Development of the Community Radiative Transfer Model (CRTM) Update

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, github: JCSDA/CRTM_dev

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).

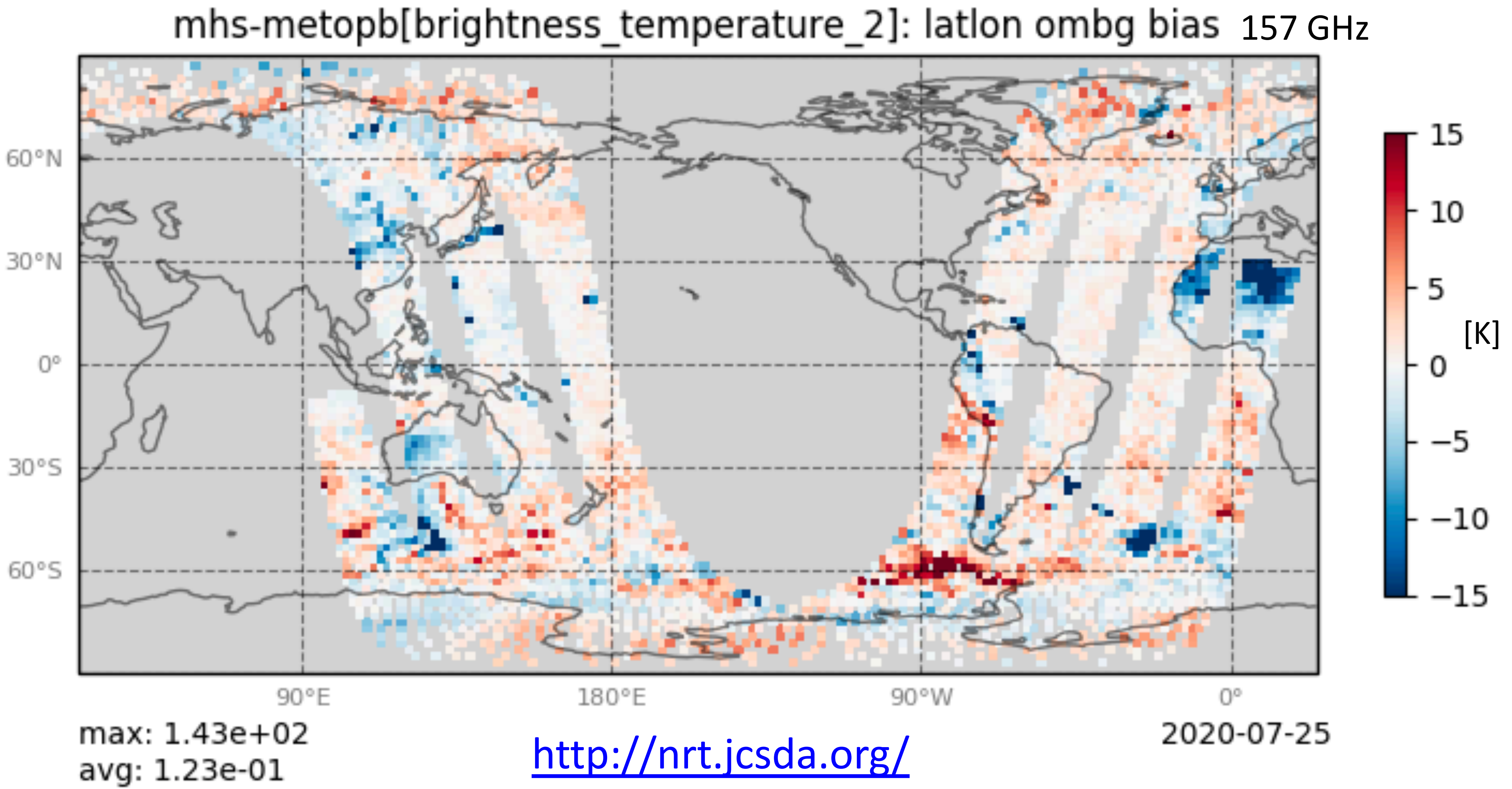
History: Originally developed (as CRTM) around 2004 by Paul van Delst, Yong Han, Fuzhong Weng, Quanhua Liu, Thomas J. Kleespies, Larry M. McMillin, and many others. CRTM Combines many previously developed models into a community framework, and supports forward, tangent linear, adjoint, and K-matrix modeling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

Research and Development

Version 2.4.0 (October 2020)
Version 3.0.0 (Spring 2021)
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/

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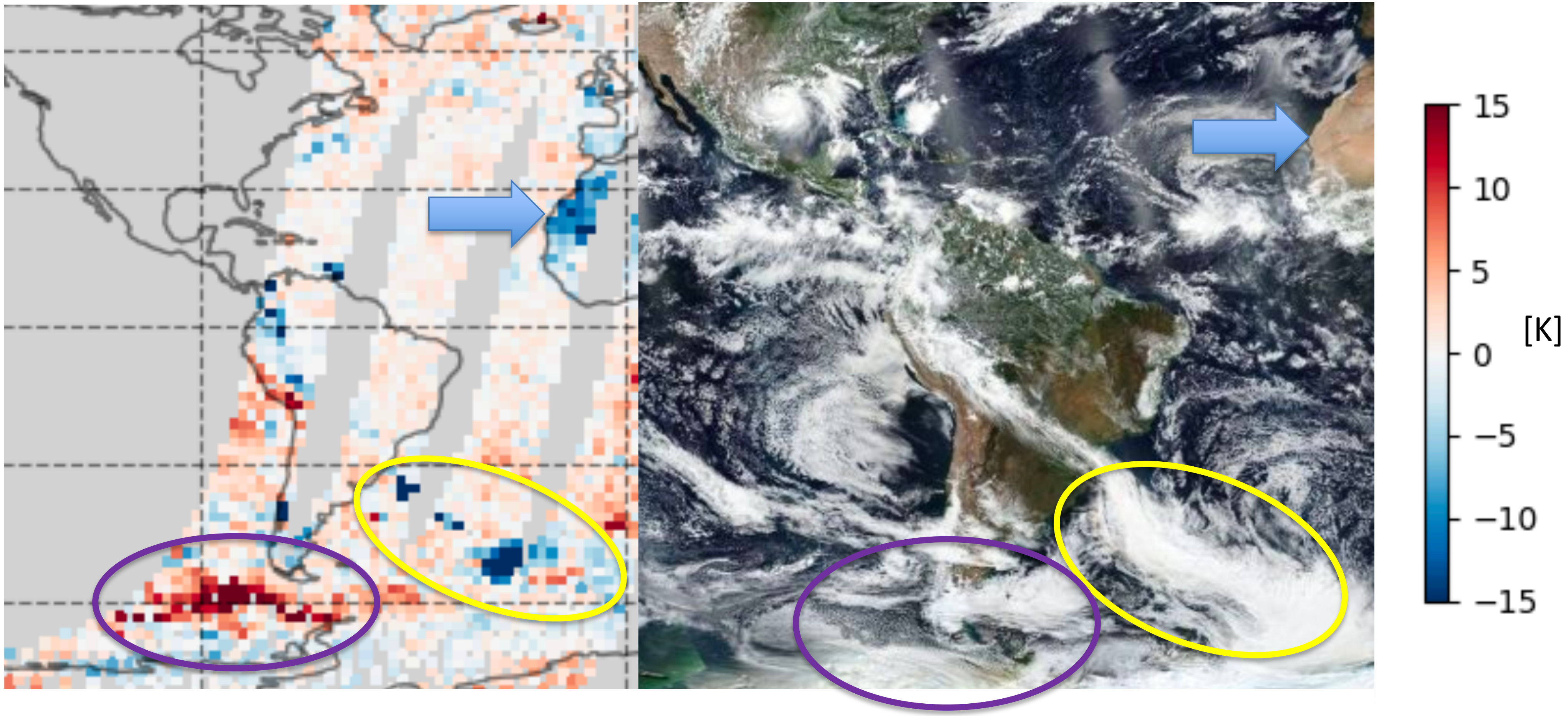


CRTM v2.4

CRTM 2.4.0 Features

- **Backwards compatibility with CRTM v2.3.0**
- (User Option) Multi-threaded **parallelization using OpenMP** directives
- **Support for upcoming and updated sensors**: Earth Observing Nanosatellite-Microwave, Sentinel-3A Sea and Land Surface Temperature (SLSTR), Meteosat-11 SEVIRI, GOES 17 ABI, Metop-C AVHRR and IASI, Soil Moisture Anisotropy Probe (SMAP), Soil Moisture Ocean Salinity (SMOS), Temporal Experiment for Storms and Tropical Systems - Demonstration (TEMPEST-D), MI-L COMS, FY4-GIIRS, TROPICS, and many more under development.
- E**xpanded scattering tables** for more physically realistic cloud and precipitation simulations. **Updated Aerosol species** and scattering properties.
- **Enhanced physical consistency** between physical models in CRTM and calling models (CHyM)
- (User Option) **netCDFv4 file formats** for lookup tables, replacing current binary format files. Binary format files will still be available.
- **Automated testing framework** following industry standard unit, regression, and implementation testing strategies. Consistent with JCSDA-wide software development and testing standards.
- Use of **industry-standard community-accessible software development** repository and issue tracking via JCSDA Github and Zenhub platforms.

Motivation for Polarized RT

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

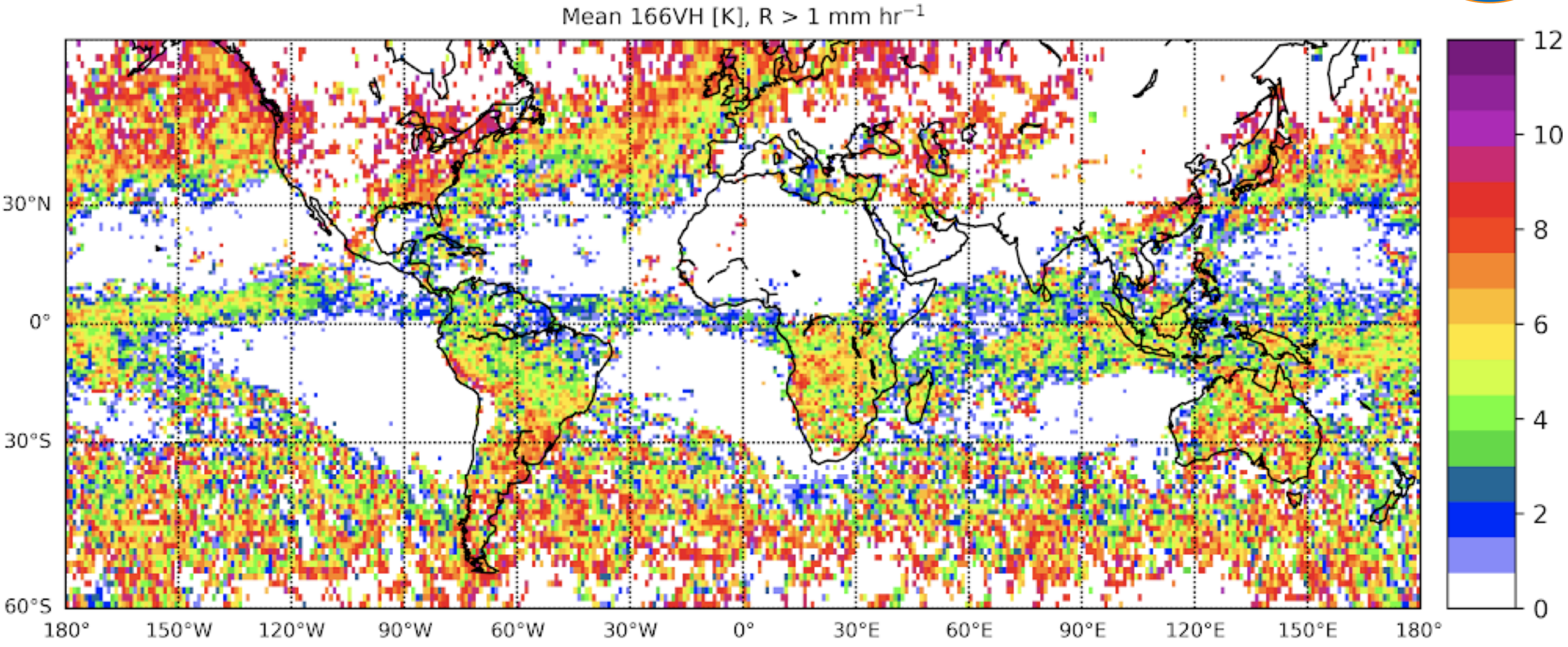


Image courtesy of V. Galligani

CRTM v3.0 Overview

- **Full Polarization Solver (IQUV)**
  - **UV capable solver** + full polarization support
- **Cloudy Radiance**
  - Produce (Polarized) CRTM Scattering Coefficients from Mie and T-Matrix spheroids in binary and **NetCDF**
  - Create physically consistent PSD-integrated tables (spectral, model-model)
- **Surface**
  - CRTM-CSEM in GFS/GSI, focusing on the comparisons among model options.
  - Initial implementation of MW ocean surface polarized BRDF model -> CSEM
  - Ocean Surface Emissivity improvements IR (IRSSE)
- **SW / IR improvements in CRTM**
  - Primary focus on aerosol impact and transmittance coefficients in VIS-impacted channels
- **Aerosols**
  - Update of CHYM to work with aerosols similar to clouds
  - Improved GOCART specification consistent with UFS
  - Update toward CMAQ specifications supporting wider range of species
- **RT Issues**: NLTE, Zeeman, U+V impacts from upper atmosphere, slant-path, etc.

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 v2.4.0 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”)

Community Hydrometeor Model

Community Hydrometeor Model (CHYM) (V 0.3)

GFS or User Particle Size Distribution (PSD)

CHYM Inputs:
Per Hydrometeor Category:
PSD-Layer Inputs (below)
Output Type (binary, netcdf),
Output filename

Interface Layer In CRTM at CRTM_CloudCoeff.f90

Single Particle Database Layer

Physical Description:
Shape, Mass (radius), Maximum Dimension, Bulk Density, Orientation, Melt Frac., Temperature, Frequency, Dielectric Const.

Scattering / Extinction Computation Outputs:
Scattering, Extinction, Asymmetry Parameter, Backscattering, and Scat. Phase Function

PSD-Integrated Database Layer

Physical Description:
Hydrometeor Category, Effective Radius, Orientation, Temperature, Humidity, Frequency, and Mass-Dimension params.

Integrated Scattering and Extinction Computation Outputs:
Scattering, Extinction, Asymmetry Parameter, Backscattering, and Full Phase Function
(for each category)

CHYM Outputs:
Per Hydrometeor Category:
Scattering, Extinction,
Asymmetry, Backscattering*,
Legendre Coeff. of Phase Func.

Processed by CRTM as standard CloudCoeff

B. Johnson (JCSDA / UCAR)

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:

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

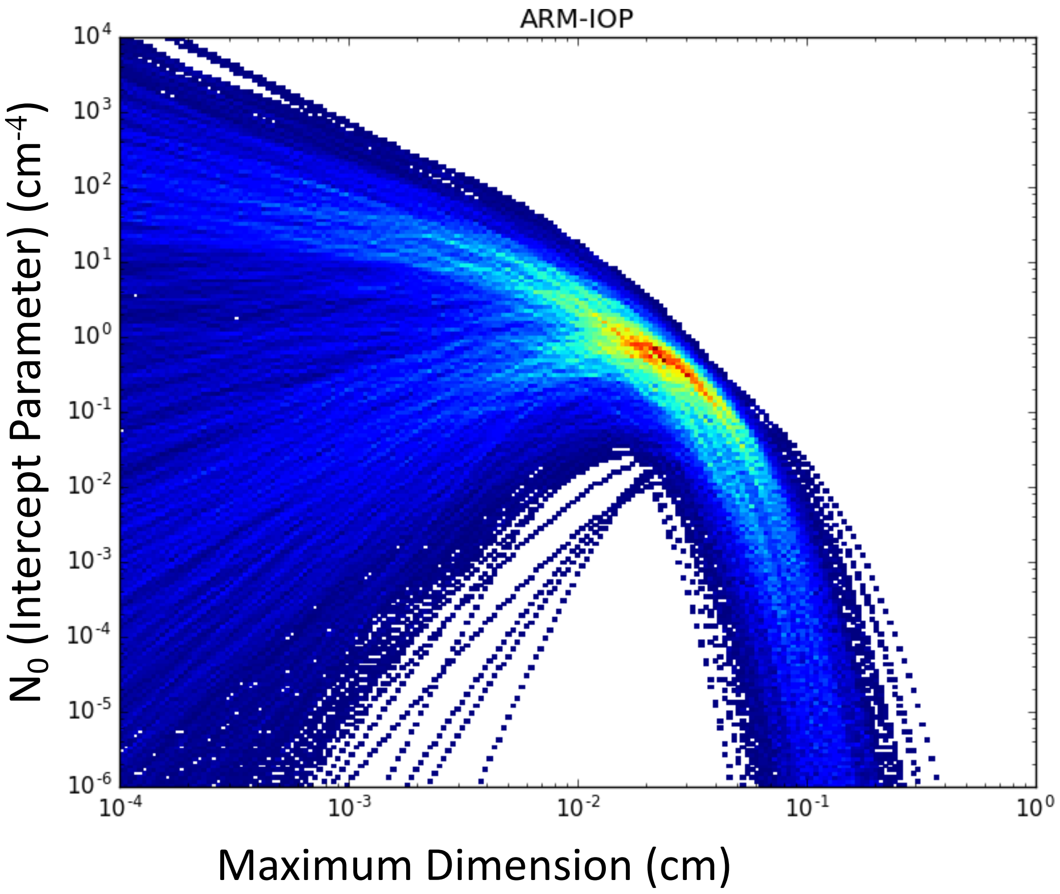
λ, the slope can be calculated from N_{tx} and q_x as:

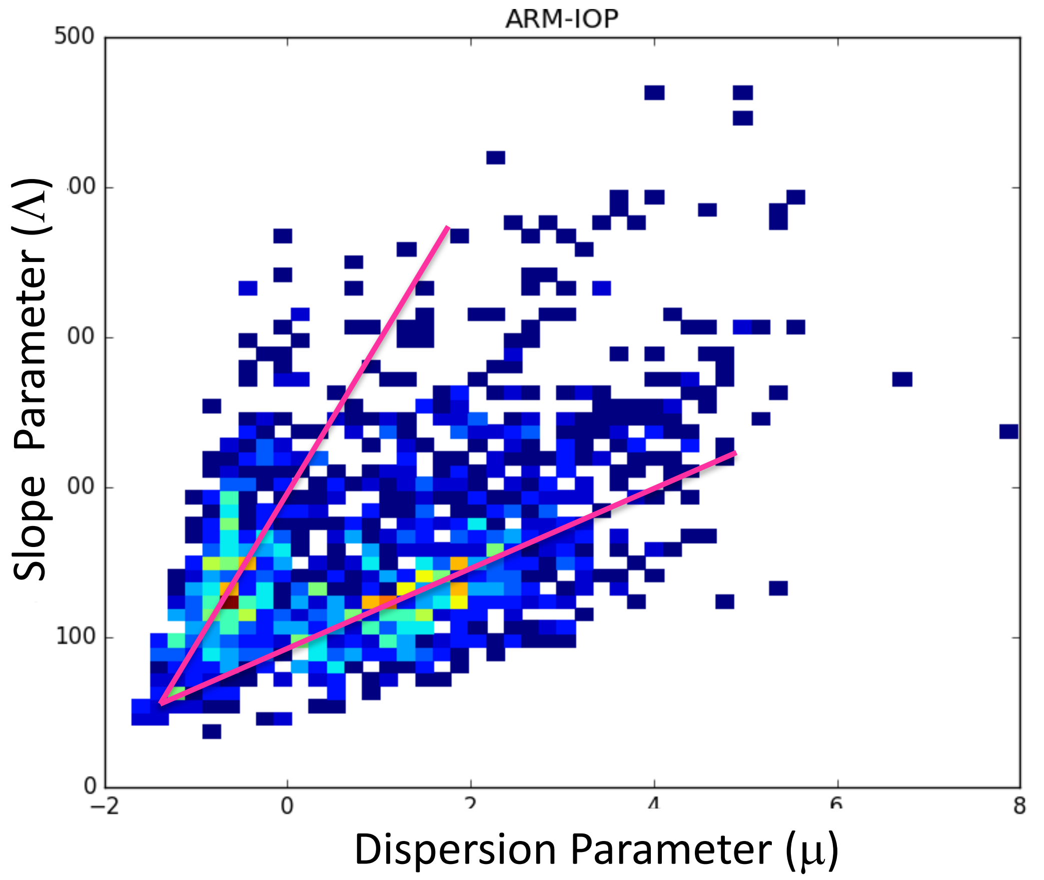
$$w_x = \rho_a q_x = a\, N_{ox}\, \Gamma(\mu + b + 1)\, \lambda^{-(\mu+b+1)} \longrightarrow \lambda = \left(\frac{a\, N_{tx}\, \Gamma(\mu + b + 1)}{\Gamma(\mu + 1)\, \rho_a q_x} \right)^{\frac{1}{b}}$$

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

Cloud Physical Modeling

Example: ARM Intensive Observation Program





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

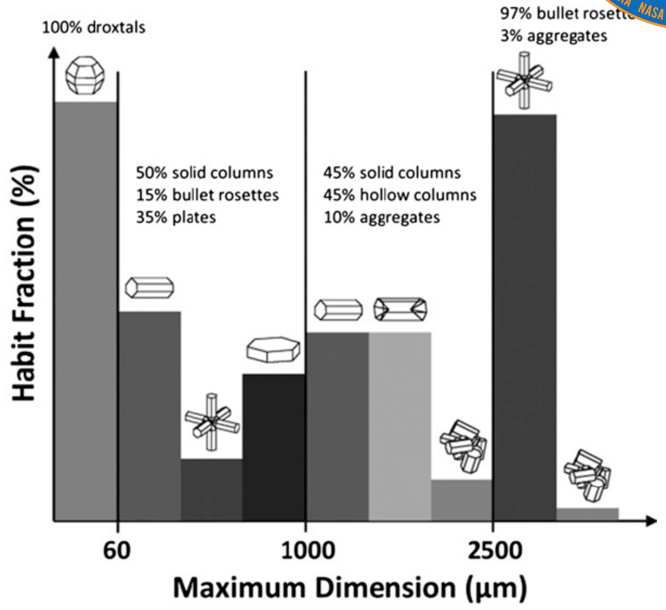
Single Particle Optical Properties

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

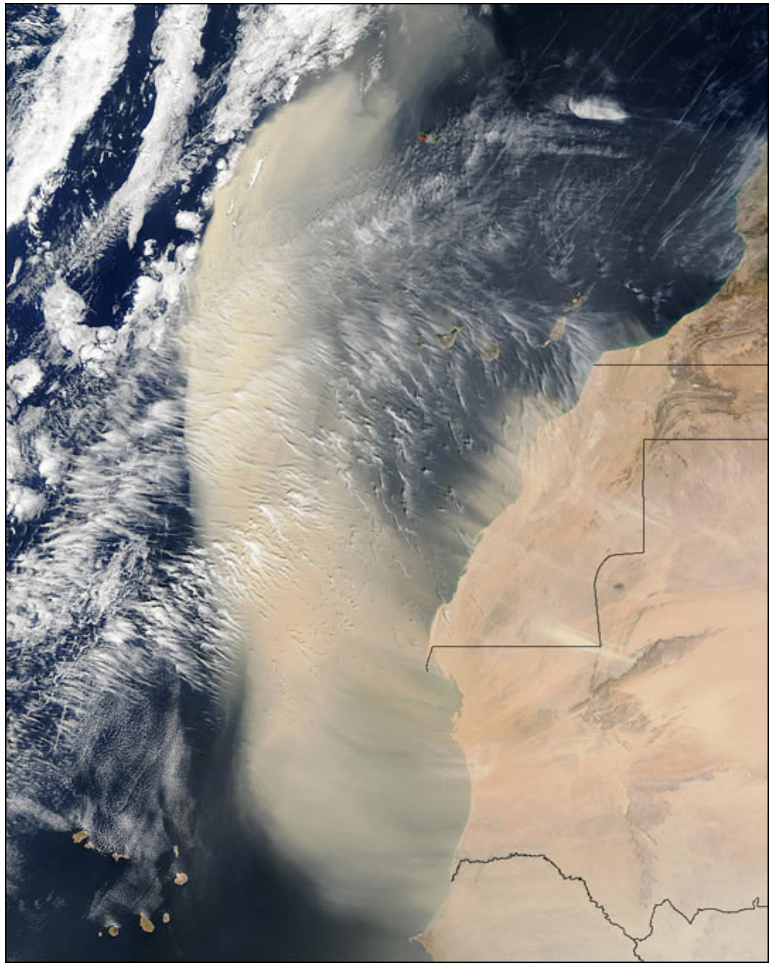
Bulk Optical Properties

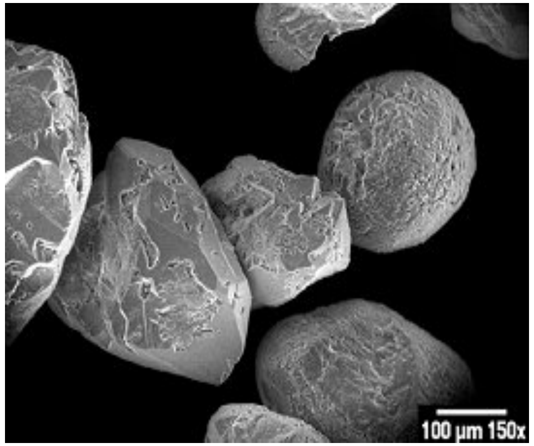
- Gamma size distribution
- Temperatures at 160K and 230K

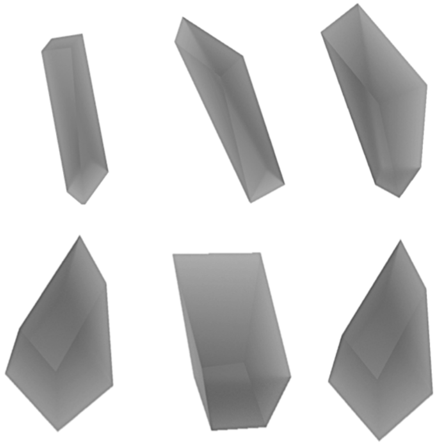
MODIS Collection 5



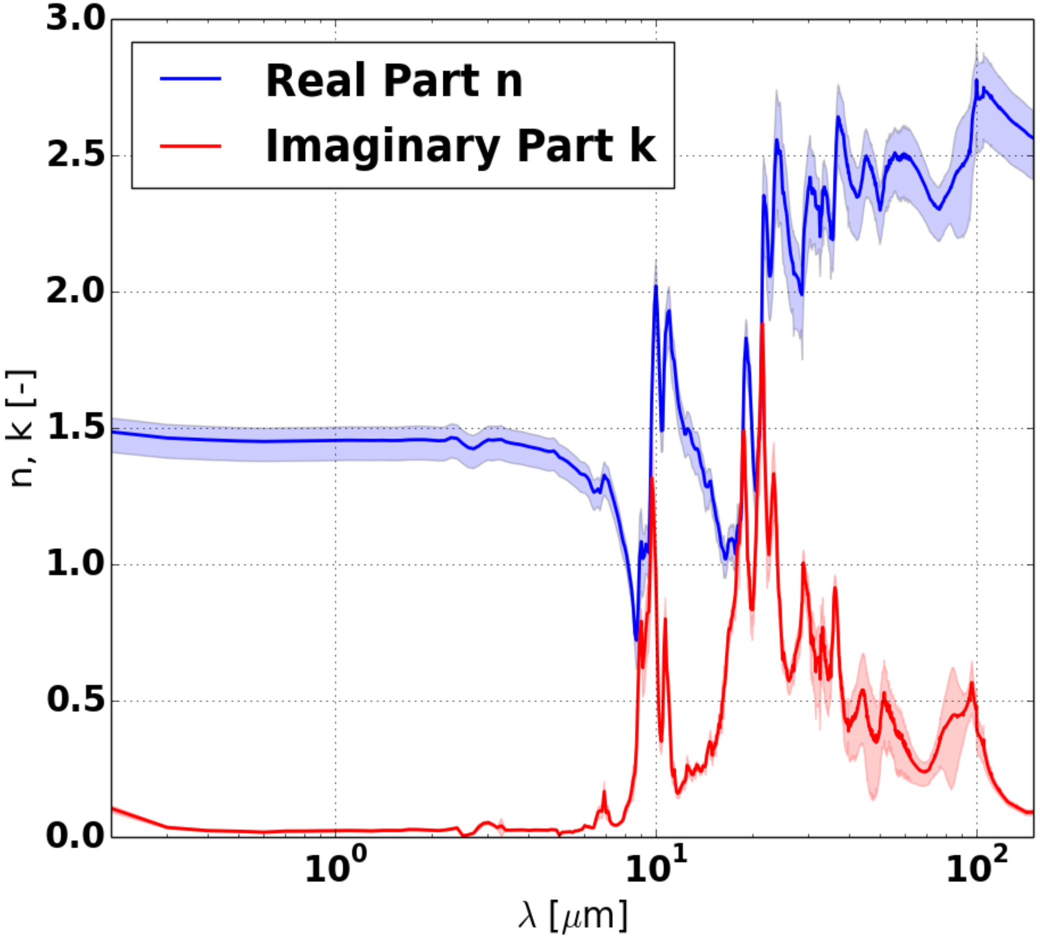
CHyM: Aerosol Properties







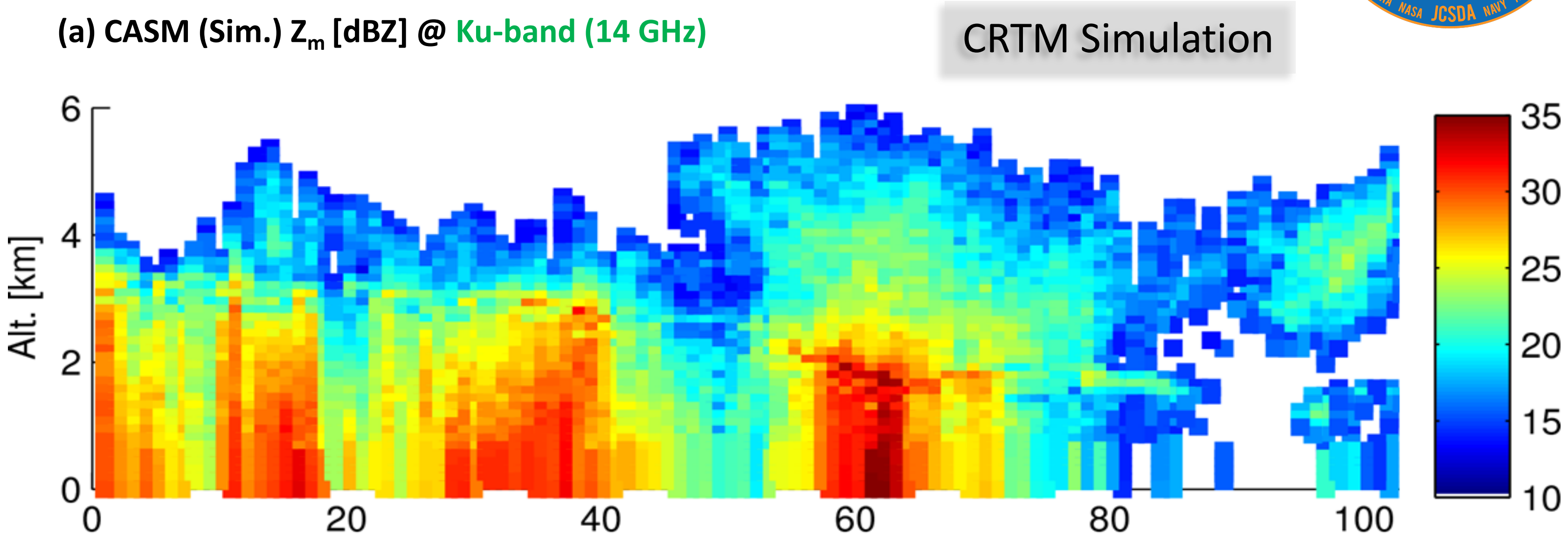
MODIS image of SAL (left). TEM image of Saharan mineral dust particles (Top); Ensemble of hexahedral shapes with tilted facets as a model for mineral dust scattering properties (Bottom).

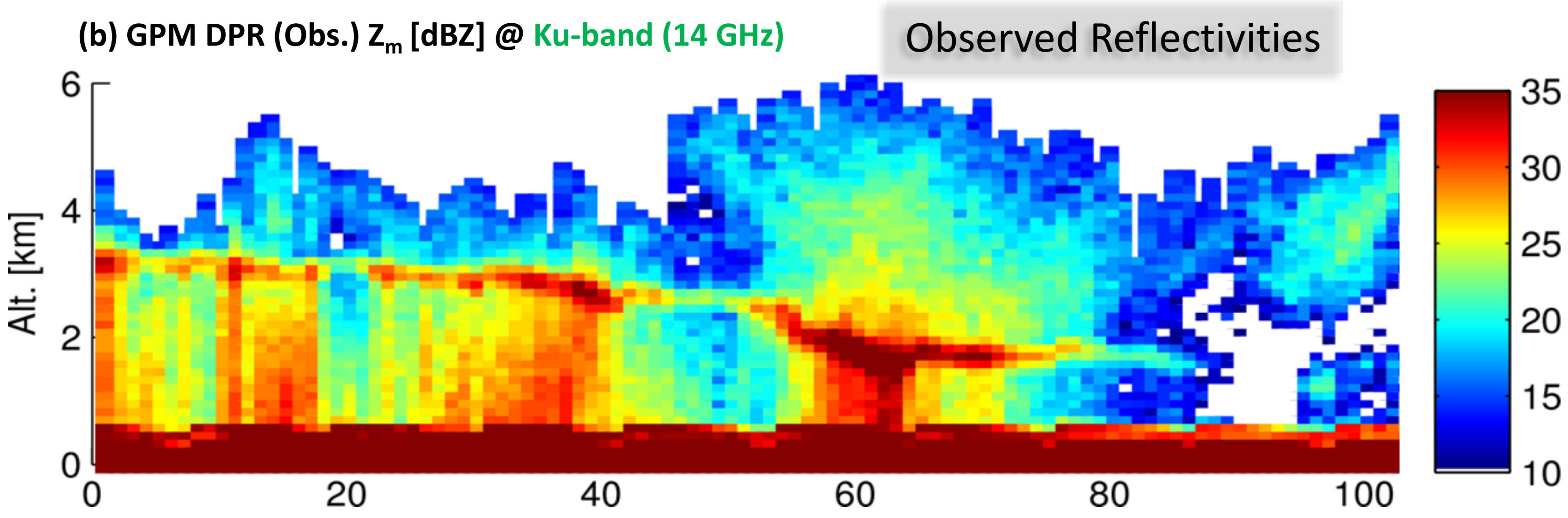


Index of refraction (mean and stdev) of Saharan mineral dust.

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