Characterization of the frontal air-sea interaction by transfer functions

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\[ \nabla \cdot \tau_s > 0 \]
\[ \nabla \times \tau_s > 0 \]

COOL
Cross-front wind
Along-front wind
WARM

Chelton et al., 2004

SCOW project:
QuikSCAT wind stress
AVHRR SST
monthly averages
Risien and Chelton 2008

Southern Hemisphere

\[ \nabla \tau \text{ (Nm}^{-3}\times10^7) \]

\[ \alpha_0 = 0.64, 1.59, 2.66 \]

\[ \nabla T \cdot e_u \text{ (°C/100km)} \]
Model for air-sea interaction at SST fronts

- Reduced gravity model capped by sharp inversion
- Forced by barotropic tropospheric pressure gradient
- Background state: SST constant

\[ h^{(0)} \quad \text{inversion, } \Delta \Theta, \text{ no flux} \]

\[ U_g \quad u^{(0)}, v^{(0)} \text{ Ekman spiral} \]

\[ \Theta^{(0)} \text{ constant} \]

\[ T^{(0)} \text{ constant} \]
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\[ U_g \]

\[ u^{(0)}, v^{(0)} \text{ Ekman spiral} \]
\[ \Theta^{(0)} \text{ constant} \]

\[ T^{(0)} \text{ constant} \]

- consider weak front \( T^{(0)} + \varepsilon T^{(1)} \), linear response
Air-sea interaction at weak SST front

$1^{st}$ order (linear) response

\[ \bar{u}^{(0)} \cdot \nabla \Theta^{(1)} = \gamma (T^{(1)} - \Theta^{(1)}) + A_h \nabla^2 \Theta^{(1)} \]

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

Air-sea interaction at weak SST front

1st order (linear) response

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

\[ \vec{u}^{(0)} \cdot \nabla \vec{u}^{(1)} + w^{* (1)} \partial_s \vec{u}^{(0)} + \hat{e}_3 \times \vec{u}^{(1)} + \nabla h^{(1)} - \partial_s E^{(0)} \partial_s \vec{u}^{(1)} = \vec{F} \]

\[ \vec{u}^{(0)} \cdot \nabla h^{(1)} + \nabla \cdot \vec{u}^{(1)} + \partial_s w^{* (1)} = 0 \]

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

Air-sea interaction at weak SST front

$1^{st}$ order (linear) response

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

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

Pressure gradient mechanism

$$\vec{F} = \nabla \int_{s}^{1} \Theta^{(1)} ds' + \partial_s \left( \delta^{(1)} \frac{\partial E}{\partial \delta} \bigg|_{\delta^{(0)}} \partial_s \vec{u}^{(0)} \right)$$

Vertical mixing mechanism

$$\vec{u}^{(0)} \cdot \nabla \vec{u}^{(1)} + w^* \partial_s \vec{u}^{(0)} + \hat{e}_3 \times \vec{u}^{(1)} + \nabla h^{(1)} - \partial_s E^{(0)} \partial_s \vec{u}^{(1)} = \vec{F}$$

Advection

Coriolis

Back pressure

Background mixing

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

Nondimensionalized by Rossby radius of deformation, boundary layer height, inversion strength etc.

Transfer function

\[ \hat{Z}_k = \hat{A}_k \hat{T}_k \]

real part: in phase relationship between \( Z \) and \( T \)
imaginary part: \( 90^\circ \) phase shifted
Transfer function for wind-stress divergence

Linear model

\[ \hat{Z}_k = \hat{A}_k \hat{T}_k \]
Transfer function for wind-stress divergence
Linear model
\[ \hat{Z}_{k} = \hat{A}_{k} \hat{T}_{k} \]
Transfer function for wind-stress divergence

Linear model

\[ \hat{Z}_k = \hat{A}_k \hat{T}_k \]

Coupling coefficient

\[ \hat{Z}_k = \alpha i \hat{e}_u \cdot \hat{k} \hat{T}_k + \hat{\epsilon} \]
Transfer function for wind-stress divergence

SCOW QuikScat/AVHRR (Risien and Chelton 2008)

1999-2009 monthly averages, Southern Hemisphere

$s$: least square fit slopes to transfer function for $k, l \in [-1,1]$
Transfer function comparison

Linear model

Observations
Transfer function comparison

Linear model

Observations

monthly average
Transfer function comparison

Linear model

Observations

few inertial periods

monthly average
Sub-monthly variations of background wind
CAM5 multi year integration

$u^{(0)}$, submonthly variability, Agulhas, CAM5.HF.32

$\log_{10} \frac{U}{U_{\text{avg}}}$

Angle/$\pi$
Transfer function comparison

Linear model

Observations

smoothed to monthly average
Conclusions

- Transfer functions provide scale-dependent and lagged characterization of atmospheric boundary layer response to mesoscale sea surface temperatures
- Linear model suggests that the transfer function depends on the background wind speed and direction
- Monthly averages smooth out the structure of the transfer function
- Comparison of linear model with estimates of the transfer function is far from perfect but encouraging
- Testing with high resolution AMSR wind and SST products and adjustment of linear model parameters/physics under way