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

Yue (Luna) Bai, Andy Thompson, Bia Villas Boas, Patrice Klein, Hector Torres

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Introduction - why wind-front interactions?

Figure from Chelton and Xie, 2010

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ybbai@caltech.edu
Introduction - why *joint impact of* wind-front interactions?

Figure from Renault et al., 2016
Introduction - why *sub-mesoscale* wind-front interactions?

Figure from Strobach et al., 2022

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ybbai@caltech.edu
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)

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

Atmosphere part:
• 6 km horizontal resolution

information exchange
Results - joint impact of thermal and current feedback

2-D feedback

![Graph showing vorticity vs. crosswind SST gradient](attachment:graph.png)

- **Current feedback:**
  - Vorticity
  - Something

- **Thermal feedback:**
  - Something
  - Crosswind SST gradient

2-D current + thermal feedbacks

- **Vorticity vs. crosswind SST gradient**
  - Thermal feedback overlap
  - Crosswind SST gradient
Results - joint impact of thermal and current 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
Results - joint impact of thermal and current feedback

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

- wind stress curl ~ $\alpha$ vorticity + $\beta$ crosswind 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)
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)
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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ybbai@caltech.edu
Results - 2-D coefficients variability

(a) Wind speed at 10m [ms⁻¹]

(b) $\alpha$ vort. coeff. [Nm⁻²/10 km]

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ybbai@caltech.edu
Results - 2-D coefficients variability

No surprise, $\alpha$ negatively correlated with wind speed (e.g. Renault et al., 2017)
Results - 2-D coefficients variability

- **(c)**  
  - $\beta$ crosswind sst grad. coeff. [Nm$^{-2}$/C]  
  - Time scale:
    - Correlation:

- **(d)**  
  - $T_{air}$ at 10m - SST [°C]  
  - Time scale:
    - Correlation:

- **(f)**  
  - Wind speed at 10m [ms$^{-1}$]  
  - $r_{W_p}$ values: 0.65, 0.76

- **(g)**  
  - $\beta$ crosswind sst grad. coeff.  
  - $r_{\beta}$ values: 0.73, 0.64, 0.40

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ybbai@caltech.edu
• high-frequency variations in $\beta \rightarrow$ air-sea $T$ difference

• slow and lagged downward momentum transfer in ABL $\rightarrow$ wind speed
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
Supplementary materials
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)
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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ybbai@caltech.edu
SI - wind stress curl reconstruction

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ybbai@caltech.edu
SI - conditional mean plots in quiescent region

![Plot of crosswind SST gradient vs wind stress curl](image)

- Wind stress curl
- Crosswind SST gradient
- Units: m/s/100km

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ybbai@caltech.edu
SI - thermal feedback

\[ \nabla \times \tau \] impacts ocean surface layer

(a) initial wind stress

(b) downwind SST gradient

(c) crosswind SST gradient

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ybbai@caltech.edu
SI - current feedback

Figure from Renault et al., 2016

\[ F_c K_c = \tau \cdot U_o < 0 \]

- wind stress
- wind \( U_a \)
- current \( U_o \)

\[ \nabla \times \tau \]

\( \zeta \)

current vorticity

wind stress curl
SI - current feedback

\[ \nabla \cdot \tau \]

current divergence

wind stress convergence - \(\nabla \cdot \tau\)