Spectral information content analysis of ISMAR frequencies – Preliminary results

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Overview

- Optimal estimation theory, reduction of degree of freedom
- ICON model
- 2-moment microphysics
- Jacobian calculation with ARTS
- Jacobians
- Apriori and retrieval error covariances
- Error reduction
- Information content

Optimal estimation theory

- Mathematical framework for estimation of information content:
  Reduction of degree of freedom

  Analysis error covariance **Sr**

  $$S_r = \left(S_a^{-1} + K^T S_y^{-1} K \right)^{-1}$$

- K   : Jacobian
  Sy   : Measurement error
 **Sx**   : Apriori covariance

Optimal estimation theory

- Mathematical framework for estimation of information content:
  Reduction of degrees of freedom

Analysis error covariance **Sr**

$$S_r = \left(S_a^{-1} + K^T S_y^{-1} K\right)^{-1}$$

Reduction of degree of freedom:

$$\Delta\mathrm{DOF} = tr\left(I - \frac{S_r}{S_x}\right)$$

- K   : Jacobian
  Sy   : Measurement error
  Sx   : Apriori covariance

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Model data

- ICON (ICOsahedral Non-hydrostatic model, developed by German Weather Service, DWD, and Max-Planck-Instiute for Meteorology)

- Cloud resolving simulation (650m) of a day in April 2013 over Germany
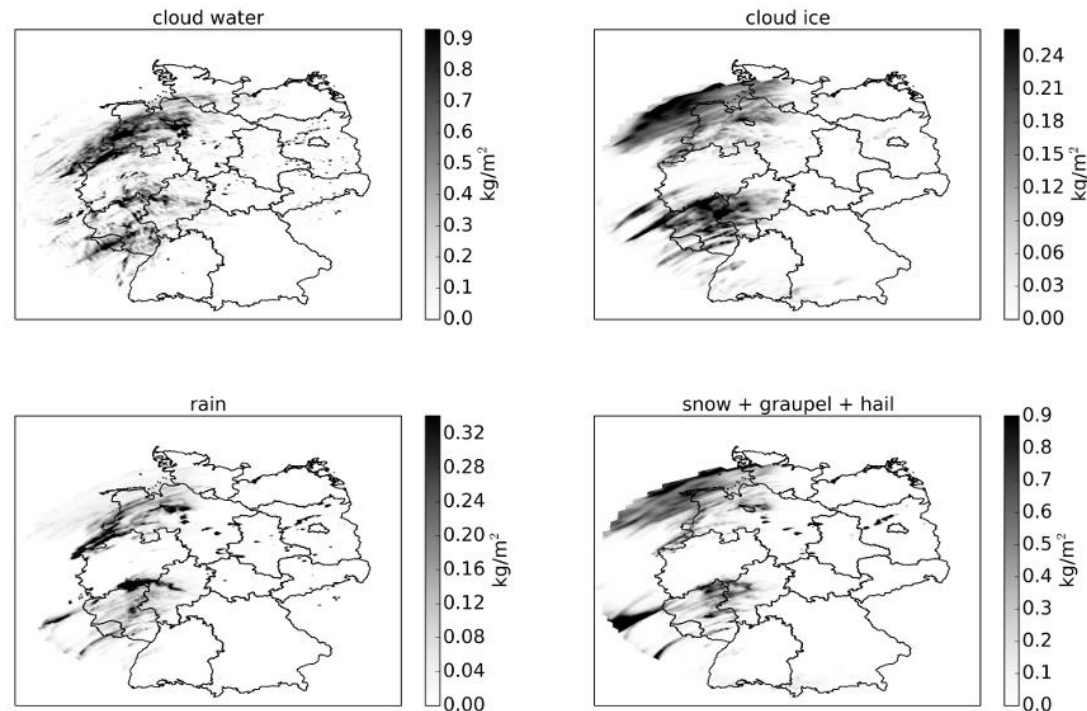
Simulation from project HD(CP)2, http://hdcp2.eu
They also have an extensive measurement database for validation.

Two-moment cloud microphysics

- Hydrometeors represented by mass and number density

  - Cloud liquid water (LWC)
  - Cloud ice(IWC)
  - Rain (RWC)
  - Snow (SWC)
  - Graupel and hail
    (not considered here)
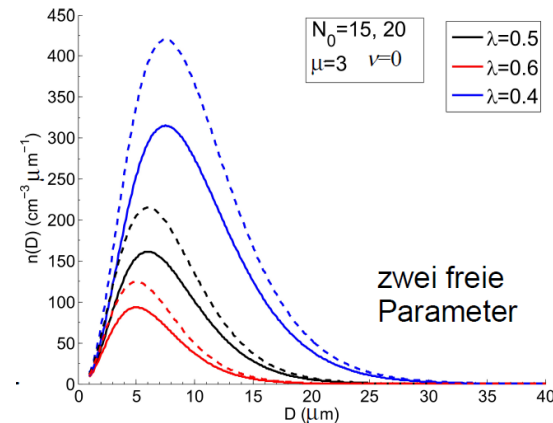
- Modified gamma distribution $\quad f(m) = A\, m^{\nu} \exp\left(-\lambda m^{\mu}\right)$

- μ and ν fixed per hydrometeor, A and λ calculated from mass and number

- Mean Particle mass by division of grid box mass density by number density

Seifert, A. and Beheng, K. D. (2006). A two-moment cloud microphysics parameterization for mixed-phase clouds. Part 1: Model description. Met. Atm. Phys., 92:45–66

Atmospheric profile

- Mean atmospheric profile from cloudy gridpoints

- Recalculated mean particle mass from mean mass density and mean number density

- → Smooth profile with all hydrometeors
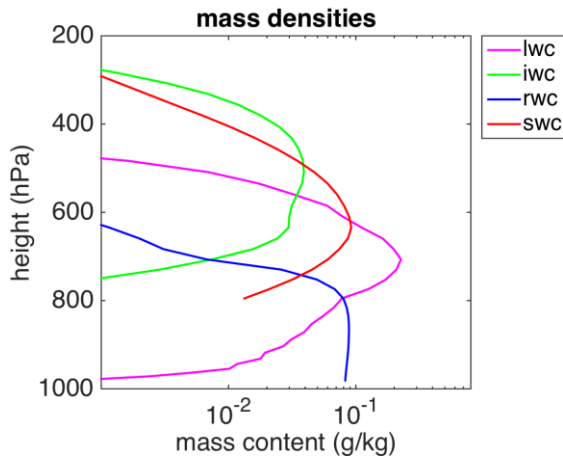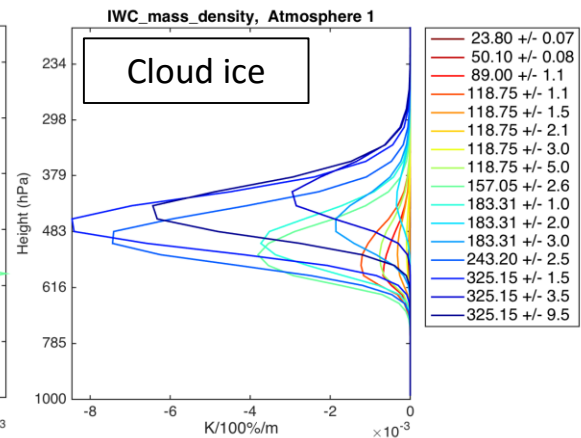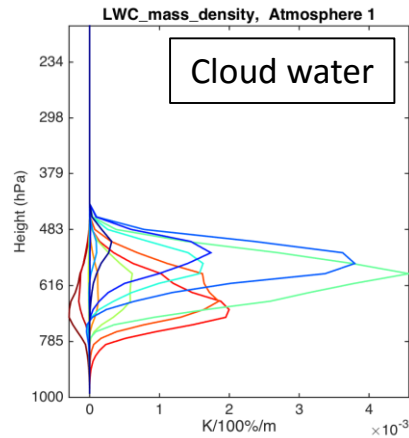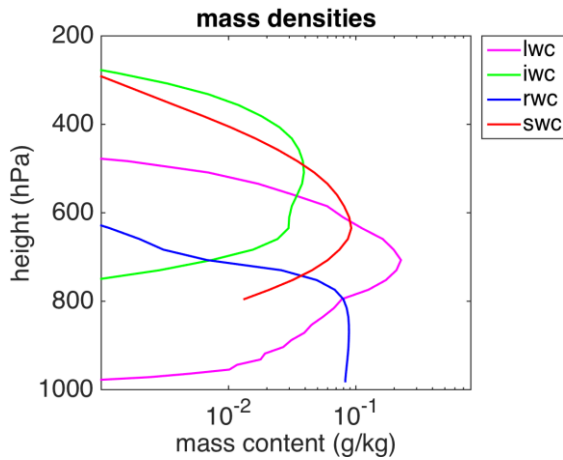
- Removed cold particles at warm temperatures
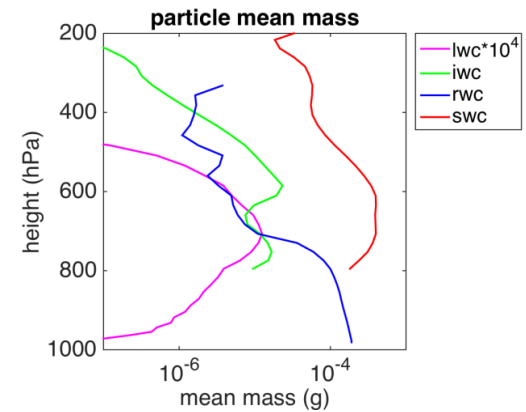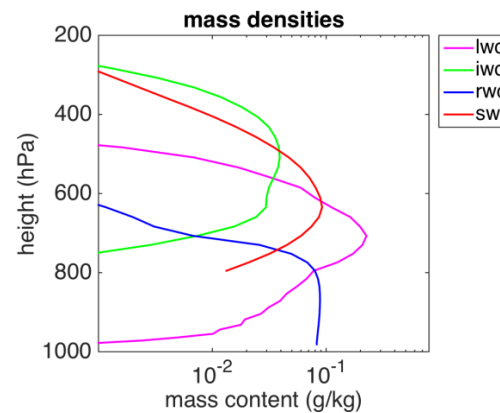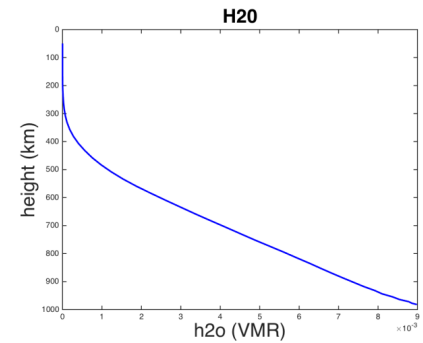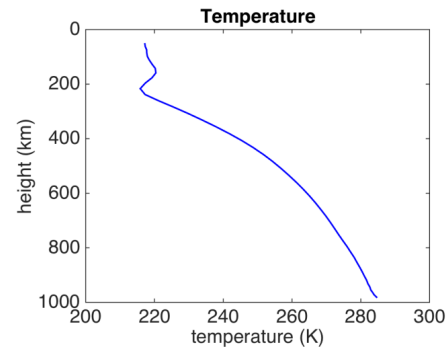
Jacobian calculation in ARTS

- Line-by-line model, explicit calculation of scattering (more from Jana and Patrick)

- Discretization of the particle size distribution on the ARTS particle size grid for scattering, slight adjustment of the particle number to preserve mass density

- Relative perturbation of 1% on each model level for humidity and hydrometeors → corresponds to retrieval in logarithmic (ln) space
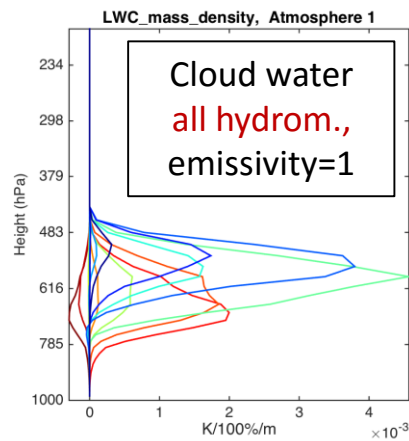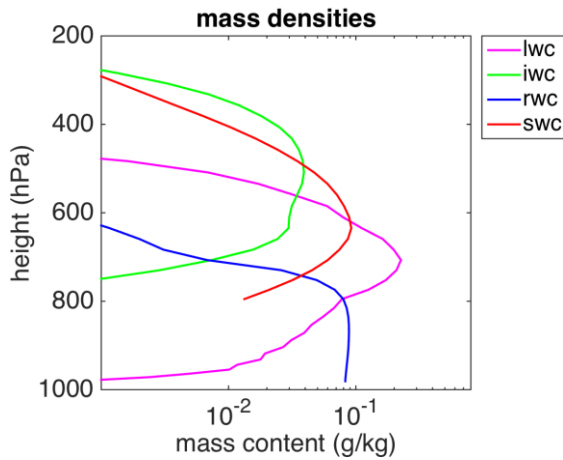
- Frequency set used : 23.8GHz up to 325.15GHz (higher frequencies underway)

H2O, Atmosphere 1

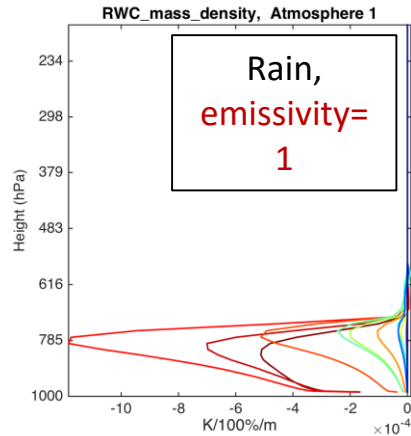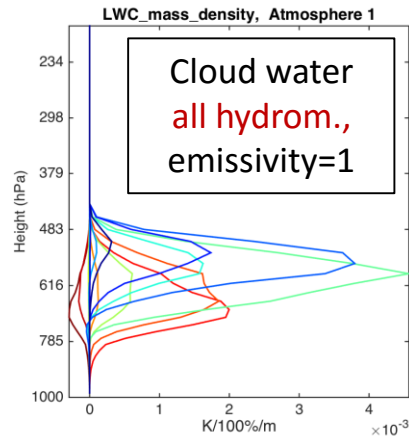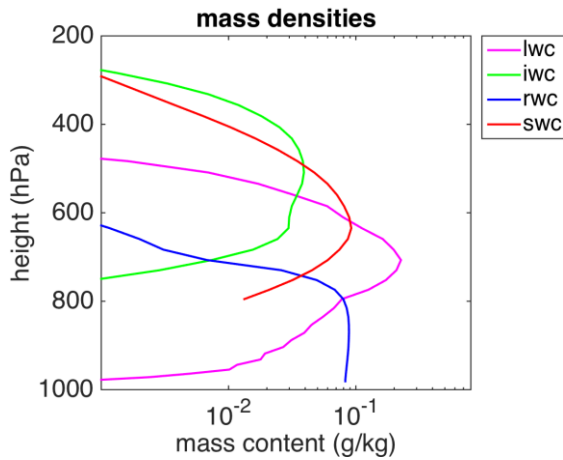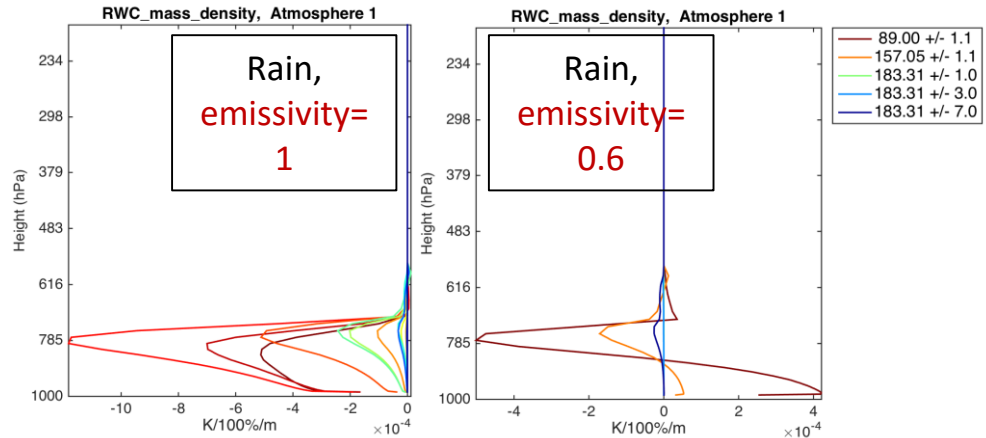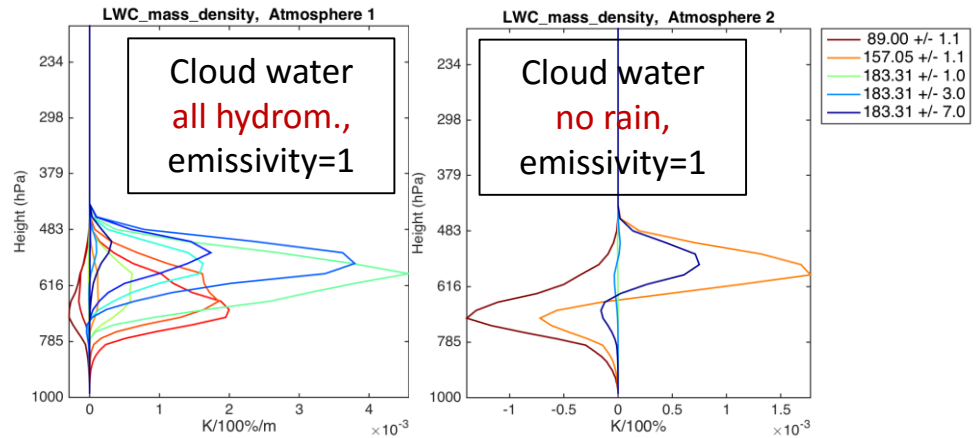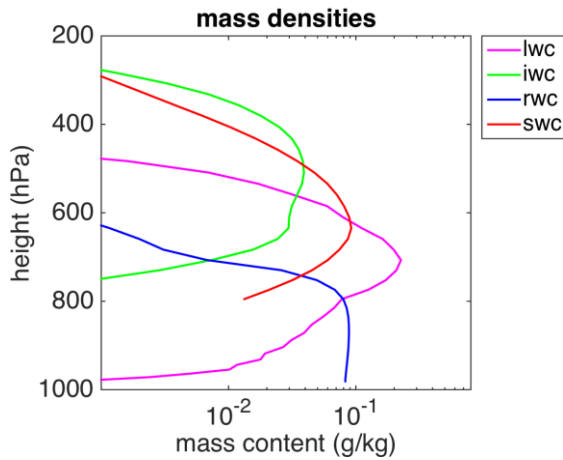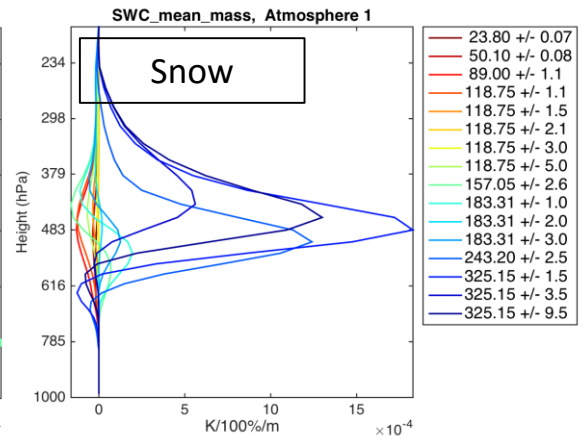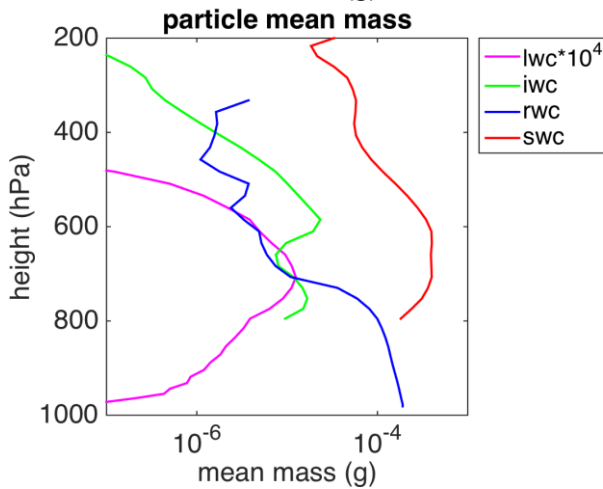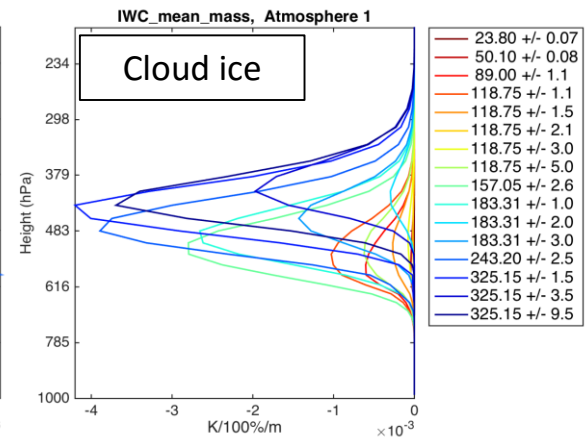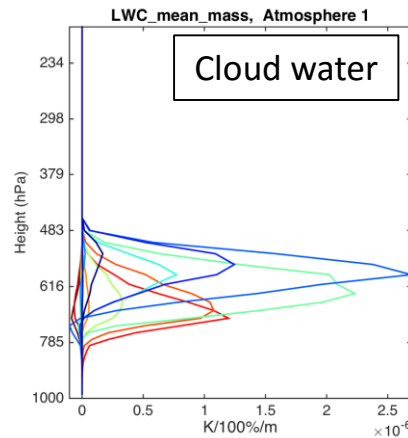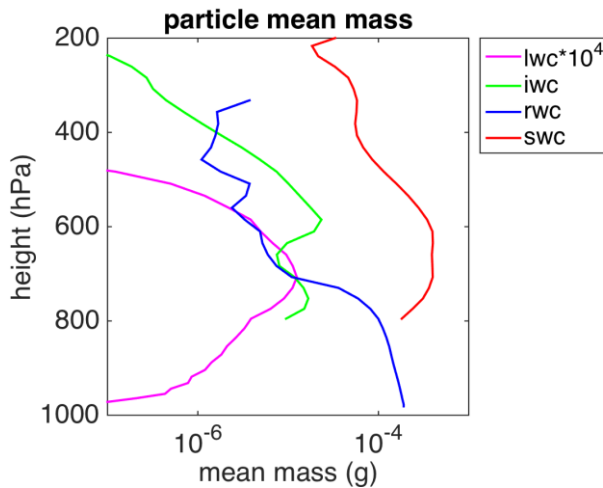|	
23.80 +/- 0.07	
50.10 +/- 0.08	
89.00 +/- 1.1	
118.75 +/- 1.1	
118.75 +/- 1.5	
118.75 +/- 2.1	
118.75 +/- 3.0	
118.75 +/- 5.0	
157.05 +/- 2.6	
183.31 +/- 1.0	
183.31 +/- 2.0	
183.31 +/- 3.0	
243.20 +/- 2.5	
325.15 +/- 1.5	
325.15 +/- 3.5	
325.15 +/- 9.5	
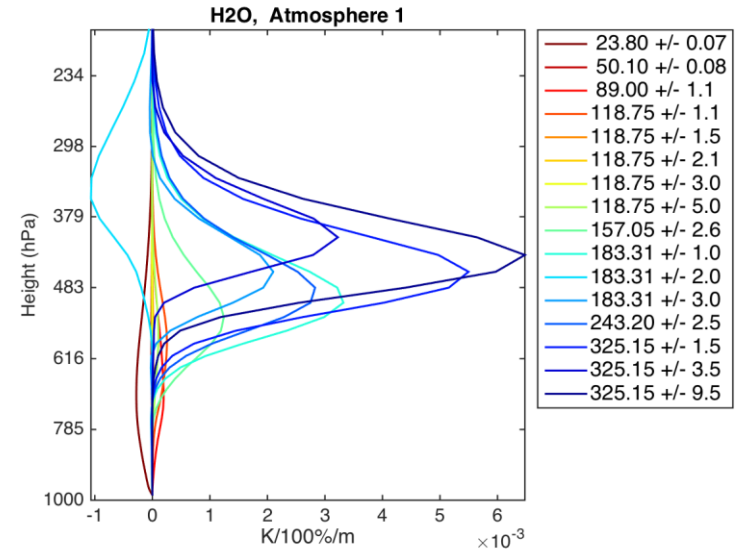
Jacobians Mass Densities

Jacobians Mass Densities - excursus

Cloud water
all hydrom.,
emissivity=1

Rain,
emissivity=
1
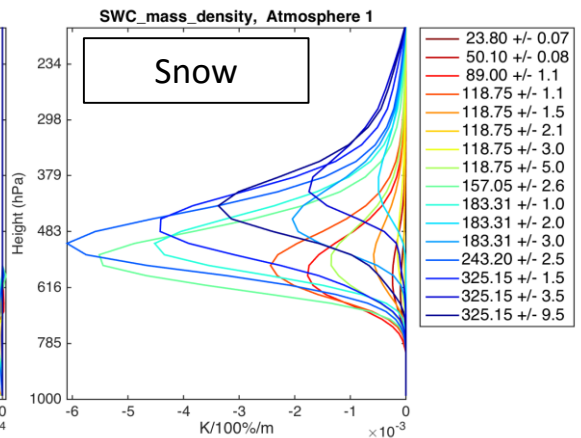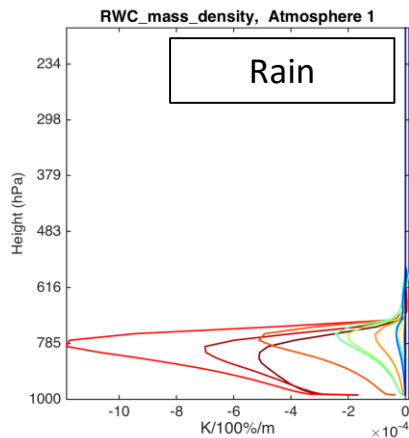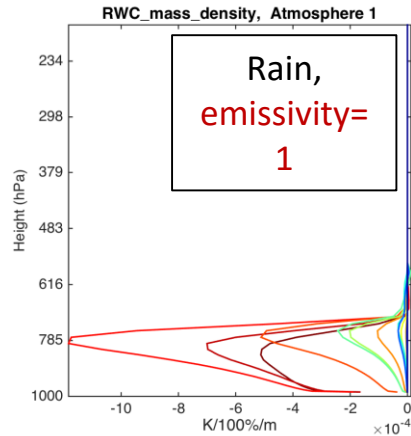
Jacobians Mass Densities - excursus
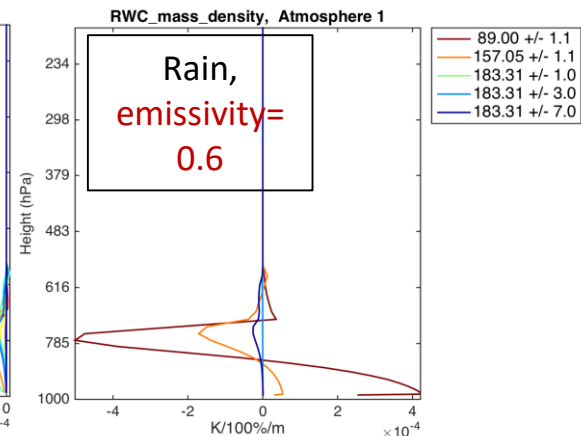
Jacobians Mass Densities - excursus

Jacobians Mean Masses
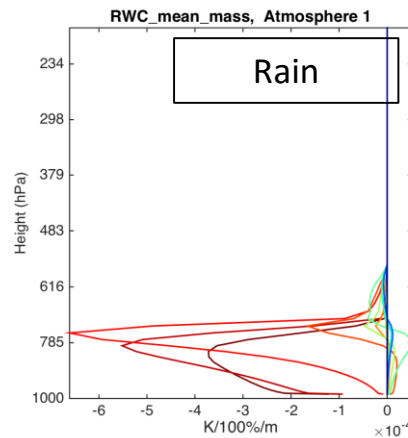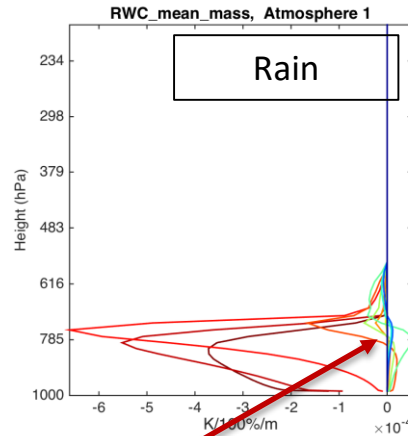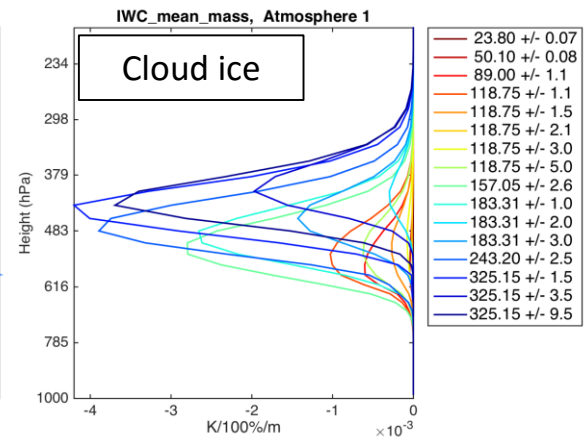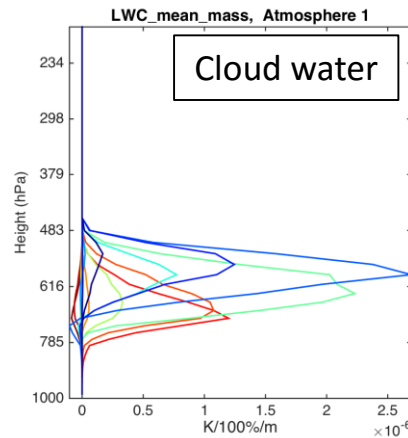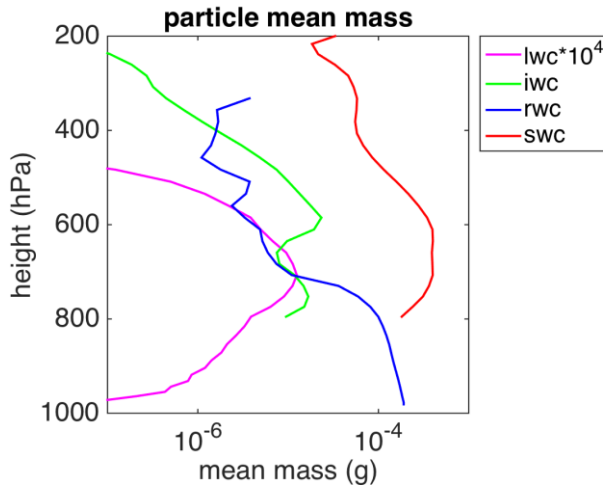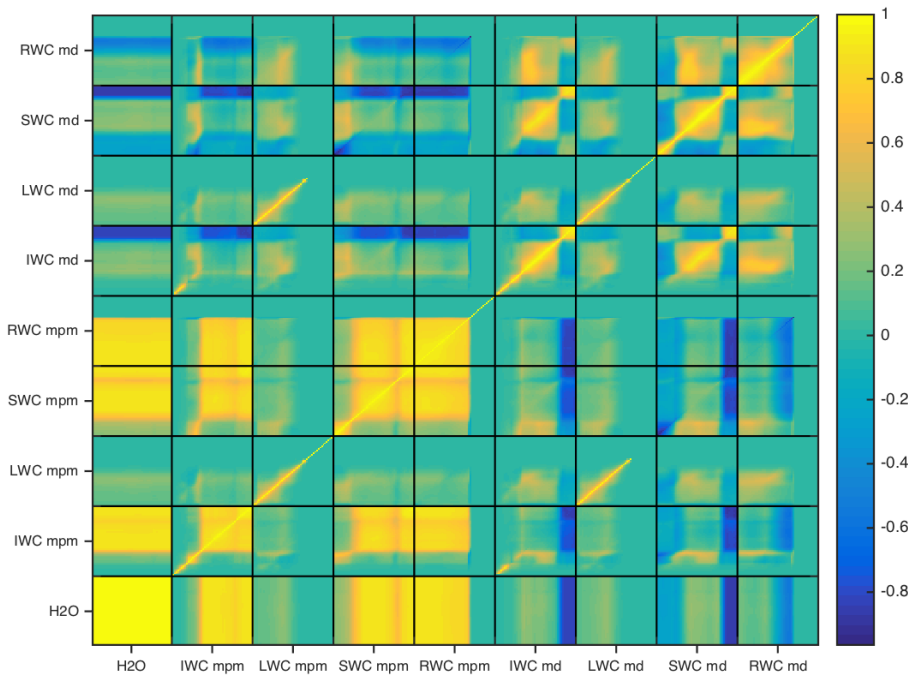
Jacobians Mean Masses
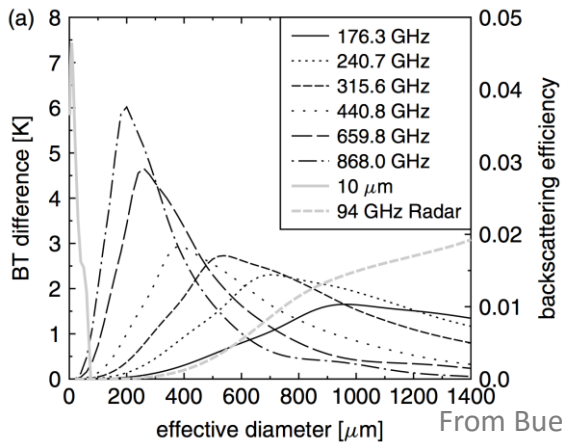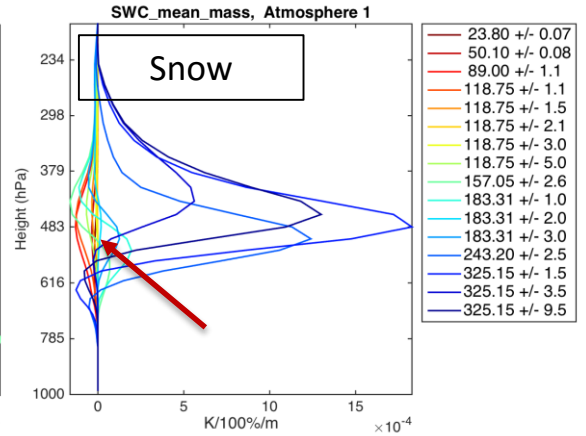
From Buehler et al., 2007. A concept for a satellite mission to measure cloud ice water path and particle size. Q. J. R. Meteorol. Soc. (133), 109-128.
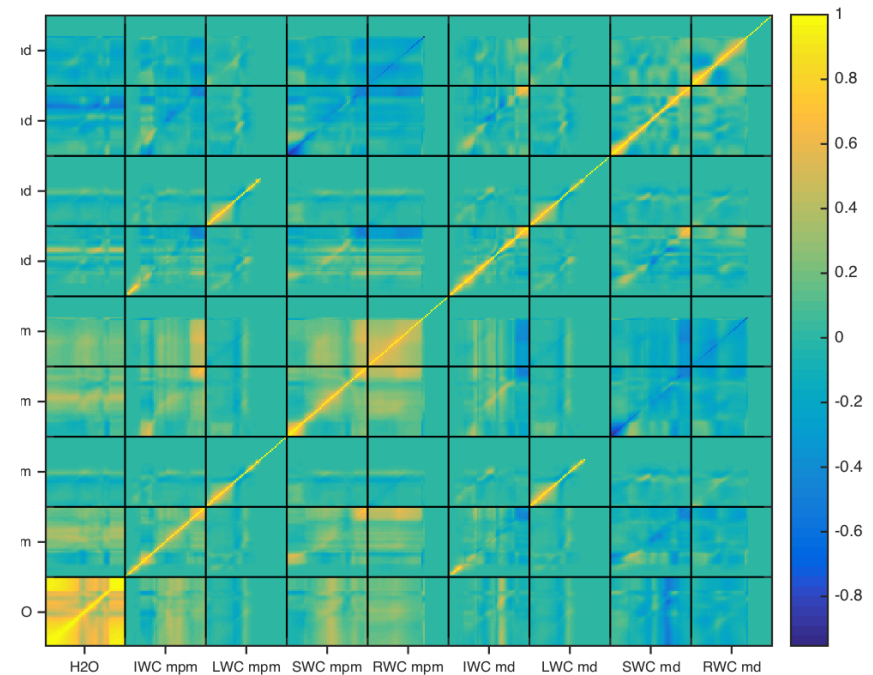
Apriori and analysis error covariance - ICON

- The initial correlations remain clearly visible but again are "diffused" through out the matrix and overall weakened
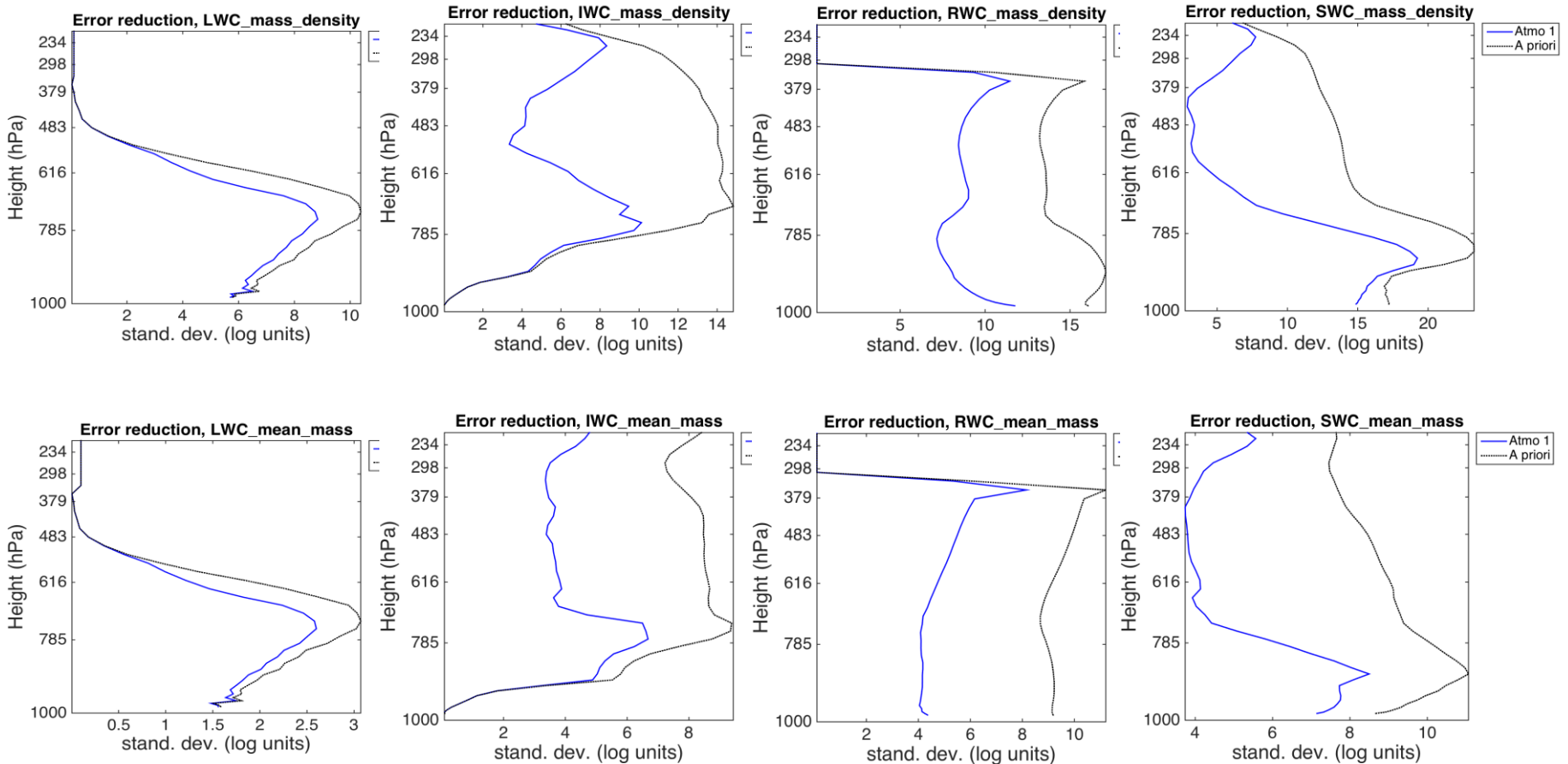
Correlation apriori covariance

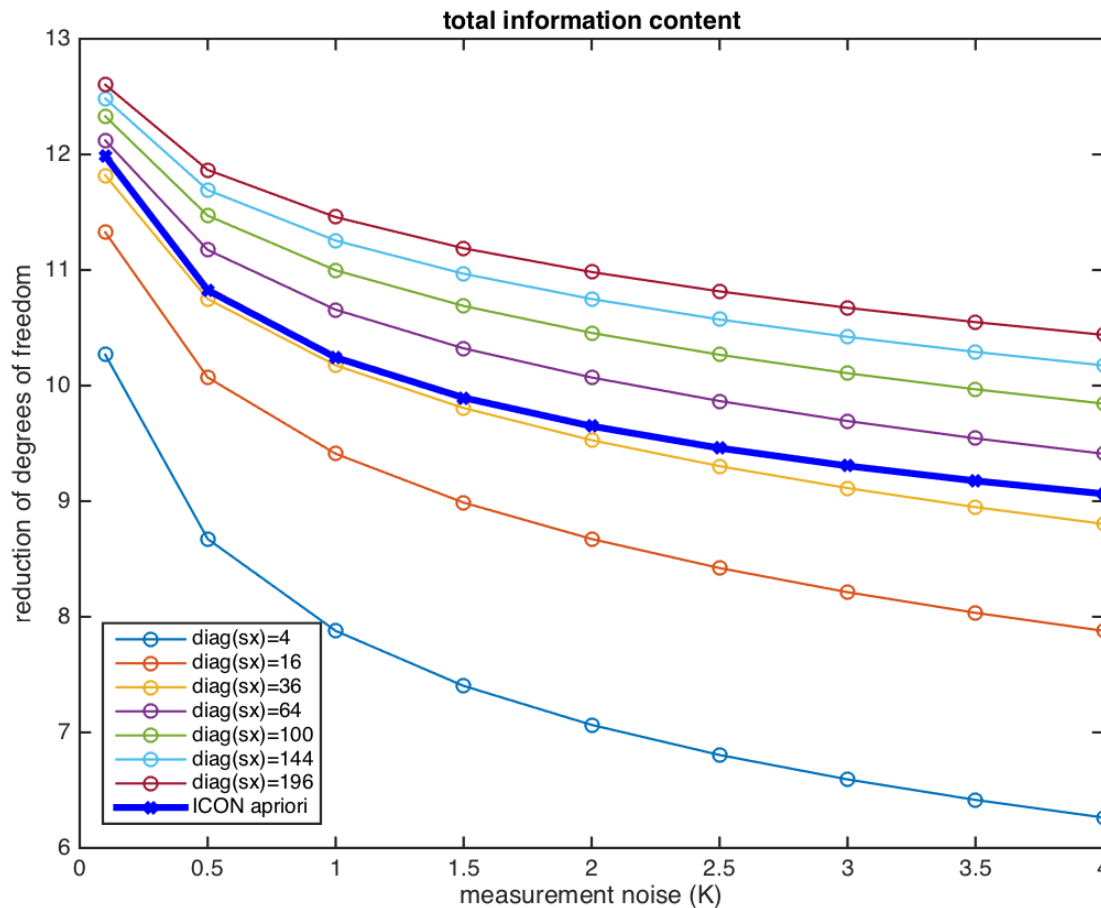Correlation analysis error covariance

Error reduction for the ICON case

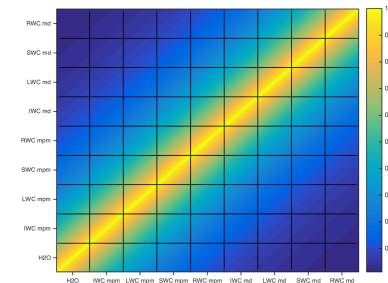- (Reminder: Square root of the diagonals of Sx and Sr)

Information - excursus

- Caveat: absolute number of ΔDOF depends on a priori and measurement noise assumptions

total information content

Thin lines from idealized a priori of this form:

Information content

- Example ICON a priori, 0.5K noise

- Total reduction of degree of freedom less than number of measurements

- Hardly information about mean masses (inclusion of higher frequencies likely improves it)

- Breakdown of the information content: how much can we poten-tially learn about the hydrometeors with this specific setup

| Total reduction of degree of freedom: 10.8256	Contri-bution
SWC mass density	2.81
mean mass	0.29
IWC mass density	2.67
mean mass	0.35
LWC mass density	2.15
mean mass	3.29e-04
RWC mass density	1.15
mean mass	0.16

Conclusions

- OEM information content analysis performed for ISMAR frequencies up to 325GHz (higher frequencies underway)

- Two-moment cloud microphysical scheme, estimation of apriori covariance from underlying ICON data

- Jacobian calculations within ARTS, cloudy Jacobians tricky and highly dependent on parameters and cloudy profile

- Reduction of degrees of freedom: How much can we learn about which parameter?
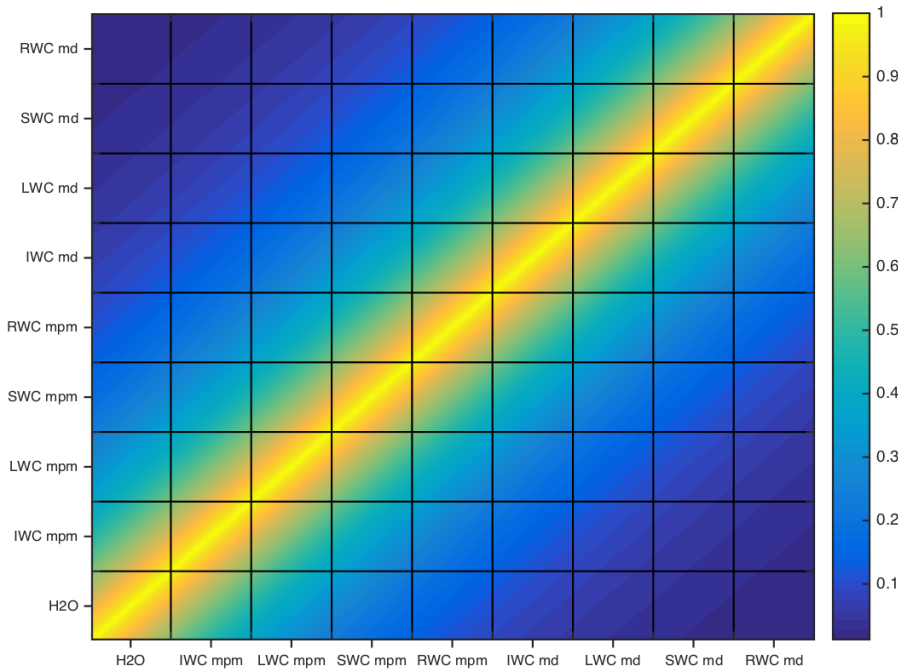
Backup slides

Jacobians T and H2O
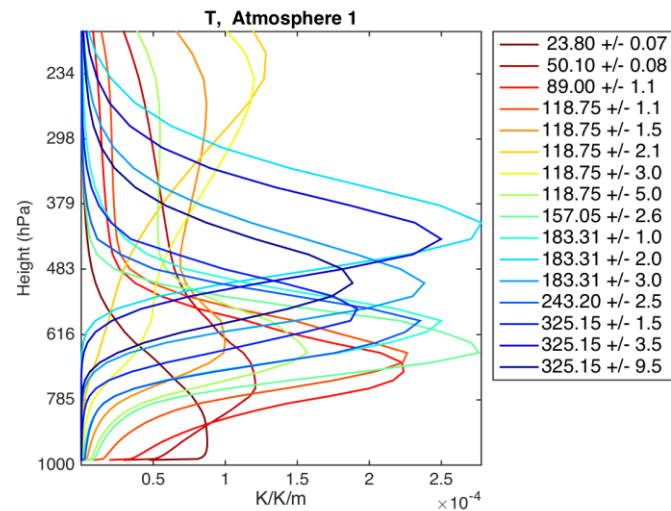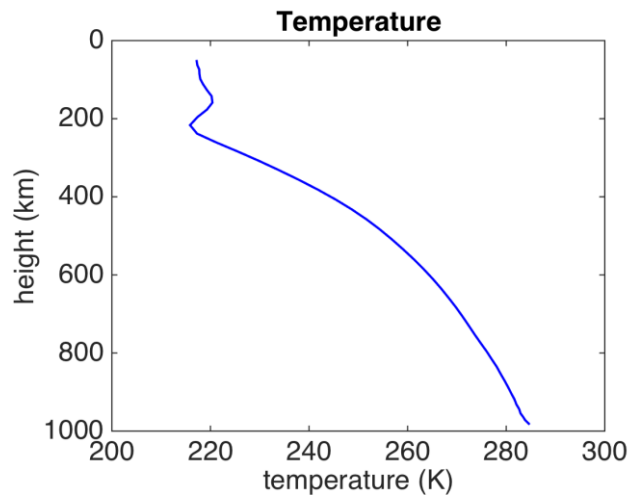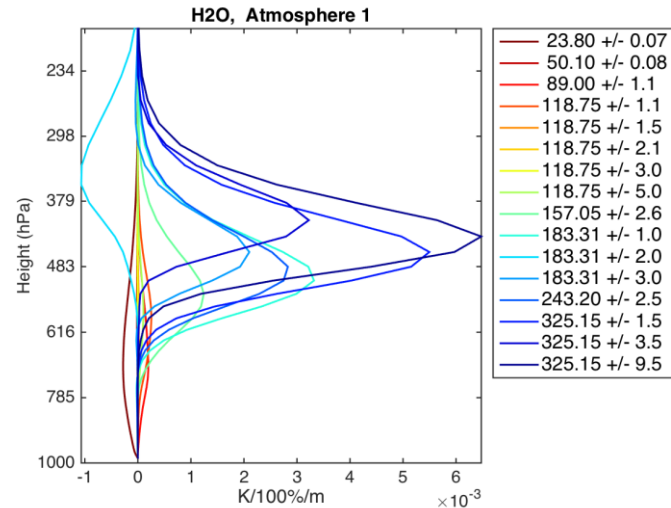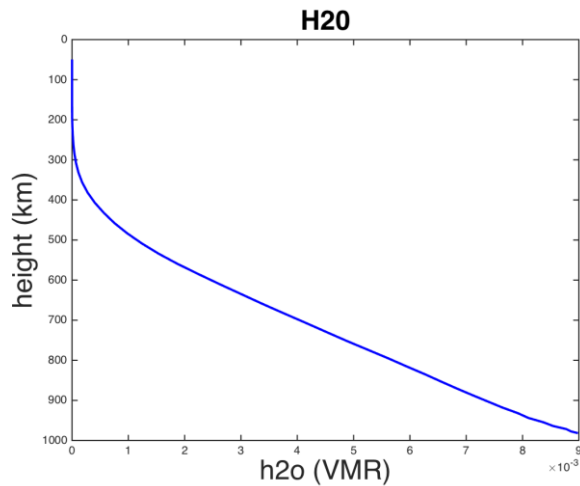
Apriori and analysis error covariance - ideal

- The initial correlations are "diffused" through out the matrix, new patterns occur

Correlation apriori covariance

Correlation analysis error covariance