AT623 Syllabus

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Teaching Assistant: None

1. Introductory overview

- Where does boundary-layer meteorology fit in the big picture of atmospheric science?
  - Dynamics across scales
    - Dynamics isn't just large-scale dynamics
    - Small-scale dynamics is interesting and important in its own right
    - Interactions across scales are most interesting of all
  - Momentum exchanges
  - Moisture exchanges
  - Energy exchanges
  - Dissipation
  - Air-sea interactions
  - Air-land interactions
  - Applications
    - Parameterizations for use in models
    - Air pollution dispersion
    - Agricultural meteorology
    - Aviation meteorology
    - Military applications
- Boundary layers in engineering applications
  - Viscosity
  - No slip
  - Shear and vorticity
  - Vortex shedding
  - The Reynolds Number
  - Form drag
- Characteristics of the atmospheric boundary layer
  - Definition
  - Turbulence
  - Surface fluxes and bulk aerodynamic formulae
  - "Stable" and "unstable" boundary layers

    - The surface layer
    - Mixed layers
    - The boundary layer top
    - Entrainment across the boundary layer top
    - The diurnal cycle of the boundary layer over land
    - Stratocumulus clouds
    - Shallow cumulus clouds
    - Deep cumulus convection
- Coupling to the land surface
- Mixed layers in the ocean and lakes
- Benthic boundary layers
- Climatology of the surface fluxes of sensible heat, latent heat, and momentum

2. Introduction to turbulence in the boundary layer

- Definition of turbulence
    - Many interacting vortices
    - Chaos
    - Many scales
    - Energy cascades
    - Thermals and rolls
- Preliminary discussion of the turbulence kinetic energy (TKE) equation, postponing the derivation until later
    - Reynolds averaging
    - Shear production
    - Buoyant production
    - Dissipation
    - Third moments
    - Pressure terms
    - Advection terms
    - "Storage" term

3. Where does turbulence come from?

- Shearing instability
    - Basic mechanism
    - The effects of stratification
    - Breaking waves
- Convective instability
    - What is buoyancy?

    - Rayleigh-Benard convection
    - Thermals and plumes

4. Large Eddy Simulation

- History
- Current applications

5. Where do fluxes come from?

- Diffusion and mixing-length theory
- Mass fluxes
- Penetrative convection

6. The surface layer

- Dimensional analysis and similarity theory
- Monin-Obukhov similarity theory
- The logarithmic wind profile
- Surface roughness
- Kansas and Minnesota experiments
- The bulk aerodynamic formulas
- The limits of similarity theory

7. Mixed layers

- What is mixing, and what can be mixed?
- Linear flux profiles
- Convective velocity scale
- Diffusion versus advection
- Entrainment across the top of a mixed layer

8. Stable boundary layers

- Nocturnal boundary layer
- The evening transition
- Drainage
- Waves

9. Ekman layers

- Force balance perspective
- Energy perspective

- Ekman spirals
- Momentum mixing
- Ekman "pumping"

10. Vegetation

- Stomates, photosynthesis, and transpiration
- The canopy air space

11. Second and third moments

- Notation
- The Reynolds stress equation
- The TKE equation revisited
- Dissipation
- Return to isotropy
- Third moments and skewness
- Scalar variances and covariances
- The connection between gradient production and dissipation

12. Linking higher-order closure to mass fluxes

- KPP
- EDMF
- Assumed distributions with higher-order closure
- Entraining and detraining plumes
- Diffusion and mass fluxes as limits that come from the variance equation
- Closure for sigma
- Double Gaussians

13. Stratocumulus-capped boundary layers

- Marine subtropical stratocumulus layers
- Buoyancy in cloudy layers
- The importance of cloud-top radiative cooling
- Evaporative cooling and cloud-top entrainment instability

14. Partly cloudy boundary layers

- Cumulus instability
- Decoupling
- Sommeria and Deardorff

- Buoyancy fluxes in partly cloudy layers
- Mesoscale organization

15. Interactions of the boundary layer with deep cumulus convection

- Cloud roots
- Updrafts
- Downdrafts
- Cold pools
- The effects of deep convection on the surface fluxes
- Elevated nocturnal convection

16. Turbulent dispersion of tracers

- Based on Section 10a of Lemone et al. 2019

17. The ocean mixed layer

- Thermocline
- Diurnal cycle
- Entrainment

18. Coupled mixed layers

- Sloping edges
- The tropical Pacific

19. Boundary layer parameterizations for large-scale models

- What's in CAM
- Issues

20. Frontiers

- The boundary layer over complex terrain
- The urban boundary layer
- Tropical cyclone boundary layers
- The Arctic boundary layer
- Beyond Monin-Obukhov similarity theory
- Stochastic back-scatter
- Direct numerical simulation
- The grey zone