Surface currents and relative-wind stress in coupled ocean-atmosphere simulations of the northern California Current System*

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*MWR, in revision

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Coupled ocean-atmosphere simulations

Goal: Examine model response to different surface-current coupling and atmospheric-model planetary boundary layer (PBL) turbulence schemes.

COAWST system: WRF atmosphere (12 km & 36 km), ROMS ocean (2 km)

ROMS: Hydrostatic, free-surface, primitive equations in terrain-following vertical coordinate (40 levels); Mellor-Yamada 2.5 turbulence scheme; regional domain nested in HYCOM output.

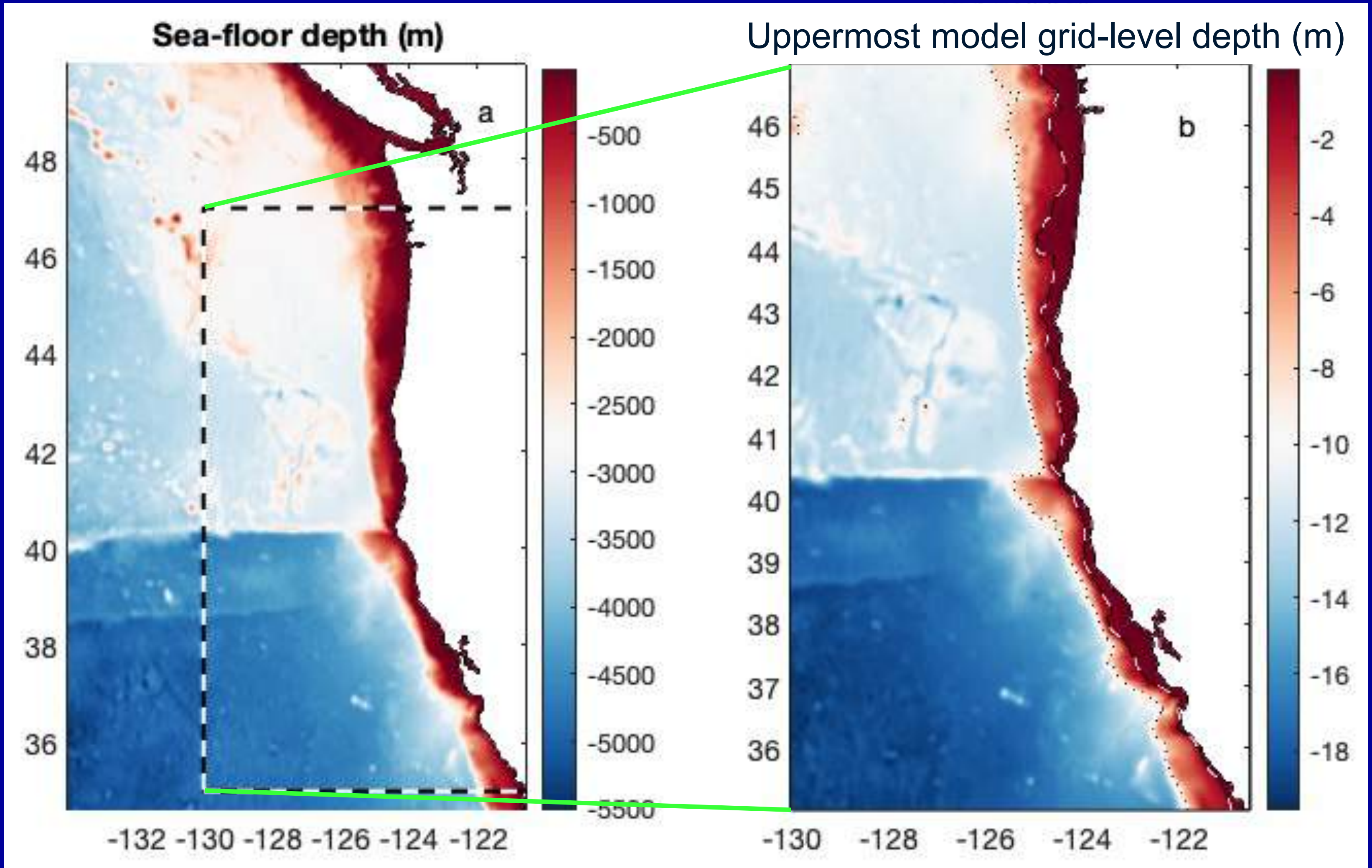
WRF: Compressible, nonhydrostatic primitive equations in terrain-following vertical coordinate (51 levels); two nested regional domains, outer nested in NCEP FNL operational analysis, inner coupled to ROMS ocean model.

Ocean simulation initialized from interpolated HYCOM analysis in October 2008; coupled model simulations begin 7 March 2009 and end 15 October 2009.

SST-stress coupling and fog & low-level stratus previously analyzed in subsets of these simulations.

The modifications to the ROMS-WRF-COAWST modeling system necessary to enable these surface-current-coupled simulations were made by Scott Durski. Modified code is being made available on GitHub by Scott.

Ocean model and analysis domains



Wind forcing and KE response with SST coupling only

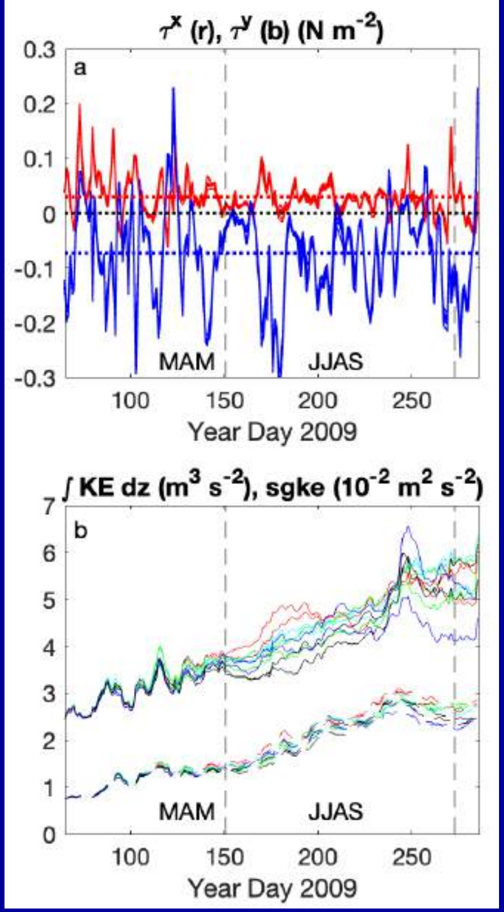
Time series

E & N stress

τ^y mean -0.07 N m^{-2}

total KE

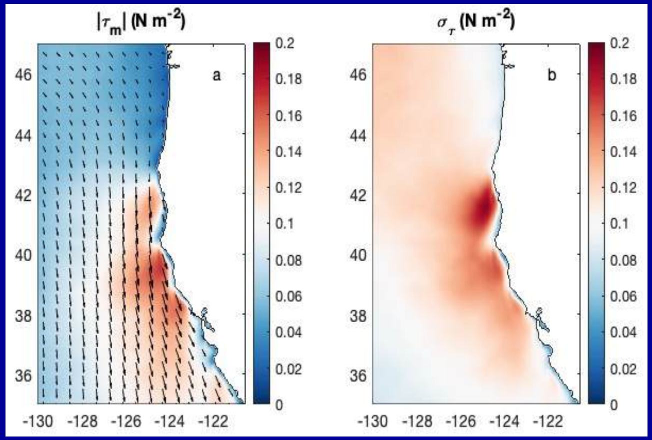
surface geostrophic KE



Mar-Oct mean stress

magnitude

std dev

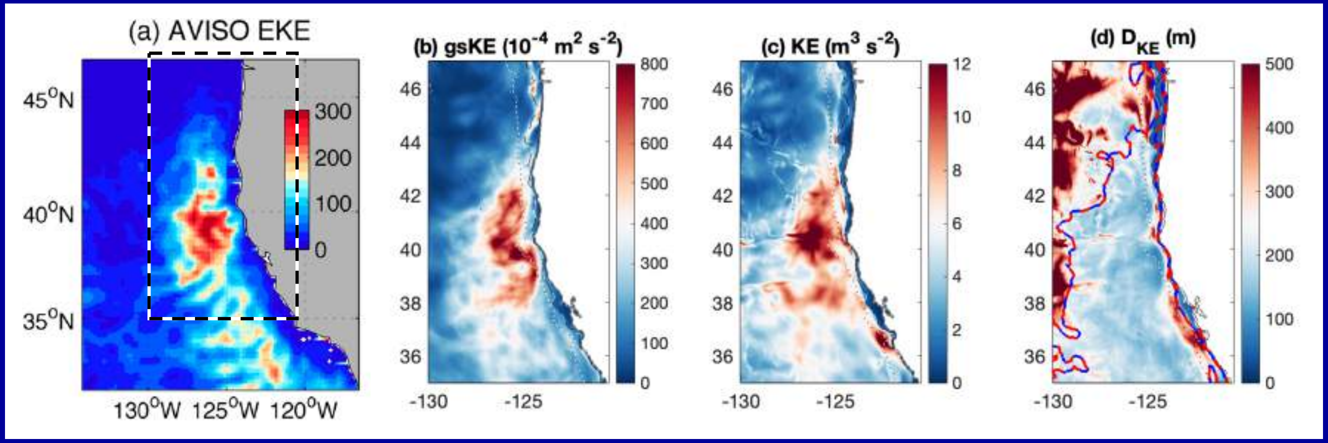


JJAS 2005-2010

surface geostrophic KE

total KE

KE depth scale (total/sfc-geo)



Coupled ocean-atmosphere simulations

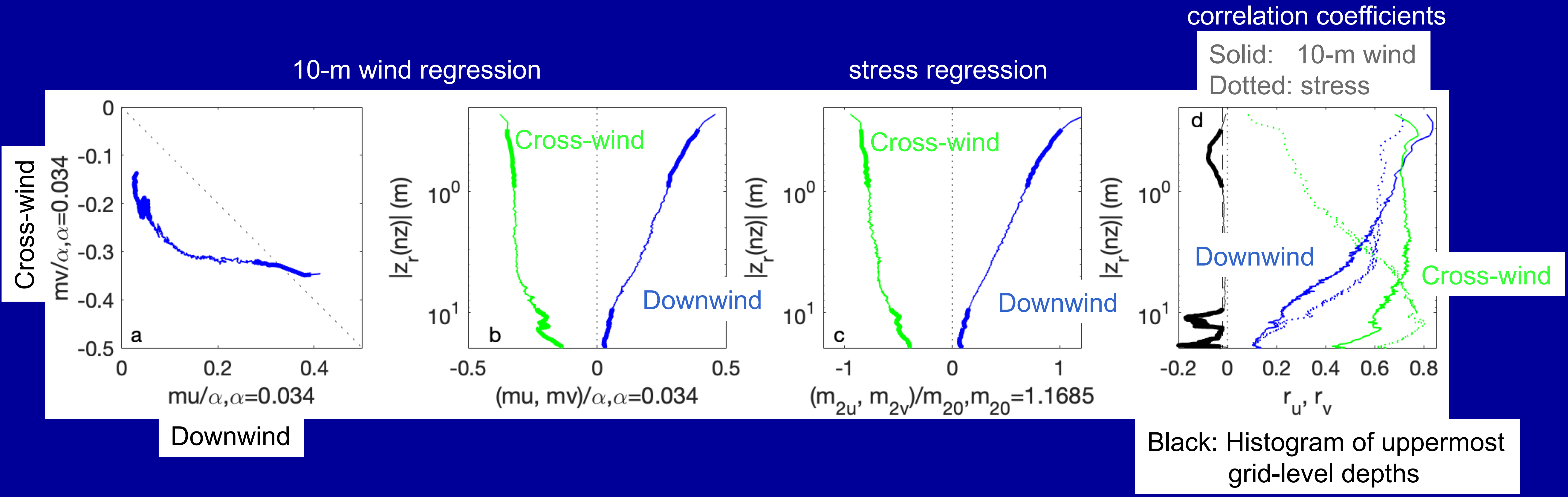
Total of 45 ensemble members:

PBL scheme / Coupling	YSU	GBM	UW	MYNN2	MYJ
Main analysis ensemble					
SST only	2	2	2	2	2*
SST + 10-m depth current	1	1	1	1	1
SST + surface geostrophic current	1	1	1	1	1
SST + uppermost grid-level current	1	1	1	1	1
SST + surface geostrophic current + wind-drift	1	1	1	1	1
SST + uppermost grid-level current + wind-drift	1	1	1	1	1
SST + surface geostrophic current/wind + universality wind-drift	1	1	1	1	1
Additional simulations					
SST + uppermost grid-level current + wind-drift + $1.05 \times C_D$	1	1	1	1	1

Model wind drift response

Mean regressions of ageostrophic uppermost grid-level velocity against 10-m wind or stress binned by grid-level depth

Near-surface (above 1-m depth):	Log-layer response, proportional to wind speed (M-Y scheme limit)
At depth (10-20 m):	Slab Ekman response, proportional to wind stress



Relative-wind (surface-current) damping of kinetic energy: differences with-minus-without surface-current coupling

Depth-integrated kinetic energy

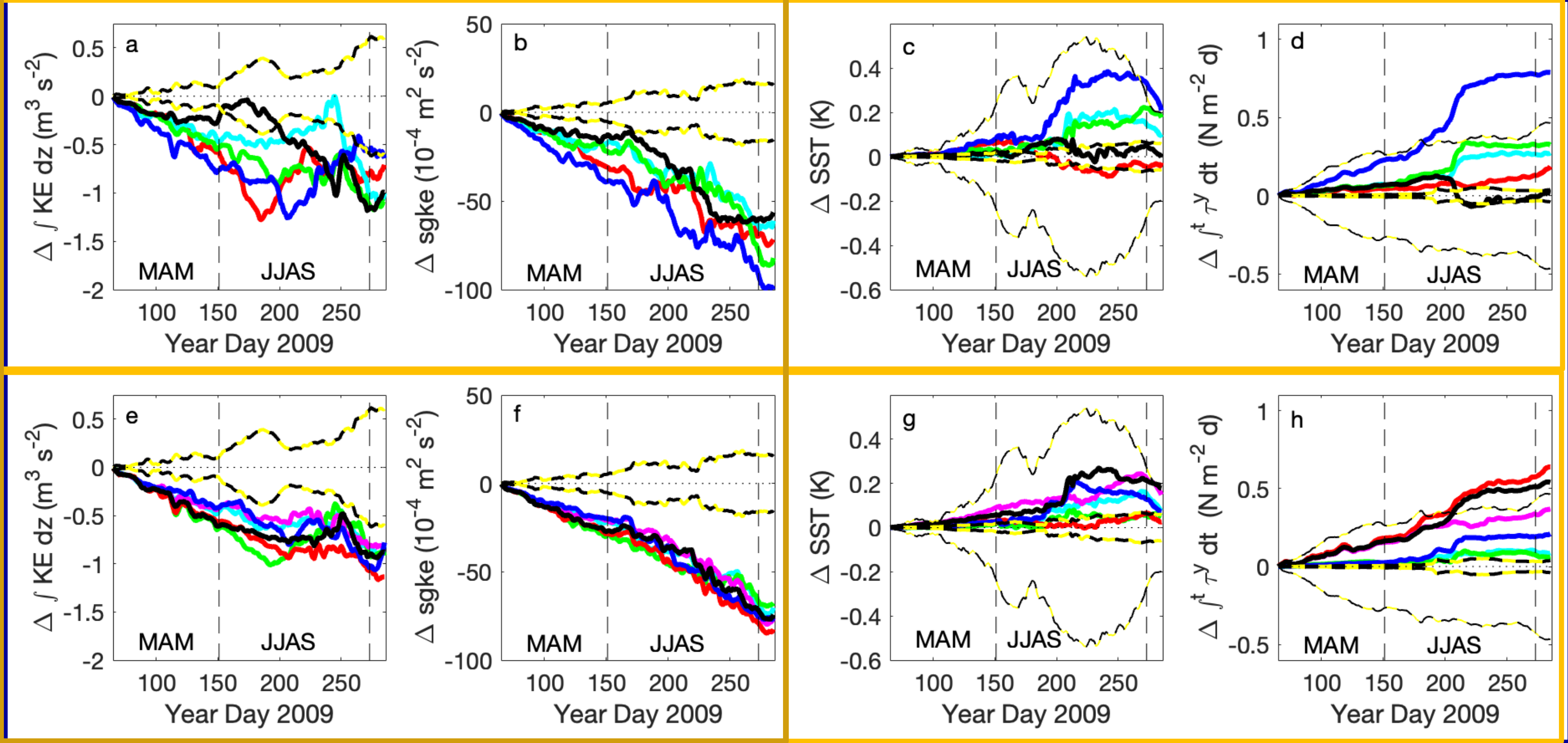
Surface geostrophic kinetic energy

SST

Time-integrated mean meridional wind stress

Grouped by PBL scheme

Grouped by surface-current for coupling



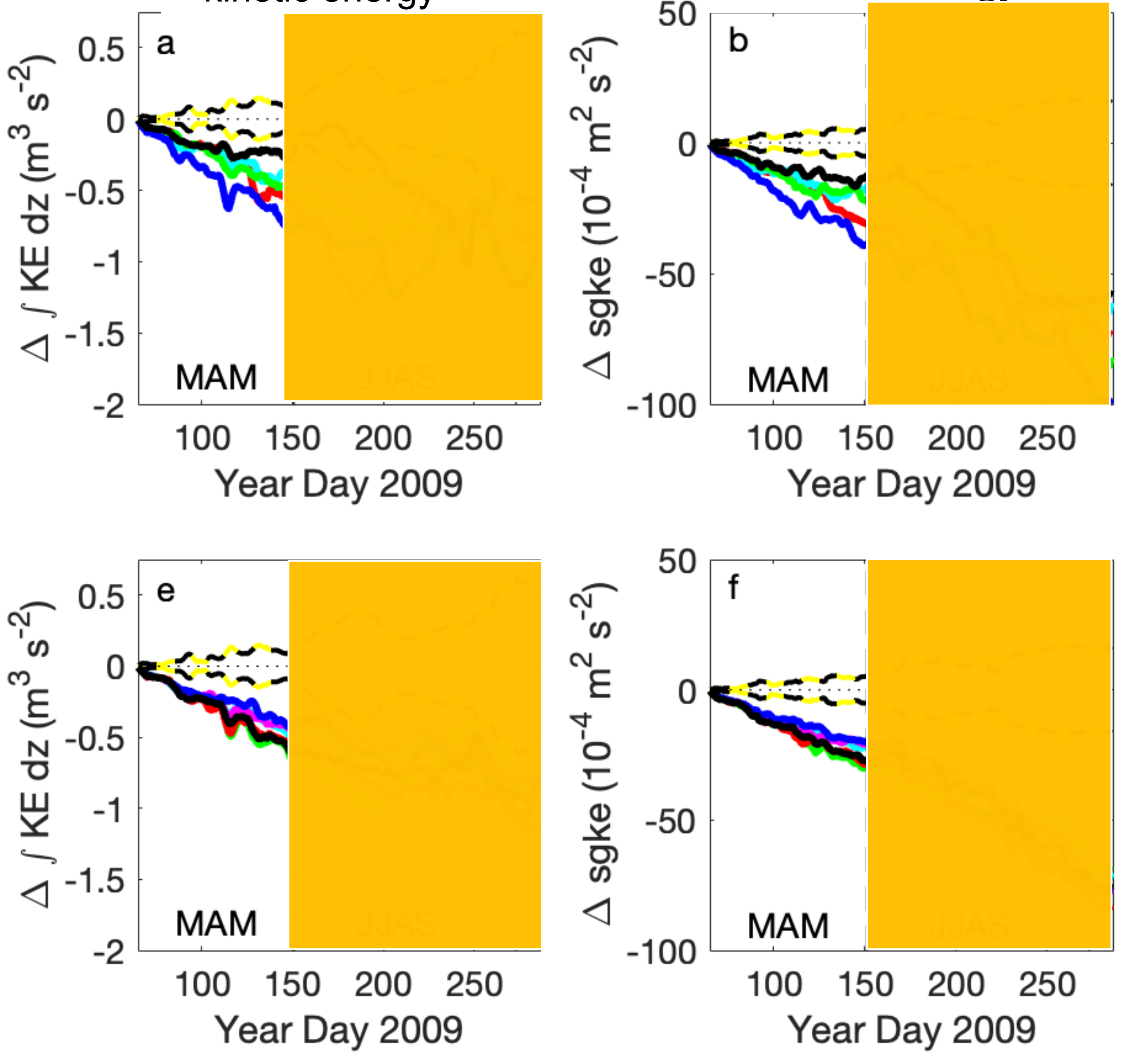
Reduced stress for wind-drift-corrected cases

Relative-w… …ace-cur… …ng of kinetic energy:

Depth-integrated kinetic energy | Surface geostrophic kinetic energy

Grouped by PBL scheme

Grouped by surface-current for coupling

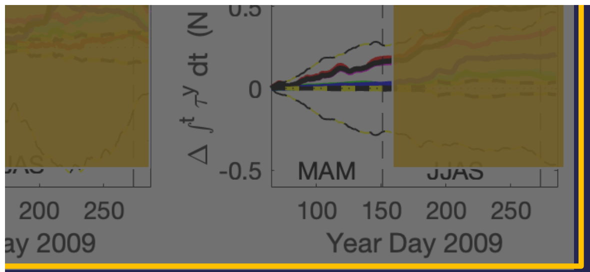


Consistent increase in kinetic energy damping with PBL scheme during MAM, when SST fluctuations are small, for PBL schemes ordered as:

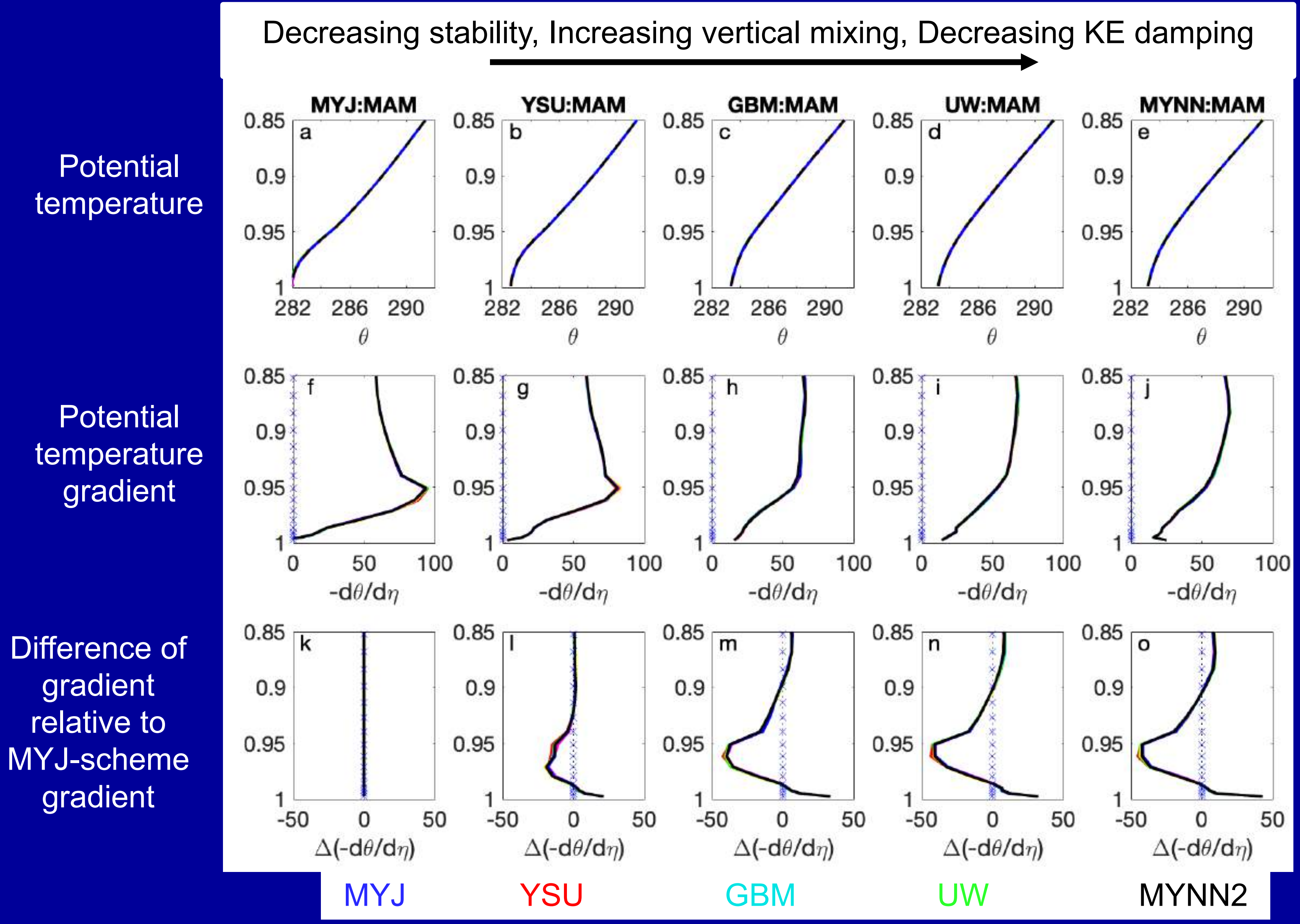
MYNN2, UW, GBM, YSU, MYJ

This is opposite to the ordering for increased SST-stress coupling found in previous analysis
(MYJ , YSU , GBM , UW, MYNN2)

(NB: We use MYJ with `sfclay=1`)



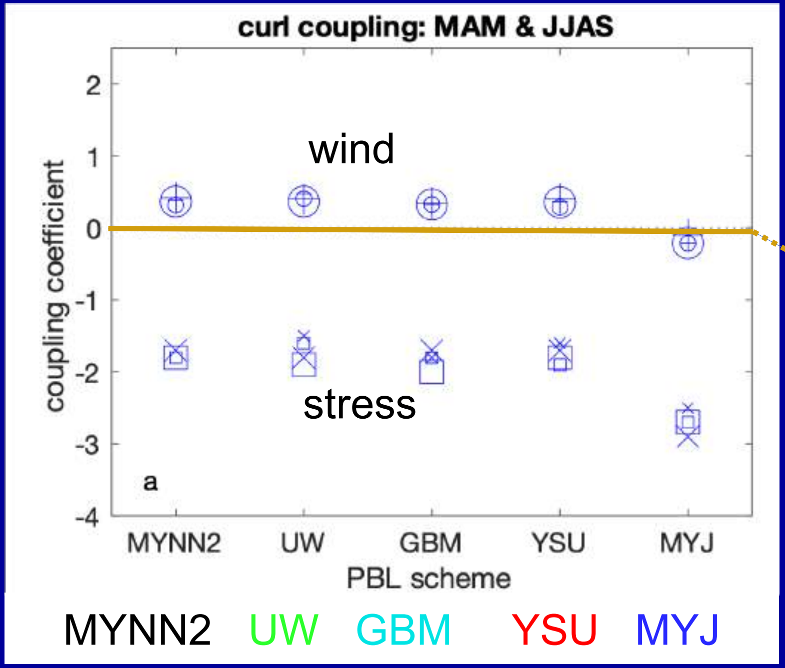
Mean atmospheric boundary layer stability (March-April-May) vs. normalized pressure level for each PBL scheme



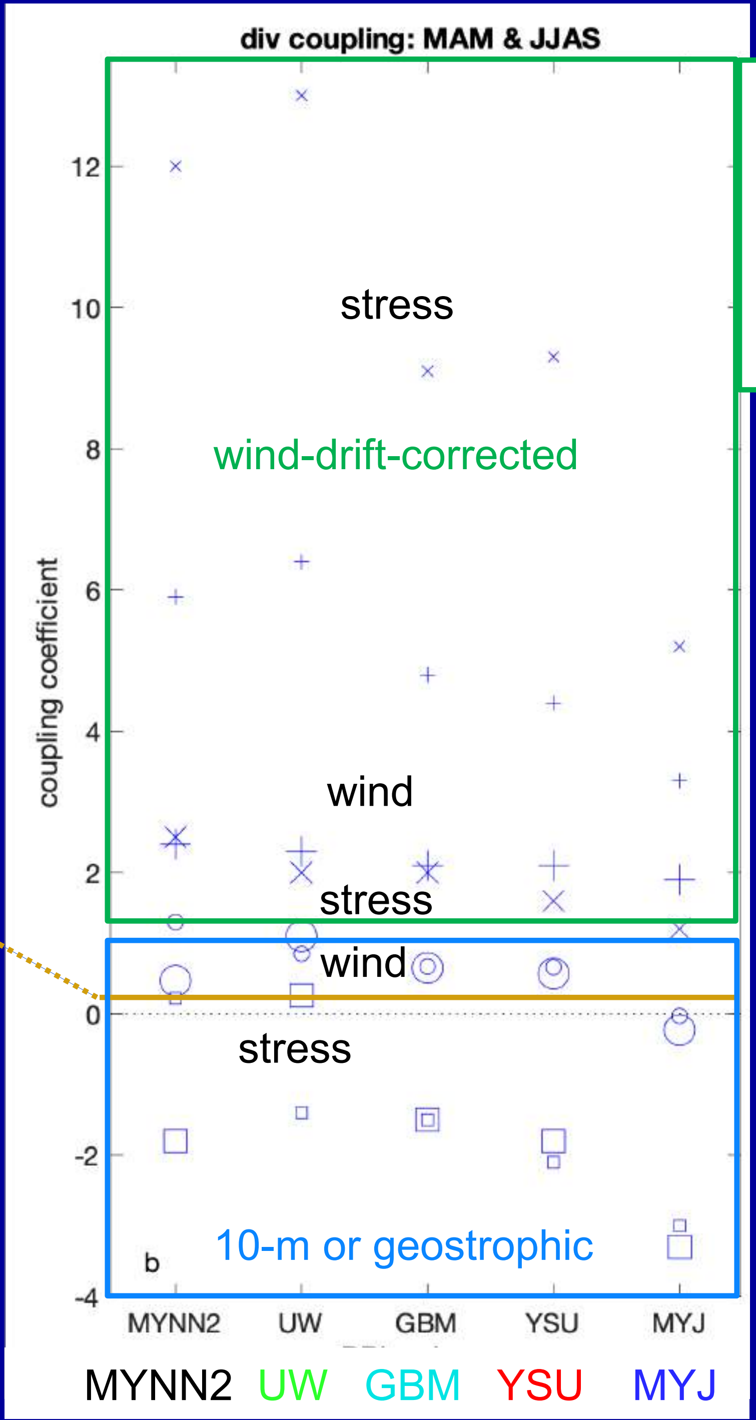
Coupling coefficients:

10-m wind (o,+) and stress (□,x) curl/divergence
vs. coupling-surface-current relative-vorticity/divergence
for March-April-May (large symbols)
and June-July-August-September (small symbols)
for 10-m or geostrophic (□,o)
and wind-drift-corrected (x,+) surface currents

curl : relative vorticity



Decreasing stability, Increasing vertical mixing, Decreasing KE damping



wind-drift response to SST-driven 10-m-wind divergence (large during JJAS when SST fluctuations are large)

divergence : divergence

Differences: wind-drift-corrected vs. 10-m or geostrophic surface current coupling

Surface geostrophic KE: Wind-drift-corrected | Difference

Geostrophic wind-work difference

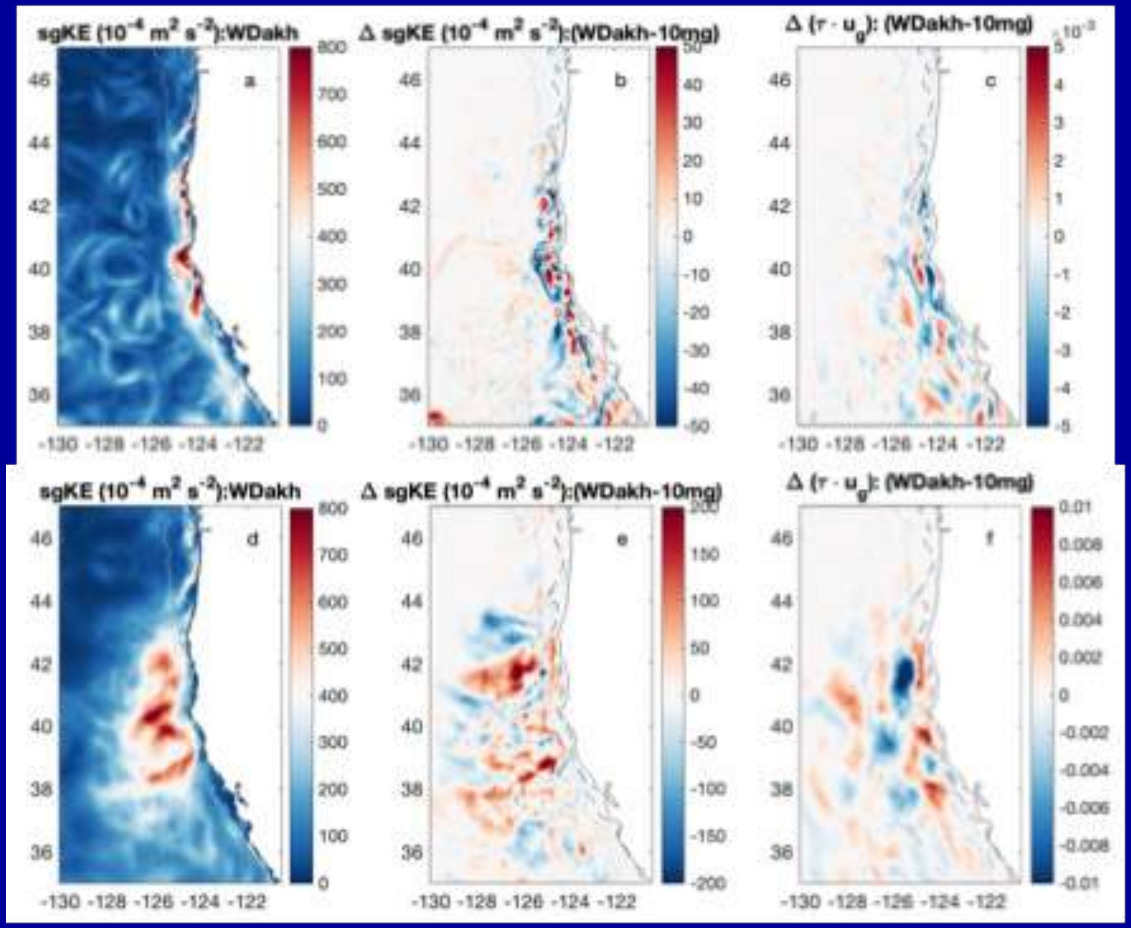
SST difference

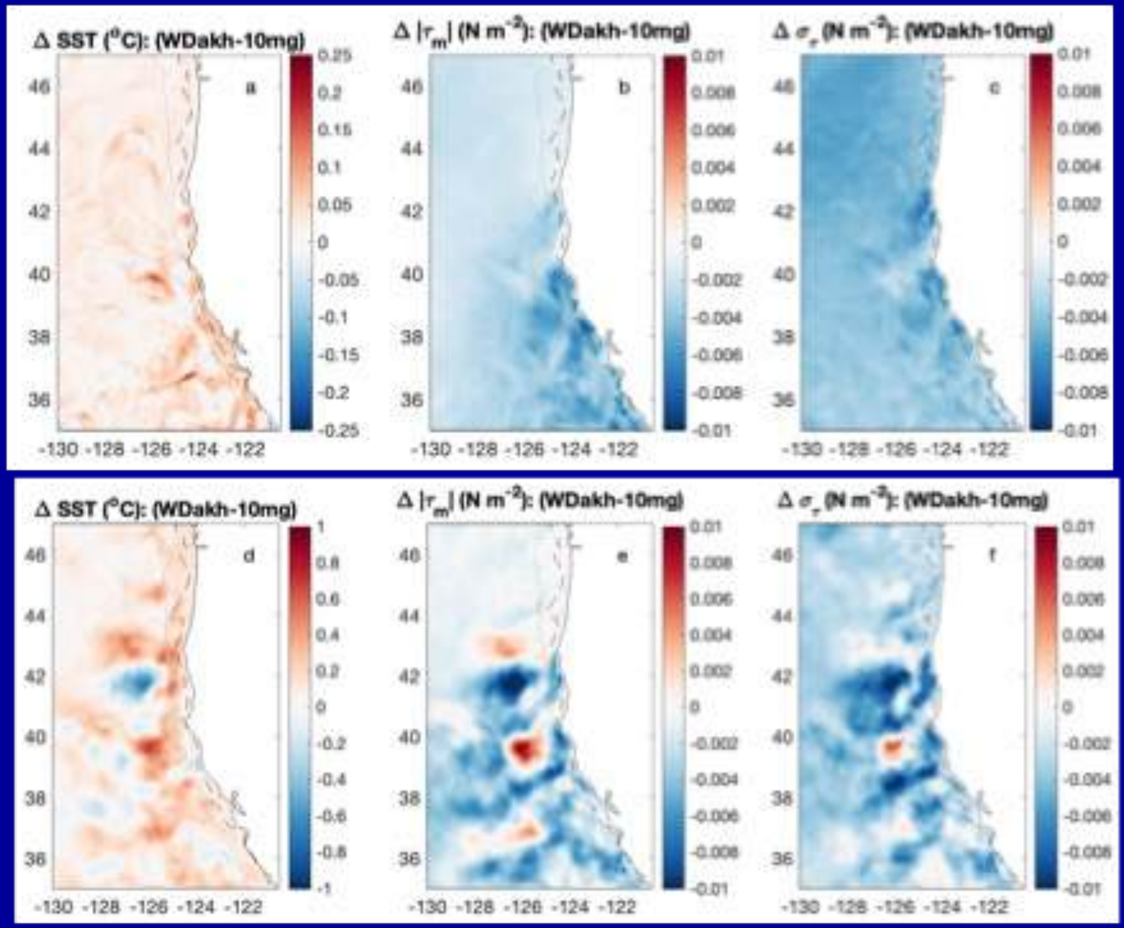
Stress mean magnitude difference

Stress std dev difference

March-April-May

June-July-August-September





KE increases where large,
decreases where small (?)

Warming, reduced stress;
SST-stress coupling during JJAS

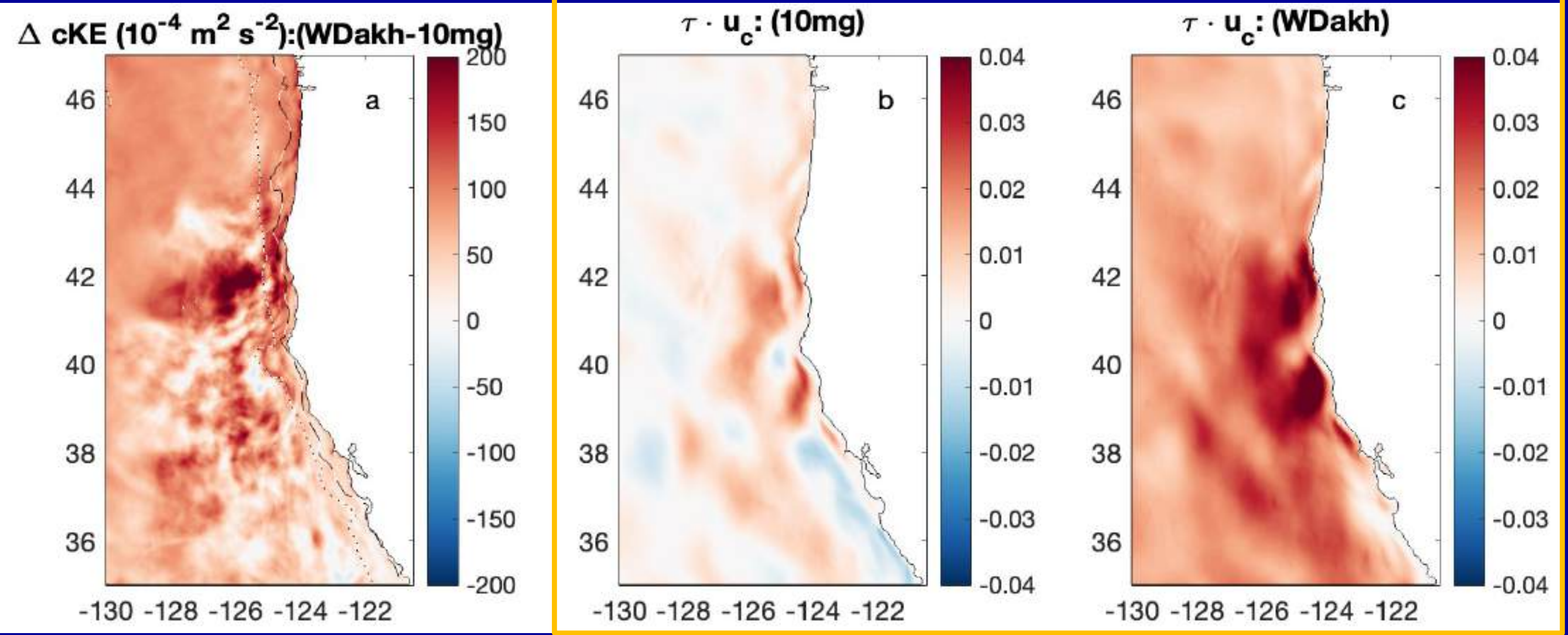
Effective wind-work for 10-m or geostrophic vs. wind-drift-corrected surface currents

Effective wind work: (mean) product of stress and coupling surface current

KE of coupling surface current

10-m or geostrophic

wind-drift-corrected

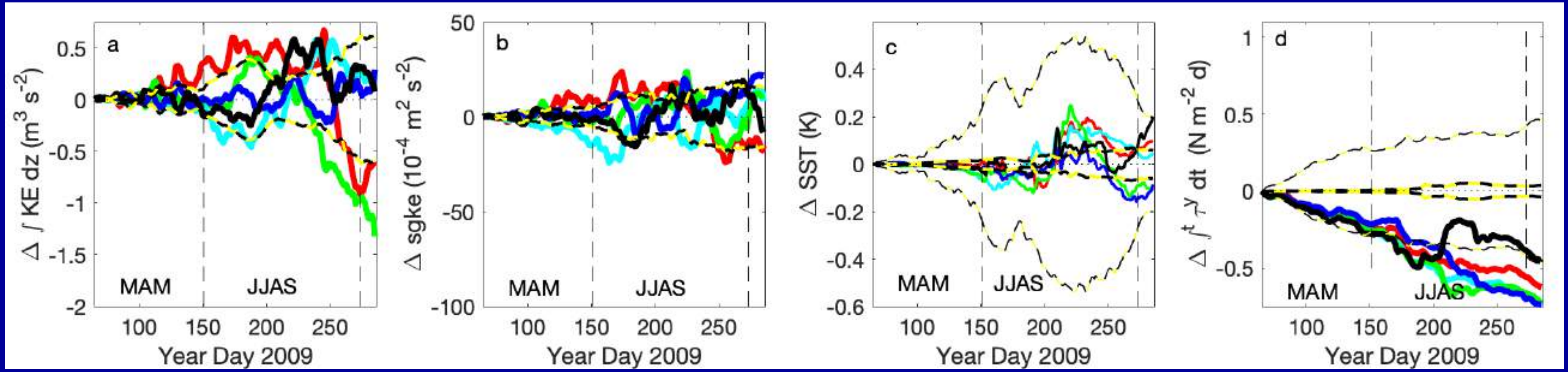


Effective wind-work is much larger for wind-drift-corrected coupling surface current (large downwind current component)

Wind-drift-corrected coupling surface-current with drag coefficient (instantaneous stress) increased by 5%

Motivation: compensate for effective reduction from “3% of wind” surface current

depth-integrated KE difference | surface geostrophic KE difference | SST difference | time-integrated mean meridional stress difference



No systematic change in KE or mean SST!

Systematic 5% increase in mean integrated upwelling forcing (meridional stress)

-0.75/220 = -0.0034
-0.0034/-0.07 = 0.05 = 5%

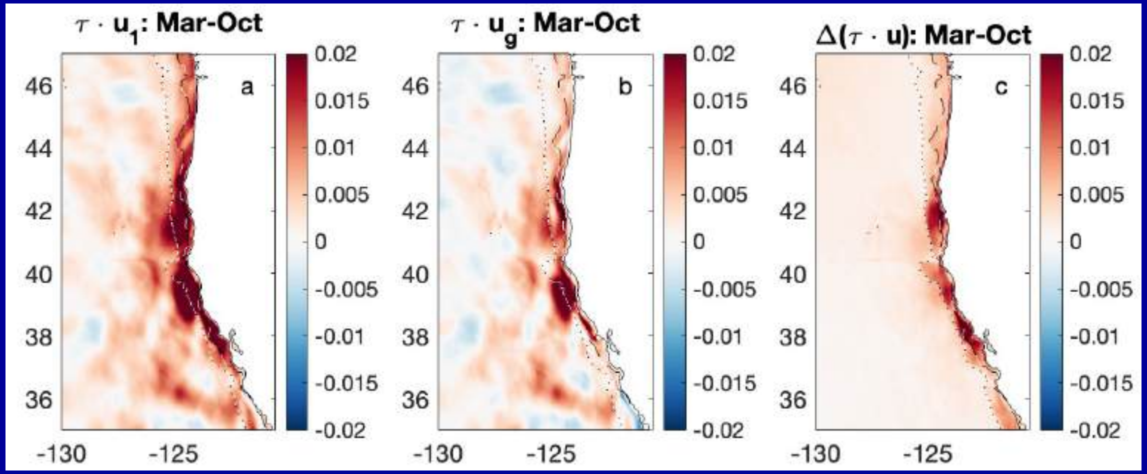
Quasi-equilibrium balance between forcing and damping (both proportional to stress, with damping also proportional to circulation)?

Summary

- Uppermost grid-level velocity has wind-drift component with log-layer structure above 1-m depth;
- Surface-current damping depends more strongly on atmospheric PBL scheme than on surface-current formulation: weaker PBL mixing gives stronger damping;
- Coupling coefficients computed relative to wind-drift-corrected surface velocities can show large apparent values, arising from wind-drift response;
- Wind-drift-corrected surface-current formulations result in large changes in the effective wind-work based on the product of stress and relative-wind surface current but in only small changes in the kinetic energy of the circulation;
- Effective change in drag coefficient from wind-drift correction has proportional effect on mean stress but not on kinetic energy, suggesting a quasi-equilibrium balance between forcing and damping.

- Mean geostrophic wind work is concentrated in the shelf and slope regions during MAM and in the offshore region during JJAS;
- During MAM, changes in kinetic energy and geostrophic wind-work in the shelf and slope regions are spatially correlated, while during JJAS, changes in geostrophic wind-work are strongly modulated by SST-stress coupling;
- Damping is stronger in the less energetic, offshore region than in the more energetic, coastal region.

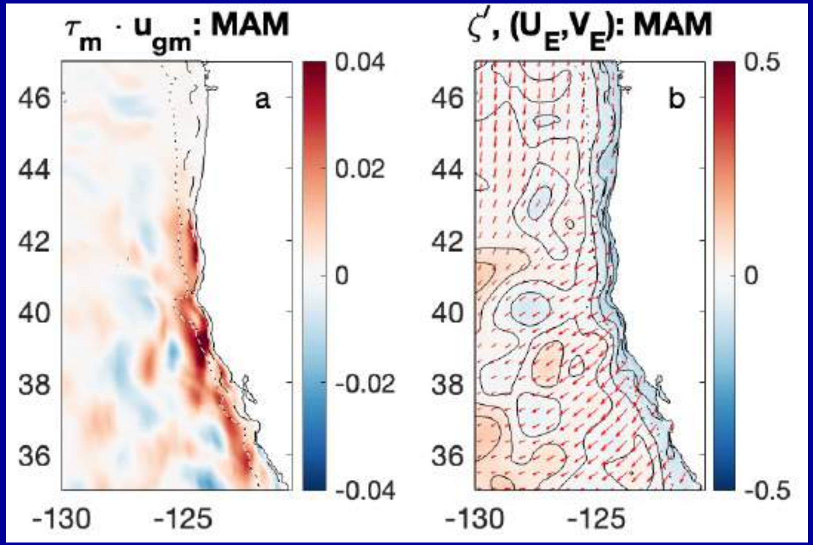
Mean total and geostrophic wind work



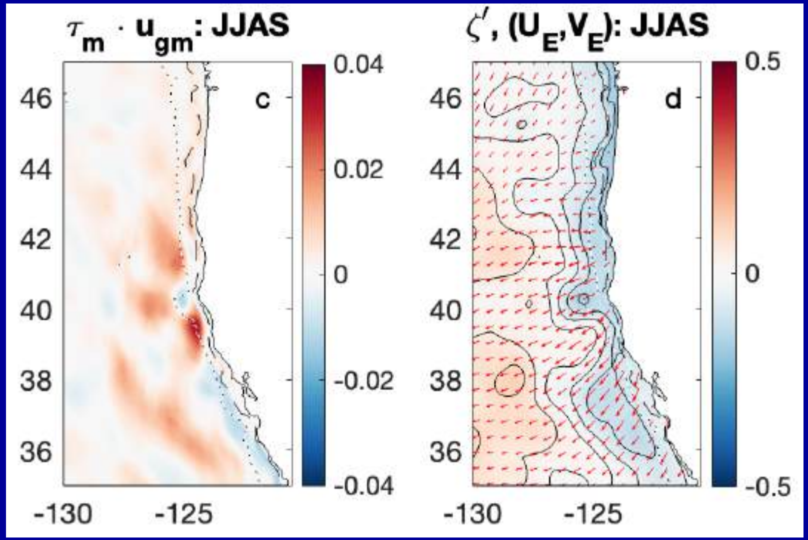
Difference over shelf arises from stronger wind-drift response over shelf (numerical artifact)

Wind work from seasonal mean stress and surface geostrophic velocity (Ekman transport up sea-surface pressure gradient)

Mean geostrophic wind work concentrated over shelf and slope during MAM



March-April-May



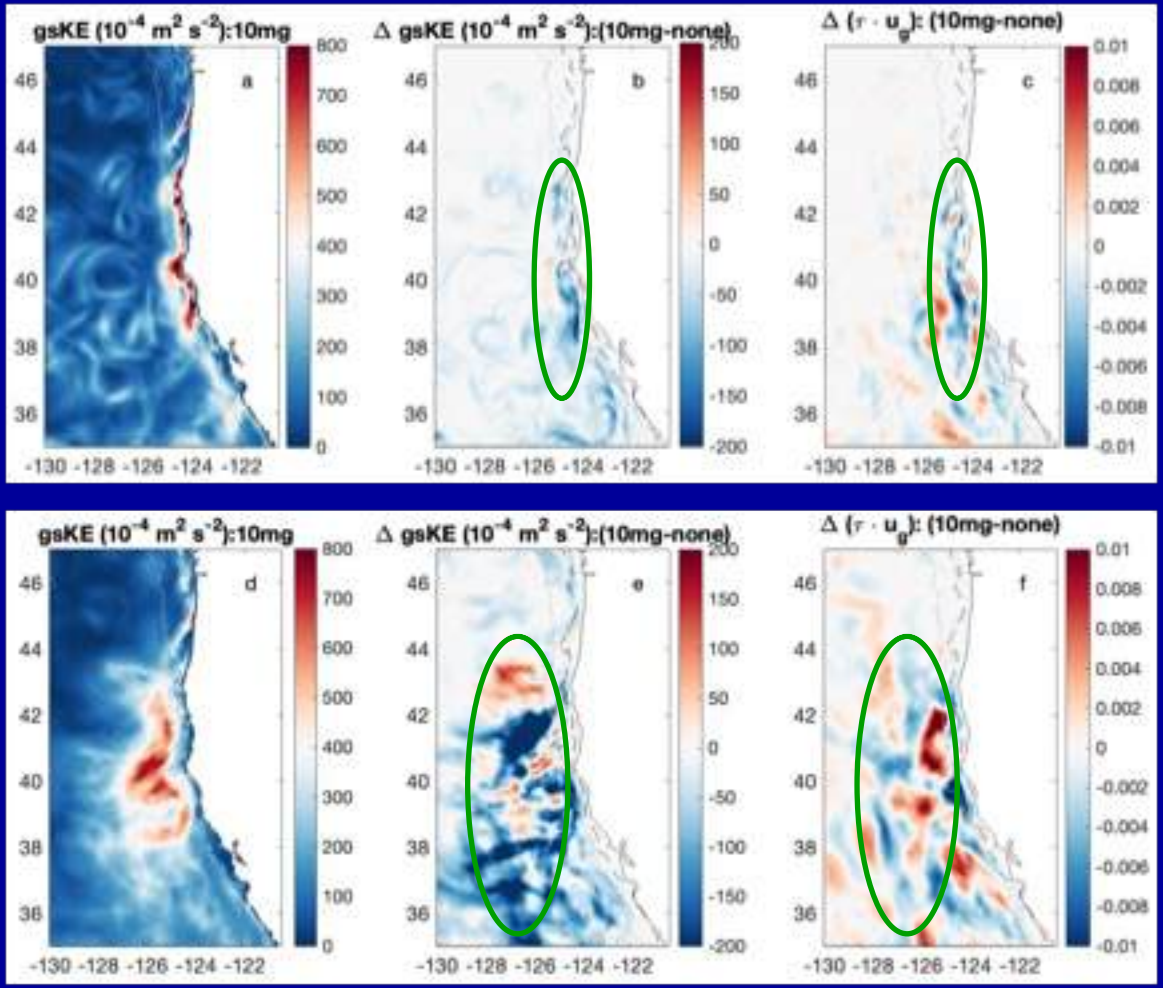
June-July-August-September

Mean geostrophic wind work stronger offshore during JJAS

Spatial patterns of geostrophic KE and wind work

March-April-May

June-July-August-September



Spatial correlation during MAM suggests direct effect of wind-work on local KE

Lack of correlation during JJAS consisten with large SST-stress coupling effects

SST-stress coupling during JJAS

Differences for 10-m or geostrophic coupling vs. SST-coupling only

SST | Mean stress magnitude | Stress standard deviation