Joint ICESat-2 Atmospheric Tutorial with CALIPSO, EarthCARE, ADM-AEOLUS and CATS

May 31-June 1, 2017

Co-hosted by Ute Herzfeld, Department of Electrical, Computer and Energy Engineering, University of Colorado at Boulder

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I. Executive Summary

A two-day Joint Atmospheric Tutorial was hosted on May 31 and June 1, 2017, at the Discovery Learning Bechtel Collaboratory, University of Colorado Boulder. The tutorial focused on expanding awareness of the planned atmospheric observations for the Ice, Cloud and land Elevation Satellite-2 (ICESat-2) mission, as well as on identifying opportunities for leveraging the ICESat-2 data with information from other satellite instruments in order to maximize its utility for the atmospheric applied and operational communities.

The tutorial was a collaboration between the ICESat-2 mission and representatives of the joint NASA and French Centre National d'Études Spatiales (CNES) Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) mission; the International Space Station (ISS)-based Clouds-Aerosol Transport System (CATS) instrument; the joint European and Japanese Earth Clouds, Aerosols and Radiation Explorer (EarthCARE) mission; and the European Space Agency's (ESA)'s Atmospheric Dynamics Mission Aeolus (ADM-Aeolus) satellite—see **Table 1** on pages 6 and 7. The tutorial featured presentations from each of these missions/investigations with the goal of increasing participant's familiarity with the objectives and atmospheric data product functionalities, as well as to encourage exploratory discussion on potential joint-product development.

One of the main questions addressed during the meeting was the potential synergy arising from overlap in operations of each of the other instruments with that of ICESat-2. **Figure 1** on page 10 summarizes the expected lifetime for each mission or investigation. ICESat-2 is expected to at least partially overlap with the operation of ADM/Aeolus and EarthCARE during the 2018 to 2022 period. Overlap with CALIPSO and CATS is doubtful, but it is not considered impossible. CALIPSO is already well beyond its projected mission lifetime and CATS has license to operate through February 2018, perhaps longer (it had a six-month requirement and three-year goal). There is, however, a possibility of a CATS "follow-on" mission (that would be known as CATS-I), which has been submitted in response to an Earth Venture Instrument-3 Announcement of Opportunity.

Knowing the expected strengths and limitations of the ICESat-2 atmospheric data was important for helping establish potential opportunities and barriers for its utilization. Expectation management was one of the primary goals of the Joint Atmospheric Tutorial. The Science Definition Team members leading the development of the atmospheric data product, Steve Palm [NASA's Goddard Space Flight Center] and Yuekui Yang [GSFC], provided a thorough description of ICESat-2's planned atmospheric data product. ICESat-2 will provide excellent nighttime data; a continuation of the cloud, aerosol and blowing snow measurements begun by ICESat and later provided by CALIPSO; and will operate in a 92° orbit, which will provide data on polar areas not surveyed by other existing or planned missions.

On the other hand, ICESat-2 will provide limited cloud detection during peak sunlight; have a limited vertical range (spanning from 13.5 km (~8.4 mi) above the surface to 0.5 km (~0.3 mi) below the surface); and may also produce a folding effect where the reflections from the Earth's surface arrive at the ATLAS instrument at the same time as returns from clouds 15 km (~9 mi) above the surface (from the next laser pulse). ICESat-2's atmospheric data product will also have a latency of about 45 days. This may prove problematic for operational users requiring data at near real time latencies (e.g. hours).

Clarification of ICESat-2's limitations spurred discussion on how to work together to find solutions for better atmospheric data products. Among the recommendations were joint aerosol studies, sharing data and data-development experiences, and looking for algorithm synergies. Discussion also centered on three potential applications—air quality prediction, weather forecasting and climate monitoring, and monitoring wildfires—that could benefit from ICESat-2 alone or in combination with other mission datasets. We identified three potential applications that could use ICESat-2 alone or in combination with other mission datasets—air quality prediction, weather forecasting and climate monitoring, and monitoring wildfires. This report provides the outcomes of this tutorial and synthesis of participant feedback.

Overall, the tutorial provided an opportunity to obtain science and operational community ideas on how to best use the ICESat-2 atmospheric data, as well as thoughts on how to tackle some of the unique challenges that the ICESat-2 atmospheric data will present. Participants found it inspiring to learn what each other is doing and were interested in continuing interaction moving forward.

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II. Introduction

On May 31 and June 1, 2017, the ICESat-2 Applications Team convened a Joint Atmospheric Tutorial at the Discovery Learning Bechtel Collaboratory at the University of Colorado Boulder. The tutorial corresponded to one of a series of pre-launch outreach events organized for the ICESat-2 Applications program. The Joint Atmospheric Tutorial was designed to expand awareness of the planned atmospheric observations for ICESat-2 and to identify opportunities for leveraging the data with information from other satellite instruments so as to maximize its utility for the atmospheric applied and operational communities.

The tutorial was a collaboration between the ICESat-2 mission and representatives of the joint NASA and French Centre National d'Études Spatiales (CNES) Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) mission; the International Space Station (ISS)-based Cloud-Aerosol Transport System (CATS) instrument; the joint European and Japanese Earth Clouds, Aerosols and Radiation Explorer (EarthCARE) mission; and the European Space Agency (ESA)'s Atmospheric Dynamics Mission–Aeolus (ADM-Aeolus) satellite—see **Table 1** on pages 6 and 7. The tutorial featured presentations from each of these missions/investigations with the goal of increasing participant's familiarity with the objectives and atmospheric data product functionalities, as well as to encourage exploratory discussion on potential for future joint-product development.

The two-day meeting was co-hosted by **Ute Herzfeld** from the Department of Electrical, Computer and Energy Engineering at the University of Colorado at Boulder. Herzfeld authors the Algorithm Theoretical Base Document for ICESat-2 Atmospheric Data Products (Part II) on detection of atmospheric layers with Steve Palm, ICESat-2 Science Definition Team member for atmosphere. She also conducts research on the detection of atmospheric layers, including tenuous cloud layers, and its potential applications in climate modeling and science. Herzfeld is interested in using ICESat-2 atmospheric data to derive blowing snow information and has proposed to conduct pre-launch research, as part of the ICESat-2 Early Adopter program, to demonstrate the feasibility of using the derived blowing snow data to increase transportation (road/aviation) safety. As a co-host of the meeting, Herzfeld played a key role in facilitating the dialogue needed to understand how to best combine data sets from different missions (originated by NASA and others) with those of ICESat-2.

The tutorial introduced two programs that are part of NASA's Applied Science Program that support the application of Earth science observations for decision making: The Health and Air Quality Applied Sciences Team (https://haqast.org) and the Mission Applications Program, including its Early Adopter Program (https:// icesat-2.gsfc.nasa.gov/early_adopters). Representation from the NSIDC Distributed Active Archive Center (DAAC), where ICESat-2 data will be archived, allowed participants to learn about the personalized support for data selection, access, and usage that the DAAC is developing for the mission. The tutorial also allowed the DAAC to gather feedback from participants on visualization of vertical profiles, three-dimensional (3D) point cloud visualization, and needs for data access, tools, and services. Participants were also enthusiastic about the live demonstration by the DAAC on Earthdata Search and exploration of imagery using Worldview Applications: https://worldview.earthdata.nasa.gov.

Overall, the tutorial was designed to align with ICESat-2's applications program goals. These are to: 1) expand awareness of the ICESat-2 mission and its data products, and 2) to provide different user communities with a venue to provide direct feedback to the ICESat-2 mission scientists on opportunities for using and leveraging the planned science data. This report provides a brief description of the tutorial goals and process, as well as of each mission/investigation involved. It also summarizes the tutorial outcomes and participant feedback to serve as baseline for future inquiries into how ICESat-2 atmospheric data products could be used by the atmospheric applied and operational communities.

Table 1: Instrument Technical Specifications

Instrument: Advanced Topographic Laser Altimetry System (ATLAS) Mission: Ice, Cloud and land Elevation Satellite-2 (ICESat-2)	
Measurement Concept	Single photon counting lidar
Wavelength	532 nm
Beams	Multibeam (3 pairs; 6 total)
Orbit	500 km mean altitude; polar, non-sun-synchronous; 92° inclination
Pulse Repetition Rate	25 Hz [400 shot aggregation, 280 m along track resolution, binned at 30-m vertical resolution (467 bins total)]
URL	https://icesat-2.gsfc.nasa.gov/

ATLAS will be the sole instrument on ICESat-2, which is scheduled for launch in 2018. ICESat-2 has four science objectives for ice sheets, sea ice, and vegetation, which drive its design. While ATLAS has no specific overall mission requirements for atmospheric science, as a global satellite mission, ICESat-2 will collect data over all of Earth's surfaces. Therefore, in addition to the sea ice, land ice, and vegetation data products, the ICESat-2 mission is also developing products for atmosphere, ocean and inland water.

Instrument: Atmospheric Lidar (ATLID) Mission: Earth Cloud Aerosol and Radiation Explorer (EarthCARE)	
Measurement Concept	High spectral resolution lidar with depolarization
Wavelength	355 nm
Beams	Single
Orbit	400 km mean altitude; polar, sun-synchronous, 97.05° inclination
Pulse Repetition Rate	38 Hz (2-pulse summation, 285 m horizontal resolution, 103-m vertical resolution)
URL	https://earth.esa.int/web/guest/missions/esa-future-missions/earthcare http://global.jaxa.jp/projects/sat/earthcare

ATLID is one of four instruments on EarthCARE, which is scheduled for launch in 2019. Compared to CALIPSO, ATLID is expected to provide improved daylight performance, direct measurement of aerosol extinction, and measurement of extinction-to-backscatter ratios.

Instrument: Atmospheric LAser Doppler INstrument (ALADIN) Mission: Atmospheric Dynamics Mission (ADM) Aeolus	
Measurement Concept	Direct detection ultraviolet Doppler wind lidar
Wavelength	355 nm
Beams	Emits circularly polarized light
Orbit	~320 km mean altitude; off-nadir, sun-synchronous; 96.97° inclination
Pulse Repetition Rate	50 Hz (2 receiver channels (one for Rayleigh and the other for Mie scattering) each sampling the wind in 24 vertical bins. 0.25 to 2 km vertical resolution of layer-average winds; altitude range up to about 30 km)
URL	http://esamultimedia.esa.int/docs/EarthObservation/AEOLUS_sheet_170809.pdf

Table 1: Instrument Technical Specifications

ALADIN is the single instrument that will be carried by the Aeolus satellite (target launch January 2018) and will be the first Doppler wind lidar in space. Aeolus-ALADIN will address the lack of homogenous global coverage of direct wind profile measurements producing horizontally projected line-of-sight wind profiles both in clear and (partly) cloudy conditions down to optically thick clouds. Aeolus measurements will be delivered in near-real-time (within 3 hours) and could benefit numerical weather prediction and aerosol assimilation in forecast and climate models.

Instrument: Cloud Aerosol Lidar with Orthogonal Polarization (CALIOP) Mission: Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO)	
Measurement Concept	Two-wavelength polarization-sensitive lidar
Wavelength	532 nm and 1064 nm
Beams	Emits circularly polarized light
Orbit	705 km mean altitude; off-nadir, sun-synchronous; 98.2° inclination
Pulse Repetition Rate	20.25 Hz (333 m horizontal resolution; 30m below 8.5 km to 60m above 8.2 km vertical resolution)
URL	https://www-calipso.larc.nasa.gov

CALIOP’s polarization lidar is one of three instruments on CALIPSO, which has been in orbit since 2006. It has two wavelengths that allow for detection of clouds, aerosols, and surfaces (the 1064-nm wavelength is used only when measuring aerosols). CALIOP has provided data that have enabled the creation of a global, multiyear dataset for improved visualization of Earth’s atmosphere to advance understanding of the role of aerosols and clouds in the climate system.

Investigation: Cloud-Aerosol Transport System (CATS) International Space Station		
Measurement Concept	Photon Counting ISS lidar with depolarization	
Wavelength	**Mode 1 (February 10-March 21, 2015)**	**Mode 2 (March 25, 2015 – Present)**
	Backscatter: 532 and 1064 nm	Backscatter: 532 and 1064 nm
	Depolarization: 532 and 1064 nm	Depolarization: 1064 nm
	Level-2 Products: 532 and 1064 nm	Level-2 Products: 1064 nm
Beams	**Mode 1**	**Mode 2**
	Multibeam	Laser 2
Orbit	~415 km mean altitude, 51° inclination	
Pulse Repetition Rate	4- and 5- KHz Lasers (350-m horizontal resolution, 60-m vertical resolution)	
URL	https://cats.gsfc.nasa.gov	

CATS, launched in 2015, was installed on the Japanese Experiment Module–Exposed Facility on the International Space Station. It is a lidar designed to, among other goals, complement the CALIPSO data record with diurnally varying cloud and aerosol vertical profiles. It is also used to monitor dynamic events such as wildfires and volcanic eruptions. CATS data products provide comprehensive coverage of the tropics and midlatitudes, which are considered the primary aerosol transport paths. CATS can detect the full extent of aerosol plumes and distinguishes clouds embedded in aerosol layers. Near-real-time data products are created within six hours of data acquisition.

III. Tutorial Description

The ICESat-2 Joint Atmospheric Tutorial with CALIPSO, CATS, EarthCARE and ADM-Aeolus was held on May 31 and June 1, 2017, in Boulder, Colorado. The tutorial was convened by the ICESat-2 Applications Team (Appendix A lists members of the team) and co-hosted in conjunction with Ute Herzfeld from the Department of Electrical, Computer and Energy Engineering at the University of Colorado Boulder. The Applications Team worked in consultation with Steve Palm and Yuekui Yang, ICESat-2 Science Definition Team members for atmosphere, and Ute Herzfeld to design the agenda for the meeting. A web conferencing system, used for the duration of the focus session, allowed for remote access by participants joining nationally and from overseas, including participation by representatives from EarthCARE and ADM-Aeolus, who were not able to attend the meeting in Colorado.

A. Goals and Process

The Joint Atmospheric Tutorial aimed to provide an in-depth description of the atmospheric observations planned for ICESat-2 and of the existing or expected atmospheric data products from other missions. A primary goal was to provide a forum for discussions, exchange of information and ideas, on the development of a new joint atmospheric product for applications relevant to operational air quality and pollution forecasting, as well as to motivate joint mission efforts. Another main goal was to identify current participant needs and requirements for new data so as to facilitate establishing possible strategic collaborations, including interest in the Early Adopter program.

The workshop brought together a total of 47 experts (listed in Appendix C)—19 in person and 28 via remote access. In person-participants were from NASA, University of Colorado Boulder, National Snow and Ice Data Center (NSIDC), Naval Research Laboratory, National Center for Atmospheric Research and the NOAA Earth System Research Laboratory. Remote access attendees were from European Space Agency, the Koninklijk Nederlands Meteorologisch Instituut [KNMI; the Royal Netherlands Meteorological Institute], the Italian Consiglio Nazionale delle Ricerche [CNR; National Research Council], Environment and Climate Change Canada, NOAA's Laboratory for Satellite Altimetry, Western States Air Resources Council, NASA's Short-term Prediction Research and Transition Center, and various national and international universities seven, national; four, international.

A meeting prospectus was developed and sent to the whole ICESat-2 applications community and posted to the ICESat-2 applications website (http://icesat-2.gsfc.nasa.gov/applications). Speakers were asked to summarize the data from their mission, and provide their perspectives on the synergistic use of data from multiple sensors in their science and applications. They were also asked to consider any challenges they anticipated in the use of ICESat-2 data in their work.

B. Agenda and Format

Overall, the tutorial sought to both inform participants on each mission's atmospheric data functionality and to receive feedback from participants on requirements and synergistic opportunities for using the data. The meeting had five sessions each followed by a discussion and question and answer period. A final extended brainstorming session was held during Day 2.

- **Session I: Welcome, Background and Context**
  This session provided welcoming remarks and context for the meeting, including presentation of tutorial objectives, see **Table 2** on page 9. The session began with a presentation by Daven Henze

of the NASA Health and Air Quality Applied Science Team, who discussed current projects and Tiger Teams to respond to evolving needs of air quality management.

Table 2: Joint Atmospheric Tutorial Objectives

Joint Atmospheric Tutorial Objectives
1. Create Awareness: Communicate the goals and describe the atmospheric products of ICESat-2, EarthCARE, CALIPSO, CATS and ADM Aeolus.
2. Identify how ICESat-2 atmospheric data could be leveraged in combination with other data sets to maximize its utility for the atmospheric applied and operational communities.
3. Increase collaboration opportunities by identifying the requirements and needs of the atmospheric data user community
4. Explore potential joint-mission atmospheric products and motivate joint mission efforts
ICESat-2 Applications Perspective on Meeting Objectives
1. Expectation Management
2. Expand and enable collaboration
3. Begin to understand the potential applications for ICESat-2 Atmospheric data

- **Session II: Synergies & Opportunities to Leverage Observations**
  Presentations were given on the ICESat-2, EarthCARE, ADM Aeolus, and CALIPSO missions, as well as on the CATS instrument. They were designed to provide participants with up-to-date detailed information on the atmospheric data corresponding to each platform and to provide perspectives on cross-mission opportunities.
- **Session III: Transforming New Data into Actionable Information - Needs and Opportunities**
  This session highlighted ongoing modeling, operational and forecasting initiatives and provided the space to identify and discuss opportunities and barriers to integrate ICESat-2 data into future goals. During the session, a number of speakers articulated the potential use of ICESat-2 based on successful application of CALIPSO data.
- **Session IV: ICESat-2 Early Adopter Program**
  Day 2 of the tutorial opened with a roundtable to highlight discussion priorities and remaining questions (see Final Brainstorming Session below for details). The roundtable was followed by an introduction to the Early Adopter program and was followed by two presentations showing current and potential Early Adopter research. The session generated new insights into possible solutions to current issues with the ICESat-2 atmospheric data, namely, ICESat-2's pulse-aliasing issue and decreased daytime layer detection due to background noise. It also provided insights into different practical applications for the research.
- **Session V: Coupling Data and Analysis**
  This session featured presentations that focused on how to use atmospheric datasets together and facilitated communication of synergistic opportunities for complementing ICESat-2 with other datasets. The session was followed by a presentation from the ICESat-2 Distributed Active Archive Center (DAAC), the National Snow and Ice Data Center (NSIDC), which included a demonstration of planned data services via the NASA Earthdata Search.
- **Final Brainstorming Session**

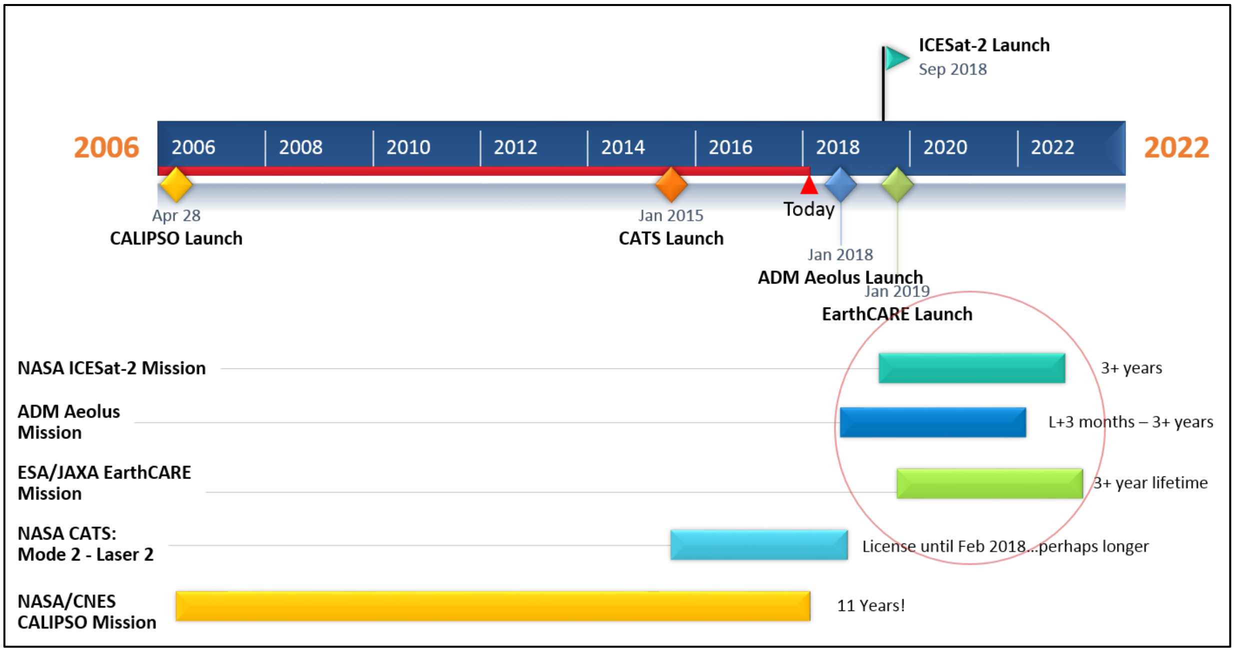
The tutorial concluded with a brainstorming session to discuss remaining shared questions and ideas. The brainstorming was guided by participants' expressed interests and by the seed questions shown in Appendix E. The participants focused on finding solutions for improving the atmospheric data products; on ideas for interaction across missions and working together to fill current gaps; on delineating differences between the different instruments; on how to leverage ICESat-2 with existing/historical information; on defining where the different mission will be coincident in time, as well as on needs for making comparisons between observations and models.

C. Outcomes

The Joint Atmospheric Tutorial described data from five different space-based Lidar instruments that are or will provide atmospheric observations: CALIOP (on CALIPSO), CATS, ATLID (on EarthCARE), ALADIN (on ADM-Aeolus), and ATLAS (on ICESat-2). A summary of the presentations for each instrument is provided in Appendix F; shown in **Table 1** on pages 6 and 7 are the technical specifications for each instrument.

One of the main questions addressed during the meeting was the possibility of overlap of each instrument with ICESat-2. **Figure 1** summarizes the expected lifetime for each mission or investigation. ICESat-2 is expected to at least partially overlap with the operation of ADM/ Aeolus and EarthCARE, during the 2018 to 2022 period. Overlap between ICESat-2 and CALIPSO is doubtful, but it is not considered impossible. CALIPSO is already well beyond its projected mission lifetime and CATS has license to operate through February 2018, perhaps longer (it had a six-month requirement and three-year goal). There is, however, a possibility of a CATS "follow-on" mission (that would be known as CATS-I), which has been submitted in response to an Earth Venture Instrument-3 Announcement of Opportunity. Nevertheless, discussion on complimentary measurements during the meeting encompassed all instruments

Figure 1. Atmospheric Missions – Possible Overlap with ICESat-2



What to expect from the ICESat-2 Atmospheric Data Product

ICESat-2's observations of the atmosphere are considered secondary science objectives of the mission; however, it is expected that ICESat-2 will provide useful data on clouds and aerosol, especially in Polar regions. As one of the primary goals of the tutorial was expectation management, a thorough description of ICESat-2's strengths and limitations with respect to the atmospheric data was provided by the SDT members.

Strengths

- **Excellent nighttime data**. ATLAS should do an excellent job detecting thin clouds and aerosols at night—down to an optical depth of approximately 0.05.
- **Continuation of measurements**. ICESat-2 will continue the cloud, aerosol, and blowing-snow measurements begun by ICESat and continued by CALIPSO.
- **Orbit**. ICESat-2 will operate in a 92° inclination orbit, providing data from polar areas not surveyed by other existing or planned missions.

Limitations

- **Limited cloud detection during peak sunlight.** Solar background noise is expected to reach up to 10 MHz due to the design of ATLAS's receiver optics and electronics. Cloud detection will be limited to an optical depth of approximately 0.5. ICESat-2 can be expected to detect clouds during day-time conditions, in some cases even tenuous (thin) clouds and aerosol layers.
- **Limited vertical range.** The atmospheric data products will span the range from 13.5 km (~8.4 mi) above the surface to 0.5 km (~0.3 mi) below the surface. Other sensors designed for cloud studies typically have a wider range; for example, CALIPSO's data span from the surface to 26 km (~16 mi) above the surface.
- **Folding effect.** The pulse repetition frequency of ATLAS is 10 kHz, which results in consecutive laser pulses being separated in flight by ~30 km (~19 mi). As a result, reflections for the Earth's surface arrive at ATLAS at the same time as returns from clouds 15 km (~9 mi) above the surface (from the next laser pulse). Consequently, a cloud layer detected at 2 km (~1.2 mi) altitude could actually be at 17 km (~10.6 mi) altitude.
- **45-day latency[1].** Measurements of along-track cloud and other significant atmosphere layer heights, blowing snow, integrated backscatter, and optical depth, will be available to users 45 days after data acquisition on the satellite.

Ideas for overcoming ICESat-2's limitations

Clarification of ICESat-2's limitations spurred discussion on how to work together to find solutions for a better atmospheric data product. Among the recommendations for working together were: joint aerosol studies, sharing data and data-development experiences, and looking for algorithm synergies. Participants emphasized the need to develop a product to minimize ICESat-2's large signal-to-noise differences between night and day data that will make it hard to conduct studies comparing day and

[1] Latency is defined as the approximate time it takes from the data acquisition on a satellite until it reaches an individual in a usable format.

night differences on cloud properties. Participants also recommended further research into methods for noise reduction to improve the usability of the daytime data.

Participants recommended using both EarthCARE and CALIPSO data to help address ICESat-2's folding effect. When the two instruments are closely aligned in space and time, EarthCARE ATLID measurements, for example, can be used to help validate those from ICESat-2's ATLAS, and possibly help understand the folding problem. Similar synergy might be achieved with CALIPSO's CALIOP and ICESat-2's ATLAS.

Lucia Mona, from the Institute of Methodologies for Environmental Analysis of the National Research Council of Italy (CNR-IMAA), also suggested exploring her folding or—*pulse-aliasing*—solution her team developed to create a flag in the ATLAS Atmosphere Cloud Layer Characteristics [ATL09] data product for ICESat-2 (refer to Appendix B for a description of ICESat-2's data products). Mona is an Early Adopter for the mission and as such has been conducting pre-launch research to demonstrate the ICESat-2 capability of providing vertical profiles of the aerosol backscatter coefficient and to define its potentialities and limits[2]. Lucia's preliminary approach to address ICESat-2's folding effect is based on the thickness of the atmospheric layer, where if the layer is thicker than 3-4 km, it is assumed to be folded down. Using this approach to create a folding flag in the ATL09 product remains to be further explored by the SDT members, as there are many instances, including in the Arctic, where this assumption is not true.

Update: A new Density-Dimension Algorithm (DDA) has been designed by Ute Herzfeld to overcome the limitations of atmospheric lidar altimeter data collected during daytime, when noise from ambient light is high. The DDA allows detection of clouds, including some thin clouds and aerosols, during daytime conditions as well. The DDA has the ability to adapt automatically to changing noise properties of daytime and night-time conditions and will be applied to derive the ICESat-2 layer products (in ATL09).

There were also several ideas for other joint studies to improve the ICESat-2 atmospheric retrievals, including calibrating aerosol and cloud statistics in polar regions; using Afternoon Constellation or "A-Train"[3] image patterns and research approaches for classifying aerosols, exploring algorithm synergies with CATS, as well as looking at how CATS and ICESat-2 cloud climatological characteristics change over the tropics. A synergetic study of blowing snow radiative properties was also proposed as part of this discussion.

Janet Intrieri [NOAA's Earth System Research Laboratory] described the potential for using ICESat-2 within NOAA's coupled ice-ocean-atmosphere forecast model—the Regional Arctic System Model – Earth System Research Laboratory (RASM-ESRL). While the primary interest is to use the sea ice thickness derived from ICESat-2 for model initialization and to compare forecasts of ice properties (e.g., ice thickness comparisons); RASM-ESRL model development could provide ICESat-2 with snow product guidance and vertical cloud property information. This would include, for example, snow forecasts and 2-3 day guidance for pointing angle locations, as well as cloud properties cross-sections.

[2] First results of Lucia Mona's investigation can be found via the following publication:
Mona, L., Amodeo, A., & D'Amico, G. (2016). Potentialities and Limits of ICESAT-2 Observation for Atmospheric Aerosol Investigation. *EPJ Web of Conferences, 119*, 04004. doi:10.1051/epjconf/201611904004

[3] The Afternoon Constellation or "A-Train" consists of eight U.S. and International Earth Science Satellites, including CALIPSO, that fly within approximately ten minutes of each other to enable concurrent science.

There was also discussion about how ICESat-2 could benefit other missions. For example, ICESat-2's attenuated backscatter profiles could be a good test of EarthCARE extinction retrievals and determining cloud and aerosol types. CATS could benefit from the ideas on how to fix some problems shared with ICESat-2—for example, the folding effect. Participants were enthusiastic about the idea of having ICESat-2 periodically point to NASA's Micro-Pulse Lidar Network (MPLNET) sites for calibration (https://mplnet.gsfc.nasa.gov). This may be important, as calibration/validation activities are not funded for ICESat-2 atmosphere data products.

Another topic of discussion was latency requirements. For example, the Naval Research Lab (NRL) in Monterey currently ingests CALIPSO observations of aerosol and dust plumes in its aerosol transport model. These observations are required within 12 hours of real time. However, other data users may not require such a fast turnaround. Further discussion is needed to understand possible approaches or solutions to ingesting ICESat-2 data operationally. Expedited process (in terms of latency) was always a goal for CALIPSO. CALIOP Level 1 and Level 2 data products were released continuously following 2 to 3 day latency from downlink in version 3.x of their data. Use of the Modern Era Retrospective-Analysis for Research (MERRA-2) reanalysis product to yield more accurate and reliable CALIOP calibration coefficients increased the latency to several weeks in the updated version 4.10 CALIOP Level 1 and Level 2 products.

During the discussion, the NSIDC DAAC sought input from participants on use cases for vertical profile visualization and inquired as to the 1) interest in vertical profile data across multiple missions, and 2) expected improvement of 3D point cloud visualization for data discovery workflow. As a response, Steve Palm indicated that it would be great to have vertical profile data for multiple missions when the instruments are co-located in space and time to a pre-defined degree and that point cloud visualization could benefit the detection of blowing snow immensely.

Potential Applications

Communication of the expected benefits and limitations of the ICESat-2 atmospheric data was important to help establish potential opportunities and barriers for its utilization in a variety of applications. During the meeting, discussion centered on four potential applications—air quality prediction, weather forecasting and climate monitoring, and monitoring wildfires—that could benefit from ICESat-2 alone or in combination with other mission datasets. Key participant feedback for each of these applications is summarized below. Further detail can be found in the Comments section for each presentation summarized in Appendix F.

Air Quality Prediction

ICESat-2 could be used to improve the accuracy of air quality prediction without providing information about atmospheric constituents or chemical composition (e.g., data on particulate matter $PM_{2.5}$). ICESat-2 will provide vertical profiles of attenuated backscatter, which is related to aerosol loading and pollution content, and may be able to provide information on the planetary boundary layer height. ICESat-2 could also be used for improving the temporal and spatial coverage of aerosol data in polar regions.

There was discussion about the benefits of complementing ICESat-2 with other datasets. For example, ICESat-2 and CALIPSO data might be used together to provide constraints on the vertical distribution of aerosols; ICESat-2 and CATS in combination might also be useful to continue the global record of detailed vertical profiles of atmospheric particulates. ICESat-2 vertical profiles could build upon current work with CALIPSO data to assess air quality above the ground, to help track the vertical movement of smoke in plumes emitted by fires.

Weather Forecasting and Climate Monitoring

ICESat-2 also could be used to provide a consistent and refined annual climatology of clouds. Discussion focused mainly on the polar regions where there is a significant lack of data. The NRL, for example, emphasized a significant lack of CALIOP information at polar latitudes, owing to its orbit in the A-Train and signal-to-noise issues, and highlighted the prospect of using ICESat-2 to fill in this polar data gap and to provide critical measurements of cirrus cloud physical properties and their occurrence.

Other ideas included leveraging ICESat-2 to complement existing and future observations. These included developing a long-term data record of aerosol content over polar regions for air quality, climate change and climatological applications by using the vertical profiles of aerosol optical properties as they become available from ATLAS together with those of CALIOP and then ATLID. Also, using ICESat-2 to extend the CloudSat-CALIPSO observations of clouds, in particular, to supercooled liquid clouds polarward of 82˚; using ICESat-2 to provide information about the diurnal cycle of clouds; and using ICESat-2 to detect Asian dust (more difficult to detect than Saharan dust because it is typically injected higher in the atmosphere and is more diffuse, both vertically and horizontally); and to detect volcanic ash.

Monitoring of Wildfires

ICESat-2 also could be used to monitor smoke aerosols. The NRL, for example, suggested using ICESat-2 data in a manner similar to what is currently done with CALIPSO data, to monitor pyrocumulonimbus (pyroCb) smoke in the upper troposphere/lower stratosphere (UTLS). ICESat-2 would help in distinguishing smoke aerosols from clouds, observing the vertical characteristics of pyroCb smoke plumes, confirming pyroCb occurrence, tracking smoke transport and UTLS lifetime, and calculating aerosol mass.

Traffic Hazard Warning

In addition to the above applications, Ute Herzfeld provided an overview of the Early Adopter research she is leading on the potential of using ICESat-2 atmospheric data to assess hazardous conditions for traffic (both air and ground traffic) due to blowing snow. High winds create thick layers of blowing snow, which hinders the heavy traffic of heavily populated regions. Ute Herzfeld will examine the applicability of a blowing snow product derived from ICESat-2 in transportation hazard warning.

Take Away Messages

Fruitful discussions were conducted on the strengths and weaknesses of the ICESat-2 atmospheric products. It was pointed out that even with the folding effect and high solar background noise levels, ICESat-2 atmosphere data can significantly complement observations from other sensors. With a 92° orbital inclination, ICESat-2 covers much of Earth’s higher-latitude regions, compared to CALIPSO (which has a 98.2° inclination), CATS (51.6° inclination), and EarthCARE (97° inclination). ICESat-2 will provide information through the atmospheric column (to 14.5 km above the surface) in addition to the detailed surface elevation, whereas other sensors usually only have information on the atmospheric column.

Awareness Creation

The joint ICESat-2 Atmospheric Tutorial provided an opportunity for interaction and comingling between the different atmospheric mission science teams, modeling, operational, and NSIDC DAAC representatives. It also created awareness of two NASA Applied Science programs that support the application of Earth science observations for decision making—the NASA Health and Air Quality Applied Sciences Team and the NASA Mission Applications Program, including it Early Adopter program.

Representation from the NSIDC allowed participants to learn about the personalized support for data selection, access and usage that the DAAC is developing for the mission. NSIDC provided an overview of the various features for discovery and access of data already in development and it solicited information on visualization of vertical profiles and 3D point cloud visualization. The NSIDC DAAC also shared a survey with participants to encourage additional feedback on needs for data access, tools and services: https://www.surveymonkey.com/r/ic2survey.

Familiarization with different missions/data products and to identify potential synergies between ICESat-2 and CALIOP, CATS, ADM-AEOLUS, and EarthCARE

It is unlikely that CALIPSO or CATS will be in operation while ICESat-2 is collecting data, although it is not impossible. ADM-AEOLUS and EarthCARE, on the other hand, are scheduled to launch in 2018 and 2019, respectively, should be operating at the same time as ICESat-2, and will be valuable for validation and comparison through periodic cross overs between these three sensors when we will have temporally and spatially coincident data. Both EarthCARE and ADM-AEOLUS are sun-synchronous and the orbit of ICESat-2 will precess through these orbits at intervals that have yet to be determined. When this happens, the data from EarthCARE and or ADM-AEOLUS can be used to compare and potentially validate the data from ICESat-2.

Explore user needs and begin to understand potential atmospheric applications for ICESat-2

The main benefit of ICESat-2's atmosphere data will be to provide continuity for the cloud, aerosol and blowing snow measurements begun by ICESat and later acquired by CALIPSO. Even though ICESat-2 will not have CALIPSO's full capability, it will still enable atmospheric measurements that will be valuable for research. Particularly, these include polar clouds, aerosol and blowing snow. Other measurements—such as cirrus cloud properties, global cloud fraction, smoke from fires, and volcanic eruptions—will also be important contributions from ICESat-2. There are some applications that require near-real-time data, which may prove to be difficult for the project to provide.

Appendix A. ICESat-2 Applications Team

The ICESat-2 mission applications program initiated in response to the 2007 National Research Council Decadal Survey for Earth Science, which identified development of applications of satellite data as a priority for all future space-borne missions. Since 2012, ICESat-2 application leads, working in concert with the mission, have been developing and implementing an applications program to improve understanding of how the global earth observations planned for ICESat-2 can be effectively used by different organizations within decision processes that lead to actions with direct societal benefits.

The focus of the ICESat-2 Applications Team, the current membership of which is listed in Table 1, is to explore the advantages of the photon-counting approach, by working with stakeholders to identify opportunities for using the new measurements in specific applications.

Table 1. ICESat-2 Applications Team Members as of January 2016

Role in ICESat-2 Mission	Members	Affiliation
ICESat-2 Program Applications Coordinator	Sabrina Delgado Arias	Science Systems and Applications Inc (SSAI), NASA's Goddard Space Flight Center (GSFC)
ICESat-2 Deputy Program Applications (DPA) Lead	Vanessa Escobar	Booz Allen & Hamilton, NASA's GSFC
ICESat-2 Program Applications Lead	Molly Brown	University of Maryland
ICESat-2 SDT Member (Hydrology) & Science Team Applications Liaison	Mike Jasinski	NASA's GSFC
ICESat-2 Deputy Project Scientist	Tom Neumann	NASA's GSFC
ICESat-2 Science Team Leader	Lori Magruder	University of Texas
NASA Headquarters Program Applications Lead	Woody Turner	NASA Headquarters (HQ)

Appendix B. Description of ICESat-2 Data Products

The planned ICESat-2 science data products are shown in Table 1. The products will conform to the HDF-5 standard.

ICESat-2 Science Data Products

Product Number	Name	Short Description	Latency*
ATL00	Telemetry Data	Raw ATLAS telemetry in packets with any duplicates removed by EDOS.	Downlinked 8 times per day
ATL01	Reformatted Telemetry	Parsed, partially reformatted, HDF5 time-ordered telemetry.	2 days
ATL02	Science Unit Converted Telemetry	Science unit converted time ordered telemetry calibrated for instrument effects. All photon events per channel per shot. Includes atmosphere raw profiles. Includes housekeeping data, engineering data, s/c position, and pointing data.	2 days
ATL03	Global Geolocated Photon Data	Precise lat, long and height above ellipsoid for all received photons determined using POD and PPD. Along-track data, per shot per beam. Geophysical corrections applied. Classification of each photon (signal vs. background) and into surface types (land ice, sea ice, ocean, etc.).	21 days
ATL04	Normalized Relative Backscatter	Along-track normalized relative backscatter profiles at full instrument resolution (25 times per second for ~30m vertical bins). Includes calibration coefficient values calculated in the polar region.	21 days
ATL06	Land Ice Height	Surface height for each beam, along and across-track slopes calculated for beam pairs. All parameters are calculated at fixed along-track increments for each beam and repeat.	45 days
ATL07	Sea Ice Height	Height of sea ice and open water leads (at varying length scale). Includes height statistics and apparent reflectance.	45 days
ATL08	Land-Vegetation Height	Height of ground and canopy surface at varying length scale. Where data permits, include estimates of canopy height, relative canopy cover, canopy height distributions, surface roughness, surface slope, and apparent reflectance.	45 days
ATL09	ATLAS Atmosphere Cloud Layer Characteristics	Along-track cloud and other significant atmosphere layer heights, blowing snow, integrated backscatter, and optical depth.	45 days
ATL10	Sea Ice Freeboard	Estimates of freeboard using sea ice heights and available sea surface heights within km length scale; contains statistics of sea surface samples used in the estimates.	45 days
ATL11	Land Ice H(t)	Time series of height at points on the ice sheet, calculated based on repeat tracks and/or crossovers.	45 days from receipt of last data in product
ATL12	Ocean Surface Height	Surface height at varying length scales. Where data permits, include estimates of height distributions, surface roughness and apparent reflectance.	45 days from receipt of last data in product
ATL13	Inland Water Body Height	Along-track inland water height extracted from Land/Water/ Vegetation product. Where data permits, includes roughness, slope and aspect.	45 days from receipt of last data in product
ATL14	Antarctic and Greenland Gridded Height	Height maps of each ice sheet for each year of the mission, based on all available ICESat-2 elevation data.	45 days from receipt of last data in product
ATL15	Antarctic and Greenland Height change	Height-change maps of each ice sheet, with error maps, for each mission year and for the whole mission.	45 days from receipt of last data in product
ALT16	ATLAS Atmosphere Weekly	Polar cloud fraction, blowing snow frequency, ground detection frequency.	45 days from receipt of last data in product
ATL17	ATLAS Atmosphere Monthly	Global cloud fraction, blowing snow and ground detection frequency.	45 days from receipt of last data in product
ATL18	Land-Vegetation Gridded Height	Gridded ground surface height, canopy height and canopy cover estimates.	45 days from receipt of last data in product
ATL19	Gridded Sea Surface Height – Open Ocean	Gridded ocean height product including coastal areas. TBD grid size. TBD merge with Sea Ice SSH.	45 days from receipt of last data in product
ATL20	Gridded Sea Ice freeboard	Gridded sea ice freeboard. (TBD length scale)	45 days from receipt of last data in product

* Latency is defined as the approximate time it takes from the data acquisition on a satellite until it reaches an individual in a usable format.
Last Update: 02/24/2015

Appendix C. List of Participants

Name	Organization	Participation
Alexander Geiss	European Space Agency	Remote
Amanda Leon	SSAI/NASA Langley Research Center (LaRC)	In-person
Amy Steiker	NSIDC	In-person
Anne Grete Straume	European Space Agency	Remote
ANWAR Maeva	Université of Antananarivo	Remote
Christopher Parrish	Oregon State University	Remote
Claudia Carabajal	NASA Goddard Space Flight Center (GSFC)	Remote
Dave Donovan	Royal Netherlands Meteorological Institute (KNMI)	In-person
Daven Henze	University of Colorado Boulder	In-person
Eugene Yu	George Mason University	Remote
Gerd-Jan Zandelhoff	KNMI	Remote
Gert-Jan Marseille	KNMI	Remote
Gregory Cesana	NASA Goddard Institute for Space Studies, Columbia University	Remote
Hector Maureira	Universidad de La Serena	Remote
Huidae Cho	Dewberry	Remote
James Campbell	Naval Research Laboratory	In-person
James Nelson	National Weather Service	Remote
Janet Intrieri	NOAA ESRL	In-person
Jason Stoker	USGS	Remote
Jeff Thayer	University of Colorado	In-person
Jeffrey Uncu	University of Toronto, Student	Remote
Jennifer Kay	CIRES, CU Bolder	In-person
Juan Martinez-Benjamin	Technical University of Catalonia UPC	Remote
Kerri Warner	ECCC	Remote
Kevin Fuell	NASA/SPoRT via UAH	Remote
Laurence Connor	NOA Laboratory for Satellite Altimetry	Remote
Lucia Mona	National Research Council of Italy, Institute of Methodologies for Environmental Analysis	Remote
Lynn Abbott	Virginia Tech	Remote
Mahsa Moussavi	CIRES, CU Bolder	In-person
Majiong Jiang	California Air Resources Board	Remote
Mark Middlebusher	Vencore, Inc	Remote
Mark Vaughan	NASA LARC	In-person
Mathini Sreetharan	Dewberry	Remote
Melanie Lacelle	Environment & Climate Change Canada (ECCC)	Remote
Neeti Neeti	TERI University	Remote
Nick Forfinski-Sarkozi	Oregon State University	Remote
Patrick Selmer	NASA GSFC	In-person
Rajesh Kumar	NCAR	In-person
Ron Kwok	JPL	Remote
Rory Barton-Grimley	University of Colorado at Boulder	In-person
Sabrina Delgado Arias	SSAI/NASA GSFC	In-person
Sandra Starkweather	NOAA-ESRL/CIRES	In-person
Shahid Khurshid	Environment & Climate Change Canada	Remote
Sharon Rodier	NASA LARC	In-person
Sheldon Drobot	Harris	In-person
Stelios Mertikas	Technical University of Crete	Remote
Stephen Palm	NASA GSFC	In-person
Steve Tanner	NSIDC	In-person
Sudhir Shrestha	Esri	Remote
Terri Fiez	University of Colorado Boulder	In-person
Tom Moore	WESTAR-WRAP	Remote
Tom Neumann	NASA GSFC	In-person
Ute Herzfeld	Computer and Energy Engineering, UC-Boulder	In-person
Warren Horowitz	Bureau of Ocean Energy Management, Alaska	Remote
Xiaomei Lu	SSAI/NASA LaRC	In-person
Yasin Elshorbany	NASA GSFC	Remote
Yuekui Yang	NASA GSFC	In-person
Zhibo Zhang	University of Maryland, Baltimore County	In-person

Appendix D. Focus Session Agenda

AGENDA

Joint ICESat-2 atmospheric tutorial *with CALIPSO, EarthCARE, ADM-Aeolus and CATS*

May 31-June 1, 2017, Bechtel Collaboratory, University of Colorado Boulder

Hosted by the NASA Ice, Cloud and land Elevation Satellite-2 (ICESat-2) Mission & UC-Boulder

Day 1

Wednesday, May 31, 2017		
Topic	Speaker	Time
Meet & Greet, Coffee		7:30-8:00 AM
Welcome, Background and Context		
Opening Remarks & Logistics	Ute Herzfeld, Department of Electrical, Computer and Energy Engineering, University of Colorado Boulder	8:00-8:05AM
Tutorial Welcome and Opening Remarks	Terri Fiez, Vice Chancelor for Research, University of Colorado Boulder	8:05-8:15 AM
Tutorial Objectives, ICESat-2 Mission Design Overview	Tom Neumann, ICESat-2 Deputy Project Scientist, NASA GSFC	8:15-8:35 AM
NASA Health and Air Quality Applied Sciences Team: Strategies, Opportunities and Interactions with Stakeholders	Daven Henze, HAQAST Member, University of Colorado Boulder	8:40-9:00 AM
ICESat-2 Applications Overview & Perspective	Sabrina Delgado Arias, Science Systems and Applications, Inc., NASA GSFC	9:05-9:15 AM
Morning Break		
Session I: Synergies & Opportunities to Leverage Observations		
The ICESat-2 Atmospheric Channel: Characteristics and Planned Products	Stephen Palm, ICESat-2 Science Definition Team Member, NASA GSFC	9:30-10:00 AM
EarthCARE: Goals and Products	[Remote] Gerd-Jan Zadelhoff, KNMI | Dave Donovan, KNMI	10:05-10:35 AM
ADM Aeolus: Atmospheric Backscatter and Extinction Profile Products	[Remote] Anne Grete Straume, ADM-Aeolus Mission Scientist, ESA	10:40-11:10 AM
Panel Discussion I: Identify Synergies and Opportunities to Leverage ICESat-2 data with ADM Aeolus & EarthCARE		11:10 AM-12:00 PM
Lunch (On Your Own/Group Order)		

Wednesday, May 31, 2017		
Topic	Speaker	Time
An Overview of the CALIPSO Atmospheric Data Products	Mark Vaughan, Algorithm Developer and Lidar Science Working Group Member, NASA LARC	1:15-1:45 AM
CATS: Instrument Overview and Products	Patrick Selmer, CATS Operations Lead, NASA GSFC	1:50-2:20 PM
Panel Discussion II: Identify Synergies and Opportunities to Leverage ICESat-2 data with CALIPSO & CATS		2:20-3:00 PM
Afternoon Break		
Session III: Transforming New Data into Actionable Information - Needs and Opportunities		
A Web System Application Framework for use of Remote Sensing Observations in Air Quality Planning	[Remote] Tom Moore, WRAP Air Quality Program Manager; WESTAR	3:15-3:35 PM
Cloud and Aerosol Measurement Priorities at NRL: Preparing for ICESat-2	James Campbell, Naval Research Laboratory	3:35-3:55 PM
RASM-ESRL Coupled Sea Ice Forecasts: Comparison of modeled ice-ocean-atmospheric processes to observations	Janet Intrieri, NOAA Earth System Research Laboratory	3:55-4:15 PM
Improving the National Air Quality Forecasting Capability (NAQFC) surface PM2.5 predictions via assimilation of MODIS AOD retrievals	Rajesh Kumar, Research Applications Laboratory, NCAR UCAR	4:15-4:35 PM
Panel Discussion III: Insights into how to Best Combine Data Sets to Improve Forecasting Capabilities		4:35-4:55 PM
Closing Remarks – Day 1 **Social Dinner**		4:55-5:00 PM 5:30 PM

Day 2

Thursday, June 1, 2017		
Topic	Speaker	Time
Meet & Greet, Coffee		8:00-8:20 AM
Session IV: ICESat-2 Early Adopter Program		
Recap of Day 1, Objectives for Day 2, & ICESat-2 Early Adopter Program	Sabrina Delgado Arias, SSAI-NASA GSFC	8:20-8:35 AM
ICESat-2: first study on potentialities and limits	[Remote] Lucia Mona, National Research Council of Italy, Institute of Methodologies for Environmental Analysis (CNR-IMAA)	8:35-8:55 AM
Detection of tenuous cloud layers, aerosols and blowing snow and applications in climate science and transportation hazard assessment	Ute Herzfeld, Department of Electrical, Computer and Energy Engineering, University of Colorado Boulder	9:00-9:20 AM

Thursday, June 1, 2017		
Topic	Speaker	Time
Q&A, Early Adopter Program Opportunities		9:20-9:45 AM
Morning Break		
Session IV: Coupling Data and Analysis		
ICESat-2 cloud property retrieval: potential of apparent surface reflectance and solar background	Yuekui Yang, ICESat-2 Science Definition Team Member, NASA GSFC	10:00-10:20 AM
Cloud and Aerosol Research Using Both CATS and CALIPSO: a comparison of similarities and differences in two lidar data sets	Sharon Rodier, NASA LARC	10:25-10:45 AM
Using spaceborne lidar observations to constrain extratropical cloud feedbacks and climate sensitivity	Jennifer Kay, Cooperative Institute for Research in Environmental Sciences, University of Colorado Boulder	10:50-11:10 AM
Improving Climate Projections: Importance of Synergistic Data Sets	[Remote] Gregory Cesana, NASA Goddard Institute for Space Studies, Columbia University	11:15-4:35 AM
Panel Discussion IV: Opportunities and Limitations of Coupling and Assimilating Satellite Observations into Models/Analyses		11:40 AM-12:00 PM
Lunch (on your own/group order)		
ICESat-2 Data Access, Services, and User Support at the NASA NSIDC DAAC	NSIDC DAAC: Amy Steiker, Product Support Specialist & Mahsa Moussavi, Science Liaison	1:15-1:45 PM
Breakout Discussions (led by panel chairs) 1. **Air Quality Forecasting** 2. **Climate Prediction** 3. **Polar Change** 4. **Visibility & Transportation**		1:50-3:00 PM
Afternoon Break – Breakout Leads Prepare Reporting (20 minutes)		
Collaborative discussion/brainstorming: • **Breakout leads report back (15 minutes)** • **Intersection of ICESat-2 Capabilities and User Needs** • **Opportunities to incorporate ICESat-2 and other data sources** • **Strategic collaborations**		3:20-4:50 PM
Summary of Actions & Closing Remarks **Tutorial Adjourned**		4:50-5:00 PM

Appendix E. Brainstorming Session – Seed Questions

	Joint Tutorial Seed Questions
1	What are the potential ICESat-2 contributions to atmospheric research applications (air quality, weather forecasting, etc.)?
2	How important is latency and high spatial resolution for atmospheric applications?
3	What are the main observational gaps?
4	What are potential collaboration opportunities between the ICESat-2, CALIOP, ADM-AEOLUS, EarthCARE, CATS, and atmospheric community?
5	Does the planned ICESat-2 atmospheric products meet the needs (temporal, geospatial) of the user communities?
6	What are some operational considerations? Could ICESat-2 support an operational product?
7	What are the principal existing long term calibration sites that are of priority interest to the atmospheric community?
8	What are the key networks that we should be engaging with regard to atmospheric applications?
9	What data services would the atmospheric community like to see from the NSIDC DAAC (e.g. search and find, visualizations)?
10	HDF5 product readers are available for Fortran, IDL and Matlab. Would other headers be useful?

Appendix F. Tutorial Presentation Summaries

Session I: Welcome, Background and Context

Tutorial Objectives, ICESat-2 Mission Design Overview; Tom Neumann, NASA GSFC

- ICESat-2 will use a micro-pulse multi-beam (6 beams) photon counting approach to provide:
    - Dense cross-track sampling to resolve surface slope on an orbit basis
    - Dense along-track sampling (~70 cm); generated by high repetition rate (10kHz)
    - Necessary dynamic range (bright/dark surfaces); generated by different beam energies
- ATLAS (Advanced Topographic Laser Altimetry System) is the sole instrument in ICESat-2 and has a laser wavelength of 532 nm.
- ICESat-2 Mission Updates:
    - Launch date in 2018: to-be-resolved (TBR)
    - ATLAS Integration & Testing (I&T) began summer 2014; most of instrument I&T completed August 2016.
    - Observatory I&T began late 2017
    - Predicted performance remains consistent
    - ATLAS testing continues – laser repair underway
    - Data product implementation well underway

NASA Health and Air Quality Applied Sciences Team: Strategies, Opportunities and Interactions with Stakeholders; Daven Henze, University of Colorado, Boulder

- The NASA Heath and Air Quality Applied Sciences Team (HAQAST) brings together people from academia, health organizations, industry, states, cities, the USFS, and EPA to establish dialogue on needs of health and air quality stakeholders. It provides guidance for use of NASA satellite data, tools and research and builds research collaborations to address current knowledge gaps.
- HAQAST has 4 new Tiger Teams including one for Supporting the use of satellite data in State Implementation Plans (Lead: Arlene Fiore, Columbia University) and another on High Resolution Particulate Matter Data for Improved Satellite-Based Assessments of Community Health (Lead: Pat Kinney, Columbia University)
- 80%-90% of ambient impacts (e.g. premature deaths, morbidity, preterm births) have been attributed to atmospheric particulate matter $PM_{2.5}$
- Vertical extinction profiles from NASA MODIS (Moderate Resolution Imaging Spectroradiometer), MISR (Multi-angle Imaging SpectroRadiometer), SeaWIFS AOD (Sea-Viewing Wide Field-of-View Sensor – Aerosol Optical Depth) and CALIOP (Cloud-Aerosol Lidar with Orthogonal Polarization) are being used for evaluation of air pollution health impacts and concentration-response relationships to increase resolution (0.01°) and expand coverage (global).

- Improvements are expected from new instruments: TROPOMI (TROPOsperhic Monitoring Instrument, VIIRS (Visible Infrared Imaging Radiometer Suite), ICESat-2, geostationary satellites, MAIA (Multi-Angle Imager for Aerosols).

Comments/Recommendations:

- ➢ ICESat-2 will provide vertical profiles of attenuated backscatter, which is related to aerosol loading and pollution content, but will not tell you anything about atmospheric constituents/chemical composition.
- ➢ ICESat-2 may be able to get planetary boundary layer (PBL) height.

Session II: Synergies & Opportunities to Leverage Observations

The ICESat-2 Atmospheric Channel: Characteristics and Planned Products; Stephen Palm, Science Systems and Applications Inc., NASA GSFC

- ICESat-2's main mission is ice sheet and sea ice altimetry, with atmosphere, ocean height, and vegetation biomass being secondary science objectives.
- The ICESat-2 atmospheric channel consists of 3 separate 14 km profiles each ranging from 13.5 km to -0.5 km in altitude with respect to local digital elevation model (DEM).
- 400 shots are summed, binned at 30 m vertical resolution (for a total of 467 bins total) and downlinked at 25 Hz data.
- ICESat-2 will provide useful data on clouds and aerosol, especially in Polar regions; nighttime data will be excellent with a cloud detection to an optical depth of approximately 0.05.
- Limitations of the atmospheric channel are:
    - limited vertical range (13.5 to -0.5 km), which may make calibration difficult
    - very poor daytime data due to laser's low energy per pulse (532nm) and high repetition rate (10 KHz); cloud detection will be limited to an optical depth of approximately 0.5
    - 15 km "folding" of scattering features: a cloud at 16 km altitude will be added to the scattering at 1 km altitude; folding of high clouds will be mainly limited/problematic in the tropics.
- Profile averaging [sacrifices horizontal resolution]: an order of magnitude increase in signal-to-noise is obtained by averaging data to 4 seconds [0.25 Hz] compared to full resolution (25 Hz)
- ICESat-2 atmospheric science applications:
    - Global cloud amount
    - Global cloud height (poleward of roughly 30°)
    - Global aerosol height (poleward of roughly 30°)
    - Column optical depth (over ocean)
    - Polar clouds and aerosol
    - Blowing snow
    - Apparent surface reflectivity

Comments/Recommendations:

- ➢ Large signal to noise difference between night and day data makes it hard to conduct studies comparing day and night differences on cloud properties. An attempt should be made to produce a product that minimizes these differences.
- ➢ Profile averaging:
    - o You are not losing that much information by averaging.
    - o Averaging will help and so will noise reduction techniques yet to be explored.

The Earth Clouds and Radiation Explorer (EarthCARE) Mission: the ATLID lidar retrieval chain; Dave Donovan & Gerd-Jan van Zadelhoff, Royal Netherlands Meteorological Institute

- EarthCARE (Earth Clouds, Aerosol Radiation Explorer) is a joint ESA/JAXA mission to be launched in 2019. Will most likely be in orbit at the same time as ICESat-2.
- EarthCARE is a four-instrument mission that will focus on measuring vertical properties of aerosol and clouds. Instruments:
    - o advanced cloud/aerosol lidar (ATLID);
    - o cloud profiling Doppler Radar (CPR);
    - o multi-spectral cloud/aerosol imager (MSI); and
    - o broad-band radiometer (BBR)
- EarthCARE will extend the record of active cloud/aerosol observation started by CALIPSO/CSAT, which is considered important for e.g. climate trend applications
- Polar sun-synchronous orbit: 25 day revisit cycle; approximately 400 km mean altitude
- Compared to CALIPSO the ATLID instrument will provide 1) improved daylight performance, 2) direct measurement of aerosol extinction and 3) measurement of extinction-to-backscatter ratio
- ATLAS and ATLID are very different Lidars and have different orbits.
- Some algorithms and developments will be relevant to both missions, e.g.:
    - o ATLID Feature Mask [uses image processing techniques to identify “targets”, resolution variable depending on feature strength (<1 km for bright cloud)]
    - o treatment of MS effects

Comments/Recommendations:

- ➢ Joint aerosol studies? Aerosols are “smooth” in comparison to many cloud types/systems.
- ➢ Independent 532 nm attenuated backscatter profiles could be good test of ECARE extinction retrievals and type determination
- ➢ 532 data could also help bridge the CALIPSO→ECARE records.
- ➢ It will make good sense to share data and experiences
    - o **ICESat-2 Mission Response:** When the two instruments are closely aligned in space and time, ECARE profiles can be used to help validate ICESat-2 and possibly help us understand the folding problem.

Aeolus and its scientific exploitation; Anne Grete Straume, European Space Agency

- Aeolus is a research mission under the Earth Explorer suite of ESA's Earth Observation Programme designed to improve our understanding and predictability of:
    - Atmospheric dynamics and global atmospheric transport
    - Global cycling of energy, water, aerosols, chemicals
- Launch: January 2018; Satellite launch readiness: October 2017; operation phase: L+3 months: 3 years.
- The World Meteorological Organization Global Observing System (GOS) lacks globally distributed direct wind observations, which are important at smaller scales and for deep atmospheric structures
    - Aeolus addresses primarily the lack of homogenous global coverage of direct wind profile measurements
        - Product: horizontally projected line-of-sight wind profiles
        - ~85 km observation from 3 km subsamples
        - From surface to ~30 km in 24 vertical layers
        - Near real-time delivery that could benefit numerical weather prediction and aerosol assimilation in forecast and climate models
    - Aeolus provides spin-off products to address large uncertainties in the estimated contribution of aerosols and clouds to the global radiative forcing
- Aeolus will demonstrate the capabilities of space-based Doppler Wind LIDARs for global wind profiling and its potential for operational use. It offers:
    - Better initial conditions for weather forecasting
    - Improved **parameterization and modeling of atmospheric processes in climate and forecast models**
- Lack of polarization information in the Aeolus measurements introduces uncertainties in polarizing scenes

Comments/Recommendations:

- ➢ ICESat-2 surface reflectivity – study of reflectivity in the hotspot direction?
    - ICESat-2 will obtain surface reflectivity from the 3 strong beams. The beams will be about 0.5 degree off of nadir and in general will not be seeing exactly 180 degree reflection from the surface (hotspot direction). The reflectivity is derived assuming a lambertian surface. The degree to which the surface is non-lambertian will introduce error into the derived surface reflectivity.
- ➢ CALIPSO, EarthCARE, CATS, ICESat-2 for atmospheric optical properties products
- ➢ Scatterometer sea surface winds (vertical representativity?)
- ➢ Atmospheric Motion Vectors from geostationary and polar orbiting satellites
- ➢ Opportunities for co-location in Polar areas

An Overview of the CALIPSO Atmospheric Data Products; Mark Vaughan, NASA LaRC

- The CALIPSO CALIOP instrument has two wavelengths (1064 nm and 532 nm) which allow for detection of clouds, aerosols and surfaces
- Product Descriptions

    - The Level 1A data is reconstructed, unprocessed instrument data at full resolution, time referenced, and annotated with ancillary information, including radiometric and geometric calibration coefficients and georeferencing parameters computed and appended, but not applied to Level 0 data. Level 1B data is level 1A data that has been processed to sensor units.
    - Level 2 data are derived geophysical variables at the same resolution and location as Level 1 source data.
    - Level 3 data are variable mapped on uniform space-time grid scales, usually with some completeness and consistency.
- Level 2 data products consist of a vertical feature mask, layer products (1/3 km layer, 1-km cloud layer, 5-km cloud layer, 5-km aerosol layer, 5-km merged layer), and profile products (cloud and aerosol profiles); uncertainties are reported for all measured and retrieved quantities.
- For the vertical feature mask, horizontal averaging is required for detection
    - aerosol classification: e.g. pollution/smoke, marine and dust
    - cloud classification: e.g. alto-stratus, deep convection, cirrus, cumulus, altocumulus
    - cloud thermodynamic phase: e.g. randomly oriented ice, horizontally oriented ice, water
- 1064 nm are only reported for aerosols
- For more information: http://journals.ametsoc.org/topic/calipso and https://www-calipso.larc.nasa.gov/resources/calipso_users_guide

CATS: Instrument Overview and Products; Patrick Selmer, NASA Goddard Space Flight Center

- CATS is a lidar utilizing the International Space Station as an affordable Earth Science platform designed to, among other goals:
    - Complement the CALIPSO data record with diurnally varying cloud and aerosol vertical profiles
    - Monitor dynamic events such as wildfires and volcanic eruptions
- CATS launched on January 10, 2015 on SPACEX5 and has operated on the ISS for over 2 years with near-continuous laser 2 operations (150+ billion shots, 6000+ hours); laser 1 failed on March 2015
- CATS provides comprehensive coverage of tropics and mid-latitudes, which are the primary aerosol transport paths.
- Data Products:
    - Level 1A: Calibrated backscatter and depolarization ratio (60 m vertical, 350 m horizontal resolution)
    - Level 1B: Attenuated total backscatter calibrated by normalizing to Rayleigh signal at night and from historical values during daytime; depolarization ratio (60 m vertical, 350 m horizontal resolution)
    - Level 2: cloud and aerosol identification; extinction profiles; and layer optical thickness (60 m vertical, 5 km horizontal resolution)

    - The CATS 1064 signal is very sensitive to subvisual layers (e.g. Calbuco plumes); the Mode 2 532 nm data is very noisy
- CATS can detect full extent of aerosol plumes and separates clouds embedded in aerosol layers
- NRT data products created within 6 hours of data acquisition include profiles of backscatter, depolarization ratio and feature mask. NRT data enables assimilation of aerosol vertical profiles into models for applications such as forecasting volcanic plume transport and predicting air quality during hazardous events.
- CATS data is being utilized for many cloud and aerosol applications:
    - Clouds Statistics and Diurnal Sampling
    - Fills in spatial/temporal gaps between CALIPSO for aerosol transport
    - Above Cloud Aerosols
    - Smoke particle sphericity
    - Stratospheric Aerosols
    - Assimilation into operational aerosol transport models
    - Injection heights for forecasting volcanic plume transport and wildfire plumes

Comments/Recommendations:

- Actual overlap with ICESat-2 is doubtful, but not impossible. CATS has license to operate through Feb. 2018 and perhaps longer
- CATS has only 1064 nm data and suffers from same "folding" issue as ICESat-2 due to the high repetition laser. Algorithms have successfully corrected signal for molecular folding and will not be as bad as what ICESat-2 will experience
- There could be a second CATS: CATS-I, submitted as a NASA EVI proposal. CATS-I would have multiple beams, wavelengths, polarization and, if built, should provide validating opportunities with ICESat-2
- CATS and ICESat-2 will complement each other and continue the global data record of detailed vertical profiles of atmospheric particulates
- CATS could benefit from ideas on how to fix some of the problems shared with ICESat-2
    - Lessons learned from CATS (how to deal with molecular folding) have been applied to ICESat-2 algorithm design.

Session III: Transforming New Data into Actionable Information - Needs and Opportunities

A Web System Application Framework for use of Remote Sensing Observations in Air Quality Planning; Tom Moore, Western States Air Resources Council – Western Regional Air Partnership (WESTAR-WRAP)

- WESTAR-WRAP supports a series of databases maintained through one infrastructure that utilize a foundational database, website, software and hardware architecture. These are:
    - National Park Service (NPS) Air Quality Conditions & Trends (https://www.nature.nps.gov/air/data/products/parks/index.cfm)
    - Federal Land Manager Environmental Database (http://views.cira.colostate.edu/fed/) – Partners: NPS and US Forest Service (USFS)

    - Southeastern Modeling, Analysis, and Planning (http://views.cira.colostate.edu/semap/) – Partners: Environmental Protection Agency (EPA) and States: Alabama, Florida, Georgia, Kentucky, Mississippi, North Carolina, South Carolina, Tennessee)
    - Intermountain West Data Warehouse (IWDW, http://views.cira.colostate.edu/tsdw/) – Partners: NPS, Bureau of Land Management (BLM), USFS, EPA, and the following states: Colorado, Wyoming, Utah and New Mexico
- Through research supported by NASA ROSES 2007 (Decision Support thorough Earth Science Research Results) the Cooperative Institute for Research in the Atmosphere or CIRES developed the Visibility Information Exchange Web System (VIEWS), which serves as the infrastructure for the WRAP's Technical Support System (TSS, http://vista.cira.colostate.edu/tss) and is now the IWDW. These support the air quality planning needs of western states and tribes through analytical tools and methods for haze planning and monitoring, emissions inventory, as well as pollutant modeling.
- Satellite data integrated into VIEWS/TSS was drawn from among several instruments and platforms including MODIS and MISR (on board Terra and Aqua), OMI (on board Aura), and CALIOP (on board CALIPSO).
- A future goal is to integrate data into IWDW from other emerging remote sensing platforms including from the ICESat-2 and TEMPO (Tropospheric Emissions: Monitoring Pollution) missions.

Comments/Recommendations:

> ➢ For assessing air quality above the ground, the VIEWS/TSS system uses the LIDAR profiles from the CALIPSO satellite to, for example, identify where in the vertical smoke rises (e.g. for smoke plumes). ICESat-2 can be used in the same way.

Cloud and Aerosol Measurement Priorities at NRL: Preparing for ICESat-2; James Campbell, Naval Research Laboratory

- NRL has an objective to apply satellite lidar measurements for applied atmospheric research, operational Navy weather forecasting and climate monitoring activities.
- NRL has made significant progress adapting CALIPSO datasets for applied atmospheric research and demonstrating their potential for operational weather forecasting and climate monitoring activities. Research elements addressed with CALIPSO:
    - Cirrus cloud physical properties and occurrence characteristics
    - Aerosol monitoring and profile assimilation for mass transport modeling systems
    - Aerosol corrections to hyperspectral radiance data assimilation
    - Aerosol climatological properties for process applications
    - Pyrocumulonimbus smoke injection into UT/LS
- Lidar provides critical measurements of cirrus clouds. Passive radiometers cannot see all cirrus; think cirrus clouds—exponentially more common than opaque—are captured as noise by passive radiometric sensors.
- Lidar can monitor/measure cirrus clouds with cloud optical depth less than 0.30.

- CALIPSO has been used for operational aerosol model assimilation; dust biases simulated on retrieved hyperspectral satellite brightness temperatures are highly dependent on aerosol loading and vertical distribution is important.
- A three-dimensional global climatology for aerosol light extinction was built using CALIPSO observations (2°x2° or 5°x5° global resolution; 100 m vertical resolution, 2006-2015 inclusive)
- NRL is currently working on a new NASA project to extend Navy aerosol model (NAAPS) assimilation over bright snow surfaces with the goal to derive a surface forcing function to estimate aerosol impact on seasonal ice breakup.
- For monitoring pyrocumulonimbus (pyroCb) smoke in the Upper Troposphere Lower Stratosphere (UTLS), spaceborne lidar can be used as/to:
    - Primary method for observing vertical characteristics of pyroCb smoke plumes
    - Distinguish smoke aerosols from clouds
    - Confirmation of pyroCb occurrence
    - Track smoke transport and UTLS lifetime
    - Calculate aerosol mass

Comments/Recommendations:

- ➢ Additional potential for ICESat-2, in addition to research elements addressed with CALIPSO, is sea ice distributions and altimetry heights for operational model assimilation.
- ➢ Cirrus properties change wherever you are in latitude—potential for ICESat-2.
- ➢ NRL lacks significant CALIOP information at polar latitudes (signal-to-noise issues); ICESat-2 could provide necessary refinement by filling in polar data gap.
- ➢ For Navy sea-ice model data assimilation:
    - Great interest in seasonal sea ice forecasting for Navy applications
    - Adaptation of ICESat-2 altimetry over ocean would greatly increase on existing buoy networks
- ➢ NRL very interested in getting ICESat-2 Level 2 data

RASM-ESRL Coupled Sea Ice Forecasts: Comparison of modeled ice-ocean-atmospheric processes to observations; Janet Intrieri, National Oceanic and Atmospheric Administration (NOAA) Earth System Research Laboratory

- Interest in using sea ice thickness derived from ICESat-2 for 0 to 10 day sea ice forecasting using the coupled ice-ocean-atmosphere wx-scale forecast model: Regional Arctic System Model – Earth System Research Laboratory (RASM-ESRL).
    - RASM-ESRL delivers 0-10 day forecasts of 3-hourly sea ice and 6-hourly atmospheric products initialized with 0Z analysis and posted daily at ~6Z
- ICESat-2 sea ice thickness observations could potentially be used to develop freeze-up season hindcasts to assess initialization sensitivity
- ICESat-2 sea ice thickness observations could potentially be used to test hypothesis related to ice edge processes

- The RASM-ESRL model is limited to the Arctic and all components are run with 10 km horizontal resolution; the model currently uses Cryosat-2 ice thickness data.

Comments/Recommendations:

- ➢ Use ICESat-2 for RASM-ESRL model initialization and to compare forecasts of ice properties (e.g. ice thickness comparisons)
- ➢ Provide ICESat-2 with snow product guidance (e.g. snow forecasts and 2-3 day guidance for pointing angle locations) and **vertical cloud property information** (e.g. cloud properties cross-sections)

Improving the National Air Quality Forecasting Capability (NAQFC) surface PM2.5 predictions via assimilation of MODIS AOD retrievals; Rajesh Kumar, National Center for Atmospheric Research (NCAR)

- The National Air Quality (AQ) Forecasting Capability (NAQFC) at the NOAA is a key tool for decision makers across the U.S. to protect the public from poor AQ.
    - NAQFC is based on the EPA Community Multiscale Air Quality (CMAQ) model (resolution: 12 km^2)
    - CMAQ underestimates observed $PM_{2.5}$ concentrations and MODIS retrieved aerosol optical depth (AOD)
- To enhance this decision-making activity, a NASA-sponsored project (PI: Luca Delle Monache, NCAR/RAL; Co-PIs: Rajesh Kumar, NCAR/RAl; Gabriele Pfister, NCAR/ACOM) aims to improve the accuracy of NOAA/NCEP short-term predictions of ground-level ozone (O3) and particulate matter less than 2.5 µm in diameter (PM2.5) and to provide reliable quantification of their uncertainty.
- Project Objective 1: Improve initialization of NOAA/NCEP Community Multiscale AQ (CMAQ) model through chemical data assimilation of satellite retrieval products and in-situ observations with the Community Gridpoint Statistical Interpolation (GSI) system.
    - GSI-CMAQ assimilation system has been developed to improve initialization of the NAQFC based on the CMAQ model
    - Data assimilation challenges include building forward operators, background error covariance and observational error covariance matrices.
- Project Objective 2: Improve CMAQ prediction accuracy and reliably quantify their uncertainty with analog-based post-processing methods
    - The assimilation system successfully improved surface PM2.5 predictions over the U.S. especially when accounting for uncertainties in both meteorology and anthropogenic emissions.
    - The assimilation system does not improve CMAQ AOD significantly which could be due to lack of uncertainties in biomass burning emissions in BE statistics, and dynamic boundary conditions in CMAQ.

Comments/Recommendations:

- ➢ ICESAT-2/CALIPSO data can provide constraints on vertical distribution of aerosols.
- ➢ Development of new algorithms for assimilating aerosol extinction profiles are required.

- Collocated measurements of ice sheets and aerosols will provide important dataset for studying the implications of increasing Asian emissions for Himalayan glaciers.
- Capacity building via training of local scientists to ensure sustained use of satellite products in developing world.

Session IV: ICESat-2 Early Adopter Program

ICESat-2: first study on potentialities and limits; Lucia Mona, CNR-IMAA, Potenza, Italy (ICESat-2 Early Adopter)

- Aerosol content over Polar Regions could provide an estimate on if and how anthropogenic activities impact on aerosol condition in remote region. Recent studies demonstrated that the aerosol content in Arctic is mainly driven by EU emissions, even if an assessment is needed about it.
    - ICESat-2 could improve the temporal and spatial coverage of aerosol data on Polar regions
- Icesat2 derived aerosol optical properties could be very valuable for investigating the impact of aerosol on cloud formation, optical properties and therefore on a radiation budget and ice cover change
    - Vertical profiles of aerosol optical properties over Polar Regions are provided by CALIOP lidar since June 2006 (16 days repetition cycle)
    - The availability of aerosol optical properties vertical profiles over Polar Regions by ICESat-2 and CALIOP (and then EarthCARE) would provide a long-term data record of aerosol content over polar region for air quality, climate change and climatological applications.
    - The potential impact of aerosol on radiation forcing and ice cover could be investigating thanks to the ICESat-2 primary products, i.e. the ice sheet heights.
    - Polar regions are close to many active volcanoes
- Aerosol measurements from satellite over ice-covered region are extremely complex for passive sensors: underneath bright surfaces; expected low aerosol content; low, sun angle conditions. All these aspects reduce the reliability of retrieval algorithm and the signal-to-noise ratio respectively.
    - The ICESAT2 lidar could overcome all these problems, even if the real feasibility of aerosol study through ICESat-2 backscatter signals has to be investigated (object of Early Adopter Research).
- Few ground based instruments available
- Potential applications of ICESat-2 data from Early Adopter research:
    - Climate
    - Air Quality
    - Volcanic Hazards
- Potential end-users: International Civil Aviation Organization (ICAO); World Meteorological Organization Volcanic Ash Scientific Advisory Group; global modelers and policy makers; local policy makers.
- Objectives of ICESat-2 Early Adopter research (very preliminary investigation)
    - Obtain statistics of layers on Polar regions above 15 km

- Develop reliability scheme for solving pulse-aliasing issue
- Test the reliability score on CALIOP data
- Define S value for backscatter retrieval using AERONET data

Comments/Recommendations:

- Probably during the day thin cloud and aerosol will be detectable only after a large amount of averaging (at least 40,000 lidar pulses i.e. about 28 km horizontal resolution).
- Limitation: ATLAS signal pulse-aliasing issue due to high repetition rate (10 KHz)
  - Calibration is limited between 9 and 13 km altitude (successful only if Polar Stratospheric Clouds are not present)
  - There is ambiguity in aerosol/cloud height product
- More can be done with needed resources; researcher working time needed
- Opportunity: EU funds available to visit the CNR-IMAA Atmospheric Observatory (CIAO) for a dedicated study (more information: www.ciao.imaa.cnr, under Access)
- Diamond dust complicates folding (or "pulse-aliasing") solution in Polar regions
- Steve Palm could use Lucia's folding/"pulse-aliasing" solution to create a flag in the data for ICESat-2

  ICESat-2 Mission Response: Currently, ICESat-2 has a folding flag in the ATL09 product which is based on the climatology of polar stratospheric cloud occurrence. There is also another flag that is based on the highest cloud top in the GEOS-5 model. Mona's approach is based on the thickness of the layer. Basically if the layer is thicker than 3-4 km, then it is assumed to be folded down. There are many instances where this is not true, even in the arctic.

Detection of tenuous cloud layers, aerosols and blowing snow and applications in climate science and transportation hazard assessment; Ute C. Herzfeld, Department of Electrical, Computer and Energy Engineering, University of Colorado at Boulder

- The ICESat-2 Challenge: Design an Algorithm for Analysis of Data from a Micro-Pulse Photon-Counting Lidar Altimeter
  - new instrumentation requires a new mathematical approach
- Development of a Density-Dimension Algorithm for Atmospheric Layer Detection (DDA-atmosphere) ongoing
  - Atmospheric data are telemetered as shot-sum data:
    - 15km total height of atmospheric data retrieval
    - 30 m height intervals
    - 400-shot sum of photon counts
    - approx. 280 m along-track intervals
    - analysis of an evolving data matrix
  - Clouds can be everywhere (different noise data collection scheme needed)
  - There can be several cloud layers at different heights.

    - Atmospheric layers can have different optical density (thin clouds, thick clouds, aerosols).
- Tenuous Atmospheric Layers: there is a potential of gaining new types of information on the atmosphere from ICESat-2

Comments/Recommendations:

- **Potential Application Area 1: Climate Science/ Climate Modeling**
    - Tenuous atmospheric layers may be hard to detect (e.g. in CALIOP layer detection) but affect estimates of radiative forcing and/or heating rates.
    - subvisible cirrus in the tropical tropopause layer
    - Asian dust (more difficult to detect than Saharan dust because it's typically injected higher in the atmosphere and is more diffuse, both vertically and horizontally)
    - Volcanic ash (e.g. Eyjafjallaj•okull eruption 2010)
- **Potential Application Area 2: transportation hazard assessment**
    - Blowing Snow
- What are algorithm synergies with CATS?

Session V: Coupling Data and Analysis

ICESat-2 cloud property retrieval: potential of apparent surface reflectance and solar background; Yuekui Yang, ICESat-2 Science Definition Team Member, NASA GSFC

- Major limiting factors to ICESat-2 atmospheric product quality:
    - Folding effect (major)
    - Background noise
        - Dark current (secondary; < 0.5 MHz)
        - Solar background (major, can reach 10 MHz)
- Solar background can overwhelm Lidar cloud returns
- For clear sky, ATLAS surface return has a much stronger signal compared to solar noise.
- Solar background noise limits ICESat-2 daytime cloud/blowing snow/aerosol analysis. New methods are needed:
    - Use apparent surface reflectance (ASR) for cloud retrievals (Yang et al. 2013, TGRS)
        - Clouds decrease ASR and produce a strong signal, which can be used for cloud detection and cloud optical thickness retrieval.
    - Turn solar background noise into a signal for cloud study (Yang et al. 2008, JAS)
        - Over dark surfaces, clouds significantly increase solar background noise, which can be used for cloud detection.
        - Once calibrated, the solar background can be used for cloud optical thickness retrieval.

Comments/Recommendations:

- Synergetic study of blowing snow radiative properties

  - Use Aqua MODIS 11µm and CERES outgoing longwave radiation images overlaid with the CALISPO track
- Looking for ideas on how to improve ICESat-2 data products and overcome its limitations.
  - **ICESat-2 Mission Response:** One approach is to research methods of noise reduction to improve the usability of daytime data.

Cloud and Aerosol Research Using Both CATS and CALIPSO: a comparison of similarities and differences in two lidar data sets; Sharon Rodier, NASA Langley Research Center

- CALIPSO and CATS are two Space LIDAR instruments collecting data but each has specific instrument, algorithm and calibration characteristics that the data user must consider during analysis
  - Layer detection: The CATS 1064 nm signal-to-noise ratio (SNR) in the stratosphere is much larger than that of CALIPSO; CATS 1064 data is higher signal to noise than CALIPSO 532 or 1064.
- CALIPSO V4.10 Released 2006 – 2016; 2017 is in the validation stage and will be released soon
- CATS – M7.2 L1B - V1-8 & L2O - V2.0 - Available late summer
- CATS – M7.1 L1B - V1-8 & L2O - V2.0 - Available late summer
- CALIPSO Laser Energy issues:
  - Laser #2 is experiencing an energy drop; due to pressure leak inside the Laser canister.
  - Anticipate turning off Laser #2 this summer
  - Laser #1 – (now in a vacuum state) will attempt to restart in the Fall 2017, hope to return to nominal operations

Comments/Recommendations:

- Unsolicited proposal at NASA HQ for CATS Follow On (CATS-FO)

Using spaceborne lidar observations to constrain extratropical cloud feedbacks and climate sensitivity; Jennifer Kay, Cooperative Institute for Research in Environmental Sciences, UC Boulder

CloudSat and CALIPSO have advanced our understanding and observing of polar hydrometeors

Science Summary (observation credit: CloudSAT+CALIPSO)

- Recent Arctic Cloud Discoveries:
  - ubiquitous liquid clouds
  - no summer cloud-sea ice feedback
  - fall sea ice loss increases fall clouds (weak feedback, sign unknown)
- “Two-way street” between models and observations needed:
  - definition/scale-aware comparisons: Be scale-aware and definition-aware when making comparisons between observations and models

    - parameterization way of thinking
    - moving beyond “model evaluation” to hypothesis testing inspired by process understanding

Comments/Recommendations:

What has been most effective and most enable complementary uses of ICESat-2 with other spaceborne lidar assets?

- Ability to apply multiple datasets to do hypothesis-driven science both at the process and climatological scale.
- Instrument simulators for comparison between observations and models. Be definition and scale aware when making comparisons.
- Self-documented and easy-to-use data products that provide basic and useful geophysical quantities. NetCDF format ideal.
- Addition of other synergistic variables co-located in space and time with ICESat-2 (e.g., temperature profiles, sea level pressure, underlying surface type)
- **ICESat-2 Mission Response:** ICESat-2 night data has a much higher signal to noise than the daytime data. An attempt should be made to make both night data and day data look to have nearly the same signal to noise so that retrievals done from these data (night vs day) can be compared.

Improving Climate Projections: Importance of Synergistic Data Sets; Grégory Cesana, Goddard Institute for Space Studies, Columbia University

- Exploiting satellite observations for model evaluation require some efforts. The use of simulator ensure that differences come mostly from models physics. Knowing precisely instrument’s limitations and choosing carefully the geophysical quantity may allow a direct comparison though.
- The synergistic use of satellites provides a more complete picture of clouds and aerosols properties. This make it possible exploring models’ biases in new ways.
- Using CALIPSO, CloudSat, AQUA and PARASOL observations, we addressed the ability of the models to represent the clouds, cloud properties and cloud-radiation interactions.
- The results shows that:
    - Clouds fill too many column upper-levels while being optically too thin
    - On the contrary clouds are lacking in subsidence areas and likely optically too thick
    - These biases contribute to radiative heating biases in the models
- Pointing out cloud and cloud-radiation biases provides guidance for modeling centers to improve the physics of their GCM, and in turn, reduces uncertainties in future climate projections

Comments/Recommendations:

- Leveraging ICESat-2 to complement existing observations:
    - Extend CloudSat-CALIPSO observations of clouds and in particular supercooled liquid clouds polarward of 82˚

- Provide useful information about the diurnal cycle of clouds (e.g. large signal water clouds)
- Precise surface elevation information could help better detect surface echoes and thus diagnose attenuation in CALIPSO observations

ICESat-2 Data Access, Services, and User Support at the NASA NSIDC DAAC; Amy Steiker & Mahsa Moussavi, National Snow and Ice Data Center

- User Support
    - Personalized support for data users with data selection, access and usage
- Discovery and Access: NASA metadata search
    - Single point of entry for access to ICESat-2 data, user guides, data access methods, tools, related data and other resources.
    - Filter and compare data sets to identify the most applicable to needs
    - Search NASA Earth Science data holdings with keyword, temporal, and spatial constraints using Earthdata Search
    - Search NASA Earth Science data holdings across multiple missions
    - interactively browse and analyze full-resolution imagery of select NASA Earth Science data using NASA Worldview
- In development: visualization of vertical profiles - Seeking vertical profile visualization use cases
    - Interested in vertical profile data across multiple missions?
        - **ICESat-2 Mission Response**: To the above question: Yes! It would be great to have vertical profile data for multiple missions when the instruments are co-located in space and time to a pre-defined degree.
    - How can 3D point cloud visualization improve your data discovery workflow?
        - **ICESat-2 Mission Response**: I think 3D point cloud visualization could benefit the detection of blowing snow immensely.
- Data Services: subsetting, reformatting, and reprojection through NASA Earthdata Search

Comments/Recommendations:

- Complimentary uses of ICESat-2 with CALIPSO/ADM-AEOLUS/CATS/EarthCARE
    - How can NSIDC better support the use of atmospheric products across missions?
- Feedback directly impacts our ICESat-2 tools/services development
    - Asking our users for valuable feedback on data access, tools, and services: https://www.surveymonkey.com/r/ic2survey