



JCSDA Community Radiative Transfer Model - Version 1 (CRTM-V1)

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1. Introduction

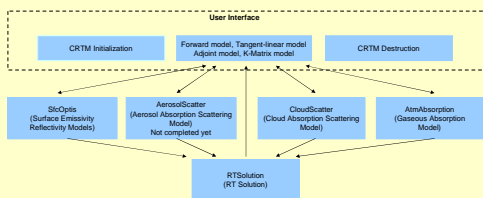
The Community Radiative Transfer Model (CRTM), developed at the US Joint Center for Satellite Data Assimilation (JCSDA), simulates satellite microwave (MW) and infrared (IR) radiances and computes radiance derivatives (Jacobians) with respect to the state variables. It is an essential component of the Gridpoint Statistical Interpolation (GSI) data assimilation system at the NOAA National Center for Environmental Prediction (NCEP) Environmental Modeling Center (EMC). The development of the CRTM was stimulated by recent research activities in the radiative transfer (RT) modeling community to fully utilize the information of satellite measurements under all weather conditions for numerical weather prediction (NWP). CRTM-V1 was implemented with many recent achievements to improve the modeling of both clear and cloudy satellite radiances. Another important purpose of developing the new model was to design a framework for research groups and developers to simplify the implementation of experimental algorithms and allow it to be easily tested and evaluated in the operational environment and thereby accelerate the transition from research to operational application. This presentation describes the theoretical background and functional implementation of CRTM-V1.

2. What can CRTM-V1 provide?

- Forward model: satellite radiance simulation $R = F(X)$
- Tangent-linear model: $\delta R = (\partial F / \partial X) \delta X$
- Adjoint model: $\delta^2 X = (\partial F / \partial X)^T \delta^2 R$
- K-Matrix (Jacobian) model: $\partial F / \partial X$
- Covering Microwave and infrared sensors

3. Component descriptions

3.1 CRTM-V1 component diagram



3.2 Gaseous absorption model (Compact OPTRAN)

The channel, or spectral-response-function (SRF) convolved transmittance is modeled as

$$T_{ch} = T_{ch,w} T_{ch,o}^* T_{ch,d}^*$$

where $T_{ch,w}$ is the water vapor transmittance and $T_{ch,o}^*$ and $T_{ch,d}^*$ are the effective transmittances of ozone and dry gas (McMillin et al. 1995), respectively. The transmittance component on the right side of the above equation is computed as

$$T_{ch,g}(A_g) = e^{-\int_0^1 k_{ch,g}(A_g) dz}$$

- A_g – integrated amount of water vapor, ozone or dry gas
- $k_{ch,g}$ – channel absorption coefficient of water vapor, ozone or dry gas

$k_{ch,g}$ is predicted as

$$Ln(k_{ch,g}(A_g)) = c_{g,0}(A_g) + \sum_{j=1}^6 c_{g,j}(A_g) x_{g,j}(A_g) \quad c_{g,j}(A_g) = \sum_{n=0}^N a_{g,j,n} Ln(A_g)^n$$

- $x_{g,j}$ – predictors such as temperature and pressure
- $a_{g,j,n}$ – constants obtained through regression

A unique feature of the compact OPTRAN algorithm is that the coefficients $c_{g,j}$ are continuous functions (polynomial) of A_g .

3.3 Surface emissivity and reflectivity models

The CRTM employs a suit of IR and MW surface emissivity and reflectivity models covering land, ocean, ice and snow surfaces.

- **IR sea surface emissivity model:** The IR sea surface emissivity model utilizes a lookup table of sea surface emissivities derived from the emissivity model for a wind-roughened sea surface (Wu and Smith, 1997). The lookup table variables are zenith angle (67 from nadir to 66.5°), frequency (153 from 600-3000cm⁻¹), and wind speed (23 from 0-15ms⁻¹). Currently linear interpolation is performed between the lookup table values.
- **IR land surface emissivity database:** The IR surface emissivity used over land, snow and ice is provided by an emissivity database (Carter et al., 2002). The database contains surface reflectance measurements as a function of wavelength in both visible and IR spectral regions for 24 surface types. The emissivity is calculated as one minus the reflectance under the assumption of a Lambertian surface in the IR spectral region.
- **MW ocean emissivity model:** The MW emissivity over ocean surface is computed using FASTEM-1 (English and Hewison, 1998). It takes satellite zenith angle, water temperature, surface wind speed, and frequency as model inputs and computes surface emissivity at vertical (V) and horizontal (H) polarizations.
- **MW land emissivity model:** The MW land emissivity model (LandEM) computes land surface emissivity for various surface types, including snow, deserts and vegetation using the two-stream radiative approximation (Weng, et al, 2001). The model takes satellite zenith angle, MW frequency, soil moisture content, vegetation fraction, soil temperature, land surface temperature and snow depth as inputs and computes surface emissivity at V and H polarizations.
- **MW empirical emissivity mode over snow and ice surfaces:** The empirical snow and ice emissivity models compute the emissivity via a combination of satellite window channel observations and emissivity databases collected from ground-based microwave instruments (Yan and Weng, 2004). The emissivity databases contain sets of emissivity spectral data measured at a zenith view angle of 50 degree for various surface types. The window channel observations are used to identify the snow or ice surface type that best describes the surface condition observed by the window channels. After a spectrum is identified, it is adjusted for the requested zenith angle by using LandEM (Weng, et al, 2001).

3.4 Cloud absorption and scattering model

Cloud optical parameters are calculated with the general Mie theory using a modified gamma distribution function. The parameters such as extinction coefficients, single scattering albedo and phase matrix elements are pre-calculated and stored in a lookup table. This table is searched with particle mean size and cloud water content. Data for liquid water cloud, ice cloud, rain cloud, snow, graupel, and hail are all included.

3.5 Radiative Transfer Solver

The RT solver module solves the RT equation for given atmospheric optical depth profile, surface emissivity and reflectivity, cloud optical parameters and source functions. The clear and cloudy cases are treated with different methods, allowing a simple and efficient solution under the clear-sky condition. For cloudy cases, the radiative transfer is solved with the Advanced Doubling-adding method (Liu and Weng, 2006), in which fast algorithms are applied to compute layer source function and vertical radiative transfer integration.

4. User Interface

The user interface comprises primarily a set of interfaces of the user callable routines. These routines are listed in Table 1. The key interface arguments for inputs and outputs are listed in Table 2. The required coefficient files, whose filenames need to be specified by the user during the CRTM initialization, are listed in Table 3.

Subprogram Name	Description
CRTM_Init	Initialize CRTM and load CRTM coefficient data.
CRTM_Set_ChannelInfo	Select sensors and channels.
CRTM_Forward	CRTM forward model.
CRTM_Tangent_Linear	CRTM tangent-linear model.
CRTM_Adjoint	CRTM Adjoint model.
CRTM_K_Matrix	CRTM K_Matrix (Jacobian) model.
CRTM_Destroy	Release memory used by CRTM.
<i>Memory allocation/deallocation subprograms</i>	
CRTM_Allocate_Atmosphere	Allocate and deallocate memory for the Atmosphere structure pointer array members.
CRTM_Allocate_Surface	Allocate and deallocate memory for the Surface structure pointer array members.
CRTM_Allocate_RTSolution	Allocate and deallocate memory for the RTSolution structure pointer array members.
CRTM_Allocate_Options	Allocate and deallocate memory for the Options structure pointer array members.

Type name	Description
Atmosphere	The forward (tangent-linear, adjoint or K-Matrix) variable of the atmospheric state.
Cloud	The forward (tangent-linear, adjoint or K-Matrix) variable of the cloud position.
Surface	The forward (tangent-linear, adjoint or K-Matrix) variable of the surface data.
RTSolution	The forward (tangent-linear, adjoint or K-Matrix) variable linking the RT solutions.
ChannelInfo	Contains selected sensor/channel information for subsequent calls to the CRTM models.
GeometryInfo	Contains satellite geometry data such as sensor and solar zenith angles.
Options	Contains optional variables such as the user-provided surface emissivity.

Table 1 CRTM interface routines

Table 2 Structure variable types used for the interface arguments

Coefficient data file	Description
Spectral coefficient (SpCoeff) file	Contains sensor spectral information (Sensor dependent).
Optical depth (TrnCoeff) coefficient file	Contains transmittance coefficient data (sensor dependent).
Cloud coefficient (CloudCoeff) file	Cloud optical parameters and lookup tables such as mass extinction coefficients, single scattering albedo, asymmetry factor and Legendre expansion coefficients.
CRTM_Optional_Coefficient (EmissCoeff) file	Contains coefficient data for computing infrared ocean surface emissivity.
Aerosol coefficient (AerosolCoeff) file	Currently a dummy file (placeholder for aerosol component).

Table 3 CRTM coefficient data files

Examples of calling the forward and K-Matrix (Jacobian) models:

```

Error_Status = CRTM_Forward( Atmosphere, Surface,           & ! inputs
                             GeometryInfo, ChannelInfo,   & ! inputs
                             RTSolution,                   & ! output
                             Options =Options)             ! optional input

Error_Status = CRTM_K_Matrix( Atmosphere, Surface,         & ! inputs
                              RTSolution_K, GeometryInfo, & ! inputs
                              ChannelInfo,                & ! input
                              Atmosphere_K, Surface_K,    & ! input/output
                              RTSolution,                  & ! output
                              Options = options )          ! optional output
  
```

5. Ongoing CRTM development projects

- Development of aerosol component matched with GOCART aerosol specifications
- Improvement of surface emissivity and reflectivity models
- Integration of the following transmittance algorithms into CRTM: OSS of AER, SARTA of UMBC and RTTOV of EUMETSAT.
- CRTM test and validation under both clear and cloudy conditions
- Implementation of the fast RT algorithm for SSMS upper-air channels

Reference

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