Fast IR modelling of cloudy infared radiances

Jérôme Vidot, James Hocking, Marco Matricardi

4th Workshop on assimilating satellite cloud and precipitation observations for NWP
ECMWF, 5 February 2020

The EUMETSAT Network of Satellite Application Facilities

NWP SAF Numerical Weather Prediction

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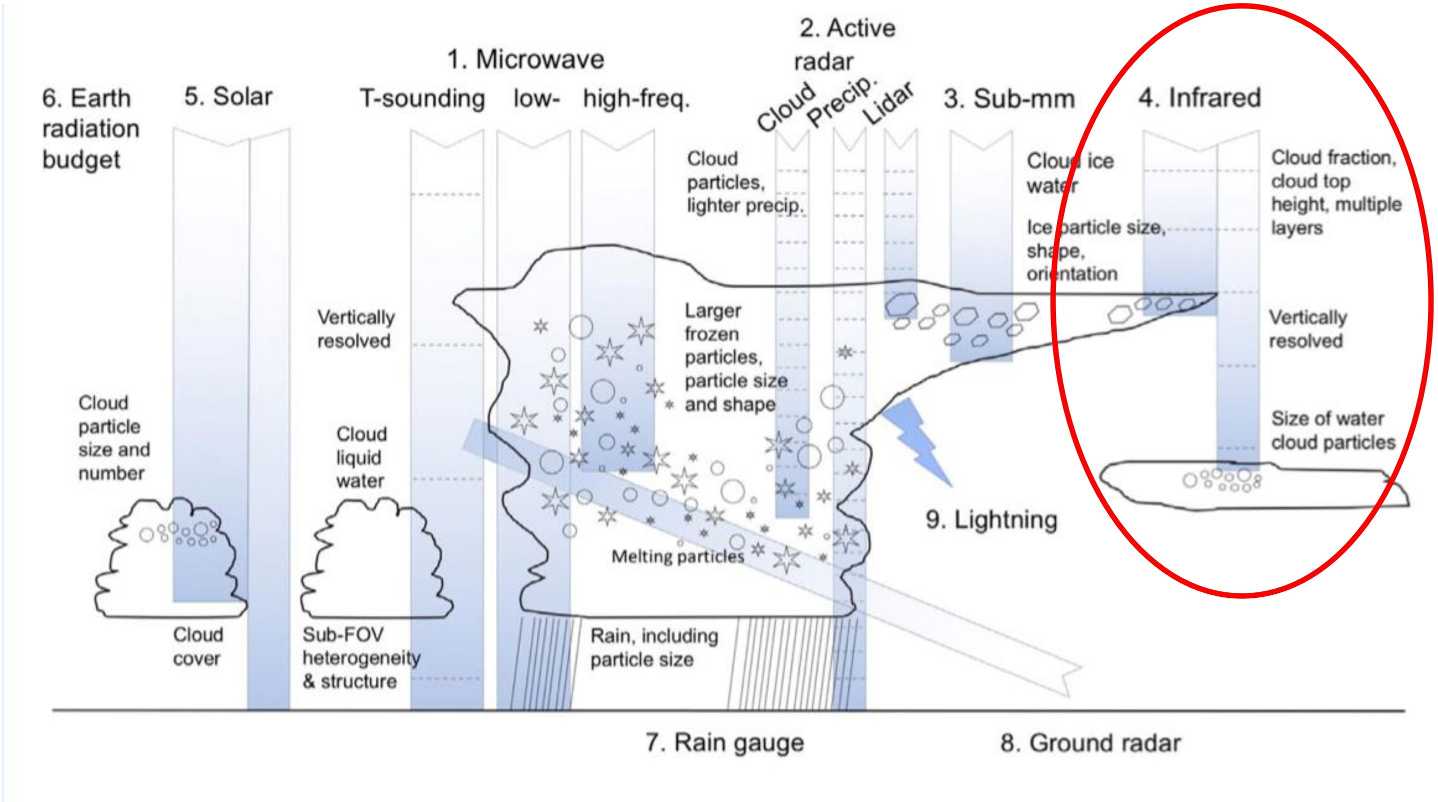
- **The scattering model & validation**
- **Conclusion & Future works**

Introduction

- **What type of cloud is the infrared domain sensitive to ?**

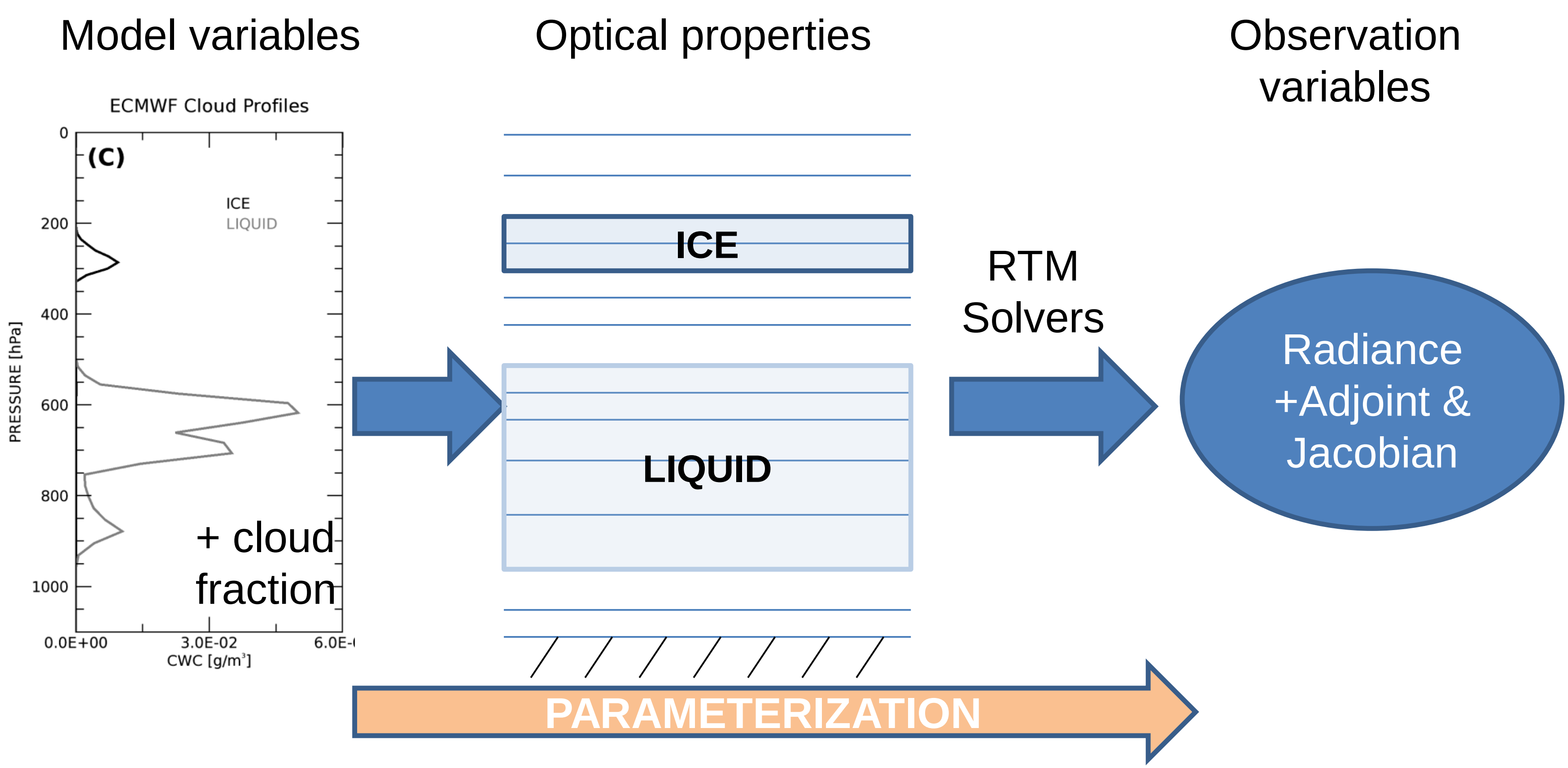


From Geer and Borman, ECMWF 2019

- Non-precipitating clouds (top layers)
- High and mid-level clouds
- Multi-layers clouds

Introduction

- **What cloud information do NWP models provide ?**



- Parameterization are used to accelerate simulations
- This complex scheme is not used in operational assimilation

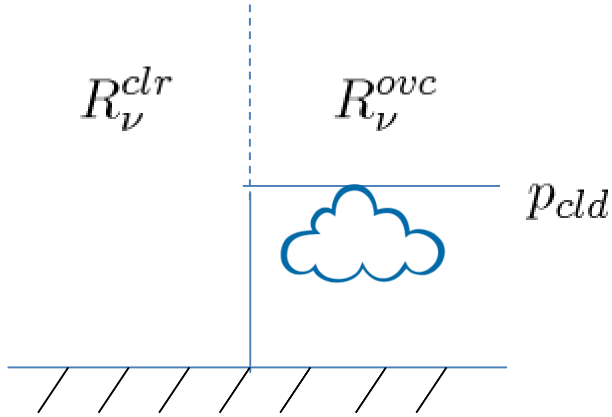
Fast cloud model : The single-layer approach

- Assumption: No scattering, independent pixel approximation (IPA)
- The cloudy radiance of a single FOV is given by:

$$R_{cld}(\mu) = (1 - N_e) R_{clr}(\mu) + N_e R_{ovc}(\mu, p_{cld})$$

$$N_e = N \epsilon_\nu^{cld}$$

(Effective cloud fraction)

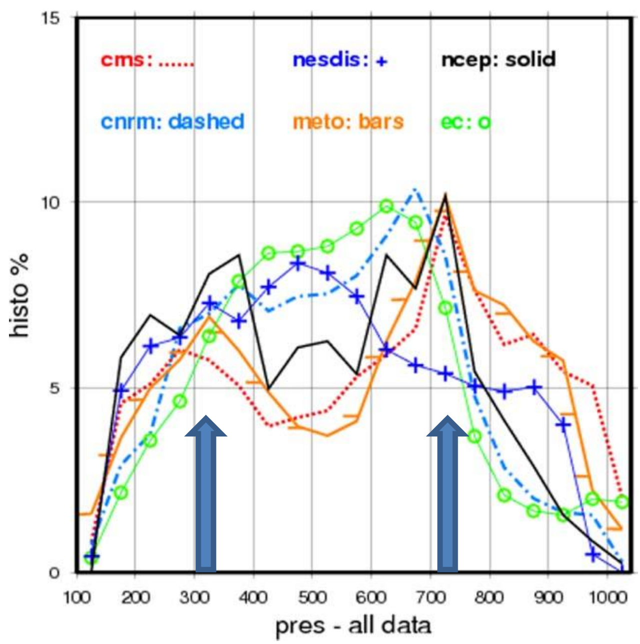


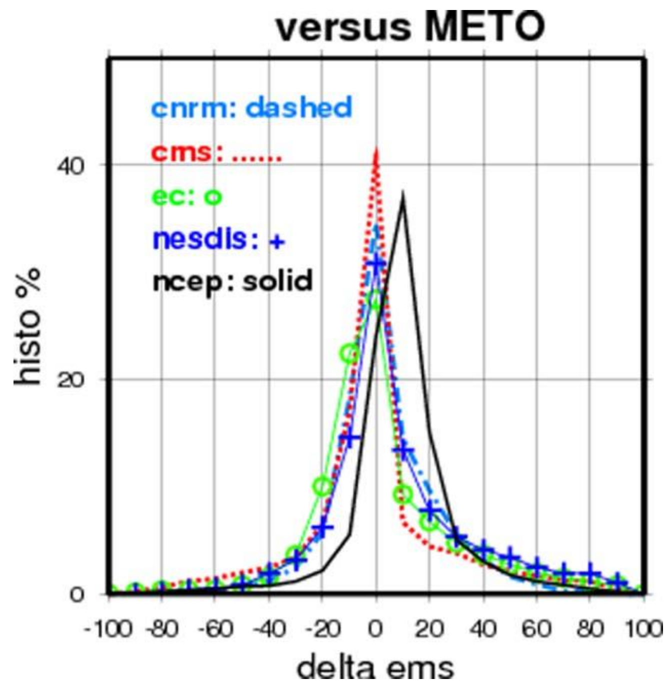
- The overcast condition corresponds to an opaque cloud (emissivity=1)
- p_{cld} and N_e can be retrieved using:
  - CO_2-slicing Method (Chahine, 1974): MF (Pangaud et al., 2009), EC (Garand et al., 2011)
  - Minimum Residual Method (Eyre and Menzel, 1989)
  - 1-D Var (Eyre, 1989) : MO (Pavelin et al., 2008)

    = > + T & q retrieval

Operational cloud products intercomparison
(Lavanant et al., 2011)

- Comparison of IASI clouds product on 12h
- Different methods, different RTM, different surface, different background profiles





- Most schemes have two main peaks around 700-800 and 300 hPa
- Most schemes show same departure of N_e relative to MetOffice
- Agreement between schemes always better for high clouds
- All methods have ambiguities with multi-layers and thin clouds

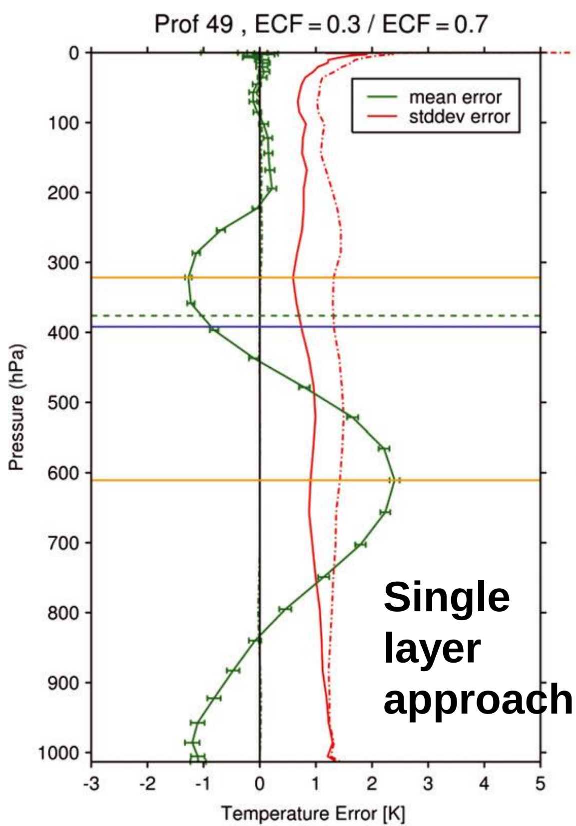
Fast cloud model: The two-layer approach

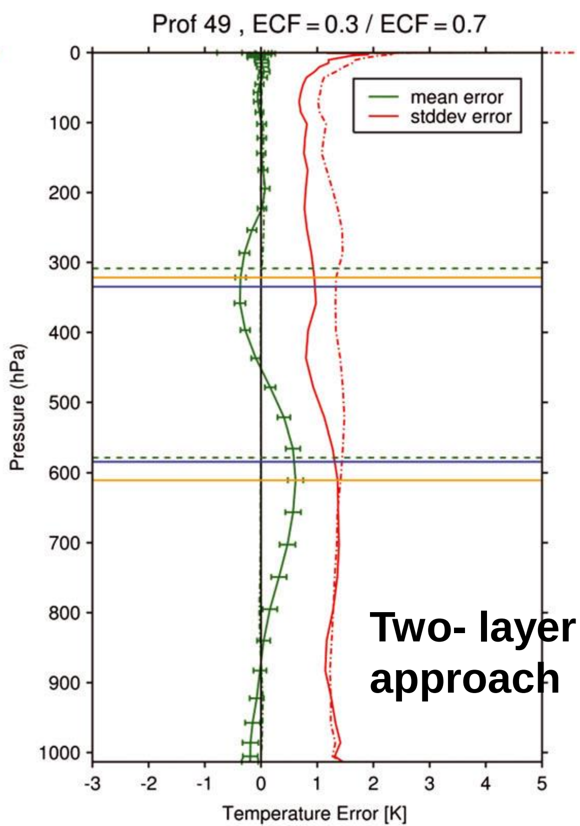
(Smith et al.,1970)

- The cloudy radiance of a single FOV is given by:

$$R_\nu^{cld} = (1 - N_{e1})(1 - N_{e2}){R_\nu}^{clr} + N_{e1} R_\nu^{ovc}(p_{cld1}) + N_{e2}(1 - N_{e1}) R_\nu^{ovc}(p_{cld2})$$

- Assumption: Random overlap between cloud layers and p1 < p2
- Show potential improvement when applied to IASI with 1DVAR (Prates et al., 2014)





The two-layer model has higher skill in determining the position of the upper layer and the atmospheric profiles

The cloud scattering approach

- Source function contribution from cloud emission and scattering

$$J(\mu) = (1 - \omega_0)B(T) + \frac{\omega_0}{2}\int_{-1}^{1} R(\mu)P(\mu;\mu')d\mu'$$

Single scattering albedo : $\omega_0 = \frac{k_s}{k_e} = \frac{k_s}{(k_a + k_s)}$

Phase function : $P(\mu;\mu')$

- The RTE cannot be solved analytically (Add-Doubling, Discrete Ord., Ord. Scat, MC,...)
- Advantage: For assimilation, no need for cloud detection & characterisation algorithms

- For fast RT cloudy modelling there are 3 issues:
  1. Optical properties of clouds from LWC and IWC profiles
  2. Cloud overlap methods to handle cloud fraction profile
  3. Fast scattering approach

Fast scattering approach in IR (RTTOV v9)

(Matricardi, 2005)

- Method based on the Chou-scaling approximation for irradiance (Chou et al., 1999)
- Assumption: the radiance field is isotropic in each hemisphere

- **Theoretical basis**:

$$\tau_{tot} = \tau_a + b\tau_s$$

$$b(\lambda) = \frac{1}{2}\int_0^1 \mathrm{d}\mu \int_{-1}^0 \overline{P(\mu,\mu')}\mathrm{d}\mu'$$

- **Advantage**: fast simulation similar to clear-sky

- Approach used for many research studies:

- IASI channels selection for cloud (Martinet et al., 2013)
- 1D-var cloud profile retrieval (Martinet et al., 2014)
- Background cloudy radiances (Okamoto et al., 2017)
- Water vapour cloudy channels assimilation (Geer, et al., 2019; Okamoto et al., 2019)

IR Liquid cloud models (RTTOV v12)

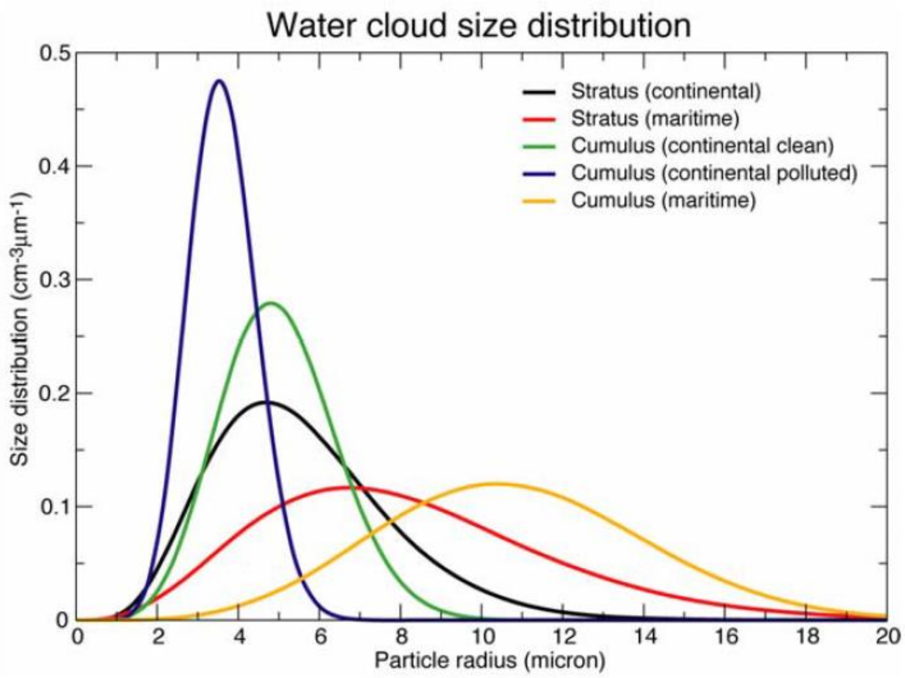
- **2 microphysical models:**

1. **OPAC (Hess et al., 1998)**
   - Particle size distribution = Modified Gamma
   - 5 cloud types: 2 Stratus (Continental, Maritime); 3 cumulus (Continental clean/polluted, Maritime)
   - Optical properties are precalculated and normalized to 1 droplet/cm³ * $N_c\,(LWC)$

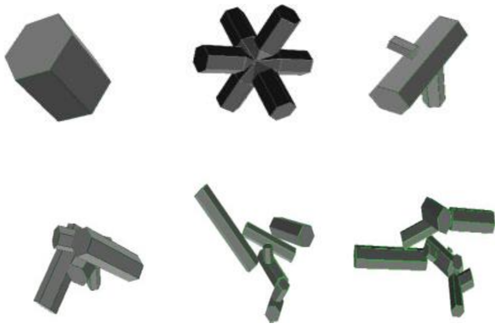
2. **D_{eff}-based LUT with $D_{eff} = f(LWC)$**
   Effective size of droplet D_{eff}
   from Libradtran RTM model

Issue with (1): choose the cloud type
=> Selection stratus/cumulus from a threshold on CAPE (Okamoto et al., 2014)

Issue with (2) :
D_{eff} is not a NWP variable



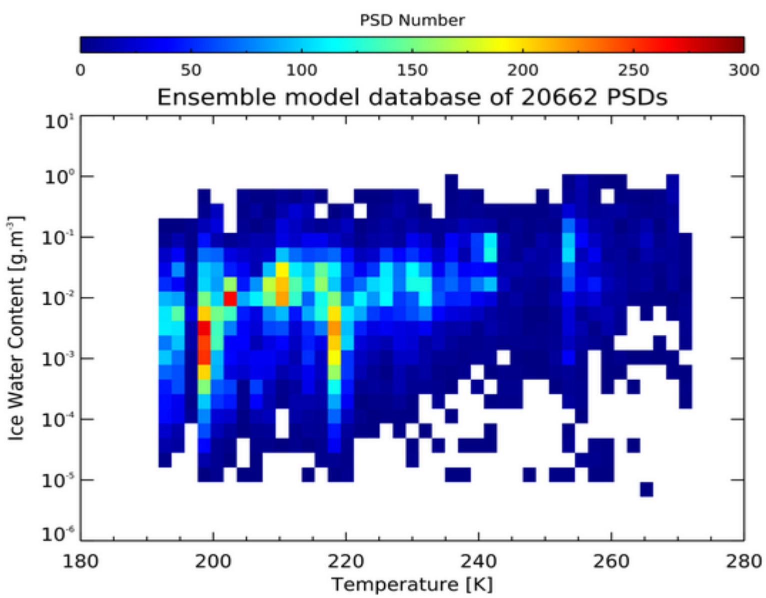
IR ice cloud models (RTTOV v12)

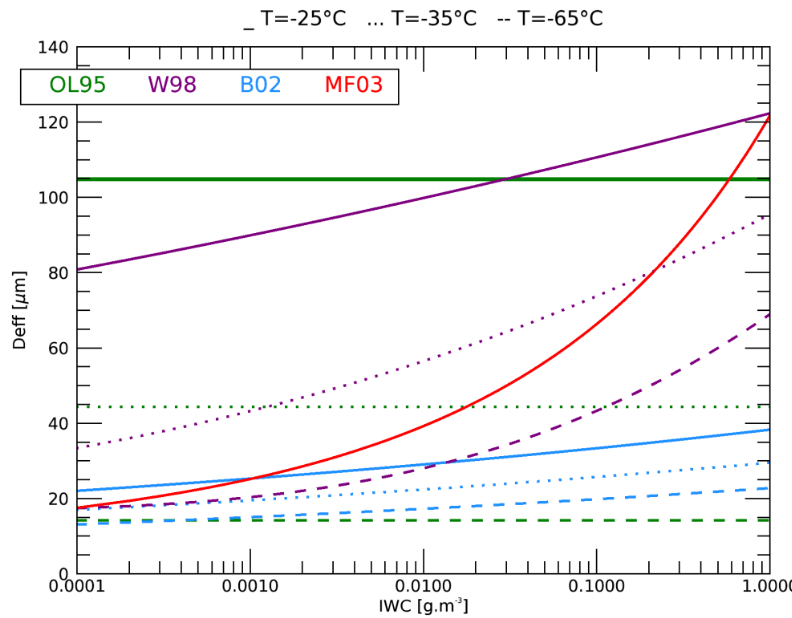


- **Baran parameterization** (Vidot et al., 2015)
  - Ensemble model of 6 ice crystal shapes (Baran et al., 2014)
  - PSD parameterization (Field et al., 2007)
  - Optical properties parametrized as function of IWC and T

- **Baum + D_{eff}-parameterization**
  - SSEC LUT (Baum et al., 2014)
  - Optical properties as function of the effective size of ice particles D_{eff}
  - 4 Parametrizations $D_{eff} = f$ (IWC and/or T):

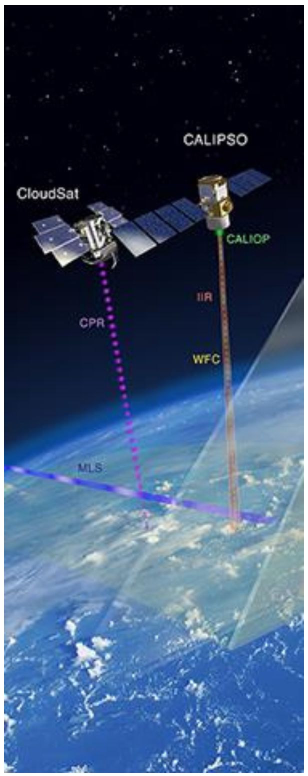
Ou and Liou (1995); Wyser (1998); Boudala et al. (2002); McFarquhar (2003)



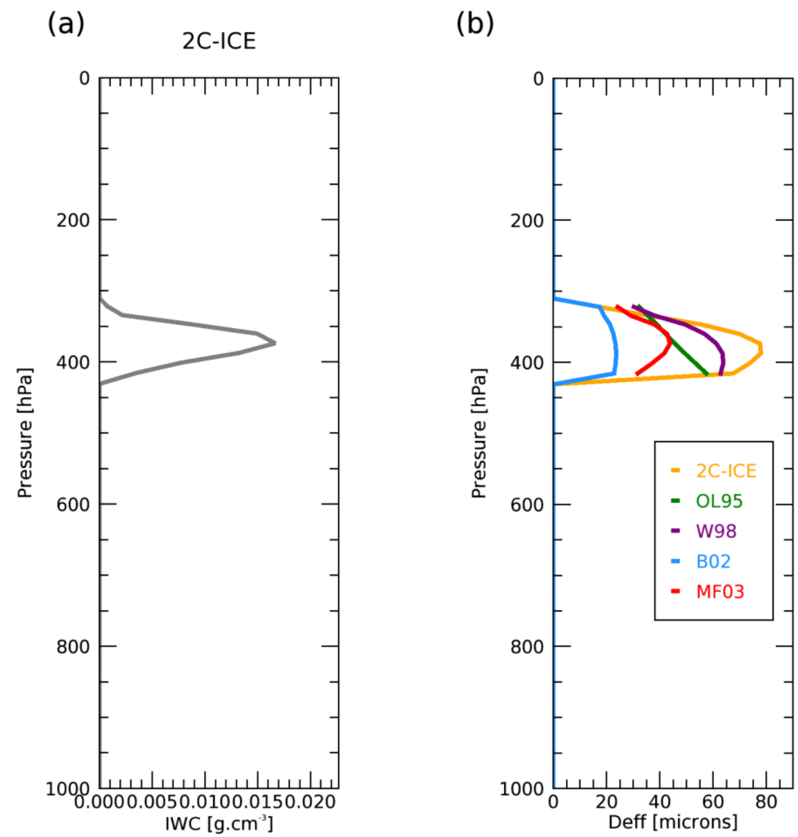


D_{eff}-parameterization effects

- Inputs are **2C-ICE** ice cloud profiles (IWC and D_{eff}, Deng et al., 2010)



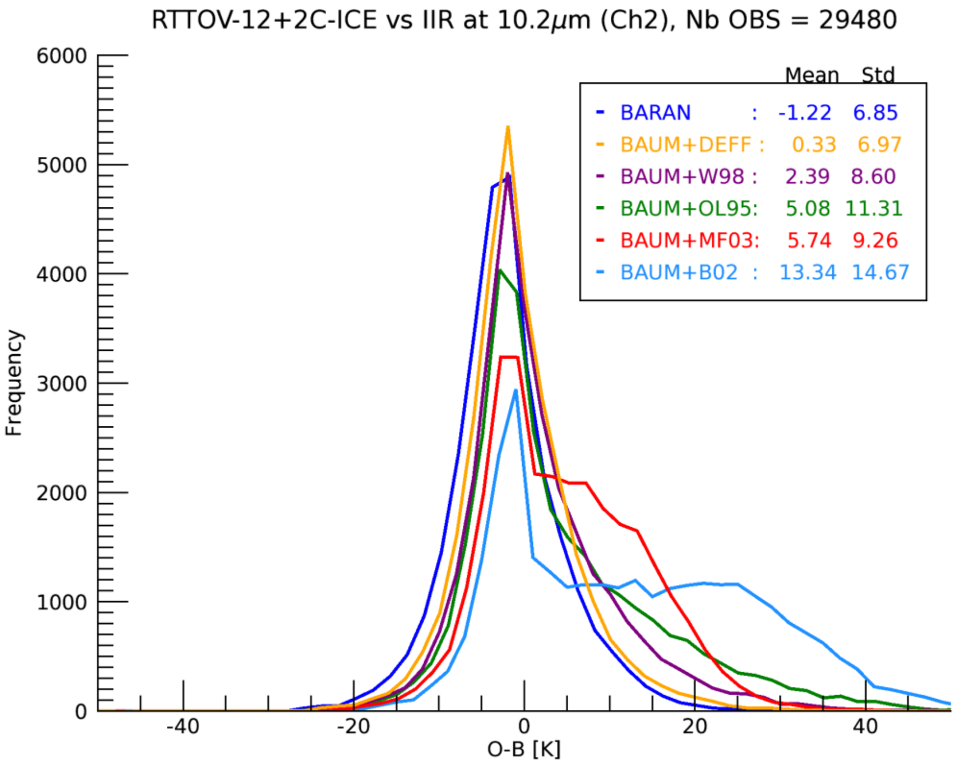
Vertical profiles
CPR
+
Caliop



- Large variability of D_{eff} profiles with RTTOV parameterizations and from 2C-ICE retrievals
- **B02** D_{eff}-parametrization gives smaller ice crystals

Validation using the A-Train

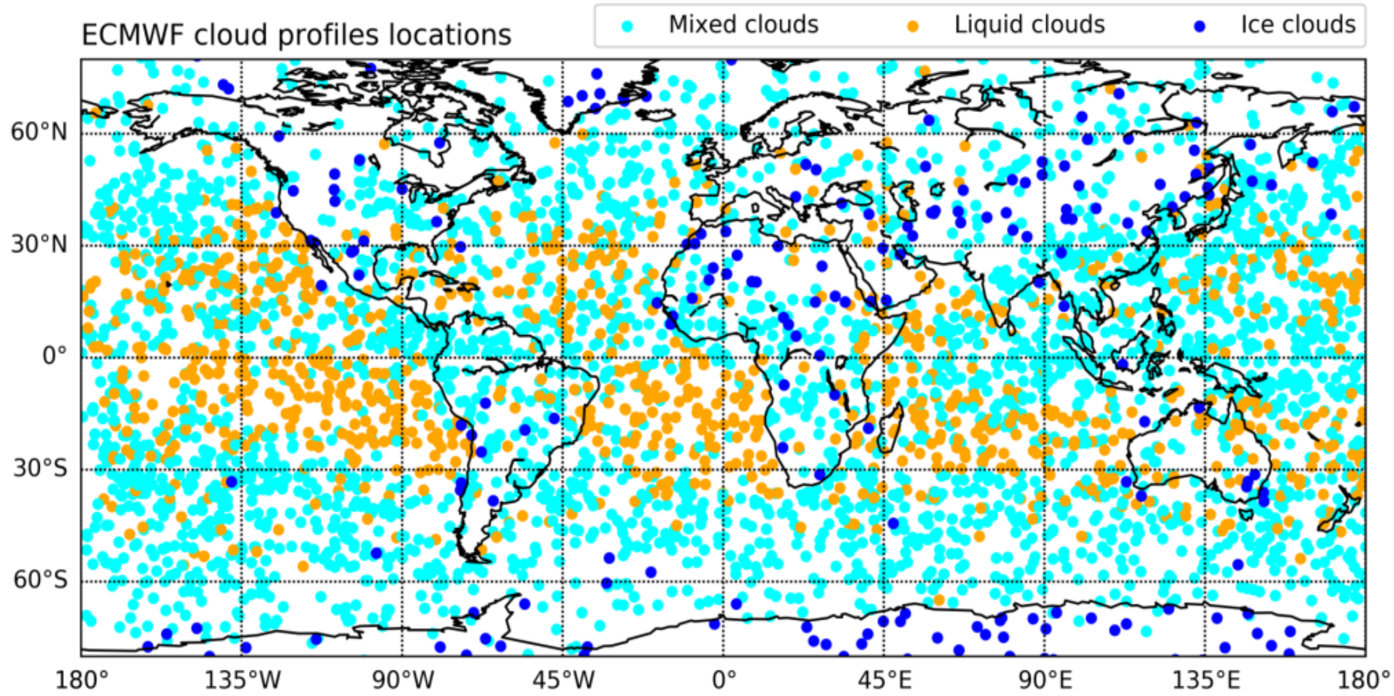
- BTs observations from IIR/Calipso (2 weeks of data)
- IIR pixels size = 1km => assumed CF(z)=1 when IWC(z) > 0



- **Baran** has lowest standard deviation (6.85 K)
- PDF with Baum and **OL95**, **MF03** and **B02** are not symmetrical.
- Baum is better if **Deff** is known and if not **W98** is the best D_{eff}-parametrization

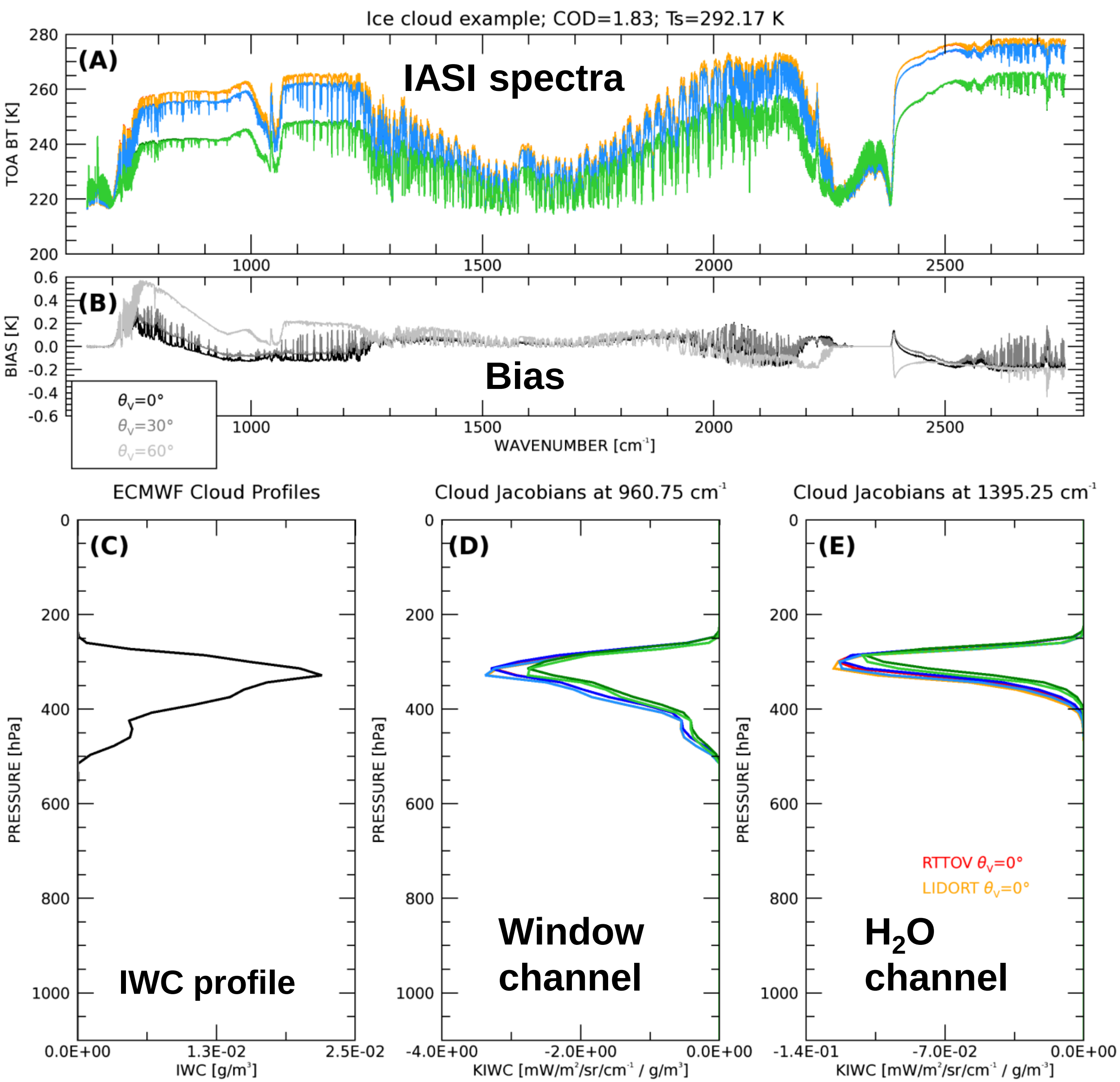
Scattering parameterization evaluation

- Comparison with the full scattering model LIDORT (Spurr, 2008)
- LIDORT is linearized => Jacobians are provided
- Evaluation using the NWPSAF 137 levels atmospheric profiles (+4000 various cloud profiles selected from 1 year of IFS)
- Baran ice cloud, OPAC liquid cloud (cloud types selected with CAPE threshold)
- Cloud overlap is not used (CF=1 whenever there is cloud layer*)*



The single layer of ice cloud

RTTOV θ_v=0°
LIDORT θ_v=0°
RTTOV θ_v=30°
LIDORT θ_v=30°
RTTOV θ_v=60°
LIDORT θ_v=60°



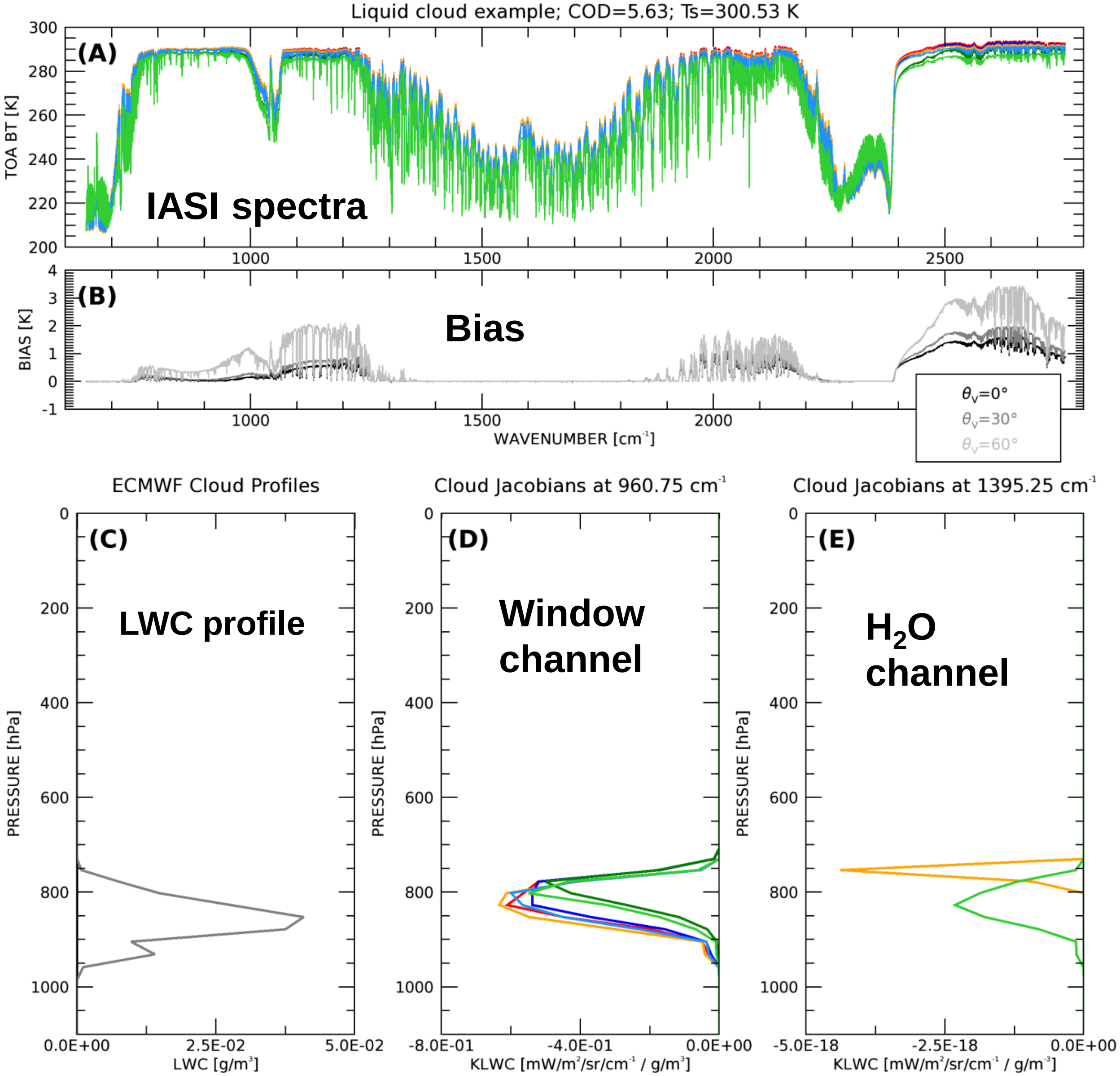
- Difference < 0.6K between RTM models for BTs

- No difference found for cloud jacobians

- In H_2O channel the sensitivity decrease faster in lowest cloud layers

The single layer of liquid cloud

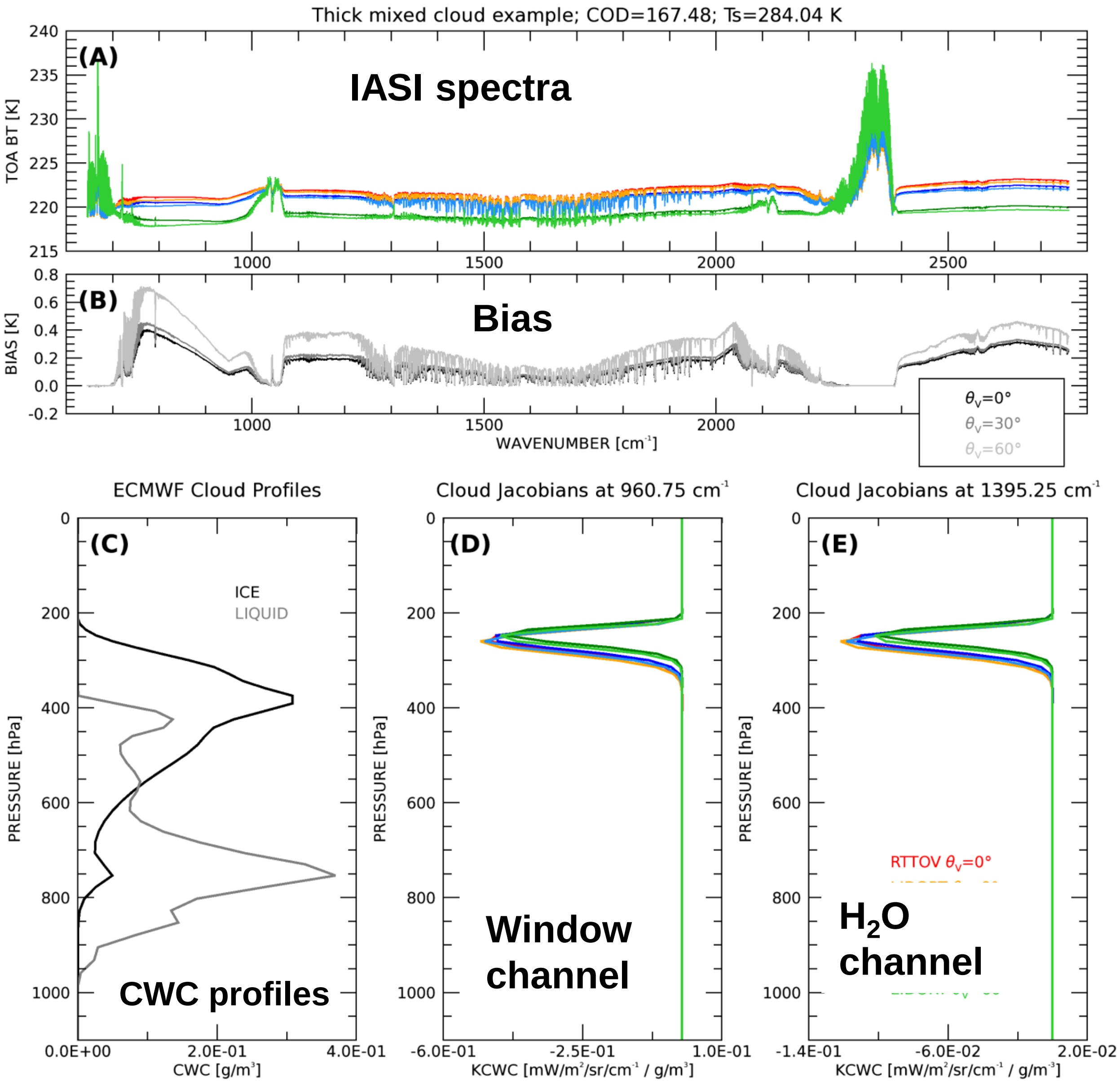
RTTOV θ_v=0°
LIDORT θ_v=0°
RTTOV θ_v=30°
LIDORT θ_v=30°
RTTOV θ_v=60°
LIDORT θ_v=60°



- Difference increase for liquid clouds (< 3K)
- Small differences found for cloud jacobians in window channel
- No sensitivity to cloud in H_2O channel

The thick mixed cloud

RTTOV θ_v=0°
LIDORT θ_v=0°
RTTOV θ_v=30°
LIDORT θ_v=30°
RTTOV θ_v=60°
LIDORT θ_v=60°



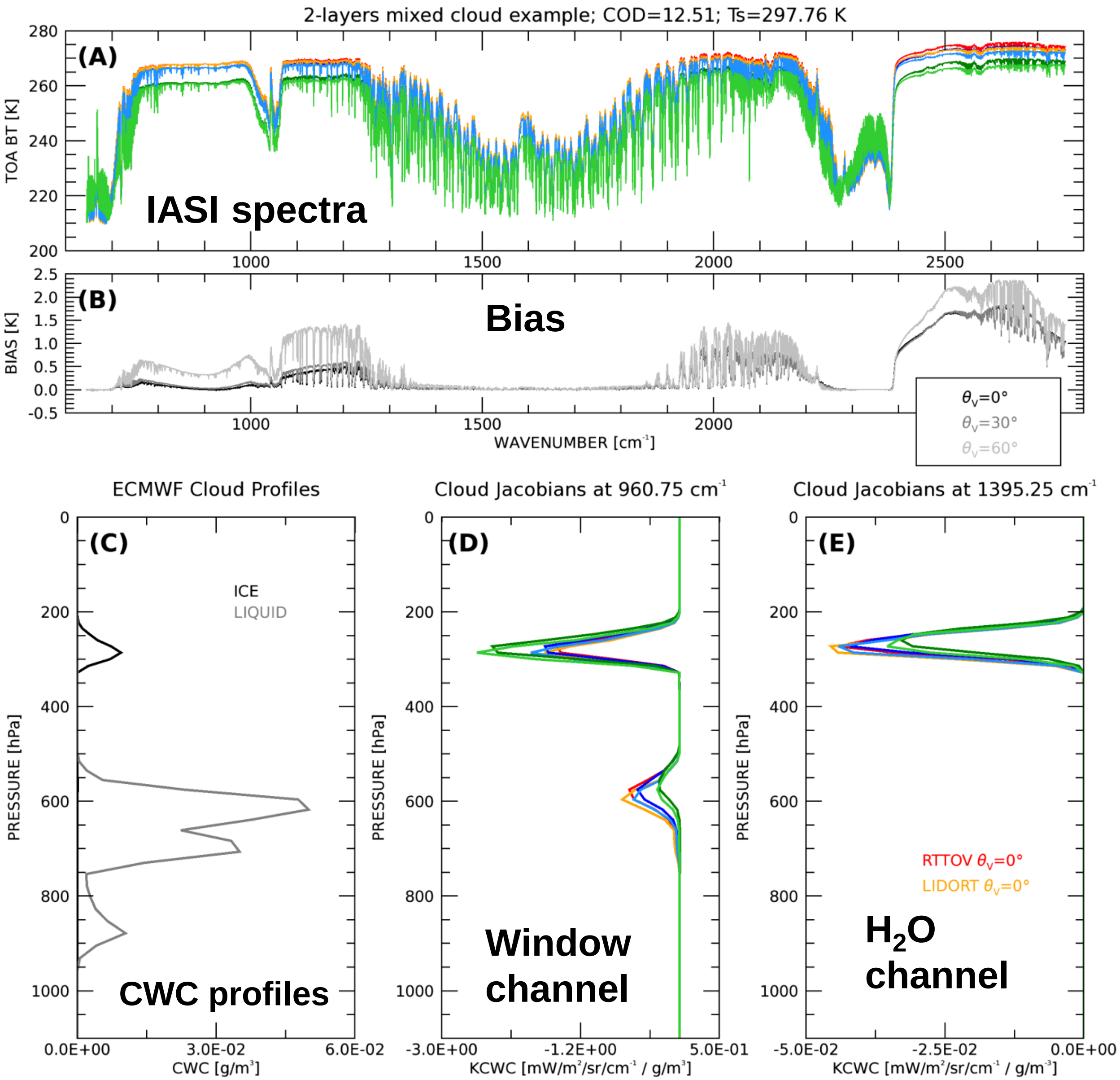
- Difference similar to single ice cloud

- No differences found for cloud jacobians

- The IR radiation is only sensitive to the top layers of the clouds

The two-layer mixed clouds

RTTOV θ_v=0°
LIDORT θ_v=0°
RTTOV θ_v=30°
LIDORT θ_v=30°
RTTOV θ_v=60°
LIDORT θ_v=60°



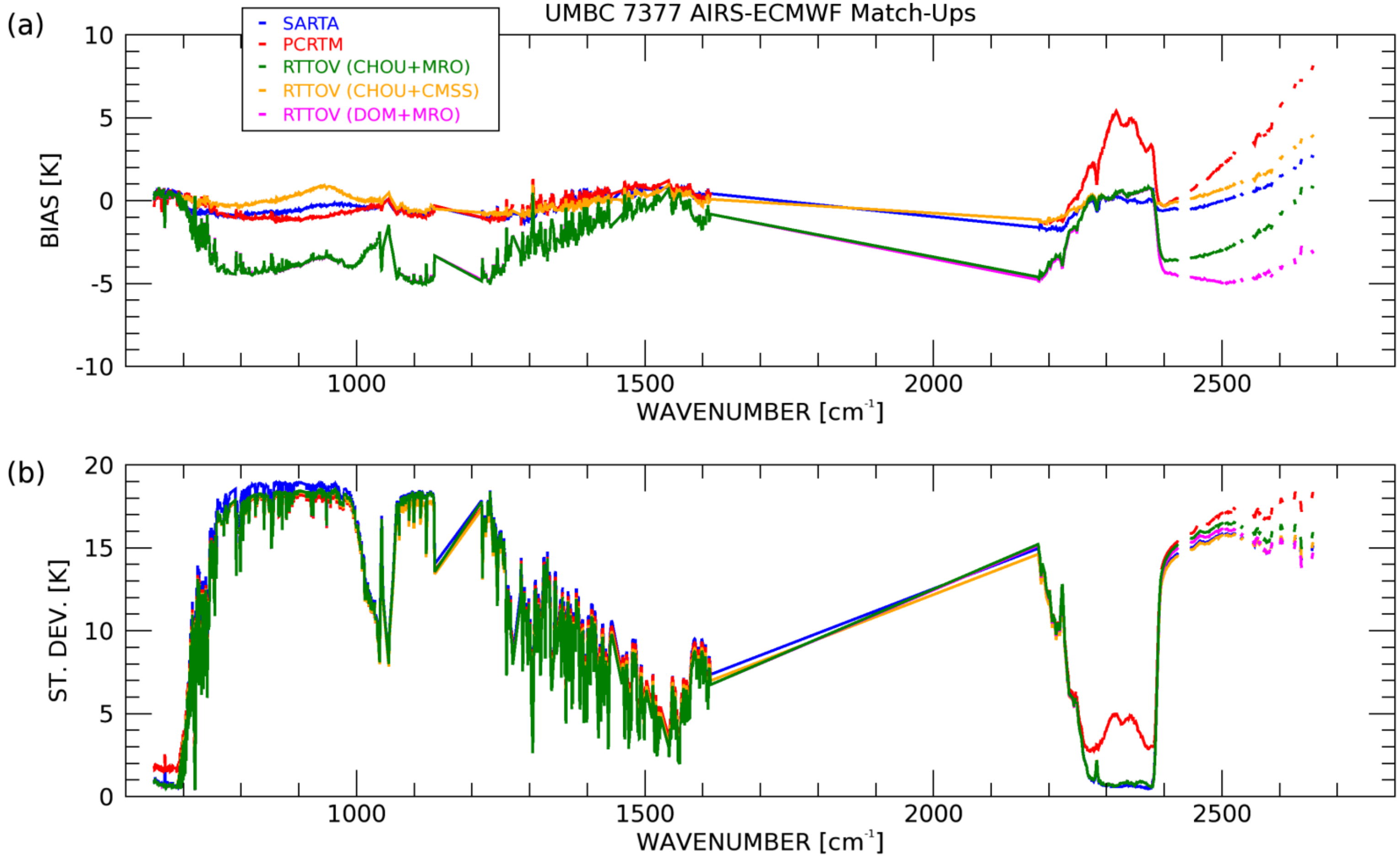
- Difference increase due to liquid cloud

- The IR radiation is still sensitive to the lower layer in window channel

- Not in H_2O channel

Cloud overlap effect

- Study done in the frame of an intercomparison exercise (Aumann et al., 2018)
- 6h of AIRS data colocated with ECMWF 91L cloud profiles
- Example for 3 RTMs and 2 overlap method for RTTOV (MRO and CMSS)
- The overlap method changes the bias, not the standard deviation



Conclusion and future works

Going beyond the single cloud layer in IR is nowadays feasible, but the fast modelling of cloud radiances has to take into account three contributions:

1. **Scattering method**

→ In RTTOV, the fast scattering approach is very efficient for ice clouds, but less efficient when liquid cloud is present (radiance and Jacobians).

→ Cloud jacobians in IR show sensitivity to multiple layers clouds

Improve the fast scattering by adding a correction as proposed by Tang et al. (2018)

2. **Cloud optical properties** over the full IR domain from IWC/LWC NWP variables

→ For current assimilation, cloud optical properties must be independent from D_{eff}

→ Cloud optical properties can be validated using the A-Train with active/passive

Looking for IR and MW spectral consistency of cloud optical properties

3. **Overlap method** from cloud fraction profile

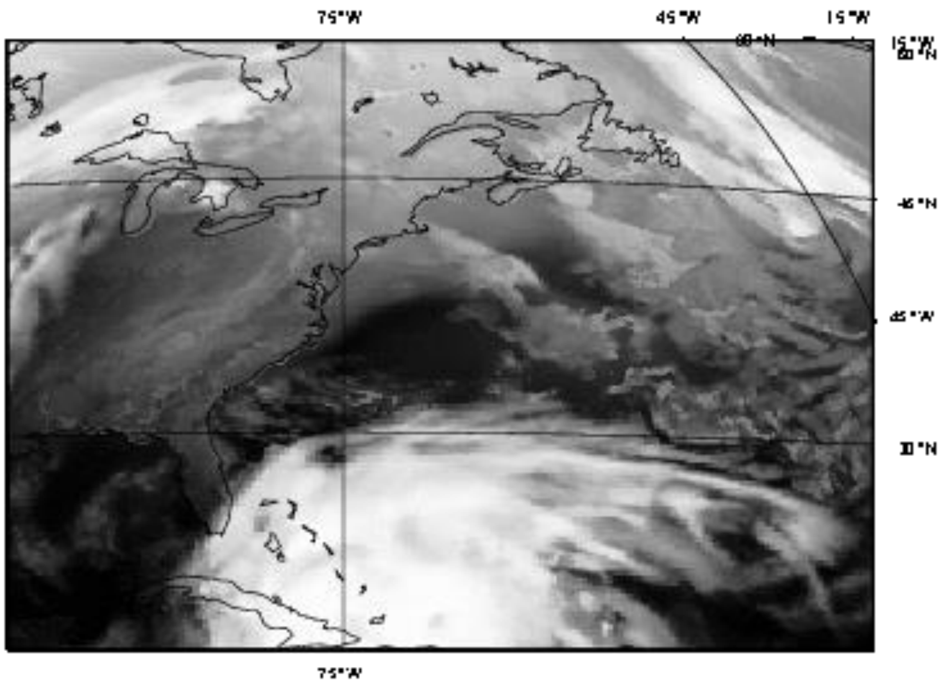
Need further studies

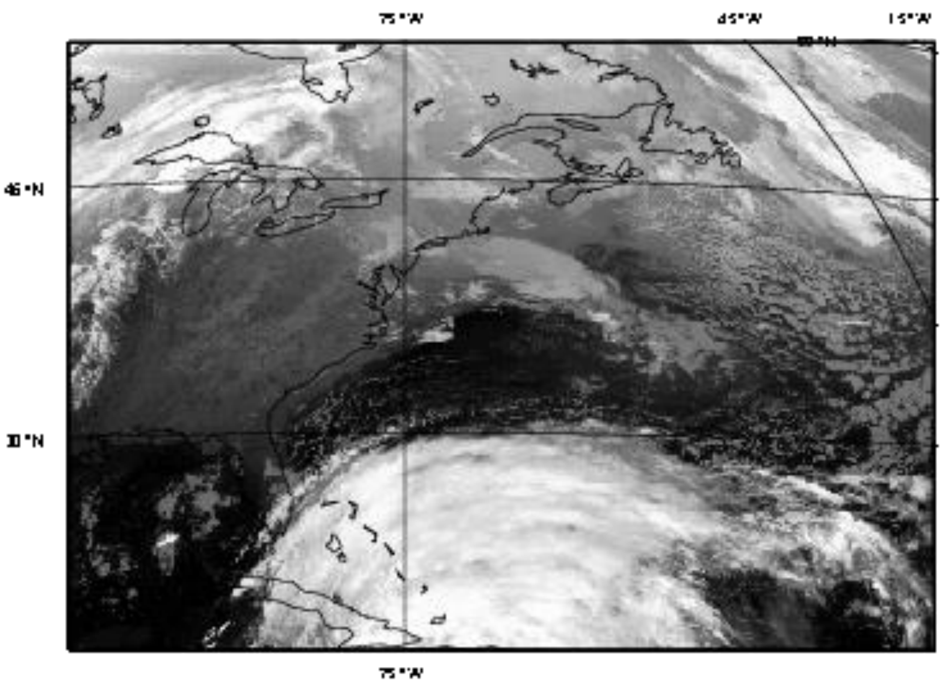
What is the priority for DA assimilation ?

Thank you for your attention

IFS + RTTOV simulations

GOES IR observations





Courtesy C. Lupu (ECMWF)