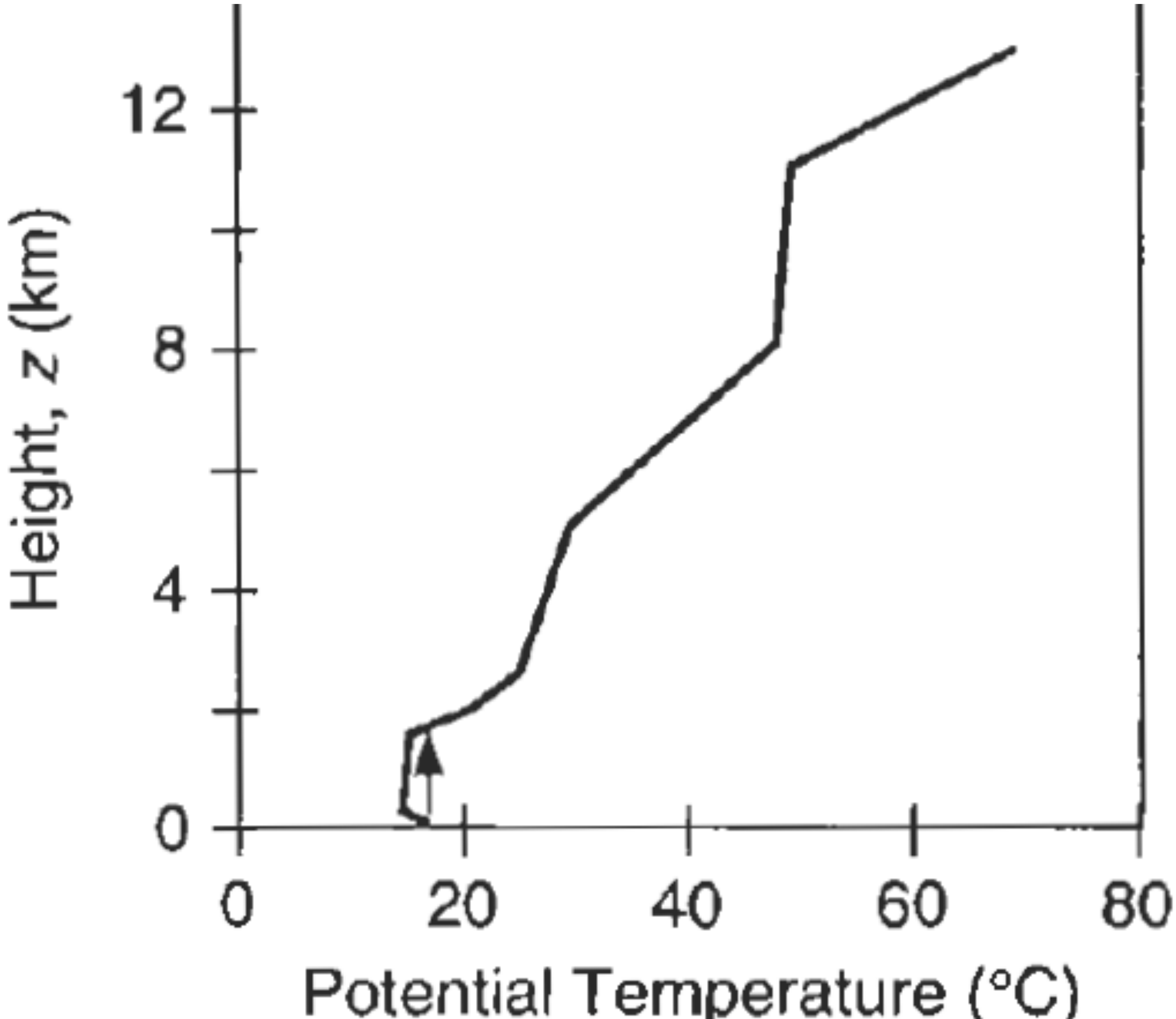
Nonlocal influence of Stratification on Turbulence and Stability

Recall HW2 problem 5.2

z (m)	$\overline{\theta_v}$ (K)	$\overline{U}$ (m/s)
80	305	18
70	305	17
60	301	15
50	300	14
40	298	10
30	294	8
20	292	7
10	292	7
0	293	2

Example Profile



Example Profile

- Let's work it out for this profile!

z (km)	T (°C)	U (m s^{-1})
13	−58	30
11	−58	60
8	−30	25
5	−19	20
3	−3	18
2.5	1	9
2	2	8
1.6	0	5
0.2	13	5
0	18	0

Example Profile

z (km)	T (°C)	U (m s^{-1})	θ (°C)	T_{avg} (k)	Δz (m)	ΔU (m s^{-1})	$\Delta\theta$ (K)
13	−58	30	69.4				
11	−58	60	49.8	215.15	2000	−30	19.6
8	−30	25	48.8	229.15	3000	35	1.4
5	−19	20	30	248.65	3000	5	18.4
3	−3	18	26.4	262.15	2000	2	3.6
2.5	1	9	25.5	272.15	500	9	0.9
2	2	8	21.6	274.65	500	1	3.9
1.6	0	5	15.68	274.15	400	3	5.92
0.2	13	5	14.96	279.65	1400	0	0.72
0	18	0	18	288.65	200	5	−3.04

5.7.2. Dynamic Stability

Dynamic stability considers both buoyancy and wind shear to determine whether the flow will become turbulent. **Wind shear** is the change of wind speed or direction with height, and can be squared to indicate the kinetic energy available to cause turbulence.

The ratio of buoyant energy to shear-kinetic energy is called the **bulk Richardson number**, *Ri*, which is dimensionless:

$$Ri = \frac{|g| \cdot \left(\Delta T_v + \Gamma_d \cdot \Delta z\right) \cdot \Delta z}{T_v \cdot \left[(\Delta U)^2 + (\Delta V)^2\right]} \qquad \bullet(5.9a)$$

and

$$Ri = \frac{|g| \cdot \Delta\theta_v \cdot \Delta z}{T_v \cdot \left[(\Delta U)^2 + (\Delta V)^2\right]} \qquad \bullet(5.9b)$$

where [$\Delta\theta_v$, ΔU, ΔV, ΔT_v] are the change of [virtual potential temperature, east-west wind component, north-south wind component, virtual temperature] across a layer of thickness Δz. As before, $\Gamma_d = 9.8 \cdot$K km^{-1} is the dry adiabatic lapse rate, and T_v must be in absolute units (K) in the denominator of eq. (5.9).

Example Profile

Layer (km)	R_B	Dynamically	Statically	Turbulent
11 to 13	1.98	Stable	Stable	no
8 to 11	0.15	Unstable	Stable	yes
5 to 8	87.02	Stable	Stable	no
3 to 5	67.29	Stable	Stable	no
2.5 to 3	0.20	Unstable	Stable	yes
2 to 2.5	69.58	Stable	Stable	no
1.6 to 2	9.41	Stable	Unstable to 1.8 km	yes to 1.8 km
0.2 to 1.6	$+\infty$	(undefined)	Unstable	yes
0 to 0.2	-0.83	Unstable	Unstable	yes

Sample Application

For the following sounding, determine the regions of turbulence.

z (km)	T (°C)	U (m s^{-1})	V (m s^{-1})
2	0	15	0
1.5	0	12	0
1.2	2	6	4
0.8	2	5	4
0.1	8	5	2
0	12	0	0

Find the Answer:

Given: The sounding above.

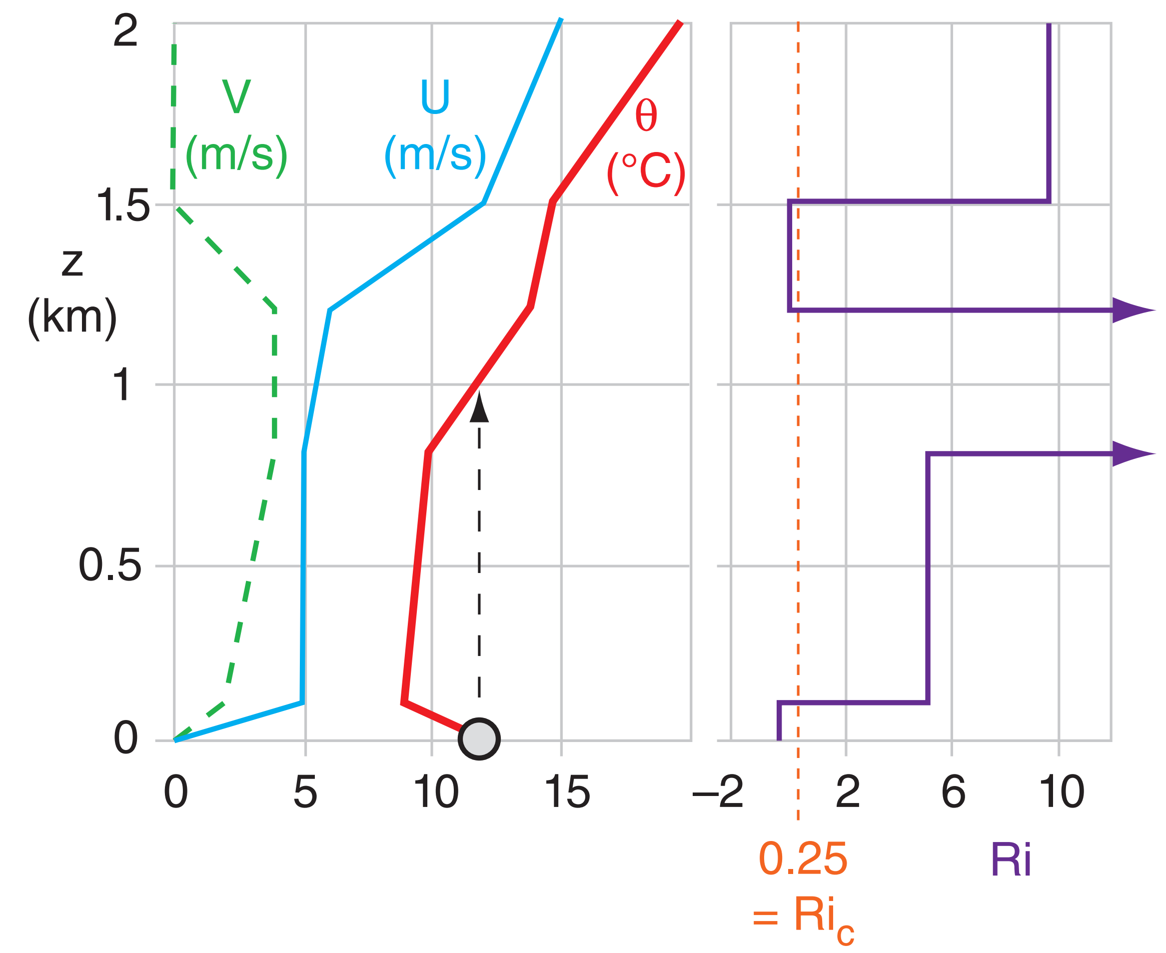
Find: a) Static stability (nonlocal parcel apex method),
b) dynamic stability, & (c) identify turbulence.

Assume dry air, so $T = T_v$.

Method: Use spreadsheet to compute θ and Ri. Note that Ri applies to the layers <u>between</u> sounding levels.

z (km)	θ (°C)	z_{layer} (km)	Ri
2	19.6		
1.5	14.7	1.5 to 2.0	9.77
1.2	13.8	1.2 to 1.5	0.19
0.8	9.8	0.8 to 1.2	55.9
0.1	9.0	0.1 to 0.8	5.25
0	12	0 to 0.1	–0.358

Next, plot these results:



a) Static Stability: Unstable & turbulent for z = 0 to 1 km, as shown by nonlocal air-parcel rise in the θ sounding.

b) Dynamic Stability: Unstable & turbulent for z = 0 to 0.1 km, & for z = 1.2 to 1.5 km, where $Ri < 0.25$.

c) Turbulence exists where the air is statically OR dynamically unstable, or both. Therefore: **<u>Turbulence at 0 - 1 km, and 1.2 to 1.5 km.</u>**

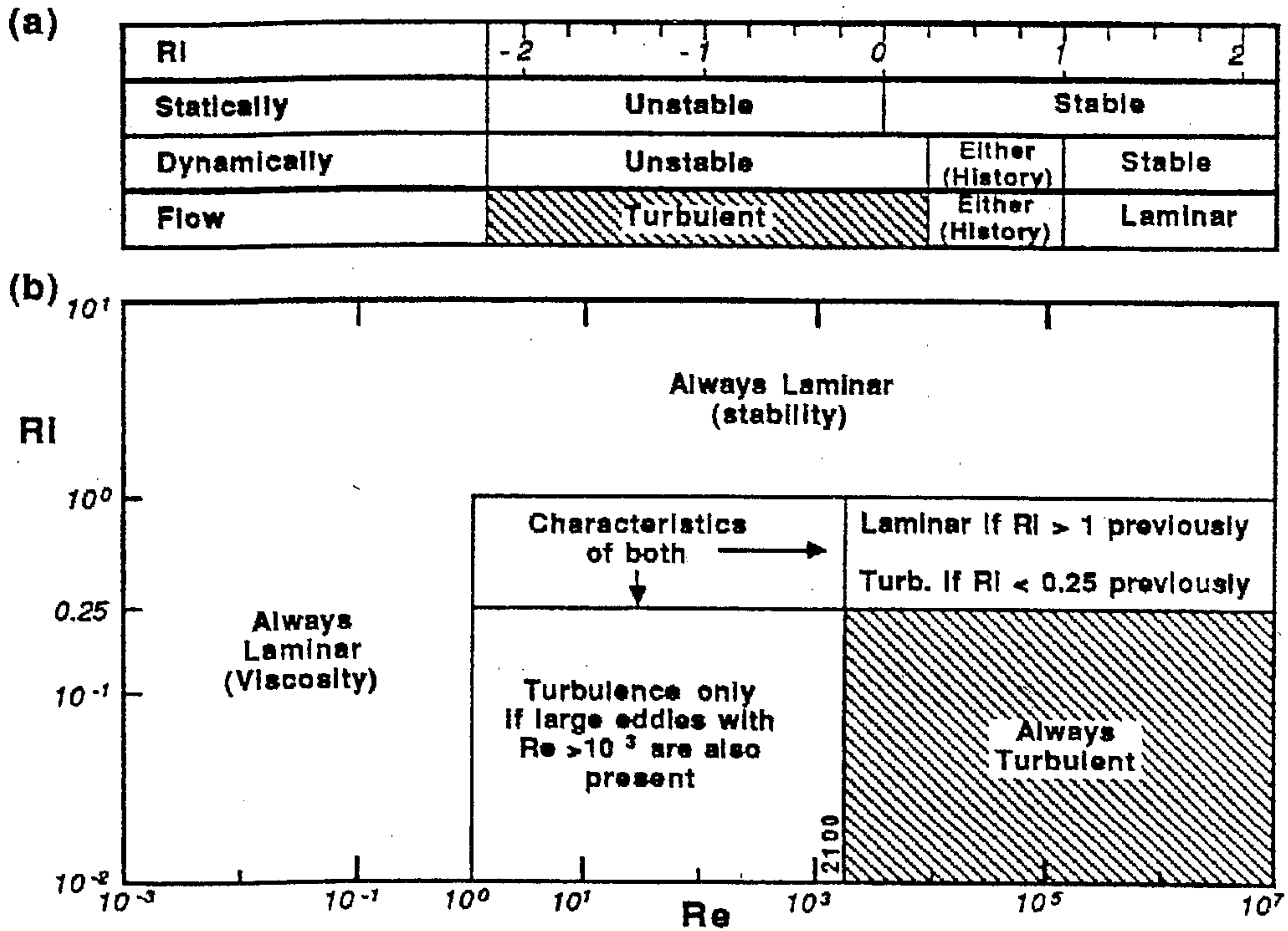
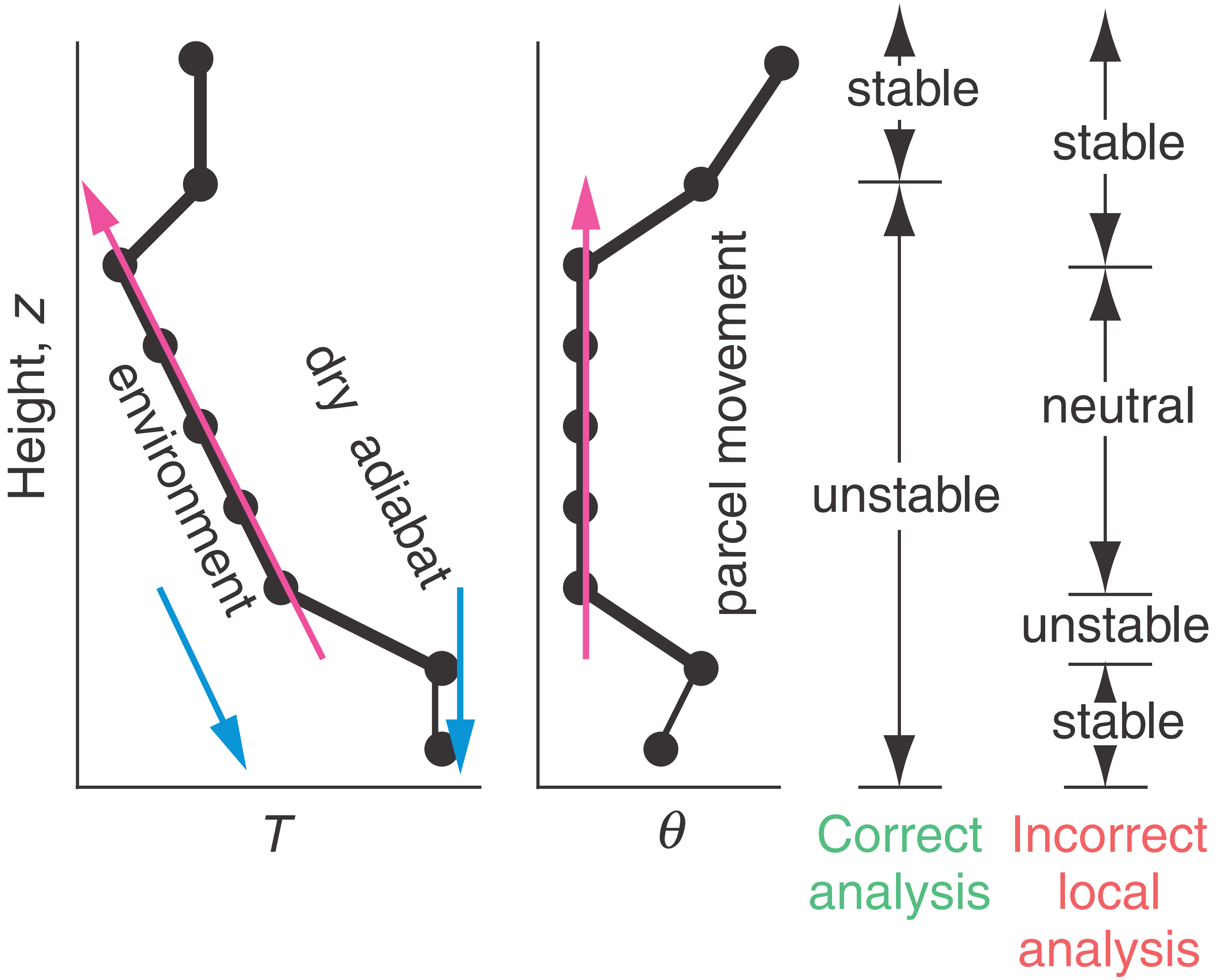


Fig. 5.24 Stability parameter relationships (see text). (After Woods, 1969).

Example Profile

- Is the middle layer neutral?
- Is the bottom layer stable?



- **Unstable** air becomes, or is, **turbulent** (irregular, gusty, stormy).
- **Stable** air becomes, or is, **laminar** (non-turbulent, smooth, non-stormy).
- **Neutral** air has no tendency to change (disturbances neither amplify or dampen).

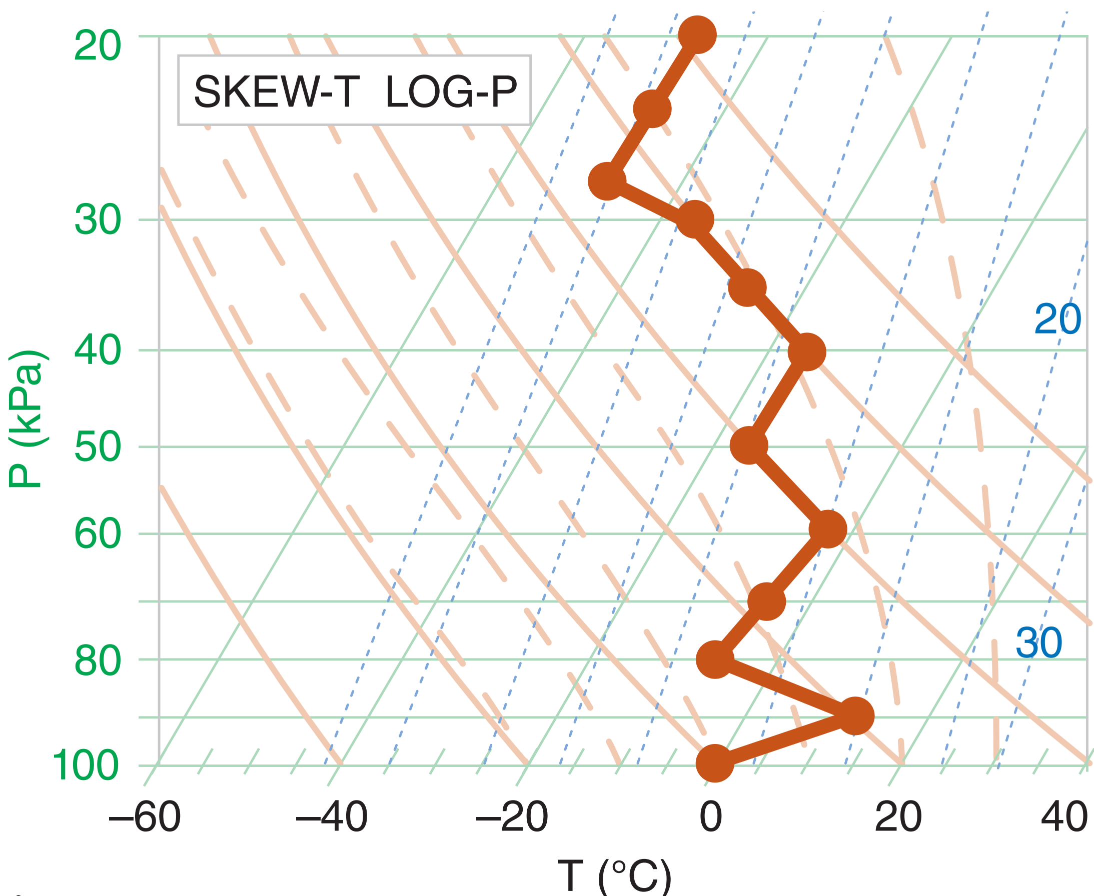


Figure 5.14a
Static stability determination. Step 1: Plot the sounding. (This sounding is contrived to illustrate all stabilities.)

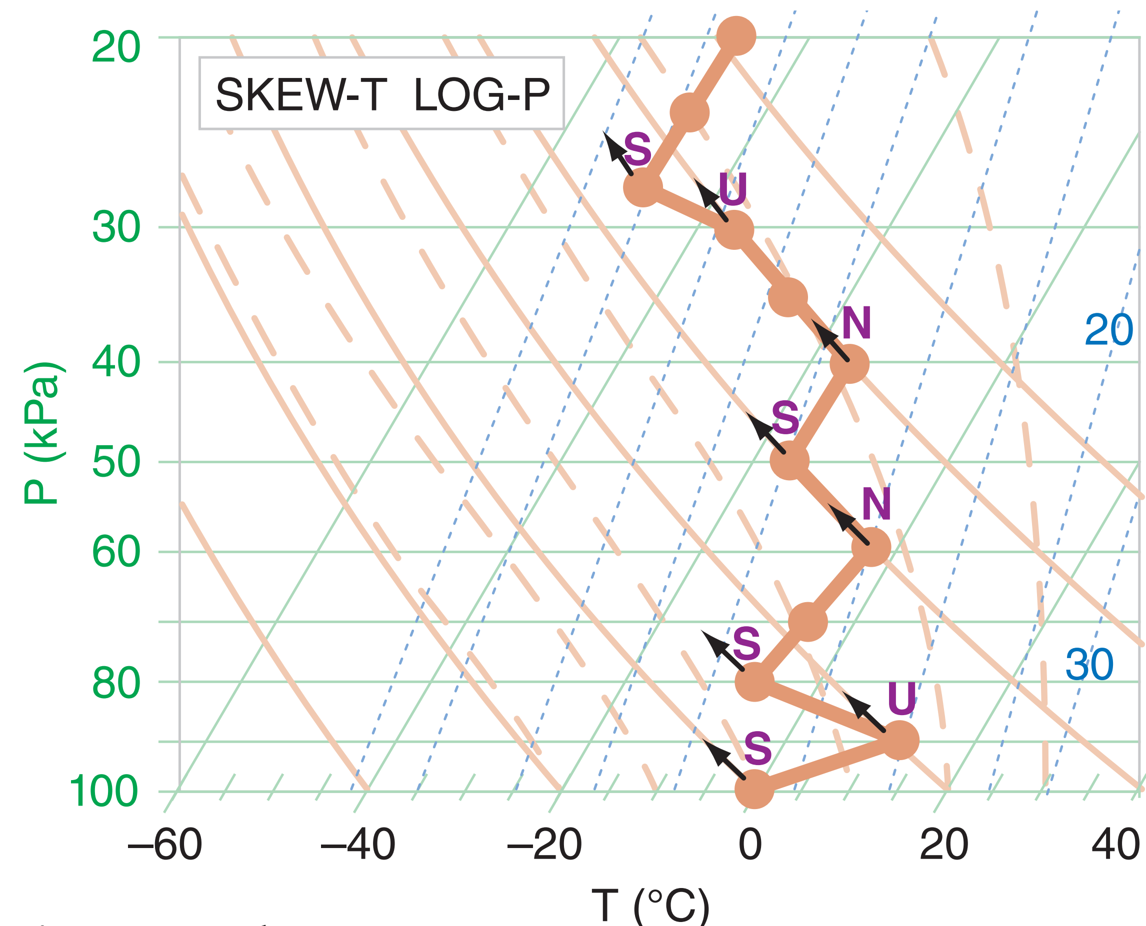


Figure 5.14b
Static stability determination. Step 2: Upward displacements. (Assume this contrived sounding is unsaturated.)

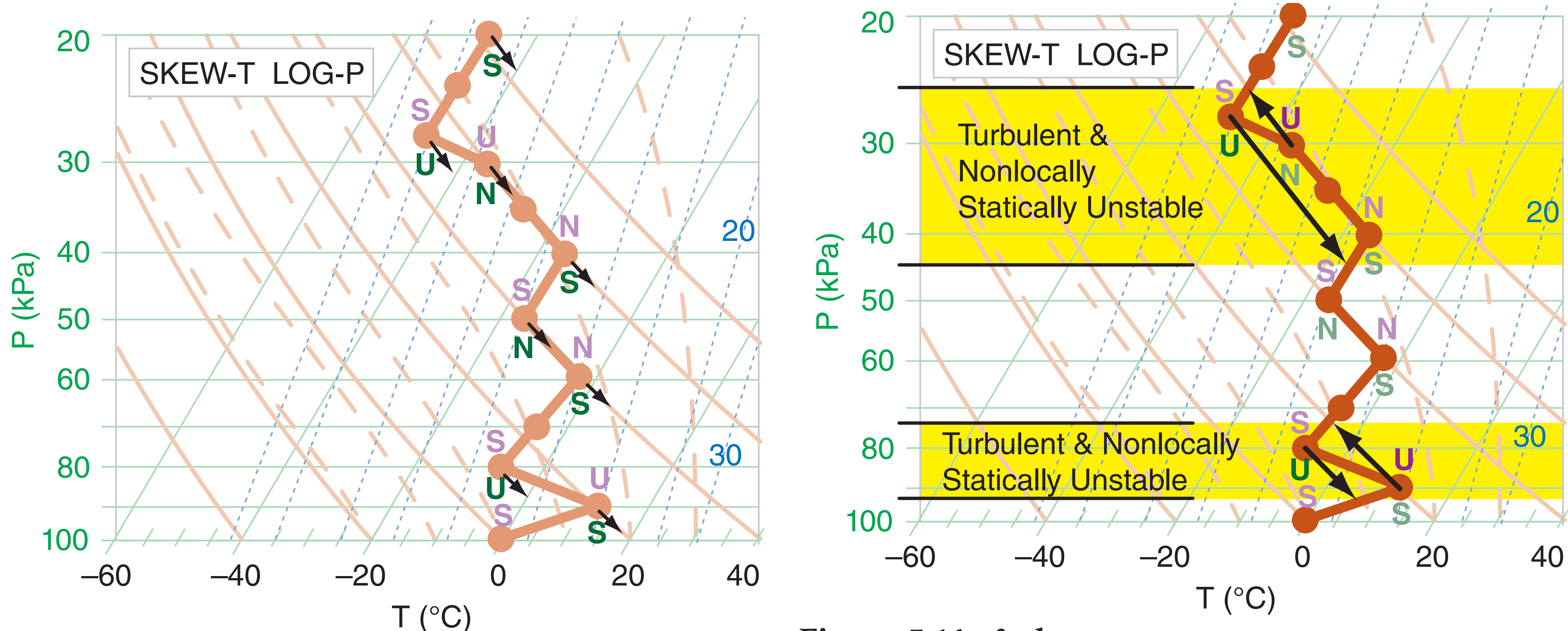


Figure 5.14c & d
Static stability determination. (c) Step 3: Downward displacement. (d) Step 4: Identify unstable regions (shaded yellow).

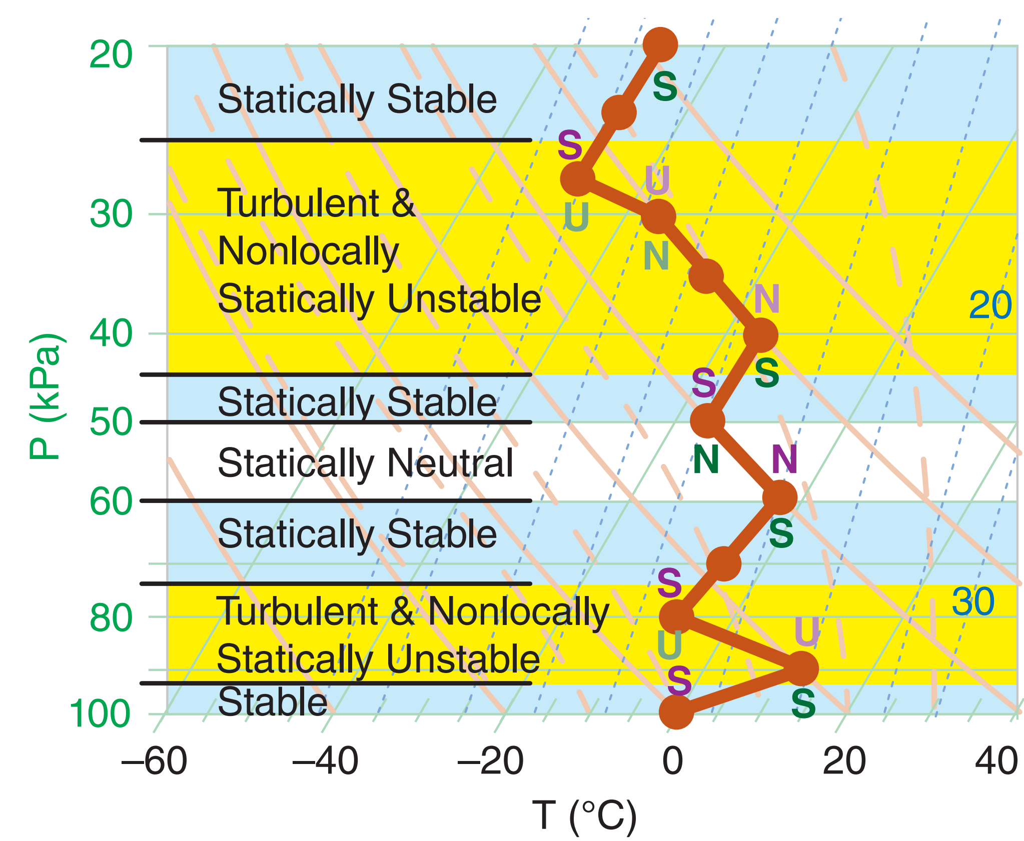


Figure 5.14e
Static stability determination. Step 5: Identify statically stable regions (shaded light blue) and neutral regions (no shading).