Fortran programs for non-scattering microwave radiative transfer

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The current version is 2024-07-03. Each routine contains a history of substantive revisions (other than comment lines). The most complete recent description of the absorption model was of the 2017 version, in section 2 of Cimini *et al*. (2018). The principal changes since then are inclusion of second-order line mixing for the 60-GHz band of oxygen, and speed-dependence for the lines at 22, 118, and 183 GHz. The sources for line parameters are documented either within the routines or in the data files h2olines_sd.asc and o3_list.asc.

Other versions can be downloaded at http://cetemps.aquila.infn.it/mwrnet/lblmrt_ns.html, or obtained from the author. Email questions or comments to phil.rosenkranz@alum.mit.edu .

This software is intended as an educational tool with limited ranges of applicability, so no guarantees are attached to any of the codes.

Bug fixes:

tbdnw_spectrum.f 1/14/2019

tbupw_spectrum.f 1/14/2019

Contents

There are two main programs:

tbdnw_spectrum.f computes a downward-propagating brightness-temperature spectrum at the bottom of the atmosphere.

tbupw_spectrum.f computes an upward-propagating brightness-temperature spectrum above a smooth ocean surface. The surface temperature is set equal to the surface-air temperature of the input atmosphere (profile.dat). Limb-scanning geometries are not treated.

These programs can be run as is, or read as examples for using the subroutines in another application. The programs ask for the maximum altitude at which to terminate the calculation. If the altitude is >40km, the azimuthal angle of propagation and the terrestrial magnetic field vector are also required, for the Zeeman calculation. Note that the direction of propagation is opposite to the direction in which the receiving antenna is pointed. The programs write to a text file and also produce encapsulated postscript plots using subroutines from the **plot** subdirectory. An efficient algorithm for averaging brightness temperature over a radiometer spectral-response function is available (Rosenkranz, 2022a).

profile.dat: input atmospheric profile. The file included here for testing has the 1976 U.S. Standard temperature profile.

example_spectrum.txt: test output from tbdnw_spectrum and tbupw_spectrum.

test_dn.eps: test postscript file from tbdnw_spectrum.

test_up.eps: test postscript file from tbupw_spectrum.

Subroutines for the lower atmosphere (below 40 km) and surface. h2oabs and o2_abs can process multiple frequencies with one call.

Name (Last substantive update) Purpose / Main Reference

h2oabs.f (8/18/2023) water-vapor absorption coefficient with speed-dependent VVW shape factor/ Rosenkranz (1998), Rosenkranz and Cimini (2019). This subroutine will write the line parameters to standard output at the first call, if DETAILS is set to .TRUE.

h2olines_sd.asc (4/20/2023) line list read by h2oabs.

h2ocon.f (3/20/2023) subroutine called by h2oabs for the self-continuum, adapted from MT-CKD version 4.1 (https://github.com/AER-RC/MT_CKD)

o2_abs.f (6/17/2024) oxygen absorption coefficient with second-order line mixing coefficients from Makarov *et* *al.* (2020), with small adjustments to satisfy applicable sum-rules and to compensate for updated line intensities.

absn2.for (6/23/2018) dry-air collision-induced absorption coefficient/ Rosenkranz (2006).

abso3.f (9/2/2021) ozone absorption coefficient.

abinto3_list.f (7/23/2018) ozone absorption-line integral/ Rosenkranz (2022b).

o3_list.asc (8/22/2022) line list read by abso3.f and abinto3_list.f

abliq12.for (6/5/2015) cloud liquid-water absorption coefficient using dilec12.

dilec9.for (6/1/2004) complex dielectric constant of fresh water ice/ Hufford (1991)

dilec10.for (11/7/2008) complex dielectric constant of seawater or fresh water/ Ellison (2006).

dilec12.for (4/15/2014) complex dielectric constant of fresh water/ Rosenkranz (2015)

ref.for (4/3/1987) reflection coefficient from a specular surface.

tbarray2.f (4/24/2023) brightness temperature calculation without scattering.

Subroutines for Zeeman-split O_2 lines (above approx. 30 km altitude). (Below 30 km, Zeeman splitting is overwhelmed by pressure broadening, and the non-split oxygen absorption routine o2_abs is applicable.)

o2absz.f (7/24/2023) computes complex propagation coefficients.

zeeman2.f (1/28/2023) Zeeman-splitting calculations, called by o2absz.

dcerror.f (12/11/2018) complex error function, called by zeeman2, o2_abs, and h2oabs.

e2rot.f (5/6/2015) calculates angles and phase factor used by tbmx.

findline.f (5/5/2022) locates a nearby O_2 line center.

tbmx.for (1/28/2023) radiative transfer through an atmospheric layer/ Rosenkranz and Staelin (1988).

Tbmx does the radiative transfer for a single slab of gas, so repeated calls are used to integrate through the atmosphere. A circular-polarization basis is used. The phase of the complex linear component (tblin) in tbmx is defined relative to the projection of magnetic field direction on the plane orthogonal to the direction of propagation. The phase factor computed in e2rot will rotate tblin to the vertical reference plane. Thus, to take into account a change in orientation of the field along the path of integration, that differential angle should be subtracted from the phase of tblin at each step of the program, which can be done by means of the phase factors and their conjugates.

In order to use the Zeeman routines, a magnetic field model is required. The International Geomagnetic Reference Field model, updated every 5 years, is available at http://www.ngdc.noaa.gov/IAGA/vmod/ Note the conversion factor 10^5 nanotesla = 1 gauss.

A note on the definition of brightness temperature:

Tbupw_spectrum.f and tbdnw_spectrum.f calculate brightness temperature as a weighted integral of physical temperatures. However, as discussed in section 1.2.4 of Janssen (1993), the cosmic background temperature Tbc is adjusted by Janssen's eq. 1.21,

Tbc = .5*.0479923*f*(efac+1.)/(efac-1.),

where efac = exp(.0479923*f/2.73),

and f is the frequency in GHz. This adjustment yields a linearization of the radiative transfer equation, when written in terms of temperature. In most cases, Tb computed by these programs is very close to the IEEE definition of brightness temperature, which is the temperature of a blackbody that would emit the same radiant intensity. The IEEE-defined brightness temperature can be recovered from the computed Tb by the inverse of eq.1.21:

Tb_{IEEE} = .0479923*f/alog((a+1.)/(a-1.)),

where a = 2.*$Tb_{computed}$/(.0479923*f).

The table below lists Tb_{IEEE} for a few values of computed Tb at several frequencies. Note that $Tb_{computed}$ will never be lower than Tbc(f).

$Tb_{computed}$ =	5	10	30	100	200
f= 30 GHz	4.97	9.98	29.99	100.00	200.00
90 GHz	4.67	9.84	29.95	99.98	199.99
150 GHz	3.97	9.55	29.86	99.96	199.98
300 GHz	.	7.93	29.42	99.83	199.91
600 GHz	.	.	27.54	99.31	199.65
800 GHz	.	.	25.33	98.76	199.38

References

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