Boundary layer structure and dynamics research

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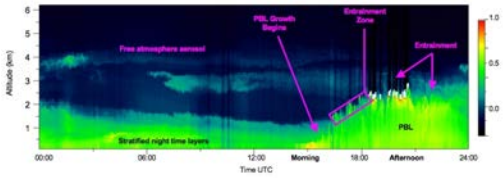
The Atmospheric Boundary Layer (ABL)

ABL: Not well characterized, poorly understood over the diurnal cycle

- Atmospheric chemistry significance: species concentrations controlled by ABL processes *(see poster for examples)*
- Wind energy, other new applications
  - Quantitative ABL information aloft critical to success
  - Wind Energy / NOAA Renewable-Energy Initiatives

- Weather forecasting and modeling
  - Acknowledged shortcoming in numerical weather prediction (NWP) models (for decades) – NOAA strategic concern
  - Called out in recent Congressional legislation: Weather Forecasting Improvement Act of 2014:
    - "improving fundamental understanding of the weather… including the boundary layer"
    - "…focus on … R & D, and transfer of knowledge, technologies, and applications… including those emphasizing rapid, fine-scale sensing of the boundary layer"

- Q: Why, in all this time, has there been so little progress in understanding ABL processes?
  - A: Inadequate measurement capability aloft through the ABL



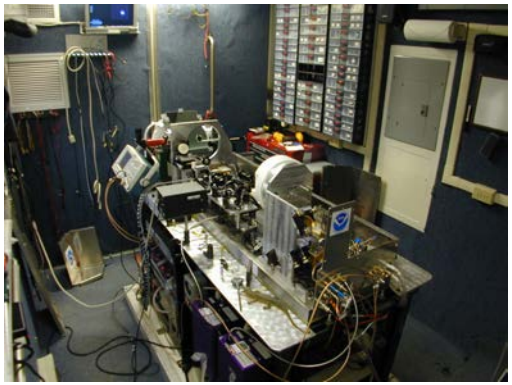
CSD/ARS has been using lidar technology to give important new insights into atmospheric boundary layer structure and dynamics

New measurement capabilities address this gap

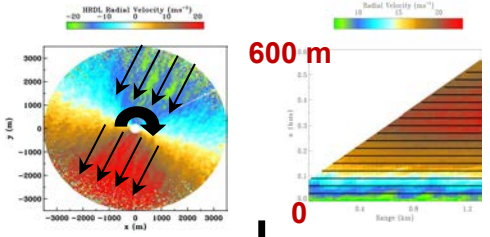
Lidar (light detection and ranging) has the necessary capabilities, e.g.,

- Ozone profiling lidar: in airborne or ground-based mode – *gives vertical structure and (airborne) horizontal variability* *[Andy Langford: (5.2); Chris Senff, (4.4)]*
- Scanning Doppler lidar: measures winds at needed resolution, precision *[Alan Brewer: (6.5]*

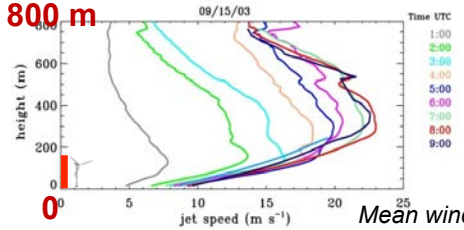
Granularity of data, *less than*:
Vertical – 5 m
Time – 5 min
Precision – 5 cm s^{-1}
First data above surface – 5 m



Scan data

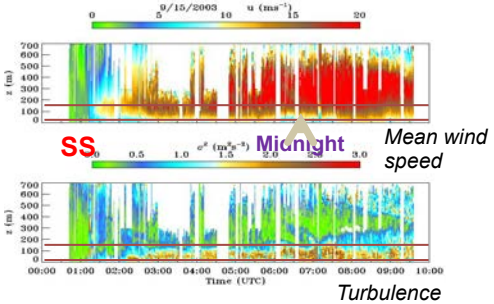


Profiles



Mean wind speed

Time-height cross section



Mean wind speed

Turbulence variance (TKE)

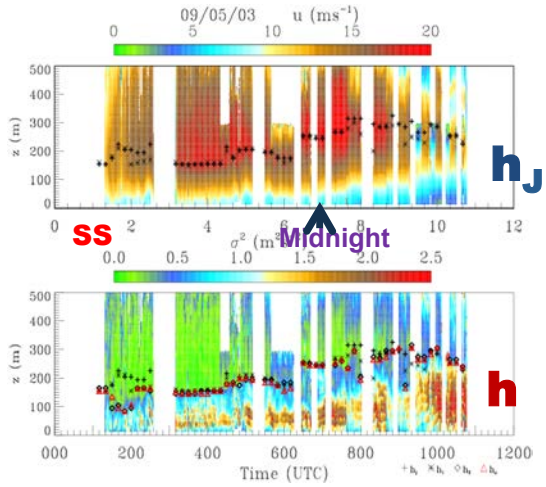
Nighttime, Stable Boundary Layer (SBL)

Atmospheric stability, lack of mixing → SBL described as "chaotic"

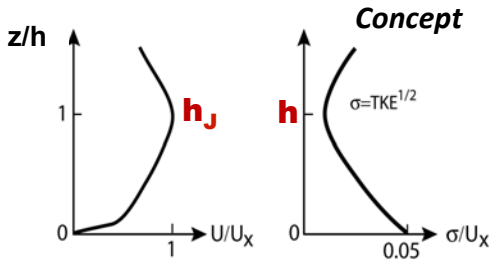
Q: can *any* generalizations be found to help understand the nocturnal SBL ?

- Using Doppler lidar, we have found:
  - Key to understanding the SBL is the low-level jet (LLJ)
  - Several quantitative relationships between mean LLJ properties and turbulence in the SBL
    - Necessary for NWP model verification (mesoscale, LES, DNS)
  - Can get generalized quantitative relationships in the SBL using appropriate instrumentation and properly accounting for the role of the LLJ

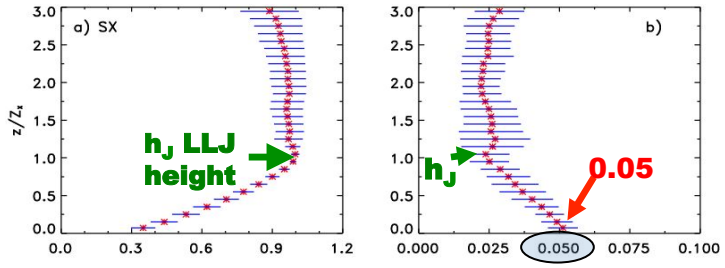
Results advance understanding of role of meteorological processes near the surface in overnight mixing and transport



Banta 2008: Acta Geophys.



Composite from lidar profile data

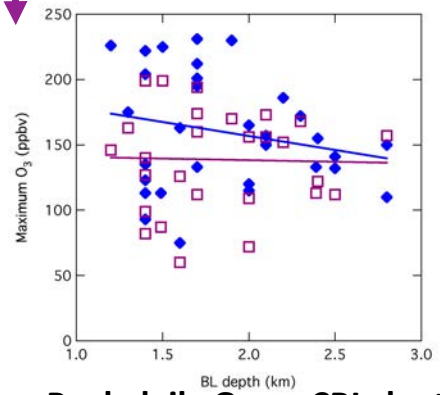


Daytime convective boundary layer (CBL, or mixed layer)

Some sample findings

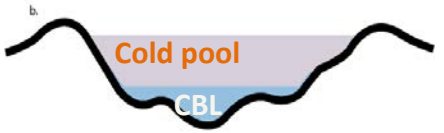
- **Mixed-layer depth *not* a major controlling factor** in predicting day-to-day variations in peak O_3 concentrations: **Houston, Texas**
  - Accurate, high-resolution *airborne measurements* of [O_3] profiles and mixed-layer depth near Houston
  - Can focus research on relevant variables (here, averaged wind speed)

- **Mixed-layer depth extremely important in Uintah Basin, Utah:**
  - Shallow mixed layer formed above cold snow surface at bottom of cold pool
  - Mixed layer found to be level, rather than terrain following (with NOAA/GMD colleagues)
    - Mixed-layer depth value depends on *where* measured
    - Significant difference in total volume of atmosphere over which pollutants are distributed, total amount of effluent inferred



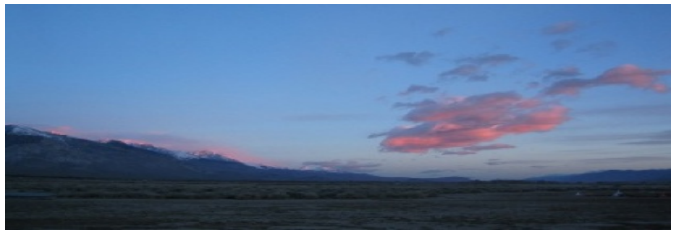
Peak daily O_3 vs. CBL depth
(Banta et al. 2011: *Atmos. Environ.*)

Terrain-following CBL



Level-topped CBL

Concluding remarks



- New instrumentation → new insights
- Mesoscale nature of ABL properties
  - Dependence of SBL properties on LLJ → mesoscale controls
  - Larger-than-local scales important to measure and understand
  - Field campaigns with regional coverage having multiscale profile-sampling arrays – needed to advance ABL understanding, modeling over the diurnal cycle
- CSD /ARS partnering with DOE, other NOAA Labs in multi-institution, multi agency measurement campaigns aimed at better understanding ABL
  - Address urgent *wind energy* need for quantitative information on flow and turbulence aloft in the turbine layer
  - Doppler lidar provides precisely this kind of information
  - Converge nicely with CSD, NOAA, Congressional requirements for better understanding and modeling of ABL
  - More information later *[Yelena Pichugina (7.5)]*