Buoyancy Parameterization in Stress Generation

W. Timothy Liu and Xiaosu Xie

- B
- S
- S
- R
- V

- Stress is turbulence generated by wind shear and buoyance (density gradient).
- Air is rarely exactly neutral in buoyance; even without temperature gradient there is always humidity gradient.
- To get equivalent neutral wind or stress from wind, stability effect is needed.
- Buoyance-induced bias may be small, but strong variations exist.
- Stability effect was formulated 4 decades ago in land experiments; its geographical and seasonal validity over ocean has not been challenged.

$$\tau = \rho C_D (U - U_S)^2$$

$$\frac{U - U_s}{U_*} = 2.5(\ln\frac{z}{z_0} - \psi_U) = \frac{1}{\sqrt{C_D}}$$

$$H = \rho c_P C_H (T - T_s)(U - U_S)$$

$$\frac{T - T_s}{T_*} = 2.5(\ln\frac{Z}{Z_T} - \psi_T) = \frac{\sqrt{C_D}}{C_H}$$

$$E = \rho C_E (Q - Q_s)(U - U_S)$$

$$\frac{Q - Q_s}{Q_*} = 2.5(\ln\frac{Z}{Z_Q} - \psi_Q) = \frac{\sqrt{C_D}}{C_E}$$

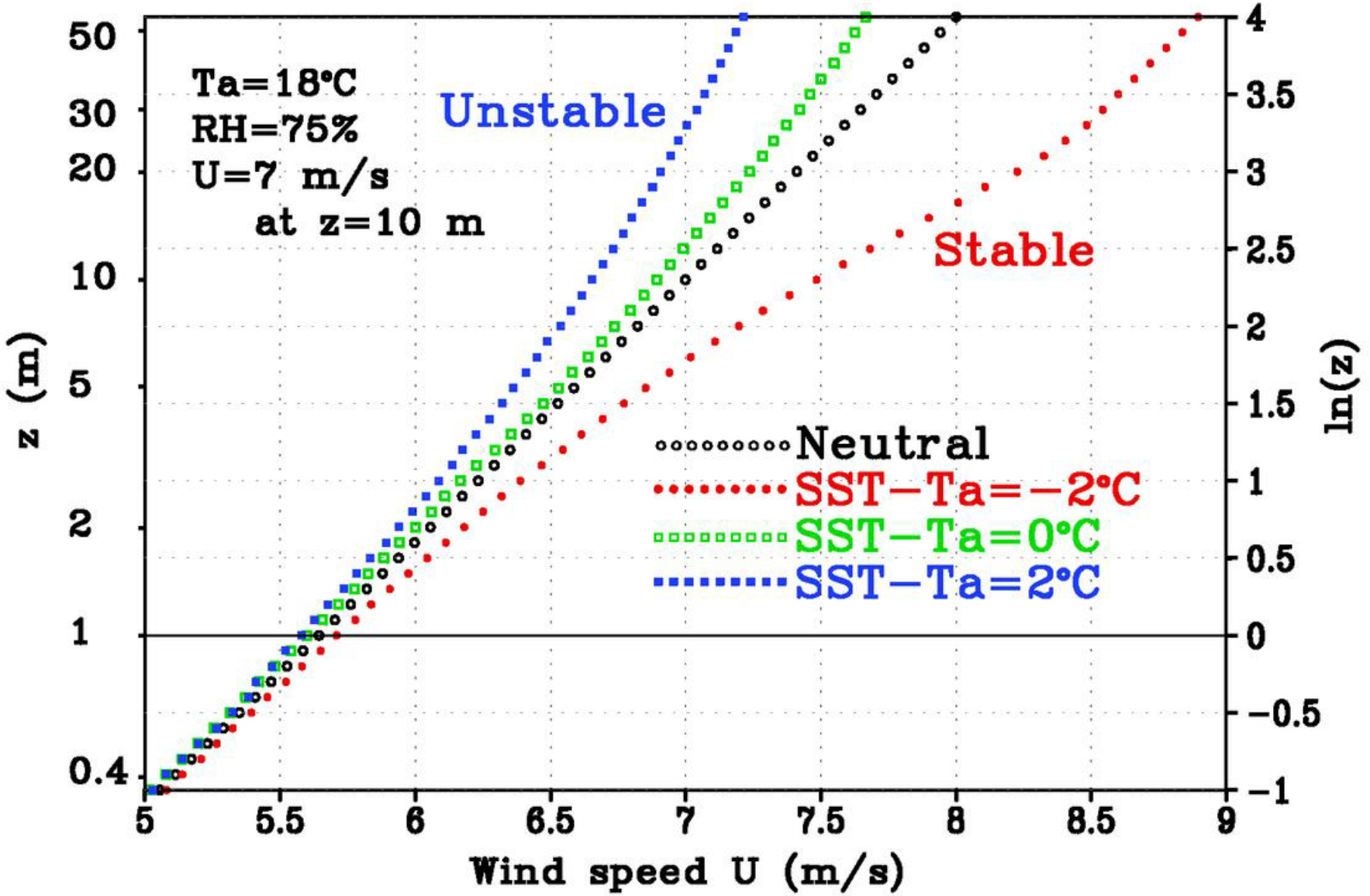
$$U_* = \sqrt{\frac{\tau}{\rho}}$$

$$T_* = -\frac{H}{\rho U_*}$$

$$Q_* = -\frac{E}{\rho U_*}$$

$$Z_o = 0.11\frac{\nu}{U_*} + 0.011\frac{U_*^2}{g}$$

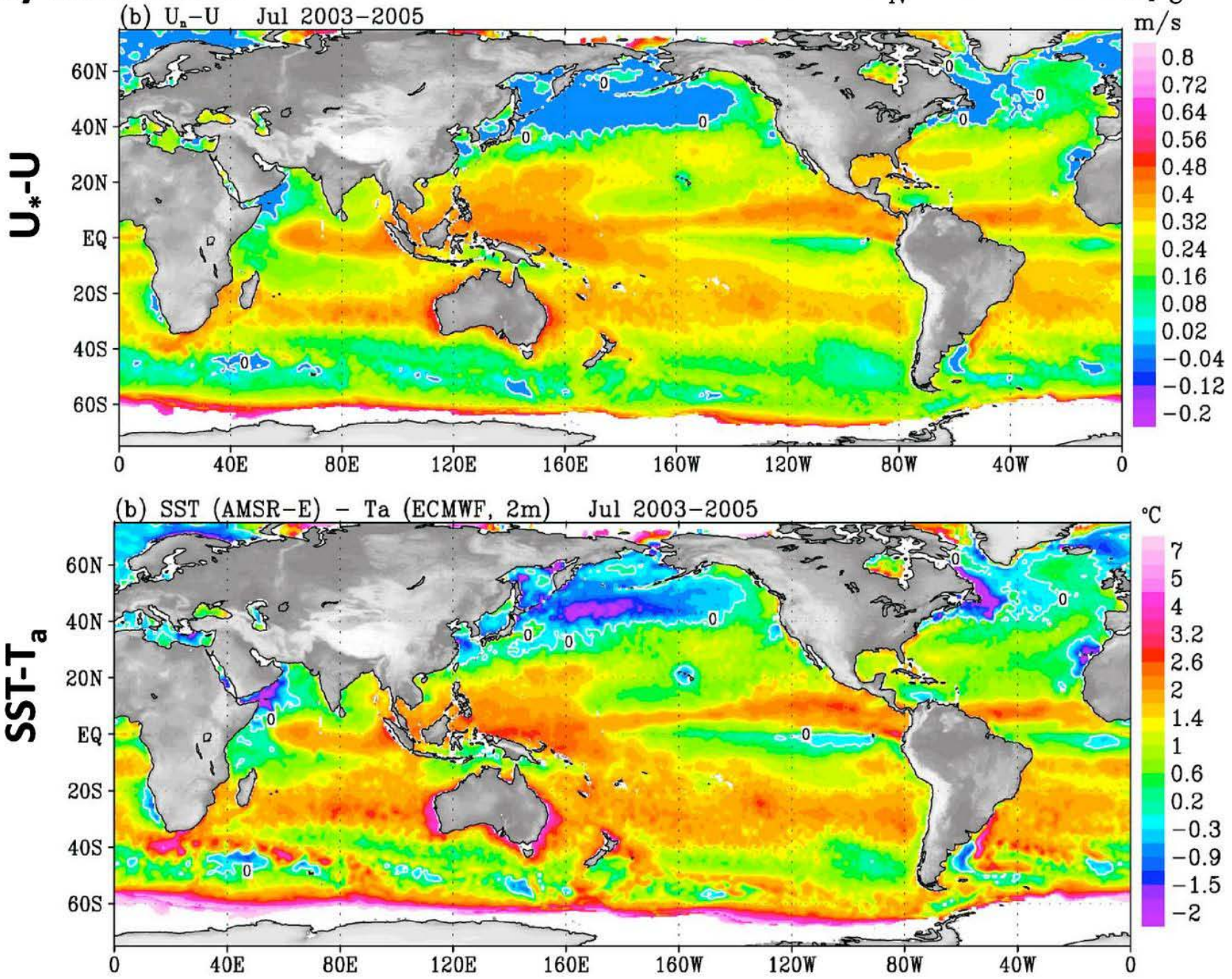
ENW is higher than actual wind under unstable condition



$$\frac{u-u_s}{u_*} = 2.5(\ln\frac{z}{z_0} - \psi_u) = \frac{1}{\sqrt{C_D}}$$

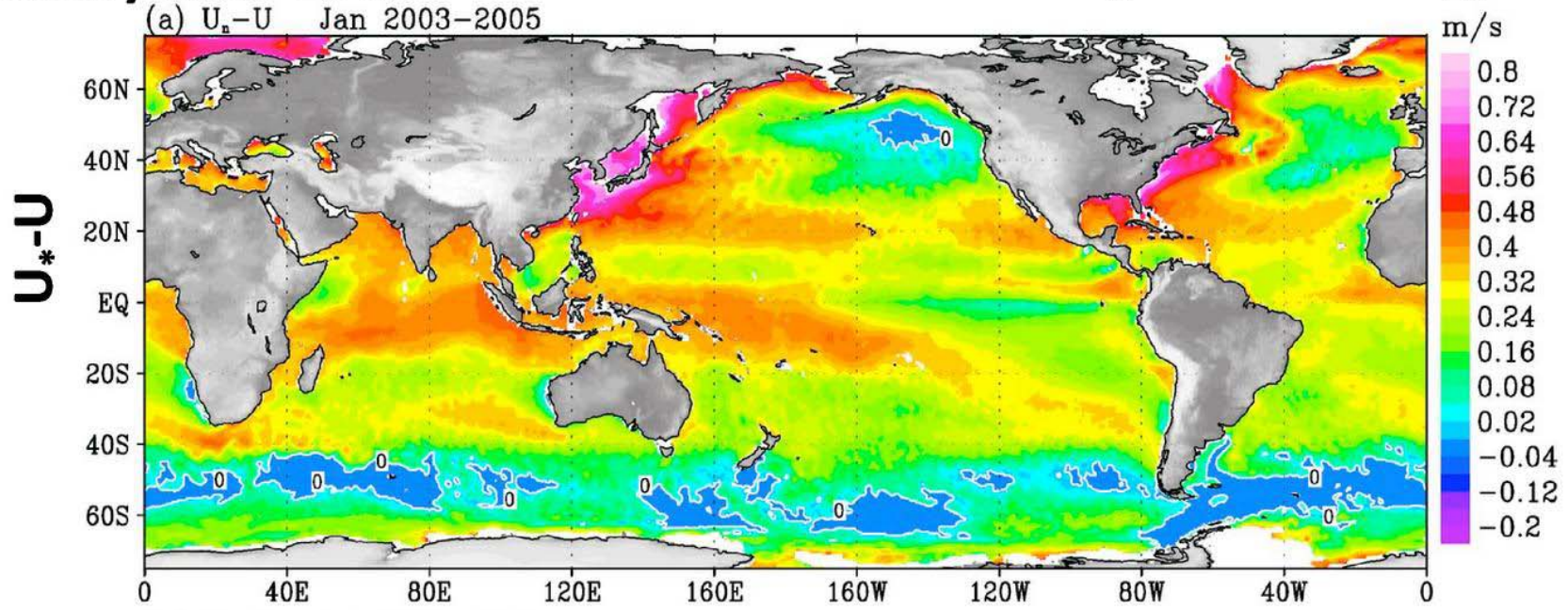
July 2003-2005

$$\delta U = U_N - U = 2.5 U_* \psi_U$$

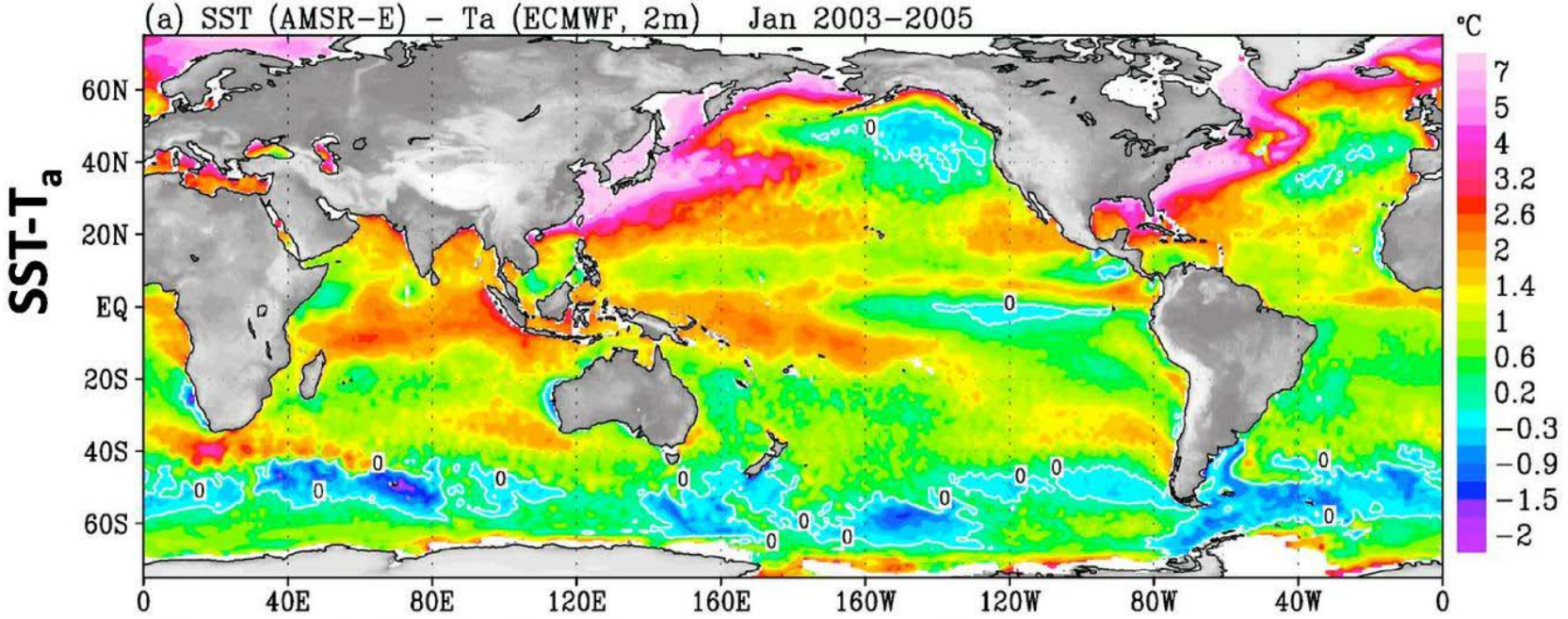


January 2003-2005

$$\delta U = U_N - U = 2.5 U_* \psi_U$$



U$_*$-U



SST-T$_a$

Similarity Theory
Buckingham theorem

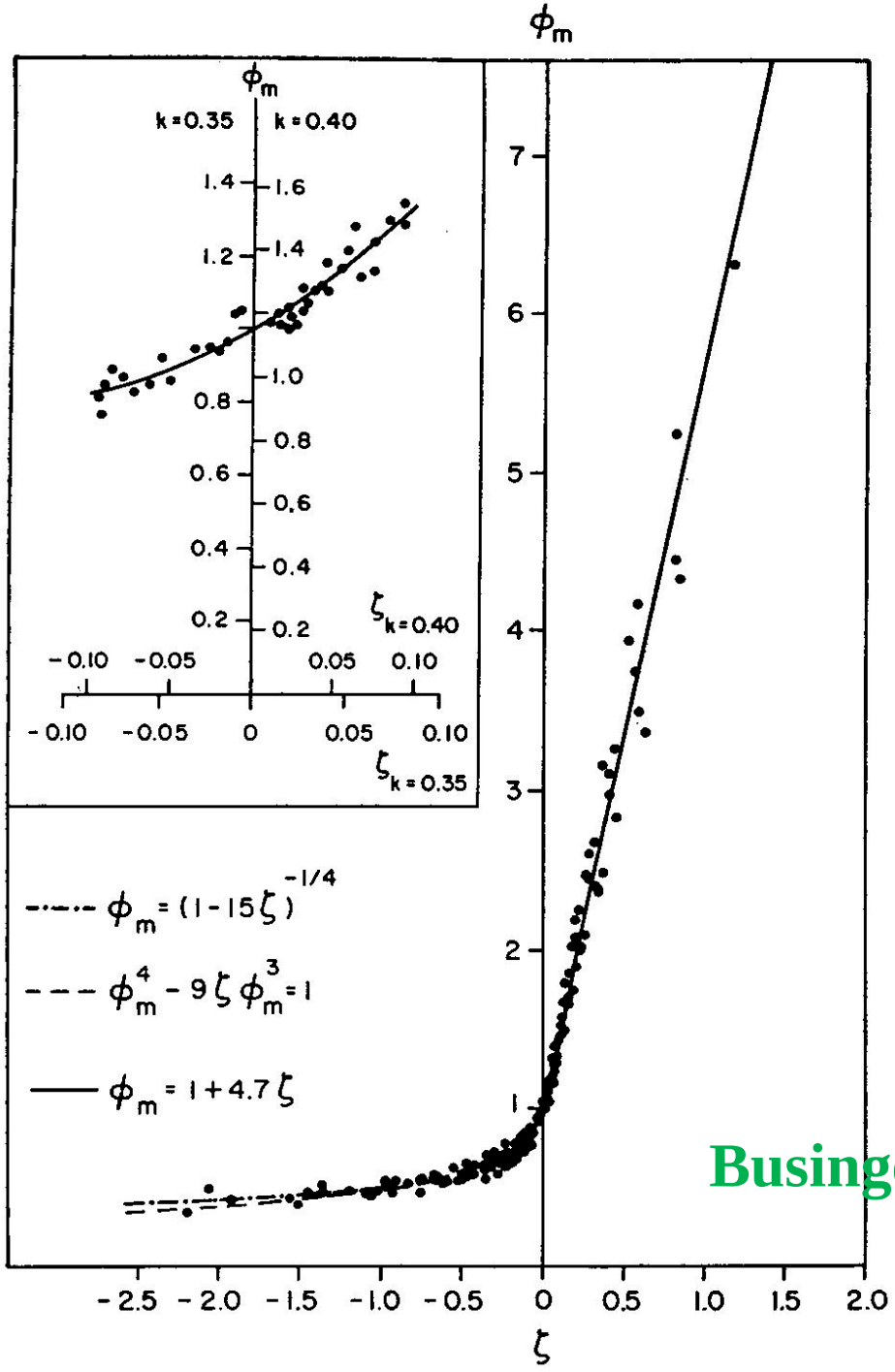
$$\frac{kz}{u_*}\frac{du}{dz} = \phi\left(\frac{z}{L}\right)$$

Obukhov (1946)

$$L = -\frac{u_*^3 c\rho T}{kgH}$$

$$\phi = \left(-\gamma\frac{z}{L}\right)^{-\frac{1}{4}}$$

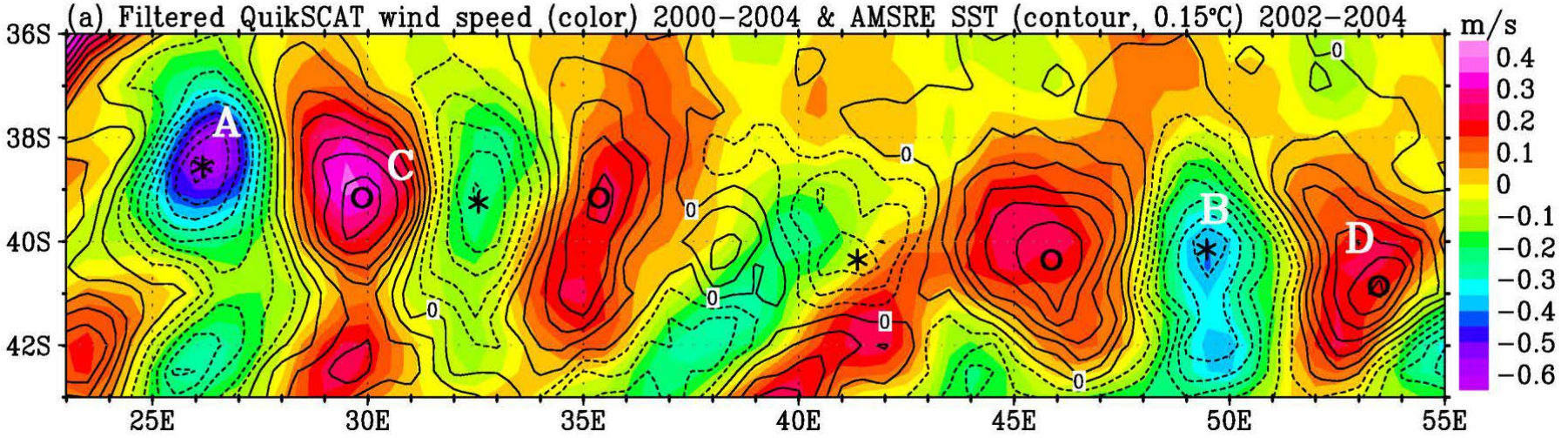
Businger & Dyer model based on Kansas & Kerang experiments



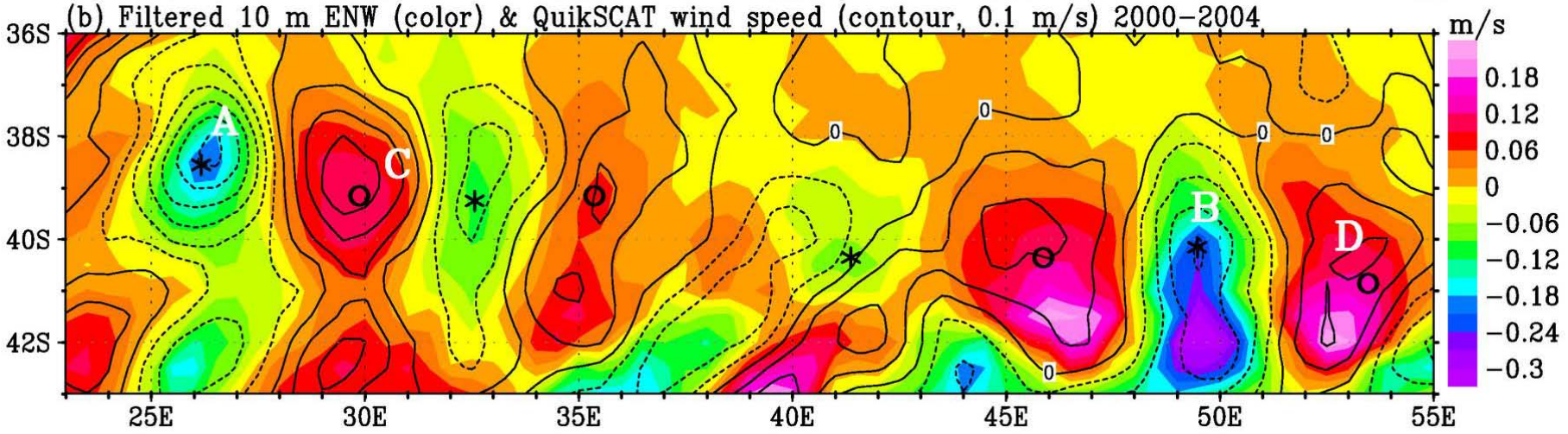
Businger et al (1971)

Observation from satellite

Agulhas



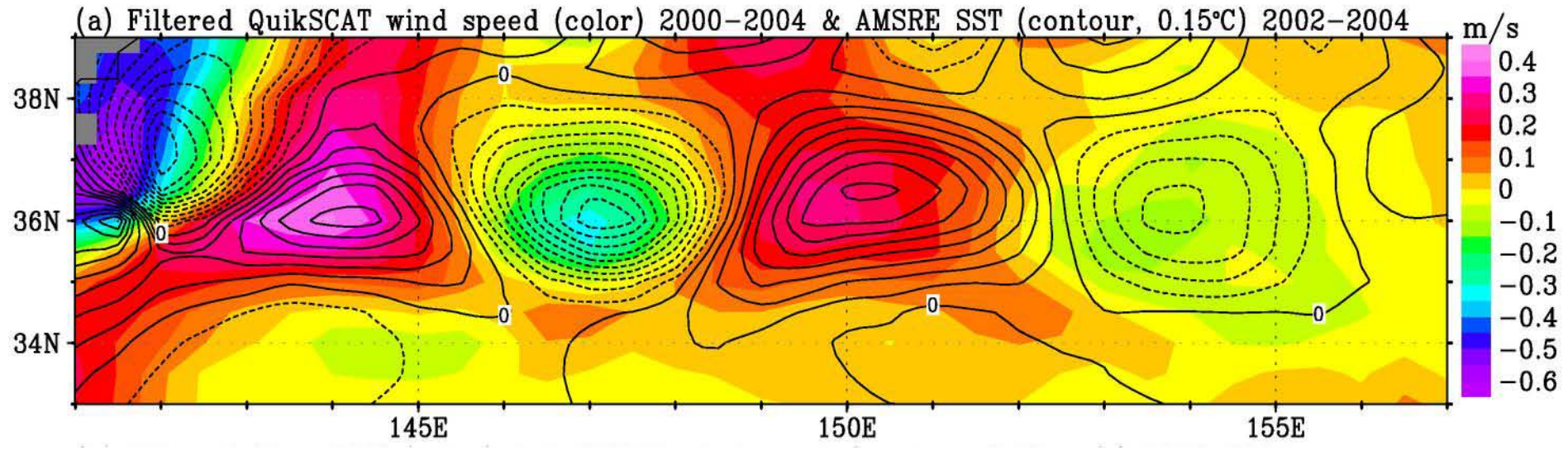
Computed from uniform wind field at 10m



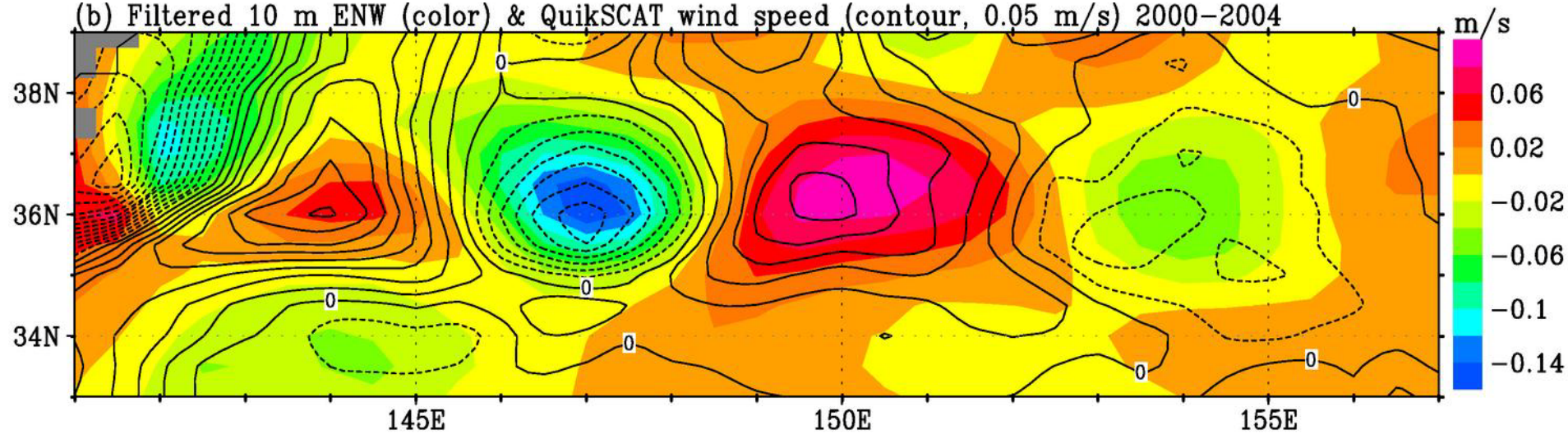
Collocation of ENW magnitude with SST is inherent in the definition of ENW and turbulent mixing theory. (Liu et al. 2007, JC)

Observation from satellite

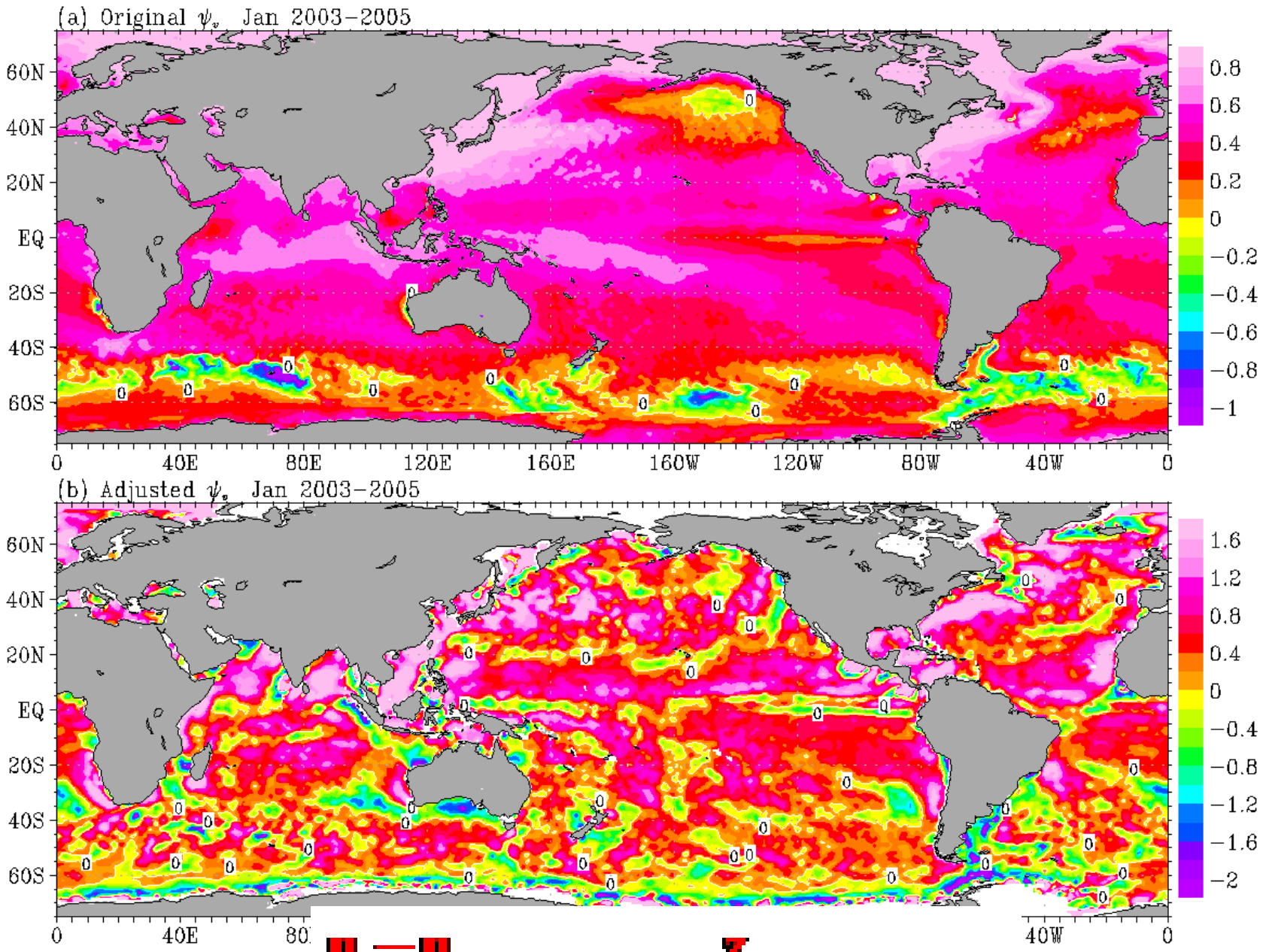
Kuroshio



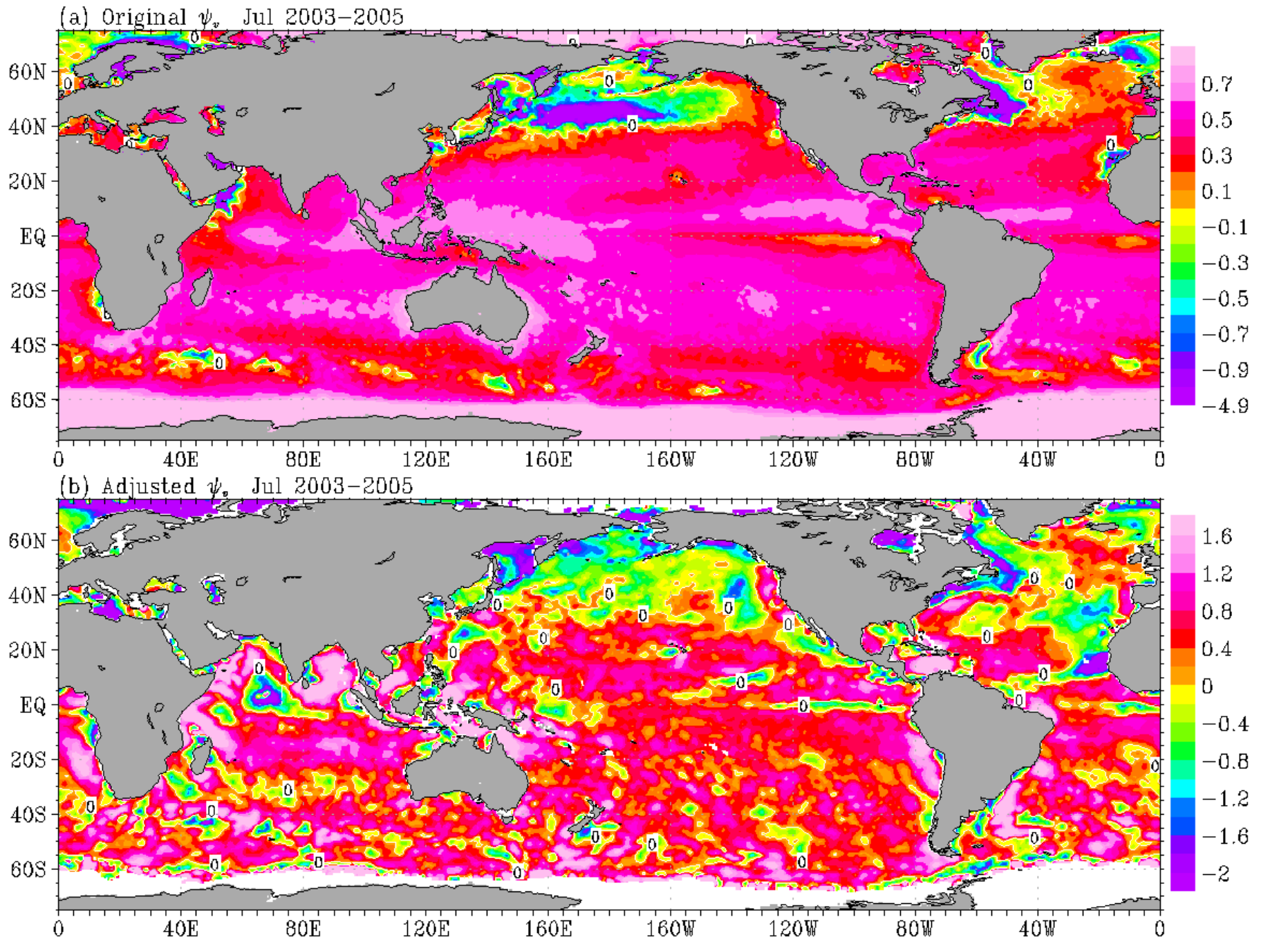
Computed from uniform wind field at 10m

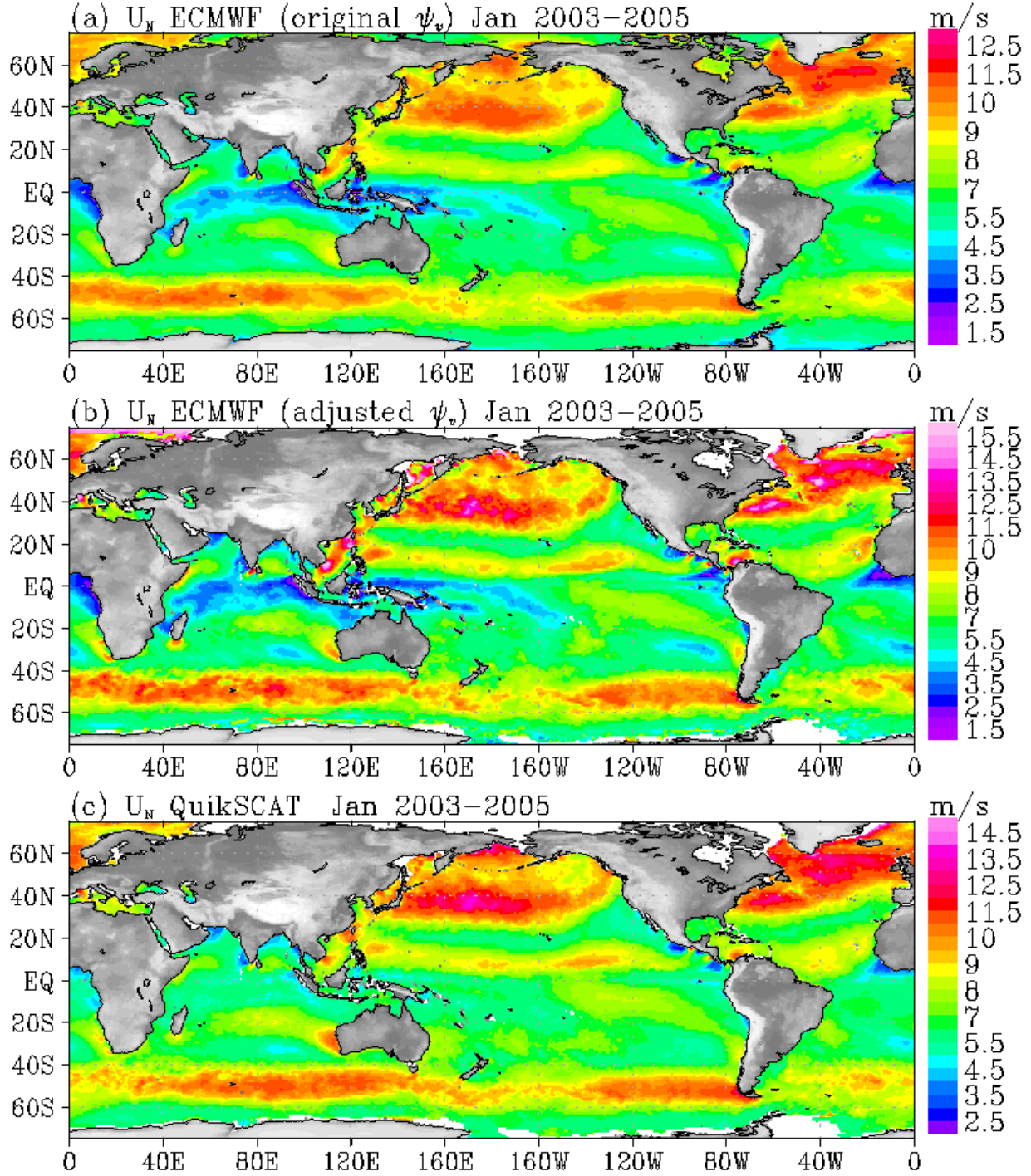


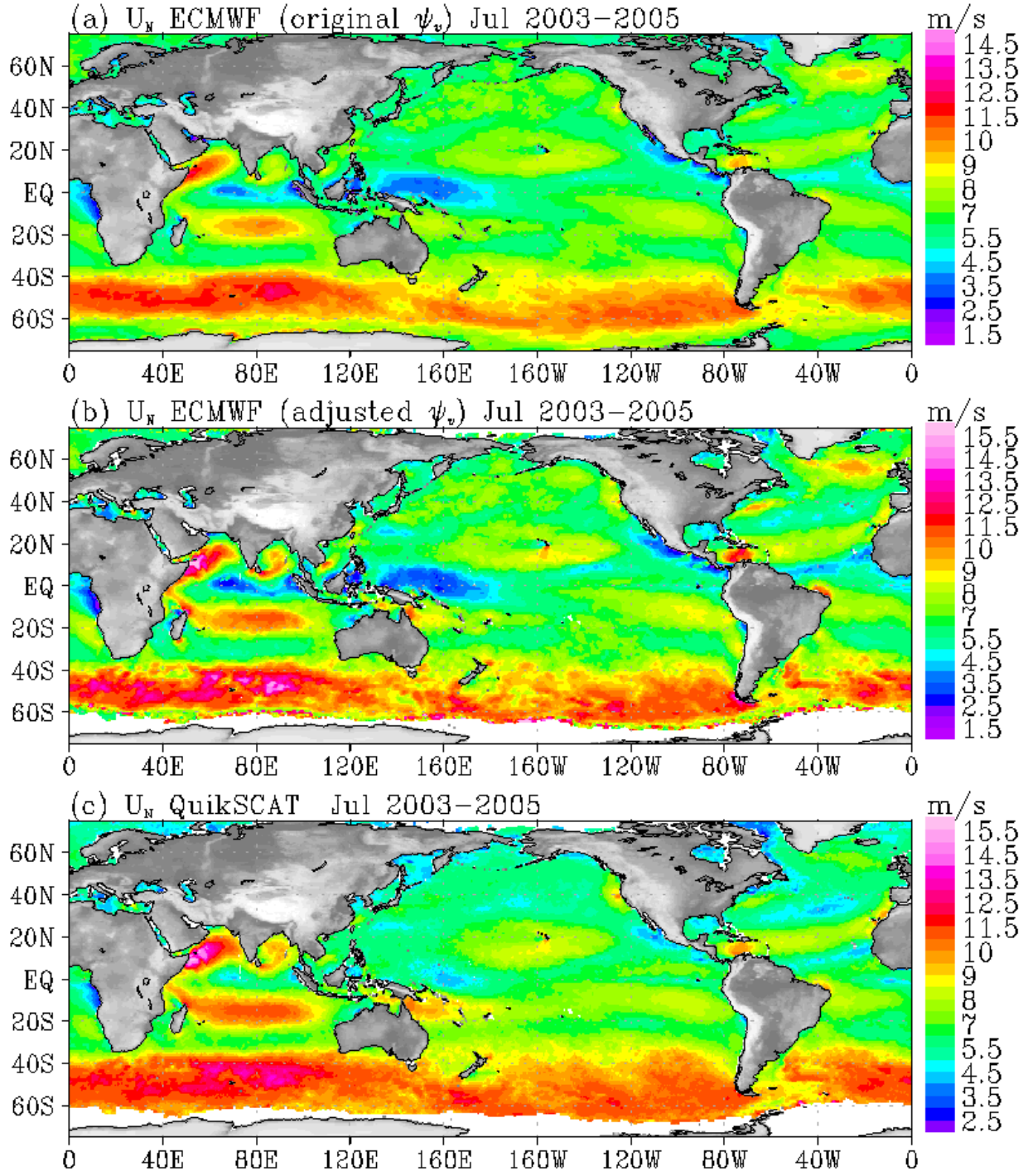
Liu et al. 2008, JO

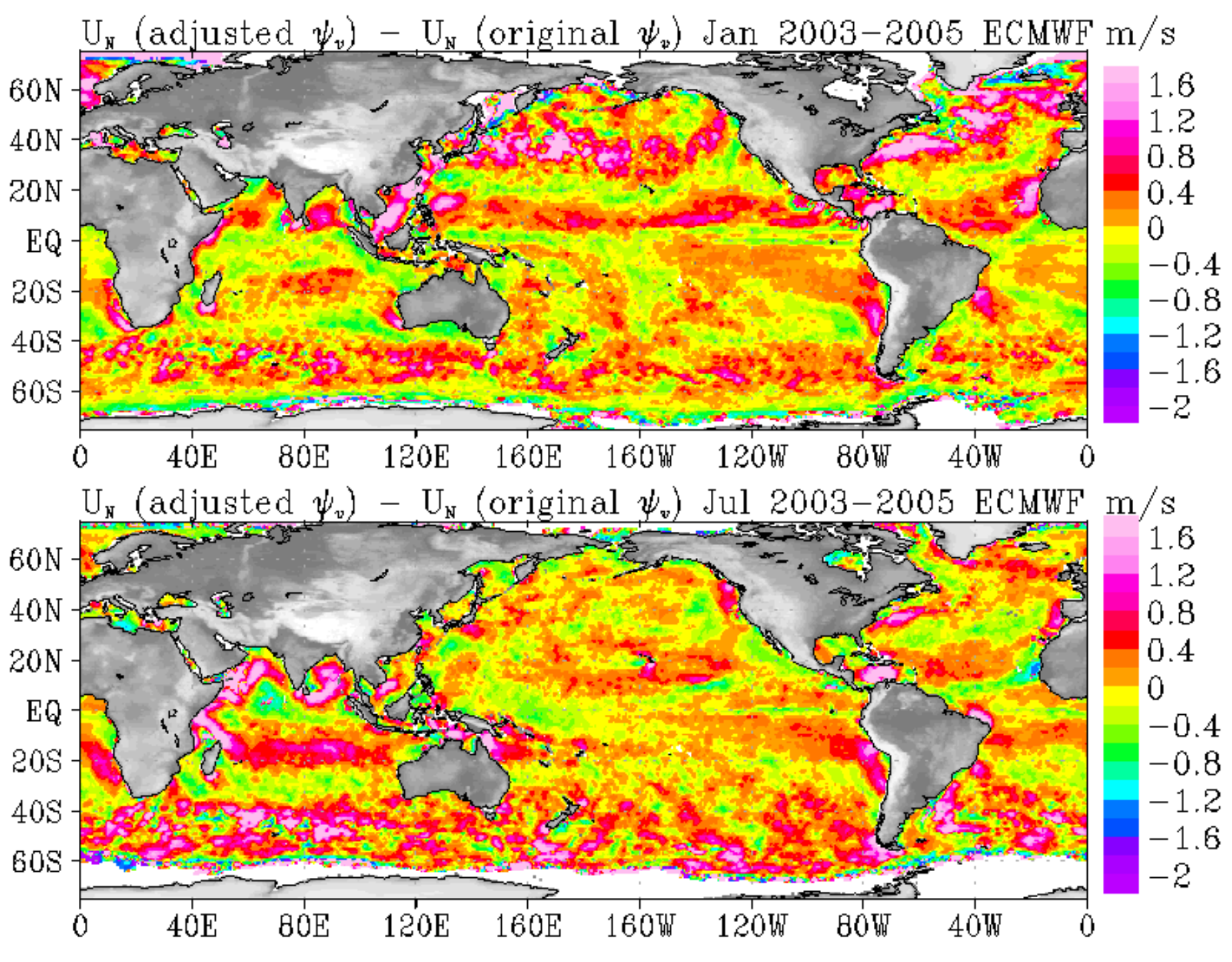


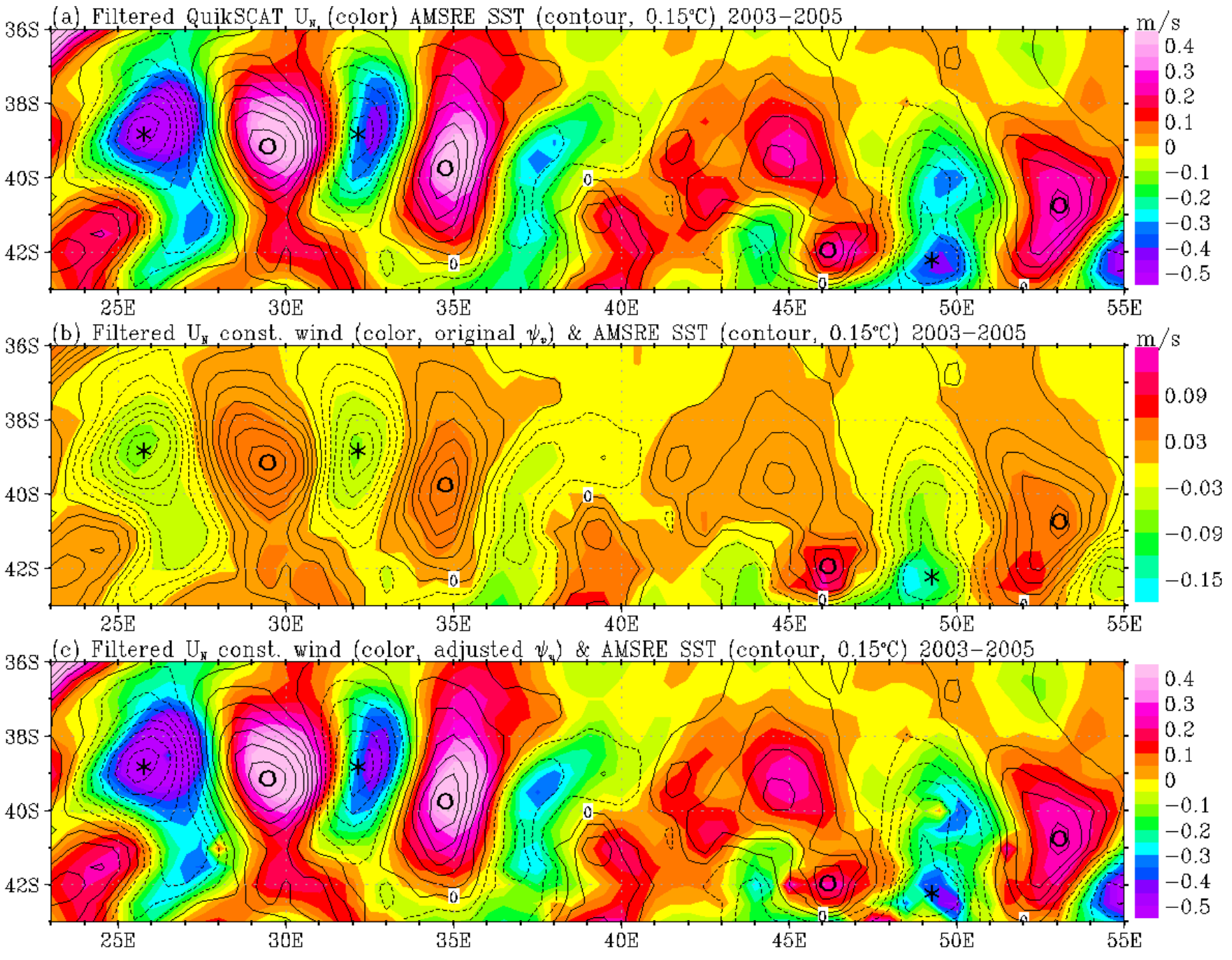
$$\frac{u - u_y}{u_*} = 2.5\left(\ln \frac{z}{z_0} - \psi_u - \delta\right)$$

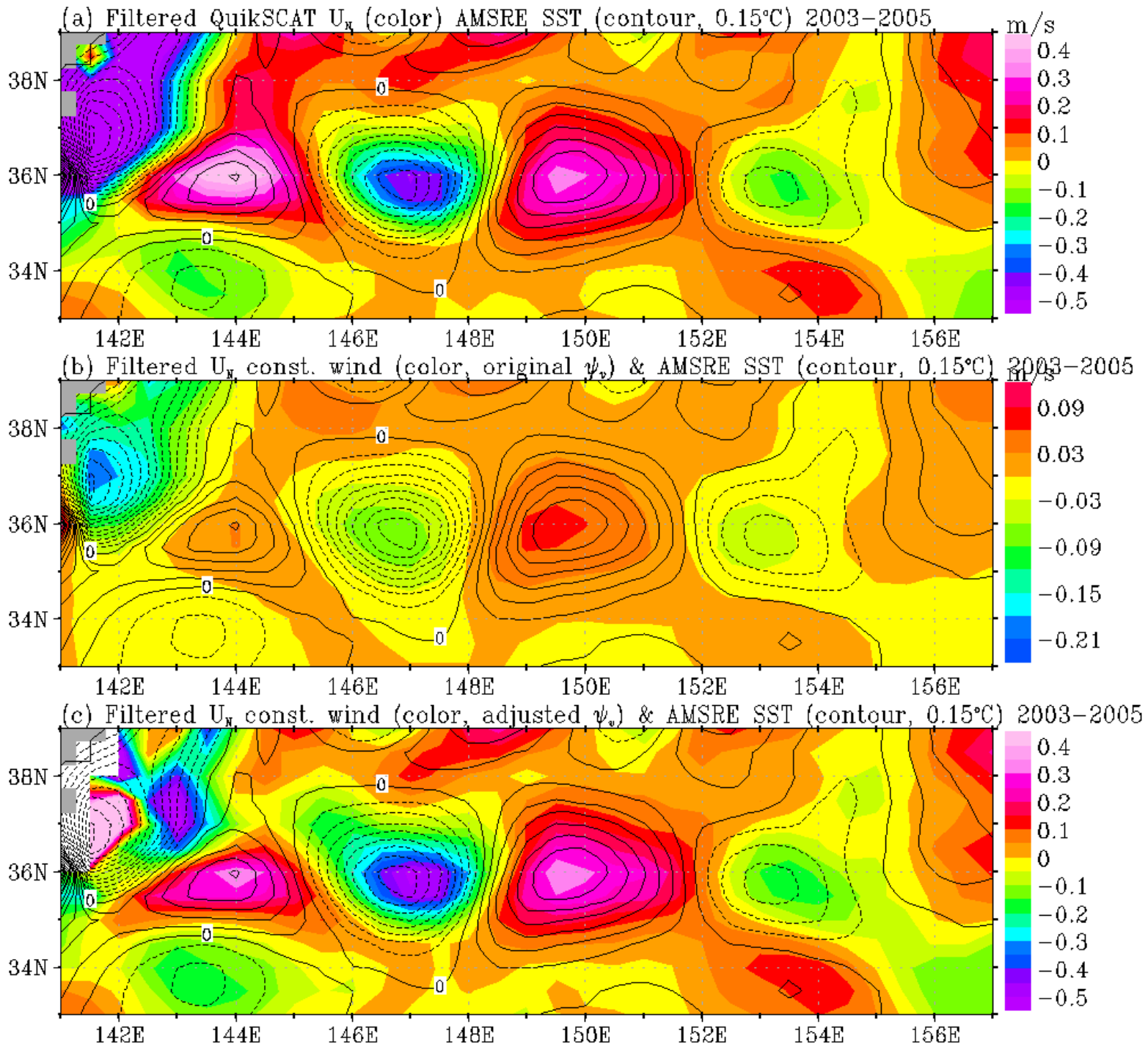

(a) Original ψ_e Jul 2003–2005
60N
40N
20N
EQ
20S
40S
60S
0
40E
80E
120E
160E
160W
120W
80W
40W
0
0.7
0.5
0.3
0.1
−0.1
−0.3
−0.5
−0.7
−0.9
−4.9
(b) Adjusted ψ_e Jul 2003–2005
60N
40N
20N
EQ
20S
40S
60S
0
40E
80E
120E
160E
160W
120W
80W
40W
0
1.6
1.2
0.8
0.4
0
−0.4
−0.8
−1.2
−1.6
−2

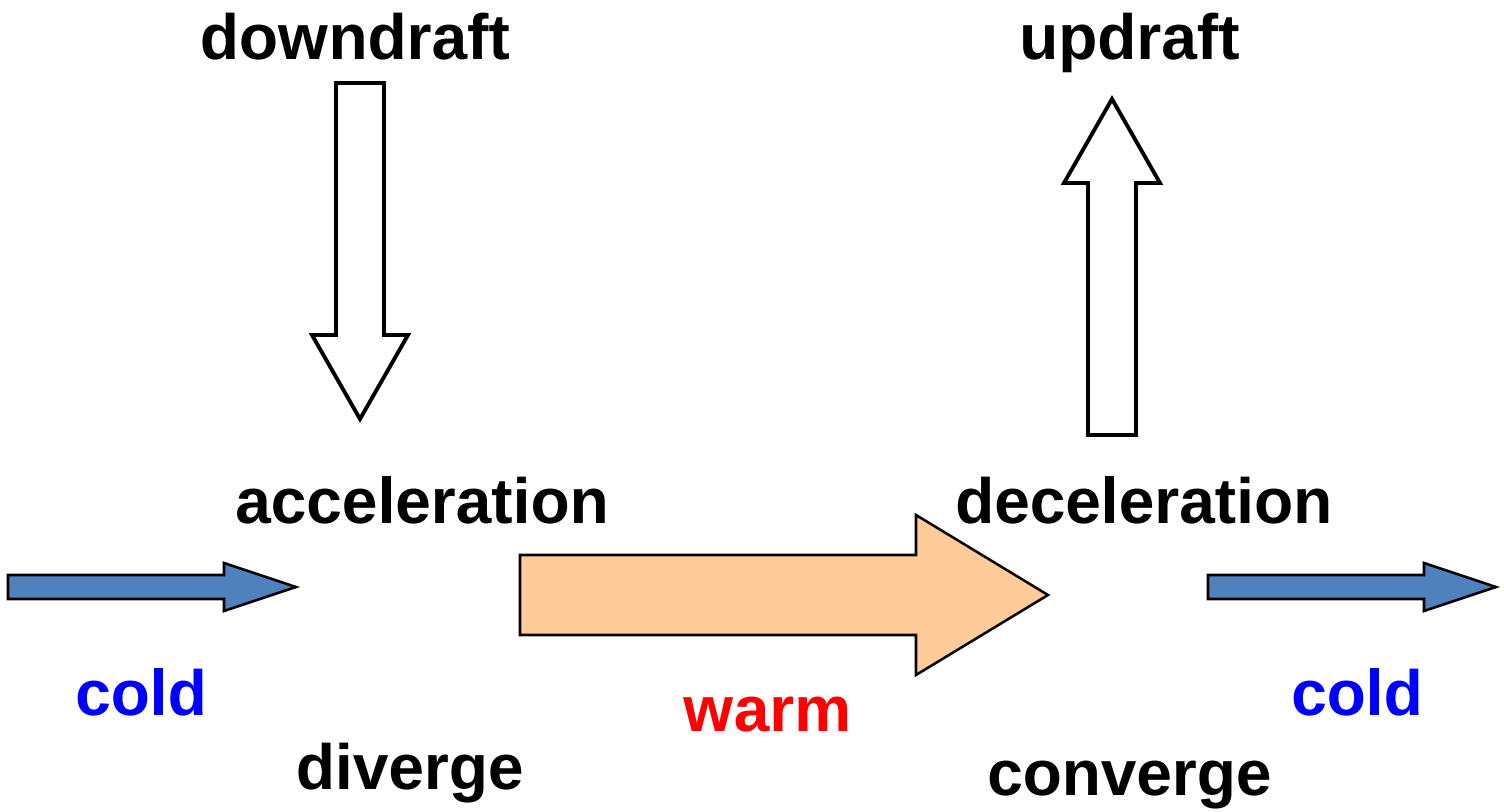

(a) U_N ECMWF (original ψ_v) Jan 2003–2005
m/s
12.5
11.5
10
9
8
7
5.5
4.5
3.5
2.5
1.5
60N
40N
20N
EQ
20S
40S
60S
0
40E
80E
120E
160E
160W
120W
80W
40W
0
(b) U_N ECMWF (adjusted ψ_v) Jan 2003–2005
m/s
15.5
14.5
13.5
12.5
11.5
10
9
8
7
5.5
4.5
3.5
2.5
1.5
60N
40N
20N
EQ
20S
40S
60S
0
40E
80E
120E
160E
160W
120W
80W
40W
0
(c) U_N QuikSCAT Jan 2003–2005
m/s
14.5
13.5
12.5
11.5
10
9
8
7
5.5
4.5
3.5
2.5
60N
40N
20N
EQ
20S
40S
60S
0
40E
80E
120E
160E
160W
120W
80W
40W
0


(a) U_N ECMWF (original ψ_v) Jul 2003–2005
(b) U_N ECMWF (adjusted ψ_v) Jul 2003–2005
(c) U_N QuikSCAT Jul 2003–2005
m/s
60N
40N
20N
EQ
20S
40S
60S
0
40E
80E
120E
160E
160W
120W
80W
40W


U_N (adjusted ψ_v) − U_N (original ψ_v) Jan 2003−2005 ECMWF m/s
60N
40N
20N
EQ
20S
40S
60S
0
40E
80E
120E
160E
160W
120W
80W
40W
0
1.6
1.2
0.8
0.4
0
−0.4
−0.8
−1.2
−1.6
−2
U_N (adjusted ψ_v) − U_N (original ψ_v) Jul 2003−2005 ECMWF m/s
60N
40N
20N
EQ
20S
40S
60S
0
40E
80E
120E
160E
160W
120W
80W
40W
0
1.6
1.2
0.8
0.4
0
−0.4
−0.8
−1.2
−1.6
−2


(a) Filtered QuikSCAT U_N (color) AMSRE SST (contour, 0.15°C) 2003–2005
m/s
0.4
0.3
0.2
0.1
0
−0.1
−0.2
−0.3
−0.4
−0.5
36S
38S
40S
42S
25E
30E
35E
40E
45E
50E
55E
(b) Filtered U_N const. wind (color, original ψ_v) & AMSRE SST (contour, 0.15°C) 2003–2005
m/s
0.09
0.03
−0.03
−0.09
−0.15
(c) Filtered U_N const. wind (color, adjusted ψ_v) & AMSRE SST (contour, 0.15°C) 2003–2005


(a) Filtered QuikSCAT U_N (color) AMSRE SST (contour, 0.15°C) 2003–2005
m/s
0.4
0.3
0.2
0.1
0
−0.1
−0.2
−0.3
−0.4
−0.5
38N
36N
34N
142E
144E
146E
148E
150E
152E
154E
156E
(b) Filtered U_N const. wind (color, original ψ_v) & AMSRE SST (contour, 0.15°C) 2003–2005
m/s
0.09
0.03
−0.03
−0.09
−0.15
−0.21
(c) Filtered U_N const. wind (color, adjusted ψ_v) & AMSRE SST (contour, 0.15°C) 2003–2005


downdraft
updraft
acceleration
deceleration
cold
warm
cold
diverge
converge

- Our knowledge on stress came from wind through turbulence parameterization in the past
- Scatterpmeters provide the first and only maps of ocean surface stress
- The data generate new perspective of turbulence productions and its relation with mesoscale convection
- New bulk parameterization of stress may be needed

Backup