National Aeronautics and Space Administration

The Planetary Boundary Layer: A Decadal Survey Incubation Challenge

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Program: Strategic Initiative

Motivation:

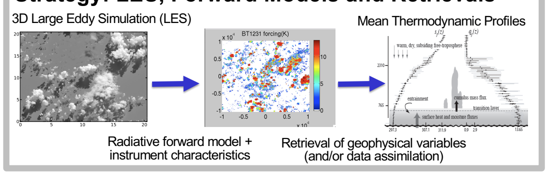
The **2017 National Academies' Earth Science Decadal Survey** recommended the planetary boundary layer (PBL) as a high-priority targeted observable for incubation studies. The Earth's atmospheric PBL is particularly challenging to observe from space.

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, moisture and heights	Microwave, hyperspectral IR sounder(s) (e.g., in geo or small sat constellation), GPS radio occultation for diurnal PBL temperature and humidity and heights; water vapor profiling DIAL lidar; and lidar for PBL height			X

Project Objective:

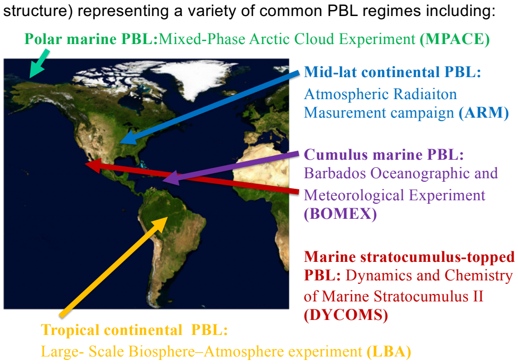
To determine a feasible and cost-effective approach to measure PBL characteristics from space in response to the needs of the Decadal Survey 2017 PBL Incubation item. This is an integrative activity, coupling our science expertise in the relevant science areas and the multiple JPL technologies relevant to probing the PBL in order to identify one or more feasible pathways to address this cross-cutting area, which includes extreme weather, cloud-climate feedbacks, air quality, carbon and GHG flux inversion, and air-sea interaction.

Strategy: LES, Forward Models and Retrievals



FY19 Results: LES

We created an LES database of PBL types (high-res, 3D turbulence structure) representing a variety of common PBL regimes including:



Benefits to NASA and JPL:

- Demonstrated high potential of JPL instrument technologies in measuring the diurnally-varying small-scale PBL thermodynamic and dynamic structures across different physical regimes
- Information content can be enhanced both by improving 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 instruments
- Results from this project should support future NASA Earth Science missions focused on measuring the PBL thermodynamic structure of the atmosphere from a global perspective.

FY19 Results: Global Navigation Satellite System-Radio Occultation (GNSS-RO)

- Developed the capability to simulate idealized GNSS-RO observations using LES outputs of temperature, pressure, and specific humidity
- Prepared the idealized RO observation framework in a 2D plane ("occultation plane") using 2D slices of the 3D LES outputs. Since RO signals traverse distances much larger than a LES domain, multiple 2D slices of the LES runs are stacked together to form a large enough horizontal domain (few hundred km)
- Performed end-to-end simulations on all available LES cases
- Demonstrated that refractivity retrievals agree well with horizontally averaged refractivity computed from LES
- The negative refractivity bias expected in some cases due to the large refractivity gradient exceeding the ducting threshold at the top of the PBL can be constrained by using other instruments.

FY19 Results: Hyperspectral shortwave and near-infrared sounding

- Performed forward MODTRAN6.0 simulations over crop and water surfaces for a spaceborne Airborne Visible-Infrared Imaging Spectrometer - Next Generation (AVIRIS-NG) instrument.
- Simulated AVIRIS-NG retrievals of surface reflectance and atmospheric correction to retrieve column water vapor over the cropland surface. Small spread in the errors, and biases of approximately 5 % or up to 1.7 mm is found
- Investigated sampling and clear sky biases assuming perfect cloud flagging, finding generally small column vapor biases between clear and cloudy scenes. The maximum bias is 1.4 mm, or 3.7 % in one RICO snapshot, and shrinks to 0.2 mm or 1.5 % in DYCOMS. This may mitigate the lack of measurements in boundary layers with extensive stratiform cloud cover, where in one LES snapshot we can only retrieve in 0.01 % of footprints after accounting for cloud shadows.

FY19 Results: Differential Absorption Radar (DAR)

- Explored the capabilities of a spaceborne DAR using realistic instrument parameters that are informed by technology research and development of a 167-174.8 GHz DAR
- Performed radar forward simulations including angle-dependent, multiple scattering from hydrometeors, and surface reflections over ocean using a quasi-specular model (the same used in CloudSat retrieval algorithms)
- Implemented inversion algorithms for retrieving in-cloud humidity profiles and total column water vapor, and explored trade-offs of precision vs. spatial averaging for a given set of instrument parameters (e.g. transmit power, antenna diameter)
- Found that DAR total column water vapor measurements can achieve high precision (< 1 mm random error) for an along-track spatial resolution of 400 meters.

FY19 Results: Infrared sounding

- Simulated retrievals using an optimal estimation approach to evaluate best-case scenarios for vertical information content for PBL water vapor from operational and recently-operated spaceborne thermal infrared sounders (AIRS, CrIS, IASI and TES)
- Explored the trade space between instrument noise and spectral resolution as these quantities relate to the information content for PBL water vapor
- Evaluated vertical information content. Since thermal IR radiances are sensitive to the atmosphere above the PBL and to species other than temperature and water, this work has involved augmentation of the sonde and LES atmospheres with additional information from available climatologies (standard atmospheres)
- Performed sensitivity studies to assess "clear-sky" LES grid boxes for the purposes of thermal IR retrievals.

FY19 Results: Microwave sounding

- Developed end-to-end forward modelling capability and tested on various LES cases
- Analyzed information content to understand the sensitivity of hyperspectral microwave frequencies along with multi-incidence angles to various PBL observables
- Investigated the ability of a spectral resolving microwave radiometer to resolve small changes in the PBL structure
- The insights provided by our forward modeling guided our development of retrieval approaches that exploit the simulated small non-linearities in the spectrum to resolve PBL information. We have formulated and tested a dictionary based Spectral Angle Mapper (SAM) based algorithm for the retrieval of PBL profiles
- Found that fully resolving the 22, 50-60, 118 and 183 GHz line shape provides new information on PBL structure not measurable with current microwave systems

FY19 Results: Multi-angle Imaging Spectroradiometer (MISR)

- Simulated reflected radiances for MISR's red channel (672 nm) at MISR's spatial sampling (275 m pixels) or better (up to LES native resolution), and its 9 viewing directions
- Examined the RICO and DYCOMS cases, and processing the LBA case
- Used simplified (1D, 2-stream) radiative transfer (RT) to convert LWP to radiance on a per-pixel basis
- Implemented high-fidelity full 3D RT for the forward modeling framework using LMU's MYSTIC Monte Carlo code
- Simulated MISR-like data with a variety of spatial resolutions used as input to legacy MISR algorithms for "zero-wind" cloud top height (CTH) retrievals.
- Uncertainty and bias analysis will be performed next.

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