X.Y UPDATES TO "MODTRAN INFRARED LIGHT IN THE ATMOSPHERE"

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The website "Modtran Infrared Light in the Atmosphere" allows the user to produce plots of radiant intensity versus wave number for user-chosen concentrations of greenhouse gases (GHG), either singly or in combination. The virtual observer may be positioned at any altitude between zero and 70 km, in 1 km increments. The downward and outgoing long-wavelength radiation (DLR and OLR) fluxes are given.

The user can choose among six model atmospheres, comprised of tropical, mid-latitude summer, midlatitude winter, subarctic summer, subarctic winter, and the 1976 U.S. Standard Atmosphere. The U.S. Standard Atmosphere is an "average around the globe" (North and Kim, 2017, p. 1497). One needs to distinguish here between "Modtran 6," a versatile, expensive, modern program one may purchase from Spectral Sciences, and Modtran Infrared Light in the Atmosphere, which we now refer to with the acronym MILIA. Modtran 6 (Spectral Sciences, 2016)—or earlier versions such as Modtran 5—is used by government agencies, researchers in the fields of atmospheric science, and for educational purposes in advanced courses (University of Washington Earth Science, 2017). MILIA, based on an old version of MODTRAN, is hosted for free online use by the University of Chicago. The version of Modtran used as the underlying program in MILIA is Modtran 3, version 1.3, released in December of 1995. MILIA was developed by David Archer for use with his textbook *Global Warming: Understanding the Forecast* for an environmental-science elective (Archer, 2007). A partial list of institutions which have used MILIA includes

1. The University of Chicago, both in the core curriculum course *Global Warming Understanding the Forecast* and in a free open-access online class *Global Warming I: The Science and Modeling of Climate Change.*
2. Weber State University in their GEOG 1400 PS *The Science of Global Warming: Myths, Realities, and Solutions.*
3. Aalto University in Espoo, Finland, for *Physics of Climate Change.*
4. Raritan Community College in New Jersey for ENVI103, *Energy and the Environment.*

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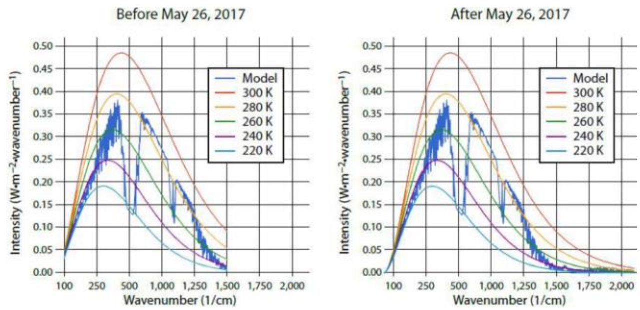

Figure 1: Comparison of the outputs from the old and new versions of MILIA, U.S. Standard Atmo- sphere location, default GHG settings, looking down- ward from 20 km.

5. University of Rochester, U.C. Santa Barbara, and Saint Marys University.

MILIA is the only free source of OLR data plots. For this reason, MILIA (or its archived predecessor still hosted at the University of Chicago "ModtranRadiation Code") has also been used in such advanced publications as North and Kim (2017) and Wilson and Gea-Banacloche (2012).

1. MILIA IMPROVEMENTS AS OF DECEMBER 2017

1.1. UNDERLYING PLANCK DISTRIBUTION

The width of the underlying Planck distribution has been increased from wavenumber in the abscissa between 100 and 1,500 wn to a wavenumber in the abscissa between 2 and 2,200 wn. See Fig. 1 for an illustration of the old and new program output.

1.2. TRACE ATMOSPHERIC COMPONENTS

The original MILIA included trace atmospheric components not included in the user interface for setting the gas composition. It was possible for these trace components to somewhat alter the output spectrum, possibly confusing the user. For example, Wilson and Gea-Banacloche (2012) use the old version of MILIA to test the results of their model. They obtained good agreement with MILIA for the forcing corresponding to the no-feedback case of doubling CO_2, but the authors stated in an aside that the MILIA spectrum, for a case with CO_2 as the only GHG, showed a dip at about 1,284 wn which the authors identified as a "secondary CO_2 absorption feature." Using SpectralCalc (Global Atmospheric Tech-

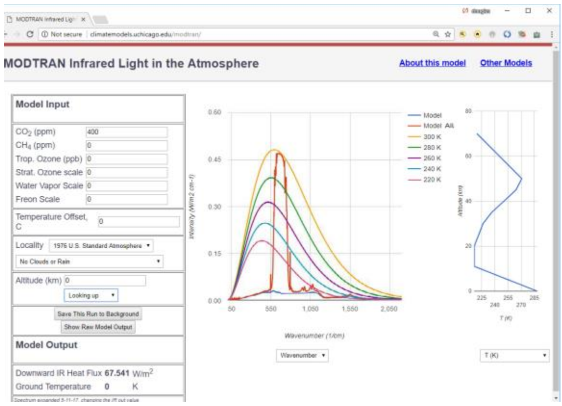

Figure 2: Comparison of DLR looking up from 0 km for aerosols plus 400 ppm CO_2 as the only GHG (red model output) to aerosols only (blue model output) in a U.S. Standard Atmosphere.

nology and Sciences, 2017) and Modtran 6 (Spectral Sciences, 2016) one can show that this feature is due to trace amounts of N_2O that Wilson and Gea-Banacloche could not zero out because there was no corresponding N_2O concentration button. In the new version of MILIA, the N_2O GHG has been removed from the underlying program input so that this feature does not appear in the MILIA output spectrum. In addition, a button has been added to control the concentration of Freon molecules.

1.3. AEROSOLS

Before these improvements were made to MILIA, there was an aerosol contribution which had a significant effect on the OLR and quite a large effect on the DLR. Yet, no concentration button was avail- able to the user. We chose to simply remove the aerosol contribution from the output, rather than con- trolling the aerosols with a concentration button. In Fig. 2, we show the DLR, before the aerosols were removed, for the case with 400 ppm CO_2 and all other GHG buttons set to zero compared to the case with all the GHG buttons set to zero.

The aerosol contribution is clearly substantial, and we could think of no reason to include a corresponding concentration button in a computer package for nonscience majors. Since there should not be an absorbing atmospheric component that gives a spectral contribution not controlled by a concentration button, the aerosol contribution was removed from the underlying program. As may be seen from Fig. 3, the aerosols contributed significantly to the absorption of the OLR before they were removed.

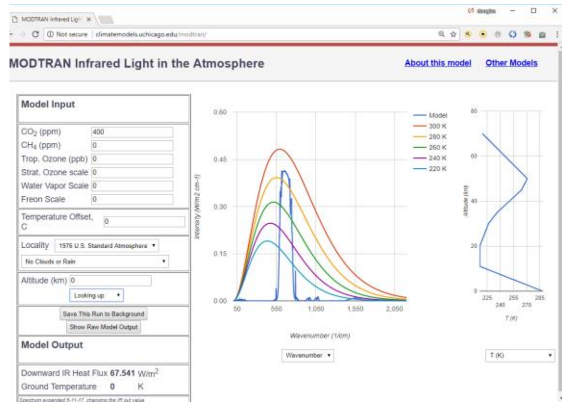

Figure 3: MILIA output without aerosols.

2. EFFECTS OF THE IMPROVEMENTS

We conclude by showing the results of OLR calculations for several important cases. The effect of the increased underlying bandwidth is shown, and the effect of increasing the emissivity from 0.971 to 1.00 is briefly discussed.

2.1. OLR FROM EARTH IN EQUILIBRIUM WITH THE INCOMING SOLAR FLUX, WITH NO GHG

It is common for basic environmental physics texts to consider the case in which the Earth is in thermal equilibrium with the Sun, assuming an albedo of 30% (Wolfson, 2012). Under such circumstances, assuming a thermal emissivity of the Earth's surface of 1.0, the equilibrium temperature of the Earth is 255 K if one "turns off" the greenhouse effect. The OLR of the Earth then comes close to 239 W/m^2 using the Stefan–Boltzmann law.

Here, we used the U.S. Standard Atmosphere and used a temperature offset of −33.2 K in MILIA to offset the Earth's temperature from 288.2 K to 255 K.

The Earth's emissivity computed by MILIA is, in the new version, 0.971. The Stefan–Boltzmann law then yields an OLR of 232.8 W/m^2. The OLR obtained from the new version of MILIA is 233.7 W/m^2 at 70 km. The error relative to the Stefan–Boltzmann law is 0.38% too high.

The Earth's emissivity computed by MILIA is, in the old version, 0.98. The Stefan–Boltzmann law then yields an OLR of 234.9 W/m^2. The OLR obtained from the old version of MILIA is 219.5 W/m^2 at 70 km. The error relative to the Stefan–Boltzmann law is 6.5% too low.

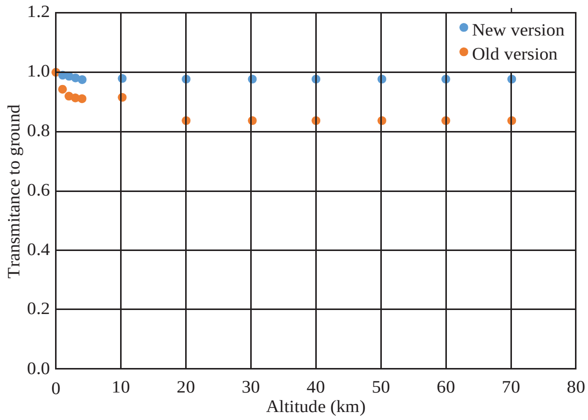

Figure 4: Numerical transmittance results for old and new versions of MILIA for a viewer looking downward from various altitudes, U.S. Standard Atmosphere, zero GHG settings, temperature offset to 255 K.

2.2. CLEAR-SKY OLR

Since clouds are difficult to analyze, there is interest in measuring clear-sky OLR values, perhaps to compare these results with top-of-the-atmosphere (TOA) measurements obtained by carefully combining worldwide TOA satellite OLR measurements. Modern results from the AIRS spectrometer aboard the Aqua satellite plus additional analysis indicate clear-sky OLR values of 274.3 W/m^2 for AIRS and a value about 0.9 W/m^2 less than the AIRS value for CERES (Chen et al., 2013). The old version of MILIA, using the U.S. Standard Atmosphere and looking down from 70 km with the default GHG, yields a clear-sky OLR value of 260 W/m^2, whereas the new version yields an OLR of 267.8 W/m^2. This is closer to the AIRS value relative to the old version, but it still appears to be significantly too low. If the emissivity is changed from 0.971 to 1.00, the OLR changes from 267.8 W/m^2 to 269.9 W/m^2.

2.3. TRANSMITTANCE

The underlying program output button provides the net transmittance results. Fig. 4 shows that, with the GHG set to zero, the user sees a transmittance close to one as expected, but the transmittance is much too low for the old version of MILIA. This improvement is mostly due to the removal of the aerosols.

3. IMPROVEMENTS STILL NEEDED

See in Fig. 5 the experimental curve from Nauru on the left for tropical DLR versus the corresponding MILIA results on the right. One notices first that the resolution of the water vapor lines appears to be much worse for MILIA than for the data. Also, the net DLR seems to be lower for MILIA. Efforts are underway to address these issues, but this improvement would require a more extensive revamping of the underlying program than we have done so far. We will attempt to address these problems, taking into account that for the DLR the source of the upper atmospheric infrared radiation will be asymmetric, unlike the source on the Earth's surface for the OLR.

4. ACKNOWLEDGMENTS

We a grateful for useful input from Alexander Berk of Spectral Sciences and Steve Carson of the award-winning blog "Science of Doom."

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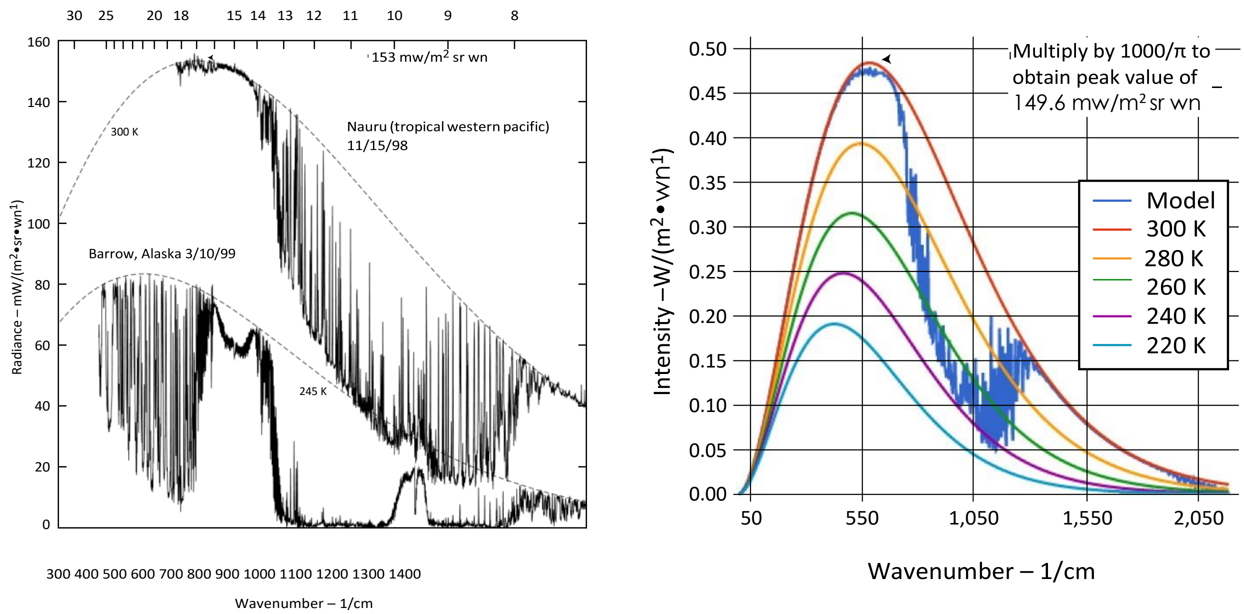

See upper curve from Nauru in the tropical western Pacific. Total DLR unspecified. From Grant W. Petty, "A First Course in Atmospheric Radiation," 2006, Sundog, p. 223.

Tropical location. The net DLR appears to be lower for MILIA, relative to the upper curve in the left-hand graph. Total DLR is 369.26 W/m^2.

Figure 5: Left panel, upper portion: Experimental DLR radiance for a tropical locality. Right panel: MILIA default DLR for a tropical locality.

Note. The tropical data were collected by a group led by Robert Knuteson, of the University of Wisconsin, Madison: "Atmospheric Emitted Radiance Interferometer. Part I: Instrument Design," by R. O. Knuteson et al., 2004, *Journal of Atmospheric and Oceanic Technology,* 21, 1763–1776.

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