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# Feedbacks between turbulent air-sea fluxes and their role in the adjustment of the Earth Climate System

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## 1. State of the art

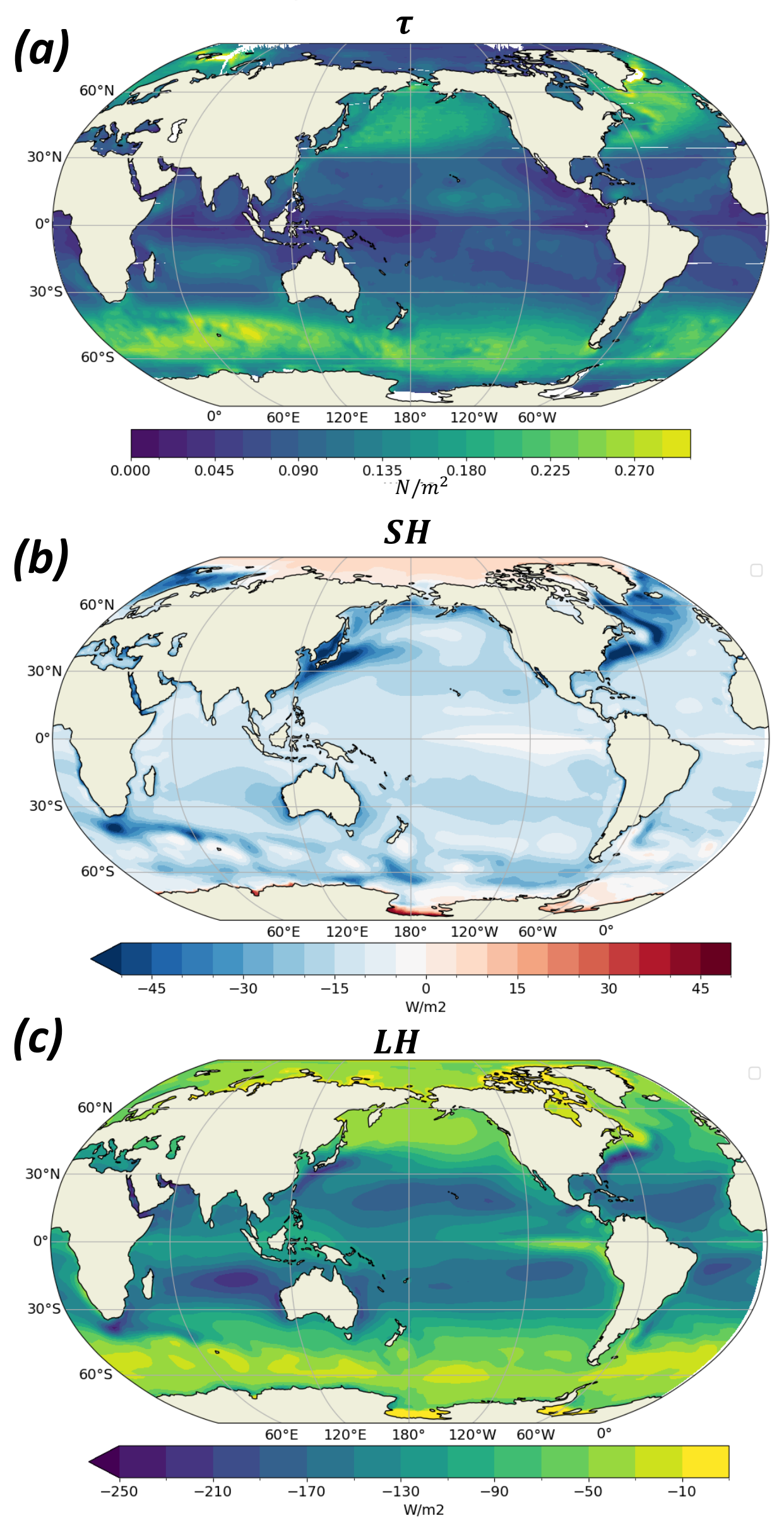

Fig 2: *Turbulent fluxes* climatological values (a) for momentum, (b) for sensible heat and (c) for latent heat in ocean-only simulation

- ❑ ***Turbulent air-sea fluxes*** are computed using ***bulk formulas:***

$$\begin{cases} \tau = \rho C_d(\Delta u)^2 \ (momentum) \\ SH = \rho C_p C_h \Delta u \Delta T \ (sensible\ heat) \\ LH = \rho L_v C_e \Delta u \Delta q \ (latent\ heat) \end{cases}$$

- ❑ $C_d, C_h, C_e$ are of large-scale prognostic variables such as wind speed, temperature, etc.
- ❑ These ***turbulent fluxes*** are poorly constrained by observations (roughly 30% uncertainties[1]) and a large panel of bulk formulas exist worldwide (NCAR, COARE, etc.).
- ❑ A poor representation of theses fluxes lead to systematic biases in coupled models and requires appropriate methodology to be properly analysed.

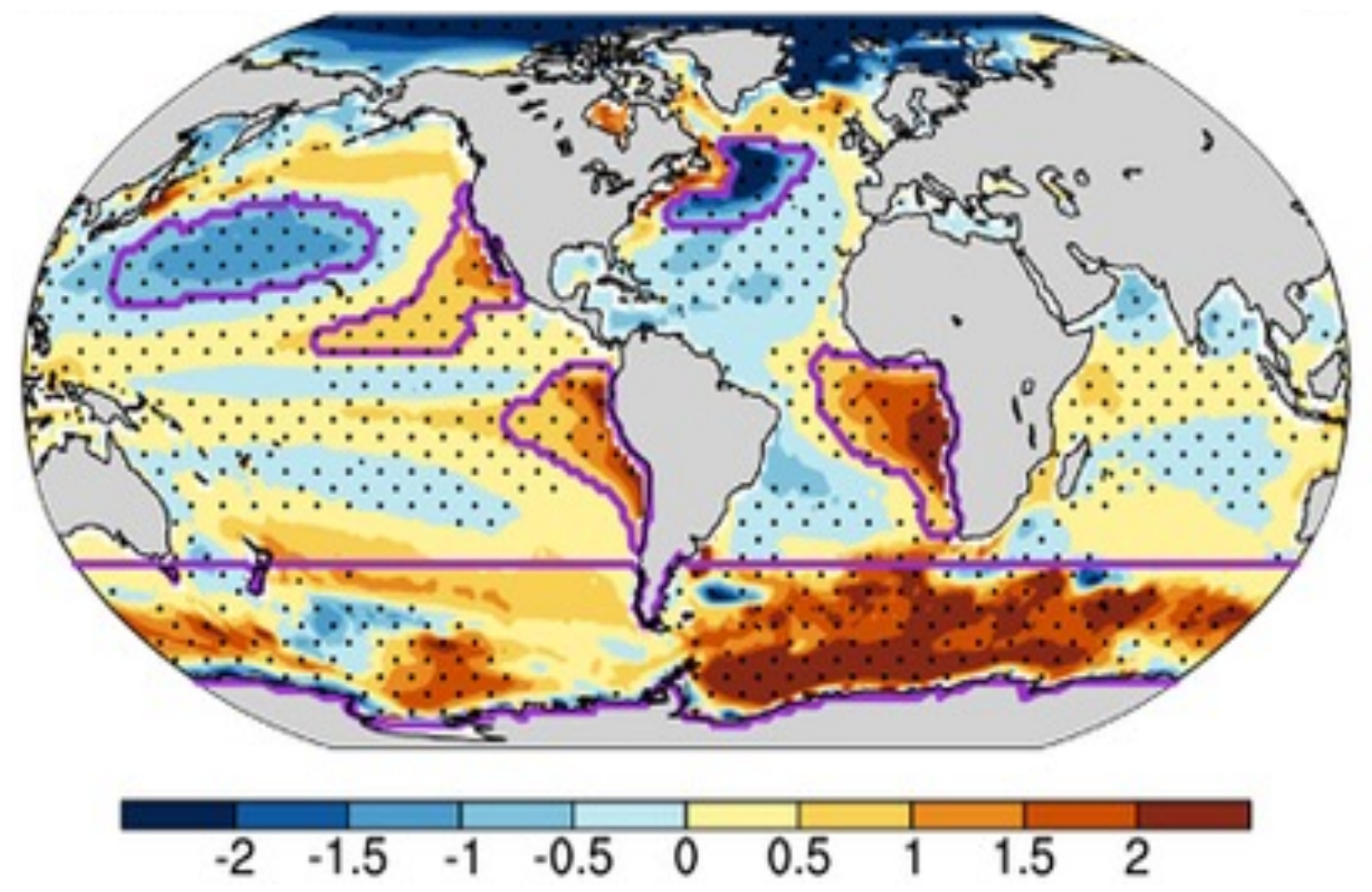

Fig 1: Average SST bias [K] for CMIP6[2]

## 4.2 The wind bias increases in coupled runs

Wind plays a prominent role in the coupled system[6] as it appears in **each flux computation**, not to mention its impact on **atmospheric/oceanic heat transport**. So, getting the wind correct is a major challenge.

For example, ocean-only runs show up to 20% differences in meridional ocean heat transport at some latitudes not because of heat content differences but because of circulation's discrepancies caused by surface drag.

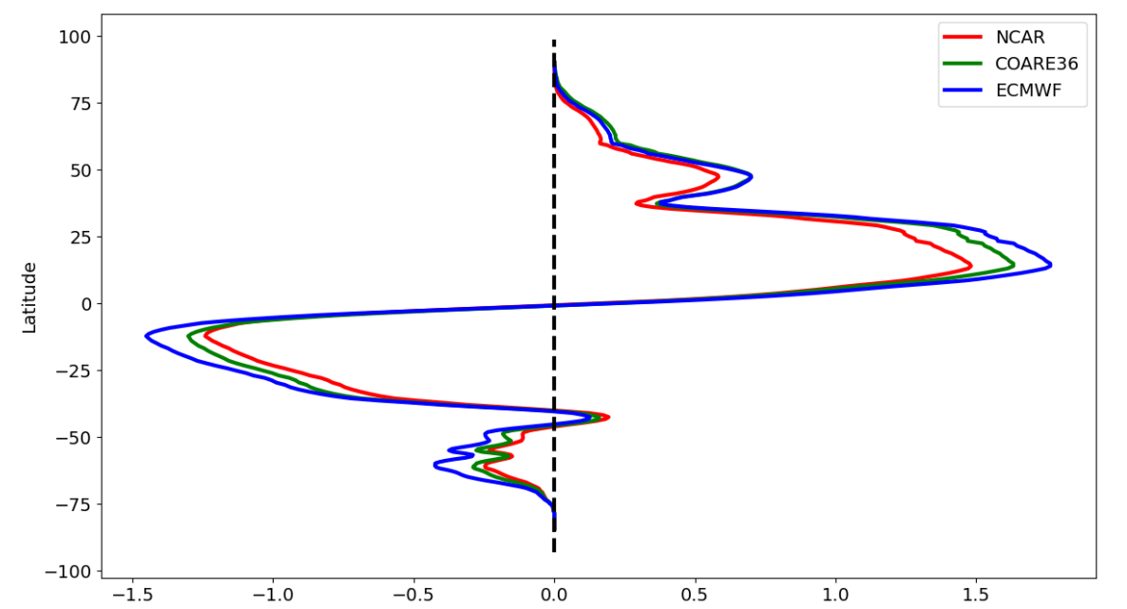

Fig 8: Merdional oceanic heat transport in $\mathcal{O}^{for}$ runs

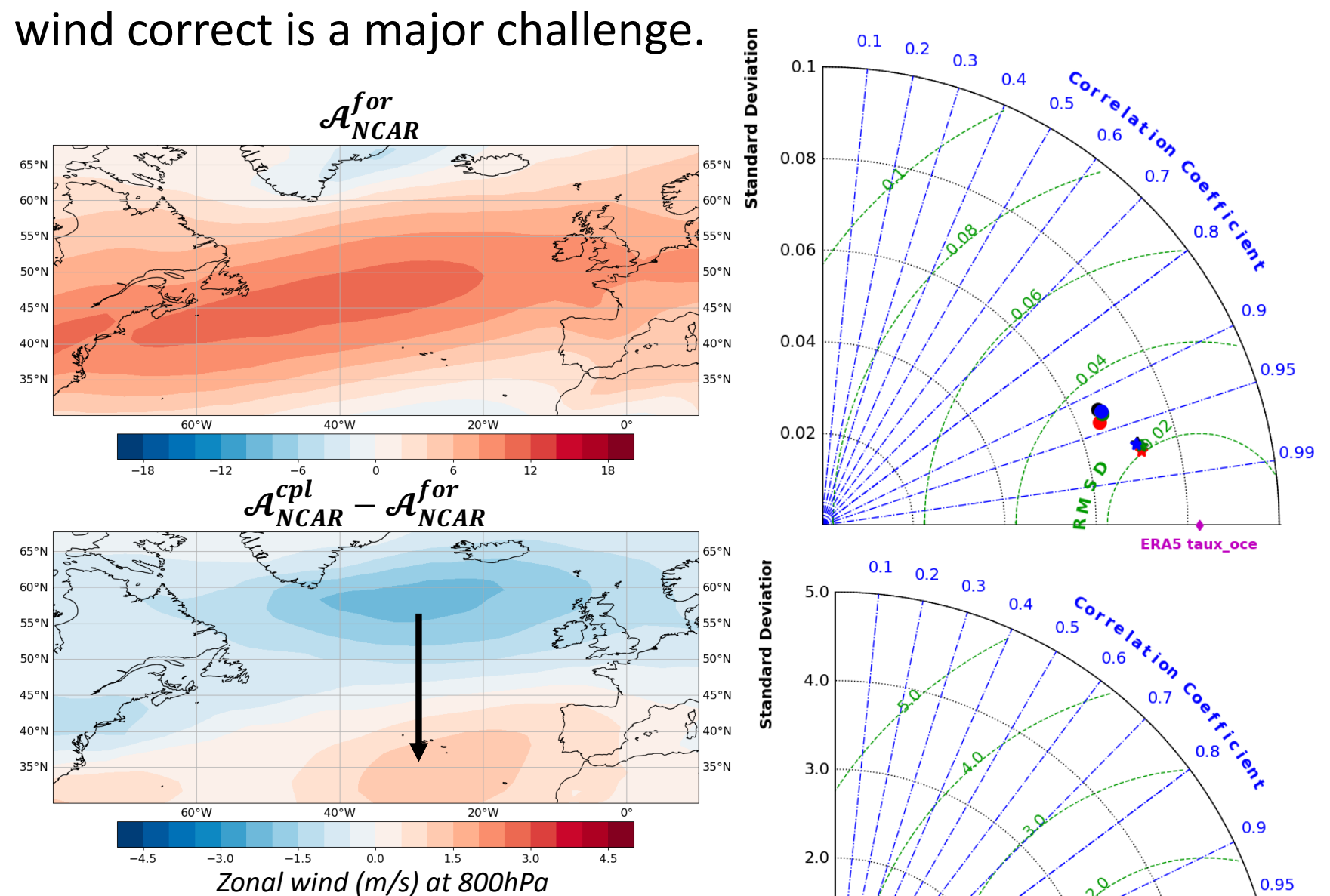

Fig 9: (a) Meridional shift of the jet stream due to coupling (b,c) Taylor's diagram of for atmosphere-only and coupled runs compared to ERA5 $(\tau, u_{10m})$

Unfortunately, it has been shown that wind biases tend to increase in coupled configuration of IPSL's models for every bulk (see Fig 9). The correlation with ERA-reanalysis (which uses also a bulk) drops for $\tau, u_{10m}$ when going from atmosphere-only to coupled runs. This can be illustrated by a meridional shift in jet stream position (which can be attributed to a change in the meridional SST gradient).

## Bibliography

1. *"Omens of coupled model biases in the CMIP5 AMIP simulations" Alina G. et al. Climate Dynamics https://doi.org/10.1007/s00382-017-4057-3*
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## 2. Objectives

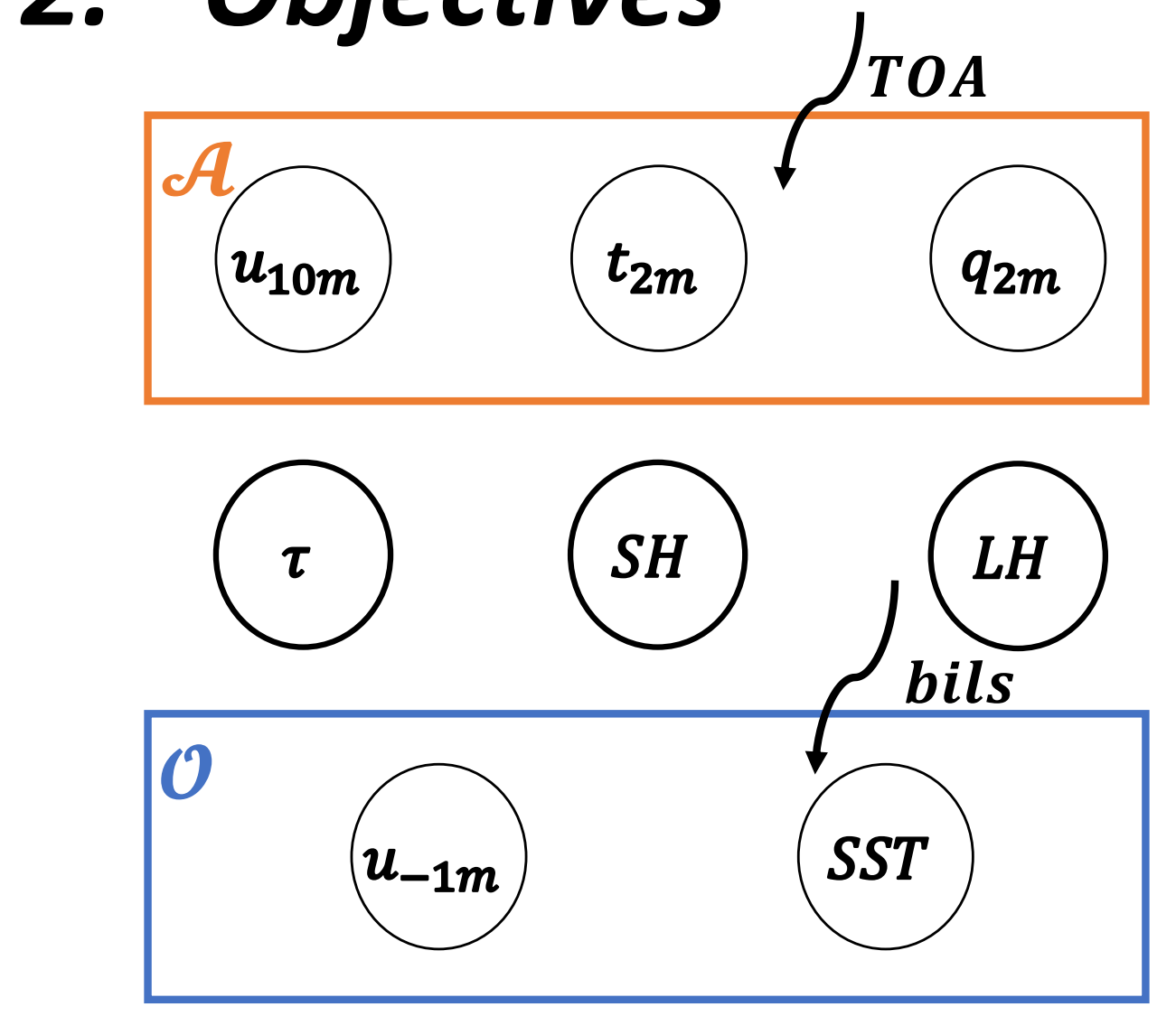


Fig 3: Air-sea interface main variables and fluxes

Changing the fluxes parametrization induces changes in surface variables ($u_{10m}, t_{2m}, q_{2m}$, SST) which in return change the flux computation within intricated feedbacks loops (see Fig 3). Our ultimate goal is to improve the physics of IPSL's models, but we have to answer these questions first:

I. **How different air-sea fluxes parametrizations impact the equilibriums of a Global Circulation Model (GCM) for forced/coupled runs ?**

II. **What can we learn about the feedbacks within the coupled system ?**

## 4.1 Changing the bulk affects the mean fluxes and variables

### $\mathcal{O}^{for}$

Within the forced ocean, we found consistency between the latent heat flux coefficient ($C_e$) computed offline and latent heat flux (LH) and Sea Surface Temperature (SST). Indeed, the more evaporative algorithm (NCAR) leads to the lowest SST.

$$C_e^{NCAR} > C_e^{COARE36} \Rightarrow$$
$$LH^{NCAR} < LH^{COARE36} < 0 \Rightarrow$$
$$SST^{NCAR} < SST^{COARE36}$$

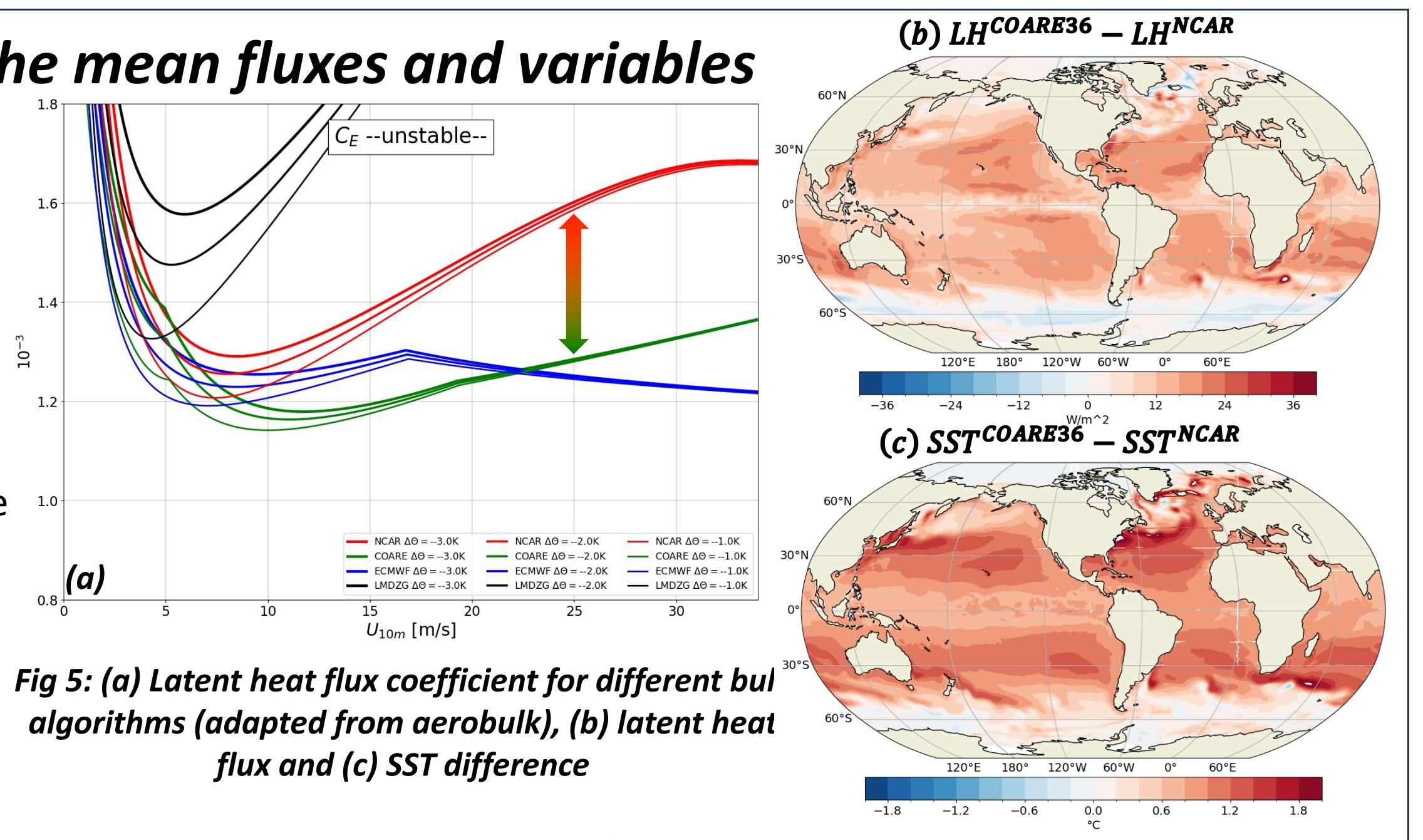


Fig 5: (a) Latent heat flux coefficient for different bul algorithms (adapted from aerobulk), (b) latent heat flux and (c) SST difference

This adjustment of SST can be understood in terms of energy balance of the ocean:

$$\partial_t \mathcal{O}_{heatc} = \iint SW_{\downarrow} + (LW_{\uparrow} + SH + LH)(SST)\, ds \sim 0W/m^2 \quad (2)$$

As shown in Fig 6, a switch from NCAR to COARE36 bulk leads to new distributions in SST, sensible and latent heat flux (as long as the net energy flux at the surface is zero).

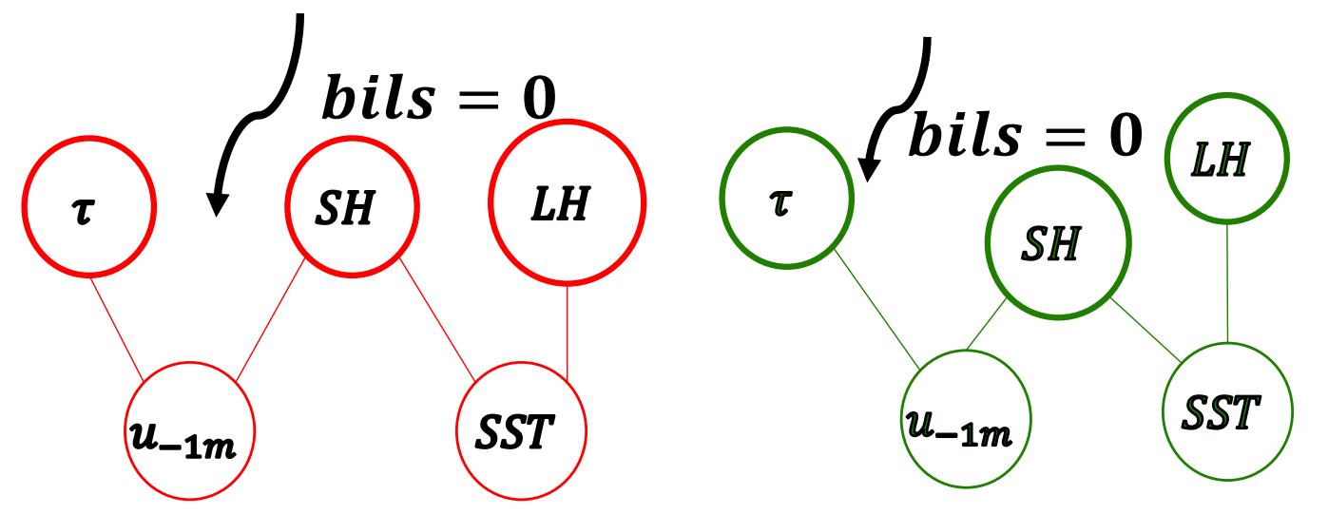


Fig 6: Illustration the disturbed relationships between variables and fluxes bet ween NCAR and COARE36

### $\mathcal{A}^{for}$

The same reasoning can be done for atmosphere-only run for momentum flux. COARE36 tend to transfer more momentum to the ocean, and it results in lower wind speed.

$$C_d^{NCAR} < C_d^{COARE36} \Rightarrow$$
$$\tau^{NCAR} < \tau^{COARE36} \Rightarrow$$
$$wind^{NCAR} > wind^{COARE36}$$

On fig 6, we clearly see additional momentum flux for COARE36 in windy regions (storm tracks, etc.) except in the southern ocean where the wind has declined because of the extra drag.

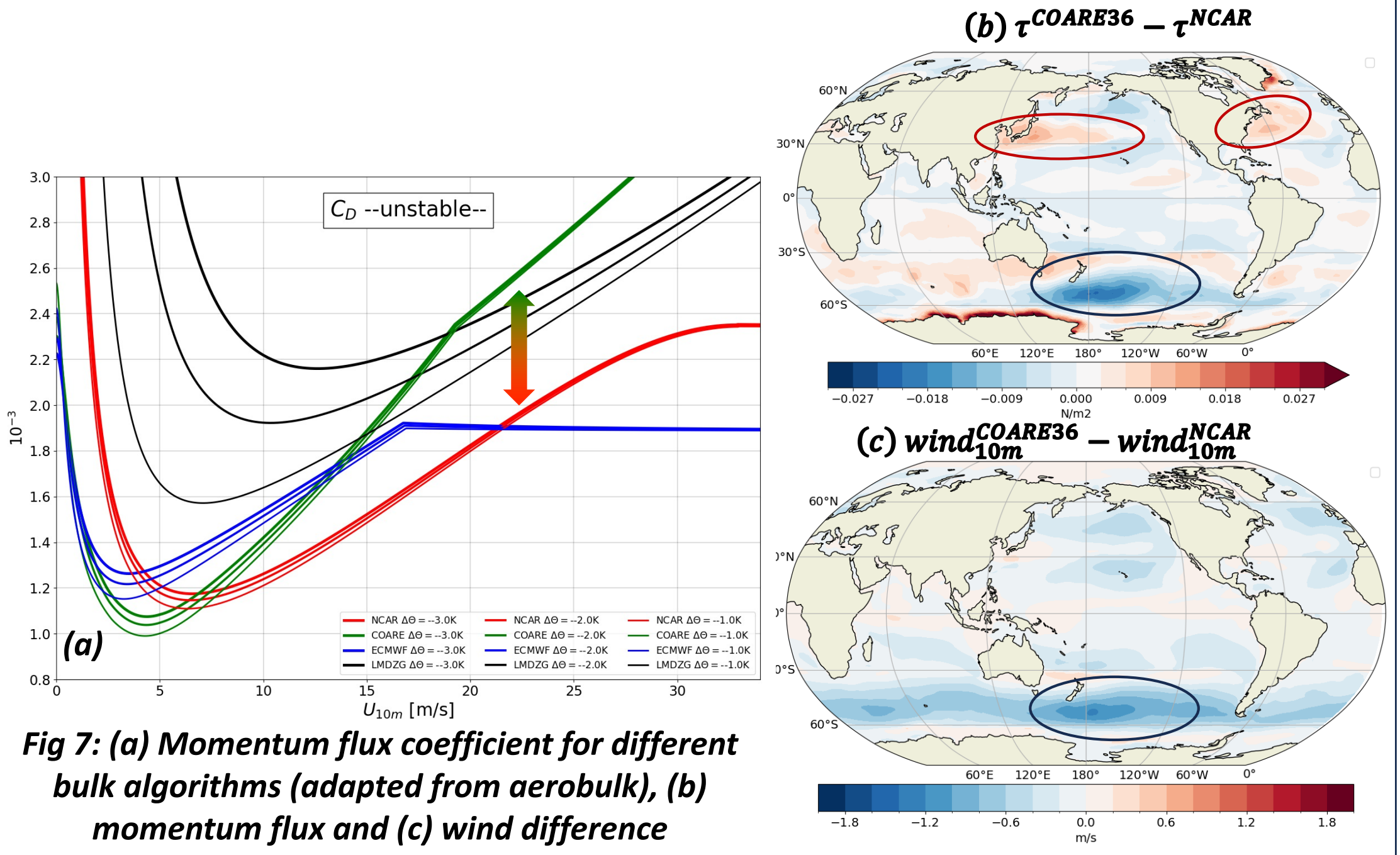


Fig 7: (a) Momentum flux coefficient for different bulk algorithms (adapted from aerobulk), (b) momentum flux and (c) wind difference

Note that the energy balance now becomes:

$$nettop = bils$$

$$\sigma_v = \sqrt{\frac{1}{N(N-1)} \sum_{i<j} (v_i - v_j)^2}$$

On fig 8 we see that the spatial pattern of bulk-disagreement for latent heat flux is very configuration dependant. Probably because of different feedback loops within the atmosphere/ocean and variables adjustment.

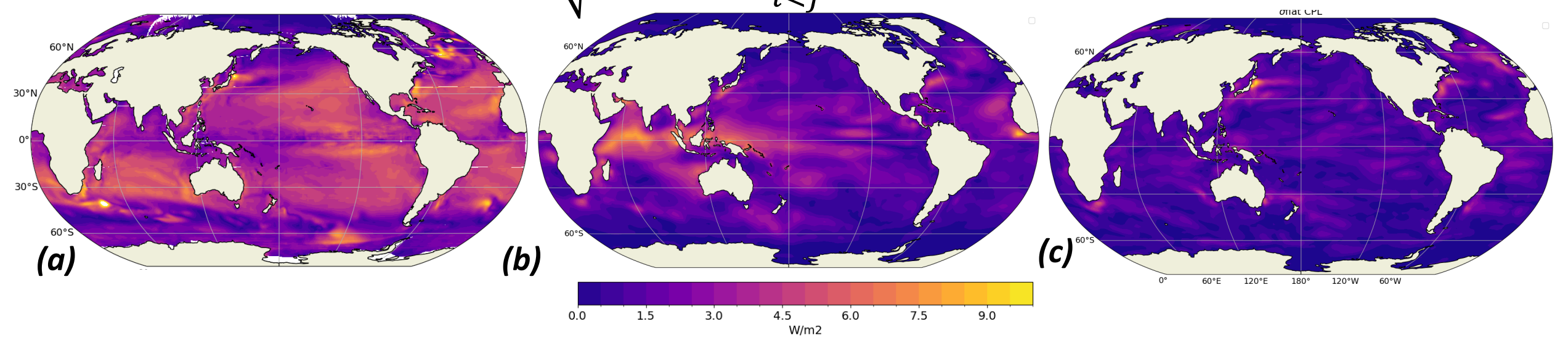


Fig 8: Mean squared differences between bulks for latent heat flux in (a) ocean only, (b) atmosphere only and (c) coupled runs

## 3. Method

In this study we will compare different air-sea fluxes parametrizations used in both forced and coupled simulations and assess the differences between each run to answer our objectives (see figure 4).

★ **Atmosphere-only runs $\mathcal{A}^{for}$**
- ✓ DYNAMICO-LMDZ model[3] with icosaedric grid (144x143x79)
- ✓ ORCHIDEE land model[4]
- ✓ Forced by climatological SSTs (1979-2008)
- ✓ 50 years of run with 20 years of spin-up

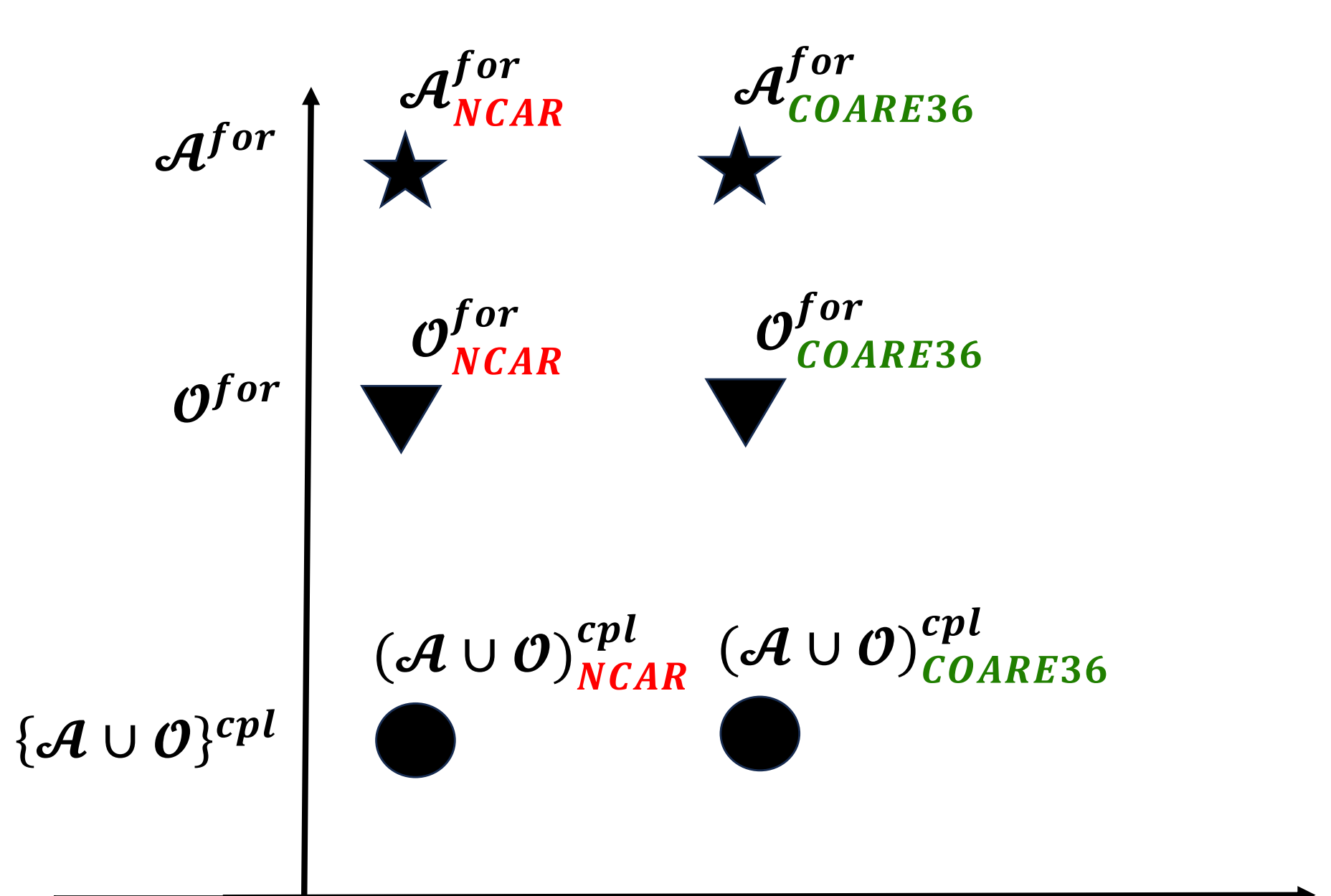
▼ **Ocean-only runs $\mathcal{O}^{for}$**
- ✓ NEMO model[5] with ORCA1 grid: Arakawa-C (360x331x75)
- ✓ Forced by a repeating atmospheric year (2009 CORE II)
- ✓ 200 years of run with 100 years of spin-up

● **Coupled runs $\{\mathcal{A} \cup \mathcal{O}\}$**
- ✓ OASIS coupling model
- ✓ 250 years of run with 200 years of spin-up (from *Levitus climatology*)

To answer our objectives:

I. We usually differentiate two bulks inside the same configuration (ex: $\mathcal{A}^{for}_{NCAR} - \mathcal{A}^{for}_{ECMWF}$ on x-axis).

II. Differences between coupled and forced runs (ex: $\mathcal{A}^{cpl}_{NCAR} - \mathcal{A}^{for}_{NCAR}$ on y-axis) exhibit many additional feedbacks, not just the one from air-sea fluxes (ex: deep convection, etc.) and requires a panel of bulks to assess systematic behaviour.



| Bulk | NCAR | COARE | ECMWF | LMDZg | LMDZng |
|---|---|---|---|---|---|
| Gustiness |  | $u_g = \beta w^*$ |  | Online diagnostic |  |
| Warm Layer |  | x | x |  |  |
| Cool Skin |  | x | x |  |  |

Fig 4: Synthetic view of simulations used in this study. X-axis denotes a changing parametrization of turbulent air-sea fluxes while Y-axis selects a configuration (ex: atmosphere alone $\mathcal{A}^{for}$)

## 4.3 The coupled system's feedback affects equilibrium

Has we have shown in 4.1 & 4.2, strong feedbacks exist between surface variables and fluxes. On Fig 9, we can see that:

- ✓ The atmospheric only runs ($\mathcal{A}^{for}$ ) perform well in terms of temperature but have **largely overestimated latent heat flux**, contributing to a net export of energy from the ocean to the atmosphere ($bils < 0$).
- ✓ Within the coupled runs ($\mathcal{A} \cup \mathcal{O}$), **a strong cooling is observed** (1°C) for both $t_{2m}$ and $SST$. This is explained by **the feedback of the ocean** which cooled rapidly due to overestimated latent heat flux and is no longer able to sustain the previous energy transfer from the ocean to the atmosphere ($bils > 0$).
- ✓ **Forced runs** usually perform well in terms of **surface variables** because of model's **tuning**[7] but there is no guarantee that they **have small biases for the good reasons** (ex: overestimated latent heat flux in the atmosphere-only runs leads to correct $t_{2m}$).

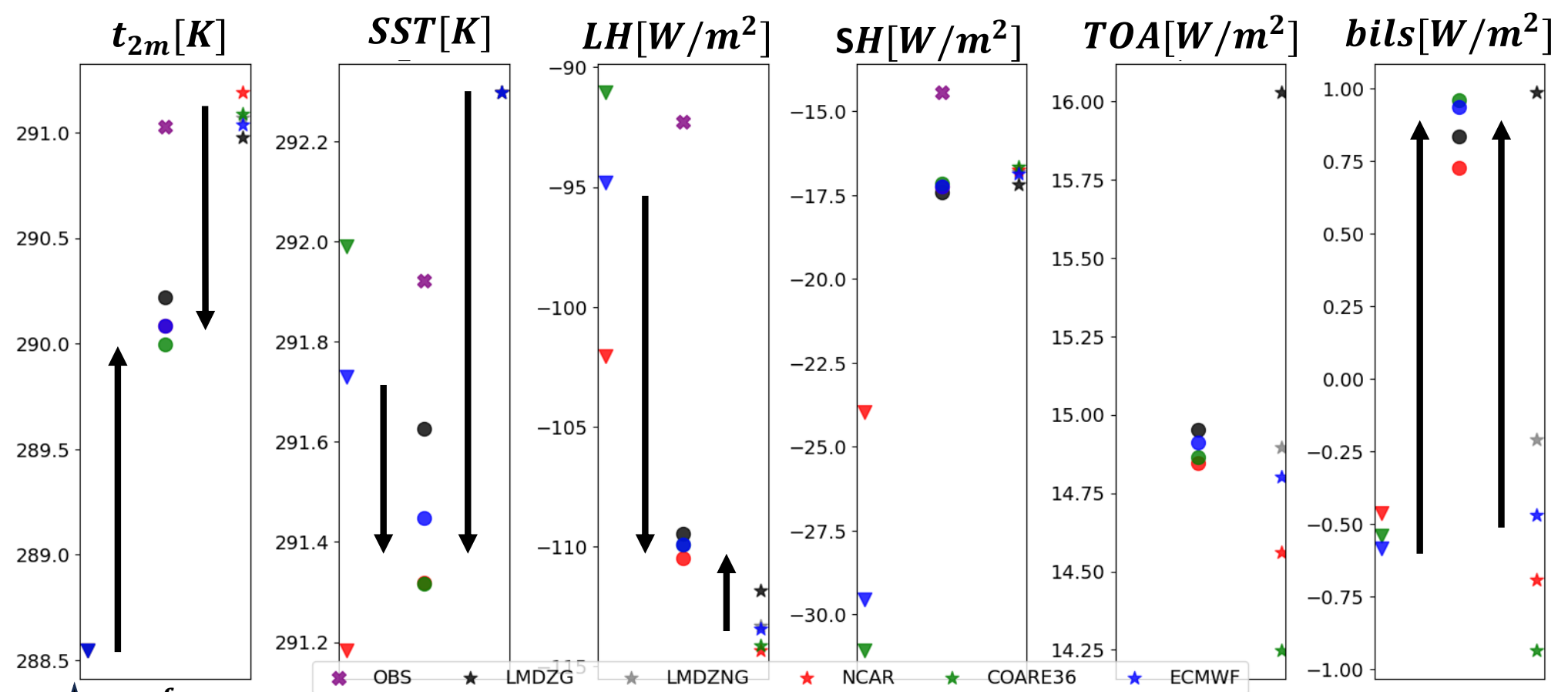


Fig 9: Averages of variables and fluxes over the ocean for different bulks (color) and configurations (symbol). Arrows denotes the transition from forced to coupled simulations.

Please note that the bulk that is less affected by the transition from atmosphere only to the coupled run is **the one that was used to tuned** the IPSL's model (LMDZg) : $bils^{LMDZg}_{\mathcal{A}^{for}} \sim bils^{LMDZg}_{\mathcal{A} \cup \mathcal{O}^{cpl}}$

## 5. Conclusions

- ❑ **Changing air-sea fluxes parametrization implies the modification of both surface fluxes and variables to maintain a net zero energy balance**
- ❑ **Strong feedbacks are at work between latent heat flux and momentum flux.**
- ❑ **The computation of ocean-atmosphere fluxes is crucial in the climate's dynamic, especially in terms of energy transport**
- ❑ **Studying coupled models with the full feedback loops is important to understand ocean-atmosphere adjustment and model biases**

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