CloudIce Mission Proposal

Letter of Intent

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Stefan Buehler and the CloudIce Mission Community

1. Mission Objectives

1.1. Importance of Cloud Ice Measurements

Clouds play a crucial role for the climate on planet Earth. They are also a major source of uncertainty in climate predictions, as affirmed by the most recent assessment report by the Intergovernmental Panel on Climate Change (IPCC) *[WMO, 2007]*. Particularly large uncertainties are associated with those clouds that consist partly or entirely of ice particles *[e.g., Stephens et al., 1990]*. The microphysical formation mechanisms of cloud ice particles are less well understood than those of liquid droplets. Also, their shapes and physical properties vary widely, complicating their interaction with radiation.

At the same time, there is a lack of reliable global measurements of cloud ice. As a consequence, different climate models exhibit large discrepancies in their cloud ice water content fields *[Waliser et al., 2009]*. For example, the annual zonal mean ice water column at 60° North ranges from approximately 20 to approximately 400 g/m² for the climate models that participated in the fourth assessment of the IPCC *[John and Soden, 2006, Fig. 1]*.

The existing space-based measurement capabilities, mostly by infrared and visible instruments, provide important information on the radiation effect of ice clouds. However, it is inherently difficult to relate these measurements to the bulk mass of ice, which is a basic climate model parameter, the parameter that can be linked to other stages of the hydrological cycle by the requirement of total water mass continuity. We therefore argue that there is a particular need for cloud ice mass measurements.

This has also been recognized by the World Meteorological Organization (WMO), which classifies the total column of cloud ice (also called Ice Water Path, IWP) as one of the Essential Climate Variables (ECV) in the framework of the Global Climate Observing System (GCOS) *[WMO, 2006]*.

1.2. Advantages of Sub-Millimeter Sensors

Active radar systems and passive millimeter/sub-millimeter instruments provide data that are directly related to the bulk mass of ice in an ice cloud. The two techniques are highly complementary. Radars, such as the CPR instruments of CloudSat and EarthCARE, provide high vertical resolution at the cost of poor horizontal coverage. Their main measurement uncertainty for ice mass is due to unavoidable assumptions on the particle size distribution.

Passive millimeter/sub-millimeter sensors, on the other hand, can provide continuous near-global coverage on a daily basis, at the cost of a poor vertical resolution. If suitable frequencies are chosen, these measurements sample different parts of the ice particle size spectrum, allowing an accurate estimation of the total ice mass *[see e.g., Buehler et al., 2007, Fig. 3]*.

1.3. Data Products

The CloudIce mission will deliver one primary data product and several important other data products. They are summarized briefly below. The GCOS guidelines for the generation of satellite-based datasets and products will be followed where relevant *[WMO, 2009]*.

Cloud Ice Water Path (IWP)

is the primary mission data product. This is the total vertical column of cloud ice. It shall be delivered with an accuracy of approximately 20%, a horizontal resolution of approximately 15 km, and continuous horizontal coverage. This horizontal resolution agrees with the grid resolution that global climate models will have in the near future. Near-global coverage is possible within 24 hours.

Ice Water Content Profiles

will be restricted to a few broad layers, such as lower-, middle-, and upper troposphere.

Particle Size

will be a parameter related to the ice mass, such as the median mass equivalent sphere diameter. This can be linked directly to particle fall speed, as shown by *Heymsfield [2003]*.

Cloud Altitude

will not be the cloud top altitude which can be observed well by infrared instruments. What CloudIce will provide is the median ice water path altitude, which is more representative for the altitude where most of the ice mass is located.

Precipitation Rate

can be retrieved due to the correlation between the amount of cloud ice and the amount of precipitation below. According to retrieval simulations, it can be delivered with a horizontal resolution of 15 km and an accuracy better than 70% for precipitation rates above 1 mm/h. Both liquid and solid precipitation can be considered. The mission will play an important role in demonstrating the benefit of sub-millimeter measurements for this application. Although this objective is recognized as important, precipitation retrieval shall not be the design driver.

1.4. Summary of Mission Objectives

The CloudIce mission will deliver urgently needed global data on ice clouds, particularly on the so far poorly characterized essential climate variable Ice Water Path (IWP), and about cloud ice particle size.

It will deliver the data with continuous spatial coverage and on a spatial scale consistent with future global climate models, to both evaluate and improve the models.

It will also demonstrate the benefit of sub-millimeter observations for precipitation retrieval.

2. Mission Characteristics

2.1. Instrument

The CloudIce mission has only one scientific instrument, the Cloud Ice Water Sub-millimeter Imaging Radiometer (CIWSIR). It is a conically scanning eleven-channel radiometer, with observation frequencies between 183 and 664 GHz. Table 1 lists the channel frequency positions and other specifications.

2.2. Heritage

The instrument is an updated version of the CIWSIR instrument that was proposed in the previous two Earth Explorer calls by the same science team. Subsequent to the 2005 submission, ESA has funded several preparatory activities for this instrument, including the establishment of mission and instrument requirements *[Buehler et al., 2007]* and the definition of an airborne demonstrator with similar sub-millimeter channels. Furthermore, the funding for the build of the airborne demonstrator has now been approved and this is expected to start in 2010. The instrument will be subsequently available for concept validation campaigns and post-launch calibration/validation.

Similar sub-millimeter channels are also planned for an ice cloud instrument on the operational platform Post-EPS, but the inclusion of this mission is not yet confirmed. Independent industry consortia (led by Astrium SAS and Thales Alenia Space Italy, respectively) have already developed conceptual designs for the Post-EPS instrument. The CloudIce mission can take advantage of these initial studies, which will allow a rapid start of the mission program, as necessary to achieve the planned launch in 2018. CloudIce would be an important precursor for this operational instrument, if it were maintained for Post-EPS.

Table 1: Channel characteristics. Position is the characteristic frequency of the channel and NeΔT the characteristic noise. Most receivers will be unpolarized, but one or two will be polarized. Details of the polarization characteristics will be fixed for the full proposal. The spatial resolution (footprint size) of all channels is 15 km.

Channel	Position	NeDT
1	183.31 ± 1.5 GHz	0.4-0.6 K
2	183.31 ± 3.5 GHz	
3	183.31 ± 7.0 GHz	
4	243.2 ± 2.5 GHz	0.5 K
5	325.15 ± 1.5 GHz	0.7-1.0 K
6	325.15 ± 3.5 GHz	
7	325.15 ± 9.5 GHz	
8	448 ± 1.4 GHz	1.2-1.9 K
9	448 ± 3.0 GHz	
10	448 ± 7.2 GHz	
11	664 ± 4.2 GHz	1.5 K

2.3. Improvements Compared to Last CIWSIR Mission Proposal

A number of critical technology developments have been implemented by ESA since the last submission. These include parallel developments for a 664 GHz receiver front-end assembly, a sub millimeter-wave calibration target, and a generic conical scan mechanism for Earth observation applications. A development study for a contactless signal-power transfer device will also soon be awarded. Existing technology developments from programs such as Planck (feedhorn assembly), Odin and Admirals (reflector technology), and Premier (receiver front-end developments at 320-360GHz) will also be applicable to this mission. Furthermore, although the airborne demonstrator is primarily a retrieval demonstration program, the experience gained from the receiver developments will also be valuable.

Scientifically, the biggest difference is the addition of precipitation as a retrieval target. This was done in recognition of the great potential of sub-millimeter measurements for this application, which emerged in simulation studies on the pertinence of mm/sub-millimeter radiometry for rain retrieval *[Defer et al., 2008]* and for the airborne demonstrator. Even though not designed for precipitation retrieval, CloudIce will be the first satellite instrument to demonstrate the use of sub-millimeter measurements for this application.

Furthermore, the CloudIce mission community has put much work into refining radiative transfer codes, developing extensive cloud property data bases, and improving retrieval algorithms. As a consequence, the entire data analysis chain is more mature today than at the time of the last call. Detailed performance simulations for cloud ice parameters, including the effect of auxiliary infrared data, can be found in *Buehler et al. [2007]* and *Jimenez et al. [2007]*. They confirm that the scientific requirements can be met with available technology.

2.4. Orbit

Retrieval simulations show that the sub-millimeter measurements benefit greatly from simultaneous infrared measurements. CloudIce will therefore fly in formation with a meteorological satellite that has either the Advanced Very High Resolution Radiometer (AVHRR) or a successor (like VII on Post-EPS). Spatial and temporal collocation of the data shall be possible within 500-2000 m and 10-30 s, respectively.

2.5. Cost

Table 2 contains rough order of magnitude cost estimates from Astrium SAS for the various mission elements. They are preliminary and will be revised for the actual mission proposal.

Table 2: ROM cost estimates.

Element	Cost estimate
CIWSIR Instrument C/D	50 M€
Platform C/D	35 M€
Mission ground segment	5 M€
Aircraft validation campaigns	5 M€
Total	**95 M€**

2.6. Other Programmatic Aspects

As stated above, CloudIce will fly in formation with an operational meteorological satellite. In case Post-EPS 1 (without the sub-millimeter instrument) would be launched already in 2018, a double launch with the same rocket could be an economically attractive option.

Quite generally, "trains" of several satellites (like the US A-train) have enormous advantages. Besides the tandem CloudIce/Metop (or CloudIce/Post-EPS), we propose that ESA consider a larger joint meteorological train with NASA, and possibly other agencies. This is not required for CloudIce to achieve its objectives, but would increase the benefit of all involved missions.

2.7. Relation to Active Missions

With a launch date in 2018, the proposed CloudIce mission will provide important cloud ice data in the time period between two active cloud missions, EarthCARE (launch 2013) and ACE (launch possibly 2018-2020, but still uncertain). Should an active mission, such as ACE, be flying simultaneously with CloudIce, it would be scientifically attractive to coordinate its orbit with CloudIce/Metop. This could either mean to have the active mission in the same train, or to have it in a lower orbit with the same equator crossing time, which would yield large amounts of collocated data in the tropics.

NASA itself is considering a sub-millimeter instrument as part of the ACE (or pre-ACE) mission. If ESA and NASA would agree to coordinate their activities, CloudIce could fulfill that role in a joint meteorological train with ACE.

2.8. Industrial Guarantee

The company Astrium SAS has reviewed the technical solution, and has assessed its feasibility within the required budget envelope with the required technology readiness level. They will confirm this during the preparation of the final proposal.

3. Team

The following scientists and technical experts are involved in the CloudIce mission proposal:

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4. References

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