Characterization of frontal air-sea interaction by spectral transfer functions

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SST

AFES model
spatially high pass
90 day average

Speed

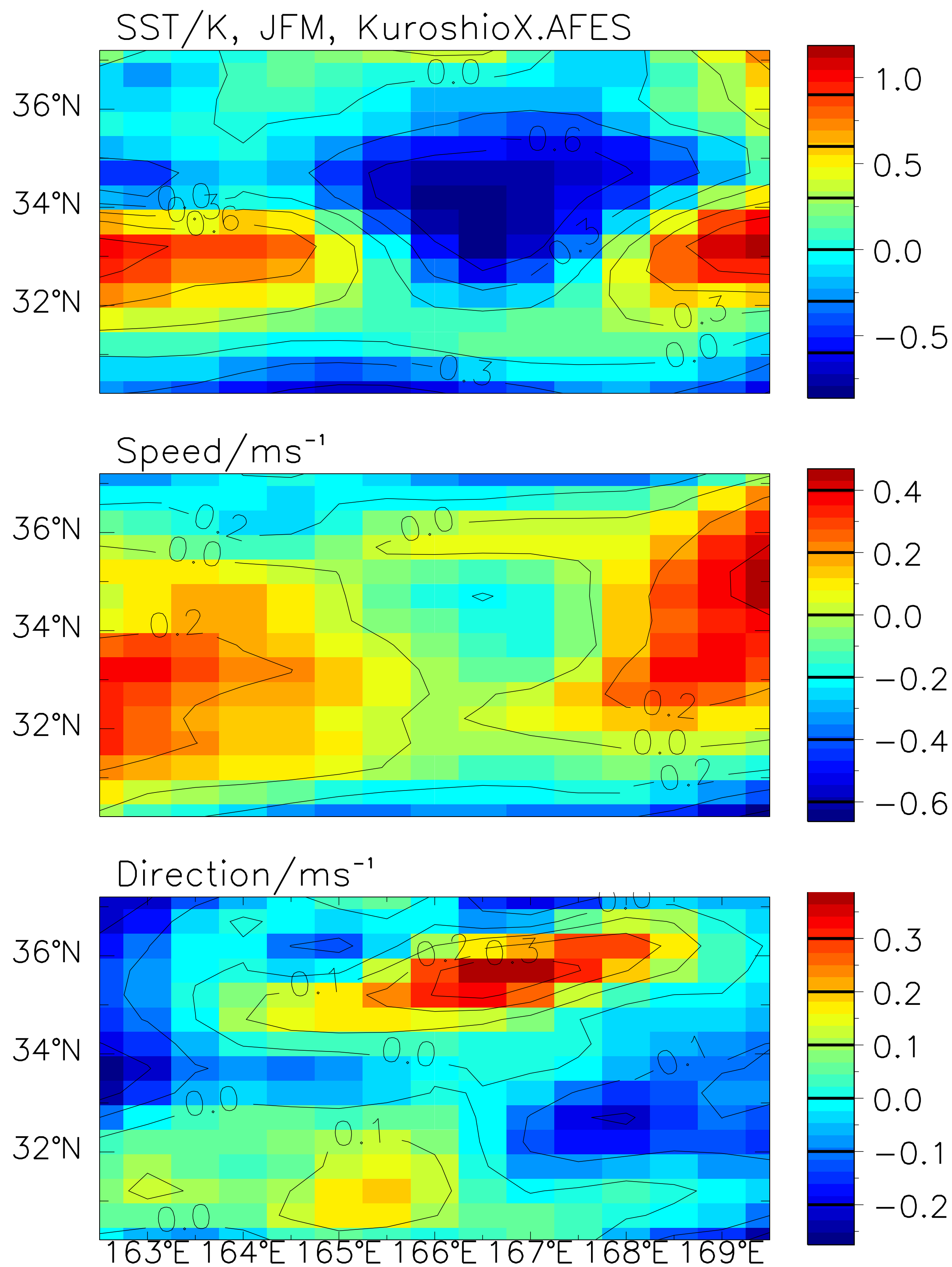
downwind

$$\hat{e}_u \cdot \vec{u}^{(1)}$$

Direction

crosswind

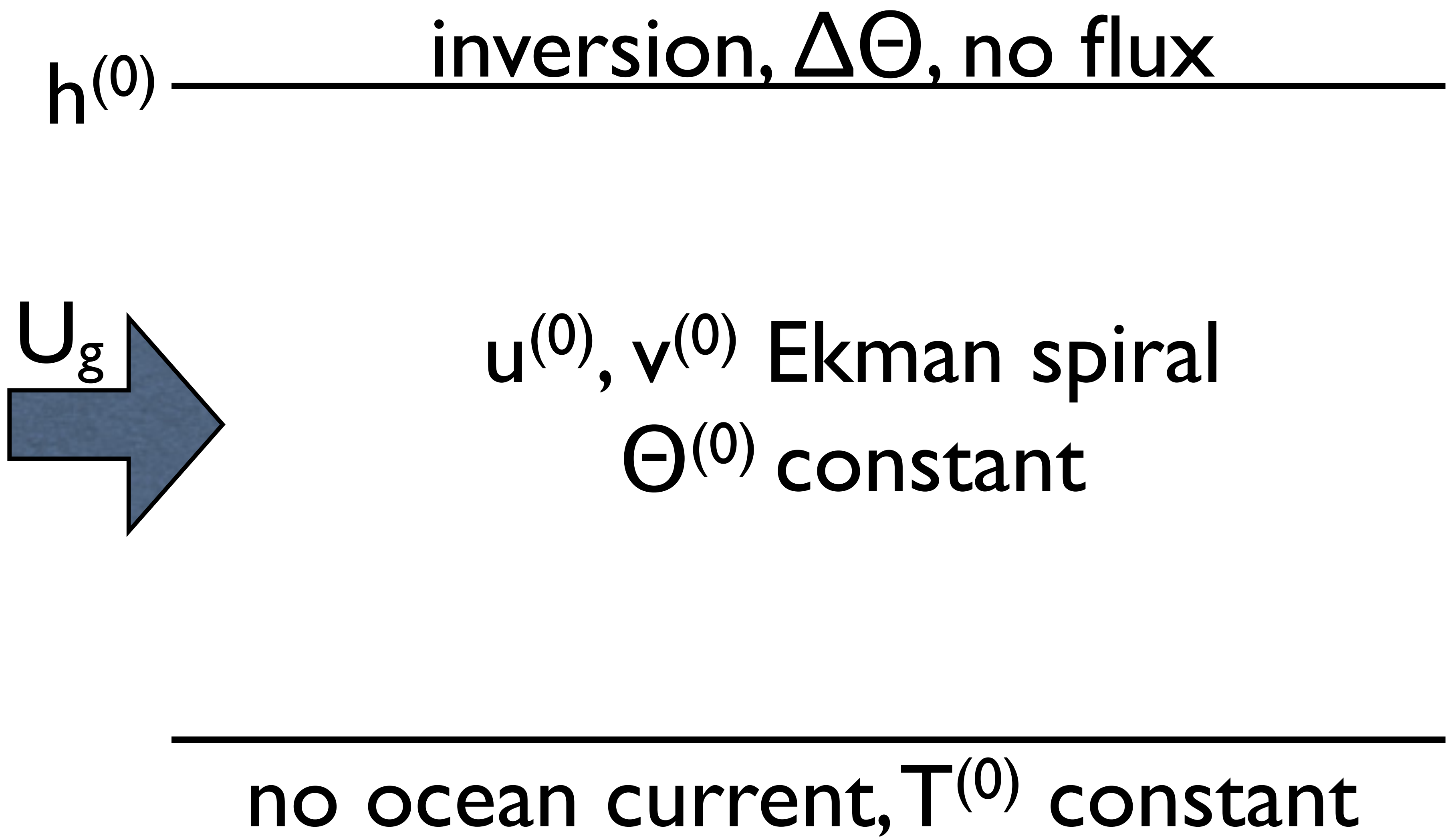
$$\hat{e}_u \times \vec{u}^{(1)}$$



Air-sea interaction at SST fronts

Schneider and Qiu, JAS, 2015

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



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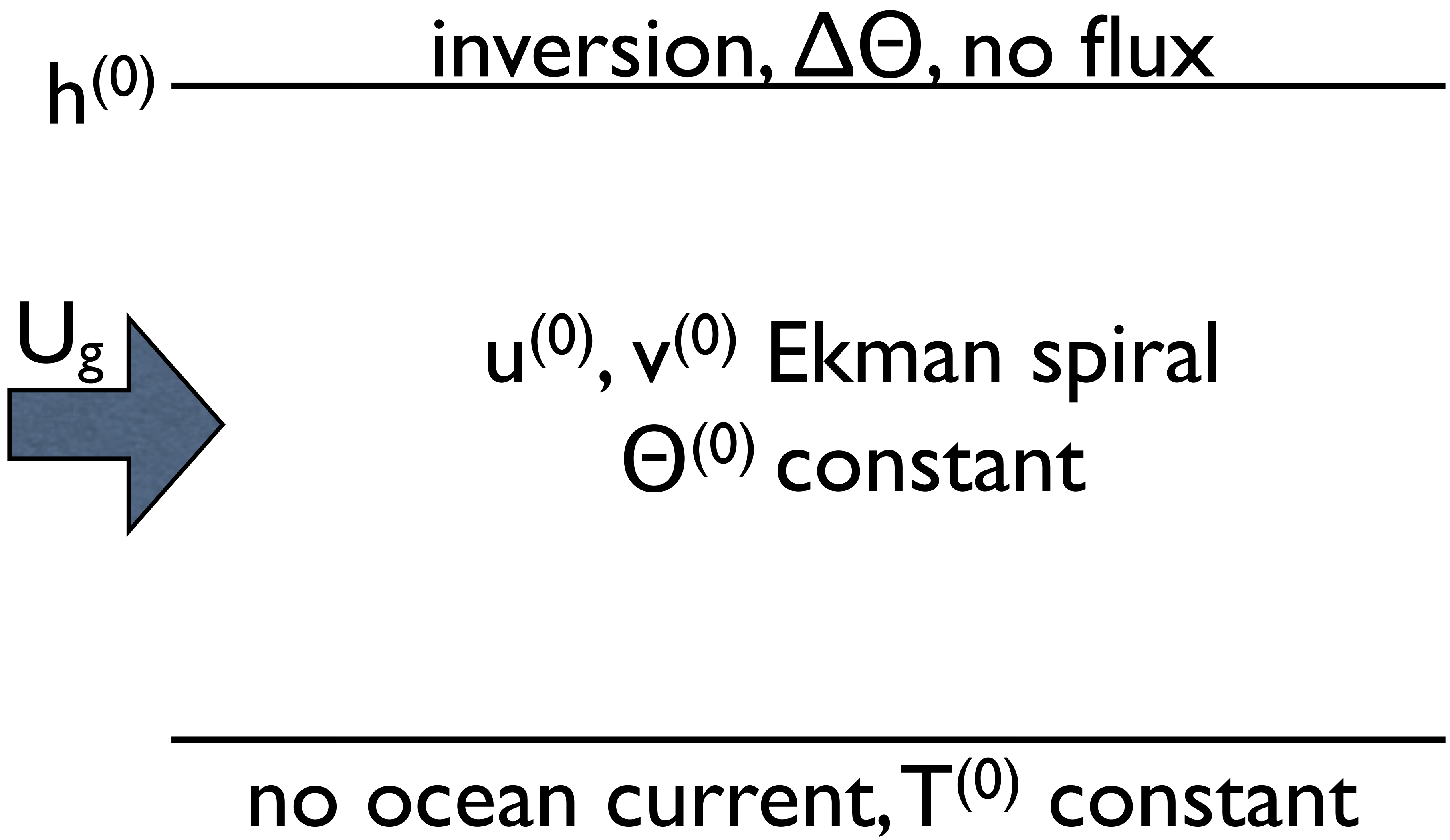


- consider weak fronts $T^{(0)} + \varepsilon\, T^{(1)}$, linear response

Air-sea interaction at weak SST front

Schneider and Qiu, JAS, 2015

1st order (linear) response

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

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

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

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

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

air-sea temperature differences modulates vertical eddy viscosity

Transfer function

Find solution in wavenumber space

dependent
variables

$$\mathbf{A}_{\vec{k}} \; \mathbf{\Phi}_{\vec{k}}^{(1)} = \mathbf{T}_{\vec{k}}^{(1)}$$

Operator
matrix

spectral SST
amplitudes

Transfer function

Find solution in wavenumber space

dependent variables

$$\mathbf{A}_{\vec{k}} \; \mathbf{\Phi}_{\vec{k}}^{(1)} = \mathbf{T}_{\vec{k}}^{(1)}$$

Operator matrix

spectral SST amplitudes

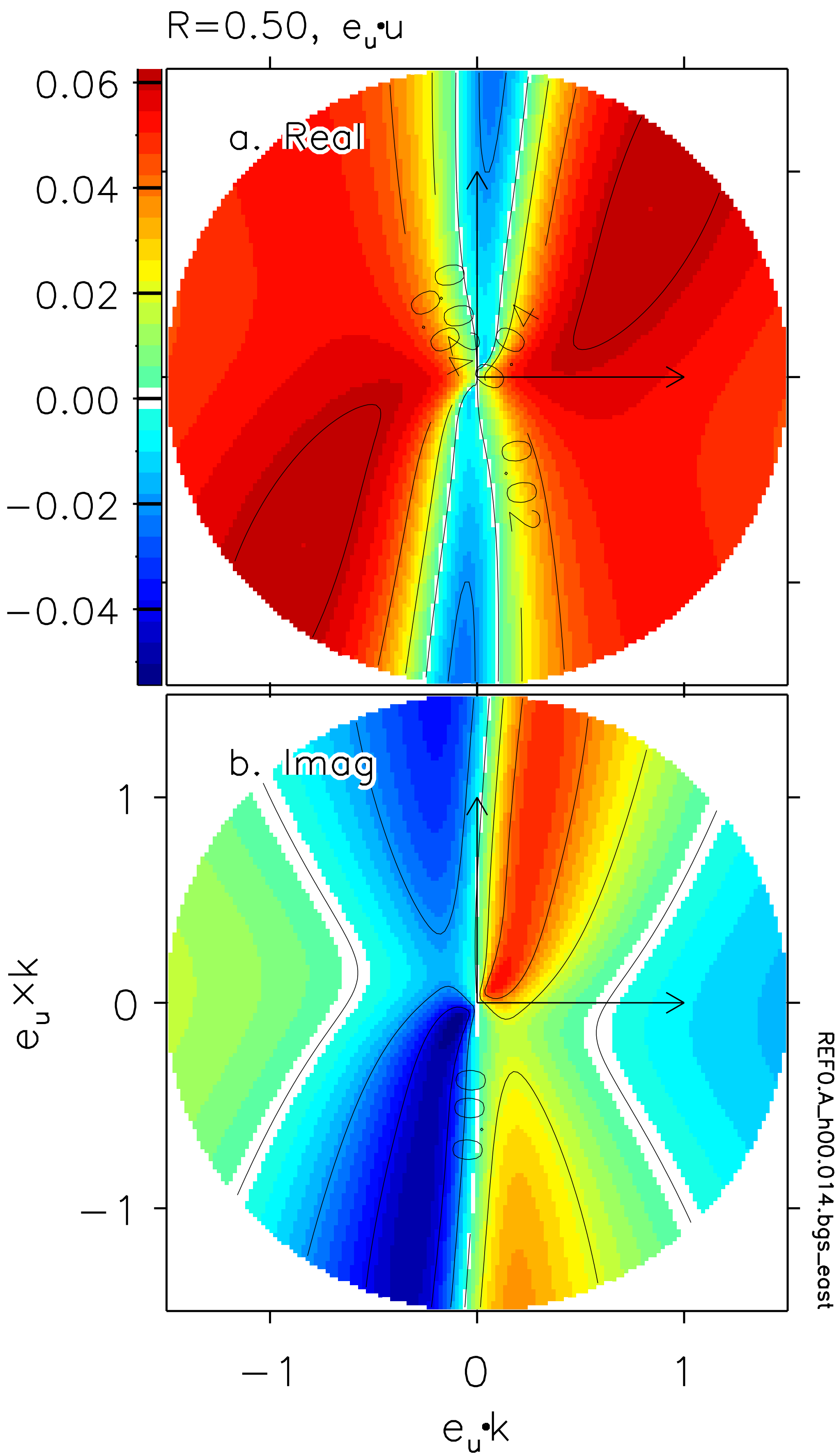
$$\boxed{\mathbf{\Phi}_{\vec{k}}^{(1)} = \mathbf{A}_{\vec{k}}^{-1} \; \mathbf{T}_{\vec{k}}^{(1)}}$$

Transfer or spectral response function
dependent on background wind speed, direction
mixing formulation

Surface wind transfer function

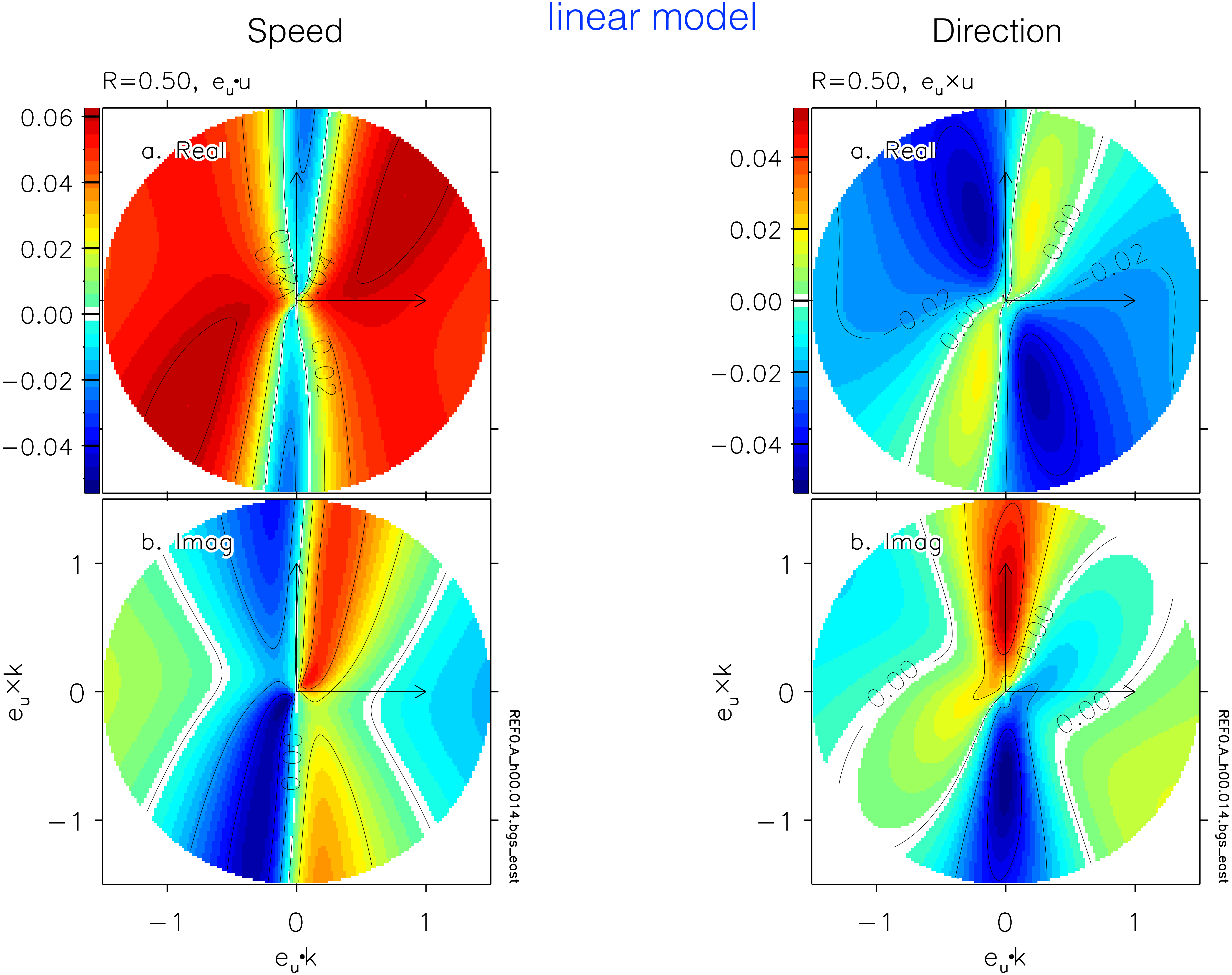
linear model

Speed



Surface wind transfer function

linear model



Atmospheric model for the Earth Simulator
AFES v3

T239, L48 (approx. 59km grid spacing)
NOAA 1/4° SST (Reynolds et al. 2007)

1982-2000, daily averages
Southern Ocean, 0°-360°, 60°S-44°S
Kuroshio Extension, 125°E-180°, 30°N-46°N

January-March

Transfer function estimated from 8°x8° 'tiles' from AFES output

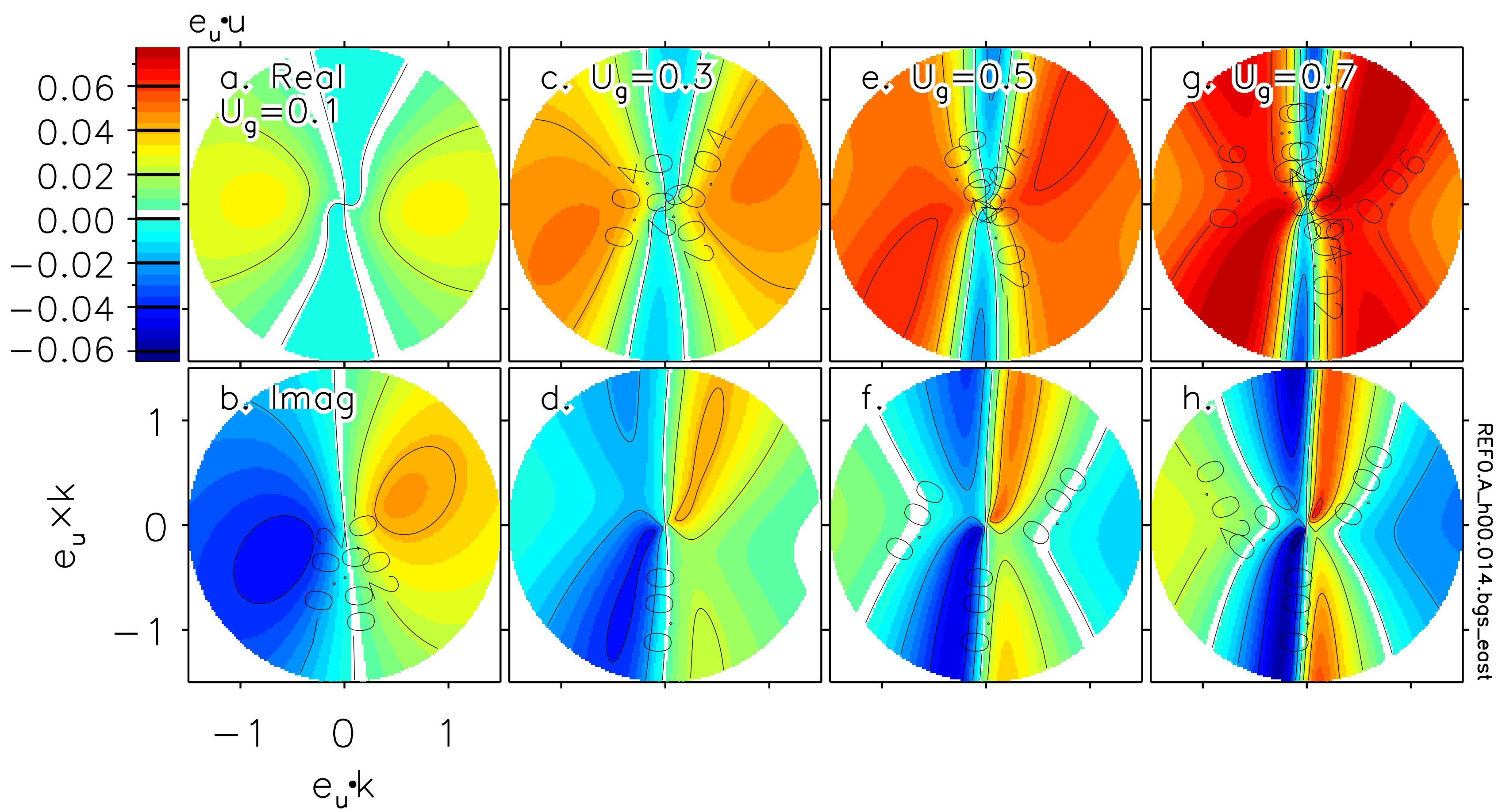
Ohfuchi et al., 2004: 10-km mesh mesoscale resolving simulations of the global atmosphere on the Earth Simulator: Preliminary outcomes of AFES (AGCM for the Earth Simulator). *J. Earth Simulator*, **1**, 8-34.

Enomoto et al. 2008: Description of AFES 2: Improvements for high-resolution and coupled simulations. In: High Resolution Numerical Modeling of the Atmosphere and Ocean, Springer New York, 77-97.

Kuwano-Yoshida, A., S. Minobe and S.-P. Xie, 2010: Precipitation response to the Gulf Stream in an atmospheric GCM. *J. Climate*, **23**, 3676-3698.

Kuwano-Yoshida, A., T. Enomoto and W. Ohfuchi, 2010: An improved PDF cloud scheme for climate simulations. *Quart. J. Roy. Met. Soc.*, **136**, 1583-1597.

Speed
Southern Ocean, JFM

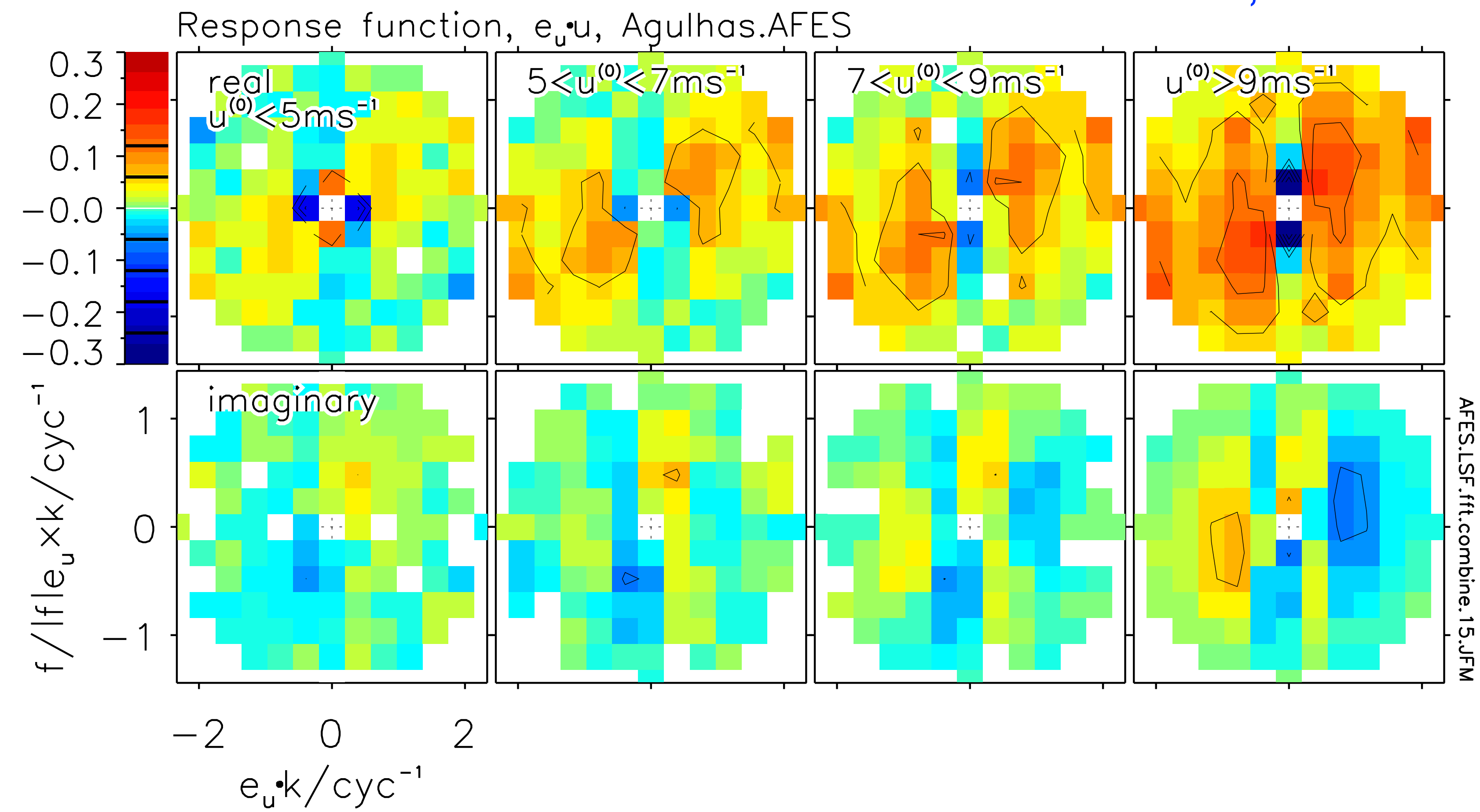


linear model

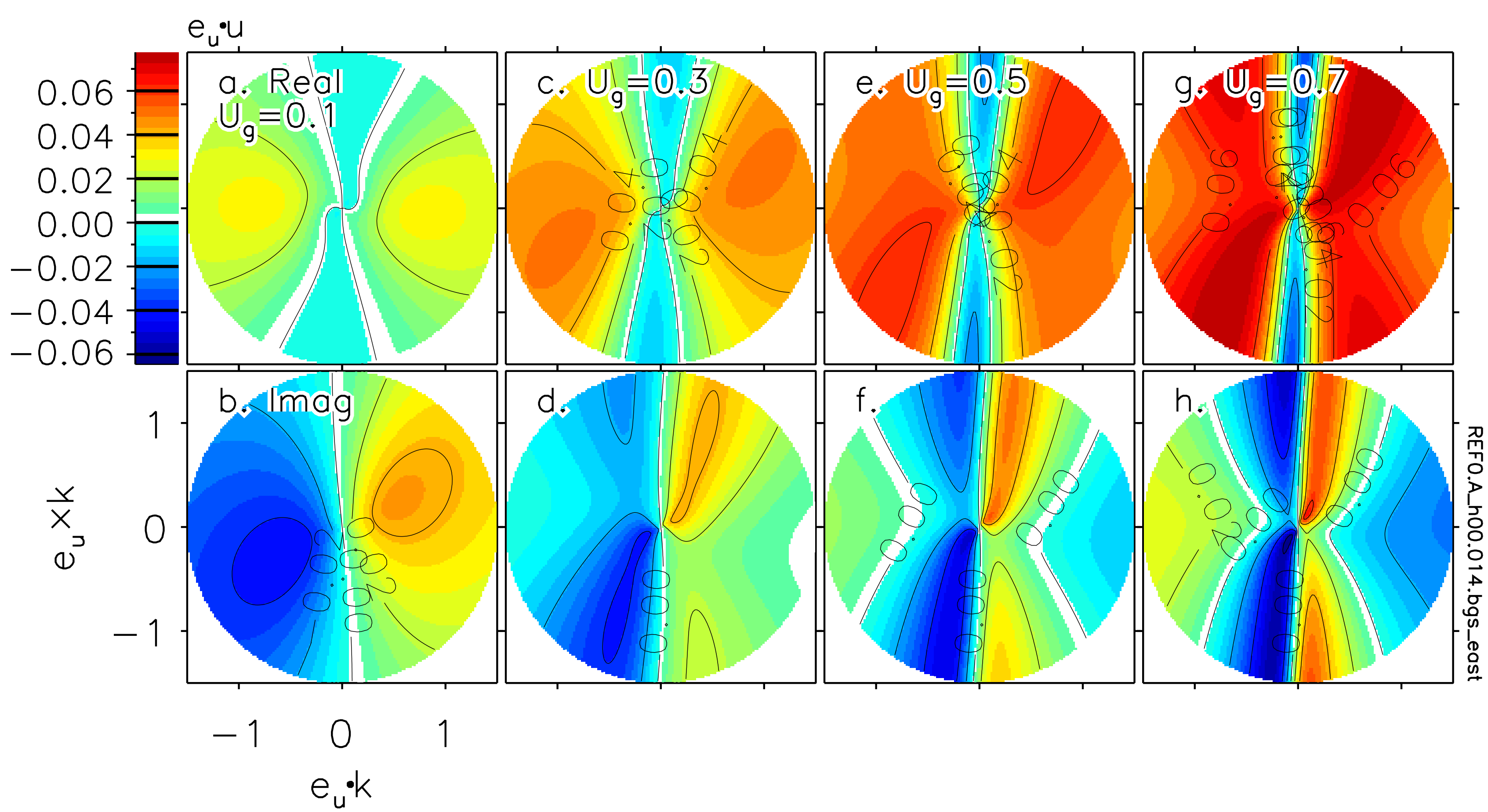
Speed scale: Gravity wave speed/inversion strength factor of ~2

Speed

Southern Ocean, JFM



AFES



linear model

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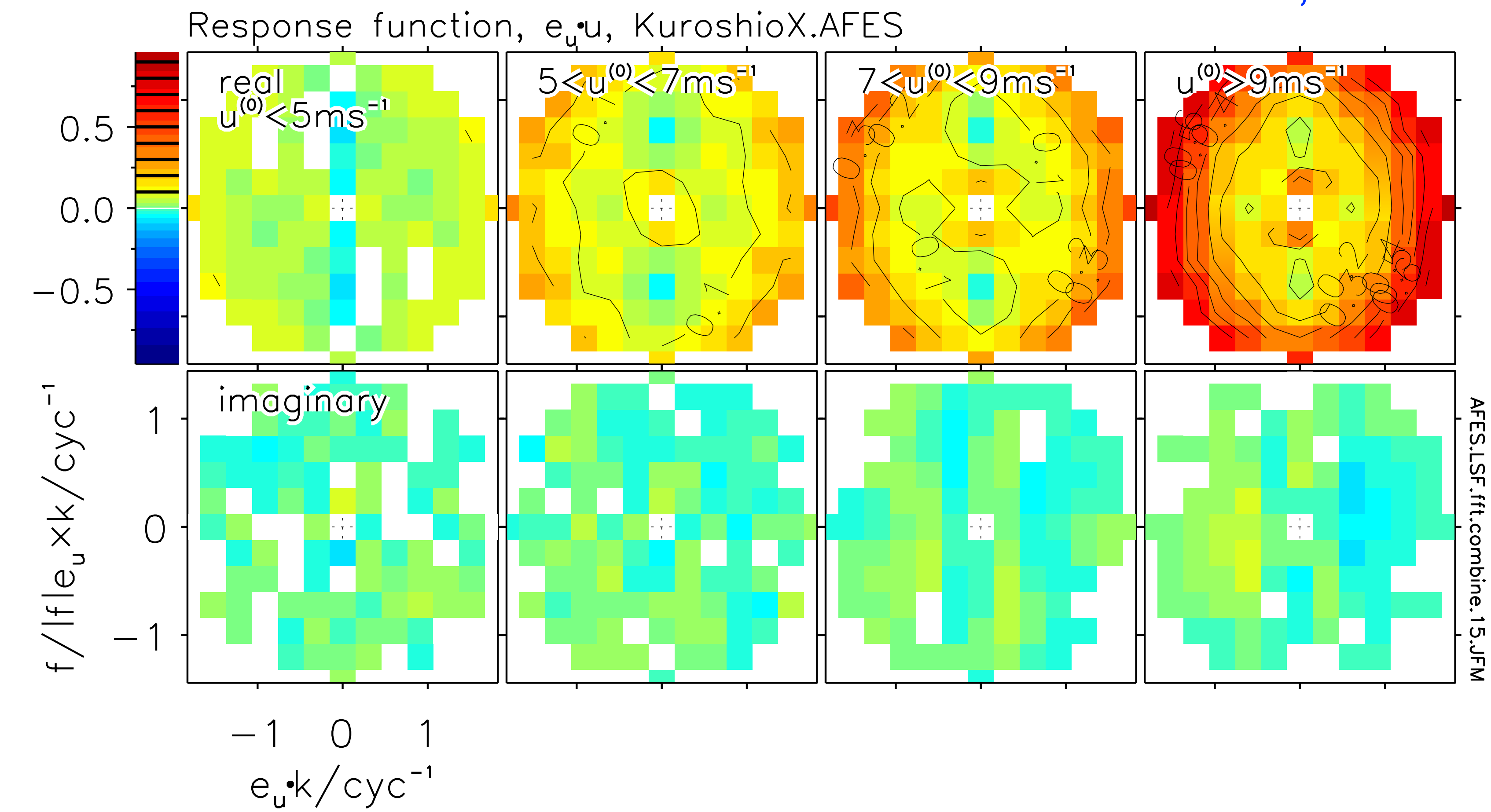
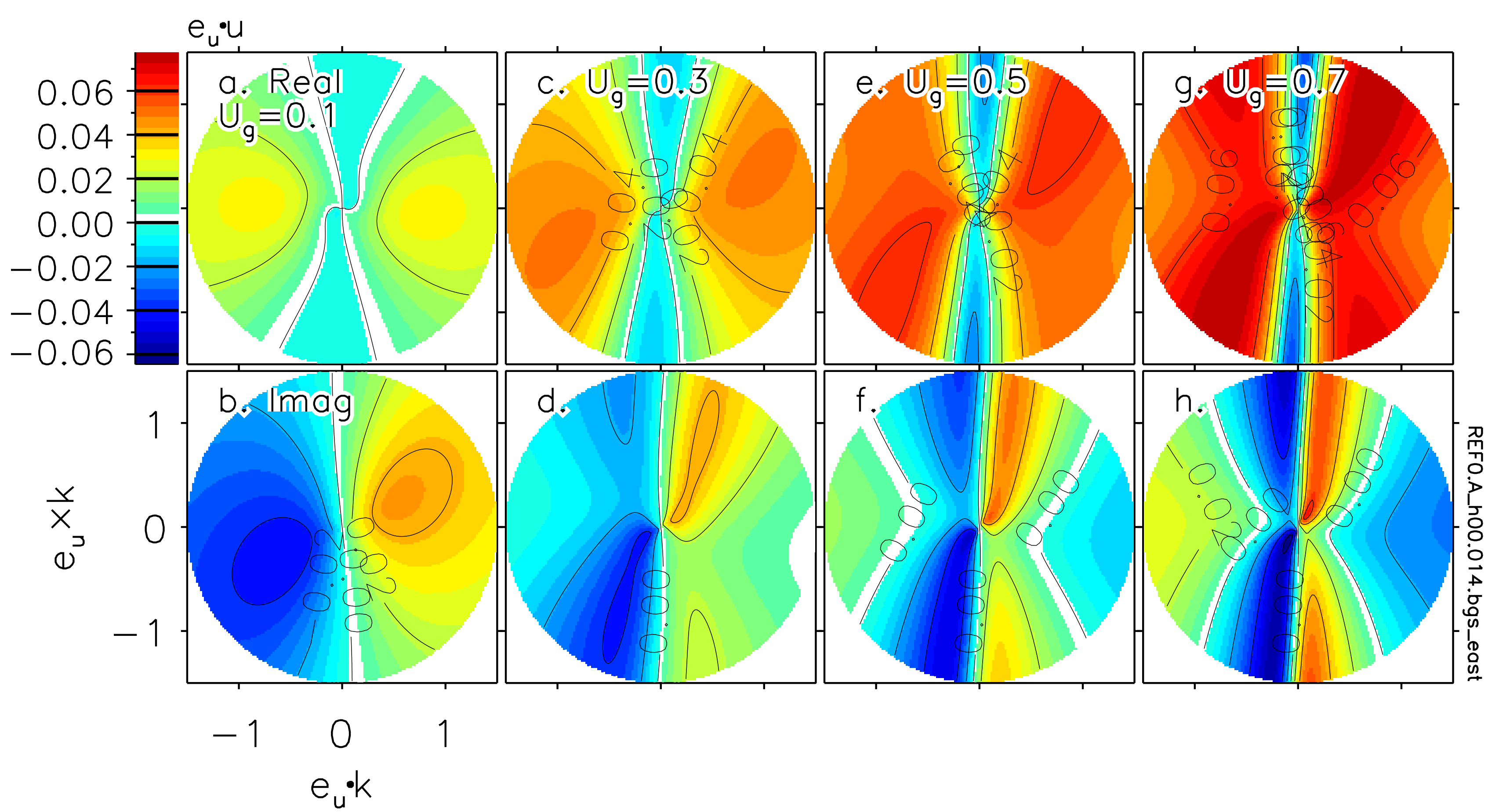
Speed

Kuroshio Extension, JFM



AFES



linear model

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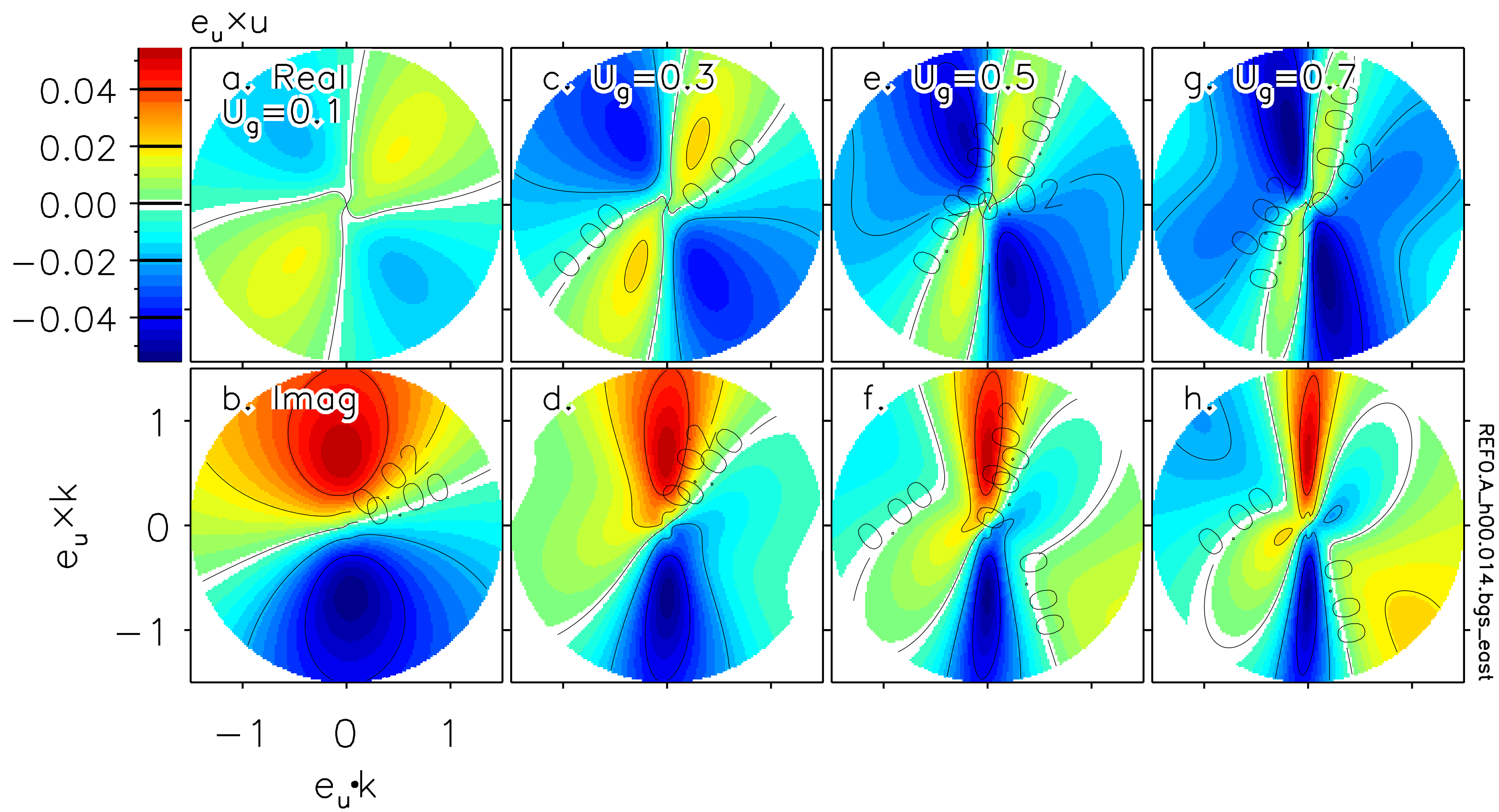
Direction

Southern Ocean, JFM



linear model

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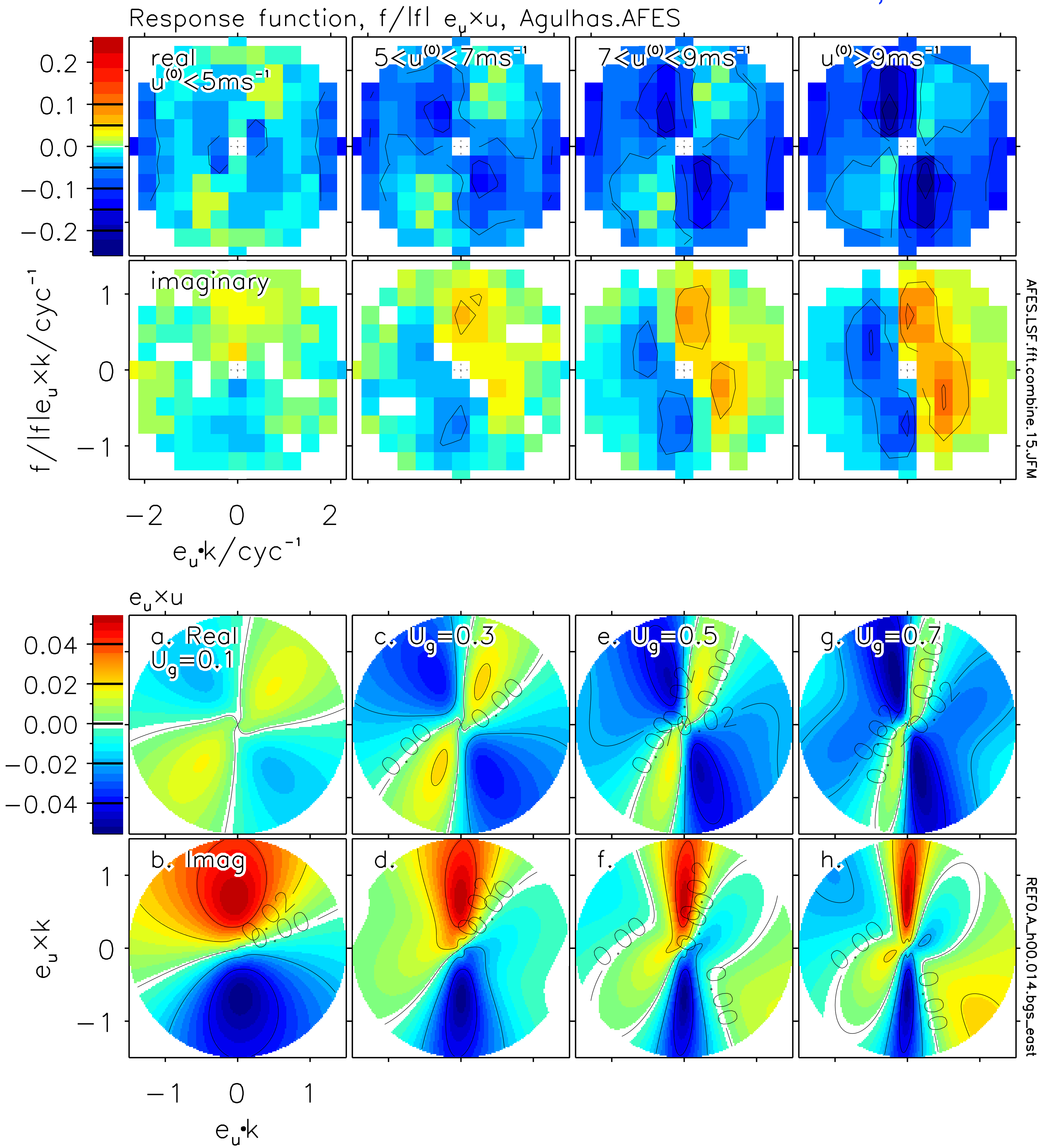
Direction

Southern Ocean, JFM



AFES

linear model

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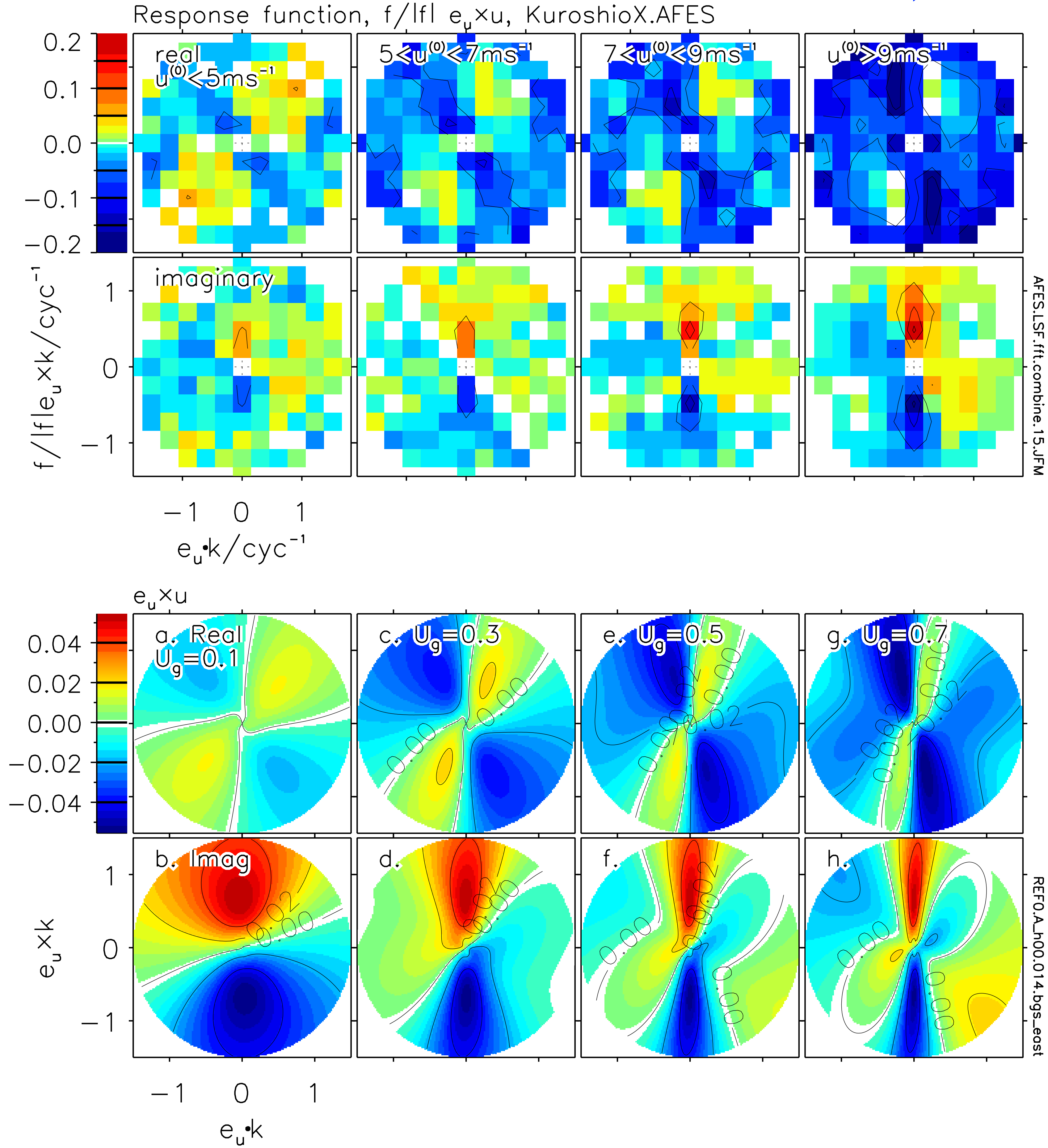
Direction

Kuroshio Extension, JFM



AFES

linear model

Speed scale: Gravity wave speed/inversion strength factor of ~2

Conclusions

- Spectral transfer functions of the SST induced atmospheric boundary layer response extend coupling coefficients to include scale dependence and spatial lags.

- Comparison of spectral transfer functions based on AFES compare favorably with the linear model in the Southern Ocean and the Kuroshio Extension. Difference may be due to the vertical mixing formulation.