The atmospheric to weak sea surface temperature fronts

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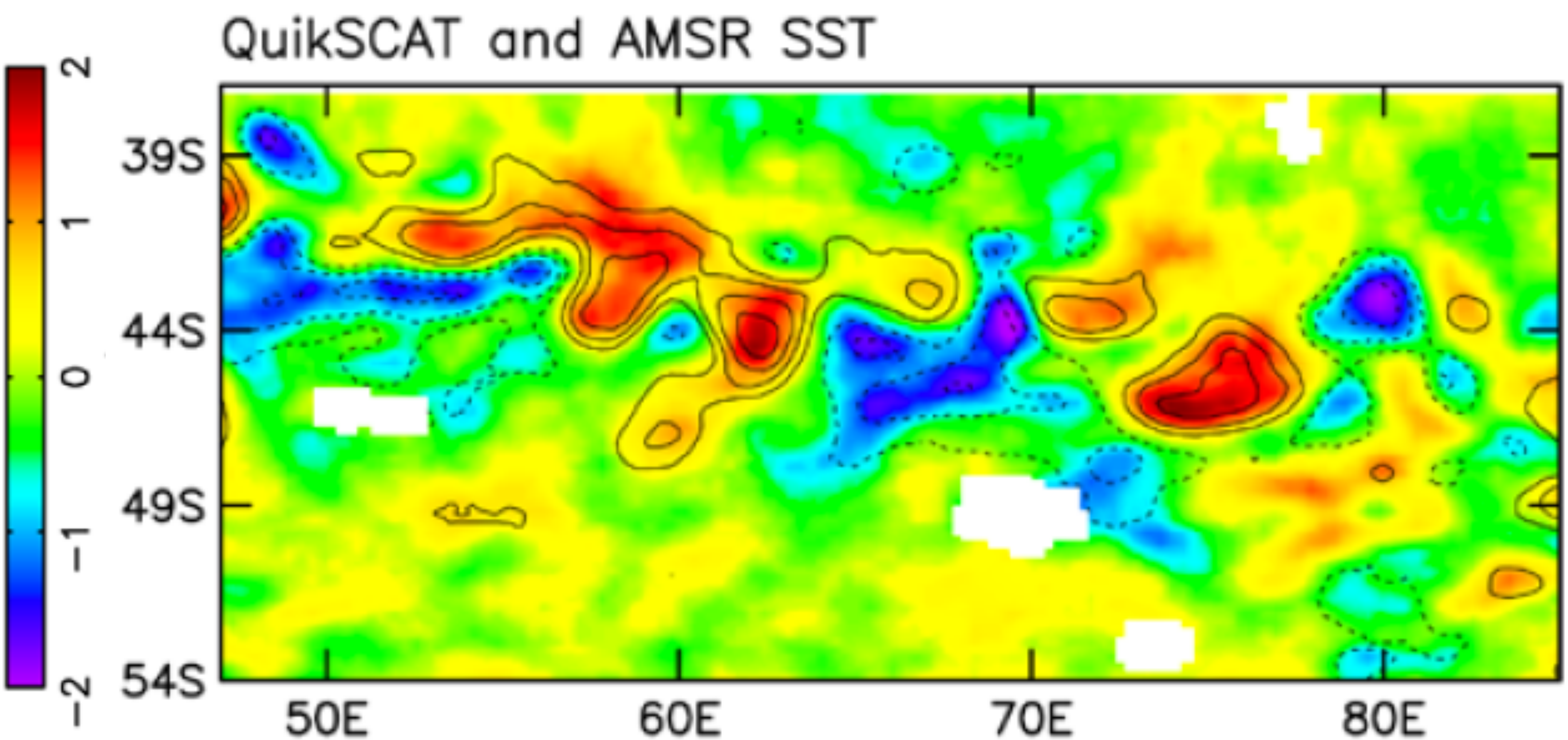
SST contour interval 1K
wind speed m/s

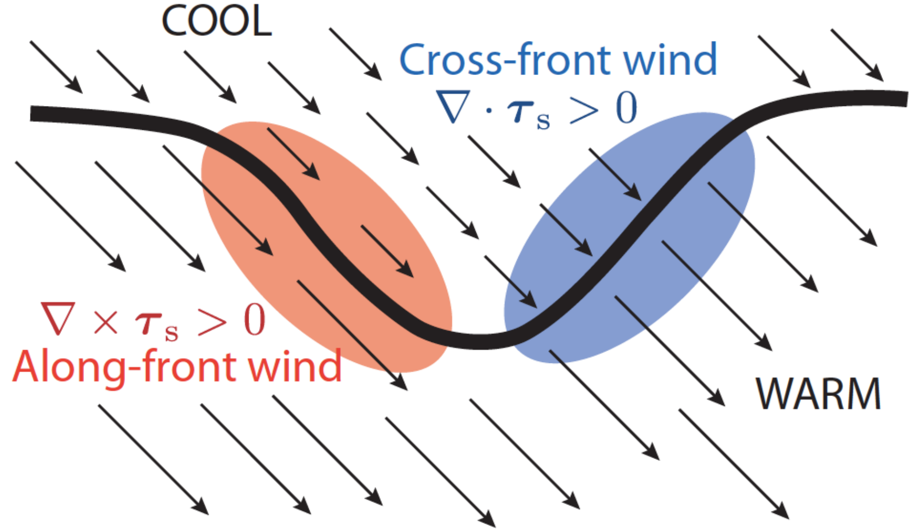


Chelton and Xie
Oceanography, 2010

July 2002, monthly average, spatially high pass filtered

Imprint of ocean mesoscale on extratropical atmosphere

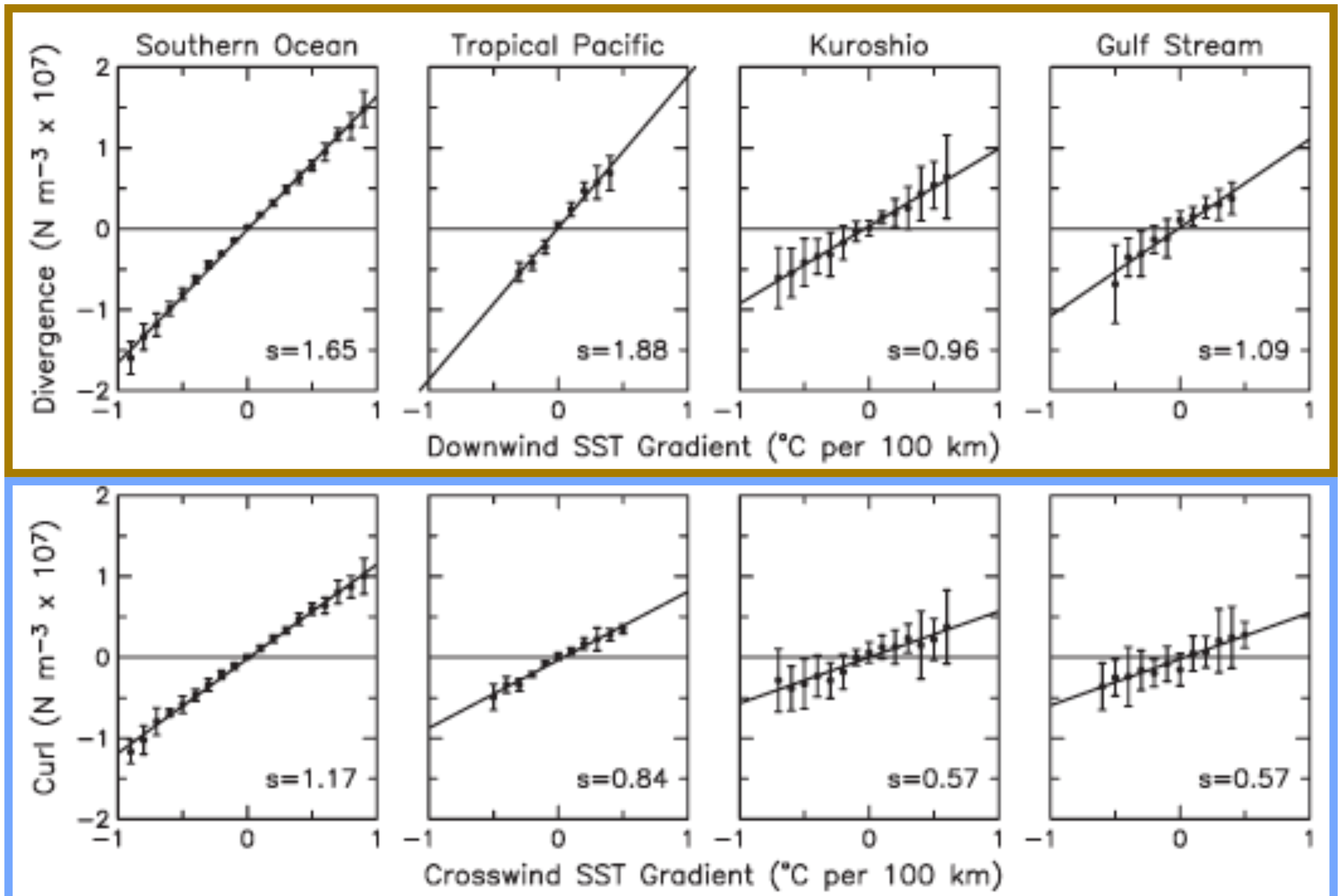
warm SST associated with **high wind speed**



Coupling coefficients

QuikSCAT
Aug 2002-July 2003

Chelton et al., Science, 2004

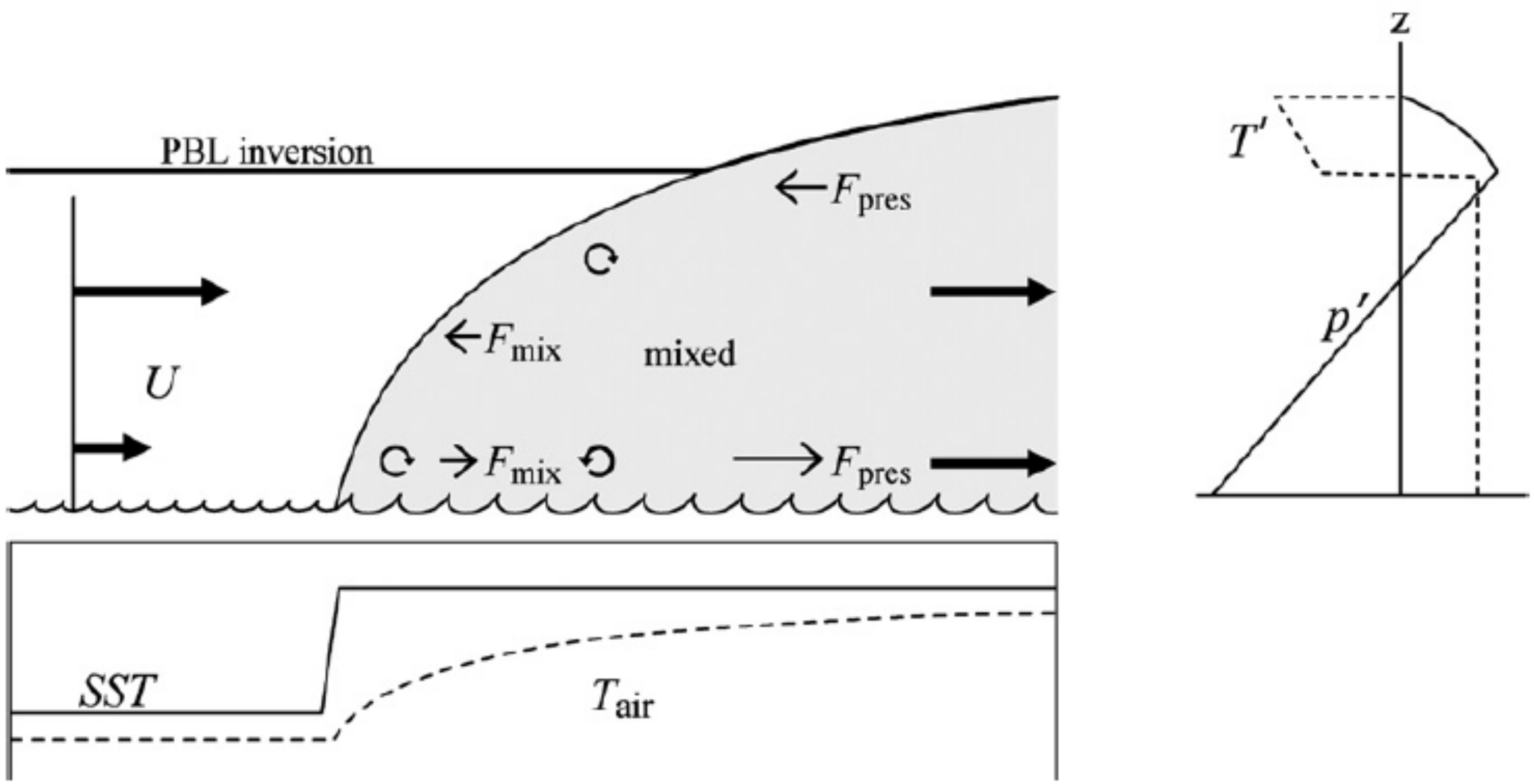


wind stress *divergence* function of *downwind* SST gradient

wind stress curl function of crosswind SST gradient

slope s consistently larger for divergence than for curl

Impact of SST fronts on lower troposphere



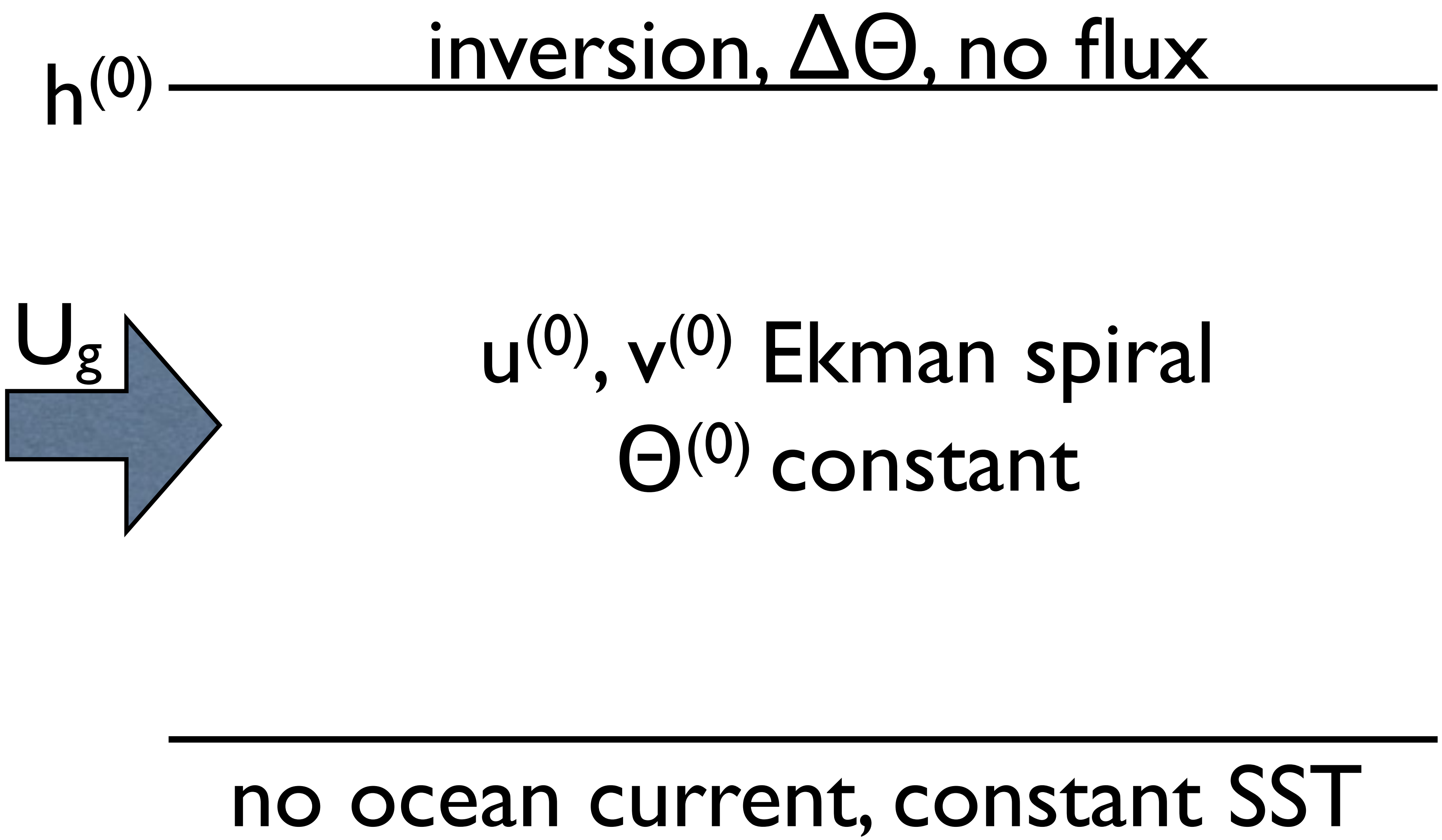
Small et al. 2008

Downstream of a warm SST front:

1. a **"Vertical Mixing"** increase in mixing entrains higher momentum from aloft (Wallace et al. 1989, Hayes et al. 1989, Samelson et al. 2006)
2. **"Pressure Effect"** imprint of SST gradient on boundary layer virtual temperature and baroclinic pressure gradients (Lindzen and Nigam 1987)
3. **"Spin-down"** Ekman transport convergences adjusts inversion height gradients to diminish surface Ekman pumping (Feliks et al. 2004)

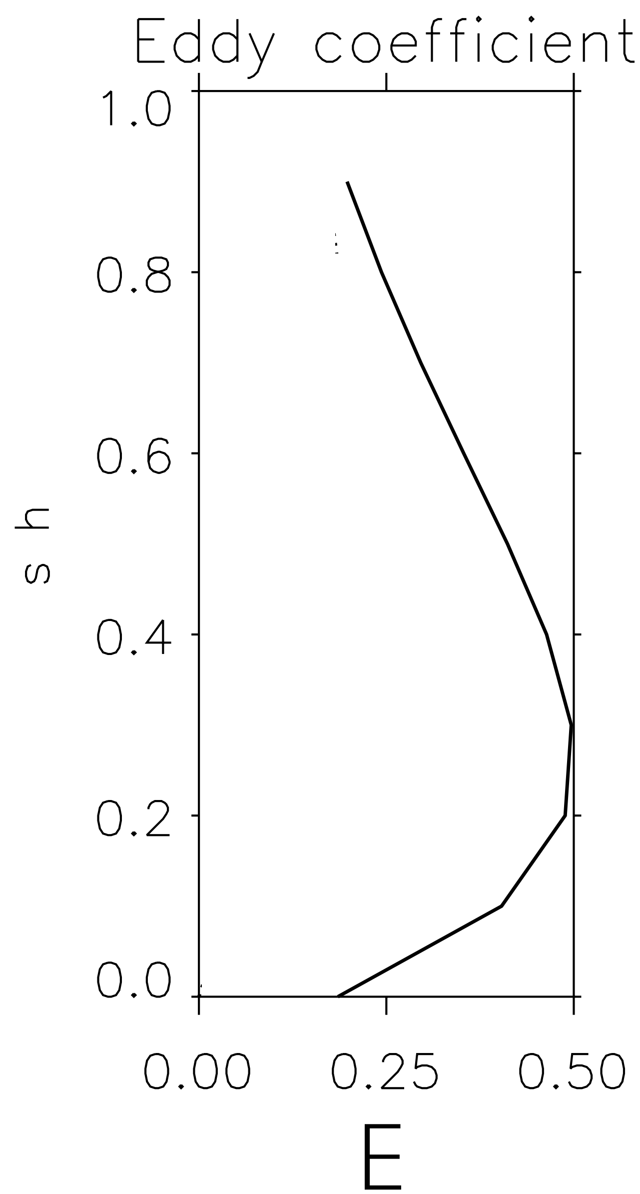
Model for air-sea interaction at SST fronts

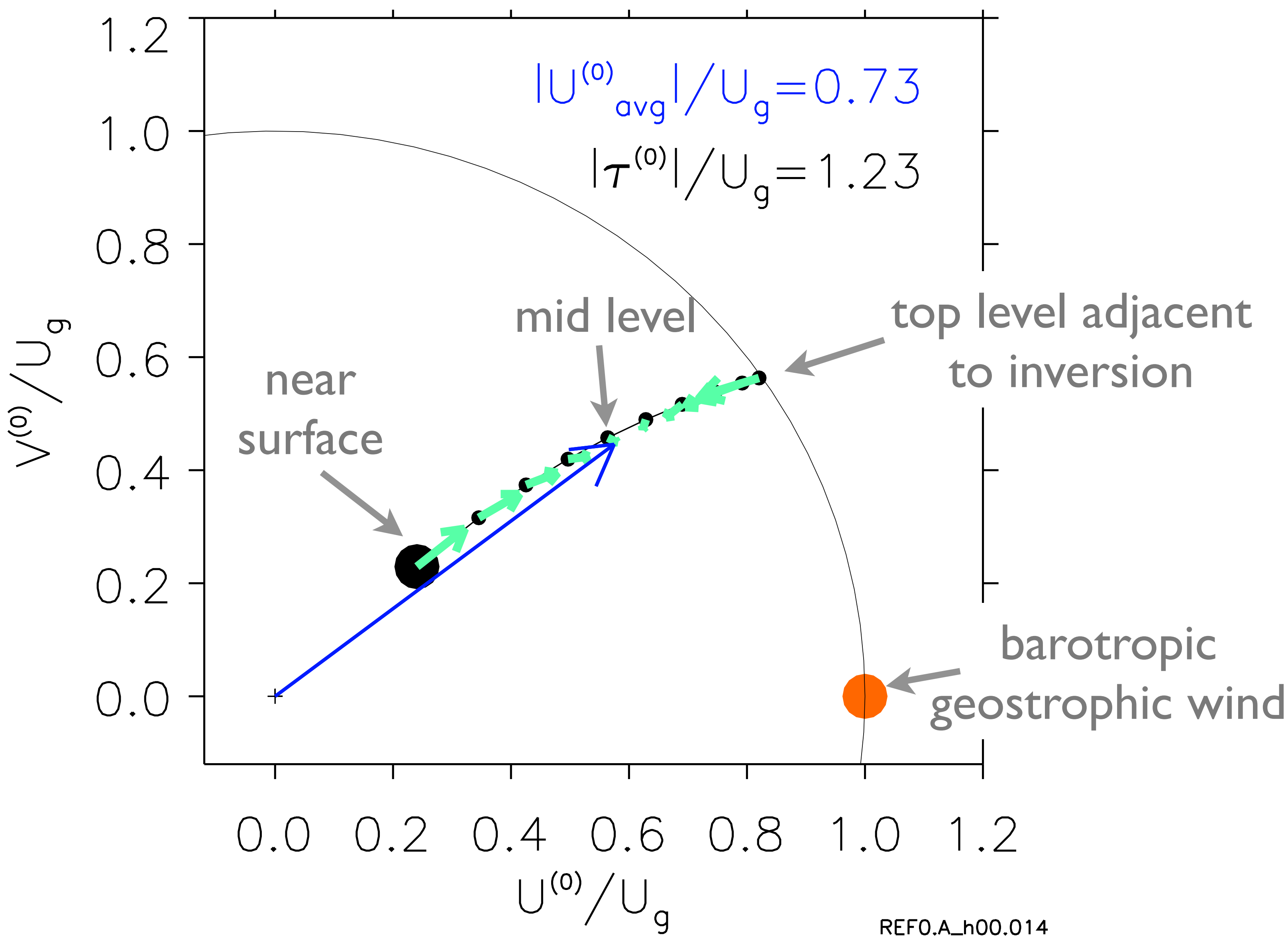
- Reduced gravity model capped by sharp inversion
- Forced by barotropic tropospheric pressure gradient
- Background Ekman spiral
- Linear response to weak SST front



Background Ekman spiral

$$\hat{e_3} \times \left(\vec{u}^{(0)} - \vec{U}_g\right) = \partial_s E^{(0)} \partial_s \vec{u}^{(0)}$$





Air-sea interaction at weak SST front
1st order (linear) response

$$\vec{u}^{(0)} \cdot \nabla\Theta^{(1)} = \gamma\left(T^{(1)} - \Theta^{(1)}\right) + A_h \nabla^2 \Theta^{(1)}$$

$$\underbrace{\vec{u}^{(0)} \cdot \nabla \vec{u}^{(1)} + w^{\star(1)} \partial_s \vec{u}^{(0)}}_{\text{advection}} + \underbrace{\hat{e_3} \times \vec{u}^{(1)}}_{\text{Coriolis}} + \underbrace{\nabla h^{(1)}}_{\text{back pressure}} - \partial_s \underbrace{E^{(0)} \partial_s \vec{u}^{(1)}}_{\text{background mixing}} = \vec{F}$$

$$\vec{u}^{(0)} \cdot \nabla h^{(1)} + \nabla \cdot \vec{u}^{(1)} + \partial_s w^{\star(1)} = 0$$

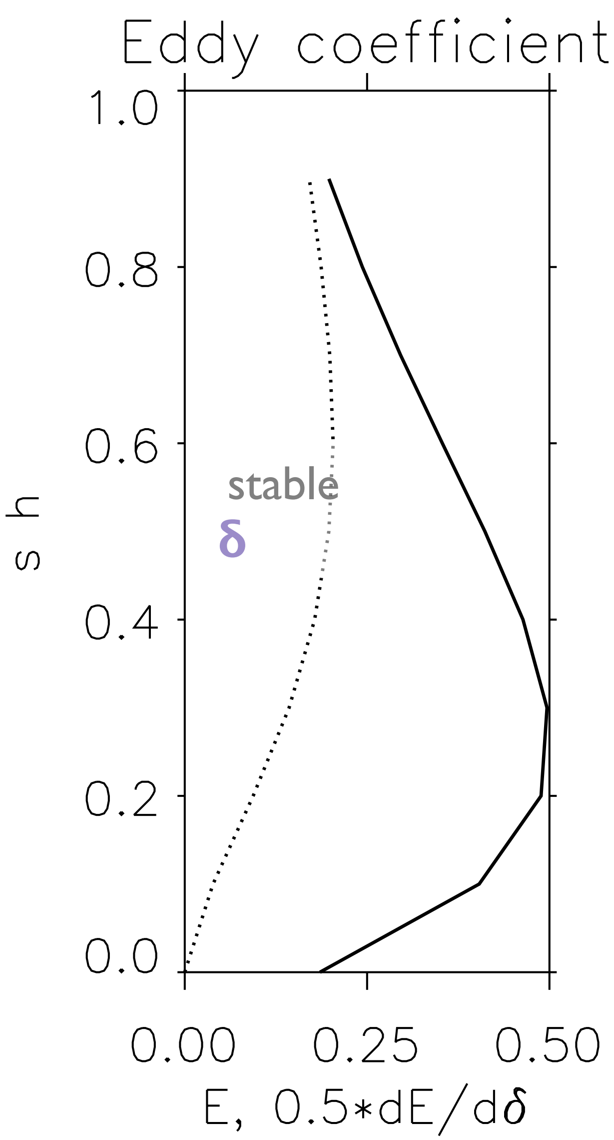
$$\vec{F} = \nabla \underbrace{\int_s^1 \Theta^{(1)} ds'}_{\text{pressure gradient mechanism}} + \partial_s \left(\underbrace{\delta^{(1)} \frac{\partial E}{\partial \delta}\bigg|_{\delta^{(0)}} \partial_s \vec{u}^{(0)}}_{\text{vertical mixing mechanism}} \right)$$

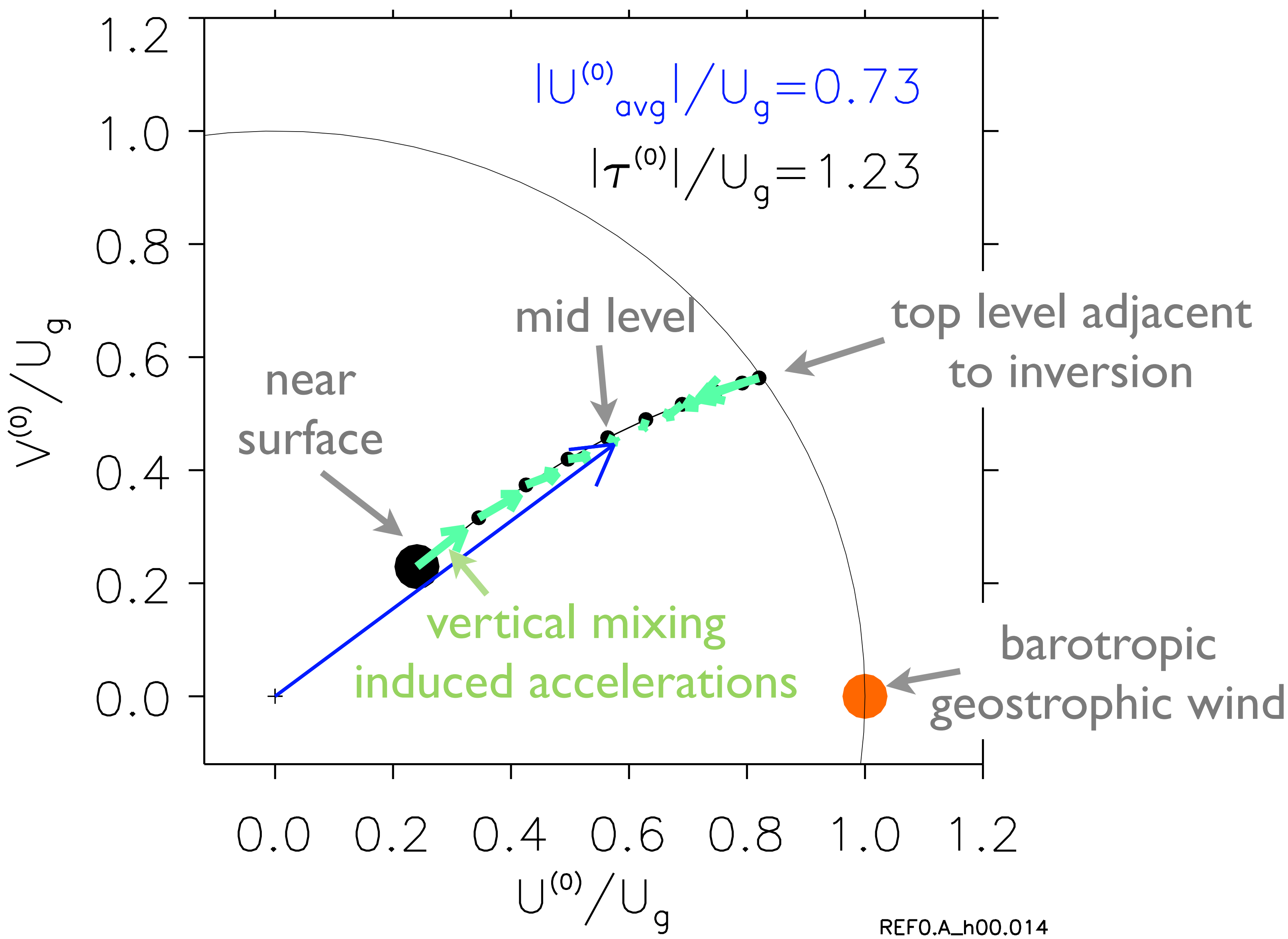
$\delta^{(1)} = T^{(1)} - \Theta^{(1)}$

air-sea temperature differences modulates vertical eddy viscosity

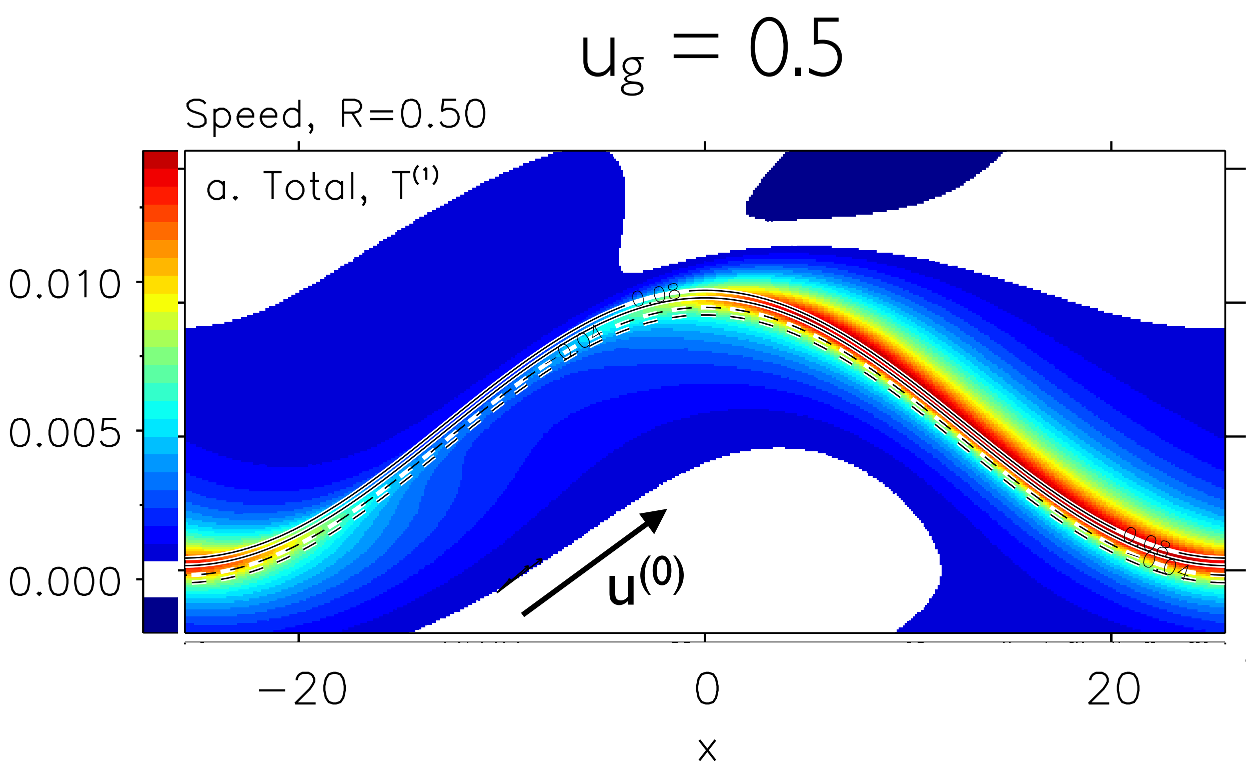
nondimensionalized by Rossby Radius of deformation, boundary layer height, inversion strength etc.

Vertical mixing effect

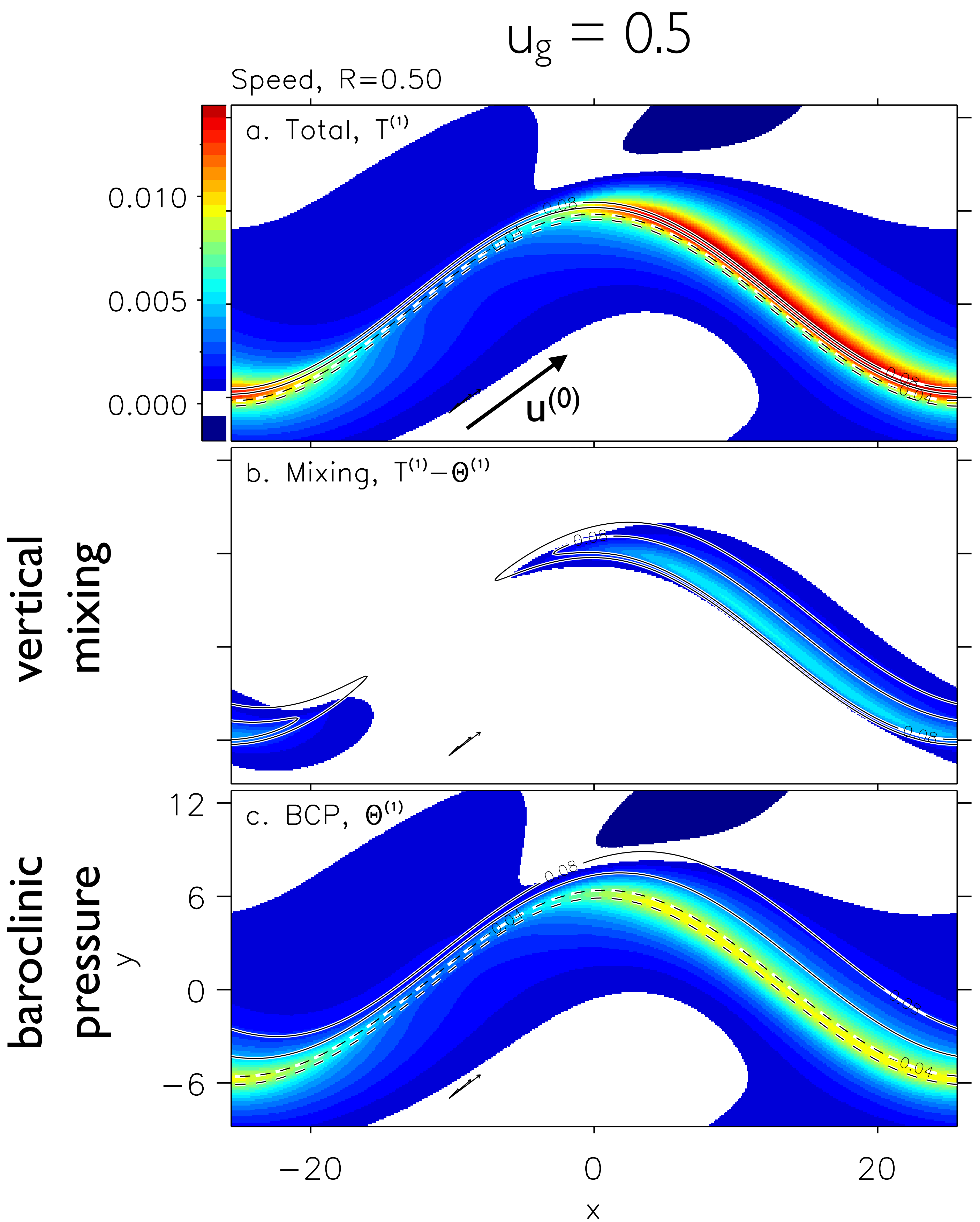




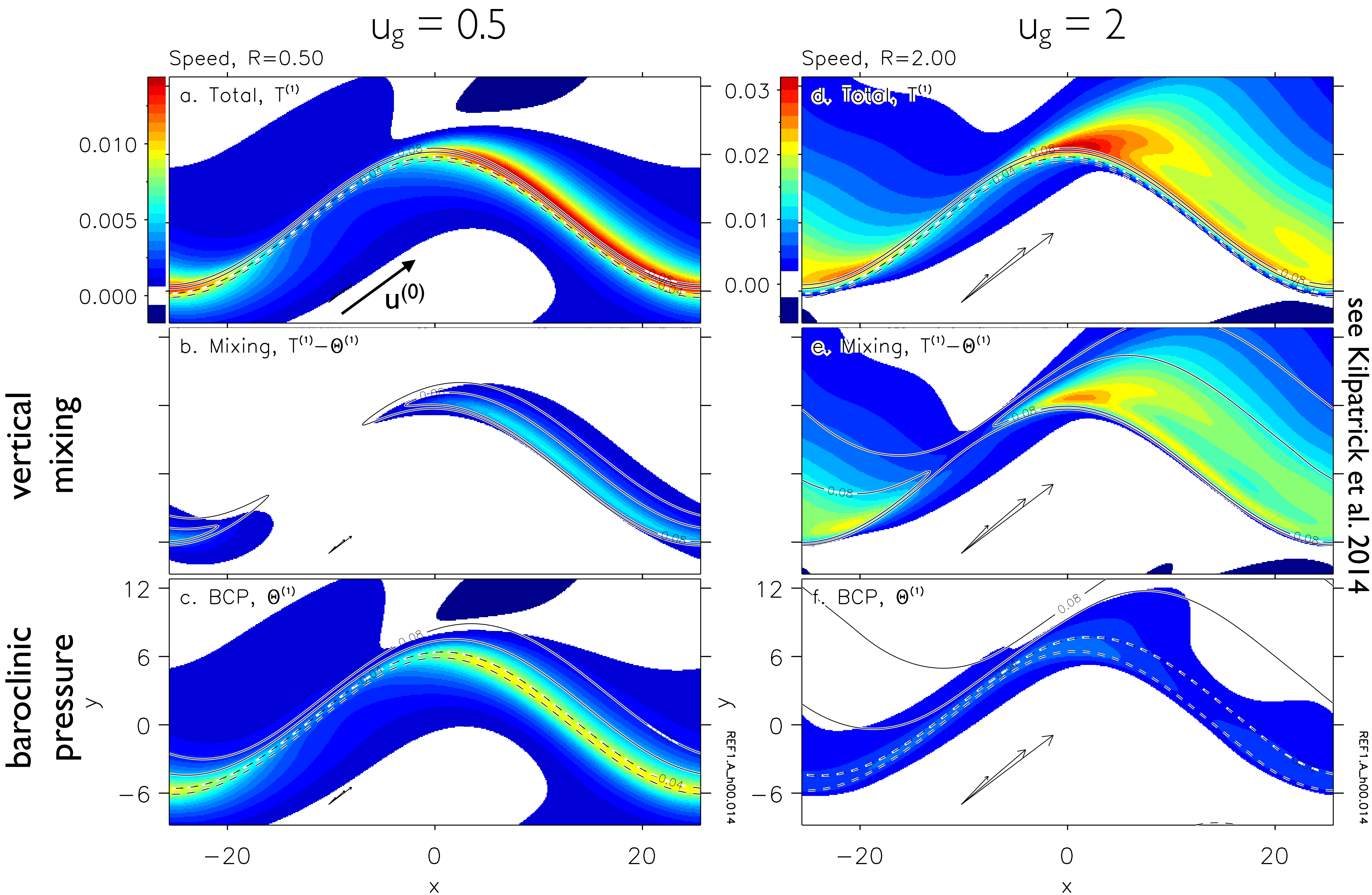
Surface wind speed



Surface wind speed

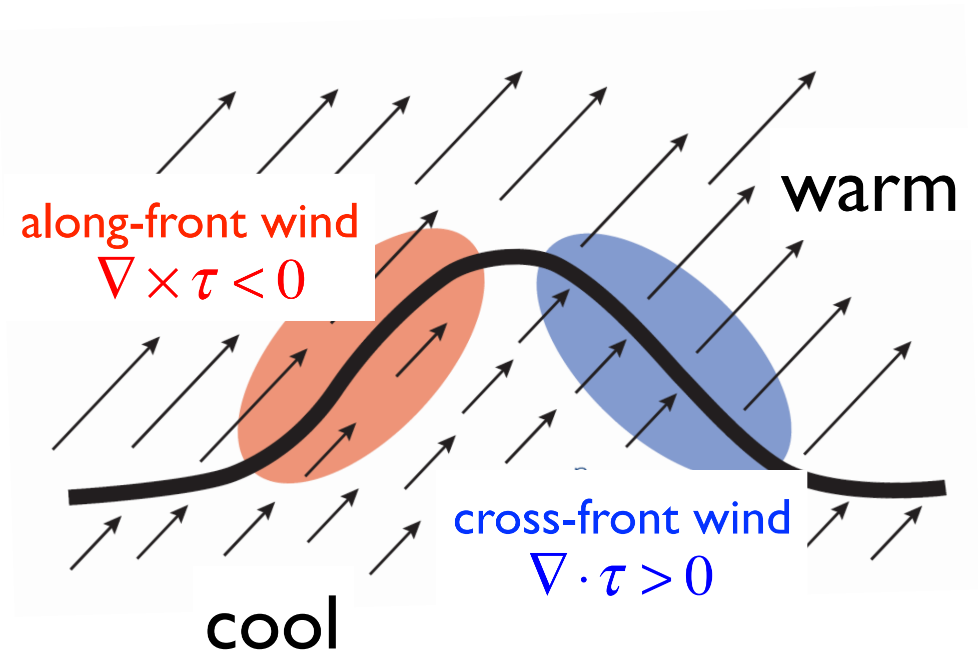


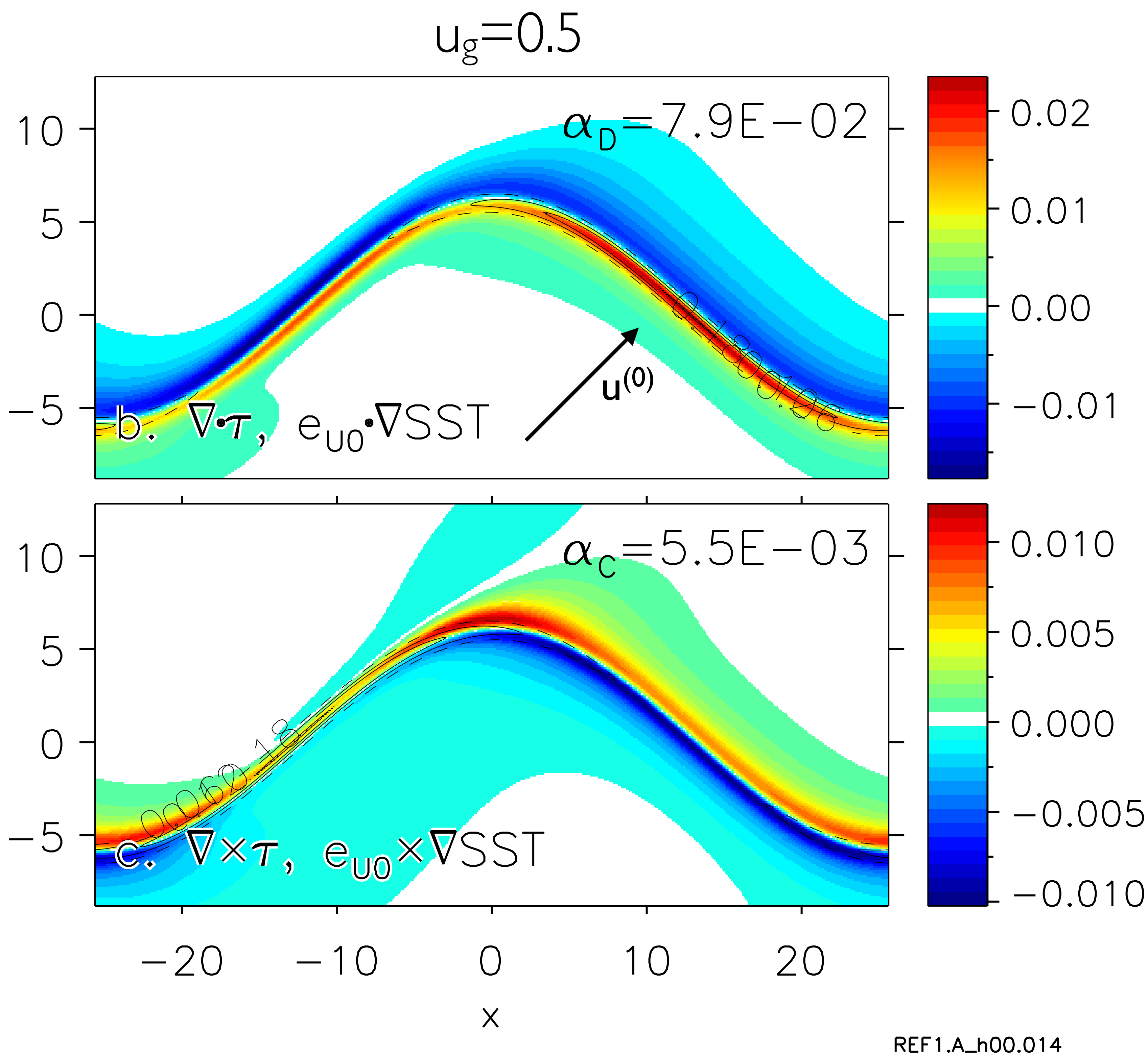
Surface wind speed



see Kilpatrick et al. 2014

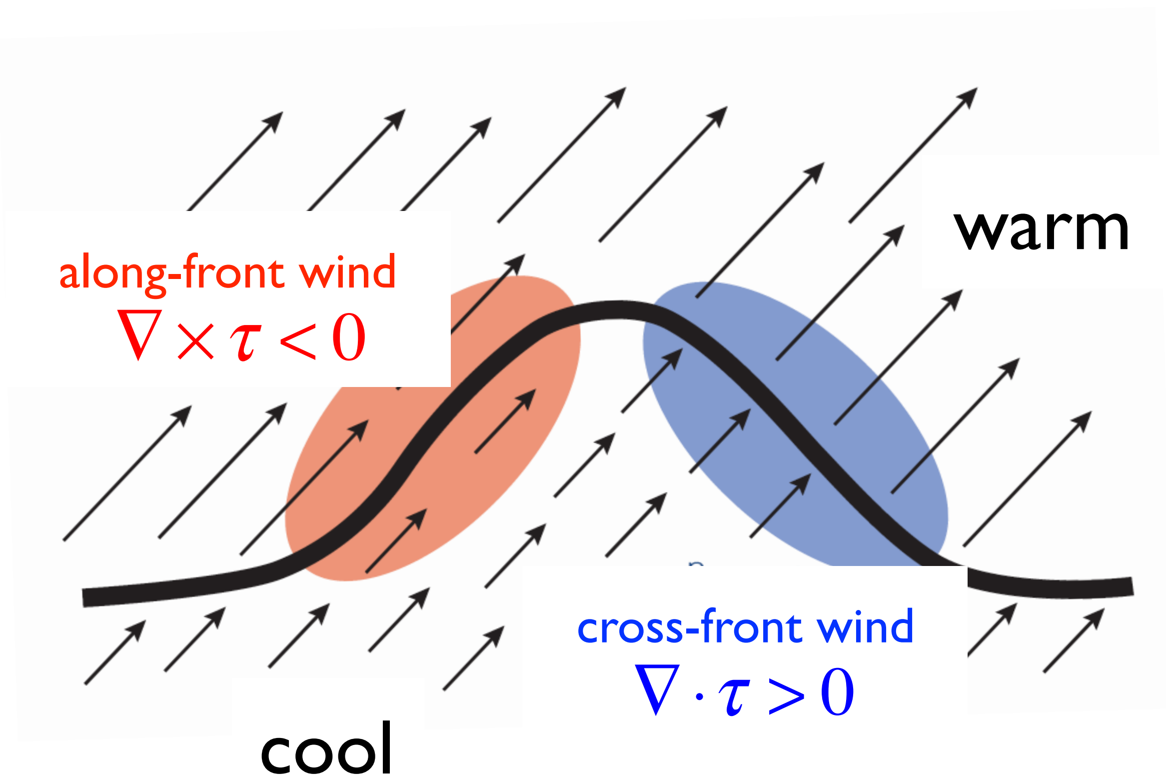
Wind stress divergence and curl



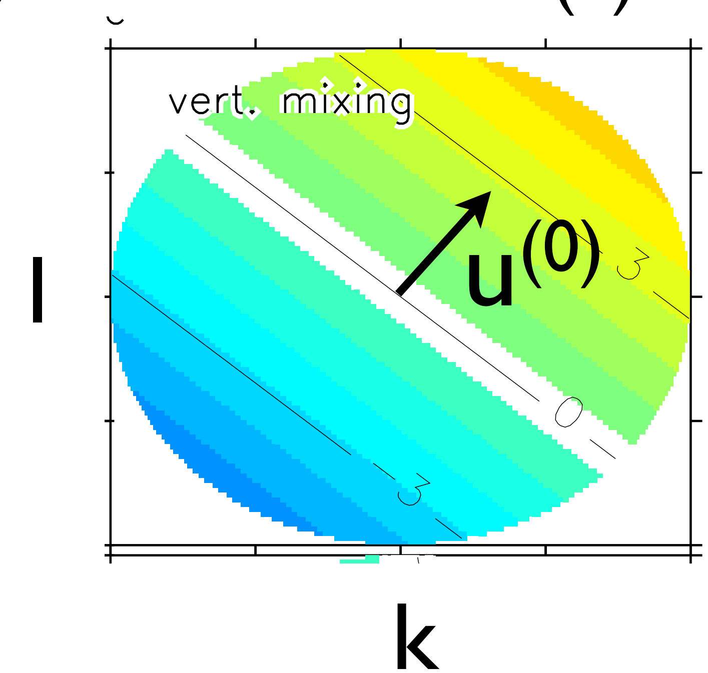


Coupling Coefficients

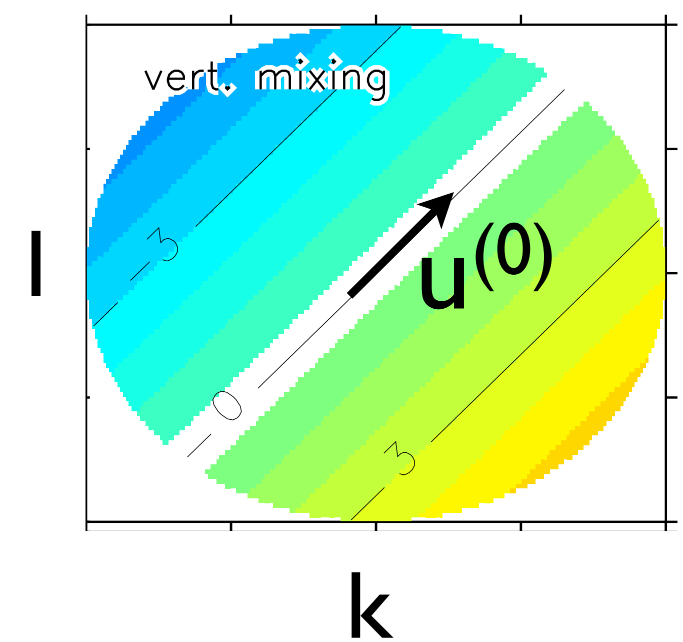
in wavenumber space



$$\nabla \cdot \tau(k,l) = \alpha_D \, i \, \mathbf{k} \cdot \mathbf{e}_{u(0)} \; T^{(1)}(k,l)$$

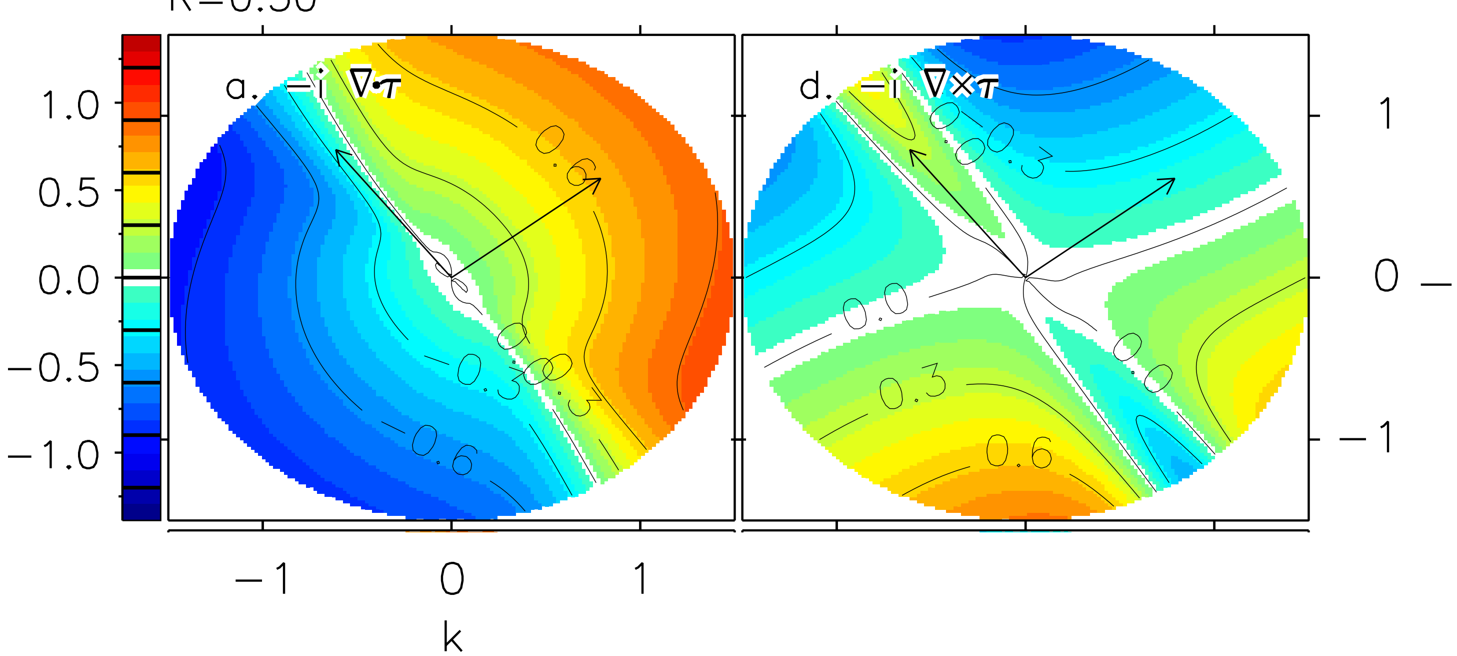


$$\nabla \times \tau(k,l) = \alpha_C \, i \, \mathbf{k} \times \mathbf{e}_{u(0)} \; T^{(1)}(k,l)$$



Spin-down

Wave-number space

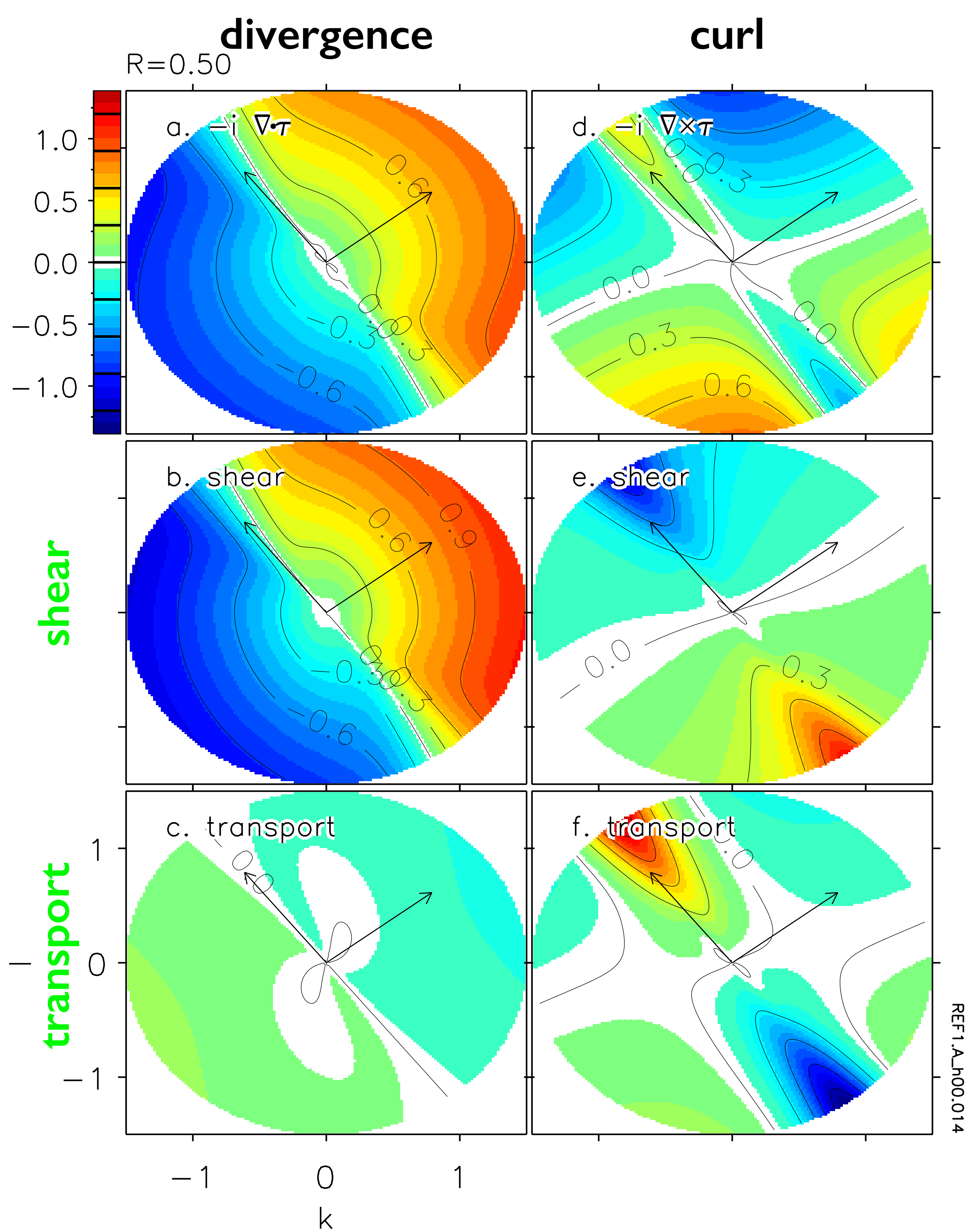


$\nabla \cdot \tau(k,l) =$
$\alpha_D \, i \, k \cdot e_{u(0)} \; T^{(1)}(k,l)$

$\nabla \times \tau(k,l) =$
$\alpha_C \, i \, k \times e_{u(0)} \; T^{(1)}(k,l)$

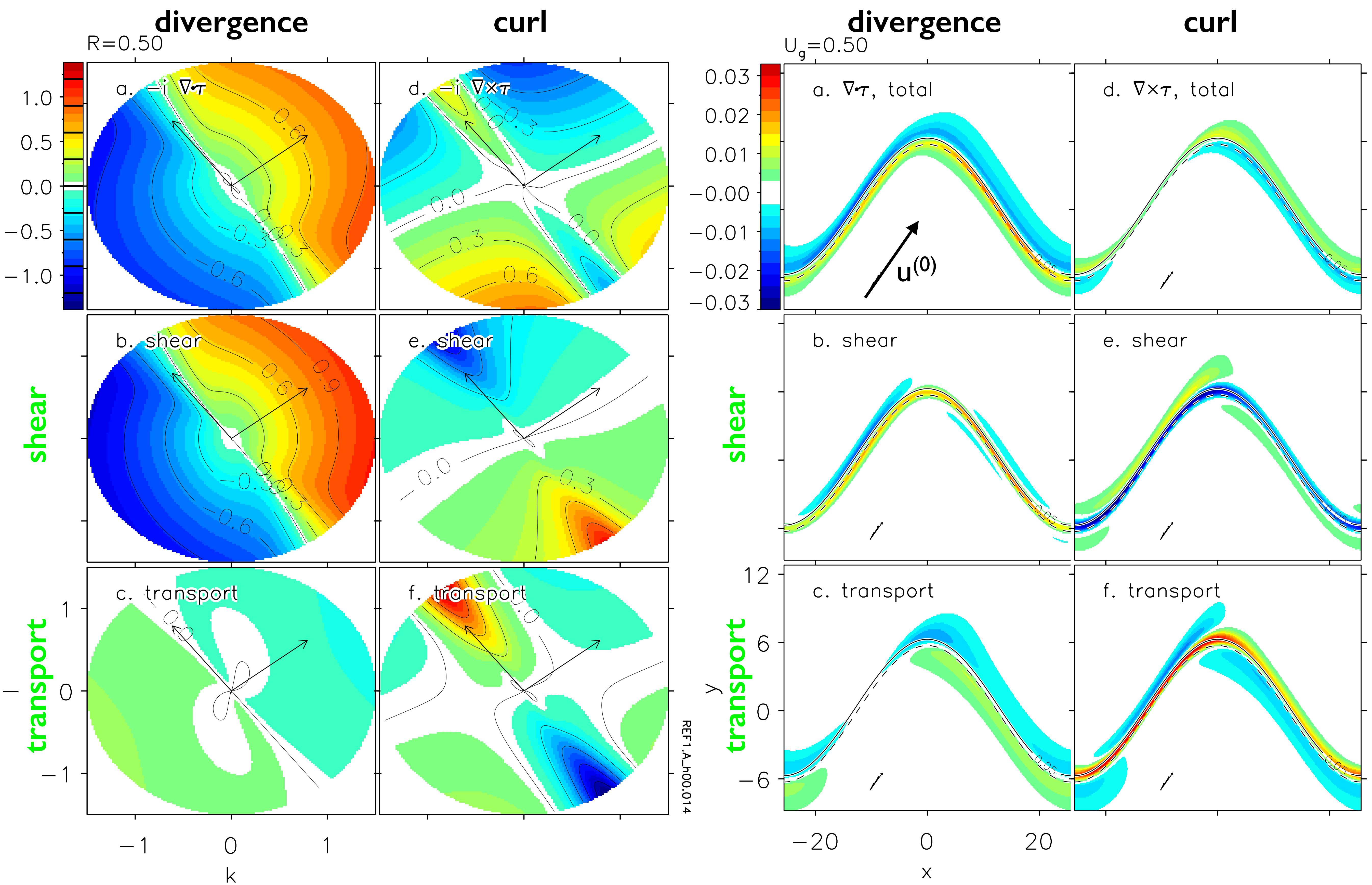
Spin-down

Wave-number space



Spin-down

Wave-number space · Physical space



Conclusions

- Linear model captures observed modulation by SST front of
  - ✓ lower/higher wind speed over cold/warm water, wind stress curl and wind stress divergence
  - ✓ wind stress *divergence*/**curl** aligned with *down*/**cross**-wind gradient of SST
  - ✓ stronger coupling coefficients for wind stress *divergence* than for **curl**
- Dynamics governed by Rossby adjustment, gravity wave response for strong, geostrophic/spin-down for weak cross-frontal winds
- Distinct coupling coefficients of *divergence*/**curl** result from *gravitational sea breeze*/**spin-down**