Cloud Ice Water Submillimeter Imaging Radiometer

CIWSIR

Letter of Intent

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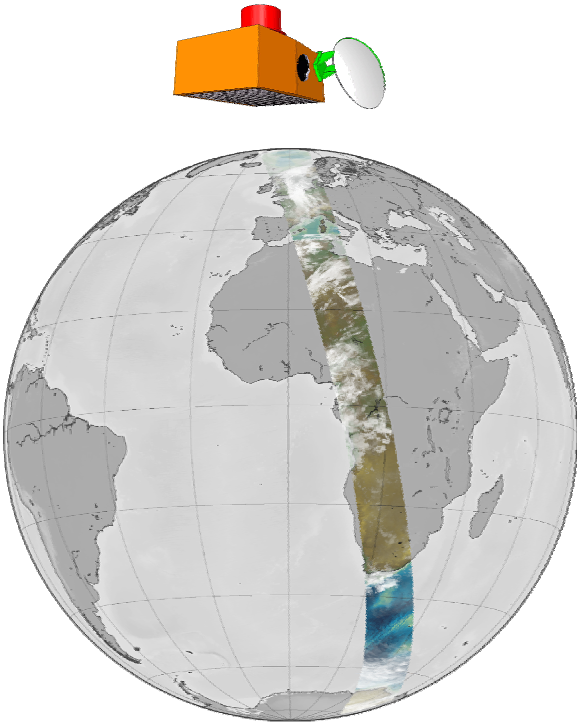

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Objectives

Ice clouds play an important role in the energy budget of the atmosphere. They are at high altitudes, absorb longwave radiation from below and, as they are cold, emit little infrared radiation. This greenhouse effect warms the earth-atmosphere system. On the other hand, thick ice clouds reflect direct solar short wave radiation, hence reduce incoming solar radiation, and hence cool the earth-atmosphere system. The net effect is crucial for the atmosphere, but will depend highly on the clouds horizontal extent, vertical position, ice water content, and ice particle microphysical properties, which all influence the clouds optical thickness. Thus, the special properties of ice clouds have a strong impact on radiative exchanges. Furthermore, ice clouds affect the energy budget by releasing latent heat during the depositional growth of ice particles. Eventually ice particles, if large enough, sink through the atmosphere and may enhance precipitation generation in lower clouds by the seeder-feeder mechanism.

The importance of clouds in weather and climate processes has been recognized through a number of observational and modeling studies and is emphasized in the third IPCC-Report [Stocker et al., 2001]. Uncertainties associated with ice clouds are particularly large, in spite of the fact that ice clouds can be seen by satellite sensors in the visible and infrared spectral range. The problem is that the available sensors give no direct information on the cloud ice water path (IWP), one of the most important cloud parameters. There are two main reasons for the need to measure IWP directly:

Firstly, almost all general circulation models (GCMs) for weather prediction and climate simulation now prognose the vertical distribution of condensate [Doms and Schättler, 1999; Roeckner et al., 1996]. The models prognose the liquid and ice water content (LWC and IWC), at each model time step and grid-point, from a water mass continuity equation. However, they are subject to considerable uncertainties and oversimplifications, largely introduced by the assumptions on ice sedimentation velocities and by the treatment of advection from one time step to the next. Thus, recent sensitivity studies, like the ones by Wilson [2000] and Reinhardt and Wacker [2004], find that LWC and IWC vary considerably depending on the assumptions made. To improve GCMs it is necessary to validate the model IWC fields and resolve the discrepancies. For this purpose, direct global measurements of IWC or at least the vertically integrated ice water path (IWP) are required, at a resolution compatible with the GCMs and fine enough to resolve typical cirrus features.

The second reason is that condensate and water vapor are the two components of the hydrological cycle in the upper troposphere, and both are currently poorly measured. The hydrological cycle is the most important subsystem of the climate system for the living conditions on the planet, hence its understanding is an important scientific goal, towards which already great progress has been made, except in the upper troposphere. To close the cycle in the upper troposphere requires measurements of the IWP, accompanied by simultaneous measurements of the water vapor concentration.

Closure of the hydrological cycle also requires an understanding of ice precipitation, a key element of uncertainty in GCM model output. There are two main ways how ice condensate is converted to ice precipitation in GCMs: through autoconversion, that is removal from the atmosphere, or by precipitation between levels. Recent mesoscale model and GCM studies have demonstrated the impact that the assumed shapes and fall velocities have on predictions of cloudiness and radiative forcing. If global data on characteristic ice particle size could be obtained, available data from many mid-latitude and tropical field campaigns, involving aircraft and ground-based radar, could be used to develop relationships between the characteristic size and the fall velocity. This would provide a means of deriving the global distribution of ice particle fall speeds to use in developing and validating ice cloud particle sedimentation velocities in GCMs.

To summarize, the objective of the proposed CIWSIR mission is to obtain global data on the fundamental parameters of ice clouds, especially cirrus: their ice water path and the characteristic size of the ice particles. An important secondary objective is to obtain simultaneous measurements of the water vapor concentration. Another important secondary objective is to obtain information on the particles predominant shapes and fall orientations, in order to allow a rough habit classification. These objectives cover the most basic and therefore most urgently needed parameters of ice clouds and the hydrological cycle in the upper troposphere. The observations should be done with a spatial and temporal resolution and coverage compatible to other meteorological satellite data and GCMs. This is not possible with any other method than the proposed sub-millimeter satellite observations.

Characteristics

Satellite measurements with visible and infrared techniques can be used to detect the presence of ice clouds and to determine the cloud top pressure as well as the clouds optical thickness or emissivity. However, the determination of IWP is either indirect or limited to semi-transparent cirrus. Recently, submillimeter radiometric measurements from satellite or aircraft in the frequency range of 300-1000 GHz have been proposed to investigate cirrus clouds [Evans, 1998 and references therein; Kunzi et al., 2001]. Since water vapor absorption is strong within this band, the lower atmosphere is in most cases opaque, therefore the surface and low clouds do not contribute to the upwelling radiation. In this frequency range, the interaction between cirrus clouds and radiation is mainly by scattering, so emission and therefore cloud temperature are not important. The situation can be described as that of a layer of cloud ice lying on top of a radiation source. Hence, the effect of the cloud is to reduce the brightness temperature compared to the clear sky case. The brightness temperature depression is proportional to the IWP, except for saturation effects that occur for high IWP at high frequencies. This linearity has the advantage that radiation averages correspond to the radiation of an average atmospheric state, i.e., problems related to beam-filling in the presence of inhomogeneities are less significant than for optical and infrared techniques.

The submillimeter frequency range presents a unique window for the observation of ice clouds, because at lower frequencies the scattering of radiation by ice particles is not strong enough to detect thin ice clouds, although thicker ice clouds associated with prominent frontal systems and heavy precipitation can be easily seen, as demonstrated by Figure 1. At the high frequency end, the usable frequency range is limited by the rising opacity due to water vapor absorption, which will hide the ice clouds from the satellite sensor at frequencies above roughly 1 THz (water vapor screening effect).

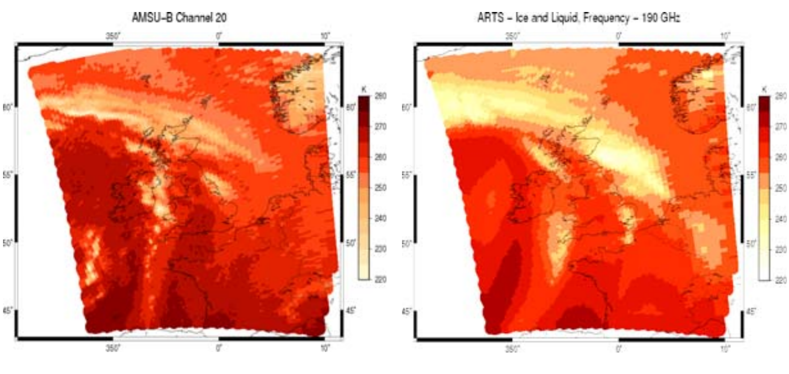

Figure 1: Left: AMSU-B Channel 20 measurements at 183±7 GHz over the UK and northern parts of continental Europe, on 25th January, 2002. Right: Radiative transfer model simulation for the same channel using inputs from the mesoscale forecast model UKMES. The bright areas show the signature of the thick ice cloud associated with a frontal system passing over the UK.

The exact relationship between IWP and brightness temperature depression for a given frequency depends on the characteristic particle size and shape. Measurements at different frequencies can be used to eliminate this ambiguity to a large extent. This technique, which has been demonstrated by retrieval simulation studies, is used by the proposed CIWSIR sensor. Primary data products will be the IWP, the characteristic size of the ice particles, and profiles of the water vapor concentration. An auxiliary data product may be a rough estimate of the ice particles predominant shape. Data analysis techniques (radiative transfer and retrieval) for the CIWSIR sensor have been perfected within the ESA funded study "Development of an RT model for frequencies between 200 and 1000 GHz" (ESTEC Contract No AO/1-4320/03/NL/FF). Although the study is still ongoing, the techniques are mature enough for instrument performance simulations and can be used as prototypes for the operational retrieval algorithms.

The proposed mission and instrument concept is based on the original CIWSIR concept [Kunzi et al., 2001] that was developed in response to the ESA call for Opportunity Mission Proposals in 2001, but takes into account new measurements of cirrus clouds, theoretical development, and technological advances that have been achieved over the past four years. The channel positions and also the technical concept have been improved, as described in the next section. Retrieval simulation studies show that auxiliary information from some simple infrared channels improves the performance for low to moderate IWP [Evans, 2003]. It is currently discussed within the mission community, whether the full proposal should include such channels on the CIWSIR platform, or rely on external data, for example from Metop.

The CIWSIR sensor should fly on a sun synchronous orbit to avoid diurnal aliasing. In principle it would be desirable to sample also the diurnal cycle of cirrus, but for this task the sampling with a single satellite would not be adequate. The overpass local time of the orbit should be chosen later, based on maximizing the synergy with other missions. An obvious choice would be close to the Metop overpass time. The sensor should use a conical scanning geometry, in order to simplify the treatment of polarization effects. The selection of the orbit altitude will then be driven by the scientific requirement to obtain near daily coverage with a conical scanner. The requirement for the mission duration is driven by the need to get sufficient statistics for the cirrus measurements and by the need to sample at least one yearly cycle. One year is thus the minimum mission duration, but two years or more would be desirable.

It is worthy of notice that the feasibility of satellite-borne radiometers operating at submillimeter frequencies has been well demonstrated by SWAS (channels up to 550GHz), SMR on Odin (channels up to 580GHz) and MLS on Aura (channels up to 2500GHz). Furthermore, the feasibility of water vapor profiling, the secondary objective, is well established by the instruments of the AMSU family. The horizontal and vertical resolution of CIWSIR will be comparable to that of AMSU-B. Nearly daily global coverage will be possible by using a polar orbiting platform.

The proposed mission is synergistic and complementary to the planned EarthCARE mission, which uses active remote sensing instruments (LIDAR and RADAR) to make point measurements of some cloud properties with high vertical resolution. In contrast to EarthCARE, CIWSIR directly measures IWP, the most important quantity for GCMs, as explained above. Furthermore, whereas EarthCARE provides only point measurements, CIWSIR provides global measurements on the same scale as the models. Thus, CIWSIR will provide the means to carry the results from process studies with EarthCARE data to global applications, such as assessing the global climatology of ice clouds and improving GCMs for climate and weather prediction. CIWSIR would also be complementary to a possible future geostationary submillimeter sensor, due to its global coverage and high spatial resolution.

Technical Concept

A strawman instrument concept has been derived based on the earlier CIWSIR concept, but taking advantage of recent developments in the key technologies required for the antenna, receiver, and mechanism subsystems. The instrument has 12 total power radiometer receiver channels, located at the GHz positions 183.31±1.5, 183.31±3.5, 183.31±7.0, 243.2±2.5, 325.15±1.5, 325.15±3.5, 325.15±9.5, 448±1.4, 448±3.0, 448±7.2, 664±4.2, and 874.4±6.0. This choice of channels is based on "scenario C" from [Evans, 2003] which gives a slightly improved retrieval performance compared to the earlier CIWSIR channel set. The two highest frequency channels are planned to measure both polarizations, so that size and shape information contained in the polarization signal can be exploited to improve the retrieval.

The instrument uses a conical scan configuration with a fixed Earth incidence angle of approximately 53°. At an orbit altitude of 830 to 870 km this results in a swath width of approximately 1800 km. The antenna design is driven by the requirement that all beams of all channels are co-aligned and that they are matched in size. This implies the need for a quasi-optical network using frequency selective surfaces to provide demultiplexing of the channels, and wire grids to provide polarization separation. The co-alignment requirement favors the use of a single antenna aperture covering all of the channels. Therefore, the proposed concept has an antenna aperture of 280mm diameter, using a dual reflector design. Unlike the earlier concept, the subreflector is located within the instrument enclosure to minimize stray radiation effects. A calibration switching mirror provides views to cold space and to an ambient temperature black body target. The antenna and integration time characteristics are chosen such that the footprint size of the measurement is approximately 15 km.

The instrument receivers cover a wide spectral range of microwave frequencies and different technologies are required for the different ranges. For example, at 183GHz, state-of-the-art MMIC low noise amplifiers (LNAs) are becoming available which could be used as the front-end of a heterodyne channel. Alternatively, the more conventional mixer front-end using a planar diode sub-harmonically pumped mixer would provide the required sensitivity. Such mixers are preferred at frequencies of up to at least 450GHz, and suitable units have been demonstrated at breadboard level. Technology choices for frequencies above 450 GHz could include both sub-harmonically and fundamentally pumped mixers, although the heritage of the latter is stronger. Noise equivalent temperatures are expected to range from below 1 K for the low frequency channels to approximately 2 K for the highest frequency channel.

The mechanism subsystem includes a number of critical functions: instrument scanning, the transfer of power and signals between the static and rotating parts of the instrument, and the maintenance of static and dynamic balance of the instrument throughout mission lifetime. The scanning and power and signal transfer functions are achieved using an integrated mechanism design that incorporates advanced rolling elements for power transfer and capacitive couplers for the transfer of signals and telemetry. These are the subject of on-going development activities being carried out by the Agency. The main physical characteristics of the instrument are listed in Table 1.

Table 1: Rough estimates of main instrument characteristics.

Scan rate (rpm)	20
Mass (kg)	45
Overall envelope (mm)	810 x 660 x 485
Power (W)	70
Data rate (kb/s)	25

Scientific and Industrial Community

Listed here are some of the individuals, companies, and research institutions that are part of the CIWSIR mission community, and have requested to be listed here. Those that have directly contributed to this document are marked with an asterisk.

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