Scientific application of YAC coupler: Spatial scale dependency of air-sea coupling

Dian Putrasahan (MPIM)

natESM training workshop

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next GEMS

CLUSTER OF EXCELLENCE
CLIMATE, CLIMATIC CHANGE, AND SOCIETY (CLICCS)

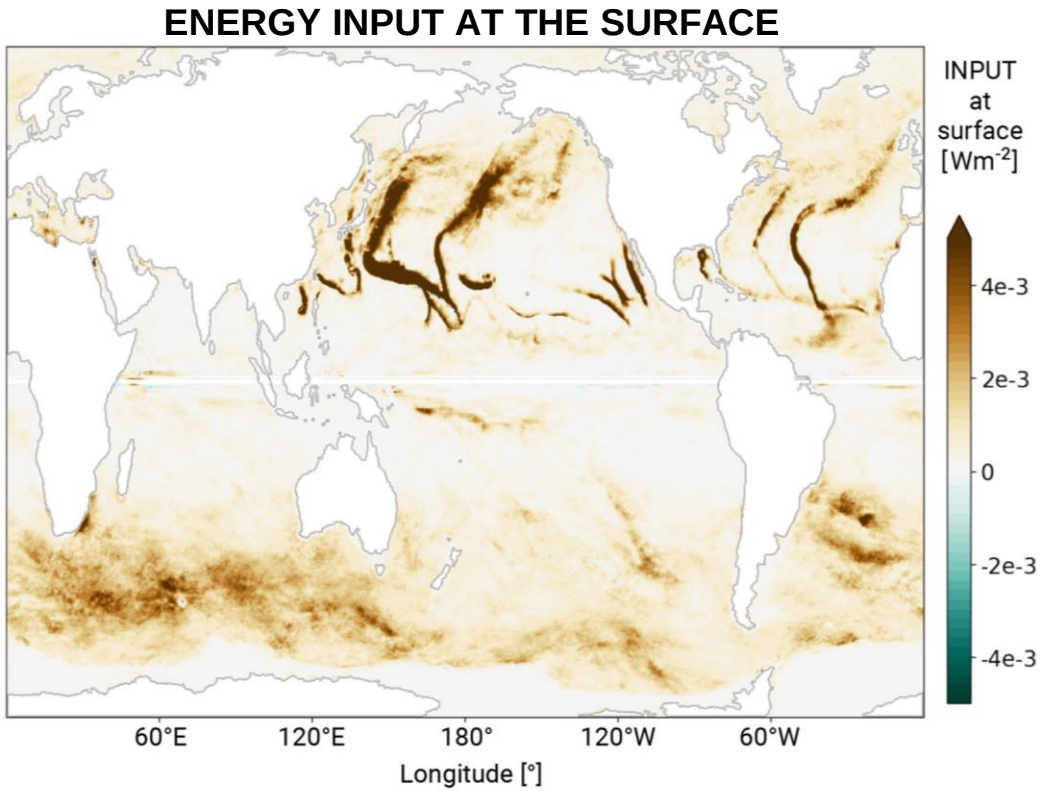
MAX-PLANCK-INSTITUT FÜR METEOROLOGIE

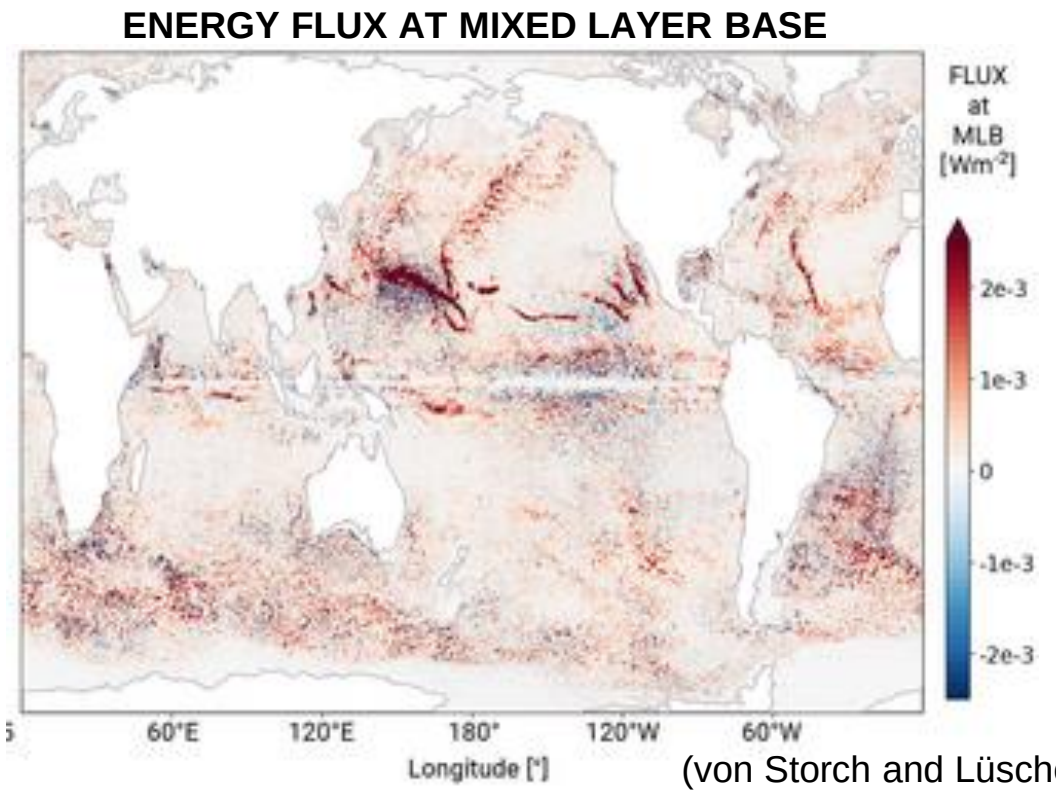
Assessing coupling in the climate system

Importance of coupling in the climate system

- Capture coupled processes such as hurricanes, ENSO, air-sea feedbacks, etc.
- Enhance/dampen existing coupled feedbacks, with implications on climate change

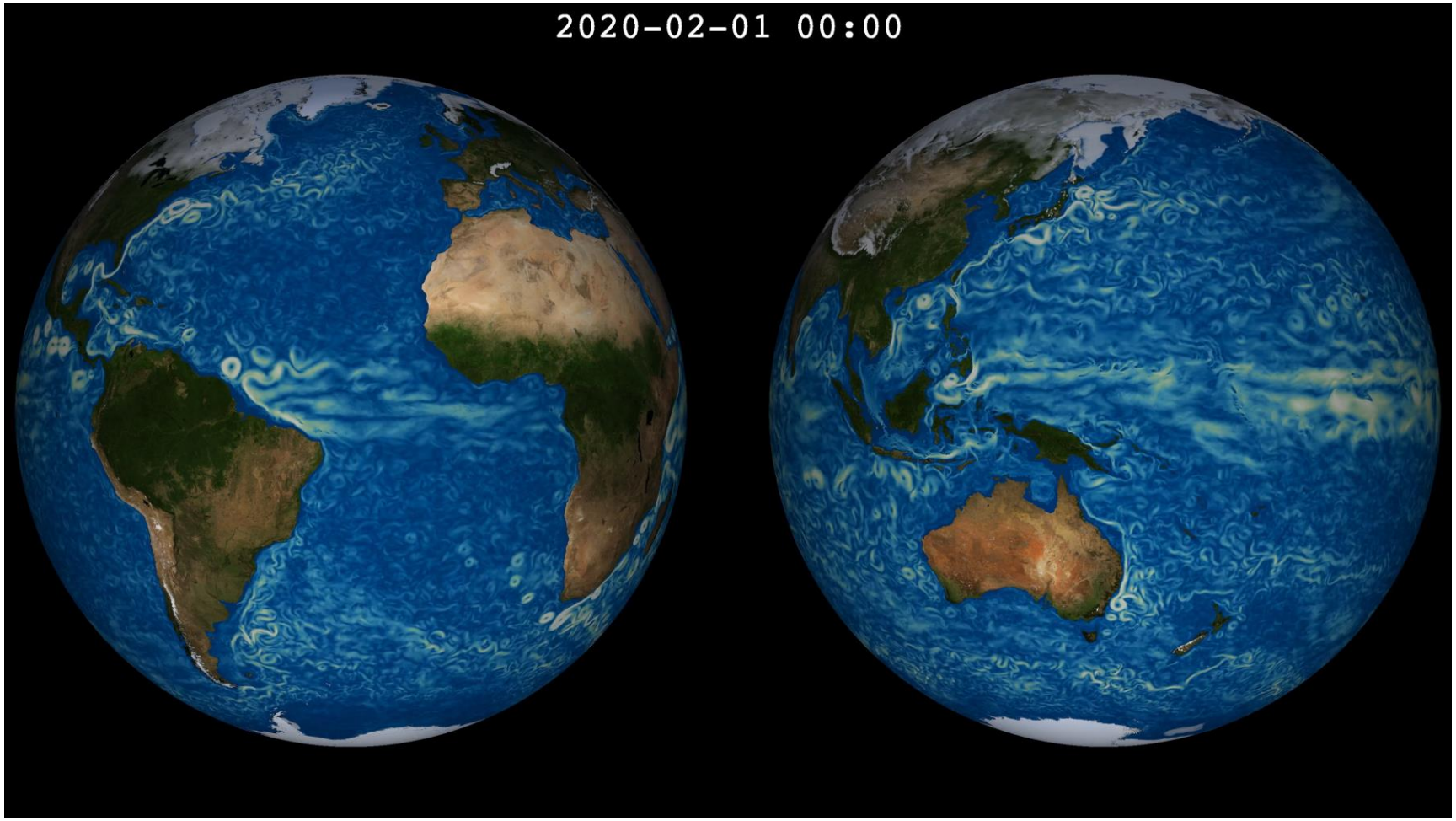
Coupler: Exchange physical (heat, momentum and freshwater/buoyancy) and chemical (BGC tracers) fluxes





(von Storch and Lüschow., 2023)

Ocean currents from coupled 10km ICON



https://www.youtube.com/watch?v=CYxod6VjOMk

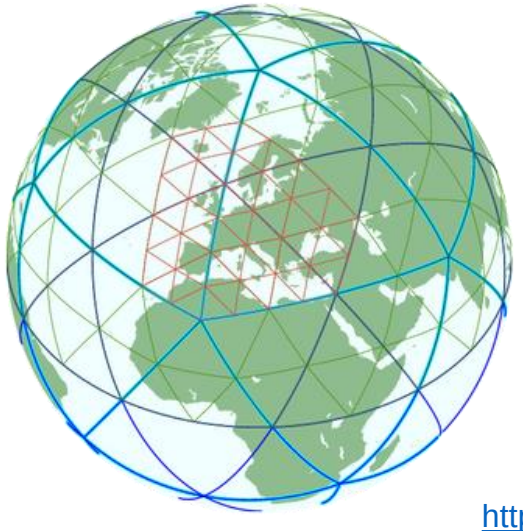
Assessing coupling in the climate system

Role of ocean mesoscale eddies on the climate system

- Focus on impact of eddies on air-sea coupling
- Coupled processes associated with ocean mesoscale that differ from the large scale

Coupled 5km oce/ 10km atm ICON simulation

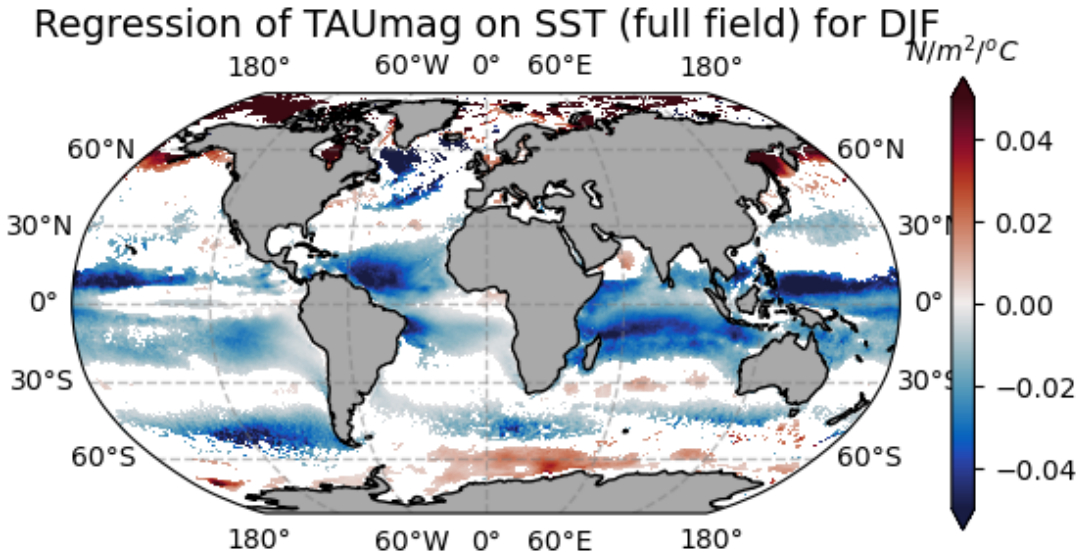
ICON-A: ICOsahedral Nonhydrostatic Atmosphere
ICON-O: ICOsahedral Hydrostatic Ocean

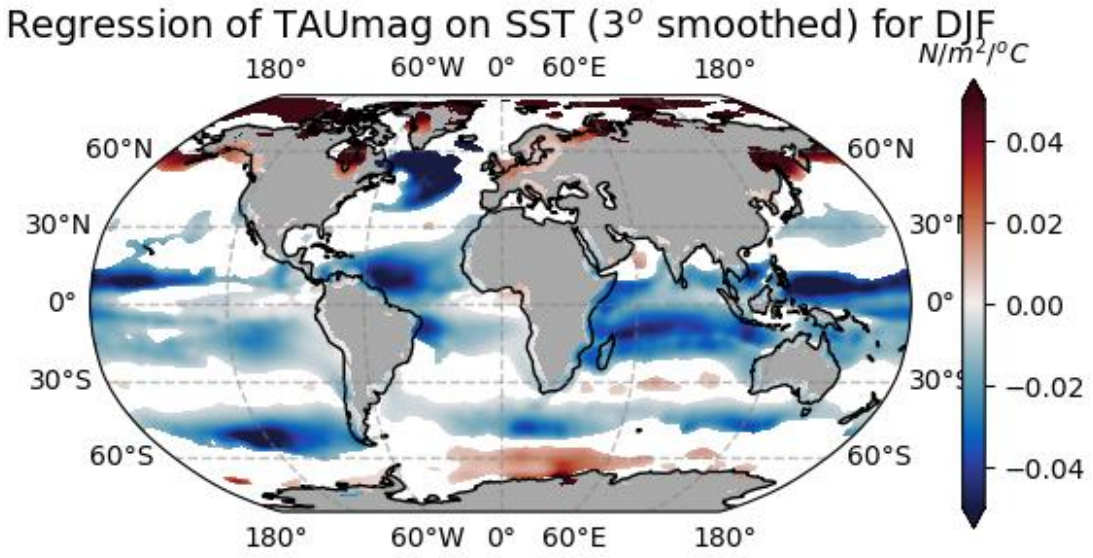


- **7-years** of data (now up to 40-years simulation)
- Monthly, **daily**, hourly surface variable outputs
- ocean spun-up with ERA5 reanalysis
- **3º spatial filter** to separate spatial scales

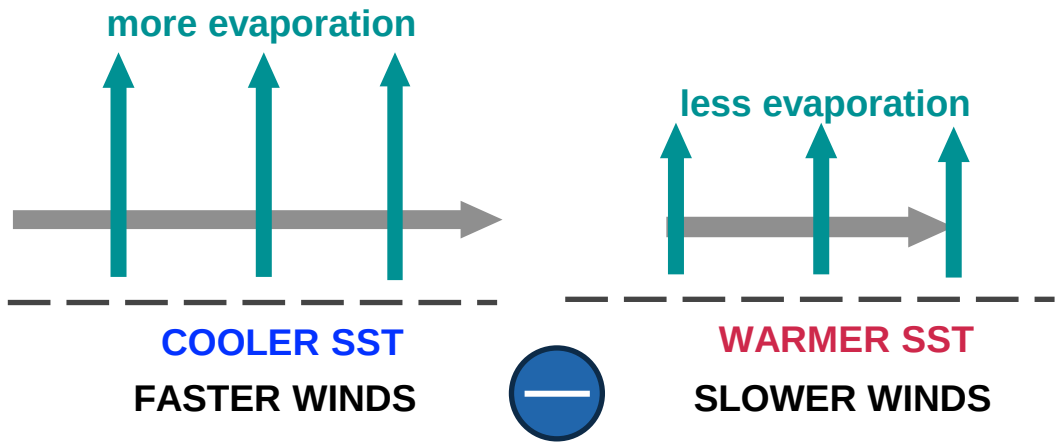
https://code.mpimet.mpg.de/projects/iconpublic

Air-sea coupling on the large scale

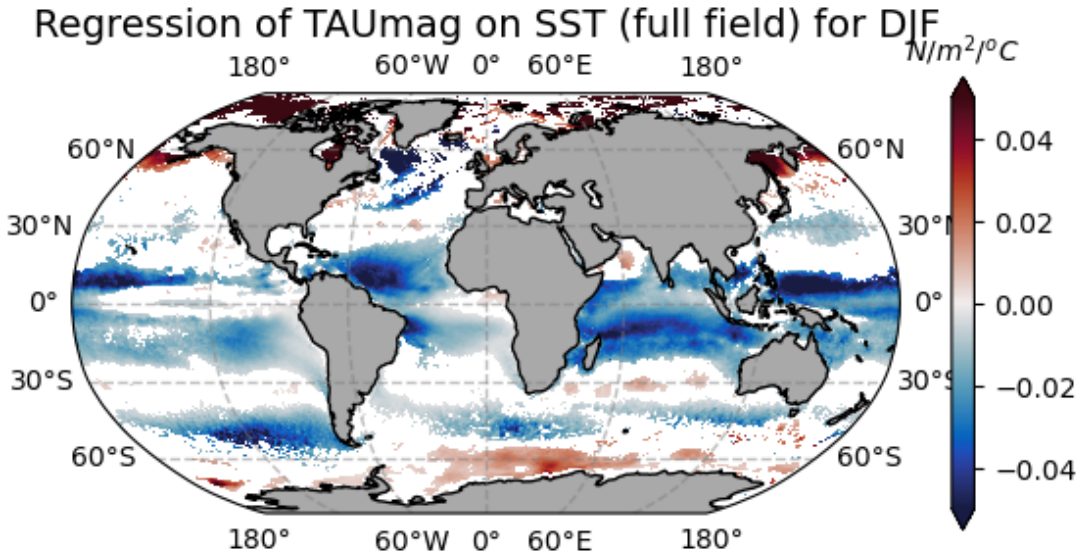


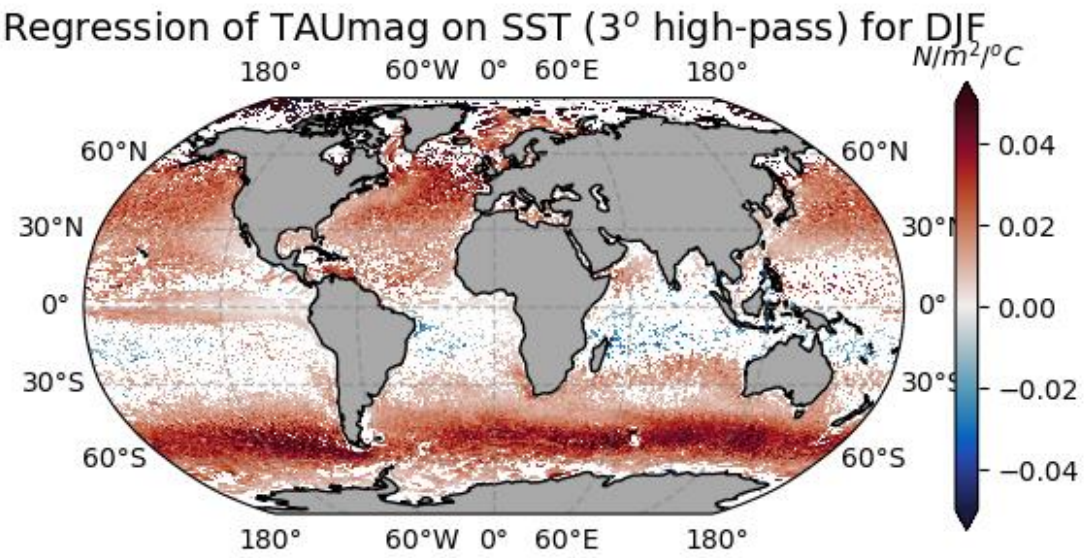


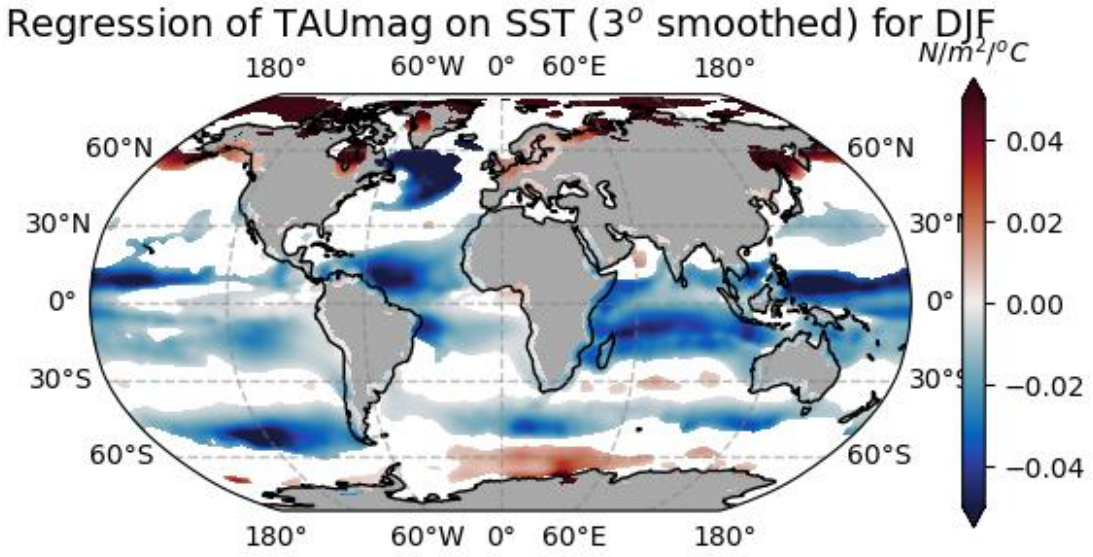
Wind-Evaporation-SST (WES feedback)



Scale dependency of air-sea coupling







What resolved mesoscale processes would give rise to the different spatial patterns of air-sea coupling?

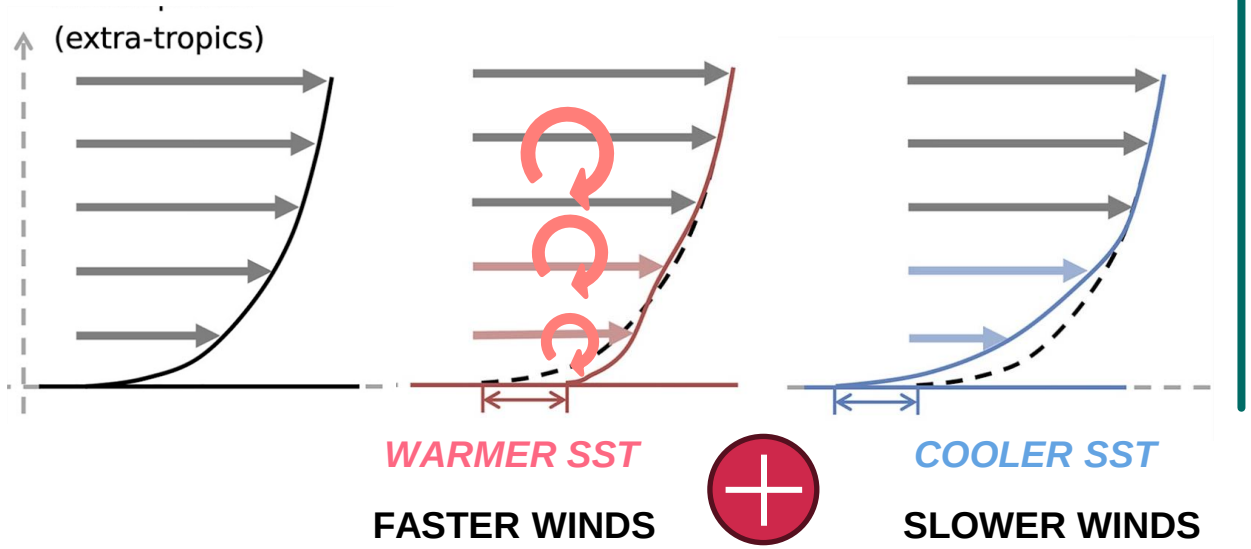
Two dynamical processes on the ocean mesoscale: thermal feedback (TFB) and current feedback (CFB)

Renault et al., 2016

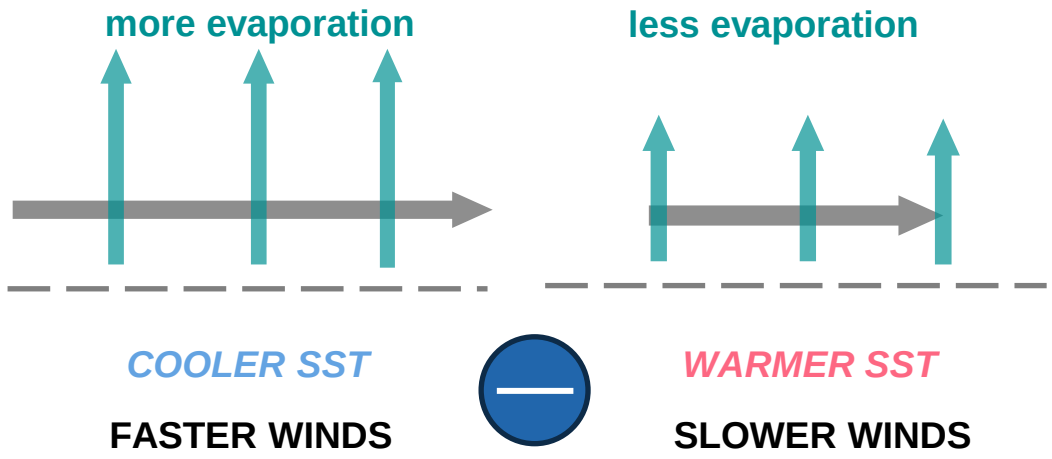
Air-sea coupling: SST and winds

Thermal Feedback (TFB)

Vertical (Downward) Mixing Mechanism



Wind-Evaporation-SST (WES feedback)



The two SST-WIND related feedbacks have opposite signs:

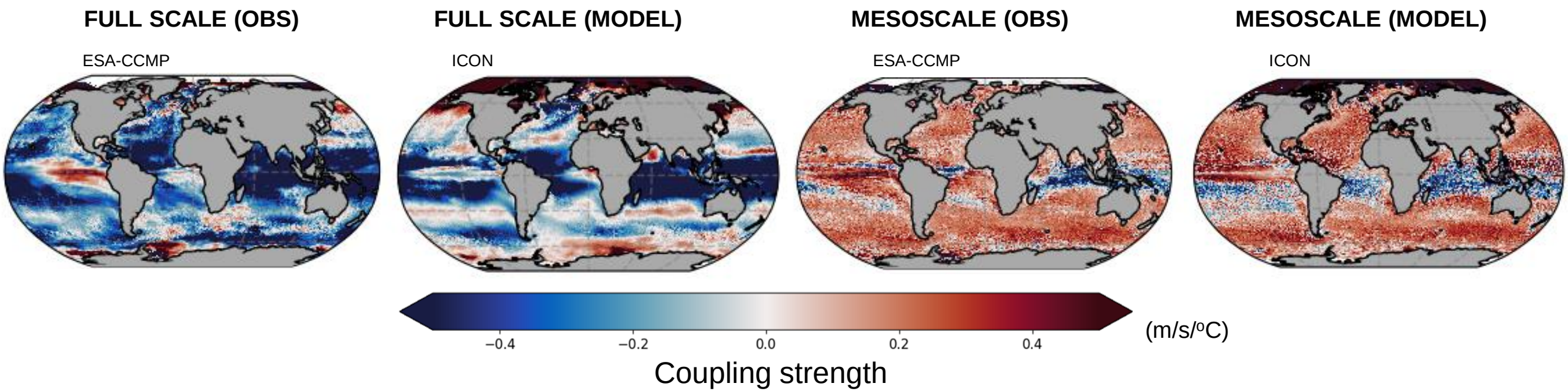
Positive ⊕ *for the* ***downward mixing mechanism****, and*

Negative ⊖ *for the* ***wind-evaporation-SST*** *feedback*

Modified from
Pasquero et al., 2021

Spatial scale dependency of SST-wind coupling

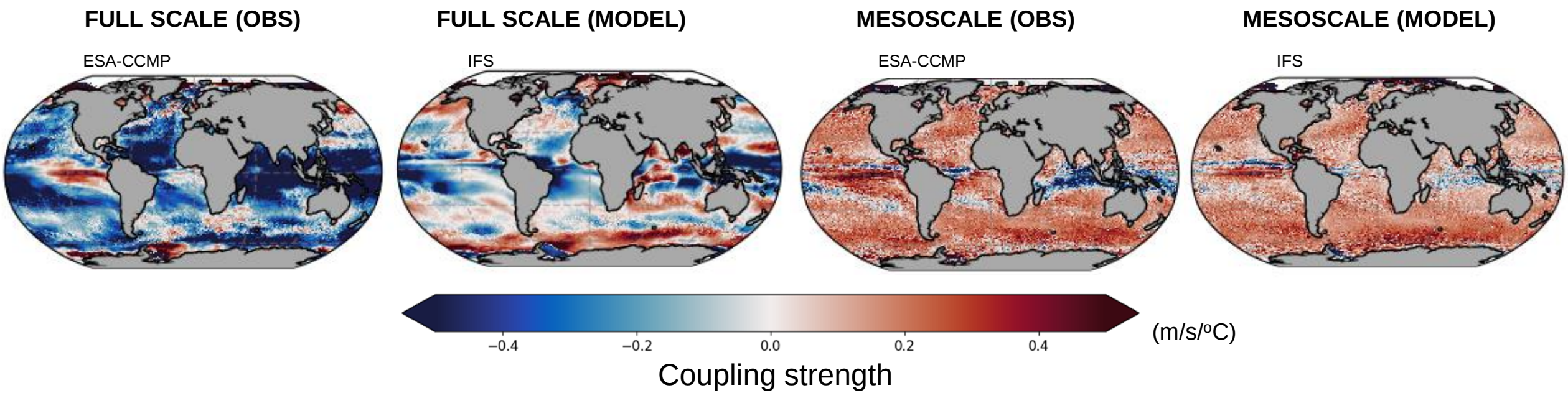
Large-scale vs mesoscale air-sea coupling



Mesoscale coupling *exhibit* ***TFB*** *that is driven by the downward mixing mechanism* ⊕

Large-scale *dominates the full scale* ***coupling*** *and is driven by the WES feedback* ⊖

Impact of coupled vs AMIP on SST-wind coupling



Mesoscale coupling *exhibit TFB that is captured by IFS-AMIP* ⊕

Large-scale coupling *is* ***not*** *really captured by IFS-AMIP*

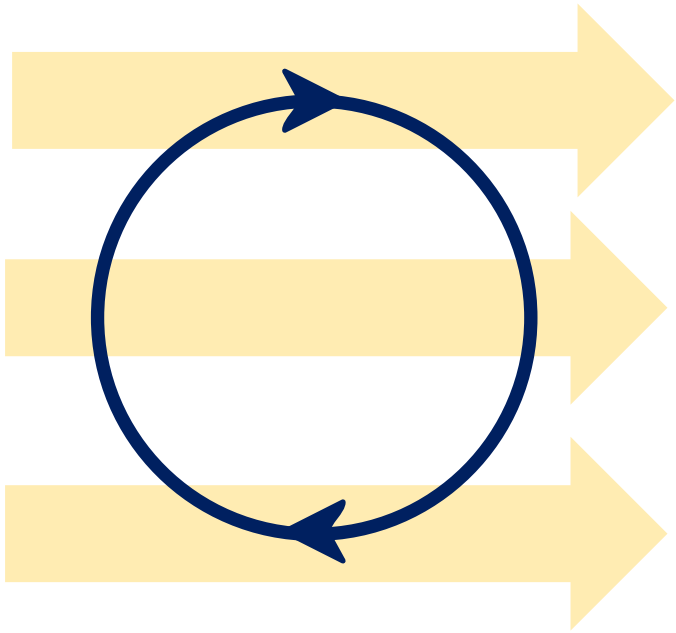
Current feedback on wind stress curl

No current feedback

Background
wind velocity

Current feedback on stress

Current feedback on wind stress curl



$\zeta < 0$

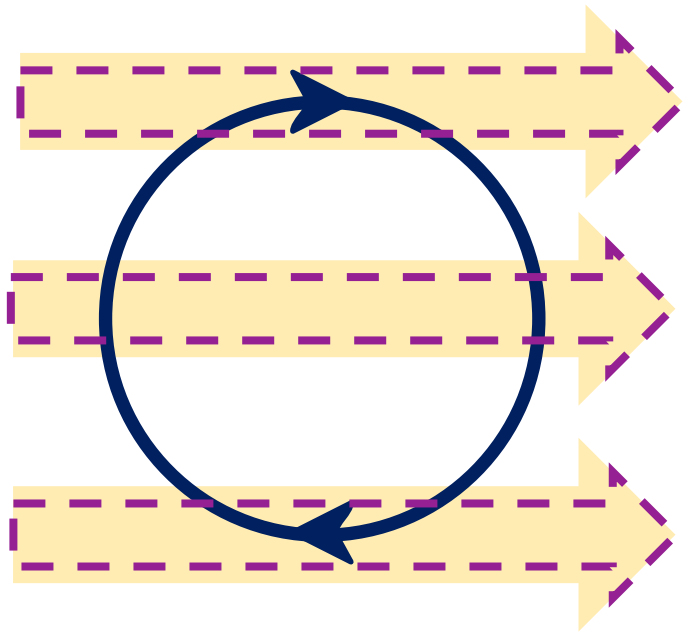
No current feedback

Current feedback on stress

Background
wind velocity

surface current

Current feedback on wind stress curl



$$\zeta < 0$$
$$(\nabla \times \vec{\tau}) = 0$$

No current feedback

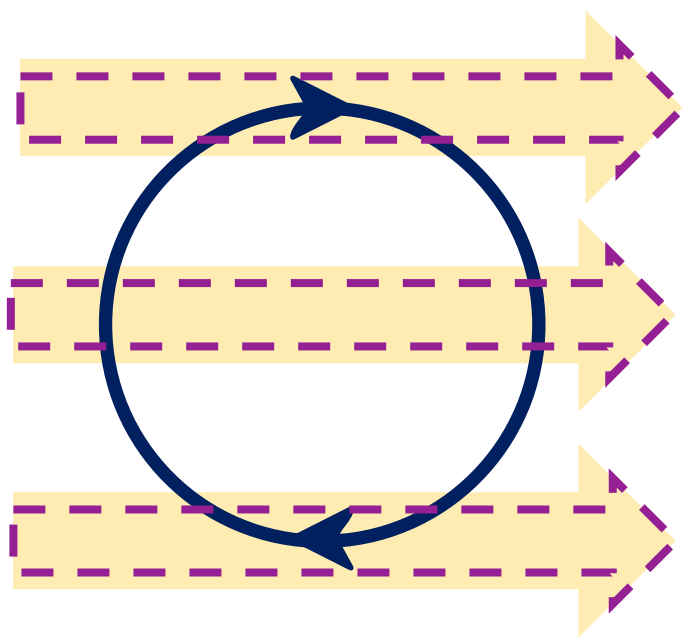
Current feedback on stress

Background wind velocity

surface current

wind stress

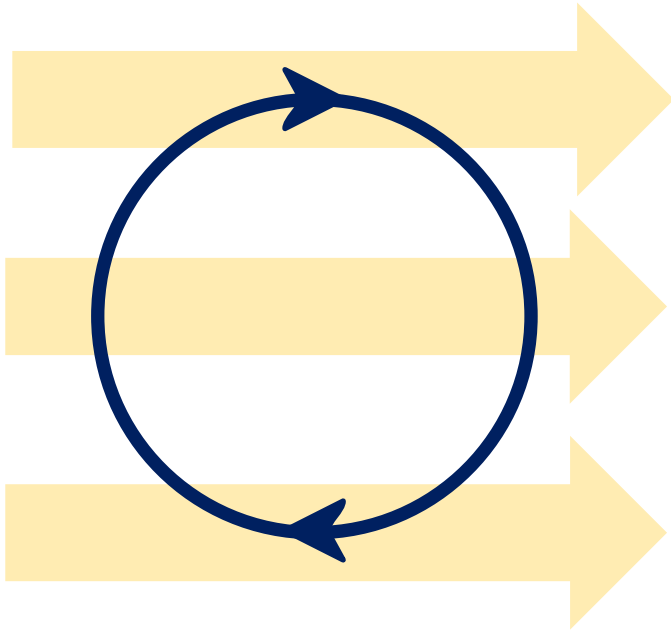
Current feedback on wind stress curl



$\zeta < 0$

$(\nabla \times \vec{\tau}) = 0$

No current feedback



$\zeta < 0$

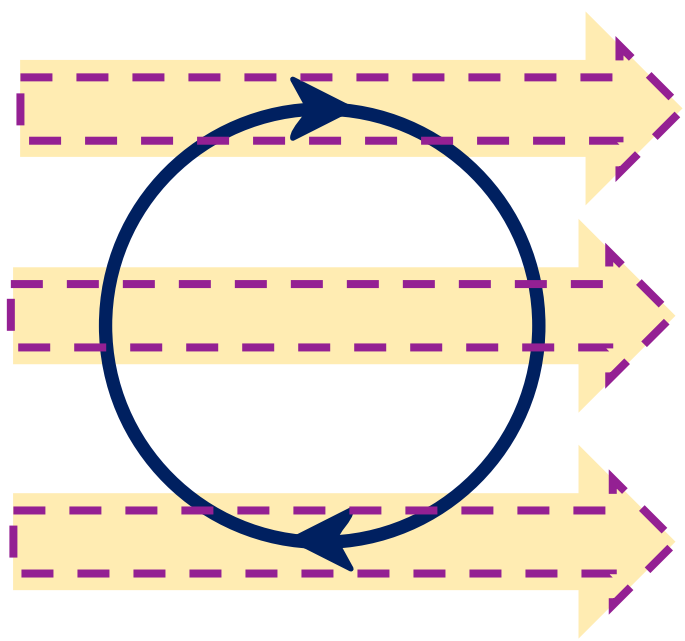
Current feedback on stress

Background
wind velocity

surface current

wind stress

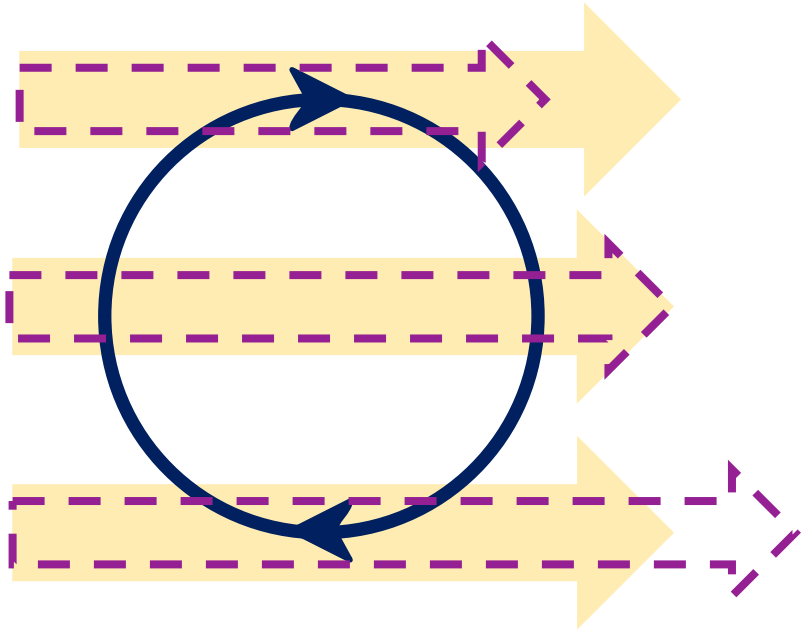
Current feedback on wind stress curl



$\zeta < 0$

$(\nabla \times \vec{\tau}) = 0$

No current feedback



$\zeta < 0$

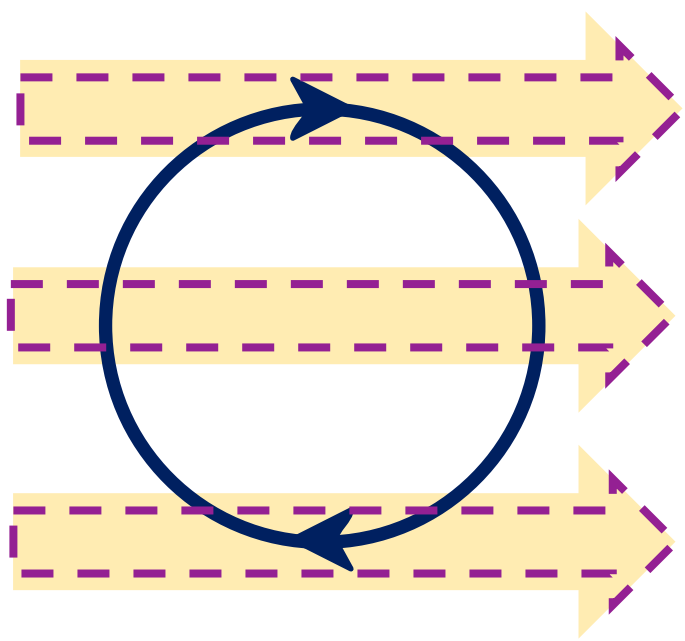
Current feedback on stress

Background
wind velocity

surface current

wind stress

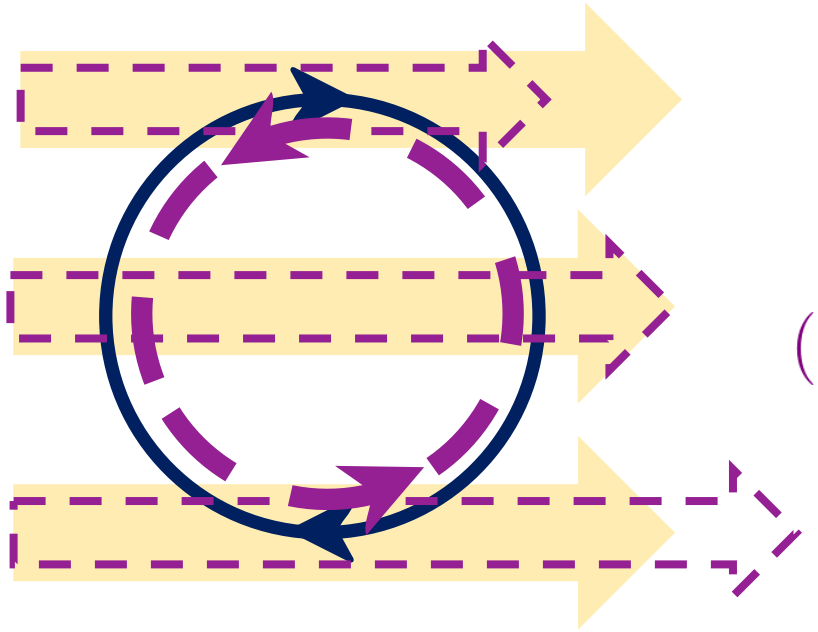
Current feedback on wind stress curl



$\zeta < 0$

$(\nabla \times \vec{\tau}) = 0$

No current feedback



$\zeta < 0$

$(\nabla \times \vec{\tau}) > 0$

Current feedback on stress

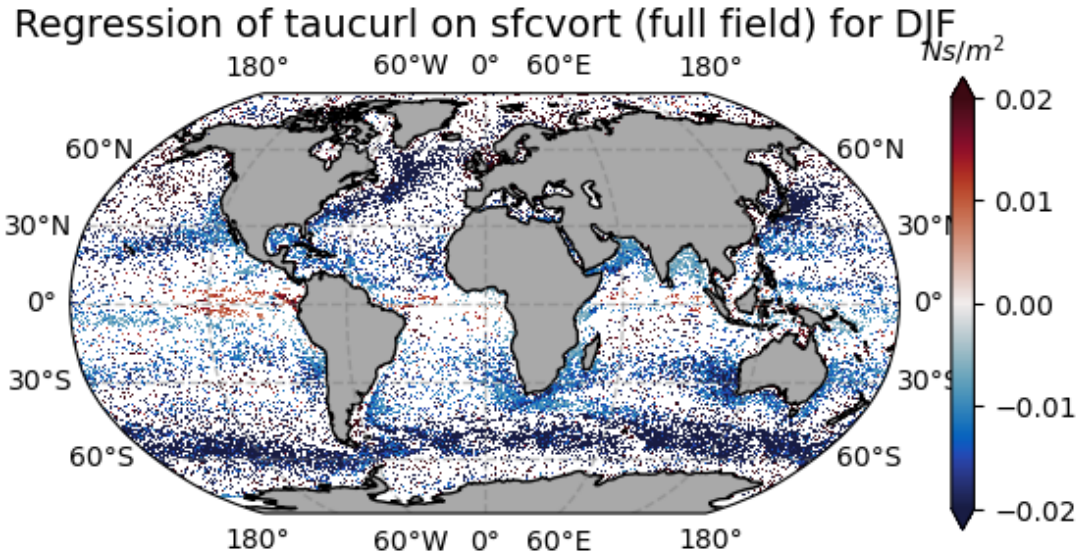
Background wind velocity

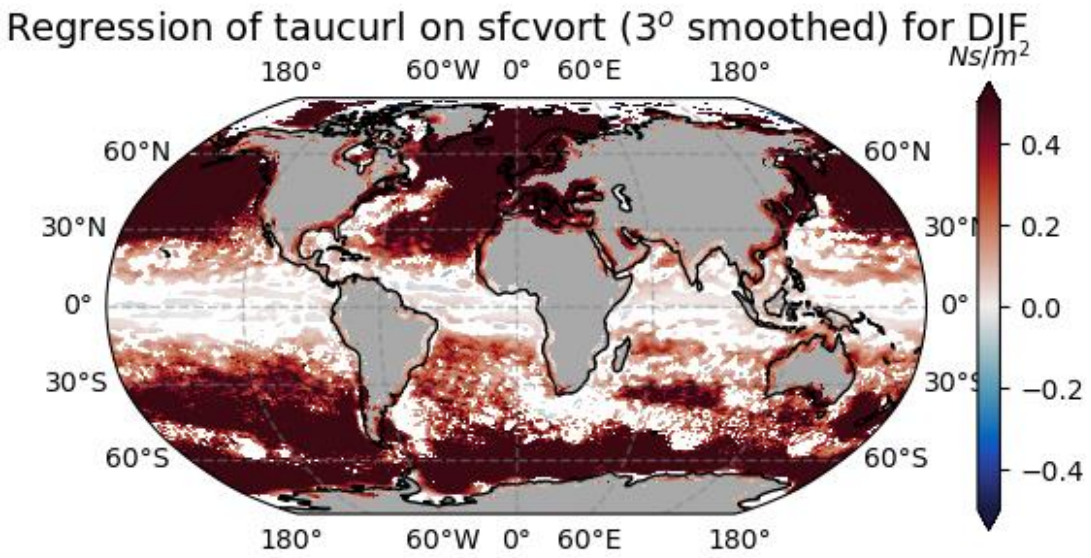
surface current

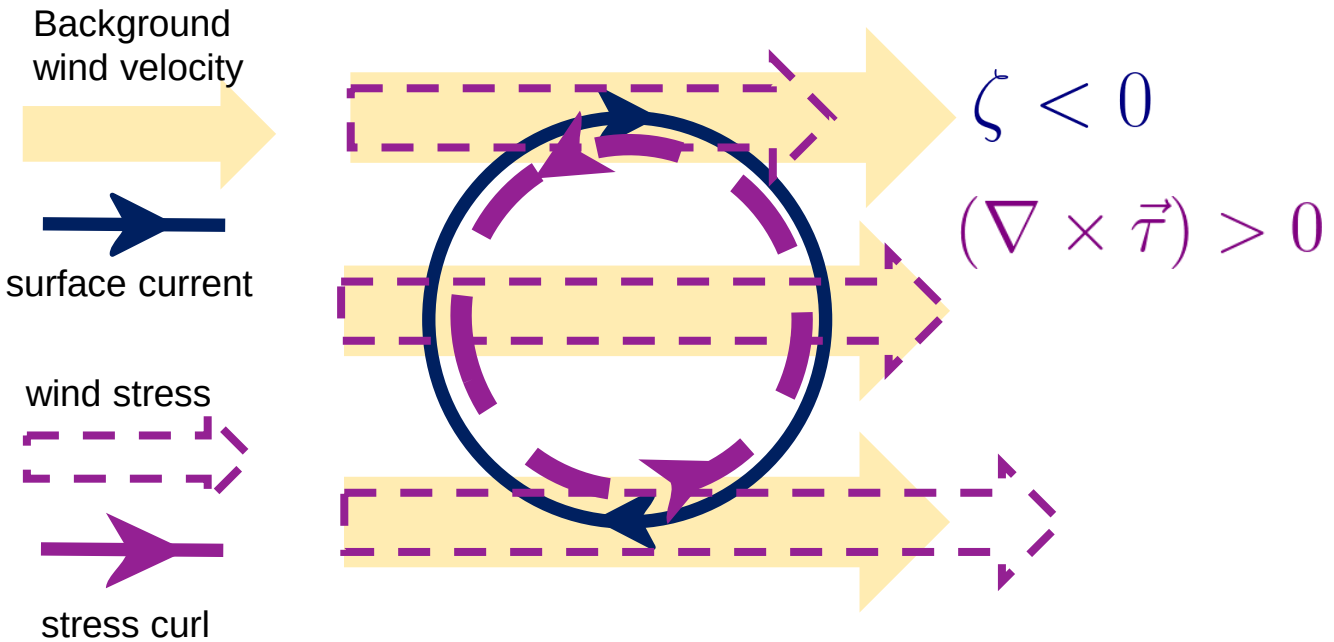
wind stress

stress curl

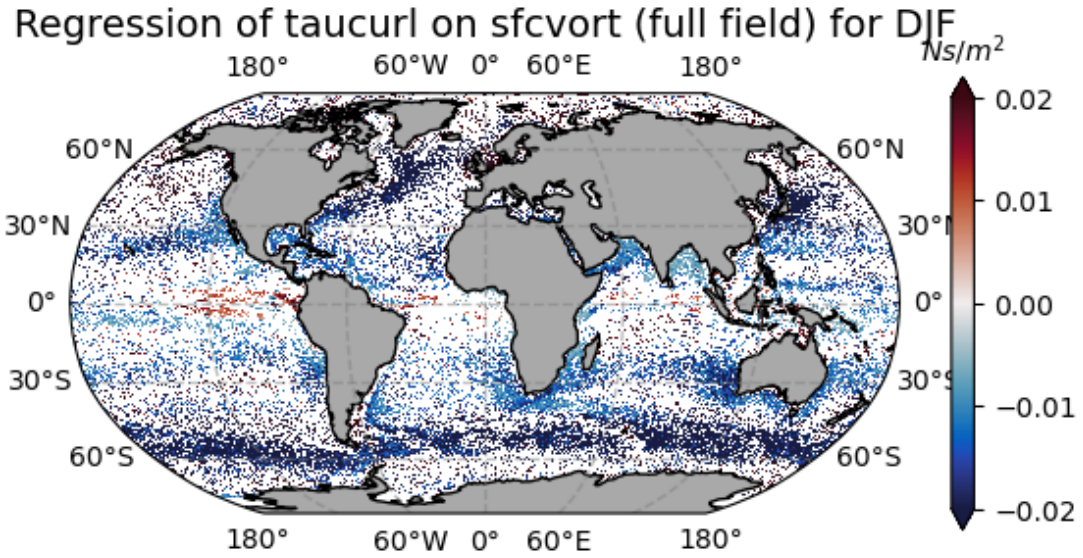
CFB: surface current vorticity and stress curl

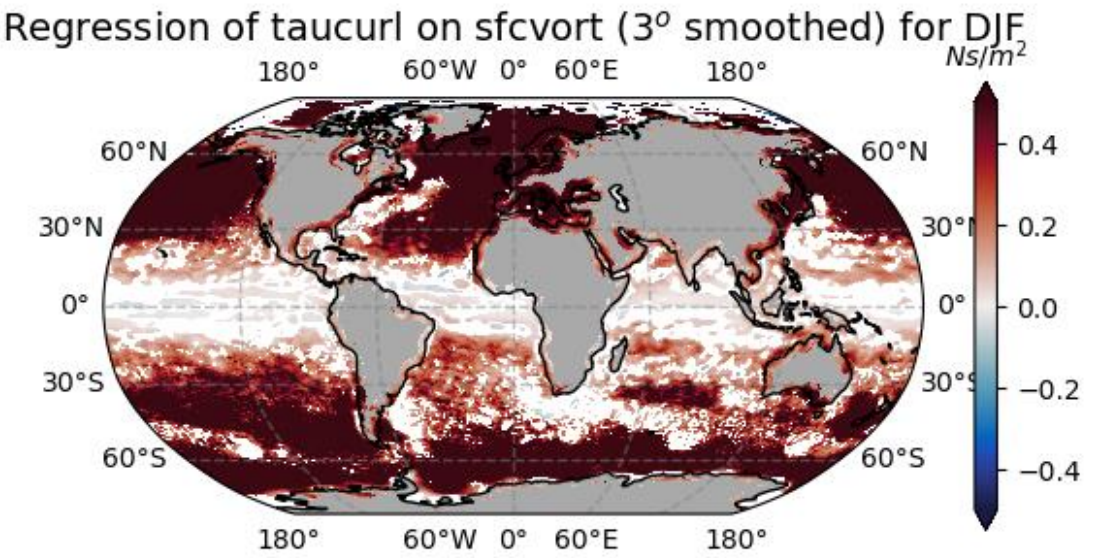


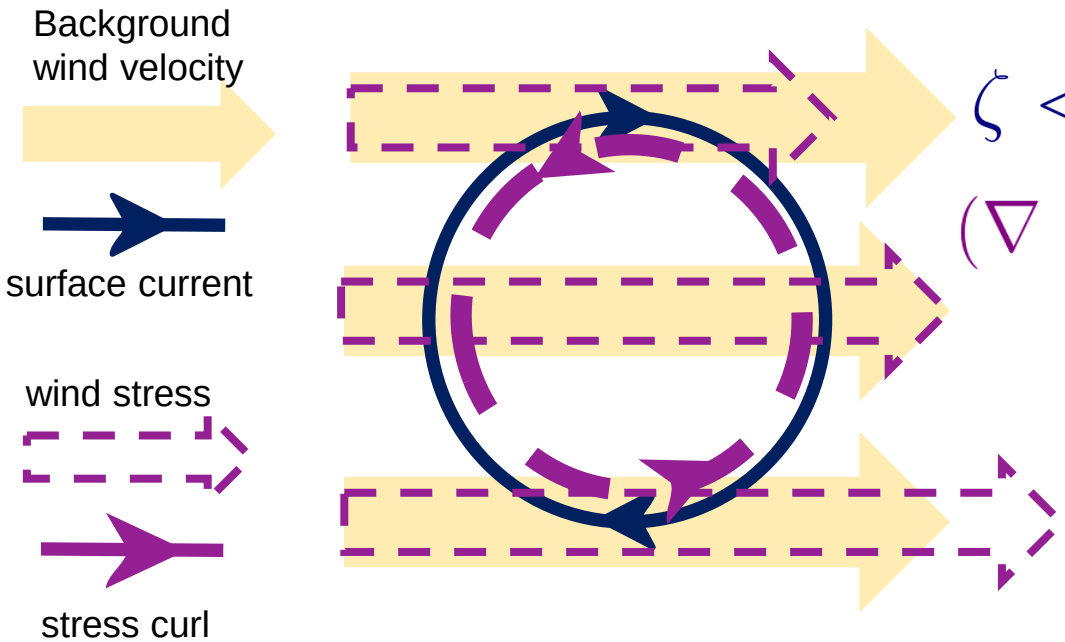


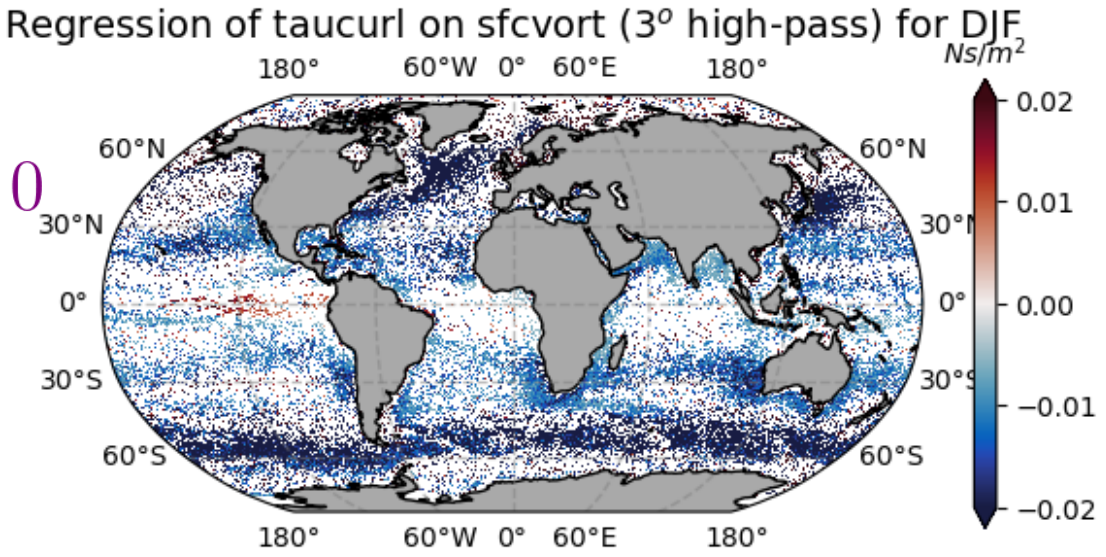


CFB: surface current vorticity and stress curl



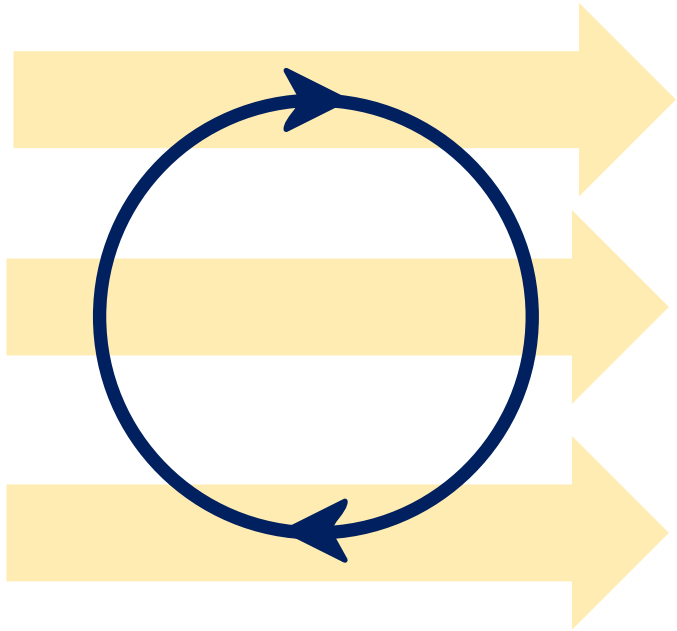






Wind input into the ocean (wind work)

$$\text{Wind work} = (\vec{\tau} \cdot \vec{u}_o)$$ ← Coupled process



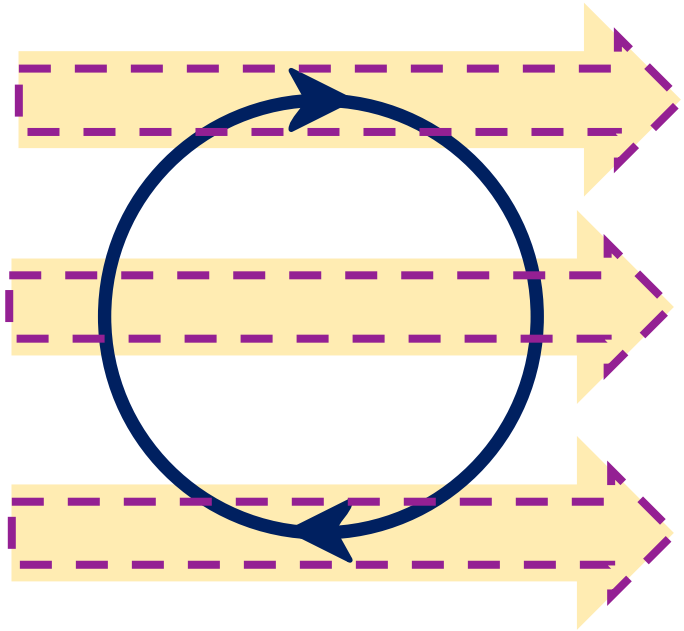
$\zeta < 0$

No current feedback

(Modified from Rai et al., 2021)

Wind input into the ocean (wind work)

$$\text{Wind work} = (\vec{\tau} \cdot \vec{u}_o)$$ ← Coupled process



$\zeta < 0$

No current feedback

Background wind velocity

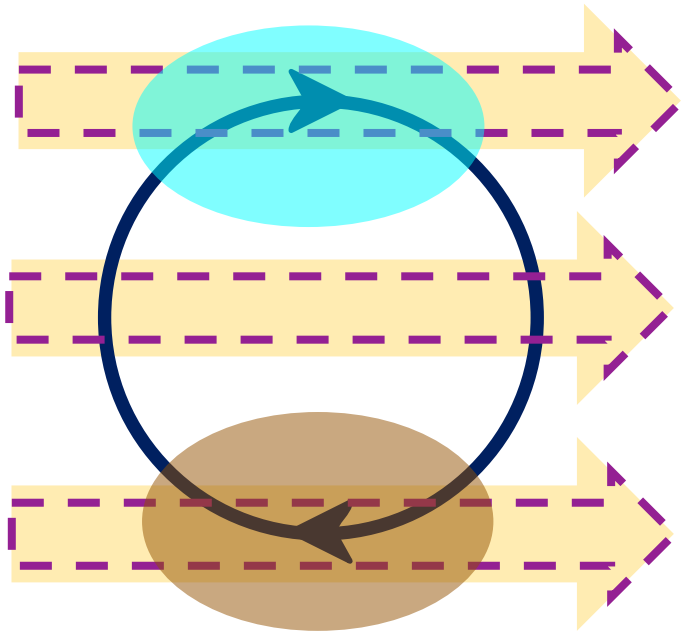
surface current

wind stress

(Modified from Rai et al., 2021)

Current feedback on wind work

$$\text{Wind work} = (\vec{\tau} \cdot \vec{u}_o)$$ ← Coupled process



$\zeta < 0$

$(\vec{\tau} \cdot \vec{u}_o) = 0$

No current feedback

Current feedback on stress

Background wind velocity

surface current

wind stress

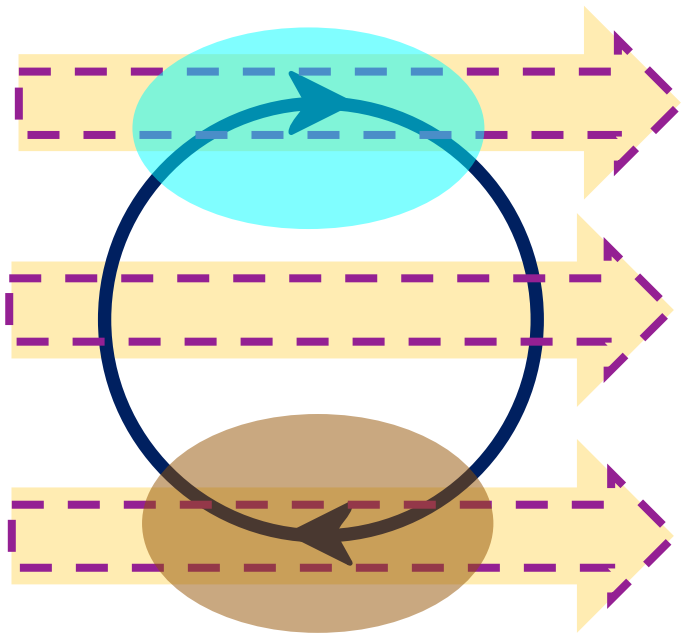
positive wind work

negative wind work

(Modified from Rai et al., 2021)

CFB on wind work ("eddy killing")

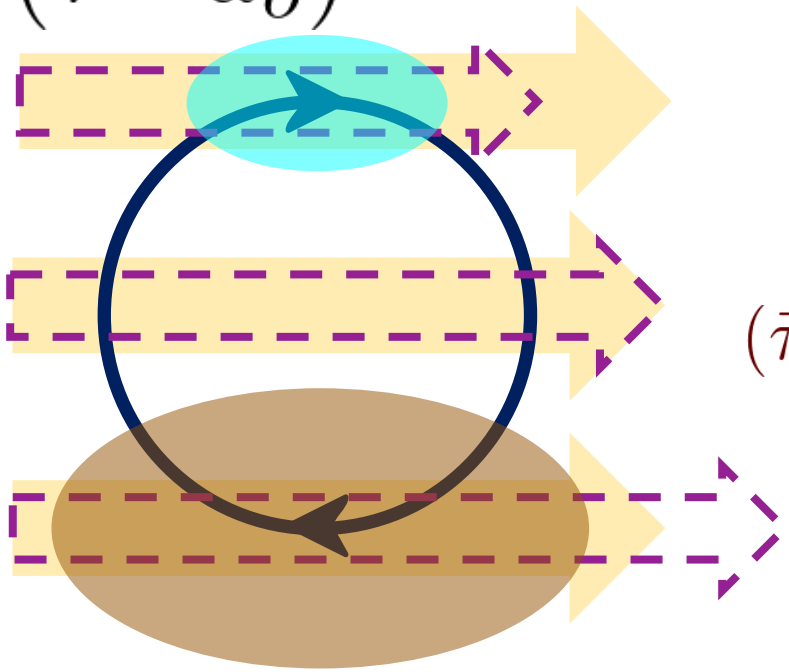
$$\text{Wind work} = (\vec{\tau} \cdot \vec{u}_o)$$ ← Coupled process



$\zeta < 0$

$(\vec{\tau} \cdot \vec{u}_o) = 0$

No current feedback



$\zeta < 0$

$(\vec{\tau} \cdot \vec{u}_o) < 0$

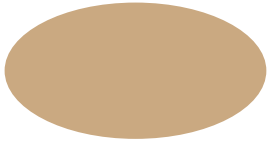
Current feedback on stress

Background wind velocity

surface current

wind stress

positive wind work

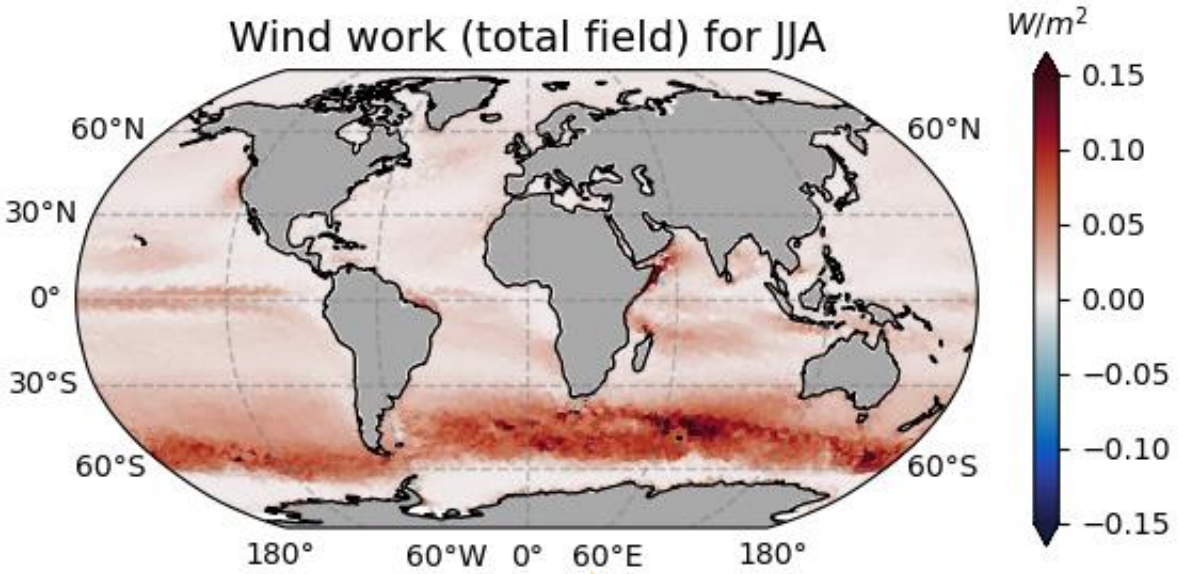


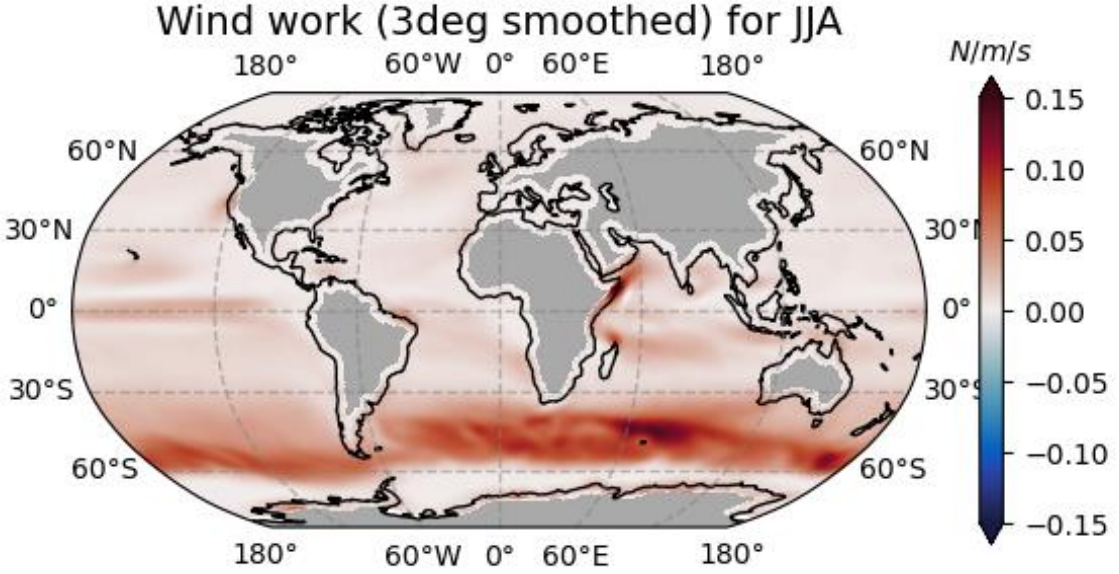
negative wind work

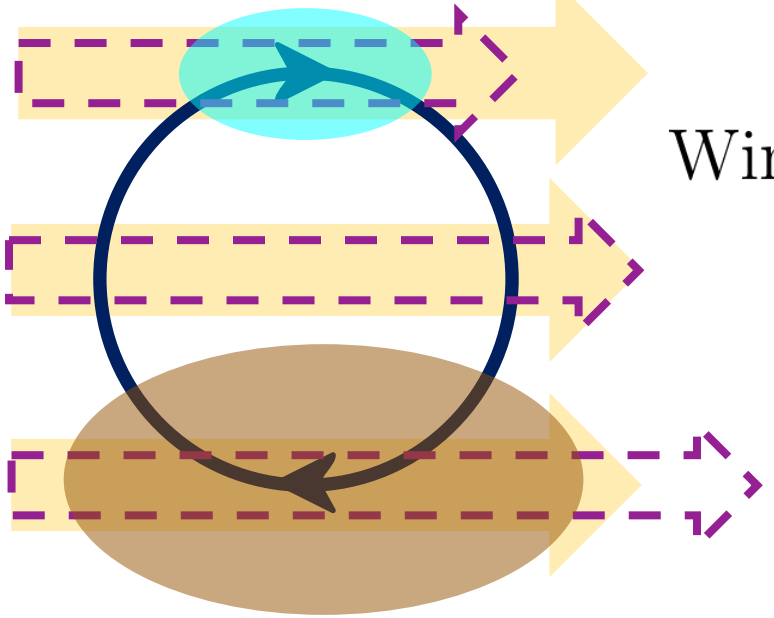
(Modified from Rai et al., 2021)

Email: dian.putrasahan@mpimet.mpg.de

CFB on wind work ("eddy killing")





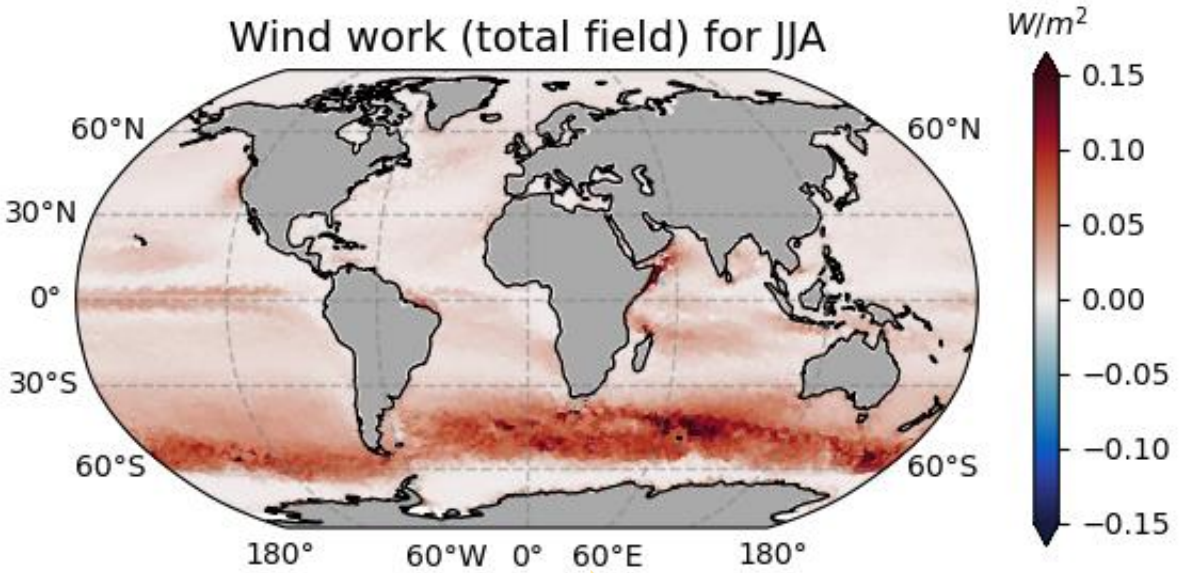


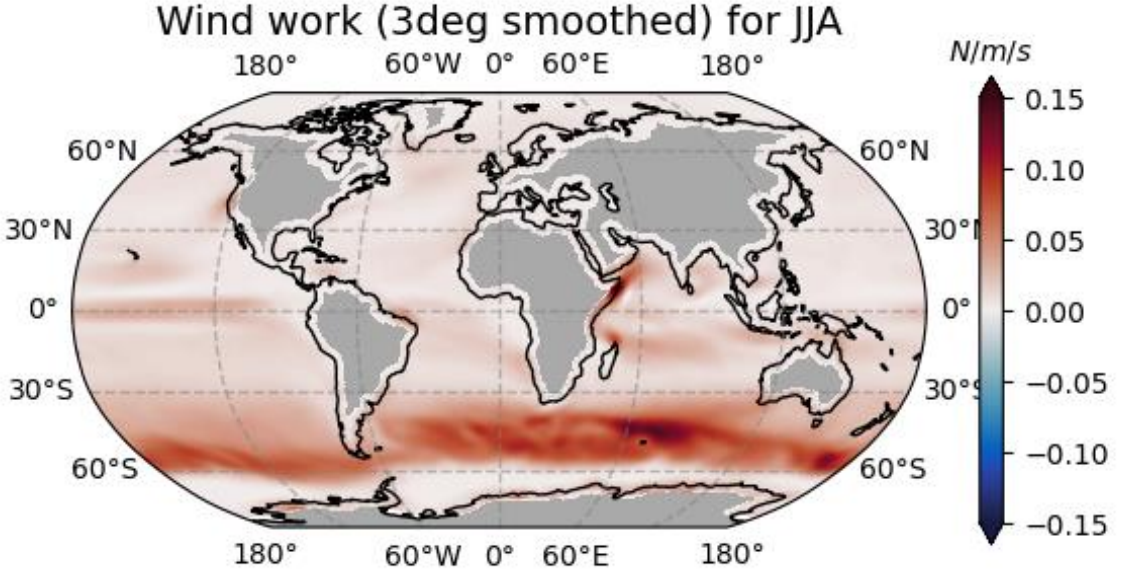
$$\text{Wind work} = (\vec{\tau} \cdot \vec{u}_o)$$

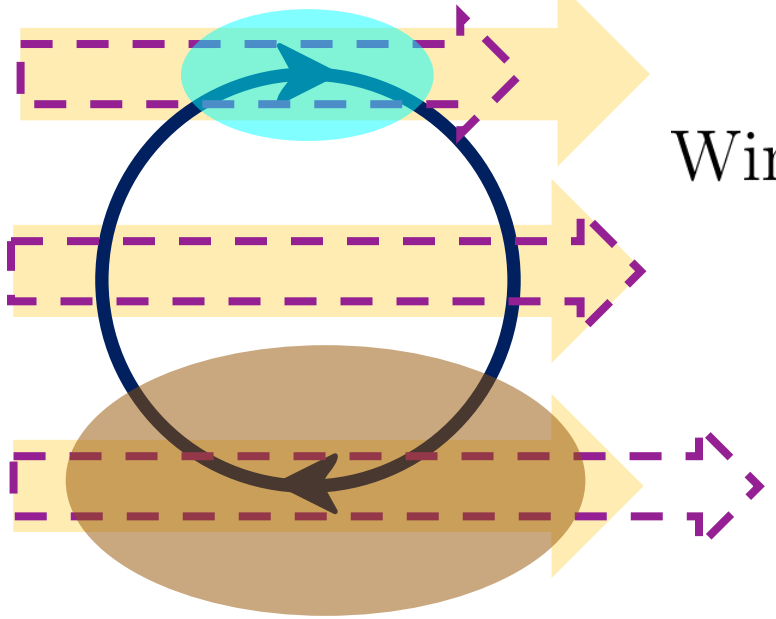
$$\zeta < 0$$

$$(\vec{\tau} \cdot \vec{u}_o) < 0$$

CFB on wind work (“eddy killing”)



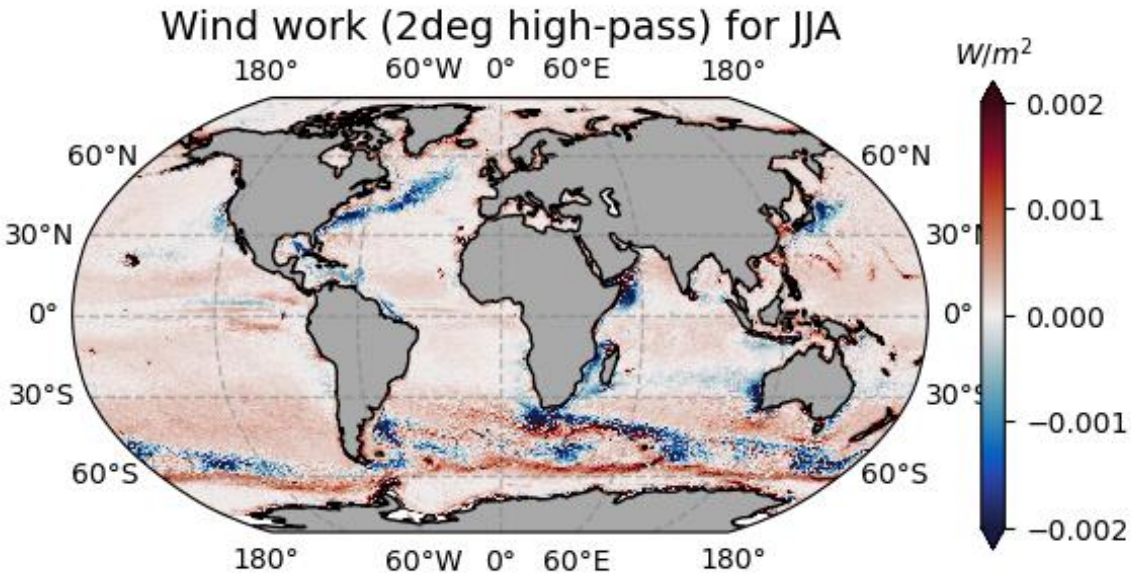




$$\text{Wind work} = (\vec{\tau} \cdot \vec{u}_o)$$

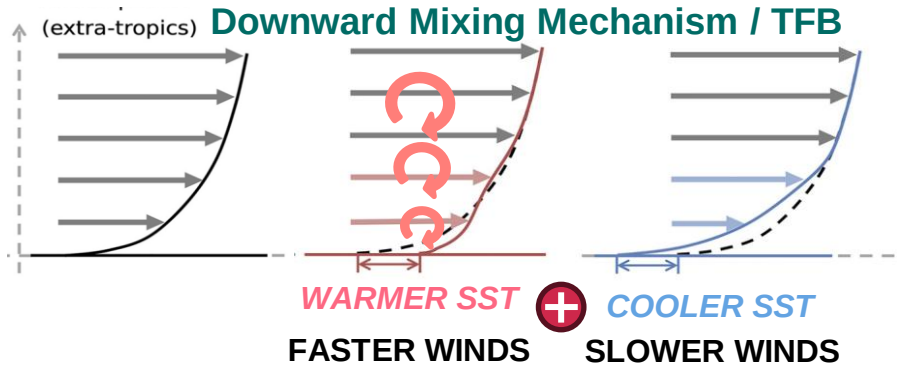
$$\zeta < 0$$

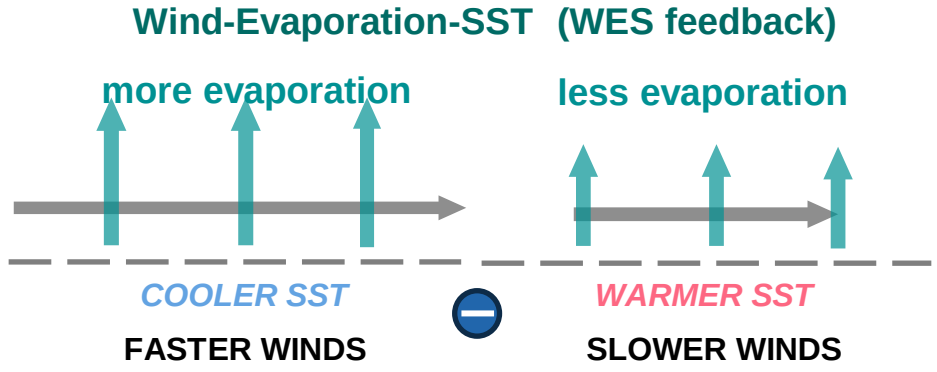
$$(\vec{\tau} \cdot \vec{u}_o) < 0$$



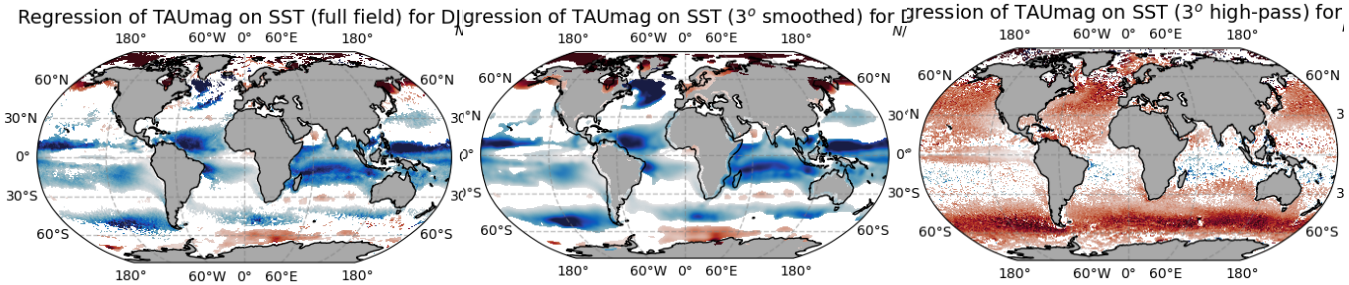
Summary:

Spatial scale dependency of dominant coupled processes produces different patterns of **air-sea coupling**





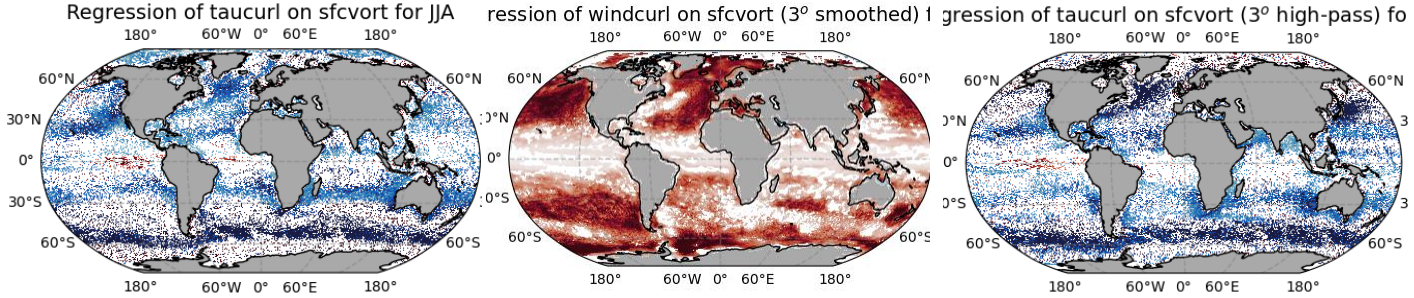
Thermal feedback: SST → wind speed / stress magnitude



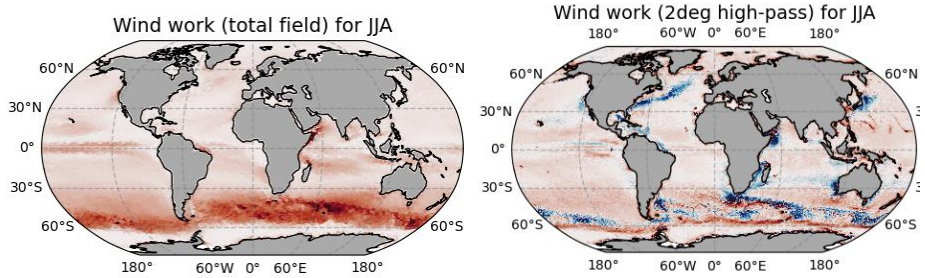
Mesoscale coupling → DMM / TFB ⊕

Large scale coupling → WES feedback ⊖

Current feedback (CFB): surface current **vorticity** → wind stress **curl**



Mesoscale CFB on **wind work ("eddy killing")**



Further thoughts: online spatial filter in YAC

~~~THANK YOU!!! ~~~

Allow for **choosing the spatial scales of air-sea coupling, be it globally or regionally**. Ability to choose at which spatial scales the atmosphere sees the ocean or vice versa, and if this has an effect on the climate system.

Sample scientific questions:

1) What implications do the spatial scale dependency of air-sea coupling have on air-sea feedback, mean state, eddy statistics, storm tracks, climate variability?
2) Is mesoscale air-sea coupling in particular regions critical for damping or amplifying heat uptake and transport?
3) What about remote impact of regional air-sea coupling (effect on teleconnections)?

External motivations:

- Global online spatial filter has not been done on GCMs!
- Several scientists have expressed interest in having an online spatial filter in ICON.