Oceanic and Atmospheric Weather Intertwined

– An observational perspective –

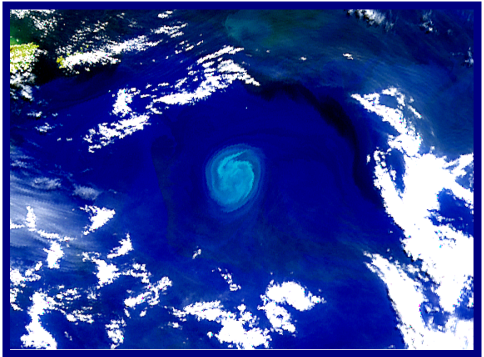
Ivy Frenger; thanks to Matthias Münnich, Reto Knutti, Nicolas Gruber, David Byrne

OMDP Workshop *Sources and Sinks of Ocean Mesoscale Eddy Energy*

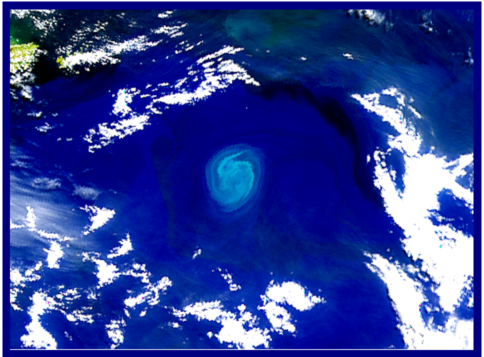
March 12 - 14 | Tallahassee

Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

GEOMAR



Ocean Color (SeaWIFS)
Drake Passage, March 1998
From Nasa Visible Earth



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OBJECTIVES

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*

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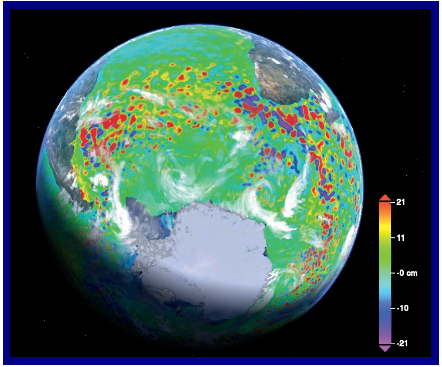
LOCAL IMPRINTS AND MECHANISMS (THERMAL)

Data:

- Satellite based observations over the Southern Ocean
- Variables: sea level anomalies (SLA), sea surface temperatures (SST), atmospheric variables
- Resolutions: spatial $^1/_3{}^\circ$, temporal weekly, years 1997 - 2010

Method:

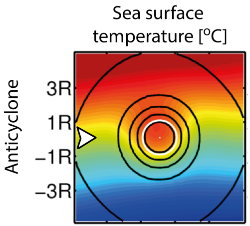
- Identification of individual eddies based on SLA
- Collocation with SST & atmospheric variables



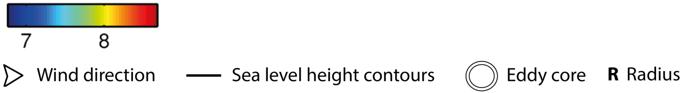
Satellite observed SLA [cm]

LOCAL IMPRINTS AND MECHANISMS (THERMAL)

Average imprint:



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

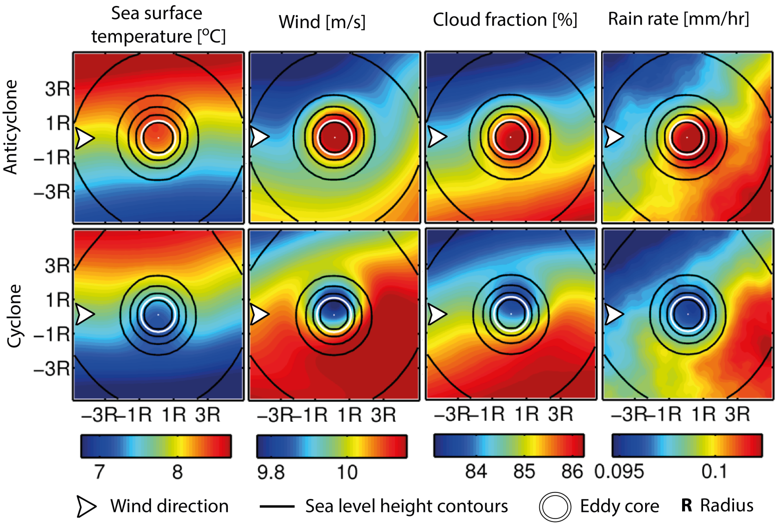


Modified from Frenger et al (2013)

LOCAL IMPRINTS AND MECHANISMS (THERMAL)

Average imprint:

- Positive correlation of SST & atmospheric anomalies.



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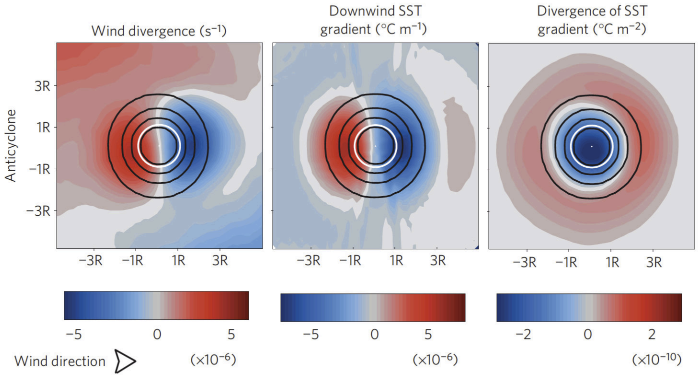
Mechanism:

- Downward turbulent mixing of momentum



Frenger et al (2013), see also Minobe et al (2008)

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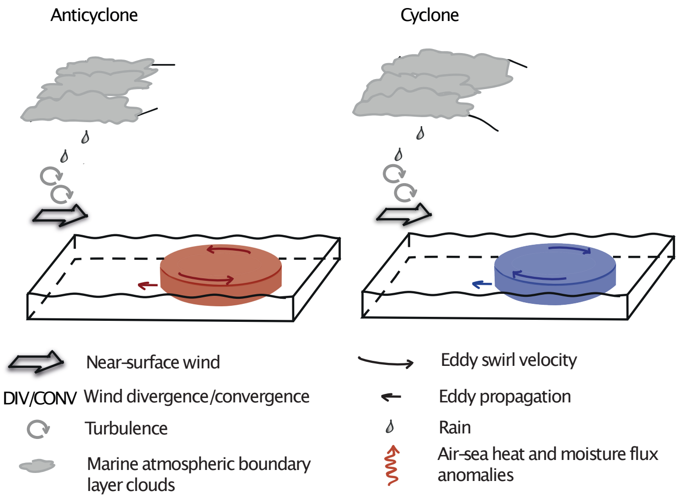

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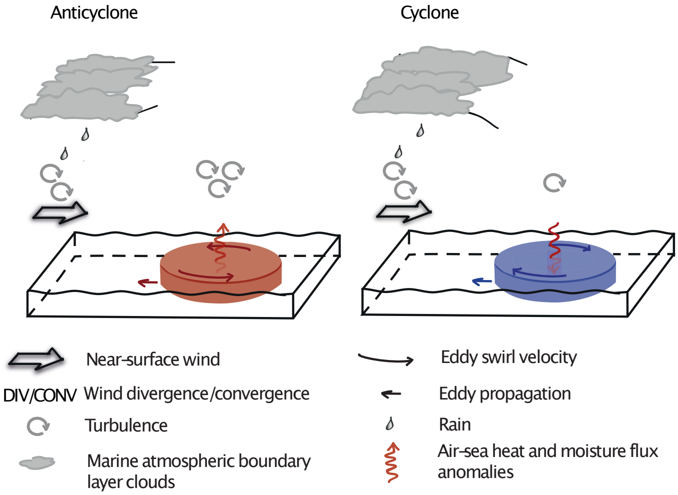

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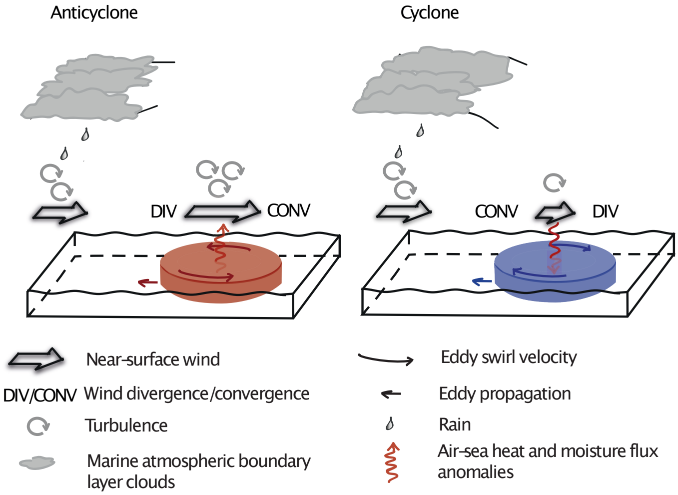

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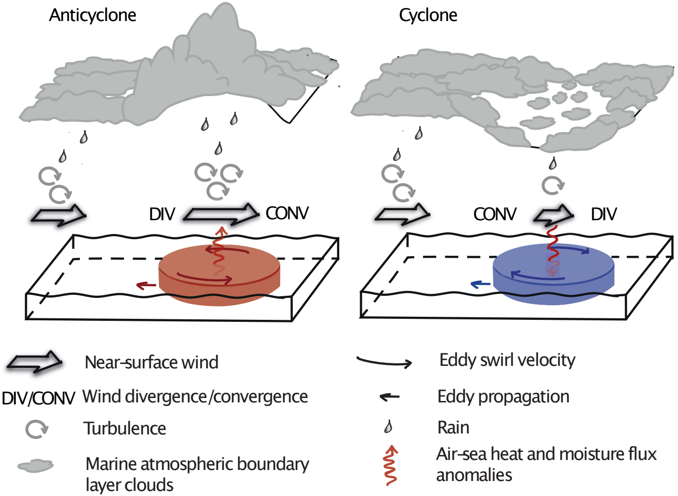


Modified from Frenger et al (2013)

LOCAL IMPRINTS AND MECHANISMS (THERMAL)

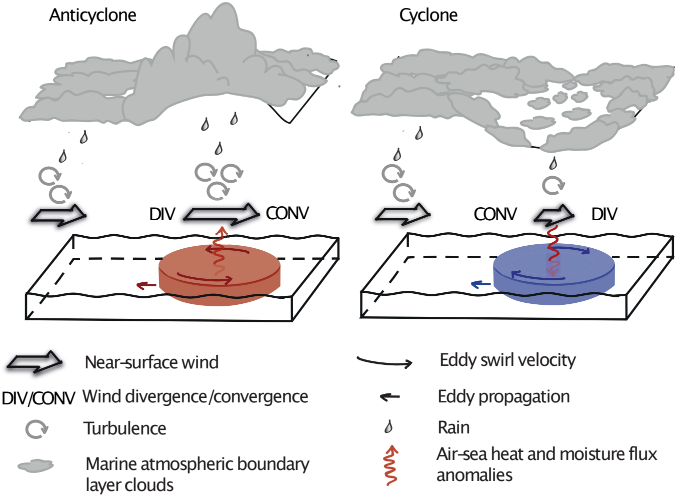
Mechanism:

- Downward turbulent mixing of momentum

Effects:

- Modulation of atmospheric extreme events

  Large-scale atmospheric effects?
  Model study Foussard et al (2019): Anchoring of storm tracks.
- Ocean eddies damped.
  E.g., Hausmann et al (2015)

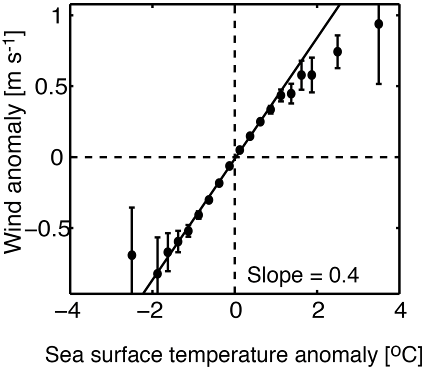


Modified from Frenger et al (2013)

LOCAL IMPRINTS AND MECHANISMS (THERMAL)
Approximate linear relationship of eddies and atmospheric quantities

1°C of sea surface temperature anomaly causes a change of ...

- ... wind speed of 5%.



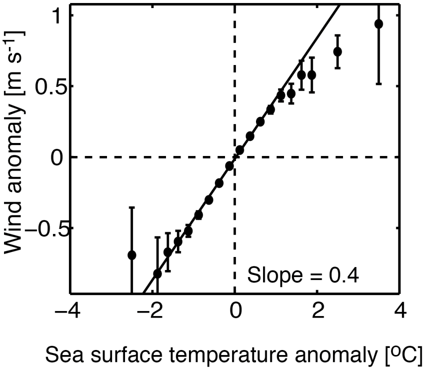
Frenger et al (2013)

Approximate linear relationship of eddies and atmospheric quantities

1°C of sea surface temperature anomaly causes a change of ...

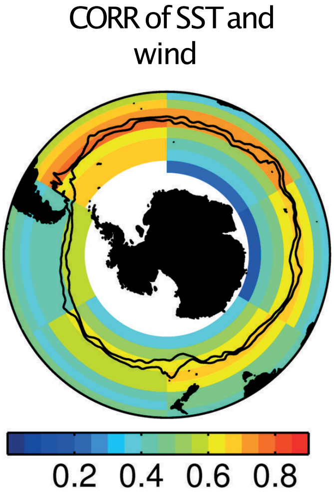
- ... wind speed of 5%.
- ... cloud fraction of 3%.
- ... liquid cloud water of 6%.
- ... rain probability of 8%.
- ... rain rate of 8%.

E.g., O'Neill et al (2005), O'Neill (2012), Park et al (2006)



Frenger et al (2013)

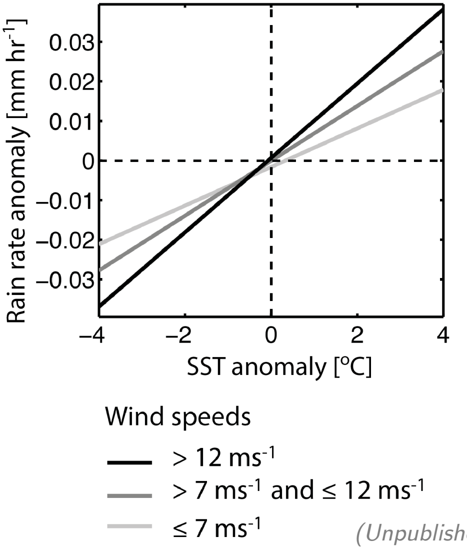
Regional and seasonal modulation of the relationship



Frenger et al (2013)

Eddies are coupled more strongly to the atmosphere ...

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



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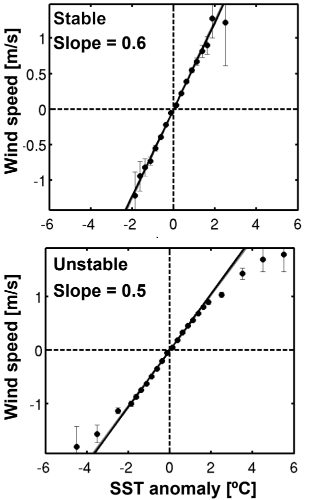
LOCAL IMPRINTS AND MECHANISMS (THERMAL)
Regional and seasonal modulation of the relationship

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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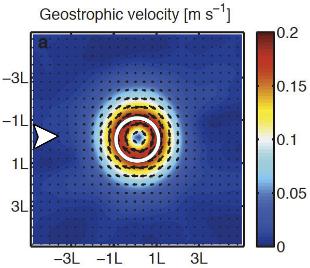
Wind stress is a result of winds and currents.



Faghmous et al (2015)

LOCAL IMPRINTS AND MECHANISMS (MECHANICAL)
Eddy currents & homogeneous winds

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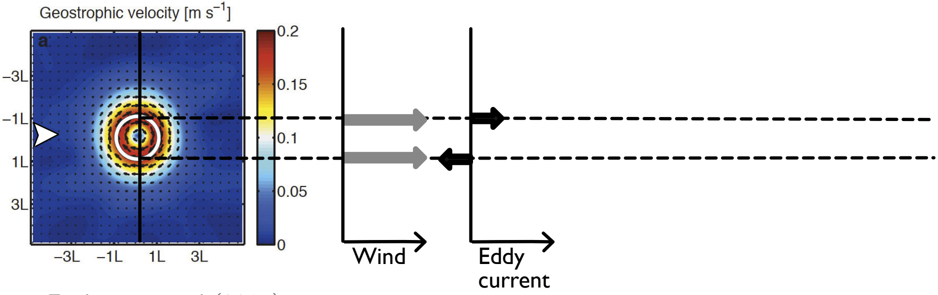

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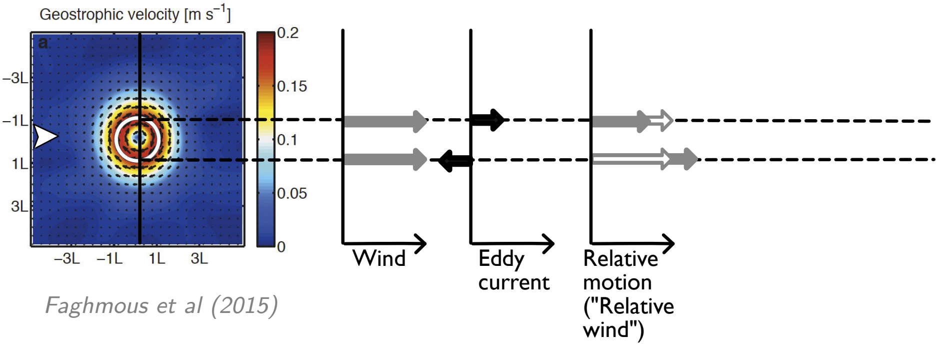
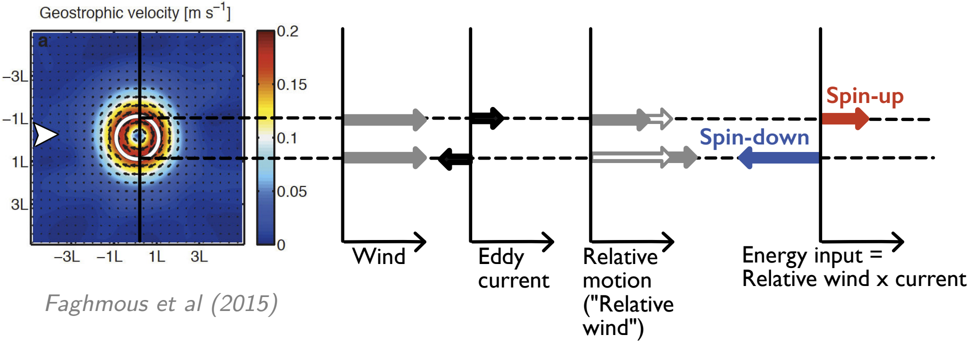


Faghmous et al (2015)

LOCAL IMPRINTS AND MECHANISMS (MECHANICAL)
Eddy currents & homogeneous winds

Wind stress is a result of winds and currents.

- Spin-down > Spin-up, eddies damped (either polarity).
- Increase of coupling with increasing winds. *Renault et al (2017), model study Abel (2018)*



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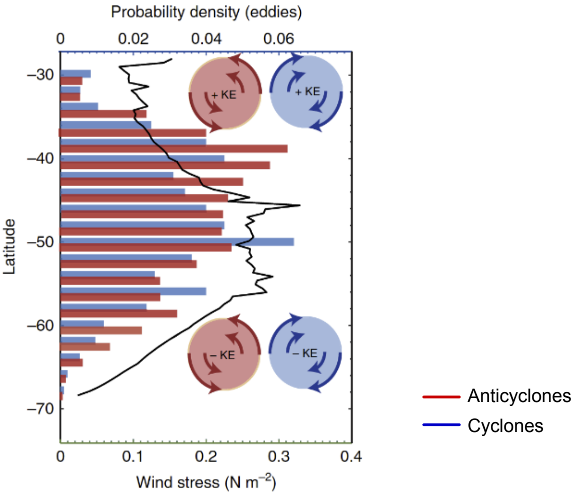
LOCAL IMPRINTS AND MECHANISMS (MECHANICAL)
Eddy currents & wind gradient at the scale of eddies

- Meridional wind gradient across the Southern Ocean.



Byrne et al (2015)

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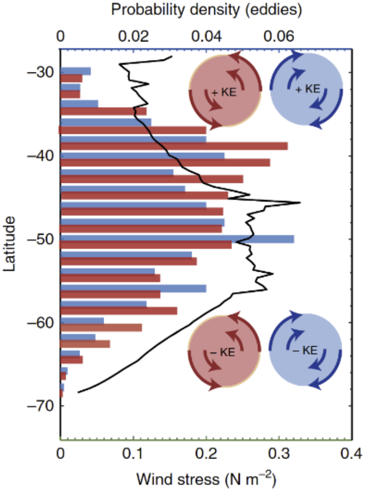

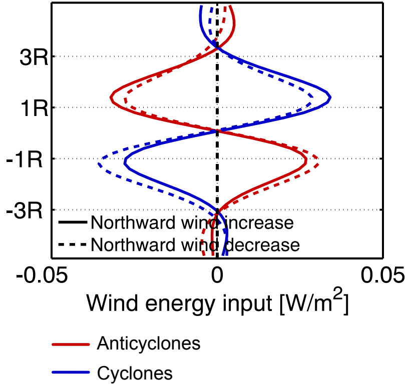

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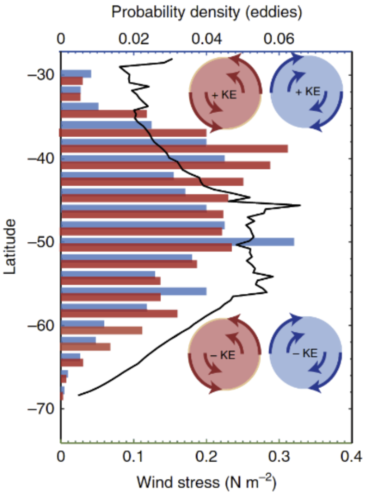
- Eddies damped or energized depending on wind gradient.



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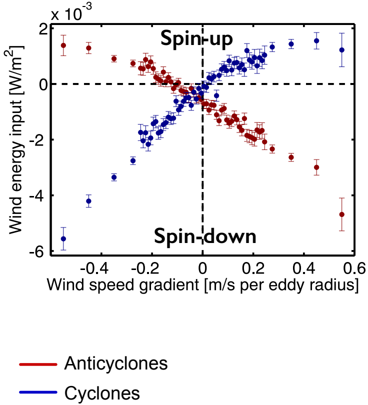

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     Wind work depends on "relative wind"; dependence on atmospheric conditions.

     Systematic damping under homogeneous winds; damping or energizing under wind gradient.
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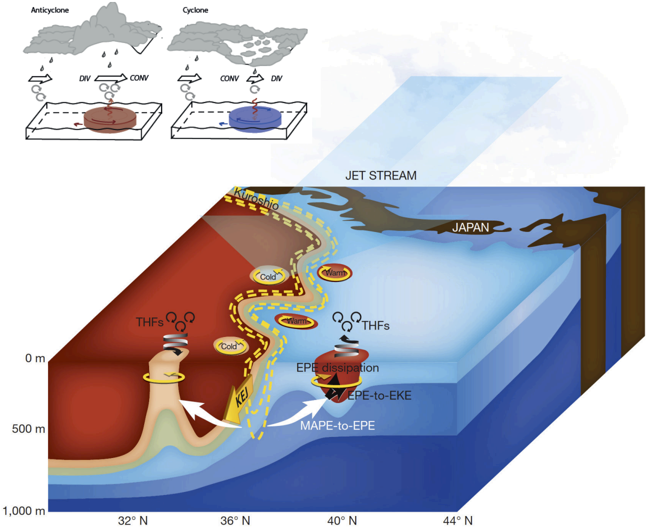
LARGE-SCALE OCEAN IMPLICATIONS (THERMAL)

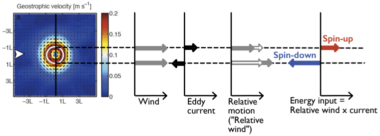
Thermal damping:

- E.g., western boundary current system energetics (current separation), seasonality of EKE, lateral eddy mixing. *Model studies Ma et al (2016), Rieck et al (2015), Shuckburgh et al (2010)*
- Model EKE reduction (several 10%) *Model studies Seo et al (2016), Abel (2018)*



Model study Ma et al (2016)

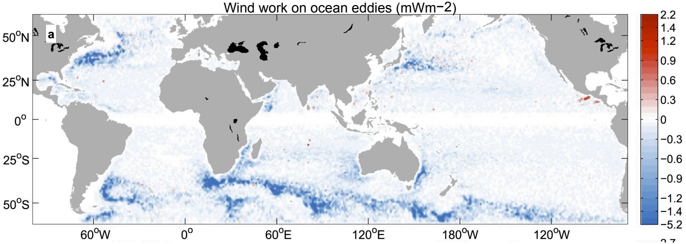
LARGE-SCALE OCEAN IMPLICATIONS (MECHANICAL)



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. *Model studies Renault et al (2016), Abel (2018)*



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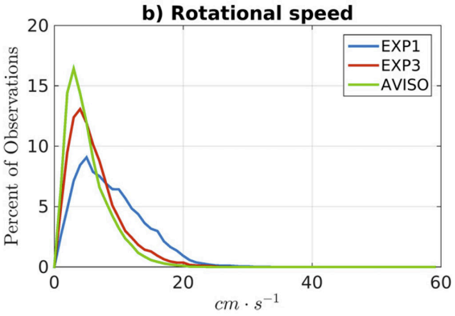
  Model EKE reduction (several 10%?),
  Dominates over thermal damping.
  Model studies Renault et al (2016), Abel (2018)
- Modulates eddy characteristics & life cycle.

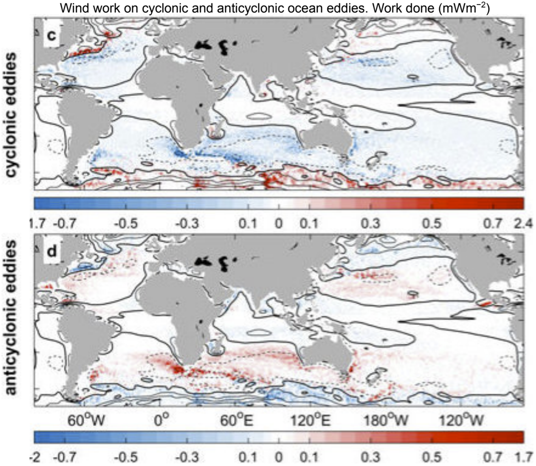


Experiments	Current feedback
EXP1	None
EXP2	Only in surface stress, using atmosphere from EXP1
EXP3	In both surface stress and in atmosphere

Model study Renault et al (2016)

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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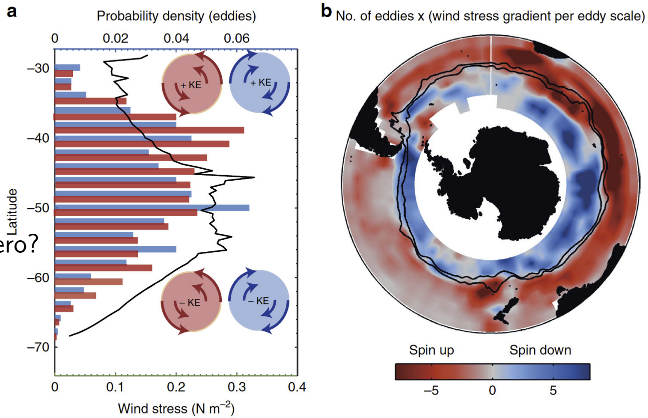
  Anticyclones coupled more strongly to the atmosphere than cyclones,
  Regional net wind energy input, global net zero?



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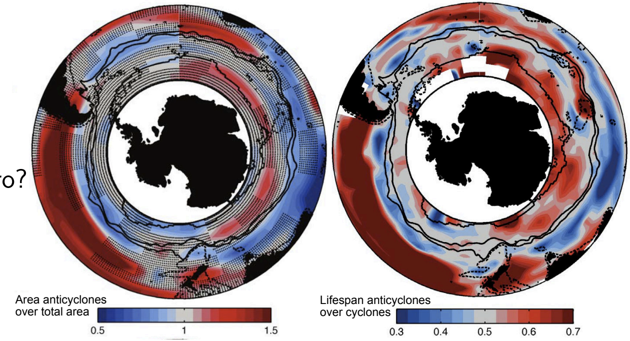
- Modulation of eddy polarity dominance?

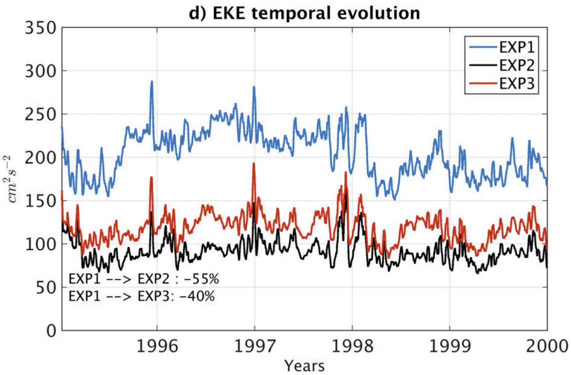


Frenger et al (2015)

LARGE-SCALE OCEAN IMPLICATIONS (MECHANICAL)

"Relative wind" subtleties:

- Modulation by current induced wind changes (weakened ocean damping, $\sim$10%)
  Model studies Renault et al (2016), Abel (2018)



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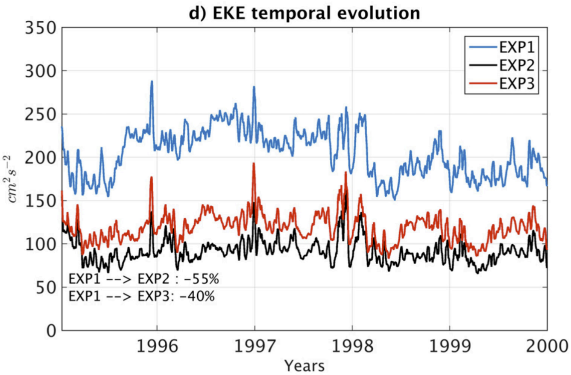
LARGE-SCALE OCEAN IMPLICATIONS (MECHANICAL)

"Relative wind" subtleties:

- Modulation by current induced wind changes (weakened ocean damping, ∼10%)
  Model studies Renault et al (2016), Abel (2018)
- Modulation by thermally induced wind changes, Current effect dominant, yet not everywhere (subtropical gyres).
  Gaube et al (2015)



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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?

ACCOUNTING FOR AIR-SEA EFFECTS OF OCEAN EDDIES IN OCEAN MODELS

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–

References (from talk, and a few more) I

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