National Aeronautics and Space Administration

The Planetary Boundary Layer: A Decadal Survey Incubation Challenge

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Program: FY21 R&TD Strategic Initiative

Strategic Focus Area: Planetary Boundary Layer: Key Weather, Air Quality and Climate Observable from Decadal Survey

OBJECTIVES

This project aimed at determining a feasible and cost-effective approach to measuring planetary boundary layer (PBL) characteristics in response to needs of the Decadal Survey 2017 PBL Incubation item. We conducted a closely coupled science and technology SRTD to ensure JPL's lead position on this topic as it relates to the 2017 DS PBL Incubation item. This was an integrative activity, coupling our science expertise in the relevant science areas and the multiple JPL technologies relevant to probing the PBL in order to identify one or more feasible pathways to address this cross-cutting area.

Specific goals:

1) To develop a modeling and OSSE framework that provides a uniform means to assessing the strengths and weaknesses of potential DS approaches to providing PBL information.

2) To apply the framework in the context of PBL DS science targets to:

a) Identify feasible approaches for addressing the PBL challenge and incubation item;

b) Increase the success of Designated & Explorer program concepts that could accommodate increased fidelity and yield for PBL information (e.g. ACCP, GHG, Trace Gases, Winds);

3) To optimally position JPL as a national leader in the context of a potential PBL mission.

BACKGROUND

The **2017 National Academies' Earth Science Decadal Survey** (DS) recommended the planetary boundary layer (PBL) as a high-priority targeted observable for incubation studies. The Earth's atmospheric PBL is particularly challenging to observe from space. The DS 2017 recommended candidate measurement approaches that can be advanced in order to measure the highly variable PBL structure from space.

TARGETED OBSERVABLE	SCIENCE/APPLICATIONS SUMMARY	CANDIDATE MEASUREMENT APPROACH	Designated	Explorer	Incubation
Planetary Boundary Layer	**Diurnal 3D PBL thermodynamic properties and 2D PBL structure** to understand the impact of PBL processes on weather and AQ through high vertical and temporal profiling of PBL temperature and water vapor, and PBL heights.	Microwave, hyperspectral IR sounder(s) (e.g., in geo or small sat constellation), GPS radio occultation for diurnal PBL temperature and water vapor, and heights; water vapor profiling DIAL lidar; and lidar for PBL height			X

PBL is the turbulent layer of the atmosphere adjacent to the ocean, land and ice surface that mediates the interactions between the surface and the troposphere. The PBL is at the heart of fundamental science challenges:

i) Cloud-climate feedback

ii) Severe storm prediction

iii) The exchanges of energy, water and carbon between the atmosphere, ocean, land, and ice are mediated by turbulent fluxes in the PBL;

iv) The depth and mixing of PBL air significantly influences air quality and human health.

APPROACH

We performed end-to-end simulations within our PBL OSSEs framework (i.e., forward simulations and retrievals) and evaluated six different candidate technologies:

- **Global Navigation Satellite System-Radio Occultation (GNSS-RO)**
- **Differential Absorption Radar (DAR)**
- **Visible to Shortwave InfraRed (VSWIR)**
- **Infrared sounding (IR)**
- **Multi-angle Imaging (MI)**
- **Microwave sounding (MW)**

Synthetic observations were produced by high-resolution large-eddy simulations (LES) of a variety of different PBL types: from the tropics (Fig. 1), through the subtropics, mid-latitudes, to subpolar and polar regions, for both land and ocean. We used the LES profiles and the forward and instrument models to simulate what specific instruments would measure for each of the different PBL types.

In addition, we studied simplified architecture and mission simulators where we pay particular attention to finding optimal combinations of instruments to achieve the stated goals of the Decadal Survey.

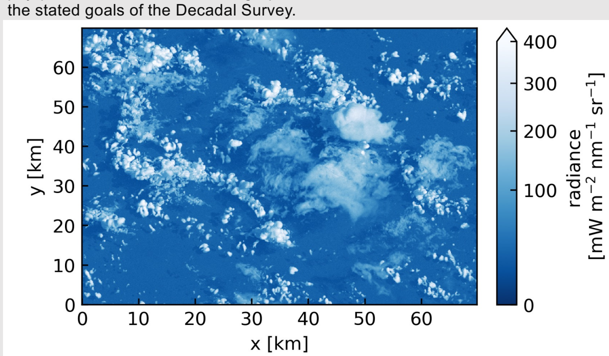


Fig. 1. Large-eddy simulation of the transition from shallow to deep convection in the tropics. Visualization was made using MYSTIC 3D radiative transfer model (MI simulator).

SIGNIFICANCE OF RESULTS / BENEFITS TO NASA/JPL

The results demonstrated the high potential of NASA instruments in measuring the varying small-scale PBL thermodynamic and dynamic structures across different flow regimes. Information content can be enhanced both by improving the technical capabilities of the instruments and through their synergy, thus expanding current state of the art measurement techniques and supporting the development of next-generation approaches. Results from this project should support future NASA Earth Science missions focused on sampling 3D PBL structures of the Earth's atmosphere for a variety of regions/flow regimes.

This project provided the first end-to-end simulation assessment of key measuring technologies and architectures to probe the thermodynamic structure of the PBL from space. As far as we are aware, no such infrastructure to perform this type of studies exists anywhere else. This work will help position JPL in a leadership role in a future NASA PBL mission.

RESULTS

GNSS-RO:

- New 1DVar retrieval method that simultaneously solves for both hi-res (~200m) T and q profiles from collocated GNSS-RO bending angles and MW brightness T => Joint RO/MW retrieval reduces the ducting and a-priori bias in the RO-alone solution
- Estimation of error caused by the a-priori and obs. uncertainties for various PBL types
- Higher SNR improves profile penetration into the PBL and higher SNR and sampling bandwidth yield more accurate retrievals of fine-scale PBL vertical structure

DAR:

- New 3-frequency retrieval algorithm that derives partial column water vapor in clear air volumes and high resolution water vapor profiles (200 m) inside of clouds/precipitation
- Significant reduction in biases; permits profiling deep into cumulus towers
- Improved precision scaling with along-track averaging by optimizing radar sampling parameters (e.g., pulse length, incoherent averaging interval)
- Accurate surface-to-cloud-base retrievals (new unique feature)

VSWIR:

- JPL code for AVIRIS/EMIT can retrieve hi-res total column water vapor (TCWV), and horizontal variability in TCWV is dominated by PBL
- Diagonal sunlight path through algorithm thwarts precise localization of TCWV, but preserves spatial statistics
- Vertical profiles from collocated sounder data could further reduce errors

IR:

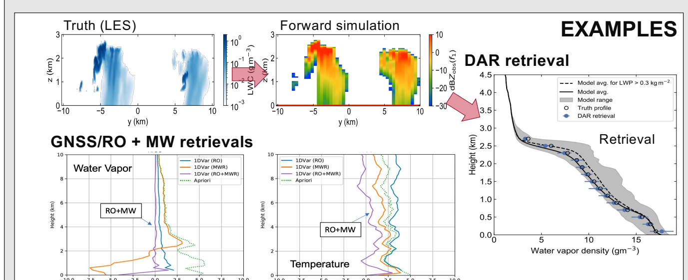
- Quantification of information content for different PBLs for current IR sounders: => Typically 1-3 degrees of freedom for each of water vapor and temperature
- Higher spectral resolution provides strong benefit, up to a limit of ~0.05 cm^{-1}
- Information content quantified for different options for limited spectral ranges
- 1200-1500 cm^{-1} range provides highest degrees of freedom for PBL water vapor

MI:

- Provided photorealistic renderings of selected LES results using the MYSTIC 3D radiative transfer code (see Fig. 1 as example)
- Enabled and participated in sensor-level OSSE for a dual bi-angular sensor system targeting cloud-top height and vertical velocity for Sc and Cu
- Collected a diverse database of 3D cloud fields and synthetic multi-angle images for future improvement of cloud tomography retrievals of PBL clouds at variable resolutions

MW:

- New forward operator to integrate into 1DVar retrieval framework with GNSS-RO => combined retrieval improves vert. resolution and accuracy of T and q retrievals
- Performed channel optimization for the PBL
- Nadir observations >30 deg and dual-polarized channels < 40 GHz improved PBL obs.
- Simulated retrieval uncertainty (subtropics): 170m PBL height, 0.7K for T, 0.6 g/kg for q



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