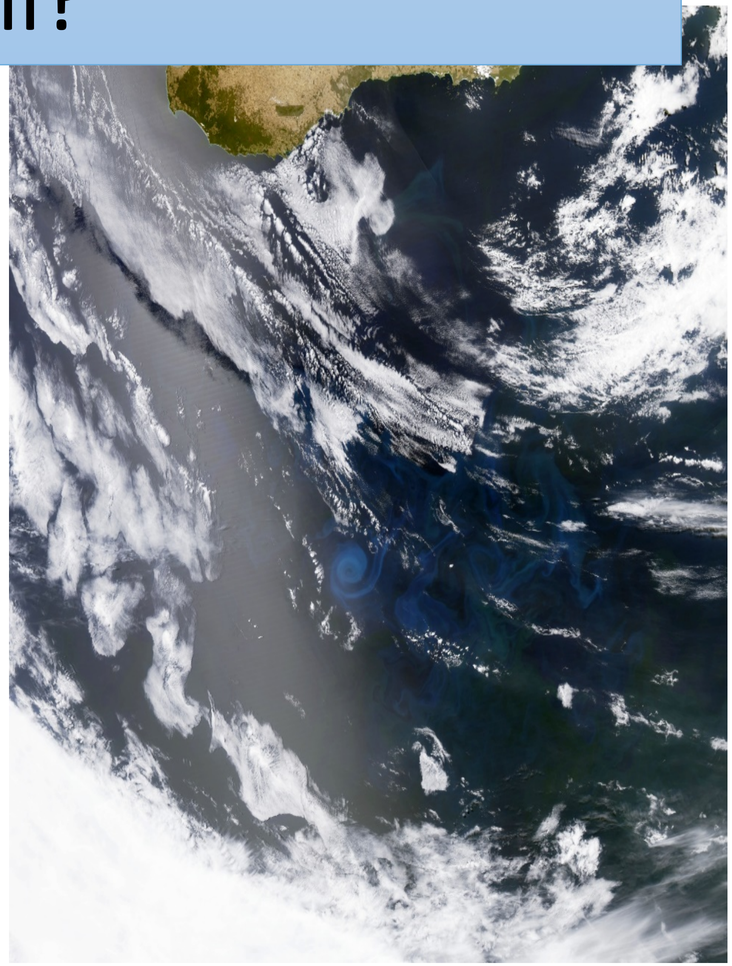
“Earth system modelling for seamless prediction: On which processes should we focus to further improve atmospheric predictive skill?”

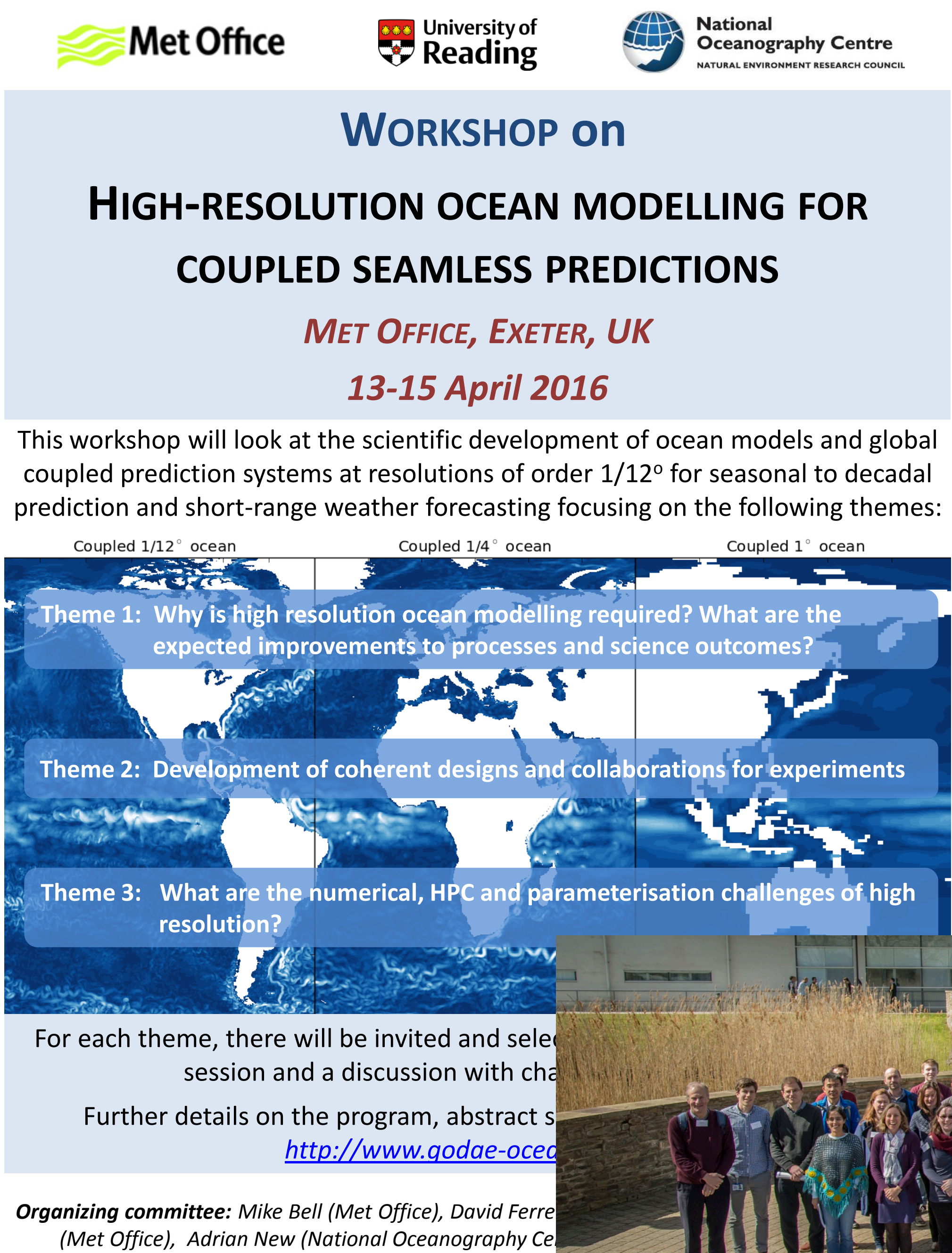
David Ferreira (Reading)

Thanks to Arnaud Czaja (Imperial College)

Short answer:
Oceans and
air-sea coupling



High-resolution coupled climate modeling: On which basis? For which science?



Met Office

University of Reading

National Oceanography Centre
NATURAL ENVIRONMENT RESEARCH COUNCIL

WORKSHOP ON

HIGH-RESOLUTION OCEAN MODELLING FOR COUPLED SEAMLESS PREDICTIONS

MET OFFICE, EXETER, UK

13-15 April 2016

This workshop will look at the scientific development of ocean models and global coupled prediction systems at resolutions of order 1/12º for seasonal to decadal prediction and short-range weather forecasting focusing on the following themes:

Theme 1: Why is high resolution ocean modelling required? What are the expected improvements to processes and science outcomes?

Theme 2: Development of coherent designs and collaborations for experiments

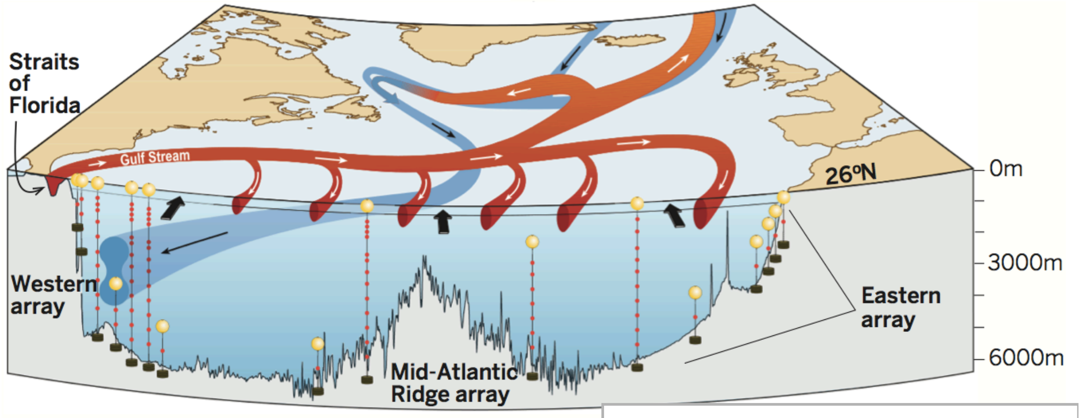
Theme 3: What are the numerical, HPC and parameterisation challenges of high resolution?

For each theme, there will be invited and selec
session and a discussion with cha

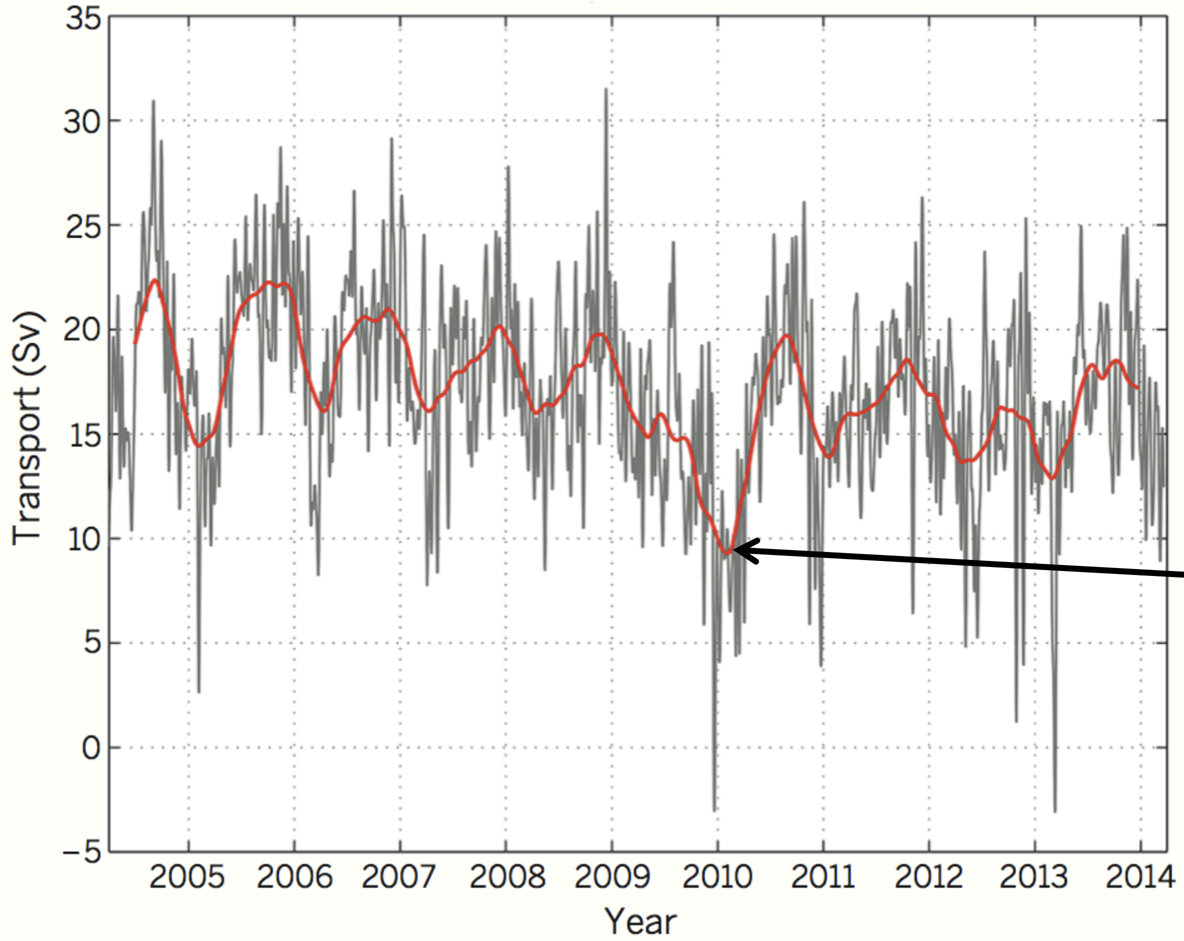
Further details on the program, abstract s
http://www.godae-ocea

Organizing committee: *Mike Bell (Met Office), David Ferre*
(Met Office), Adrian New (National Oceanography Ce

Atlantic Meridional overturning circulation



RAPID Array, at 26N



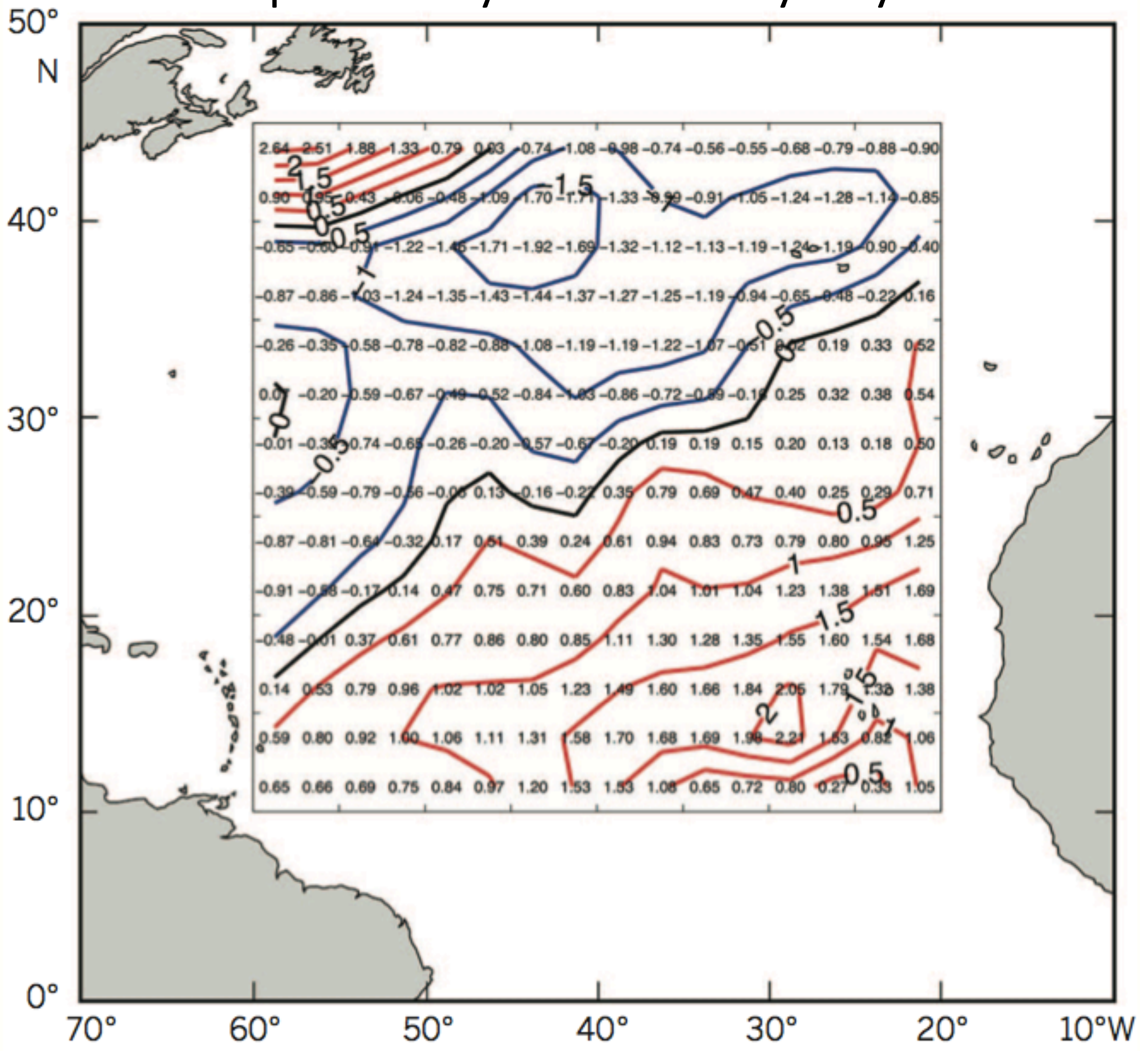
- Trend = -0.5 Sv/year

- Event lies outside of predicted range by coupled climate models
- OHT: divided by 3

Srokosz and Bryden (2015)

Impact of the 2009-2010 AMOC event

Temp Anomaly at 50 m: May-July 2010

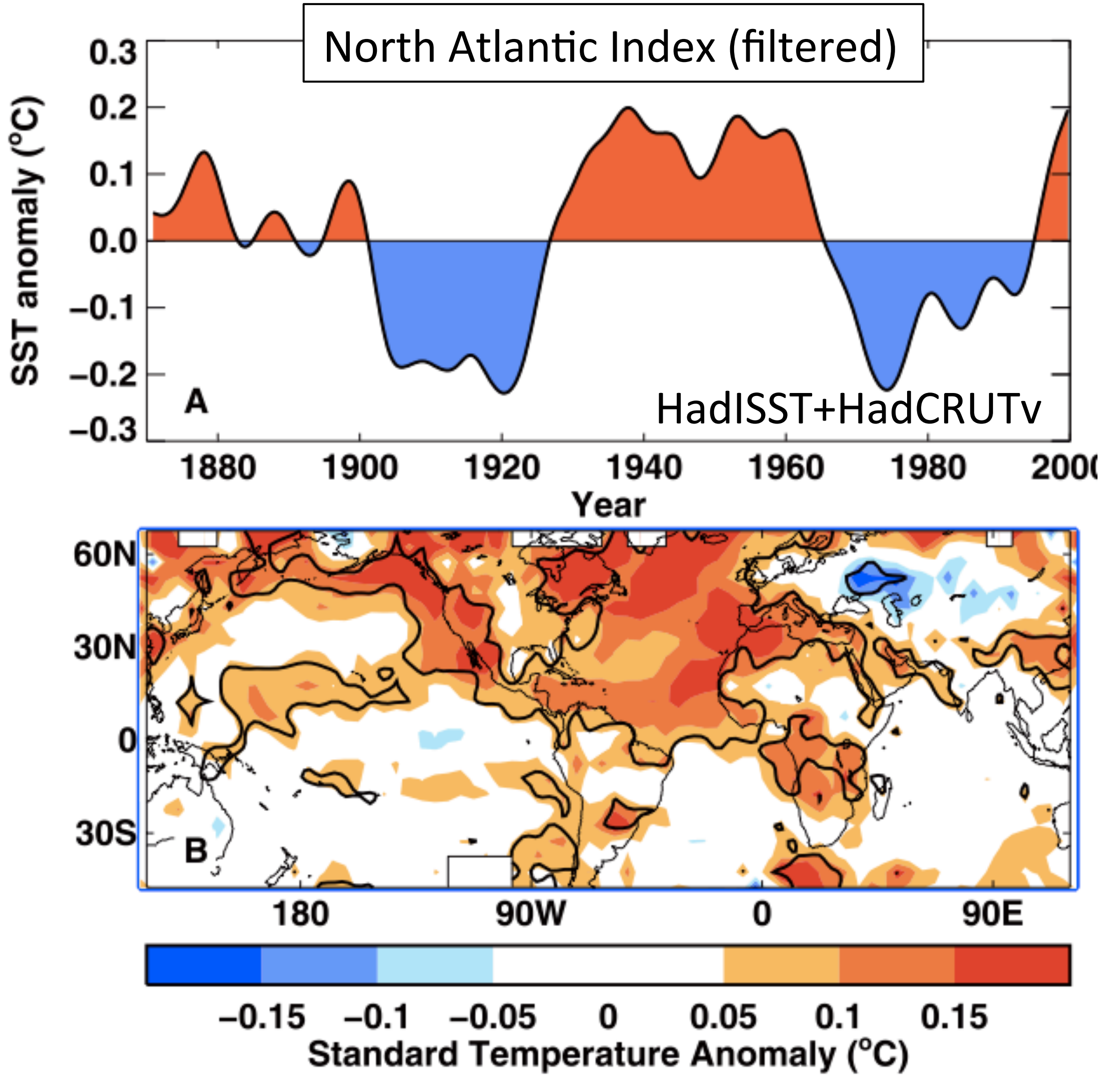


Srokosz and Bryden (2015)

- Re-emergence of SSTA in winter 2010-2011, possibly contributed to the persistence of negative NAO → potential for improved prediction of NAO and winter conditions,
- One of the strongest hurricane season,
- Within a 2-year period the sea level rise by 128 mm, a 1-in-850–year event (Goddar et al. 2015)

Atlantic Multidecadal oscillation

- Mechanism not well established,
- Possibly driven by AMOC variability (although atmospheric origin has been suggested)

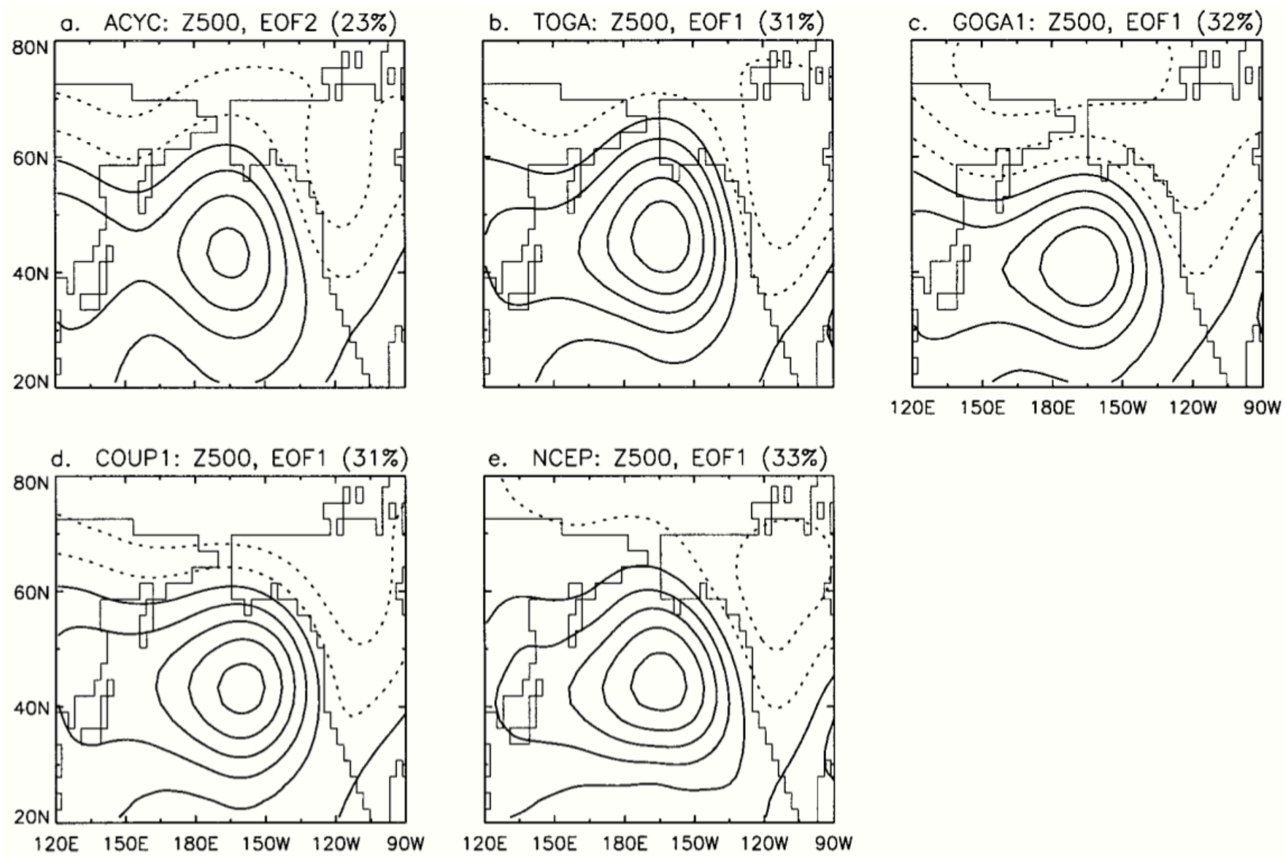


- Sahel drought [Folland et al., 1986; Rowell et al., 1995],
- variability in Northeast Brazilian rainfall [Folland et al., 2001],
- North American climate [Sutton and Hodson, 2005],
- river flows [Enfield et al., 2001],
- frequency of Atlantic hurricanes [Goldenberg et al., 2001].

Knight et al. (2005)

Standard paradigm from coarse climate models' study

- The main patterns of extra-tropical atmospheric variability are well reproduced in absence of oceanic variability
- This contrasts sharply with the Tropics where interannual variability changes dramatically in absence of ocean dynamics (ENSO)

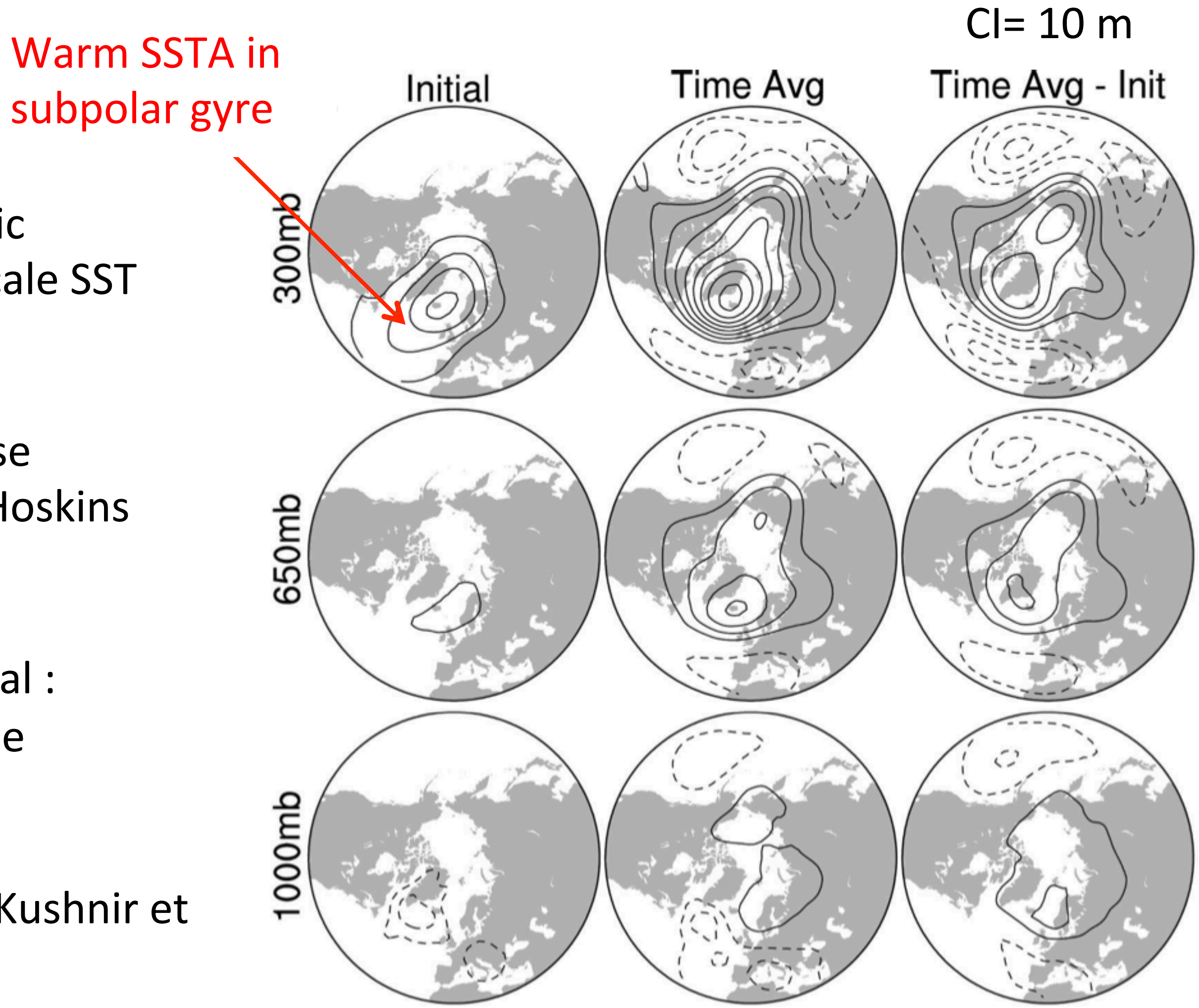


Saravanan (1998)

Atmospheric response to large-scale SST anomalies

Consensus view of the atmospheric response to extra-tropical large-scale SST anomalies:

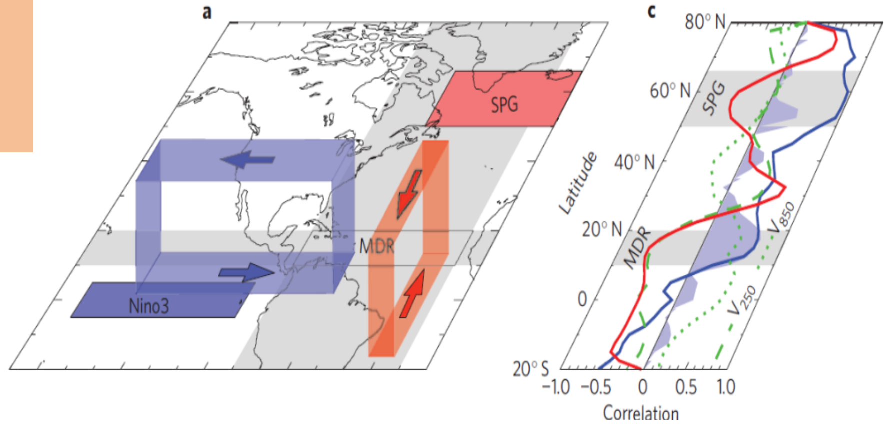
- low-level Low pressure response downstream of a warm SSTA (Hoskins and Karoly, 1981)
- nonlinear dynamics are essential : conversion from baroclinic to be equivalent barotropic ,
- however, inconsistent results (Kushnir et al. (2002).



Ferreira and Frankignoul, 2005; Deser et al. 2007

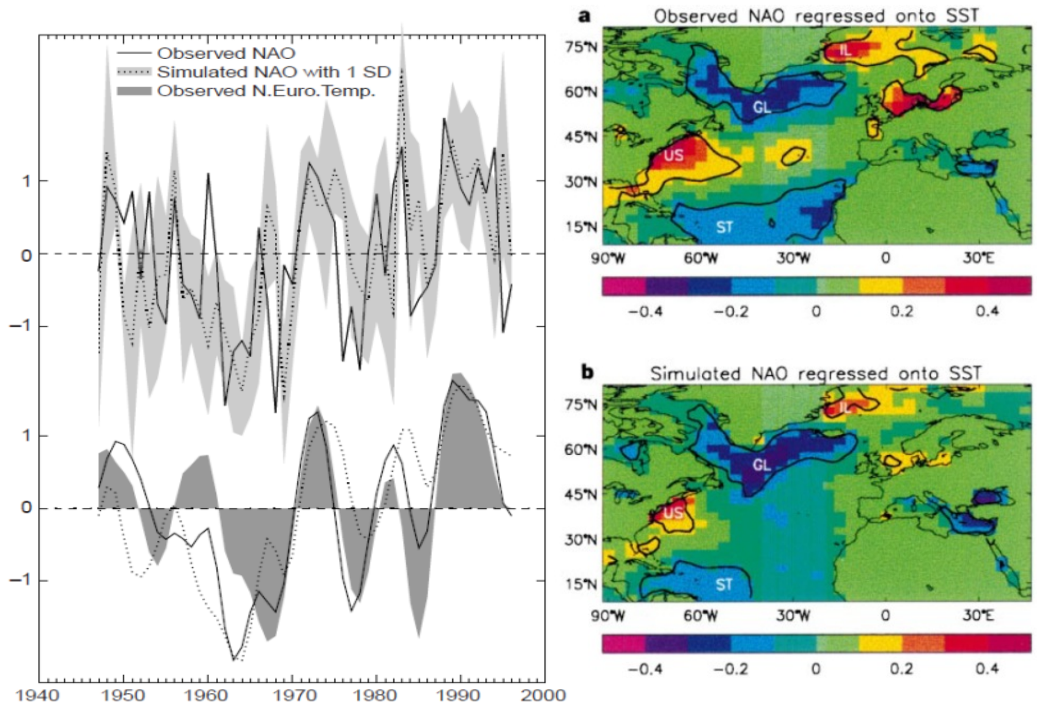
Oceans provide "memory" to the climate

Standard paradigm from coarse climate models' study



Smith et al. (2010)

- Even if some predictability arises from the extra-tropical oceans (e.g., Smith et al., 2010), it is small in comparison to the total atmospheric variability (e.g., at most 16% of NAO interannual variance can be attributed to North Atlantic SST in Rodwell et al., 1999)
- But see also Scaife et al. (2014)



Rodwell et al. 1999

Oceans provide "memory" to the climate

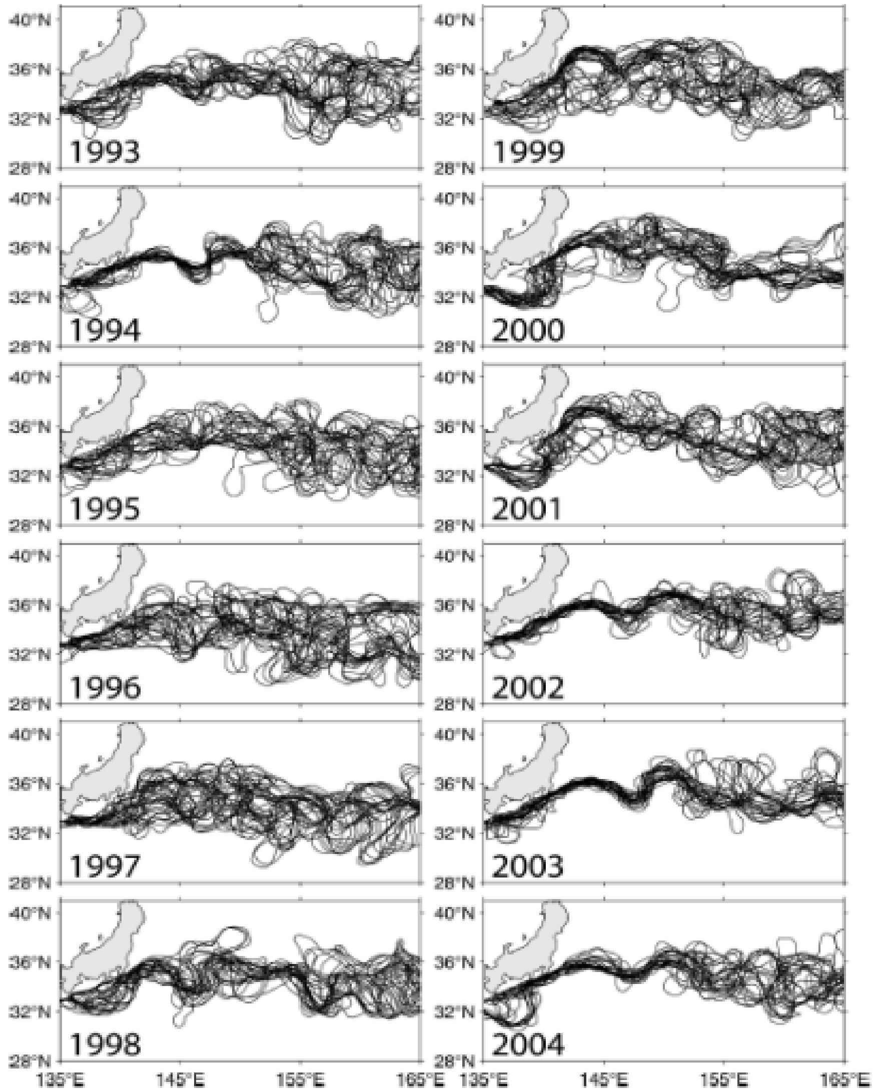
<u>Might the coarse resolution models be missing…</u>

→ The right amount of (intrinsic) variability in ocean?

→ Some mechanisms of ocean-atmosphere coupling?

i) Western boundary currents
ii) The global eddy field

SSH-170cm plotted every 14 days

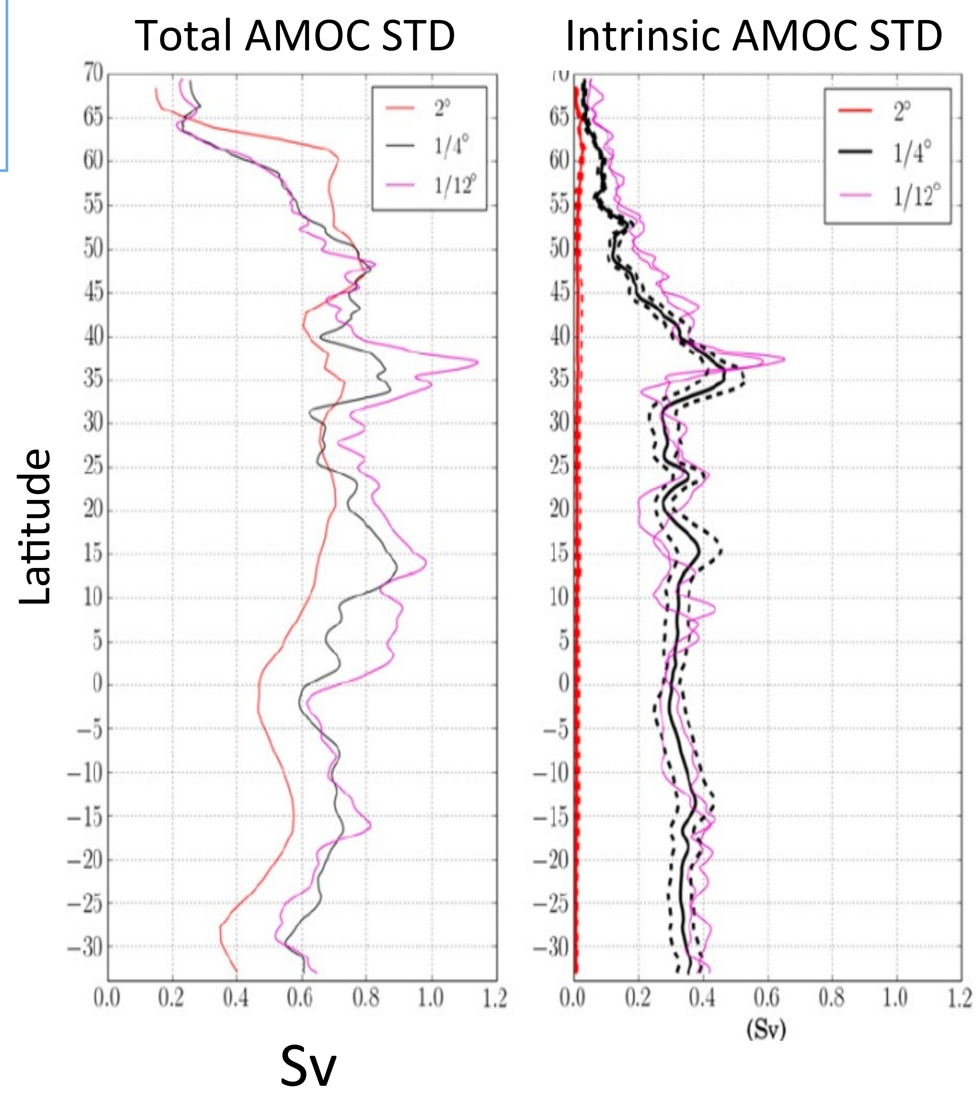


Qiu and Chen (2005)

Gregorio et al. (2016)

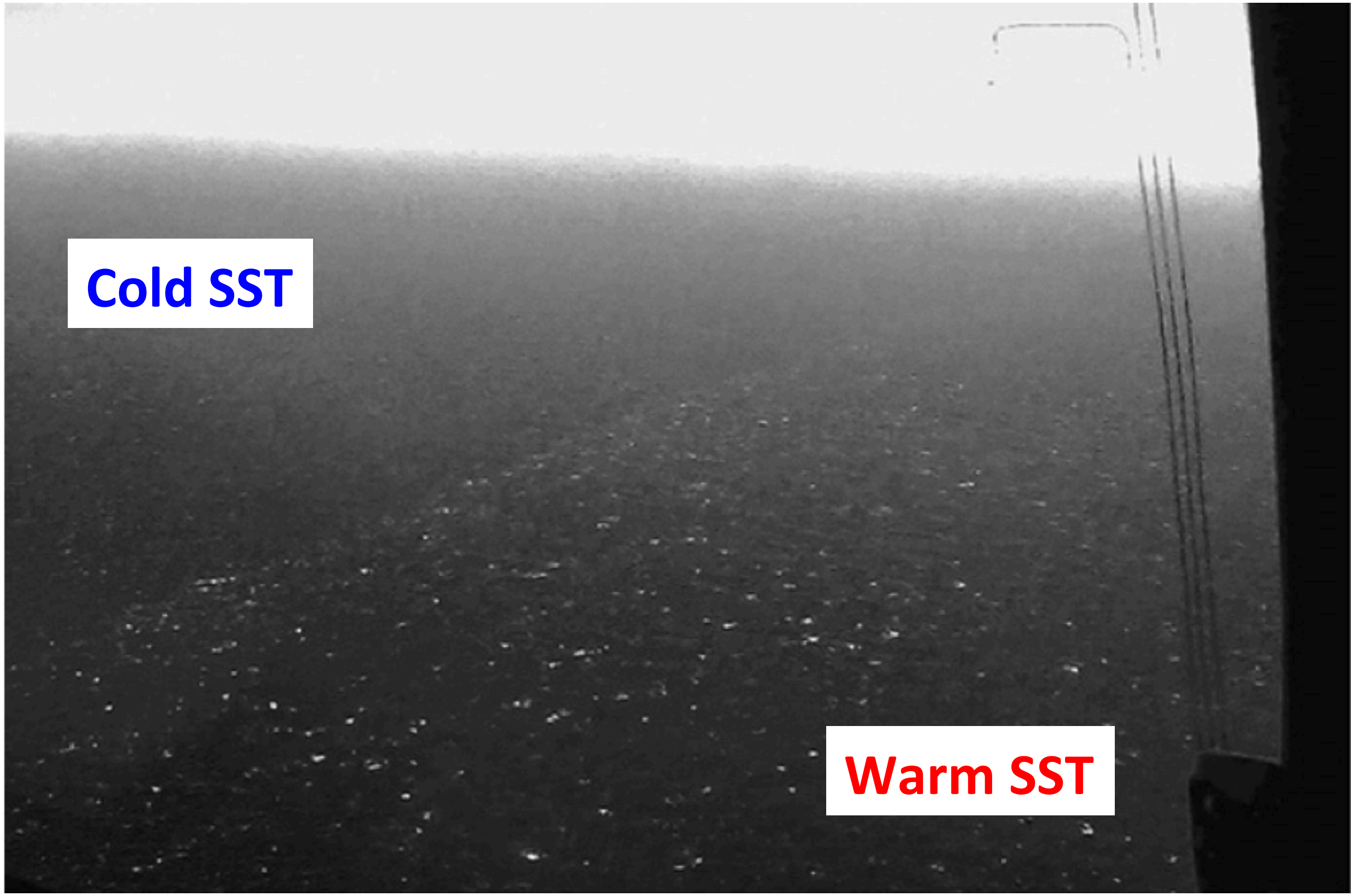
Modelling the ocean variability requires high-resolution models

- A significant fraction (~50%) of their variability on interannual to decadal timescales is intrinsic and exists in absence of such variability in the atmosphere *at sufficiently high spatial ocean resolution*.



See also Hu and Deser (2013, GRL), Penduff et al. (2011, JPO)

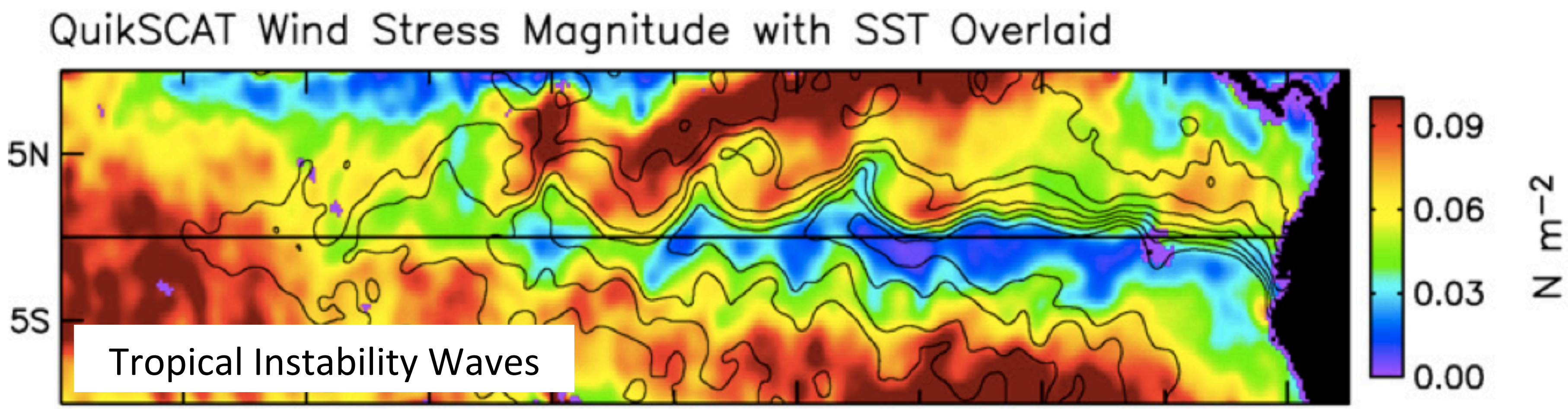
Air-sea interactions over ocean fronts and eddies



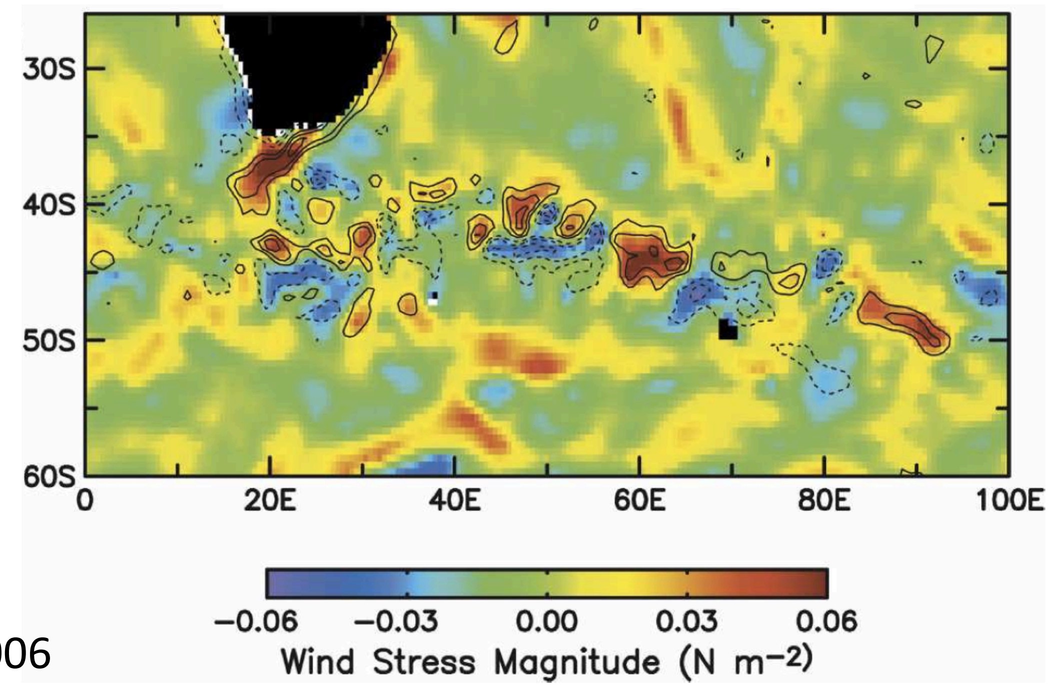
Increased winds ←→ warm SSTs

Chelton et al. 2006, Small et al. 2008

Air-sea interactions at the ocean mesoscale



Wind stress (color) & SST (black)



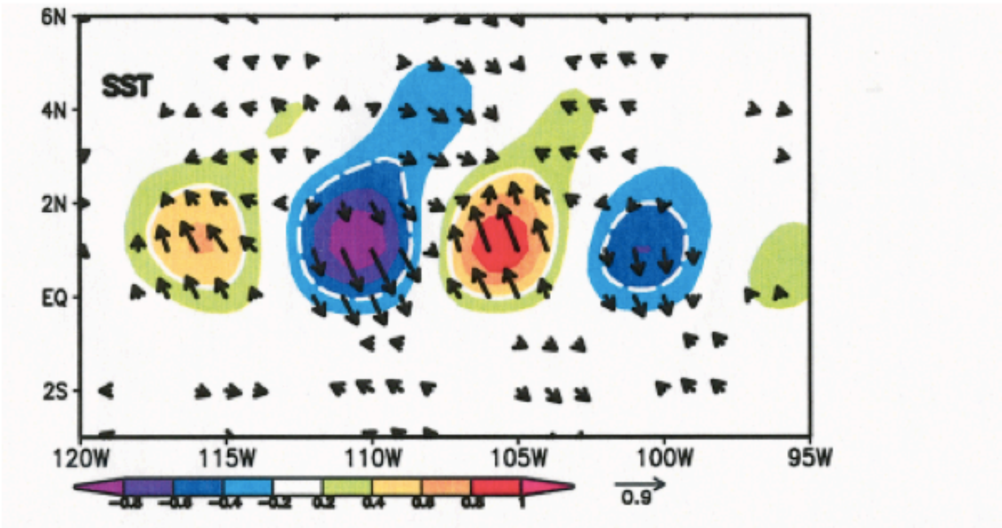
<u>Eddy-ABL interaction:</u>
Ocean turbulence is imprinted on to the global Marine Boundary Layer

Small et al. 2008, Maloney and Chelton 2006

Comparison with the "old" way: air-sea interactions at the basin scale

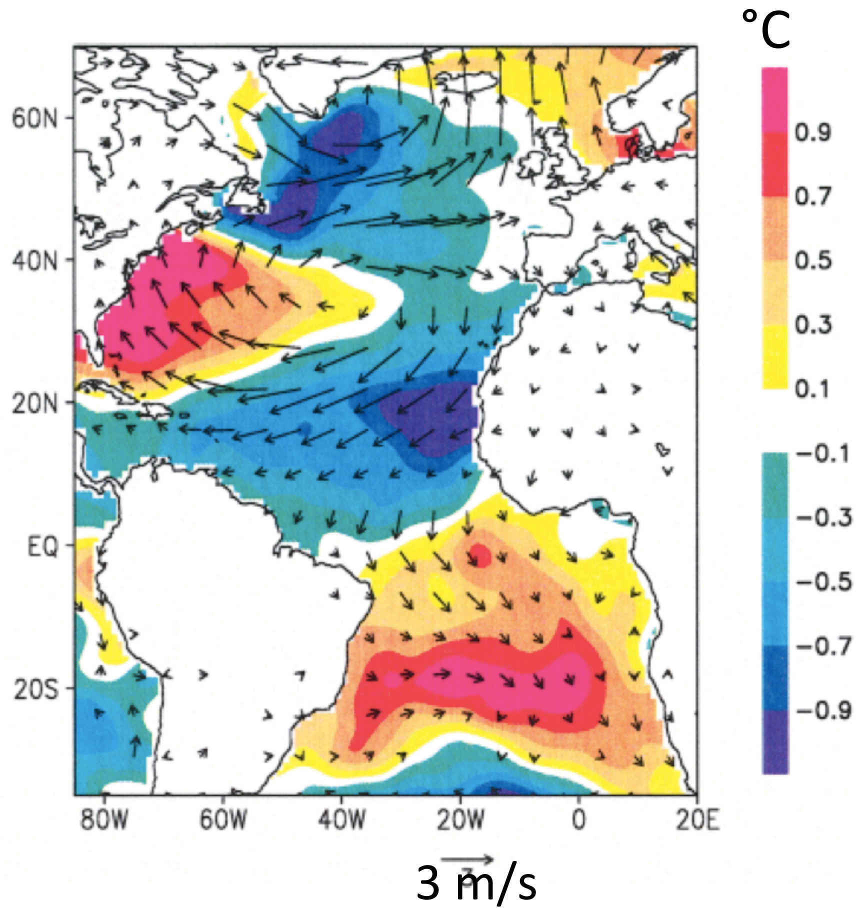
Composite of TIWs:

Increased winds ←→ warm SSTs



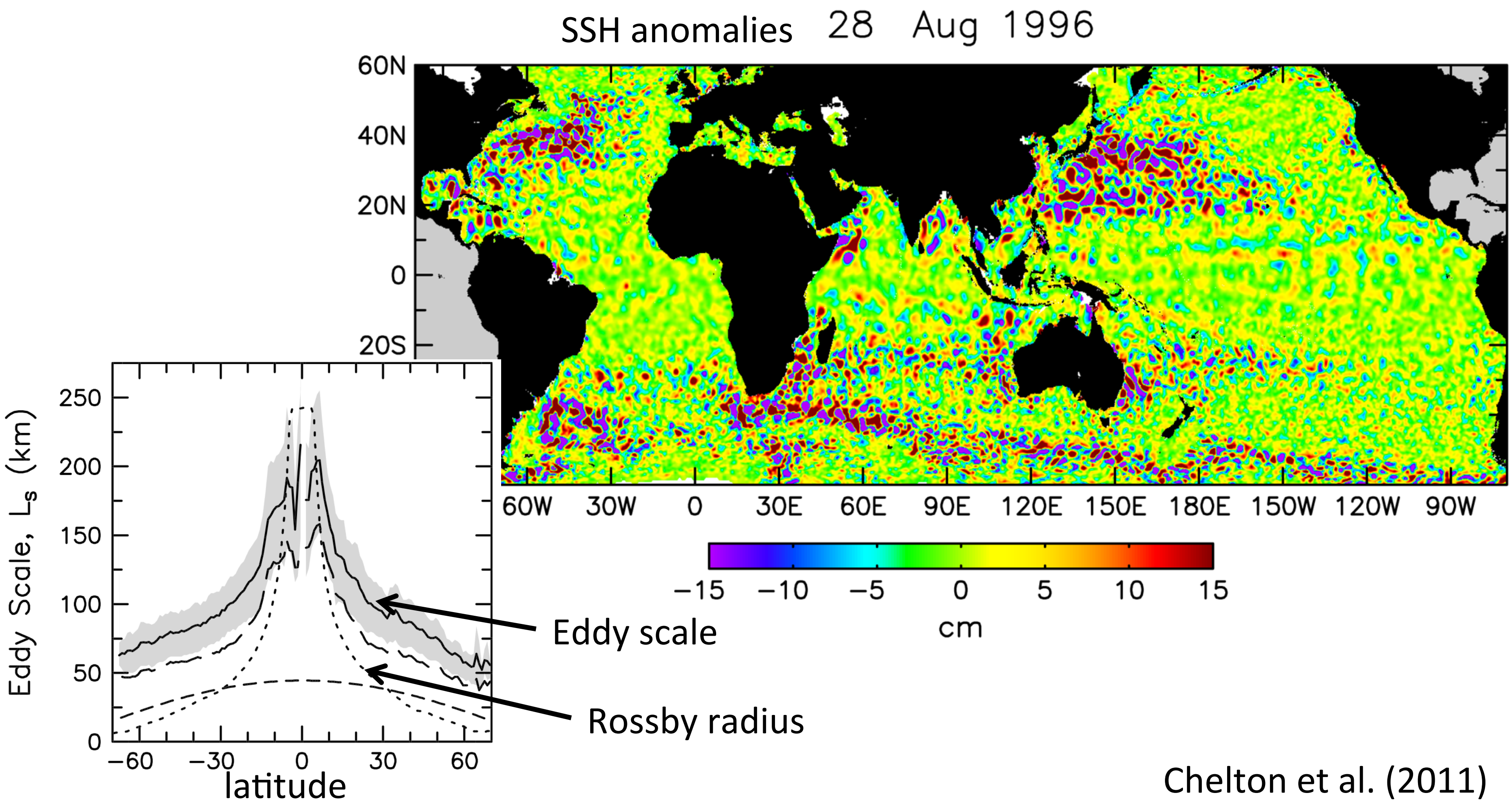
NAO+ / SST tripole anomaly

Increased wind ←→ cold SSTs



Mesoscale eddies are everywhere

- Coherent vortices, radius of about 50-100 km
- Generated by baroclinic and barotropic instabilities
- over 20 years, ~215,000 eddies with lifetimes of 4 weeks or longer lifetime

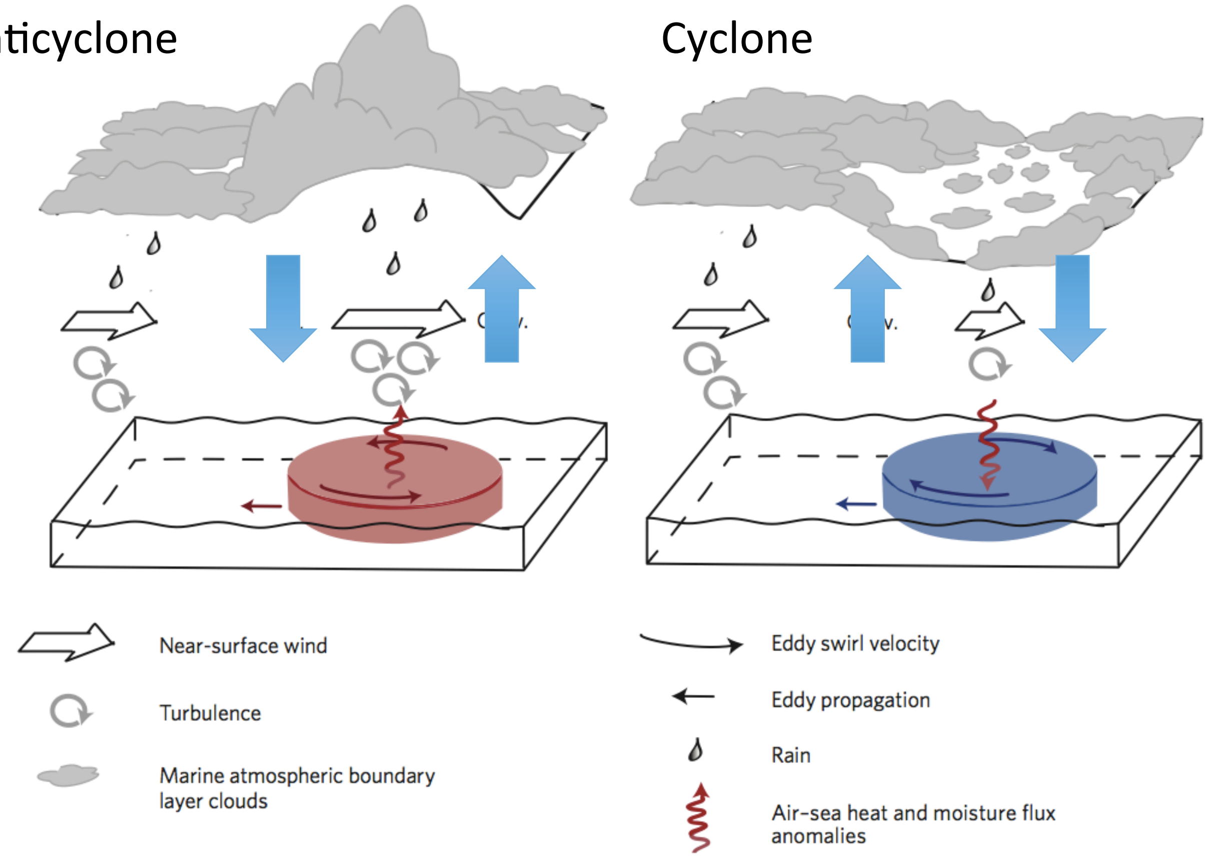


Chelton et al. (2011)

Mechanism I

- Dominant mechanism: Modulation of the ABL vertical mixing

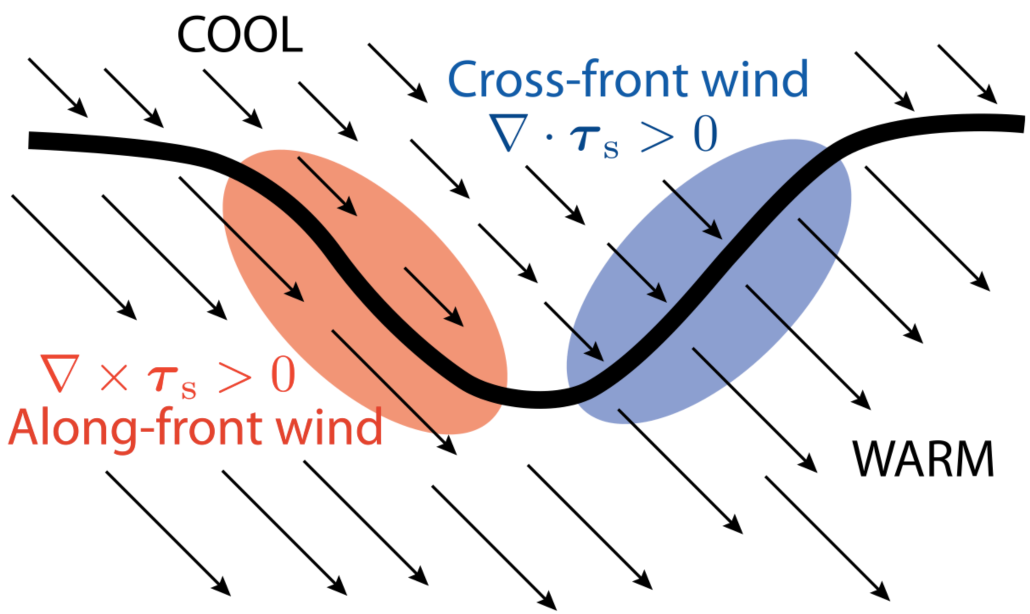
- Warmer SST
→ Decreased vertical stability
→ Downward momentum flux
→ Decreased shear
→ Larger surface winds



Pressure gradient adjustment does not appear important but it may depend on the scale.

Frenger et al. (2013)

Mechanism II

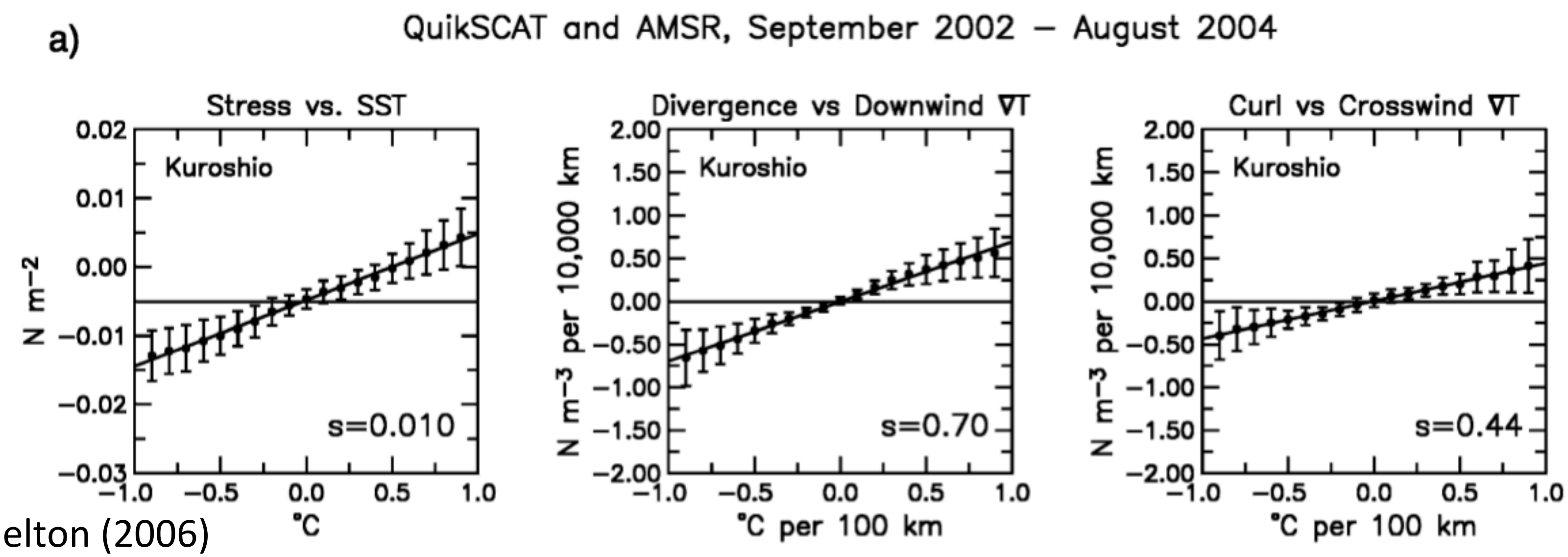


On the oceanic mesoscale:

$$\vec{u}' \propto T'$$

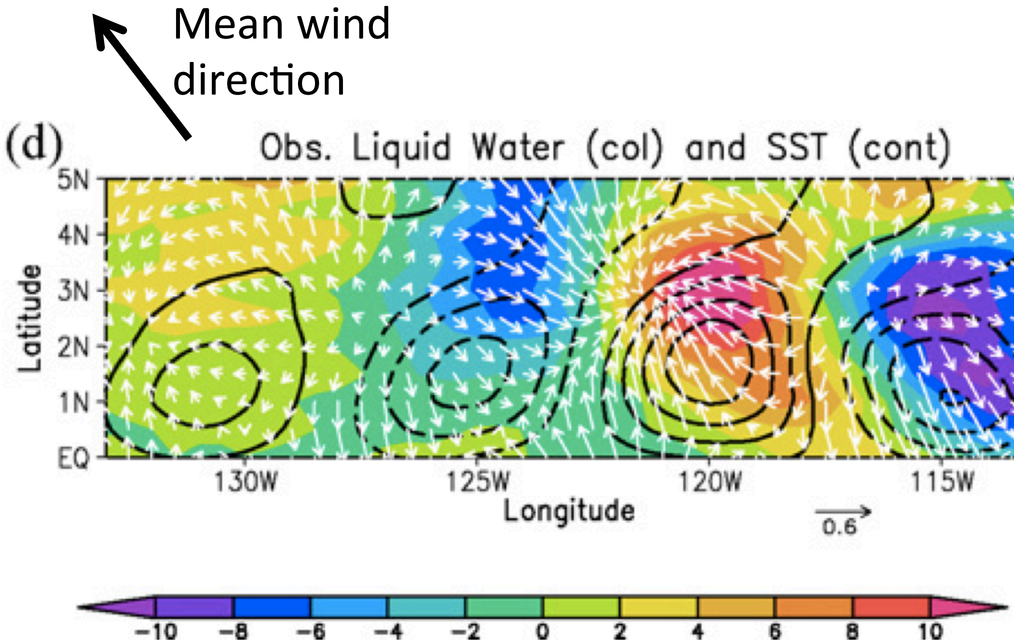
$$\nabla \times \vec{u} \propto \text{crosswind } \nabla T$$

$$\nabla \cdot \vec{u} \propto \text{downwind } \nabla T$$



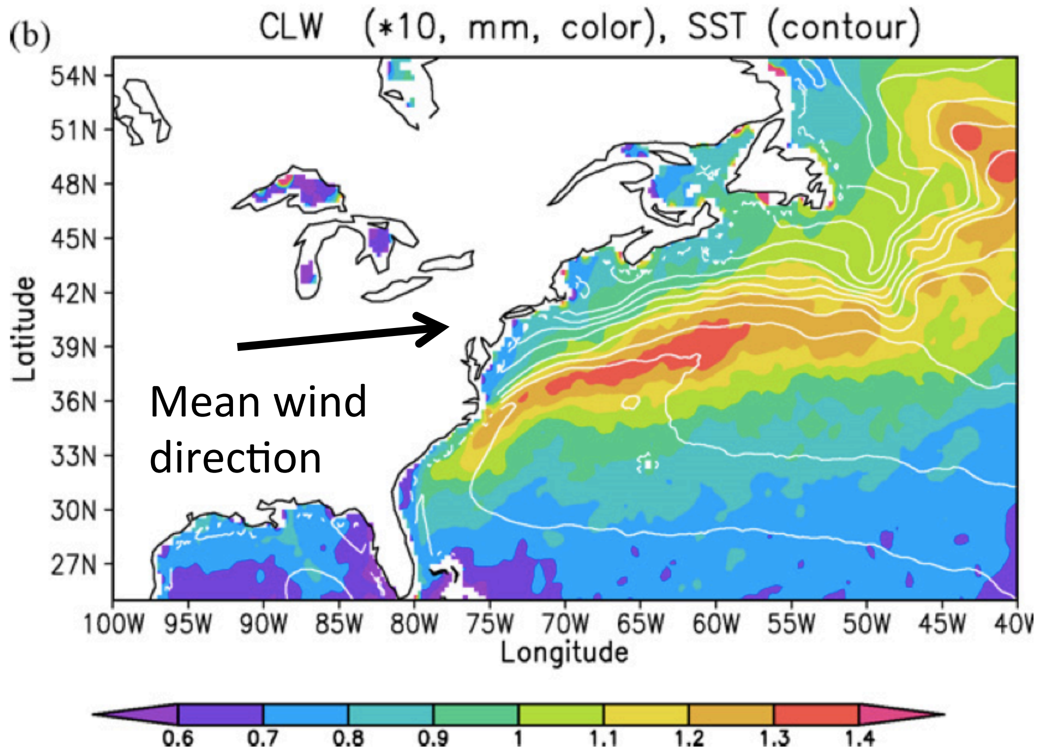
Maloney and Chelton (2006)

Contrast between transient mesoscale features and large-scale fronts



Composite of TIWs

3-year mean
over the Gulf
Stream

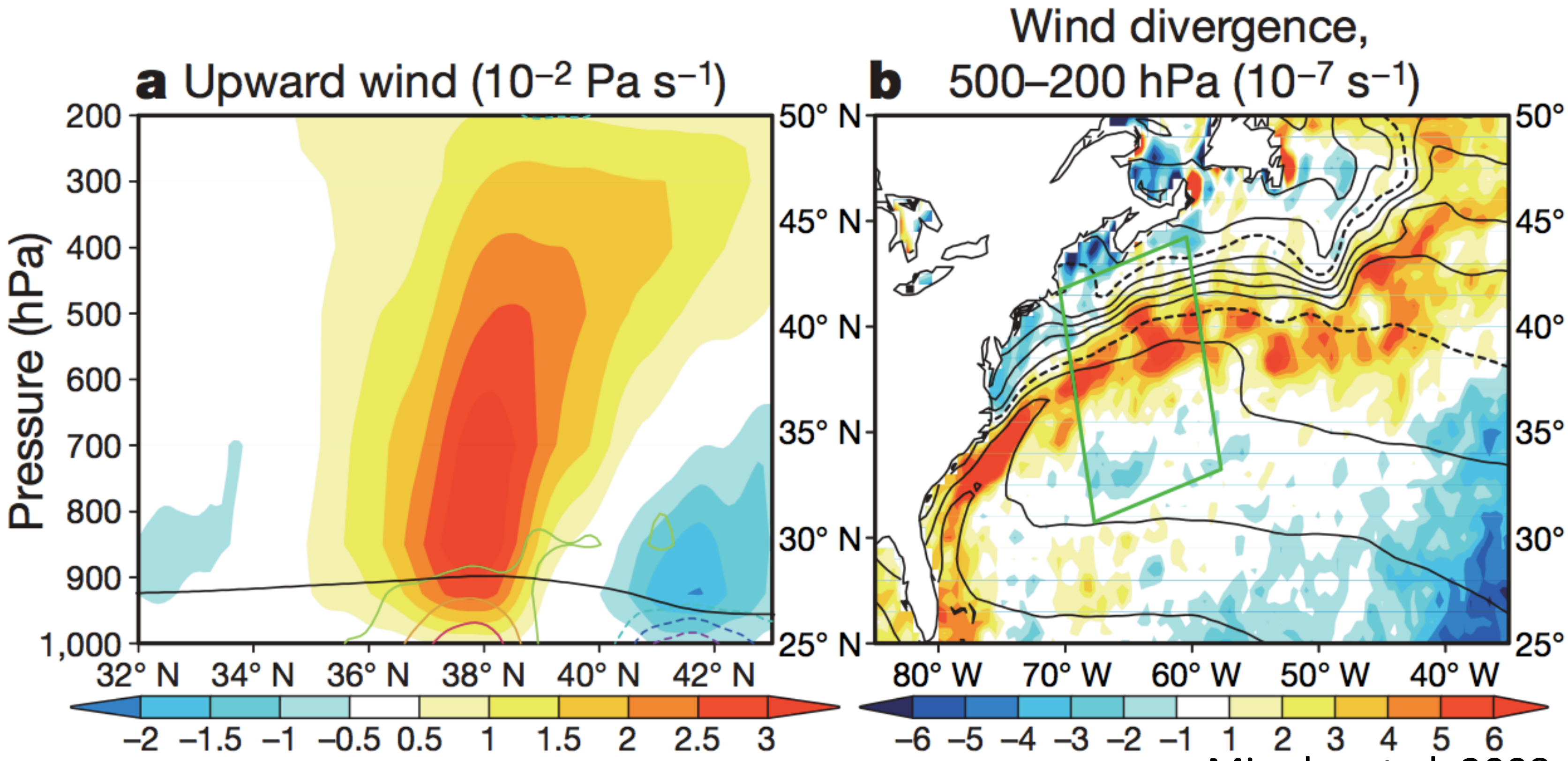


Small et al. (2008)

Effects on the free troposhere: fronts

- SST-induced convergence and divergence → drive vertical motion → *effect on free troposphere*
- Seen over the Gulf Stream (Minobe et al., 2008, Czaja and Blunt, 2011)
- Underestimation of tropospheric response to SST anomaly

ECMWF reanalysis

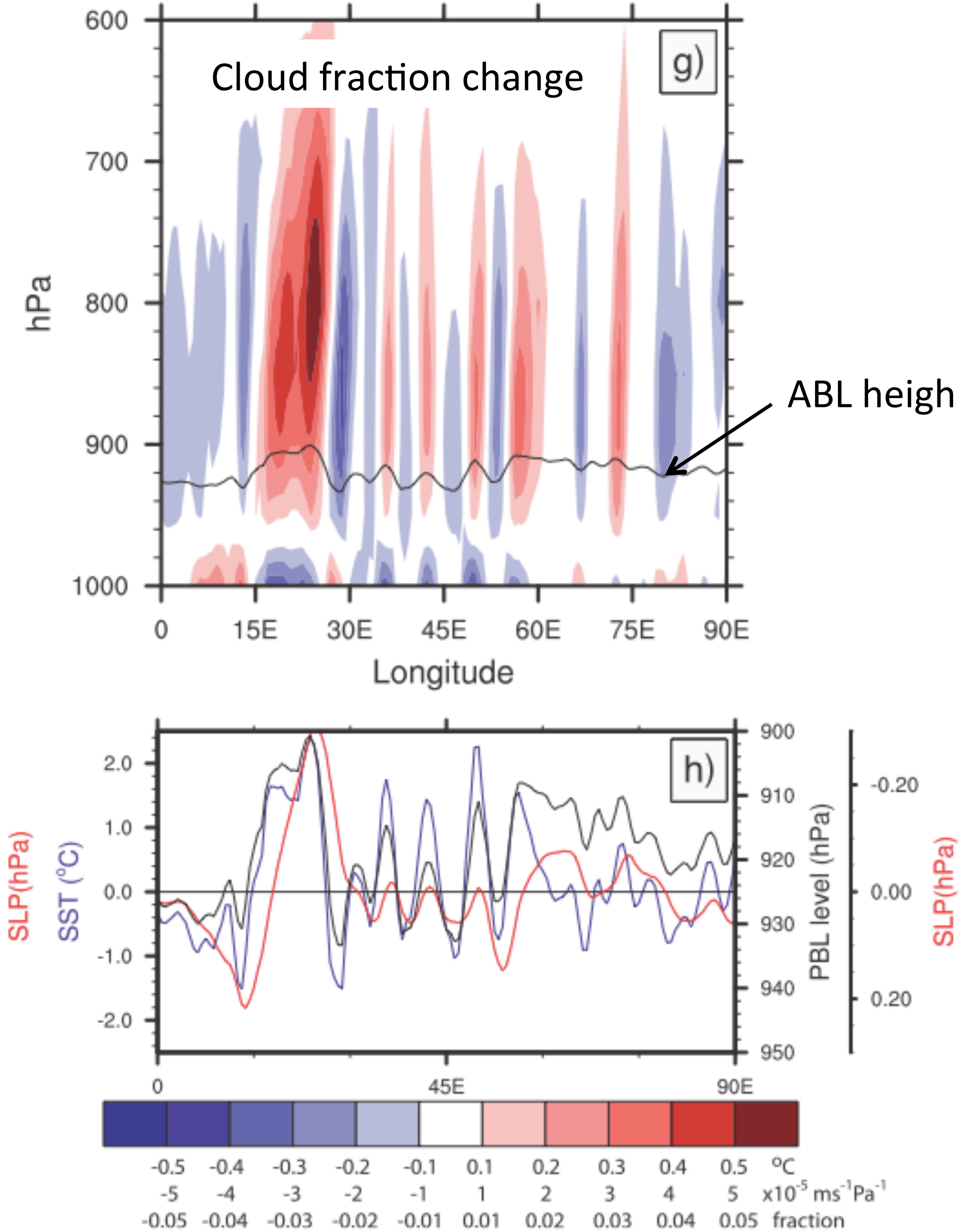


Minobe et al. 2008

Effects extend into the free troposphere: mesoscale eddies

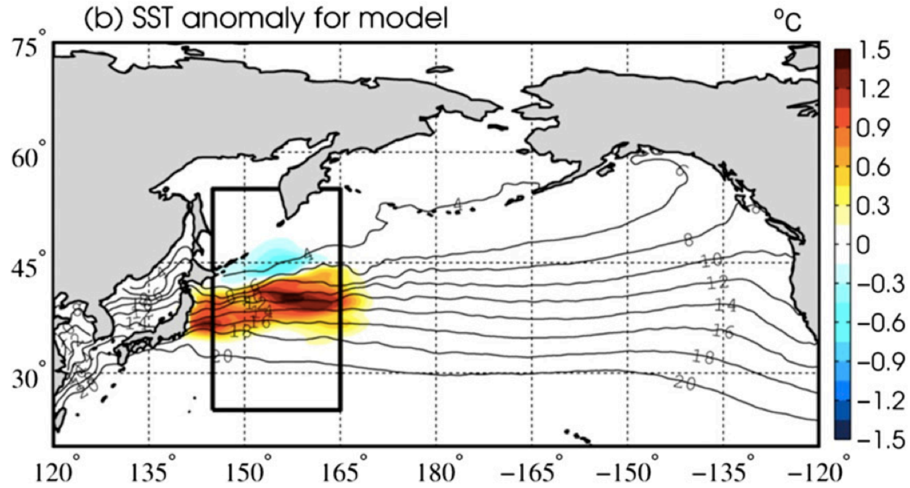
→ Net effects beyond the marine boundary layer are beginning to be seen in modelling studies (e.g., Bryan et al., 2011)
ex: all sky planetary albedo

→ If anything, a substantial source of variability at small/short scale (requires *both* models at high-res)



Effect of Western Boundary Current variability on the atmosphere: contrasting resolutions

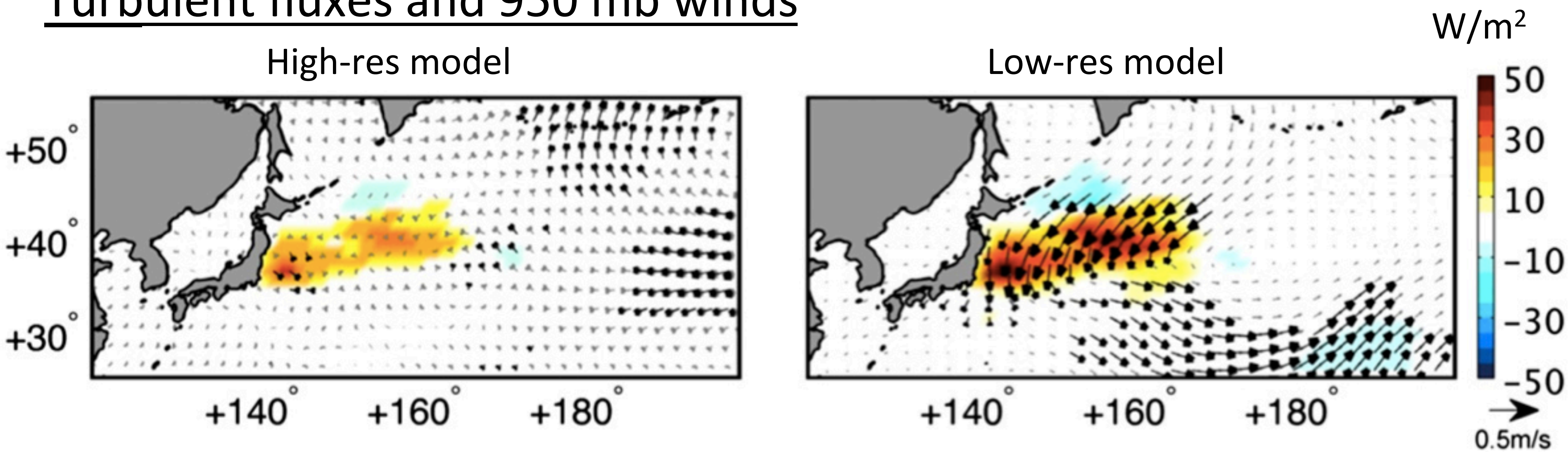
Prescribed SST anomaly



Turbulent fluxes and 950 mb winds

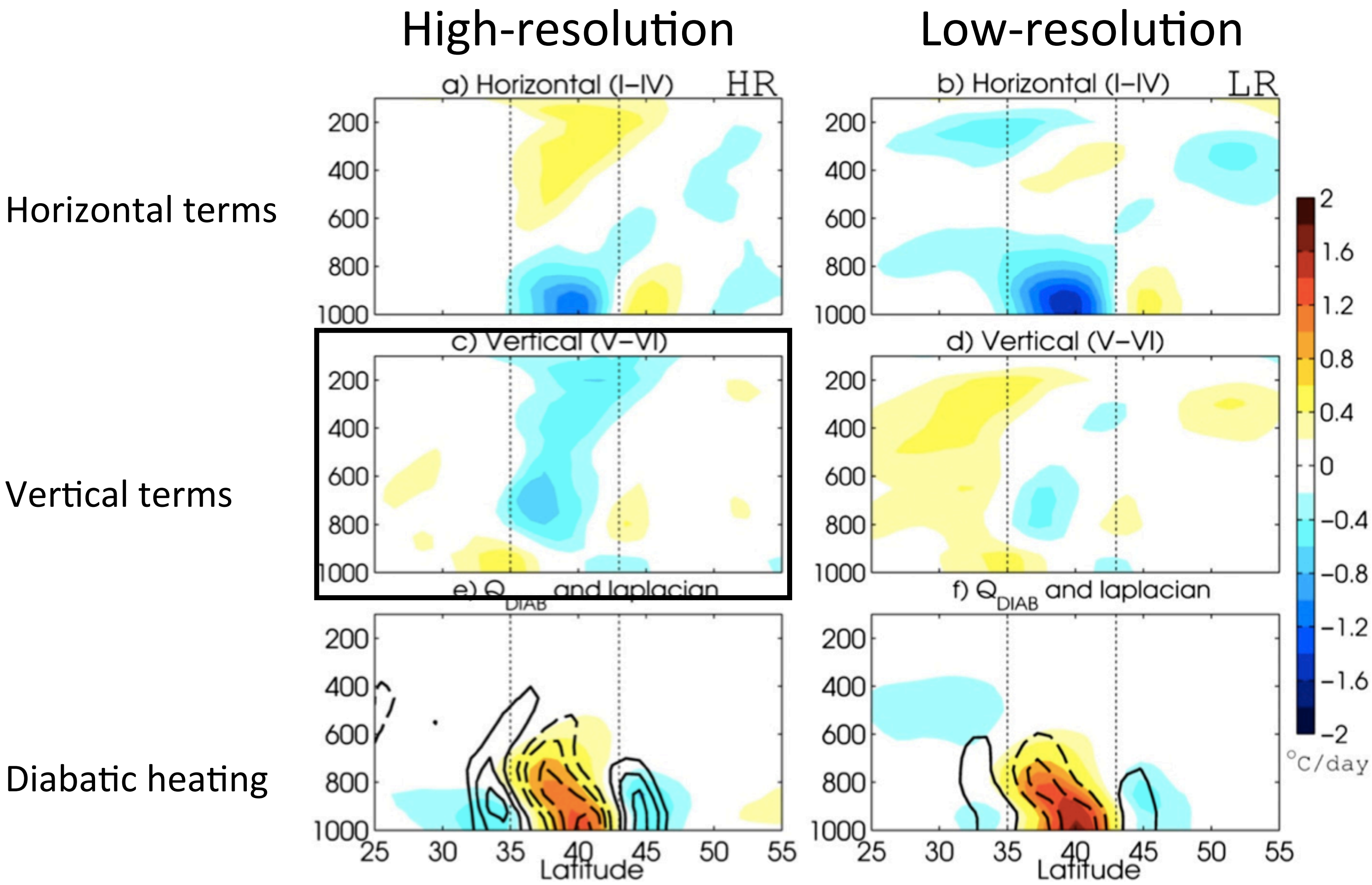
High-res model

Low-res model



Smirnov et al. (2015)

Heat balance: changes fundamentally with resolution

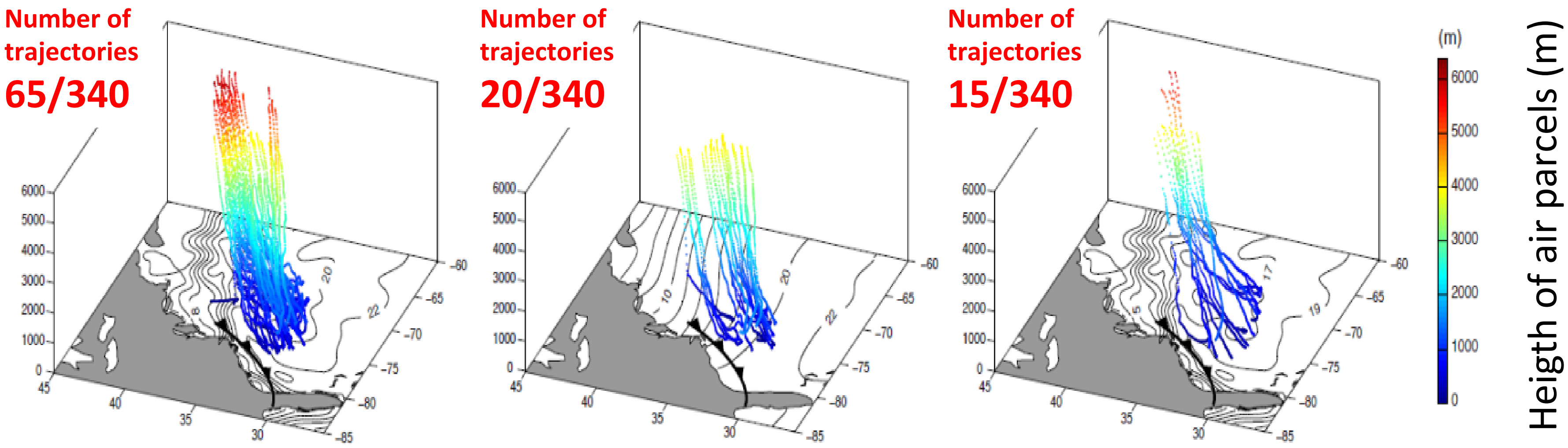


- SSTA directly impact transient eddies, rather than the large-scale atmospheric flow (transient eddies being a feedback)

Smirnov et al. (2015)

Vertical, rather than horizontal, flows

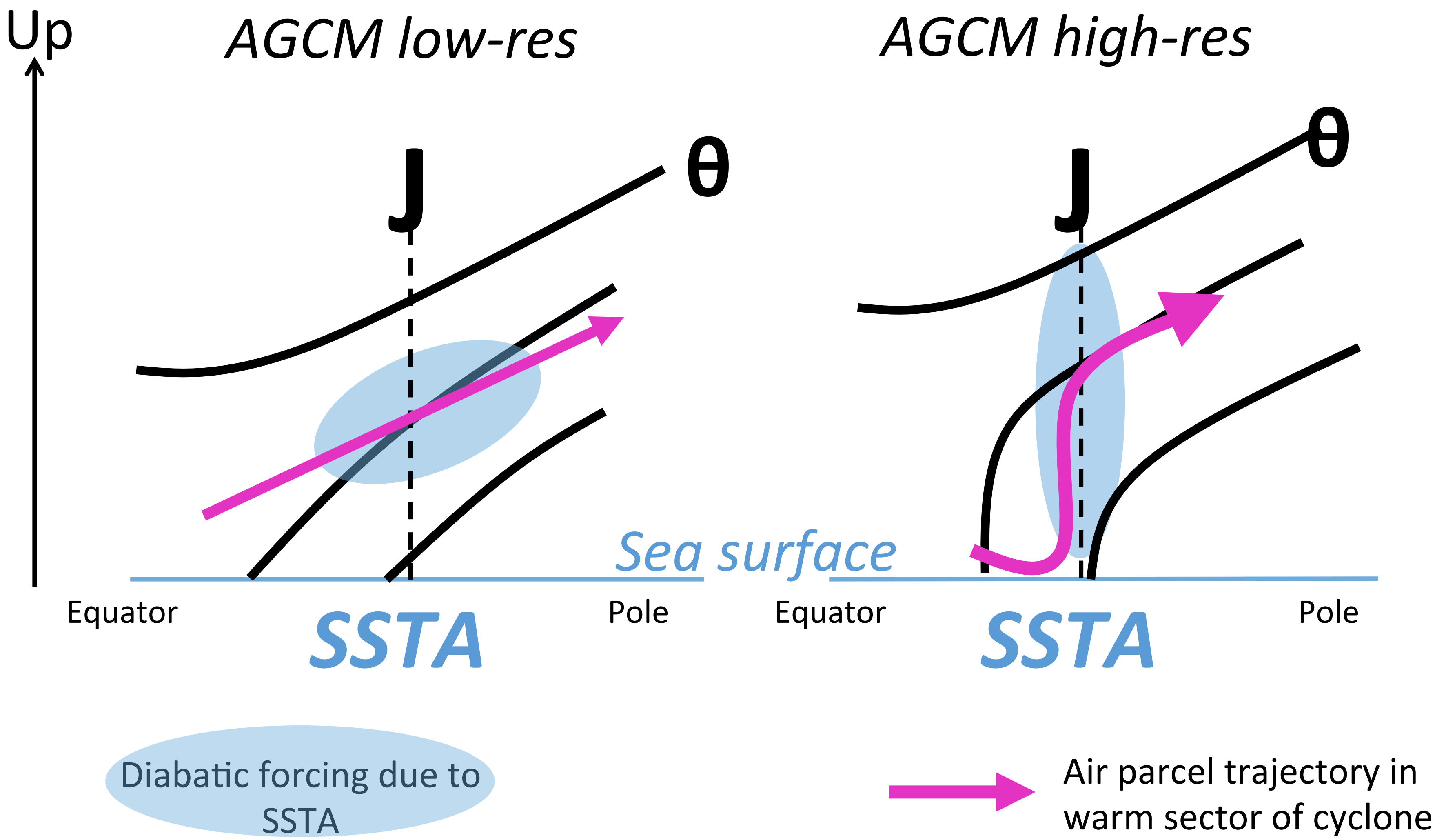
- Oceanic variability can impact the atmospheric storm-track in models of ***sufficiently high atmospheric resolution*** (Smirnov et al., 2015; Sheldon et al., 2016)
- The mechanism involves a modulation of the frontal circulation of cyclones by the underlying SST distribution



Realistic SSTs ***Smoothed SSTs*** ***Realistic SSTs -3K***

Back-trajectories from a simulation of a cyclone with the Met-UM at 12km resolution (Sheldon et al. 2016)

A new paradigm?



Arnaud Czaja (Imperial College)

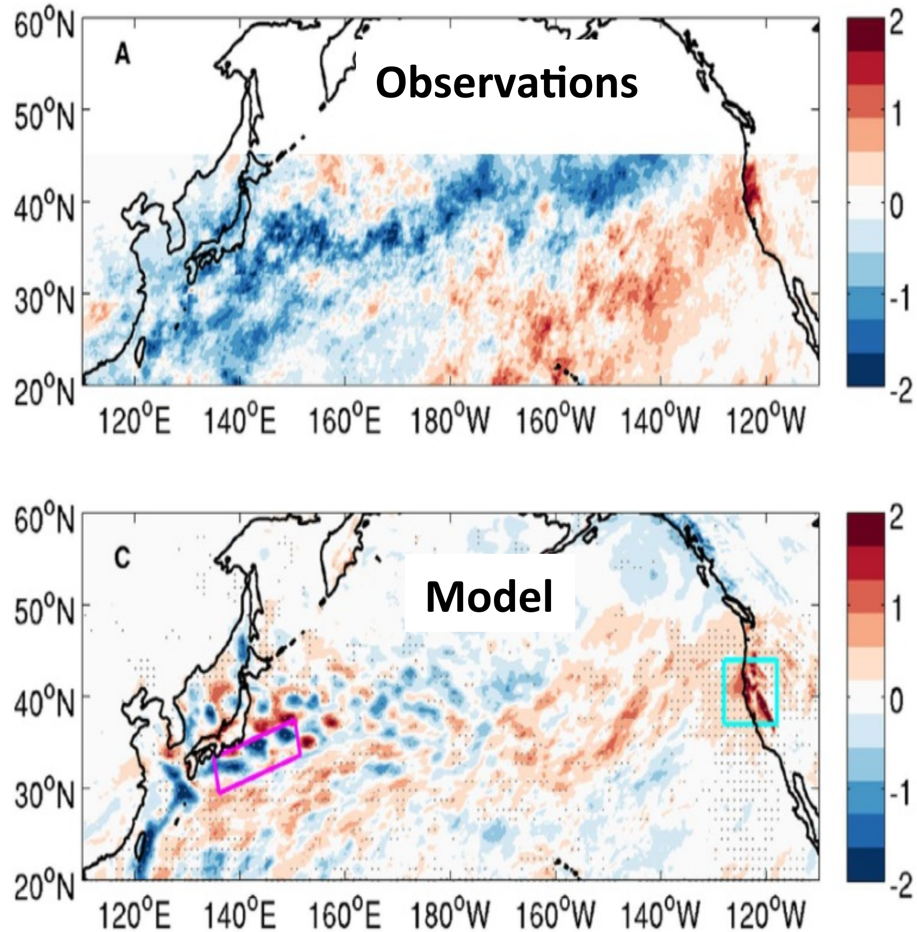
(Remote) Impact of ocean eddies on atmospheric precipitation

- US rainfall influenced by the presence of mesoscale eddies: rectifier effect of mesoscale SST on diabatic heating suggested

Precipitation anomalies (mm/day)

TRMM: five "eddy rich – eddy poor" Kuroshio In NDJFM

CTRL-SMOOTHED SST runs In NDJFM



Ma et al. (2015)

Conclusion

- Observations point to strong air-sea coupling on the oceanic mesoscale: fronts, eddies,

- Coupling/predictability: a shift of focus away from large-scale modes of variability (NAO, THC) at least in the extratropics,

- Impact of small scale SST variability on atmospheric circulation differs from the “old” paradigm (e.g. Kushnir et al. 2002)
  - Impact vertical, rather horizontal, flow
  - Directly impact storm tracks, rather than large-scale flow

- Growing literature on this topic: Smirnov et al. (2012, 2015), Xu et al. 2010, Jclim, Small et al. (2014), Nakamura et collaborators, and others

- New emerging concepts/dynamics but still no clear evidence that increased resolution leads to more skillful prediction