Lecture Notes on Boundary Layer Meteorology

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Abstract
Notes of Lectures and addional information from books:
An introduction to boundary layer meteorology([1]).

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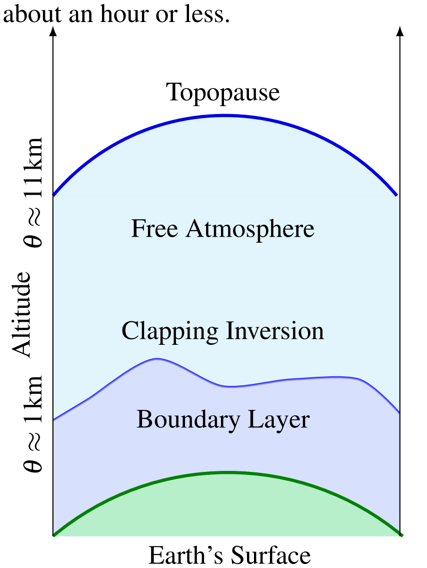
1. Lecture 1 09/01/2025

1.1 Introduction to Boundary Layer

The Boundary Layer can be defined as part of the troposphere that is directly influenced by the presence of the Earth's surface and responds to surface forcings with a time scale of about an hour or less.



1.2 Boundary layer forcing mecchanism

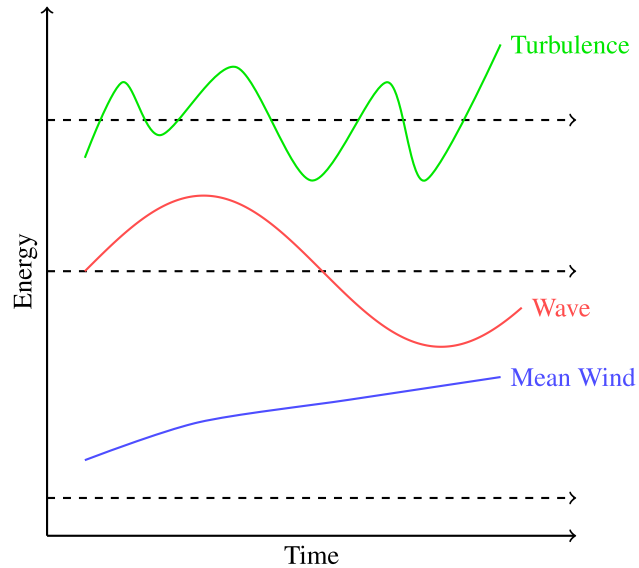
What physical process modify boundary layer air parcel?

1. Heat transfer to.from the ground.
2. Frictional drag.
3. Evaporation/transpiration.
4. Terrain-induced flow modification.
5. Pollution emission.

1.3 Types of air flow or wind

Air flow or wind can be decomposed into following 3 types:

1. **Mean Wind** $(\bar{u}, \bar{v}, \bar{w})$: Represents the average wind components in the horizontal $(\bar{u}, \bar{v})$ and vertical $(\bar{w})$ directions. It is important for the horizontal transport of quantities such as moisture, heat, momentum, and pollutants, a process known as advection.
2. **Waves**: Atmospheric waves, such as gravity waves, occur mostly at night in the nocturnal boundary layer (NBL). They can influence the structure of the boundary layer and the transport of energy.
3. **Turbulence**: The vertical transport of moisture, heat, momentum, and pollutants is primarily dominated by turbulence, which is characterized by chaotic and irregular motion.

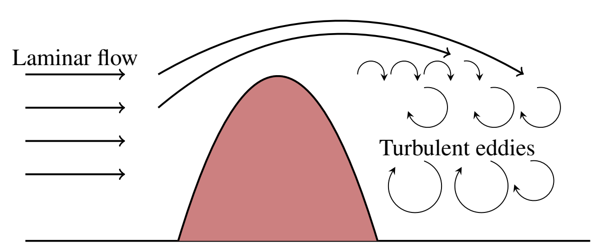


1.4 Eddies

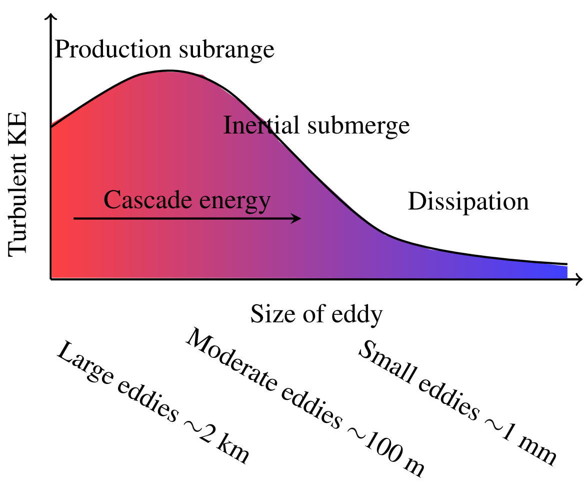
Eddies are formed due to the interaction of currents with obstacles like coastlines, underwater topography, or other currents, as well as from the instability of larger current systems. Eddies exhibit a rotational flow pattern, either clockwise or counterclockwise. Eddies can vary from size 100 to 3000 metres and also can exists as small as few millimetres. Small eddies might last for seconds to minutes, while larger oceanic eddies can persist for weeks, months, or even years.

1.5 Turbulence Generation Mechanisms

- **Solar Heating**: Solar heating generates thermals, which are essentially larger eddies that drive turbulence in the atmospheric boundary layer.
- **Wind Shear**: Variations in wind speed or direction with height create wind shear, which is a significant source of turbulence.
- **Obstacle-Induced Flow**: Deflected flow around obstacles such as trees, buildings, or other structures generates turbulent eddies downstream of these obstacles, creating turbulent wakes.



Large eddies will break into smaller eddies after which small eddies dissipates from K.E. to thermal energy.

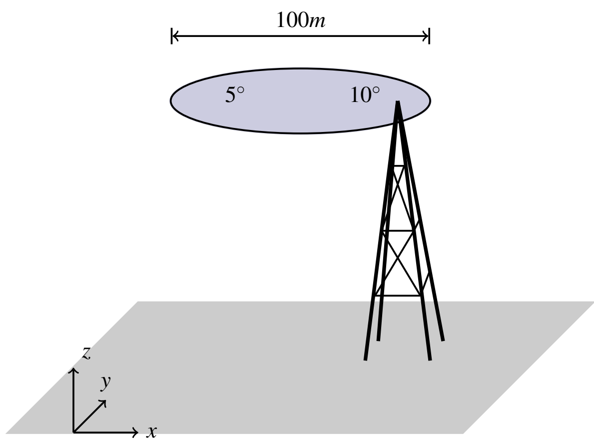

Production subrange
Inertial submerge
Cascade energy
Dissipation
Turbulent KE
Size of eddy
Large eddies ~2 km
Moderate eddies ~100 m
Small eddies ~1 mm

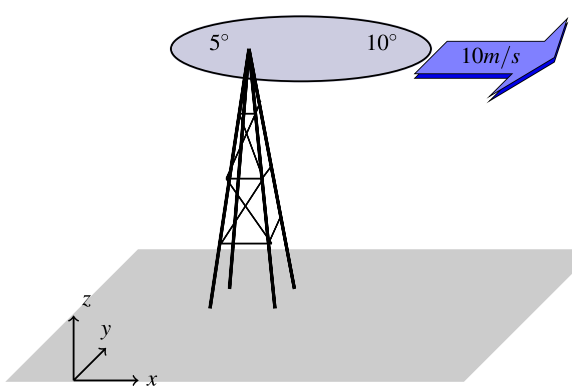
Todo:
1. BLD figure

2. Leture 2 15/01/2025

2.1 Taylor's Hypothesis

- When studying atmospheric boundary layer (ABL), It is not easy to create a snapshot of turbulence in the Atmosphere.
- Hence it is easier and cheaper to make measurements of point in the atmoshpere for a longer time, then an instantaneous snapshot.
- So we just consider the atmoshpere is frozen.
- ***Taylor suggested that turbulence can be considered frozen as it advects past sensor.***





$$\frac{\partial T}{\partial x} = 0.05\text{K/m}, \quad \frac{\partial T}{\partial t} = -0.5\text{K/s}$$

$$\underbrace{\cancel{\frac{DT}{Dt}}}_{\substack{\text{Total derivative = 0}\\ \text{(Taylor's hypothesis)}}} = \underbrace{\frac{\partial T}{\partial t}}_{\text{Local derivative}} + \underbrace{u\frac{\partial T}{\partial x}}_{\text{Advective term}}$$

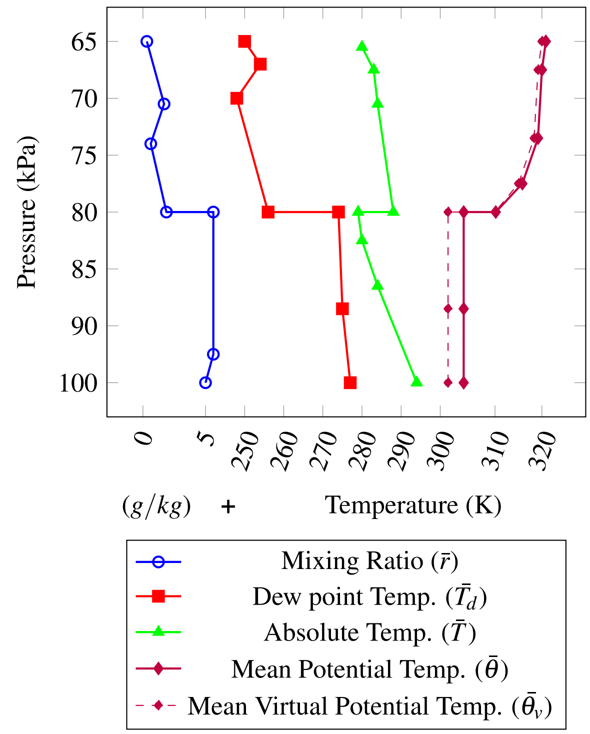
2.2 Virtual Potential Temperature

Virtual potential temperature:

$$\theta_v = \theta(1+0.61r) \tag{1}$$

Virtual temperature:

$$T_v = T(1+0.61r) \tag{2}$$



Question 2.1:

Given 25°C termperature, mixing ratio $\bar{r}$ is 20g/kg, measured Pressurere at 900hPa, find virtual potential temperature.

Answer 2.1:

Solution:

$$\begin{aligned}
\theta &= T \times \left(\frac{1000}{P}\right)^{0.286} \\
&= 298 \times \left(\frac{1000}{900}\right)^{0.286} \\
&= 332.222K \\
\theta_v &= \theta \times \left(1+0.61r\right) \\
&= 332.22 \times \left(1+0.61 \times 0.025\right) \\
&= 336.273K
\end{aligned}$$

$$\theta_v - \theta \approx 4.05K$$

2.3 Boundary Layer Depth and Structure

- Mixed layer
- Boundary layer
- Residual layer
- Capping Inversion
- Nauturnal Boundary layer

2.4 Stability and plumming behaviour

Incomplete

References

[1] R. B. Stull. *An introduction to boundary layer meteorology*. Atmospheric Sciences Library. Kluwer Academic Publishers, 1988.