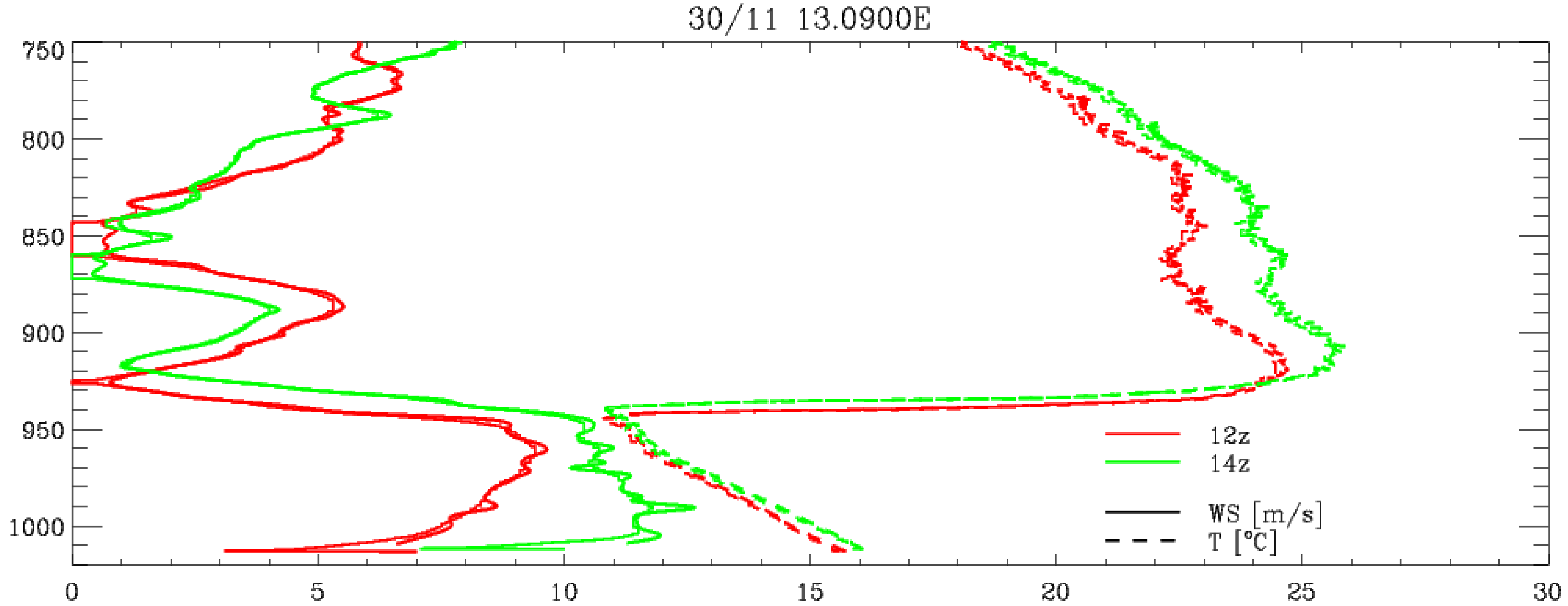
Part III: simulations, predictions, and climate change:

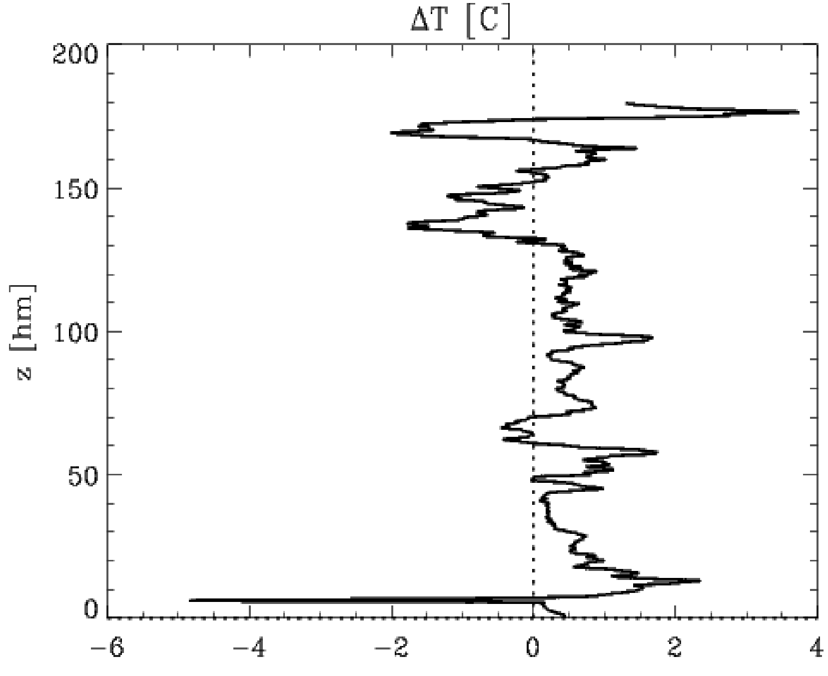
the challenges

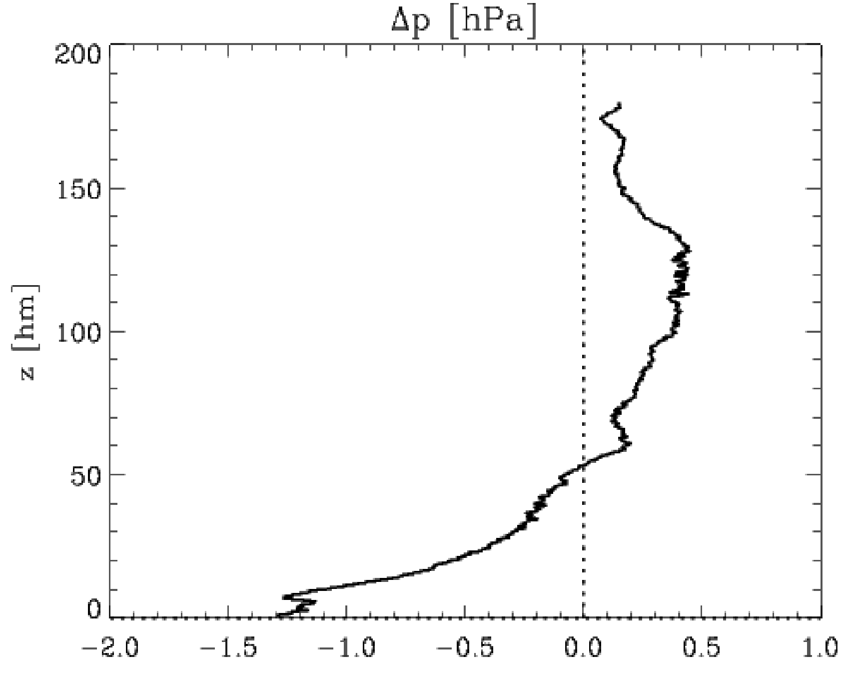
Catch-up from last lecture: observations and reanalyses in the EBUS

Synoptic-scale frontal forcing can dominate short time scales



Mv

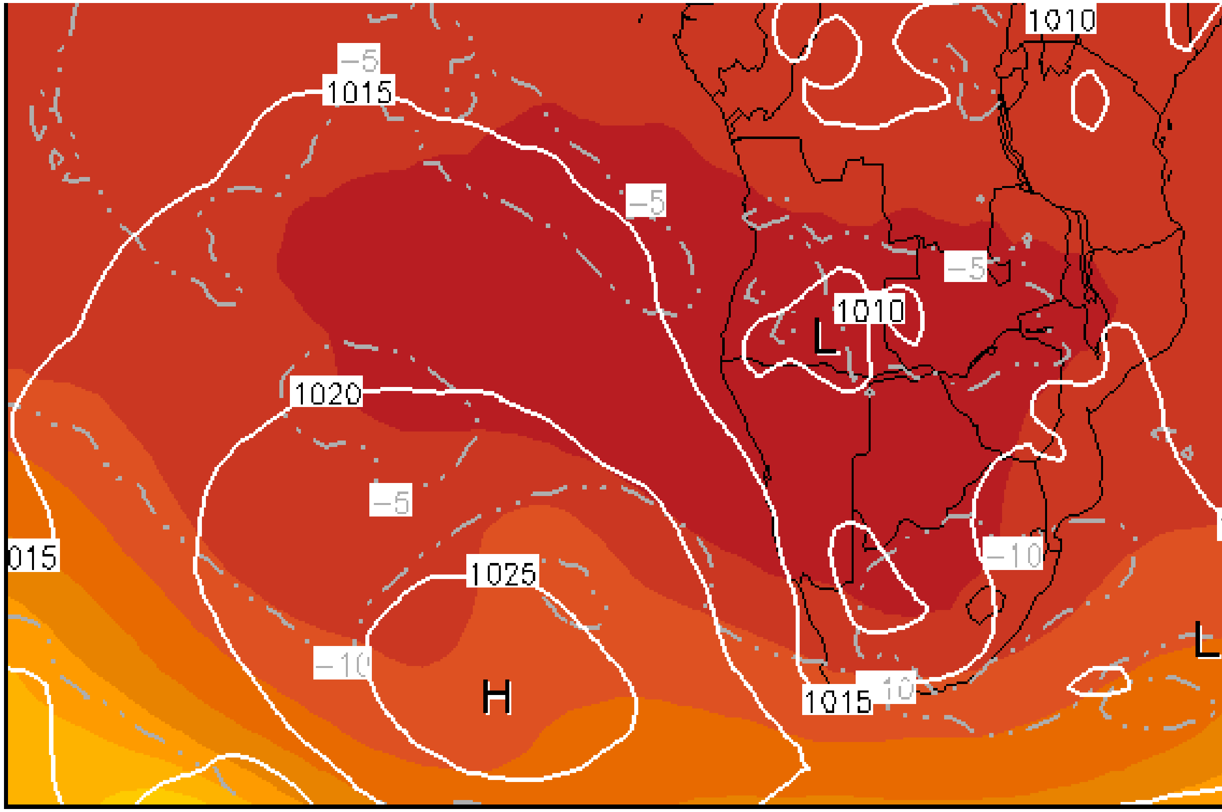





30.11.2017 14:28


30.11.2017 14:57

Init: Thu,30NOV2017 12Z 500 hPa Geopot. (gpdm), T (C), Bodendruck (hPa)



OPERATIONAL 0.250°
zentrale
zentrale.de

Valid: Thu,30NOV2017 12Z

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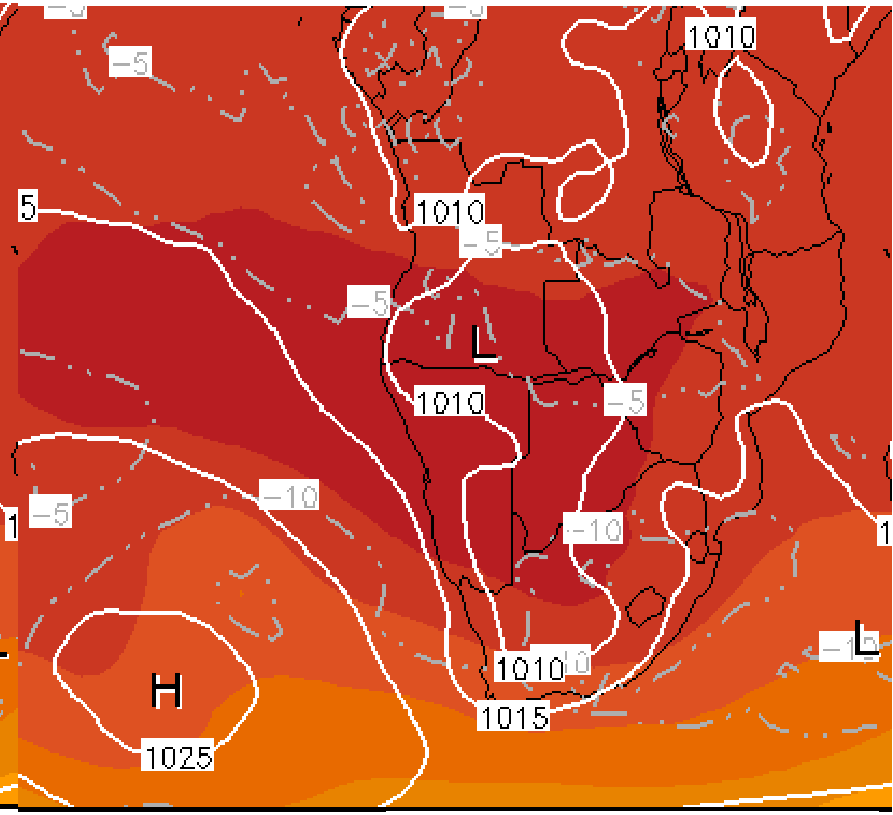

Valid: Thu,30NOV2017 15Z

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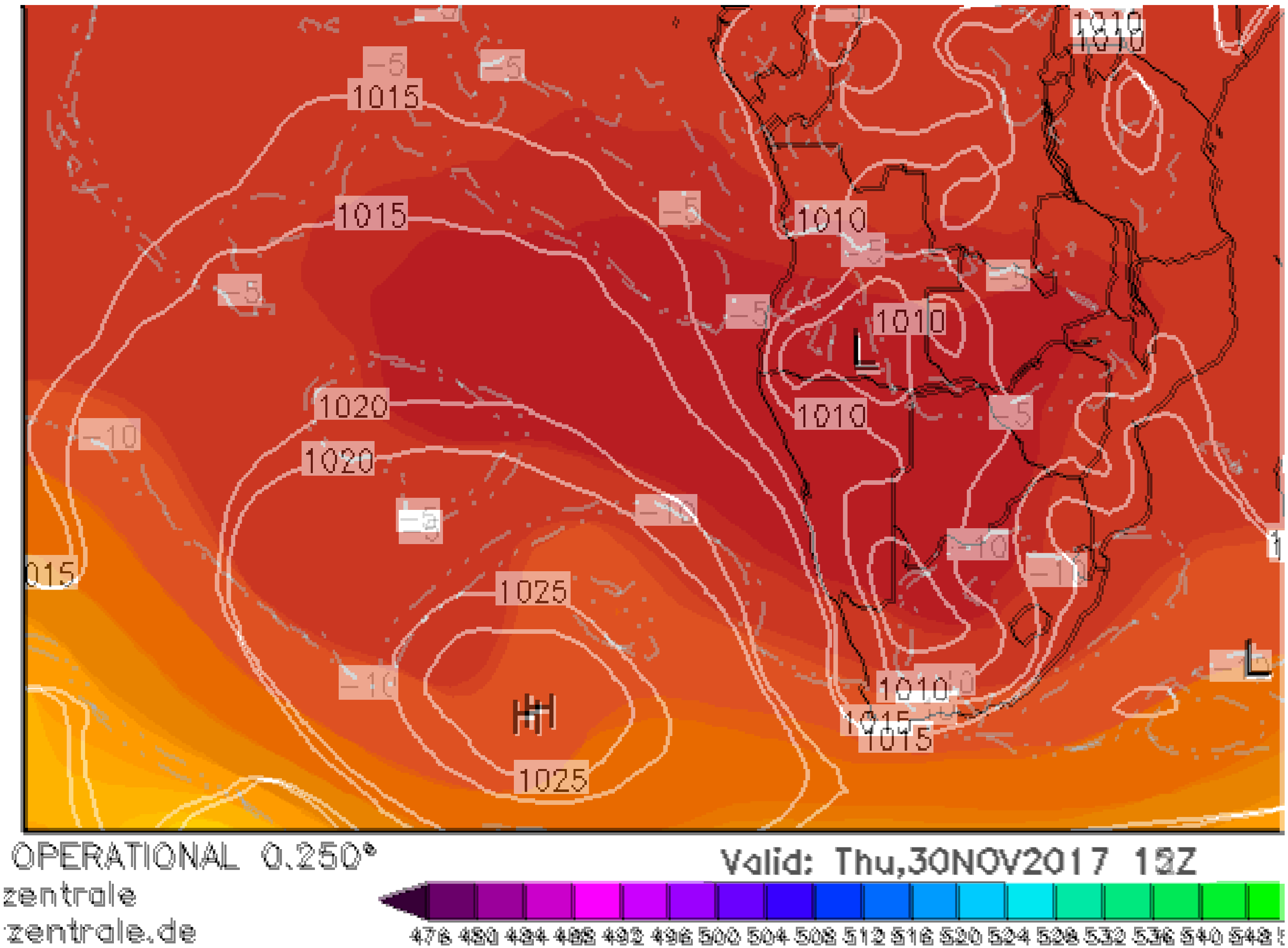
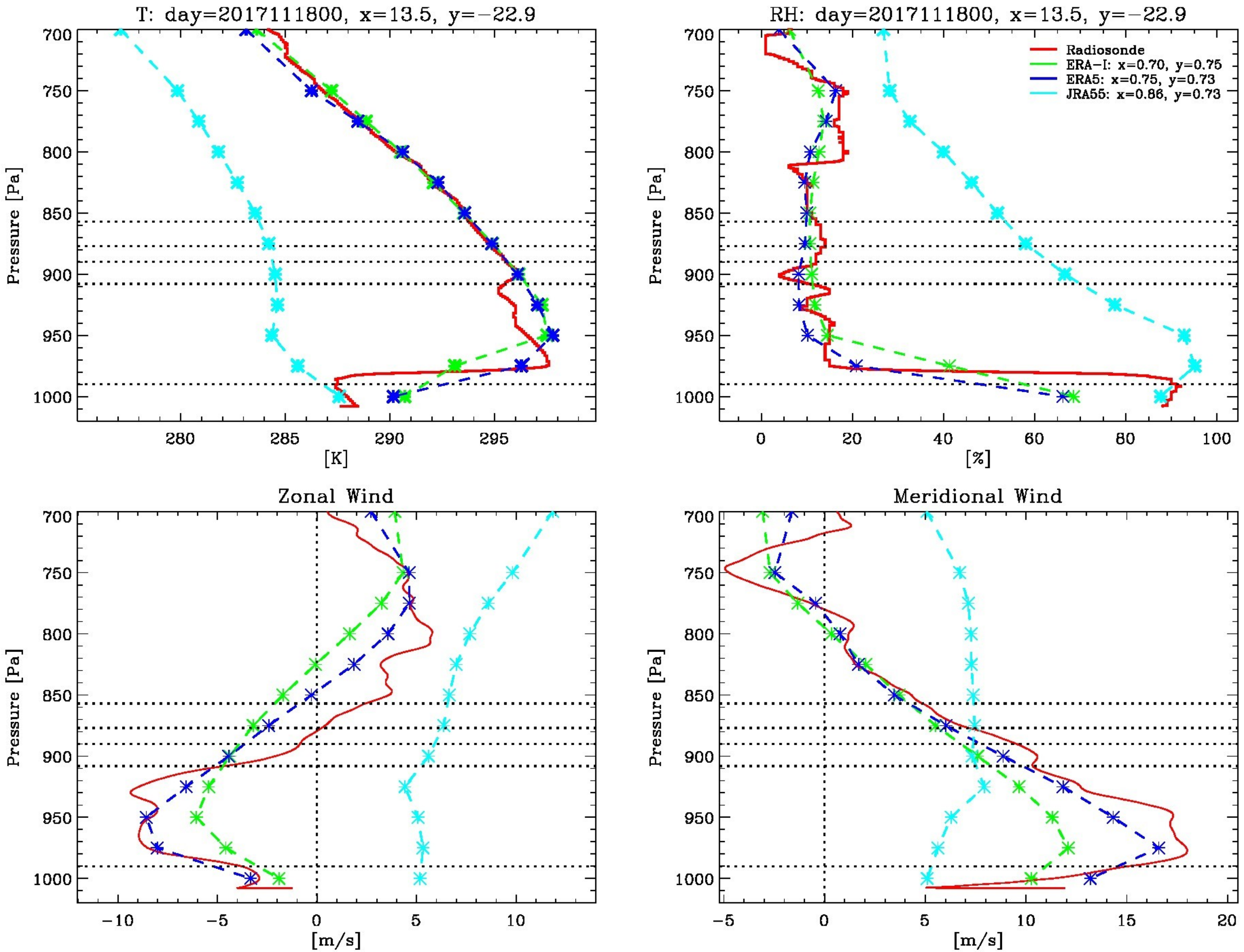
Init: Thu,30NOV2017 12Z 500 hPa Geopot. (gpdm), T (C), Bodendruck (hPa)



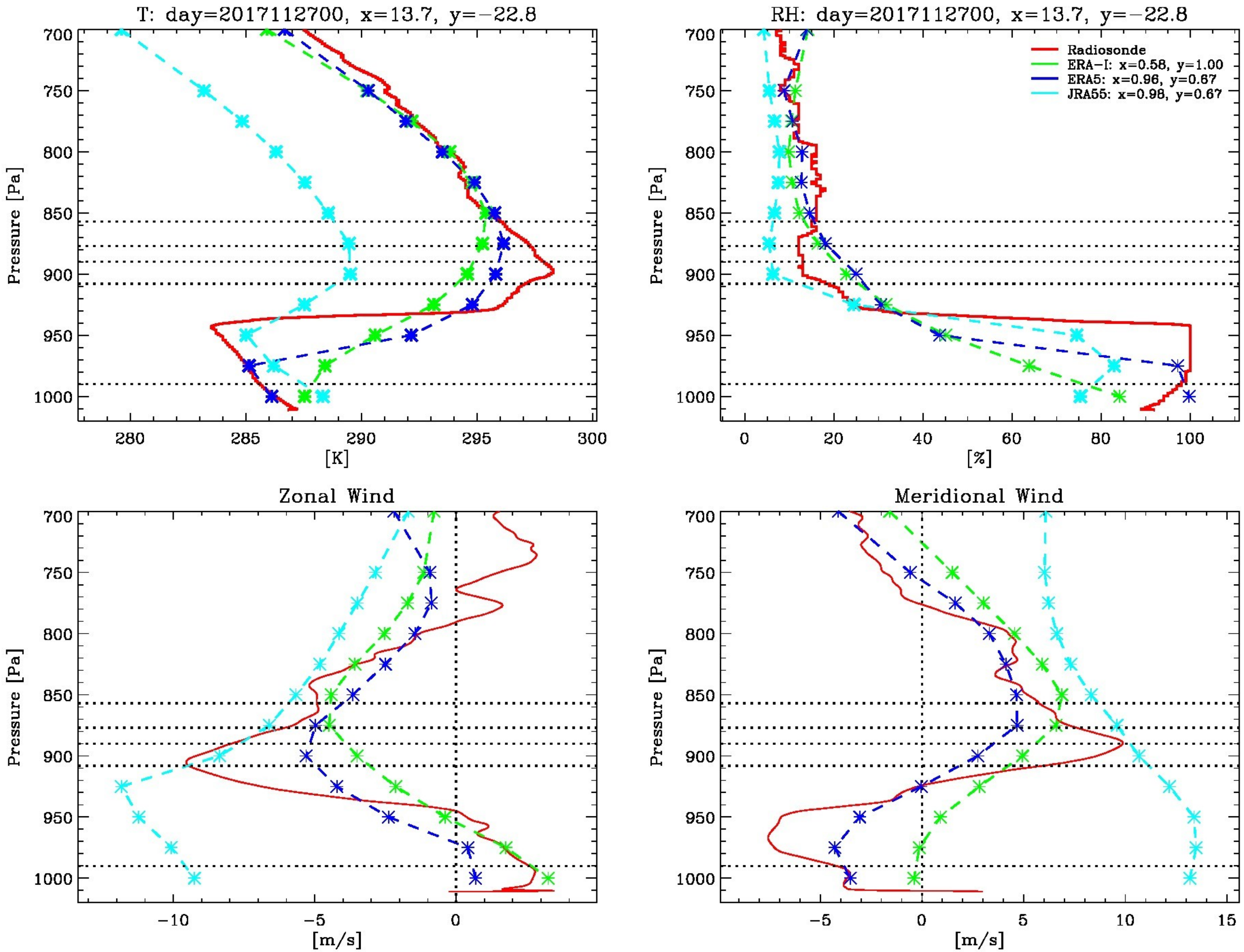
IV. atmospheric observations and models in the EBUS

IV. atmospheric observations and models in the EBUS

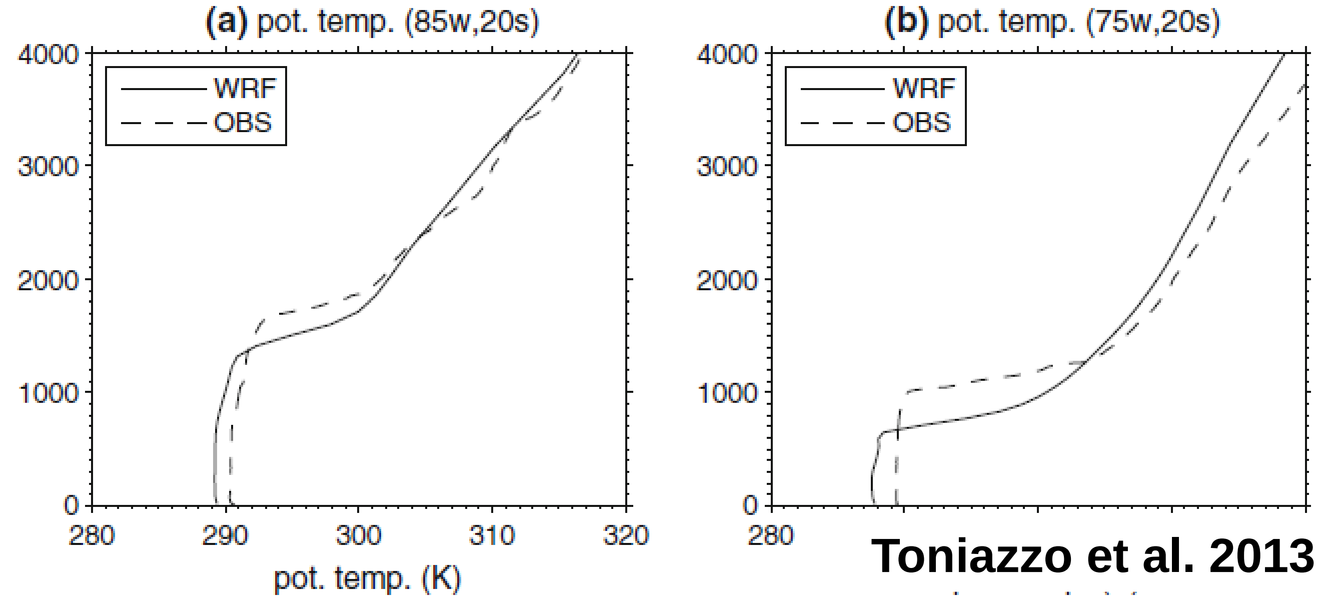
Radiosonde profiles against reanalysis products in the Benguela



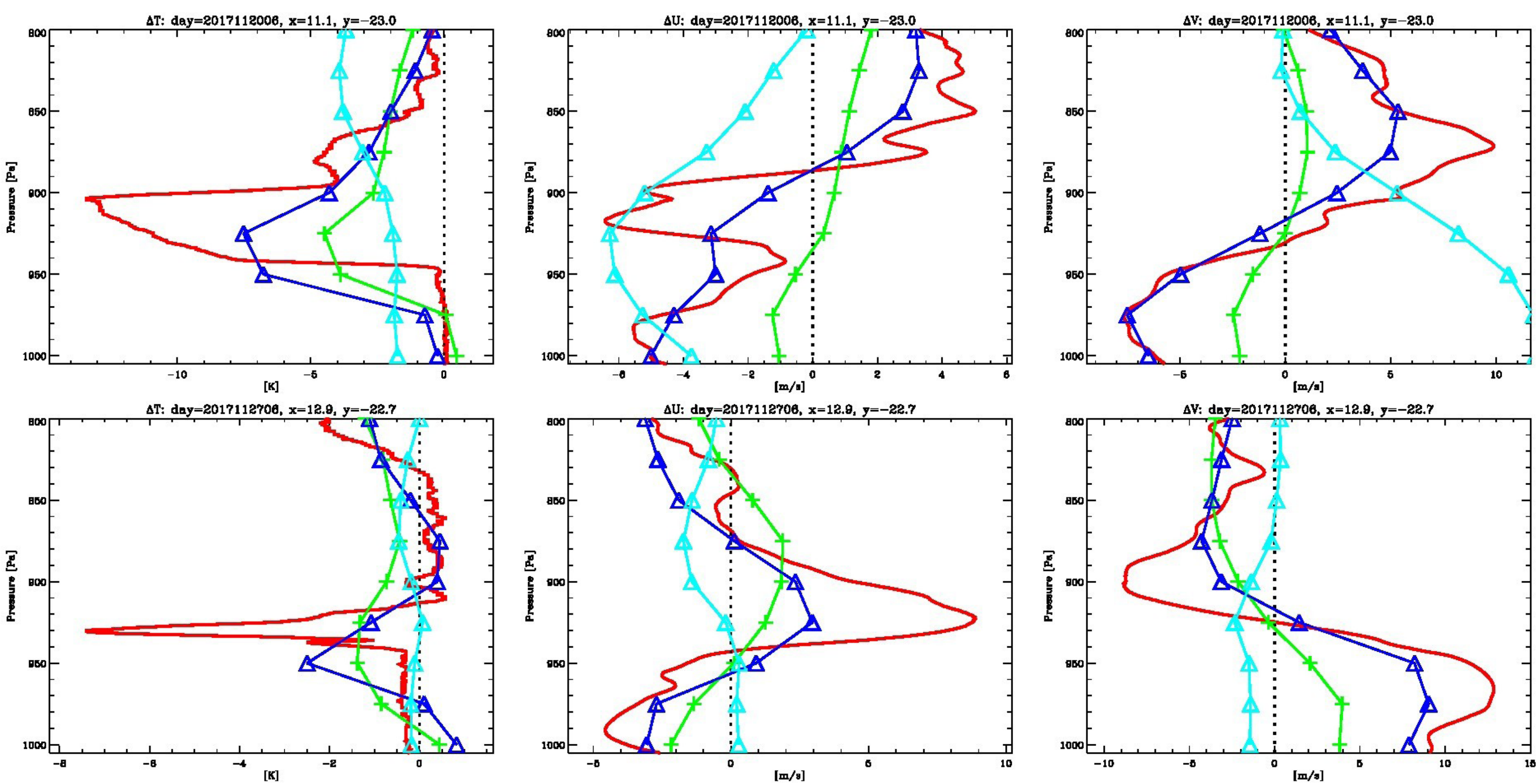
Radiosonde profiles against reanalysis products in the Benguela



The scarcity of in-situ data acquisition in operation product leads to systematic biases in the reanalyses which tend to reflect common model biases.



Toniazzo et al. 2013



by

Kathleen Rhona Peard

Thesis Presented for the Degree of

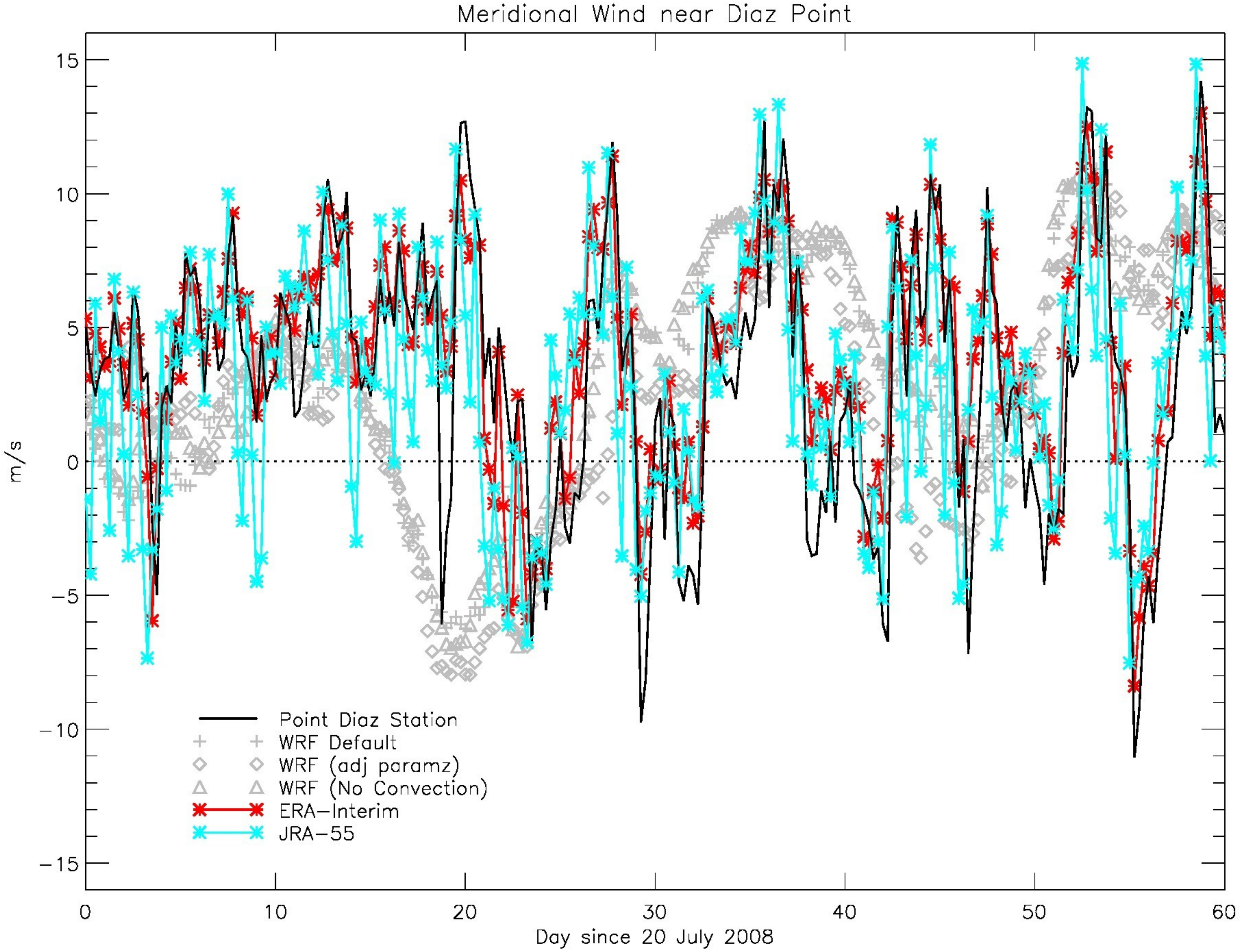
MASTER OF SCIENCE

In the Department of Oceanography

UNIVERSITY OF CAPE TOWN

May 2007

Acquired in-situ wind observations (Cape Diaz, Luedritz)



Courtesy: Jean-Paul Roux

A recent *intercomparison* of reanalysis and satellite products

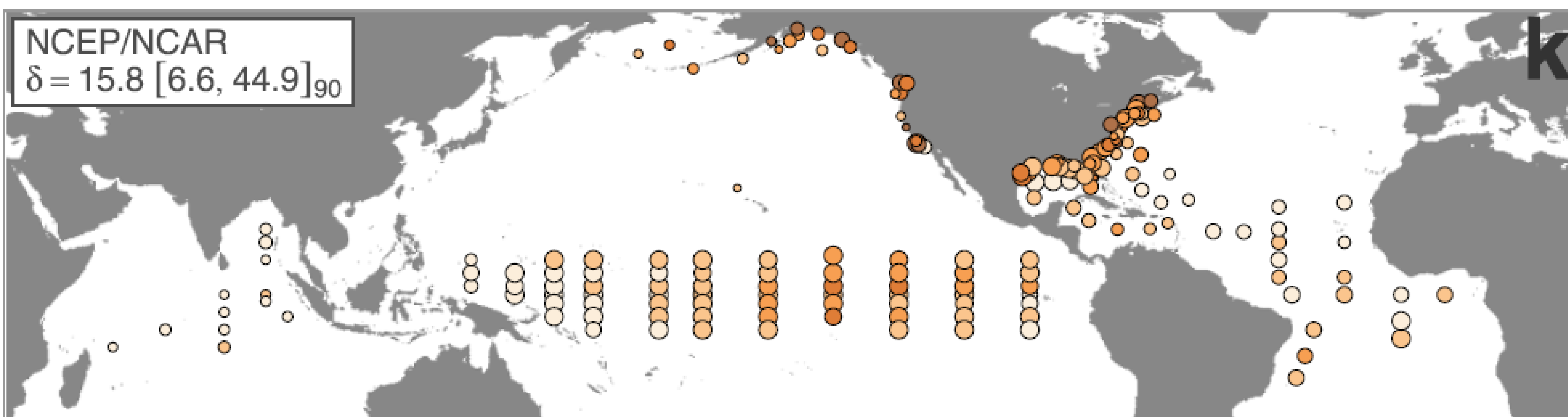
Contents lists available at ScienceDirect

Ocean Modelling

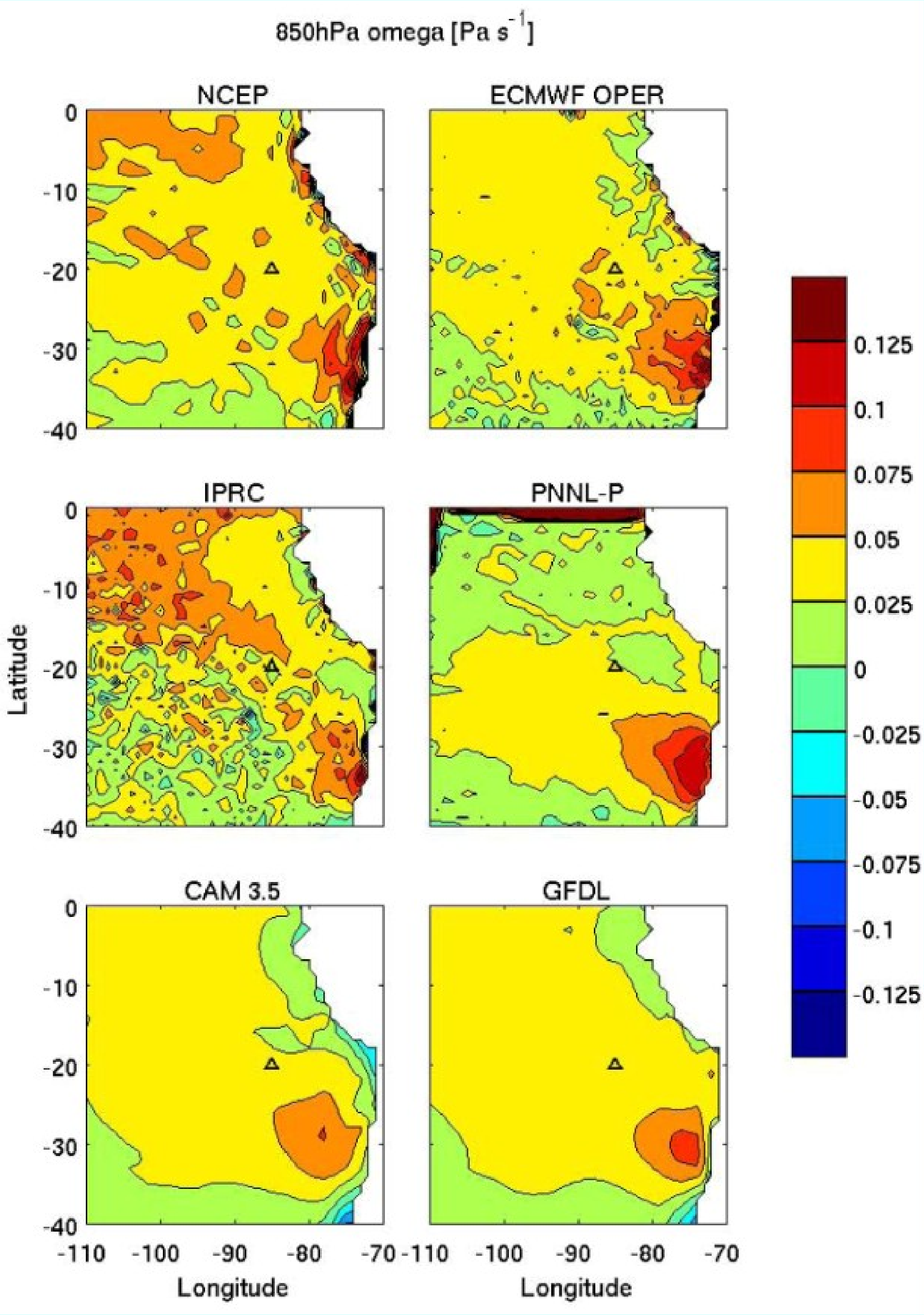
journal homepage: www.elsevier.com/locate/ocemod

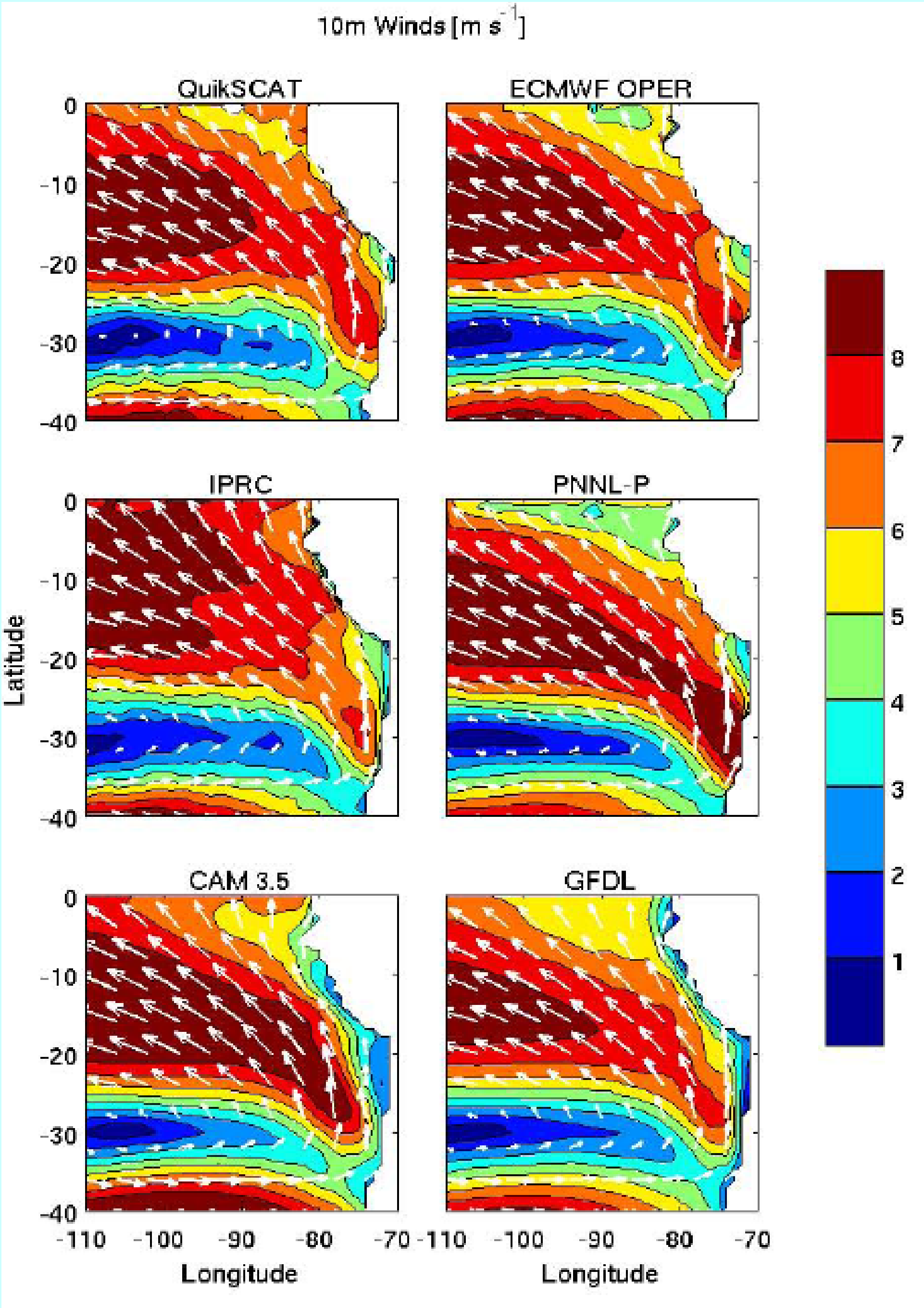
Surface winds from atmospheric reanalysis lead to contrasting oceanic forcing and coastal upwelling patterns

Fernando G. Taboada[*,a,b], Charles A. Stock[a], Stephen M. Griffies[a], John Dunne[a], Jasmin G. John[a], R. Justin Small[c], Hiroyuki Tsujino[d]



However...





Wyant et al. 2010 (PreVOCA)

Klein et al. 2017

Table 1 Most prominent cloud-controlling factors affecting tropical low clouds, their physical explanation, and their support from observational and large-eddy simulation modeling studies

Cloud-controlling factor	Physical explanation	Observational support	Modeling support
Strengthened inversion stability	Reduced mixing across inversion keeps boundary layer shallower, more humid and more cloudy	Wood and Bretherton (2006)	Bretherton et al. (2013)
Reduced subsidence	Deeper boundary layer increases cloud	Myers and Norris (2013)	Blossey et al. (2013)
Increased horizontal cold advection	Greater destabilization of the surface–atmosphere interface increases upward buoyancy flux promoting more clouds	Norris and Iacobellis (2005)	N/A
Increased free-tropospheric humidity	Entrainment drying is reduced, thus moistening the boundary layer and increasing cloud	M16	van der Dussen et al. (2015)
Decreased downward longwave radiation	Reduced downward longwave radiation increases cloud-top radiative cooling, driving more turbulence supporting cloud	Christensen et al. (2013)	Bretherton et al. (2013)
Colder Sea-surface temperature (*SST*)	Colder temperature reduces the efficiency of entrainment necessitating more cloud to produce a given entrainment rate	Q15	Bretherton and Blossey (2014)
Increased surface wind speed	Increased surface driven shear mixing increases latent heat flux and cloud	Brueck et al. (2015)	Bretherton et al. (2013)

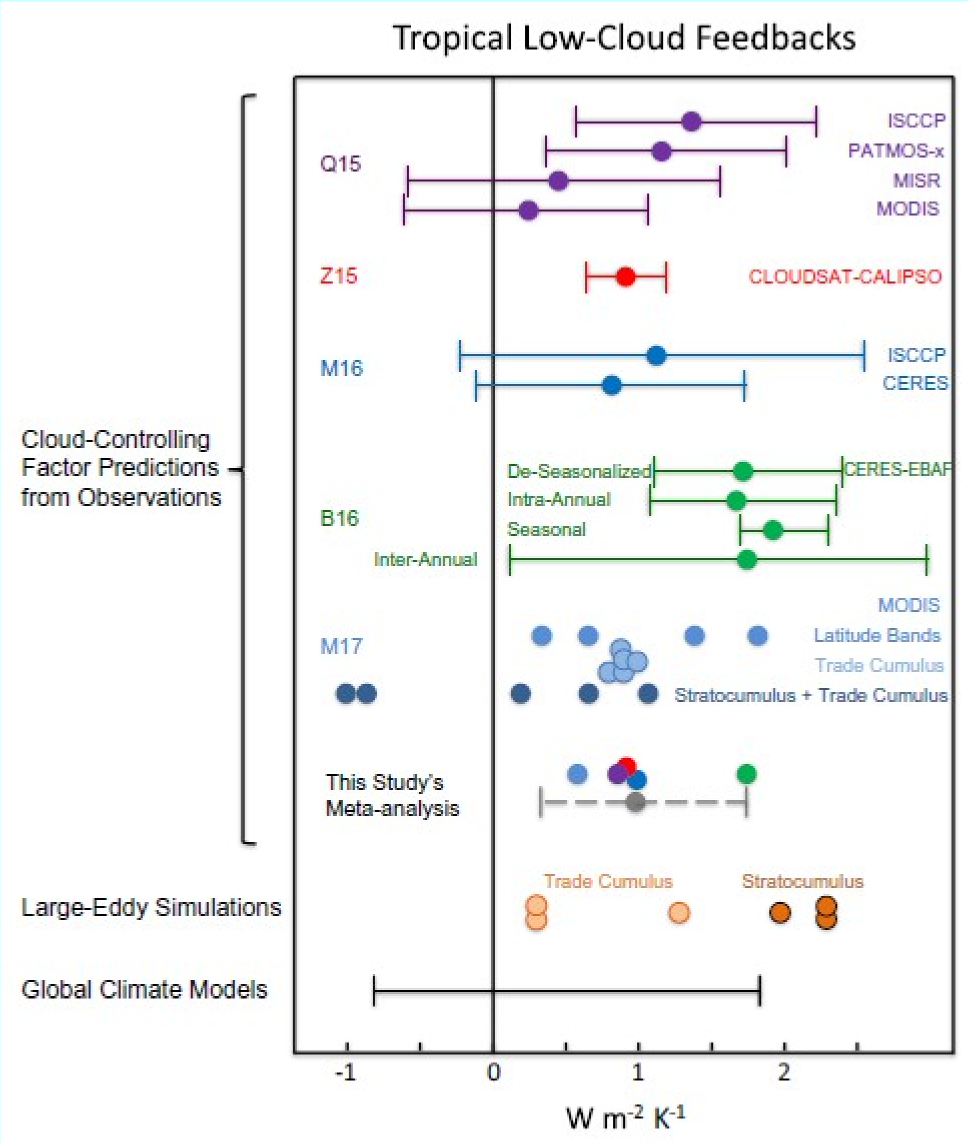


Fig. 3 Values of local tropical low-cloud feedbacks predicted from recent observational studies, large-eddy simulations and global climate models. Local feedbacks are defined as the local change in top-of-atmosphere radiation from tropical low clouds per degree increase in global mean surface air temperature. Bar widths for observational studies (unavailable for M17) and this study's meta-analysis represent 90% confidence intervals. Values from individual large-eddy simulation studies are shown. The bar width for global climate models indicates the range of model results. See the "Appendix" for details

this approach [...] relies primarily on observations of the cloud response to controlling factors and does not depend on the simulation of clouds by climate models. (It does rely on model predictions of how the controlling factors change with climate, however).
[...]
Our synthesis of the results from these studies is that the contribution of tropical low clouds to the global mean cloud feedback is 0.25 ± 0.18 W m-2 K-1
[...]
The range of local cloud feedbacks from large-eddy simulations is 0.3–2.3 W m-2 K-1

So, models...

Climate prediction today

Climate prediction today

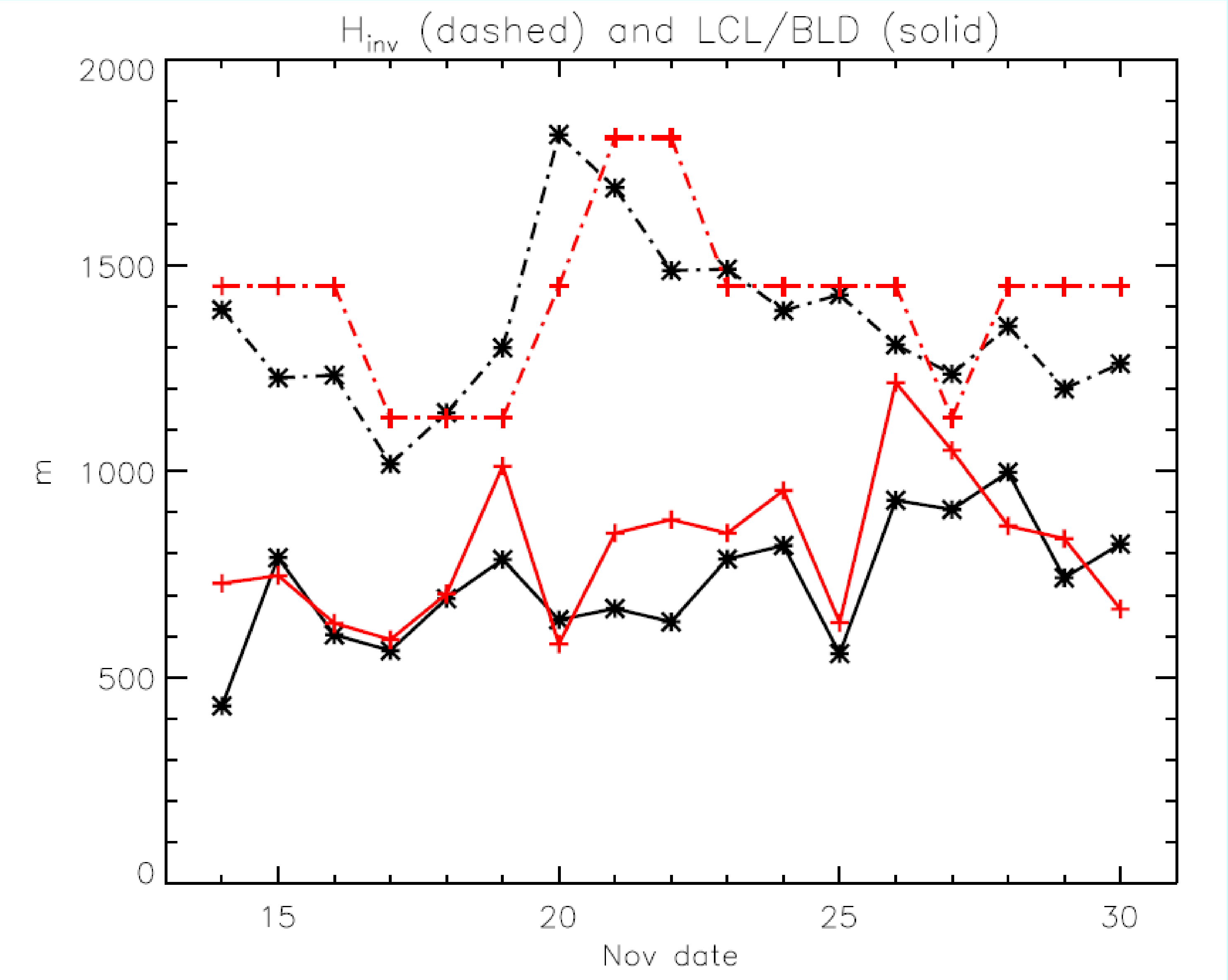
"Model" (e.g. CESM2)

Climate prediction today

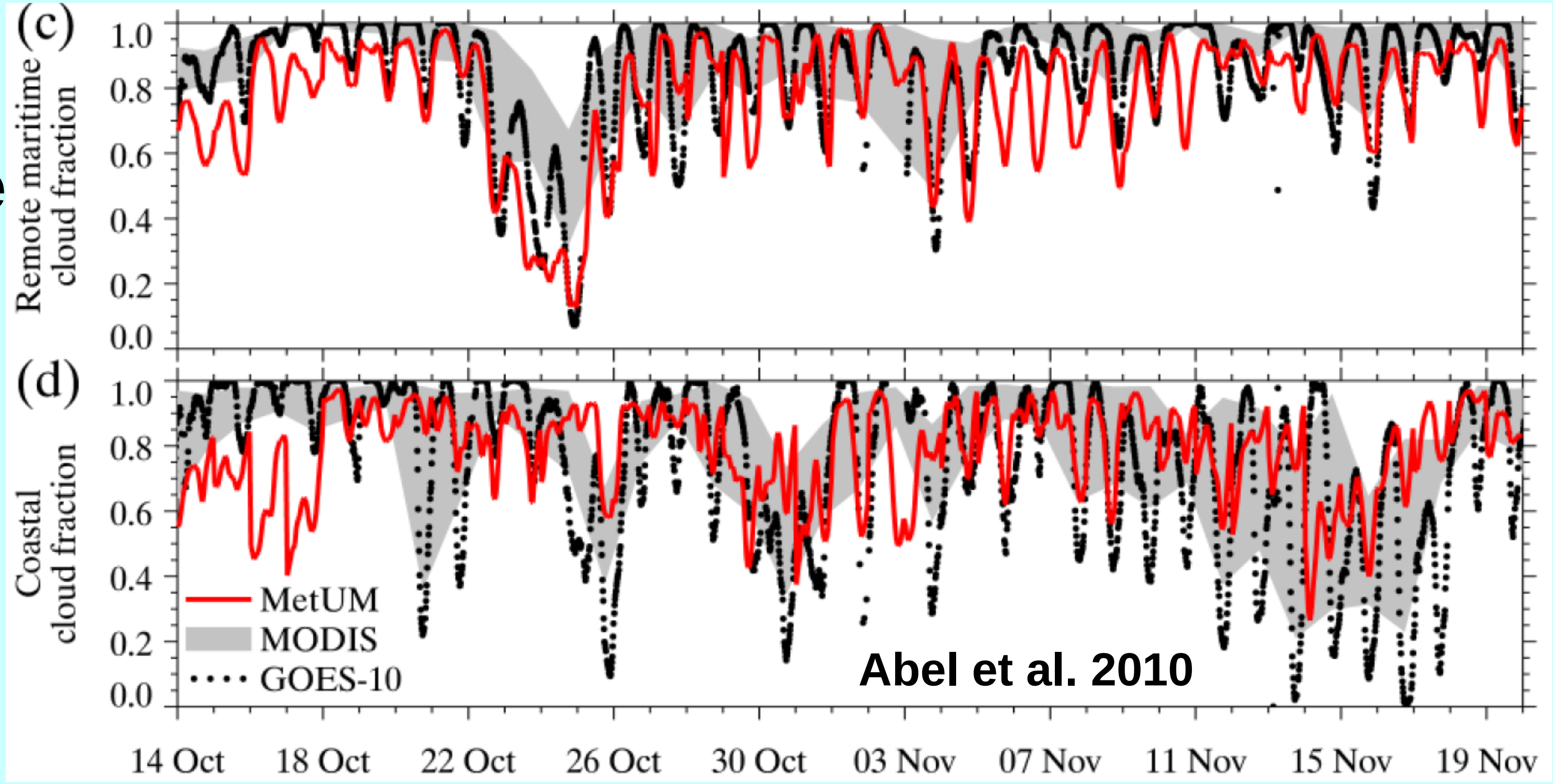
“Model” (e.g. CESM2)

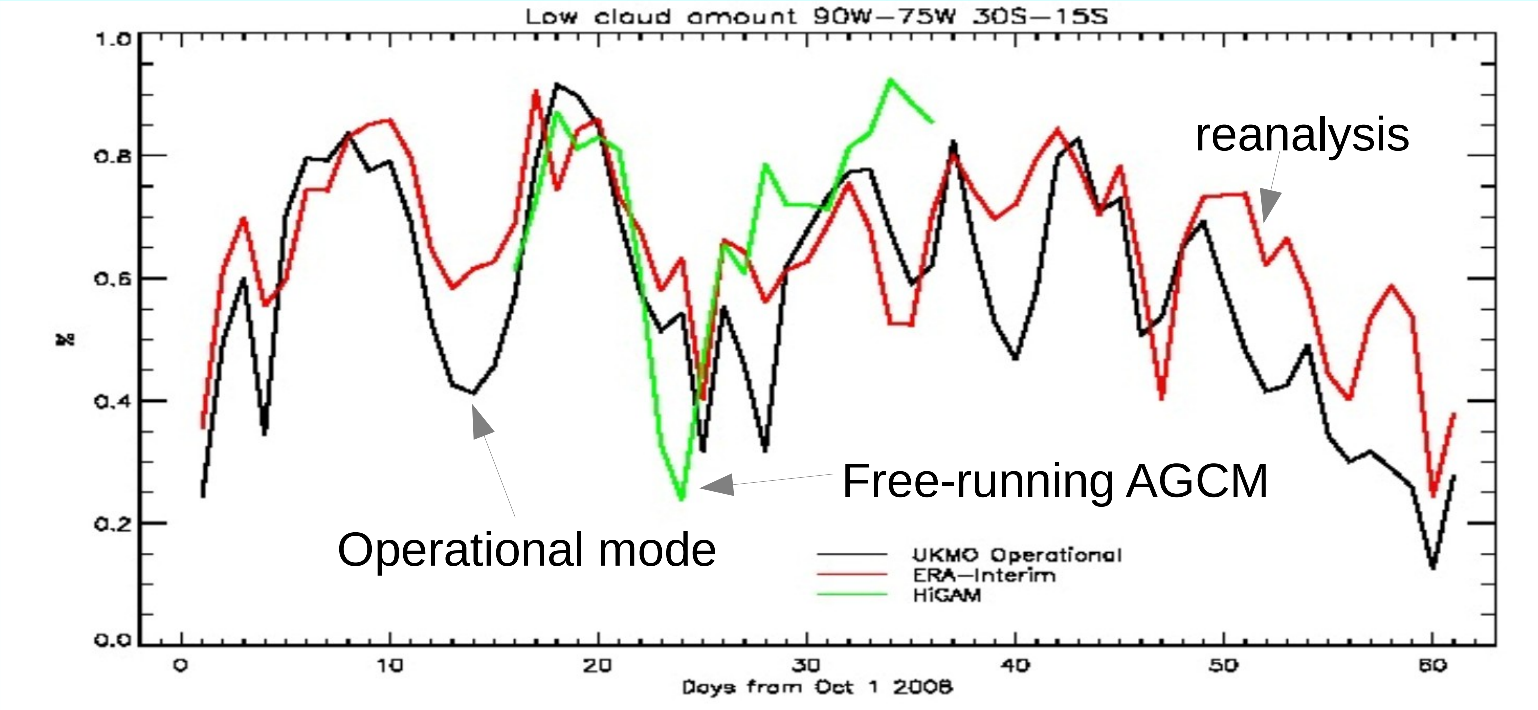
“Scientist” (e.g. me)

The Pacific Sc inversion in forecast models



At least some models are also able to capture the dynamically forced Sc variability





This ability is not critically resolution-dependent

High dynamical complexity

The California Current System

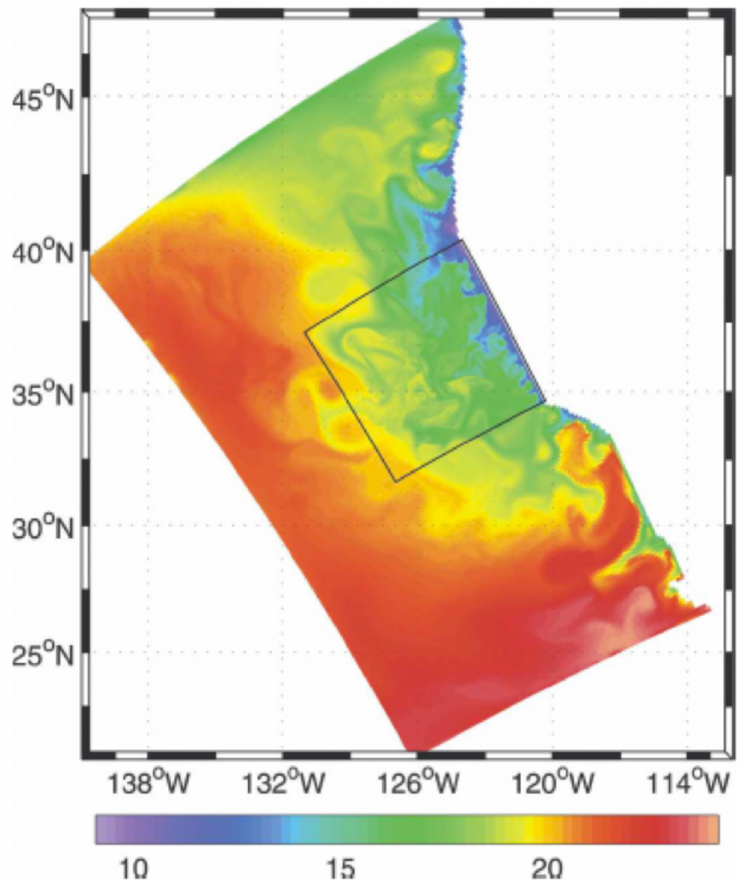
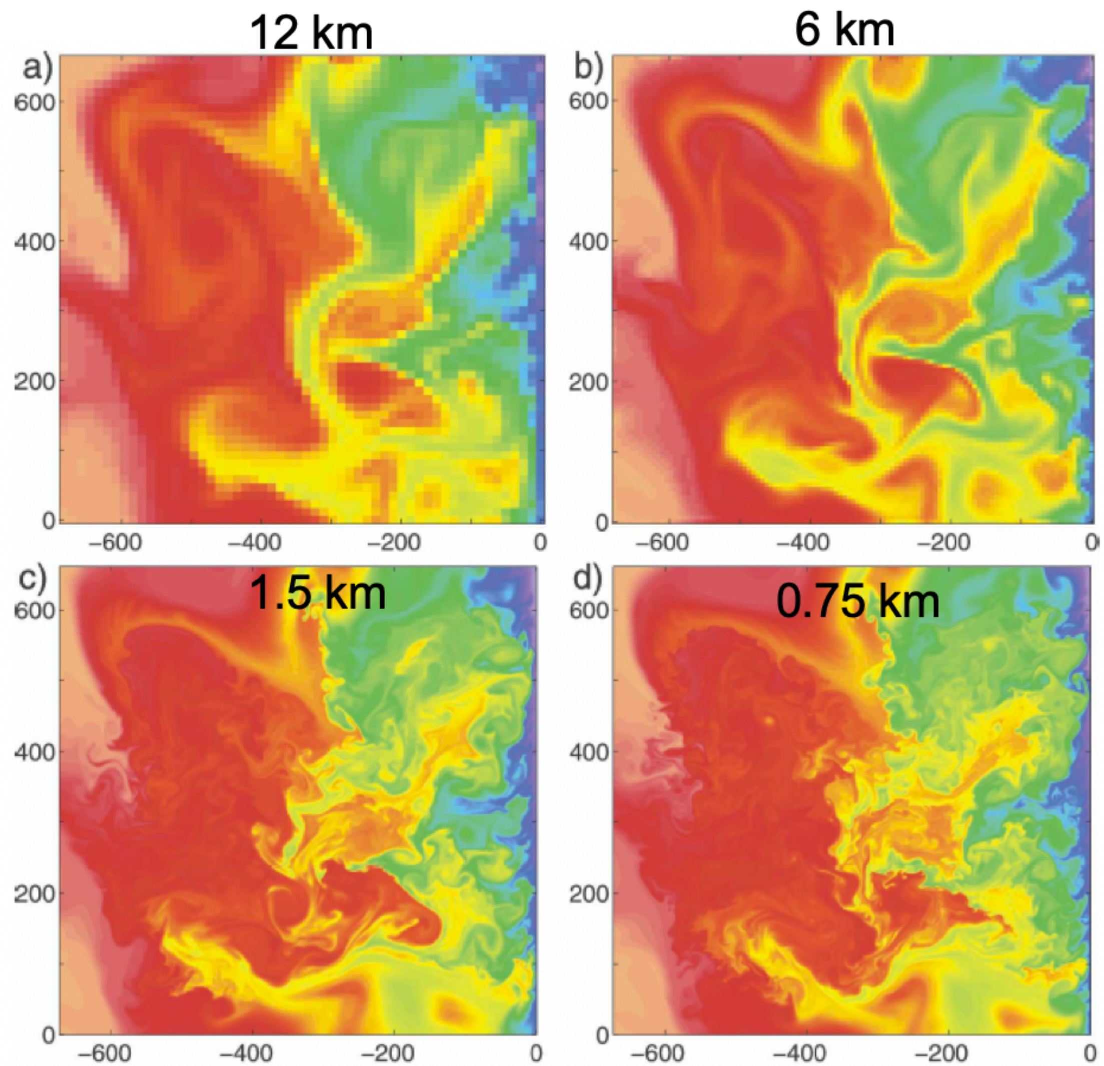
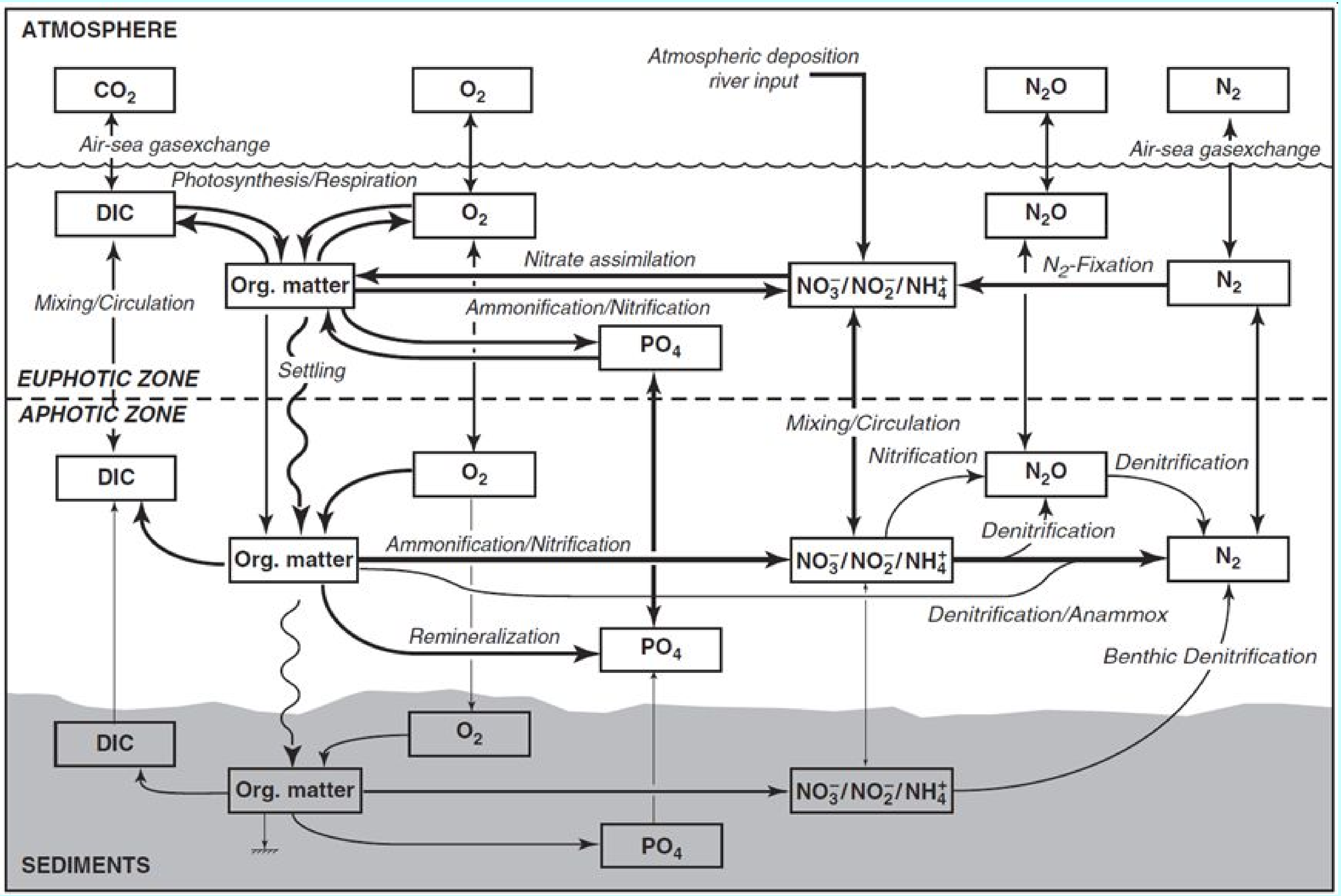


FIG. 1. Instantaneous SST at t = 30 days. The SST computed from ICC3 is superimposed onto the full USW12 field. The boundaries of the ICC domains are delineated by black lines.

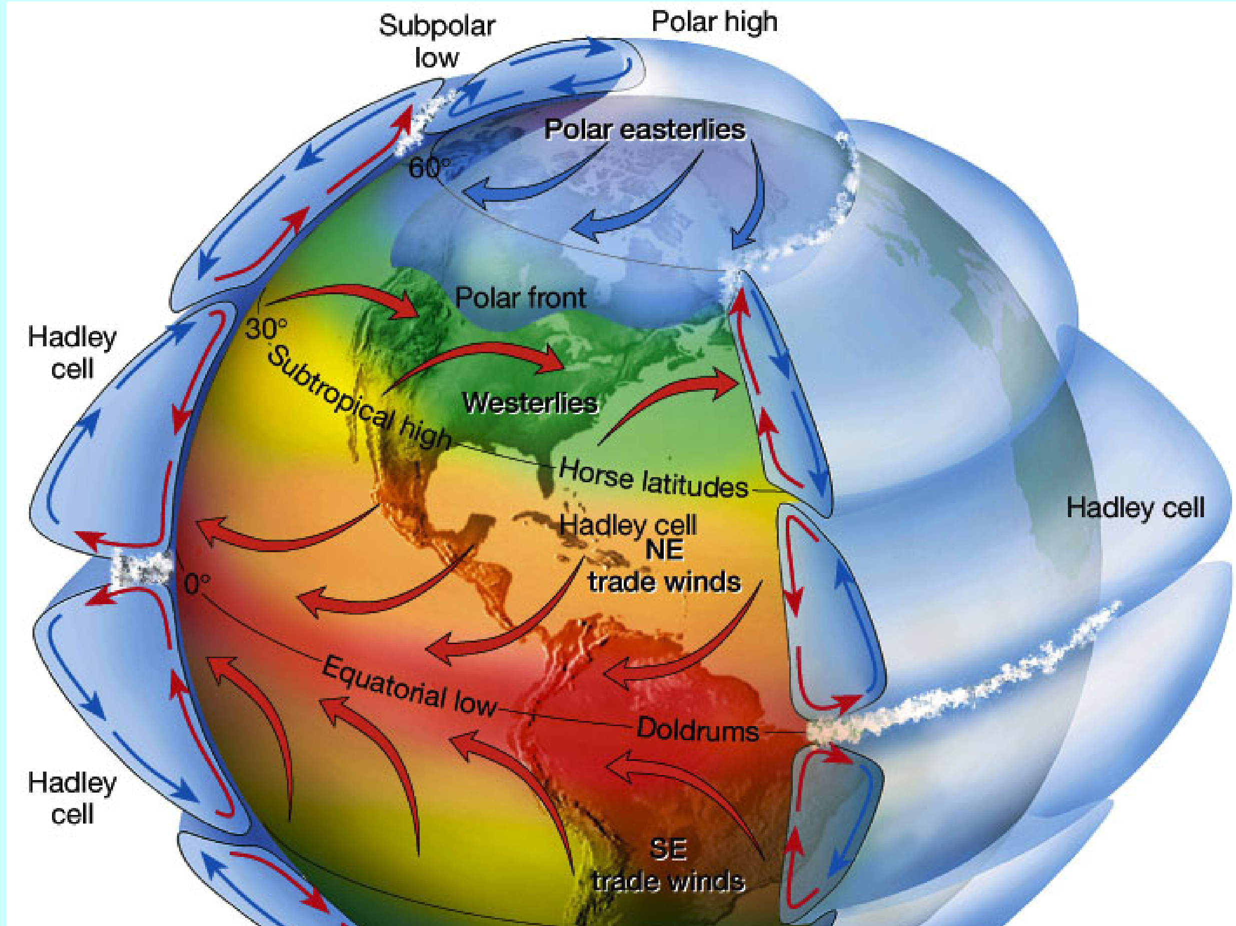


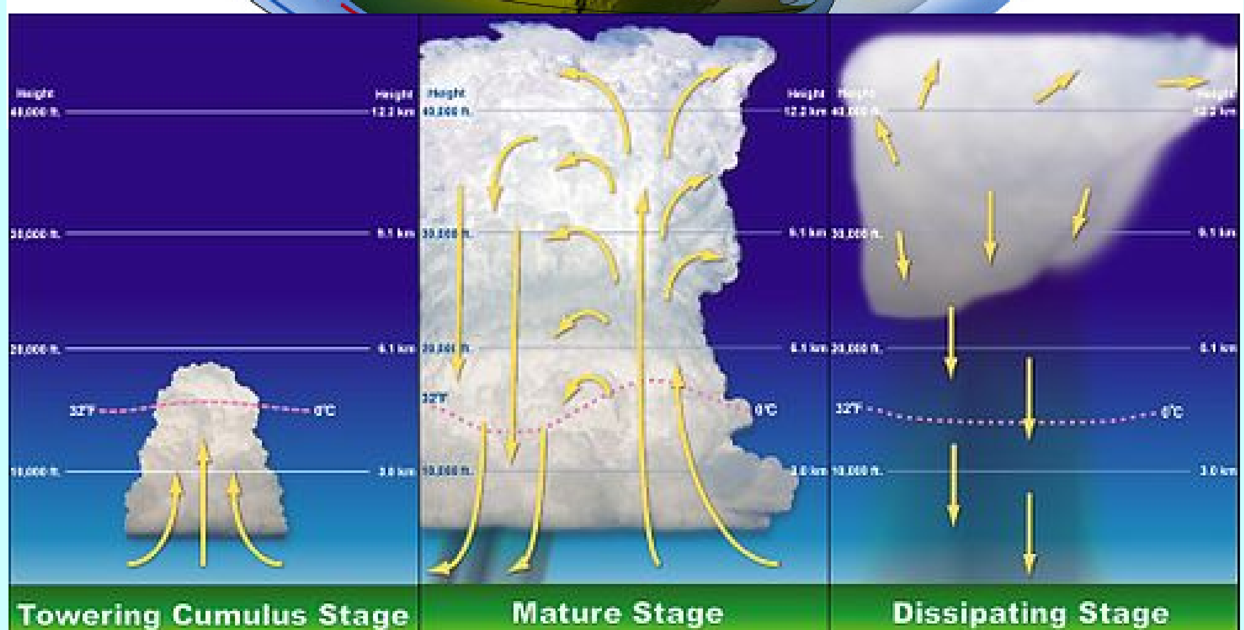
Capet et al, JPO 2008a

High system complexity

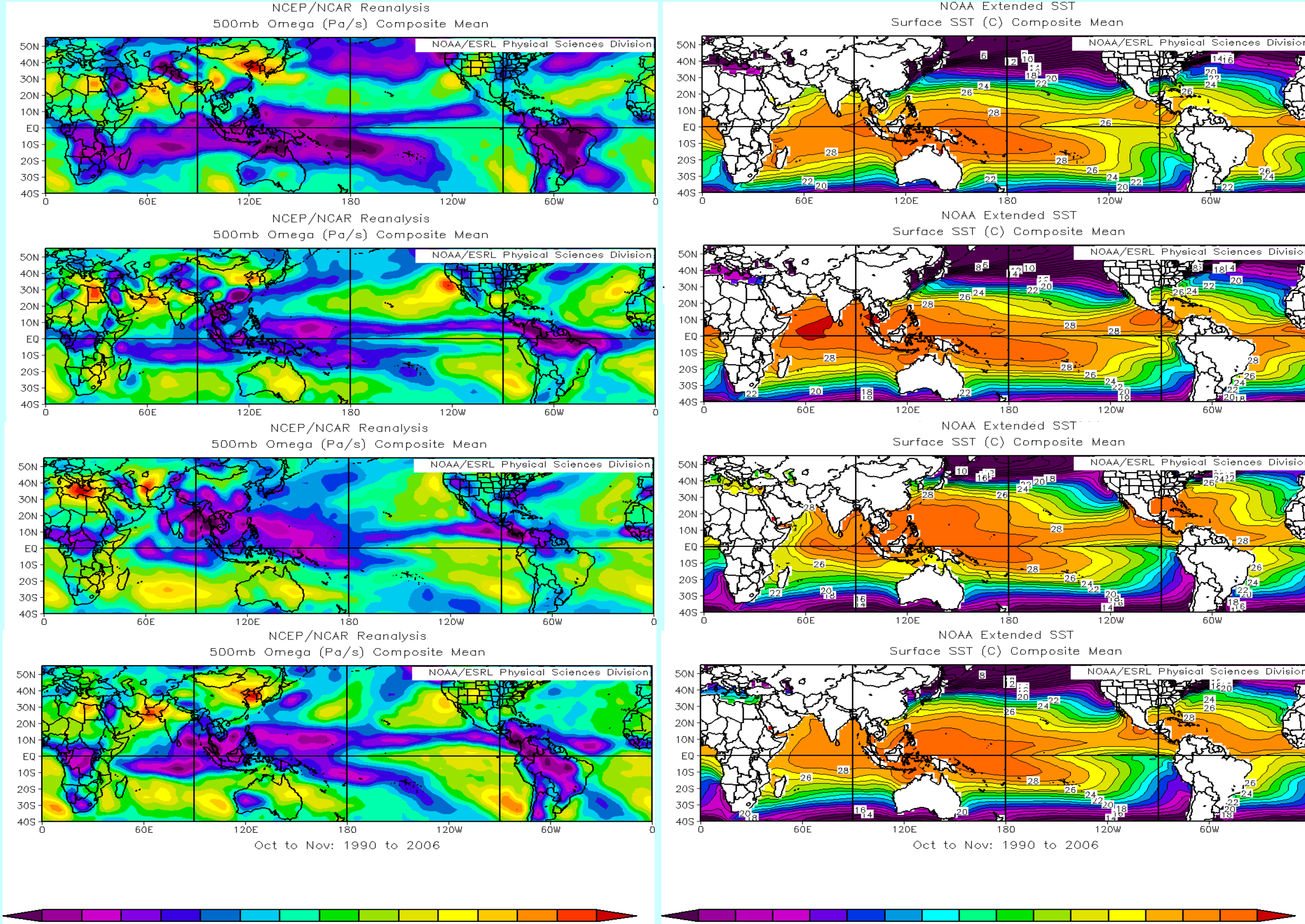


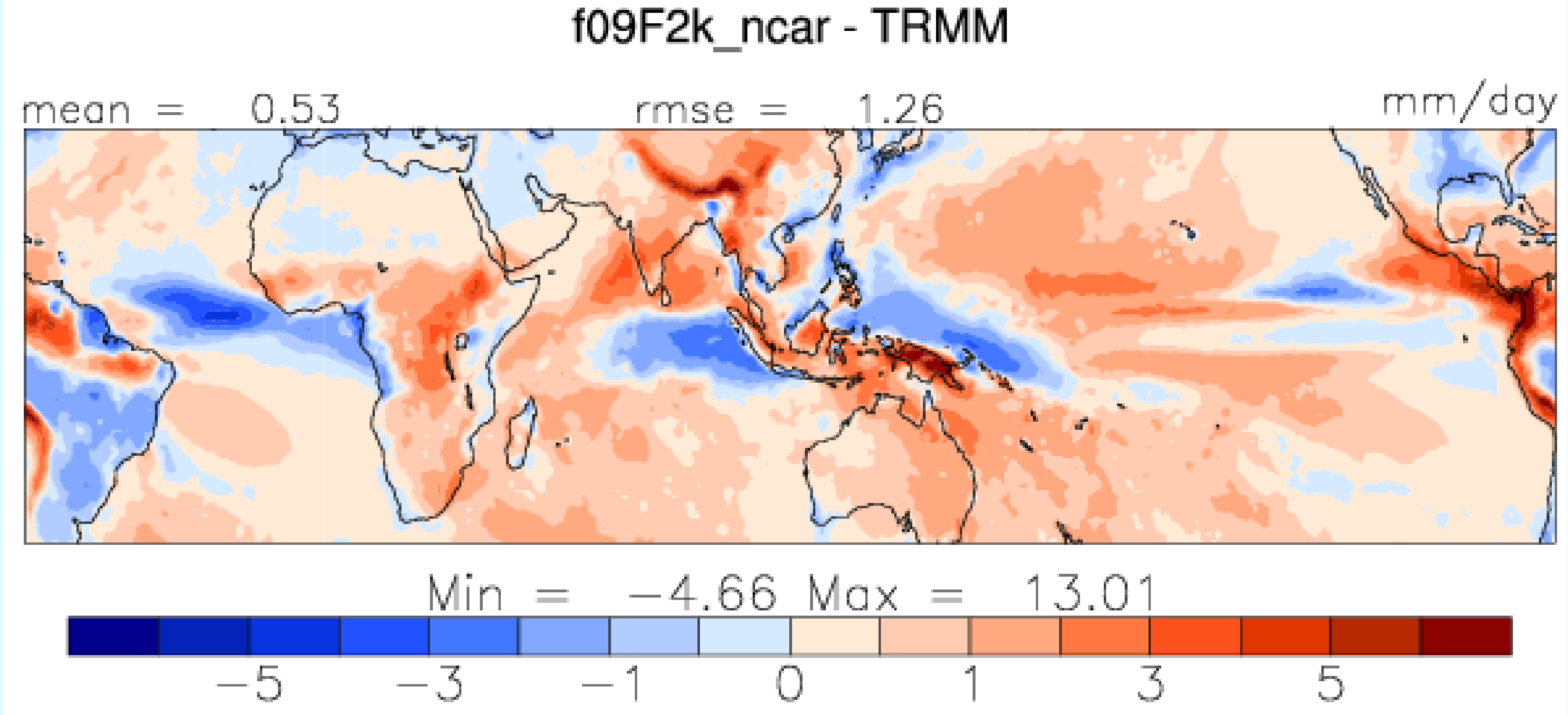
The global circulation and moist convection

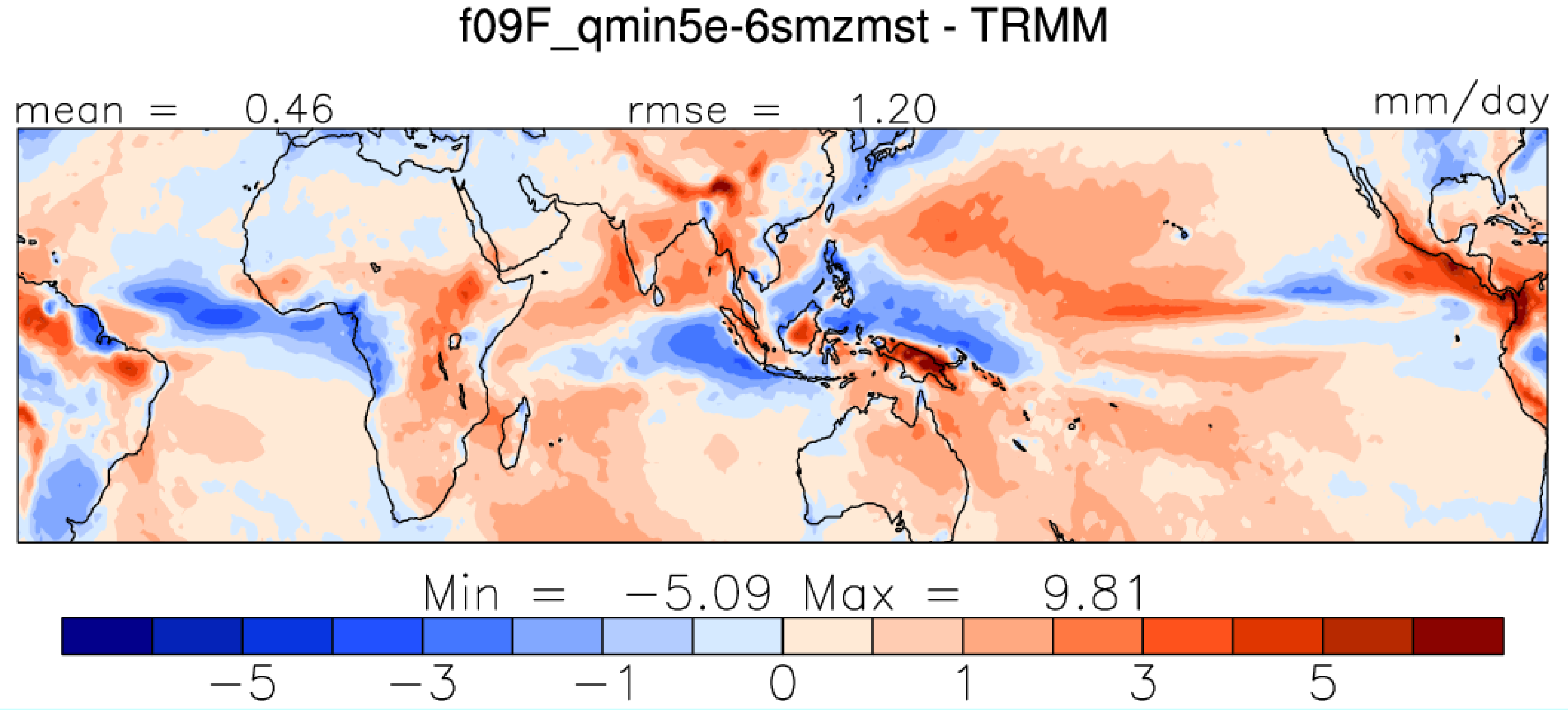




The annual march of the SSTs and of the ITCZ

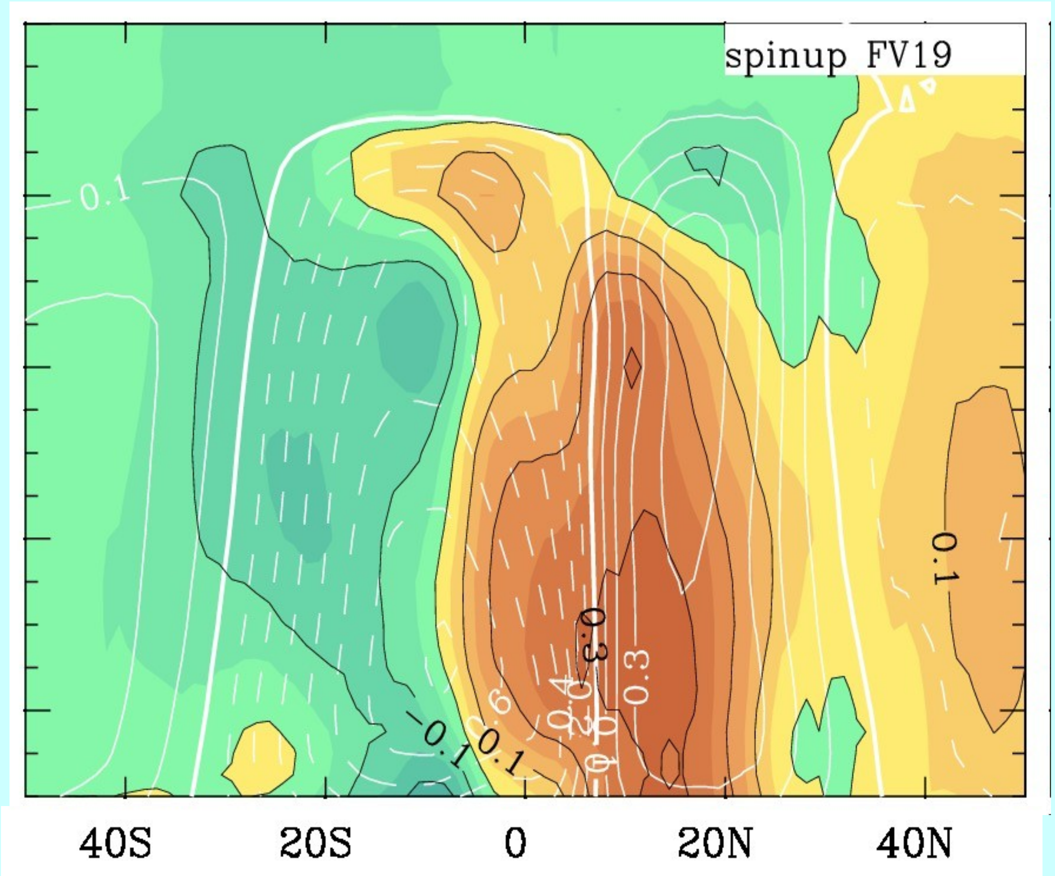


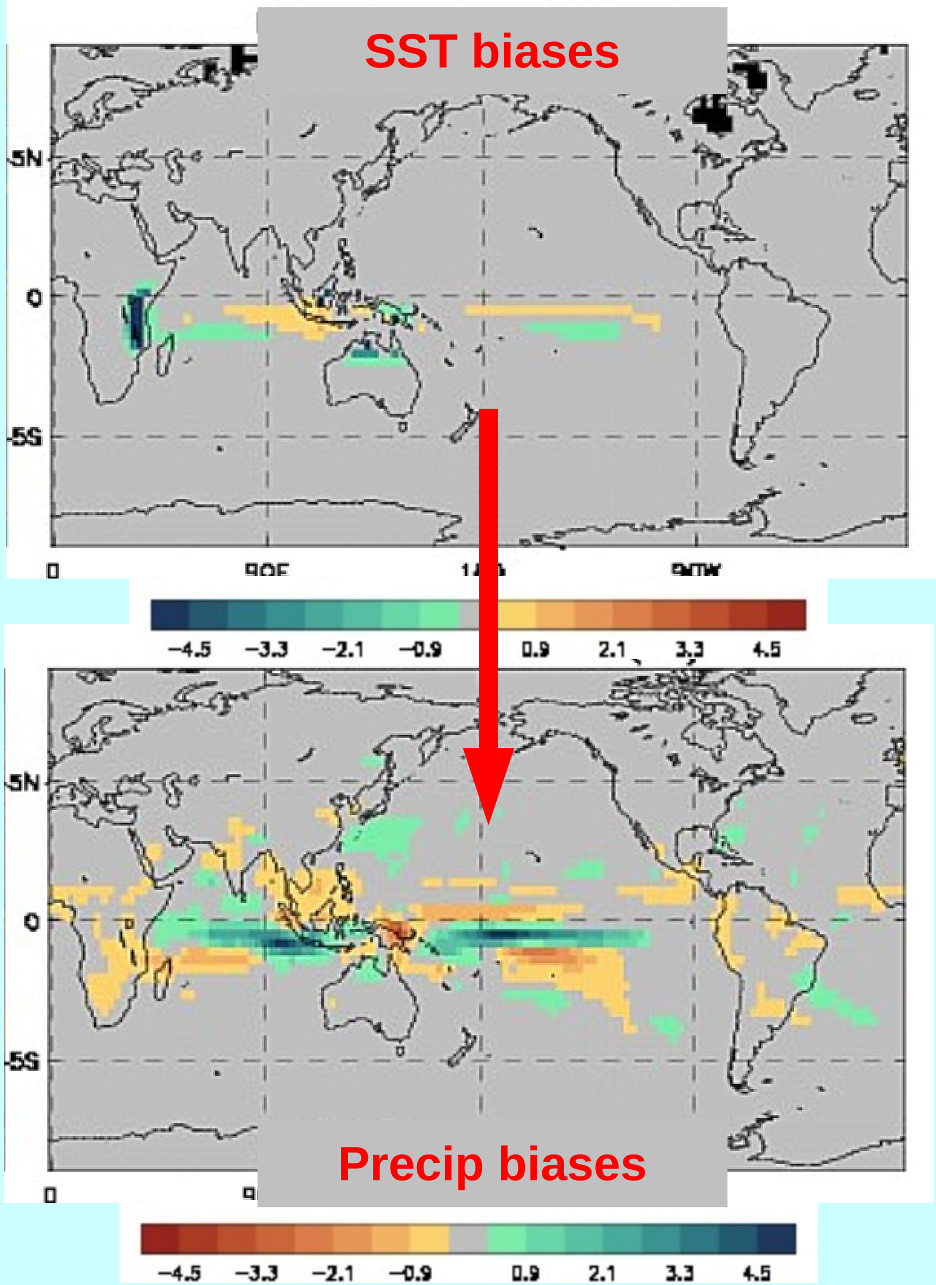

f09F2k_ncar - TRMM
mean = 0.53
rmse = 1.26
mm/day
Min = −4.66 Max = 13.01
−5
−3
−1
0
1
3
5


f09F_qmin5e-6smzmst - TRMM
mean = 0.46
rmse = 1.20
mm/day
Min = −5.09 Max = 9.81
−5
−3
−1
0
1
3
5

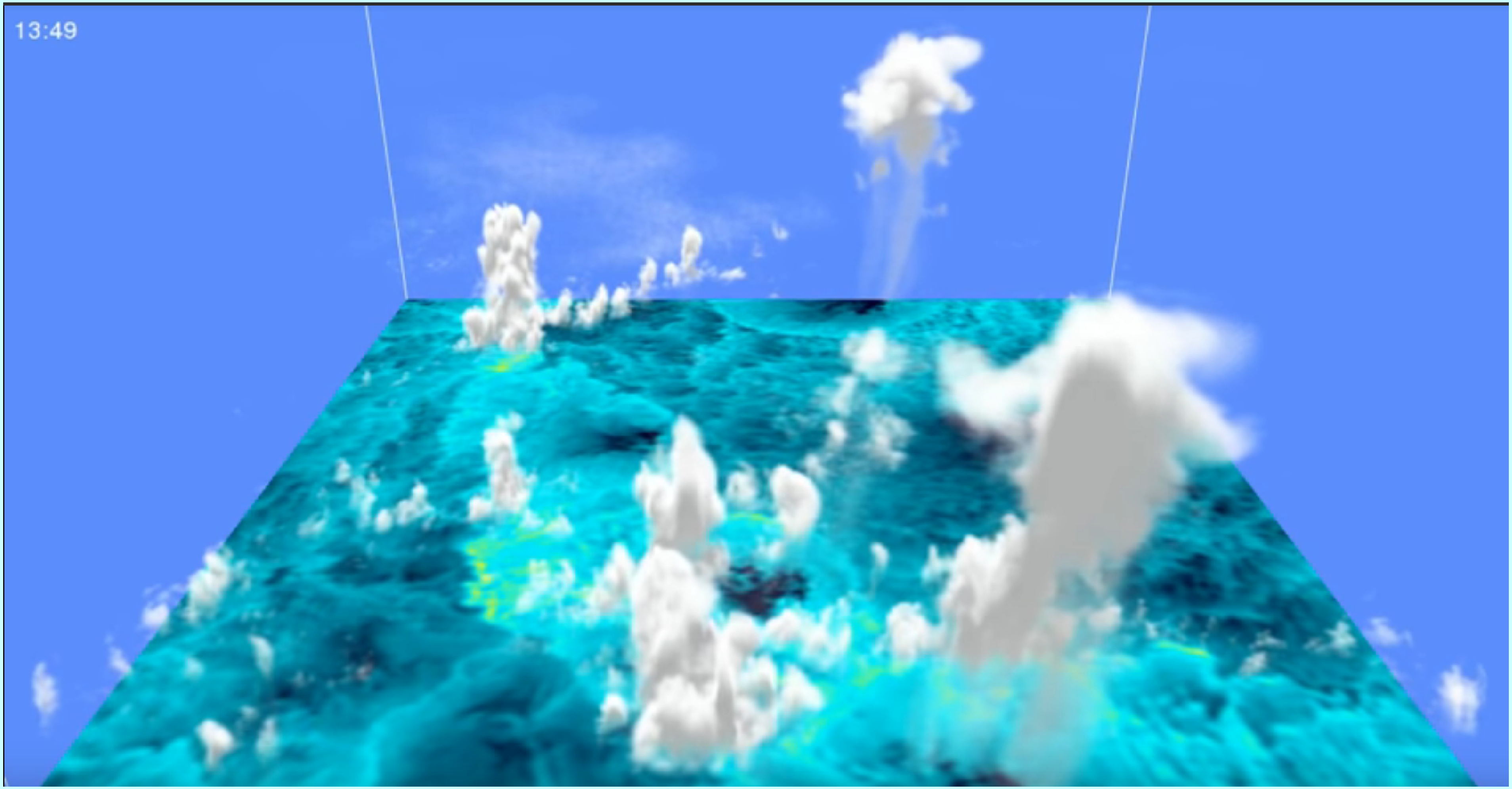
NorESM CAM4 biases

- Hadley circulation too symmetric
- Double ITCZ
- ENSO active predominantly in ASO
- Excessive precip over SA & central Africa



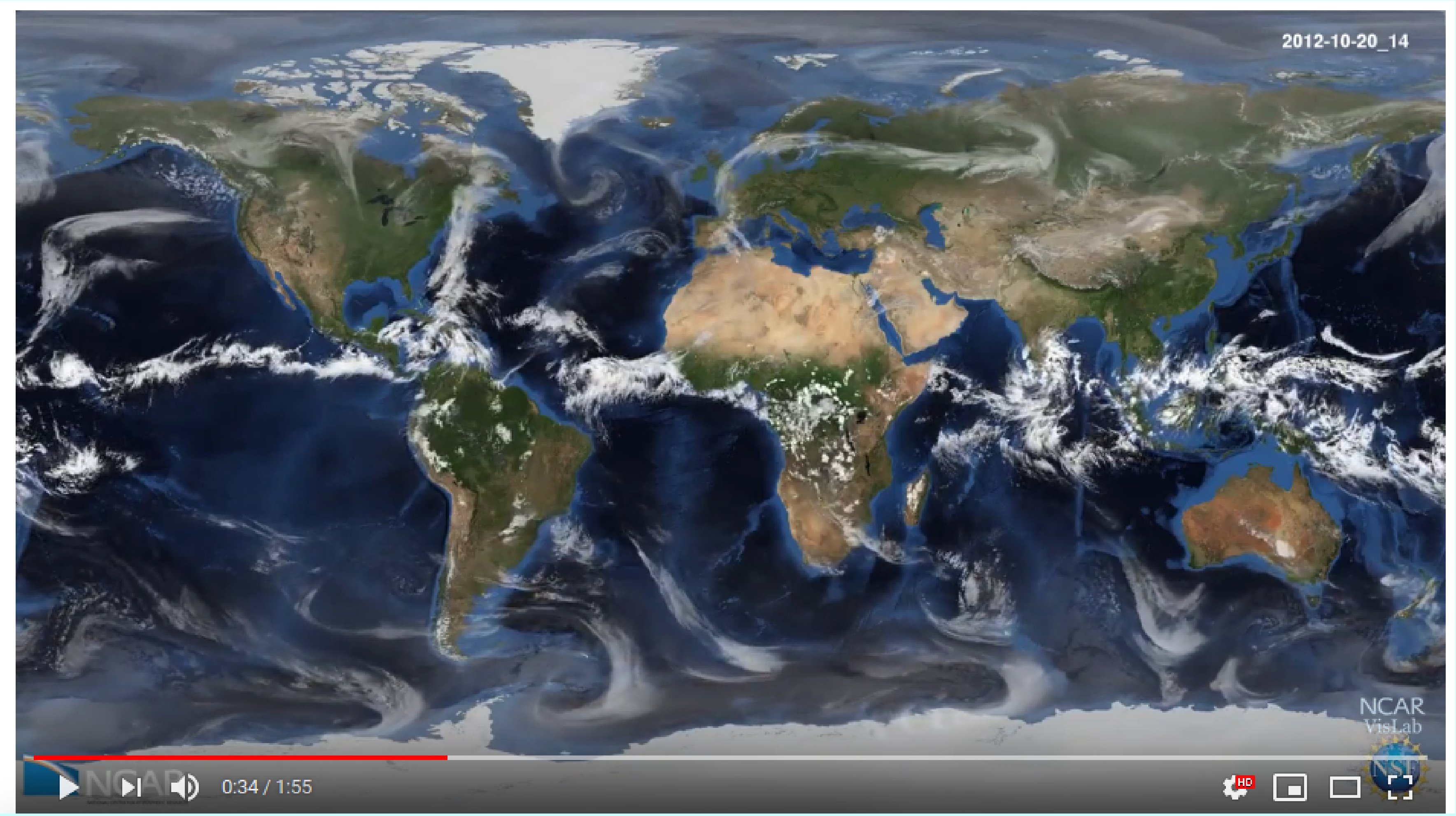


GALES model (deep convection case)



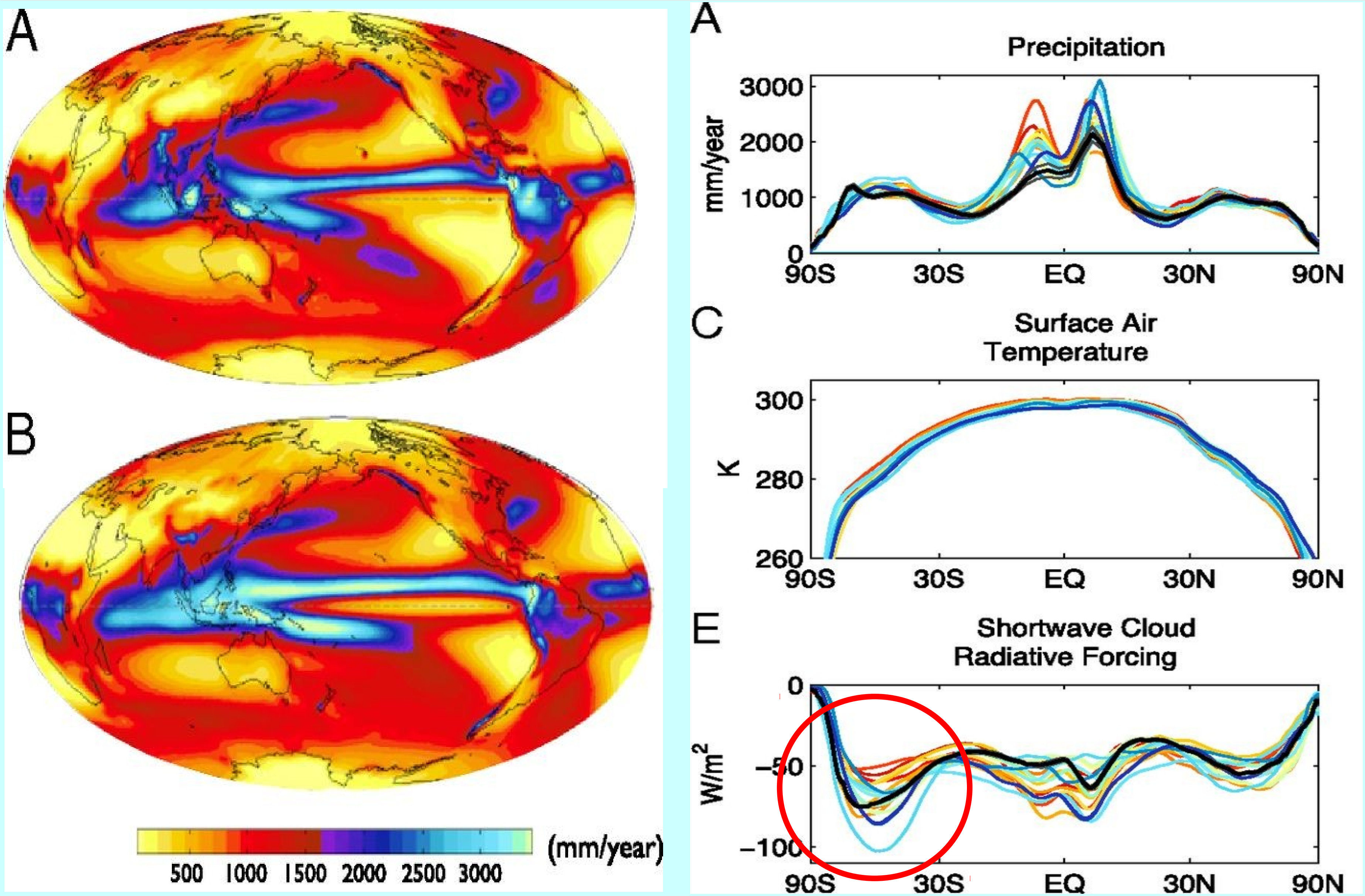
https://www.youtube.com/watch?v=Bb0HnaYNUx4

MPAS 4km simulation



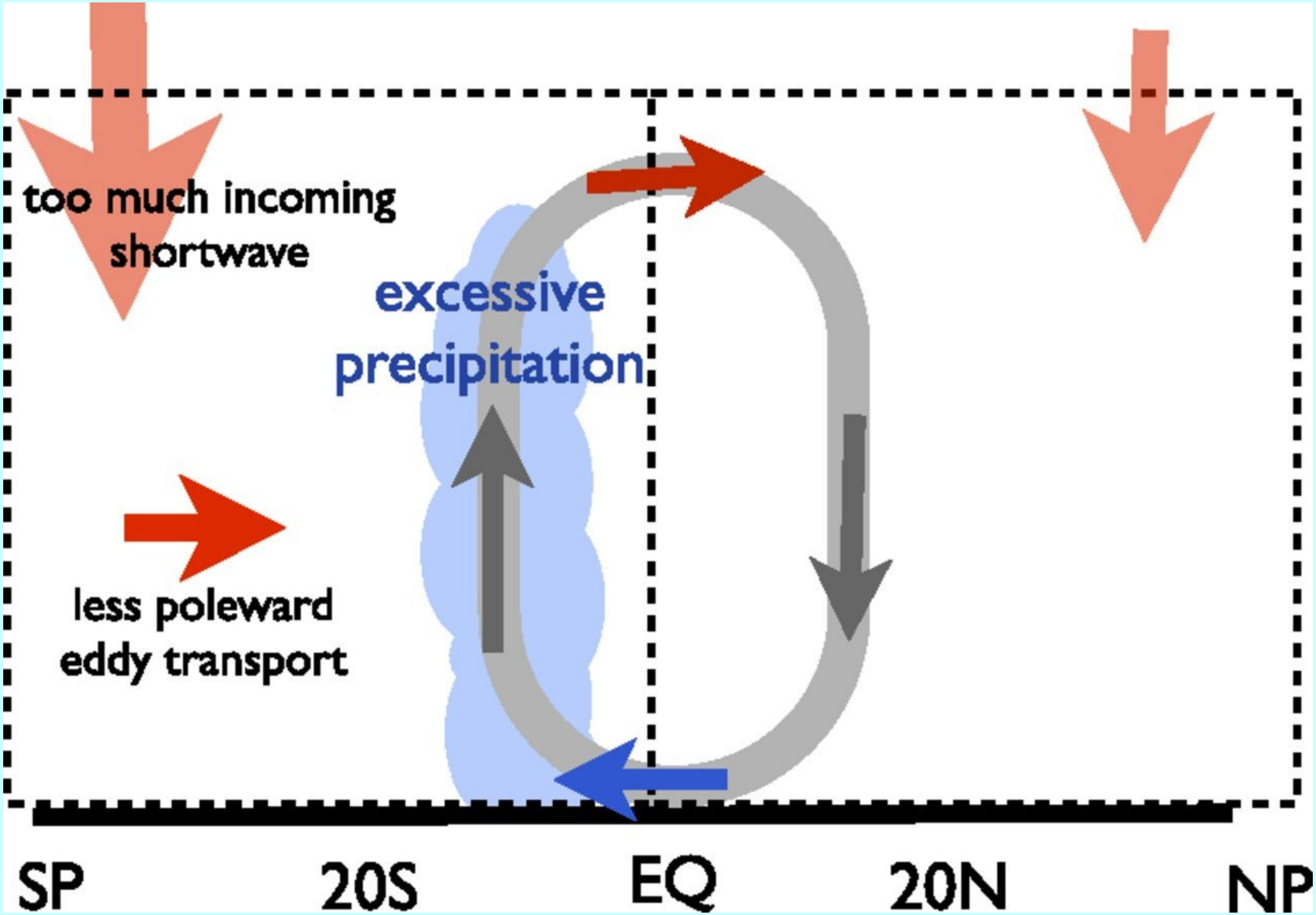
https://www.youtube.com/watch?v=UmiB4Ynd9AI

The Hadley circulation of most CMIP5 models is severely biased



Hwang Y , and Frierson D M W PNAS 2013;110:4935-4940

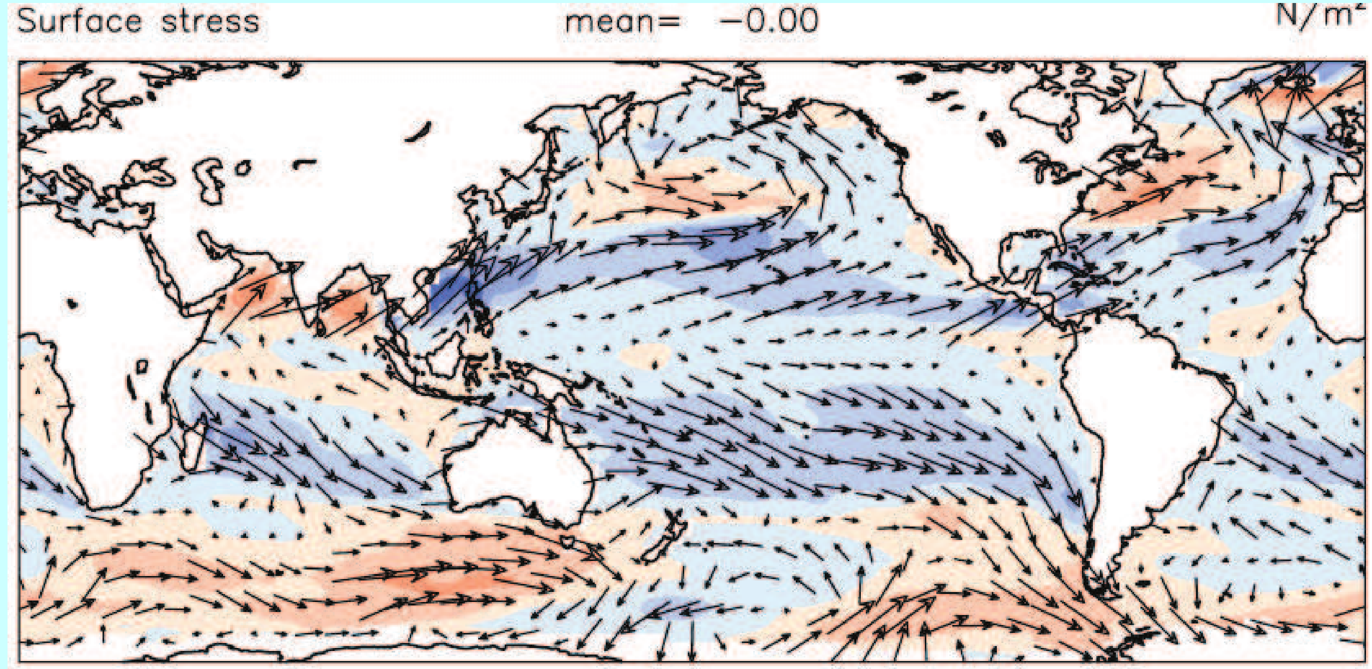
Schematic of the proposed mechanism for the double-ITCZ bias.

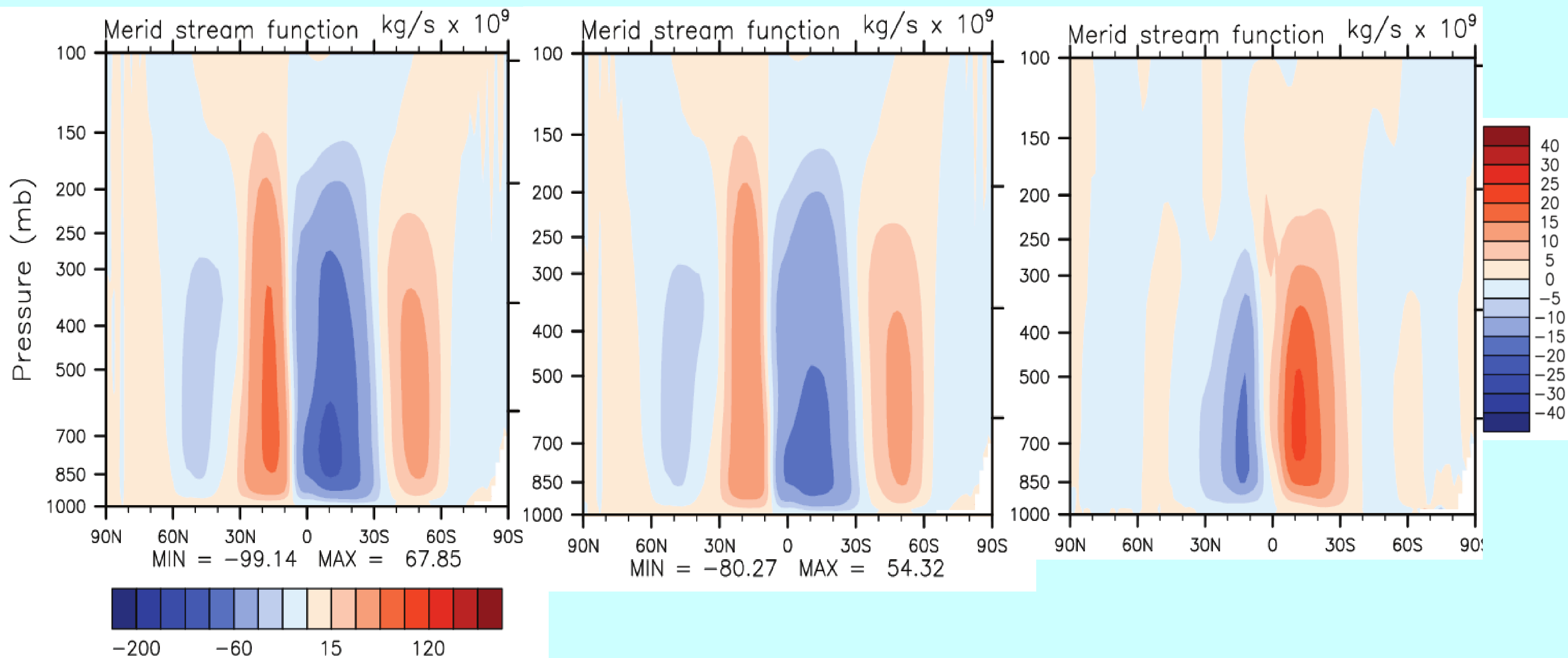


Hwang Y , and Frierson D M W PNAS 2013;110:4935-4940

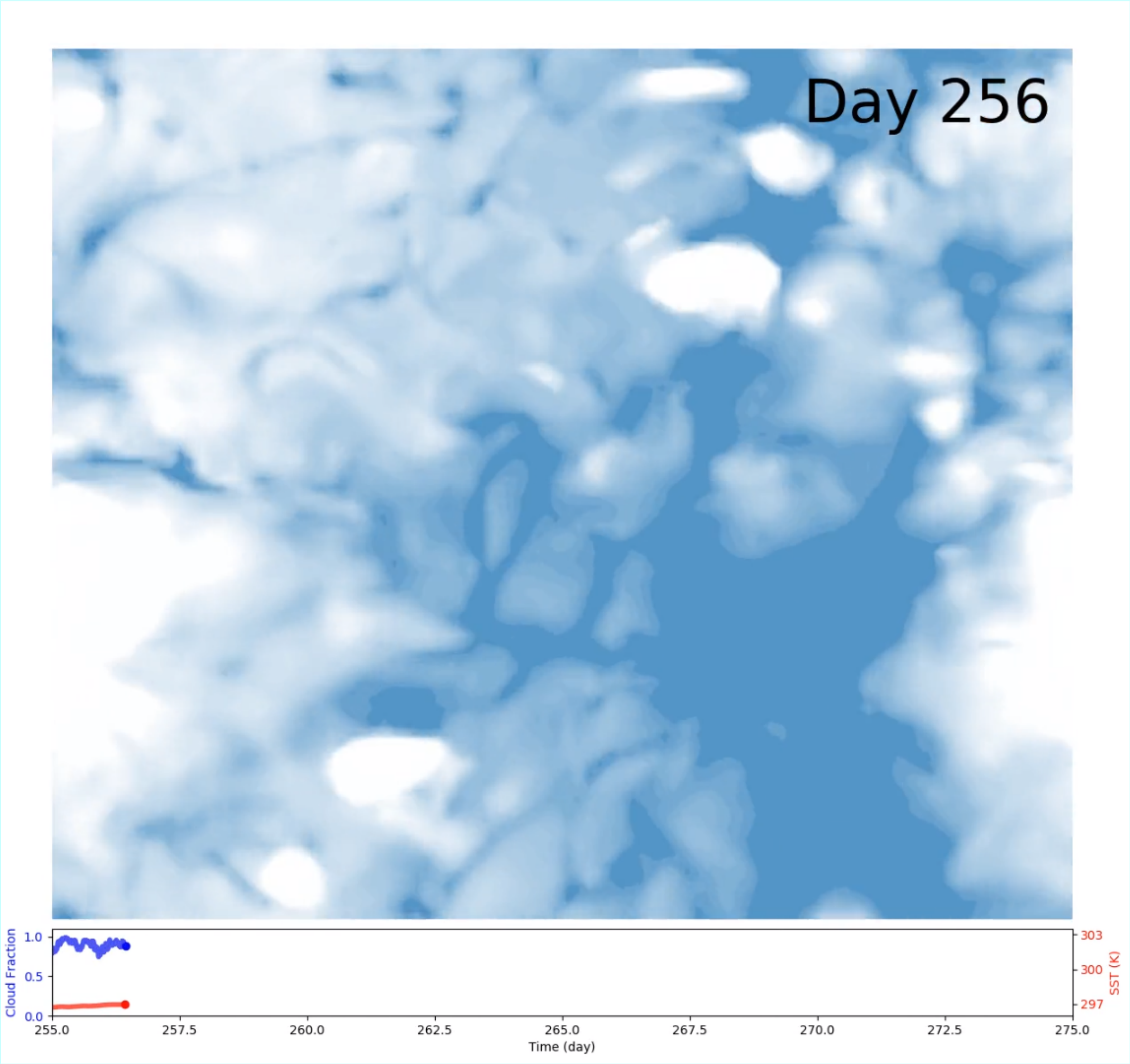
Impact of conserving angular momentum under (numerical) advection

(Toniazzo et al 2019, under revision in JAMES)



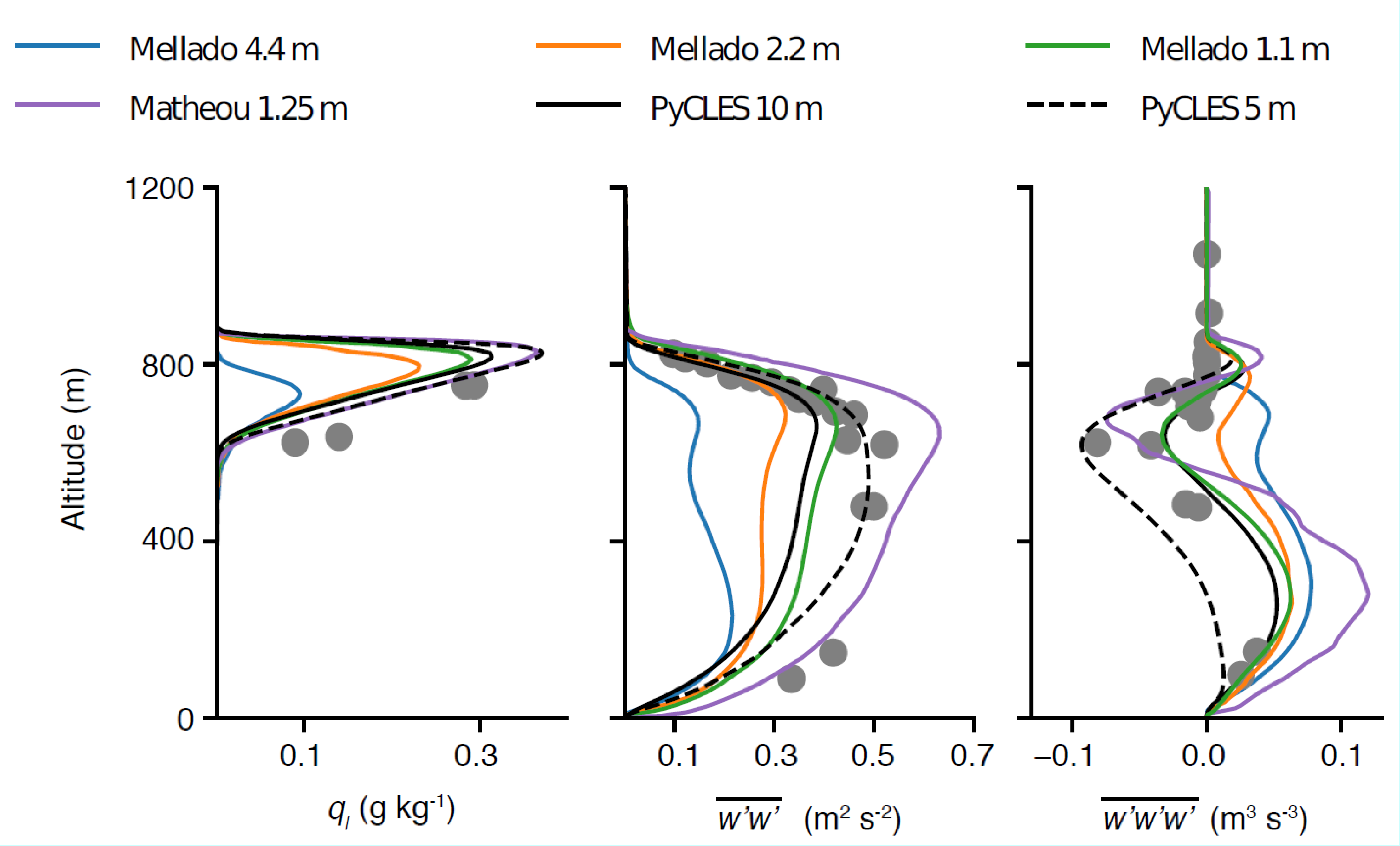


PyCLES model (DYCOMS II simulation)



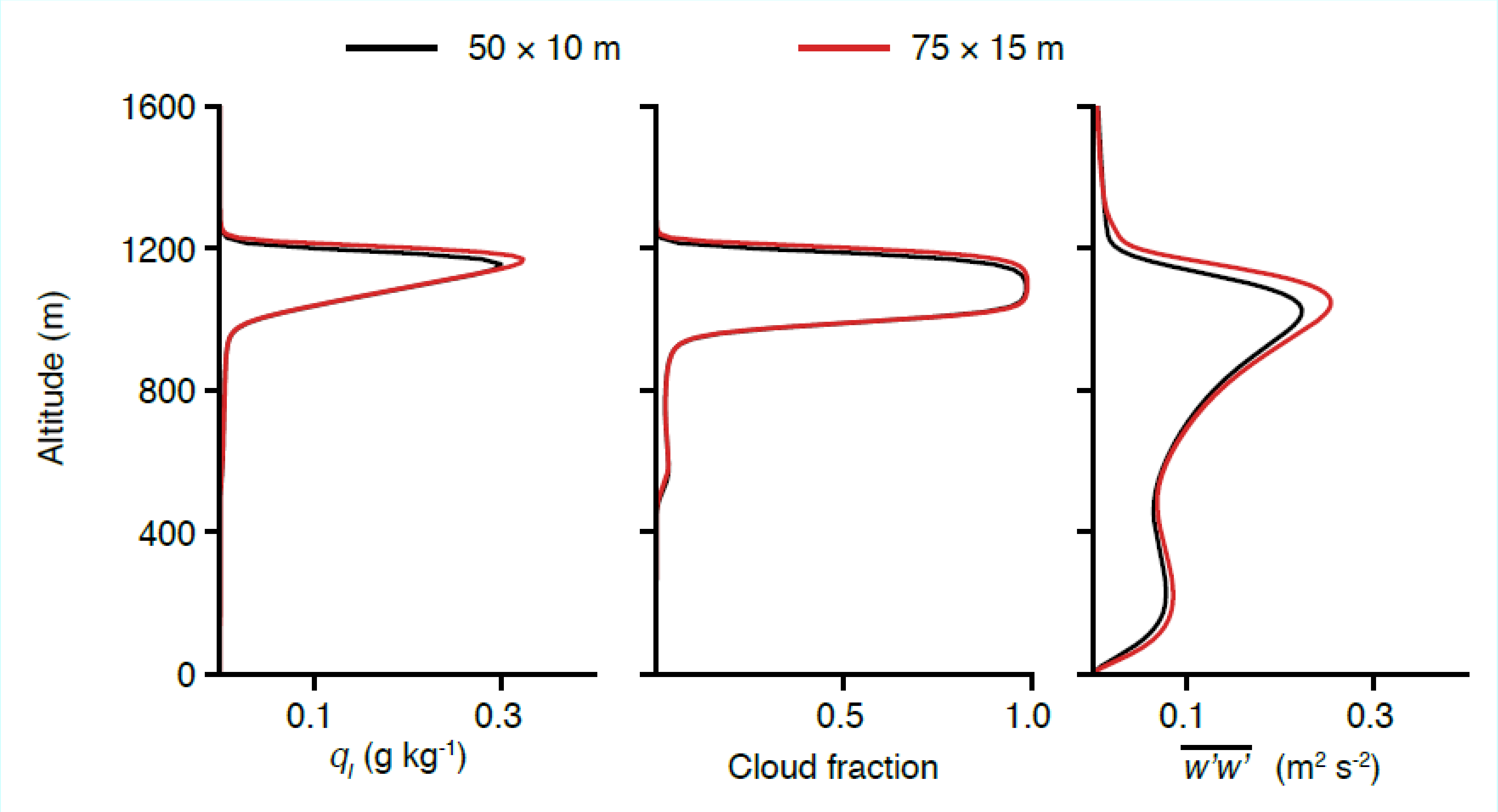
/home/thomas/literature/Schneider_etal_2019_ScLES.SImovie.mp4

/home/thomas/literature/Schneider_etal_2019_ScLES.SImovie.mp4



The horizontal and vertical grid spacings are 50 m and 10 m, respectively, for a total of 2 million grid points. We conducted additional simulations at a coarser resolution (75 m × 15 m), with essentially unchanged results (Supplementary Fig. 4). Therefore, although our LES resolution is not sufficient to have reached numerical convergence, we are confident in the numerical robustness of the results.

/home/thomas/literature/Schneider_etal_2019_ScLES.SImovie.mp4



..., we are confident in the numerical robustness of the results.

The 1:1 map of the world

“In the Deserts of the West, still today, there are tattered Ruins of that Map, inhabited by Animals and Beggars; in all the Land there is no other Relic of the Disciplines of Geography.”

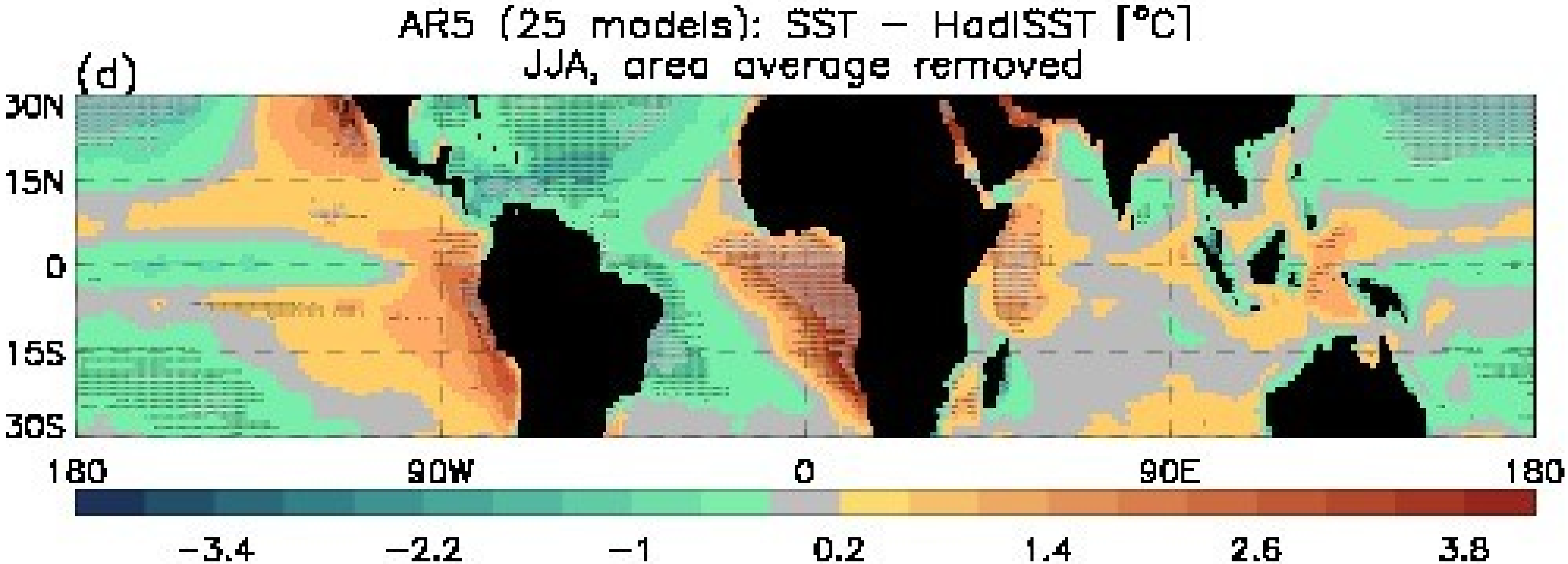
Jorge Luis Borges: Del Rigor en la Ciencia. (Translation A. Hurley).

Analysis of CMIP5 simulations

Persistent model errors

Summer (JJA) Sea Surface temperature bias pattern in CMIP5 ensemble

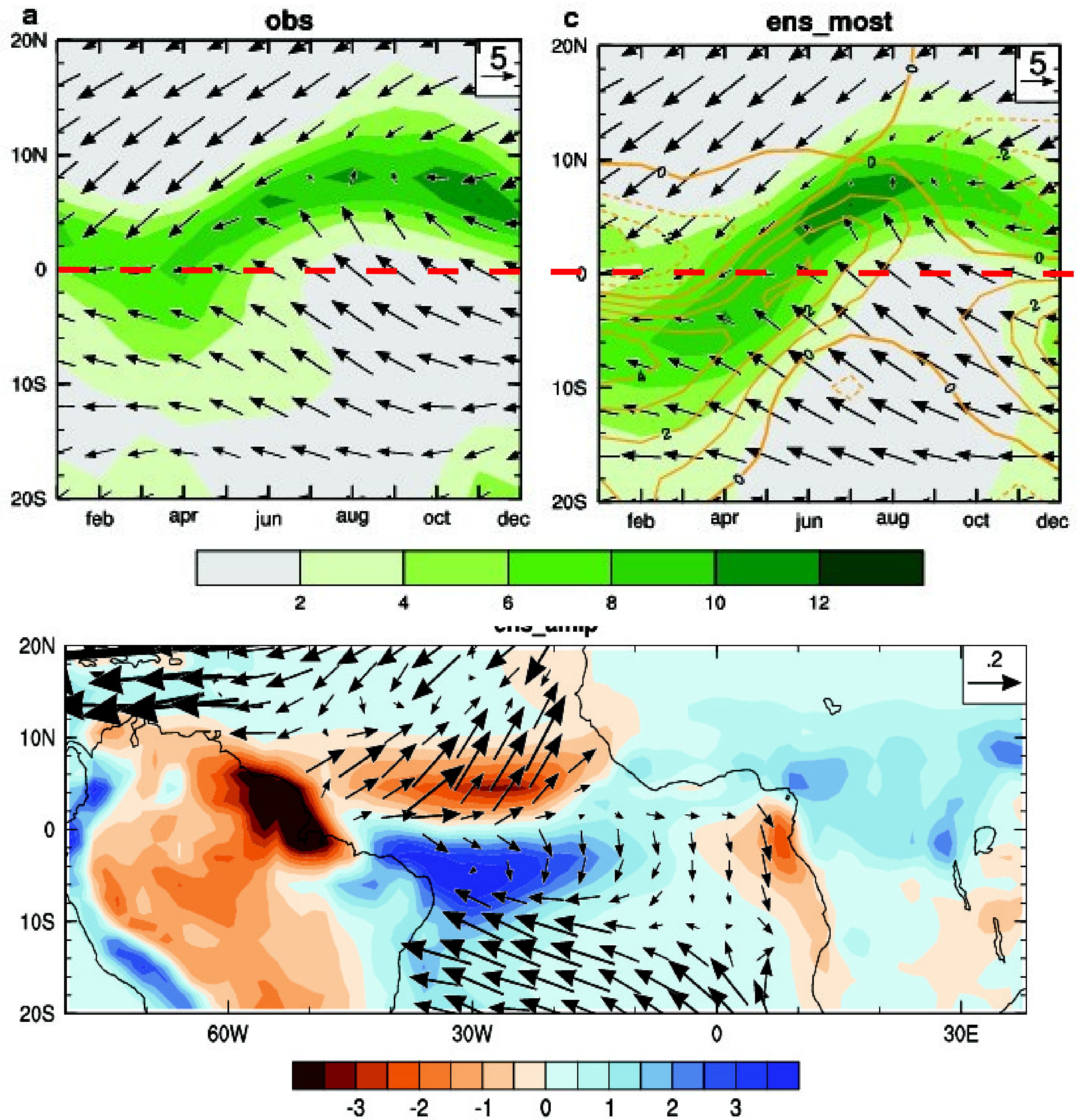
White stipples indicate model biases that are consistent across all CMIPx models



Toniazzo and Woolnough, 2013

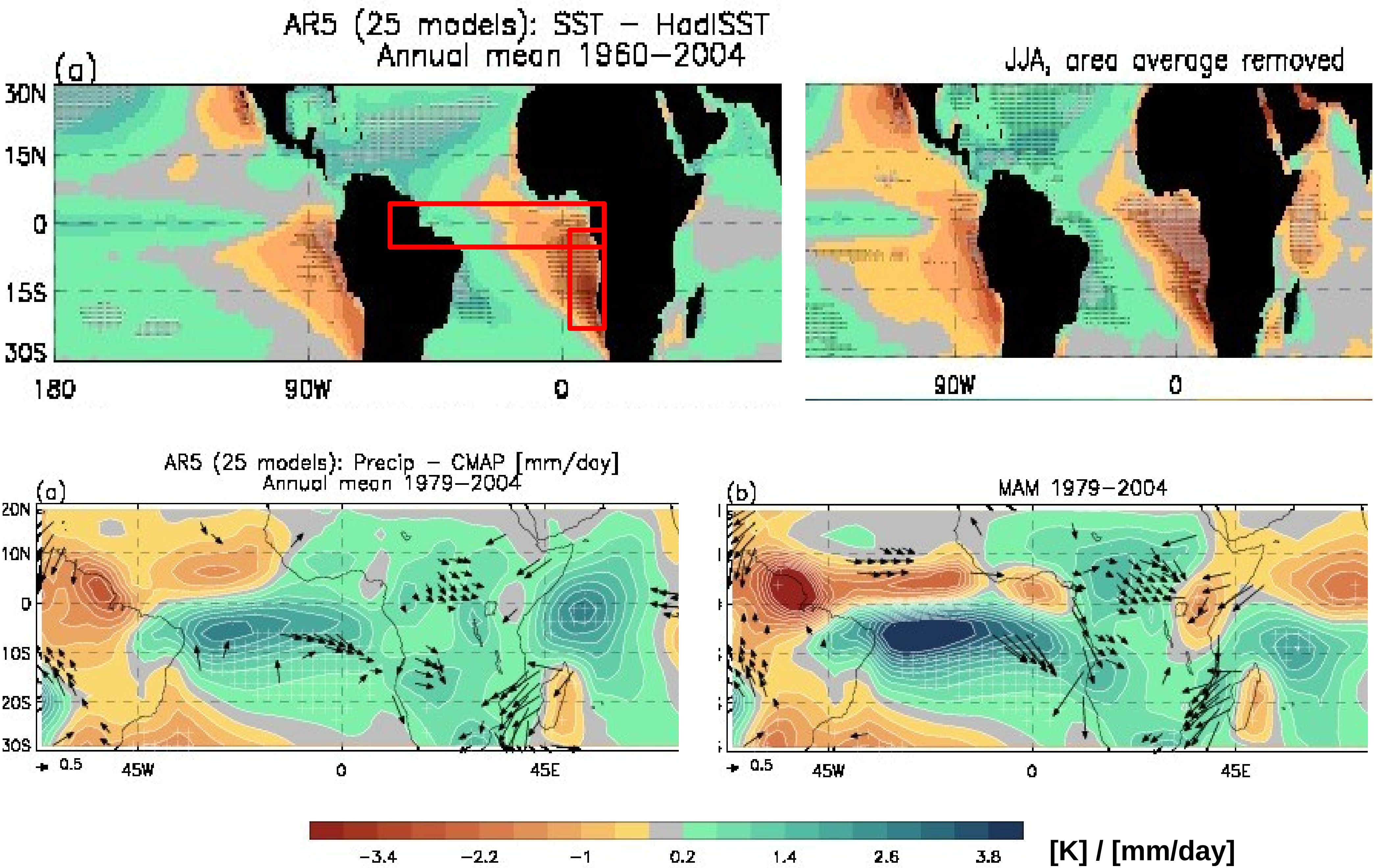
Can we improve climate prediction in the Tropical Atlantic by improving model simulations?

Model mean-state and seasonal-cycle biases related to the large-scale distribution of convective precipitation



Richter et al. 2012

The CMIP5 set shows ubiquity of warm & wet error in south Atlantic



An analysis of error growth in initialised decadal forecasts

- We analyse the errors as a function of lead time in the initialised decadal hindcast integrations in CMIP5
- This allows isolating areas of fast and slow error growth, potential mechanisms “before” and “after” coupling, and causal relationships linking atmospheric and oceanic errors.

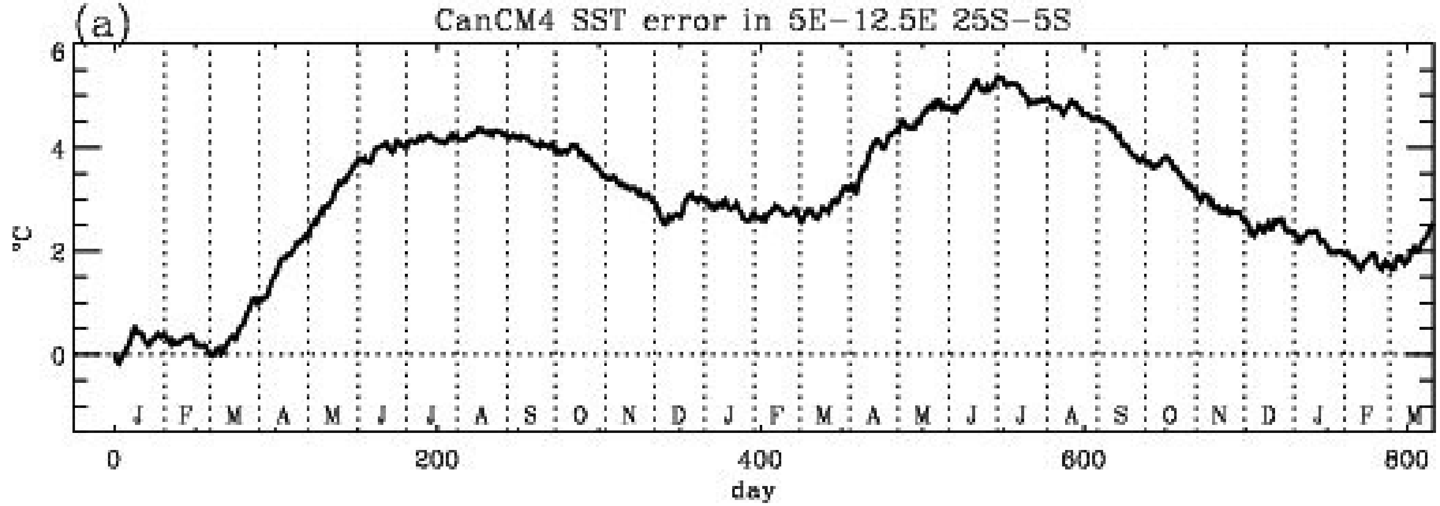
➔ we focus primarily on the generation of SST errors in the marine coastal region of the South-East Atlantic

➔ restricted to models with a good ensemble of **full-field** initialised hindcasts and **high-frequency diagnostics**

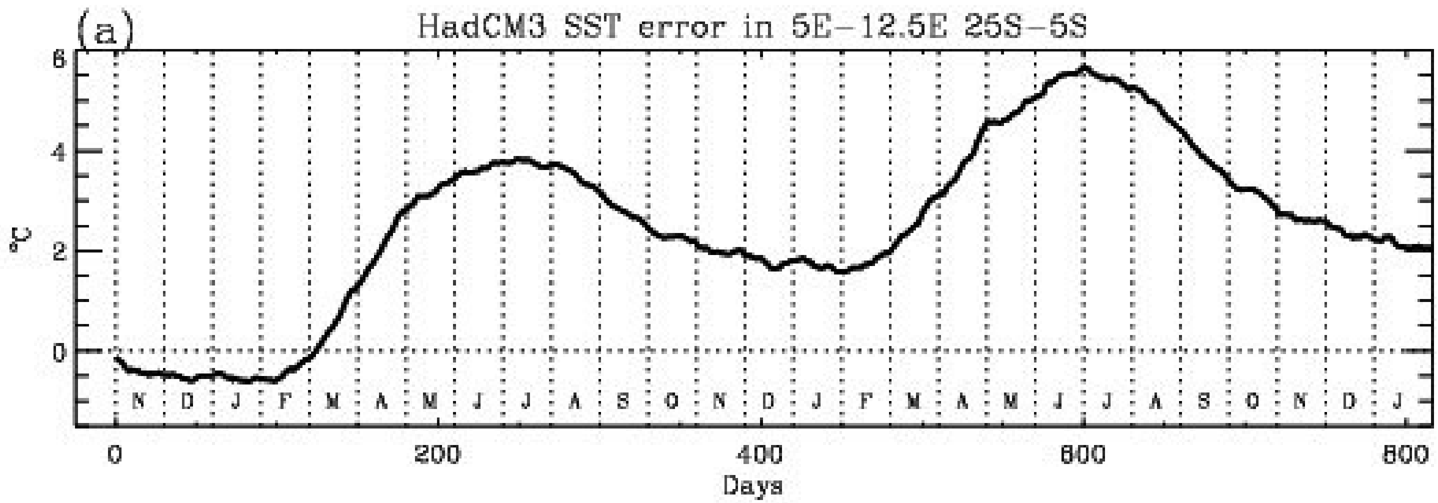
➔ Grand total of suitable CMIP5 hindcast sets at the time of analysis was 3.

Three models from CMIP5

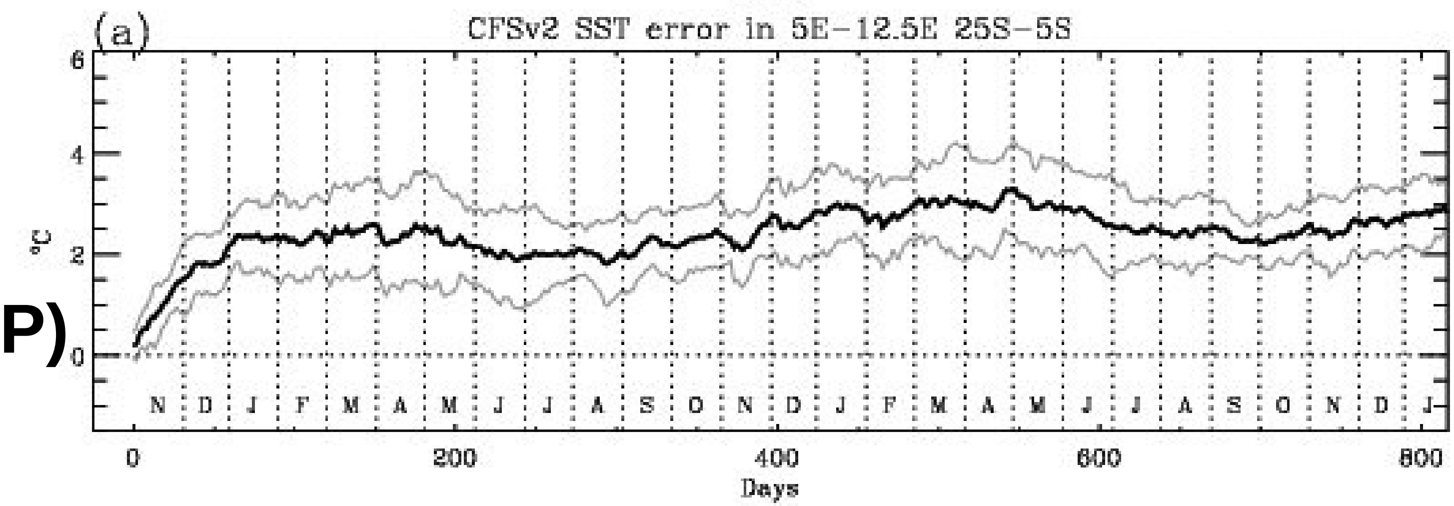
CanCM4 (CCCma)



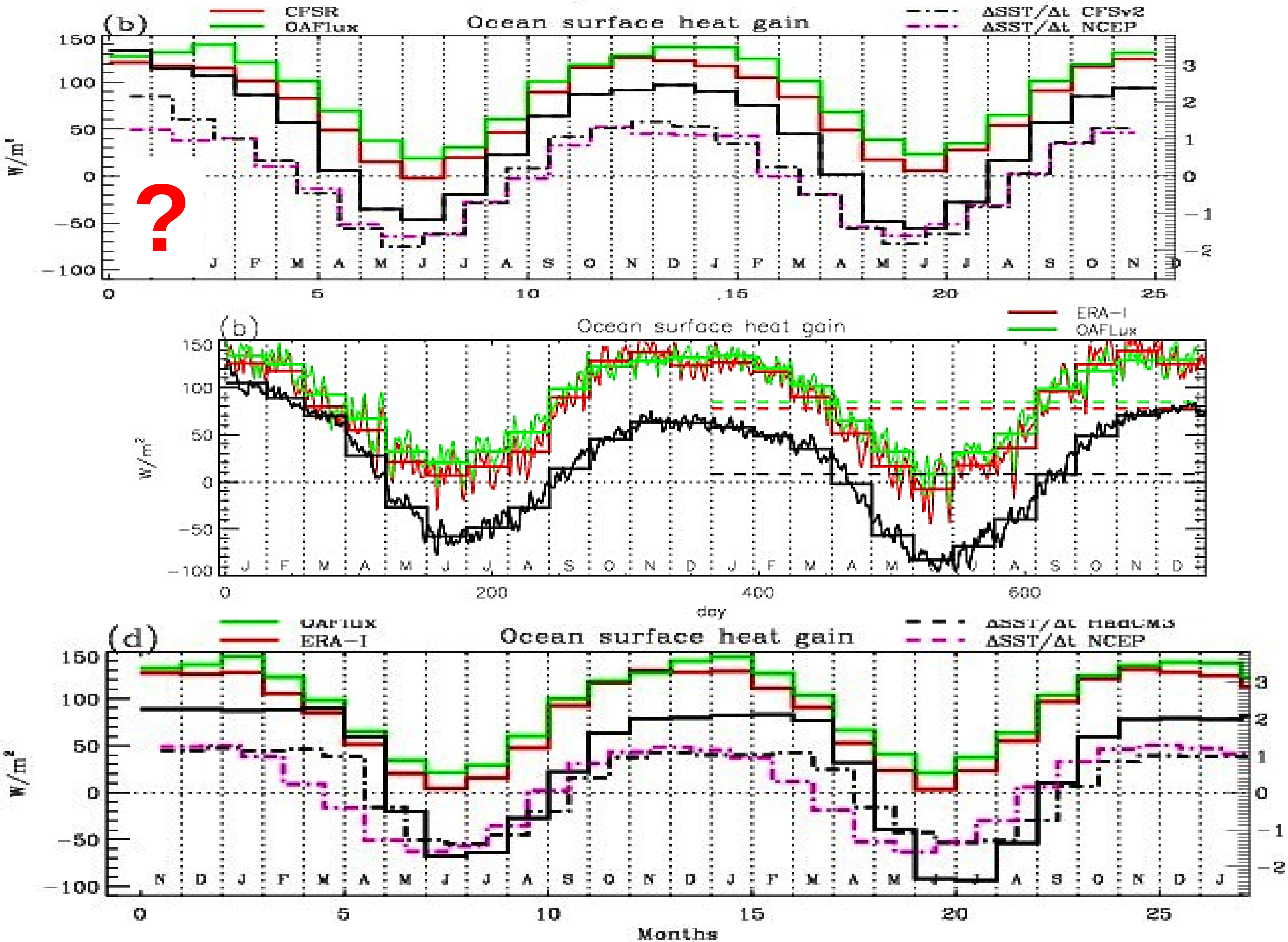
HadCM3 (UKMO)



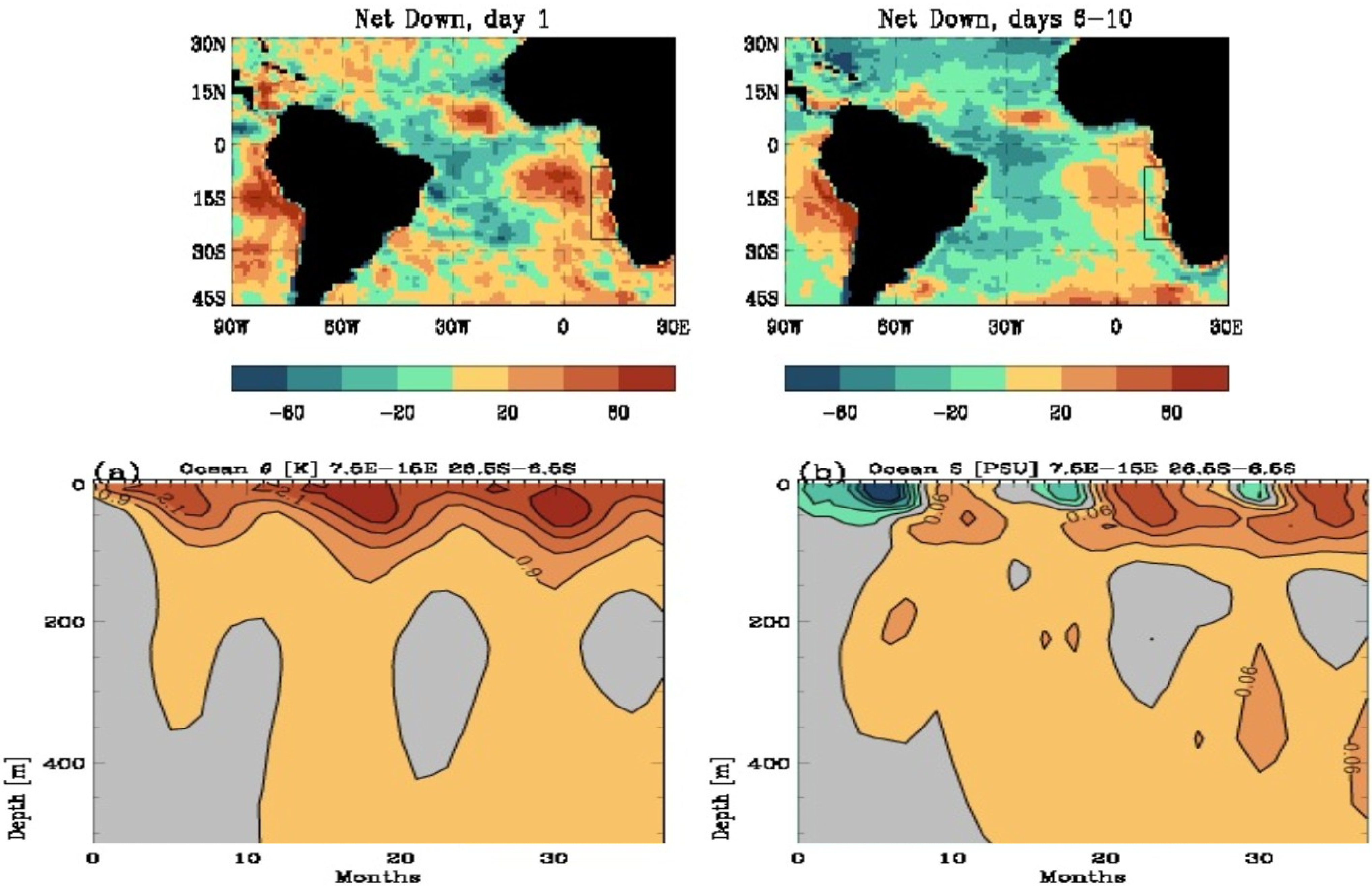
CFSv2-2011 (NOAA-NCEP)



Proximate causes I: surface heat fluxes

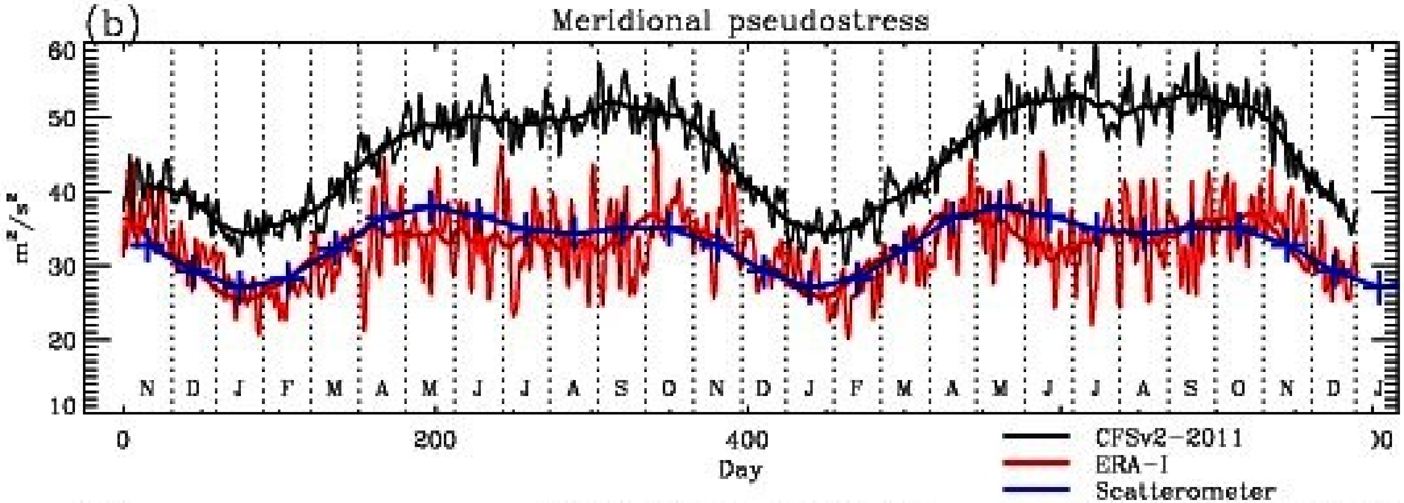


Monthly-means hide the evolution: large & immediate warming by SHF in CFS

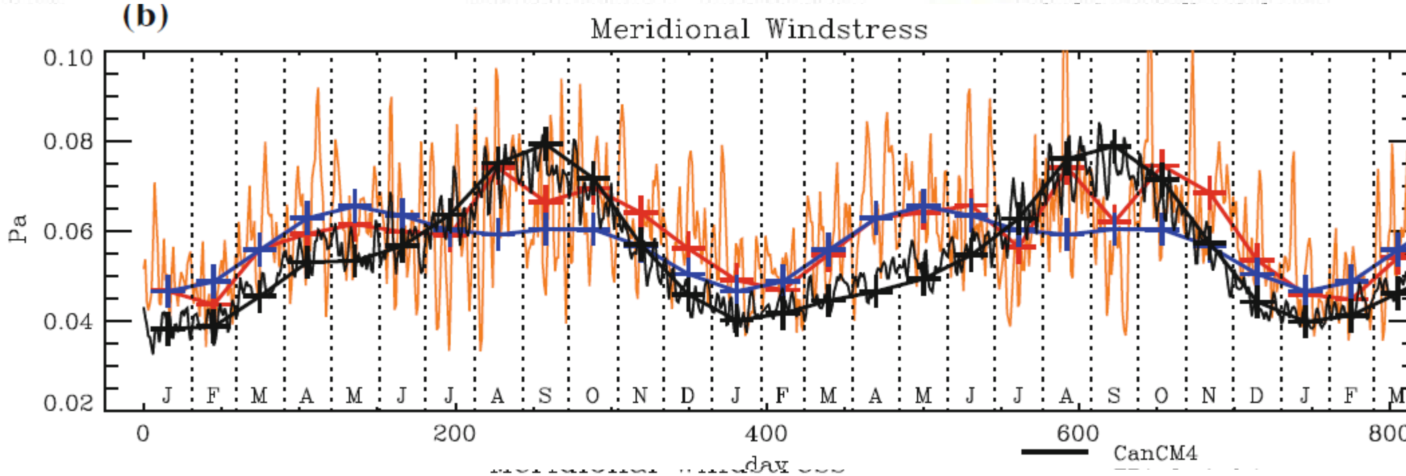


Proximate causes II: coastal windstress (a)

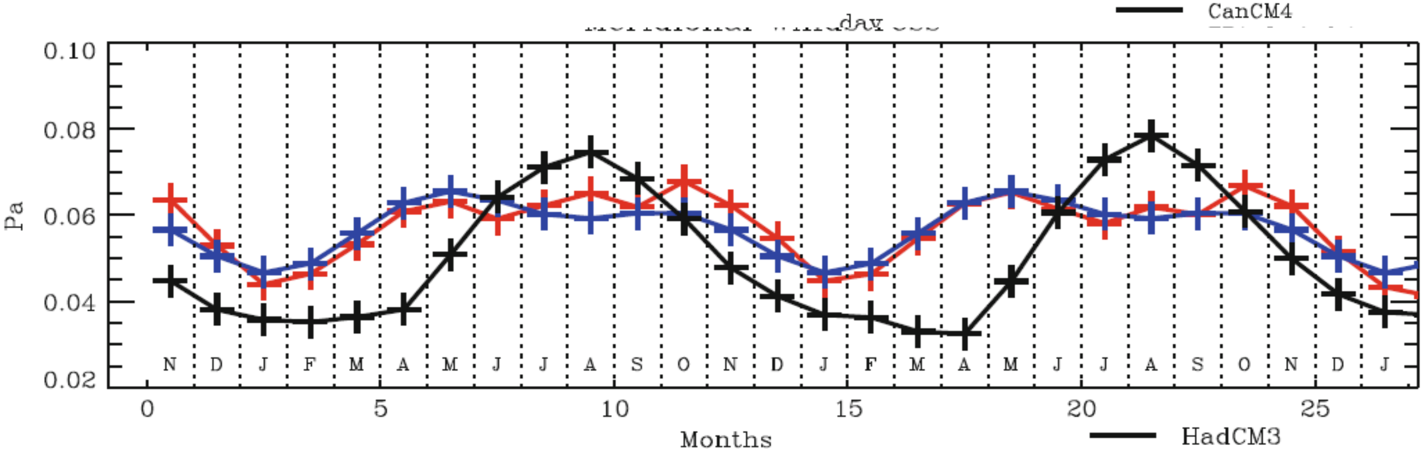
CFS



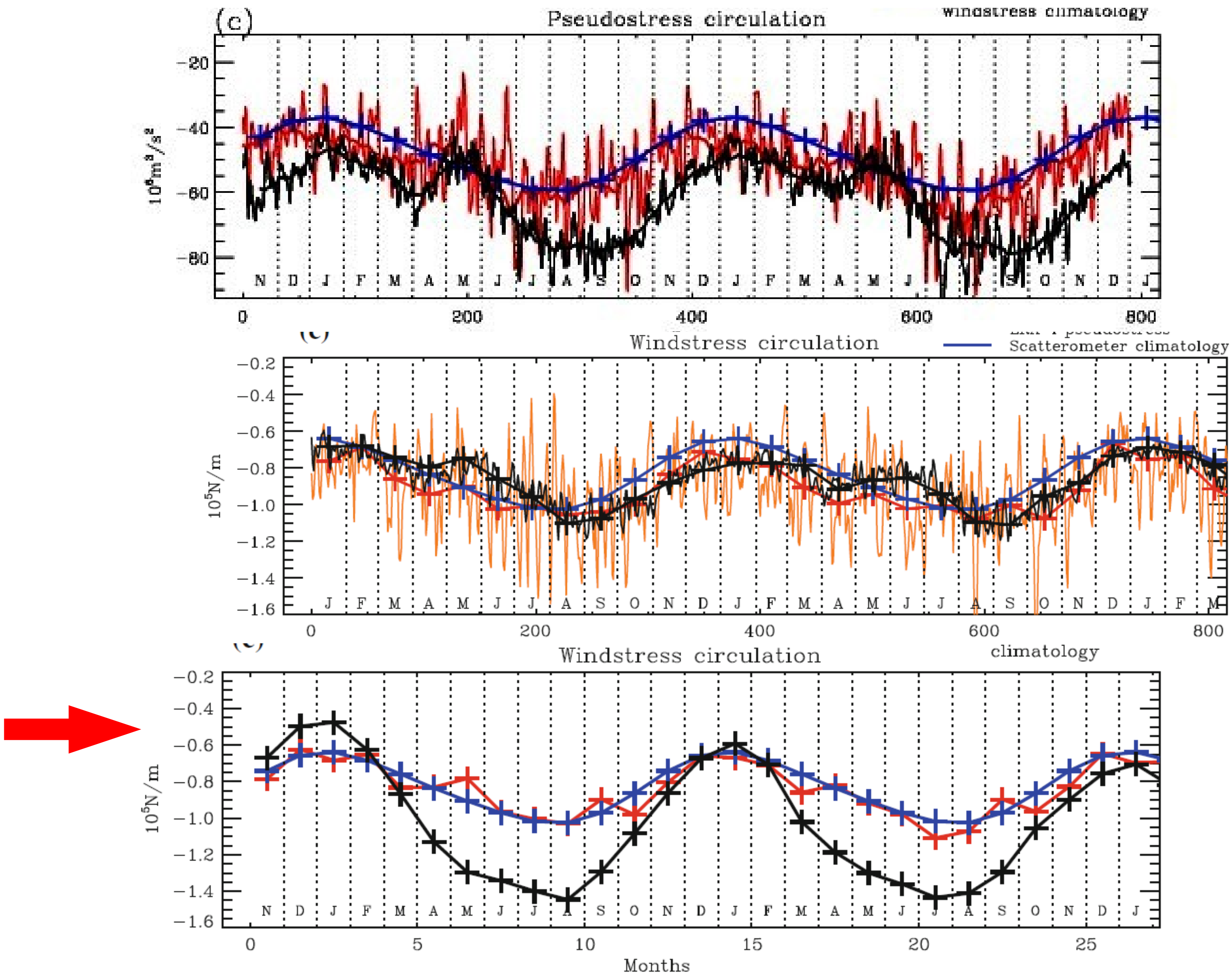
CM4



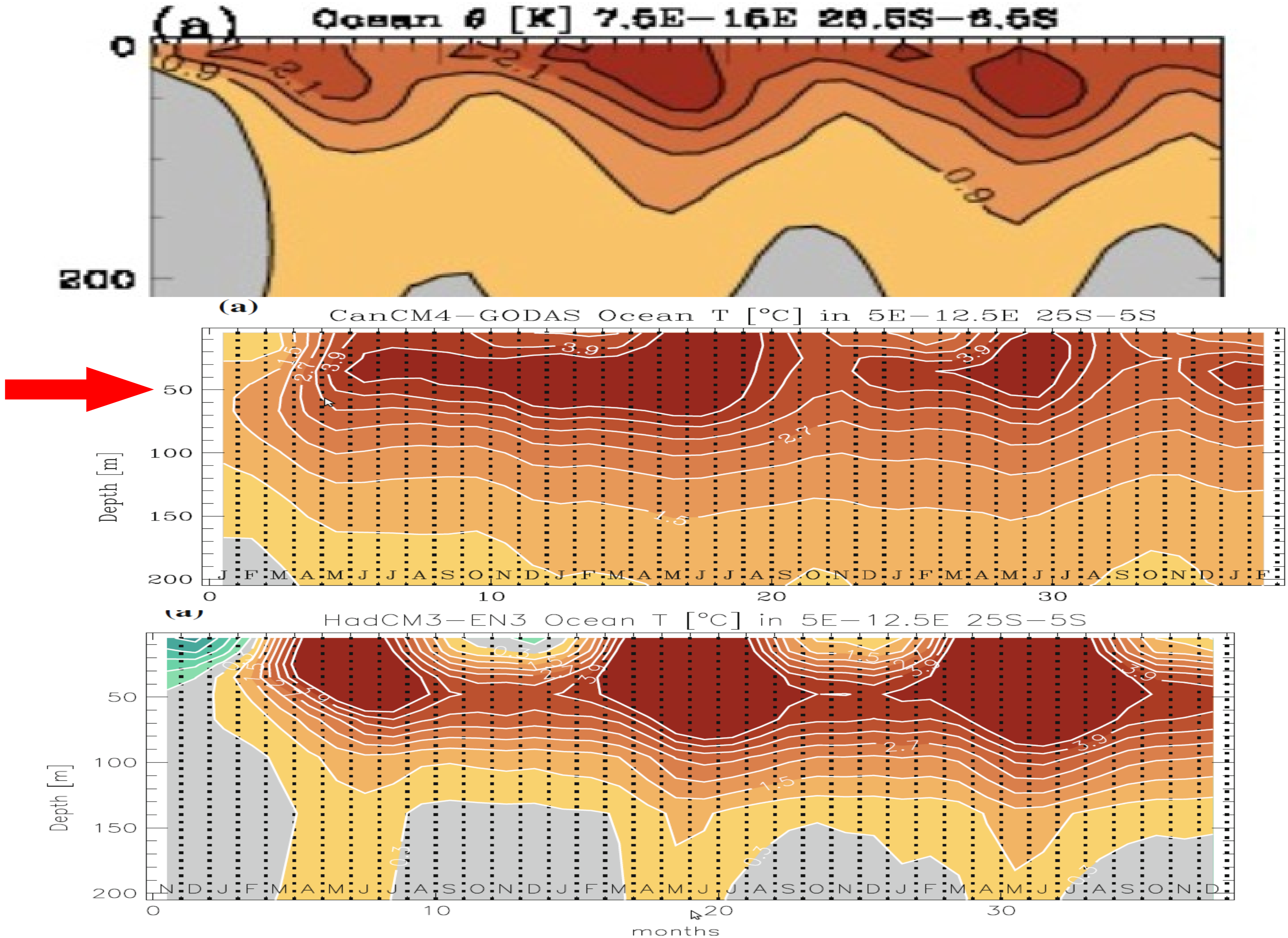
CM3



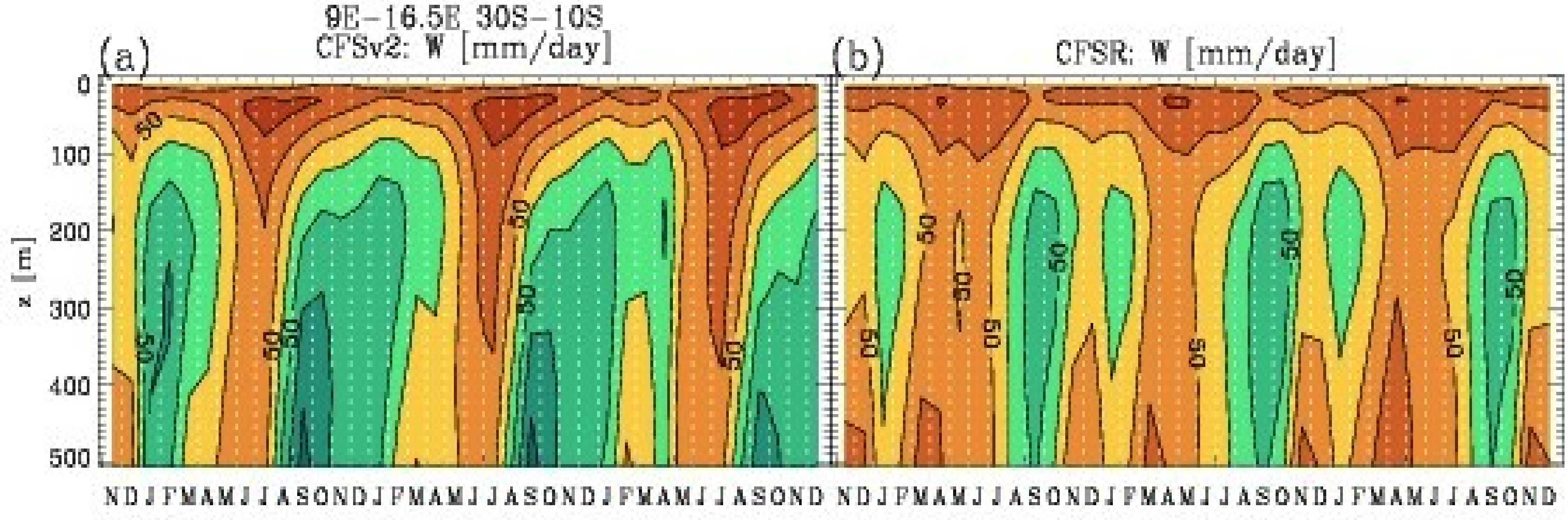
Proximate causes II: coastal windstress (b)

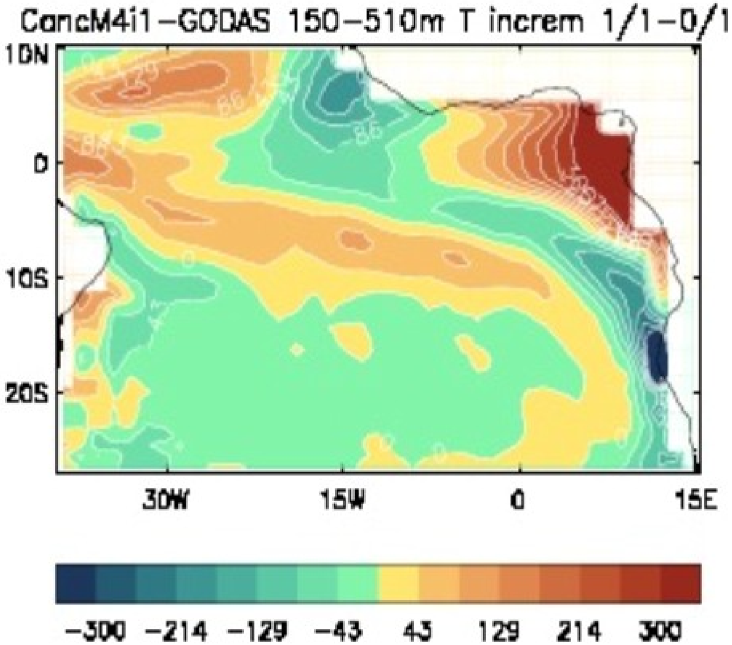


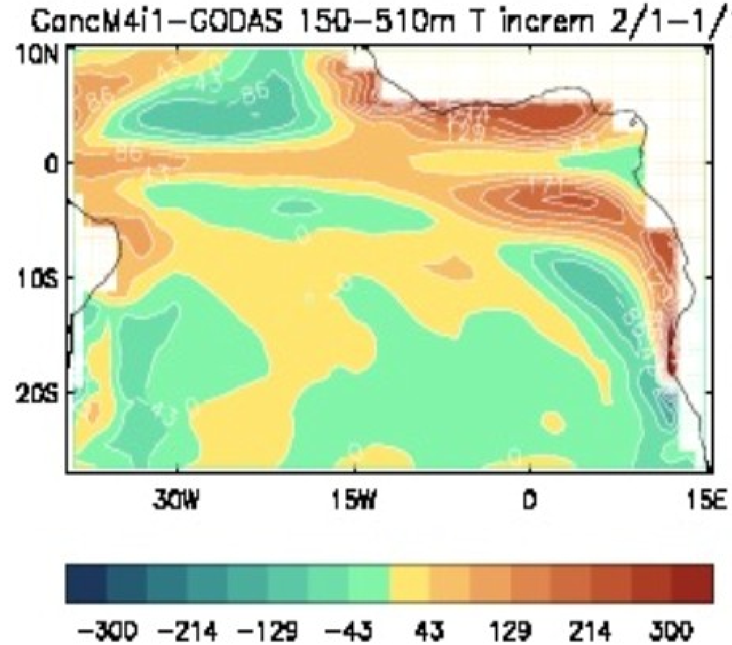
Associated biases I: subsurface OTs



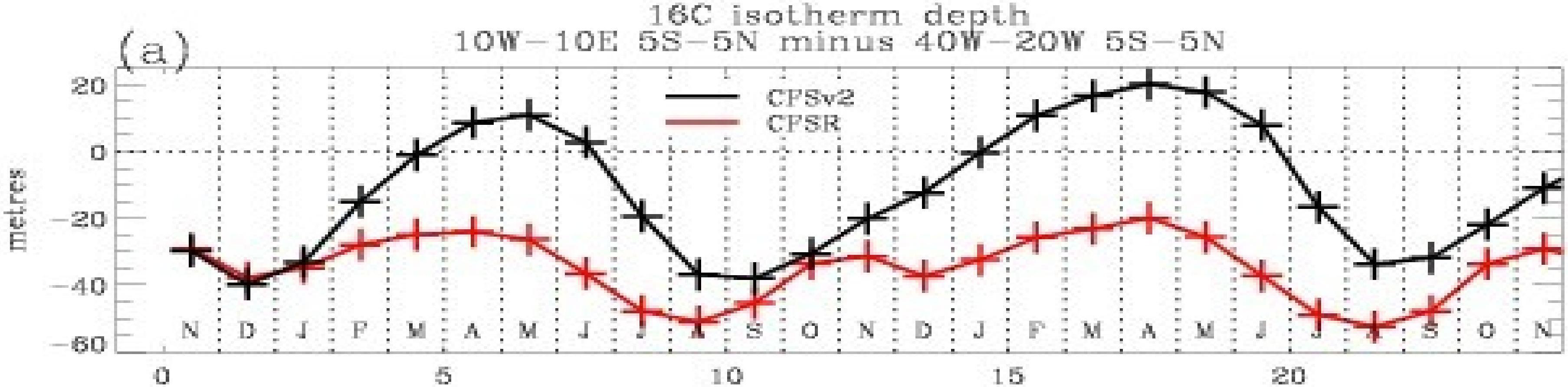
Non-proximate causes I: ocean waves

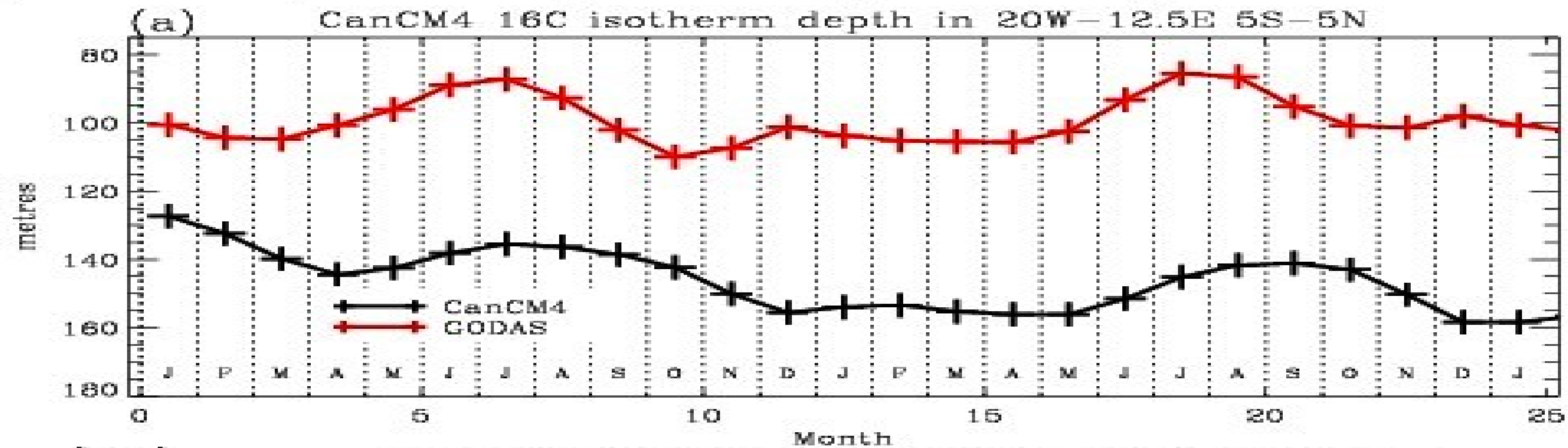


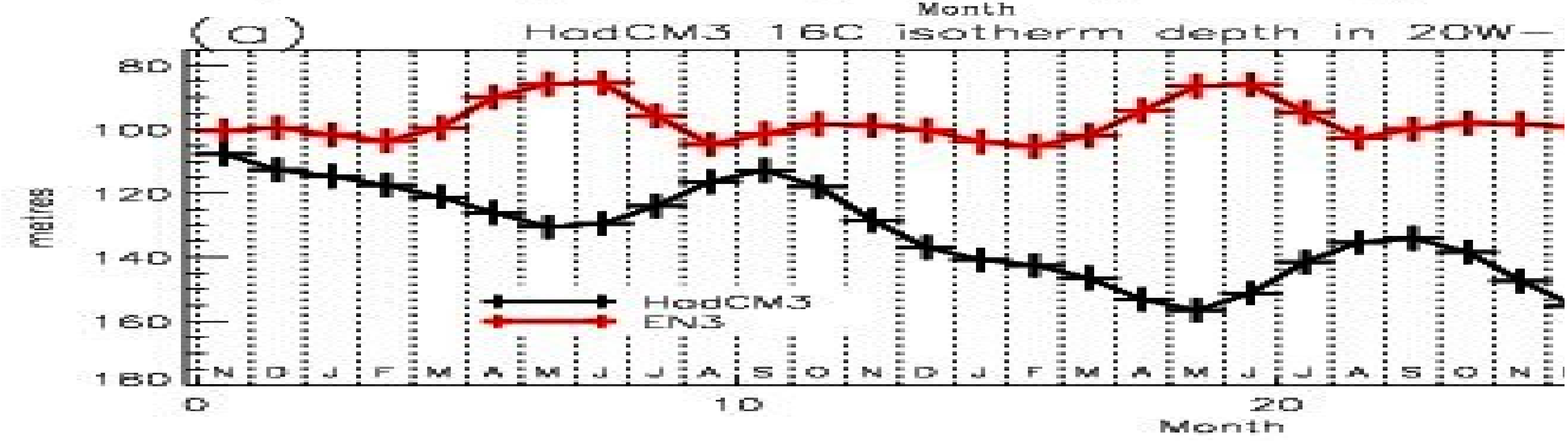




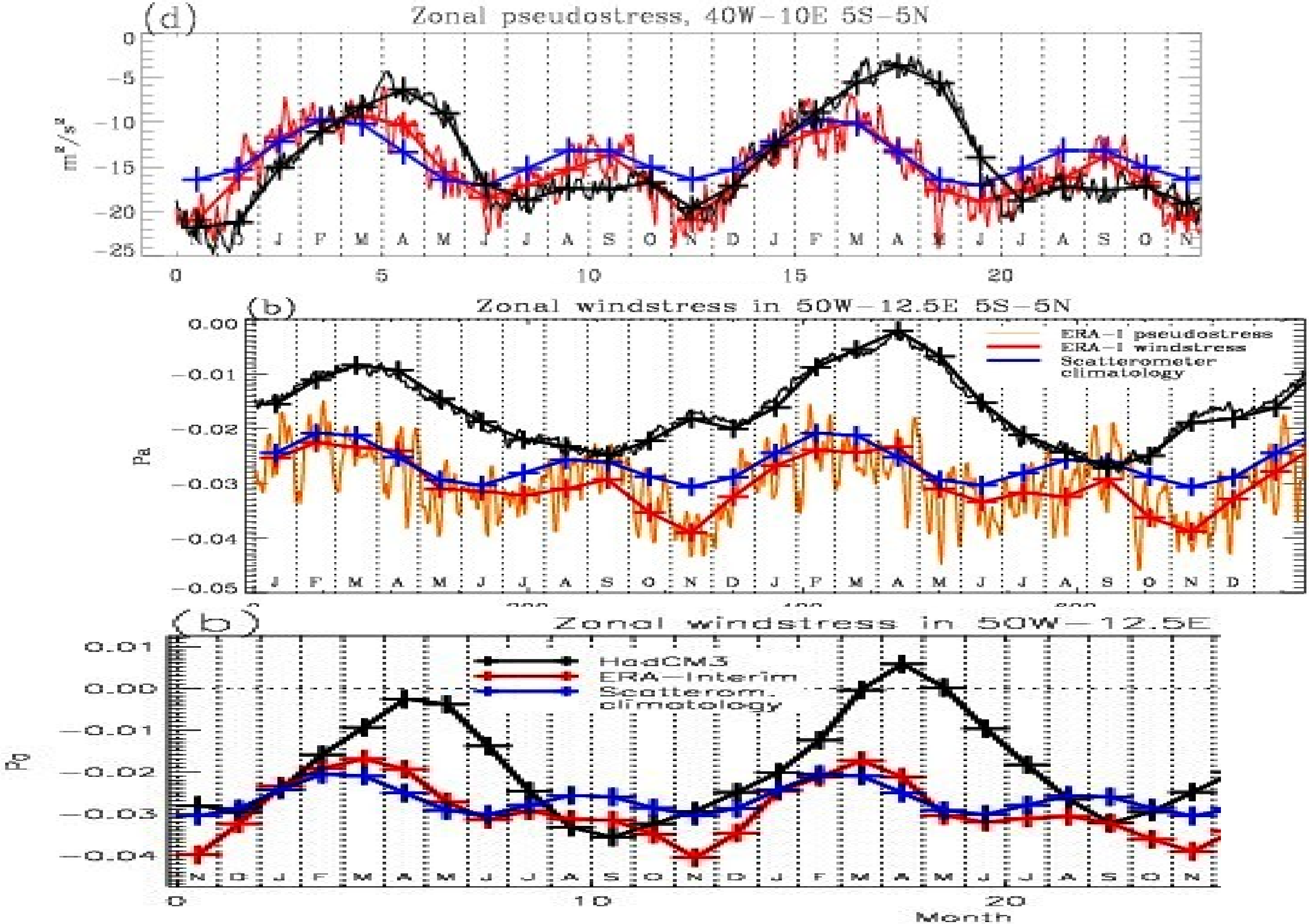
Non-proximate causes II: equatorial thermocline



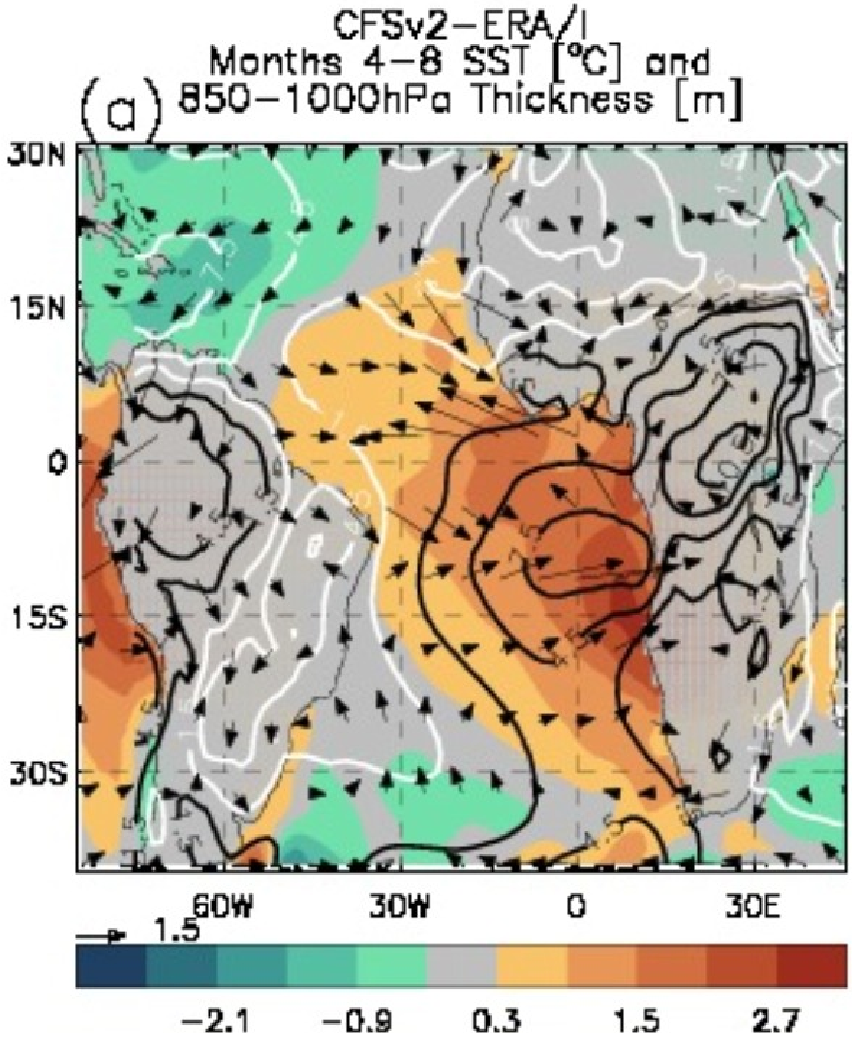


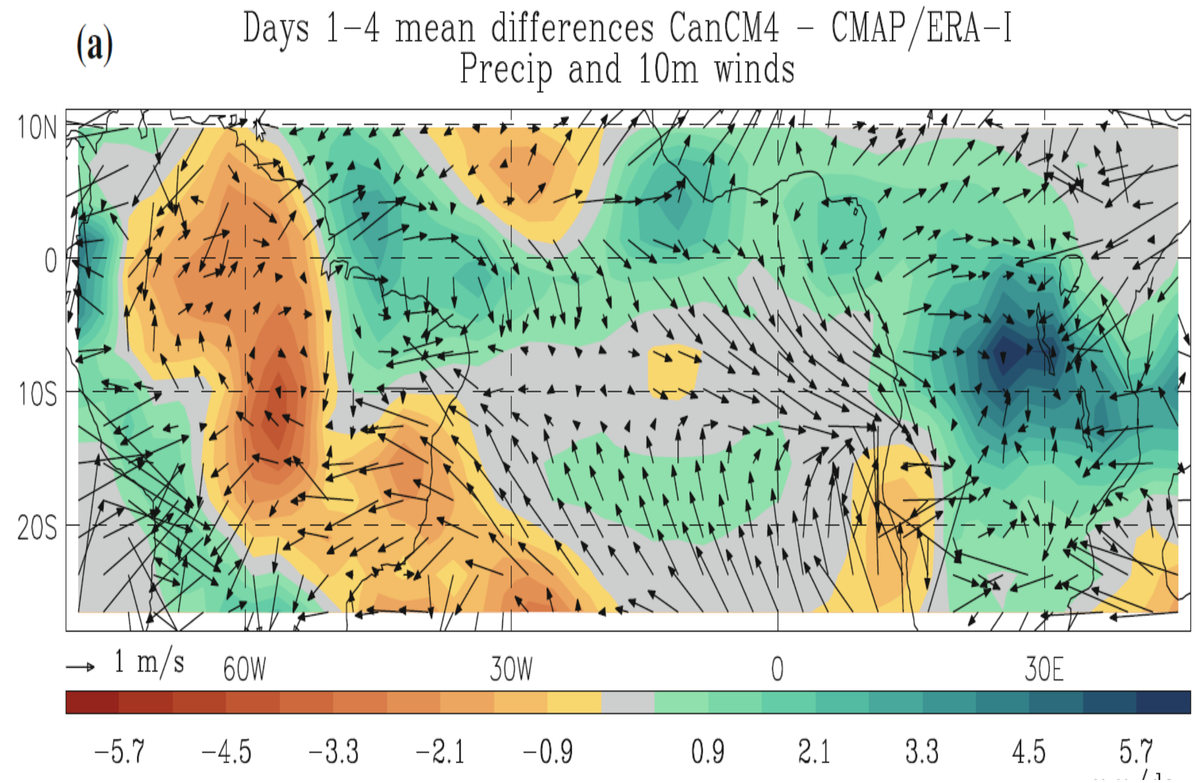


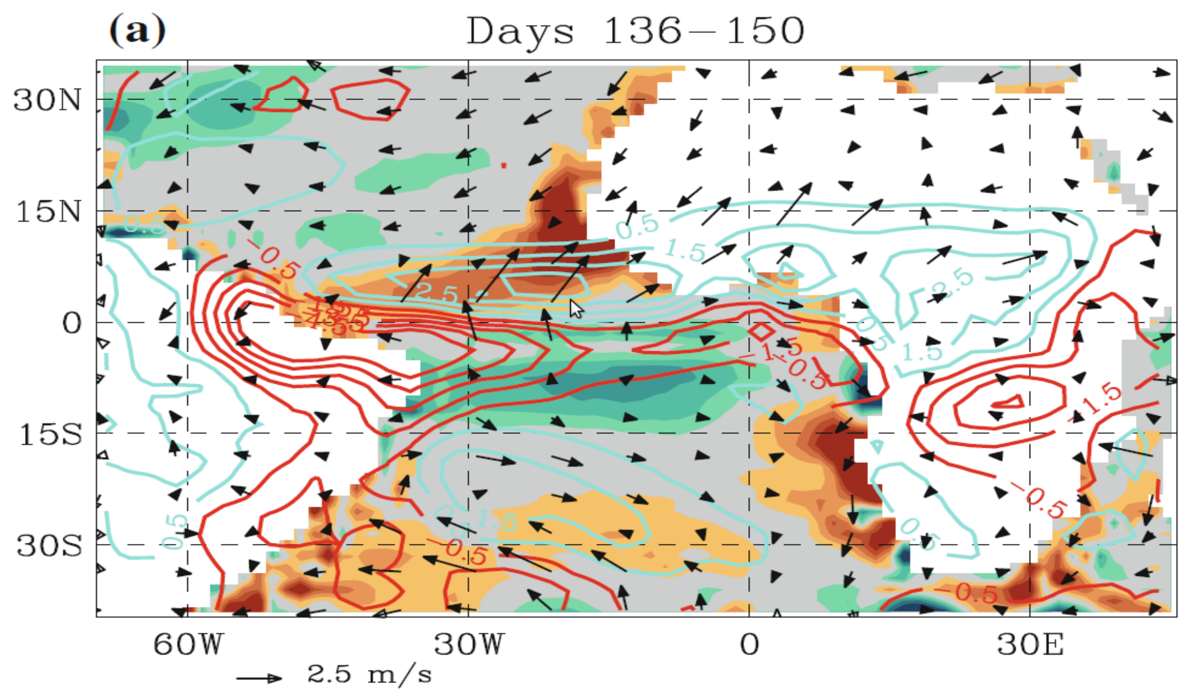
Non-proximate causes III: equatorial winds



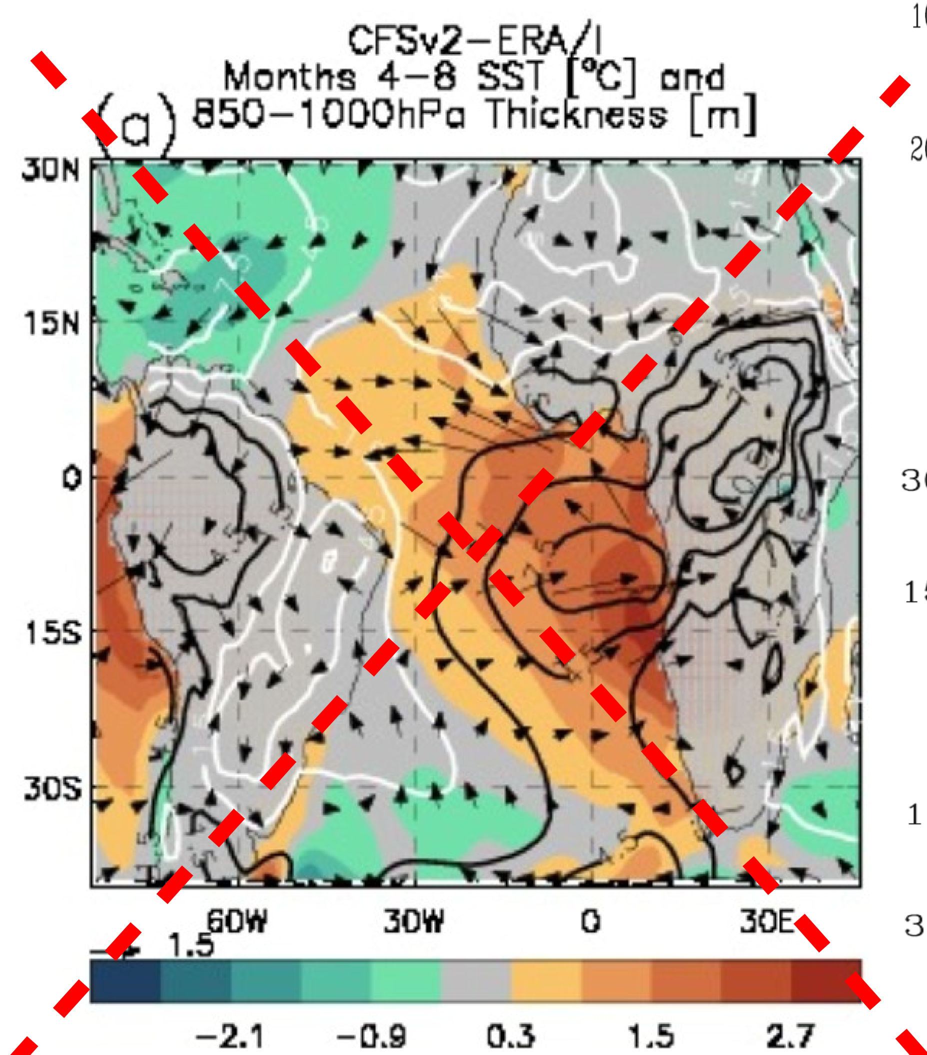
Non-proximate causes IV: atmospheric circulation

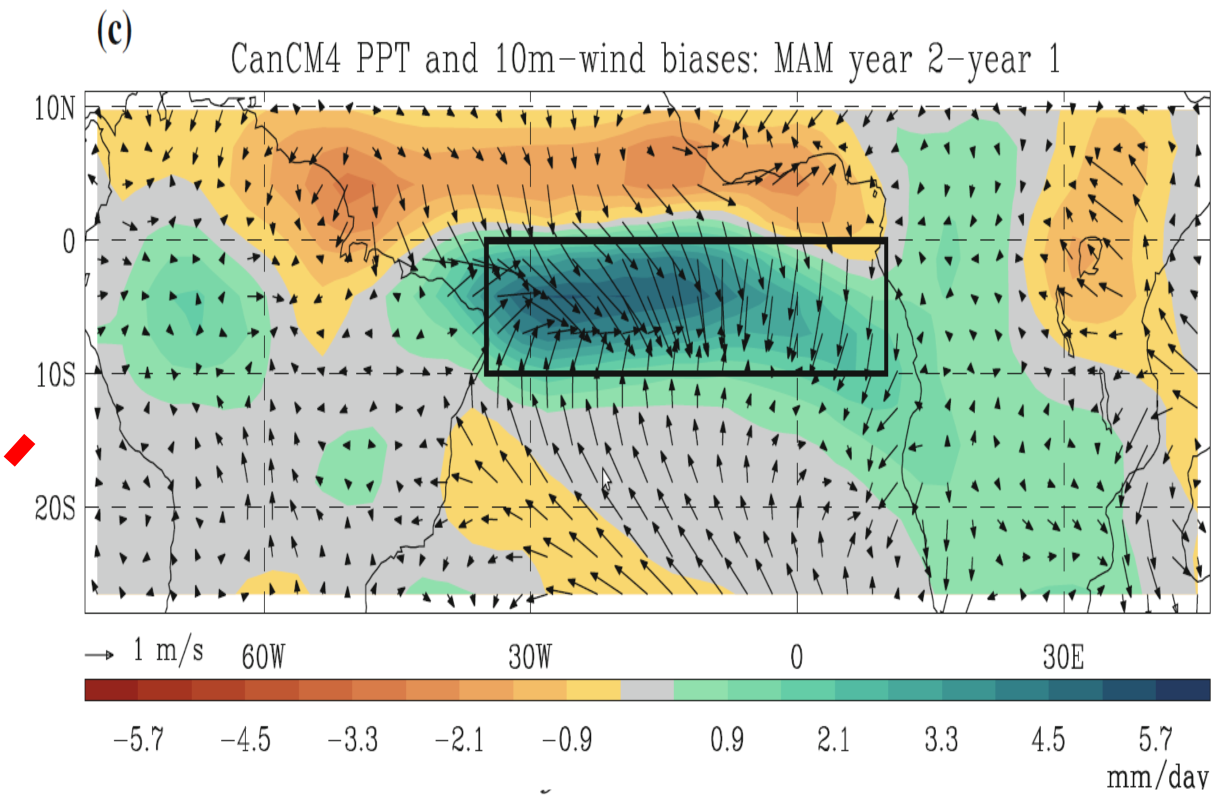


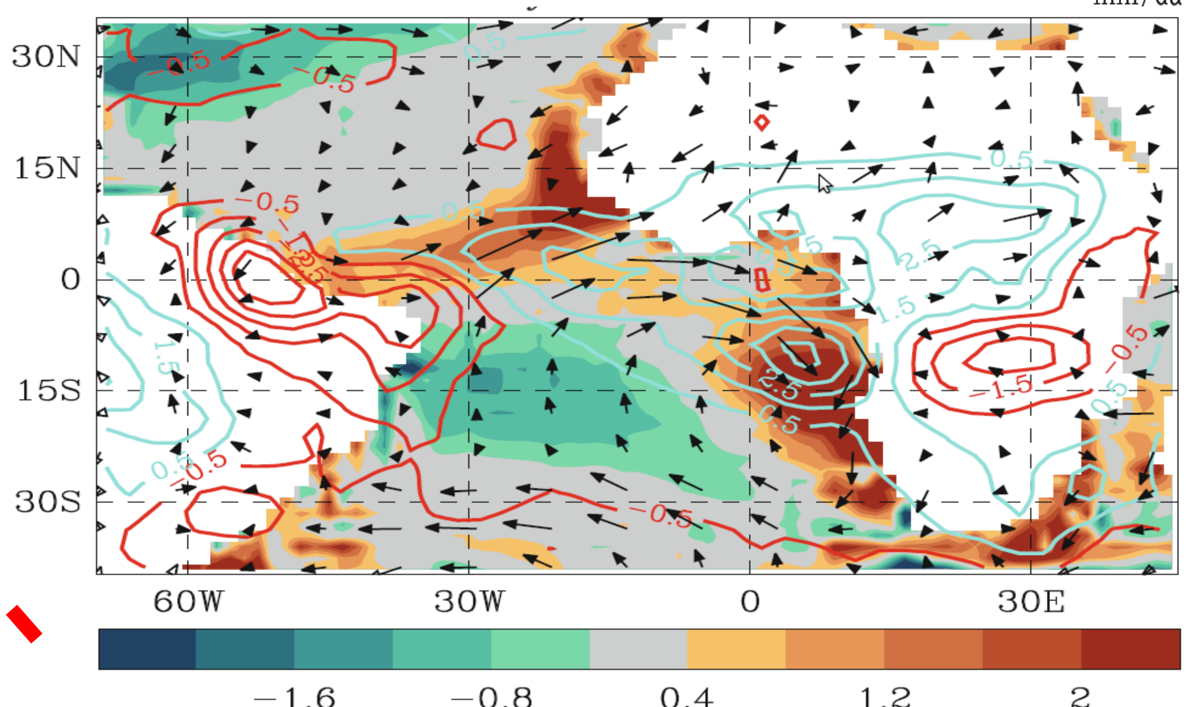




Non-proximate causes V: feedbacks!

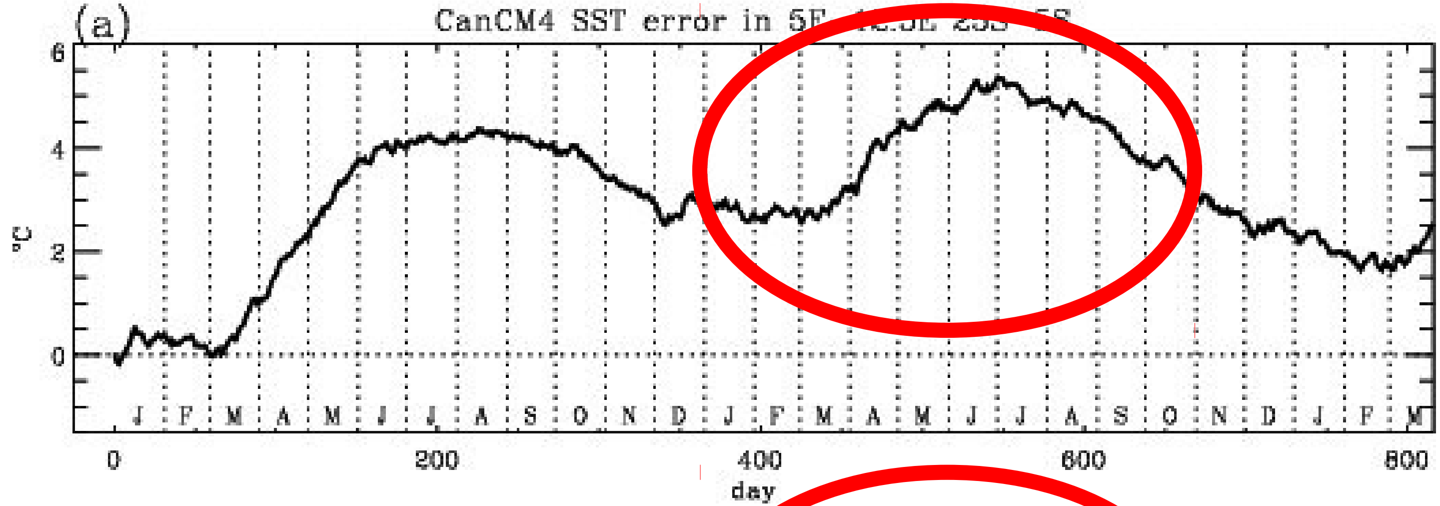




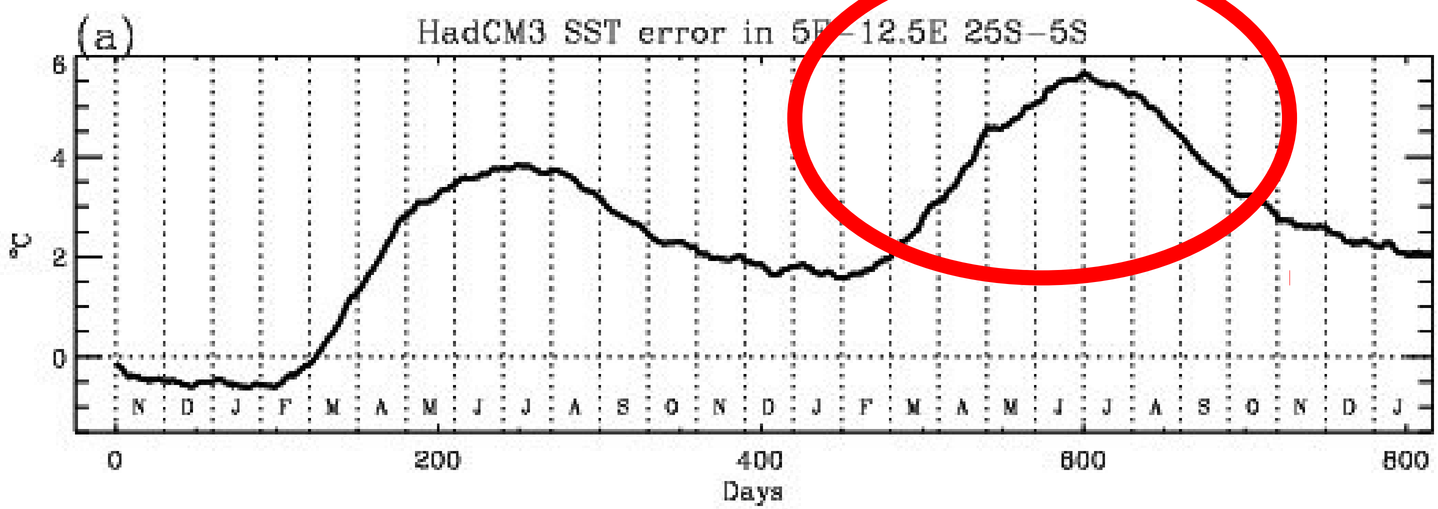


Three models from CMIP5

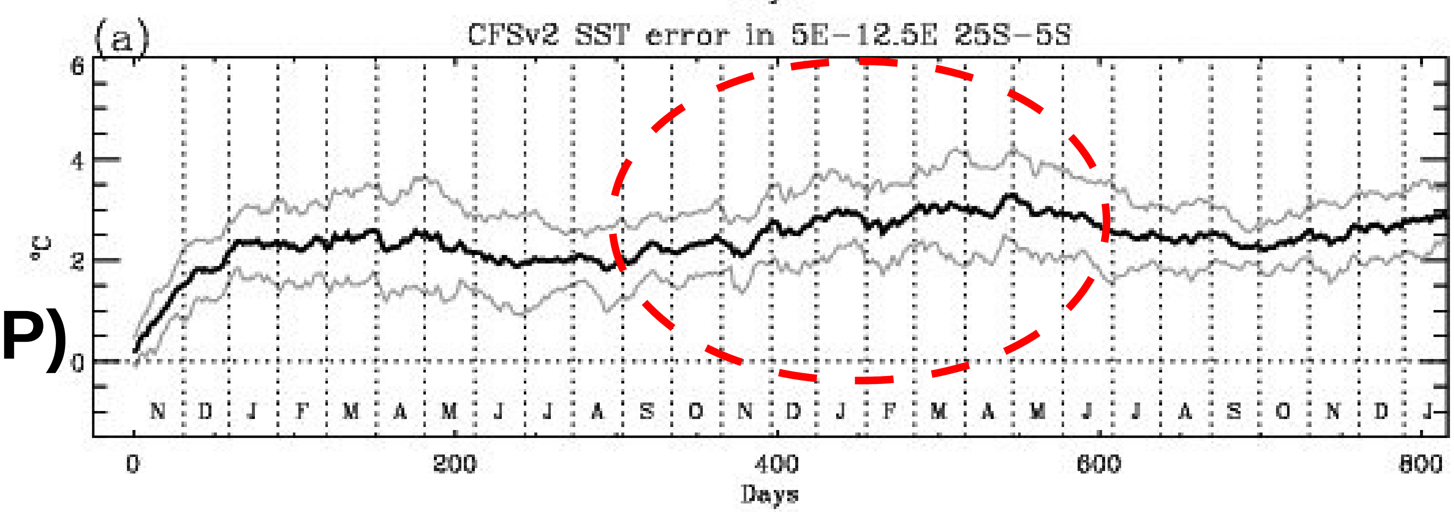
CanCM4 (CCCma)



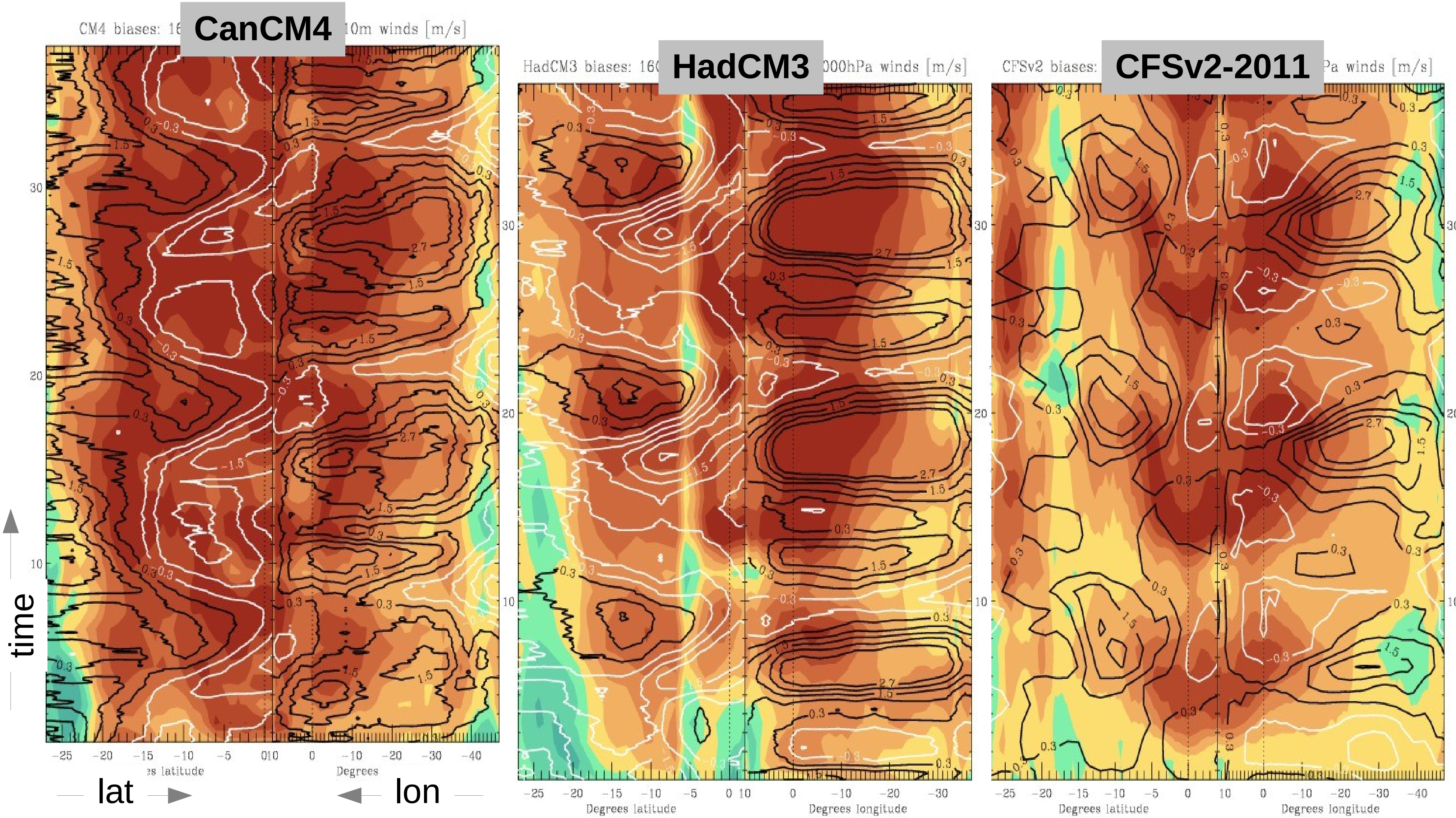
HadCM3 (UKMO)



CFSv2-2011 (NOAA-NCEP)



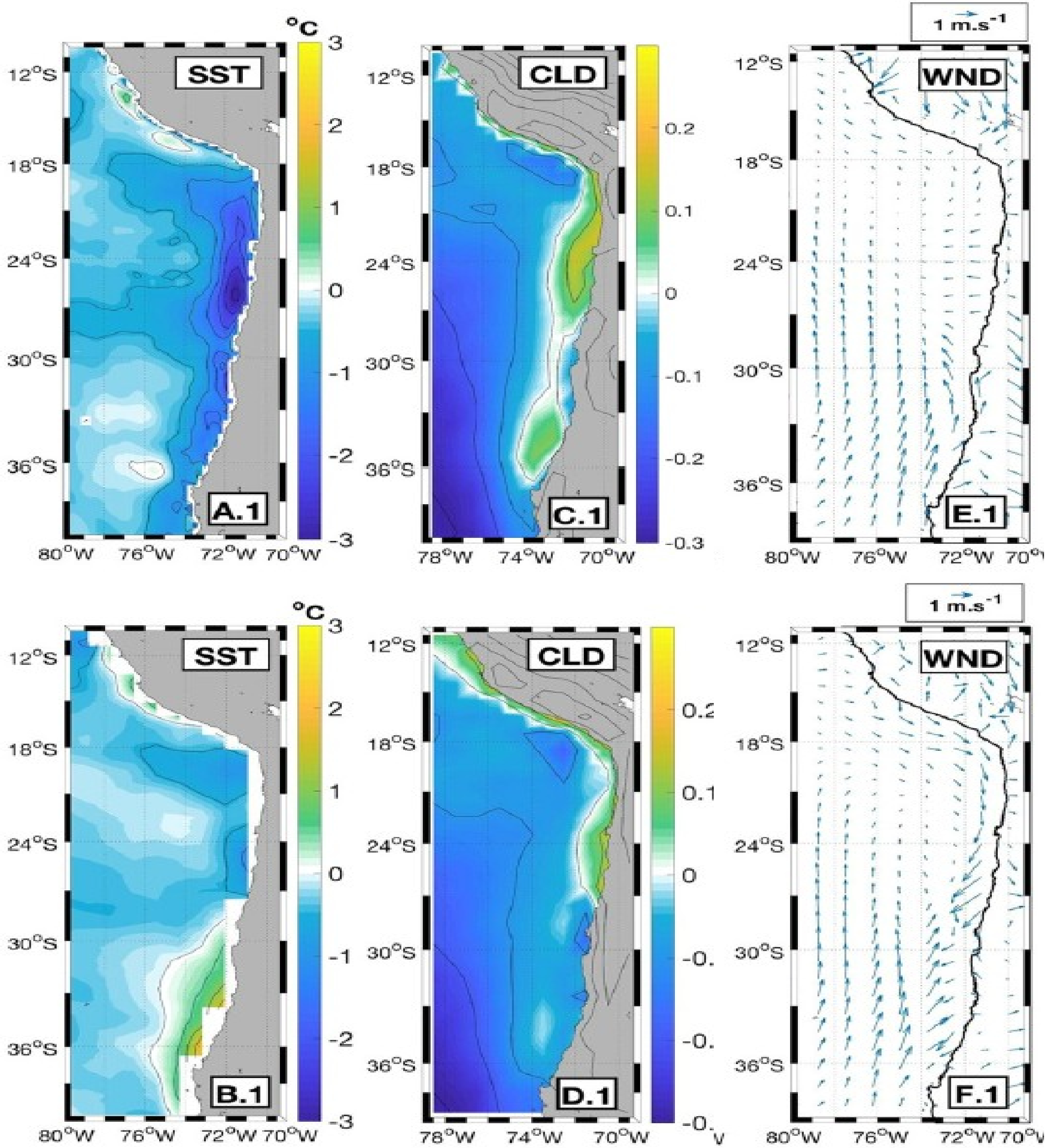
SEA ocean bias development in CMIP5 hindcasts



Combined Hovmueller diagrams (lat-time, left, along African coast, plus lon-time, right, along the Equatorial Atlantic) for the biases of the 16C isotherm depth (colours) and of the near-surface wind (contours: meridional component on left, zonal on right; black for positive values, white for negative values) for each of the three decadal hindcast systems analysed for initial error development from the CMIP5 ensemble in the tropical Atlantic. CFSv2 shows a centre of development mainly in the Gulf of Guinea, which however is triggered by excessive surface SW all along the eastern seaboard; before that couples, winds are mostly OK. CM4 has large initial zonal wind errors over the Equator, and thrmcl depth anomalies propagate into the Benguela area from there. CM3 has negative initial meridional wind errors in the Benguela which triggers a local warming; this later couples with the Equatorial winds generating additional thermocline errors that intensify the warming.

Part III: model climatologies and their biases

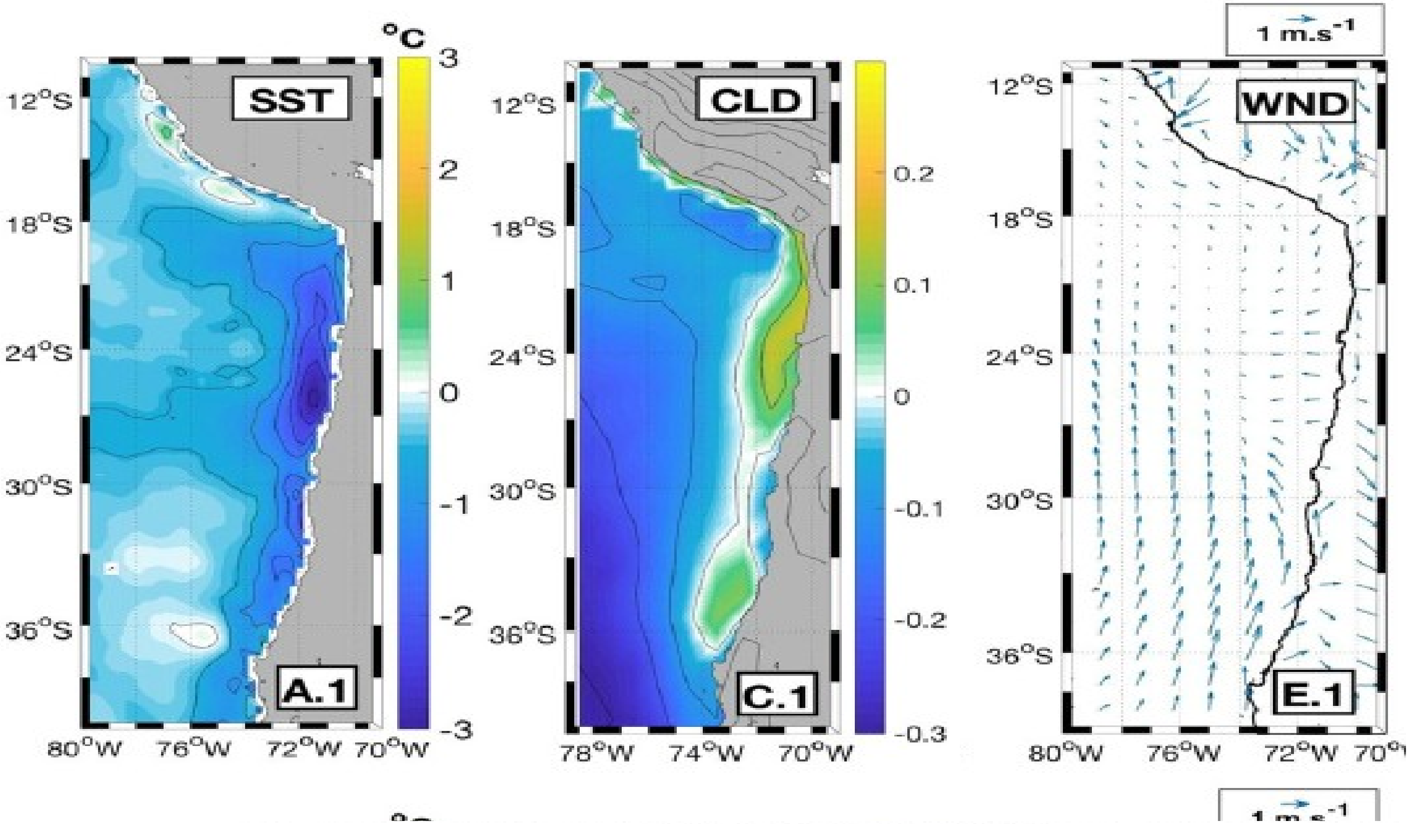
b. current work



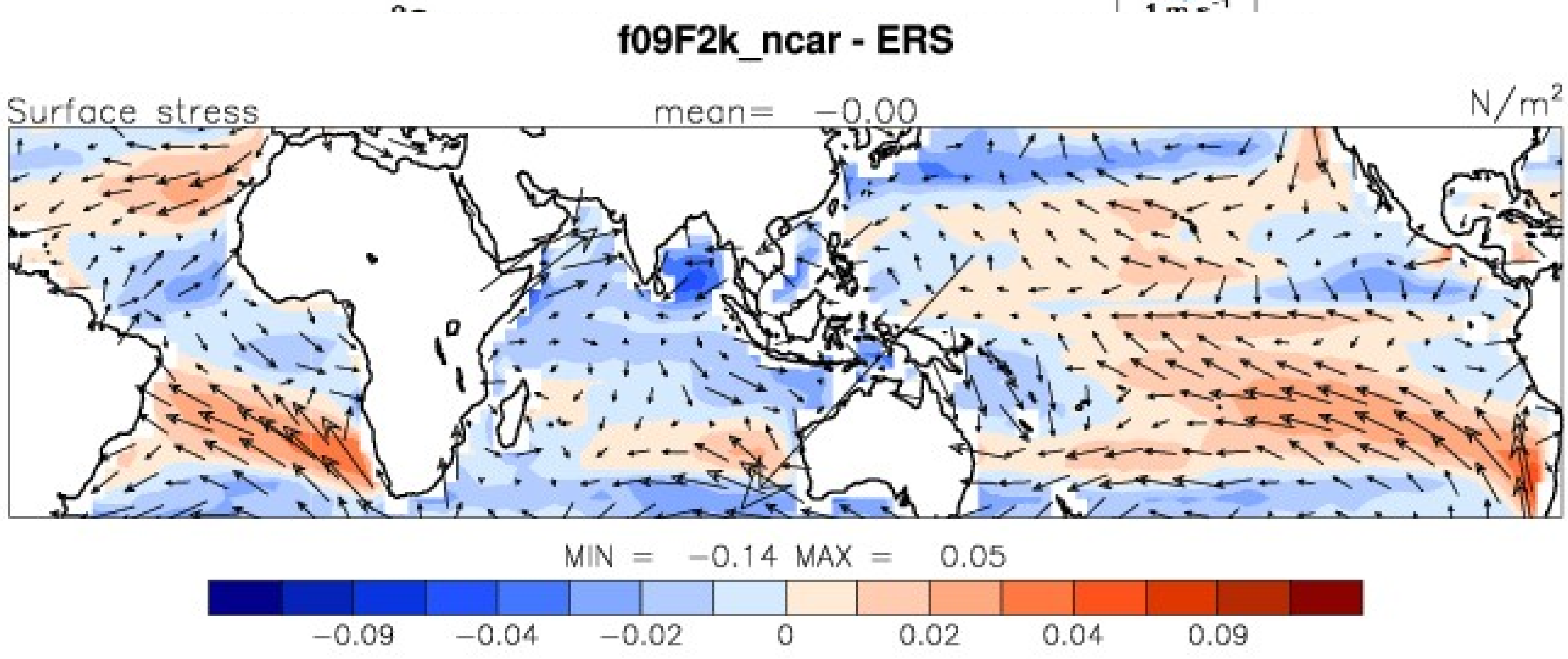
De Silveira et al. 2019: impact of resolution on CCSM4 biases in Humboldt US

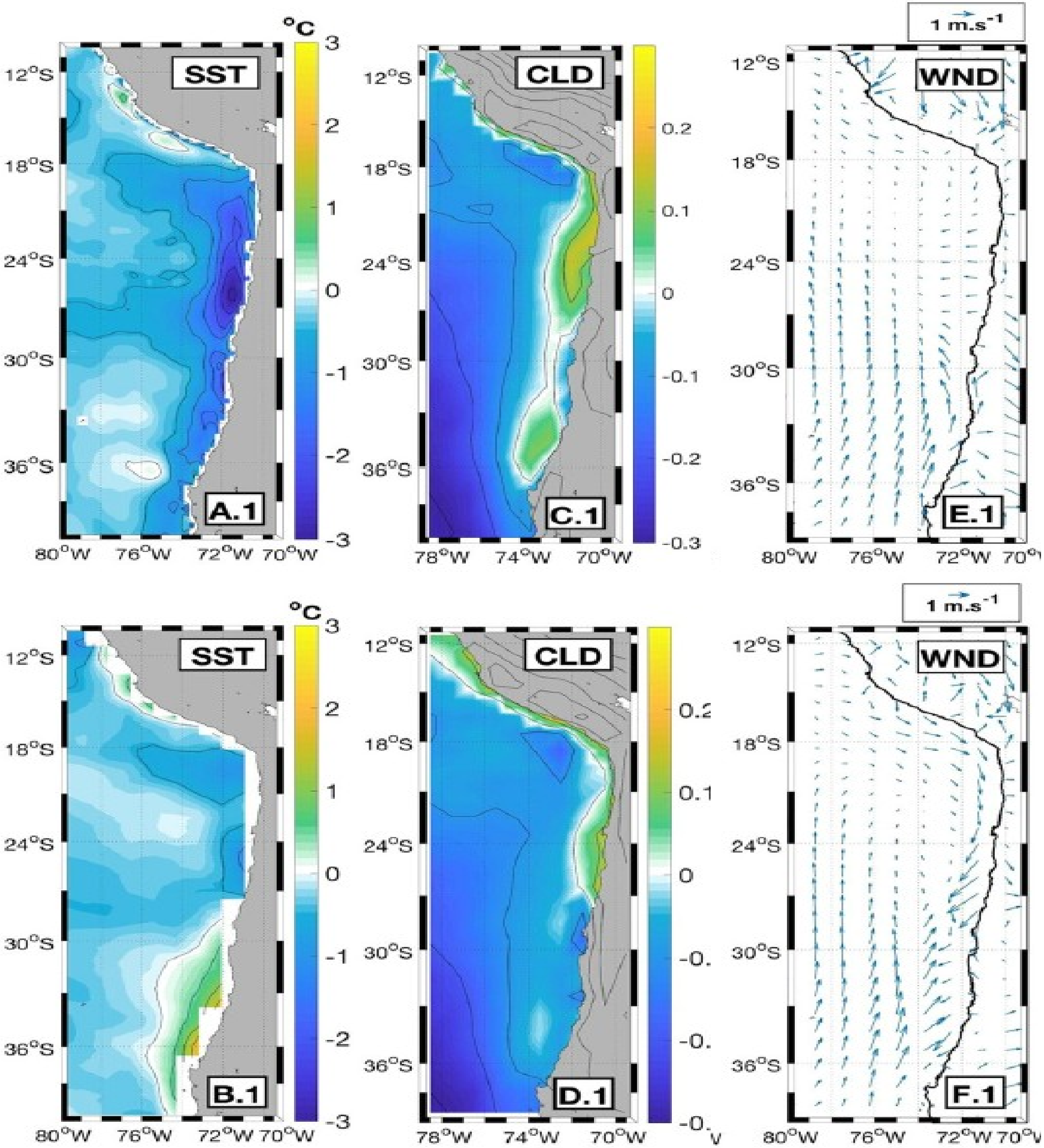
- Persistent problems with marine Sc
- At higher resolution south/south-easterlies too strong

De Silveira et al. 2019: impact of resolution on CCSM4 biases in Humboldt US



- Persistent problems with marine Sc
- Overall simulated atm. circulation probably too intense



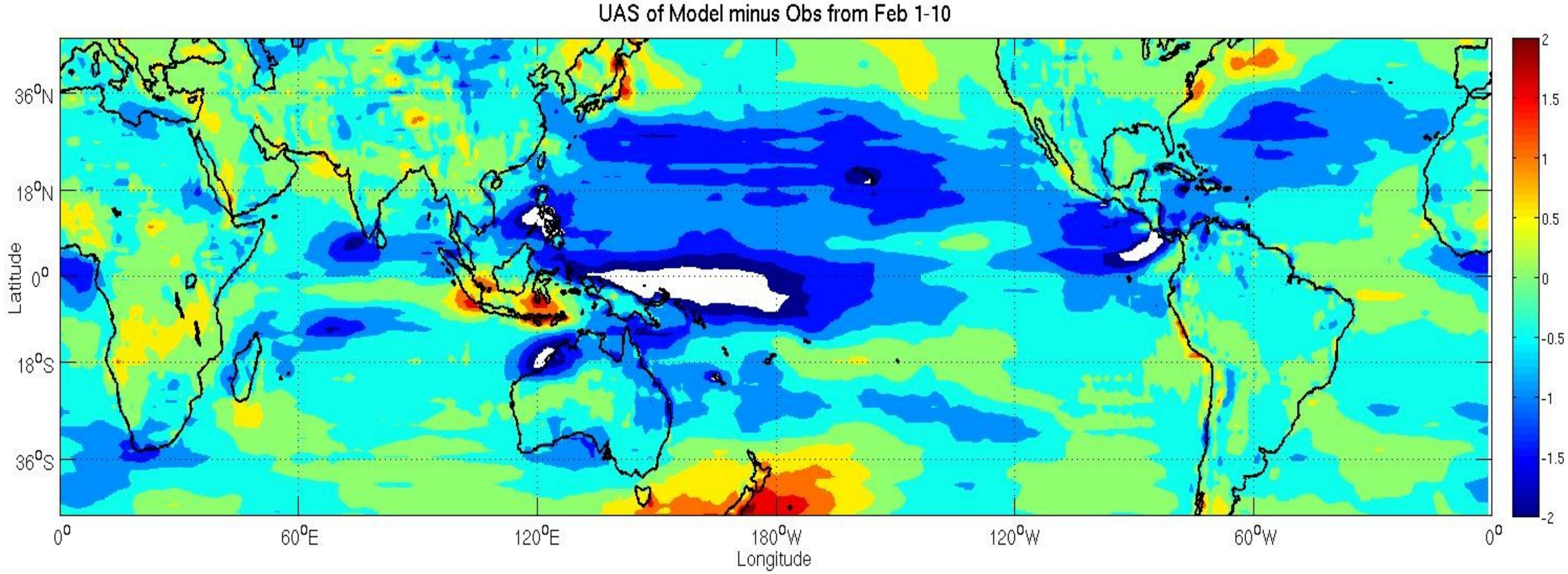


De Silveira et al. 2019: impact of resolution on CCSM4 biases in Humboldt US

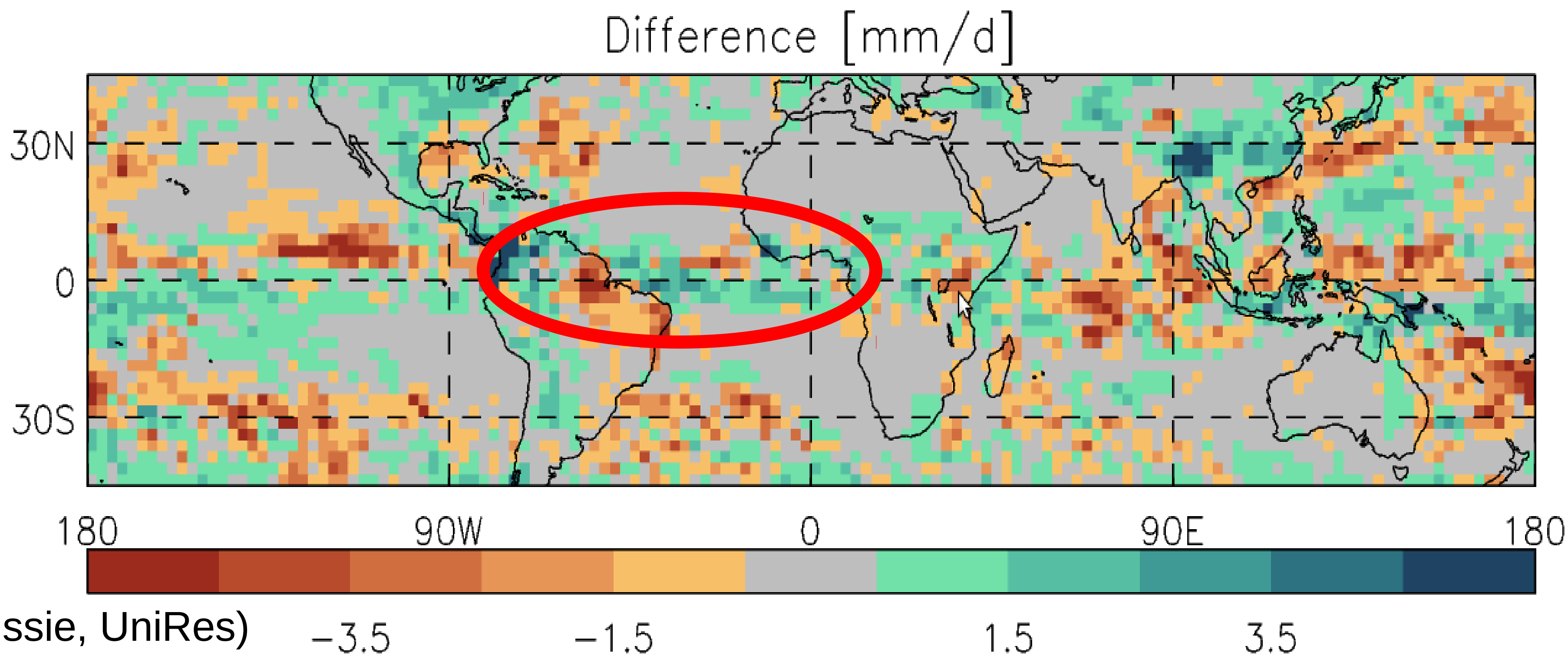
- Persistent problems with marine Sc
- Overall simulated atm. circulation probably too intense (error compensation with SSTs at low resolution)

Fast error development in seasonal hindcasts

February: zonal wind in tropical Pacific



May: ITCZ in tropical Atlantic

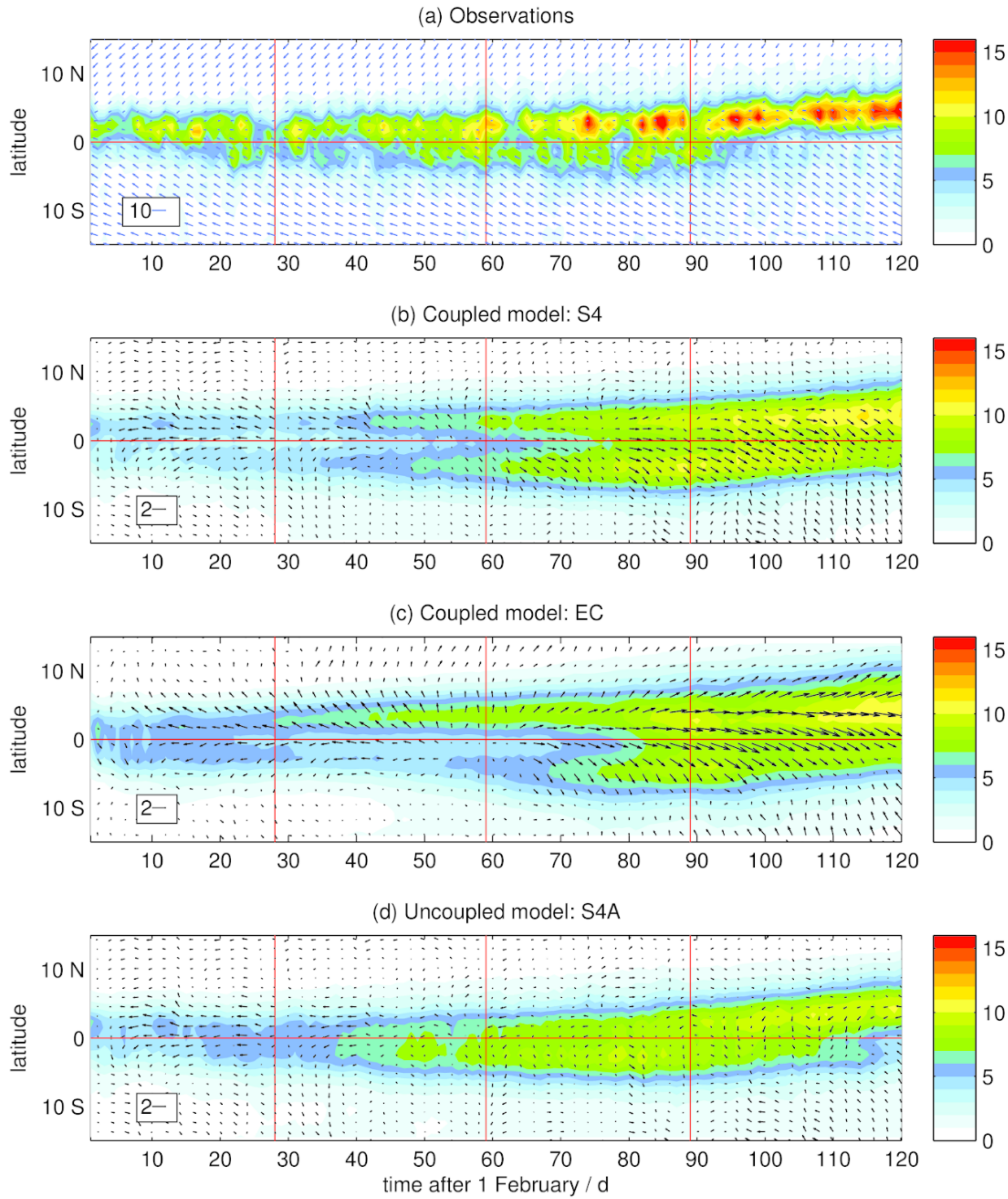


(Teferi Demissie, UniRes)

The systematic ias develops when a certain dynamicl regime sets in, irrespective of initialisation date.

PV constraint to cross-equatorial flow dependent on PBL stability the likely cause.

(Shonk, Demissie and Toniazzo 2019, under revision in ACP)

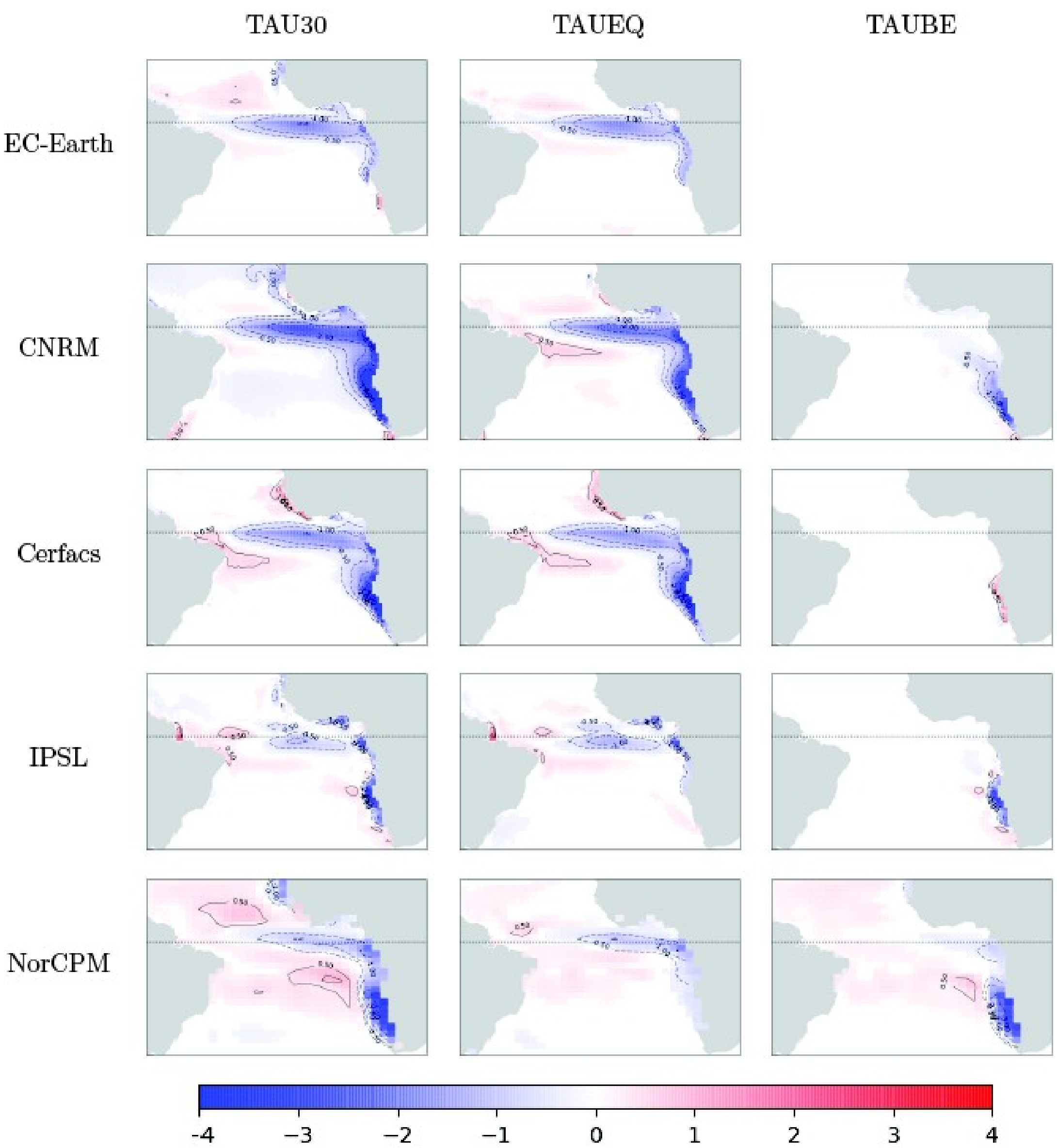


III: Beyond diagnosis: sensitivity experiments in forecast mode

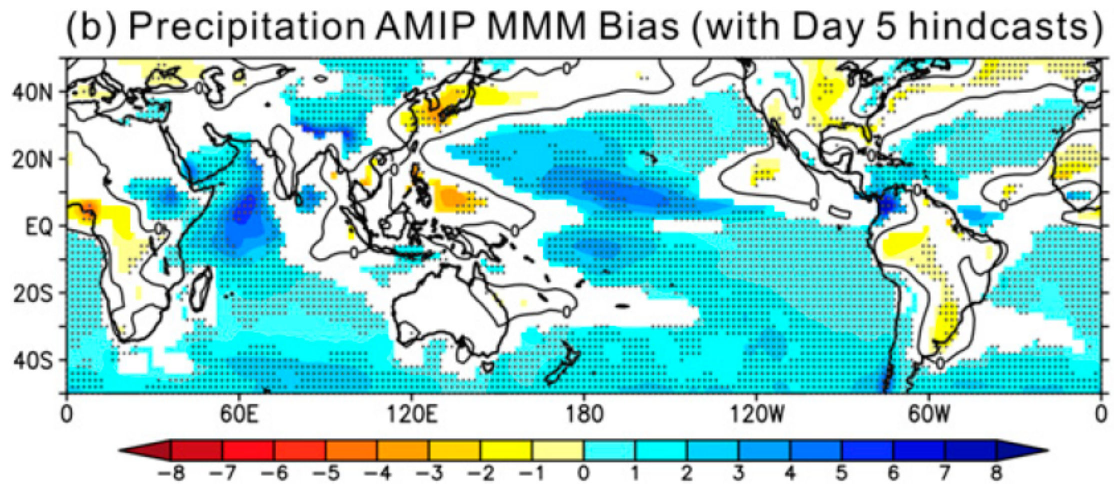
1. Correct biases surface heat and/or momentum fluxes e.g. over Equatorial region

2. Test effects on forecasts

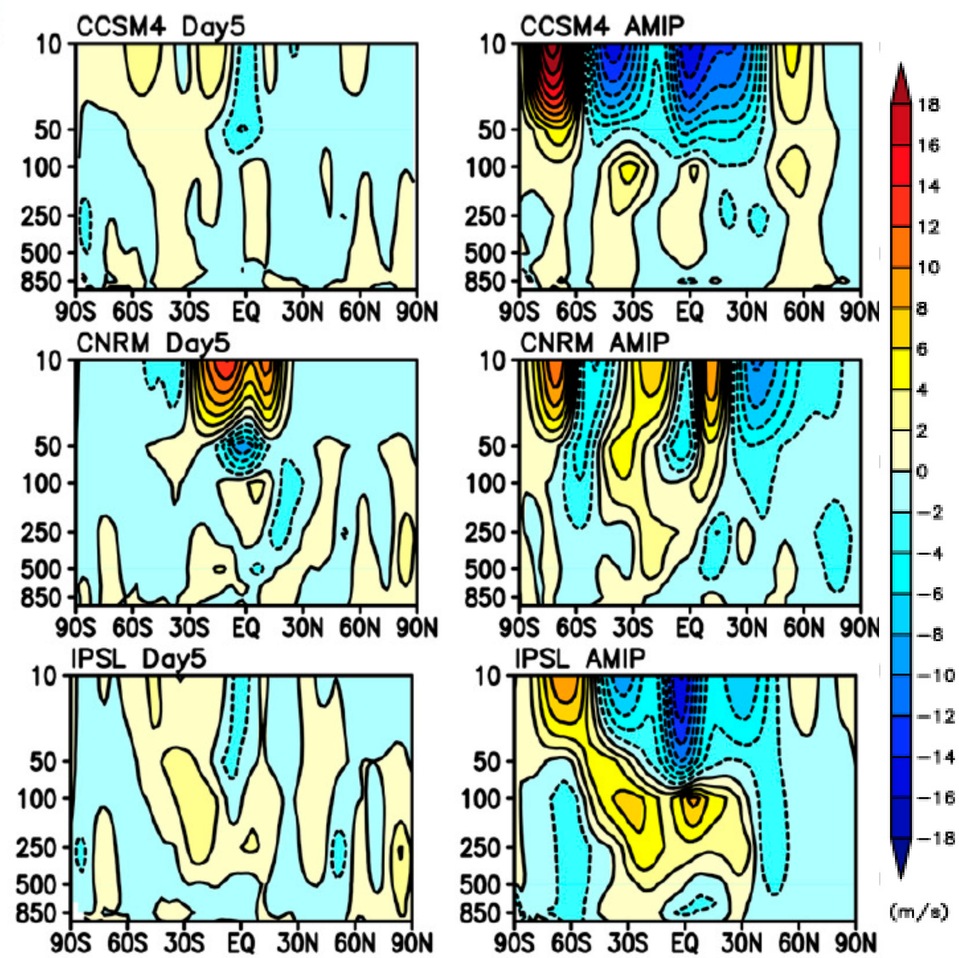
Voldoire A. et al 2019



II: Development of “fast” biases in “TAMIP” integrations



Ma, H.-Y., et al., 2014: *On the Correspondence between Mean Forecast Errors and Climate Errors in CMIP5 Models.* J.Clim. **27**, 1781-1798



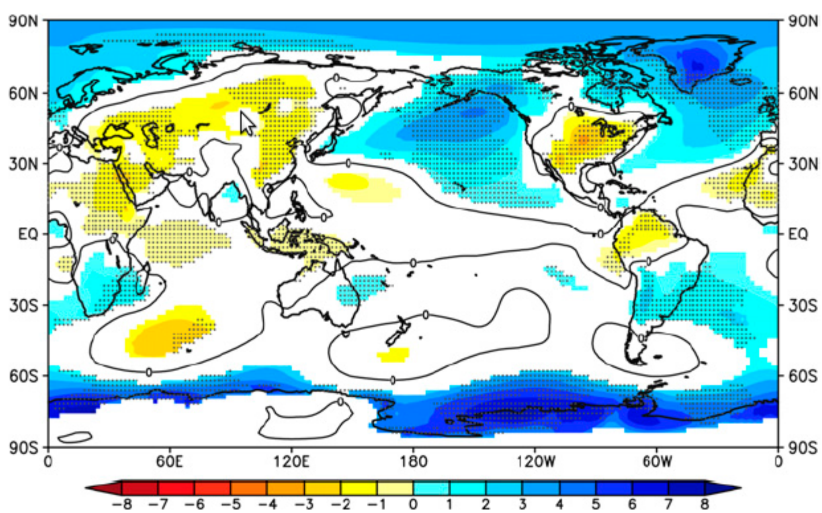
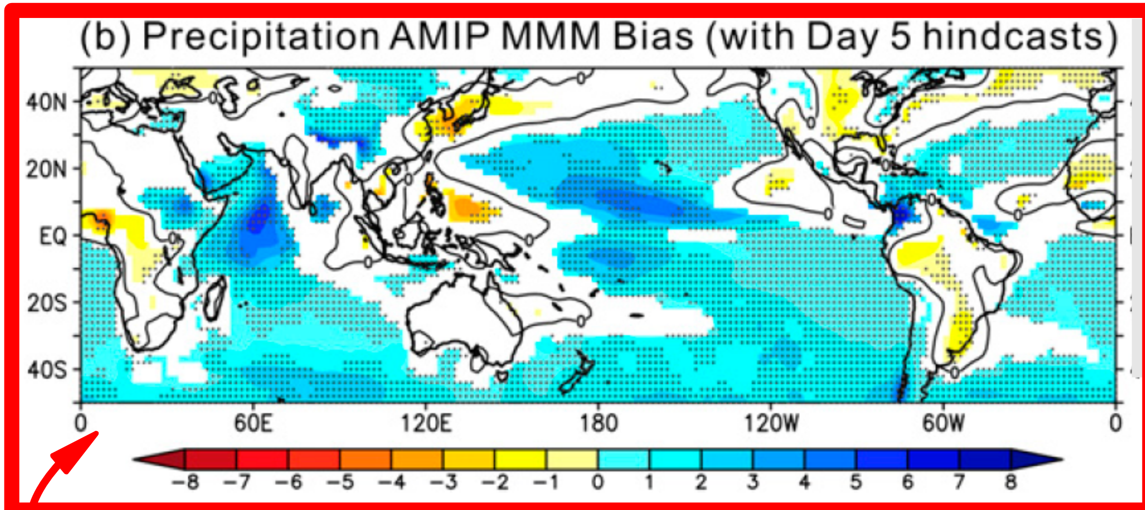
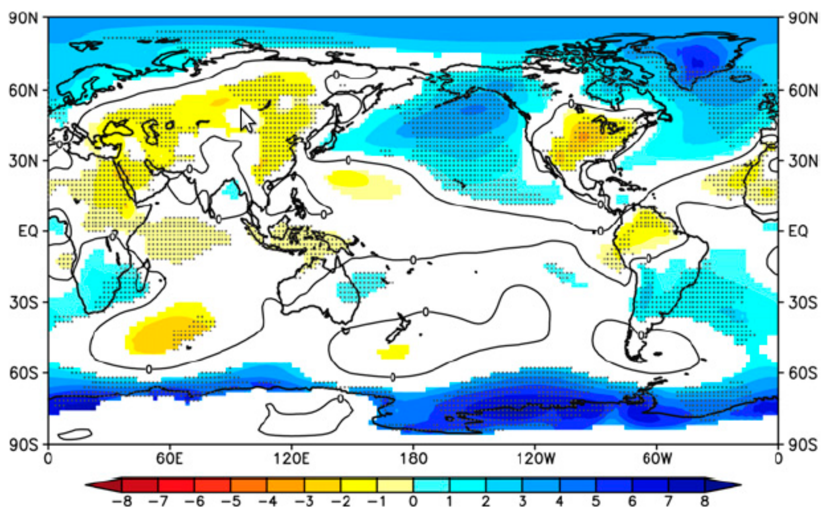


FIG. 12. As in Fig. 5b, but for sea level pressure (hPa).

II: Development of "fast" biases in "TAMIP" integrations



- Biases of 5-day forecasts from ERA/I i.c.'s
- Diabatically coupled dynamical fields affected
- Large-scale (zonal-mean) wind drifts
- Bearing some resemblance with climatological biases



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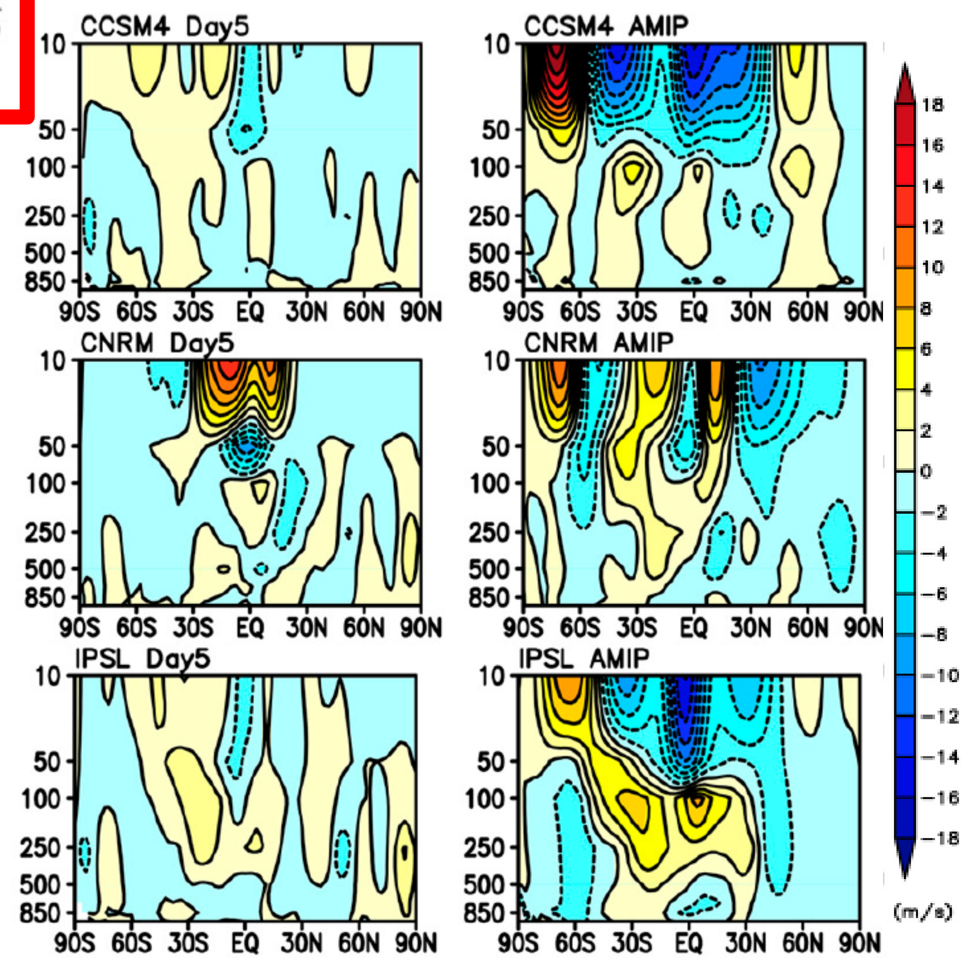

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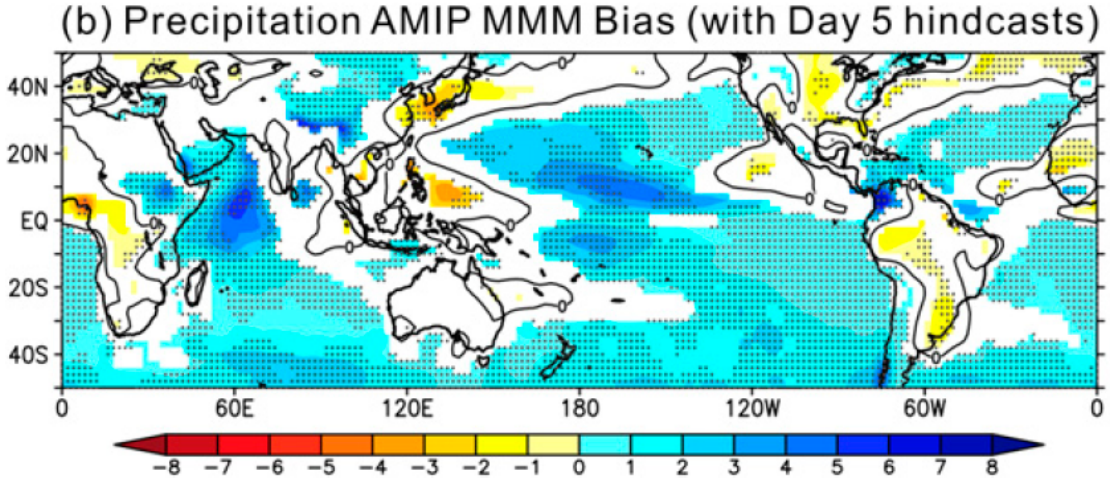

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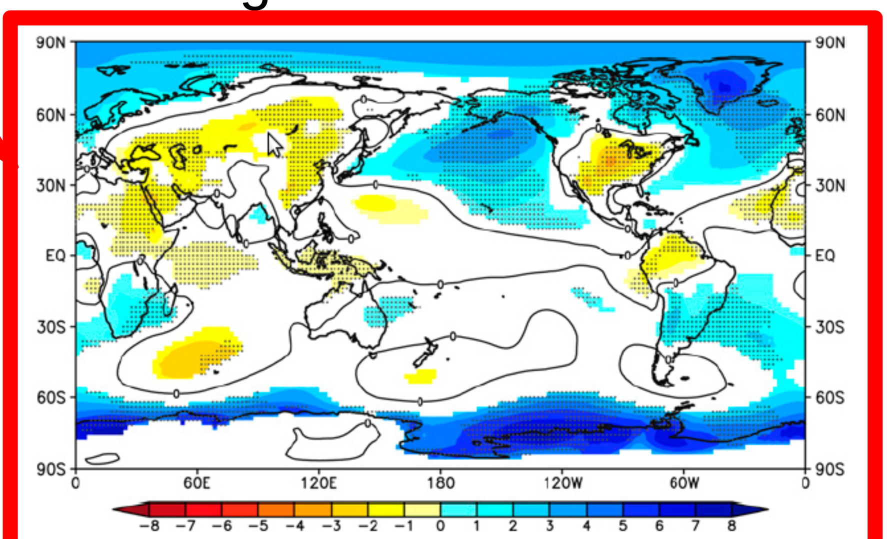

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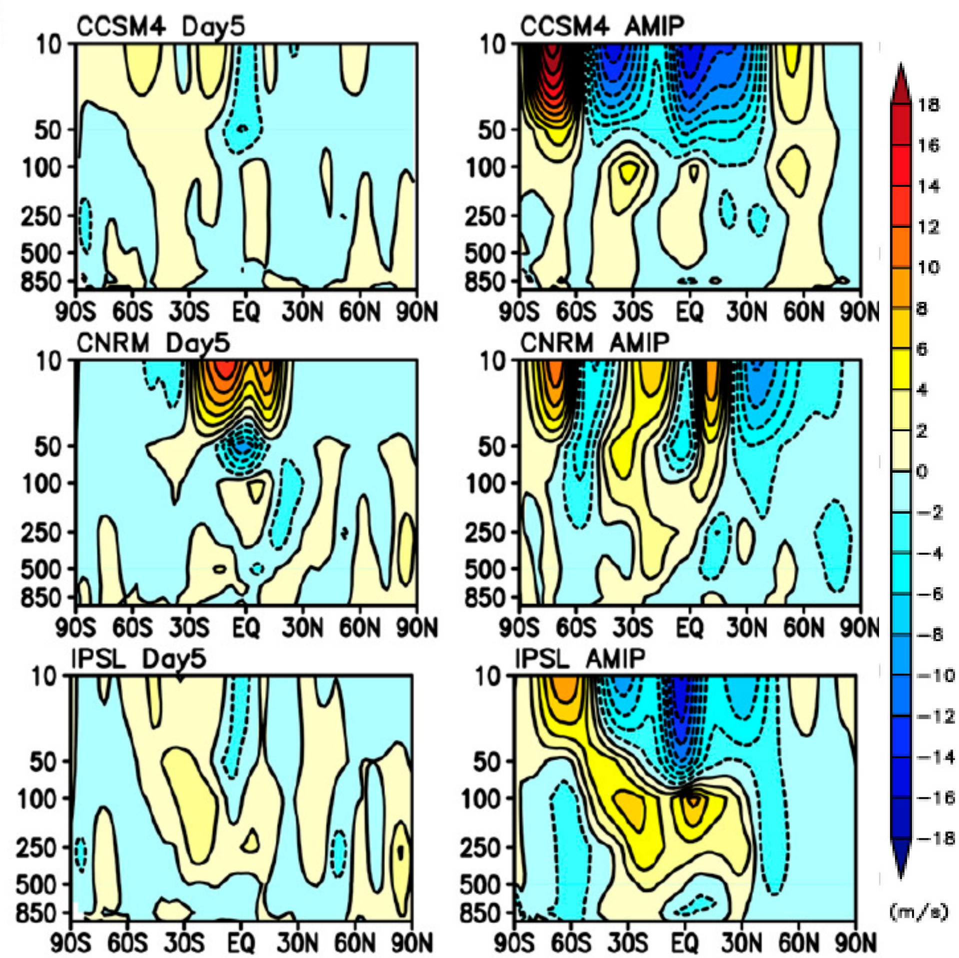

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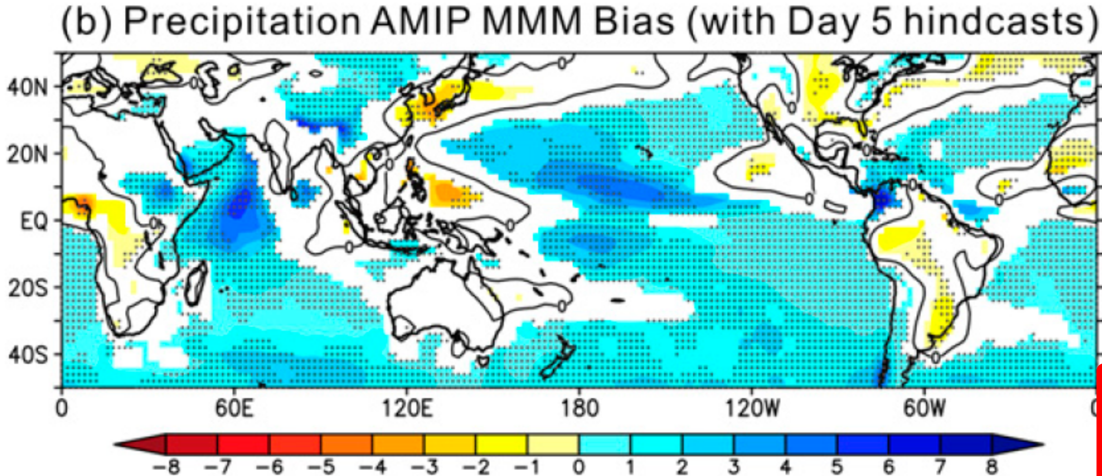

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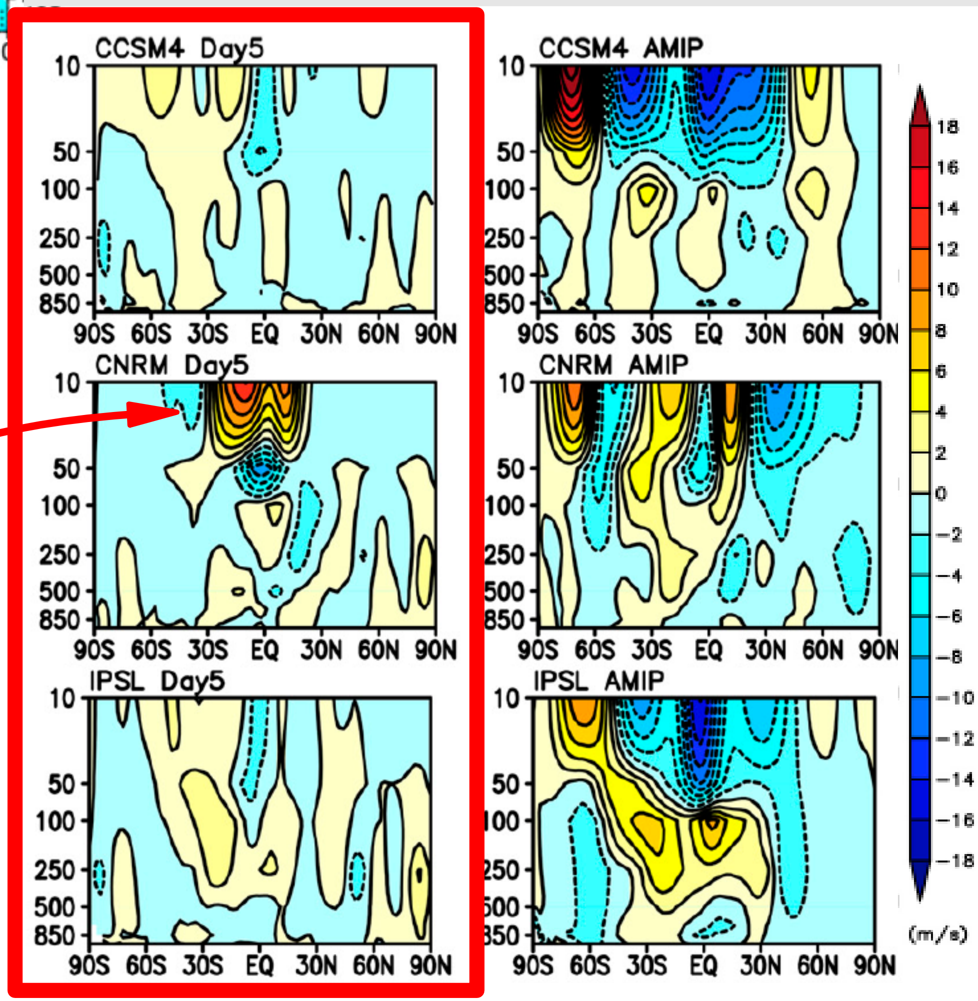

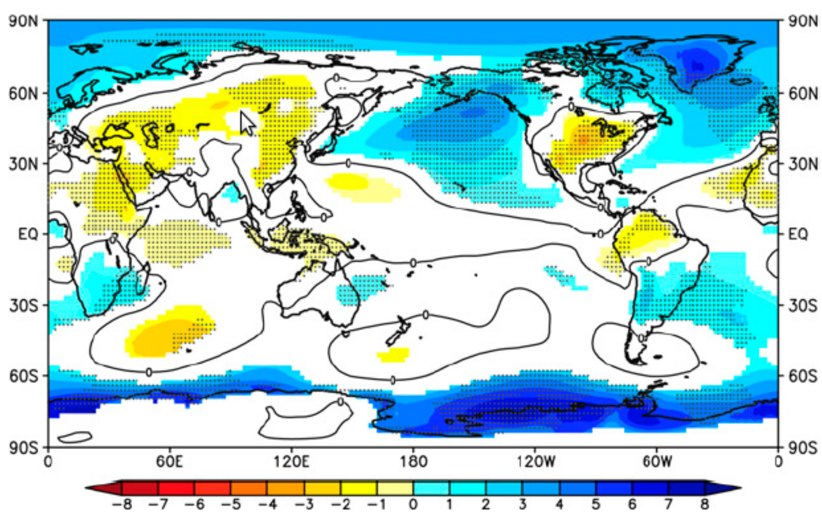

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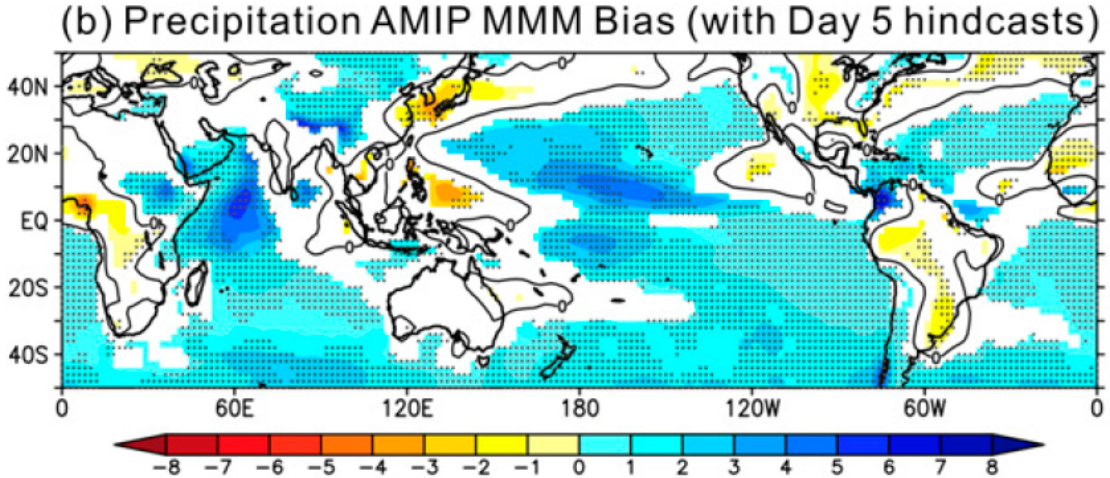

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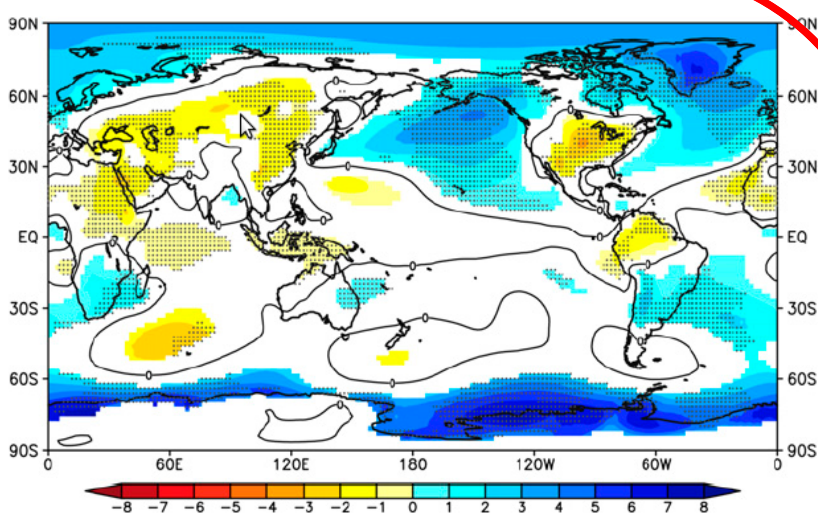

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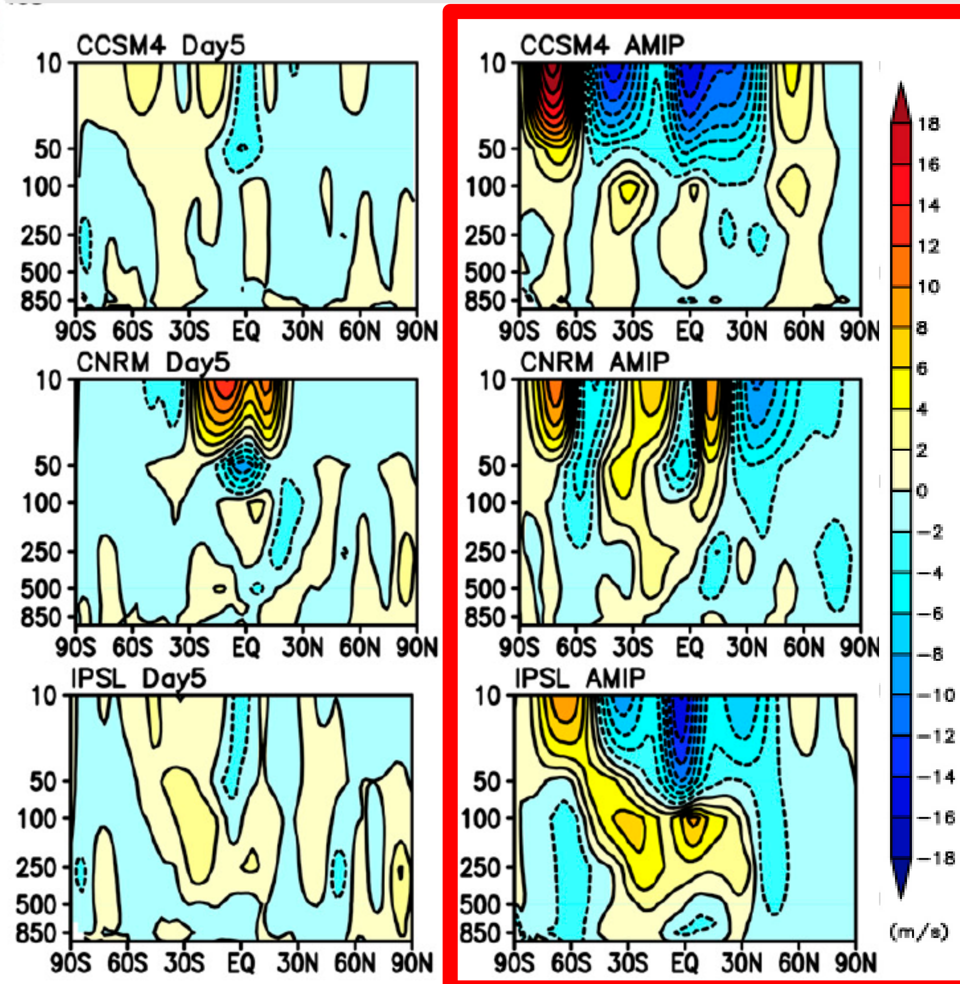
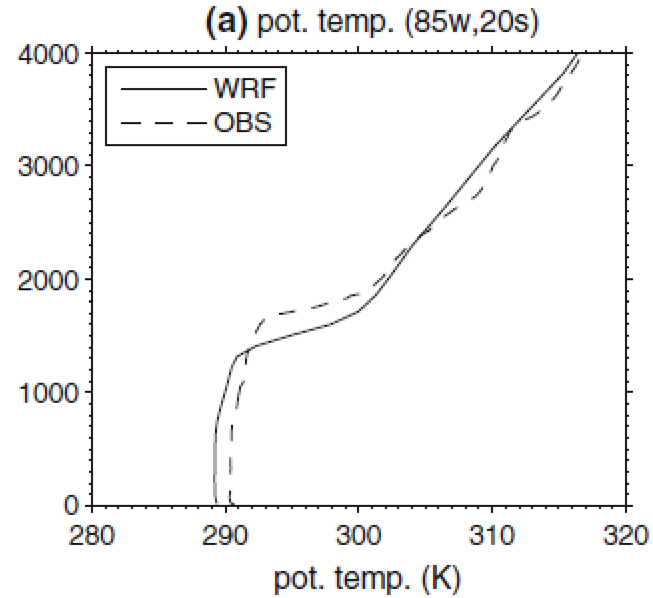
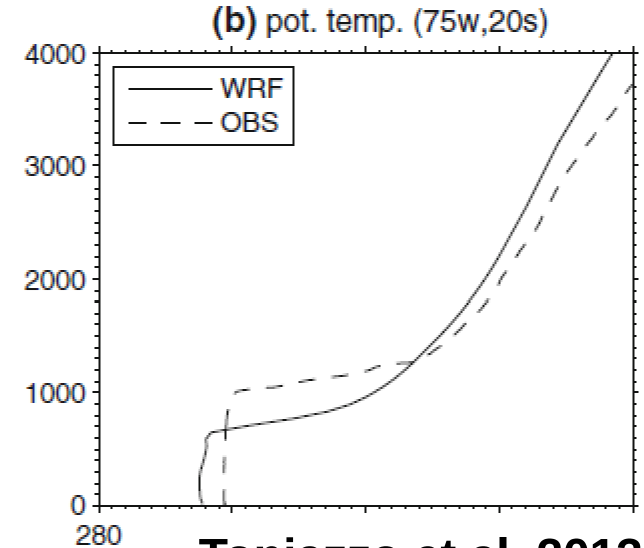
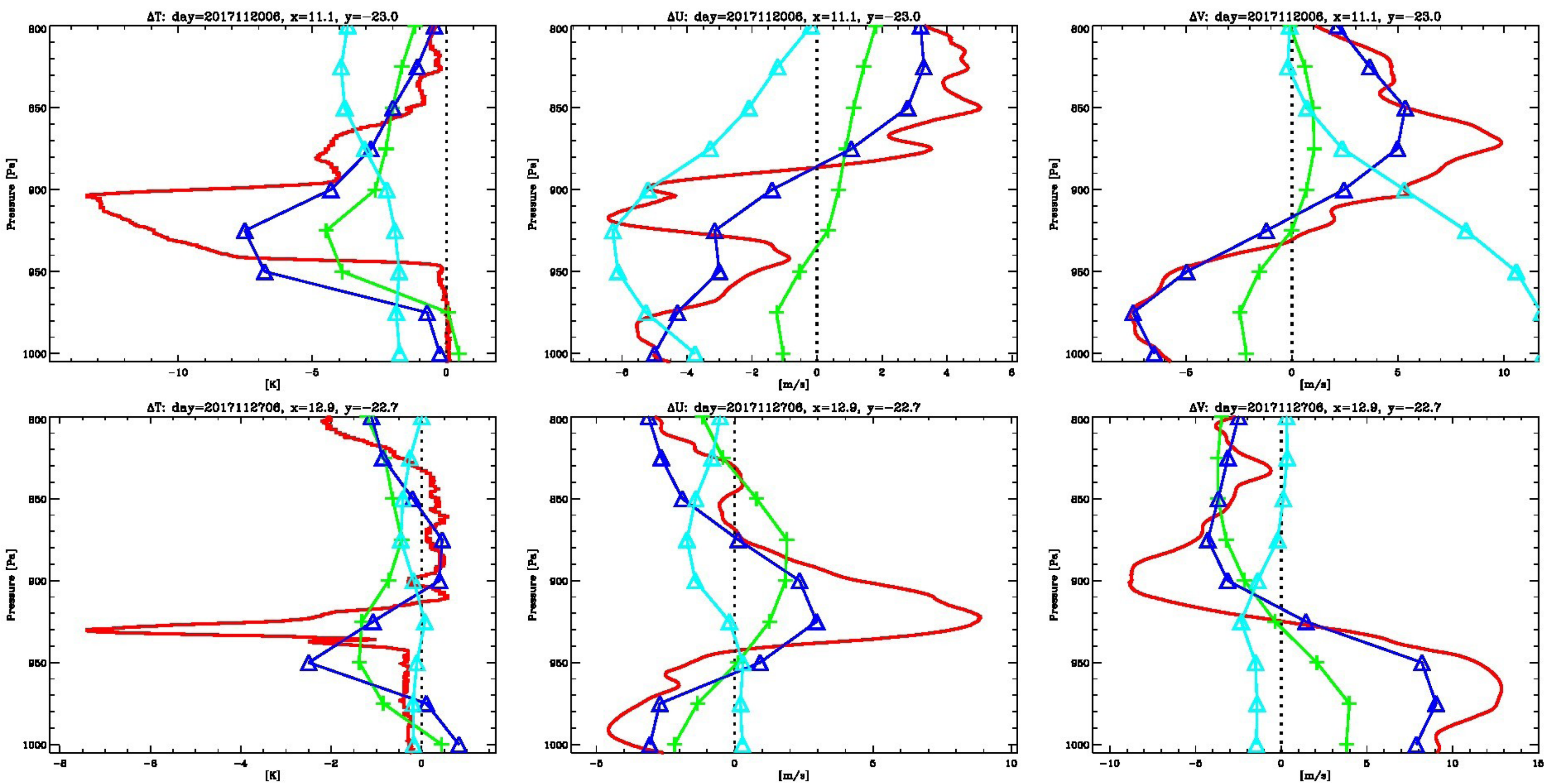


Fast growing, observationally unconstrained systematic biases affect reanalysis products



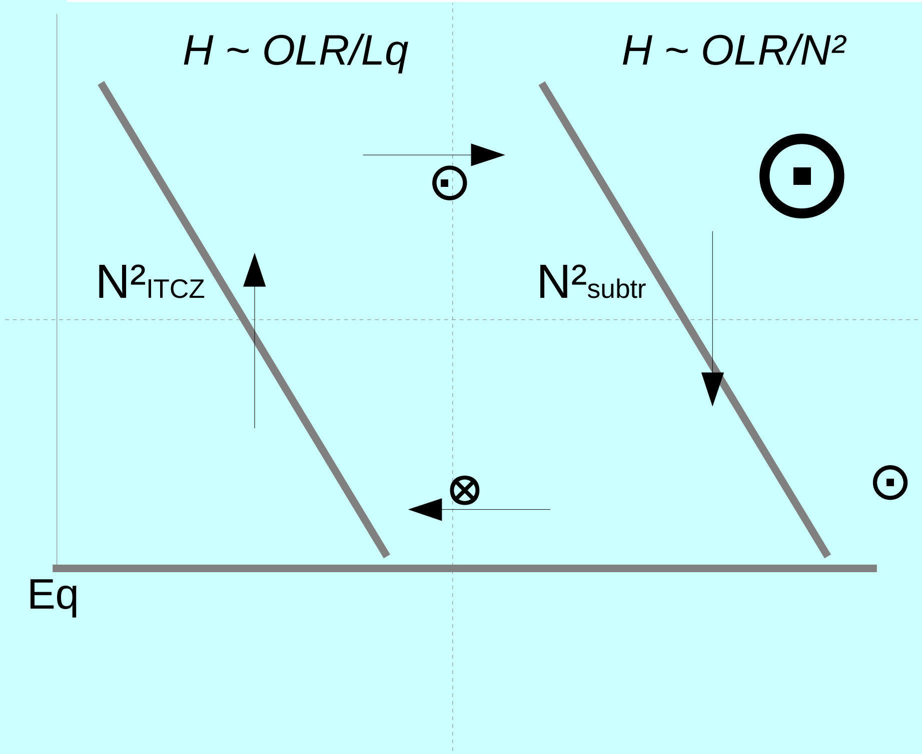


Toniazzo et al. 2013

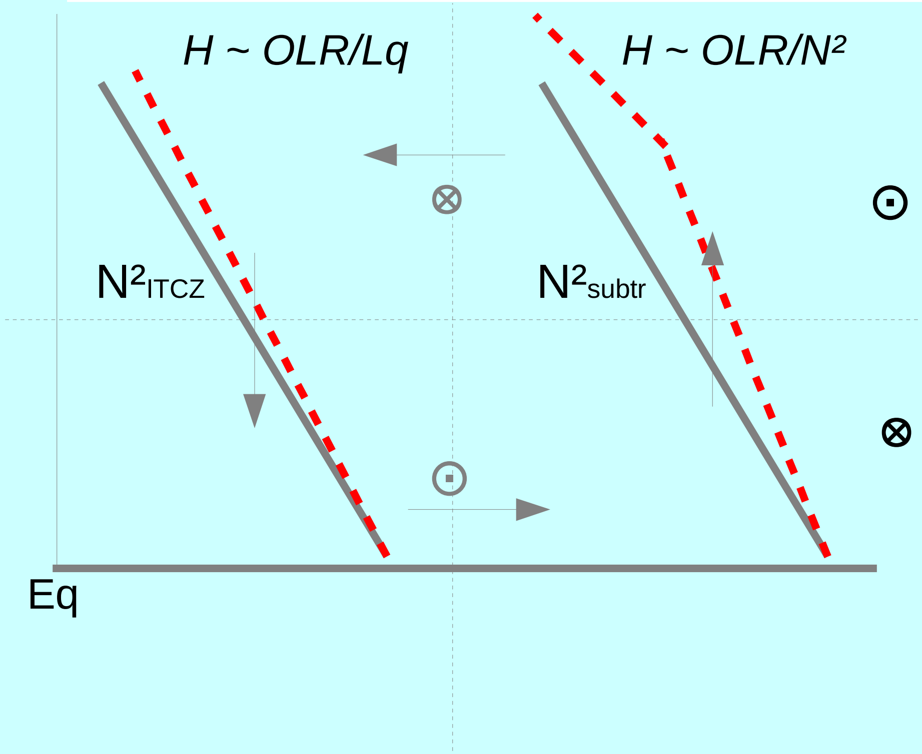


What we *know*

Held and Soden 2006 and the role of subtropical warming



Held and Soden 2006 and the role of subtropical warming



$\delta(M_c q) \sim \delta OLR$

But

$\delta OLR \sim 2$ %/K and $\delta q \sim 7$ %/K

Therefore

$\delta M_c \sim -5$ %/K

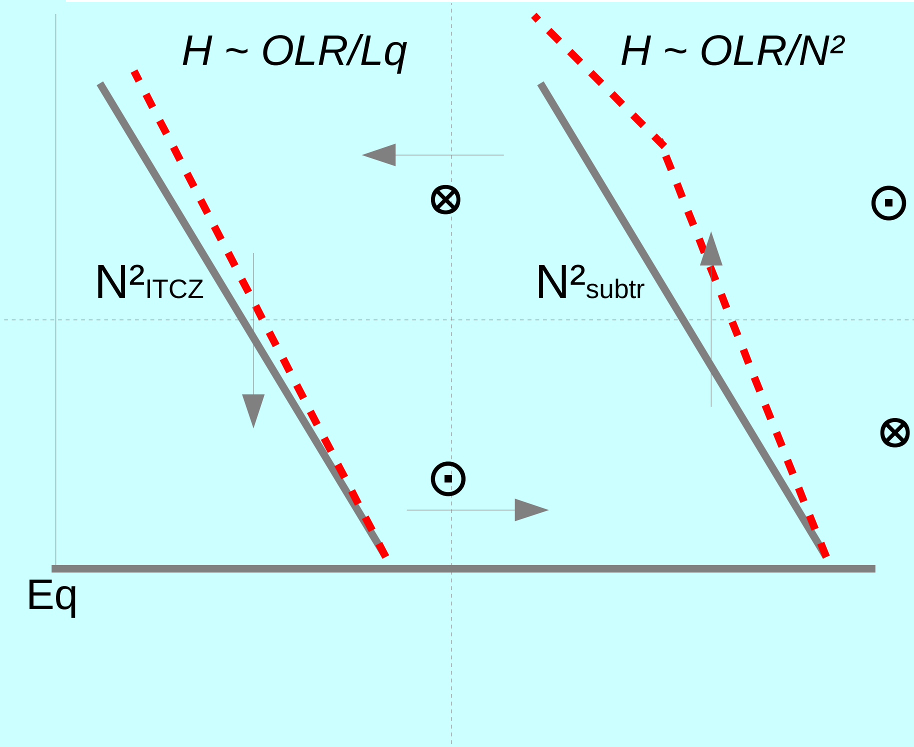
Convective adjustment also implies

$\delta N^2_{ITCZ} \sim 2$ %/K

If $H \sim M_c$, then for the subtropics

$\delta N^2_{subtr} \sim 7$ %/K.

Held and Soden 2006 and the role of subtropical warming



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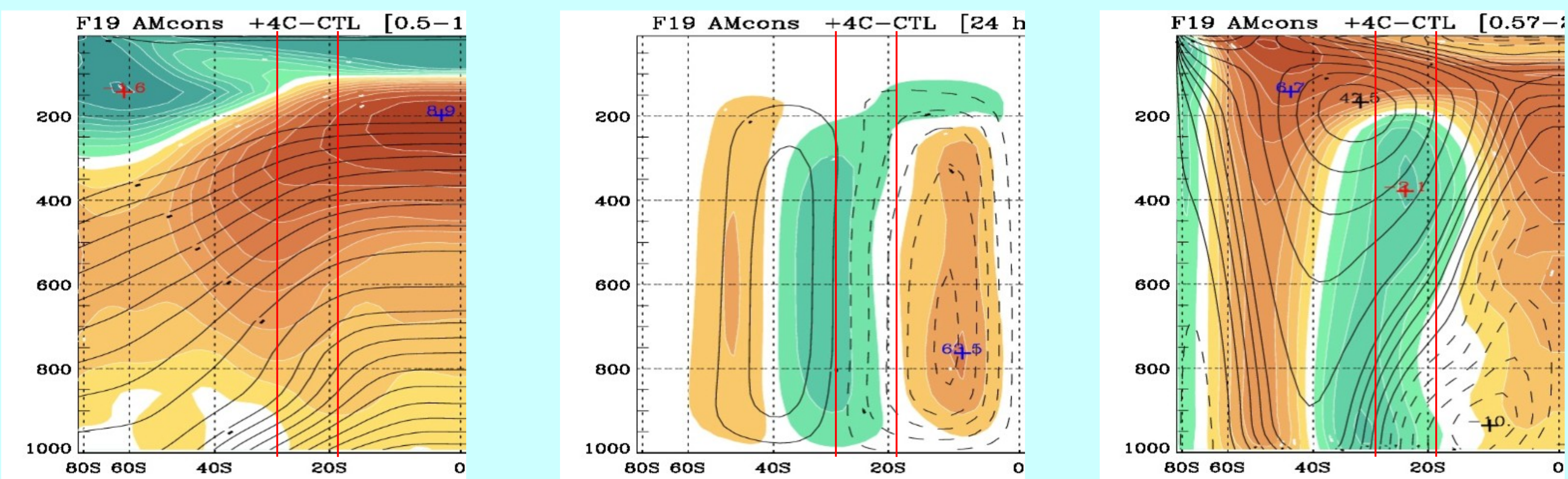
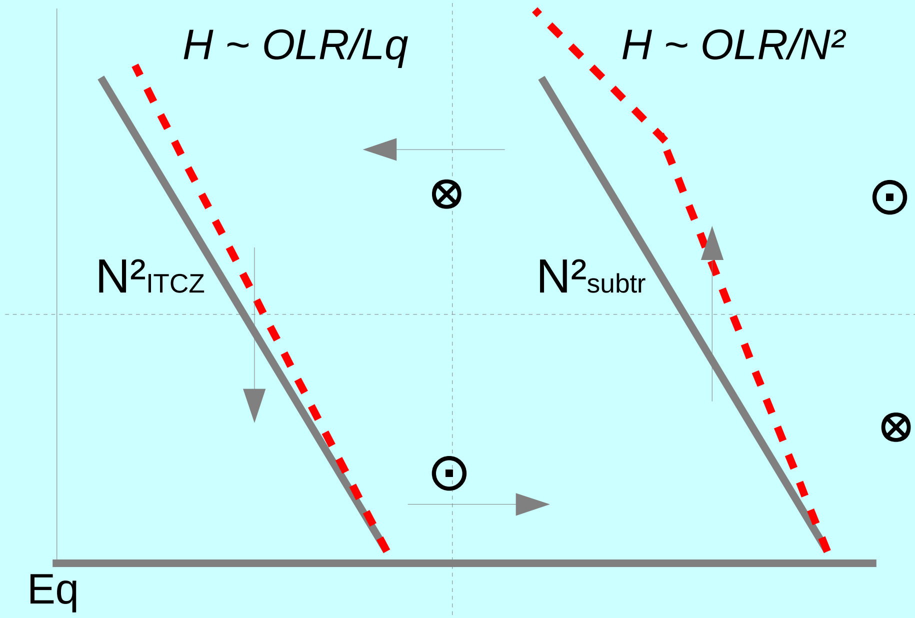


Held and Soden 2006 and the role of subtropical warming



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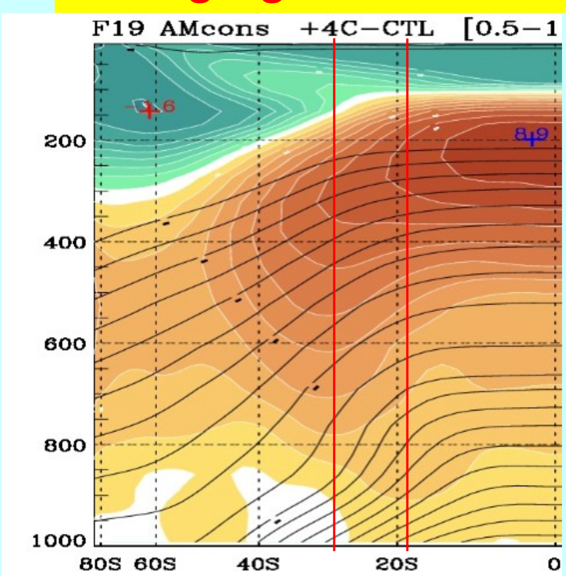
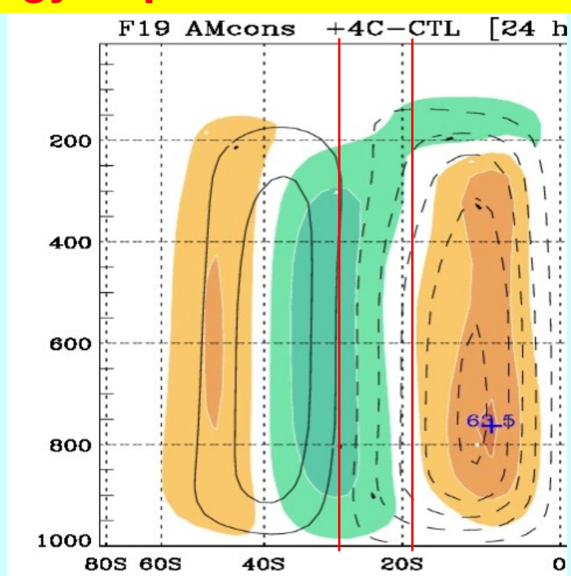
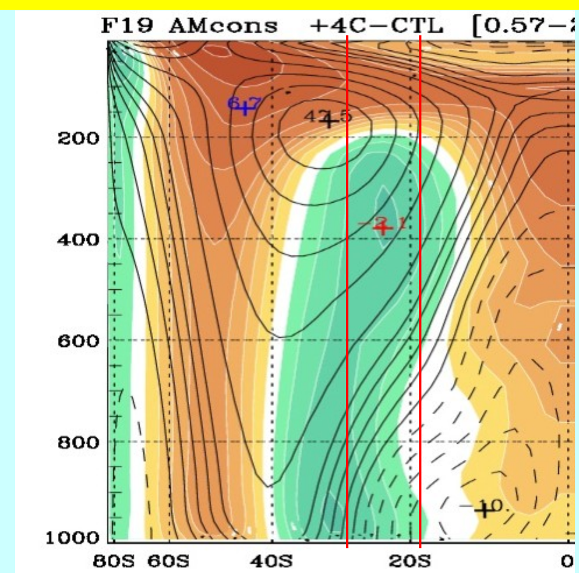
$\delta N^2_{subtr} \sim 7$ %/K.

Hence reduced thermal wind in subtropics. Since also $\delta N^2_{subpolar}$ is small, there is **increased thermal wind in mid-latitudes**. But the **HC subsequently responds to changing mid-latitude energy exports**.







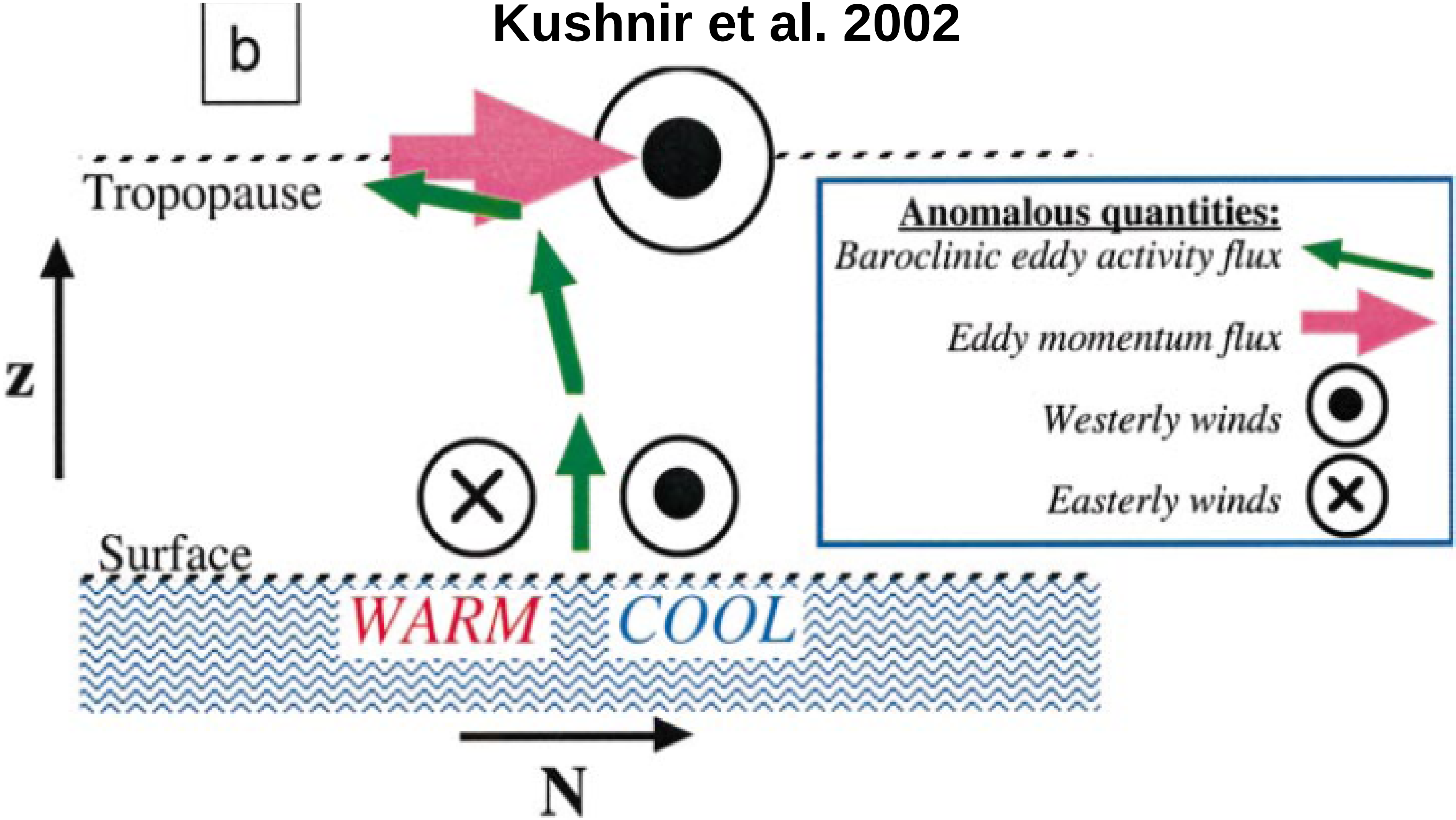
- **Subtropical subsidence will weaken**
- **Stratification will strengthen**

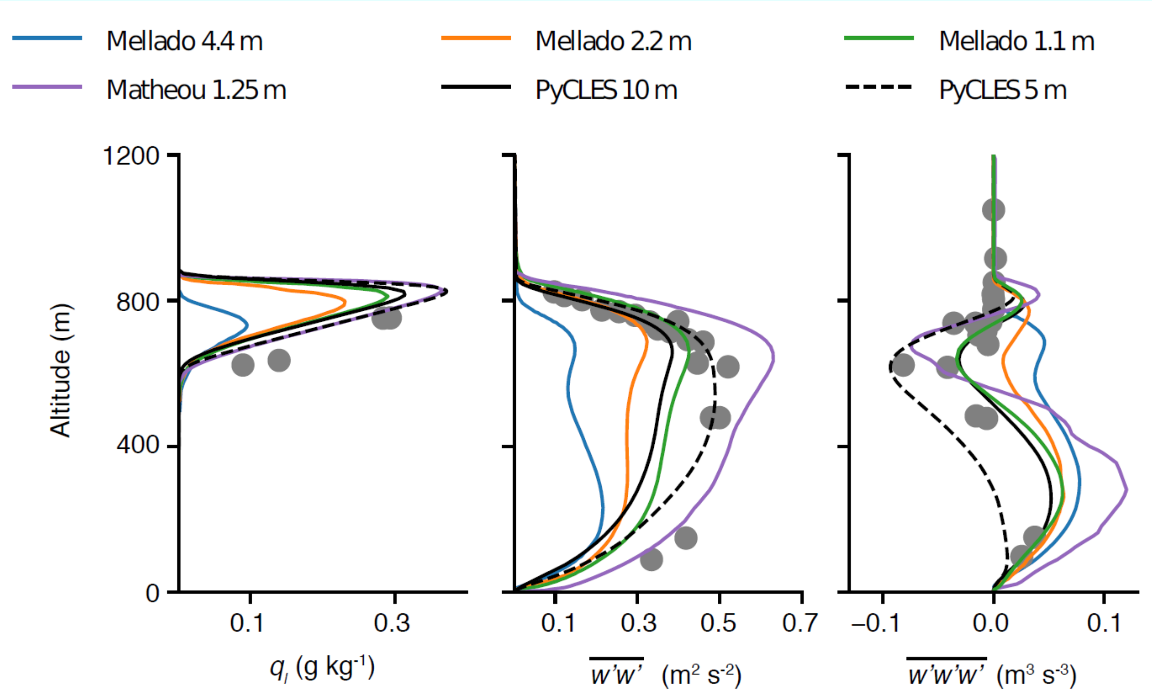
Hadley circulation *<u>may</u>* expand, but this is uncertain because...

Mid-latitude eddy fluxes represent a feedback on the tropical energy budget, circulation and ITCZ

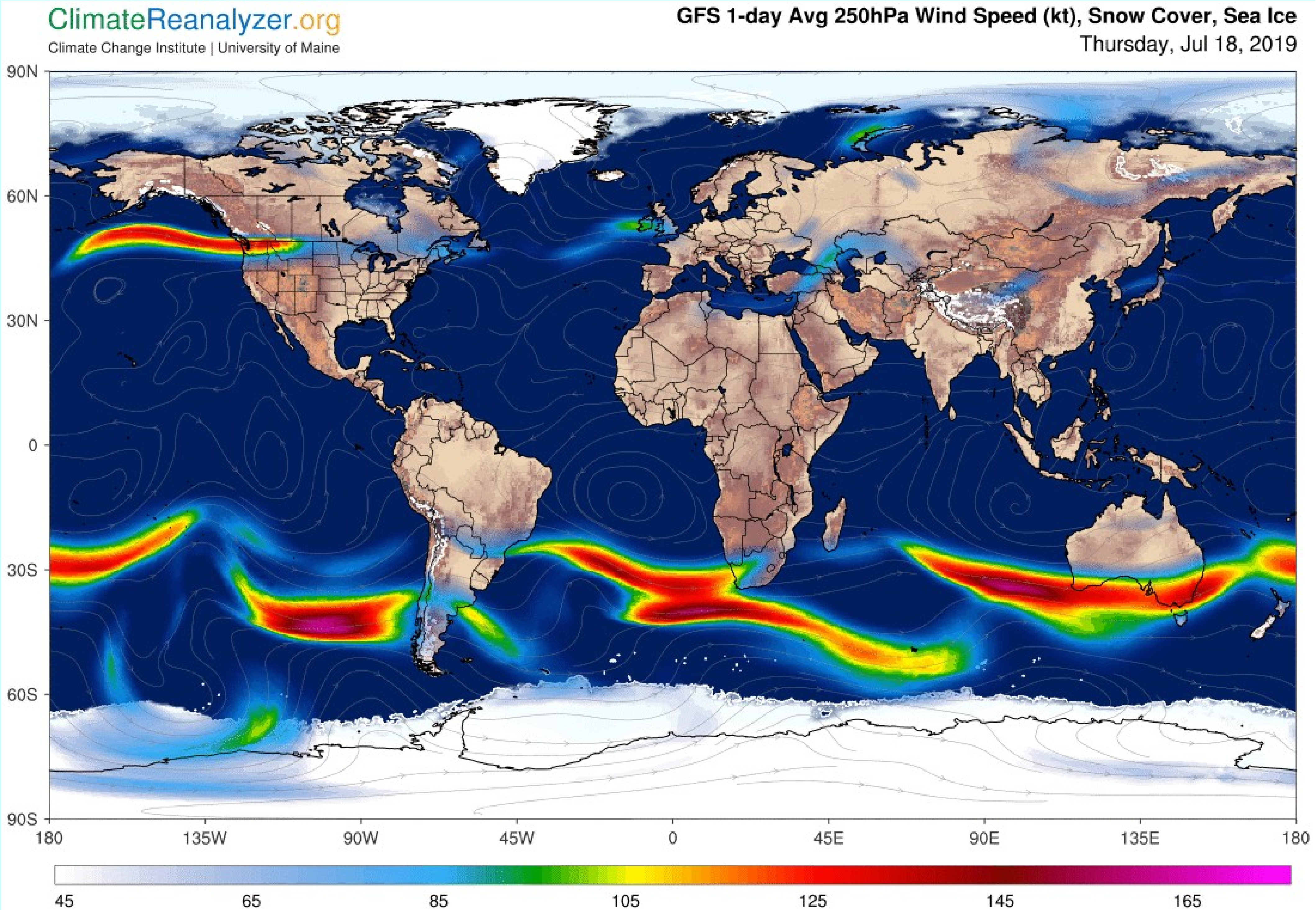
Atmospheric GCM Response to Extratropical SST Anomalies: Synthesis and Evaluation*

Kushnir et al. 2002





the large-scale subsidence in the troposphere weakens under warming[32], which lifts the cloud tops and counteracts the instability[15,19,24]. Indeed, when we weaken the parameterized large-scale subsidence by 1 or 3% per Kelvin of tropical SST increase (within the range of GCM responses to warming[33]), the stratocumulus instability occurs at higher CO_2 levels: around 1,400 ppm with 1% K^{-1} subsidence weakening, and around ***2,200*** *ppm with 3% K^{-1}*



ClimateReanalyzer.org
Climate Change Institute | University of Maine
GFS 1-day Avg 250hPa Wind Speed (kt), Snow Cover, Sea Ice
Thursday, Jul 18, 2019
90N
60N
30N
0
30S
60S
90S
180
135W
90W
45W
0
45E
90E
135E
180
45
65
85
105
125
145
165

A few important points

1. Observational constraints are still too weak or uncertain
2. Modelling certain aspects of the climate (e.g. EBUS upwelling) requires understanding the physical mechanisms that govern them
3. In the case of the coastal jet, and important controlling factor is subsidence, via its implied thermal advection
4. Model are capable of simulating the related dynamics, but the climate feedbacks are uncertain
5. They fall short particularly in the background, large-scale circulation
6. This can and is probably often due to global imbalances
7. One way to analyse model errors is by imposing observed initial conditions and let them evolve freely
8. Another is to design idealised set-ups where the relevant mechanism (e.g. conservation of angular momentum) is tested in isolation
9. GCM at present do not reliably simulate feedbacks between forcing and circulation