A Global Planetary Boundary Layer Observatory: The Cloudy PBL White Paper

By

Cloudy PBL White Paper Team

1. Summary

Fundamental planetary boundary layer (PBL) science questions and societal applications urgently require a global PBL observatory based on a core PBL orbital component with strong synergy between orbital, suborbital and surface platforms. The focus of this new global PBL observatory will be on producing novel, global and detailed observations of the PBL thermodynamic structure using innovative observational technologies and architectures, complemented by critical innovations in PBL data science and physical modeling.

2.1 Why? Motivation

The PBL modulates the interactions between the surface and the free atmosphere and plays a fundamental role in the weather and climate that impacts our health, societies and economies. The PBL thermodynamic structure influences all these processes and is central to understanding the transport of key atmospheric constituents. Improved global observations of PBL thermodynamic profiles and PBL height are essential to improve weather and air quality forecasts. Key PBL physical regimes and processes are illustrated in figure 1.

Figure 1. A schematic depiction of key PBL physical regimes and processes.

The Earth science community has expressed great interest in improving the characterization of the PBL in the latest National Academies of Sciences, Engineering and Medicine (NASEM) 2017-2027 decadal survey for Earth Science and Applications from Space (ESAS). Specifically, higher spatial and temporal resolution observations of PBL temperature and water vapor profiles, and of PBL height, were selected as priorities by the decadal survey, which recommended a PBL mission in its incubation class (NASEM 2018). In response, NASA established the Decadal Survey Incubation (DSI) program and a PBL Study Team focused on prioritizing PBL science and technology that would require advancement and development prior to implementation.

The NASA PBL Study Team report (Teixeira et al. 2021, 2025), hereafter T21, identified (i) a set of critical PBL science questions and applications topics in the context of Earth system science; (ii) specific PBL needs from a data assimilation, modeling (large-eddy simulation, regional, global) and prediction perspectives; (iii) critical geophysical observables and their associated spatial and temporal measurement requirements so as to address the key PBL science questions and applications topics; (iv) observational gaps from the current program of record; and (v) practical yet effective emerging approaches and technologies to address measurement requirements using a range of system architectures.

2.2 Why? Science

A vision for PBL science can be divided in four essential science goals: (i) PBL, convection and extreme weather; (ii) cloudy PBL; (iii) PBL and surface interaction; and (iv) PBL modeling, mixing and air quality. Table 1 briefly summarizes the four essential PBL science goals and key topics associated with each of them. In T21, more detail is presented in terms of science goals and specific questions as well as the connections to measurement requirements. Note that G4 is different from the first three goals as it is more directly focused on modelling and applications.

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

Table 1. Summary of the PBL science goals and key topics.

In the context of the cloudy PBL, the key questions are focused on different aspects of the relation between PBL temperature and water vapor structure and other key physics processes prevalent in the cloudy PBL. Namely, how the PBL temperature and water vapor structure interacts with (i) clouds, (ii) the surface and the free troposphere, and (iii) the mesoscale structure of the atmosphere. In this context, the interaction between the cloudy PBL and the ocean/land/ice surface is absolutely critical. The Science and Applications Traceability Matrix (SATM) in table 2, adapted and updated from T21, provides more detail on the specific science questions, the geophysical variables, measurement requirements, and measurement technologies.

Goal	Science Questions	Geophysical Variables and Measurement Requirements	Potential Measurement Technologies
G2. Cloudy PBL	**Q2.1**: How do the PBL thermodynamic structure and cloud properties covary and interact with each other? **Q2.2**: How are these PBL-cloud interactions mediated by turbulent surface fluxes and overlying free tropospheric thermodynamic conditions? **Q2.3**: What is the role of mesoscale variability in modulating the vertical structure of the cloudy PBL temperature and water vapor?	• **T** and **q** profiles (in PBL and free troposphere) with 100-200 m vertical resolution (Δz) in clear and cloudy conditions • **T** and **q** profiles at 1 km horizontal resolution (Δx) • **T** and **q** uncertainties of 1K and 10% or better. • PBL height from **T** and **q** profile vertical gradients Synergistic Measurements: • Cloud properties • Radiative fluxes • Surface turbulent fluxes	**Vertical resolution:** • **GNSS RO** can measure **T** or **q** profiles with Δz=100m (scattered sampling) • **DIAL** can measure clear sky **q** profiles with Δz=200m (2D curtain) • **DAR** can measure cloudy sky **q** profiles with Δz=200m (2D curtain) **Horizontal Resolution:** • **IR** sounding can measure **T, q** profiles at Δx=1km • **MW** sounding can measure **T, q** profiles at Δx=5km

Table 2. Cloudy PBL SATM adapted and updated from T21.

2.3 Why? Applications and Science to Action

Key applications involving the PBL span several different time and space scales. Critical examples include high-impact meteorology; air quality; atmospheric dispersion; urban weather and climate; hydrometeorology; agriculture; climate projections; renewable energy; marine weather; fisheries; ecosystems; transportation; wildfire applications; radio wave propagation; and infectious diseases. Broadly, and as will be discussed in the following section, numerical weather prediction is at the heart of several of these applications given the importance of data assimilation (analysis) and weather forecasting products for so many applications of weather data. In here, we provide more details on some key specific applications.

Critical application fields in the context of the cloudy PBL include:

Marine weather – Marine weather forecasts are of significant value to a wide range of societal needs from economic to national security. Dense low clouds and fog, and spray in high winds impact visibility and creates hazardous operating conditions. These conditions in the marine PBL are most difficult to forecast. The difficulty of operating in the marine environment ranging from poor visibility to high seas conditions places a premium on marine weather forecasts.

Transportation – On short time scales, these include aviation weather forecasts (e.g., fog, ceiling heights, turbulence, convection). Maritime transport is critically important worldwide, with approximately 90% of traded goods carried by ship. Improving the accuracy of marine weather forecasts, as discussed above, is crucial to marine transportation.

Radio wave propagation – Knowledge of the near real-time thermodynamic structure of the atmosphere, especially surface-based and elevated inversions, helps to characterize and predict the existence and locations of ducting layers that affect radio wave propagation and are extremely important for military and homeland security applications.

Air quality (AQ) – The accuracy of AQ monitoring and prediction depends on the understanding and accurate representation of PBL processes in data assimilation systems and prediction models. Better measurements and understanding of PBL height, PBL thermodynamic and mixing processes as well as how these processes influence atmospheric chemistry will lead to better monitoring and prediction.

Dispersion – The dispersion of atmospheric constituents is highly dependent on the PBL thermodynamic structure. Dispersion models simulate complex transport, chemical transformation, and deposition. Some examples of dispersion applications include tracking and forecasting the release of radioactive material, smoke from wildfire, windblown dust, pollutants, allergens and volcanic ash.

Renewable energy – Improved PBL forecasts can help integrate both wind and solar energy more efficiently into the grid. Solar energy is strongly affected by the presence of PBL clouds which are extremely difficult to forecast. This community requires improved predictions of PBL clouds, which requires an improved understanding of PBL thermodynamic properties and processes that lead to cloud formation and dissipation.

2.4 Why? Timeliness

There are several key reasons related to weather, wildfire, climate, and other applications why it is urgent to improve the quality of observations of the PBL thermodynamic structure, including:

Numerical weather prediction (NWP) and data assimilation (including reanalysis) systems have improved over time, but there remains potential for significant improvement associated with more accurate PBL observations and models. Assimilation of space-based global PBL thermodynamic structure would lead to better initial conditions for (global and regional) weather forecast models and more accurate global re-analyses. More detailed observations of global PBL structure will also lead to improved PBL models and parameterizations. Observing System Simulation Experiments (OSSEs) using NWP data assimilation systems will be critical to better define the optimal PBL mission characteristics to improve weather prediction (Zeng et al. 2020).

Wildfires are becoming more frequent and intense, posing increasing threats to life, property, and ecosystems. PBL observations of temperature and water vapor are crucial for characterizing the fire environment and PBL height is integral to predicting and tracking smoke plumes. Improved observations of PBL structure and height will lead to better-coupled weather and wildfire models, improving fire prediction, behavior, and smoke forecasts.

Climate model projections remain highly uncertain, and it is essential, for decision makers, to reduce these uncertainties. Much of the uncertainty regarding these projections is anchored in cloudy PBL feedbacks. To systematically improve climate model PBL parameterizations, more detailed observations of the global PBL thermodynamic structure are crucial. Space-borne observations provide the only means of obtaining the global coverage required over key regions that are remote and vast. Fridlind et al. (2025), via use of the Earth system model (ESM) autocalibration framework of Elsaesser et al. (2025), developed an approach that enables the determination of the value of potential future improvements in PBL thermodynamic observations on constraining cloud feedbacks in an ESM. As specifications for a PBL mission are iteratively formulated, such a tool can be regularly used for quantitatively determining the value that proposed spatial/temporal resolutions and measurement uncertainty thresholds add for constraining ESMs. It represents a new way to use ESMs in satellite mission planning.

Air quality and dispersion significantly impact human health, particularly in and around cities. PBL height strongly modulates the impacts of surface pollutant emissions via dilution (lower air quality is associated with a shallower PBL). Improved observations of PBL height and thermodynamic structure will lead to improved air quality characterization and forecasts.

3.1 What? Geophysical Variables and Measurement Requirements

The essential geophysical variables identified as uniquely required to address the four PBL science goals, and the cloudy PBL science questions are:

- PBL profiles of temperature.
- PBL profiles of water vapor.
- PBL height.

The specific SATMs presented in T21 (mentioned above) lead 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.

3.2 What? Synergy between observations and models

A key aspect is improved PBL observation–model synergy. Data assimilation has been critical for operational weather prediction and reanalysis, and a global PBL observatory will no doubt improve the ability to represent and predict the PBL in weather prediction and analysis. The use of model data to complement, and address gaps in observations is well established and should be improved. For example, data from large-eddy simulation (LES) models can complement observations in providing deeper insight into PBL physical processes. Innovative approaches using data science (retrieval algorithms, data fusion and assimilation, AI) and physical models will be critical to optimally extract essential information from the global PBL observatory.

4.1 How? Technology

A global PBL observatory should include the following essential measurement technologies:

High horizontal resolution hyperspectral infrared (IR) (1 km) and microwave (MW) (5 km) sounders in low Earth orbit (LEO) to provide 3D temperature and water vapor structure context to active sensors, potentially on SmallSat or CubeSat constellations (to provide higher temporal sampling).

Differential Absorption Lidar (DIAL) and Differential Absorption Radar (DAR) in suborbital platforms and potentially in LEO to provide accurate, high vertical resolution water vapor profiles, and temperature profiles in liquid phase clouds (DAR), and high horizontal resolution (1 km) estimates of PBL height (DIAL).

Radio Occultation (RO) in LEO using larger constellations of GNSS-RO receivers and/or novel orbital configurations and signal frequencies to provide high-vertical resolution (100-200 m) and temporal sampling of temperature and/or water vapor profiles and estimates of PBL height.

A global PBL observatory will rely on a **strong synergy between orbital, suborbital and surface** observations, and will take advantage in an effective manner of the **Program of Record** (POR) observations from a variety of platforms (orbital, suborbital, and surface), in particular from **geostationary hyperspectral IR sounding**, through international (e.g., EUMETSAT) and national inter-agency (NOAA) collaborations, to dramatically increase temporal sampling of temperature and water vapor profiles.

In addition, other measurement technologies could potentially play a significant role in a global PBL observatory. Using **backscatter lidar** in LEO in optimal combinations with some of the key approaches above has shown promising results. **Multi-angle** observations in LEO could potentially provide 3D PBL information using computed tomographic reconstruction methods.

As mentioned, data science (retrievals, data assimilation and fusion, AI) and atmospheric physical model innovations will be needed to optimally combine all the different sources of observed PBL thermodynamic information from a diversity of instruments and platforms.

4.2 How? Measurement Strategy

The need for a variety of different measurement approaches from orbital, suborbital and surface platforms (figure 2), and their optimal combinations, will critically require a sophisticated measurement strategy and architecture. In this context, the following key points should guide the development of a global PBL observatory measurement strategy:

- An orbital component that combines IR, MW and RO in an optimal manner would satisfy the PBL measurement requirements from space.
- Strong synergy between orbital and suborbital measurements will be essential to address key PBL science questions.
- DAR and DIAL could fly in dedicated suborbital campaigns prior and during the PBL space mission duration to achieve this strong orbital-suborbital synergy.

Other key points include:

- Strong synergy between orbital and surface-based remote sensing is also critical to address issues related to temporal sampling and local effects and products.
- Multiple instruments and strong focus on surface and suborbital components help create a variety of possibilities for national and international partnerships.
- A critical challenge will be the development of algorithms to optimally take advantage of this synergy between orbital-suborbital-surface observations. Modern data science approaches involving state estimation, data fusion and assimilation, and AI will be developed and studied.

Additional broader points include the fact that we should aim to make the global PBL observatory data available in near-real time (NRT) to NWP centers and other users. These PBL measurements are expected to be highly valuable and having the NWP community strongly committed to this mission would be extremely positive. Combining our global PBL data with thermodynamic weather observations from the POR and commercial assets will ultimately lead to an optimal utilization of all available resources.

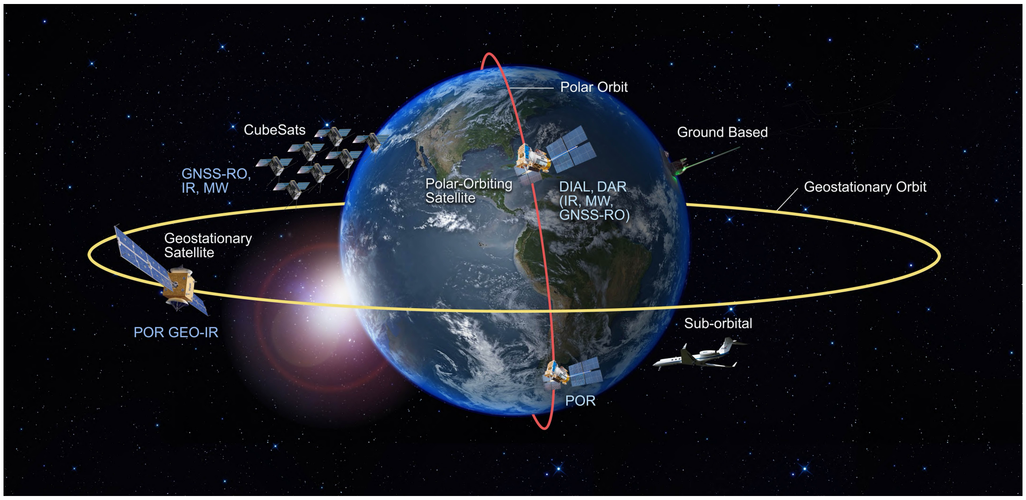

Figure 2. Overarching architecture highlighting critical components of a future global PBL observatory: LEO satellites, geostationary satellites, suborbital platforms and ground-based assets.

4.3 How? Orbital Component

The orbital component of the global PBL observatory will likely be focused on three key orbital instrument technologies (IR, MW and RO). This will require **critical innovations** in these technologies. In particular:

- Innovations to enhance the spectral coverage and resolution of MW observations.
- Innovations to enhance the spatial resolution of IR observations.
- Innovations to enhance the sampling of RO observations.

4.3.1 GNSS Radio Occultation

Radio occultation (RO) of the Earth's atmosphere using signals from the Global Navigation Satellite Systems (GNSS) is well suited for space-based probing of the PBL (e.g., Sokolovskiy et al. 2024). GNSS RO measurements can produce profiles with vertical resolution close to 100-200 m in the PBL. GNSS RO is an inexpensive remote sensing technique, thus enabling satellite constellations in LEO. Commercial RO entities can play a vital role in such constellations with NASA guidance and collaboration. The consensus of the RO science community is that RO performance in the PBL will continue to benefit from RO receiver gain that exceeds present capabilities and from improved open-loop signal tracking algorithms.

New RO joint retrievals with collocated MW and IR observations are being developed to mitigate RO biases. Intercomparisons of RO retrievals in the PBL by independent RO processing centers have shown to be highly effective in characterizing the uncertainties in retrieved products. It would be critical to perform simulation studies of RO in the PBL that consider the effects due to the 3D atmosphere, inhomogeneities from small to large scales, data modulations on the GNSS signals, and reflection from the ocean surface. Such simulations can be used to investigate more realistically the impacts of varying levels of RO receiver gain and the impacts of different RO tracking algorithms.

4.3.2 Microwave Sounders

The NASA PBL study team (T21) and this Cloudy PBL white paper have identified "hyperspectral" MW sounders as a key component of a future global PBL observatory focused on characterizing PBL thermodynamic profiles (e.g., Gambacorta et al. 2023). The thermodynamic structure of the PBL is encoded in the shape of the MW spectrum around the 22 GHz water vapor line and in the wings/windows of the 50-60, 118 and 183 GHz absorption lines. PBL relevant spectral regions are 18-50 GHz, 70-113 GHz and 125-175 GHz. Current spaceborne passive MW systems measure only 7% of the available spectrum in frequencies below 200 GHz. Existing MW sounder systems sub-optimally sample the PBL since they are configured to uniformly sample the full tropospheric and stratospheric temperature and water vapor profiles with a limited number (~10s) of channels.

The so-called MW window regions, which contain most of PBL thermodynamic information, are not measured by current or future planned sounder systems. This has been primarily due to historical technological limitations of analog MW systems and lack of sampling requirements specific to the PBL. The next generation systems in development at NASA and other organizations use new broadband spectrometer technology that allows - for the first-time – for complete sampling of the spectrum below 200 GHz, returning all available PBL information in the MW spectrum. Algorithms are in development to efficiently use this new spectral information and new observation approaches (e.g., multi-angle sounding) to extract more PBL information than has been possible before, with the aim of resolving vertical thermodynamic structures.

4.3.3 Infrared Sounders

Over the last 20 years, Infrared (IR) hyperspectral sounders have clearly demonstrated great accuracy, precision and stability in measuring temperature and water vapor vertical structure, albeit with poor vertical resolution and sampling in cloudy regions. Advances in detector and optics technology can now enable IR instruments to be developed with greater spatial, spectral, and temporal resolution for LEO and GEO, potentially improving their value to PBL science requirements.

Recent OSSEs have been used to quantify trade-offs in PBL vertical resolution associated with different instrument characteristics and suggest that vertical resolutions of 0.5 km are potentially possible with spectral resolutions of order 0.1 cm^{-1} combined with radiometric noise approximately 3 times lower than the European Infrared Atmospheric Sounding Interferometer (IASI) instrument (e.g., Kurowski et al. 2023). These OSSE approaches could be used to quantify the vertical resolution achievable with combinations of IR sensors with other measurement techniques. A key advantage of IR sounding is that it is feasible to obtain horizontal resolutions of the order of 1 km from space, uniquely satisfying the horizontal resolution requirements for a future global PBL observatory. In fact, IR sounders on LEO with high spatial resolutions of order 1 km are possible with today's technology, although trade studies between horizontal resolution, swath size and IR cloud-free sampling will have to be performed to find the optimal IR sampling strategy.

4.3.4 Potential Mission Architectures

While a variety of detailed studies need to be performed to investigate and determine what the optimal global PBL observatory architecture should be, a possible architecture for the orbital component could consist of a close-formation constellation of RO satellites flying in tandem with one or two LEO satellites hosting hyperspectral MW and IR instruments.

One possible RO constellation could consist of nine satellites in a right ascension of ascending node (RAAN)-spread formation of three groups of three satellites. The mean motion and the inclination of all satellites' orbits should be identical, with a low inclination determined to assure adequate RO sounding coverage throughout the tropics. The mission threshold lifetime should be

5 years to circumvent the possible aliasing of the annual cycle into the diurnal cycle. The result will be RO soundings systematically clustered temporally and spatially and with the same ray-path orientation at the tangent point. Two radiance sounder satellites would have orbits separated from the center of the RO constellation in the cross-track dimension to guarantee collocations with the RO soundings. This mission architecture would provide a data stream tailored to the PBL in ways that are not possible with sun-synchronous satellites co-hosting all instruments (RO, MW, IR): by regularly sweeping through the diurnal cycle, assuring extremely high gain RO, and systematically clustering RO soundings.

This type of architecture would leverage key information from each remote sensing technique for PBL sounding. RO offers high vertical resolution and sensitivity to PBL water vapor; IR offers sensitivity to PBL temperature and water vapor in clear skies with high spatial resolution; and MW offers sensitivity to PBL temperature and water vapor in (almost) all-sky conditions and information that can resolve biases in RO. The clustering of RO soundings makes the mission architecture unique, extending the high vertical resolution of RO into the horizontal and enabling the application of techniques such as tomography and neural networks to yield high-resolution 3D PBL reconstructions from collocated nadir sounding measurements. Finally, RO constellations of opportunity already provide significant impact in NWP, but systematic clustering of RO soundings with collocated hyperspectral MW and IR soundings offers a new avenue for research in data assimilation in regional and global models. Note that collaboration with commercial GNSS-RO assets in these mission scenarios could be of great relevance.

4.4 How? Orbital-Suborbital Synergy

4.4.1 Science Overview and Statement of the Problem

Progress on observation of the cloudy PBL will require synergy between orbital and suborbital observational strategies. Here, one specific suborbital sampling strategy is suggested to address key uncertainties unlikely to be gleaned from orbital observations. The proposed problem is the evolution of the cloudy marine PBL as it transitions from stratocumulus to cumulus PBL regimes and the interplay between the clouds and the PBL thermodynamic vertical structure, the surface fluxes, and the exchanges with the free troposphere. Despite decades of important developments, current models continue to struggle to accurately represent the evolution of marine PBL clouds, which significantly impacts weather, seasonal and climate predictions.

A key question that can only be addressed by the strong orbital-suborbital synergy is how the PBL mesoscale and vertical structures interact and influence the interactions with the surface and free troposphere. Sustained suborbital observations with state-of-the-art measurements are needed to improve our understanding of how PBL processes affect weather forecasts through detailed profiling of PBL temperature and water vapor.

4.4.2 Aircraft Sampling Strategy

A potential mission concept would employ a comprehensive flight strategy using either the NASA 777, P-3 Orion, or Gulfstream GV aircraft capable of 8+ hour flights with both high and low-altitude ocean operations, strategically based out of a West Coast NASA Center to access critical transitional cloud regimes in the eastern Pacific. A NASA Center like NASA Armstrong would be the optimal base of operations because it is ideally positioned on the edge of a climatological transition in cloudiness - from the often fully overcast cloudy PBL region off the US mainland to shallow cumulus dominated PBL regimes to the south and west. This location provides access to diverse cloud morphologies ranging from stratocumulus to cumulus, and from disorganized mesoscale cellular convection to aggregated/clustered shallow cumulus systems. The sampling approach involves tracking selected cloud systems in a Lagrangian manner to track the evolution from stratocumulus to cumulus. The aircraft utilizes remote operations out of Hawaii to track the atmospheric flow through these cloud morphologies. The stratocumulus-to-cumulus cloud transition occurs over several days permitting a mission strategy that could accommodate multiple samples of the same PBL airmass over the course of a single regime transition via repeated flights between Armstrong and Hawaii. These flights would be conducted in summer or early fall seasons to complement the growing atmospheric river (AR) reconnaissance program providing routine dropsondes in the winter season over the Pacific basin.

While the focus of this white paper is the cloudy PBL, the proposed sampling strategy could be expanded to investigate key questions regarding PBL interaction with deep convection and with the ocean surface, using Hawaii and potentially Guam for additional remote operations.

4.4.3 Minimum Measurement Requirements

This concept requires both in situ and remote sensing instrumentation to provide comprehensive observations. This could be accomplished via integration on a single aircraft platform or ideally two aircraft flying in tandem. Key remote sensing measurements include accurate and high vertical resolution water vapor and temperature profiles with 1 km horizontal and 200 m vertical resolution in clear and cloudy conditions, radar reflectivity measurements for cloud/precipitation characterization, aerosol backscatter and surface wind measurements for coupling cloud processes to ambient background aerosol conditions (namely sea salt), and vertical motion detection in both cloudy and clear conditions. The payload should also include in-situ turbulent winds, size distribution cloud probes, cloud microphysical probes, and dropsondes.

4.4.4 Relation to Orbital Assets

This mission concept relates to orbital measurements in critical respects. The orbital sensors provide key observations on mesoscale variability that are essential to address the science questions and provide a global perspective to the problem. The suborbital measurements provide validation data for orbital sounding instruments. Finally, flying active and passive sounders on orbital and suborbital platforms creates a unique opportunity for joint retrieval, data fusion/assimilation and AI techniques, to optimally combine high information content suborbital observations and global coverage satellite observations to produce joint orbital-suborbital products.

4.5 How? Orbital-Surface Synergy

A variety of PBL processes evolve quickly, requiring higher temporal and/or vertical resolution to accurately depict their evolution. The required resolutions can be difficult to achieve from orbital sensors alone, but surface-based instrument systems have demonstrated their ability to capture these details. Surface-based sensors that provide thermodynamic profiles are equivalent to point sensors: they are only able to provide information directly above the instrument (or at best, a small vertical cone around the remote sensor) and thus are unable to provide information on the PBL spatial variability. Gaining this spatial information could be achieved using a dense network of surface-based remote sensors; however, this is not possible to achieve globally. A novel alternative is to optimally merge surface-based with orbital observations into a cohesive data suite, so that the latter can utilize the information content of the former to acquire good vertical resolution and spatial context. Properly integrating the information from orbital and surface-based instruments is non-trivial, due to the different fields-of-view and the need to account for spatial variability in the two footprints. However, if these challenges can be overcome, this synergy could enable a unique and powerful range of science and applications. Data science innovations, including data assimilation, fusion and AI, combined with an intelligent utilization of PBL physical and dynamical models will lead to novel and unique PBL datasets consisting of optimal combinations of orbital, suborbital and surface-based observations.

5. Key Conclusions

The need for a variety of different measurement approaches from orbital, suborbital and surface platforms and their optimal combinations, will critically require a sophisticated measurement strategy and architecture for a future global PBL observatory. An orbital component that combines IR, MW and RO in an optimal manner would satisfy the measurement requirements from space.

Strong synergy between orbital, suborbital and surface PBL remote sensing will be critically required for a global PBL observatory and will lead to dedicated suborbital campaigns for the duration of the PBL mission, and to joint orbital-suborbital-surface products that will require sophisticated retrieval algorithms to optimally extract PBL information from the combination of all these observations. These dedicated suborbital campaigns should be carried out during the orbital deployment period of the global PBL observatory as well as prior to that to prepare for the orbital deployment. During this preparatory (or bridge) period, the suborbital data would be combined with the current POR to prepare for the full orbital-suborbital PBL mission.

The suborbital component should include DIAL, DAR, RO, IR and MW assets, and should focus on science questions that can only be addressed by a combination of orbital and suborbital assets. Note that new suborbital platforms offer the opportunity to synergize PBL science with related areas of interest including cloud properties, aerosols and winds.

The described need for multiple instruments and the focus on strong synergies between orbital, suborbital and surface-based measurement components create a variety of possibilities for national and international partnerships.

Critical innovations in PBL data science (retrieval algorithms, data assimilation and fusion, AI) and PBL physics modeling are required to be able to take advantage of the multiple instruments and the strong orbital-suborbital-surface synergy.

While an orbital component combining IR, MW and RO would satisfy the PBL measurement requirements, detailed studies are needed to precisely determine what the optimal orbital architecture should be and how to combine it effectively with the suborbital and surface components.

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