Cloud Ice Water Submillimeter Imaging Radiometer

CIWSIR

Mission Proposal

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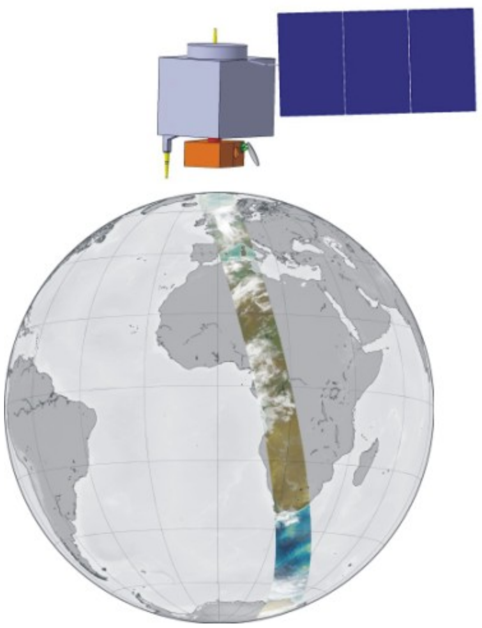

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APPENDIX

1 Objectives

The main objective of the CIWSIR mission is to obtain global data on the ice water content of cirrus clouds. This section explains why such data are urgently needed and how they can be obtained by the CIWSIR measurement principle.

1.1 Ice Clouds

1.1.1 Ice Clouds in the Climate System

Cloud ice 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 life on the planet, hence its understanding is an important scientific goal. Great progress has already been made towards this goal, except in the upper troposphere, where our knowledge is still very limited.

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, cirrus clouds reflect incoming solar short wave radiation and hence cool the Earth-atmosphere system. The net effect is crucial for the atmosphere, but will depend highly on the cloud's horizontal extent, vertical position, ice water content, and ice particle microphysical properties, which all influence the cloud's optical thickness. Thus, the special properties of cirrus clouds have a strong impact on radiative exchanges. Furthermore, cirrus clouds affect the atmospheric energy budget by releasing latent heat during the depositional growth of ice particles and by absorbing heat upon their sublimation. Eventually ice particles, if large enough, settle 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 Report of the Intergovernmental Panel on Climate Change (IPCC) [Stocker et al., 2001].

1.1.2 Representation of Ice Clouds in Climate Models

All general circulation models (GCMs) for weather prediction and climate simulation now forecast the vertical distribution of condensate [Doms and Schättler, 1999; Roeckner et al., 2003]. Most models contain the liquid and ice water content (LWC and IWC) as prognostic variables, and forecast their value at each model time step and grid-point from separate water mass continuity equations [see e.g., Lohmann and Roeckner, 1996]. However, the models contain 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 illustrate this, Figure 1.1 (left plot) shows a climatology for zonal annual mean ice water path (IWP) for different climate models from the IPCC AR4 model data archive. The IWP is the vertically integrated IWC. It varies by up to an order of magnitude between the different models. The discrepancies in the model predicted IWP response to a CO_2 doubling (right plot of Figure 1.1) are even more striking. Even the sign of the response is uncertain. Some models predict an increase of cloud ice at latitudes where others predict a decrease.

These discrepancies in IWP arise because the different models make different assumptions on ice particle properties and on how cloud ice particles are converted to precipitation. Most important in this respect are assumptions on ice particle size, mass, and cross-sectional area, because these properties directly influence the particle fall velocities [Heymsfield and Iaquinta, 2000; Kristjansson et al., 2002].

In the context of this proposal, we will describe the characteristic size of ice particles by the median mass equivalent sphere diameter *D*. It is defined such that half of the total mass of ice will be in particles with an equivalent sphere diameter smaller than *D*, whereas the other half of the mass of ice will be in particles with an equivalent sphere diameter larger than *D*. Ice particle fall velocities depend on the ratio of the particle mass to its area perpendicular to the fall direction. Heymsfield and Iaquinta [2000] have shown how this dependence can be parameterized as a function of the particle size. Thus, information on *D* can be used to derive information on ice particle fall speeds.

Global climate models have now a typical horizontal resolution of 100 to 400 km. It is expected that by 2013, the expected flight time of CIWSIR, the resolution will have improved down to 20 to 100 km.

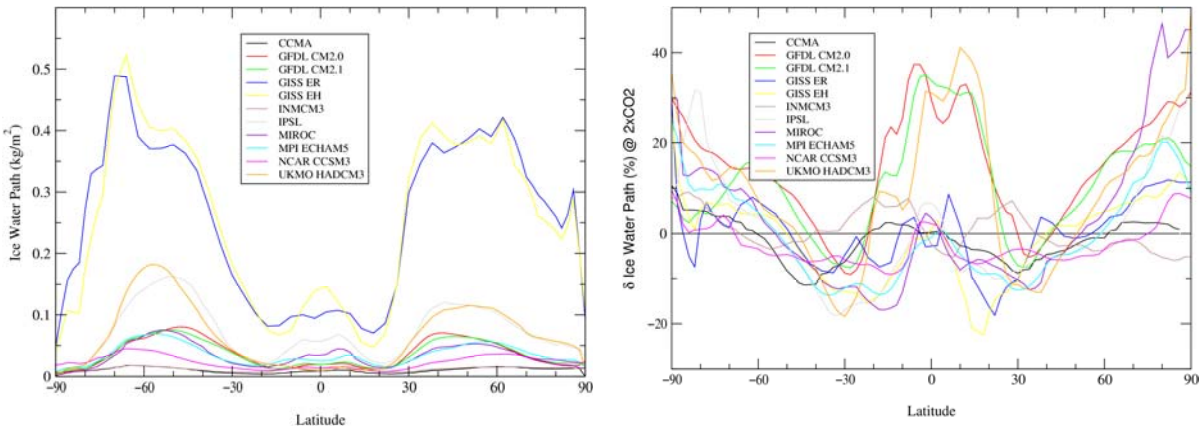


Figure 1.1: Left: The climatology of zonal annual mean IWP from various climate models in the IPCC AR4 data archive. Right: Model predictions of the relative change in zonal annual mean IWP after a CO_2 doubling. Note the large discrepancies between the different models, both in the present mean state and in the predicted response to a changing CO_2 concentration.

1.2 Measurements

1.2.1 In-Situ Measurements

In-situ measurements with aircraft-borne sensors provide the most detailed information on ice clouds. Good summaries of recent measurement campaigns are given in Lynch et al. [2002], and more recently in Heymsfield et al. [2004], Stubenrauch et al. [2004], and Gayet et al. [2004]. From these campaigns we know the typical sizes and shapes of ice particles in clouds. We have also learned that ice particles tend to be larger for higher temperatures and higher IWC, and tend to be smaller for low temperature and IWC. However, the natural variability is very large and therefore parameterizations of the particle size distribution as a function of temperature and IWC can be only rough approximations.

The validation of global circulation models requires global data with long time coverage. For economical and practical reasons this can not be achieved with in-situ measurements.

1.2.2 Operational Satellite Measurements

Satellite-borne remote sensing instruments can provide frequent global measurements of the atmosphere on a long-term basis. The existing instruments operate in different parts of the electromagnetic spectrum and use a number of techniques to detect and measure ice clouds.

Infrared (IR) sensors like HIRS see mostly the thermal emission by the clouds. Ice clouds are radiatively colder than the surface, because they are at high altitudes where the ambient temperature is low. With IR sensors one can determine IWP and *D* for semitransparent cirrus clouds [Stubenrauch et al., 2004]. Such clouds on average have an IWP of only 30 g/m^2. For thicker cirrus clouds the method is not applicable, because they act like blackbodies and the sensor sees only the emission from the cloud top.

Sensors in the ultraviolet and visible (UV/Vis) spectral range, such as POLDER, see the sunlight reflected by the clouds. The reflectivity depends strongly on ice particle size and shape, therefore such measurements can be used for a retrieval of *D* and for a rough crystal habit classification. The measurement only works if the surface albedo is not too high. Furthermore, for thick clouds the measurement is limited to particles near the cloud top. Instruments like ATSR-2 that have both Vis and IR channels can use emitted and reflected radiation simultaneously.

Microwave sensors, such as AMSU-B and SSM-T2, detect the cloud transmission, seeing through even thick ice clouds. The principle of this measurement is explained in detail in Section 1.3. The currently operational microwave sensors are sensitive only to thick ice clouds, such as deep convective clouds [Hong et al., 2005], because the interaction of millimeter wave radiation with cloud ice particles is not very strong. It will be shown below that for sub-mm wave radiation the interaction is much stronger.

1.2.3 Planned Satellite Measurements

The planned ESA mission EarthCARE will use two active sensors and two passive sensors to study aerosol and cloud profiles, as well as radiation fluxes, and will thus considerably widen our knowledge of aerosols, clouds, and their interaction with radiation. Cloud IWC will be measured by a cloud profiling radar (CPR) at 94 GHz with high vertical resolution (< 400 m). Data will be acquired in spots of approximately 1 km diameter along the satellite track. With prior assumptions on the particle size distribution CPR is estimated to provide IWC measurements with an accuracy of a factor of 2 [Poiares Baptista and Leibrandt, 2001]. Before EarthCARE, the American CLOUDSAT mission will fly a CPR with roughly comparable performance [Stephens et al., 2002]. Section 2.3 discusses the important role of these missions for the CIWSIR mission.

1.2.4 Missing Measurements

To improve climate prediction it is necessary to validate the IWC fields of GCMs and resolve the discrepancies. For this purpose, direct global measurements of IWC or its vertical integral IWP are required, at a resolution compatible with the GCMs and fine enough to resolve typical cirrus features. Global measurements of *D* are needed to constrain the GCMs assumptions on ice particle size, and hence ice particle fall velocity.

1.3 CIWSIR Measurement Principle

Submillimeter (sub-mm) 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]. The following subsections describe the principles of sub-mm cirrus measurements.

1.3.1 Observation Geometry

A schematic picture of the CIWSIR observation geometry is shown in Figure 1.2. Since water vapor absorption is strong in the sub-mm wave spectral range, the lower atmosphere is in most cases opaque. This has the desired effect that the surface and low clouds do not contribute to the upwelling radiation. Furthermore, 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 in good approximation 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.

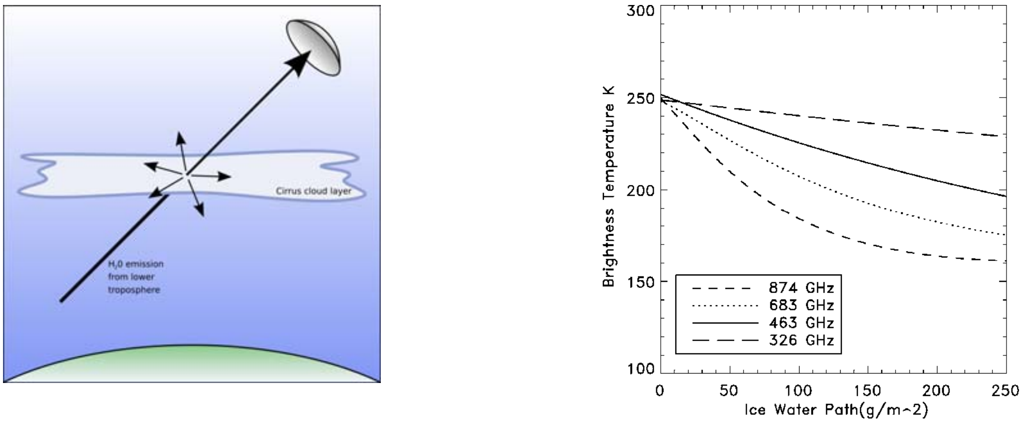


Figure 1.2: Left: The CIWSIR observation geometry. Some of the upwelling radiation is scattered away by the ice cloud. Right: Sensitivity of radiance to IWP for some different frequencies in the sub-mm wave spectral range. Conditions: midlatitude-winter, nadir viewing direction, homogeneous cloud between 5 and 7 km altitude, spherical ice particles of 200 µm diameter. The radiative transfer model used to generate this and subsequent figures is the Atmospheric Radiative Transfer Simulator ARTS [Emde et al., 2004].

1.3.2 Ice Cloud Signal in the sub-mm Spectral Range

Figure 1.3 gives an example how thick ice clouds are seen at microwave frequencies by the AMSU-B instrument. It shows in the top row some AMSU data at 183±7 GHz, and a model IWP field for comparison. The bottom row shows simulated radiances for the same AMSU channel and for a CIWSIR channel at 664 GHz. The figure demonstrates that the cloud signal is more pronounced at higher frequencies. 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). The sub-mm frequency range thus presents a unique window for the observation of ice clouds.

1.3.3 Sensitivity to Different Particle Sizes

The interaction of ice particles with radiation depends strongly on the ratio of particle size and wavelength. Figure 1.4 shows the sensitivity to particles of different sizes for the proposed CIWSIR channels. For comparison, the sensitivity for IR measurements and for radar backscatter at 94 GHz (CLOUDSAT and EarthCARE CPR) are also shown. As demonstrated by the figure, measurements at different frequencies can be used to sample the particle size distribution. To make accurate measurements of IWC or IWP, it is important that a significant part of the size distribution is sampled, significant here meaning a part that contains a significant fraction of the total mass of ice. Parts of the size distribution that are not sampled will lead to errors in IWC, because the mass of ice hidden in particles of that size must be estimated from assumptions on the size distribution. This is the reason why neither IR measurements (seeing only very small particles), nor radar measurements (seeing only very large particles) can provide very accurate estimates of IWC. Only sub-mm measurements, combined with IR measurements for the very small ice particles can provide a reasonable coverage of the size distribution.

Scattering properties of ice particles depend not only on particle size, but also on particle shape and orientation. However, this effect is much smaller than the size effect, because the asymmetric scattering properties of individual ice crystals are effectively averaged over many different shapes and orientations. From model simulations and from sub-mm limb sounder data gathered by the EOS-MLS instrument we know that the effective scattering properties are close to those of horizontally oriented oblate spheroids with moderate aspect ratios. Davis et al. [2005] found an aspect ratio of 1.2±0.2. Such moderate aspect ratios will affect the total intensity of the scattered radiation only slightly, but will introduce polarization that can be detected by a suitable sensor, as shown in Figure 1.5.

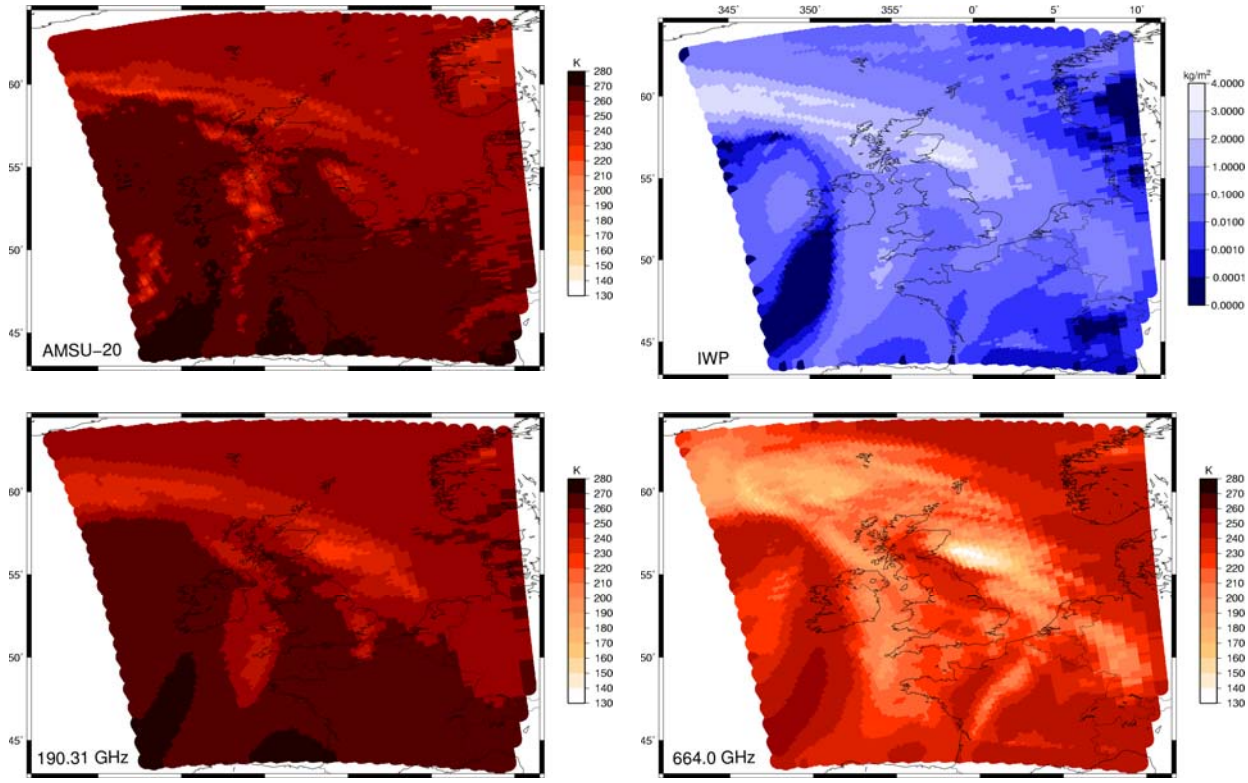


Figure 1.3: Top left: AMSU Channel 20 measurements at 183.31±7 GHz over the UK and northern parts of continental Europe, on 25th January, 2002. The bright areas show the signature of the thick ice cloud associated with a frontal system passing over the UK. Top right: Ice Water Path (IWP) from the Met Office (UK) mesoscale model. Bottom left: Simulated AMSU measurement, based on the mesoscale model atmosphere. Bottom right: Simulated CIWSIR measurement at 664 GHz. The simulations were done with the RT model ARTS, assuming a McFarquhar and Heymsfield [1997] size distribution for the ice particles. The simulation for AMSU used the correct AMSU viewing angles, the one for CIWSIR a fixed viewing angle of 45°. Note the much stronger sensitivity to ice for the higher frequency.

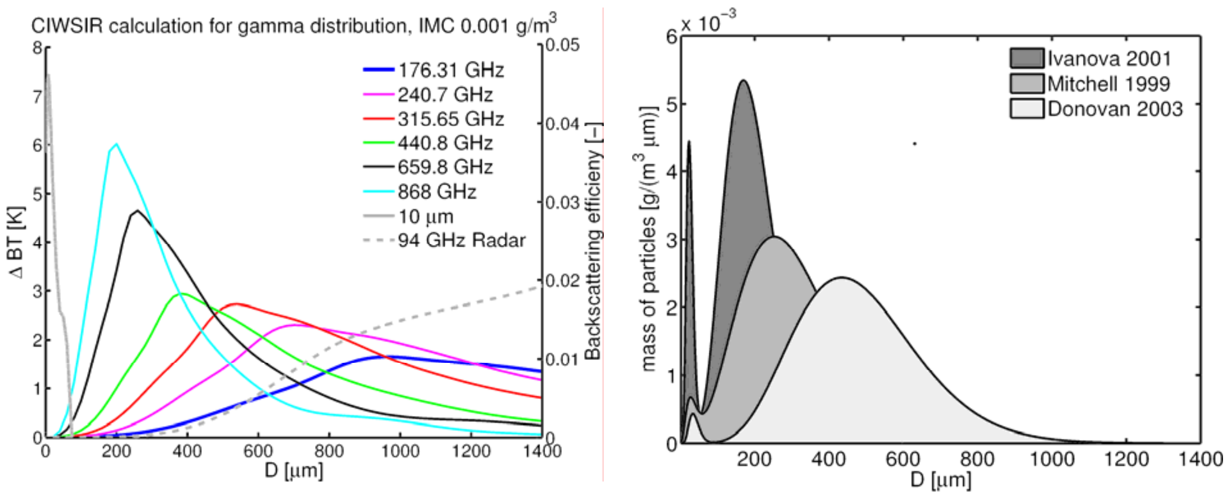


Figure 1.4: Left plot: The sensitivity of measurements at different frequencies to particle size. To generate this figure, a fixed amount of cloud ice (0.001 g/m²) was put into narrow size distributions with different D. For each D the difference between clear-sky and cloudy radiance is displayed. For comparison, the two grey curves show the size sensitivity for IR radiances at 10 µm (solid), and for radar backscatter measurements at 94 GHz (dashed). The right axis is for the radar curve, the left axis for all other curves. Right plot: Three typical ice particle size distributions from the literature (mass per size bin).

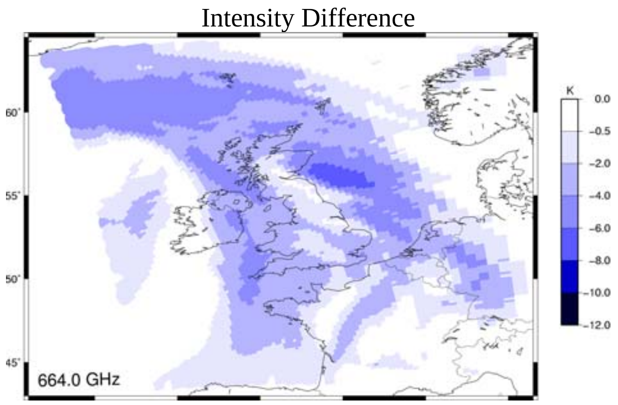
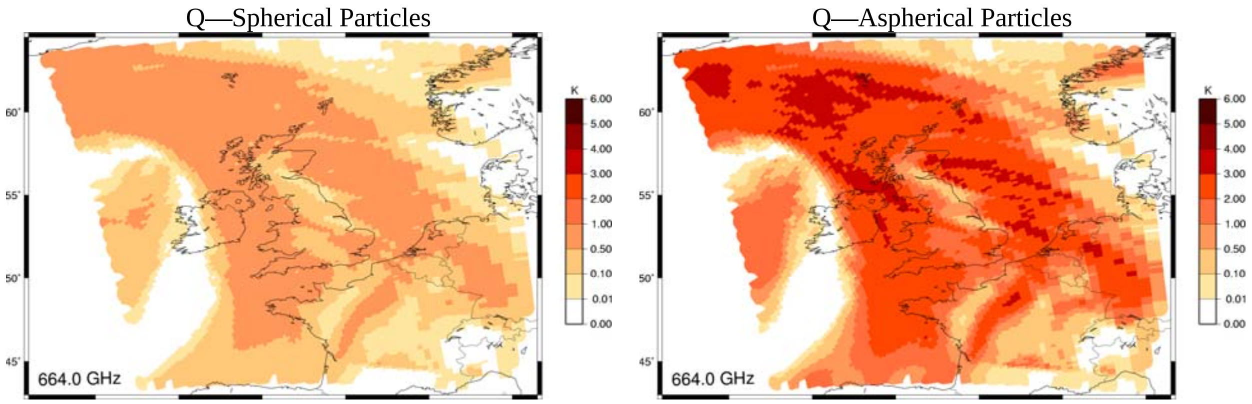


Figure 1.5: Comparison of ice cloud signal for spheres and horizontally oriented oblate spheroids with aspect ratio 1.5 at 664 GHz. The assumed size distribution in both cases was that of McFarquhar and Heymsfield [1997], the viewing angle was 45°, the frequency 664 GHz. Left: Difference in intensity (first Stokes component). Compared to the absolute value of the cloud signal (compare Figure 1.4) the differences are not very large. Middle: Q (second Stokes component) for spherical particles. Right: Q for the oriented aspherical particles.



1.4 Summary of CIWSIR Objectives

The objective of the proposed CIWSIR mission is to obtain global data on the fundamental parameters of ice clouds, their ice water path and the characteristic size of the ice particles. These are the most basic and therefore most urgently needed parameters of ice clouds 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.

2 Characteristics

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.

In particular, two ESTEC studies are important in this context: the study ‘Development of a Radiative Transfer Model for Frequencies between 200 and 1000 GHz’ (contract No. 17632/03/NL/FF), which is already well on its way, and the study ‘Establishment of Mission and Instrument Requirements to Observe Cirrus Clouds at Sub-millimeter Wavelengths’ (contract No. 19053/05/NL/AR), which has just started on July 1, 2005. These studies will be henceforth referred to as ESA_RT study and ESA_SUBMM study, respectively.

2.1 Observational Requirements

Table 2.1: Summary of observational requirements. See text for explanations.

Parameter	*Threshold*	*Target*
Observation time period	1 year	5 years
Coverage	near global in 2 days	global in 1 day
Spatial resolution	20 km	10 km
IWP accuracy	50%	20%
IWP range	50-3000 g/m^2	1-3000 g/m^2
D accuracy	50%	25%
D range	50-500 µm	20-700 µm

The observational requirements of CIWSIR follow from the missing measurements summarized in Section 1.2.4, and are summarized in Table 2.1. GCM validation requires IWP measurements with global coverage. The threshold requirement is near global coverage in two days, the target is global coverage in one day. The horizontal resolution must be consistent with the expected GCM resolution at the time of launch and with other operational meteorological satellite data. We estimate the threshold resolution to be 20 km, and the target resolution to be 10 km. The threshold mission duration is one year, in order to cover at least one yearly cycle. The target mission duration is five years for better statistics.

According to Ohring et al. [2004], IWP has to be measured to an accuracy of 25% for climate monitoring purposes. We therefore define the target accuracy for CIWSIR IWP measurements as 20% with a threshold accuracy of 50%, which is still a factor of 2 better than what can be achieved with EarthCARE. From mesoscale models and aircraft campaigns, we know that IWP has a very large dynamic range of approximately 1-3000 g/m^2. It is important that CIWSIR covers the medium to thick clouds. IR sensors like TOVS, AIRS, or IASI can provide IWP information for clouds of up to 90 g/m^2. The lower end of the CIWSIR dynamic range is therefore not so critical, but it is desirable to have a large overlap with the range of IR techniques. From these considerations we derive a threshold dynamical range of the IWP measurement of 50-3000 g/m^2, and a target range of 1-3000 g/m^2, where it is clear that at the lower end of the dynamical range relative errors will significantly increase. Very thin ice clouds of less than a few g/m^2 may also play an important role for the climate and for atmospheric chemistry, but they are not part of the CIWSIR science objective.

For *D* the accuracy requirement is more difficult to quantify, but we estimate that the threshold where size information would be useful is also at an accuracy of 50%, and the target at 25%. From in-situ measurements we know that the dynamic range of *D* is approximately 50 to 600 µm.

The measurements should preferably be taken at approximately fixed local times, to avoid aliasing of the diurnal cycle of ice clouds.

2.2 Mission Requirements

2.2.1 Channel Set and Radiometric Requirements

As explained in Section 1.3.3, measurements at several frequencies are needed to sample the ice particle size distribution. Figure 2.1 shows the positions and widths of the proposed CIWSIR channels relative to radiation spectra for clear-sky and cloudy conditions. A summary of channel positions and radiometric requirements can be found in Table 2.2. These radiometric requirements are driven by the need to detect the cloud signal over the radiometric noise. Because of the increase of the cloud signal with frequency, somewhat higher noise can be tolerated at high frequencies.

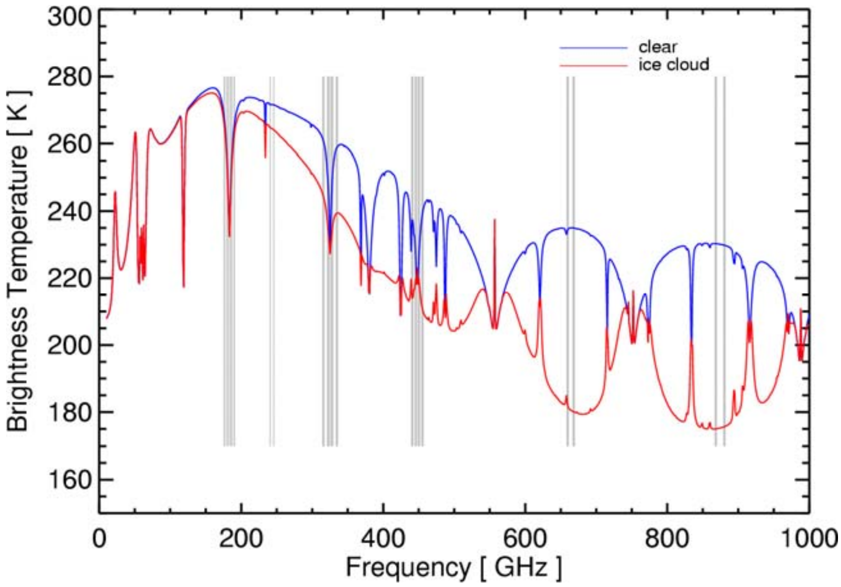


Figure 2.1: The sub-mm spectrum of a clear-sky and a cloudy midlatitude-winter atmosphere with bars indicating the positions of the CIWSIR channels. Assumed was a homogeneous cloud from 8 to 10 km with an IWC of 0.04 g/m^3, consisting of spherical ice particles with 100 µm radius.

The validity of these requirements was confirmed by retrieval simulations, which are discussed in Section 2.4. It is planned to refine the channel positions and radiometric requirements by detailed retrieval simulations within the ongoing ESA_SUBMM study.

2.2.2 Formation with MetOp

As described in Section 1.3, simultaneous IR data are needed to sample the smallest ice particles and thin cirrus clouds. In principle, there are two options to achieve this, a dedicated CIWSIR IR radiometer, or a tandem flight with an existing satellite with IR channels. CIWSIR will follow the second option and fly in tandem with MetOp. The IR data will be provided by the AVHRR/3 and IASI instruments on MetOp. The co-registration of the data will be done in the data processing chain. The high resolution AVHRR/3 data (1.1 km resolution at nadir) can relatively easily be mapped to the larger CIWSIR pixels and will additionally provide an estimate of the sub-CIWSIR-pixel cloud inhomogeneity. The mapping of the coarser resolution IASI data (12 km resolution at nadir) to the CIWSIR pixels will be more difficult, but will provide added value for scientific studies of not too inhomogeneous cloud types, such as large scale cirrus.

The combination with MetOp has the important additional advantage that the full meteorological sensor suite of MetOp can be used to provide ancillary data for the IWP retrieval and for scientific studies with the CIWSIR data. Particularly useful will be the humidity and temperature data from MHS and IASI, as well as data on cloud top altitude and cover from AVHRR/3.

2.2.3 Orbit and Scan Characteristics

The orbit requirements are driven by the need for simultaneous MetOp data. The cloud scene at 15 km resolution should not change significantly between the MetOp and the CIWSIR measurement, leading to a threshold time difference between the two measurements of 10 minutes and a target time difference of 1 minute.

As shown in Section 1.3, scattering by ice particles introduces polarization effects. It is therefore necessary to observe at a fixed Earth incidence angle and with fixed polarization characteristics. These requirements can be met by a conical scanner. The scan angle has to be a compromise between achieving good coverage (favors large Earth incidence angles) and avoiding too high atmospheric opacity (favors small Earth incidence angles). The exact value is not very critical, since opacity changes only slowly for moderate viewing angles. A good compromise is an Earth incidence angle of approximately 53°, which is also consistent with other conically scanning satellite instruments. The coverage requirements defined in Section 2.1 can be met with such a sensor. It will be checked within the ongoing ESA_SUBMM study whether a slightly higher or lower viewing angle has any significant advantage.

2.2.4 Summary of Mission Requirements

Table 2.2 summarizes the requirements discussed in Sections 2.2.1 to 2.2.3. How they can be realized technically and programmatically is discussed in Section 3.

Table 2.2: A summary of the most important mission requirements.

Parameter			*Threshold*	*Target*
Mission duration			1 year	5 years
Time difference to MetOp observation			10 min.	1 min.
Earth incidence angle			fixed, between 40° and 60°	
Footprint size			20 km	10 km
Channels			*Radiometric Sensitivity*	
No.	Frequency	Pol.		
1	183.31±1.5 GHz	V	2 K	0.5 K
2	183.31±3.5 GHz	V	2 K	0.5 K
3	183.31±7.0 GHz	V	2 K	0.5 K
4	243.2±2.5 GHz	V	2 K	0.5 K
5	325.15±1.5 GHz	V	2 K	0.5 K
6	325.15±3.5 GHz	V	2 K	0.5 K
7	325.15±9.5 GHz	V	2 K	0.5 K
8	448±1.4 GHz	V	2 K	0.5 K
9	448±3.0 GHz	V	2 K	0.5 K
10	448±7.2 GHz	V	2 K	0.5 K
11	664±4.2 GHz	H+V	3 K	0.5 K
12	874.4±6.0 GHz	H+V	3 K	0.5 K

2.3 Synergies with other Missions

CIWSIR is synergistic to MetOp, because it effectively adds important additional meteorological parameters (IWP, *D*) to the list of meteorological MetOp products. It is also synergistic to geostationary sensors such as Meteosat Second Generation (MSG), because the accurate twice-daily IWP and *D* data of CIWSIR can be used to calibrate MSG ice parameter retrieval algorithms, thus improving the knowledge on ice clouds also on the high resolution time scale of MSG observations. These synergies make CIWSIR useful for operational meteorology, such as numerical weather prediction (NWP), although NWP is not the primary goal of the CIWSIR mission. The strong interest of meteorological agencies in the CIWSIR data is demonstrated by the letters of support in the appendix.

Scientifically, CIWSIR will significantly extend the CLOUDSAT mission, which is scheduled for autumn 2005, and the EarthCARE mission, which is scheduled for 2012, one year before CIWSIR. These missions with active sensors are designed to drastically improve our knowledge on clouds by providing spot-samples of cloud profiles. They are expected to decrease the current large uncertainty in the global climatology of cirrus IWP down to a remaining uncertainty of approximately a factor of two [Poiares Baptista, J. P. V. and Leibrandt, 2001; Stephens et al., 2002]. The CLOUDSAT and EarthCARE data on cloud occurrence and cloud properties will be important inputs to the operational CIWSIR retrieval algorithms.

CIWSIR itself will extend the knowledge of ice clouds by pushing the uncertainty in the global IWP climatology down to approximately 25% and by providing global data with a resolution and coverage suitable for direct comparison to GCMs and to other meteorological satellite data.

Thus, CIWSIR will provide the means to carry the results from process studies with CLOUDSAT and 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 sub-mm sensor, due to its global coverage and high spatial resolution.

2.4 Retrieval Simulations

Data analysis techniques (radiative transfer and retrieval) for the CIWSIR sensor have been refined within the ESA_RT study. 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.

Three different types of retrieval algorithms can be used for the CIWSIR data analysis: Bayesian interpolation, neural networks, and variational methods, such as optimal estimation (OEM, also called 1D-var), 3D-var, or 4D-var. The first two types of algorithms rely on a training database containing a large number of atmospheric states, their IWP and *D*, and their associated sub-mm radiances, simulated by a radiative transfer (RT) model.

In Bayesian interpolation the retrieved IWP and *D* are found by computing a mean of the IWP and *D* values in the database, weighted by the distance of the measurement from each simulated measurement, employing Bayes' theorem. The method is described in detail in Evans et al. [2002].

In neural network retrieval methods, the database is used to train the net. This consists in estimating the parameters of a function that approximates the mapping between radiances and cloud parameters. Training the neural network requires some time, but then the retrievals are faster than the retrievals with the Bayesian interpolation method. If the neural network is properly set up and trained, it will give similar results to a Bayesian interpolation, as the neural network will also give the average a posteriori solution [Bishop, 1995].

In contrast to the above two methods, which are basically Monte Carlo methods (they use a set of random atmospheric states for training), variational methods such as OEM and 3D-var are analytical, and require RT algorithms that can supply Jacobians or at least adjoints together with the simulated radiances.

For a statistical assessment of the CIWSIR performance for a wide range of different atmospheric states, the Bayesian interpolation method is best suited. Figure 2.2 shows some simulation results. In each simulation the training database contained 10^6 cases and the test database was independent of the training database and contained 10^4 cases. The left column of the figure shows the estimated performance for IWP for tropical (top) and midlatitude winter (bottom) conditions. Shown is the median of the absolute value of the relative error for each IWP bin. The median absolute error is preferred here over the mean, because the retrieval error statistics are not Gaussian. The right column of the figure shows the same for the size *D*.

In Figure 2.2 two separate curves are shown: the performance of the 12 channel CIWSIR set alone, and the performance with added AVHRR/3 channels at 10.8 and 12.0 µm. For the IR channels a noise of 0.12 K at 300 K scene temperature was assumed, consistent with MetOp documentation. For the CIWSIR channels a noise increasing from approximately 1 K for the lowest channels to approximately 2 K for the highest channels was assumed, consistent with the CIWSIR instrument performance estimate in Section 3.1.4. The simulations confirm that CIWSIR can meet the observation requirements defined in Section 2.1. More detailed retrieval simulations will be carried out in the framework of the ESA_SUBMM study.

The basic validity of the retrieval algorithm has already been demonstrated with sub-mm aircraft radiometer data during the CRYSTAL-FACE campaign [Evans et al., 2005]. Additionally, we suggest to verify the performance of IWP and *D* retrieval from sub-mm measurements by dedicated campaigns with existing aircraft-borne instruments. More details about this can be found in Section 4.1.3.

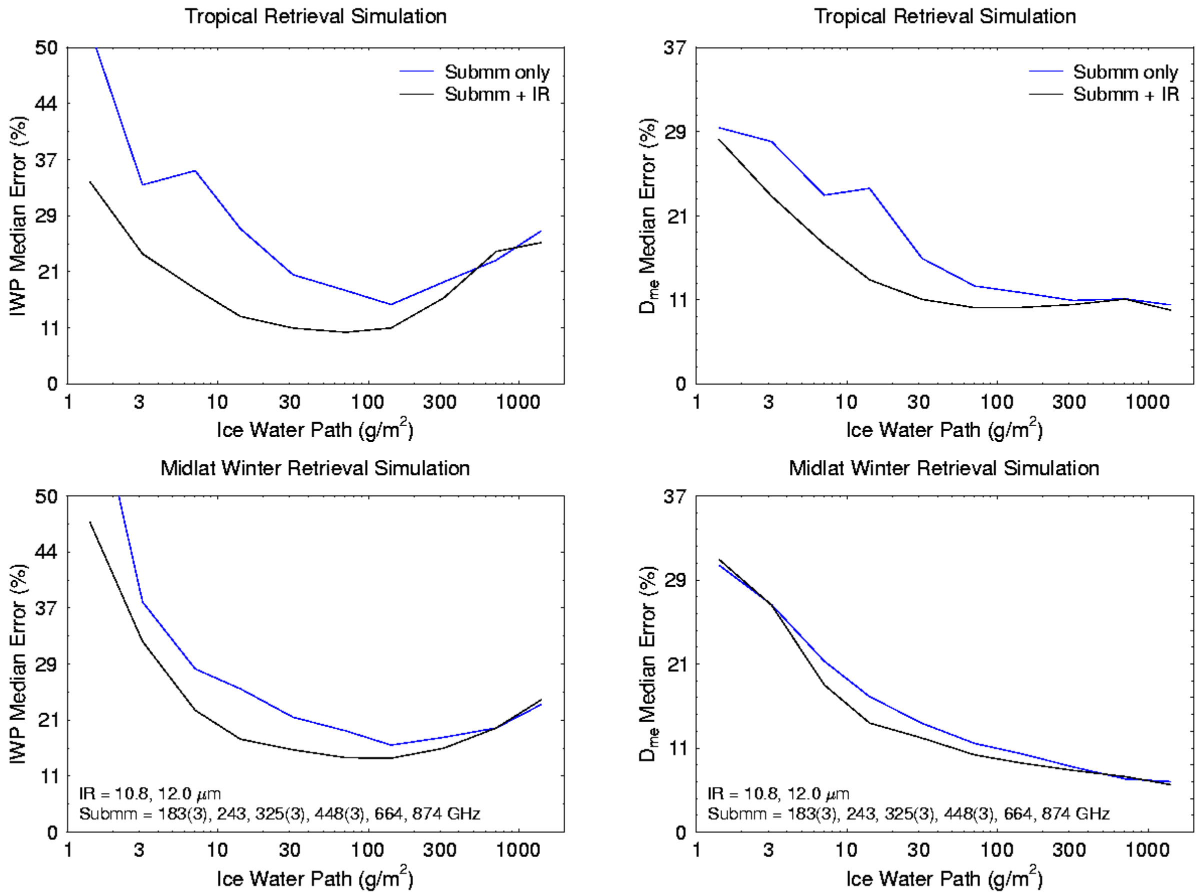


Figure 2.2: Simulated Bayesian interpolation retrieval performance as a function of IWP. Left column: Retrieval performance for IWP for tropical (top) and midlatitude winter (bottom) atmospheric conditions. Right column: The same for D for tropical (top) and midlatitude winter (bottom) atmospheric conditions. Separate curves show performance with and without added IR channels from MetOp.

3 Technical Concept

3.1 Instrument

3.1.1 Instrument Requirements

The key radiometric requirements for the instrument are presented in Table 2.2. The instrument is a conical scanner with a nadir offset angle of ~45° to give the required Earth incidence angle at the proposed orbit height. A reflector aperture of 300 mm is needed to provide a footprint size of ~15km. A scan rate of ~20 rpm provides 20% overlap for footprints in the along track direction.

3.1.2 Instrument 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 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 (FSS) 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. 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 within the instrument enclosure.

The receivers cover a wide spectral range of microwave frequencies and different technologies are required for the different ranges. For example, at 183 GHz, 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 450 GHz, 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.

The mechanism subsystem includes two critical functions, the instrument scanning and the transfer of power and signals between the static and rotating parts of the instrument. These 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.

3.1.3 Technologies and Heritage

Table 3.1 lists the critical technologies for the instrument and states their heritage. A number of technology development programs are required, all of which can be completed successfully within the proposed schedule.

3.1.4 Predicted Performance and Compliance

The predicted performance of the instrument is summarized in Table 3.2 and exceeds the threshold requirements in all areas. The mass of the instrument is 60 kg including 20% contingency, and the power consumption is less than 90 W including 20% contingency. The average data rate is less than 25 kbit/s.

Table 3.1: Technology heritage summary

Subsystem	Component	Heritage	Comments
Antenna	FSS	sub-mm wave FSS elements developed by Cardiff University for Planck HFI. mm wave FSS elements developed by Queen's University, Belfast	
	Horns	Corrugated and Potter feedhorns available from Thomas Keating, RAL etc	Have been developed for e.g. Herschel HiFi
Receiver	sub-mm wave mixers	Planar mixers are used on EOS-MLS on Aura at 649 GHz and 2.5THz	European technology is less mature than US technology so appropriate development programmes are required
	mm-wave mixers	European mixers have been qualified and flown on MHS and HSB. Commercial devices are available at frequencies to at least 500 GHz	All mixers to date use diodes from US, however, some European developments are underway or are planned
	local oscillators	DRO and multiplier LO chains demonstrated by e.g. Chalmers University	Some further development and qualification may be required for highest frequencies
Mechanisms	Scan mechanism	Breadboard design produced for MIMR. Current developments underway for ESA	Scan rate and mission lifetime are not demanding
	Power and signal transfer device	Currently advanced contactless designs are being developed and breadboarded for ESA	

Table 3.2: Estimated instrument performance.

Centre Frequency (GHz)	Bandwidth (GHz)	NeΔT (K)	Radiometric Accuracy (K)	Polarization	Footprint (km)	Co-registration (km)	Beam Efficiency (%)	Cross-Polar (dB)
183.31 ± 1.5	1.4	1.2	1	V	15±0.05	0.5	95	-25
183.31 ± 3.5	2.0	1.0	1	V	15±0.05	0.5	95	-25
183.31 ± 7.0	3.0	0.8	1	V	15±0.05	0.5	95	-25
243.2 ± 2.5	3.0	1.1	1	V	15±0.05	0.5	95	-25
325.15 ± 1.5	1.6	1.4	1	V	15±0.05	0.5	95	-25
325.15 ± 3.5	2.4	1.2	1	V	15±0.05	0.5	95	-25
325.15 ± 9.5	3.0	1.1	1	V	15±0.05	0.5	95	-25
448 ± 1.4	1.2	1.7	1	V	15±0.05	0.5	95	-25
448 ± 3.0	2.0	1.4	1	V	15±0.05	0.5	95	-25
448 ± 7.2	3.0	1.2	1	V	15±0.05	0.5	95	-25
664 ± 4.2	3.0	1.3	1	H & V	15±0.05	0.5	95	-25
874.4 ± 6.0	3.0	2.1	1	H & V	15±0.05	0.5	95	-25

3.2 System

In the frame of this proposal a first iteration of the system design has been performed. The most important system aspects are addressed below.

3.2.1 System Requirements

As outlined in section 2.3 the orbit definition of the CIWSIR spacecraft is driven by the need for synchronous MetOp data. Therefore, a tandem formation with MetOp is envisaged, leading to the same principle orbit parameters (800 km altitude, sun synchronous orbit (SSO), 9.30 h LTDN). The time difference between the MetOp and the CIWSIR measurements shall be lower than 1 minute (target). CIWSIR can fly either before or after the MetOp satellite. The CIWSIR satellite needs to provide a platform for a rotating instrument. This requires a compensation of the angular momentum of the moving mass (around 60 kg).

3.2.2 Satellite Concept

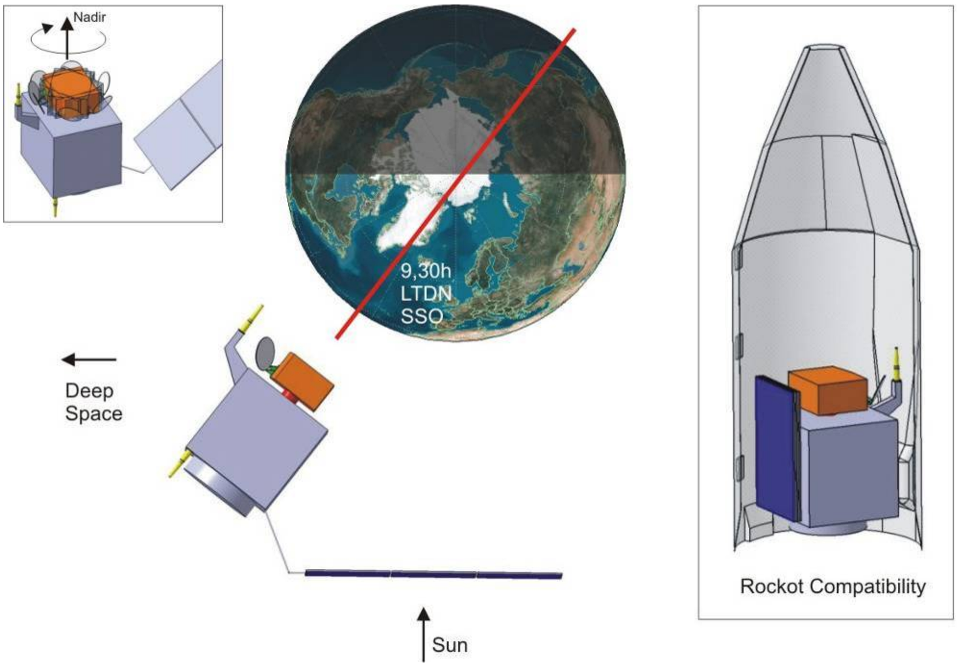


Figure 3.1: Exemplary configuration including compatibility with Rockot fairing envelope.

The sun synchronous orbit leads in a first iteration to a solar array configuration similar to MetOp with a single wing rotating solar array which is during the illuminated part of the orbit always optimal oriented towards the sun (see Figure 3.1). A first power budget calculation leads to an effective solar array size of around 5 m². An optional implementation of a body fixed and consequently larger solar array can also be envisaged.

The orbit also offers due to its SSO characteristic a dedicated deep space field of view. This ensures that the instrument sees deep space once per scan cycle.

The pointing accuracy requirements for the attitude and orbital control subsystem (AOCS) are moderate. Formation flying with MetOp will have a limited impact on the orbit maintenance strategy and needs to be reflected within the propellant budget. Nevertheless, it appears to be not of specific criticality for the system design apart from the compensation of the disturbances introduced by the rotation of the instrument. Those disturbances require a compensation of the angular momentum. This could be achieved by an additional rotating mass at the instrument mechanism leading to a higher degree of complexity. Alternatively, a momentum wheel within the spacecraft bus can be used which is either controlled by the instrument itself or by the AOCS. In any case the control has to be performed in a closed loop with the instrument. Those aspects have already been studied and found feasible within the EGPM and MIMR mission studies.

The thermal control of the spacecraft for the defined SSO is considered to be standard and successfully implemented in various Earth observation missions. The instrument radiators are currently foreseen to be nadir looking. This appears to be sufficient as the power requirements for the instrument are moderate. Additional radiation capabilities are provided towards deep space.

Due to the relatively low data rate of the instrument (around 25 kbit/s), payload as well as spacecraft TT&C data can be transferred via a single S-Band link assuming Kiruna as a ground station. The nadir-oriented antenna is accommodated on a support bracket to ensure spherical coverage. The antenna does not protrude within the instrument field of view.

A preliminary mass budget has been calculated leading to a launch mass of around 650 kg including maturity factors and 20% system margin. This supports the optional launch with various so-called low cost launchers like Rockot, Vega, Cosmos, Angara 1.1. Dnepr is in the first iteration not feasible as it does not provide the required performance into the 800 km orbit. However, it could be feasible if additional orbit transfer capabilities are provided by the spacecraft bus. An exemplary accommodation within the Rockot fairing is depicted in Figure 3.1.

3.2.3 Ground Segment

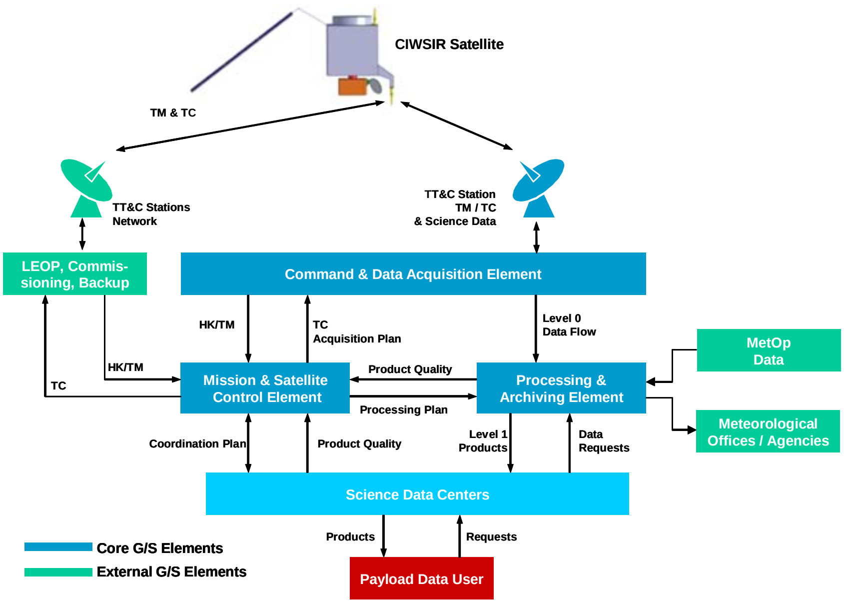
The ground segment for the CIWSIR mission will be based on the standard ESA ground segment elements offering mission planning and operations (Mission Operations and Satellite Control Element, MSCE), satellite data acquisitions (Command and Data Acquisition Element, CDAE), and data processing and archiving (Processing and Archiving Element, PAE). It shall also provide a suitable interface to the science data users (Science Data Centre, SDC). The overall goal is that the ground segment shall be designed to minimize operation costs.

For the MSCE the ESA/ESOC facilities are assumed, while the CDAE will make use of the facilities in Kiruna, supported by the standard LEOP ground segment during the launch phase. Due to the low data rate of CIWSIR, it is possible to employ for the data downlink the 1 Mbit/s standard S-Band downlink. Within the PAE, here ESRIN is assumed, the following CEOS compliant definitions of data level and products will be generated:

- Level 0 data products: unprocessed payload data in chronological order at full space/time resolution with all supplementary information to be used in subsequent processing (e.g. orbital data, health, time conversion, etc.) appended.
- Level 1 data products: pre-processed geo-located payload data in chronological order at full/time resolution with all corrections (geometric, radiometric, etc.) appended.

Due to the fact that CIWSIR will make use of co-located MetOp data, it is assumed that the IASI and AVHRR Level 1 data will be forwarded from the MetOp ground segment to the CIWSIR PAE. It is further assumed, that the Level 1 data can also be provided to European meteorological weather services. The processed and archived CIWSIR Level 1 data products will be made available to the SDC for higher level data product generation (Level 2 and higher), i.e., fully processed geo-located geophysical products. The archiving facilities shall allow data retrievals for up to ten years after launch. User access to the data archive shall be provided via existing links like the Internet (World Wide Web) or off-line (other media), depending on the amount of data. Figure 3.2 gives an overview over the CIWSIR ground segment structure.

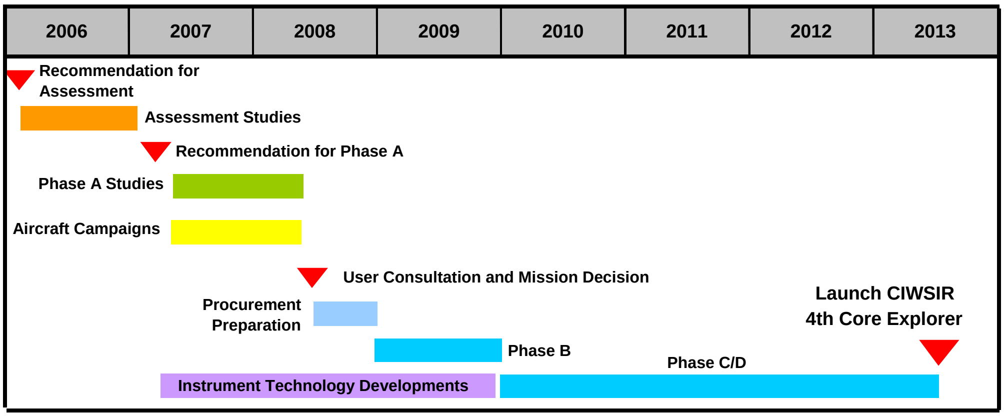
Figure 3.2: CIWSIR ground segment, composed of standard ESA/ESOC elements to minimize overall ground segment procurement and operations costs.



4 Programmatics

4.1 Schedule

Figure 4.1: CIWSIR mission selection procedure and programme development.



As stated in the ESA Earth Explorer Call, the 4th Core Explorer shall be selected by undergoing an assessment phase for further evaluation of the technical concept. After a second selection procedure, three missions will be proposed for Phase A. These Phase A studies are assumed to be performed in 2007/2008, followed by a user consultation meeting in mid 2008 to finally select the 4th Core Explorer. Based on this schedule, the overall Phase B-C/D planning is shown below with a typical duration of 4.5 years, allowing to launch CIWSIR in mid 2013. This schedule will enable the development of the necessary instrument technologies, which are described in the next section. For these activities, basically 2 to 3 years are available, assuming that Phase C/D starts at the end of 2009. Figure 4.1 gives a graphical summary of the proposed CIWSIR mission schedule.

4.2 Instrument and Platform Development Needs

For the instrument, the following development needs have been identified: mixers and mixer diodes, local oscillators for the higher frequency channel receivers, and the scan mechanism and power and signal transfer device. The latter are currently the subject of an ongoing activity by the Agency.

For the single instrument platform, it is assumed that the standard bus equipment can be procured on a COTS basis, while for the large rotating mass of the instrument momentum-compensation and dynamic balancing is required. The feasibility of momentum-compensation using the satellite reaction wheel was investigated and found feasible within the ESA EGPM Phase A study. It can therefore be concluded, that the CIWSIR platform is generally feasible and that the foreseen assessment studies will allow to identify early enough, whether dedicated developments are necessary before initiating the Phase B.

4.3 Aircraft Campaigns

We propose to verify the performance of IWP and *D* retrieval from sub-mm measurements by dedicated campaigns with existing aircraft-borne instruments. This requires simultaneously (a) in-situ measurements of IWC and particle size distribution, and (b) sub-mm radiance measurements above the clouds. To achieve this, two aircraft are needed: one flying inside the clouds, one flying above the clouds. Details of two available sub-mm aircraft radiometers are summarized in Table 4.1. Both instrument teams have expressed their interest in participating in CIWSIR pre-flight campaigns. Also, both teams currently make efforts to further extend the capabilities of their instruments at high frequencies. For CoSSIR it is planned to replace the three 487 GHz channels by a 640 GHz dual polarization channel and an 874 GHz channel. For PSR-S it is planned to replace the set of three 380 GHz channels by a set of five 380 GHz channels.

For the simultaneous in-situ measurements several of the existing airborne ice particle sensors can be used (see Section 1.2.1). The CIWSIR associated scientists include experts on sub-mm aircraft measurements and experts on aircraft in-situ cirrus measurements. In this context it is also of interest that a new high altitude and long range research aircraft (HALO) is planned to be available in Germany from 2008. This will open very good opportunities for CIWSIR validation campaigns during the mission flight.

Table 4.1: A summary of available sub-mm aircraft radiometers and their main features.

Radiometer	*Location*	*Responsible*	*Channels [GHz]*	*Platform*
CoSSIR	GSFC, Greenbelt, Md., USA	J. Wang	183 H (3x) 380 H (4x) 487 V, H (3x) 640 H	ER-2
PSR-S	NOAA-ETL, Boulder, Co., USA	A. Gasiewski	183 V (7x) 340 V, H, U 380 V (3x) 425 V (5x) 500 10 µm IR V,H	P-3, DC-8, ER-2, WB-57, Geophysica

4.4 Cost Estimates

Table 4.2 presents rough order of magnitude (ROM) cost estimates for the main mission elements based on 2005 economic conditions. Development program costs include the development of the receivers, the scan mechanism, and the power and signal transfer device for the instrument. The platform and launcher cost estimates have been provided by EADS Astrium GmbH, and are based on the assumption that Astrium acts as prime contractor for the manufacturing and procurement of the entire satellite, while the instrument will be manufactured and provided by a subcontractor. It includes prime management, PA, system engineering, as well as platform and instrument AIT activities for Phase B&C/D. It also includes procurement costs of all platform hardware elements, as described in Section 3.2. In Table 4.2, indicative costs have also been included for the launcher and for the aircraft campaigns during phase A. Ground segment costs are not given, but will be determined during phase A. The table shows that CIWSIR can be realized well within the 300 M€ budget that was indicated for the mission call.

Table 4.2: ROM cost estimates.

Element	*Cost estimate*
Development program and breadboards	15 M€
Instrument C/D	70 M€
Platform C/D	65 M€
Launcher (e.g., Rockot)	15 M€
Ground segment	standard ESA ground segment
Aircraft campaigns	5 M€

5 Relevance to Evaluation Criteria

5.1 Research Objectives of the Earth Explorer Program

The proposed mission addresses several research objectives of the Earth Explorer Program. It contributes to theme 2 'physical climate' and theme 4 'anthropogenic impact'. Within theme 2 it specifically closes an important gap in our knowledge of the hydrological cycle, and of the atmospheric radiation balance. Within theme 4, the first accurate global observations of IWP and *D* by CIWSIR will allow us to validate and improve GCMs and thus to improve climate predictions.

5.2 Need, Usefulness and Excellence

Measurements of cloud ice water are urgently needed, as explained in Section 1. As demonstrated in Section 2, CIWSIR performs well over the very large dynamical range of IWP. The measurement will be global and with a spatial and temporal resolution consistent with circulation models and established meteorological satellite data. This means that the scientific community can directly use the data without having to get accustomed to exotic data properties. There is a very strong synergy with the meteorological sensor suite on MetOp with which CIWSIR will fly in tandem.

5.3 Uniqueness and Complementarity

CIWSIR will be unique, because there is so far no satellite sensor dedicated to measure cloud ice. The proposed instrumentation of sub-mm radiometers is also unique, although it has strong heritage from limb sounding chemistry instruments. CIWSIR will complement and extend the cloud ice measurements by EarthCARE, as explained in Section 2.3.

There are current activities to measure cloud ice in the sub-mm spectral range in the USA, and a sensor with a concept similar to CIWSIR, called SIRICE, is being proposed to NASA. The science teams of both proposed missions have a well-established collaboration. For example, existing airborne sub-mm radiometers in the US will be available for dedicated CIWSIR campaigns during phase A, as explained in Section 4.1.3.

5.4 Degree of Innovation

CIWSIR will be the first sub-mm satellite instrument for meteorological observations. It can pave the way for future operational meteorological sensors of the same kind, or for a sub-mm sensor on a geostationary platform.

5.5 Feasibility and Level of Maturity

5.5.1 Science

Retrieval capabilities have been demonstrated by simulation studies [Evans et al., 2002] and by using aircraft data [Evans et al., 2005]. Tools for such studies (RT and retrieval algorithms) have been developed in the framework of the ESA_RT study. Possible optimizations of the sensor concept are studied in the ongoing ESA_SUBMM study. The signal of ice clouds in the sub-mm has also been confirmed by data from the limb sounders Odin and EOS-MLS [Davis et al., 2005]. To further increase the confidence in the retrieval capabilities of CIWSIR, dedicated campaigns with existing airborne instruments, accompanied by simultaneous in-situ cloud measurements, are proposed to be carried out during phase A.

5.5.2 Technology

All of the required technology development programs are realistic and achievable in the proposed timeframe. For the receiver equipments the required performance has been demonstrated in the US, so it is the development of European technologies that is relevant. Development of the critical mechanism functions is ongoing, based on reliable non-contacting approaches for the transmission of signal and power between the scanning instrument and the spacecraft.

5.6 Timeliness

Scientifically, a flight time shortly after EarthCARE is optimal, so that all experience and science results from EarthCARE can be used for the retrieval and data interpretation. Technologically, sub-mm radiometry has been proven feasible in space by Odin and EOS-MLS. The development of a European sensor using this key technology appears strategically wise at this point in time.

5.7 Programmatics

Compared to other proposed missions, CIWSIR is relatively low cost and low technological and scientific risk. By its synergy with MetOp it provides added value to an already established operational mission. By its scientific complementarity to EarthCARE it can help to maintain or expand the European lead in the important scientific field of cloud research.

5.8 Other Research Programs

The goals of CIWSIR are in-line with the ongoing EU research framework program and with the world climate research program (WCRP). Hence, the mission will contribute significantly to these programs.

6 Industrial Team

Section 3 of this proposal is based on the work of an industrial team, including: Janet Charlton (Sula Systems Ltd, UK), Pat Foster (MAAS, UK), *Mark Jarrett (Sula Systems Ltd, UK), *Manfred Langemann (EADS Astrium GmbH, DE), Dave Matheson (RAL, UK), Thomas Rose (RPG, DE), Reiner Schricke (EADS Astrium GmbH, DE). Lead authors are marked with an asterisk.

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Appendix: Letters of Support

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14 July 2005

Dear Dr. Buehler,

I am writing to offer the strong support of the Met Office for the Cloud Ice Water Sub-millimetre Imaging Radiometer (CIWSIR) proposed by the consortium led by yourself.

Considering the global observing system as a whole, observations of cloud ice water is a major gap. This is recognised by WMO in the context of global and regional NWP and also accurate description of clouds remains one of the key problems identified by IPCC. Current instruments such as the Microwave Humidity Sounder are insensitive to small ice hydrometeors and can not therefore give reliable information on ice water content. CIWSIR would fill this gap and provide information of unprecedented quality on global distribution and variability of ice water content. The mission could also demonstrate the potential of a sub-millimetre instrument in geostationary orbit.

If the mission is approved the Met Office will initiate projects to use the data. In particular the Met Office would

- use the data to evaluate the ice water climatology of global and regional NWP systems
- use the data to study ice cloud processes
- evaluate the feasibility of direct assimilation of such data into 4D-var

In recent years NWP centres and the NWP SAF have invested considerable resources into improving the capability to exploit satellite millimetre and sub-millimetre observations of ice clouds. For example the NWP SAF has extended the radiative transfer model, RTTOV, to simulate cloud affected sub-millimetre radiances and has collaborated with the groups developing the ARTS radiative transfer model. The Met Office is adding an ice cloud incrementing operator to its 4D-var data assimilation system. The Joint Center for Satellite Data Assimilation in the United States has developed several new radiative transfer models for simulating cloudy radiances in the context of the Community Radiative Transfer Model. Therefore the meteorological community not only requires the gap in the global observing system for cloud ice water to be filled but is now in a very strong position to exploit millimetre and sub-millimetre wavelength radiances.

Yours sincerely,

John Eyre
Head of Satellite Applications, Met Office

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Offenbach, 02. August 2005

CIWSIR: Letter of support

Dear Dr Bühler,

we would like to express our strong support for the Cloud Ice Water Sub-millimetre Imaging Radiometer (CIWSIR) proposal.

Considering the satellite component of the Global Observing System (GOS) and its use for climate monitoring purposes cloud ice water information presents a major gap in the present system. Cloud ice water retrievals employing measurements from present operational instruments are limited to either very thin cirrus clouds (infrared instruments) or very thick ice clouds (microwave instruments). CIWSIR is undoubtedly a step forward to fill this gap and to provide information on the global variability of ice water content.

The Satellite Application Facility on Climate Monitoring (CMSAF) has invested considerable resources to intensify the use of satellite radiances for climate monitoring purposes. Cloud macro- and microphysical geophysical products play a key role in climate monitoring because of their coequal importance for the energy budget and the hydrological cycle of the atmosphere. The potential benefit of CIWSIR data for the CMSAF is improving climatological estimates of cloud ice water content and to further investigate the impact of the improved cloud ice information on radiation budget estimates.

Best regards,

Martin Werscheck
(Acting Head Climate Monitoring Department)

Wolfgang Benesch
(Head Remote Sensing Division)

ECMWF European Centre for Medium-Range Weather Forecasts

Europäisches Zentrum für mittelfristige Wettervorhersage • Centre européen pour les prévisions météorologiques à moyen terme
Europees Centrum voor weervoorspellingen op middellange termijn • Centro europeo per le previsioni meteorologiche a medio termine

9499005

10 August 2005

Our ref: R57.5.2/PB/0524

Dr. Stefan Buehler
Institut für Umweltphysik (IUP)
Universität Bremen
Otto-Hahn-Allee 1
28359 Bremen
Deutschland

Dear Dr. Buehler

I want to express the interest of ECMWF for the Cloud Ice and Water Sub-millimetre Imaging Radiometer (CIWSIR) mission which you are in the process of proposing as an Earth Explorer Core Mission to be funded by the European Space Agency (ESA).

The major mission objective of ice cloud monitoring as well as the retrieval of ice cloud microphysical properties from space represents a fundamental requirement of present and future Numerical Weather Prediction (NWP) systems. The physical processes involved in ice cloud formation are not well known and the model parametrizations of formation processes and ice cloud optical properties are extremely simplified in current modelling systems. A global observing system that complements measurements of liquid and mixed-phase clouds and precipitation would greatly enhance our understanding of cloud processes and lead the way for the implementation of improved physical parametrizations in NWP models.

ECMWF has participated in several projects that focus on the validation of cloud and precipitation forecasts with satellite observations from existing and planned missions such as the Tropical Rainfall Measuring Mission (TRMM), Cloudsat, EarthCARE and the European contribution to the Global Precipitation Measurement (GPM) mission (EGPM). In the long-term, these studies aim at better model analyses, which means better forecast initializations through the introduction of such data into the four-dimensional variational data assimilation system. This has been successfully

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demonstrated by the operational assimilation of rain affected microwave observations since June 28, 2005. Future planning includes the extension towards the assimilation of cloud affected infrared (e.g. Spinning Enhanced Visible and Infrared Imager, SEVIRI) and microwave data (Advanced Microwave Sounding Unit, AMSU-B) which will ultimately lead to ice cloud observations to be provided with good global coverage by sub-millimetre observations from CIWSIR.

Yours sincerely

Philippe Bougeault
Head of Research Department

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KNMI

Koninklijk Nederlands Meteorologisch Instituut

Stefan Bueler
University of Bremen
Otto-Hahn-Allee 1
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Date
August 11, 2005
Our reference
2005/954
Your reference

Contact

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Enclosure(s)

Subject
CIWSIR

Dear Dr. Bueler

I am writing to offer the strong support to you for the proposal on the Cloud-Ice Water-Sub-millimeter Imaging Radiometer.

There is very little if any global information on ice water and ice particles. At the same time we know that their influence on the Global Climate System is very large. The last several IPCC reports have clearly outlined the importance of clouds in the climate system. As you point out in the proposal, ice clouds are quite different from water clouds as they are located in different (higher) layers of the atmosphere and consist of non-spherical particles, thus exorting a substantially different influence on the radiative budget of the atmosphere.

At KNMI, we are involved many satellite mission (such as EarthCare) and both in observational studies of cirrus clouds (at Cabauw) and modelling studies (using our Regional Climate Model, RACMO) that focus on the impact of different parameterisations of cirrus (ice) clouds in climate models. Already we find that small changes in paramaterisations alter the modelled radiation budgets substantially. Furthermore, the data from synergistic radar / lidar observations at Cabauw indicate that the simple cloud ice water versus temperature relationships do not universally hold.

The proposal, as written by you and your consortium, is an excellent and timely contribution to our understanding of the physics and distribution of ice cloud and its microphysical properties. It fills in an important gap in our climate observation system. KNMI would be highly interested to employ the measurements coming from the CIWSIR as a primary link to our climate model outputs. Furthermore, the data would serve as an important addition to our radiation budget closure studies that rely on synergistic remote sensing observations.

Sincerely

Reinout Boers
Head
Atmospheric Research Department
KNMI (Royal Dutch Meteorological Institute)
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UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL ENVIRONMENTAL SATELLITE, DATA
AND INFORMATION SERVICE
Suitland, Maryland 20746-4304

August 12, 2005

Dr. Stefan Buehler
University of Bremen
Otto-Hahn-Allee 1
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Germany

5. SEP. 2005

Dear Dr. Buehler:

I am sending you this letter to express my support to the effort you are leading in proposing the Cloud Ice Water Sub-millimeter Imaging Radiometer (CIWSIR) mission.

Our knowledge of cirrus-cloud ice amounts and characteristics could be greatly enhanced with instruments operating in the sub-millimeter spectral region where sensitivity to cloud parameters is greater. The current sensors can indeed provide information about ice clouds with either small or large particle sizes. The proposed mission would fill the gap by using an innovative and yet mature enough technology, based on sub-millimeter frequencies. CIWSIR will also provide critical information about atmospheric water vapor in the upper troposphere.

NOAA and its affiliated Joint Center for Satellite Data Assimilation (JCSDA) has invested in recent years in the development of a state-of-the-art community radiative transfer model (CRTM) capable of simulating not only radiances (in millimeter, sub-millimeter and IR spectral regions) but also Jacobians and adjoints, necessary to perform data assimilation of cloud/ice/precipitation-impacted radiances, a process that has already begun and is expected to further mature in the coming years. Therefore, we will be looking forward to exploiting CIWSIR measurements in our data assimilation system to assess their impact on NWP forecast skills. CIWSIR-derived measurements will also be very beneficial to climate studies.

Additionally, CIWSIR represents a step toward having a geostationary-based microwave/sub-millimeter sensor that our organization is advocating as a future mission.

Good luck with your endeavor.

Sincerely,

Dr. Fuzhong Weng, Chief
Sensor Physics Branch
NOAA/NESDIS
Office of Research and Applications