BL diurnal cycle over land

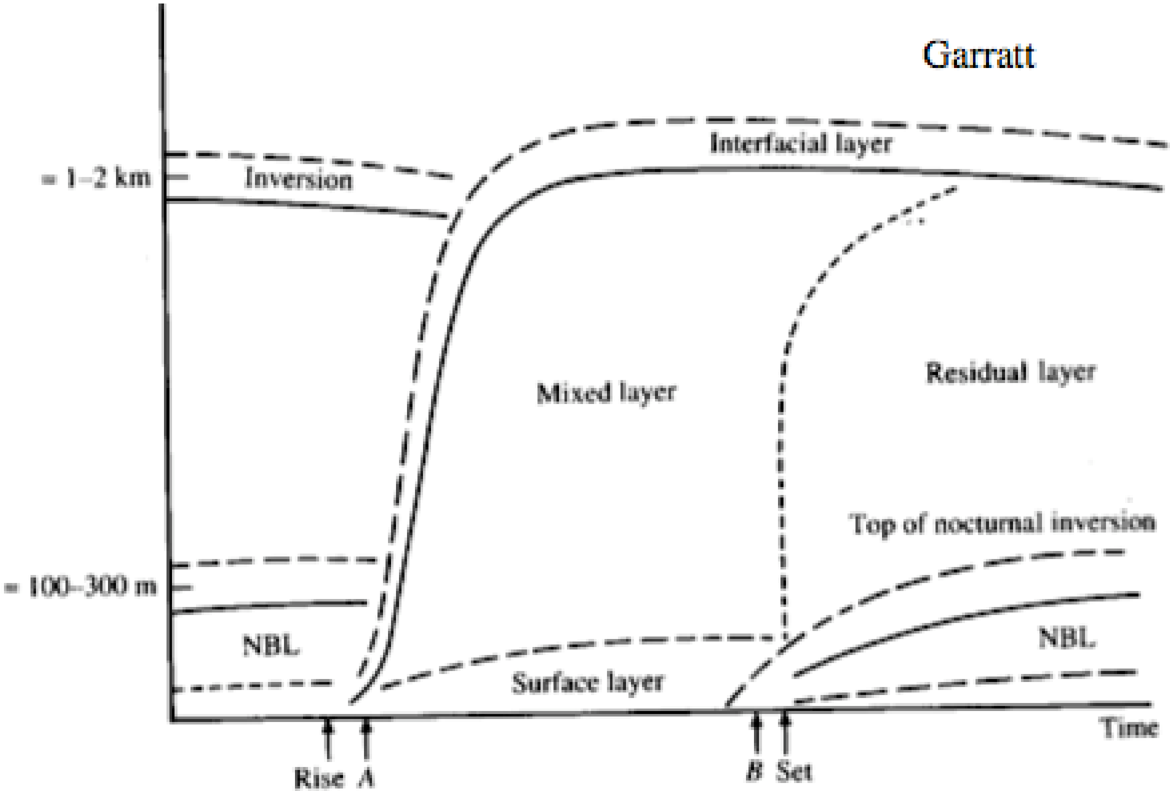
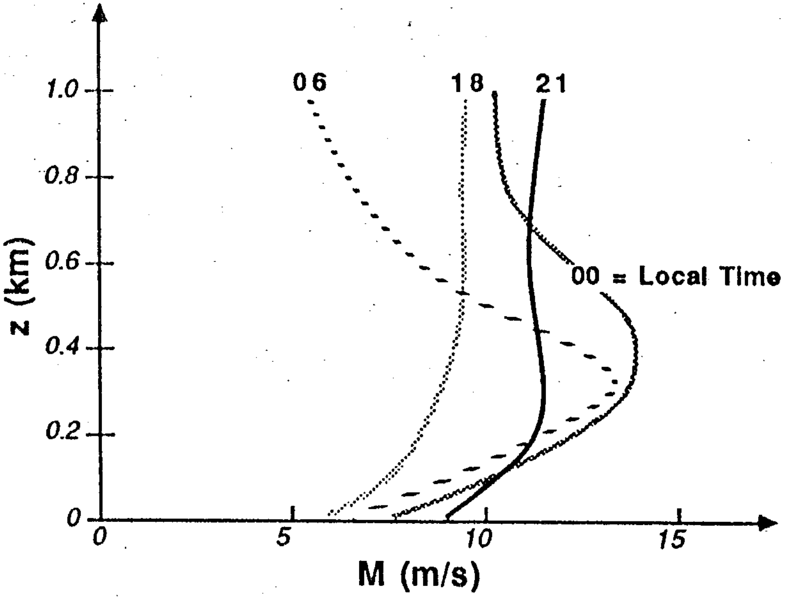


Fig. 6.1 Schematic representation of ABL evolution throughout the diurnal period over land under clear skies.

Fig. 12.15
Nocturnal jet evolution during night 13-14 of Wangara. (After Malcher and Kraus, 1983.)



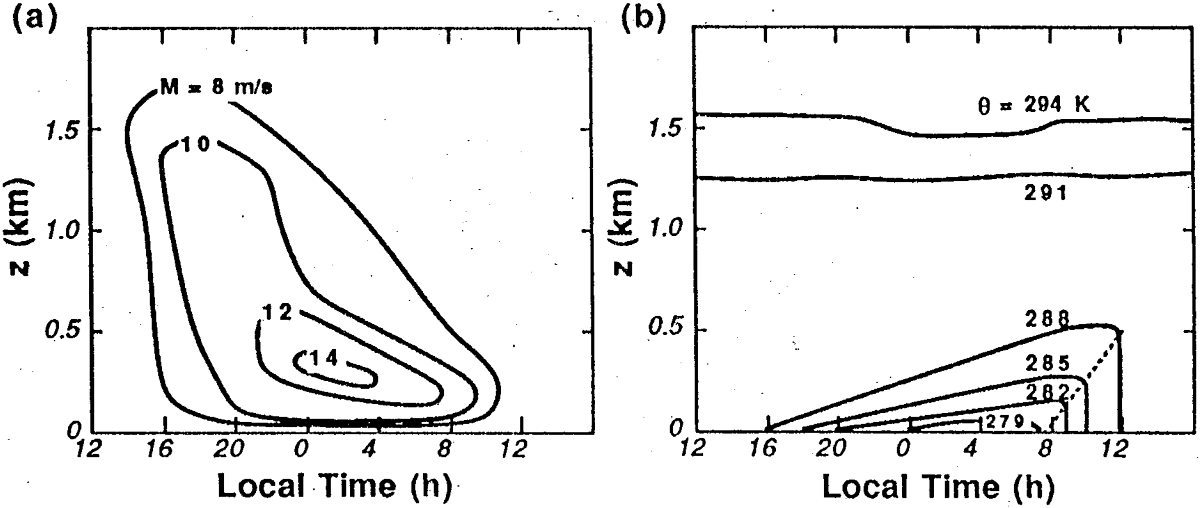


Fig. 12.16 (a) Wind speed and (b) potential temperature evolution during Wangara Night 13-14. (After Malcher and Kraus, 1983).

Nocturnal jet development

Garratt

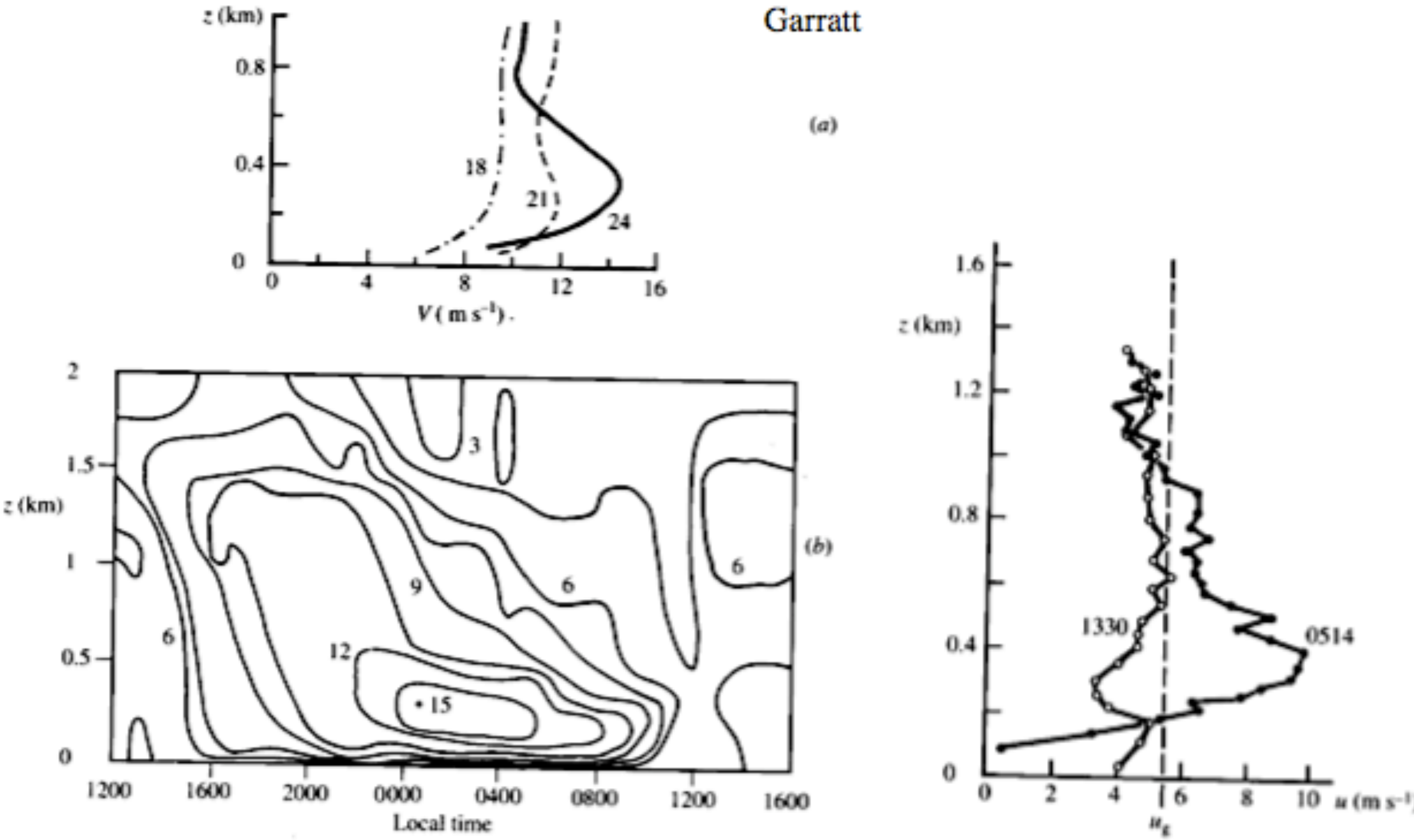


Fig. 6.18 Observations illustrating the formation of the nocturnal jet. (*a*) Wind-speed profiles on day 13 of WANGARA, local times indicated. (*b*) Height–time cross-section of wind speed (in $m\,s^{-1}$) on days 13/14 at WANGARA. Isopleths of wind speed are drawn at $1.5\,m\,s^{-1}$ intervals. (*c*) Profiles of the u-component of the wind velocity, with the x-axis along the geostrophic wind direction, for mid-afternoon (1330 UT, 6 August, 1974) and early morning (0514, 7 August, 1974) near Ascot, England. After Thorpe and Guymer (1977), *Quarterly Journal of the Royal Meteorological Society*.

12.5.3 Inertial Oscillation

During the daytime, winds in the ML are subgeostrophic because of strong frictional drag at the ground. At sunset when ML turbulence ceases, pressure gradients tend to accelerate the winds back toward geostrophic. However, the Coriolis force induces an ***inertial oscillation*** in the wind, causing it to become supergeostrophic later at night (Blackadar, 1957). Details of this oscillation are now discussed.

The starting point in this analysis are momentum equations (3.5.3c & d) for the boundary layer. For simplicity, choose a coordinate system such that $V_g = 0$, and abbreviate the Reynolds stress divergence (friction) terms by $\partial\overline{u'w'}/\partial z \equiv f_c \cdot F_u$, and $\partial\overline{v'w'}/\partial z \equiv f_c \cdot F_v$, where F_u and F_v have units of velocity. The equations become:

$$\frac{d\overline{U}}{dt} = +f_c\,\overline{V} \qquad - f_c F_u \tag{12.5.3a}$$

$$\frac{d\overline{V}}{dt} = f_c(\overline{U_g} - \overline{U}) - f_c F_v \tag{12.5.3b}$$

Initially, the winds are subgeostrophic, so we must first determine the daytime ML winds to be used as initial conditions for the nocturnal case. Assuming steady state during the day, the above equations can be easily solved for the winds:

$$\overline{U}_{day} = \overline{U_g} - F_{v\,day}$$

$$\overline{V}_{day} = F_{u\,day} \qquad (12.5.3c)$$

In this form, we see that F_u and F_v represent the departure of the winds from geostrophic (i.e., the ***geostrophic departure***).

Next, assume that friction suddenly disappears above the surface layer at sunset, and that friction remains zero throughout the night. The nocturnal winds are expected to evolve with time, so we cannot assume steady state. Combine (12.5.3 a & b) into one equation by taking the time derivative of the first equation, and then substituting in the second equation:

$$\frac{d^2\overline{U}}{dt^2} = -f_c^2(\overline{U} - \overline{U_g})$$

The solution will be of the form:

$$\overline{U} - \overline{U_g} = A\sin(f_c t) + B\cos(f_c t)$$

The parameters A and B are then determined from the initial conditions (12.5 3c), yielding $A = F_{u\ day}$ and $B = -F_{v\ day}$. The final result is then:

$$\overline{U}_{night} = \overline{U_g} + F_{u\ day} \cdot \sin(f_c t) - F_{v\ day} \cdot \cos(f_c t)$$

$$\overline{V}_{night} = F_{u\ day} \cdot \cos(f_c t) + F_{v\ day} \cdot \sin(f_c t) \qquad (12.5.3d)$$

We see that the winds oscillate about the geostrophic value, but never converge to the geostrophic value in this idealized scenario. The period of oscillation, called the ***inertial period***, is $2\pi/f_c$. At midlatitudes, the inertial period is about 17 h. The magnitude of the oscillation at night depends on the amount of geostrophic departure at the end of the day. Typical geostrophic departures are on the order of 2 to 5 m/s at the end of the day, leading to nocturnal jet maxima that can be 2 to 5 m/s faster than geostrophic (Garratt, 1985; and Kraus, et al., 1985).

12.5.4 Example

Problem. Frictional drag during the day results in geostrophic departures of $F_u = F_v = 3$ m/s at sunset. Calculate and plot the resulting nocturnal winds for every hour over a full inertial period. Also determine the time of occurrence and maximum speed of the nocturnal jet. Assume $f_c = 10^{-4}\ s^{-1}$, $U_g = 10$ m/s, and $V_g = 0$.

Solution. Solving (12.5.3d) using the conditions above gives the winds listed in the Table 12-1. These are plotted as a hodograph in Fig 12.18. We see that the wind vectors describe a circle about the geostrophic wind, with a radius of 4.24 m/s. A maximum wind speed of 14.24 m/s is reached about 6.5 h after sunset. In fact, the wind speeds are supergeostrophic for about a 9 h period.

Discussion. Initially, the winds are subgeostrophic and cross the isobars toward low pressure, as expected with friction. Shortly after sunset, the winds continue to turn toward low pressure (Mahrt, 1981). However, between 7 and 15 h after sunset the winds cross the isobars toward high pressure during a portion of the inertial oscillation. Such ageostrophic winds can lead to convergence regions that can trigger thunderstorms.

Also, midlatitude nights last only 8 to 16 h, depending on the season and latitude. Thus, the full cycle of the oscillation might not be realized before daytime mixing destroys the nocturnal jet.

Table 12-1. Example of an inertial oscillation.

t (h)	$U - U_g$ (m/s)	V_g (m/s)	t (h)	$U - U_g$ (m/s)	V_g (m/s)
0	-3.00	3.00	10	1.36	-4.02
1	-1.75	3.86	11	-0.14	-4.24
2	-0.28	4.23	12	-1.62	-3.92
3	1.23	4.06	13	-2.90	-3.10
4	2.58	3.37	14	-3.81	-1.88
5	3.60	2.24	15	-4.22	-0.41
6	4.16	0.83	16	-4.10	1.10
7	4.19	-0.69	17	-3.45	2.47
8	3.67	-2.12	17.45	-3.00	3.00
9	2.69	-3.28			

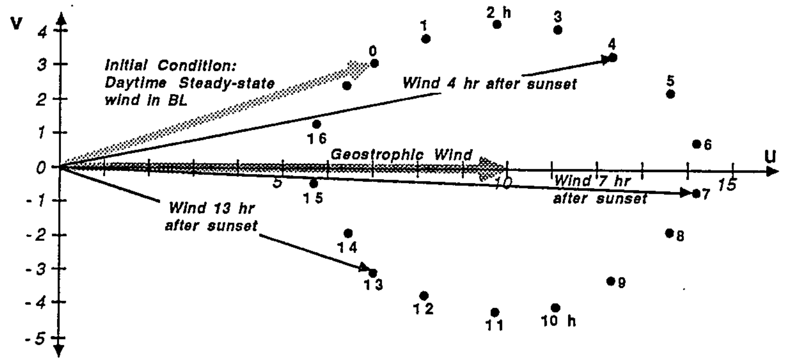


Fig. 12.18 Diurnal variation of the low level jet associated with the inertial oscillation.

Inertial oscillation and nocturnal jet

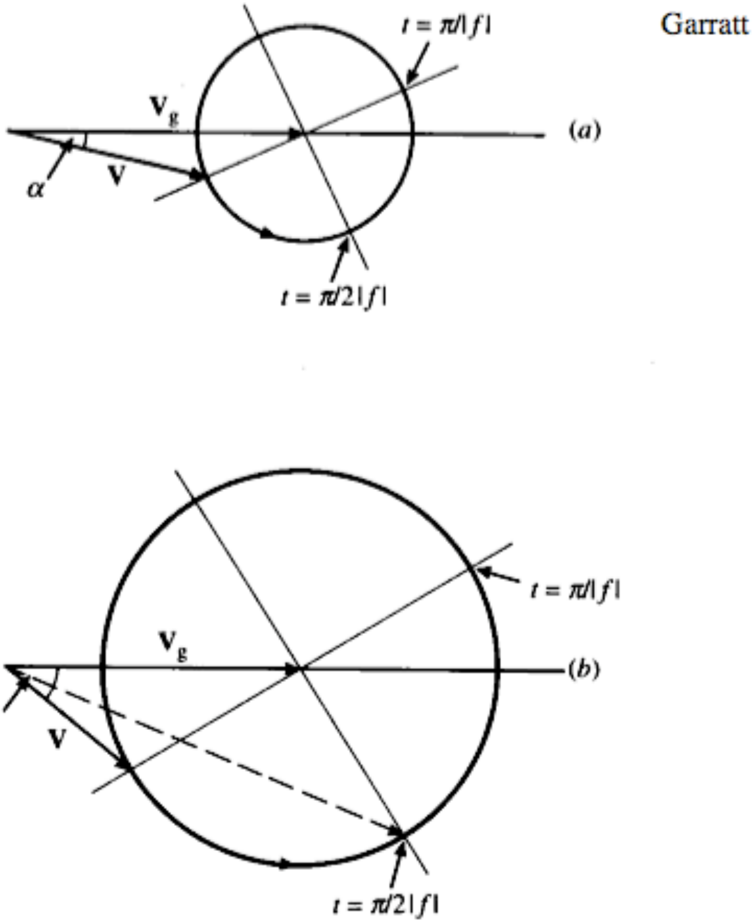


Fig. 6.19 Illustrated solutions of the unbalanced momentum equation (Eq. 6.77) for (*a*) a low-roughness surface and (*b*) a high-roughness surface; undamped inertial oscillations are shown for the southern hemisphere in the form of anticlockwise rotation of the wind vector (**V**) about the geostrophic wind vector ($\mathbf{V}_g$).