Atmospheric Sciences 6220: Boundary Layer Meteorology

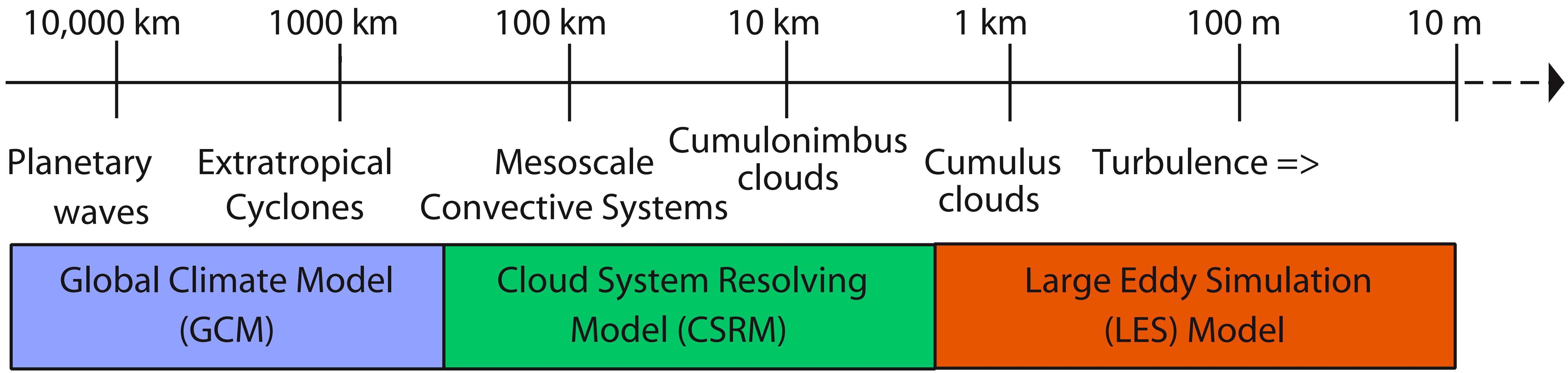
Micrometeorology

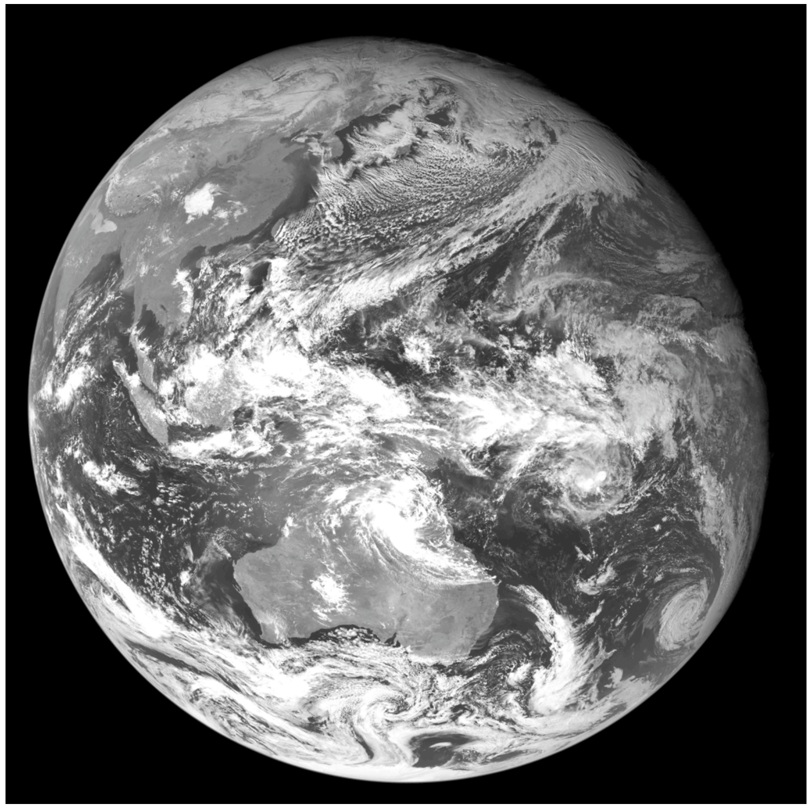
- Atmospheric motions range in size from about a millimeter to the earth's circumference (40,000 km) horizontally and the entire depth of the atmosphere in the vertical direction. [See the diagram *Scales of Atmospheric Motion*.]

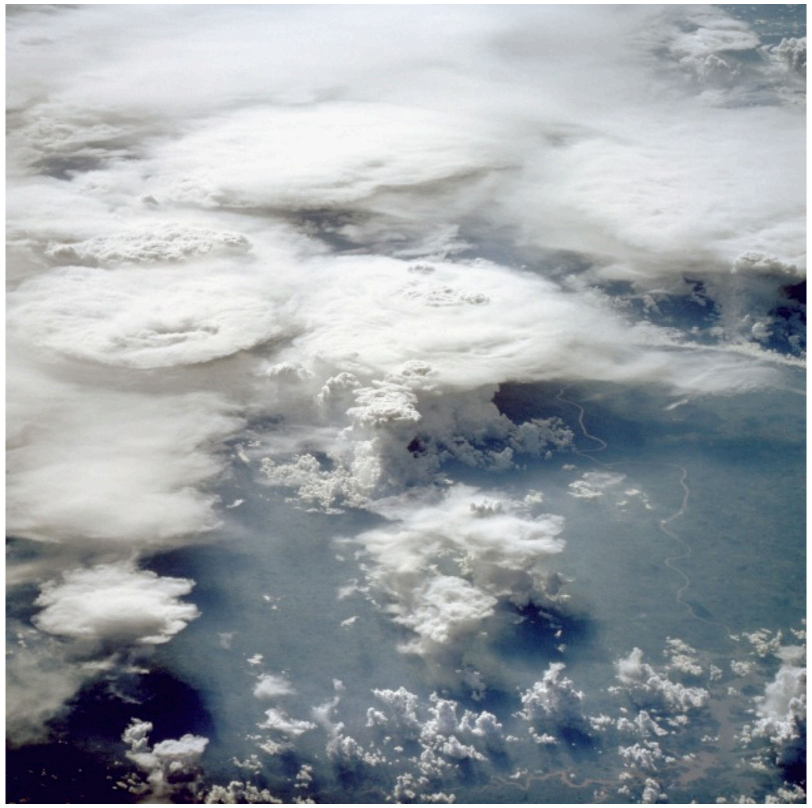
- The corresponding time scales range from fractions of a second to several months or years.

- *Micrometeorology* deals with the smaller-scale motions within the atmospheric (or planetary) boundary layer.

Scales of Atmospheric Motion







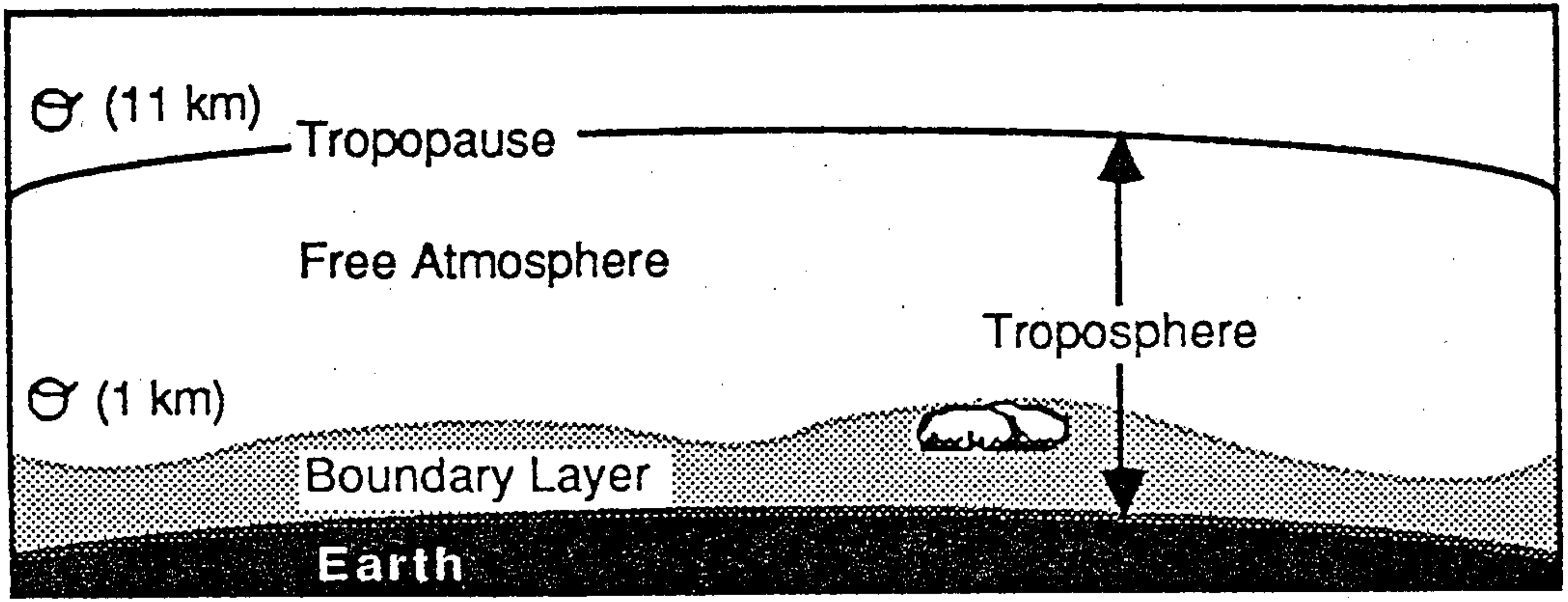
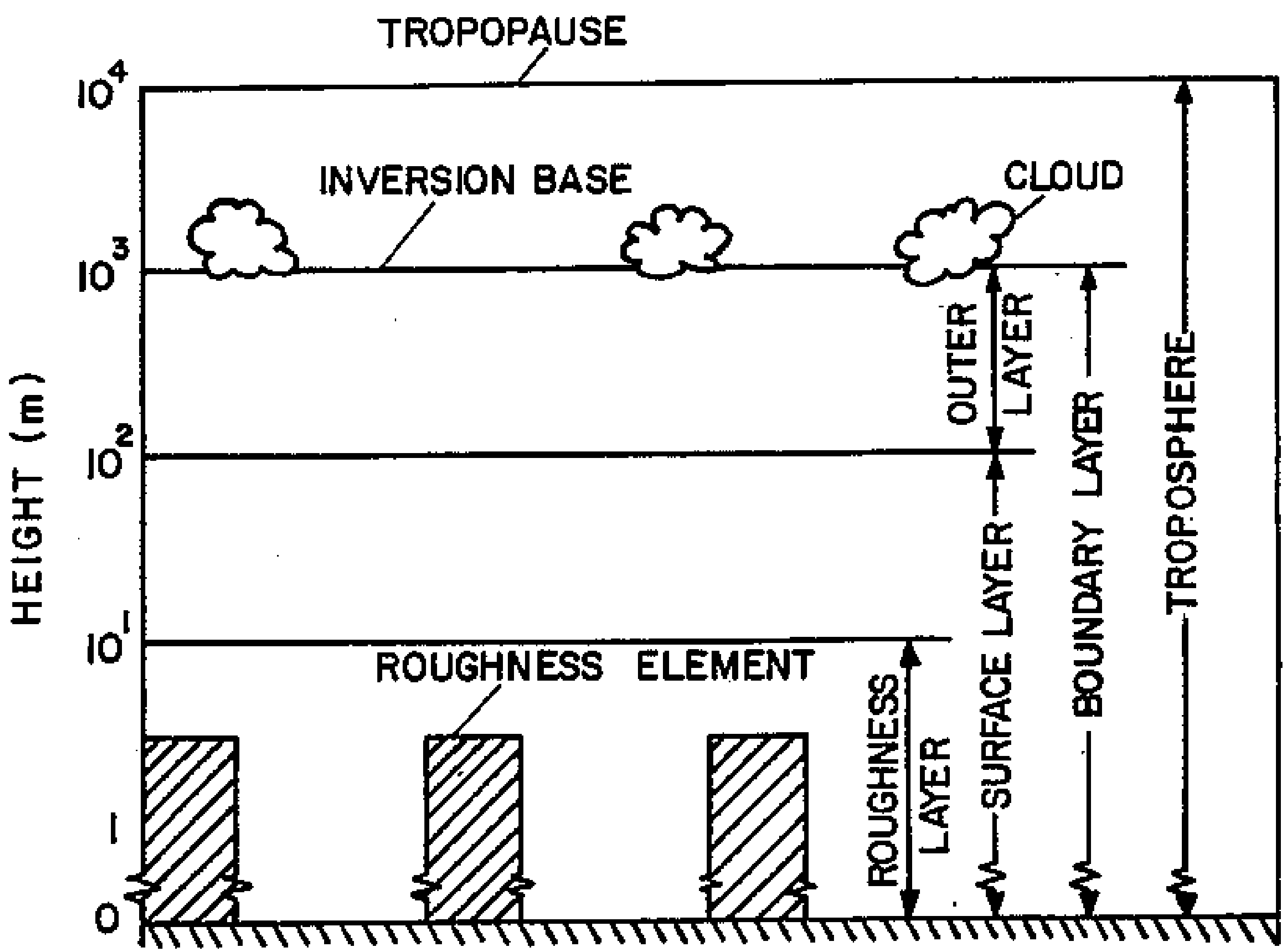


Fig. 1.1 The troposphere can be divided into two parts: a boundary layer (shaded) near the surface and the free atmosphere above it.

The Atmospheric Boundary Layer

- The *atmospheric (or planetary) boundary layer* (ABL, or PBL) is strongly influenced directly by interaction with the earth's surface.



- This is due ultimately to molecular viscosity (and molecular conduction of heat) in the *viscous sublayer* within a few mm of the surface.

- Viscosity causes the velocity to vanish at the surface: *no-slip boundary condition.* [**Draw schematic wind profile.**]

- This causes large velocity gradients near the surface, which leads to *turbulent eddies.*

- These eddies cannot be resolved by synoptic or mesoscale observing networks.

- The eddies transfer momentum to the surface and latent and sensible heat from the surface very effectively, and many times faster than by molecular diffusion.

- The ABL produced by such *turbulent transport* ranges in depth from 30 m to 3 km. On average over land it is 1 km deep (with a pronounced diurnal cycle), and over the ocean it is 500 m deep (with little diurnal variation).

- The structure of the ABL is due to turbulence. In the *free atmosphere* (above the ABL), turbulence is usually unimportant.

Atmospheric Turbulence

- *Turbulent flow* contains irregular, quasi-random motions that span a continuous range of space and time scales. [**Visualizations (3).**]
- Such motions cause nearby air parcels to drift apart and thereby *mix* properties such as momentum and potential temperature.
- The sizes of turbulent eddies range from about 1000 m (ABL depth) to 1 mm (smallest allowed by viscosity).
- Horizontal and vertical length scales of turbulent eddies are similar.

LES of passive scalar in a convective boundary layer

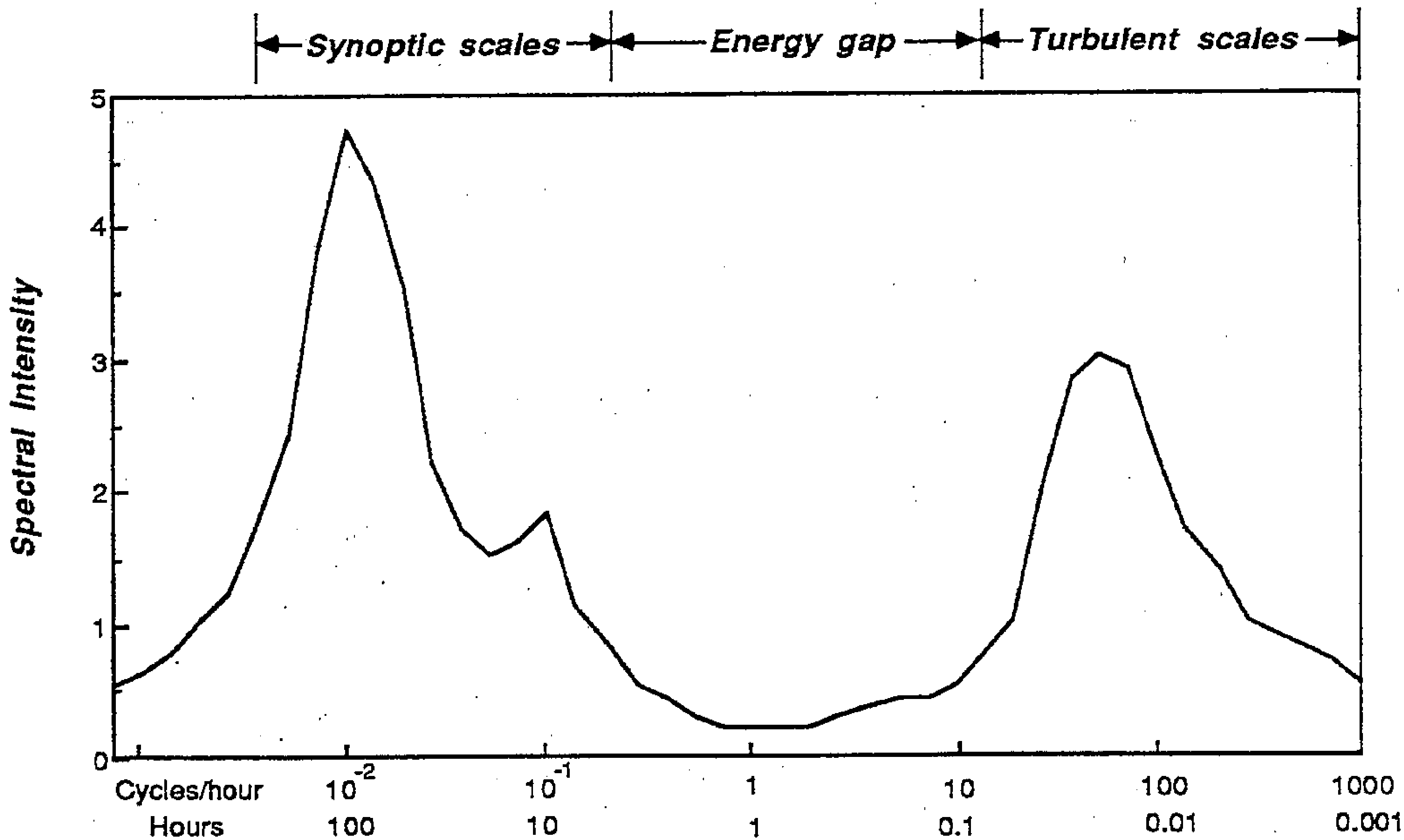


Fig. 2.2 Schematic spectrum of wind speed near the ground estimated from a study of Van der Hoven (1957).

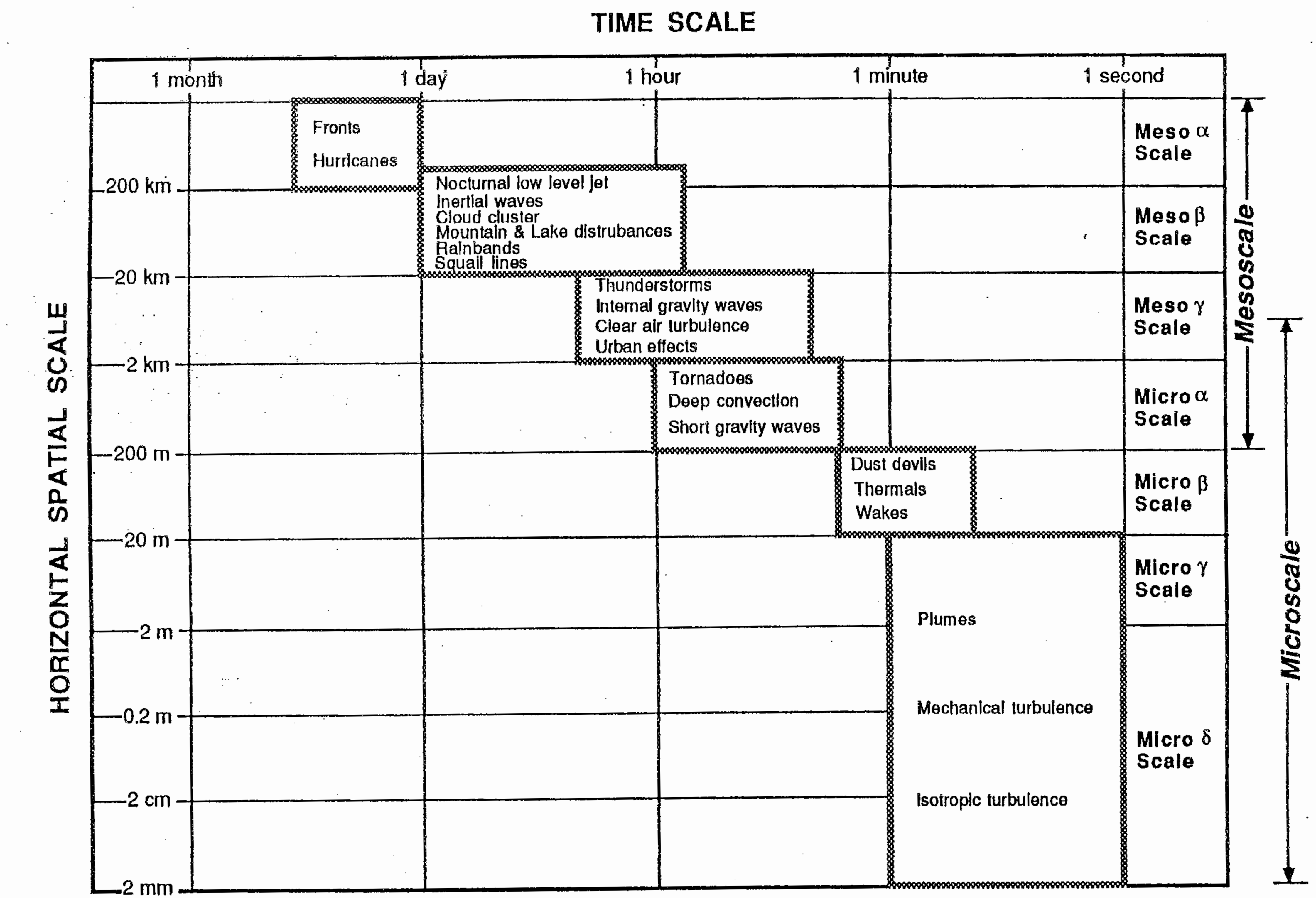
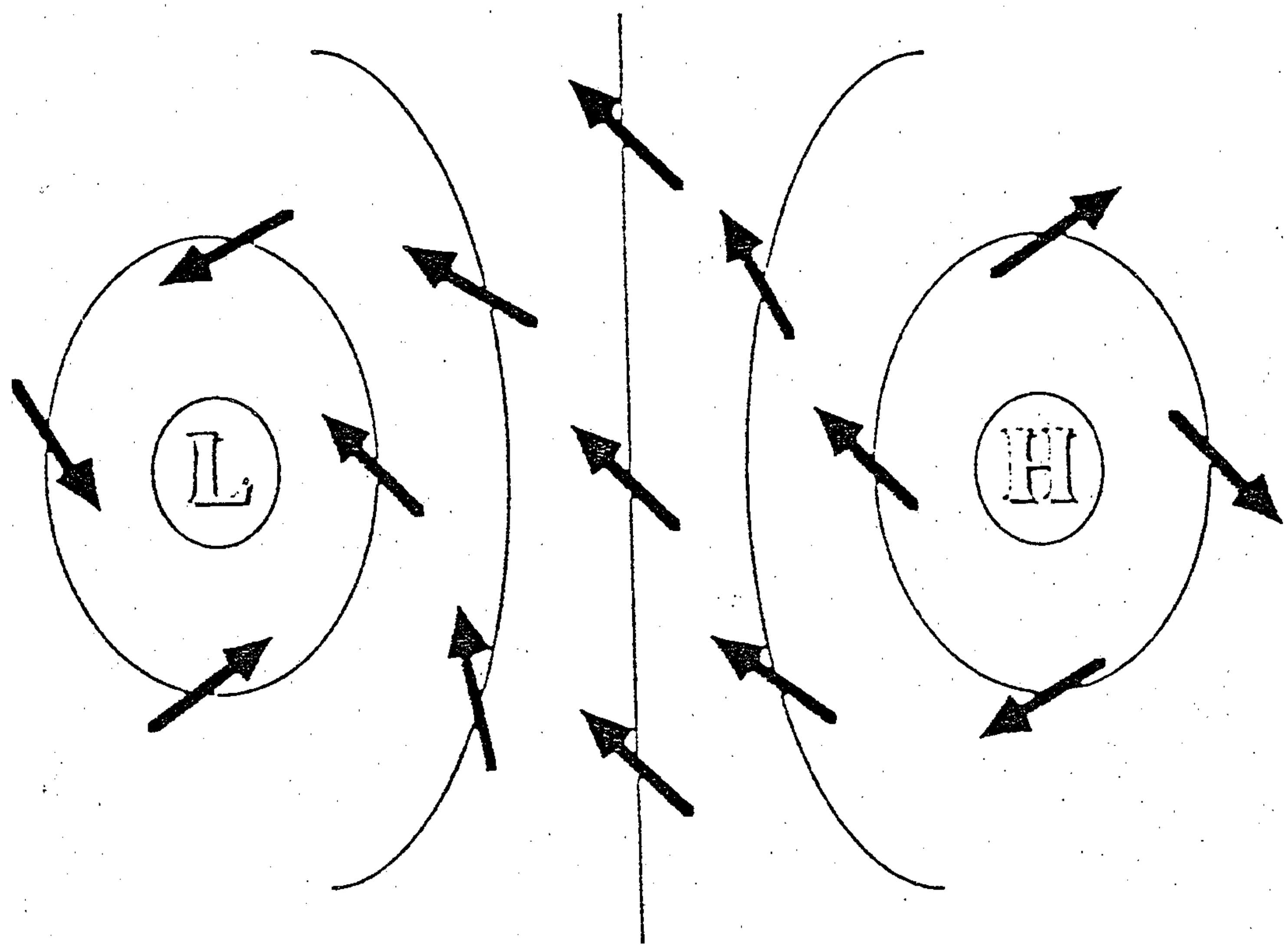


Fig. 1.15 Typical time and space orders of magnitude for micro and mesoscales.

- Although not resolved by meteorological observing networks, turbulent eddies on the ABL are very important and their effects cannot be neglected.
- Due to their effects, *geostrophic balance* is not a good approximation to the large-scale wind field in the PBL. This diagram shows schematic surface isobars and wind vectors.



- The ABL is also the source of air that rises into *convective clouds*, and is affected by downdrafts and precipitation from such clouds.

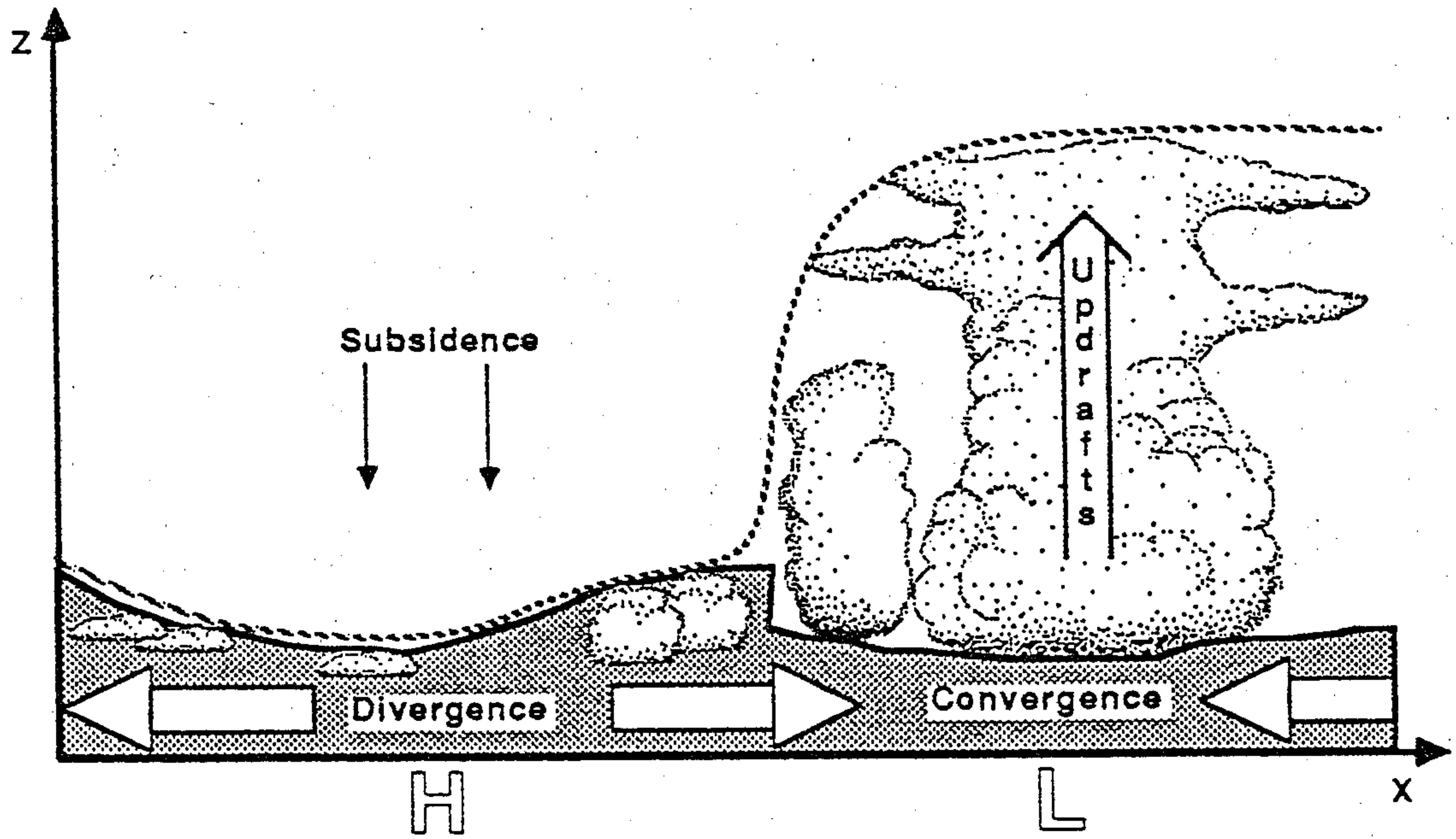


Fig. 1.6 Schematic of synoptic - scale variation of boundary layer depth between centers of surface high (H) and low (L) pressure. The dotted line shows the maximum height reached by surface modified air during a one-hour period. The solid line encloses the shaded region, which is most studied by boudary-layer meteorlogists.

Diurnal Cycle of Fair-Weather ABL over Land

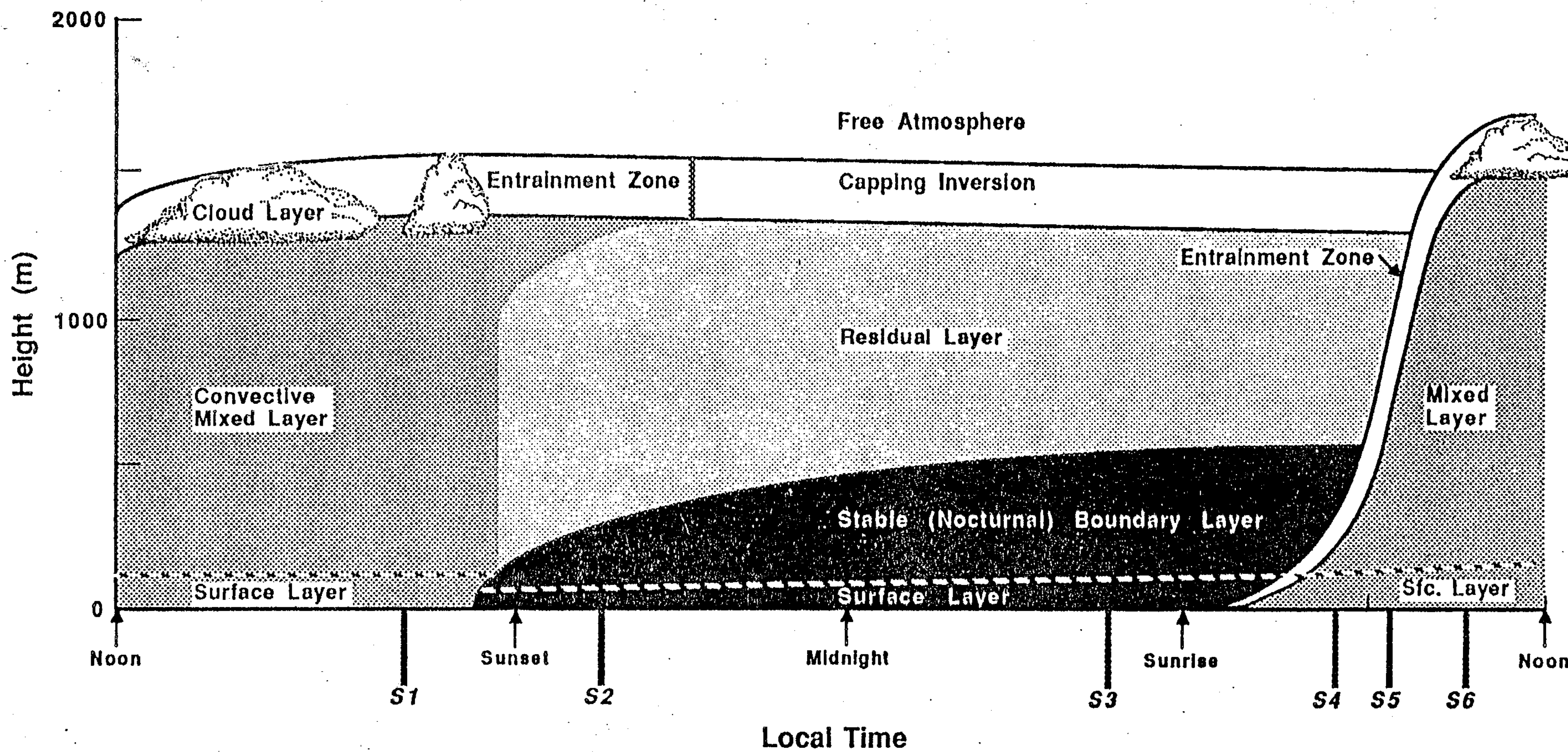


Fig. 1.7 The boundary layer in high pressure regions over land consists of three major parts: a very turbulent mixed layer; a less-turbulent residual layer containing former mixed-layer air; and a nocturnal stable boundary layer of sporadic turbulence. The mixed layer can be subdivided into a cloud layer and a subcloud layer. Time markers indicated by S1-S6 will be used in Fig. 1.12.

Table 1-1. Comparison of boundary layer and free atmosphere characteristics.

Property	Boundary Layer	Free Atmosphere
Turbulence	• Almost continuously turbulent over its whole depth.	• Sporadic CAT in thin layers of large horizontal extent.
Friction	• Strong drag against the earth's surface. Large energy dissipation.	• Small viscous dissipation.
Dispersion	• Rapid turbulent mixing in the vertical and horizontal.	• Small molecular diffusion. Often rapid horizontal transport by mean wind.
Winds	• Near logarithmic wind speed profile in the surface layer. Subgeostrophic, cross-isobaric flow common.	• Winds nearly geostrophic.
Vertical Transport	• Turbulence dominates.	• Mean wind and cumulus-scale dominate
Thickness	• Varies between 100 m to 3 km in time and space. Diurnal oscillations over land.	• Less variable. 8-18 km. Slow time variations.

From Arya (1988):

1.3.2 Applications

In the following text, we have listed some of the possible areas of application of micrometeorology together with the subareas or activities in which micrometeorological information may be especially useful.

1. Air pollution meteorology
   - Atmospheric transport and diffusion of pollutants
   - Atmospheric deposition on land and water surfaces
   - Prediction of local, urban, and regional air quality
   - Selection of sites for power plants and other major industries
   - Selection of sites for monitoring urban and regional air pollution
   - Industrial operations with emissions dependent on meteorological conditions
   - Agricultural operations such as dusting, spraying, and burning
   - Military operations with considerations of obscurity and dispersion of contaminants

2. Mesoscale meteorology
   - Urban boundary layer and heat island
   - Land–sea breezes
   - Drainage and mountain valley winds
   - Dust devils, water spouts, and tornadoes
   - Development of fronts and cyclones
3. Macrometeorology
   - Atmospheric predictability
   - Long-range weather forecasting

- Siting and exposure of meteorological stations
- General circulation and climate modeling

4. Agricultural and forest meteorology
    - Prediction of surface temperatures and frost conditions
    - Soil temperature and moisture
    - Evapotranspiration and water budget
    - Energy balance of a plant cover
    - Carbon dioxide exchanges within the plant canopy
    - Temperature, humidity, and winds in the canopy
    - Protection of crops and shrubs from strong winds and frost
    - Wind erosion of soil and protective measures
    - Effects of acid rain and other pollutants on plants and trees

5. Urban planning and management
    - Prediction and abatement of ground fogs
    - Heating and cooling requirements
    - Wind loading and designing of structures
    - Wind sheltering and protective measures
    - Instituting air pollution control measures
    - Flow and dispersion around buildings
    - Prediction of road surface temperature and possible icing
6. Physical oceanography
    - Prediction of storm surges
    - Prediction of the sea state
    - Dynamics of the oceanic mixed layer
    - Movement of sea ice
    - Modeling large-scale oceanic circulations
    - Navigation
    - Radio transmission