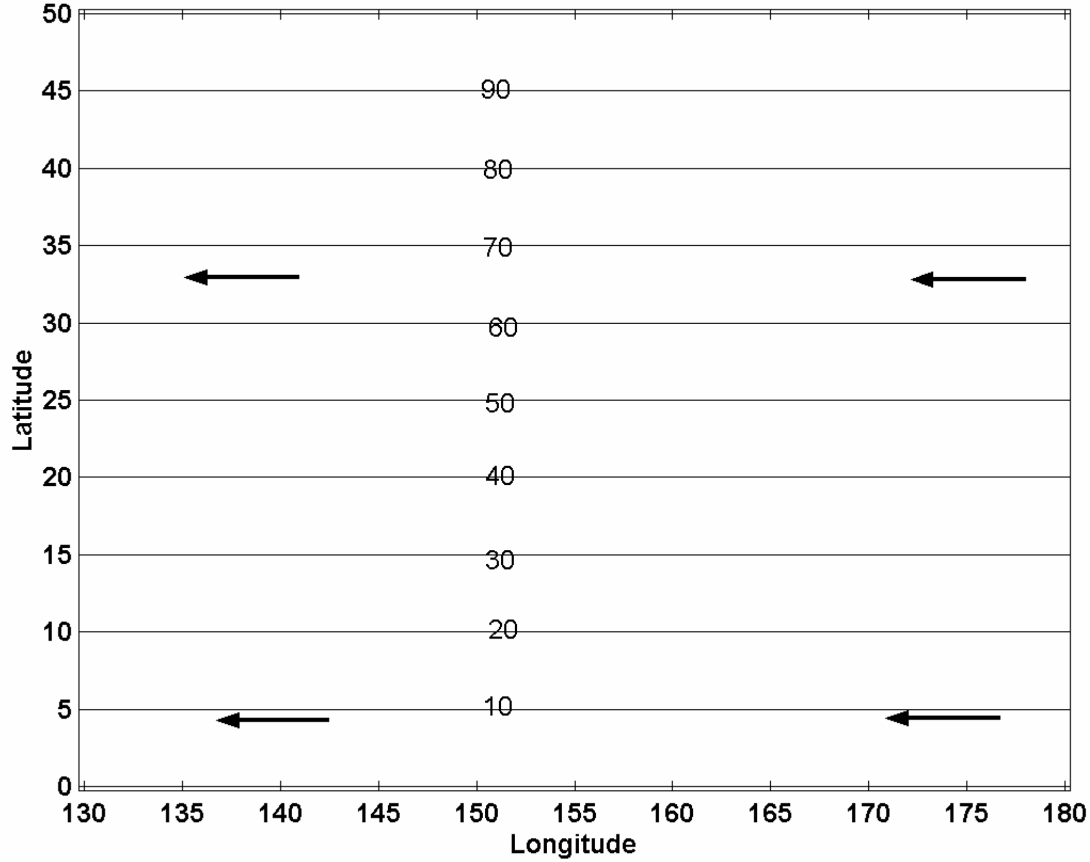
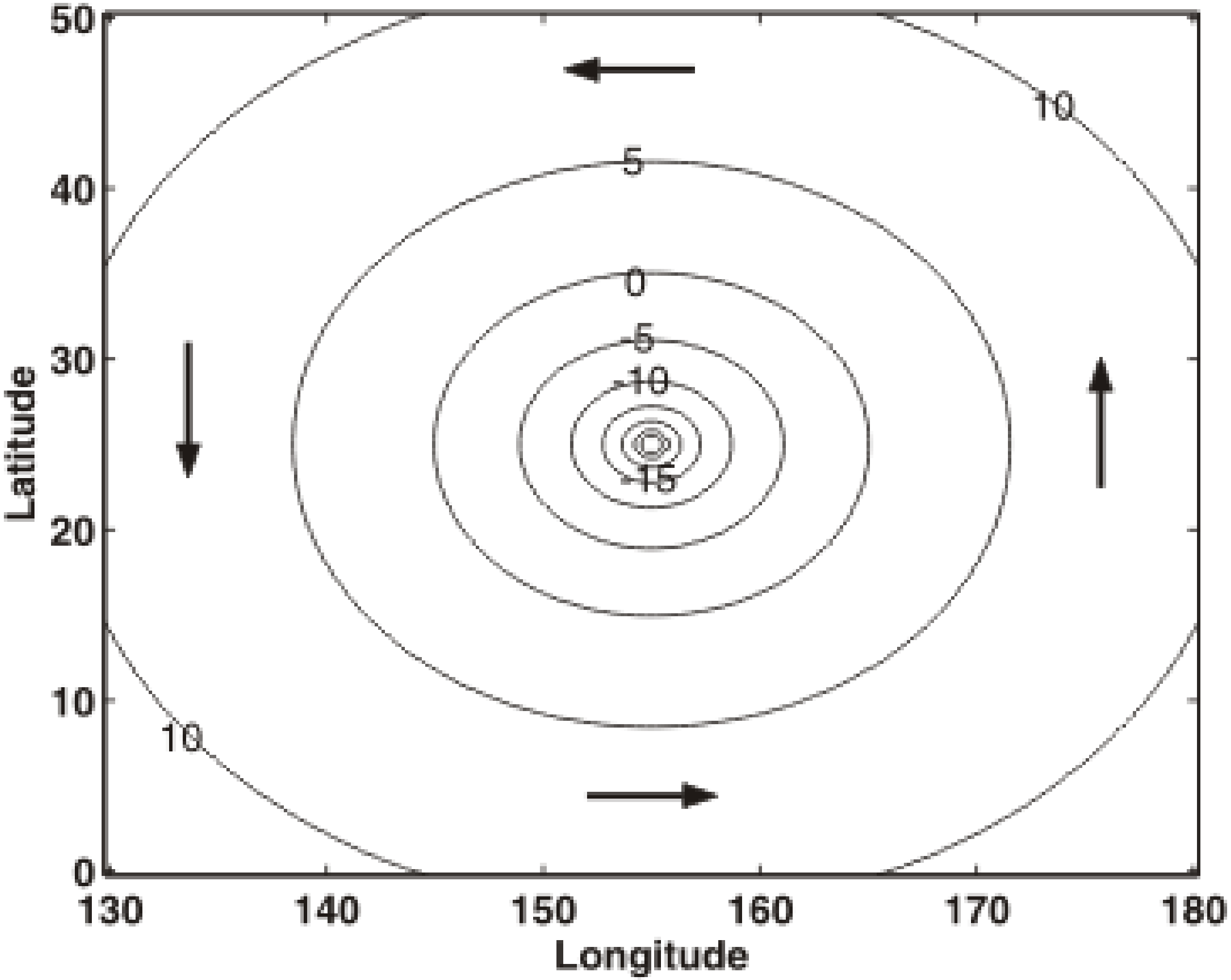
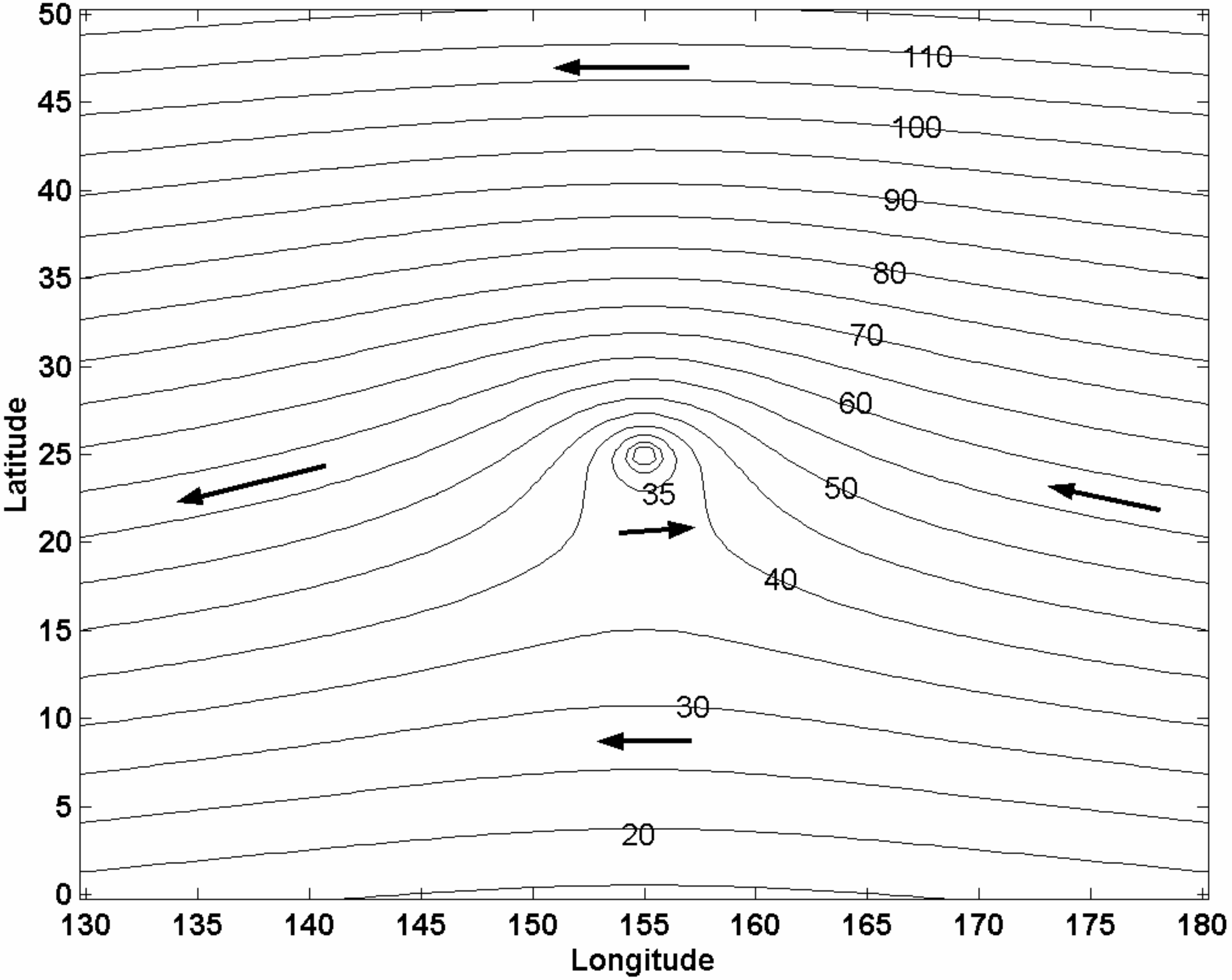
Tropical Cyclone Motion

Tropical cyclones move approximately with a suitably defined vertical vector average of the flow in which they are embedded





50
40
30
20
10
0
Latitude
130
140
150
160
170
180
Longitude
10
5
0
-5
-10
-15
10


110
100
90
80
70
60
50
40
35
30
20
Latitude
Longitude
0
5
10
15
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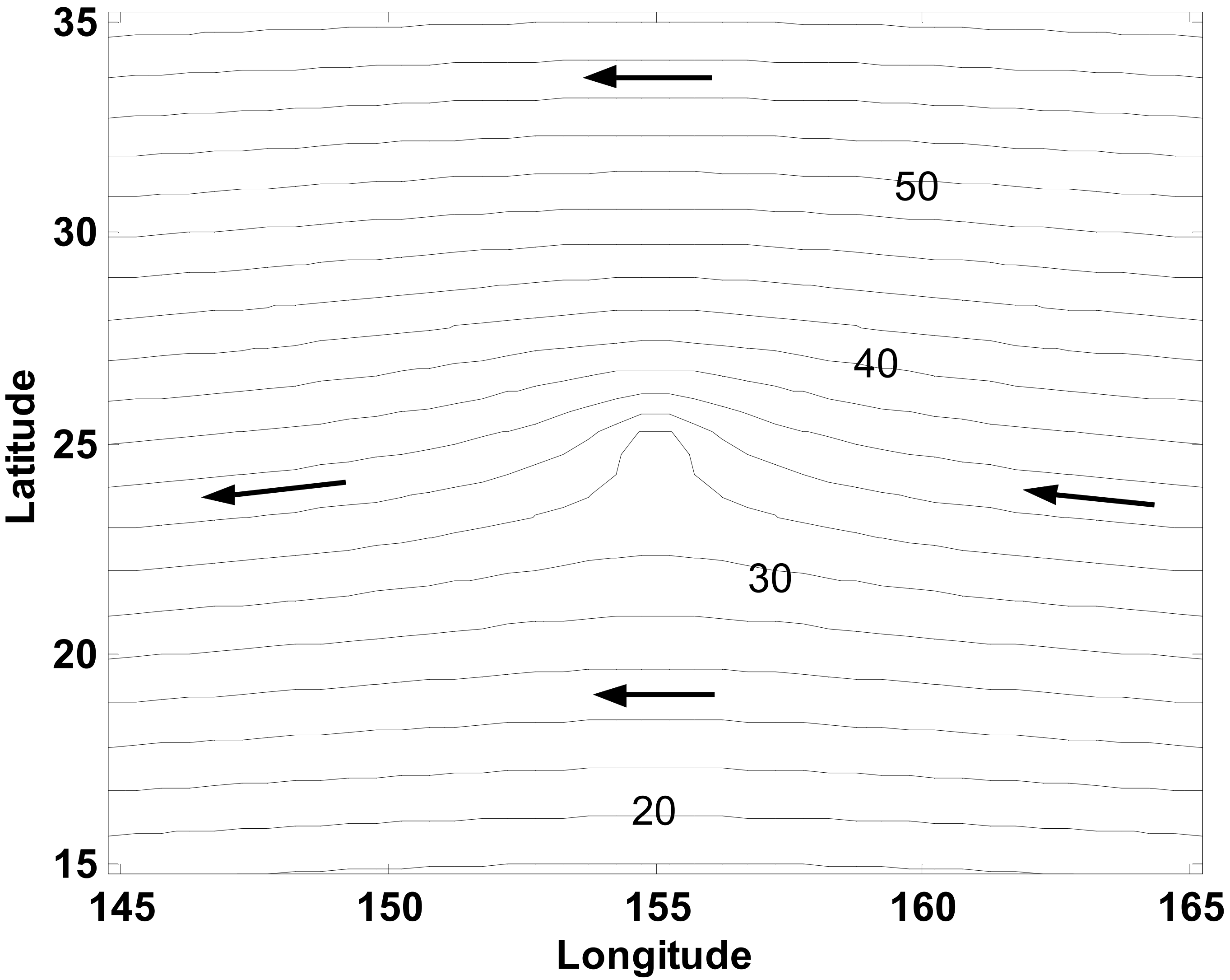
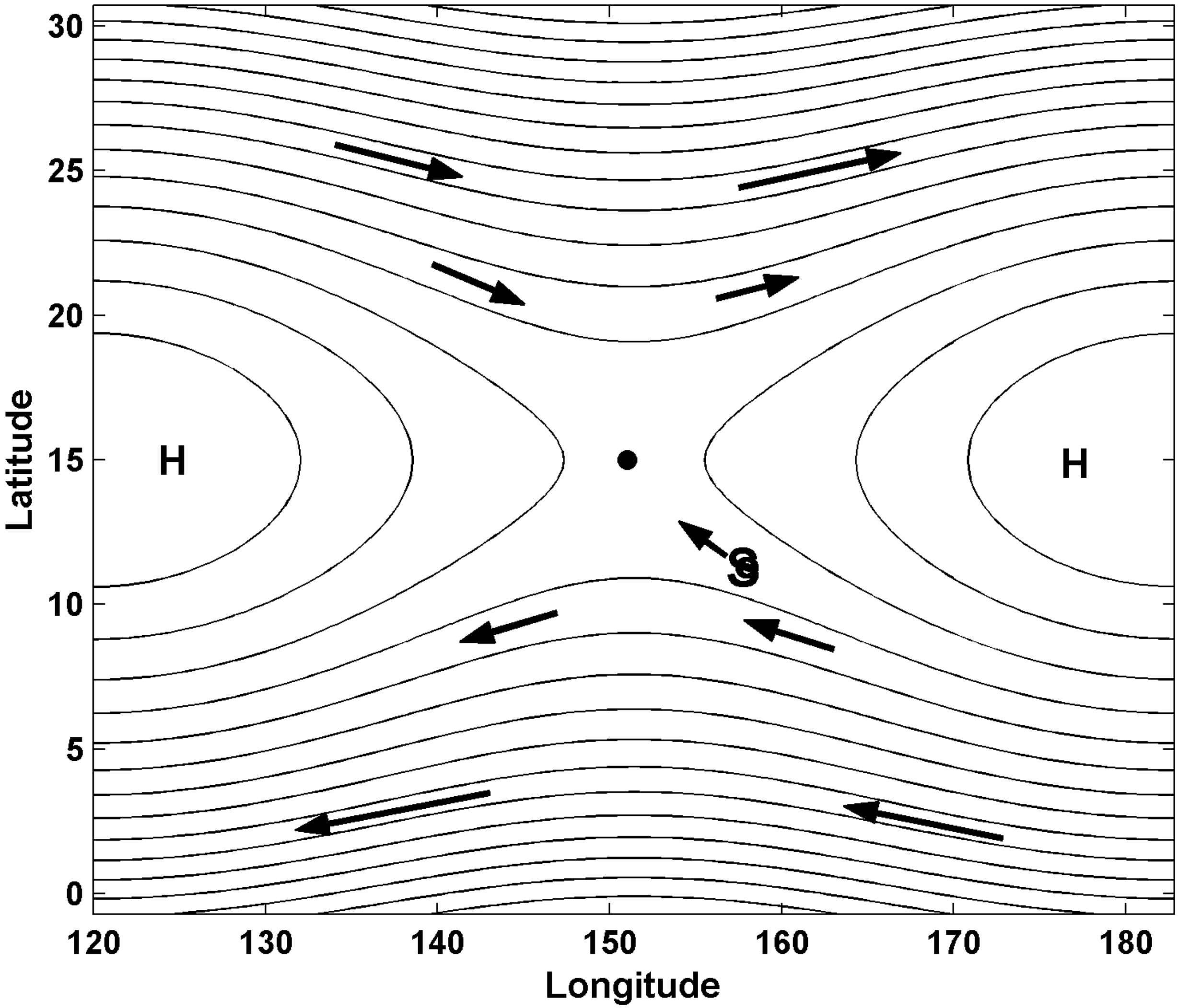
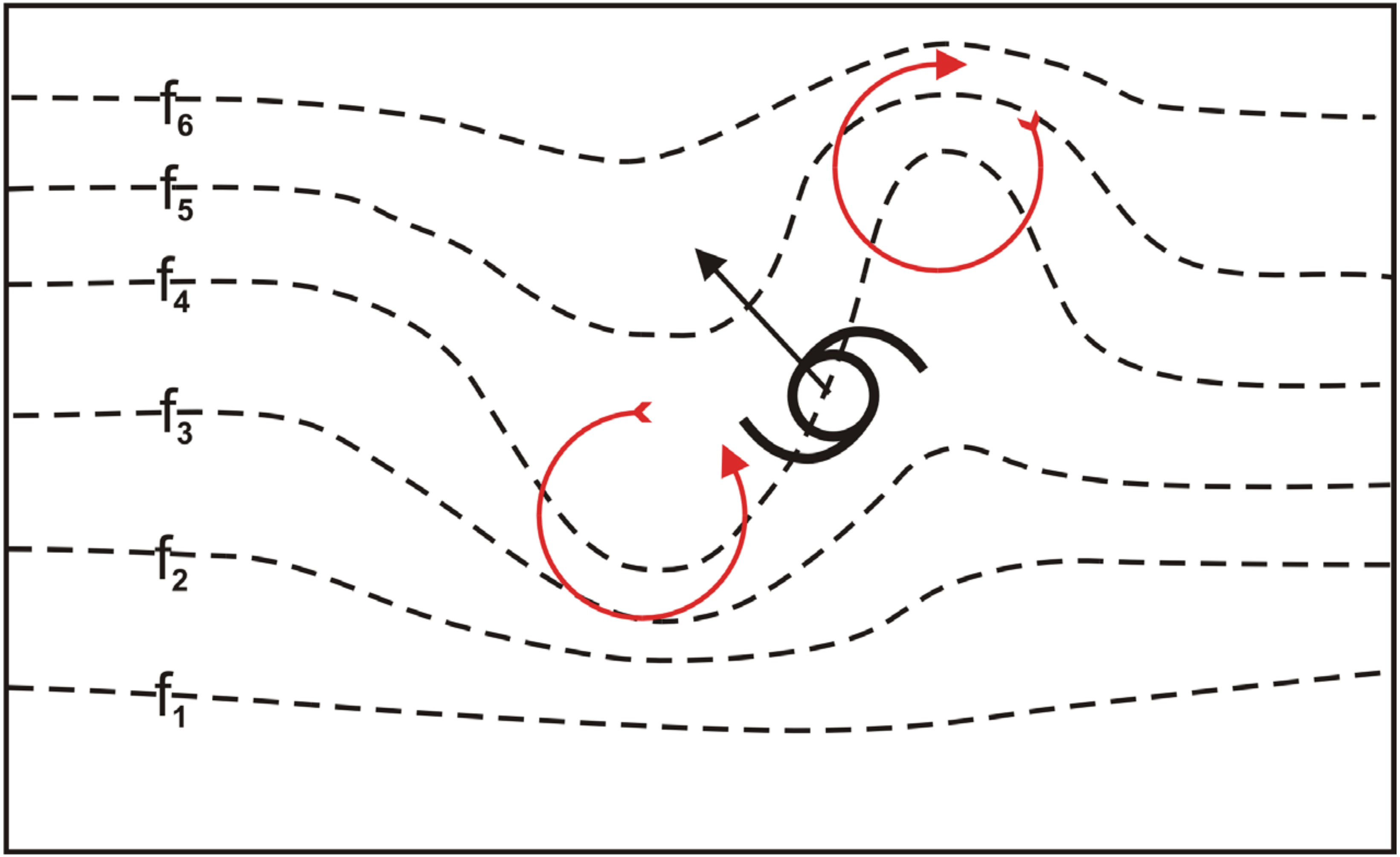
25
30
35
40
45
50
130
135
140
145
150
155
160
165
170
175
180


50
40
30
20
35
30
25
20
15
145
150
155
160
165
Latitude
Longitude

Lagrangian chaos:



Vortices in PV gradients:

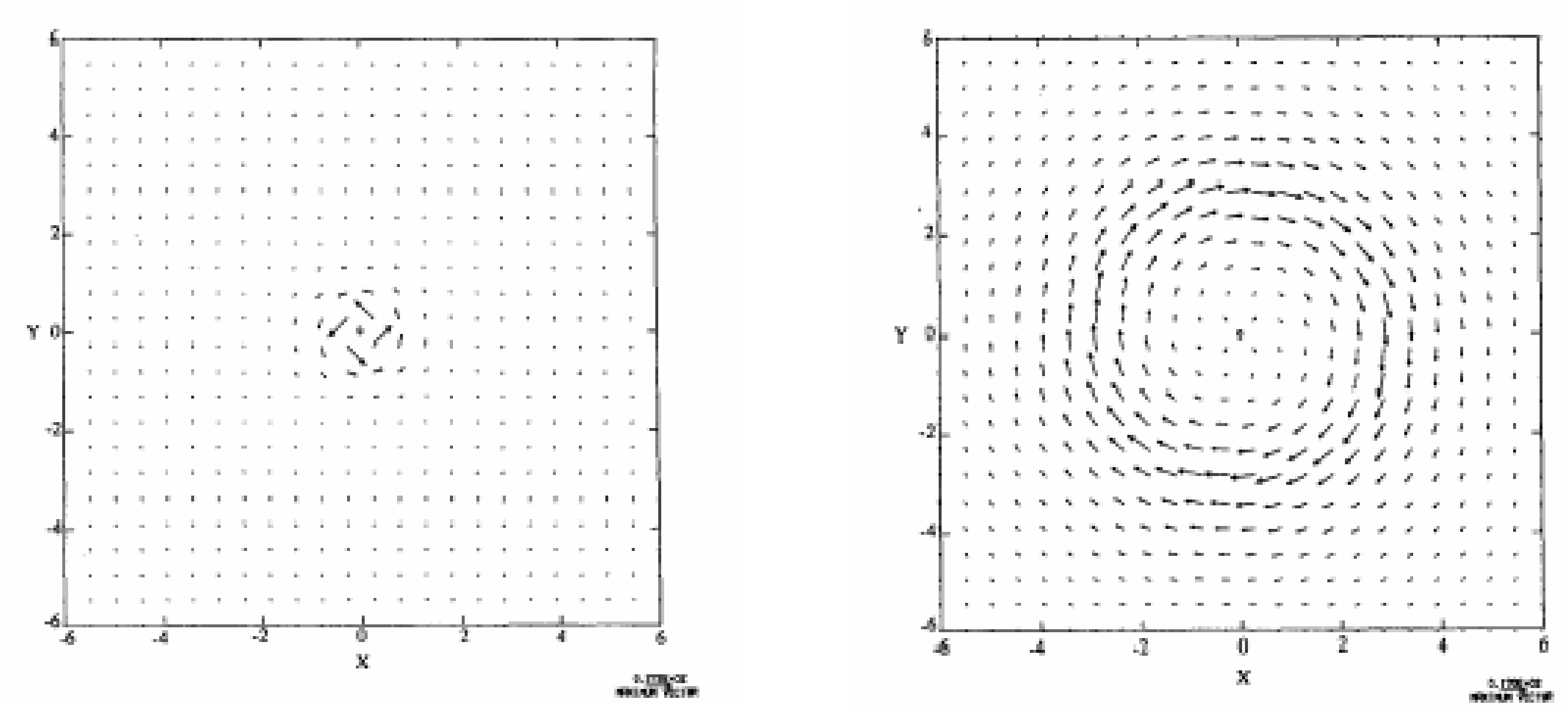


Baroclinic vortices in shear: A simple model

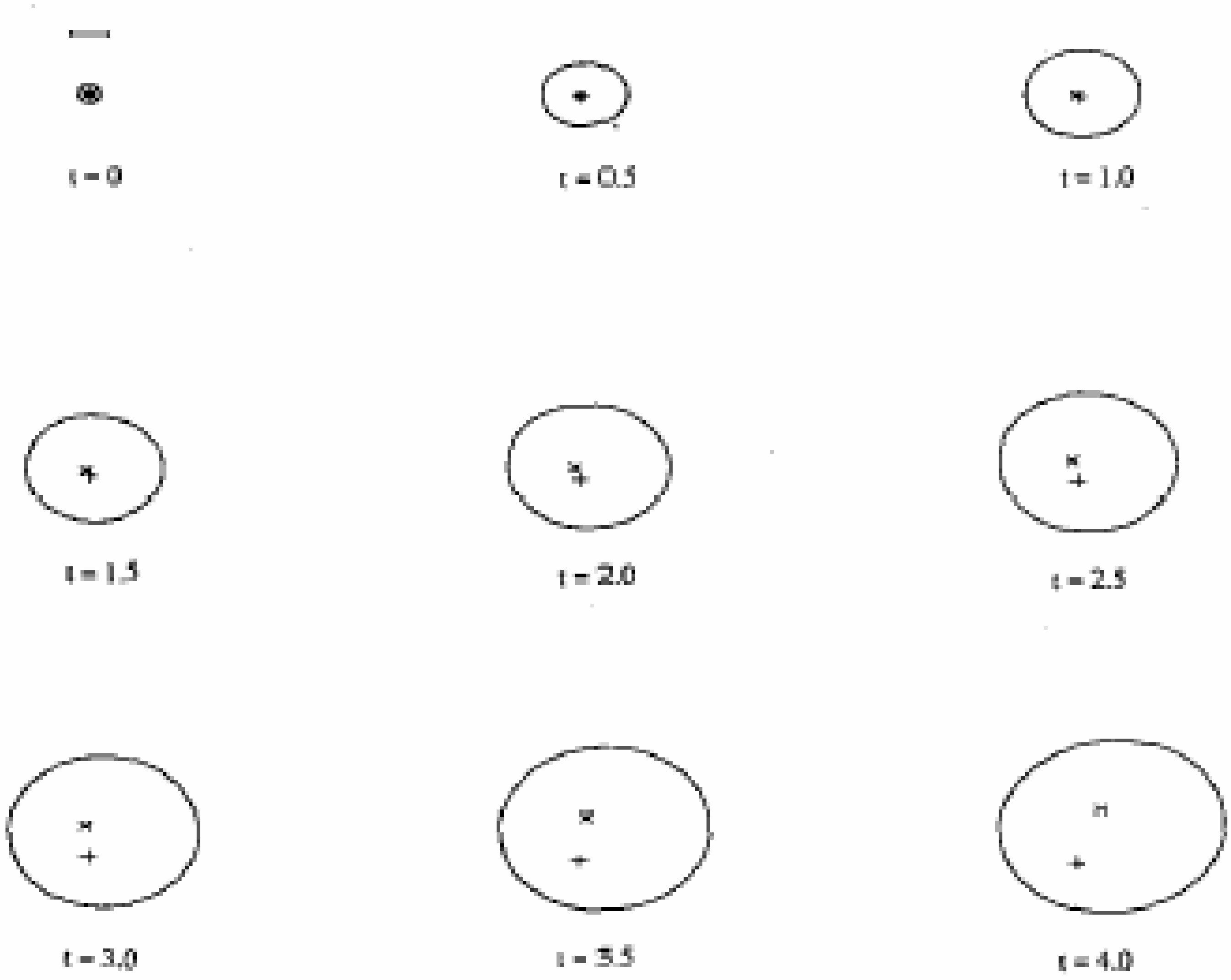
- Two layers, with zero effective PV gradient, but upper layer moving with respect to lower layer
- Lower layer contains point potential vortex, whose circulation projects outward and upward
- Upper layer has point source of zero PV air co-located with lower point vortex; zero PV air separated from surroundings by a single, expanding contour
- Flow owing to upper level PV anomaly solved by contour dynamics

(From Wu and Emanuel, 1993)

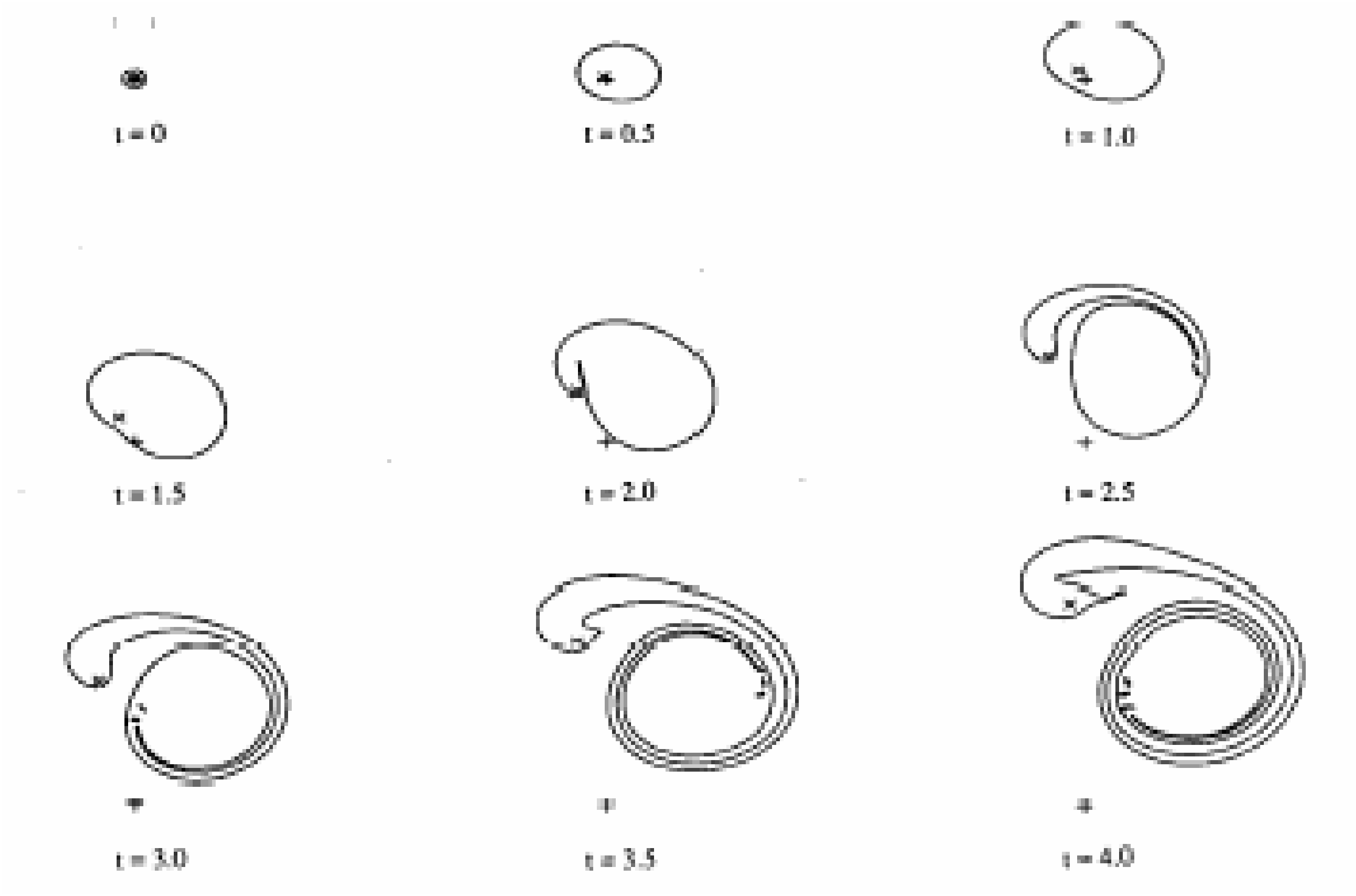
Lower (left) and upper (right) flows for zero shear:



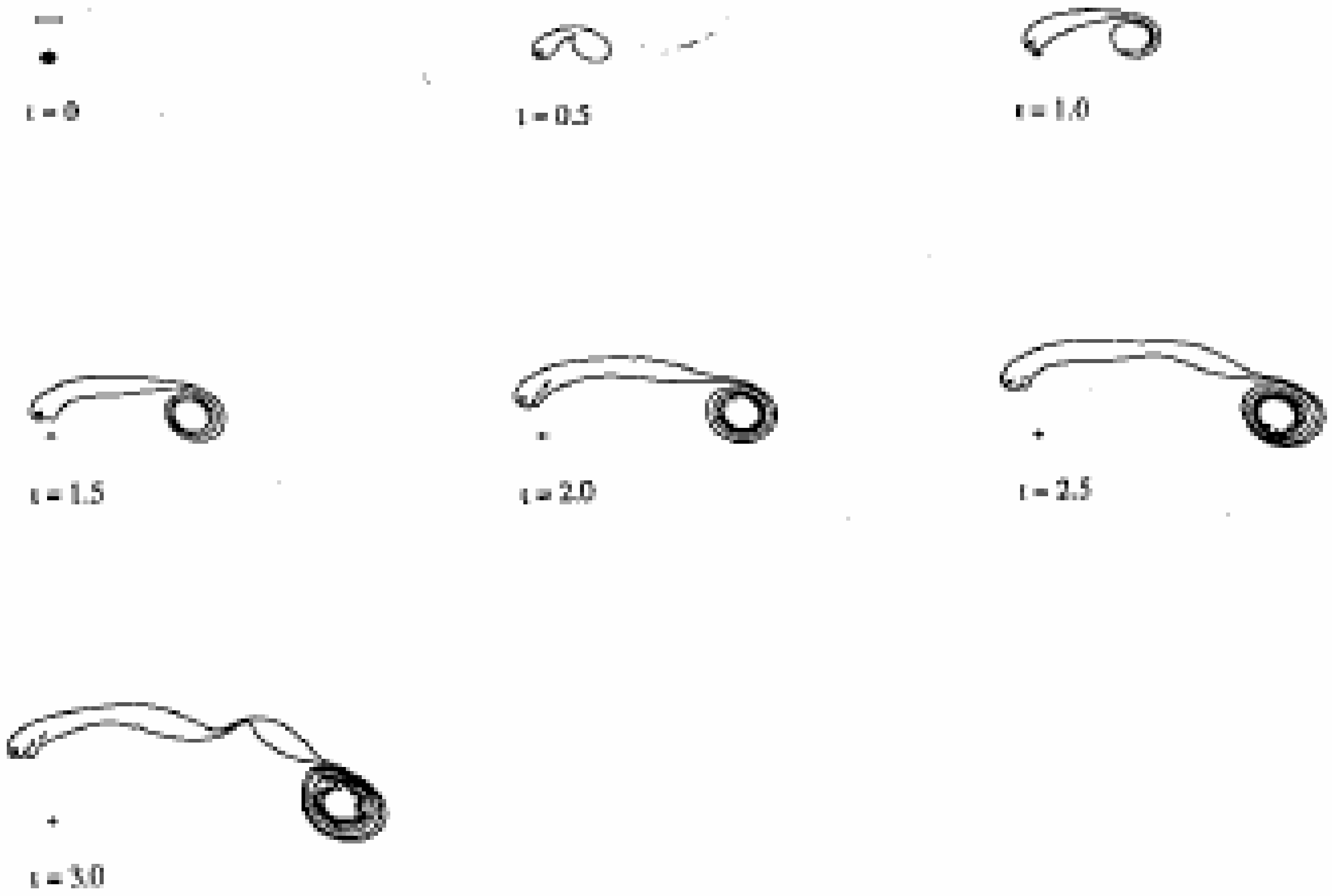
Evolution of upper layer votex patch when weak shear is present



Evolution of upper layer votex patch when moderate shear is present



Evolution of upper layer votex patch when strong shear is present



t = 0

t = 0.5

t = 1.0

t = 1.5

t = 2.0

t = 2.5

t = 3.0

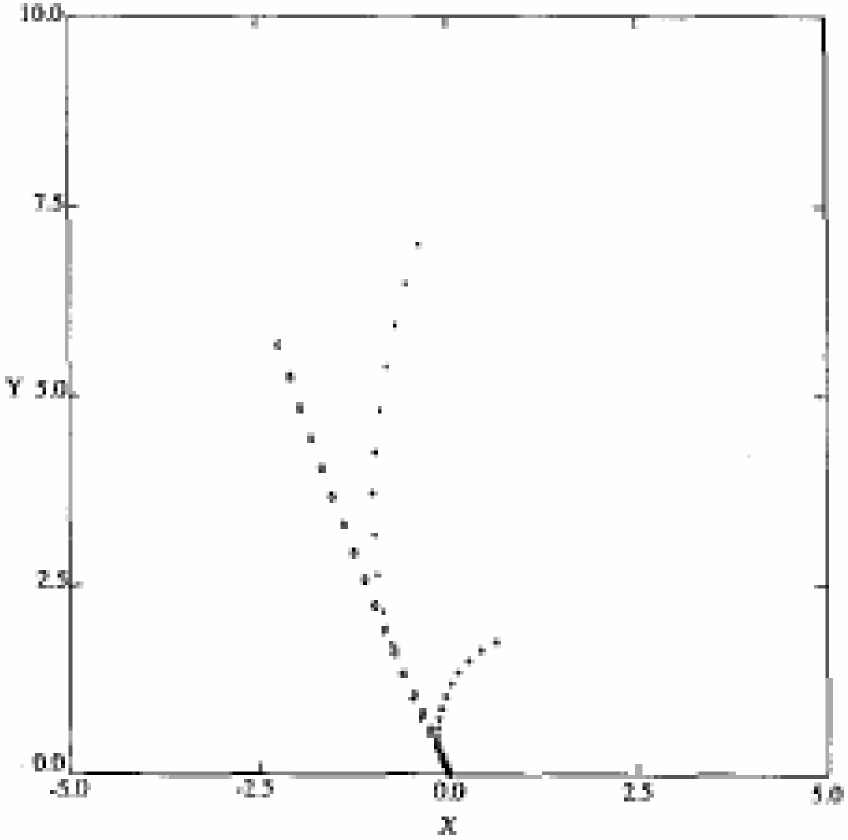


FIG. 11. Trajectories (units of 500 km) of the lower-layer vortex for $\epsilon = 0.25$, $\gamma = 0.79$, and $\chi = 0.25$ (shown as "+"); $\chi = 1.25$ (shown as "*"); and $\chi = 5$ (shown as "O").

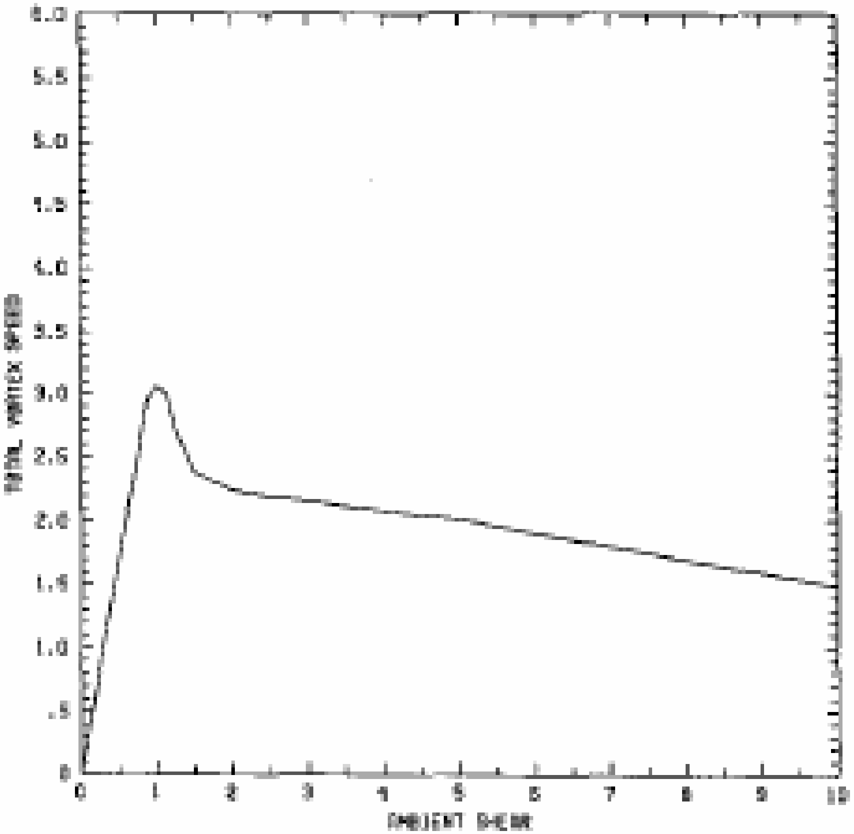
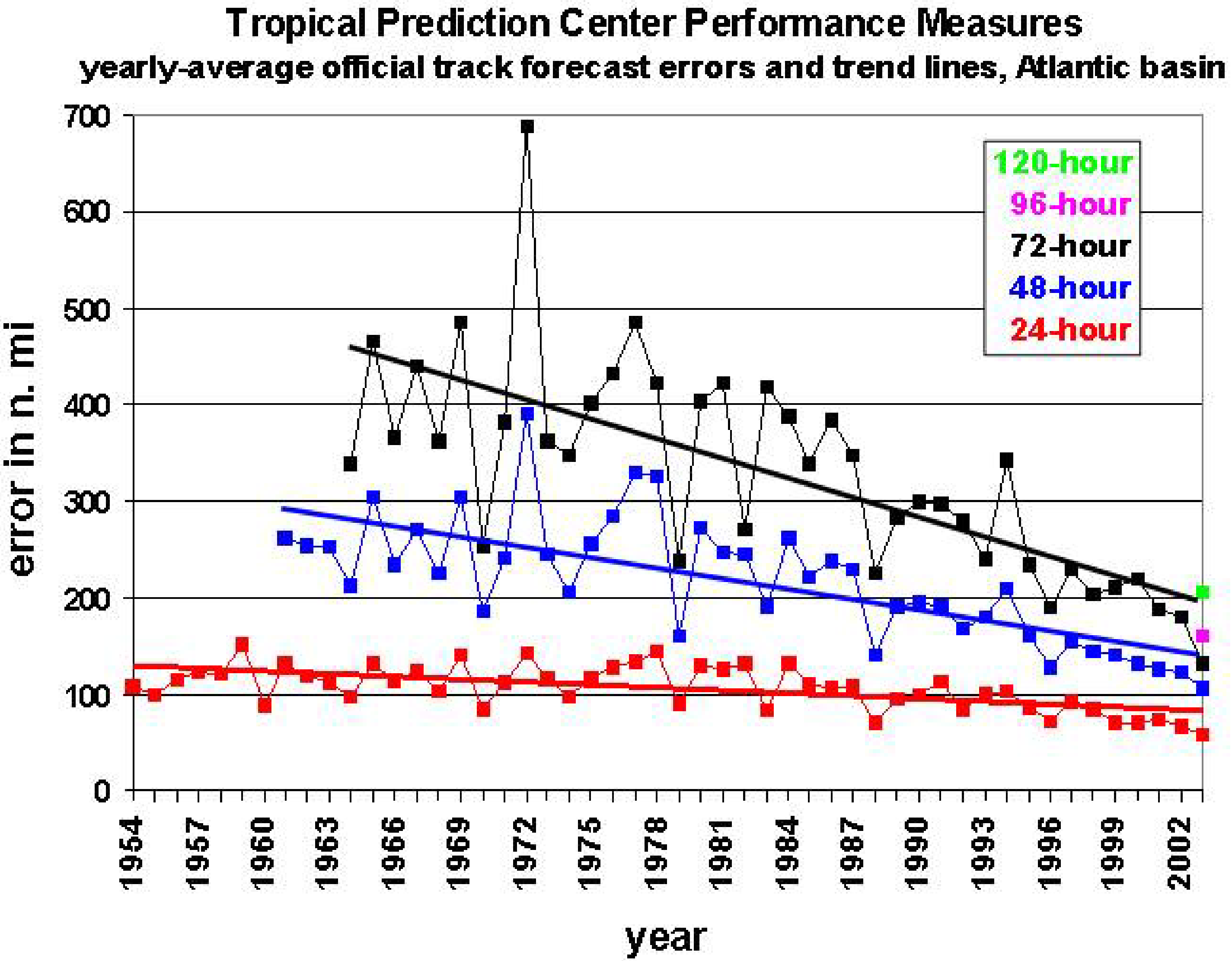
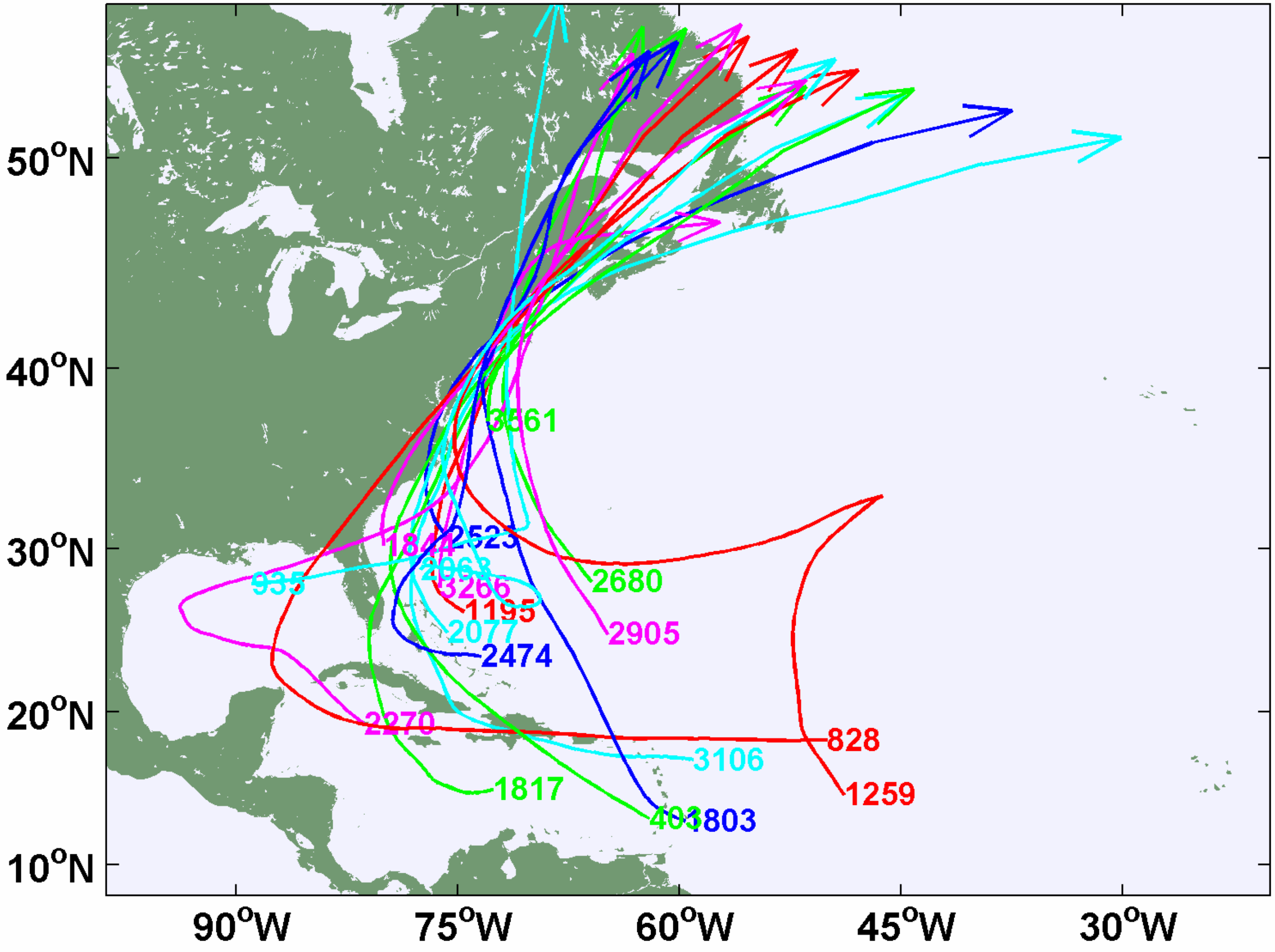


FIG. 12. The relation between the maximum induced vortex speed and the magnitude of the vertical shears (χ) for $\epsilon = 0.25$ and $\gamma = 0.79$.

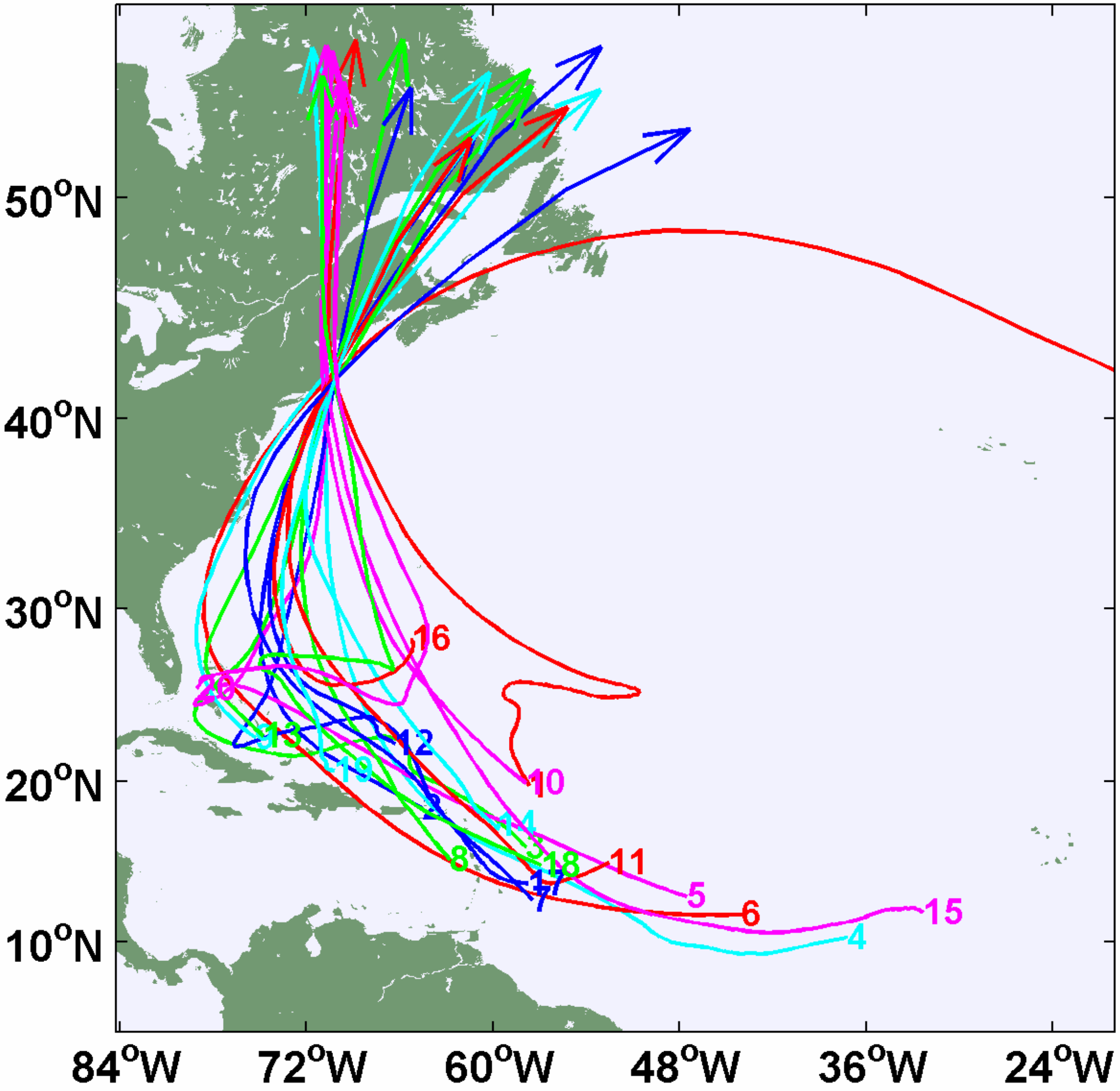
Operational prediction of tropical cyclone tracks:



Example: 20 random tracks passing within 100 km of Boston

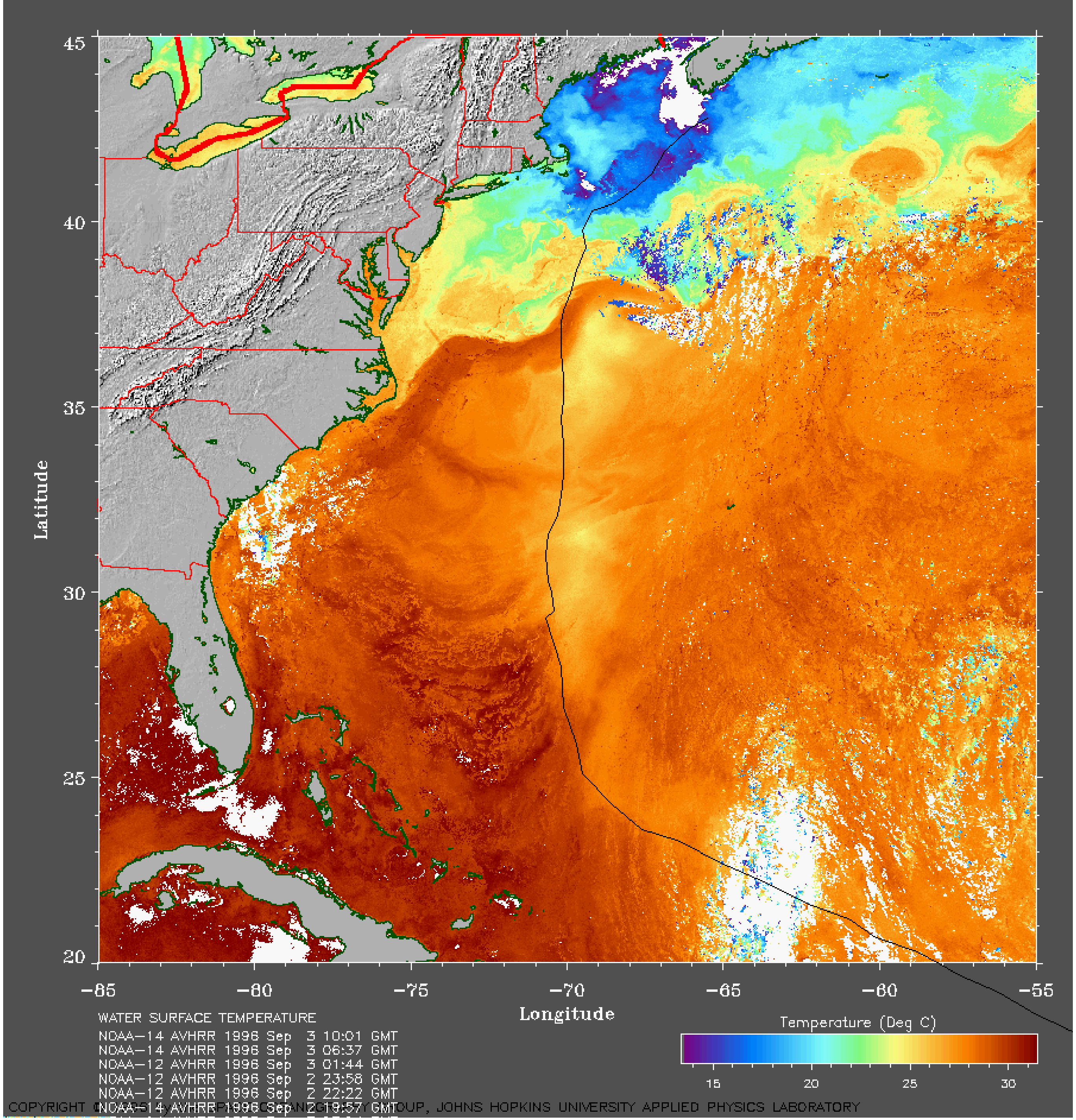


20 “worst” tracks:



Interaction of Tropical Cyclones with the Upper Ocean

- Resonance with near-inertial oscillations
- Mixed layer cooling by entrainment
- Coupled models


45
40
35
30
25
20
Latitude
-85
-80
-75
-70
-65
-60
-55
Longitude
WATER SURFACE TEMPERATURE
NOAA-14 AVHRR 1996 Sep 3 10:01 GMT
NOAA-14 AVHRR 1996 Sep 3 06:37 GMT
NOAA-12 AVHRR 1996 Sep 3 01:44 GMT
NOAA-12 AVHRR 1996 Sep 2 23:58 GMT
NOAA-12 AVHRR 1996 Sep 2 22:22 GMT
NOAA-14 AVHRR 1996 Sep 2 19:57 GMT
Temperature (Deg C)
15
20
25
30

Change on SST needed to cancel increase in enthalpy in core:

$$L_v q^*(T_a)H + c_p T_a = L_v q^*(T_a - \Delta T) + c_p (T_a - \Delta T)$$

$$L_v q^*(T_a - \Delta T) \cong L_v q^*(T_a) - L_v \frac{\partial q^*}{\partial T}\Delta T$$

$$= L_v q^*(T_a) - L_v \frac{L_v q^*}{R_v T_a^2}\Delta T$$

$$\rightarrow \Delta T \cong \frac{L_v q^*\left(1 - H\right)}{c_p + \frac{L_v{}^2 q^*}{R_v T_a^2}} \cong 2.5^o C$$

Physics of near-inertial oscillations:

PEs linearized about a rotating stratified fluid at rest:

$$\frac{\partial u}{\partial t} = -\alpha_0 \frac{\partial p}{\partial x} + fv$$

$$\frac{\partial v}{\partial t} = -\alpha_0 \frac{\partial p}{\partial y} - fu$$

$$\frac{\partial w}{\partial t} = -\alpha_0 \frac{\partial p}{\partial z} + B$$

$$\frac{\partial B}{\partial t} = -N^2 w$$

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0$$

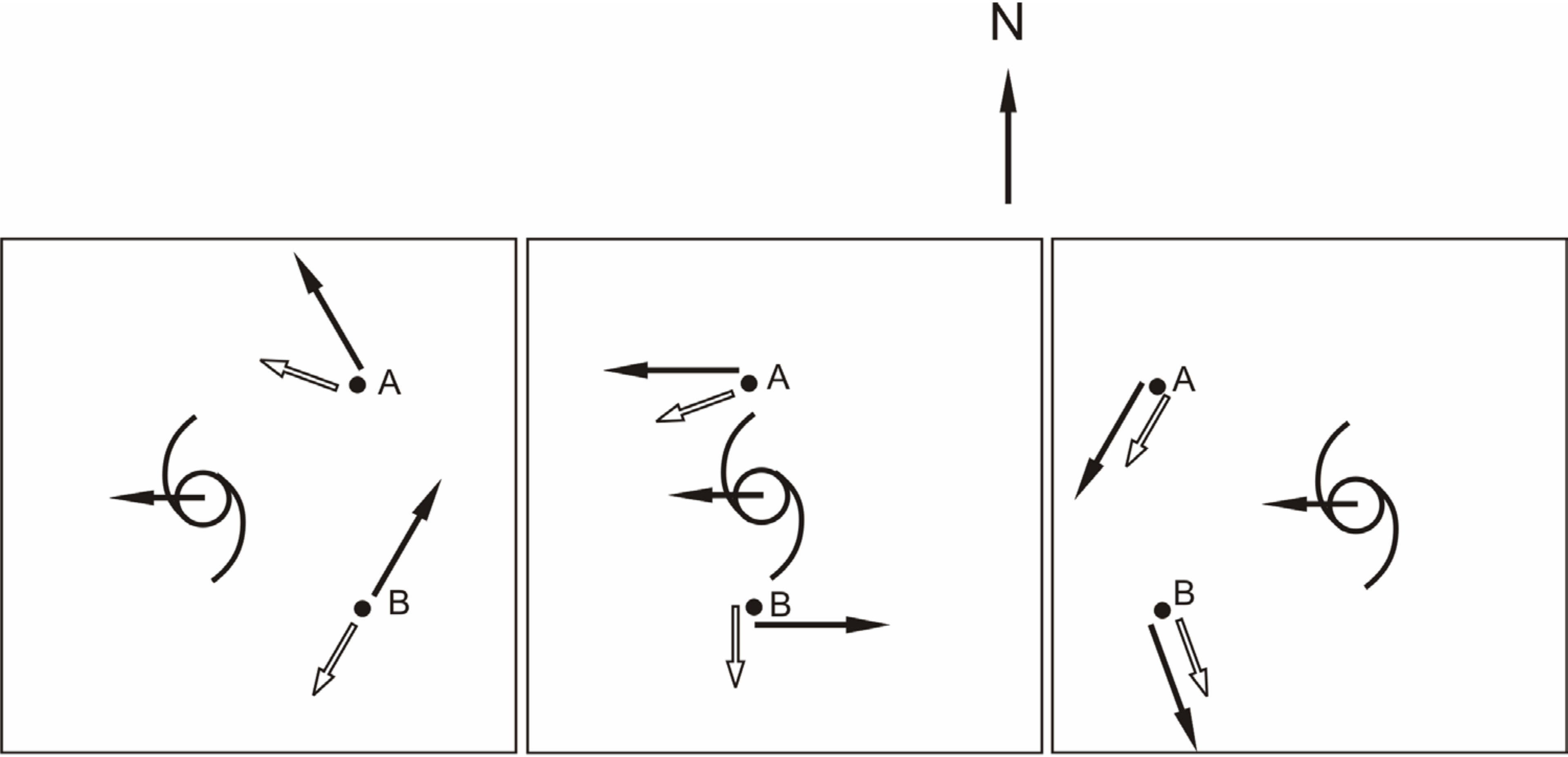
$$\rightarrow \frac{\partial^2}{\partial t^2}\nabla_3^2 w + N^2\nabla_2^2 w + f^2\frac{\partial^2 w}{\partial t^2} = 0$$

$$w = w_0 e^{i\left(kx+ly+rz-\omega t\right)}$$

$$\omega^2 = N^2\frac{\lambda^2}{\lambda^2+r^2} + f^2\frac{r^2}{\lambda^2+r^2},$$

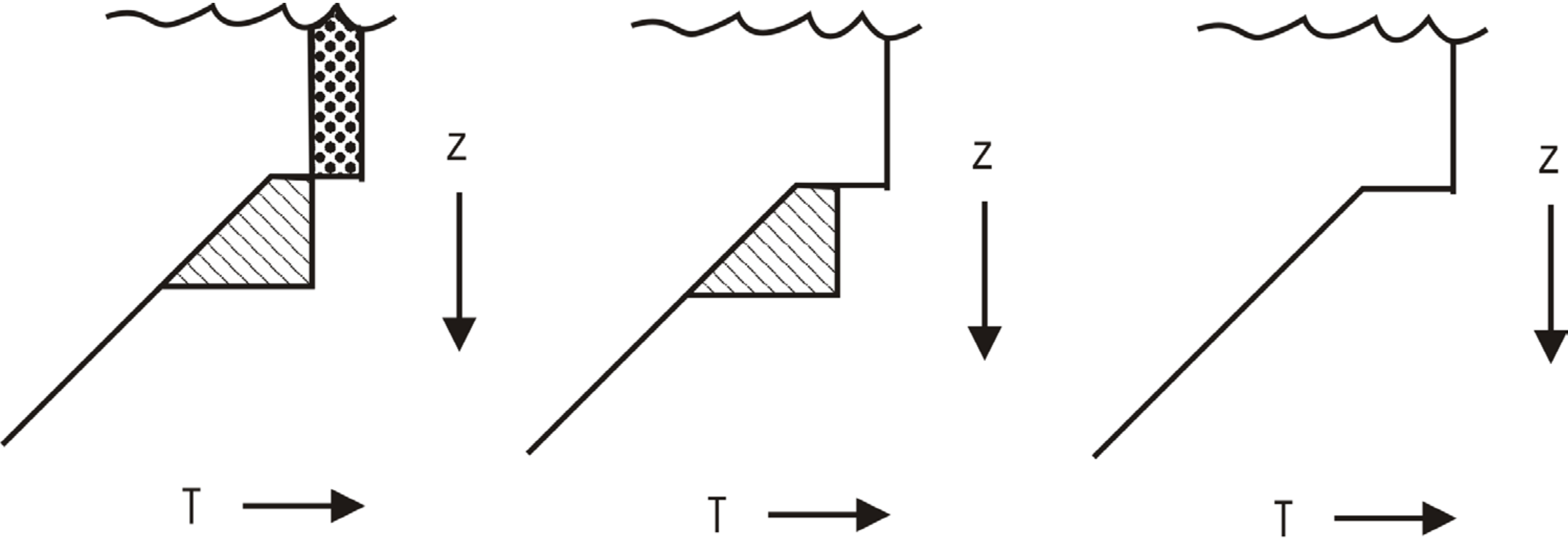
$$\lambda^2 \equiv k^2 + l^2$$

$$\omega^2 \cong f^2 \quad for \quad r^2 >> \frac{N^2}{f^2}\lambda^2$$



(c) (b) (a)

Mixing and Entrainment:



(a) (b) (c)

Entrainment Formulation:

Criticality of a Bulk Richardson Number:

$$Ri \equiv \frac{gh\Delta\rho}{\rho u^2}$$

Assume that density jump is what would result from eroding a constant background stratification down to depth *h* :

$$Ri \equiv \frac{1}{2}\frac{h^2 N^2}{u^2}$$

Equivalently, $\boxed{Nh = R'u}$ (1)

$$R' \equiv \sqrt{2Ri}$$

Criticality assumption: R' = *constant.*

Mixed layer momentum conservation (neglecting Coriolis turning) :

$$\frac{\partial\left(\rho_w u h\right)}{\partial t} = \rho_a u_*^2 . \qquad (2)$$

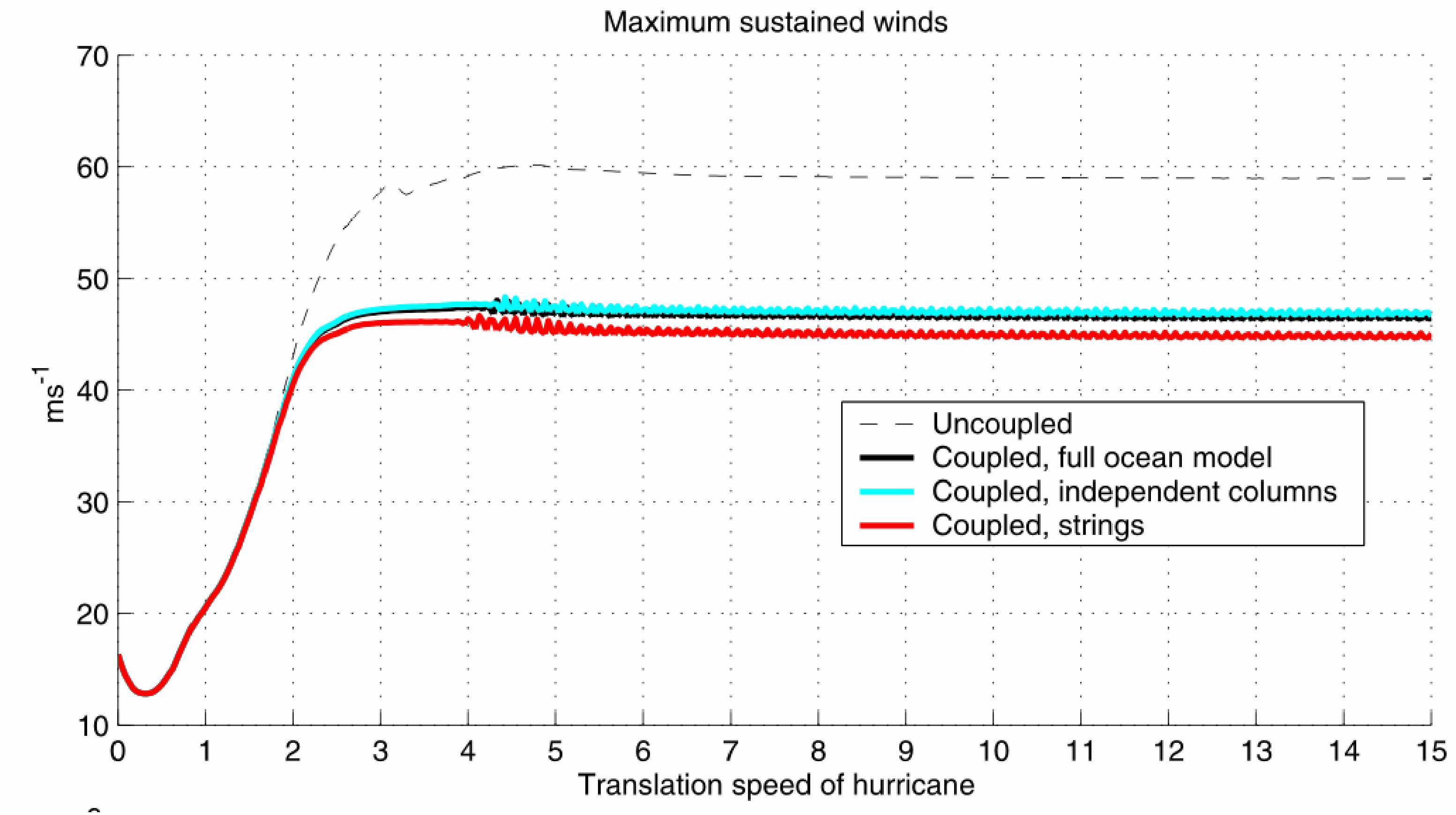
$$u_*^2 \equiv C_D \,|\, \mathbf{V} \,|^2$$

Combine (2) with (1):

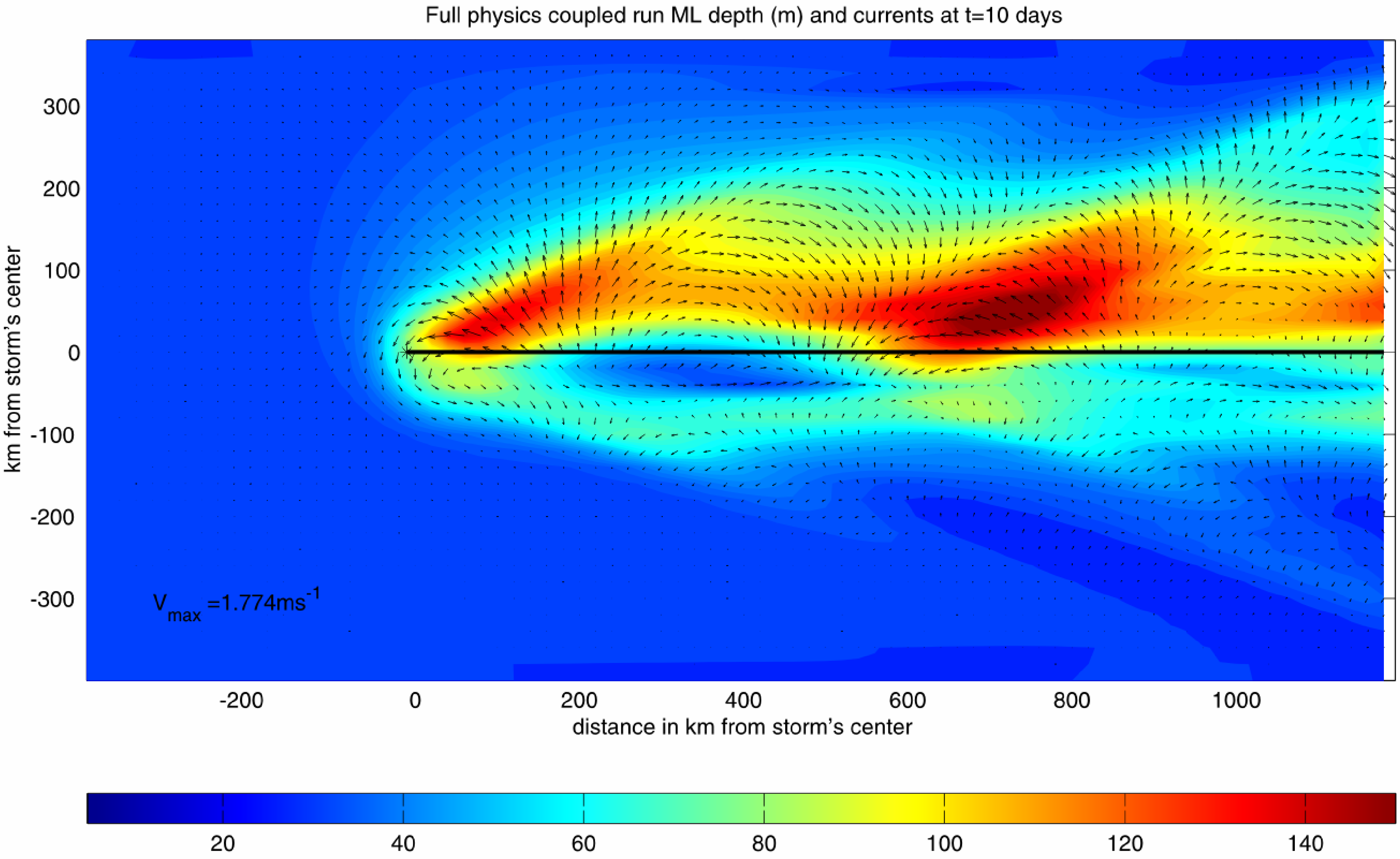
$$\frac{\partial h^2}{\partial t} = R' \frac{\rho_a}{\rho_w} \frac{u_*^2}{N}$$

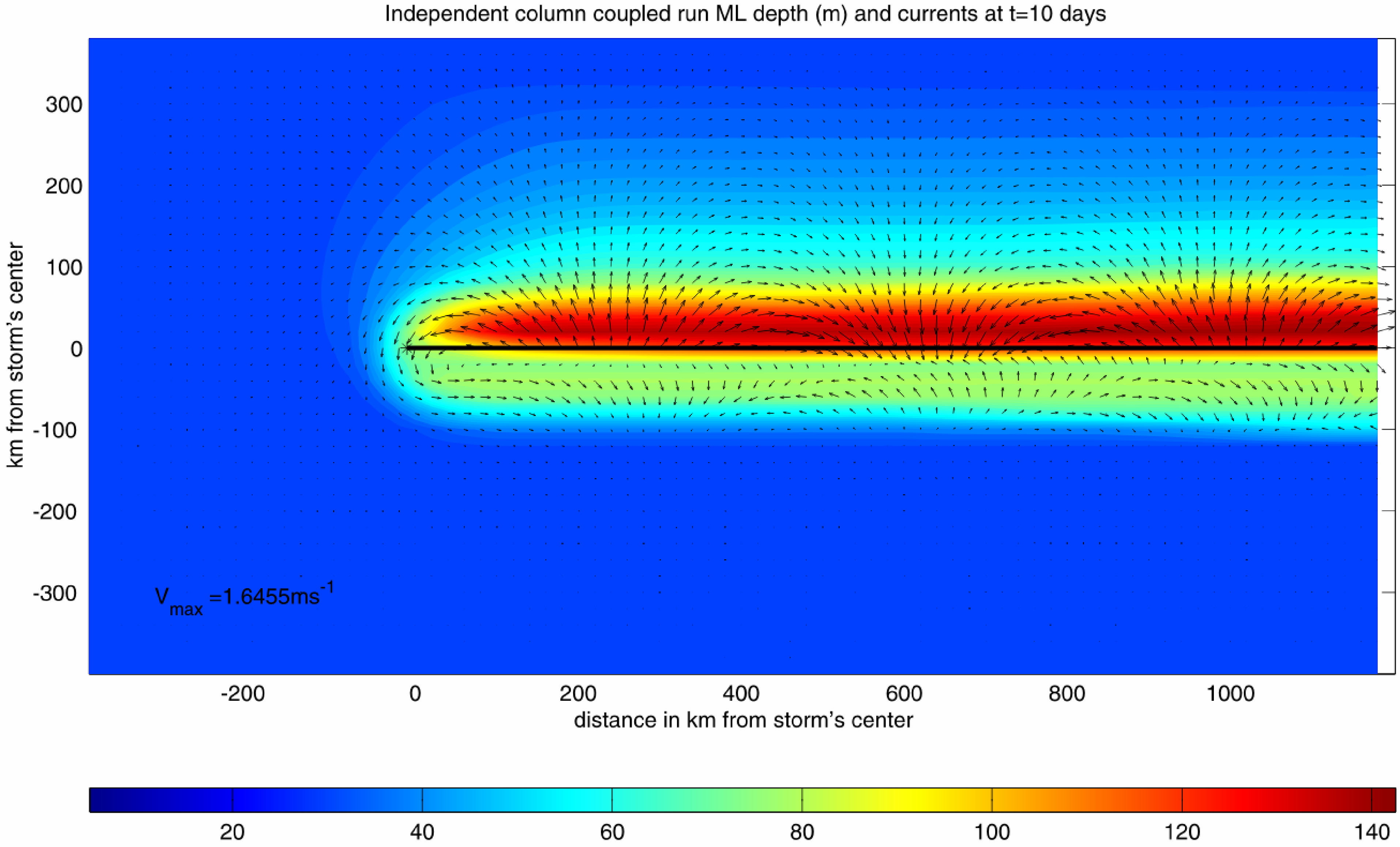
Note: units of diffusivity

Comparison with same atmospheric model coupled to 3-D ocean model; idealized runs: Full model (black), string model (red)

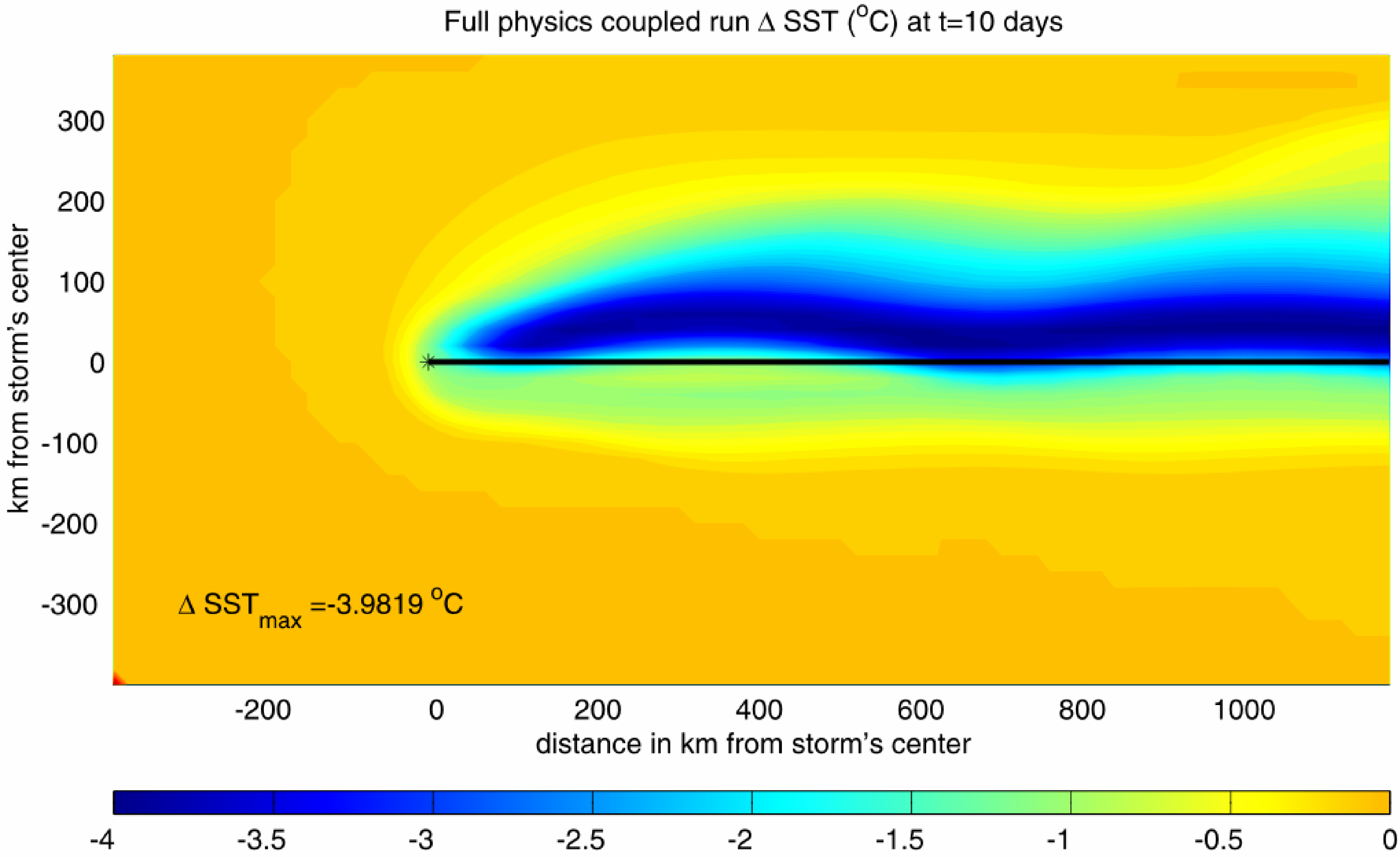


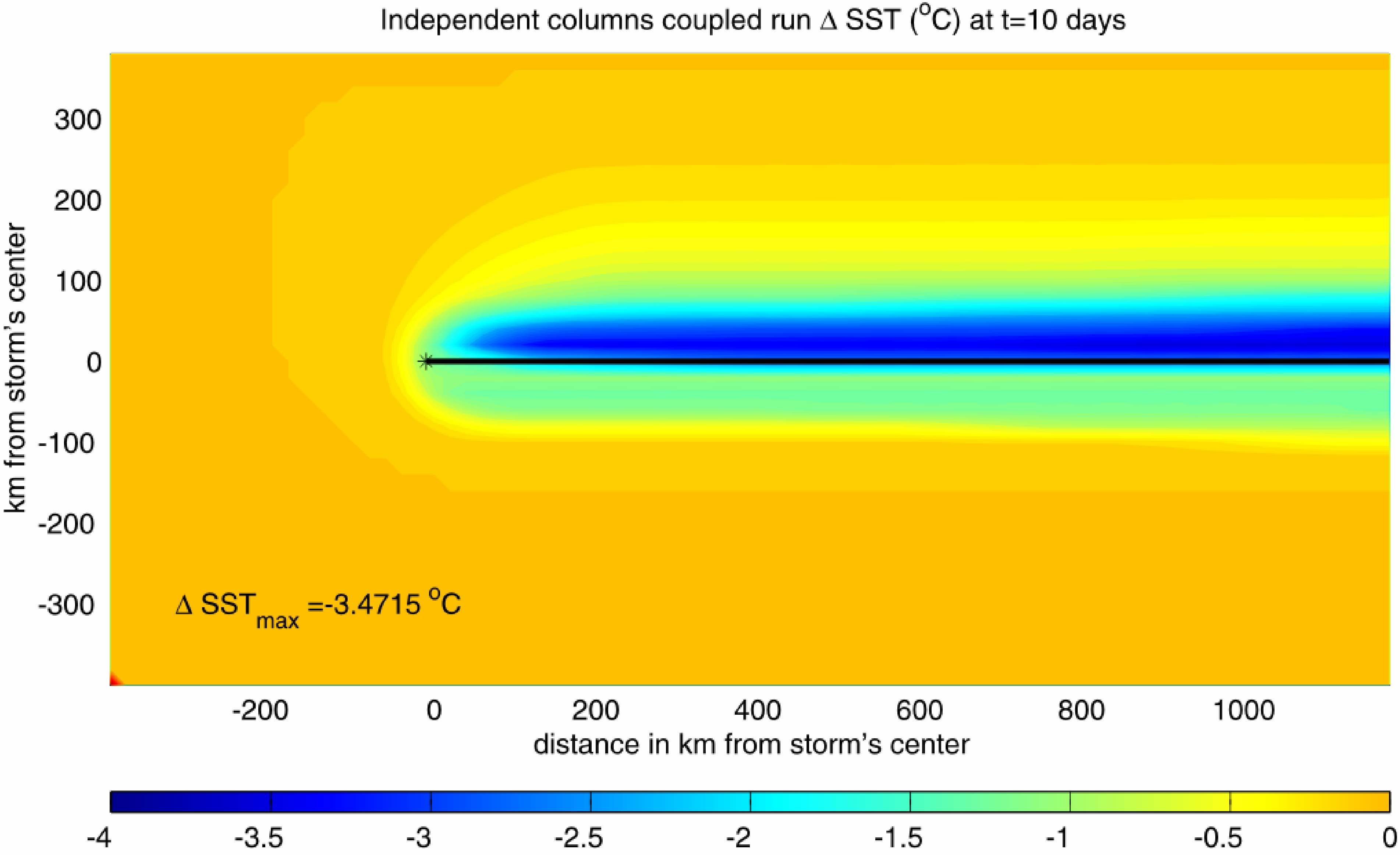
Mixed layer depth and currents




Independent column coupled run ML depth (m) and currents at t=10 days
300
200
100
0
-100
-200
-300
km from storm's center
V_max =1.6455ms^-1
-200
0
200
400
600
800
1000
distance in km from storm's center
20
40
60
80
100
120
140

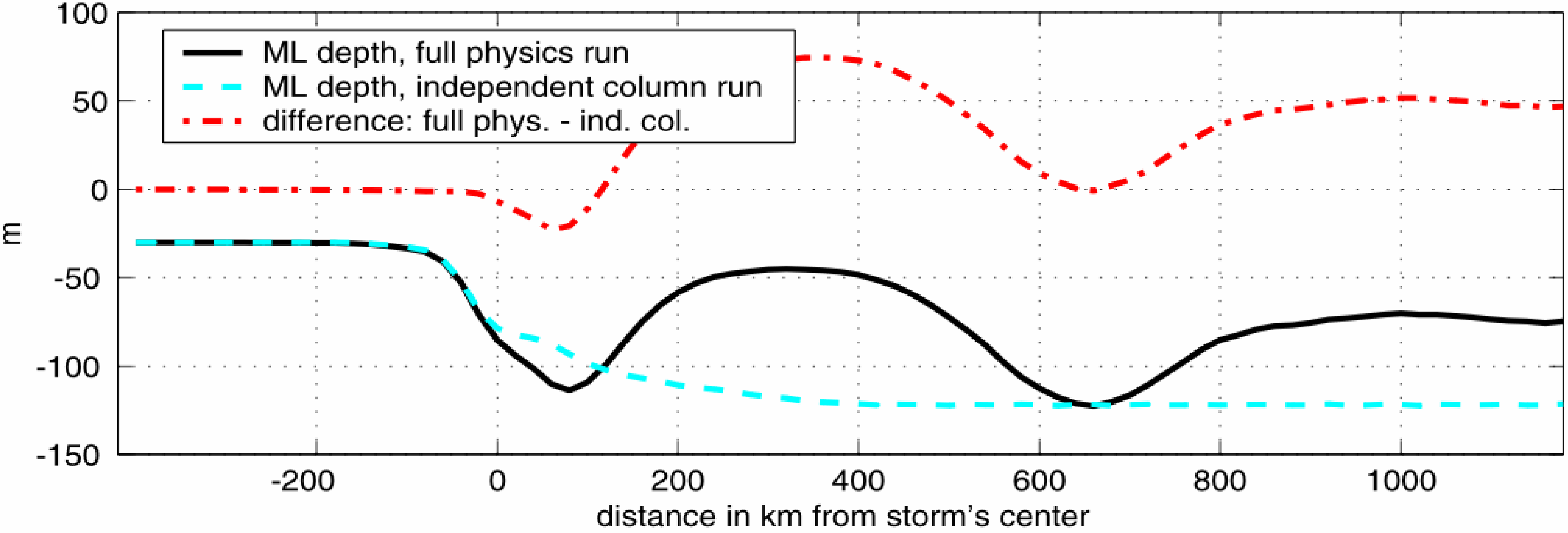
SST Change


Full physics coupled run Δ SST (°C) at t=10 days
300
200
100
0
-100
-200
-300
km from storm's center
Δ SST$_{max}$ =-3.9819 °C
-200
0
200
400
600
800
1000
distance in km from storm's center
-4
-3.5
-3
-2.5
-2
-1.5
-1
-0.5
0

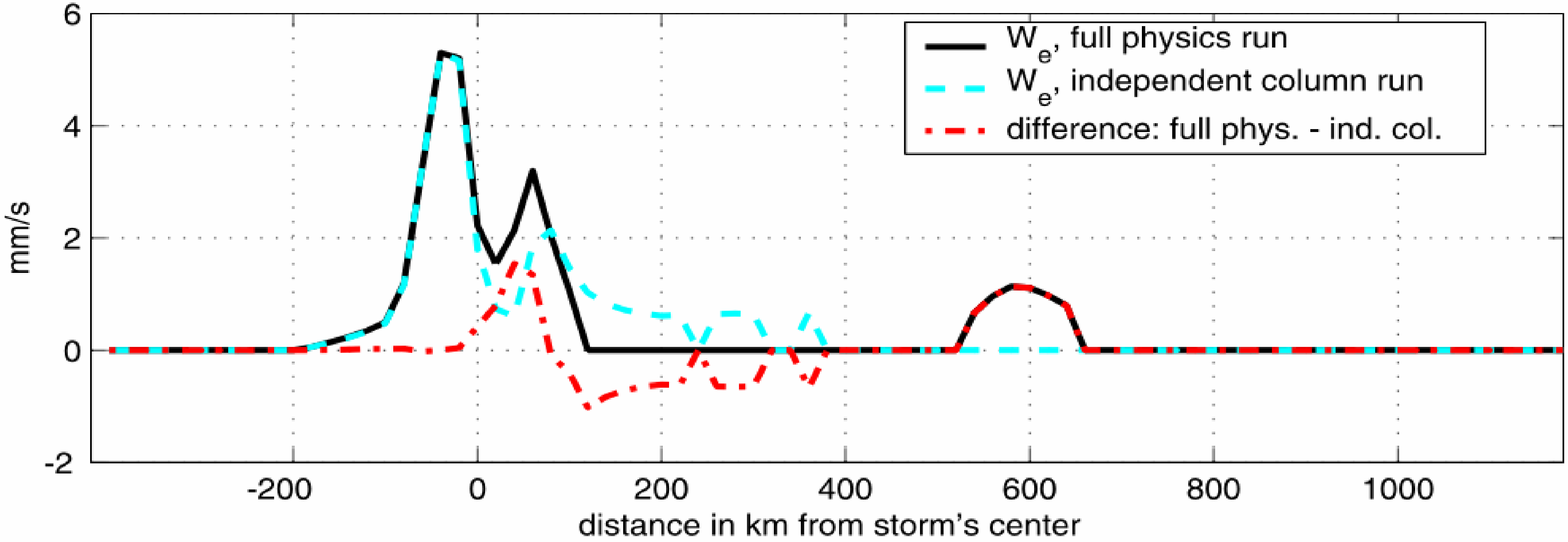


Independent columns coupled run Δ SST (^{o}C) at t=10 days

(a) Mixed-layer depth on the axis of the storm's motion (m)



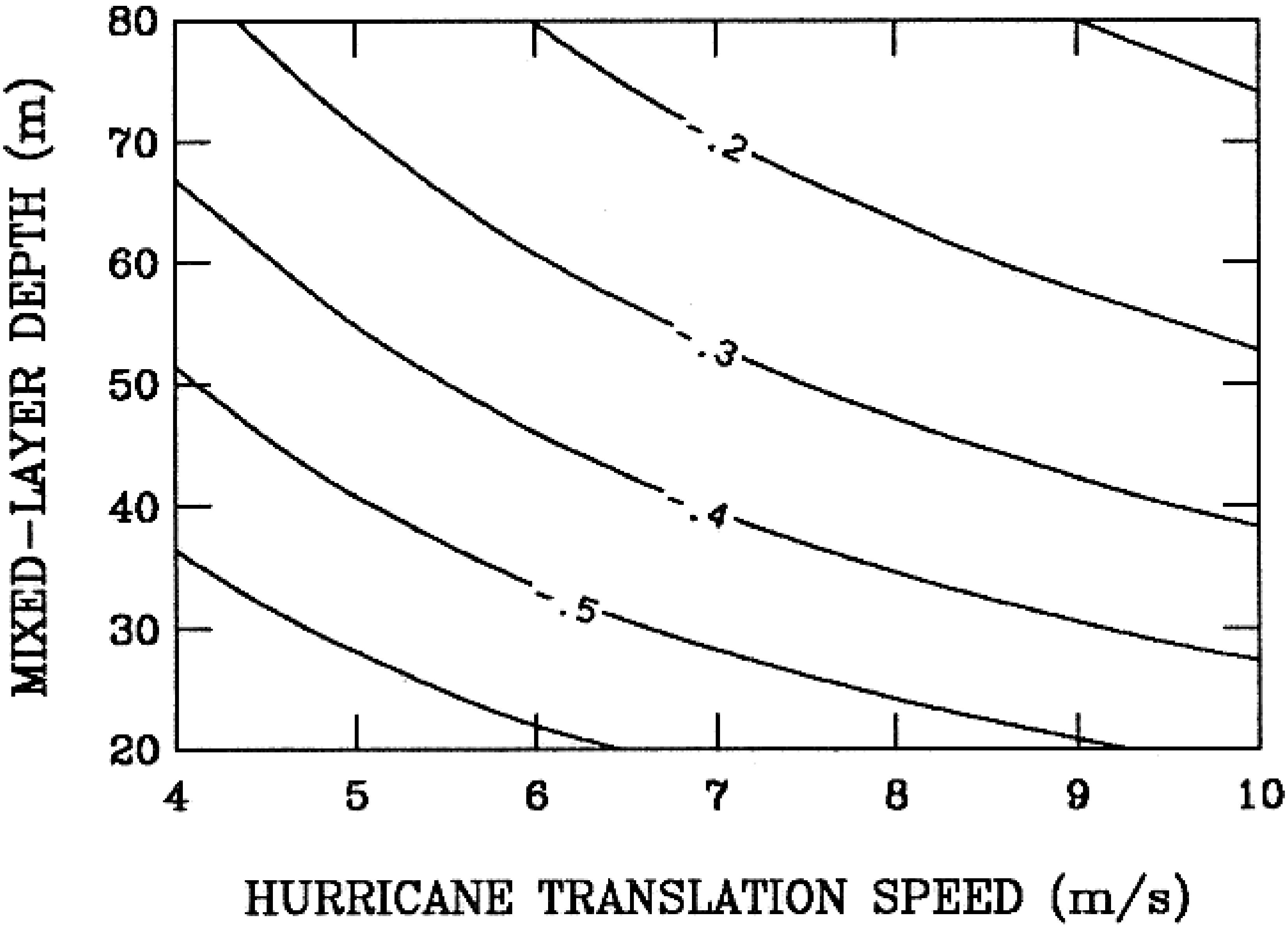
(b) The entrainment velocity, W_e, on the axis of the storm's motion (mm/s)



Define feedback factor:

$$F_{SST} = \frac{\Delta p}{\Delta p\,|_{SST}} - 1,$$

where $\Delta p\,|_{SST}$ is the central pressure drop at fixed SST. Do many, many numerical expreiments, varying SST, Coriolis parameter, traslantion speed, etc. Curve fit dependence of F_{SST} on these parameters. Result:



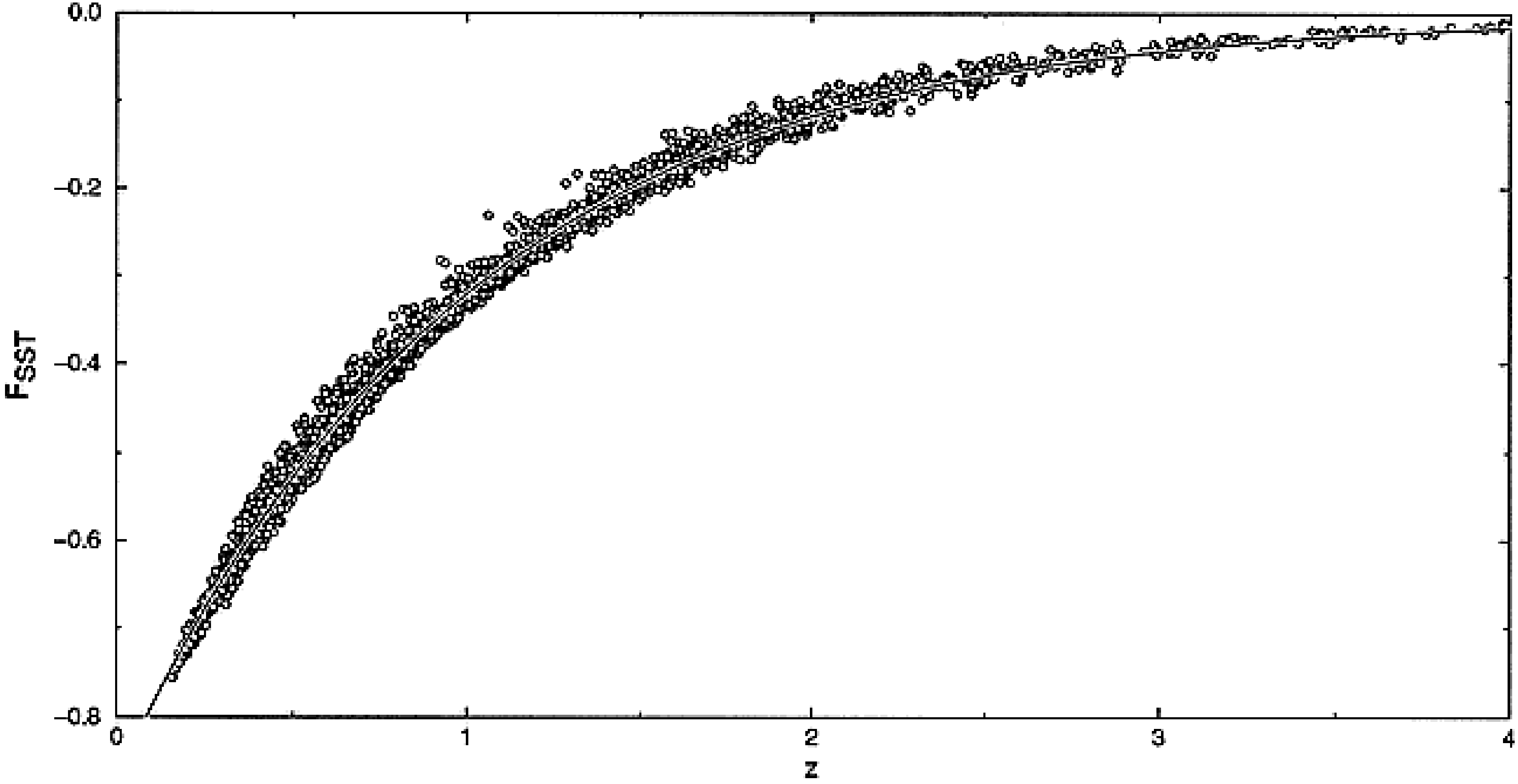
80
70
60
50
40
30
20
MIXED-LAYER DEPTH (m)
4
5
6
7
8
9
10
HURRICANE TRANSLATION SPEED (m/s)
.2
.3
.4
.5

$$F_{SST} = -0.87e^{-z}$$

$$z \equiv 0.55\left(\frac{h_0}{30\,m}\right)^{1.04}\left(\frac{u_T}{6\,m\,s^{-1}}\right)^{0.97}\left(\frac{\Delta p\,|_{SST}}{50\,hPa}\right)^{-0.78}\times$$

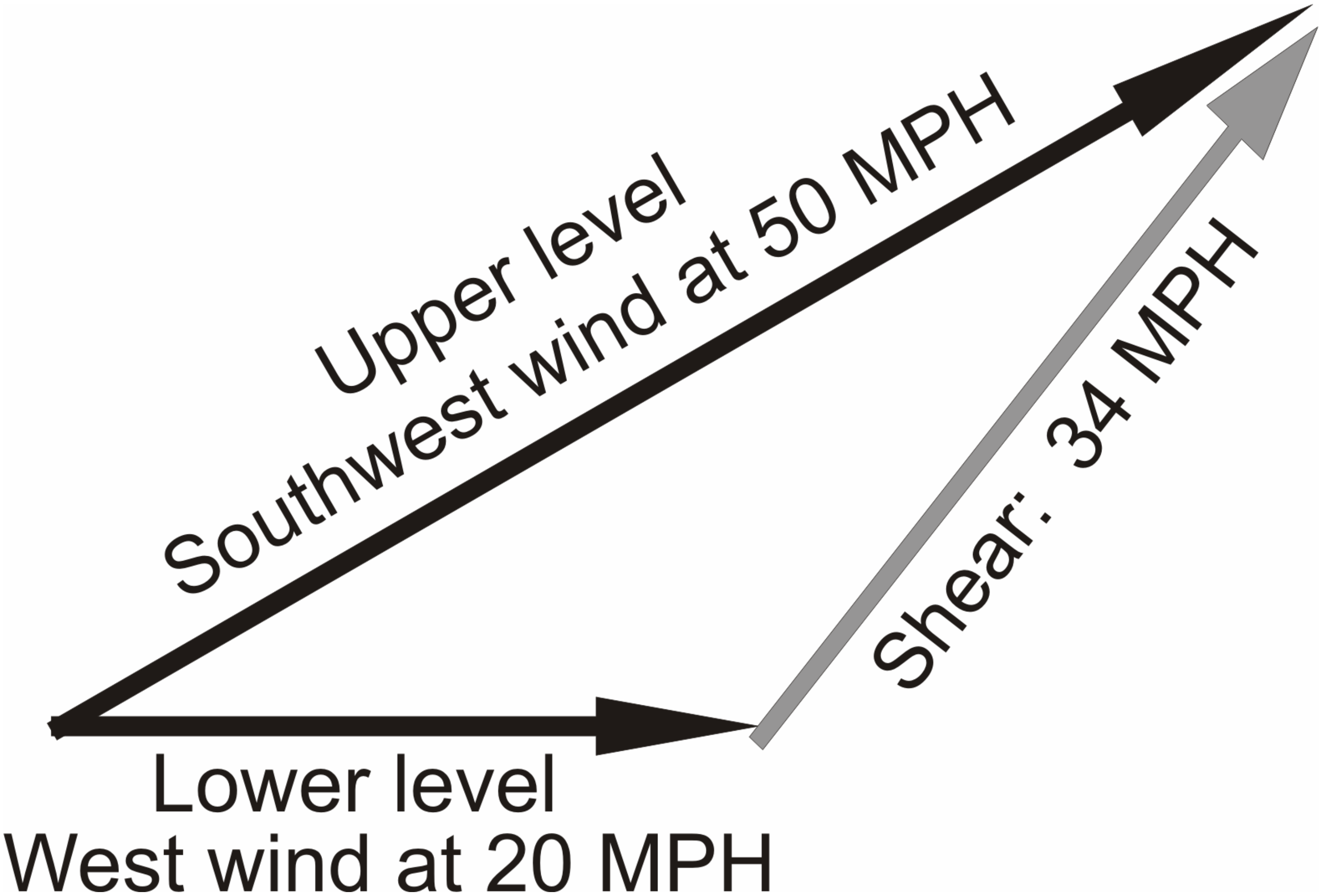
$$\eta^{-0.85}\left(\frac{f}{5\times10^{-5}\,s^{-1}}\right)^{0.59}\left(\frac{\Gamma}{8\times10^{-2}\,K\,m^{-1}}\right)^{-0.40}\left(\frac{1-\mathcal{H}}{0.2}\right)^{0.46}$$

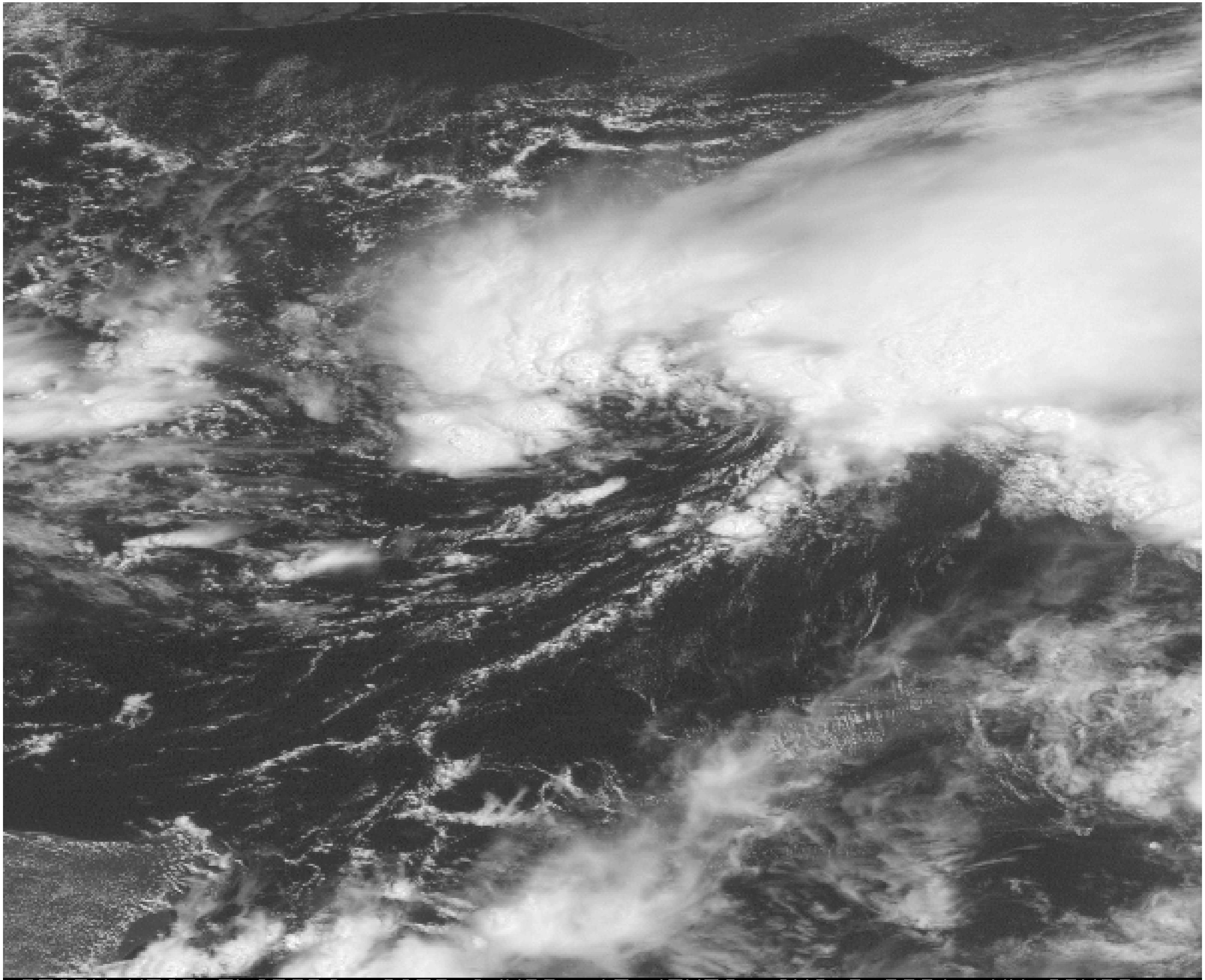
η= storm size scaling factor


0.0
-0.2
-0.4
-0.6
-0.8
F_{SST}
0
1
2
3
4
z

Effects of Environmental Wind Shear

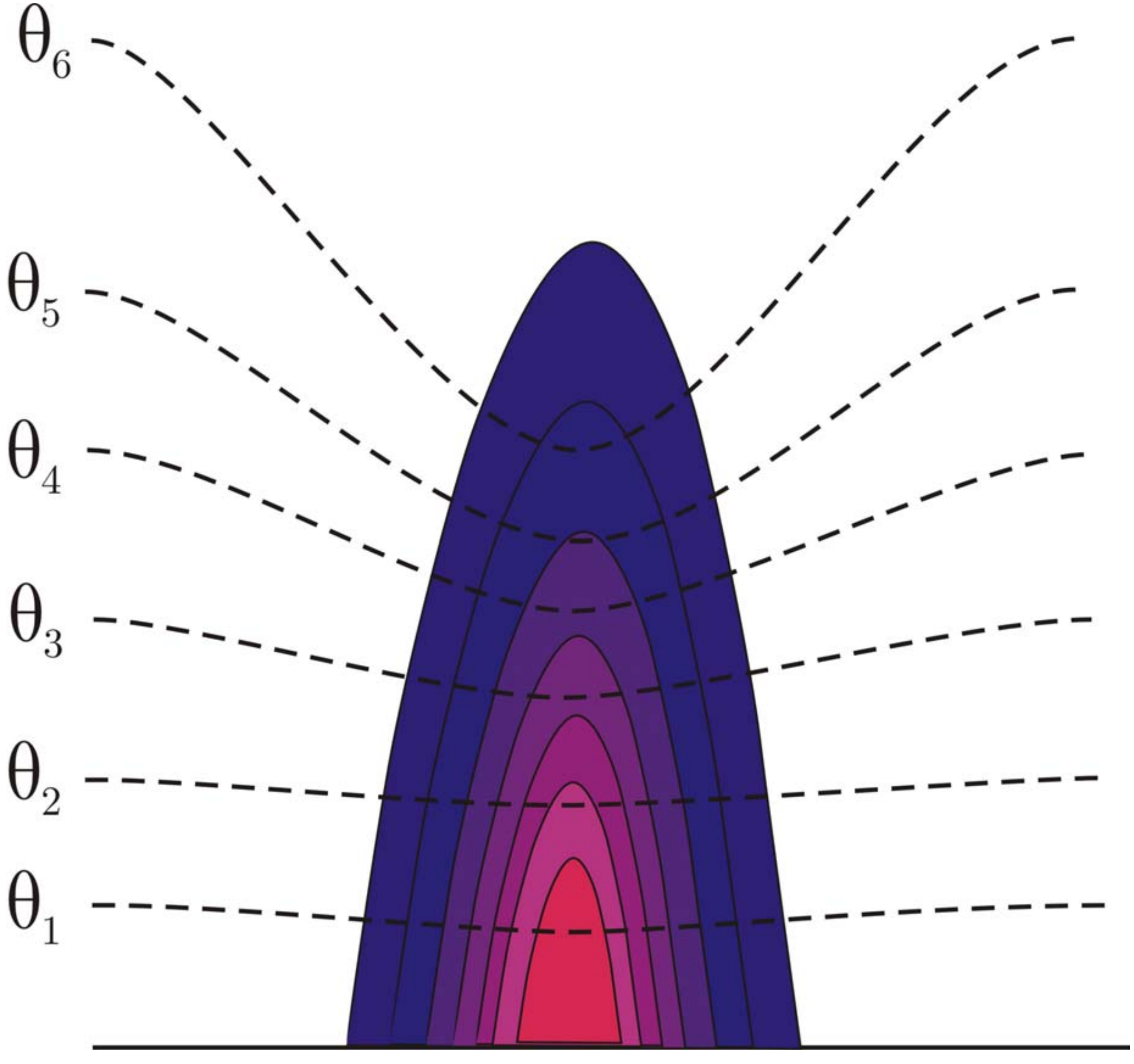
- Dynamical effects
- Thermodynamic effects
- Net effect on intensity


Upper level
Southwest wind at 50 MPH
Shear: 34 MPH
Lower level
West wind at 20 MPH

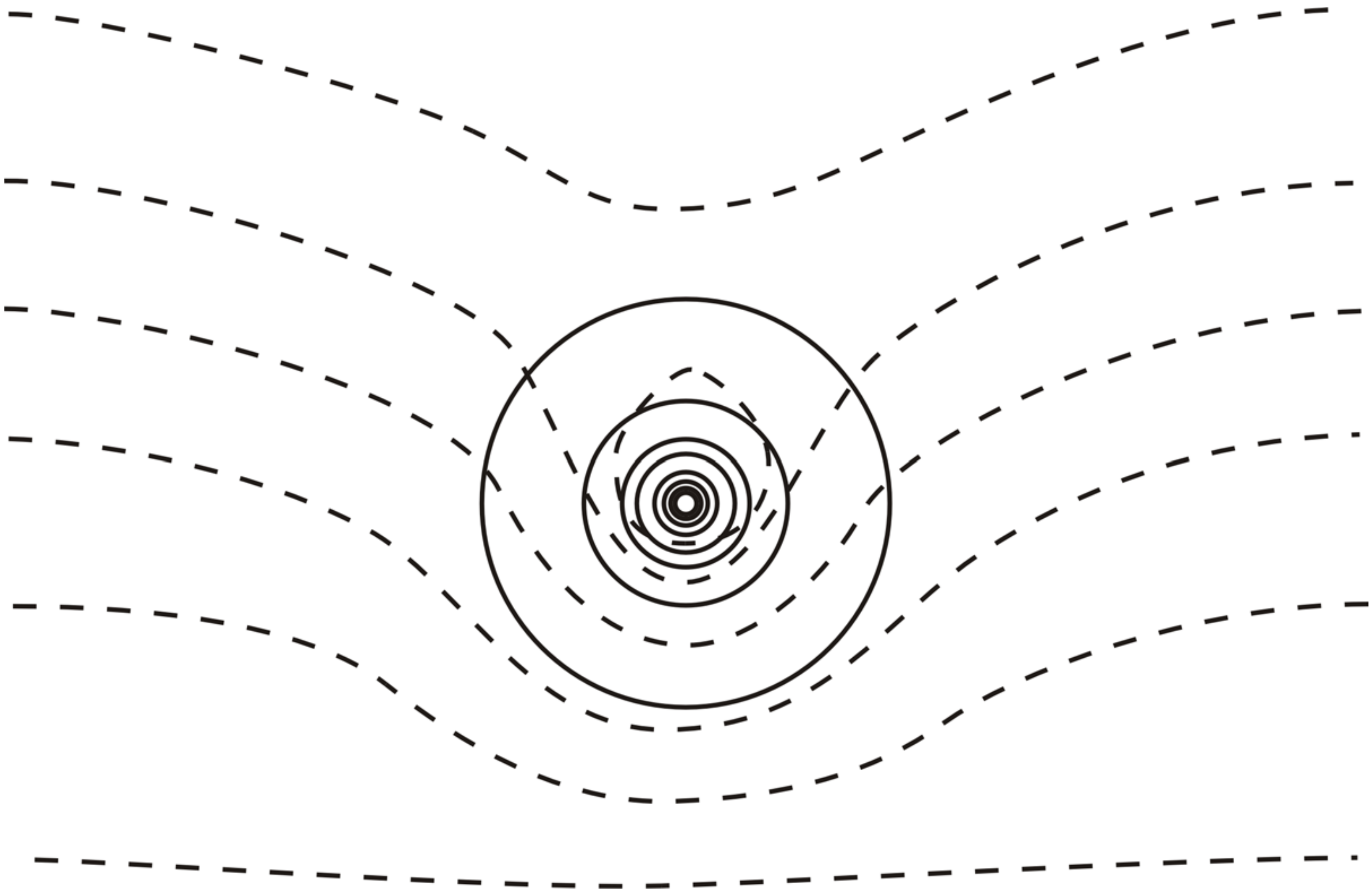


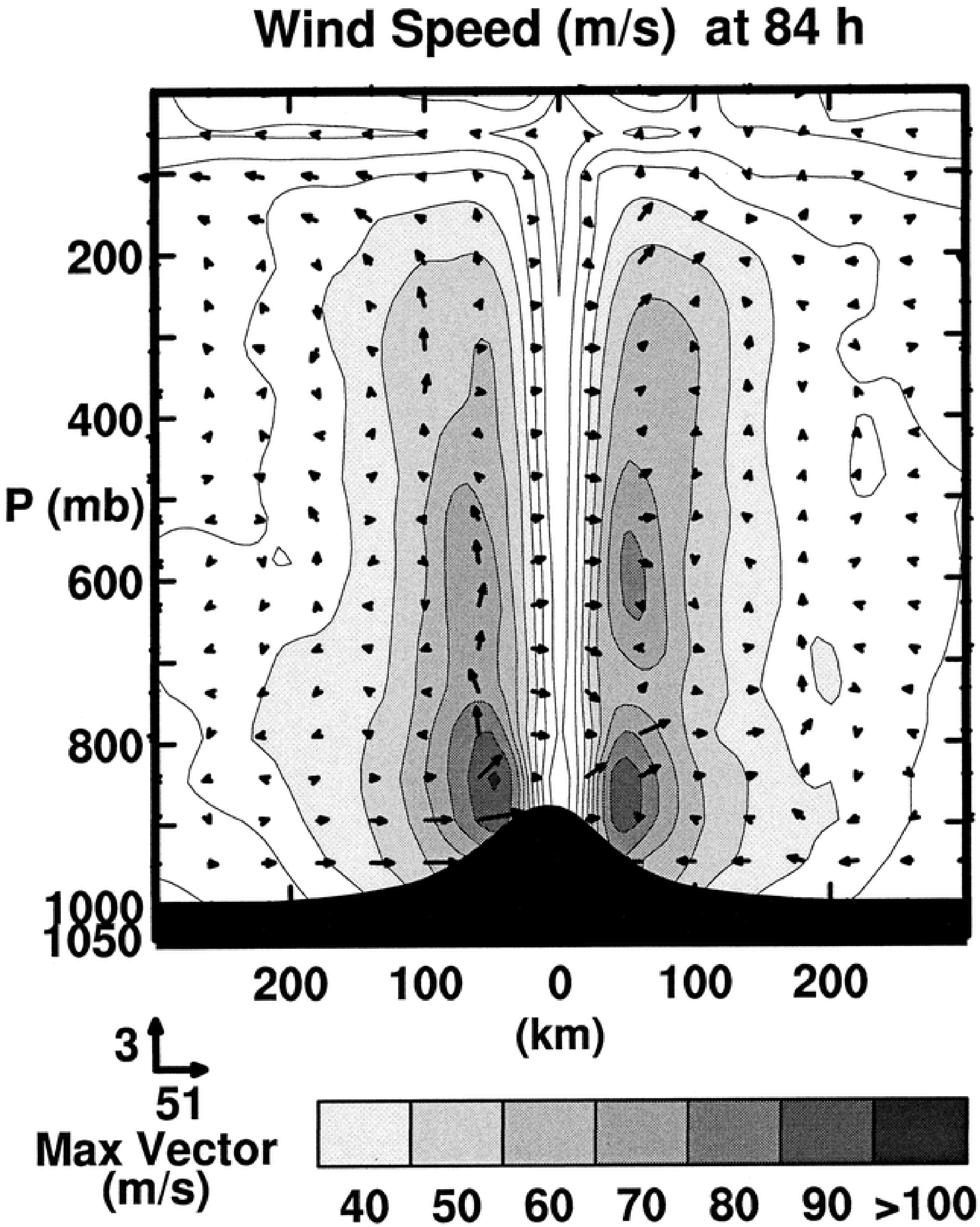
STORM NEAR FLORIDA GOES-8/VIS 15:45UTC AUG 2 2001 UW-CIMSS

PV dynamics



Streamlines (dashed) and θ surfaces (solid)




Wind Speed (m/s) at 84 h
P (mb)
200
400
600
800
1000
1050
200
100
0
100
200
(km)
3
51
Max Vector
(m/s)
40
50
60
70
80
90
>100

Wind Speed (m/s) at 60 h