The response of the Atmospheric Ekman Layer and Ekman Pumping to Sea Surface Temperature Fronts

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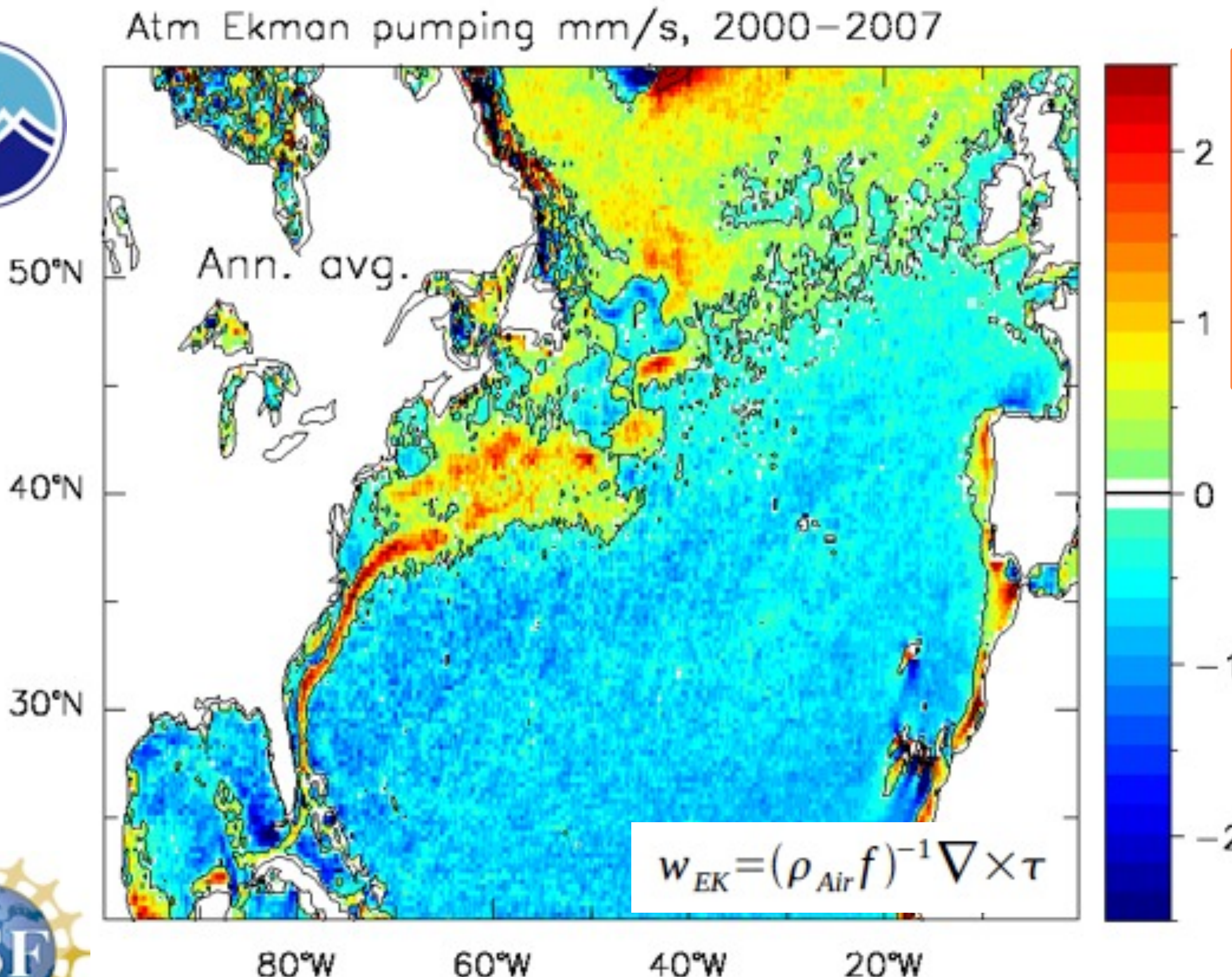


$$w_{EK} = (\rho_{Air} f)^{-1} \nabla \times \tau$$

stress = Quikscat pseudo wind stress times drag coefficient of 10^{-3}

U.S. DEPARTMENT OF ENERGY
"Ocean-Atmosphere-Interaction from Meso- to Planetary-Scale"
J. Small et al.

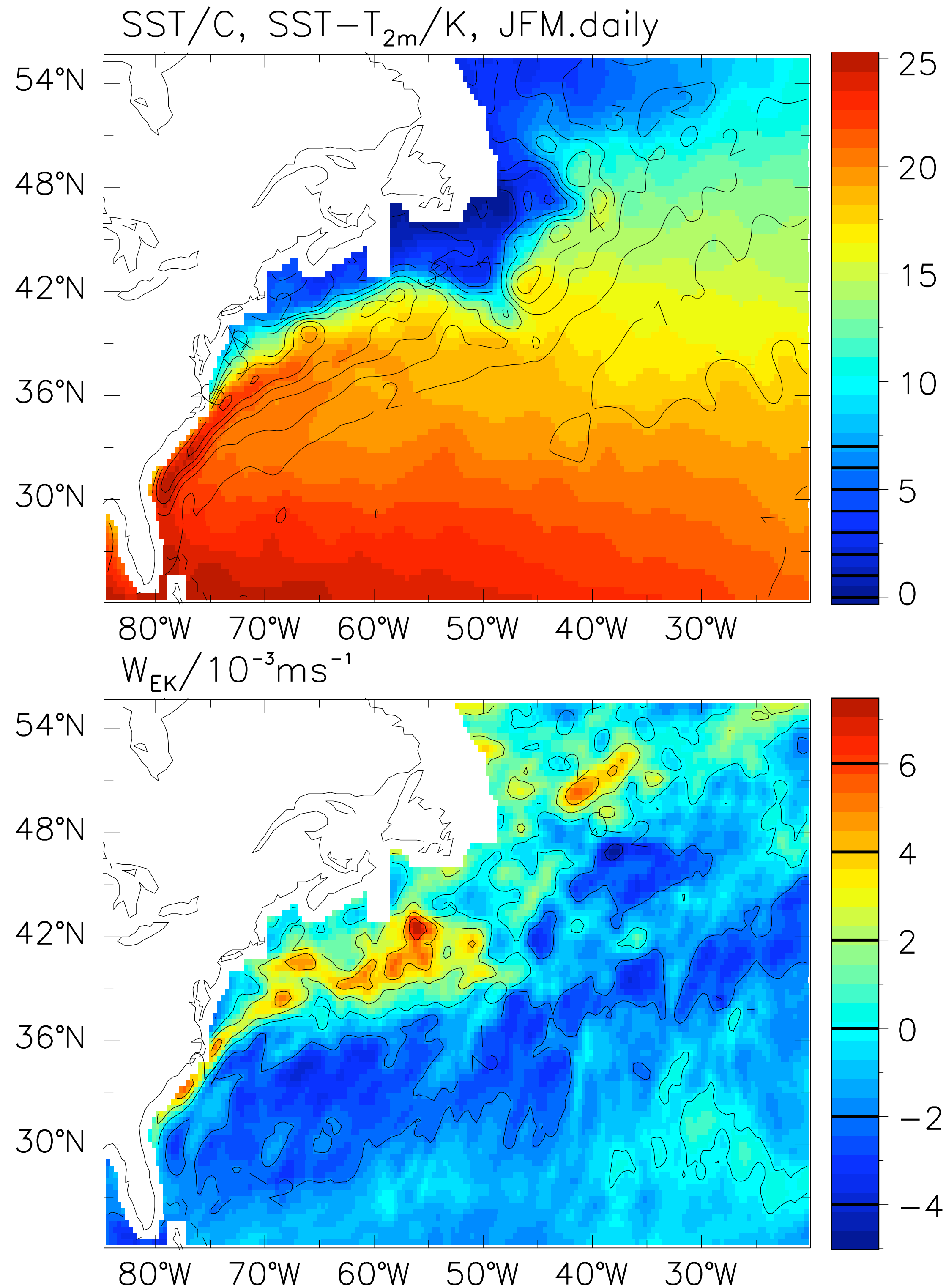
Impact of sharp SST fronts

Ekman layer
surface stress impacted by stability (Wallace et al. 1989) and by surface thermal wind (Feliks et al. 2004, Cronin and Kessler 2009)

Thermal boundary layer
Air-sea heat flux imprint SST front on near surface temperature and pressure gradients (Lindzen and Nigam 1987, Minobe et al. 2008)

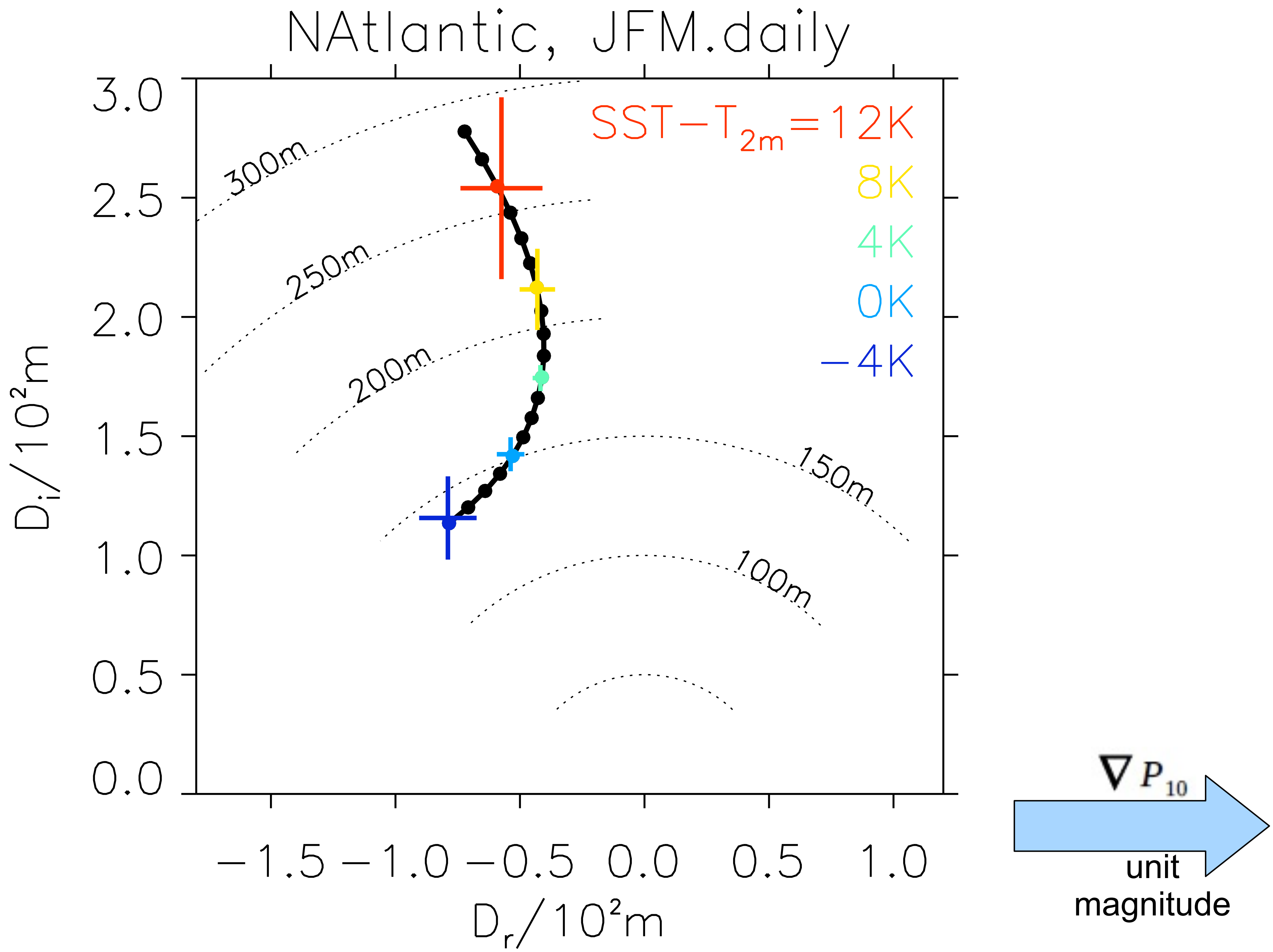
Spin-down
Ekman pumping displaces background stratification and adjusts surface pressure (Holton 1965)

- ECMWF operation analysis
- daily, January-March 2008
- TL799L91 resolution of model (20km). gridded to 1/3°x1/3°

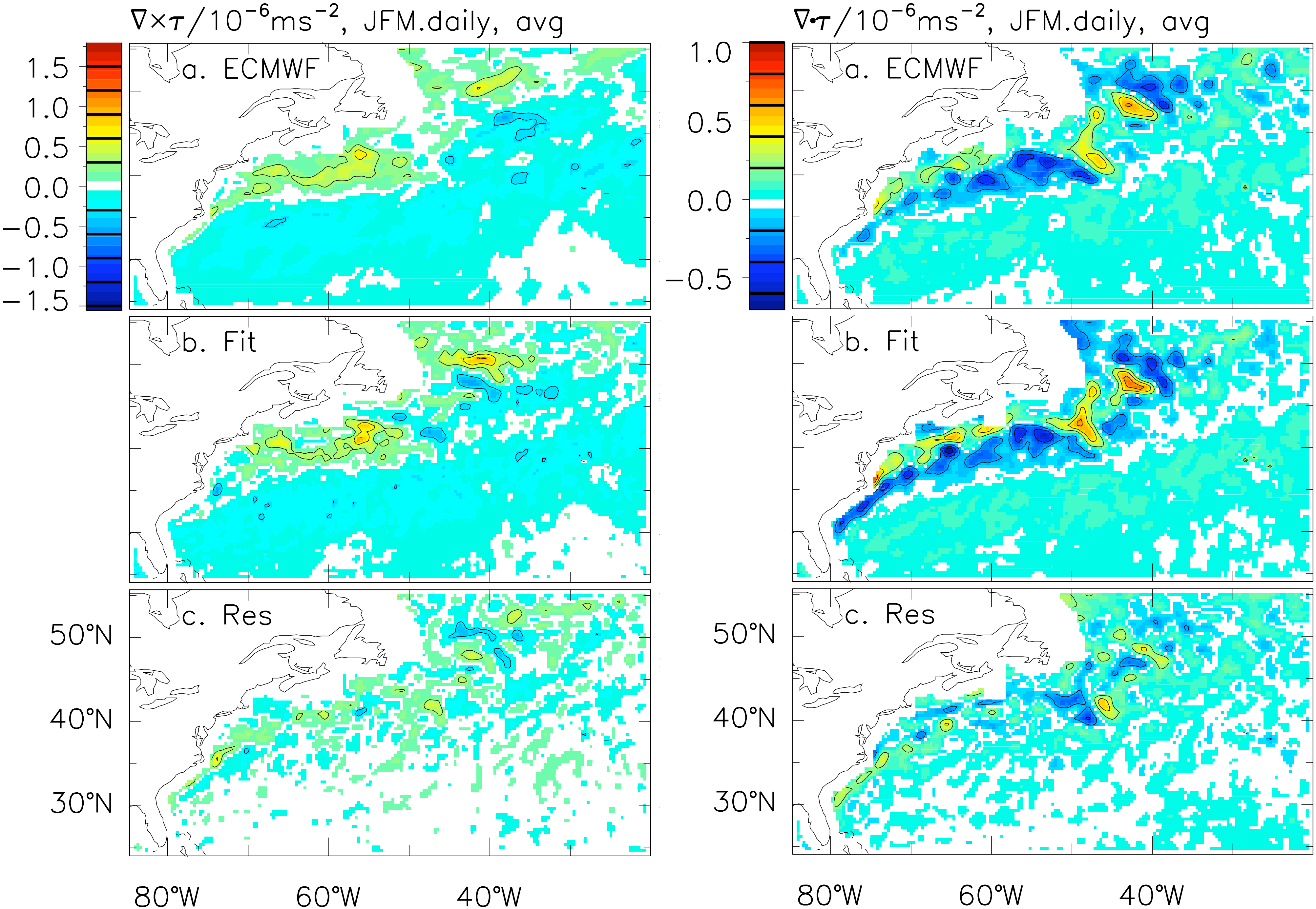


Ekman momentum balance

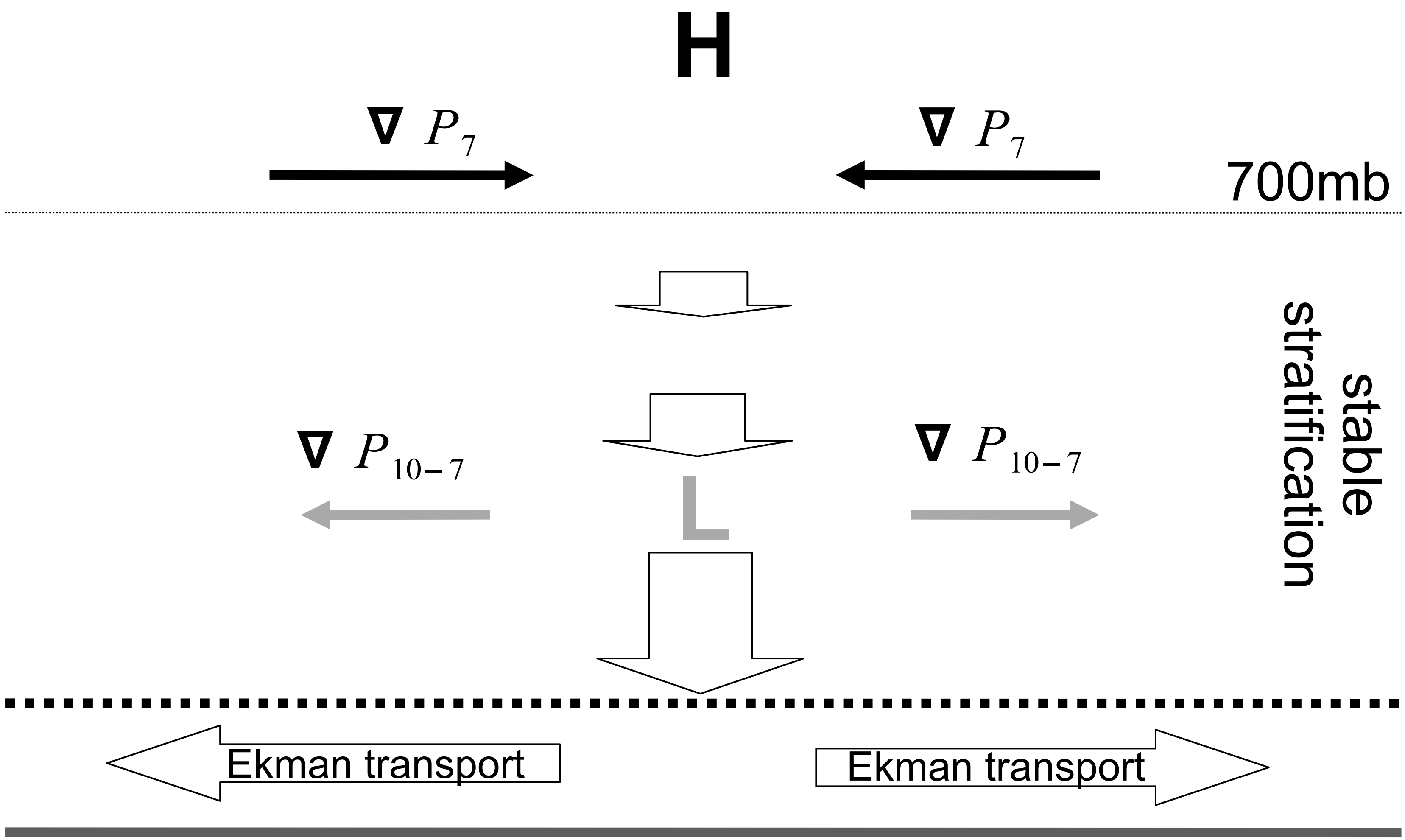
$$P_{10}^{-1}\boldsymbol{\tau} = \boldsymbol{D}\nabla \ln P_{10} + \boldsymbol{D}\boldsymbol{E}\nabla \ln T_{2m} + \ldots$$



Seasonal averages of wind stress curl and divergence



Spin-down



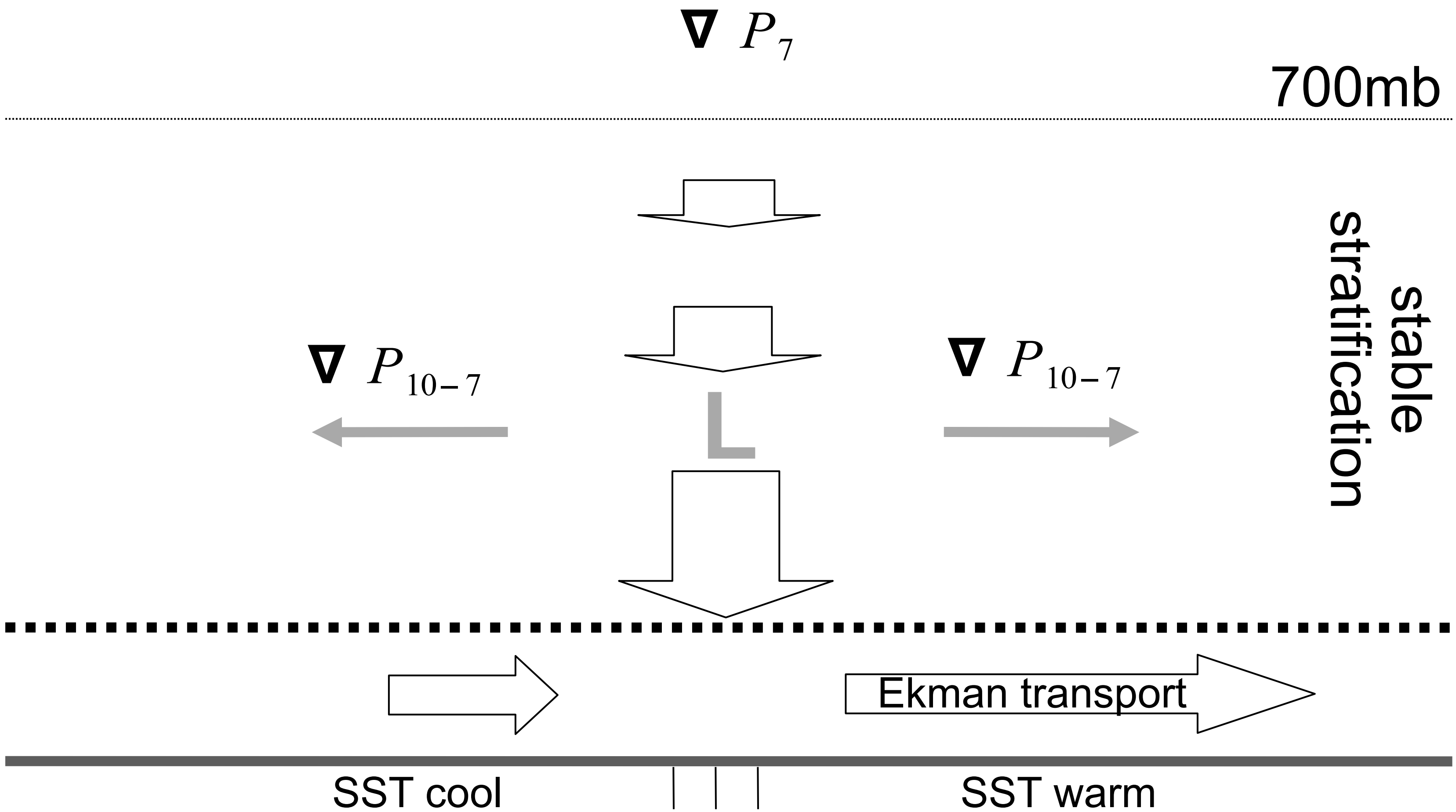
$$P_{10}^{-1}\boldsymbol{\tau} = \boldsymbol{D}\nabla \ln P_{10} + D\boldsymbol{E}\nabla \ln T_{2m}$$

$$P_{10} = P_7 + P_{10-7}$$

$$\nabla \times \boldsymbol{\tau} = C_{P7} + C_{P10-7} + C_{T2m} = 0$$

'Spin down', Holton 1965, Pedlosky 1967

Spin-down

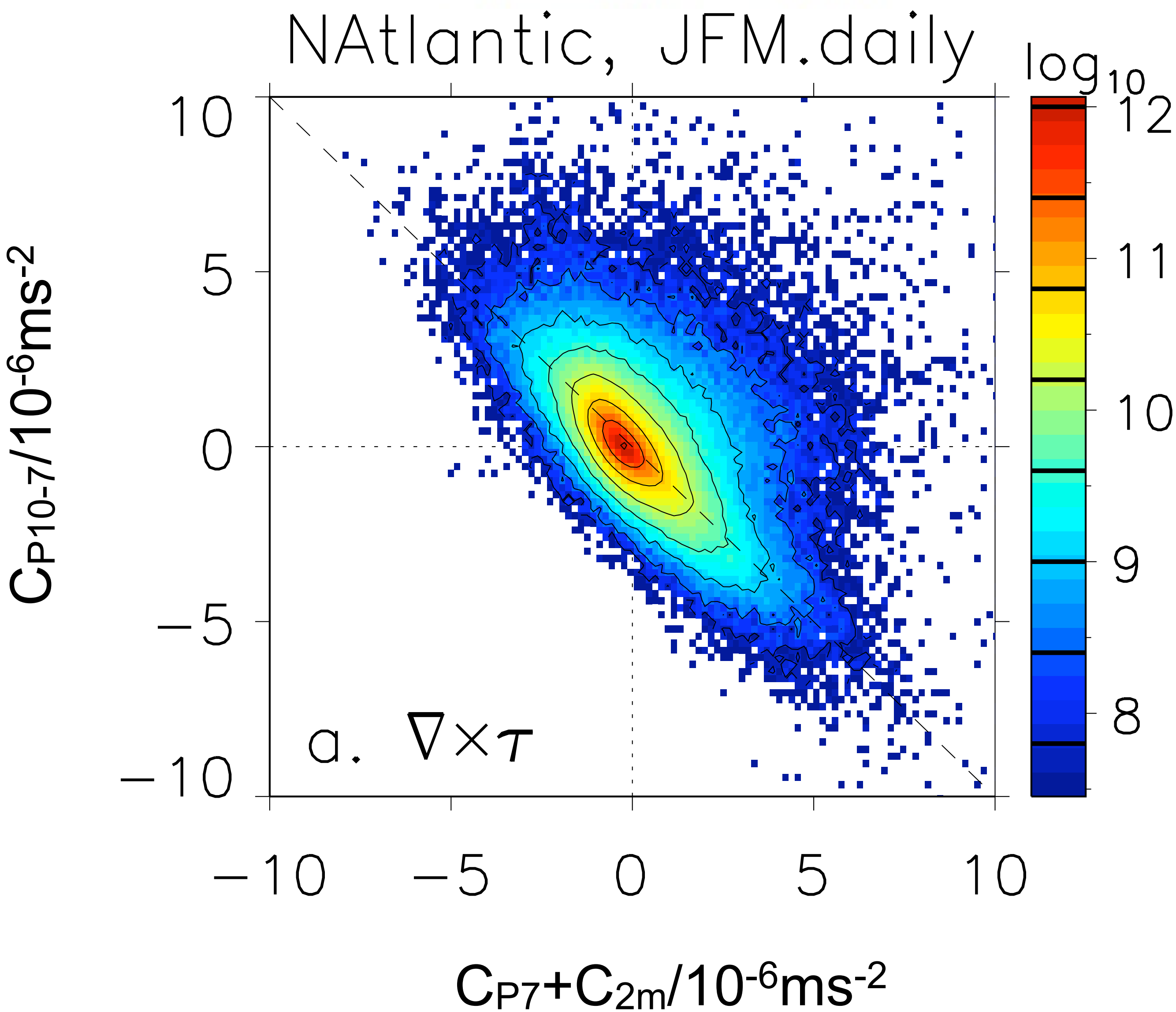


$$\nabla \times \tau = C_{P7} + C_{P10-7} + C_{T2m} = 0$$

Spin-down

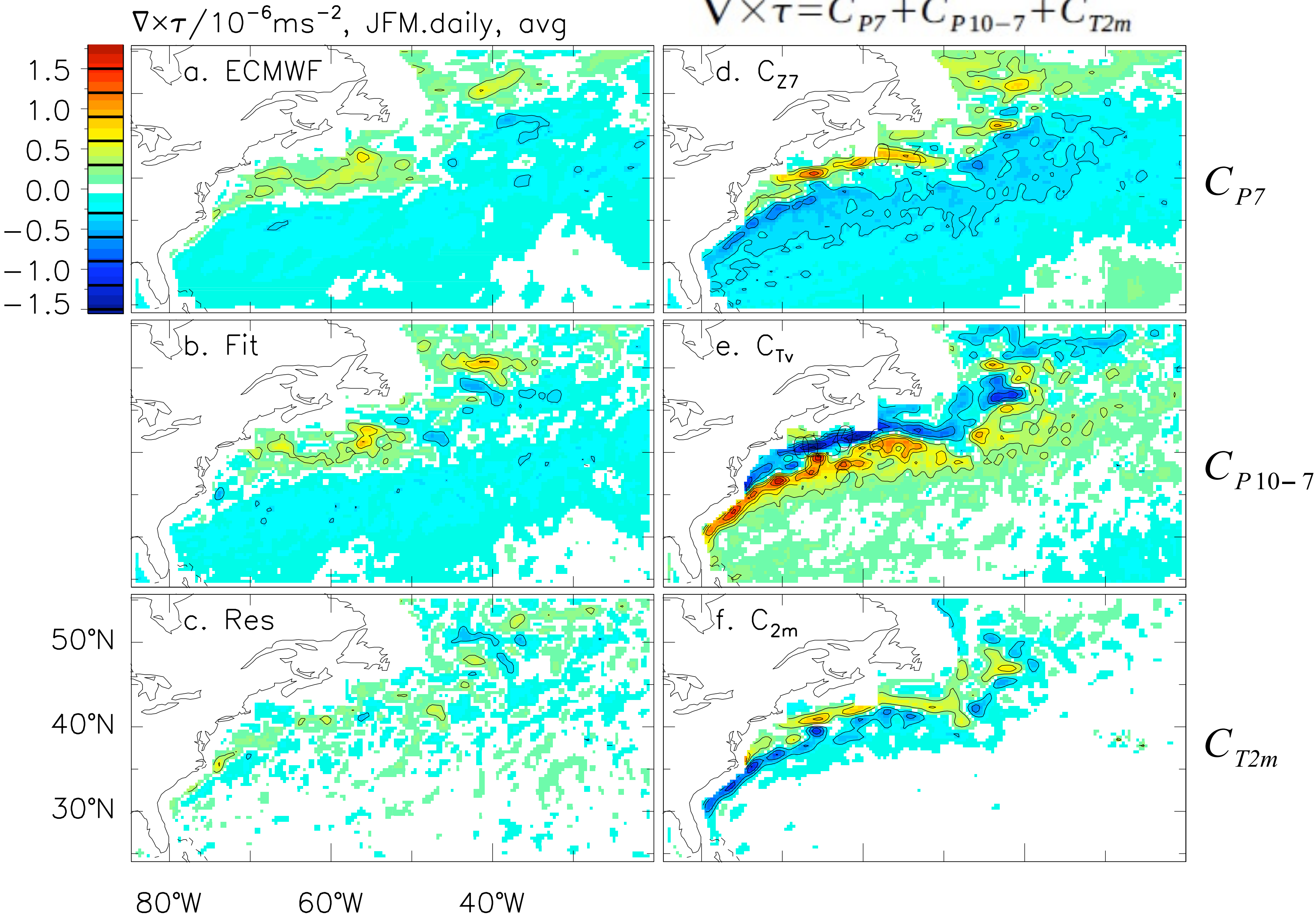
$$\nabla\times\tau = 0$$

$$C_{P7}+C_{T2m}=-C_{P10-7}$$

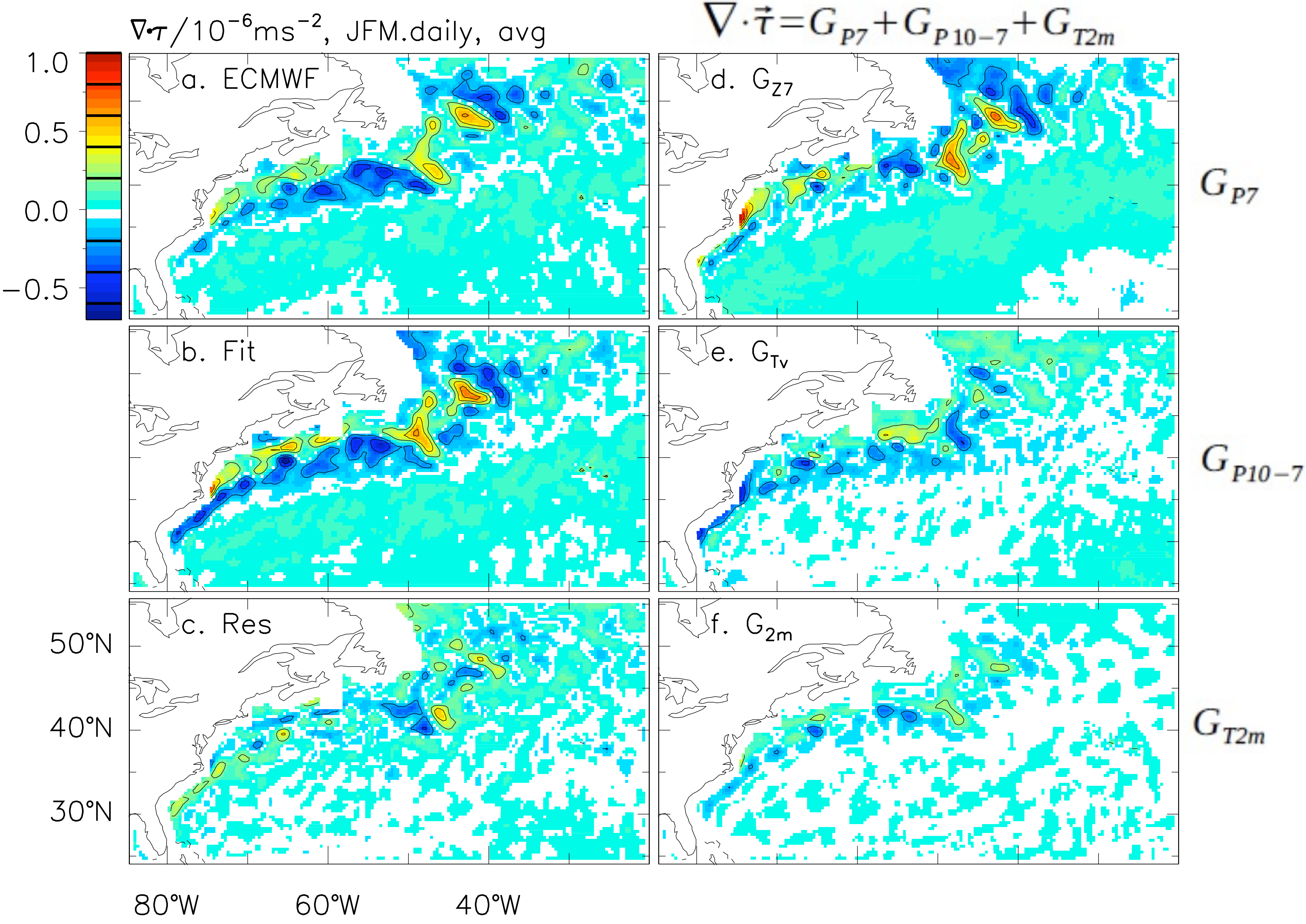


Components of Ekman pumping

$$\nabla \times \tau = C_{P7} + C_{P10-7} + C_{T2m}$$



Components of wind stress divergence



Conclusions

• In the vicinity of strong SST front the atmospheric Ekman layer is strongly affected by changes of mixing and near surface pressure gradients.

• Near SST fronts, the response of the Ekman layer results from nonlinear coupling of the momentum balance, the surface heat budget, and the near surface vorticity budgets.

• Spin-down imprints changes to stability on the near surface pressure gradients.

• Ocean fronts may impact the tropospheric circulation and storm track via *frictional* effects in the Ekman layer and Ekman pumping.

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Ekman Pumping

Classical (Charney and Eliassen 1949)

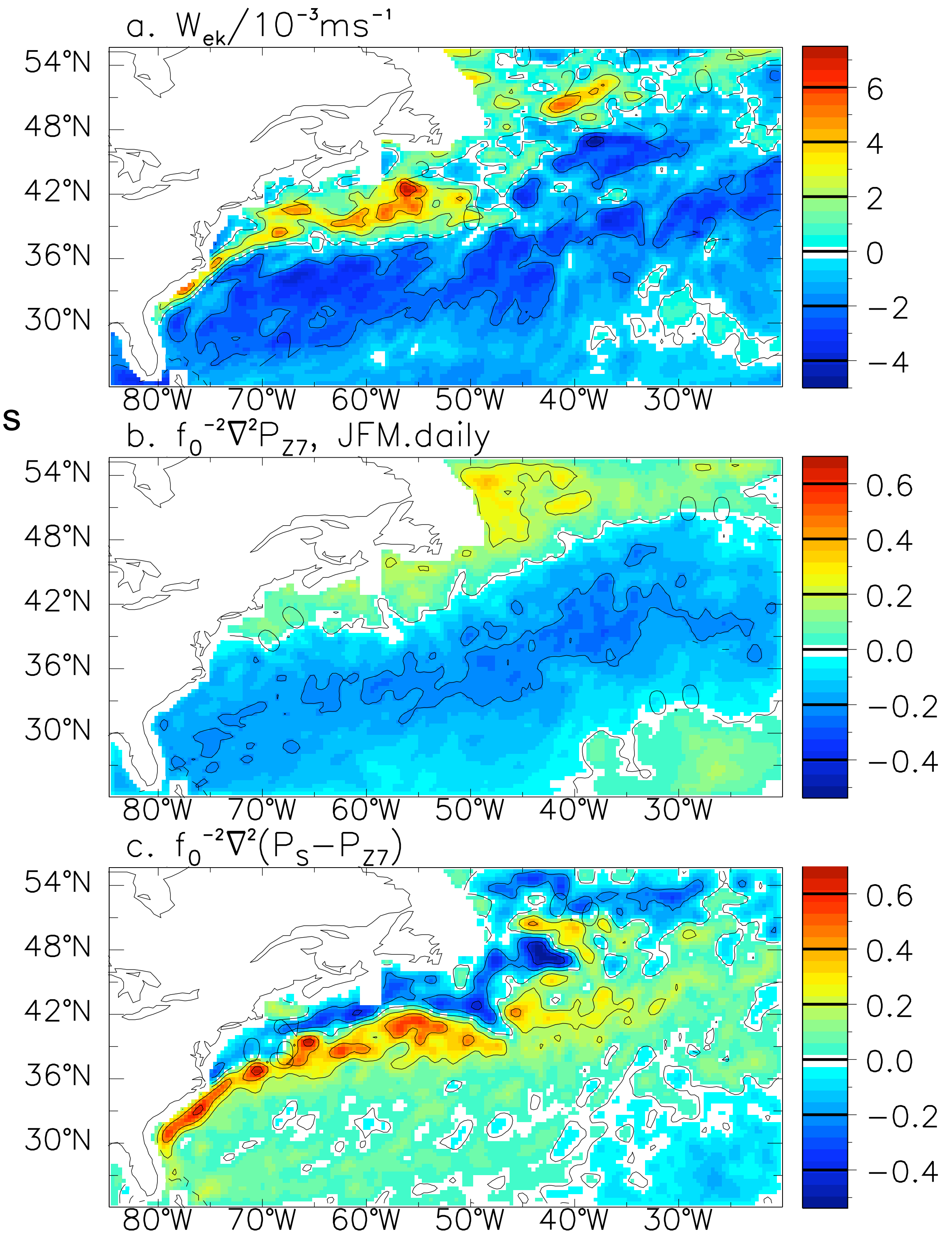
- driven by pressure gradient of free troposphere
- small Ekman number of geostrophic winds
- constant Ekman depth

$$w_{Ek} = \sqrt{\frac{A}{2f}} \; (\rho f)^{-1} \nabla^2 P$$

∇P_7 ———— 700mb

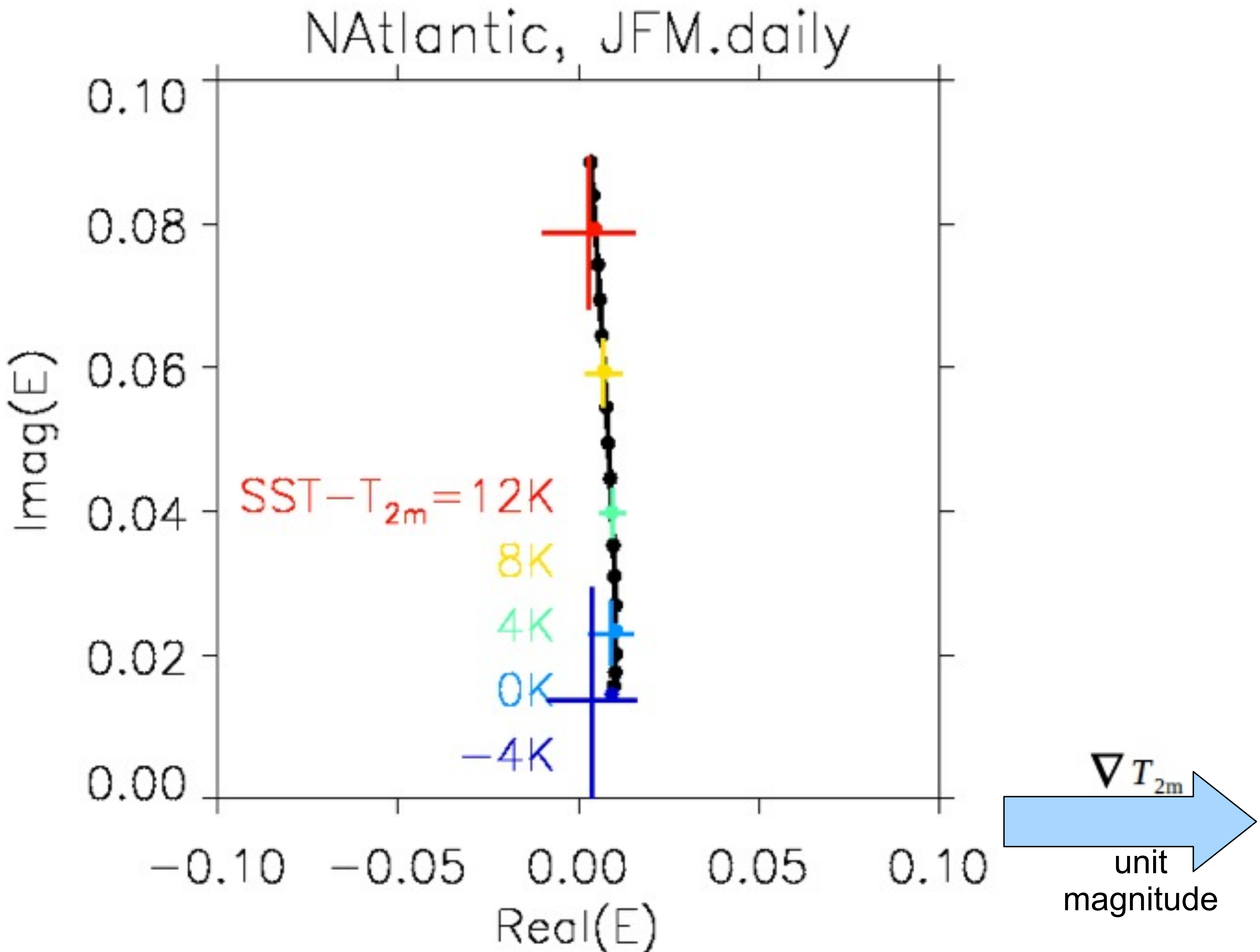
$$\nabla P_{10-7} = \nabla (P_{10} - P_7)$$

∇P_{10} ———— 1000mb



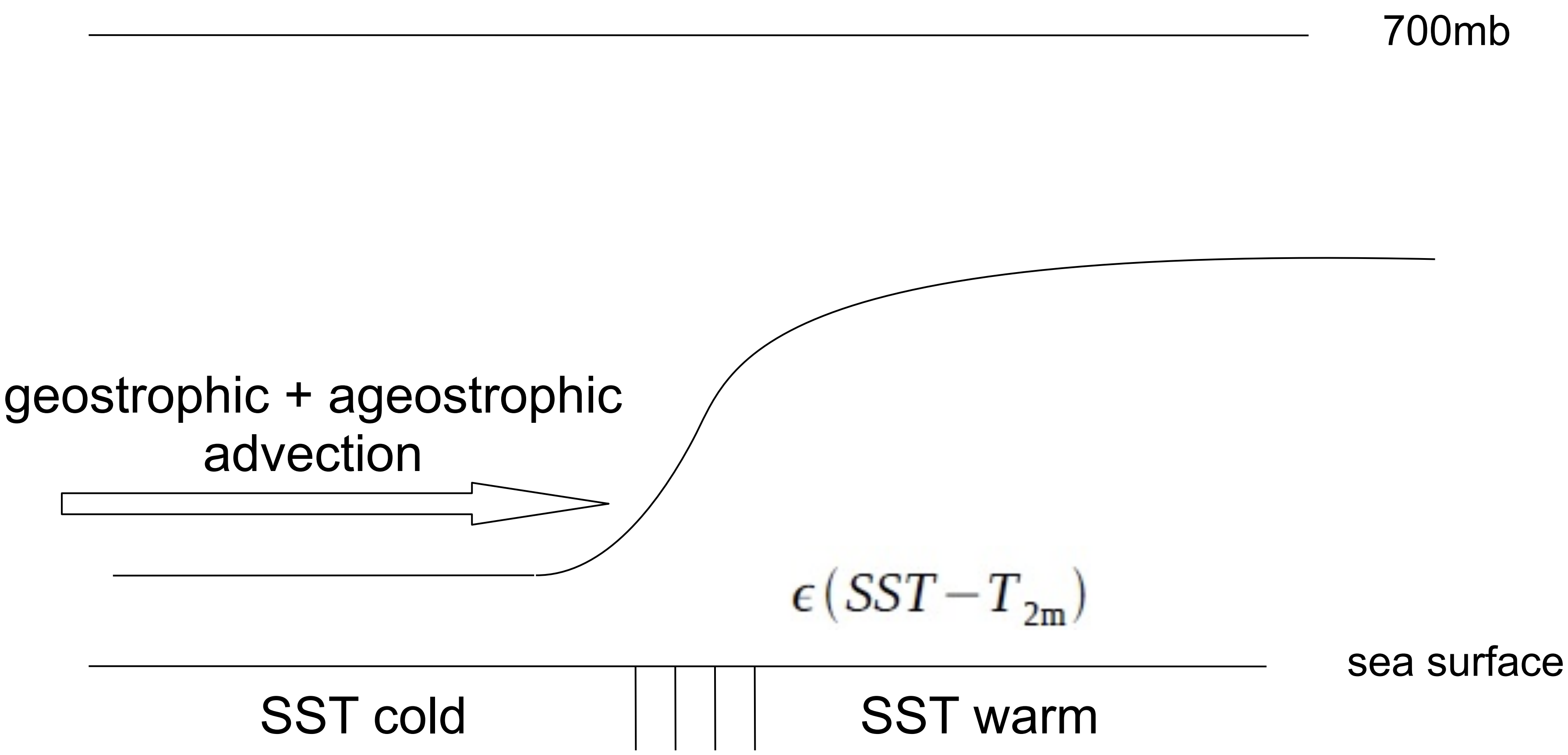
Ekman momentum balance II

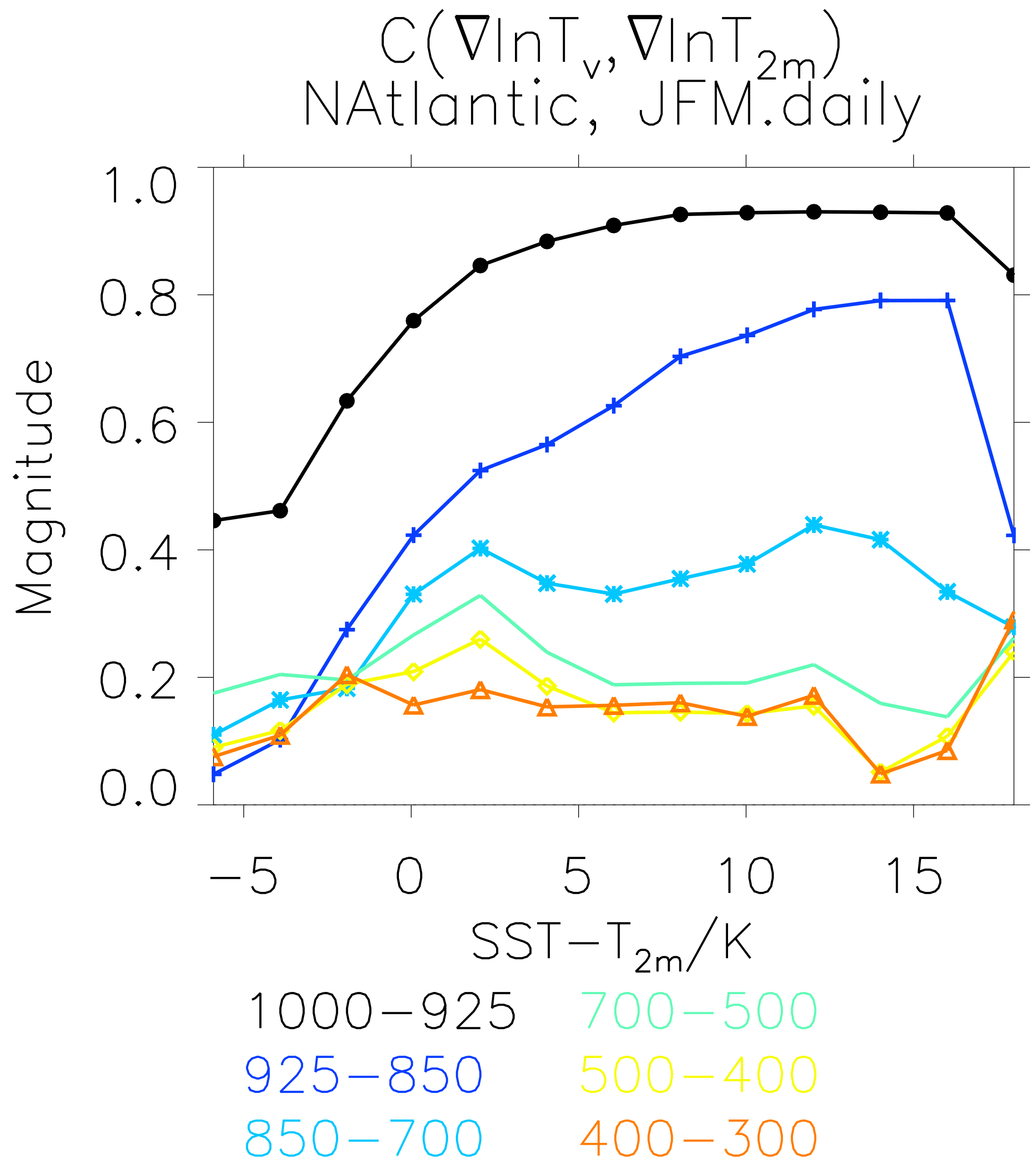
$$P_{10}^{-1}\boldsymbol{\tau} = \boldsymbol{D}\nabla \ln P_{10} + \boldsymbol{D}\boldsymbol{E}\nabla \ln T_{2m} + \ldots$$

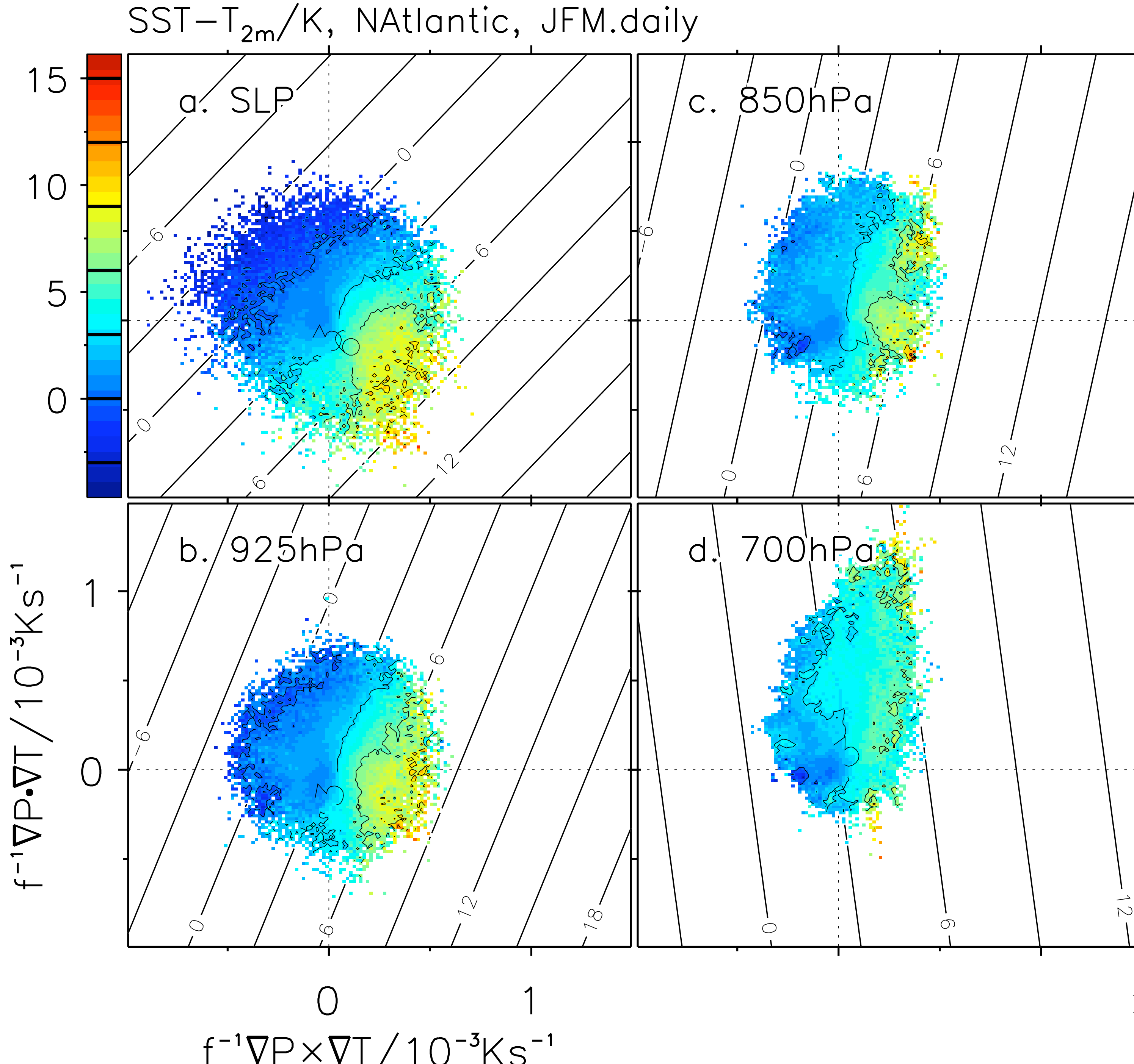


Thermal boundary layer heat budget

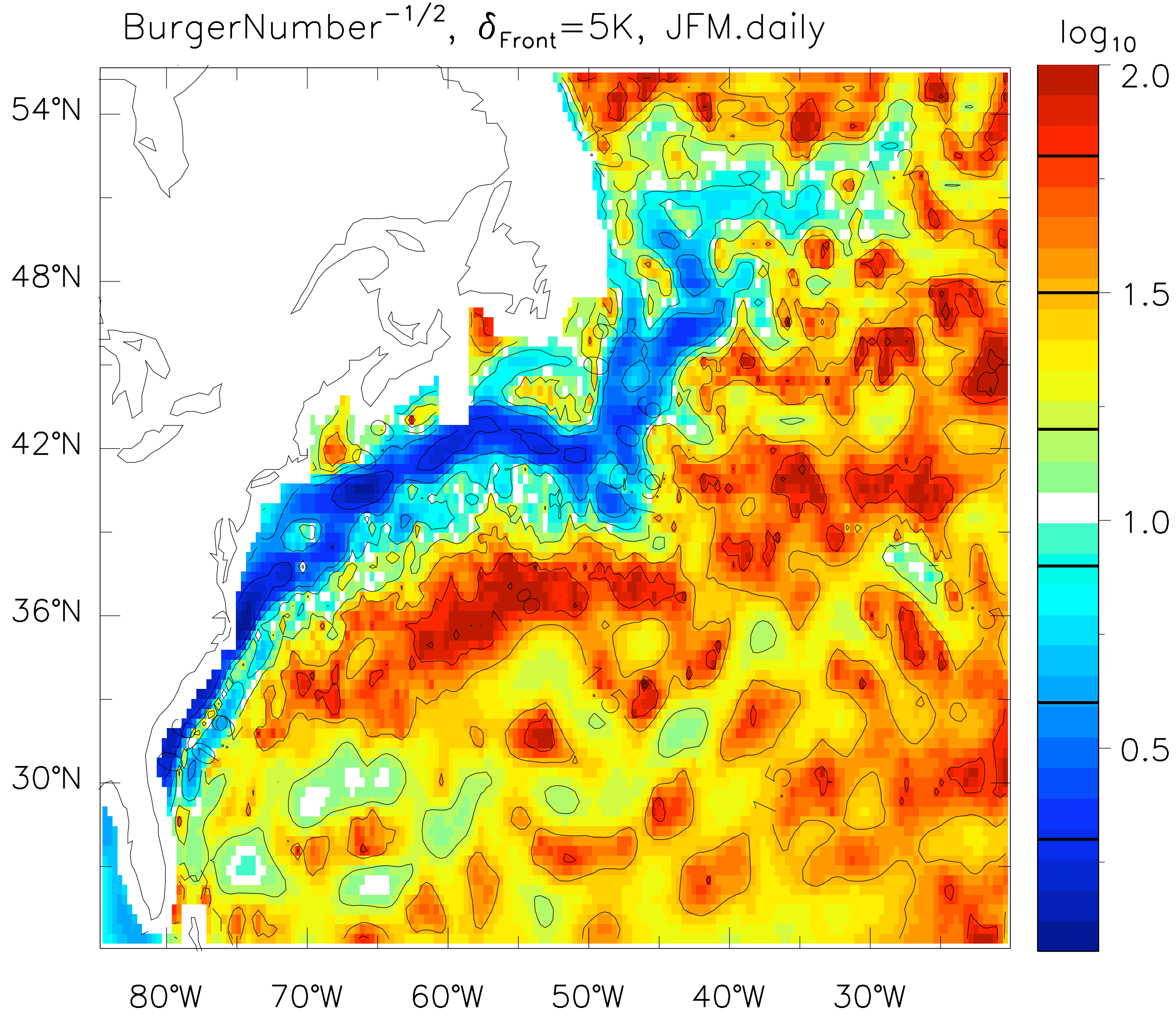
steady balance of horizontal advection,
air-sea heat exchange and entrainment from above



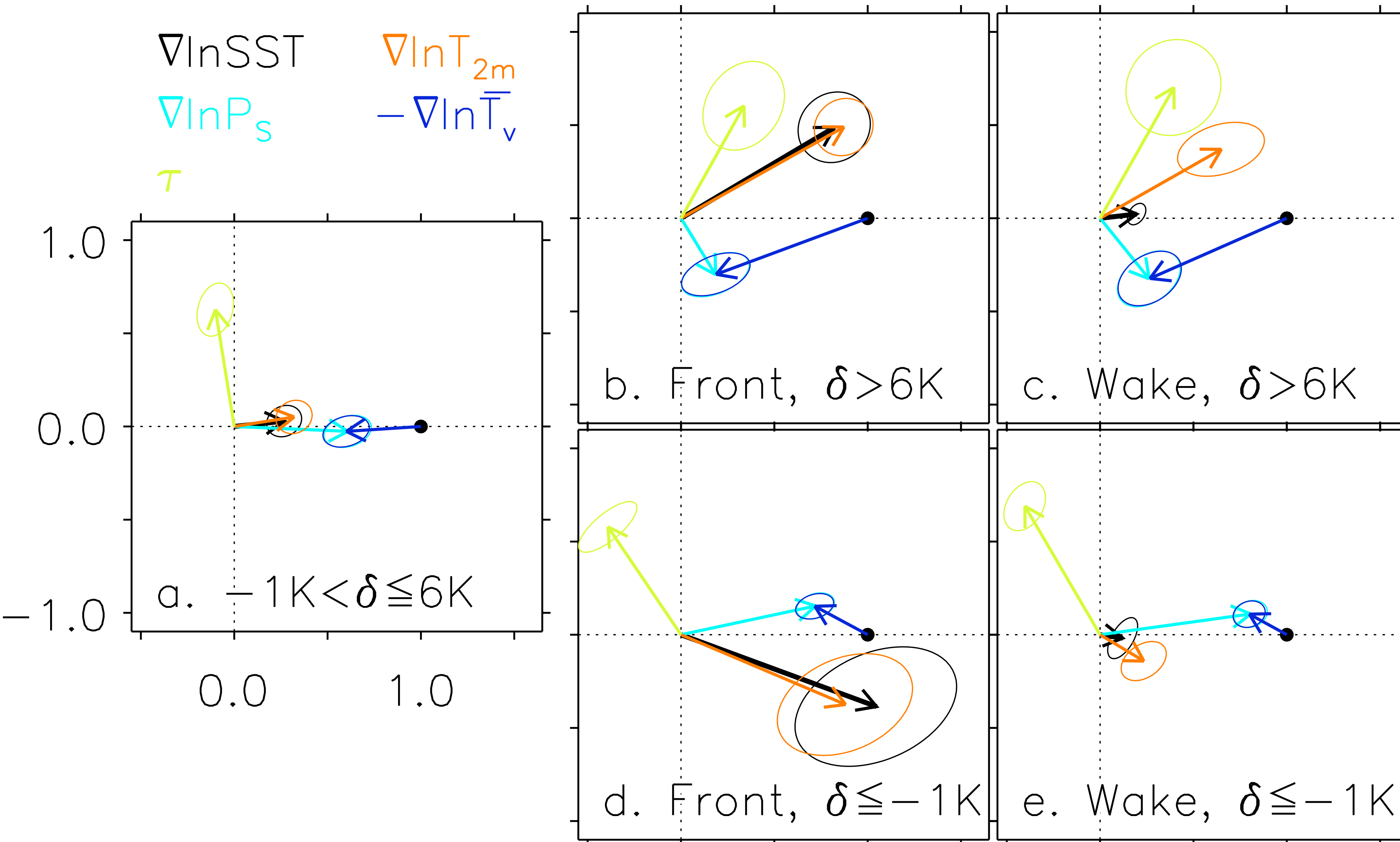

C(∇lnT_v,∇lnT_2m)
NAtlantic, JFM.daily
1.0
0.8
0.6
0.4
0.2
0.0
Magnitude
−5
0
5
10
15
SST−T_2m/K
1000−925
925−850
850−700
700−500
500−400
400−300



SST−T2m/K, NAtlantic, JFM.daily
a. SLP
b. 925hPa
c. 850hPa
d. 700hPa
f⁻¹∇P•∇T/10⁻³Ks⁻¹
f⁻¹∇P×∇T/10⁻³Ks⁻¹



BurgerNumber$^{-1/2}$, δ_{Front}=5K, JFM.daily
log$_{10}$
2.0
1.5
1.0
0.5
54°N
48°N
42°N
36°N
30°N
80°W
70°W
60°W
50°W
40°W
30°W


∇lnSST
∇lnT2m
∇lnPs
−∇lnT̄v
τ
1.0
0.0
−1.0
0.0
1.0
a. −1K<δ≦6K
b. Front, δ>6K
c. Wake, δ>6K
d. Front, δ≦−1K
e. Wake, δ≦−1K