National Aeronautics and
Space Administration

CRTM Active Sensor Module and Cloud Scattering Parameters Generated Using the Discrete Dipole Approximation Technique

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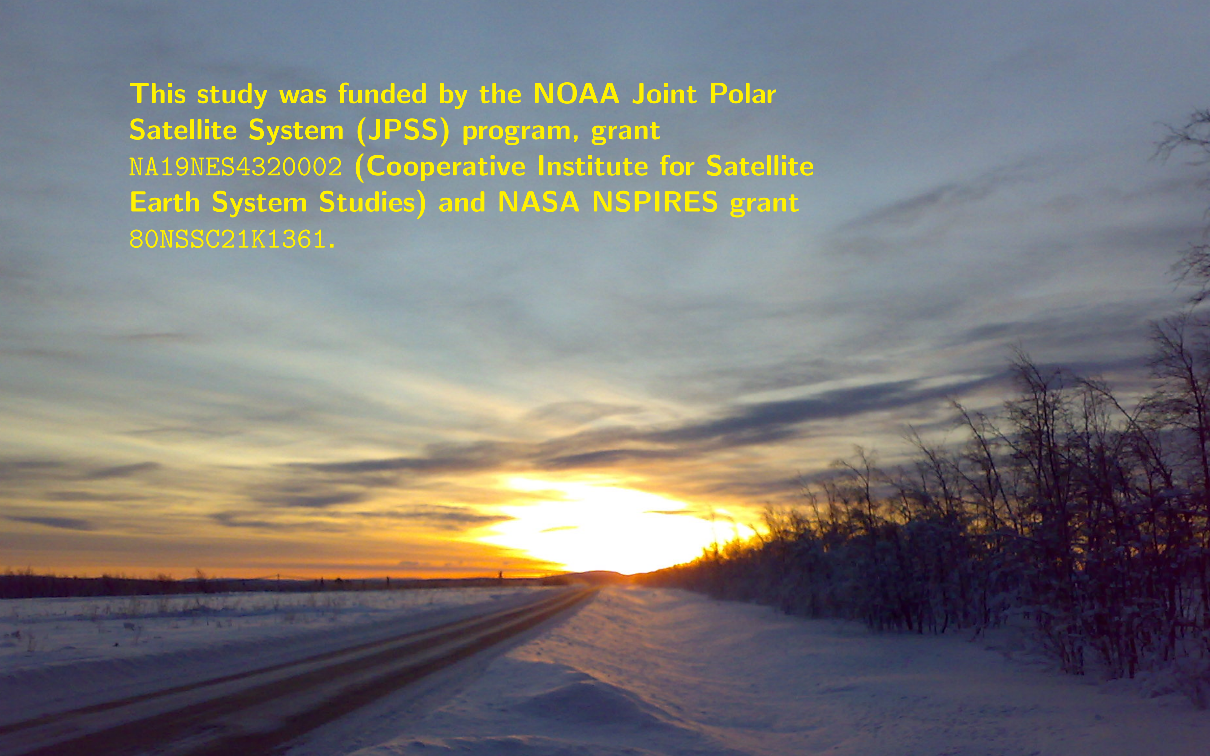
Thanks to Patrick Stegmann, Benjamin Johnsson, Patrick Eriksson, Alan Geer and many others!

October 31, 2022



This study was funded by the NOAA Joint Polar Satellite System (JPSS) program, grant NA19NES4320002 (Cooperative Institute for Satellite Earth System Studies) and NASA NSPIRES grant 80NSSC21K1361.

Outline

All-weather radiative transfer calculations

Cost function for 3D-Var Data Assimilation:

$$J(\vec{x}) = \overbrace{\frac{1}{2}(\vec{x} - \vec{x_b})^T \vec{B}^{-1}(\vec{x} - \vec{x_b})}^{J_b} + \overbrace{\frac{1}{2}(H(\vec{x}) - \vec{y})^T \vec{R}^{-1}(H(\vec{x}) - \vec{y})}^{J_o}$$

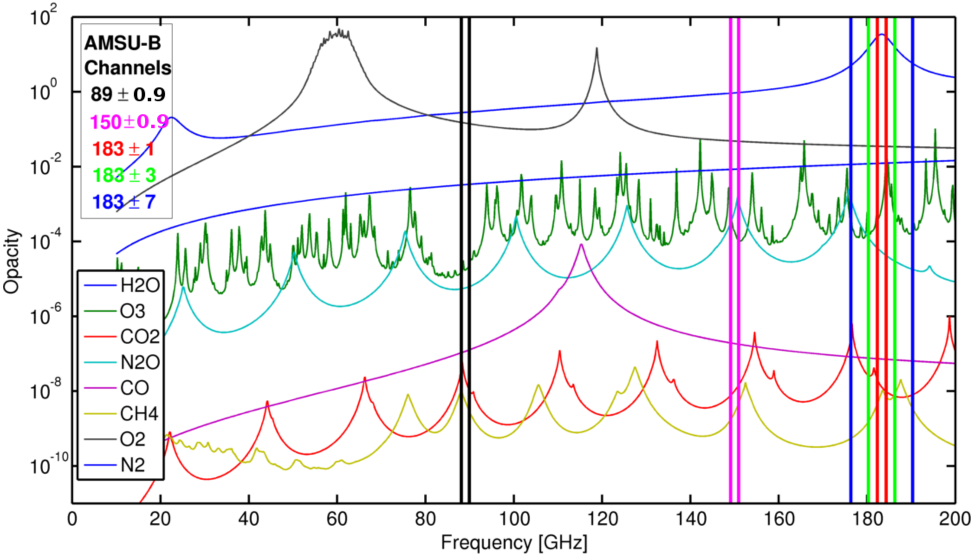
Relation between the observations (y) and the forward operator (H) can be expressed as: $y = H(\vec{x}, \vec{p_b}, \vec{p_s}) + \epsilon$

$\vec{x}$ state vector, $\vec{p_b}$ parameters such as shape and size distribution of hydrometers, $\vec{p_s}$ indicates the scattering parameters (e.g., phase function)

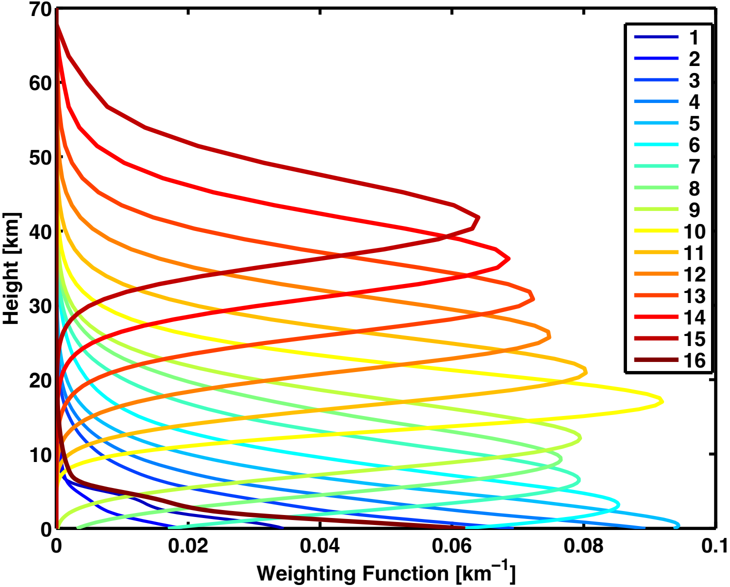
$$\frac{dI_\nu}{dx} = -(\alpha_\nu + S_\nu)I_\nu + \alpha_\nu B_\nu(T) + S_\nu J_\nu$$

$$J_\nu = \int p_\nu(\Omega) I_\nu d\Omega$$

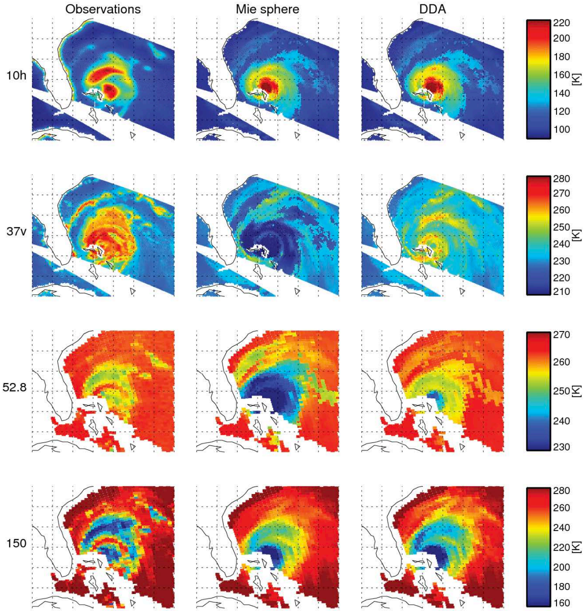
Microwave spectrum



Weighting Functions



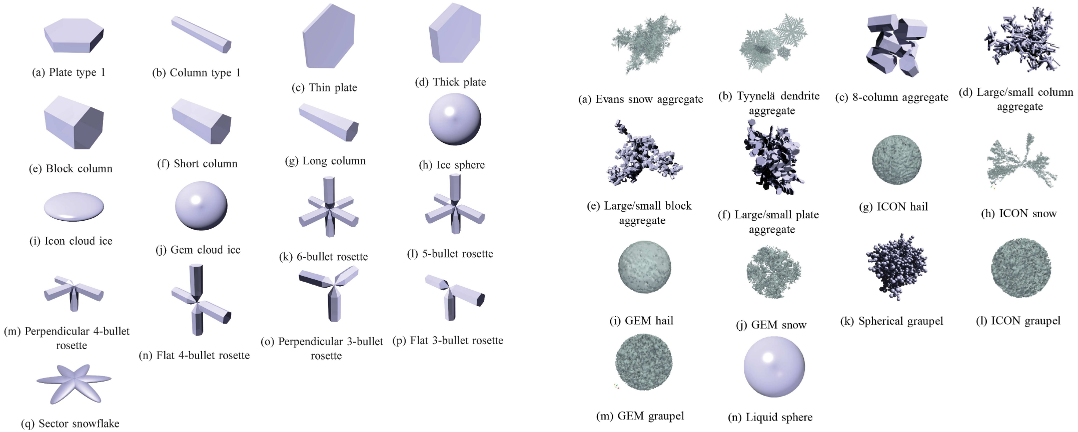
Motivation



Observed and simulated Tb's using the DDA and Mie theory over Hurricane Irene (Geer and Baordo, 2014a).

First column shows observations from SSMI/S and TMI, the second column shows the Mie calculated Tb's, and the third column shows the DDA calculated Tb's.

ARTS DDA Database



(a) Single crystal

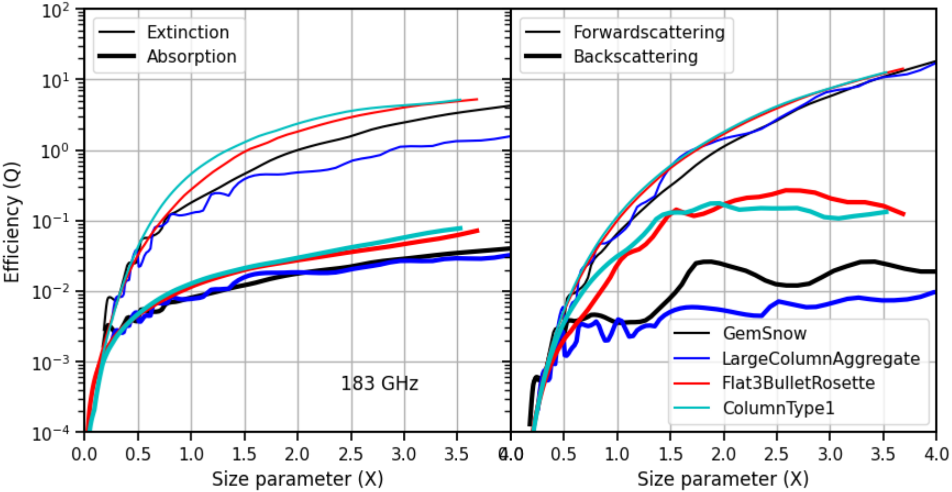
(b) Aggregates and liquid habits

Figure 4: Single crystal, aggregate, and liquid habits included in the database generated by *Eriksson et al.* (2018). Note that although habits "h" and "j" may look identical in the image, they have different aspect ratio.

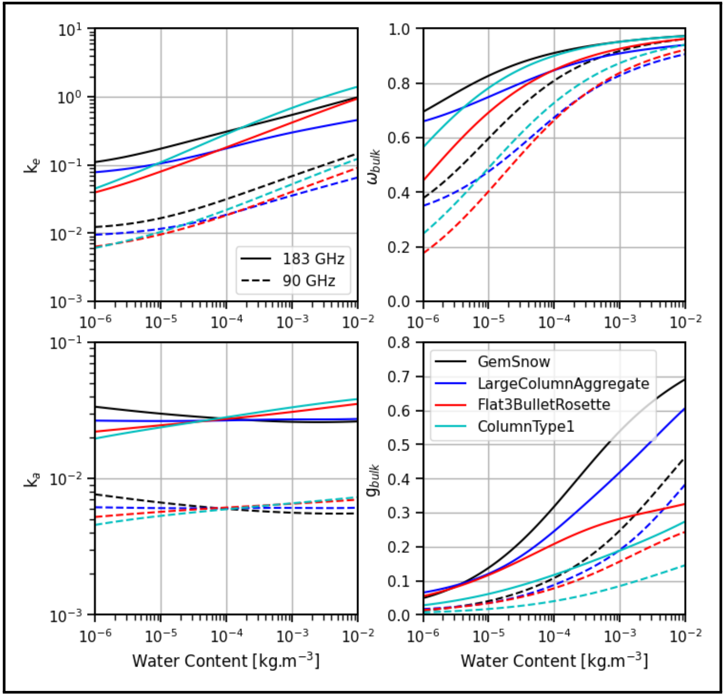
Objectives

- Implement DDA databases into CRTM and modify the code to be able to run all-sky calculations using the DDA lookup tables.
- Evaluate the DDA lookup tables and determine the best DDA shapes for both snow and cloud ice that can yield the best agreement between observed and simulate ATMS Tb's.
- Evaluate the impact of hydrometeor particle size distributions on the CRTM all-sky scattering calculations in comparison with ATMS observations.
- Prepare FV3GFS/JEDI system including modifying required interfaces for CRTM to perform data assimilation using the DDA lookup tables.
- Evaluate the impact of microphysics schemes on the DDA scattering calculations using the GFS/JEDI framework and the ATMS observations.
- Evaluate the impact of the model and observation resolutions on the assimilation of ATMS observations using the DDA lookup tables

$$Q_\lambda = \frac{\sigma_\lambda}{\pi r^2} \qquad x = \frac{\pi D}{\lambda}$$

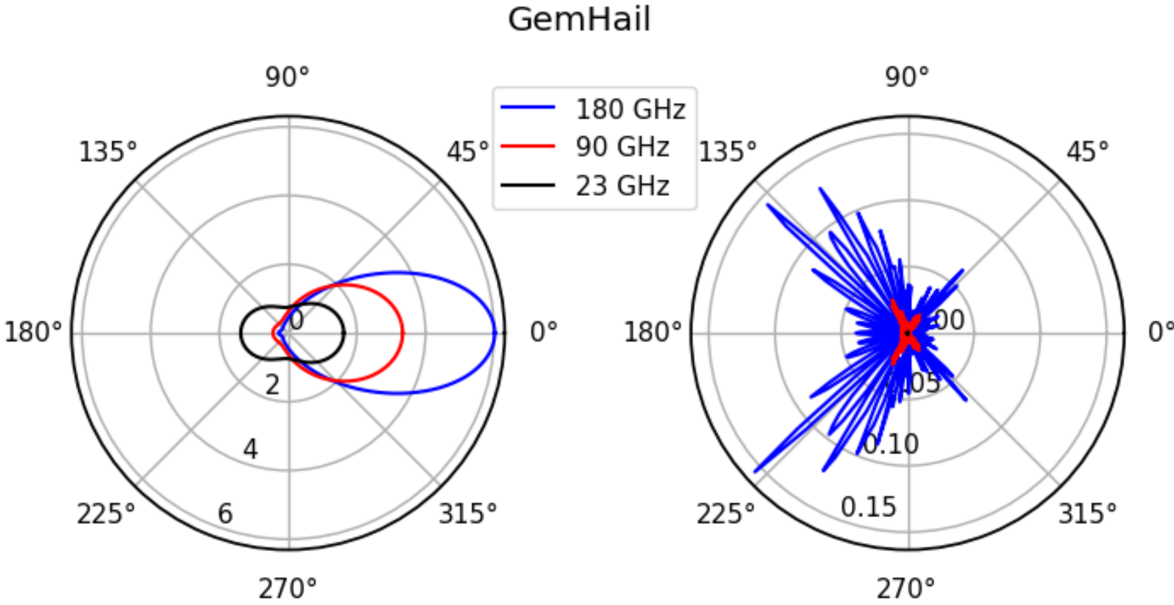


Extinction and backscattering efficiencies from the ARTS database for several different habits (Temp: 260 K)

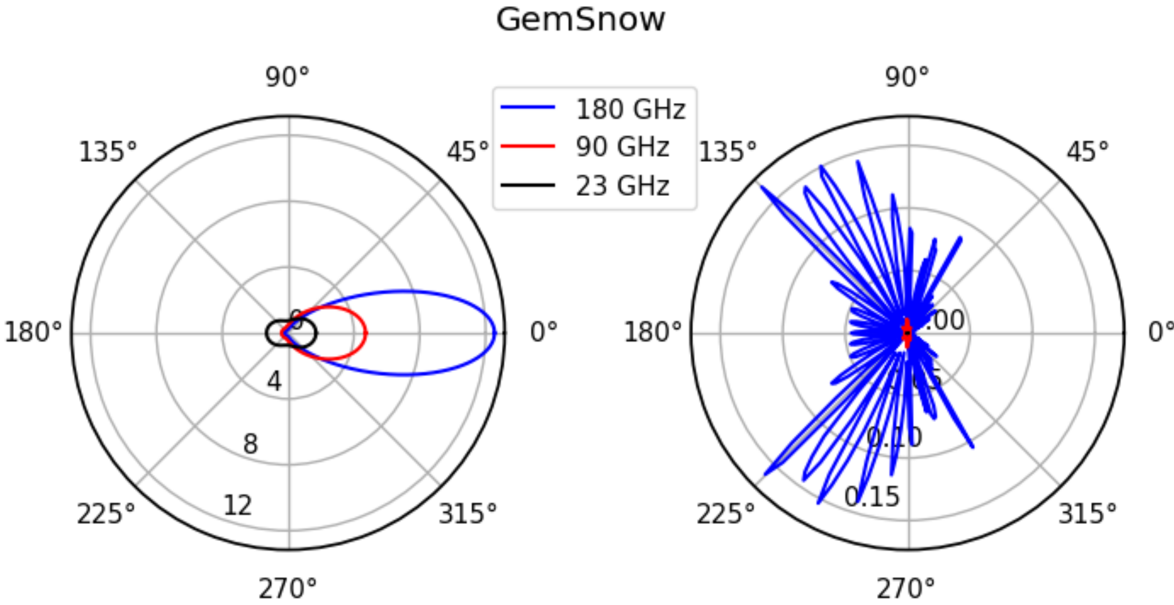


CRTM mass scattering parameters computed from the ARTS database for different habits at 183 and 90 GHz and a temperature of 260 K

Legendre fit for GemHail



Legendre fit for Sector Snowflake



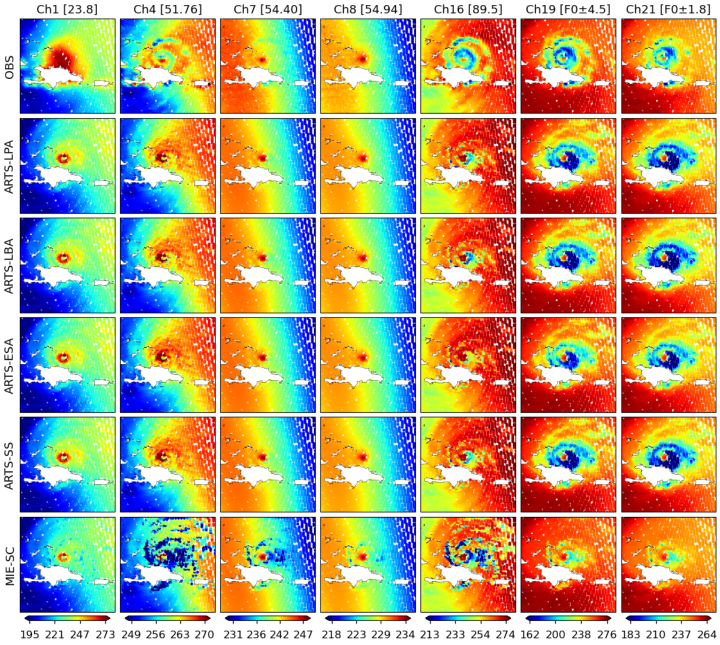
Temperature and Water Content Grids

Current CRTM CloudCoeff:
dimensions:
n_MW_Frequencies = 31 ;
n_MW_Radii = 10 ;
n_IR_Frequencies = 61 ;
n_IR_Radii = 10 ;
n_Temperatures = 5 ;
n_Densities = 3 ;
n_IR_Densities = 4 ;
n_Legendre_Terms = 39 ;
n_Phase_Elements = 1 ;

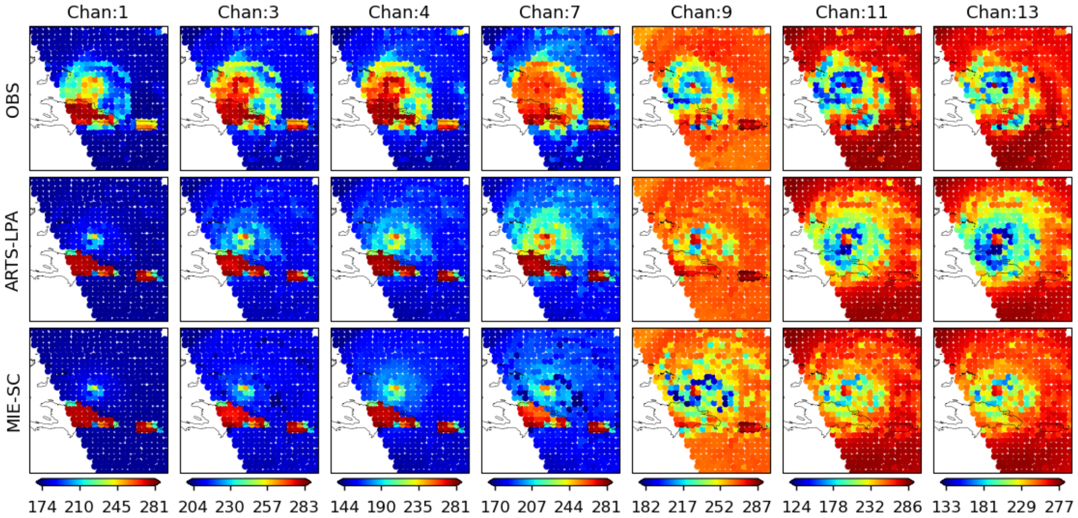
New DDA CloudCoeff:
dimensions:
n_MW_Frequencies = 200; 1-200 GHz ;
n_IR_Frequencies = 61 ;
n_MW_Radii = 200 ;
n_IR_Radii = 10 ;
n_Temperatures = 8 ;
n_MW_Densities = 18 ;
n_Phase_Elements = 1 ;
n_Legendre_Terms = 39 ;
n_IR_Densities = 4 ;

CRTM interface changes

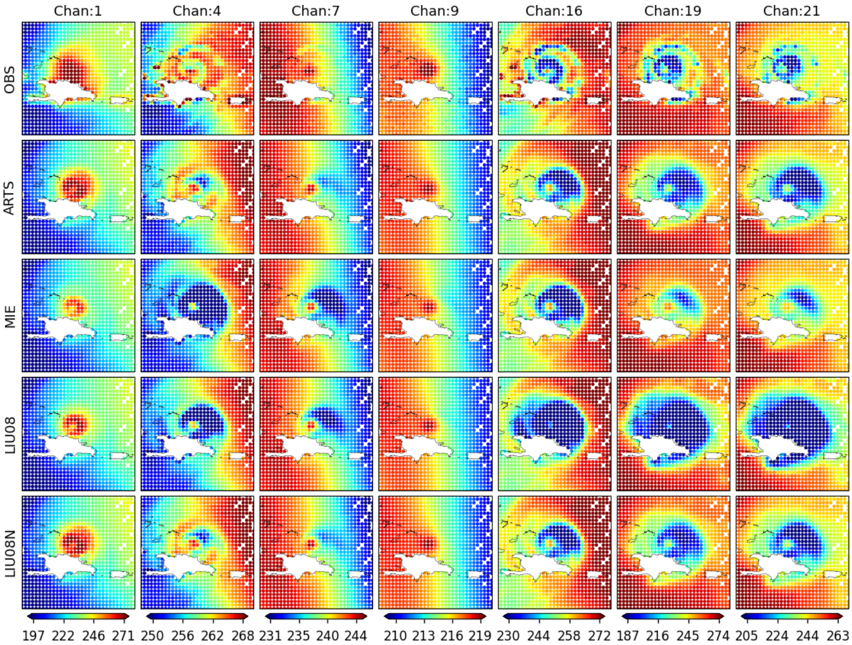
- Unless you want to use a new habit, no changes in the control files required!
- The code will check the CloudCoeff file and if Reff is not present then will use water vapor content for interpolation and ignore the effective radius even if provided.
- Effective radius is very subjective as cannot be measured so one would require to pick a method for calculating effective radius from water content, temperature, etc, but water content is often directly provided by the NWP model.
- In addition to the available cloud types (`WATER_CLOUD`, `RAIN_CLOUD`, `SNOW_CLOUD`, `GRAUPEL_CLOUD`, `ICE_CLOUD`, `HAIL_CLOUD`, which correspond to `LiquidSphere`, `LiquidSphere`, `SectorSnowflake`, `GemGraupel`, `IceSphere`, `GemHail`, the following cloud types can also be defined for the ARTS dataset (note that the word CLOUD is not required here):
  `PlateType1`, `ColumnType1`, `SixBulletRosette`, `Perpendicular4_BulletRosette`, `Flat3_BulletRosette`, `IconCloudIce`, `SectorSnowflake`, `EvansSnowAggregate`, `EightColumnAggregate`, `LargePlateAggregate`, `LargeColumnAggregate`, `LargeBlockAggregate`, `IconSnow`, `IconHail`, `GemGraupel`, `GemSnow`, `GemHail`, `IceSphere`.



ATMS observed vs. CRTM simulated Tbs for Hurricane Irma, Sept 07, 2017 at 18 UTC, using IFS as input (all clouds considered) and different CRTM CloudCoef files.



GPM/GMI observed vs. CRTM simulated Tbs for Hurricane Irma, Sept 07, 2017 at 16 UTC, using IFS as input (all clouds considered) and different CRTM CloudCoef files.



ATMS observed vs. CRTM simulated Tbs for Hurricane Irma, Sept 07, 2017 at 18 UTC, using Era5 as input (all clouds considered) and different CRTM CloudCoef

Histogram Difference Index

$$G_i = \left(\sum_{\text{bins}} \left| \log \frac{\#\text{simulated}}{\#\text{observed}} \right| \right) / \#\text{bins observed}$$

Chan Num	1	2	3	4	5	7	9	11	16	17	18	19	20	21	22	Sum
ARTS-PT1	41	65	24	23	59	42	34	49	48	29	28	31	35	36	41	583
ARTS-CT1	41	53	24	21	66	40	34	49	49	30	29	28	37	35	41	578
ARTS-SBR	41	54	22	23	65	40	34	49	54	31	28	30	34	34	38	578
ARTS-P4BR	41	53	22	21	66	40	34	49	56	32	24	29	32	35	38	574
ARTS-F3BR	41	52	21	21	67	40	34	49	56	32	25	28	32	36	38	573
ARTS-ICI	41	52	23	24	64	42	34	49	50	28	28	32	34	37	43	583
ARTS-SS	41	53	23	23	67	40	34	49	49	28	28	28	34	37	41	574
ARTS-ESA	42	51	19	24	74	41	34	49	62	39	32	29	33	38	37	604
ARTS-ECA	44	52	24	23	62	42	33	49	47	31	26	30	35	39	44	579
ARTS-LPA	41	54	22	24	66	40	34	49	49	31	27	28	35	35	42	577
ARTS-LCA	41	52	21	21	69	40	34	49	59	37	25	28	32	39	37	585
ARTS-LBA	41	54	22	22	57	42	34	49	47	30	31	34	35	42	47	586
ARTS-ISN	41	53	23	23	67	40	34	49	52	31	28	29	34	34	41	578
MIE-SC	66	88	46	30	65	38	39	49	38	58	57	55	49	47	48	772

Histogram Difference Index

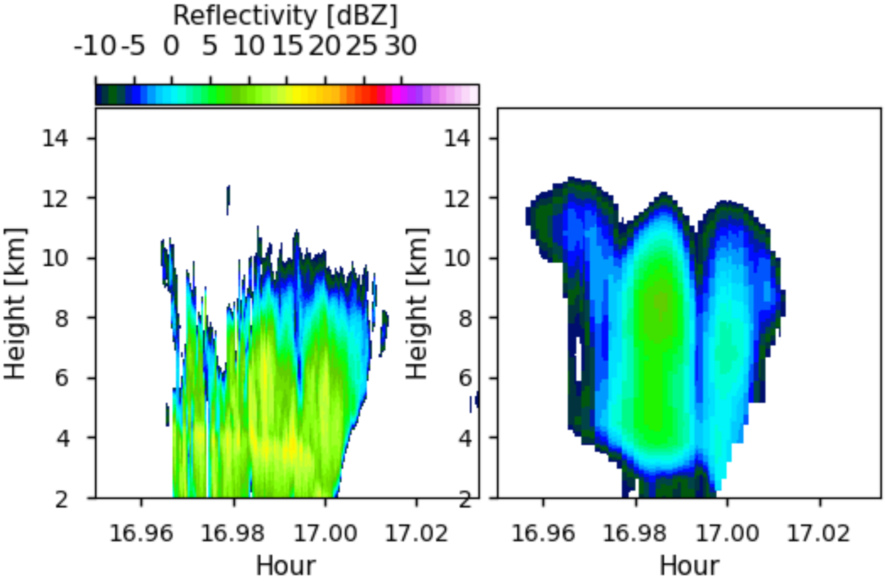
Chan Num	1	2	3	4	5	7	9	11	16	17	18	19	20	21	22	Sum
ARTS-PT1	23	64	20	23	20	14	13	12	20	26	21	22	25	31	33	368
ARTS-CT1	24	52	19	22	19	14	13	12	21	28	21	21	28	33	31	356
ARTS-SBR	24	52	19	22	18	14	13	12	21	34	24	24	27	30	31	364
ARTS-P4BR	24	52	19	23	19	14	13	12	21	34	21	24	29	29	32	364
ARTS-F3BR	24	52	18	23	20	14	13	12	21	33	21	22	27	29	29	358
ARTS-ICI	23	55	19	22	21	15	13	12	20	25	22	24	27	29	35	362
ARTS-SS	24	52	19	22	19	14	13	12	21	27	19	21	29	32	32	355
ARTS-ESA	24	52	16	22	18	14	13	12	21	41	28	23	29	32	31	377
ARTS-ECA	23	53	19	22	21	15	13	12	20	27	22	22	29	33	35	366
ARTS-LPA	24	53	19	22	18	14	13	12	21	28	18	23	29	29	31	354
ARTS-LCA	24	52	18	23	19	14	13	12	21	39	23	24	29	33	33	375
ARTS-LBA	23	53	19	23	20	15	13	12	20	25	25	23	30	33	39	373
ARTS-ISN	24	52	19	23	19	14	13	12	21	26	22	24	27	28	30	351
MIE-SC	36	86	30	43	28	16	13	12	19	63	68	66	59	55	53	646

Histogram Difference Index - GFDL Microphysics

Chan Num	1	2	3	4	5	7	9	11	16	17	18	19	20	21	22	Sum
ARTS-LPA	47	58	25	24	49	36	33	49	42	81	69	58	49	39	38	698
ARTS-LBA	47	58	26	23	44	35	34	49	40	64	46	38	32	30	30	597
ARTS-ISN	46	56	31	19	45	34	34	49	35	79	79	67	55	44	38	711
ARTS-ESA	49	55	28	20	40	34	34	49	41	85	91	83	74	65	58	805
ARTS-SS	49	55	28	20	44	34	35	49	37	32	34	32	37	32	36	552
MIE-SC	66	88	46	30	65	38	39	49	38	58	57	55	49	47	48	772

Field 2007 Mid-latitude

Chan Num	1	2	3	4	5	7	9	11	16	17	18	19	20	21	22	Sum
ARTS-LPA	41	54	22	24	66	40	34	49	49	31	27	28	35	35	42	577
ARTS-LBA	41	54	22	22	57	42	34	49	47	30	31	34	35	42	47	586
ARTS-ISN	41	53	23	23	67	40	34	49	52	31	28	29	34	34	41	578
ARTS-ESA	42	51	19	24	74	41	34	49	62	39	32	29	33	38	37	604
ARTS-SS	41	53	23	23	67	40	34	49	49	28	28	28	34	37	41	574



Cloudsat CPR reflectivity simulated for a single event Sept 7, 2017 at 11:00 UTC using Era5 profiles as input.

Conclusions

- CRTM radar simulator as well as its adjoint and tangent linear are implemented and tested
- Work is in progress to evaluate the active module especially within the JEDI DA system
- A new scattering dataset generated using the DDA method was implemented into CRTM and evaluated using a collocated reanalysis and satellite dataset
- The new lookup tables no longer require parameters such as effective radius that are not provided by the model
- The new cloud coefficient is generated at much higher resolution for both frequency and mass/size
- The mass backscattering coefficient is included in the new lookup tables
- The ARTS DDA lookup tables perform largely better than current CRTM cloud lookup tables


Thank you for
your attention!