CIWSIR: A Proposed ESA Mission to Measure Cloud Ice Water Path

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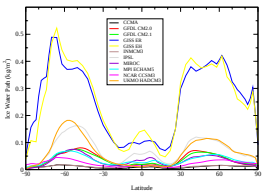
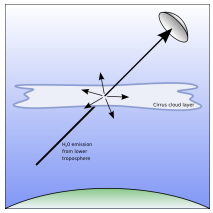
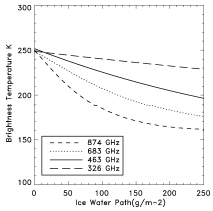


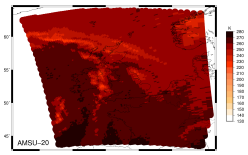
The uncertainties associated with the feedback of clouds, particularly ice clouds, in the climate system, are responsible for a significant part of the uncertainty in climate predictions. Even the present climatology of ice in the atmosphere is very uncertain. The top plot in the figure to the left shows that zonal mean ice water path (IWP) climatologies vary by one order of magnitude between the different models in the IPCC AR 4 archive. For a double-CO2 scenario, the models do not even agree on the sign of the zonal mean IWP change (bottom plot). Another important ice cloud parameter, which is even more uncertain, is ice particle size. The size determines the fall speed of the ice particles and thus has a large impact on cloud ice fields in circulation models.

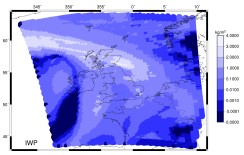
The highest frequency of the Advanced Microwave Sounding Unit B (AMSU-B) is 183+7 GHz (Channel 20). This is too low to detect weak ice clouds, but strong ones can be easily seen. The left-most plot below shows AMSU-B Channel 20 data taken on 2002-01-25 over the UK, a day with an intense winter storm. The second plot shows the IWP field from the Met Office mesoscale model, which shows up to more than 3 kg/m² of ice. As the third plot shows, we can model the AMSU data very well with a scattering radiative transfer model. (The model used was the Atmospheric Radiative Transfer Simulator, ARTS.) The cloud signal is in this case up to approximately 30 K. At 664 GHz (right plot) the signal is much stronger, even for small IWP.

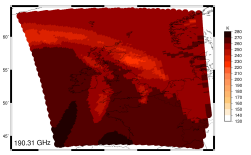
The Cloud Ice Water Submillimeter Imaging Radiometer (CIWSIR) is an instrument concept that has been proposed to the European Space Agency (ESA) in the last call for Earth Explorer missions. It exploits the fact that ice clouds are semi-transparent to sub-millimeter radiation (top plot in figure on the right). The ice particles in the cloud scatter away a part of the upwelling thermal radiation from lower layers of the atmosphere, thus reducing the brightness temperature (BT) measured by a receiver on a satellite. For not too thick ice clouds the BT depression is linear in IWP (bottom plot). The sensitivity depends strongly on particle size and frequency, since radiation with a wavelength close to the particle size is scattered most efficiently.

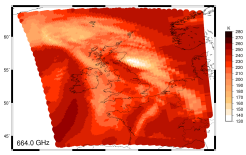


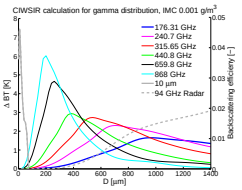


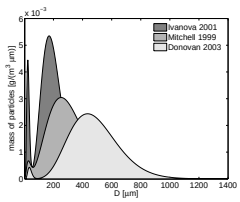


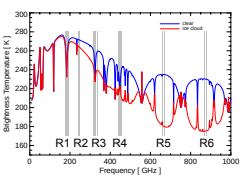












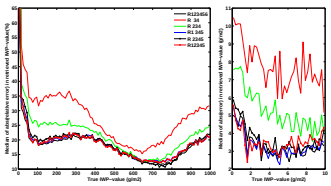
The sensitivity of sub-mm radiances at a given frequency to cloud ice depends strongly on the particle size. The top figure to the left illustrates this by showing for different measurement frequencies the signal of a fixed amount of ice, that is put in a narrow size distribution at the frequency denoted by the x-axis. At 868 GHz the instrument is most sensitive to particles of approximately 200 micron diameter, at 240 GHz to particles of approximately 700 micron diameter. IR measurements at 10 micron wavelength see only small particles below 100 micron diameter. Radar measurements are most sensitive to the largest particles of 1000 micron or more, because of the characteristic wavelength dependence of the backscatter coefficient.

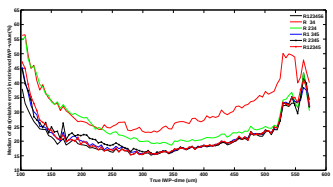
The middle plot shows some size distribution parameterizations from the literature. Sub-mm channels can cover a large part of the distributions, but the small mode below 100 micron will only be seen by IR channels.

The bottom plot shows the sub-mm channel setup that was proposed in the CIWSIR Earth Explorer proposal. It consists of 6 radiometers, with labels as indicated in the plot. Radiometers R1, R3, and R4 have 3 channels each, the others only 1 channel each, resulting in a total of 12 channels.

An ESA study optimizing the CIWSIR concept and channel selection is currently ongoing. The study includes also an industry component to derive possible hardware configurations. The figures on the right show retrieval simulation results from this study. These are neural network retrievals, based on an elaborate dataset of random atmospheric states, including random variations in cloud microphysics. Shown is the performance for the retrieval of IWP as a function of true IWP (top) and true D (bottom). The errors are median errors, rather than RMS errors, because RMS errors are dominated by rare outlier cases. The performance is shown for different radiometer subsets. The bottom plot demonstrates, that both very high and very low frequency radiometers are necessary, in order to get good accuracy for very small and very large particles, respectively.

The assumed noise level in this simulation varied from channel to channel, from 0.5 K for some low frequency channels to 1.7 K for the highest frequency channel. For the full configuration, the IWP accuracy is mostly below 20%, the D (median particle size) accuracy is mostly below 10%, and the zmed (median IWP cloud altitude) accuracy is around 300 m. The detection threshold (100% relative error) for IWP is between 3 and 5 g/m², depending on instrument configuration. For higher noise levels, the performance degrades gracefully, for example, if the noise level is doubled, the detection threshold changes to somewhere between 4.5 and 7 g/m².





Acknowledgements

The top left figure was made by B. Soden, University of Miami. The schematic drawing on the top right was made by Oliver Lemke, Lulea Technical University. The poster was put together on behalf of the CIWSIR Science Community. We gratefully acknowledge the support of the community for the preparation of the CIWSIR mission proposal, from which much of the material here is drawn. We also gratefully acknowledge the help from the ARTS radiative transfer model community.