Modulation of Ocean Dynamics by (Sub)Mesoscale Ocean-Wave-Atmosphere Interactions: Current Knowledge and Limitations

L. Renault, Mesoscale and Frontal-Scale Air-Sea Interactions Workshop, 06/03/2023
Thermal Feedback, here correlation between wind speed and SST anomalies with spatial high-pass filtering (from radiometry and scatterometry)

Current Feedback, here sinks of energy from mesoscale eddies to the atmosphere

Wave Feedbacks, a missing piece?

Seo, 2017

I won’t focus on air-sea-land …
Mesoscale Thermal Feedback: First pathway via Wind Anomalies

Chelton et al., 2010

\[ \nabla \times u, \nabla \times \tau > 0 \quad \nabla \cdot u, \nabla \cdot \tau > 0 \]

Chelton et al., 2007

Modulation of wind and stress observed by satellite

Wind and Stress are modulated by SST anomalies and gradients

Renault et al., under review

a) 18 August 2002, QuikSCAT and AMSR

Chelton et al., 2007

5 N m$^{-2}$ per $10^6$ km
5 cm d$^{-1}$ upwelling
at 40°N

Renault et al., under review
Ekman Pumping in the ocean that impact eddy propagation
But generally weak effect on the EKE (Seo et al., 2016)

First Pathway via Wind Anomalies has a Weak Impact on the Ocean Dynamics

No significant effect on the exchange of energy between eddies and atmosphere

Confirmed by estimating the resulting baroclinic instability → no effect

Only TFB $\langle w'b' \rangle \sim 0$ and $\langle u'\tau' \rangle \sim 0$
Mesoscale Thermal Feedback: Second pathway via Surface Heat Fluxes

Correlation between Turbulent Heat Flux and SST anomalies

Kirtman et al., 2012
Correlation between Turbulent Heat Flux and SST anomalies

Kirtman et al., 2012

Transfer of Potential Energy from Mesoscale Eddies to the Atmosphere

Bishop et al., 2020
Correlation between Turbulent Heat Flux and SST anomalies

Reduction of baroclinic conversion of energy

TFB Induced Heat Fluxes can cause a Damping of the EKE

- Ma et al. (2016): damping of EKE by ~10%
- Seo et al., (2016): no impact

Transfer of Potential Energy from Mesoscale Eddies to the Atmosphere
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Reduction of baroclinic conversion of energy
Ma et al., 2016

Strong dependance on the spatial filter uses when sending the SST to the atmosphere

No Filter
~1000 km
~300 km

Renault et al., under review
Observations are missing at those scales!

More information on Igor’s Poster!
Main Effect of (sub)mesoscale Current Feedback is a Sink of Energy from Eddies to the Atmosphere

Renault et al., 2016

Bulk formula for surface wind stress:

\[ \tau = \rho C_D |U_a - U_o|^2 \]

usually approximated as

\[ \tau \approx \tau_a = \rho C_D |U_a|^2 \]

More generally, for \( U_o \ll U_a \)

\[ \tau = \tau_a + \tau' \]

\[ \tau' \approx s_\tau U_o, \quad s_\tau \propto -|U_a| \]

Eddy wind work done the ocean:

\[ FeKe = \langle \tau \cdot U_o \rangle \approx s_\tau U_o^2 \propto -|U_a|U_o^2 < 0 \]

=> oceanic energy loss and atmospheric gain vis a vis a resting ocean.

\[ \rightarrow \text{Global Sinks of Energy} \]

\[ \rightarrow \text{The Ocean drags the Atmosphere} \]
This Sink of Energy is Present at All Scales!

Tidal Scale
Renault and Marchesiello, 2022

Internal Tides Scale
Delpech et al., under revision

Submesoscale
Renault et al., 2018

Not Observed!

Mesoscale, Partly Observed
(see also Rai et al., 2021), but Large Uncertainties

Renault et al., 2017
It causes the Eddy Killing Process a Damping of Mesoscale Eddies

- 44% US West Coast (Seo et al., 2016, Renault et al., 2016a)
  - 27% North Atlantic (Renault et al., 2016b)
  - 25% Agulhas Current (Renault et al., 2017a)
  - 40% South East Pacific (Oerder et al. 2017)
  - 25% Gulf of Mexico (Larrañaga et al., 2022)

Seo et al., 2023; Renault et al., 2023
Also present at Submesoscale, but balanced by more Baroclinic Conversion caused by Ekman Pumping

More Baroclinic Conversion

Reduction of SKE by ~15%

Renault et al., 2018

Renault et al., 2018
An Upscaling Impact: Stabilization of Western Boundary Current

Reduction of the Eddy-Mean Flow Interaction
(the Inverse Cascade of Energy)

Renault et al., 2019
An Upscaling Impact: Stabilization of Western Boundary Current

Reduction of the Eddy-Mean Flow Interaction (the Inverse Cascade of Energy)

Path of the Gulf Stream

Renault et al., 2019
An Upscaling Impact: Stabilization of Western Boundary Current

Reduction of the Eddy-Mean Flow Interaction (the Inverse Cascade of Energy)

Difference of SST indirectly caused by Current Feedback

Path of the Gulf Stream

See al Seo 2017, Renault et al., 2017, Seo et al., 2022
Role of the Surface Gravity Waves?

Dx=30m, with and without wave forcing

Impact on submesoscale currents through vortex force

Impact on the atmosphere and retroaction on the Ocean?

Impact at Mesoscale?
Surface current, temperature, wind at the same time and same scales

Heat fluxes approximation without the knowledge of total surface current

Windwork at submesoscale, tidal scale, mesoscale, etc

Disentangle TFB and CFB effect

EKE damping and subsequent reduction of cascade of energy

Not only geostrophic current but also total and over the Equatorial region

Eddy Killing, Cascade of Energy, etc

Modeling:

Need to revisit bulk flux formula, validity at fine-scale/HF, waves?

Coupled models often have an inconsistency between the atmosphere and wave models bulk formulas

Submesoscale and Wave coupling need more studies

Climate Impact
Renault et al., 2019a

Large Uncertainties in the surface stress response because of smoothness and non-coherent observations (AVISO and QuikSCAT).

Surface Current Vorticity and Surface Stress Curl

Wind Response is unknown from the obs., we need to know the surface current coherently with the stress

Surface Current Vorticity and 10-m Wind Curl

Importance of having a good enough estimate:

- Drive Windwork
- Force an Ocean Model (e.g., OMIP)
- Local to Large-Scale Impact
- No information over Equator

Observations

Models

Large Difference!

Renault et al., 2019a

Observations

Models

Fake Observations

Should be positive!

Error reproduced by model
Need SST, Surface Currents, and Surface Stress

Error of 10-15% because we don’t know the surface current

Coupling Coefficient TFB overestimated, see also Luna’s poster
Thank you !
a) \[
\frac{\Delta H - \Delta H_\text{r}}{\Delta H_\text{r}} \times 100
\]