Ocean-Atmosphere interactions over mesoscale features: Impact on atmosphere at larges scales?

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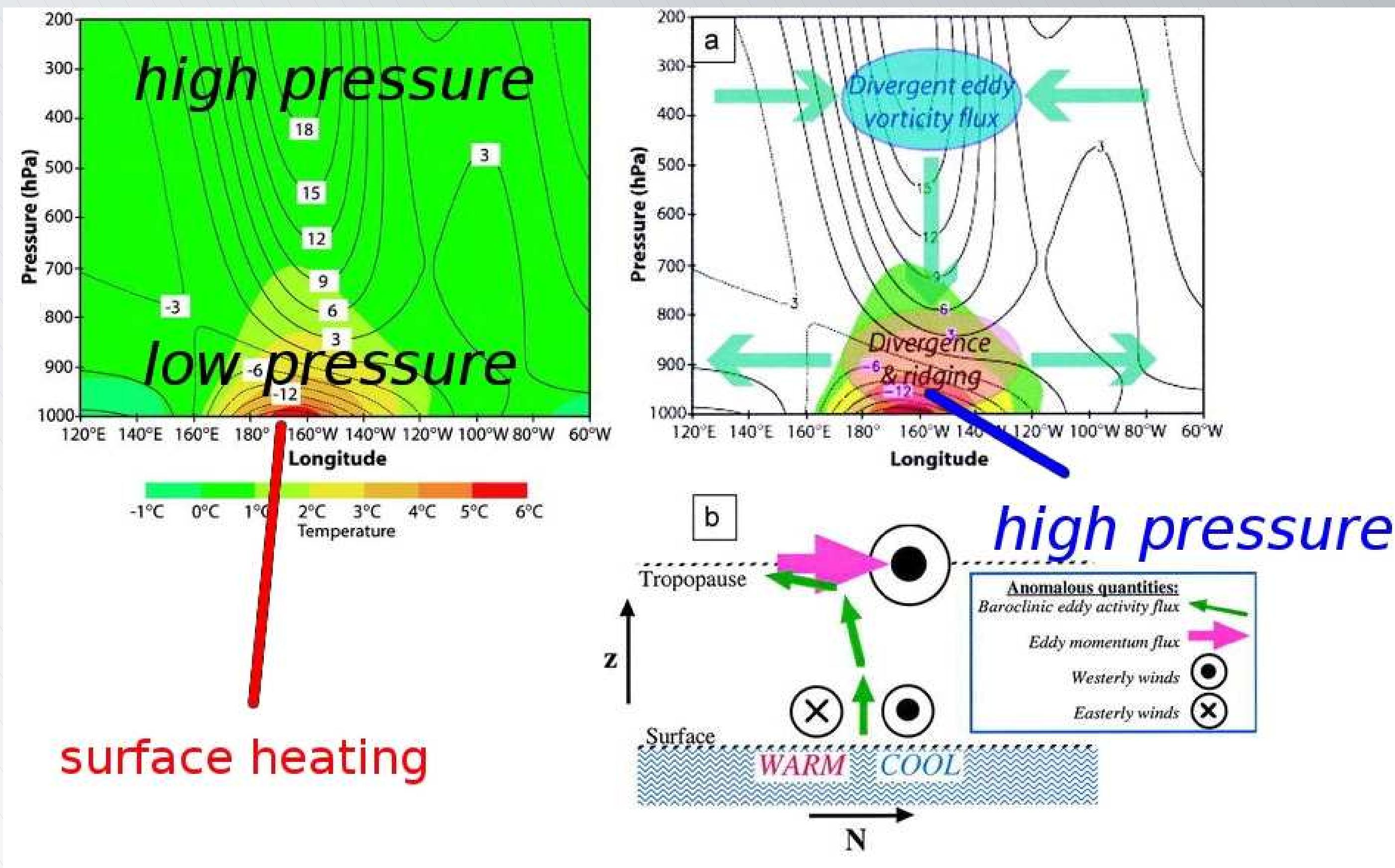
Effects of SST anomalies on the large-scale atmospheric circulation at midlatitudes have been studied since a long time

(e.g. reviews of Frankignoul 1985, Robinson 2000, Kushnir et al. 2002)



- first, a baroclinic atmospheric response to surface heating
- second, a barotropic response through eddy fluxes

State of the art before 2000

Numerous studies on the effect of midlatitude SST anomalies:

- mostly confined to the marine atmospheric boundary layer (discussed in previous talk by Larry O’Neill)
- weak response of the upper troposphere (Kushnir et al. 2002, Ferreira and Frankignoul 2008)
- tropical SST anomalies are responsible of a much stronger midlatitude atmospheric response (Held et al. 2002)

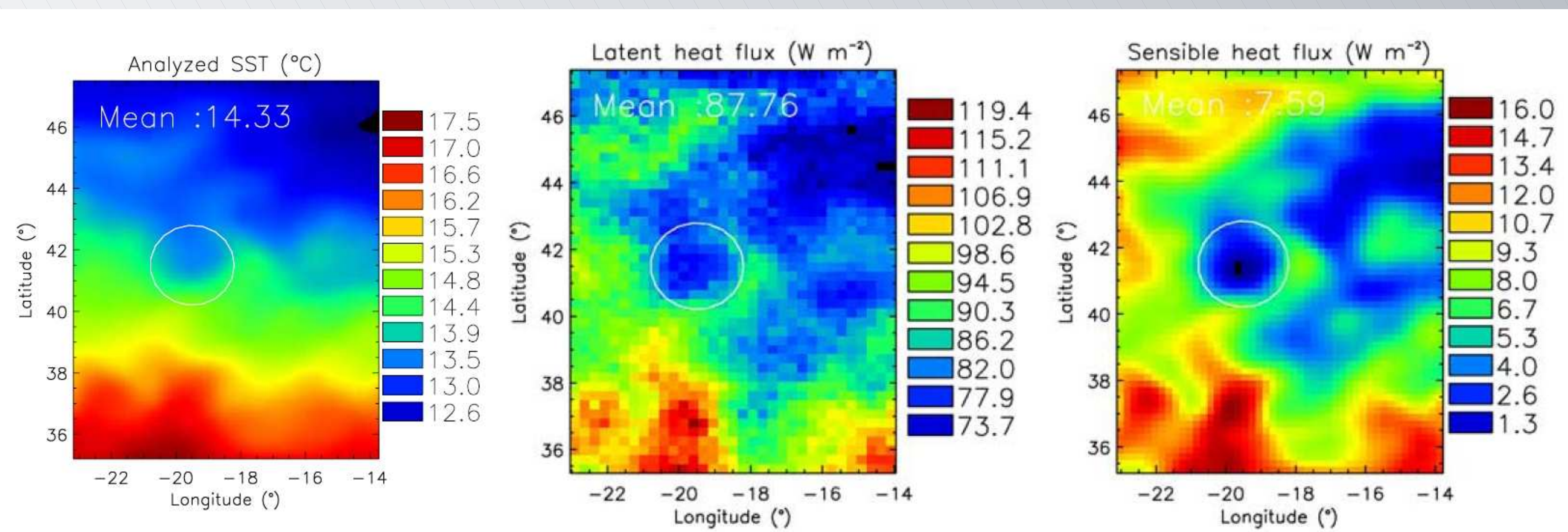
Important limitation of studies before 2000:

- low spatial resolution of numerical models (less than 300km for the atmosphere)

Oceanic mesoscales and atmospheric boundary layer processes

Impact of mesoscales on both turbulent fluxes and surface winds mostly detected through satellite observations

(Chelton et al. 2004, Small et al. 2004, last talk of L. O'Neill)



observations during POMME experiment (in North-East Atlantic), air-sea fluxes modified over a cold cyclonic eddy (Bourras et al. 2004)

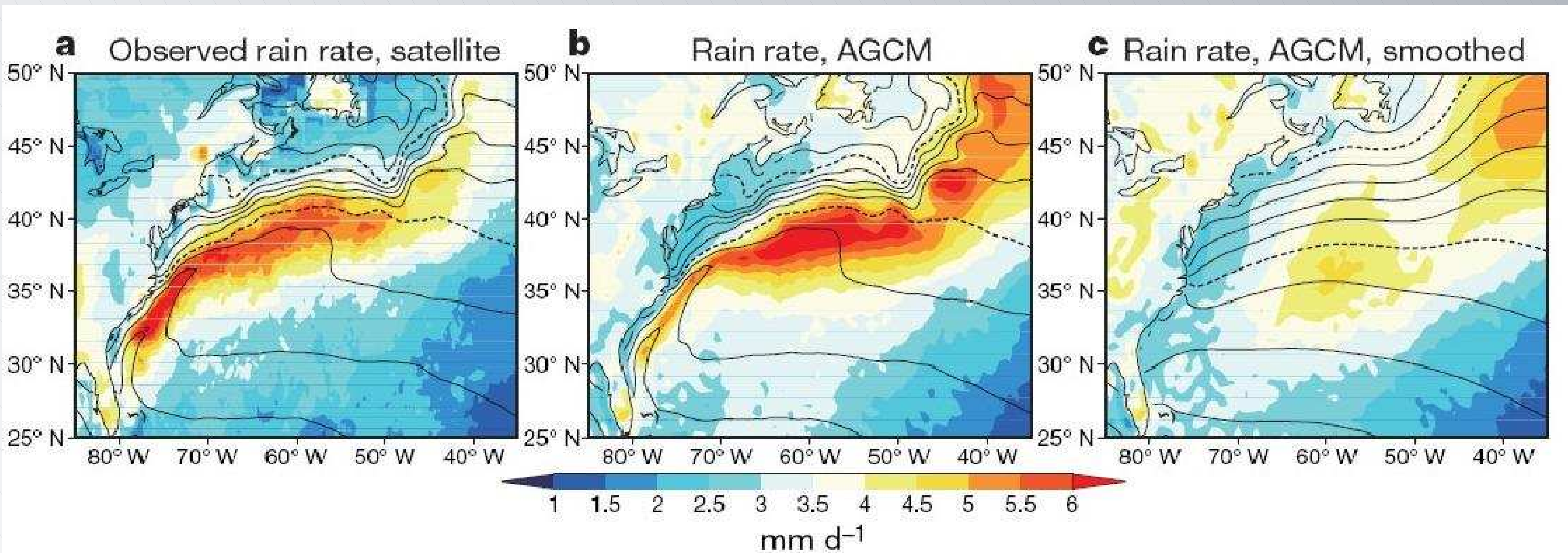
Deep atmospheric response to oceanic mesoscales?

Since 2000, new evidence from numerical models and observations that the atmospheric response to oceanic mesoscales, such as SST fronts associated with Western Boundary Currents, is not confined to the MABL but extends to the free atmosphere up to the tropopause:

- Collocation of atmospheric storm-tracks with SST fronts such as Kuroshio, Gulf Stream, ACC (Nakamura et al. 2004, Deremble et al. 2010)
- Rainwall anchored on the warm side of SST front of the Gulf Stream (Minobe et al. 2008)
- Atmospheric temperature can be affected by persistent (over months) SST anomalies induced by Agulhas Extension Meanders (Liu et al. 2007)

What matters most is the SST gradient and not the SST anomaly

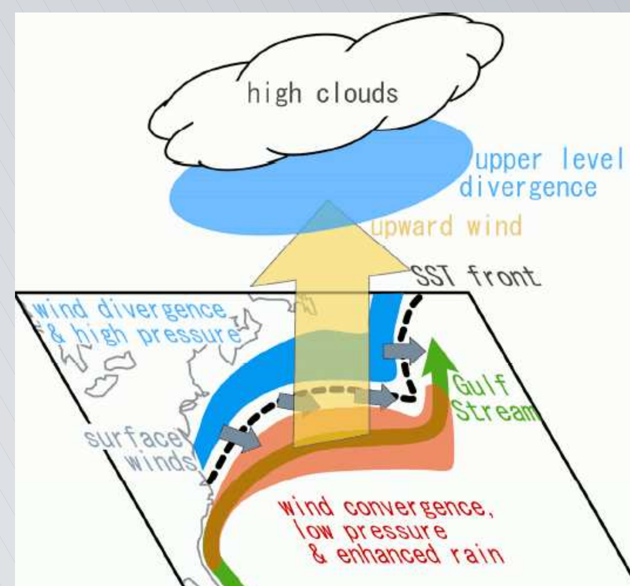
Impact of SST fronts



high-resolution atmospheric model forced by SST

(Minobe et al. 2008)

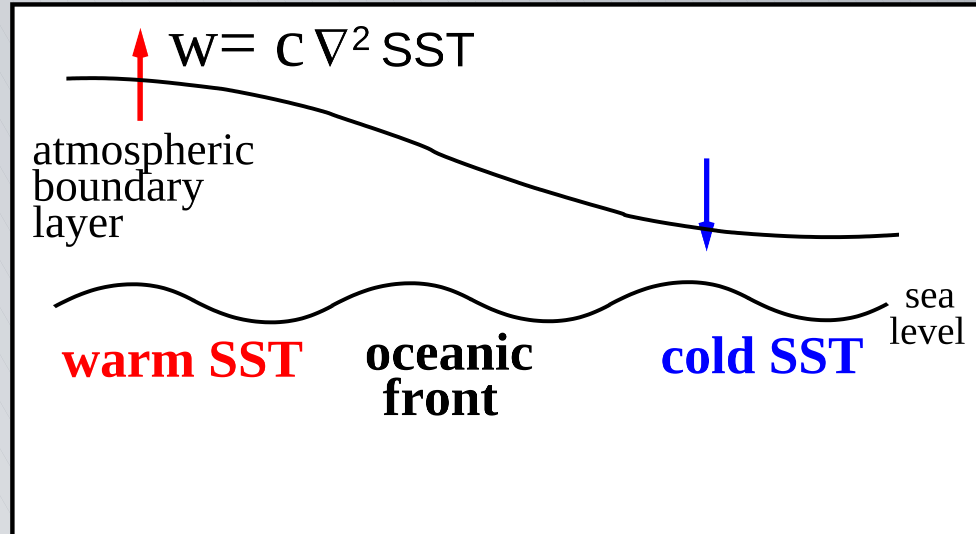
⇒SST gradients localize rain wall



Mechanisms

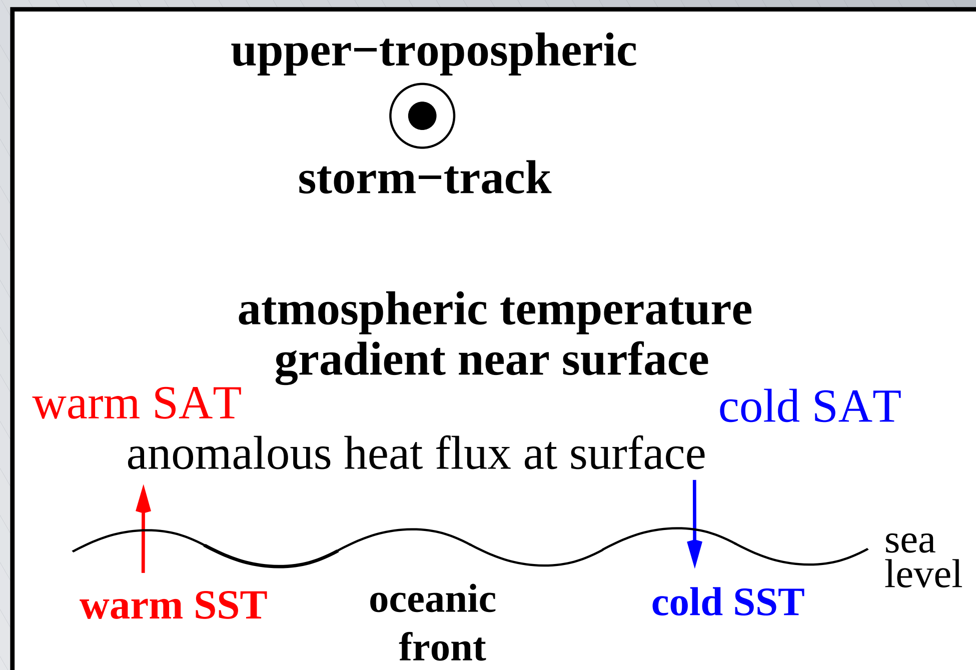
low-level wind convergence due to SST and Atmospheric Boundary layer (MABL)

(Lindzen and Nigam, 1987, Feliks et al. 2004, Minobe et al. 2008)



oceanic baroclinic adjustment: SST gradient ⇒ SAT gradient⇒storm-track

(Nakamura et al. 2004)



Mechanisms for large-scale atmospheric influence

Midlatitude SST gradients are responsible of

- Surface atmospheric wind convergence
  through boundary layer processes (Lindzen and Nigam, 1987)
- Surface atmospheric temperature gradients
  which impact the storm-track through baroclinic instability
  at least for large-scale oceanic currents
  (Nakamura et al. 2004)
- Moisture supply on the warm side of large-scale SST front
  which impacts the storm-track through latent heat release
  (Minobe et al. 2008, Deremble et al. 2010, submitted)

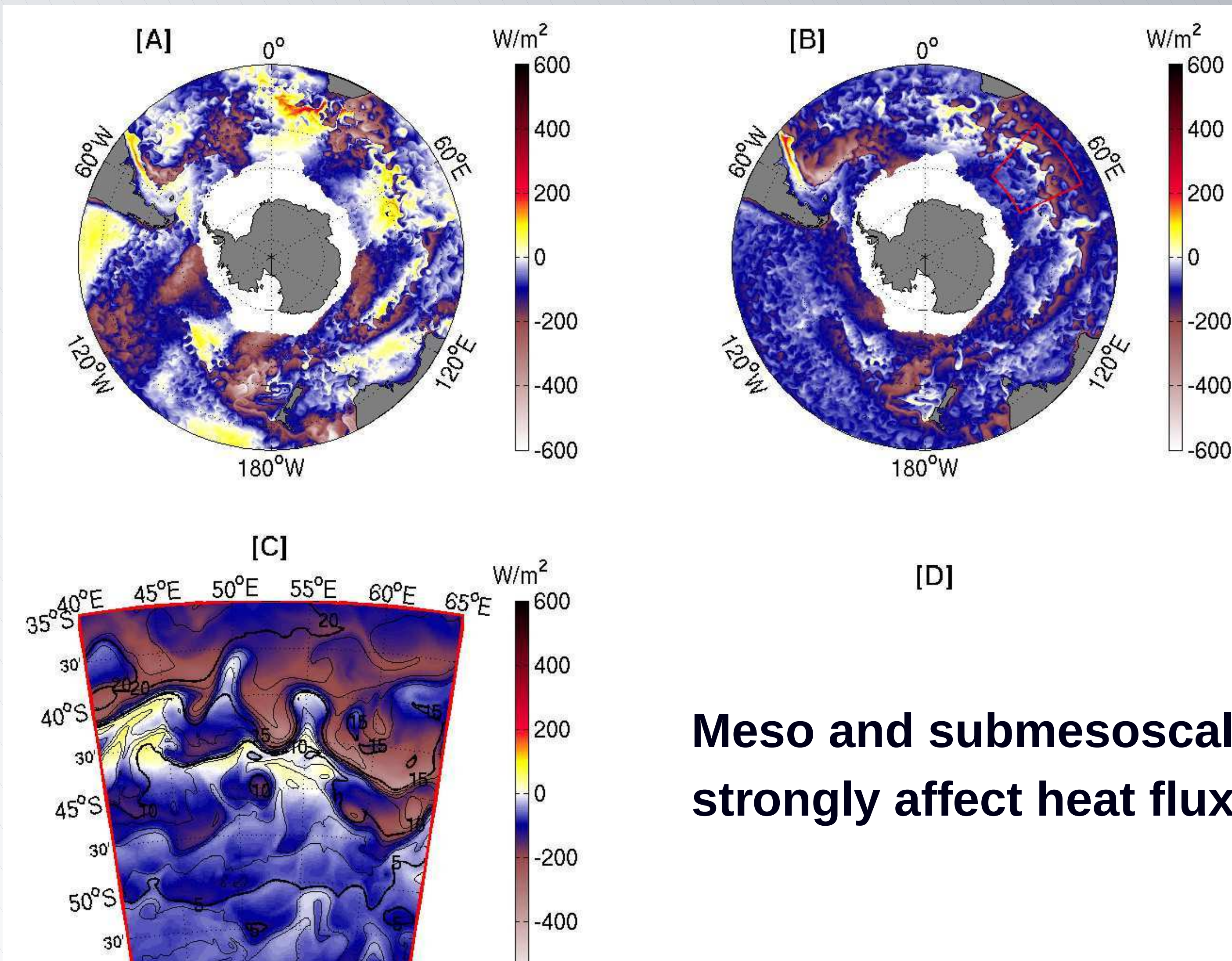
Possible impact of oceanic mesoscale eddies?

- Studies of Feliks et al. (2007) and Minobe et al. (2008) show that an atmospheric model needs a resolution at least of 50 km to represent the effect of midlatitude SST fronts
- Study by Deremble et al. (submitted) shows that only a SST front of at least **1 K/100 km** may impact the tropospheric storm-track

- Mesoscale eddies often have such SST variations
- Oceanic eddies are persistent (a few months)
  $\Rightarrow$ net effect on the atmosphere
- Air-sea coupling can also modify oceanic eddy dynamics

Surface heat fluxes in a simulation (Shuckburg et al. submitted)

A: a snapshop of a daily surface heat flux   B and C: monthly mean



Meso and submesoscales strongly affect heat fluxes

(forced ocean by NCEP reanalysis)

Possible impact of oceanic mesoscale eddies?

Strong modulation of air-sea fluxes by eddies and submesoscales through heat content of oceanic surface layer:

- SST anomalies (eddies)
- mixed layer depth (eddies and submesoscale filaments)

Some personal guesses:

- Impact of air-sea interactions on large-scale atmosphere depends on spatial heterogeneity of SST gradients
  (one large-scale front vs numerous submesoscale fronts)
- The atmospheric surface wind convergence induced by oceanic eddies may provide enhanced atmospheric variability
- Water vapor supplied by warm surface oceanic eddies may strengthen the coupling with the tropospheric storm-track

Impact of air-sea coupling on ocean mesoscales

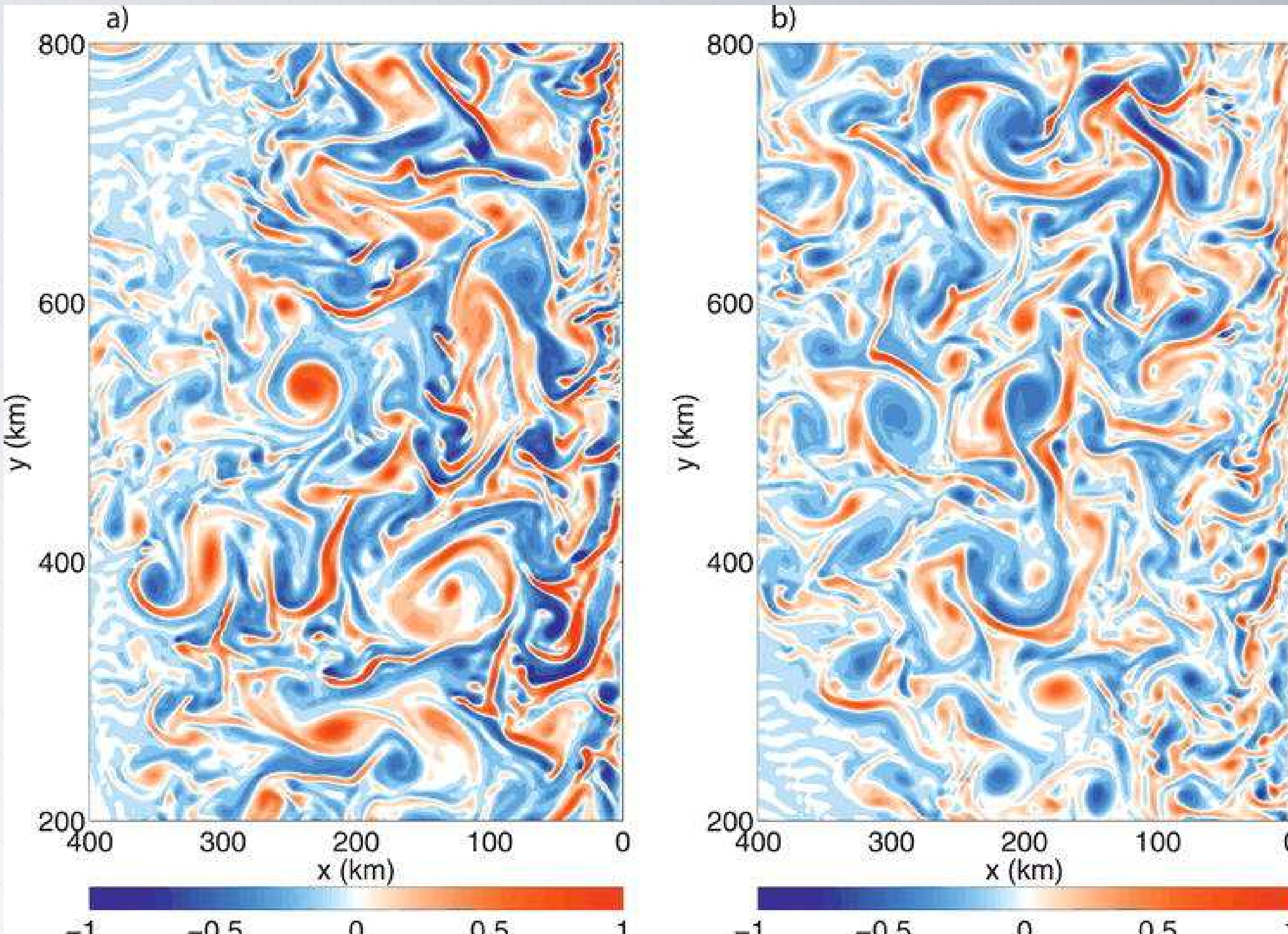
Ocean forced through

- surface heat fluxes
- Ekman transport (winds)
- wind-driven mixed-layer deepening

- Potential vorticity injection into the ocean modulated by meso and submesoscales
  - may restratify or destratify the upper ocean (Thomas and Ferrari)
  - reduction of the usable wind-work on the general oceanic circulation (Thomas and Taylor, 2010)
- Near-inertial oscillations organised by mesoscales (Klein et al. 2003)
  - enhance small-scale oceanic mixing (Klein et al. 2004)

Ocean simulation with simple atmospheric boundary layer

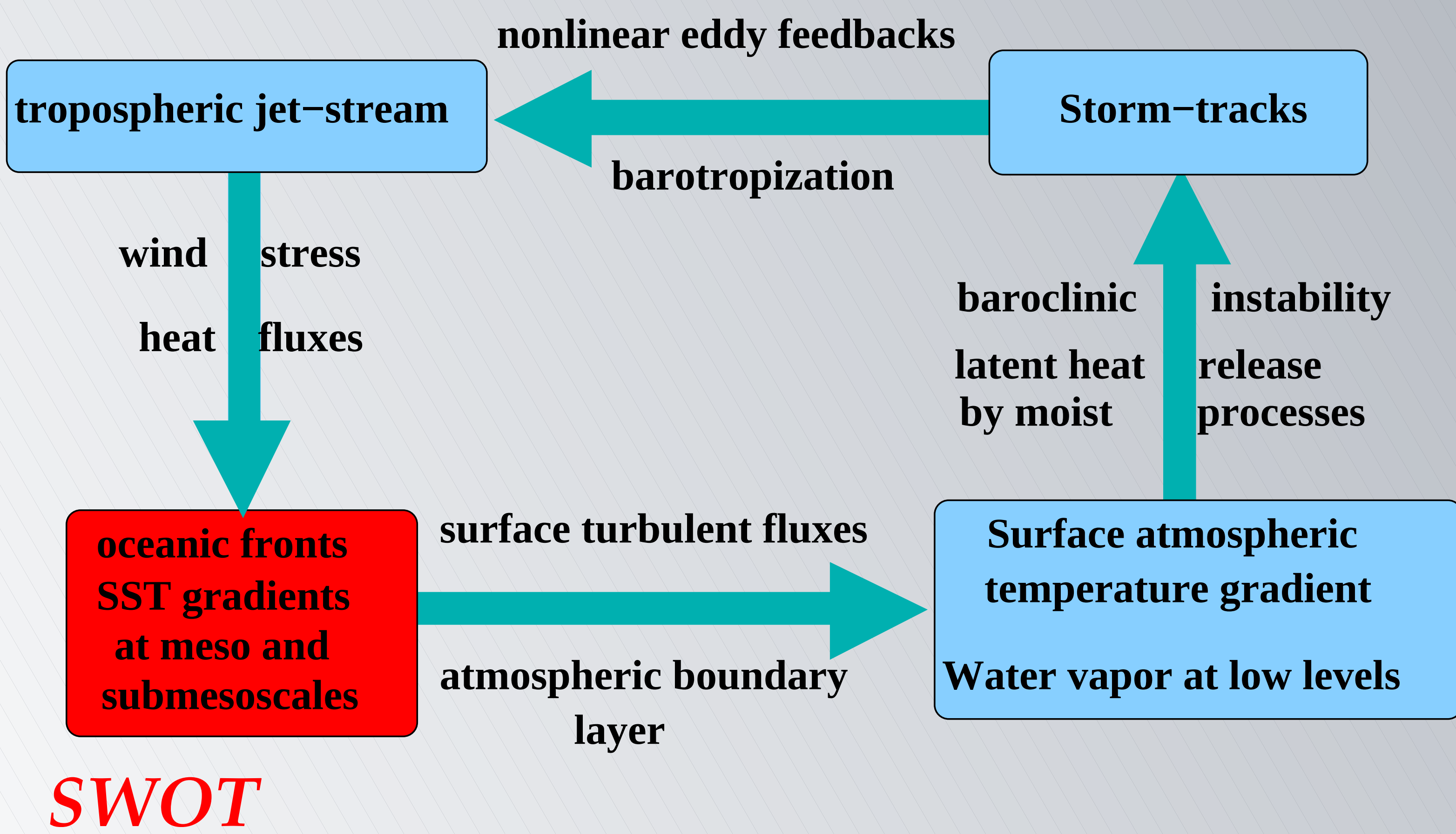
Relative vorticity ($/f_0$) at surface in two simulations (Jin et al. 2010)



without coupling   with air-sea coupling

$\Rightarrow$ **Air-sea coupling may favor oceanic anticyclones**

Conclusions



Storm life-cycle sensitive to SST

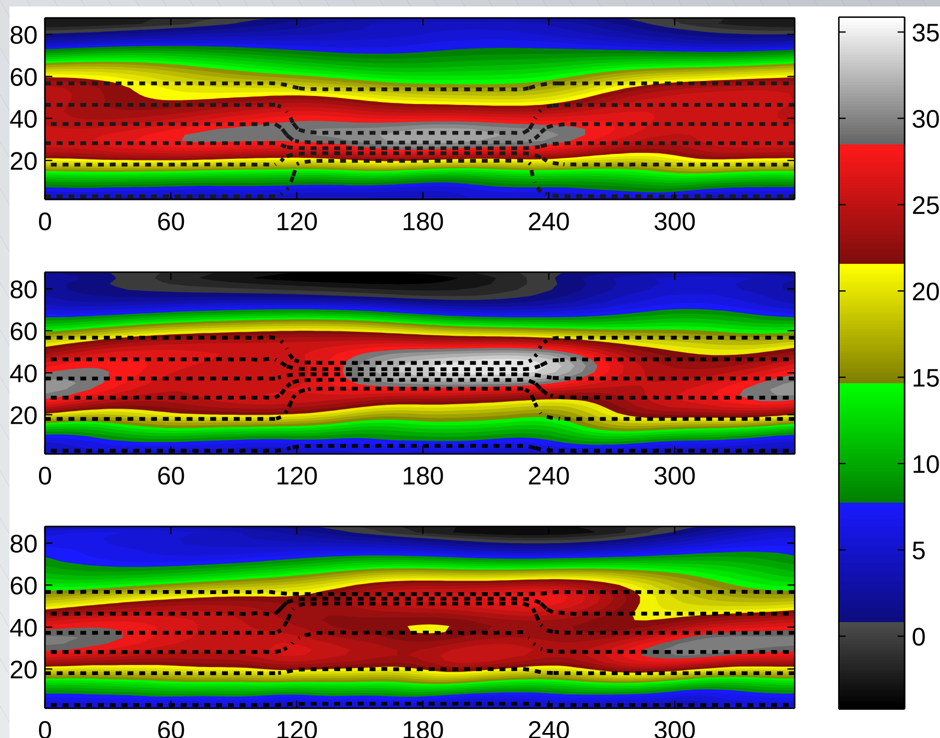
Doyle and Warner (1993): storm development and trajectory sensitive to SST resolution

Xie et al. (2002) and Thiebaux et al. (2003). Yamamoto and Hirose (2007)

Giordani and Caniaux

Jacobs et al. (2008): high resolution remotely sensed SST data affect the track by changing the location of lower-tropospheric frontal boundaries through thermally-induced near-surface convergence and differential turbulent heat flux

Impact of SST fronts

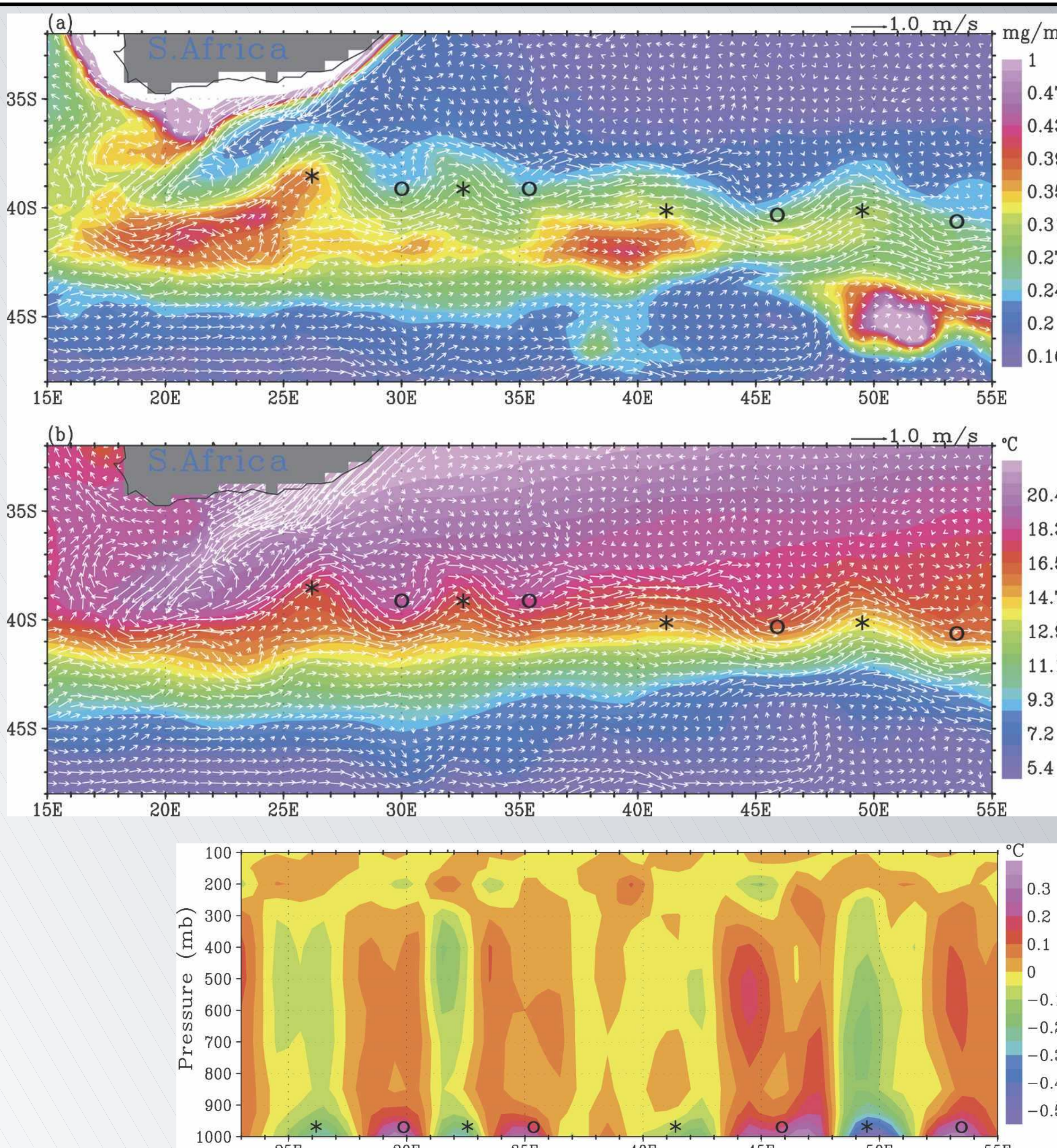


200 hPa zonal wind (in color) and SST contours (black and dash curve)

in 3 QG simulations with 3 different SST fronts

⇒ **Location of jet-stream and storm-track follows the SST front**

(Deremble et al. 2010 submitted)



(Liu et al. 2007)