Copertina

Corso di Fisica dello Strato Limite Atmosferico

Analisi dimensionale e di scala e le grandezze scala tipiche dell'ABL

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Sommario della lezione

- Fondamenti dell'analisi dimensionale e di scala per affrontare problemi fisici (alla lavagna)
- I modelli della realtà descrittivi ed esplicativi (alla lavagna)
- Il teorema di Buckingham o teorema Π (alla lavagna)
- Applicazioni dell'analisi di scala e confronto tra modello descrittivo e esplicativo dello stesso sistema fisico (alla lavagna)
- Esempi di grandezze scala utilizzate nello studio dello Strato Limite Atmosferico
- Bibliografia di riferimento e per approfondimenti.

L'approccio esplicativo e la ricchezza delle grandezze utilizzate (lunghezza)

Length:

z	= height above the surface
h or z_i	= depth of the boundary layer (or mixed layer)
H	= SBL integral length scale = heat-flux-history scale
L	$= -[\overline{u'w'}_s{}^2 + \overline{v'w'}_s{}^2]^{3/4} / [k \cdot (g/\overline{\theta_v}) \cdot (\overline{w'\theta_v'}_s)]$ = Obukhov length
L_L	$= -[\overline{u'w'}^2 + \overline{v'w'}^2]^{3/4} / [k \cdot (g/\overline{\theta_v}) \cdot (\overline{w'\theta_v'})]$ = local Obukhov length
h_e	$= u_*/f_c$ = Ekman layer depth
λ_{max}	= Wavelength corresponding to peak in turbulence spectrum
H	= height of obstacle
W	= width of obstacle
z_o	= aerodynamic roughness length
Z_s	= scale of surface features or roughness

L'approccio esplicativo e la ricchezza delle grandezze utilizzate (velocità)

Velocity:

u_* $= [\overline{u'w'}_s^{\,2} + \overline{v'w'}_s^{\,2}]^{1/4}$ = friction velocity

w_* $= [(g/\overline{\theta_v})\cdot\overline{w'\theta_v'}_s \cdot z_i]^{1/3}$ = convective velocity scale

w_{Lf} $= [(g/\overline{\theta_v})\cdot\overline{w'\theta_v'}\cdot z]^{1/3}$ = local free convection velocity scale

u_L $= [\overline{u'w'}^2+\overline{v'w'}^2]^{1/4}$ = local (friction) velocity scale

V_B $= [(g/\Delta\overline{\theta_{v\ s}})\cdot\overline{w'\theta_v'}\cdot H]^{1/3}$ = SBL buoyancy velocity scale

V_M $= (Z_s/\rho)^{1/2}[(\partial P/\partial x)^2+(\partial P/\partial y)^2]_s^{1/4}$ = mechanical forcing scale

u_*^{ML} $= u_*^2/w_*$ = convective stress scale velocity

$\overline{G}$ or $\overline{U}_g$ = geostrophic wind speed

$\overline{G}_s$ = geostrophic wind speed at the surface

$\overline{G}_{z_i}$ = geostrophic wind at the top of the boundary layer

$\langle\overline{G}\rangle$ = geostrophic wind speed averaged over the boundary layer

$\overline{U}$ or $\overline{M}$ = wind speed

$\overline{M}_S$ = wind speed at the surface

$\overline{M}_{z_i}$ = wind speed at the top of the boundary layer

$\langle\overline{M}\rangle$ = wind speed averaged over the boundary layer

$(TKE)^{1/2}$ or $\bar{e}^{1/2}$ = square root of turbulence kinetic energy

$(k\,z\,\varepsilon)^{2/3}$ = dissipation velocity scale in the surface layer

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L'approccio esplicativo e la ricchezza delle grandezze utilizzate (temperatura)

Temperature:

$\theta_*^{ML} = \overline{w'\theta_v'}_s / w_*$ = convective (ML) temperature scale

$\theta_*^{SL} = -\overline{w'\theta_v'}_s / u_*$ = surface-layer temperature scale

$\theta_{Lf} = \overline{w'\theta_v'} / w_{Lf}$ = local free-convection temperature scale

$\theta_L = -\overline{w'\theta_v'} / u_L$ = local temperature scale

$\theta_* = \overline{w'\theta_v'}_s$ /(any other velocity scale)

$\langle\overline{\theta}_v\rangle$ = mixed-layer average of $\overline{\theta}_v$

$\Delta\theta_s = \langle\overline{\theta}_v\rangle - \overline{\theta}_{vs}$ = SBL surface cooling (inversion strength)

L'approccio esplicativo e la ricchezza delle grandezze utilizzate (umidità)

Moisture:

$q_*^{ML} = \overline{w'q'}_s / w_* =$ convective (ML) humidity scale

$q_*^{SL} = -\overline{w'q'}_s / u_* =$ surface-layer humidity scale

$q_{Lf} = \overline{w'q'} / w_{Lf} =$ local free-convection humidity scale

$q_L = -\overline{w'q'} / u_L =$ local humidity scale

$q_* = \overline{w'q'}_s /$(any other velocity scale)

L'approccio esplicativo e la ricchezza delle grandezze utilizzate (umidità)

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$q_L = -\overline{w'q'} / u_L =$ local humidity scale

$q_* = \overline{w'q'}_s /$(any other velocity scale)

L'approccio esplicativo e la ricchezza delle grandezze utilizzate (tempo)

Time:	$1/f_c$	= inertial period, where f_c is the Coriolis parameter
	$1/N_{BV}$	= buoyant period, where N_{BV} is the Brunt-Väisälä frequency
	$1/f_{max}$	= eddy period, where f_{max} is the frequency at the peak in the turbulence spectrum
	t_*^{ML}	$= z_i / w_*$ = convective (ML) time scale
	t_*^{SL}	$= z / u_*$ = surface-layer time scale
	$x/\overline{U}$	= time required for wind to move distance x

Il Richardson number e la stabilità del ABL

In ABL stabili, dove la convezione non è spontanea per il gradiente termico verticale è $\frac{\partial \theta}{\partial z} > 0$

Energia cinetica turbolenta → Energia potenziale

$$\frac{\partial(TKE/m)}{\partial t} = Ad + M + B + Tr - \varepsilon$$

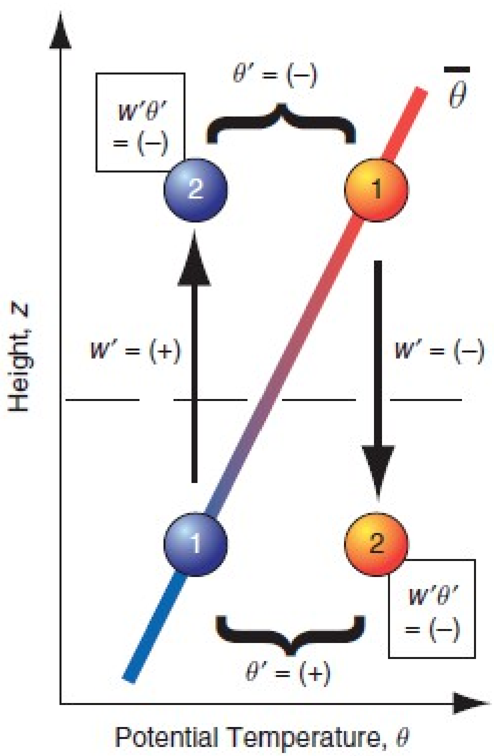
- Ad: Avvezione
- M: Generazione meccanica (wind shear)
- B: Generazione o dissipazione per gravità (buoyancy)
- Tr: Trasporto turbolento
- ε: Dissipazione molecolare

Il Richardson number e la stabilità del ABL

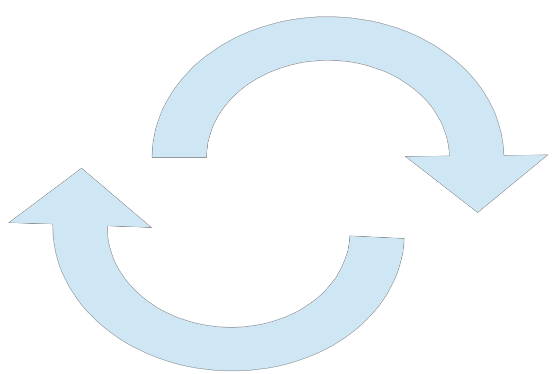
L'energia cinetica turbolenta viene utilizzata per spostare lungo la verticale masse d'aria in un ambiente stabile, quindi viene compiuto lavoro che va ad aumentare l'energia potenziale dell'aria

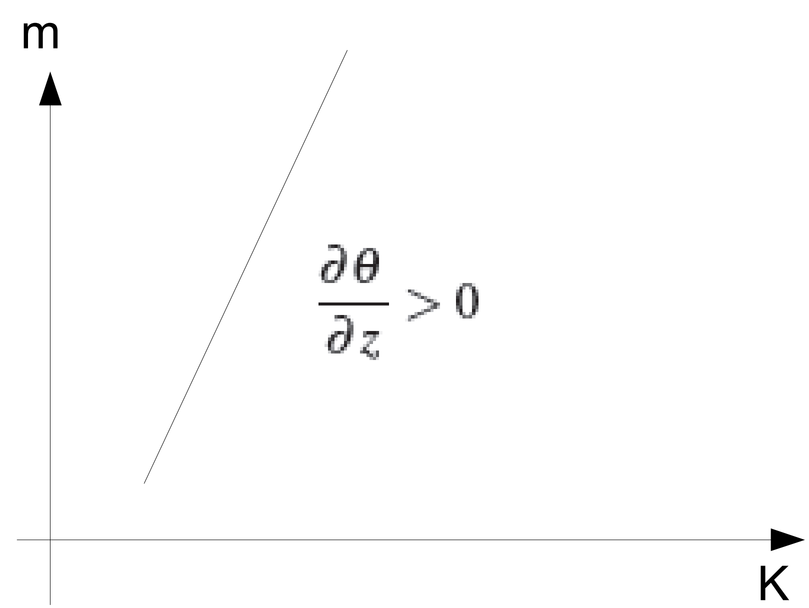
$$Ri = \frac{-B}{M} = \frac{\frac{g}{\overline{T}_v}\frac{\partial\overline{\theta}_v}{\partial z}}{\left(\frac{\partial\overline{u}}{\partial z}\right)^2+\left(\frac{\partial\overline{v}}{\partial z}\right)^2}$$

Frequenza di Brunt Väisälä



(b) Statically stable: $\partial\overline{\theta}/\partial z > 0$.





Alcuni risultati sperimentali sul numero di Richardson

ARGOMENTO DI TESI COMPUTAZIONALE

$$Ri = \frac{-B}{M} = \frac{\frac{g}{\overline{T}_v}\frac{\partial \overline{\theta}_v}{\partial z}}{\left(\frac{\partial \overline{u}}{\partial z}\right)^2 + \left(\frac{\partial \overline{v}}{\partial z}\right)^2}$$

(3.75). Laminar flow becomes turbulent when Ri drops below the critical value $Ri_c = 0.25$. Turbulent flow often stays turbulent, even for Richardson numbers as large as 1.0, but becomes laminar at larger values of Ri. The presence or absence of turbulence for $0.25 < Ri < 1.0$ depends on the history of the flow: a behavior analogous to hysteresis. Flows for which $Ri_c < 0.25$ are said to be *dynamically unstable*.

Osservazione dell'instabilità di Kelvin-Helmholtz in atmosfera

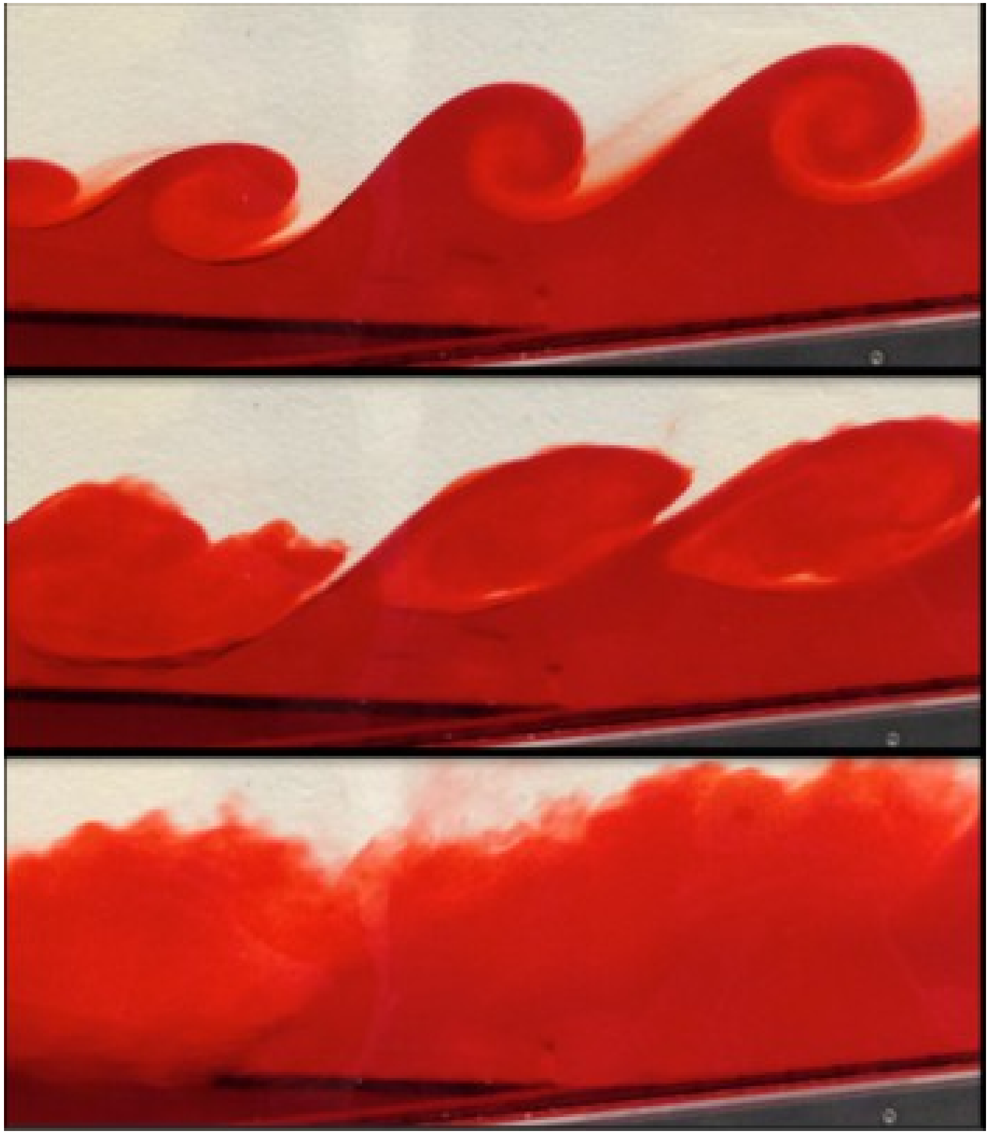
When the shear in laminar flow across a density interface (e.g., between cold air below and warm air above) increases to the point at which the flow becomes dynamically unstable, the turbulence onset grows as a *Kelvin-Helmholtz (KH) instability* on the interface. First, small waves appear that grow in amplitude and curl over on themselves.

Evoluzione dell'instabilità di Kelvin-Helmholtz

t = 1

t = 2

t = 3



La velocità della scala convettiva e l'instabilità del ABL

In ABL instabili, dove la convezione è spontanea per il gradiente termico verticale è $\frac{\partial \theta}{\partial z} < 0$

Energia cinetica turbolenta ← Energia potenziale

$$\frac{\partial (TKE/m)}{\partial t} = Ad + M + B + Tr - \varepsilon$$

- Ad: Avvezione
- M: Generazione meccanica (wind shear)
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ABL instabile: la velocità della scala convettiva

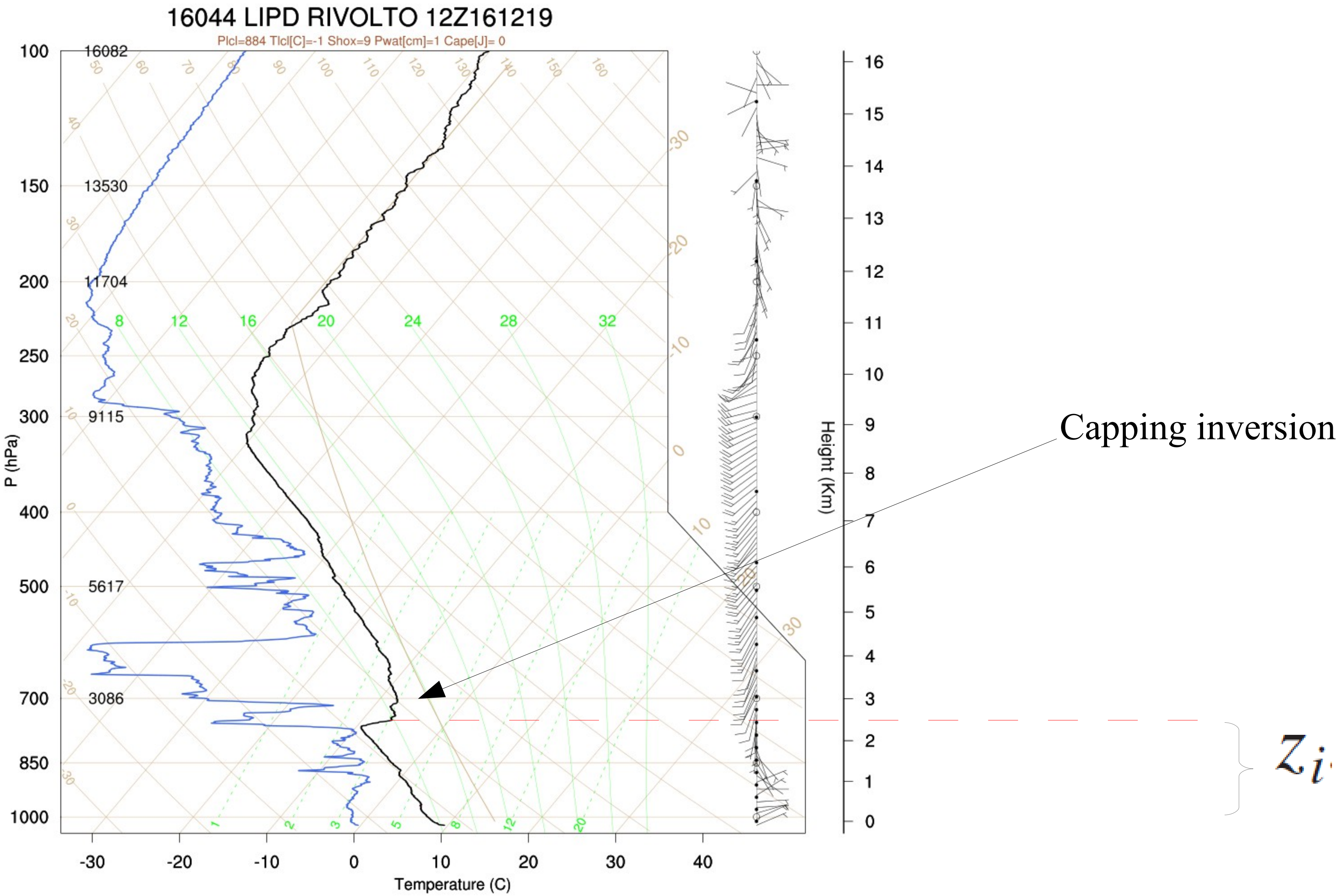
unstably stratified boundary layer is the *Deardorff velocity scale*

$$w_* = \left[\frac{g \cdot z_i}{T_v} \overline{w'\theta'_s} \right]^{1/3} \qquad (9.13)$$

where z_i is the depth of the boundary layer and the subscript s denotes at the surface. Values of w_* have been determined from field measurements and numerical simulations under a wide range of conditions. Typical magnitudes of w_* are $\sim 1 \text{ m s}^{-1}$, which corresponds to the average updraft velocities of thermals.

ABL instabili; la capping inversion height

The altitude of the capping inversion, z_i, is the relevant length scale for the whole boundary layer for statically unstable and neutral conditions.



ARGOMENTO E PER ESAME

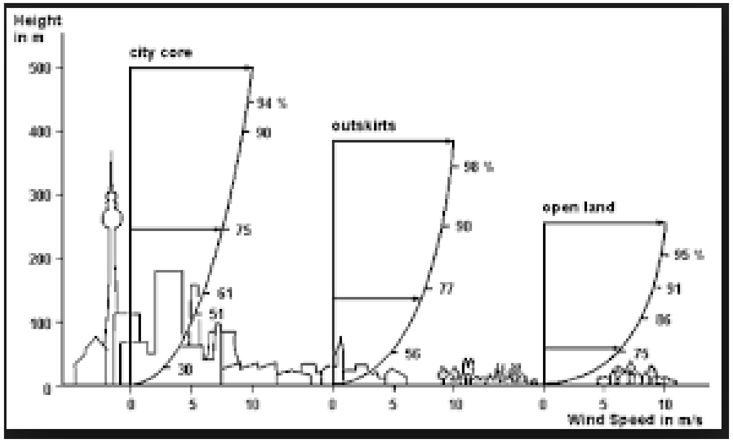
La friction velocity e l'ABL neutro

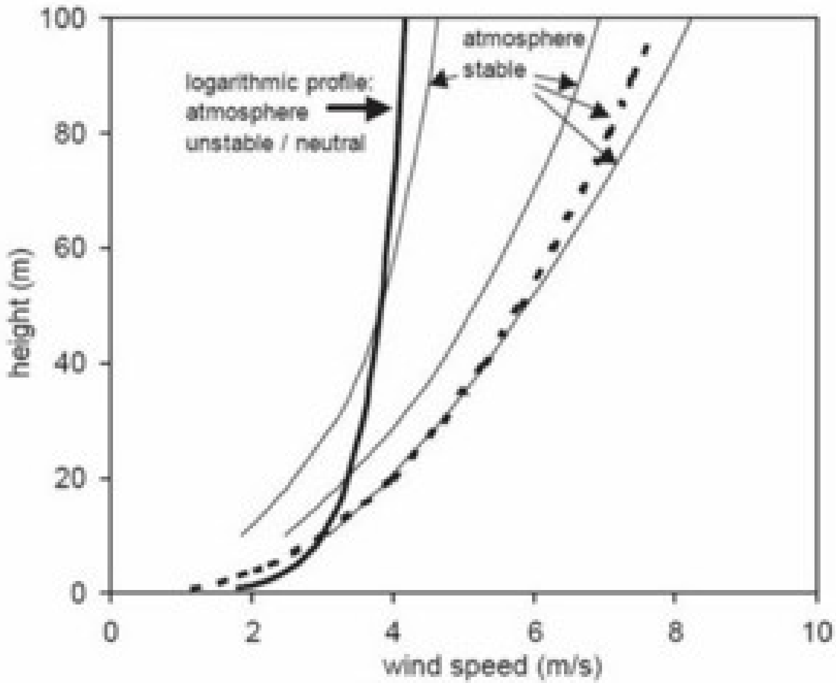
Another scale u_*, the *friction velocity*, is most applicable to statically neutral conditions in the surface layer, within which the turbulence is mostly mechanically generated. It is given by

$$u_* = \left[\overline{u'w'}^2 + \overline{v'w'}^2\right]^{1/4} = \left|\frac{\tau_s}{\rho}\right|^{1/2} \qquad (9.14)$$

where ρ is air density, τ_s is *stress* at the surface (i.e., drag force per unit surface area), and covariances $\overline{u'w'}$ and $\overline{v'w'}$ are the *kinematic momentum fluxes* (vertical fluxes of u and v horizontal momentum, respectively).

Il profilo verticale dell'intensità del vento in ABL neutrali (ruolo della friction velocity)





Where:

u = windspeed (ms⁻¹)

u = friction velocity (ms⁻¹)*

k = Von Karman's constant (0.4)

z = height (m)

d = zero-displacement height (m)

z_0 = roughness length

(after Oke, 1976)

$$u_z = \frac{u_*}{\kappa}\left[\ln\left(\frac{z-d}{z_0}\right) + \psi(z, z_0, L)\right]$$

$\psi(z, z_0, L)$ = stability term

Lunghezze scala di particolare rilievo per il Surface Layer

bottom 5% of the boundary layer (referred to as the *surface layer*), an important length scale is the *aerodynamic roughness length*, z_0, which indicates the roughness of the surface (see Table 9.2)

Table 9.2 The Davenport classification, where z_o is aerodynamic roughness length and C_{DN} is the corresponding drag coefficient for neutral static stability[a]

z_0 (m)	Classification	Landscape	C_{DN}
0.0002	Sea	Calm sea, paved areas, snow-covered flat plain, tide flat, smooth desert.	0.0014
0.005	Smooth	Beaches, pack ice, morass, snow-covered fields.	0.0028
0.03	Open	Grass prairie or farm fields, tundra, airports, heather.	0.0047
0.1	Roughly open	Cultivated area with low crops and occasional obstacles (single bushes).	0.0075
0.25	Rough	High crops, crops of varied height, scattered obstacles such as trees or hedgerows, vineyards.	0.012
0.5	Very rough	Mixed farm fields and forest clumps, orchards, scattered buildings.	0.018
1.0	Closed	Regular coverage with large size obstacles with open spaces roughly equal to obstacle heights, suburban houses, villages, mature forests.	0.030
≥2	Chaotic	Centers of large towns and cities, irregular forests with scattered clearings.	0.062

[a] From Preprints *12th Amer. Meteorol. Soc. Symposium on Applied Climatology*, 2000, pp. 96–99.

Lunghezze scala di particolare rilievo per il Surface Layer: la Obukhov length

roughness of the surface (see Table 9.2). For statically nonneutral conditions in the surface layer, there is an additional length scale, called the *Obukhov length*

$$L \equiv \frac{-u_*{}^3}{k \cdot (g/T_v) \cdot \left(\overline{w'\theta'}\right)_s}, \qquad (9.15)$$

where $k = 0.4$ is the von Karman constant. The absolute value of L is the height below which mechanically generated turbulence dominates.

Sintesi sulle grandezze scala più importanti nei diversi regimi di ABL

Per gli ABL **instabili** le grandezze scala più importanti sono:
- La convective scale velocity w_*
- La capping inversion z_i

Per i surface layer **neutri** le grandezze scala più importanti sono:
- La friction velocity u_*
- La roughness z_0

Per i surface layer **non neutri** le grandezze scala sono:
- La friction velocity u_*
- La roughness z_0
- La lunghezza di Obukhov L

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