Development of the Community Radiative Transfer Model (CRTM) In Support of UFS Applications

CRTM Team:

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CRTM: A Community Model

- **CRTM is a Community Model**
  - Open Source and Open Access
  - Version Control (git) and peer review
  - Distributed Collaboration (GitHub, Zenhub, Confluence, Google)
  - Modern Fortran (2003+)
- **Education and Outreach**
  - CRTM User/Developer Workshop
    - Feb 28, 2020 Monterey, CA (*slots still available*)
  - JCSDA Summer Colloquium
  - Code Sprints
    - CRTM-Coef Jan 21 – 31 2020, College Park
    - CRTM-Surf March 2020, Boulder
  - Seminars / Colloquia
  - JCSDA.org website

What is the CRTM?

CRTM is the "Community Radiative Transfer Model"

Goal: Fast and accurate community radiative transfer model to enable assimilation of satellite radiances under all weather conditions, covering UV, VIS, Near-IR, IR, FarIR, subMM, MW

Type: 1-D, plane-parallel, multi-stream matrix operator method, advanced method of moments solver, with specular and non-specular surface reflections.

Has aerosol (GO-CART), cloud (2 species), precipitation (4 species); with unpolarized scattering and absorption (in 2.x). Computes gaseous absorption/emission for 6 gaseous species (ODPS).

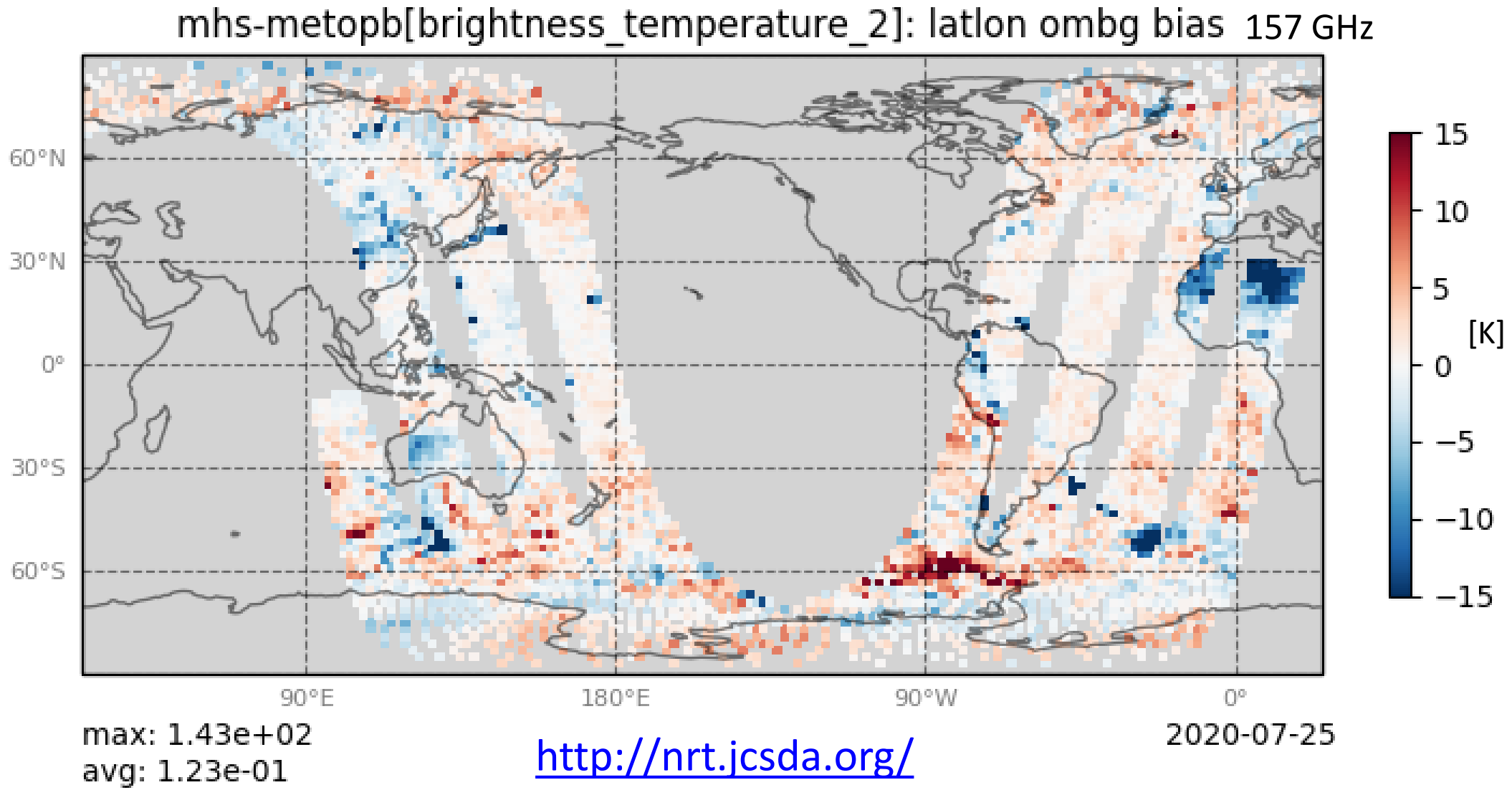
History: Originally developed (as CRTM) around 2004 by Paul van Delst, Yong Han, Fuzhong Weng, Quanhua Liu, Thomas J. Kleespies, Larry M. McMillin, and many others. CRTM Combines many previously developed models into a community framework, and supports forward, tangent linear, adjoint, and K-matrix modeling of emitted/reflected radiances, with code legacy going back to the mid 1970s (e.g., OPTRAN: McMillin).

Research and Development

Version 3.0.0 progress
Transmittance Coefficient Generation (CRTM-COEF)
CRTM Scattering Indicator, code optimization and solver testing
Community Hydrometeor Model (CHyM)
Community Active Sensor Module (CASM)
Community Surface Emissivity Model (CSEM)
JCSDA coordination (JEDI, NIO, SOCA) and collaboration (RTTOV)

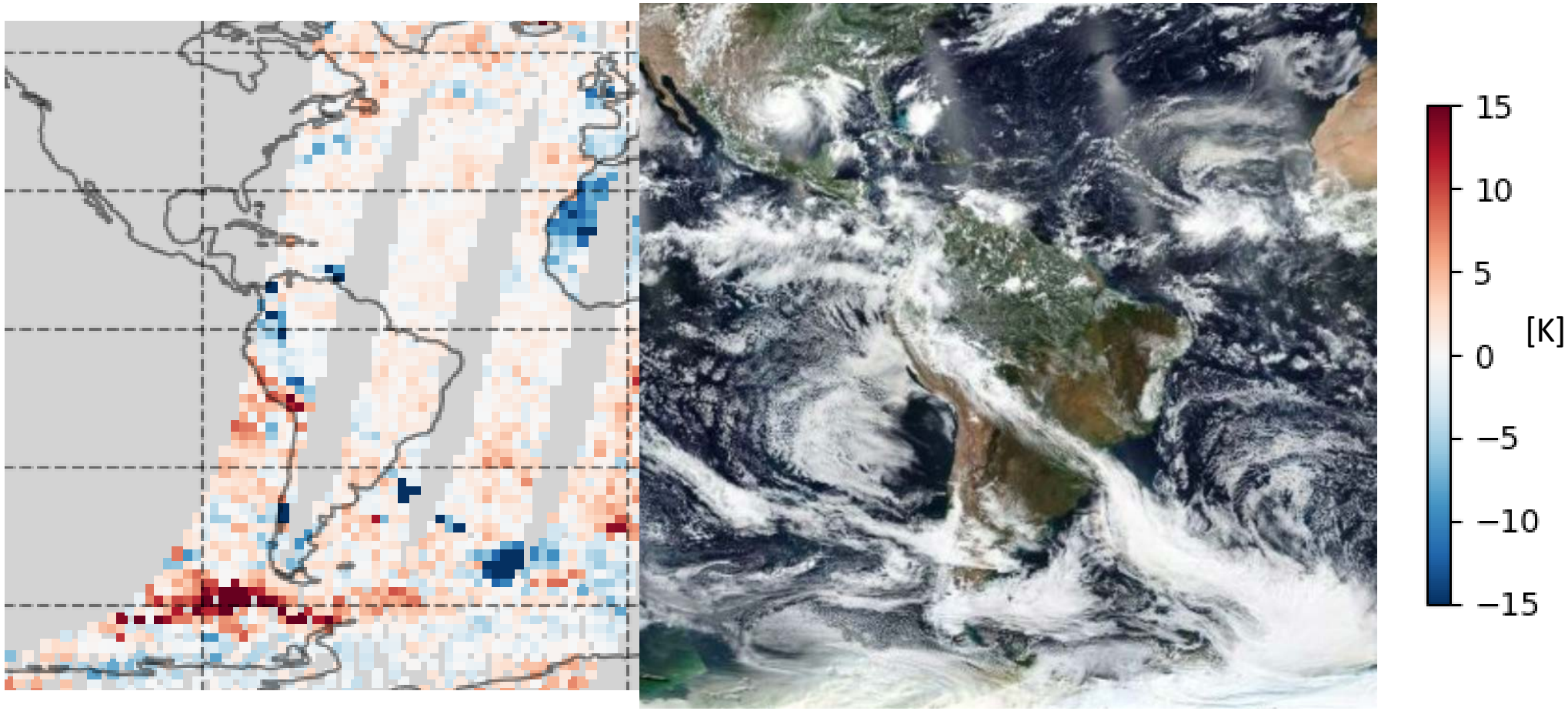
Motivation for Cloudy RT Improvements

- JEDI FV3-GFS model fields -> CRTM simulated **METOP-B MHS** O-B



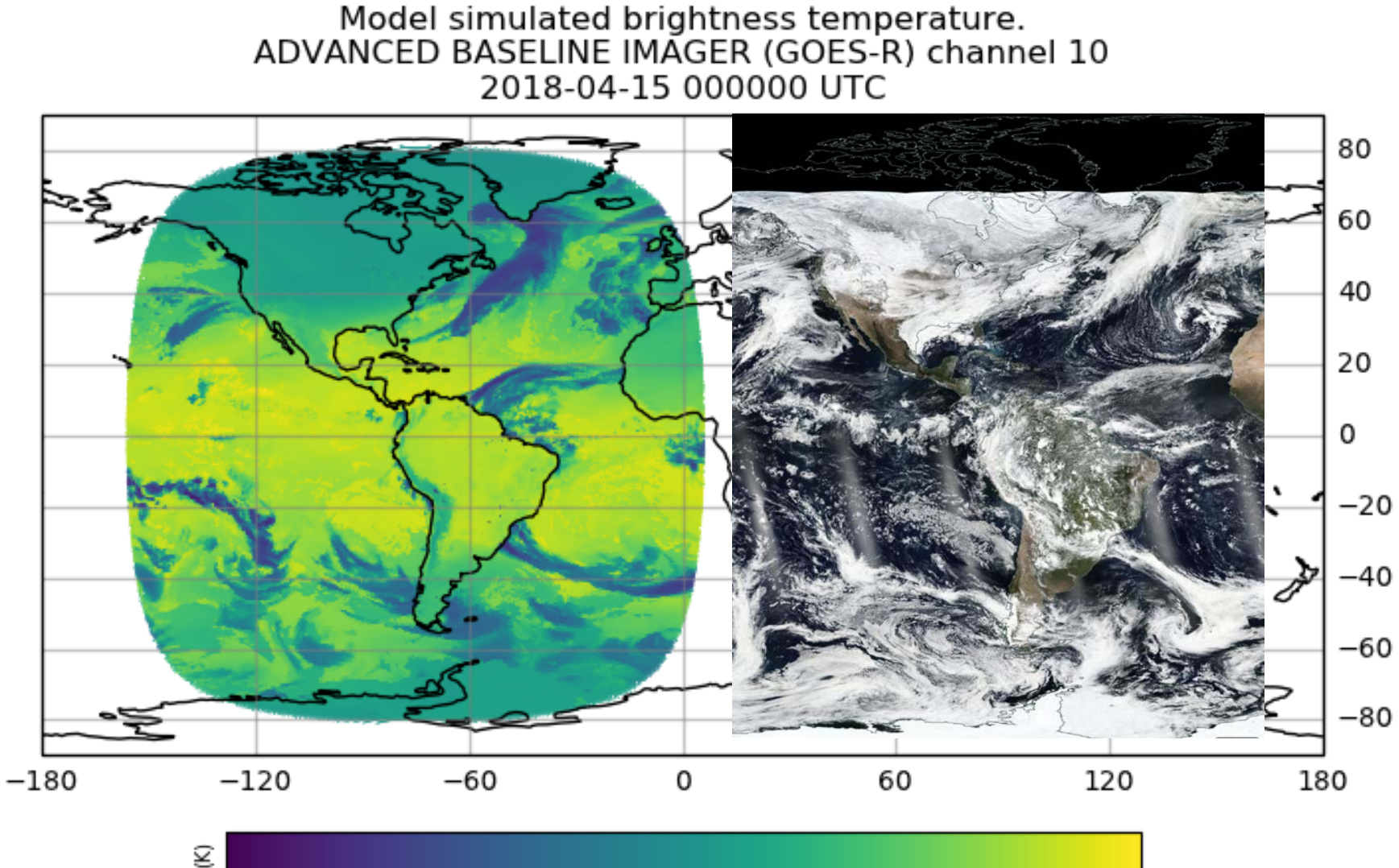
http://nrt.jcsda.org/

Motivation for Cloudy RT Improvements



Motivation for Cloudy RT Improvements

- JEDI FV3-GFS model fields -> CRTM simulated **GOES-16 ABI** radiance



CRTM v3.0 Alpha

- **Status of CRTM v3.0 Alpha**
  - Modification of CRTM v2.3.1-beta to include full polarization support, and UV support (provided by Q. Liu)
  - **Status**: Core solver work for initial implementation is completed for full stokes polarization.
    - Paper: Liu, Q. and Cao, C., 2019. *Analytic expressions of the Transmission, Reflection, and source function for the community radiative transfer model*. Journal of Quantitative Spectroscopy and Radiative Transfer, 226, pp.115-126.
  - **Numerically consistent** with CRTM v2.3.0 for n_stokes = 1
  - **Requires significant effort** (CRTM v3.0 Beta) toward updating and testing the science modules to support polarized RT: such as clouds, aerosols, gases, and surface properties.
  - **UV support** (**OMPS implemented**: “u.omps-tc_npp”)

CRTM v3.0 Alpha

Comparison of different polarized solvers:

DA = RT3, Doubling-Adding method (Evans, 1991)

VLIDORT = Linearized Vector discrete ordinate RTM (Spurr, 2005)

ADA = Adding-Doubling solver (CRTM 1.x)

AMOM = Advanced matrix operator method (CRTM 2.x)

Table 10

Comparison of CPU time usage between VLIDORT and AMOM. Phase function for an atmosphere of randomly oriented oblate spheroids and 16 streams are used. The solar flux is normalized to π, the solar zenith angle is 36.8699 (the cosine of the solar zenith angle is 0.8), and the surface albedo is 0.25. Single scattering albedo is 1.0. VLIDORT requires the single scattering is less than 1.0 and we use the single scattering albedo of 0.99999. The upwelling radiance is for a viewing (zenith) angle of 50.21°.

Layer optical depth	VLIDORT (seconds)	AMOM (seconds)
100	0.096	0.076
10	0.096	0.063
1	0.096	0.054
0.1	0.095	0.048

Table 4a

Pure Rayleigh atmosphere of optical depth of 0.1 using 4 streams

	I	Q	U	V
DA	0.215409	−0.000316	−0.020898	0.0
VLIDORT	0.215409	−0.000316	−0.020898	0.0
ADA	0.215409	−0.000316	−0.020897	0.0
AMOM	0.215409	−0.000316	−0.020897	0.0

Table 4b

Same as Table 4a, but using 16 streams.

	I	Q	U	V
DA	0.216527	−0.000214	−0.021456	0.0
VLIDORT	0.216526	−0.000214	−0.021456	0.0
ADA	0.216526	−0.000214	−0.021455	0.0
AMOM	0.216526	−0.000214	−0.021455	0.0

Table 5a

Same as Table 4a, but for an optical depth of 1.

	I	Q	U	V
DA	0.374199	0.008465	−0.124870	0.0
VLIDORT	0.374189	0.008464	−0.124868	0.0
ADA	0.374197	0.008467	−0.124864	0.0
AMOM	0.374196	0.008467	−0.124864	0.0

Liu, Q. and Cao, C., 2019. *Analytic expressions of the Transmission, Reflection, and source function for the community radiative transfer model*. Journal of Quantitative Spectroscopy and Radiative Transfer, 226, pp.115-126.

Motivation for Polarized RT

GPM GMI V-H Brightness Temperature difference at 166 GHz.

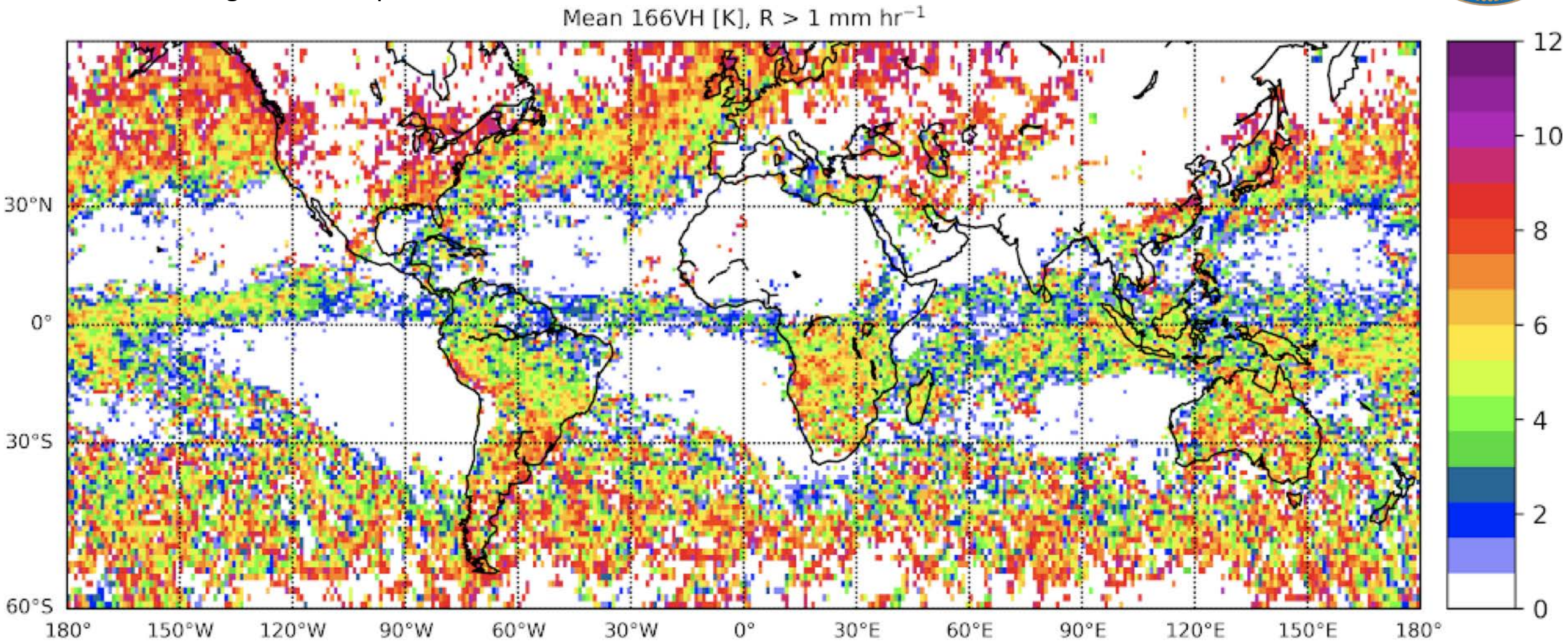
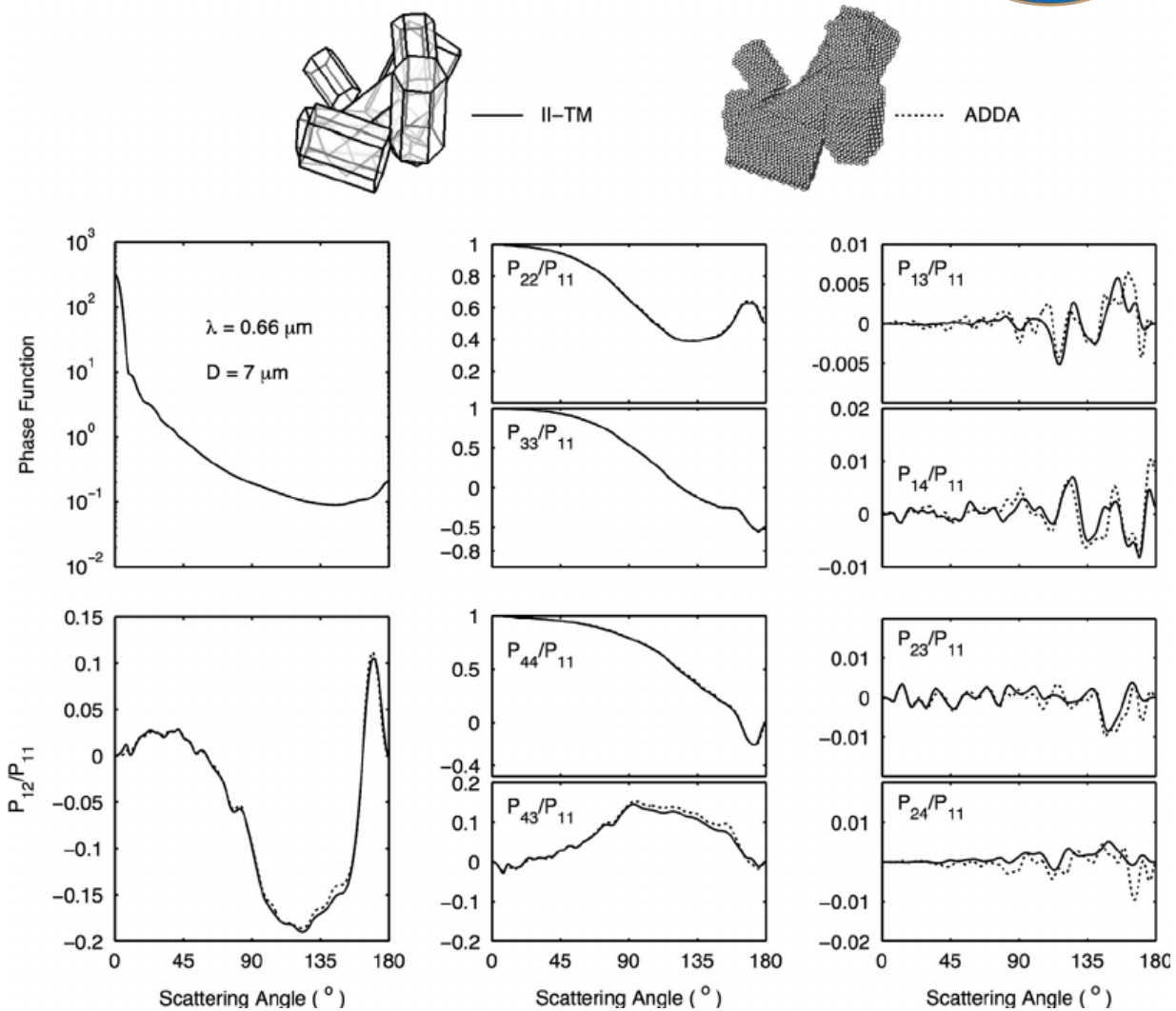


Image courtesy of V. Galligani

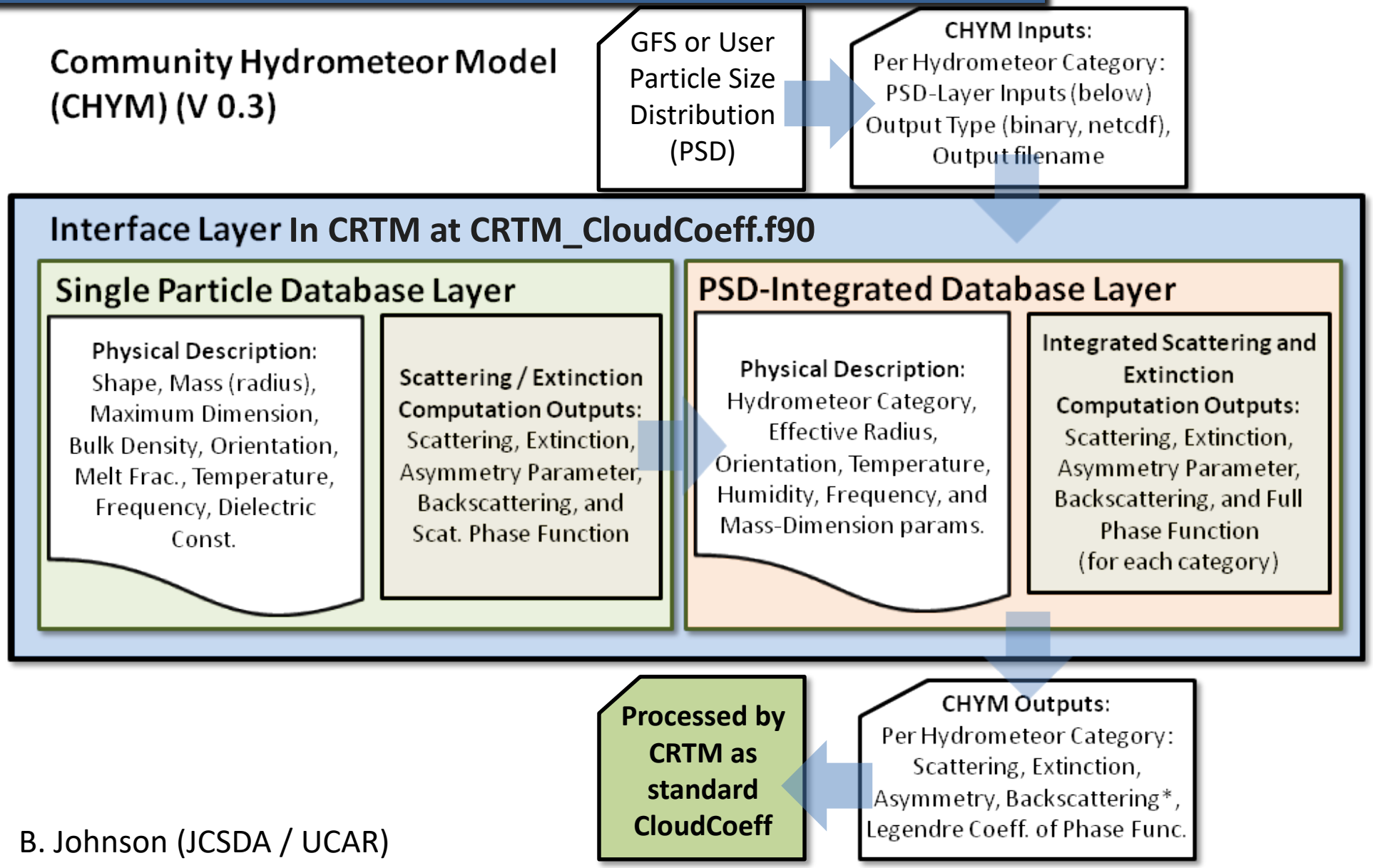
CRTM v3.0 Beta Focus

Cloud-impacted radiance and physical model simulation improvements (UV, VIS, IR, MW)

- Community Hydrometeor Model (CHYM)
  - Development continuing, and creating new polarized MW, IR, and VIS integrated cloud and aerosol scattering tables that are more closely linked with model assumed microphysical properties.
  - Initial netCDF transition and conversion.
  - Updating Space-based radar support with linear polarization capabilities
- *Current focus is on tool development e.g.:*
  - https://github.com/PStegmann/INSPECT_CloudCoeff
  - https://github.com/JCSDA/CRTM_coef
- **Community Surface Emissivity Model** (Ming Chen)
  - Need extend CSEM capabilities to support fully polarized surface BRDFs for ocean and land



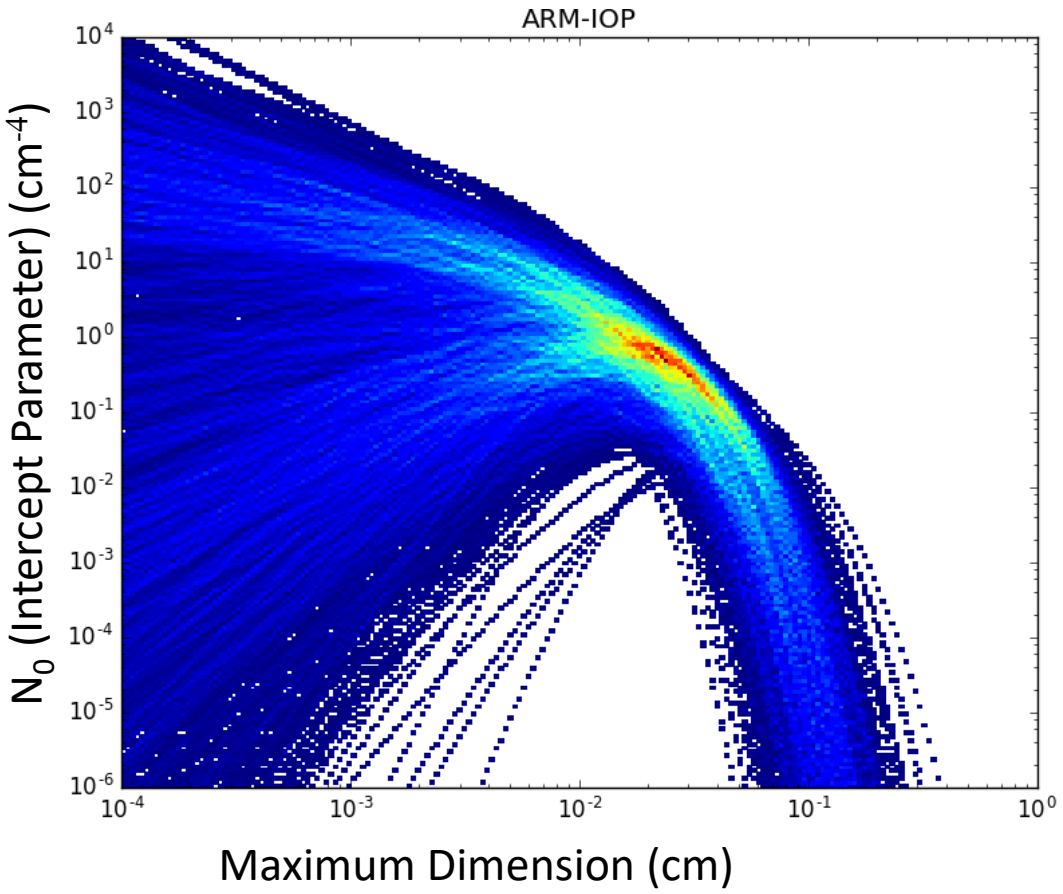
Community Hydrometeor Model

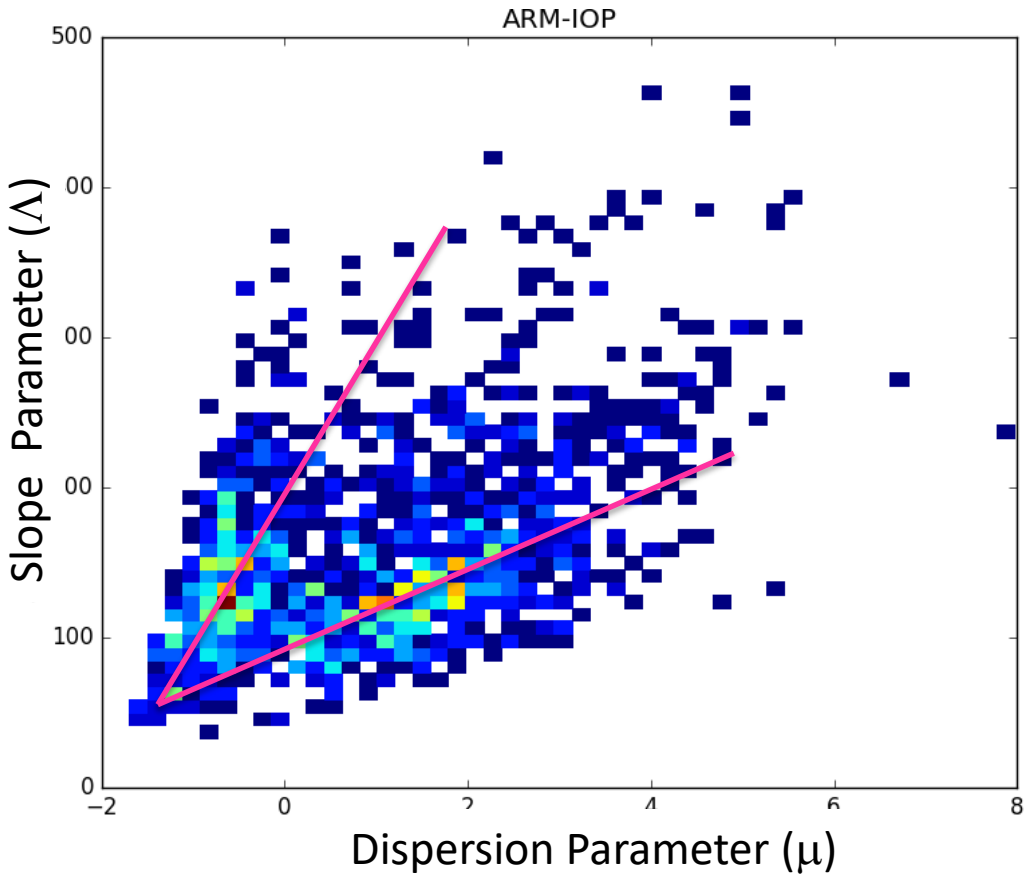


B. Johnson (JCSDA / UCAR)

Cloud Physical Modeling

Example: ARM Intensive Observation Program





Three parameter Gamma Distribution

For **single-moment** species (hydrometeor mixing ratio q_x is prognostic) :

N_{ox} is either fixed or prescribed as a function of temperature or mixing ratio

μ is set to zero for exponential distribution (Marshall-Palmer) or prescribed

λ, the slope can be calculated from hydrometeor mixing ratio q_x as:

$$w_x = \rho_a q_x = a\, N_{ox}\, \Gamma(\mu + b + 1)\, \lambda^{-(\mu+b+1)} \longrightarrow \lambda = \left(\frac{a\, N_{ox}\, \Gamma(\mu + b + 1)}{\rho_a q_x}\right)^{\frac{1}{\mu+b+1}}$$

Mapping of single-moment model mixing ratio to PSD parameters

For **double-moment** species (both mixing ratio q_x and total number concentration N_{tx} are prognostic) :

μ is set to zero for exponential distribution (Marshell-Palmer) or prescribed

N_{0x}, the intercept can be calculated from N_{tx} as:

$$N_{tx} = N_{ox}\, \Gamma(\mu + 1)\, \lambda^{-(\mu+1)} \longrightarrow N_{ox} = \frac{N_{tx}\, \lambda^{\mu+1}}{\Gamma(\mu + 1)}$$

λ, the slope can be calculated from N_{tx} and q_x as:

$$w_x = \rho_a q_x = a\, N_{ox}\, \Gamma(\mu + b + 1)\, \lambda^{-(\mu+b+1)} \longrightarrow \lambda = \left(\frac{a\, N_{tx}\, \Gamma(\mu + b + 1)}{\Gamma(\mu + 1)\, \rho_a q_x}\right)^{\frac{1}{b}}$$

Mapping of double-moment concentration and mixing ratio to PSD parameters

Particle Microphysics and Scattering

MODIS Collection 6

- A single habit ice model
- an ensemble of aggregates composed of eight severely roughened columns for ice cloud particles

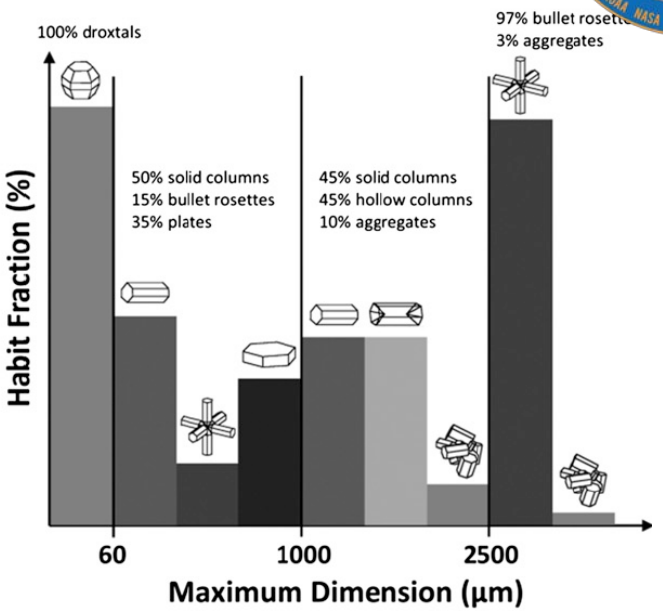
Single Particle Optical Properties

- Discrete Dipole Approximation (DDA)
- Invariant Embedded T-Matrix (IITM)
- Geometric Optics (GO) for larger particles

Bulk Optical Properties

- Gamma size distribution
- Temperatures at 160K and 230K

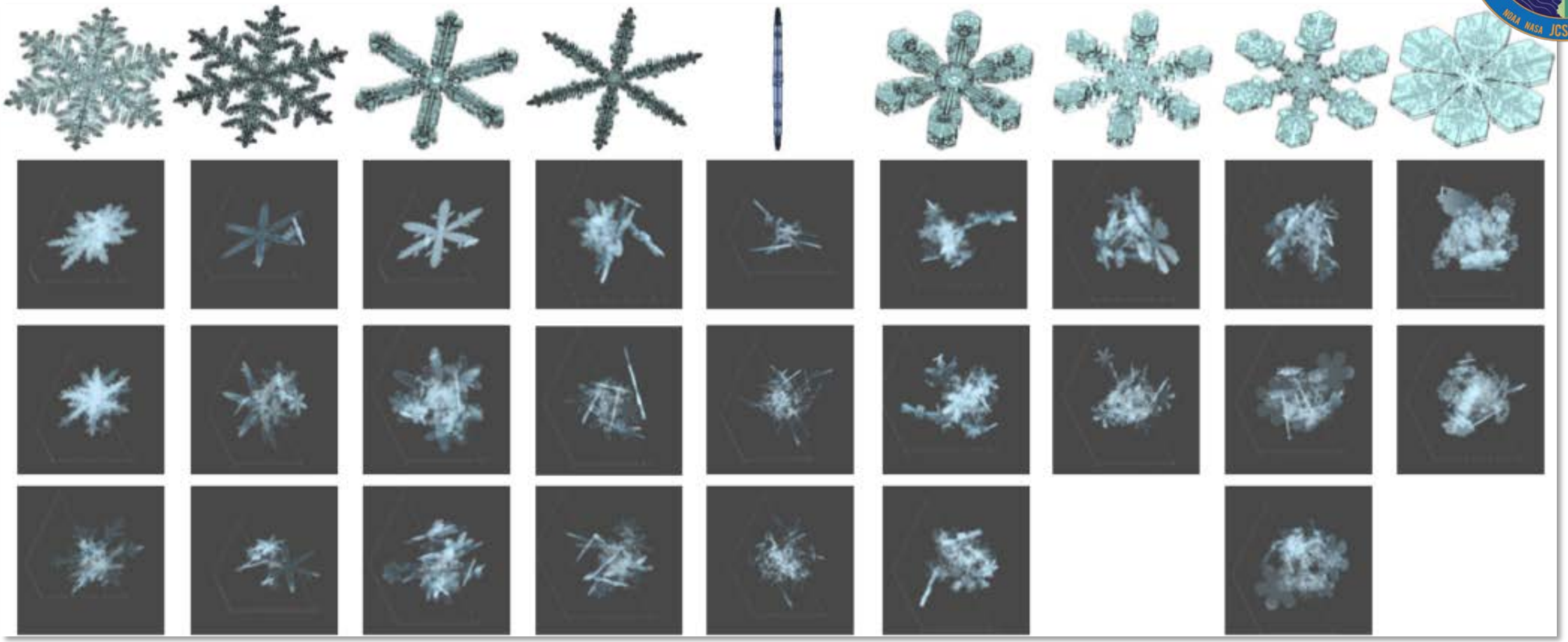
MODIS Collection 5



MODID Collection 6

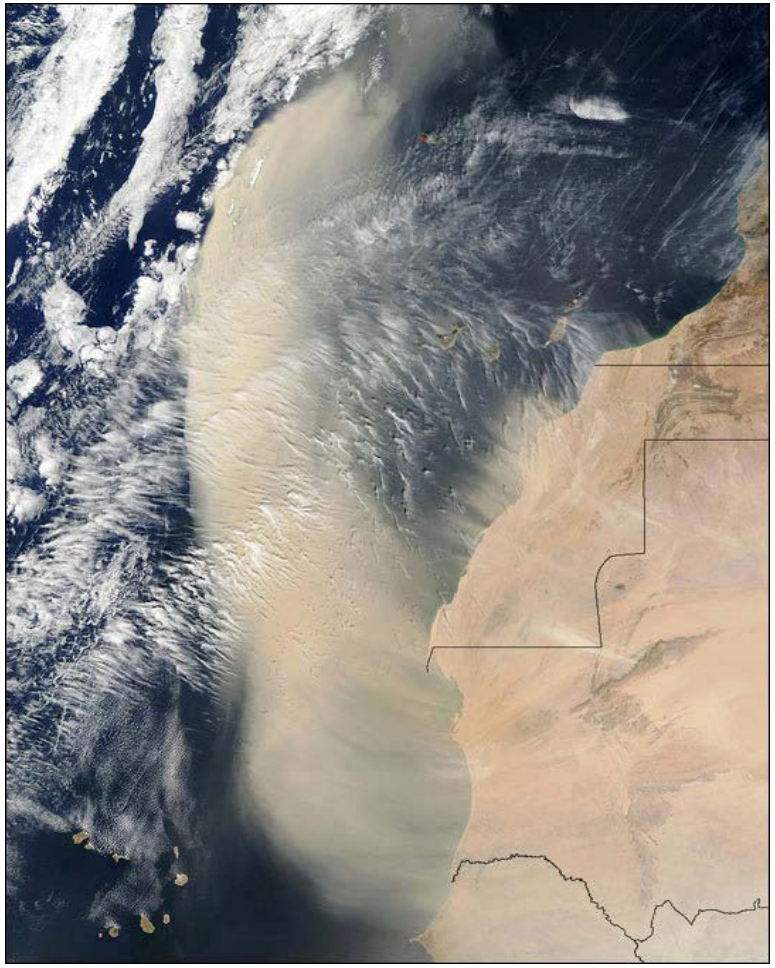
Particle Microphysics and Scattering

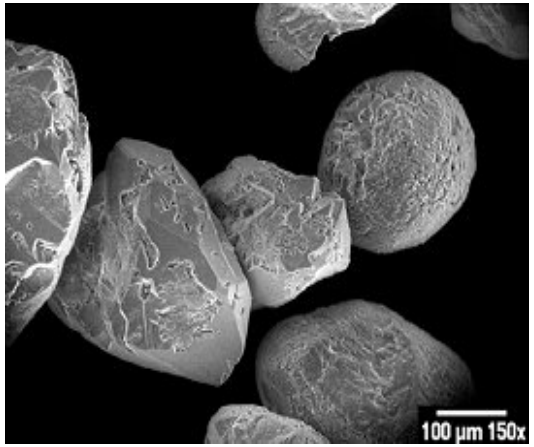
Single-particle database example:

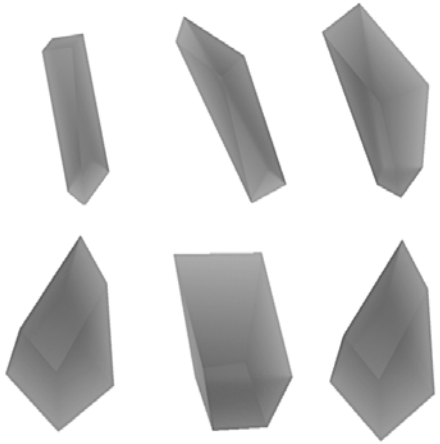


The physical database contains 2126 pristine particle files, based on the above 9 base shapes, ranging from columns to plates to dendrites. Effective radius ranges from 60 to 1000 microns. The aggregate particle database, based on aggregates of the 9 base shapes above, consists of about 8100 aggregate shapes, with varying masses and constituent ice crystals. Effective radius ranges from 100 microns up to 5000 microns.

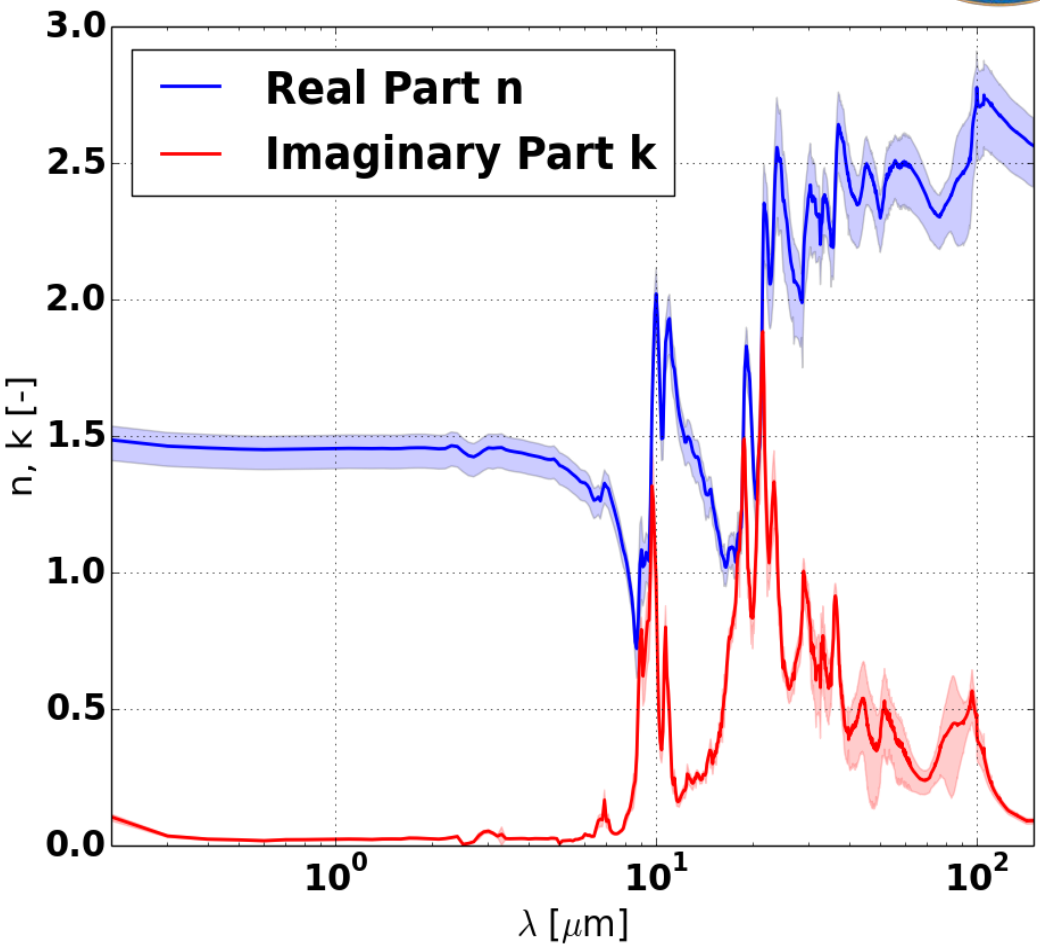
CHyM: Aerosol Properties







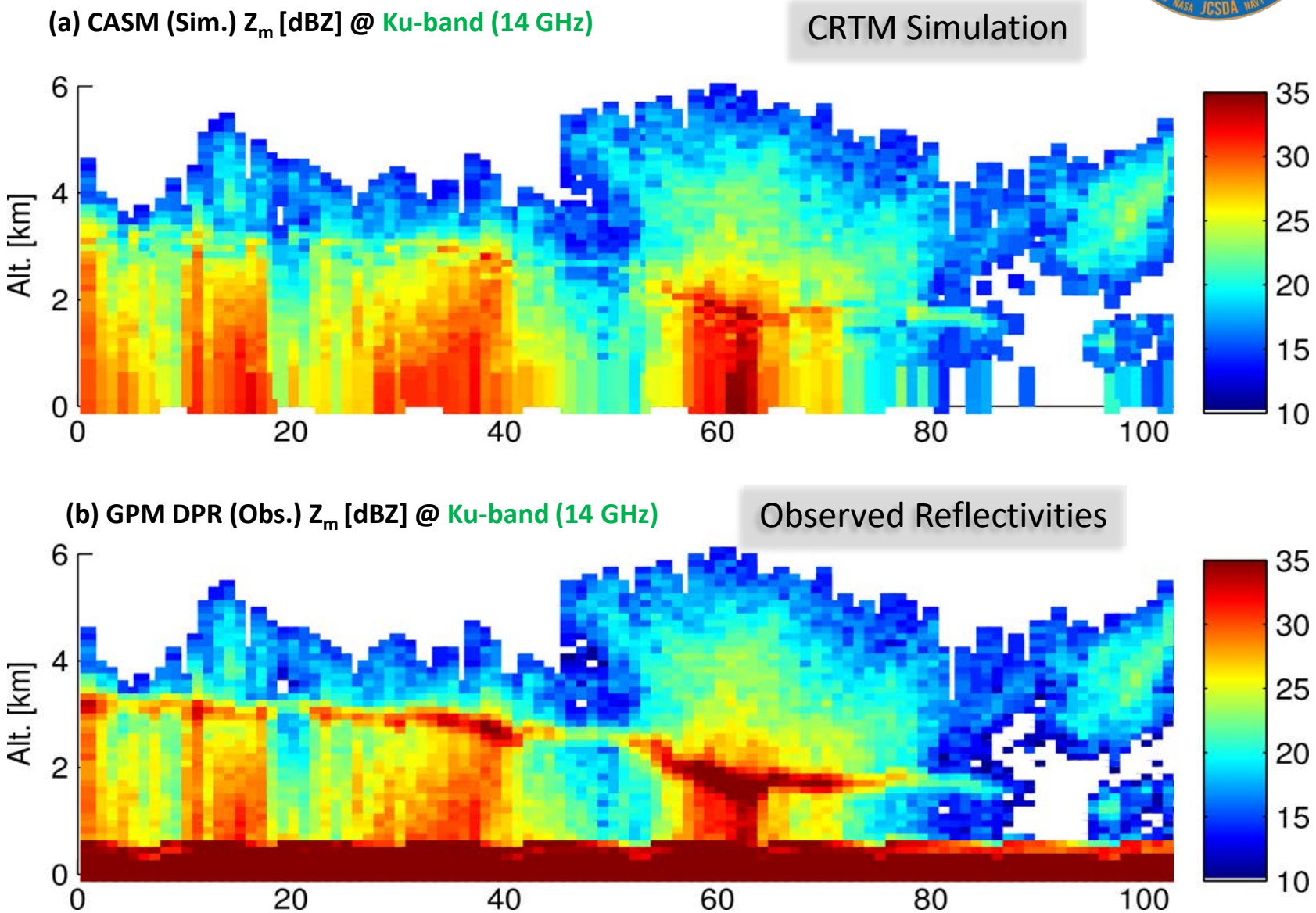
MODIS image of SAL (left). TEM image of Saharan mineral dust particles (Top); Ensemble of hexahedral shapes with tilted facets as a model for mineral dust scattering properties (Bottom).



Index of refraction (mean and stdev) of Saharan mineral dust.

CASM: Space-based RADAR/LIDAR

- Goal: Active Space-based Radar Simulation and Jacobians for satellite DA
- Tested for Ku, Ka, and W
- Output: Radar reflectivity and 2-way PIA
- Status: TL and AD models under testing
- Next: Melting layer model, ground-based radar, polarization



For More Information

Visit: https://www.jcsda.org/

Please join our CRTM google group:

Support:
https://groups.google.com/forum/#!forum/crtm-support

CRTM support email:
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Email: Benjamin.T.Johnson@noaa.gov for direct support, questions, and comments