Numerical Weather Prediction (NWP)

Parameterization and physical processes:

Basic concepts of Planetary boundary layer, Land surface processes, Convection (Deep cumulus and shallow convection), Large scale condensation, Radiation (short wave and long wave parameterization), Cloud Radiation interaction, Dry and moist convective adjustment processes, Cloud microphysical parameterization

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Forecasters Training Course (FTC) Batch No. 192

Books to follow..

An Introduction of Dynamic Meteorology, James R. Holton

Atmospheric Science: An Introductory Survey by Wallace and Hobbs

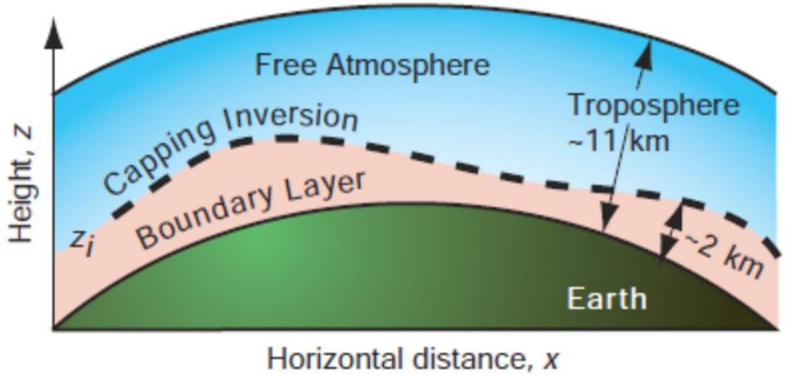
Fundamental of Atmospheric Modelling, Mark Z. Jacobson

Basic concepts of Planetary boundary layer

Definition and major characteristics

The planetary boundary layer is that portion of the atmosphere in which the flow field is strongly influenced directly by interaction with the surface of the earth.

The thickness of the boundary layer is quite variable in space and time. Normally 1 or 2 km thick (i.e., occupying the bottom 10 to 20% of the troposphere), it can range from tens of meters to 4 km or more.



Vertical cross section of the Earth and troposphere showing the atmospheric boundary layer as the lowest portion of the troposphere.

Capping inversion: A stable layer between the boundary layer below and the rest of the troposphere above (free troposphere).

This stable layer traps turbulence, pollutants, and moisture below it and prevents most of the surface friction from being felt by the free atmosphere.

Stability of the boundary layer:

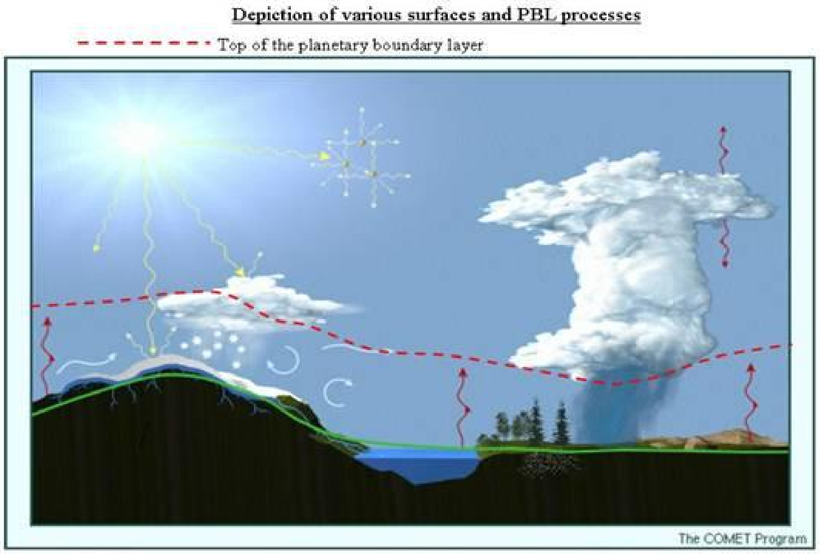
Unstable : whenever the surface is warmer than the air, such as during a sunny day with light winds over land, or when cold air is advected over a warmer water surface. This boundary layer is in a state of free convection, with vigorous thermal updrafts and downdrafts.

Stable : when the surface is colder than the air, such as during a clear night over land, or when warm air is advected over colder water.

Neutral: boundary layers form during windy and overcast conditions, and are in a state of forced convection.

Factors determine the PBL depth and its mean vertical structure:

- The free atmosphere wind speed
- The surface heat (more exactly buoyancy) balance
- The free atmosphere density stratification
- The free atmosphere vertical wind shear or baroclinicity.

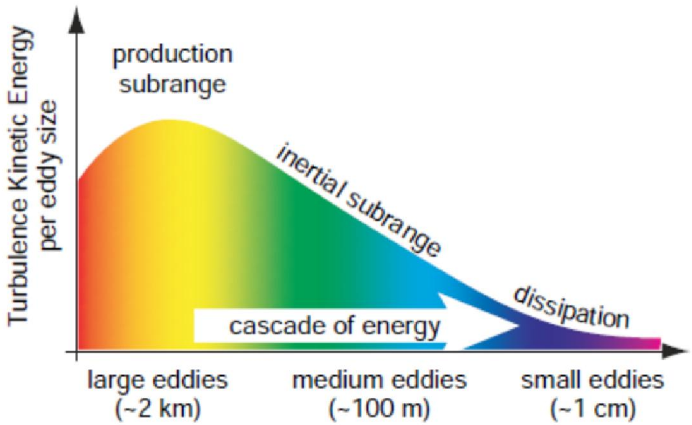


Atmospheric Turbulence

- Turbulent flow contains irregular quasi-random motions spanning a continuous spectrum of spatial and temporal scales.
- Such eddies cause nearby air parcels to drift apart and thus mix properties such as momentum and potential temperature across the boundary layer.
- Unlike the large-scale rotational flows, which have depth scales that are small compared to their horizontal scales, the turbulent eddies of concern in the planetary boundary layer tend to have similar scales in the horizontal and vertical.
- Turbulent communication between the surface and the air is quite rapid (within about 30 min or less), allowing the air to quickly take on characteristics of the underlying surface.

Table 9.1 Scales of horizontal motion in the atmosphere

Larger than	Scale	Name
20,000 km		Planetary scale
2,000 km		Synoptic scale
200 km	Meso-α	Mesoscale
20 km	Meso-β	Mesoscale
2 km	Meso-γ	Mesoscale
200 m	Micro-α	Boundary-layer turbulence
20 m	Micro-β	Surface-layer turbulence
2 m	Micro-γ	Inertial subrange turbulence
2 mm	Micro-δ	Fine-scale turbulence
Air molecules	Molecular	Viscous dissipation subrange



The spectrum of turbulence kinetic energy. The total turbulence kinetic energy (TKE) is given by the area under the curve. Production of TKE is at the large scales (analogous to the longer wavelengths in the electromagnetic spectrum, as indicated by the colors). TKE cascades through medium-size eddies to be dissipated by molecular viscosity at the small-eddy scale.

Turbulence kinetic energy (TKE) is not conserved. It is continually *dissipated* into internal energy by molecular viscosity. This dissipation usually happens at only the smallest size (1 mm diameter) eddies, but it affects all turbulent scales because of the turbulent cascade of energy from larger to smaller scales.

For turbulence to exist, there must be continual generation of turbulence from shear or buoyancy to offset the transfer of kinetic energy down the spectrum of ever-smaller eddy sizes toward eventual dissipation.

But why does nature produce turbulence?

Turbulence is a natural response to instabilities in the flow-a response that tends to reduce the instability.
For example, on a sunny day the warm ground heats the bottom layers of air, making the air statically unstable. The flow reacts to this instability by creating thermal circulations, which move warm air up and cold air down until a new equilibrium is reached. Once this convective adjustment has occurred, the flow is statically neutral and turbulence ceases. The reason why turbulence can persist on sunny days is because of continual destabilization by external forcings (i.e., heating of the ground by the sun), which offsets continual stabilization by turbulence.

What is the role of turbulence in the boundary layer?

Even when observations are taken with very short temporal and spatial separations, a turbulent flow will always have scales that are unresolvable because they have frequencies greater than the observation frequency and spatial scales smaller than the scale of separation of the observations.

Outside the boundary layer, in the free atmosphere, the problem of unresolved scales of motion is usually not a serious one for the diagnosis or forecasting of synoptic and larger scale circulations. The eddies that contain the bulk of the energy in the free atmosphere are resolved by the synoptic network.

However, in the boundary layer, unresolved turbulent eddies are of critical importance. Through their transport of heat and moisture away from the surface they maintain the surface energy balance, and through their transport of momentum to the surface they maintain the momentum balance.

The latter process dramatically alters the momentum balance of the large-scale flow in the boundary layer so that geostrophic balance is no longer an adequate approximation to the large-scale wind field.

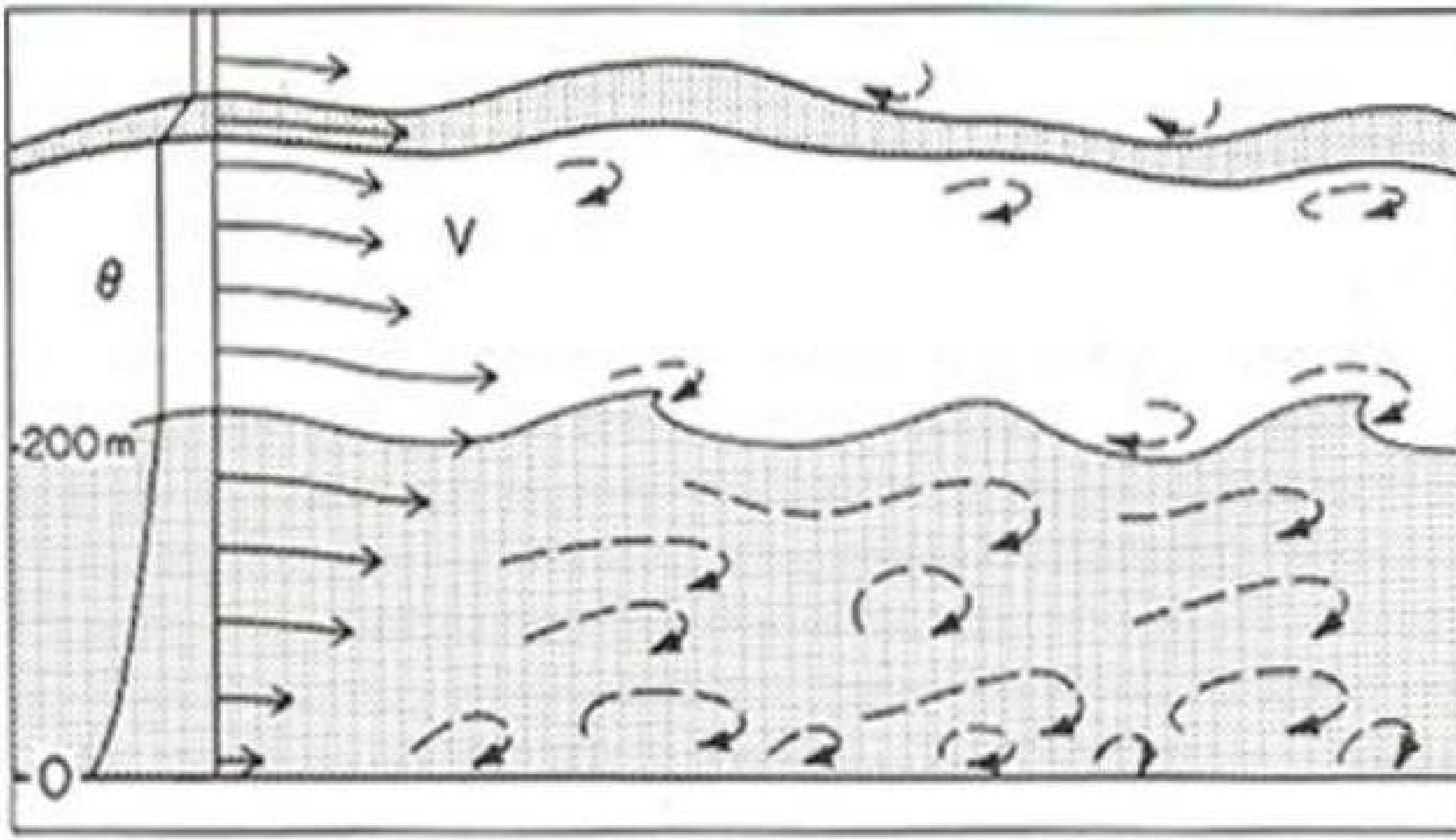


FIG. 1.5. Schematic of stable boundary layer flow showing eddy structure, waves, and elevated inversion layer (from Wyngaard, 1990).