Sub-mesoscale wind-front interactions: The combined impact of thermal and current feedback

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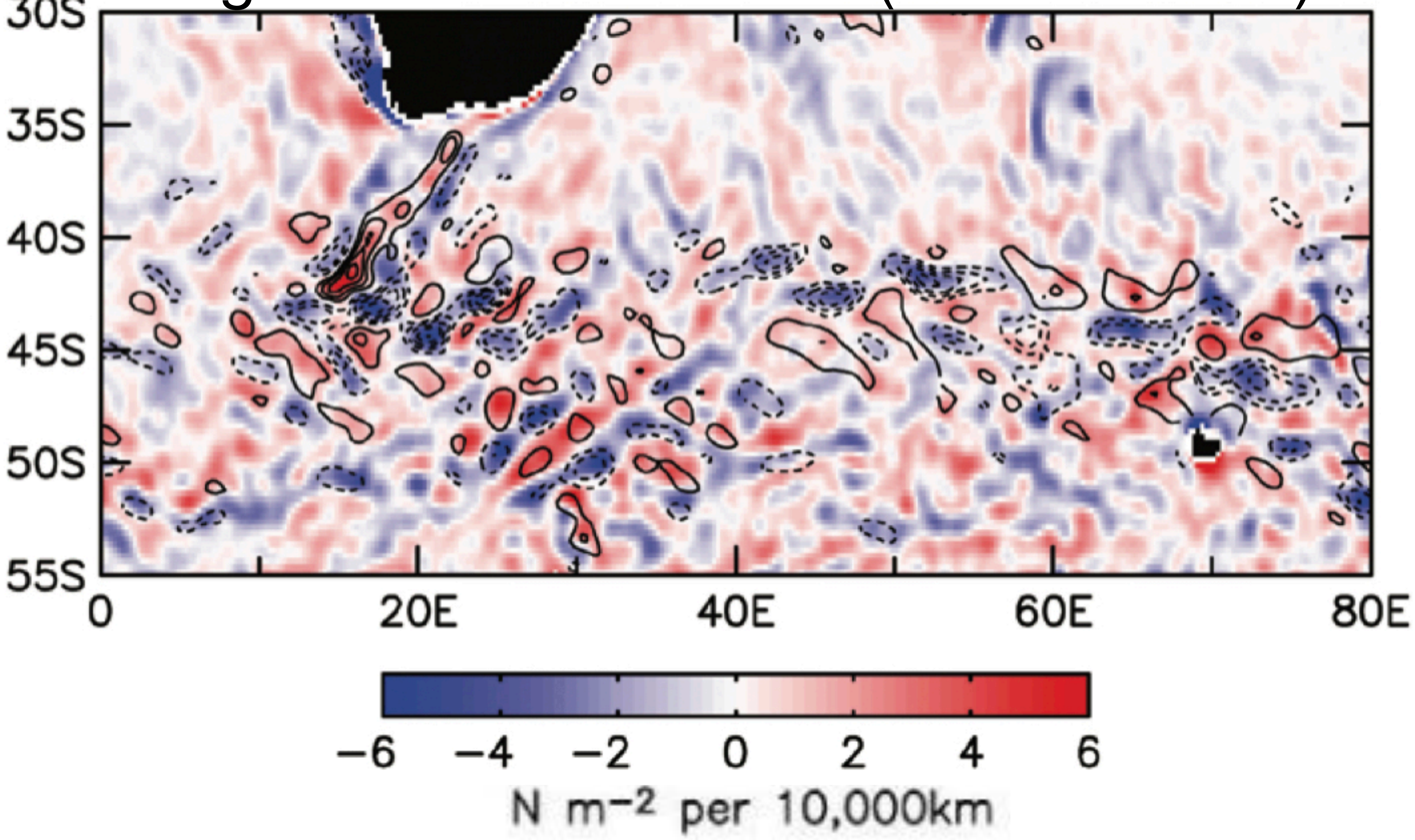
Patrice Klein, Hector Torres

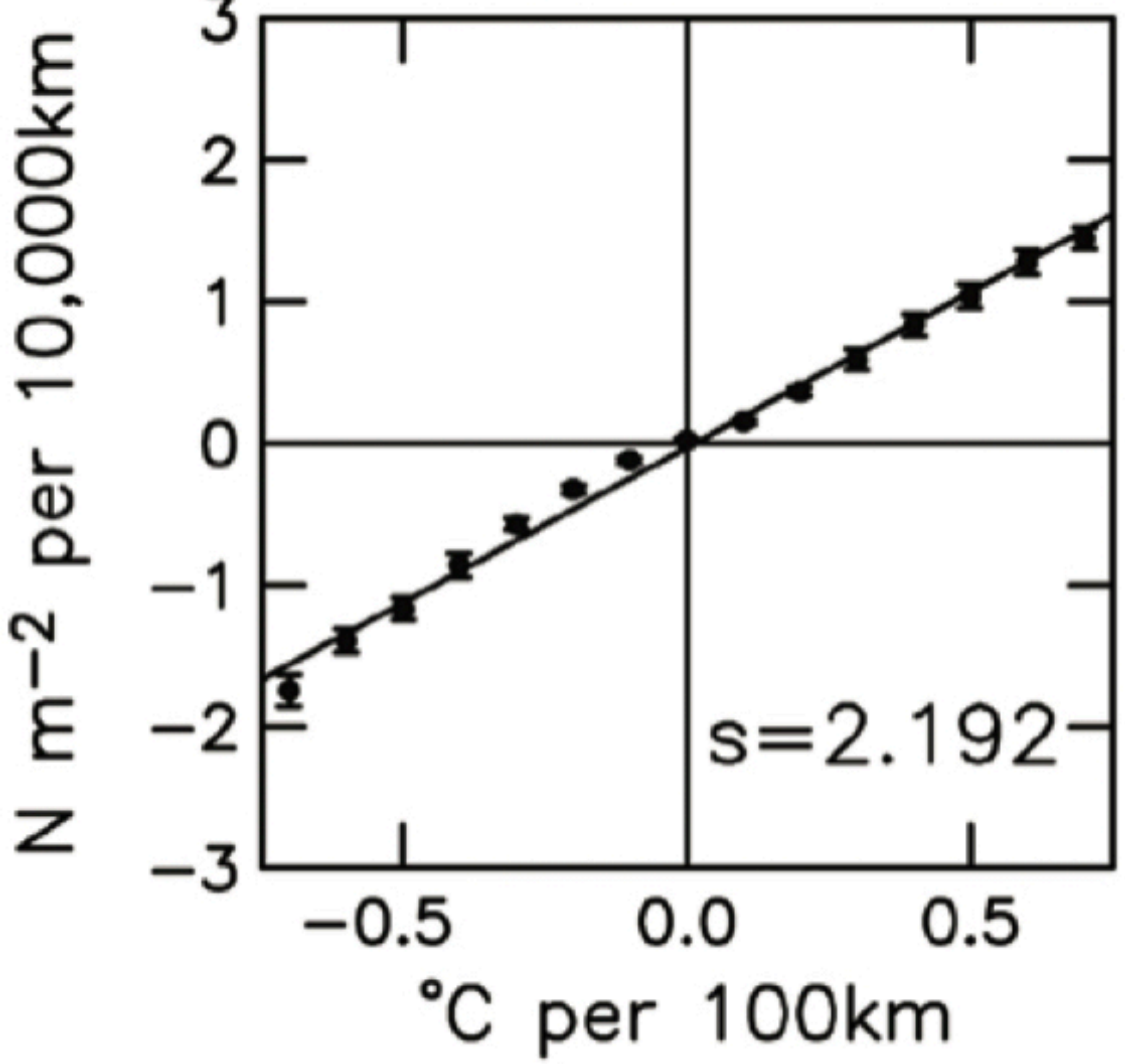
Mesoscale and Frontal-Scale Air-Sea Interactions Workshop
March 6th, 2023 @ Boulder, CO

Introduction - why wind-front interactions?

Agulhas Return Current (Jan-Feb 2008)



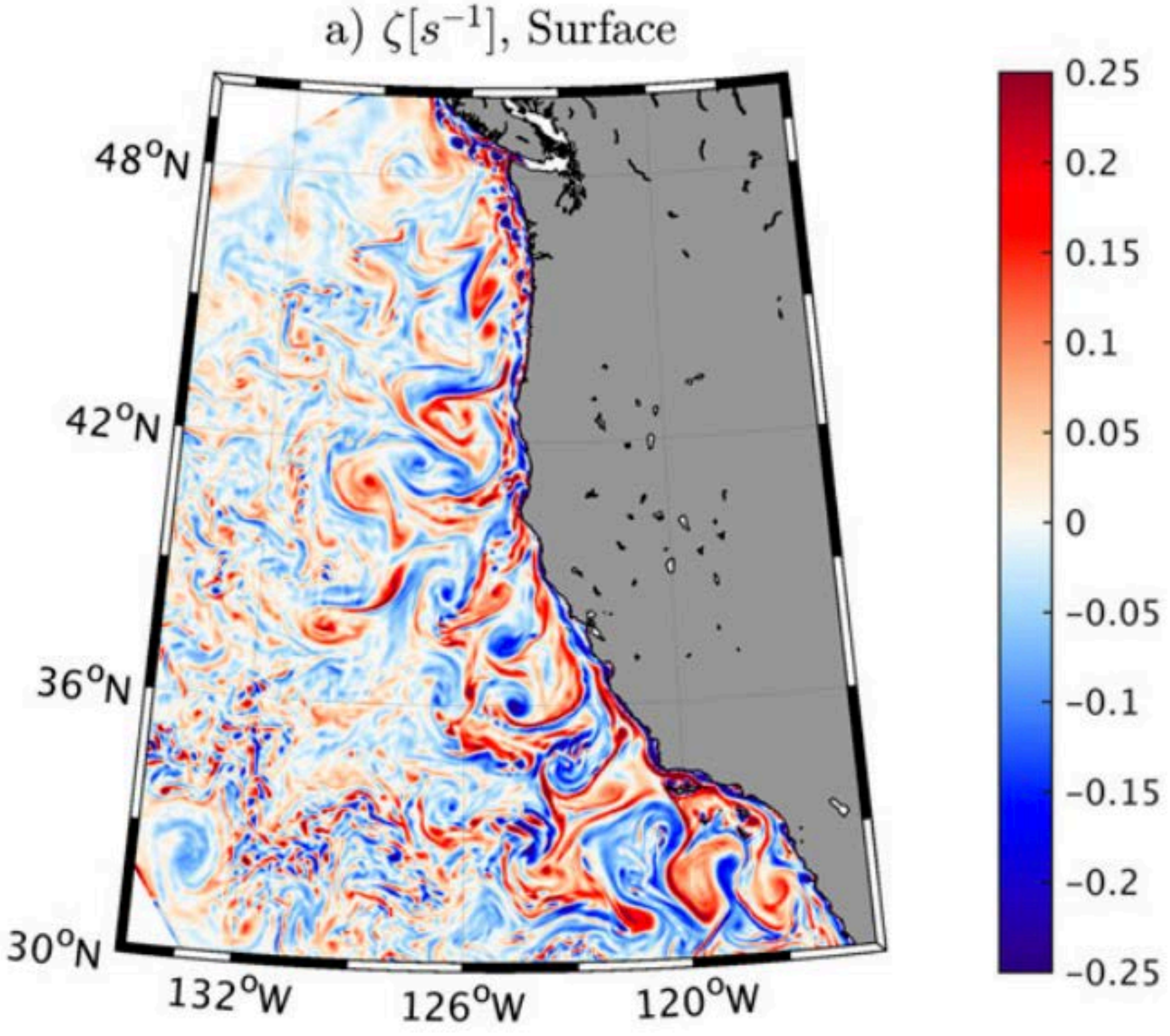
1-D thermal feedback



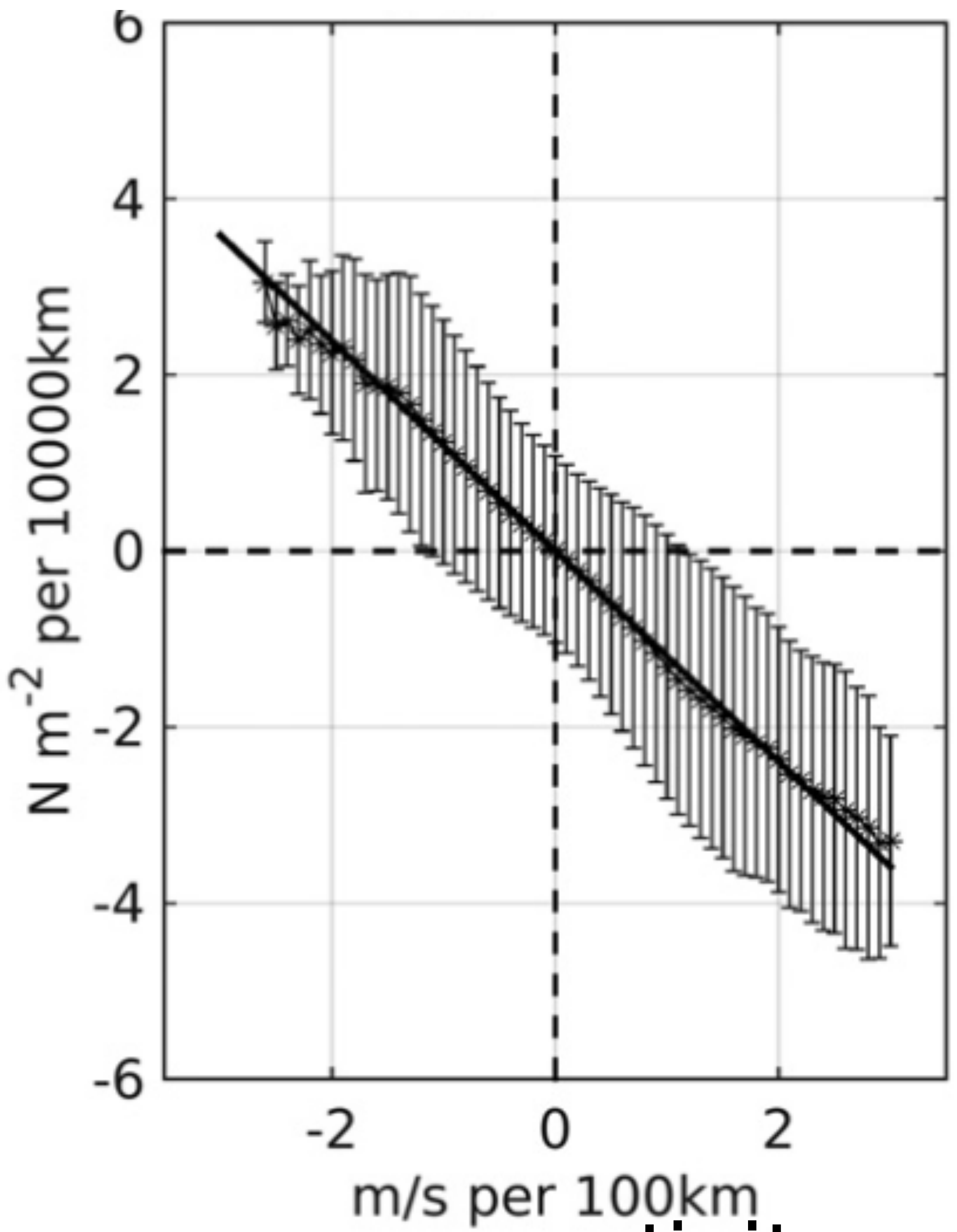
crosswind sst gradient

Figure from Chelton and Xie, 2010

Introduction - why *joint impact of* wind-front interactions?



1-D current feedback



ocean vorticity

Figure from Renault et al., 2016

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Introduction - why *sub-mesoscale* wind-front interactions?

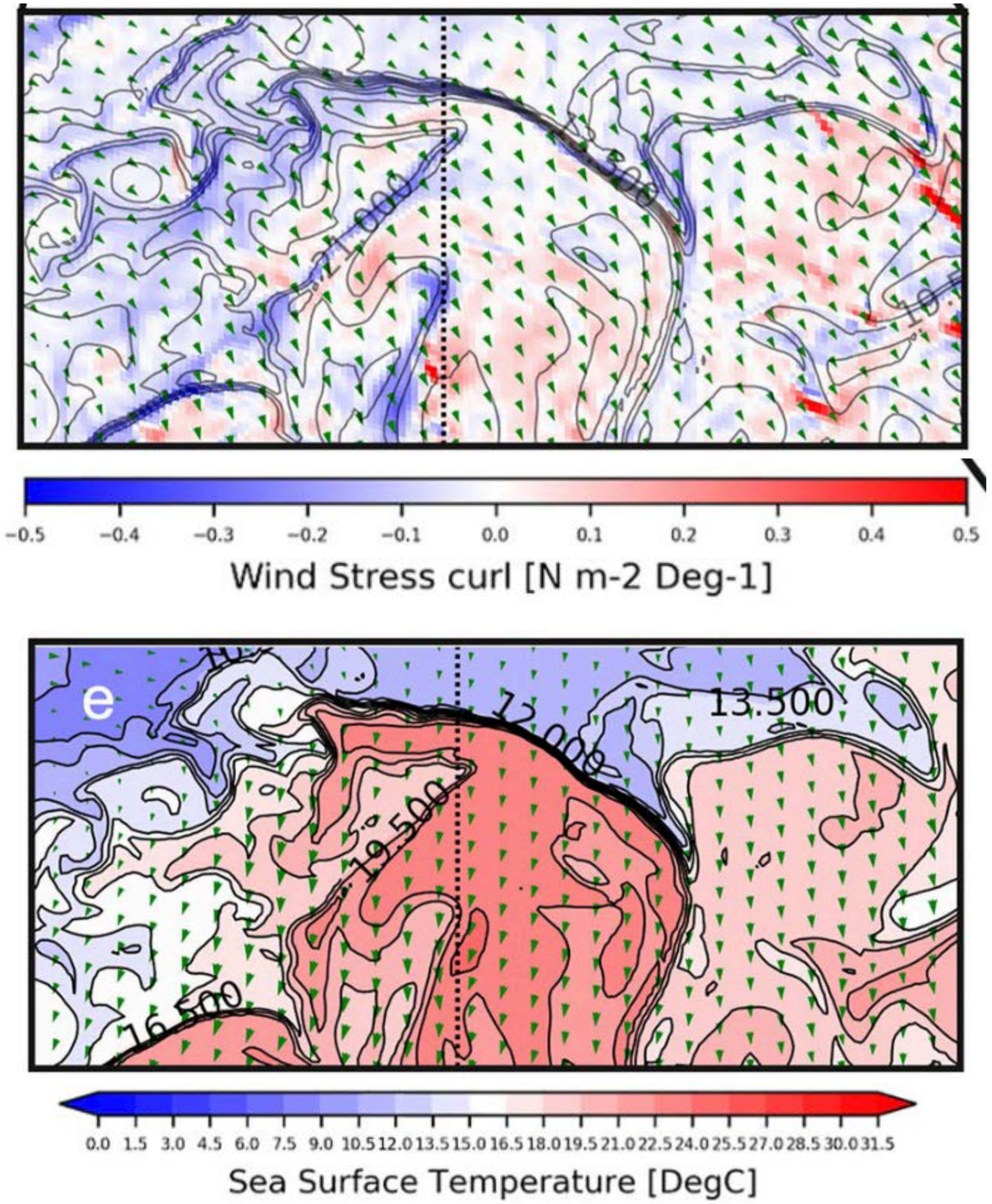
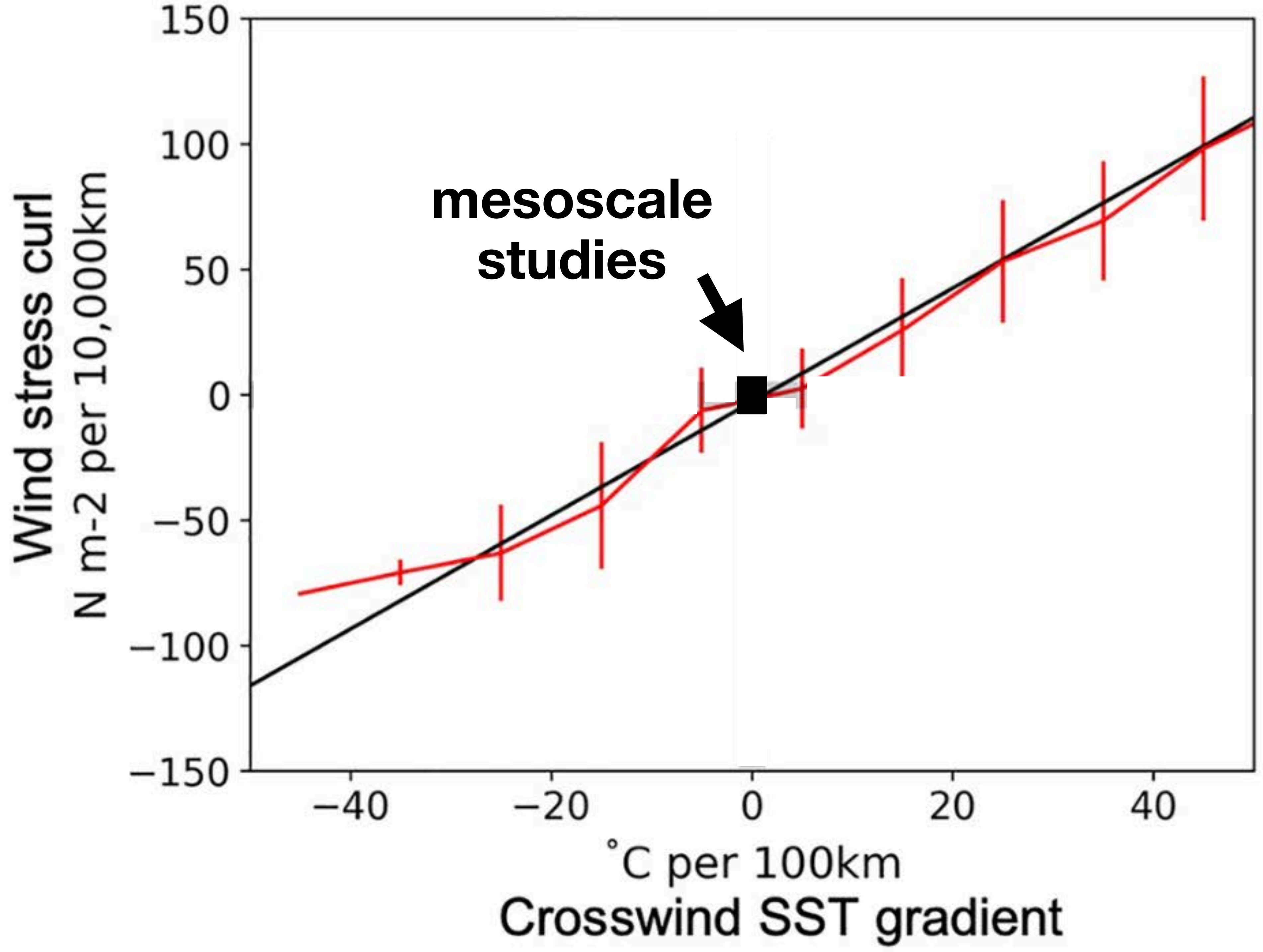


Figure from Strobach et al., 2022

1-D thermal feedback



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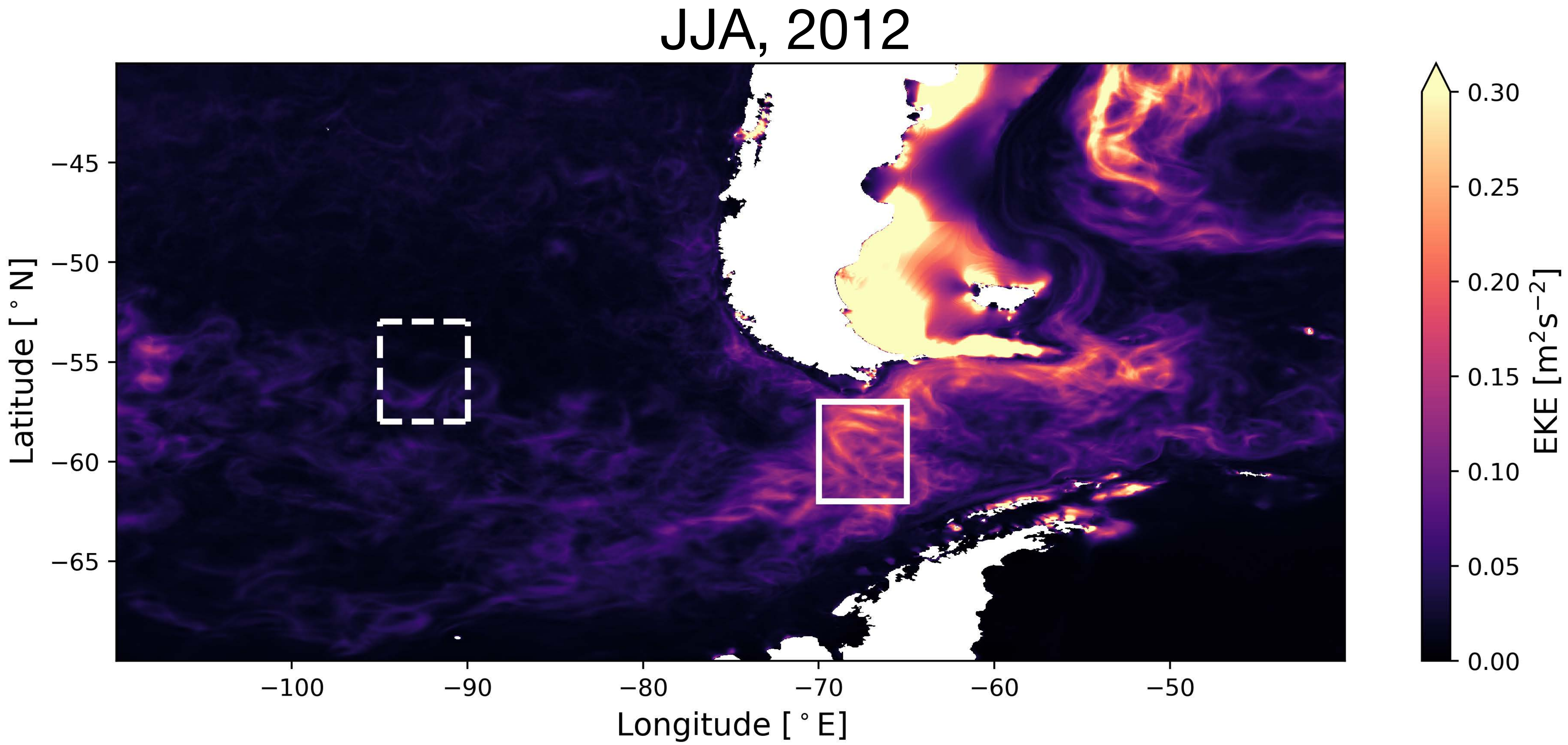
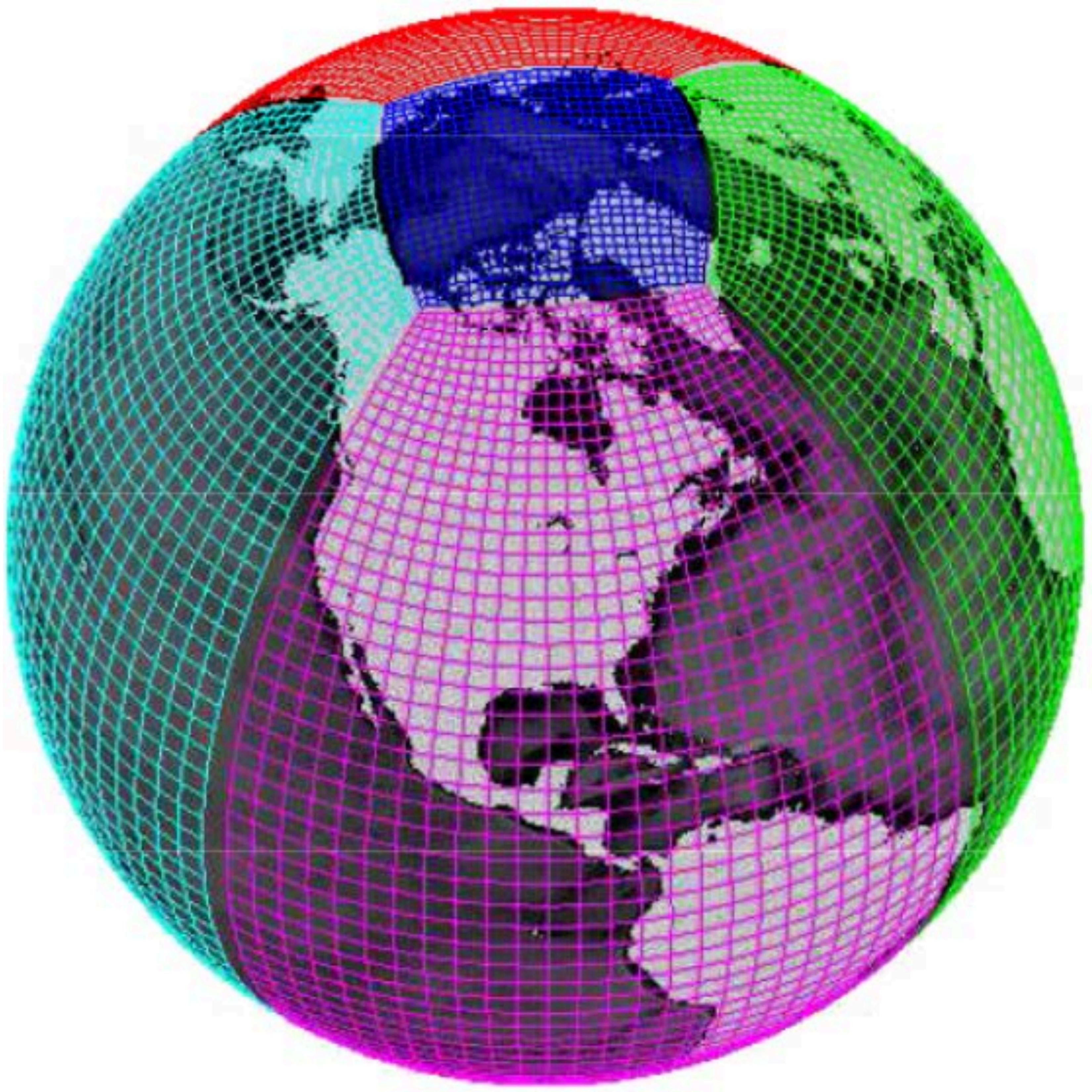
Focus and Goals



- **High-frequency submesoscale** wind-front interactions
- **Joint (non-linear) impact of** thermal and current feedback on **wind stress curl**

Method - high resolution global air-sea coupled model

GEOS/MIT Coupled Simulation (c1440 - llc 2160)



Latitude-**L**ongitude-**C**ap 2160

Ocean part:

- hourly output
- 2-4 km (1/24˚) horizontal resolution
- Other global coupled model: ~0.25 or 1˚

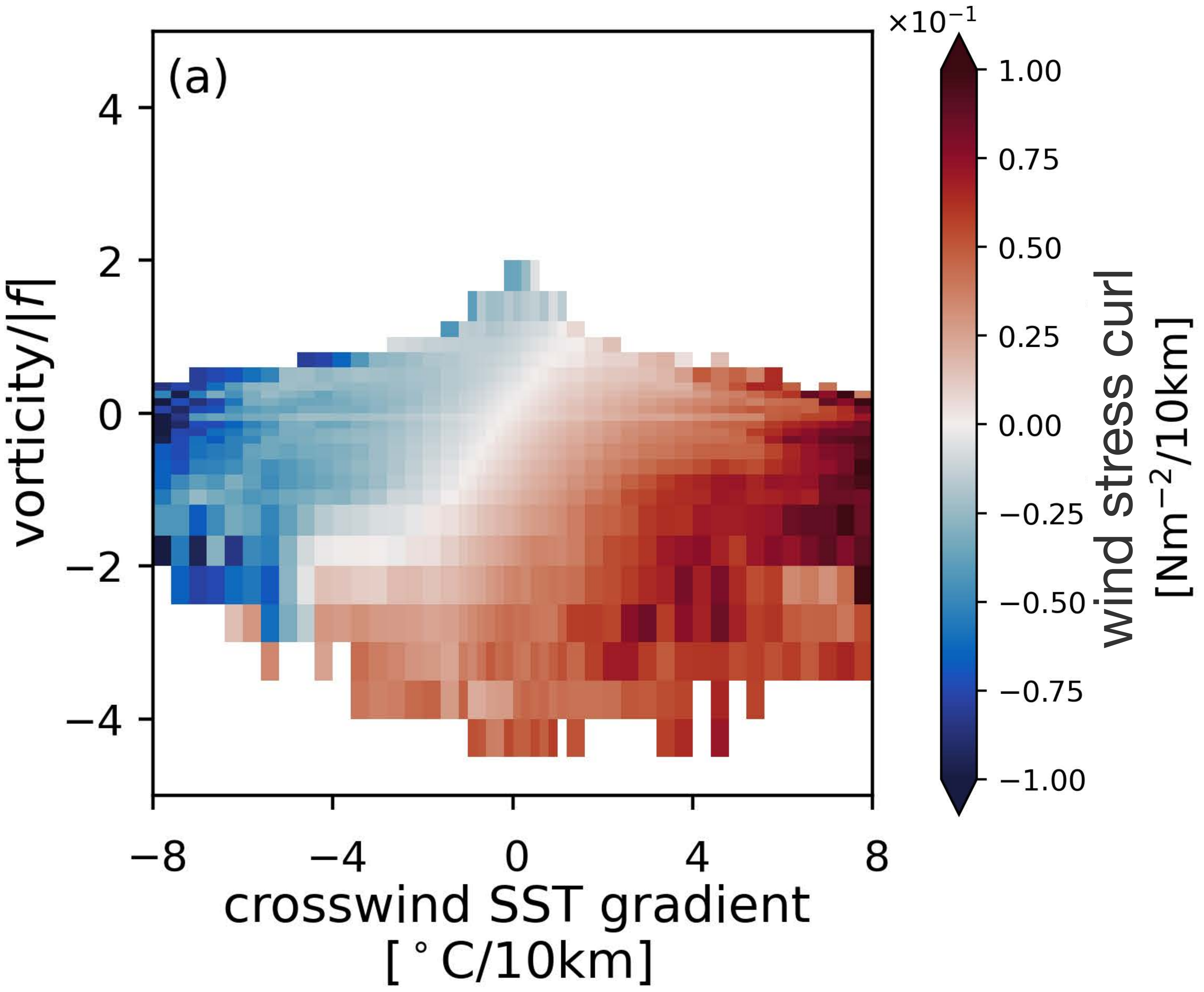
information exchange

Atmosphere part:

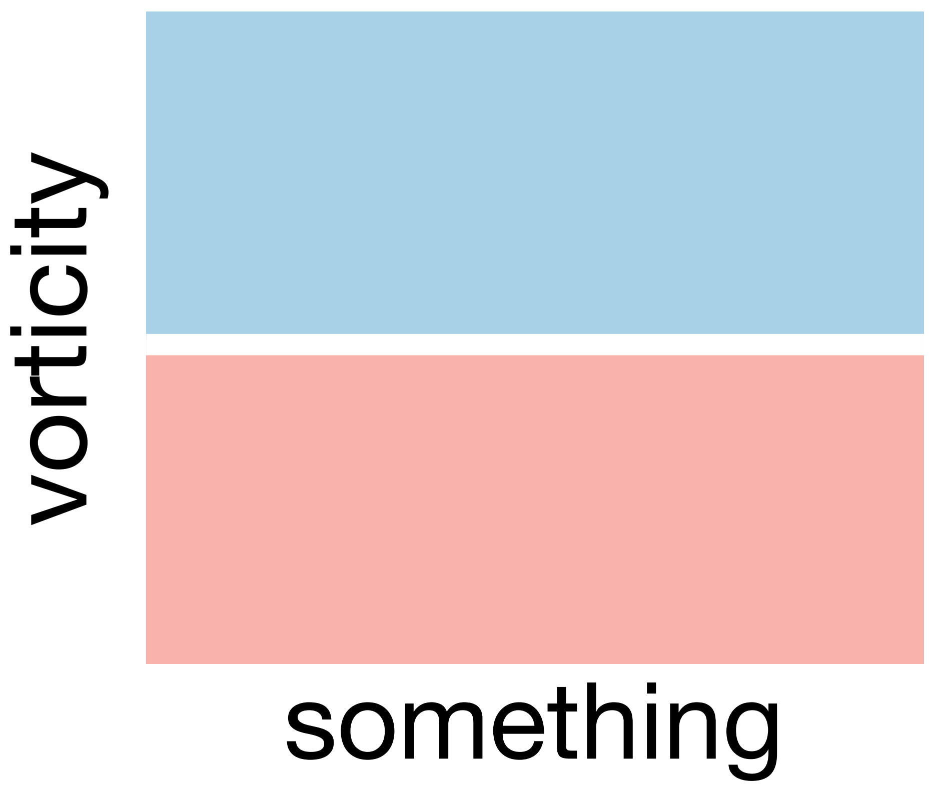
- 6 km horizontal resolution

Results - joint impact of thermal and current feedback

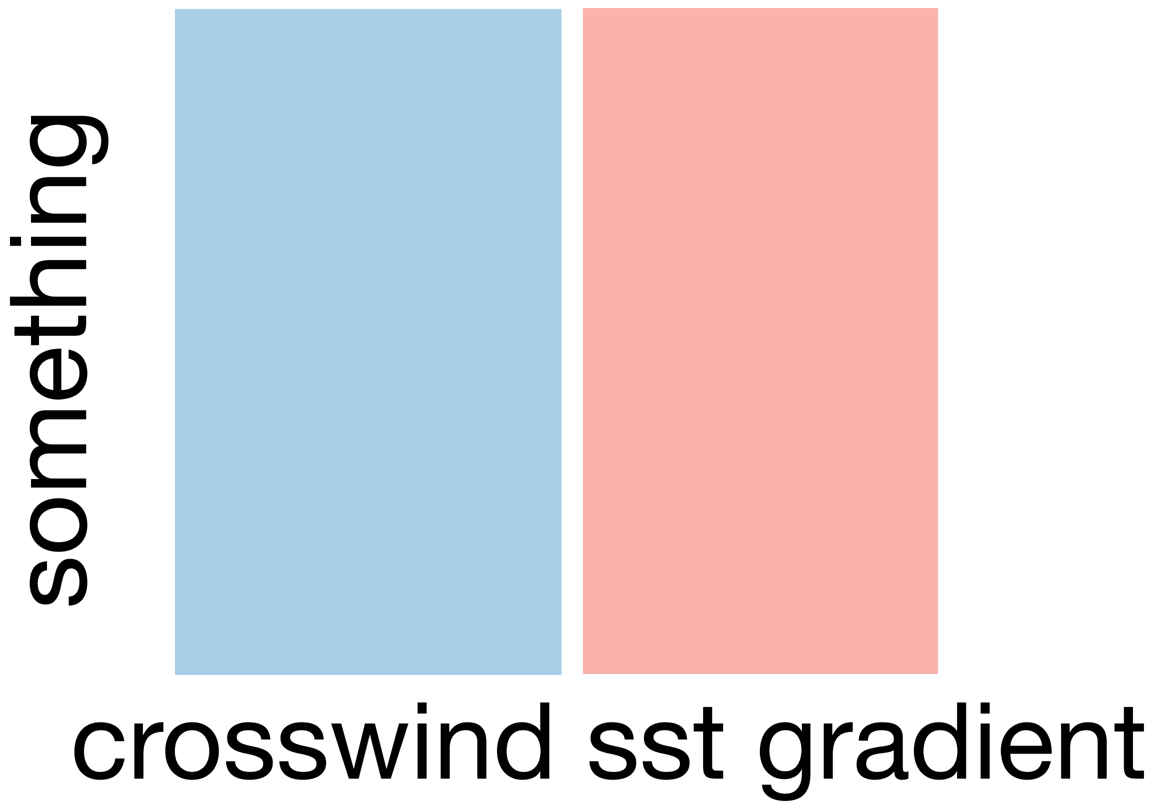
2-D feedback



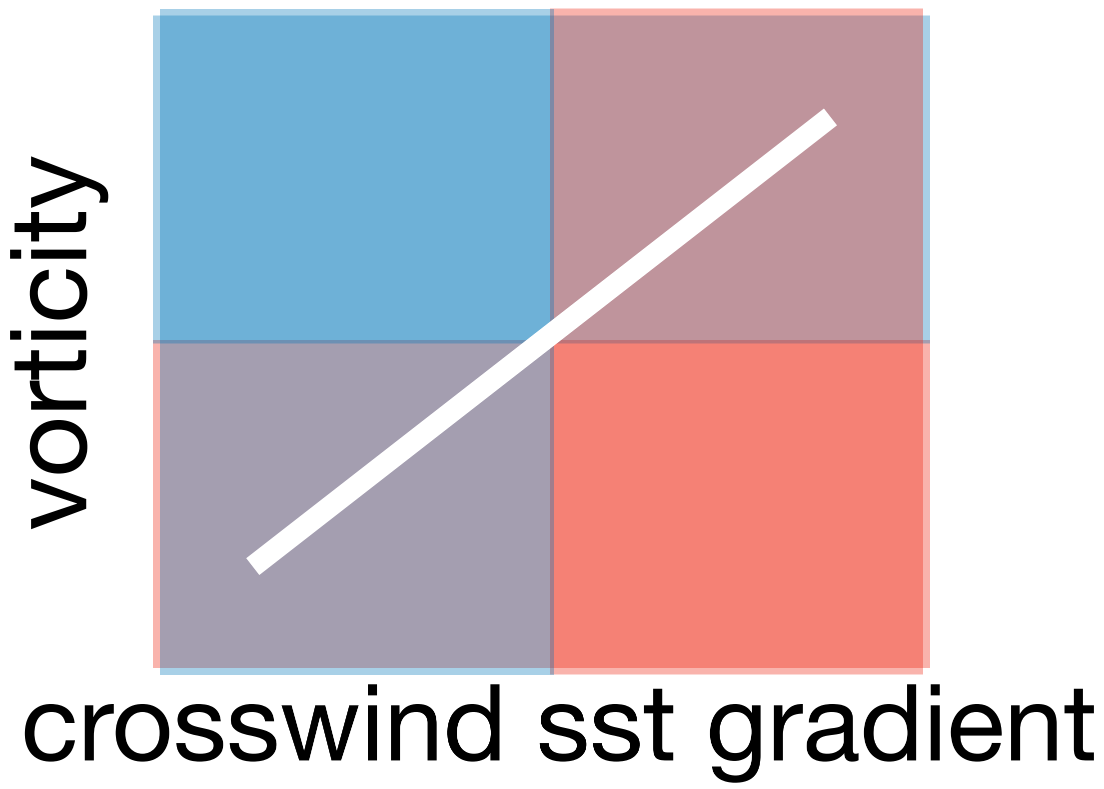
current feedback:



thermal feedback:



2-D current + thermal feedbacks



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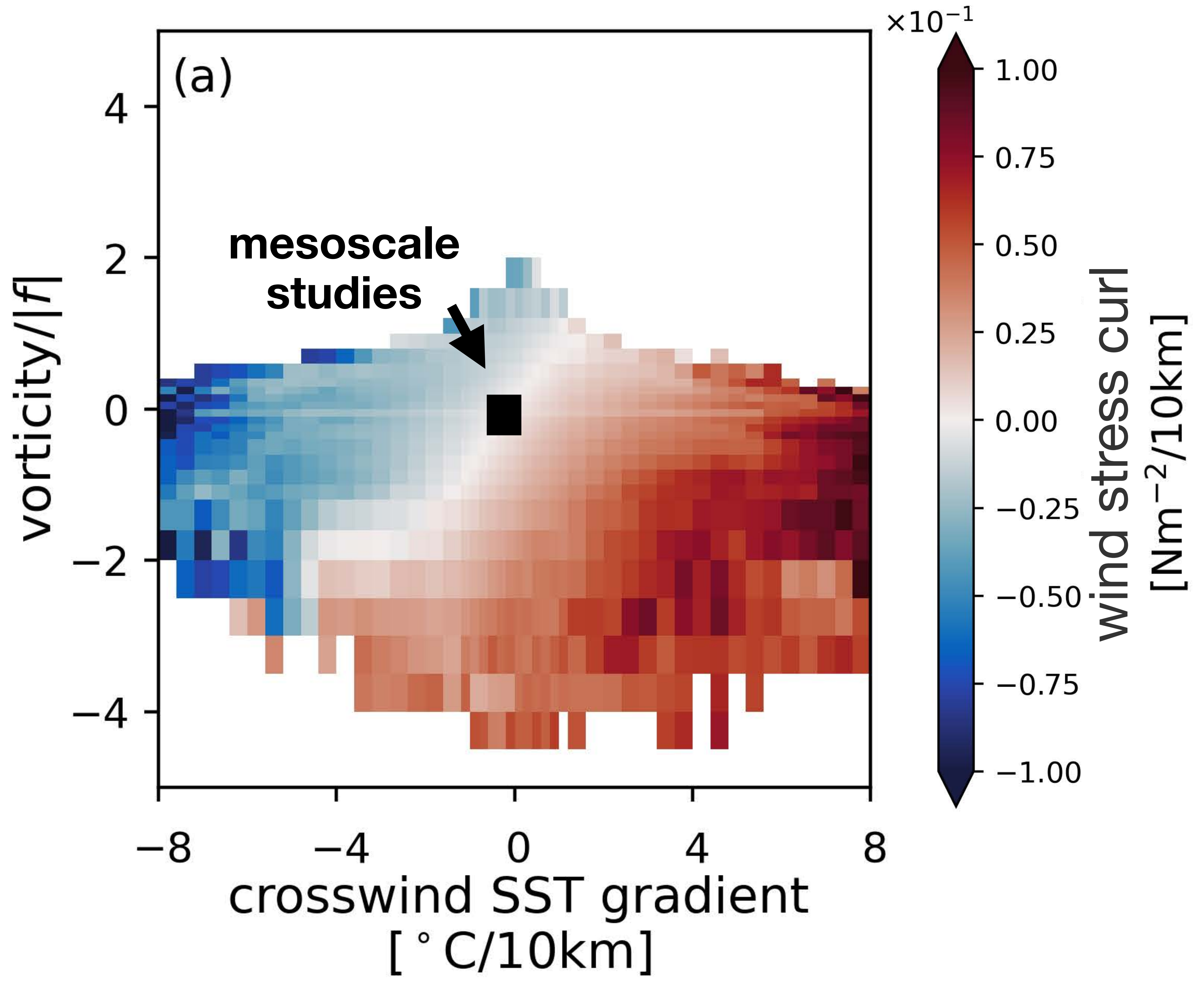
Results - joint impact of thermal and current feedback

2-D feedback



- **Current and thermal feedback work in tandem** to modify $\nabla \times \tau$, **~20 times stronger** than in previous mesoscale studies
- Strong potential to **affect ocean vertical velocity**

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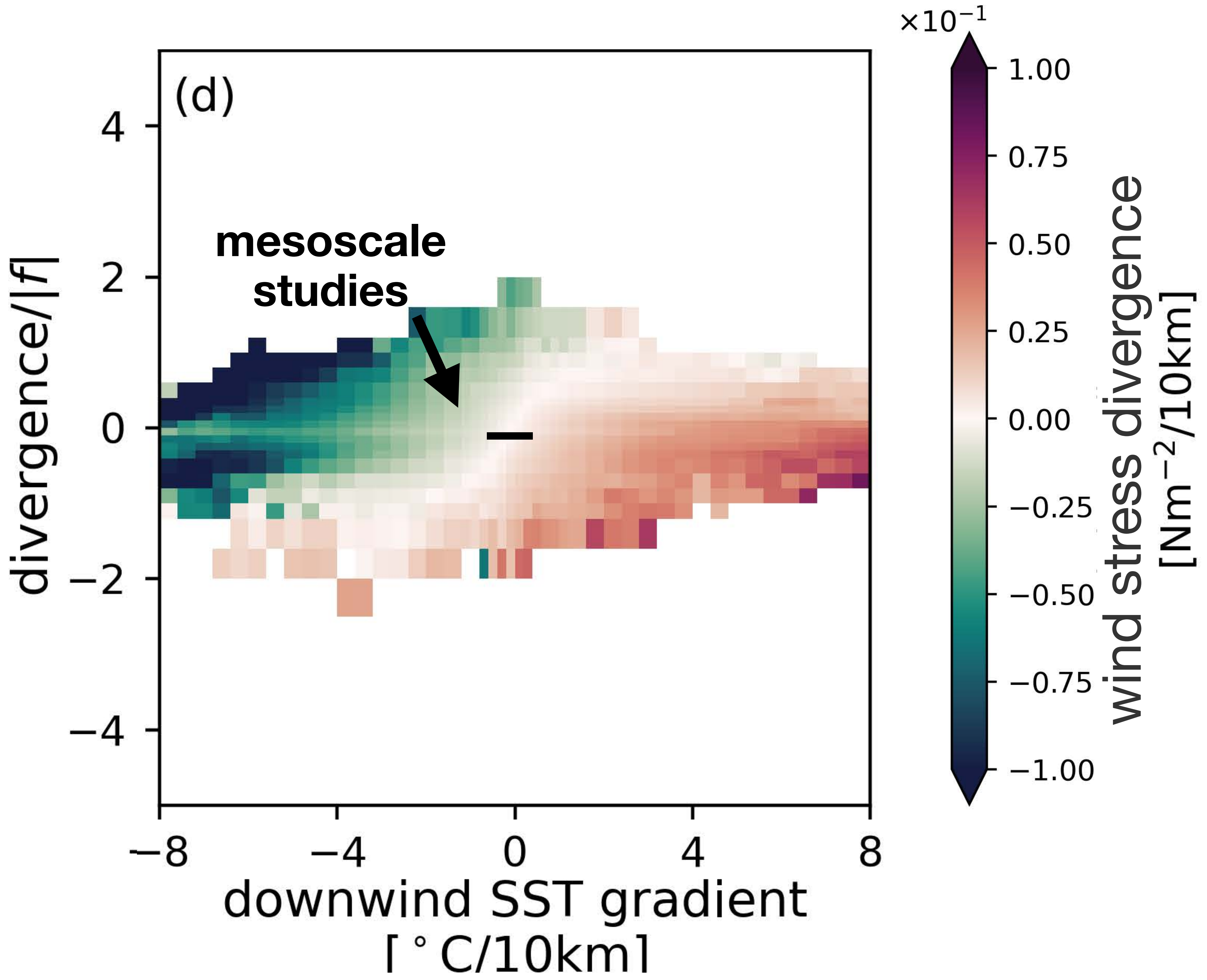
Results - joint impact of thermal and current feedback

2-D feedback



- **Sub-mesoscale ocean divergence is negatively correlated with wind stress divergence**
- **Strong potential to affect vertical motions in the atmospheric boundary layer**

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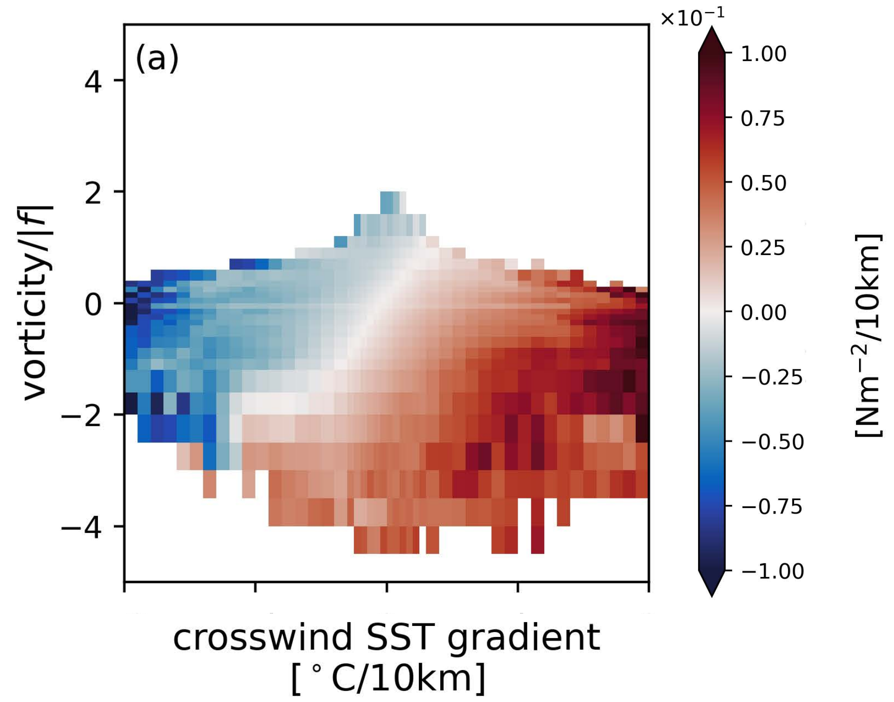
Results - wind stress curl reconstruction

- wind stress curl ~ αvorticity + βcrosswind sst gradient

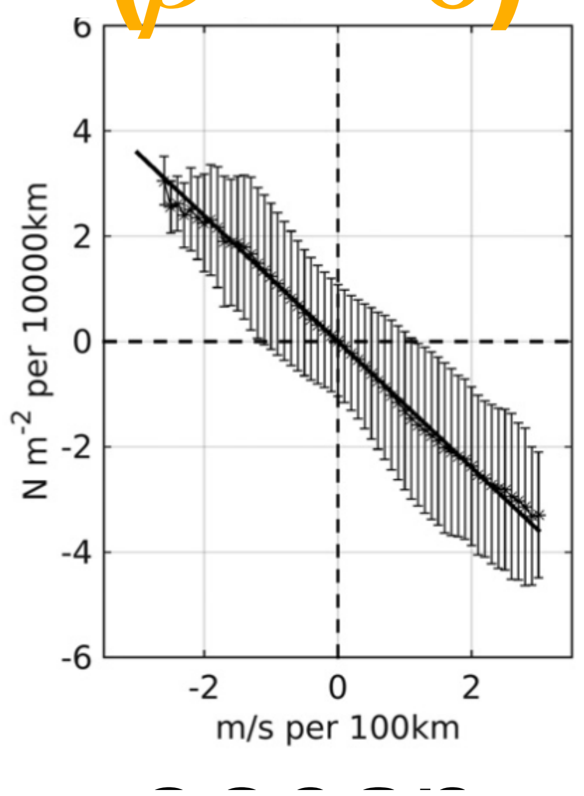
  limitation: only wind stress curl induced by wind-front interactions

- 4 ways of reconstruction and coefficient calculation:

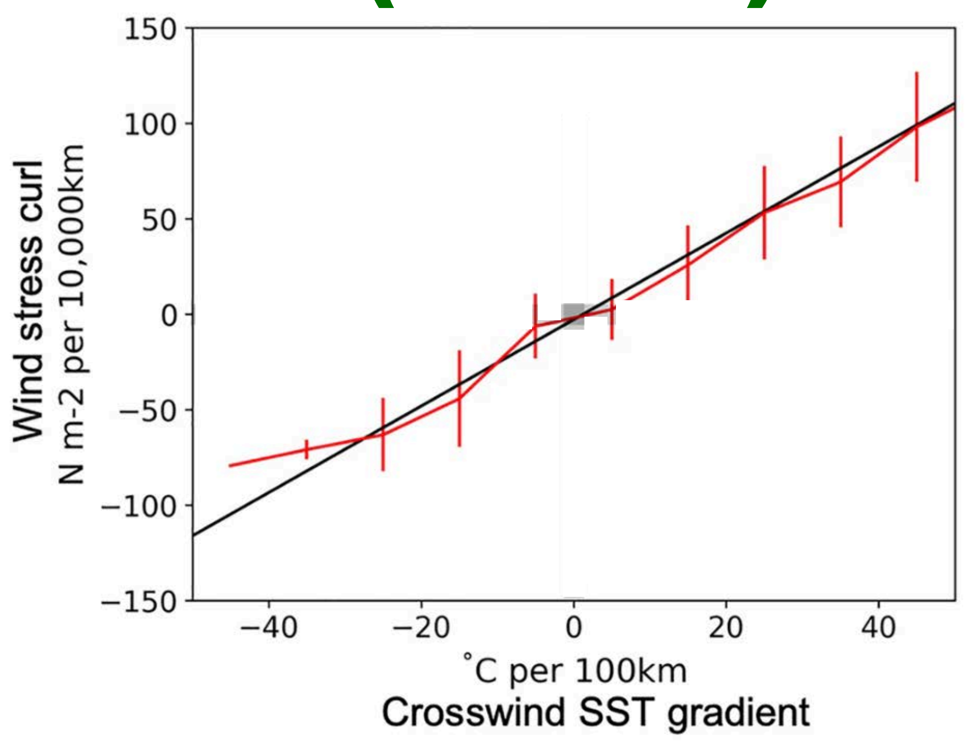
2-D (non-linear sum)



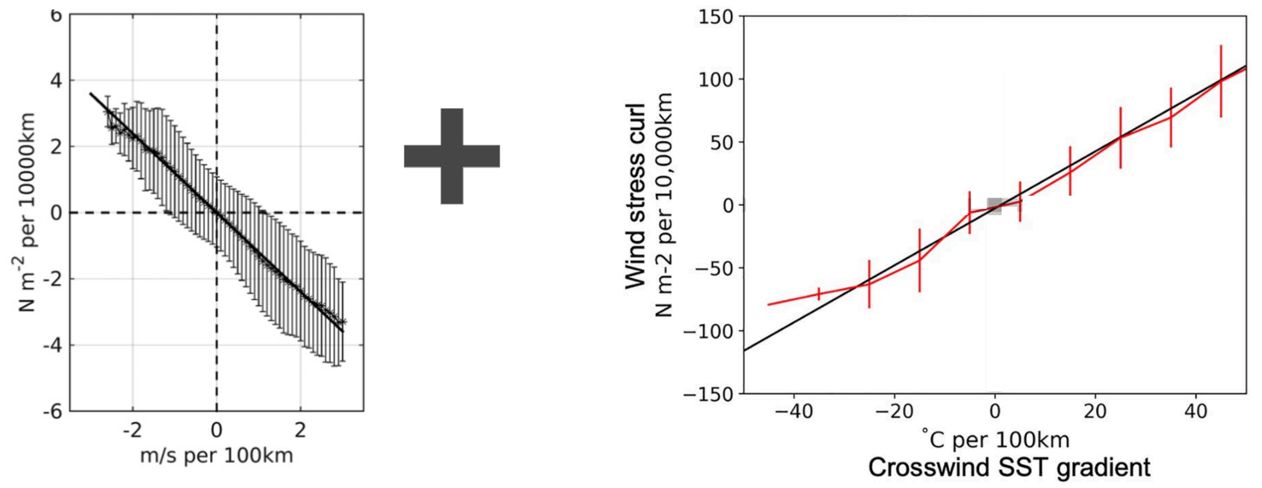
1-D current ($\beta = 0$)



1-D thermal ($\alpha = 0$)



1-D C+T (linear sum)



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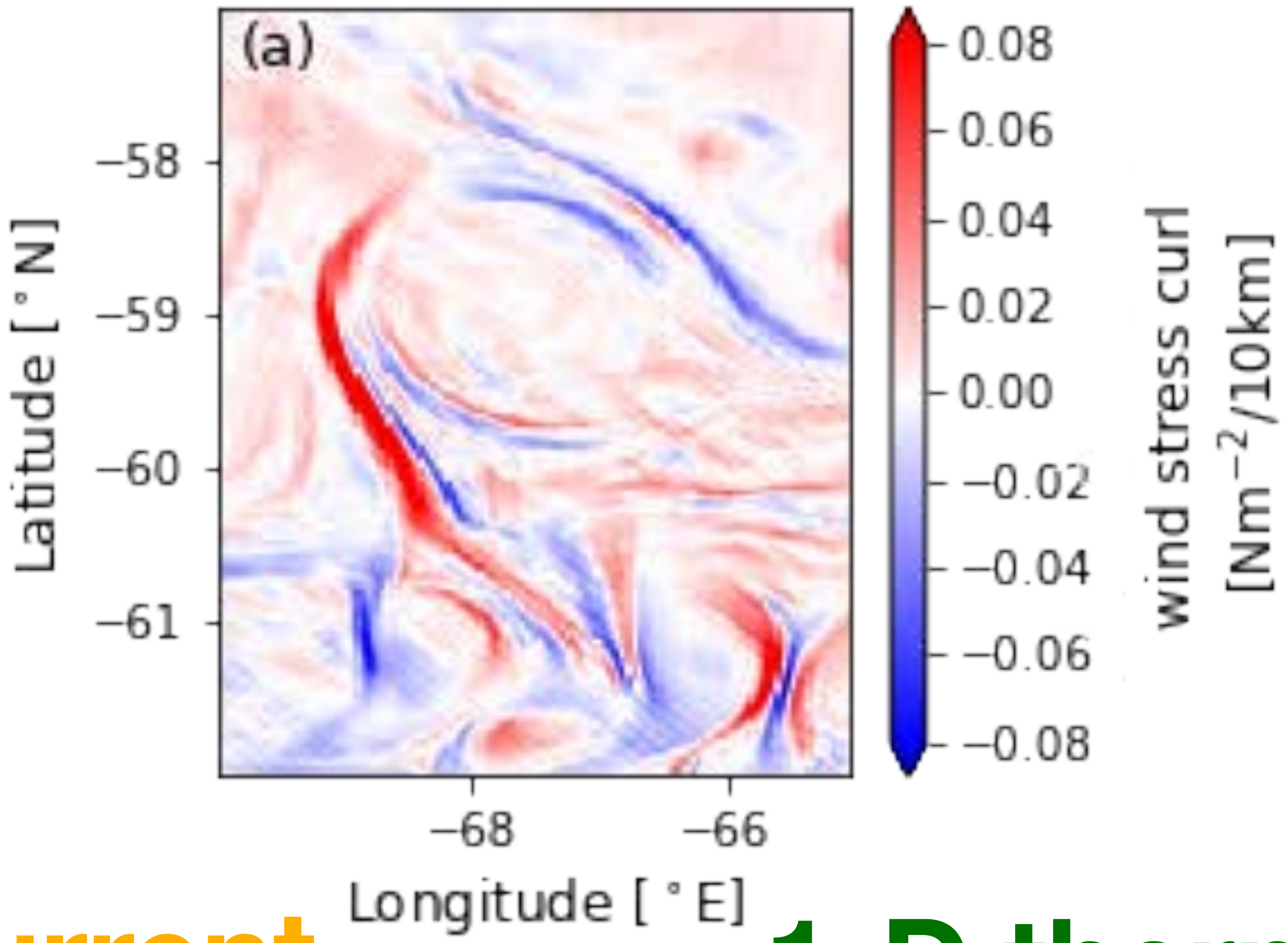
Results - wind stress curl reconstruction

simulated wind
stress curl (truth):

July 8th, 20:00

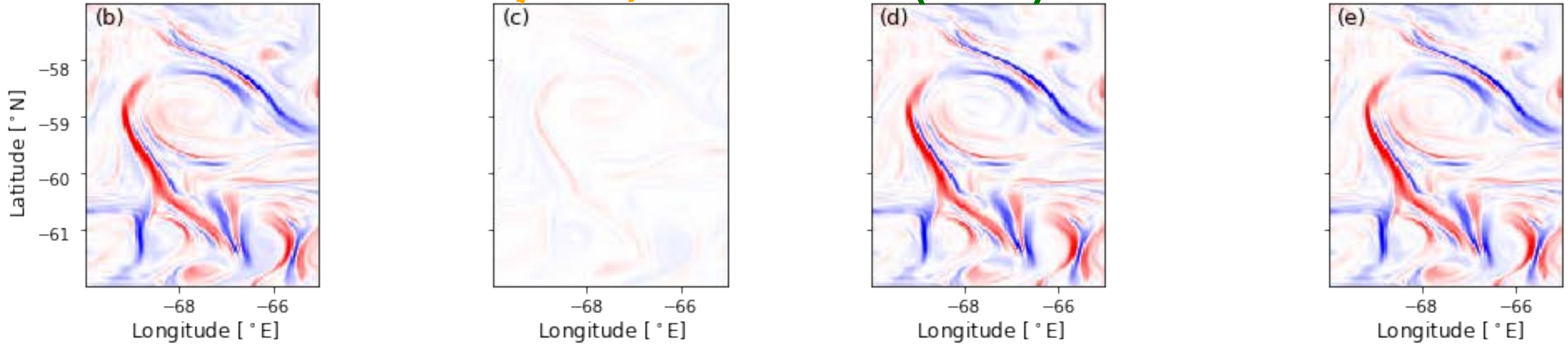


2-D (non-linear sum)

1-D current ($\beta = 0$)

1-D thermal ($\alpha = 0$)

1-D C+T (linear sum)



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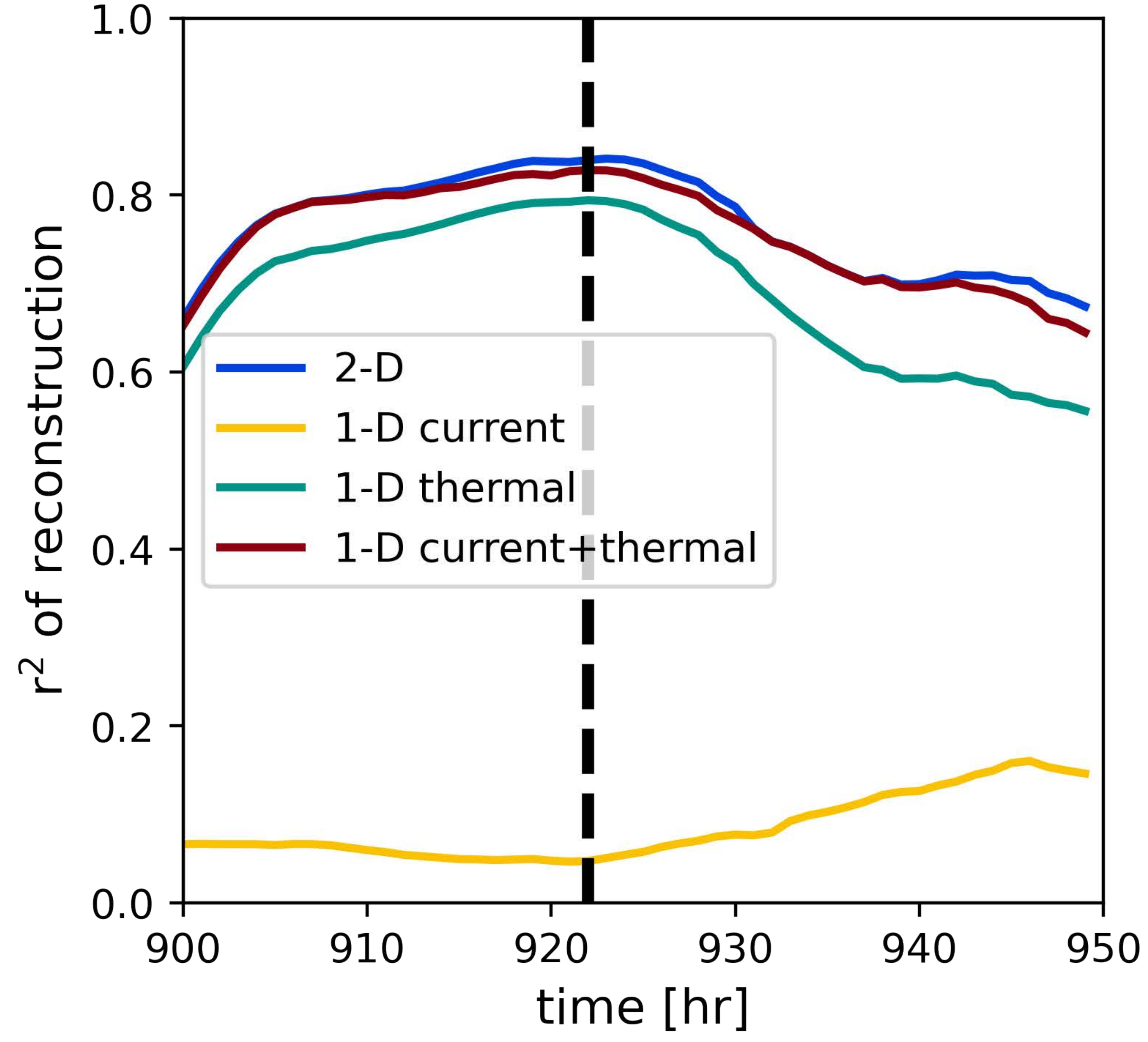
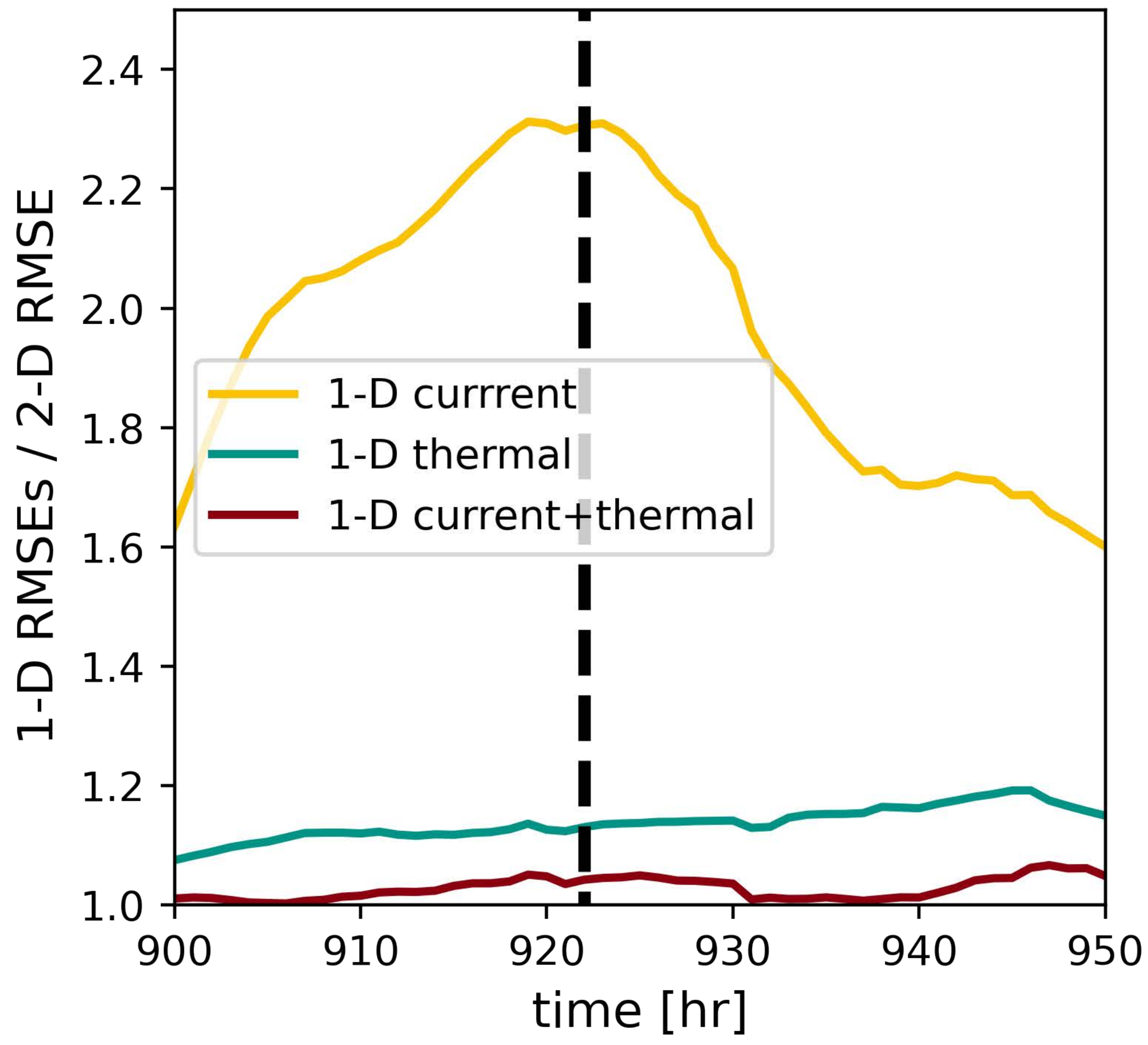
Results - wind stress curl reconstruction

Percentage of true wind stress curl explained



Root-mean square error with true wind stress curl,

1-D reconstructions / 2-D



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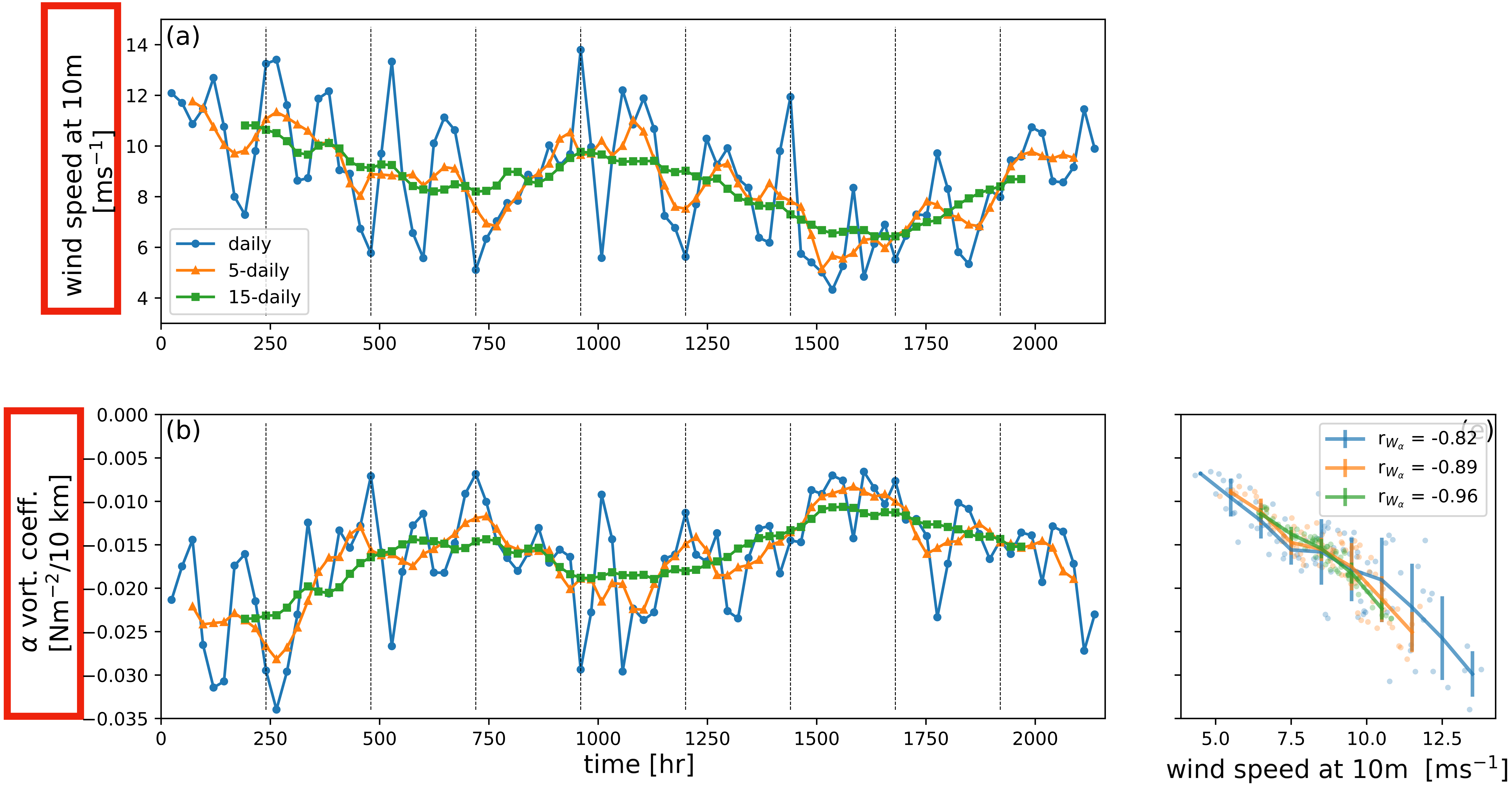
Results - 2-D coefficients variability



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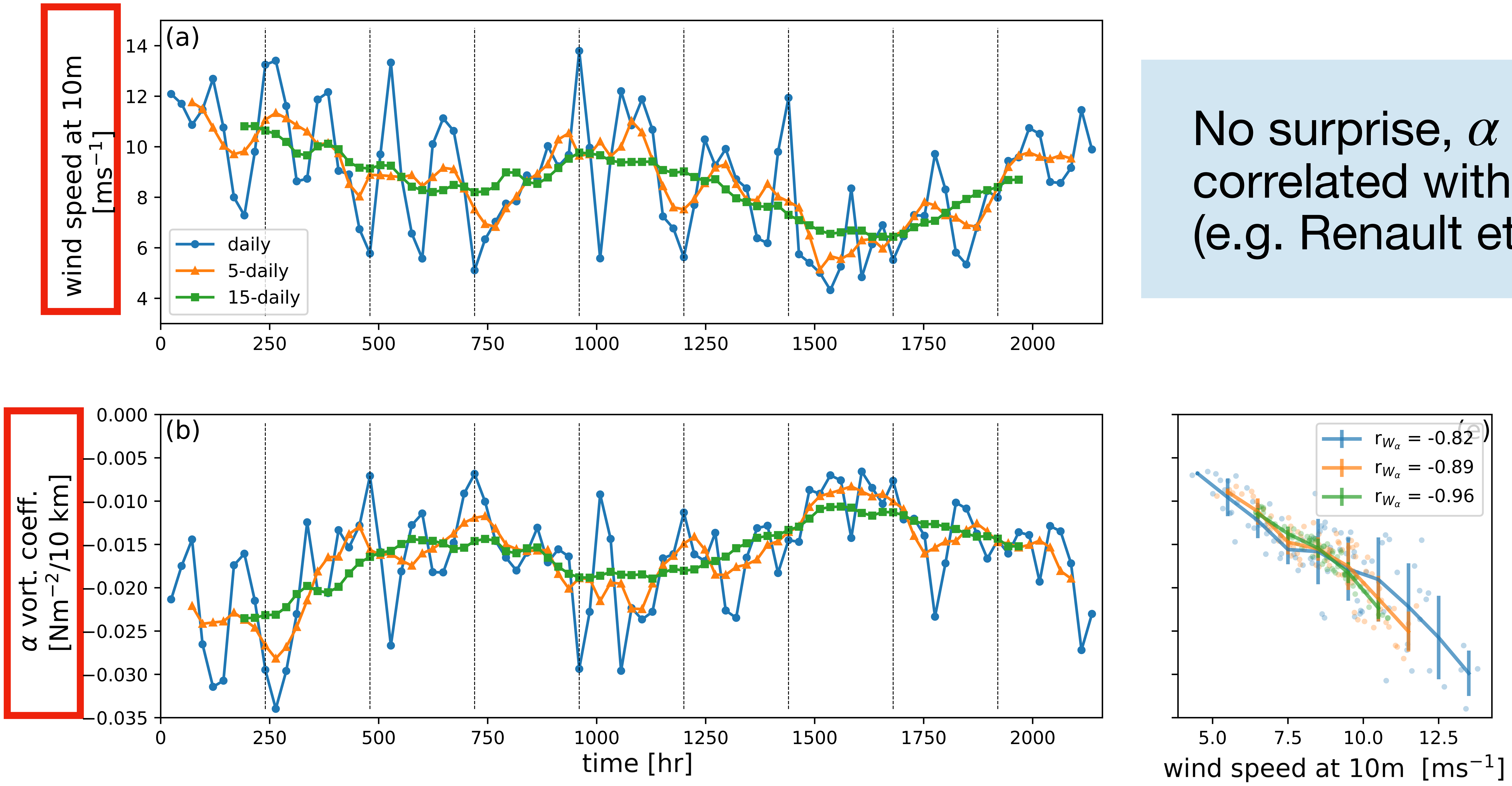
Results - 2-D coefficients variability



No surprise, α negatively correlated with wind speed (e.g. Renault et al., 2017)

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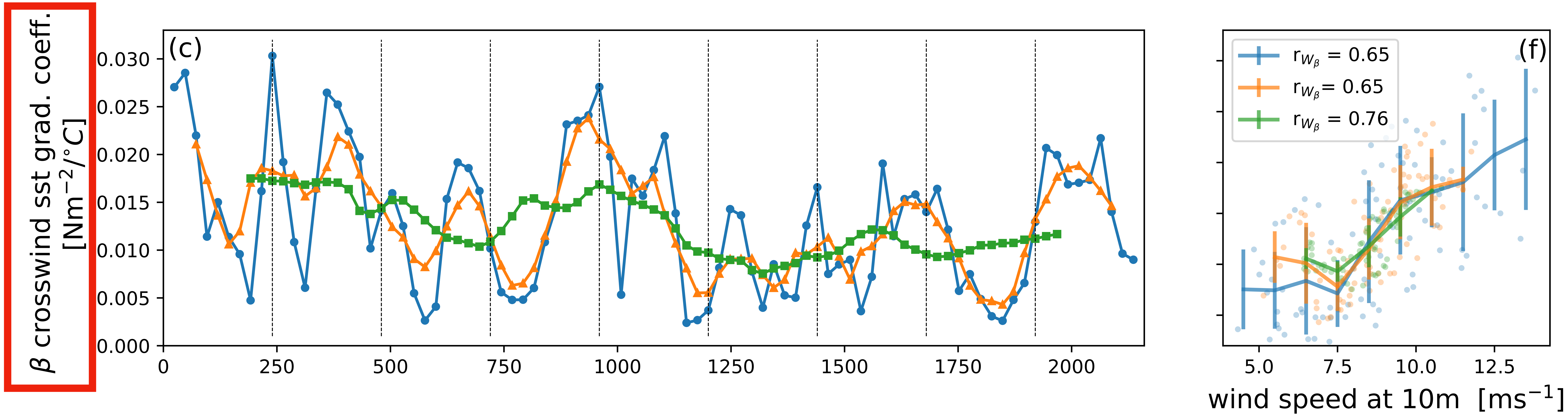
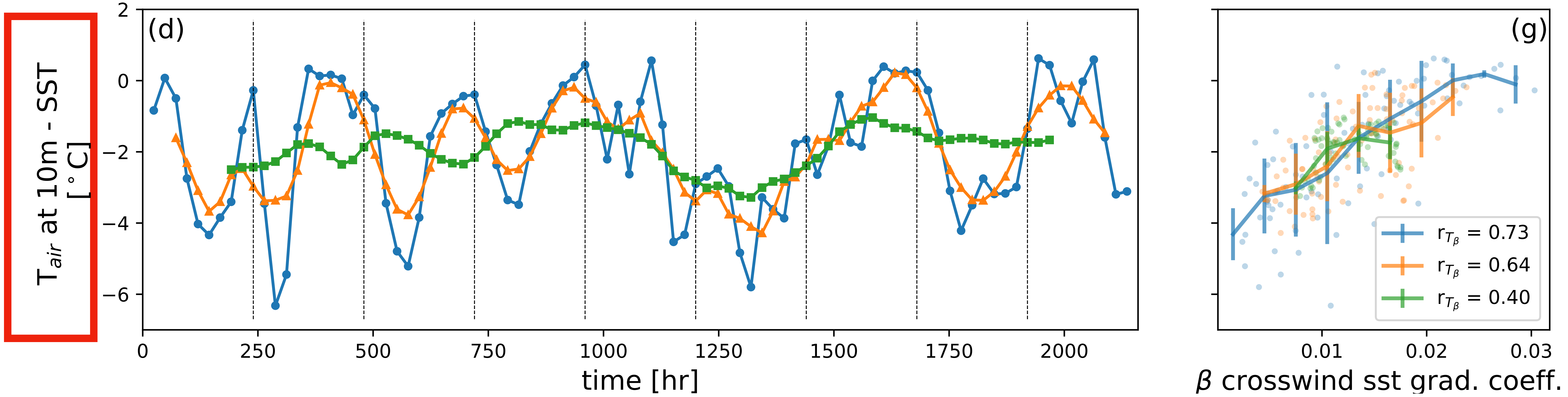
Results - 2-D coefficients variability



time scale ⬆️

correlation ⬆️



time scale ⬆️

correlation ⬇️

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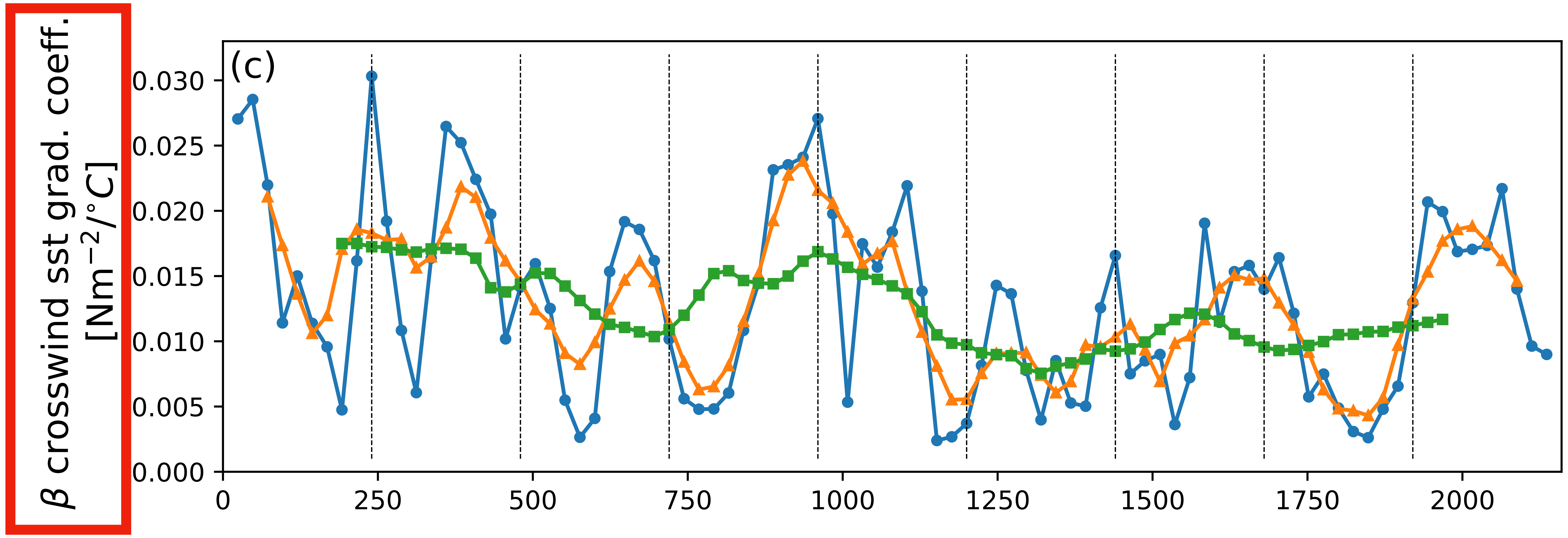
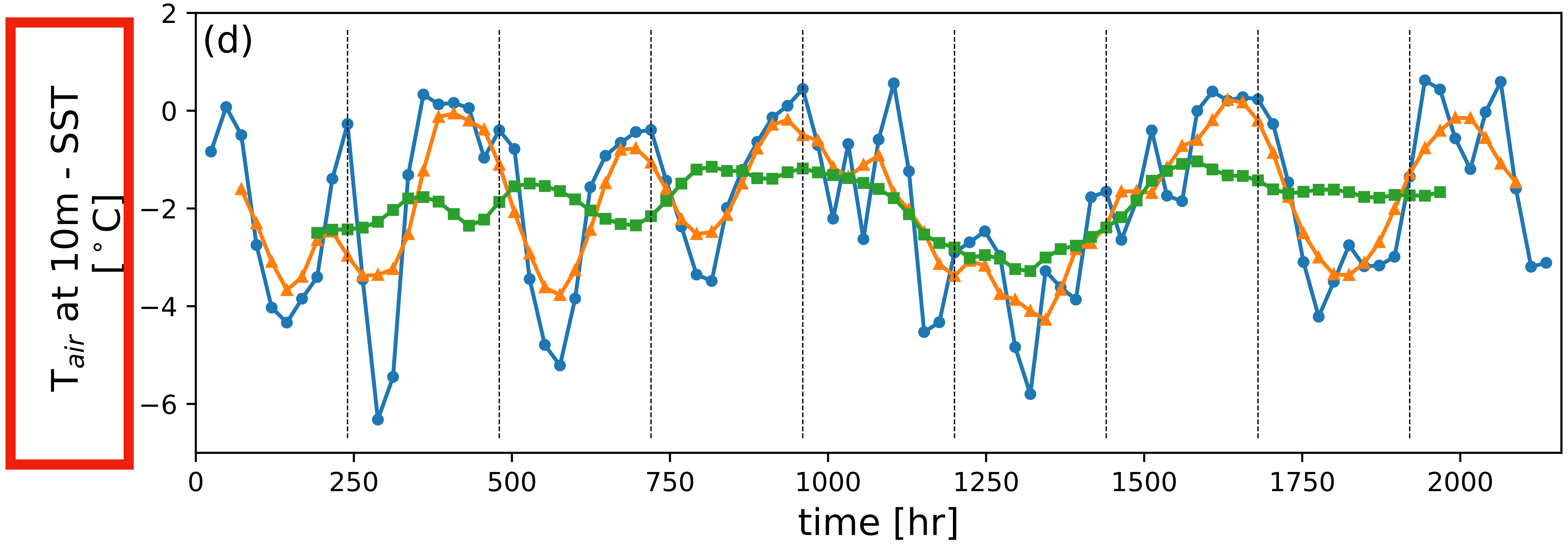
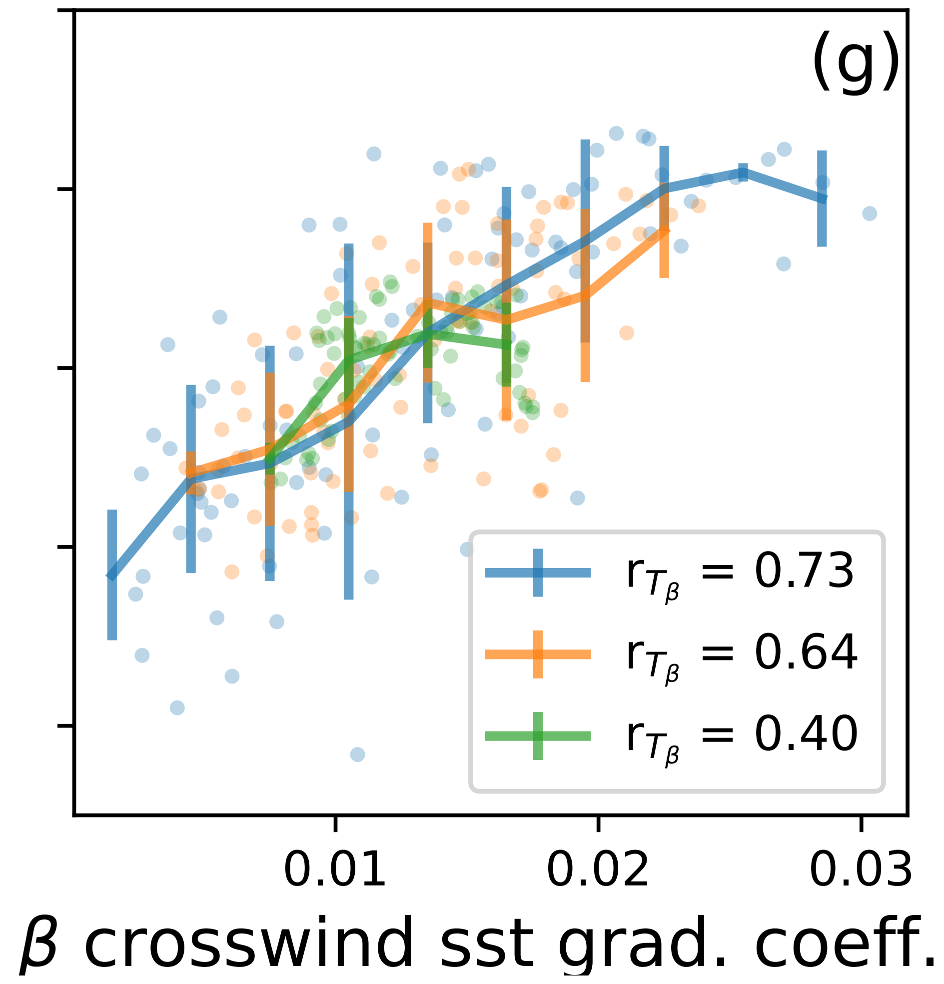
Results - 2-D coefficients variability





- high-frequency variations in β -> air-sea T difference
- slow and lagged downward momentum transfer in ABL -> wind speed



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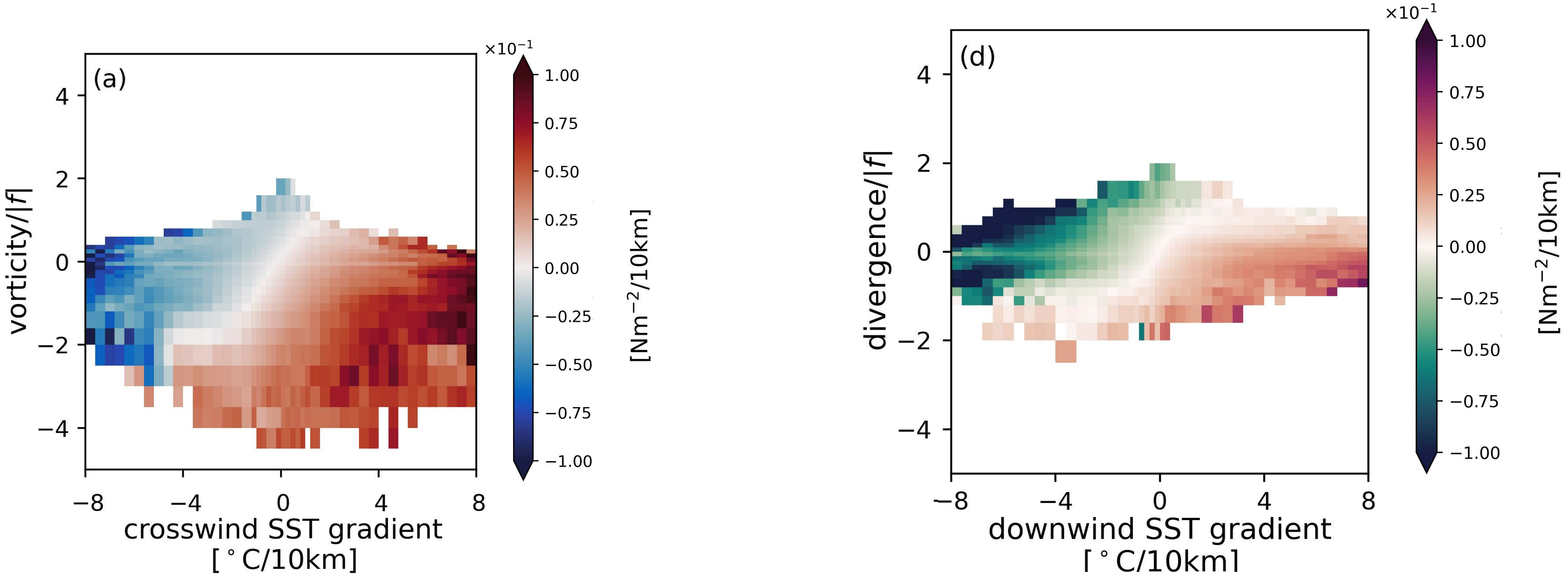
Results - summary

- Sub-mesoscale wind-front interactions are ~20 times stronger than at mesoscale
- Current (vorticity/divergence) and thermal (sst gradients) feedbacks have joint impacts on wind stress curl/divergence; both are required to explain anomalous values in wind stress fields
- Relative contribution of current and thermal feedback are determined by wind speed and air-sea temperature difference



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Supplementary materials

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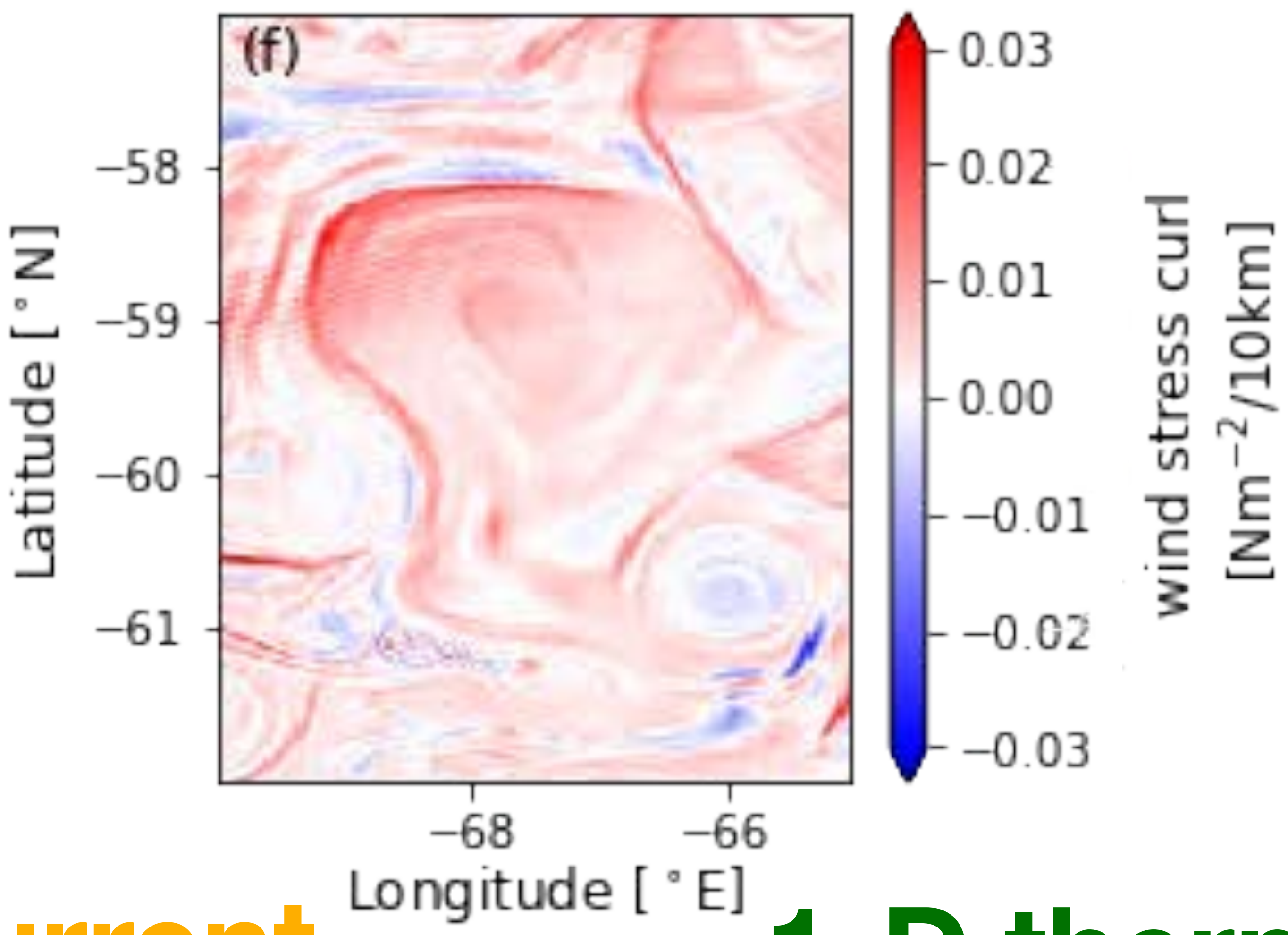
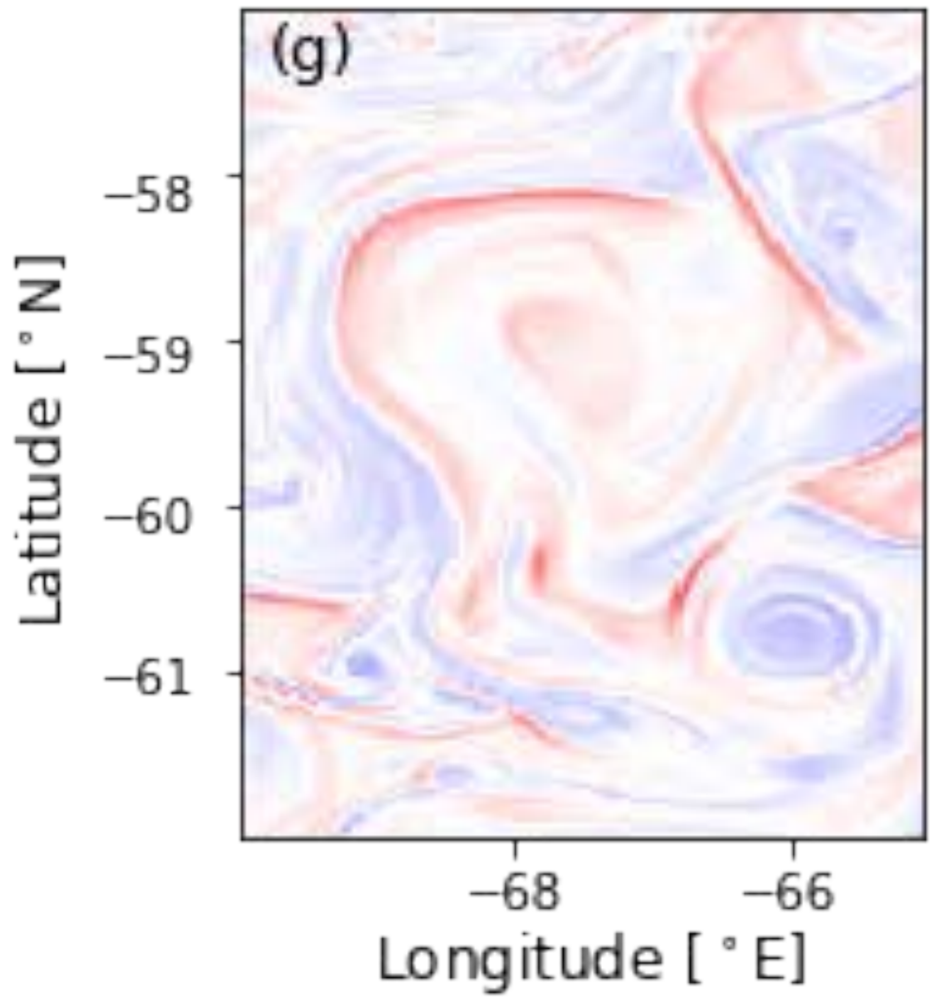
SI - wind stress curl reconstruction

simulated wind stress curl (truth):

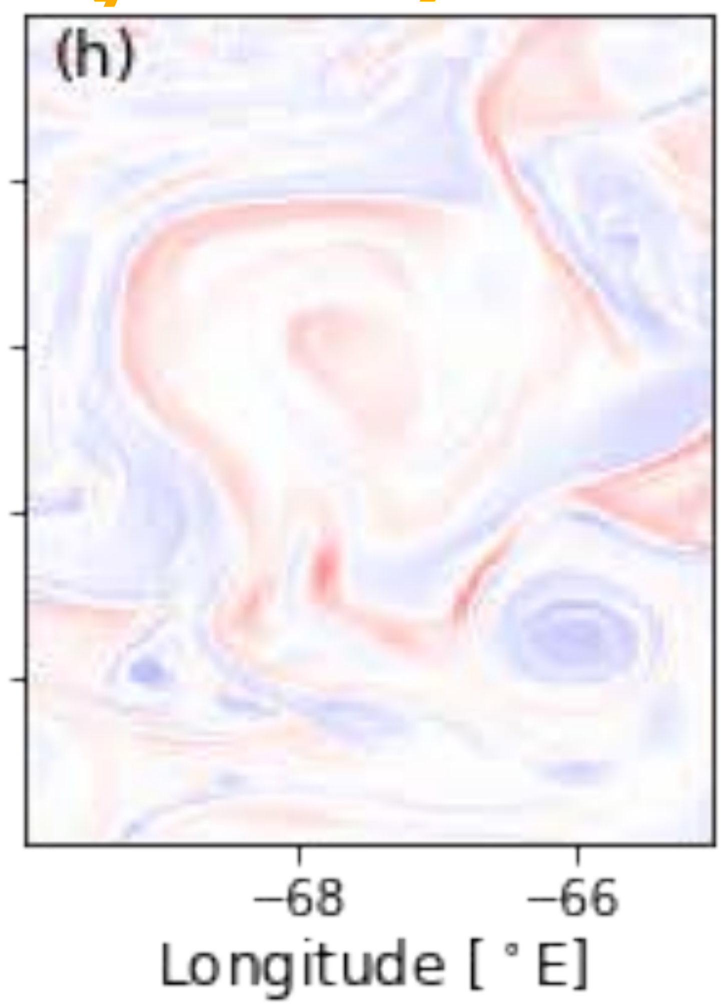
July 27th, 03:00



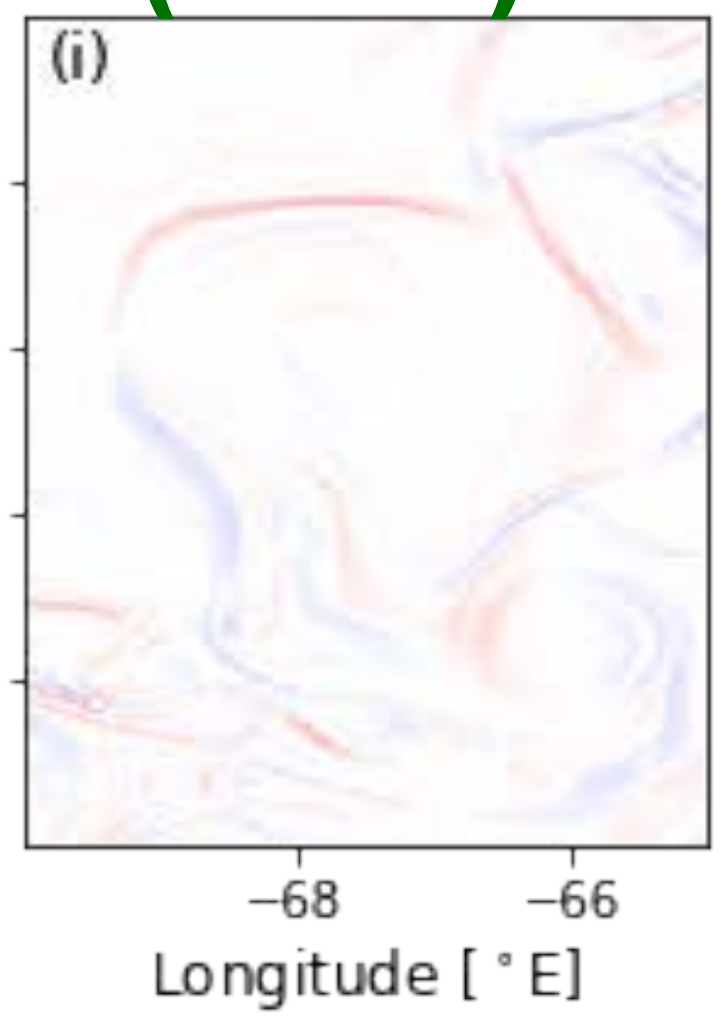
2-D (non-linear sum)



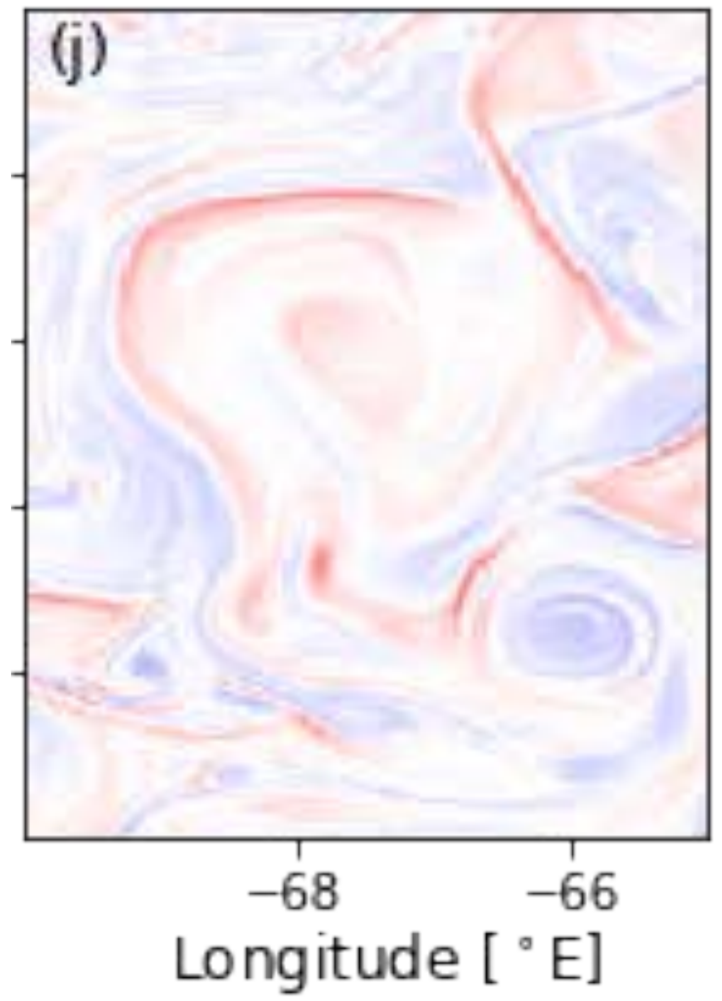
1-D current ($\beta = 0$)



1-D thermal ($\alpha = 0$)



1-D C+T (linear sum)



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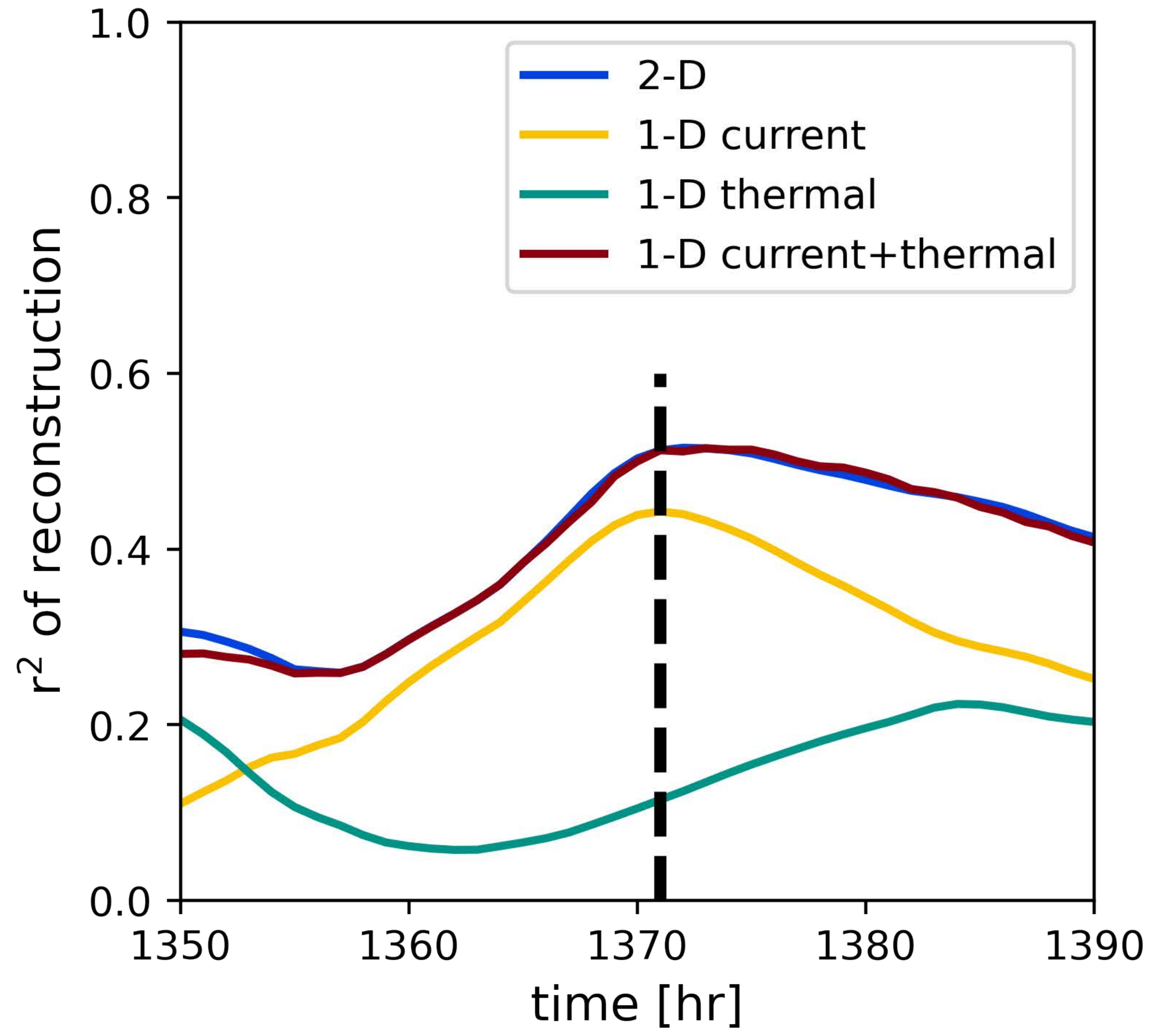
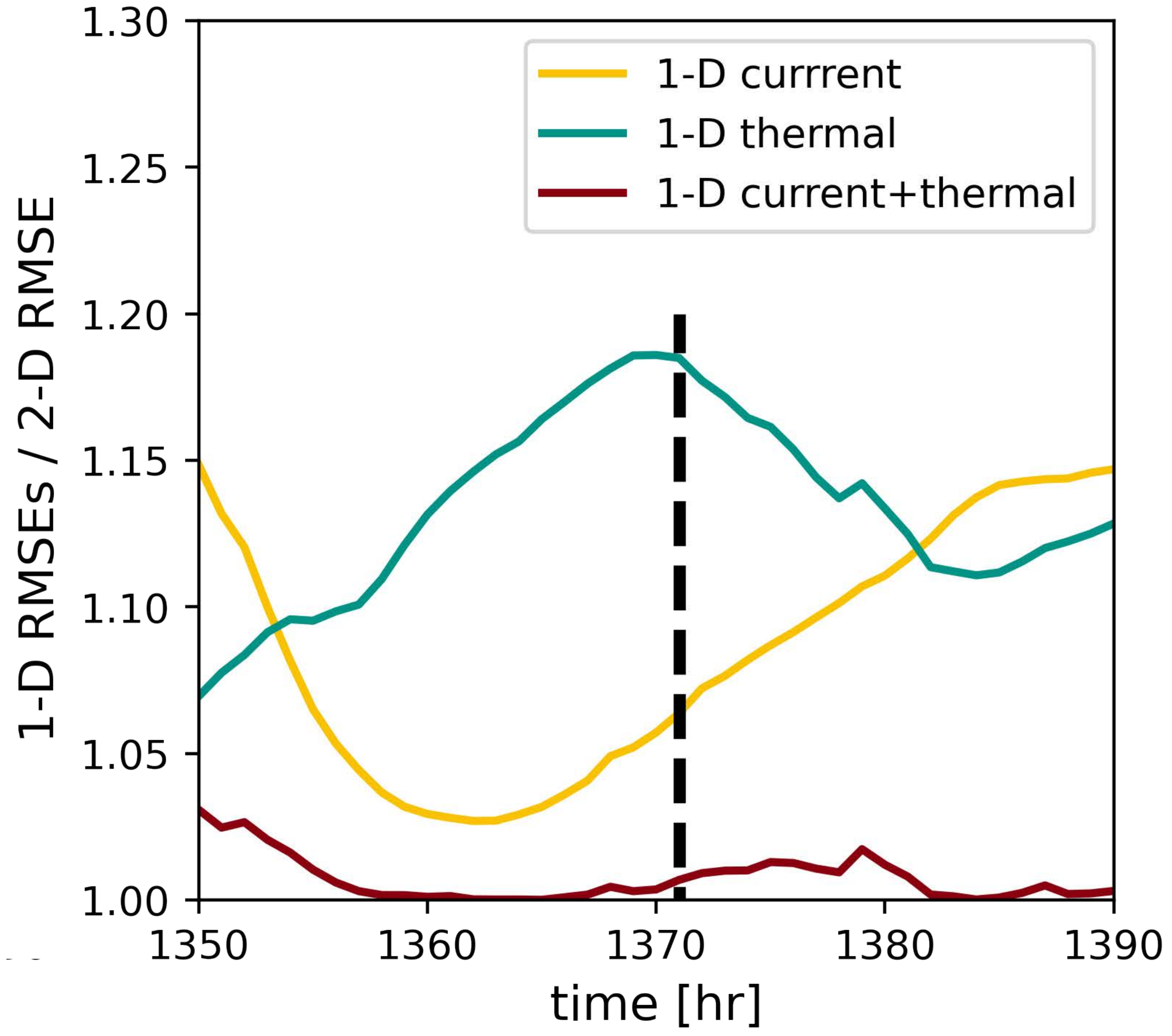
SI - wind stress curl reconstruction

Percentage of true wind stress curl explained



Root-mean square error with true wind stress curl,

1-D reconstructions / 2-D



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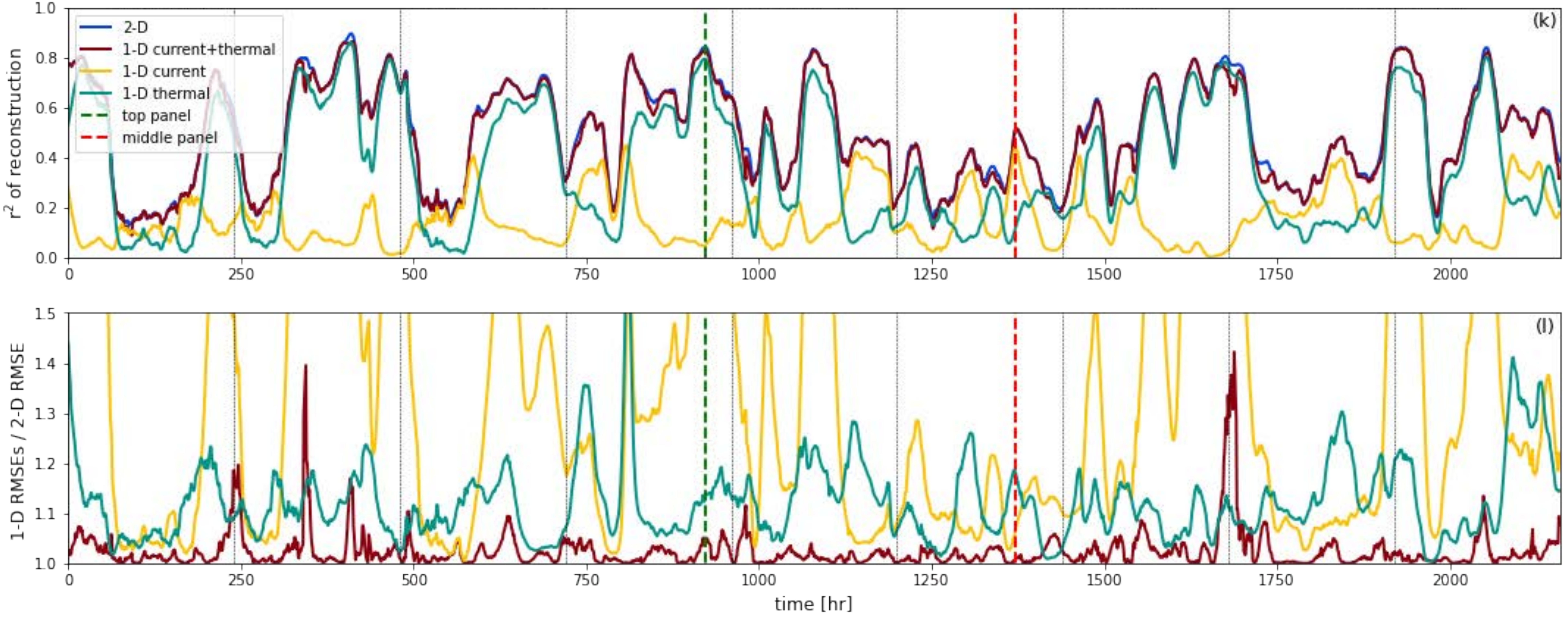
SI - wind stress curl reconstruction



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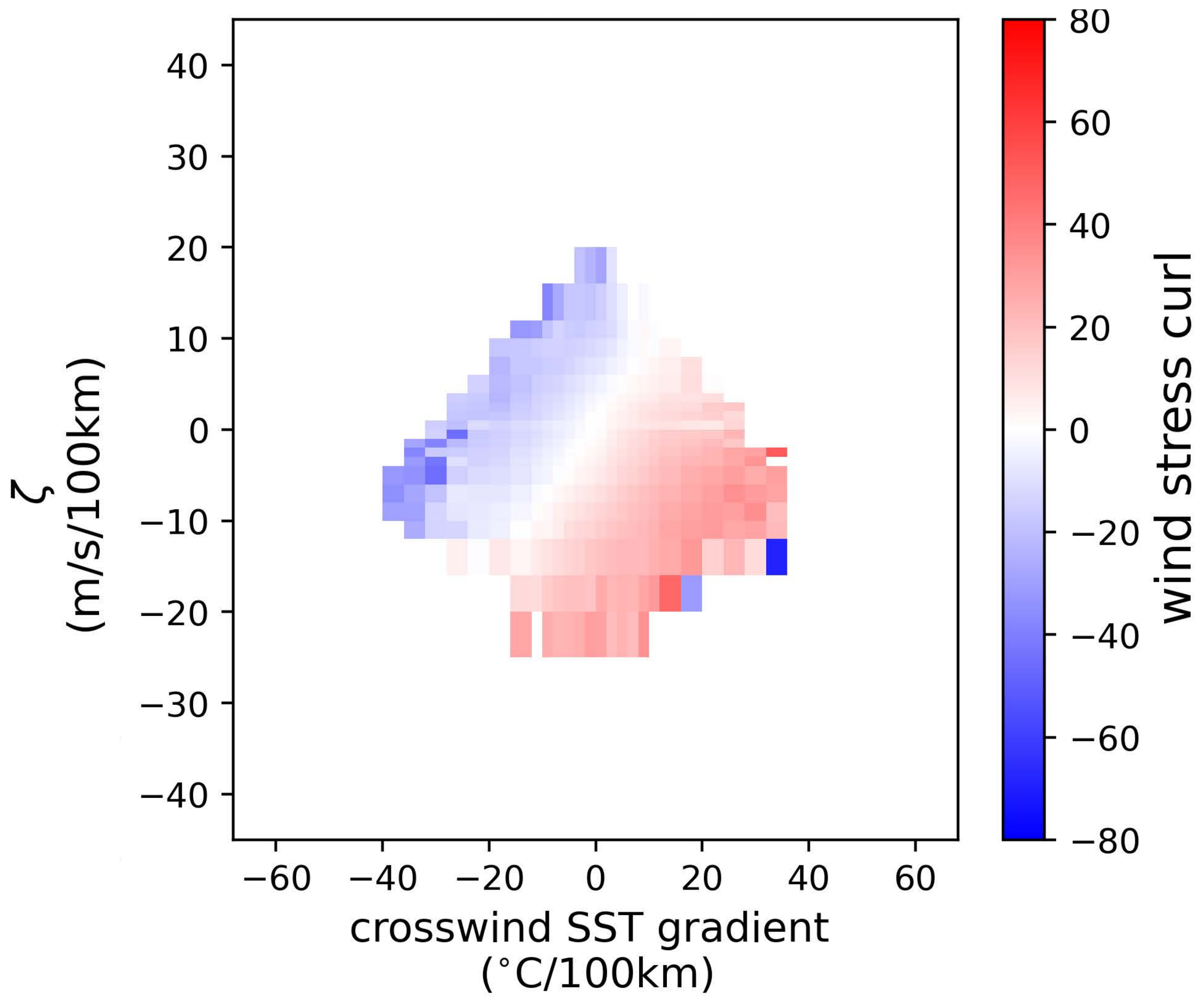
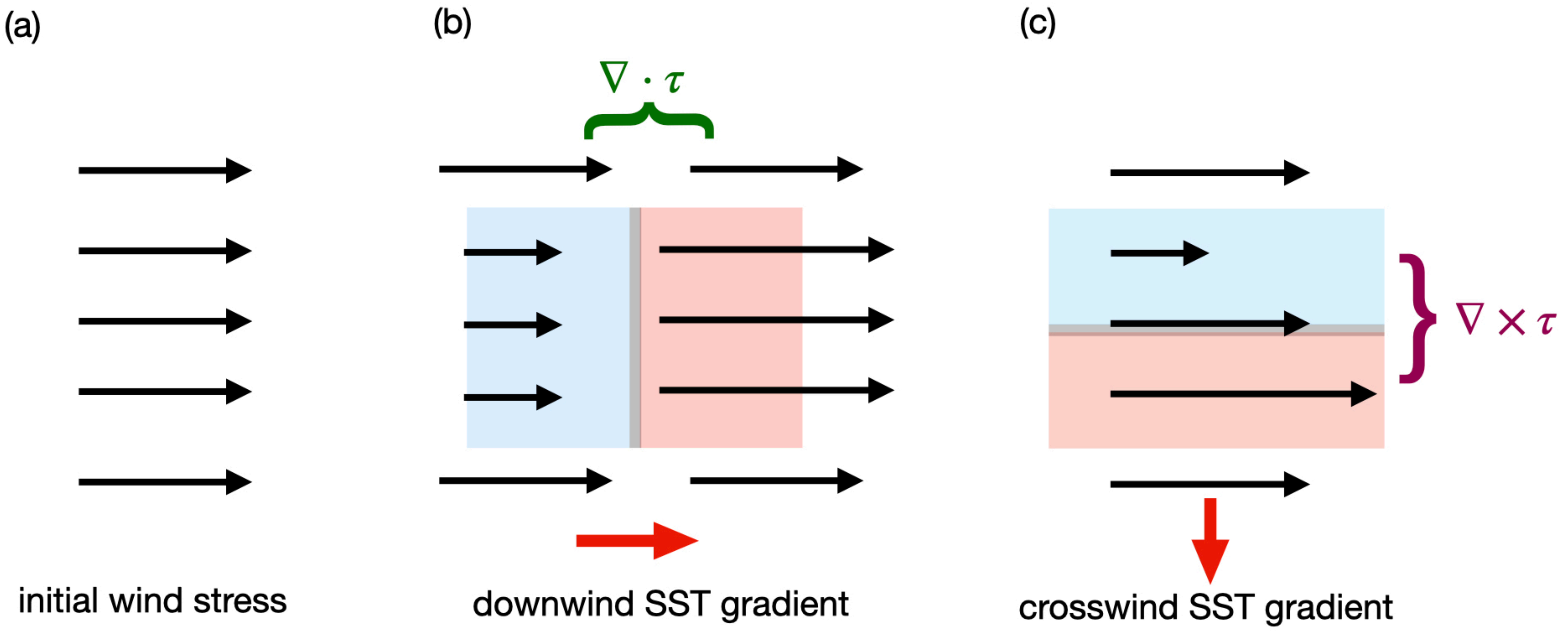
SI - conditional mean plots in quiescent region



SI - thermal feedback



$\nabla \times \tau$ impacts ocean surface layer

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SI - current feedback

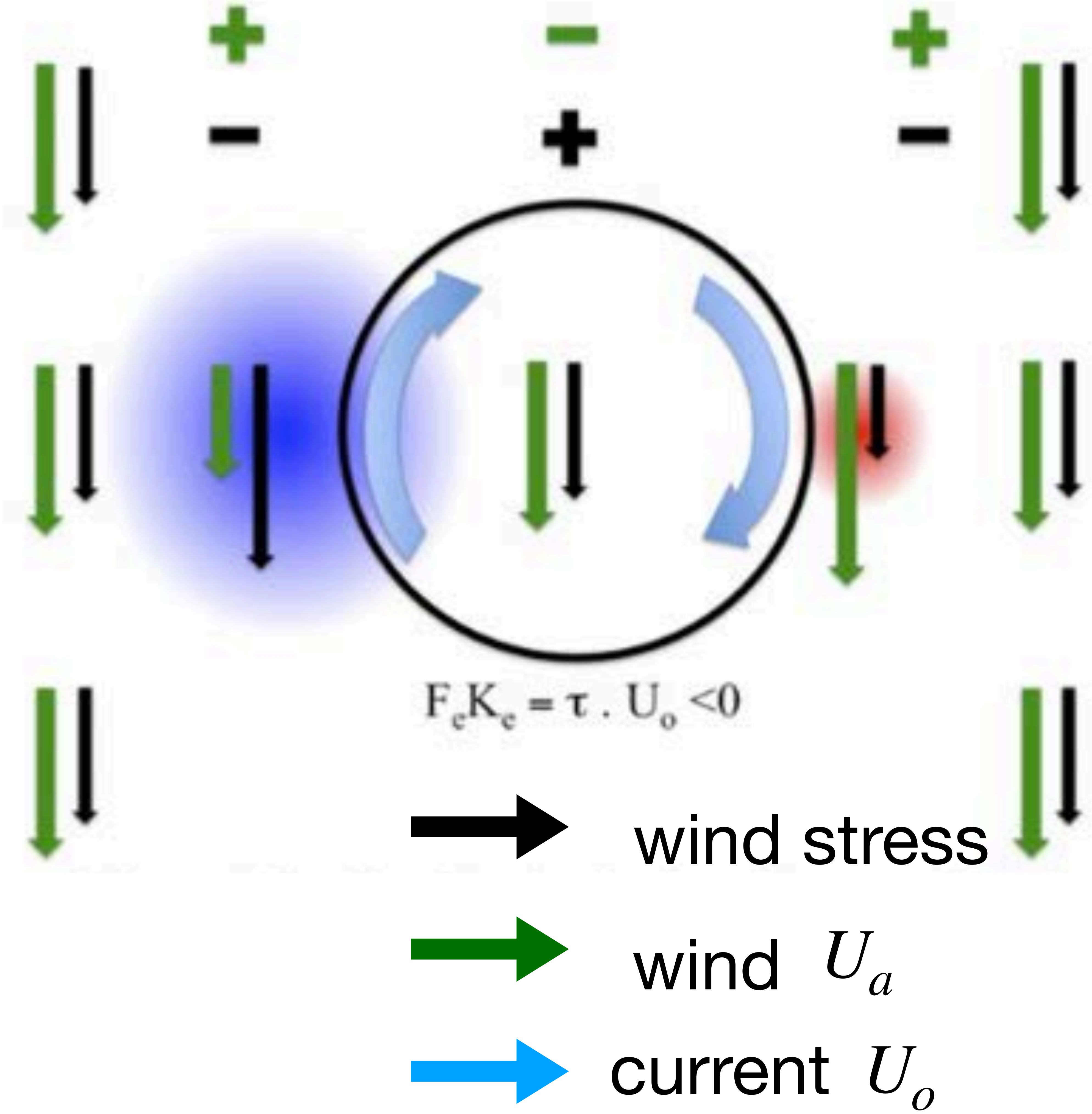

Figure from Renault et al., 2016

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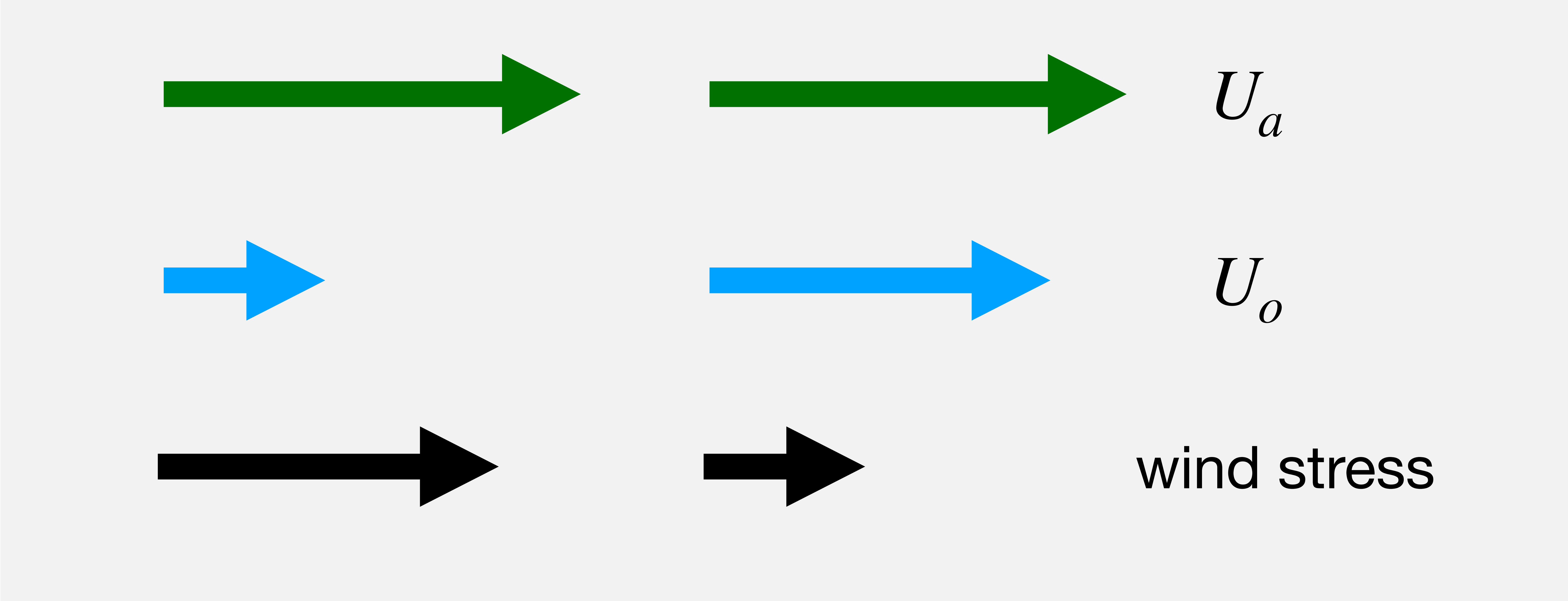
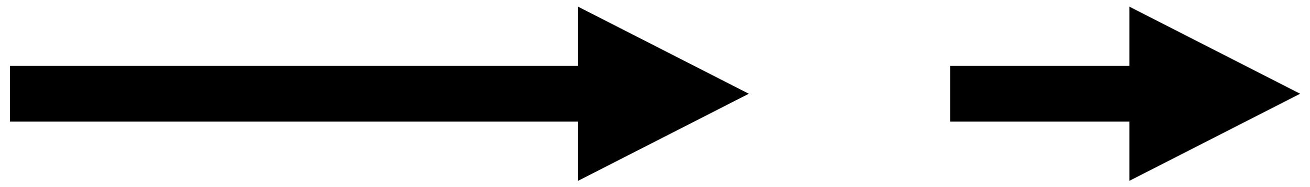
SI - current feedback



current divergence



wind stress convergence - $\nabla \cdot \tau$

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