Local Climate Variables and Climate Sensitivity

Lab #6 Report

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Contents

Introduction Climate change is a global phenomenon that has been fueled by human activity around the world. The heating associated with the rapid introduction of CO2 in the atmosphere since the Industrial Revolution is predicted to have widespread impacts on agriculture, water levels, and destructive weather events across the globe. While the effects of climate change will produce challenges for the whole world to face, it is dangerous to assume that these challenges will be the same for different communities. The atmosphere's temperature and composition affect the way heat is trapped above a locality through the greenhouse effect. These qualities also vary with latitude and season. The purpose of this project is to determine the climate sensitivity for different geographic settings to better understand how the effects of climate change will be distributed across the world. This is important to coordinate preparation for climate related challenges and protect vulnerable populations. To do this, the Modtran model was run for 6 different atmosphere types to determine the effect a forced doubling of CO2 would have on the intensity of outgoing radiation and how much temperatures would have to rise to correct for this change in outgoing radiation. The expected temperature rise was calculated for a fixed water vapor pressure and a fixed relative humidity at each atmosphere.

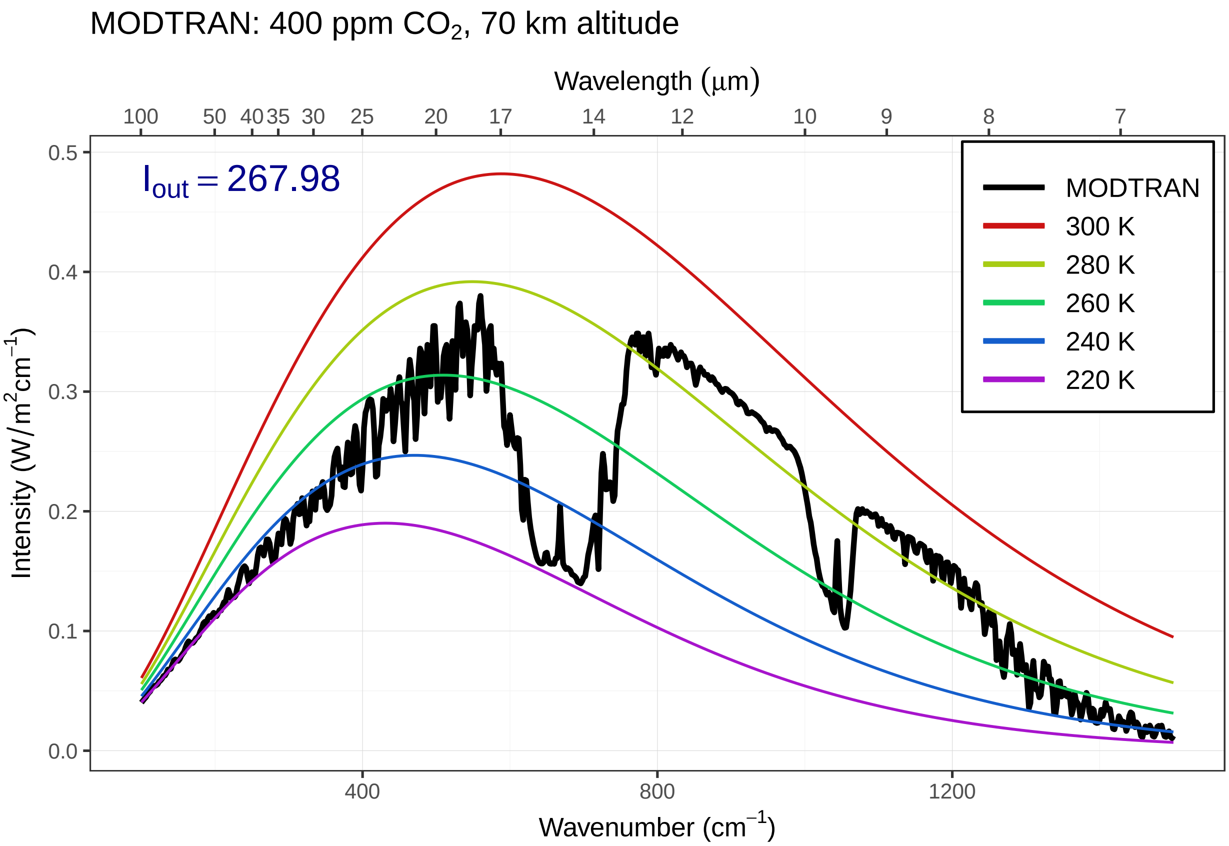
Methods Modtran was run first for the Standard 1976 U.S. Atmosphere at a CO2 concentration of 400ppm and default settings for all other parameters. This concentration of CO2 represents approximate current levels of CO2 in the atmosphere. The intensity of outgoing emitted radiation was determined across the emitted wavelengths. Then, the model was run again with all parameters held constant but CO2 doubled at a value of 800ppm. The new intensity of outgoing radiation was determined. The next task was to determine the change in temperature necessary to return intensity of outgoing radiation to the level previous to the forced addition of CO2. This was done for both an atmosphere where water vapor is fixed at a constant vapor pressure and an atmosphere where water vapor is fixed at a constant relative humidity. Modtran was run again for the Standard 1976 U.S. atmosphere with a concentration of 800ppm and "h2o_fixed" set to the default "vapor pressure," as in the previous run. This time, however, the value "Delta_t" was adjusted until the run produced an outgoing radiation intensity that was equal to that value when CO2 was set to 400ppm. Next, this procedure for determining the change in temperature was repeated for an "h20_fixed" value of “relative humidity.” The four runs listed above were replicated for each of the 5 remaining atmosphere types (tropical, mid-latitude summer, mid-latitude winter, subarctic summer, subarctic winter. This was done by changing the value of “atmosphere” in the code for the above trials.

Here is our code! 1976 STANDARD US ATMOSPHERE

```
run_modtran(filename = "_data/modtran_nineteen76us_baseline.txt", co2_ppm = 400, atmosph
modtran_nineteen76us_baseline=read_modtran("_data/modtran_nineteen76us_baseline.txt")
nineteen76usbaseline_i_out=modtran_nineteen76us_baseline$i_out
nineteen76usbaseline_i_out
```

```
## [1] 267.9779
```

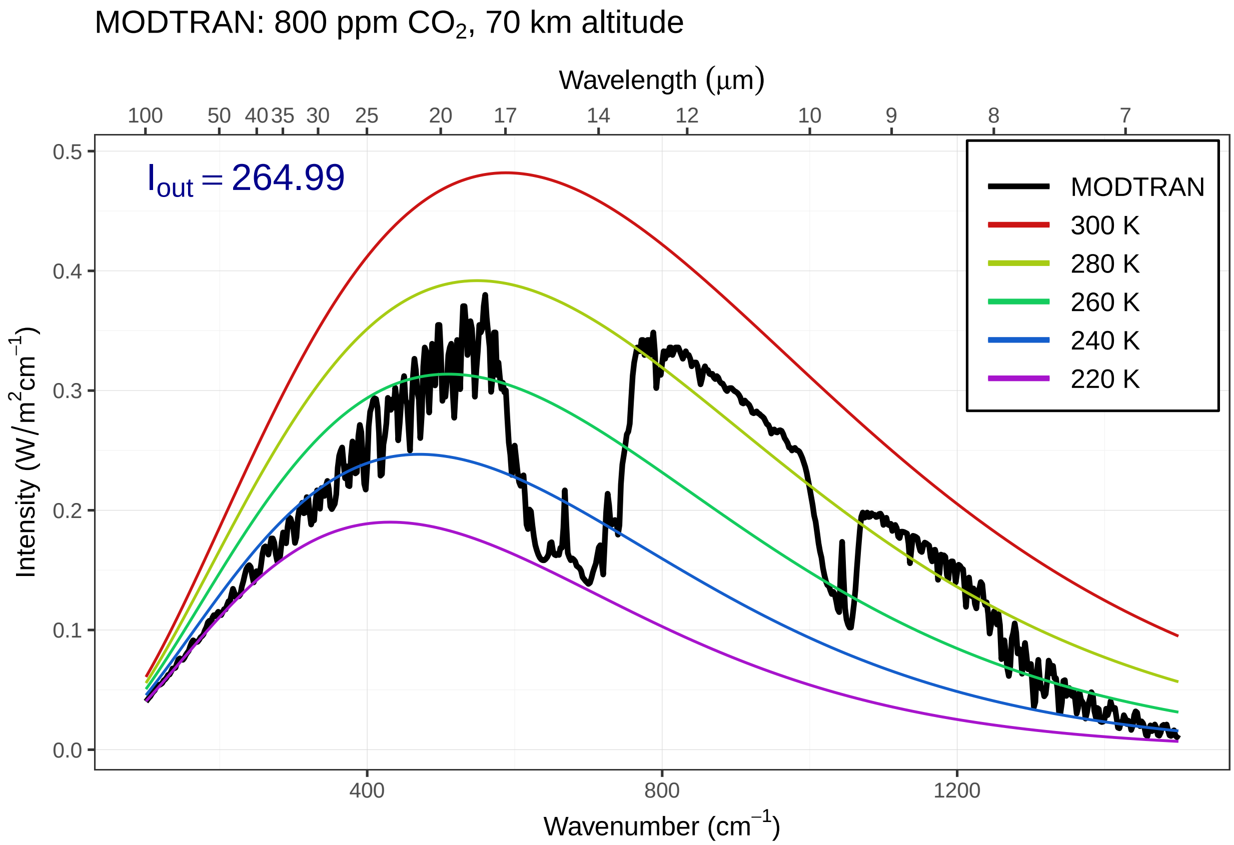
```
plot_modtran("_data/modtran_nineteen76us_baseline.txt")
```




```
run_modtran(filename = "_data/modtran_nineteen76us_increaseco2.txt", co2_ppm = 800, atmo
modtran_nineteen76us_increaseco2=read_modtran("_data/modtran_nineteen76us_increaseco2.tx
nineteen76usincreaseco2_i_out=modtran_nineteen76us_increaseco2$i_out
nineteen76usincreaseco2_i_out
```

```
## [1] 264.9933
```

```r
plot_modtran("_data/modtran_nineteen76us_increaseco2.txt")
```




```r
run_modtran(filename = "_data/modtran_nineteen76us_restore_watvap.txt", co2_ppm = 800, a
modtran_nineteen76us_restore_watvap=read_modtran("_data/modtran_nineteen76us_restore_wat
nineteen76usrestorewatvap_i_out=modtran_nineteen76us_restore_watvap$i_out
nineteen76usrestorewatvap_i_out
```

```
## [1] 267.9779
```

```r
run_modtran(filename = "_data/modtran_nineteen76us_restorehum.txt", co2_ppm = 800, atmos
modtran_nineteen76us_restorehum=read_modtran("_data/modtran_nineteen76us_restorehum.txt'
nineteen76usrestorehum_i_out=modtran_nineteen76us_restorehum$i_out
nineteen76usrestorehum_i_out
```

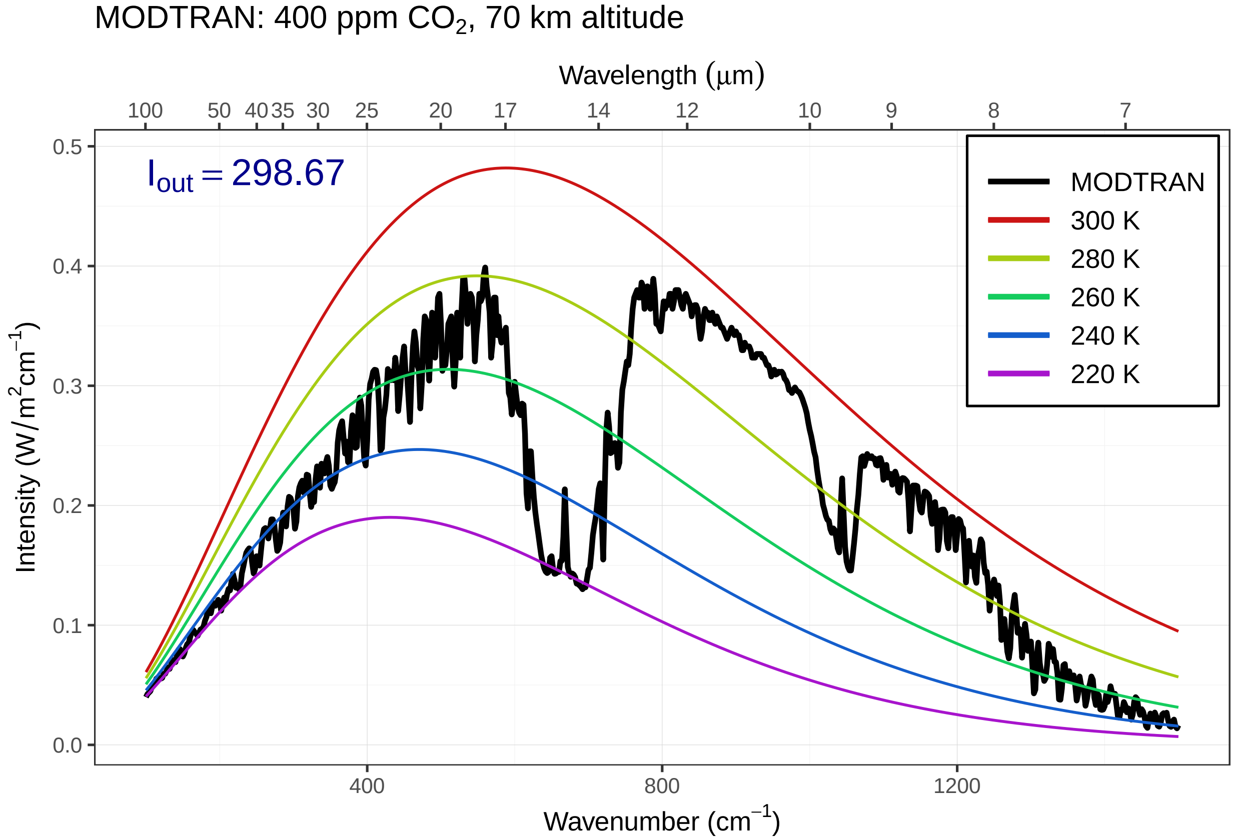
```
## [1] 267.9779
```

TROPICAL ATMOSPHERE

```r
run_modtran(filename = "_data/modtran_tropical_baseline.txt", co2_ppm = 400, atmosphere=
modtran_tropical_baseline=read_modtran("_data/modtran_tropical_baseline.txt")
tropicalbaseline_i_out=modtran_tropical_baseline$i_out
tropicalbaseline_i_out
```

```
## [1] 298.6712
```

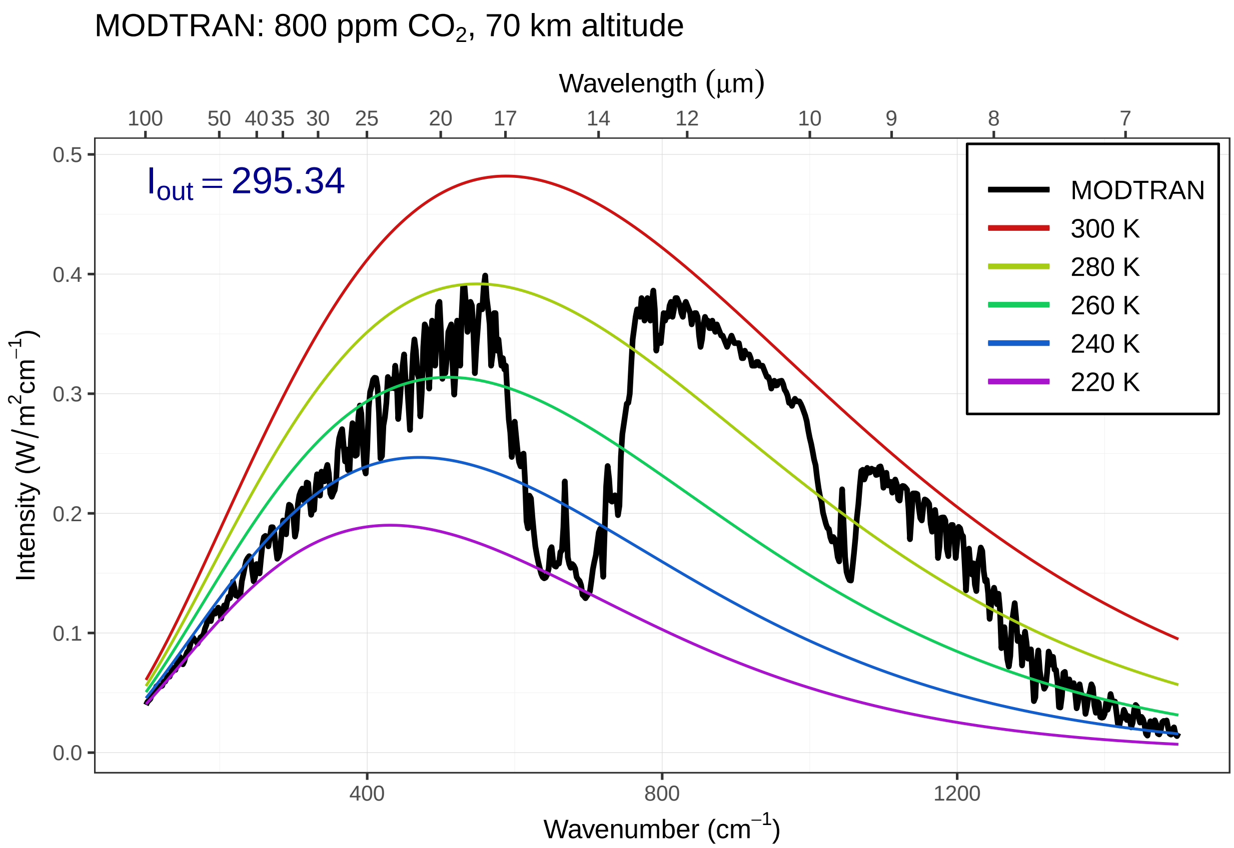
```r
plot_modtran("_data/modtran_tropical_baseline.txt")
```




```r
run_modtran(filename = "_data/modtran_tropical_increaseco2.txt", co2_ppm = 800, atmosphe
modtran_tropical_increaseco2=read_modtran("_data/modtran_tropical_increaseco2.txt")
tropicalincreaseco2_i_out=modtran_tropical_increaseco2$i_out
tropicalincreaseco2_i_out
```

```
## [1] 295.3411
```

```r
plot_modtran("_data/modtran_tropical_increaseco2.txt")
```




```
run_modtran(filename = "_data/modtran_tropical_restore_watvap.txt", co2_ppm = 800, atmos
modtran_tropical_restore_watvap=read_modtran("_data/modtran_tropical_restore_watvap.txt'
tropicalrestorewatvap_i_out=modtran_tropical_restore_watvap$i_out
tropicalrestorewatvap_i_out
```

```
## [1] 298.6712
```

```
run_modtran(filename = "_data/modtran_tropical_restorehum.txt", co2_ppm = 800, atmospher
modtran_tropical_restorehum=read_modtran("_data/modtran_tropical_restorehum.txt")
tropicalrestorehum_i_out=modtran_tropical_restorehum$i_out
tropicalrestorehum_i_out
```

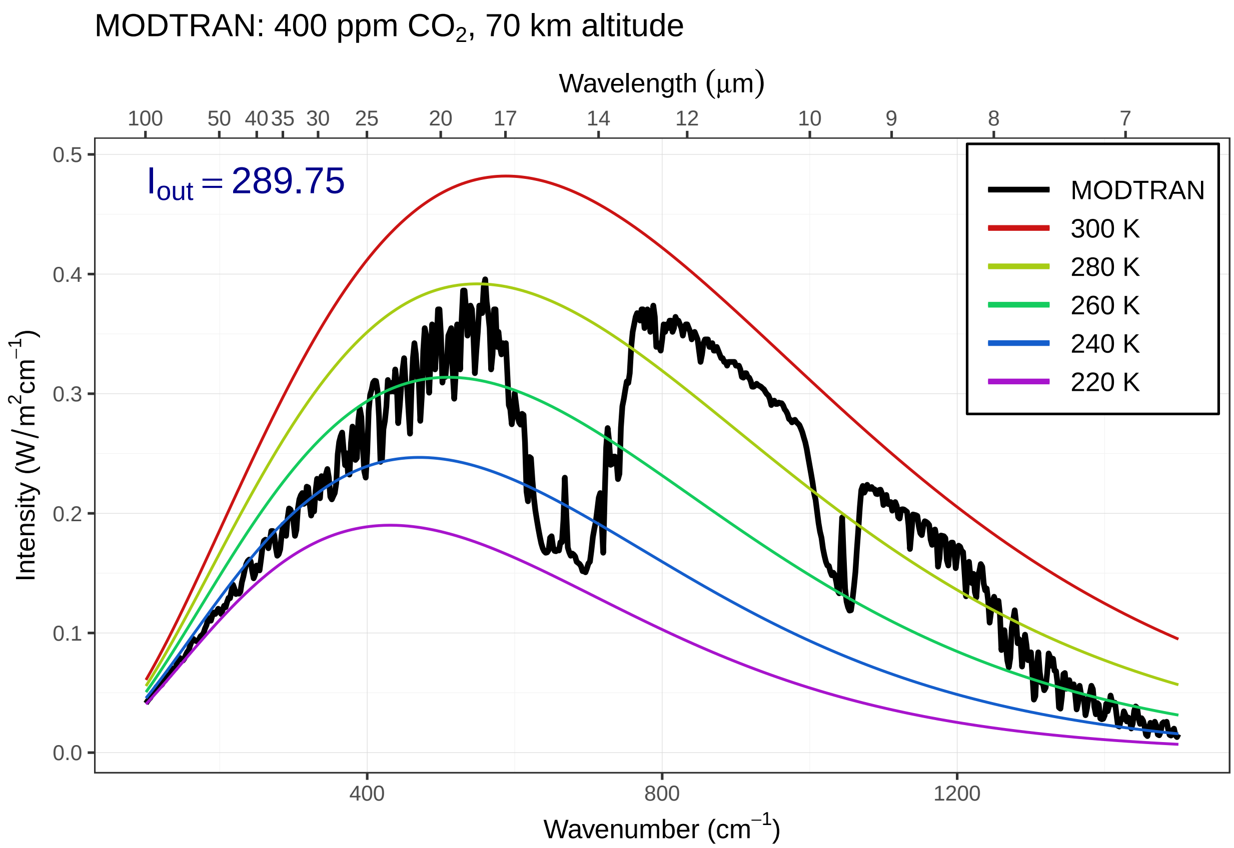
```
## [1] 298.6712
```

MIDLATITUDE SUMMER

```
run_modtran(filename = "_data/modtran_mlsummer_baseline.txt", co2_ppm = 400, atmosphere=
modtran_mlsummer_baseline=read_modtran("_data/modtran_mlsummer_baseline.txt")
mlsummerbaseline_i_out=modtran_mlsummer_baseline$i_out
mlsummerbaseline_i_out
```

```
## [1] 289.7491
```

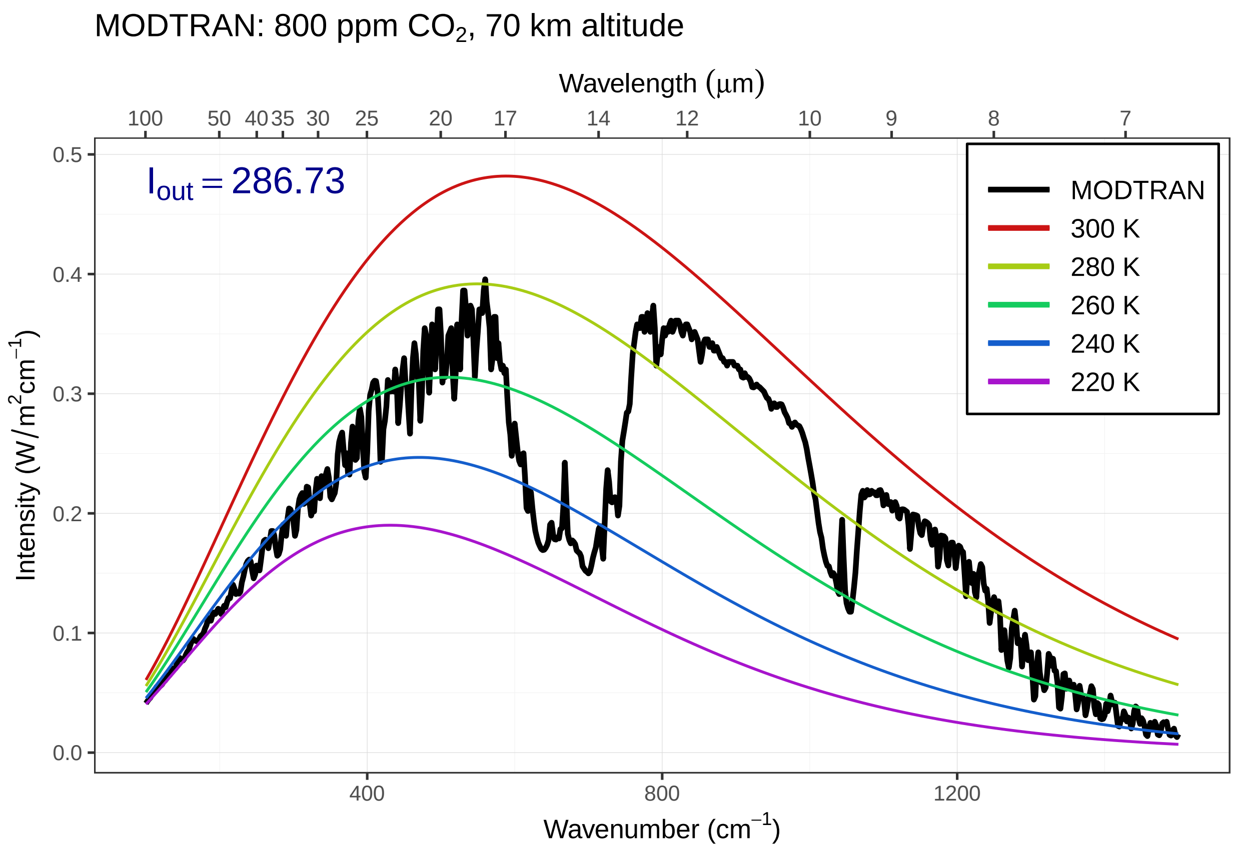
```
plot_modtran("_data/modtran_mlsummer_baseline.txt")
```




```
run_modtran(filename = "_data/modtran_mlsummer_increaseco2.txt", co2_ppm = 800, atmosphe
modtran_mlsummer_increaseco2=read_modtran("_data/modtran_mlsummer_increaseco2.txt")
mlsummerincreaseco2_i_out=modtran_mlsummer_increaseco2$i_out
mlsummerincreaseco2_i_out
```

```
## [1] 286.7332
```

```
plot_modtran("_data/modtran_mlsummer_increaseco2.txt")
```




```
run_modtran(filename = "_data/modtran_mlsummer_restore_watvap.txt", co2_ppm = 800, atmos
modtran_mlsummer_restore_watvap=read_modtran("_data/modtran_mlsummer_restore_watvap.txt'
mlsummerrestorewatvap_i_out=modtran_mlsummer_restore_watvap$i_out
mlsummerrestorewatvap_i_out
```

```
## [1] 289.7491
```

```
run_modtran(filename = "_data/modtran_mlsummer_restorehum.txt", co2_ppm = 800, atmospher
modtran_mlsummer_restorehum=read_modtran("_data/modtran_mlsummer_restorehum.txt")
mlsummerrestorehum_i_out=modtran_mlsummer_restorehum$i_out
mlsummerrestorehum_i_out
```

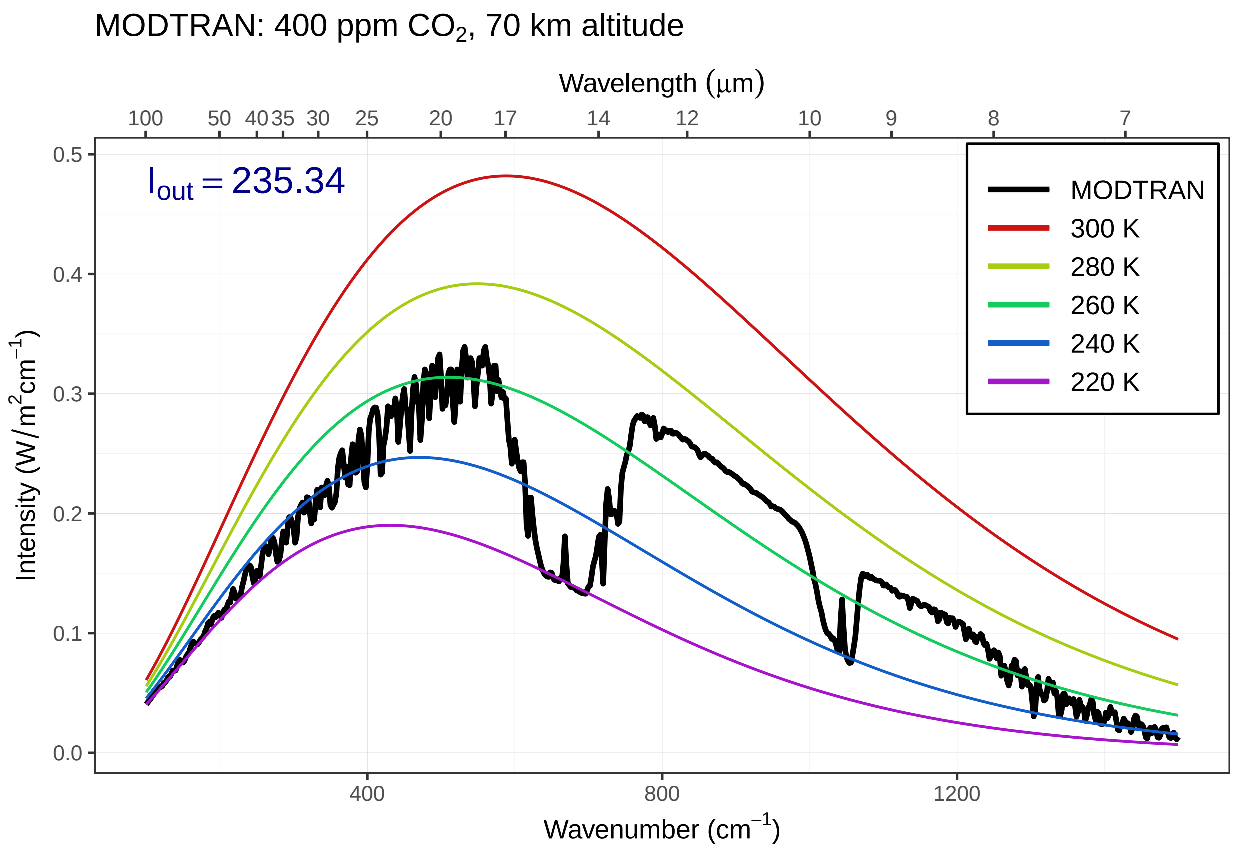
```
## [1] 289.7491
```

MIDLATITUDE WINTER

```
run_modtran(filename = "_data/modtran_mlwinter_baseline.txt", co2_ppm = 400, atmosphere=
modtran_mlwinter_baseline=read_modtran("_data/modtran_mlwinter_baseline.txt")
mlwinterbaseline_i_out=modtran_mlwinter_baseline$i_out
mlwinterbaseline_i_out
```

```
## [1] 235.3367
```

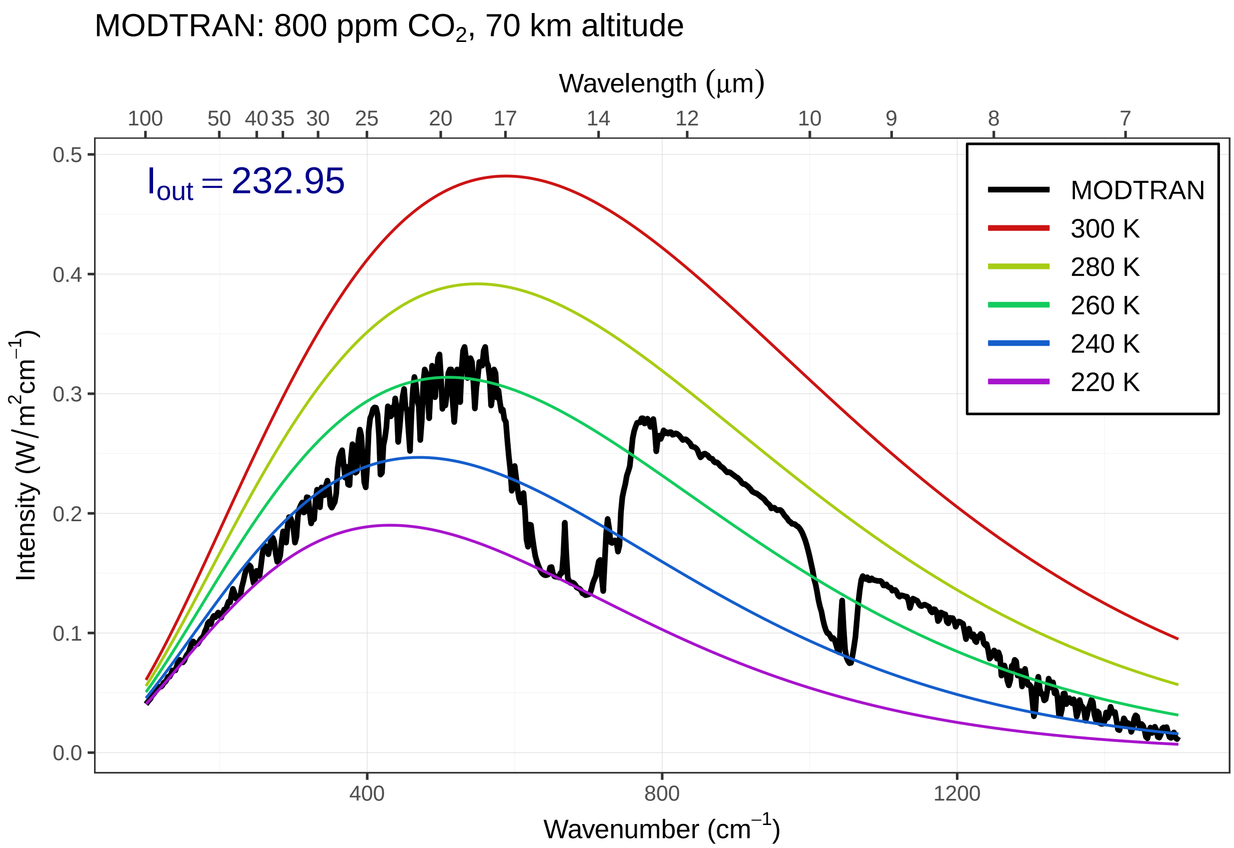
```
plot_modtran("_data/modtran_mlwinter_baseline.txt")
```




```
run_modtran(filename = "_data/modtran_mlwinter_increaseco2.txt", co2_ppm = 800, atmosphe
modtran_mlwinter_increaseco2=read_modtran("_data/modtran_mlwinter_increaseco2.txt")
mlwinterincreaseco2_i_out=modtran_mlwinter_increaseco2$i_out
mlwinterincreaseco2_i_out
```

```
## [1] 232.9491
```

```
plot_modtran("_data/modtran_mlwinter_increaseco2.txt")
```




```r
run_modtran(filename = "_data/modtran_mlwinter_restore_watvap.txt", co2_ppm = 800, atmos
modtran_mlwinter_restore_watvap=read_modtran("_data/modtran_mlwinter_restore_watvap.txt'
mlwinterrestorewatvap_i_out=modtran_mlwinter_restore_watvap$i_out
mlwinterrestorewatvap_i_out
```

```
## [1] 235.3367
```

```r
run_modtran(filename = "_data/modtran_mlwinter_restorehum.txt", co2_ppm = 800, atmospher
modtran_mlwinter_restorehum=read_modtran("_data/modtran_mlwinter_restorehum.txt")
mlwinterrestorehum_i_out=modtran_mlwinter_restorehum$i_out
mlwinterrestorehum_i_out
```

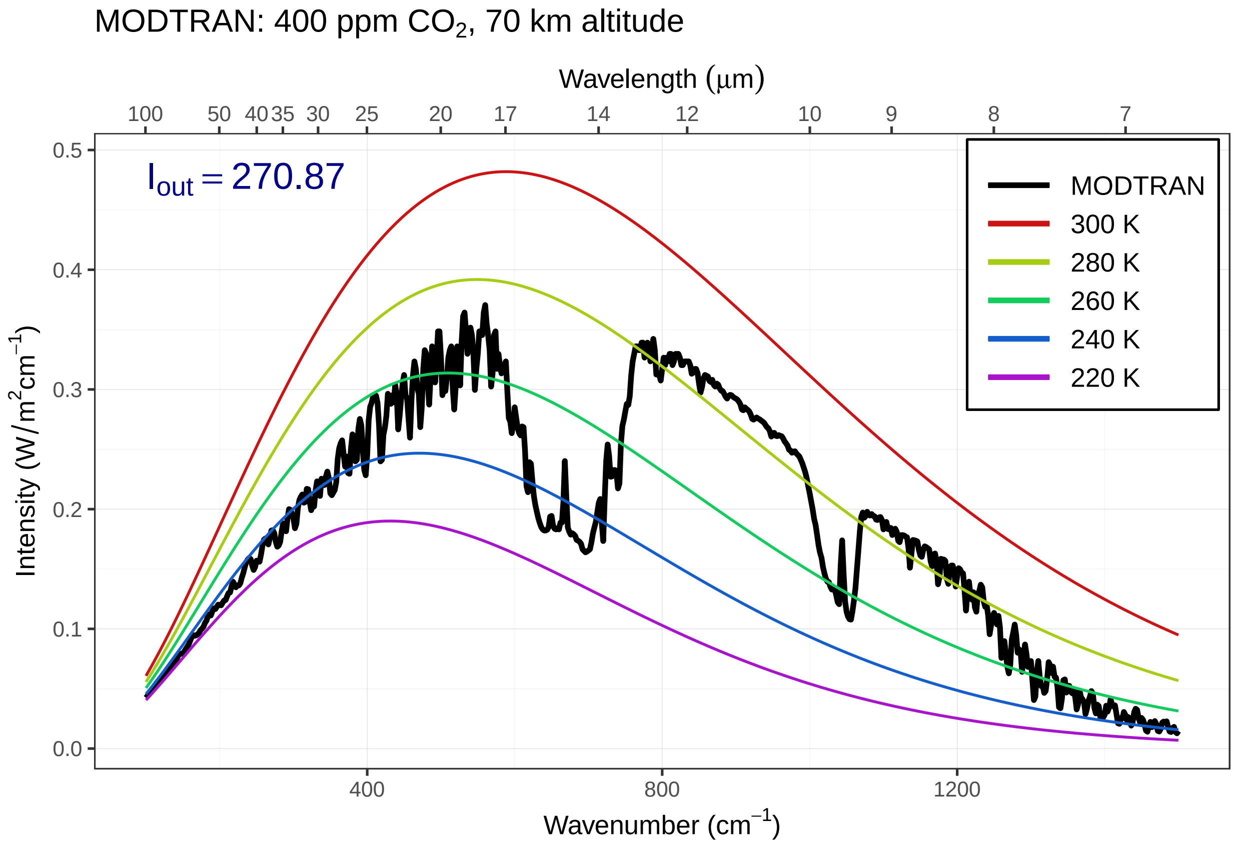
```
## [1] 235.3367
```

SUBARCTIC SUMMER

```r
run_modtran(filename = "_data/modtran_subsum_baseline.txt", co2_ppm = 400, atmosphere="s
modtran_subsum_baseline=read_modtran("_data/modtran_subsum_baseline.txt")
subsumbaseline_i_out=modtran_subsum_baseline$i_out
subsumbaseline_i_out
```

```
## [1] 270.8681
```

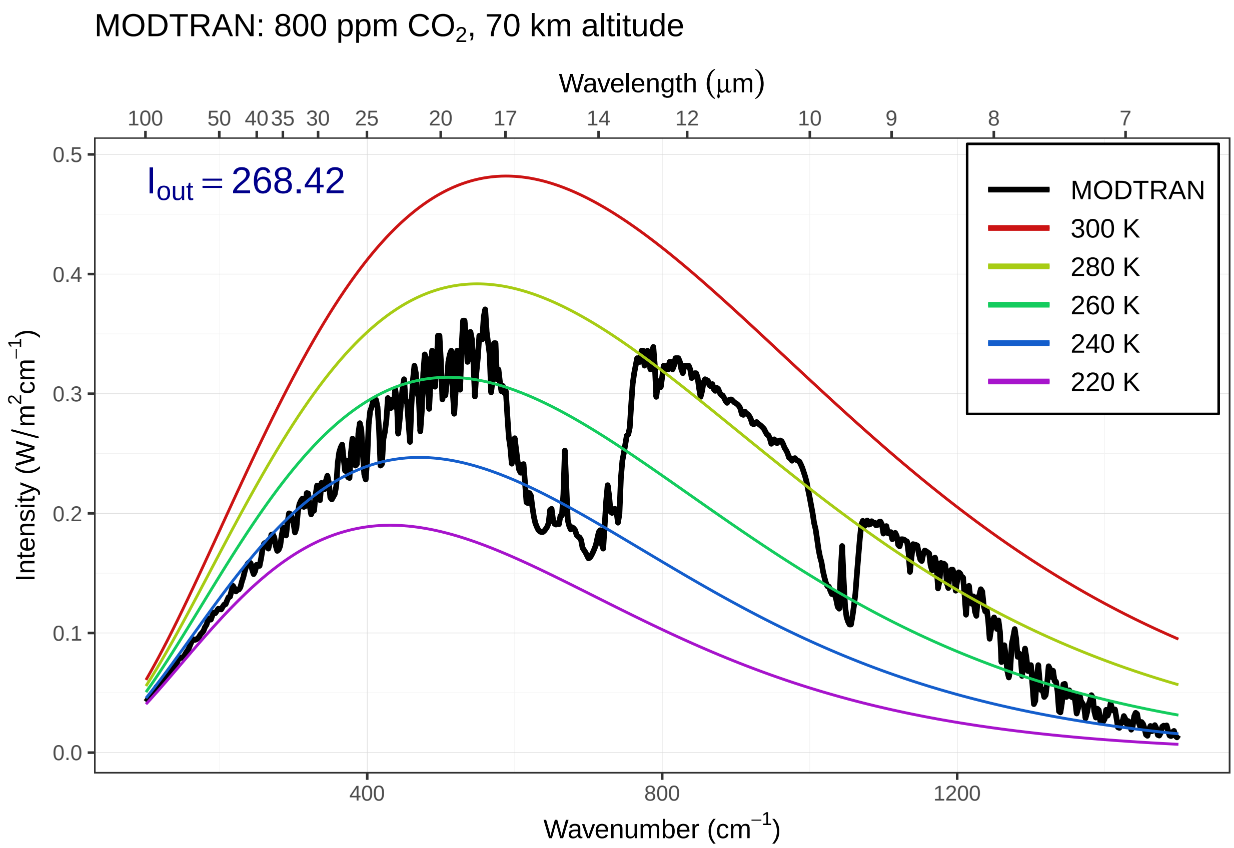
```r
plot_modtran("_data/modtran_subsum_baseline.txt")
```




```
run_modtran(filename = "_data/modtran_subsum_increaseco2.txt", co2_ppm = 800, atmosphere
modtran_subsum_increaseco2=read_modtran("_data/modtran_subsum_increaseco2.txt")
subsumincreaseco2_i_out=modtran_subsum_increaseco2$i_out
subsumincreaseco2_i_out
```

```
## [1] 268.4177
```

```
plot_modtran("_data/modtran_subsum_increaseco2.txt")
```




```
run_modtran(filename = "_data/modtran_subsum_restore_watvap.txt", co2_ppm = 800, atmosph
modtran_subsum_restore_watvap=read_modtran("_data/modtran_subsum_restore_watvap.txt")
subsumrestorewatvap_i_out=modtran_subsum_restore_watvap$i_out
subsumrestorewatvap_i_out
```

```
## [1] 270.8681
```

```
run_modtran(filename = "_data/modtran_subsum_restorehum.txt", co2_ppm = 800, atmosphere=
modtran_subsum_restorehum=read_modtran("_data/modtran_subsum_restorehum.txt")
subsumrestorehum_i_out=modtran_subsum_restorehum$i_out
subsumrestorehum_i_out
```

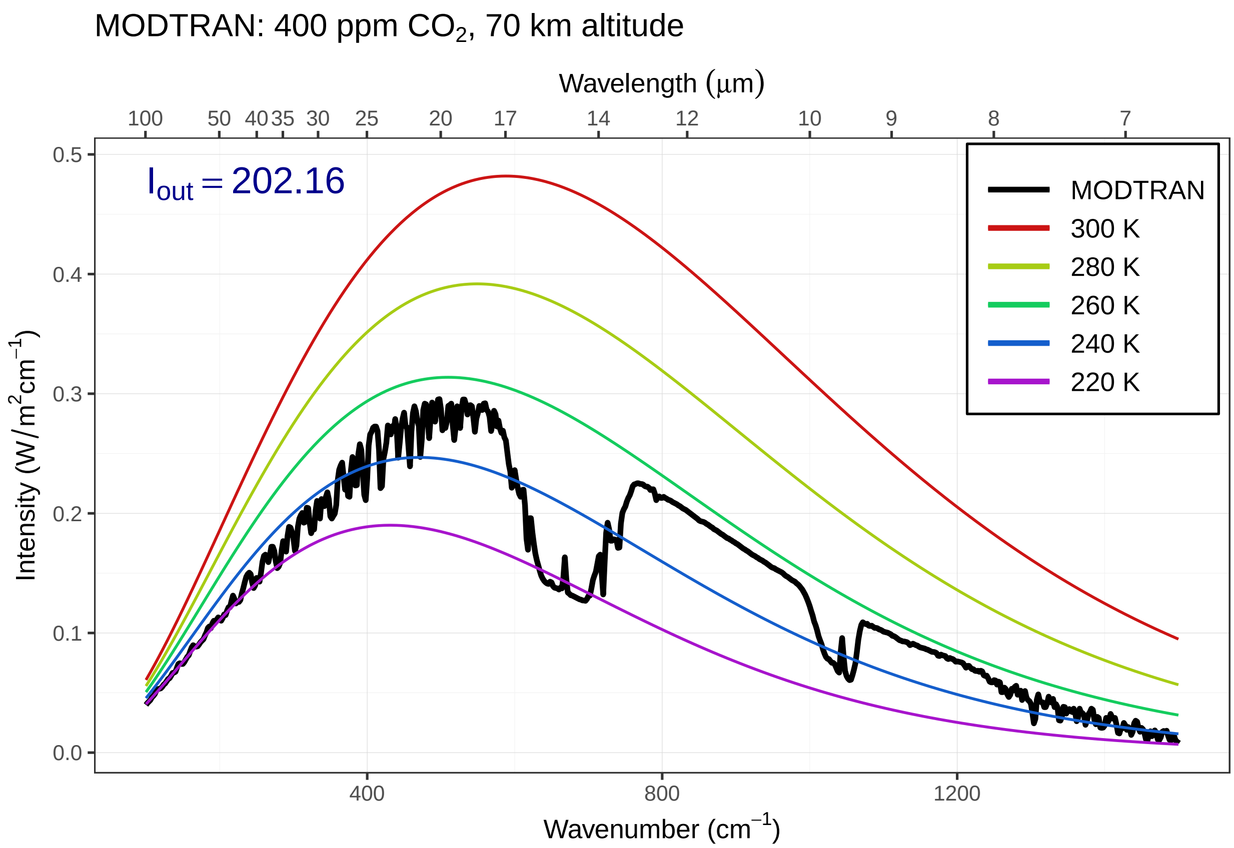
```
## [1] 270.8681
```

SUBARCTIC WINTER

```
run_modtran(filename = "_data/modtran_subwint_baseline.txt", co2_ppm = 400, atmosphere="
modtran_subwint_baseline=read_modtran("_data/modtran_subwint_baseline.txt")
subwintbaseline_i_out=modtran_subwint_baseline$i_out
subwintbaseline_i_out
```

```
## [1] 202.1615
```

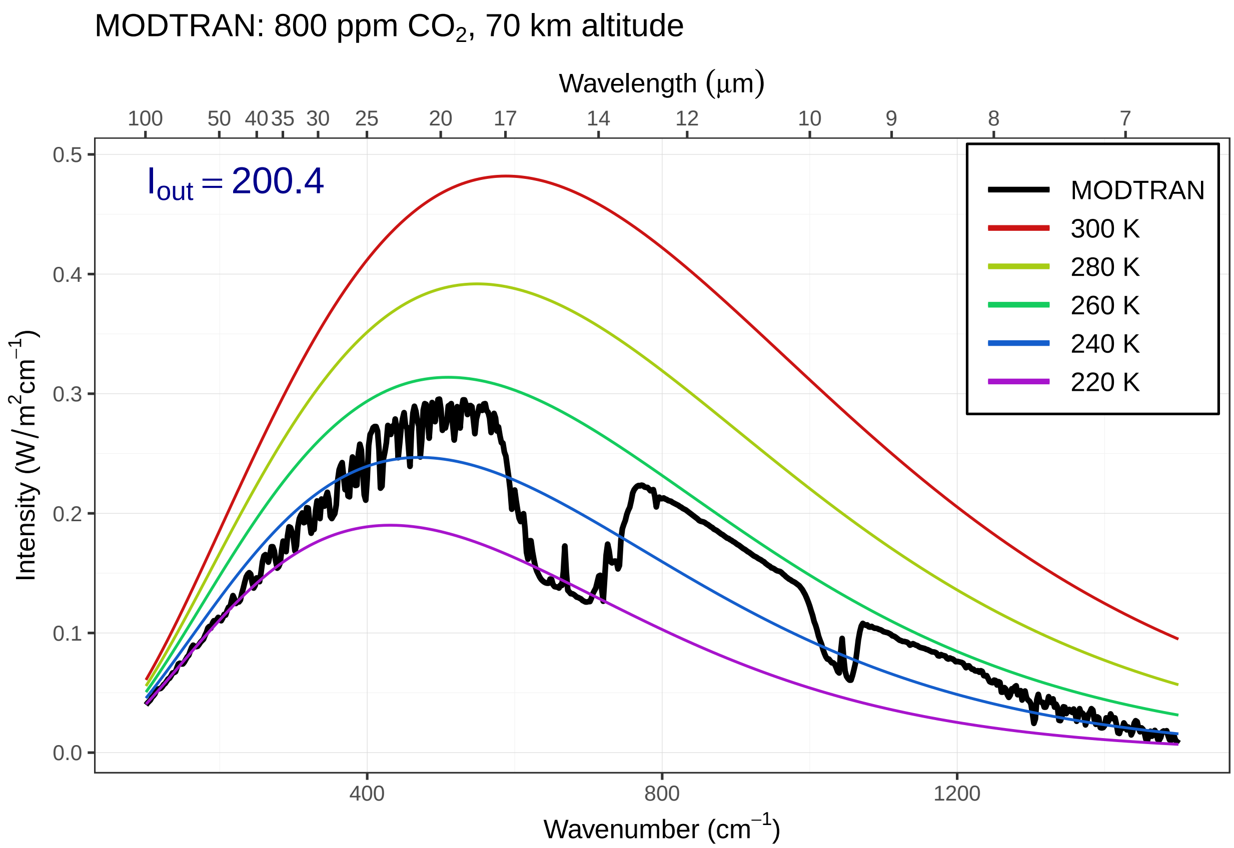
```
plot_modtran("_data/modtran_subwint_baseline.txt")
```




```r
run_modtran(filename = "_data/modtran_subwint_increaseco2.txt", co2_ppm = 800, atmospher
modtran_subwint_increaseco2=read_modtran("_data/modtran_subwint_increaseco2.txt")
subwintincreaseco2_i_out=modtran_subwint_increaseco2$i_out
subwintincreaseco2_i_out
```

```
## [1] 200.4022
```

```r
plot_modtran("_data/modtran_subwint_increaseco2.txt")
```




```r
run_modtran(filename = "_data/modtran_subwint_restore_watvap.txt", co2_ppm = 800, atmosp
modtran_subwint_restore_watvap=read_modtran("_data/modtran_subwint_restore_watvap.txt")
subwintrestorewatvap_i_out=modtran_subwint_restore_watvap$i_out
subwintrestorewatvap_i_out
```

```
## [1] 202.1615
```

```r
run_modtran(filename = "_data/modtran_subwint_restorehum.txt", co2_ppm = 800, atmosphere
modtran_subwint_restorehum=read_modtran("_data/modtran_subwint_restorehum.txt")
subwintrestorehum_i_out=modtran_subwint_restorehum$i_out
subwintrestorehum_i_out
```

```
## [1] 202.1615
```

Results

```r
frame_data (
~"Atmosphere",~"I_out with 400 ppm CO2 (W/m^2)",~"I_out with 800 ppm CO2 (W/m^2)",~"Stab
"1976 Standard U.S.", nineteen76usbaseline_i_out, nineteen76usincreaseco2_i_out, 0.75, 1
"Tropical", tropicalbaseline_i_out, tropicalincreaseco2_i_out, 0.76, 1.21,
"Midlatitude Summer", mlsummerbaseline_i_out, mlsummerincreaseco2_i_out, 0.715, 1.03,
"Midlatitude Winter", mlwinterbaseline_i_out, mlwinterincreaseco2_i_out, 0.653, 0.83,
"Subarctic Summer", subsumbaseline_i_out, subsumincreaseco2_i_out, 0.6, 0.83,
"Subarctic Winter", subwintbaseline_i_out, subwintincreaseco2_i_out, 0.54, 0.64
```

```
)
```

```
## Warning: `frame_data()` is deprecated, use `tribble()`.
## This warning is displayed once per session.
```

```
## # A tibble: 6 x 5
##   Atmosphere `I_out with 400... `I_out with 800... `Stabilizing de... `Stabilizing de
##   <chr>                   <dbl>             <dbl>             <dbl>             <dbl>
## 1 1976 Stan...             268.              265.              0.75              1.06
## 2 Tropical                299.              295.             0.76              1.21
## 3 Midlatitu...             290.              287.              0.715             1.03
## 4 Midlatitu...             235.              233.              0.653             0.83
## 5 Subarctic...             271.              268.              0.6               0.83
## 6 Subarctic...             202.              200.              0.54              0.64
```

```
frame_data (
~"Atmosphere",~"Decrease in I_out (W/m^2)",~"Percent Decrease",
"1976 Standard U.S.", nineteen76usbaseline_i_out-nineteen76usincreaseco2_i_out, ((( nine
"Tropical", tropicalbaseline_i_out-tropicalincreaseco2_i_out, ((( tropicalbaseline_i_out
"Midlatitude Summer", mlsummerbaseline_i_out-mlsummerincreaseco2_i_out, ((( mlsummerbase
"Midlatitude Winter", mlwinterbaseline_i_out-mlwinterincreaseco2_i_out, ((( mlwinterbase
"Subarctic Summer", subsumbaseline_i_out-subsumincreaseco2_i_out, ((( subsumbaseline_i_o
"Subarctic Winter", subwintbaseline_i_out-subwintincreaseco2_i_out, ((( subwintbaseline_
)
```

```
## # A tibble: 6 x 3
##   Atmosphere         `Decrease in I_out (W/m^2)` `Percent Decrease`
##   <chr>                                    <dbl>              <dbl>
## 1 1976 Standard U.S.                        2.98              1.11
## 2 Tropical                                  3.33              1.11
## 3 Midlatitude Summer                        3.02              1.04
## 4 Midlatitude Winter                        2.39              1.01
## 5 Subarctic Summer                          2.45              0.905
## 6 Subarctic Winter                          1.76              0.870
```

With 400 ppm CO2 set as the parameter, our experiment showed the greatest initial I_out value in the tropical atmosphere with an I_out of 298.6712 W/m2. The lowest I_out value of 202.1615 W/m2 was in the subarctic winter atmosphere. The 1976 Standard Atmosphere had an I_out of I267.9779 W/m2. After an increase in the atmospheric CO2 parameter to 800 ppm, we observed intensities of 295.3411 W/m2 in the tropical atmosphere simulation, 200.4022 W/m2 in the subarctic summer simulation, and 264.9933 W/m2 in the 1976 Standard Atmosphere. This increase in CO2 resulted in a decrease in I_out across the board. Plots showing the intensity of emitted radiation for the spectrum of emitted wavenumbers showed a wider CO2 absorption window after the addition of CO2. This decrease in intensity of outgoing radiation was found for each atmosphere type and used to calculate the percent decrease in I_out. The 1976 Standard Atmosphere showed a percent decrease in I_out of 1.114%. The tropics showed the largest percent decrease at 1.115%. The subarctic winter showed the lowest percent decrease at 0.870%. We also looked at the surface temperature increase required in each locality to return post-spike I_out levels to pre-spike levels. With fixed water vapor pressure, the 1976 Standard Atmosphere showed a predicted 0.750 °C increase in temperature. The temperature increase for a tropical atmosphere was higher at 0.760 °C. For the summer atmospheres of both midlatitude and subarctic latitudes, the temperature increase was less than the tropical and 1976 Standard Atmosphere atmospheres with increases of 0.716 °C and 0.600 °C, respectively. The winter atmospheres produced much less warming. The midlatitude winter had a temperature increase of 0.653 °C and the subarctic winter showed an increase of 0.540 °C. Note that the temperature increase for the subarctic summer was still less than the midlatitude winter. In this model where the vapor pressure of water is held constant the tropics warmed more than the midlatitude summer by a difference of 0.044 °C. The tropics increased in temperature more than the 1976 Standard Atmosphere by a difference of 0.010 °C. The general trend above was repeated in the model where water vapor was held to a constant relative humidity. However, the magnitude of temperature change was greater across all atmosphere types. The 1976 Standard Atmosphere increased by 1.06 °C. The tropical atmosphere warmed by 1.21 °C. The midlatitude summer and winter warmed by 1.03 °C and 0.83 °C, respectively. These values were again higher than the subarctic summer and winter which warmed by 0.83 °C and 0.64 °C. Note here that the midlatitude winter and subarctic summer experienced the same increase. For this model, where water vapor was fixed at a constant relative humidity, the tropics warmed more than the midlatitude summer by a difference of 0.18 °C. The warming was 0.15 °C greater for the tropics than for the 1976 Standard U.S. atmosphere.

Conclusion Our data reveal several key factors regarding the effects of increasing carbon dioxide levels and the associated climate change on diverse regions throughout the globe. First, we found a general trend that warmer locations exhibit higher outgoing radiation intensity levels. This is to be expected, as these hotter regions receive more incoming solar radiation and thus must balance this with higher levels of outgoing radiation. Next, following an increase in atmospheric CO2, we saw a general trend that warmer, more humid regions experienced greater decreases in outgoing radiation than colder, drier regions. The tropical atmosphere I_out went down by a magnitude of 3.33 W/m2, a 1.15% decrease, while the subarctic winter atmosphere I_out, at the lower end of the spectrum, decreased by a magnitude of 1.76 W/m2, a 0.87% decrease. Of course, we would expect the tropical atmosphere to demonstrate the highest I_out decrease as all atmospheres studied were put under the same CO2 spike and the tropical atmosphere had the highest base I_out. Thus, if all atmospheres lost the same percentage of I_out, then the tropical atmosphere would lose the most. However, the percentage I_out decrease tells a more interesting story, as the tropical atmosphere also led the other subjects in percent decrease. This is likely due to the fact that the tropical atmosphere has both the highest temperature and a higher fixed vapor pressure of water in the modelling of this atmosphere. This high H2O would be a factor in a CO2 increase where higher CO2 levels would lead to higher temperatures and a greater greenhouse effect due to the higher vapor pressure of H2O. Therefore, we see that increased H2O levels in a region lead to greater sensitivity to changes in CO2 and subsequent larger drops in I_out. This trend is echoed, with slight variation, throughout the regional dataset we compiled. Our research also sheds light on the way CO2 affects the rise of temperature in different regions. Holding water vapor pressure fixed, we see a similar trend in the temperature rise required to bring outgoing radiation back into balance post CO2 spike as we did with the I_out decreases. It is the tropical atmosphere that requires the highest temperature change (0.76 °C) and the subarctic winter atmosphere the lowest (0.54 °C). This is likely due to the fact that atmospheres experiencing greater decrease in I_out levels require higher temperature changes to return their I_out to equilibrium levels. Finally, the data here shows how humidity and water vapor play a role in defining the effect of climate change on a region. When holding relative humidity constant, we saw an increase, relative to when we held water vapor pressure constant, in the temperature change required to return I_out to its pre-spike levels across the board in the different atmospheres. The order of these temperature change magnitudes stayed the same, except that the change in the subarctic summer atmosphere increased enough to match that of the midlatitude winter atmosphere. The tropical atmosphere demonstrated the highest increase of 0.45 °C, with the second highest increase coming in the midlatitude summer region (0.315 °C). This phenomenon is likely because holding relative humidity fixed allows water vapor pressure in the modeled atmosphere to change with temperature, and, as mentioned before, the tropical atmosphere has the higher h2o values. These large h2o values would result in an influx of water vapor as the temperature warmed in these tropical regions, increasing the greenhouse effect and requiring higher temperature increase to balance I_out levels. What our data and research most powerfully show is the disparate effects that atmospheric carbon dioxide and climate change have on different regions of the world. Because of their solar exposure and higher humidity it is the regions closest to the equator, namely the tropical areas of the world, that will be hit the hardest by greenhouse gases. These regions will experience temperature rise on a greater level than areas at higher latitudes and will also be subject to more ruthless feedback loops (water vapor). These regions are also some of those most vulnerable and at-risk from the dangers of climate change. Many countries in the tropical and midlatitude regions already struggle with droughts and natural disasters which may only be exacerbated by climate change (EPA, 2017). Additionally, developing nations in the tropical regions may struggle to find resources to address climate related issues. The results of the modeling showed regional differences in the effects of climate change. These results demonstrate the need for further exploration of this topic. The different atmosphere types used in this model vary in their temperatures and gas compositions. These differences lead to the variation in temperature change. The regions of the world differ in more ways than their atmospheric composition and temperature. If this work is to be continued, more variables that differ by latitude should be examined for their effects on warming. Precipitation, clouding, and atmospheric circulation through convection were not explored in this experiment. Future research should explore these variables.

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