Computational Models of Hurricanes: A simple model

- Hydrostatic and gradient balance above PBL
- Moist adiabatic lapse rates on M surfaces above PBL
- Parameterized convection
- Parameterized turbulence

Horizontal Equation of Motion

Remember vertical equation:

$$\frac{dw}{dt} = -\alpha \frac{\partial p}{\partial z} - g$$

Horizontal momentum equation in inertial coordinates:

$$\frac{du}{dt} = -\alpha \frac{\partial p}{\partial x}$$

In rotating earth coordinates:

$$\frac{du}{dt} = -\alpha \frac{\partial p}{\partial x} + fv,$$

$$f \equiv 2\Omega \sin\left(\theta\right)$$

In cylindrical coordinates:

$$\frac{du}{dt} = -\alpha \frac{\partial p}{\partial r} + fv + \frac{v^2}{r}$$

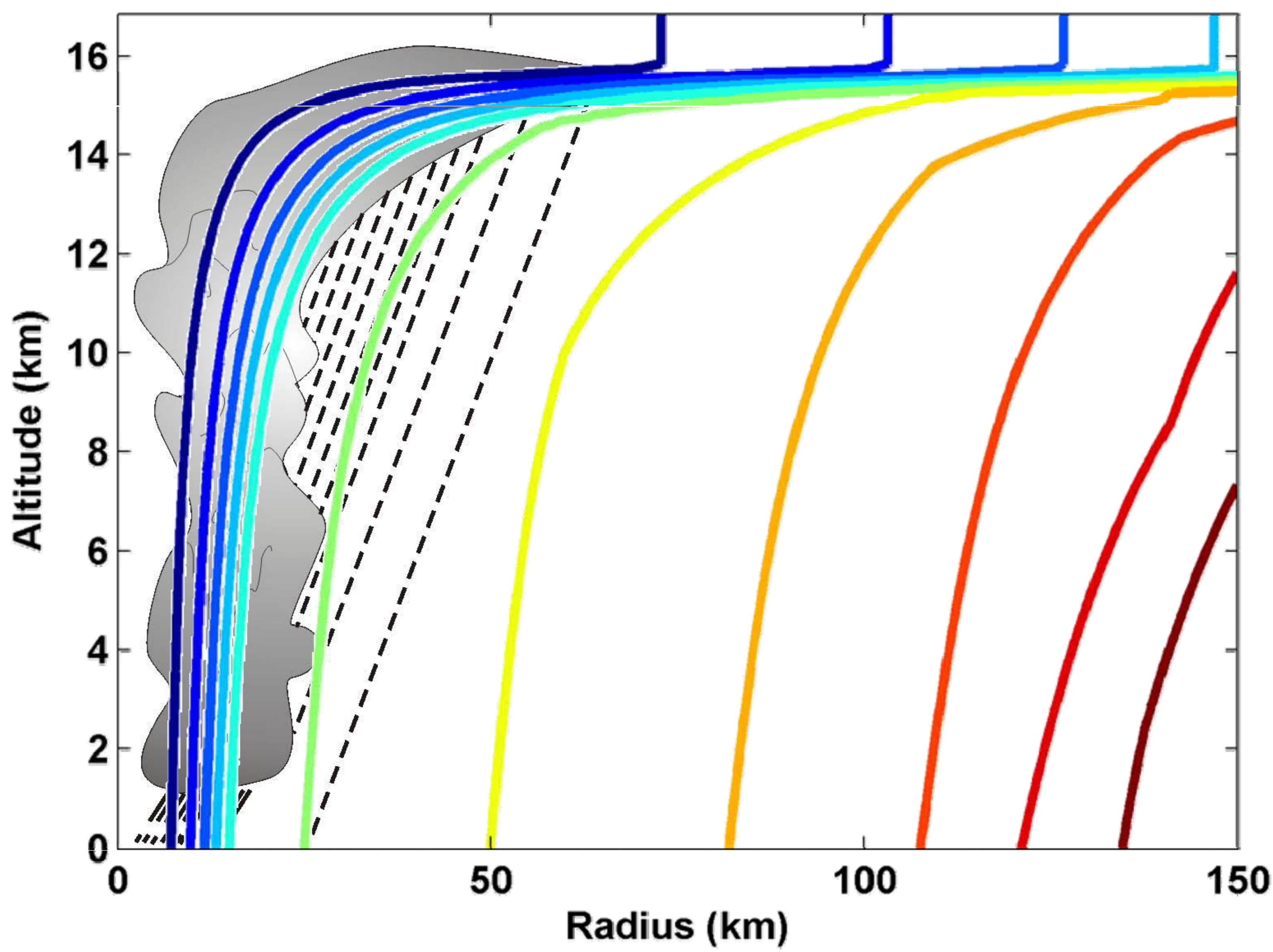
Gradient Balance:

$$\alpha \frac{\partial p}{\partial r} \cong fv + \frac{v^2}{r}$$

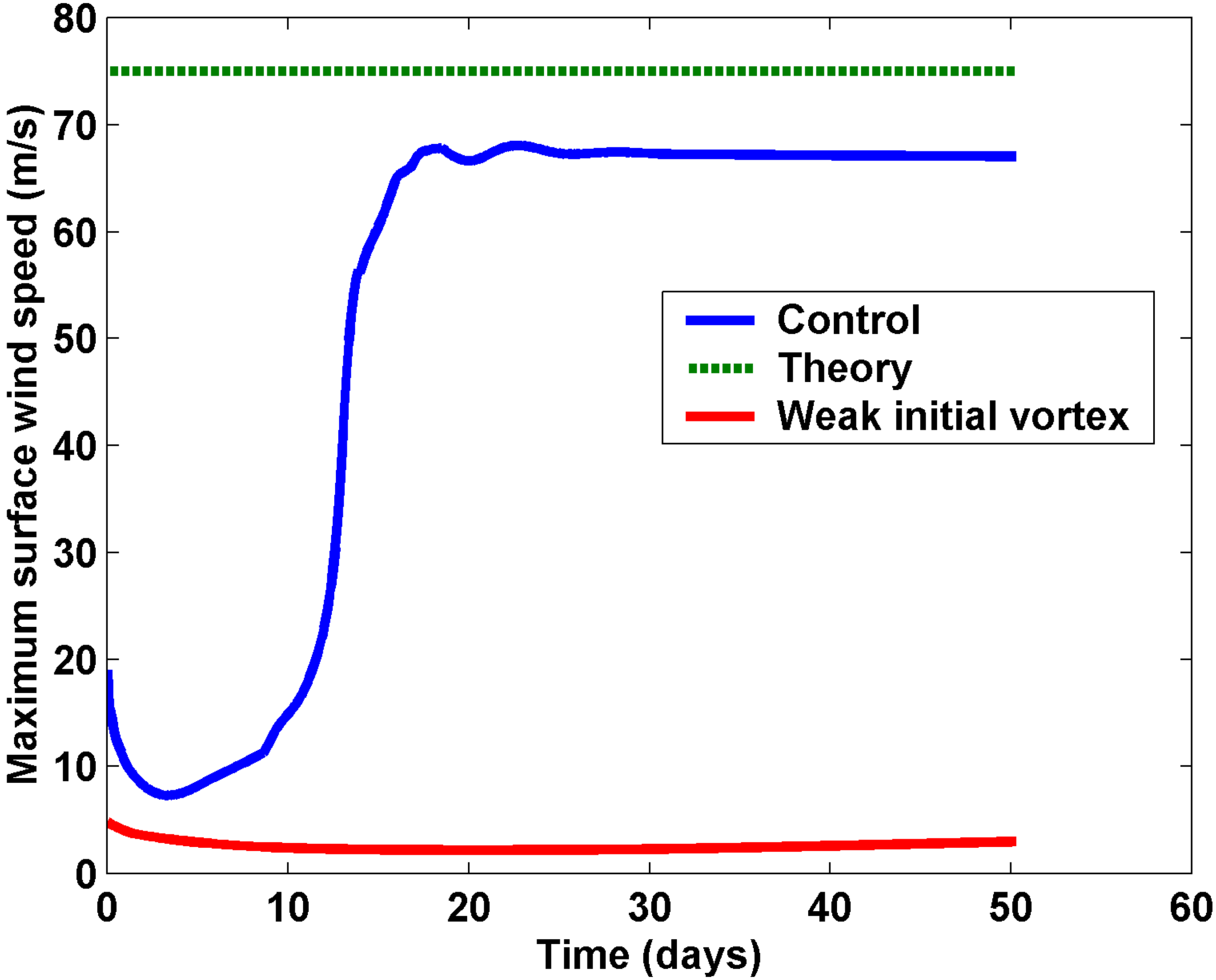
Transformed radial coordinate:
Potential Radius:

$$\frac{f}{2}R^2 \equiv M = rV + \frac{f}{2}r^2$$

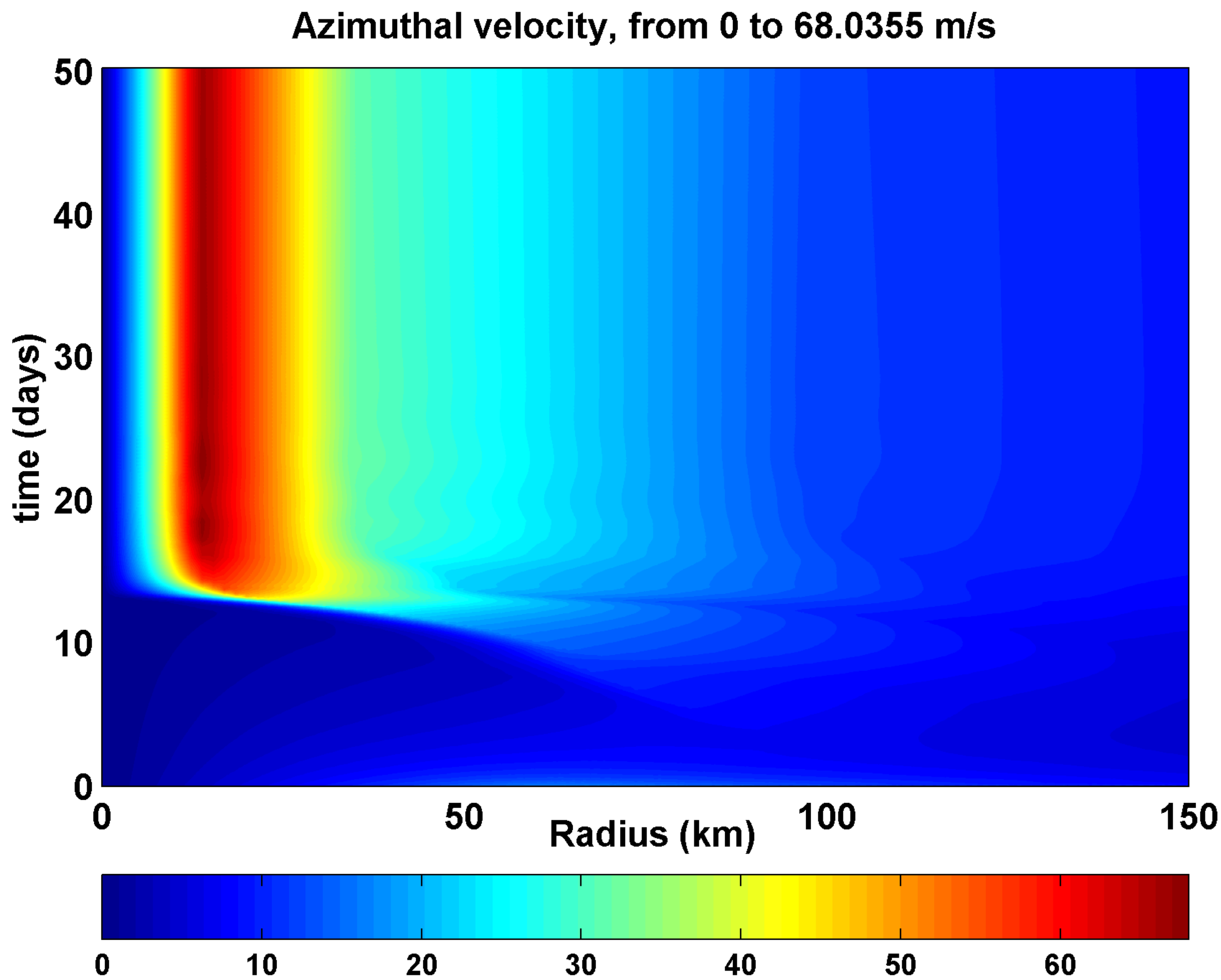
Example of Distribution of R surfaces

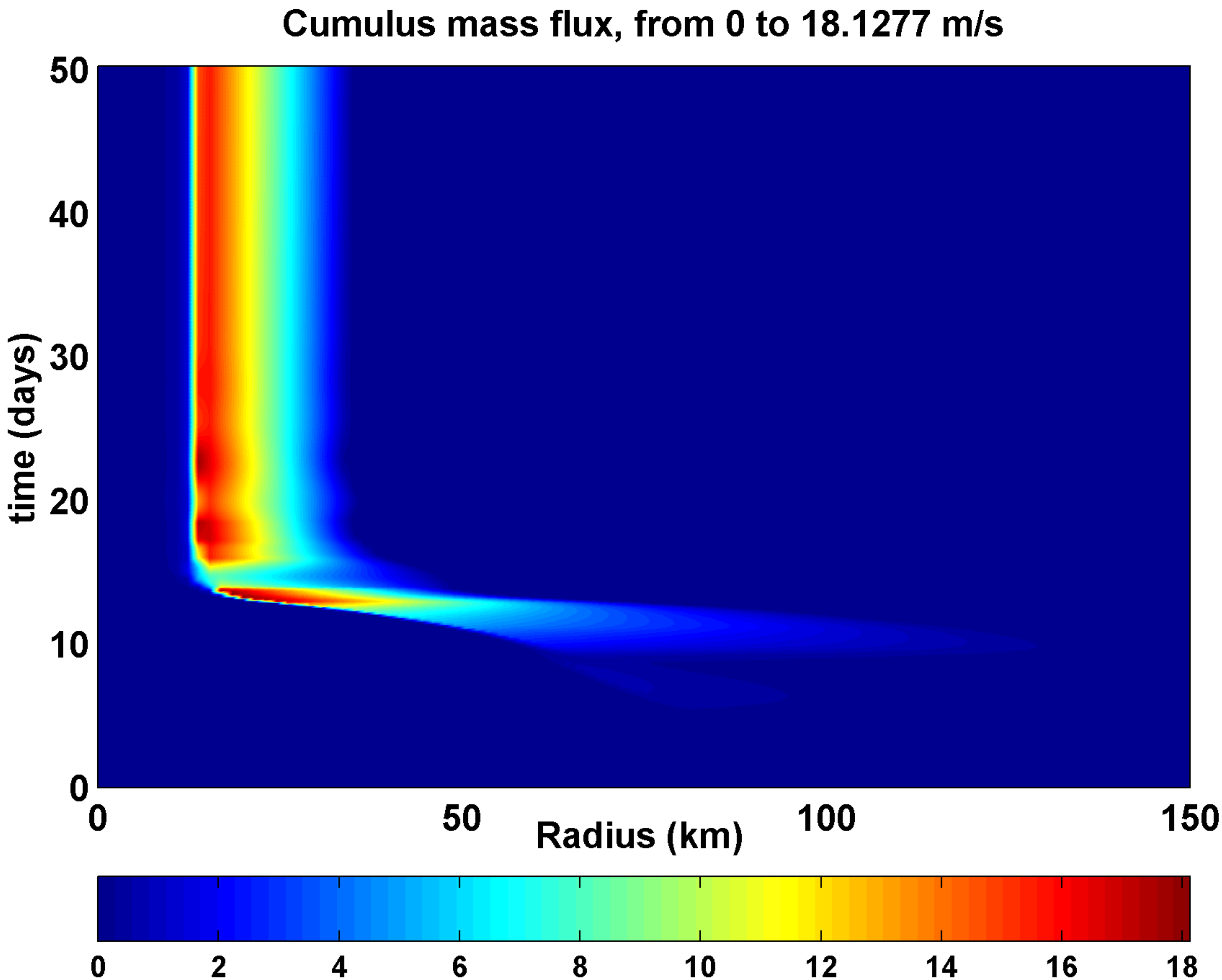


Model behavior

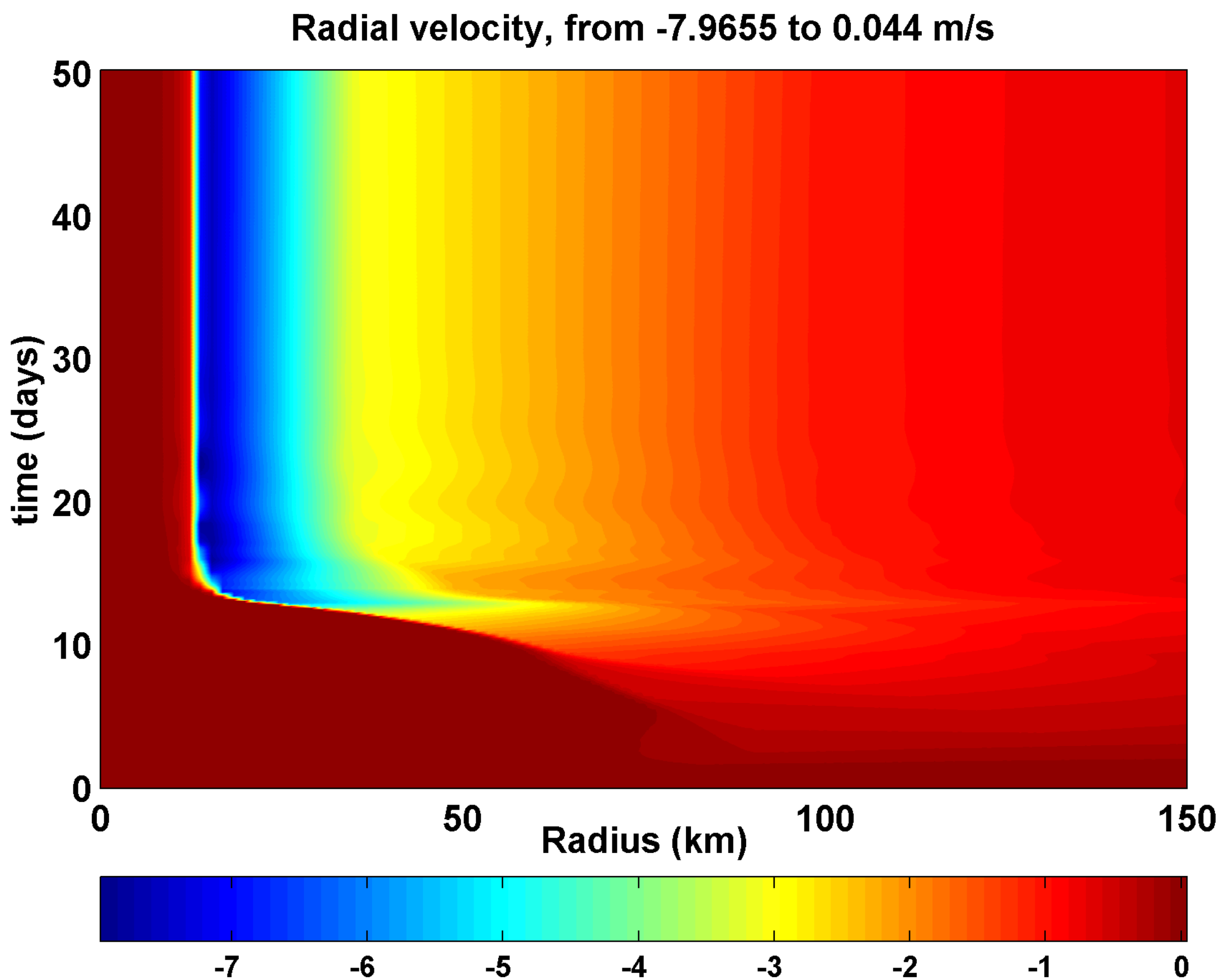


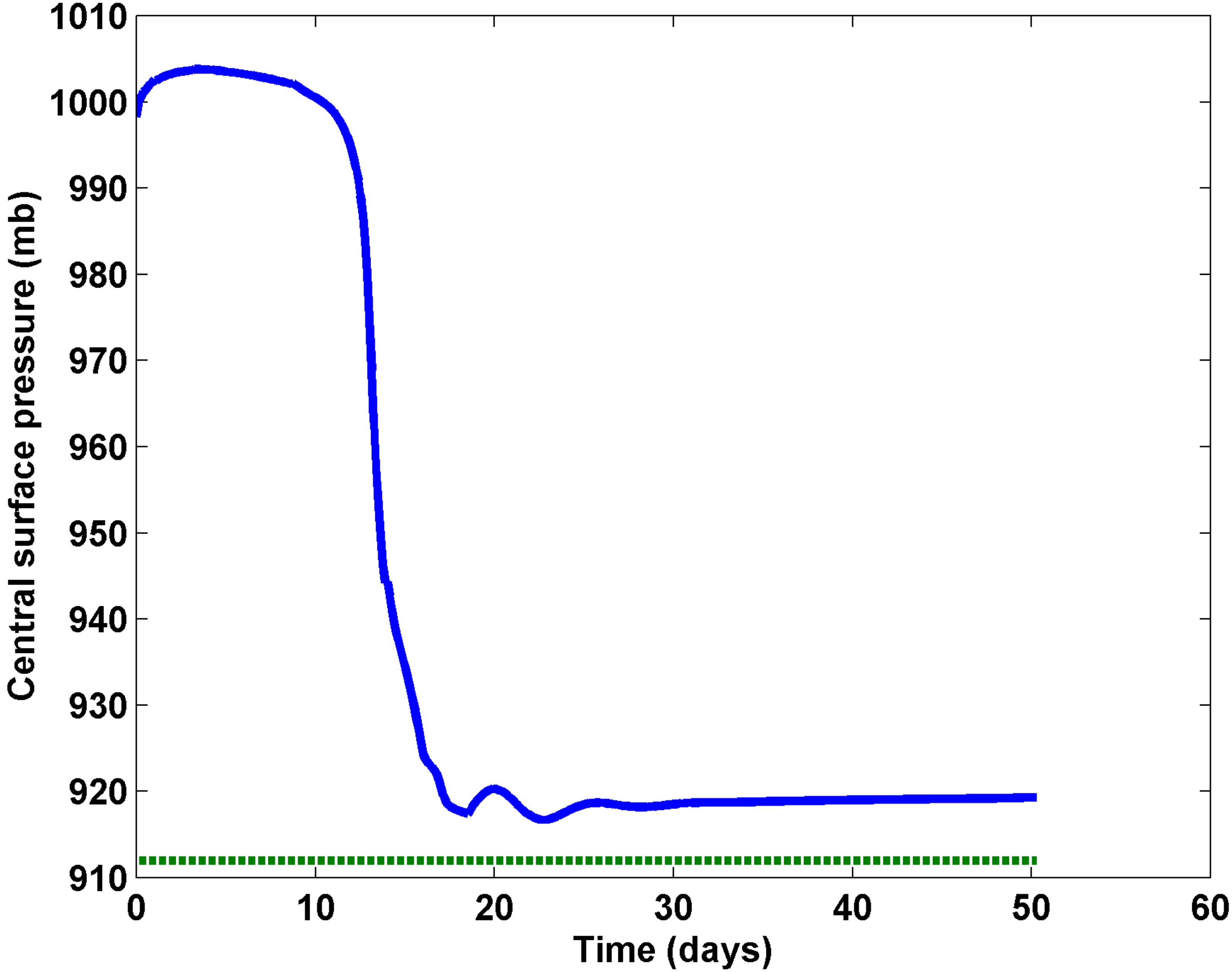
Character of control simulation



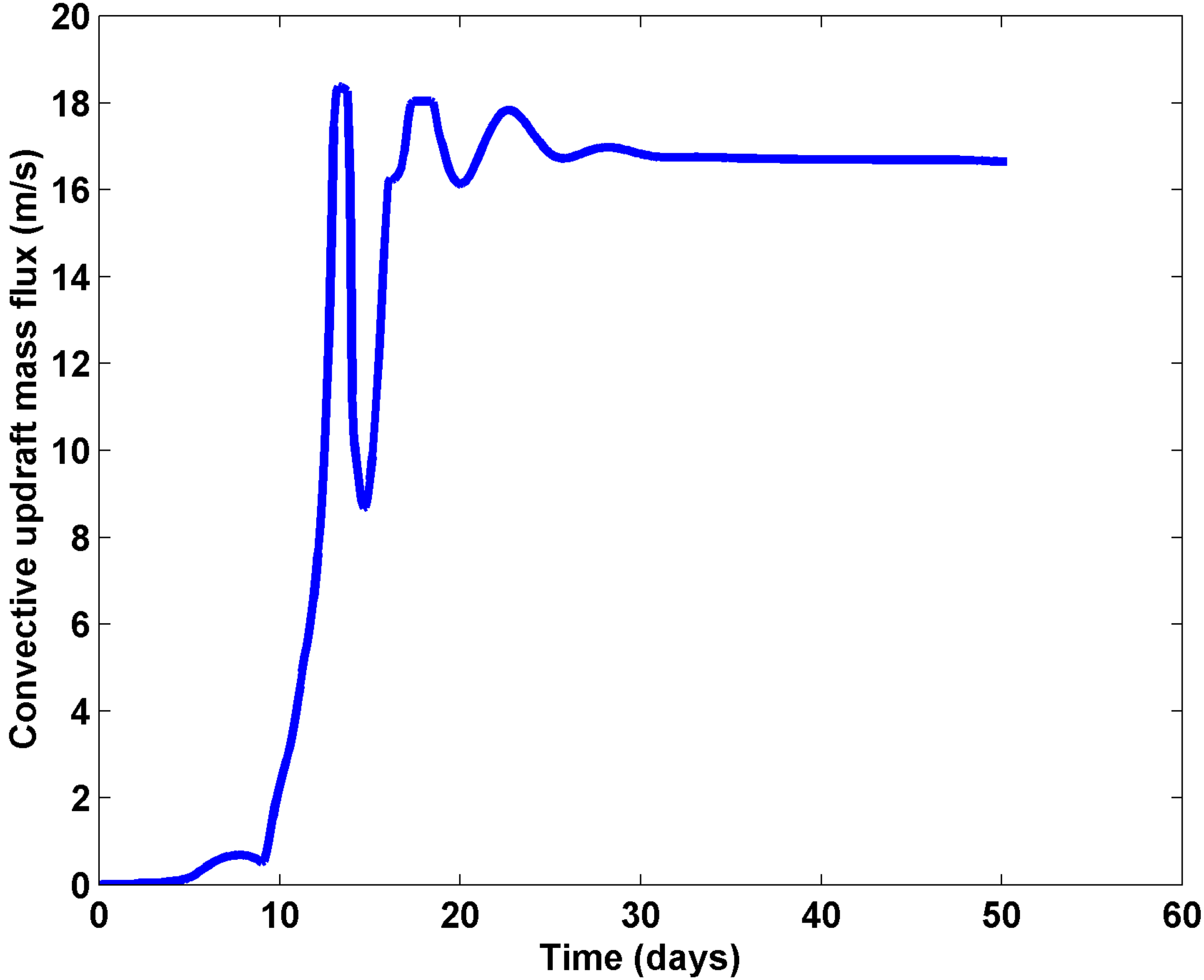


Cumulus mass flux, from 0 to 18.1277 m/s
time (days)
Radius (km)
0
10
20
30
40
50
0
50
100
150
0
2
4
6
8
10
12
14
16
18

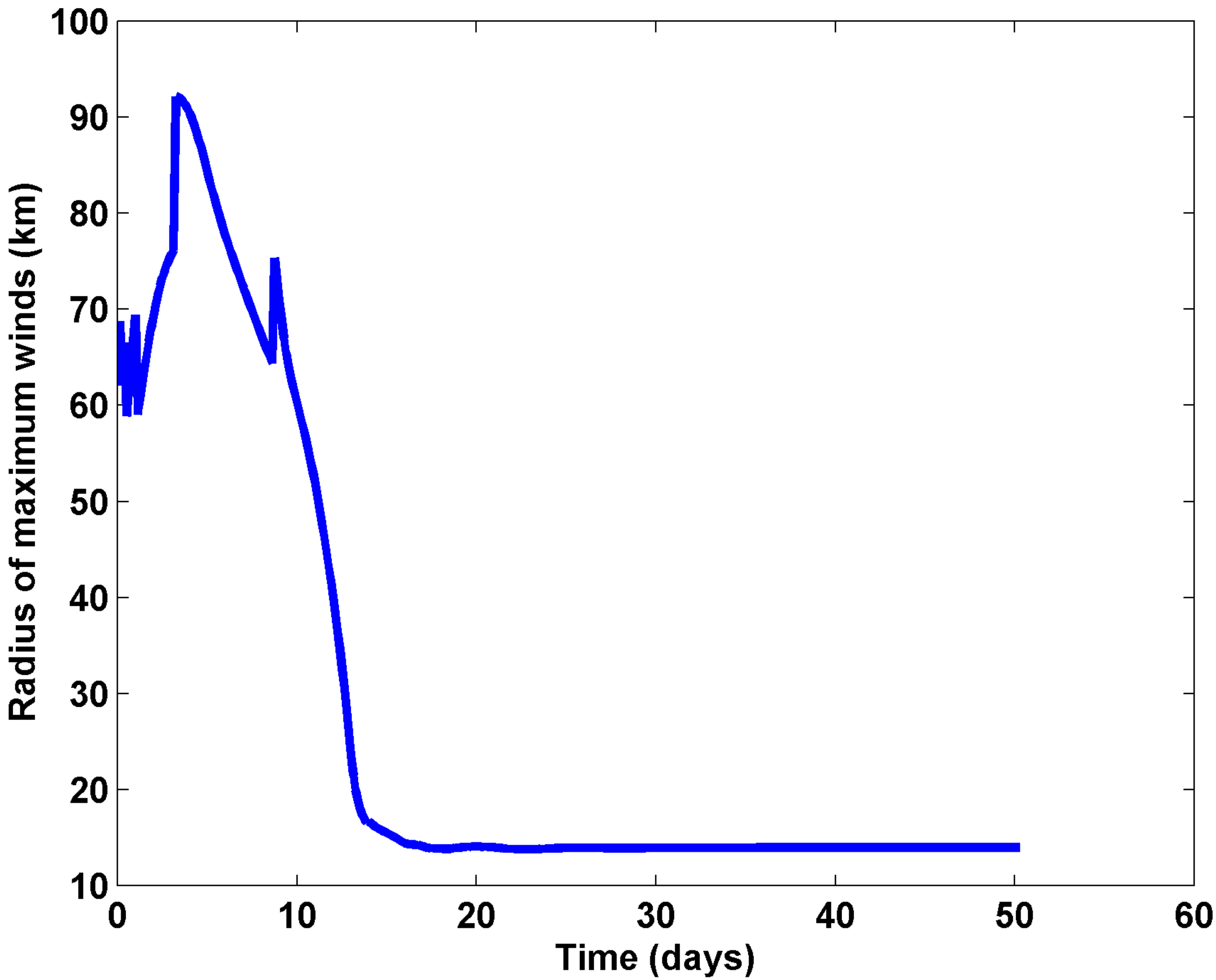

Radial velocity, from -7.9655 to 0.044 m/s
50
40
30
20
10
0
time (days)
0
50
100
150
Radius (km)
-7
-6
-5
-4
-3
-2
-1
0



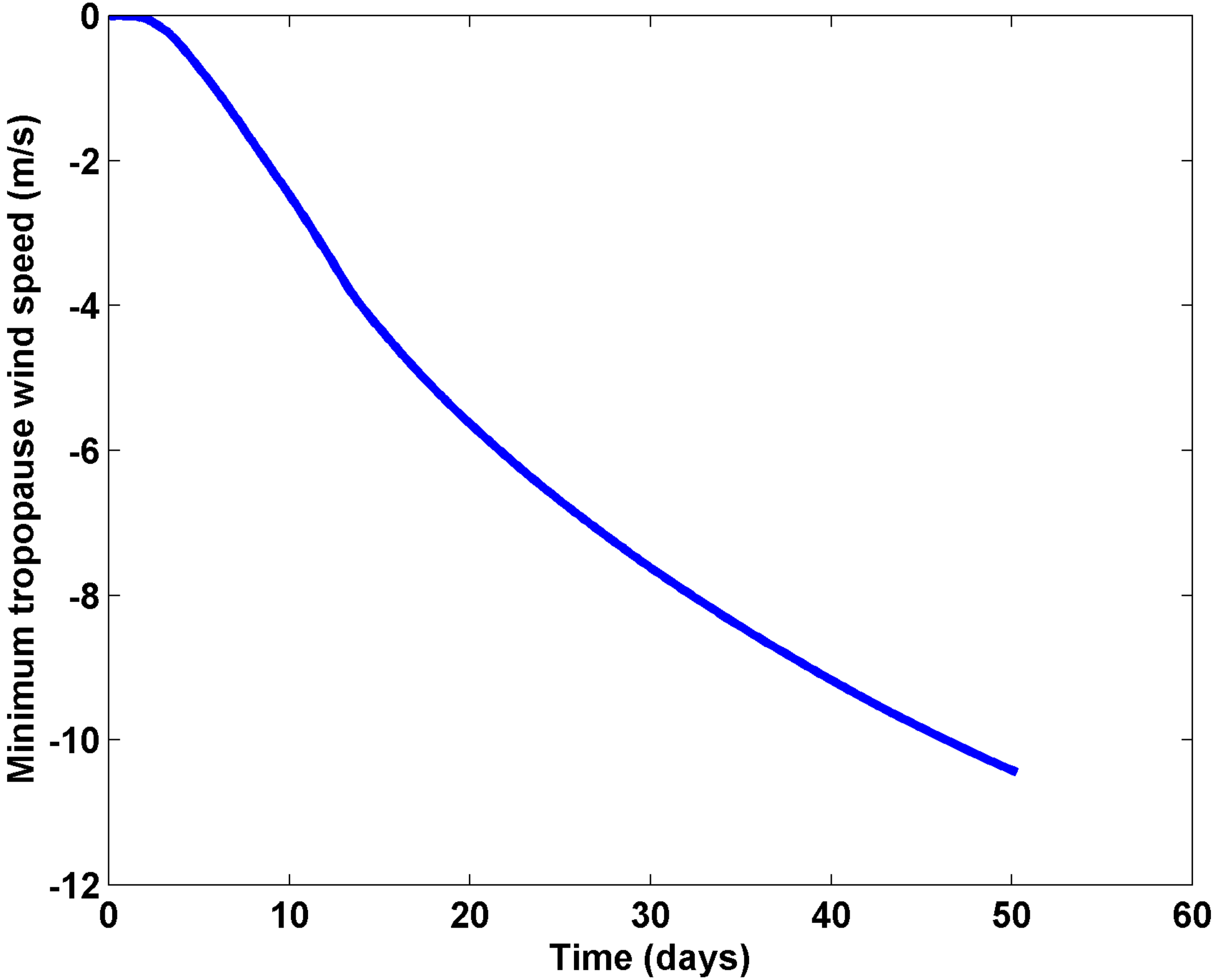
Central surface pressure (mb)
1010
1000
990
980
970
960
950
940
930
920
910
0
10
20
30
40
50
60
Time (days)



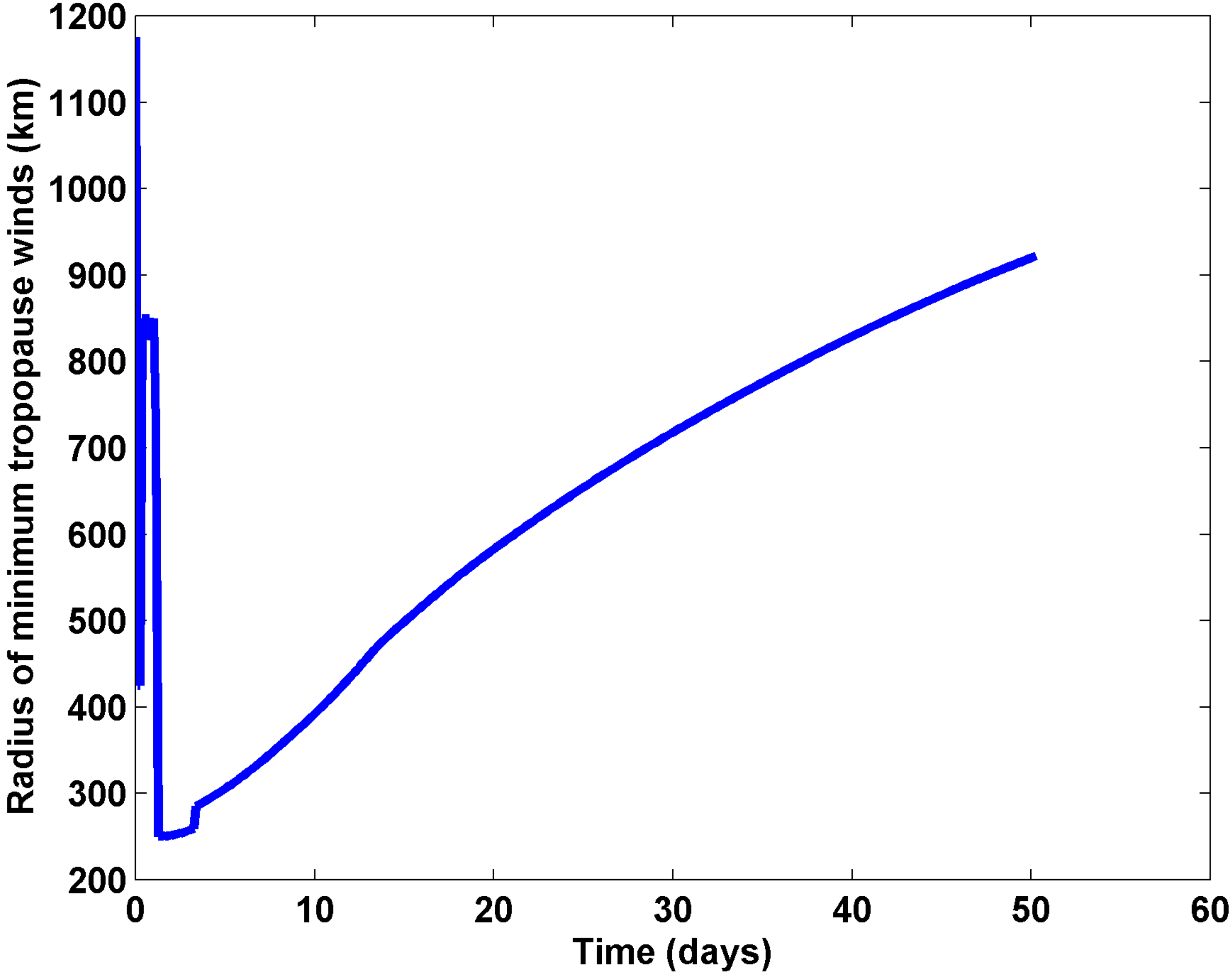
Convective updraft mass flux (m/s)
Time (days)
20
18
16
14
12
10
8
6
4
2
0
0
10
20
30
40
50
60



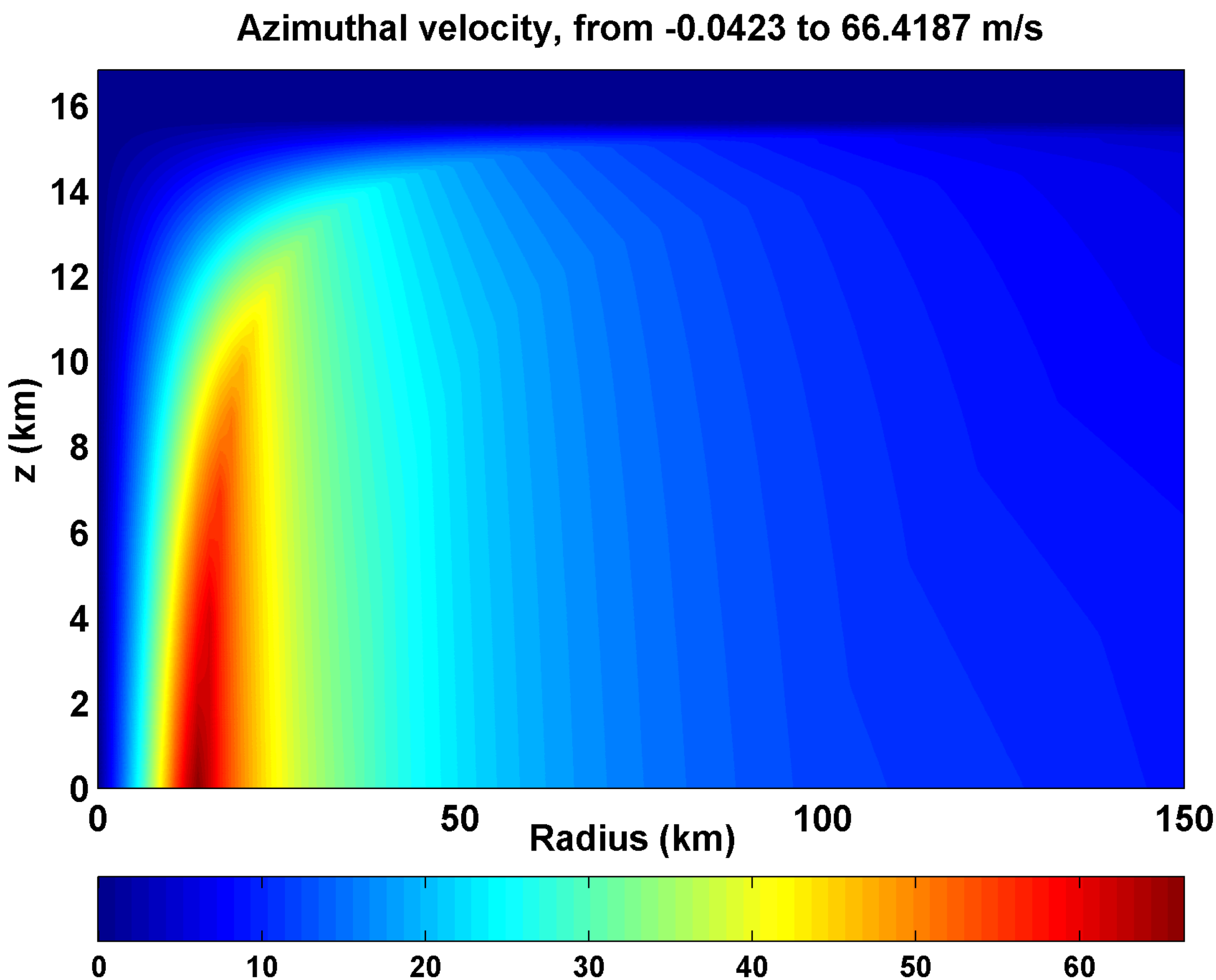
Radius of maximum winds (km)
100
90
80
70
60
50
40
30
20
10
0
10
20
30
40
50
60
Time (days)



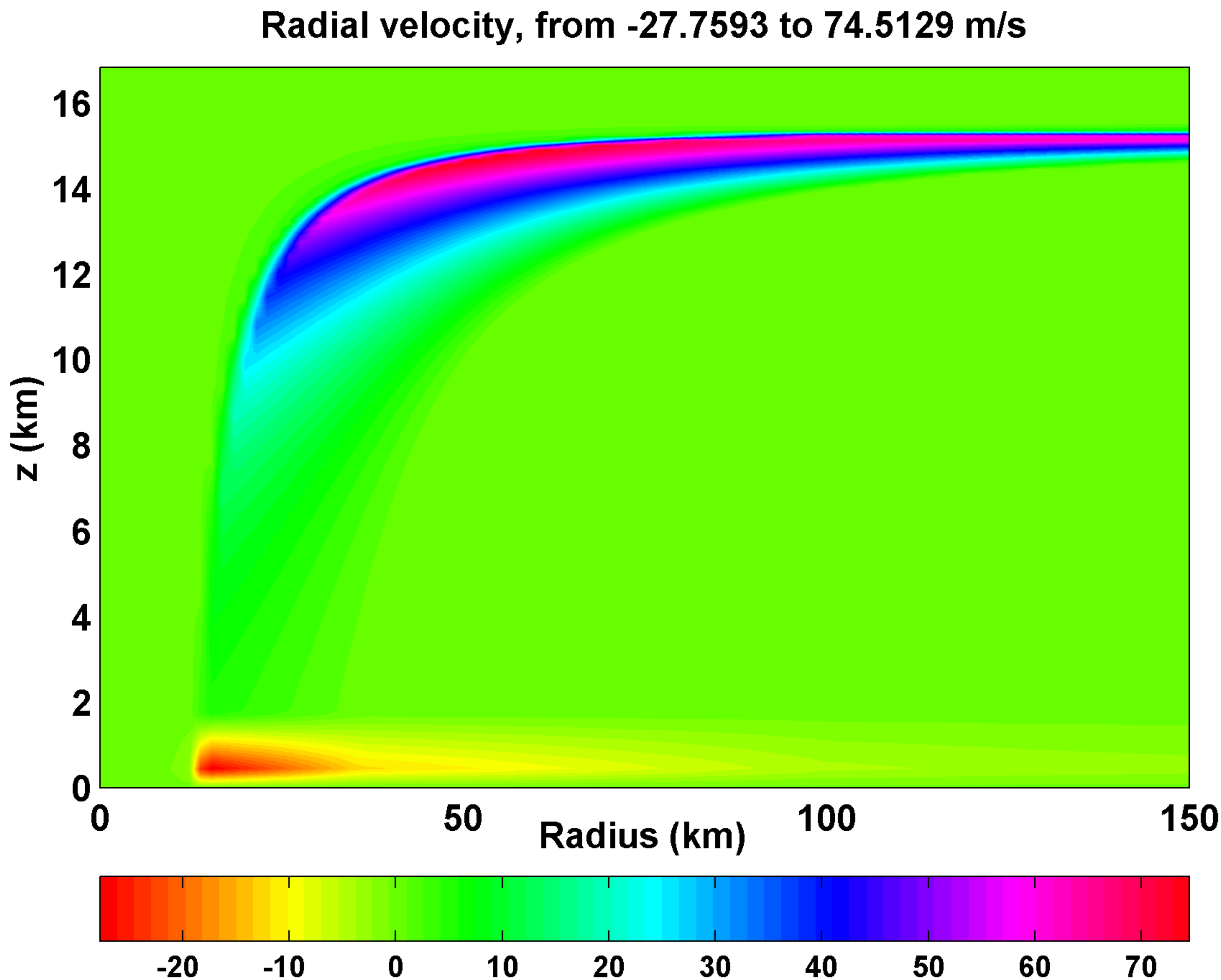
Minimum tropopause wind speed (m/s)
0
-2
-4
-6
-8
-10
-12
0
10
20
30
40
50
60
Time (days)

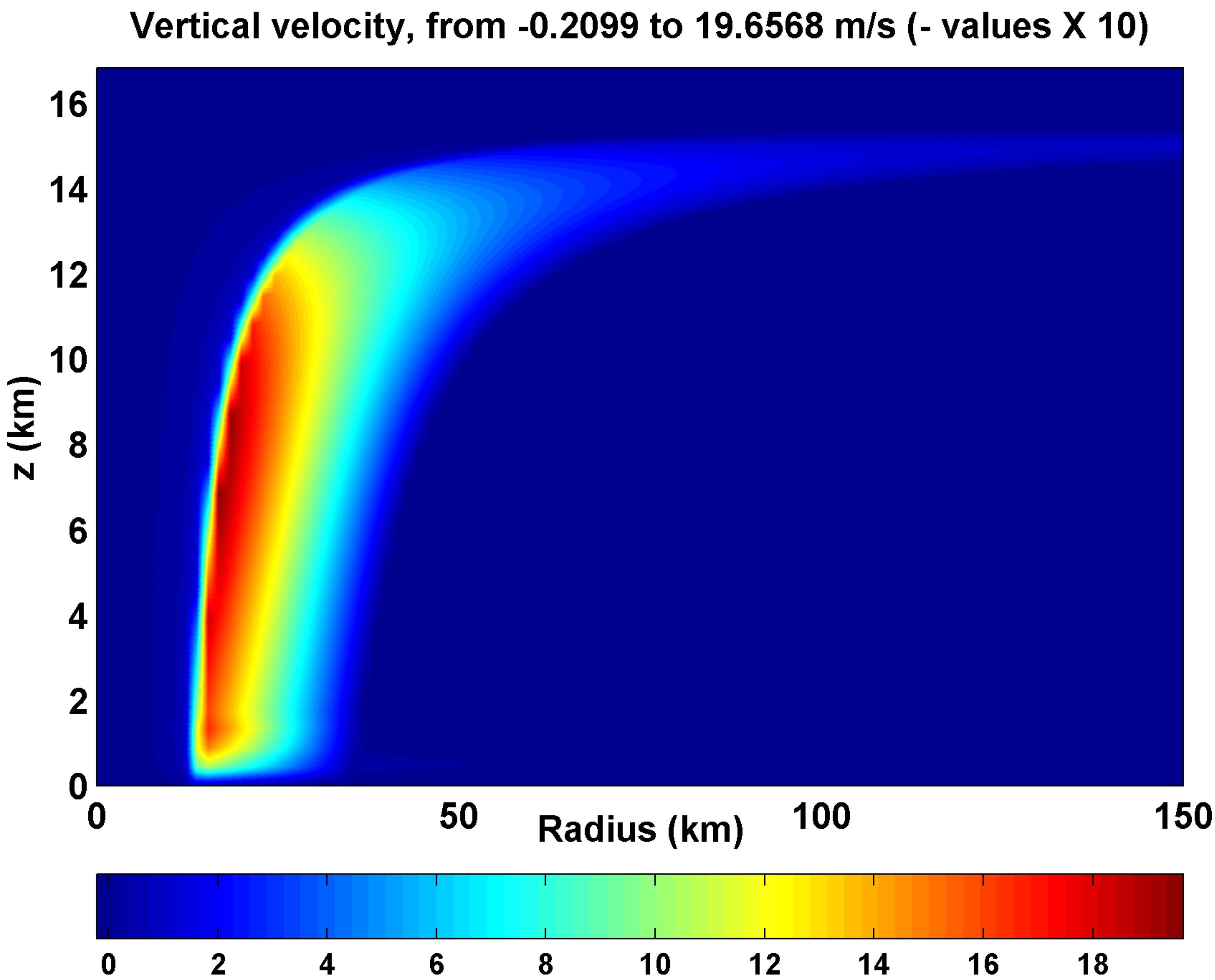


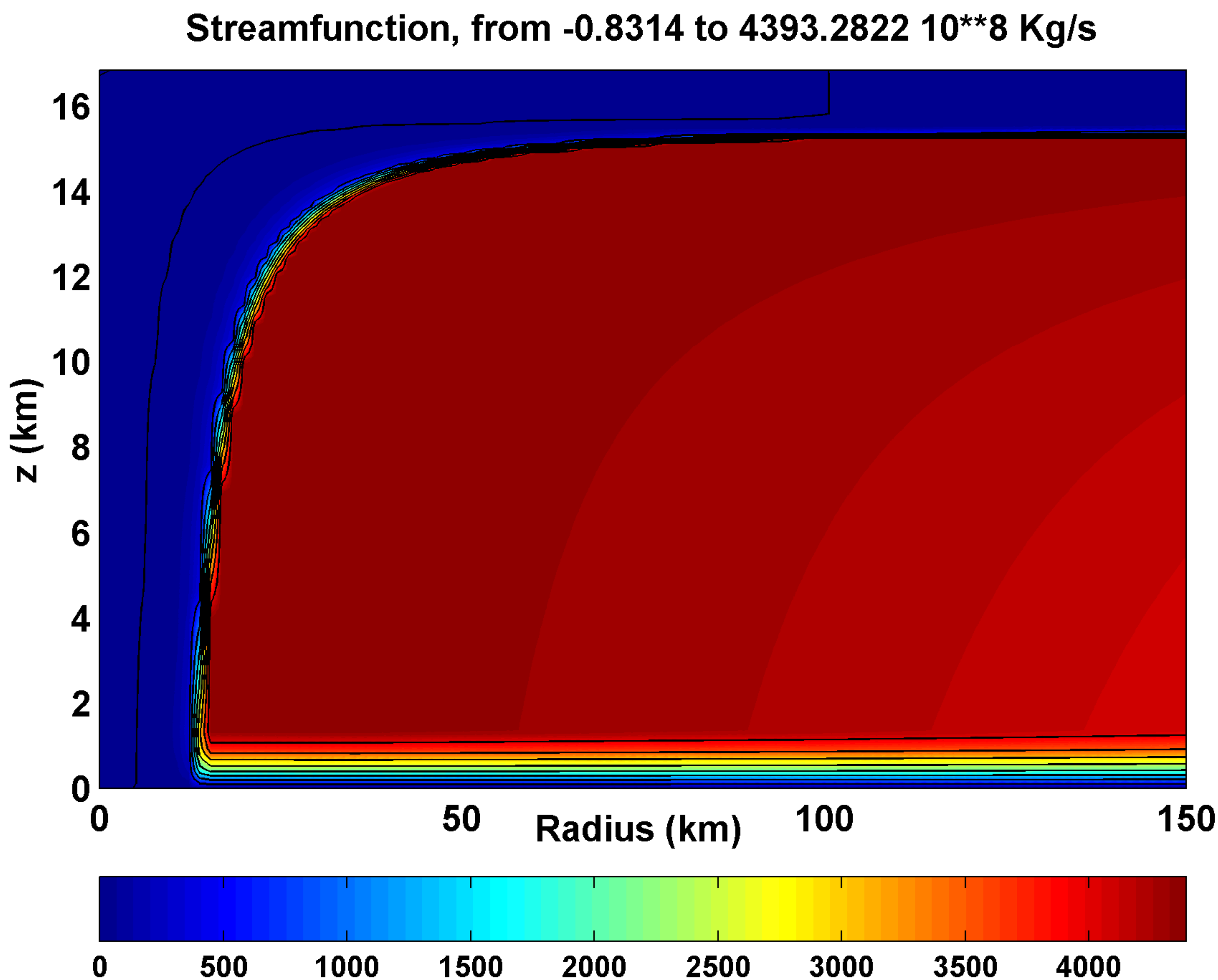
Radius of minimum tropopause winds (km)
1200
1100
1000
900
800
700
600
500
400
300
200
0
10
20
30
40
50
60
Time (days)



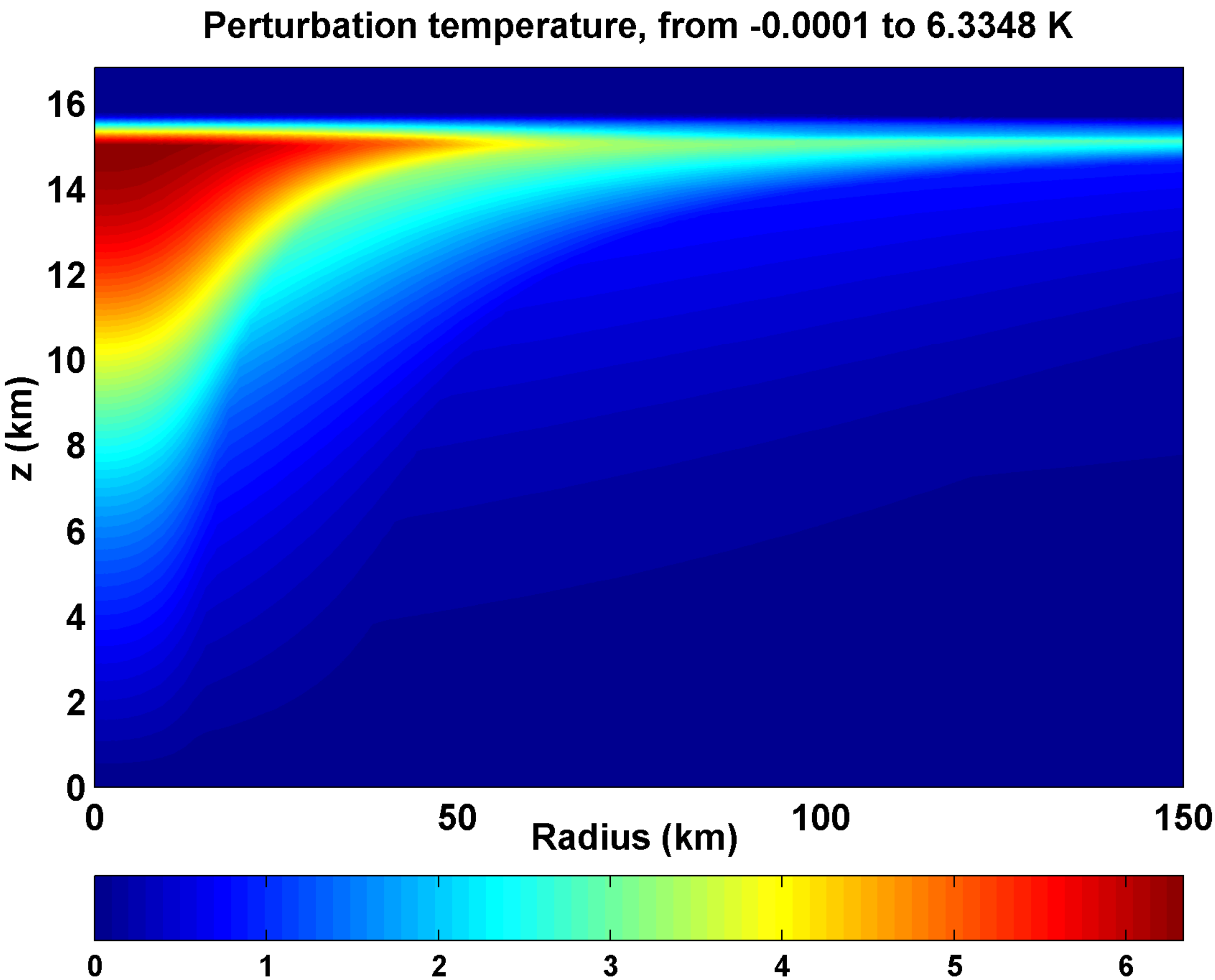
Azimuthal velocity, from -0.0423 to 66.4187 m/s
z (km)
16
14
12
10
8
6
4
2
0
0
50
100
150
Radius (km)
0
10
20
30
40
50
60


Radial velocity, from -27.7593 to 74.5129 m/s
z (km)
16
14
12
10
8
6
4
2
0
0
50
100
150
Radius (km)
-20
-10
0
10
20
30
40
50
60
70

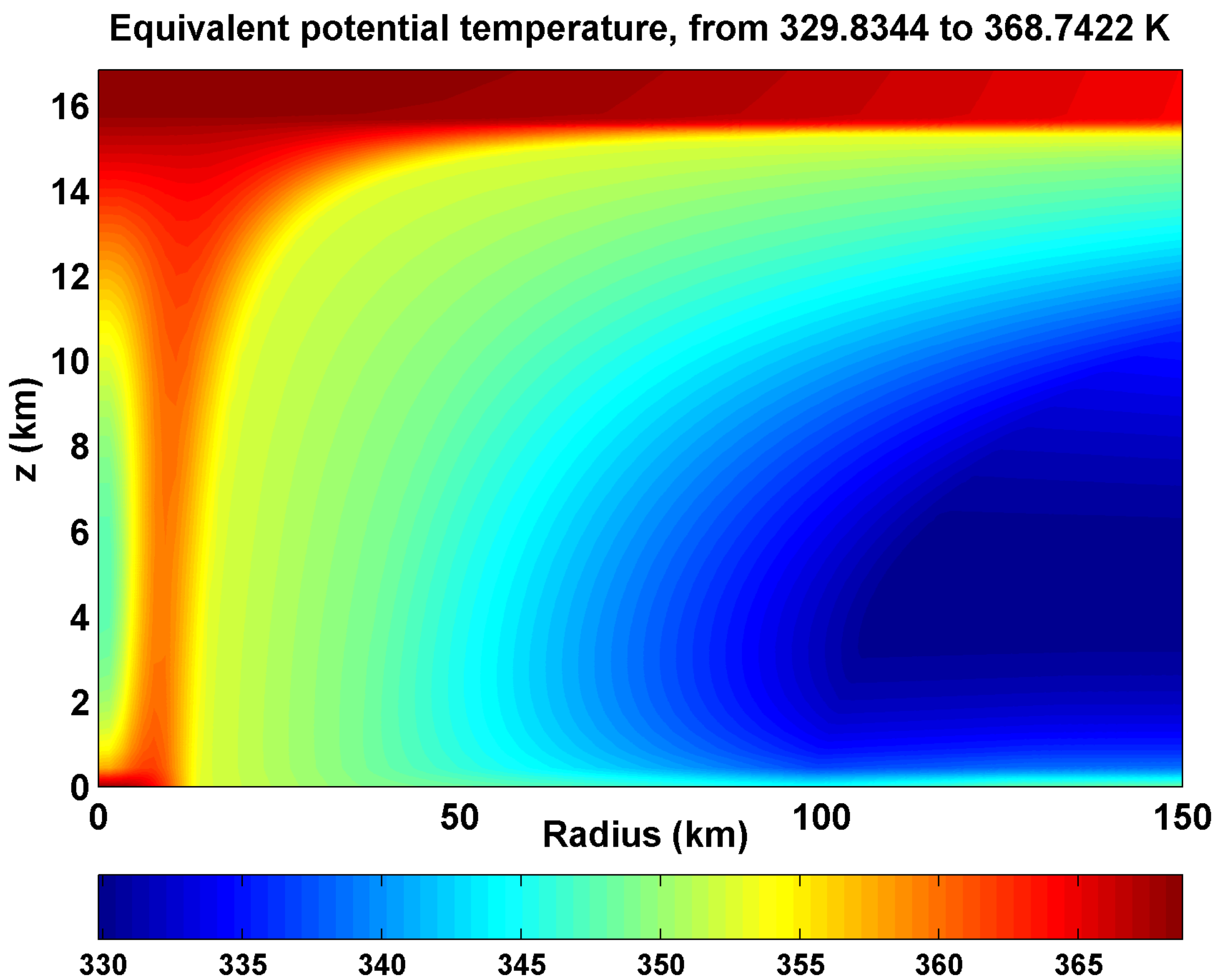

Vertical velocity, from -0.2099 to 19.6568 m/s (- values X 10)
z (km)
0
2
4
6
8
10
12
14
16
Radius (km)
0
50
100
150
0
2
4
6
8
10
12
14
16
18



Streamfunction, from -0.8314 to 4393.2822 10**8 Kg/s
z (km)
0
2
4
6
8
10
12
14
16
Radius (km)
0
50
100
150
0
500
1000
1500
2000
2500
3000
3500
4000

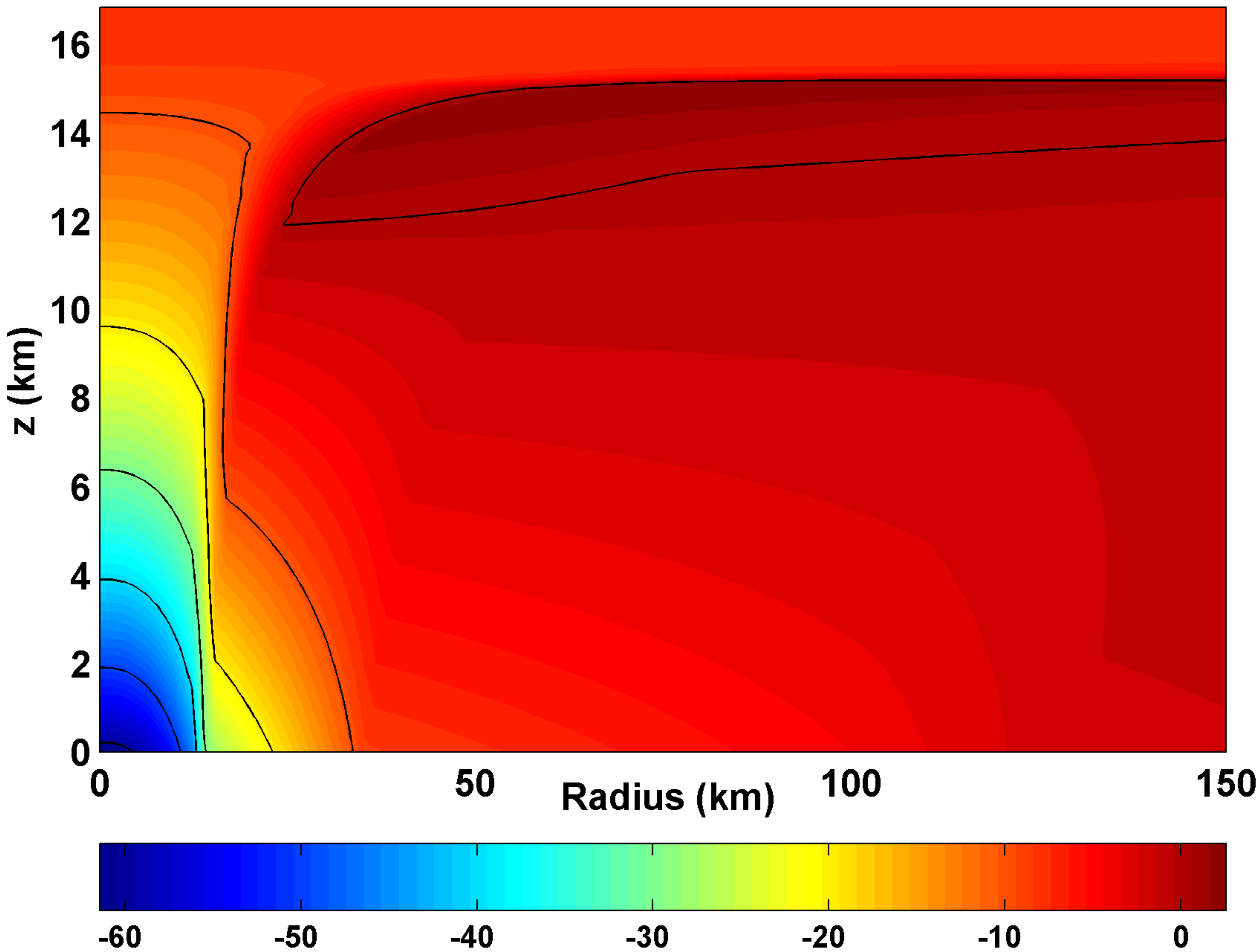


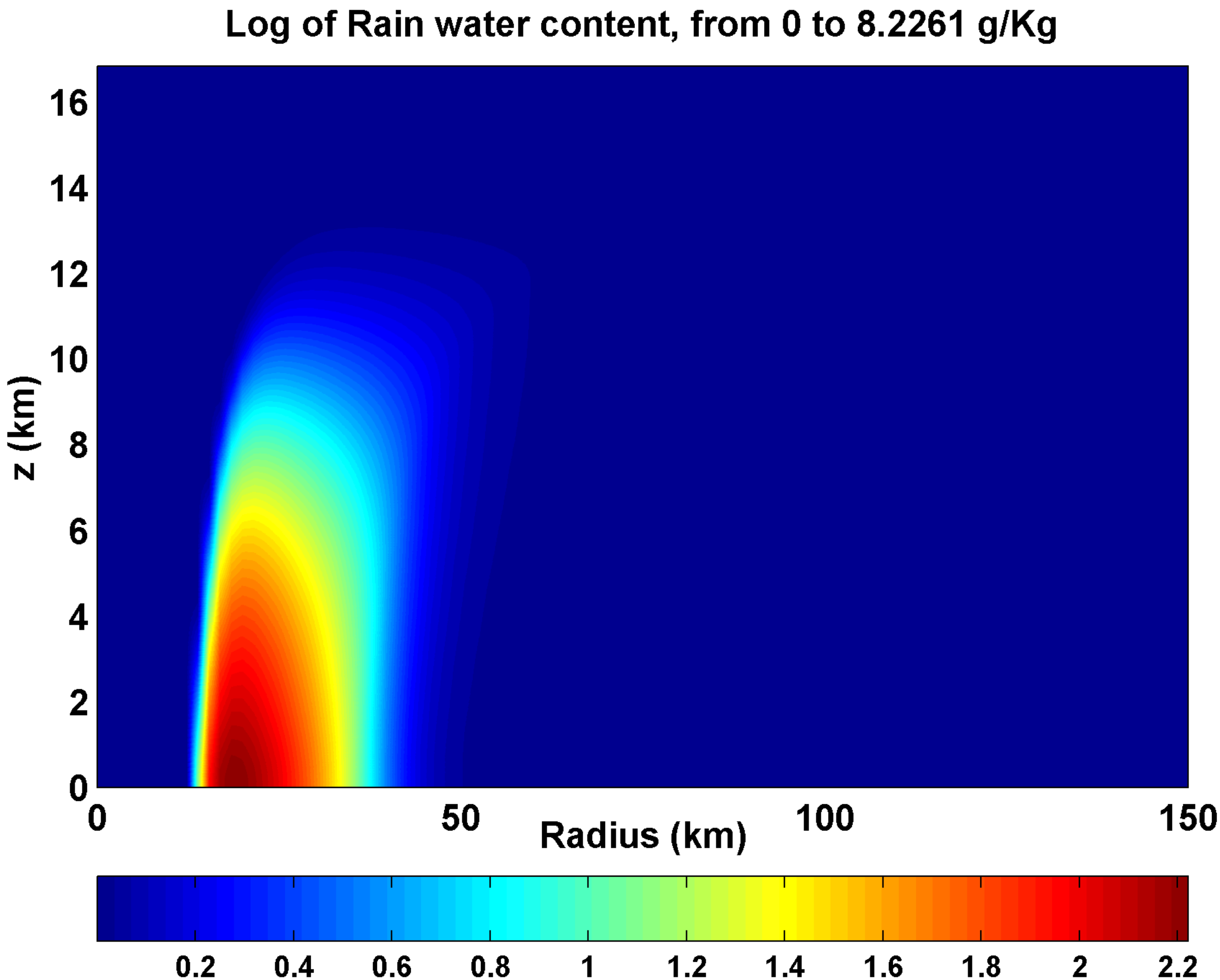
Perturbation temperature, from -0.0001 to 6.3348 K
z (km)
0
2
4
6
8
10
12
14
16
0
50
100
150
Radius (km)
0
1
2
3
4
5
6



Equivalent potential temperature, from 329.8344 to 368.7422 K
z (km)
0
2
4
6
8
10
12
14
16
0
50
100
150
Radius (km)
330
335
340
345
350
355
360
365

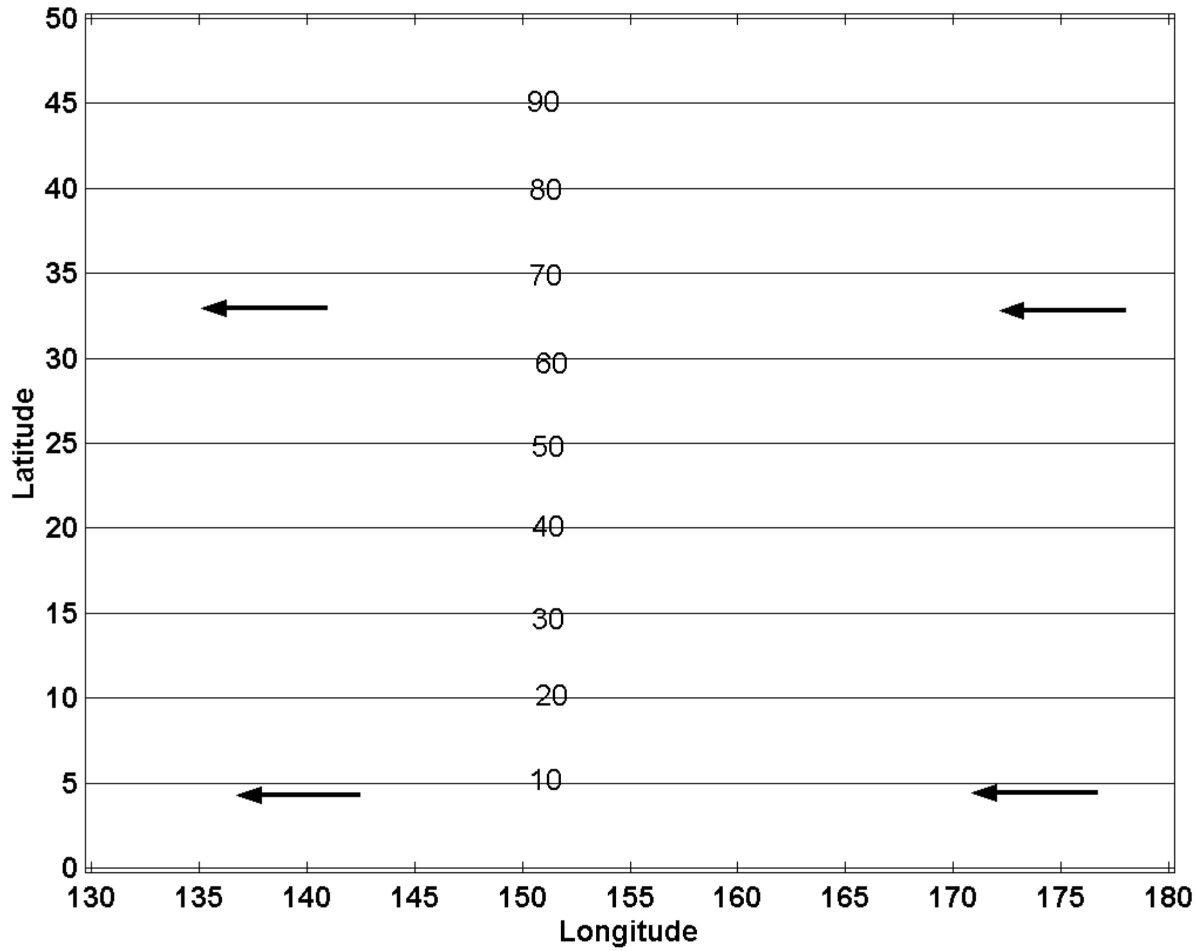
Perturbation pressure, from -61.4327 to 2.5845 mb

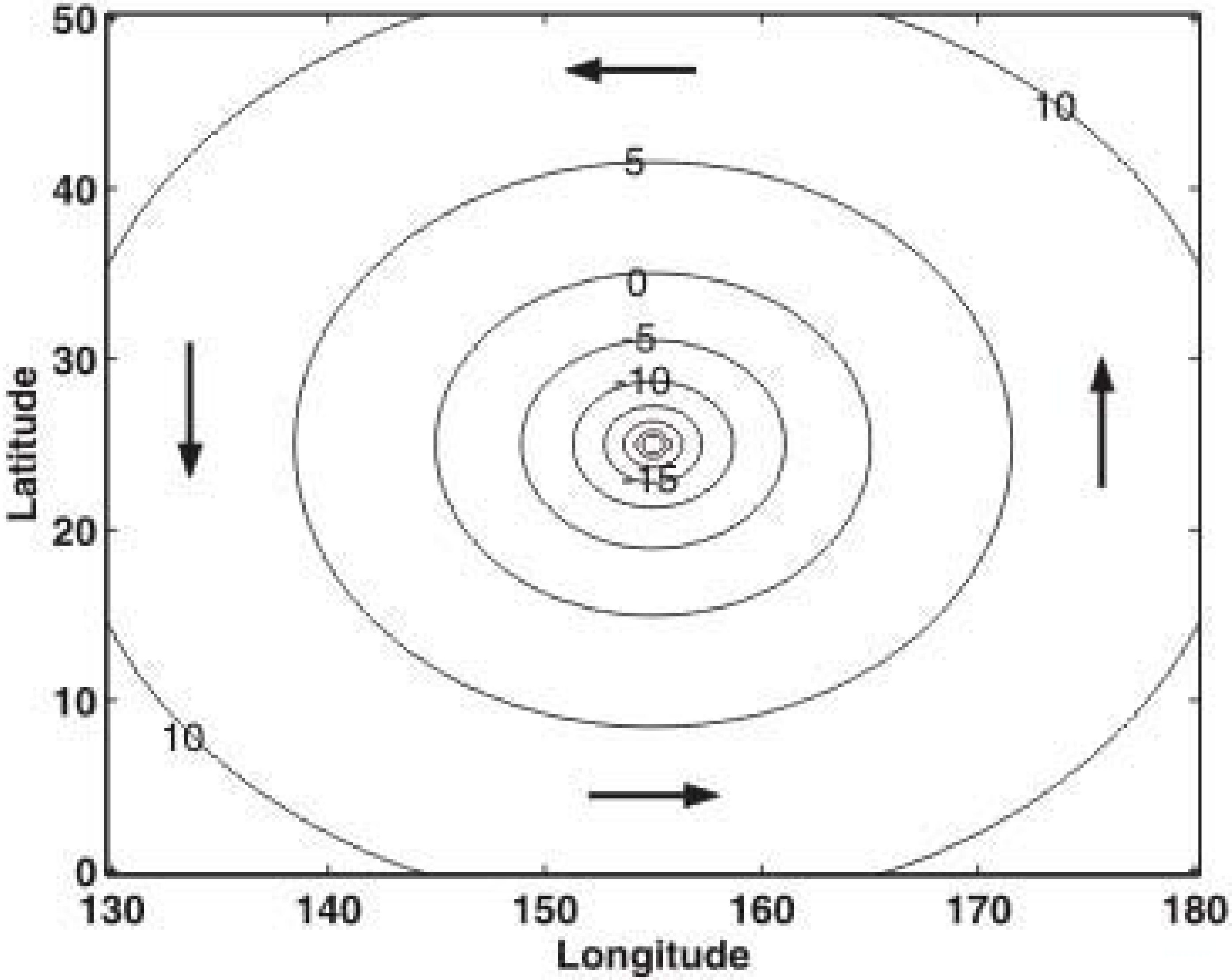


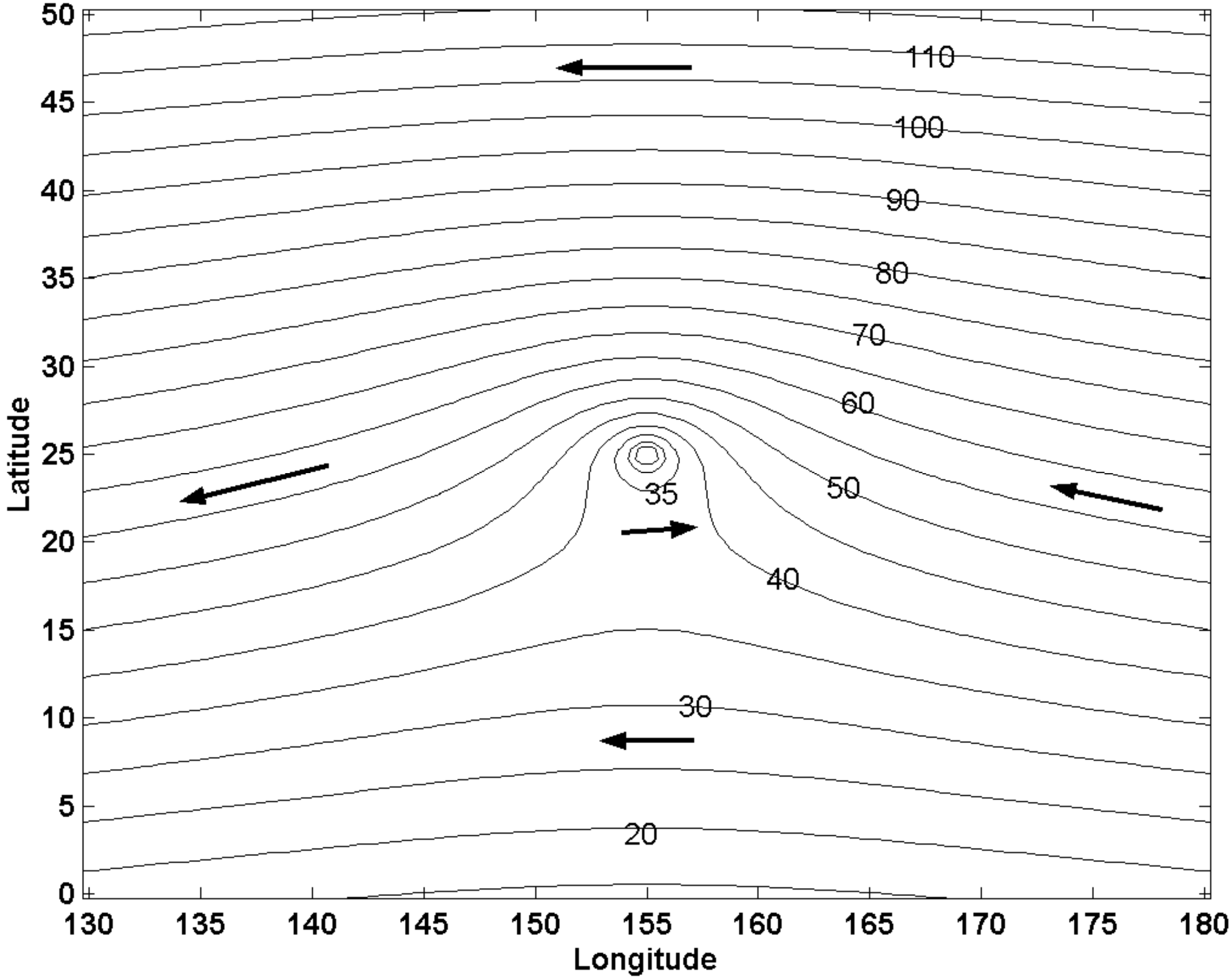

Log of Rain water content, from 0 to 8.2261 g/Kg
z (km)
16
14
12
10
8
6
4
2
0
0
50
100
150
Radius (km)
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
2.2

Tropical Cyclone Motion

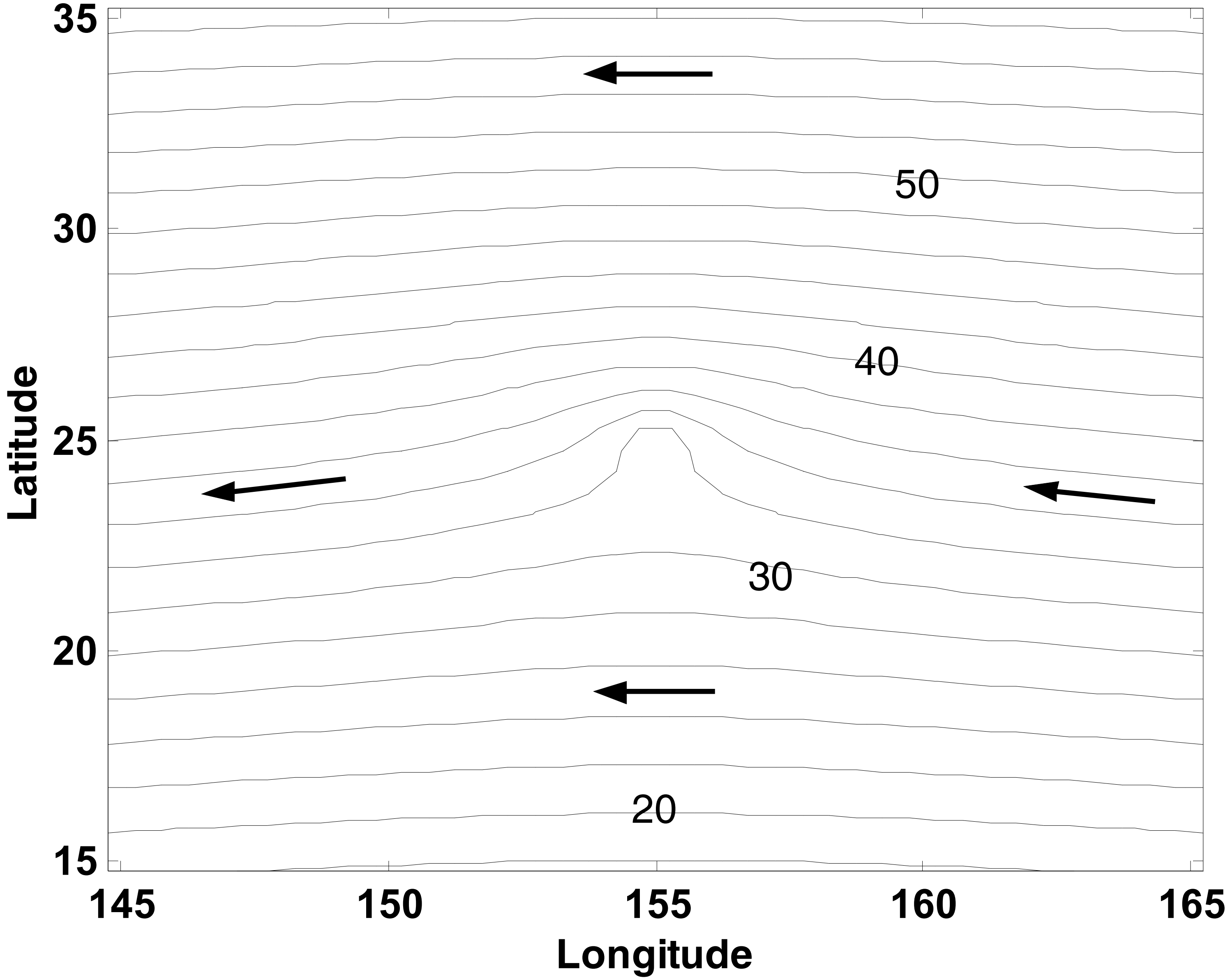
Tropical cyclones move approximately with a suitably defined vertical vector average of the flow in which they are embedded




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

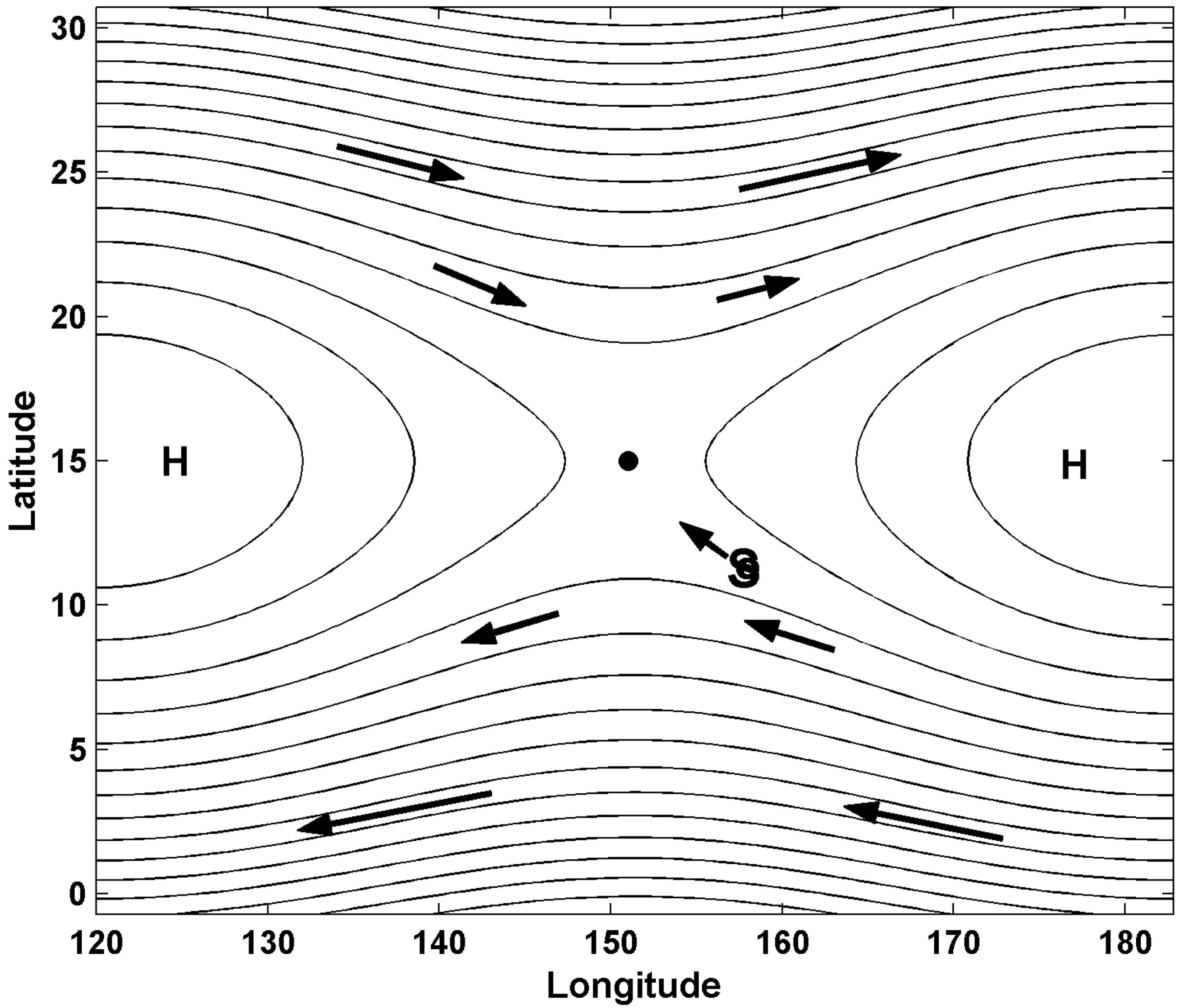


110
100
90
80
70
60
50
35
40
30
20
Latitude
Longitude
50
45
40
35
30
25
20
15
10
5
0
130
135
140
145
150
155
160
165
170
175
180

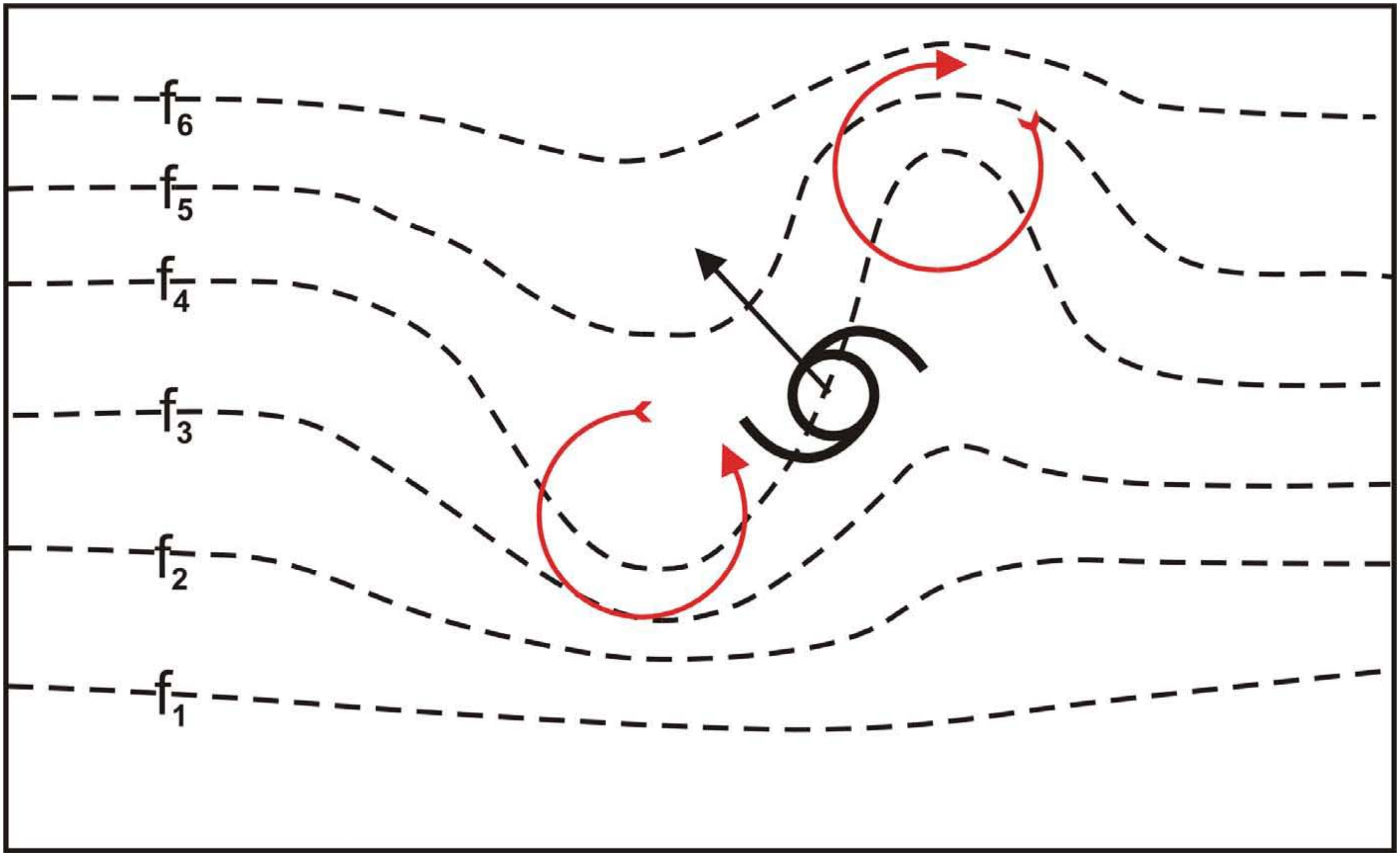


35
30
25
20
15
Latitude
50
40
30
20
145
150
155
160
165
Longitude

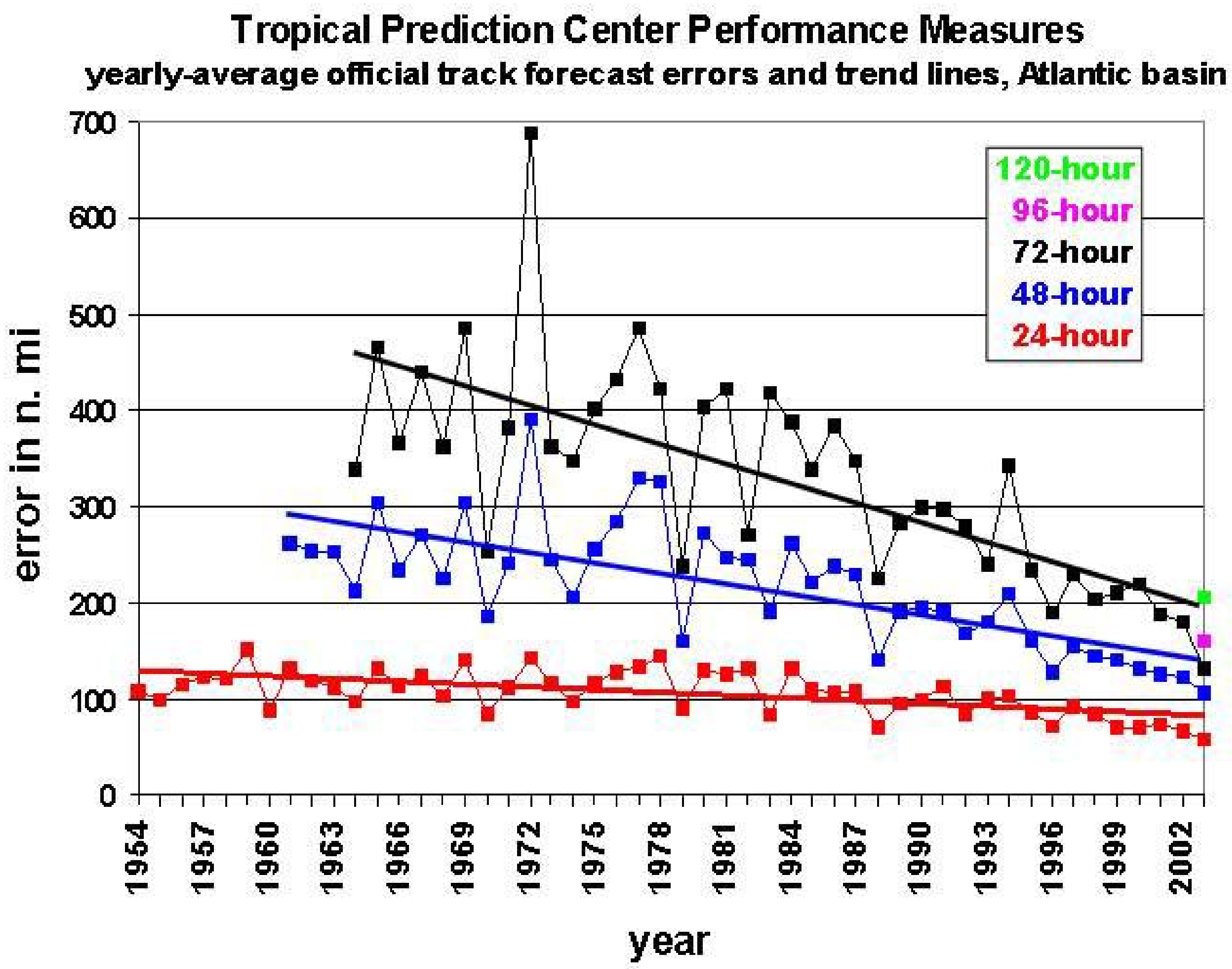
Lagrangian chaos:



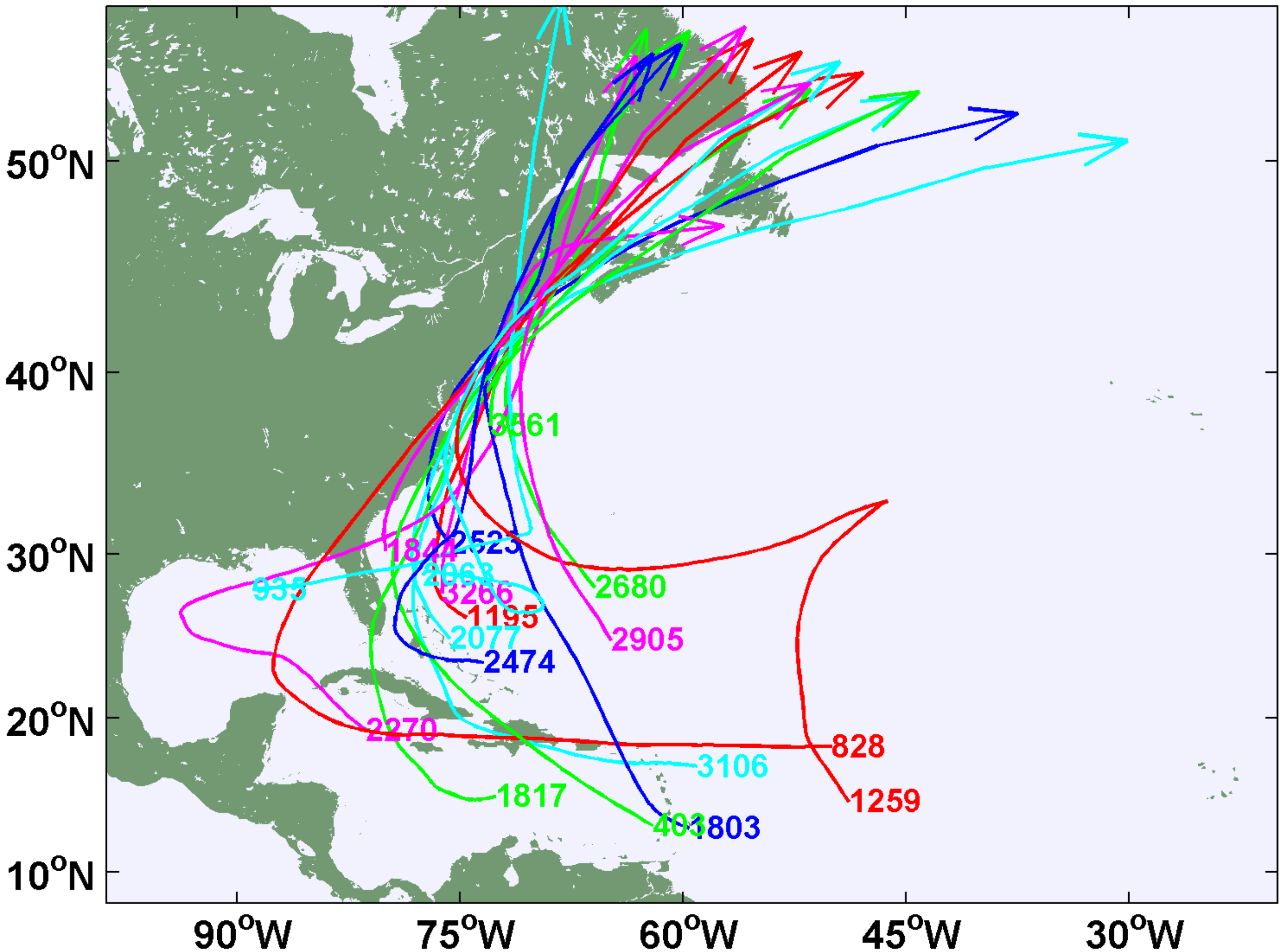
“Beta Gyres”



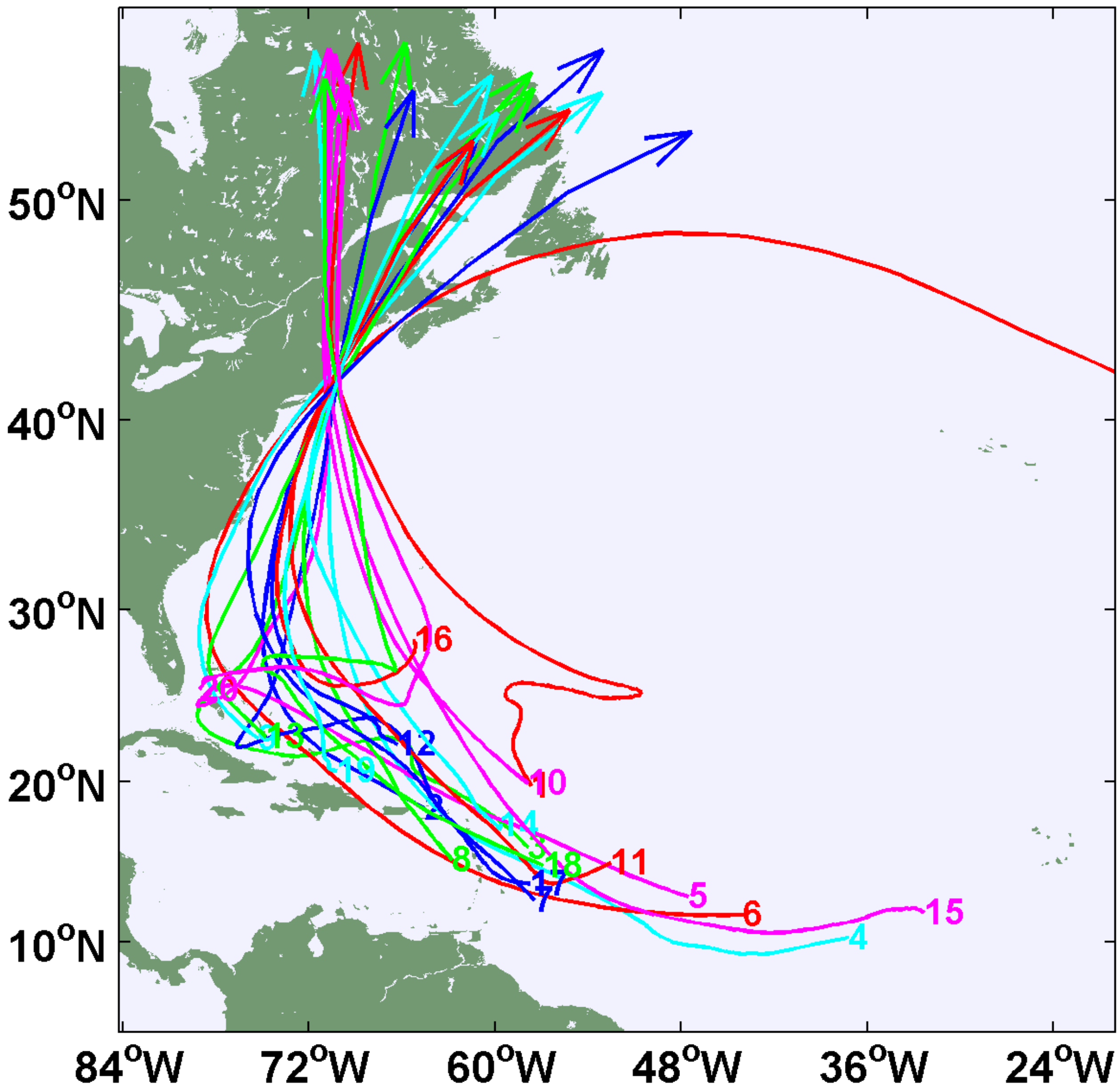
Operational prediction of tropical cyclone tracks:



Example: 20 random tracks passing within 100 km of Boston



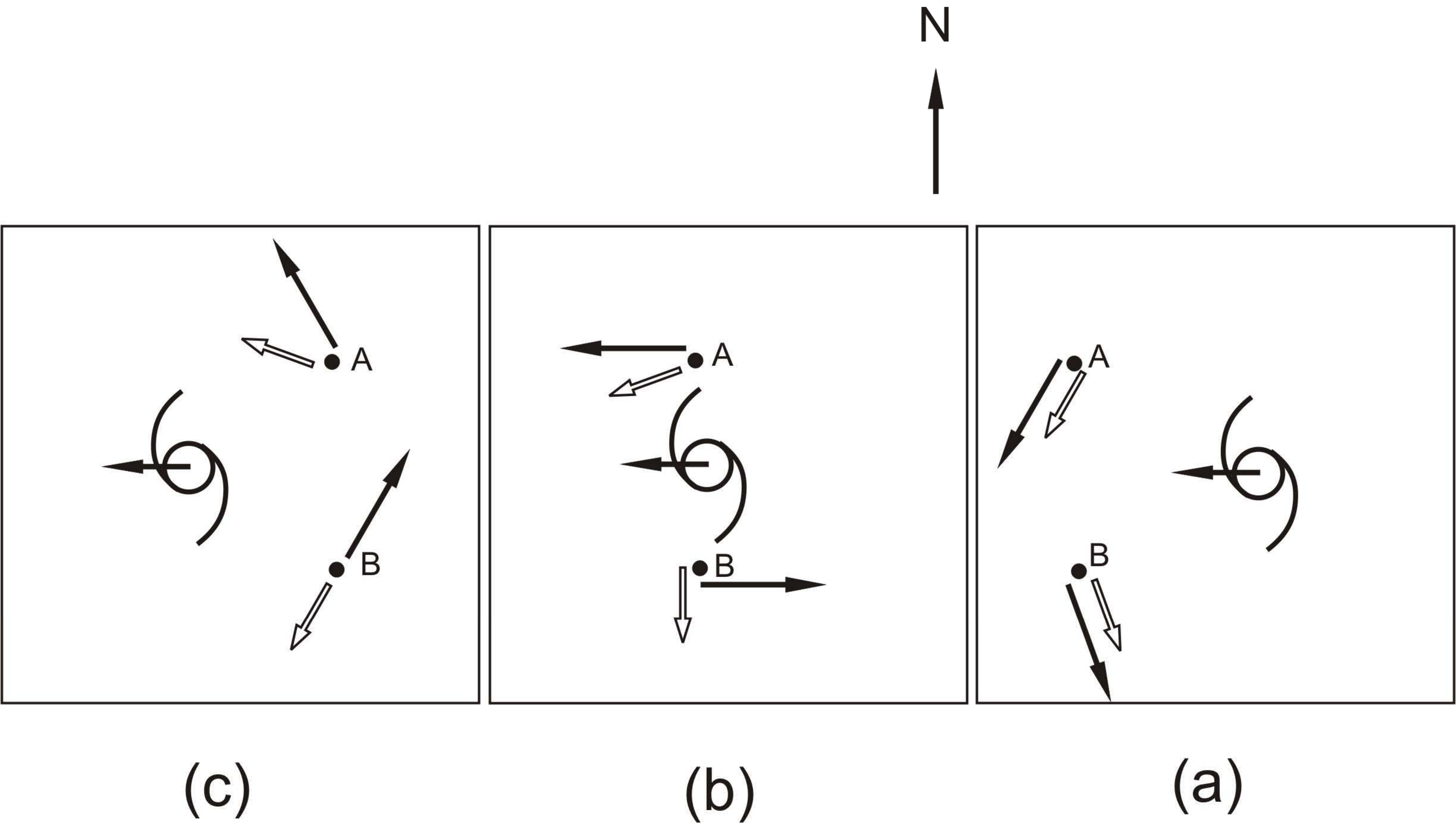
20 “worst” tracks:



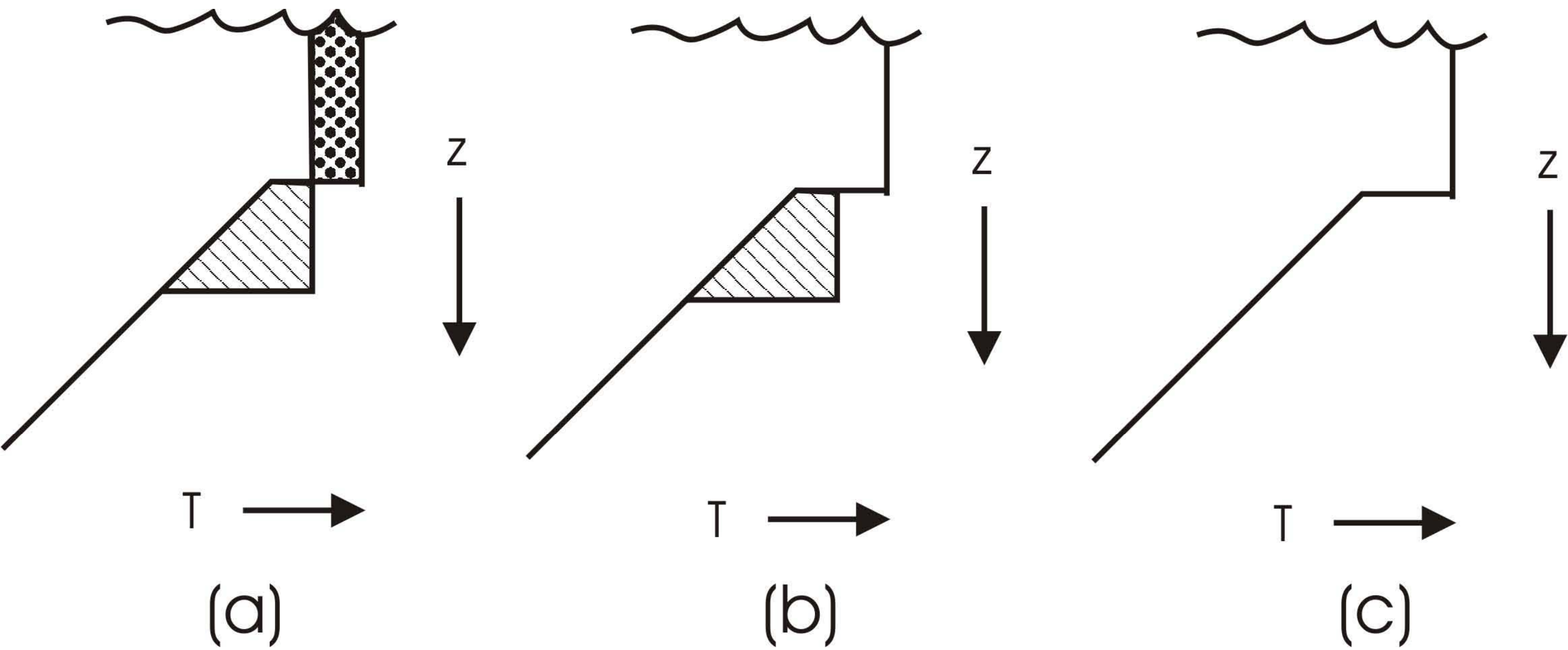
Interaction of Tropical Cyclones with the Upper Ocean

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

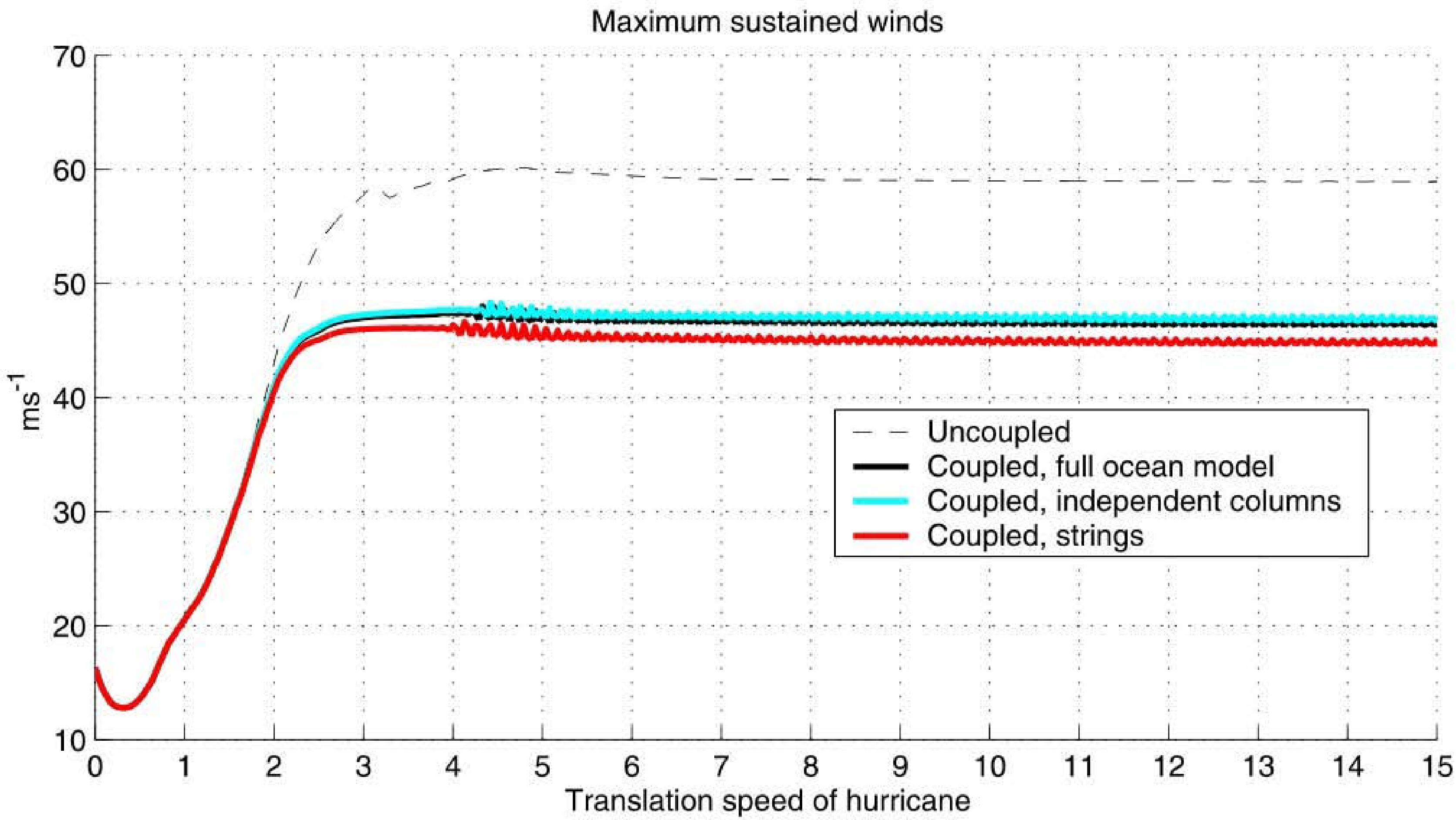
Excitation of Inertial Oscillations



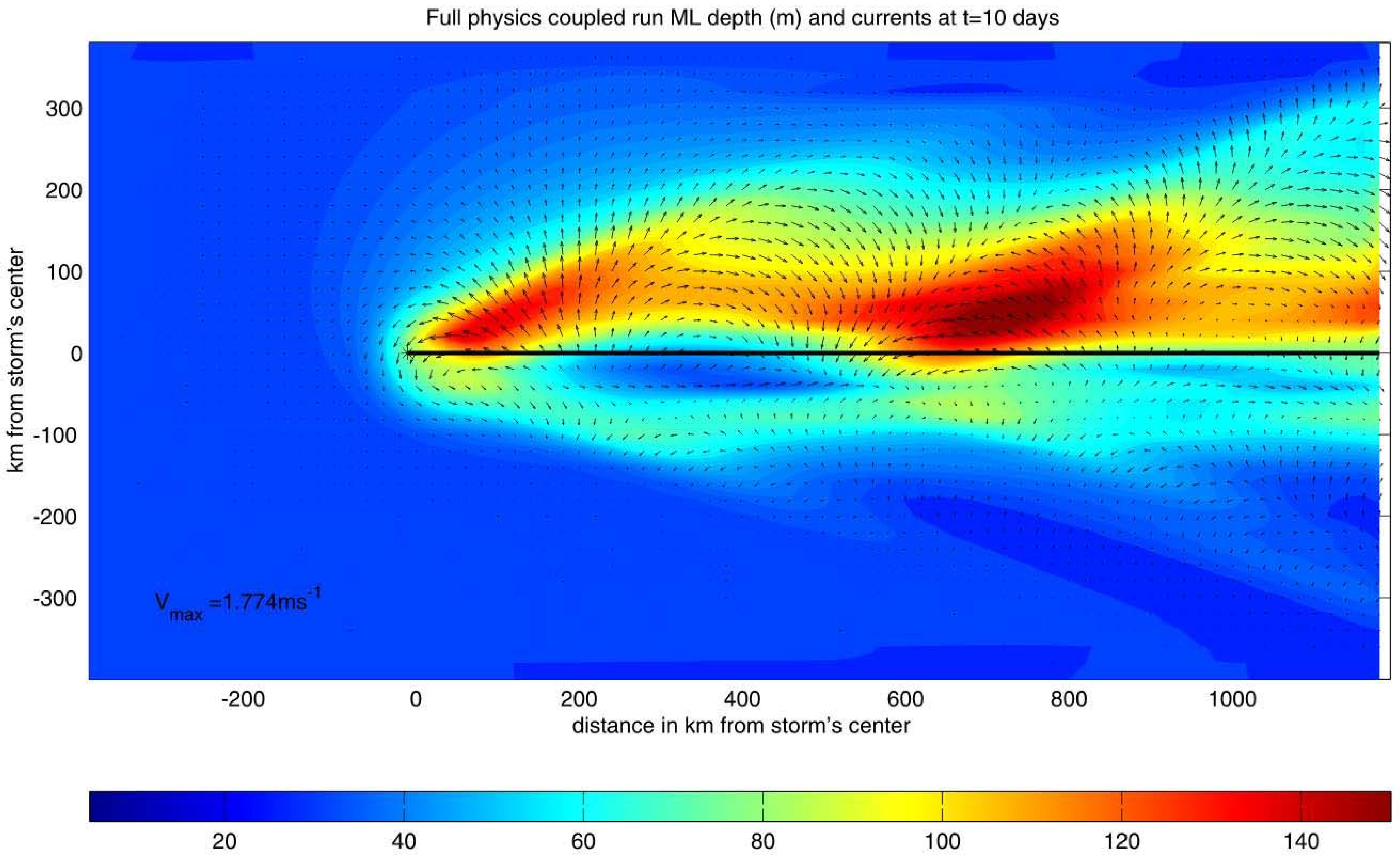
Mixing and Entrainment:

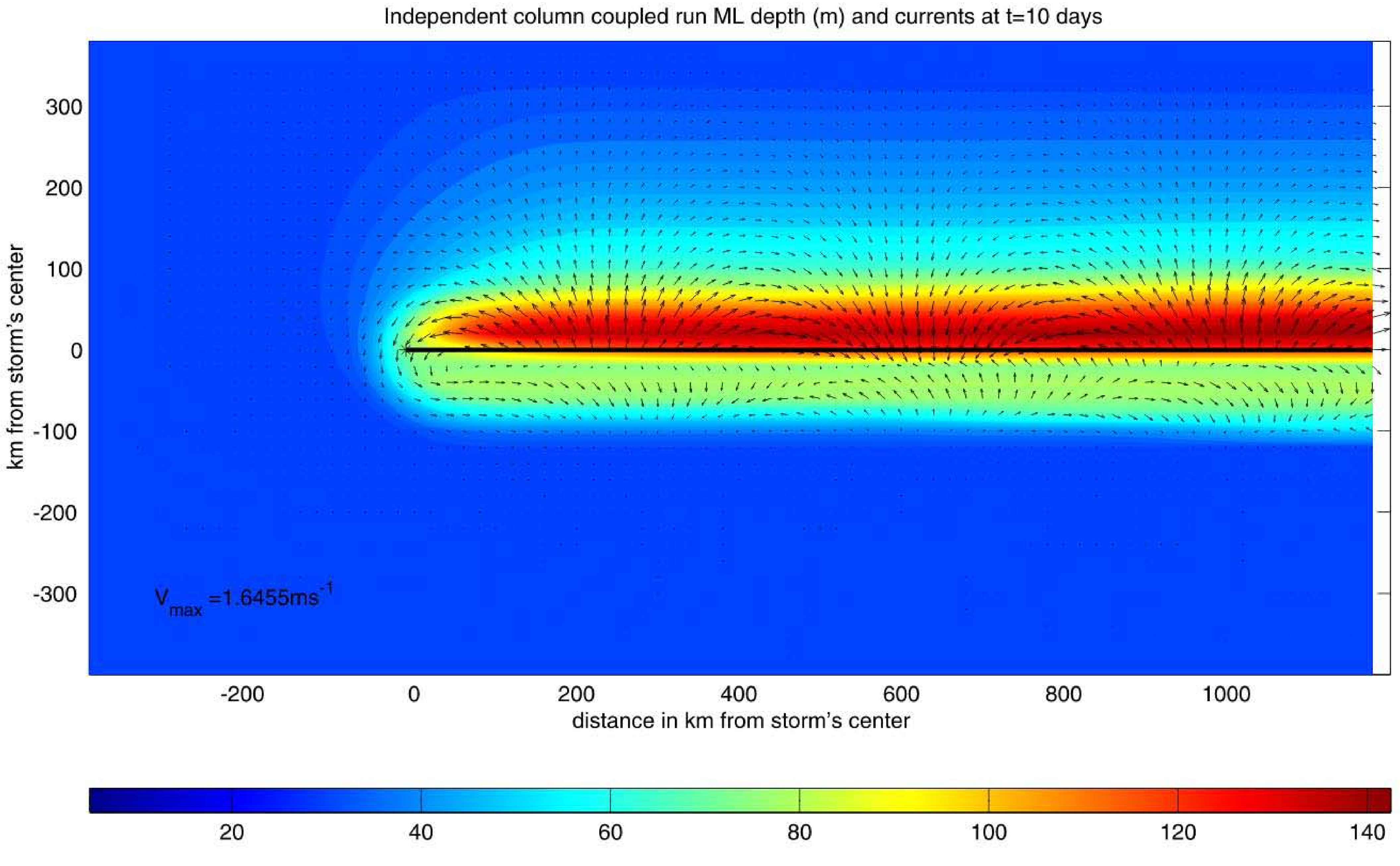


Comparison with same atmospheric model coupled to 3-D ocean model; idealized runs: Full model (black), string model (red)

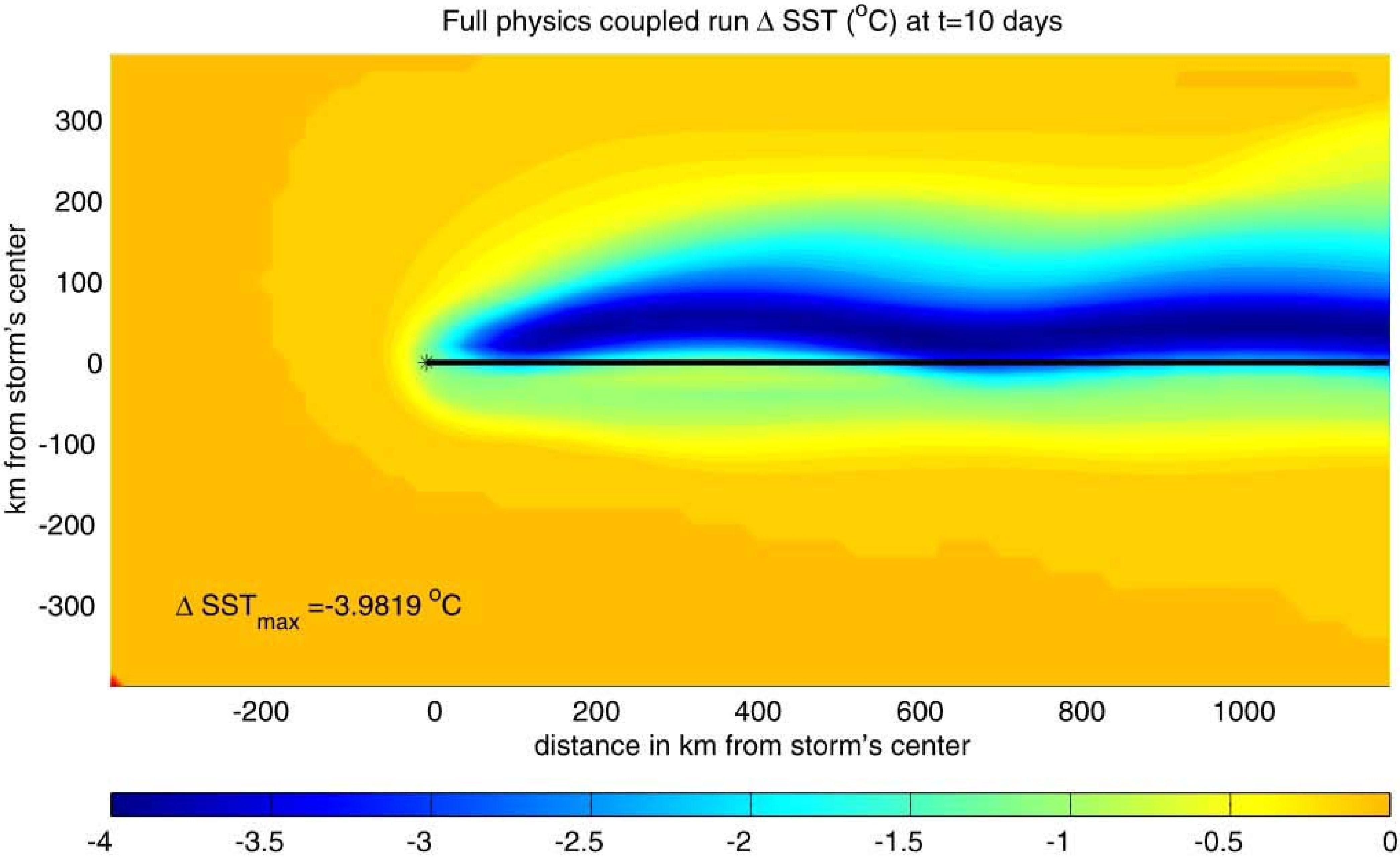


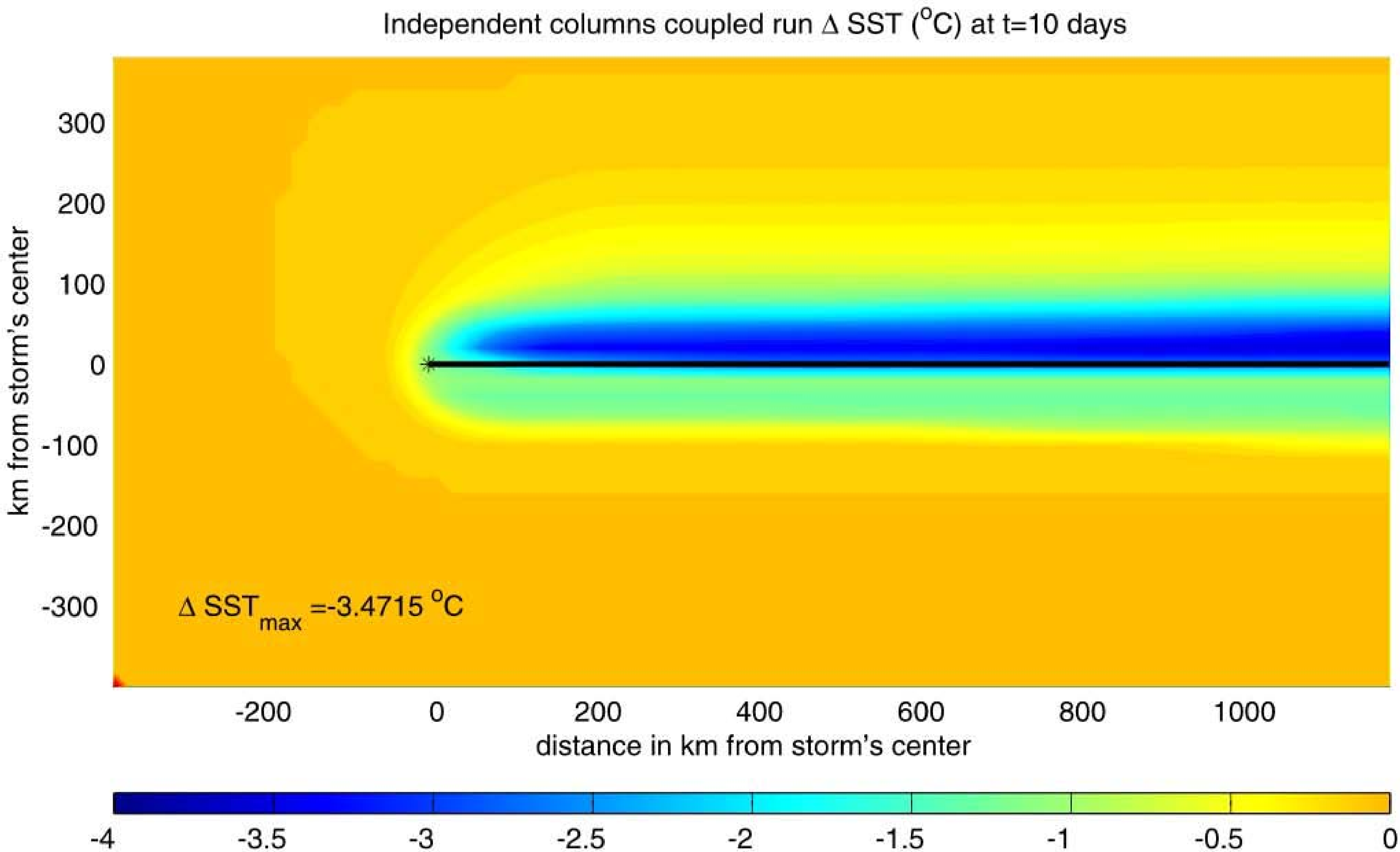
Mixed layer depth and currents



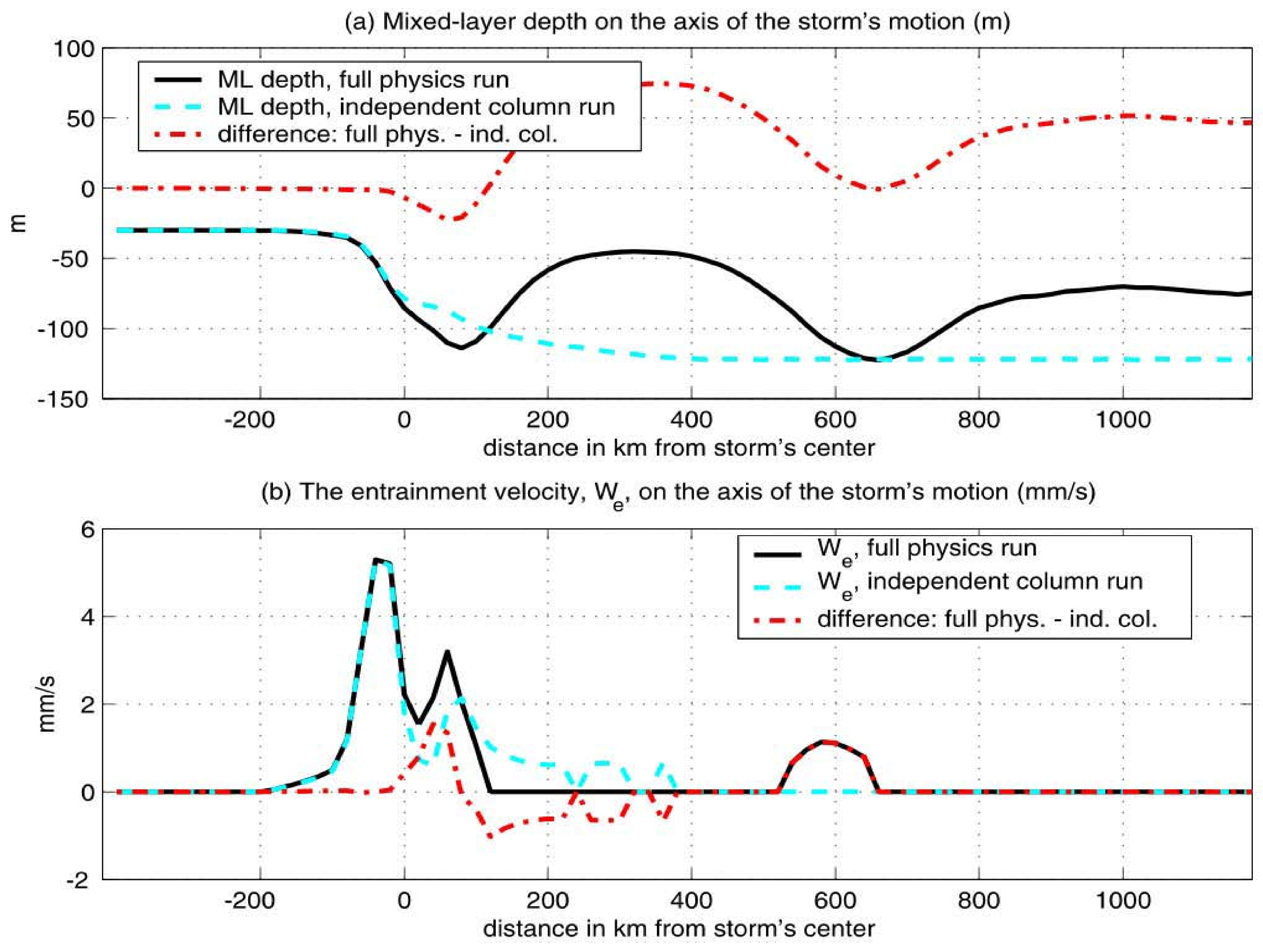

Independent column coupled run ML depth (m) and currents at t=10 days
300
200
100
0
-100
-200
-300
km from storm's center
V
max
=1.6455ms
-1
-200
0
200
400
600
800
1000
distance in km from storm's center
20
40
60
80
100
120
140

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 (°C) at t=10 days
km from storm's center
300
200
100
0
-100
-200
-300
Δ SST$_{max}$ =-3.4715 °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

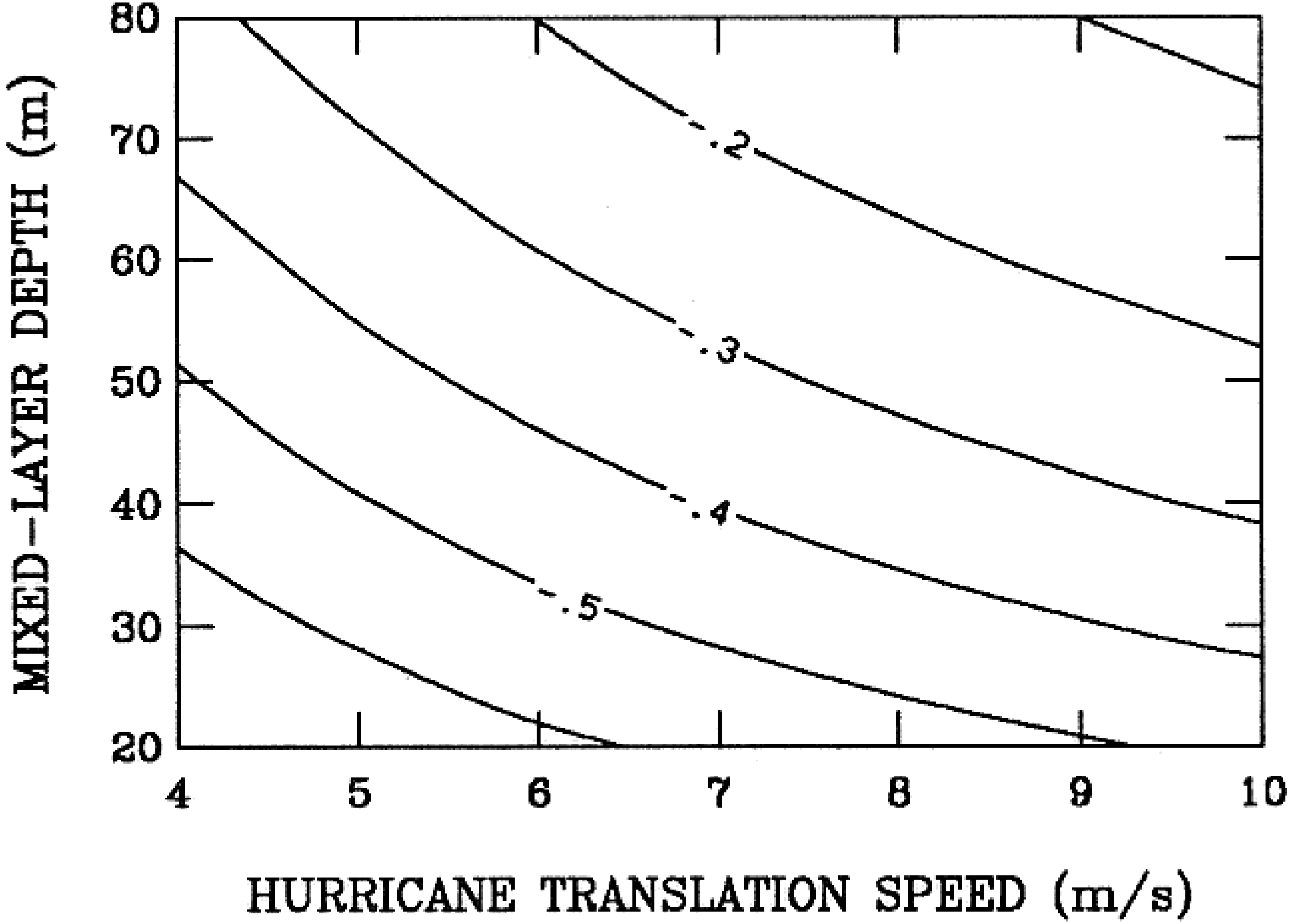


(a) Mixed-layer depth on the axis of the storm's motion (m)
ML depth, full physics run
ML depth, independent column run
difference: full phys. - ind. col.
100
50
0
-50
-100
-150
m
-200
0
200
400
600
800
1000
distance in km from storm's center
(b) The entrainment velocity, W_e, on the axis of the storm's motion (mm/s)
W_e, full physics run
W_e, independent column run
difference: full phys. - ind. col.
6
4
2
0
-2
mm/s
-200
0
200
400
600
800
1000
distance in km from storm's center

Define feedback factor:

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

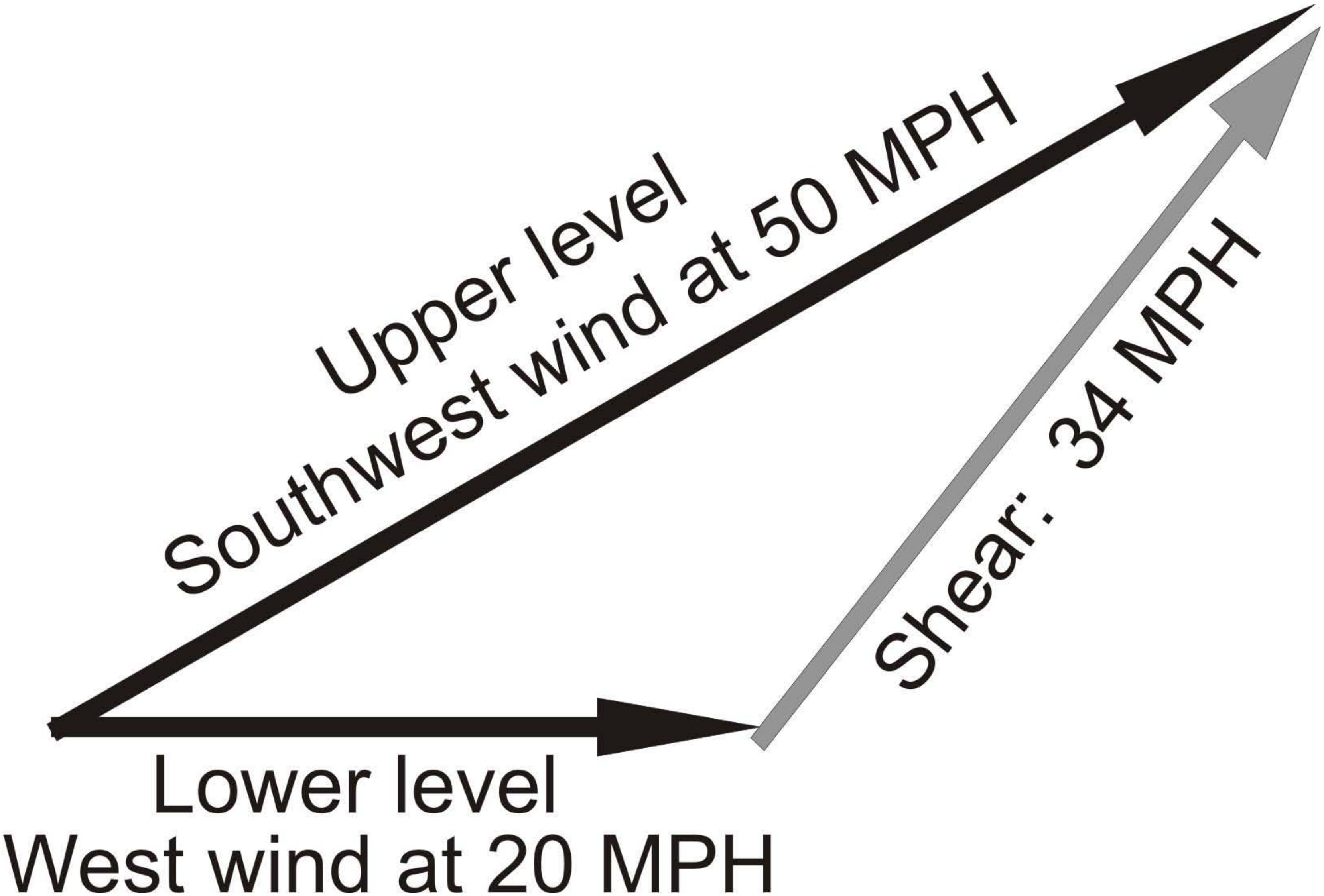
where $\Delta p \,|_{SST}$ is the central pressure drop at fixed SST. Do many, many numerical expreiments, varying SST, Coriolis parameter, traslantion speed, etc. Curve fit dependence of F_{SST} on these parameters. Result:



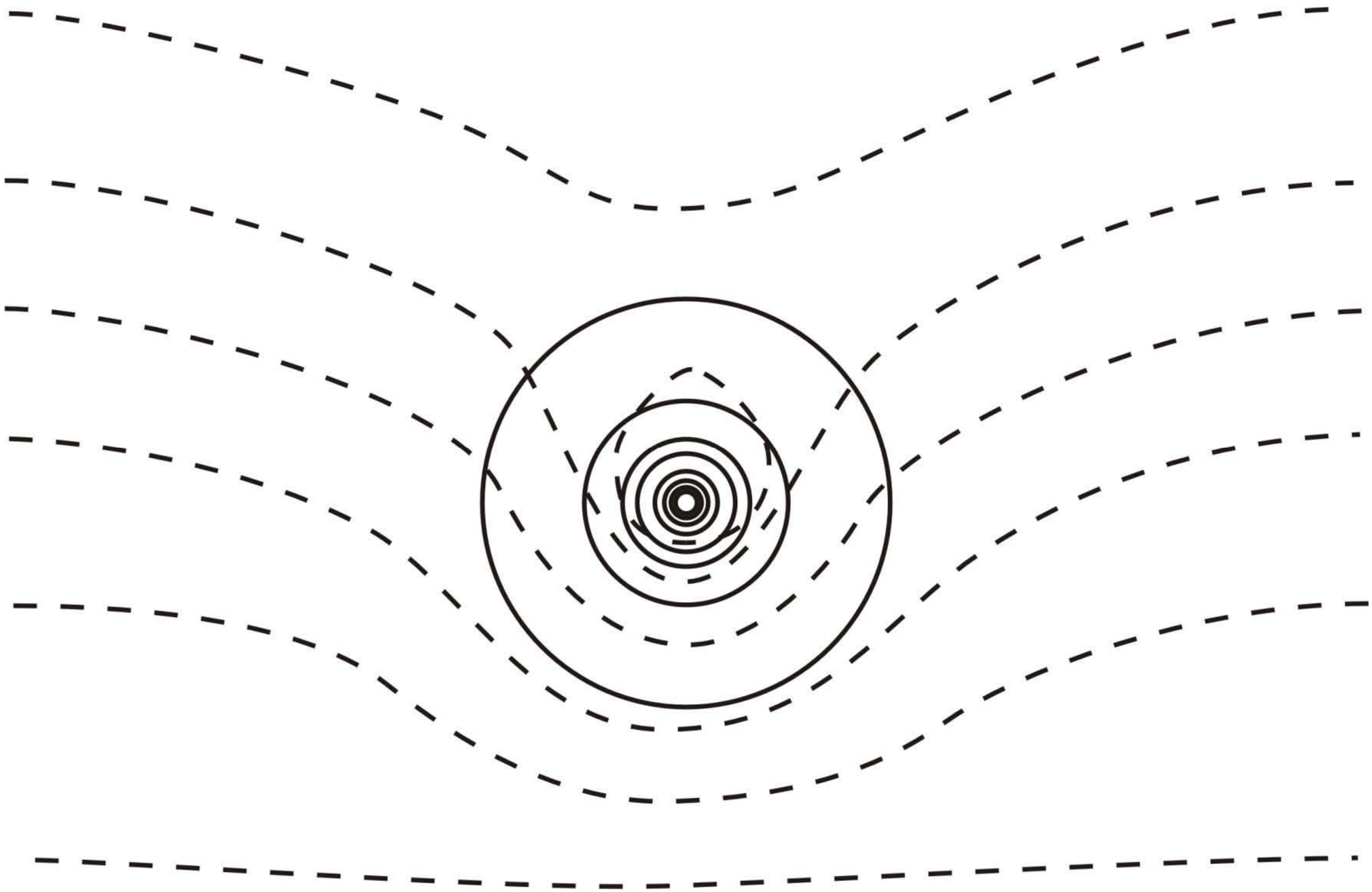
.2
.3
.4
.5
80
70
60
50
40
30
20
MIXED-LAYER DEPTH (m)
4
5
6
7
8
9
10
HURRICANE TRANSLATION SPEED (m/s)

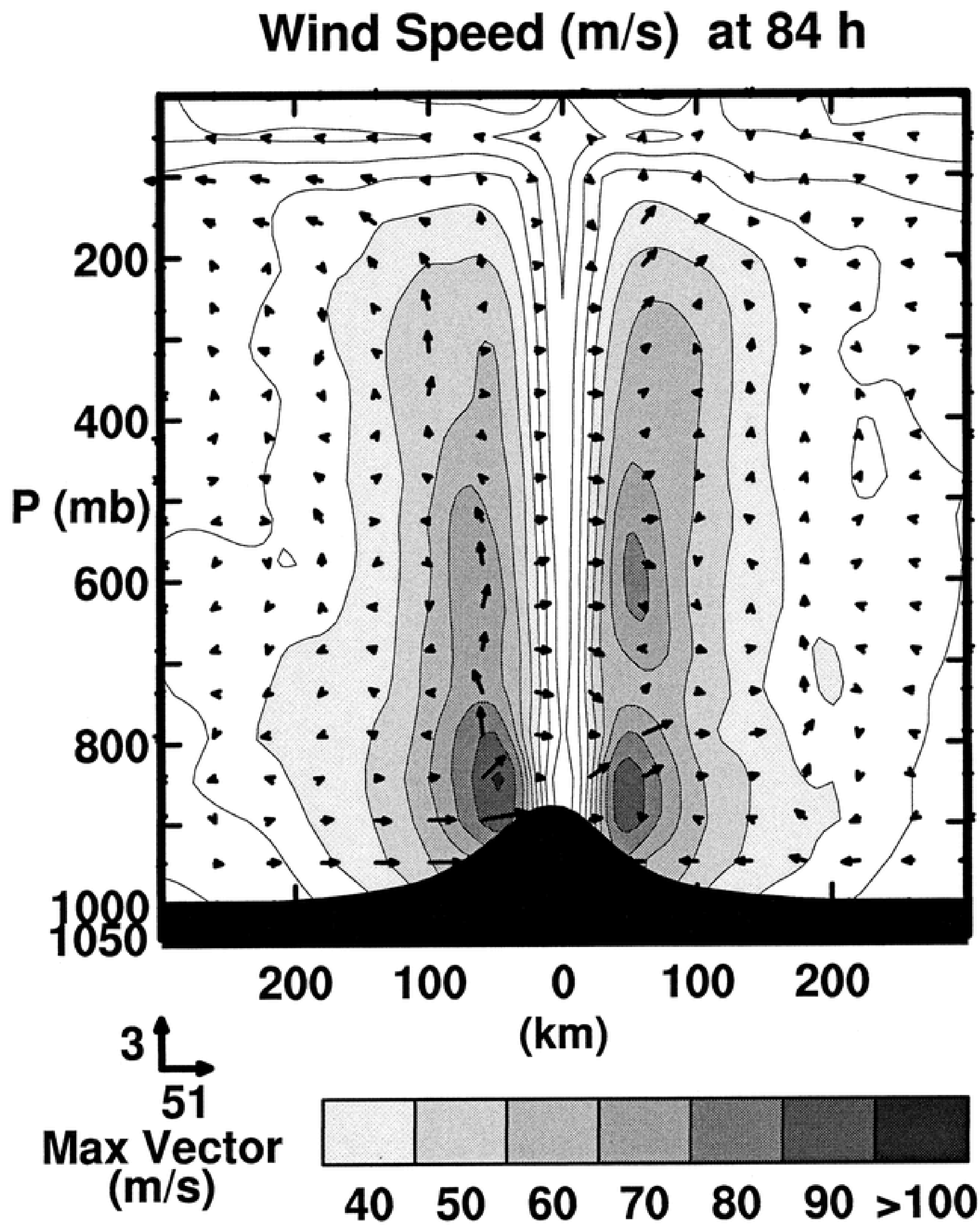
Effects of Environmental Wind Shear

- Dynamical effects
- Thermodynamic effects
- Net effect on intensity

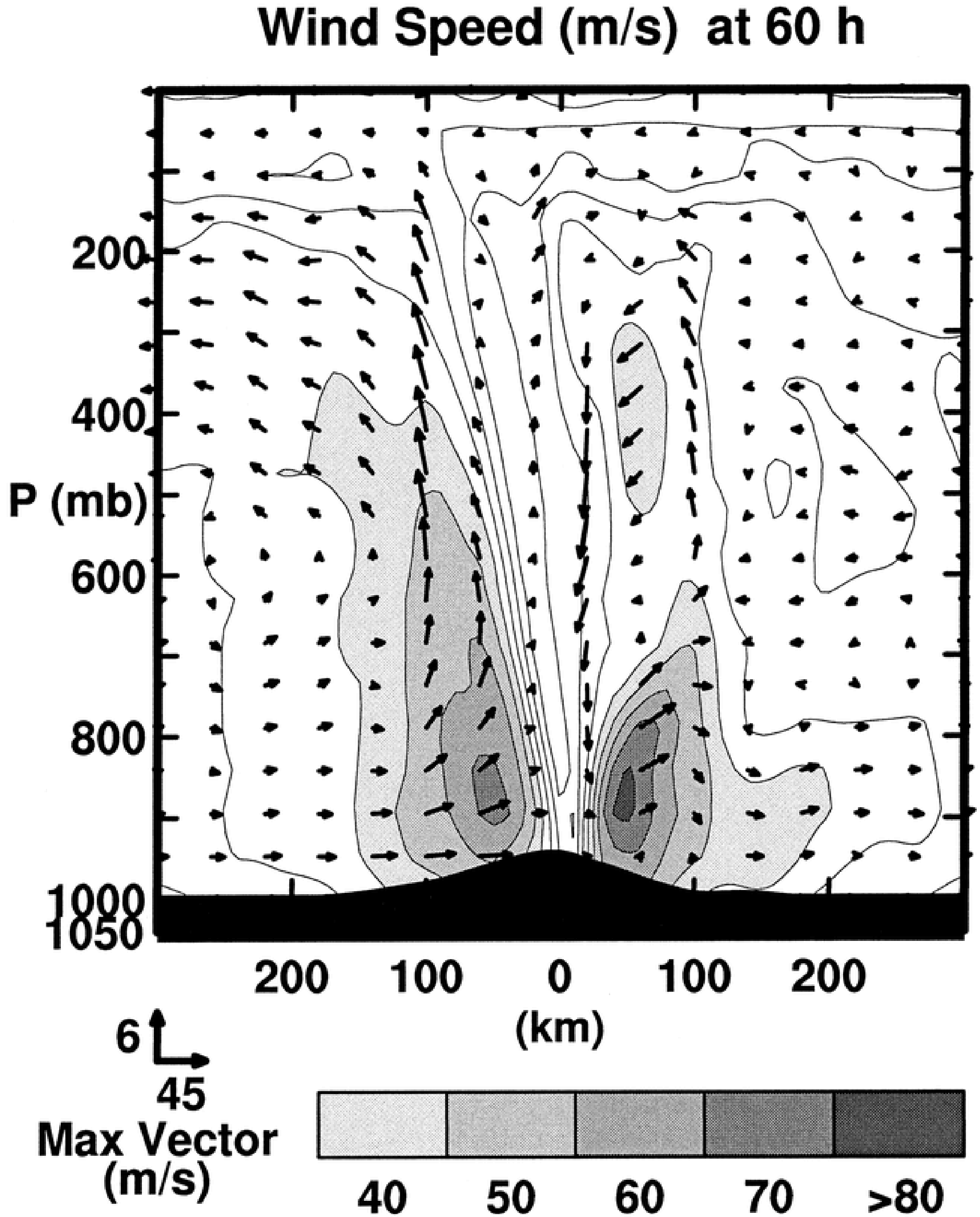

Upper level
Southwest wind at 50 MPH
Shear: 34 MPH
Lower level
West wind at 20 MPH

Streamlines (dashed) and θ surfaces (solid)





Wind Speed (m/s) at 84 h
200
400
P (mb)
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
P (mb)
200
400
600
800
1000
1050
200
100
0
100
200
(km)
6
45
Max Vector
(m/s)
40
50
60
70
>80

12.103 Science and Policy of Natural Hazards
Spring 2010