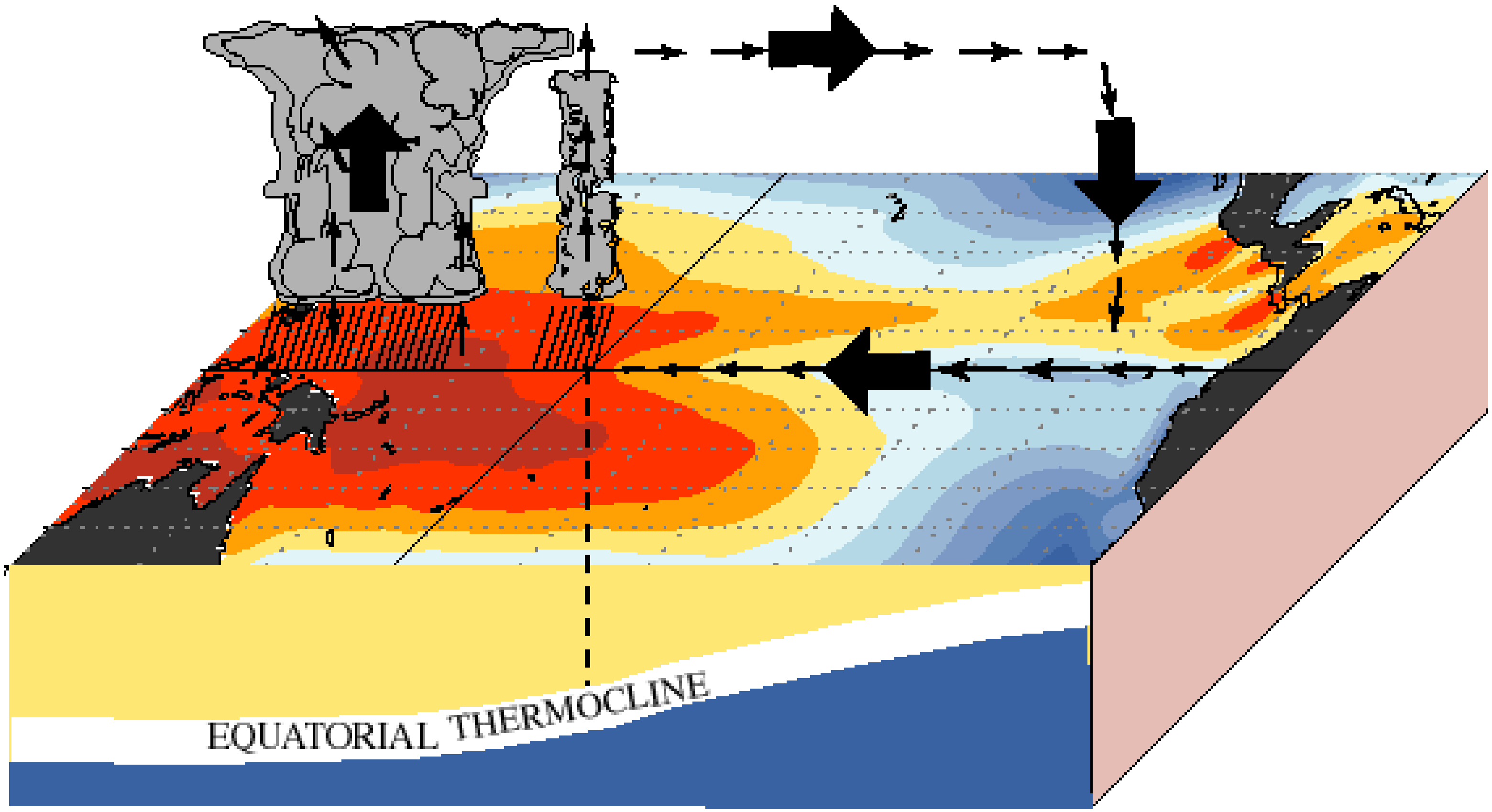
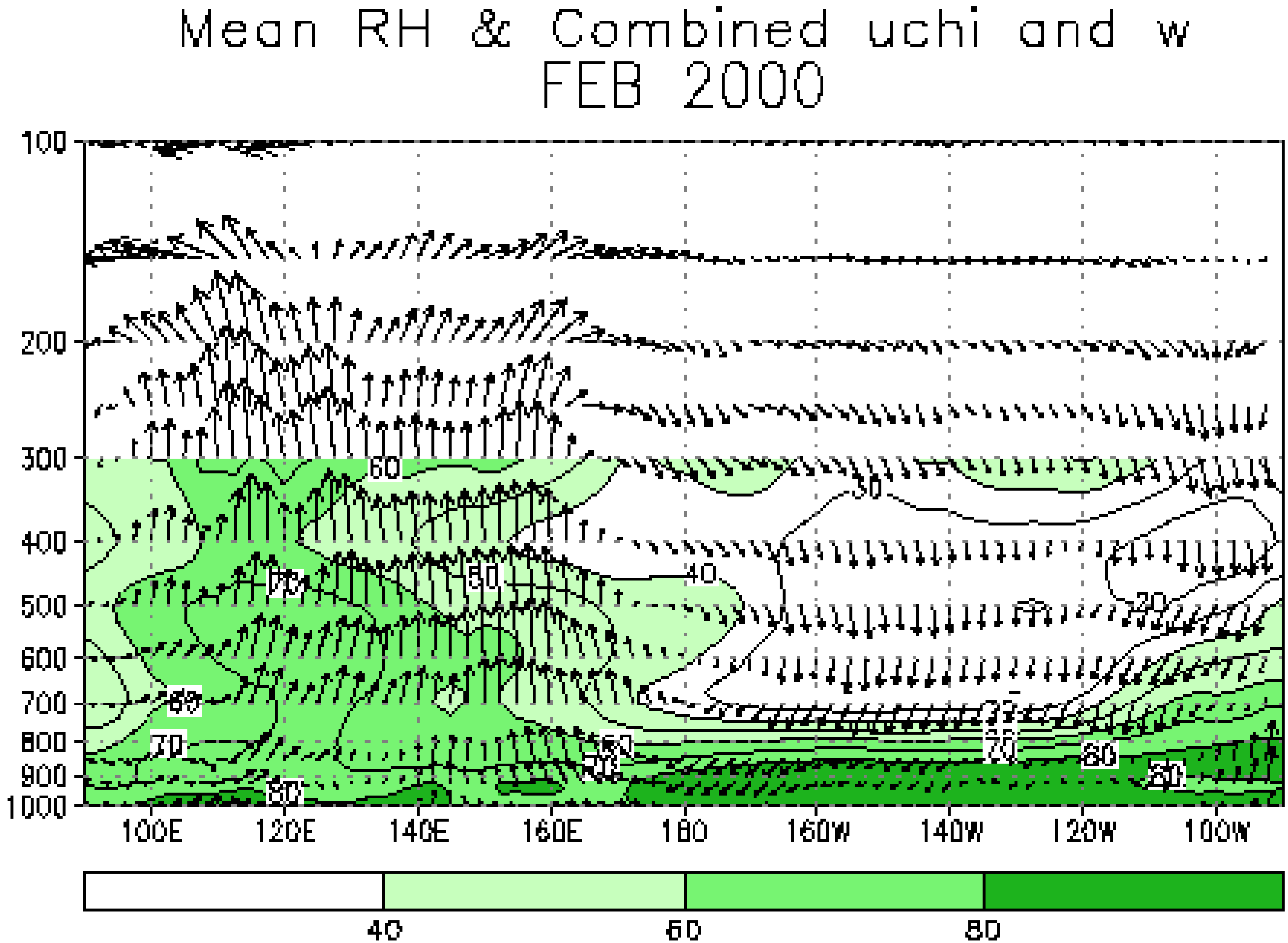
The Walker Circulation

December - February Normal Conditions





Mean RH & Combined uchi and w
FEB 2000
100
200
300
400
500
600
700
800
900
1000
100E
120E
140E
160E
180
160W
140W
120W
100W
40
60
80

Annual average SST and surface wind. Halpert and Ropelewski (1989).

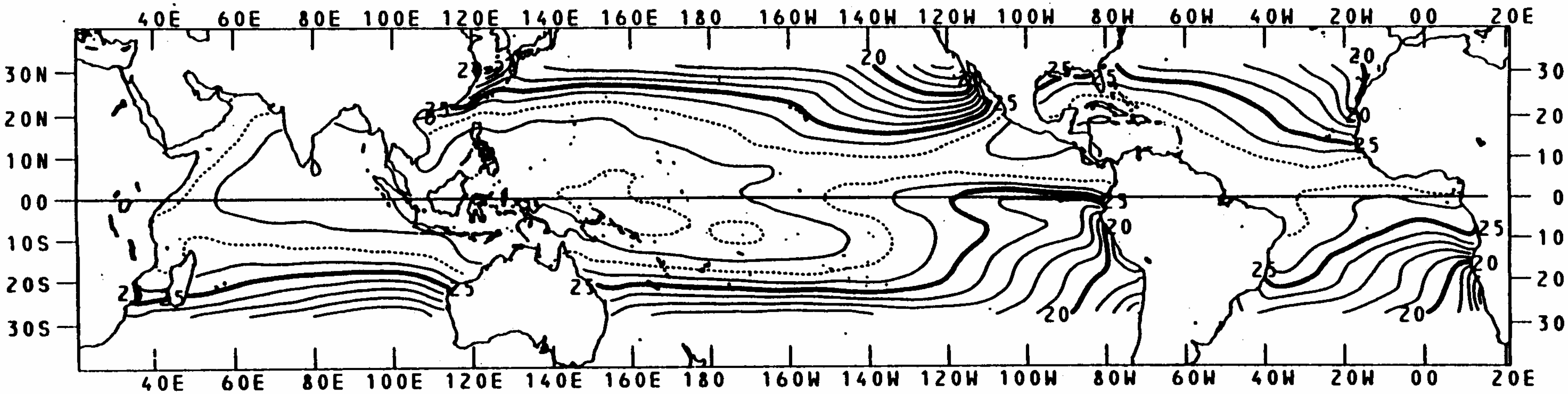


Figure 1. Annual SST mean for the period 1950-1979. The contour interval is 1.0°C. Dashed contours are 27°C and 29°C.

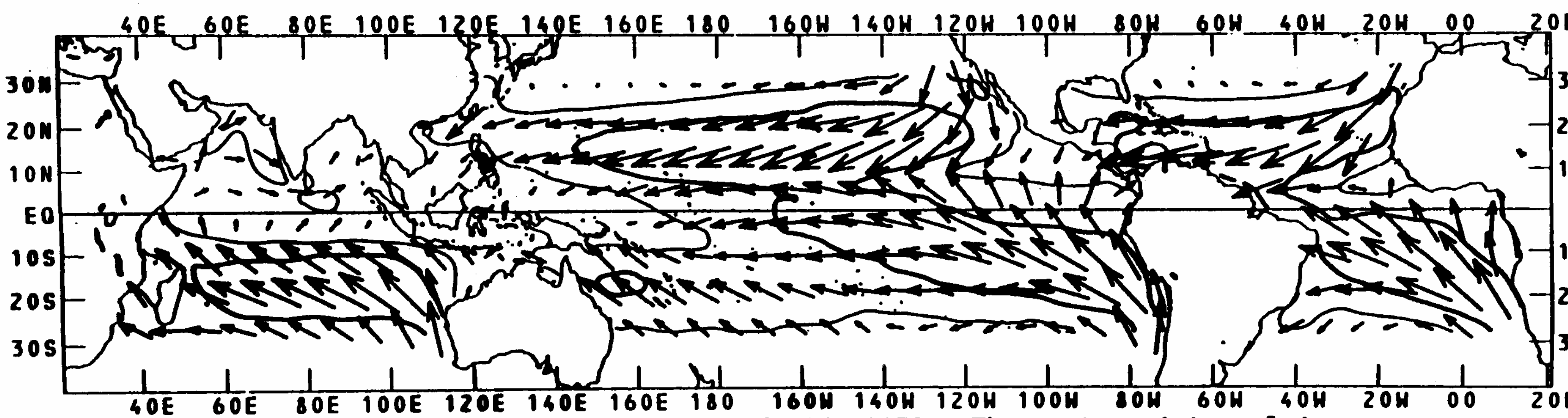
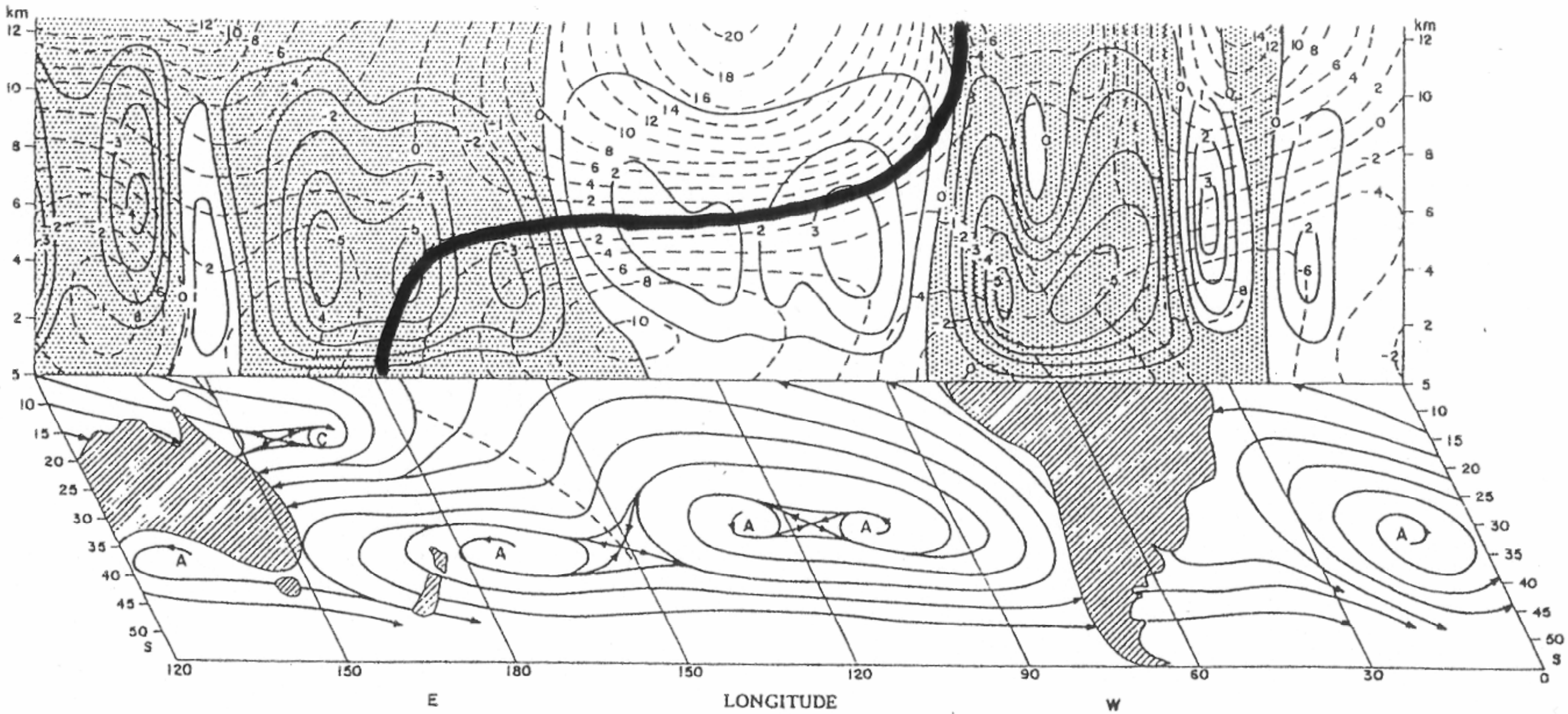


Figure 52. Annual vector wind for the period 1950-1979. The contour interval is 2.5 m/s. The 5 m/s isopleth is emphasized.



b

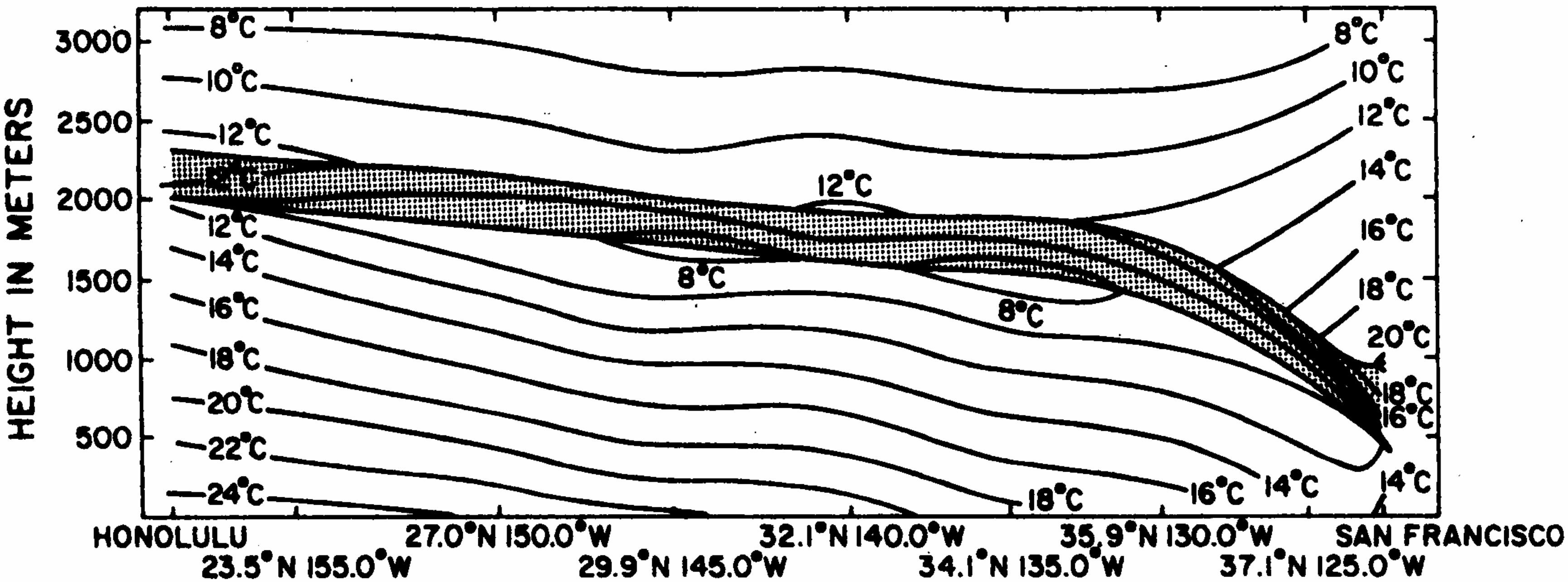


FIG. 14.7 Cross section showing average temperature (°C) between San Francisco and Honolulu in summer; inversion layer shaded. (After Neiburger *et al.*, 1961.)

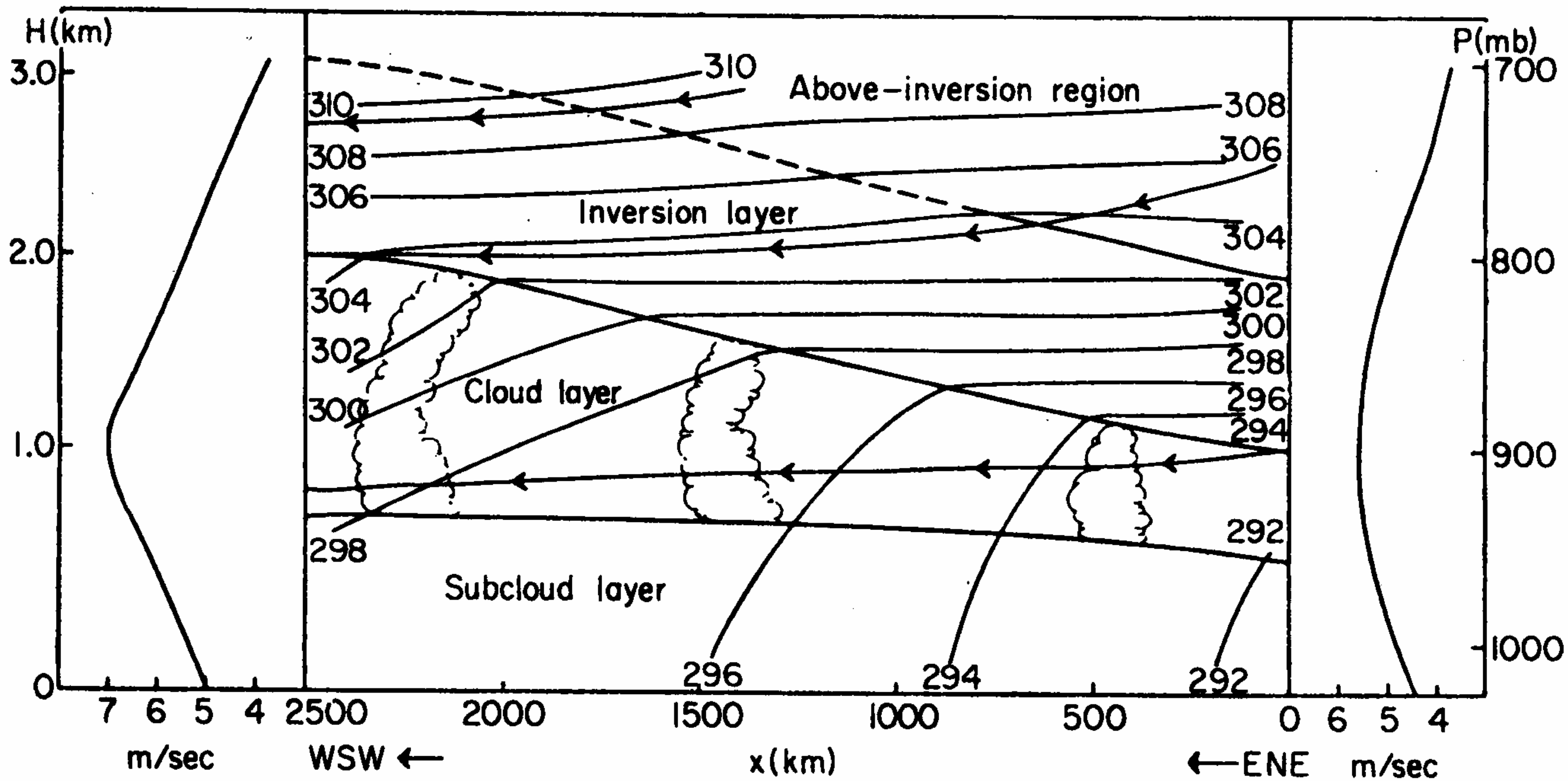


FIG. 14.8 Mean cross section approximately along low-level trade-wind trajectory between ship at 32°N, 136°W (right side) and Honolulu, for July–October 1945. Thin lines, potential temperature (°K); arrows, mean trajectories inferred from divergence; heavier lines delineate layers of interest. On right and left, vertical wind profiles at upstream and downstream ends. (After Malkus, 1956.)

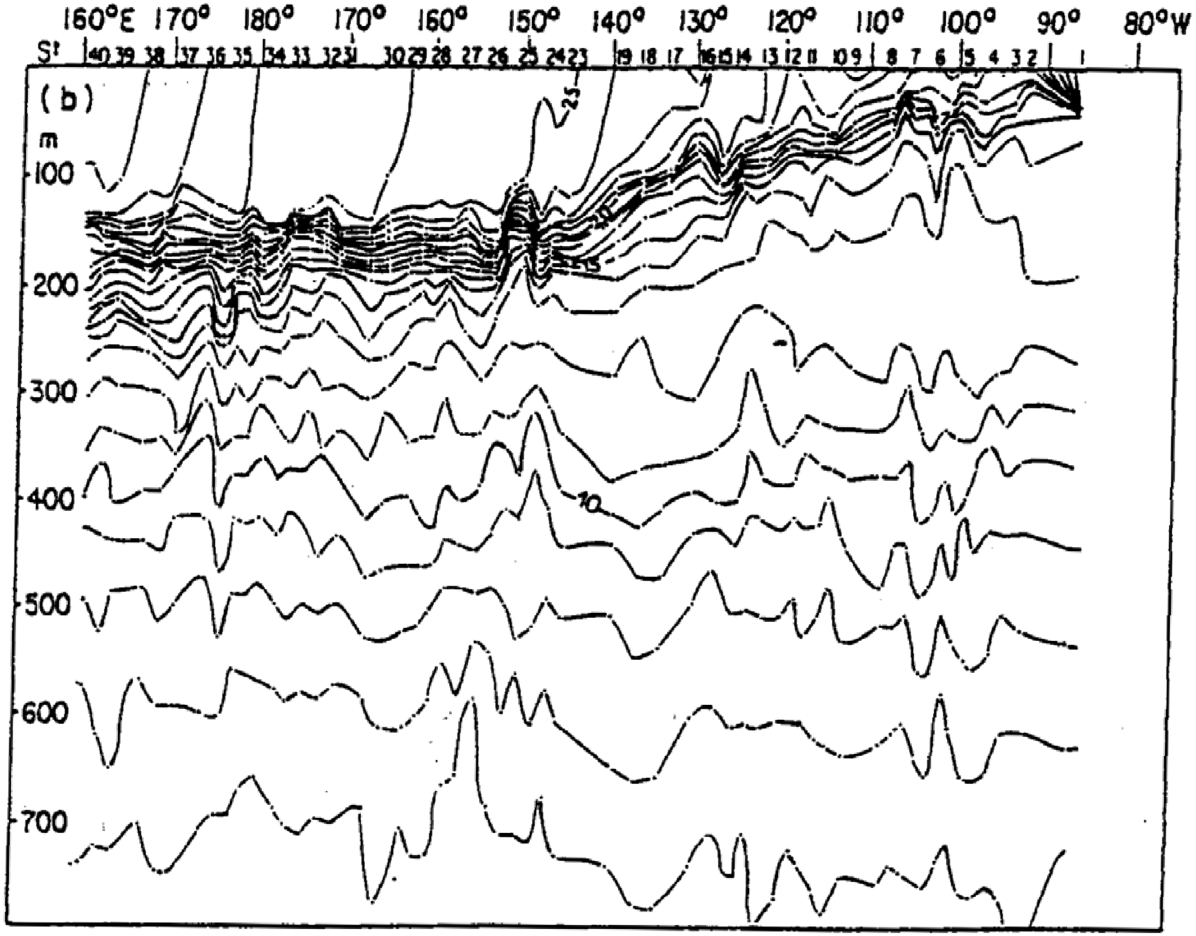


Fig. 11.17. ~~(a) Variation of dynamic height at various levels relative to 700 db and~~ (b) isotherms along the equator in the Pacific Ocean. The pressure gradient is of the sign required to balance the wind stress and to drive the current below the level at which the stress is acting. In the west, where the mixed layer is deep, the pressure gradient is largely associated with a temperature gradient in the mixed layer. In the east, the pressure gradient is associated with the tilt of the thermocline. This tilt brings cold water close to the surface in the east, thus making the surface temperature here sensitive to small changes in the winds, heating rate, etc. [From Lemasson and Piton (1968, Figs. 1 and 2).]

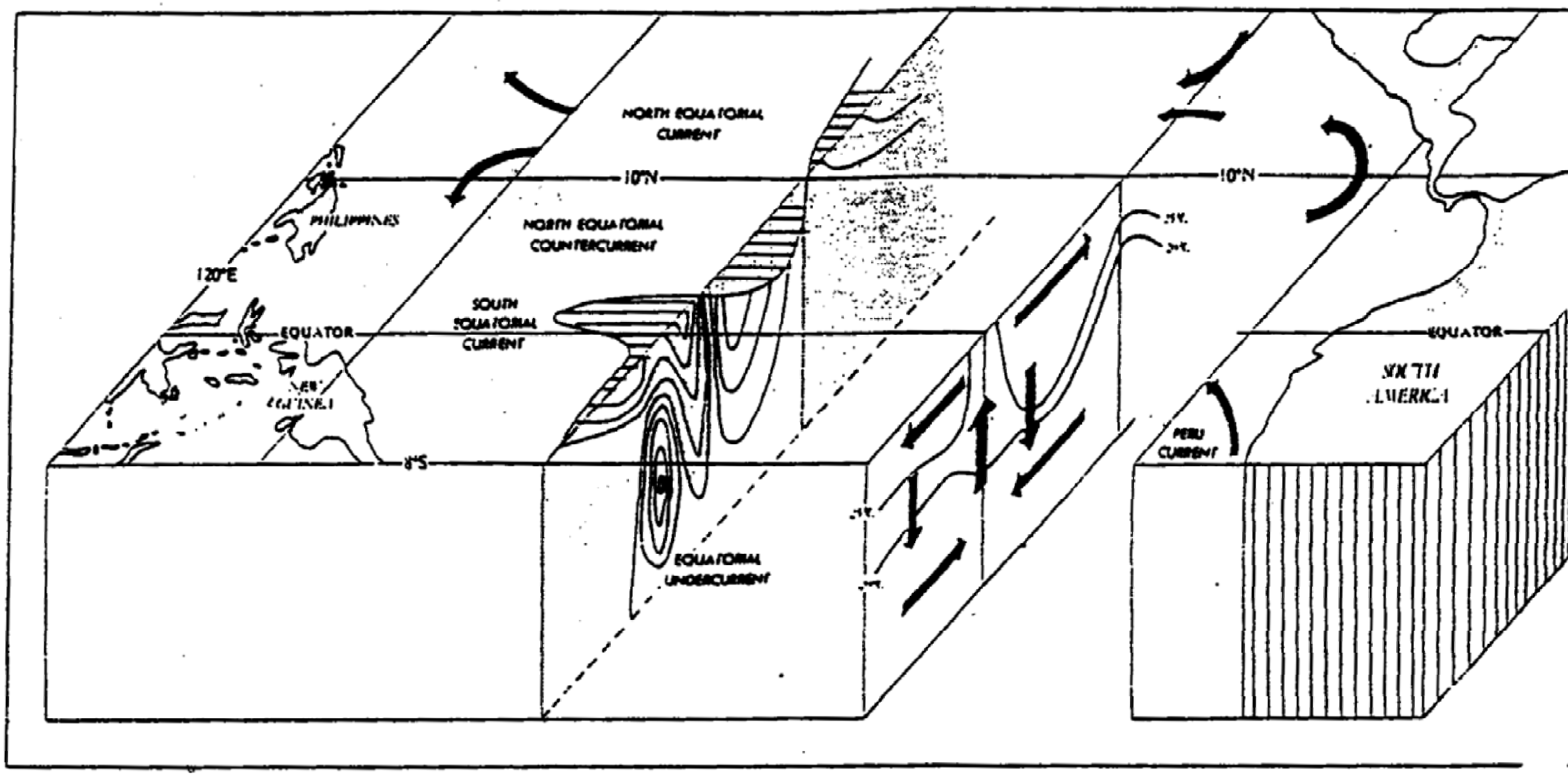
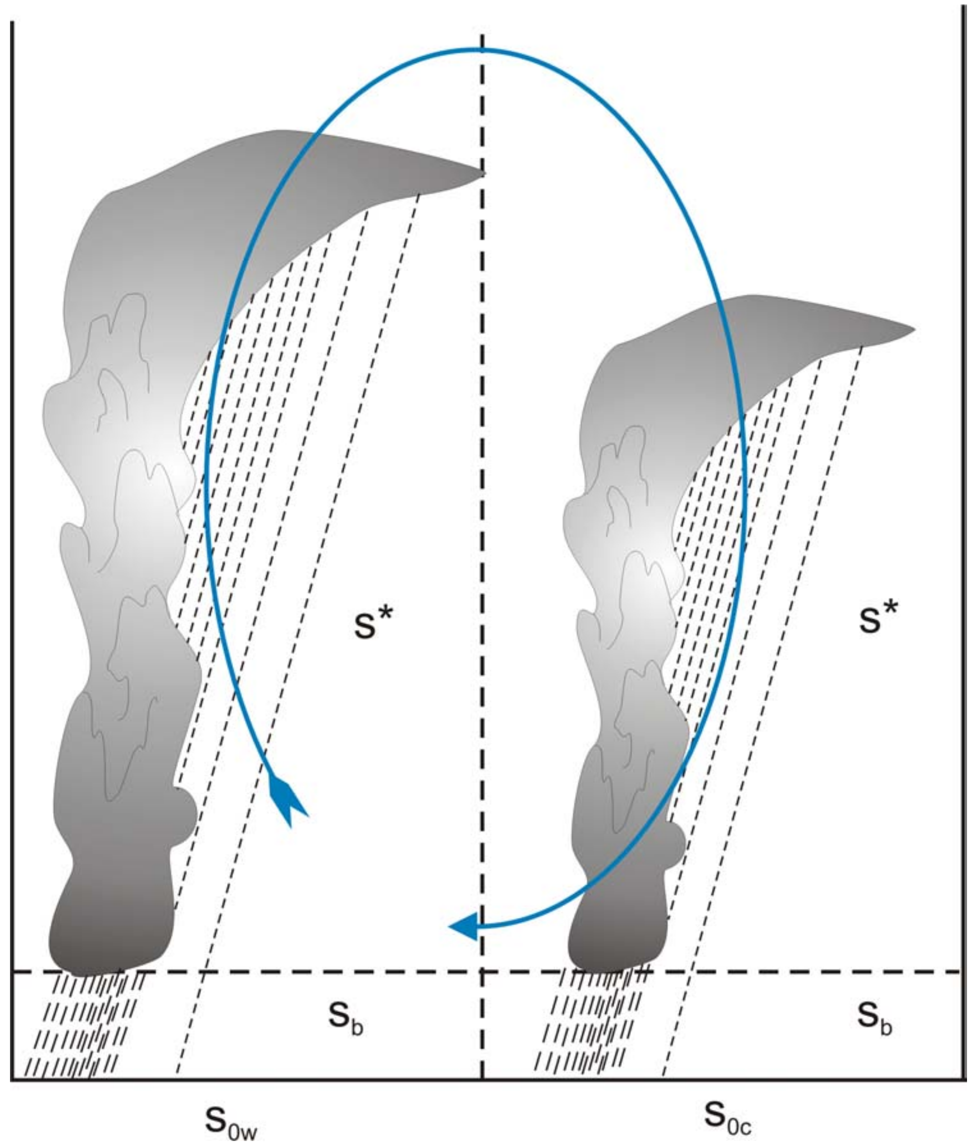
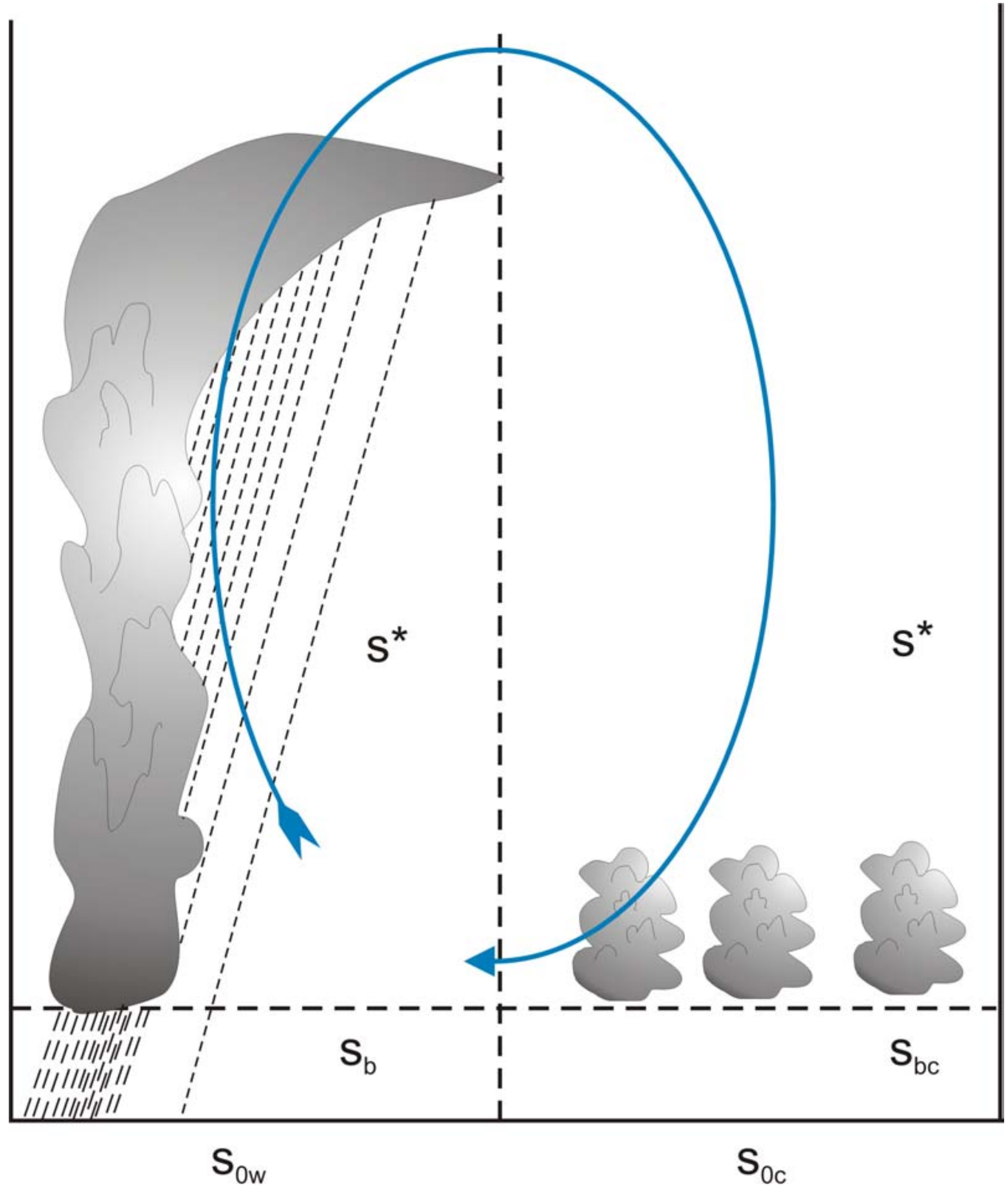


Figure 2.1. A schematic diagram of the horizontal and vertical circulation in the tropical Pacific Ocean.

Two-Box Model:



Weak circulation: Deep convection in both boxes



Strong circulation: Deep convection only in warm box

Sub-cloud layer QE:

$$w = \frac{1}{1-\gamma\varepsilon_p}\left[\frac{\varepsilon_p F_s}{s_b - s_m} - \frac{\dot{Q}_{cool}}{\mathbf{S}}\right],$$

$$M_u = \frac{1}{1-\gamma\varepsilon_p}\left[\frac{F_s}{s_b - s_m} - \frac{\gamma\dot{Q}_{cool}}{\mathbf{S}}\right]$$

Mass Continuity:

$$w_w = -w_c$$

For convenience:

$$C_D |\mathbf{V}| = constant$$

$$\frac{\dot{Q}_{cool}}{\mathbf{S}} \equiv R = constant$$

$$s_b - s_m \equiv \Delta s = constant$$

Scale variables:

$$w \rightarrow \frac{R}{1-\gamma\varepsilon_p} w,$$

$$M_u \rightarrow \frac{R\gamma}{1-\gamma\varepsilon_p} M,$$

$$s \to \frac{R\Delta s}{C_D |\mathbf{V}| \varepsilon_p} s,$$

$$\alpha \equiv \frac{1}{\gamma \varepsilon_p}$$

Nondimensional equations:

$$w = s_0 - s - 1,$$

$$M = \alpha \left(s_0 - s \right) - 1$$

Requirement that $w_w = -w_c$ **:**

$$s = \frac{1}{2}\left(s_{0w} + s_{0c}\right) - 1,$$

$$w_w = -w_c = \frac{1}{2}\left(s_{0w} - s_{0c}\right),$$

$$M_w = \alpha - 1 + \frac{\alpha}{2}\left(s_{0w} - s_{0c}\right),$$

$$M_c = \alpha - 1 - \frac{\alpha}{2}\left(s_{0w} - s_{0c}\right).$$

Convection ceases when $M_c < 0$:

$$s_{0w} - s_{0c} > \frac{2(\alpha - 1)}{\alpha}$$

Balance in cold box when $M_c = 0$:

(Dimensional): $w_c = -R$ (free atmosphere)

$$-\gamma w_c = \frac{C_D |\mathbf{V}|}{\Delta s}\left(s_{0c} - s_c\right)$$ (boundary layer)

Nondimensional solutions for cold box:

$$w_c(=-w_w) = -\frac{\alpha - 1}{\alpha},$$

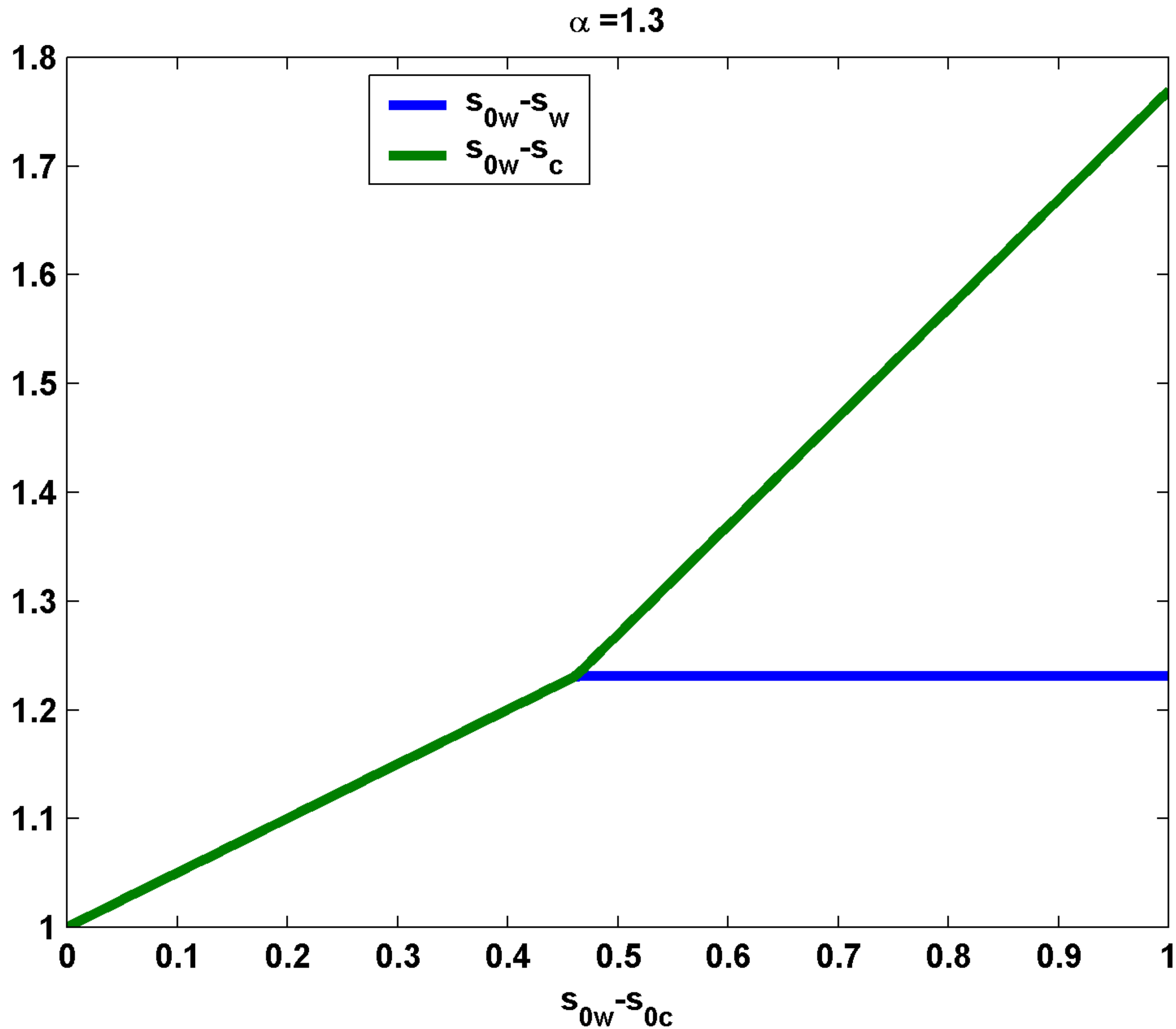
$$s_c = s_{0c} - 1/\alpha .$$

Nondimensional solutions for warm box:

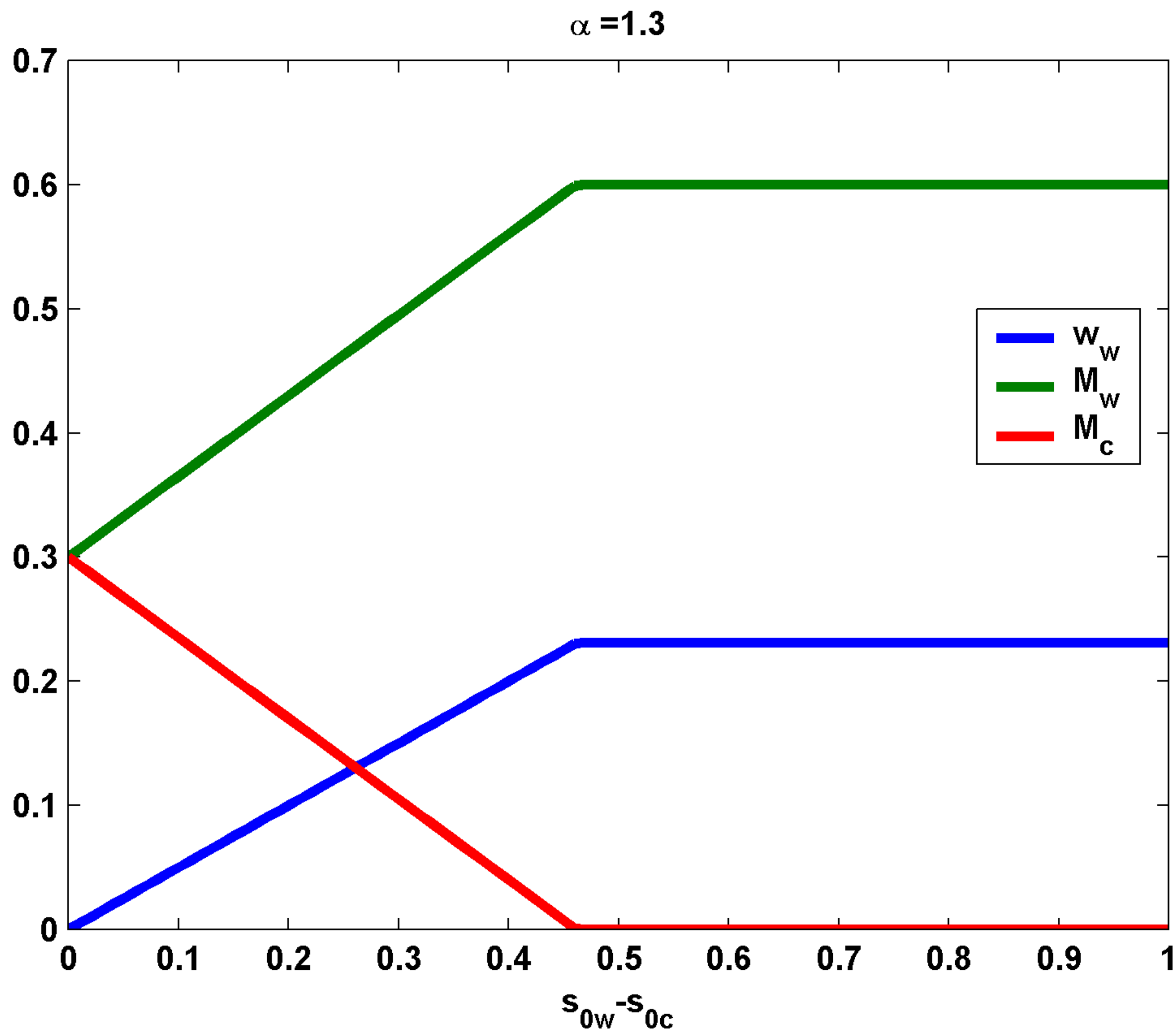
$$w_w = s_{0w} - s_w - 1 = 1 - 1/\alpha$$

$$\rightarrow s_w = s_{0w} + \frac{1}{\alpha} - 2$$

$$M_w = \alpha\left(s_{0w} - s_w\right) - 1 = 2\left(\alpha - 1\right).$$

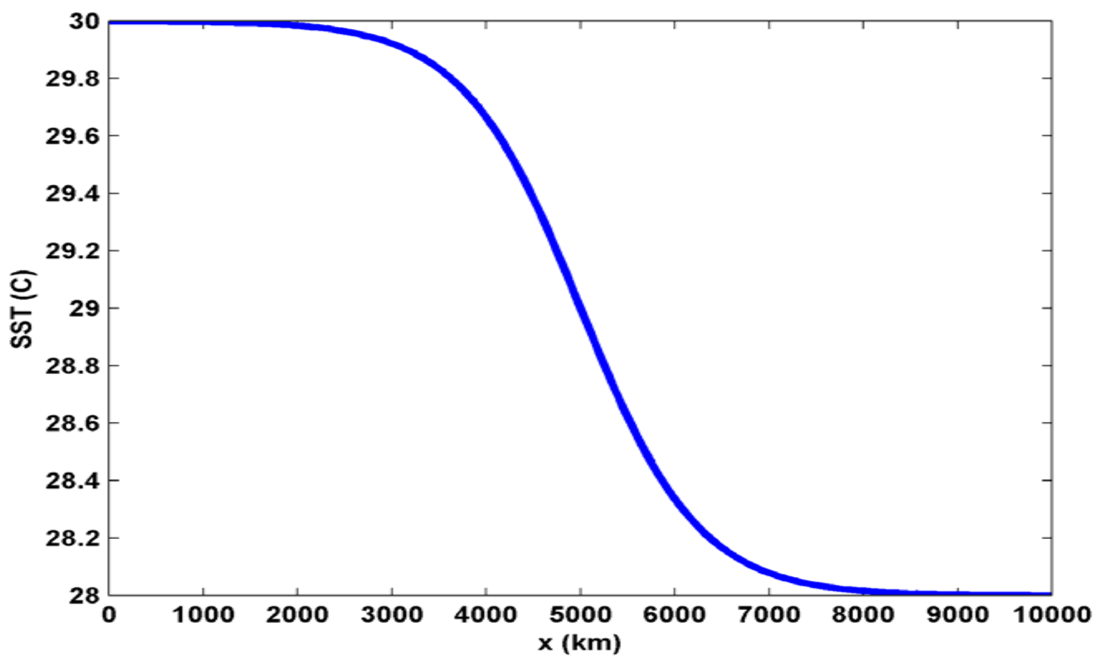


α =1.3
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
s_{0w}-s_w
s_{0w}-s_c
s_{0w}-s_{0c}

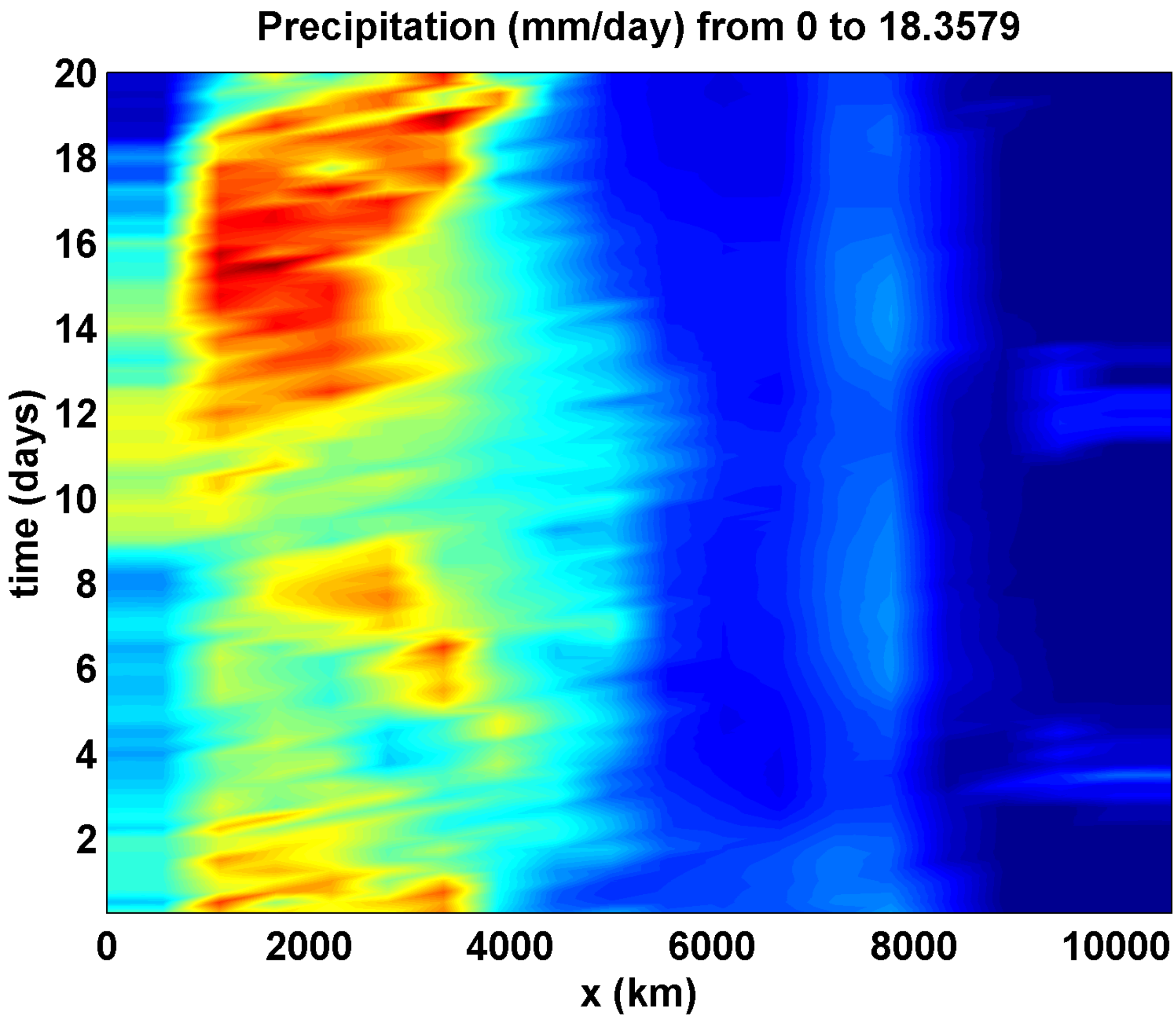


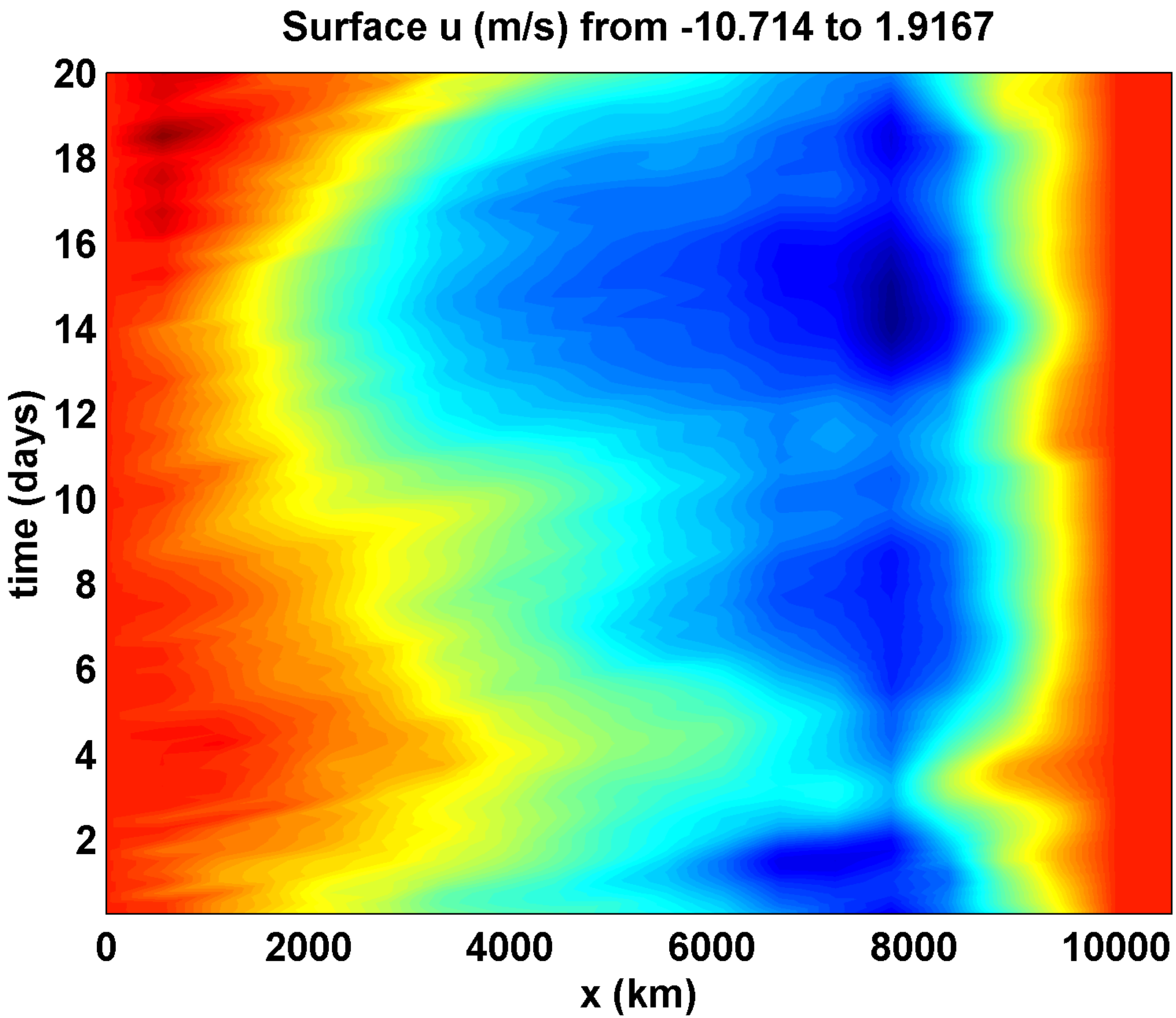
α =1.3
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
w_w
M_w
M_c
s_{0w}-s_{0c}

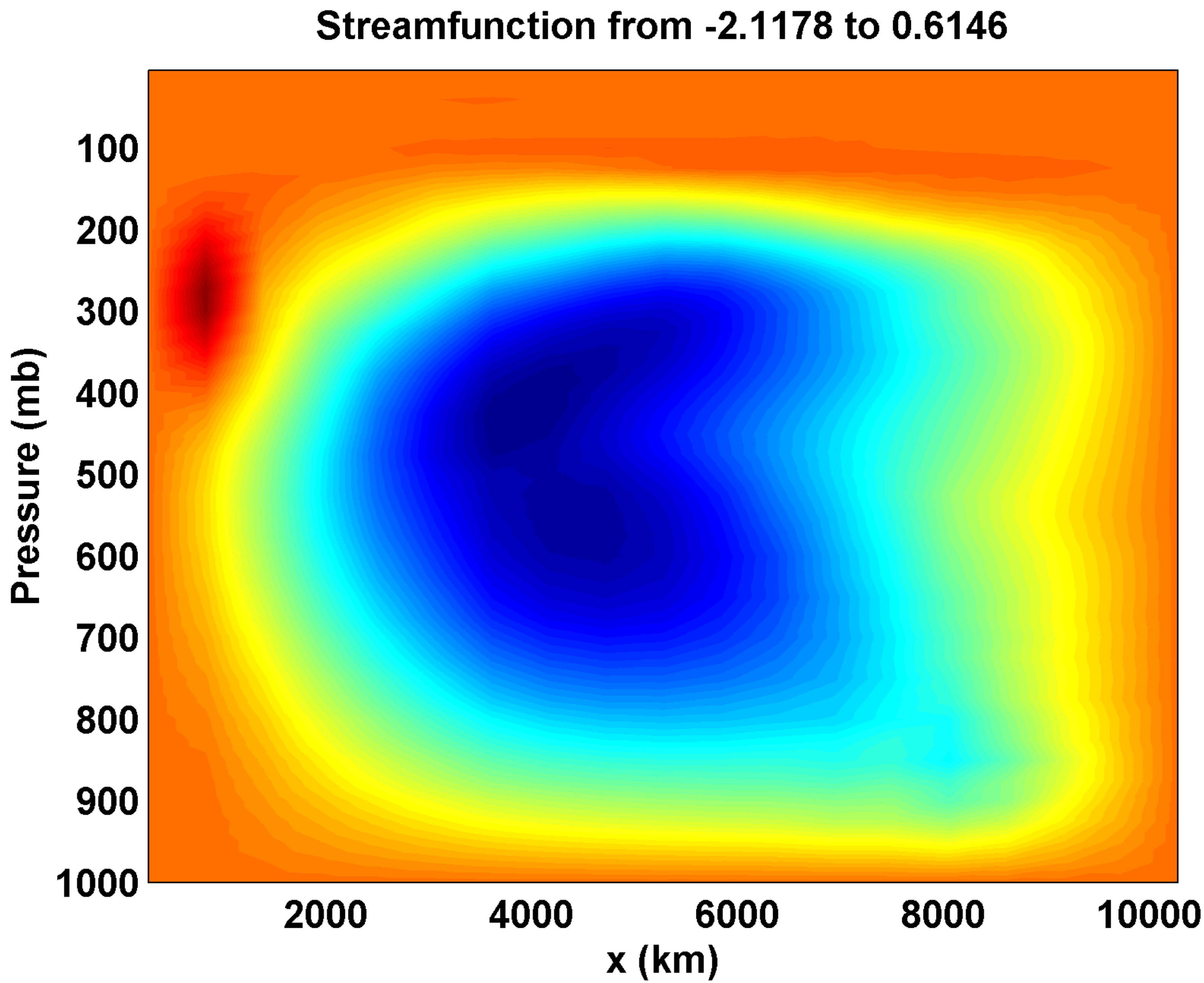
Simulations with 2-D model using 20 columns spanning 100 degrees of longitude

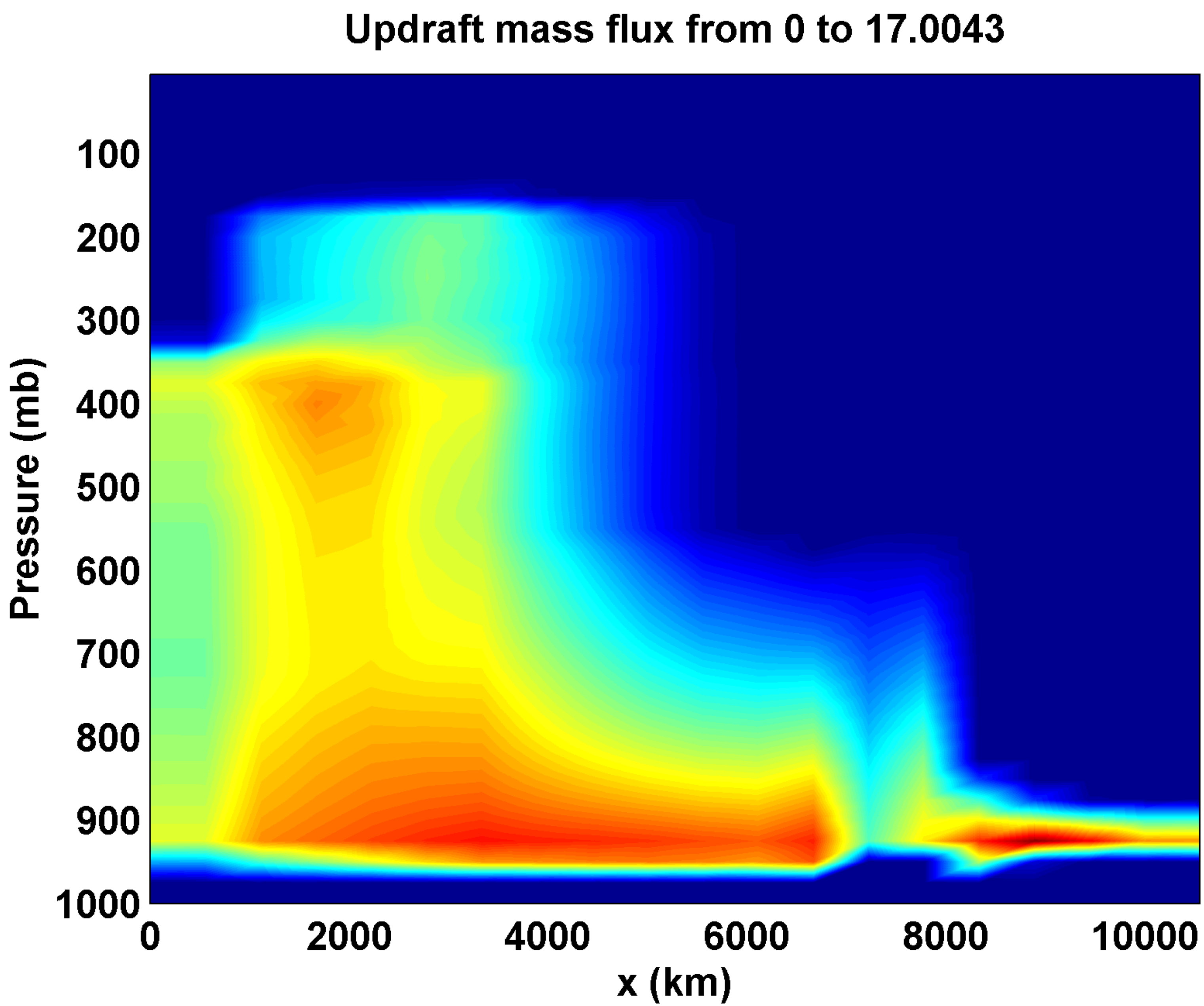


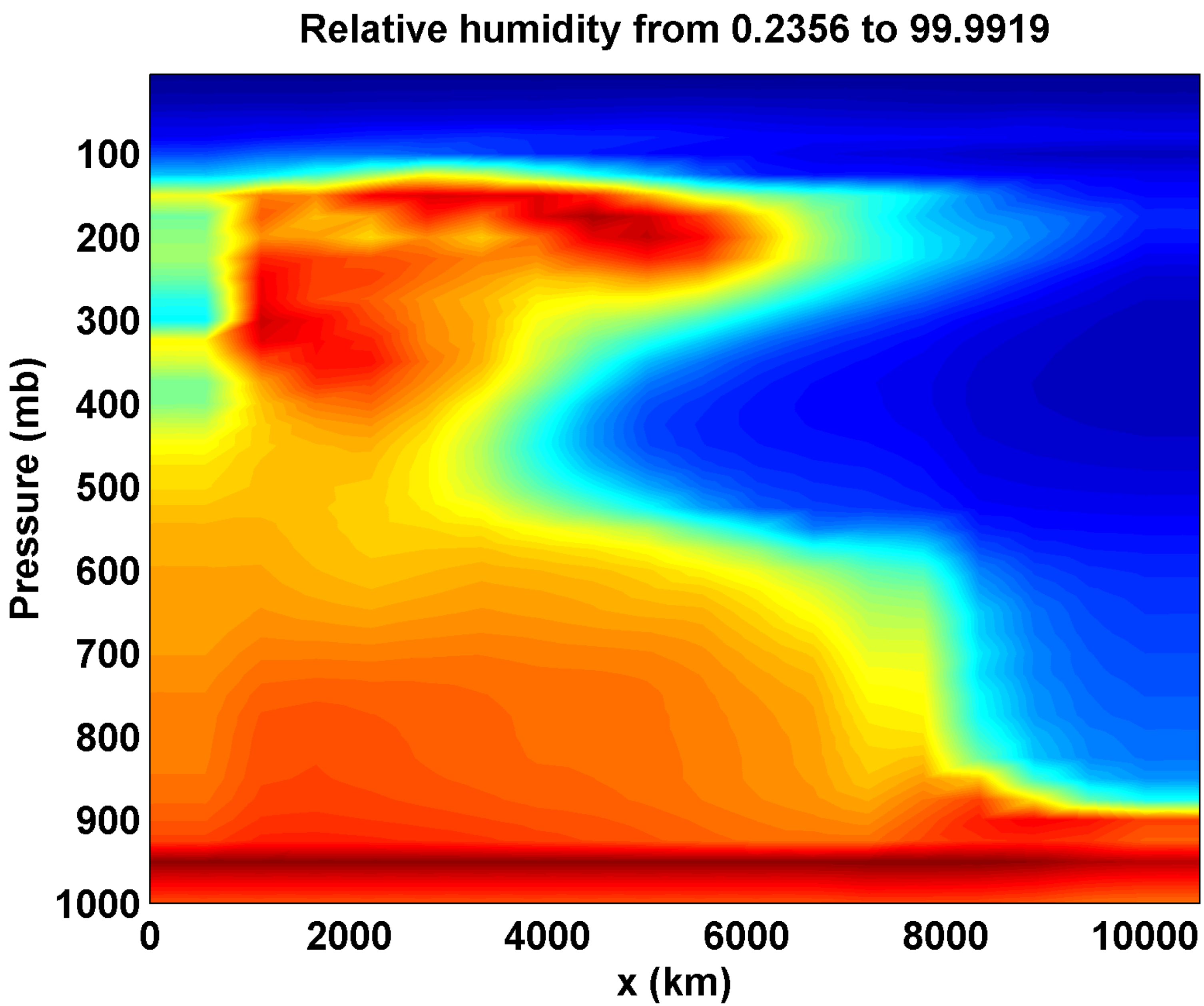
$$\Delta SST = 2^o C$$

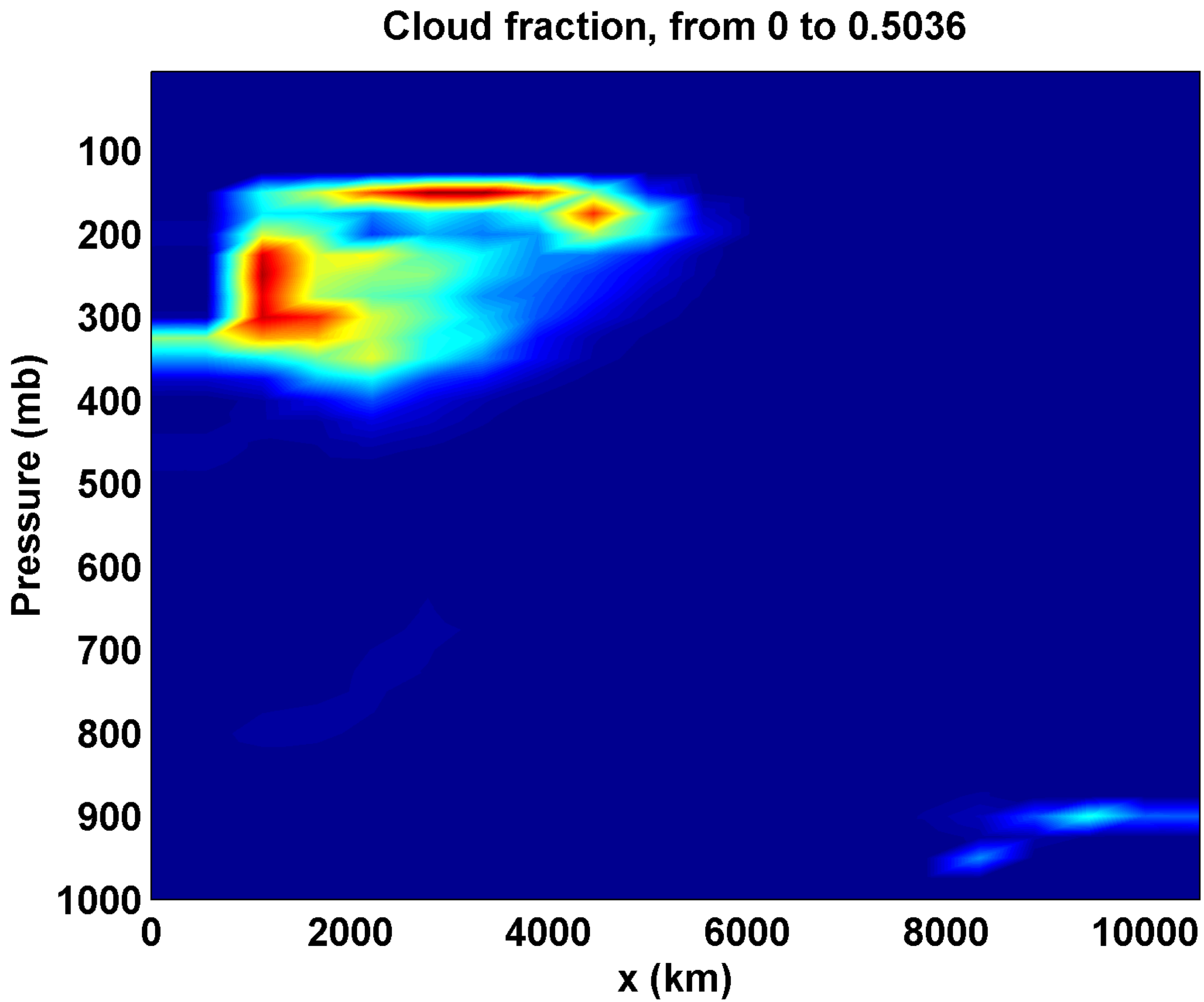



Surface u (m/s) from -10.714 to 1.9167
time (days)
x (km)
0
2000
4000
6000
8000
10000
2
4
6
8
10
12
14
16
18
20

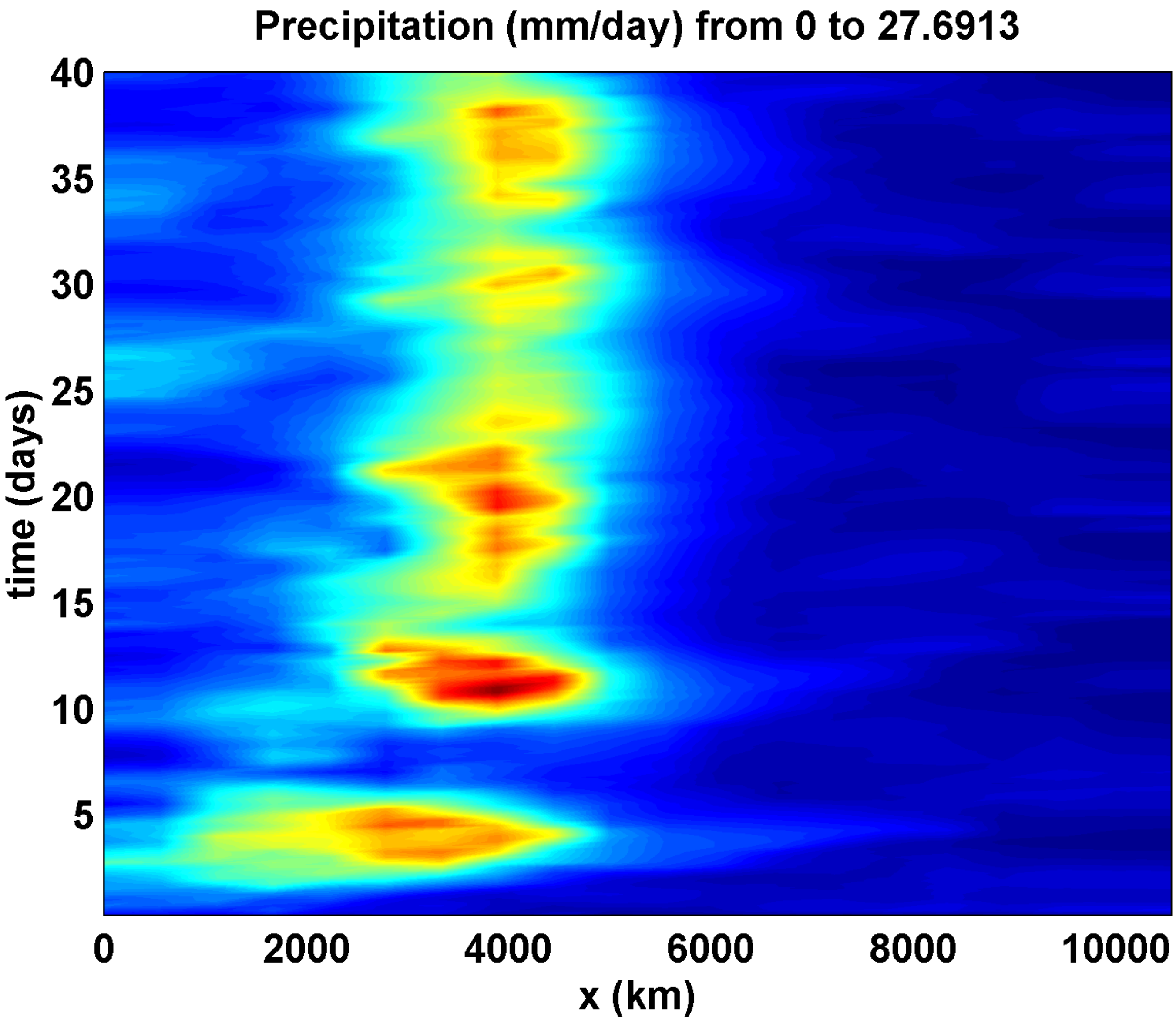

Streamfunction from -2.1178 to 0.6146
Pressure (mb)
100
200
300
400
500
600
700
800
900
1000
2000
4000
6000
8000
10000
x (km)

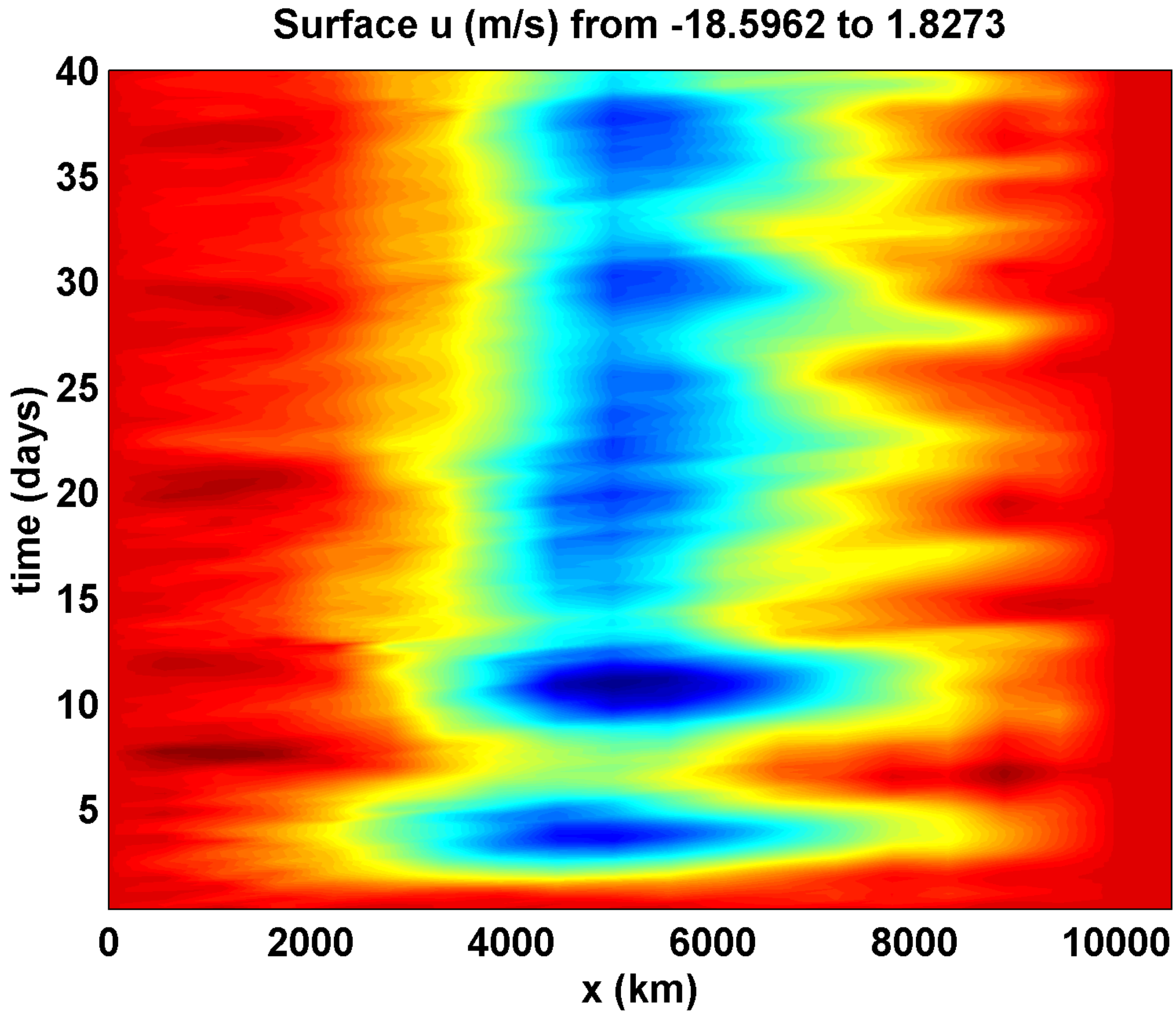

Updraft mass flux from 0 to 17.0043
Pressure (mb)
100
200
300
400
500
600
700
800
900
1000
0
2000
4000
6000
8000
10000
x (km)


Relative humidity from 0.2356 to 99.9919
Pressure (mb)
100
200
300
400
500
600
700
800
900
1000
0
2000
4000
6000
8000
10000
x (km)

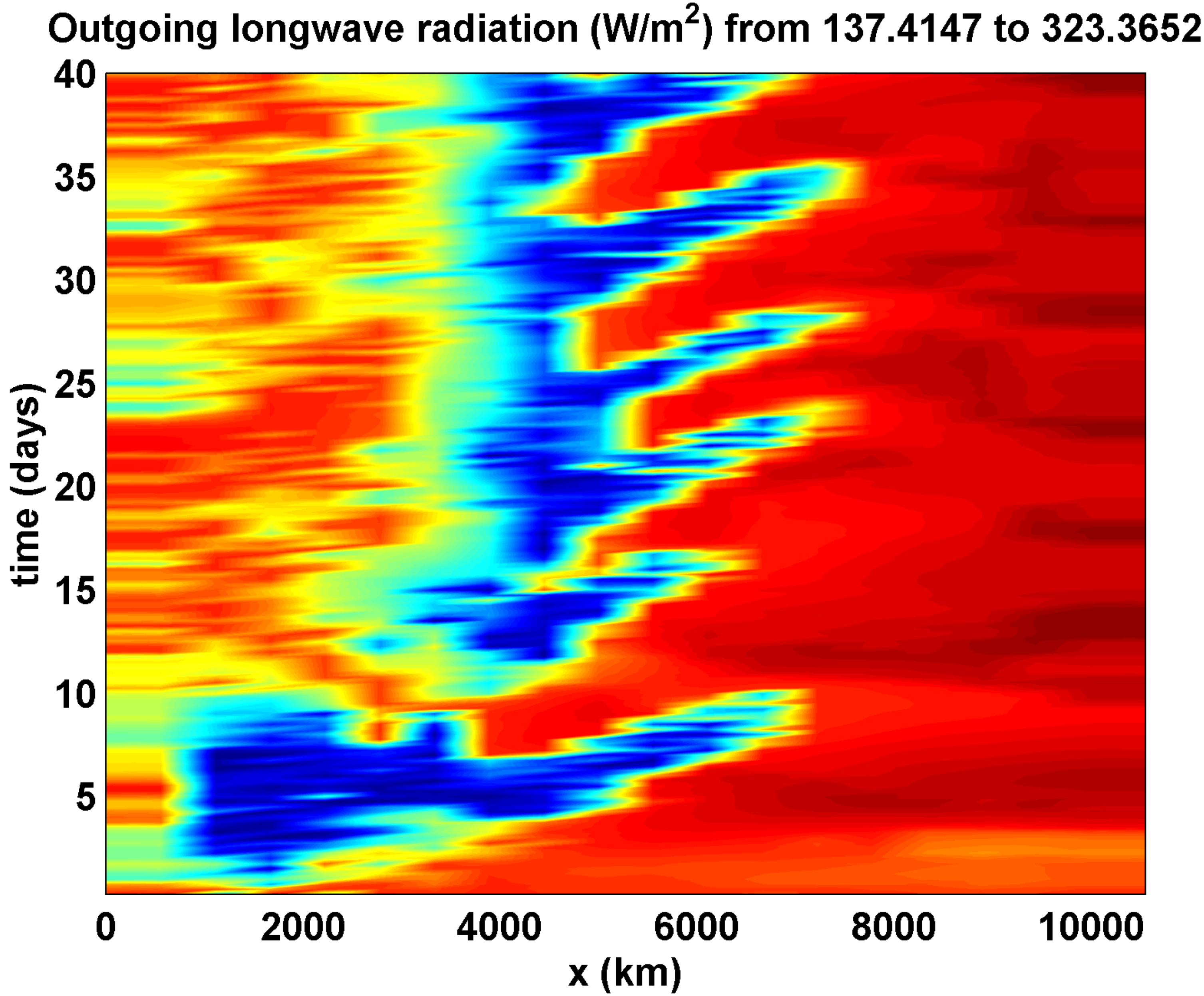

Cloud fraction, from 0 to 0.5036
Pressure (mb)
100
200
300
400
500
600
700
800
900
1000
0
2000
4000
6000
8000
10000
x (km)

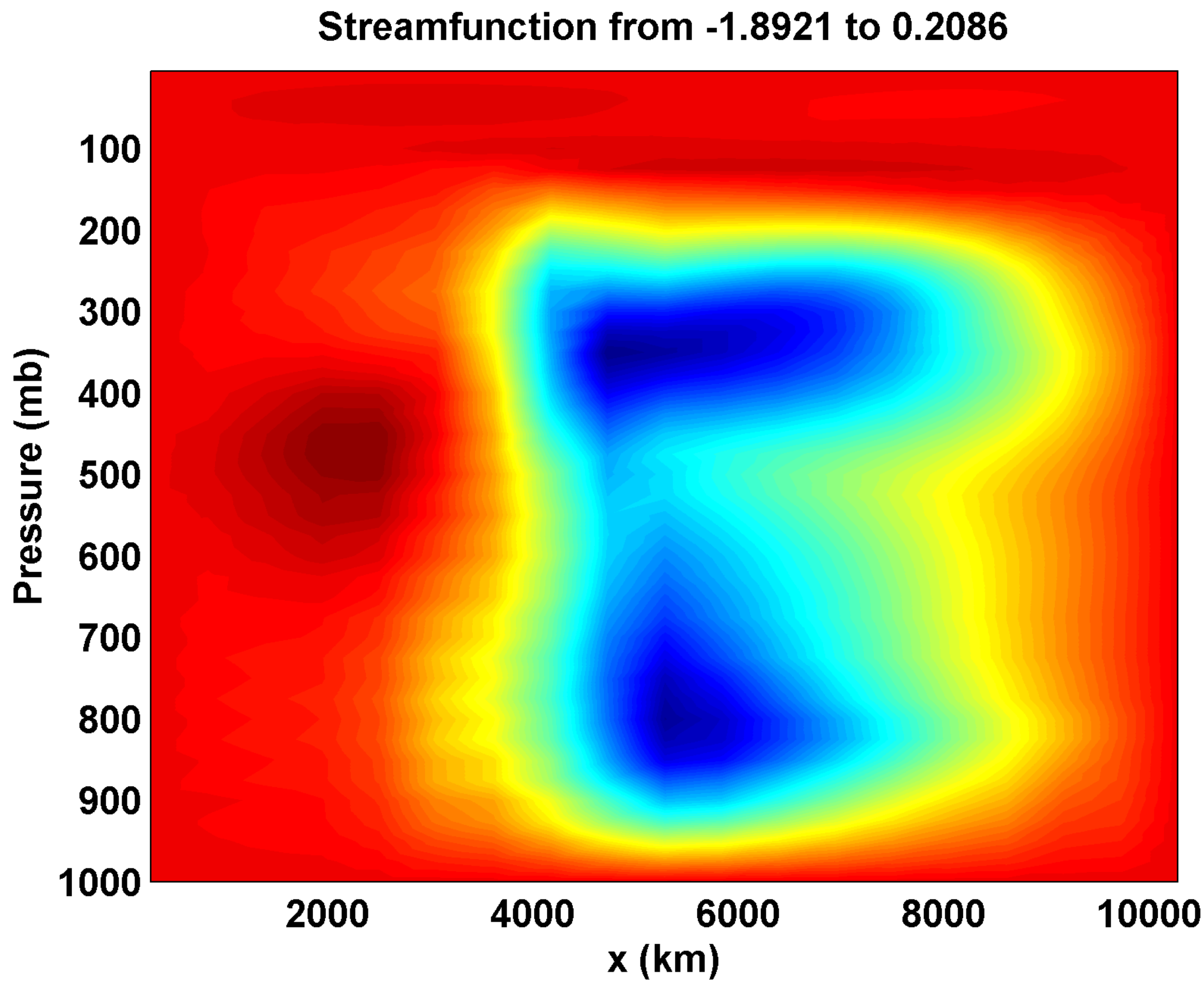
$$\Delta SST = 5^{o} C$$

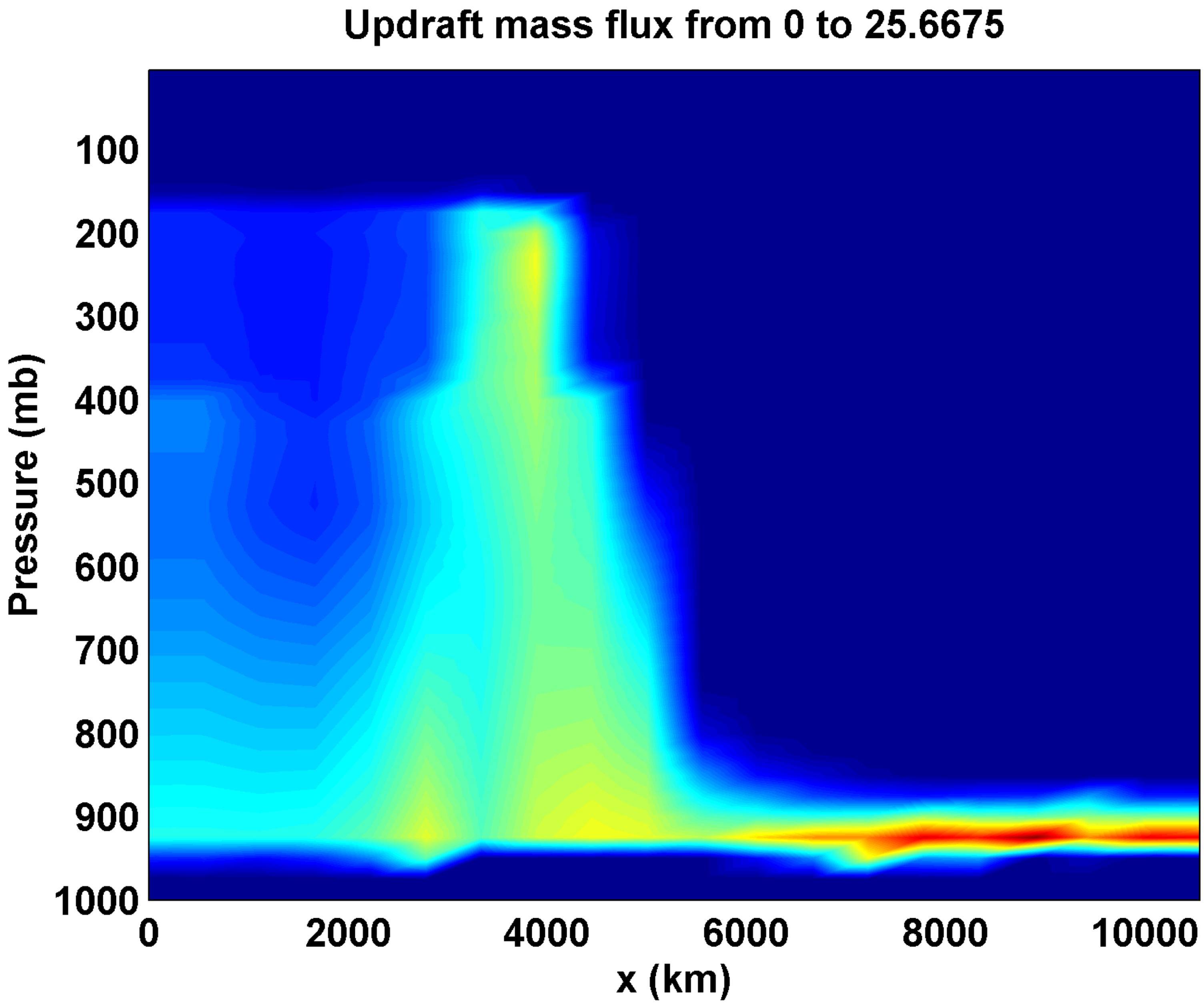




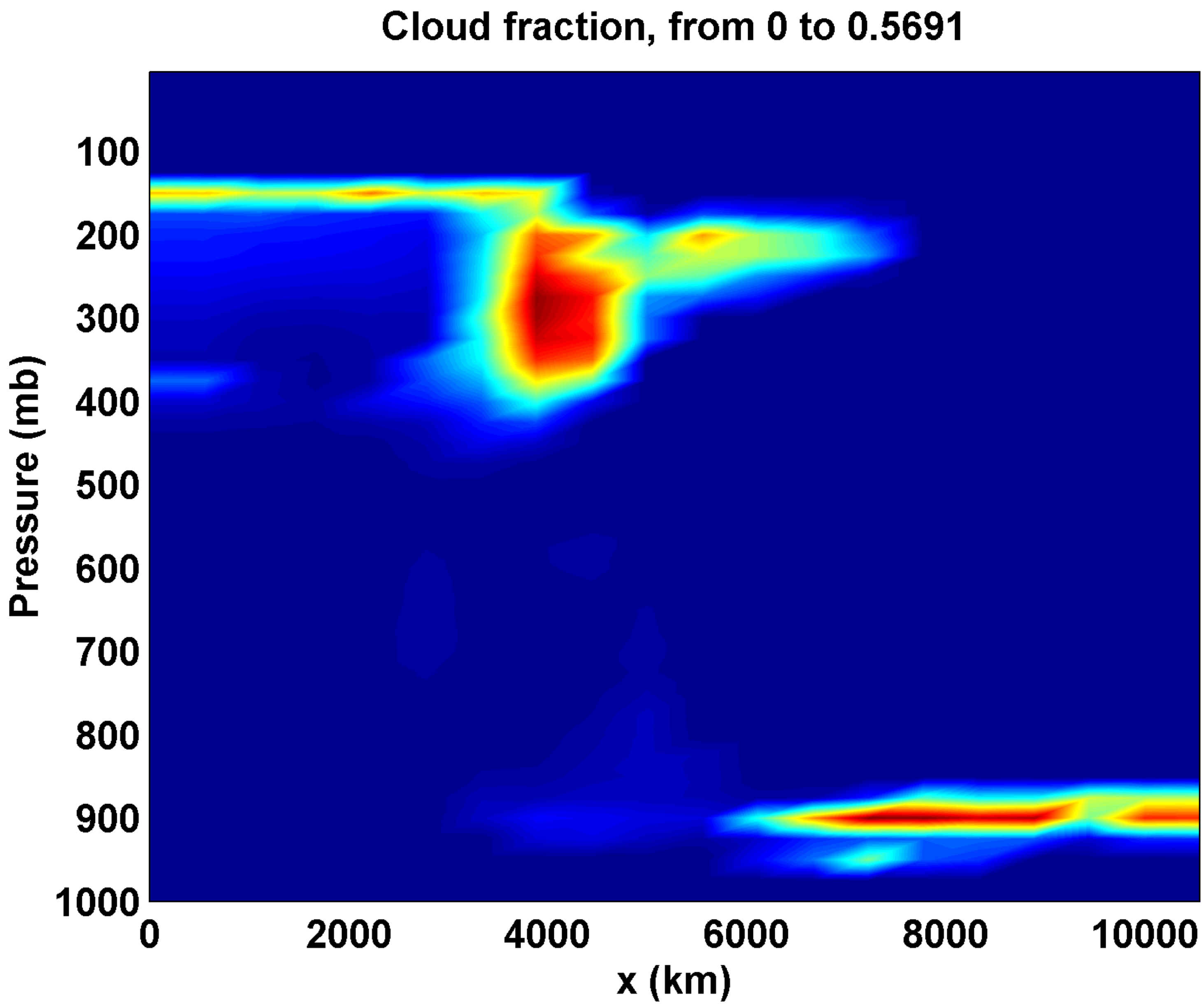
Surface u (m/s) from -18.5962 to 1.8273
time (days)
40
35
30
25
20
15
10
5
0
2000
4000
6000
8000
10000
x (km)

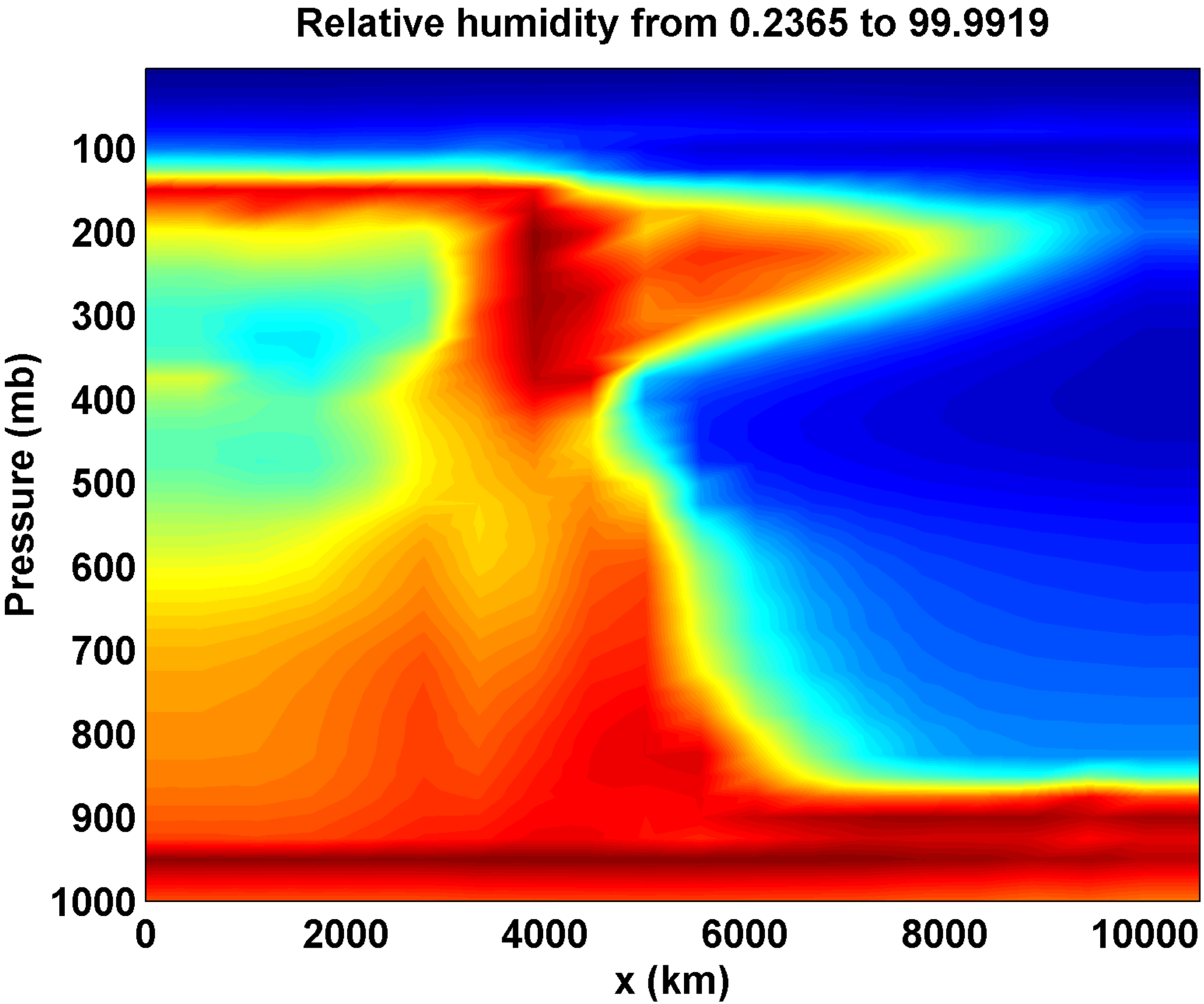

Outgoing longwave radiation (W/m2) from 137.4147 to 323.3652
40
35
30
25
20
15
10
5
time (days)
0
2000
4000
6000
8000
10000
x (km)

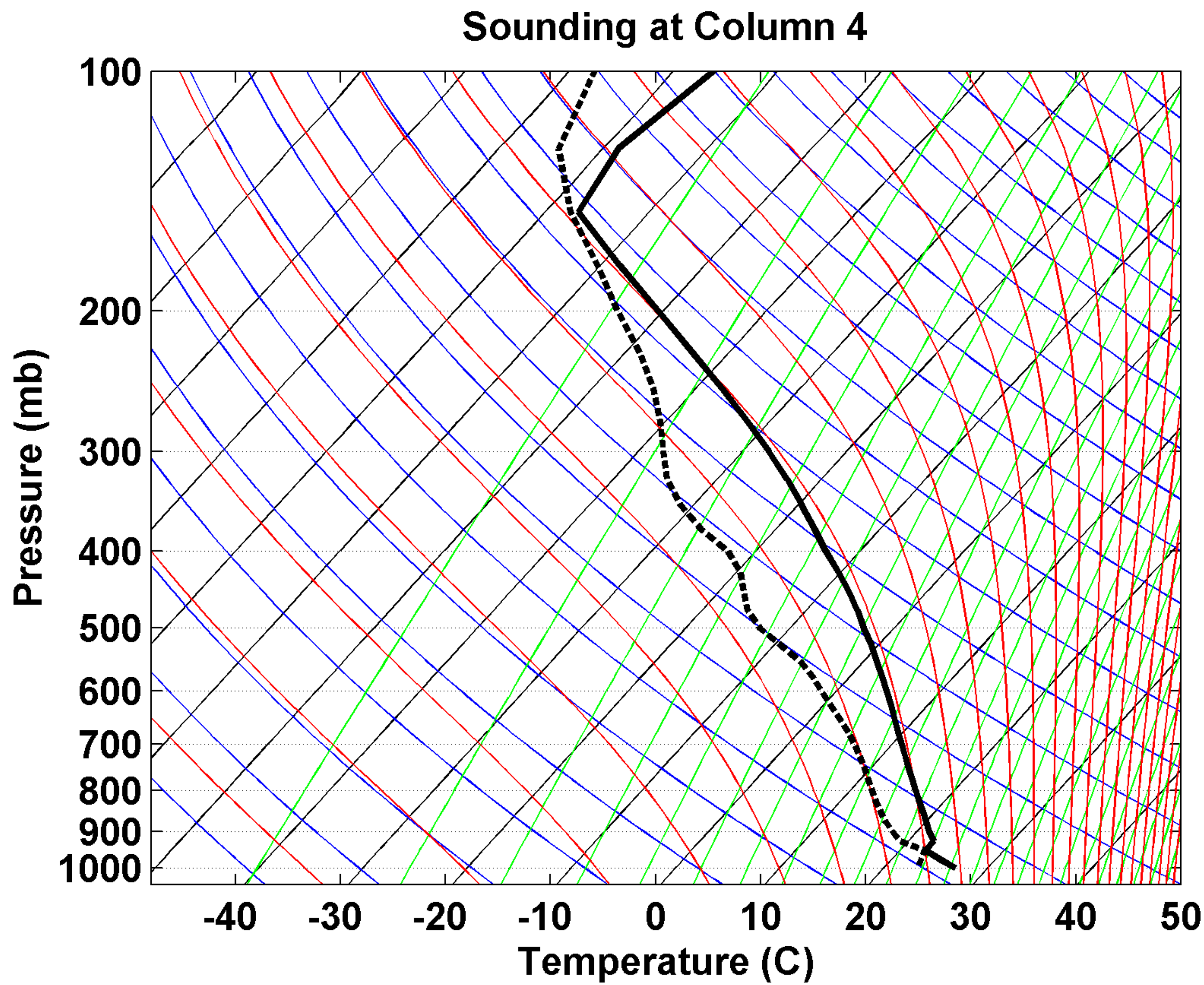

Streamfunction from -1.8921 to 0.2086
Pressure (mb)
100
200
300
400
500
600
700
800
900
1000
2000
4000
6000
8000
10000
x (km)



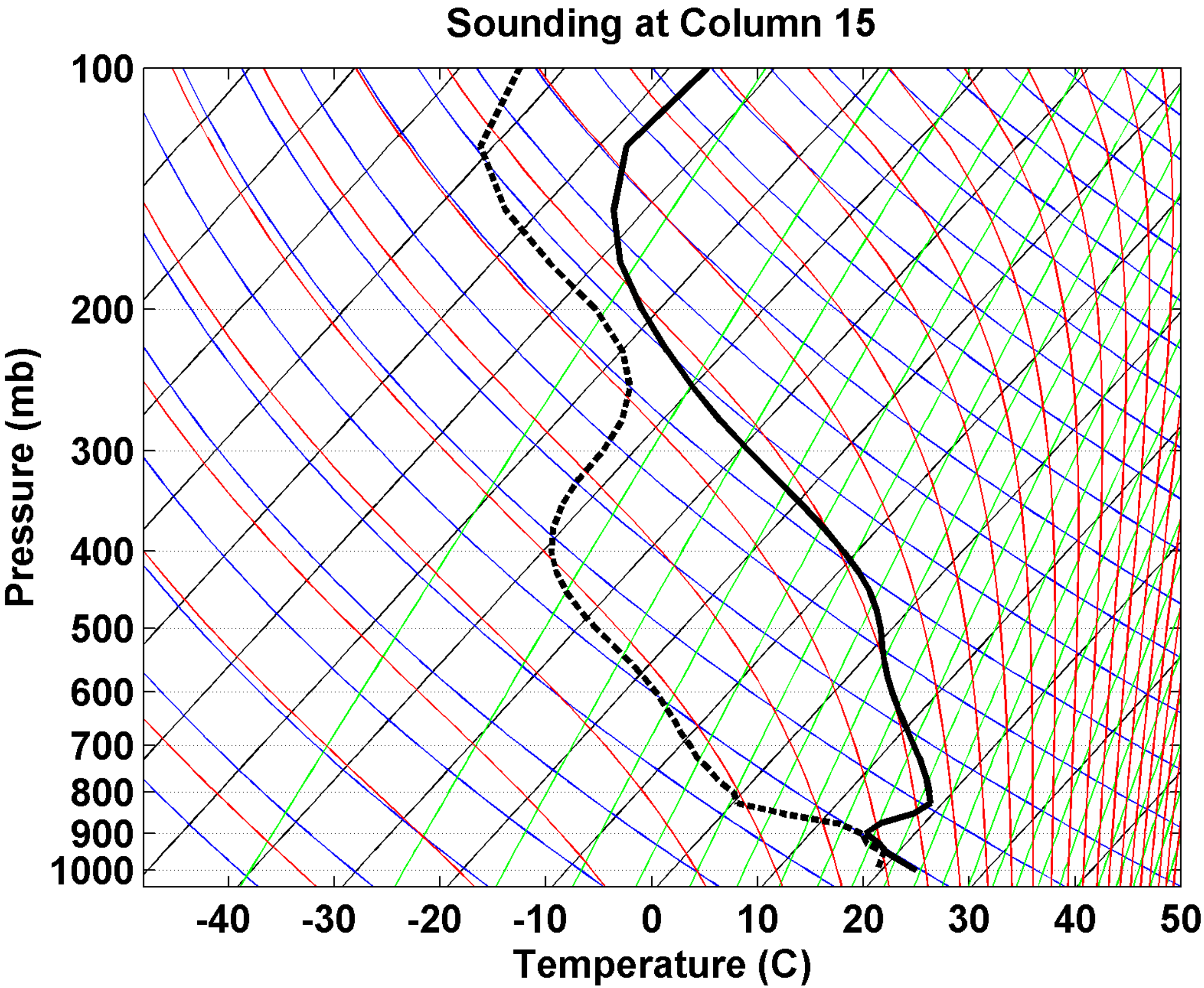
Updraft mass flux from 0 to 25.6675
Pressure (mb)
100
200
300
400
500
600
700
800
900
1000
0
2000
4000
6000
8000
10000
x (km)


Cloud fraction, from 0 to 0.5691
Pressure (mb)
100
200
300
400
500
600
700
800
900
1000
0
2000
4000
6000
8000
10000
x (km)


Relative humidity from 0.2365 to 99.9919
Pressure (mb)
100
200
300
400
500
600
700
800
900
1000
0
2000
4000
6000
8000
10000
x (km)



Sounding at Column 4
100
200
300
400
500
600
700
800
900
1000
Pressure (mb)
-40
-30
-20
-10
0
10
20
30
40
50
Temperature (C)



Sounding at Column 15
100
200
300
400
500
600
700
800
900
1000
Pressure (mb)
-40
-30
-20
-10
0
10
20
30
40
50
Temperature (C)