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

<table>
<thead>
<tr>
<th>Version 3.0.0 progress</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmittance Coefficient Generation (CRTM-COEF)</td>
</tr>
<tr>
<td>CRTM Scattering Indicator, code optimization and solver testing</td>
</tr>
<tr>
<td>Community Hydrometeor Model (CHyM)</td>
</tr>
<tr>
<td>Community Active Sensor Module (CASM)</td>
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<tr>
<td>Community Surface Emissivity Model (CSEM)</td>
</tr>
<tr>
<td>JCSDA coordination (JEDI, NIO, SOCA) and collaboration (RTTOV)</td>
</tr>
</tbody>
</table>
Motivation for Cloudy RT Improvements

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

mhs-metopb[brightness_temperature_2]: latlon omgb bias 157 GHz

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
  
  Model simulated brightness temperature.
  ADVANCED BASELINE IMAGER (GOES-R) channel 10
  2018-04-15 000000 UTC
• 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.
  – **Numerically consistent** with CRTM v2.3.0 for \( n_{\text{stokes}} = 1 \)
  – **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”)
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 \( \pi \), 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°.

<table>
<thead>
<tr>
<th>Layer optical depth</th>
<th>VLIDORT (seconds)</th>
<th>AMOM (seconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>0.096</td>
<td>0.076</td>
</tr>
<tr>
<td>10</td>
<td>0.096</td>
<td>0.063</td>
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<tr>
<td>1</td>
<td>0.096</td>
<td>0.054</td>
</tr>
<tr>
<td>0.1</td>
<td>0.095</td>
<td>0.048</td>
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</tbody>
</table>

Table 4a
Pure Rayleigh atmosphere of optical depth of 0.1 using 4 streams.

<table>
<thead>
<tr>
<th></th>
<th>I</th>
<th>Q</th>
<th>U</th>
<th>V</th>
</tr>
</thead>
<tbody>
<tr>
<td>DA</td>
<td>0.215409</td>
<td>-0.000316</td>
<td>-0.020898</td>
<td>0.0</td>
</tr>
<tr>
<td>VLIDORT</td>
<td>0.215409</td>
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<td>0.0</td>
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<tr>
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<td>-0.000316</td>
<td>-0.020897</td>
<td>0.0</td>
</tr>
</tbody>
</table>

Table 4b
Same as Table 4a, but using 16 streams.

<table>
<thead>
<tr>
<th></th>
<th>I</th>
<th>Q</th>
<th>U</th>
<th>V</th>
</tr>
</thead>
<tbody>
<tr>
<td>DA</td>
<td>0.216527</td>
<td>-0.000214</td>
<td>-0.021456</td>
<td>0.0</td>
</tr>
<tr>
<td>VLIDORT</td>
<td>0.216526</td>
<td>-0.000214</td>
<td>-0.021456</td>
<td>0.0</td>
</tr>
<tr>
<td>ADA</td>
<td>0.216526</td>
<td>-0.000214</td>
<td>-0.021455</td>
<td>0.0</td>
</tr>
<tr>
<td>AMOM</td>
<td>0.216526</td>
<td>-0.000214</td>
<td>-0.021455</td>
<td>0.0</td>
</tr>
</tbody>
</table>

Table 5a
Same as Table 4a, but for an optical depth of 1.

<table>
<thead>
<tr>
<th></th>
<th>I</th>
<th>Q</th>
<th>U</th>
<th>V</th>
</tr>
</thead>
<tbody>
<tr>
<td>DA</td>
<td>0.374199</td>
<td>0.008465</td>
<td>-0.124870</td>
<td>0.0</td>
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<tr>
<td>VLIDORT</td>
<td>0.374189</td>
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<tr>
<td>ADA</td>
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<td>0.008467</td>
<td>-0.124864</td>
<td>0.0</td>
</tr>
<tr>
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<td>0.374196</td>
<td>0.008467</td>
<td>-0.124864</td>
<td>0.0</td>
</tr>
</tbody>
</table>

Motivation for Polarized RT

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

Image courtesy of V. Galligani
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

CRTM v3.0 Beta Focus
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

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)

Processed by CRTM as standard CloudCoeff

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

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
- $\mu$ is set to zero for exponential distribution (Marshall-Palmer) or prescribed
- $\lambda$, the slope can be calculated from hydrometeor mixing ratio $q_x$ as:

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

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

- $\mu$ is set to zero for exponential distribution (Marshall-Palmer) or prescribed
- $N_{ox}$, the intercept can be calculated from $N_{tx}$ as:

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

- $\lambda$, the slope can be calculated from $N_{tx}$ and $q_x$ as:

$$w_x = \rho_a q_x = a \ N_{ox} \ \Gamma(\mu + b + 1) \ \lambda^{-(\mu+b+1)} \quad \rightarrow \quad \lambda = \left(\frac{a \ N_{tx} \ \Gamma(\mu + b + 1)}{\Gamma(\mu + 1) \ \rho_a q_x}\right)^{1/5}$$
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
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.
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.
• 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: crtm-support@googlegroups.com

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