUS) Research Focus

Motivation—

- *Coupled models exhibit some of the largest surface-ocean biases in EBUS regions.*
- *Historical observations and hypotheses suggest close association between EBUS dynamics and large-scale climate conditions.*
- *EBUS are of disproportionate ecological, economical, and biogeochemical importance.*

Overarching questions:

- *How are EBUS dynamics represented in models?*
- *How are these dynamics associated with larger-scale climate change?*
- *What are the feedbacks between EBUS and larger-scale climate properties?*
- *What are the implications of EBUS changes for ecosystems and biogeochemical conditions?*

4, semi-permanent, eastern boundary upwelling systems

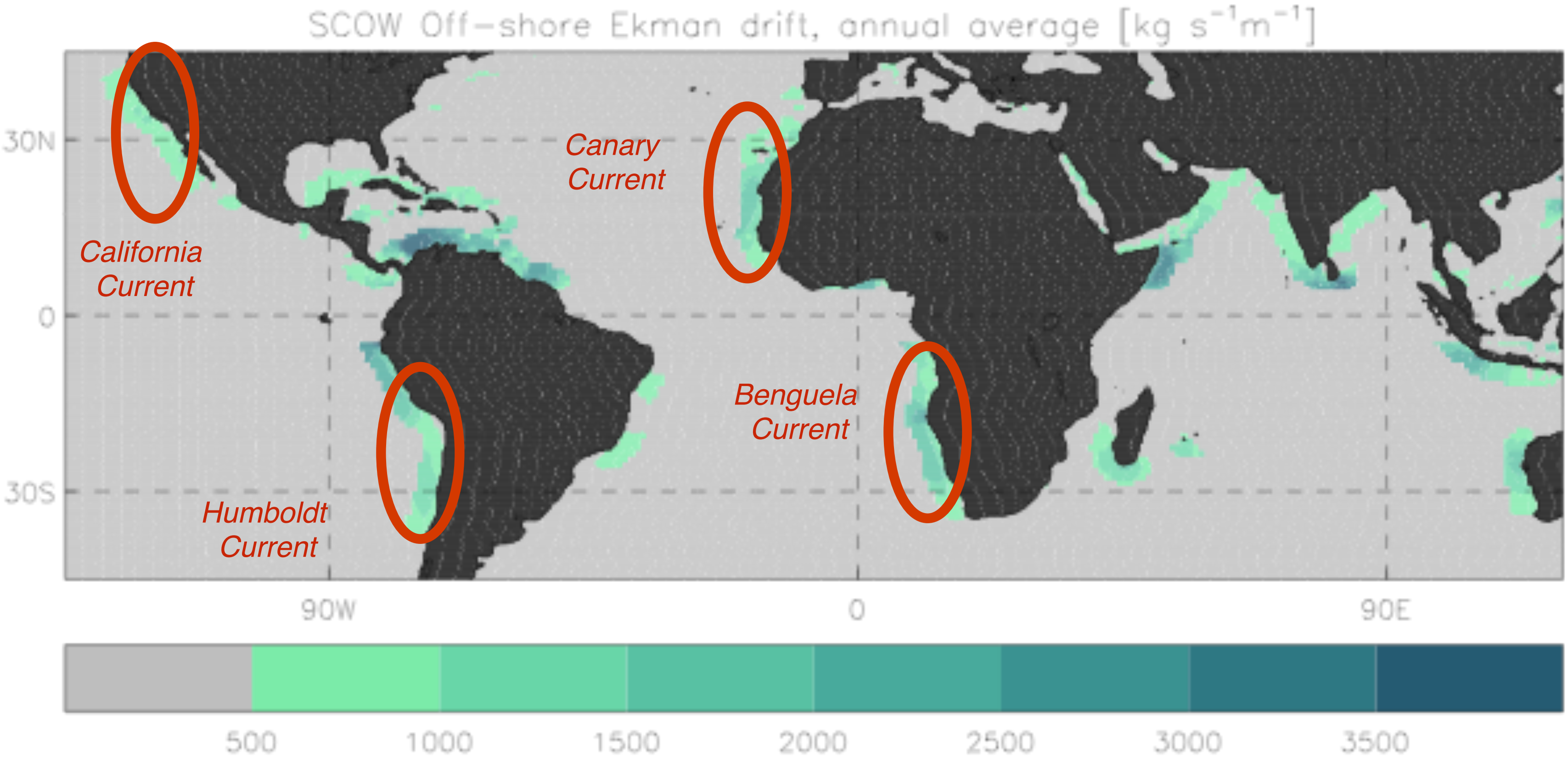
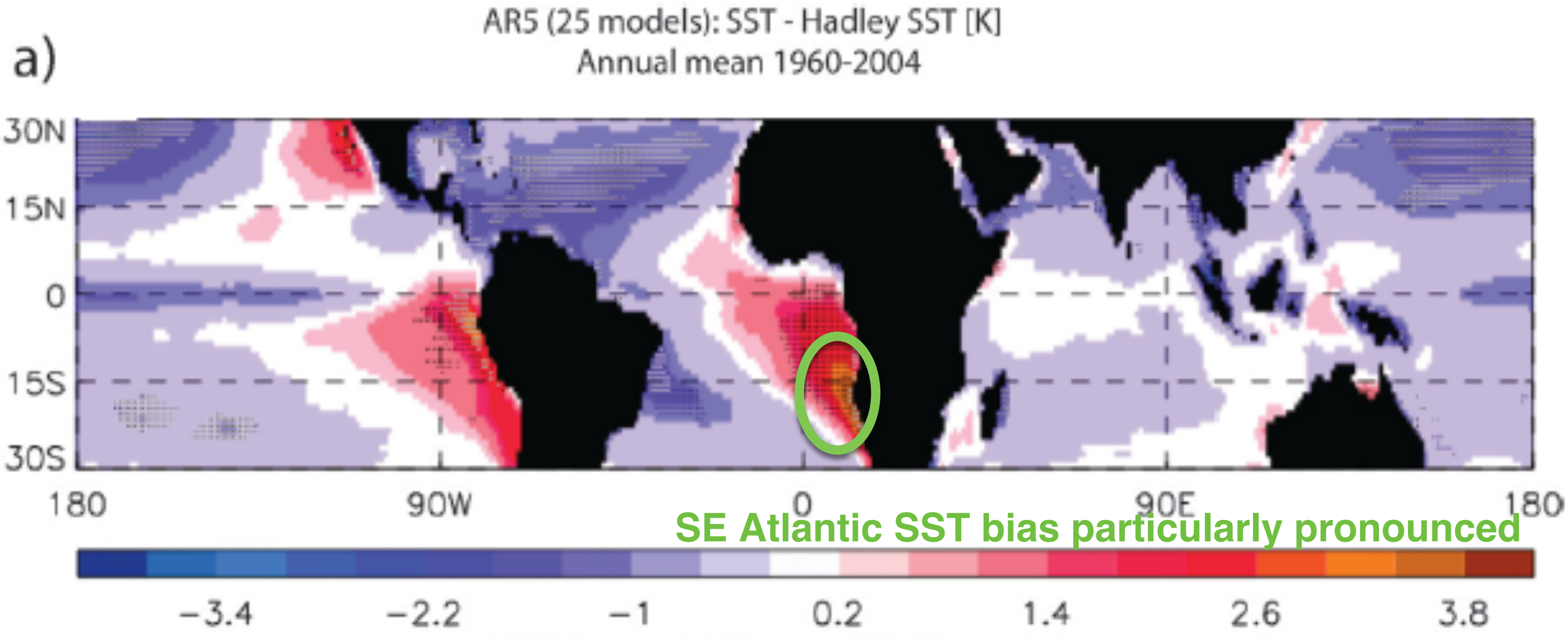


fig. by Thomas Toniazzo

SST biases in CGCMs largest in EBUS regions

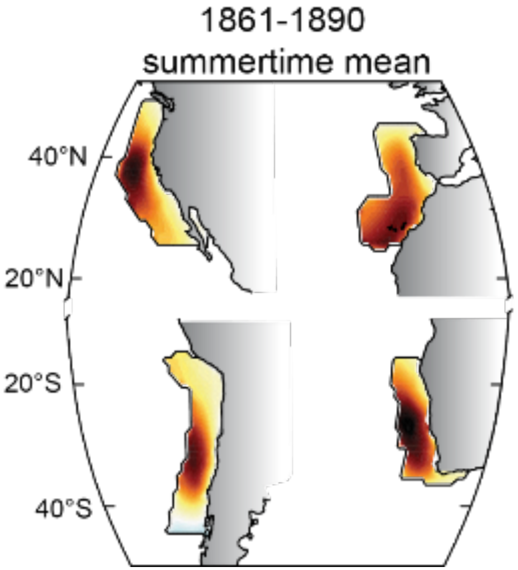
Prevailing winds and currents advect those biases downwind and affect the low cloud cover downstream



SE Atlantic SST bias particularly pronounced

BAMS, 2016, doi:10.1175/BAMS-D-15-00274.1
adapted from Toniazzo and Woolnough, 2014

Anthropogenic changes in wind intensity are fairly subtle…

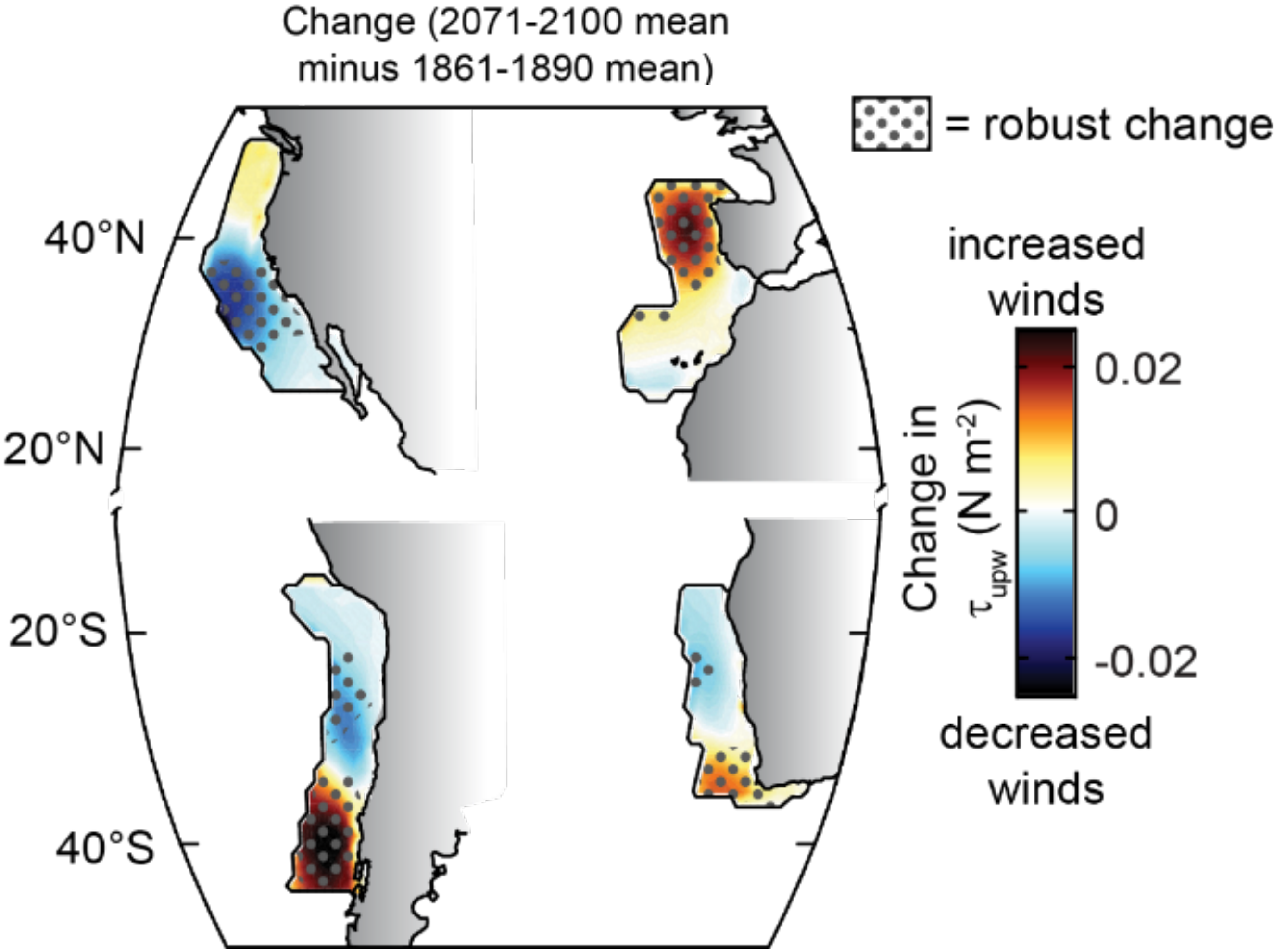


Rykaczewski *et al.* (2015)

Anthropogenic changes in wind intensity are fairly subtle…

Upwelling intensity tends to increase in the poleward halves…

… but decrease in the equatorward portions of the upwelling systems.



Rykaczewski *et al.* (2015)

Broad questions

CLIVAR RF

Links between large-scale climate processes and EBUS

- What ***processes*** control the atmospheric dynamics associated with EBUS?
- How are these processes represented in ***global and regional models***?
- What mechanisms relate EBUS atmospheric and oceanic variability ***to large-scale climate patterns***?
- What are the ***effects of upwelling*** on the regional and global air temperatures, precipitation and wind patterns?
- How can the ***temporal and spatial variability*** of upwelled waters be described?

CLIVAR RF with SCOR WG

Biogeochemical responses and consequences

- What key physical and biological processes control primary ***production***, air-sea CO_2 ***flux***, and carbon ***export*** in EBUS?
- What are the ***relative contributions of EBUS*** to large-scale productivity and intensity of oxygen minimum zones?
- How will natural and anthropogenic factors influence ***carbon cycling and deoxygenation*** in EBUS?
- How do mixing, stratification, and source-water properties influence the composition of the ***plankton community*** and survival of larval ***fishes***?

2019 ICTP “Summer School” on EBUS

“Eastern Boundary Upwelling Systems: Assessing and understanding their changes and predicting their future”

The school will stimulate discussion and new ideas concerning the mechanisms that influence the responses of EBUSs to climate variability and change.

The school will be followed by an EBUS Research Focus meeting.

	DAY 1 **Monday, July 15**	**DAY 2** **Tuesday, July 16**	**DAY 3** **Wednesday, July 17**	**DAY 4** **Thursday, July 18**	**DAY 5** **Friday, July 19**
09:00-09:45	**Introduction of Lecturers and Participants**	**Processes determining cloudiness distributions in EBUS regions: Part 1** (*P. Zuidema*)	**Response of the ocean to wind fields** (*M. Schmidt*)	**Large-scale biogeochemistry and plankton ecology in EBUS** (*R. Rykaczewski*)	**Equatorial and coastal wave teleconnections in the EBUSs** (*A. Lazar*)
09:45-10:30	**Eastern Boundary Upwelling Systems: importance and critical processes** (co-Organizers)	**Atm. circulation and coastal topography** (*R. Garreaud*)	**Transport and mixing at the ocean mesoscale** (*A. Bracco*)	**Role of (sub)Mesoscale for biogeochemistry and ecology in EBUS** (*I. Frenger*)	**Variability and equatorial teleconnections** (*R.Garreaud, A. Miller*)
10:30-10:45	**Break**	**Break**	**Break**	**Break**	**Break**
10:45-11:30	**Historical variability in EBUS and considerations about their future** (*R. Rykaczewski*)	**Drivers of coastal along-shore winds and their variability** (*T. Toniazzo*)	**Processes controlling SSTs** (*A. Lazar*)	**Biogeochemical Models in EBUS** (*I. Frenger*)	**Downscaling of climate change impacts on EBUS biogeochemistry** (*F. Chai*)
11:30-12:15	**Climatology of the atmospheric circulation** (*T. Toniazzo*)	**Cloud impacts across time scales** (*R. Garreaud*)	**Transport and mixing at the ocean submesoscales** (*A. Bracco*)	**Upwelling impacts on the world's largest fishery, the Peruvian anchoveta** (*F. Chai*)	**EBUS biases and uncertainties in global and regional models** (T. Toniazzo, R. Farneti)
12:15-13:00	**Climatological ocean dynamics** (*M. Schmidt*)	**Processes determining cloudiness distributions in EBUS regions: Part 2** (*P. Zuidema*)	**Coupled atmosphere-ocean feedbacks** (*A. Miller*)	**Data assimilation; adjoint models** (*A. Miller*)	**Alongshore winds in IPCC model projections** (*R. Rykaczewski*)
13:00-16:00	**Lunch/Swim**	**Lunch/Swim**	**Lunch/Swim**	**Lunch/Swim**	**Lunch/Swim**
16:00-17:30	**The NetCDF format, data sources, and analysis tools** (Introduction: *M.Schmidt, supervision: Lecturers*)	**Data Analysis/Case Study** (Introduction: R. Garreaud, R. Rykaczewski, T.Toniazzo, P. Zuidema; supervision: Lecturers)	**Participants' Poster Session**	**The ICTP regional coupled model and the West Africa EBUS** (*R. Farneti*)	**Debate on clmate change in EBUS: selection of hypotheses from the literature** (Students)
17:30-17:45	**Break**	**Break**	**Break**	**Break**	**Break**
17:45-19:00	**Welcome Reception**	**Data Analysis/Case Study** (supervision: Lecturers)	**Participants' Poster Session**	**TBD** (*A. Lazar,* *R. Farneti*)	**Debate on climate change in EBUS: discussion on hypotheses** (*Students*)

2019 ICTP "Summer School" on EBUS

Friday evening "debate"

How will EBUS respond to future climate change?

Different, mutually inconsistent hypotheses have been proposed.

Based on the literature and what you learn during the week, we hope to have a group discussion, LED BY YOU, about some of these ideas.

What are the merits of hypotheses of future change in EBUS?
What are weaknesses or shortcomings of the ideas?
What steps need to be taken to help better understand EBUS responses?

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Some potentially useful papers:

Bakun, A, BA Black, SJ Bograd, M García-Reyes, AJ Miller, RR Rykaczewski, and WJ Sydeman. 2015. Anticipated effects of climate change on coastal upwelling ecosystems. *Current Climate Change Reports* **1:**85-93, doi:10.1007/s40641-015-0008-4.

Brady, RX, NS Lovenduski, MA Alexander, M Jacox, and N Gruber. 2019. On the role of climate modes in modulating the air–sea CO2 fluxes in eastern boundary upwelling systems *Biogeosciences* **16**:329-346, doi.org/10.5194/bg-16-329-2019.

García-Reyes, M, WJ Sydeman, DS Schoeman, RR Rykaczewski, BA Black, AJ Smit, and SJ Bograd. 2015. Under pressure: Climate change, upwelling and eastern boundary upwelling ecosystems. *Frontiers in Marine Science* **2:**109, doi:10.3389/fmars. 2015.00109.

Muñoz, RC and R Garreaud. 2005. Dynamics of the low-level jet off the west coast of subtropical South America. *Mon. Weather Rev.* **133:**3661-3677.

https://drive.google.com/drive/folders/1kesLephEOaNtqdtuZn21K064O0ZkvAK3

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Some potentially useful papers (cont.):

Seabra, R, V Rubén, AM Santos, M Gómez-Gesteira, C Meneghesso, DS Wethey, and FP Lima. 2019. Reduced nearshore warming associated with Eastern Boundary Upwelling Systems. *Frontiers in Marine Science* **6**, doi:10.3389/fmars.2019.00104

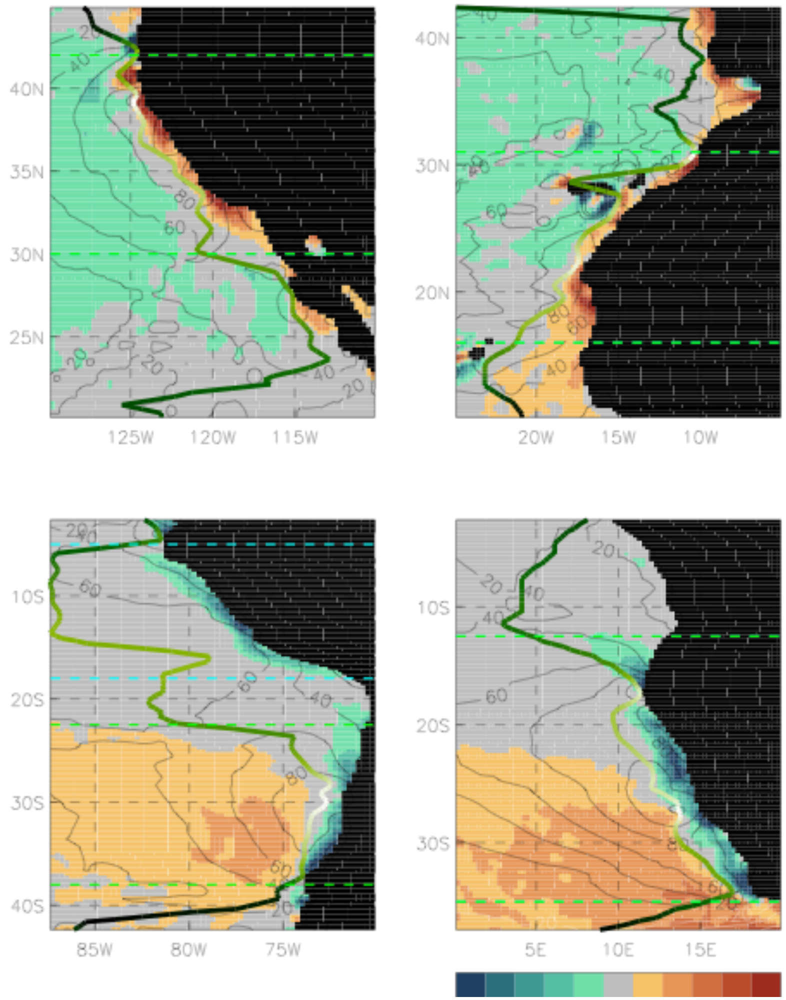
Toniazzo, T, SJ Abel, R Wood, CR Mechoso, G Allen, and LC Shaffrey. 2011. Large-scale and synoptic meteorology in the south-east Pacific during the observations campaign VOCALS-REx in austral Spring 2008. *Atmos. Chem. Phys.* **11:**4977-5009.

Wang, D, TC Gouhier, BA Menge, and AR Ganguly. 2015. Intensification and spatial homogenization of coastal upwelling under climate change. *Nature* **518:**390-394.

Zuidema, P, P Chang, B Medeiros, BP Kirtman, R Mechoso, EK Schneider, T Toniazzo, I Richter, RJ Small, K Bellomo, P Brandt, S de Szoeke, JT Farrar, E Jung, S Kato, M Li, C Patricola, Z Wang, R Wood, and Z Xu. 2016. Challenges and prospects for reducing coupled climate model SST biases in the eastern tropical Atlantic and Pacific Oceans: The U.S. CLIVAR Eastern Tropical Oceans Synthesis Working Group. Bulletin of the American Meteorological Society, doi:10.1175/BAMS-D-15-00274.1.

Some background on our key questions…

Basic theory attributes the eastern boundary oceanic upwelling to the low-level wind spatial structure



SCOW along−shore windstress [mPa] and windstress curl [N/km^3]
annual average

Figure 2: Windstress curl (colour maps), surface along-shore windstress (line contours defined as in Figure 1 and the location and intensity of the maximum along-shore windstress (green/white crosses) according to the SCOW climatology.

along-shore windstress (lines)
=> Ekman divergence

wind stress curl (color)
=> Ekman pumping

Coarse-resolution models are typically too dissipative, overestimating upwelling induced by wind-stress curl.

fig. by Thomas Toniazzo

southeast Atlantic example

Scatterometer, with 10-km res., ID's 2 distinct coastal jets, missed in coarser models.

Wind-stress maximum is placed too far offshore in coarse models, excessive cyclonic wind-stress curl forces warm, southward current (Xu et al. 2014; Small et al. 2015); too diffuse thermoclines reinforce the SST bias.

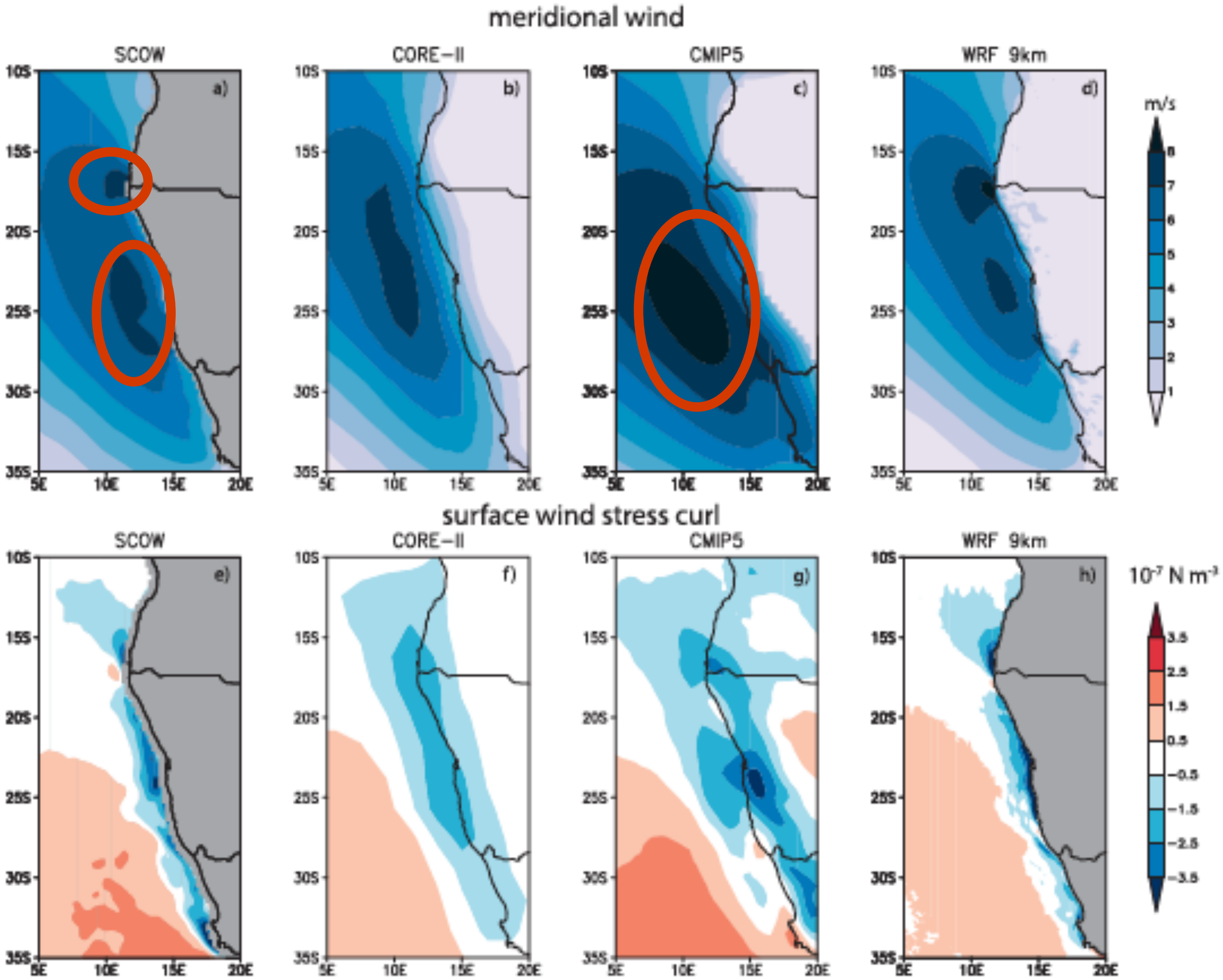


Fig. 12. Coastal southeast Atlantic (a)–(d) meridional winds at 10 m and (e)–(h) surface wind stress curls differ significantly between observations and models and depend on spatial resolution: (a),(e) 0.25° SCOW ocean surface wind vectors, averaged 1999–2009; (b),(f) 1° CORE2 ocean forcing dataset, averaged 1999–2009; (c),(g) CMIP5 multi-model mean, averaged 1984–2004; and (d),(h) a 9-km simulation with the Weather Research and Forecasting Model averaged 2005–08. See further discussion in Patricola and Chang (2016, manuscript submitted to *Climate Dyn.*)

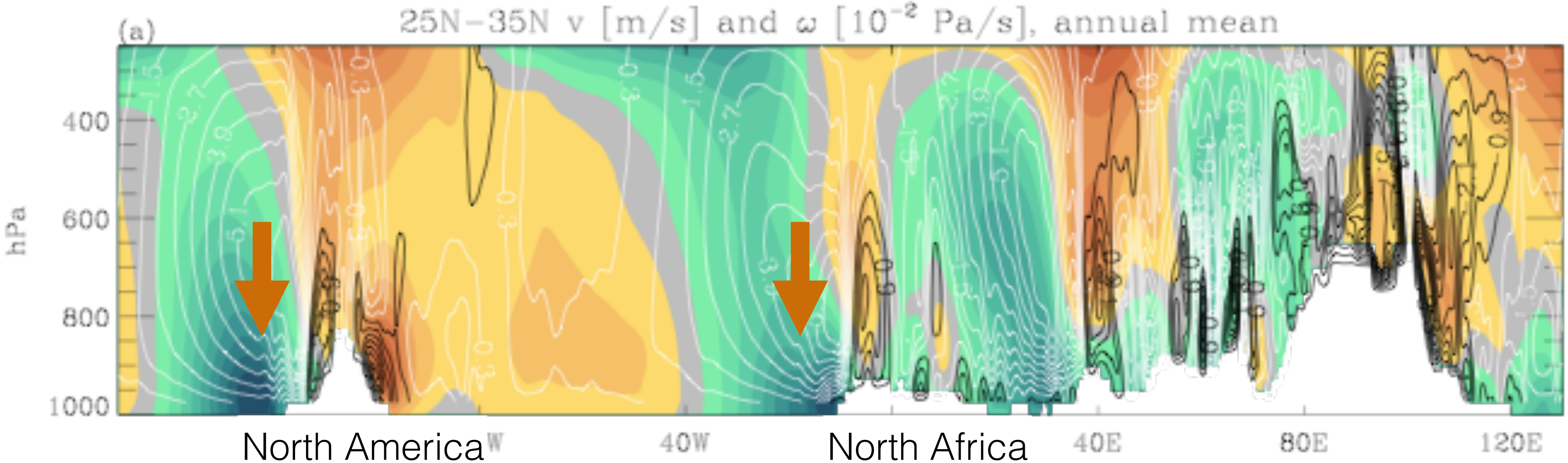
doi:10.1175/BAMS-D-15-00274.1, see Patricola and Chang, 2017, Climate Dynamics for more

Subsidence is driven by radiative cooling over the EBUS in approximate balance with baroclinic meridional poleward winds

$$\beta v \approx f \partial_p \omega .$$

northern hemisphere 25N-35N

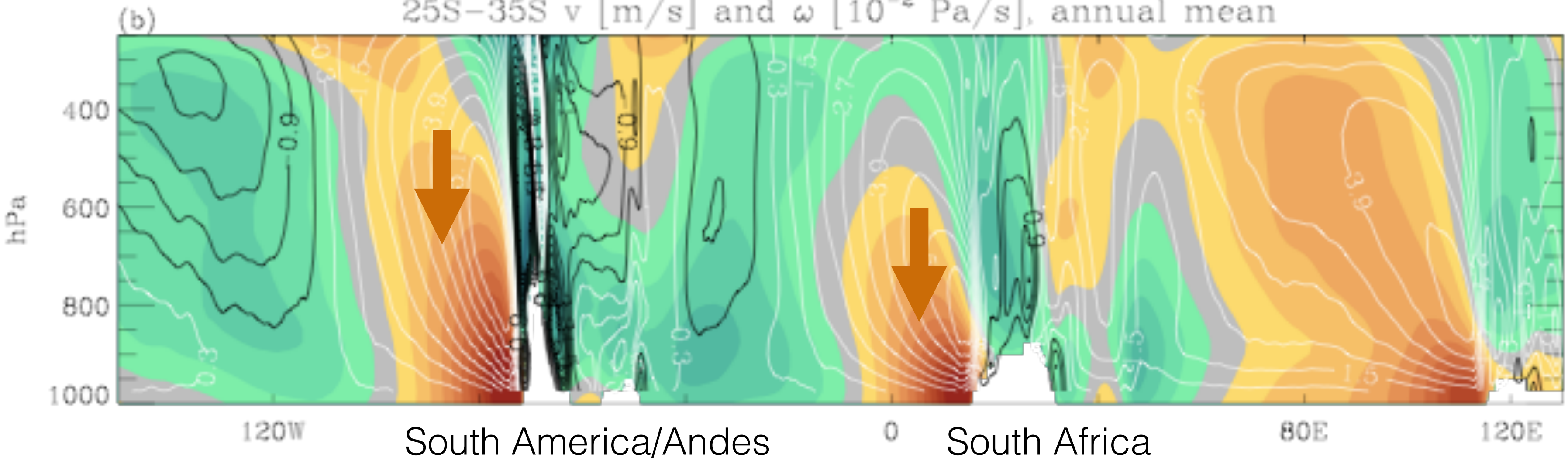
ERA-Interim data. omega=contours; meridional wind=color



North America

North Africa

southern hemisphere 25S-35S

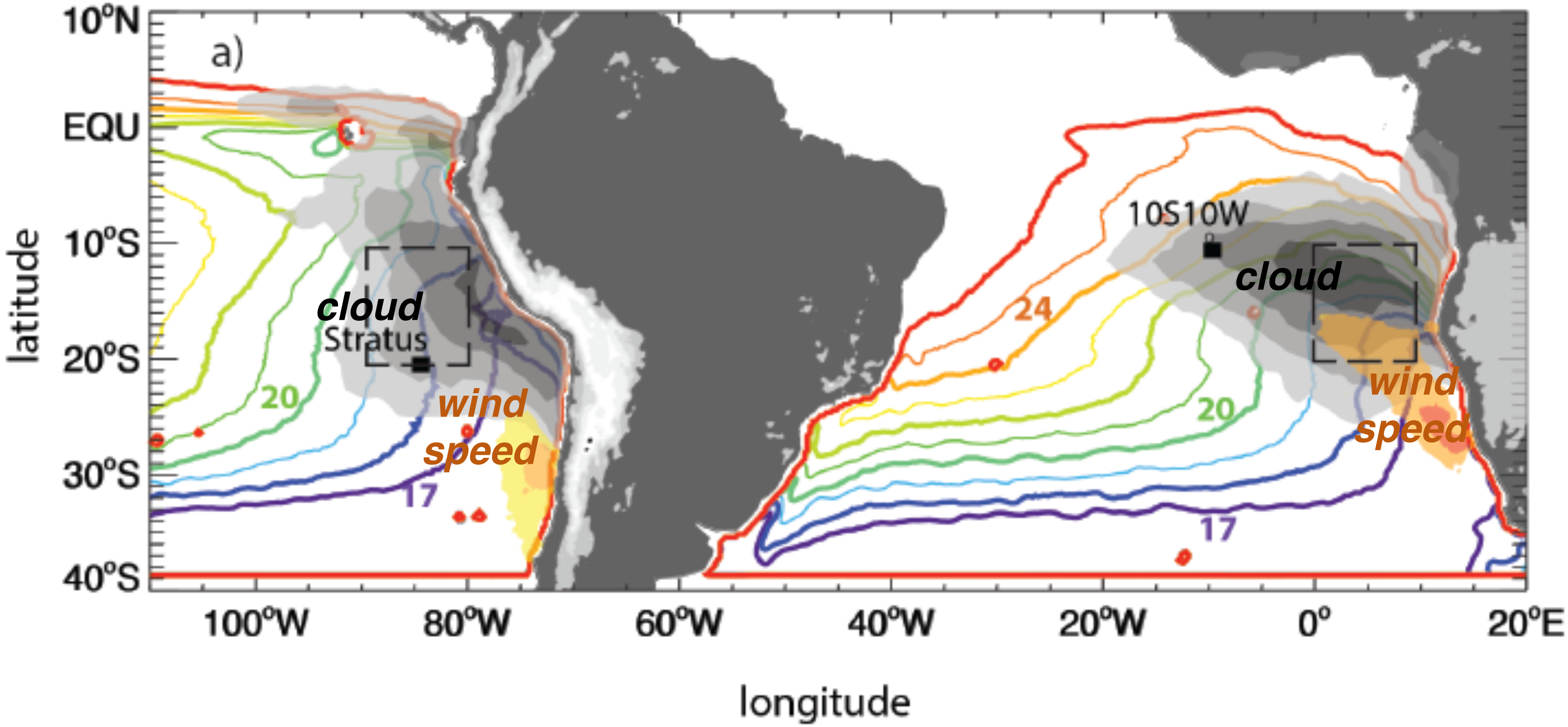


South America/Andes

South Africa

fig. by Thomas Toniazzo

Relationship between low cloud cover and the coastal jets varies between the EBUS regions, affects the EBUS surface energy balance



Nevertheless, each EBUS will be affected differently by topography/bathymetry

e.g., the atmospheric structure establishing the capping stability inversion and its relationship to cloudiness

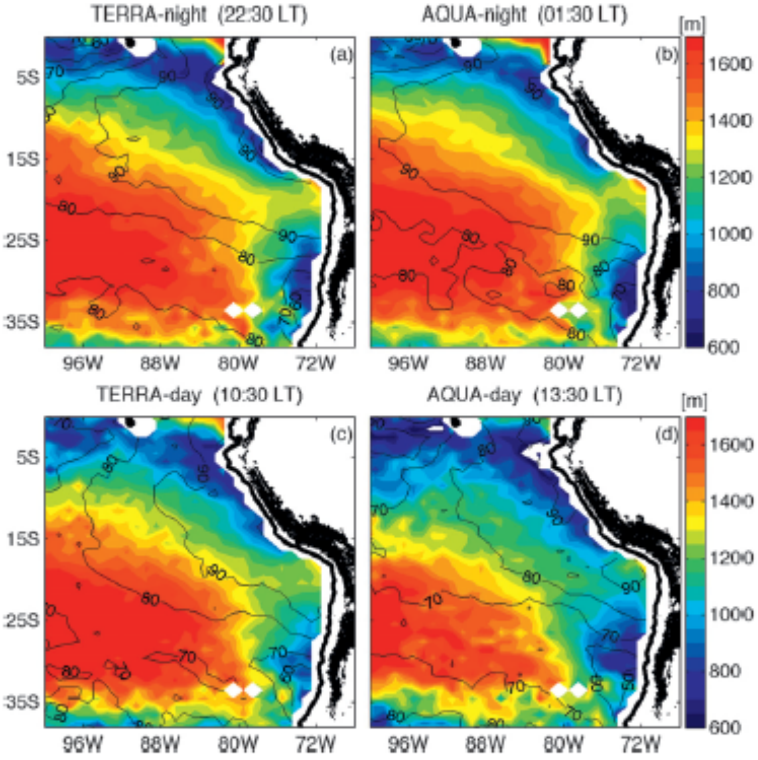


FIG. 9. Mean cloud-top height fields for October 2005, 2006, and 2007 combined for (a) *Terra* night, at 2230 LT, (b) *Aqua* night, at 0130 LT, (c) *Terra* day, at 1030 LT, and (d) *Aqua* day, at 1330 LT. Values are based on the samples possessing a cloud fraction >90% only, with typically at least one-third of all samples contributing when cloud fractions, indicated by the contour lines, exceed 70%. Land elevations exceeding 3 km at 10-min spatial resolution are also indicated.

Zuidema et al., 2009, JCLI

The coastal SE Pacific has a high cloud cover capping the oceanic upwelling region, with a strong diurnal cycle in the cloud top height driven by the neighboring land heating

=> impacts the surface energy budget

in contrast, extensive SE Atlantic coastal clearings more likely linked to strong coastal subsidence producing very low inversions => surface moisture cannot reach its lifting condensation level

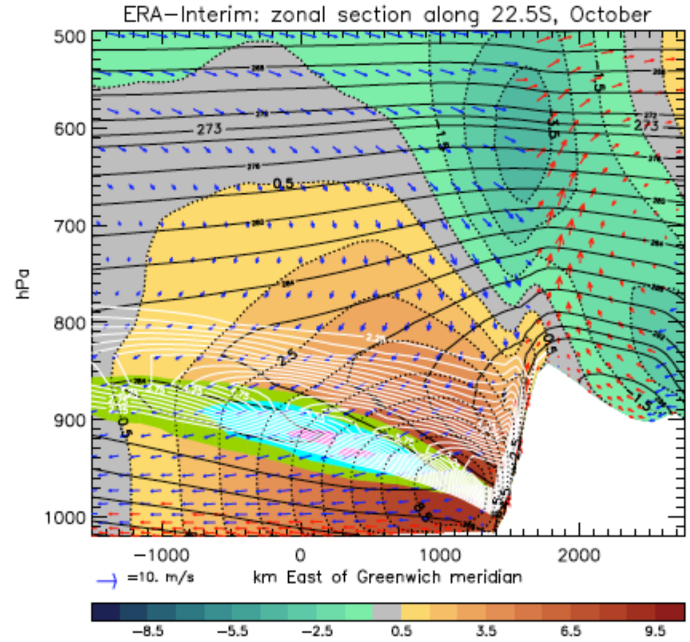
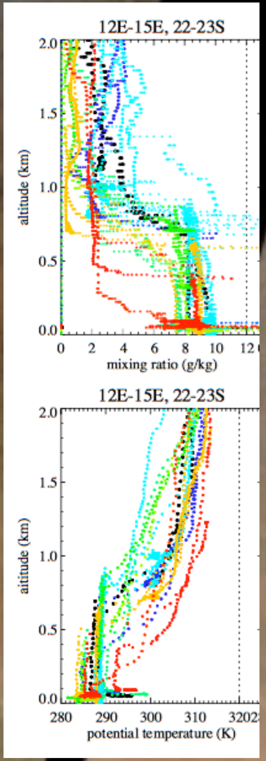


fig. by Thomas Toniazzo

Figure 5: Zonal section along 22-23S in the Eastern Atlantic, illustrating the distribution of meridional (colour-filled, black dashed countours, spacing 0.5 m/s), zonal and vertical wind components (arrows, in red for ascent and in blue for descent; scale on the bottom left, in m/s for the zonal component, and mPa/s for the vertical component), temperature (black solid contour lines, spacing 2 K, plus 0 ^{0}C and 20 ^{0}C isotherms as thicker black lines), static stability (white contour lines, spacing $0.5\times10^{-2}s^{-1}$ between $2.25\times10^{-2}s^{-1}$ and $4.25\times10^{-2}s^{-1}$, and cloud concentration (above 0.2,

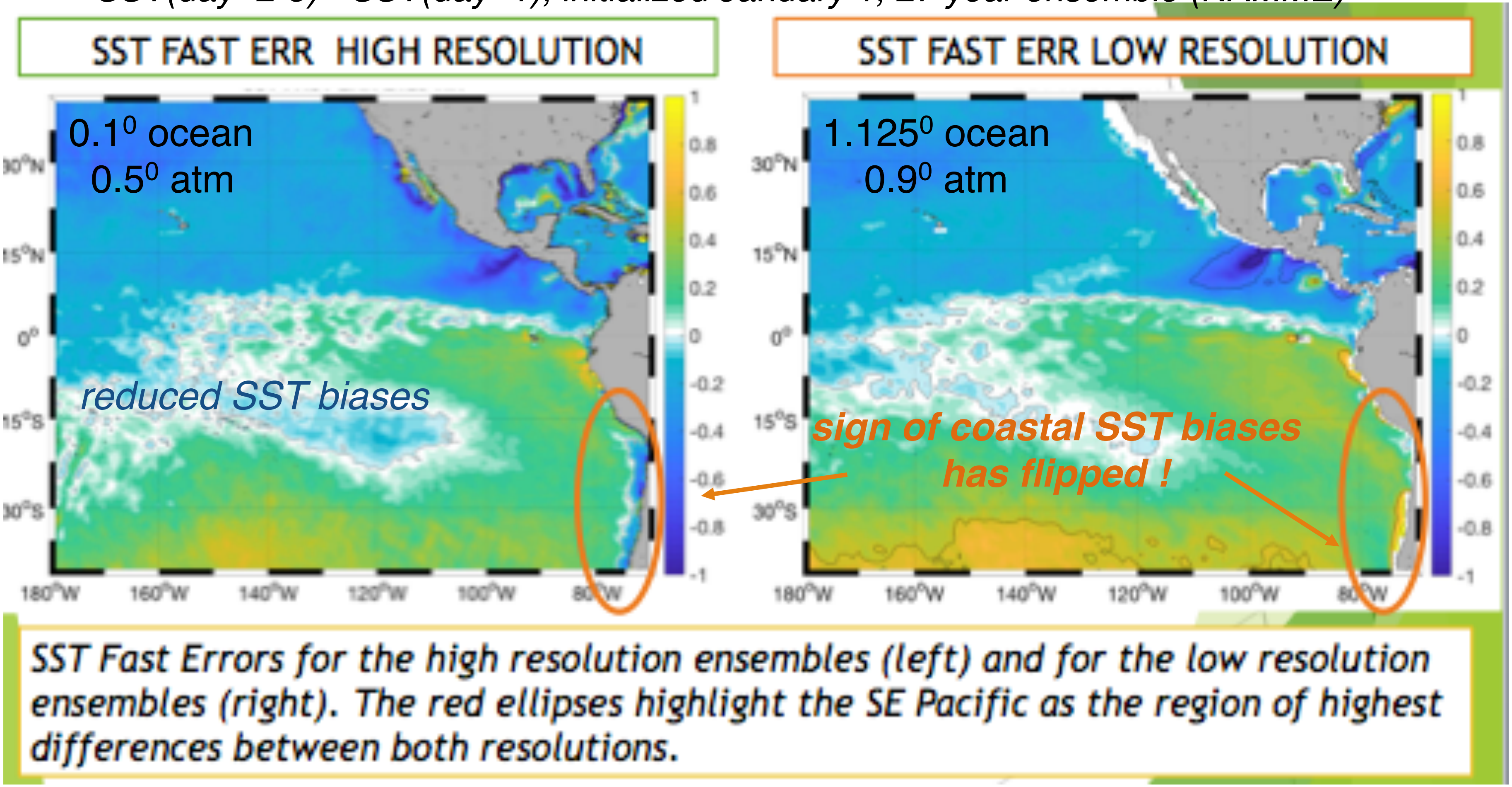


aircraft ascents/descents out of Walvis Bay one in-situ data source

Improvements in model resolution reduce SST bias overall, but…..

high vs low resolution CCSM4-RSMAS,

SST(day=2-5) - SST(day=1), initialized January 1, 27 year ensemble (NAMME)



SST FAST ERR HIGH RESOLUTION

0.1^0 ocean
0.5^0 atm

reduced SST biases

SST FAST ERR LOW RESOLUTION

1.125^0 ocean
0.9^0 atm

sign of coastal SST biases has flipped !

SST Fast Errors for the high resolution ensembles (left) and for the low resolution ensembles (right). The red ellipses highlight the SE Pacific as the region of highest differences between both resolutions.

Isabel Porto da Silveira AGU 2017 presentation, Zuidema, Kirtman

We currently think (speculate) the cause is related to precipitation on east Andes, encouraging atmospheric ascent

high-res

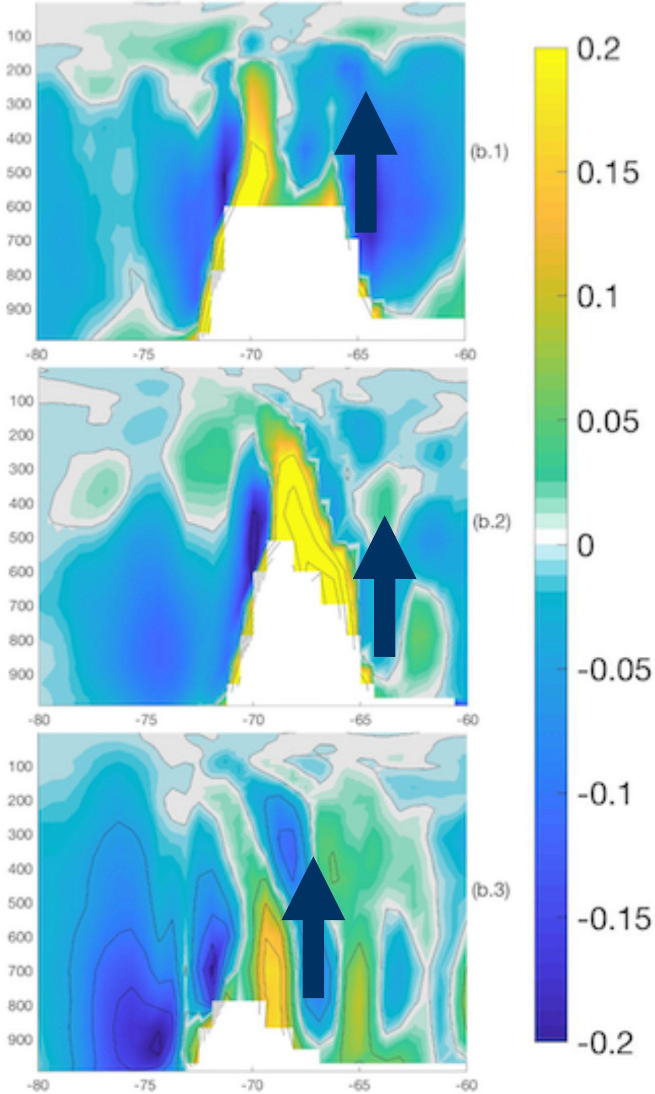
atmospheric vertical velocity

low-res

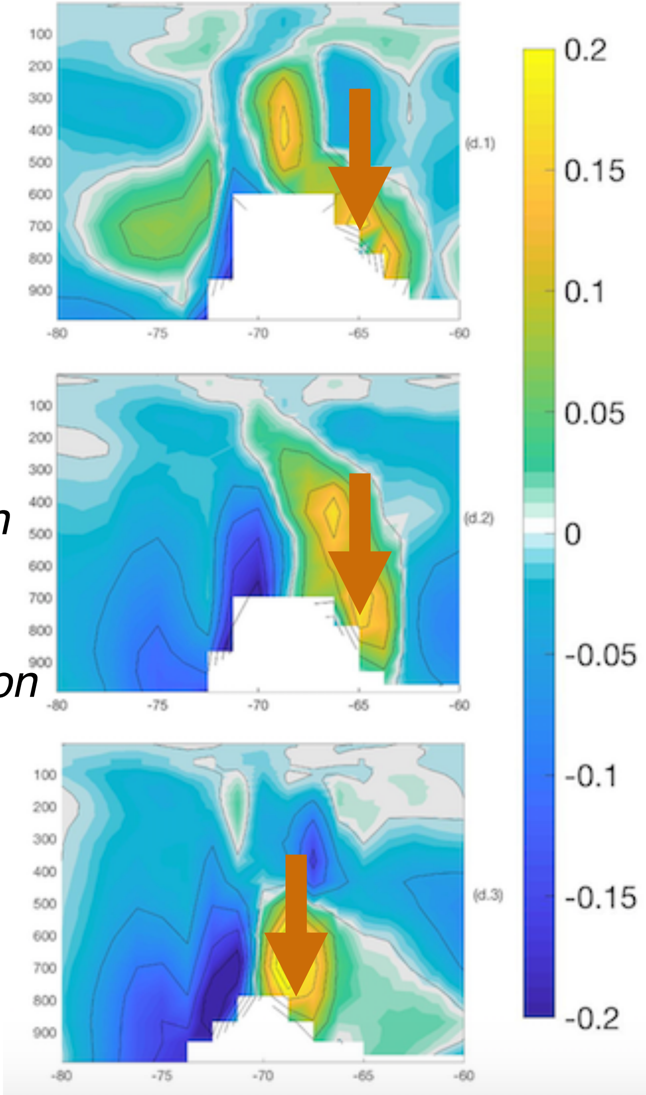
17S

27S

37S



reasonable to expect SE Atlantic fast-SST error growth will depend differently on resolution in this model



2018 Ocean Sciences Meeting: Session EP34B –

Biophysical Dynamics of Eastern Boundary Upwelling Ecosystems in a Changing Ocean: Closing the Gap Between Wind Stress and Ecosystem Productivity

Co-chairs Ryan Rykaczewski, Enrique Curchitser, Ruben Escribano, and Michael Jacox

2018 ECCWO symposium: Session 7 –

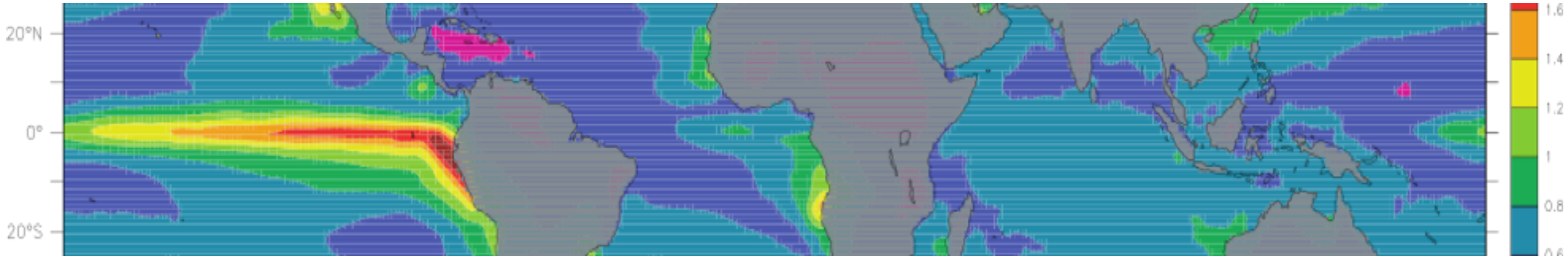
Eastern Boundary upwelling systems: diversity, coupled dynamics and sensitivity to climate change”

Co-chairs Ivonne Montes and Ryan Rykaczewski

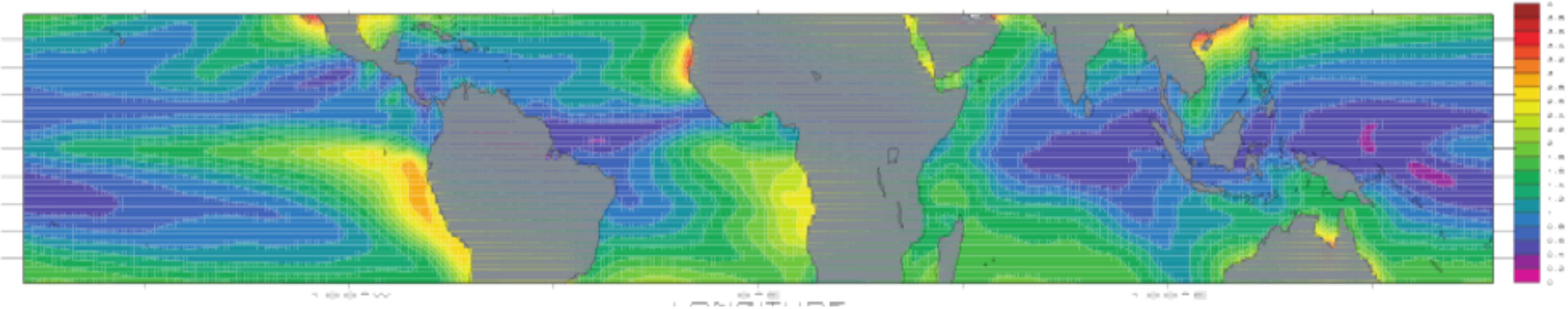
Any advice from ARP?

extra slides

inter annual variability (of SST?)



inter seasonal variability



but, each EBUS will be affected differently by topography/ bathymetry

mean seasonal cycle in equatorward along-shore wind-stress
offshore distance of the wind-stress maximum (green lines)

(SCOW)

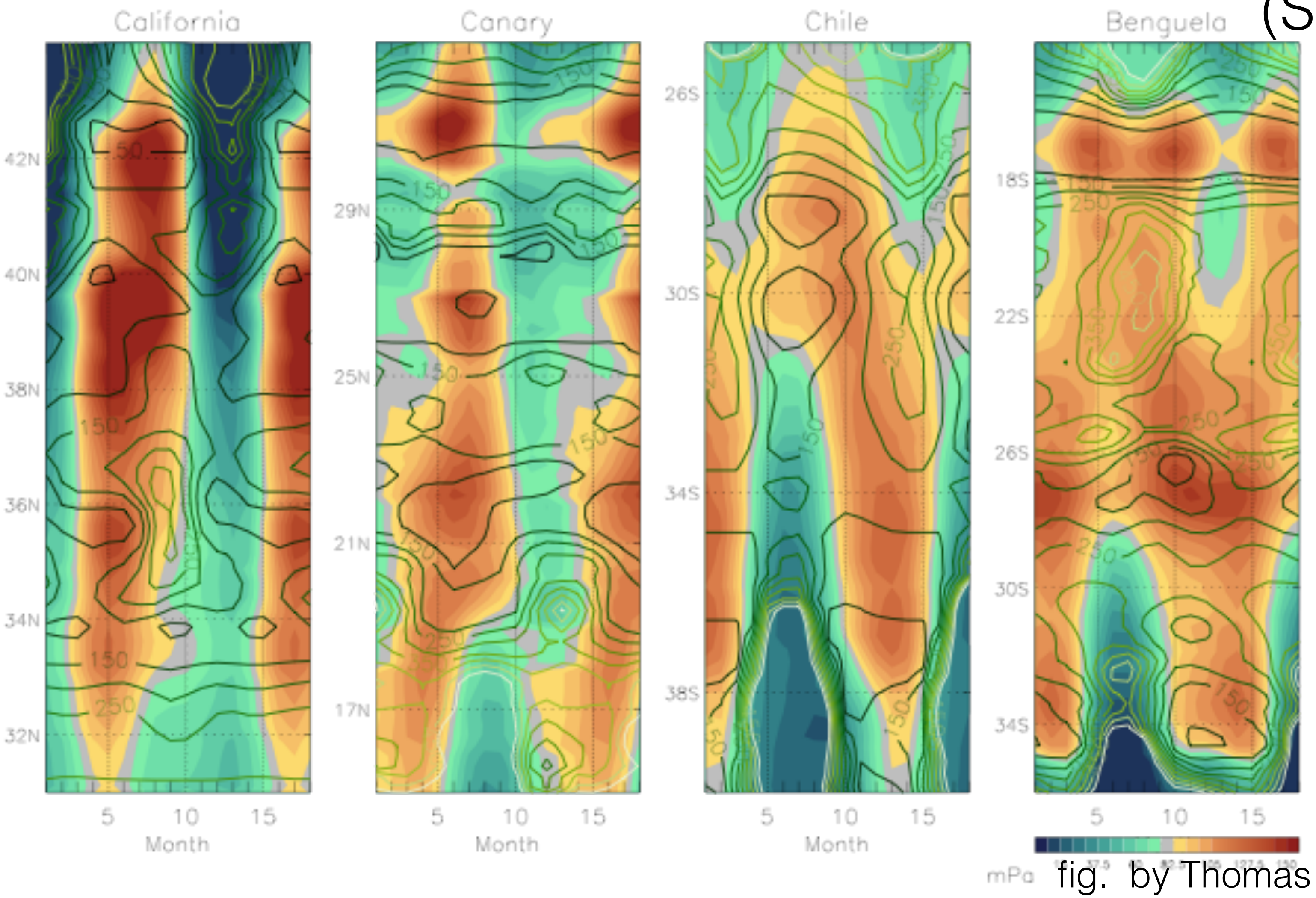


fig. by Thomas Toniazzo