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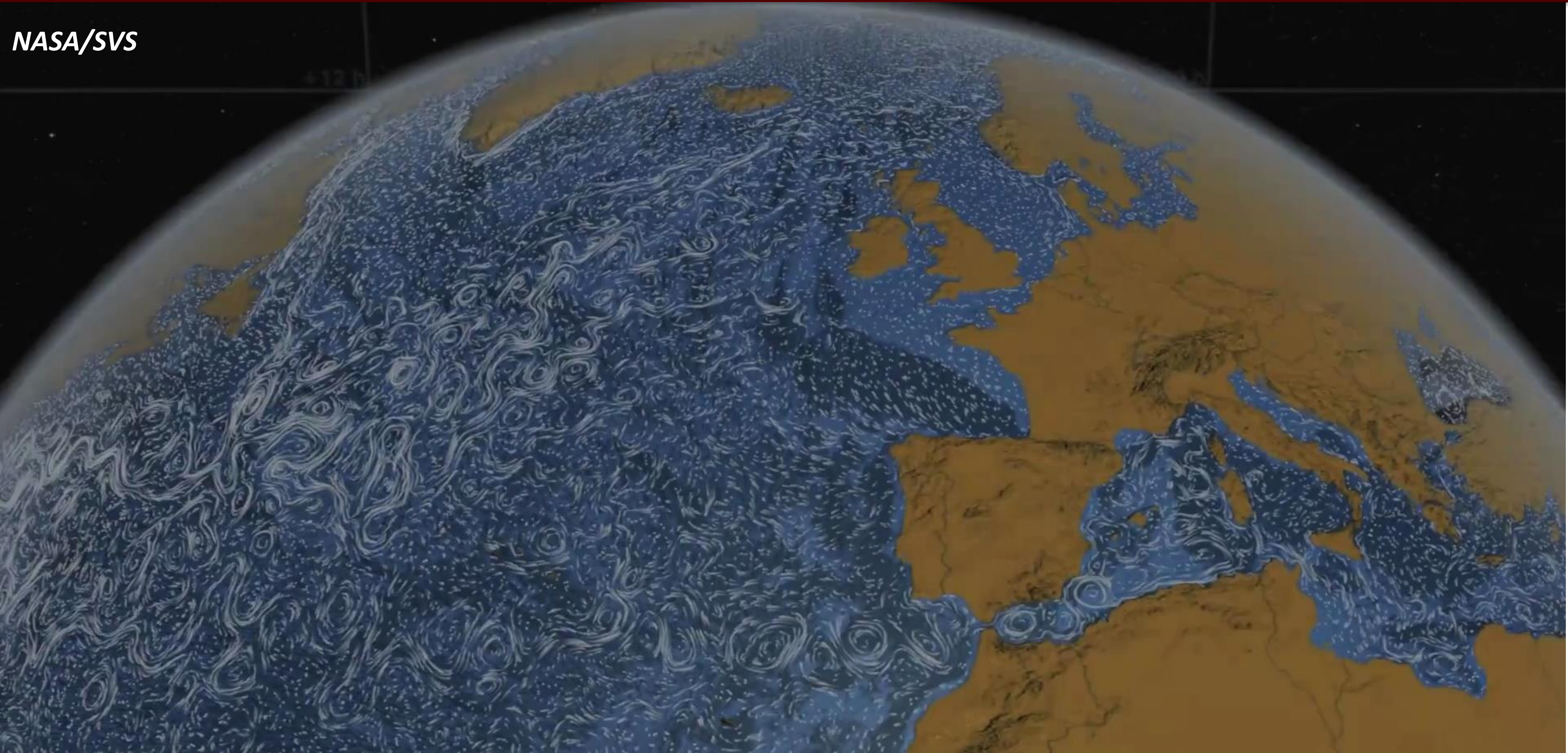
Contributions from Xiaohui Ma, Raffaele Montuoro, Xue Liu, Zhao Jing, R. Saravanan

NASA/SVS



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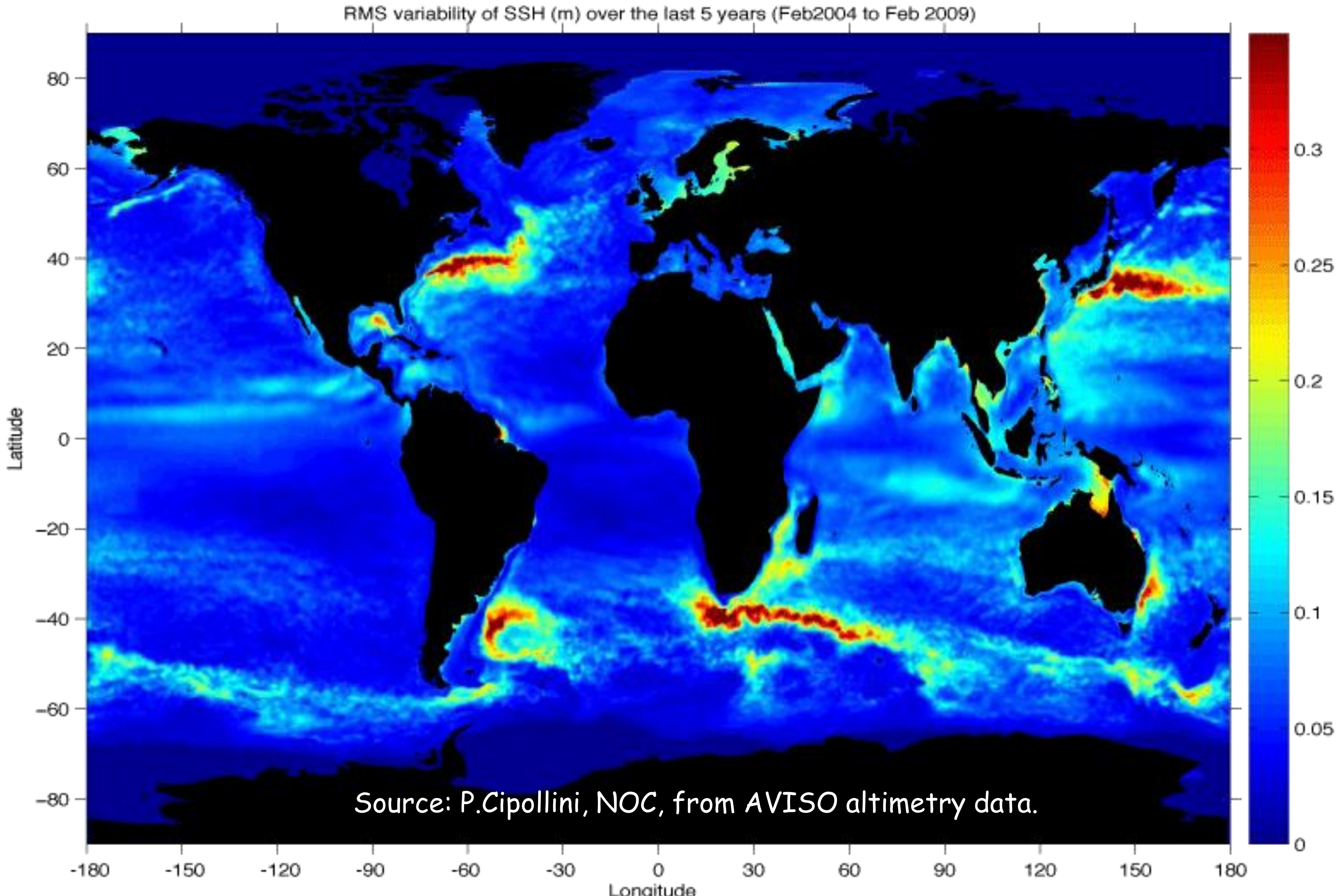
Ocean Eddy Activity Measured from Space



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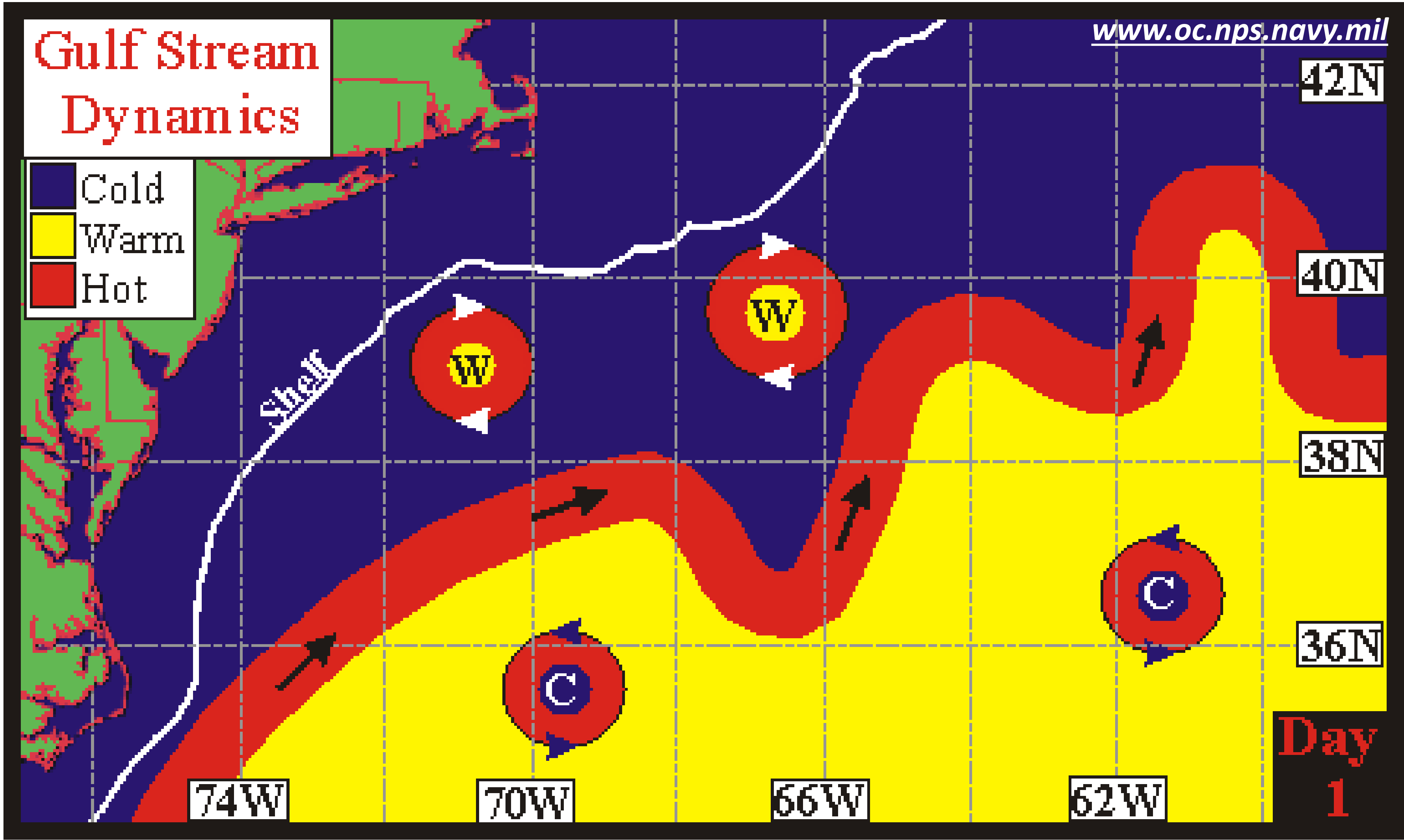
Schematics of Eddy Generation Mechanism



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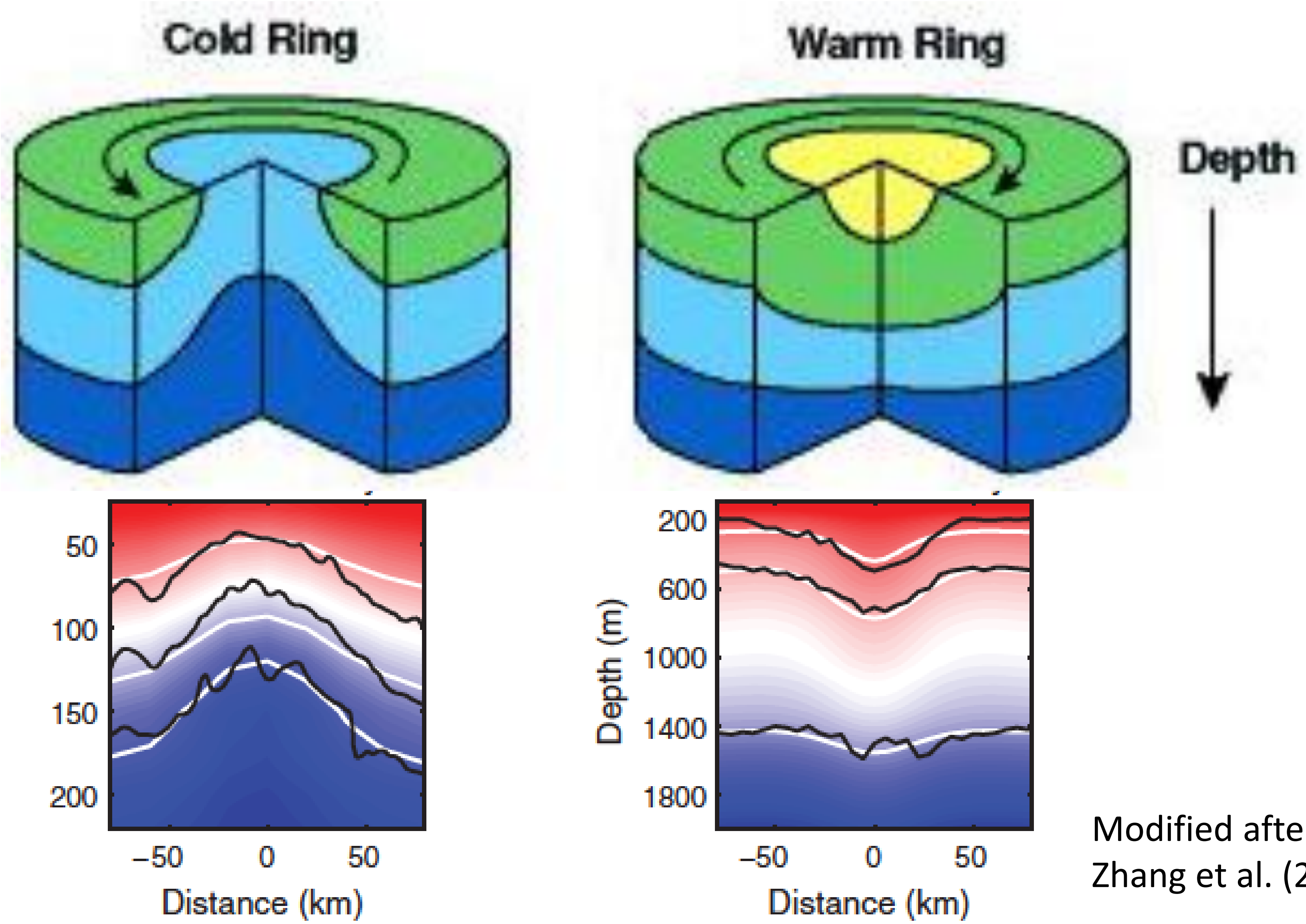
Warm Anticyclonic vs Cold Cyclonic Eddies



Modified after Zhang et al. (2014)

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What Do We Know About Ocean Mesoscale Eddies

- Oceanic analogy to storms in the atmosphere, generated mostly by hydrodynamic instabilities near the 1st baroclinic Rossby deformation scale, and ubiquitous in the oceans
- Eddy energy generally exceeds the mean flow energy by an order of magnitude or more
- 10 ~ 300 km in diameter, one rotation in 10 ~ 30 days, move at speeds of ~ 0.5 knots (~0.25 m/s), can last for months
- Transport mass, heat, salt, carbon, and nutrients and play a significant role in the global budgets of these quantities
- Strong impact on the ecosystem, and on most operational oceanography applications (e.g., marine safety, pollution monitoring, offshore industry, fisheries, etc.)
- Strong SST anomalies that can directly interact with the atmosphere, exerting local and remote influence on climate

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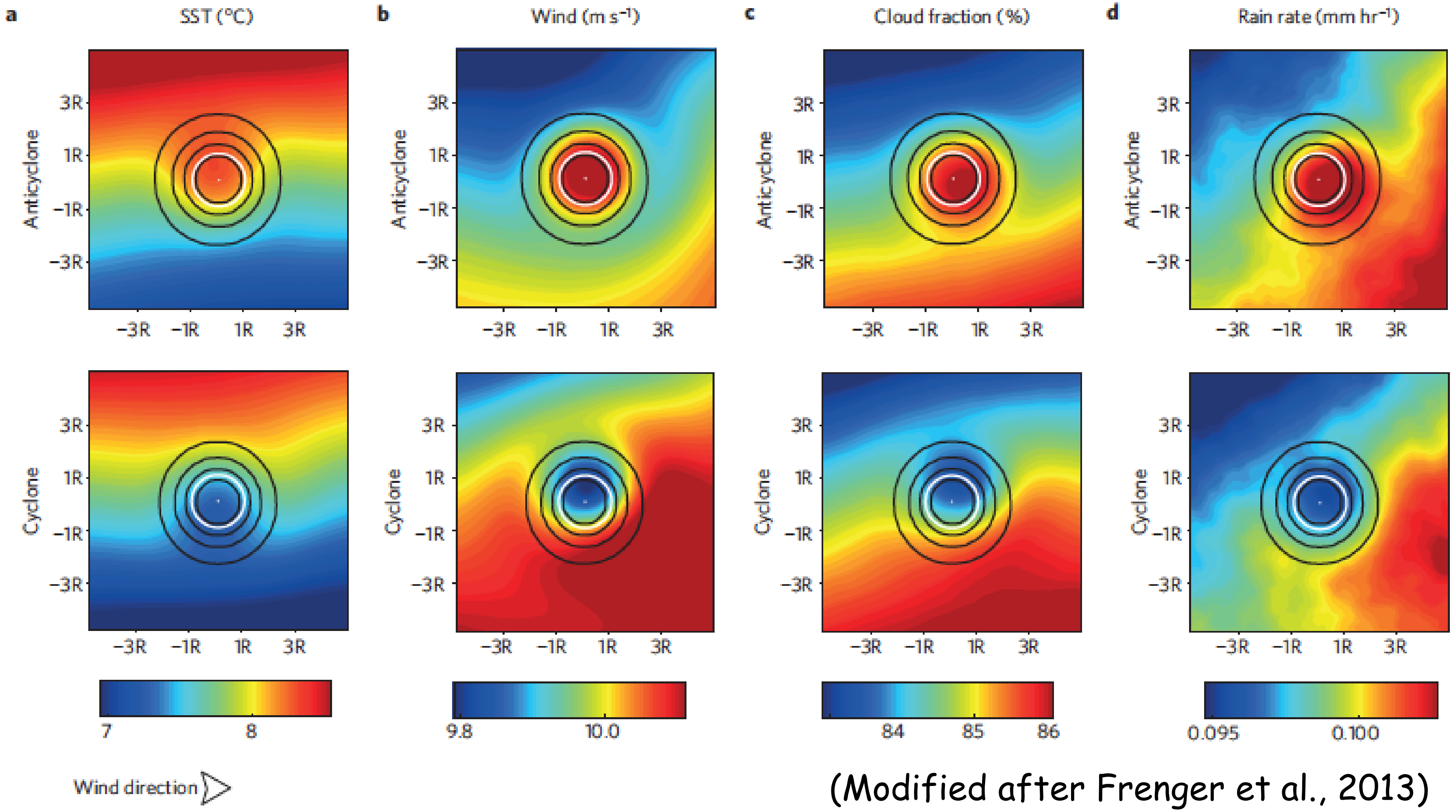
Observational Evidence for Eddies' Impact



(Modified after Frenger et al., 2013)

Figure 2 | Mean eddy and pattern of its atmospheric imprint. a, SST (±0.04 °C). **b**, Wind speed (±0.01 ms^{-1}). **c**, Cloud fraction (±0.1%). **d**, Rain rate (±10^{-3} mm h^{-1}). Shown are mean composite maps of the >600,000 individual eddy realizations south of 30 °S, divided into anticyclones and cyclones. White circles mark the eddy core as detected with the Okubo–Weiss parameter and black lines denote sea level anomaly contours associated with the eddy. Before averaging, the eddies were scaled according to their individual eddy amplitude and radius (*R*), interpolated and rotated so that the large-scale wind is from left to right.

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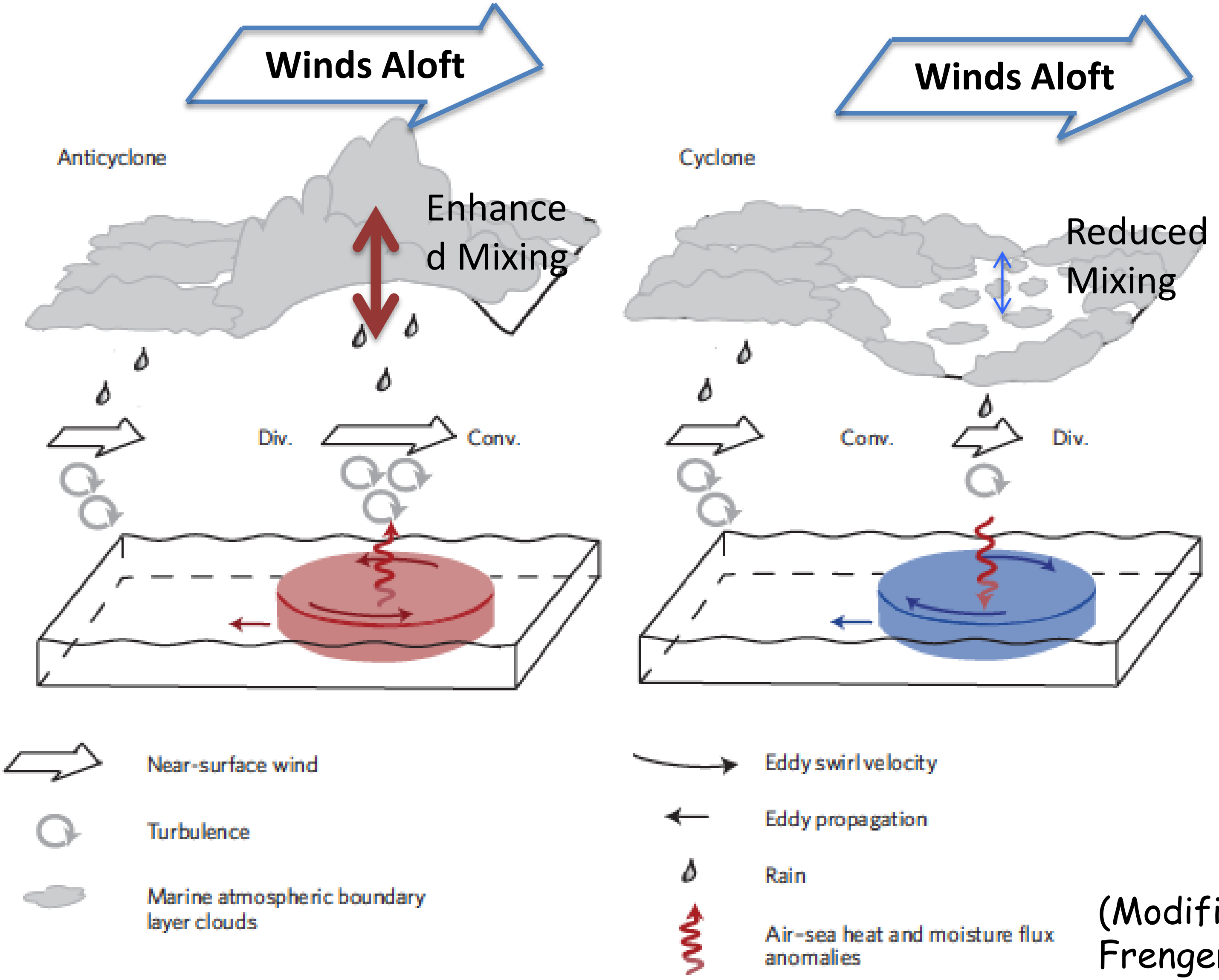
Ocean Mesoscale Eddy – Atmosphere (OMEA) Feedback Mechanism



(Modified after Frenger et al., 2013)

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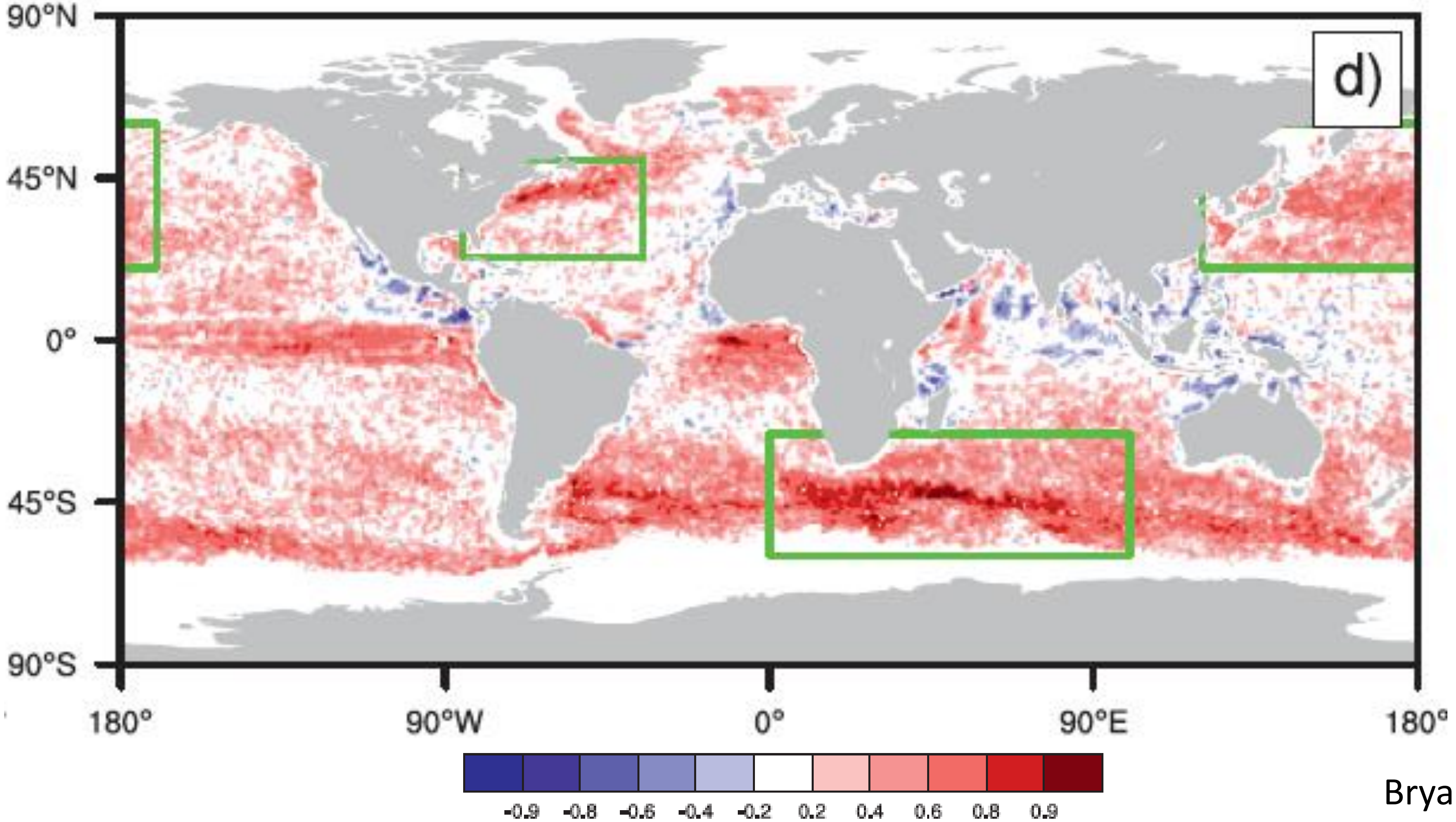
Temporal Correlation Between Spatially High-pass Filtered Satellite Measured QuickSCAT Wind Speed and AMSR SST (2002 to 2006)



Bryan et al. (2010)

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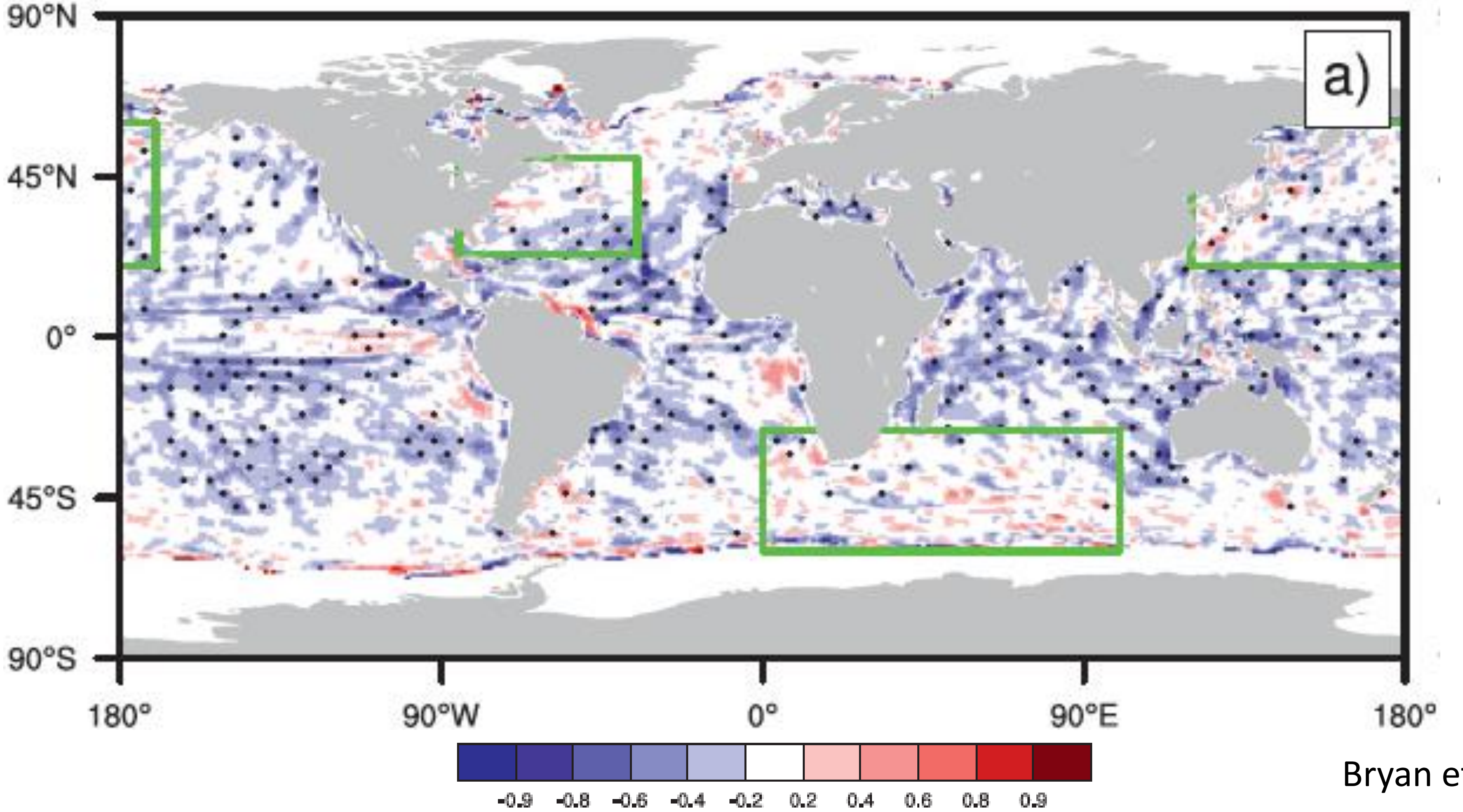
Temporal Correlation Between Spatially High-pass Filtered Simulated Wind Speed and SST From Std CCSM4 (1° Ocean and 0.5° Atmos)



Bryan et al. (2010)

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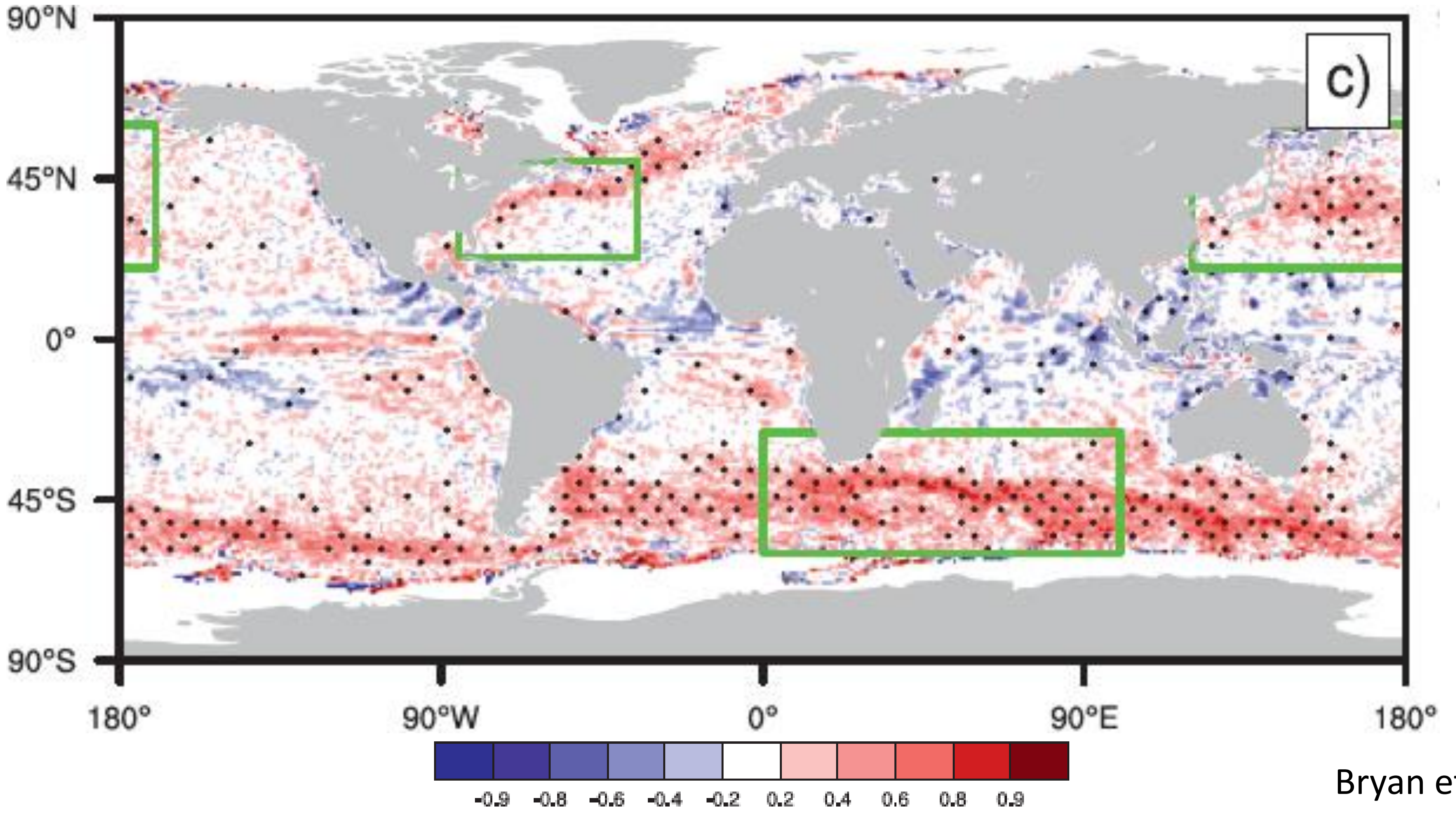
Temporal Correlation Between Spatially High-pass Filtered Simulated Wind Speed and SST From H-Res CCSM4 (0.1° Ocean & 0.25° Atmos)



Bryan et al. (2010)

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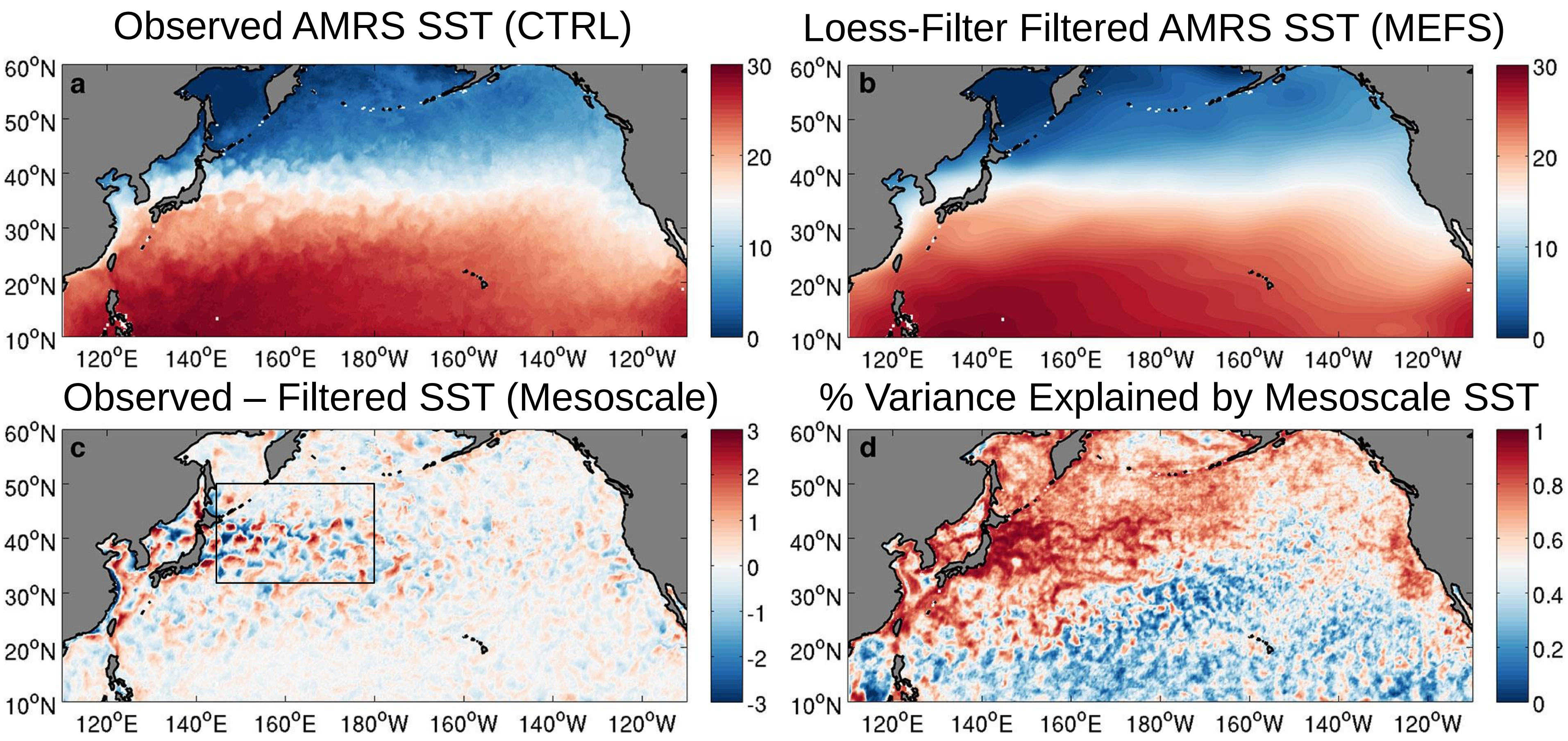
Quantifying the Effect of Ocean Eddies on the Atmosphere



In the Kuroshio Extension region more than 80% of the SST variance can be explained by the mesoscale SST

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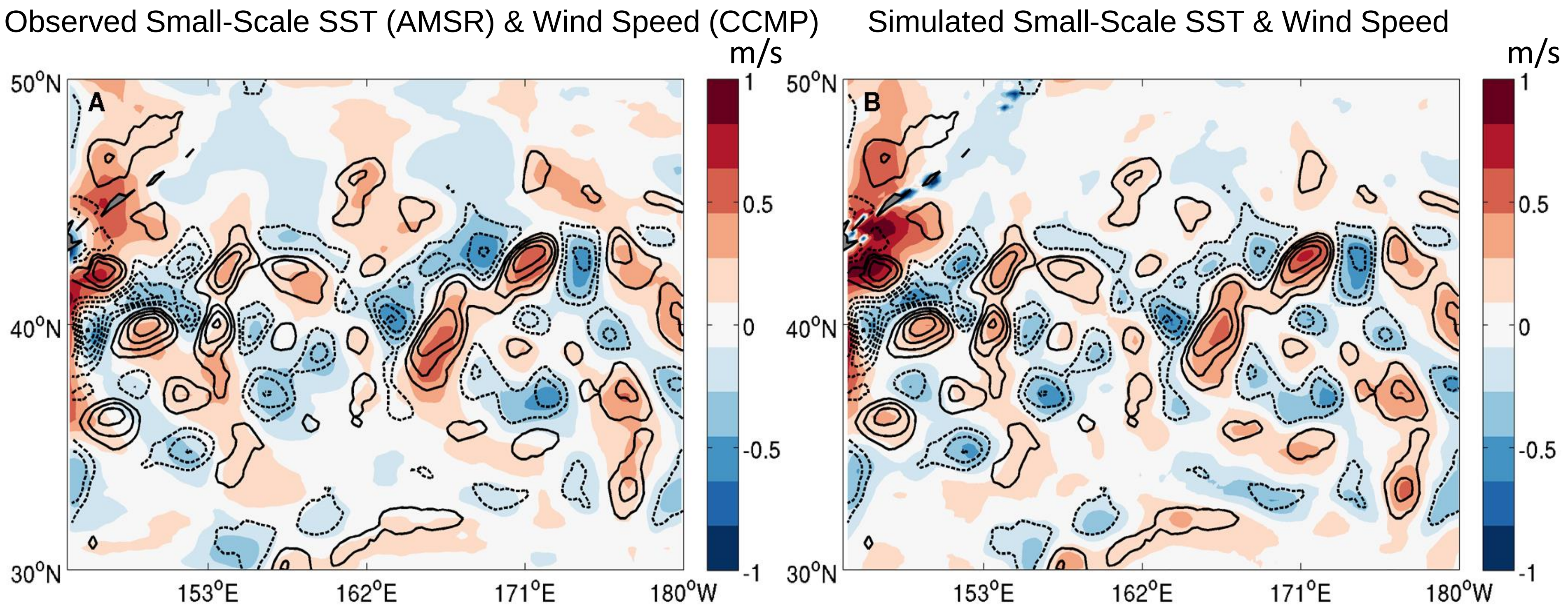
Observed vs. 27km WRF Simulated Surface Wind-SST Relationship



WRF model (27 km, 30-levels) faithfully reproduced the observed surface wind – SST relationship that high (low) wind speed coincides with warm (cold) eddies in the Kuroshio extension region, as shown by Chelton et al. (2004)

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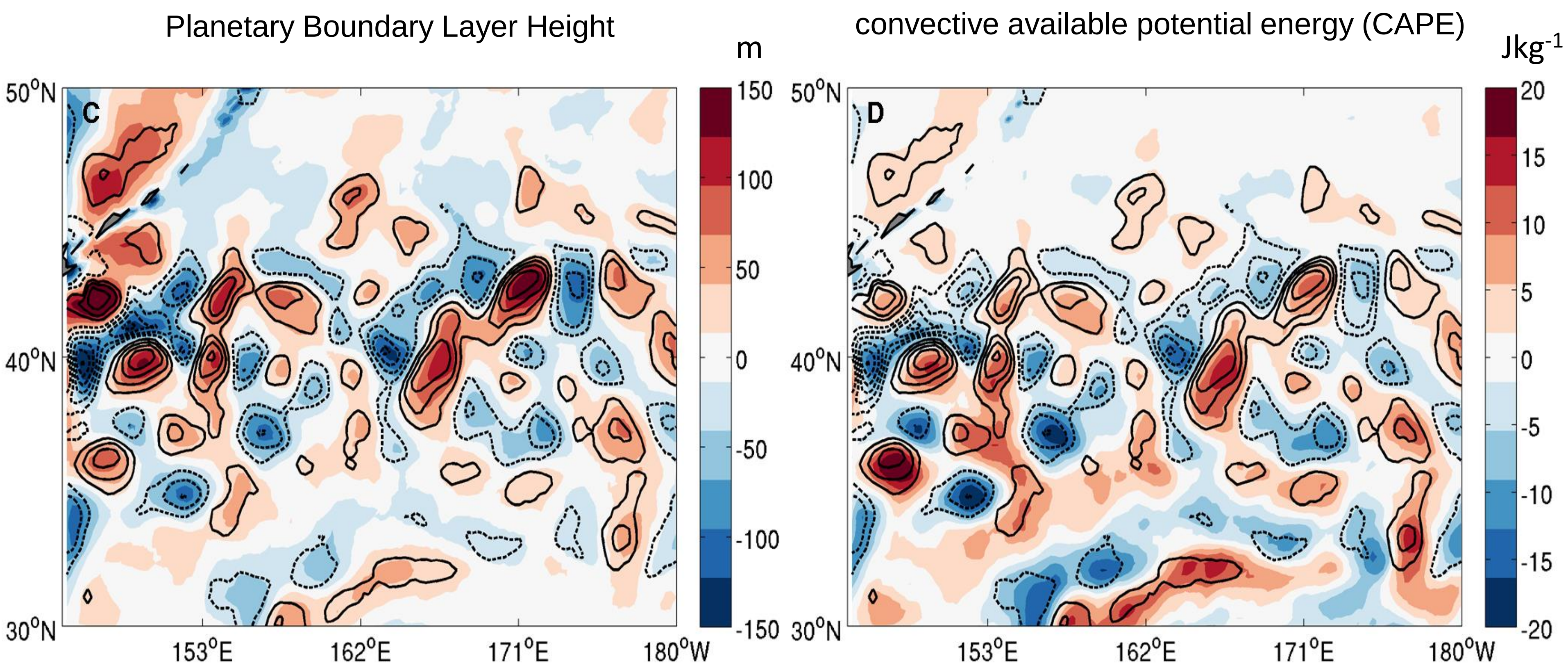
WRF Simulated Planetary Boundary Layer Height and CAPE Response



WRF not only simulates the observed surface wind – SST relationship, but also reveals a well-defined PBL height and CAPE response to meso-scale SST forcing.

(From Ma et al. 2015)

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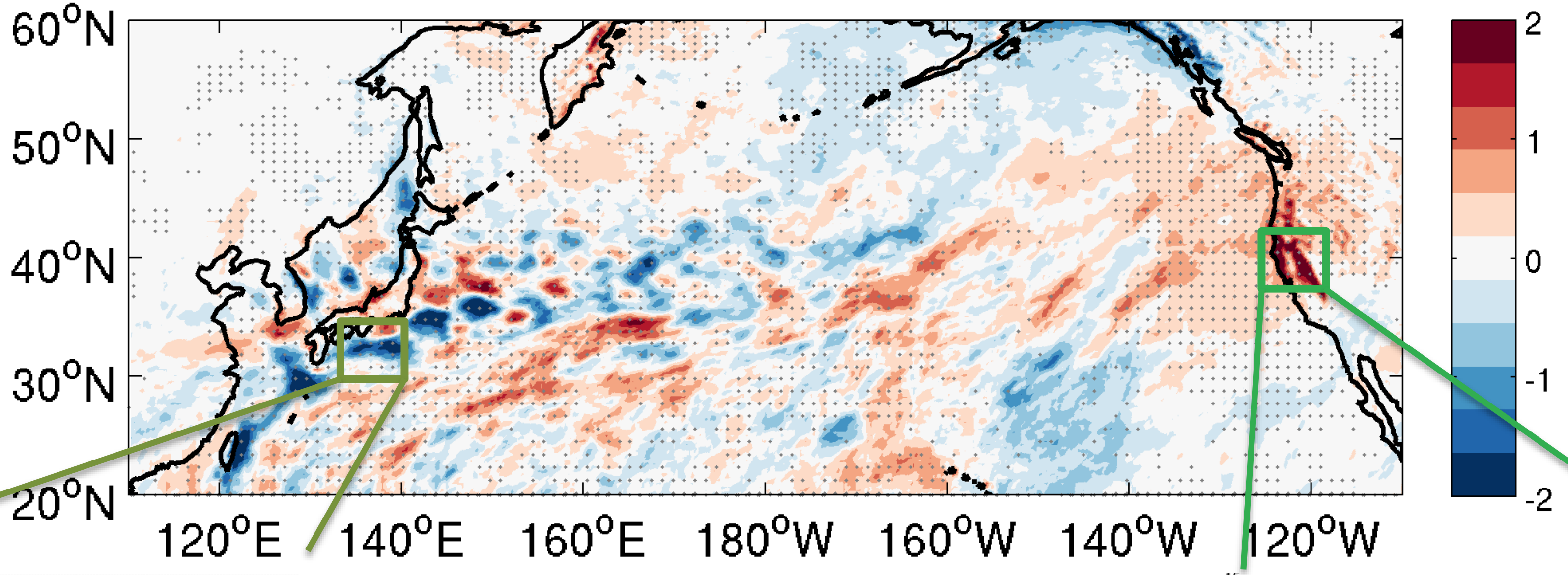
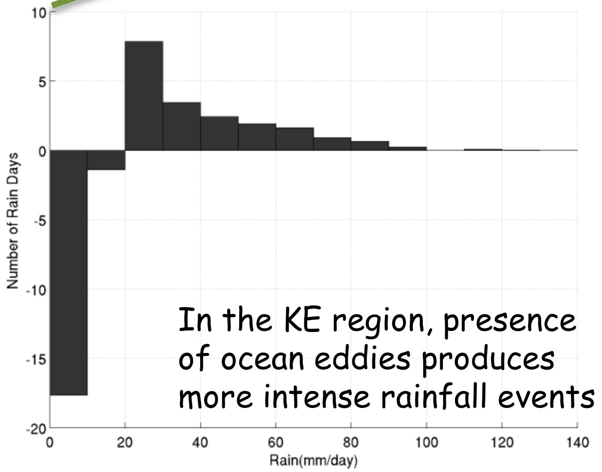
Difference in Rainfall Response Between MEFS and CTRL

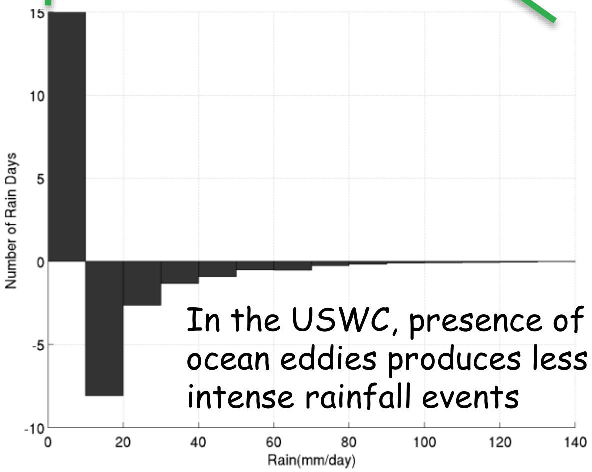
Simulated Rainfall Difference (MEFS-CTRL Simulations)





In the KE region, presence of ocean eddies produces more intense rainfall events

Difference in Rainfall PDFs (CTRL-MEFS Simulations)



In the USWC, presence of ocean eddies produces less intense rainfall events

(From Ma et al. 2015)

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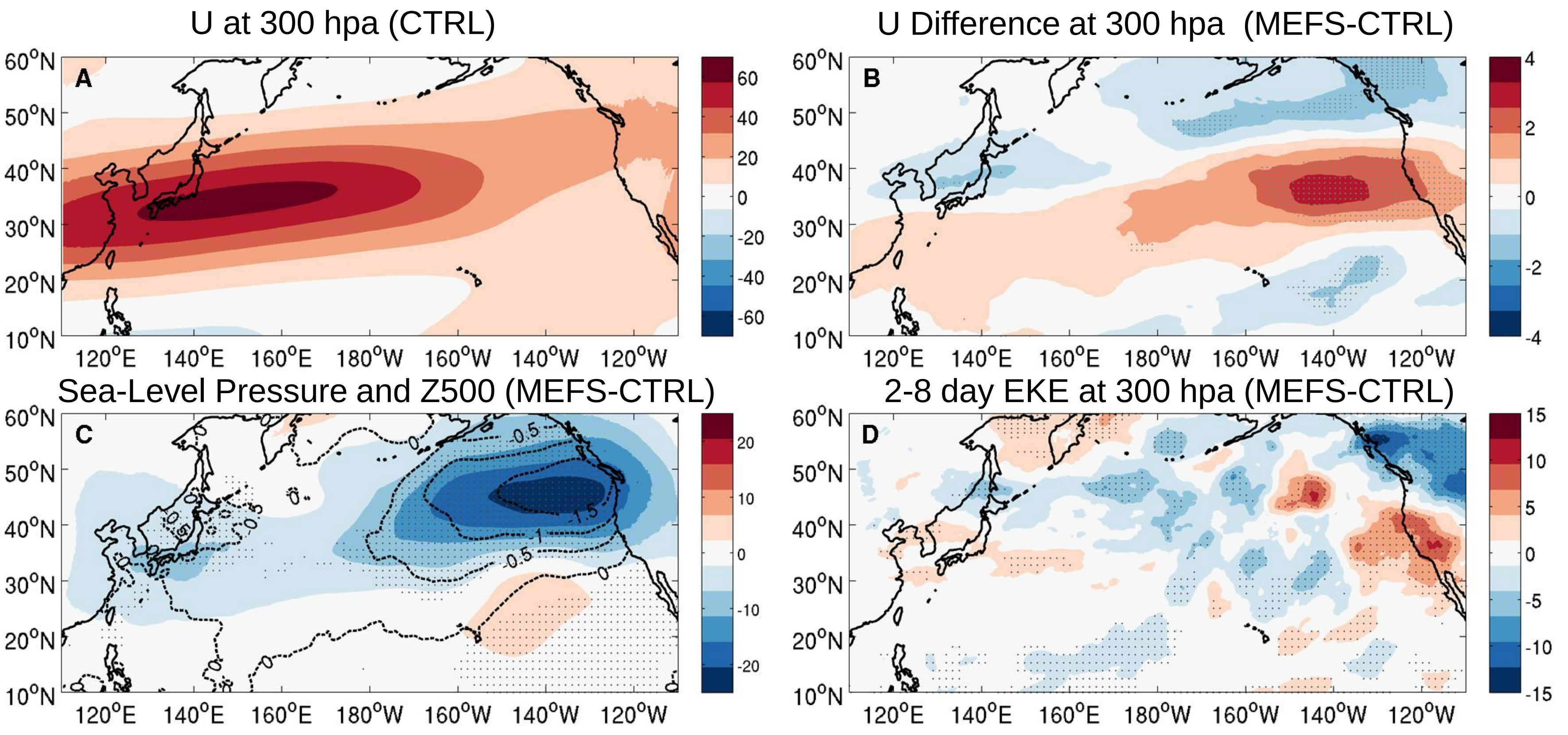
Difference in Mean Flow and Storm Track



Removing ocean eddies causes a southward shift in the jet stream and upper level storm track in the eastern north Pacific and an equivalent barotropic response.

(From Ma et al. 2015)

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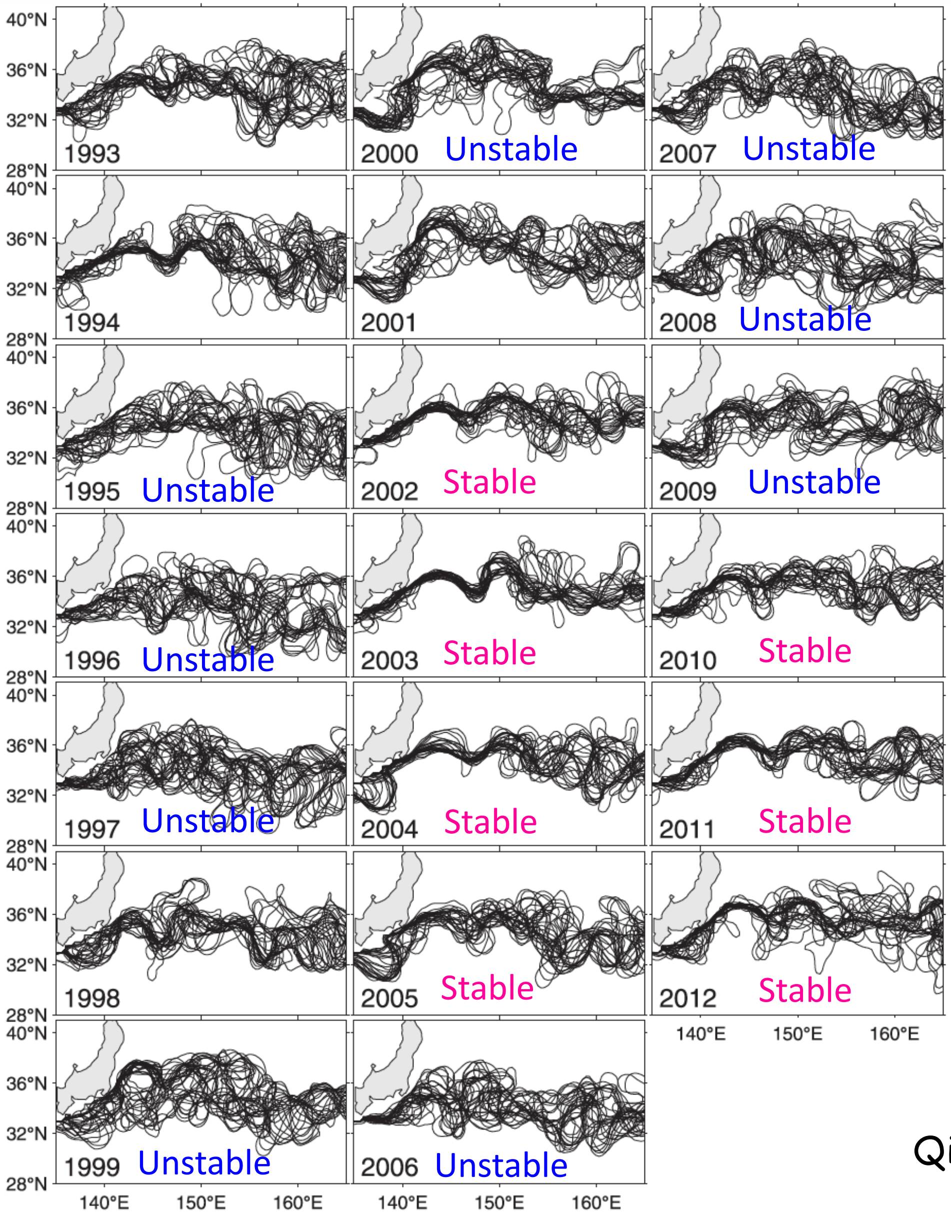
Variability of the Kuroshio Observed by Satellite SSH



The Kuroshio exhibits well-defined interannual to decadal variability in its meandering pattern

Qiu et al. (2014)

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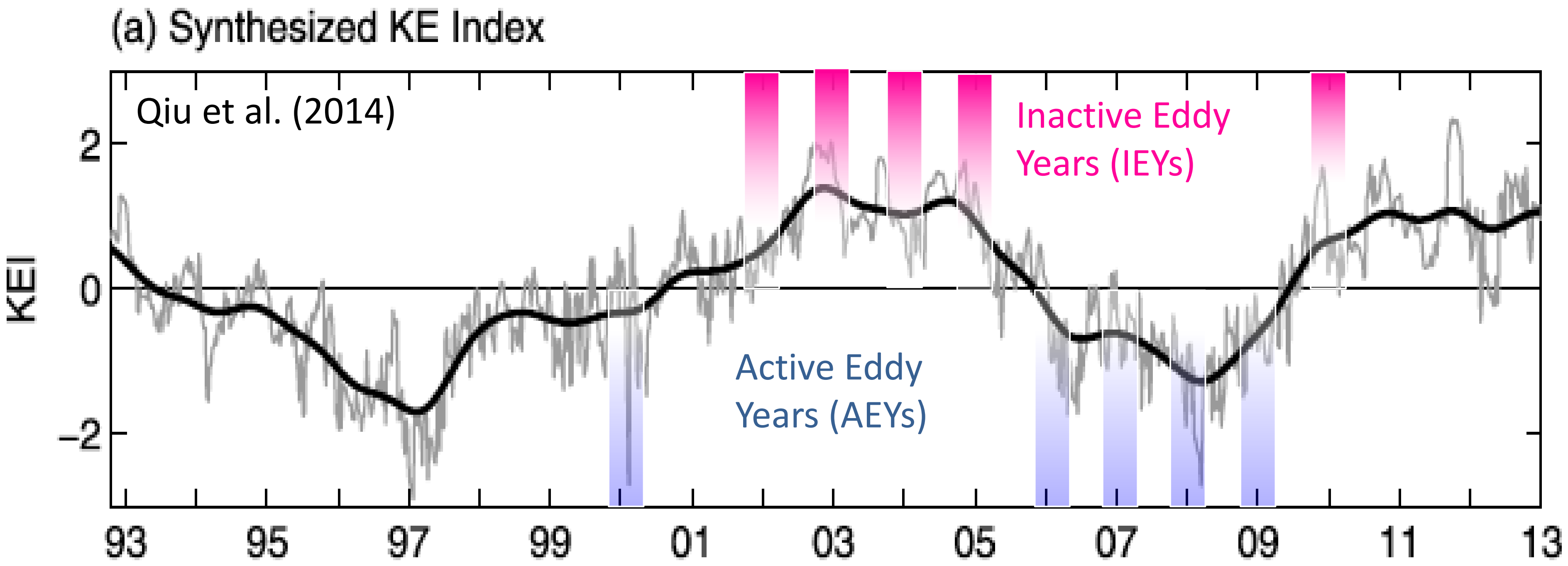
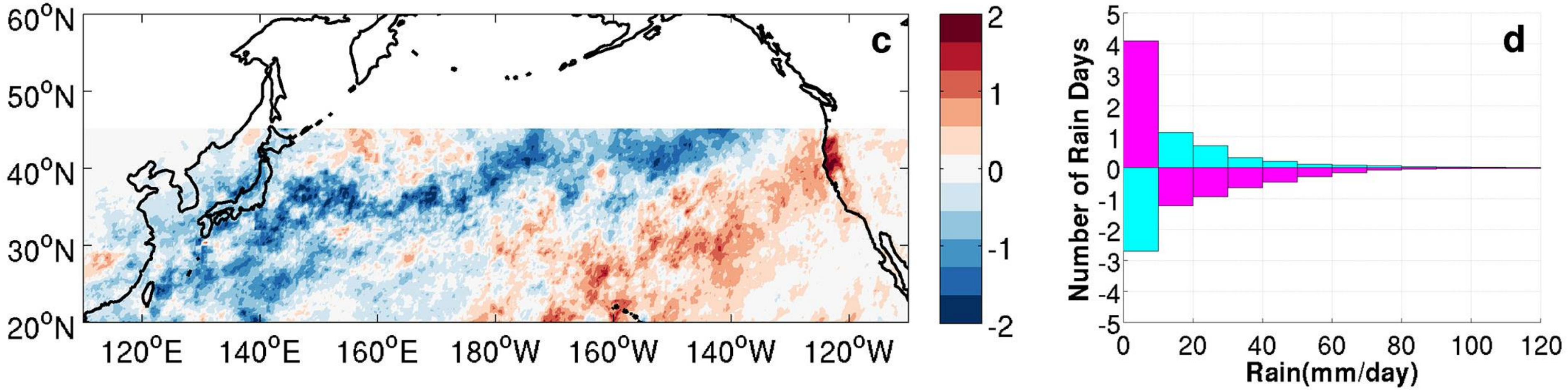
TRMM Rainfall Analysis





(From Ma et al. 2015)

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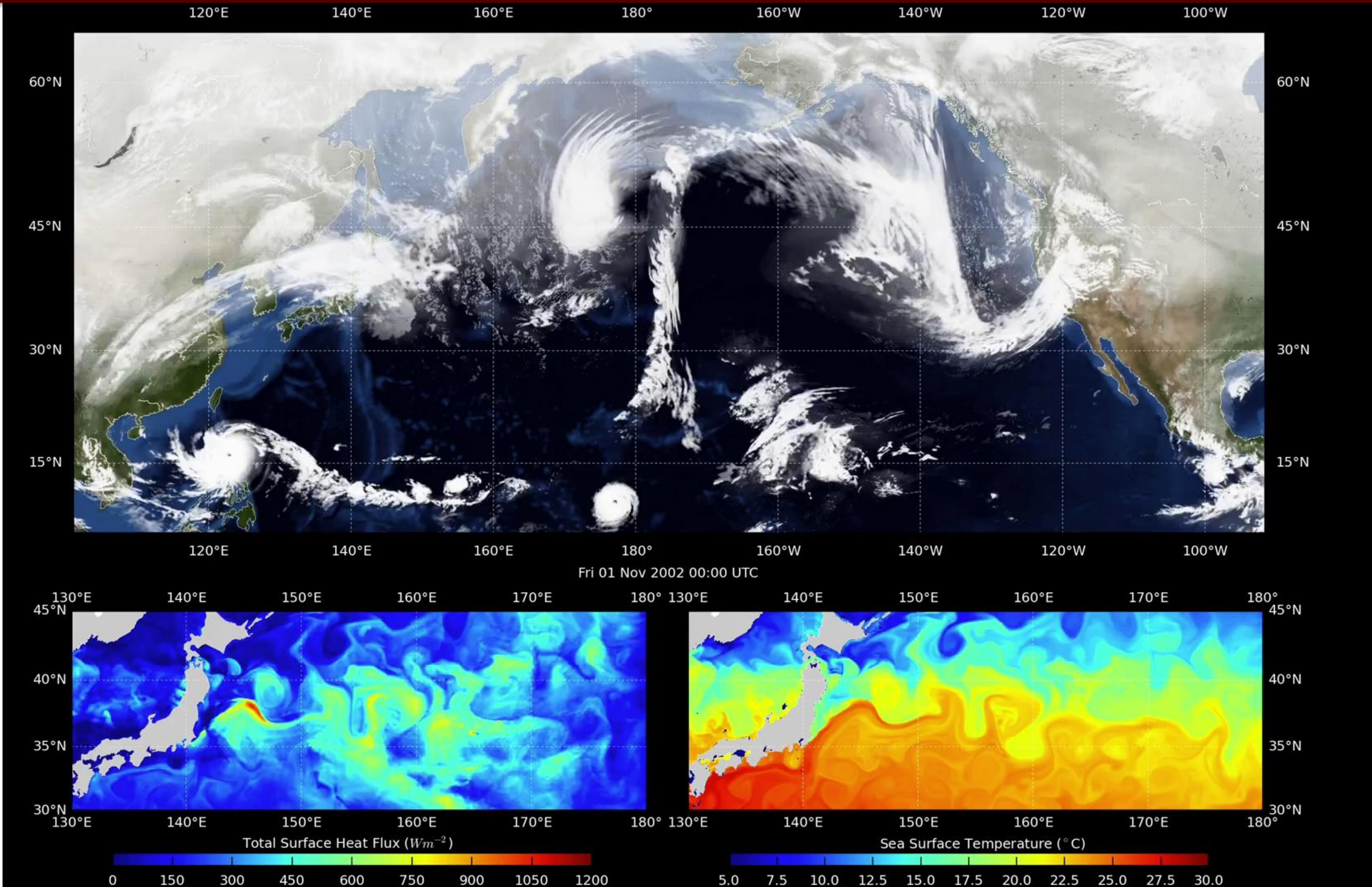
How Can OMEA Feedback Affect the Kuroshio Extension Current and Front?



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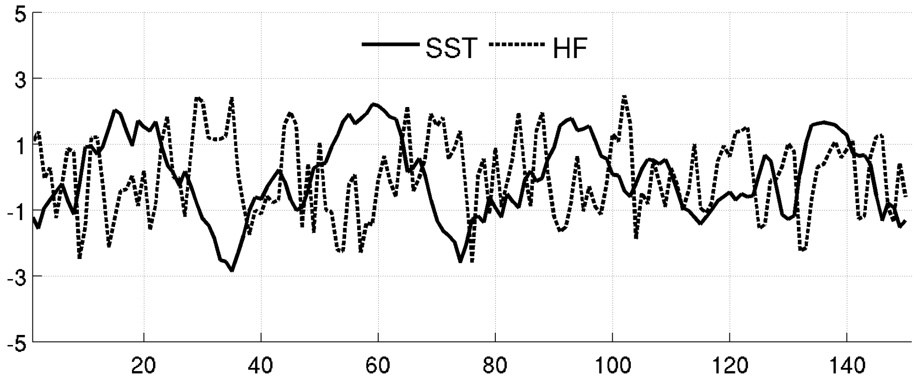
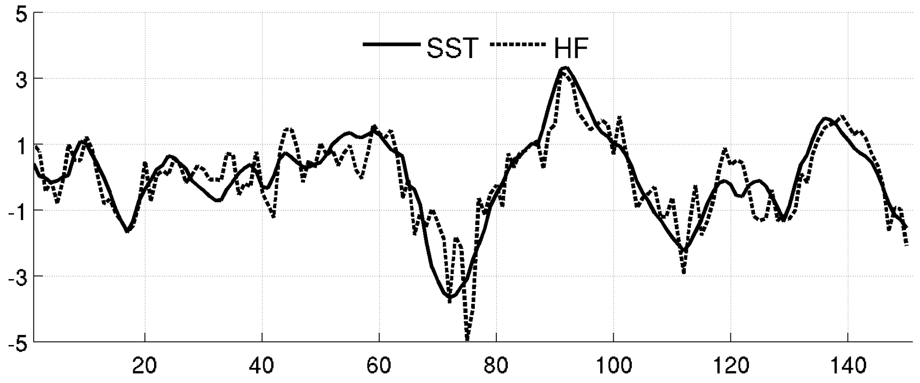
A Loess filter of half width 15°x5° was used to separate small-scale from large scale variability

Large-Scale THF-SST Relationship vs. Small-Scale THF-SST Relationship

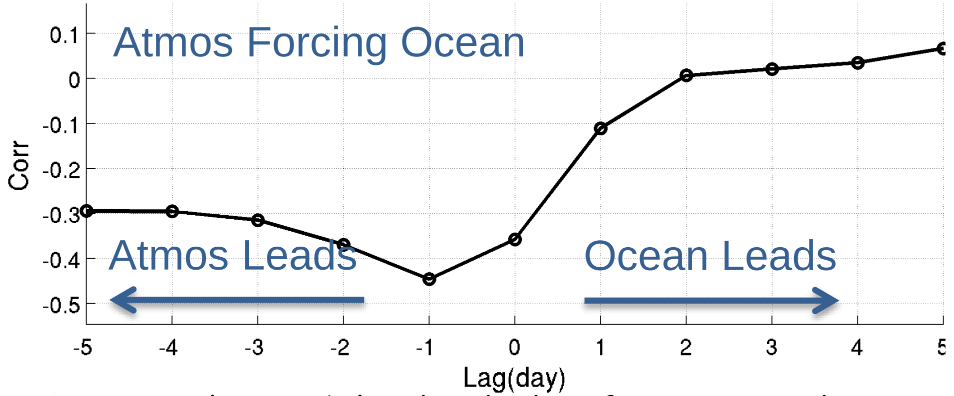
Large-Scale SST and Turbulent Heat Flux (THF)



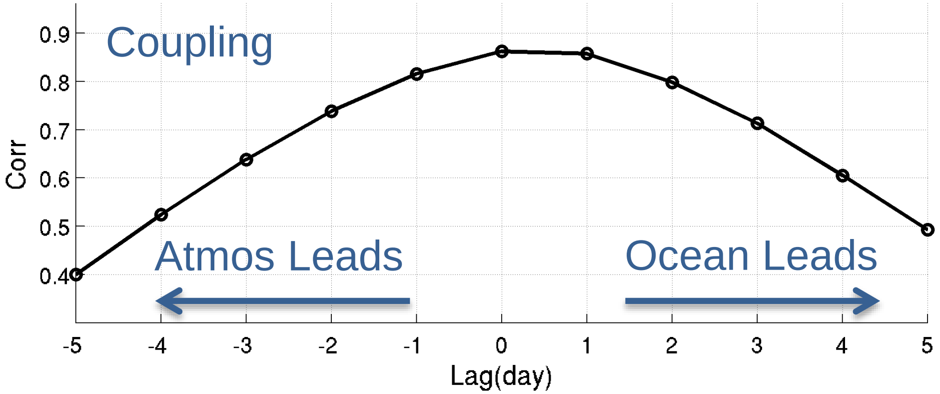
Small-Scale SST and Turbulent Heat Flux (THF)



Lag Correlation Between Large-Scale SST and THF



Lag Correlation Between Small-Scale SST and THF



Large-scale variability has higher frequency with atmosphere leading ocean, suggesting that atmosphere forces ocean Small-scale variability has lower frequency with zero lag, suggesting that atmosphere and ocean are coupled

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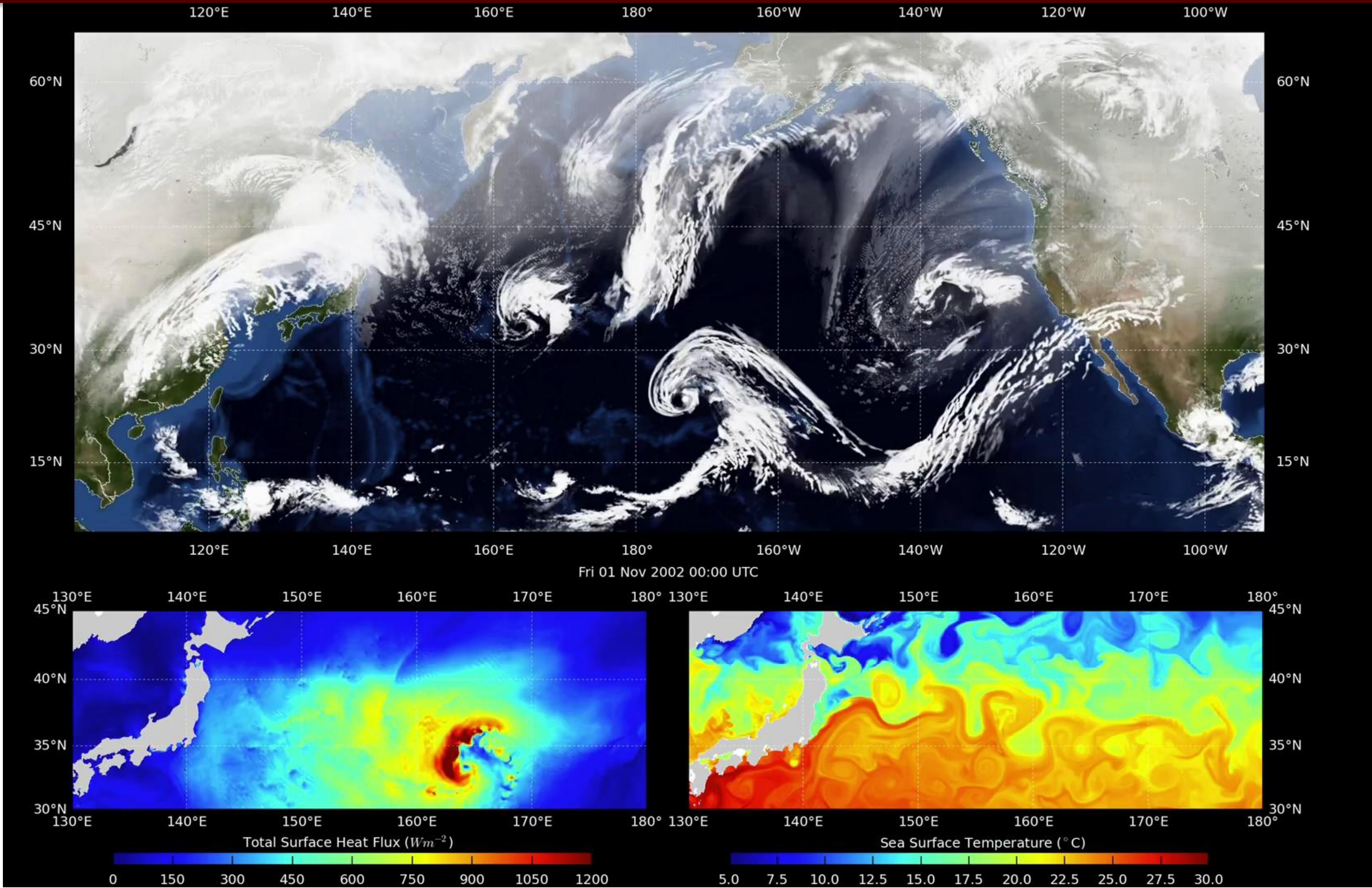
9km-CRCM SST-Filtered Simulation



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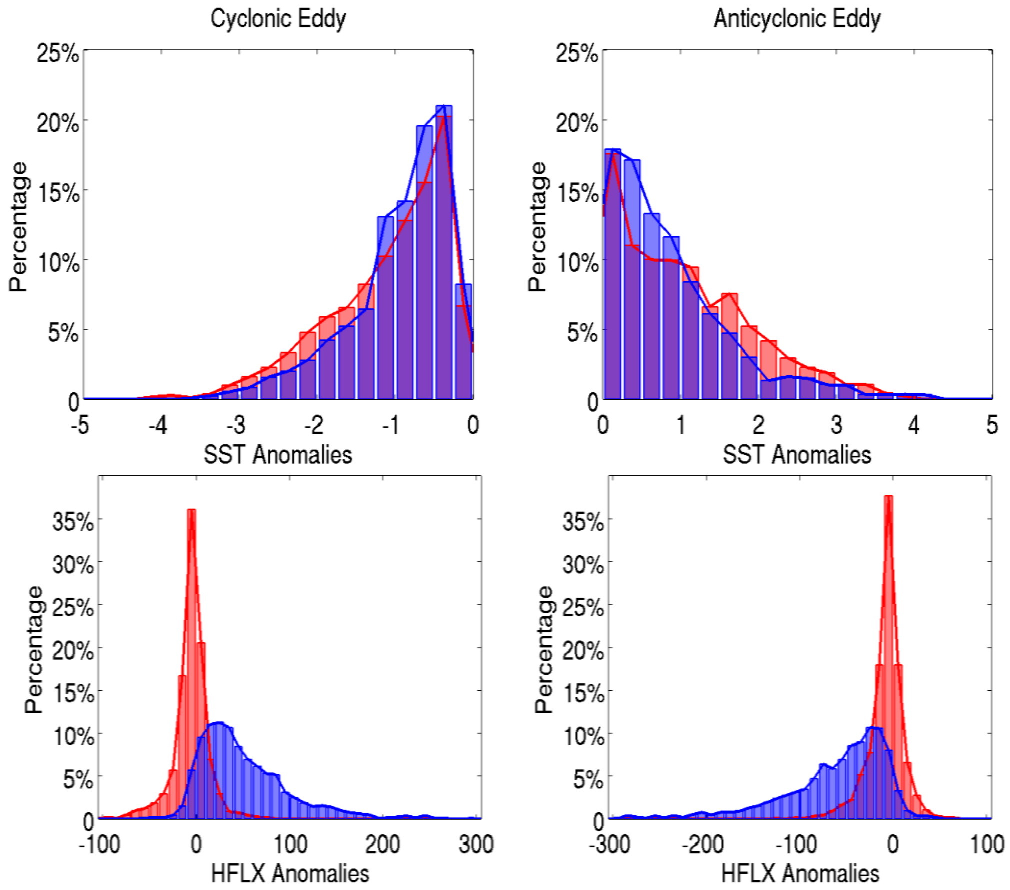
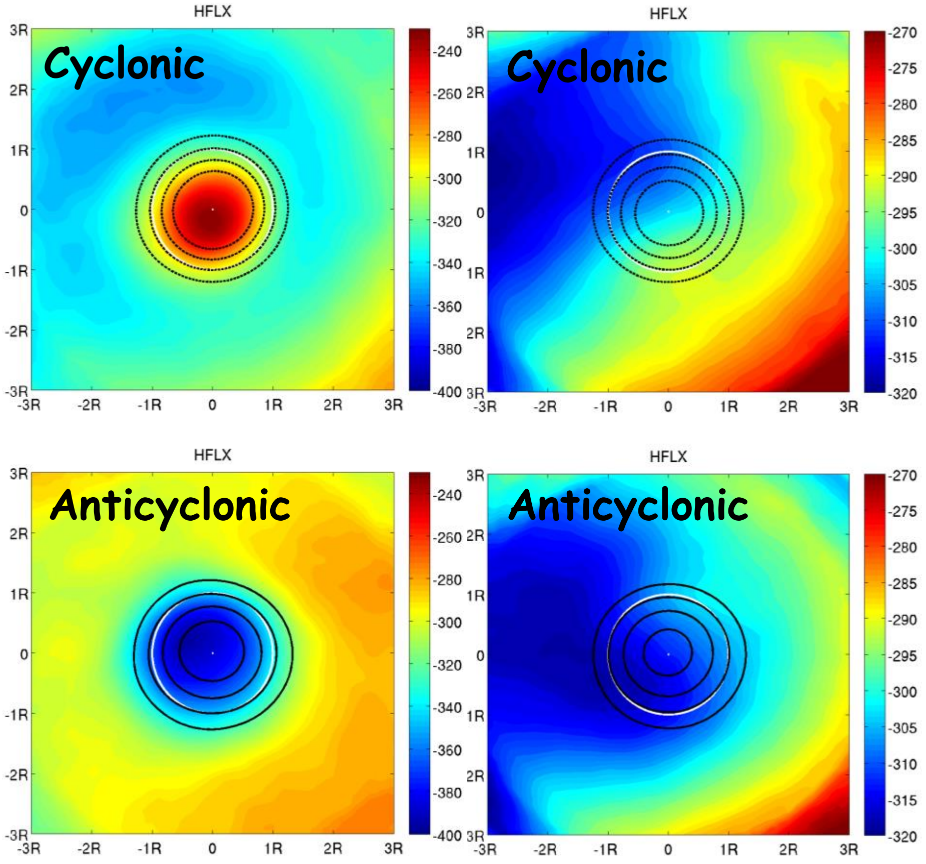
Ocean Eddies in CTRL and Filtered 9km-CRCM Simulations

PDFs of Ocean Eddies



CTRL(blue) Filtered (red)

Turbulent Heat Flux Composite



CTRL Filtered

(From Xue Liu)

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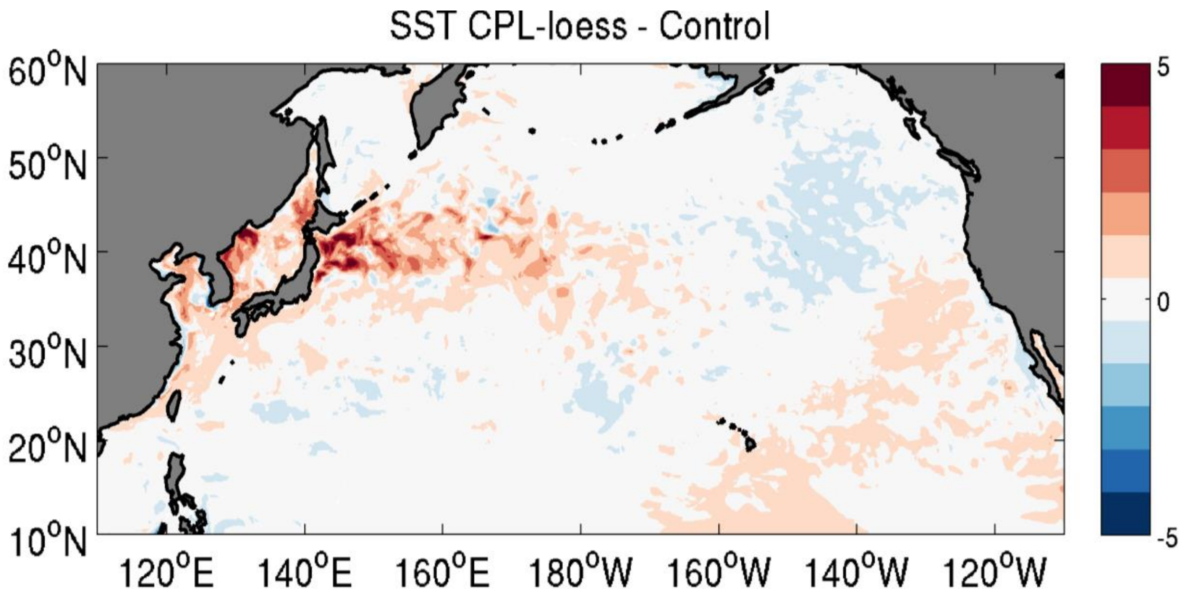
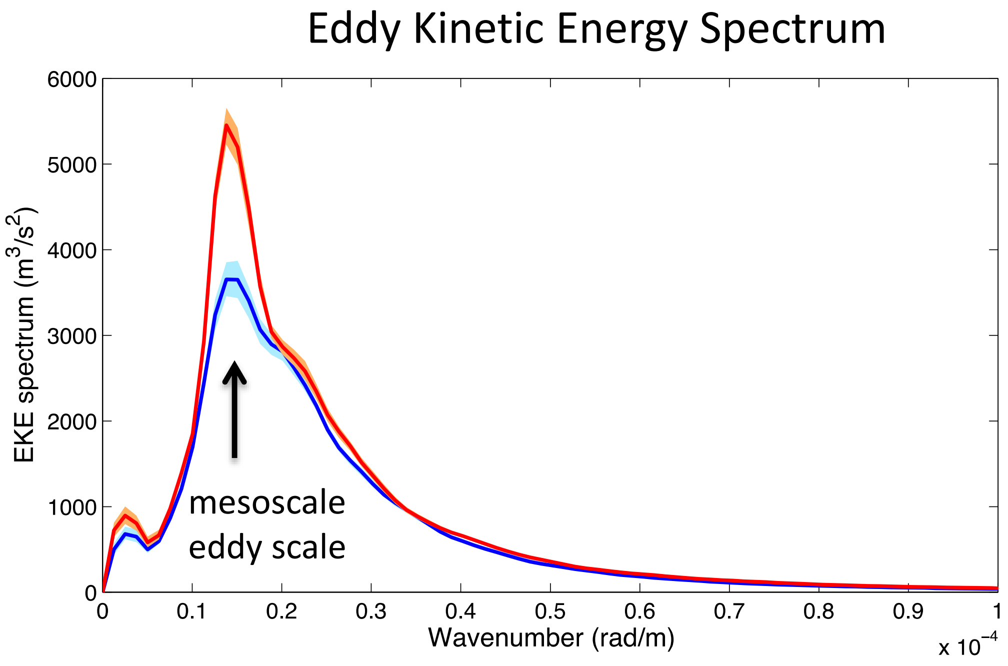
Difference in SST and EKE Between CPL-MEFS & CPL-CTRL





- Substantial surface warming (~3-5C) occurs north of the Kuroshio after filtering the effect of ocean eddies on atmosphere
- ~40% increase in mesoscale eddy kinetic energy in the absence of OMEA feedback

(From Zhao Jing)

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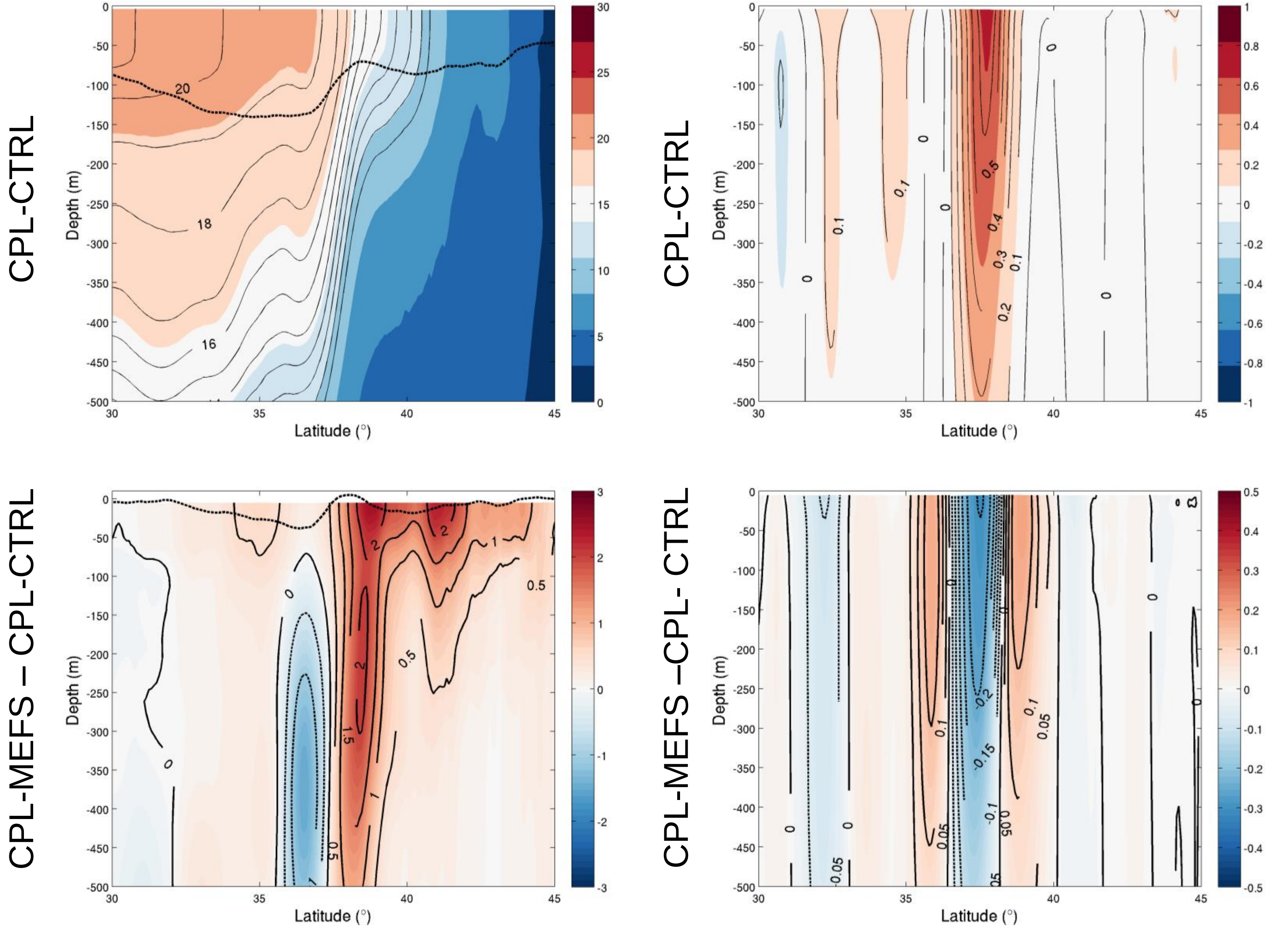
Difference in the KE Between CPL-MEFS and CPL-CTRL

T Averaged Between 140°E-180°E **U Averaged Between 140°E-180°E**



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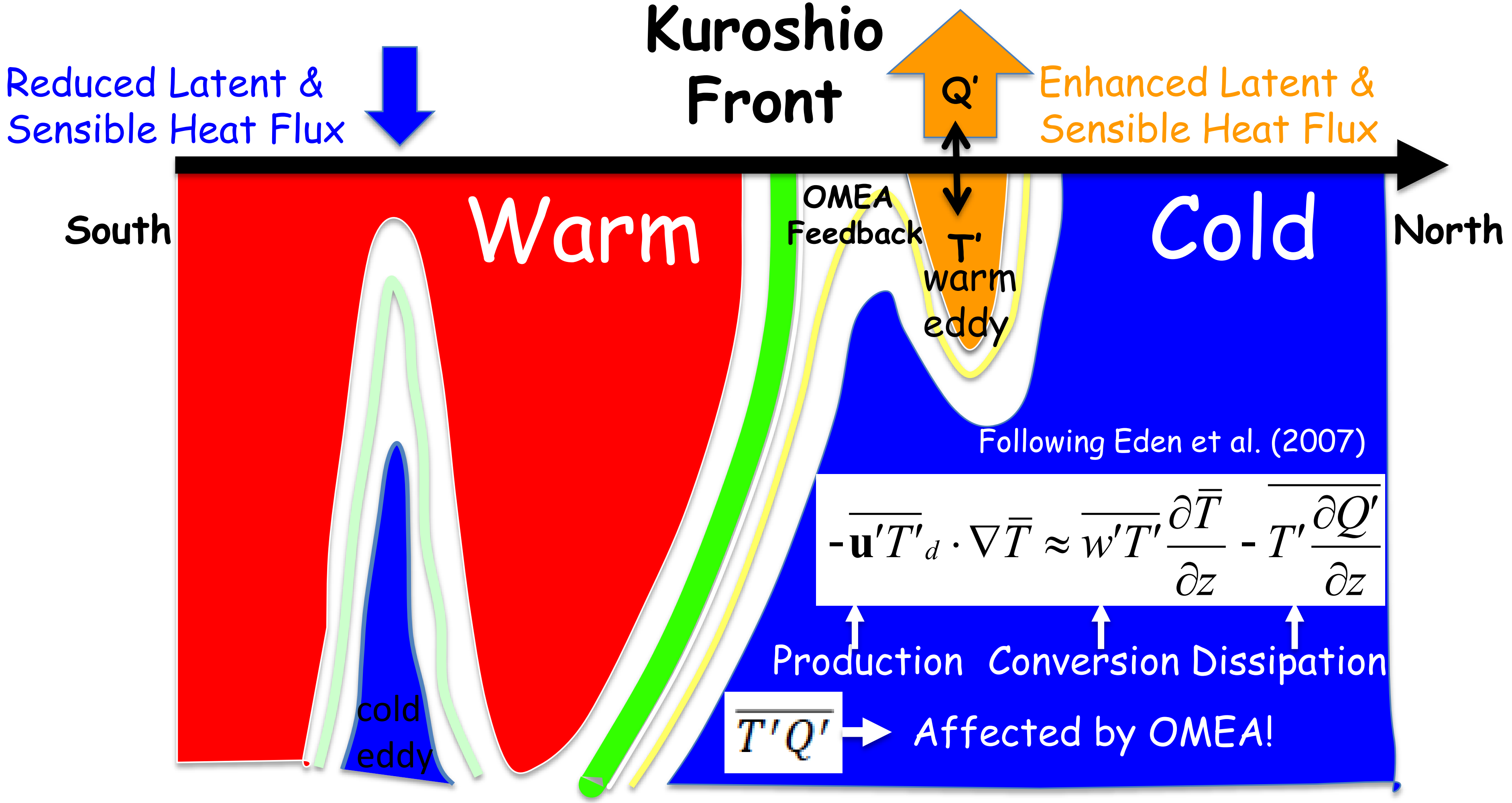
Maintenance of Kuroshio Front by OMEA Feedback



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Summary

- Available high-resolution satellite observations and climate model simulations reveal a strong OMEA interaction
- This interaction not only affects local atmospheric boundary processes, but more importantly may remotely affect large-scale atmospheric circulations and thus climate variability
- OMEA feedback can further impact ocean circulations, affecting the maintenance of strong oceanic fronts
- Much remains to be understood about OMEA interaction and its potential impact Observations and models need to be improved to fully resolve the multi-scale processes

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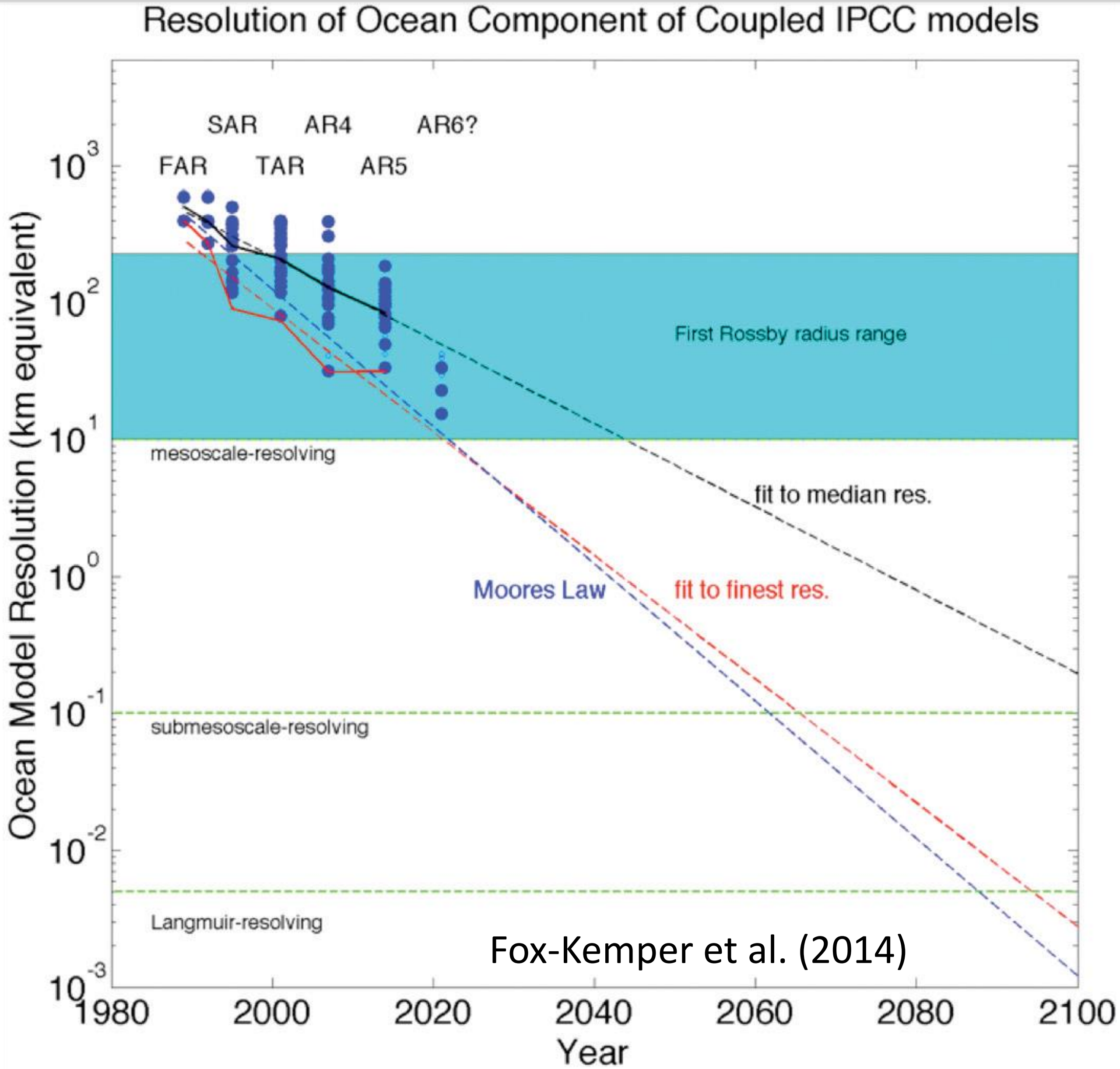
Resolution of Climate Models



Fox-Kemper et al. (2014)