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MEETING SUMMARIES

A WORKSHOP ON REMOTE SENSING OF THE ATMOSPHERE IN ANTICIPATION OF THE EARTHCARE SATELLITE MISSION

ANNA E. LUEBKE, JULIEN DELANOË, VINCENT NOEL, HÉLÈNE CHEPFER, AND BJORN STEVENS

The German Earth Cloud, Aerosol, and Radiation Explorer (EarthCARE) community and the French Expecting EarthCARE Learning from the A-Train (EECLAT) community, both dedicated to the use of Earth observing satellites for research on clouds, aerosols, precipitation, and radiation, came together for a joint workshop¹ in January 2018. Its purpose was to provide a venue to share expertise and to encourage future collaboration between the two communities. The workshop focused on the use of remote sensing instrumentation for atmospheric observations, with special attention paid to the National Aeronautics and Space Administration's (NASA) A-Train constellation of Earth observing satellites and the upcoming joint EarthCARE satellite mission

EARTHCARE-EECLAT JOINT WORKSHOP 2018

WHAT: This was the first joint workshop between the German Earth Cloud, Aerosol, and Radiation Explorer (EarthCARE) community and the French "Expecting EarthCARE Learning from the A-Train" (EECLAT) community. The aim of the workshop was to share recent work related to remote sensing of clouds, aerosols, precipitation, and radiation and to strengthen cooperation in preparation for the upcoming EarthCARE satellite mission.

WHEN: 29–31 January 2018

WHERE: Colmar, France

between the European Space Agency (ESA) and the Japan Aerospace Exploration Agency (JAXA). Sixty-eight participants from French and German universities and research institutes attended. The majority of the workshop was dedicated to the presentation of recent research, and a final group discussion was held to identify the topic(s) that could serve as the basis for framing future science initiatives based on the anticipated outputs and strengths of EarthCARE.

BACKGROUND. Clouds, aerosols, precipitation, and radiant energy transfer play a key role in Earth's

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¹ The workshop was coorganized by the German EarthCARE Project Office and the French EECLAT community and took place at the Grand Hôtel Bristol along the French–German border in Colmar, France.

climate system as individual components as well as through complex interactions with each other. Observations from airborne, ground-based, and satellite remote sensing instrumentation are extremely useful tools for obtaining a better understanding of these processes and subsequently constraining their influence on Earth's energy budget. However, the limitations in instrument capabilities and the challenges associated with obtaining spatially and temporally representative observations present obstacles for improving our understanding. Fortunately, the robust heritage of Earth observing satellites (e.g., the A-Train) and the technological advances being offered by future satellites provide a promising opportunity for obtaining the global observations needed to further our understanding of the climate system. The upcoming EarthCARE satellite will comprise four remote sensing instruments—the first-ever spaceborne Doppler radar [Cloud Profiling Radar (CPR)], a high spectral resolution lidar [atmospheric lidar (ATLID)], a multispectral imager (MSI), and a broadband radiometer (BBR)—and is the next evolution in multi-instrument, spaceborne observations and synergistic data products.

The French and German communities have considerable expertise in the use of both active and passive remote sensing instrumentation. They are dedicated to the development and implementation of retrieval techniques that are designed to exploit remote sensing instrumentation capabilities in order to provide the most accurate observations possible. Additionally, model simulations are being used as environments for testing retrieval algorithms and process understanding in a variety of atmospheric scenarios. This also provides an important link to a new type of model, global storm-resolving models, being developed to study Earth's climate. By virtue of their ability to resolve the same processes that the satellites measure and on the same scale, the combination of these models with space-based active remote sensing offers the best possibility for advancing our understanding of the climate system.

Since 2011, the EECLAT project has supported and united a community of scientists who use spaceborne observations from the A-Train to do research and learn about the Earth's atmosphere. The EECLAT community focuses on developing innovative science applications from active remote sensing instrumentation aboard satellites such as the *Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations* (CALIPSO), and *CloudSat*, and those from the upcoming *Aeolus* and EarthCARE satellite missions. They have met annually for the past six

years to foster discussions through the presentation of ongoing research activities and the development of new ones. More information about EECLAT can be found at <http://eeclat.ipsl.jussieu.fr>.

The German EarthCARE Project Office was established in March 2017 with the main purpose of building an EarthCARE science community in Germany in order to support and make use of the upcoming EarthCARE satellite mission. The objectives of the project office include providing information and outreach to the science community and German public; developing the user concept for the German EarthCARE community through coordinated research efforts, including calibration, validation, and science activities; and identifying how EarthCARE can be used to address open science questions through collaborative initiatives. The project office website is located at www.mpimet.mpg.de/en/science/the-atmosphere-in-the-earth-system/earthcare/.

WORKSHOP HIGHLIGHTS. The overall theme of the workshop was the use of active and passive remote sensing instrumentation for the observation of clouds, aerosols, precipitation, and radiation. More specifically, the use or incorporation of current (e.g., A-Train) and upcoming (e.g., EarthCARE) Earth observing satellites was highlighted in the presentations and discussions. Over the course of three days, a total of 34 presentations were given. The workshop agenda, presentations, and a list of participants can be found at <http://eeclat.ipsl.jussieu.fr/2018/02/02/earth-care-eeclat-2018-joint-workshop/>.

Several presentations focused on observations of clouds and understanding their connection to dynamics and other atmospheric processes. It was shown that the information obtained about cloud properties from active sensors (i.e., radar and lidar) can lead to further conclusions about their radiative effects, help to identify specific parameters that are active in feedback mechanisms, and ultimately demonstrate how cloud radiative effects can impact large-scale circulation. These types of instruments can also be deployed in remote or undersampled locations to investigate interesting topics, such as the interaction between katabatic winds and precipitation in Antarctica, which is missed by current satellites, and the characterization of aerosols in Siberia.

Observations and fluxes derived from passive remote sensing instruments were also presented along with details about their use in conjunction with radiative transfer simulations in order to identify how cloud heating rates are impacted by cloud micro- and

macrophysics and inversion and aerosol layers at cloud top. The importance of synergistic retrievals that use both active and passive instrumentation was demonstrated by a study showing how passive observations can serve to constrain ice water content observations from lidar. Newer concepts were also introduced, such as how far infrared radiometry can be used for cirrus cloud retrievals.

From a modeling perspective, lidar data from the the Cloud–Aerosol Lidar with Orthogonal Polarization (CALIOP) instrument on *CALIPSO* was shown to be a helpful constraint in general circulation models (GCMs) for improving the diagnosis of cloud biases, thus illustrating the effectiveness of incorporating observations into model studies. Techniques for improving individual or synergistic retrievals of cloud products from active and passive instruments were presented as well. This included studies on understanding how the use of parameterizations and differences in instrument properties, such as radar frequency, can have an influence on retrieved parameters.

A full day of the workshop was dedicated to the EarthCARE satellite mission. The two invited speakers, Dr. Anthony J. Illingworth from the University of Reading and Dr. David Donovan from the Royal Netherlands Meteorological Institute (KNMI), headlined the day's talks with extended discussions on the preparation of the satellite's retrieval algorithms. Dr. Illingworth highlighted EarthCARE's synergy and the associated challenges of developing retrieval algorithms for those products with regard to features such as mixed-phase clouds and rimed ice. Dr. Donovan reported on the status of the algorithm developments for level 2 data products and on the use of KNMI's EarthCARE simulator (ECSIM), which is used to test the retrievals on different scenes. Overall, the algorithms are stable, but the science included in their development requires further testing to improve features like target classification schemes and performance in different atmospheric scenarios.

Other presentations during the day focused on how the community is preparing for the calibration and validation of the satellite. The ground-based sites and networks that will be used to directly evaluate EarthCARE were presented. It was noted that having multiple sites is particularly advantageous because it increases the likelihood of sampling in a variety of atmospheric conditions. The use of thoroughly tested and well-documented synergy between airborne instruments or between current satellites was also shown as a validation technique,

and these synergistic retrievals can also be directly applicable for enhancing EarthCARE's output and usefulness. To demonstrate another potential tool for the validation of EarthCARE's aerosol data products and to understand the kinds of aerosol properties we can expect to retrieve from ATLID, an aerosol climatology built from observations and expanded through global modeling was presented. Finally, the use of high-resolution simulations was also proposed as a method for validation of the cloud and aerosol products. It could also serve as an environment for developing an algorithm for simultaneous liquid and ice cloud retrievals that takes advantage of radar, lidar, and radiometer synergy.

OUTCOME. The workshop concluded with a group discussion aimed at identifying key topics that EarthCARE could be useful in addressing and that the community could ultimately use as the basis for developing scientific initiatives. Specifically, the continuation of the observational record provided by the A-Train satellites, namely *CloudSat* and *CALIPSO*, as well as the improved vertical profiles of clouds and aerosols, were agreed upon as the most exciting anticipated output from the EarthCARE satellite mission. Complete and accurate vertical profiles of clouds and aerosols have historically been very challenging to obtain due to instrument limitations, resulting in uncertainties associated with their spatial and temporal distributions and their optical and radiative properties. When the vertical profiles of clouds and aerosols are known, their heating rate profiles can be accurately calculated, which provides much needed information on how clouds and aerosols and their respective properties interact with and influence Earth's radiative feedbacks and budget. As described below, the advancements being made with EarthCARE's CPR and ATLID provide an exciting opportunity for finally obtaining those profiles.

The CPR is more sensitive than current satellite radars, like *CloudSat*, and this will enable it to better capture shallow and low-level clouds. This not only supplies a more complete vertical cloud distribution, but also improves observations of clouds that are known to be climatically relevant. Furthermore, upcoming field work such as the French–German Elucidating the Role of Cloud-Circulation Coupling in Climate (EUREC4A) campaign in 2020 will also look into the distribution of these low-level clouds in the Atlantic trade wind region and how they are intertwined with circulation and heating. EarthCARE would provide an opportunity to expand those results

to a more global picture in an effort to understand how low-level clouds change in a warming world.

Also, the effects of cirrus clouds have been poorly represented due to difficulties in obtaining accurate information concerning their ice water content and the shape, density, and orientation of their ice crystals, all of which have an impact on their radiative effects. However, the use of a high spectral resolution lidar will improve the detection of these clouds and their properties because this measurement technique will provide an accurate lidar ratio S , which may be used to calculate extinction in lidar retrievals. Current satellites rely on assumptions to calculate S , which introduces a potential source of error in lidar data products. Knowing S is also extremely useful for providing accurate profiles of aerosols and more sophisticated aerosol typing.

The first joint workshop between the German EarthCARE community and the French EECLAT community was very successful. In addition to the exchange of scientific knowledge and expertise, the workshop proved to be an excellent opportunity for encouraging future collaboration between these two European communities in pursuit of common goals.

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