Toward a Global Planetary Boundary Layer Observing System: NASA PBL Incubation Study Team Report

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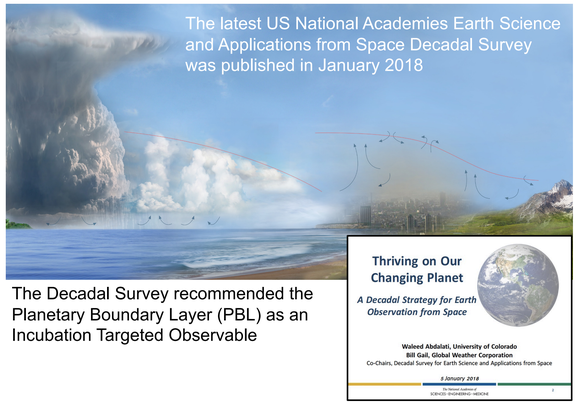
National Aeronautics and Space Administration

Planetary Boundary Layer Incubation



The Decadal Survey recommended the Planetary Boundary Layer (PBL) as an Incubation Targeted Observable

Planetary Boundary Layer
2017 NAS Earth Science Decadal Survey

TARGETED OBSERVABLE	SCIENCE/APPLICATIONS SUMMARY	CANDIDATE MEASUREMENT APPROACH	Designated	Explorer	Incubation
Atmospheric Winds	**3D winds in troposphere/PBL** for transport of pollutants/carbon/aerosol and water vapor, wind energy, cloud dynamics and convection, and large-scale circulation	Active sensing (lidar, radar, scatterometer); passive imagery or radiometry-based atmos. motion vectors (AMVs) tracking; or lidar**		x	x
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
Surface Topography & Vegetation	**High-resolution global topography** including bare surface land topography ice topography, vegetation structure, and shallow water bathymetry	Radar; or lidar**			x

Incubation: Measurement/mission approach not mature enough for inclusion as Designated Observable or Explorer class - **requiring investment and work during next few years**

Planetary Boundary Layer
Targeted Observables Table

TARGETED OBSERVABLE	SCIENCE & APPLICATIONS SUMMARY	SCI&APPS PRIORITIES (M? VI, I	RELATED ESAS 2007 and POR	IDENTIFIED NEED/GAP	CANDIDATE MEASUREMENT APPROACH	ESAS 2017 DISPOSITION
TO-H Planetary Boundary Layer	• Temperature • Water vapor • PBL height	- H-3a - W-1a, 2a, 3a, 10a - - - C-2b, 4a, 7a, 7b, 7c, 7d, 7e	*ESAS 2007:* PATH *POR:* AMSU/Aqua, AIRS/Aqua, CrIS/JPSS, ISAI/MetOp, AMSU MetOp, COSMIC, MHS/MetOp, CALIPSO, GOES-R, AMSR	POR lacks sufficient horizontal and temporal resolution	*Similar to:* AIRS, AMSU, COSMIC • Microwave & hyperspectral IR sounders; lidar for PBL height • Sampling with 3-20km horizontal, 0.2-1km vertical, 1-4hr temporal resolution	INCUBATION PROGRAM ELEMENT Consider opportunistic use of data from recommended TO-1/2 investment for PBL height

PBL is High Priority: Cuts across panels (Weather and AQ, Climate, Water Resources, Ecosystems) and Integrating Themes
PBL was a *most important objective* for Weather and AQ panel

PBL Measurement Approaches: GNSS RO, Hyperspectral IR, MW sounding, SW, Lidar/DIAL, Radar/DAR → complementary approaches

Which measurement approaches/architectures coupled with modeling/DA will optimally address PBL science requirements?

NASA PBL Incubation Study Team

Science Lead – Joao Teixeira (JPL)
Technology Co-Lead – Jeff Piepmeier (GSFC)
Tech. Deputy Co-Lead – Amin Nehrir (LaRC)
Additional Team Members: Chi Ao (JPL), Shuyi Chen (UW), Carol Anne Clayson (WHOI), Ann Fridlind (NASA GISS), Matthew Lebsock (JPL), Will McCarty (NASA GSFC), Haydee Salmun (CUNY), Joe Santanello (NASA GSFC), Dave Turner (NOAA), Zhien Wang (University of Colorado), Xubin Zeng (University of Arizona)

Summary timeline:

- Team started working January 2020
- Developed charter of PBL Study Team
- Developed preliminary Science Traceability Matrix (SATM)
- NASA PBL Incubation Workshop (19, 20, 26, 27 May 2020)
- Interim report delivered to NASA HQ (September 2020)
- Technology Survey to the PBL community (October 2020)
- Final PBL report delivered to NASA HQ and published (April 2021)
- Decadal Survey Incubation AO ESTO (and R&A) - summer 2021

https://science.nasa.gov/earth-science/decadal-pbl

NASA PBL Study Team Charter

The summarized **charter** of the NASA PBL Study Team was to:

- Identify the most **critical PBL science and applications questions** in the context of Earth System science
- Identify specific **PBL needs from a data-assimilation, modeling and prediction** (weather, climate, regional, LES) perspectives;
- Identify the **critical geophysical observables** and their associated spatial and temporal **measurement requirements** (resolution, sampling) so as to address the key PBL questions and needs;
- Identify the **observational gaps** from the current program of record;

NASA PBL Study Team Charter

- Identify practical yet effective **emerging measurement approaches and technologies** to address measurement goals from space;
- Develop a **technology roadmap** to enable a future orbital observing system (in combination with suborbital and ground-based observations, models and data-assimilation systems);
- Identify **simulator methodologies** to explore optimal combinations of potential measurement approaches and technologies;
- Develop a **strategy to field emerging airborne instruments** in science campaigns;
- Synthesize these findings in a preliminary PBL Science and Applications Traceability Matrix (**SATM**)
- Produce **the PBL Report**

Summarized PBL SATM

Overarching PBL Vision	Science Goal	Science Topics (summarized questions)
Globally characterize the thermodynamic structure of the PBL	**G1. PBL, Convection and Extreme Weather**	**Q1.1:** PBL, Convection and Mesoscale **Q1.2:** Shallow and Deep Convection **Q1.3:** PBL, Surface processes and Precipitation
	G2. Cloudy PBL	**Q2.1:** PBL Thermodynamics and Clouds **Q2.2:** PBL Clouds, Surface Fluxes and Free Troposphere **Q2.3:** PBL, Clouds and Mesoscale
	G3. PBL and Surface Interaction	**Q3.1:** PBL Thermodynamics and Surface Fluxes **Q3.2:** Water Vapor Near the Surface **Q3.3:** Surface Heterogeneity, PBL and Convection **Q3.4:** PBL Thermodynamics and Extremes
	G4. PBL Modeling, Mixing and Air Quality	**Q4.1:** PBL Mixing and Transport **Q4.2:** PBL Parameterizations and Models

PBL Geophysical Variables and Requirements

The essential geophysical variables identified as uniquely required to address the four science goals are:
- PBL profiles of temperature.
- PBL profiles of water vapor.
- PBL height.

The SATM leads to the following measurement requirements (that can only be satisfied with a combination of different technologies):
- Vertical resolutions as fine as 100-200 m.
- Horizontal resolutions as fine as 1 km.
- Temporal sampling of at least 4 times per day.

A Global PBL Observing System

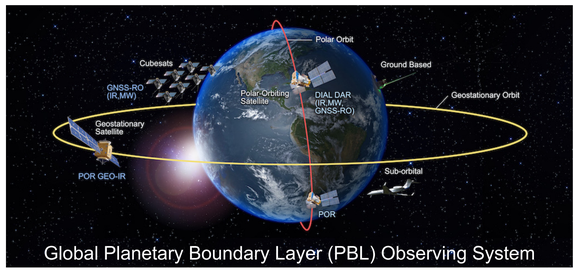
A global Planetary Boundary Layer (PBL) observing system is urgently needed to address fundamental PBL science questions and societal applications related to weather, climate and air quality.

This PBL observing system should optimally:
- combine new space-based observations of the PBL thermodynamic structure
- with complementary surface-based and suborbital assets,
- while taking advantage of, and helping improve, modeling and data assimilation systems.

PBL Global Observing System: A Mission of Discovery

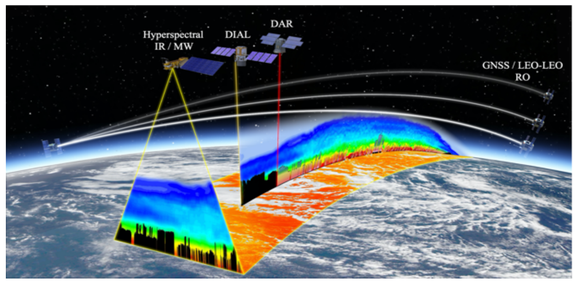
Why the need for a global space-based PBL observing system:

- Key PBL science questions are about the interactions between **PBL thermodynamics** and **global processes**
- Interactions between the **mesoscale and PBL thermodynamic structure** are a key PBL science topic: **global (space-based) perspective** is essential to observe these interactions
- Global (space-based) perspective will allow to observe the **wide variety of PBL structures all around the globe**
- **Space-based PBL observing system** will likely lead to the **discovery of new types of PBL thermodynamic structures** particularly over sparsely observed regions such as the oceans and the polar regions.



Global Planetary Boundary Layer (PBL) Observing System

Essential components:
- **DIAL** and **DAR** in LEO for high vertical resolution (200 m) water vapor
- **IR** and **MW** sounders (high horizontal resol.) in LEO CubeSat constellations
- **Radio Occultation**: larger constellations of GNSS-RO receivers and/or novel orbital configurations
- **Geostationary** hyperspectral **IR** sounders (EUMETSAT, NOAA)
- PBL **modeling** and **data assimilation**



- Active sounders (DIAL and DAR) in LEO to provide high vertical resolution (order 200 m) water vapor profiles
- High horizontal resolution hyperspectral IR and MW sounders in LEO to provide 3D temperature and water vapor structure context to DIAL+DAR observations (potentially Small/CubeSat constellations)

PBL Science and Technology Roadmap