AMSU[1] Observations of SST[2] Influence on the Troposphere over the Gulf Stream

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List of Acronyms:

[1] AMSU = Advanced Microwave Sounding Unit

[2] SST = Sea Surface Temperature

[3] CIOSS = Cooperative Institute for Oceanographic Satellite Studies, Oregon State University

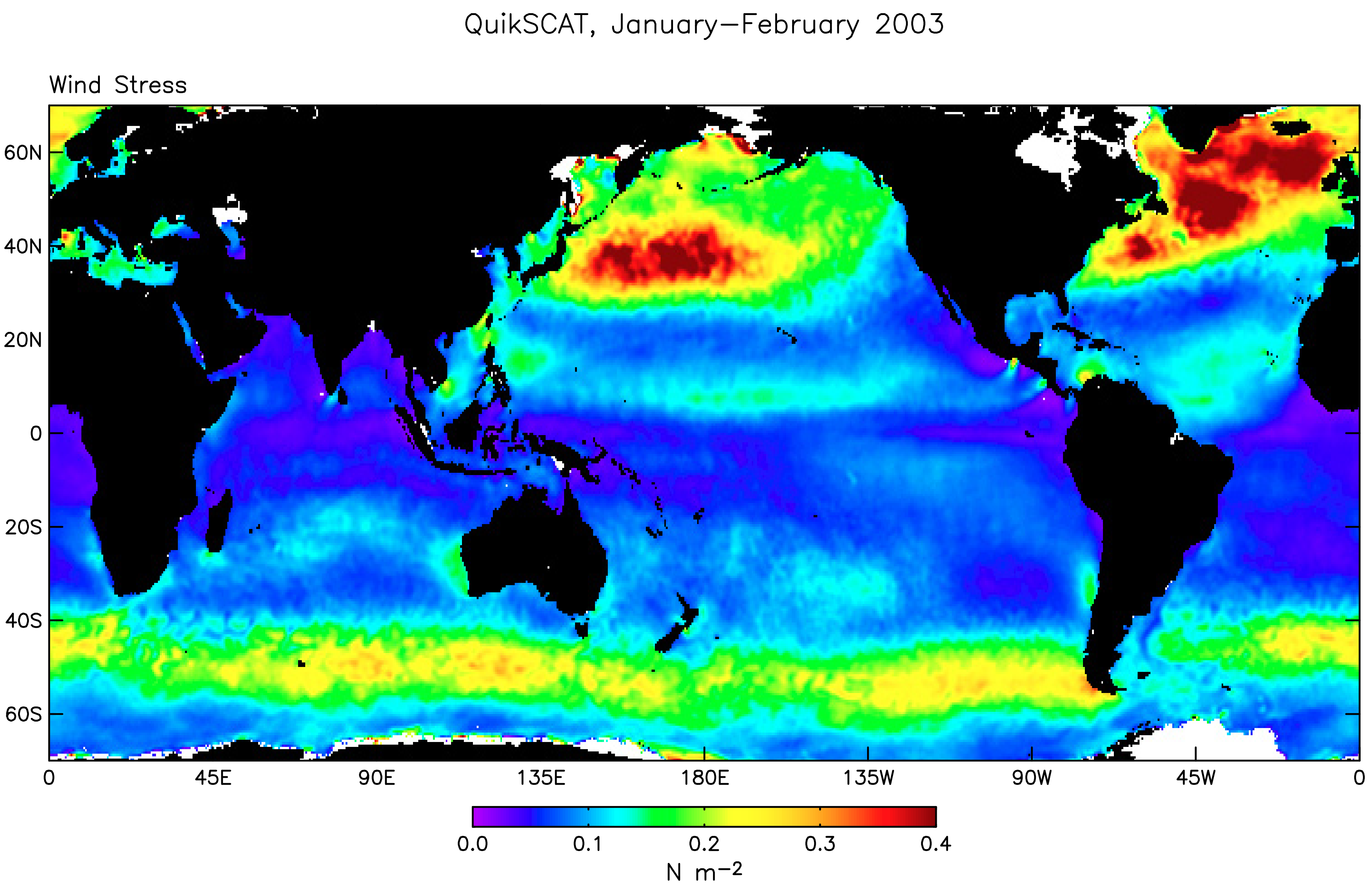
[4] CIRA = Cooperative Institute for Research in the Atmosphere, Colorado State University

[5] NESDIS/RAMMB = National Environmental Satellite and Data Information Service/ Regional and Mesoscale Meteorology Branch

Overview

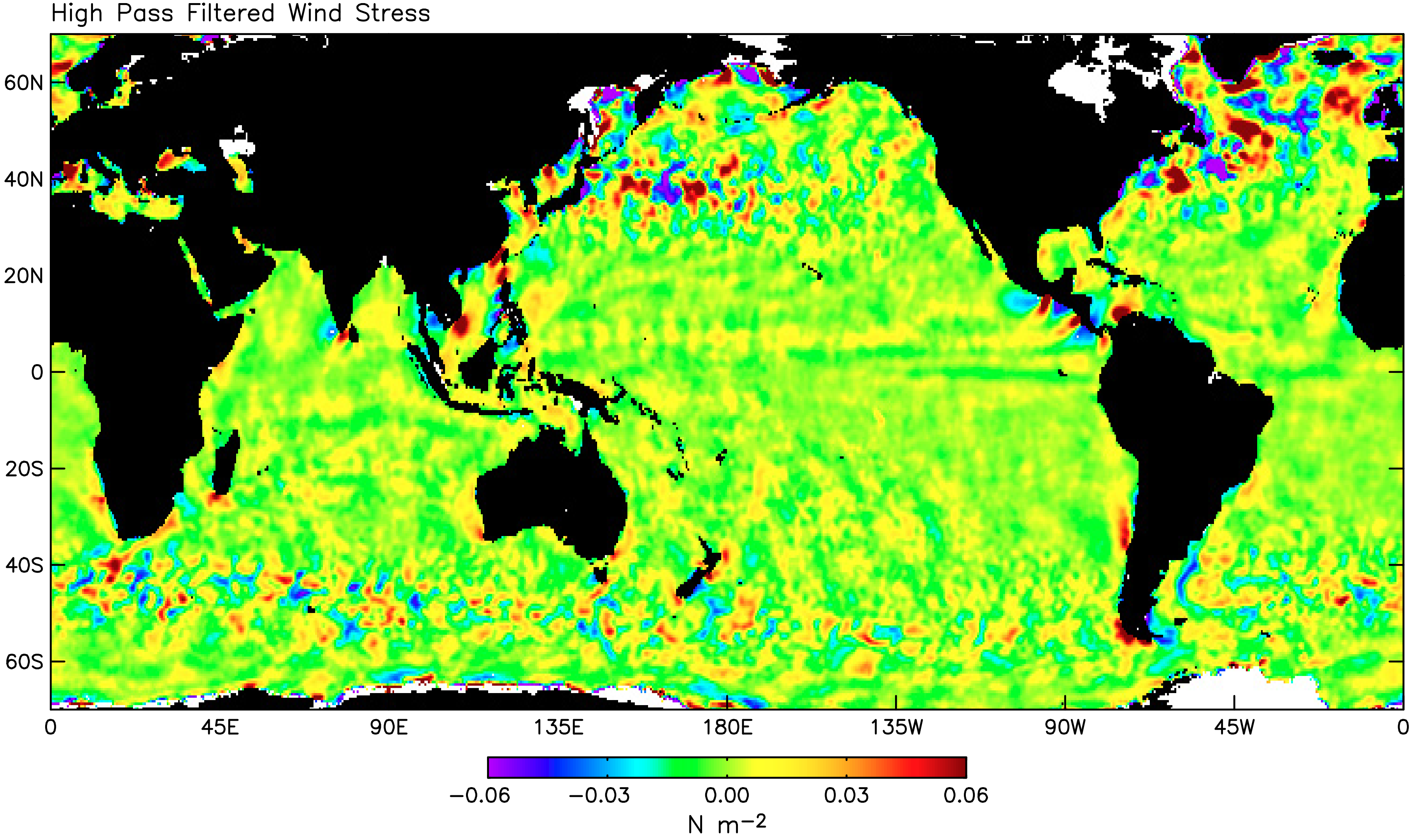
- Brief review of SST influence on surface winds from QuikSCAT and AMSR.
- Background motivation for analysis of AMSU winds in the Gulf Stream region.
  - *Minobe et al. (2008) model-based analysis of SST influence on the troposphere.*
  - *Underestimation of surface wind response to SST in the ECMWF model used in the Minobe et al (2008) study suggests that it likely underestimates the tropospheric response as well.*
- Estimates of temperature, vorticity, vertical velocity, and divergence in the troposphere from AMSU temperature profiles in the Gulf Stream region in February 2007.

2-Month Average Wind Stress Magnitude



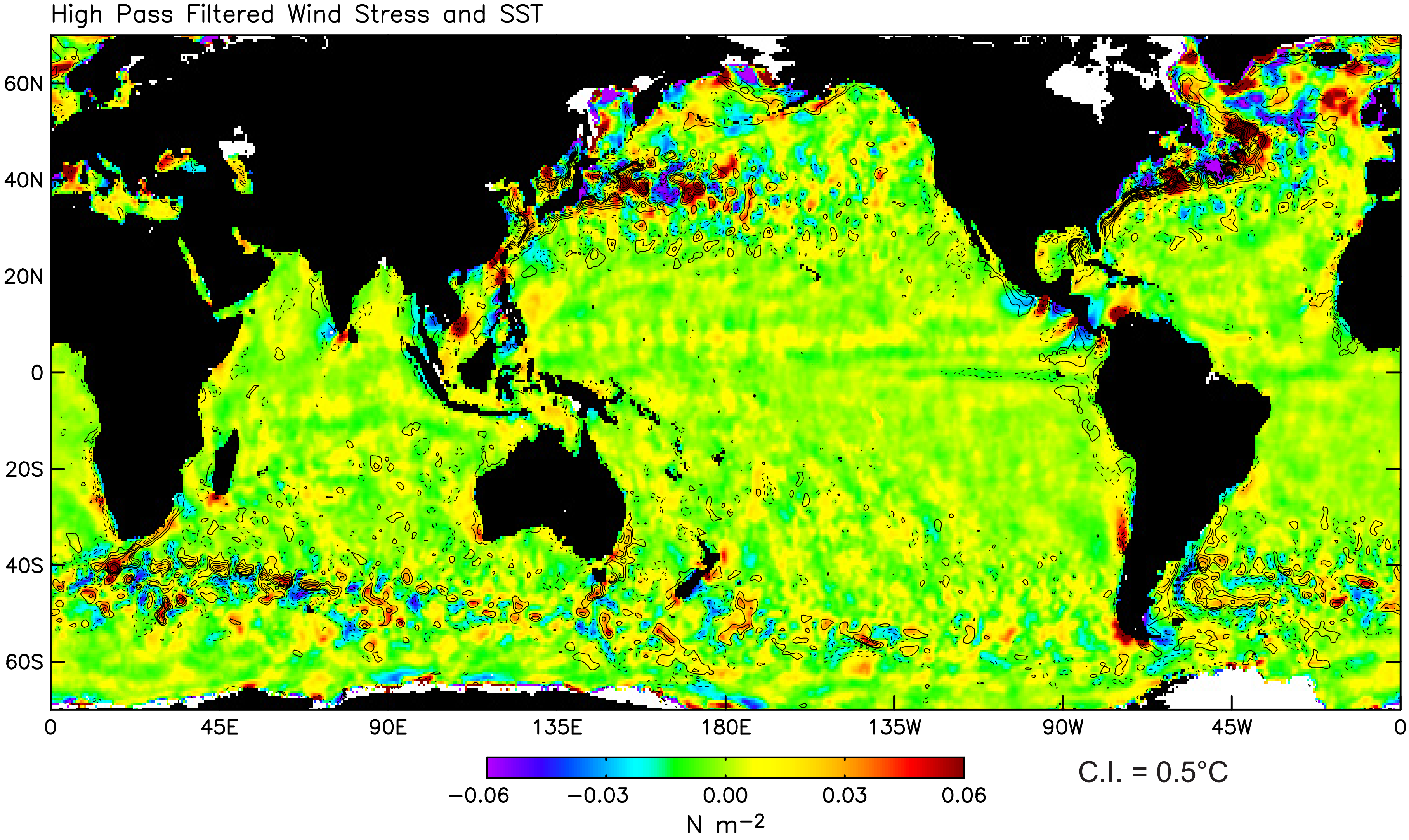
2-Month Average Wind Stress Magnitude
(Spatially High-Pass Filtered)

QuikSCAT, January–February 2003

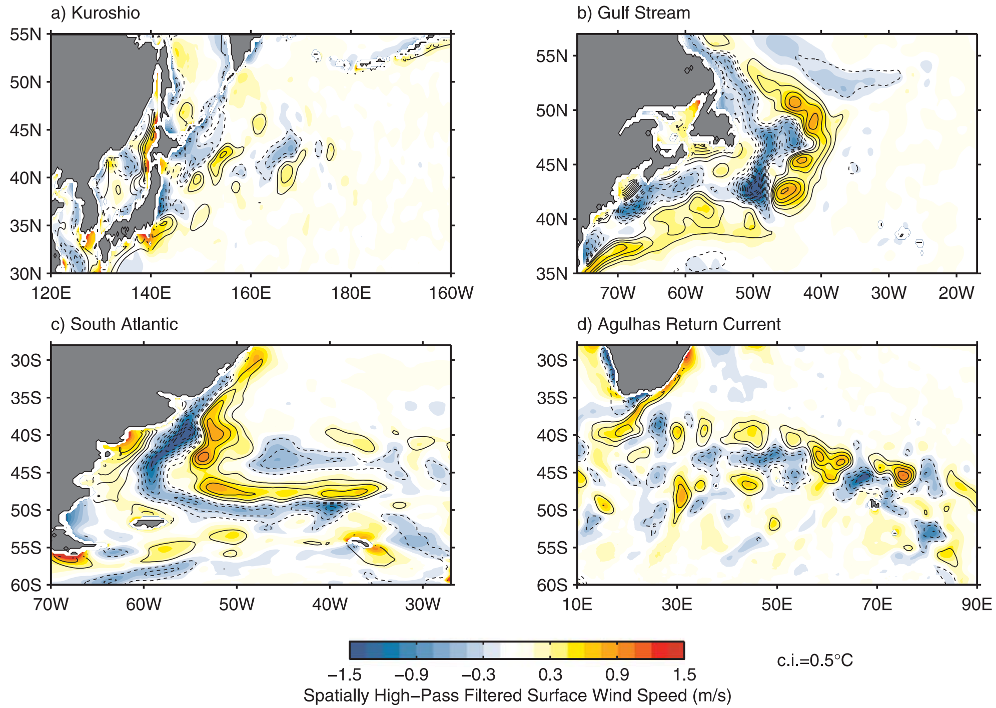


2-Month Average Wind Stress Magnitude and SST
(Spatially High-Pass Filtered)

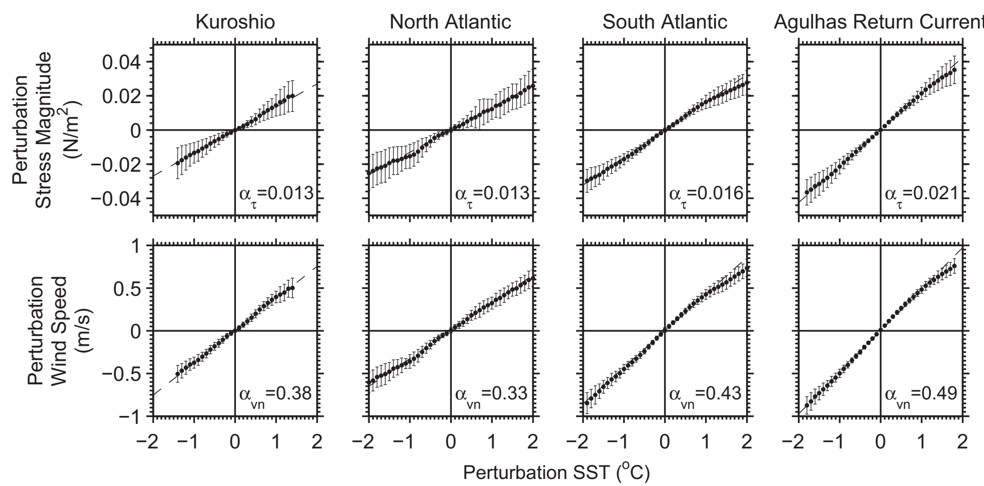
QuikSCAT, January–February 2003



Spatially High-Pass Filtered 6-Year Averages of Wind Speed with Contours of SST



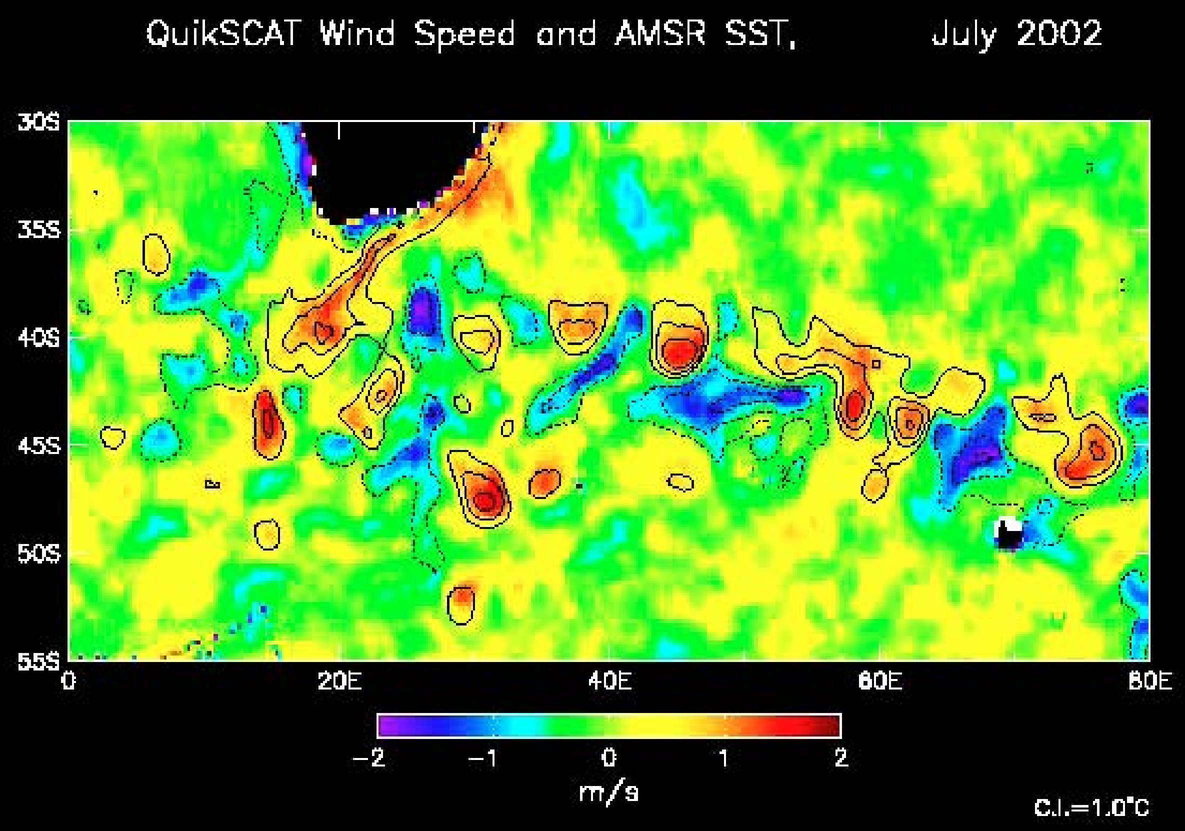
Linear Relationships Between Wind Stress and SST and Between Wind Speed and SST



From O'Neill et al. (2010a; 2010b)

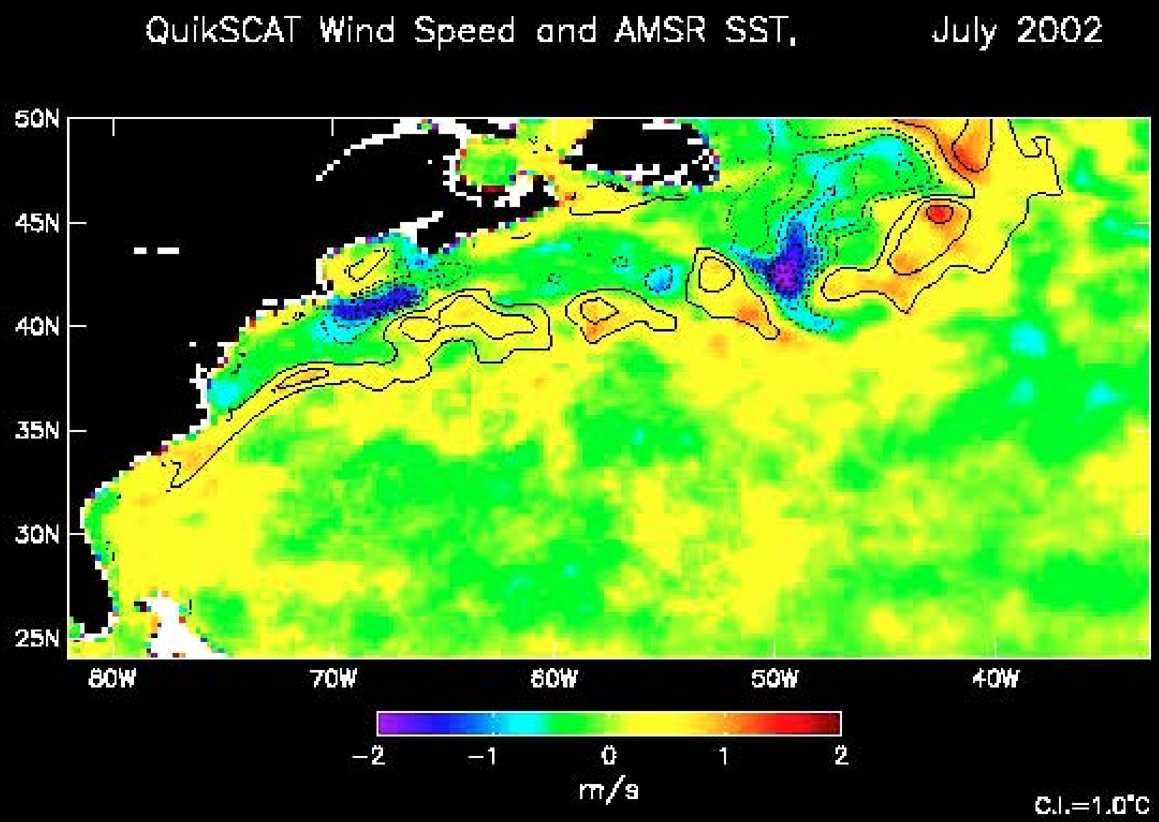
Animation of Spatially High-Pass Filtered Monthly Average SST and Wind Stress Magnitude in the Agulhas Return Current Region

(July 2002 - December 2009)

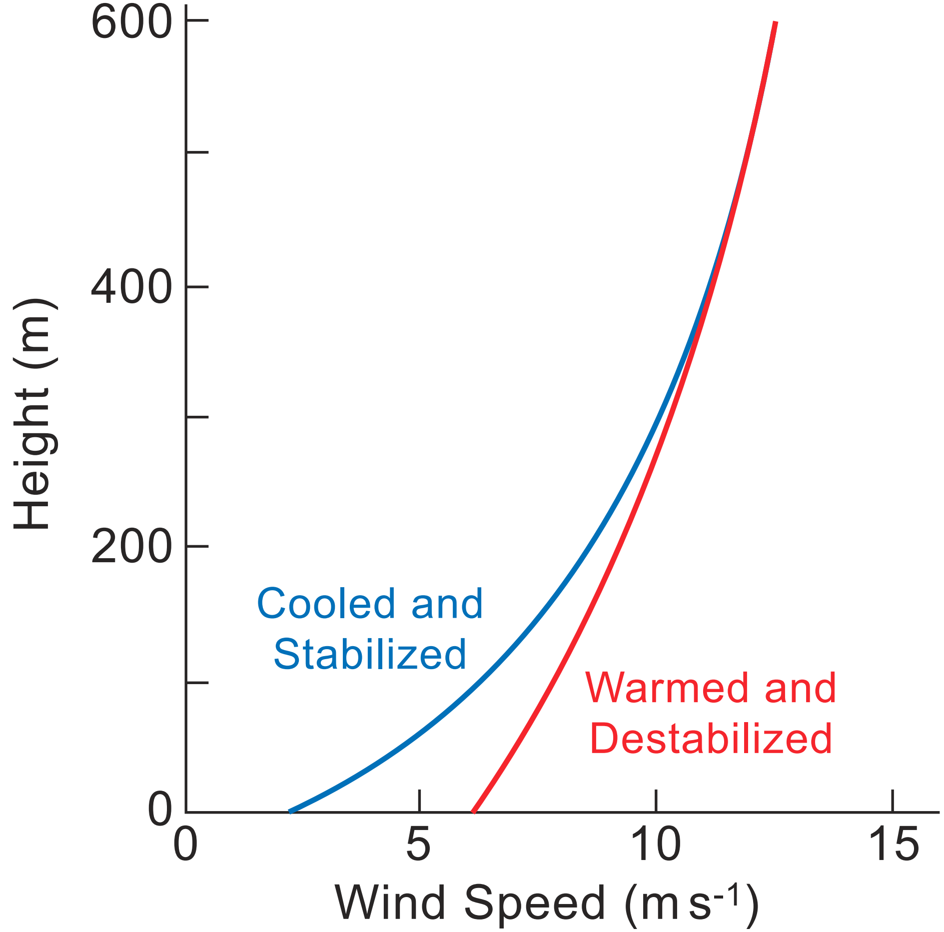


Animation of Spatially High-Pass Filtered Monthly Average SST and Wind Stress Magnitude in the Gulf Stream Region

(July 2002 - December 2009)



Schematic Summary of SST Influence on the Wind Speed Profile in the Marine Atmospheric Boundary Layer



This is similar to diurnal variation of the atmospheric boundary layer over land:

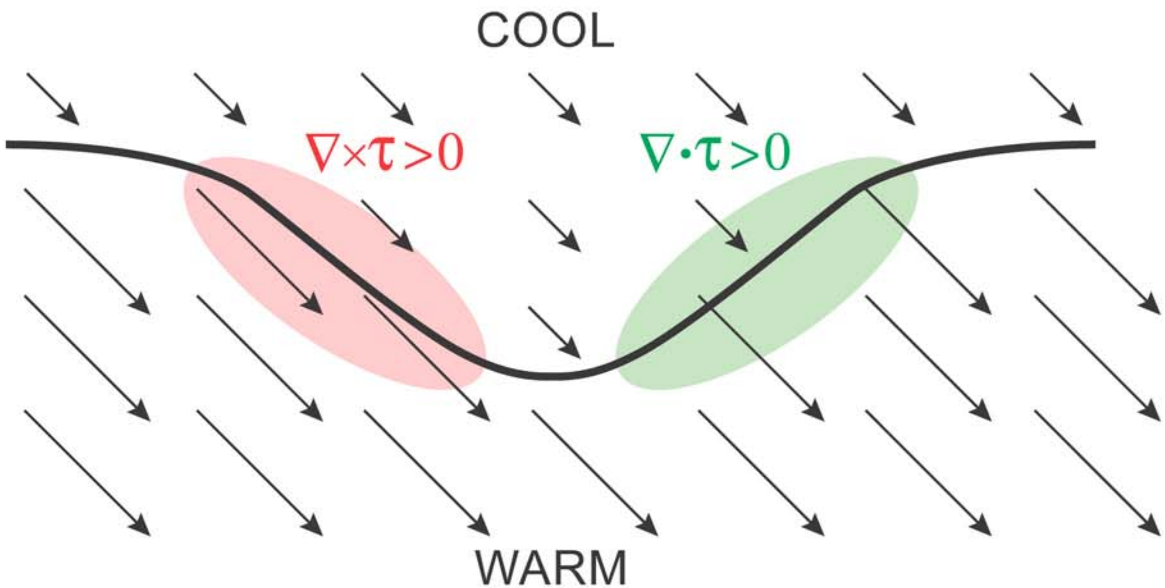
- *nocturnal stable boundary layer from radiative cooling*
- *daytime unstable boundary layer from solar heating of the land*

Note that vertical turbulent mixing is not the only term that is important in the momentum balance. The nonlinear advection and pressure gradient terms are also important, especially the latter.

This coupling between SST on scales smaller than ~1000 km is opposite the negative correlation that occurs on basin scales:

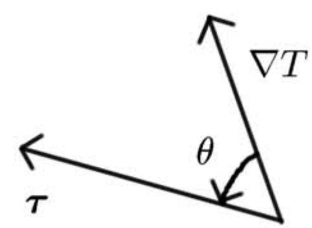
- *surface winds are <u>positively</u> correlated with SST on these small scales.*

SST Effects on the Curl and Divergence of Surface Wind Stress



Wind Stress Curl $\quad \nabla \times \boldsymbol{\tau} \sim \underbrace{\nabla T \times \hat{\boldsymbol{\tau}} = |\nabla T| \sin\theta}_{\text{Crosswind SST Gradient}}$

Wind Stress Divergence $\quad \nabla \cdot \boldsymbol{\tau} \sim \underbrace{\nabla T \cdot \hat{\boldsymbol{\tau}} = |\nabla T| \cos\theta}_{\text{Downwind SST Gradient}}$



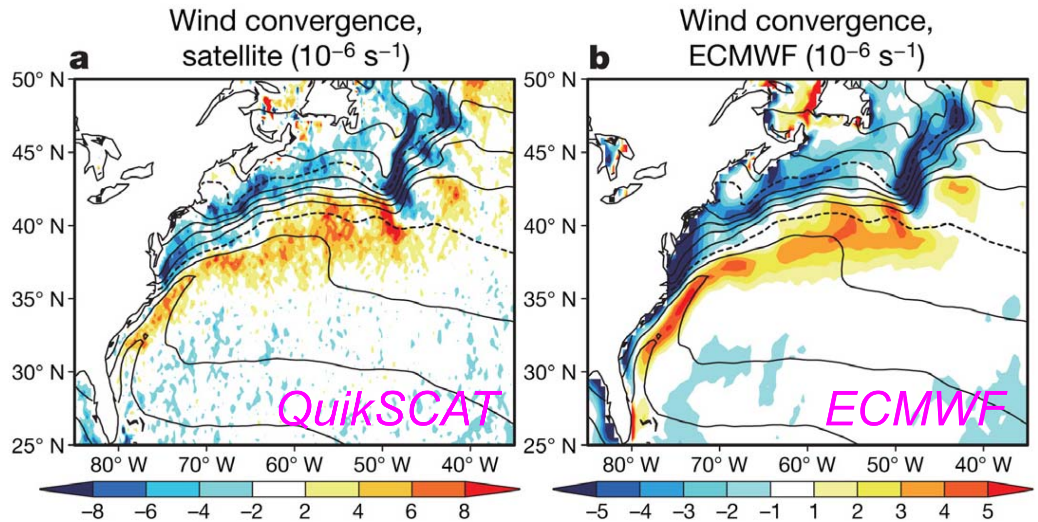
Influence of the Gulf Stream on the troposphere

Shoshiro Minobe[1], Akira Kuwano-Yoshida[2], Nobumasa Komori[2], Shang-Ping Xie[3,4] & Richard Justin Small[3]

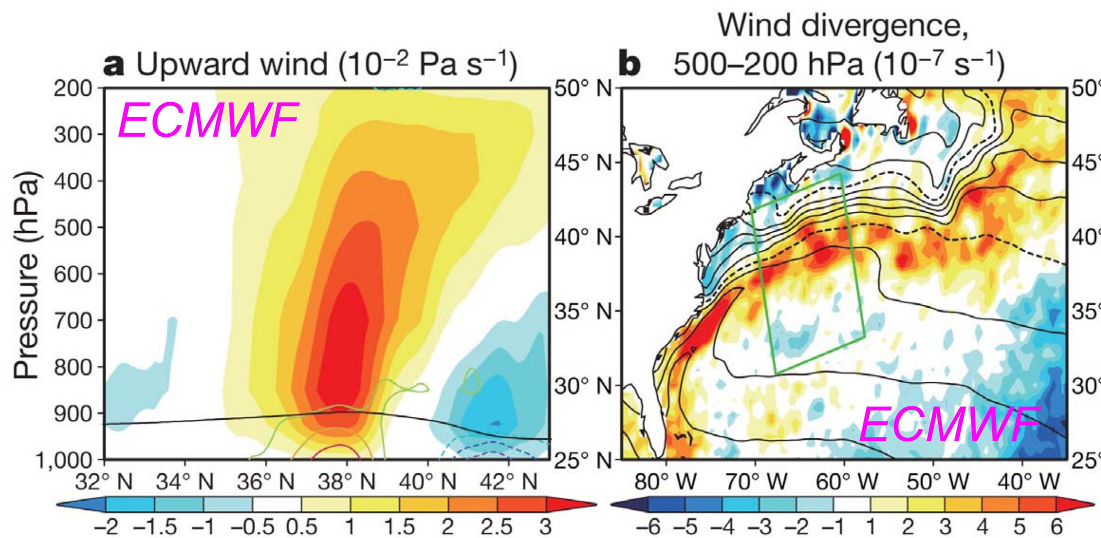
Vol 452 | 13 March 2008 | doi:10.1038/nature06690

Surface Wind Convergence

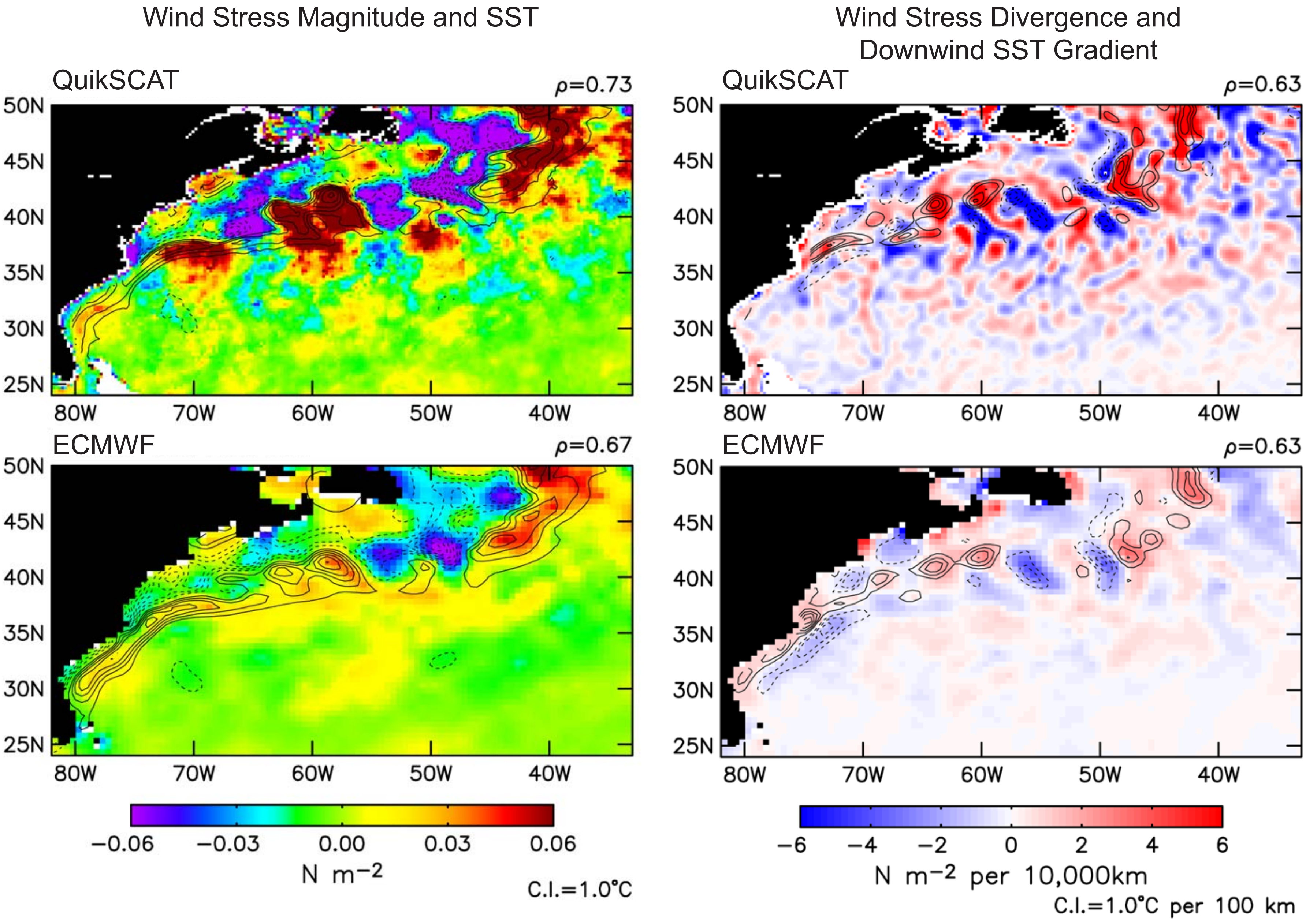
Note the different scale of the color bar for ECMWF



Upward Velocity, and Divergence in the Upper Troposphere



Surface Wind Response to SST in QuikSCAT Observations and the ECMWF Operational Forecast Model



Since the ECMWF model underestimates the surface wind response to SST by about a factor of 2, it seems likely that it also underestimates the tropospheric response to SST.

To investigate this, we are analyzing the AMSU profiles of temperature through the troposphere and boundary layer to estimate horizontal and vertical velocity fields from the Linear Balanced Model.

The resolution of AMSU temperature profiles is about 100 hPa vertically with a footprint size that increases from about 50 km at nadir to about 150 km at the outer edges of the swath.

The AMSU temperature data were gridded on a 0.5º x 0.5º grid with a vertical grid spacing of 50 hPa for the analysis presented here.

Wind Estimates from AMSU Profiles of Temperature

Step 1: The Rotational Component of the Wind Field

The hydrostatic equation for the atmosphere with the ideal gas law is

$$\frac{\partial \Phi}{\partial p} = -\frac{RT}{p},$$

where Φ is the geopotential height, p is pressure, T is the temperature sounding measured by AMSU, and R is the gas constant for dry air.

The hydrostatic equation was integrated downward using the geopotential $\Phi(p = 50 \text{ hPa})$ from the NCEP operational model as an upper boundary condition to obtain the 3-dimensional geopotential field, $\Phi(x, y, p)$.

A 3-dimensional streamfunction field $\psi(x, y, p)$ was then obtained from $\Phi(x, y, p)$ using the linear balance equation,

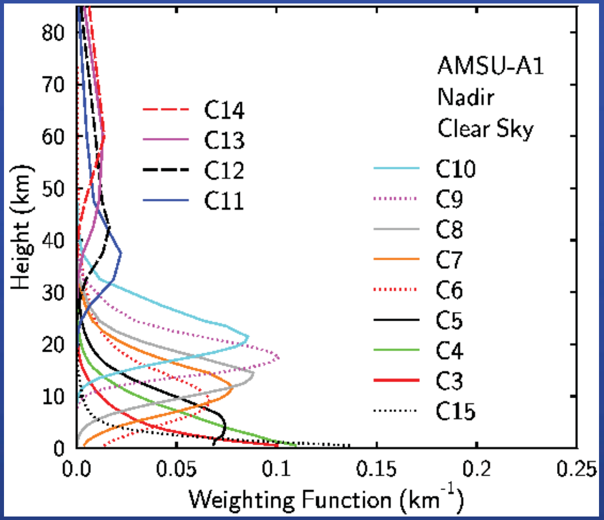
$$\nabla \cdot f \nabla \psi(x, y, p) = \nabla^2 \Phi(x, y, p).$$

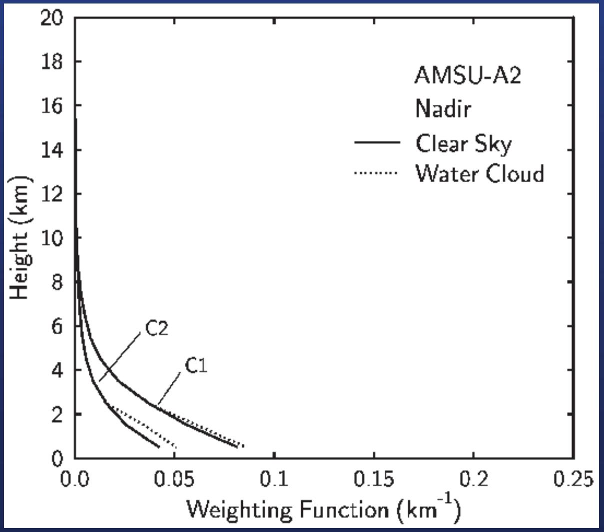
Boundary conditions for $\psi(x, y, p)$ were again obtained from the NCEP operational forecast model.

Finally, the nondivergent component of the vector wind field and the relative vorticity were obtained from the streamfunction field by

$$\mathbf{v}_\psi(x, y, p) = \hat{k} \times \nabla \psi(x, y, p)$$

$$\zeta(x, y, p) = \nabla \times \mathbf{v}_\psi = \nabla^2 \psi(x, y, p).$$





Wind Estimates from AMSU Profiles of Temperature

Step 2: The Vertical Velocity and Divergence of the Wind Field

The vertical velocity (total derivative of pressure following an air parcel) is $\omega = Dp/Dt$, which can be obtained diagnostically from a pair of equations that are derived from the vorticity and thermodynamic equations of the Linear Balanced Model,

$$\left[\bar{\sigma}\nabla^2 + f^2\frac{\partial^2}{\partial p^2}\right]\omega = f\frac{\partial}{\partial p}\left[\mathbf{v}_\psi\cdot\nabla\left(f+\nabla^2\psi\right)\right] - \nabla^2\left(\mathbf{v}_\psi\cdot\nabla\frac{\partial\phi}{\partial p}\right) - \nabla f\cdot\nabla\frac{\partial^2\psi}{\partial p\partial t}$$

$$\nabla^2\frac{\partial\psi}{\partial t} = -\mathbf{v}_\psi\cdot\nabla\left(f+\nabla^2\psi\right) + f\frac{\partial\omega}{\partial p}$$

where

- $\bar{\sigma}$ is a domain-averaged static stability parameter that is a function of pressure only and can be computed from the geopotential ϕ that is defined in terms of the AMSU temperature profiles in Step 1.
- The streamfunction ψ and the nondivergent component $\mathbf{v}_\psi$ of the wind field were obtained in Step 1.
- Convective heating and internal friction have been neglected (see Summary slide).

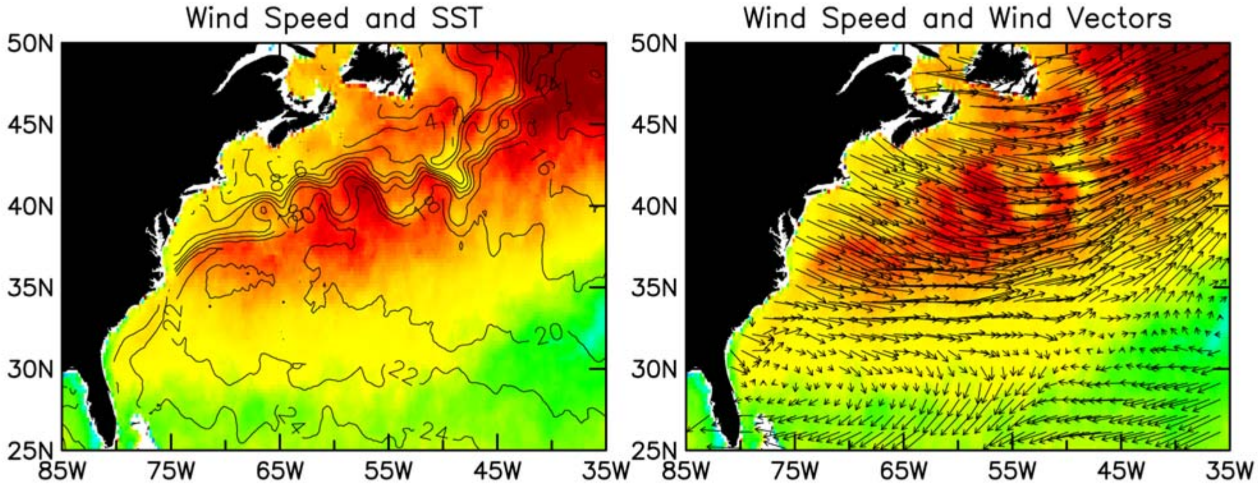
The two unknowns in this equation are ω and $\partial\psi/\partial t$. Because of the time derivative, these equations are not strictly diagnostic. The equations can be solved iteratively until convergence to obtain both ω and $\partial\psi/\partial t$ starting with an initial guess of $\omega = 0$. A bottom boundary condition of $\omega = 0$ at the sea surface is assumed.

The resulting solution for ω is then used to compute the divergence from the continuity equation,

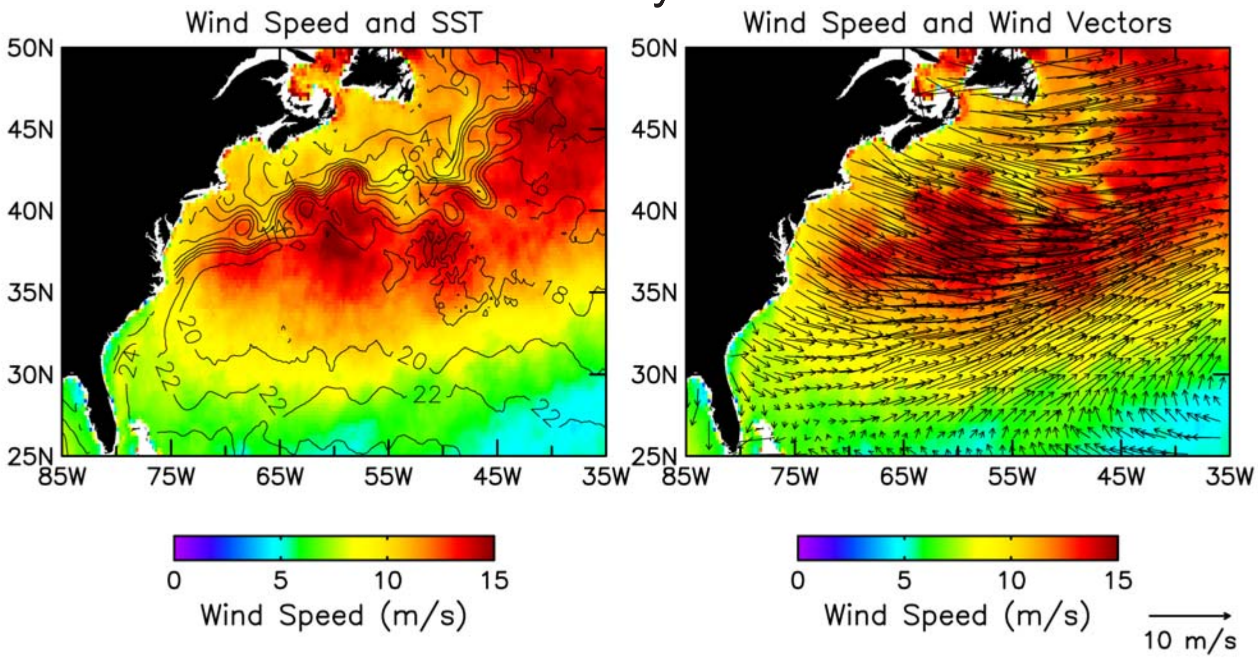
$$\nabla\cdot\mathbf{v} = -\frac{\partial\omega}{\partial p}$$

Two Case Study Months Chosen Based on QuikSCAT Winds and AMSR SST

January 2007



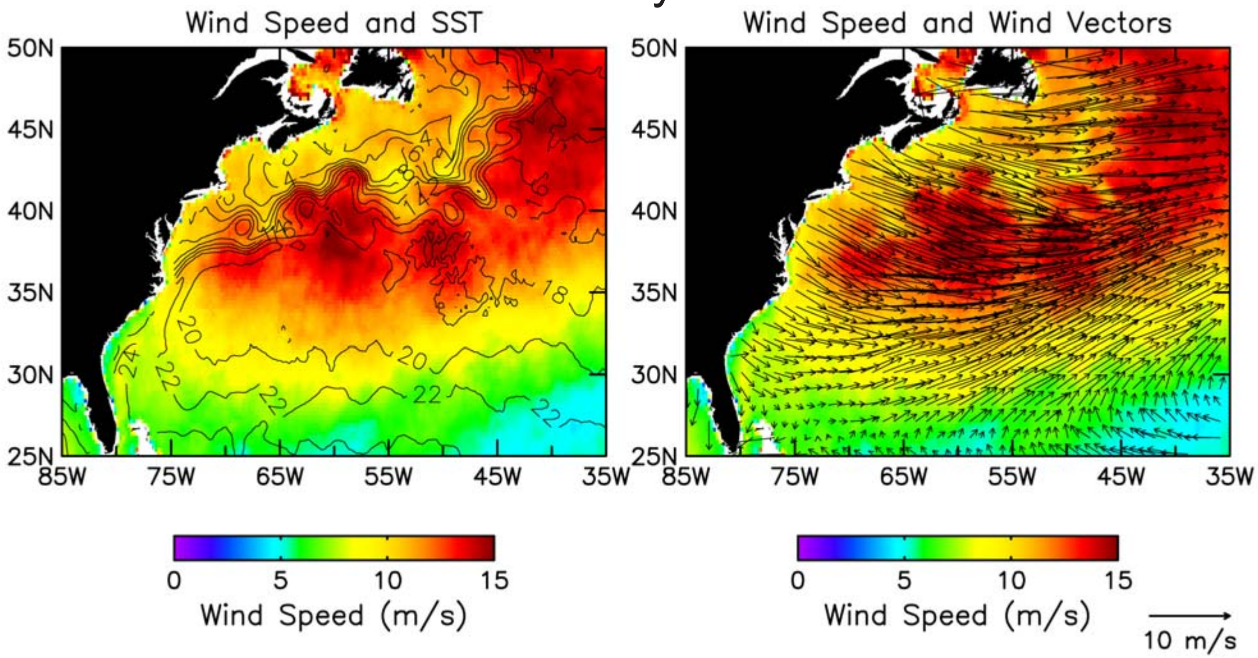
February 2007



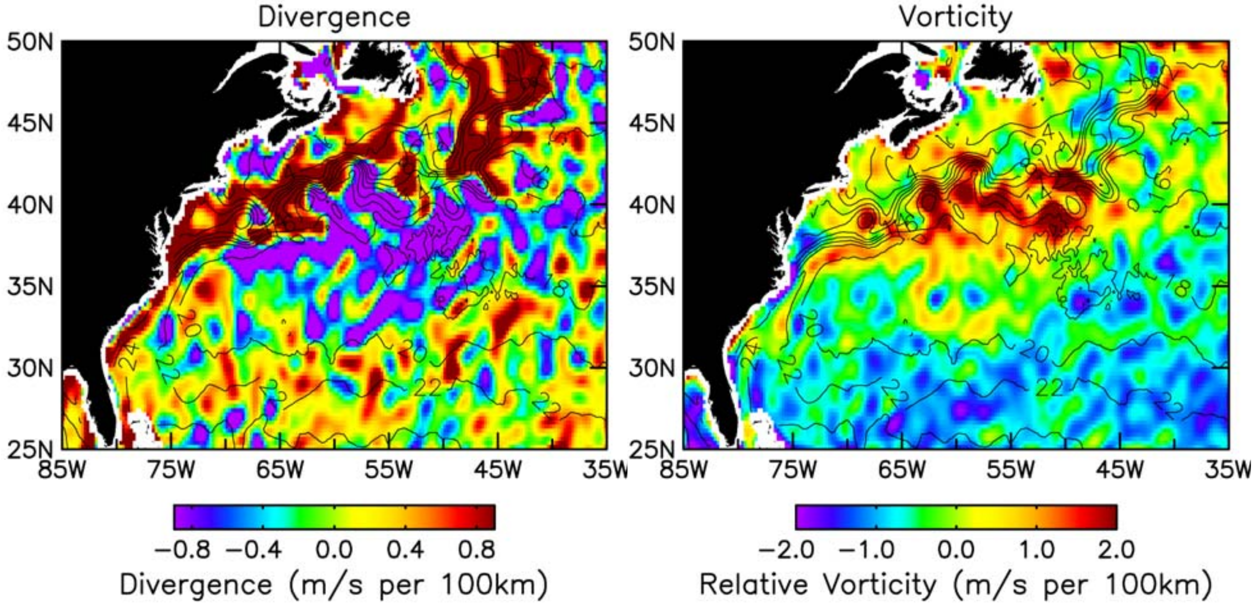
Two Case Study Months Chosen Based on QuikSCAT Winds and AMSR SST

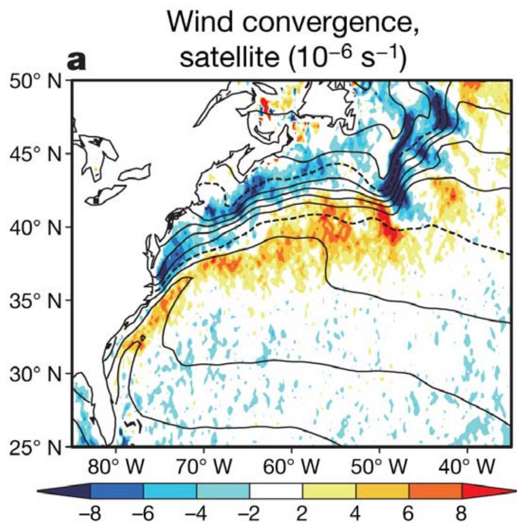
This presentation focuses on February 2007

February 2007



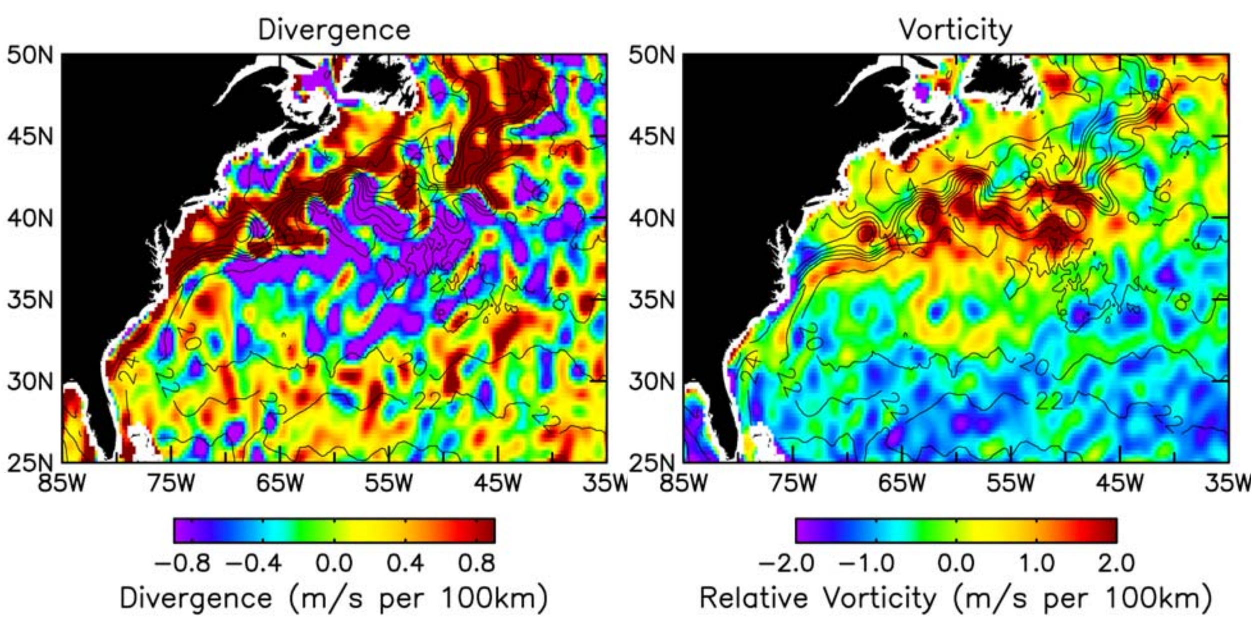
QuikSCAT Surface Wind **Divergence** and Vorticity with contours of AMSR SST
February 2007



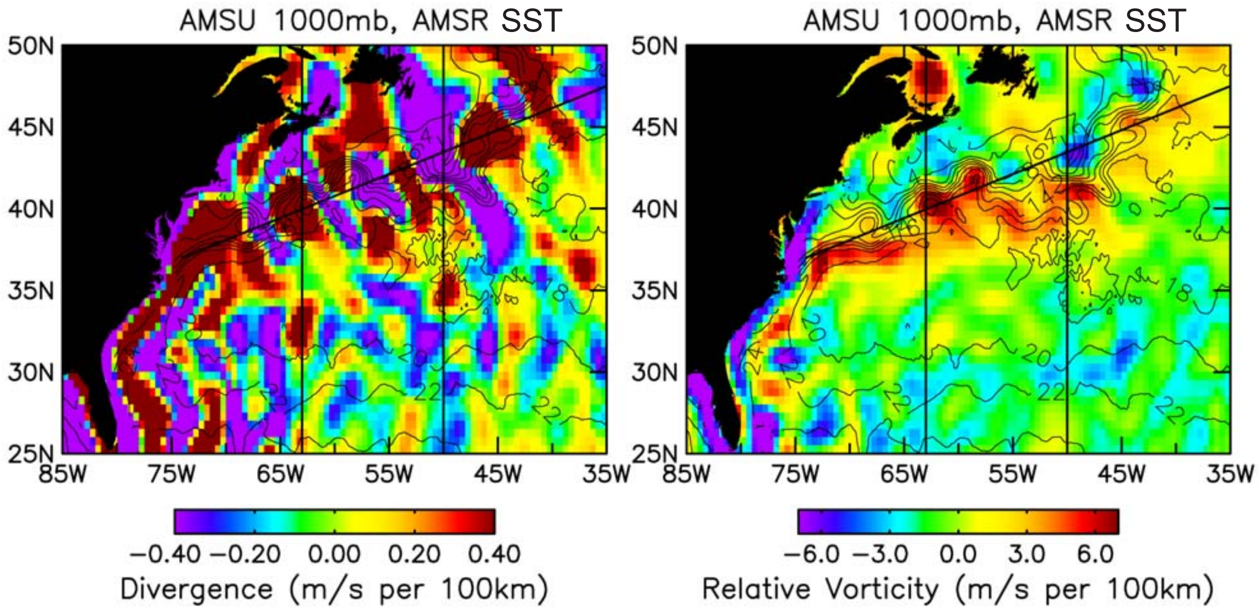


*Compare with 4-Year Average Surface Wind **Convergence** from Minobe et al. (2008)*

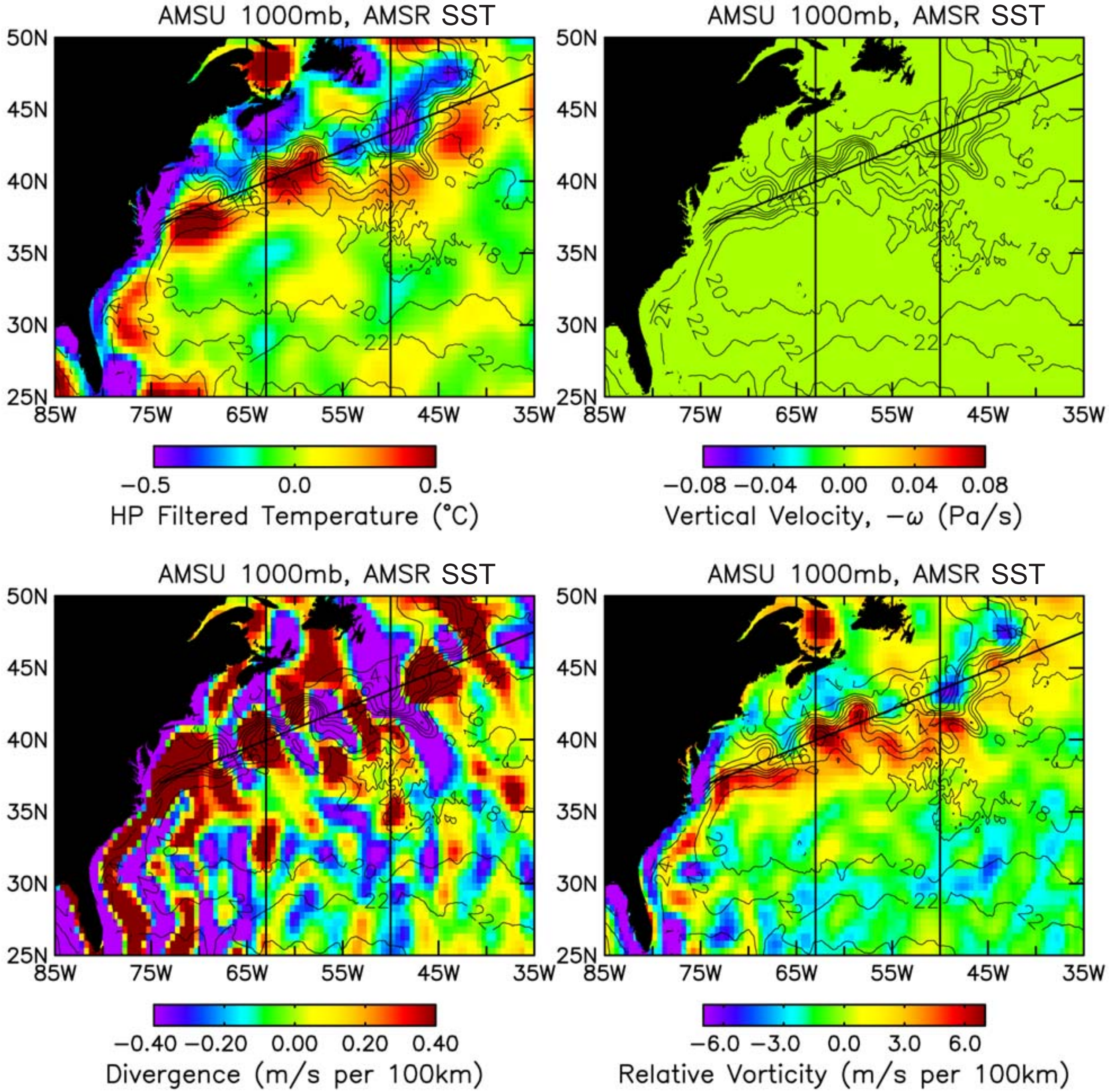
QuikSCAT Surface Wind **Divergence** and Vorticity with contours of AMSR SST February 2007



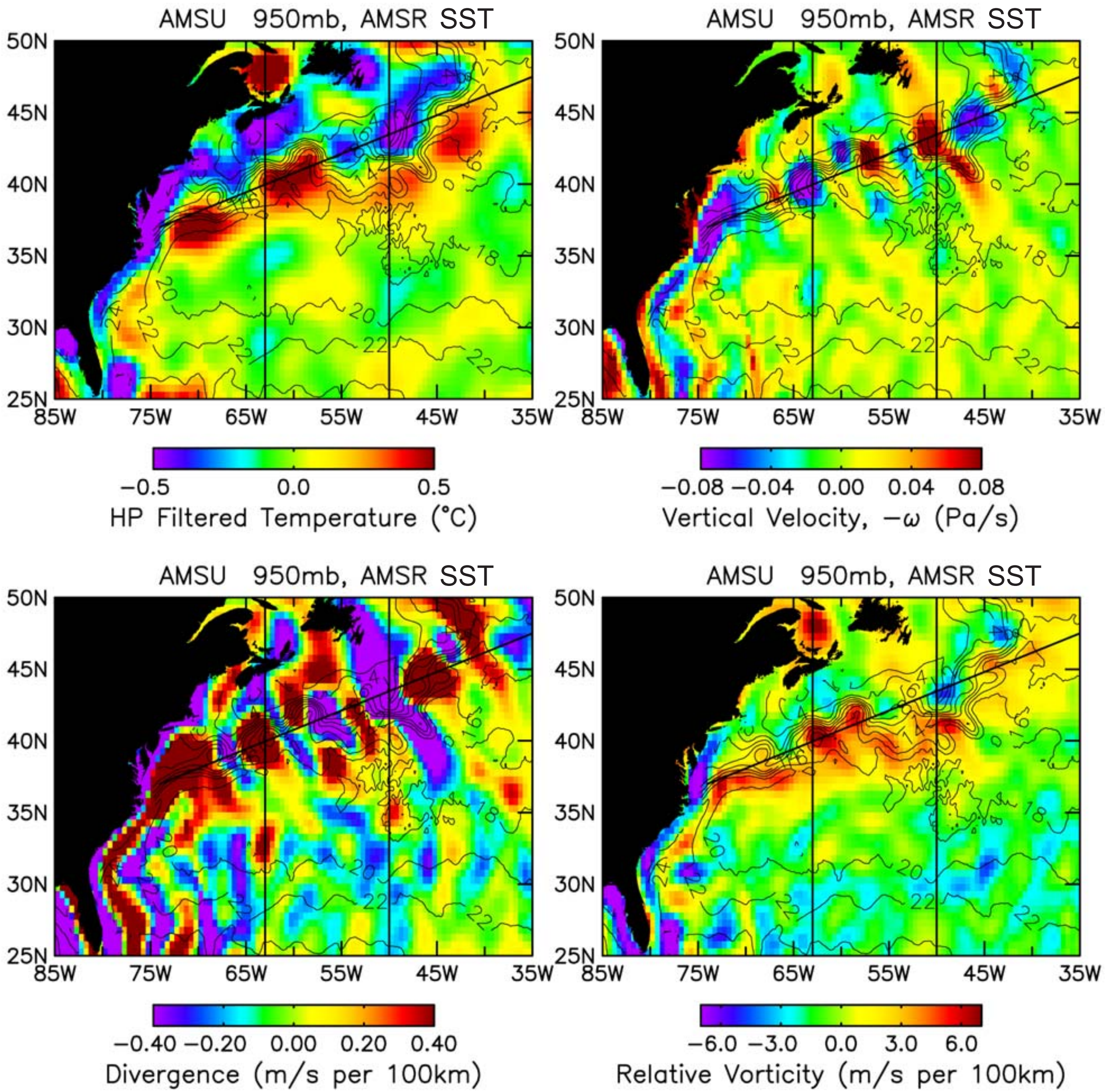
AMSU 1000 mb Wind Divergence and Vorticity with contours of AMSR SST
February 2007



February 2007



February 2007



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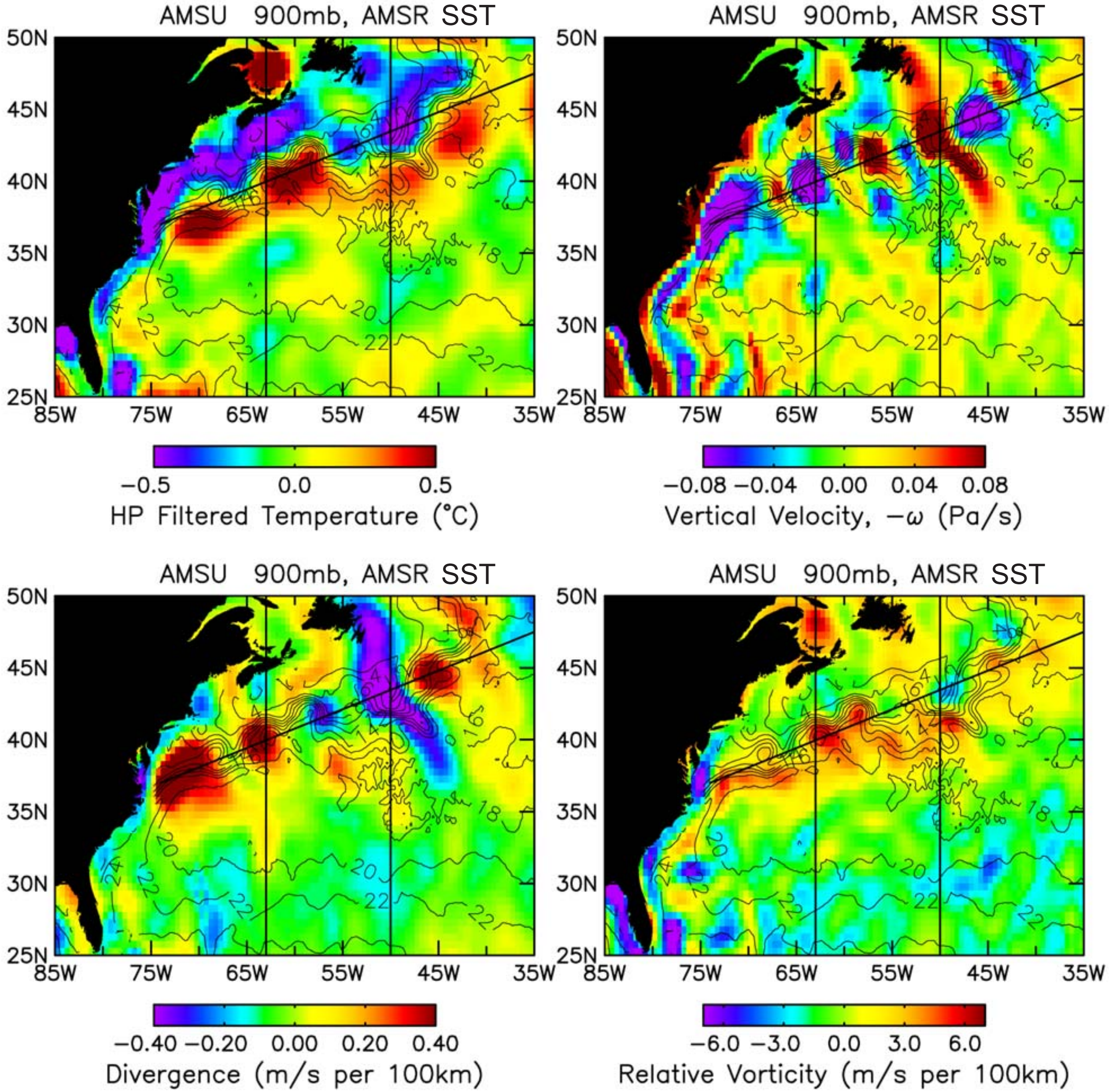
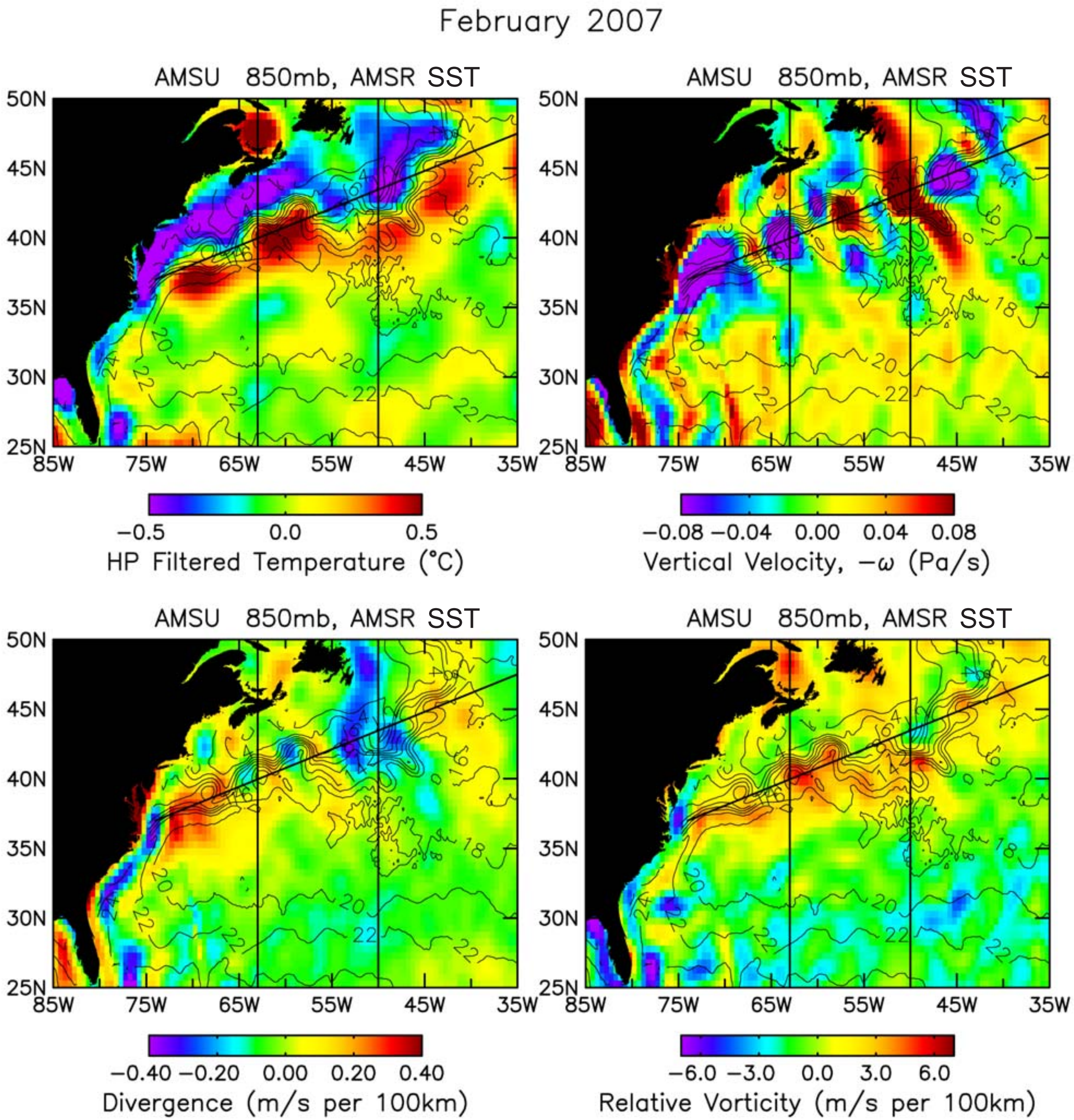
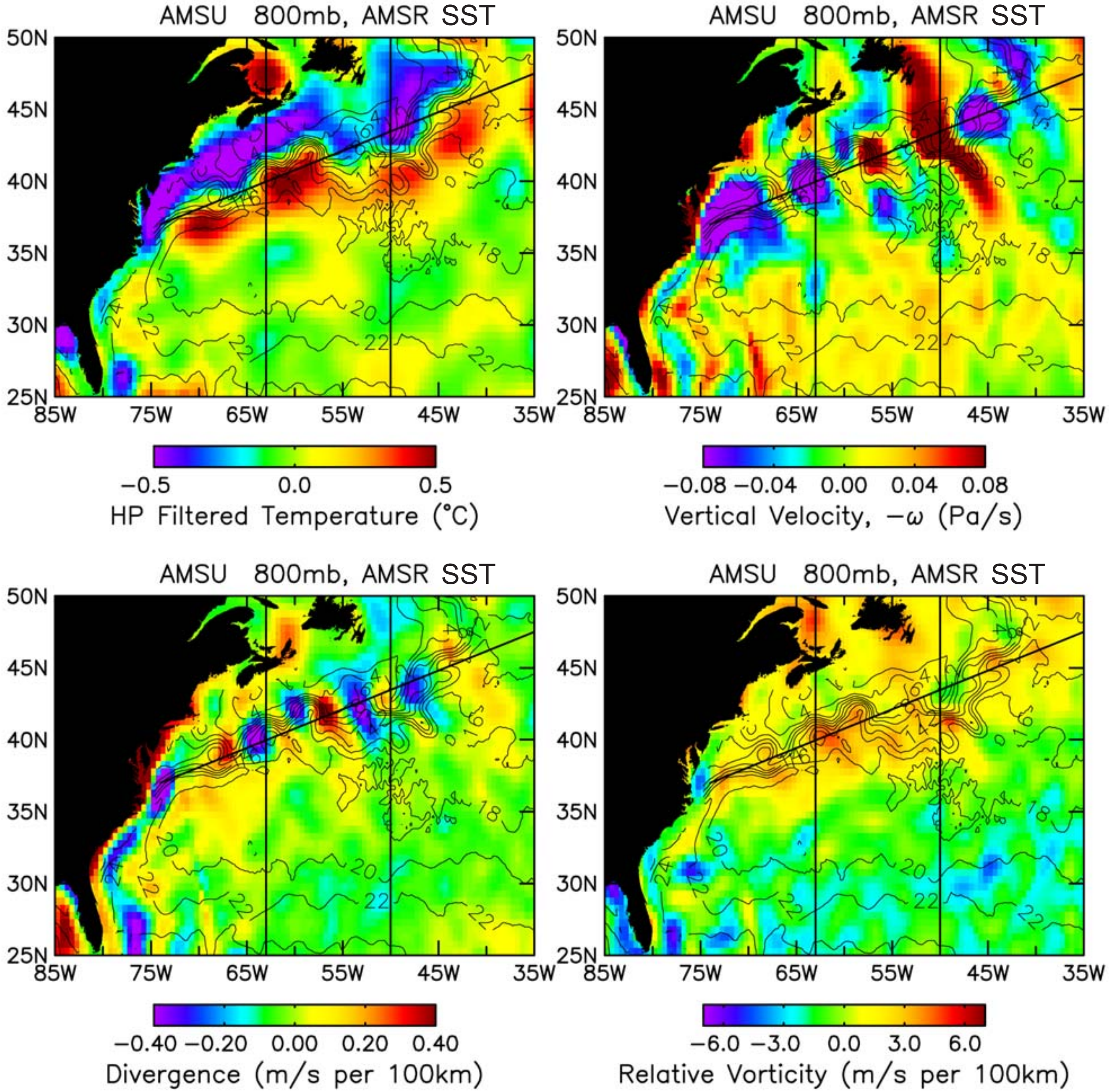



February 2007
AMSU 850mb, AMSR SST
50N
45N
40N
35N
30N
25N
85W
75W
65W
55W
45W
35W
−0.5
0.0
0.5
HP Filtered Temperature (°C)
AMSU 850mb, AMSR SST
−0.08 −0.04 0.00 0.04 0.08
Vertical Velocity, −ω (Pa/s)
AMSU 850mb, AMSR SST
−0.40 −0.20 0.00 0.20 0.40
Divergence (m/s per 100km)
AMSU 850mb, AMSR SST
−6.0 −3.0 0.0 3.0 6.0
Relative Vorticity (m/s per 100km)

February 2007



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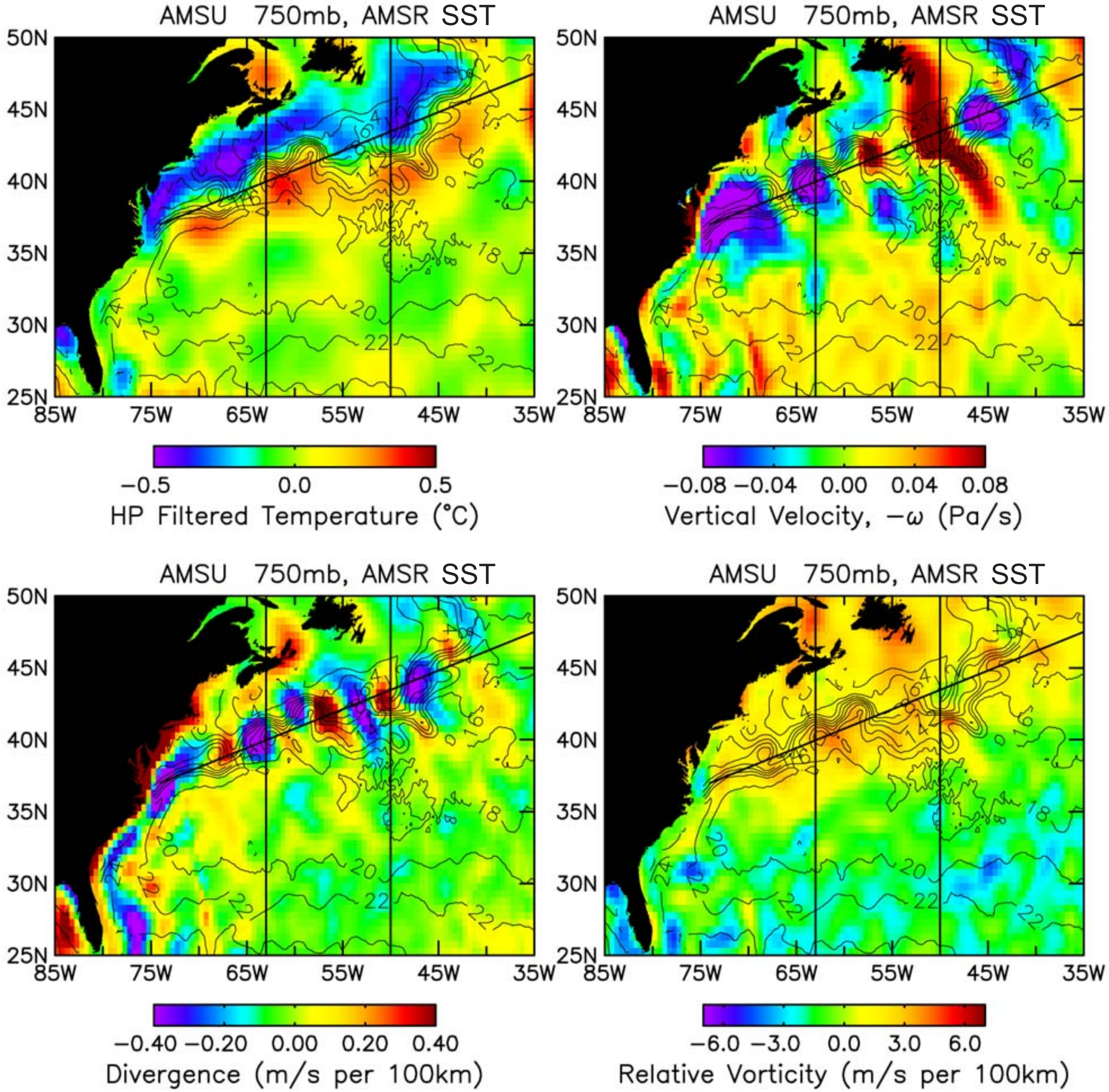

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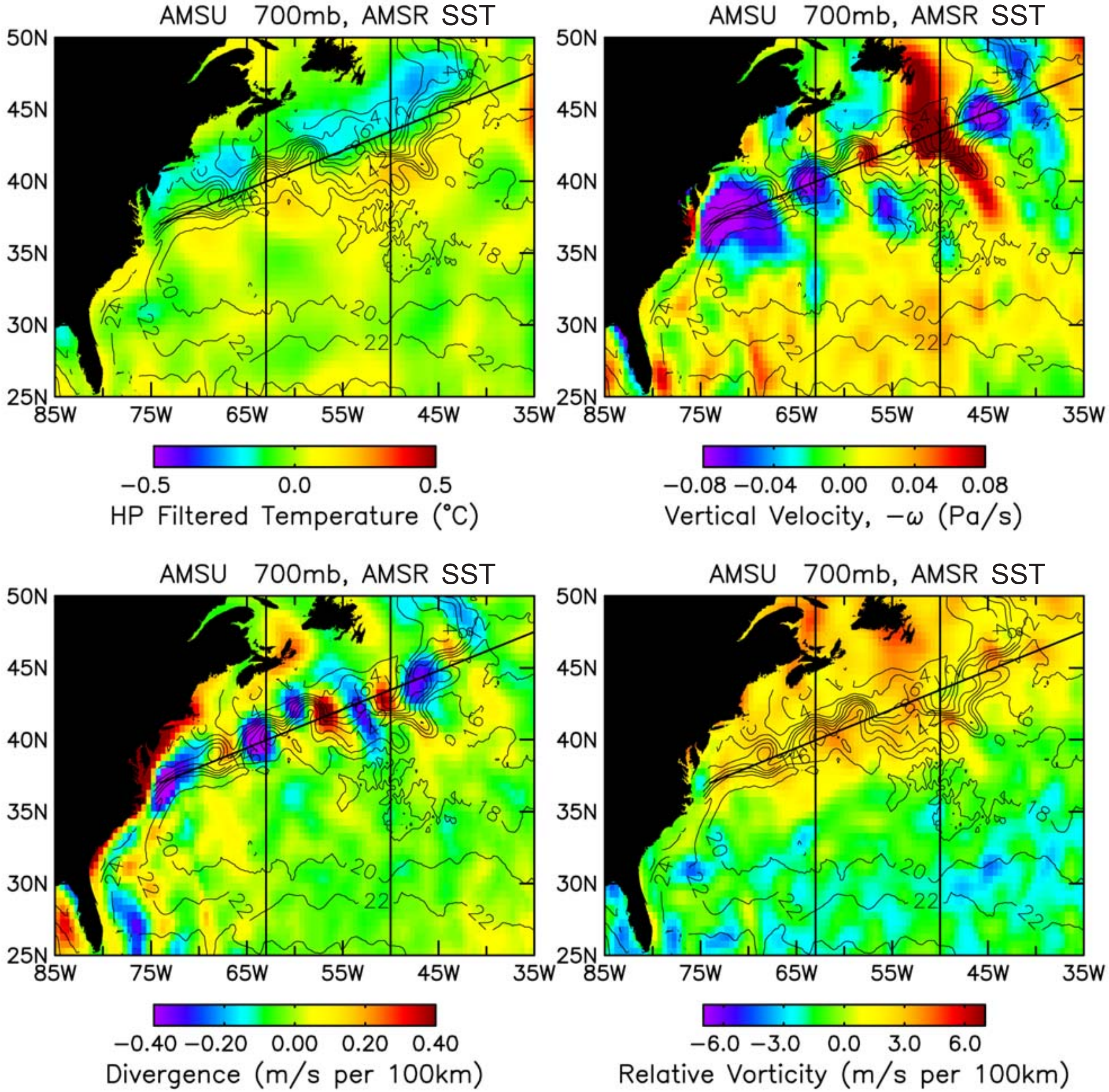

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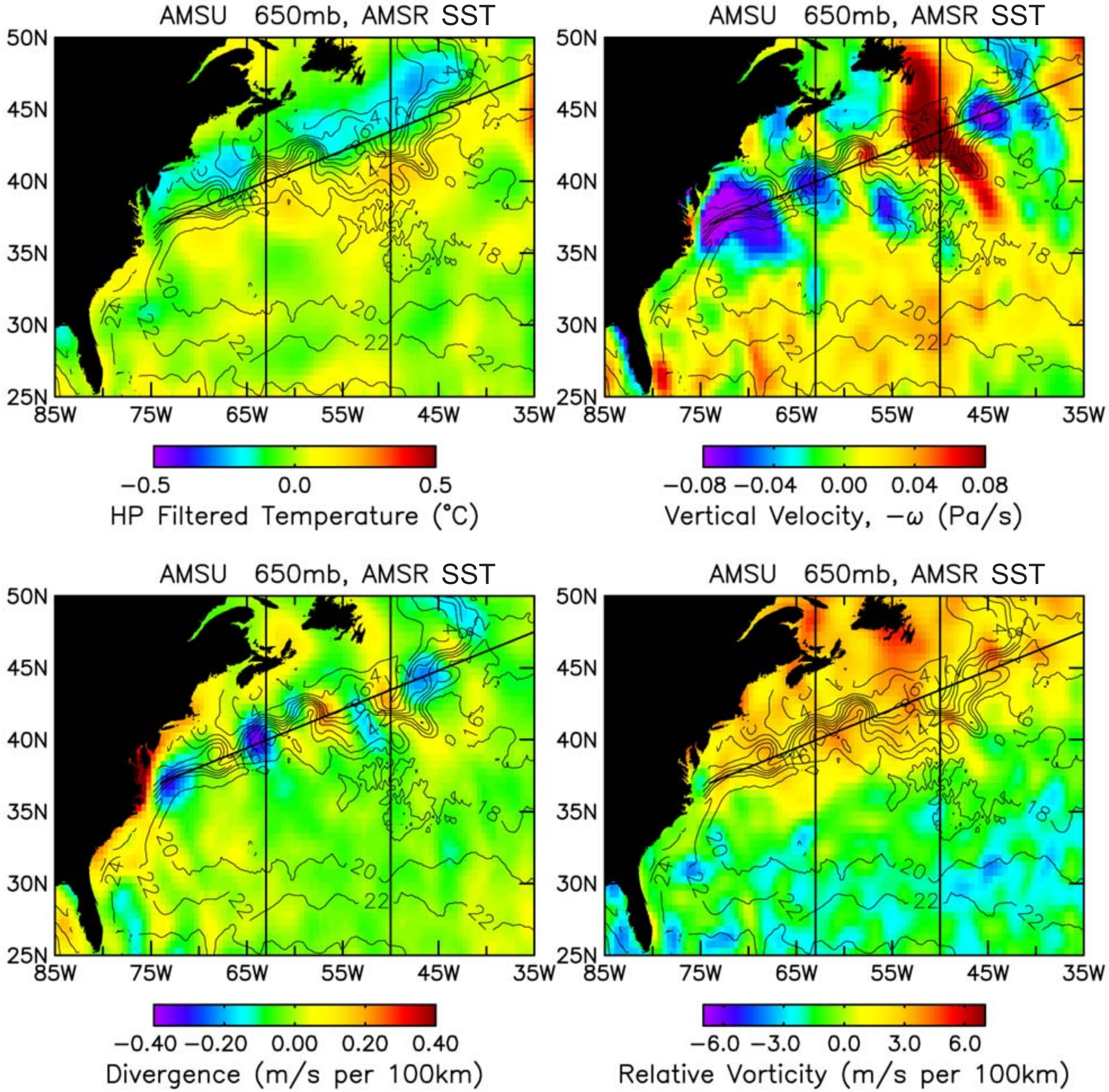

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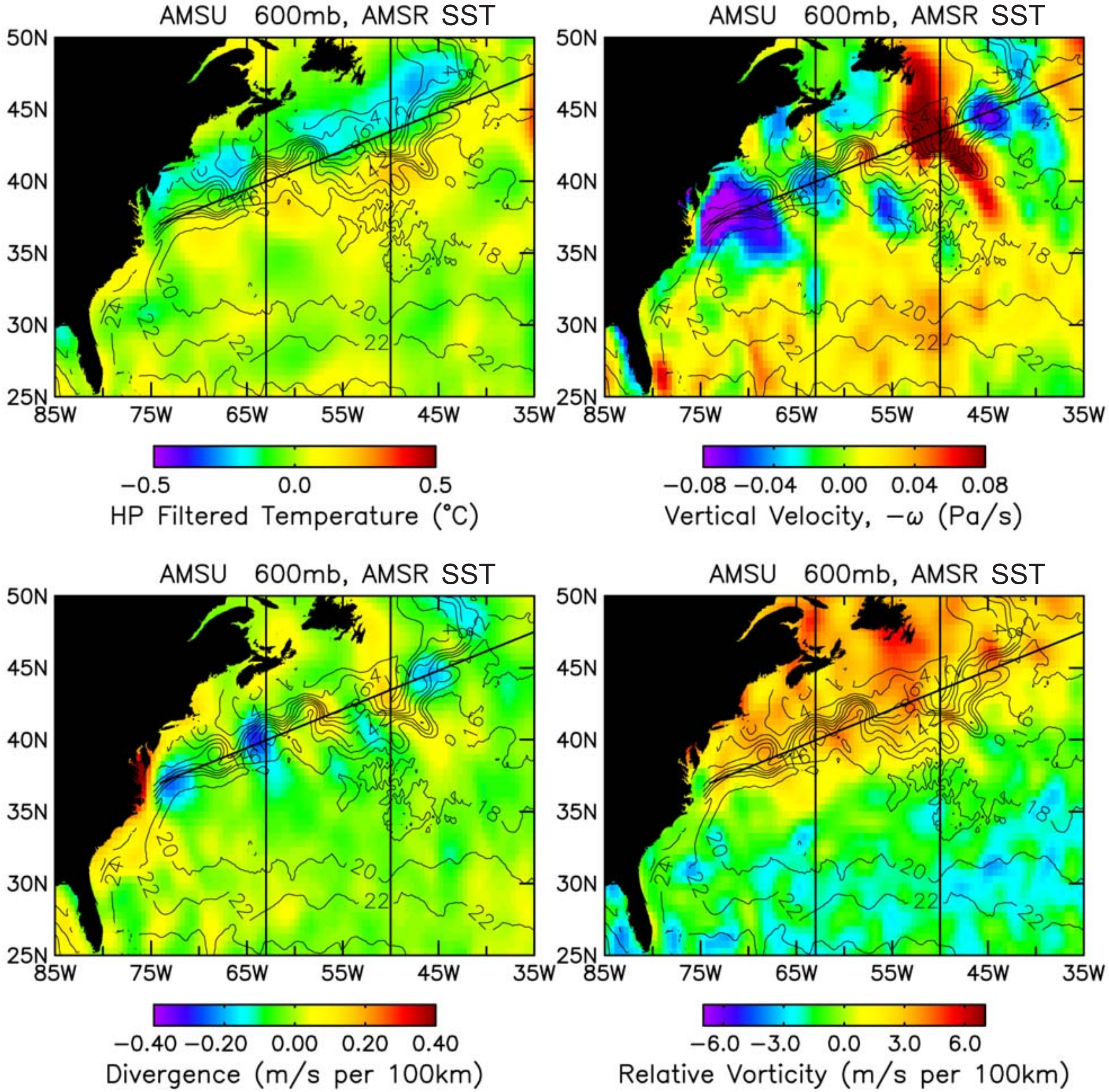

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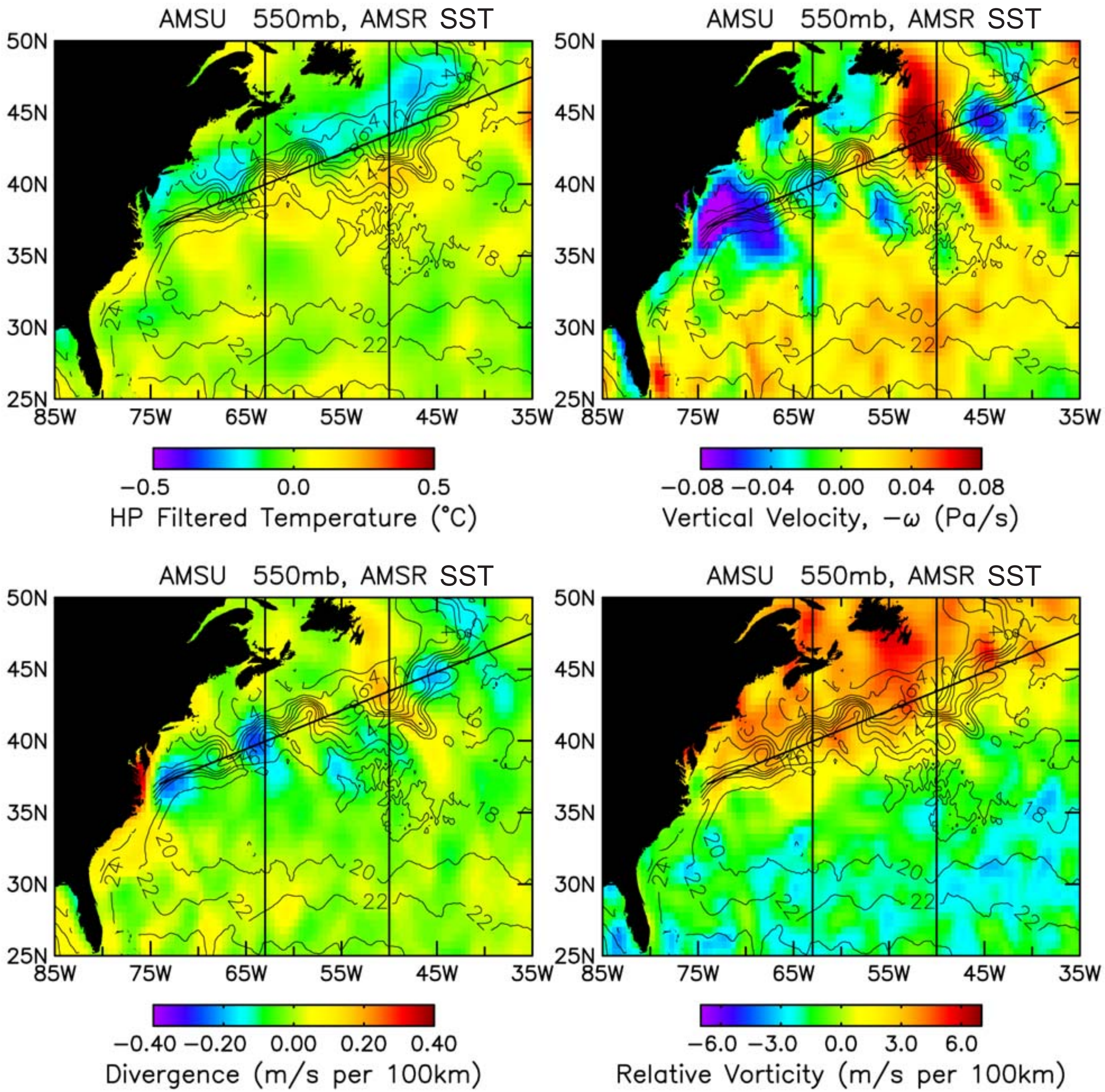

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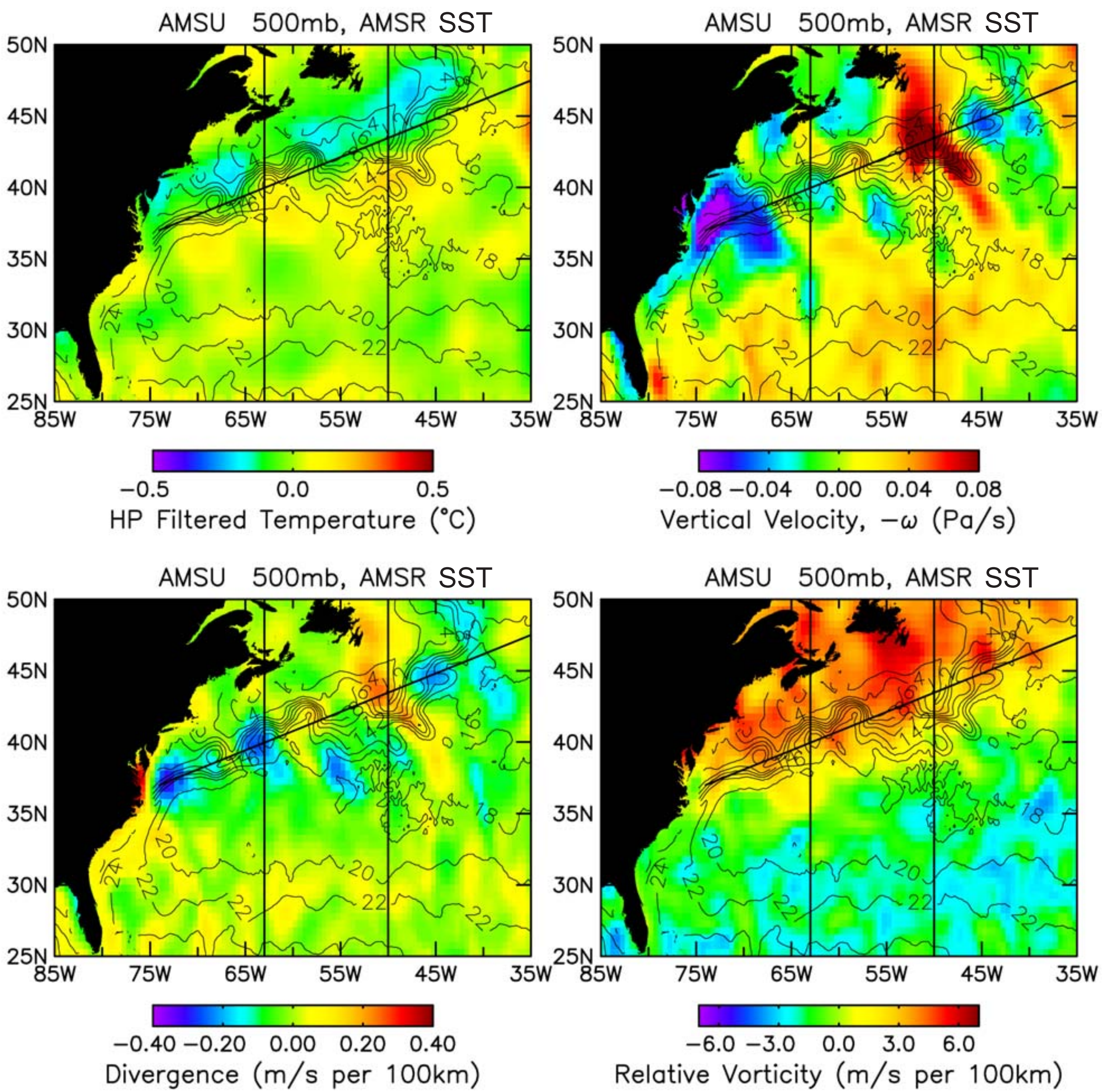

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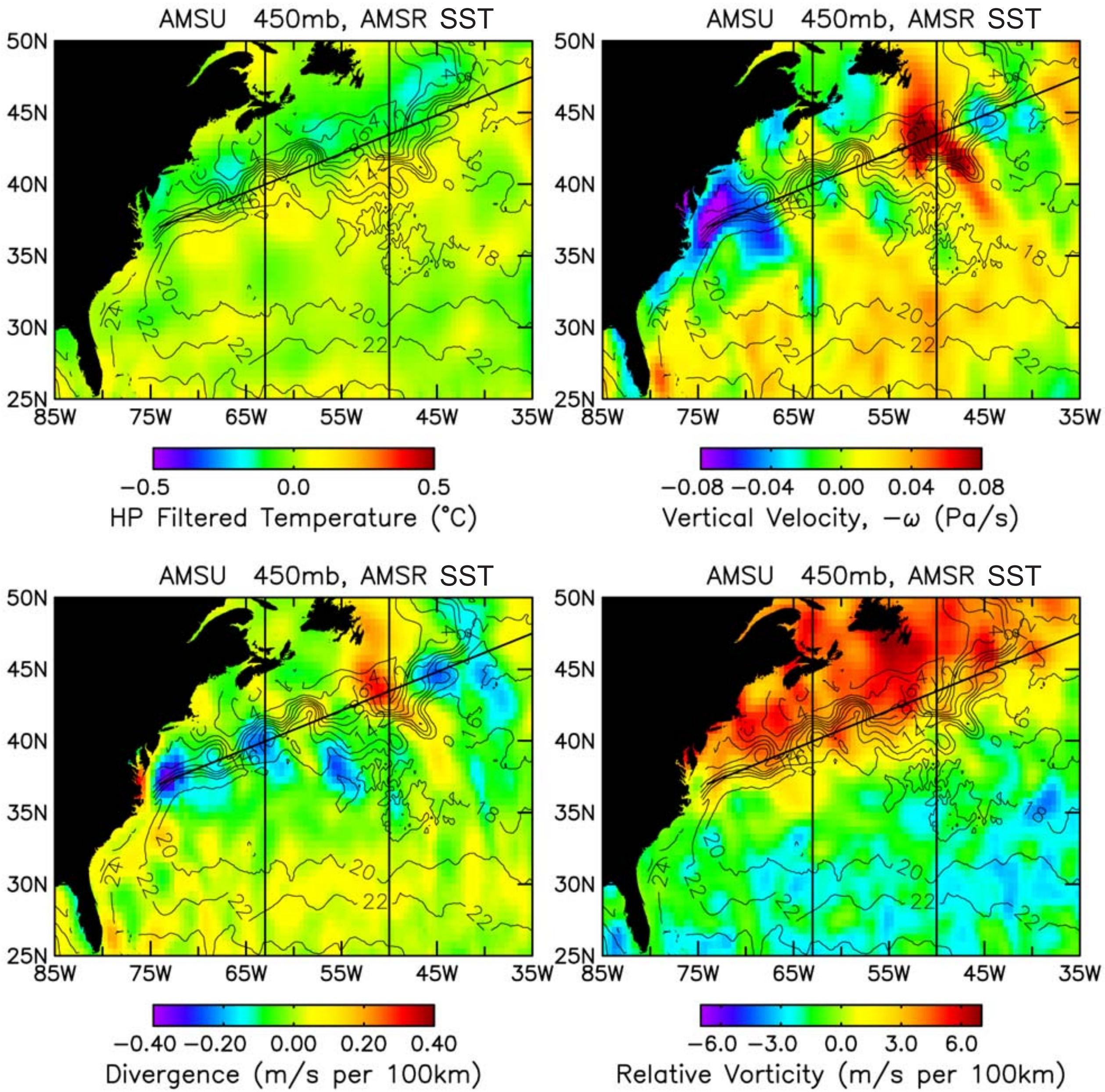

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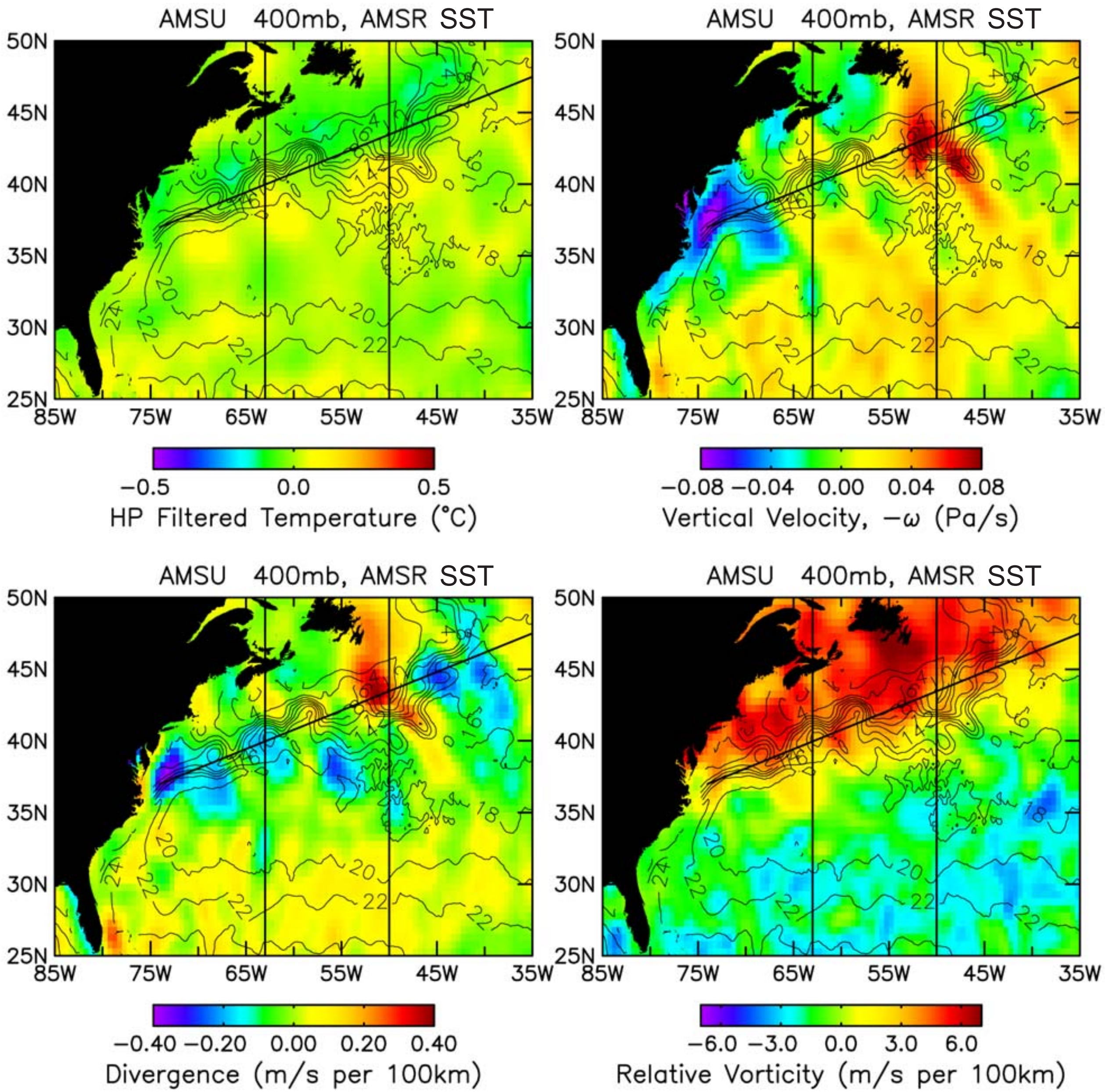

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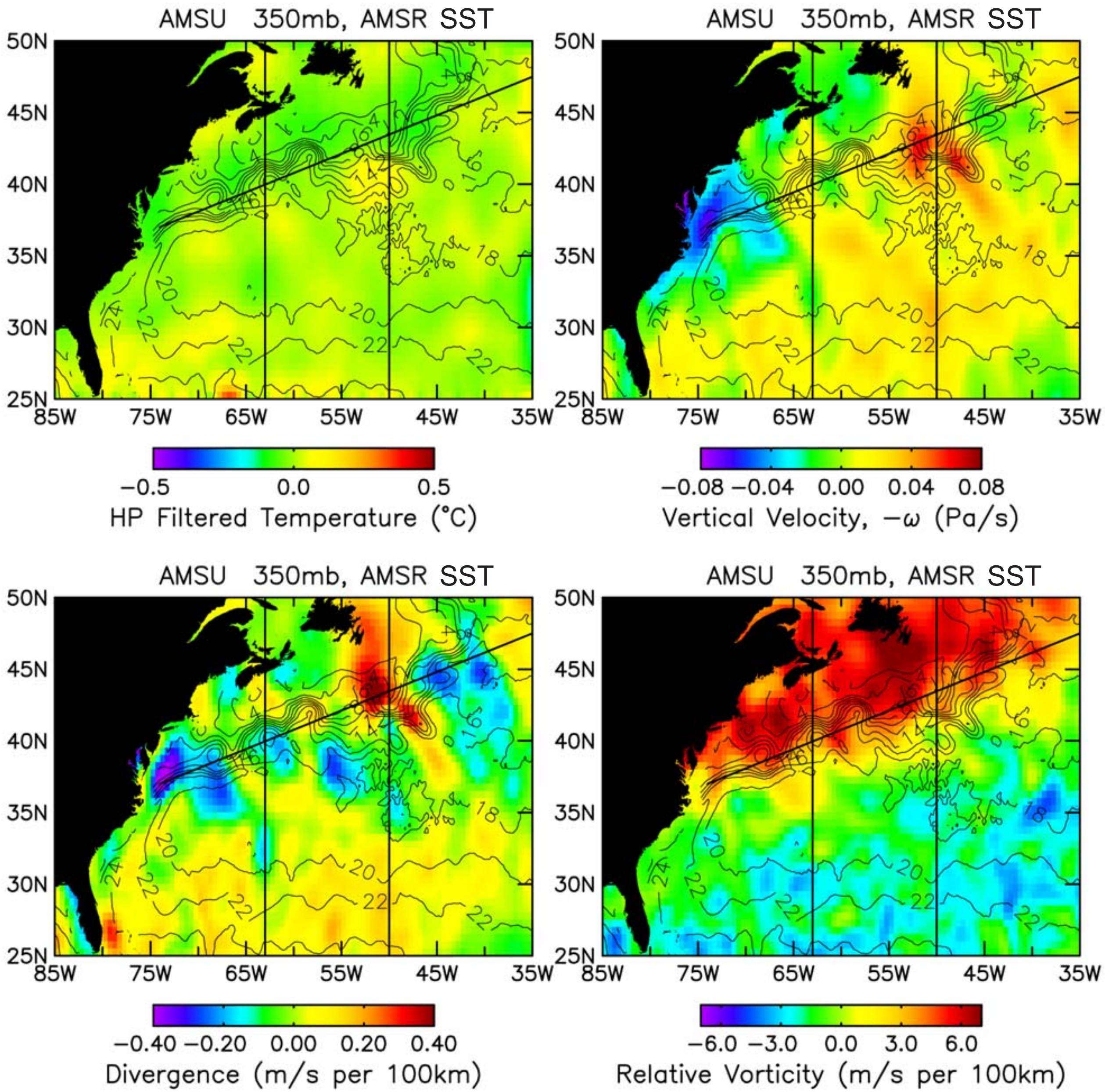

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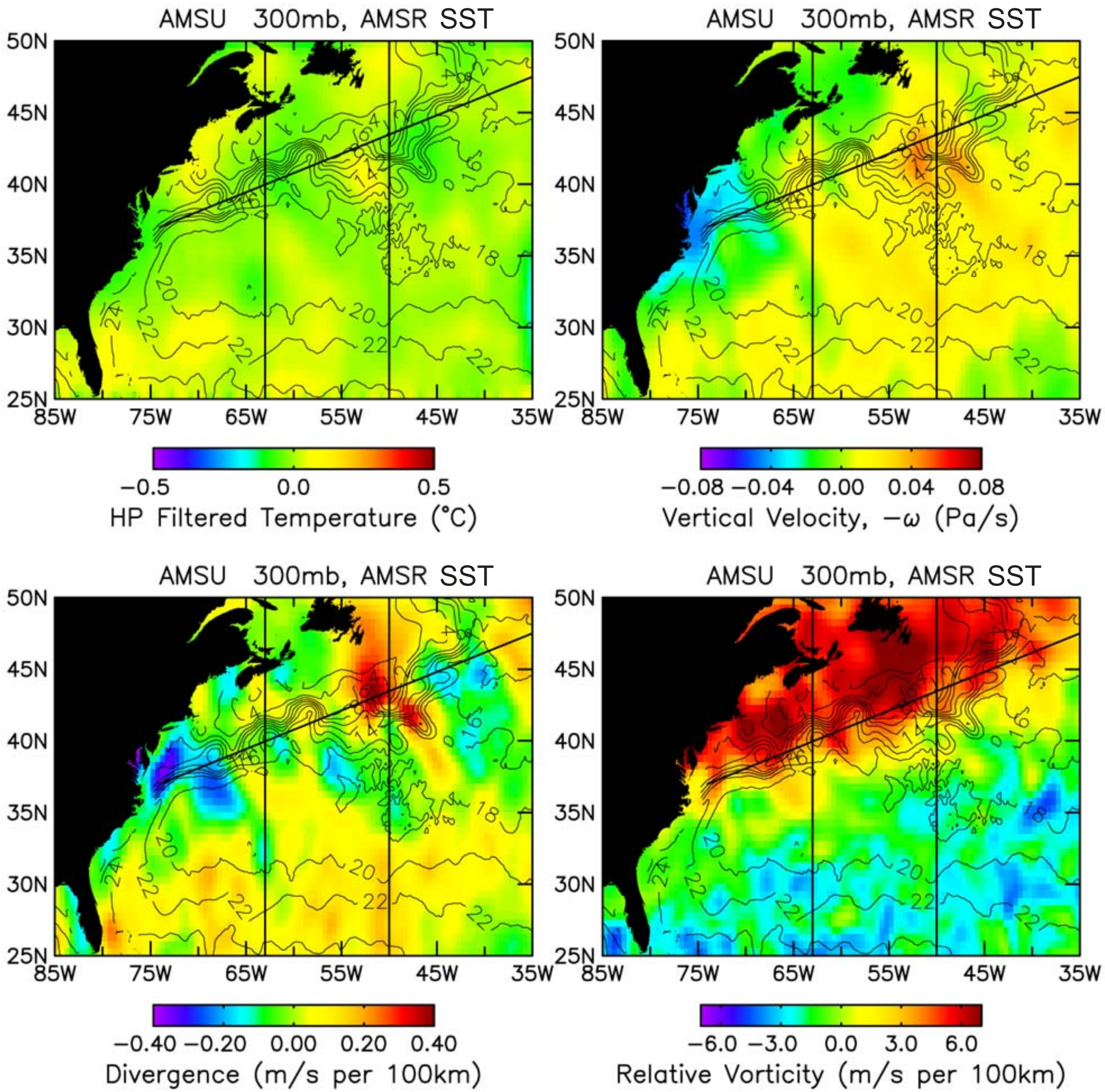

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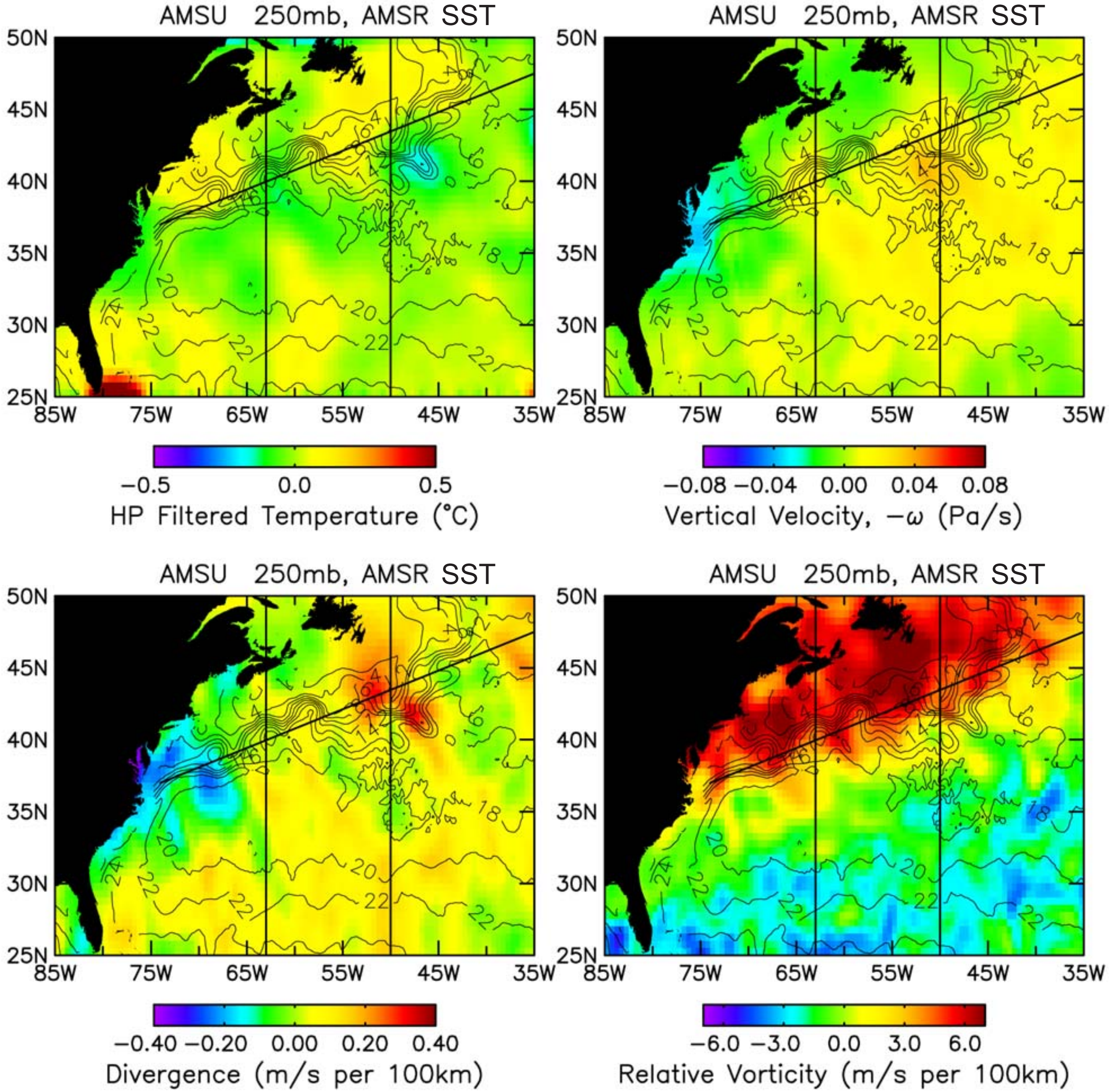

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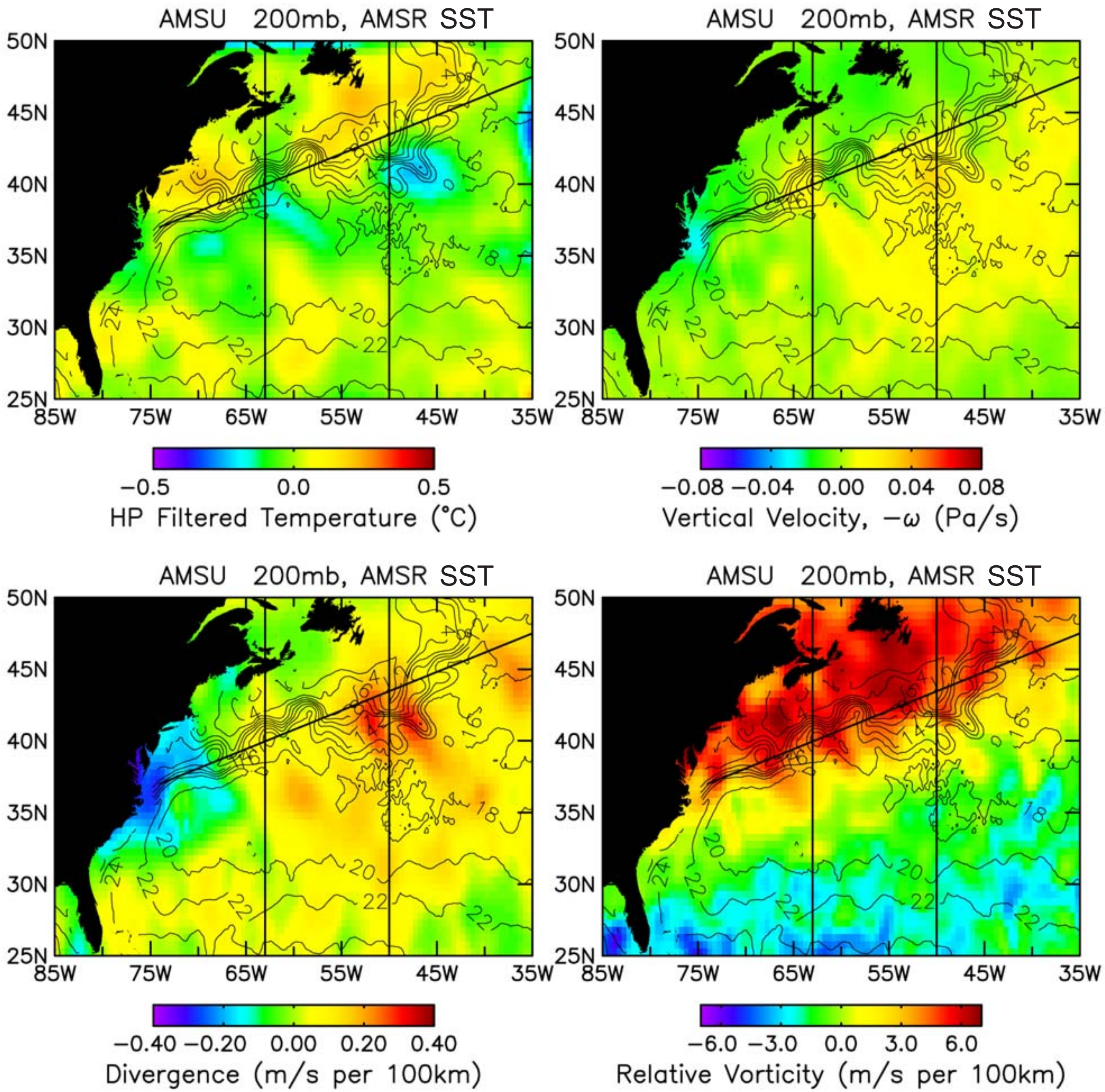
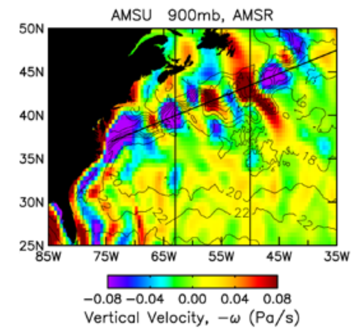
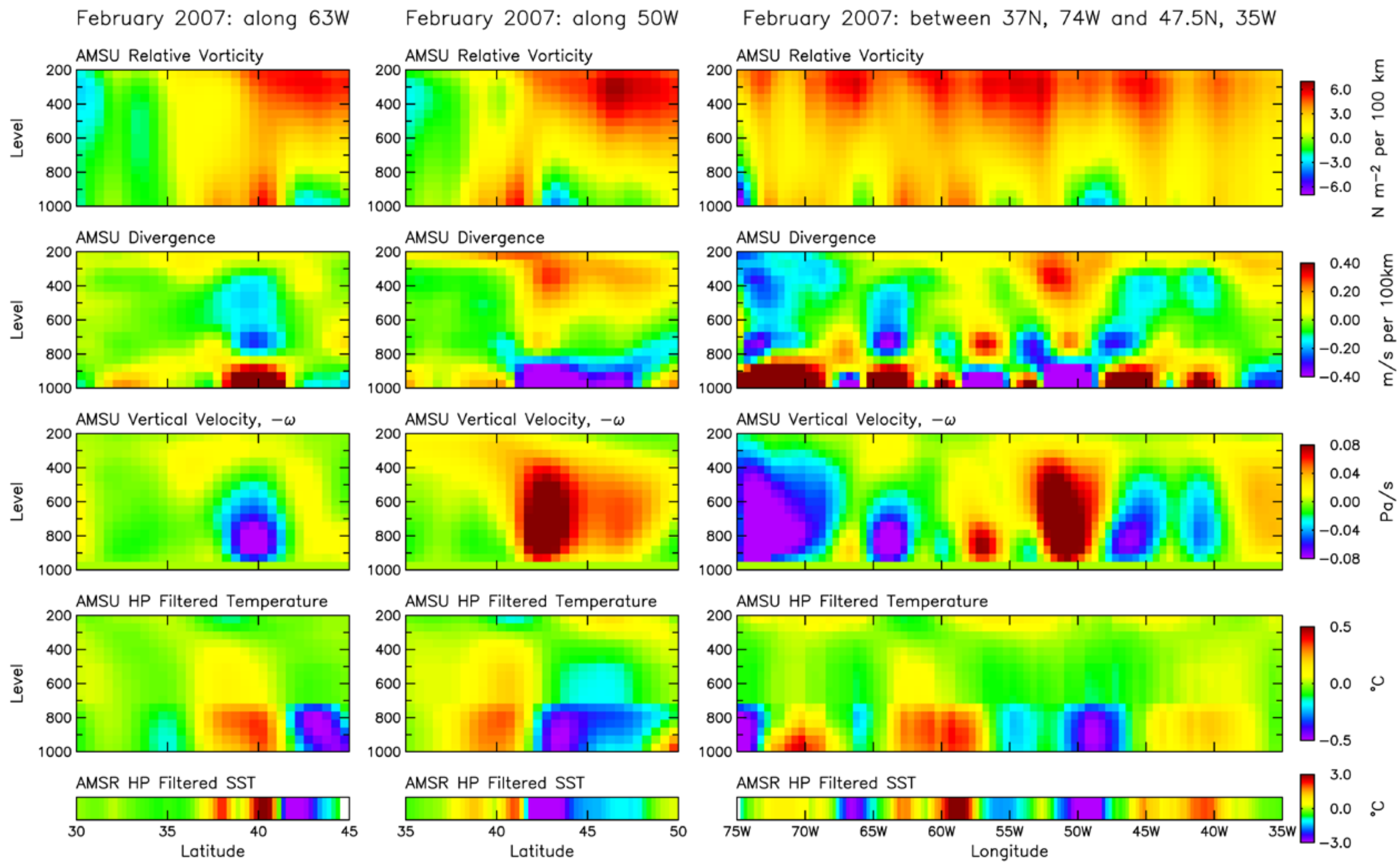


Vertical Sections of AMSU Temperature and Derived Quantities (Vorticity, Vertical Velocity and Divergence)

February 2007





Summary

- AMSU temperature profiles provide an exciting new observational dataset for investigation of SST influence on the troposphere.
  - *The AMSU data are complementary to scatterometer observations of SST influence on surface winds.*
- The AMSU data show clear evidence for SST influence on vorticity, divergence and vertical velocity throughout the troposphere.
  - *These tropospheric responses may have far-reaching effects on the general circulation of the atmosphere.*
- The vertical velocity estimates derived from AMSU data are dynamically forced by the surface divergence field, rather than thermodynamically forced by heating of the marine atmospheric boundary layer.

This research was supported by NOAA and NASA

Caveats

- The irrotational winds presented here from Step 2 are the result of only dynamical forcing by the nondivergent part of the wind field obtained from Step 1.
- The effects of heating and friction that have been neglected may both have as large an effect as divergence on the vertical velocity.

Next Steps

- Compare the AMSU estimates of vorticity, divergence and vertical velocity to the ECMWF model fields. (NCEP wind fields are inadquate for this purpose.)
- Determine the relative importance of dynamical forcing, convective heating, and internal friction on the SST-induced vorticity, divergence and vertical velocity.
  - *This will be done through a combination of mesoscale modeling and data analysis.*
- Estimate surface pressure from the AMSU temperature profiles to investigate the importance of SST-induced surface pressure perturbations to the surface divergence and vertical velocity fields in the Gulf Stream region.
  - *The Minobe et al. (2008) study based on model pressure and wind fields suggests that SST influence on surface pressure may be more important than the frictional effects of SST-induced vertical turbulent mixing.*

This research was supported by NOAA and NASA