EERIE Science Hour: Mesoscale air-sea coupling (Eulerian and Lagrangian perspectives)

Presenters: Dian Putrasahan (MPIM), Malcolm Roberts (UK MetOffice)
Hosted by WP5 leads: Niki Gruber (ETH) and Dian Putrasahan
January 25, 2024

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Funded by the European Union

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Overarching theme

EERIE's main scientific goal is addressing the role of ocean mesoscale eddies on the climate system. In this science hour, we would like to generate discussions following the overall theme:

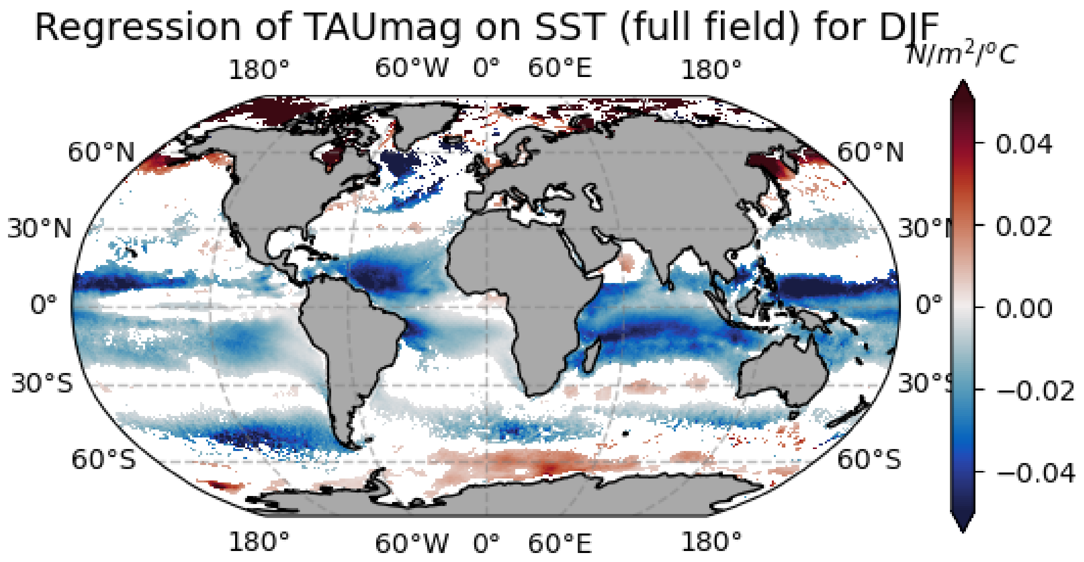
1) How well do models represent the ocean mesoscales?
2) How can we quantify mesoscale eddy impact on the ocean, atmosphere, sea-ice and coupling?
3) What processes are associated with the ocean mesoscale that differ from the large-scale?
4) How do we extract the impact of mesoscales?

- Focus on the representation of mesoscale eddies in models and their impact on local air-sea coupling.

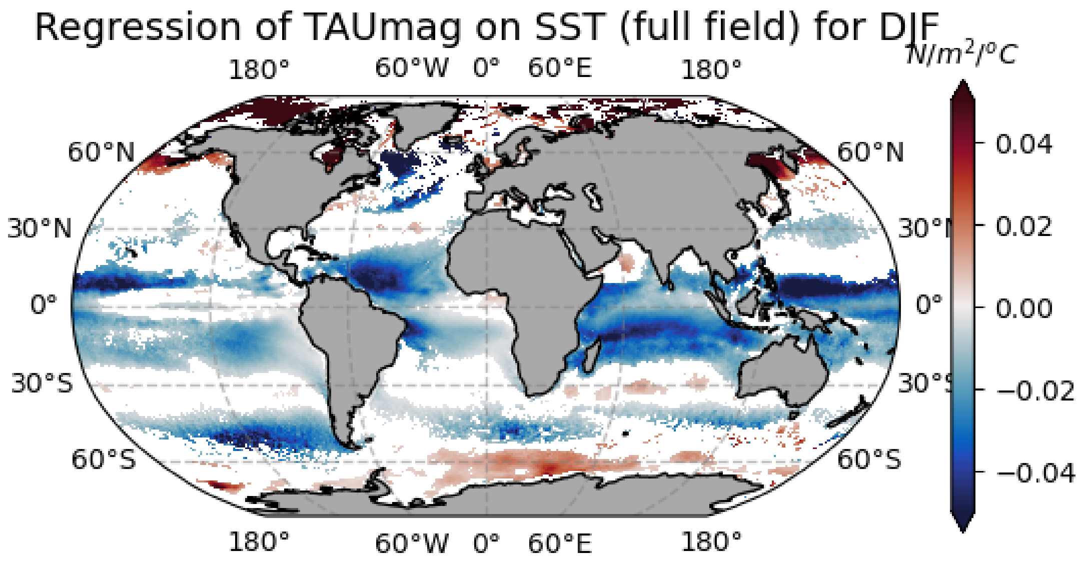
01

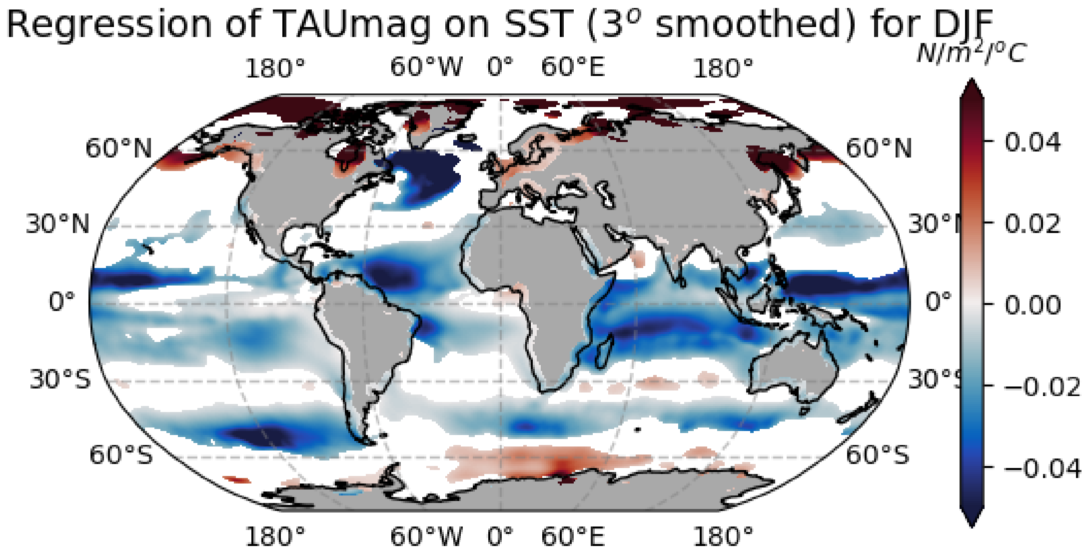
Eulerian view

Scale dependency of SST & windstress coupling

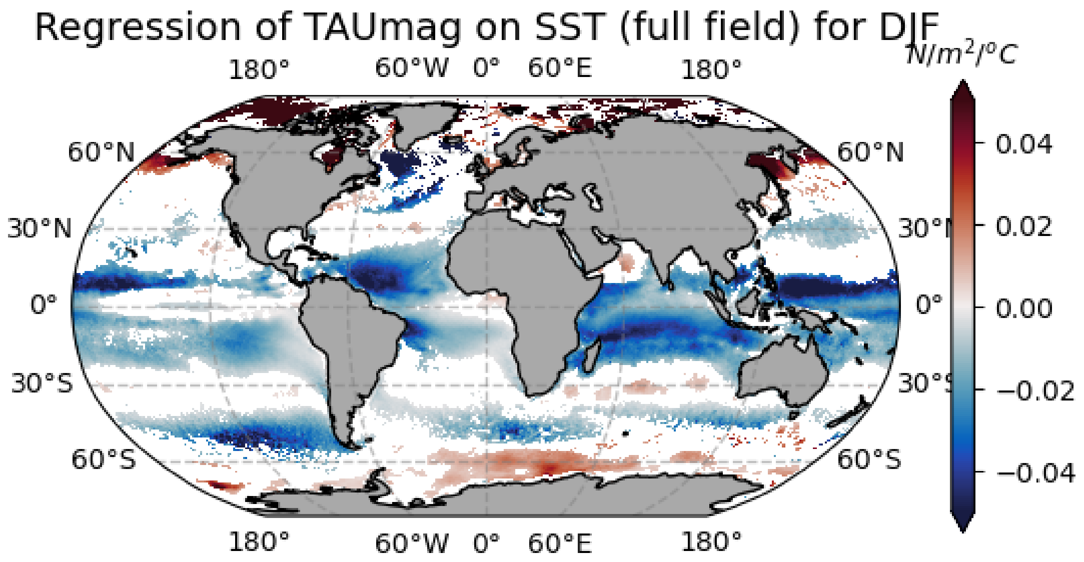


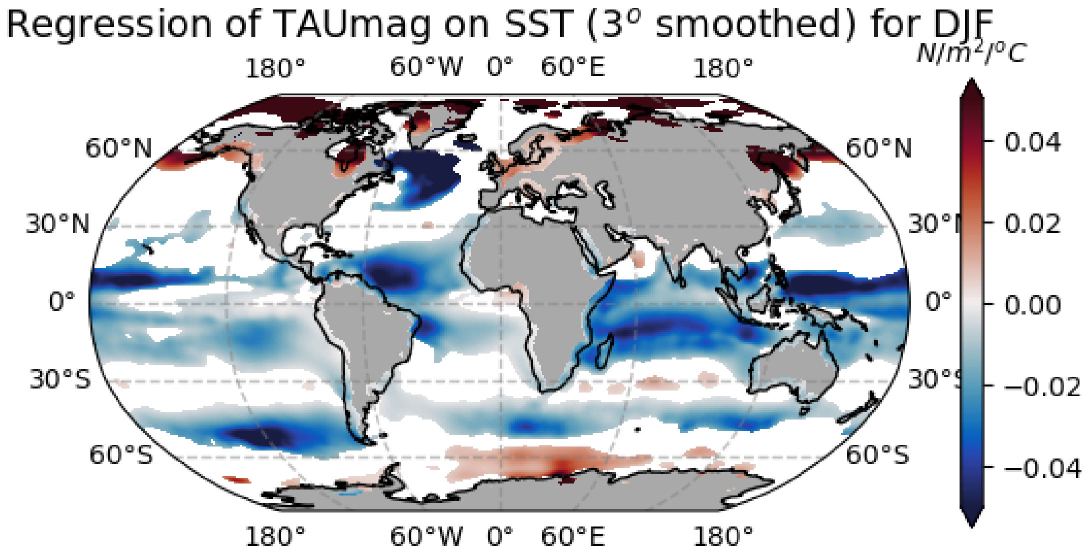
Scale dependency of SST & windstress coupling

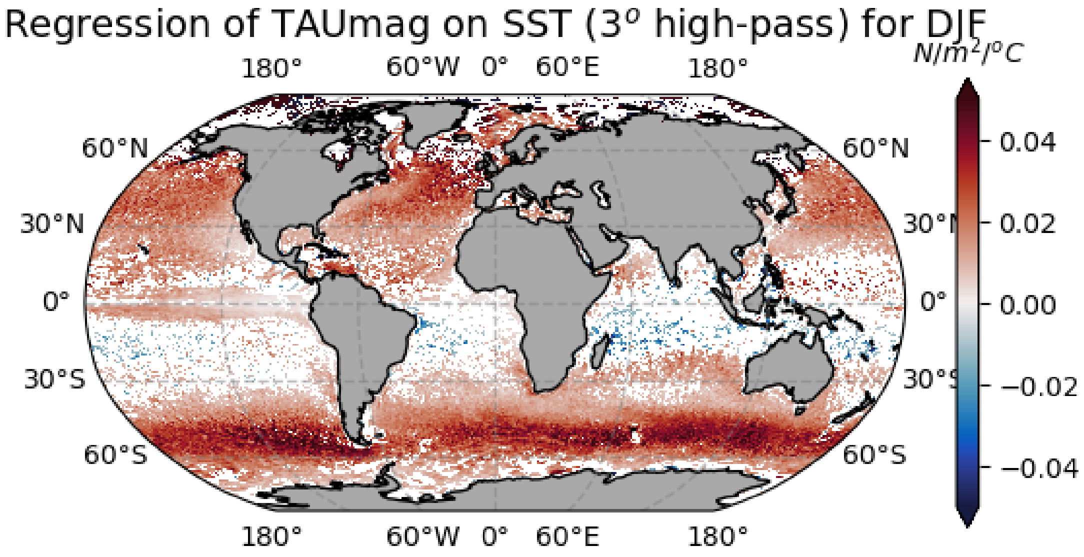




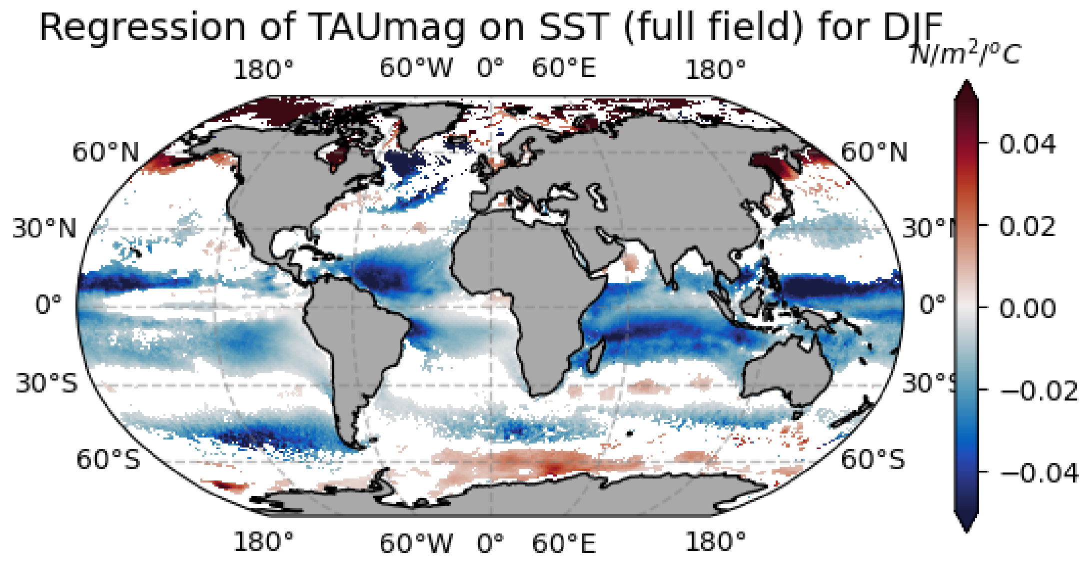
Scale dependency of SST & windstress coupling





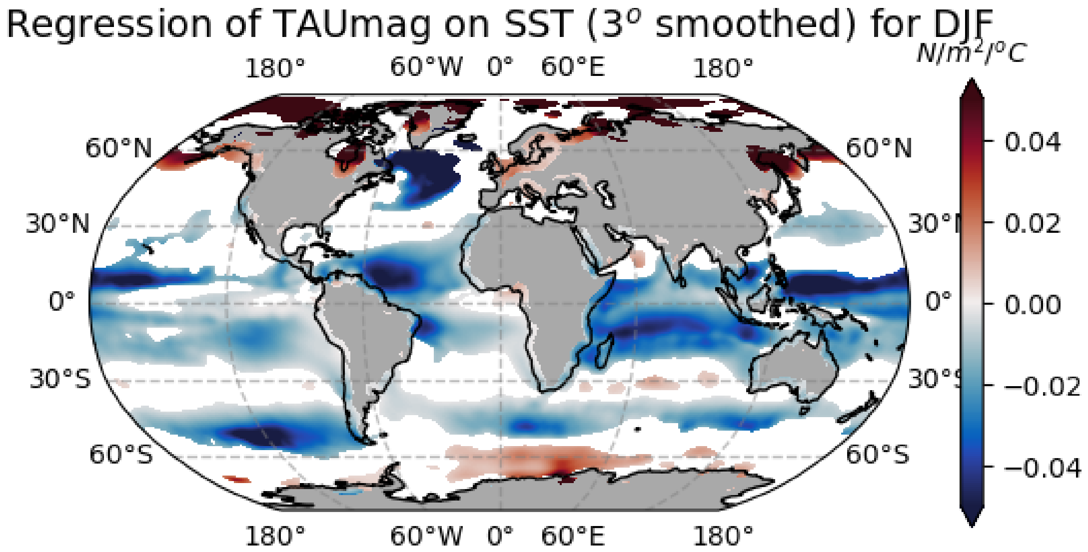


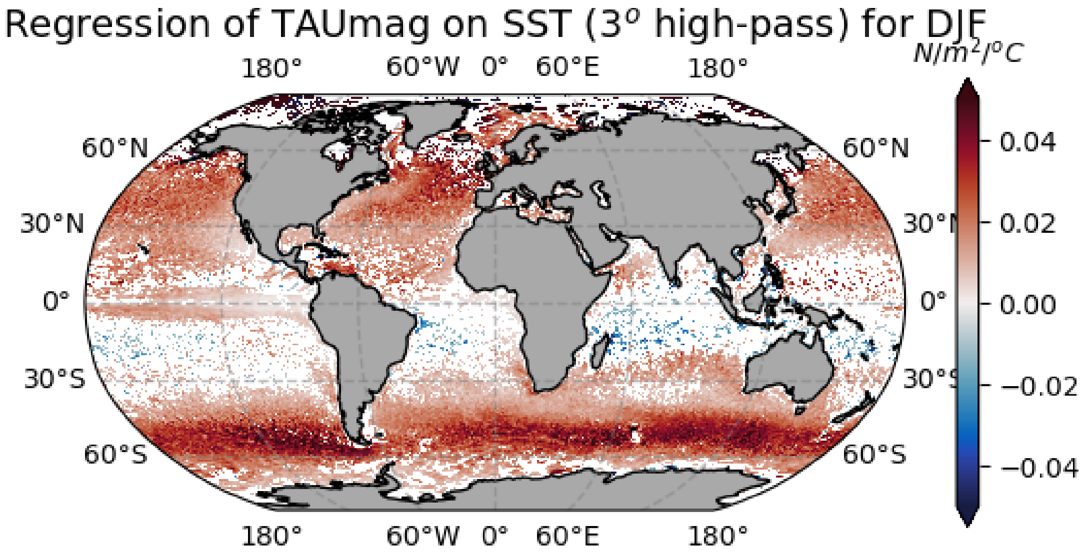
Scale dependency of SST & windstress coupling



What resolved mesoscale processes vs large-scale 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)





Thermal feedback (TFB) and Current feedback (CFB)

Table 1
Coupling Coefficients

Coefficient	Description
s_τ	Surface current vorticity and surface stress curl
s_w	Surface current vorticity and wind curl
s_{Cstr}	Cross-wind SST and surface stress curl
s_{Cu}	Cross-wind SST and 10-m wind curl
s_{Dstr}	Down-wind SST and surface stress divergence
s_{Du}	Down-wind SST and 10-m wind divergence
s_{str}	SST and surface stress magnitude
s_u	SST and 10-m wind magnitude

(Renault et al., 2016)

CFB

“bottom-up” effect: surface currents directly affect stress and wind

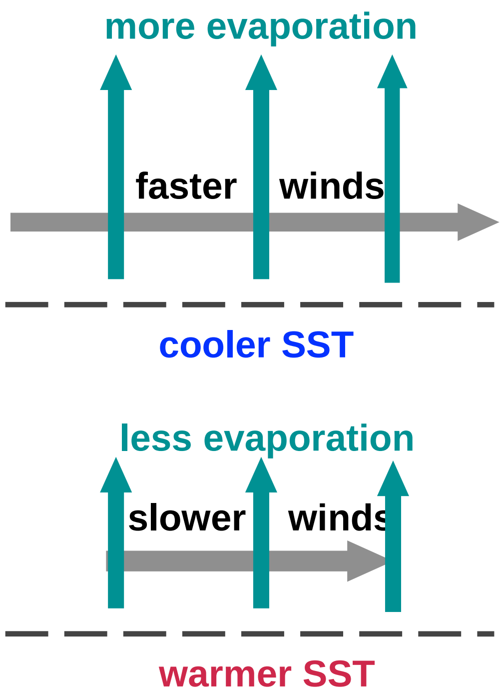
TFB

"top-down" effect: impact of SST and/or SST gradients on ABL turbulence and surface wind and stress (vertical mixing mechanism)

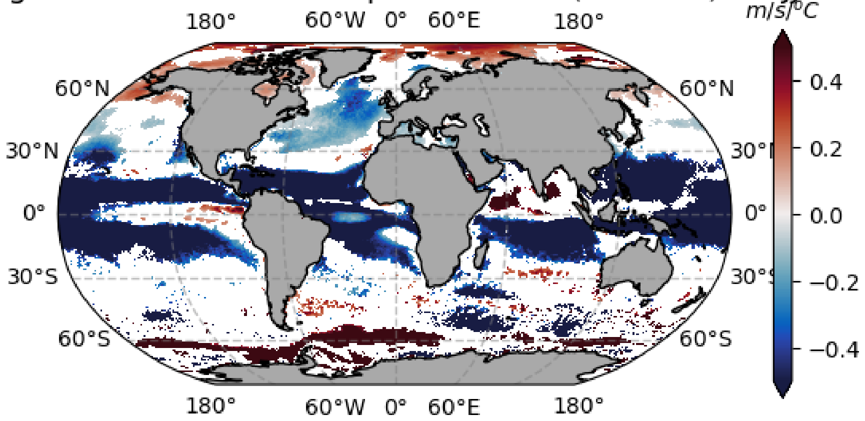
Thermal feedback (TFB)

SST and 10m wind speed

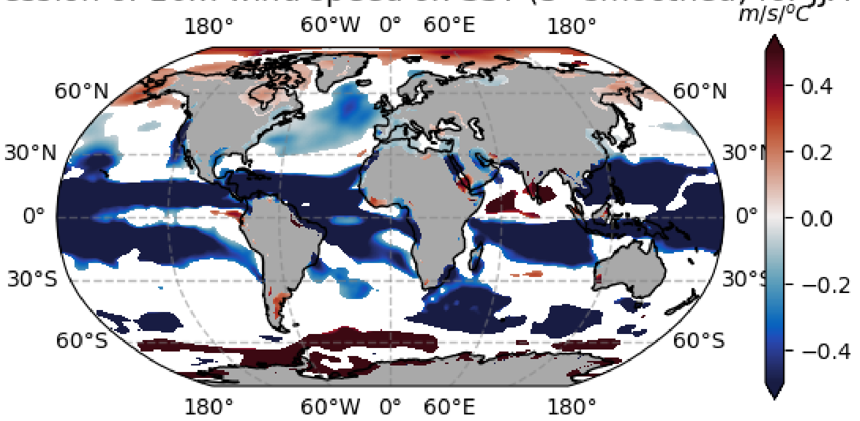
Wind-Evaporation-SST (WES feedback)



Regression of 10m wind speed on SST (full field) for JJA



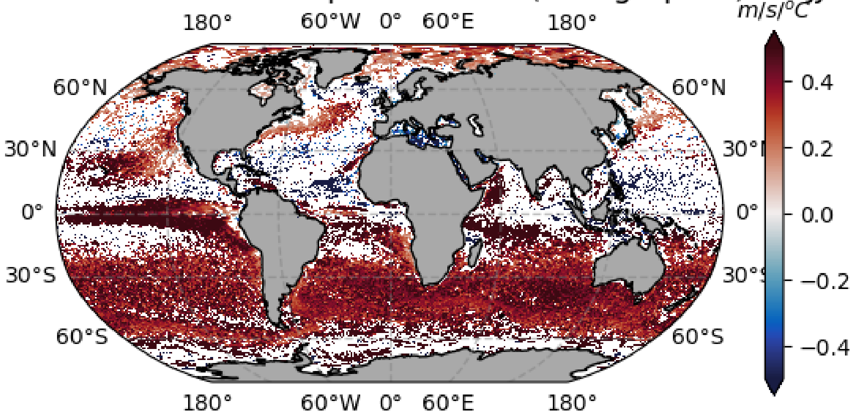
Regression of 10m wind speed on SST (3^o smoothed) for JJA



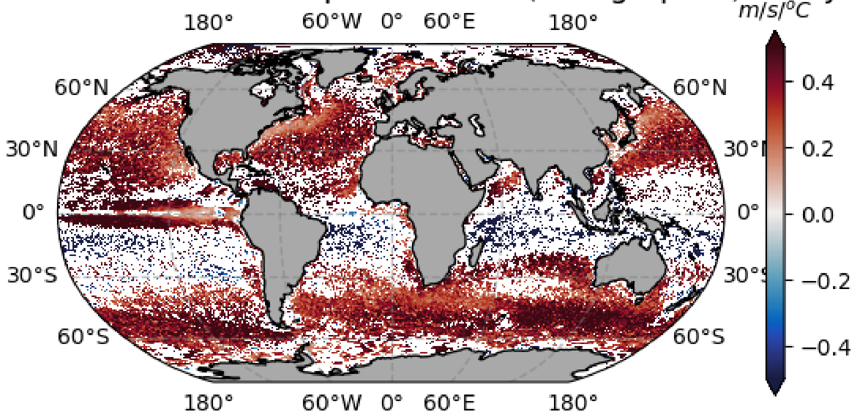
Thermal feedback (TFB)

SST and 10m wind speed

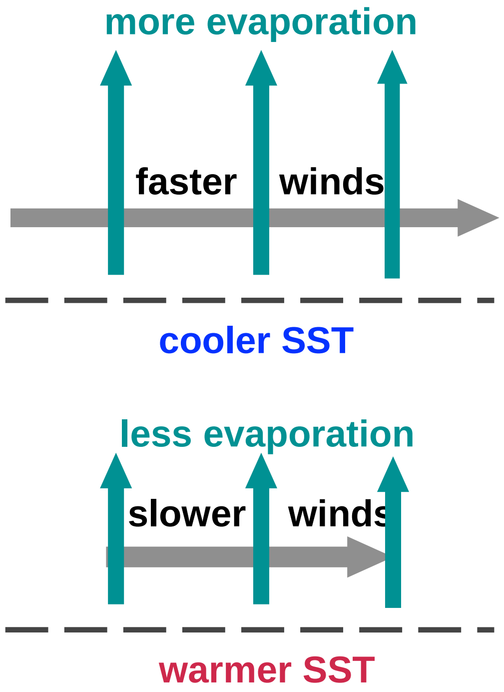
Regression of 10m wind speed on SST (3^o high-pass) for JJA



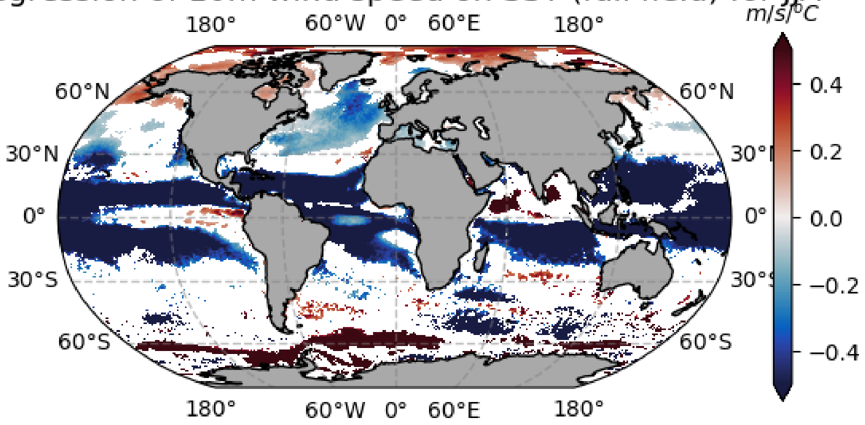
Regression of 10m wind speed on SST (3^o high-pass) for DJF



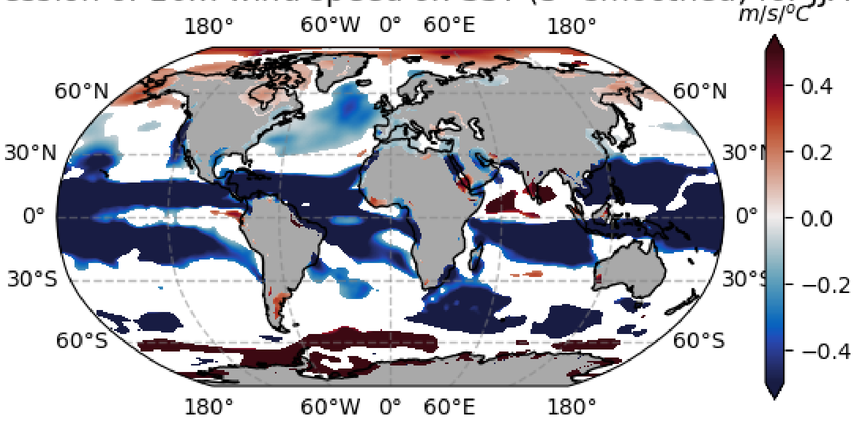
Wind-Evaporation-SST (WES feedback)



Regression of 10m wind speed on SST (full field) for JJA

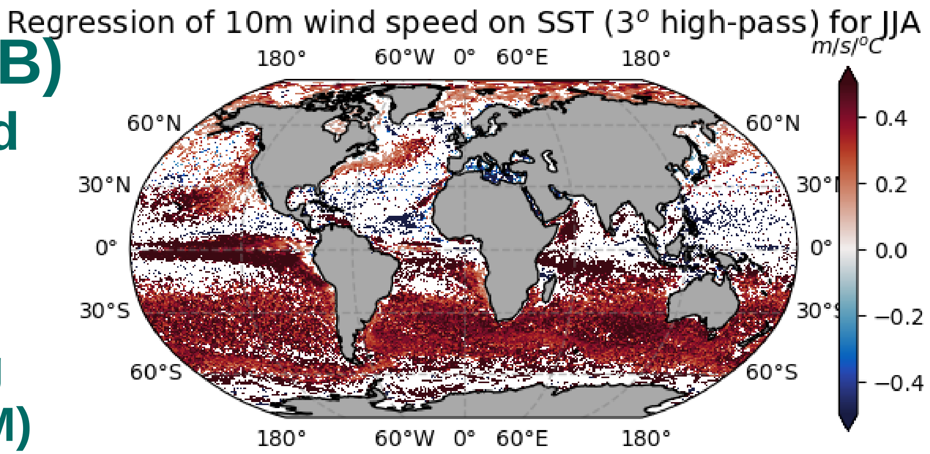


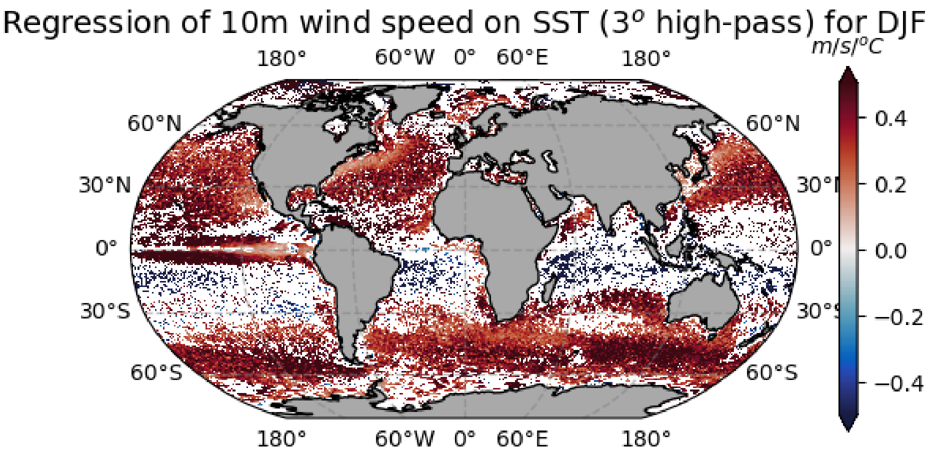
Regression of 10m wind speed on SST (3^o smoothed) for JJA



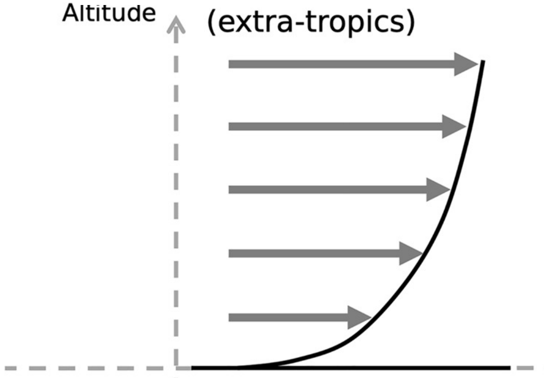
Thermal feedback (TFB)

SST and 10m wind speed

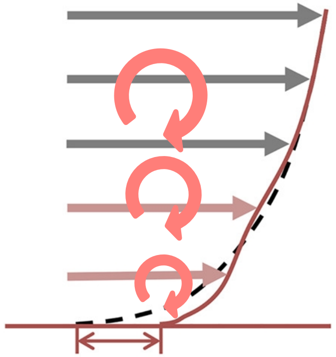




Vertical Mixing Mechanism (VMM)

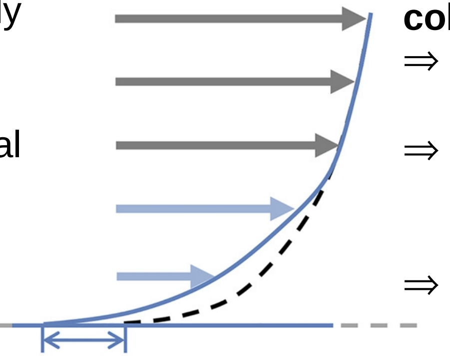


Modified from Pasquero et al., 2021



Warm SST anomaly

warm SST anomaly
⇒ destabilize atmosphere
⇒ enhance vertical transfer of momentum
⇒ **increased surface winds**



Cold SST anomaly

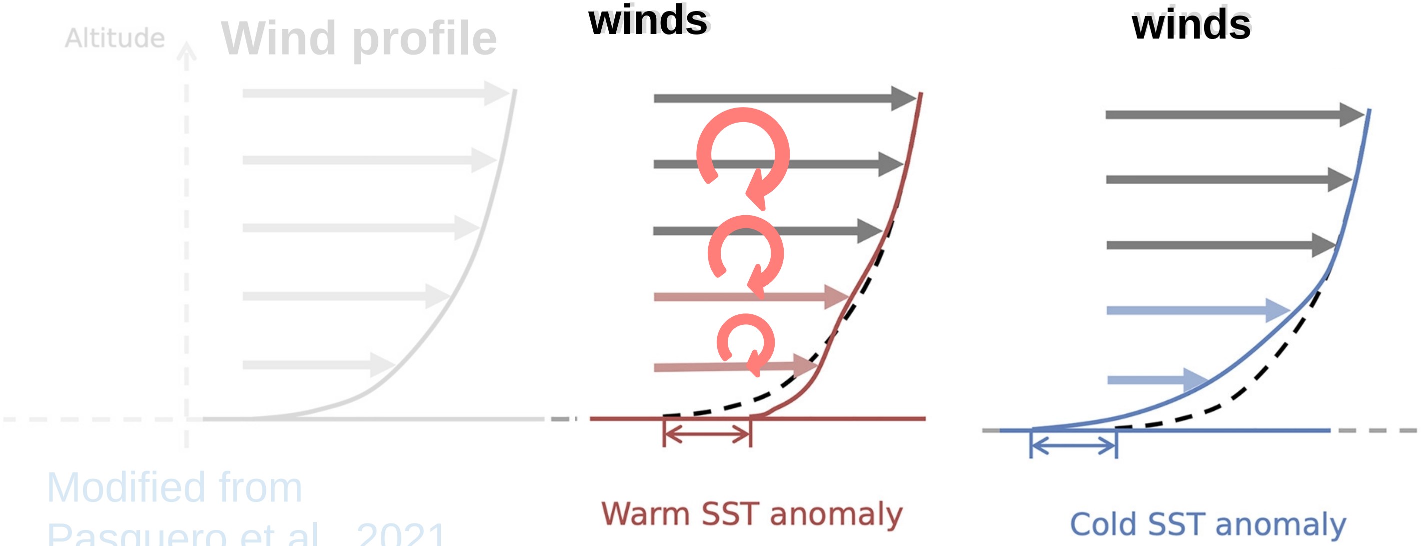
cold SST anomaly
⇒ stabilize atmosphere
⇒ inhibit vertical transfer of momentum
⇒ **reduced surface winds**

Wind-Evaporation-SST (WES feedback)

TFB via Vertical mixing mechanism (VMM)

warm SST anomaly
⇒ destabilize atmosphere
⇒ enhance vertical transfer of momentum
⇒ **increased surface winds**

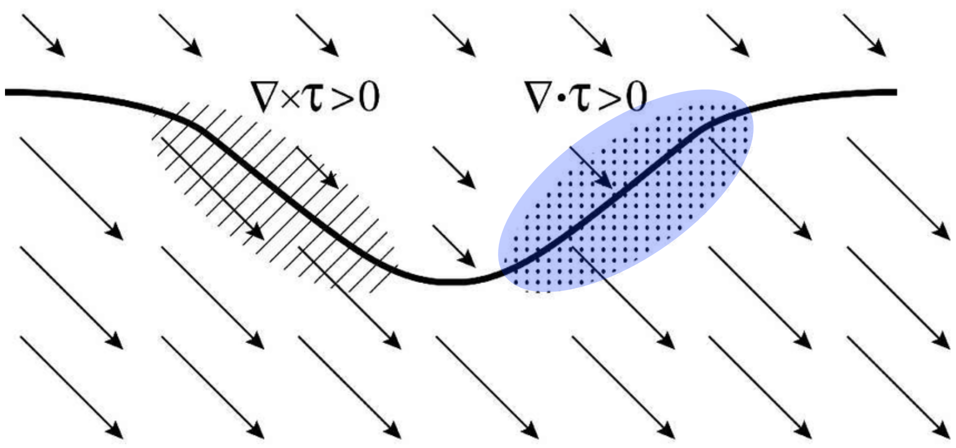
cold SST anomaly
⇒ stabilize atmosphere
⇒ inhibit vertical transfer of momentum
⇒ **reduced surface winds**



Modified from Pasquero et al., 2021

Winds blowing over **cold to warm SST** anomaly will produce anomalous **surface divergence**

COOL



(Chelton et al., 2001) WARM

TFB via Vertical mixing mechanism (VMM)

warm SST anomaly
⇒ destabilize atmosphere
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cold SST anomaly
⇒ stabilize atmosphere
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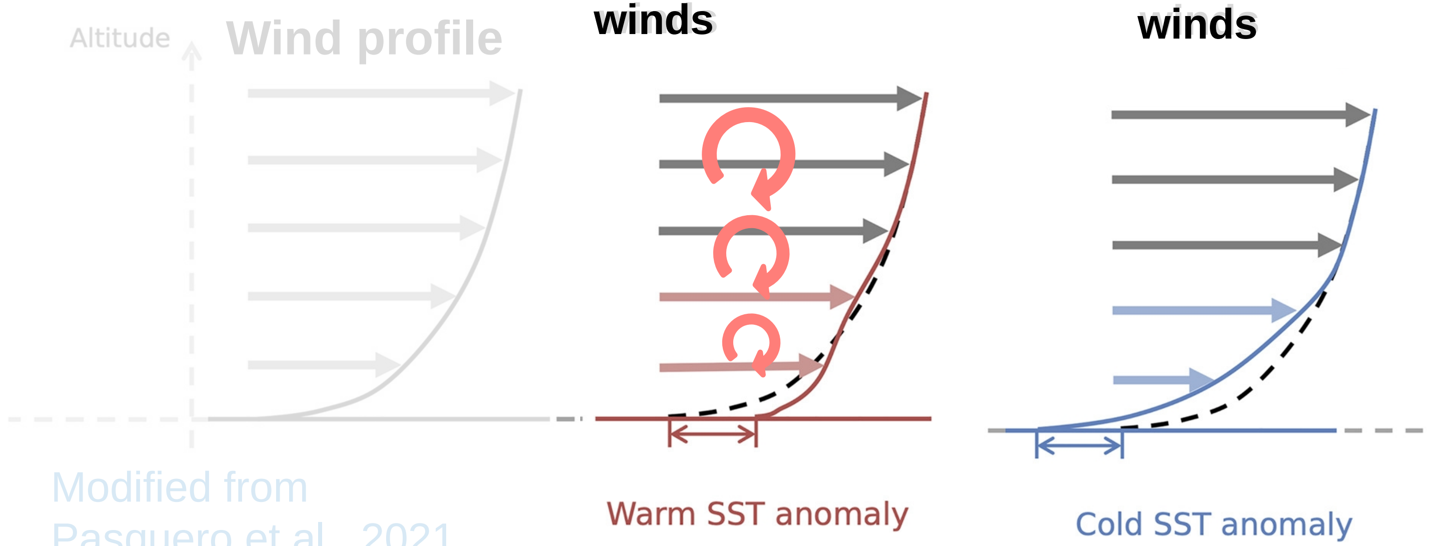
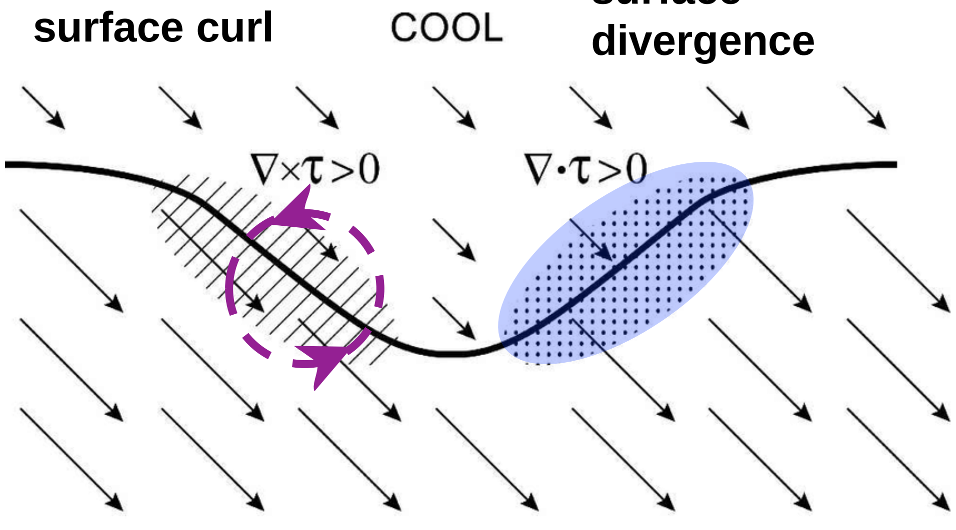


Modified from Pasquero et al., 2021

Winds blowing along **SST isotherm** anomaly will produce anomalous **surface curl**

Winds blowing over **cold to warm SST** anomaly will produce anomalous **surface divergence**



(Chelton et al., 2001)

TFB via Vertical mixing mechanism (VMM)

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⇒ stabilize atmosphere
⇒ inhibit vertical transfer of momentum
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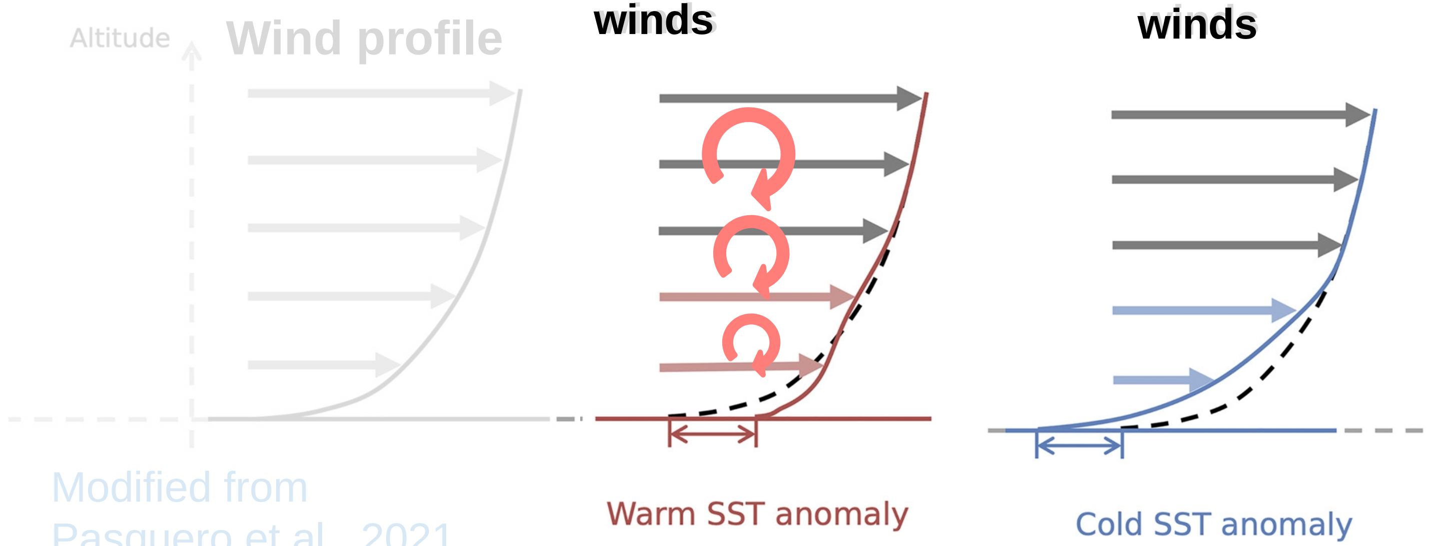

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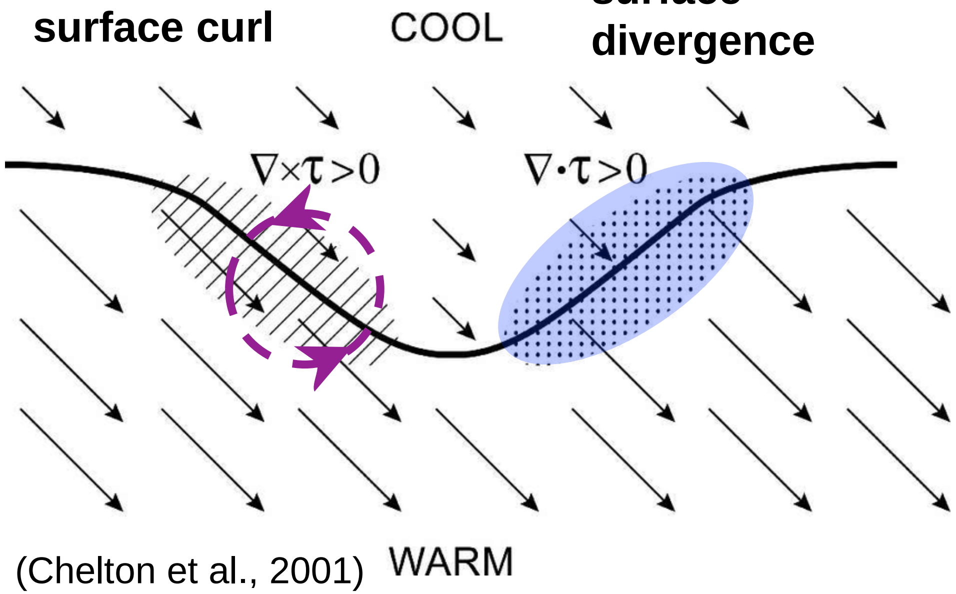
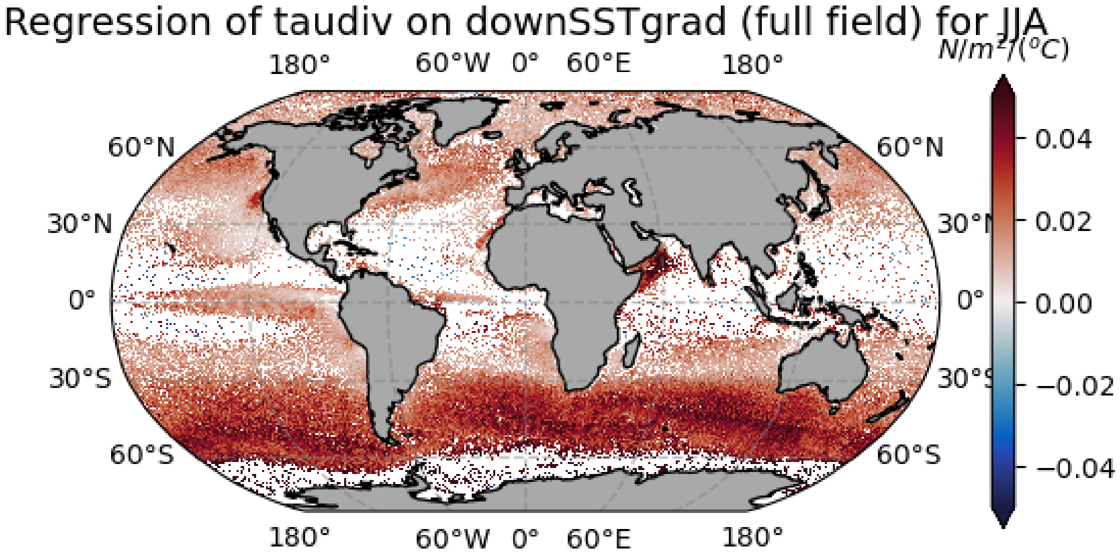
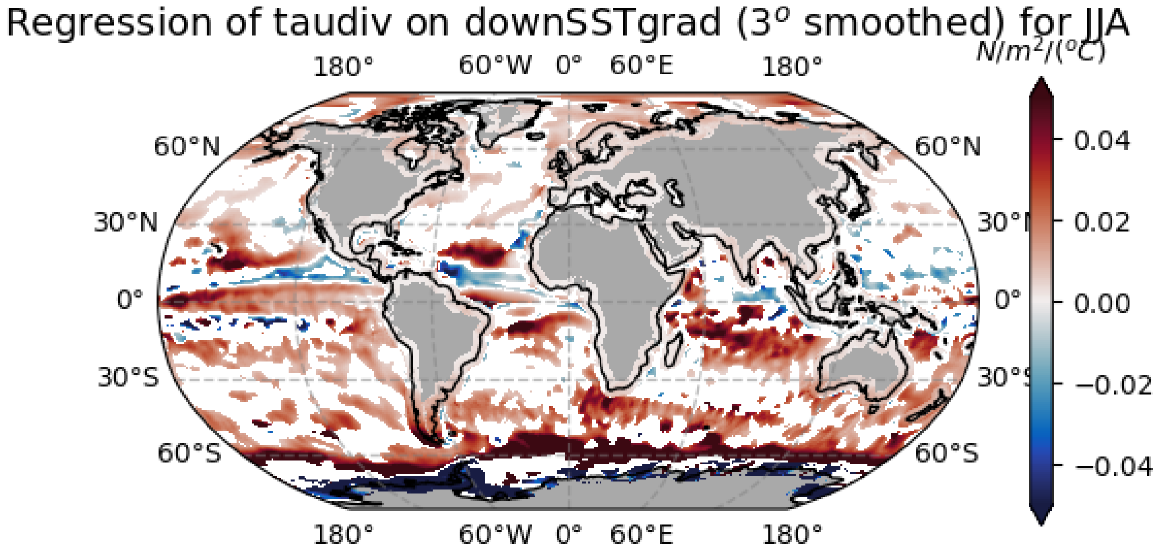


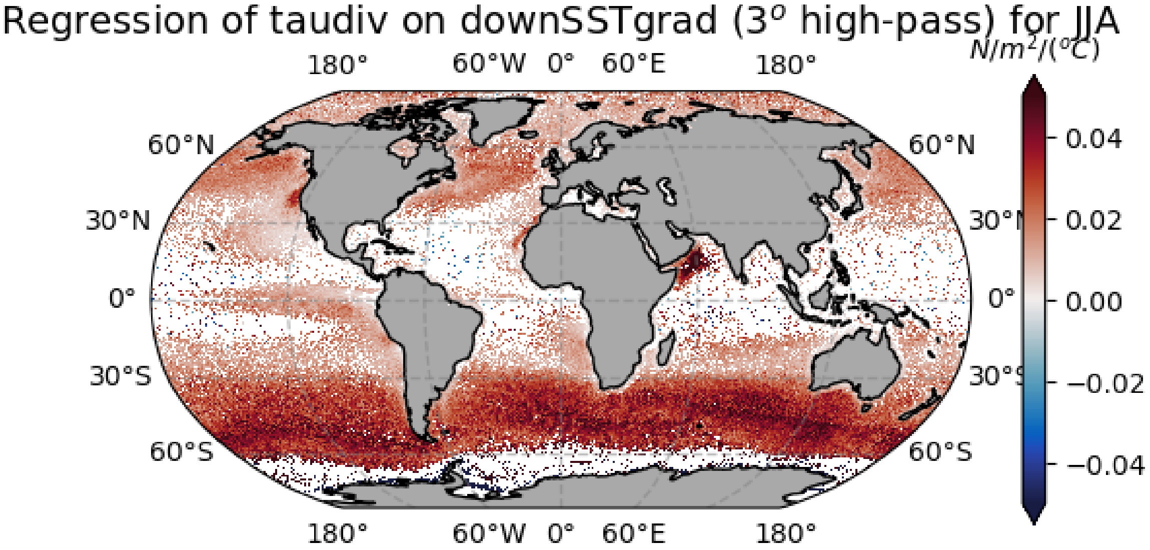
(Chelton et al., 2001)

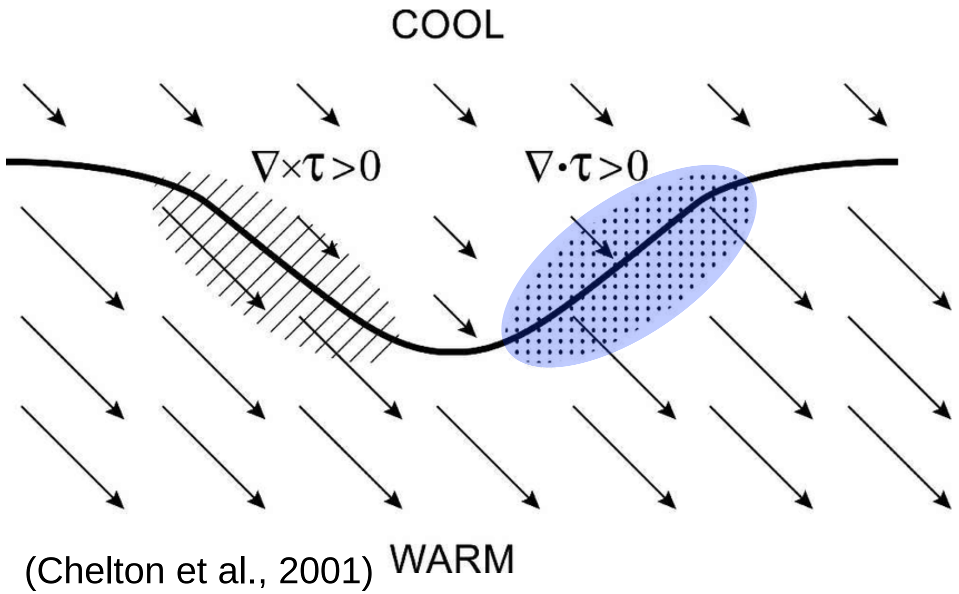
Thermal feedback estimated using:
SST □ wind speed / stress magnitude
downwind SST gradients □ wind/stress **divergence**
crosswind SST gradients □ wind/stress **curl**

TFB: downwind SST gradient and wind stress divergence



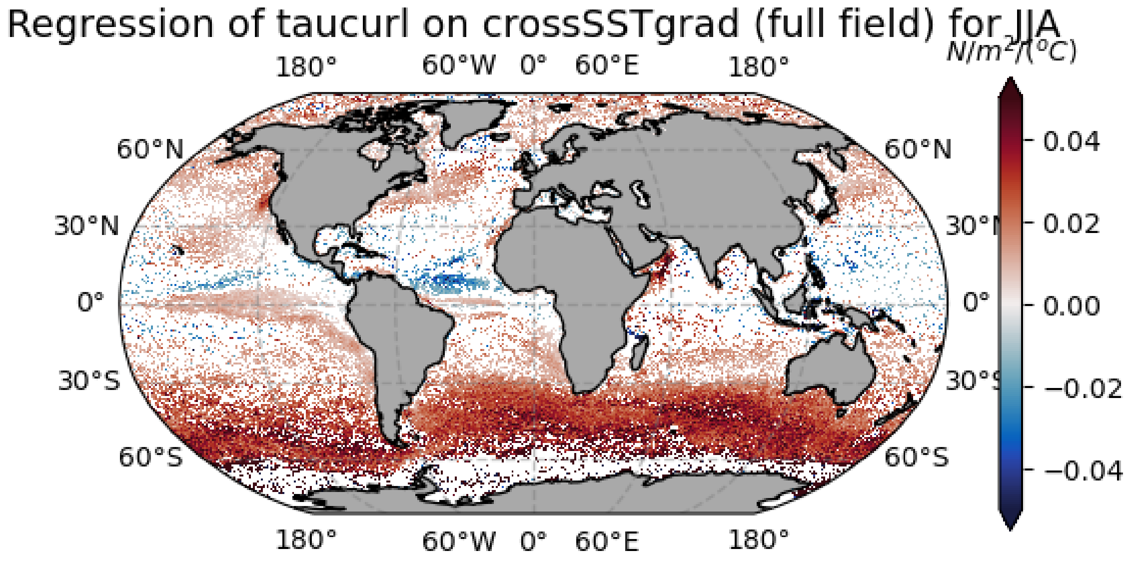


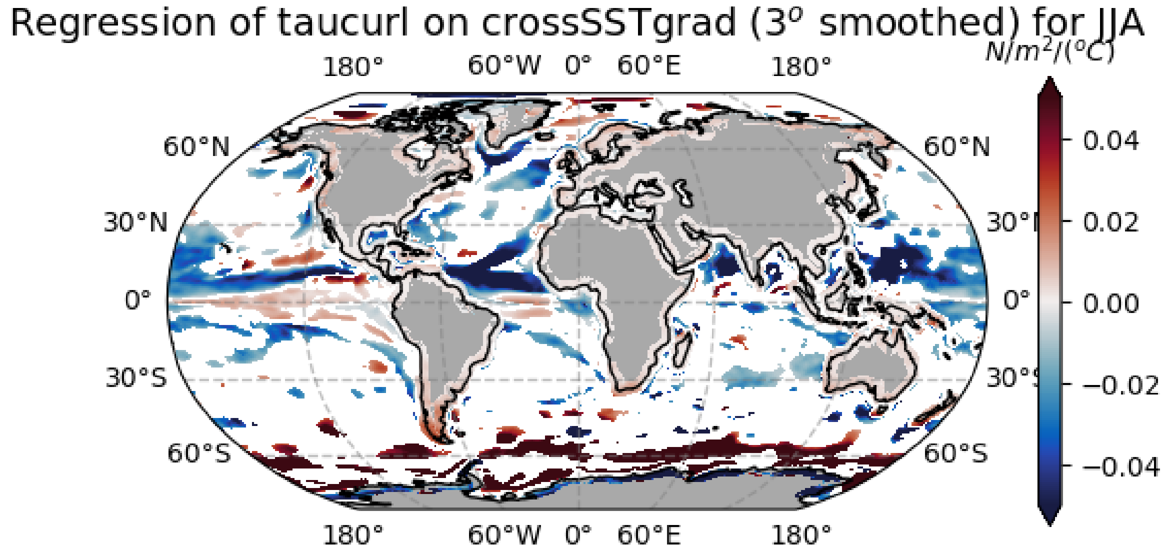


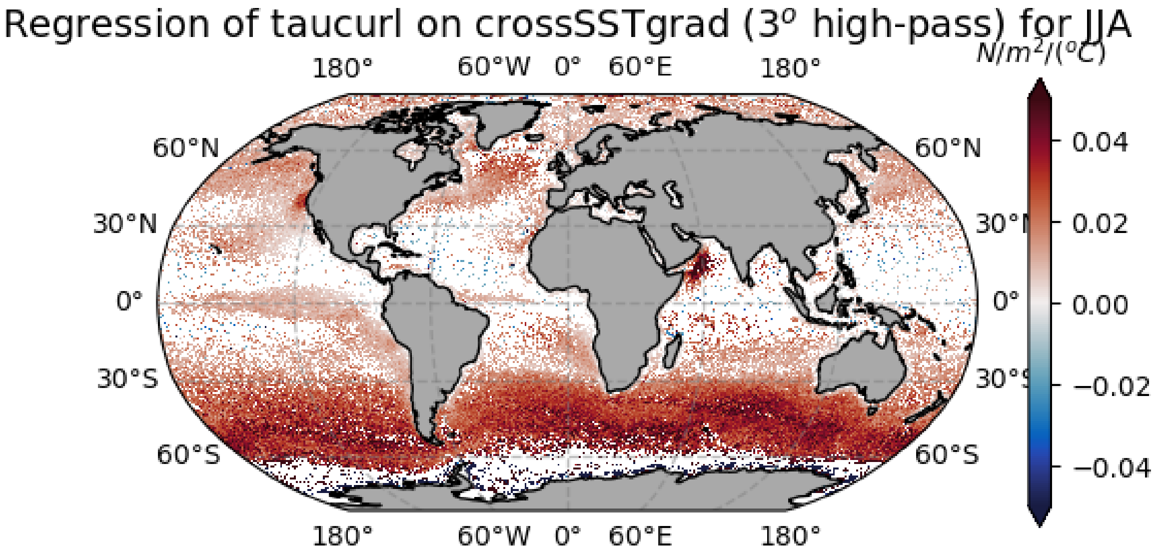


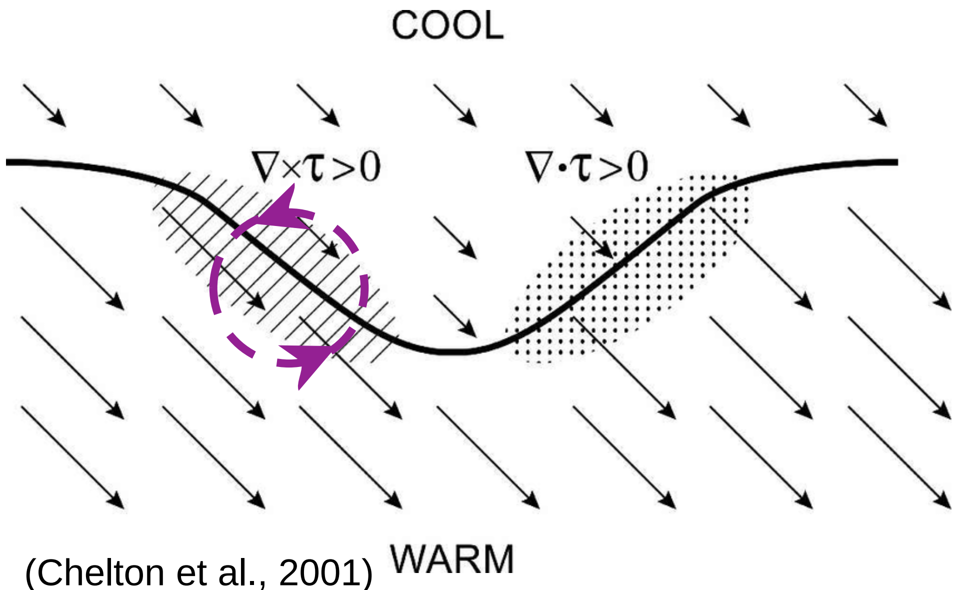
(Chelton et al., 2001)

TFB: crosswind SST gradient and wind stress curl









(Chelton et al., 2001)

Current feedback (CFB)

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Coupling Coefficients

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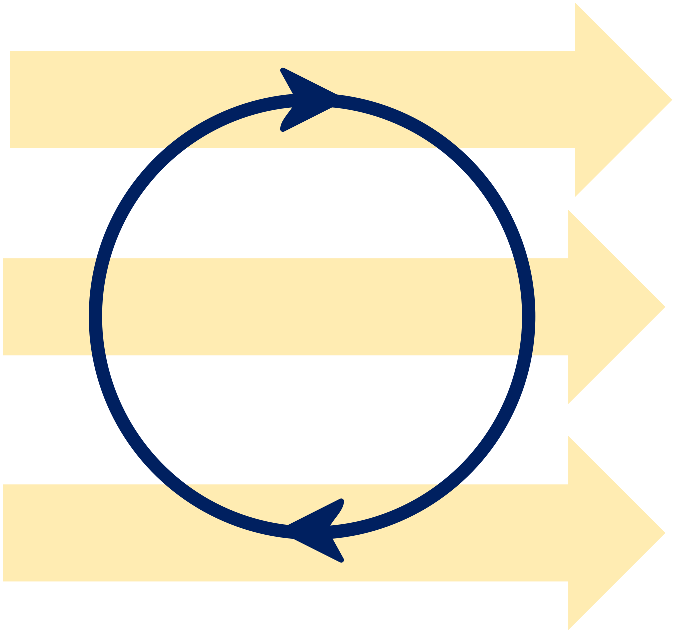
(Renault et al., 2016)

CFB

"bottom-up" effect: surface currents directly affect stress and wind

CFB on stress curl vs wind curl

$\zeta < 0$

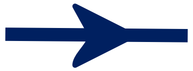


No current feedback

Current feedback on stress

Current feedback on wind

Background
wind velocity

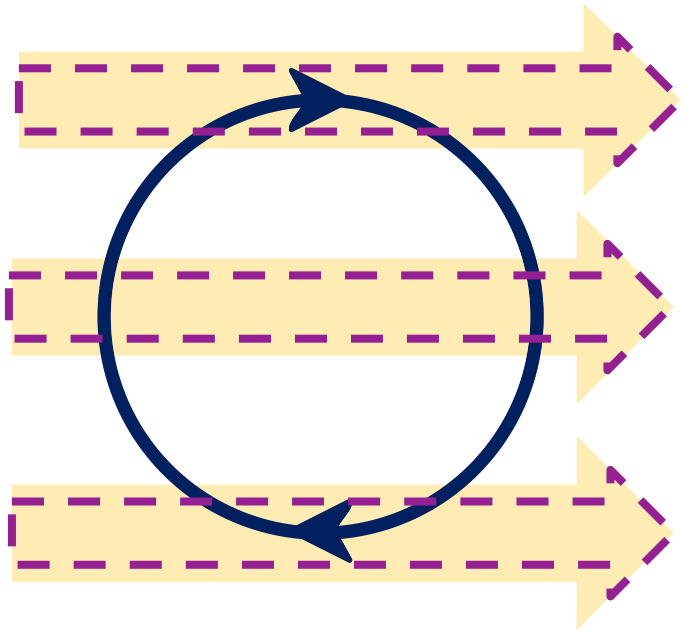


surface current

CFB on stress curl vs wind curl

$$\zeta < 0$$

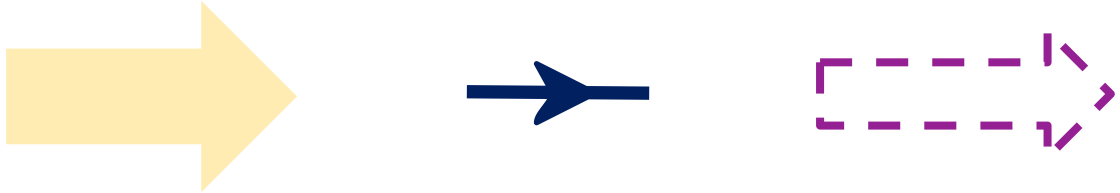
$$(\nabla \times \vec{\tau}) = 0$$



No current feedback

Current feedback on stress

Current feedback on wind



Background wind velocity

surface current

wind stress

CFB on stress curl vs wind curl

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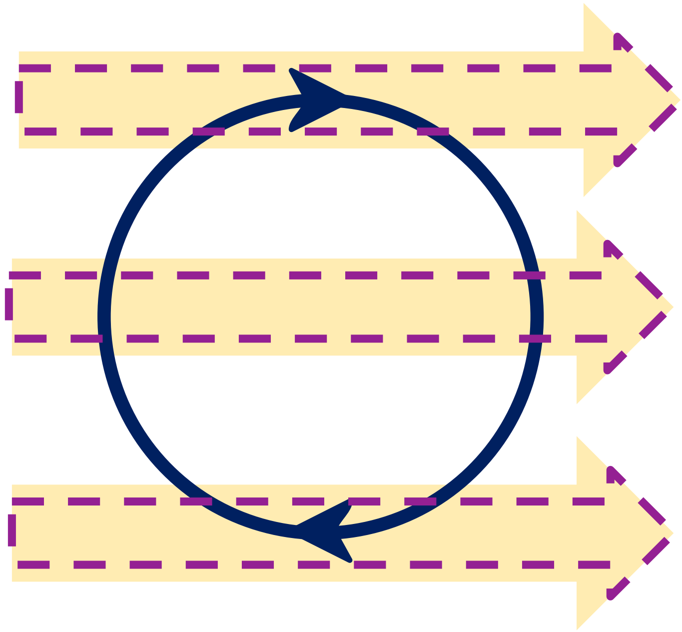
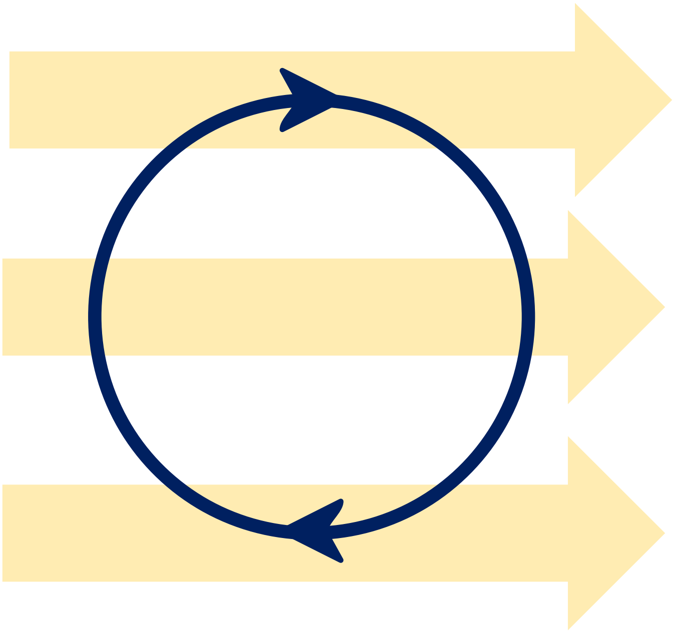


No current feedback

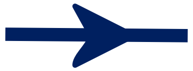
$\zeta < 0$



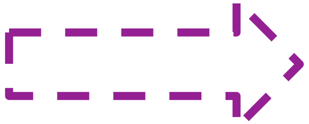
Current feedback on stress

Current feedback on wind

Background wind velocity

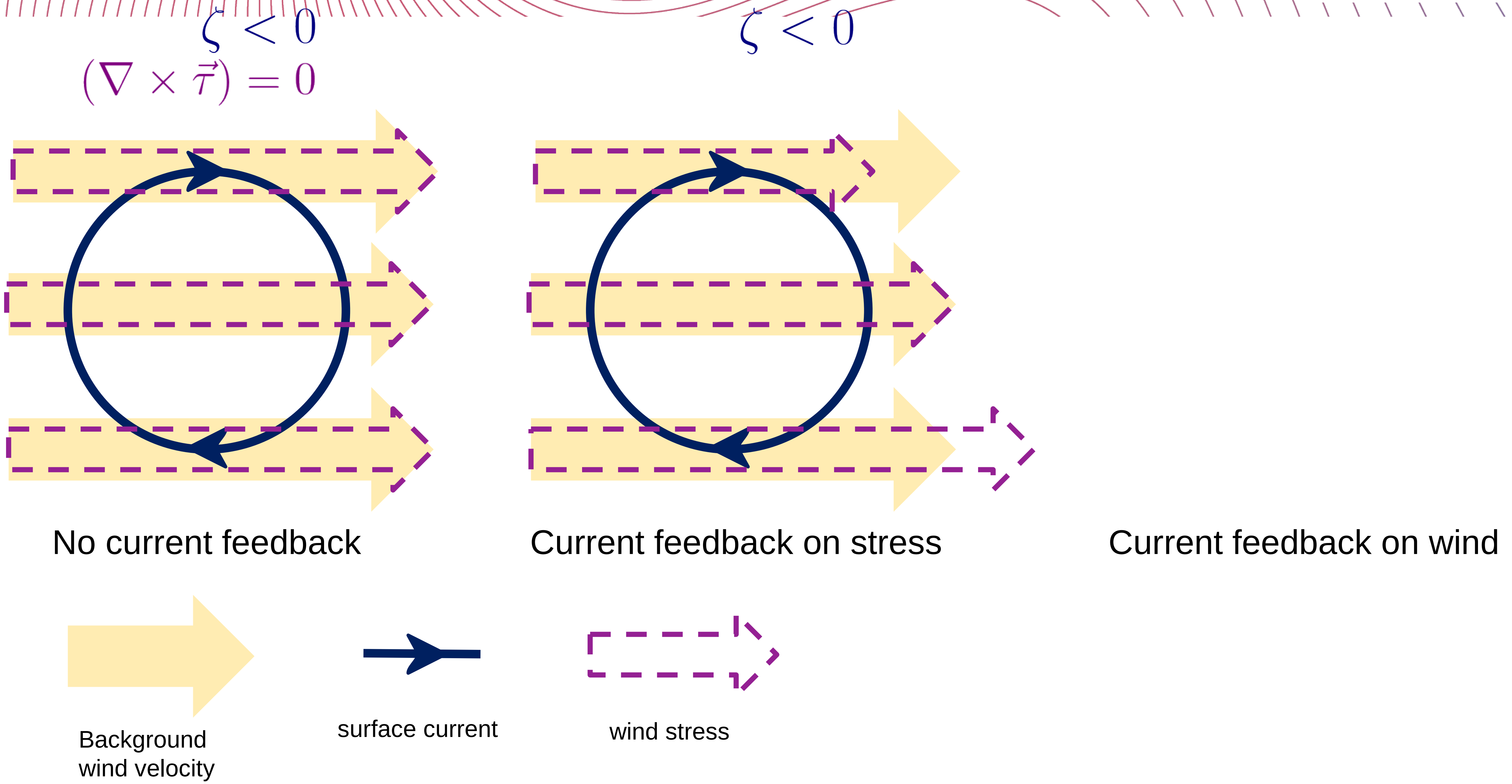


surface current



wind stress

CFB on stress curl vs wind curl



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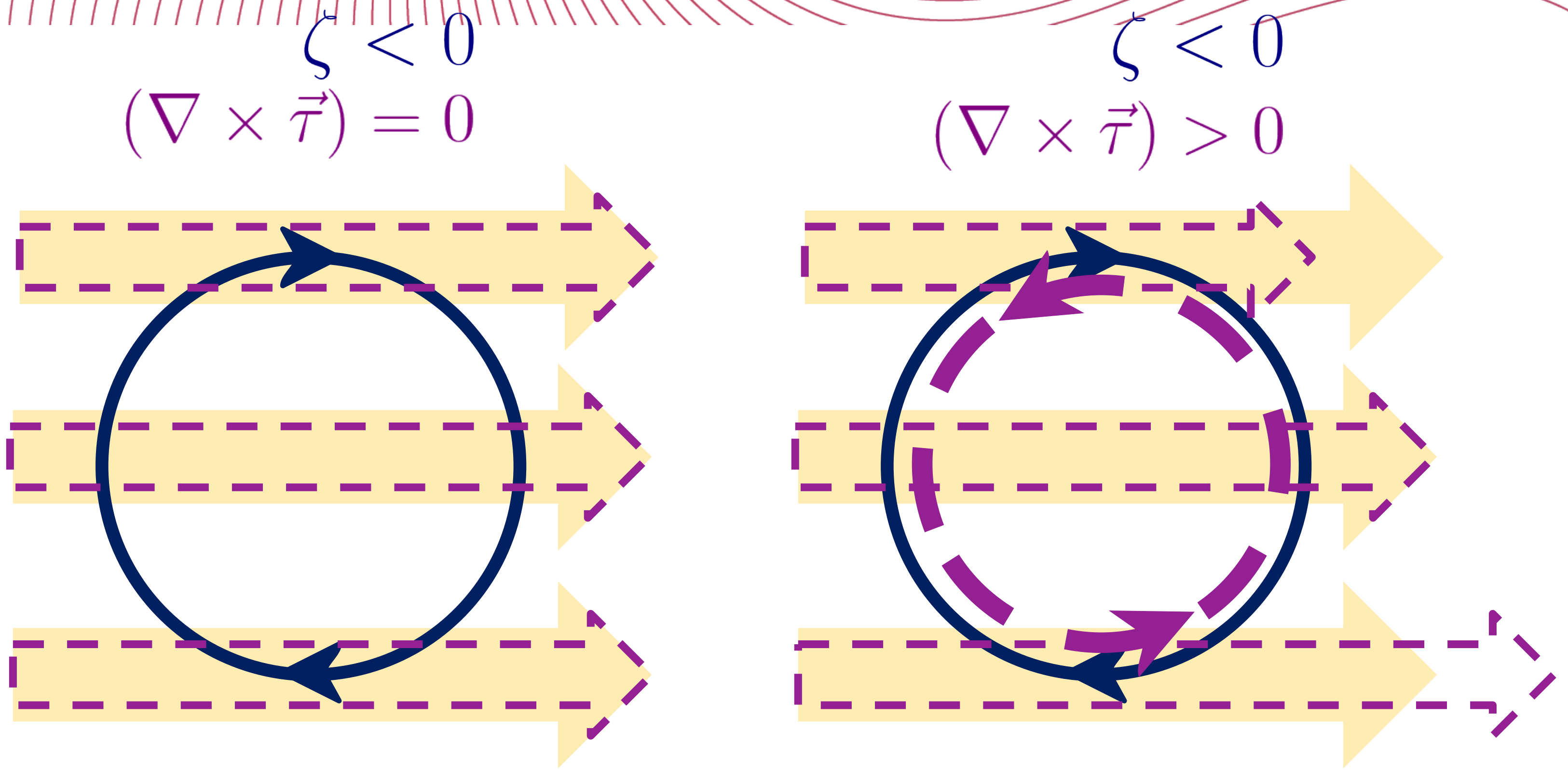
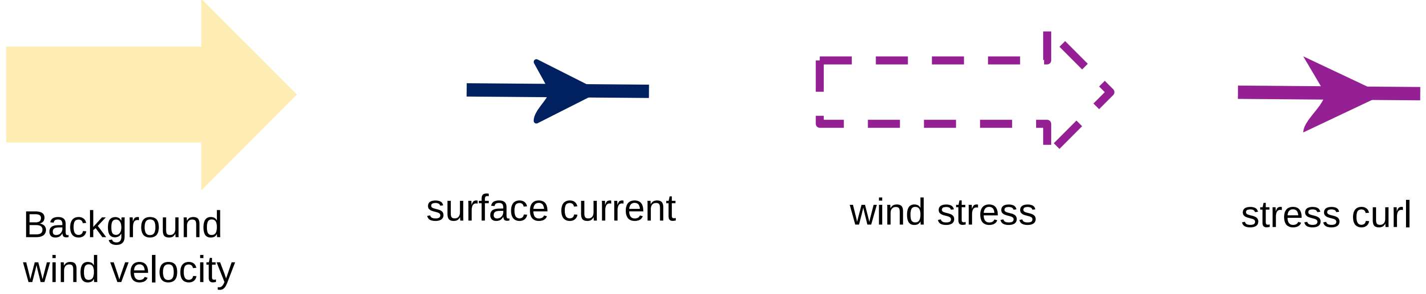
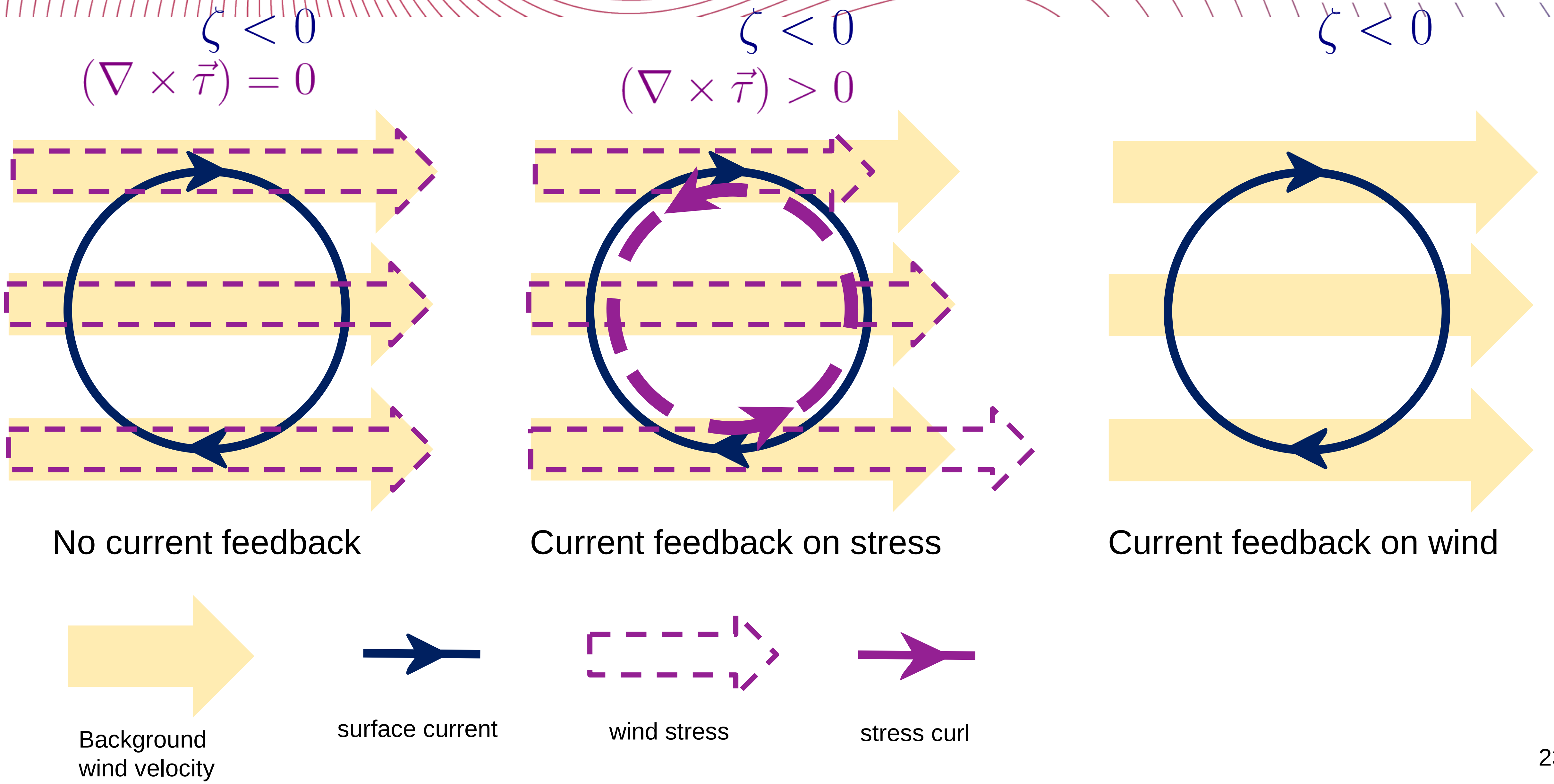


No current feedback | Current feedback on stress | Current feedback on wind



CFB on stress curl vs wind curl



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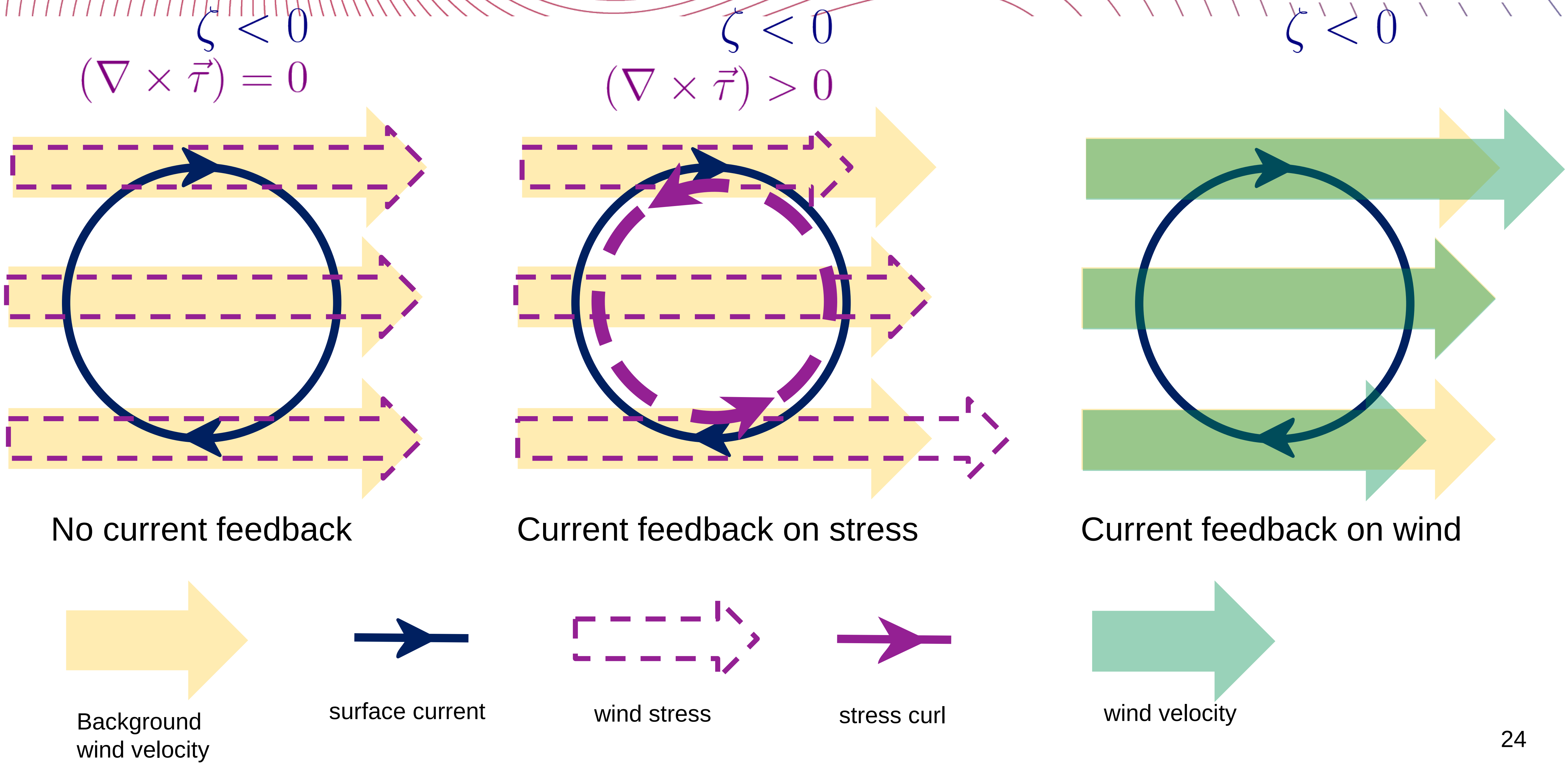

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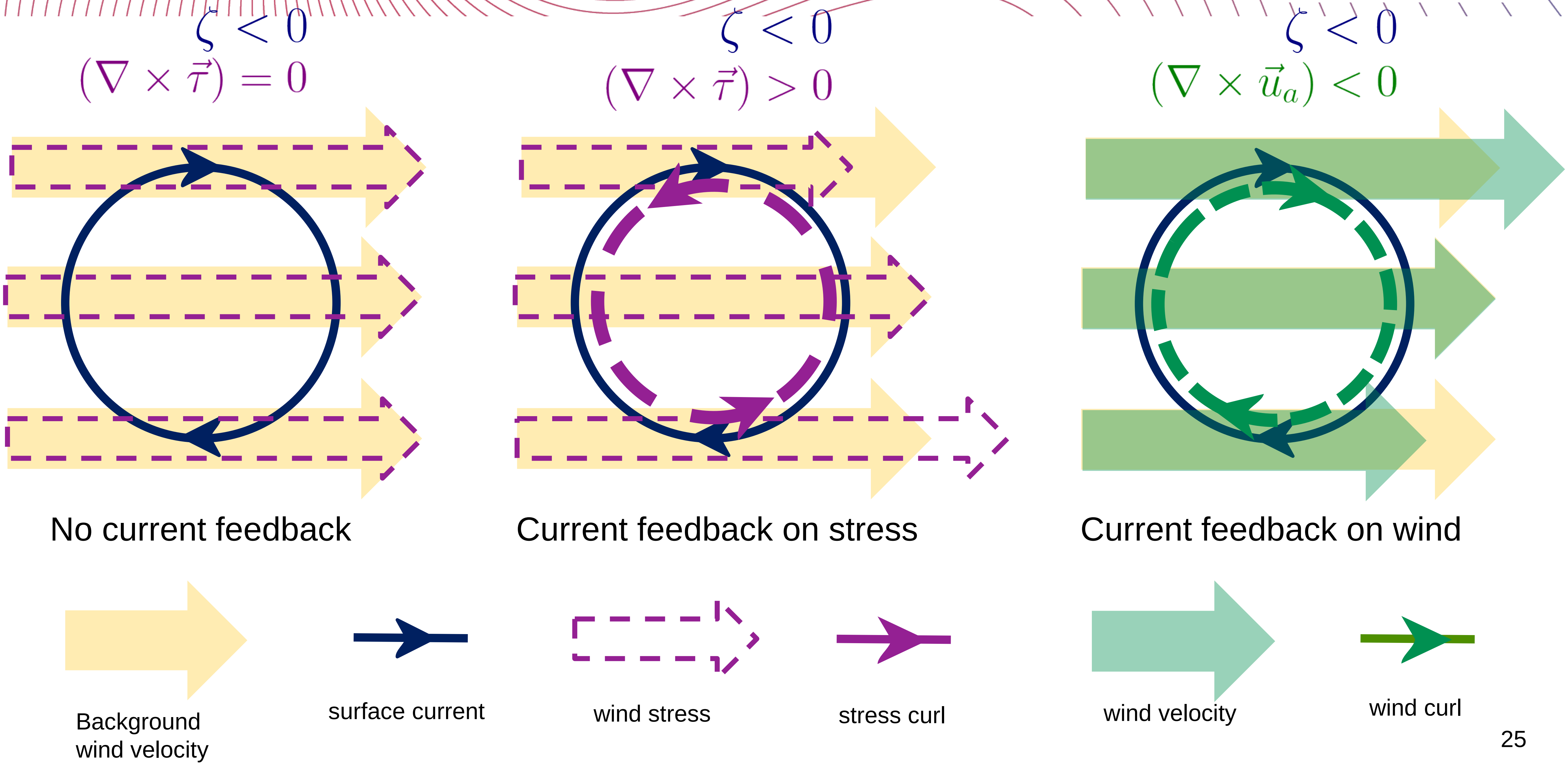
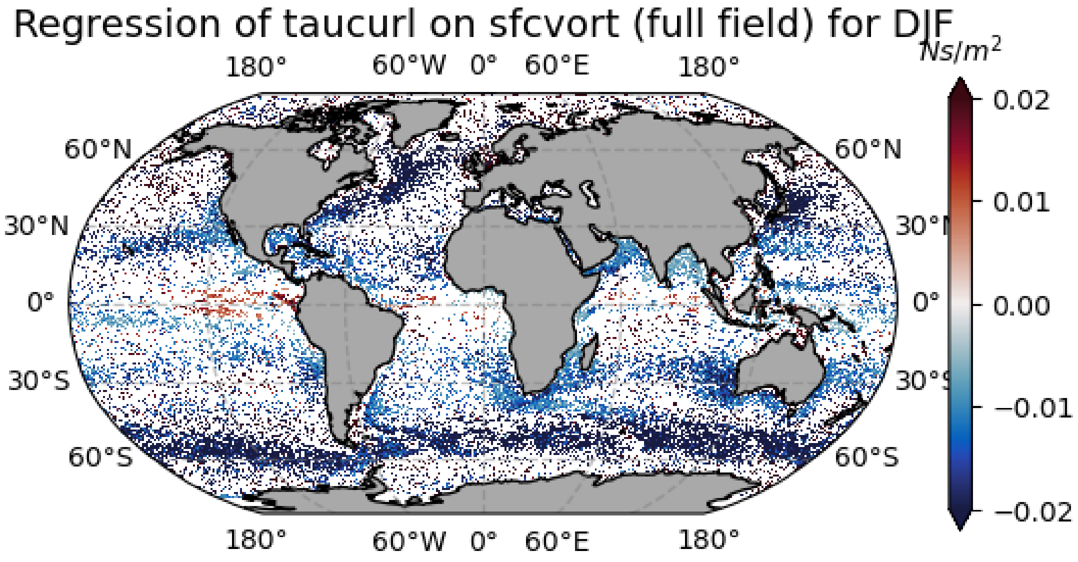
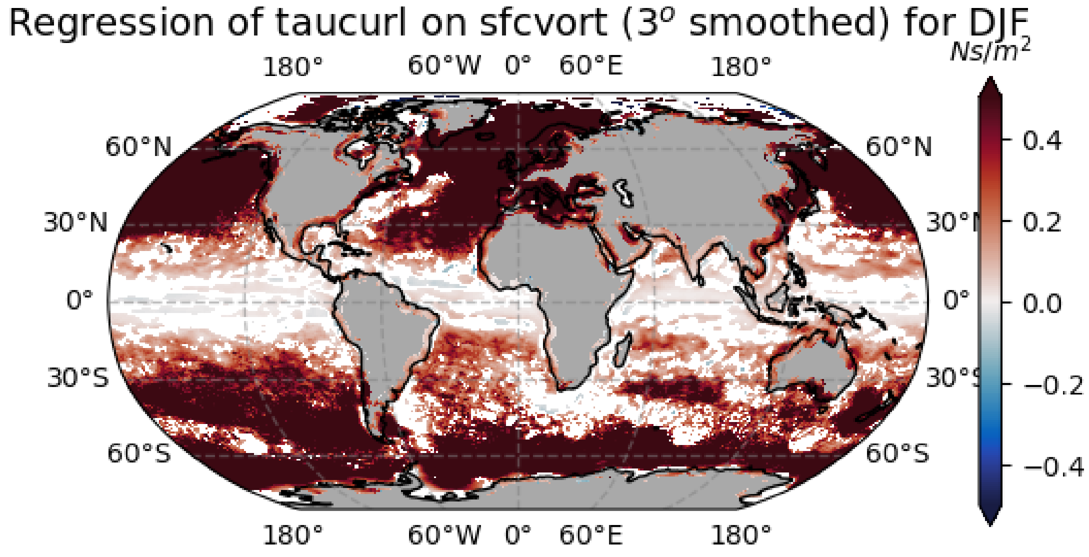
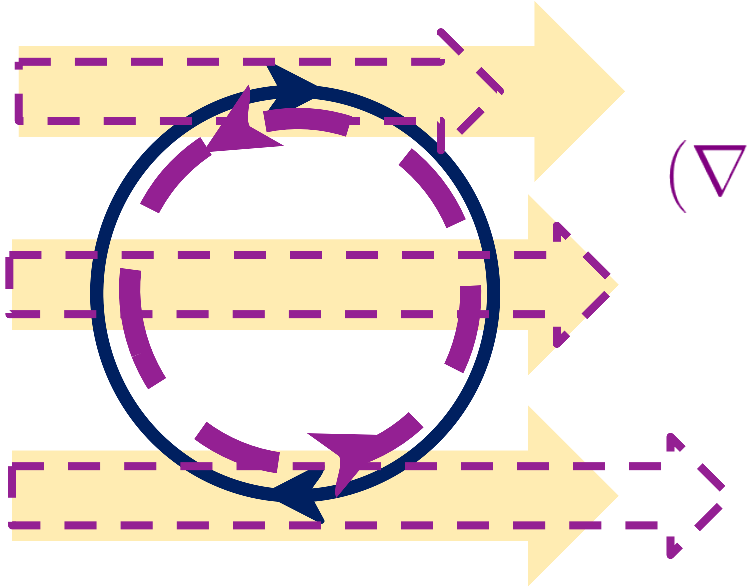


CFB: surface current vorticity and stress curl

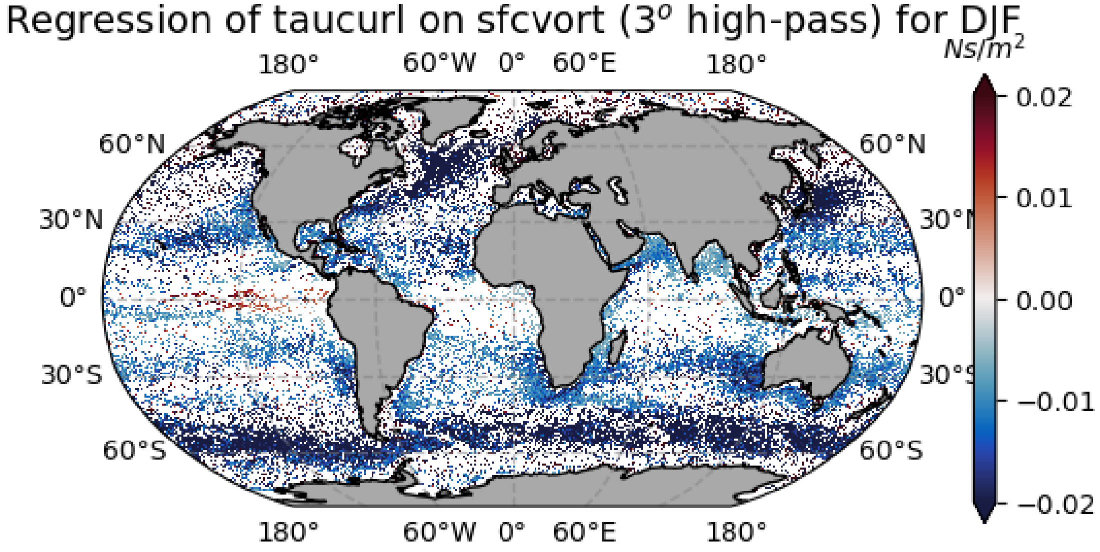




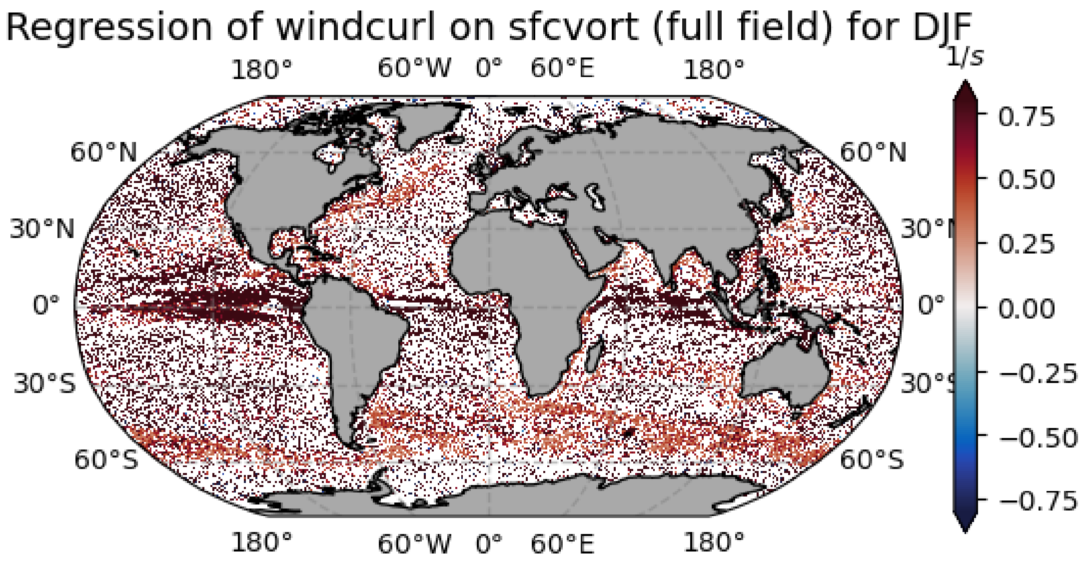


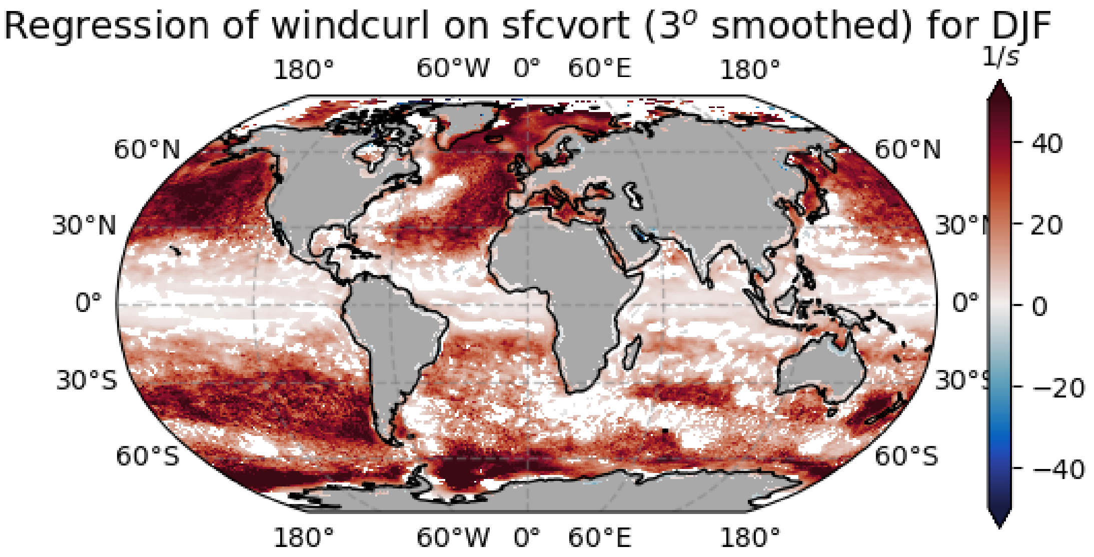
$$\zeta < 0$$

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



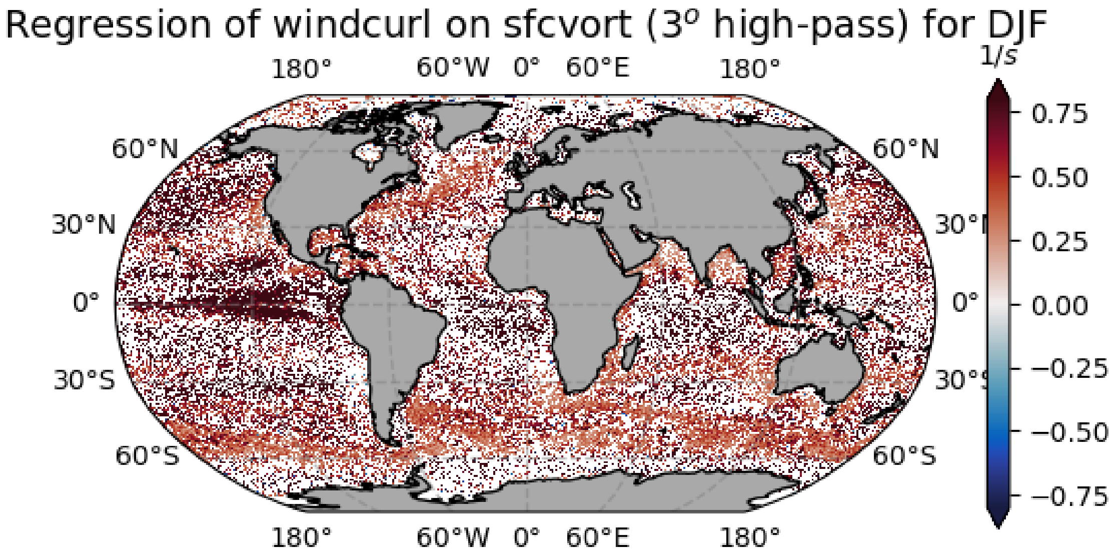
CFB: surface current vorticity and wind curl



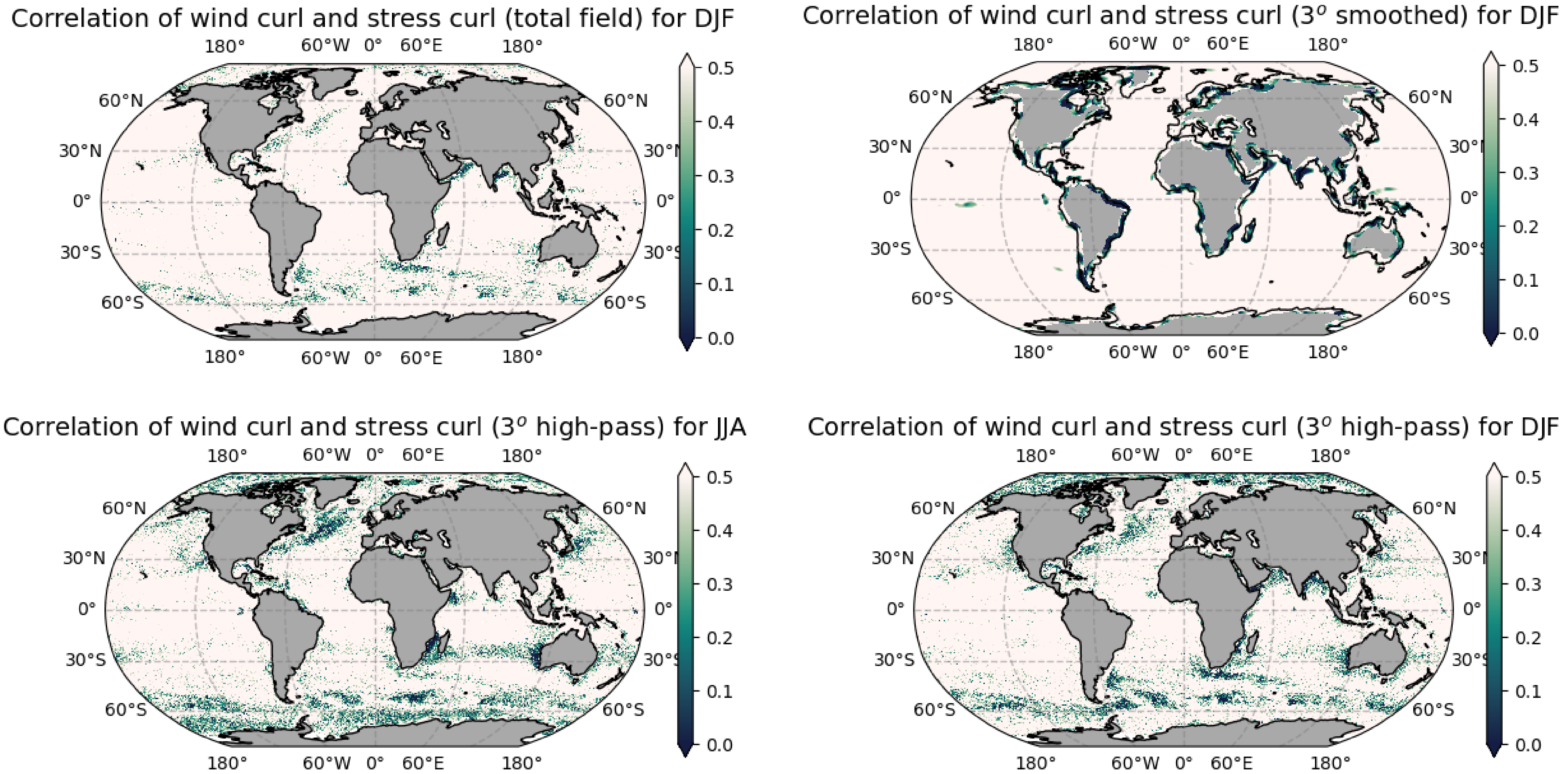


$$\zeta < 0$$

$$(\nabla \times \vec{u}_a) < 0$$

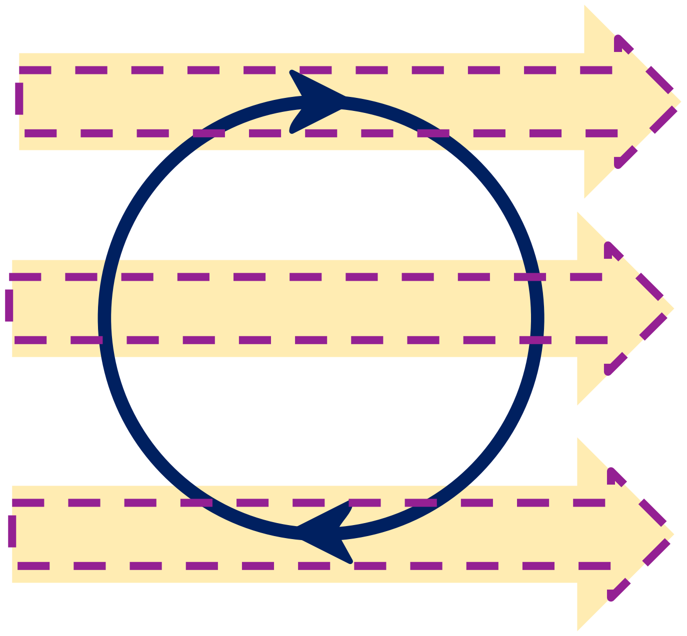


Scale dependency: stress curl vs wind curl



CFB on wind work (“eddy killing”)

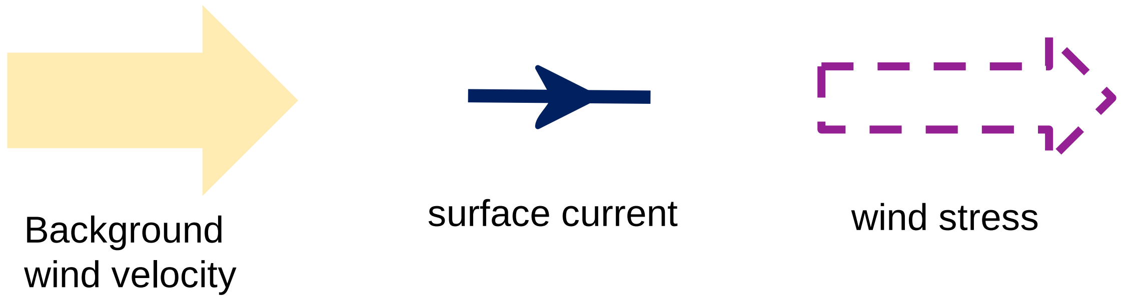
$$\text{Wind work} = (\vec{\tau} \cdot \vec{u}_o)$$



$\zeta < 0$

No current feedback

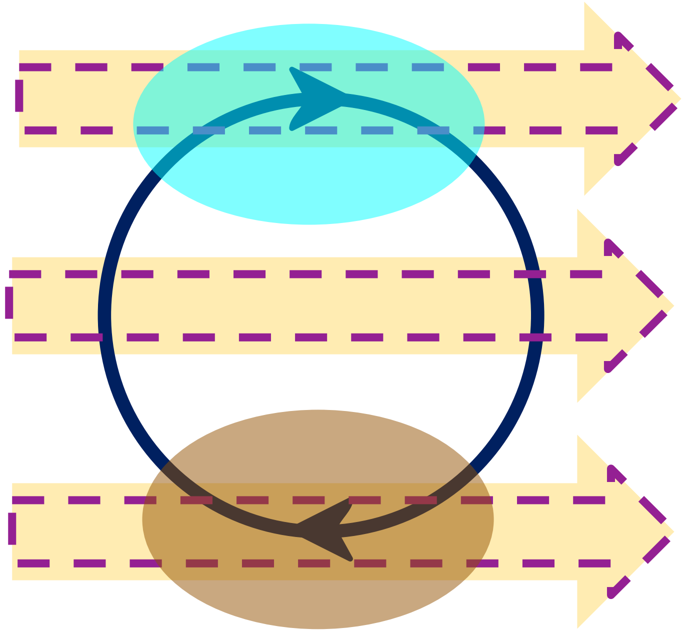
Current feedback on stress



(Modified from Rai et al., 2021)

CFB on wind work ("eddy killing")

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



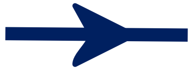
$$\zeta < 0$$

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

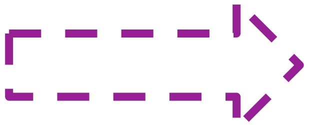
No current feedback

Current feedback on stress

Background
wind velocity

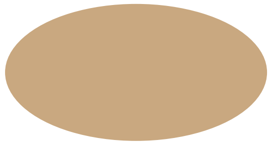


surface current



wind stress

positive wind work

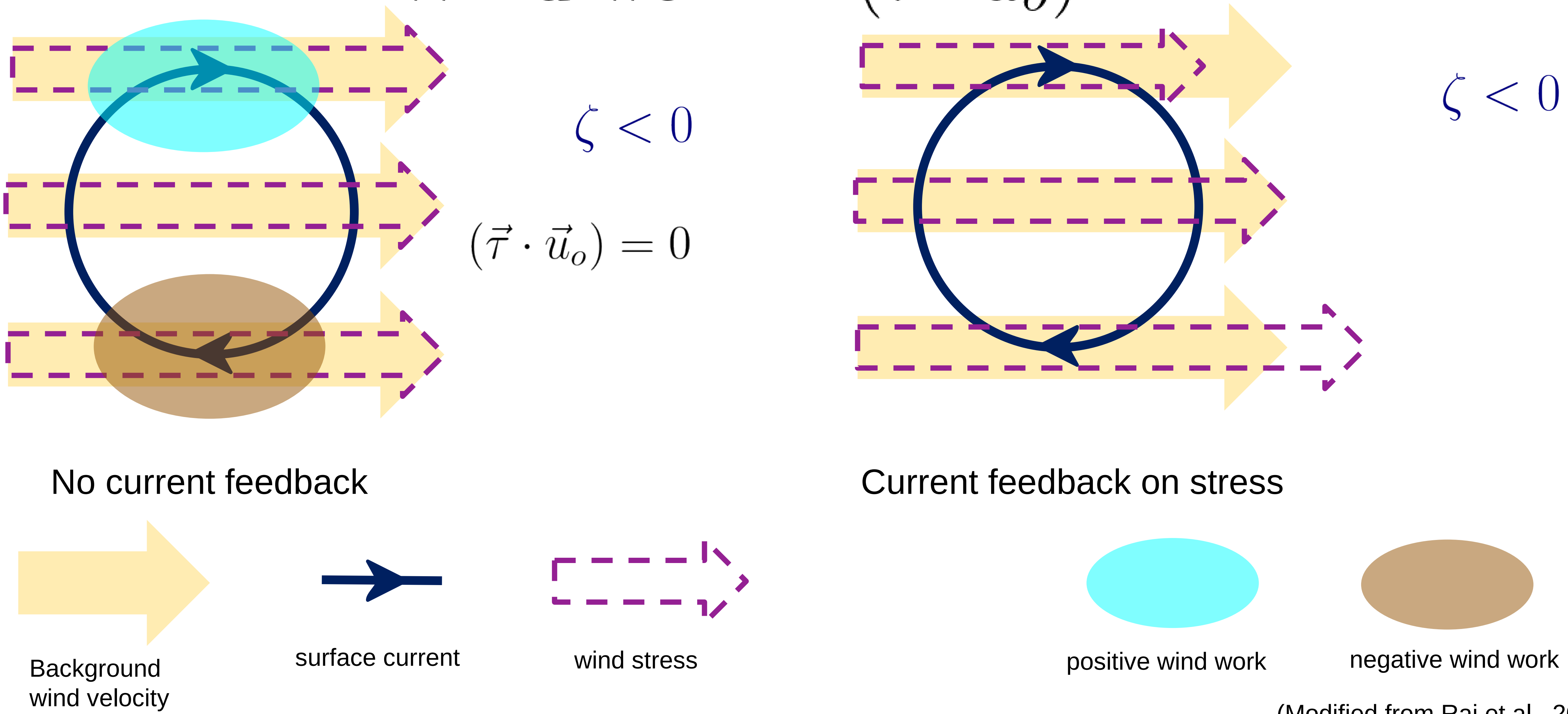


negative wind work

(Modified from Rai et al., 2021)

CFB on wind work (“eddy killing”)

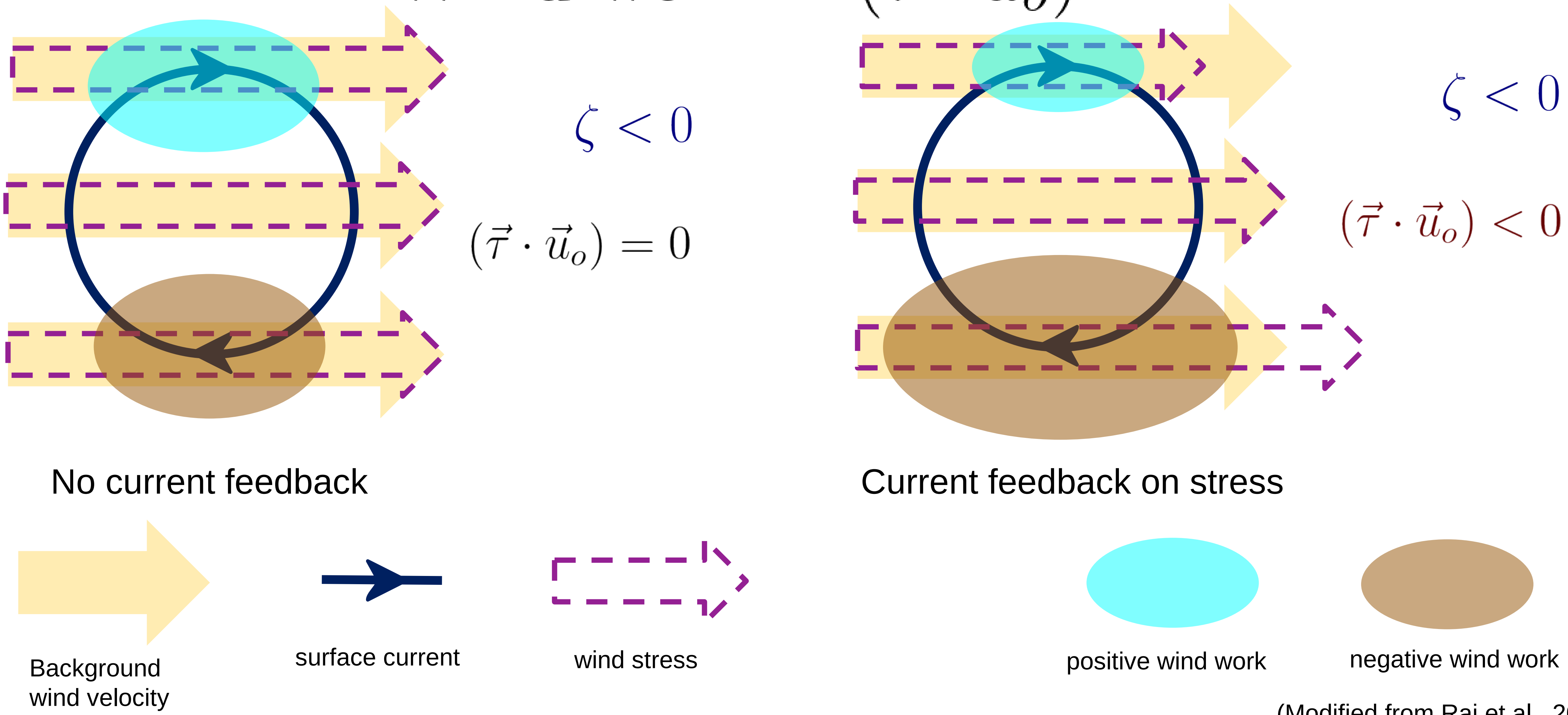
$$\text{Wind work} = (\vec{\tau} \cdot \vec{u}_o)$$



(Modified from Rai et al., 2021)

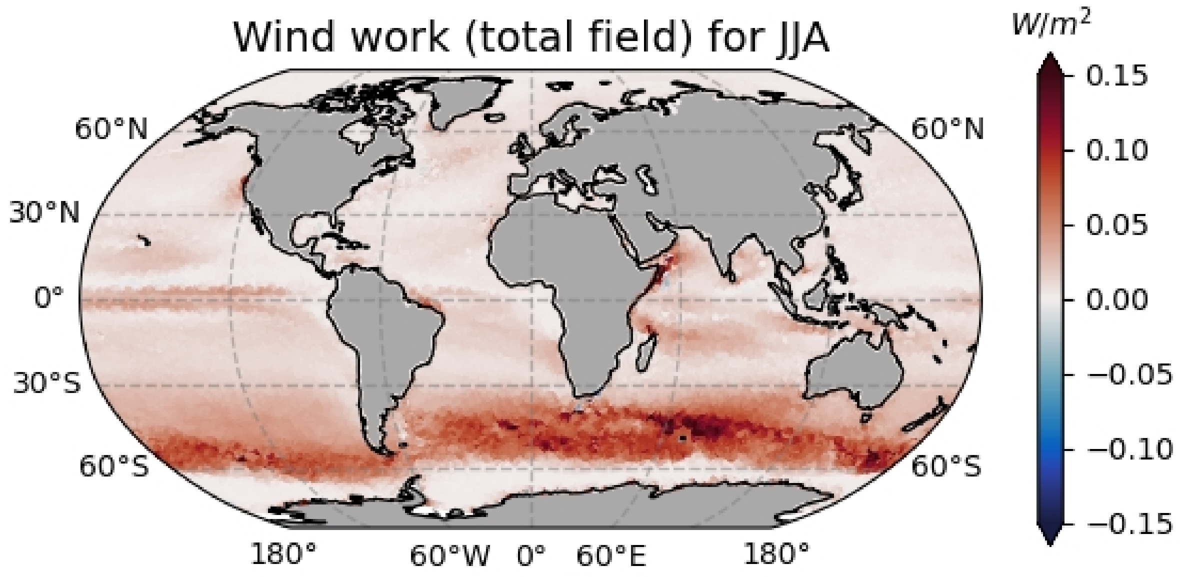
CFB on wind work ("eddy killing")

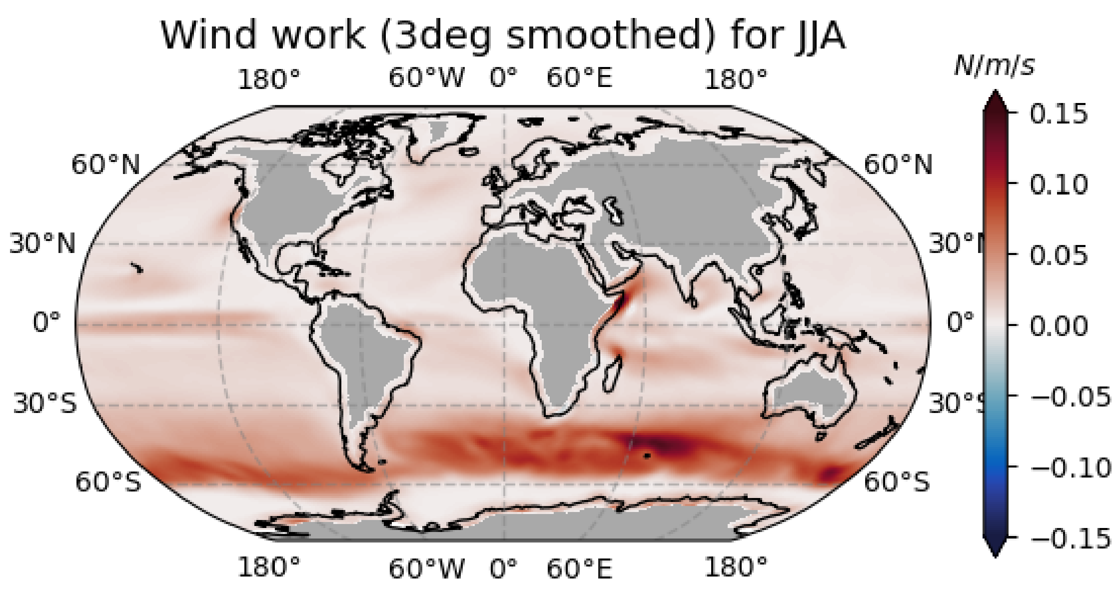
$$\text{Wind work} = (\vec{\tau} \cdot \vec{u}_o)$$



(Modified from Rai et al., 2021)

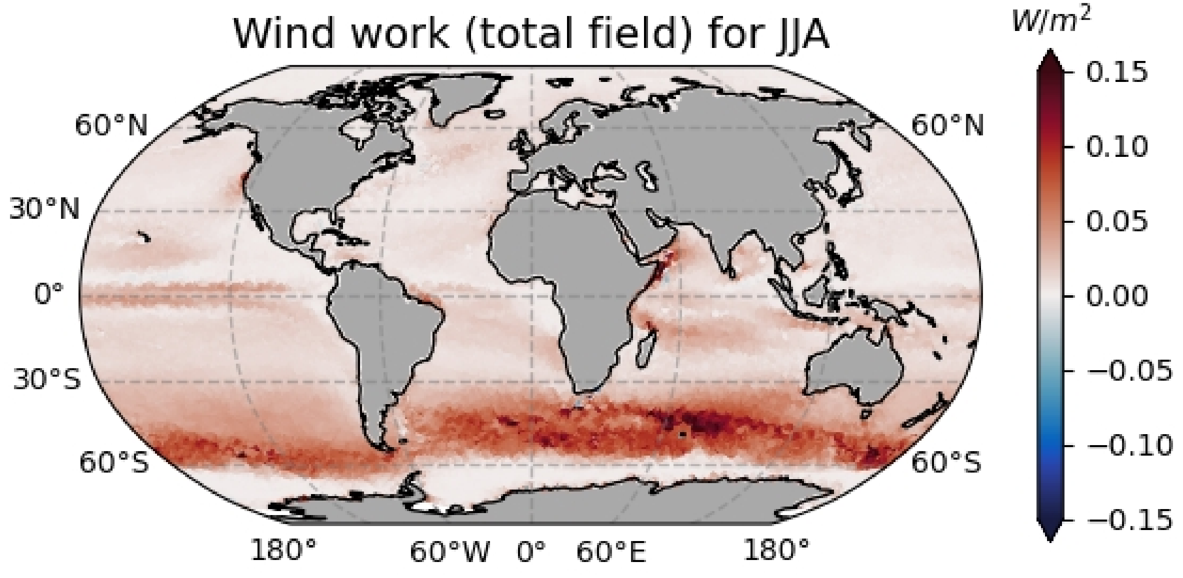
CFB on wind work ("eddy killing")



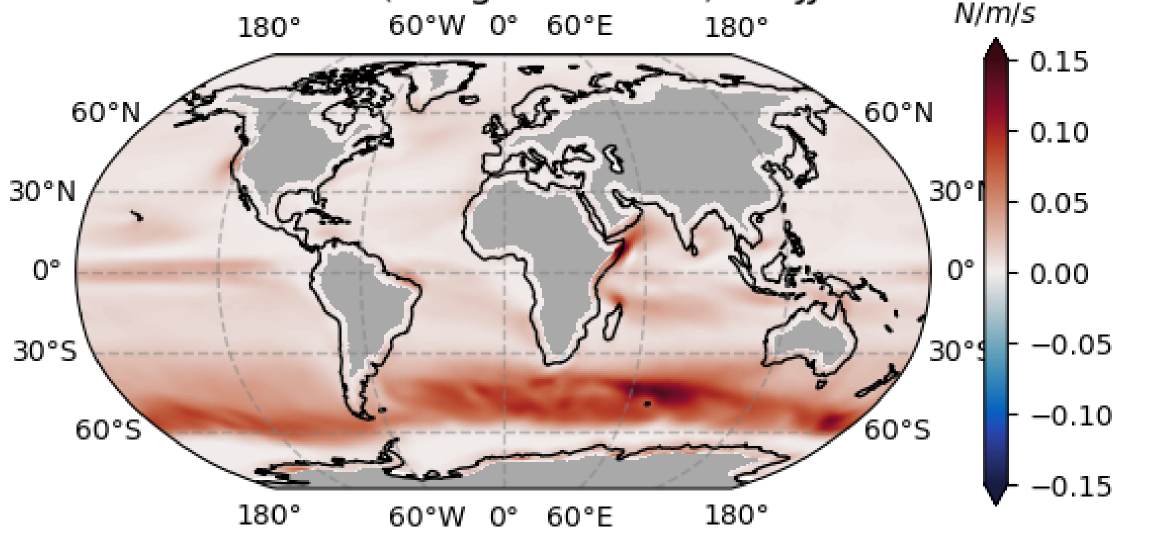


CFB on wind work ("eddy killing")

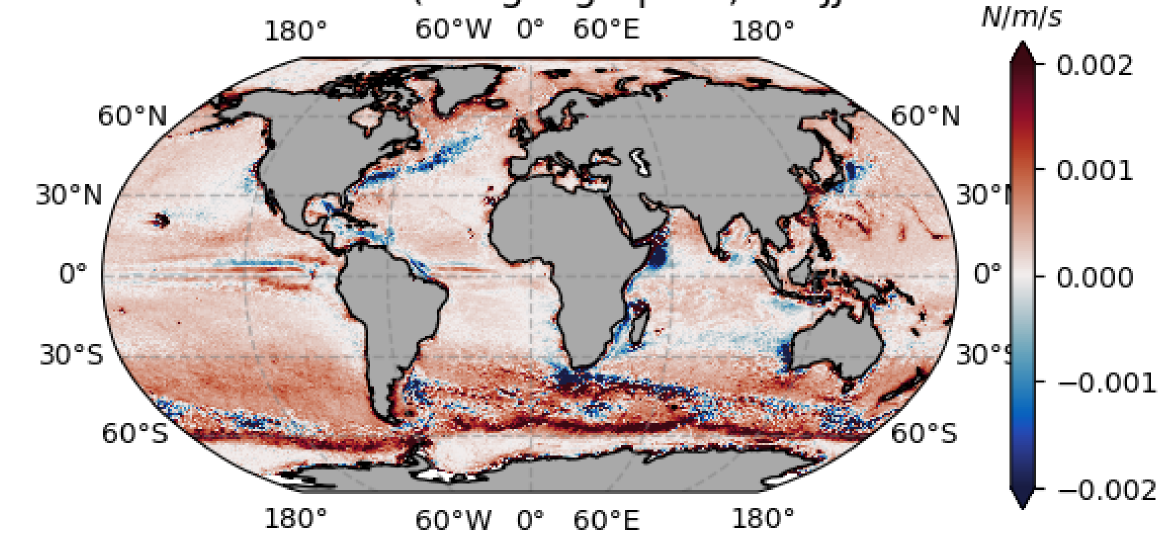
Wind work (total field) for JJA



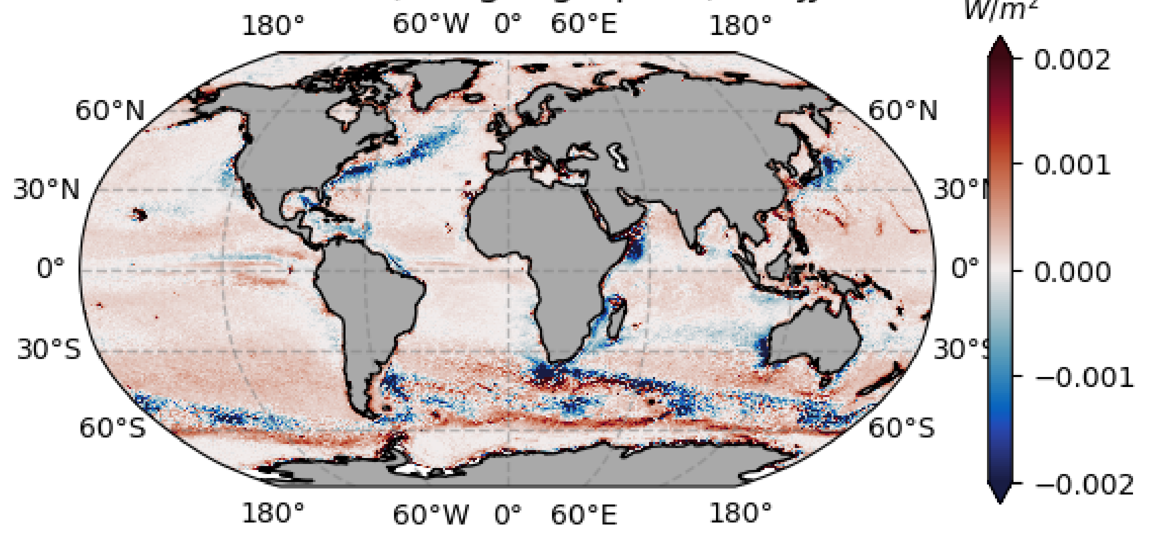
Wind work (3deg smoothed) for JJA



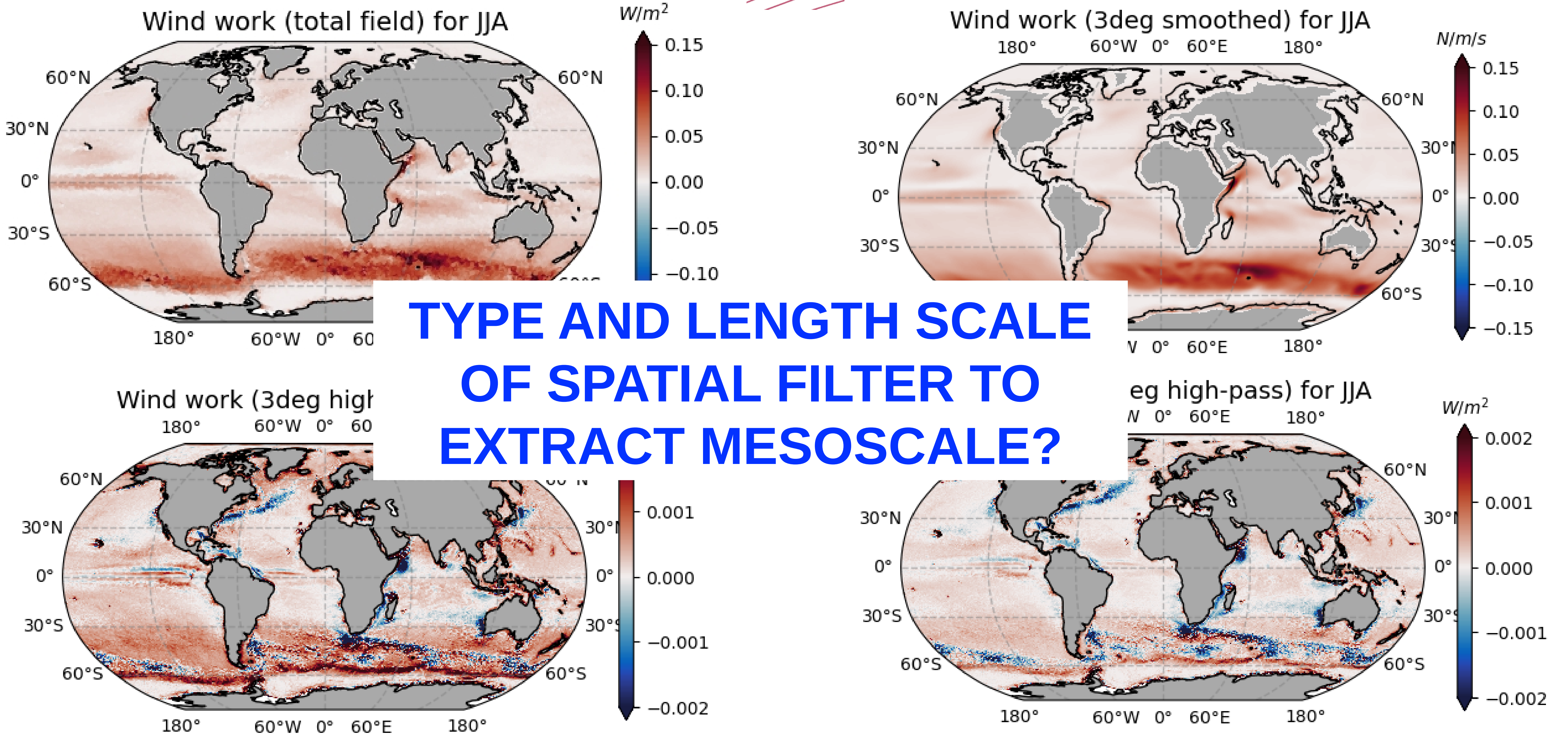
Wind work (3deg high-pass) for JJA



Wind work (2deg high-pass) for JJA



CFB on wind work (“eddy killing”)



TYPE AND LENGTH SCALE OF SPATIAL FILTER TO EXTRACT MESOSCALE?

Thoughts for discussion

1) How can we quantify mesoscale eddy impact?

    Metrics and diagnostics

    https://docs.google.com/spreadsheets/d/1ZC9Hka-7AF6r27uREU6eUwiTTTqXKQoCM6l2Ar-UYdw/edit#gid=0

2) What processes are associated with the ocean mesoscale that differ from the large-scale?

3) How do we extract the impact of mesoscales?

    Types and length scales (fixed vs varying) of spatial filters

~~~THANK YOU!!! ~~~

02

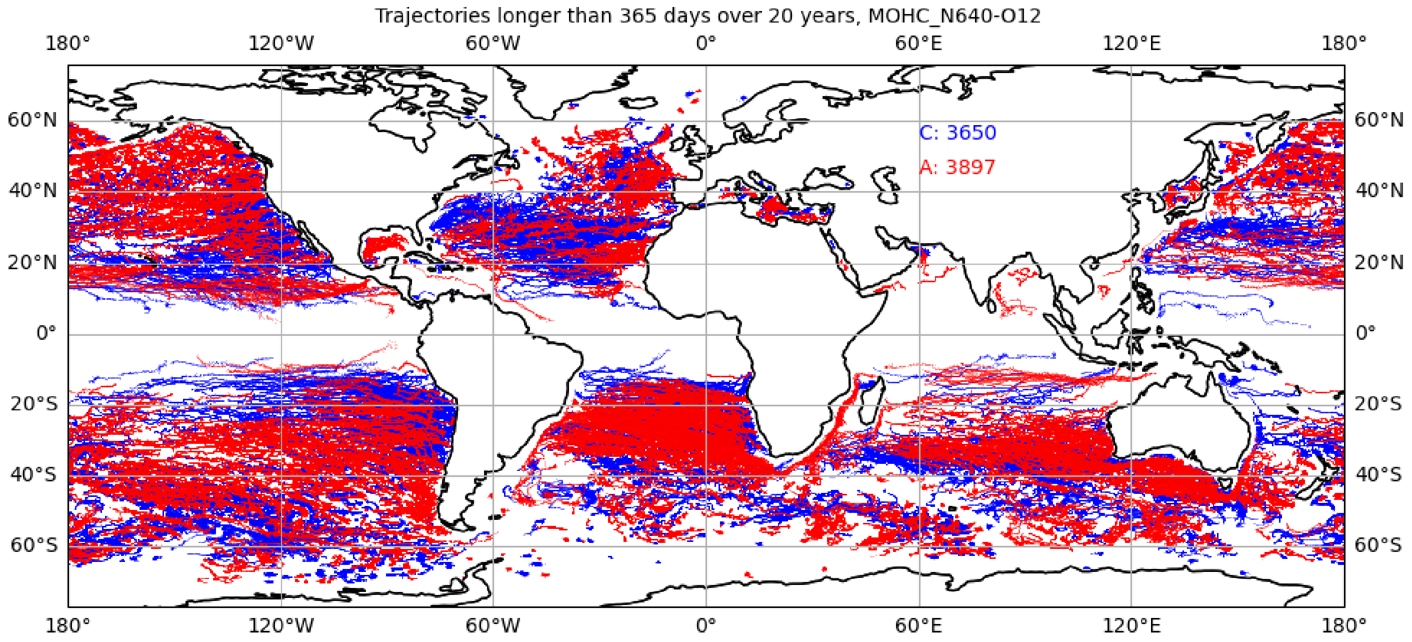
Lagrangian perspective

Use py-eddy-tracker across models (as used for AVISO eddy tracking)
Model data is regridded to 1/4x1/4˚ before tracking (same grid as AVISO uses)
Ongoing work, only some models shown here (more data is available, just not used yet)
Thanks to Dian and others for the non-Met Office model plots, and for the code for composites (from the Hackathon)

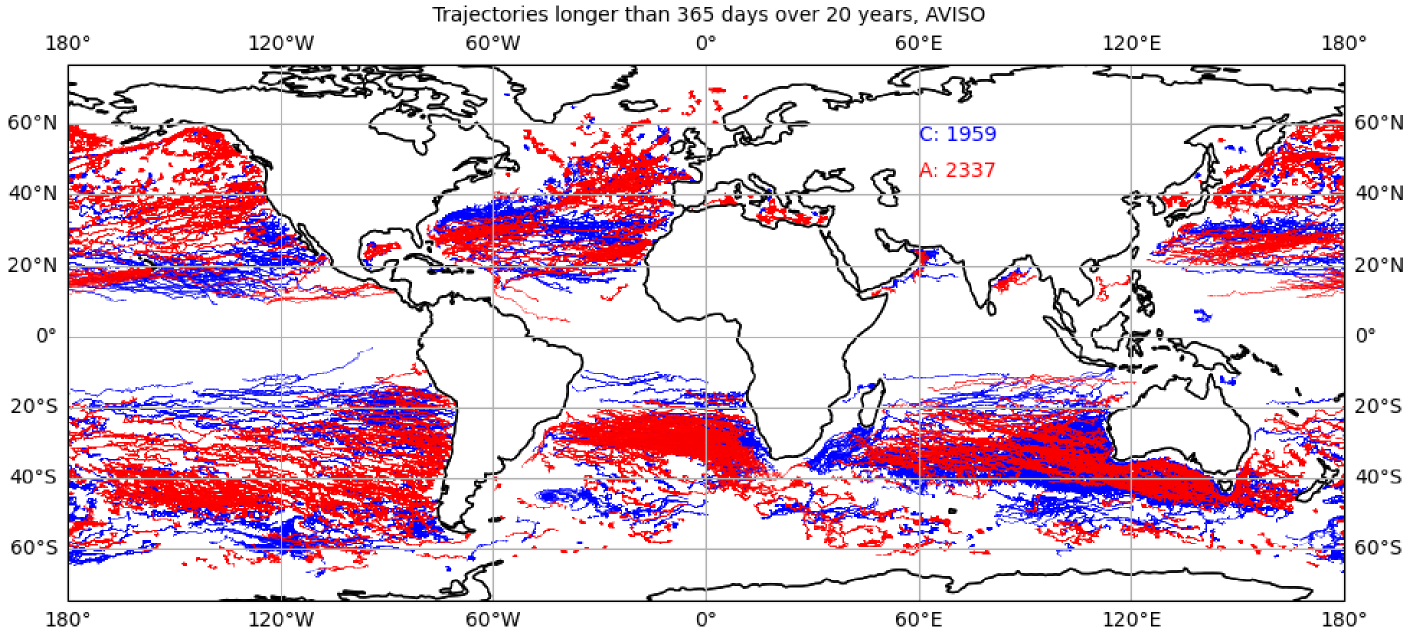
Funded by the European Union

EERIE models

Institution	MOHC	MPI-M	AWI	BSC	ECMWF
Model name	HadGEM3 GC5-EERIE	ICON	AWI	BSC	ECMWF-IFS
Model components	UM NEMO4.0.4 SI3	ICON-A ICON-O	IFS CY48R1 FESOM2 FESIM2	IFS CY48R1 NEMO4.0.7 SI3	IFS CY48R1
Atmos dynamical scheme (grid)	Grid point (SISL, lat-long)	Icosahedral	Spectral (cubic, octahedral, reduced Gaussian)	Spectral (cubic octohedral, reduced Gaussian)	Spectral (cubic octohedral, reduced Gaussian)
Atmos grid name	N96 , N216, N640	R2B8	Tco1279/Tco639	Tco1279	Tco1279/Tco319
Atmos mesh spacing 0N	208, 93, 31	10	8/16	8	8/31
Atmos mesh spacing 50N	135, 60, 20	10	9/18	9	9/36
Atmos model levels (top)	85 (85km)	90 (0.01 hPa)	137 (0.01 hPa)	137 (0.01 hPa)	137 (0.01 hPa)
Ocean grid name	eORCA(1,025,12)	R2B9	FESOM	eORCA12	NA
Ocean nominal res (km)	100, 25, 8	5	13-4.5	8	NA
Ocean levels	75	72	70	75	NA
Simulations (phase 1)	CMIP6-like (1850-2100)	HighResMIP-coupled (1950-2100)	HighResMIP-coupled (1950-2100)	HighResMIP-coupled (1950-2100)	HighResMIP-AMIP (1982-2022)

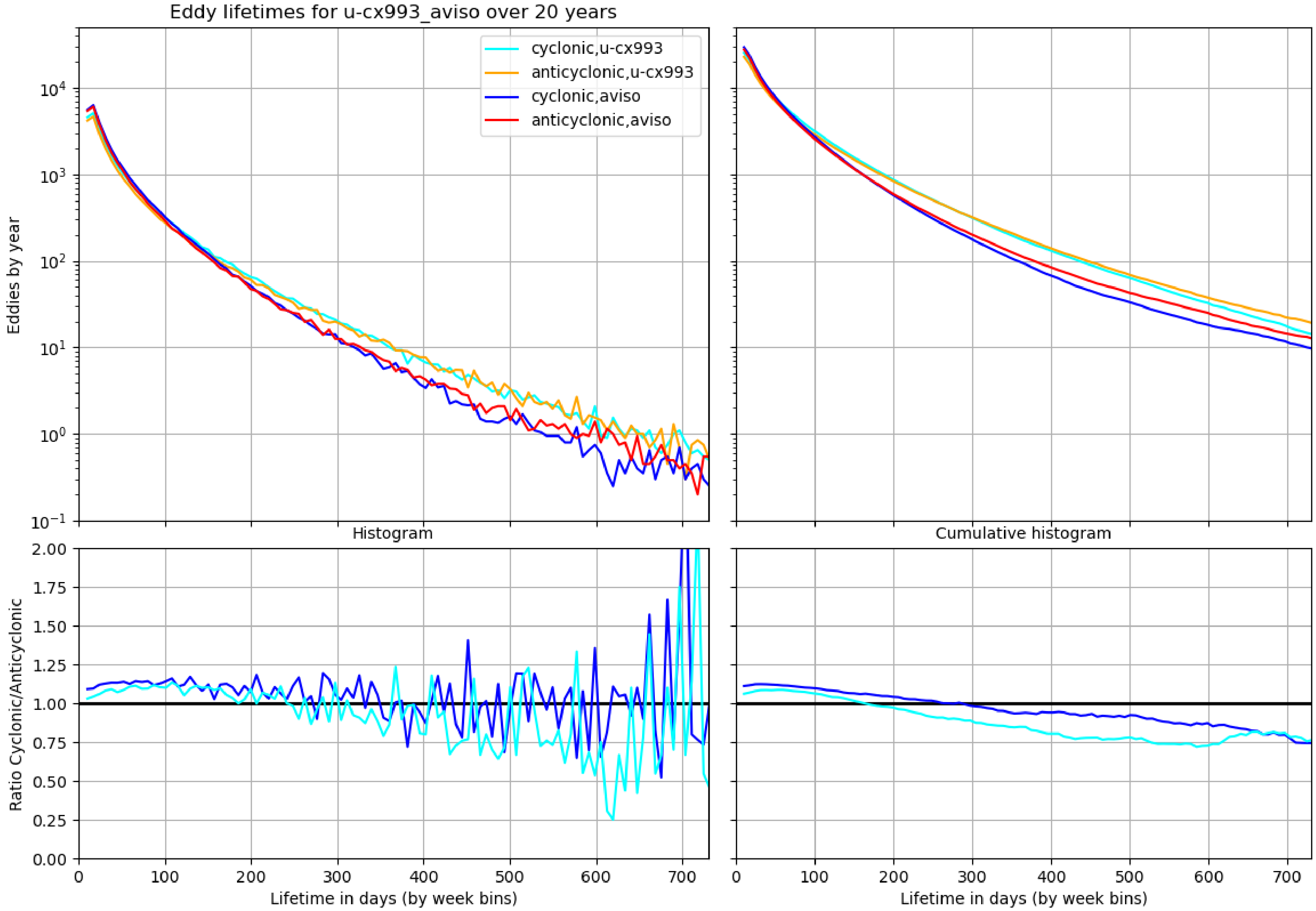


piControl simulation
20km-1/12°, 20 years,
eddies longer than 1 year,
data regridded to 1/4°
before tracking,
tracking is ongoing with
model simulation



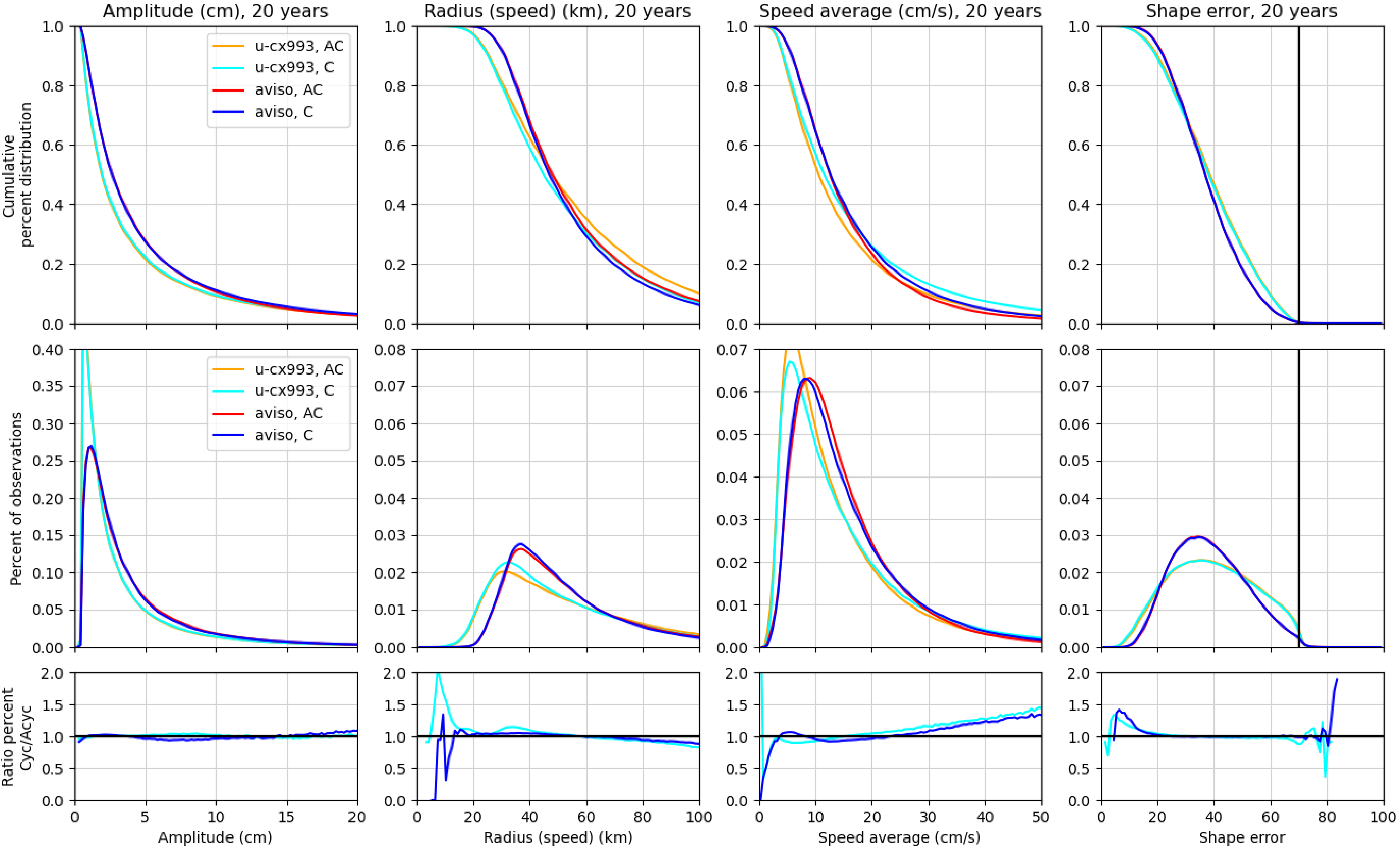
AVISO observations
20 years,
eddies longer than 1
year,
data on 1/4° grid

Tracked eddy metrics (2)



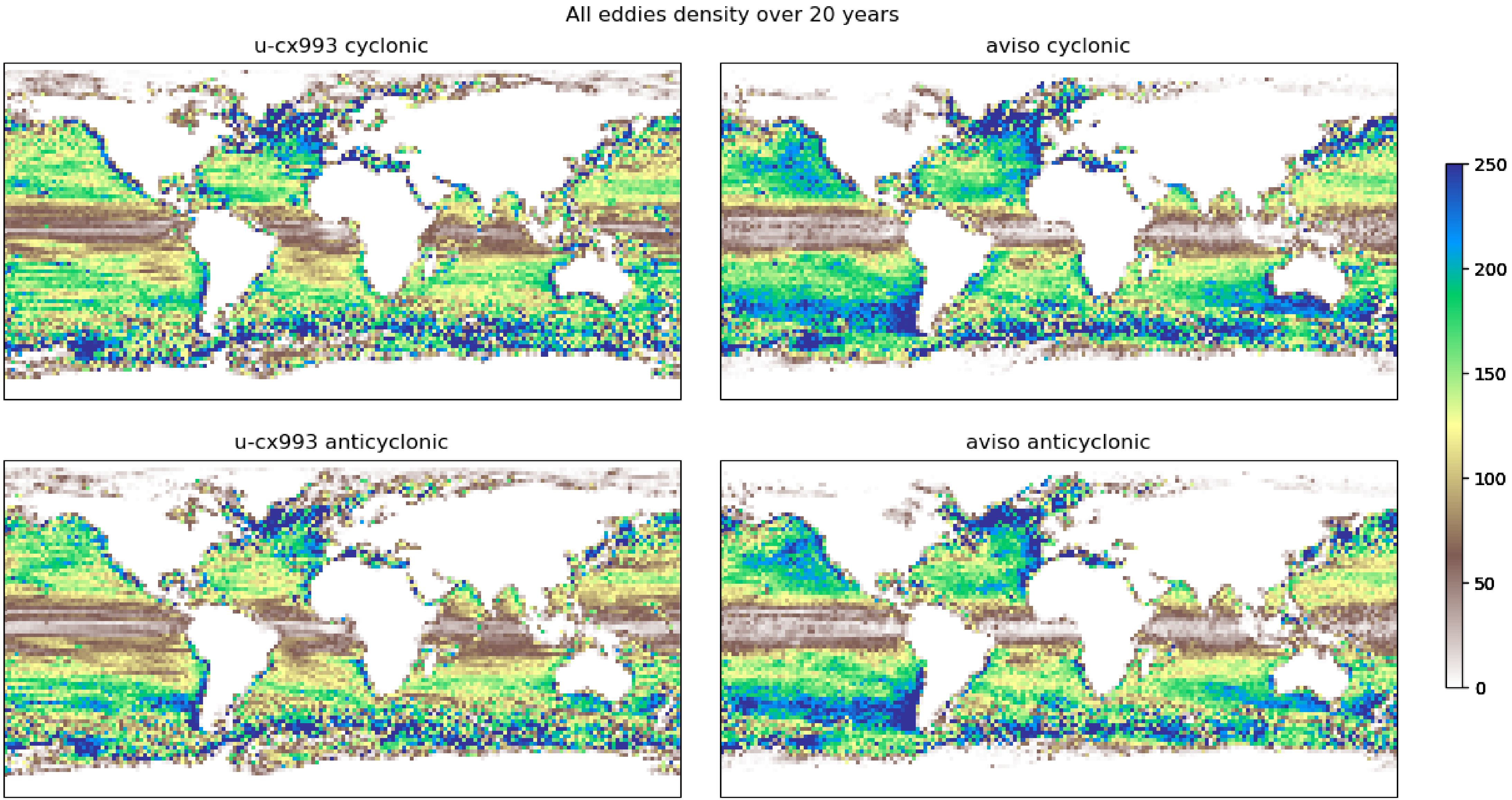
u-cx993 – HadGEM3-GC5-EERIE
20km-1/12˚
piControl

Tracked global eddy metrics



u-cx993 – HadGEM3-GC5-EERIE
20km-1/12°
piControl

Eddy track density

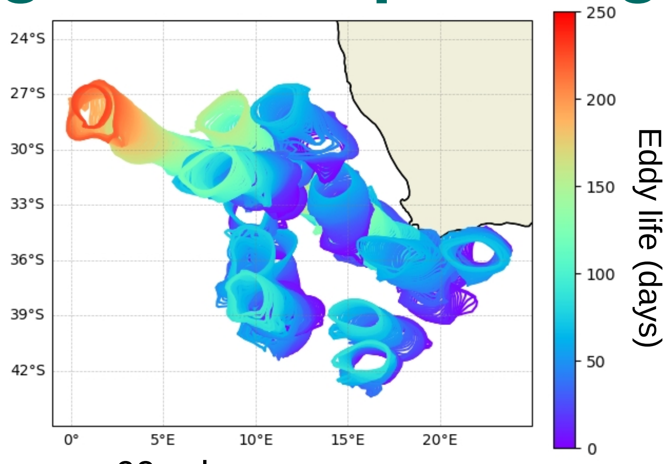


Histogram of all eddies in 2˚x2˚ boxes over 20 years

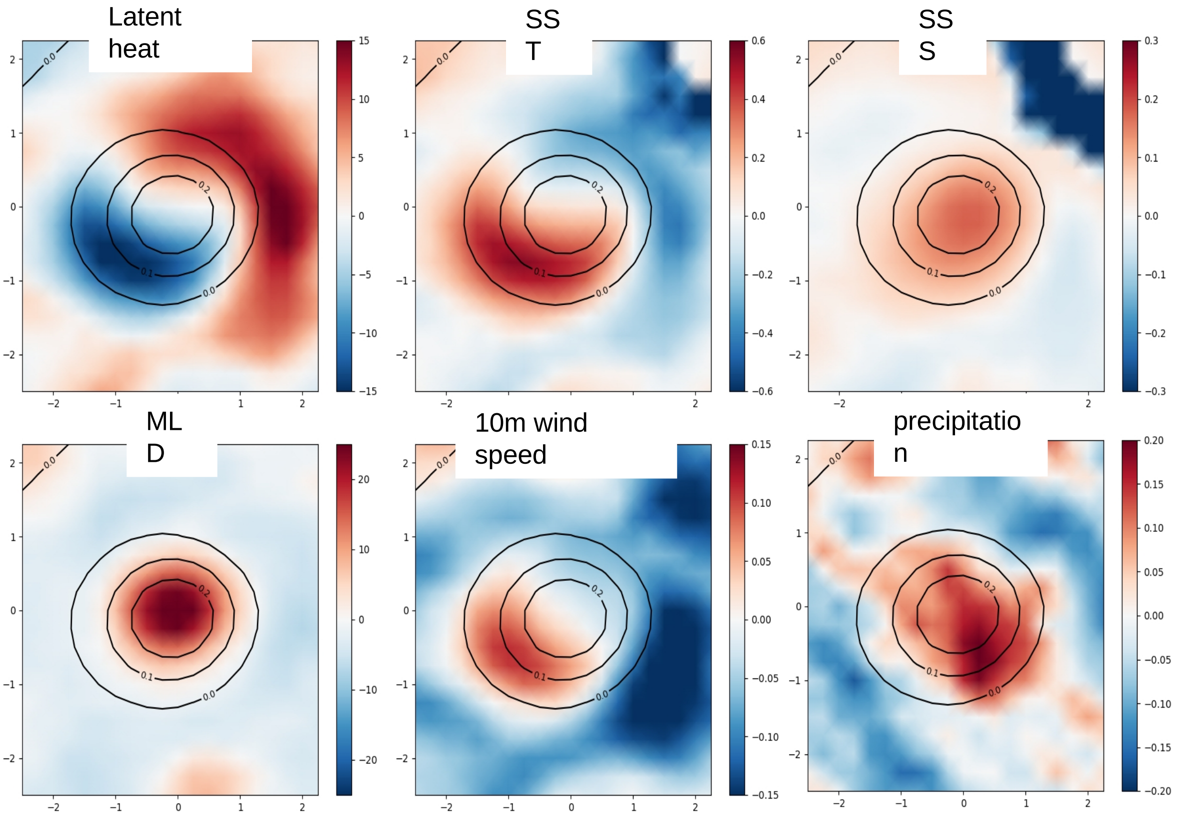
Eddy tracking and compositing

Lifetime and track of Agulhas anticyclones

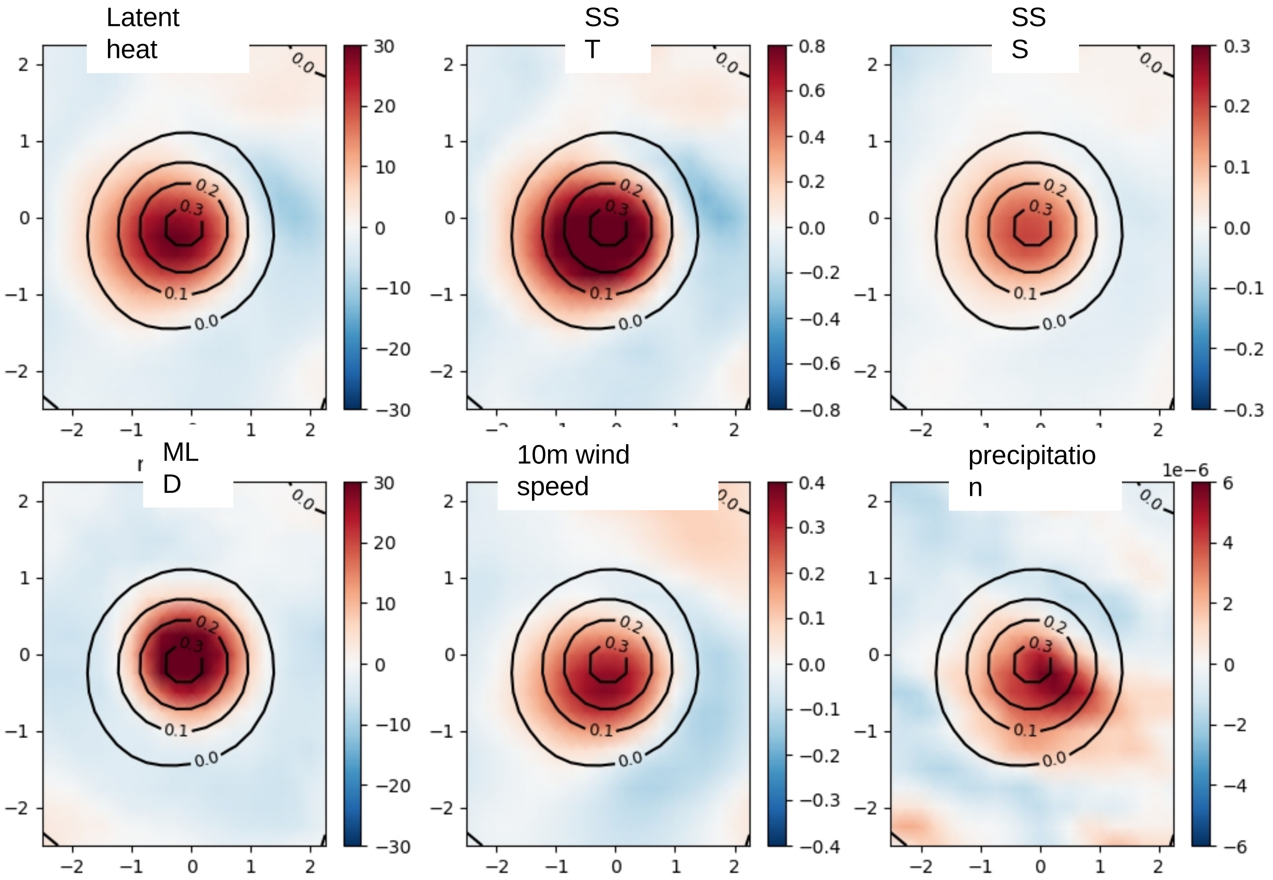
Somewhat different py-eddy-tracker settings between models
Note different scales



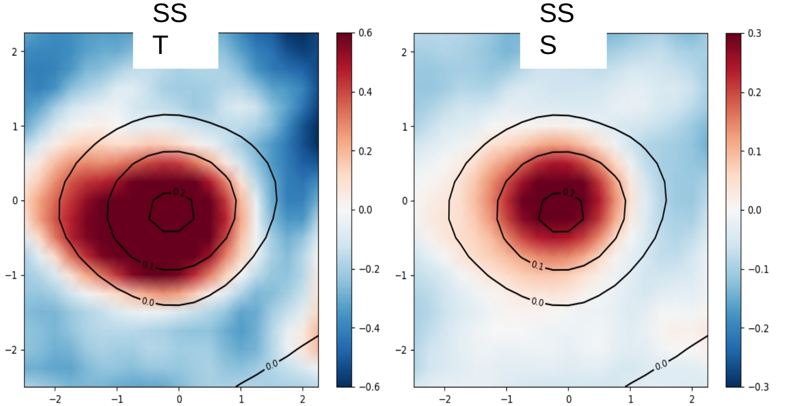
ICON (10km-5km), 7 years, 60+ days



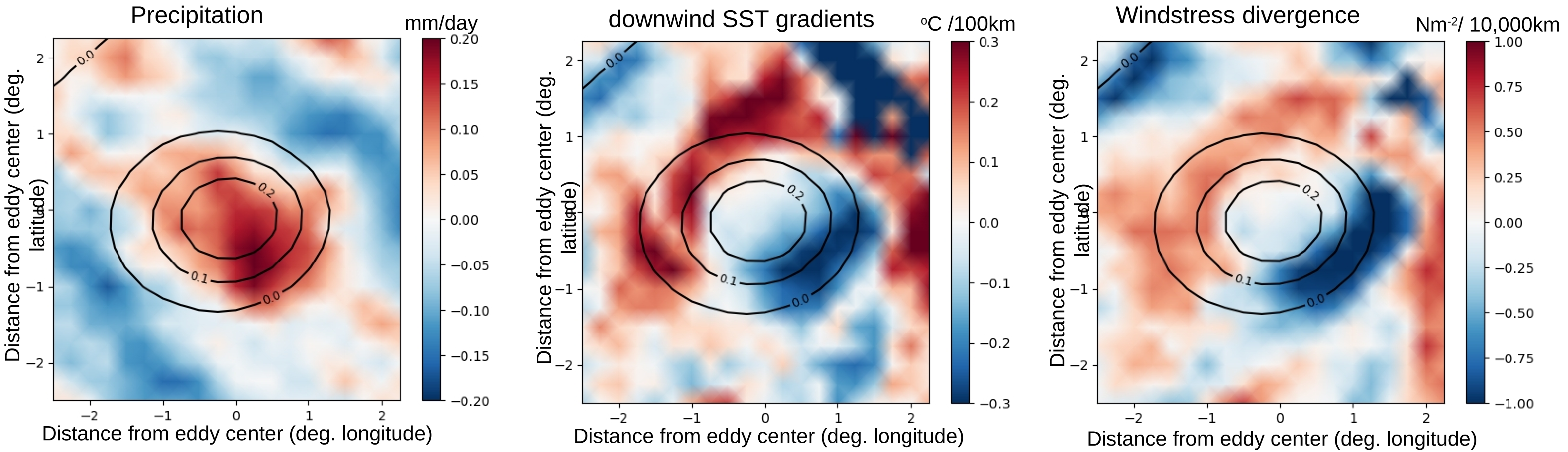
UM-NEMO (20km-8km) – 4 years, 90+ days



IFS-FESOM (9km-(13-4.50km)), 7 years, 60+ days



Mesoscale eddy impact on atmosphere over Agulhas Rings



ICON (10km-5km), 7 years, 60+ days

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UK Research and Innovation

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