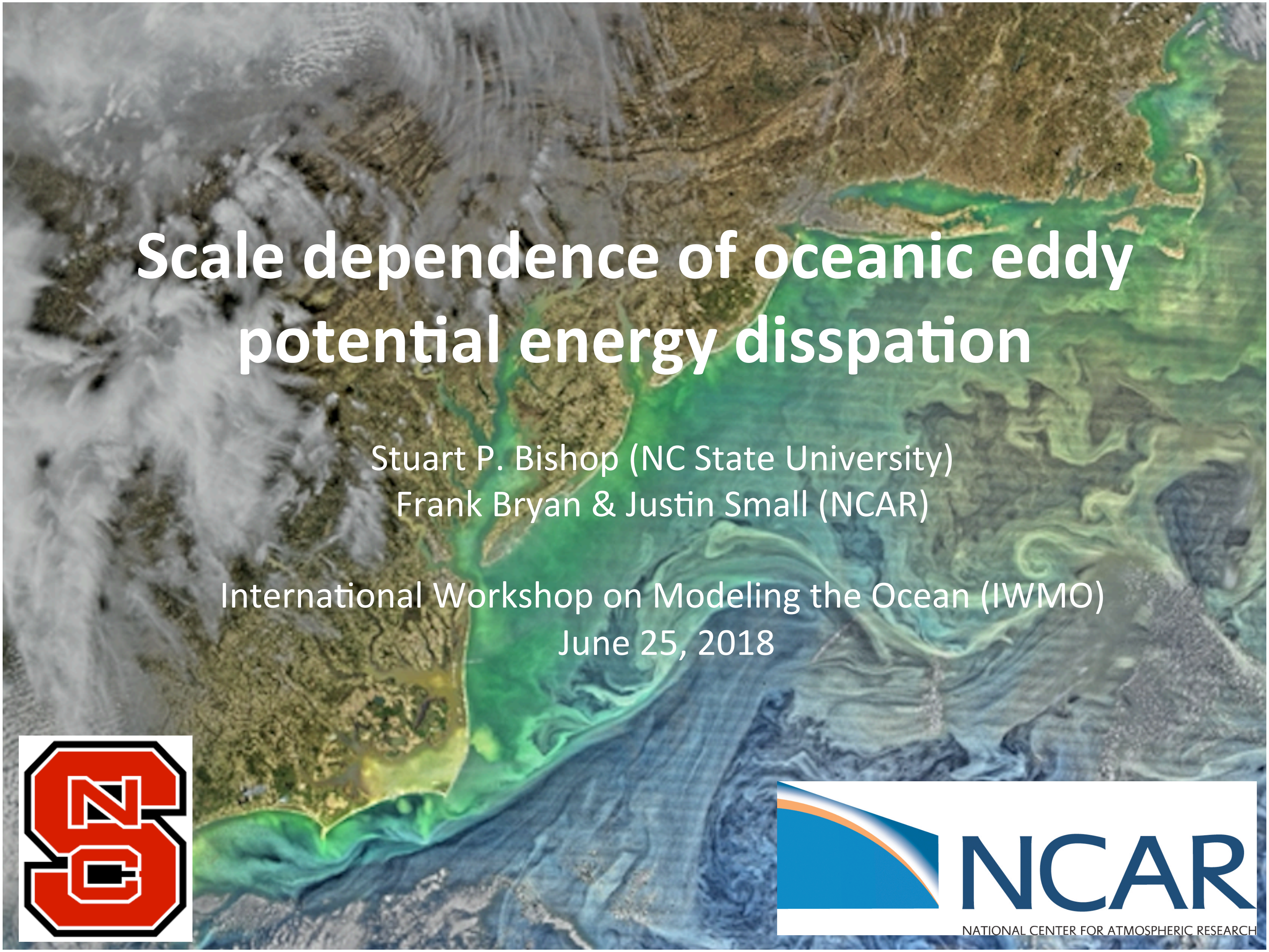


Scale dependence of oceanic eddy potential energy disspation

Stuart P. Bishop (NC State University)
Frank Bryan & Justin Small (NCAR)

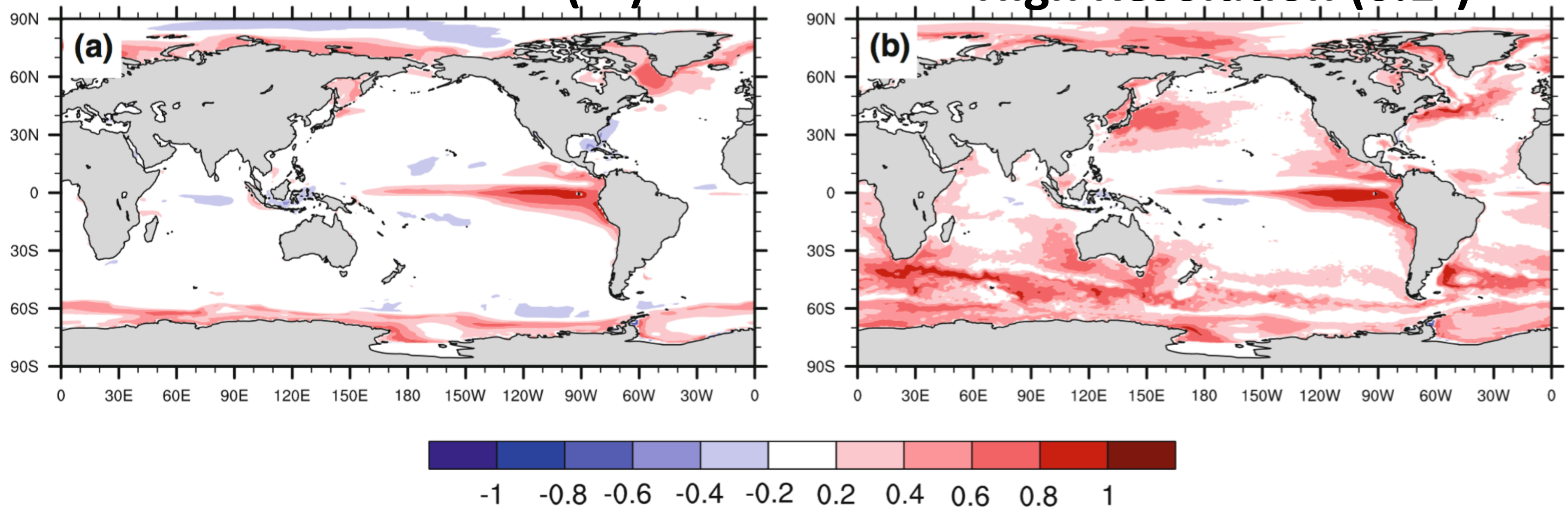
International Workshop on Modeling the Ocean (IWMO)
June 25, 2018

NATIONAL CENTER FOR ATMOSPHERIC RESEARCH

Air-Sea interaction in coupled climate models

$$\overline{T'Q'_o}$$

Low Resolution (1°) | **High Resolution (0.1°)**



$\overline{(\ )}$ = Time Mean

$(\ )'$ = Deviation from monthly climatology (removes an average seasonal cycle)

Q_o = Turbulent Heat Flux (+ve out of the ocean)

Kirtman et al. (2009)

Air-Sea interaction in coupled climate models

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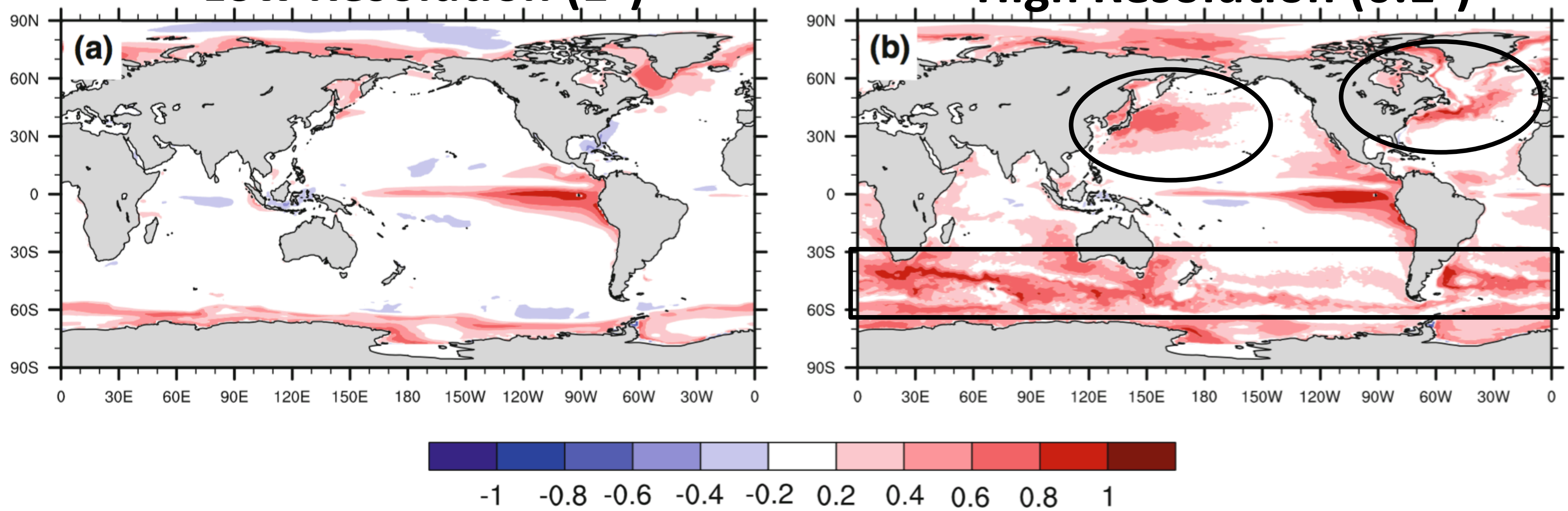
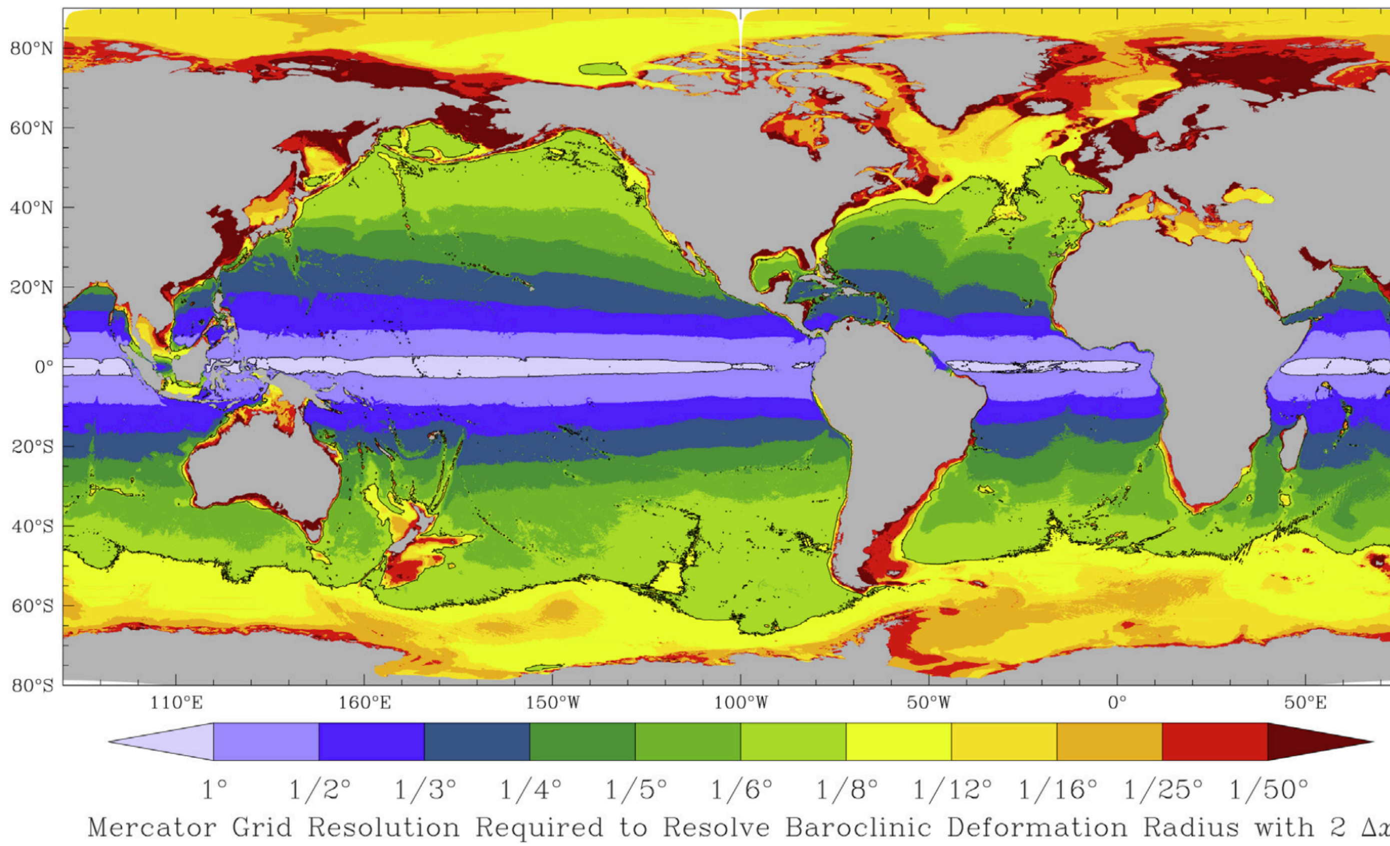


- Correlation in coupled simulations at 0.1° resolution is large and positive in Eastern and Western Boundary Current regions and Southern Ocean ACC.
- Are mesoscale eddies responsible and why?

Kirtman et al. (2009)

What resolution is needed to resolve baroclinic mesoscale eddies?



- 0.1^{o} resolves 1st baroclinic mesoscale eddies up to midlatitudes.
- Higher resolution is needed at high latitudes and coastal regions.
  - Shallow long continental shelf and marginal seas noted, *e.g.* Argentine Continental Shelf.

Hallberg 2013 OM

A simple stochastic EB model for midlatitude air-sea interaction

$$\frac{dT_a}{dt} = \alpha(T_o - T_a) - \gamma_a T_a + N_a$$

Atmospheric weather noise

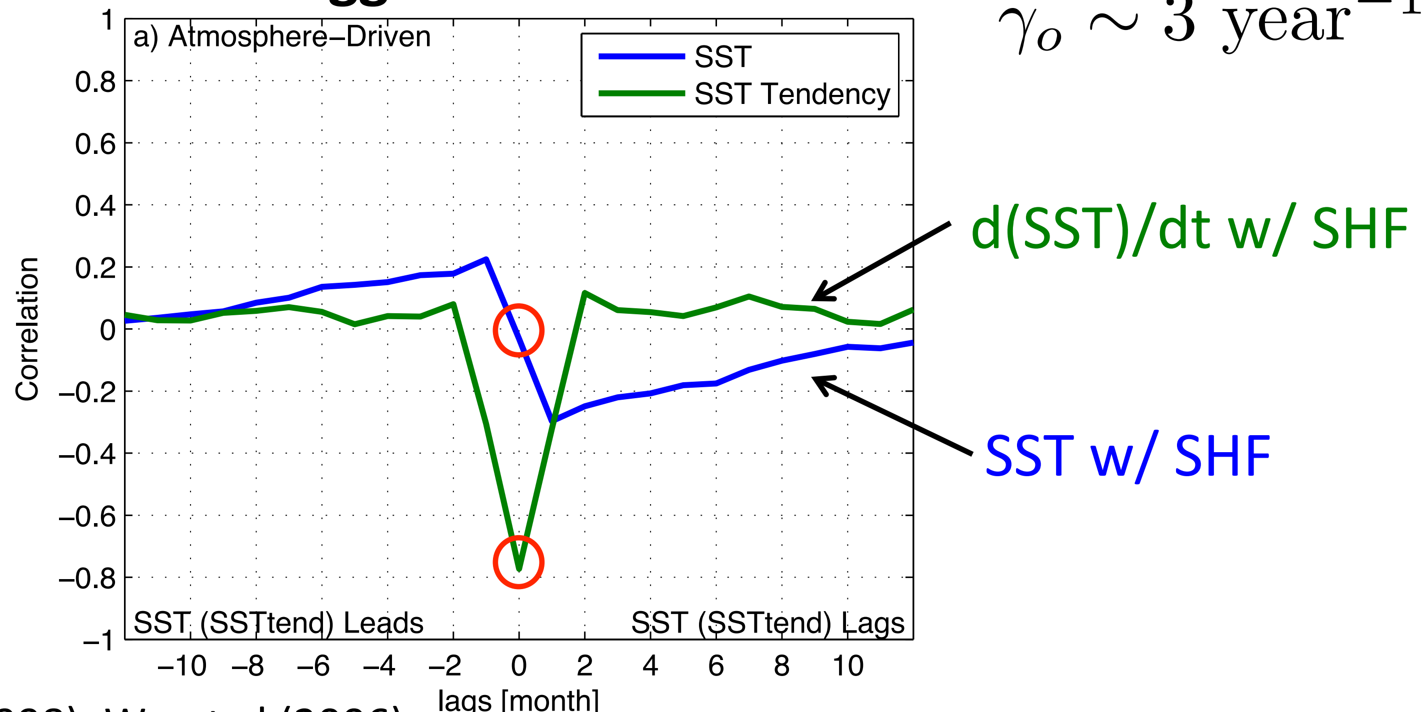
$$\frac{dT_o}{dt} = \beta(T_a - T_o) - \gamma_o T_o$$

$$\beta \sim \alpha/20$$

$$\gamma_a \sim 6 \text{ day}^{-1}$$

$$\gamma_o \sim 3 \text{ year}^{-1}$$

Lagged Correlation



Barsugli and Battisti (1998); Wu et al (2006)

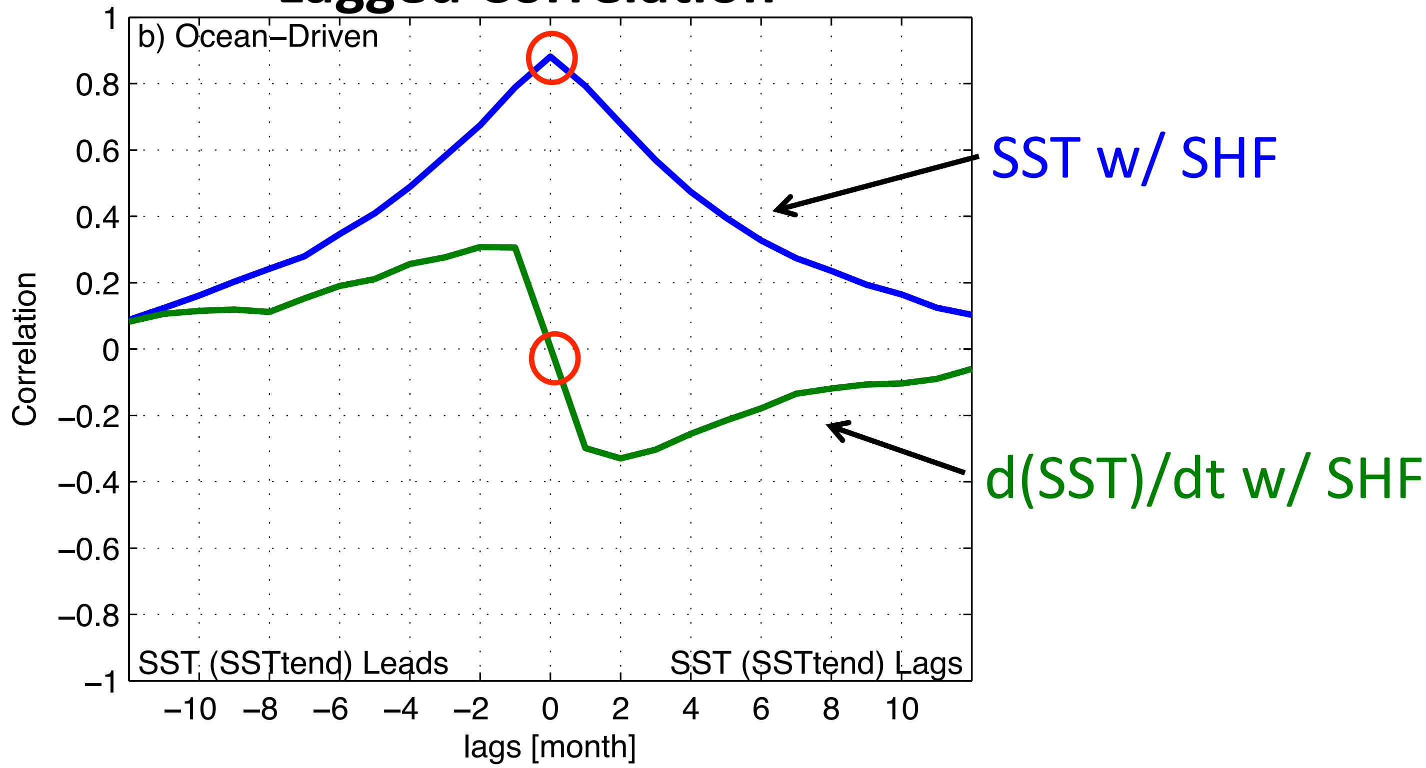
An alternative model: Oceanic-driven variability

$$\frac{dT_a}{dt} = \alpha(T_o - T_a) - \gamma_a T_a$$

$$\frac{dT_o}{dt} = \beta(T_a - T_o) - \gamma_o T_o + N_o$$

Oceanic weather noise

Lagged Correlation



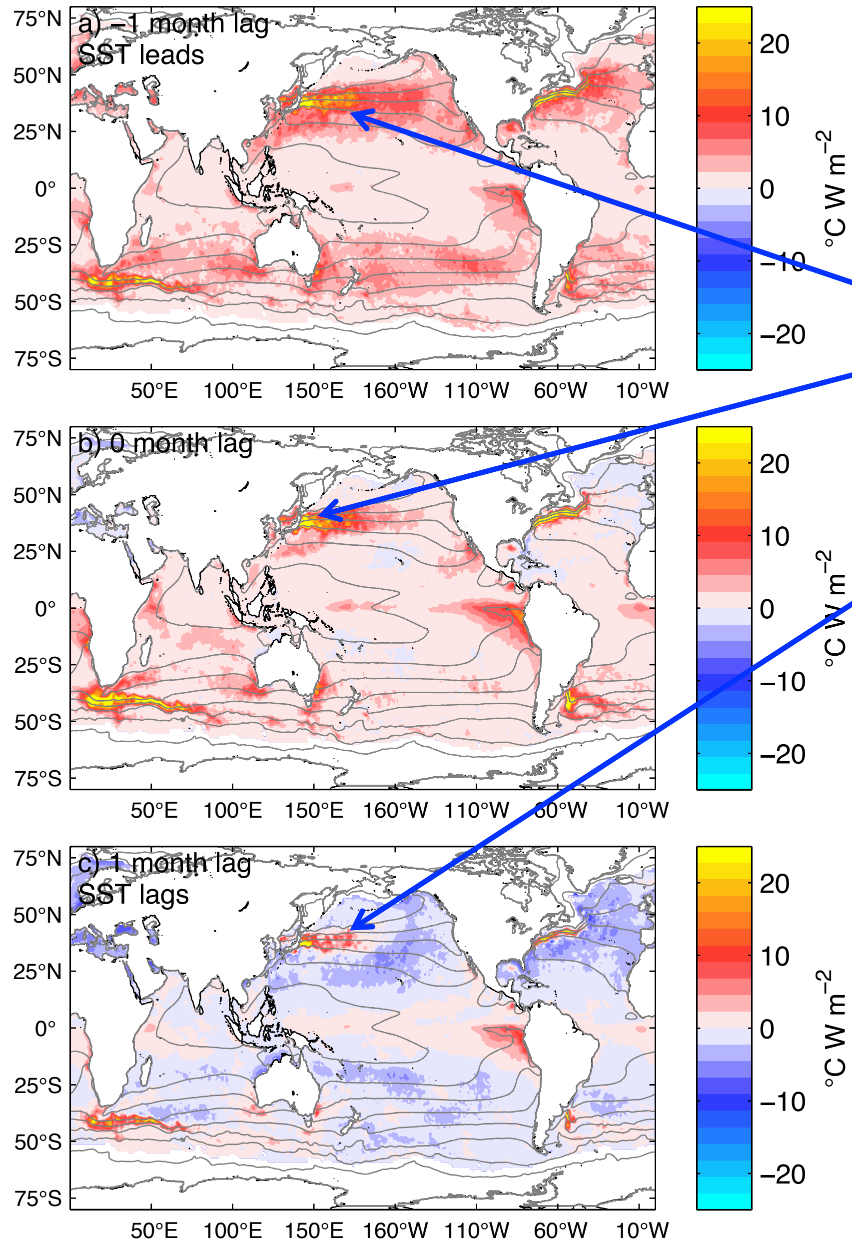
Wu et al. (2006)

SST-SHF Lagged Covariance (Ocean-Driven)

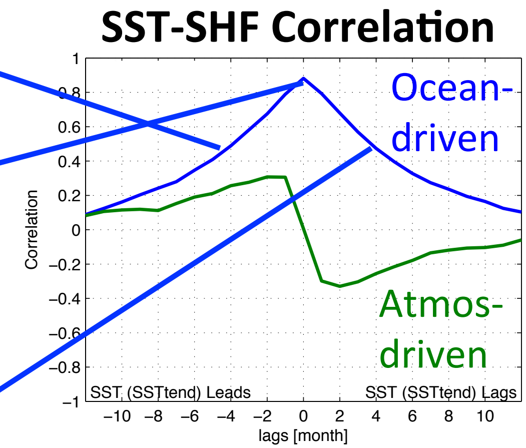
SST Leads by 1 month

Simultaneous

SST Lags by 1 month



Symmetric



Analysis Methodology

- 0.25° NOAA OISST
- 1° OAFlux Turbulent heat fluxes (latent+sensible)
  - 1985-present
  - Remapped to 0.25° NOAA OISST grid
- Monthly-averaged data
- Anomalies (mean climatology removed)
- Removed Niño 3.4 by linear regression

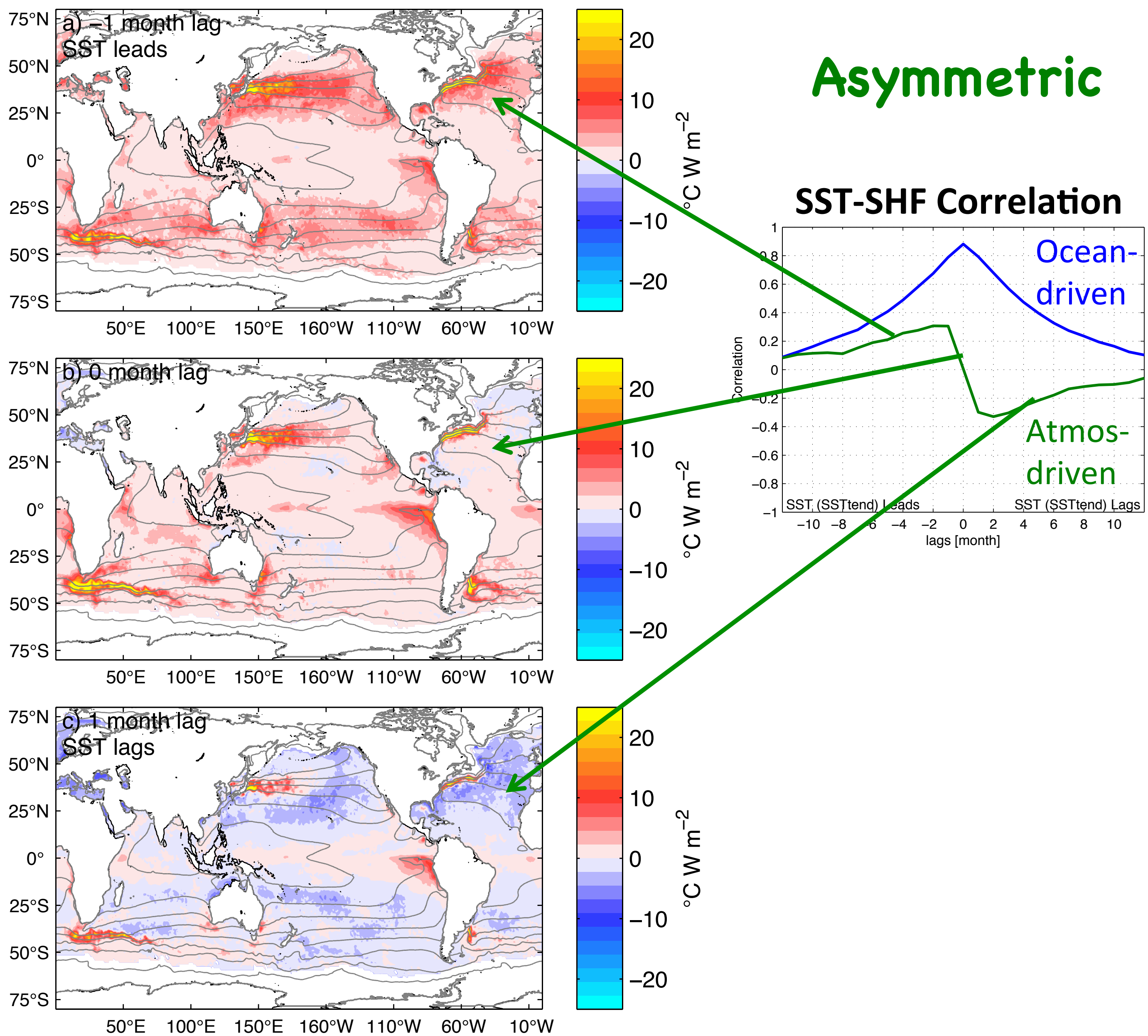
Bishop et al. (2017)

SST-SHF Lagged Covariance (Atmosphere-Driven)

SST Leads by 1 month

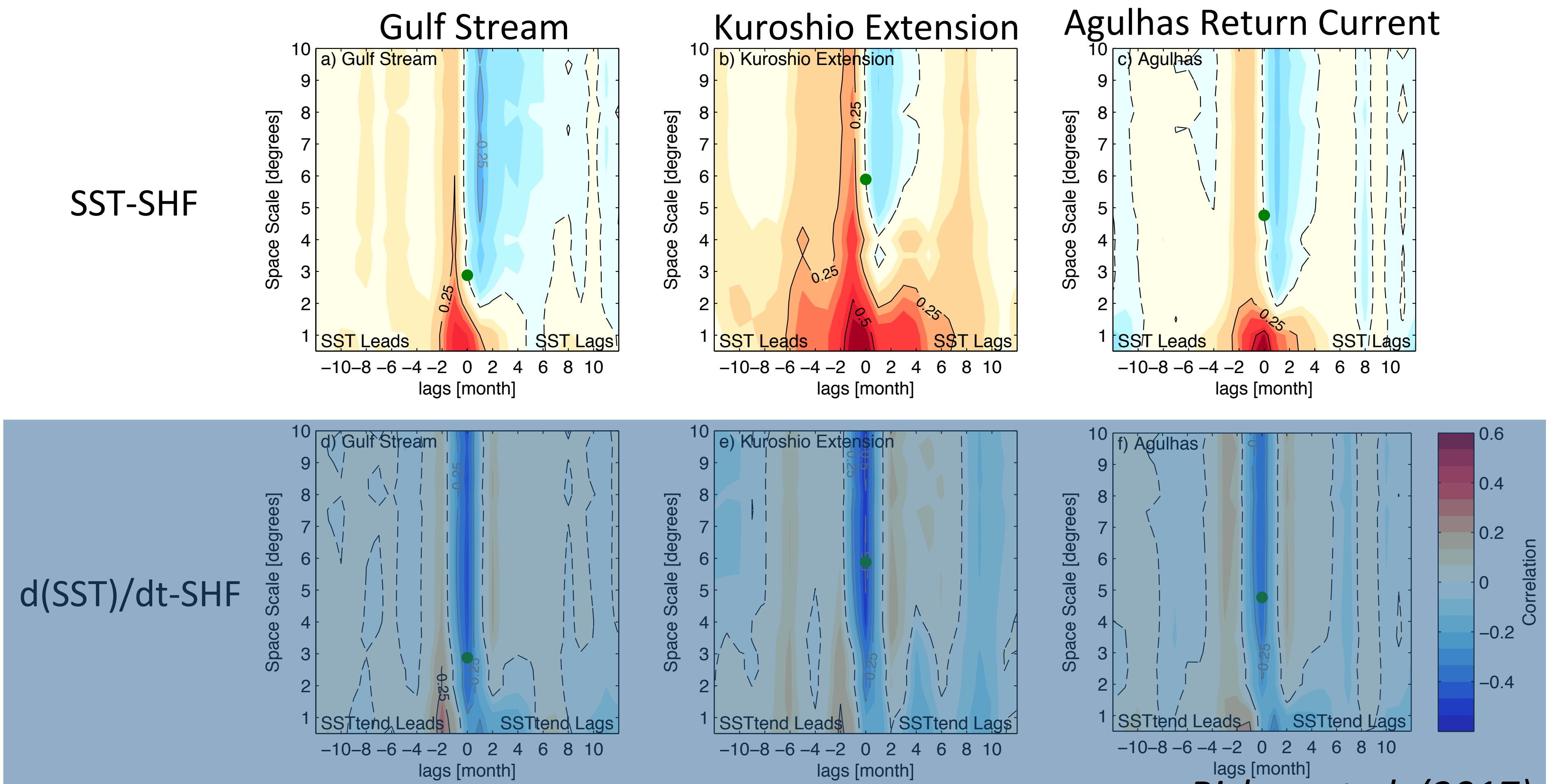
Simultaneous

SST Lags by 1 month



Bishop et al. (2017)

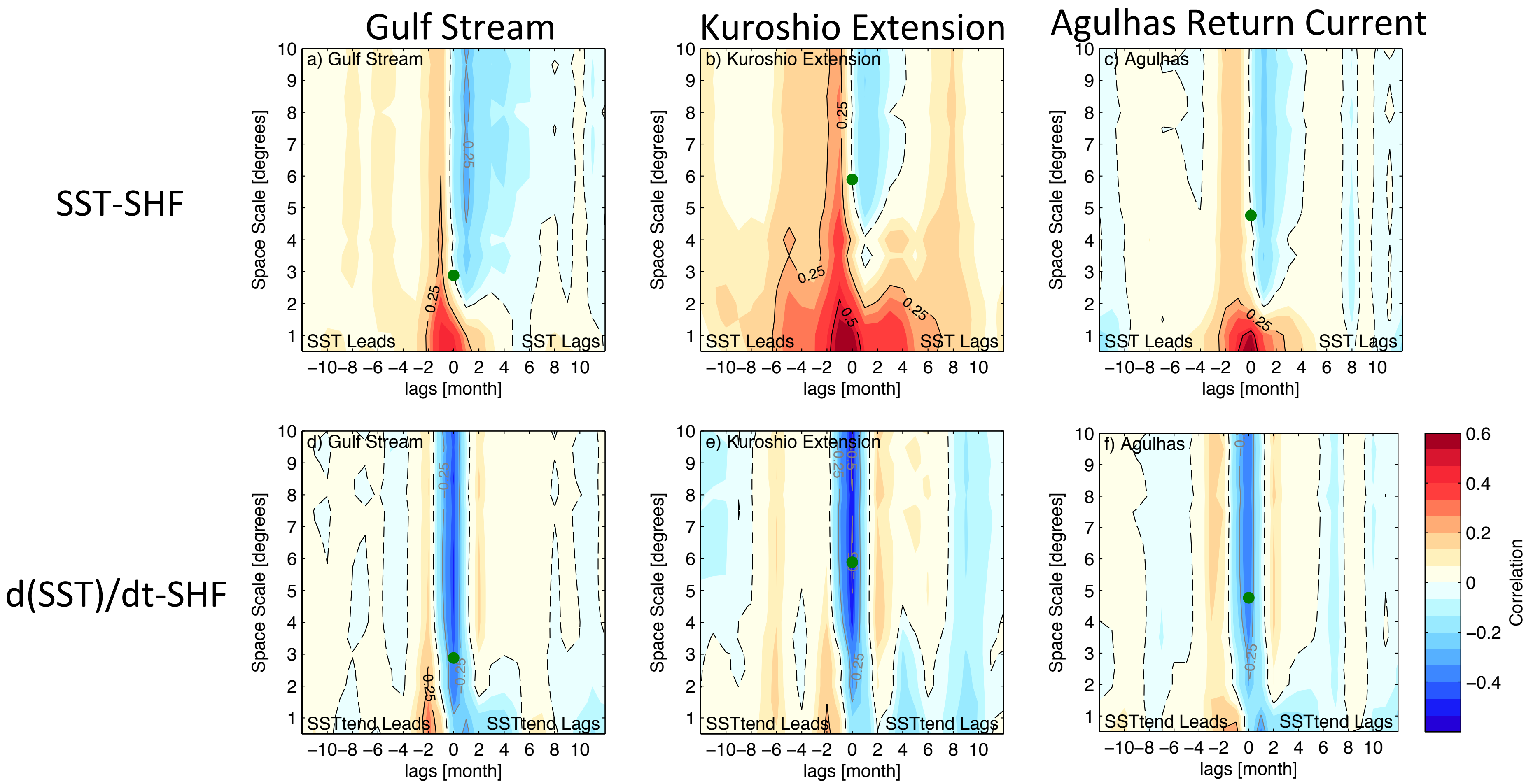
Space-scale dependence in WBCs



Bishop et al. (2017)

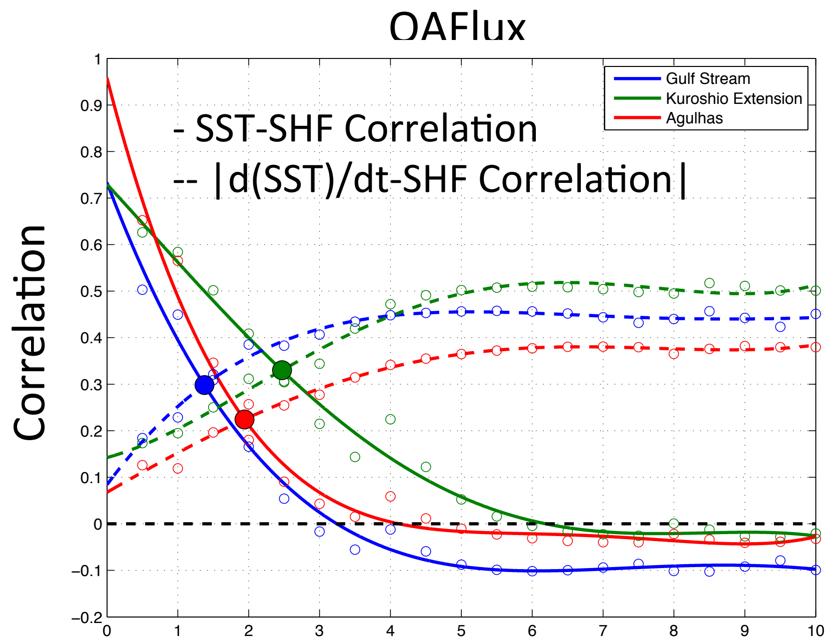
- WBC locations transition from ocean- to atmos-driven SST variability
  - Symmetric to asymmetric lagged SST-SHF correlation
  - Asymmetric to symmetric lagged SST Tendency-SHF correlation.

Space-scale dependence in WBCs

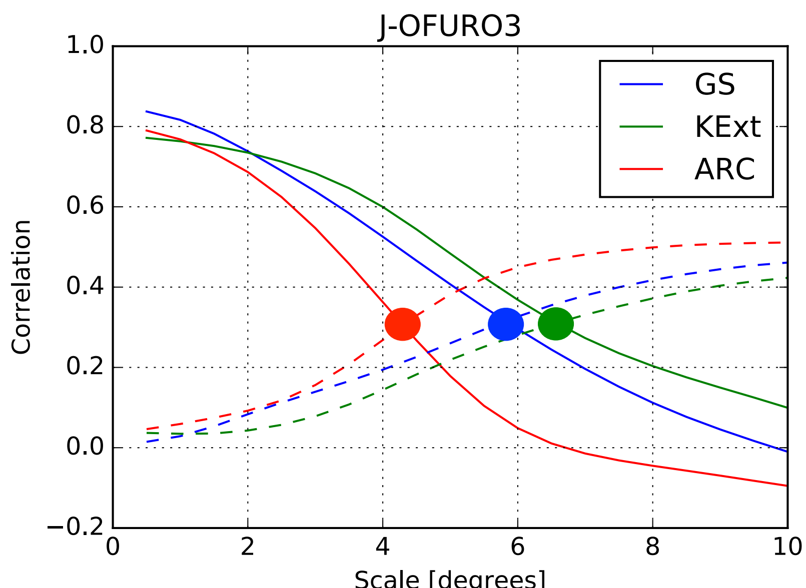


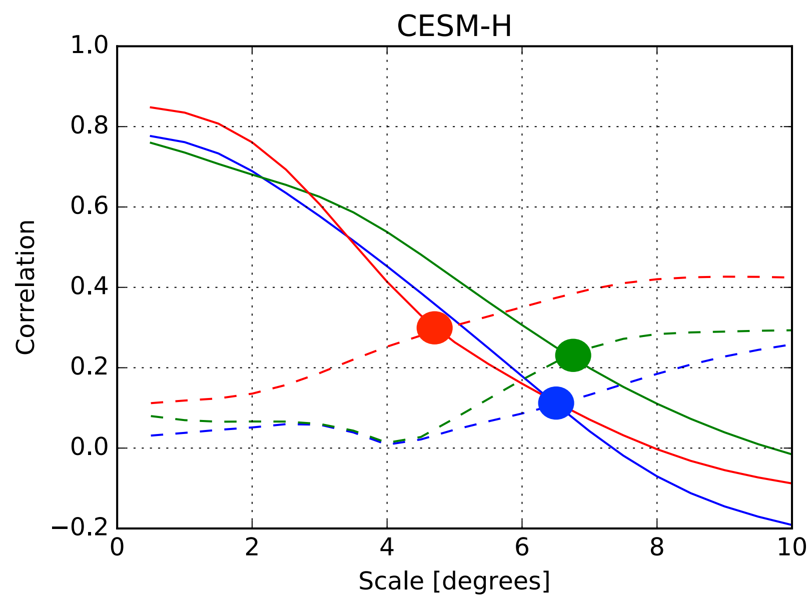
- WBC locations transition from ocean- to atmos-driven SST variability
  - Symmetric to asymmetric lagged SST-SHF correlation
  - Asymmetric to symmetric lagged SST Tendency-SHF correlation.

Transition Length Scale



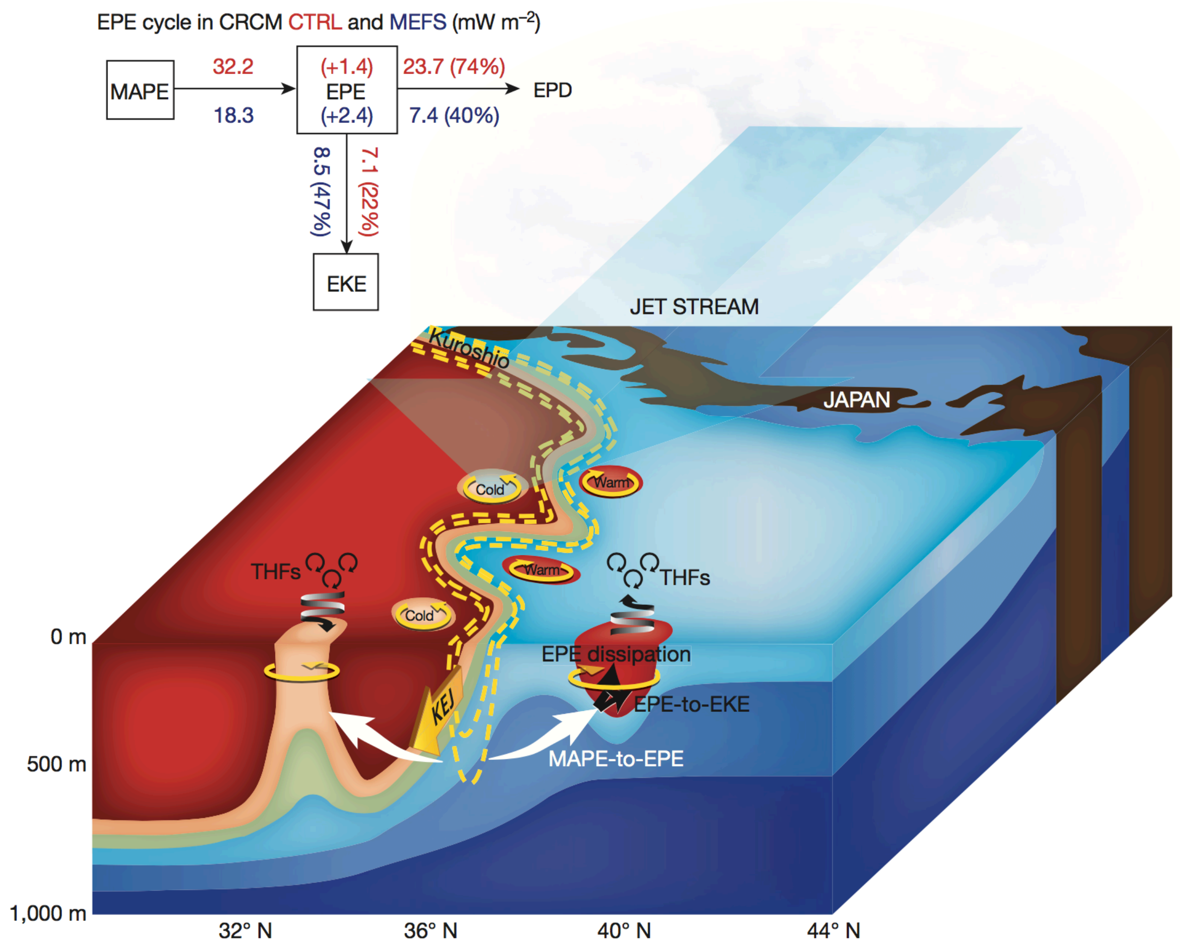
Bishop et al. 2017





Small et al. 2018 (in prep)

EPE Dissipation (EPD)

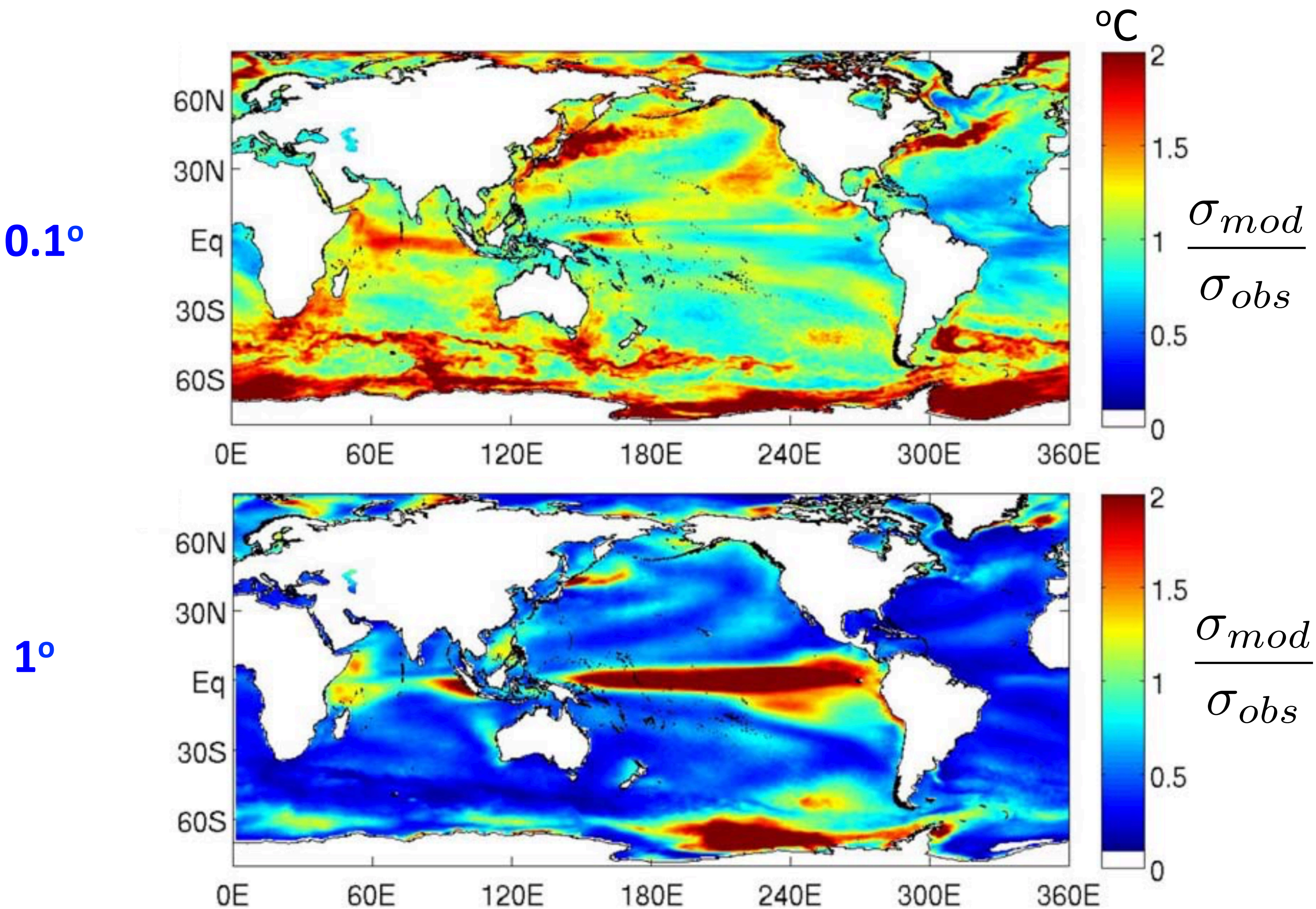


$$G(P_e) = \int_{\mathcal{S}} \frac{\alpha^2 g^2}{c_p N_o^2} \overline{T' Q_o'} \, \mathrm{d}\mathcal{S}$$

- OME-A feedback dominates eddy potential energy destruction, which dissipates more than **70%** of the EPE extracted from the Kuroshio Extension Jet.

Ma et al. 2016 Nature

SST variance is high in coupled models

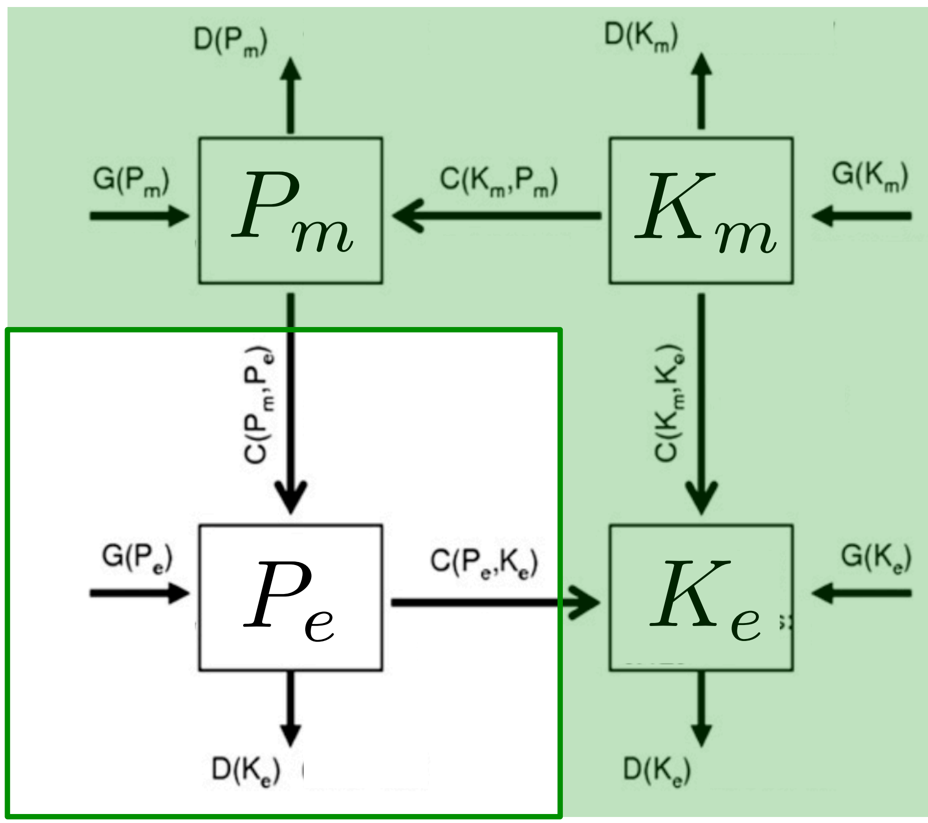


Small et al. 2014 JAMES

Lorenz Energy Diagram

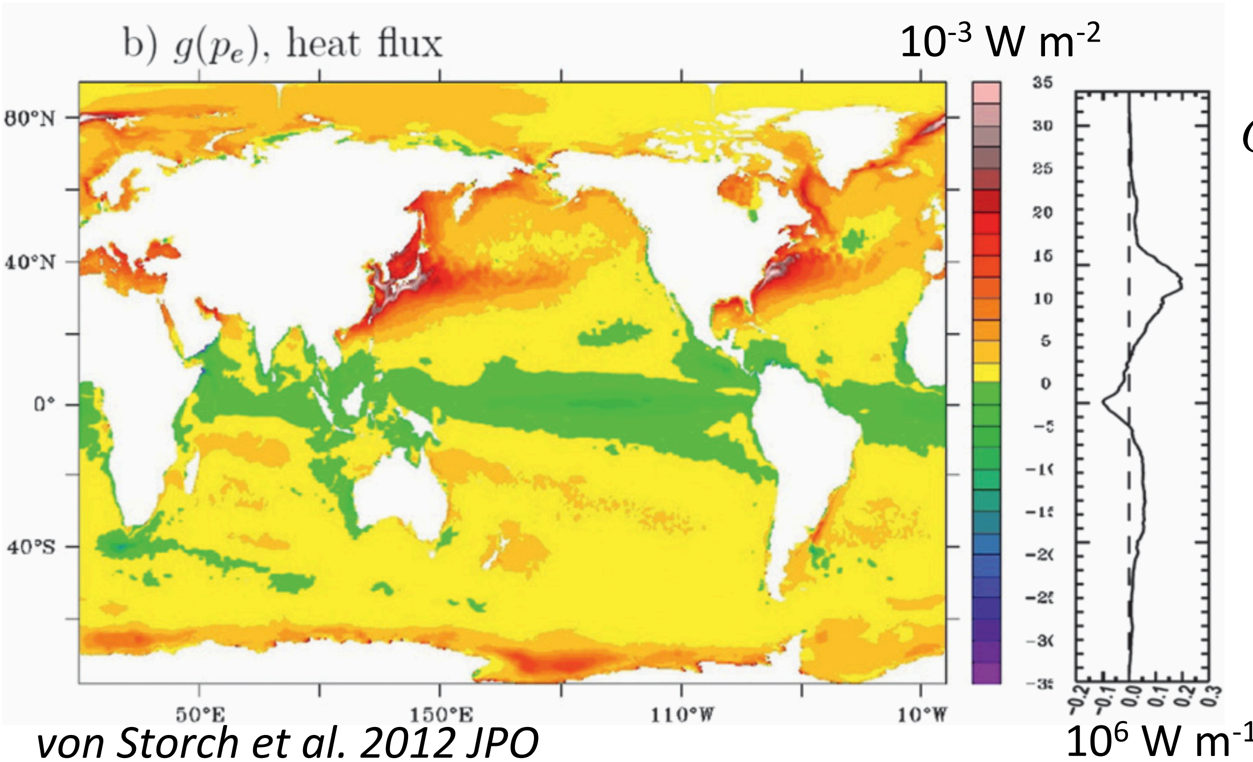
Eddy Potential Energy Equation

$$\frac{dP_e}{dt} = G(P_e) + C(P_m, P_e) - C(P_e, K_e) - D(P_e)$$



Adapted from
von Storch et al. 2012

EPE Generation

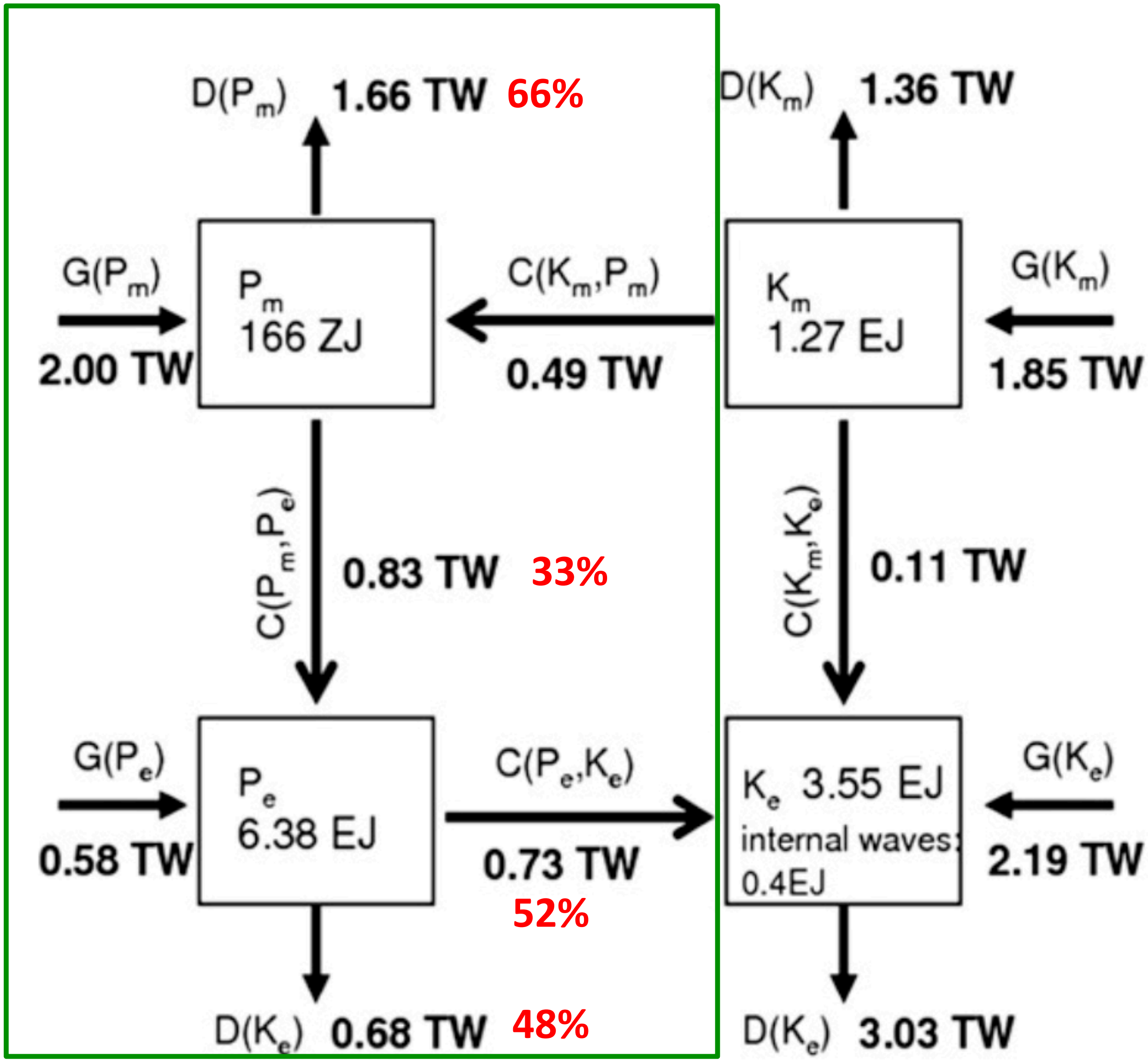


$$G(P_{\mathrm{e}}) = \int_{\mathcal{S}} \frac{\alpha^2 g^2}{c_p N_o^2} \overline{T' Q_o'} \mathrm{d}\mathcal{S}$$

von Storch et al. 2012 JPO

- **STORM/NCEP simulation**:
  - *0.1^o horizontal resolution.*
  - *After 25 year spinup forced with NCEP-NCAR 6 hourly reanalysis from 1948-2010.*
- The Western Boundary Current are EPE generation regions.
- However, their definition of an “eddy” includes a mean seasonal cycle.
- Dynamically mesoscale eddies form from shear-flow instabilities that do not have intrinsic time scales matching seasonal variations.

Ocean Lorenz Energy Diagram



von Storch et al. 2012 JPO

Conversion Terms

TW = 10^{12} W

Energy Reservoirs

ZJ = 10^{21} J P_m

EJ = 10^{18} J

EPE Generation Data Sets

- **J-OFURO3 (Japanese Ocean Flux Data sets with Use of Remote Sensing Observations version 3)**
  - Monthly from 2002-2013
  - 0.25 Degree
  - SST, NHF, SWR, LWR, SHF, LHF
  - Sign convention **negative** heat flux is out of the ocean

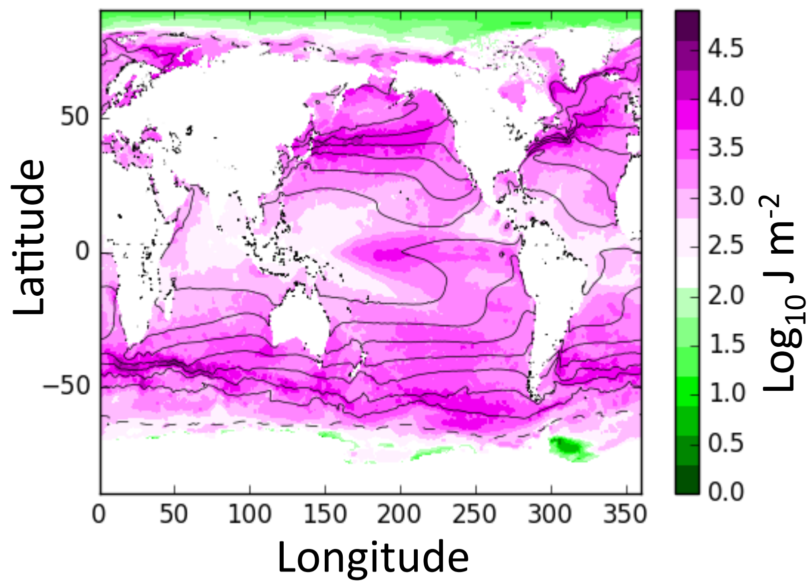
$$Q_o = Q_{sw} + Q_{lw} + Q_s + Q_l$$

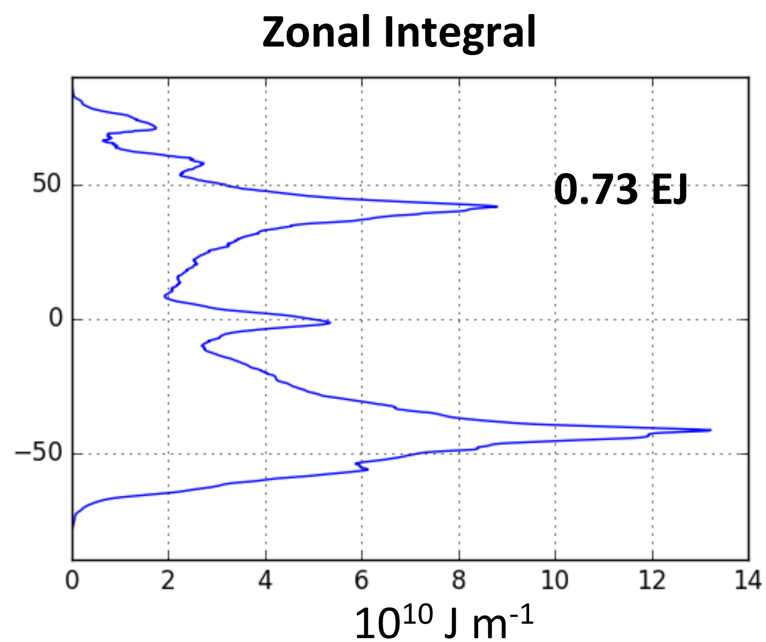
NHF SWR LWR SHF LHF

  - "Eddy" terms are deviations from the 2002-2013 climatological mean
- **MIMOC (Monthly Isopycnal / Mixed-layer Ocean Climatology)**
  - Climatology of mixed layer depths from Argo floats
  - 0.5 degree, remapped to 0.25 J-OFURO3 grid

Mixed Layer Eddy Potential Energy

$$\rho_o \frac{\alpha^2 g^2}{2N_o^2}\overline{h}\overline{T'^2}$$





11% of von Storch full water column estimate

$$P_e^{ML} = \int_{\mathcal{S}} \frac{1}{2}\frac{\rho_o}{N_o^2}\overline{h}\overline{b'^2}\mathrm{d}\mathcal{S} \approx \int_{\mathcal{S}} \rho_o \frac{\alpha^2 g^2}{2N_o^2}\overline{h}\overline{T'^2}\mathrm{d}\mathcal{S}$$

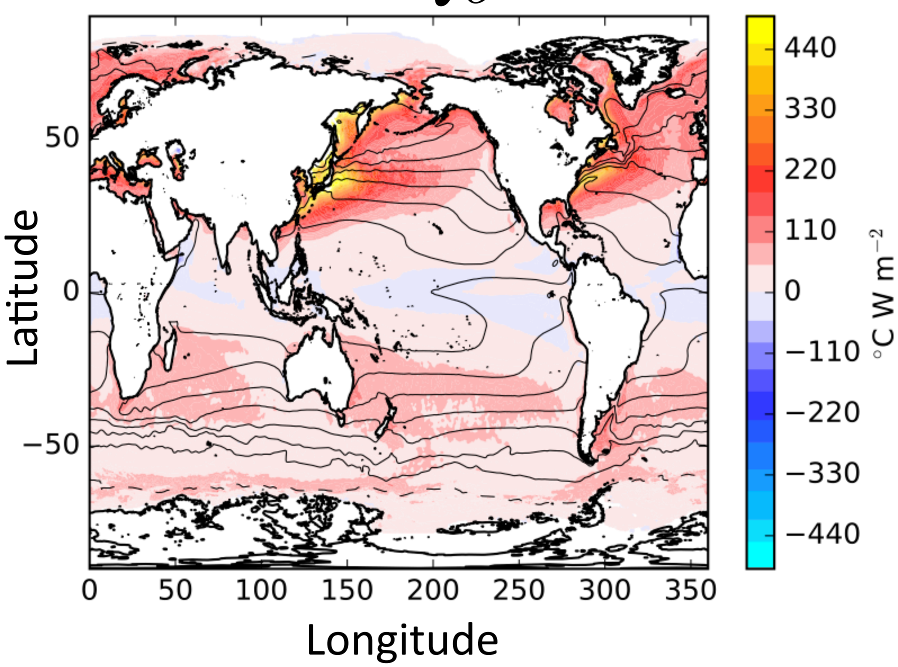
Thermal EPE Generation

3-Way Decomposition

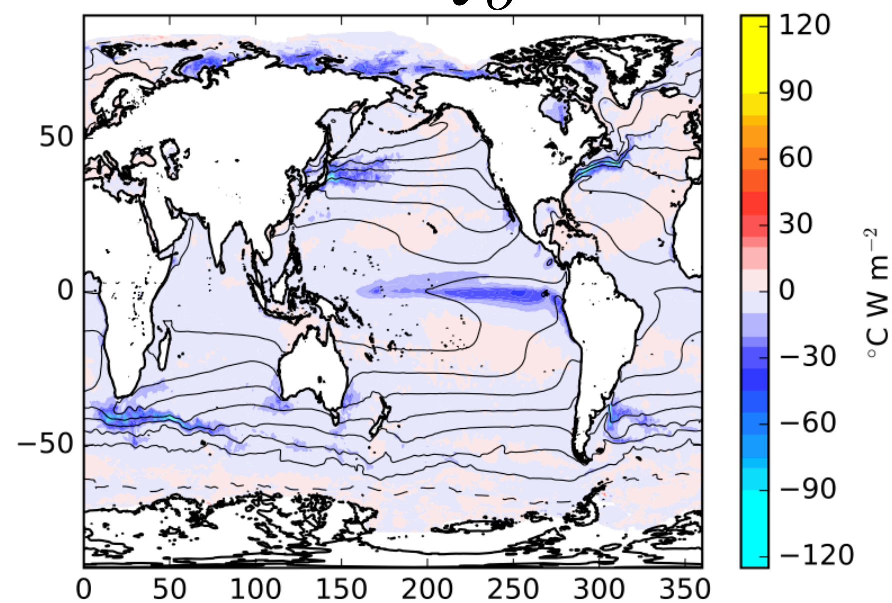
$$\overline{T^* Q_o} = \overline{T^*}\ \overline{Q_o} + \overline{T^* Q_o}^{s} + \overline{T' Q_o'}$$

Mean **Seasonal** **Transient**

$$\overline{T^* Q_o}^{s}$$

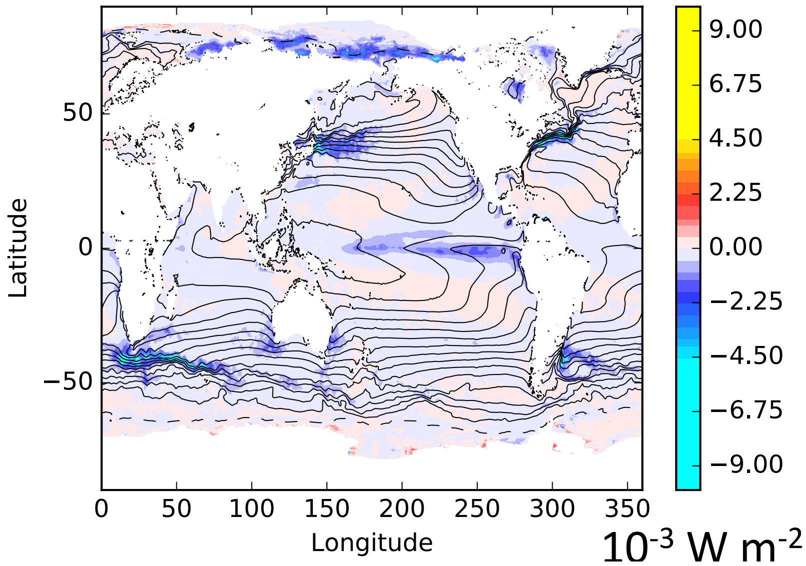


$$\overline{T' Q_o'}$$

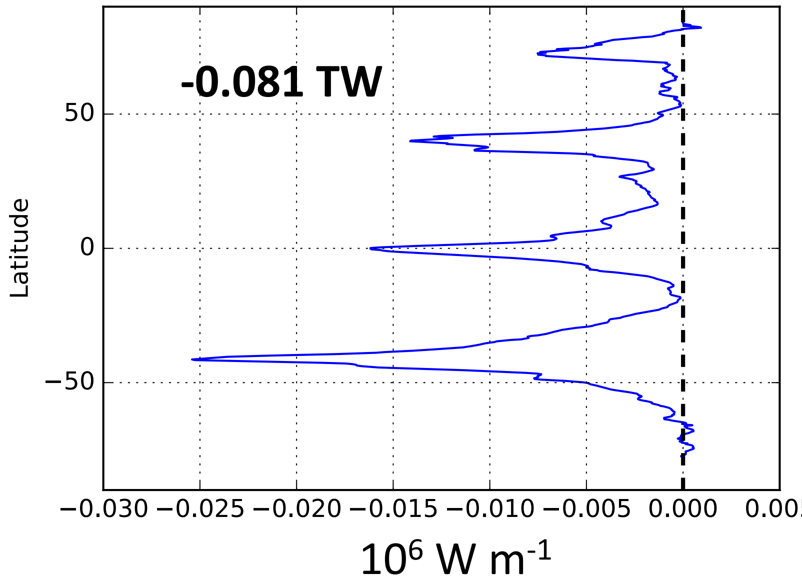


Damping of EPE

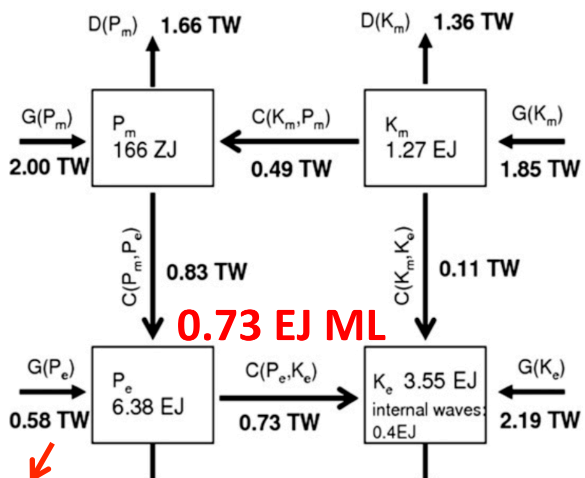
$$\frac{\alpha^2 g^2}{c_p N_o^2}\overline{T'Q'_o}$$



$$\oint \frac{\alpha^2 g^2}{c_p N_o^2}\overline{T'Q'_o}\,\mathrm{d}x$$



$$G(P_e) = \int_{\mathcal{S}} \frac{\alpha^2 g^2}{c_p N_o^2}\overline{T'Q'_o}\,\mathrm{d}\mathcal{S}$$



-0.081 TW

14% of $G(P_e)$ in von Storch

Conclusions

1. Boundary Current regions exhibit air-sea feedbacks that show ocean internal processes (mesoscale eddies) drive SST variability.

2. Air-sea feedbacks diminish with spatial scale and are absent by **1-7 degrees** (~100-1000 km) depending on geographic location.

3. SST variability in J-OFURO3 accounts for ~**0.73 EJ** (11% of global *von Storch et al. 2012*) EPE in the oceanic mixed layer.

4. Impacts of air-sea interaction in the WBCs and ACC act to dampen EPE available to be converted to EKE, which is not represented in low-resolution coupled climate models. **-0.1 TW** [14% of *von Storch et al. 2012* G(P_e)] of energy damped by mesoscale eddies.