The Importance and Current Limitations of Planetary Boundary Layer (PBL) Retrieval from Space for Land-Atmosphere Coupling Studies

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NASA ENERGY AND WATER CYCLE STUDY

Motivation

- *Process-level* understanding of **L-A Coupling** is critical to model evaluation and development.
- The **convective PBL** serves as a key component and modulator of L-A interactions, such that PBL **structure and evolution** are key observables of Earth's coupled system.
- In-situ (e.g. radiosonde) and ground based approaches to PBL remote sensing are limited and discontinuous in nature.
- Here we assess the ***capabilities and limitations of routine PBL retrieval from satellite*** in terms of resolution and accuracy needed to be useful for L-A, hydrology, cloud/convection, pollution, or model development applications.

Satellite Instruments

IR Sounding/AIRS: Atmospheric Infrared Sounder aboard NASA's Aqua satellite. AIRS uses a hyperspectral infrared spectrometer with over 2300 channels to retrieve vertical profiles of temperature and humidity. Two recent algorithm versions (V6 and 6.28) are compared in this study.

IR Sounding/GOES: GOES/GOES-R retrieves thermodynamic soundings using 19-channels in the IR with high temporal (hourly+) and spatial (<10km) resolution, but with broad weighting functions and coarse vertical resolution.

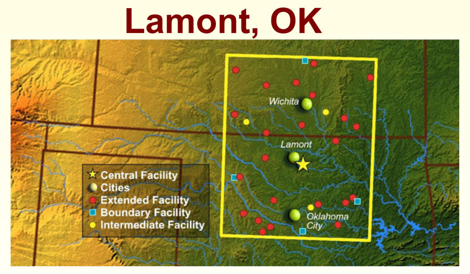
Lidar/CALIPSO: Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations. Composed of Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP), Infrared Imaging Radiometer (IIR), and Wide Field Camera (WFC). CALIOP (used here) uses a laser to measure backscatter from aerosols (Hostetler et al. 2006) at 532 nm.

Lidar/CATS: Cloud-Aerosol Transport System aboard the International Space Station (ISS). CATS uses high repetition rate lasers to measure backscatter from aerosols (Yorks et al. 2015) at 1064 nm.

GPS/COSMIC: GPS Radio Occultation (RO) measures atmospheric refractivity (N) profiles that can be used to infer temperature and humidity.

Site Observations

ARM-SGP
Central Facility
Lamont, OK



- **Radiosonde Field Campaign @ SGP Site**
  - -DOE-ARM supported
  - -Summer 2015
  - -**Hourly+** launches
  - -12 IOP days

'Enhanced Soundings for Local Coupling Studies (ESLCS)'
-Data freely available from DOE-ARM and PIs (C. Ferguson)

LoCo Diagnostics & Requirements for PBL Observations

Goals of LoCo

- Evaluate the '**links in the chain**' and their sensitivities to land -PBL perturbations as follows:

'LoCo Process-Chain'

$$\Delta SM \rightarrow \Delta EF \rightarrow \Delta PBL \rightarrow \Delta ENT \rightarrow \Delta T,q_{2m} \blacktriangleright \Delta Clouds/P$$

(a) (b) (c) (d)
SM: Soil Moisture PBL: Mixed-layer properties
ENT: Entrainment fluxes
EF: Evaporative Fraction P: Precipitation

LoCo Metrics

- Mixing Diagram Analysis (Betts 92; Santanello et al. 2009)
- EF vs. PBL Height (Santanello et al. 2009,11,13)
- LCL Deficit (Santanello et al. 20111,13)
- Coupling Drought Index (CDI) (Roundy et al. 2012)
- CTP-HIlow (Findell et al. 2003)

*Each requires PBL information

Table 1. Requirements for TD Profilers, Which Are Useful for Monitoring, Verification, DA, and Process Studies (Compiled From *Weckwerth et al.* [1999], *Wulfmeyer et al.* [2003], *ESA* [2001, 2004], and *WMO* [2004, 2005])

Parameter	Monitoring	Verification	Data Assimilation	Process Studies
Vertical resolution in ABL (m)				
Surface layer	10–30	10–30	10–30	10
Mixed layer	100–300	100–300	100–300	10–100
Interfacial layer	10–100	10–100	100	10–100
Lower free troposphere	300–500	300–500	300–500	100
Time resolution (min)	<60	<15	5–15	1/60 to 1
WV noise error (%)	<10	<5	<10 + noise error covariance matrix	<10
WV bias (%)[a]	2–5	2–5	<5	<5
T noise error (K)[a]	1	1	1	0.5
T bias (K)	0.2–0.5	0.2–0.5	0.2–0.5	0.2–0.5
Latency (min)	—	—	1 for nowcasting; Minutes to 1 h for short-range weather forecasting	—
Horizontal resolution of network	Mesoscale	Meso-beta to meso-gamma scale	Meso-beta to meso-gamma scale	Turbulence to meso-gamma scale
Coverage			All climate regions	

[a]Must be time independent. Courtesy of Volker Wulfmeyer (2015)

IR Sounding / AIRS

AIRS-based Temperature and Humidity Profiles vs. Radiosonde

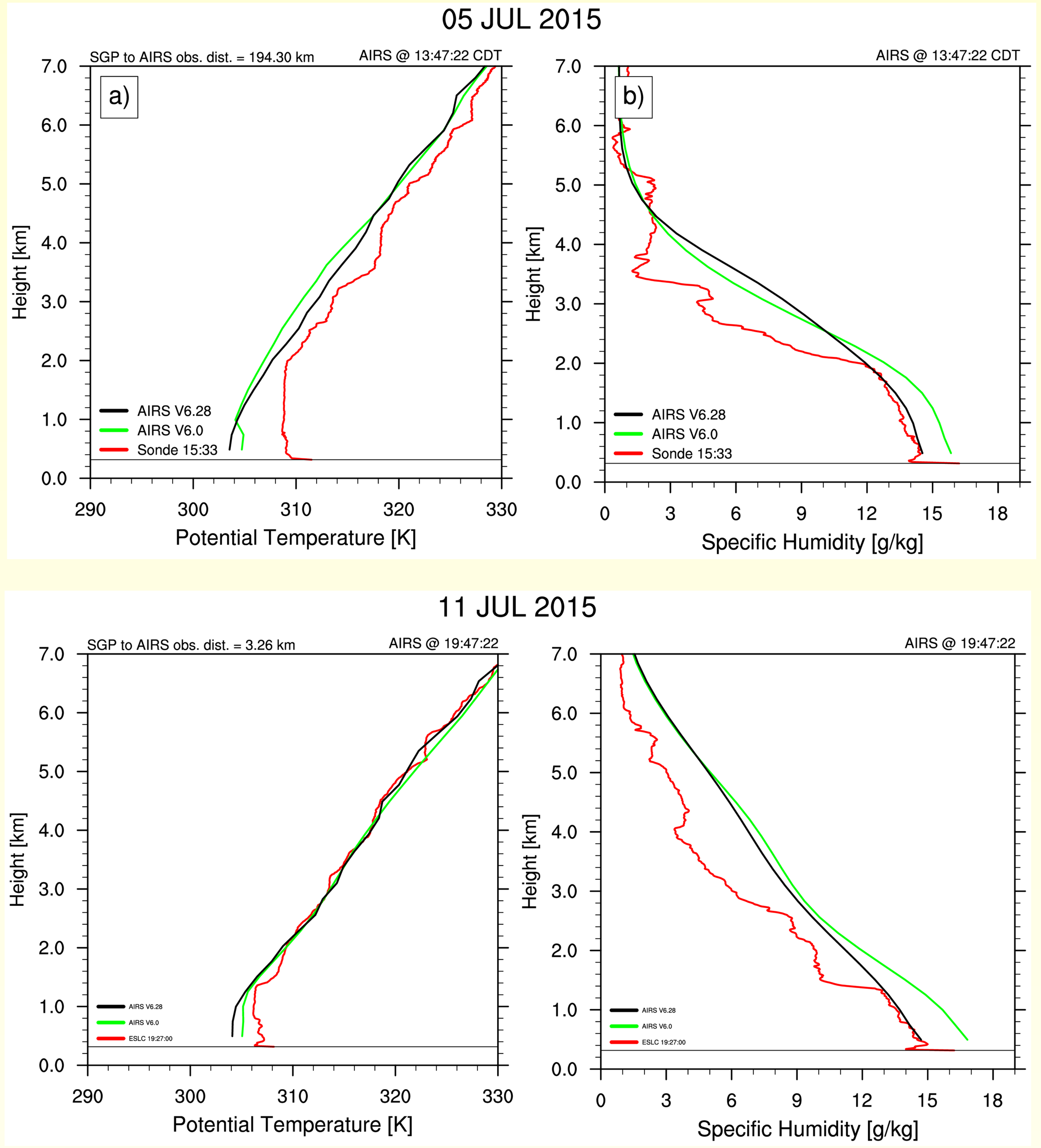
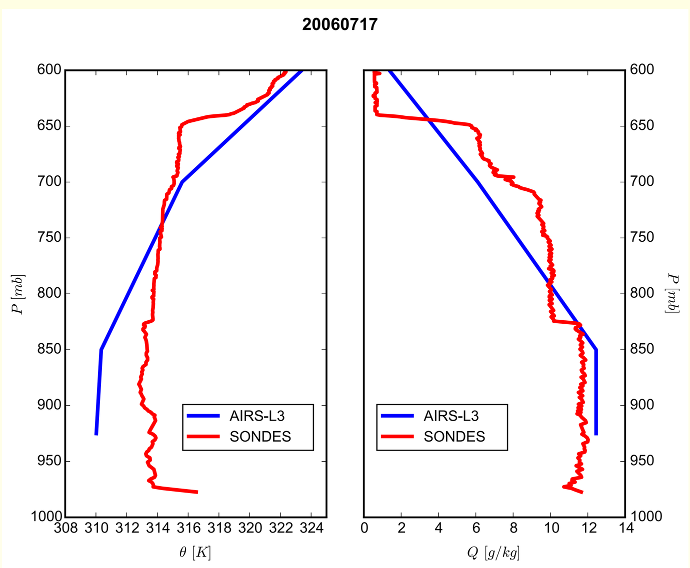


Figure 1: AIRS L2 profile retrievals vs. closest radiosonde launches at SGP site. V6.28 has improved sampling of IR channels sensitive to the PBL and to water vapor.

- 2002-present
- 2x daily retrievals
- 1:30am/pm
- 2378 IR channels
- 45km spatial resolution
- 1-2km vertical resolution
  - 1K temperature
  - 20% humidity



L3 Gridded Profiles @ 1-deg Horizontal Resolution

Lidar / CALIPSO & CATS

- 2006-present
- 14-day revisit time
- 10:30am/pm
- Lidar
  - Backscatter gradient
  - Aerosol density
  - PBL height
- 333m horizontal resolution
- 30m vertical resolution

CALIPSO and CATS Backscatter Retrieval

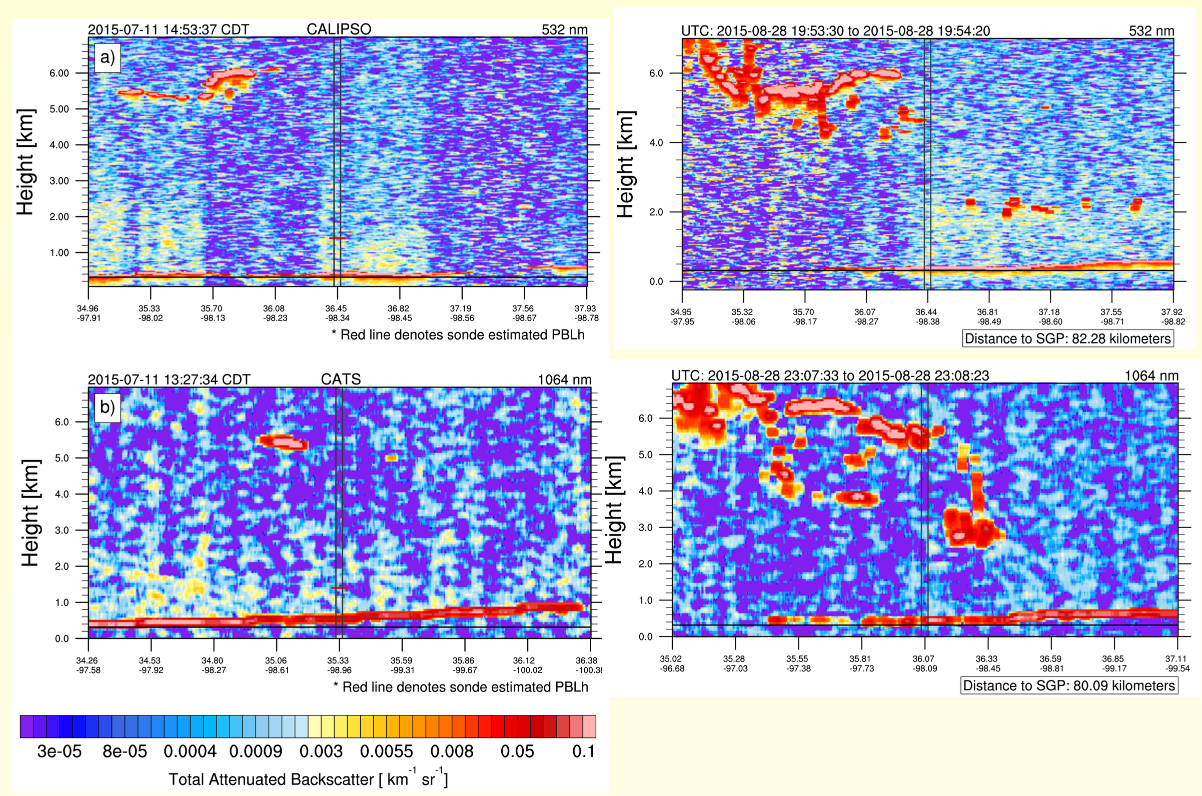


Figure 2: Horizontal cross-sections (overpasses) nearest to the SGP site (black column) of backscatter retrieved from CALIPSO and CATS instruments. The thin red line depicts the PBL observed by radiosonde.

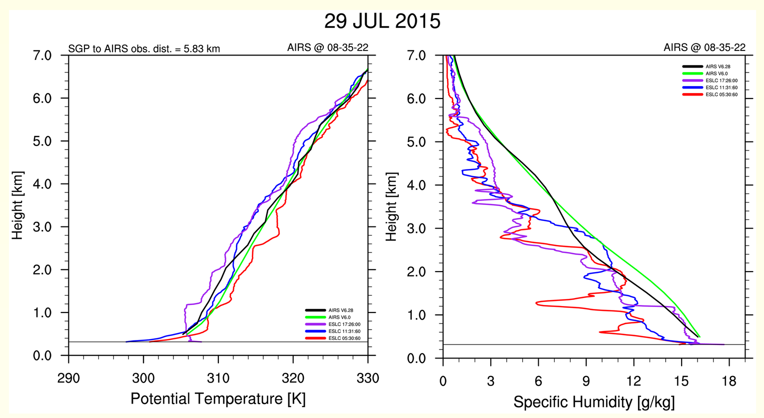
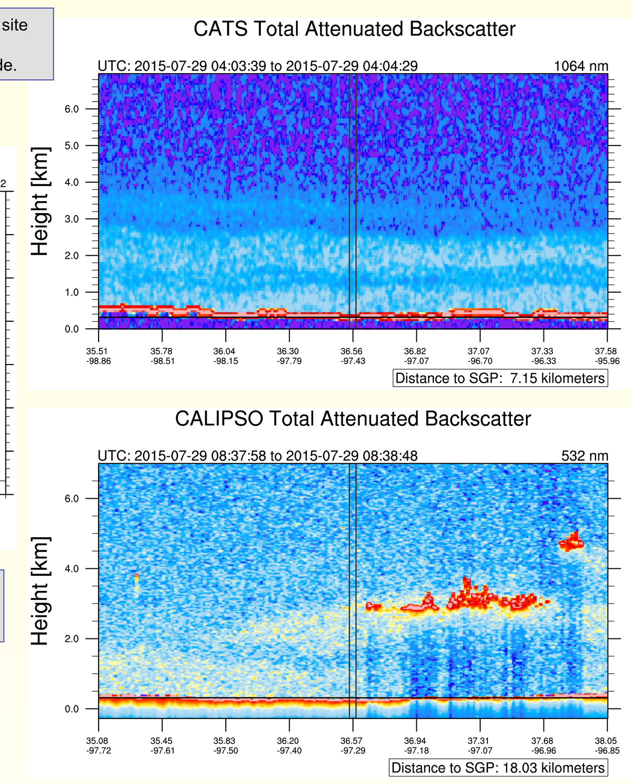


Figure 3: Same as Fig. 2, but for the nighttime overpasses of AIRS, CALIPSO and CATS vs. radiosonde. The 2 residual layers can be seen in the radiosonde profiles (red), and are clearly visible in the CALIPS and CATS backscatter profiles.



GPS/COSMIC Profiling

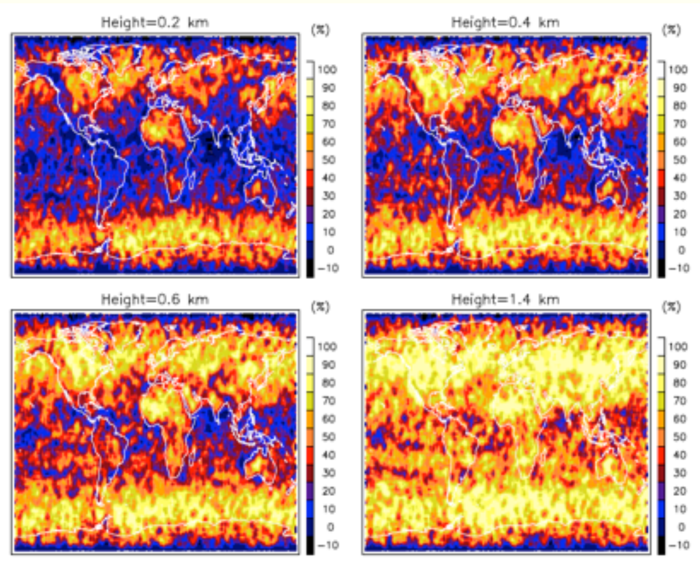


Figure 4: COSMIC RO refractivity retrievals in Jan 2008 show a sharp decrease in percentage of measurements reaching the lower troposphere, particularly in the tropics. Height is the altitude above terrain, and the map grid is 2°x2° in latitude-longitude.

- 2006-present
- Atmospheric refractivity
  - Sensitive to topography
  - Confounded by WV
- 200km spatial sampling
  - Irregular in time and space
- 200m vertical resolution

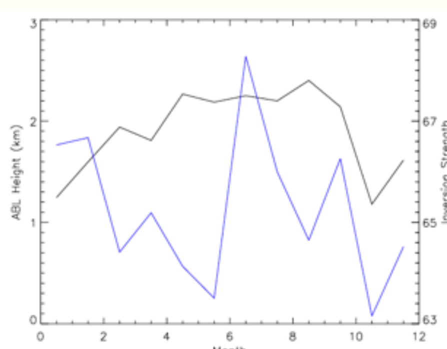


Figure 5: Preliminary results of seasonally varying ABLH (in black) and -dN/dZ inversion strength (in blue) for the ARM-SGP site, derived using Method 3 from COSMIC.

Summary of Current Capabilities

Today's spaceborne instruments have limited PBL sensitivity:

- **Hyperspectral Sounders (e.g. AIRS/IASI)** are the most capable in terms of *spectral resolution* but have not been tailored for PBL sounding and are confounded by surface emissivity.
- **Lidar (e.g. CALIPSO)** can obtain high *vertical resolution*, but is limited in return time and spatial sampling and does not provide thermodynamic state information.
- **Geostationary (e.g. GOES-R)** have frequent *temporal sampling*, coarse spectral bands and PBL resolution.
- **GPS-RO (e.g. COSMIC)** retrieves profiles, but is limited in PBL by sampling and confounding issues related to humidity/topography.

- Thus, each of these sensors has some advantages, but also considerable limitations that make them impractical for PBL studies.

Future Initiatives

2017 NRC Decadal Survey
2 white papers submitted:
(1) Scientific and societal importance of PBL
(2) Measurement requirements and potential instrument/mission approaches

LoCo Working Group (GEWEX)
-Stressing importance of PBL metrics and variables for model development (CMIP6)

NASA-GSFC Science Task Group
-Charged with assessing current status and short/long-term plan for PBL monitoring from space

Conclusions

- As highlighted by the NRC and NASA communities, there is an **established and growing need for routine PBL measurements over land** for a range of applications.
- **The PBL remains a major gap in our observational suite**, as today's spaceborne instruments cannot reach the required targets in terms of accuracy or resolution.
- There is a **lack of focused effort or planning (short or long-term) in** place for improving lower tropospheric retrievals over land.
- **Other components of WEC cycle monitoring** (e.g. GPM, SMAP, GRACE, SWOT) are now in place, and thus the importance of PBL information will continue to rise.
- **New mission concepts** such as high-spectral GEO and high-spatial AIRS should provide incremental improvements, but it **may require advanced active sensors** to achieve required PBL targets.

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•**Santanello et al., 2013**: Diagnosing the Nature of Land–Atmosphere Coupling: A Case Study of Dry/Wet Extremes in the U.S. Southern Great Plains. *J. Hydrometeor,* 14, 3–24.
•**Santanello et al., 2011:** Diagnosing the Sensitivity of Local Land-Atmosphere Coupling via the Soil Moisture-Boundary Layer Interaction. *J. Hydrometeor.*, 12, 766-786.
•**Santanello et al., 2009:** A modeling and observational framework for diagnosing local land-atmosphere coupling on diurnal time scales. *J. Hydrometeor.,* 10, 577-599.
•**Wulfmeyer et al., 2015**. A review of the remote sensing of lower tropospheric thermodynamic profiles and its indispensable role for the understanding and the simulation of water and energy cycles, *Rev. Geophys.,* 53, 819–895.

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