RTTOV v13 Test Suite

James Hocking

Met Office

Pascal Brunel

MétéoFrance

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Version	Date	Author / changed by	Remarks
0.1	30/03/20	JH	First draft for v13 beta.
1.0	18/09/20	JH	Updates for release.
1.1	07/10/21	JH	Updates for v13.1.
1.2	31/10/22	JH	Updates for v13.2.

Table of Contents

1. *Introduction*

NB The instructions for testing RTTOV given in the user guide should be sufficient for most users who simply wish to verify their RTTOV installation. This document provides comprehensive information about the test suite.

There are two parts to the RTTOV test suite: the first is a comprehensive and flexible test executable `rttov_test.exe` which is controlled via the `rttov_test.pl` script and allows most aspects of RTTOV to be configured and run from the command-line. This is described in detail in sections 1-7 of this document.

The second part consists of a set of stand-alone test executables, each with an associated script to run it. These include scripts to run the demonstration `example_*fwd.exe` and `example_k.exe` programs and additional tests for RTTOV-SCATT, the emissivity and BRDF atlases, and are described in section 8.

Section 9 gives an overview of a Python-based plotting utility which may be used to visualise the output from test runs carried out using `rttov_test.pl`.

The RTTOV v13 test suite is essentially the same as that in RTTOV v12. The test suite allows most aspects of RTTOV to be configured either on the command-line or via input files.

RTTOV tests definition and scripts are located in the `rttov_test` subdirectory. The `tests.0` directory contains the data required to run the tests (these are atmospheric and ground data and a reference to the RTTOV coefficients). Test outputs for the `myarch` architecture are located in `tests.1.myarch` by default. Test references are kept in directories whose name ends with `.2` ; for instance, `test_fwd.2` contains the test references for the `test_fwd.sh` test script.

The following scripts and executables are involved in RTTOV tests execution:

- `rttov_test.pl;` this script requires Perl >= 5.6 to be installed as `/usr/bin/perl`.
- `rttov_test.exe;` this runs one or more tests and should be called using `rttov_test.pl`.
- `rttov_conv_coef.exe;` this extracts channels from coefficient files and/or converts them to/from formatted/unformatted/HDF5 format.
- `rttov_make_opt_param.exe;` this creates cloud/aerosol explicit optical property input files based on the cloud/aerosol coefficient files and associated cloud/aerosol profiles. This enables easy comparisons of cloud/aerosol simulations with explicit optical properties and with predefined particle types which is an important validation task.

By default, the predefined tests expect to find the `rtcoef_rttov13` coefficient directory in the RTTOV top directory containing following sub-directories:

`rttov13pred54L/`	v13 predictor files on 54 levels
`rttov13pred101L/`	v13 predictor files on 101 levels (hi-res sounders only)
`rttov7pred54L/`	v7 predictor files on 54 levels (variable o3)
`rttov7pred101L/`	v7 predictor files on 101 levels (hi-res sounders only)
`rttov8pred51L/`	v8 predictor files on 51 levels (variable o3, co2)
`rttov8pred54L/`	v8 predictor files on 54 levels (variable o3, co2)
`rttov8pred101L/`	v8 predictor files on 101 levels (variable o3, co2)
`rttov9pred54L/`	v9 predictor files on 54 levels (variable o3, co2)
`rttov9pred101L/`	v9 predictor files on 101 levels (hi-res sounders only, all variable gases)
`cldaer_visir/`	VIS/IR cloud and aerosol scattering coefficient files
`cldaer_ir/`	cloud and aerosol scattering coefficient files for “IR-only” coef files
`mfasis_lut/`	MFASIS look-up table (LUT) files
`mfasis_nn/`	MFASIS-NN coefficient files
`hydrotable/`	MW scattering coefficient files
`pc/`	Principal Components (PC-RTTOV) coefficient files
`htfrtc/`	HTFRTC coefficient files

Note that the majority of tests involving hyperspectral IR sounders require the coefficient files in HDF5 format.

`rttov_test.pl` should always be run from the `rttov_test/` directory. Whenever this script is run, either the `ARCH` environment variable must be set or it must be supplied as an argument to `rttov_test.pl`. It is possible to ask for the list of tests defined in `tests.0`:

```
$ ./rttov_test.pl ARCH=ifort LIST_ONLY=1
                    +-------------------------------------------------------------------------------------------------------- number of Channels
                    |     +-------------------------------------------------------------------------------------------------- number of Profiles
                    |     |    +--------------------------------------------------------------------------------------------- number of Levels
                    |     |    | +------------------------------------------------------------------------------------------- calcEmis true
                    |     |    | |+------------------------------------------------------------------------------------------ calcRefl true
                    |     |    | ||+----------------------------------------------------------------------------------------- rttov-Scatt
                    |     |    | |||+---------------------------------------------------------------------------------------- Aerosols
                    |     |    | ||||+--------------------------------------------------------------------------------------- Clouds
                    |     |    | |||||+-------------------------------------------------------------------------------------- Gas units
                    |     |    | ||||||                       +-------------------------------------------------------------- Mw clw scheme
                    |     |    | ||||||                       |+------------------------------------------------------------- lUsercfrac
                    |     |    | ||||||                       ||+------------------------------------------------------------ Radar
                    |     |    | ||||||                       |||+----------------------------------------------------------- IR scattering model
                    |     |    | ||||||                       ||||+---------------------------------------------------------- VIS scattering model
                    |     |    | ||||||                       |||||+--------------------------------------------------------- do Checkinput
                    |     |    | ||||||                       ||||||+-------------------------------------------------------- Apply reg limits
                    |     |    | ||||||                       |||||||+------------------------------------------------------- Reg limit extrap
                    |     |    | ||||||                       ||||||||+------------------------------------------------------ space Top
                    |     |    | ||||||                       |||||||||+----------------------------------------------------- Gradients wrt pressure
                    |     |    | ||||||                       ||||||||||+---------------------------------------------------- Interpolation mode
                    |     |    | ||||||                       ||||||||||| +-------------------------------------------------- sWitchrad
                    |     |    | ||||||                       ||||||||||| |+------------------------------------------------- Plane-parallel
                    |     |    | ||||||                       ||||||||||| ||+------------------------------------------------ Refraction
                    |     |    | ||||||                       ||||||||||| |||+----------------------------------------------- Lin-in-tau for downwelling rad
                    |     |    | ||||||                       ||||||||||| ||||+---------------------------------------------- use s2m%T in opdep calc
                    |     |    | ||||||                       ||||||||||| |||||+--------------------------------------------- use s2m%Q
                    |     |    | ||||||                       ||||||||||| ||||||+-------------------------------------------- Lambertian surface
                    |     |    | ||||||                       ||||||||||| |||||||+------------------------------------------- lambertian Fixed angle
                    |     |    | ||||||                       ||||||||||| ||||||||+------------------------------------------ Solar radiation
                    |     |    | ||||||                       ||||||||||| |||||||||+----------------------------------------- NLTE correction
                    |     |    | ||||||                       ||||||||||| ||||||||||+---------------------------------------- Fastem version
                    |     |    | ||||||                       ||||||||||| |||||||||||+--------------------------------------- IR sea emis model
                    |     |    | ||||||                       ||||||||||| ||||||||||||+-------------------------------------- Solar Sea brdf model
                    |     |    | ||||||                       ||||||||||| |||||||||||||    +--------------------------------- scale TL/AD Increments
                    |     |    | ||||||                       ||||||||||| |||||||||||||    |    +---------------------------- scale TL/AD Output
                    |     |    | ||||||                       ||||||||||| |||||||||||||    |    | +-------------------------- number of Threads
                    |     |    | ||||||                       ||||||||||| |||||||||||||    |    | |    +--------------------- Multiplicity
                    |     |    | ||||||                       ||||||||||| |||||||||||||    |    | |    |    +---------------- call RTTOV N times
                    |     |    | ||||||                       ||||||||||| |||||||||||||    |    | |    |    | +-------------- Channel by channel
                    |     |    | ||||||                       ||||||||||| |||||||||||||    |    | |    |    | |+------------- Profile by profile
                    |     |    | ||||||                       ||||||||||| |||||||||||||    |    | |    |    | ||+------------ Temp allocation
                    |     |    | ||||||                       ||||||||||| |||||||||||||    |    | |    |    | |||+----------- All coef channels read
```

```
               |     |    | ||||||                       ||||||||||| |||||||||||||    |    | |    |    | ||||+----------- Format of extracted coefs
               |     |    | ||||||                       ||||||||||| |||||||||||||    |    | |    |    | |||||+---------- Ignore small values
               |     |    | ||||||                       ||||||||||| |||||||||||||    |    | |    |    | ||||||+--------- Direct
               |     |    | ||||||                       ||||||||||| |||||||||||||    |    | |    |    | |||||||+-------- Tangent linear
               |     |    | ||||||                       ||||||||||| |||||||||||||    |    | |    |    | ||||||||+------- Adjoint
               |     |    | ||||||                       ||||||||||| |||||||||||||    |    | |    |    | |||||||||+------ K-matrix
               |     |    | ||||||                       ||||||||||| |||||||||||||    |    | |    |    | ||||||||||+----- Brute force k-matrix
               |     |    | ||||||                       ||||||||||| |||||||||||||    |    | |    |    | |||||||||||+---- Tangent linear k-matrix
               |     |    | ||||||                       ||||||||||| |||||||||||||    |    | |    |    | ||||||||||||+--- Adjoint k-matrix
               |     |    | ||||||                       ||||||||||| |||||||||||||    |    | |    |    | |||||||||||||+-- Taylor test
TEST_ID        C     P    L ERSACG         GASES         MURIVCARTGI WPRLTQLFSNFIS    I    O T    M    N CPTAFIDTAKBTAT
abi/001         60     6  54 X....2 o3                    2..21X.XX.1 X.XXXX.X..622    1    1 0    1    1 ..............
abi/002         60     6  54 X....2 o3                    2..21X.XX.1 X.XXXX.X..622    1    1 0    1    1 ..............
abi/003         60     6  54 X....2 o3                    2..21X.XX.1 X.XXXX.X..622    1    1 0    1    1 ..............
```

...

It is possible to filter the list with a regular expression; for instance:

```
$ ./rttov_test.pl LIST_ONLY=1 TEST_MATCH=avhrr
```

would display the list of tests whose name contains “`avhrr`”.

2. *High level options*

The list of tests from the previous subsection shows the description of each test; on the left hand side the following information appears:

- The name of the test.
- The total number of channels being simulated (across all profiles).
- The number of profiles.
- The number of input pressure levels.
- Whether RTTOV will calculate any surface emissivities internally.
- Whether RTTOV will calculate any surface reflectances internally.
- Whether this is an RTTOV-SCATT test.
- Whether this test contains VIS/IR scattering aerosol data (F=>optical properties from coefficient file; P=>explicit optical properties).
- Whether this test contains VIS/IR scattering cloud data (F=>optical properties from coefficient file; P=>explicit optical properties).
- The gas units used for the simulation (see user guide for values).
- The list of gases which appear in the test input data.

On the right hand side are listed the options which can be changed at run time (many of these correspond directly to members of the RTTOV options structure; more options can be modified than are displayed):

- The clear-sky MW CLW absorption scheme.
- The setting of the lusercfrac boolean for RTTOV-SCATT.
- Flag indicating RTTOV-SCATT radar simulation.
- The IR scattering model (for thermal emission).
- The visible scattering model (for solar radiation).
- Setting of do_checkinput boolean.
- Setting of apply_reg_limits boolean to restrict profiles within regression limits.
- Setting of reg_limit_extrap boolean for profile extrapolation at the top of the atmosphere.
- Setting of spacetop boolean.
- Setting of lgradp boolean.
- The interpolation mode to be used (the interpolator is automatically switched on if required).
- Setting of the switchrad boolean.
- Setting of the plane-parallel boolean.

- Setting of addrefrac boolean (atmospheric refraction).
- Setting of rad_down_lin_tau boolean.
- Setting of use_t2m_opdep boolean.
- Setting of use_q2m boolean.
- Setting of do_lambertian boolean.
- Setting of lambertian_fixed_angle boolean.
- Setting of addsolar boolean.
- Setting of do_nlte_correction boolean.
- The version of FASTEM to be used.
- The IR sea surface emissivity model to be used.
- The solar sea BRDF model to be used.
- Scale factor applied to TL/AD increments.
- Scale factor applied to TL/AD output.
- Number of threads; this option activates the RTTOV parallel routines. A value of 0 implies that the regular RTTOV high level routines will be run.
- Multiplicity; this expands the test data by some factor. A multiplicity of 10 applied to a test case with 2 profiles and 5 channels each will cause the test to be run with 20 profiles with 5 channels each.
- Number of times the test case is run (within the same invocation of `rttov_test.exe`).
- Flag indicating test will be run on each channel separately.
- Flag indicating test will be run for all channels on each profile separately.
- Temp allocation flag. RTTOV is run with temporary data allocated outside the RTTOV high level routines (i.e. using the rttov_alloc_traj subroutine).
- Flag to indicate all channels are read from the coefficient file. RTTOV may then be called for a subset of channels. If not set only the required channels are read from the coefficient file.
- Format of extracted coefficients. It is possible to extract the coefficient data for the channels which are actually used in the test. The extracted coefficient data will be saved for future re-use in the `coefs.1.myarch` directory. The `rttov_conv_coef.exe` binary is used for extracting these data. If coefficient extraction has been activated (by passing COEF_EXTRACT=1), this item will indicate the format of the extracted coefficients: `formatted (F)`, `unformatted (U)` or `HDF5 (H)`.
- “Ignoretiny” flag: if set the test suite will ignore small values when checking the data which can be useful for screening out insignificant differences from the output.
- Direct, tl, ad, k, k_bf, k_tl, k_ad. These flags activate some calculations:
  - `DIRECT=1` : the direct model
  - `TL=1` : the tangent linear model
  - `AD=1` : the adjoint model
  - `K = 1` : the K matrix computation
  - `K_BF=1` : calculation of an approximation of the K matrix using the direct model
  - `K_TL=1` : exact calculation of the K matrix using the tangent linear model
  - `K_AD=1` : exact calculation of the K matrix using the adjoint model
- Carry out Taylor test.

All available options can be listed by typing:

```
$ ./rttov_test.pl ARCH=ifort HELP=1

   + ARCH=...                             mandatory unless $ARCH environment variable is set

   + SESSION=...                          test session name (default: tests)
   + BIN=bin                          directory where binary executables are kept;
                                      this path is relative to RTTOV top directory
                                      (default: bin)

   + SCHED_CMD=aprun                  if specified this inserts commands before each
                                      executable is called by rttov_test.pl. This includes
                                      rttov_conv_coef.exe, rttov_make_opt_param.exe and
                                      rttov_test.exe. This can be used to invoke a task
                                      scheduler for example. You can supply additional
                                      arguments by enclosing the command in quotes, e.g.
                                      SCHED_CMD="aprun --abc" (default: empty string)

   + TEST_LIST=hirs/01,airs/51,...    comma separated list of tests to be run; it
                                      is also possible to define tests such as:
                                      hirs/01+airs/51; in this case, hirs/01 and
                                      airs/51 will be run from within the same
                                      executable (default: all tests)

   + TEST_MATCH=hirs                  regex to filter the tests

   + LIST_ONLY=1                      do not run tests, show list (default: 0/false)

   + COEF_EXTRACT=1                   extract needed coefficients data; this should not
                                      be used for tests where the number of channels
                                      varies from profile to profile (default: 0/false)

   + COEF_FORMAT=formatted            format for extracting coefficient data:
                                      formatted/unformatted/hdf5; has no effect unless
                                      COEF_EXTRACT=1 (default: formatted)

   + LALLCHANS=1                      force all channels to be read from the coefficient
                                      file; ignored if COEF_EXTRACT=1 (default: 0/false)

   + TEMP_ALLOC=1                     run RTTOV with temporary data allocated
                                      outside RTTOV (default: 0/false)

   + MULT=10                          number of channels and profiles is increased by
                                      a factor of MULT (default: 1)

   + NTIMES=10                        number times to run RTTOV (default: 1)

   + NTHREADS=2                       number of threads to run RTTOV (rttov_direct
                                      rttov_tl, rttov_ad, rttov_k) with; a value of 1 or
                                      more will force RTTOV to be called via the parallel
                                      interface (default: 0)

   + PRINT=1                          print results to disk (default: 1/true)

   + PRINT_OPTS=1                     prints options structure to test log (default: 0/false)

   + PRINT_PROFILES=1                 prints profiles structures to test log (default: 0/false)

   + PRINT_QUALITY=1                  prints radiance quality flags to test log (default: 0/false)

   + DIRECT=1 TL=1, AD=1, K=1, K_BF=1, K_TL=1, K_AD=1
                                      enables direct, tangent linear, adjoint, K matrix,
                                      brute force K matrix, tangent linear K matrix,
                                      adjoint K matrix (defaults: 0/false)

   + TAYLOR=1                         performs Taylor test per profile (default: 0/false)

   + TAYLOR_BY_CHAN=1                 performs Taylor test per channel (default: 0/false)

   + TAYLOR_ON_BTREFL=1               Taylor test calculated on BTs/refls rather than
                                      radiances. If the simulation involves both visible
                                      and IR channels this should be used in conjunction
                                      with TAYLOR_BY_CHAN=1 (default: 0/false)

   + CALC_RAD2=1                      calculate secondary radiances (only applies to
                                      rttov_direct) (default: 0/false)

   + CALC_EMIS_TERMS=1                calculate RTTOV-SCATT emissivity retrieval terms
                                      structure (only applies to RTTOV-SCATT direct model)
                                      (default: 0/false)

   + TEST_REF=...                     provides reference data to check direct/tl/ad/k
                                      tests results against when CHECK=1 (default: none)

   + CHECK=1                          performs check between direct/tl/ad/k and the
                                      supplied TEST_REF reference data, performs internal
                                      consistency checks on k_bf/k_tl/k_ad/k, and checks
                                      that TAYLOR test output converges correctly
                                      (default: 1/true)

   + DOREAL=1                         performs k_bf/k comparison in real values, default
                                      is test in scaled integers (default: 0/false)
```

```
 + IGNORETINY=1                   ignores small absolute values and small relative
                                  differences when reporting differences
                                  (default: 0/false)

 + TINYABS=1.E-11                 with IGNORETINY ignore differences when values being
                                  compared are smaller than this (default: 1.E-11)

 + TINYREL=1.E-5                  with IGNORETINY ignore relative differences smaller
                                  than this (default: 1.E-5)

 + REALPREC=16                    specify number of significant figures in real output
                                  (default: 6)

 + PRINT_ERROR=0                  print error in the test listing (default: 1/true)

 + SCALE_INC=2                    scale increments for TL/AD computations by
                                  a factor of SCALE_INC (default: 1.0)

 + SCALE_OUT=2                    scale TL/AD output of TL/AD computations by
                                  a factor of SCALE_OUT (default: 1.0)

 + SWITCHRAD=0                    sets the switchrad boolean (default: 1/true)

 + REFRACTION=0                   (de)activates refraction (default: 1/true)

 + USE_T2M_OPDEP=0                use s2m%t input profile variable in optical depth
                                  calculation (default: 1/true)

 + USE_Q2M=0                      use s2m%q input profile variable (default: 1/true)

 + USE_TSKIN_EFF=1                use per-channel effective skin temperature inputs
                                  (default: 0/false)

 + PLANE_PARALLEL=1               set plane_parallel boolean; NB plane parallel
                                  atmosphere is automatically used for DOM simulations
                                  (default: 0/false)

 + RAD_DOWN_LIN_TAU=0             set rad_down_lin_tau boolean (default: 1/true)

 + DTAU_TEST=1                    set dtau_test boolean (default: 0/false)

 + TRANSMITTANCES_ONLY=1          only compute transmittances, no radiances (default: 0/false)

 + SOLAR=1                        activates solar radiation (default: 0/false)

 + RAYLEIGH_MAX_WAVELENGTH=1.     set the maximum channel wavelength (microns) for which to
                                  calculate Rayleigh scattering (default: 2 microns)

 + RAYLEIGH_MIN_PRESSURE=10.      set the pressure (hPa) below which Rayleigh scattering
                                  is ignored (default: 0 hPa)

 + RAYLEIGH_SINGLE_SCATT=0        set the rayleigh_single_scatt boolean (default: 1/true)

 + DO_NLTE=1                      sets the do_nlte_correction flag to true
                                  (default: 0/false)

 + GRID_BOX_AVG_CLOUD=0           set the grid_box_avg_cloud boolean (default: 1/true)

 + CLDCOL_THRESHOLD=-1.0          set the value of cldcol_threshold (default: -1.0)

 + CLOUD_OVERLAP=1                set the cloud overlap scheme (default: 1)

 + CC_LOW_CLOUD_TOP=1100.         set the value of cc_low_cloud_top (default: 750hPa)

 + IR_SCATT_MODEL=1               set the IR scattering model (default: 2/Chou-scaling)

 + VIS_SCATT_MODEL=1              set the visible/near-IR scattering model (default: 1/DOM)

 + DOM_NSTREAMS=16                set the value of dom_nstreams (default: 8)

 + DOM_ACCURACY=1.E-4             set the value of dom_accuracy (default: 0.)

 + DOM_OPDEP_THRESH=10.           set value of dom_opdep_threshold (default: 0.)

 + DOM_RAYLEIGH=1                 include full Rayleigh multiple-scattering in solar DOM
                                  simulations (default: 0/false)

 + RAYLEIGH_DEPOL=1               include depolarisation in Rayleigh multiple-scattering
                                  phase functions (default: 0/false)

 + ZERO_CLOUD=1                   for a cloudy simulation, set cloud concentrations or
                                  user cloud optical properties to zero; intended for
                                  testing clear-sky DOM Rayleigh (default: 0/false)

 + ZERO_AEROSOL=1                 for an aerosol simulation, set aerosol concentrations or
                                  user aerosol optical properties to zero; intended for
```

```
                                     testing clear-sky DOM Rayleigh (default: 0/false)

  + DO_LAMBERTIAN=1                  computes reflected downwelling radiation lambertian
                                     reflected instead of specular (default: 0/false)

  + LAMBERTIAN_FIXED_ANGLE=0         selects fixed/parameterised effective angle for lambertian
                                     option (default: 1/true)

  + IR_SEA_EMIS_MODEL=1              set the IR sea surface emissivity model (default: 2)

  + SOLAR_SEA_BRDF_MODEL=1           set the solar sea surface BRDF model (default: 2)

  + FASTEM_VERSION=5                 set the version of FASTEM to use for MW emissivity
                                     calculations (default: 6)

  + FASTEM3_RWD_FIX=0                set the fastem3_rwd_fix boolean (default: 1/true)

  + MW_CLW_SCHEME=3                  set the MW CLW absorption scheme (default: 2)

  + MW_CLW_CLOUD_TOP=300.            set the MW CLW cloud top variable (default: 322hPa)

  + SUPPLY_FOAM_FRACTION=1           sets the supply_foam_fraction boolean which controls
                                     whether FASTEM uses the input foam fraction value in
                                     the input profile or not (default: 0/false)

  + ADDINTERP=1                      sets the addinterp boolean. NB if the input pressure
                                     levels differ to the coef file levels then the RTTOV
                                     interpolator is switched on automatically by the
                                     test suite so this switch is not usually required
                                     (default: 0/false)

  + INTERP_MODE=5                    sets the interpolation mode; see user guide for valid
                                     settings; has no effect if interpolation is off
                                     (default: 1)

  + REG_LIMIT_EXTRAP=0               sets the reg_limit_extrap boolean which, if true,
                                     extrapolates the input profile at the top of the
                                     atmosphere using the regression limits
                                     (default: 1/true)

  + LGRADP=1                         sets the lgradp boolean which is used to include
                                     variations wrt pressure if the internal RTTOV
                                     interpolation is used (default: 0/false)

  + SPACETOP=0                       sets the spacetop boolean (default: 1/true)

  + USER_CHECK_OPTS=1                run rttov_user_options_checkinput to check
                                     consistency between input options and coefs
                                     (default: 0/false)

  + USER_CHECK_PROF=1                run rttov_user_profile_checkinput to check input
                                     profiles are within limits (default: 0/false)

  + GAS_UNITS=1                      sets the gas units RTTOV is run with; the test
                                     suite will convert from INPUT_GAS_UNITS if they are
                                     different. This option sets profiles(:) % gas_units.
                                     Valid settings:
                                       2 = ppmv over moist air
                                       1 = kg/kg over moist air
                                       0 = ppmv over dry air (negative values also work)
                                     The vast majority of test suite input profiles are
                                     in units of ppmv over moist air.
                                     (default: 2/ppmv over moist air)

  + INPUT_GAS_UNITS=1                specifies the gas units of the input test suite files.
                                     If unspecified on the commandline, the value of
                                     INPUT_GAS_UNITS is taken from gas_units.txt.
                                     If this file is not present, the default is ppmv over
                                     moist air. By specifying this on the commandline
                                     any value in gas_units.txt is over-ruled.
                                     If INPUT_GAS_UNITS differs from GAS_UNITS, the test
                                     suite will convert the input profiles before
                                     calling RTTOV. Valid settings:
                                       2 = ppmv over moist air
                                       1 = kg/kg over moist air
                                       0 = ppmv over dry air (negative values also work)
                                     NB RTTOV is always run with units GAS_UNITS so, for
                                     example, Jacobians are in units of GAS_UNITS rather
                                     than the units of the input files.
                                     (default: defined by gas_units.txt, otherwise
                                     2/ppmv over moist air)

  + FIX_HGPL=0                       sets the fix_hgpl boolean (default: 1/true)

  + DO_CHECKINPUT=0                  sets the do_checkinput boolean (default: 1/true)

  + APPLY_REG_LIMITS=1               sets the apply_reg_limits boolean (default: 0/false)
```

```
+ OPDEP13_GAS_CLIP=0                 sets the opdep13_gas_clip boolean (default: 1/true)

+ VERBOSE=0                          sets the verbose boolean (default: 1/true)

+ RADAR=1                            activate an RTTOV-SCATT radar simulation (default: 0/false)

+ MULTI_HYDRO_FRAC=1                 run test with per-hydrometeor cloud fraction profiles
                                   instead of a single cloud fraction profile
                                   (default: 0/false)

+ LUSERCFRAC=1                       sets lusercfrac boolean for RTTOV-SCATT (default: 0/false)

+ CC_THRESHOLD=0.01                  sets the cc_threshold option for RTTOV-SCATT (default: 0.001)

+ ICE_POLARISATION=-1.               sets the ice_polarisation option for RTTOV-SCATT
                                   (default: 1.40)

+ POL_MODE=2                         sets the polarisation mode for RTTOV-SCATT
                                   (default: 1/empirical scaling)

+ HYDRO_CFRAC_TLAD=0                 sets hydro_cfrac_tlad boolean for RTTOV-SCATT
                                   (default: 1/true)

+ ZERO_HYDRO_TLAD=1                  sets zero_hydro_tlad boolean for RTTOV-SCATT
                                   (default: 0/false)

+ NO_FLUX_CONV=1                     sets flux_conversion to zero for RTTOV-SCATT
                                   (default: 0/false)

+ HTFRTC=1                           run HTFRTC model (default: 0/false)

+ HTFRTC_SIMPLE_CLOUD=1              sets the simple_cloud boolean for HTFRTC (default: 0/false)

+ HTFRTC_OVERCAST=1                  sets the overcast boolean for HTFRTC (default: 0/false)

+ DO_OPDEP_CALC=0                    enable/disable RTTOV gas optical depth parameterisation
                                   (default: 1/true)

+ NO_OPT_PARAM_TLADK=1               run TL/AD/K simulations without cld/aer_opt_param as
                                   active TL/AD/K variables (default: 0/false)

+ PROF_BY_PROF=1                     run RTTOV a single profile at a time, NTHREADS is
                                   ignored (default: 0/false)

+ CHAN_BY_CHAN=1                     run RTTOV a single channel at a time, NTHREADS is
                                   ignored (default: 0/false)

+ EMIS=0.8                           if supplied sets calcemis to FALSE and all input
                                   surface emissivities are set to the given value
                                   (i.e. overrides emissivity.txt input file)

+ REFL=0.3                           if supplied sets calcrefl to FALSE and all input
                                   surface reflectances are set to the given value
                                   (i.e. overrides reflectance.txt input file)

+ DIFFUSE_REFL=0.3                   should be used with REFL, if supplied surface
                                   diffuse reflectances are set to the given value
                                   (i.e. overrides reflectance_diffuse.txt input file)
                                   Note that calcrefl is not affected.

+ SURFTYPE=0                         if supplied sets surftype to the given value
                                   for all profiles (i.e. overrides values from input
                                   profile data)

+ SPECULARITY=0.5                    if supplied sets specularity parameter to the given
                                   value for all profiles and channels (i.e. overrides
                                   values from input specularity.txt if present)

+ TSKIN_EFF_FROM_PROF=1              if true tskin_eff is taken from corresponding profile
                                   tskin (for testing purposes), if false tskin_eff
                                   is computed differently for each channel by
                                   perturbing the profile tskin; only applies when
                                   use_tksin_eff is true (default: 0/false)

+ ZENANG=50.                         if supplied sets zenith angle to the given value
                                   for all profiles (i.e. overrides values from input
                                   profile data)

+ SUNZENANG=50.                      if supplied sets solar zenith angle to the given
                                   value for all profiles (i.e. overrides values from
                                   input profile data)

+ FIX2M=1                            if supplied sets the 2m p, T, q and o3 values to
                                   those from the bottom level in the input profile
                                   (i.e. overrides 2m values from input profile data)
```

```
  + VISIR_CLW_SCHEME=1               if supplied sets profile clw_scheme variable to the
                                     given value for all profiles (i.e. overrides values
                                     from input profile data)

  + VISIR_ICE_SCHEME=1               if supplied sets profile ice_scheme variable to the
                                     given value for all profiles (i.e. overrides values
                                     from input profile data)

  + CFRACTION=0.                     if supplied sets cfraction (simple cloud scheme cloud
                                     fraction) to the given  value for all profiles (i.e.
                                     overrides values from input profile data)

  + {GAS}_MAX_PPMV=400.              specify max ppmv scaling for optional trace gases.
                                     Uses rttov_scale_ref_gas_prof subroutine to create
                                     gas profile(s) from RTTOV background profiles.

  + {GAS}_COL_INT=5.E-3              specify column-integrated scaling in kg/m^2 for
                                     optional trace gases. Uses rttov_scale_ref_gas_prof
                                     subroutine to create gas profile(s) from RTTOV
                                     background profiles.

  + O3_COL_INT_DU=300.               specify column-integrated scaling in Dobson units for
                                     ozone profile. Uses rttov_scale_ref_gas_prof subroutine
                                     to create ozone profile(s) from RTTOV background profile.

  + PACK=directory-name

  + UNPACK=directory-name

  + DR_HOOK=1                        activates DR_HOOK (RTTOV has to be compiled with
                                     DR_HOOK library, default: 0/false)

  + FTRACE=1                         activates FTRACE (RTTOV has to be compiled with
                                     -ftrace option, default: 0/false)

  + MEMCHECK=1                       run RTTOV through valgrind's memcheck tool with
                                     some default options for memory leak checking.
                                     Valgrind must be installed on your system
                                     (default: 0/false)

  + MASSIF=1                         run RTTOV through valgrind's massif tool with
                                     some default options for testing peak memory
                                     usage. Valgrind must be installed on your
                                     system (default: 0/false)

  + ALLMOD=1                         shortcut: run all models
                                     (same as DIRECT=1 TL=1 AD=1 K=1)

  + KCONS=1                          shortcut: run K consistency tests
                                     (same as K=1 K_TL=1 K_AD=1)

  + CEU=1                            shortcut: extract coefficients to an unformatted
                                     file (same as COEF_EXTRACT=1, COEF_FORMAT=unformatted)

  + CEH=1                            shortcut: extract coefficients to an HDF5
                                     file (same as COEF_EXTRACT=1, COEF_FORMAT=hdf5)

  + CPU=1                            shortcut: turn off output for timing testing
                                     (same as PRINT=0, VERBOSE=0)
```

We detail here the options we have not explained yet and whose meaning might not be obvious from the description above:

- `ARCH=myarch` specifies the architecture being tested. Test results will be saved in `tests.1.myarch` unless `SESSION` is specified.
- `BIN=install-myarch/bin` has to be specified is RTTOV has been compiled and installed elsewhere than at the top of the RTTOV distribution. This occurs when the `INSTALLDIR=install-myarch` parameter is specified on the command line of `make`. Note that BIN specifies a path relative to the RTTOV top level directory.
- `SCHED_CMD=...` is intended to allow the test suite to be run in distributed processing environments (e.g. supercomputers) similar to those in which RTTOV is to be implemented. You can specify a task scheduler command (e.g. “aprun”) which will be inserted before each executable is run by `rttov_test.pl`. You can supply additional arguments by enclosing the whole command in quotes

e.g. SCHED_CMD="aprun --abc".

- TEST_LIST=hirs/001,airs/001 is a comma separated list of tests. It is also possible to run several tests in the same execution of rttov_test.exe by join test ids with a "+"; for instance TEST_LIST=hirs/001+avhrr/001+amsua/001 will make rttov_test.exe run these three tests together: data will be allocated for these tests, coefficients files will be read, calculations will be made and eventually data will be deallocated.
- PRINT_ERROR=1 will print error messages as tests run (the default is true, but it can be deactivated).
- DR_HOOK=1 will take care of setting the right options for activating DR_HOOK and saving its output.
- PRINT=1 will cause rttov_test.exe to save its results (default is true, but it can be disabled): when running performance tests this should be turned off and you should also set VERBOSE=0.
- LALLCHANS=1 will force rttov_test.exe to load coefficient data for all channels and to manage a subset of them in the calculations.
- ADDINTERP=1 will switch the RTTOV interpolation on. The test suite switches the interpolation on automatically whenever it is required, otherwise it is turned off. Therefore this flag is NOT generally required. It is intended for use by developers.
- INPUT_GAS_UNITS specifies the gas units of the profiles defined in the test input files. If absent the test suite will assume the units as specified by the gas_units.txt input file. If this is not present the test suite assumes units of ppmv over moist air.
- GAS_UNITS specifies the gas units with which RTTOV should be run. If these differ to units of the input profile data (as determined by INPUT_GAS_UNITS) the test suite will convert the profiles to the units specified by GAS_UNITS before calling RTTOV. Between them the INPUT_AS_UNITS and GAS_UNITS options allow RTTOV to be tested with all allowed values of profiles(:)%gas_units without having to provide store profile data in all units.
- EMIS, REFL, SURFTYPE, ZENANG, SUNZENANG (and others) : these allow various input profile variables to be overridden with the specified value for all profiles. This can be useful for certain experiments since the test suite profiles are set up to test a wide range of input values.

3. Testing DIRECT/TL/AD/K consistency

When several of DIRECT, TL, AD, K, K_BF, K_TL, K_AD are activated it is possible to check the consistency:

- of the calculations performed by the DIRECT, TL, AD and K models. In this case the output values are compared against test reference data specified by the TEST_REF option.
- of the K matrix calculations of K, K_BF, K_TL, K_AD; the K_BF which is computed in the subroutine rttov_k_bf is only an approximation of the K matrix calculated using finite differences; K_TL and K_AD (computed in rttov_k_tl and rttov_k_ad) should be identical to the K matrix (as computed by rttov_k) although very small differences are sometimes observed.

The option CHECK=1 (set by default) activates this verification. The differences appear in the test log and are recorded in the test output directory. The differences when they appear may have to be more closely examined and may be caused by some rounding errors dependent on the processor and/or compiler. It is common for tests to report some differences other than those due to rounding errors which do not necessarily indicate problems with the code, particularly in relation to the internal consistency checks:

- The tangent linear, adjoint, and K model Jacobians should in theory be identical, but there may be differences in the least significant digits due to rounding errors and differences in the code paths.
- With the LGRADP=1 option, the pressure K Jacobian in some layers will often differ slightly to the TL Jacobian. Small differences may also be observed in the cloud fraction (“cfrac”) Jacobians for cloudy IR simulations.
- The RTTOV-SCATT K model shows cloud/hydrometeor sensitivity even in clear layers. The K_BF does not replicate this behaviour so care must be taken when comparing K model and K_BF output for RTTOV-SCATT. When looking at the RTTOV-SCATT K_BF, it is recommended to run with LGRADP=1 otherwise the K_BF pressure Jacobians will be zero, unlike the K model Jacobians which always have some pressure sensitivity.

The comparisons between the K, K_TL and K_AD Jacobians are done exactly i.e. all differences are reported. However, the brute force Jacobian (K_BF) is expected to differ slightly from the others. By default, the BF comparison is done by scaling the Jacobian values up to integers and reporting differences which exceed a threshold specified in the code. If the DOREAL=1 option is specified then the BF comparison is carried out on real values, and differences are reported if they exceed 10% of the K matrix values. This can result in many differences being reported which do not necessarily indicate problems. The DOREAL option is intended for use by developers.

For the K/K_TL/K_AD consistency checks and the comparisons to reference data, the test suite can be configured to ignore small differences. This is enabled by setting `IGNORETINY=1`. There are two associated parameters: differences will not be reported for any output values which are smaller in absolute value than `TINYABS` (1.E-11 by default). Relative differences smaller than `TINYREL` (1.E-5 by default) are also ignored.

The `TAYLOR` argument can be used to test consistency between the direct and tangent linear (TL) code. This compares the TL output with a “brute force” TL calculated with the direct model by perturbing the input profile. The comparison is repeated with decreasing perturbations, and the ratio of the real and brute force TLs should approach 1.0. The output of the Taylor test is written to the file `taylor_test.log`. The output is examined by the test script and the calculated ratios will be printed out for any profiles which do not appear to be converging to 1.0. This automated checking sometimes flags false positives (i.e. it flags differences where no problem exists), but has not been observed to give false negatives. Note that as the perturbations become very small, rounding errors begin to cause the ratio to deviate significantly from 1.0. The Taylor test ratio is calculated for a sum of radiances over all channels. To calculate separate ratios for each channel supply the `TAYLOR_BY_CHAN=1` argument to `rttov_test.pl`. To compute the Taylor test on BTs/reflectances instead of radiances supply the `TAYLOR_ON_BTREFL=1` argument: for RTTOV-SCATT the Taylor test is always computed on BTs.

4. *Looking at a test output*

Run the following command (from the rttov_test/ directory):

```
$ ./rttov_test.pl ARCH=myarch TEST_LIST=hirs/517,avhrr/415 DIRECT=1 K=1

Start: 30/03/2020 13:20:38
                    +--------------------------------------------------------------------------------------------------------- number of Channels
                    |     +--------------------------------------------------------------------------------------------------- number of Profiles
                    |     |    +---------------------------------------------------------------------------------------------- number of Levels
                    |     |    | +-------------------------------------------------------------------------------------------- calcEmis true
                    |     |    | |+------------------------------------------------------------------------------------------- calcRefl true
                    |     |    | ||+------------------------------------------------------------------------------------------ rttov-Scatt
                    |     |    | |||+----------------------------------------------------------------------------------------- Aerosols
                    |     |    | ||||+---------------------------------------------------------------------------------------- Clouds
                    |     |    | |||||+--------------------------------------------------------------------------------------- Gas units
                    |     |    | ||||||                       +--------------------------------------------------------------- Mw clw scheme
                    |     |    | ||||||                       |+-------------------------------------------------------------- lUsercfrac
                    |     |    | ||||||                       ||+------------------------------------------------------------- Radar
                    |     |    | ||||||                       |||+------------------------------------------------------------ IR scattering model
                    |     |    | ||||||                       ||||+----------------------------------------------------------- VIS scattering model
                    |     |    | ||||||                       |||||+---------------------------------------------------------- do Checkinput
                    |     |    | ||||||                       ||||||+--------------------------------------------------------- Apply reg limits
                    |     |    | ||||||                       |||||||+-------------------------------------------------------- Reg limit extrap
                    |     |    | ||||||                       ||||||||+------------------------------------------------------- space Top
                    |     |    | ||||||                       |||||||||+------------------------------------------------------ Gradients wrt pressure
                    |     |    | ||||||                       ||||||||||+----------------------------------------------------- Interpolation mode
                    |     |    | ||||||                       ||||||||||| +--------------------------------------------------- sWitchrad
                    |     |    | ||||||                       ||||||||||| |+-------------------------------------------------- Plane-parallel
                    |     |    | ||||||                       ||||||||||| ||+------------------------------------------------- Refraction
                    |     |    | ||||||                       ||||||||||| |||+------------------------------------------------ Lin-in-tau for downwelling rad
                    |     |    | ||||||                       ||||||||||| ||||+----------------------------------------------- use s2m%T in opdep calc
                    |     |    | ||||||                       ||||||||||| |||||+---------------------------------------------- use s2m%Q
                    |     |    | ||||||                       ||||||||||| ||||||+--------------------------------------------- Lambertian surface
                    |     |    | ||||||                       ||||||||||| |||||||+-------------------------------------------- lambertian Fixed angle
                    |     |    | ||||||                       ||||||||||| ||||||||+------------------------------------------- Solar radiation
                    |     |    | ||||||                       ||||||||||| |||||||||+------------------------------------------ NLTE correction
                    |     |    | ||||||                       ||||||||||| ||||||||||+----------------------------------------- Fastem version
                    |     |    | ||||||                       ||||||||||| |||||||||||+---------------------------------------- IR sea emis model
                    |     |    | ||||||                       ||||||||||| ||||||||||||+--------------------------------------- Solar Sea brdf model
                    |     |    | ||||||                       ||||||||||| |||||||||||||    +---------------------------------- scale TL/AD Increments
                    |     |    | ||||||                       ||||||||||| |||||||||||||    |    +----------------------------- scale TL/AD Output
                    |     |    | ||||||                       ||||||||||| |||||||||||||    |    | +--------------------------- number of Threads
                    |     |    | ||||||                       ||||||||||| |||||||||||||    |    | |    +---------------------- Multiplicity
                    |     |    | ||||||                       ||||||||||| |||||||||||||    |    | |    |    +----------------- call RTTOV N times
                    |     |    | ||||||                       ||||||||||| |||||||||||||    |    | |    |    | +--------------- Channel by channel
                    |     |    | ||||||                       ||||||||||| |||||||||||||    |    | |    |    | |+-------------- Profile by profile
                    |     |    | ||||||                       ||||||||||| |||||||||||||    |    | |    |    | ||+------------- Temp allocation
                    |     |    | ||||||                       ||||||||||| |||||||||||||    |    | |    |    | |||+------------ All coef channels read
                    |     |    | ||||||                       ||||||||||| |||||||||||||    |    | |    |    | ||||+----------- Format of extracted coefs
                    |     |    | ||||||                       ||||||||||| |||||||||||||    |    | |    |    | |||||+---------- Ignore small values
                    |     |    | ||||||                       ||||||||||| |||||||||||||    |    | |    |    | ||||||+--------- Direct
                    |     |    | ||||||                       ||||||||||| |||||||||||||    |    | |    |    | |||||||+-------- Tangent linear
                    |     |    | ||||||                       ||||||||||| |||||||||||||    |    | |    |    | ||||||||+------- Adjoint
                    |     |    | ||||||                       ||||||||||| |||||||||||||    |    | |    |    | |||||||||+------ K-matrix
                    |     |    | ||||||                       ||||||||||| |||||||||||||    |    | |    |    | ||||||||||+----- Brute force k-matrix
                    |     |    | ||||||                       ||||||||||| |||||||||||||    |    | |    |    | |||||||||||+---- Tangent linear k-matrix
                    |     |    | ||||||                       ||||||||||| |||||||||||||    |    | |    |    | ||||||||||||+--- Adjoint k-matrix
                    |     |    | ||||||                       ||||||||||| |||||||||||||    |    | |    |    | |||||||||||||+-- Taylor test
     TEST_ID        C     P    L ERSACG         GASES         MURIVCARTGI WPRLTQLFSNFIS    I    O T    M    N CPTAFIDTAKBTAT  REAL TIME   USER TIME STATUS
    hirs/517        114    6  54 X....2 co2 o3                2..21X.XX.1 X.XXXX.X..622    1    1 0    1    1 ......X..X....       0.27        0.17   OK
    avhrr/415        36    6  54 X....2 o3                    2..21X.XX.1 X.XXXX.X..622    1    1 0    1    1 ......X..X....       0.18        0.06   OK

End: 30/03/2020 13:20:39

Ran 2 tests, 2 = OK
```

Note that if your RTTOV has been compiled in a custom directory using the `INSTALLDIR` Makefile parameter, you have to use the `BIN=...` option as explained in the previous section. The `rttov_test` directory may contain a `arch/myarch` file holding the the myarch related environment variables to be exported before running the tests (this is optional, but may help debugging).

Two tests have been run separately: `hirs/517` and `avhrr/415`. It is possible to run them together by typing:

```
$ ./rttov_test.pl ARCH=myarch TEST_LIST=hirs/517+avhrr/415 DIRECT=1 K=1

     TEST_ID        C     P    L ERSACG         GASES         MURIVCARTGI WPRLTQLFSNFIS    I    O T    M    N CPTAFIDTAKBTAT  REAL TIME   USER TIME STATUS
    hirs/517        114    6  54 X....2 co2 o3                2..21X.XX.1 X.XXXX.X..622    1    1 0    1    1 ......X..X....
    avhrr/415        36    6  54 X....2 o3                    2..21X.XX.1 X.XXXX.X..622    1    1 0    1    1 ......X..X....       0.35        0.21   OK
```

The directory `tests.1.myarch/avhrr/517/out` contains the results of the `avhrr/415` test; it contains the following files:

```
./env.sh                       # compiler related environment variables (if any)
./run.sh                       # shell script to re-run the test by hand
                               # ( just type ./run.sh from the test output
                               #   directory )
./direct
./direct/transmission.txt      # transmission data produced by rttov_direct
./direct/radiance.txt          # radiance data producted by rttov_direct
./direct/emissivity_out.txt    # surface emissivities used by rttov_direct
./rttov_test.log               # standard error and output of rttov_test.exe
./rttov_test.txt               # namelist for rttov_test.exe
./interpolation.log            # log recording whether interpolation was on or off
./gas_units.log                # log recording the assumed gas units
./k
./k/transmission.txt           # transmission data produced by rttov_k
./k/radiance.txt               # radiance data produced by rttov_k
./k/emissivity_out.txt         # surface emissivities used by rttov_k
./k/emissivity_k.txt           # gradient of the radiances relative to the
                               # emissivity
./k/profiles_k.txt             # gradient of the radiance relative to the
                               # atmospheric and surface data
```

Note that if you have run the combined test `hirs/517+avhrr/415`, then the log for the combined test, `rttov_test.log`, is dumped in the last test directory (`tests.1.myarch/avhrr/415/out`). Note however that test outputs are stored in separate test directories.

The `.txt` files contain the results of RTTOV calculations in a human readable format. For instance:

```
$ cat direct/radiance.txt
RADIANCE%TOTAL = (
  0.540943        102.074        114.200
 )
RADIANCE%BT = (
   295.845        293.697        291.063
 )
RADIANCE%CLEAR = (
  0.589340        104.358        115.790
 )
RADIANCE%BT_CLEAR = (
   297.827        295.120        292.030
 )
```

It is possible to have results saved in a directory whose name is not `tests.1.myarch`; for this purpose, it is necessary to append the `SESSION=mysession` argument to the list of parameters passed to `rttov_test.pl`; results will then be saved to the `mysession.1.myarch` directory.

5. *Creating a new test*

Test definition is located in the `tests.0` directory; every subdirectory of `tests.0` which contains an “`in`” subdirectory is interpreted by `rttov_test.pl` as a test definition.
This in subdirectory must contain the following files:

● `./lprofiles.txt`	`# profile list (chanprof(:)%prof)`
● `./channels.txt`	`# channel list (chanprof(:)%chan)`
● `./coef.txt`	`# coefficient file namelist`
● `./profiles/001/atm/p.txt`	`# pressure levels ( hPa )`
● `./profiles/001/atm/t.txt`	`# temperature ( K )`
● `./profiles/001/atm/q.txt`	`# water vapour ( ppmv or kg/kg )`
● `./profiles/001/ground/skin.txt`	`# skin parameters`
● `./profiles/001/ground/s2m.txt`	`# s2m parameters`
● `./profiles/001/be.txt`	`# magnetic field parameters`
● `./profiles/001/angles.txt`	`# satellite and solar geometry, latitude, longitude and surface elevation.`

It may also contain the following files:

● `./calcemis.txt`	`# calcemis flags for RTTOV`
● `./emissivity.txt`	`# emissivity`
● `./calcrefl.txt`	`# calcrefl flags for RTTOV`
● `./reflectance.txt`	`# surface BRDF`
● `./reflectance_diffuse.txt`	`# surface diffuse reflectance`
● `./profiles/001/datetime.txt`	`# date and time of profile`
● `./profiles/001/gas_units.txt`	`# Gas units namelist`
● `./profiles/001/atm/clw.txt`	`# Cloud liquid water ( kg/kg )`
● `./profiles/001/atm/n2o.txt`	`# N2O ( ppmv or kg/kg )`
● `./profiles/001/atm/co2.txt`	`# CO2 ( ppmv or kg/kg )`
● `./profiles/001/atm/ch4.txt`	`# CH4 ( ppmv or kg/kg )`
● `./profiles/001/atm/o3.txt`	`# O3 ( ppmv or kg/kg )`
● `./profiles/001/atm/co.txt`	`# CO ( ppmv or kg/kg )`
● `./profiles/001/atm/so2.txt`	`# SO2 ( ppmv or kg/kg )`
● `./profiles/001/atm/simple_cloud.txt`	`# simple cloud parameters`
● `./profiles/001/atm/clw_scheme.txt`	`# visible/IR CLW scheme`
● `./profiles/001/atm/ice_scheme.txt`	`# visible/IR ice cloud parameterisation`
● `./profiles/001/atm/mmr_cldaer.txt`	`# units for aerosol/cloud profiles`
● `./profiles/001/atm/clwde.txt`	`# CLW particle effective diameter ( µm )`
● `./profiles/001/atm/icede.txt`	`# ice particle effective diameter ( µm )`
● `./profiles/001/atm/aerosl.txt`	`# aerosol concentrations (units as per mmr_cldaer.txt)`
● `./profiles/001/atm/cfrac.txt`	`# cloud fraction`
● `./profiles/001/atm/cloud.txt`	`# cloud liquid/ice water content (units as per mmr_cldaer.txt)`
● `./profiles/001/atm/cld_profiles.txt`	`# cloud/hydrometeor inputs for RTTOV-SCATT`
● `./aer_opt_param.txt`	`# aerosol optical parameter profiles`
● `./cld_opt_param.txt`	`cloud optical parameter profiles`

For PC-RTTOV or HTFRTC calculations:

● `./pcscores.txt`	`# regression set and number of pcscores`
● `./channels_rec.txt`	`# reconstructed channels (optional)`

In order to run PC-RTTOV tests the `pcscores.txt` file should be present: this automatically sets addpc to true. The PC-RTTOV coefficient file must be specified in `coef.txt`. For HTFRTC simulations you must additionally specify `HTFRTC=1` and specify the HTFRTC coefficient files in `coef.txt`.

For tests involving pressure modulated cells (e.g. using the new PMC shift SSU coefficients) the following file is mandatory for the input of the cell pressures:

- ./pmc.txt # cell pressure for each channel

Creating a new test is just the matter of creating a new subdirectory of tests.0. The easiest is to copy a pre-existing test and modify it to suit your needs.

The configuration described above is a single profile configuration (profile 001): adding more profiles involves creating additional directories named 002, 003, etc with data laid out as described above.

The format of data within most of the above files is clear upon inspection of an existing example. The exceptions to this are the aerosol/cloud optical parameter files (aer_opt_param.txt/cld_opt_param.txt). It is not necessarily recommended to run these simulations in the test suite as the input file format is slightly complicated for reasons of efficiency. It is described below. Note that if a cloud/aerosol coefficient file is specified in coef.txt and cloud/aerosol profiles are specified in the profiles directory and the cld_opt_param.txt/aer_opt_param.txt file contains less than 100 bytes of data the test suite will automatically construct the cld_opt_param.txt/aer_opt_param.txt files from the coefficient file and the associated profile data using the rttov_make_opt_params.exe binary which is compiled with RTTOV. The test will then run using the explicit optical property inputs.

The data are read directly into the *rttov_opt_param* Fortran type (see user guide) as follows:

- number of Legendre coefficients (nmom), number of phase angles (nphangle) (two integer values)
- abs(1:nlayers,1:nchanprof)
- sca(1:nlayers,1:nchanprof)
- bpr(1:nlayers,1:nchanprof)

```
If nmom > 0 :
      For each channel in chanprof i :
            For each layer lay :
                  If sca(lay,i) > 0.
                        legcoef(1:nmom+1,lay,i)
If nphangle > 0 :
      phangle(1:nphangle)
      For each channel in chanprof i :
            If coefs%coef%ss_val_chn(chanprof(i)%chan) > 0 :
                  For each layer lay :
                        If sca(lay,i) > 0.
                              pha(1:nphangle,lay,i)
```

In order to run visible/IR aerosol scattering tests either the aer_opt_param.txt or the aerosl.txt files should be present (the aer_opt_param.txt file takes precedence). If running simulations with the pre-defined aerosol types, the aerosol coefficient file must be specified in coef.txt.

In order to run visible/IR cloud scattering tests either the cld_opt_param.txt or the cloud.txt files should be present (the cld_opt_param.txt file takes precedence). For cloud simulations, there must also be a cfrac.txt file. If running simulations with the pre-defined cloud types, the cloud coefficient file must be specified in coef.txt.

For MFASIS simulations, the MFASIS LUT or NN file must be specified in coef.txt and you must additionally specify MFASIS as the VIS_SCATT_MODEL (3 for LUT, 4 for NN) and set SOLAR=1. Note that the test suite cloud profiles include cases with all liquid and ice cloud particle types/parameterisations. MFASIS is restricted to the liquid (LUT only) and ice (LUT and NN) properties used to train the model (see the user guide). It is possible to override the liquid and ice properties for all profiles using the VISIR_CLW_SCHEME and VISIR_ICE_SCHEME arguments to rttov_test.pl.

The calcemis.txt, emissivity.txt, calcrefl.txt and reflectance.txt files are optional. If the calcemis.txt file is missing calcemis(:) defaults to true in the call to RTTOV and likewise if calcrefl.txt is missing calcrefl(:) defaults to true. If you supply these files values must be present for *all* simulated channels in each of the these files.

RTTOV-SCATT tests are activated if a hydrotable filename is specified in the coef.txt input file. This also requires the presence of the atm/cld_profiles.txt file. The format of this file is as follows: the first line contains the value of nhydro which must be consistent with the hydrotable specified in coef.txt (5 for the default NWP SAF hydrotables). The second line contains nhydro integers representing the flux_conversion array. The third line contains a user cloud cfraction value. This only affects the simulation if the LUSERCFRAC=1 option is passed to rttov_test.pl. Following this are a number of columns containing nlevels values each. From left to right these are the RTTOV-SCATT ph array, nhydro hydrometeor arrays (in the order specified in the hydrotable – rain, snow, graupel, cloud liquid, cloud ice for the default tables), and then nhydro cloud fraction (hydro_frac) profiles. Either one (the default) or all of the hydro_frac profiles will be used, the latter if MULTI_HYDRO_FRAC=1 is passed to rttov_test.pl. Note that when the ph array is passed to RTTOV-SCATT it has nlevels+1 values: the final value is automatically set to the 2m pressure by the test suite. Note also that for RTTOV-SCATT tests all channels are always read from the coefficient file, but it is possible to simulate only a subset of channels as specified in the channels.txt and lprofiles.txt files. If the ARO-scaled POL_MODE is selected then the sensor independent look-up table ScalingFactorForBulkProperties.rssp is read in. Typically there is no need to do anything special: the test suite will assume the file is in the same directory as the hydrotable, but it is possible to specify the location of the file in coef.txt if required.

6. *Testing against a reference*

A set of tests with reference output (where appropriate) are provided for users. These tests demonstrate the capabilities of RTTOV v13 for a range of instruments, and the comparison to the reference output can confirm that the code has been compiled correctly. References are provided in `*.2` directories.

We provide the following user test scripts:

- `test_fwd.sh` tests the forward model for a wide range of instruments
- `test_rttov13.sh` tests the full code (direct/TL/AD/K) for a range of instruments
- `test_rttov13_hires.sh` tests the full code for hyperspectral IR sounders
- `test_solar.sh` tests solar calculations
- `test_pc.sh` tests the Principal Component calculations
- `test_multi_instrument.sh` tests RTTOV running for multiple instruments together
- `test_htfrtc.sh` tests HTFRTC simulations

NB Due to the memory management of the Intel Fortran compiler, users compiling with ifort on Linux may need to increase the stack size by executing the following command before all tests will run correctly:

```
$ ulimit -s unlimited
```

In addition, when running the PC-RTTOV K model with multiple threads under ifort, users may need to increase the OMP stack size as well to allow tests to run:

```
$ export OMP_STACKSIZE=1000M
```

Note that the majority of the tests for hyperspectral IR sounders expect HDF5 format coefficient files. It is not necessary to run every test script to validate your installation of RTTOV: running the ***`test_rttov13.sh`*** script is sufficient for this and this depends only on coefficient files included in the distribution.

The list of tests above (excluding the `test_htfrtc.sh` script) may be run using a single script:

```
$ ./test_core.sh ARCH=myarch [BIN=install-myarch/bin]
```

Alternatively each script may be called individually. The test scripts can be run with any of the parameters described above for `rttov_test.pl` (though naturally some options will make comparison to the test reference output invalid). In particular, either the `ARCH` environment variable must be set or `ARCH=myarch` must be passed as an argument to the script. If you have specified `INSTALLDIR=install-myarch`, then the `BIN=install-myarch/bin` should be provided to the script.

We describe here `test_rttov13.sh`:

```
$ cat test_rttov13.sh
#!/bin/sh

# User test

# Tests RTTOV v13 direct/TL/AD/K clear-sky simulations for various MW and IR instruments.
```

```
ARG_ARCH=`perl -e 'for(@ARGV){m/^ARCH=(\S+)$/o && print "$1";}' $*`
if [ ! "x$ARG_ARCH" = "x" ]; then
  ARCH=$ARG_ARCH
fi
if [ "x$ARCH" = "x" ];
then
  echo 'Please supply ARCH'
  exit 1
fi

set -x

SESSION=test_rttov13
OPTS="IGNORETINY=1 $*"
WHAT="DIRECT=1 TL=1 AD=1 K=1"
CHECK="CHECK=1 TEST_REF=$SESSION.2"

./rttov_test.pl SESSION=$SESSION $WHAT $CHECK ARCH=$ARCH $OPTS -- << EOF
  TEST_LIST=amsre/301
  TEST_LIST=amsua/301,amsua/321clw
  TEST_LIST=amsub/301
  TEST_LIST=msu/301
  TEST_LIST=ssmis/301,ssmis/321
  TEST_LIST=windsat/301
  TEST_LIST=hirs/517                APPLY_REG_LIMITS=1
  TEST_LIST=modis/401               SOLAR=1
  TEST_LIST=seviri/524              SOLAR=1
EOF
```

This test script runs several lists of tests, saves results to the `test_rttov13.1.myarch` directory and compares them to the reference `test_rttov13.2`.

Note that a reference is merely a test output directory renamed with a `.2`.

Some test scripts may use the `COEF_EXTRACT=1` argument which causes coefficients to be extracted to the `coefs.1.myarch` directory for efficiency. Repeated runs of the tests will be faster because these extracted coefficients will be used. However if changes are made in the `rtcoef_rttov13` directory (for example updating coefficient files), then `coefs.1.myarch` should be deleted to ensure the updated files are used by the tests. For RTTOV-SCATT tests, if coefficient extraction/format conversion is activated the hydrotable file will be converted to binary format regardless of the setting of the output format.

A very thorough set of tests are employed by the developers to validate the code comprehensively. This is described in the RTTOV Test Plan. These include tests for every coefficient file provided with RTTOV v13, full tests of all capabilities of RTTOV (including the internal consistency checks described in section 3), checking consistency between the direct and TL using the Taylor test (described in section 3), checking linearity of the TL and AD code, and testing on diverse profile datasets. The scripts and reference output for these tests are not included in the RTTOV v13 package provided to users.

7. *Testing performance*

The test scripts used by developers for comparing performance between RTTOV versions are not included in the package. However you can test RTTOV performance by running any given test with the NTIMES parameter to repeat the simulation multiple times. Usually hundreds or thousands of times is appropriate – depending on the simulation being performed – to get a large enough run-time to be meaningful and repeatable. It is important to set `PRINT=0` and `VERBOSE=0` so that no test output is written.

If RTTOV has been compiled with OpenMP (see user guide) it is possible to use the parameter to see the impact on the real run-time when the RTTOV parallel routines are invoked.

8. *Additional test scripts*

A number of additional test scripts are supplied which provide examples for running RTTOV, a stand-alone test for RTTOV-SCATT, tests for the emissivity and BRDF atlases, and tests for other routines in the user interface. These test scripts are described here.

Running examples of code calling RTTOV v13

There are several example programs in `src/test/` which demonstrate how to run the RTTOV forward model for various types of simulations and a simple example of a clear-sky K model call:

`example_fwd.F90`	simple example for clear-sky simulations
`example_atlas_fwd.F90`	as `example_fwd.F90` but also using the emissivity and BRDF atlases
`example_cld_file_fwd.F90`	example for cloud simulations using pre-defined particle types
`example_cld_param_fwd.F90`	example for cloud simulations using explicit optical parameters
`example_cld_mfasis_fwd.F90`	example for MFASIS-LUT cloud simulations
`example_cld_mfasis_nn_fwd.F90`	example for MFASIS-NN cloud simulations
`example_aer_file_fwd.F90`	example for aerosol simulations using pre-defined particle types
`example_aer_param_fwd.F90`	example for aerosol simulations using explicit optical parameters
`example_rttovscatt_fwd.F90`	example for RTTOV-SCATT simulations
`example_pc_fwd.F90`	example for PC-RTTOV simulations
`example_htfrtc_fwd.F90`	example for HTFRTC simulations
`example_k.F90`	example of calling the K model for clear-sky simulations

These examples may be used as a starting point for your own applications. Each of these programs may be run using a shell script with the name `run_example_*.sh` corresponding to the executable name. Near the top of each script is a small section where inputs may be configured such as the coefficient file and its location and the name of the input file(s) for profile data.

The scripts may be run by typing (for example):

```
$ ./run_example_fwd.sh ARCH=myarch [BIN=bindir]
```

Test reference output is in the folder named `test_example.2/`. Input files for the scripts and test output files are in the `test_example.1/` directory. The outputs consist of files named `output_example_*.dat.myarch` and diff files named `diff_example_*.myarch` showing the differences between the test outputs and the corresponding reference outputs. The diff files should typically have zero size although sometimes small differences are seen the least significant digits of some output values.

RTTOV-SCATT testing and example code

The `test_rttovscatt.sh` shell script may be used to verify the RTTOV-SCATT code. You may need to edit the first few lines of this script to specify the location of the RTTOV coefficient files (by default assumed to be in `rtcoef_rttov13/`). The script may then be run by typing:

```
$ ./test_rttovscatt.sh ARCH=myarch [BIN=bindir]
```

Test reference output is in `test_rttovscatt.2/`. Input files for the script are in the `test_rttovscatt.1/` directory, and this is also where the test output is written. The output consists of files named `output.NN.rttov_scatt.myarch` and `diff.NN.myarch` (where NN is 01, 02, etc), the latter being diff files showing differences compared to the test reference data. The script will exit cleanly if no internal errors are found. The diff file should typically have zero size if no errors occurred.

There is also an example program `mw_scatt/example_rttovscatt.F90` demonstrating how to perform direct and Jacobian calculations with RTTOV-SCATT. Once `test_rttovscatt.sh` has been run, the required links to coefficient files are set up within `test_rttovscatt.1/`. You may then call `example_rttovscatt.exe` (located in `bin/`) from this directory to run the example code. Note there is no reference output for this example program.

Emissivity and BRDF atlas testing

To use the atlases RTTOV must be compiled with HDF5 (see the user guide). The only exception is the TELSEM2 atlas as the data files for this atlas are in ASCII format. There is one test script per atlas:

• `test_uwiremis_atlas.sh`	UWIRemis IR emissivity atlas
• `test_camel_atlas.sh`	CAMEL IR emissivity atlas
• `test_camel_clim_atlas.sh`	CAMEL climatology IR emissivity atlas
• `test_telsem2_atlas.sh`	TELSEM2 MW atlas and interpolator
• `test_cnrm_mw_atlas.sh`	CNRM MW atlas
• `test_brdf_atlas.sh`	BRDF atlas

These test scripts each run a test program for the respective atlas. The test programs initialise the atlas, return emissivity/BRDF values for a series of profiles/locations and then deallocate the atlas. The emissivities/BRDFs are written to an output file. You may need to edit the first few lines of each script to specify the location of the RTTOV coefficient files (by default assumed to be in `rtcoef_rttov13/rttov13pred54L/`), and the location of the emissivity and BRDF atlas data files (by default assumed to be in `emis_data/` and `brdf_data/`). Note that the IR emissivity atlas tests require all of the IR atlas files to be downloaded (including the covariance files and the angular correction files).

The scripts are all run in the same way, for example:

```
$ ./test_uwiremis_atlas.sh ARCH=myarch [BIN=bindir]
```

For the emissivity atlases test reference output is in `test_emis_atlas.2/`. Input files for the scripts are in the `test_emis_atlas.1/` directory, and this is also where the test output is written. The output consists of files named `output_*_atlas.NN.myarch` according to the name of the atlas where NN is 01, 02, etc. The scripts also write diff files named `diff_*_atlas.NN.myarch` showing the difference between the test output and the reference output. The difference files should have zero size.

Similarly, the BRDF atlas test reference output is in `test_brdf_atlas.2/`. Input files for the scripts are in the `test_brdf_atlas.1/` directory, and this is also where the test output is written. The output consists of a file named `output_brdf_atlas.1.myarch`. The script also writes a diff file named `diff_brdf_atlas.1.myarch` showing the difference between the test output and the reference output. The difference files should have zero size.

Note that it may be easier and more practical to test the atlases using `example_atlas_fwd.sh` instead. This provides an example of calling the atlas in the context of running RTTOV simulations and does not require the optional atlas data (e.g. covariance files) to be downloaded.

Testing the rttov_get_sea_emis/brdf subroutines

The user-level rttov_get_sea_emis and rttov_get_sea_brdf subroutines are used to obtain surface emissivities and reflectances from the internal RTTOV surface models without running full simulations. A test program `rttov_test_get_sea_emisbrdf.exe` and associated calling script `test_get_sea_emis_brdf.sh` have been created to test these subroutines.

The script is run in the same way as the other test scripts described above, for example:

```
$ ./test_test_get_sea_emisbrdf.sh ARCH=myarch [BIN=bindir]
```

This test uses profile data contained in `test_example.1/`. It compares emissivities and reflectances returned by the external subroutines with those from RTTOV simulations and ensures the values are identical. There is no external test reference data. This test is intended for RTTOV developers.

Testing the rttov_calc_geo_sat_angles and rttov_calc_solar_angles subroutines

Two executables exist to test each of these routines. The nature of the calculations means they should not change. As such the subroutines contain input and reference output data against which the subroutines are checked. The subroutines can simply be executed with no arguments and the output will indicate whether the tests were successful or not. These tests are intended for RTTOV developers.

Testing the model allocation subroutines

The user-level rttov_alloc_direct/tl/ad/k subroutines are used to allocate any/all arrays and data structures required for running RTTOV simulations. A test program test program `rttov_test_model_alloc.exe` and associated calling script `test_model_alloc.sh` have been created to test these subroutines.

The script is run in the same way as the other test scripts described above, for example:

```
$ ./test_model_alloc.sh ARCH=myarch [BIN=bindir]
```

This test requires no input data. It exercises the allocation routines maximally, confirms that arrays are allocated with the expected dimensions, and then deallocates all arrays. The script uses the valgrind memcheck tool to test for memory leaks. There is no external test reference data. This test is intended for RTTOV developers.

9. *Visualising test suite output*

A Python-based plotting tool is provided in the rttov `rttov_test/` directory which enables plots to be made of various input/output test suite data such as profile variables, radiances, weighting functions, and Jacobians. The code is compatible with Python 3 (Python 2 is no longer supported), and requires numpy, matplotlib and wxPython. It can be invoked from within the `rttov_test/` directory as follows:

```
$ ./rttov_test_plot.py
```

All interface widgets have associated tool-tips which are displayed when the mouse pointer is hovered over them. These give guidance on how to use the interface.

Before displaying test output a test should be run for the direct and K code. For example:

```
$ ./rttov_test.pl ARCH=ifort TEST_LIST=atms/301 DIRECT=1 K=1 SWITCHRAD=1
```

The “Test dir” text boxes should then be set to the top level test output directory. For this example, this is “tests.1.ifort/atms/301”.

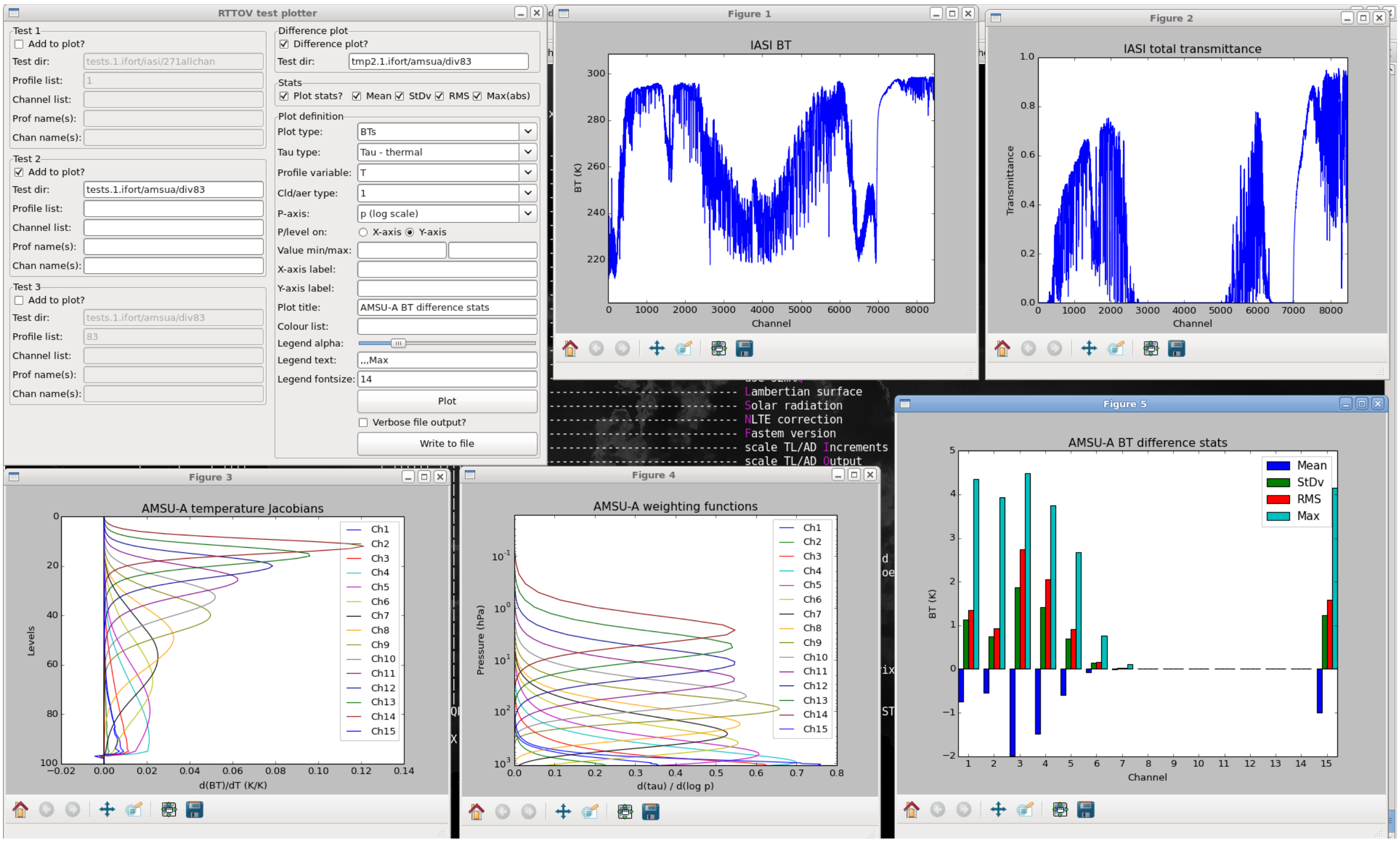
The profile and channel list text boxes can be left blank to plot output for all profiles associated with the test and all channels defined for each profile or they can contain comma-separated lists of profile and channel numbers to plot. The profile and channel name text boxes can be used to optionally label the individual profiles and channels for the legend. If left blank default labels are used.

On the right-hand side of the interface various plot types can be selected along with associated parameters such as the profile variable to plot (for example for Jacobian plots).

It is also possible to make difference plots for most plot types: in this case select the “Difference plot” check-box and input another test directory name. The resulting plot will show the differences between corresponding profiles/channels in all selected tests on the left-hand side of the interface and the same profiles/channels in the difference test directory. Note that the two tests must have been run the for same profiles/channels.

If you enable the “Plot stats” option, the GUI will plot any or all of the mean, standard deviation, RMS and maximum absolute value over all profiles for each channel: this is very useful when combined with difference plots for displaying statistics of the differences between two tests.

Finally, the plotted data may be extracted to a comma-separated ASCII file by clicking the “Write to file” button and providing an output file name when prompted. Additional comments can be written out in the file to help interpret the data: this is selected by checking the “Verbose file output?” check-box.



RTTOV test plotter

Test 1
□ Add to plot?
Test dir: tests.1.ifort/iasi/271allchan
Profile list: 1
Channel list:
Prof name(s):
Chan name(s):

Test 2
☑ Add to plot?
Test dir: tests.1.ifort/amsua/div83
Profile list:
Channel list:
Prof name(s):
Chan name(s):

Test 3
□ Add to plot?
Test dir: tests.1.ifort/amsua/div83
Profile list: 83
Channel list:
Prof name(s):
Chan name(s):

Difference plot
☑ Difference plot?
Test dir: tmp2.1.ifort/amsua/div83

Stats
☑ Plot stats? ☑ Mean ☑ StDv ☑ RMS ☑ Max(abs)

Plot definition
Plot type: BTs
Tau type: Tau - thermal
Profile variable: T
Cld/aer type: 1
P-axis: p (log scale)
P/level on: ○ X-axis ● Y-axis
Value min/max:
X-axis label:
Y-axis label:
Plot title: AMSU-A BT difference stats
Colour list:
Legend alpha:
Legend text: ,,,Max
Legend fontsize: 14
Plot
□ Verbose file output?
Write to file

```
------------------------------ Lambertian surface
------------------------------ Solar radiation
------------------------------ NLTE correction
------------------------------ Fastem version
------------------------------ scale TL/AD Increments
------------------------------ scale TL/AD Output
```