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Frequently Asked Questions about LNFL and LBLRTM AER, Inc.

1 General LBLRTM Description

LBLRTM (Line-By-Line Radiative Transfer Model) is an accurate and efficient line-by-line radiative transfer model derived from the Fast Atmospheric Signature Code (FASCODE). LBLRTM has been, and continues to be, extensively validated against atmospheric radiance spectra from the ultraviolet to the sub-millimeter.

The HITRAN database (http://cfa-www.harvard.edu/hitran) provides the basis for the line parameters used in LBLRTM. These line parameters, as well as additional line parameters from other sources, are extracted for use in LBLRTM by a line file creation program called LNFL. A line parameter database built from HITRAN and suitable for use with LNFL is available from the AER RT web site (rtweb.aer.com).
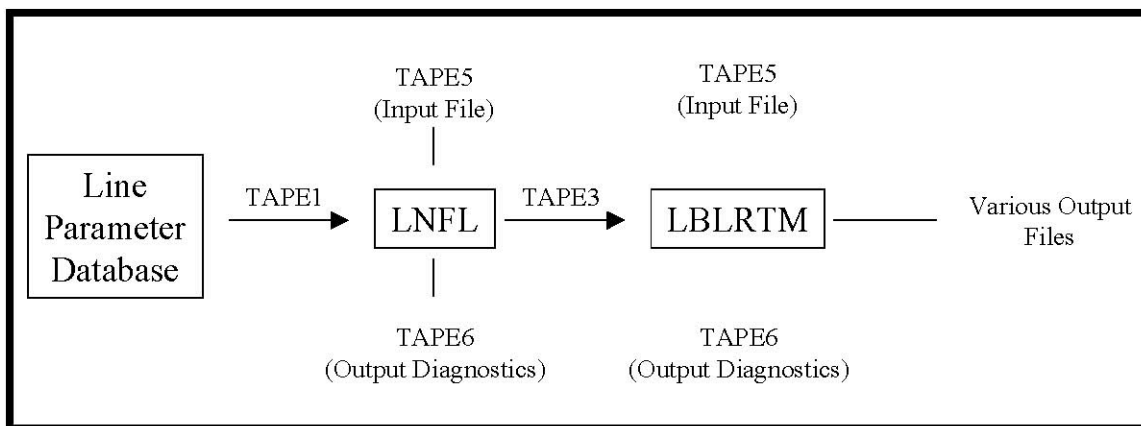
2 General LNFL/LBLRTM File Information

2.1 Platforms on which LBLRTM can be run

It is recommended that LNFL and LBLRTM be compiled in Fortran 90.

Table 1. Current LBLRTM supported platforms.

System	Manufacturer	Compiler	Single	Double
IRIX	SGI		F90, f77	F90, f77
SOLARIS	SUN		F90, f77	F90, f77
AIX	IBM		F90	F90
LINUX		Pgi	F90	F90
LINUX	INTEL		F90	F90
OS X	APPLE	Absoft	F90	F90
OS X	APPLE	Gnu	G95	g95
OS X	APPLE	Ibm_xl	F90	F90
OS X	Intel		ifort	

LBLRTM has previously been run on DEC alpha, Cray, MS-DOS, and HP platforms.

Some users have ported the code to the Windows/DOS environment. AER presently does not officially support this implementation, however, the following description of how LBLRTM was used in XP by a user is provided below.

Using LBLRTM in XP

Provide by Christopher Rice, Air Force Institute of Technology (AFIT)):

- Obtain the newest Intel Fortran Compiler (v 9.1) and Visual Studio.net 2003.
- Install visual studio .net 2003.
- Install Intel Fortran Compiler (Fortran compiler options will appear in MSVS 2003 after
  the Intel Fortran Compiler is installed.
- Decompress source codes for LBLRTM and LNFL into their appropriate folders.
- Compile LNFL:
  - o Open Visual Studio 2003.
  - o Open a new project.
  - o Select "Intel Fortran Projects" under "Project Types" and choose "Console Application" from "Templates".
  - o Name this project accordingly. (EG: LNFL_Exe)
  - o After the project is created a "Solution Explorer" will show the solution named as above. Right click on "Source Files" and add the following files:
    - lnfl.f90
    - util_dos.f90
  - o Note that the "util_linux_intel" makefile can be used as a reference for the files to be included, replacing "util_linux.f90" with the file "util_dos.f90".
  - o Make sure the compiler is set to "release" NOT "debug".
  - o Build the Project.

- On successful build find the .exe in the "release" folder where the project is saved.
- Compile LBLRTM:
  - Open Visual Studio 2003.
  - Open a new project.
  - Select "Intel Fortran Projects" under "Project Types" and choose "Console Application" from "Templates".
  - Name this project accordingly. (EG: LBLRTM_Exe)
  - After the project is created a "Solution Explorer" will show a solution named as above. Right click on "Source Files" and add the following files:
    - contnm.f90
    - fftscn.f90
    - lblatm.f90
    - lbldum.f90
    - lbllow.f90
    - lblrtm.f90
    - nonlte.f90 • oprop.f90
    - pltlbl.f90
    - postsub.f90
    - solar.f90
    - testmm.f90
    - util_dos.f90
    - xmerge.f90
  - Note that the "util_linux_intel" makefile can be used as a reference for the files to be included, replacing "util_linux.f90" with the file "util_dos.f90".
  - Make sure the compiler is set to "release" NOT "debug" – LBLRTM will not operate correctly when compiled in "Debug" mode.
  - Build the Project.
  - On successful build find the exe in the "release" folder where the project is saved.
- Use LNFL with TAPE5 to create TAPE3 as described in the documentation,
- Use TAPE3 with LBLRTM to satisfy your requirements as described in documentation.

2.2 Issues relating to unformatted files on UNIX and LINUX systems

Unformatted files are often not compatible between systems due to differences in the way the bytes are written to the files (big-endian versus little-endian). Note that the "byteswap" option available with most compilers will not work with most LBLRTM unformatted output files because of the mixing of real and integer data within records.

2.3 LNFL/LBLRTM Naming Convention

Specific information on the input/output files from LNFL and LBLRTM is located in their respective input files, lnfl_instructions and lblrtm_instructions, and the examples provided in the code tar files.

Most file names are given as "TAPEx" where x is a one- or two-digit number. The name is case-sensitive, and is uppercase. Tape numbers may be same for LNFL and LBLRTM but do not represent identical files. For example, the primary LNFL input file is TAPE5, and the primary LBLRTM input file is TAPE5. However, they have neither the same input information nor the same formatting. The instruction manual for each code details the input file information.

2.4 LNFL/LBLRTM Input File (TAPE5) Format

The TAPE5 input files are read as formatted FORTRAN. As a consequence of the formatted read, any blank space will be read as "zero". Thus, one may leave blanks for most of the parameters and within the code they will default to an acceptable value.

Real numbers format input as either "E" or "F" format, with the entire number within the range specified in the input instructions. Integers must be specified exactly in the integer format. For example, the spectral bandwidth (v1 to v2) in LBLRTM TAPE5 is input as 10 character real numbers. This means that the value can be written anywhere within these 10 characters, as long as there is a decimal point (e.g. "---600.000" or "-600.000--", where "-" is a blank space).

Integers are read in with the "I" format. For example, the model atmosphere (iatm) in LBLRTM TAPE5 is input as "I5", so it must be "----2", and not "2----" as this will be read as 20000.

2.5 LBLRTM Output File Format

The general structure of the files involves the use of panels, which are blocks of output usually containing 2400 points. Each panel contains a header to describe the starting and ending points of the panel (v1 and v2), the spectral spacing of the points (dvp), and the number of points in the panel (npts). The panel header is followed by either one or two (see below) blocks of output, consisting of npts points.

TAPE12: Radiances and transmittances
(1) file header
(2,i)-panel header
(3,i) radiances
(4,i) transmittances
Lines 2-4 repeat for i=1,N times to cover the entire spectral region.

TAPE11: Filtered radiance or transmittance (also applies to any user-designated output file which contains radiances, transmittances, or optical depths, such as the "ODint" file)
(1)file header
(2,i)-panel header
(3,i) radiances or transmittances
Lines 2-3 repeat for i=1,N times to cover the entire spectral region.

Note that a limited amount of spectral output information may also be put in the TAPE6 using the MPTS/NPTS options of TAPE5 record 1.2.

3 Instructions and Tips for Running LNFL

LNFL is used to generate a unformatted file (TAPE3) of all the line parameters required by LBLRTM.

3.1 Input files for LNFL
TAPE1: The line parameter database in ASCII format (also available on www.rtweb.aer.com). TAPE5: LNFL input file.

3.2 Output files for LNFL

TAPE3: Unformatted LNFL output file containing the line parameters for LBLRTM.
TAPE6: Informational output file.
TAPE7: Optional output file containing ASCII version of the parameters contained in TAPE3.

3.3 Sequence for running LNFL
- Download latest LNFL tar code (containing the source code) and the latest line parameter database from rtweb.aer.com.
- Compile LNFL using the makefiles found in the LNFL tar file. Note, one needs to compile in the build directory.
- Link the line parameter database to TAPE1 in the LNFL working directory.
- Remove TAPE3 file from the LNFL working directory.
- Edit necessary parameters in the TAPE5 input file. Note that the beginning and ending wavenumber (v1, v2) in TAPE5 must extend at least 25 cm^{-1} beyond each end of the desired spectral range for the LBLRTM calculations.
- Run the LNFL code.

4 Instructions and Tips for Compiling and Running LBLRTM

LBLRTM is used to generate line-by-line upwelling and downwelling transmittances and radiances.

4.1 Required input files for LBLRTM

TAPE3: Unformatted file containing line parameter information, generated by LNFL (see above). The TAPE3 file should include lines from at least 25 cm^{-1} on either end of the calculation region.

TAPE5: Input file required to run LBLRTM.

The spectral interval (v1, v2) for any LBLRTM run must not exceed 2000 cm^{-1} (see instruction manual).

Other input files are required if you are using the solar source function, cross sections, surface emissivity, etc. See the LBLRTM instruction manual and provide example.

4.2 Layer numbering scheme

The LBLRTM convention is that layer 1 is at the highest pressure level (lowest altitude). The layer information for a given run may be found in TAPE6.

4.3 Output files for LBLRTM

TAPE6: Informational output file
TAPE11: Unformatted file containing filtered output, if requested in TAPE5.
TAPE12: Unformatted file containing transmittances/radiances.
ASCII file of unformatted unformatted files can be requested in the LBLRTM TAPE5 (see pltlbl variable in Record 12).
Unformatted optical depth files can be requested in the LBLRTM using options specified in TAPE5.

4.4 Sequence for running LBLRTM
- Download latest LBLRTM tar code (containing the source code) and the latest line parameter database from rtweb.aer.com.
- Compile LBLRTM following makefiles in the LBLRTM tar file. Note, one needs to compile in the build directory
- Link the line parameter database (TAPE3 from LNFL) to the LBLRTM working directory.
- Edit any parameters necessary in the input file TAPE5.
- Run the LBLRTM code.

5 General Questions

5.1 What is the difference between a line-by-line calculation and a band-model calculation?

Absorption/emission spectra are comprised of a complicated array of spectral lines. The HITRAN 2008 Database (Version 13.0) contains over 2,713,000 lines for 39

different molecules. In order to resolve these individual lines, a nominal spectral sampling rate of less than the mean line half width must be utilized. Such highly resolved radiative transfer calculations are called line-by-line (LBL) calculations. The computational time associated with calculating broadband fluxes from LBL calculations is formidable. A band model aims to simplify radiative transfer calculations by using approximations to represent the line-by-line characteristics of a particular spectral interval. Band models are appropriate for situations where the desired spectral resolution is much smaller than the Lorentz and Doppler widths of the spectral lines. Such approximations are also of use in general circulation models.

5.2 What are the standard units used in LBLRTM calculations?

Wavenumber: cm^{-1}
Radiance:
$W/(cm^{-2} sr$
$cm^{-1})$
Brightness
Temperature:
K Analytic
Jacobians
(dR/dx):

        molecules: $[W / (cm^{-2} sr cm^{-1})] / [log(volume mixing ratio)]$
        temperature: $[W / (cm^{-2} sr cm^{-1})] / [K]$

5.3 Radiance Derivatives (Jacobians)

This section describes the Analytical Jacobian capability in LBLRTM, Version 10.0 and later. The results from earlier versions are not reliable and should NOT be used.

The implementation of the analytic Jacobians in LBLRTM has been designed to require a minimal amount of setup on the part of the user while exploiting pre-existing LBLRTM calculation options. There are three steps required to obtain layer and level Analytic Jacobians

Step A: Create the ODint_lll files using IMRG=1 and IOD =3; lll is the layer number. Following LBLRTM convention, layer 1 is at the highest pressure level (lowest altitude). The spectral grid for the monochromatic calculation is determined by the DV of the highest layer (DVSET is automatically set by the program).

Step B: Create the RDDN_lll files which provide the radiances from the top of the profile to level lll using IMRG=40 and IOD=3. Note that the RDDNlayer_001 file is the downwelling radiance at the surface. The ODint files from Step A are used for this calculation.

Step C: Create the layer and level Analytic Jacobian files in directory AJ; RDderivUPW_xx_lll and LEV_RDderivUPW_xx_lll are the layer and level derivatives files of the upwelling radiance at the upper boundary of the profile (IMRG=41 and IOD=3) taken with respect to state parameter xx. Similarly, the files RDderivDNW_xx_lll and LEV_RDderivDNW_xx_lll are obtained for the downwelling radiance at the lower boundary (IMRG=40 and IOD=3) with the Jacobian taken with respect to state vector type xx where:

> xx = -1 surface parameters
> xx = 0 temperature
> xx = mol molecule number (1-38)

Multiple runs of Step C may be performed once Step A and Step B have been run, the radiometric representation for the Jacobians having been established,

All the unformatted files resulting from these operations are fully consistent with LBLRTM files. The layer and level Jacobian files have the Radiance Jacobians in the normal radiance panel and the transmittance from the lowest boundary of the problem to the bottom level of the layer lll in the transmittance panel or to the designated level in the case of level Jacobians. These transmittances are included only to retain consistency with the LBLRTM file structures. Consequently, postprocessing including the application of selected instrument functions is accomplished in a manner identical to that for radiances. Note that selecting brightness temperature in the postprocessing will not provide a meaningful result. In general, the input parameters for AJ calculations is described in the LBLRTM instructions where the required parameter is described, particularly note RECORD 1.2.b. The scanmrg option (IMRG=42,43 in this case) has not been tested and should be used with extreme caution.

Finally, a script has been included with ALL necessary files to run a sample set of Jacobian calculations. A second script has been provided to perform symmetric finite difference calculations to check the AJ results. A PowerPoint document with plots showing the results from the two scripts has been included. The file lblrtm_AJ_readme.txt explains the two scripts.

5.4 Is it possible to scale the profile of one or more species?

Yes. The instructions for using this capability are provided in the lblrtm instructions. See records 1.3, 1.3.a and 1.3.b.

5.5 Does LBLRTM include heavy molecule parameters (cross-sectional species)?

Heavy molecules (such as CCL4, F11, and others listed in Table II of the lblrtm_instruction manual) can be included in LBLRTM calculations by setting the

IXSECT input variable to 1 and adding Record 2.2 or Record 3.7 to the LBLRTM TAPE5. An additional file (FSCDXS) and directory (xs) are required for these calculations and can be obtained from the LBLRTM example tar file (available from rtweb.aer.com).

5.6 Format of external surface emissivity/reflectivity files

Sea surface spectral emissivity/reflectivity files are provided with the example (available from rtweb.aer.com). The files must have the file names of "EMISSIVITY" and "REFLECTIVITY". The format is as follows:

V1EMIS, V2EMIS, DVEMIS, NLIMEM

(3E1
0.3,5
X,I5)
ZEM
IS(1
…N)
     (E15.7)

V1EMIS -> Initial emissivity/reflectivity frequency value (cm^{-1})
V2EMIS -> Finial emissivity/reflectivity frequency value (cm^{-1})
DVEMIS -> Is the frequency increment (cm^{-1})
NLIMEM -> Number of spectral emissivity/reflectivity points in the file

*Note: It is assumed that the spectral emissivity/reflectivity points are equally spaced and there is a maximum number of points (see instructions).

5.7 Absorption due to clouds/aerosols and LOWTRAN5 routines

Absorption due to clouds and aerosols can be computed in LBLRTM by setting the IAERSL flag in the input TAPE5 file (refer to instructions). This flag allows for LBLRTM to utilize the aerosol capabilities of LOWTRAN5.

5.8 Solar Radiance

Solar radiance calculations can be performed by utilizing LBLRTM input options such as IEMIT=2 and a particular solar source function file SOLAR.RAD. A SOLAR.RAD file can be generated with program extract_solar available on the AER RT web site and the Kurucz solar source function. The Kurucz solar source function has been used in AER's research in shortwave radiation and is based on theoretical radiative transfer calculations for the solar atmosphere. The solar source function is available is at a high spectral resolution (i.e. for monochromatic calculations) and 1 cm^{-1} resolution.

5.9 Line coupling/mixing

Line coupling parameters are utilized in LBLRTM for O_2, CO_2 and CH_4. The line coupling parameters are provided in the AER line parameter database (available from rtweb.aer.com) and are written to the line parameter input file (TAPE3) by LNFL.

5.10 What is the appropriate reference for LBLRTM calculations in journal articles and presentations?

Clough SA, Shephard MW, Mlawer EJ, Delamere JS, Iacono MJ, Cady-Pereira K, Boukabara S, Brown PD.Atmospheric radiative transfer modeling: a summary of the AER codes • SHORT COMMUNICATION• J Quant. Spectrosc. and Radiat Transfer, 91, 233-244 (2005).

Also, please refer to rtweb.aer.com for the complete list of references.

5.11 How do you calculate fluxes?

Source code and instructions available: http://rtweb.aer.com/radsum_frame.html