Boundary Layer Flows and Turbulence

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Jielun Sun, Jordi Vila, Andrey Grachev, Tim Wagner, Dan Li, and contributions from many colleagues attending the breakout discussions

Overall Summary

- Many similarities among the scientific frontiers and instrument needs identified by the three speakers and in the breakout sessions
  - Stable Boundary Layers, Convective Boundary Layers and Entrainment Processes, and Influence of Topography and Landuse
- We decided to organize summary based on overarching themes rather than based on the three original topics
  - **Structure of the Entire Planetary Boundary Layer (PBL) and Interactions with the Free Troposphere**
  - **Structure of the Entire PBL and Interactions with the Land Surface**
  - **Spatial and Temporal Variability of the PBL**
- One more theme to highlight: **measurements of chemical species throughout the BL, integrated with traditional BL observations, are extremely useful for advancing the understanding of BL processes and for meeting societal needs**

Structure of entire PBL interacting with the free troposphere

- SBL
  - Understanding basic characteristics of turbulence structure and its representation in models
  - Interactions between kinetic and thermal energy
  - Role of intermittent and wave flow
- CBL
  - Transition of boundary layers from clear to cloudy
  - Boundary layer top processes (entrainment, shear, waves, subsidence)
  - Aerosol processes
- Complex
  - Definition of the BL in complex terrain and urban areas
- General: is the concept of the mixing height appropriate?
  - Vertical profile of turbulence parameters is what is really needed!

Structure of entire PBL interacting with the land surface

- SBL
  - Interactions between SBL and large coherent eddies
  - Structure of stable boundary layer over plant and urban canopies
  - Radiative flux divergence near the surface
- CBL
  - Surface energy balances and its relationship to turbulence
  - Turbulence, biology, and chemistry interactions in and above canopies
- Complex
  - Structure, dynamics and turbulence properties in the canopy (vegetation/urban) layer, roughness sublayer and mountain BLs.
  - Urban dome circulation vs. urban plume?
    - Conditions in which they form, details about flow and turbulence characteristics, impacts on air quality and convection

Spatial and temporal variability of the PBL

- SBL and CBL
  - Heterogeneity of thermal and frictional properties
    - Step changes in surface properties
    - Patchy variability in surface properties
  - Physics of morning and afternoon transitions
  - Role of advection and larger scale forcings
- Complex
  - Topographical forcings
  - Dynamic feedbacks between boundary layers and convection
    - Influence on precipitation (type, intensity)
  - Impacts of natural and anthropogenic changes of the land-surface characteristics and possible related emissions of trace gases and aerosols caused by
    - Wildfires, oil and gas exploration, renewable energy, natural disasters, seasonal changes in vegetation
- General: new theoretical approaches for dealing with variability
  - Stochastic approaches, probability density functions (how do we best describe them?)

Instruments (in LAOF, suggested improvement, not in LAOF, future development)

- Ground-based in situ
  - Network of towers with eddy covariance sensors, state variables, and atmospheric composition (including aerosols) at multiple levels
    - Ideally 50 to 100 towers to support projects with high spatial variability and topographical complexity (CentNet)
  - Four component radiometers at multiple levels
  - Soil/water temperature and moisture profiles and soil heat flux
  - Plant characteristics (leaf area index, stomata, conductance)
  - Nanobarometer (>10 Hz)
  - Surface drag sensors over land (or water)
- Airborne in situ
  - Radiosondes (up and down transects)
  - Tethered balloons
  - Research and commercial aircraft (state variables and fluxes)
  - UASes (state variables and turbulence)

Instruments (in LAOF, suggested improvement, not in LAOF, future development)

- **Remote**
  - **Network of kinematic profilers**
    - Scanning Doppler wind lidars (with option of dual and triple Doppler lidar scans)
    - Radar wind profilers and Doppler radar analysis (at wavelength suitable for clear-air and precipitation studies)
  - Network of profiling radiometers for continuous T, q profiles
    - Atmospheric Emitted Radiance Interferometer (AERI)
    - Microwave radiometers
  - **Active remote sensors**
    - **Differential Absorption Lidar (DIAL)**
    - Raman lidar
    - Ceilometers
    - Scintillometer (optical and microwave)
    - **Cloud radar**
  - Infrared and all-sky cameras