Oceanic and Atmospheric Weather Intertwined
– An observational perspective –

Ivy Frenger; thanks to Matthias Männich, Reto Knutti, Nicolas Gruber, David Byrne

OMDP Workshop *Sources and Sinks of Ocean Mesoscale Eddy Energy*
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How do the ocean and atmosphere interact at the ocean mesoscale and does the interaction matter?

1. *LOCAL IMPRINTS AND MECHANISMS*
   - Thermal
   - Mechanical

2. *LARGE-SCALE OCEAN IMPLICATIONS*
OBJECTIVES

How do the ocean and atmosphere interact at the ocean mesoscale and does the interaction matter?

1 LOCAL IMPRINTS AND MECHANISMS
   - Thermal \textit{(case study Southern Ocean)}
   - Mechanical

2 LARGE-SCALE OCEAN IMPLICATIONS
LOCAL IMPRINTS AND MECHANISMS (THERMAL)

**Data:**
- Satellite based observations over the Southern Ocean
- Variables: sea level anomalies (SLA), sea surface temperatures (SST), atmospheric variables
- Resolutions: spatial $\frac{1}{3}^\circ$, temporal weekly, years 1997 - 2010

**Method:**
- Identification of individual eddies based on SLA
- Collocation with SST & atmospheric variables
LOCAL IMPRINTS AND MECHANISMS (THERMAL)

Average imprint:

Several 10,000 snapshots of eddies.
Rotated according to ambient wind.

Modified from Frenger et al (2013)
**Average imprint:**

- Positive correlation of SST & atmospheric anomalies.

*Modified from Frenger et al (2013)*
Mechanism:

- Downward turbulent mixing of momentum

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Additional details:

- Modulation of atmospheric extreme events
- Large-scale atmospheric effects?
  - Ocean eddies damped.
  - E.g., Hausmann et al (2015)

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![Diagram showing anticyclone and cyclone with various labels for wind divergence/convergence, turbulence, near-surface wind, eddy swirl velocity, eddy propagation, rain, and air-sea heat and moisture flux anomalies.](Modified from Frenger et al (2013))
Mechanism:

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- Downward turbulent mixing of momentum

**Effects:**

- Modulation of atmospheric extreme events
- Ocean eddies damped.
  
  *E.g., Hausmann et al (2015)*

Large-scale atmospheric effects?


*Modified from Frenger et al (2013)*
1°C of sea surface temperature anomaly causes a change of ...

- ... wind speed of 5%.
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- ... wind speed of 5%.
- ... cloud fraction of 3%.
- ... liquid cloud water of 6%.
- ... rain probability of 8%.
- ... rain rate of 8%.

Regional and seasonal modulation of the relationship between SST and wind
Eddies are coupled more strongly to the atmosphere ...

- with higher wind speeds

*Spall et al (2007)*

![Diagram](image_url)

**Wind speeds**
- $> 12 \text{ m s}^{-1}$
- $> 7 \text{ m s}^{-1}$ and $\leq 12 \text{ m s}^{-1}$
- $\leq 7 \text{ m s}^{-1}$

(Unpublished)
Eddies are coupled more strongly to the atmosphere ...

- ... with higher wind speeds
  *Spall et al (2007)*

- ... with higher/lower atmospheric instability?
  *Model study Byrne et al (2015)*
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2. **LARGE-SCALE OCEAN IMPLICATIONS**
Wind stress is a result of winds and currents.

*Faghmous et al (2015)*
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_Faghmous et al (2015)_
Wind stress is a result of winds and currents.

- Spin-down > Spin-up, eddies damped (either polarity).

*Faghmous et al (2015)*
Meridional wind gradient across the Southern Ocean.

Byrne et al (2015)
Meridional wind gradient across the Southern Ocean.

Modulation of wind energy input.

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Meridional wind gradient across the Southern Ocean.

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Eddies damped or energized depending on wind gradient.
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     Systematic damping under homogeneous winds; damping or energizing under wind gradient.

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2  LARGE-SCALE OCEAN IMPLICATIONS
Thermal damping:

- E.g., western boundary current system energetics (current separation), seasonality of EKE, lateral eddy mixing.  

- Model EKE reduction (several 10%)
Mechanical damping:

- Dominant in regions of high EKE and high winds speeds, e.g., western boundary currents, Antarctic Circumpolar Current.

- Negative wind work of 20-30GW, 
  *Xu et al (2016), Renault et al (2017)*

Model EKE reduction (several 10%), Dominates over thermal damping. 
Mechanical damping:

- Dominant in regions of high EKE and high winds speeds, e.g., western boundary currents, Antarctic Circumpolar Current.


- Modulates eddy characteristics & life cycle.
**Mechanical damping or energizing (wind gradient effect):**

- E.g., energizing of anticyclonic eddies in the subtropical gyres.  
  *Xu et al (2016), Model study Byrne et al (2016)*

- Compensation of anticyclones and cyclones?

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*Wind work on cyclonic and anticyclonic ocean eddies. Work done (mWm$^{-2}$)*

*Regional net wind energy input, global net zero?*
Mechanical damping or energizing (wind gradient effect):

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  *Xu et al (2016), Model study Byrne et al (2016)*

- Compensation of anticyclones and cyclones?
  Anticyclones coupled more strongly to the atmosphere than cyclones, 
  Regional net wind energy input, global net zero?

Byrne et al (2016)
**Large-scale ocean implications (Mechanical)**

**Mechanical damping or energizing (wind gradient effect):**

- E.g., energizing of anticyclonic eddies in the subtropical gyres.  
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- Compensation of anticyclones and cyclones?  
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- Modulation of eddy polarity dominance?

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*Frenger et al (2015)*
"Relative wind" subtleties:

- Modulation by current induced wind changes (weakened ocean damping, \(\sim 10\%\))

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- Modulation by current induced wind changes (weakened ocean damping, \(\sim 10\%\))
  

- Modulation by thermally induced wind changes, Current effect dominant, yet not everywhere (subtropical gyres).
  

- EKE temporal evolution

<table>
<thead>
<tr>
<th>Experiments</th>
<th>Current feedback</th>
</tr>
</thead>
<tbody>
<tr>
<td>EXP1</td>
<td>None</td>
</tr>
<tr>
<td>EXP2</td>
<td>Only in surface stress, using atmosphere from EXP1</td>
</tr>
<tr>
<td>EXP3</td>
<td>In both surface stress and in atmosphere</td>
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2. **LARGE-SCALE OCEAN IMPLICATIONS**
   Mechanical negative effect dominates globally (net damping).
   Watch out for subtleties and compensating effects for parameterizations.
   More to discover? Net effect on marine biogeochemistry?
Take home messages for ocean modeling (non-exhaustive suggestions):

See also, e.g., model studies Renault (2016, 2017), Abel (2018)

- Do not use QuikSCAT (satellite) to force ocean-only models, that is "wrong" relative winds (mismatch of model mesoscale currents and observed mesoscale wind variability). Rather use (coarse) atmospheric reanalysis products and account for current in wind stress calculation (damping of several 10%).
- Account for wind modulation due to mesoscale currents (damping reduced by \(\sim 10\%\)) and wind modulation due to mesoscale SST anomalies.
- Coupled ocean-atmosphere models: calculate fluxes on ocean grid (KE error 6-10%).
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–Thank you–


D Byrne, M Münich, I Frenger, and N Gruber, *Mesoscale atmosphere ocean coupling enhances the transfer of wind energy into the ocean*, Nat Commun 7 (2016), Article number:ncomms11867.


D B Chelton and S-P Xie, *Coupled ocean-atmosphere interaction at oceanic mesoscales*, Oceanography 23 (2010), 52–69.
References (from talk, and a few more) II


