The Community Radiative Transfer Model (CRTM)

In memory of Paul van Delst

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JCSDA Structure (2017)
CRTM Current Status

• https://svnemc.ncep.noaa.gov/trac/crtm/
• Current Operational Version is 2.2.3
• Version 2.3.0 (released on 11/28/2017)
  – v2.3.0 will likely be the last semimajor (2.x) release
  – Version Format: [major.semimajor.minor]
  – minor releases will occur as needed
• v3.0.0 will be the next major release (Late 2018 est.)
• Documentation updates will occur in parallel with release development
  – Use of community focused development tools (e.g., Atlassian: JIRA, BitBucket, Confluence, etc.) to enable ease of collaboration and version control.
Scientific changes

1. All-Sky radiance simulation under various cloud_fraction conditions.
2. Use of all-sky transmittances in FASTEM-X reflection correction.
3. Improve surface reflectance in radiative transfer calculation for Microwave under scattering conditions.
4. Add ATMS Sealce emissivity module.
5. Fix the simulation near 3.9 micron by adding solar contribution in ADA_Module.
7. Updates of CRTM antenna correction coefficients for MHS_N19/Metop-a.
8. Update AIRS coefficients for including NLTE correction.

* In this release, there is a new feature for the simulation of all-sky (cloudy) radiance, which utilizes Fortran class function, and now CRTM will support the new compiler with class function, such as ifort version (14.0+, 15.0+, 16.0+), gfortran version (gcc 4.8.5, 4.9, 5.4, 6.4, 7.2), pg/17.3, ftn/2.3.0.
T670 DA time: 48 MPI, various thread counts (1,2,4,6,12) node counts=(2,4,8,12,24) Note: “Other” is a residual calculation from max values, thus an underestimate

This shows how well GSI scales with increased number of cores, while CRTM time stays flat due to the lack of openMP / MPI directives.

Rosinski & Etherton (ESRL)
T670 DA time: 48 MPI, various thread counts (1,2,4,6,12) node counts=(2,4,8,12,24) Note: “Other” is a residual calculation from max values, thus an underestimate

Now CRTM scales similar to GSI using OpenMP directives. Relative load imbalance (purple) is reduced as well.
Ultrafast Solvers for Enhanced CRTM Performance in Cloudy Atmospheres

Tom Greenwald (University of Wisconsin-Madison)
Ralf Bennartz (Vanderbilt University)

• Overview:
  – Exploit analytic 2/4-stream solvers to optimize the CRTM in calculating all-sky (including aerosols) microwave and IR radiances
  – Demonstrate impact of these improvements in the GOES-5 DAS and GDAS
• Progress:
  – Created new CRTM solver modules
    • EDD: Delta-Eddington (Bauer et al. 2005)
    • P2S: Polarized (I,Q) 2-stream (Liu and Weng 2002)
  – Modified CRTM code to allow use of these new solvers
  – Successfully built the CRTM Library with the new modifications
  – Testing of the solvers is in progress
Community Hydrometeor Model (CHYM) (V 0.3)

Community Hydrometeor Model (CHYM) (V 0.3)

Interface Layer In CRTM at CRTM_CloudCoeff.f90

Single Particle Database Layer

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


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

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

B. Johnson (JCSDA / UCAR)
CHYM Approach

• (1) Development of the microphysical parameters of clouds and precipitation (Lead: Emily Liu)
  – Relate to the current and planned GFS microphysical assumptions.
  – converting mixing ratios into particle size distributions (PSD) and habit distributions, consistent with the microphysics schemes

• (2) Creating the PSD-integrated scattering properties (Lead: Ben Johnson).
  – Extend and replace current CloudCoeff.bin lookup table, consistency with above microphysics
Observed Ice Particle Size Distribution

PSDs plotted using data downloaded from Brian Baum’s website:
http://www.ssec.wisc.edu/ice_models/microphysical_data.htm
Cloud Microphysical Modeling [2/3]

Observed Ice Particle Size Distribution

PSDs plotted using data downloaded from Brian Baum’s website:
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Cloud Microphysical Modeling [3/3]

![Graphs showing cloud microphysical properties](image-url)
• **Current Status:**
  – Cloud physical data has been collected (from B. Baum’s work)
  – Single-particle scattering database from P. Yang’s group (Jiachen Deng, Patrick Stegmann) available
  – Stand-alone code to create new CRTM scattering tables (with and without backscattering) is working (non-automated)
  – **Given a PSD, mass-diameter relationship, temperature, and habit distribution, we can now construct updated scattering tables.**

• **Next Steps:**
  – Construct scattering tables for the regimes presented here
  – Stand-alone testing within CRTM
  – Preliminary GSI testing (single-cycle)
  – Preliminary GFS testing (without automatic table selection) Targeting ITSC-21 conference at end of November.
  – Implement method to communicate GFS microphysics to CRTM to enable automatic table selection. Targeting CRTM v 3.0.0 release.
CSEM New Components

- New ocean surface MW FASTEM version with enhanced performance in frequency bands lower than 19GHz and zenith angles larger than 60 degrees. The forward and tangent-linear modules have been implemented. Coding of the adjoint module is on the way. The calibration of the new FASTEM model was performed with several in-situ data sets.
- Ocean surface MW BRDF model for coupling with the upper-level CRTM multi-stream cloudy scattering scheme. Coding of the forward BRDF module is on the way.

Ming Chen, ESSIC/UMD
CRTM-CSEM Interfacing Implementation

CSEM Applications (CRTM_SfcOptics Module)

Top-Down
- CSEM Algorithm Register
- CSEM Interfacing Modules
- CSEM I/O Data Structures

Bottom Up
- Physical Models
  - RT schemes
    - Dielectric models
- Atlas (Maps) and LUTs
  - Model Data Reader
    - Model Data Files
  - Atlas and LUT Readers
    - Atlas LUT Data Files
- Sensor-Based Algorithms
  - Regression Data Readers
    - Regression Data Files

Ming Chen, ESSIC/UMD
The original two-scale physical model is applicable to a much wider frequency range, but the current FASTEM 6 is limited to 200GHz.

A new FASTEM version (NFASTEM) has been developed to cover L-band to submillimeter channels.

It agrees very well with FASTEM 6 at channels lower than 200GHz, as well as with TESSEM at channels over 200GHz.
In general, the previous FASTEM versions were developed for zenith/view angles less than 60 degree. FASTEM 6 also turned off the 3\textsuperscript{rd} and 4\textsuperscript{th} Stokes components. TESSEM is similar to FASTEM 6 except for the frequency extension to submillimeter channels.

The NFASTEM provides full-Stokes component calculations. The azimuthal variations in NFASTEM now agree well with the observations (Red) in both magnitude and phase change.

Ming Chen, ESSIC/UMD
Ongoing Work/Future Plans [1/2]

- **CRTM 2.3.0 post-release integration testing**
  - Documentation update

- **Coefficient Generation Toolkit**

- **Optimization Plans** [J. Rosinski / B. Etherton]
  - Thread via OpenMP the loop over observations in GSI routine setuprad.f90
  - Redesign CRTM data structures to enable vectorization of inner loops (vertical dependencies within inner loops prevent this now)

- **Solver Plans** [T. Greenwald/R. Bennartz]
  - Continue testing of the solvers
  - Add scattering indicator routine to the CRTM to help characterize the degree of scattering in a given atmospheric profile
  - Conduct benchmark timing/accuracy tests using NWP model data and determine optimum configuration for solvers
Ongoing Work/Future Plans [2/2]

• Physical Properties Ongoing Work
  – **Aerosols**: Develop new scattering tables to conform with updated aerosol properties (PSD, index of refraction, etc.) in coordination with the A-Team. Updated specifications using CMAQ.
  – **CSEM**: Continue the CRTM-CSEM integration efforts so that we may have a working version of the integrated CRTM-CSEM package as soon as possible for demonstration and various testing purposes. The implementation of new CSEM functionality and components will depend on the priority and the requirements of the user community.
  – **Microphysics / CHYM**: Continue expanding microphysics database, and testing newly-created scattering tables in stand-alone CRTM and in GSI/GFS for analysis and forecast impact assessment.
  – **CLBLM**: Transition to STAR
  – **Shortwave / IR improvements**: Seeking new hire for NASA GMAO position to focus on this requirement
Questions / Comments?

- CRTM TRAC page (documentation)
  https://svnemc.ncep.noaa.gov/trac/crtm
- CRTM SVN repository (version control)
  https://svnemc.ncep.noaa.gov/projects/crtm
- CRTM FTP site
  ftp://ftp.emc.ncep.noaa.gov/jcsda/CRTM
- Coming Soon!
  - New community-focused integrated documentation, GIT-based version control, user-support, release / build / testing environment (under development, FY18 target)
### CRTM Optimization Status

- Run REL-2.3.0-beta for 100 profiles on Theia machine, and compared with REL-2.2.3.
- For hyperspectral IR sensors, like CrIS, the all sky (Cloud_Fraction) run can save about 10% CPU time than run CRTM twice for Clear and Cloudy conditions.

<table>
<thead>
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<th>Timing_test 100 profiles</th>
<th>Clear-Sky</th>
<th></th>
<th></th>
<th>All-Sky: (Clear + Cloudy)</th>
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<td>30.404</td>
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</table>
Ice Crystal Model

User Input
- Size Distribution \( n(D) \)
- Characteristic Diameter \( D_e \)
- Mass-Dimension Relationship \( m(D) = aD^b \)
- Ice Water Content \( w_x = \rho_a q_x \)
- Number Concentration \( N_t \)

Size Distribution
- Habit Distribution
- Convolve each single particle optical property with the size and habit distribution to obtain distribution mean (bulk) ice particle optical property
- Parameterize distribution mean (bulk) ice particle optical properties as a function of characteristic diameter:
  \[ k_{\text{ext}}(D_e, \nu), k_{\text{sca}}(D_e, \nu), \omega, g(D_e, \nu), P(\theta, D_e, \nu) \]

Distribution Mean (Bulk) Ice Particle Optical Properties
- Ice Water Content
- Is the output IWC approximately equal to the input?
- There is no doubt that mixture of habit is more realistic, but are we using the habit distribution which best represents the nature?
- Should we parameterize the cloud optical properties using the same ice crystal database and model for the radiation model used in GFS for consistency?
• Thread loop over channels in CRTM_K_Matrix_module.f90 using OpenMP
  – ~5X speedup using 6 OMP threads
  – ~8X speedup using 12 OMP threads
• Numerous code changes are required to enable OpenMP threading, but no significant structural changes to the code
• However, explicit vectorization of code will require substantial code rewrite.