RTTOV-6 - TECHNICAL DESCRIPTION

1. GENERAL REMARKS

The purpose of this report is to document the technical aspects of RTTOV-6. Scientific and validation documentation can be found in the RTTOV-6 scientific and validation report. The model is available in both Fortran 77 and Fortran 90 versions and an installation guide is available for users to install RTTOV-6 on their own system and test it out. The code is available from ECMWF data services via ftp (for a compressed UNIX tar file of the F90 or F77code) or on 2 floppy disks for the F77 code. The main features of RTTOV-6 are:

- RTTOV-6 is the latest version of a fast radiative transfer model which has been under development since 1990. It computes top of atmosphere radiances and equivalent black body brightness temperatures for satellite infrared and microwave radiometers given an input atmospheric profile of temperature, water vapour and optionally ozone and cloud liquid water. It also outputs intermediate products of the RT calculations in addition (e.g. surface to space transmittances, transmittance profiles, cloudy radiance from each layer, surface emissivity, etc).
- It supports many different satellite radiance observations as defined in the Annex with the same model but using different RT coefficient files as input. A single documented ASCII RT coefficient file is used as input for each satellite series type. This facilitates export of the code and makes it clear what values are used. The code does however accept a binary input for operational purposes where I/O is an important consideration.
- It allows a different surface emissivity to be input for each radiometer channel and if the input is set to zero values are computed internally in the model and returned in the output. For infrared channels the ISEM-6 model (Sherlock, 1999) is used and for microwave channels over the ocean the FASTEM model (English and Hewison, 1998) is used.
- A check is applied on the input profile variables to make sure they are within sensible limits of the regression used to compute the coefficients. If they are outside the defined limits but still physically reasonable a calculation will still be performed but a flag is returned in the range (10-19). If the profile is not physically reasonable RTTOV-6 will return with an error flag >20 set *but still attempt a computation*.

2. CHANGES FROM RTTOV-5

The scientific changes are outlined in more detail in the scientific and validation report but for completeness a list of changes from the previous version of RTTOV (RTTOV-5) are given here together with the technical changes:

- Activation of cloud liquid water concentration profile to optionally affect microwave channel transmittances.
- Addition of infrared surface emissivity model for ocean and more realistic constant values specified for land.
- Modification to water vapour transmittance calculation for AMSU-B water vapour channels (AMSU channels 18-20) to give much improved accuracy in computed radiances.
- Error in GENLN2 transmittance reference profile corrected which has removed spikes in infrared Jacobians for the upper levels.
- The Liebe microwave model transmittances have been computed on a finer spectral grid which has improved the computation of some of the AMSU-A upper level sounding channels.
- Addition of coefficients for SSM/I, TMI, AVHRR and GOES imager + measured filters now used for SEVIRI simulations.
- Revision of soft profile limits to be wider as regressions still work well beyond limits. This will reduce number of error flags returned.
- Addition of unit number variable for reading coefficient file to ***RTTVI*** input variables.
- More optimisation of code for running on supercomputers.

3. DOCUMENTATION OF RTTOV-6 CODE STRUCTURE

RTTOV-6 consists of a setup routine and 4 associated models:

RTTVI routine to set up arrays for RTTOV

RTTOV the radiative transfer model itself,
RTTOVTL its tangent linear model,
RTTOVAD its adjoint model and
RTTOVK its gradient matrix model.

If you are only interested in the forward model and not the gradient routines then the TL/K/AD routines are not required which significantly reduces the number of routines you need.

Firstly ***RTTVI*** must be called to set up the necessary arrays for the satellite series required (i.e. NOAA, METEOSAT, DMSP, GOES, AVHRR) and the satellite ids for each series (as defined in Tables 1 and 2 of Annex). The *cparam.h* include file defines the array sizes for running RTTOV-6. It is recommended the user modifies this file to set the array size for his particular application. The variables in the file are defined in Table 1. If the rt_coefficient file supplied is used then only those variables in ***italics*** should be modified. **JPNSAT** refers to the maximum number of satellites of all series to be used at any one time, **JPPF** to the maximum number of profiles to be processed in any one call to RTTOV and **JPCHUS** to the maximum number of channels required to be simulated by RTTOV.

PARAMETER (JPNOAA=11)	! MAX NO. OF NOAA AVHRR SATS IN COEF FILE
PARAMETER (JPTOVS=15)	! MAX NO. OF NOAA TOVS/ATOVS SATS IN COEF FILE
PARAMETER (JPDMSP= 9)	! MAX NO. OF DMSP SATS IN COEF FILE
PARAMETER (JPMET = 4)	! MAX NO. OF METEOSAT SATS IN COEF FILE
PARAMETER (JPGOES= 5)	! MAX NO. OF GOES SATS IN COEF FILE
PARAMETER (JPNSAT=12)	! MAX NO. OF SATELLITES TO BE USED
PARAMETER (JPLEV=43)	! NO. OF PRESSURE LEVELS IN PROFILE
PARAMETER (JPNAV=4)	! NO. OF PROFILE VARIABLES IN PROFILE
PARAMETER (JPNSAV=5)	! NO. OF SURFACE AIR VARIABLES
PARAMETER (JPNSSV=1)	! NO. OF SKIN VARIABLES
PARAMETER (JPNCV=2)	! NO. OF CLOUD VARIABLES
PARAMETER (JPPF=1) ‡	***! MAX NO. PROFILES FOR EACH RTTOV CALL***
PARAMETER (JPCH=47)	! MAX. NO. OF CHANNELS IN PARAM FILE
PARAMETER (JPHIR=20)	! MAX. NO. OF HIRS CHANNELS IN PARAM FILE
PARAMETER (JPMSU=4)	! MAX. NO. OF MSU CHANNELS IN PARAM FILE
PARAMETER (JPAMSU=20)	! MAX. NO. OF AMSU CHANNELS IN PARAM FILE
PARAMETER (JPSSU=3)	! MAX. NO. OF SSU CHANNELS IN PARAM FILE
PARAMETER (JPVTPR=16)	! MAX NO. OF VTPR CHANNELS IN PARAM FILE
PARAMETER (JPSSMI=7)	! MAX NO. OF SSM/I CHANNELS IN PARAM FILE
PARAMETER (JPAVHRR = 3)	! MAX NO. OF AVHRR CHANNELS IN PARAM FILE
PARAMETER (JPGOESIM = 4)	! MAX NO. OF GOES IMAGER CHANNELS IN PARAM FILE
PARAMETER (JPCHUS=39)	***! MAX. NO. OF CHANNELS REQ'D FOR COMPUTATION***
PARAMETER (JPCHPF=JPPF*JPCHUS)	! MAX NO. OF PROFS * CHANS REQUIRED
PARAMETER (JPCOFM=10)	! MIXED GAS COEFFS (MAX)
PARAMETER (JPCOFW=10)	! WATER VAPOUR COEFFS (MAX)
PARAMETER (JPCOFO=10)	! OZONE COEFFS (MAX)
PARAMETER (JMWCLDTOP = 25)	! UPPER LEVEL FOR LWP CALC
PARAMETER (JPST=10)	! MAX NO. OF SURFACE TYPES

‡ (set to 1 for scalar machine, and to ~50 for a vector machine for optimal performance)

Table 1. RTTOV-6 include file cparam.h

RTTVI sets up the arrays and loads in all the constants from the rt_coefficient file(s) and is only called once for all satellites. **RTTOV** actually performs the RT calculation for the specified satellite ids and channel numbers given valid profile arrays. The subroutine calling structure for **RTTVI** and **RTTOV** is shown in Figures 1 and 2. For users who require the tangent-linear, adjoint or K routines of RTTOV-6 the calls are **RTTOVTL**, **RTTOVAD** and **RTTOVK** respectively with the same subroutines called inside with the endings TL, AD, K. The details of the calling interfaces are given in section 4.

4 DOCUMENTATION OF RTTOV-6 INTERFACES

4.1 RTTVI Interface

The only change to the RTTVI interface is an additional integer parameter, KIU1, to specify the unit number through which to read the rt_coef files. If set to zero a unit number of 10 is assumed (as for RTTOV-5).

```
CALL RTTVI(IERR,KPPF,KPNSAT,KPLEV,KPCH,KPCHUS,KPNAV,KPNSAV,
KPNSSV,KPNCV,NSERIES,NSATID,NSUBTYPE,
KSERIES,KSATID,KSUBTYPE,MAXSERIES,MAXSATID,
MAXSUBTYPE,PRESLEV,OTMIN,OTMAX,OQMIN,OQMAX,OOZMIN,OOZMAX, KIU1)
```

RTTVI is called only once for more than one satellite series; tovcf.F, eumcf.F, ssmcf.F etc. are called from RTTVI as required.

Arguments:

Input:

```
NSERIES                        - NUMBER OF SATELLITE SERIES REQUESTED
NSATID(MAXSERIES)              - NUMBER OF SATELLITE ID'S FOR EACH SERIES
NSUBTYPE(MAXSERIES)            - NUMBER OF SUBTYPES FOR EACH SERIES ( set to 1)
KSERIES(MAXSERIES)             - LIST OF REQUESTED SERIES
KSATID(MAXSERIES,MAXSATID)     - LIST OF REQUESTED SATID'S FOR EACH SERIES
KSUBTYPE(MAXSERIES,MAXSUBTYPE) - LIST OF REQUIRED SUBTYPES FOR EACH SERIES
MAXSERIES                      - MAXIMUM NUMBER OF SERIES
MAXSATID                       - MAXIMUM NUMBER OF SATELLITES PER  SERIES
MAXSUBTYPE                     - MAXIMUM NUMBER OF SUBTYPES FOR EACH SERIES
KIU1                           - UNIT NUMBER FOR READING RT COEFF FILES
```

Output:

```
IERR                           - ERROR FLAG, RETURNS IERR /= 0 IF ERROR
KPPF                           - MAX NUMBER PROFILES PROCESSED IN PARALLEL
KPNSAT                         - MAX NUMBER OF SATELLITES
KPLEV                          - NUMBER OF RT LEVELS
KPCH                           - MAX NUMBER OF CHANNELS
KPCHUS                         - MAX NUMBER. OF CHANNELS USED
KPNAV                          - MAX NO OF PROFILE VARIABLES
KPNSAV                         - MAX NO OF SURFACE VARIABLES
KPNSSV                         - MAX NO OF SKIN VARIABLES
KPNCV                          - MAX NO OF CLOUD VARIABLES
PRESLEV                        - KPLEV PRESSURE LEVELS FOR RT CALCULATIONS
OTMIN(JPLEV)                   - MIN TEMP PROFILE ARRAY
OTMAX(JPLEV)                   - MAX TEMP PROFILE ARRAY
OQMIN(JPLEV)                   - MIN SPECIFIC HUMIDITY PROFILE ARRAY
OQMAX(JPLEV)                   - MAX SPECIFIC HUMIDITY PROFILE ARRAY
OOZMIN(JPLEV)                  - MIN OZONE PROFILE ARRAY
OOZMAX(JPLEV)                  - MAX OZONE PROFILE ARRAY
IVCH(KPCH,KPNSAT)              - ARRAY PER SATELLITE OF VALID CHANNEL NUMBERS
```

Notes

Series numbers have been arbitrarily assigned as:

```
(A)TOVS = 1   TMI&SSM/I = 2   METEOSAT/MSG = 3   GOES = 4   AVHRR = 5
```

Satellite identifiers are defined in the Annex. Satellite instrument sub-types are always set to 1 at present as the parameter is not used but may be used later to discriminate between different radiance types (e.g. 1b or preprocessed radiances):

```
(A)TOVS= 1    MVIRI=1   SEVIRI=1 SSM/I=1 etc
```

4.2 RTTOV interface

There is no change to the interface to the RTTOV subroutine although the surface type of 2 in KSURF is now activated as sea-ice for the infrared emissvity model:

```
CALL RTTOV(KNPF,KLENPF,KNAV,KNSAV,KNSSV,KNCV,PPRES,PANGL,PANGA,
PANGS,PANGSA,PGRODY,KSURF,KSAT,KNCHPF,KCHAN,KPROF,
PAV,PSAV,PSSV,PCV,PEMIS,IFAIL,PRAD,PTB,PRDOV,PRDO,PTAU,PTAUSF)
```

The terms "constant" and "variable" are employed here in the sense used in variational analysis, i.e. an input variable is a parameter with respect to which a gradient will be calculated in the associated tangent linear (TL) and adjoint (AD) routines.

Input constants

```
KNPF             number of profiles(no restriction affects memory
                 requirements)
KLENPF           length of atmospheric  profile vectors
KNAV             number of atmospheric profile variables
KNSAV            number of surface air variables
KNSSV            number of surface skin variables
KNCV             number of cloud variables
PPRES(KLENPF)    pressure levels (hPa) of atmospheric profile vectors
PANGL(KNPF)      satellite local zenith angle ( deg)
PANGA(KNPF)      satellite local azimuth angle ( deg)
PANGS(KNPF)      solar zenith angle at surface ( deg)
PANGSA(KNPF)     relative satellite solar azimuth angle.
PGRODY(6,KNPF)   grody type microwave emissivity  coeffs
KSURF(KNPF)      surface type index (0=land, 1=sea, 2=sea-ice)
KSAT             satellite index (see RTTVI)
KNCHPF           number of output radiances (= channels used * profiles)
KCHAN(KNCHPF)    channel indices (for output vectors)
KPROF(KNCHPF)    profile indices (for output vectors)
```

Input variables

```
PAV(KLENPF,KNAV,KNPF)   atmospheric profile variables (see Table 2)
PSAV(KNSAV,KNPF)        surface air variables (see Table 2)
PSSV(KNSSV,KNPF)        surface skin variables (see Table 2)
PCV(KNCV,KNPF)          cloud variables (see Table 2)
```

Input/output variables

```
PEMIS(KNCHPF,KNPF)      surface emissivity for each channel. If set to
                        zero on input for infrared or microwave channels
                        the ISEM-6/FASTEM model is used (over sea) and the
                        computed values returned as output (see table 3).
```

Output constants

```
IFAIL(KNPF,JPNSAT)      return  flag  (0=OK,10-19=outside  profile  limits,
                        >20=unphysical profile) See Table 4.
```

Output variables

```
PRAD(KNCHPF)            radiances (mW/cm-1/ster/sq.m)
```

```
PTB(KNCHPF)              brightness temperatures ( degK)
PRDOV(KNCHPF,KLENPF)     overcast radiance at each level in  mW/m2/sr/cm-1
PRDO(KNCHPF)             overcast radiance at cloud top in mW/m 2/sr/cm-1
PTAU(KNCHPF,KLENPF)      transmittance from each standard pressure level
PTAUSF(KNCHPF)           transmittance from surface
```

Position in vector/element	Profile Array Contents	Units
1 to NLEV/1	Temperature profile	degK
1 to NLEV/2	Water vapour profile	Kg/Kg
1 to NLEV/3	Ozone profile ‡	Kg/Kg
1 to NLEV/4	Liquid water concentration profile (optional)	Kg/Kg
Position in vector	**Surface Array Contents**	**Units**
1	Surface 2m temperature	degK
2	Surface 2m water vapour	Kg/Kg
3	Surface pressure	hPa
4	2 m vector wind speed u	$m.s^{-1}$
5	2 m vector wind speed v	$m.s^{-1}$
Position in vector	**Surface Skin Array Contents**	**Units**
1	Radiative skin temperature	degK
Position in vector	**Cloud Array Contents**	**Units**
1	Cloud top pressure	hPa
2	Cloud fractional cover	0-1
Position in vector	**Surface Emissivity Array Contents**	**Units**
1 to NCHAN	Surface emissivity (if set to zero provide default value as defined in Table 3)	0-1

‡ If unavailable initialise to reference ozone profile in rt_coef file.

Table 2. Profile vectors for model. NLEV is the number of profile levels and NCHAN the number of channels. All the arrays have another dimension for profile number to allow vectorising of the code.

Input •ϵ	Forward Output •ϵ	Tangent Linear Output ∂•ϵ
	INFRARED	
0	Land=0.98/sea-ice=0.99/sea= $\bullet\epsilon_{ISEM}$	∂•ϵ about 0.98/0.99 ϵ $\bullet_{ISEM}$
Non-zero	as input	∂•ϵ about • input
	MICROWAVE	
0	Land/sea-ice=0.9/sea= $\bullet_{FASTEM}$	Land/sea-ice ∂•ϵ about 0.9 sea ∂•ϵ computed from ∂u, ∂v, ∂sst about $\bullet_{FASTEM}$
Non-zero	as input	∂•ϵ about • input

Table 3. Output values of • ϵ and ∂ • ϵ arrays for infrared and microwave channels for forward and gradient routines

IFAIL value	Meaning
0	Profile OK
11	Temp profile outside limits
12	Water vapour profile outside limits
13	Ozone profile outside limits
14	Surface temp outside limits
15	Surface water vapour outside limits
16	Surface wind speed outside limits
20	Input pressure levels do not match coef file
21	Temperature profile unphysical
22	Water vapour profile unphysical
23	Ozone profile unphysical
24	Surface temperature unphysical
25	Surface water vapour unphysical
26	Surface wind unphysical
27	Surface pressure unphysical

Table 4. Values for IFAIL flag from RTTOV

5. RTTOV-6 COEFFICIENT FILES

The RT coefficient files contain all the coefficients required by RTTOV specific to a particular instrument and satellite. They also define some of the fundamental constant values from which the coefficients are computed to ensure consistency throughout. There is currently a different coefficient file for each satellite series as defined in 4.1 and the Annex. These (or a symbolic link to these) need to reside in the same directory as the executable file of RTTOV (see installation guide). The file names are the same as for RTTOV-5. An option exists to read binary versions of the coefficient files and is invoked by placing a file (or symbolic link) called rt_coef_ieee.dat in the same directory (for (A)TOVS). These binary files have to be produced on the target machine and so cannot be supplied. Code to write them is available on request from the NWP-SAF. This aspect of the code has only been tested for ATOVS.

For (A)TOVS the default option for the export package is to provide only the coefficients for NOAA-11 to NOAA-15. A bigger file containing coefficients for all the NOAA satellites is available on request. The METEOSAT coefficient file now contains coefficients computed using the measured SEVIRI filter response functions. Coefficient files for SSM/I and TMI, AVHRR and GOES imager are only available for RTTOV-6.

Note that RTTOV-5 coefficient files can be used with the RTTOV-6 code and should give results very similar to the RTTOV-5 code but as shown in the validation report it is believed the RTTOV-6 radiances are more accurate. RTTOV-6 coefficient files cannot be read by the RTTOV-5 code.

Figure 1. Subroutine tree for RTTOV-6 setup call

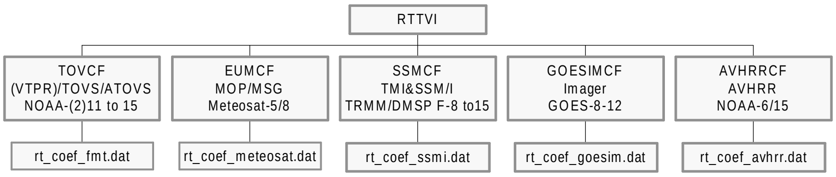
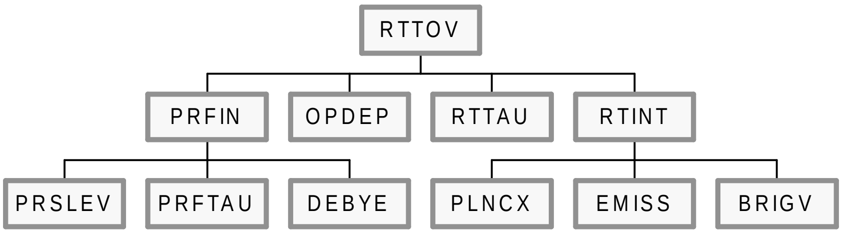


Figure 2. Subroutine tree for RTTOV-6 main call



6. References

English S.J. and T.J. Hewison 1998 A fast generic millimetre wave emissivity model. *Microwave Remote Sensing of the Atmosphere and Environment Proc. SPIE* **3503** *22-30*

Sherlock, V. 1999 ISEM-6: Infrared Surface Emissivity Model for RTTOV-6. *NWP SAF report.*

ANNEX: RTTOV-6 sensors

Table 1. RTTOV-6 (A)TOVS coefficients available in file: rt_coef_fmt.dat

Platform	**Rttov Sat id**	**Sensors**			**Valid Channel Numbers**‡
NOAA-2	1	VTPR			1-8
NOAA-3	2	VTPR			1-8
NOAA-4	3	VTPR			1-8
NOAA-5	4	VTPR			1-8
TIROS-N	5	HIRS/2	MSU	SSU	1-20,21-24,25-27
NOAA-6	6	HIRS/2	MSU	SSU	1-20,21-24,25-27
NOAA-7	7	HIRS/2	MSU	SSU	1-20,21-24,25-27
NOAA-8	8	HIRS/2	MSU	SSU	1-20,21-24,25-27
NOAA-9	9	HIRS/2	MSU	SSU	1-20,21-24,25-27
NOAA-10	10	HIRS/2	MSU		1-20,21-24
NOAA-11	11	HIRS/2	MSU	SSU	1-20,21-24,25-27
NOAA-12	12	HIRS/2	MSU		1-20,21-24
NOAA-14	14	HIRS/2	MSU	SSU	1-20,21-24,25-27
NOAA-15	15	HIRS/3	AMSU-A	AMSU-B	1-20,28-42,43-47

‡*Definition of each channel number (in wavenumbers) is included in file*

Table 2. RTTOV-6 other RT coefficients available

rt_coef_ssmi.dat			
Platform (series=2)	RTTOV sat id	Sensor	Channel numbers
TRMM	7	TMI	1-9
DMSP-F8/8	8	SSM/I	1-7
DMSP-F9/9	9	SSM/I	1-7
DMSP-F10/10	10	SSM/I	1-7
DMSP-F11/11	11	SSM/I	1-7
DMSP-F12/12	12	SSM/I	1-7
DMSP-F13/13	13	SSM/I	1-7
DMSP-F14/14	14	SSM/I	1-7
DMSP-F15/15	15	SSM/I	1-7
rt_coef_meteosat.dat			
Platform (series=3)	RTTOV sat id	Sensor	Channel numbers
METEOSAT-5	5	MVIRI	1-2
METEOSAT-6	6	MVIRI	1-2
METEOSAT-7	7	MVIRI	1-2
METEOSAT-8	8	SEVIRI	1-8
rt_coef_goes.dat			
Platform (series=4)	RTTOV sat id	Sensor	Channel numbers
GOES-8	8	GOES-IMAGER	1-4
GOES-9	9	GOES-IMAGER	1-4
GOES-10	10	GOES-IMAGER	1-4
GOES-11	11	GOES-IMAGER	1-4
GOES-12	12	GOES-IMAGER	1-4
rt_coef_avhrr.dat			
Platform (series=5)	RTTOV sat id	Sensor	Channel numbers
NOAA-6	6	AVHRR-1	1-2
NOAA-7	7	AVHRR-2	1-3
NOAA-8	8	AVHRR-1	1-2
NOAA-9	9	AVHRR-2	1-3
NOAA-10	10	AVHRR-1	1-2
NOAA-11	11	AVHRR-2	1-3
NOAA-12	12	AVHRR-1	1-2
NOAA-14	14	AVHRR-2	1-3
NOAA-15	15	AVHRR-3	1-3