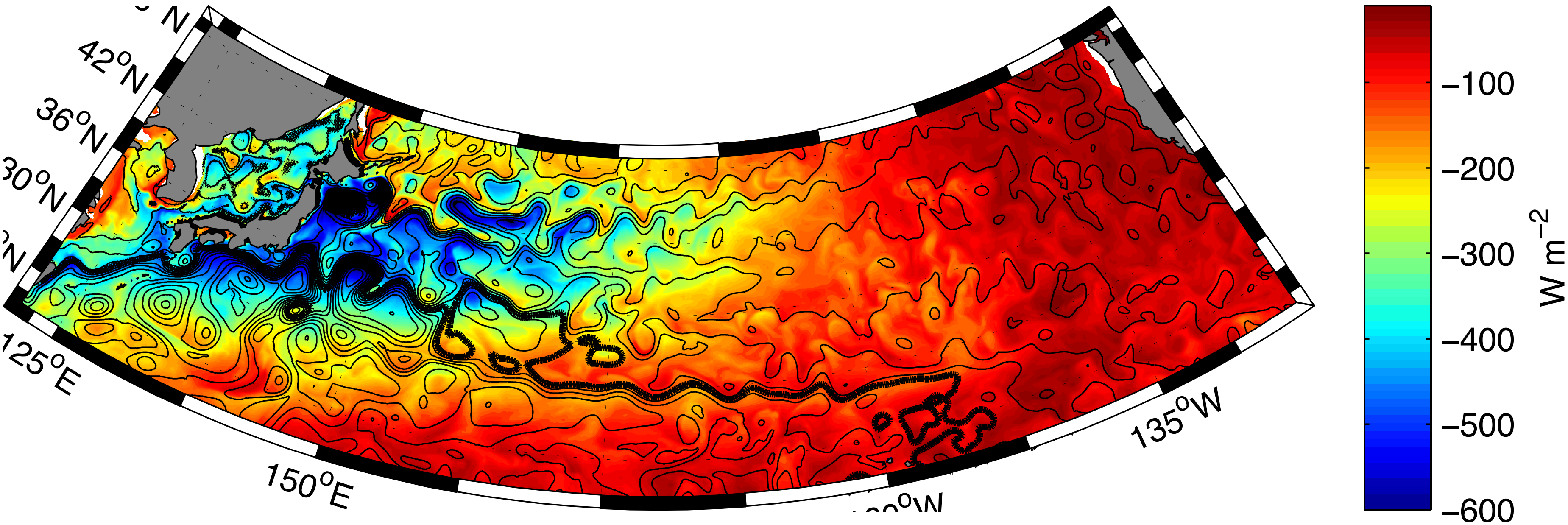
# The influence of mesoscale eddies on wintertime air-sea interaction in the Kuroshio Extension region

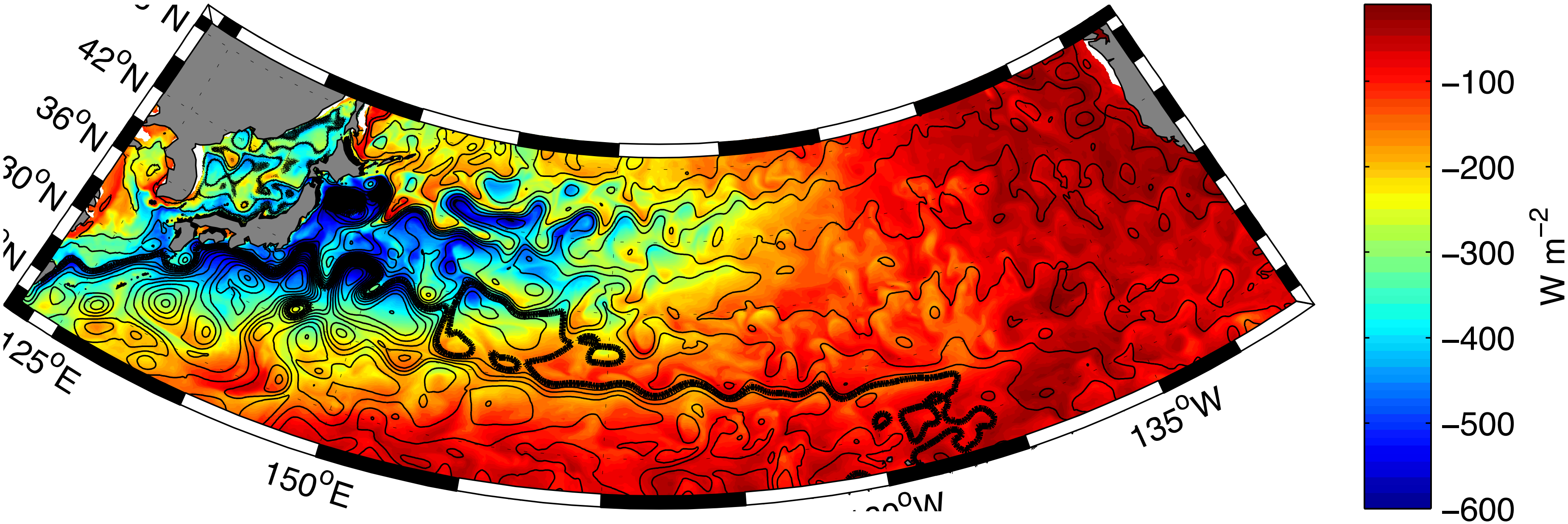



**Stuart P. Bishop, Frank O. Bryan, and Justin Small**

**National Center for Atmospheric Research**

**CESM Workshop, Breckenridge June 17, 2014**

# Evidence for Bjerknes compensation in the North Pacific

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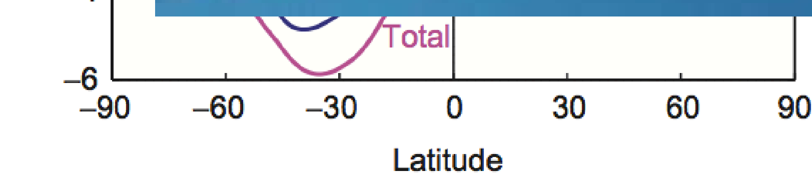
# Outline

- Introduction to meridional heat transport (MHT) and eddies in the ocean and atmosphere
- Feedbacks of ocean eddies on the atmosphere
- High resolution (HR) fully-coupled climate simulation using CESM
- Ocean and atmospheric response in HR CESM
- Evidence for “Bjerknes Compensation” in the North Pacific

# Meridional Heat Transport


From *Ocean Circulation and Climate: A 21st Perspective*

- Earth receives insolation from the sun:
  - e tropics
  - es
  - re
  - rd to
  - ical
  - at
  - sphere
- How does the ocean do this?

# Bjerknes Compensation

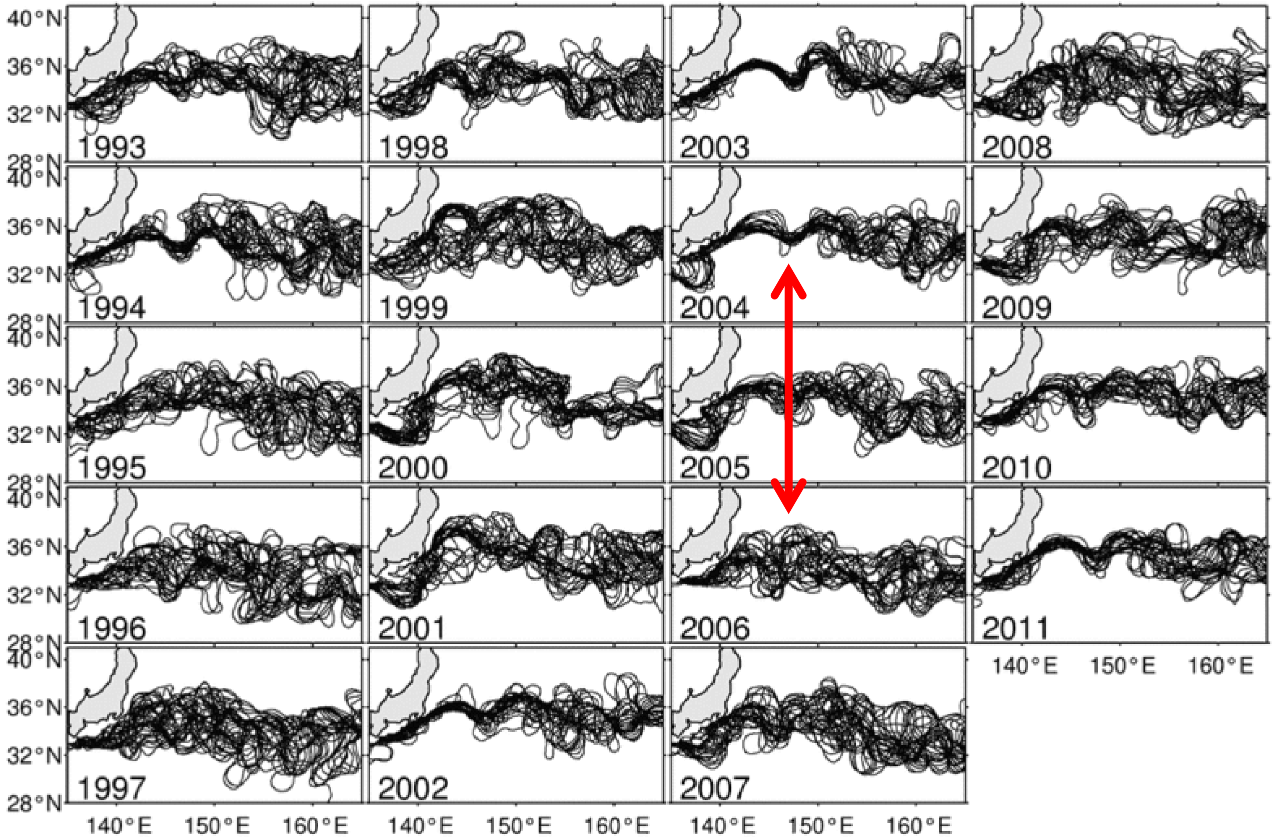
- Bjerknes (1964), Atlantic Air-Sea Interaction
- When net TOA radiation is zero, if there is a reduction in MHT by the ocean this reduction must be compensated by the atmosphere

$$\int_0^L \int_{-h}^0 \rho_0 C_p^o \overline{v_o T_o} dz dx = - \int_0^L \int_0^H \rho_a C_p^a \overline{v_a T_a} dz dx$$

- North Atlantic was favored as a region for this due to the MOC and decadal time scales linked to the AMO
- Farneti and Vallis (2013) quoting Bjerknes (1964) “the atmosphere is likely to drive the ocean at interannual time scales, while for decadal-multidecadal periods it is ocean dynamics that prevail.”


Srokosz et al. 2013, BAMS

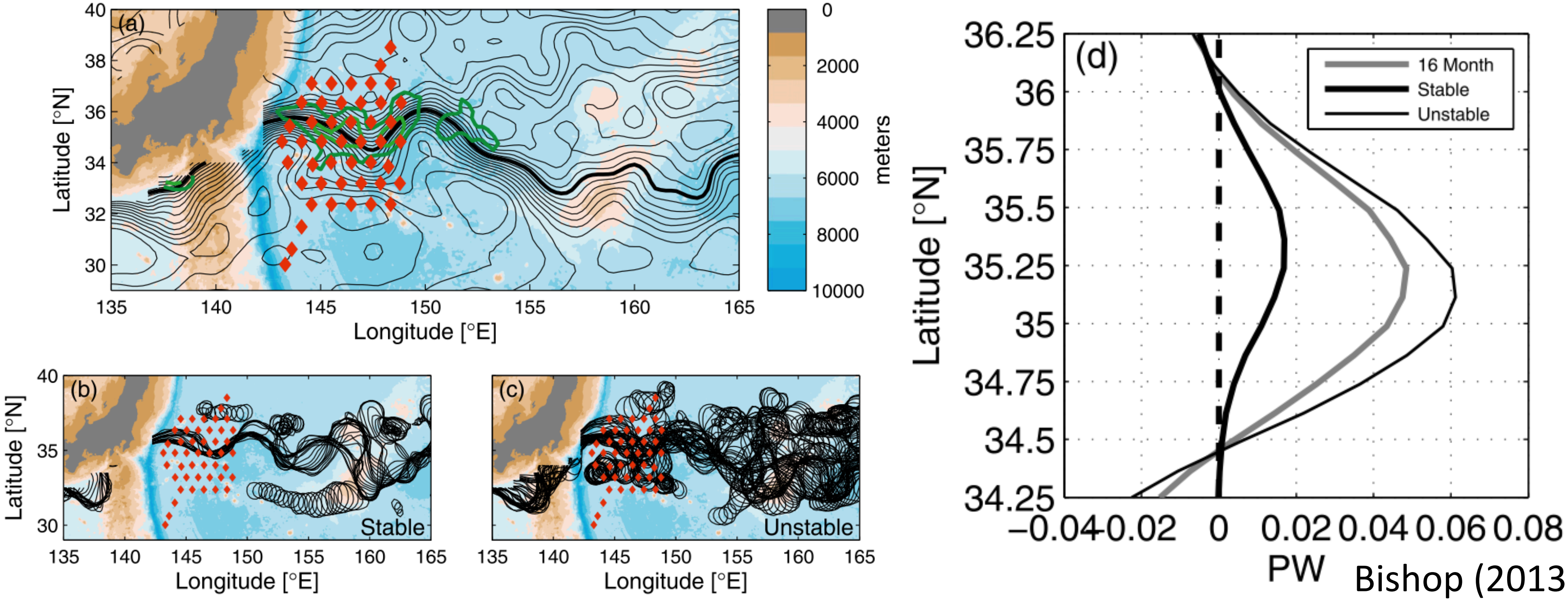
# Kuroshio Extension
## Decadal Variability




Updated from Qiu and Chen 2005
http://www.aviso.altimetry.fr/en/news/idm/2012/mar-2012-following-kuroshio-paths.html

- "Stable" years
  - 1993-1994, 2002-2005, 2011
- "Unstable" years
  - 1995-2001, 2006-1010
- Stable characteristics:
  - Strong transport (strong meridional SST gradient)
  - Weak small amplitude eddies
  - Small meridonal eddy heat transport (Presumably)
- Unstable characteristics:
  - Weaker transport (weaker meridional SST gradient)
  - Strong high amplitude eddies
  - Large meridional eddy heat transport

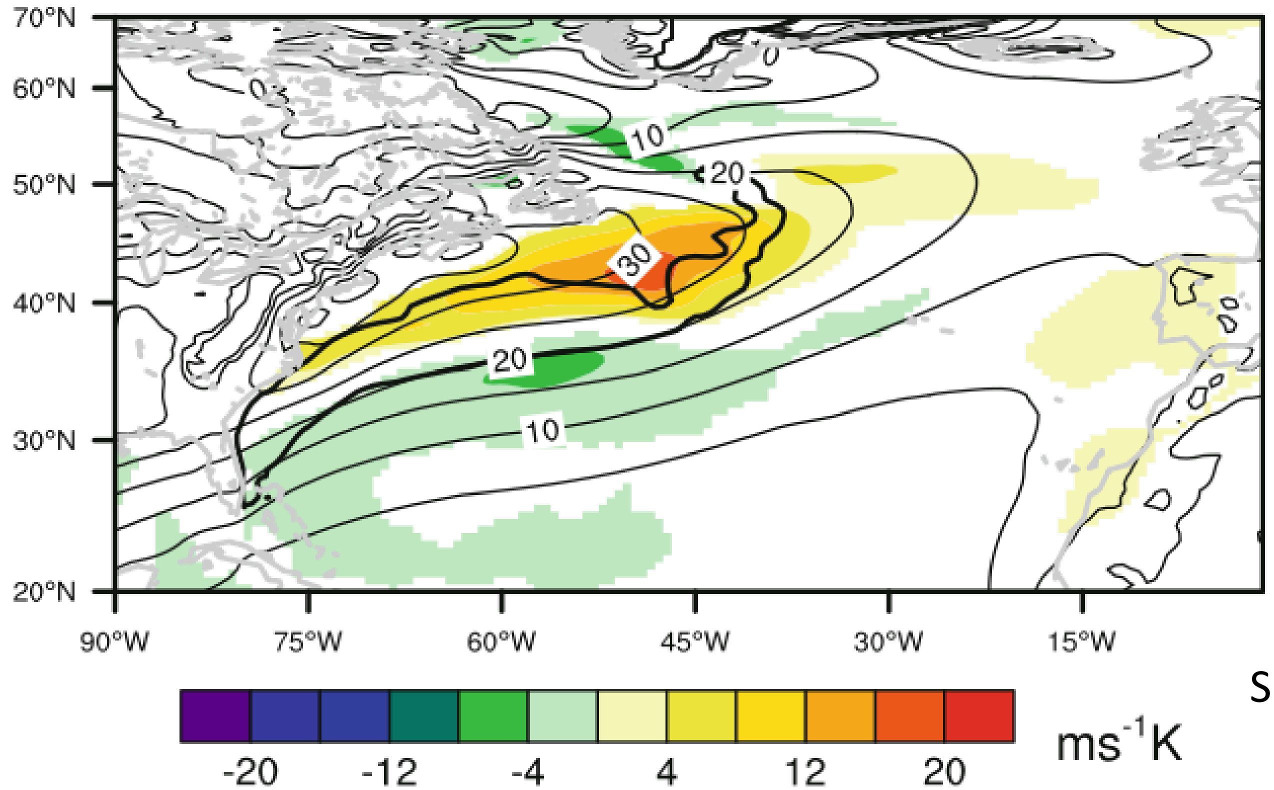
# Kuroshio Extension System Study (KESS)




Bishop (2013)

- Oberservational field study from 2004-2006
- Captured a transition from stable to unstable state
- Meridional eddy heat transport was 3X larger during the unstable state

# Smoothed vs. Unsmoothed SST Fronts




Small et al. 2013

- Climate simulation with CAM4: 0.5º with 0.25º Reynolds SST boundary conditions.
- Experiments with smoothed and unsmoothed SST.
- Unsmoothed fronts produced up to 20-40% higher eddy heat and moisture fluxes.
- Sharp fronts affected not only the lower troposphere, but affected the free troposphere.

# High-Resolution Fully-Coupled CESM Simulation

Movie courtesy of Tim Scheitlin (NCAR Visualization Lab)

## Model

- Community Earth System Model:
  - $0.1^0$ Ocean (POP2)
  - $0.25^0$ Atmosphere (CAM5)
- Fully coupled (atmosphere-ocean)
  - 6 hourly
- 100 years
- Monthly archived data
- Advantages of model over observations:
  - Subsurface oceanic data
  - Long time series for statistical robustness

# ASD run status and acknowledgements

A new high-resolution global climate simulation using Community Atmosphere Model version 5 and an eddy-resolving ocean model.

Justin Small, Julio Bacmeister, David Bailey, Allison Baker, Stuart Bishop, Frank Bryan, Julie Caron, John Dennis, Ernesto Muñoz, Markus Jochum, David Lawrence, Bob Tomas, Joe Tribbia, Yu-heng Tseng, Mariana Vertenstein

**Paper *nearly complete***

**ABSTRACT**

High-resolution global climate modeling holds the promise of capturing planetary-scale climate modes and small-scale (regional and sometimes extreme) features simultaneously, including their mutual interaction. This paper discusses a new state-of-the-art high-resolution Community

**ACKNOWLEDGEMENTS**

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Posters here using ASD data:

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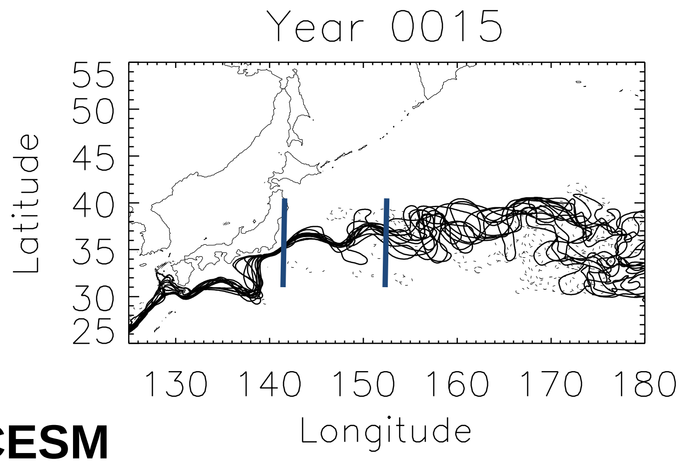
Small, Curchitser, Kauffman, Large

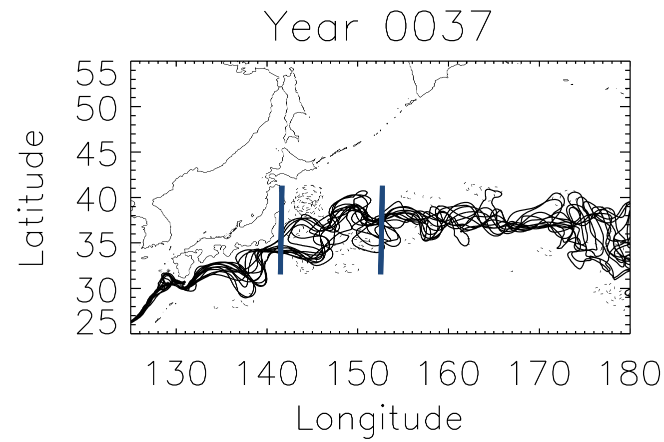
**Sensitivity of modeled dynamics to atmosphere and ocean resolution in the CESM**

Tomas, Small, Tseng, Bailey and ASD group

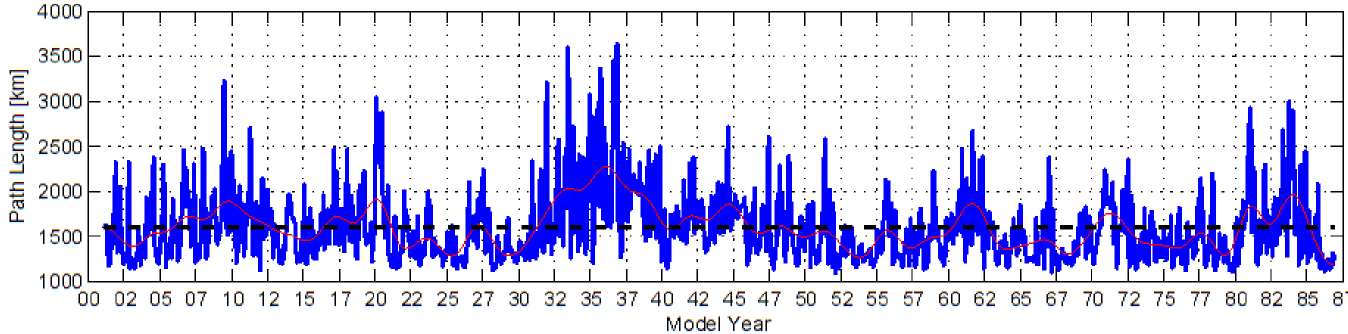
**DATA AVAILABLE ON EARTH SYSTEM GRID**

# Decadal Variability in CESM

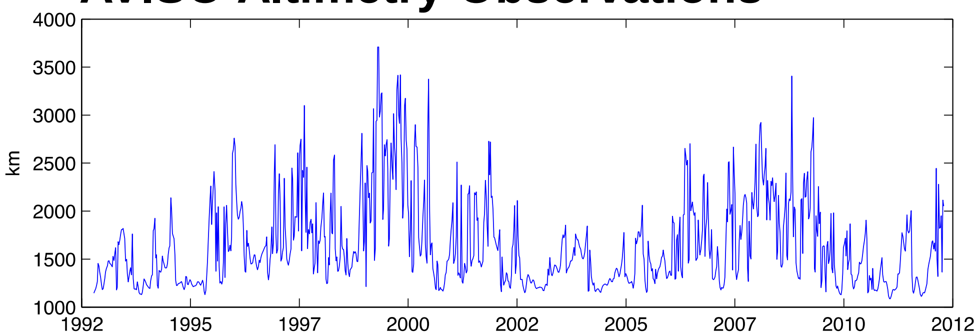



**CESM**

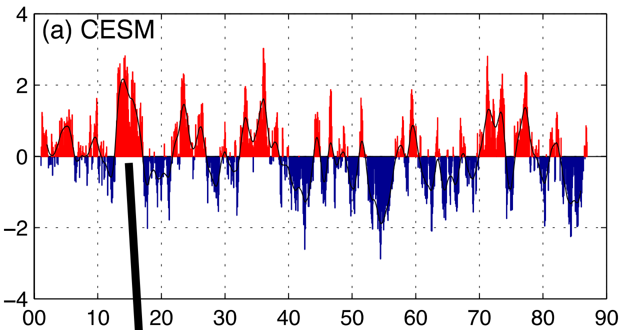


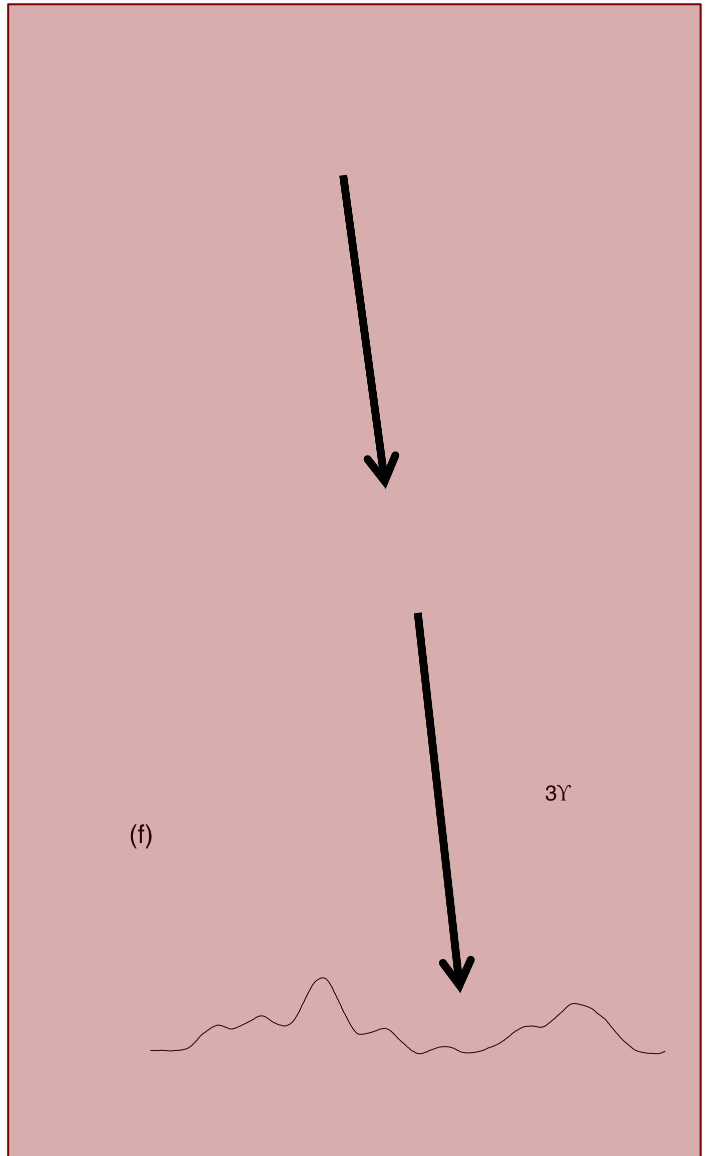

**AVISO Altimetry Observations**




- Path length between $141^0$-$153^0$E
  - Longer path length = more eddies
  - Shorter path length = less eddies
- Model exhibits variability similar to observations

# Kuroshio Variability and PDO



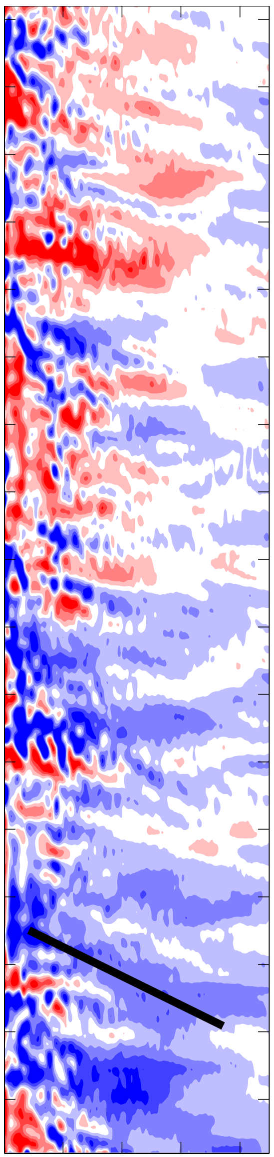




- Phase of PDO leads jet latitude by ~3-4 years
- Seen in both observations and model
- Jet latitude precedes meander variability
  - Northerly jet has a more "stable" meander state
  - Southern jet has a more "unstable" meander state

Bishop et al. in prep

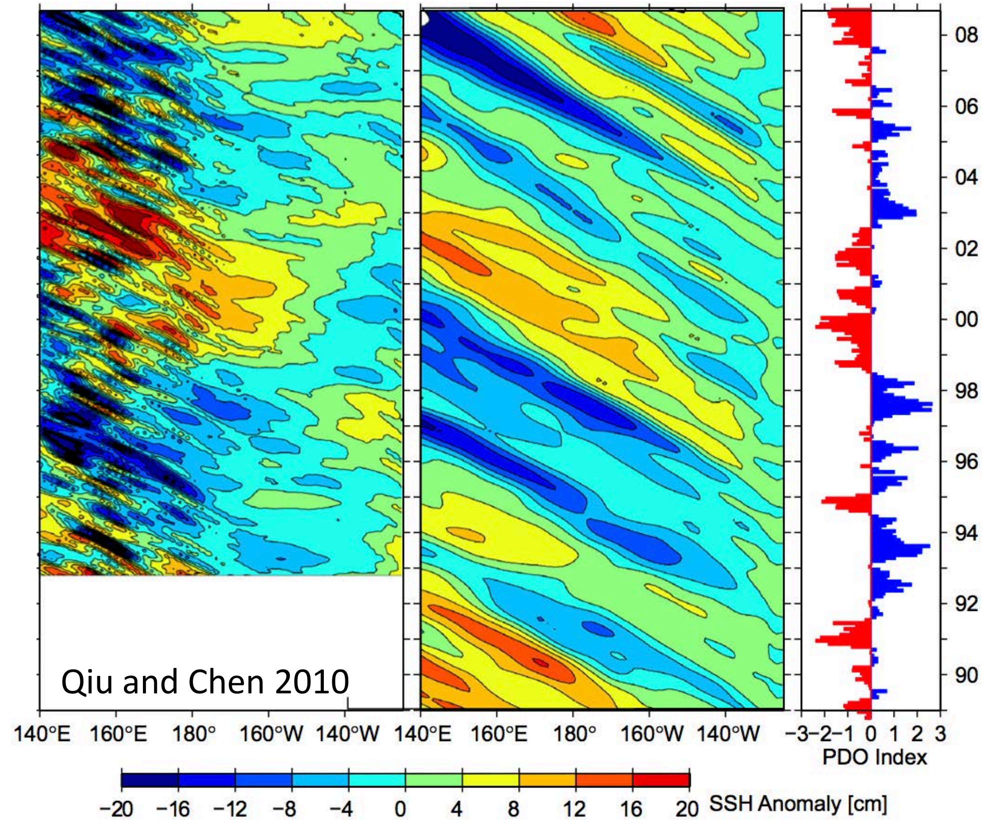
# PDO & SSH Anomalies

**CESM**



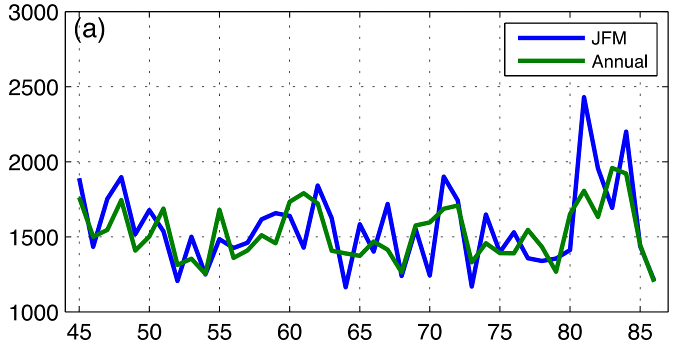
Bishop et al. in prep

**Observations+Rossby Wave Model**




- Phase of PDO drives SSH anomalies that propagate west from the central Pacific
- SSHa's drive meridional shifts of the jet
  - Positive SSHa shifts the jet North
  - Negative SSHa shifts the jet South

# "Waviness" Index (KEI)

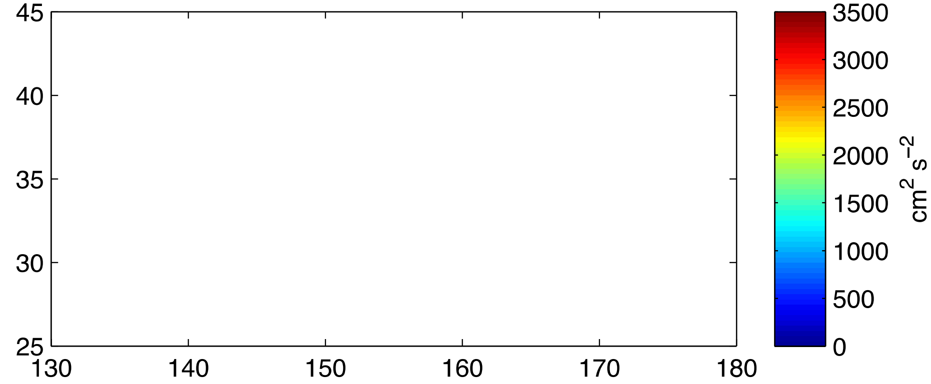



Bishop et al. in prep

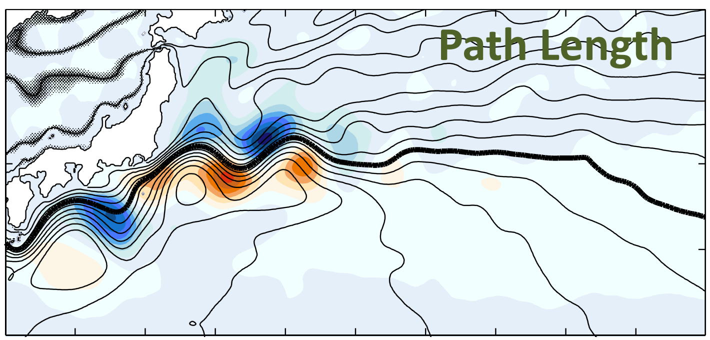
- Index: negative normalized path length
  - +ve "Stable"
  - -ve "Unstable"
- Index: JFM mean (blue), annual mean (green)
- Most years if JFM "stable" annual mean is "stable" too (68% chance)
- Composite threshold = 0.25 (1/4 standard deviation)

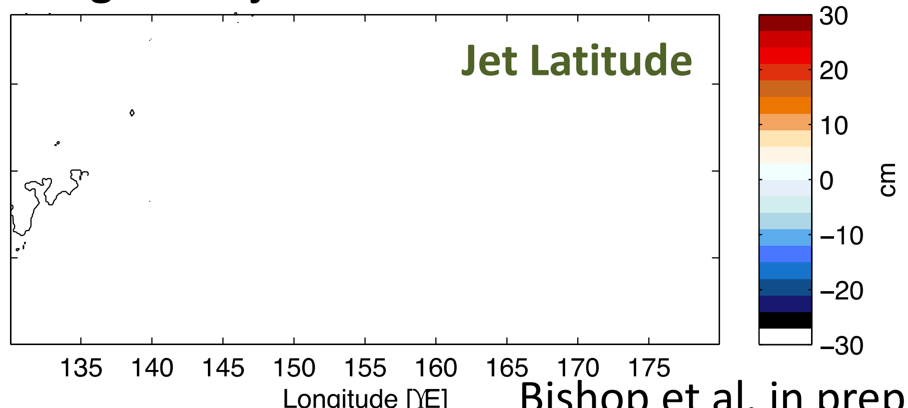
# Stable vs. Unstable SSH

**Composite (±0.25) of SSH and EKE**




**Regression of SSH onto normalized path length and jet latitude**



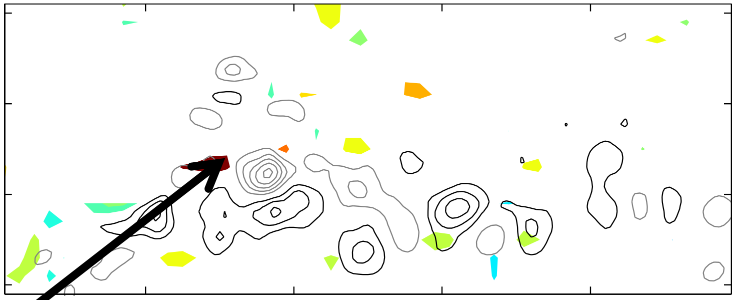

Bishop et al. in prep

- Stable vs. Unstable:
  - Tighter front (ΔSSH of 84 vs. 60 cm between 34°-36°N at 145°E)
  - Tight swath of EKE along the jet
  - SSH is higher (lower) to the south (north) – higher transport
  - Stronger Southern Recirculation Gyre

# Wintertime Surface Heat Flux

**CESM**

**OAFlux**



Longitude [ΥE]

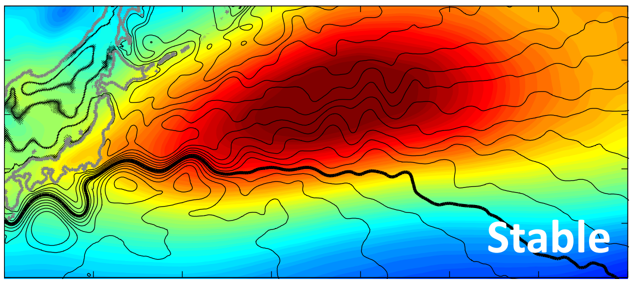
**Excess fuel for storms in stable states**

Bishop et al. in prep

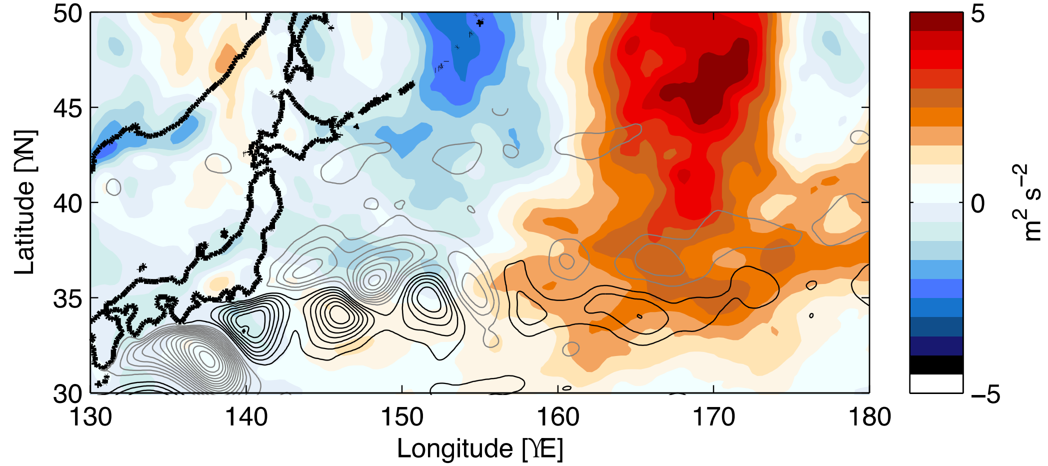
- JFM composite difference shows enhanced SHFs during stable meandering states
  - ~100 W $m^{-2}$ north and near the coast
  - Excess fuel for storms?

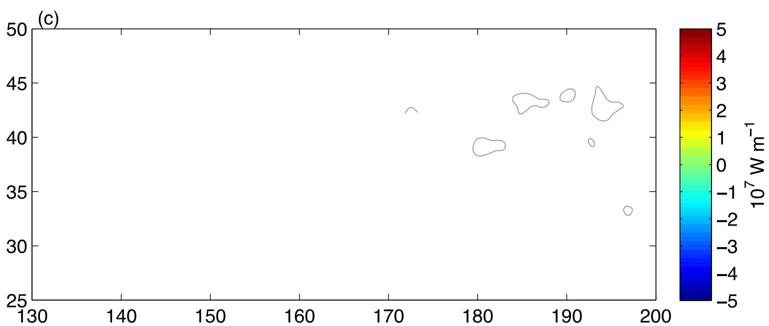
# Atmospheric Response: Storm Track & Eddy Heat Flux

**Composite of vertically-integrated EHF**




**Regression of JFM V'V' onto KEI**

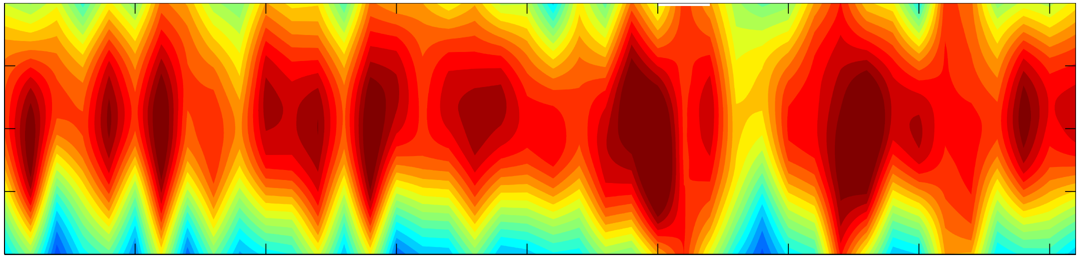



Bishop et al. in prep

- Storm track is enhanced along and north downstream.
- Meridional eddy heat fluxes (MEHFs) are enhanced during stable meandering states.
- MEHFs are enhanced geographically where storm track is enhanced.

# Meridional Eddy Heat Transport (Atmosphere)



Difference

tream Axis [km]

(c)

$$\frac{1}{g}\int_{p_0}^{p_s}(C_p\overline{v'T'}+L\overline{v'q'})dp$$

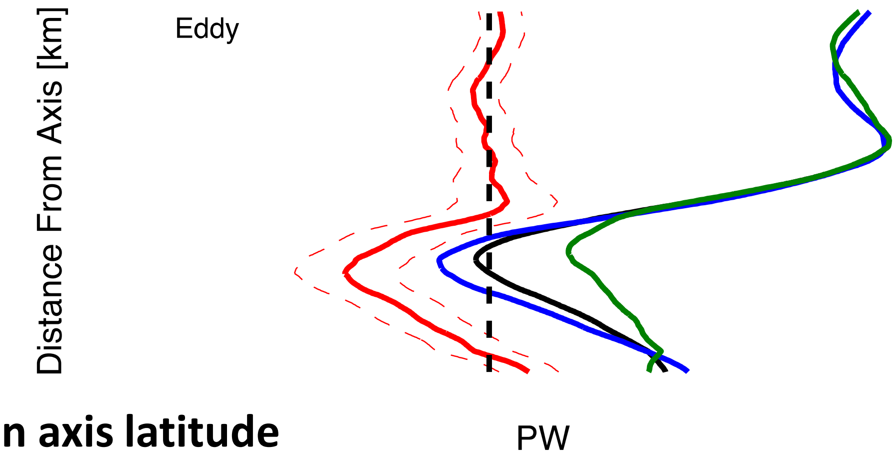
- MEHT:
  - combination of temperature and moisture fluxes
  - Vertically integrated from 50 hPa → surface
  - Zonally integrated across Pacific basin

- MEHT was calculated relative to Jet Stream axis (maximum 850 hPa zonal mean wind, Ari Solomon personal communication)

- MEHT is enhanced by ~0.1 PW at its maximum during +ve KEI

Bishop et al. in prep

# Meridional Eddy Heat Transport (Ocean)




**-- Kuroshio Extension axis latitude**

- MEHT has a range of ±0.3 PW
- Stable states have the persistence of negative MEHT just south of the Kuroshio Extension jet core
- Aoki et al. (2013) notes persistence of negative MEHT south of the Gulf Stream and Kuroshio Extension (only 5 years of OFES simulation)
- Attributed to southward migration of warm water cores from cold-core rings interacting with meanders
- Unstable state has a larger MEHT by 0.07±0.02 PW

Bishop et al. in prep

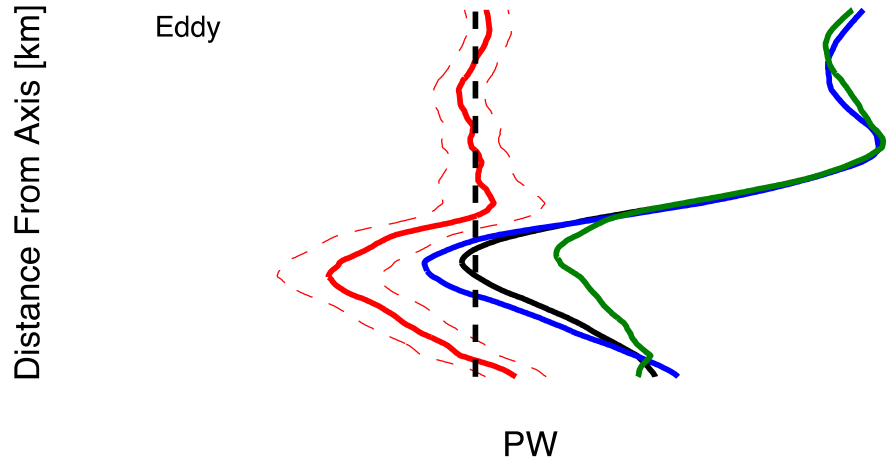
# Local Bjerknes Compensation

**Atmosphere**

tream Axis [km]

(c)

**Ocean**




- The atmosphere and ocean have a degree of compensation (other studies did not find a perfect compensation in the N. Atl.):
  - Compensation is not coincident in space or time.
  - Atmosphere compensates during winter
  - Future work will look at this compensation throughout the year
- Local compensation was not expected since the atmosphere could compensate for the ocean anywhere on the globe!

# Conclusions & Future Work

- Wintertime air-sea fluxes affect atmospheric circulation in high-resolution climate simulations with important implications for climate
- Fully-coupled simulation resembles observations with interannual to decadal variability in the Kuroshio Extension
- The atmosphere and ocean partially compensate as in “Bjerknes Compensation”
- Future Work:
  - Determine what the originis of negative MEHT south of the jet during stable states.
  - Perform a full ocean heat budget to determine what processes are responsible for driving the atmospheric response in stable vs. unstable states (advection, heat content tendency, etc…)

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