A. Cover Page

Cloud Ice Water Sub-millimetre Imaging Radiometer

CIWSIR

Submitted
in Response to the Second Call for Proposals for Earth Explorer Opportunity Missions

by

Klaus Künzi [1])
Institute of Environmental Physics
University of Bremen
Germany

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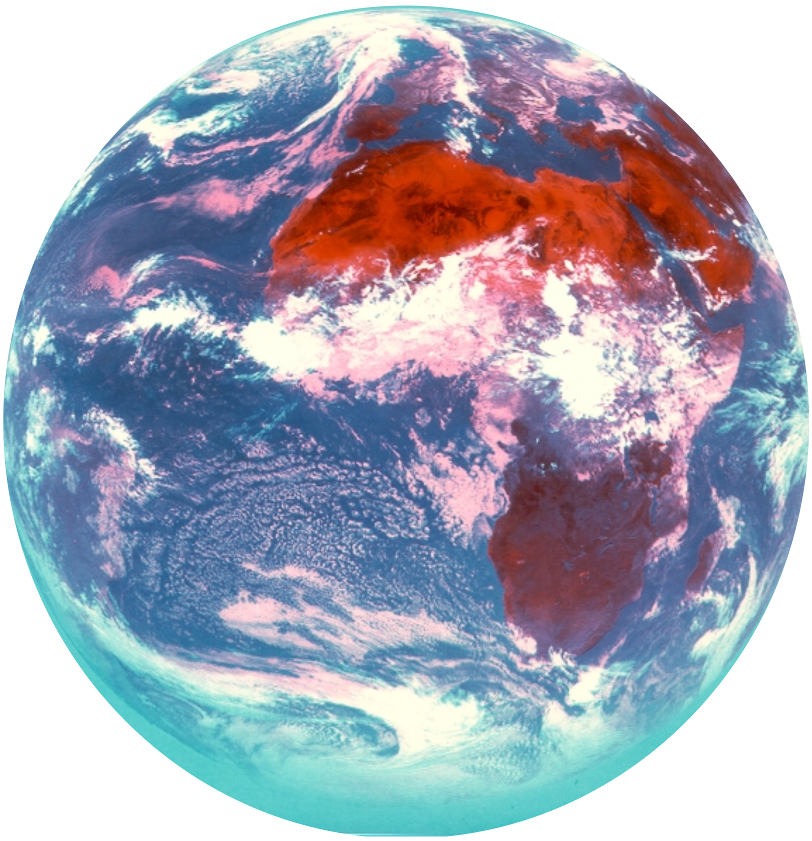
[1]) see note on PI in Annex 1, "Team Composition"



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B. Executive Summary

Atmospheric clouds play an essential role in the earth - atmosphere system for several reasons. Clouds are central for the atmospheric part of the hydrological cycle, they regulate the radiative transfer and hence the primary energy available to the whole earth-system, they have a thermal impact by the release of latent heat, and they affect the chemical composition of the atmosphere. Because of the many interactions in the atmospheric system, clouds are an important factor for weather and climate on broad spatial and temporal scales.

The importance of clouds for climate studies and weather forecast has long been recognised through a number of observational and modelling studies, and is particularly emphasised in the third IPCC-report (2001). This interest in clods is in contrast with the fact that clouds are considered as "one of the least understood components of the weather and climate system" (Liou, 1992, p.172).

Because of the clouds' undoubtedly important role in the global climate and the response of clouds to a potential global climate change, we need to improve our understanding about the microscopic and macroscopic properties by appropriate measuring techniques. These will help to establish a reliable climatology of cirrus clouds and to improve and validate the representation of clouds in numerical models. Only if we can observe globally atmospheric water in the gaseous, liquid, and solid state can we expect to make a step forward in answering important questions like: What will be the effect of a changing cloud cover on climate? Our very limited understanding of clouds and their role in climate is a major reason for the large uncertainty in estimating the mean global warming for a doubling of the CO_2-content, estimated values given in the IPCC-report vary from 2.0 K to 4.5 K (IPCC, 2001).

Especially our present knowledge of cirrus clouds is still insufficient with respect to their role in climate, and how to handle cirrus clouds in GCMs and in numerical weather forecast models. For example, the mean cirrus cover over the U.S. varies from 20 % to 70 % according to various authors considering different sensors. It is important to note that the cirrus ice density necessary to cause strong reflection of incoming solar radiation may be only a few percent of the available ambient water vapour density. Thus, cirrus clouds are a major amplifier of the effects of water vapour on the global energy budget. Missions presently in preparation (CloudSat train in the US) or being considered (EarthCARE in Europe) are addressing this topic. The nadir viewing active instruments (LIDAR and RADAR) to be used in these missions will provide important vertical cloud profiles, but give very limited spatial sampling. Therefore they will have large errors for a climatology of cloud properties at the Global Circulation Model (GCM) grid box scale. In comparison, CIWSIR has a wide swath giving nearly daily global coverage for a statistically representative climatology. To summarize, in addition to the above mentioned active instruments fulfilling a needed "process study" goal, CIWSIR is focused on upper tropospheric ice clouds at the regional scale. Data on this scale is needed for climatological studies, model optimisation, and is highly important in meteorology. The latter application may eventually lead to an operational CIWSIR sensor.

From the large research activities in this area it can easily be seen that a better understanding of ice clouds characteristics and temporal and spatial variability is considered a key research issue in meteorology and climatology. CIWSIR will fill a gap in providing data not available from ground based, air borne or the presently considered space borne instruments.

CIWSIR is a well focused urgently needed mission to improve our knowledge on the ice mass in the atmosphere making use of available sensor technology. The CIWSIR mission is widely supported by scientists active in atmospheric sciences such as meteorology and climatology.

C. Detailed Description of the Proposal[1])

C.1. SCIENTIFIC JUSTIFICATION

C.1.1. Role of Cirrus Clouds in the Atmosphere

The important role of clouds in weather forecast and climate processes has been demonstrated by a number of observations and by modelling studies (e.g. Liou, 1992), and is particularly emphasised in the third IPCC-Report (IPCC, 2001). Of special interest is the impact of cirriform cloud on the evolution of the atmosphere. The term 'cirrus' clouds is meant to comprise all cirriform clouds, which are characterised by a fibrous appearance. Such clouds are found all over the globe and in each season. They are formed in the upper troposphere at altitudes of roughly 5 to 13 km at mid latitudes and somewhat higher and lower in tropical and Arctic regions, respectively. Cirrus cloud formation, evolution, and dissipation are mainly associated with large scale synoptic features and the upper outflow region of deep cumulonimbus (Liou, 1992, p.176). However, our present knowledge of characteristic properties of cirrus clouds with respect to their role in climate to their treatment in GCM's and in numerical weather forecast models is still insufficient. For example, the mean cirrus cover over the U.S. varies from 20 % to 70 % according to various authors considering different sensors (Wylie, 1998).

Cirrus clouds influence the state of the atmosphere by a number of mechanisms. These high clouds absorb long wave radiation emitted below the clouds, and due to their low temperature emit little infrared radiation; this effect results in a general warming of the earth-atmosphere-system. On the other hand, cirrus clouds reflect direct solar short wave radiation hence have a cooling effect. The net impact is crucial for the atmosphere, but will depend highly on the cloud's horizontal extent, vertical position, and ice particle size and shape distributions (Zhang et al. 1999). Thus, the specific properties of cirrus clouds are crucial for radiative processes. Based on radiative transfer calculations for a larger number of observed ice particle size distributions, Schlimme and Macke (2001) have estimated the uncertainties in solar broadband fluxes due to natural variations in the cloud microphysical properties to be as large as 15 to 20 W/m^2. Thus, remote sensing of both the ice water content and the particle size distribution are highly important to improve our understanding of the radiation budget of cirrus clouds. Furthermore, cirrus clouds affect the energy budget by release of latent heat during depositional growth of ice particles, and ice particles, if large enough, sediment through the atmosphere and may enhance precipitation generation in lower clouds by the seeder-feeder mechanism.

C.1.2. State of the Art

C.1.2.1. Cirrus characteristic as derived from surface and airborne in situ observations

In typical textbooks, representative microphysical conditions in cirrus clouds are characterised by a number concentration of 0.03 cm^{-3}, an ice mass per volume of 0.025 g/m^3, and a mean length of 250 µm (e.g. Salby, 1996). On the other hand, in-situ observations generally show that these parameters vary over a wide range so that representative microphysical properties are weakly characterized by observationally derived mean values. This also holds for the vertical distribution, as is illustrated by figure C.1.1 showing the variations in ice particle size and shape as functions of height for given temperature and humidity. It is important to note that the cirrus ice density necessary to cause

[1]) An instrument similar to CIWSIR is also part of the RIGHT payload, a proposal submitted by the PI Bizzarro Bizzarri, Italy, in RIGHT the sensor CIWSIR serves the same purpose as in the CIWSIR project.

strong reflection of incoming solar radiation may be only a few percent of the available ambient water vapour density. Thus, cirrus clouds are a major amplifier of the effects of water vapour on the global energy budget.

Our present knowledge of the microphysical properties of cirrus clouds is based on in situ, RADAR and LIDAR measurements. In-situ observations performed in the last two decades have revealed that the ice water content can vary from less than 10^{-4} g/m^3 to over 10^{-1} g/m^3, and that ice crystals show a large range of sizes from smaller than 20 µm to more than 2000 µm and a great variety in shapes (Heymsfield 1975; Brown 1993; Noone et al. 1993; McFarquhar and Heymsfield 1996; Goodman et al. 1998; Lawson et al. 1998, Heymsfield and McFarquhar 2002). Recent campaign results have been used to parameterise the ice crystal size distribution in terms of the ambient temperature and ice water content (Heymsfield and Platt 1984; McFarquhar and Heymsfield 1997). For tropical cirrus clouds, the parameterisation of McFarquhar and Heymsfield (1997) using the combination of a first-order gamma function describing the size distribution of ice crystals smaller than 100 µm and a lognormal function for larger particles was found to be accurate in estimating ice mass, area and number of particles and in predicting the optical properties of cirrus clouds. The observed shapes of atmospheric crystals frequently show a dependence on ambient air temperature. Heymsfield and Platt (1984) found that at temperatures below –50 °C single crystals are predominant, while in the range from -40 °C to -20 °C complex crystal clusters prevail. Several typical rosettes of the latter are shown in figure C.1.2.

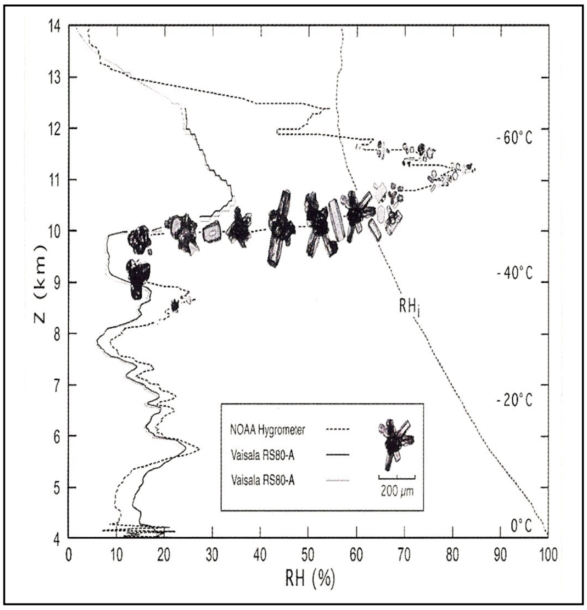


Figure C.1.1. – Altitude dependence of microphysical characteristics of ice crystals from Miloshevich et al. (2001)

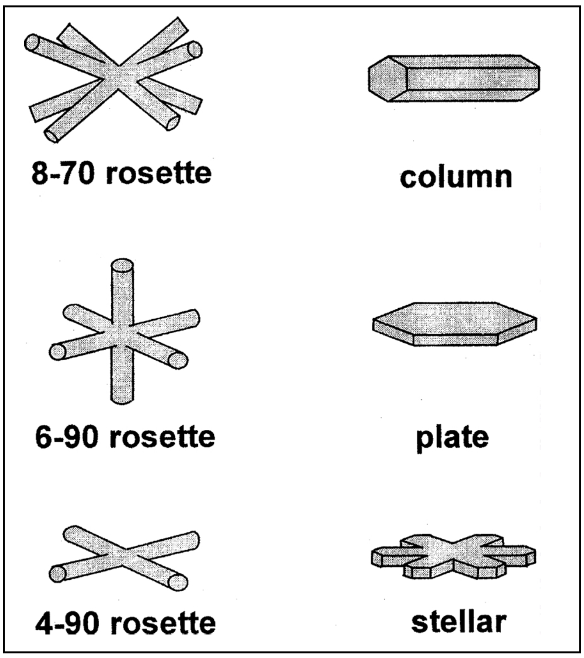


Figure C.1.2. – Typical ice crystal forms, the more complicated rosettes are mainly found for temperatures in the range of -40 °C to -20 °C (Aydin and Walsh 1999)

LIDAR and RADAR have shown their effectiveness in detecting cloud base and top height and in measuring vertical structure of thin cirrus clouds (Sassen 1994; Matrosov 1997). A one-year climatology of cirrus cloud properties has been derived by Mace et al. (2001). It is based on a data set collected by an up-looking millimetre-wave cloud RADAR operated continuously in the Southern Great Plains in Oklahoma. The measurements show that cirrus clouds were present during 22 % of the whole time and had a mean layer thickness of 2 km. They had mean values of IWP of 8 g/m^2, effective radius of 35 µm and an ice crystal concentration of 100 particles per litre. However, all cloud properties showed a high degree of variability. This technique has the major disadvantage that only those cirrus can be observed which are not obscured by lower clouds, and we have to expect this to cause an unwanted bias.

Not only the size and shape of ice crystals are important parameters, but also their orientations has a considerable influence on the radiative properties of cirrus clouds; this has been investigated both experimentally and in radiative transfer models. Observations with ground-based LIDAR (e.g. Thomas et al., 1990) and with airborne measurements (e.g. Chepfer et al., 1998) have shown that some crystals have in general a preferred horizontal orientation. Although the radiative impact of a preferred orientation is difficult to quantify, Shanks et al. (1998) and Chepfer et al. (1998) have shown that the horizontal orientation of ice crystals in cirrus clouds tend to increase the cirrus cloud albedo.

A recent compilation of in-situ ice particle size distributions from various field campaigns (see Tab. C.1.1) demonstrates that the in-situ microphysical properties significantly differ from experiment to experiment and that the correlation of cirrus microphysics with ambient atmospheric conditions is poor. Figure C.1.3 illustrates this situation by showing the effective radius for each size distribution given in table C.1.1 as a function of the air temperature. Hence, it must be concluded that no reliable Climatology of cirrus microphysical properties exists from in-situ measurements, which further emphasises the need for global satellite observations of both ice water content and ice particle sizes.

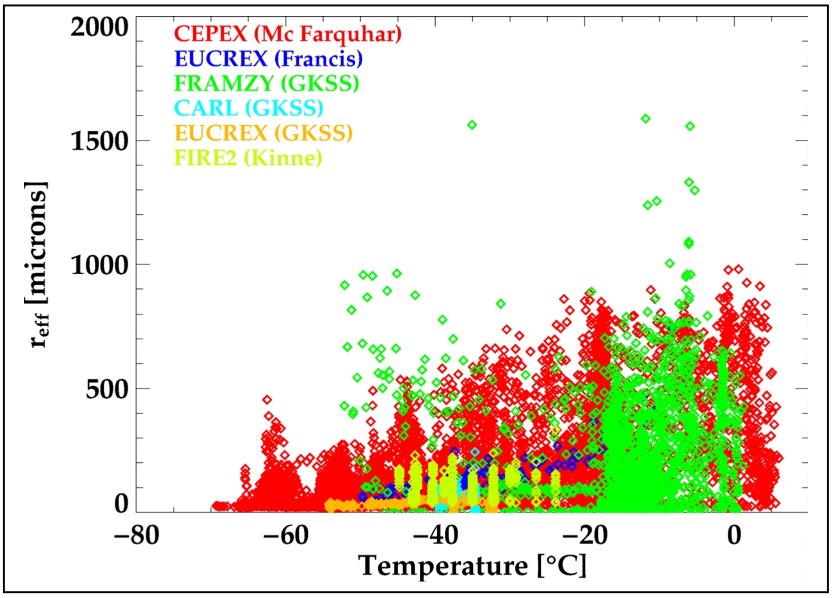


Figure C.1.3 - Distribution of effective particle size over ambient temperature, according to various campaigns. For more information on campaigns see table C.1.1.

Table C.1.1. - Overview of ice particle size distributions used in the compilation of regional cirrus microphysical properties performed in the EC-project CIRAMOSA.
Acronyms of campaigns: CEPEX = Central Equatorial Pacific Experiment, EUCREX = European Cloud and Radiation Experiment, FRAMZY = Cyclones in the Fram Strait and their impact on the sea ice (original acronym in German), CARL = investigation of Clouds by ground-based and Airborne RADAR and LIDAR, FIRE = First ISCCP Regional Experiment.
Acronyms of instruments: ASSP = Advanced Single Scattering Probe, FSSP = Forward Single Scattering Probe, 1DC and 2DC = 1 or 2 Dimensional array to detect clouds, 1DP and 2DP = 1 or 2 Dimensional photodiode array to detect Precipitation.

Experiment	Number	Temperature Information available	IWC data available	Instruments
CEPEX	12507	Yes	Yes	ASSP, 1DC, 2DP
EUCREX	110	Partly	No	FSSP 2DC, 2DP
FRAMZY	2003	Yes	No	FSSP, 2DC, 2DP
CARL	798	Partly	Partly	FSSP, 2DC, 2DP
EUCREX	420	Yes	Partly	FSSP, 2DP
FIRE 2	1254	Yes	Yes	2DC, 2DP

C.1.2.2. Remote Sensing Observations

Passive sensors onboard aircraft and satellites, especially those working in visible and infrared bands, have widely been used in measuring cirrus cloud temperature, optical thickness and characteristic particle size (Ou et al. 1993, 1998; Francis et al. 1998; Han et al. 1999).

Several multiple-view (including dual-view) multi-wavelength instruments are in orbit or scheduled to be launched soon, designed to measure the radiation in the visible and infrared range (Tab. C.1.2.). An example are the studies for the ATSR-2 (Along Track Scanning Radiometer) instrument (Baran et al. 1998, 1999). They have shown that such measurements can be used to estimate the dominating habit of the ice crystals, and to estimate their maximum dimension. The dominating habit of the ice crystals is selected from a set of hypothetic crystals each consisting of polycrystals of size 25 µm and 100 µm, hexagonal columns with an aspect ratio of 1 and 4, bullet rosettes of 240 µm, and hexagonal plates with aspect ratios 0.34 and 0.16. The demonstrated case study was limited to a tropical cirrus anvil. In addition, for better performance of the procedure water clouds underlying the cirrus is avoided and only cirrus clouds over sea are considered.

Table C1.2. - Comparison of the multiple-view multiwavelength instruments ATSR-2, POLDER and MISR.

Instrument	ATSR 2, AATSR	POLDER	MISR
Plattform	ERS-2, ENVISAT	ADEOS, ADEOS-2	TERRA
Number of along track view angles	2	Up to 14	9
Maximal view angle	56^o	60^o	70.5^o
Time between extreme View angles [min]	2	4	7
Short-wave bands [nm]	555, 659, 865, 1600	443, 490, 565, 670, 763, 765, 865, 910	446, 558, 672, 866
Footprint [km]	1x1	6x7	0.275x0.275
Swath width [km]	512	2200	360

These instruments are particularly valuable for semi-transparent cirrus clouds where the effective dimension of the crystal size is less than 40 µm, and optical thickness is less than 10. Although visible-near infrared based multi-wavelength and multi-view instruments may become very useful for the remote sensing of cirrus clouds, they are subject to several constraints:

- The ice water path (IWP) is estimated as a linear function of the retrieved optical depth τ and the ratio of volume and projected area of the particle. This fact induces two error sources into the bulk estimation of IWP: (1) Because the large particles are situated deep in regions of the clouds not accessible with these wavelengths, the retrievals of the volume will be biased toward the cloud top, even for a cloud optical thickness well below the limit value of the instrument (e.g. 50 for ATSR). (2) At these wavelengths the effects of water vapour and ice on τ cannot be decoupled.
- For the infrared channels a critical uncertainty for thin cirrus is the lack of knowledge about the temperature profile because thin cirrus might not be thin vertically and thermal channels become saturated (i.e. the emissivity tends to be close to 1) for τ greater than about 2.
- The sun glint over ocean can be a very strong signal in a particular direction.
- Over land both the surface reflection and emissivity may be anisotropic.
- Over bright surfaces such as ice and snow, semi-transparent and intermediate thickness clouds may degrade the retrieval results.
- The retrieval requires the representation of the vertical cloud structure (in terms of particle size and shape) in the forward model and the assumption of plane-parallel clouds. This is a major concern especially for tropical convection.
- The shape information is determined from multiple views of the same scene at different incidence angles. This procedure is limited to optically thin clouds since multiple scattering effects smooth out the scattering phase functions for optically thicker cloud.

In view of the ice particle orientation, Chepfer et al. (1999) found in a global case study with the POLDER instrument aboard ADEOS that in at least 40 % of the pixels (each with area of 6 x 6 km^2) containing ice clouds the crystals exhibit a preferred horizontal orientation. This occurs in situations with particular dynamics, for example if the ice crystals are large enough (>15 µm) to start falling (Shanks and Lynch, 1995). However, it can be inferred that none of the presently available techniques is capable to measure all interesting parameters of cirrus clouds globally with the required temporal and spatial coverage, and that new techniques are therefore needed.

Satellite measurements with visible and infrared sounders can be used to detect the presence of cirrus clouds and to determine the cloud-top altitude (from the cloud-top temperature), as well as optical depth. As an example, Wylie and Menzel (1999) derived a statistics of the spatial distribution of high cloud cover from an eight-year period of HIRS data all over the globe, except the Polar Regions. However, observations at these wavelengths are very limited when determining cloud internal properties, because clouds will frequently be opaque at this short wavelength.

Sub-millimetre radiometric measurements from satellites or aircraft in the frequency range of 300 to 1000GHz (i.e. wavelength: 1.0 to 0.3 mm) have been proposed to investigate cirrus clouds (Gasiewski, 1992, Evans and Stephens 1995a, b; Evans et al. 1998, 1999, Kunzi et al., 1999). Since water vapour absorption is strong in this frequency range, the lower atmosphere is in most cases opaque, so that the surface and low clouds do not contribute to the up-welling radiation. The strong response to clouds has been shown in cirrus anvil aircraft overflights using channels at 325 GHz (Gasiewski et al, 1994). In addition, ice particles are only weak absorbers, and consequently emit very little sub-millimetre radiation, making the physical temperature of cirrus clouds unimportant to radiometric measurements. The wavelength in this band is comparable to the size of ice particles found in cirrus clouds; therefore the scattering process is in the Rayleigh and Mie regimes. As a result, the extinction of cirrus clouds and consequently the radiometric signal is proportional to the volume (mass) of ice particles and is also sensitive to the ice particle size and shape. Because the up-welling sub-millimetre radiation does not saturate for most cirrus clouds the radiative transfer remains linear. In simulations Evans et al. (1998) found that the brightness temperature depression due to the presence of cirrus clouds for a down-looking radiometer is closely related to the ice water path, furthermore the mean size of ice crystals can be estimated using the ratio of brightness temperature depressions measured at two frequencies. In addition these simulations performed at two orthogonal polarisations (vertical and horizontal) also have shown that the depolarisation effects of horizontally oriented non-spherical ice particles might be used to determine the ice particle shape, however the fact that cirrus clouds contain a mixture of ice crystals with different shapes and sizes may limit the applicability of this technique. Evans et al. (1998) suggested, among others, that a sub-millimetre radiometer dedicated to the investigation of cirrus clouds should have multiple channels in order to cover a wide range of total columnar ice and particle sizes and it should include a 183 GHz channel for determining the atmospheric background emission. As a result, four channels at 183±1.6, 495, 665 and 890 GHz have been recommended (Evans et al. 1998). A similar sensor, but with somewhat modified frequencies taking into account weighting function matching and avoiding ozone resonance lines, has been proposed by Kunzi et al. (1999). In this latter study the frequencies 150, 183±1, ±3, ±7, 220, 462, 683 and 874 GHz have been recommended.

More recently, radiometric measurements from aircraft were carried out by Wang et al. (1998b, 1999). By using radiometers operating at frequencies from 89 GHz to 340 GHz, they found that the brightness temperature depression caused by cirrus increases dramatically with frequency and for frequencies below 200 GHz, only for heavy clouds a significant depression occurres (e.g. cirrus with ice water path of >300 g/m^2). Furthermore the studies by Wang et al. (1998b, 1999) also revealed that it is necessary to have multi-channel measurements at frequencies higher than 340 GHz in order to retrieve cloud parameters over a wide range. In particular Wang et al. (1999) showed the importance of a precise and coincident measurement of the background emission, when observing thin cirrus clouds with small ice particles

C.1.2.3. Representation in Models

In numerical weather prediction models and climate simulation models the effect of cloud microphysical processes and of radiative processes are treated by sophisticated parameterisations. Examples are given by e.g. Doms and Schättler (1999) for the German mesoscale weather forecast model, or Roeckner et al. (1996) for the ECHAM climate model, Wilson and Ballard (1999), for the UKMO unified model, Del Genio (1996) for the GISS Global Circulation Model (GCM), Fowler et al. (1996) for the CSU GCM.

Simulation studies with such models provide time dependent fields of liquid water and ice concentration fields. Hence they may be used to e.g. generate a climatology for these variables and help to mitigate the problem due to missing data. However despite the great improvements in treating clouds in GCM's the state of the art parameterisation is still suffering from many severe problems. The 3rd IPCC-report states (IPCC, 2001, pp. 49-50): "Clouds represent a significant source of potential error in climate simulations. The possibility that models underestimate systematically surface absorption in clouds remains a controversial matter. The sign of the net cloud feedback is still a matter of uncertainty." Further uncertainties arise from precipitation processes and their spatial and temporal distributions. An example for the uncertainty still existing is given by the comparative sensitivity study of Del Genio et al. (1996) showing that the choice of the cloud parameterisation in the GISS GCM affects strongly the strength of the hydrological cycle and of the general circulation. Moreover, Wilson (2000) shows in another comparative study using the UKMO climate model wide differences in the zonal mean water and ice paths for different cloud physics parameterisations.

The objective for paying attention to cloud microphysics in weather forecast and general circulation models is twofold: (1) to describe the evolution of the model cloud including formation of precipitation and (2) to understand the effect of clouds on radiative transfer. Both objectives ideally require not a parameterisation but a detailed model for the evolution of the size distribution of drops and ice particles; this, however, is currently not feasible. Instead, in typical parameterisation schemes applied in weather forecast and climate models the ensemble of condensate particles is subdivided into few categories like cloud droplets, rain drops, and one or more categories of ice particles. Each of the categories is characterized by only a single independent quantity, which is usually the bulk water mass concentration; any other parameter that characterises the state of the cloud, such as number density, mean size, and size distribution, must be derived from that quantity or it must be estimated a priori. Moreover, for ice particles also their shape has to be assumed, despite the fact that the shape depends in a complicated way on nucleation conditions, and on the growth history. These restrictions cause a severe ambiguity when calculating characteristic quantities of particles such as the mean effective diameter for an ice particle ensemble. The latter is an important quantity to characterise the radiative transfer in ice clouds.

The lack of information on the microstate of the model clouds not only causes errors in the simulated fields of condensate concentrations and precipitation rates, but also causes severe problems for calculating the radiative transfer in clouds. As to the treatment of radiative transfer, all necessary optical parameters related to the microphysical properties of the cloud have to be specified by rather crude assumptions. Until recently, the parameterisations of radiative properties of ice clouds have been treated by very simplified models assuming ice crystals of a given size, e.g. 30 µm and with a fixed shape (e.g. spherical or hexagonal). Today more sophisticated models are available e.g. Kristjansson et al. (2000) have investigated the impact of the parameterisation scheme by Mitchell et al. (1996) for optical properties of ice crystals on the climate of two global circulation models (GCMs), the NCAR CCM3 and the UKMO-model. This scheme, based on anomalous diffraction approximation, a parameterisation for internal reflection and refraction effects, and designed for efficient implementation in GCMs expresses the single-scattering properties of a polydispersion of ice crystals as polynomials in the mean maximum dimension of the crystal. Kristjansson et al. (2000) find a large sensitivity to both size and shape, particular in the tropics. Smaller sizes lead to enhanced short wave and long wave cloud forcing. For a given IWP and size, aspherical crystals are significantly brighter in the short wave range, and more absorbing in the long wave region compared to spherical particles, and this effect is very much dependent on the particle shape. The study of Kristjansson et al. (2000) clearly documents the large uncertainty in model results arising from the inevitably rough assumptions on ice crystals. As an example, the effect on radiative warming is quantified. If in the parameterisation the crystal mean size is assumed to vary in a given way with temperature, then the mean size is small in the cold, upper troposphere, especially in the tropics, and larger elsewhere. As a consequence, there is a significant radiative warming effect around 1 K in the annual average in the upper tropical troposphere and at high latitudes, compared to the reference model run. For a single month, this effect may amount up to 2.5 K (January). This warming leads to a reduction in the model biases.

In summary, important information on a number of cloud parameters cannot be predicted by those models, but it has to be estimated from model predicted parameters or from limited observational data. These estimates are particularly poor for cirrus clouds. An improved treatment of clouds in models requires especially for ice clouds, a further improved parameterisation concept together with the availability of more reliable information on the cloud micro- and macro state. Anappropriate space borne sensor such as CIWSIR can provide the missing data to a large extent.

Another severe problem concerns model validation. For this purpose, a large database is needed including information on the predicted variables, i.e. at present mass concentrations of water and of ice, as well as on those parameters, which are diagnosed or prescribed. This data base needs to be global and should cover all seasons for validating GCM's, and in the case of weather forecast models the data have to be available on a daily base. Both requirements can be met only by appropriate space borne sensors such as CIWSIR.

C.1.3. Scientific Goals

The scientific goal of CIWSIR is to improve our understanding of the hydrologic cycle. CIWSIR will establish a quantitative database for the amount of cirrus clouds and their ice mass contents as well as provide information on the cirrus clouds microstate. The data set should be of high spatial and the best possible temporal resolution and cover all regions and seasons in order to be representative for all weather situations to allow building a cirrus climatology. As in situ observations as well as local RADAR and LIDAR soundings are not suitable for this purpose, global satellite measurements are required. These should be performed by sensors operating in frequency ranges where the clouds are not opaque.

For this purpose, a sub-millimetre sensor is selected. This frequency range offers the advantages pointed out in section C.1.2. The measurements will allow retrieving information on the total mass of ice in an upper tropospheric column of air and on characteristic particle size and shape.

Primary data products will be upper tropospheric vertically integrated ice mass concentrations, the characteristic size of the ice particles, and an estimate of the predominant shape. Nearly daily global coverage will be possible by using a polar orbiting platform. These data products are some of the most basic, and therefore most urgently needed, cirrus parameters, and they are not measurable with comparable coverage in time and space by any other method. CIWSIR will provide measurements needed to obtain the five science objectives:

1. The global and continuous observations provide a necessary basis to derive a climatology of cirrus properties. This information is of great value for climate research because cirrus clouds are highly important for radiative transfer, and therefore on the energy budget of the atmosphere.
2. The very large data set covering the IWP and the median mass equivalent sphere diameter (D_{me}), generated with CIWSIR can directly be compared with results of global circulation models for e.g. climate studies, and of numerical weather prediction models.
3. The wealth of detailed information expected from CIWSIR should provide hints to improve the parameterised treatment of ice cloud microphysics in models.
4. Provided a sufficient lifetime of CIWSIR or a later follow-on missions, possibly as part of an operational meteorological satellite payload, also long-term trends can be detected.

C.1.4. Other planned Satellite Missions suitable for Cirrus Cloud Detection

C.1.4.1 Overview of missions

Because of the widely recognized, urgent need for global bulk and microphysical information on cirrus clouds, several satellite missions are currently being planned in addition to the existing ones:

CloudSat is a multi-satellite, multi-sensor experiment designed to measure cloud properties critical for understanding their effects on both weather and climate. The key observations are the vertical profiles of cloud liquid water and ice content and related cloud physical and radiative properties. The spacecraft payload consists of a millimetre wave RADAR operating at 94 GHz. It has a footprint of 1400 m. CloudSat will fly in tight formation (460 km, 60 sec) with the ESSP-3, a satellite carrying a dual-wavelength polarisation-sensitive backscattering LIDAR, in order to allow a synergistic retrieval of cloud particle size and IWC from the combination of RADAR and LIDAR data. The two satellites CloudSat and ESSP-3 (henceforth together referred to as CloudSat) will follow in a somewhat looser formation behind the AQUA and AURA satellites (multi-sensor platforms which are part of NASA's Earth Observing System) and behind PARASOL (a CNES satellite carrying a polarimeter similar to POLDER). ESSP-3 will provide high-resolution vertical profiles of aerosols and clouds. AQUA will carry a variety of passive microwave, infrared, and optical instruments.

EarthCARE (Earth Clouds, Aerosols and Radiation Explorer, ESA 2001) is planned as an ESA Earth Explorer Core mission scheduled for launch in the 2008 to 2010 time frame. Its scientific objectives are to determine in a consistent manner the global distribution of vertical profiles of cloud and aerosol characteristics. The payload consists of a millimetre RADAR operating at 94 GHz with a surface resolution of 650x1000 m^2, a backscatter LIDAR operating at 355 nm with 20 m footprint, and three passive instruments, a Fourier Transform Spectrometer for spectrally resolved top of atmosphere (TOA) fluxes, a multi-spectral imager operating in the visible and IR bands, and a broadband radiometer to estimate the reflected short wave and emitted long wave TOA fluxes.

The most important differences of EarthCARE compared to CloudSat are the RADAR with a higher sensitivity and an additional Doppler capability with a resolution of 1 m/s. The cloud profiling instruments of both CloudSat and EarthCARE will be far from providing daily global coverage, in fact the measurements are a series of "snapshots" of about 1 km footprint along the sub-satellite tracks.

GPM, the Global Precipitation Mission is a follow-on mission to TRMM (Tropical Rainfall Measuring Mission, launched in 1997). The payload will include a 35 GHz RADAR in order to complement the 14 GHz RADAR on the current TRMM. Both RADARs will only detect very dense, e.g. precipitating clouds.

C.1.4.2. Quantitative Comparison of Retrieval Performance of various Sensors and Sensor Combinations

Evans has performed quantitative comparisons of the retrieval performance of the ice water column (IWC) and the median mass equivalent sphere diameter (D_{me}) from simulated data of CIWSIR, a 94 GHz RADAR, the infrared channels 4 and 5 of GOES (10.2-11.2 µm and 11.5-12.5 µm), and their synergetic potential for both tropical and mid latitude winter atmospheres. Figure C.1.4 shows some results for the IWC retrieval. Among all single-instrument simulations, CIWSIR has the smallest retrieval error for almost all considered cloud top heights h. Only for very high tropical clouds (h>17 km) with small particles GOES performs better, and the RADAR has some advantage for low mid latitude ice clouds (h <8 km).

Combining CIWSIR and cloud RADAR data leads to a considerable improvement of the retrieval error in all considered cases; combining with the GOES channels 4 and 5 improves the retrieval as well except for mid latitude winter clouds with h<7 km. For the retrieval of D_{me}, similar results hold. If comparing the IWP retrieval error as a function of the IWP (shown later, Fig. C.2.12), again the CIWSIR performs best, if compared with cloud RADAR and GOES channels 4 and 5, for IWP values above 10 g/m^2 for both tropical and mid latitude atmospheres. More details of the simulation study are given in section C.2.

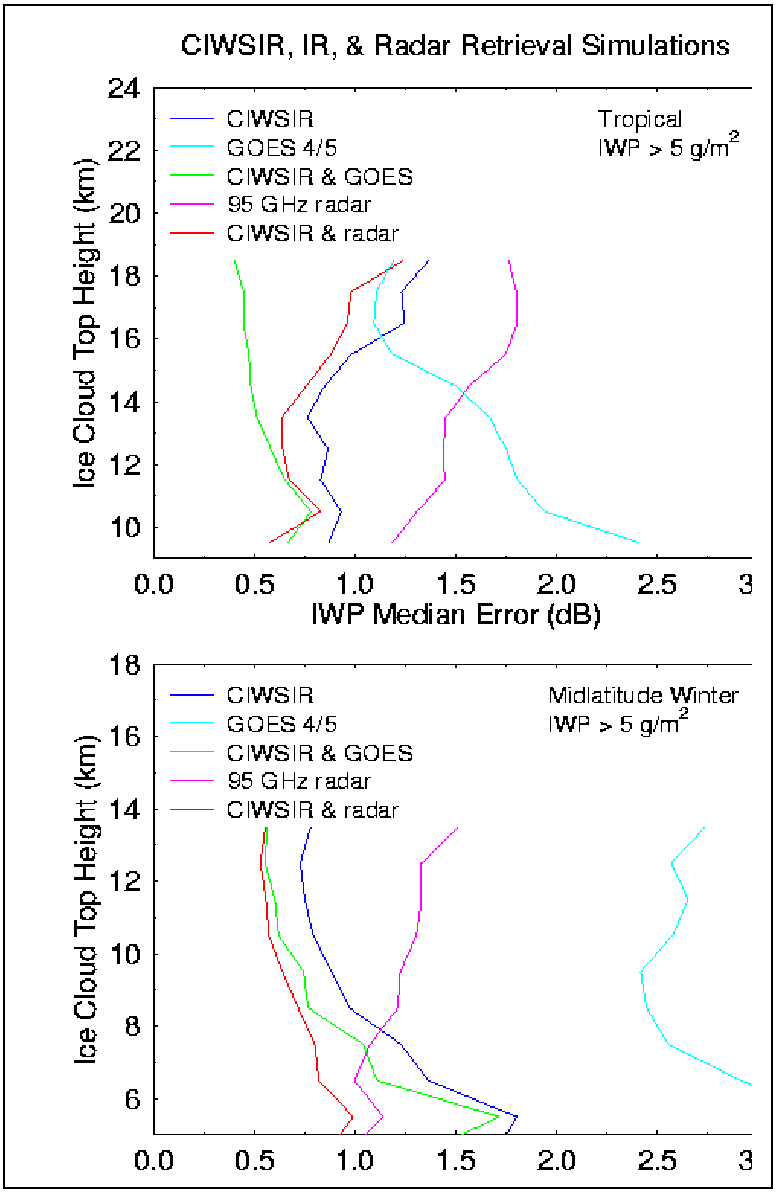


Figure C.1.4. - Comparison of the retrieval error for the ice water column (IWC) for a tropical atmosphere (top) and a mid latitude atmosphere (bottom) of various sensors and sensor combinations. More details can be found in the section C.2 where these calculations are discussed in detail. The error is given in decibel [dB] according to

$$error = 10 \cdot \left| \log 10 \left(\frac{retrieved\ value}{true\ value} \right) \right|$$

Note: 1 dB corresponds to:

$$\frac{retrieved\ value}{true\ value} \approx 1.25$$

and 3 dB correspond to:

$$\frac{retrieved\ value}{true\ value} \approx 2.0$$

C.1.4.3. Complementarity with other Missions and Sensors

The active sensors on CloudSat and EarthCARE. The most characteristic differences between CIWSIR and the missions CloudSat and EarthCARE (henceforth called active missions) in view of remote sensing of cirrus clouds are:

- The nadir viewing active instruments of EarthCARE and CloudSat will provide important vertical cloud profiles, but give very limited spatial sampling. Thus the active missions would have large errors for a climatology of cloud properties at the GCM grid box scale. CIWSIR has a wide swath giving nearly global coverage for a monthly climatology statistically representative at 2.5 degree or better.
- The broad spatial coverage of CIWSIR will allow measuring the mean diurnal cycle of ice cloud properties if an appropriate orbit is chosen. For the active missions a sun synchronous orbit has been selected because their limited spatial sampling will not support diurnal investigations.
- The active missions, especially EarthCARE, are intended to measure optically thin, but still radiatively significant cirrus. Both active missions will have poor accuracy for optically thick ice clouds in which the LIDAR is blocked and the RADAR will have to be used alone. These

optically thick ice clouds (e.g. convective anvils and frontal clouds) contain a large fraction of the total ice mass, though they cover only a small area.

To summarize, the active missions are needed process study missions broadly measuring clouds and aerosols at the scale of 10km, while CIWSIR is a mission providing daily global coverage for the upper tropospheric ice clouds at the regional scale. For both active missions CIWSIR can complement the measurements when flying simultaneously (CloudSat) or as a precursor (for EarthCARE). In particular the following topics can be identified:

1. The detailed cloud profiles, although only a snapshot covering a very small fraction of the CIWSIR footprint of about 10x10 km^2, may allow validating and improving the retrievals of CIWSIR. The CIWSIR data products IWP and mean effective particle size (D_{me}) may be cross-validated with the vertical profiles of the same parameters, obtained by the active sensors. In both tropic and mid latitude winter atmospheres the retrieval of IWC and D_{me} can be improved considerably by simultaneously using of CIWSIR and RADAR data, as has already been shown above by model calculations.
2. The near daily global coverage of CIWSIR will be essential to extend or interpolate the retrievals of the active sensors over large regions. Although desirable, this option does not require observations performed simultaneously. Rather, a climatological approach can be adopted.

Passive visible/near infrared instruments. The comparison of infrared sensors in the range of the GOES channels 4 and 5 (10.2-11.2 μm and 11.5-12.5 μm) as well as the potential of improvement when using data of both sensors simultaneously has been shown in section C.1.4.2. The best synergy is achieved by combining CIWSIR with an infrared sensor in the tropics for retrieving IWP and D_{me}. It should be noted that suitable infrared observations could be obtained with many sensors on various meteorological satellites, e.g. GOES, MSG, NOAA and METOP. Some infrared sensors have a much higher spectral resolution, e.g. MODIS on AQUA and TERRA or IASI on METOP, so when using these sensors an even better performance can be expected. Moreover, combining CIWSIR with a profiling sensor will allow obtaining nearly simultaneous and accurate temperature and humidity profiles, a valuable tool for model validation or assimilation. Among the various possible partners for a tandem satellite configuration, strong candidates offering a multitude of sensors with a high potential of synergy are the NOAA and in the future the METOP missions. Among the sensors aboard METOP offering a synergy with CIWSIR are MHS (183 and 150 GHz channels providing all weather humidity profiles), AVHRR/3 (cloud detection), and IASI (temperature and humidity sounding). However it should be noted that this data is of advantage but by no means essential for CIWSIR. The separation in time between the two satellites should be below the typical time for a 10 km (footprint) displacement of cirrus clouds, which means less than 10 minutes.

In summary, a well-defined strategy of inter-linked research activities will help to extend the objectives in order to exploit the synergy with other sensors to a maximum. Among the missions which benefit by data provided by CIWSIR are the operational satellites NOAA, DMSP and, in future NPOESS, METOP and GCOM, and the experimental missions ENVISAT, ADEOS-II, AQUA, TERRA and AURA. In addition also the geostationary meteorological satellites such as METEOSAT and MSG will take advantage of CIWSIR for retrieving ice cloud properties particularly in the tropics.

C.1.5. Contribution to International Programmes

CIWSIR contributes to the ESA Living Planet Programme (ESA SP-1227), Theme 2 (Physical Climate), which states the need for "observations of the three-dimensional distribution of clouds...and their interaction with radiative and dynamic fields". The topic addressed here is the "fast components of climate", focussing on the Upper Troposphere/Lower Stratosphere (UTLS). CIWSIR addresses specifically ice clouds, one of the least explored, although important cloud types (IPCC, 2001). Especially their role in a global change scenario needs a better understanding. Thus CIWSIR also contributes to Theme 4 (Atmosphere and Marine Environment: Anthropogenic Impact) of the ESA Living Planet Programme.

CIWSIR is relevant to the Global Energy and Water cycle Experiment (GEWEX) project of the World Climate Research Project (WCRP) by contributing:

- CIWSIR contributes to the International Satellite Cloud Climatology Project (ISCCP) providing a cirrus climatology in terms of IWC, D_{me} and shape information.
- CIWSIR Provides validation data sets to the GEWEX Cloud System Study (GCSS). The aim of GCSS is to develop new physically based cloud parameterisations based on cloud resolving models for different cloud systems for numerical weather prediction and climate models. The deliverables of CIWSIR will be of interest for the Work Group 2 (Cirrus Cloud Systems) and Work Group 4 (Precipitating Convective Cloud Systems).

As for the relevance to European Commission (EC) research programmes, CIWSIR is in line with the programme "Energy, environment and sustainable development" of the Key Action 2 (Global change, climate and biodiversity), Theme 2.4 (European component of the global observing systems). The CIWSIR mission furthermore is also consistent with the aim of the COST action 723 (The Upper Troposphere and Lower Stratosphere) which has been approved by the EC, and is currently being established. A close interaction with the COST action is assured as its initiator (S. Bühler) is member of the CIWSIR scientific Core Team. Moreover, CIWSIR is relevant to the Global Monitoring for Environment and Security (GMES), specifically to the Priority Theme 'Global Atmosphere Monitoring.

The present project CIWSIR is based on the sensor of the same name that has been studied during the two-year project CLOUDS (A Cloud and Radiation monitoring satellite) funded by the EC under contract ENV4-CT98-0733. If CIWSIR is implemented, it would be the first mission developed by ESA as a follow-on of a research activity initiated by the EC. It must be noted, however, that the channel specifications have undergone a substantial revision in order to optimise the retrieval performance.

C.2. General Mission Characteristics

C.2.1. Sub-mm Measurements for Upper Tropospheric Ice Clouds

The frequency region between roughly 200 and 1500 GHz has unique properties with respect to the remote sensing of upper tropospheric ice clouds. There, liquid water and ice particles interact very differently with radiation, due to the different behaviour of the complex refractive index. Liquid particles mainly act as absorbers, whereas ice particles mainly act as scatterers.

Since water vapour absorption is also strong within this band, the lower atmosphere is for most cases opaque; therefore the surface, low clouds, and rain do not contribute to the up-welling radiation. The fact that the interaction between the cloud ice particles and the radiation is strongly dominated by scattering has the important consequence that the emission from the cloud particles, and hence the cloud temperature, are not of great importance. Overall, the situation can be sketched as that of a layer of cloud ice lying on top of a radiation source (Figure C.2.1). The effect of the cloud is to reduce the brightness temperature compared to the clear sky case.

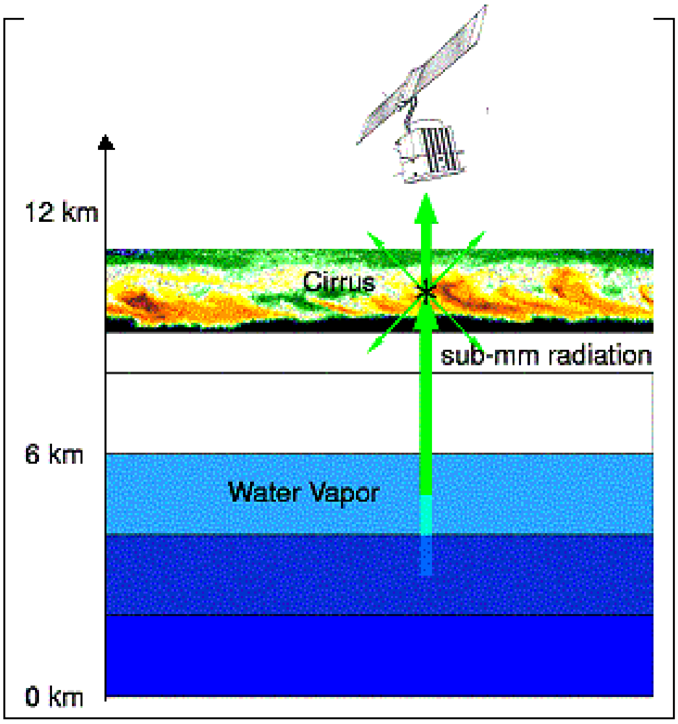


Figure C.2.1 - A schematic view of the CIWSIR observation geometry. In the presence of an ice cloud, the up-welling radiation from lower layers of the atmosphere is reduced, because some of the radiation is scattered away to other directions.

Figure C.2.2 shows that the brightness temperature depression due to the presence of ice particles for a down-looking radiometer is closely related to the total mass of ice in the observation path (called ice water path or IWP). Furthermore, over a large range of IWP and frequency the radiative transfer (RT) occurs in the linear regime, i.e., the brightness temperature depression is proportional to the IWP. Saturation effects can be observed only at very high frequencies or high IWP (the 874 GHz curve in the top plot). The figure also shows that the signal of ice clouds in the sub-millimetre wave spectral range is quite strong and should be easily detectable by state-of-the-art receivers.

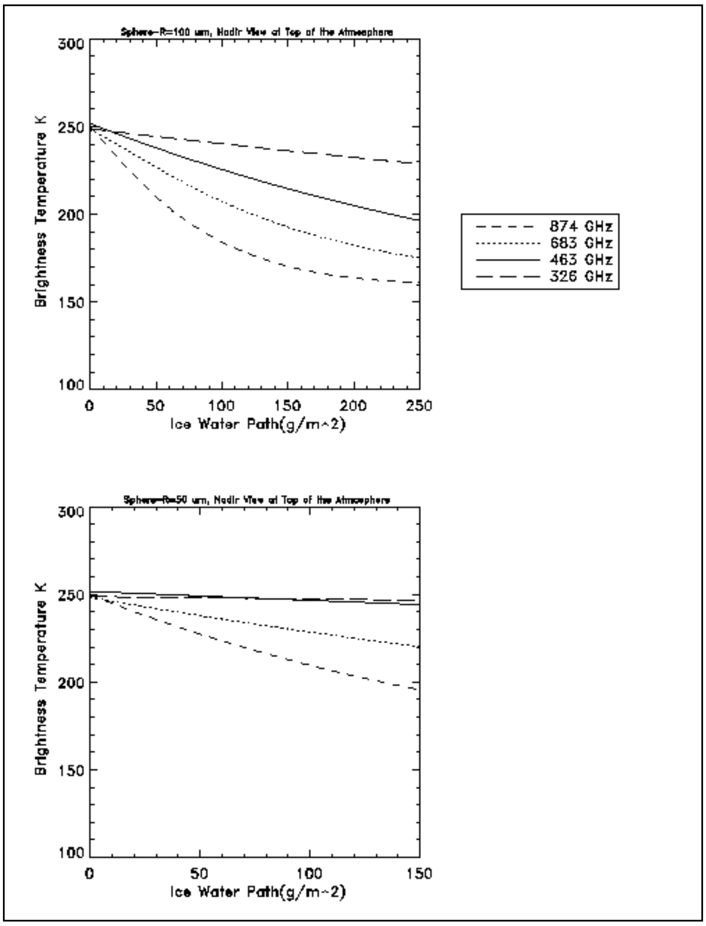


Figure C.2.2. – Up-welling radiance (zenith angle 0 degrees) at different sub-millimetre wavelengths for a mid latitude winter scenario and a homogenous ice cloud consisting of spherical ice particles. Top plot: Cloud from 5 to 7 km altitude, particle radius 100 µm. Bottom plot: Cloud from 9 to 10 km altitude, particle radius 50 µm. The horizontal axis shows the ice water path (IWP), i.e., the vertically integrated ice water content. The vertical axis shows the radiance in units of Planck brightness temperature. The calculation has been performed with a plane parallel successive order of scattering model.

The linearity of the RT 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 non-linearities, which are significant for optical and IR techniques, are much less severe.

As the figure shows, the sensitivity (change in brightness temperature per change in IWP) depends on the particle size. Hence, several channels over a wide range of frequencies are necessary to collect enough information to simultaneously retrieve IWP and effective particle size (Gasiewski, 1992). For a size and shape distribution of ice particles, a convenient measure of the effective size is D_{me}, the median diameter of the mass-equivalent sphere (Evans et al., 1998).

Additionally, as already mentioned in Section C.1, polarization measurements may provide information on the particle shape. This conclusion stems from the simulation work of Evans et al. (1998) done for horizontally oriented ice particles. Recent work of Miao et al. (2001) further shows that the polarization signal (expressed as the brightness temperature difference between the vertically and horizontally polarized channels) can be strong enough at high frequencies (>200 GHz) even for randomly oriented non-spherical ice particles. The polarization difference is found to be closely related to the characteristic particle size if the ice particles in the cirrus cloud are nearly spherical (see Figure C2.3.a). For cylindrical and plate-form ice particles the polarization difference is a function of both the characteristic particle size and the aspect ratio. An example for cylindrical particles is shown in Figure C2.3.b. Therefore, multi-channel polarization measurements at high frequencies can provide useful information on the cloud particles shape. However the two figures presented may overestimate the polarization difference for randomly oriented particles, because the effect of multiple-scattering is not included. On the other hand, for horizontally oriented particles the effect may be even larger.

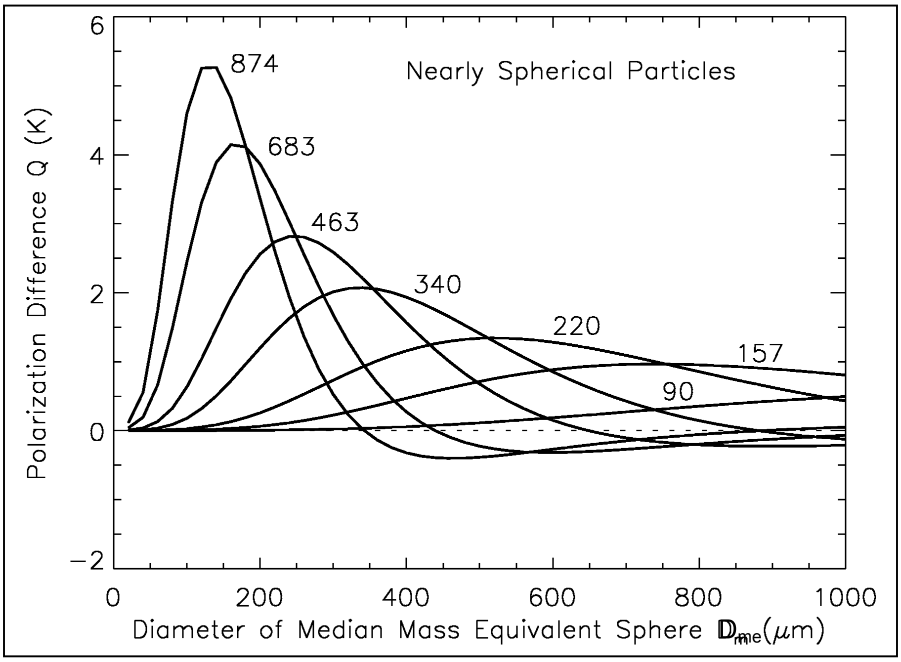


Figure C.2.3.a. - Simulated polarization differences measured by a space-borne radiometer for clouds composed of randomly oriented, nearly spherical particles. Particle size follows a modified Gamma distribution with α=1. The integrated ice water content of the cirrus cloud along the line of sight is 100 g/m^2. Satellite zenith angle is 54 degree. D_{me} is the diameter of the median mass equivalent sphere.

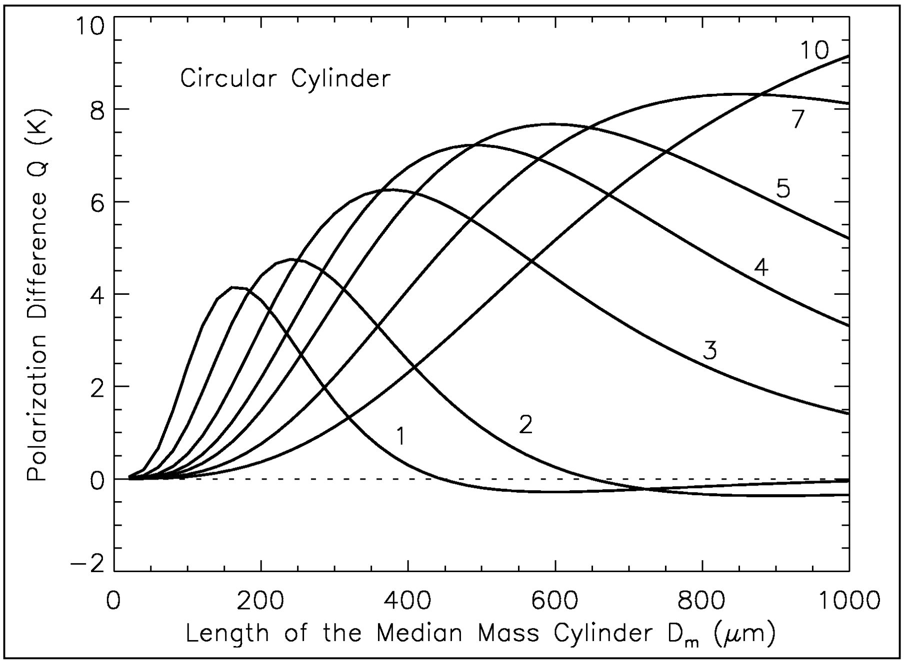


Figure C.2.3.b. - Same as figure C2.3.a but for randomly oriented circular cylinders with different aspect ratios (denoted close to curves) at 683 GHz. D_m represents the length of the median mass cylinder.

Figure C.2.4 shows simulated radiances over a wide frequency range for different IWP and different D_{me}. The top plot (different IWP) demonstrates that large IWP can be sensed because the scattering behaviour causes the brightness temperatures to go well below the physical temperatures. The bottom plot (different D_m) demonstrates that the dependence on frequency of the scattering signal depends strongly and uniquely on the particle size. For small particles the maximum signal occurs at the highest frequency. For larger particles the frequency of the maximum signal depends on the size. To exploit this behaviour, a cirrus sensor needs a set of channels that are quite far apart in frequency, in order to be sensitive to a wide range of IWP and D_{me}. The frequencies cannot be too far apart, however, because even for clouds with low IWP one wants to have a cloud signal in at least two different channels.

Besides these parameters, the signal also depends on cloud altitude, due to the so-called water vapour screening effect (Figure C.2.5). This effect originates from the violation of the idealized observing situation that was sketched in figure C.2.1. If the ice cloud altitude is too low, then the lower part of the cloud will be in the altitude region, which is influenced by water vapour absorption. To compensate for this effect, a cirrus sensor needs a set of channels with different sensing altitude (i.e., different clear sky weighting functions).

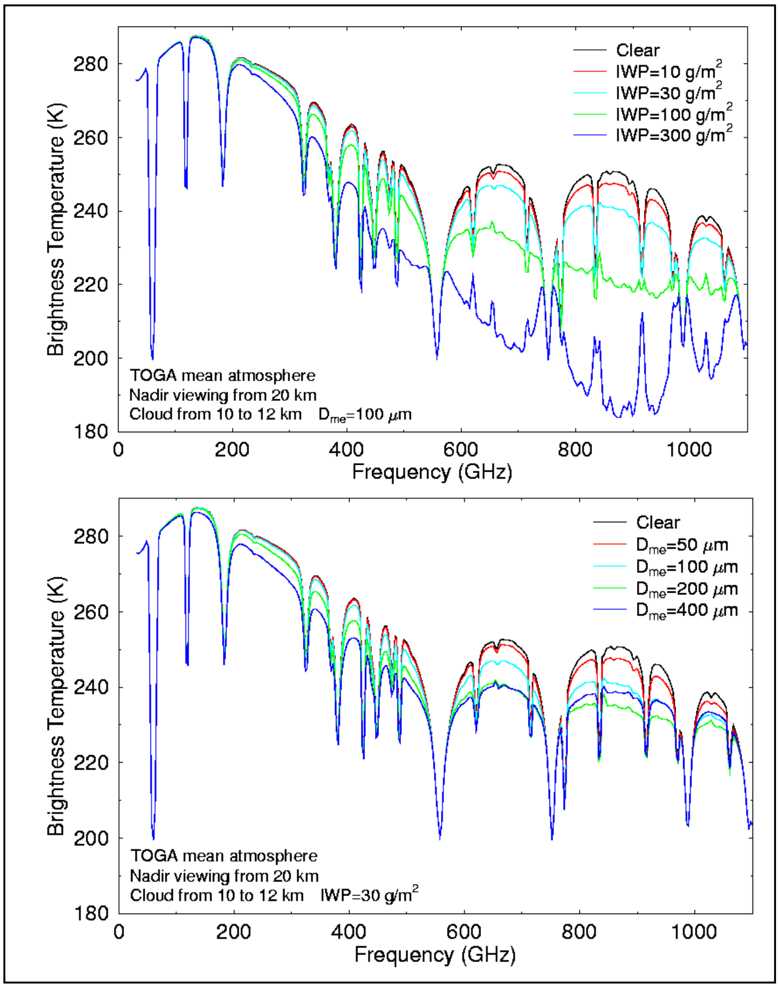


Figure C.2.4. - Simulated radiances for different IWP (top) and D_{me} bottom.

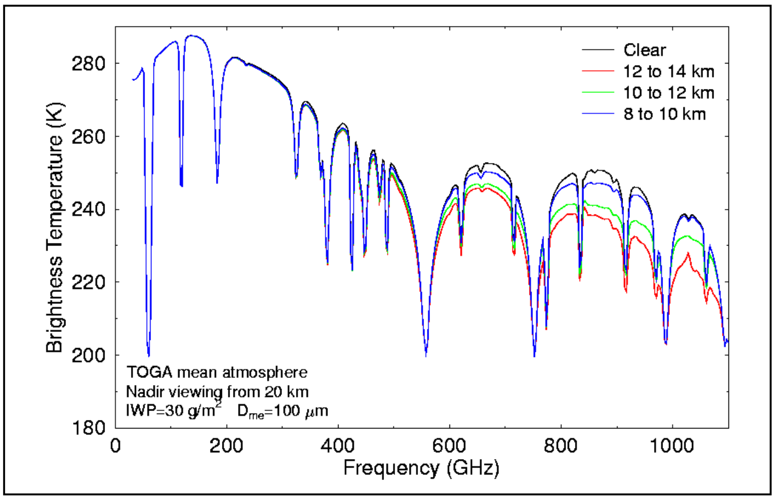


Figure C.2.5 - Radiances for various cloud altitudes.

C.2.2. Channel Selection

From the discussion in the previous section, it follows that one has to find a suitable set of channels in order to distinguish the signals from the three parameters IWP, D_{me}, and cloud altitude, and also in order to achieve a good coverage of the expected variability of these parameters. Furthermore, some lower frequency channels are necessary in order to determine the atmospheric background emission. The retrieval algorithm assumes that all channels are viewing the same air mass. Therefore, it is an important requirement that all channels have similar footprints.

Some basic principles can be applied in the selection of appropriate channels: (a) selecting channels with similar radiances and weighting functions over a wide range of frequencies, (b) using double sideband heterodyne receivers with local oscillator frequencies on water vapour spectral lines, in order to achieve multiple channels with weighting functions peaking at different altitudes for each intermediate frequency for a particular receiver, (c) avoiding interfering ozone lines as best as possible, and (d) selecting the optimum bandwidth in order to achieve low noise while keeping weighting functions narrow.

Several sets of channels based on these principles were compared by means of retrieval simulations similar to the ones described in Section C.2.3. Due to the limited space available, only the scenario that was finally selected is described here. It is summarized in table C.2.1.

Table C.2.1. - A summary of CIWSIR channel data. The first column gives the local oscillator (LO) frequency, the second column the offset (±) with respect to the channel centre frequency. The third column lists the system noise temperature as estimated by our industrial partner RPG. The fourth column gives the assumed width per pass band and the fifth column the noise equivalent temperature (NET), resulting from the radiometer formula with an assumed integration time of 2.5 ms. The last column gives the one sigma error assumed in the retrieval simulations. This is based on the assumption that for each channel there is an additional 1 K instrumental error, due to calibration uncertainties, etc., that is uncorrelated to the radiometric noise. The letters H and V at the end of the first column indicate horizontal and vertical polarization.

Local Osc. Freq. f_{LO} [GHz]	**Intermediate freq. f_{IF} [GHz]**	**T_{sys} [K]**	**Channel width Δf [GHz]**	**Noise Equiv. Temp. NET [K]**	**σ [K]**
183.31	1.47	1000	1.38	0.54	1.14
183.31	2.85	1000	1.38	0.54	1.14
183.31	4.50	1000	1.92	0.46	1.10
325.15	1.50	2000	1.68	0.98	1.40
325.15	3.18	2000	1.68	0.98	1.40
325.15	5.94	2000	3.00	0.73	1.24
448.00	1.44	2500	1.56	1.27	1.61
448.00	3.00	2500	1.56	1.27	1.61
448.00	7.20	2500	3.00	0.91	1.35
H 682.95	6.00	3000	3.00	1.10	1.48
V 682.95	6.00	3000	3.00	1.10	1.48
H 874.38	6.00	5000	3.00	1.83	2.08
V 874.38	6.00	5000	3.00	1.83	2.08

Figure C.2.6 gives an overview over the position of the CIWSIR channels. The central frequencies for the receivers were spread out in order to cover a large spectral range. At the same time channels centred on water vapour spectral lines can be adjusted to sense different altitudes by picking the right intermediate frequency. Figure C.2.7 presents a detailed picture for each of the receivers. The two high frequency channels (682.95 and 874.38 GHz) are measuring at two orthogonal different polarizations.

In this way one can select five channels with rather similar weighting functions at 183.31±1.47, 325.15±1.50, 448.00±7.20, 682.95±6,00, 874.38±6.00 GHz. Additional channels have been added to extend the altitude coverage: further from the line centre for 183.31 and 325.15 GHz in order to sense lower altitudes, and closer to the line centre for 448.00 GHz in order to sense higher altitudes. Weighting functions for the CIWSIR channels are shown in figure C.2.8.

The bandwidths for the first three receivers, which are centred on spectral lines, were chosen to be as large as possible without overlapping, in order to minimize the radiometric noise. It was checked that the weighting functions for these channels are not significantly wider than the monochromatic ones. Figure C.2.9 demonstrates this for the 325.15 GHz receiver. The bandwidths and positions of the two high frequency receivers were chosen such as to minimize the interference by ozone lines.

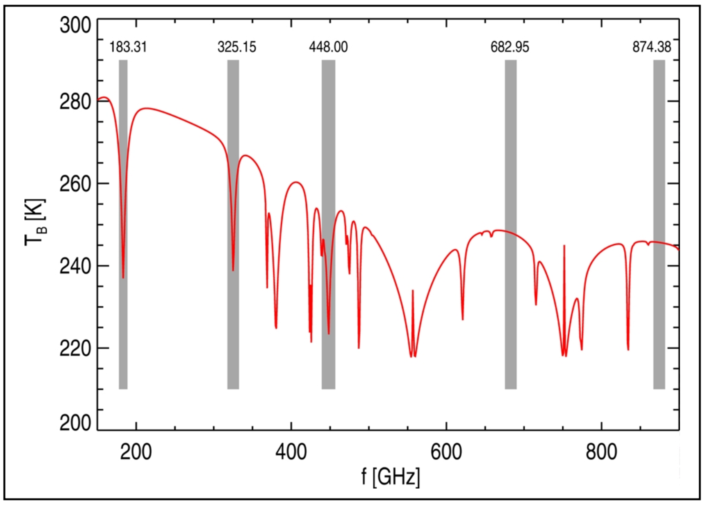


Figure C.2.6. – The clear sky radiance spectrum as measured by a satellite radiometer. Grey bars mark the CIWSIR frequency ranges.

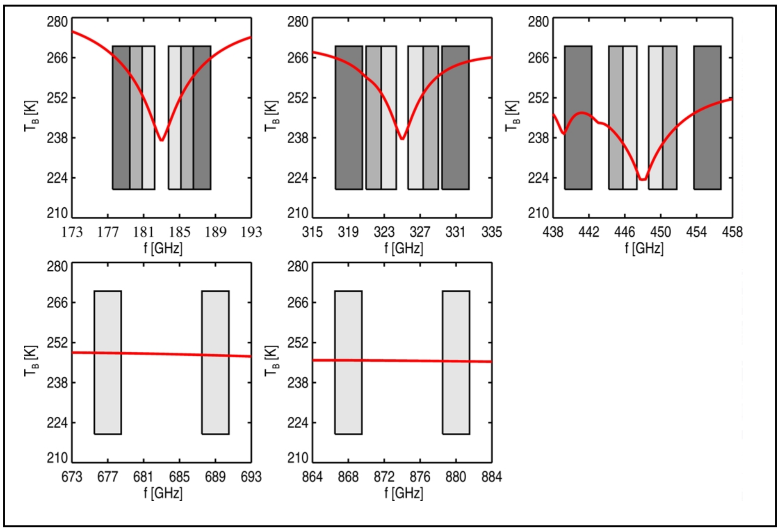


Figure C.2.7. – Same as figure C.2.6, but zooming on the CIWSIR channels. Each channel comprises two sidebands. The three lower frequency receivers have three sub-channels each, marked here in different shades of grey.

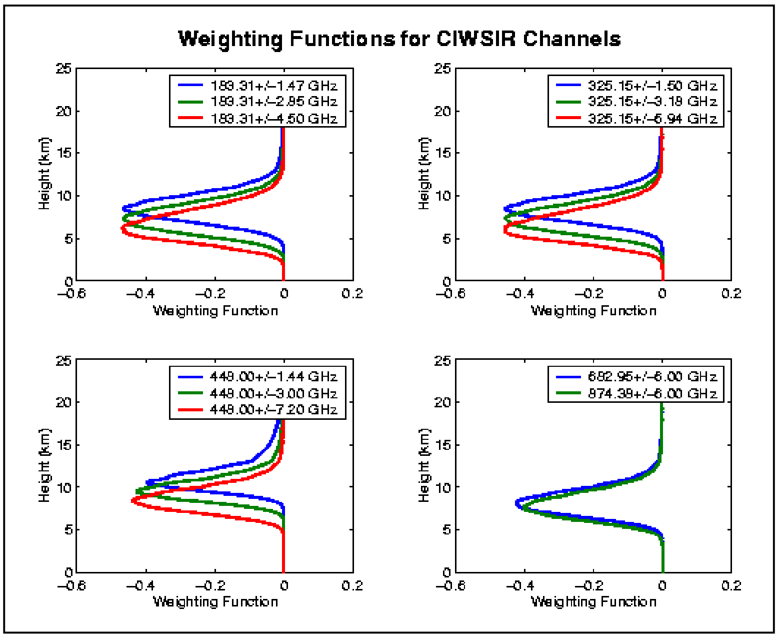


Figure C.2.8. - Water vapour weighting functions for all CIWSIR channels. These are differential weighting functions (derivative of radiances with respect to water vapour volume mixing ratio, in relative units).

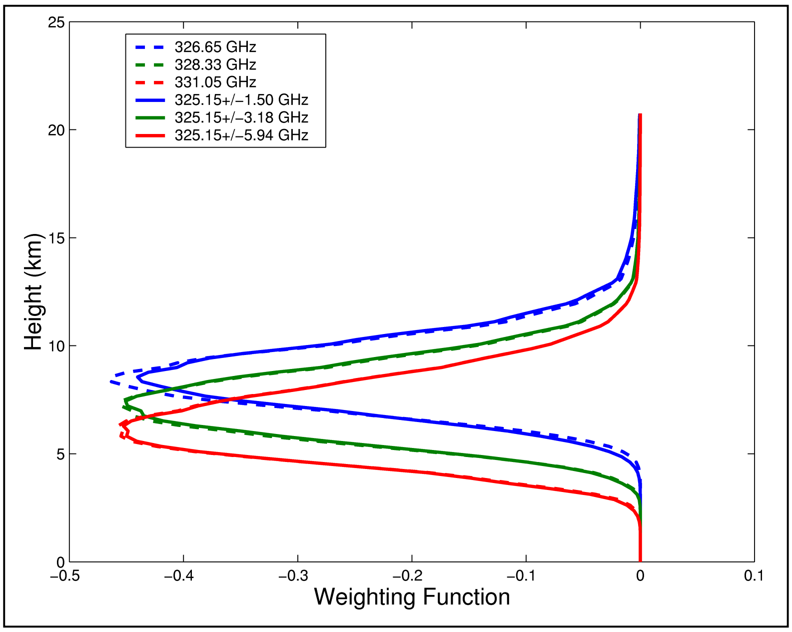


Figure C.2.9. - Monochromatic (dashed) and true band-integrated (solid) differential water vapour weighting functions for the three channels centred on the 325.15 GHz water vapour line. Monochromatic weighting functions are calculated only for the band centre frequency, band-integrated weighting functions are integrated over both sidebands, considering the channel widths given in table C.2.1.

C.2.3. Retrieval Simulations

Retrieval simulations are performed to show the expected accuracy of the CIWSIR ice water path (IWP) and particle size D_{me} retrievals for various situations. The simulations are performed for two situations: tropical convective cirrus anvils and mid latitude winter synoptic ice clouds. For each retrieval simulation 10,000 atmospheres are randomly generated with a realistic range of temperature and humidity profiles, cirrus cloud heights and thickness, vertically inhomogeneous Ice Water Content (IWC) and D_{me}, and ice particle shape and size distribution. A radiative transfer model is used to simulate CIWSIR brightness temperatures for these profiles, and gaussian noise (with a standard deviation given in table C.2.1) is added to the observations to simulate instrument and model errors. The simulated observations are input to the Bayesian retrieval algorithm described below, and the resulting retrieved cirrus IWP and D_{me} are compared to the true values.

C.2.3.1. Bayesian Retrieval Algorithm

The retrieval algorithm used in the simulations is a Bayesian integration method (Evans et al., 2001). This algorithm is also suitable for the operational CIWSIR algorithm because it is computationally efficient, introduces *a priori* information in a clearly defined manner, and retrieves uncertainty estimates along with accurate ice cloud parameters. The Bayesian retrieval algorithm is based on Bayes theorem of probability theory:

$$p_{post}(x \mid T) = \frac{p_f(T \mid x) p_p(x)}{p_p(T)}$$

where x is the vector comprising cloud and atmosphere parameters, and T is the vector of measured brightness temperatures. The probability density function (pdf) $p_p(x)$ represents our knowledge of the atmospheric column before taking a measurement. The conditional pdf $p_f(T|x)$ is the distribution of brightness temperatures for a given atmosphere, which is closely related to the forward radiative transfer problem. The forward pdf is assumed to be a normal distribution of measurement errors around brightness temperatures simulated by a radiative transfer model, $T_{sim,i}$, i.e.

$$p_f(T|x) = \prod_i N\left[\frac{T_{sim,i}(x) - T_{obs,i}}{\sigma_i}\right]$$

where $T_{obs,i}$ is the i^{th} brightness temperature with measurement respectively modelling error of σ_i. The resulting posterior pdf $p_{post}(x|T)$ gives the probability distribution of the atmospheric parameters for a given measurement.

A retrieval is made by integrating the posterior pdf to find the mean parameter vector, x_{ret}. A Monte Carlo integration is performed over the high dimensional parameter space by randomly generating the atmospheric parameters for many cases. To have an efficient algorithm the simulated brightness temperatures for these cases are pre-computed with a radiative transfer model and stored in a database. The random cases in the database are distributed according to the prior pdf. This simplifies the Bayes integral for the retrieved vector to

$$x_{ret} = \frac{\sum_i x_i \exp\left[-\frac{1}{2}\chi_i^2\right]}{\sum_i \exp\left[-\frac{1}{2}\chi_i^2\right]} \qquad x_i \text{ from } p_p(x)$$

where χ^2 is the usual normalized measure of the disagreement between the observed and database brightness temperature vectors. A similar summation gives the standard deviation around the mean vector, which is an estimate of the uncertainty in the retrieval.

C.2.3.2. Retrieval Database Generation

Generation of the database of atmospheric parameters and corresponding brightness temperatures is the key element of the Bayesian algorithm. The first step in generating the database is to create random profiles of temperature, water vapour, liquid and ice cloud properties such as water content and median particle size, and surface emissivity. The distribution of these parameters is the a priori information in the retrieval, so it is important that the profiles are realistic and completely covers the possible parameter range. The parameters that specify the cloudy atmospheric profiles are chosen from joint probability distributions, instead of using observed profiles. This is necessary because up to one million profiles may be needed and the Monte Carlo integration requires that each case be independent. Since the atmosphere and cloud parameters in the database are distributed according to the prior pdf, there will be databases for different seasons and regions of the globe.

The second part of generating the database is to simulate the CIWSIR sub-millimetre and other observations with a radiative transfer model. The fast hybrid Eddington-single-scattering-method (Deeter and Evans, 1998) model is used. For efficiency the monochromatic absorption profiles for an input atmosphere are interpolated in temperature and water vapour from reference profiles calculated with an appropriate algorithm. The single scattering information for gamma particle size distributions is calculated for randomly oriented non-spherical particles with the Discrete Dipole Approximation (DDA) for the microwave channels and using volume and area equivalent sphere Mie scattering for infrared channels.

The retrieval database temperature and relative humidity profiles are generated with the correct statistics and vertical correlations using principal component analysis. The principle components are calculated from 118 tropical or 72 mid latitude winter profiles. The mean and variability of the temperature and relative humidity profiles from 10,000 realizations is shown in figure C.2.10. Multilayer ice clouds and midlevel water clouds are generated with realistic geometric properties. There may be one or two ice cloud layers. The lower portion of an ice cloud may be a liquid cloud layer if it is below a random temperature based transition level. The choice of the cloud geometry distributions is based on observed cloud height and thickness distributions obtained from RADAR and LIDAR. The upper ice cloud top height is gaussian distributed, the gap distance between the two ice clouds and the cloud thickness has an exponential distribution. All the distributions are independent.

The microphysical properties of ice clouds in the databases are based on in situ 2DC probe observations of cirrus. The mid latitude winter simulation uses 700 cirrus size distributions from the FIRE-I experiment in October, 1986 (Heymsfield et al., 1990). The tropical simulation uses 3000 size distributions from the CEPEX experiment in 1993 (McFarquhar and Heymsfield, 1996). The cirrus microphysical generation procedure uses the observed relationship between IWC, D_{me}, and temperature. The parameters of a trivariate normal distribution are specified with the 3x3 covariance matrix of ln(IWC), ln(D_{me}), and temperature derived from the observed size distributions. The randomly generated ice cloud heights and thickness are used to index into the random temperature profiles to get cloud top and bottom temperatures. Given the top and bottom temperature, the IWC and D_{me} at the top and bottom of the cloud are generated randomly from the lognormal distribution. The D_{me} varies linearly with height inside the cloud, while the IWC varies as a power law in D_{me}. This procedure simulates the observed cirrus microphysical relationships, such as smaller particles at colder temperatures and lower IWC with smaller particles. The ice particle size distribution width and particle shape is uniform and chosen randomly within each cloud. The liquid clouds that are attached to the bottom of an ice cloud have a liquid water content equal to the bottom IWC and a fixed particle size.

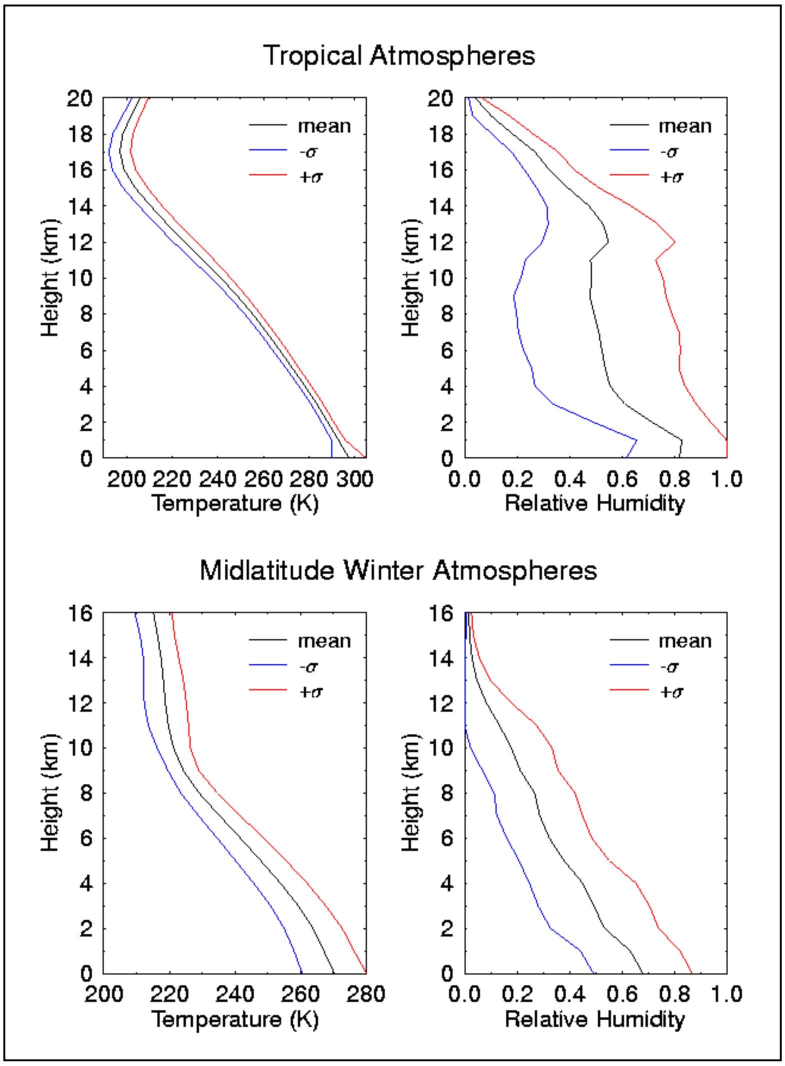


Figure C.2.10. - The mean and mean ± standard deviation profiles of temperature and relative humidity from 10,000 randomly generated profiles for the tropical and mid latitude winter simulations.

C.2.3.3. Retrieval Simulation Procedures

The synthetic CIWSIR observations for the retrieval simulations are made with the same procedure as used to generate the retrieval database profiles. It is not realistic, however, to use the same statistics for testing the database as for the retrieval database because the cirrus cloud statistics are not well known. Therefore, the testing and retrieval databases have the following differences:

- The testing database ice cloud geometry statistics are obtained from ARM cloud boundary datasets derived from cloud RADAR and LIDAR in wintertime Oklahoma or the Tropical West Pacific. The time-height cloud mask is averaged to 900 seconds and 250 m in height to approximately match the CIWSIR footprint scale. There are one or two independent cloud layers in the testing database. The retrieval database consists of only single layer clouds having different distribution parameters. Table C.2.2 gives the retrieval and testing database cloud geometry parameters for the two simulations.
- The testing database cirrus microphysical statistics are altered from the retrieval database by multiplying the IWC values by 2, but keeping the other parameters of the trivariate (ln(IWC), ln(D_{me}), T) normal distribution fixed.
- The testing database clouds are randomly chosen to have a particle shape of either 4 or 7 bullet rosettes, while the retrieval database clouds have an equal mixture of randomly oriented 4 and 7 bullet rosettes.

Table C.2.2. - Parameters of the probability distributions describing the cloud geometry for an Ice to liquid transition temperature in the range of 253 to 273 K

Parameter	Tropical Atmosphere		Mid latitude Atmosphere	
	Retrieval	Test	Retrieval	Test
Probability of two ice cloud layers	0.0	0.33	0.0	0.33
Mean height of cloud top [km]	13.5	14.7	-	-
Temperature of mean cloud top height [K]	-	-	233	233
Standard deviation of cloud top height [km]	2.5	2.0	2.5	1.6
Mean upper cloud thickness [km]	1.0	0.7	1.5	1.2
Mean cloud gap distance [km]	-	1.2	-	1.5
Mean lower cloud thickness [km]	-	0.9	-	1.7

The statistics of the 10,000 randomly generated clouds used for testing are listed in table C.2.3. The typical cirrus cloud has a smaller IWP and D_{me} in the tropical simulation than in the mid latitude winter simulation. Liquid clouds are contained in 1.4 % of the tropical and 5.5 % of the mid latitude winter cases. For the tropical simulation 38 % of the clouds have IWP <5 g/m^2, while for the mid latitude winter simulation 17 % have IWP <5 g/m^2. However, only 1.4 % and 0.8 % of the total ice mass is contained in clouds with IWP <5 g/m^2 (the approximate sensitivity limit of CIWSIR). The distinction between the fraction of clouds and the fraction of total IWP is important, since the goal of the mission is to sense total regional ice mass, not individual cloud IWP.

Table C.2.3. - Statistics of the randomly generated ice clouds with IWP the ice water path, D_{me} the median mass equivalent sphere diameter, Z_{top} cloud altitude, and Z_{bot} cloud bottom cloud altitude.

Tropical Atmosphere					
Parameter	Mean	Median	Standard Deviation	Minimum	Maximum
IWP [g/m^2]	50.6	9.2	137	0.01	2680
D_{me} [µm]	117	97	69	23	464
Z_{top} [km]	14.7	14.7	2.0	8.0	21.9
Z_{bot} [km]	13.3	13.4	2.4	4.6	21.6

Mid latitude Winter Atmosphere					
Parameter	Mean	Median	Standard Deviation	Minimum	Maximum
IWP [g/m^2]	59.2	23.8	102.8	0.14	1624
D_{me} [µm]	238	230	69	63	481
Z_{top} [km]	9.7	9.5	2.3	2.6	19.0
Z_{bot} [km]	7.7	7.6	2.9	2.9	17.5

To compare the sub-millimetre cirrus remote sensing technique with other methods and to determine possible synergies, retrieval simulations are performed for two infrared channels and for a cloud RADAR. The infrared split window technique is well known to contain information about optical depth and particle size for thinner clouds with small particles. GOES imager channels 4 and 5 (10.7 µm and 12 µm) radiances are simulated with three term pseudo-k-distributions, and noise with rms of 0.6 and 0.7 (mWcm)/(m^{2}st) is added. Since vertically integrated cloud properties are desired, the 95 GHz RADAR simulation uses vertically integrated backscattering and mean backscattering weighted height as the two observables. The RADAR backscattering calculation is performed with DDA for the same non-spherical particles. Detector noise is added to the integrated backscattering to limit the sensitivity to –38 dBZ (the sensitivity of the proposed EarthCARE RADAR for 500 m range gates) and 1 dB rms multiplicative calibration noise is also included.

The retrieval simulations are designed to be as realistic as possible. However, the large uncertainty in cirrus cloud property statistics measured by in situ probes implies significant uncertainties in the retrieval simulation results given below. Nevertheless, the general characteristics of the simulation results should be correct. The two cirrus types simulated (tropical and mid latitude winter) are not representative of all ice clouds. In particular, thicker precipitating ice clouds are not considered at all, though CIWSIR is expected to have the ability to retrieve ice water path in these clouds as well.

C.2.3.4 Single Pixel Retrieval Accuracy

Comparing the retrieved parameters to the known values assesses the IWP and D_{me} retrieval errors. Since IWP varies by orders of magnitudes, the error is expressed in a fractional sense using the logarithmic difference expressed in decibels (dB) (see also figure C.1.3). The fractional error is applied to cases with IWP above 5 g/m^2 because a fractional error for IWP near zero is meaningless. Instead of the RMS difference, a more robust statistic, the median of the absolute value of the error is used. Thus, over all the retrievals being combined for an error estimate, 50 % have a dB error less than the median error, and 50 % have a larger error. For a zero mean gaussian distribution the root mean square error is 1.48 times the median absolute error. A 1 dB error is a factor of $10^{\pm 0.1}$ or about 1.25, while a 3 dB error is a factor of 2.

Figure C.2.11 compares the IWP and D_{me} retrieval accuracy for the full 11-channel CIWSIR configuration to a 10-channel configuration in which the 874 GHz channel is dropped. There is little degradation from removing the 874 GHz channel for the mid latitude winter simulation which has large particles, but the 874 GHz channel substantially improves the IWP retrievals of the high altitude tropical cirrus clouds which have small particles. The tropical cirrus retrievals of both IWP and D_{me} are improved by combining CIWSIR and two split-window infrared channels. The overall median IWP retrieval errors are less than 1 dB for the full CIWSIR configuration.

Figure C.2.12 compares the IWP retrieval accuracy of CIWSIR with a cloud RADAR and two split-window infrared channels. The infrared only retrievals have poor accuracy for the mid latitude winter clouds, which have large particles, and for the lower altitude or higher IWP tropical clouds which are optically thick. The RADAR only retrievals are significantly worse than the CIWSIR retrievals except for clouds with low IWP, which can be detected by a highly sensitive (-38 dBZ) RADAR, and for lower altitude mid latitude ice clouds, which are obscured by sub-millimetre water vapour absorption. There is a modest improvement in IWP retrieval accuracy, over CIWSIR alone, by combining RADAR and CIWSIR data, especially for the mid latitude winter simulation. For single pixel retrievals, however, the synergy between the sub-millimetre and the infrared is greater than the synergy between sub-millimetre and RADAR. The infrared's sensitivity to optically thin clouds with smaller particles complements the sub-millimetre's sensitivity to larger particles and higher IWP.

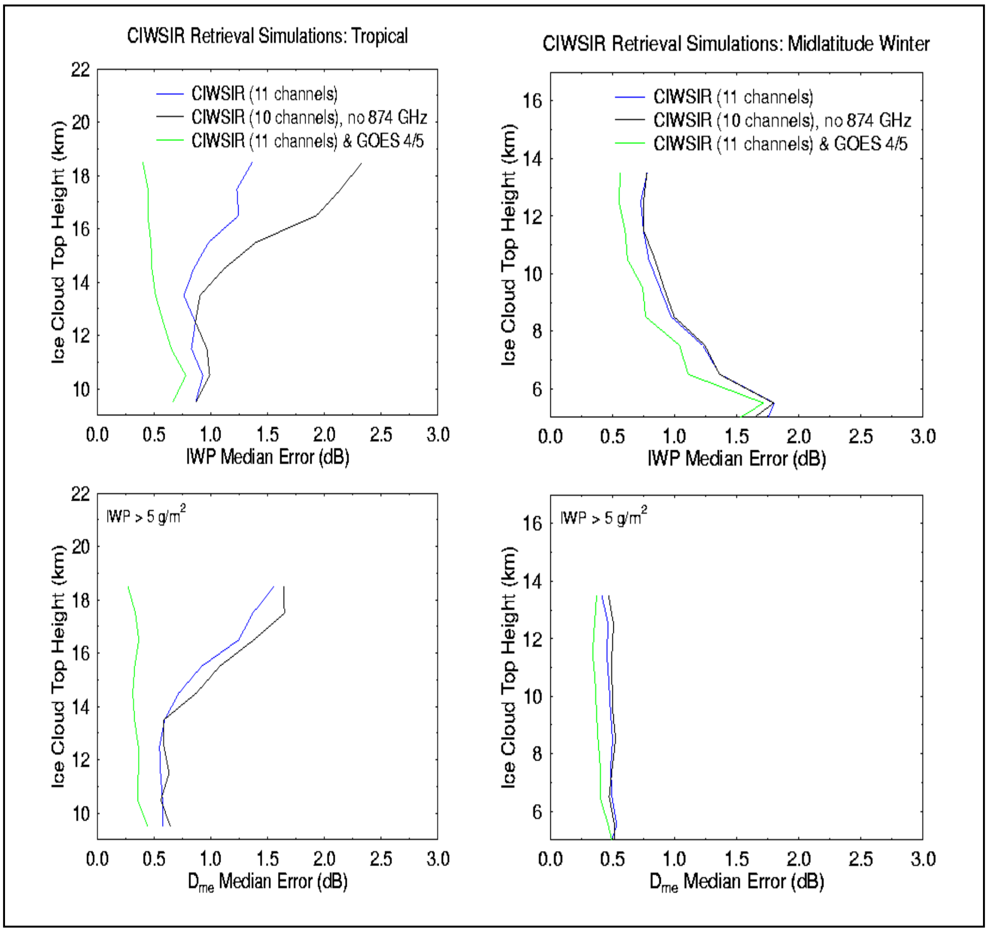


Figure C.2.11. - IWP and D_{me} median error as a function of cloud top height for tropical and mid latitude winter simulations. Three potential CIWSIR configurations are shown.

The most important use of CIWSIR measurements would be to determine the average IWP over an area to compare with climate model fields for evaluating GCMs. Averaging reduces the random retrieval errors and also the sampling errors. Sampling errors arise from estimating the mean of a population by measuring only some samples. A low Earth orbit only allows a satellite instrument to measure a small fraction of the time series of cloud properties in a particular GCM grid box. Nevertheless, the mean ice water path can be well estimated if enough independent samples of the time series are measured. However, if the mean over the diurnal cycle is desired, then the measurements have to cover the complete diurnal cycle.

C.2.3.5. Area averaged Retrieval Accuracy

The area averaged sampling and retrieval errors are estimated by averaging the IWP over groups of cases in the testing dataset. The N=10,000 simulated cases are divided into N/M groups of M independent samples each. The sampling error is the rms of the difference between the mean true IWP in each group and the mean over all 10,000 cases. The retrieval error is the rms over the groups of the difference between the mean true IWP and mean retrieved IWP of each group. The retrieval error does not include the sampling error. The pixel averaged sampling and retrieval errors are absolute (not fractional) errors expressed in g/m^2.

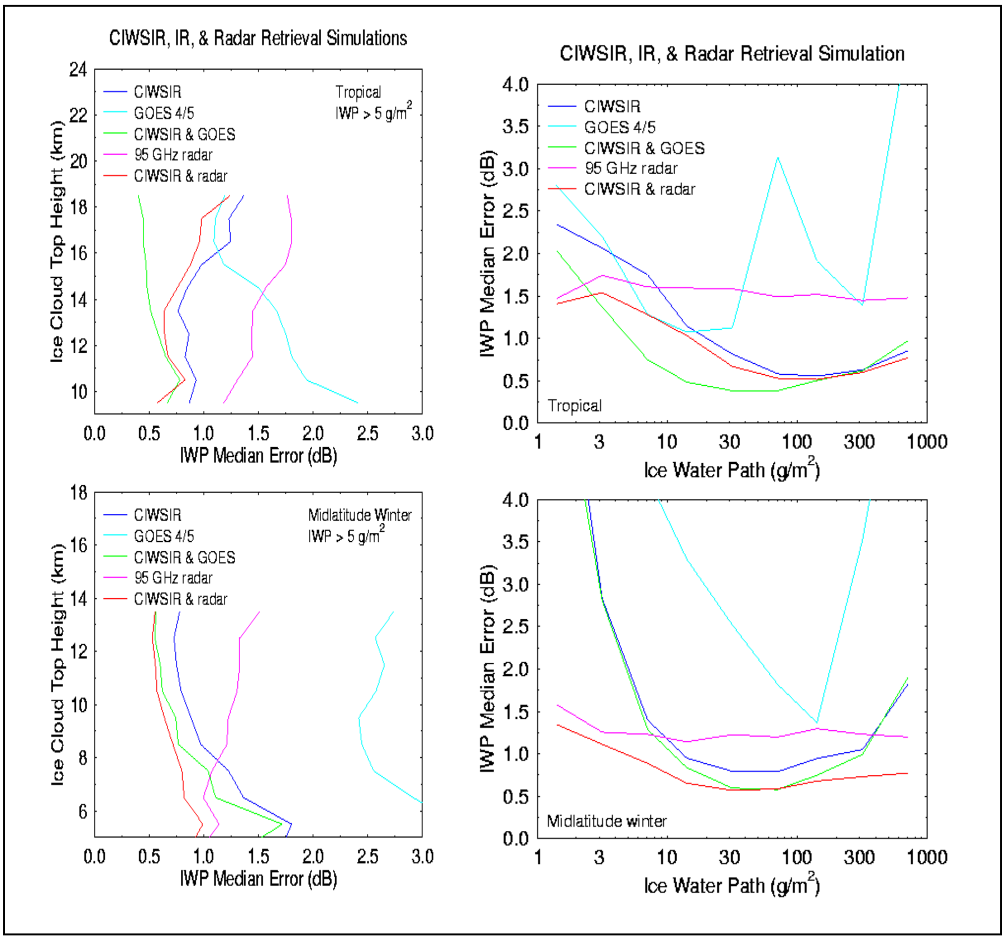


Figure C.2.12. - IWP median error as a function of cloud top height and IWP for tropical and mid latitude winter retrieval simulations. The full 11 channel CISWIR configuration is compared to and combined with 10.7 μm and 12 μm GOES channels and with integrated back-scatter and mean height from a 95 GHz RADAR.

Figure C.2.13 shows how the rms sampling and retrieval errors depend on the number of independent samples for the tropical and mid latitude winter simulations. The sampling error almost perfectly follows the expected $M^{0.5}$ dependence until the number of groups becomes small. It is important to note that for single samples, the rms sampling error for ice water path is larger than the mean. For these simulated clouds it takes 50 to 100 independent samples to reduce the sampling error to 25 % of the mean. The rms IWP retrieval error is comparable to the mean IWP for single pixel samples due to a few bad retrievals at high IWP that dominant the rms. The rms retrieval error is well below the sampling error until a large number of independent samples are averaged, and then the retrieval error tends to reach asymptotically a constant value. The CIWSIR rms retrieval error is about a factor of two lower than the RADAR retrieval error for 500 samples. The addition of two infrared channels to the CIWSIR (not shown) does not significantly reduce the retrieval error until it drops below about 5 g/m^2.

It is difficult to relate the number of observed pixels to the number of independent samples because nearby pixels are well correlated in cirrus fields. If we assume a 50 km decorrelation length, then a nadir-viewing instrument such as a RADAR measures 5 independent samples in a 250 km GCM grid box per orbital pass. The nadir-viewing instrument in a sun synchronous orbit samples a tropical grid box about 3 times per month at one of the two local times available. The wide swath CIWSIR in a sun synchronous orbit would measure 25 independent samples in a 250 km grid box per orbital pass and sample each tropical grid box 15 times per month. Thus in one month the nadir viewing instrument obtains about 13 samples in each tropical grid box at one of the two local times, while the CIWSIR obtains about 375 independent samples. Using the tropical simulation results from the figure shows that the nadir viewing instrument is dominated by sampling error and has an IWP rms error of 37 g/m^2 (compared to the mean of 50 g/m^2), while the CIWSIR has comparable sampling and retrieval errors with a total rms error of 6.3 g/m^2.

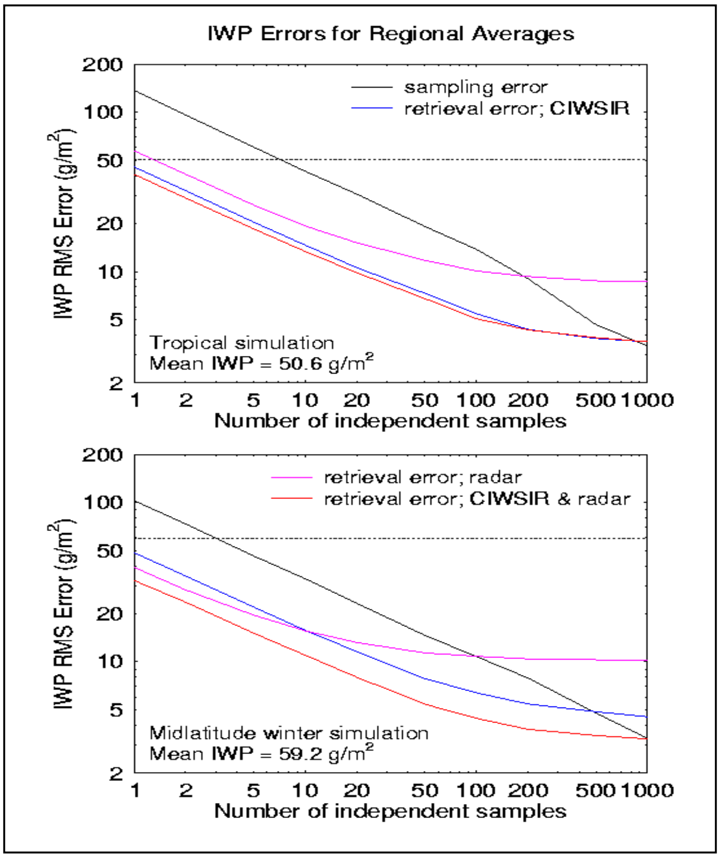


Figure C.2.13. - The RMS sampling and retrieval errors in ice water path for averaging a number of independent samples. The pixel averaged retrieval error for CISWIR alone, RADAR alone, and the combination. The mean IWP is indicated with a dotted line and listed in the lower left.

C.2.4. Other Mission Characteristics

Two different orbit types are possible for CIWSIR: (a) sun-synchronous orbit, or (b) non-sun-synchronous orbit. The orbit has not only consequences for the spatial and temporal sampling of CIWSIR, but also for possible synergies with other missions, as discussed in Section C.1.4.

Option (a) has the advantage that the mission can fly in tandem with an operational meteorological sensor. Among the various possible tandem partners, a strong candidate offering a multitude of sensors with a high potential synergy is the METOP mission. If it is possible to operate and manoeuvre CIWSIR in a fashion to fly in a short and constant distance from METOP so that both satellites scan the Earth in a distance of not more that 10 minutes, i.e., below the typical 10 km displacement time of upper tropospheric ice clouds, this innovative technique would allow a high synergy between the sub-millimetre measurements taken by CIWSIR and the infrared measurements taken by METOP (The synergistic effect of sub-millimetre and infrared measurements has already been demonstrated in the previous Sections).

On the other hand, option (b) has the advantage that the entire diurnal cycle could be measured, which would be very valuable. The disadvantage of this option is that synergistic infrared data is only available in limited areas from geostationary satellites. Furthermore, the usefulness of such an orbit depends on the resulting sampling errors (which would depend on the orbit inclination and precessing rate). Because of these uncertainties, option (b) should be assessed in a detailed sampling study in Phase A. The baseline option for now is option (a).

A mission duration of three years would allow for an initial assessment of the global upper tropospheric ice climatology, which may eventually lead to an operational sensor on later meteorological satellites.

The field of view must be sufficiently small to resolve the spatial scale of upper tropospheric ice clouds, around 10 km. Such a field of view is easily feasible, as outline in the technical section of the proposal.

The theoretical studies described previously have shown the sensitivity of sub-millimetre radiance to the presence of upper troposphere ice clouds. The theoretical expectations have been confirmed recently with sub-millimetre radiance measurements made by the Far-IR Spectrometer for Cirrus (FIRSC) (Vanek et al., 2001). This aircraft-based instrument is a polarizing beam-splitter Fourier Transform Spectrometer (FTS) with a He3 cryogenic (0.3 K) bolometer detector. During the Atmospheric Radiation Measurement FIRE Water Vapour EXperiment (AFWEX) in December 2000, FIRSC flew on the Proteus aircraft and measured sub-millimetre brightness temperature spectra (Figure C.2.14). Cloud RADAR indicated a cirrus layer from 6 to 10 km altitude. The spectra demonstrate that large brightness temperatures changes from clear sky can occur in cirrus conditions at sub-millimetre frequencies.

Although these measurements impressively demonstrate the potential of sub-millimetre sensing of ice clouds, our correct understanding of the radiative transfer, as well as the prototype retrieval algorithms, should be carefully tested with pre-launch aircraft campaigns with an instrument with the exact CIWSIR instrumental characteristics. During the CIWSIR mission a validation campaigns are scheduled in close co-operation with NOAA/ETL using several airborne instruments on various aircraft (see also section C.3).

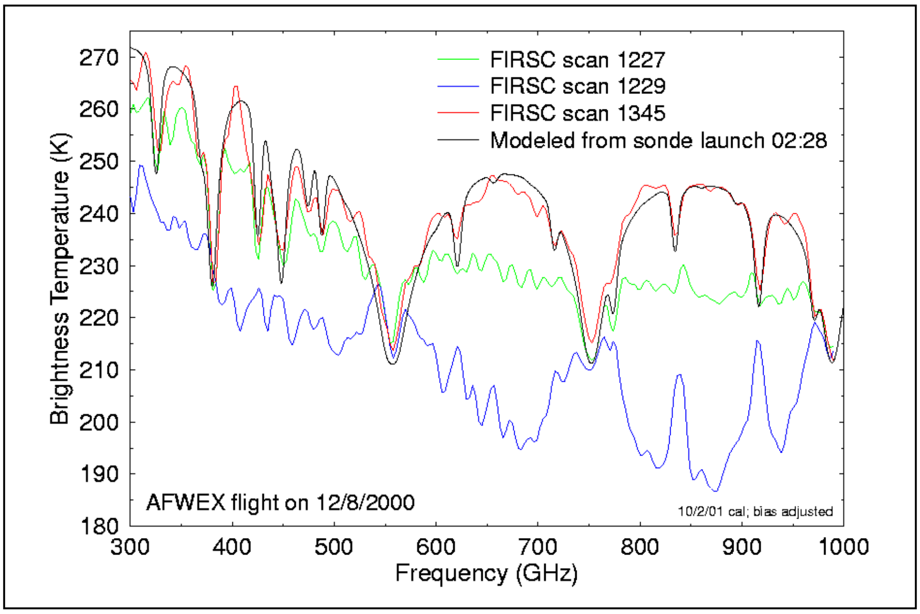


Figure C.2.14. - Example FIRSC observations from December 8, 2000 UTC near the ARM site in Oklahoma. Scan 1345 was a clear-sky condition and scans 1227 and 1229 were two cirrus situations with presumably different IWP and particle size. The spurious features are likely due to scene changes during the FTS scan as the aircraft flew over inhomogeneous cirrus.

C.3. Technical Concept

C.3.1. The CIWSIR Radiometer Package

The CIWSIR sensor is a microwave radiometer measuring thermal emission over a frequency range from approximately 180 GHz (wavelength ≈1.7 mm) to nearly 800 GHz (wavelength ≈0.4 mm) emitted from the earth atmosphere. A conical scanning scheme allows to achieve a near daily global coverage of the whole Earth, see figure C.3.1. Furthermore this observing geometry also permits to observe each surface pixel twice, once in the forward direction and again in the backward direction. A further advantage of this geometry is the constant incidence angle at the Earth surface facilitating the retrieval and allowing to more easily measure polarization effects.

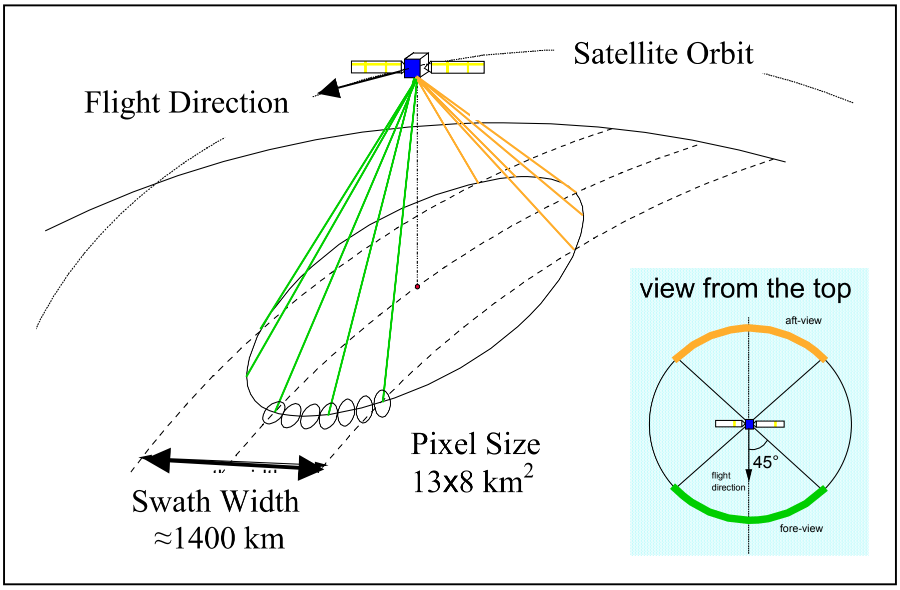


Figure C.3.1 – The conical scan geometry employed for the CIWSIR sensor

C.3.1.1 Quasi Optics

The optical system layout is driven by the requirement that all beams of all channels have to be co aligned in order to observe simultaneously the same pixel. Furthermore the scientific requirements need a footprint size of approximately 10 km. Considering the baseline orbit altitude of 830 km leads to an antenna diameter of 400 mm at 183 GHz. The co alignment requirement implies the need for a quasioptical frequency multiplexer (QMux).

Since it is difficult to illuminate one antenna with all five frequency bands ranging from approximately 183 GHz to nearly 900 GHz, a solution using to separate main antennas was chosen. The second antenna (parabolic) with a diameter of 160 mm serves the 448, 683 and 874 GHz bands (see figure C.3.2). This design simplifies the QMux design significantly because it reduces the number of frequency selective devices. In addition the band separation of the 183 and 325 GHz bands can be done with a simple wire grid avoiding sensitivity degradation due to dichroic plate losses (Figure C.3.3).

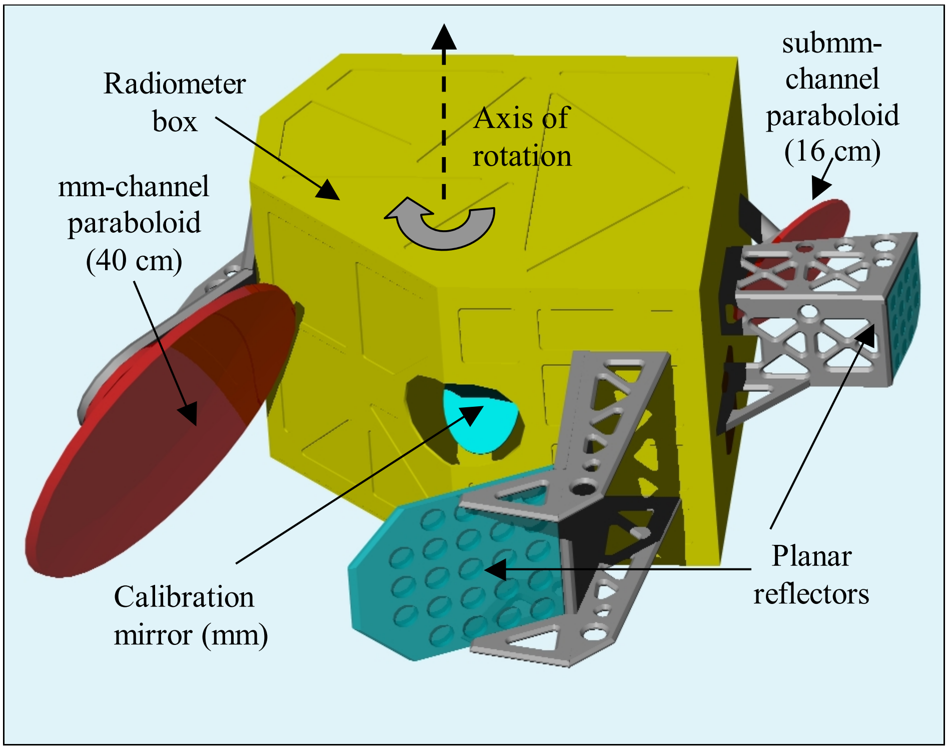


Figure C.3.2. - CIWSIR sensor package with the imaging parabolic antennas.

The basic design will use a complete sensor package comprising the high frequency and analogue elements of the receiver. The whole sensor package as shown in figure C.3.2 will be mounted beneath the satellite main body and rotate with a constant speed of 1 revolution every 2 seconds (0.5 Hz) around the axis also shown in figure C.3.2. This design allows to observe the target area twice, once in a forward direction and later looking backward. The extreme positions to the left and right of the satellite track are used for hot and cold calibrations respectively.

The main characteristics of the sensor are summarized in table C.3.1. Details can be found in the text.

Table C.3.1. – Summary instrument features of CIWSIR (H = 840 km)

Channels	5 in the range 183-880 GHz
IFOV	0.35° corresponding to an ellipse of 13 x 7.8 km^2 of area equivalent to 10 km circular, identical for all channels
Scanning	Conical, Nadir Angle at Sensor $\alpha = 45°$, Incidence Angle at Earth Surface $\zeta = 53.2°$, fore- and aft- views by $\pm 45°$ in azimuth, swath $\approx$ 1400 km
Sampling	1 scan / 2 s, 1 feed/channel, readings at 2.5 ms intervals
Antennae	L = 40 cm for the channels 1 and 2 at 183 and 325 GHz, L = 16 cm for channels 3,4 and 5 at 448, 683 and 874 GHz
Detection	Subharmonic Schottky-mixers for mm- channels 1, 2 and 3. Fundamentally pumped mixers for channels 4 and 5
Resources	Mass: 70 kg; volume (cylindrical): Ø 1100 mm, h = 430 mm. Electrical power: 100 W; data rate 58 kbps + HK

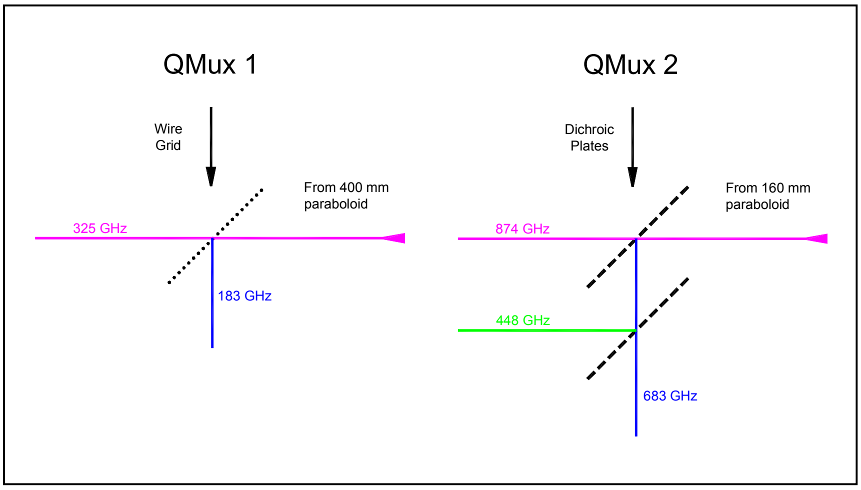


Figure C.3.3. - Quasioptical multiplexers for the two antenna systems.

A dichroic plate is a quasioptical high pass filter utilizing circular waveguides, which are at cut-off for the reflected band. Holes are drilled into the plate in a triangular pattern to bring the holes as close together as possible in order to minimize the diffraction lobes. Dichroic Plates are a good choice for separating frequencies which are not to closely spaced; typical transmission losses for a well designed plate is < 1dB. A total of two plates are needed for QMux 2 to separate the channels at 448, 683 and 874 GHz.

To co-align the beams with a maximum error of 10 %, the beams have to be parallel to better than 0.07 degrees° which can be done as has shown in other ESA/ESTEC projects (e.g. FIRST). Antenna performance and beam interaction with the satellite structure has to be measured in a suitable compact range. Recently antenna measurements at 500 GHz were presented by ASTRIUM. Their facility can be easily extended up to 640 GHz by adding frequency doublers to an existing system operated at 322 GHz. For measurements at the highest CIWSIR frequency of 880 GHz suitable sources have recently be developed for the FIRST project as will be discussed later. Therefore antenna measurements are considered to be within the state of the art for the CIWSIR bands.

C.3.1.2. Receiver Calibration

Two independent calibration systems are proposed: One for the 183/325 GHz channels and another one for the 448/683/874 GHz channels. Each calibration system consists of a light weight planar calibration mirror and calibration targets at ambient temperature. The mirrors are driven by a reliable 3 phase stepper motor (life time >6 years) with a step and settle time of <0.25 seconds. The stepper repeatability is <0.02°. The stepper controller accurately monitors the absolute mirror position and uses a reference position for initialisation.

The cold sky direction is shown in figure C.3.4. As mentioned earlier the sensor package rotates with a 0.5 Hz frequency. Calibration is performed for each revolution at the extreme positions to the left and right of the satellite track with an integration time of 30 ms for hot and cold calibrations.

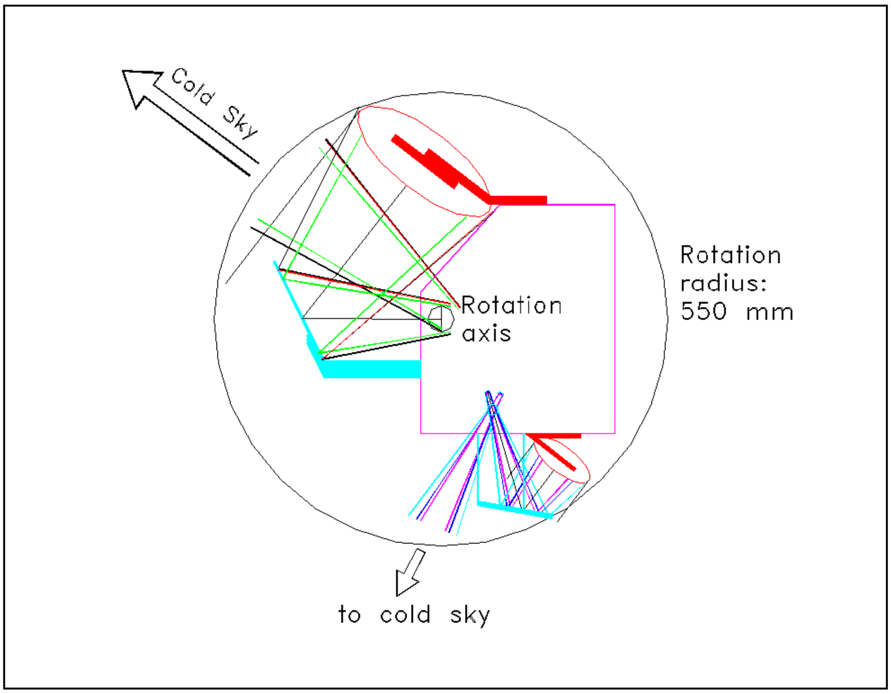


Figure C.3.4. - CIWSIR top view with the cold sky beam positions. For the 183/325 GHz the cold sky viewing direction is between the external planar mirror and the parabolic mirror. The instrument rotation axis is chosen in such a way to minimise the rotation diameter envelope (1100 mm).

Deep space is used as a cold target (≈2.7 K). The ambient temperature load is a pyramidal shaped absorber made from Ferrosorb CR-117 which is approved for space applications. Its reflectivity is less than -30 dB. The physical temperature of the target is accurately monitored by a Pt-type precision sensor to ±0.1 K. The ambient temperature load is thermally isolated to reduce thermal gradients. An active temperature stabilisation is not foreseen to avoid a temperature gradient between the radiating absorber surface and the absorber bulk material where the temperature is monitored. For an accurate calibration it is not important to keep the target temperature constant but to know exactly the radiometric temperature.

C.3.1.3. Receiver Technology

The CIWSIR receivers cover a wide spectral range of microwave frequencies so that two different receiver technologies are applied for optimum channel sensitivity. At 183, 325 and 448 GHz balanced subharmonically pumped mixers (SHM) are the best choice, since for fundamentally pumped mixers the required wide IF-bandwidths are difficult to achieve. At 183 GHz planar SHMs have been successfully designed and tested with DSB noise temperatures <1000 K. Planar Schottky diode technology for these mixers has been recently shown to be applicable up to at least 460 GHz.

At frequencies above 500 GHz fundamentally pumped mixers are preferred due to their superior sensitivity. At 683 and 874 GHz the IF requirements are feasible with this mixer type, an example is an uncooled Schottky diode receiver system operating at 640 GHz with a DSB system noise temperatures of <3000 K and a IF bandwidth of 4.5 GHz.

In the past Schottky diode receivers operating close to one THz suffered from low local oscillator power, because a standard Gunn/Multiplier chain delivers a maximum of only 150µW. Taking optical losses (diplexers, SSB filters, windows, mirrors etc.) into account this amount of power is not sufficient to drive the mixer to saturation, which is important for optimising the sensitivity. A recent development performed for the FIRST satellite project makes use of a 100 GHz high power amplifier chain, which delivers about 250 mW at ambient temperature over a wide bandwidth (92 to 110 GHz). Furthermore multi-diode planar Schottky multipliers have been developed to handle such high input power. Using this design concept a multiplier chain comprising 3 doublers driven by a 100 GHz amplifier using a synthesized reference signal as input has provided 1 mW of output power at 800 GHz. This power is sufficient to operate fundamental mixers operating near 1 THz under optimal conditions. Figure C.3.5 outlines the basic layout for all channels.

Due to thermal variations to be expected during one orbit (0-40°C) an effective frequency stabilisation is important. Especially for the high frequency receivers (683 and 874 GHz) where quasioptical Fabry Perot diplexers (FFP) are used the LO frequency stability is essential as will be discussed later (Critical Items). Furthermore phase stabilized LOs offer a much lower phase noise level than free running oscillators.

The receivers using SHMs (183, 325 and 448 GHz) can be equipped with local oscillators (LOs) comprising PLL stabilized Gunn oscillators or synthesizers in the 75 to 110 GHz range. Typical phase noise at 100 kHz off carrier is: -115 dBc, at 1 MHz off carrier: -140 dBc, the frequency stability over the operating temperature range (0-40°C): ±4.5 kHz at 424 GHz. The LO Gunn diodes are thermally stabilized to minimize amplitude drifts.

All IF chains are integrated planar structures with minimum power consumption and volume. Each of the detectors comprises its own 16 bit low power ADC to avoid spurious noise pickup on analogue signal cables and to improve redundancy. All data that leaves the receivers are in digitised form. Therefore data transfer between the rotating sensor package and the main satellite bus is in digital form only.

C.3.2. Critical Sensor Elements

A critical component for the very high frequency receivers (683 and 874 GHz) is the quasioptical diplexers needed to combine the signal and LO beams. Folded Fabry Perot Interferometers (FFPI) have been selected for this application for the following reasons: With this interferometer a wider IF bandwidth can be obtained than in the case of a polarisation rotating interferometer. On the other hand the LO coupling to the FFPI is more critical in terms of frequency drifts. In general the FFPI is mechanically compact and makes use of metal meshes, which are easier to handle than wire grids. The FFPI can be designed in several versions (quadratic or triangular, dual triangular) where the triangular FFPI offers the most compact and mechanically simple design. The cascaded triangular (dual triangular) FFPI has the advantage to be less sensitive to LO frequency drifts but is more complicated in terms of fabrication and adjustment. As an example figure C.3.6 shows the diplexer operated in a 680 GHz receiver and its transmission characteristic. For reasons of compactness and fabrication we selected the triangular FFPI version. In a triangular resonator the beam performs an odd number of reflections, and the vertical LO-cross polarisation is suppressed.

The FPI comprises two reflective meshes (typically 70% reflectivity) forming a resonator The optical distance between these meshes is close to $\lambda_{IF}/4$ and the structure is tuned to be resonant for the LO frequency. The LO beam is transmitted through the interferometer while the signal bands are reflected. The transmission characteristic for the 874 GHz FFPI-diplexer is shown in figure C.3.6. The IF bandwidth is 3 GHz with a centre frequency of 6 GHz. Both sidebands are shown. It is obvious that the two sideband reflection characteristics are very flat while the LO transmission has a narrow peak. The peaking LO transmission is critical when temperature changes lead to a thermal expansion or contraction of the diplexer. For the example shown in figure C.3.5 a 10% LO transmission change is caused by a 3 µm change of the optical mesh distance. A temperature change of 40°C, as assumed for the CIWSIR mission during one orbit, would lead to a linear diplexer expansion of a tolerable 0.6 µm when using INVAR. By an appropriate thermal isolation the temperature changes can be further reduced.

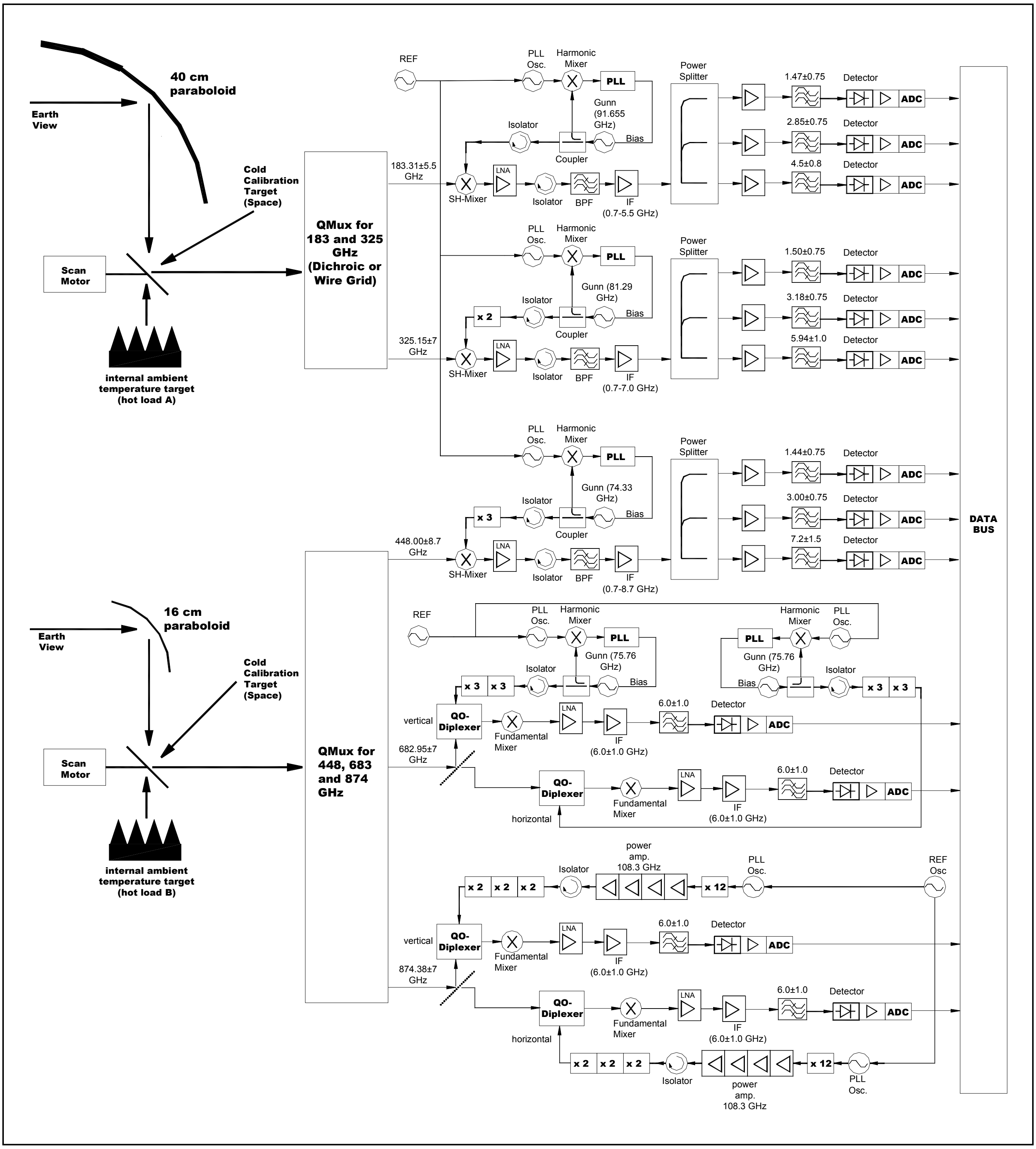


Figure. C.3.5. - CIWSIR schematic system layout.

Another critical specification is the LO frequency stability. From figure C.3.6 it can be seen that a 10% transmission change is caused by a 250 MHz LO frequency shift. Therefore the LO's are either using synthesized reference frequencies or phase lock circuits (PLL) in order to stabilise the local oscillator frequencies.

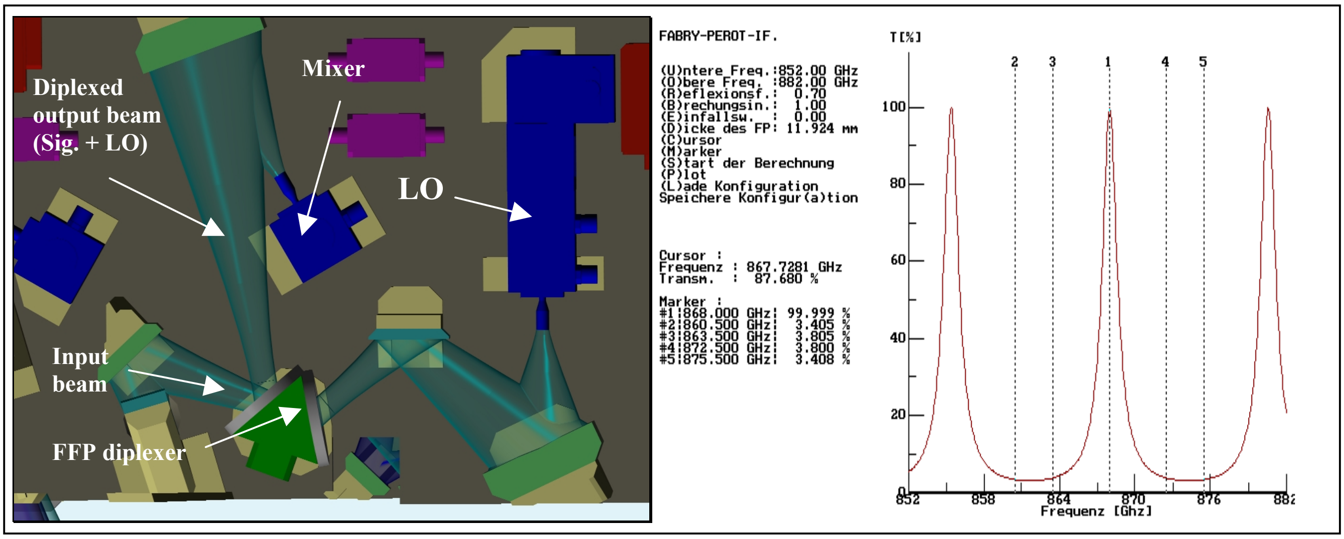


Figure C.3.6. - Quasioptical Diplexer of the 683 GHz channel (horizontal polarisation) and the 874 GHz diplexer transmission characteristics.

Table C.3.2 summarizes the achievable sensitivities and characteristics of the CIWSIR receivers. These numbers are in agreement with the requirements outline in chapter C.2. With the exception of the two high frequency channels, all other channel are single polarized.

Table C.3.2. - List of required and expected receiver sensitivities

ν (GHz)	**Δν (MHz)**	**Required NEΔT (K)**	**Expected System Noise Temp. DSB [K]**	**Integration time τ (ms)**	**Expected NEΔT (K)**
183.31 ± 1.47	1380	1.14	1000	2.5	0.54
183.31 ± 2.85	1380	1.14	1000	2.5	0.54
183.31 ± 4.5	1920	1.14	1000	2.5	0.46

ν (GHz)	**Δν (MHz)**	**Required NEΔT (K)**	**Expected System Noise Temp. DSB [K]**	**Integration time τ (ms)**	**Expected NEΔT (K)**
325.15 ± 1.50	1680	1.40	2000	2.5	0.98
325.15 ± 3.18	1680	1.40	2000	2.5	0.98
325.15 ± 5.94	3000	1.24	2000	2.5	0.73

ν (GHz)	**Δν (MHz)**	**Required NEΔT (K)**	**Expected System Noise Temp. DSB [K]**	**Integration time τ (ms)**	**Expected NEΔT (K)**
448.00 ± 1.44	1560	1.61	2500	2.5	1.27
448.00 ± 3.00	1560	1.61	2500	2.5	1.27
448.00 ± 7.20	3000	1.35	2500	2.5	0.91

ν (GHz)	**Δν (MHz)**	**Required NEΔT (K)**	**Expected System Noise Temp. DSB [K]**	**Integration time τ (ms)**	**Polarization**	**Expected NEΔT (K)**
682.95 ± 6.0	3000	1.48	3000	2.5	dual	1.10
874.38 ± 6.0	3000	2.08	5000	2.5	dual	1.83

The CIWSIR mechanical and electric characteristics of the sensor package are summarized in table C.3.3 and table C.3.4.

C.3.3. – Mass budget for the CIWSIR sensor package

Unit/Subassembly	Allocated mass [kg]
Frame structure	10.0
Outer shell (incl. insulation)	10.0
Optic boards	7
Elliptical mirrors	2
Pedestals, mounting elements	5
RF-components	8.0
IF-components	3.0
Grids, dichroics	1.5
Planar mirrors	2
DC-DC converters, power supplies, data acquisition system	8.0
Scanning mirror, motor and calibration targets	5.0
Cables	5.0
Total	**66.5**

C.3.5. – Electrical power requirements for the CIWSIR sensor

Unit/Subassembly	Allocated power
Receivers	35 W
Control and processing	20 W
Power supplies, DC-DC converter losses	20 W
Average power cons. for calibration system (hot load and stepper)	5 W
Thermal stabilization (LOs, IF amplifiers)	20 W
TOTAL	**100 W**

C.3.3. CIWSIR Satellite Bus

A dedicated, small satellite for the CIWSIR Sensor is based on an upgrade of the flight proven SAFIR and MITA Satellite Buses. MITA fits well concerning shape and general mission aspects. Bus electronics are mainly based on SAFIR. Further subsystems like Sensor Support Unit and ACS are derived from DIAMANT / MSC and ABRIXAS.

The main Design drivers for the CIWSIR mission are:

- High average power requirements per orbit of ~ 220 W requires relatively big solar panels (~3 m^2). As baseline a configuration with 2 deployable panels is chosen (see figure below). Optionally only 1 panel can be used in conjunction with rotation of the satellite around the nadir axis for sun pointing. In this latter case the scanning speed of the instrument must be controlled.
- To maintain the nadir pointing attitude of the rotating instrument (Moment of Inertia $I_{zz} \approx 10$ kgm^2, angular velocity 0.5 revolutions/s), the resulting angular momentum ≈30 Nms has to be balanced by a reverse rotating reaction wheel.
- The optional tandem flight constellation with an operational polar orbiting satellite, e.g. METOP requires an Orbital control system to maintain the orbit and position. As baseline a cold gas system is envisaged.

The SAFIR/MITA heritage and a sketch of the CIWSIR satellite is shown below in figure C.3.7.

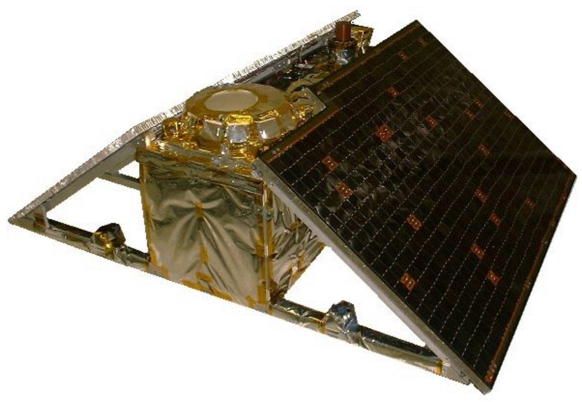
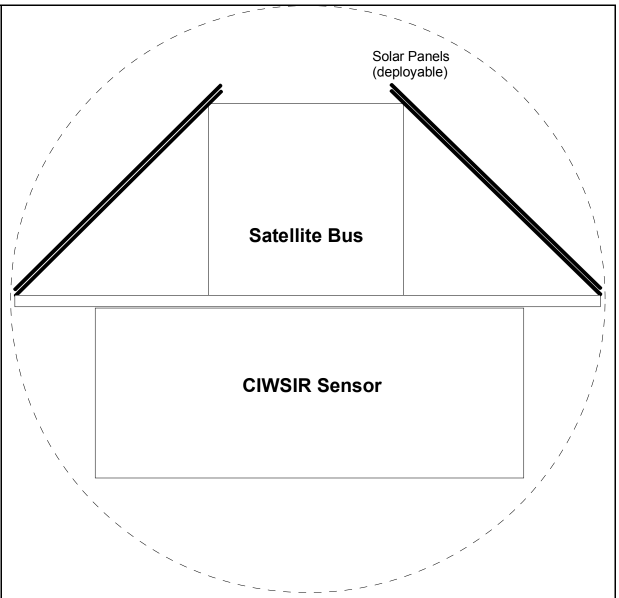
	
SAFIR/MITA satellite	CIWSIR satellite (envelope ∅ = 1,5 m, Max height 1,7 m)

Figure C.3.7. - CIWSIR Satellite bus outline

A summary of the various satellite parameters is given in table C.3.6.

C.3.4. Ground Segment

For the ground segment the existing infrastructure of ESA is proposed as baseline for Mission Operation (e.g. ESOC). For TT&C one S-Band station with one regular contact per week is sufficient (TBC). Additional contacts during LEOP and on request of Mission Control are required.

For Data Reception the Trade Off between S- or X-band data downlink is driven by Space Segment complexity versus Ground Segment complexity. In case of X-band one more or less arbitrary station can be used (e.g. Kiruna), since less than 5 minutes contact per day are required. In case of S-band a minimum network of 3 stations is needed to achieve ~260 minutes of contact per day (e.g. Kiruna, Maspalomas, Perth). At this stage of the project X-band transmission is proposed as baseline.

Data Pre-processing of Level 1 Products (geometric correction and radiometric calibration) and Archiving is proposed to be performed by the same station that is finally chosen for data receiving. Mission Control is performed by OHB and members of the leading science team.

The data utilisation will be shared among the Science Team members, it is expected that in a first task the data will be validated using a combination of auxiliary data, models and information collected during dedicated campaigns. The second step will be implementation of the algorithms for volume processing of the data to get from level 1 to level 2. Finally selected level 3 products will be generated and data assimilation schemes will be implemented.

All data utilisation activities will be co-ordinated by the Core Science Team.

Table C.3.6. – CIWSIR satellite bus characteristics

Weight	320 kg including a maximum of 70 kg for the CIWSIR Sensor
Overall dimensions	1,5 x 1,7 x 1 m^3 (Launch configuration)
Orbit	Sun synchronous at 830 km altitude RAAN 9:40 (Constellation to METOP +/- 10 min)
Design life	3 years
Launcher	Baseline COSMOS
Stabilization	3 axes stabilized, nadir pointing
Operation	Permanent CIWSIR data take (nadir pointing) and recording, additional data downlink
Power	Average power of about 220 W with a peak value of about 270 W during transmission, all incl. 100 W P/L power Primary power generation by fixed solar panels (GaAs, ≈ 3 m^2), NiH_2 batteries
Thermal	Passive with radiators
Attitude control	Three axis stabilisation system, pointing accuracy: ±0,07°, knowledge ±0,01°, based on star sensors, magnetometers, reaction wheels, magnetic torquers
Orbit Control (optional)	Acquire and maintain constellation to METOP, distance within 10 min ± 1min based on Cold Gas System, Δv requirement ≈60 m/s (acquisition, maintenance)
De-Orbit function (optional)	Based on OCS, additional Δv requirement ~ 230 m/s (de-orbit)
Onboard Data Handling	Data handling based on DSP processor operating system: real time multitasking
Sensor Control Computer	Instrument, Storage and Communication Control based on DSP processor
Data storage	16 Gbit, Science data volume 5,2 Gbit/day (356 Mbit/orbit)
Telemetry and tracking	TM/TC protocole CCSDS compatible TM: S band, Bit rate: 512 kbps, TC: S band, Bit rate: 4 Kbps
Communication	X band link: 30 Mbps, link data volume ~7,8 Gbit/ day (incl. overheads), downlink time per day < 5 min

C.3.5. Launcher

A detailed analysis of different launch options for CIWSIR will be performed during phase A. The Russian COSMOS launcher has been selected as the baseline launcher for CIWSIR in terms of reliability and cost efficiency.

The COSMOS launcher is a two-stage liquid propellant space transportation system for small to medium payloads into low Earth orbits. It is the world's most successful launcher with an efficiency of 97,4% successful attempts for a total of over 740 launches.

A further criteria for the selection of COSMOS are the experiences at OHB-System made during the launch campaigns of ABRIXAS and CHAMP, which have both been successfully performed by a

Joint Venture between OHB-System and the Russian companies PO/KB Polyot and Rosvooruzhenie SMMF.

The suitability of COSMOS for the launch of CIWSIR can be seen when considering the payload volume and payload mass, in relation to COSMOS performance in figure C.3.8.

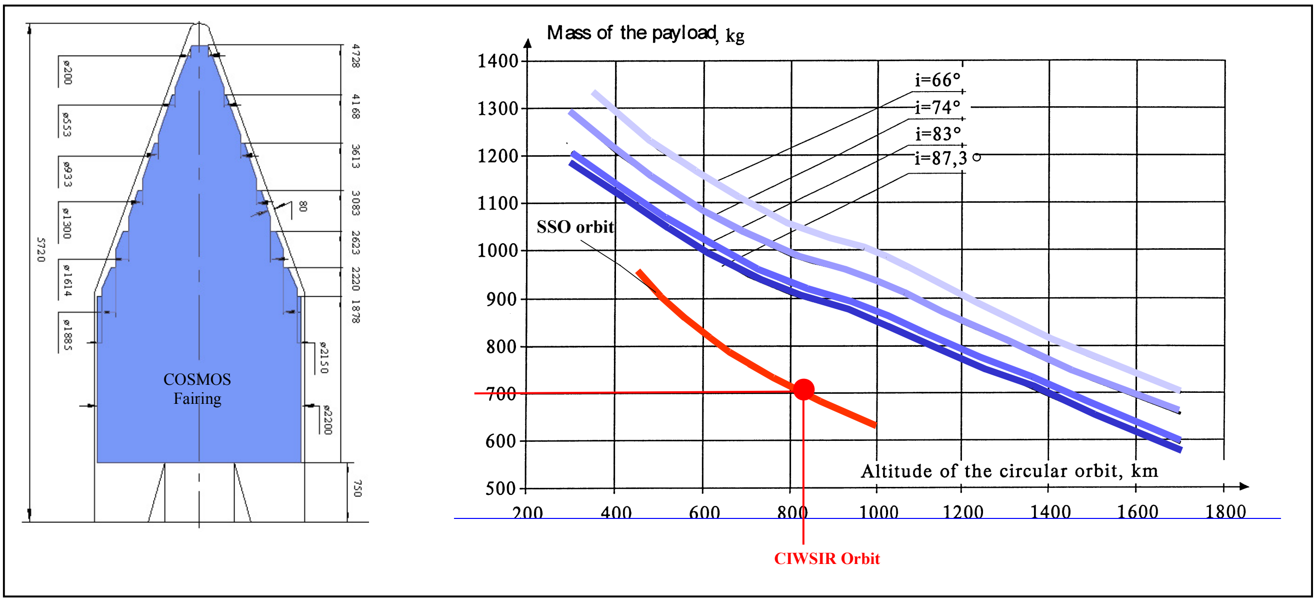


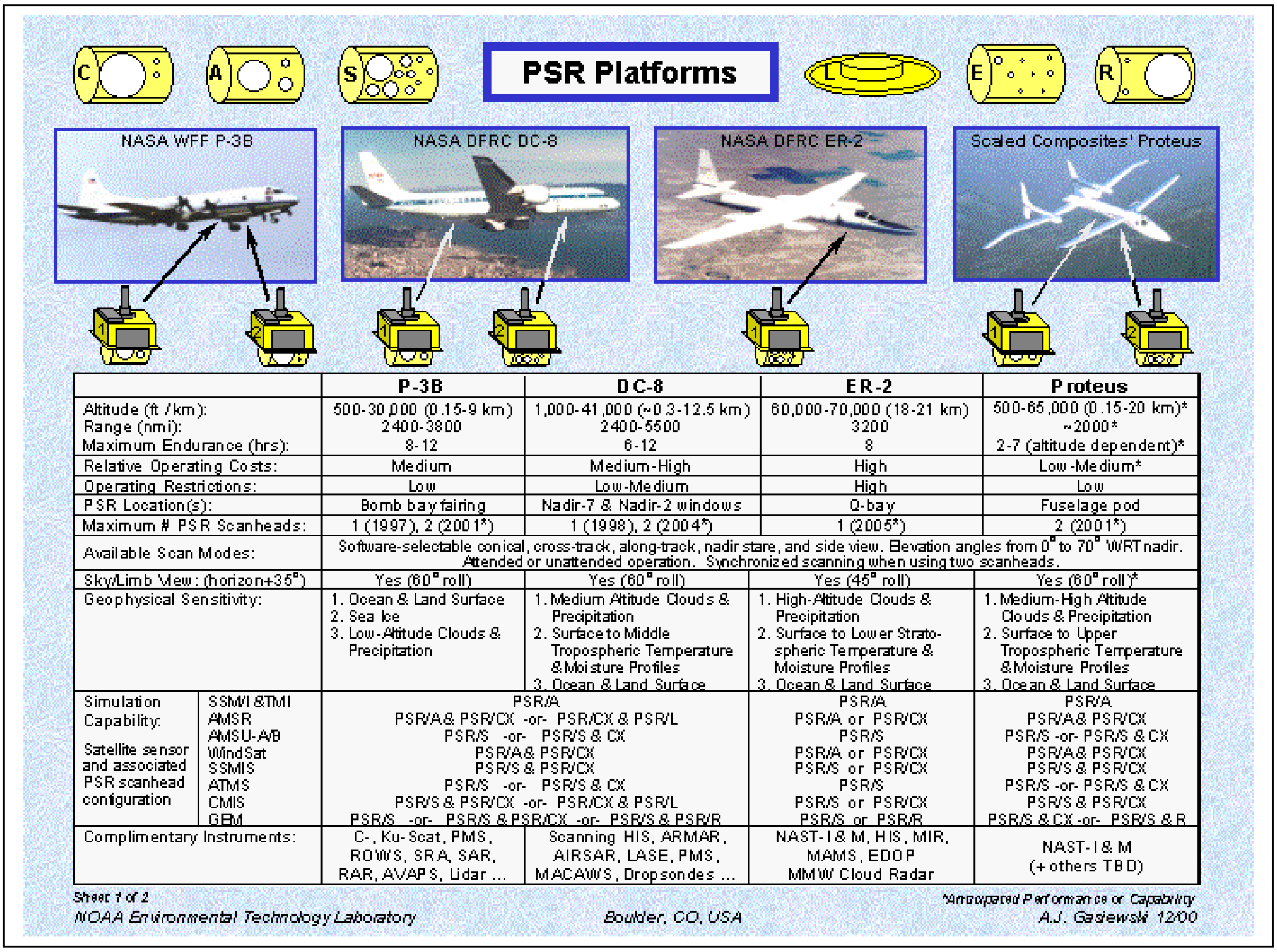
Figure C.3.8. - COSMOS launch capacity with respect to payload volume and mass

C.3.6. Pre-Launch Test and Post-Launch Validation Campaigns

A successful CIWSIR project will need a considerable research effort pre-launch in order to test and optimize retrieval algorithm and post-launch a complete validation of the collected data will be needed. Bothe activities will require airborne sensors capable to operate above the area of intereset, wihich is the upper troposphere and tropopause region. Therefore we plan make use of suitable sensors already available, and will also use the engineering model (EM) and to the some extent the engineering model (PFM) of the CIWSIR instrument (see also section C.4) as sensor on a suite of various aircraft. Access to the aircraft is provided by NOAA/ETL which has large experience in conducting research campaigns using aircraft with the appropriate capabilities for our campaigns. For details of available aircraft and senors see figure C.3.9. The range of aircraft includes platforms with maximum altitudes ranging from 8 km (NASA WFF P-3B) to high altitude aircraft such as the ER-2 and Proteus with a ceiling of more than 20 km. All aircraft can carry the standard NOAA instrumentation and will also be able to accommmodate the CIWSIR EM/PFM instrument.

As expressed in the letter of support provided by William D. Neff, Director, NOAA/ETL (see also section C.5, "Implementation") NOAA/ETL will provide support for the campaigns including access to appropriate aircraft and provide support for interfacing CIWSIR hardware into the scan heads. In addition NOAA/ETL will take the lead in campaigns and the collection of correlative data for validating the CIWSIR algorithms and measurements.

It is important to note that this contribution is instrumental for the success of the CIWSIR project, and at present NOAA/ETL is the only organisation able to provide the necessary aircraft to conduct these campaigns.



		P-3B	DC-8	ER-2	Proteus
Altitude (ft / km): Range (nmi): Maximum Endurance (hrs):		500-30,000 (0.15-9 km) 2400-3800 8-12	1,000-41,000 (~0.3-12.5 km) 2400-5500 6-12	60,000-70,000 (18-21 km) 3200 8	500-65,000 (0.15-20 km)* ~2000* 2-7 (altitude dependent)*
Relative Operating Costs:		Medium	Medium-High	High	Low-Medium*
Operating Restrictions:		Low	Low-Medium	High	Low
PSR Location(s):		Bomb bay fairing	Nadir-7 & Nadir-2 windows	Q-bay	Fuselage pod
Maximum # PSR Scanheads:		1 (1997), 2 (2001*)	1 (1998), 2 (2004*)	1 (2005*)	2 (2001*)
Available Scan Modes:		Software-selectable conical, cross-track, along-track, nadir stare, and side view. Elevation angles from 0° to 70° WRT nadir. Attended or unattended operation. Synchronized scanning when using two scanheads.			
Sky/Limb View: (horizon+35°)		Yes (60° roll)	Yes (60° roll)	Yes (45° roll)	Yes (60° roll)*
Geophysical Sensitivity:		1. Ocean & Land Surface 2. Sea Ice 3. Low-Altitude Clouds & Precipitation	1. Medium Altitude Clouds & Precipitation 2. Surface to Middle Tropospheric Temperature & Moisture Profiles 3. Ocean & Land Surface	1. High-Altitude Clouds & Precipitation 2. Surface to Lower Stratospheric Temperature & Moisture Profiles 3. Ocean & Land Surface	1. Medium-High Altitude Clouds & Precipitation 2. Surface to Upper Tropospheric Temperature & Moisture Profiles 3. Ocean & Land Surface
Simulation Capability: Satellite sensor and associated PSR scanhead configuration	SSM/I &TMI	PSR/A		PSR/A	PSR/A
	AMSR	PSR/A & PSR/CX -or- PSR/CX & PSR/L		PSR/A or PSR/CX	PSR/A & PSR/CX
	AMSU-A/B	PSR/S -or- PSR/S & CX		PSR/S	PSR/S -or- PSR/S & CX
	WindSat	PSR/A & PSR/CX		PSR/A or PSR/CX	PSR/A & PSR/CX
	SSMIS	PSR/S & PSR/CX		PSR/S or PSR/CX	PSR/S & PSR/CX
	ATMS	PSR/S -or- PSR/S & CX		PSR/S	PSR/S -or- PSR/S & CX
	CMIS	PSR/S & PSR/CX -or- PSR/CX & PSR/L		PSR/S or PSR/CX	PSR/S & PSR/CX
	GEM	PSR/S -or- PSR/S & PSR/CX -or- PSR/S & PSR/R		PSR/S or PSR/R	PSR/S & CX -or- PSR/S & R
Complimentary Instruments:		C-, Ku-Scat, PMS, ROWS, SRA, SAR, RAR, AVAPS, Lidar ...	Scanning HIS, ARMAR, AIRSAR, LASE, PMS, MACAWS, Dropsondes ...	NAST-I & M, HIS, MIR, MAMS, EDOP MMW Cloud Radar	NAST-I & M (+ others TBD)

Figure C.3.9. – Aircraft available for atmospheric research at NOA/ETL, and characteristics of standard sensors

C.4. Mission Elements an associated Costs

C.4.1. Costs for Sensor Package

The cost estimate has been performed making the following assumptions on the model philosophy:

- Engineering model (EM) with reduced number of channels (but covering all frequencies). The EM shall cover all critical aspects of the receiver technology and is intended to demonstrate the feasibility of the proposed specifications.
- Protoflight model (PFM), which is completely space, qualified. Components from the PFM can be used as spare if required. The PFM is equivalent to the flight model (FM) and is qualified to the same level as the FM.
- Flight Model (FM)

The estimated costs for the CIWSIR receiver section can be found in table C.4.1.

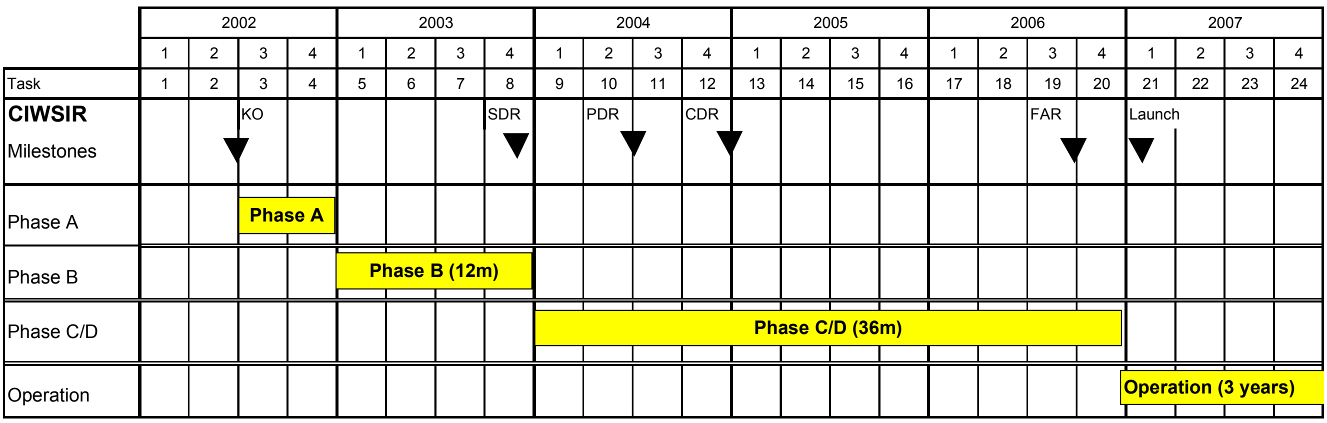
Table C.4.1. – Cost estimate for CIWSIR sensor package

Model	Personal Costs [M€]	Qualification & Tests [M€]	Test Equipm. [M€]	Overheads [M€]	Receiver Components [M€]	
EM	0.6	0.4	0.5	0.1	0.4	
PFM	6	2.8	2.5	0.5	1.3	
FM	5.4	2.8	0	0.4	1.3	
Subtotal	12	6	3	1	3	**25 M€**
Sensor Support Unit						5 M€
					Total	**30 M€**

It is expected to use a combination of the PFM and EM also in the prelaunch phase for airborne scientific campaigns and during the mission for validation campaigns, as outline in Section C.2.

C.4.2. Mission Elements and Associated Costs

Based on the mission and instrument requirements a development program of 18 month Phase A/B and 36 month Phase C/D is estimated compliant with the timing and funding limitations given by the 2nd call for EEOMs for a launch in 2007 (see schedule below).



A cost estimate based on the results of the CLOUDS Phase-A study has been made by industry. The total cost for the CIWSIR mission, including the instrument, the satellite bus, integration and launch, the ground segment and data exploitation is estimated in the order of 80 M€ with some funding (see table C.4.2 and table C.4.3) from other sources.

The cost estimation for the CIWSIR mission and elements were estimated taking into account the following heritage and assumptions:

- Small Satellite Heritage: SAFIR 1/2, LLMS, ABRIXAS, MITA
- For the platform, standard elements already developed for the mentioned missions can be used. More mission specific elements are the attitude and orbit control subsystem (AOCS) and the electrical power system.
- The platform costs comprise 1 flight model (FM) and 1 engineering model (EM). The EM covers only selected components like OBDH, Sensor Control Computer and Data Storage. The EM will be used as functional model and for I/F testing.
- The launch costs are based on a dedicated launch. As the launcher allows secondary payloads a cost reduction may be achieved.
- The Sensor Support Unit comprises Sensor Control Computer, Data Storage and Downlink

An overall cost summary and assumed funding sources can be found in the following table C.4.2 and table C.4.3 (corresponding to "Table 3" and "Table 4" in the Call for Proposals).

Table C.4.2. – Mission elements and activities: implementation and funding sources assumptions

Mission Elements		Implementation	Assumed Funding Source
Science preparation	Scientific definition studies	Scientific Inst. Research Centres	ESA, National, EC
	Campaigns	Industry & Scientific Inst.	ESA, NOAA, National
System engineering and assembly, integration and test		Industry (FUCHS GROUP)	ESA
Space segment	Instruments	Industry (RPG)	ESA
	Platform	Industry (FUCHS GROUP)	ESA
	Launcher	Industry (FUCHS GROUP)	ESA
Ground segment facilities	Command & acquisition stations	ESA	ESA
	Operations centre	ESA (ESOC)	ESA
	Processing and archiving	ESA (Level 1)	ESA
Mission control and data exploitation	Mission control	Industry (FUCHS GROUP), Science Team	ESA
	Data utilisation	Science team and Scientific community Operational services	National, EC

Table C.4.3. – Cost Estimates

Mission Elements		Cost Estimates ESA	Cost Estimates Other
Science preparation	Scientific definition studies	0.5 M€	1 M€
	Campaigns	0.5 M€	1.5 M€
System engineering and assembly integration and test		5 M€	
Space segment	Instrument incl. Sensor Support Unit	30 M€	
	Platform incl. OCS[1])	24 M€	
	Launcher	13 M€	
Ground segment facilities	S-band Command (1 contact/ week) & X-band acquisition stations (1 contact/ day)	1,5 M€	
	Operations centre	1 M€	
	Processing and archiving (level 1)	1,5 M€	
Mission control and data exploitation	Mission control	1,5 M€	
	Data utilisation		1.5 M€
Total Costs		**78,5 M€**	**4 M€**

[1]) OCS: Orbital Control System to maintain tandem orbit with METOP

C.5. Implementation

The CIWSIR team consists of three different elements, first the core science team includes all the scientists actively working on the CIWSIR team either with respect to the scientifique or technical aspects, details can be found in table C.5.1. The core team will also be responsible together with appropriate organisations to process the data from level 0 up to level 2 and 3. The scientists on the core team all have large expertise in atmospheric remote sensing, and are recognized experts in this field.

Next comes the large group of interested scientists, the so called Science Team, here we find mainly data useres ranging from scinetists to meteorologists and climatologists, main emphasis of this group is on data usage, and not on the sensor or the retrieval, this group will be interested in level 2 and 3 data, or level 1 for data assimilation.

The core science group is supported by industry for the hardware development and testing. In the baseline these companies have been selected based on there large expertise in the particular sensor technology and with respect to there experience in the design and launch of small satellites.

Table C.5.1. – Core Science Team Members

Partner	Affiliation	Country	Key Activity
Dr. S. Bühler	University of Bremen	Germany	Radiative Transfer, Retrieval, non resonant water vapour absorption
Dr. P. Eriksson	Chalmers University	Sweden	Retrieval, Spectroscopy, co-ordination with ODIN Project
Dr. F. Evans	University of Colorado	USA	Radiative Transfer, Retrieval, scattering by non-spherical particles
Dr A. Gasiewski	NOAA/ Environmental Technology Laboratory	USA	Airborne Tests and Validation, data use in meteorology
Dr. G. Heygster	University of Bremen	Germany	Meteorological Applications, radiative transfer and retrieval
Prof. Dr. N. Kämpfer	University of Bern	Switzerland	Test of Quasi-Optical parts, receiver performance
Prof. Dr. K, Künzi	University of Bremen	Germany	PI
Dr. A Macke	University of Kiel	German	Non-spherical particles
Dr. J. Miao	University of Bremen	Germany	Radiative Transfer, effect of minor atmospheric constituents
Dr. J. Notholt [1])	Presently: Alfred-Wegener-Institute Potsdam	Germany	Role of Water in the UTLS, water vapour isotopes
Dr. J. Urban	Bordeaux University	France	Spectroscopy, Water Vapour
Dr. U. Wacker	Alfred-Wegener-Institute Bremerhaven	Germany	Microphysics of clouds, numerical modelling

[1]) Starting 1 April 2002 Dr. Notholt will join the Institute of Environmental Physics, University of Bremen, see also note at beginning of Annex 1, "Team Composition"

C.5.1 Supporting Meteorological Organizations

The following meteorological organizations have expressed a particular interest in the CIWSIR project (in alphabetical order):

- DWD, German Weather Sertvice, point of contact is Dr. W. Benesch
- Hadley Centre for Climate Prediction and research, point of contact is Dr. J.M. Edwards
- Meteorological Office, UK, point of contact is Dr. A.J. Baran
- NOAA/ETL, USA, point of contact is Dr. A. Gasiewski

Letters of recommendation signed by the approriate representatives of these organisations can be found in Annex 3, "Letters of Recommendation".

Annex 1: Team Composition

The Team includes 3 different types of participants, (a) the scientific core Team, (b) the wider scientific team and (c) the industrial partners. The listing in each category is in alphabetical order.

Note on PI activity:

This proposal is submitted by the PI Prof. Dr. Klaus Kunzi, however if CIWSIR is selected he will have retired (2004), before CIWSIR is being launched. Dr. Justus Notholt a well-known scientist in atmospheric research is Prof. Kunzi's designated successor. Dr. Notholt will start working in the Institute of Environmental Physics at the University of Bremen on 1 April 2002. Therefore a nearly 2-year overlap exists between Prof Kunzi and Dr. Notholt, ample time to allow Dr. Notholt to acquire the necessary expertise to lead the CIWSIR team at the University of Bremen. Dr. Notholt has expressed his great interest in this project and he is committed to continue the needed activities of the CIWSIR mission. Furthermore the continuing support for CIWSIR will be secured by Dr. G. Heygster (Senior Scientist with tenure at the Institute of Environmental Physics, University of Bremen) who is presently a core science team member for this project.

(A) The Core Team

Dr. S. A. Bühler

Date of birth: 29 October 1969
Nationality: German
Address: University of Bremen
Fachbereich 1
Institute of Environmental Physics
P.O. Box 33 04 40
D-28334 Bremen, Germany
e-mail: sbuehler@uni-bremen.de

Phone: +49 (421) 218-4417
+49 (421) 218-4065 (Secretary)
Fax: +49 (421) 218-4555

Professional Interests and Experience:
Interests:

- Radiative transfer modelling
- Inversion algorithms
- Millimetre and sub-millimetre limb and nadir sounding
- Water vapour and other continuum emitters
- Distribution of water vapour in the atmosphere
- Climate feedback of water vapour and cirrus clouds

Project Experience:

Since 1995:	Work on ESTEC projects: ESTEC/Contract No 10998/94/NL/CN (Continuum Study) ESTEC/Contract No 11581/95/NL/CN (Spectroscopy Study) ESTEC/Contract No 12053/97/NL/CN (MASTER Study) ESTEC/Contract No 11979/97/NL/CN (SOPRANO Study) ESTEC/Contract No 13348/98/NL/GD (MASTER Study Extension)
Since 1998:	Member of COST 712 Workshop and project group 2
Since 1998:	Project manager of DLR Project 50 EE 9815 (JEM / SMILES)
April 1999:	Organizer of international radiative transfer workshop (Bredbeck I)
June 2000:	Organizer of international radiative transfer workshop (Bredbeck II)
Since 2000:	Funding by AFO 2000-C, Project 07 ATC 04 (UTH-MOS)
Since 2001:	Assistant Professor at the University of Bremen

Education:

1990-1993:	Undergraduate student, University of Tübingen, Dept. of Physics
1993:	Vordiplom, University of Tübingen
1993-1994:	Graduate student, State University of New York at Stony Brook, Dept. of Physics
1994:	Master, SUNY at Stony Brook. Thesis: A Study of Atmospheric Opacity near 275 GHz at very low Temperatures
1994-1998:	PhD student, University of Bremen, Institute of Remote Sensing
August 1998:	PhD, University of Bremen. Thesis: Microwave Limb Sounding of the Stratosphere and Upper Troposphere

Publications:
So far 25 publications. A detailed list can be found on http://www.sat.uni-bremen.de/members/sab

Dr. Patrick Eriksson

Date of birth: 25 November 1964
Nationality: Swedish

Address: Dept. of Radio and Space Science
Chalmers University of Technology
SE-412 96 Goteborg, Sweden
Phone: +46 31 7721832
Fax: +49 31 7721884
e-mail: patrick@rss.chalmers.se

Professional Interests and Experience:
Special interests:
- Microwave and sub-mm atmospheric observations
- Radiative transfer modelling
- Retrieval methodology
- Water in the atmosphere

Teaching in remote sensing and atmospheric physics

Dr. Patrick Eriksson has more than 7 years experience of forward modelling and retrievals of microwave and sub-mm atmospheric observations. The work has been focused on the sub-mm radiometer on-board the Odin satellite, the first and only operational sub-mm limb sounder, and he is a key person regarding the evaluation of these on-going measurements. He has been involved in a number of ESTEC studies on sub-mm limb sounding, and was leading the ESTEC project 15341/01/NL/SF (WATS). As a collaboration with Dr. S. Buhler, three international workshops on sub-mm radiative transfer has been held, and a public, modular, forward model has been developed (ARTS).

Education:
1999: Ph.D., Environmental Sciences, Chalmers University of Technology
1996: Licentiate of Engineering, Chalmers University of Technology
1990: M.Sc., Engineering Physics, Chalmers University of Technology

Publications:
About 40 publications. A list of the latest publications can be found at
http://www.rss.chalmers.se/gem/Contacts/Patrick_Eriksson.html

Dr. K. Franklin Evans,

Date of birth: 6 January 1962
Nationality: USA
Address: University of Colorado Phone: (303) 492-4994
311 UCB Fax: (303) 492-3524
Program in Atmospheric and Oceanic Sciences
Boulder, CO 80309 USA
email: evans@nit.colorado.edu

Professional Interests and Experience:

Interests:
Sub millimeter remote sensing of cirrus
Cloud retrieval algorithms
Radiative transfer models
Three-dimensional radiative transfer
Stochastic cloud models

Dr. Evans' modeling and algorithm development largely initiated the field of sub millimeter cirrus remote sensing, and he is involved with three groups (JPL, NASA/Langley, and NASA/Goddard) developing aircraft-based sub millimeter radiometers. His remote sensing algorithm research emphasizes the importance of understanding the radiative transfer problem and determining retrieval accuracy.

Dr. Evans is a member of the cirrus field experiment CRYSTAL-FACE science team and serves on the CloudSat science team (Graeme Stephens, P.I.). He currently serves as chair of the AMS Committee on Atmospheric Radiation. Dr. Evans received the American Meteorological Society Henry G. Houghton award in January 2001.

1985-1987: Image Processing Lab, Jet Propulsion Laboratory
1987-1993: Graduate Research Assistant, Colorado State University
1994-2000: Assistant Professor, University of Colorado
2000-2002: Associate Professor, University of Colorado

Education:
1983: B.S., Physics, California Institute of Technology
1986: M.S., Astronomy, California Institute of Technology
1990: M.S., Atmospheric Science, Colorado State University
1993: Ph.D., Atmospheric Science, Colorado State University

Thesis: Microwave Remote Sensing Algorithms for Cirrus Clouds and Precipitation

Publications:
24 peer reviewed publications.
See http://nit.colorado.edu/ for full vitae

Dr. Georg Heygster

Date of birth: 22 February 1951
Nationality: German
Address: University of Bremen
Fachbereich 1
Institute of Environmental Physics
P.O. Box 33 04 40
D-28334 Bremen, Germany
Email: heygster@uni-bremen.de

Phone: +49 (421) 218-3910
+49(421) 218-4065 (Secretary)
Fax: +49(421)218-4555

Professional Interests and Experience:
Research and Teaching in Remote Sensing and Geophysics. Of particular interest are applications in meteorology, Atmospheric Physics, studies on remote sensing of the Cryosphere, Polar Atmosphere, and ice clouds.

In charge of many research projects funded by EU, ESA, DFG, BMBF, DLR and others. These projects include the development of retrieval algorithms for microwave and other sensors, conducting campaigns and the interpretation and application of these results.

1988 -	Senior scientist at the University of Bremen, Institute of Environmental Physics
1979-1987	Computer Centre of the University of Bremen, Germany
1976-1979	Max-Planck-Institute of experimental medicine, Göttingen, Ph.D. thesis in image processing
1972-1973	University of Grenoble, France

Education:

1979:	Dr. rer. nat. (Ph.D.) in Physics from the University of Göttingen, Germany
1975:	Diploma (MS) in Physics from the University of Göttingen, Germany
1969:	Abitur (Matriculation Examination), Tellkampfschule Hannover

Selected Publications:

R. Fuhrhop, T.C. Grenfell, G. Heygster, K.-P. Johnsen, P. Schlüssel, Meeno Schrader, C. Simmer: A combined radiative transfer model for sea ice, open ocean, and atmosphere. Radio Science 33,2 (March 1998), 303-316

T. Hunewinkel, T. Markus, G. Heygster: Improved Determination of the Sea Ice Edge with SSM/I Data for Small-Scale Analysis. IEEE Tr. GRS 36,5 (Sept. 1998) 1795-1808

J. Miao, K.-P. Johnsen, S. Kern, G. Heygster, K. Kunzi: Signature of Clouds over Antarctic Sea Ice Detected by the Special Sensor Microwave/Imager. IEEE Tr. GRS 38,5 (Sep. 2000) 2333-2344

J. Miao, K. Kunzi, G. Heygster, T.A. Lachlan-Cope, J. Turner: Atmospheric water vapor over Antarctica derived from Special Sensor Microwave/Temperature 2 data. JGR 106, D10 (May 2001) 10287-10203

L. Kaleschke, C. Luepkes, T. Vihma, J. Haarpaintner, A. Bochert, J. Hartmann, G. Heygster: SSM/I lsea ice remote sensing of mesoscale ocean-atmosphere interaction analysis. Can. J. Remote Sensing, 2001,.

Prof. Dr. Niklaus Kämpfer

Address: Institute of Applied Physics
Sidlerstr. 5, 3012 Bern
Phone: +41 31 631 89 08   Fax: +41 31 631 37 65
email: kaempfer@mw.iap.unibe.ch
Date of birth: 6.12.1953

Education:

1994	Professor for applied physics at the University of Bern
1985	Degree in Pedagogy and Didactics for teachers
1983	Dr. phil. nat. (Ph.D.) in Physics from the University of Bern, Investigation of the solar atmosphere with optical, microwave and X-ray techniques
1979	Diploma (M.Sc.) in Physics from the University of Bern, Switzerland Design of a high-speed CCD-Camera for the observation of solar flares

Professional Experience:

since 2000	Acting director of the Institute of Applied Physics (IAP), University of Bern
since 1994	Head of Microwave department at the IAP
1988-1994	Head of Atmospheric Physics group Supervision of Diploma and Ph.D. students Co-Principal Investigator of MAS on Space Shuttle
1990/99	Participation in different EC-projects such as SESAME, EASOE, ESMOS, ESMOS, WAVE, EMCOR, COSE, EOUROSOLVE.
1983 - 1988	Management of the Space-Shuttle experiment Microwave Atmospheric Sounder (MAS) at IAP. Intense international collaboration with Industry and Research Laboratories, in particular Dornier, Max-Planck Institute for Aeronomy (Germany), Naval Research Laboratory (NRL) Washington DC., NASA-Marshall Space Flight Center and NASA Kennedy Space Center. Participation in two aircraft campaigns in the US, together with NRL.
1983	Teaching Physics at High School level
1982	Collaboration with Stockholm University, Solar Telescope on La Palma
1979 - 1983	Research Associate, Solar Physics Division, University of Bern

Membership:

Member of the International Ozone Commission
Member of the Steering Committee of NDSC (Network for the detection of stratospheric change)
Member of the Swiss delegation at ESA (European Space Agency) in DOSTAG
Member of the Swiss advisory board of Global Atmospheric Watch, GAW-CH
Member of the Comm. of Climate and Atmospheric Research of SANW
Member of the Comm. of Space Research of SANW
Member of the Comm. of Remote Sensing of SANW
IEEE, SPIE, AGU, SPG

Prof. Dr. K. Kunzi

Date of birth: 19 February 1939
Nationality: Swiss
Address: University of Bremen
Fachbereich 1
Institute of Environmental Physics
P.O. Box 33 04 40
D-28334 Bremen, Germany
e-mail: kunzi@uni-bremen.de

Phone: +49 (421) 218-3909
+49 (421) 218-4065 (Secretary)
Fax: +49 (421) 218-4555

Professional Interests and Experience:
Research and Teaching in Remote Sensing and Geophysics. Of particular interest are applications in meteorology, Atmospheric-Physics and -Chemistry, studies of the Ocean and Cryosphere, and the design and development of remote sensing instrumentation to be used on the ground, in aircraft and on space-platforms.

Principal Investigator or Co-Investigator for a number of space experiments. Member in international and national advisory bodies (e.g., European Union EU, European Space Agency ESA/ESTEC and the Deutsche Forschungsgemeinschaft DFG). Member in several professional organizations such as IEEE, AGU, EGS, DPG, SPG etc.

In charge of many research projects funded by EU, ESA, DFG, BMBF, DLR and others. These projects include the development of sensor hardware and software, conducting campaigns, includes the final data analysis from sensor data to Geophysical parameters, and the interpretation and application of these results.

1988-	Full Professor at the University of Bremen, Institute of Environmental Physics and Institute of Remote Sensing, Germany
1983	Guest Professor at the Technical University of Denmark, Lyngby/Copenhagen
1974-1988	University of Bern, Institute of Applied Physics, Switzerland
1972-1974	Research Associate, MIT Electrical Engineering Dept., Boston, USA
1971-1972	Visiting scientist (fellowship from the University of Bern) at MIT Research Laboratory of Electronics, Boston, USA
1966-1971	University of Bern, Switzerland.

Education:

1970:	Dr. Phil. Nat. (Ph.D.) in Physics from the University of Bern, Switzerland
1966:	Diploma (MS) in Physics from the University of Bern, Switzerland.
1959:	Matura (Matriculation Examination) Type C, Realgymnasium Bern, Switzerland.

Publications: Over 200 Publications, contributions to books and conferences.

for more information: http://www.iup.physik.uni-bremen.de

Dr. A. Macke

Date of birth: 17 October 1962
Nationality: German
Address: Institute for Marine Research
Marine Meteorology
Düsternbrooker Weg 20
D-24105 Kiel, Germany
email: amacke@ifm.uni-kiel.de
phone +49 431 600 4057
fax +49 431 600 1515

Professional Interests and Experience:
- Light scattering at non-spherical particles
- Radiative transfer in the cloudy atmosphere
- Teaching in General Meteorology, Radiative Transfer, Remote Sensing
- Co-investigator in European (CIRAMOSA, CLIWA-NET, CM SAF) and German (4DWOLKEN) research projects
- Organization of several EGS Symposia, Guest-Editor in Phys. Chem. Earth, and Ann. Geophys.
- Member of the GEWEX Radiation Panel

1997 - Assistant Professor at the University of Kiel, Institute for Marine Research
1995 - 1996 Post Doc at the Columbia University, New York and NASA Goddard Institute for Space Studies
1993 - 1995 Research Scientist at the GKSS Research Center, Geesthacht

Education:
1994: Dr. rer. nat. (Ph.D) in Geophysics from the University of Hamburg, Germany
1990: Diploma (MS) in Physics from the University of Cologne, Germany
1982: Abitur (Matriculation Examination), Städt. Gymn. Köln-Mühlheim

Publications: Over 50 publications, contributions to books and conferences

for more information:
http://www.ifm.uni-kiel.de/fb/fb1/me/data/pers/amacke.html~

Dr. J. Miao

Date of birth: 18 July 1963
Nationality: Chinese
Address: University of Bremen
Fachbereich 1
Institute of Environmental Physics
P.O. Box 33 04 40
D-28334 Bremen, Germany
e-mail: jmiao@uni-bremen.de
Phone: +49 (421) 218-4520
+49 (421) 218-4065 (Sec.)
Fax: +49 (421) 218-4555

Professional Interests and Experience:

Interests:

- Modelling of scattering from non-spherical particles and rough surfaces
- Algorithm development for geophysical parameters retrieval from satellite data
- Radiometer system evaluation and design

Working Experience:

1982-1984: Engineer at the Institute of Remote Sensing Instrumentation, Chinese Aerospace, Beijing, China.
1984-1993: Research associate at the Electromagnetic Laboratory of the Beijing University of Aeronautics and Astronautics, Beijing, China.
Since 1998: Research associate at the Institute of Environmental Physics, University of Bremen, Bremen, Germany

Education:

July 1982: B.S.E.E. degree, National University of Defence Technology, Dept. of Electrical Engineering.
Jan. 1987: M.S.E.E. degree, Beijing University of Aeronautics and Astronautics, Dept. of Electrical Engineering.
July 1998: Ph.D. degree, University of Bremen, Institute of Environmental Physics.

Publications:
So far 11 publications

Dr. J. Notholt

Date of birth: 29 June 1958
Nationality: German
Address: Alfred Wegener Institute for Polar and Marine Research
Phone: +49 (331) 288-2101
Fax: +49 (331) 288-2178
e-mail: jnotholt@awi-potsdam.de

Interests:

- Trace gas and aerosol measurement techniques in remote sensing
- Fourier Transform Spectroscopy.
- Differential Optical Absorption Spectroscopy.
- Atmospheric chemistry and physics.
- Application of trace gas Isotope concentrations in atmospheric research.
- Laser spectroscopy.
- Radiative transfer in remote sensing, inversion algorithms.

Experience:

- Principal investigator in several EU-projects (ESMOS I and II, ESMOS Arctic, COSE, SAMMOA, SOGE).
- Principal investigator within the NDSC (Network for Detection of Stratospheric Change) for the FTIR trace gas observations at Spitsbergen.
- Principal investigator within the NDSC (Network for Detection of Stratospheric Change) for the FTIR trace gas observations during ship cruises.

1999-2001	lecturer at the Free University of Berlin
1990-1991	Senior scientist at the Alfred Wegener Institute for Polar and Marine Research, Potsdam, atmospheric physics section.
1990-1991	Research associate at the Alfred Wegener Institute for Polar and Marine Research, Bremerhaven, chemistry section.
1989-1990	Post Doc stipend at the Joint Research Center, Environment institute, Ispra/Italy.

Education:

1999:	Habilitation in Atmospheric physics at the Free University of Berlin.
1989:	Dr. rer. nat. in Physics from the University of Kassel (surface science).
1988:	Research stay at the University of Otago, Chemistry Department, Dunedin/New Zeeland (surface electrochemistry).
1985:	Diploma in Physics from the University of Kassel (solid state physics).
1978:	Abitur (Matriculation Examination) Wilhelmsgymnasium Kassel.

Publications: Over 50 peer reviewed publications.

for more information: http://www.awi-potsdam.de

Dr. Joachim Urban

Observatoire de Bordeaux
2 Rue de l'Observatoire
B.P. 89
33270 Floirac
France

Phone: (++33).(0)5.57.77.61.39
Fax : (++33).(0)5.57.77.61.55
e-mail: urban@observ.u-bordeaux.fr

Date of birth: December 2, 1964
Nationality: German

Professional Experience and Interest: Eight years experience in mm- and sub-mm wave heterodyne instrumentation dedicated to atmospheric research, scientific research based on airborne and ground based remote measurements of stratospheric and mesospheric trace gases. Participation and/or contribution to various European measurement campaigns related to stratospheric research such as EASOE (1991-92), SESAME I+III (1994-95), and THESEO (1999-2000). Work on ESA studies on 'Upper Troposphere/ Lower Stratosphere Sounding' and 'Retrieval of Data from Sub-millimetre Limb Sounding'. Definition studies of heterodyne instrumentation dedicated to UT/LS sounding for CNES. Member of the Odin-SMR retrieval group, responsible for radiative transfer and inversion modelling in the French part of the Odin-SMR ground segment.

Qualifications and Experience:

July 1998 - Research scientist at the Observatoire de l'Université Bordeaux 1, CNRS/INSU.

1997 – 1998: Research scientist at the Institute of Remote Sensing, University of Bremen, Germany.

Education:

November 27, 1997: Ph.D. in natural sciences (Dr.rer.nat.), University of Bremen. Thesis: Measurements of stratospheric trace gases such as ClO, HCl, N_2O, O_3, H_2O and OH by airborne submm-wave-radiometry at 650 and 2500GHz.

1993 – 1997: Research associate / Ph.D.-student at the Institute of Environmental Physics, University of Bremen.

April 20, 1993: Diploma in Physics, University of Bremen. Thesis: Retrieval of the atmospheric pressure from trace gas emission lines measured in limb-sounding geometry.

1986 - 1993: Undergraduate student at the University of Bremen.

Publications: About 15-20 publications and contributions to conferences.

Priv.-Doz. Dr. Ulrike Wacker

Date of birth: 24 June 1954
Nationality: German
Address: Stiftung Alfred-Wegener-Institut für Polar- und Meeresforschung (AWI)
(Alfred Wegener Institute Foundation for Polar- and Marine Research)
P.O. Box 120161
27515 Bremerhaven, Germany
e-mail: uwacker@awi-bremerhaven.de

Phone: ++49 471 4831-1813
-1750 (Secretary)
Fax: -1797

Professional Interests and Experience:
Research and teaching in atmospheric sciences, especially in dynamic meteorology, atmospheric thermodynamics, cloud physics, and numerical modelling.
Head of the Section 'Large Scale Circulation' in the Department 'Climate System' at the AWI.

2000 -	Senior Scientist at the AWI, Department 'Climate System'
1990 - 2000	University of Frankfurt/Main
1985 - 1990	Deutscher Wetterdienst, Research Department, Offenbach
1980 - 1985	University of Frankfurt/Main

Education

1996	Habilitation for 'Meteorology' from University of Frankfurt/Main
	2000 Transfer of Habilitation (for "Environmental Physics") to University of Bremen
1984	Dr. phil.nat in Meteorology from University of Frankfurt/Main
1979	Diploma in Meteorology from University of Bonn
1973	Abitur, Rhein-Wied-Gymnasium Neuwied

Publications: about 50 publications and contributions to conferences

(B) Science Team

Dr. Stephan Bakan
Max-Planck-Institut für Meteorologie, Hamburg
Germany
E-mail: bakan@dkrz.de

Dr. Anthony Baran
The Met. Office (UK)
UK
Email: anthony.baran@metoffice.com

Dr.Wolfgang Benesch
Head, Remote Sensing Division
Deutscher Wetterdienst, Offenbach
Germany
Email: wolfgang.benesch@dwd.de

Dr. Bizzarro Bizzarri
Alenia Aerospazio, Roma
Italy
E-mail: bibizzar@tin.it

Dr.Susanne Crewell
Meteorologisches Institut, Universität Bonn
Germany
E-mail: SCREWELL@uni-bonn.de

Dr. Emilio Cuevas
Observatorio Atmospherico de Izana
Spain
E-mail: ecuevas@inm.es

Dr. Michel Desbois, Directeur de Recherche au CNRS,
Laboratoire de Météorologie Dynamique, Ecole Polytechnique, Paris
France
E-mail: desbois@lmd.polytechnique.fr

Dr. John M. Edwards
Hadley Centre for Climate
Prediction & Research
UK
E-mail: john.m.Edwards@metoffice.com

Dr. Hendrik Elbern
University of Köln
Germany
E-mail: he@eurad.Uni-Koeln.DE

Dr. Manuel Gil
Instituto Nacional de Técnica Aeroespacial,
Spain
E-mail: gilm@inta.es

Dr. Nils Gustafsson
Swedish Meteorological and Hydrographic Institute
Sweden
e-mail: Nils.Gustafsson@smhi.se

Prof. Dr. Thomas Hauf
Institut für Meteorologie und Klimatologie
Universität Hannover
Germany
e-mail: hauf@muk.uni-hannover.de

Dr. Jörg Hartmann
Alfred-Wegener-Institute for Polar and Marine Research, Bremerhaven
Germany
E-mail: jhartmann@AWI-Bremerhaven.de

Daniela Jacob
Deutsches Klimarechenzentrum
Germany
e-mail: jacob@dkrz.de

Prof. Esko Kyrö
FMI-Arctic Research Centre
FIN-99600 Sodankylä
Finland
e-mail: esko.kyro@fmi.fi

Dr. William Lahoz
Data Assimilation Research Center, Edinburgh
UK
Email: wal@met.reading.ac.uk

Dr. David Lary
Department of Chemistry, Cambridge University, Cambridge
UK
e-mail: djl10@cam.ac.uk

Dr. Bernard Legras
Laboratoire de Meteorologie Dynamique, Paris
France
E-mail: legras@lmd.ens.fr

Dr. Ulrich Leiterer
German Weather Service, Offenbach
Germany
E-mail: Ulrich.Leiterer@dwd.de

Dr. Zenobia Litynska
Polish Weather Service,
Poland
E-mail: zenoblit@pol.pl

Dr. D. Nagel
GKSS Research Center, Geesthacht
Germany
E-mail: dagmar.nagel@gkss.de

Dr. Joëlle Ovarlez
LMD Ecole Polytechnique, Paris
France
E-mail: joelle.ovarlez@polytechnique.fr

Prof. Dr. Eberhard Ruprecht
Institut für Meereskunde an der Universität Kiel
Germany
E-mail: eruprecht@ifm.uni-kiel.de

Prof. Dr. Clemens Simmer
Meteorological Institute, University Bonn
Germany
Email: csimmer@uni-bonn.de

Prof. Dr. Tony Slingo
NERC Envrionmental System Science Centre (ESSC)
University of Reading
Great Britain
Email: tony.slingo@metoffice.com

Dr. Petteri Taalas
Finish Meteorological Institute
Finland
E-mail: Petteri.Taalas@fmi.fi

Dr. P.F.J. van Velthoven
KNMI (Royal Netherlands Meteorological Institute)
Netherlands
E-mail: velthove@knmi.nl

(C) INDUSTRIAL TEAM

Responsible for CIWSIR Instrument:

RPG, Meckenheim, Germany

The company was found in 1978 in Meckenheim, Germany and is specialised in advanced study, design and building of remote sensing instrumentation, specifically in the microwave and sub-mm ranges. The company has built and qualified many mm and sub-mm components for space projects like MLS (NASA), ODIN (SSC), SMILES (NASDA) and EOS (NASA). In this project they will be responsible for the design and manufacture of the mm and sum-mm radiometer. RPG's world wide activities are mainly focused on customer specified products ranging from complete radiometers and spectrometers for radio astronomy, meteorology, ESR or plasma science to RADAR sensors for diagnostic purposes in the centimetre, millimetre and sub-millimetre frequency range. In addition the company contributes to research programs for the development of new microwave techniques and offers consultation in the design and characterisation of complex systems and quasi-optics.

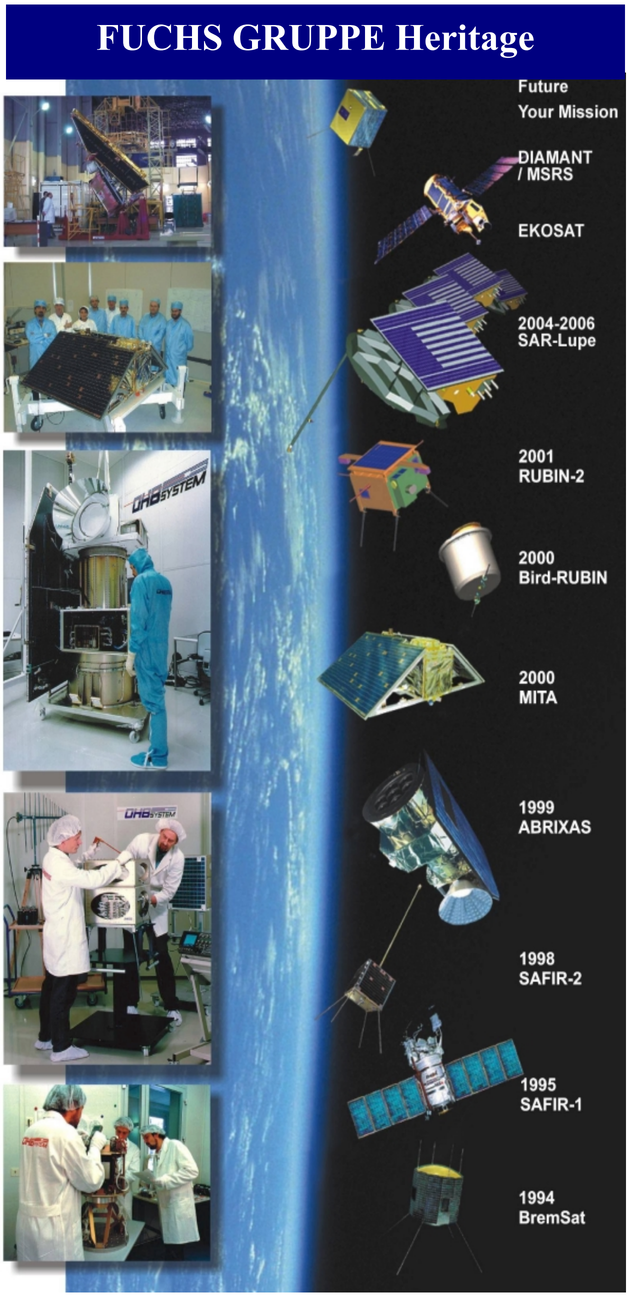
The spectrum of RPG's products includes:

- Microwave Components
- Complete Cooled and Un-cooled Front-ends
- Spectrometers
- Electronics

Responsible for Platform, Power, Data Handling and Launch

OHB, Bremen, Germany

OHB-SYSTEM, located in Bremen is a mid-size company, of approximately 140 employees, with a number of affiliations and subsidiaries in Germany and Italy, and a branch office in Russia. Together with its affiliated companies, *OHB-SYSTEM* forms the privately-owned and family managed *FUCHS GRUPPE* (approximately 290 employees in total). Mainly active in the fields of space and environmental technology, as well as in wireless telecommunication, *OHB-SYSTEM* is a major group-independent industry partner for national and international projects, including system engineering, studies, design, development and manufacturing for space, environmental and telecommunication products.



Additional to *OHB-SYSTEM* there are two OHB sister companies, which are active in satellite system and subsystem development:

Carlo Gavazzi Space S.p.A., being the most important manufacturer of small Satellites in Italy, and

STS Systemtechnik Schwerin GmbH.

Together with *COSMOS INTERNATIONAL GMBH*, another *FUCHS GRUPPE* subsidiary, and Russian partner companies *OHB-SYSTEM* provides launch services with the most successful launcher in the world COSMOS. Close contacts to other, Russian launch providers are available at *OHB-SYSTEM*.

OHB-SYSTEM has gained extensive experience during the past years on both national and European projects. The space activities of *OHB-SYSTEM* are among others:

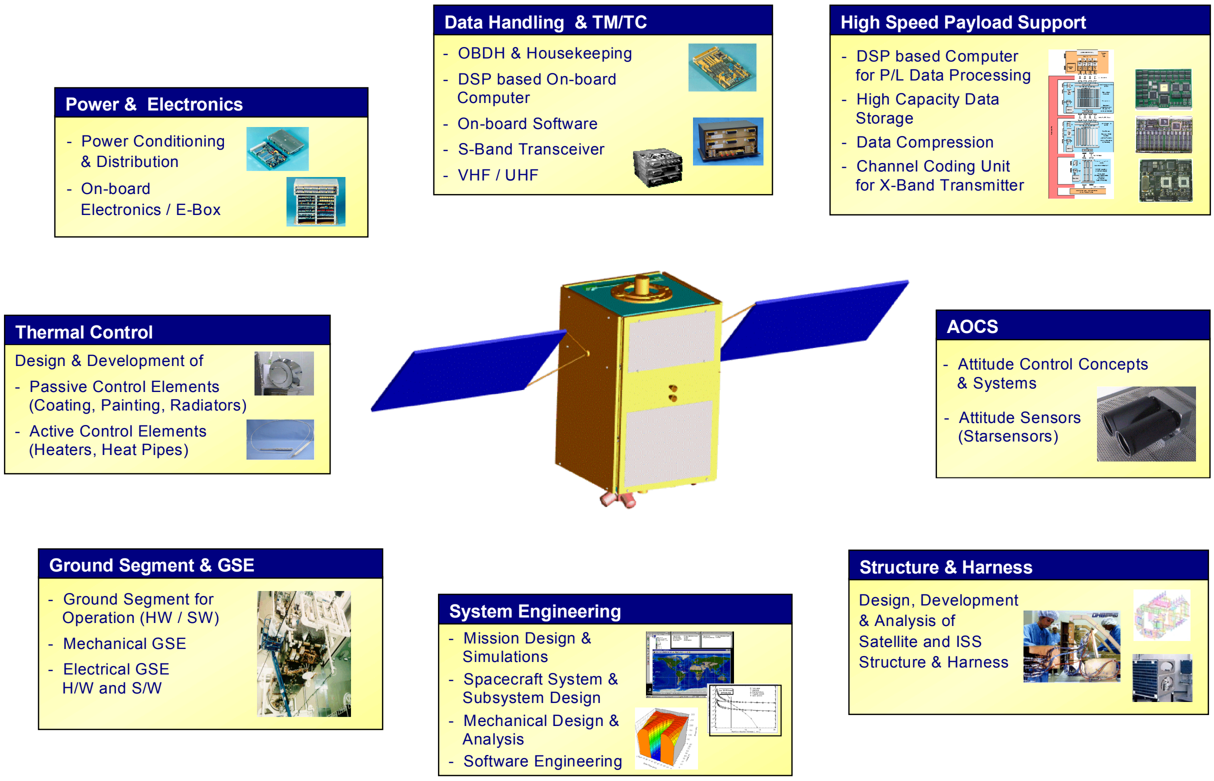
- Small satellite systems and subsystems for telecommunication, science and earth observation,
- Advanced & High Speed Processing System for EO-Applications,
- System/ subsystem engineering for manned and unmanned missions,
- Microgravity systems and experiment facilities for microgravity research,
- Organisation of satellite launch services,
- Mobile communication terminals and rescue buoys using LEO and GEO data transmission,
- Ground equipment for space systems.

Relevant Projects

OHB-System has been very active in the last years in very relevant, up to basically similar work on space-borne remote-sensing as well as on scientific research satellite programmes. These activities are pursuant to our corporate's strategic goals:

- achieving technological excellence and leadership in the small to medium satellite classes, and
- establishing scientific and commercial satellite application services.

OHB-System has long standing experiences in small satellite mission and subsystem development (see figure below).



OHB-System – Spacecraft Design & Development

As a member of the *F*UCHS *G*RUPPE*, OHB-S*YSTEM has long standing experiences in small satellite mission and subsystem development and brings in their experiences in the development, launch and operations of small and medium sized satellites, such as:

- BREMSAT (Re-entry Experiment),
- SAFIR-1 & 2 (Communication System),
- DIAMANT (with an Multi-Spectral High-Resolution System - MSRS),
- MITA (Italian Technology Demonstration Platform), and
- Radar satellite constellation.

For detailed company information refer to our homepage www.ohb-system.de.

Annex 2: References

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Edwards J.M. and A. Slingo, 1996: Studies with a flexible new radiation code, I, Choosing a configuration for a large-scale model. Q.J.R. Meteorol. Soc., 122, 689-719

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Fowler L.D. and D.A. Randall, 1996: Liquid and ice cloud microphysics in the CSU general circulation model, part II, Impact on cloudiness, the earth's radiation budget, and the general circulation of the atmosphere. J. Clim., 9, 530-560.

Francis, P.N., P. Hignett, and A. Macke, 1998: The retrieval of cirrus cloud properties from aircraft multi-spectral reflectance measurements during EUCREX'93. Q. J. R. Meteorol. Soc., 124, 1273-1291

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Gasiewski, A.J., Jackson, D.M., Wang, J.R., Racette, P.E., and Zacharias, D.S., 1994, Airborne Imaging of Tropospheric Emission at Millimeter and Submillimeter Wavelengths, Proceedings of the 1994 International Geoscience and Remote Sensing Symposium, vol. 2, pp. 663-665.

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Annex 3: Letters of Recommendation

Deutscher Wetterdienst, German Weather Service:

Deutscher Wetterdienst
GB Basisdienste
Referat Fernerkundung

DWD

TELEFAX

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Please forward immediately

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Number of pages (inclusive this page) 1

an/to: **Prof. Dr. Klaus Künzi**
Institut für Umweltphysik
Universität Bremen

Telefon:

Telefax: 0421 - 218 4555

Datum: 13. Dezember 2001

von/from: **Wolfgang Benesch**

Telefon: 069 - 8062 2701

Telefax: 069 - 8062 3687

Geschäftszeichen: BD FK

CIWSIR Proposal

Dear Prof. Künzi,

This is to express the strong support of the Deutscher Wetterdienst for the proposed Cloud Ice Water Sub-millimetre Imaging Radiometer (CIWSIR) .

The resulting data and products are among other application areas of specific interest in the context of the EUMETSAT Satellite Application Facility on Climate Monitoring (CM-SAF). The DWD is the host institute of the CM-SAF and has the responsibility for the work packages on clouds, radiation at the surface and humidity in the atmosphere. CIWSIR products are of significance for the activities on cloud parameters in the CM-SAF but also in the context of the other mentioned work packages.

Yours sincerely,

Wolfgang Benesch

Wolfgang Benesch
Head, Remote Sensing Division

Dienstgebäude, Frankfurter Straße 135 · 63067 Offenbach am Main, Tel. 069 / 8062 - 0
Kontoverbindung: Bundeskasse Frankfurt · Postbank Frankfurt · Kto-Nr. 8971-608 · BLZ: 500 100 60

Hadley Centre for Climate Prediction and Research, UK:

Met Office Hadley Centre for Climate Prediction and Research London Road Bracknell
Berkshire RG12 2SY United Kingdom
Tel: 0845 300 0300 Fax: 0845 300 1300 www.metoffice.gov.uk

Met Office

Dr. Georg Heygster
Institute of Environmental Physics
P.O. Box 330440
D-28334
Bremen
Germany

Direct tel: +44 (0) 1344 856906
Direct fax: +44 (0) 1344 854898
E-mail: john.m.edwards@metoffice.com

14 December 2001

Dear Dr. Heygster,

Cloud Ice Water Sub-millimetre Imaging Radiometer (CIWSIR)

This is to confirm our support for the principle of your proposed Cloud Ice Water Sub-millimetre Imaging Radiometer (CIWSIR) instrument, to be submitted to ESA in response to the second call for proposals for Earth Explorer Opportunity Missions. Information on cloud ice is extremely important for the evaluation of the treatment of cloud microphysics and precipitation processes in climate models and at present there is very little reliable information on this quantity. Your proposed instrument could therefore make a valuable contribution.

Yours sincerely,

J. M. Edwards

Dr. John M.Edwards
Manager, Clouds and Radiation Group

POSITIVE ABOUT DISABLED PEOPLE

INVESTOR IN PEOPLE

Meteorological Office, UK:

Met Office Building Y46 Cody Technology Park Ively Road
Farnborough Hampshire GU14 0LX United Kingdom
Tel: 0845 300 0300 Fax: 0845 300 1300 www.metoffice.com

Dr G Heygster,
Institute of Environmental Physics,
University of Bremen,
P.O. Box 330440,
D-28334 Bremen,
Germany

Direct tel: +44 (0)1252 395401
Direct fax: +44 (0)1252 376588
E-mail: john.foot@metoffice.com

Date: 7th December 2001

Our ref: M/MRF/5/1

Dr Georg Heygster,

Proposal for Earth Explorer Opportunity Missions - CIWSIR

As Head of the Atmospheric Process Research branch of the Met Office I am writing to you to offer my strong support for the CIWSIR (Cloud Ice Water Sub-millimetre Imaging Radiometer) proposal by the consortium led by Dr Klaus Kunzi. This is in response to the AO on the ESA Earth Explorer Opportunity Missions.

Accurate description of clouds in climate prediction models remains a key problem identified by IPCC. This is particularly true of ice clouds where quantitative accurate description of the cloud microphysics and radiative properties are incomplete yet alone the knowledge of the physics of all the potential feedbacks in the climate system.

The CIWSIR instrument offers a real opportunity to make advancement in determining the global climatology of ice water path. Although CIWSIR is far from a direct measurement, it does not suffer from many of the disadvantages that limit current measurement techniques.

If this instrument was to be supported, then my research branch would be anxious to get involved in the supporting work through: -

- detailed modeling of ice crystal scattering,
- detailed radiative and microphysical measurement campaigns using our access to the UK research aircraft, including passive microwave measurements, and through
- our close links to the Hadley Centre, promote the use of the data to ensure it addresses the key issues relevant to IPCC.

I hope this proposal is supported by ESA.

Yours sincerely,

John S Foot

Dr John Foot, Head of Atmospheric Processes Research

NOAA/ETL, USA

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
Oceanic and Atmospheric Research Laboratories
Environmental Technology Laboratory
325 Broadway - David Skaggs Research Center
Boulder, Colorado 80303

December 13, 2001

Professor Klaus Kunzi
Institute of Environmental Physics
University Bremen
P.O. Box 33 04 40
D-28334 Bremen
GERMANY

Dear Professor Kunzi:

The NOAA Environmental Technology Laboratory (ETL) is pleased to initiate collaboration with the University of Bremen in supporting the concept studies and on-orbit validation of the proposed ESA/ESTEC Cloud Ice Water Submillimetre Imaging Radiometer (CIWSIR). CIWSIR is anticipated to be an important element of a global cloud observation system, and complimentary to the U.S. NASA CloudSat sensor, to be launched later this decade. The generation of an accurate global data base of upper tropospheric cloud water and ice content is particularly important for numerical climate modeling and climate change studies being carried on within NOAA.

We intend that our support of the CIWSIR project will focus on in-kind collaboration with personnel from the University of Bremen on the observation and interpretation of submillimeter-wave imagery of clouds using NOAA's airborne Polarimetric Scanning Radiometer (PSR) system. NOAA/ETL is planning to operate this sensor, which will include several submillimeter-wave radiometer channels pertinent to the interpretation of CIWSIR data, during flights on the NASA WB-57F high altitude aircraft starting in the latter part of 2002. Pending ESA's issuance of an award for CIWSIR, we would intend that initial flight campaigns focus on the measurement and interpretation of submillimeter-wave brightness temperatures over cirrus clouds in support of CIWSIR algorithm development. Pending further a successful launch of CIWSIR, we would intend that later flights focus on the validation of CIWSIR brightness temperature and cloud content measurements.

Collaboration on the CIWSIR project would occur on a no-exchange of funds basis. University of Bremen personnel would be invited to participate in the ETL flights, data processing, and data interpretation efforts at their own cost, in exchange for prior access to the PSR data that would be critical for CIWSIR algorithm development and validation. Similarly, ETL personnel would be invited to participate on the CIWSIR science team, and would be expected to be provided prior access to the post-launch raw and processed data to support NOAA global climate studies. In turn, ETL will be expected to organize pre- and post-launch flight opportunities using their PSR/S sensor.

NOAA/ETL will also work with the University of Bremen to develop on a cost-permitting basis a new PSR scanhead (PSR/E) specifically suited for CIWSIR validation. To this end, ETL, will provide opportunities for the development and operation of PSR/E, and work with the University of Bremen on a no-exchange of funds basis in operating and interpreting the data from the PSR/E scanhead. In return, submillimeter-wave radiometers for the PSR/E would be provided by the University of Bremen.

Pending issuance of an award for the development of CIWSIR, the above collaborative activities will be formalized through a Memo of Understanding between NOAA/ETL and the University of Bremen.

We look forward to working jointly with ESA and the University of Bremen on this important environmental sensor.

Sincerely,

William D. Neff
Acting Director
Environmental Technology Laboratory