Ocean sensitivity to bulk formulae parameterization: a NEMO-ORCA025 model study

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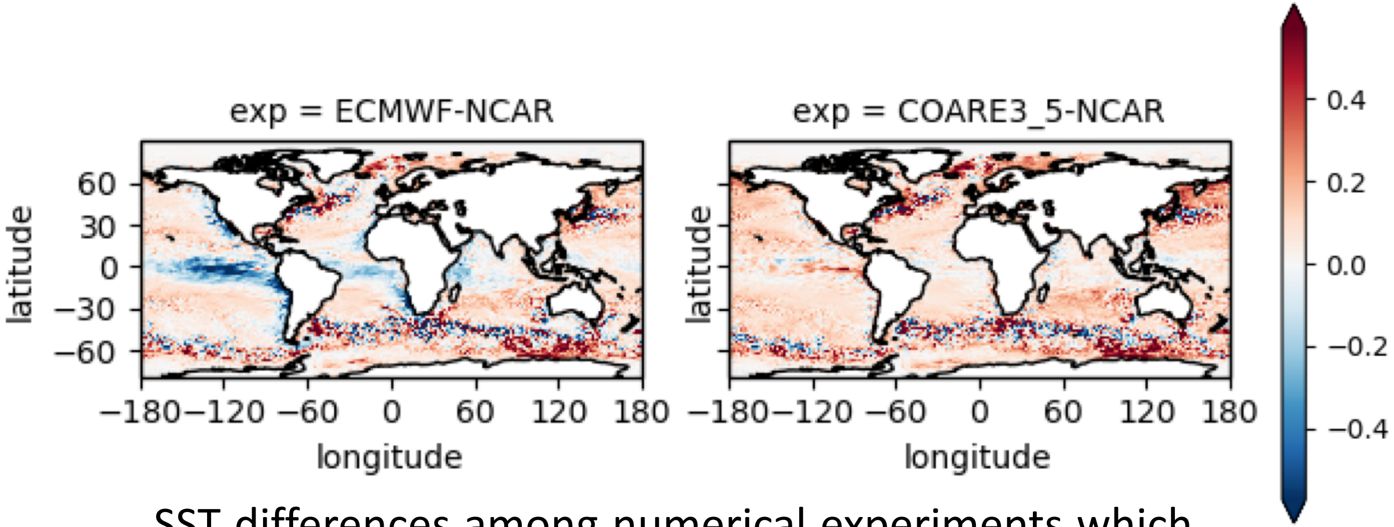
Background



SST differences among numerical experiments which differ only for the bulk formula used (ECMWF, NCAR and COARE3.5) using NEMOv4.0.1.

Scientific question:

Which role do the atmospheric forcing, the skin temperature and the wind transfer coefficient play in driving SST differences among experiments?

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NEMO allows the choice of 3 different bulk algorithms to compute turbulent fluxes:

Wind Stress

$$\tau = \rho C_d u u_z$$

τ = the wind stress
ρ =density of air
C_D= Transfer Coefficient
u_z = wind speed vector at height z.
u = scalar wind speed $|u_z|$

Sensible Heat

$$Q_H = \rho C_p C_t(\theta_z - \theta_0)u$$

Q_H = sensible hear
C_p = heat capacity of moist air
C_t= Transfer Coefficient
ϑ_0 = sea surface temperature or skin temperature
ϑ_z = potential temperature at z

Latent heat

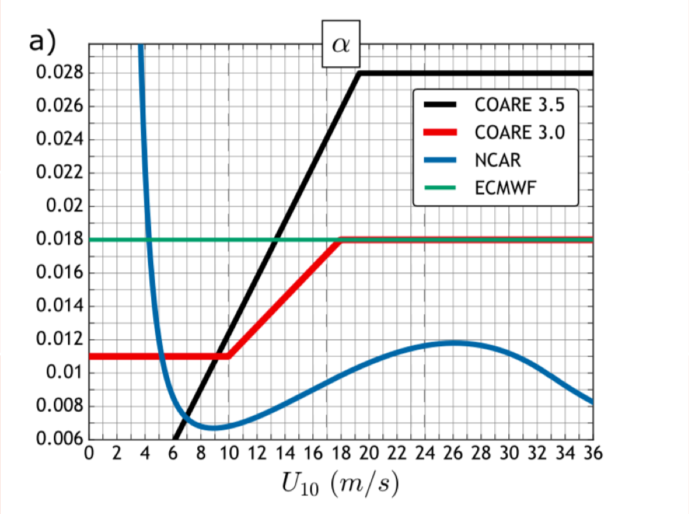
$$Q_L = -L_v \rho C_q(q_0 - q_z)u$$

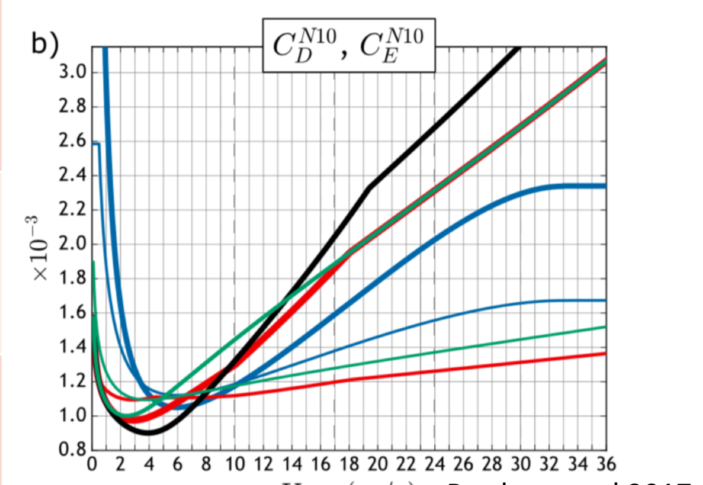
Q_L = latent heat
L_v = latent heat of vaporization of water
C_q= Transfer Coefficient
q_0= saturation-specific humidity at surface
q_z= saturation-specific humidity of air at z

$C_D(z_0, \varphi)$ where $z_0 = \frac{0.11\nu}{u_*} + \frac{\alpha u_*^2}{g}$

ϕ is the stability function, Z_0 is roughness length, ν is the kinematic viscosity, u_* is the friction velocity, **g** is the gravitational acceleration and α is the Charnock coefficient, which varies in different algorithms.

Bulk Algorithm	ϑ_0	Charnock Parameter (α)	C_D transfer coefficient
COARE3.5 (Edson et al 2013)	Skin Temperature		
ECMWF (ECMWF Report, 2015)	Skin Temperature		
NCAR (Large and Yeager 2009)	SST		





Brodeau et al 2017

We performed 4 sets of experiments using the ORCA025 configuration (~ 25km of horizontal resolution):

Set of Experiments	NEMO v	Experiments	Forcing	T Skin	Period
JRA55_2y_NOSKIN	4.0.1	1) ECMWF 2) COARE 3.5 3) NCAR	JRA55dov.1.4 (55Km of resolution, 3hourly, absolute wind)	NO	2015-2016
ERA5_2y_NOSKIN	4.0.1	1) ECMWF 2) COARE 3.5 3) NCAR	ERA5 (30Km of resolution, hourly, absolute wind)	NO	2015-2016
ERA5_4y_NOSKIN	4.0.1	1) ECMWF 2) COARE 3.5 3) NCAR	ERA5 (absolute wind)	NO	2015-2018
ERA5_4y_SKIN	trunk version (not officially released)	1) ECMWF 2) COARE 3.5 3) NCAR	ERA5 (absolute wind)	YES for ECMWF and COARE3.5	2015-2018

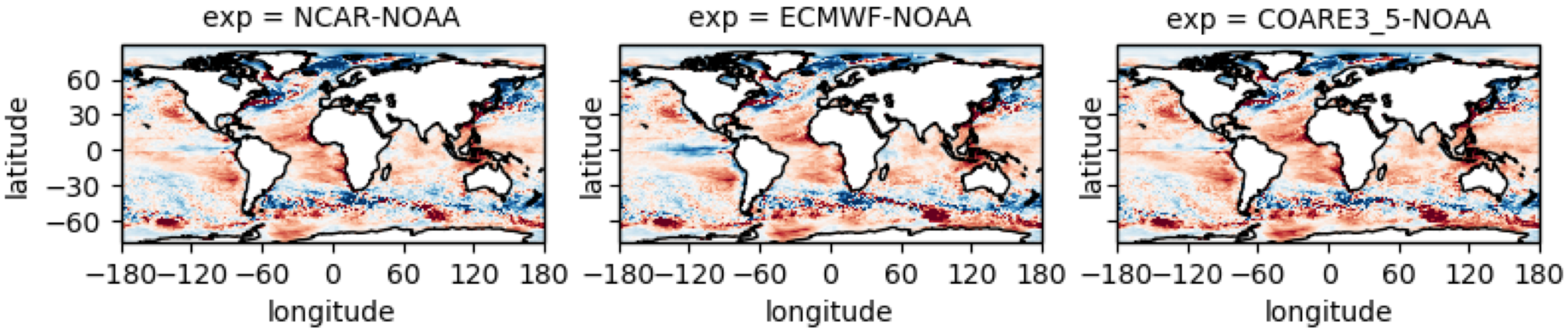
Atmospheric Forcing role (rows 1–2)

Skin Temperature role (rows 3–4)

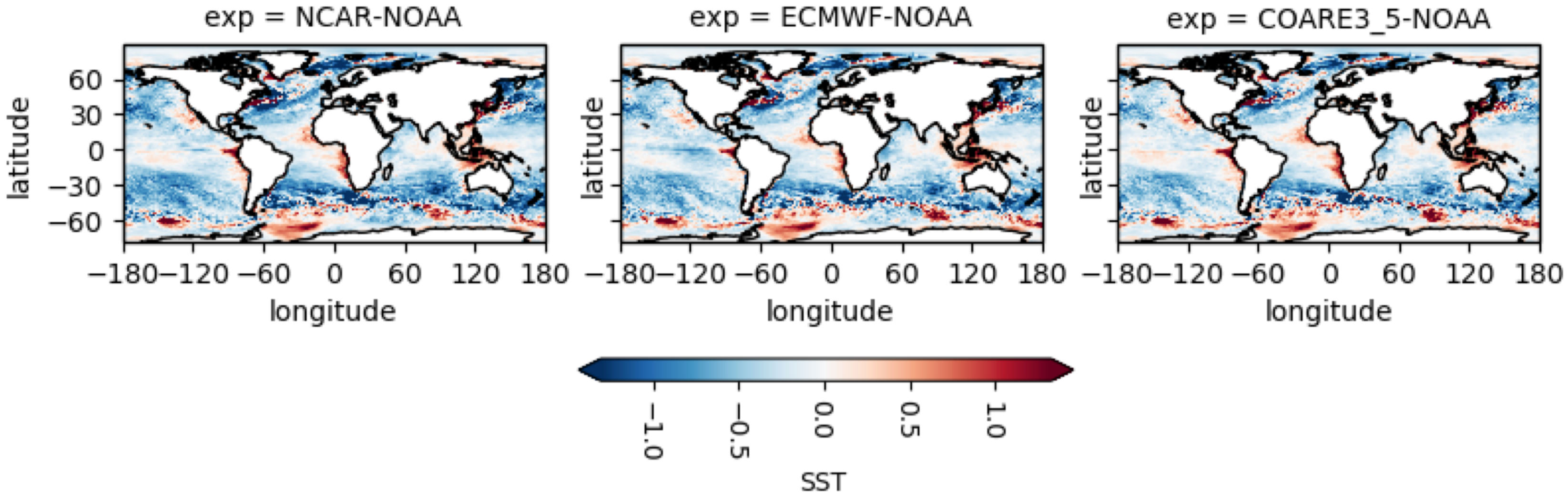
Wind transfer coefficient computation role

JRA55_2y_NOSKIN vs ERA5_2y_NOSKIN

JRA55_2y_NOSKIN



ERA5_2y_NOSKIN

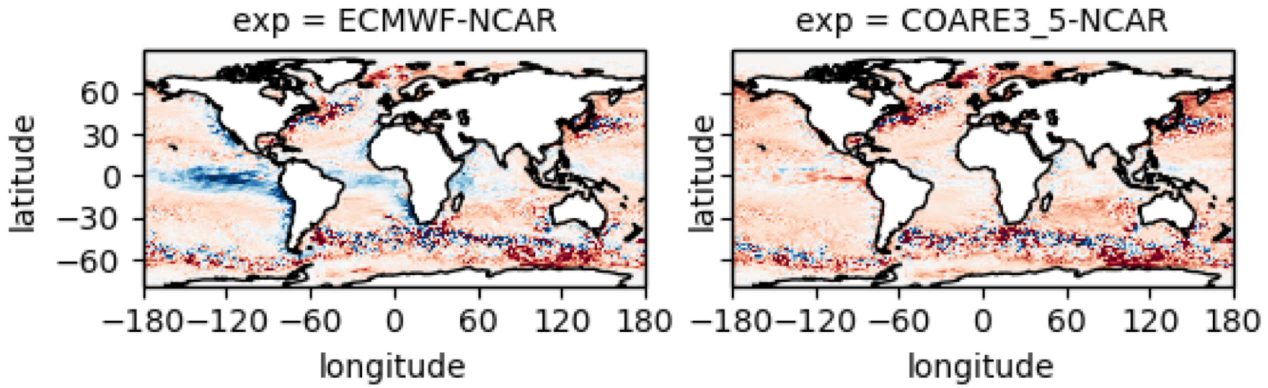


The role of the atmospheric forcing in driving the SST field is inferred from the SST differences between experiments of each set with respect to NOAA SST (Reynolds et al. 2007).

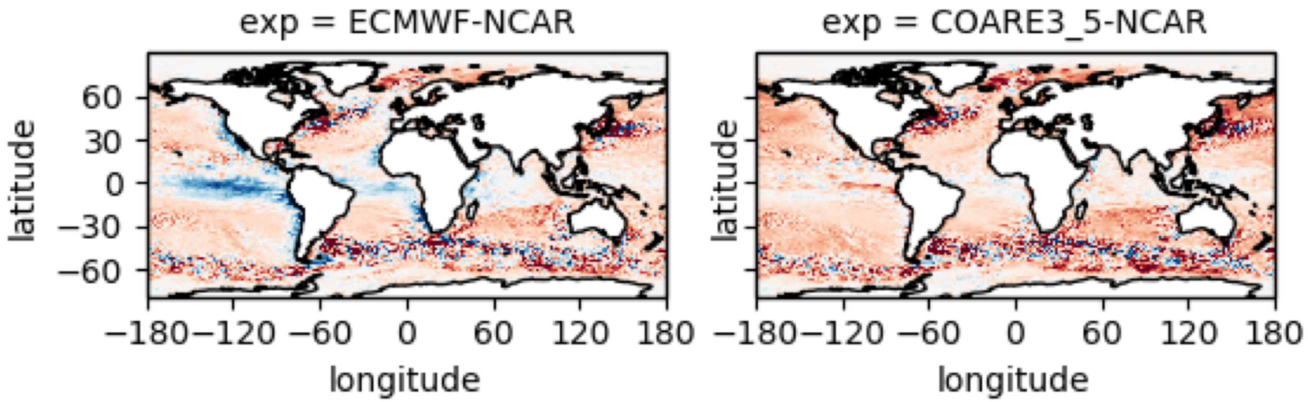
In the open ocean the two set of experiments, forced by the two reanalyses, present SST biases of opposite sign: **the JRA55do warm biases are, in the ERA5 set, damped and turned in weak cold biases, especially over Atlantic basin.** In both set of simulations, Eastern Boundary Upwelling Systems (EBUS, seat of one of the most persistent biases in the OGCM) and Antarctica are warmer and Arctic ocean is colder compared to observations.

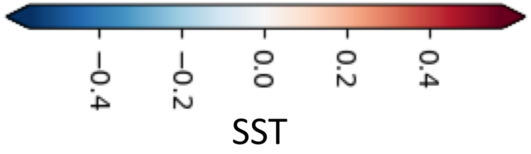
JRA55_2y_NOSKIN vs ERA5_2y_NOSKIN

JRA55_2y_NOSKIN



ERA5_2y_NOSKIN



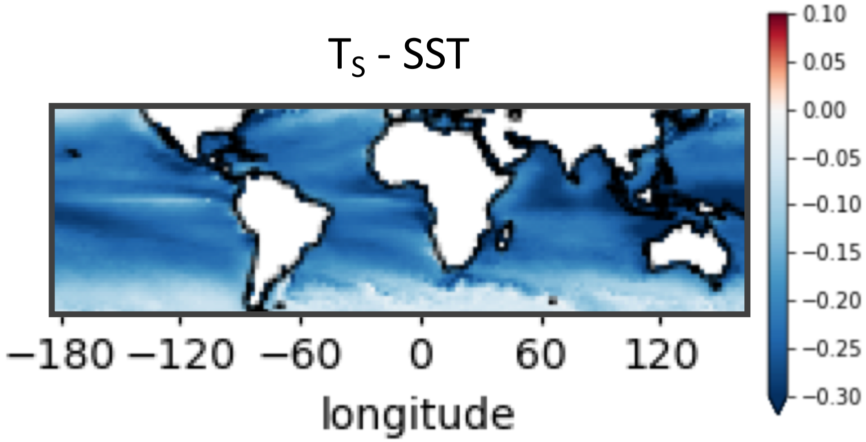


Distribution of SST differences between experiments of JRA55 and ERA5 present the same pattern: using ECMWF bulk, SST is colder than NCAR and COARE3.5 over EBUS and over equatorial Pacific and Atlantic, with a maximum value up to 0.6°C. **The discrepancy is forcing independent.**

ERA5_4y_NOSKIN vs ERA5_4y_SKIN

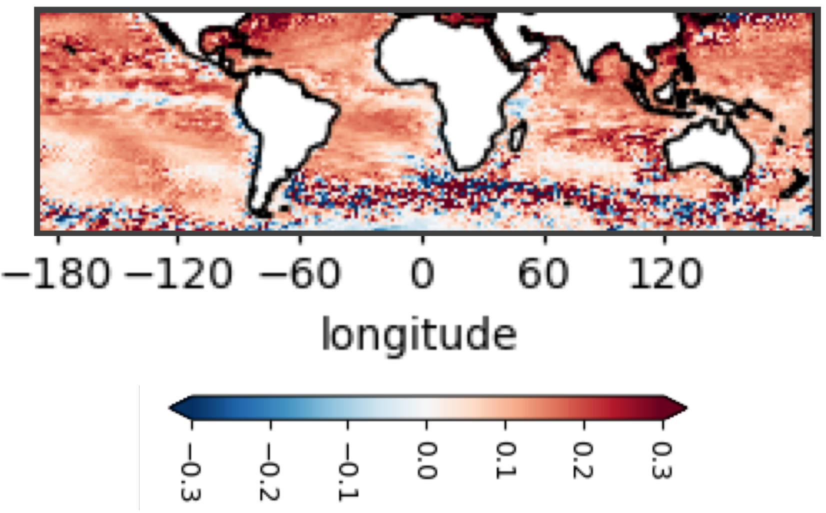
COARE3.5

T_S - SST



SST Differences

exp = SKIN-NOSKIN

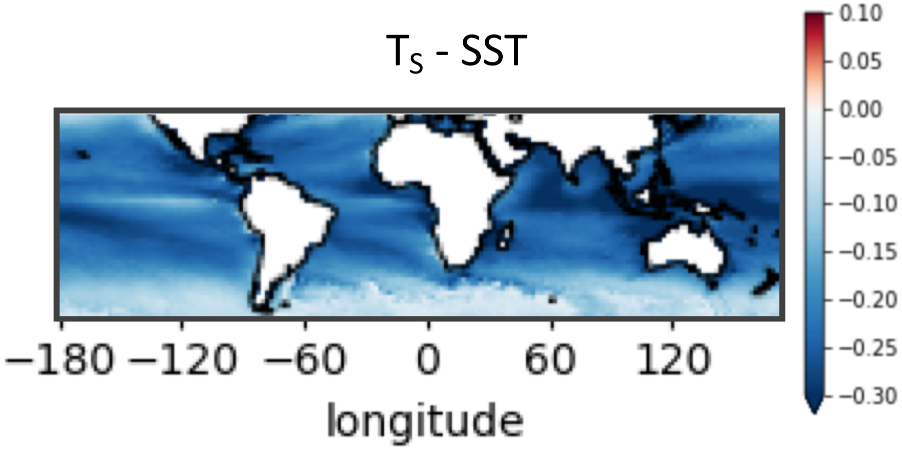


The skin temperature is 0.3°C colder than SST on average. The use of the Cool Skin and Warm Layer (CSWL) scheme to calculate the flux may substantially reduces the evaporation and total turbulent heat flux likely mitigating the cold temperature differences. <u>SST differences between SKIN-NOSKIN experiments results positive for both COARE3.5 and ECMWF bulk formulae.</u>

In the tropical Pacific and Southern ocean the differences are negligible, approximately near zero. <u>**The discrepancies among algorithms are not explained by the implementation of the CSWL scheme.**</u>

ECMWF

T_S - SST



SST Differences

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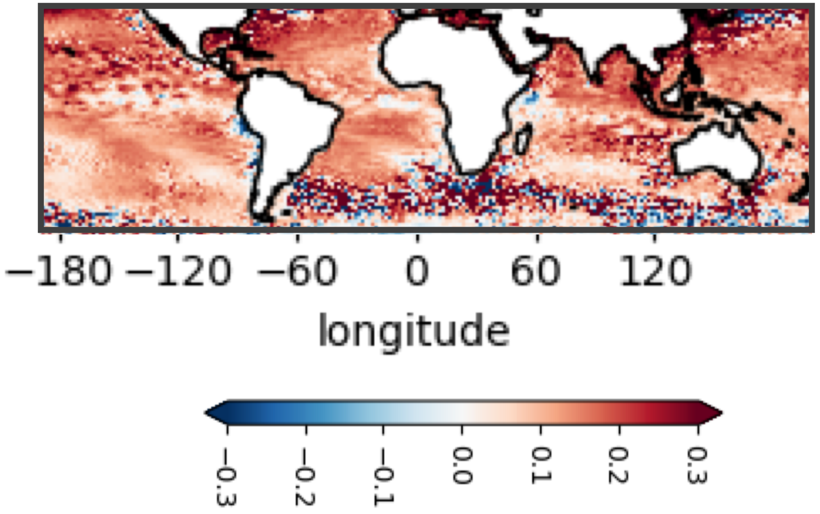
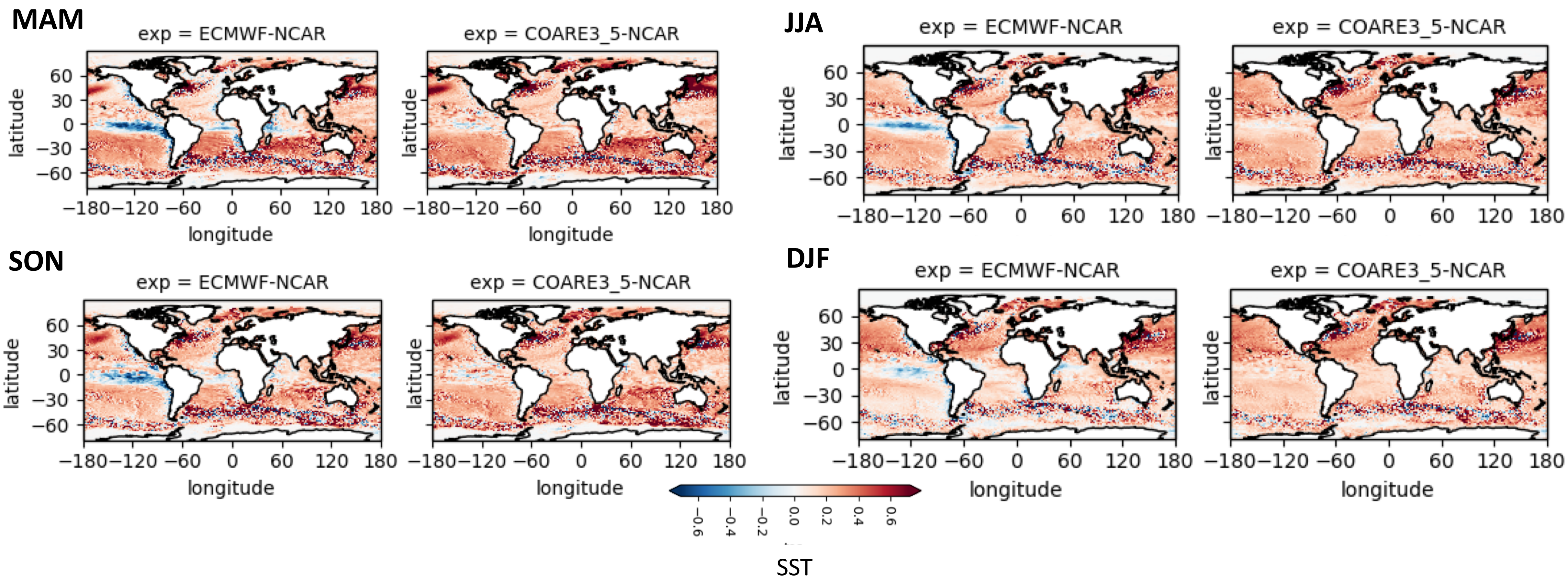


Wind role

Seasonal SST Differences among experiments

SST Differences

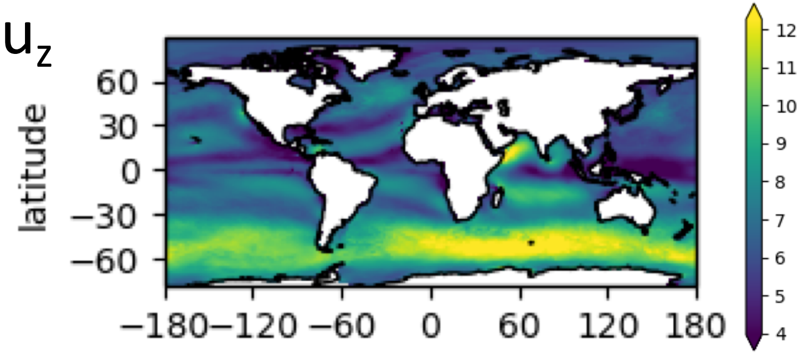
ERA5_4y_SKIN



Overall ECMWF and COARE3.5 are warmer than NCAR experiment due to the implementation of the skin temperature. ECMWF experiment shows the peculiar colder temperature along tropical Pacific and along EBUS which varies through the seasons. **The SST difference signature is intense during Summer and Fall with a peak in Spring**, while is almost damped during winter season. **Spring season is selected to investigate the possible drivers** that determine the ECMWF peculiar ocean response.

$$\tau = \rho C_d u u_z$$

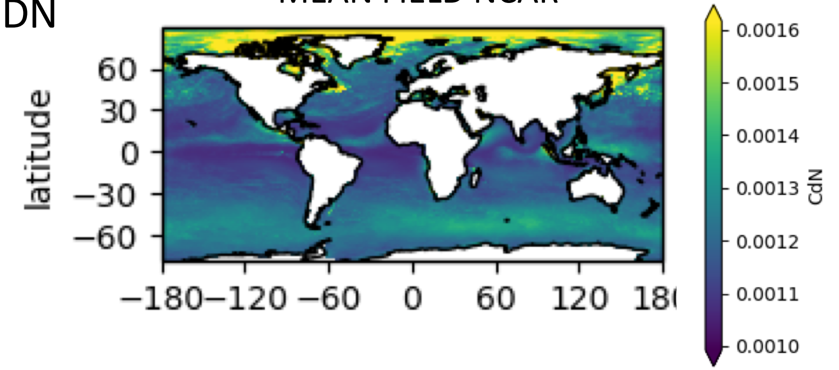
u_z

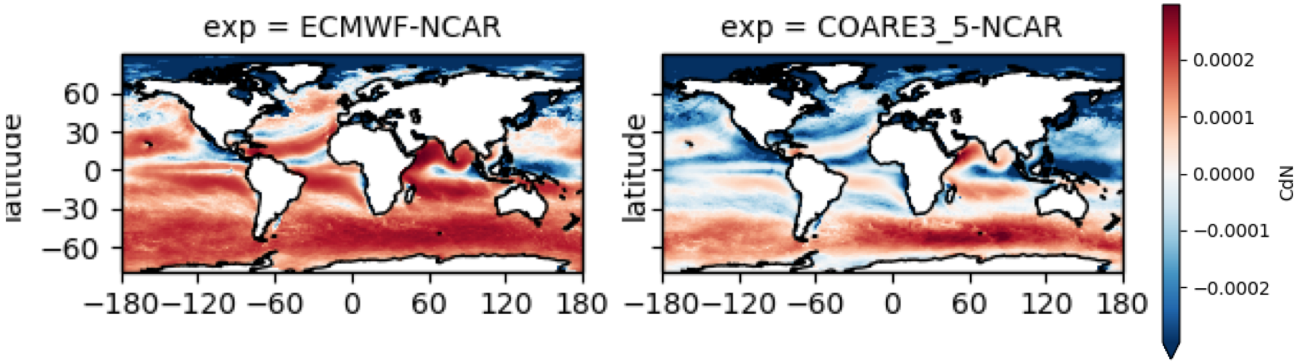


For wind speeds above 5 m/s the C_D of COARE3.5 and, in particular the ECMWF C_D, are larger than NCAR C_D. On the other hand, from calm up to light breeze conditions (u_z < 5 m/s), the C_D of NCAR is larger than COARE3.5 and ECMWF C_D. C_D and C_{DN} differences among experiments show similar patterns suggesting that the coefficient differences are more related to neutral coefficient (C_{DN}) calculation rather than to his stability correction (added to C_{DN} to get C_D coefficients).

C_{DN}

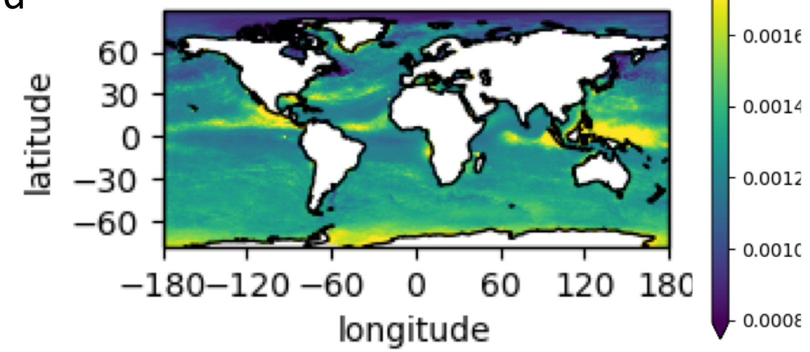
MEAN FIELD NCAR

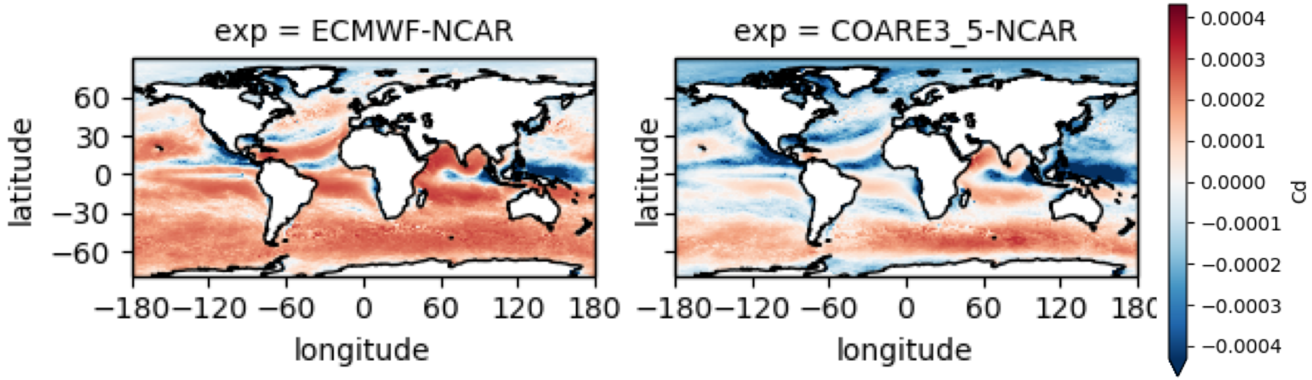




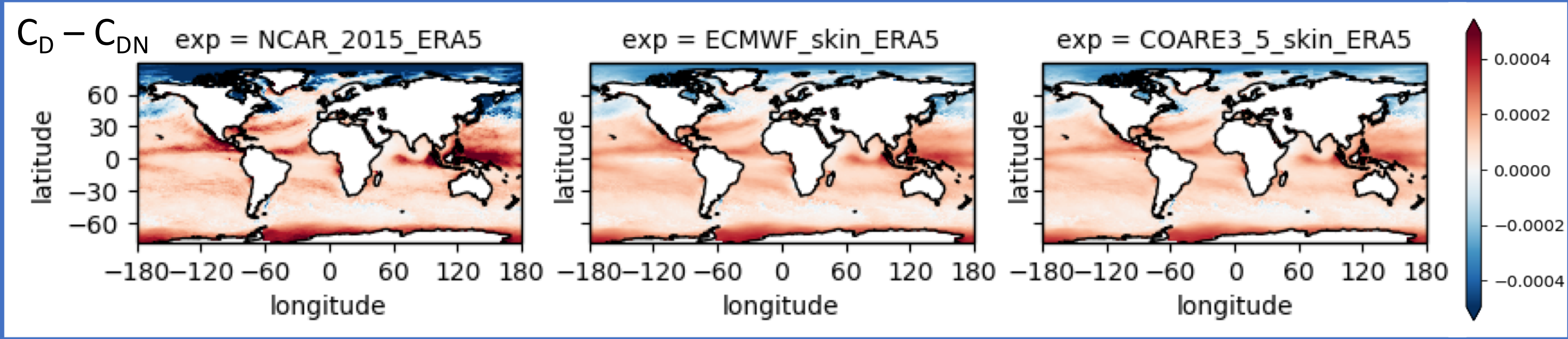
C_d

MEAN FIELD NCAR





For wind speeds above 5 m/s the C_D of COARE3.5 and, in particular the ECMWF C_D, are larger than ...

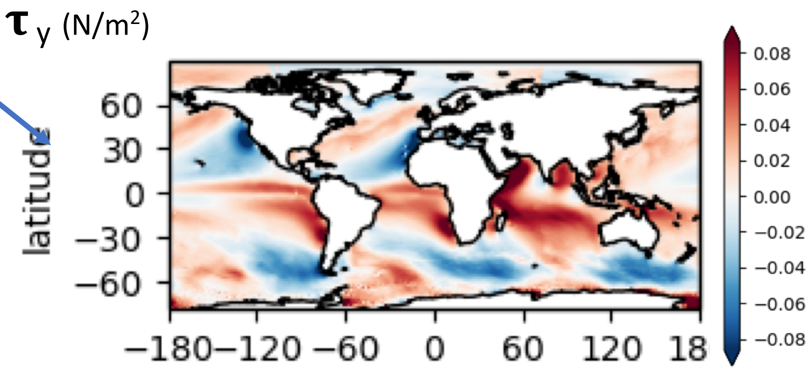


The patterns of differences are really similar among experiments.

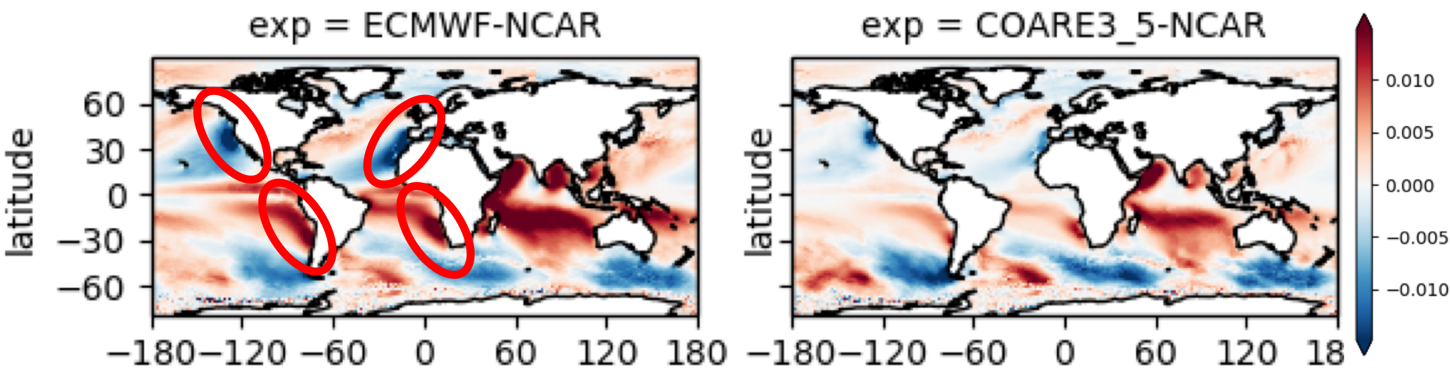
C_{DN} - C_D pattern is positive in regions dominated by unstable condition, tropical band, and sea-ice covered areas and negative in atmospheric stable regions (e.g. Arctic ocean during no sea-ice season).

$\tau = \rho C_d u u_z$

MEAN FIELD NCAR



DIFFERENCES AMONG EXPERIMENTS



- **u_z > 5 m/s**, the C_D of COARE3.5 and, in particular the ECMWF C_D, are larger than NCAR C_D. **This leads to a substantial increase of the wind stress over the ACC, over northern midlatitudes (e.g. EBUS), and Atlantic storm for ECMWF experiment and, with lower extent, for COARE3.5 experiment.**
- From calm up to light breeze conditions **(u_z < 5 m/s),** the C_D of NCAR is larger than that COARE3.5 C_D and to lower extend to ECMWF C_D. These conditions occur quite frequently north of the tropical band during spring (5°N-10°N) and over the tropical band during winter. **The differences lead to a slightly decrease of the wind stress in these areas for ECMWF experiment and to a substantial decrease of wind stress for COARE3.5 experiment.**

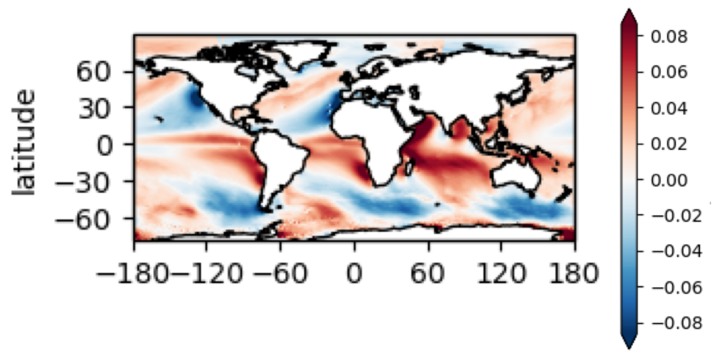
The increased meridional wind stress, for ECMWF experiment along EBUS could explain the cold temperature difference, due to the well-kwon wind-driven dynamics (e.g. coastal upwelling) along these areas.

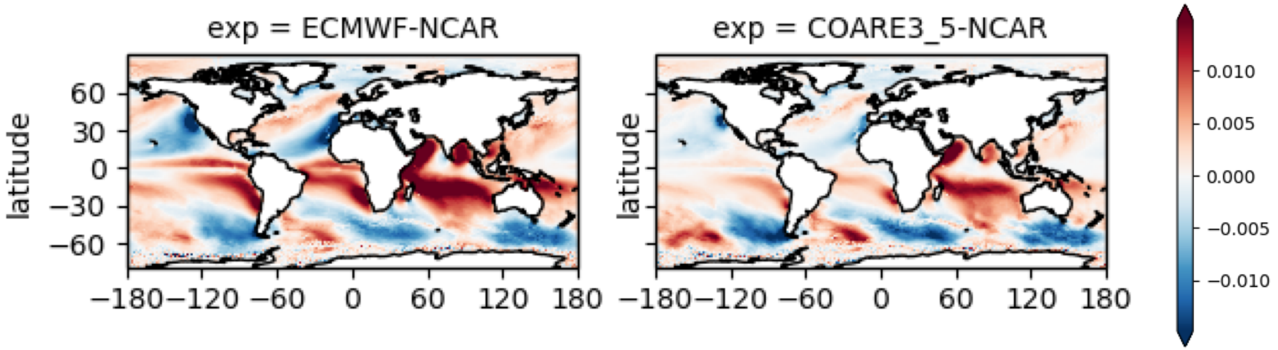
$$\tau = \rho C_d u u_z$$

MEAN FIELD NCAR

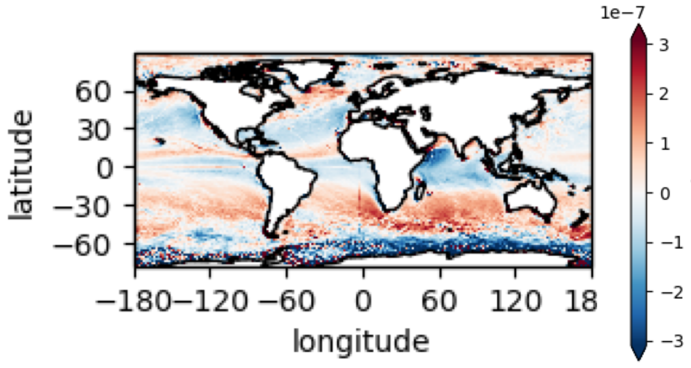
DIFFERENCES AMONG EXPERIMENTS

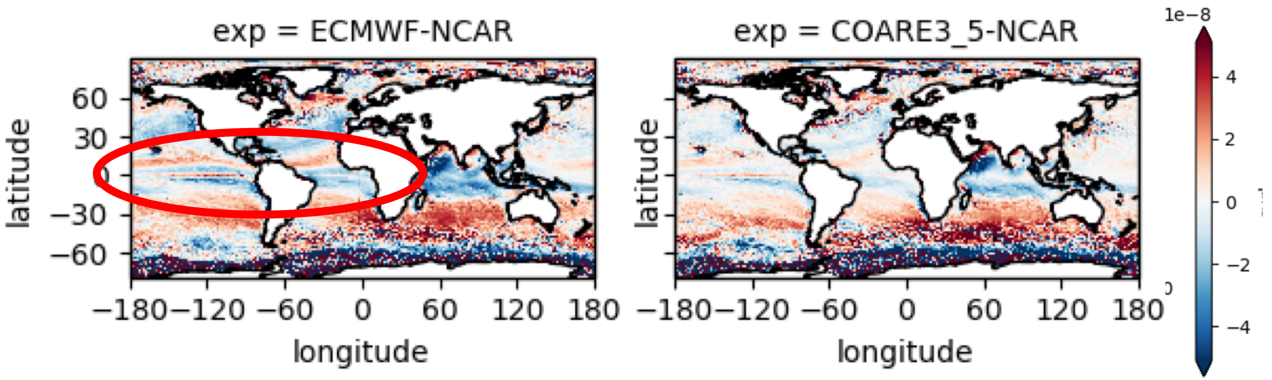
(N/m²)





Curl(**τ**) (N/m³)

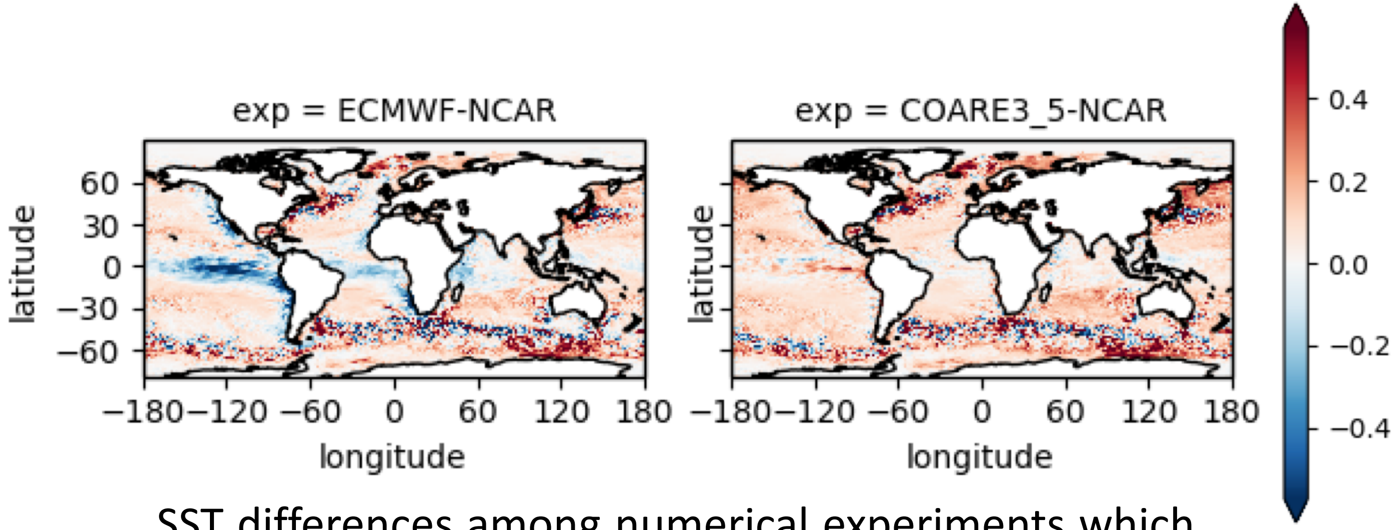




The pattern of wind stress curl in the Tropics is dominated by a positive **band of curl along 5°–10°N where the northeast trades build to the north, and a positive narrow strip of curl just north of the Equator** sustained by the lateral gradient of wind stress generated by the acceleration of southeast trades surface winds over the northern front of the equatorial cold tongue accompanied by a **more extended band of negative curl to the south**. The stronger southeast trades in ECMWF experiment over the equatorial cold tongue (5°S-5°N) result in stronger negative stress curl when crossing the southern SST front, and form a strip of positive curl when crossing over the northern SST front.

Stronger positive curl north of equator and stronger negative curl south of equator in ECMWF experiment likely enhance Ekman pumping along the equatorial cold tongue.

Background



SST differences among numerical experiments which differ only for the bulk formula used (ECMWF, NCAR and COARE3.5) using NEMO4.0.1.

Scientific question:

Which role do the atmospheric forcing, the skin temperature and the wind transfer coefficient play in driving SST differences among experiments?

Preliminary Results:

- **Atmospheric Forcing?**
  The results are forcing independent.

- **Skin Temperature (T skin)?**
  T skin does not impact results.

- **Wind transfer coefficient computation?**
  Wind stress differences could explain part of the SST differences pattern.

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