ALL-SKY INFORMATION CONTENT ANALYSIS FOR NOVEL PASSIVE MICRO-WAVE INSTRUMENTS IN THE RANGE FROM 23.8 GHZ UP TO 874.4 GHZ

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Scope

Global observations of clouds, especially ice clouds, are desirable to quantify the clouds' effect on the climate, improve weather forecasting, and to constrain climate models. Passive sub-millimeter observations become more and more important tools to gain such datasets. Future missions, such as the Ice Ckud Imager (ICI), employ channels in the sub-millimeter range to observe ice clouds. Yet the hydrometeor Jacobians in these channels strongly depend on the atmospheric conditions. We investigate how much information we gain from observations with 24 channels in the range from 23 GHz up to 874 GHz about the cloudy atmosphere, depending on atmospheric composition. For this purpose we employ an ICON simulation with a two-moment microphysics scheme as data basis and use ARTS to simulate the respective Jacobians and measurements. We quantify the results using the reduction of degrees of freedom.

Clear-sky Jacobians

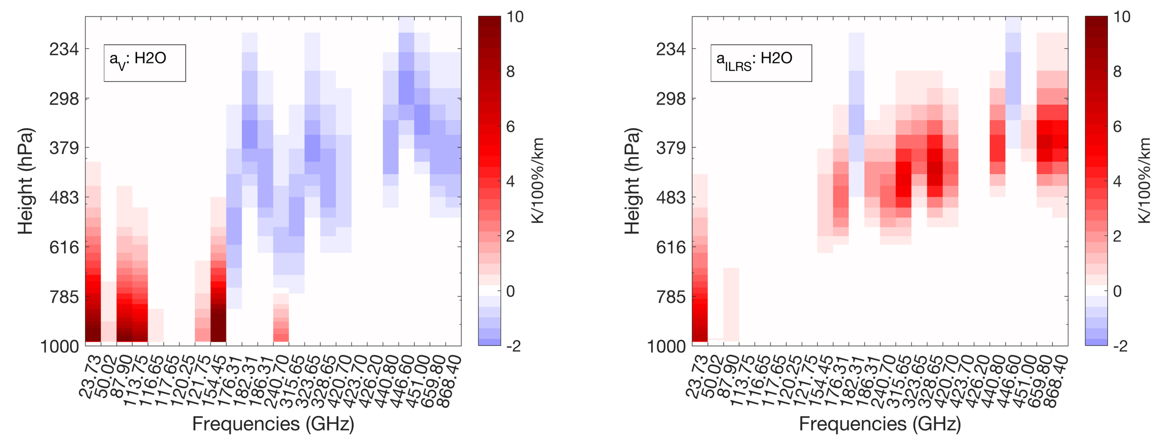

Fig. 1: Water vapour Jacobians for the clear-sky case a_V (left) and for the all-hydrometeor case a_{ILRS} (right). Averages of the sidebands are shown, the labels on the abscissa denote the left sideband of the channel.

Cloudy-sky Jacobians

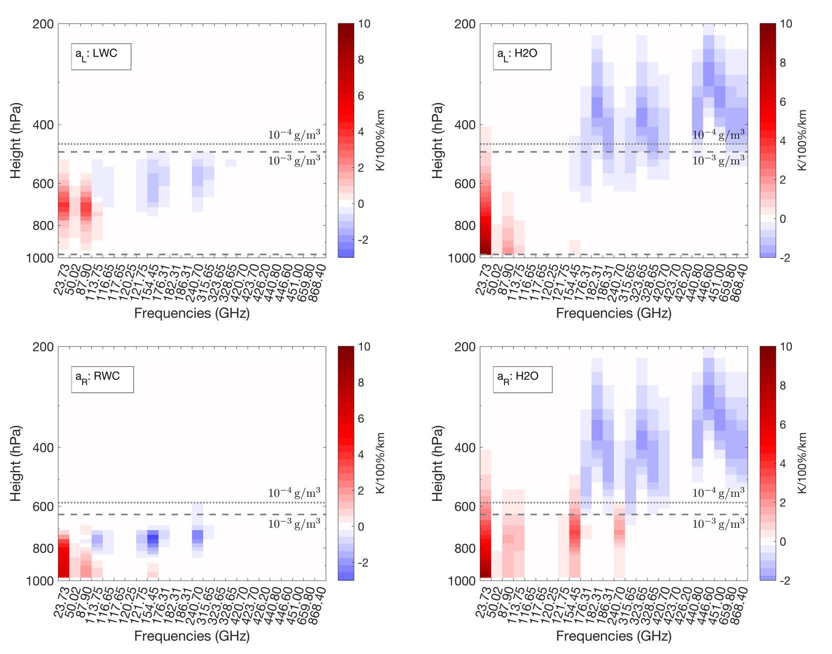

Fig. 2: LWC (top left) and Water vapour (top right) Jacobians for a_L (see Table 1 for nomenclature), RWC (bottom left) and Water vapour (bottom right) Jacobians for a_R. The dashed (dotted) grey line denotes the height in which the mass content of the respective hydrometeor is nearest 10^{-3} g/m³ (10^{-3} g/m³).

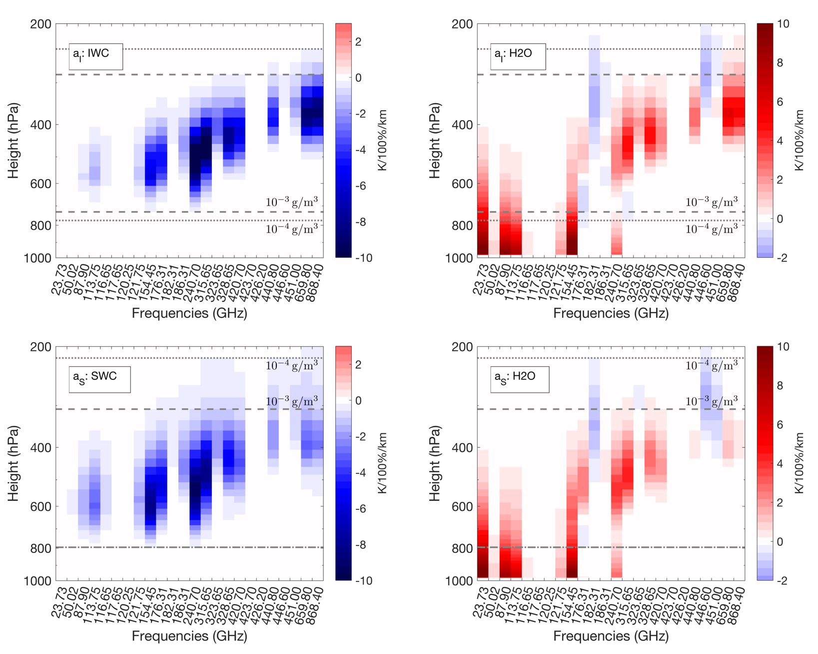

Fig. 4: IWC (top left) and Water vapour (top right) Jacobians for a_I, SWC (bottom left) and Water vapour (bottom right) Jacobians for a_S. The dashed (dotted) grey line denotes the height in which the mass content of the respective hydrometeor is nearest 10^{-3} g/m³ (10^{-3} g/m³).

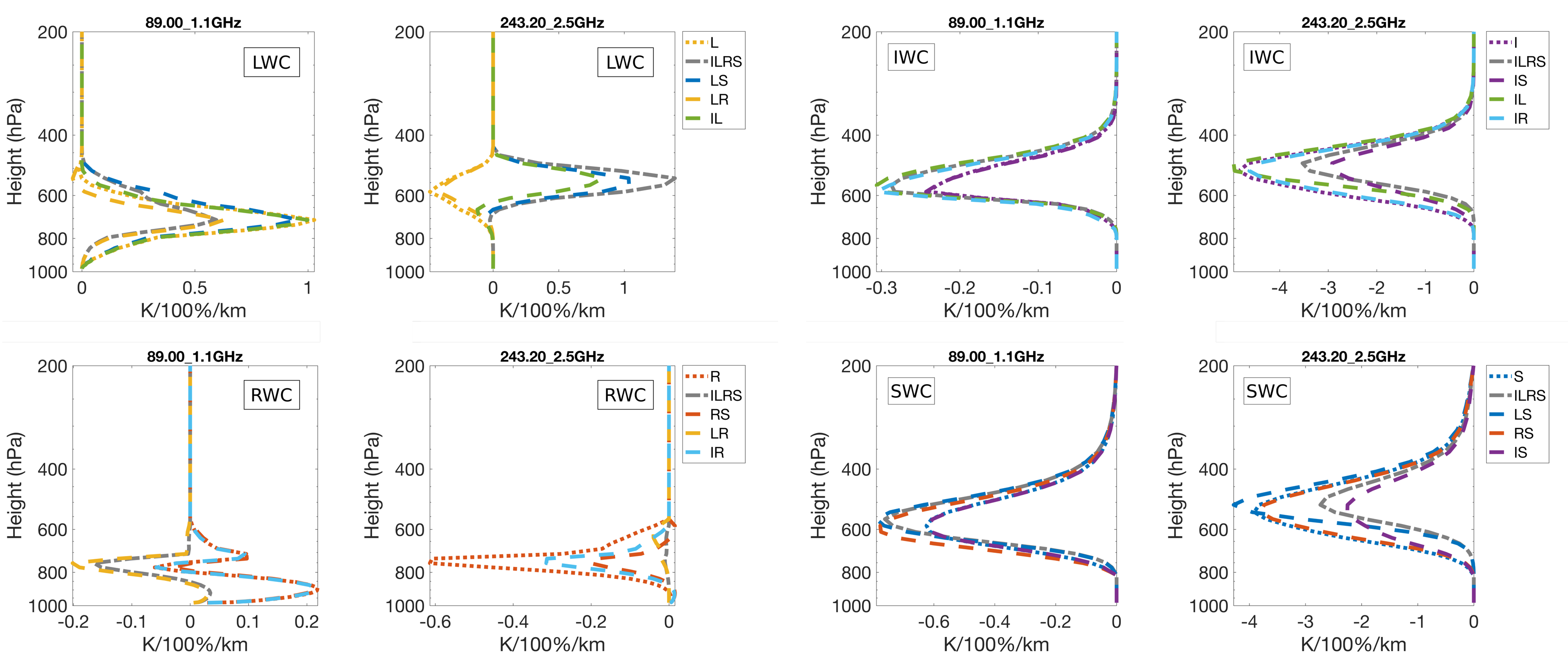

Fig. 5: LWC / IWC (top row) and RWC / SWC (bottom row) Jacobians for the 89.0 GHz (left column) and the 243.2 GHz (right column) channel. Shown are atmospheres containing pairs of hydrometeors and the all hydrometeor atmosphere. The labels in the legend correspond to the atmospheric composition X given in Table 1. Note different axis in the different plots.

- ARTS *(version 2.3.296)*
  - Jacobians calculated by perturbation
  - ICON-consistent particle size distribution
  - LWC, RWC spherical, IWC soft spheres (900 kg/m^3), scattering properties by Mie theory
  - SWC aggregates, Liu (2008) for channels up to 334 GHz, Hong et al. (2009) for channels higher than that
  - DOIT scattering solver (Emde et al. 2004)
  - HITRAN (Rothmann et al 2013) for molecular gas absorption, MT_CKD (Mlawer et al. 2012) for continuum absorption of water vapour (v. 2.52) and oxygen (v. 1.00)
  - Pencil beam, 53° off nadir, specular reflection, surface reflectivity = 0.6 for all channels

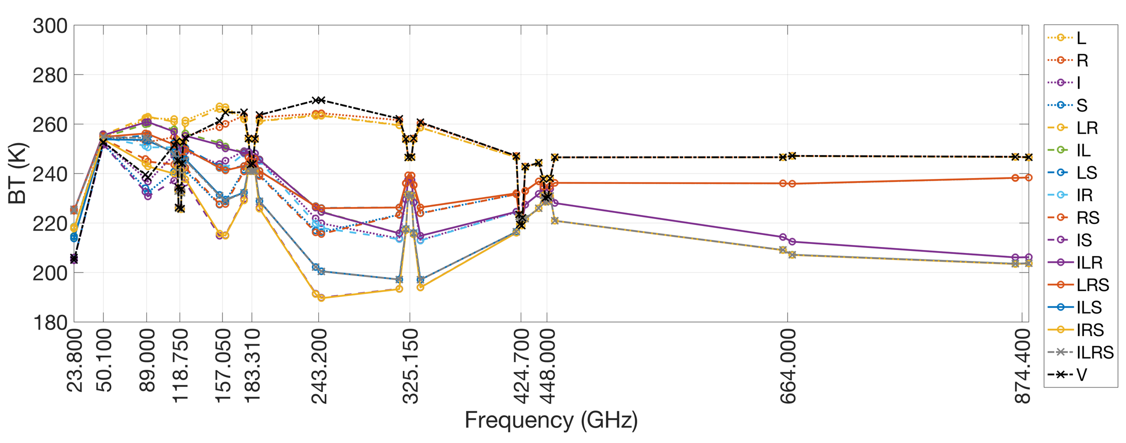

Fig. 3: Brightness temperature spectrum for ε = 0.6 for the 16 combinations of the base profile. The legend corresponds to the composition suffixes X defined in Table 1. The labels on the abscissa are the center frequencies of the channels. The curve labeled "V" is for water vapor only, without any hydrometeors. Although not mentioned in the legend, vapor is also present in all the other calculations.

ICON + 2-moment microphysics

- ICON (Icosahedral Non-hydrostatic model, Heinze et al., 2017)
  - High-resolution simulation with 2-moment microphysics (Seifert and Beheng 2006)
  - Number and mass mixing ratio for liquid water content, cloud ice water content, rain water content, snow water content
  - Idealized mean base atmosphere
  - 16 different combinations of hydrometeor types (Table 1)

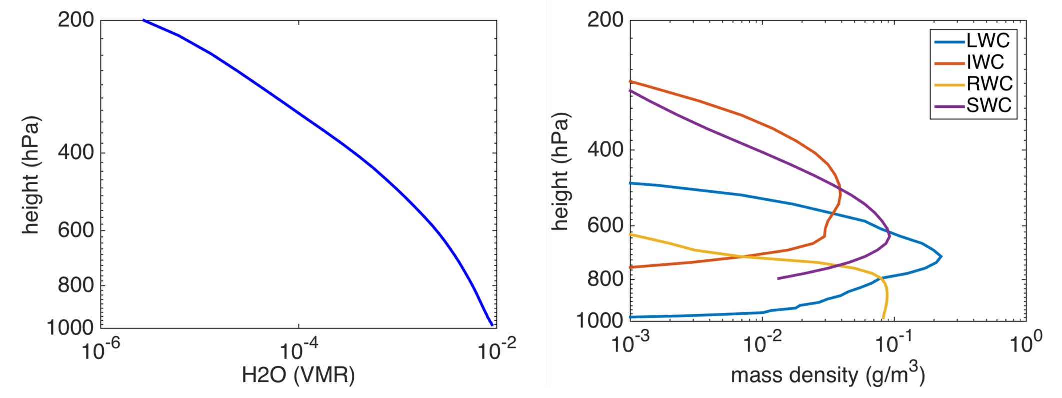

Fig. 6: Idealised atmospheric base profile. Water vapour volume mixing ratio (VMR, left) and particle mass densities (right) for liquid cloud water (LWC), cloud ice (IWC), rain (RWC) and snow (SWC).

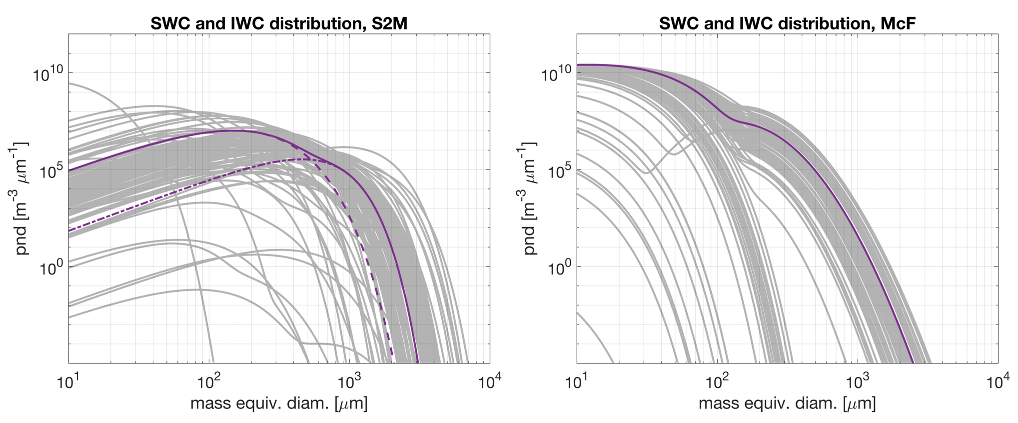

Fig. 7: Size distributions for the idealised mean profile (purple) and 90 simulated profiles (grey) derived from the two-moment scheme in ICON (left) and from the parameterization by McFarquhar and Heymsfield (1997) (right) at 550 hPa each. For the two moment scheme the sum of the distributions for IWC and SWC is shown for all profiles, and the individual distributions for IWC (dash-dotted) and SWC (dashed) are shown for the mean profile. For the McFarquhar and Heymsfield scheme, the distribution for the sum of IWC and SWC is shown, no individual distributions exist in that parameterization. The same IWCs and SWCs stemming directly from the ICON simulation and at the height 550 hPa have been used in both cases.

		Atmosphere															
		a_V	a_L	a_R	a_I	a_S	a_{LR}	a_{LI}	a_{LS}	a_{RI}	a_{RS}	a_{IS}	a_{LRI}	a_{LRS}	a_{LIS}	a_{RIS}	a_{LRIS}
Hydrometeors	Vapour	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	LWC		X				X	X	X				X	X	X		X
	RWC			X			X			X	X		X	X		X	X
	IWC				X			X		X		X	X		X	X	X
	SWC					X			X		X	X		X	X	X	X

Table 1: Atmospheric compositions used in the analysis of the dependency of the information content on the atmospheric composition.

Information content

- Definition
  - $\Delta\mathrm{DOF} = \mathrm{trace}\left(I - S_r S_a^{-1}\right)$
  - I identity matrix, S_a a priori covariance matrix, S_r a posteriori (analysis) error covariance matrix
  - $S_r = \left(S_a^{-1} + J^T S_y^{-1} J\right)^{-1}$
- Jacobians
  - Jacobian J calculated explicitly by perturbation (1% successively at each hight level)
- Relative perturbation corresponds to retrieval in ln space —> also a priori matrix in ln space

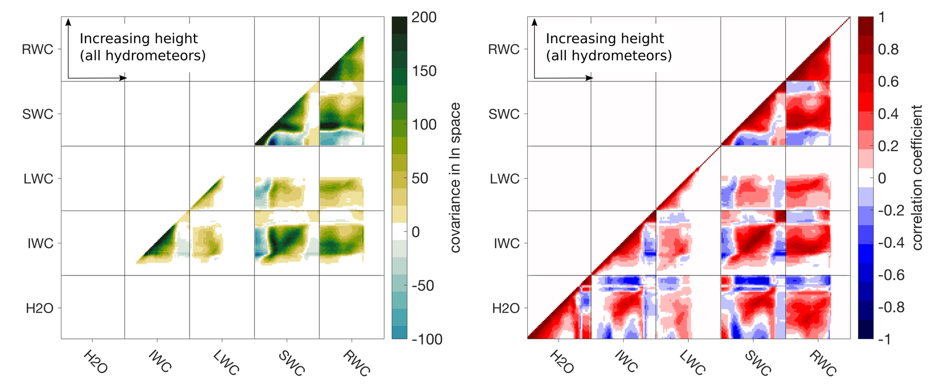

Fig. 8: A priori error covariance S_a (left) and the corresponding correlation matrix (right). Only the lower triangle is shown for clarity, since the matrices are symmetric. The block matrices correspond to the (auto-)correlation for one or between two quantities. They have the dimension of 49×49 height levels each. Note that the variability of water vapour is so small in comparison to the hydrometeors (in the range 0 to 1) that it cannot be seen in the a priori covariance (left).

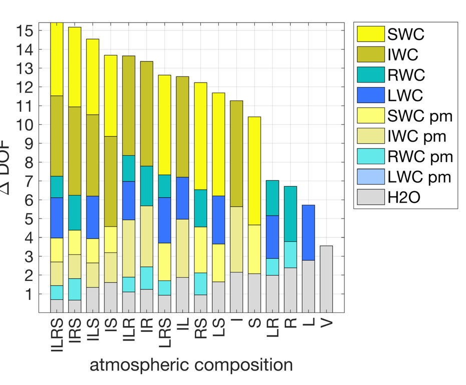

Fig. 9: Information content ΔDOF for all compositions a_{X_i}, ranked after total ΔDOF (pm particle mean mass).

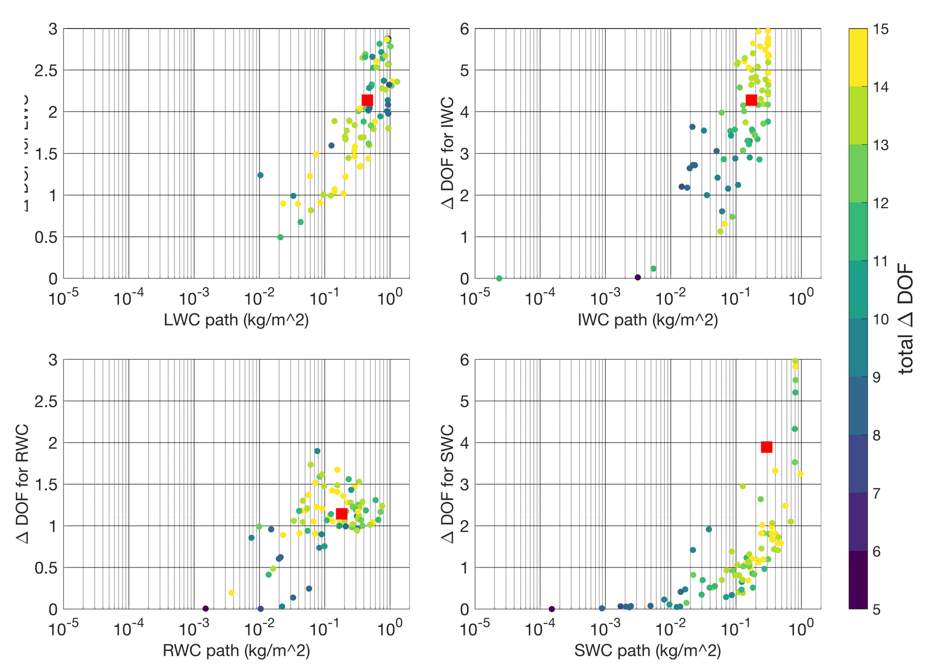

Fig. 10: ΔDOF for the different hydrometeor mass densities over their respective column integrated path for 90 realistic atmospheres. The total ΔDOF is illustrated by color. The red square corresponds to the value from the idealised base profile. Note the different y axis for liquid and frozen hydrometeors.

Conclusions

- The Jacobians strongly depend on the atmospheric composition. Yet the information content gained for the different hydrometeors is robust.
- With the chosen set of channels we gain 4 to 5 independent pieces of information about IWC and SWC, and even some information about the frozen hydrometeor mean mass. This also holds for the ICI channels (not shown). There is only about 2 pieces of independent information about the liquid hydrometeor mass densities LWC and RWC, and hardly any about their mean masses. The ICI channels contain almost no information about the liquid phase (not shown).
- The microphysical assumptions matter much for the simulation of the radiative transfer. Exact number of small ice particles is unclear, and atmospheric models distribute cloud and precipitation particles to different classes while in reality the transition is smooth.

References Emde et al., 2004, J. Geophys. Res, 109, D24207. Heinze et al., 2017, Q.J.R. Meteorol. Soc., 143, 69-100. Hong et al., 2009, J. Geophys. Res., 114, D06201. Liu, 2008, Bull. Amer. Met. Soc., 89, 1563-1570. McFarquhar and Heymsfield, 1997, J. Atmos. Sci., 54, 2187-2200. Mlawer et al., 2012, Phil. Trans. R. Soc. A, 370, 2520-2556. Rothmann et al., 2013, J. Quant. Spectrosc. Transfer, 130, 4-50. Seifert and Beheng, 2016, Met. Atm. Phys., 92, 45-66.

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