WORK PACKAGE

DOCUMENT NUMBER	EQUIPMENT OR SUB-SYSTEM

SUBJECT

Standard Atmospheres

DISTRIBUTION

CONCLUSIONS/DECISIONS/AMENDMENTS

1. This work package describes several standard atmospheres used in previous projects: (1) Set-A, (2) OSSIM, and (3) Morticia. The conditions cover typical and extreme conditions as used in the projects.

2. The atmospheric profiles captured here are not all equally analysed. Set-A is analysed in detail (most of this document describes various aspect of Set-A models. The OSSIM and Mortica atmospheric profiles are contained in the repository, but not analysed here.

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DATE	DATE	DATE May 7, 2020
PREVIOUS PACKAGE NO.	SUPERSEDING PACKAGE NO.	CURRENT PACKAGE NO.

CONTENTS

1 INTRODUCTION

A number of 'standard' atmospheres were defined to cover the expected range of climatic conditions to be used in design analyses and optimisations. This document defines and analyses the Modtran-calculated transmittance data. Modtran 5.0 was used in these calculations.

The path definitions and data are stored in the git repository at
`https://github.com/NelisW/StandardAtmospheres.git`

1.1 Atmosphere Scenarios

1.1.1 OSSIM Atmosphere Scenarios

The OSSIM data files have two variations: a Lowtran version and a Modtran version. The Modtran version has the word Modtran appended to the filename. The filenames have the `*.inp` extension, but these are standard `tape5` files.

OSSIM Modtran files are normally slant paths.

Modtran lattitude/longitude conventions is North of the Equator and West of Greenwich.

The files reported here have aerosol types, surface albedo, visibility and date and time of day. OSSIM overwrites these values with the values supplied in the scenario files.

1.1.1.1 DCOTBMLSNavMar15Nov11hMod4

MLS, Navy Maritime, good 65 km visibility

Mid-Latitude Summer, Navy Maritime aerosol with 4.1 $\mathrm{m\,s^{-1}}$ wind speed (current and 24-hour average) with visibility of 65 km, ground level P=1012 mbar, T=21C, RH=76%, 14 g/m^3 absolute humidity. The lattitude/longitude are -34.454° (South) and 339.601° (West from Greenwich). Local time is 11:00 (09:00 GMT) on day 319 (15 November).

1.1.1.2 Irene_somer_dag

Summer day in Pretoria, 23 km visibility

Summer day in Irene, Pretoria. User model (21 layers), 23 km visibility Rural aerosol, ground level 1413 metre above sea level, P=849 mbar, T=24.8C, RH=61%, 13.9 g/m^3 absolute humidity.

1.1.1.3 MidlatitudeSummer

MLS, moderate temperature, 23 km visibility

MLS, 23 km visibility Rural aerosol, P=1012 mbar, T=21C, RH=76%, 14 g/m^3 absolute humidity.

1.1.1.4 MidlatitudeWinter

MLW, cold, 23 km visibility

MLW, 23 km visibility Rural aerosol, P=1018 mbar, T=-1C, RH=77%, 3 g/m^3 absolute humidity.

1.1.1.5 USStandardModtran

US Standard, cool 23 km visibility

US Standard, 23 km visibility Rural aerosol, P=1013 mbar, T=15C, RH=46%, 5.9 g/m^3 absolute humidity.

1.1.1.6 UserDefinedTemplate

This file is not used directly in its original form in OSSIM. This file is a template used when a meteorological file is used. The meteorological file contents is used to overwrite some fields in this template file.

1.1.1.7 Tropical

Moderate temperature, 23 km Rural visibility

Tropical, 23 km visibility Rural aerosol, ground level P=1013 mbar, T=26.5C, RH=75%, 18.8 g/m^3 absolute humidity.

This is the same as Set-A TropicalUrban.

1.1.1.8 SubarticWinter

Sub-Artic winter day, very cold with moderate visibility

Sub-Arctic Winter, 23 km visibility Rural aerosol P=1013 mbar, T=-15.9C, RH=80%, 1 g/m^3 absolute humidity.

1.1.1.9 SubarticSummer:

Scandinavian summer day

Sub-Arctic Summer, 23 km visibility Rural aerosol, P=1010 mbar, T=14C, RH=75%, 9 g/m^3 absolute humidity.

1.1.1.10 PretoriaTropicalRural23km15NovXXh

Warm temperature, 23 km Rural visibility, different times of day

Tropical, 23 km visibility Rural aerosol, ground level P=1013 mbar, T=26.5C, RH=75%, 18.8 g/m^3 absolute humidity. The lattitude/longitude are for Pretoria at -25.75° (South) and 331.71° (West from Greenwich). Three different local times are used in the separate files [09:00, 12:00, 15:00] (07:00, 10:00, 13:00 GMT) on day 319 (15 November).

The terrain albedo is zero for all the terrains, except for `PretoriaTropicalRural23km15Nov09h-desertAlbedo` which uses the Modtran desert albedo.

1.1.1.11 Overberg_2_2_1996

Summer day in Pretoria, 23 km visibility

Summer day at Overberg Test Range, Western Cape. User model (33 layers), 23 km visibility Rural aerosol, 0 metre above sea level, at ground level P=1011 mbar, T=26.5C, RH=69%, 17.3 g/m^3 absolute humidity.

1.1.2 Morticia Atmosphere Scenarios

To be completed later.

1.1.3 Set-A Atmosphere Scenarios

1.1.3.1 ExtremeHotLowHumidity

very hot, low humidity, 75 km Desert visibility - no wind, clear day in the desert

User model (36 layers), 70 km visibility Desert aerosol, ground level P=1030 mbar, T=44C, RH=30%, 18.1 g/m^3 absolute humidity.

1.1.3.2 ExtremeHumidity:

very high humidity - Arabian gulf, tropical Africa / Amazon

User model (36 layers), 23 km visibility Rural aerosol, ground level P=1030 mbar, T=35C, RH=95%, 37.9 g/m^3 absolute humidity. At sea level, this atmosphere corresponds with the highest recorded dew point at 34 °C. MIL-HDBK-310 indicates that the probability of absolute humidity exceeding this level is significantly less than 1%. This corresponds to the highest recorded humidity ever, recorded in Sharjah in the UAE.

1.1.3.3 MidLatMaritimeSummer:

Mediterranean coastal summer day good visibility

Mid-Latitude Summer, 23 km visibility Maritime aerosol, ground level P=1012 mbar, T=21C, RH=76%, 14 g/m^3 absolute humidity.

1.1.3.4 MidLatMaritimeWinter:

Mediterranean coastal winter day poor visibility

Mid-Latitude Winter, 10 km visibility Maritime aerosol, ground level P=1018 mbar, T=-1C, RH=77%, 3 g/m^3 absolute humidity.

1.1.3.5 ScandinavianSummer:

Scandinavian summer day, windy conditions

Sub-Arctic Summer, 31 km visibility Navy Maritime aerosol (wind speed 20 m/s, 24 hr ave 8 m/s), ground level P=1010 mbar, T=14C, RH=75%, 9 g/m^3 absolute humidity.

1.1.3.6 ScandinavianWinter:

Scandinavian winter day, windy conditions

Sub-Arctic Winter, 31 km visibility Navy Maritime aerosol (wind speed 20 m/s, 24 hr ave 8 m/s), ground level P=1010 mbar, T=-15.9C, RH=80%, 1 g/m^3 absolute humidity.

1.1.3.7 TropicalDesert:

Moderate temperature, 75 km Desert visibility - no wind, clear day in the desert

Tropical, 75 km visibility Desert aerosol, ground level P=1013 mbar, T=26.5C, RH=75%, 18.8 g/m^3 absolute humidity.

1.1.3.8 TropicalRural:

Moderate temperature, 23 km Rural visibility

Tropical, 23 km visibility Rural aerosol, ground level P=1013 mbar, T=26.5C, RH=75%, 18.8 g/m^3 absolute humidity.

1.1.3.9 TropicalUrban:

Moderate temperature, 5 km Urban visibility

Tropical, 5 km visibility Urban aerosol, ground level P=1013 mbar, T=26.5C, RH=75%, 18.8 g/m^3 absolute humidity.

1.1.3.10 USStdNavyMarVis23km:

Moderately Low temperature, moderate humidity, 23 km Navy Maritime visibility

US Standard, 23 km visibility Navy Maritime aerosol, ground level P=1013 mbar, T=15C, RH=46%, 5.9 g/m^3 absolute humidity. Windspeed of 7.4 m/s corresponds to a Beaufort sea state 4.

2 SET-A ATMOSPHERES

2.1 Introduction

The ground height for all atmospheric models is at sea level.

The paths were calculated from the stated altitude at a slant angle of 45 deg down to earth (zenith angle of 135 degrees), but then normalised to a 1 km path length (irrespective of the actual path length). This normalised path length is then later used to calculate the transmittance along the actual path length.

Within the constraints of a few assumptions, the transmittance for a path at a slant angle of -45 degrees can be used to calculate the transmittance at any other downward slant path angle. These constraints are

1. The new path starts at the same altitude for which the original data was calculated.
2. The earth is flat, and hence the curvature of atmospheric profiles are ignored.
3. The path length is adapted to account for the different path length at a different slant angle.
4. The path intersects the ground, even if at infinity for slant angles minutely below the horizontal.

2.2 Data formats

The following data files are available:

./scenario/alt/scenario-altm.1km

Atmo transmittance normalised to 1 km path length, irrespective of actual path length. Space delimited text file, col0=wavelength in um, col1=transmittance First line describes the file scenario and altitude. These files conform to the NV-IPM vector file format.

./scenario/scenario.png

A plot of normalised transmittance values for all altitudes.

./AllScen-altm.png

A plot of normalised transmittance values for all scenarios at the stated altitude.

./scenario/scenario.xlsx

An Excel spreadsheet of normalised transmittance values for all altitudes for stated scenario.

2.3 Preparing for Analysis

The analysis is done with the `Analyse-Standard-Atmospheres.ipynb` notebook. However, before running the notebook the Python scripts must be executed to create all the Modtran tape5 files in the many different folders.

See Listing 5.1 for the code to prepare the environment.

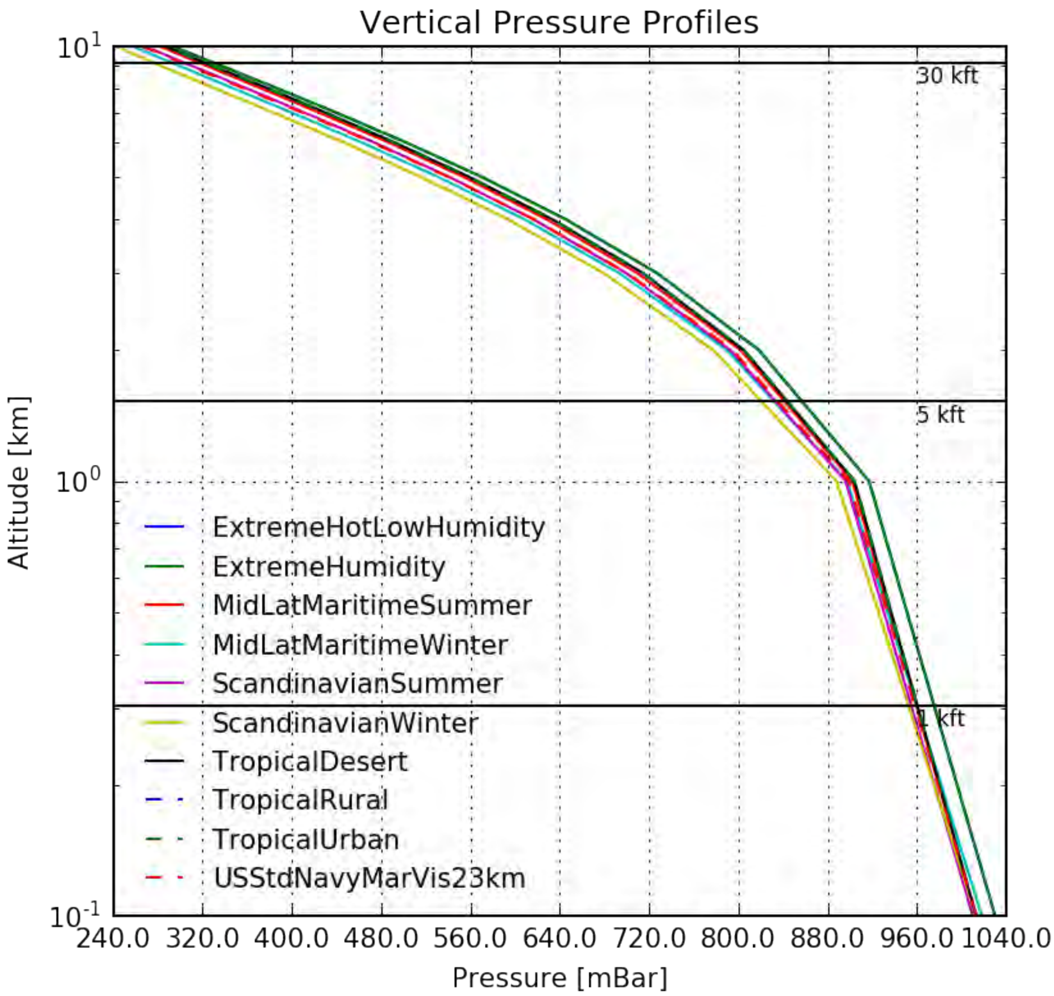
Load the standard atmospheric atmospheres definitions.

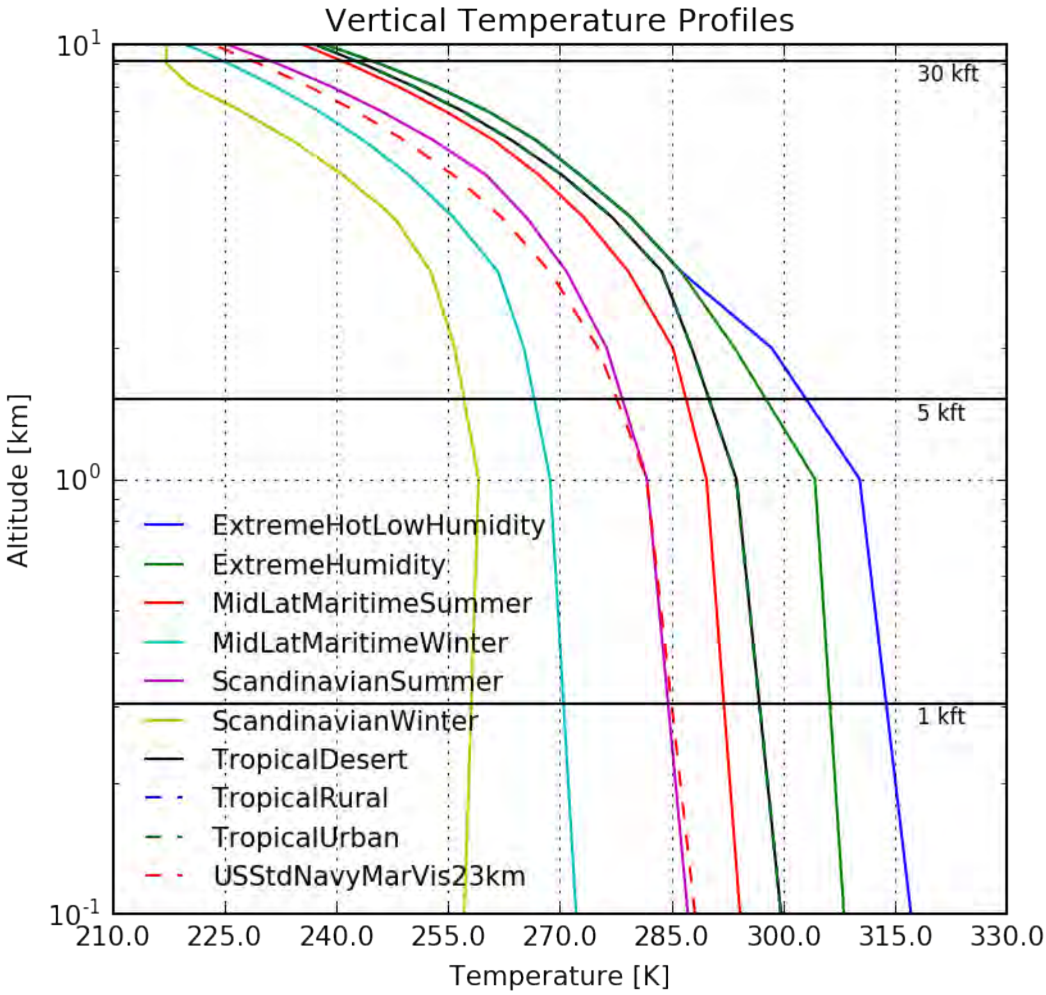
See Listing 5.2 for the code to define the atmospheres.

2.4 Atmospheric Vertical Profiles

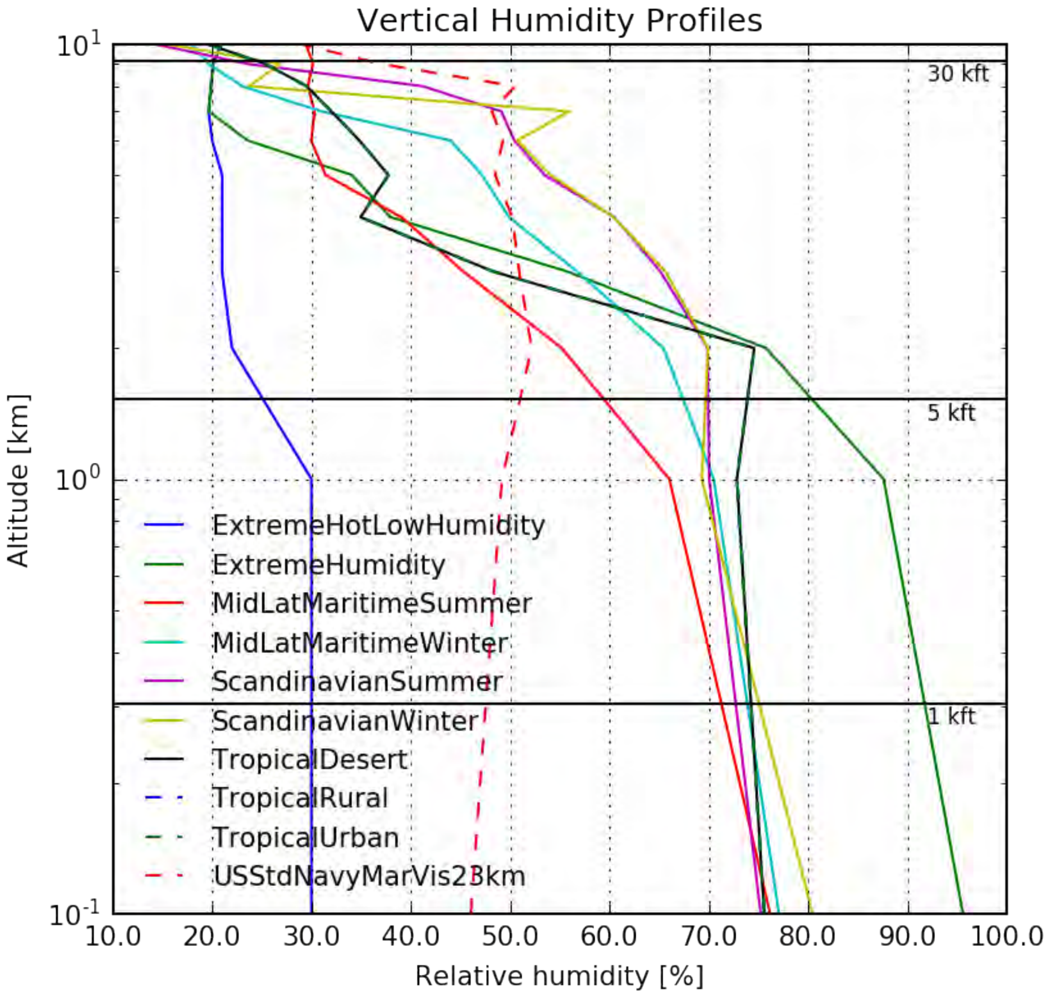
The vertical profiles are extracted from the tape6 files.

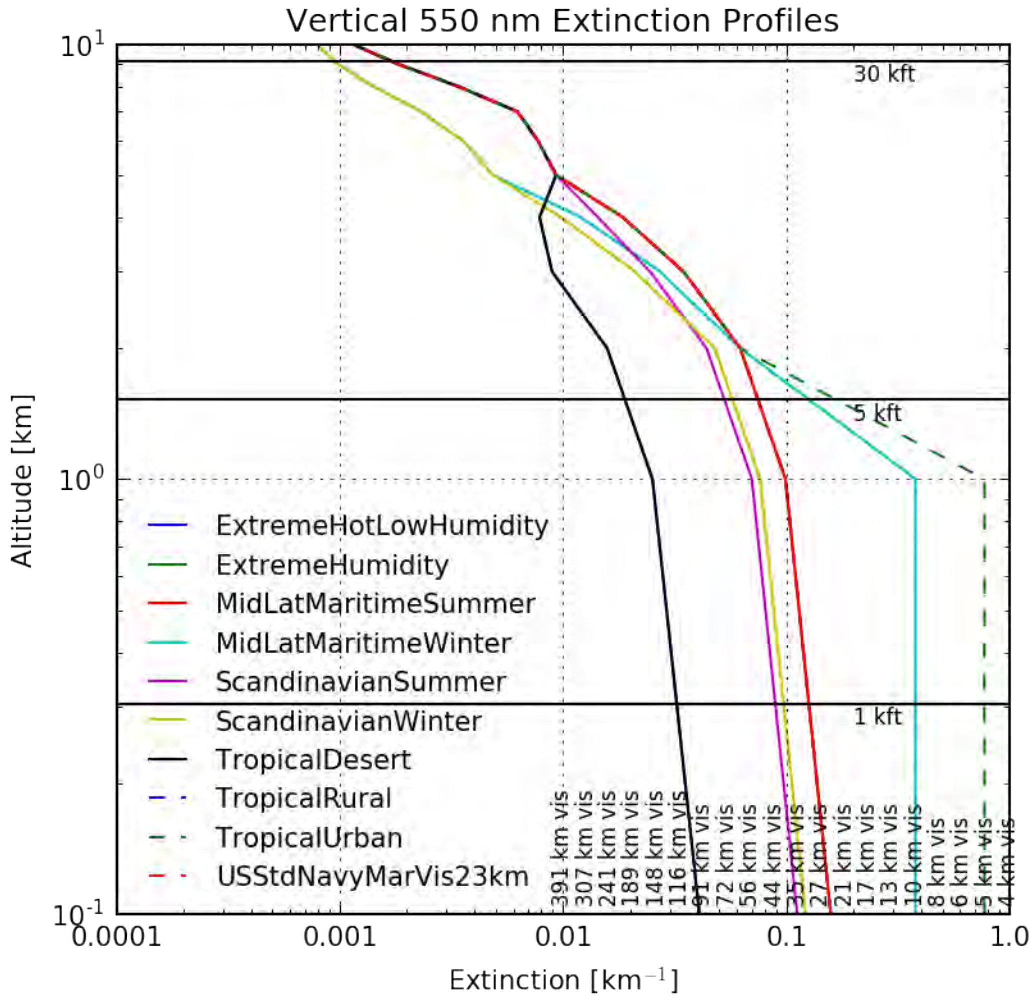
See Listing 5.3 for the code to plot the vertical profiles.





Vertical Temperature Profiles
Altitude [km]
Temperature [K]
30 kft
5 kft
1 kft
ExtremeHotLowHumidity
ExtremeHumidity
MidLatMaritimeSummer
MidLatMaritimeWinter
ScandinavianSummer
ScandinavianWinter
TropicalDesert
TropicalRural
TropicalUrban
USStdNavyMarVis23km


Vertical Humidity Profiles
10^1
10^0
10^{-1}
Altitude [km]
30 kft
5 kft
1 kft
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
100.0
Relative humidity [%]
ExtremeHotLowHumidity
ExtremeHumidity
MidLatMaritimeSummer
MidLatMaritimeWinter
ScandinavianSummer
ScandinavianWinter
TropicalDesert
TropicalRural
TropicalUrban
USStdNavyMarVis23km



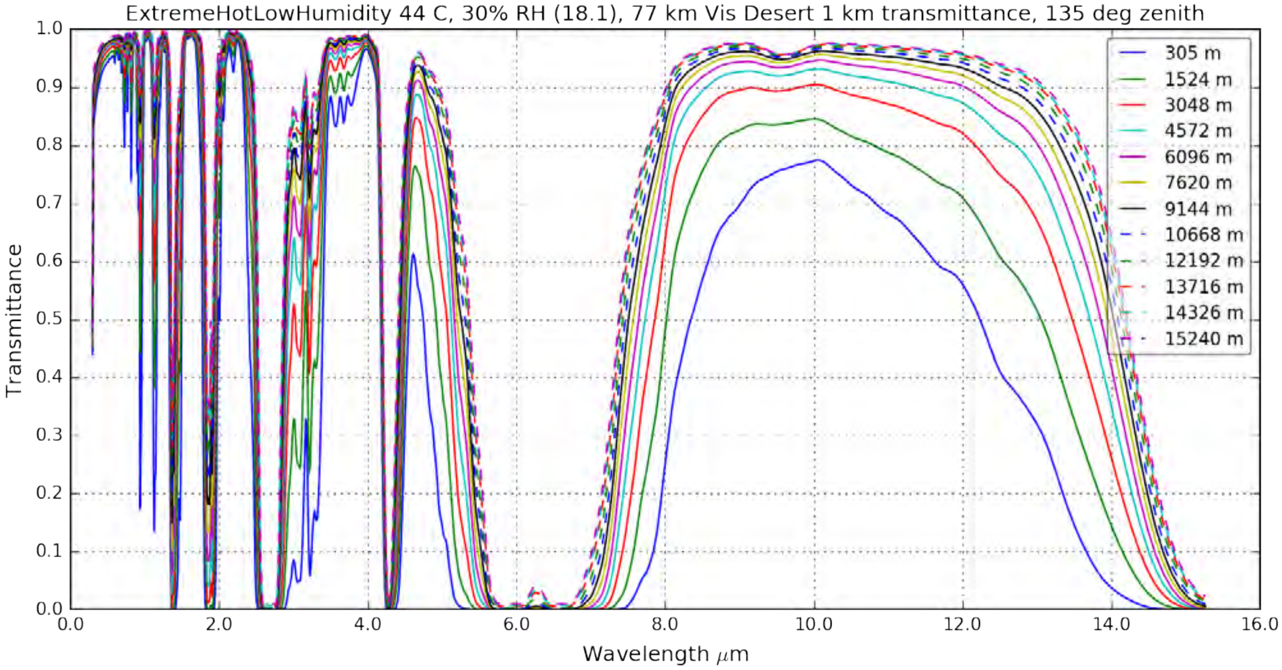
2.5 Spectral Transmittance Plots

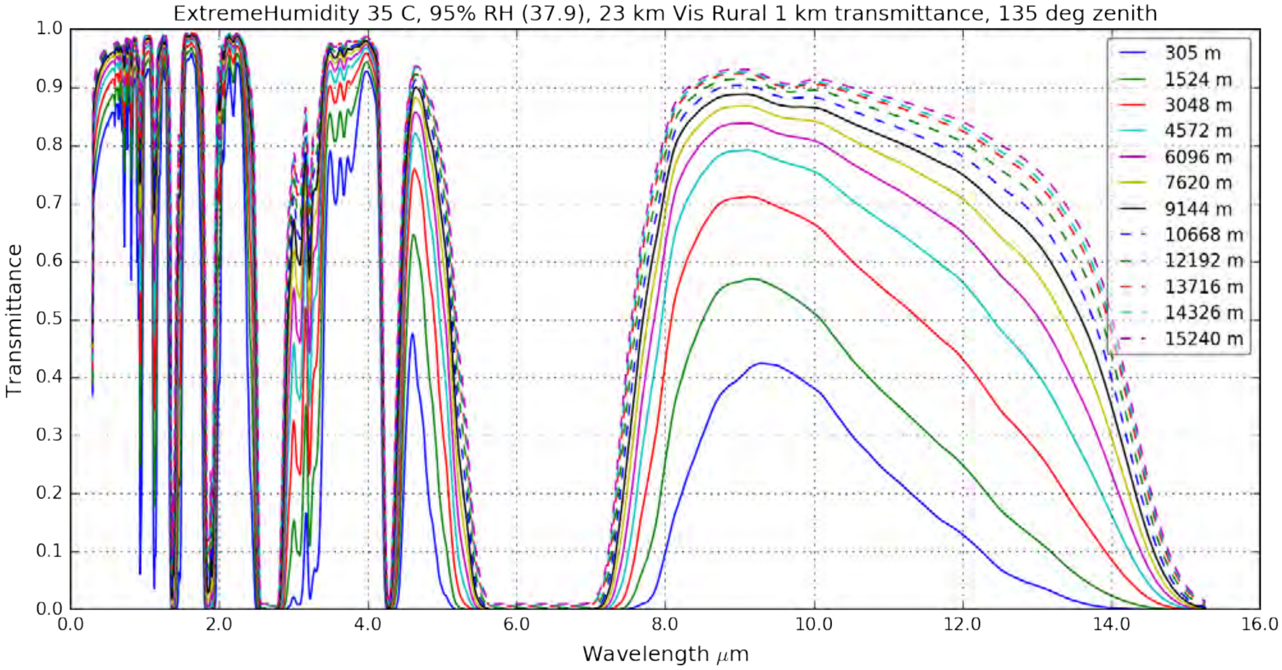
Plot the spectral transmittance for 1-km path length. Two sets of plots are shown:

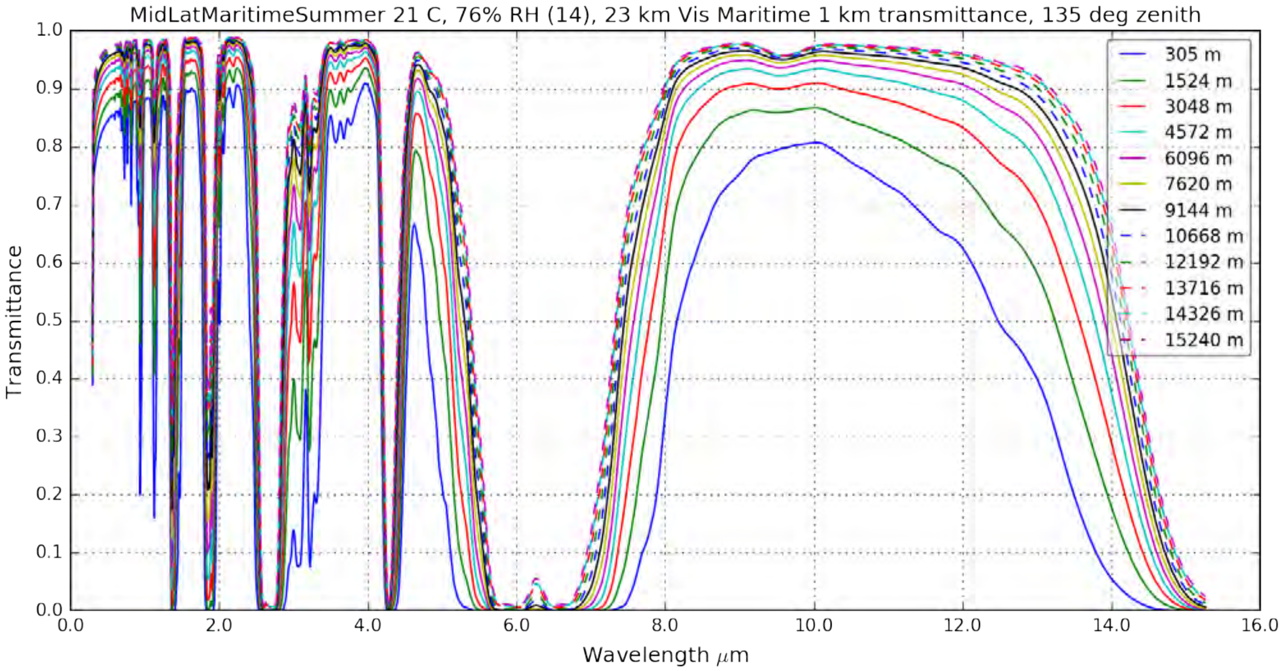
1. For each atmosphere, plot the transmittance at different altitudes.
2. For shared altitudes, plot the different atmosphere's transmittance.

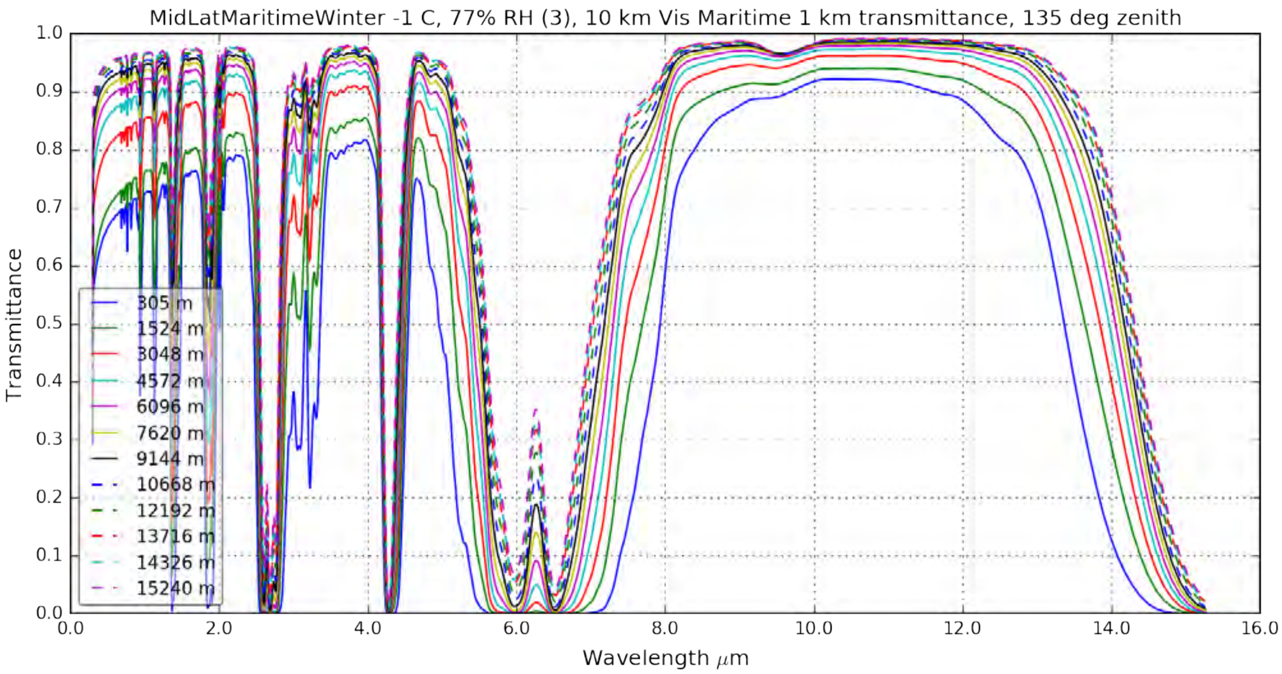
See Listing 5.4 for the code to plot the spectral transmittance.

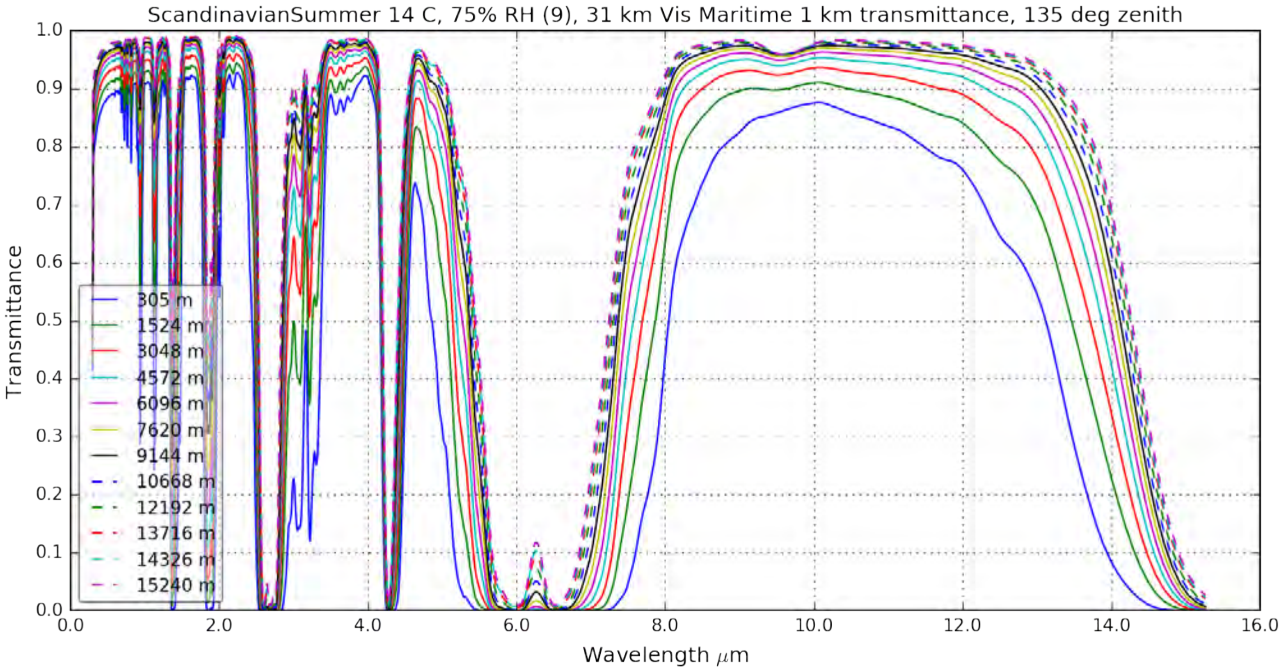
```
C:\Miniconda3\envs\py27\lib\site-packages\matplotlib\pyplot.py:516: RuntimeWarning: More than 20 figures have been opened. ↵
     Figures created through the pyplot interface (`matplotlib.pyplot.figure`) are retained until explicitly closed and may ↵
     consume too much memory. (To control this warning, see the rcParam `figure.max_open_warning`).
  max_open_warning, RuntimeWarning)
```


ExtremeHotLowHumidity 44 C, 30% RH (18.1), 77 km Vis Desert 1 km transmittance, 135 deg zenith
Transmittance
Wavelength μm
305 m
1524 m
3048 m
4572 m
6096 m
7620 m
9144 m
10668 m
12192 m
13716 m
14326 m
15240 m

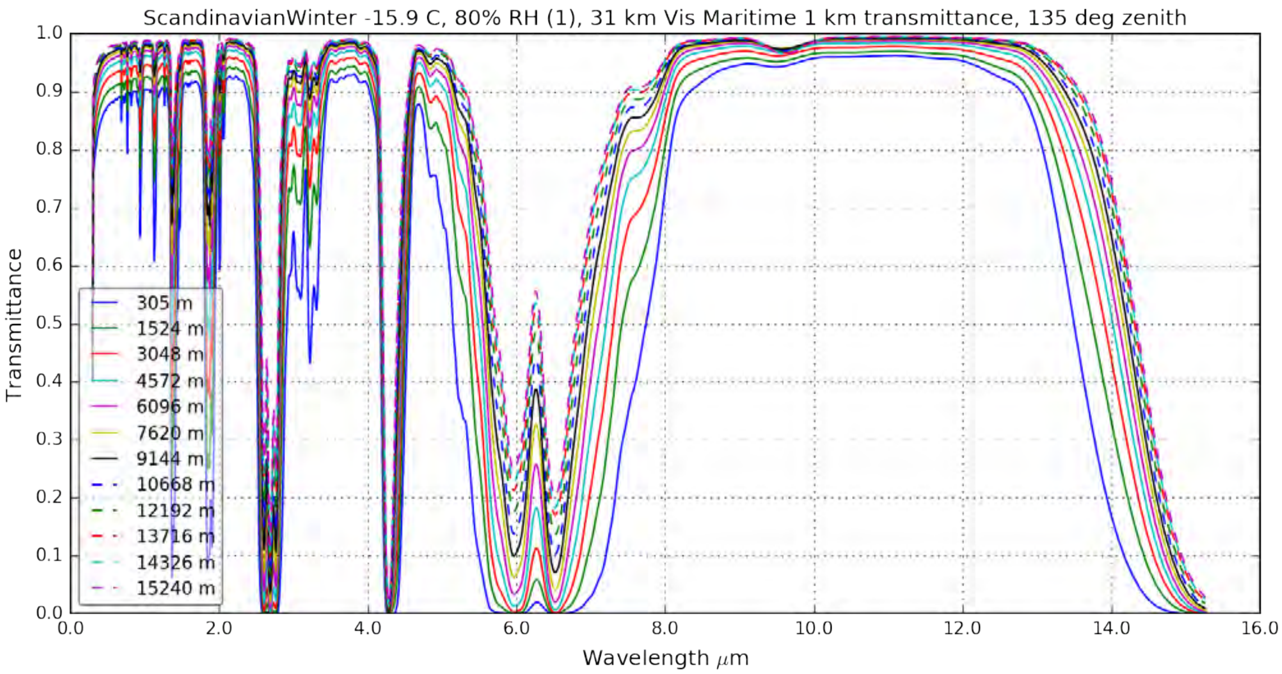

ExtremeHumidity 35 C, 95% RH (37.9), 23 km Vis Rural 1 km transmittance, 135 deg zenith
Transmittance
Wavelength μm
305 m
1524 m
3048 m
4572 m
6096 m
7620 m
9144 m
10668 m
12192 m
13716 m
14326 m
15240 m


MidLatMaritimeSummer 21 C, 76% RH (14), 23 km Vis Maritime 1 km transmittance, 135 deg zenith
Transmittance
Wavelength μm
305 m
1524 m
3048 m
4572 m
6096 m
7620 m
9144 m
10668 m
12192 m
13716 m
14326 m
15240 m

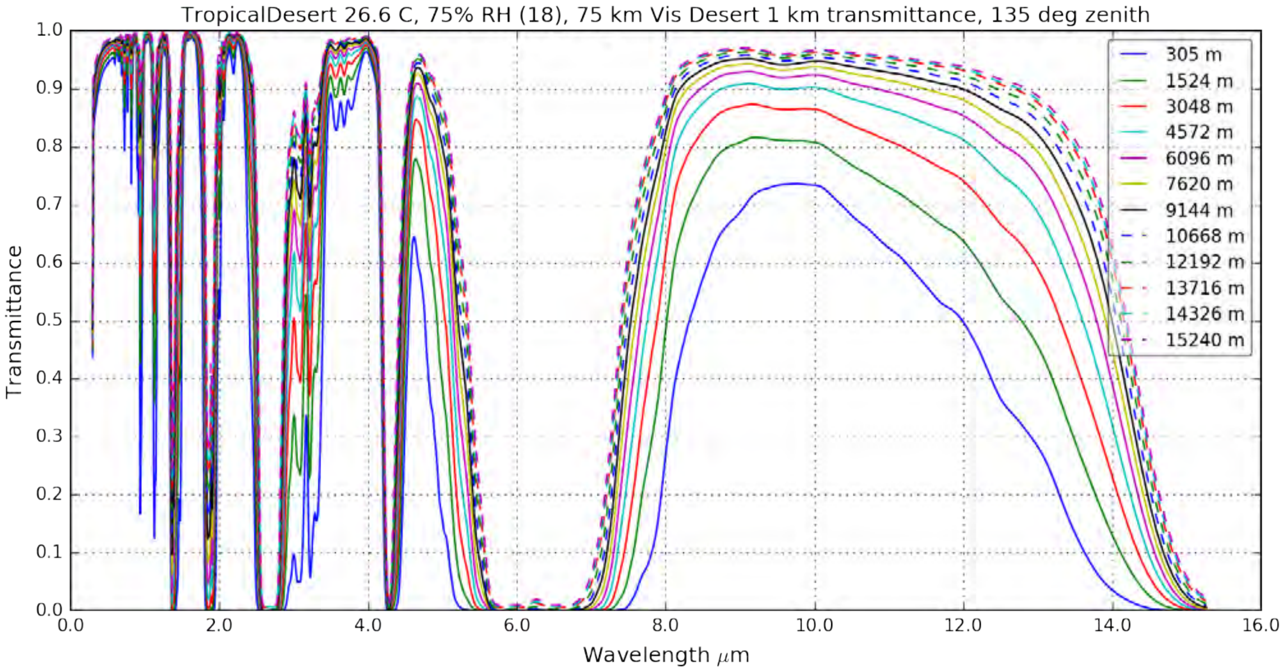

MidLatMaritimeWinter -1 C, 77% RH (3), 10 km Vis Maritime 1 km transmittance, 135 deg zenith
Transmittance
Wavelength μm
305 m
1524 m
3048 m
4572 m
6096 m
7620 m
9144 m
10668 m
12192 m
13716 m
14326 m
15240 m

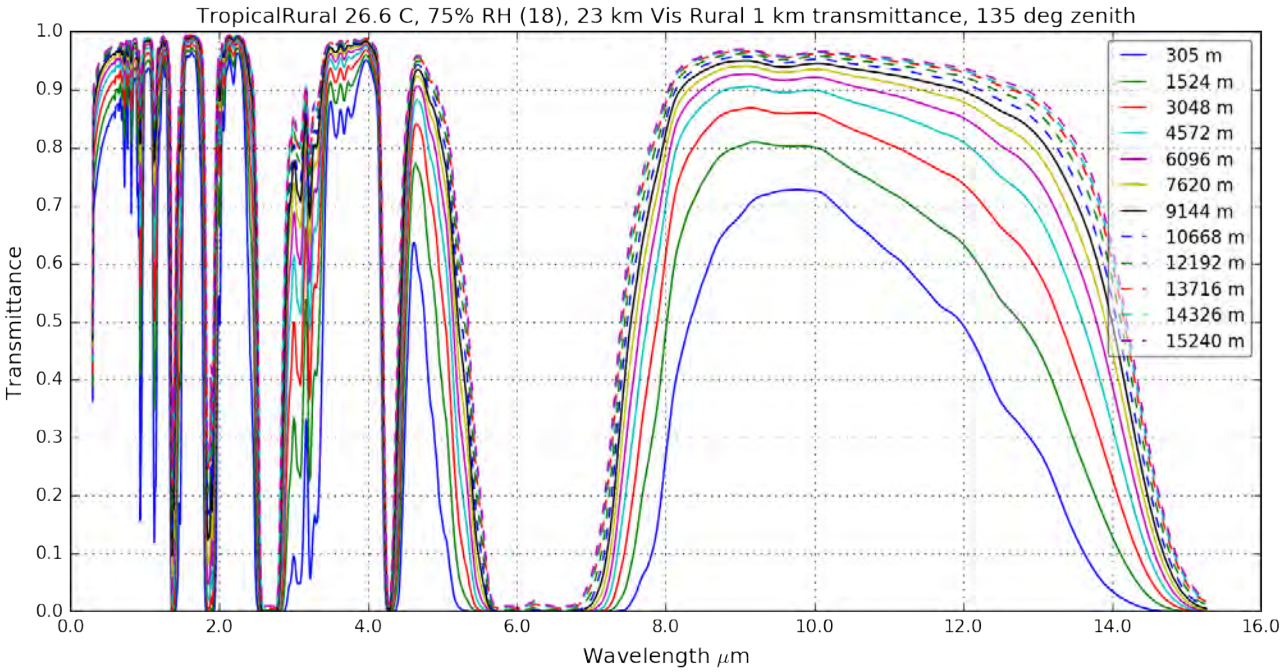


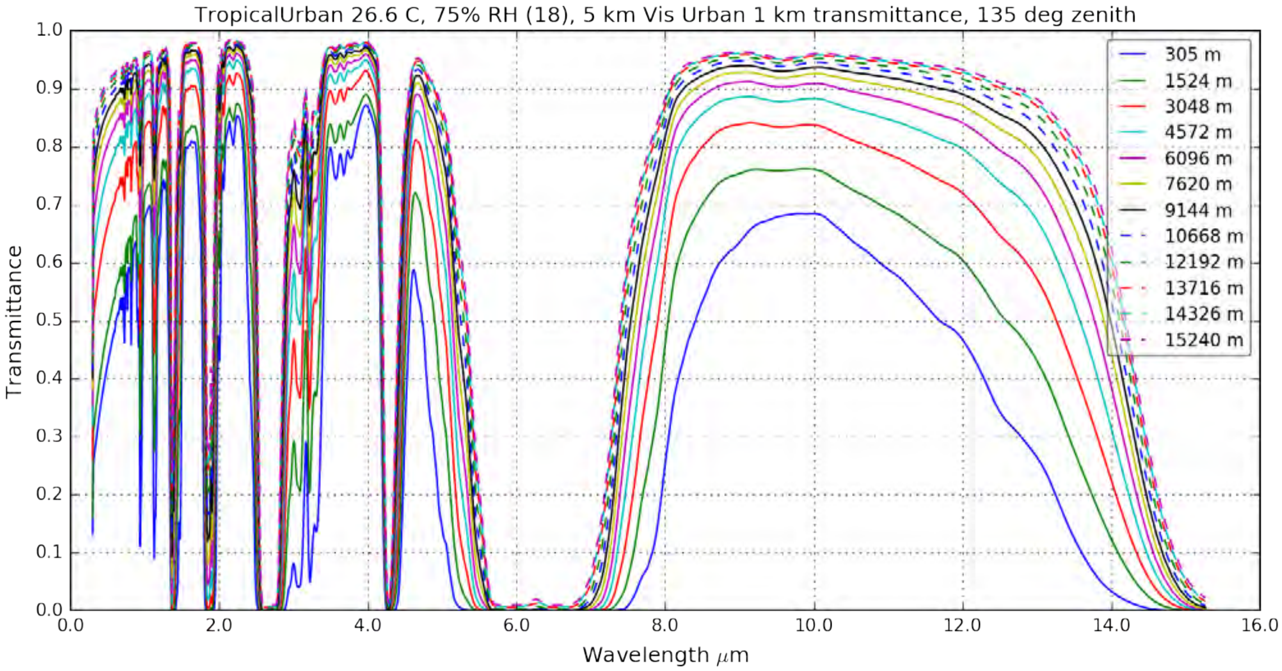
ScandinavianSummer 14 C, 75% RH (9), 31 km Vis Maritime 1 km transmittance, 135 deg zenith
Transmittance
Wavelength μm
305 m
1524 m
3048 m
4572 m
6096 m
7620 m
9144 m
10668 m
12192 m
13716 m
14326 m
15240 m

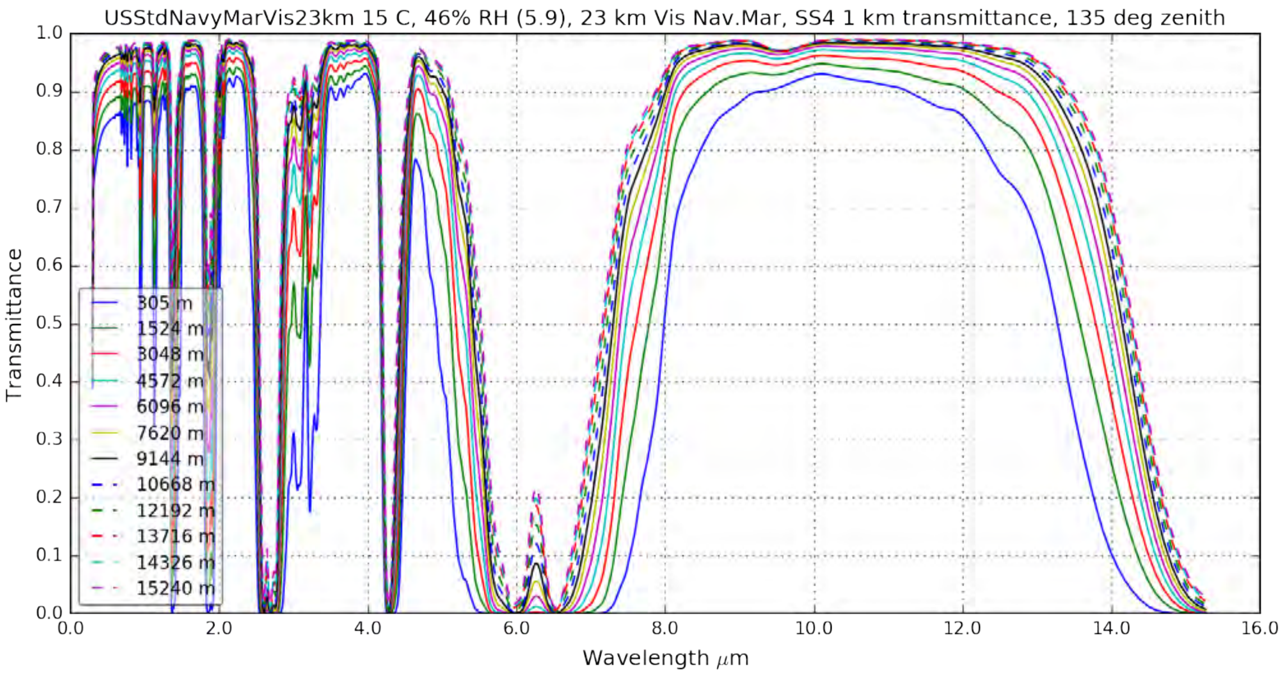


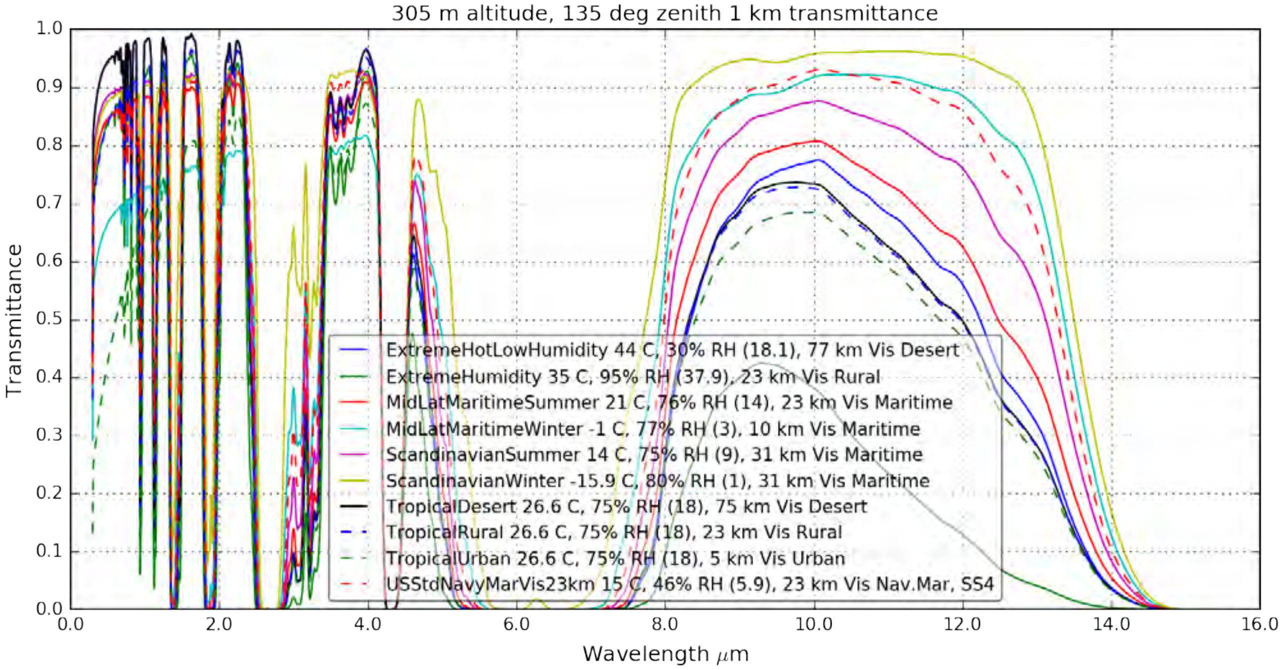
ScandinavianWinter -15.9 C, 80% RH (1), 31 km Vis Maritime 1 km transmittance, 135 deg zenith
Transmittance
Wavelength μm
305 m
1524 m
3048 m
4572 m
6096 m
7620 m
9144 m
10668 m
12192 m
13716 m
14326 m
15240 m

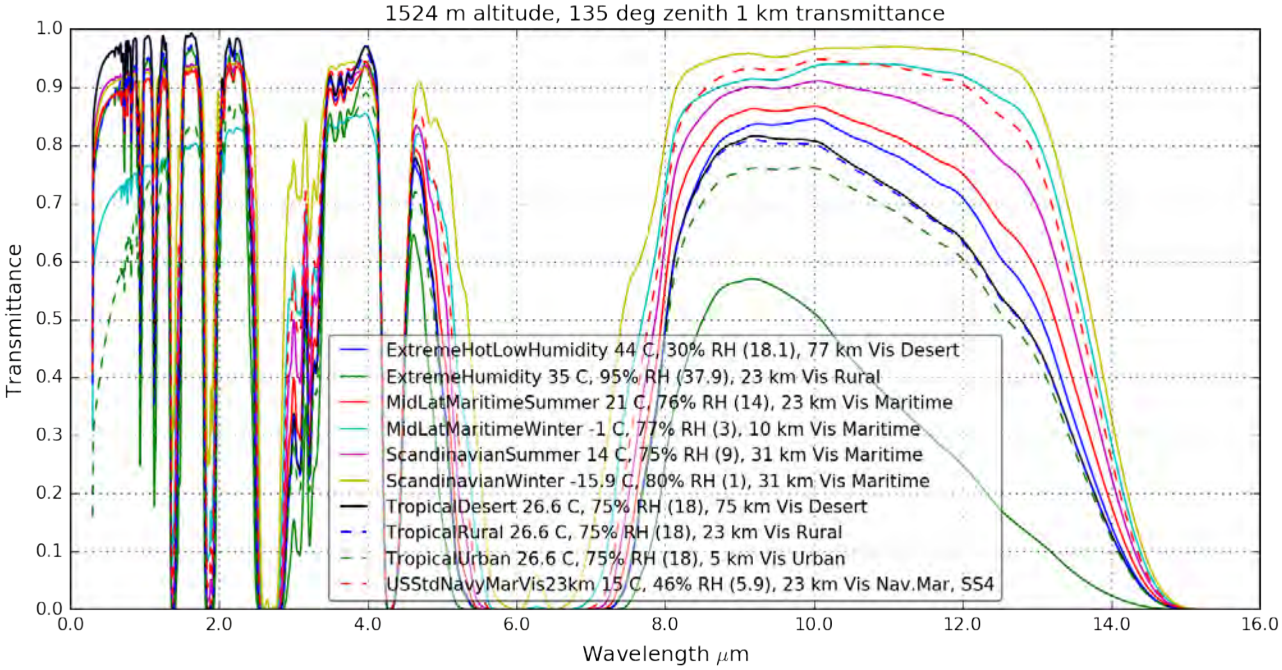

TropicalDesert 26.6 C, 75% RH (18), 75 km Vis Desert 1 km transmittance, 135 deg zenith
Transmittance
Wavelength μm
305 m
1524 m
3048 m
4572 m
6096 m
7620 m
9144 m
10668 m
12192 m
13716 m
14326 m
15240 m

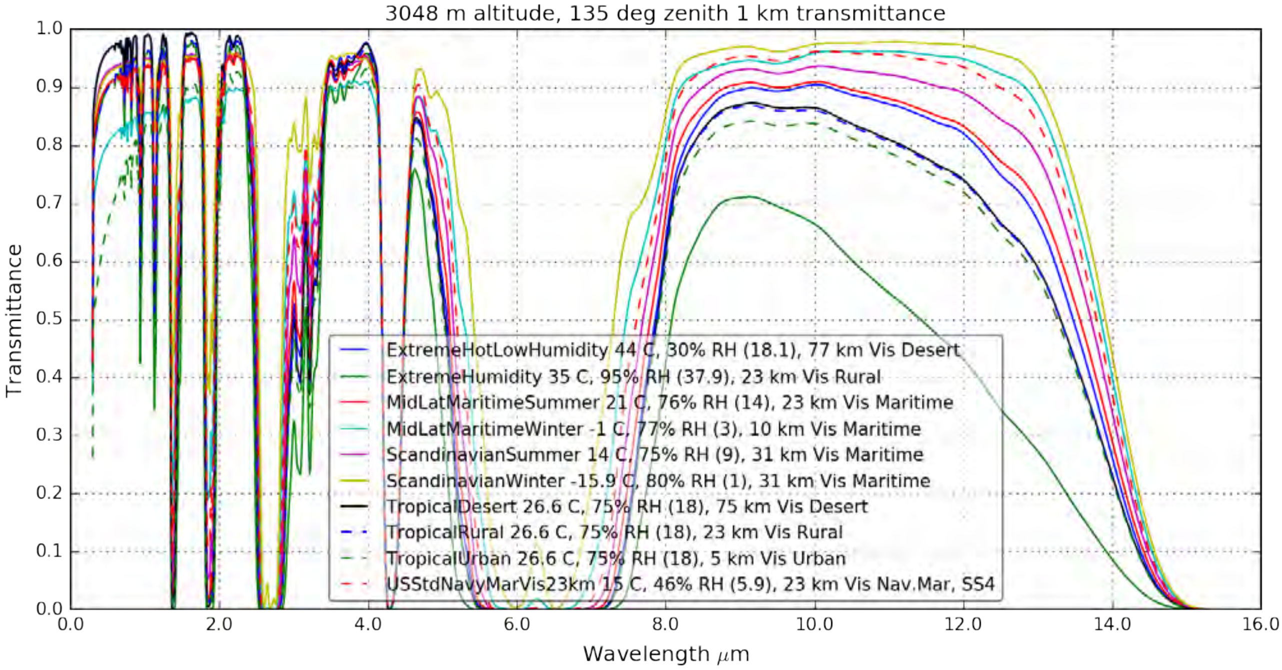

TropicalRural 26.6 C, 75% RH (18), 23 km Vis Rural 1 km transmittance, 135 deg zenith
Transmittance
Wavelength μm
305 m
1524 m
3048 m
4572 m
6096 m
7620 m
9144 m
10668 m
12192 m
13716 m
14326 m
15240 m

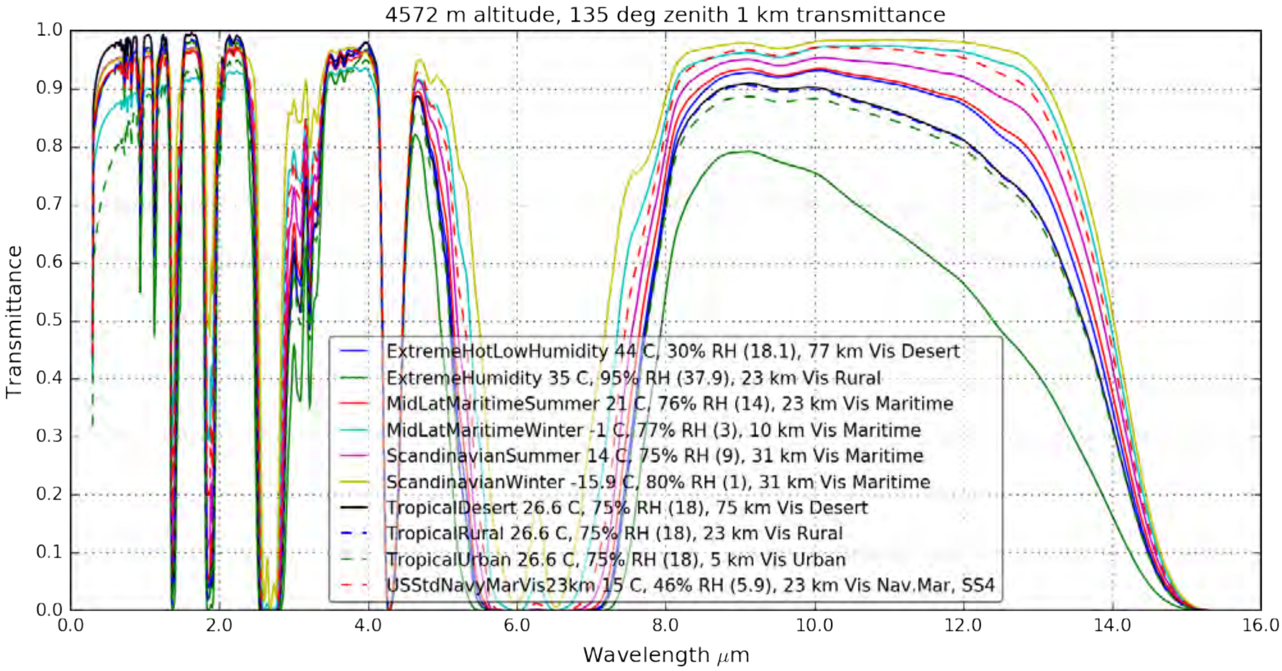

TropicalUrban 26.6 C, 75% RH (18), 5 km Vis Urban 1 km transmittance, 135 deg zenith
Transmittance
Wavelength μm
305 m
1524 m
3048 m
4572 m
6096 m
7620 m
9144 m
10668 m
12192 m
13716 m
14326 m
15240 m

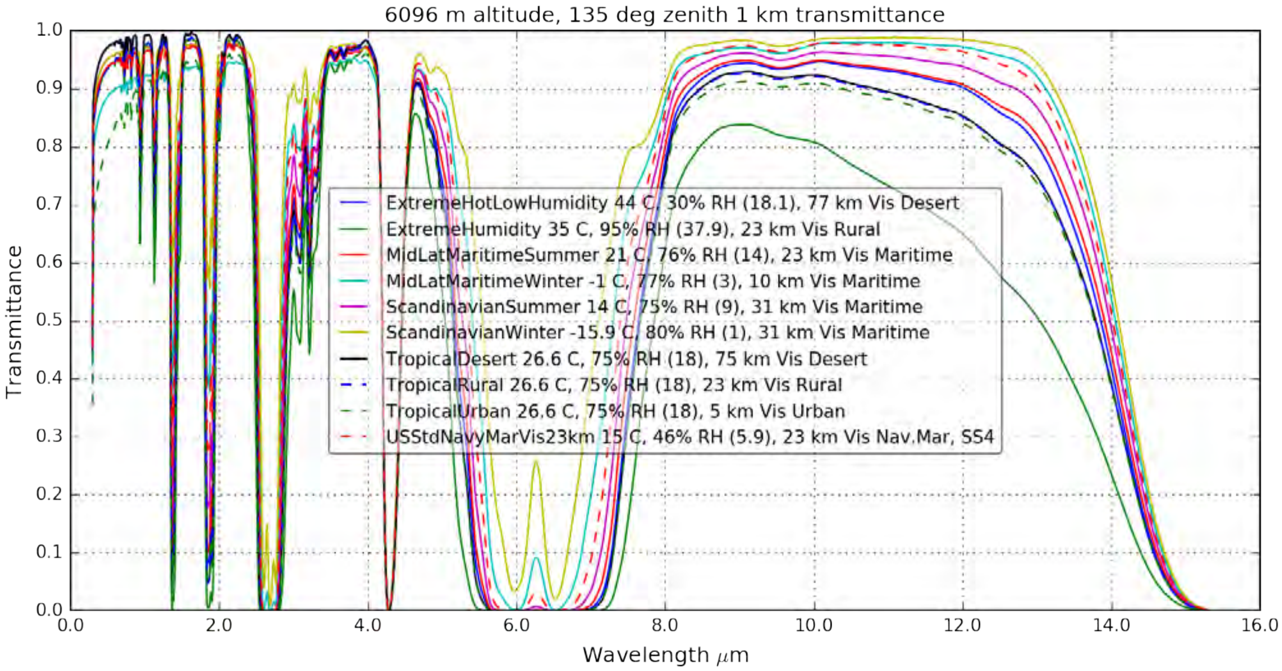

USStdNavyMarVis23km 15 C, 46% RH (5.9), 23 km Vis Nav.Mar, SS4 1 km transmittance, 135 deg zenith
Transmittance
Wavelength μm
305 m
1524 m
3048 m
4572 m
6096 m
7620 m
9144 m
10668 m
12192 m
13716 m
14326 m
15240 m

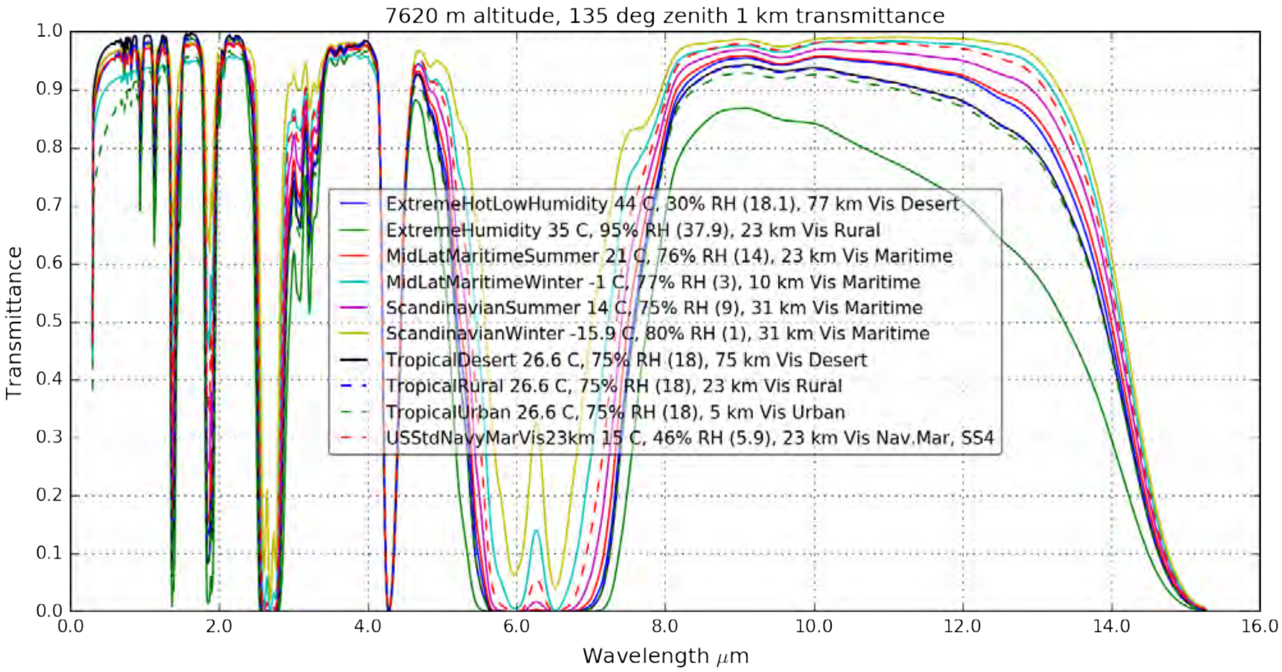

305 m altitude, 135 deg zenith 1 km transmittance
Transmittance
Wavelength µm
ExtremeHotLowHumidity 44 C, 30% RH (18.1), 77 km Vis Desert
ExtremeHumidity 35 C, 95% RH (37.9), 23 km Vis Rural
MidLatMaritimeSummer 21 C, 76% RH (14), 23 km Vis Maritime
MidLatMaritimeWinter -1 C, 77% RH (3), 10 km Vis Maritime
ScandinavianSummer 14 C, 75% RH (9), 31 km Vis Maritime
ScandinavianWinter -15.9 C, 80% RH (1), 31 km Vis Maritime
TropicalDesert 26.6 C, 75% RH (18), 75 km Vis Desert
TropicalRural 26.6 C, 75% RH (18), 23 km Vis Rural
TropicalUrban 26.6 C, 75% RH (18), 5 km Vis Urban
USStdNavyMarVis23km 15 C, 46% RH (5.9), 23 km Vis Nav.Mar, SS4

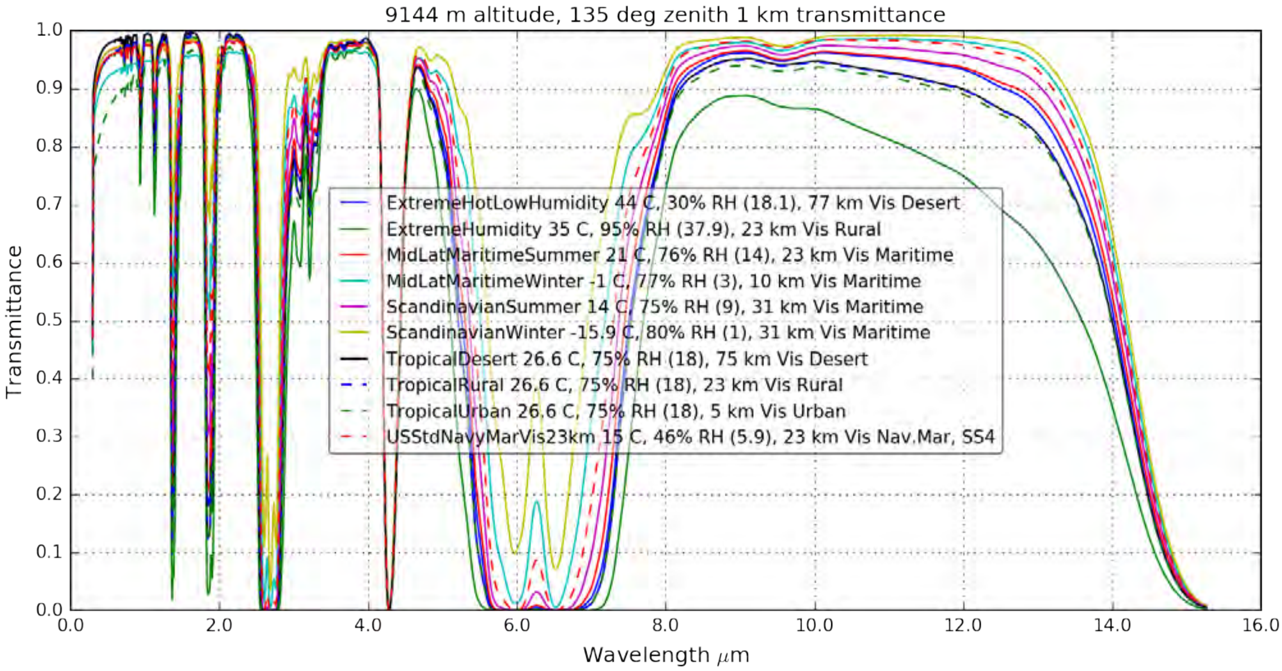

1524 m altitude, 135 deg zenith 1 km transmittance
Transmittance
Wavelength µm
ExtremeHotLowHumidity 44 C, 30% RH (18.1), 77 km Vis Desert
ExtremeHumidity 35 C, 95% RH (37.9), 23 km Vis Rural
MidLatMaritimeSummer 21 C, 76% RH (14), 23 km Vis Maritime
MidLatMaritimeWinter -1 C, 77% RH (3), 10 km Vis Maritime
ScandinavianSummer 14 C, 75% RH (9), 31 km Vis Maritime
ScandinavianWinter -15.9 C, 80% RH (1), 31 km Vis Maritime
TropicalDesert 26.6 C, 75% RH (18), 75 km Vis Desert
TropicalRural 26.6 C, 75% RH (18), 23 km Vis Rural
TropicalUrban 26.6 C, 75% RH (18), 5 km Vis Urban
USStdNavyMarVis23km 15 C, 46% RH (5.9), 23 km Vis Nav.Mar, SS4

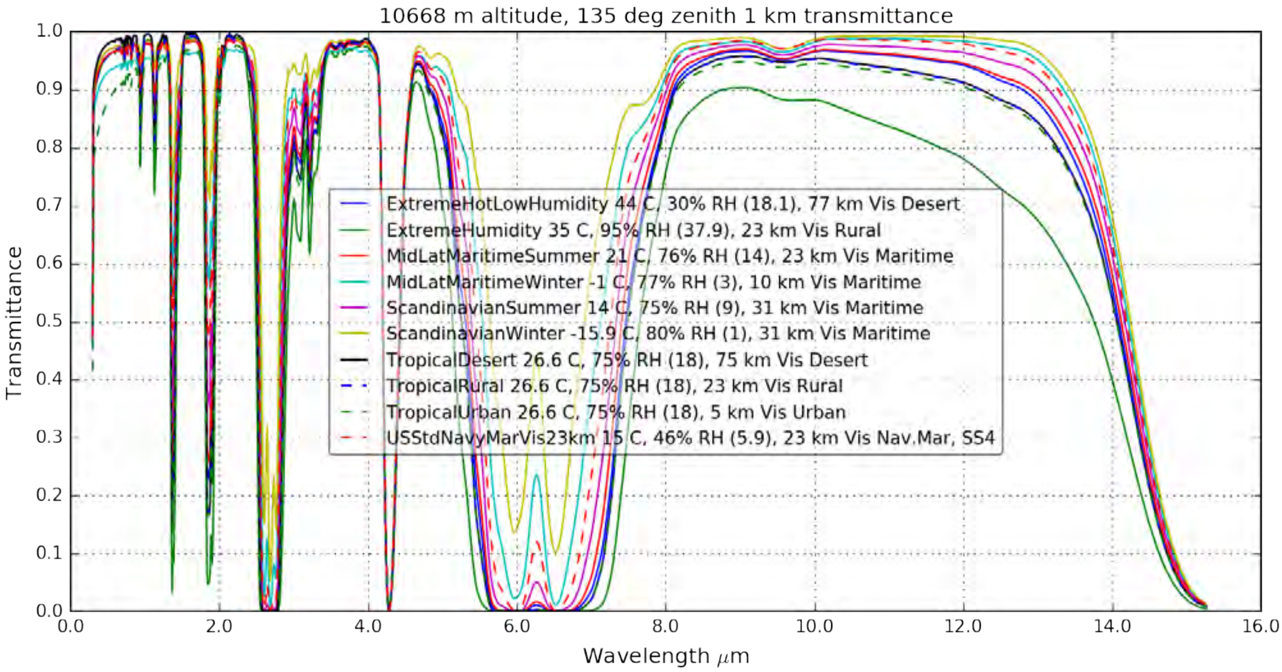

3048 m altitude, 135 deg zenith 1 km transmittance
Transmittance
Wavelength μm
ExtremeHotLowHumidity 44 C, 30% RH (18.1), 77 km Vis Desert
ExtremeHumidity 35 C, 95% RH (37.9), 23 km Vis Rural
MidLatMaritimeSummer 21 C, 76% RH (14), 23 km Vis Maritime
MidLatMaritimeWinter -1 C, 77% RH (3), 10 km Vis Maritime
ScandinavianSummer 14 C, 75% RH (9), 31 km Vis Maritime
ScandinavianWinter -15.9 C, 80% RH (1), 31 km Vis Maritime
TropicalDesert 26.6 C, 75% RH (18), 75 km Vis Desert
TropicalRural 26.6 C, 75% RH (18), 23 km Vis Rural
TropicalUrban 26.6 C, 75% RH (18), 5 km Vis Urban
USStdNavyMarVis23km 15 C, 46% RH (5.9), 23 km Vis Nav.Mar, SS4

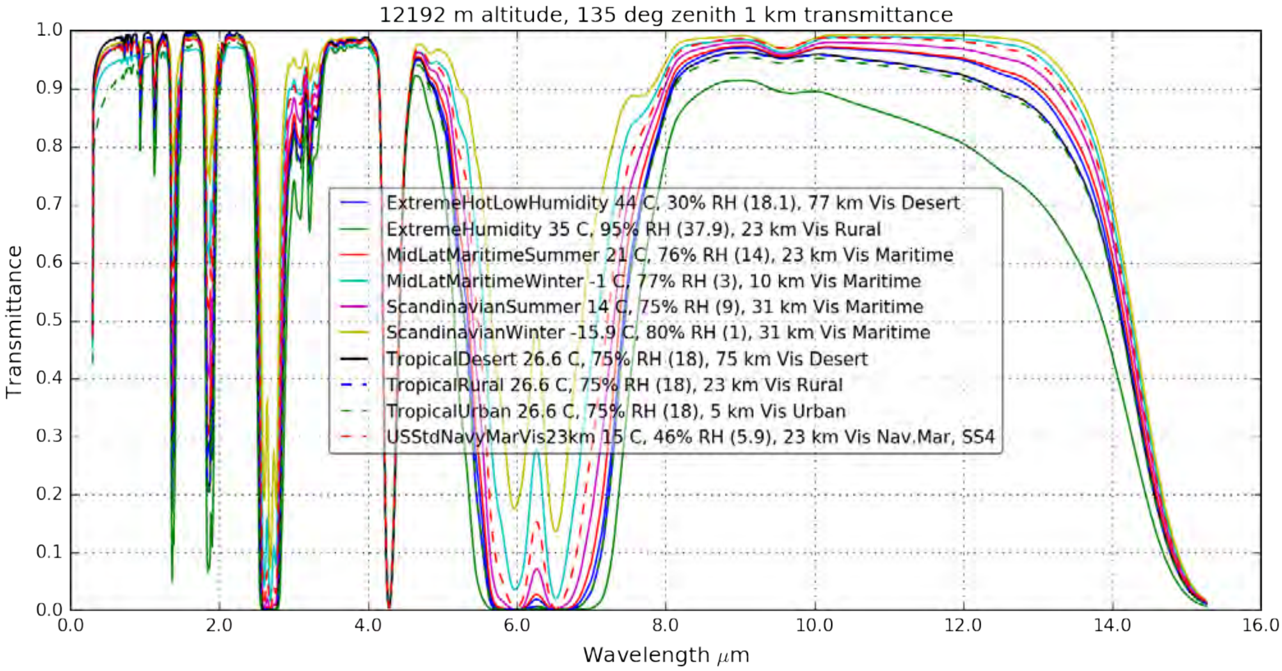

4572 m altitude, 135 deg zenith 1 km transmittance
Transmittance
Wavelength μm
ExtremeHotLowHumidity 44 C, 30% RH (18.1), 77 km Vis Desert
ExtremeHumidity 35 C, 95% RH (37.9), 23 km Vis Rural
MidLatMaritimeSummer 21 C, 76% RH (14), 23 km Vis Maritime
MidLatMaritimeWinter -1 C, 77% RH (3), 10 km Vis Maritime
ScandinavianSummer 14 C, 75% RH (9), 31 km Vis Maritime
ScandinavianWinter -15.9 C, 80% RH (1), 31 km Vis Maritime
TropicalDesert 26.6 C, 75% RH (18), 75 km Vis Desert
TropicalRural 26.6 C, 75% RH (18), 23 km Vis Rural
TropicalUrban 26.6 C, 75% RH (18), 5 km Vis Urban
USStdNavyMarVis23km 15 C, 46% RH (5.9), 23 km Vis Nav.Mar, SS4


6096 m altitude, 135 deg zenith 1 km transmittance
Transmittance
Wavelength μm
ExtremeHotLowHumidity 44 C, 30% RH (18.1), 77 km Vis Desert
ExtremeHumidity 35 C, 95% RH (37.9), 23 km Vis Rural
MidLatMaritimeSummer 21 C, 76% RH (14), 23 km Vis Maritime
MidLatMaritimeWinter -1 C, 77% RH (3), 10 km Vis Maritime
ScandinavianSummer 14 C, 75% RH (9), 31 km Vis Maritime
ScandinavianWinter -15.9 C, 80% RH (1), 31 km Vis Maritime
TropicalDesert 26.6 C, 75% RH (18), 75 km Vis Desert
TropicalRural 26.6 C, 75% RH (18), 23 km Vis Rural
TropicalUrban 26.6 C, 75% RH (18), 5 km Vis Urban
USStdNavyMarVis23km 15 C, 46% RH (5.9), 23 km Vis Nav.Mar, SS4

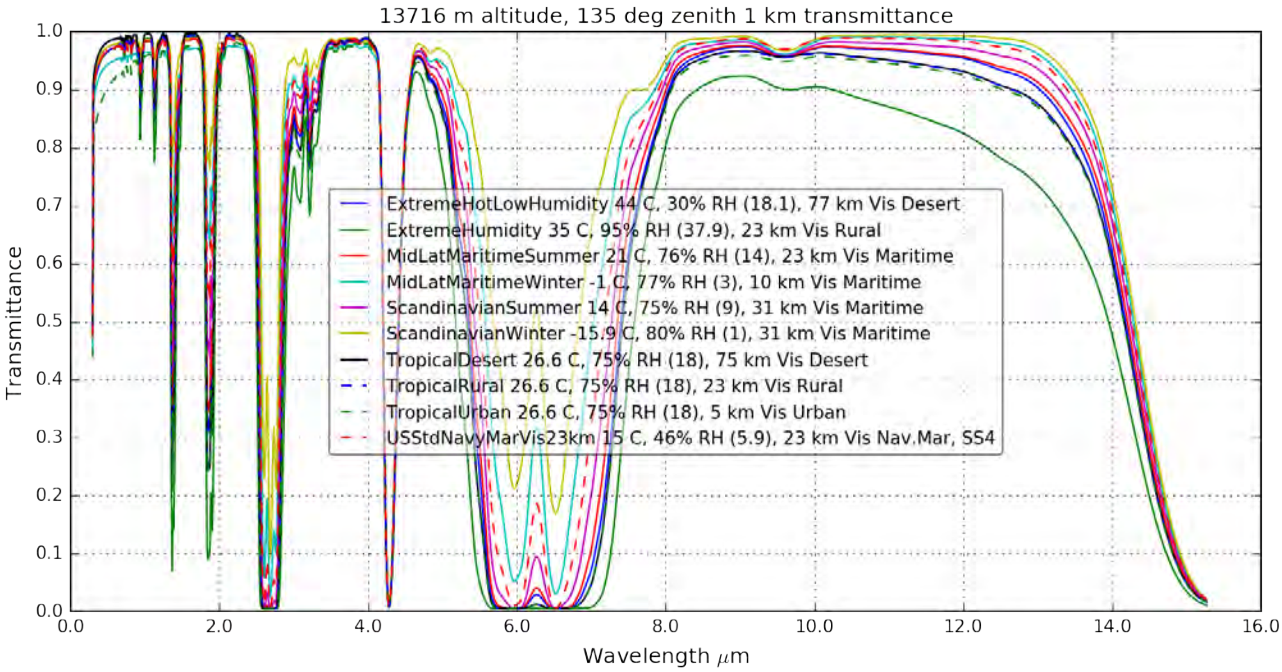

7620 m altitude, 135 deg zenith 1 km transmittance
Transmittance
Wavelength μm
ExtremeHotLowHumidity 44 C, 30% RH (18.1), 77 km Vis Desert
ExtremeHumidity 35 C, 95% RH (37.9), 23 km Vis Rural
MidLatMaritimeSummer 21 C, 76% RH (14), 23 km Vis Maritime
MidLatMaritimeWinter -1 C, 77% RH (3), 10 km Vis Maritime
ScandinavianSummer 14 C, 75% RH (9), 31 km Vis Maritime
ScandinavianWinter -15.9 C, 80% RH (1), 31 km Vis Maritime
TropicalDesert 26.6 C, 75% RH (18), 75 km Vis Desert
TropicalRural 26.6 C, 75% RH (18), 23 km Vis Rural
TropicalUrban 26.6 C, 75% RH (18), 5 km Vis Urban
USStdNavyMarVis23km 15 C, 46% RH (5.9), 23 km Vis Nav.Mar, SS4


9144 m altitude, 135 deg zenith 1 km transmittance
Transmittance
Wavelength μm
ExtremeHotLowHumidity 44 C, 30% RH (18.1), 77 km Vis Desert
ExtremeHumidity 35 C, 95% RH (37.9), 23 km Vis Rural
MidLatMaritimeSummer 21 C, 76% RH (14), 23 km Vis Maritime
MidLatMaritimeWinter -1 C, 77% RH (3), 10 km Vis Maritime
ScandinavianSummer 14 C, 75% RH (9), 31 km Vis Maritime
ScandinavianWinter -15.9 C, 80% RH (1), 31 km Vis Maritime
TropicalDesert 26.6 C, 75% RH (18), 75 km Vis Desert
TropicalRural 26.6 C, 75% RH (18), 23 km Vis Rural
TropicalUrban 26.6 C, 75% RH (18), 5 km Vis Urban
USStdNavyMarVis23km 15 C, 46% RH (5.9), 23 km Vis Nav.Mar, SS4

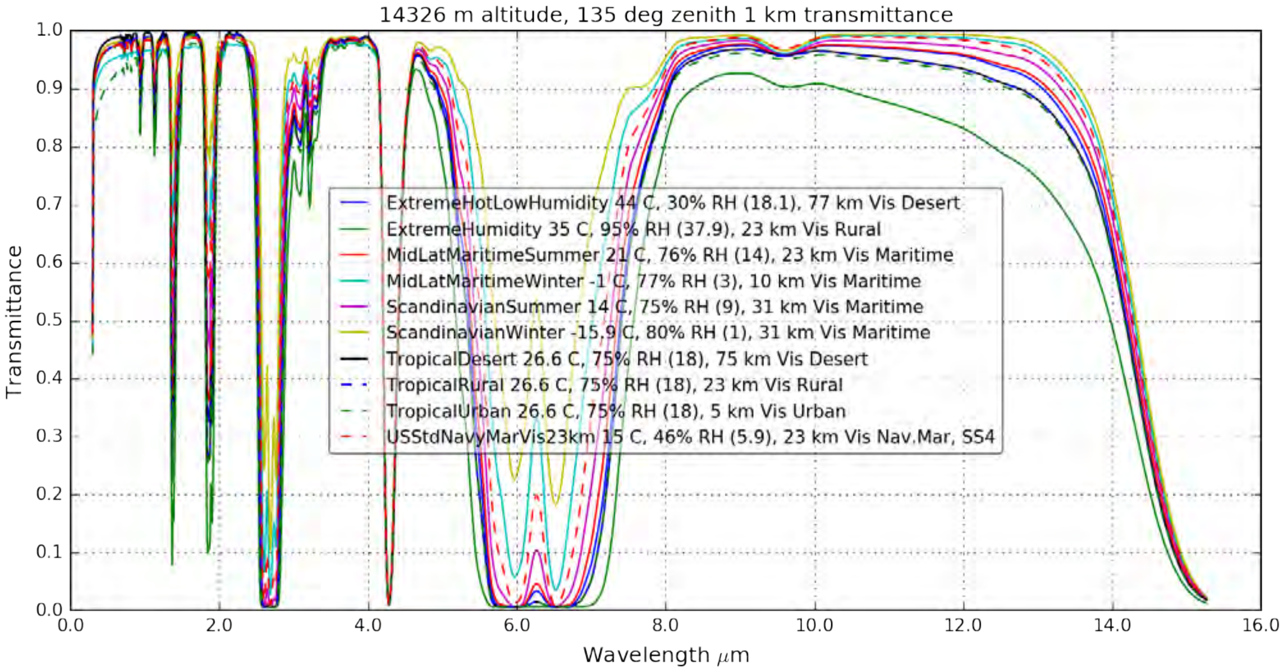

10668 m altitude, 135 deg zenith 1 km transmittance
Transmittance
Wavelength μm
ExtremeHotLowHumidity 44 C, 30% RH (18.1), 77 km Vis Desert
ExtremeHumidity 35 C, 95% RH (37.9), 23 km Vis Rural
MidLatMaritimeSummer 21 C, 76% RH (14), 23 km Vis Maritime
MidLatMaritimeWinter -1 C, 77% RH (3), 10 km Vis Maritime
ScandinavianSummer 14 C, 75% RH (9), 31 km Vis Maritime
ScandinavianWinter -15.9 C, 80% RH (1), 31 km Vis Maritime
TropicalDesert 26.6 C, 75% RH (18), 75 km Vis Desert
TropicalRural 26.6 C, 75% RH (18), 23 km Vis Rural
TropicalUrban 26.6 C, 75% RH (18), 5 km Vis Urban
USStdNavyMarVis23km 15 C, 46% RH (5.9), 23 km Vis Nav.Mar, SS4

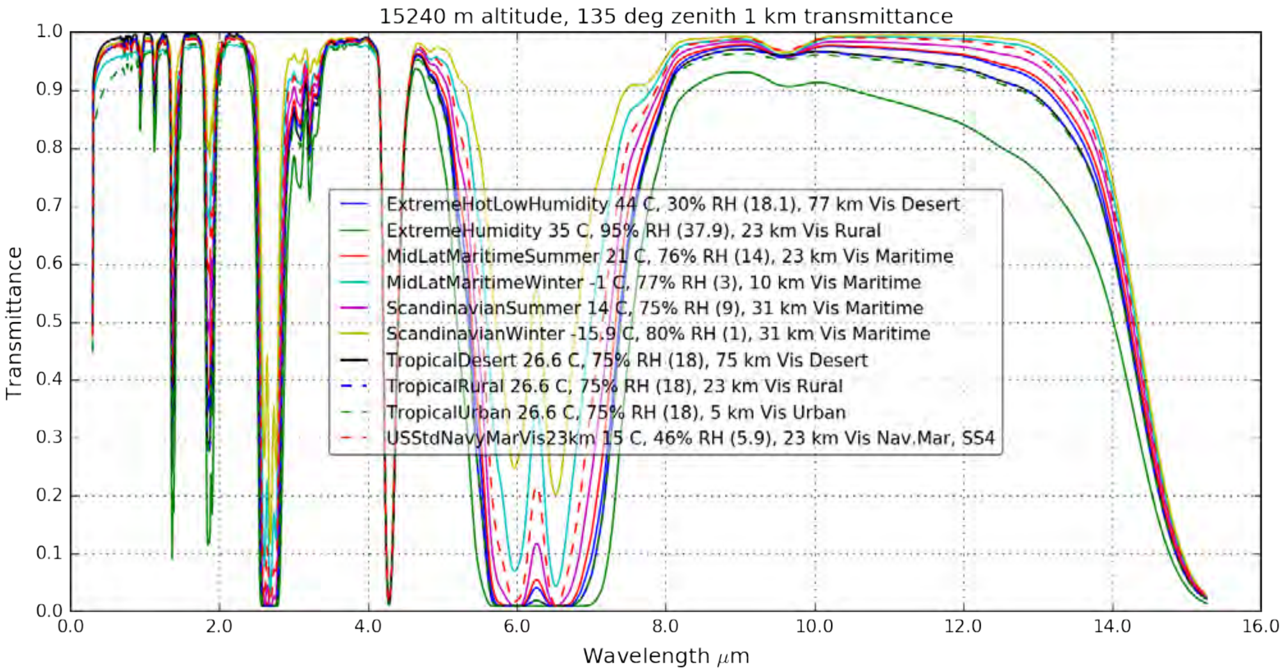


12192 m altitude, 135 deg zenith 1 km transmittance
Transmittance
Wavelength μm
ExtremeHotLowHumidity 44 C, 30% RH (18.1), 77 km Vis Desert
ExtremeHumidity 35 C, 95% RH (37.9), 23 km Vis Rural
MidLatMaritimeSummer 21 C, 76% RH (14), 23 km Vis Maritime
MidLatMaritimeWinter -1 C, 77% RH (3), 10 km Vis Maritime
ScandinavianSummer 14 C, 75% RH (9), 31 km Vis Maritime
ScandinavianWinter -15.9 C, 80% RH (1), 31 km Vis Maritime
TropicalDesert 26.6 C, 75% RH (18), 75 km Vis Desert
TropicalRural 26.6 C, 75% RH (18), 23 km Vis Rural
TropicalUrban 26.6 C, 75% RH (18), 5 km Vis Urban
USStdNavyMarVis23km 15 C, 46% RH (5.9), 23 km Vis Nav.Mar, SS4



13716 m altitude, 135 deg zenith 1 km transmittance
Transmittance
Wavelength μm
ExtremeHotLowHumidity 44 C, 30% RH (18.1), 77 km Vis Desert
ExtremeHumidity 35 C, 95% RH (37.9), 23 km Vis Rural
MidLatMaritimeSummer 21 C, 76% RH (14), 23 km Vis Maritime
MidLatMaritimeWinter -1 C, 77% RH (3), 10 km Vis Maritime
ScandinavianSummer 14 C, 75% RH (9), 31 km Vis Maritime
ScandinavianWinter -15.9 C, 80% RH (1), 31 km Vis Maritime
TropicalDesert 26.6 C, 75% RH (18), 75 km Vis Desert
TropicalRural 26.6 C, 75% RH (18), 23 km Vis Rural
TropicalUrban 26.6 C, 75% RH (18), 5 km Vis Urban
USStdNavyMarVis23km 15 C, 46% RH (5.9), 23 km Vis Nav.Mar, SS4





2.6 Apparent Atmospheric Temperature

The apparent temperature of the atmosphere is a complex function of the temperature profile along the path. For slant paths in inhomogeneous atmospheres the effective temperature is affected stronger by the path sections closer to the sensor than path sections further away.

It can be shown that the path radiance in the infrared can be approximated by

$$L_{\rm path} = (1-\tau)\, L(T_{\rm bb}) \tag{2.1}$$

This implies that if $L_{\rm path}$ and τ are known $T_{\rm bb}$ can be determined. The solution is determined by fitting a curve of the above shape to the Modtran-calculated path radiance, finding $T_{\rm bb}$ for the best fit. Only the thermal path radiance is used, which has most of its optical flux at wavenumbers below 2500 cm^{-1}.

The analysis below considers three spectral bands: (1) a band in the 3.5-4.8 μm range, (1) a band in the 8.3-12 μm range, and (3) a band that covers *four* windows in the 3.2-12.5 μm range.

It turns out that the temperatures calculated for the 3.5-4.8 μm band is similar to the average or broadband temperature, because of the mix of CO_2 absorption and good transmittance in this band.

At low altitudes all the atmospheric temperatures are similar but at high altitudes there can be a significant spread in the values.

The term 'best fit' is not easily defined. It is not clear what a simple fit through all the data really mean. Several options were considered: (1) use only the spectral ranges with high transmittance, (2) use only the spectral ranges with poor transmittance, (3) use all the data, and (4) calculate the mean value of the first two options. The results of these two approaches are shown below in the example graphs. The temperatures calculated from all the data and the mean of the high and low transmittance temperatures are broadly in agreement.

If the apparent atmosphere temperatures are used in applications where the path radiance in the atmospheric windows are required, it is proposed that the 'high transmittance' temperature values be used. These values will be more applicable to the in-band path radiance.

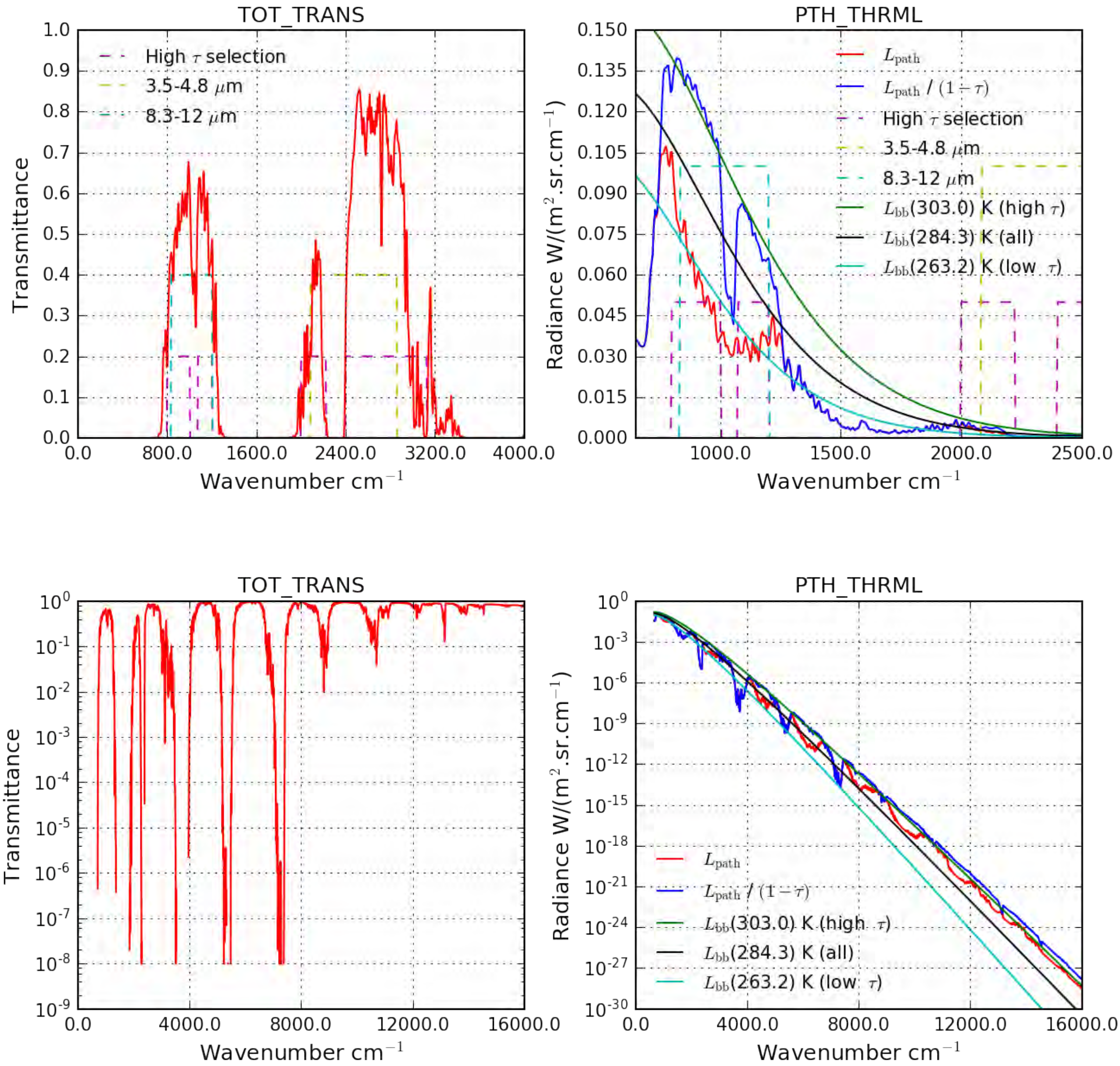
The results shown in the graphs and tables below are for the following conditions:

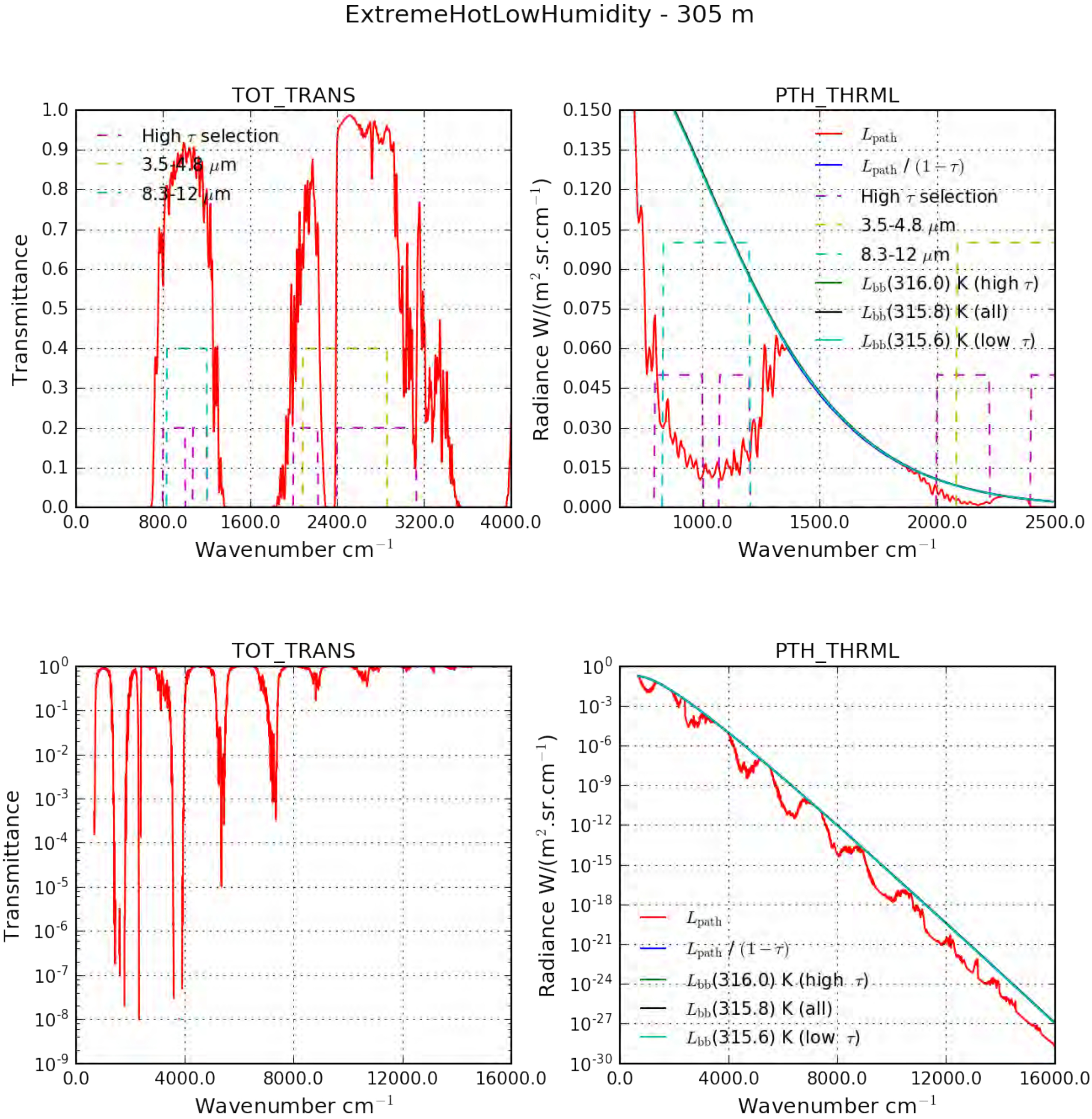
Heading	Meaning
TmpLoTau	Apparent temperature in all spectral ranges with low transmittance
TmpHiTau	Apparent temperature in all spectral ranges with high transmittance
3.5-4.8	Apparent temperature in the full spectral band (including absorption)
8.3-12	Apparent temperature in the full spectral band (including absorption)
TmpAve	Arithmetic Average (TmpLoTau+TmpHiTau)/2
TmpAll	Apparent temperature over the total spectral range

See Listing 5.5 for the code to return Placnk radiator radiance.

See Listing 5.6 for the code to calculate and plot atmospheric temperature.

ExtremeHotLowHumidity - 15240 m





See Listing 5.7 for the code to process and print atmospheric transmittance.

Atmosphere	Altitude	TmpLoTau	TmpHiTau	3.5-4.8	8.3-12	TmpAve	TmpAll
ExtremeHotLowHumidity	305.0	315.6	316.0	315.8	316.0	315.8	315.8
ExtremeHotLowHumidity	1524.0	307.7	311.3	309.5	311.4	309.5	309.4
ExtremeHotLowHumidity	3048.0	296.5	307.3	300.7	307.4	301.9	301.6
ExtremeHotLowHumidity	4572.0	290.0	305.6	295.5	305.4	297.8	297.5
ExtremeHotLowHumidity	6096.0	284.9	304.6	291.9	304.1	294.7	294.5
ExtremeHotLowHumidity	7620.0	280.3	304.0	289.4	303.1	292.2	292.1
ExtremeHotLowHumidity	9144.0	276.0	303.7	287.5	302.3	289.8	289.9
ExtremeHotLowHumidity	10668.0	272.1	303.5	286.1	301.4	287.8	288.2
ExtremeHotLowHumidity	12192.0	268.6	303.3	285.2	300.6	286.0	286.6
ExtremeHotLowHumidity	13716.0	265.6	303.1	284.5	299.6	284.4	285.3
ExtremeHotLowHumidity	14326.0	264.5	303.1	284.3	299.2	283.8	284.8
ExtremeHotLowHumidity	15240.0	263.1	303.0	284.0	298.7	283.0	284.2

Atmosphere	Altitude	TmpLoTau	TmpHiTau	3.5-4.8	8.3-12	TmpAve	TmpAll
ExtremeHumidity	305.0	307.2	307.4	307.4	307.4	307.3	307.3
ExtremeHumidity	1524.0	301.0	303.6	302.8	303.7	302.3	302.2
ExtremeHumidity	3048.0	291.6	298.6	295.6	299.1	295.1	294.9
ExtremeHumidity	4572.0	285.8	297.1	291.2	297.6	291.5	291.2
ExtremeHumidity	6096.0	281.1	296.6	288.1	296.9	288.8	288.6
ExtremeHumidity	7620.0	277.0	296.3	285.7	296.4	286.6	286.5
ExtremeHumidity	9144.0	272.9	296.1	284.0	296.0	284.5	284.6
ExtremeHumidity	10668.0	269.3	296.0	282.7	295.5	282.7	282.9
ExtremeHumidity	12192.0	266.0	295.9	281.8	294.9	281.0	281.4
ExtremeHumidity	13716.0	263.3	295.9	281.3	294.3	279.6	280.3
ExtremeHumidity	14326.0	262.3	295.8	281.1	294.0	279.1	279.8
ExtremeHumidity	15240.0	261.0	295.8	280.8	293.6	278.4	279.3

Atmosphere	Altitude	TmpLoTau	TmpHiTau	3.5-4.8	8.3-12	TmpAve	TmpAll
MidLatMaritimeSummer	305.0	293.2	293.4	293.3	293.4	293.3	293.3
MidLatMaritimeSummer	1524.0	289.1	290.7	289.8	290.7	289.9	289.8
MidLatMaritimeSummer	3048.0	283.7	288.3	285.4	288.4	286.0	285.9
MidLatMaritimeSummer	4572.0	278.5	287.0	281.5	286.9	282.7	282.6
MidLatMaritimeSummer	6096.0	273.8	286.3	278.4	286.0	280.1	279.9
MidLatMaritimeSummer	7620.0	269.5	285.9	276.0	285.3	277.7	277.6
MidLatMaritimeSummer	9144.0	265.5	285.6	274.1	284.6	275.6	275.6
MidLatMaritimeSummer	10668.0	262.1	285.5	272.9	283.9	273.8	274.0
MidLatMaritimeSummer	12192.0	258.9	285.3	272.0	283.2	272.1	272.5
MidLatMaritimeSummer	13716.0	256.4	285.2	271.3	282.4	270.8	271.4
MidLatMaritimeSummer	14326.0	255.8	285.1	271.2	282.1	270.5	271.1
MidLatMaritimeSummer	15240.0	255.1	285.1	270.9	281.7	270.1	270.7

	Altitude	TmpLoTau	TmpHiTau	3.5-4.8	8.3-12	TmpAve	TmpAll
Atmosphere							
MidLatMaritimeWinter	305.0	271.5	271.6	271.5	271.6	271.5	271.5
MidLatMaritimeWinter	1524.0	268.4	269.6	268.9	269.6	269.0	269.0
MidLatMaritimeWinter	3048.0	265.0	268.2	266.2	268.2	266.6	266.5
MidLatMaritimeWinter	4572.0	260.4	267.4	263.2	267.3	263.9	263.8
MidLatMaritimeWinter	6096.0	255.9	266.9	260.6	266.5	261.4	261.3
MidLatMaritimeWinter	7620.0	251.9	266.5	258.6	265.7	259.2	259.1
MidLatMaritimeWinter	9144.0	248.0	266.3	257.1	264.9	257.1	257.2
MidLatMaritimeWinter	10668.0	244.9	266.0	256.1	263.8	255.4	255.6
MidLatMaritimeWinter	12192.0	243.2	265.8	255.4	262.8	254.5	254.8
MidLatMaritimeWinter	13716.0	242.0	265.5	254.9	262.0	253.8	254.1
MidLatMaritimeWinter	14326.0	241.7	265.4	254.7	261.7	253.5	253.9
MidLatMaritimeWinter	15240.0	241.2	265.3	254.4	261.4	253.3	253.6

	Altitude	TmpLoTau	TmpHiTau	3.5-4.8	8.3-12	TmpAve	TmpAll
Atmosphere							
ScandinavianSummer	305.0	286.0	286.3	286.2	286.3	286.2	286.2
ScandinavianSummer	1524.0	281.2	283.0	281.9	283.1	282.1	282.0
ScandinavianSummer	3048.0	275.6	280.2	277.3	280.2	277.9	277.8
ScandinavianSummer	4572.0	270.7	278.8	273.7	278.7	274.8	274.6
ScandinavianSummer	6096.0	265.9	278.0	270.6	277.7	271.9	271.8
ScandinavianSummer	7620.0	261.3	277.6	268.2	276.9	269.4	269.4
ScandinavianSummer	9144.0	257.2	277.3	266.5	276.1	267.2	267.4
ScandinavianSummer	10668.0	254.0	277.1	265.4	275.2	265.6	265.8
ScandinavianSummer	12192.0	252.5	277.0	264.7	274.3	264.7	265.1
ScandinavianSummer	13716.0	251.5	276.8	264.2	273.5	264.1	264.5
ScandinavianSummer	14326.0	251.2	276.7	264.0	273.3	263.9	264.3
ScandinavianSummer	15240.0	250.8	276.6	263.8	272.9	263.7	264.1

	Altitude	TmpLoTau	TmpHiTau	3.5-4.8	8.3-12	TmpAve	TmpAll
Atmosphere							
ScandinavianWinter	305.0	257.5	257.4	257.5	257.4	257.5	257.5
ScandinavianWinter	1524.0	258.0	258.1	258.1	258.1	258.1	258.0
ScandinavianWinter	3048.0	255.1	257.1	255.9	257.1	256.1	256.1
ScandinavianWinter	4572.0	251.0	256.5	253.0	256.4	253.7	253.6
ScandinavianWinter	6096.0	246.1	256.0	250.1	255.6	251.1	250.9
ScandinavianWinter	7620.0	241.6	255.6	247.8	254.7	248.6	248.5
ScandinavianWinter	9144.0	238.0	255.3	246.3	253.6	246.7	246.7
ScandinavianWinter	10668.0	236.4	255.0	245.4	252.5	245.7	245.7
ScandinavianWinter	12192.0	235.5	254.7	244.8	251.8	245.1	245.1
ScandinavianWinter	13716.0	234.8	254.4	244.3	251.1	244.6	244.7
ScandinavianWinter	14326.0	234.6	254.3	244.1	250.9	244.5	244.5
ScandinavianWinter	15240.0	234.3	254.2	243.8	250.6	244.2	244.3

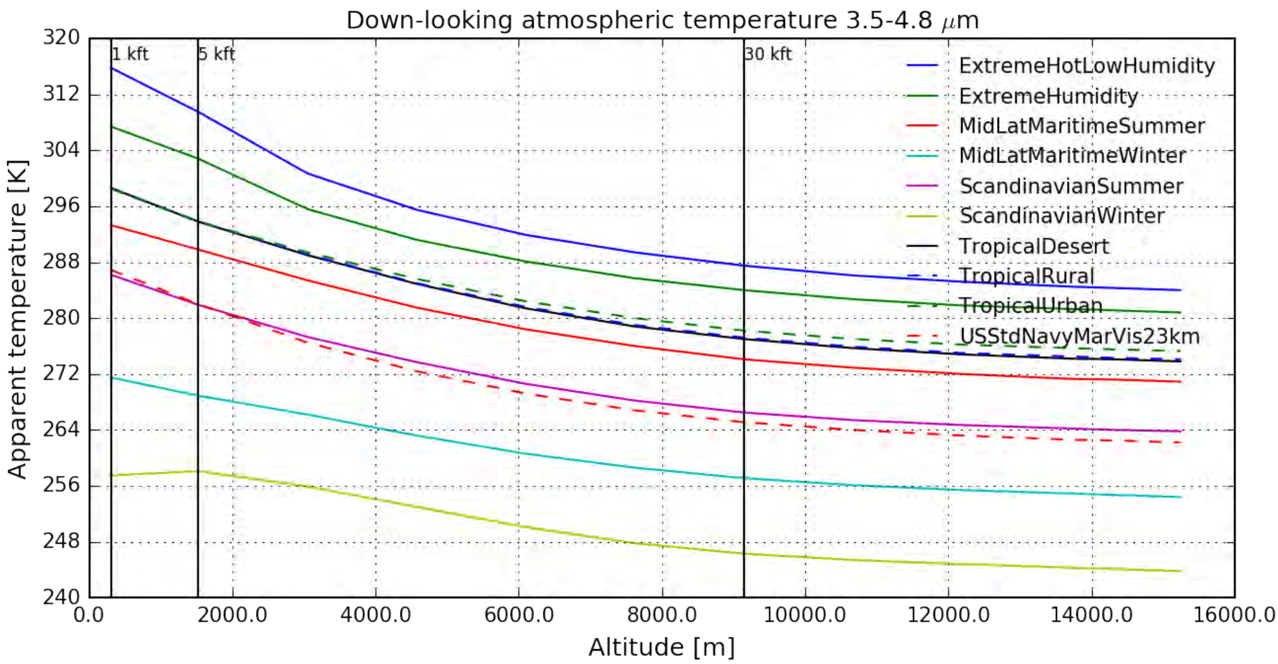
	Altitude	TmpLoTau	TmpHiTau	3.5-4.8	8.3-12	TmpAve	TmpAll
Atmosphere							
TropicalDesert	305.0	298.4	298.7	298.6	298.7	298.5	298.5
TropicalDesert	1524.0	292.7	294.8	293.8	294.9	293.8	293.7
TropicalDesert	3048.0	287.3	291.7	289.0	291.9	289.5	289.4
TropicalDesert	4572.0	281.9	290.5	284.9	290.6	286.2	286.0
TropicalDesert	6096.0	276.8	289.7	281.4	289.7	283.3	283.1
TropicalDesert	7620.0	272.5	289.3	278.8	289.2	280.9	280.8
TropicalDesert	9144.0	268.8	289.1	277.0	288.8	278.9	278.9
TropicalDesert	10668.0	265.6	289.0	275.7	288.4	277.3	277.5
TropicalDesert	12192.0	262.8	288.9	274.8	288.1	275.9	276.2
TropicalDesert	13716.0	260.4	288.8	274.2	287.7	274.6	275.2
TropicalDesert	14326.0	259.5	288.8	274.1	287.6	274.2	274.8
TropicalDesert	15240.0	258.3	288.8	273.8	287.4	273.6	274.3

	Altitude	TmpLoTau	TmpHiTau	3.5-4.8	8.3-12	TmpAve	TmpAll
Atmosphere							
TropicalRural	305.0	298.4	298.7	298.6	298.7	298.5	298.5
TropicalRural	1524.0	292.7	294.8	293.8	294.9	293.8	293.7
TropicalRural	3048.0	287.3	291.7	289.1	291.8	289.5	289.3
TropicalRural	4572.0	281.9	290.5	285.0	290.6	286.2	286.0
TropicalRural	6096.0	276.8	289.7	281.6	289.7	283.3	283.1
TropicalRural	7620.0	272.5	289.3	279.0	289.2	280.9	280.8
TropicalRural	9144.0	268.8	289.1	277.2	288.8	279.0	279.0
TropicalRural	10668.0	265.6	289.0	275.9	288.4	277.3	277.5
TropicalRural	12192.0	262.9	288.9	275.0	288.1	275.9	276.2
TropicalRural	13716.0	260.5	288.8	274.5	287.7	274.7	275.2
TropicalRural	14326.0	259.6	288.8	274.3	287.6	274.2	274.8
TropicalRural	15240.0	258.4	288.8	274.1	287.4	273.6	274.3

	Altitude	TmpLoTau	TmpHiTau	3.5-4.8	8.3-12	TmpAve	TmpAll
Atmosphere							
TropicalUrban	305.0	298.4	298.7	298.5	298.7	298.5	298.5
TropicalUrban	1524.0	292.7	294.8	293.8	294.9	293.7	293.7
TropicalUrban	3048.0	287.3	291.8	289.4	292.0	289.6	289.5
TropicalUrban	4572.0	282.0	290.7	285.6	290.9	286.3	286.1
TropicalUrban	6096.0	276.9	290.0	282.4	290.1	283.5	283.3
TropicalUrban	7620.0	272.7	289.7	280.0	289.6	281.2	281.1
TropicalUrban	9144.0	269.0	289.5	278.2	289.2	279.2	279.2
TropicalUrban	10668.0	265.8	289.3	277.0	288.9	277.6	277.8
TropicalUrban	12192.0	263.1	289.3	276.2	288.6	276.2	276.5
TropicalUrban	13716.0	260.8	289.2	275.7	288.2	275.0	275.5
TropicalUrban	14326.0	259.9	289.2	275.5	288.1	274.5	275.1
TropicalUrban	15240.0	258.7	289.1	275.3	287.9	273.9	274.6

	Altitude	TmpLoTau	TmpHiTau	3.5-4.8	8.3-12	TmpAve	TmpAll
Atmosphere							
USStdNavyMarVis23km	305.0	286.8	287.1	286.9	287.1	286.9	286.9
USStdNavyMarVis23km	1524.0	281.1	283.3	282.0	283.3	282.2	282.1
USStdNavyMarVis23km	3048.0	274.5	279.9	276.5	279.9	277.2	277.1
USStdNavyMarVis23km	4572.0	268.8	278.2	272.4	278.1	273.5	273.4
USStdNavyMarVis23km	6096.0	263.8	277.3	269.2	276.9	270.5	270.4
USStdNavyMarVis23km	7620.0	259.4	276.8	266.8	276.0	268.1	268.1
USStdNavyMarVis23km	9144.0	255.4	276.4	265.1	275.2	265.9	266.1
USStdNavyMarVis23km	10668.0	251.8	276.2	264.0	274.2	264.0	264.3
USStdNavyMarVis23km	12192.0	249.3	275.9	263.2	273.1	262.6	263.1
USStdNavyMarVis23km	13716.0	248.0	275.7	262.6	272.2	261.8	262.4
USStdNavyMarVis23km	14326.0	247.5	275.6	262.5	271.9	261.6	262.1
USStdNavyMarVis23km	15240.0	247.0	275.5	262.2	271.4	261.2	261.8

See Listing 5.8 for the code to plot atmospheric temperature.



2.7 Effective Transmittance in Spectral Bands

The effective transmittance in a number of spectral bands are calculated next. The effective transmittance is calculated using

$$\tau_{\rm eff} = \frac{\int_{\lambda_1}^{\lambda_2} \tau_\lambda \, L_{\lambda{\rm source}} \, d\lambda}{\int_{\lambda_1}^{\lambda_2} L_{\lambda{\rm source}} \, d\lambda} = e^{-\gamma R} \tag{2.2}$$

where the integration limits are defined by the spectral band, and the source radiance is calculated as a sum of reflected sunlight and emitted thermal radiation at 300 K,

$$L_{\lambda{\rm source}} = (1 \,-\, \rho)\, L_{\rm planck}(300K) + \xi \, \rho \, L_{\rm planck}(6000K) \tag{2.3}$$

where $\xi = 2.1 \times 10^{-5}$ accounts for the sun's distance and area, ρ is the surface reflection (default value 0.3) and $L_{\rm planck}$ is Planck law radiance. The exact value of reflectance is only important in the MWIR spectral band; in other bands the value divides out in the normalisation, and becomes unimportant.

The spectral bands are defined as follows:

See Listing 5.9 for the code to define the spectral bands.

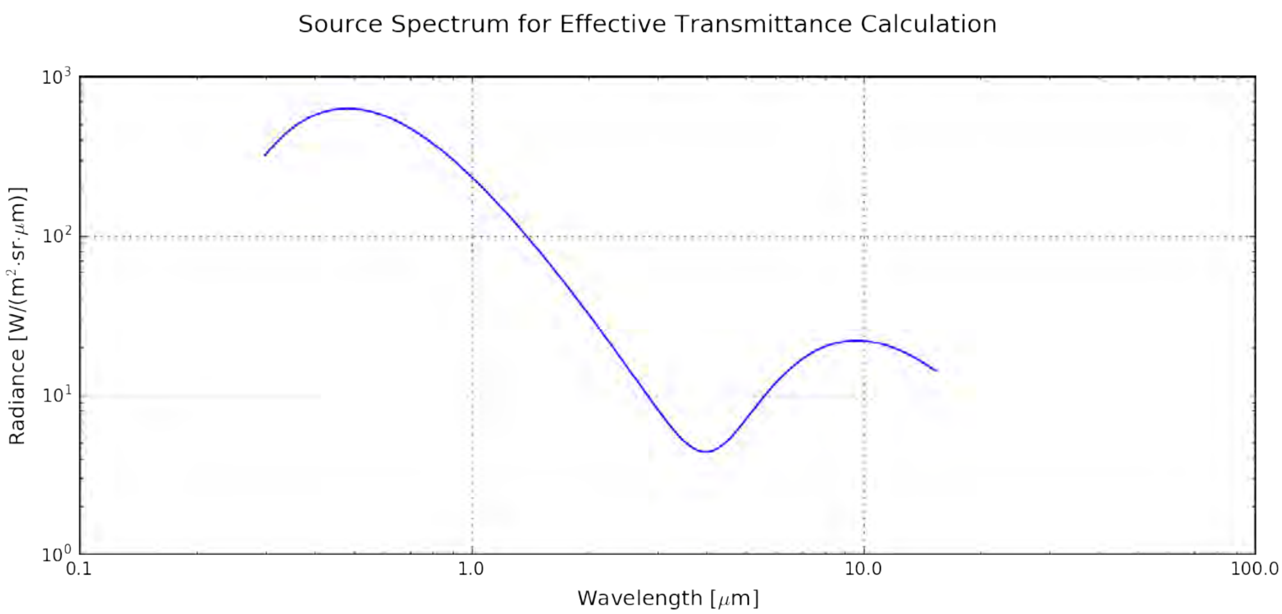
```
{'NIR': [0.7, 0.9], 'Visible': [0.43, 0.69], 'MWIR': [3.6, 4.9], 'LWIR': [8.0, 12.0], 'SWIR': [1.0, 1.7]}
['Visible', 'NIR', 'SWIR', 'MWIR', 'LWIR']
```

The function `analyseTau` calculates the effective transmittance and creates a Pandas dataframe with the results.

See Listing 5.10 for the code to calculate effective transmittance.

Calculate the effective transmittance dataframe for the path length as shown below. The source spectral radiance used in the calculation is also shown below.

See Listing 5.11 for the code to define atmospheric conditions.



See Listing 5.12 for the code to sort and process the data.

Next manipulate the data to extract and display the effective transmittance values in tabular form for the different altitudes.

The data in the following tables describe two different path types in a somewhat confusing manner. Please note the following:

1. Slant path from altitude to ground: The first table in the set provides the effective transmittance along the slant path, from the stated altitude to ground, with a slant angle of -45 deg. The path length quoted here ranges from altitude to ground at a fixed slant angle.

2. Near horizontal path: The second table in the set provides the effective transmittance but scaled to a fixed path length (e.g. 5 km) from the stated altitude, but at some arbitrary slant angle that would give a path length of the stated fixed path length. In other words the slant angle is

adjusted to provide a path length of 5 km. This does not make sense for altitudes above 5 km, but the values are calculated anyway.

See Listing 5.13 for the code to build the result tables.

Altitude 305 m, slant path length 431 m, (recalculated from 1 km data set)

	EffTauSlant				
SpecRange	Visible	NIR	SWIR	MWIR	LWIR
Atmosphere					
ExtremeHotLowHumidity 44 C, 30% RH (18.1), 77 km Vis Desert	0.977	0.962	0.783	0.694	0.835
ExtremeHumidity 35 C, 95% RH (37.9), 23 km Vis Rural	0.930	0.914	0.718	0.636	0.585
MidLatMaritimeSummer 21 C, 76% RH (14), 23 km Vis Maritime	0.931	0.923	0.770	0.702	0.865
MidLatMaritimeWinter -1 C, 77% RH (3), 10 km Vis Maritime	0.843	0.855	0.779	0.712	0.946
ScandinavianSummer 14 C, 75% RH (9), 31 km Vis Maritime	0.949	0.943	0.805	0.725	0.910
ScandinavianWinter -15.9 C, 80% RH (1), 31 km Vis Maritime	0.945	0.950	0.892	0.759	0.974
TropicalDesert 26.6 C, 75% RH (18), 75 km Vis Desert	0.976	0.962	0.784	0.702	0.818
TropicalRural 26.6 C, 75% RH (18), 23 km Vis Rural	0.931	0.933	0.770	0.698	0.814
TropicalUrban 26.6 C, 75% RH (18), 5 km Vis Urban	0.714	0.779	0.692	0.673	0.794
USStdNavyMarVis23km 15 C, 46% RH (5.9), 23 km Vis Nav.Mar, SS4	0.932	0.932	0.819	0.738	0.943

Altitude 305 m, fixed path length 5000 m, (recalculated from 1 km data set)

	EffTauRange				
SpecRange	Visible	NIR	SWIR	MWIR	LWIR
Atmosphere					
ExtremeHotLowHumidity 44 C, 30% RH (18.1), 77 km Vis Desert	0.764	0.688	0.500	0.252	0.156
ExtremeHumidity 35 C, 95% RH (37.9), 23 km Vis Rural	0.438	0.419	0.351	0.166	0.004
MidLatMaritimeSummer 21 C, 76% RH (14), 23 km Vis Maritime	0.440	0.415	0.316	0.206	0.216
MidLatMaritimeWinter -1 C, 77% RH (3), 10 km Vis Maritime	0.139	0.164	0.149	0.172	0.550
ScandinavianSummer 14 C, 75% RH (9), 31 km Vis Maritime	0.548	0.521	0.385	0.253	0.370
ScandinavianWinter -15.9 C, 80% RH (1), 31 km Vis Maritime	0.522	0.557	0.458	0.352	0.752
TropicalDesert 26.6 C, 75% RH (18), 75 km Vis Desert	0.763	0.689	0.503	0.252	0.122
TropicalRural 26.6 C, 75% RH (18), 23 km Vis Rural	0.444	0.482	0.410	0.236	0.116
TropicalUrban 26.6 C, 75% RH (18), 5 km Vis Urban	0.022	0.061	0.122	0.152	0.086
USStdNavyMarVis23km 15 C, 46% RH (5.9), 23 km Vis Nav.Mar, SS4	0.445	0.455	0.361	0.291	0.541

Altitude 1524 m, slant path length 2155 m, (recalculated from 1 km data set)

	EffTauSlant				
SpecRange	Visible	NIR	SWIR	MWIR	LWIR
Atmosphere					
ExtremeHotLowHumidity 44 C, 30% RH (18.1), 77 km Vis Desert	0.911	0.890	0.671	0.497	0.599
ExtremeHumidity 35 C, 95% RH (37.9), 23 km Vis Rural	0.756	0.752	0.569	0.400	0.185
MidLatMaritimeSummer 21 C, 76% RH (14), 23 km Vis Maritime	0.758	0.757	0.594	0.492	0.654
MidLatMaritimeWinter -1 C, 77% RH (3), 10 km Vis Maritime	0.472	0.514	0.469	0.467	0.828
ScandinavianSummer 14 C, 75% RH (9), 31 km Vis Maritime	0.815	0.810	0.642	0.525	0.752
ScandinavianWinter -15.9 C, 80% RH (1), 31 km Vis Maritime	0.802	0.823	0.729	0.581	0.906
TropicalDesert 26.6 C, 75% RH (18), 75 km Vis Desert	0.910	0.889	0.671	0.501	0.540
TropicalRural 26.6 C, 75% RH (18), 23 km Vis Rural	0.759	0.789	0.627	0.491	0.532
TropicalUrban 26.6 C, 75% RH (18), 5 km Vis Urban	0.243	0.363	0.395	0.418	0.475
USStdNavyMarVis23km 15 C, 46% RH (5.9), 23 km Vis Nav.Mar, SS4	0.760	0.772	0.641	0.551	0.835

Altitude 1524 m, fixed path length 5000 m, (recalculated from 1 km data set)

SpecRange	EffTauRange				
	Visible	NIR	SWIR	MWIR	LWIR
Atmosphere					
ExtremeHotLowHumidity 44 C, 30% RH (18.1), 77 km Vis Desert	0.806	0.774	0.563	0.329	0.316
ExtremeHumidity 35 C, 95% RH (37.9), 23 km Vis Rural	0.524	0.532	0.426	0.233	0.026
MidLatMaritimeSummer 21 C, 76% RH (14), 23 km Vis Maritime	0.527	0.529	0.408	0.302	0.382
MidLatMaritimeWinter -1 C, 77% RH (3), 10 km Vis Maritime	0.176	0.214	0.206	0.251	0.651
ScandinavianSummer 14 C, 75% RH (9), 31 km Vis Maritime	0.623	0.617	0.465	0.339	0.524
ScandinavianWinter -15.9 C, 80% RH (1), 31 km Vis Maritime	0.601	0.638	0.539	0.417	0.799
TropicalDesert 26.6 C, 75% RH (18), 75 km Vis Desert	0.804	0.772	0.564	0.330	0.251
TropicalRural 26.6 C, 75% RH (18), 23 km Vis Rural	0.530	0.586	0.482	0.314	0.242
TropicalUrban 26.6 C, 75% RH (18), 5 km Vis Urban	0.039	0.098	0.167	0.215	0.185
USStdNavyMarVis23km 15 C, 46% RH (5.9), 23 km Vis Nav.Mar, SS4	0.530	0.552	0.444	0.375	0.665

Altitude 3048 m, slant path length 4311 m, (recalculated from 1 km data set)

SpecRange	EffTauSlant				
	Visible	NIR	SWIR	MWIR	LWIR
Atmosphere					
ExtremeHotLowHumidity 44 C, 30% RH (18.1), 77 km Vis Desert	0.863	0.857	0.644	0.441	0.548
ExtremeHumidity 35 C, 95% RH (37.9), 23 km Vis Rural	0.656	0.677	0.526	0.341	0.133
MidLatMaritimeSummer 21 C, 76% RH (14), 23 km Vis Maritime	0.658	0.674	0.530	0.419	0.578
MidLatMaritimeWinter -1 C, 77% RH (3), 10 km Vis Maritime	0.404	0.456	0.416	0.407	0.789
ScandinavianSummer 14 C, 75% RH (9), 31 km Vis Maritime	0.732	0.739	0.580	0.449	0.681
ScandinavianWinter -15.9 C, 80% RH (1), 31 km Vis Maritime	0.718	0.755	0.660	0.509	0.867
TropicalDesert 26.6 C, 75% RH (18), 75 km Vis Desert	0.861	0.850	0.634	0.432	0.443
TropicalRural 26.6 C, 75% RH (18), 23 km Vis Rural	0.659	0.713	0.574	0.419	0.433
TropicalUrban 26.6 C, 75% RH (18), 5 km Vis Urban	0.204	0.320	0.356	0.354	0.385
USStdNavyMarVis23km 15 C, 46% RH (5.9), 23 km Vis Nav.Mar, SS4	0.660	0.689	0.570	0.478	0.781

Altitude 3048 m, fixed path length 5000 m, (recalculated from 1 km data set)

SpecRange	EffTauRange				
	Visible	NIR	SWIR	MWIR	LWIR
Atmosphere					
ExtremeHotLowHumidity 44 C, 30% RH (18.1), 77 km Vis Desert	0.843	0.838	0.625	0.411	0.500
ExtremeHumidity 35 C, 95% RH (37.9), 23 km Vis Rural	0.613	0.638	0.500	0.310	0.098
MidLatMaritimeSummer 21 C, 76% RH (14), 23 km Vis Maritime	0.615	0.633	0.497	0.385	0.531
MidLatMaritimeWinter -1 C, 77% RH (3), 10 km Vis Maritime	0.350	0.402	0.369	0.370	0.760
ScandinavianSummer 14 C, 75% RH (9), 31 km Vis Maritime	0.696	0.705	0.548	0.416	0.641
ScandinavianWinter -15.9 C, 80% RH (1), 31 km Vis Maritime	0.681	0.722	0.626	0.480	0.847
TropicalDesert 26.6 C, 75% RH (18), 75 km Vis Desert	0.841	0.829	0.614	0.401	0.390
TropicalRural 26.6 C, 75% RH (18), 23 km Vis Rural	0.617	0.677	0.548	0.387	0.381
TropicalUrban 26.6 C, 75% RH (18), 5 km Vis Urban	0.159	0.267	0.315	0.318	0.332
USStdNavyMarVis23km 15 C, 46% RH (5.9), 23 km Vis Nav.Mar, SS4	0.618	0.650	0.535	0.447	0.752

Altitude 4572 m, slant path length 6466 m, (recalculated from 1 km data set)

	EffTauSlant				
SpecRange	Visible	NIR	SWIR	MWIR	LWIR
Atmosphere					
ExtremeHotLowHumidity 44 C, 30% RH (18.1), 77 km Vis Desert	0.830	0.840	0.634	0.416	0.533
ExtremeHumidity 35 C, 95% RH (37.9), 23 km Vis Rural	0.613	0.652	0.513	0.320	0.125
MidLatMaritimeSummer 21 C, 76% RH (14), 23 km Vis Maritime	0.615	0.648	0.516	0.393	0.557
MidLatMaritimeWinter -1 C, 77% RH (3), 10 km Vis Maritime	0.384	0.443	0.407	0.385	0.775
ScandinavianSummer 14 C, 75% RH (9), 31 km Vis Maritime	0.692	0.716	0.564	0.422	0.658
ScandinavianWinter -15.9 C, 80% RH (1), 31 km Vis Maritime	0.685	0.738	0.646	0.484	0.854
TropicalDesert 26.6 C, 75% RH (18), 75 km Vis Desert	0.829	0.831	0.622	0.405	0.424
TropicalRural 26.6 C, 75% RH (18), 23 km Vis Rural	0.617	0.686	0.559	0.393	0.414
TropicalUrban 26.6 C, 75% RH (18), 5 km Vis Urban	0.192	0.308	0.346	0.332	0.368
USStdNavyMarVis23km 15 C, 46% RH (5.9), 23 km Vis Nav.Mar, SS4	0.617	0.664	0.555	0.451	0.763

Altitude 4572 m, fixed path length 5000 m, (recalculated from 1 km data set)

	EffTauRange				
SpecRange	Visible	NIR	SWIR	MWIR	LWIR
Atmosphere					
ExtremeHotLowHumidity 44 C, 30% RH (18.1), 77 km Vis Desert	0.866	0.873	0.668	0.468	0.612
ExtremeHumidity 35 C, 95% RH (37.9), 23 km Vis Rural	0.685	0.716	0.557	0.374	0.195
MidLatMaritimeSummer 21 C, 76% RH (14), 23 km Vis Maritime	0.687	0.714	0.572	0.450	0.634
MidLatMaritimeWinter -1 C, 77% RH (3), 10 km Vis Maritime	0.476	0.533	0.485	0.446	0.820
ScandinavianSummer 14 C, 75% RH (9), 31 km Vis Maritime	0.752	0.772	0.617	0.477	0.722
ScandinavianWinter -15.9 C, 80% RH (1), 31 km Vis Maritime	0.746	0.790	0.700	0.532	0.885
TropicalDesert 26.6 C, 75% RH (18), 75 km Vis Desert	0.864	0.865	0.655	0.458	0.512
TropicalRural 26.6 C, 75% RH (18), 23 km Vis Rural	0.688	0.746	0.604	0.448	0.503
TropicalUrban 26.6 C, 75% RH (18), 5 km Vis Urban	0.278	0.401	0.417	0.393	0.459
USStdNavyMarVis23km 15 C, 46% RH (5.9), 23 km Vis Nav.Mar, SS4	0.689	0.728	0.613	0.503	0.810

Altitude 6096 m, slant path length 8621 m, (recalculated from 1 km data set)

	EffTauSlant				
SpecRange	Visible	NIR	SWIR	MWIR	LWIR
Atmosphere					
ExtremeHotLowHumidity 44 C, 30% RH (18.1), 77 km Vis Desert	0.801	0.826	0.627	0.401	0.524
ExtremeHumidity 35 C, 95% RH (37.9), 23 km Vis Rural	0.591	0.640	0.508	0.309	0.122
MidLatMaritimeSummer 21 C, 76% RH (14), 23 km Vis Maritime	0.593	0.637	0.510	0.379	0.547
MidLatMaritimeWinter -1 C, 77% RH (3), 10 km Vis Maritime	0.373	0.438	0.403	0.372	0.766
ScandinavianSummer 14 C, 75% RH (9), 31 km Vis Maritime	0.667	0.703	0.557	0.407	0.647
ScandinavianWinter -15.9 C, 80% RH (1), 31 km Vis Maritime	0.667	0.730	0.640	0.469	0.847
TropicalDesert 26.6 C, 75% RH (18), 75 km Vis Desert	0.800	0.816	0.614	0.390	0.416
TropicalRural 26.6 C, 75% RH (18), 23 km Vis Rural	0.595	0.674	0.552	0.379	0.407
TropicalUrban 26.6 C, 75% RH (18), 5 km Vis Urban	0.185	0.303	0.342	0.320	0.361
USStdNavyMarVis23km 15 C, 46% RH (5.9), 23 km Vis Nav.Mar, SS4	0.595	0.653	0.548	0.436	0.754

Altitude 6096 m, fixed path length 5000 m, (recalculated from 1 km data set)

	EffTauRange				
SpecRange	Visible	NIR	SWIR	MWIR	LWIR
Atmosphere					
ExtremeHotLowHumidity 44 C, 30% RH (18.1), 77 km Vis Desert	0.879	0.893	0.700	0.509	0.684
ExtremeHumidity 35 C, 95% RH (37.9), 23 km Vis Rural	0.737	0.768	0.599	0.424	0.284
MidLatMaritimeSummer 21 C, 76% RH (14), 23 km Vis Maritime	0.738	0.768	0.625	0.497	0.702
MidLatMaritimeWinter -1 C, 77% RH (3), 10 km Vis Maritime	0.564	0.619	0.564	0.496	0.855
ScandinavianSummer 14 C, 75% RH (9), 31 km Vis Maritime	0.790	0.814	0.665	0.520	0.775
ScandinavianWinter -15.9 C, 80% RH (1), 31 km Vis Maritime	0.790	0.833	0.749	0.567	0.907
TropicalDesert 26.6 C, 75% RH (18), 75 km Vis Desert	0.878	0.887	0.687	0.500	0.596
TropicalRural 26.6 C, 75% RH (18), 23 km Vis Rural	0.739	0.793	0.646	0.492	0.589
TropicalUrban 26.6 C, 75% RH (18), 5 km Vis Urban	0.374	0.498	0.489	0.446	0.550
USStdNavyMarVis23km 15 C, 46% RH (5.9), 23 km Vis Nav.Mar, SS4	0.740	0.780	0.666	0.542	0.847

Altitude 7620 m, slant path length 10776 m, (recalculated from 1 km data set)

	EffTauSlant				
SpecRange	Visible	NIR	SWIR	MWIR	LWIR
Atmosphere					
ExtremeHotLowHumidity 44 C, 30% RH (18.1), 77 km Vis Desert	0.779	0.816	0.622	0.392	0.517
ExtremeHumidity 35 C, 95% RH (37.9), 23 km Vis Rural	0.575	0.633	0.505	0.302	0.120
MidLatMaritimeSummer 21 C, 76% RH (14), 23 km Vis Maritime	0.577	0.629	0.506	0.371	0.540
MidLatMaritimeWinter -1 C, 77% RH (3), 10 km Vis Maritime	0.366	0.435	0.401	0.364	0.759
ScandinavianSummer 14 C, 75% RH (9), 31 km Vis Maritime	0.649	0.695	0.553	0.398	0.640
ScandinavianWinter -15.9 C, 80% RH (1), 31 km Vis Maritime	0.654	0.725	0.637	0.459	0.839
TropicalDesert 26.6 C, 75% RH (18), 75 km Vis Desert	0.778	0.807	0.610	0.381	0.411
TropicalRural 26.6 C, 75% RH (18), 23 km Vis Rural	0.579	0.666	0.549	0.370	0.402
TropicalUrban 26.6 C, 75% RH (18), 5 km Vis Urban	0.180	0.299	0.340	0.312	0.357
USStdNavyMarVis23km 15 C, 46% RH (5.9), 23 km Vis Nav.Mar, SS4	0.579	0.645	0.544	0.426	0.748

Altitude 7620 m, fixed path length 5000 m, (recalculated from 1 km data set)

	EffTauRange				
SpecRange	Visible	NIR	SWIR	MWIR	LWIR
Atmosphere					
ExtremeHotLowHumidity 44 C, 30% RH (18.1), 77 km Vis Desert	0.890	0.908	0.725	0.541	0.732
ExtremeHumidity 35 C, 95% RH (37.9), 23 km Vis Rural	0.773	0.805	0.632	0.463	0.359
MidLatMaritimeSummer 21 C, 76% RH (14), 23 km Vis Maritime	0.774	0.805	0.663	0.532	0.748
MidLatMaritimeWinter -1 C, 77% RH (3), 10 km Vis Maritime	0.626	0.679	0.621	0.533	0.878
ScandinavianSummer 14 C, 75% RH (9), 31 km Vis Maritime	0.818	0.844	0.701	0.553	0.810
ScandinavianWinter -15.9 C, 80% RH (1), 31 km Vis Maritime	0.820	0.861	0.785	0.594	0.921
TropicalDesert 26.6 C, 75% RH (18), 75 km Vis Desert	0.889	0.903	0.712	0.534	0.657
TropicalRural 26.6 C, 75% RH (18), 23 km Vis Rural	0.775	0.826	0.678	0.526	0.650
TropicalUrban 26.6 C, 75% RH (18), 5 km Vis Urban	0.448	0.569	0.542	0.487	0.616
USStdNavyMarVis23km 15 C, 46% RH (5.9), 23 km Vis Nav.Mar, SS4	0.775	0.815	0.705	0.572	0.872

Altitude 9144 m, slant path length 12932 m, (recalculated from 1 km data set)

	EffTauSlant				
SpecRange	Visible	NIR	SWIR	MWIR	LWIR
Atmosphere					
ExtremeHotLowHumidity 44 C, 30% RH (18.1), 77 km Vis Desert	0.765	0.811	0.620	0.386	0.512
ExtremeHumidity 35 C, 95% RH (37.9), 23 km Vis Rural	0.565	0.628	0.503	0.297	0.118
MidLatMaritimeSummer 21 C, 76% RH (14), 23 km Vis Maritime	0.567	0.625	0.504	0.365	0.535
MidLatMaritimeWinter -1 C, 77% RH (3), 10 km Vis Maritime	0.361	0.433	0.400	0.359	0.751
ScandinavianSummer 14 C, 75% RH (9), 31 km Vis Maritime	0.638	0.691	0.551	0.392	0.633
ScandinavianWinter -15.9 C, 80% RH (1), 31 km Vis Maritime	0.644	0.722	0.636	0.453	0.830
TropicalDesert 26.6 C, 75% RH (18), 75 km Vis Desert	0.764	0.801	0.608	0.375	0.408
TropicalRural 26.6 C, 75% RH (18), 23 km Vis Rural	0.569	0.661	0.547	0.364	0.399
TropicalUrban 26.6 C, 75% RH (18), 5 km Vis Urban	0.177	0.297	0.339	0.307	0.355
USStdNavyMarVis23km 15 C, 46% RH (5.9), 23 km Vis Nav.Mar, SS4	0.569	0.641	0.542	0.419	0.743

Altitude 9144 m, fixed path length 5000 m, (recalculated from 1 km data set)

	EffTauRange				
SpecRange	Visible	NIR	SWIR	MWIR	LWIR
Atmosphere					
ExtremeHotLowHumidity 44 C, 30% RH (18.1), 77 km Vis Desert	0.901	0.920	0.746	0.566	0.767
ExtremeHumidity 35 C, 95% RH (37.9), 23 km Vis Rural	0.801	0.832	0.658	0.495	0.422
MidLatMaritimeSummer 21 C, 76% RH (14), 23 km Vis Maritime	0.802	0.832	0.694	0.560	0.782
MidLatMaritimeWinter -1 C, 77% RH (3), 10 km Vis Maritime	0.673	0.723	0.664	0.562	0.893
ScandinavianSummer 14 C, 75% RH (9), 31 km Vis Maritime	0.839	0.865	0.729	0.579	0.835
ScandinavianWinter -15.9 C, 80% RH (1), 31 km Vis Maritime	0.843	0.881	0.811	0.615	0.929
TropicalDesert 26.6 C, 75% RH (18), 75 km Vis Desert	0.900	0.915	0.733	0.561	0.702
TropicalRural 26.6 C, 75% RH (18), 23 km Vis Rural	0.803	0.850	0.704	0.554	0.696
TropicalUrban 26.6 C, 75% RH (18), 5 km Vis Urban	0.509	0.623	0.584	0.520	0.665
USStdNavyMarVis23km 15 C, 46% RH (5.9), 23 km Vis Nav.Mar, SS4	0.803	0.841	0.735	0.595	0.889

Altitude 10668 m, slant path length 15087 m, (recalculated from 1 km data set)

	EffTauSlant				
SpecRange	Visible	NIR	SWIR	MWIR	LWIR
Atmosphere					
ExtremeHotLowHumidity 44 C, 30% RH (18.1), 77 km Vis Desert	0.755	0.807	0.619	0.381	0.507
ExtremeHumidity 35 C, 95% RH (37.9), 23 km Vis Rural	0.558	0.626	0.502	0.293	0.117
MidLatMaritimeSummer 21 C, 76% RH (14), 23 km Vis Maritime	0.560	0.622	0.503	0.360	0.530
MidLatMaritimeWinter -1 C, 77% RH (3), 10 km Vis Maritime	0.356	0.432	0.399	0.355	0.741
ScandinavianSummer 14 C, 75% RH (9), 31 km Vis Maritime	0.629	0.688	0.550	0.388	0.626
ScandinavianWinter -15.9 C, 80% RH (1), 31 km Vis Maritime	0.637	0.719	0.635	0.448	0.818
TropicalDesert 26.6 C, 75% RH (18), 75 km Vis Desert	0.755	0.798	0.607	0.371	0.406
TropicalRural 26.6 C, 75% RH (18), 23 km Vis Rural	0.562	0.658	0.545	0.360	0.397
TropicalUrban 26.6 C, 75% RH (18), 5 km Vis Urban	0.175	0.296	0.338	0.304	0.353
USStdNavyMarVis23km 15 C, 46% RH (5.9), 23 km Vis Nav.Mar, SS4	0.562	0.638	0.541	0.415	0.736

Altitude 10668 m, fixed path length 5000 m, (recalculated from 1 km data set)

	EffTauRange				
SpecRange	Visible	NIR	SWIR	MWIR	LWIR
Atmosphere					
ExtremeHotLowHumidity 44 C, 30% RH (18.1), 77 km Vis Desert	0.910	0.930	0.763	0.588	0.794
ExtremeHumidity 35 C, 95% RH (37.9), 23 km Vis Rural	0.823	0.852	0.680	0.522	0.474
MidLatMaritimeSummer 21 C, 76% RH (14), 23 km Vis Maritime	0.824	0.853	0.718	0.582	0.807
MidLatMaritimeWinter -1 C, 77% RH (3), 10 km Vis Maritime	0.709	0.756	0.698	0.585	0.903
ScandinavianSummer 14 C, 75% RH (9), 31 km Vis Maritime	0.857	0.882	0.752	0.601	0.853
ScandinavianWinter -15.9 C, 80% RH (1), 31 km Vis Maritime	0.860	0.896	0.832	0.633	0.934
TropicalDesert 26.6 C, 75% RH (18), 75 km Vis Desert	0.910	0.926	0.751	0.583	0.736
TropicalRural 26.6 C, 75% RH (18), 23 km Vis Rural	0.825	0.868	0.725	0.577	0.731
TropicalUrban 26.6 C, 75% RH (18), 5 km Vis Urban	0.557	0.665	0.618	0.546	0.703
USStdNavyMarVis23km 15 C, 46% RH (5.9), 23 km Vis Nav.Mar, SS4	0.825	0.861	0.759	0.615	0.901

Altitude 12192 m, slant path length 17242 m, (recalculated from 1 km data set)

	EffTauSlant				
SpecRange	Visible	NIR	SWIR	MWIR	LWIR
Atmosphere					
ExtremeHotLowHumidity 44 C, 30% RH (18.1), 77 km Vis Desert	0.747	0.805	0.618	0.378	0.501
ExtremeHumidity 35 C, 95% RH (37.9), 23 km Vis Rural	0.552	0.624	0.501	0.291	0.115
MidLatMaritimeSummer 21 C, 76% RH (14), 23 km Vis Maritime	0.554	0.621	0.503	0.357	0.524
MidLatMaritimeWinter -1 C, 77% RH (3), 10 km Vis Maritime	0.352	0.430	0.399	0.352	0.729
ScandinavianSummer 14 C, 75% RH (9), 31 km Vis Maritime	0.623	0.686	0.549	0.385	0.617
ScandinavianWinter -15.9 C, 80% RH (1), 31 km Vis Maritime	0.630	0.718	0.634	0.444	0.807
TropicalDesert 26.6 C, 75% RH (18), 75 km Vis Desert	0.747	0.796	0.606	0.368	0.404
TropicalRural 26.6 C, 75% RH (18), 23 km Vis Rural	0.556	0.657	0.545	0.357	0.395
TropicalUrban 26.6 C, 75% RH (18), 5 km Vis Urban	0.174	0.295	0.337	0.301	0.351
USStdNavyMarVis23km 15 C, 46% RH (5.9), 23 km Vis Nav.Mar, SS4	0.556	0.636	0.540	0.411	0.727

Altitude 12192 m, fixed path length 5000 m, (recalculated from 1 km data set)

	EffTauRange				
SpecRange	Visible	NIR	SWIR	MWIR	LWIR
Atmosphere					
ExtremeHotLowHumidity 44 C, 30% RH (18.1), 77 km Vis Desert	0.918	0.937	0.778	0.606	0.814
ExtremeHumidity 35 C, 95% RH (37.9), 23 km Vis Rural	0.840	0.868	0.698	0.545	0.517
MidLatMaritimeSummer 21 C, 76% RH (14), 23 km Vis Maritime	0.841	0.869	0.738	0.602	0.826
MidLatMaritimeWinter -1 C, 77% RH (3), 10 km Vis Maritime	0.738	0.782	0.726	0.605	0.910
ScandinavianSummer 14 C, 75% RH (9), 31 km Vis Maritime	0.871	0.895	0.770	0.618	0.866
ScandinavianWinter -15.9 C, 80% RH (1), 31 km Vis Maritime	0.874	0.908	0.848	0.648	0.937
TropicalDesert 26.6 C, 75% RH (18), 75 km Vis Desert	0.918	0.934	0.766	0.602	0.764
TropicalRural 26.6 C, 75% RH (18), 23 km Vis Rural	0.842	0.883	0.742	0.597	0.759
TropicalUrban 26.6 C, 75% RH (18), 5 km Vis Urban	0.598	0.699	0.646	0.568	0.733
USStdNavyMarVis23km 15 C, 46% RH (5.9), 23 km Vis Nav.Mar, SS4	0.842	0.876	0.778	0.631	0.909

Altitude 13716 m, slant path length 19397 m, (recalculated from 1 km data set)

	EffTauSlant				
SpecRange	Visible	NIR	SWIR	MWIR	LWIR
Atmosphere					
ExtremeHotLowHumidity 44 C, 30% RH (18.1), 77 km Vis Desert	0.741	0.803	0.617	0.375	0.495
ExtremeHumidity 35 C, 95% RH (37.9), 23 km Vis Rural	0.547	0.623	0.501	0.289	0.113
MidLatMaritimeSummer 21 C, 76% RH (14), 23 km Vis Maritime	0.549	0.619	0.502	0.355	0.518
MidLatMaritimeWinter -1 C, 77% RH (3), 10 km Vis Maritime	0.349	0.429	0.398	0.349	0.718
ScandinavianSummer 14 C, 75% RH (9), 31 km Vis Maritime	0.617	0.684	0.549	0.382	0.608
ScandinavianWinter -15.9 C, 80% RH (1), 31 km Vis Maritime	0.625	0.716	0.634	0.441	0.796
TropicalDesert 26.6 C, 75% RH (18), 75 km Vis Desert	0.741	0.794	0.605	0.366	0.402
TropicalRural 26.6 C, 75% RH (18), 23 km Vis Rural	0.552	0.655	0.544	0.355	0.393
TropicalUrban 26.6 C, 75% RH (18), 5 km Vis Urban	0.172	0.294	0.337	0.299	0.349
USStdNavyMarVis23km 15 C, 46% RH (5.9), 23 km Vis Nav.Mar, SS4	0.551	0.635	0.539	0.409	0.718

Altitude 13716 m, fixed path length 5000 m, (recalculated from 1 km data set)

	EffTauRange				
SpecRange	Visible	NIR	SWIR	MWIR	LWIR
Atmosphere					
ExtremeHotLowHumidity 44 C, 30% RH (18.1), 77 km Vis Desert	0.925	0.943	0.790	0.621	0.830
ExtremeHumidity 35 C, 95% RH (37.9), 23 km Vis Rural	0.854	0.881	0.714	0.565	0.553
MidLatMaritimeSummer 21 C, 76% RH (14), 23 km Vis Maritime	0.856	0.882	0.755	0.618	0.841
MidLatMaritimeWinter -1 C, 77% RH (3), 10 km Vis Maritime	0.761	0.803	0.748	0.621	0.915
ScandinavianSummer 14 C, 75% RH (9), 31 km Vis Maritime	0.882	0.906	0.786	0.634	0.876
ScandinavianWinter -15.9 C, 80% RH (1), 31 km Vis Maritime	0.885	0.917	0.862	0.661	0.940
TropicalDesert 26.6 C, 75% RH (18), 75 km Vis Desert	0.925	0.940	0.778	0.618	0.785
TropicalRural 26.6 C, 75% RH (18), 23 km Vis Rural	0.856	0.895	0.757	0.613	0.781
TropicalUrban 26.6 C, 75% RH (18), 5 km Vis Urban	0.631	0.727	0.669	0.587	0.758
USStdNavyMarVis23km 15 C, 46% RH (5.9), 23 km Vis Nav.Mar, SS4	0.857	0.889	0.795	0.645	0.916

Altitude 14326 m, slant path length 20260 m, (recalculated from 1 km data set)

	EffTauSlant				
SpecRange	Visible	NIR	SWIR	MWIR	LWIR
Atmosphere					
ExtremeHotLowHumidity 44 C, 30% RH (18.1), 77 km Vis Desert	0.738	0.803	0.617	0.374	0.493
ExtremeHumidity 35 C, 95% RH (37.9), 23 km Vis Rural	0.545	0.622	0.501	0.288	0.112
MidLatMaritimeSummer 21 C, 76% RH (14), 23 km Vis Maritime	0.547	0.619	0.502	0.354	0.516
MidLatMaritimeWinter -1 C, 77% RH (3), 10 km Vis Maritime	0.348	0.429	0.398	0.348	0.714
ScandinavianSummer 14 C, 75% RH (9), 31 km Vis Maritime	0.615	0.684	0.549	0.381	0.605
ScandinavianWinter -15.9 C, 80% RH (1), 31 km Vis Maritime	0.623	0.715	0.633	0.440	0.791
TropicalDesert 26.6 C, 75% RH (18), 75 km Vis Desert	0.739	0.793	0.605	0.365	0.401
TropicalRural 26.6 C, 75% RH (18), 23 km Vis Rural	0.550	0.655	0.544	0.354	0.392
TropicalUrban 26.6 C, 75% RH (18), 5 km Vis Urban	0.172	0.294	0.337	0.299	0.348
USStdNavyMarVis23km 15 C, 46% RH (5.9), 23 km Vis Nav.Mar, SS4	0.549	0.634	0.539	0.408	0.715

Altitude 14326 m, fixed path length 5000 m, (recalculated from 1 km data set)

	EffTauRange				
SpecRange	Visible	NIR	SWIR	MWIR	LWIR
Atmosphere					
ExtremeHotLowHumidity 44 C, 30% RH (18.1), 77 km Vis Desert	0.927	0.945	0.794	0.627	0.835
ExtremeHumidity 35 C, 95% RH (37.9), 23 km Vis Rural	0.859	0.886	0.720	0.572	0.566
MidLatMaritimeSummer 21 C, 76% RH (14), 23 km Vis Maritime	0.861	0.887	0.761	0.624	0.846
MidLatMaritimeWinter -1 C, 77% RH (3), 10 km Vis Maritime	0.769	0.811	0.756	0.627	0.917
ScandinavianSummer 14 C, 75% RH (9), 31 km Vis Maritime	0.886	0.909	0.791	0.639	0.880
ScandinavianWinter -15.9 C, 80% RH (1), 31 km Vis Maritime	0.889	0.920	0.866	0.665	0.941
TropicalDesert 26.6 C, 75% RH (18), 75 km Vis Desert	0.927	0.942	0.783	0.624	0.793
TropicalRural 26.6 C, 75% RH (18), 23 km Vis Rural	0.861	0.899	0.763	0.619	0.789
TropicalUrban 26.6 C, 75% RH (18), 5 km Vis Urban	0.643	0.737	0.677	0.594	0.766
USStdNavyMarVis23km 15 C, 46% RH (5.9), 23 km Vis Nav.Mar, SS4	0.862	0.893	0.801	0.650	0.918

Altitude 15240 m, slant path length 21553 m, (recalculated from 1 km data set)

	EffTauSlant				
SpecRange	Visible	NIR	SWIR	MWIR	LWIR
Atmosphere					
ExtremeHotLowHumidity 44 C, 30% RH (18.1), 77 km Vis Desert	0.735	0.802	0.617	0.373	0.489
ExtremeHumidity 35 C, 95% RH (37.9), 23 km Vis Rural	0.543	0.621	0.500	0.287	0.111
MidLatMaritimeSummer 21 C, 76% RH (14), 23 km Vis Maritime	0.545	0.618	0.502	0.353	0.512
MidLatMaritimeWinter -1 C, 77% RH (3), 10 km Vis Maritime	0.346	0.428	0.398	0.347	0.709
ScandinavianSummer 14 C, 75% RH (9), 31 km Vis Maritime	0.613	0.683	0.549	0.380	0.601
ScandinavianWinter -15.9 C, 80% RH (1), 31 km Vis Maritime	0.620	0.714	0.633	0.439	0.784
TropicalDesert 26.6 C, 75% RH (18), 75 km Vis Desert	0.736	0.793	0.605	0.364	0.400
TropicalRural 26.6 C, 75% RH (18), 23 km Vis Rural	0.548	0.654	0.544	0.353	0.391
TropicalUrban 26.6 C, 75% RH (18), 5 km Vis Urban	0.171	0.293	0.337	0.298	0.347
USStdNavyMarVis23km 15 C, 46% RH (5.9), 23 km Vis Nav.Mar, SS4	0.547	0.634	0.539	0.407	0.710

Altitude 15240 m, fixed path length 5000 m, (recalculated from 1 km data set)

	EffTauRange				
SpecRange	Visible	NIR	SWIR	MWIR	LWIR
Atmosphere					
ExtremeHotLowHumidity 44 C, 30% RH (18.1), 77 km Vis Desert	0.930	0.948	0.801	0.635	0.843
ExtremeHumidity 35 C, 95% RH (37.9), 23 km Vis Rural	0.866	0.892	0.728	0.582	0.584
MidLatMaritimeSummer 21 C, 76% RH (14), 23 km Vis Maritime	0.868	0.893	0.770	0.632	0.853
MidLatMaritimeWinter -1 C, 77% RH (3), 10 km Vis Maritime	0.781	0.821	0.767	0.636	0.919
ScandinavianSummer 14 C, 75% RH (9), 31 km Vis Maritime	0.892	0.914	0.799	0.647	0.885
ScandinavianWinter -15.9 C, 80% RH (1), 31 km Vis Maritime	0.894	0.924	0.873	0.672	0.942
TropicalDesert 26.6 C, 75% RH (18), 75 km Vis Desert	0.930	0.945	0.789	0.632	0.804
TropicalRural 26.6 C, 75% RH (18), 23 km Vis Rural	0.868	0.904	0.770	0.628	0.799
TropicalUrban 26.6 C, 75% RH (18), 5 km Vis Urban	0.660	0.750	0.689	0.604	0.778
USStdNavyMarVis23km 15 C, 46% RH (5.9), 23 km Vis Nav.Mar, SS4	0.868	0.899	0.809	0.658	0.921

2.8 Effective transmittance and path radiance to space vs sensor zenith angle

Consider a set of paths to space from the sea level at varying zenith angles from vertically up, down to the horizon. This section plots the effective transmittance and path radiance along these paths for the standard atmospheres. The effective transmittance is calculated for source temperatures of 6000 K and 300 K. The path radiance is calculated in radiant and photon rate units.

The data is pre-calculated with the function `domodtran-elevation.py` and the results stored in an Excel spreadsheet.

See Listing 5.14 for the code to load the data and print the column headings.

```
Index([u'Atmo', u'Altitude', u'Zenith', u'SpecBand', u'ToaWattTot', u'ToaWatt', u'BoaWattTot', u'BoaWatt', u'LpathWatt', u'↵
      ToaQTot', u'ToaQ', u'BoaQTot', u'BoaQ', u'LpathQ', u'effTauSun',
       u'effTau300'],
      dtype='object')
```

The columns in the spreadsheet are as follows:

```
u'Atmo' is the type of atmosphere
u'Altitude' is the ground altitude
u'Zenith' is the zenith angle
u'SpecBand' is the spectral band
u'ToaWattTot' is the wideband top-of-atmosphere radiant irradiance
u'ToaWatt' is the inband top-of-atmosphere radiant irradiance
u'BoaWattTot' is the wideband bottom-of-atmosphere radiant irradiance
u'BoaWatt' is the inband bottom-of-atmosphere radiant irradiance
u'LpathWatt' is the inband path radiant radiance
u'ToaQTot' is the wideband top-of-atmosphere photon rate irradiance
u'ToaQ' is the inband top-of-atmosphere photon rate irradiance
u'BoaQTot' is the wideband bottom-of-atmosphere photon rate irradiance
u'BoaQ' is the inband bottom-of-atmosphere photon rate irradiance
u'LpathQ' is the inband path photon rate radiance
u'effTauSun' is the inband effective transmittance for a 6000 K source
u'effTau300' is the inband effective transmittance for a 300 K source
```

where 'wideband' means over the full spectral range of 0.29 to 15.2 μm and 'inband' means the standard spectral band defined as follows:

See Listing 5.15 for the code ro print the spectral ranges.

```
{'NIR': [0.7, 0.9], 'Visible': [0.43, 0.69], 'MWIR': [3.6, 4.9], 'LWIR': [8.0, 12.0], 'SWIR': [1.0, 1.7]}
```

The path radiance calculation does not include the sun's direct illumination, but it does include the halo scattering of sunlight. The Modtran `tape6` file contains the following:

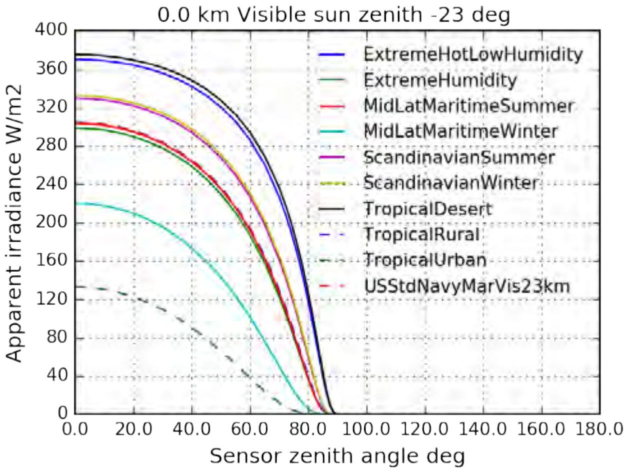
```
LATITUDE AT H1ALT =                0.0000 DEG NORTH OF EQUATOR
LONGITUDE AT H1ALT =               0.0000 DEG WEST OF GREENWICH

SUBSOLAR LATITUDE =              -23.0700 DEG NORTH OF EQUATOR
SUBSOLAR LONGITUDE =             359.1925 DEG WEST OF GREENWICH
TIME (<0 UNDEF) =                        12.0000 GREENWICH TIME
PATH AZIMUTH (FROM H1ALT TO H2ALT) =      0.0000 DEG EAST OF NORTH
DAY OF THE YEAR =                        1

 EXTRATERRESTIAL SOURCE IS THE SUN
```

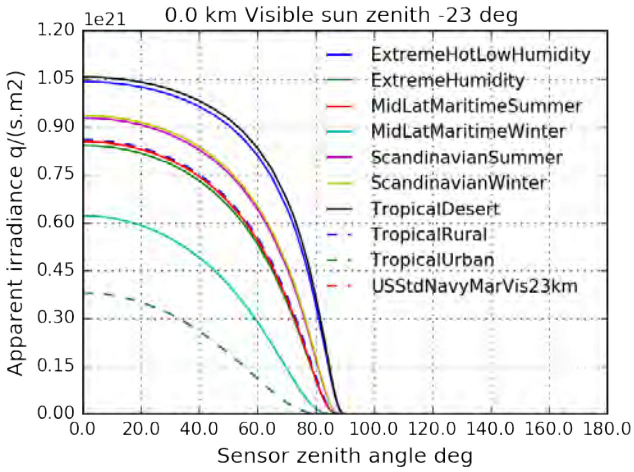
from which we see that the azimuth direction for the sensor elevation scans in this section is exactly North. The sun is 23 degrees South of the equator, so the sun direction is outside (South) of the sensor elevation scan direction (North). The sun is relatively close to the equator, so the halo effect is visible in the data. The sky radiance close to the sun will be even higher than the value shown here (because the maximum value shown here is still 23 degrees from the sun).

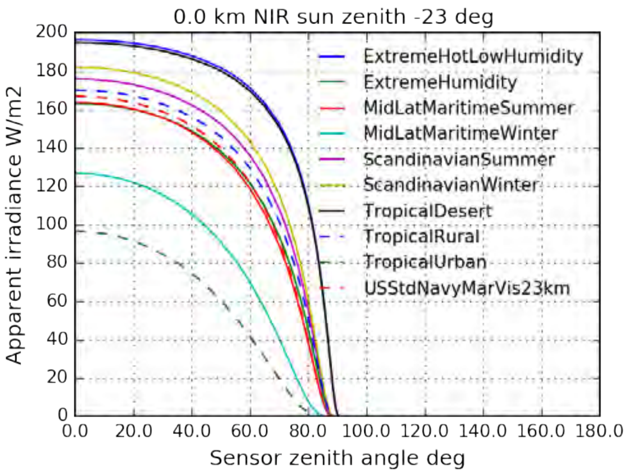
The first series of plots show the bottom-of-atmosphere apparent irradiance. The sun is stationary at a position 23 degrees south of the vertical, and the sensor is viewing the earth from different zenith angles. Note that in this configuration the photons pass through the entire atmosphere twice: first from the sun to the earth and then from the earth to the sensor. This means that the visible band true irradiance at zero zenith is around 800 W/m^2, which corresponds with the prediction at http://www.instesre.org/Solar/BirdModelNew.htm. These values are much higher than the value given in Auelmann's paper on page 46 — his graph is incorrect.

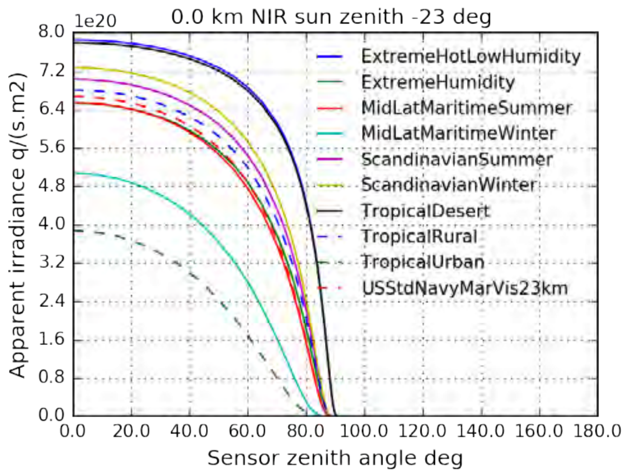
At increasing zenith angles the apparent irradiance decreases because of the decreasing atmospheric transmittance.

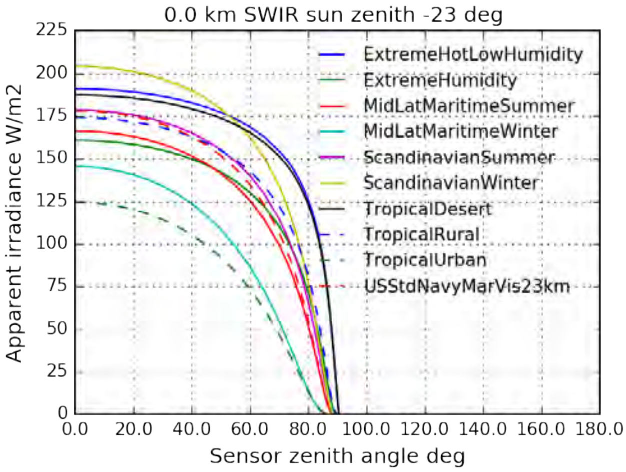
See Listing 5.16 for the code to plot the direct irradiance on ground level for the different spectral bands.

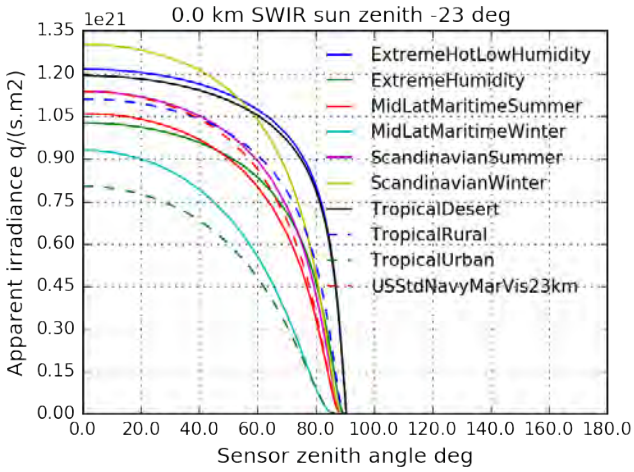


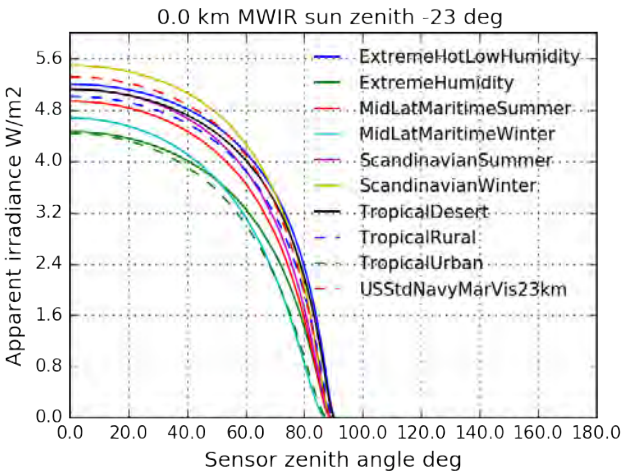


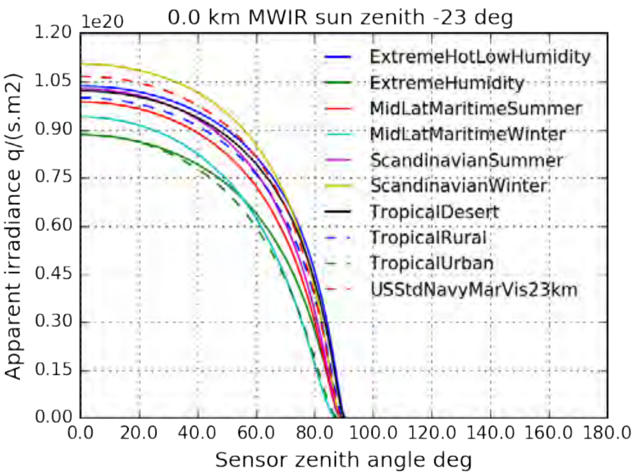


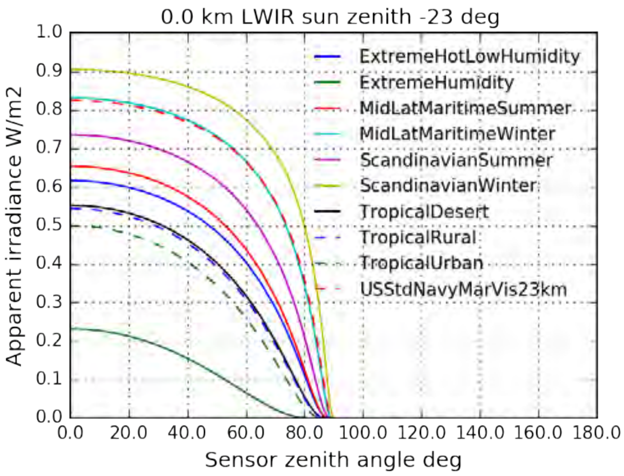


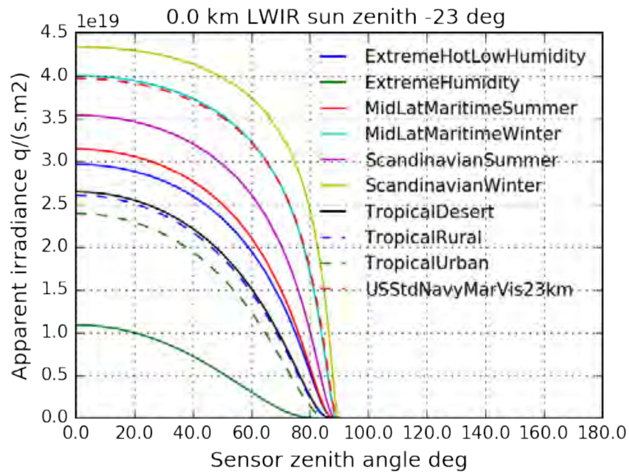












The next set of graphs show the path radiance for the different spectral bands and for different altitudes. At zero altitude only zenith angles above the horizon are displayed. At high altitudes the path radiance for all lookup and lookdown angles are displayed.

1. Vis/NIR/SWIR: The atmospheres with high aerosol content has high path radiance closer to the vertical (nearer the sun), whereas the atmospheres with low aerosol content has lower path radiance near the vertical. The ratio in path radiance near the vertical is more than double (closer to the sun it will be even higher).

2. Vis/NIR/SWIR: At zenith angles more than 40 degrees from the sun, there is relatively little difference in path radiance between the different atmospheres, except near the horizon where aerosol differences lead to differences in path radiance.

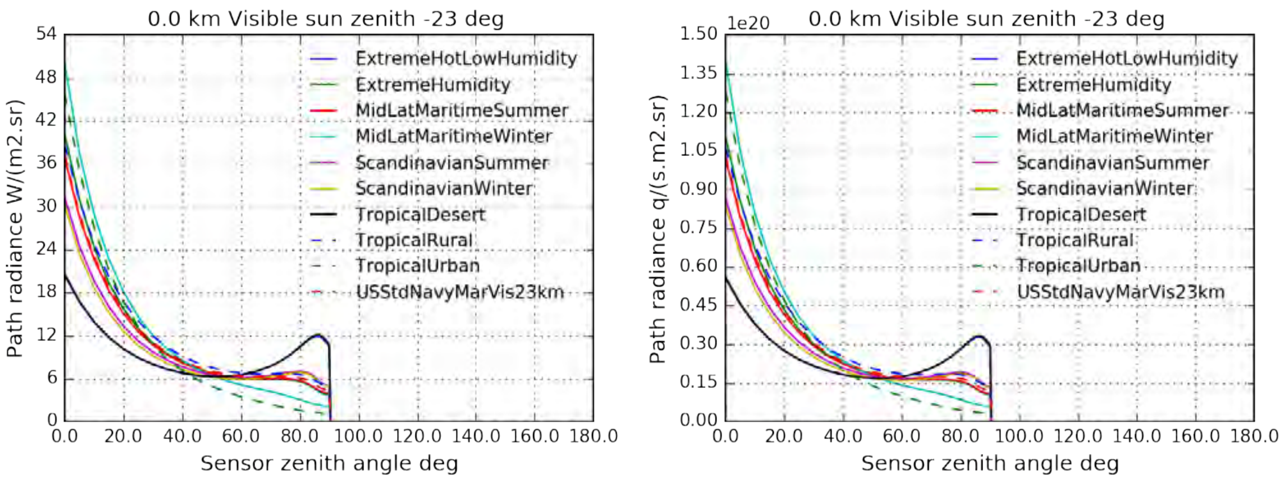
3. Vis/NIR/SWIR: Towards the horizon the path radiance of high aerosol atmospheres is *lower* than low aerosol atmosphere path radiance. Visually, I suspect that with aerosol atmospheres will have a white/grey horizon, whereas a high aerosol atmosphere has a red/brown horizon. This is probably because high aerosol atmospheres already lost much of the sunlight in the halo around the sun, with less photons available on the horizon.

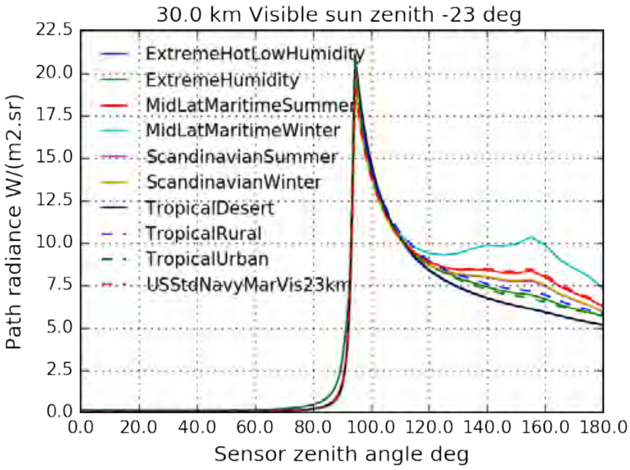
4. MWIR/LWIR: the path radiance near the sun or at small zenith angles is relatively small compared to the path radiance nearer the horizon. The atmospheric temperature plays a major role: hot atmospheres have higher path radiance. Winter atmospheres have MWIR path radiance generally below 0.5 W/(m^2.sr), whereas the really hot atmospheres have MWIR path radiance exceeding 1 W/(m^2.sr).

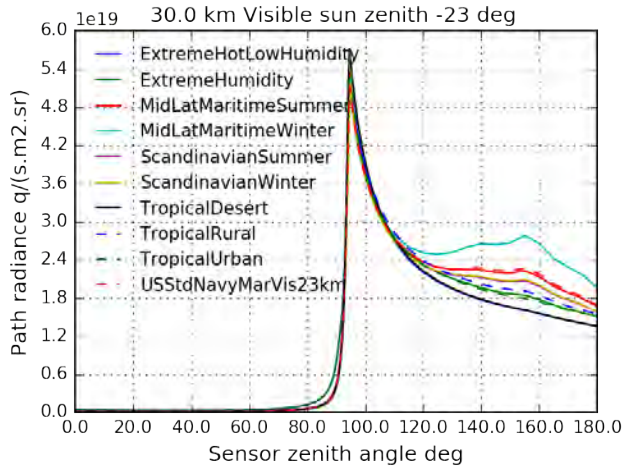
5. The MWIR path radiance is less strongly affected by absolute humidity, and more by temperature.

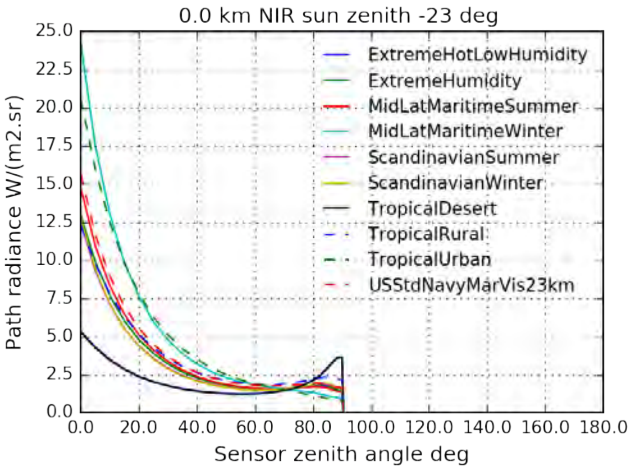
6. The LWIR path radiance is strongly affected by absolute humidity, but also by temperature (keep in mind that atmospheres at higher temperatures allows higher absolute humidity).

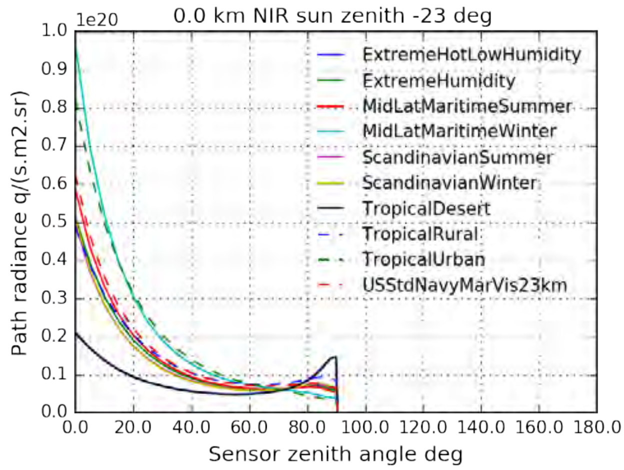
See Listing 5.17 for the code to plot the path radiance for the different spectral bands.

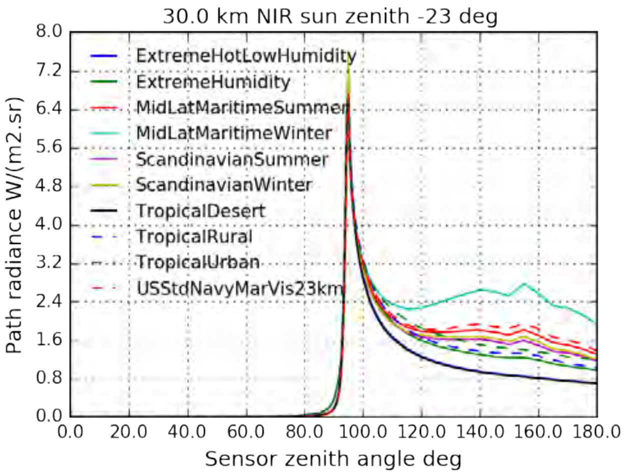


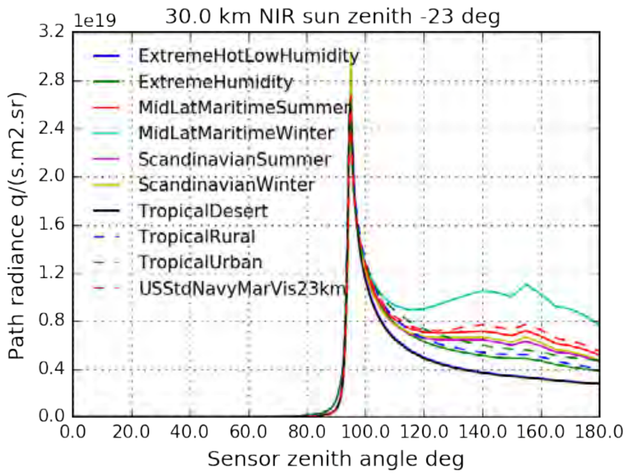

30.0 km Visible sun zenith -23 deg
Path radiance W/(m2.sr)
Sensor zenith angle deg
ExtremeHotLowHumidity
ExtremeHumidity
MidLatMaritimeSummer
MidLatMaritimeWinter
ScandinavianSummer
ScandinavianWinter
TropicalDesert
TropicalRural
TropicalUrban
USStdNavyMarVis23km

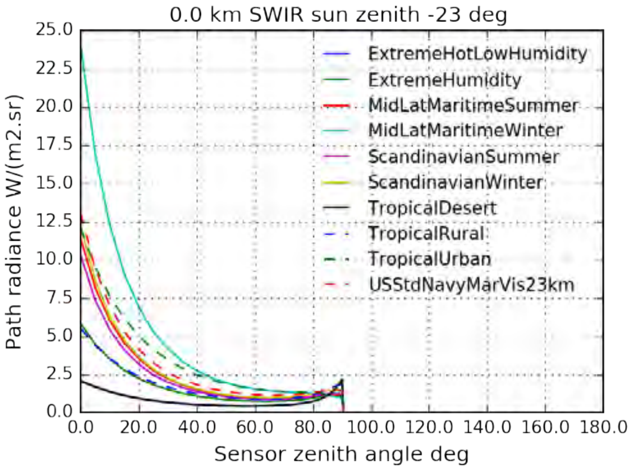

30.0 km Visible sun zenith -23 deg
1e19
Path radiance q/(s.m2.sr)
Sensor zenith angle deg
ExtremeHotLowHumidity
ExtremeHumidity
MidLatMaritimeSummer
MidLatMaritimeWinter
ScandinavianSummer
ScandinavianWinter
TropicalDesert
TropicalRural
TropicalUrban
USStdNavyMarVis23km

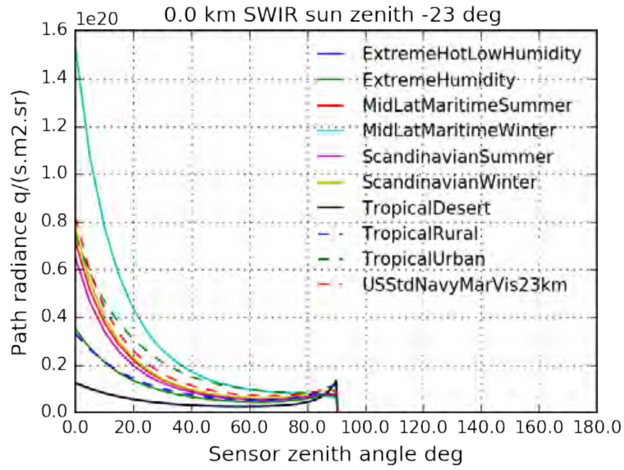

0.0 km NIR sun zenith -23 deg
Path radiance W/(m2.sr)
Sensor zenith angle deg
ExtremeHotLowHumidity
ExtremeHumidity
MidLatMaritimeSummer
MidLatMaritimeWinter
ScandinavianSummer
ScandinavianWinter
TropicalDesert
TropicalRural
TropicalUrban
USStdNavyMarVis23km

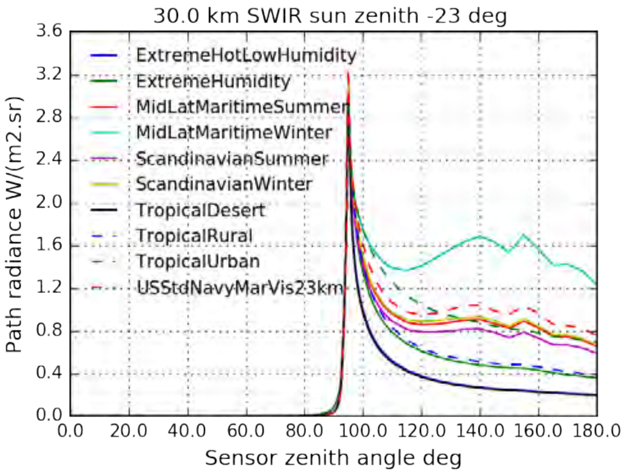

0.0 km NIR sun zenith -23 deg
1e20
Path radiance q/(s.m2.sr)
Sensor zenith angle deg
ExtremeHotLowHumidity
ExtremeHumidity
MidLatMaritimeSummer
MidLatMaritimeWinter
ScandinavianSummer
ScandinavianWinter
TropicalDesert
TropicalRural
TropicalUrban
USStdNavyMarVis23km

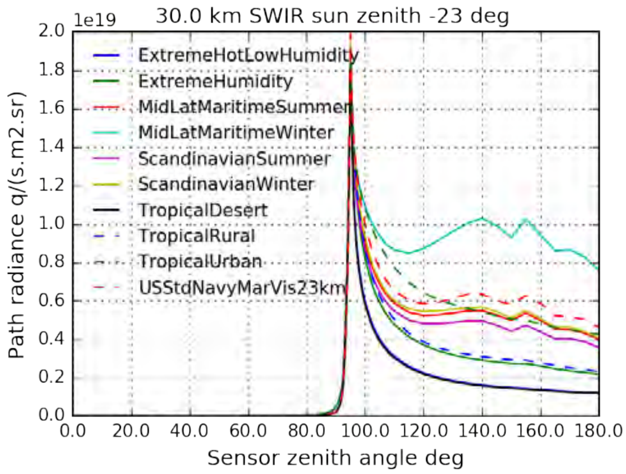

30.0 km NIR sun zenith -23 deg
Path radiance W/(m2.sr)
Sensor zenith angle deg
ExtremeHotLowHumidity
ExtremeHumidity
MidLatMaritimeSummer
MidLatMaritimeWinter
ScandinavianSummer
ScandinavianWinter
TropicalDesert
TropicalRural
TropicalUrban
USStdNavyMarVis23km

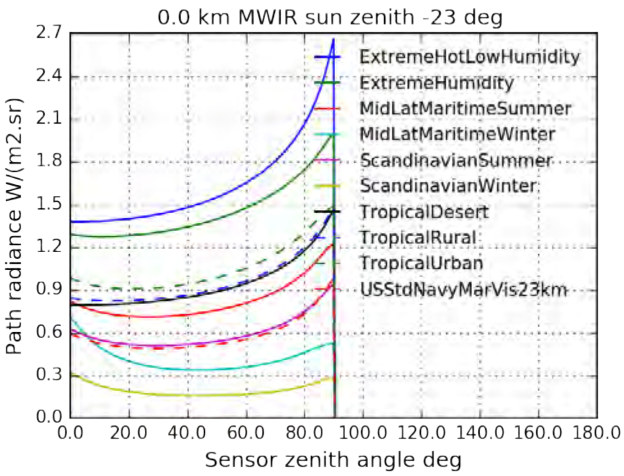

30.0 km NIR sun zenith -23 deg
1e19
Path radiance q/(s.m2.sr)
Sensor zenith angle deg
ExtremeHotLowHumidity
ExtremeHumidity
MidLatMaritimeSummer
MidLatMaritimeWinter
ScandinavianSummer
ScandinavianWinter
TropicalDesert
TropicalRural
TropicalUrban
USStdNavyMarVis23km

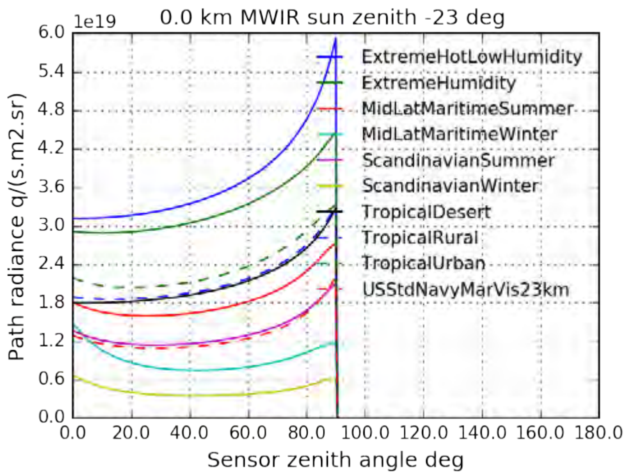

0.0 km SWIR sun zenith -23 deg
Path radiance W/(m2.sr)
Sensor zenith angle deg
ExtremeHotLowHumidity
ExtremeHumidity
MidLatMaritimeSummer
MidLatMaritimeWinter
ScandinavianSummer
ScandinavianWinter
TropicalDesert
TropicalRural
TropicalUrban
USStdNavyMarVis23km

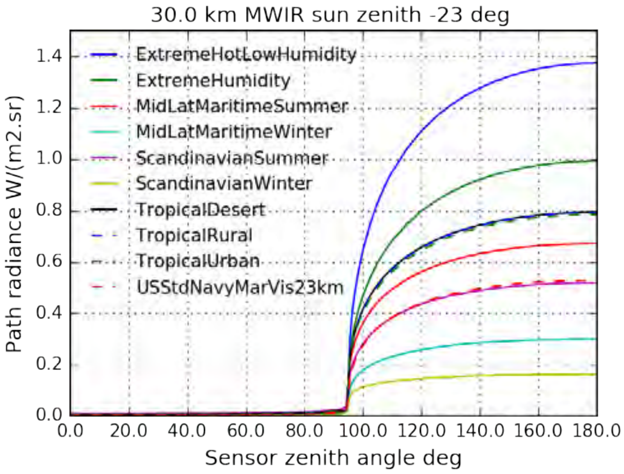

0.0 km SWIR sun zenith -23 deg
1e20
Path radiance q/(s.m2.sr)
Sensor zenith angle deg
ExtremeHotLowHumidity
ExtremeHumidity
MidLatMaritimeSummer
MidLatMaritimeWinter
ScandinavianSummer
ScandinavianWinter
TropicalDesert
TropicalRural
TropicalUrban
USStdNavyMarVis23km

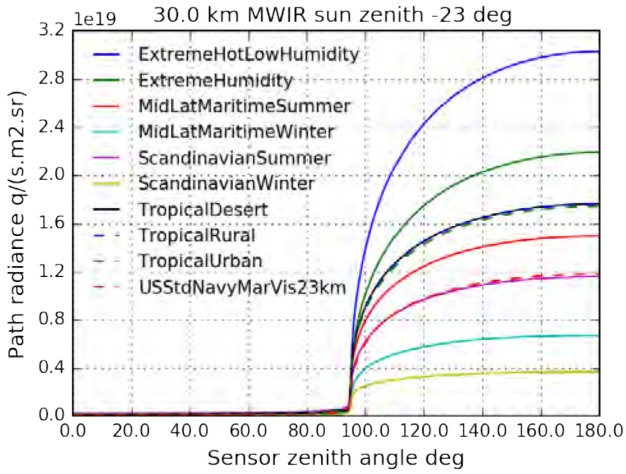

30.0 km SWIR sun zenith -23 deg
Path radiance W/(m2.sr)
Sensor zenith angle deg
ExtremeHotLowHumidity
ExtremeHumidity
MidLatMaritimeSummer
MidLatMaritimeWinter
ScandinavianSummer
ScandinavianWinter
TropicalDesert
TropicalRural
TropicalUrban
USStdNavyMarVis23km

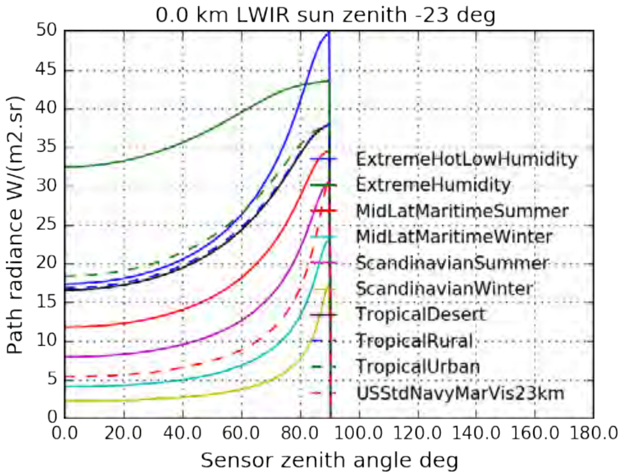

30.0 km SWIR sun zenith -23 deg
1e19
Path radiance q/(s.m2.sr)
Sensor zenith angle deg
ExtremeHotLowHumidity
ExtremeHumidity
MidLatMaritimeSummer
MidLatMaritimeWinter
ScandinavianSummer
ScandinavianWinter
TropicalDesert
TropicalRural
TropicalUrban
USStdNavyMarVis23km

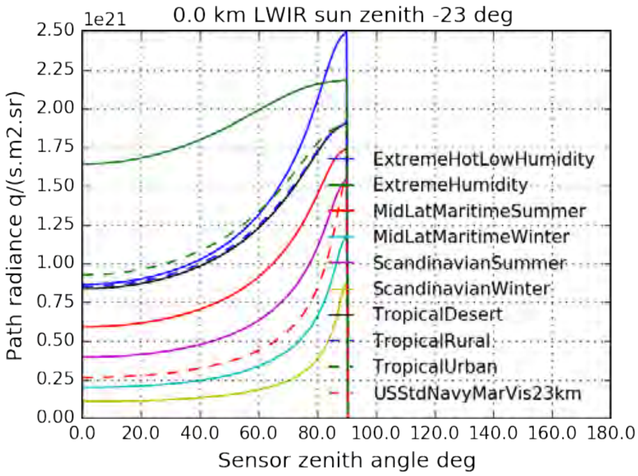

0.0 km MWIR sun zenith -23 deg
Path radiance W/(m2.sr)
Sensor zenith angle deg
ExtremeHotLowHumidity
ExtremeHumidity
MidLatMaritimeSummer
MidLatMaritimeWinter
ScandinavianSummer
ScandinavianWinter
TropicalDesert
TropicalRural
TropicalUrban
USStdNavyMarVis23km

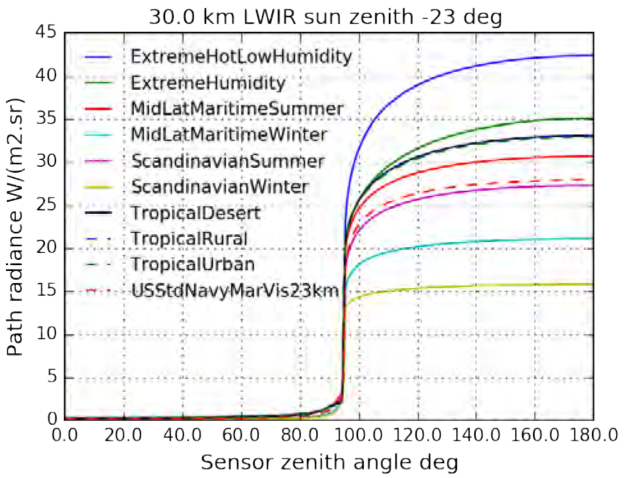

0.0 km MWIR sun zenith -23 deg
1e19
Path radiance q/(s.m2.sr)
Sensor zenith angle deg
ExtremeHotLowHumidity
ExtremeHumidity
MidLatMaritimeSummer
MidLatMaritimeWinter
ScandinavianSummer
ScandinavianWinter
TropicalDesert
TropicalRural
TropicalUrban
USStdNavyMarVis23km

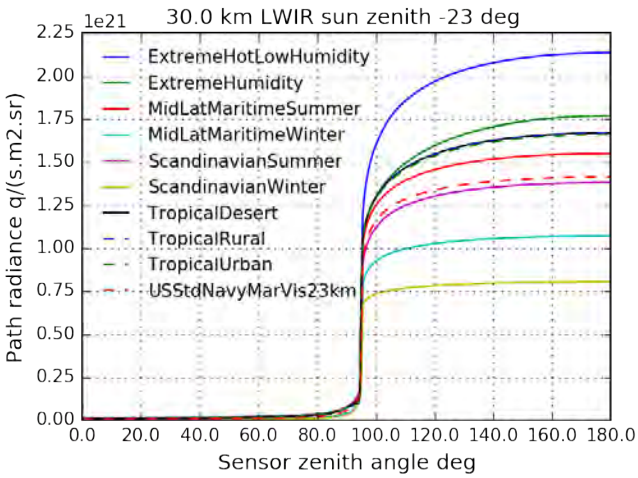




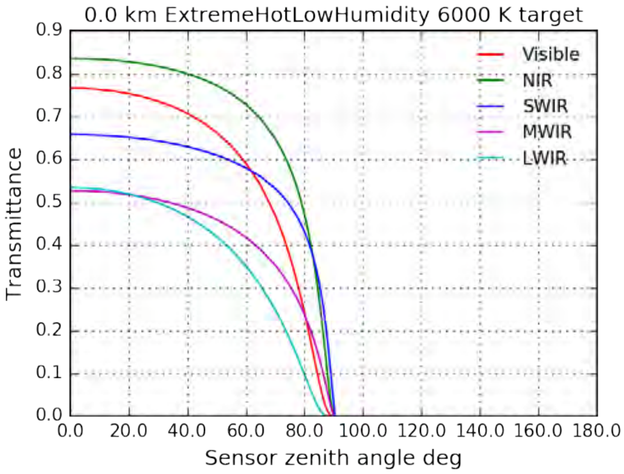


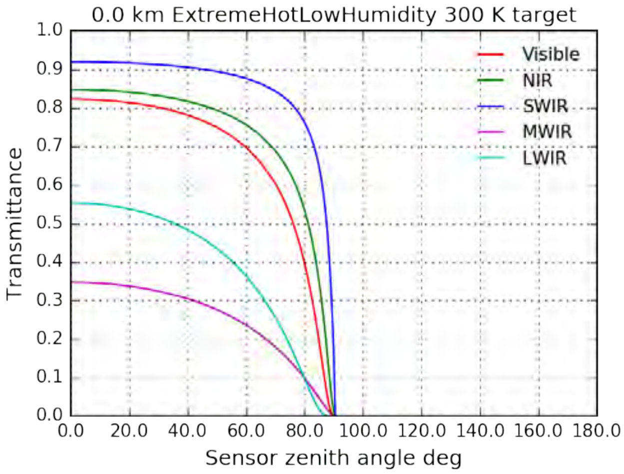


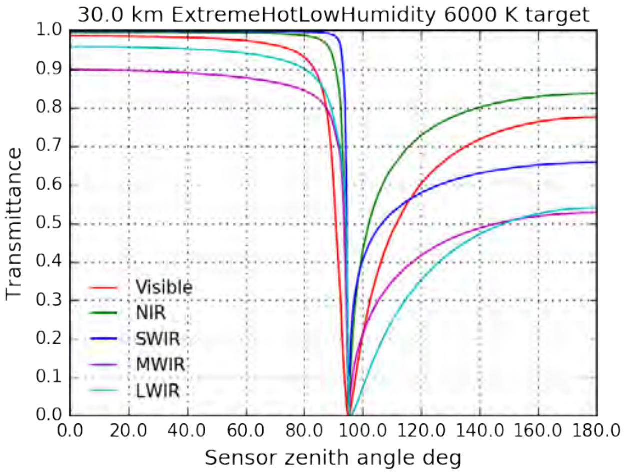


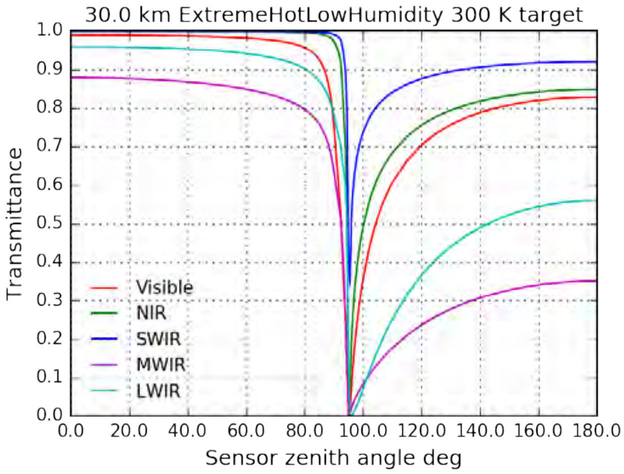


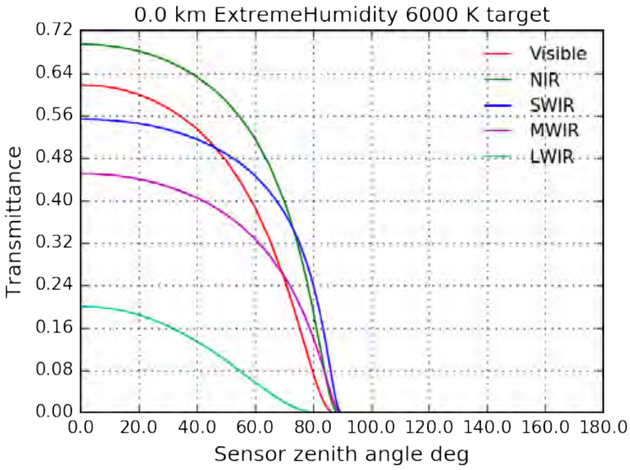
See Listing 5.18 for the code to plot the effective transmittance for the different atmospheres.

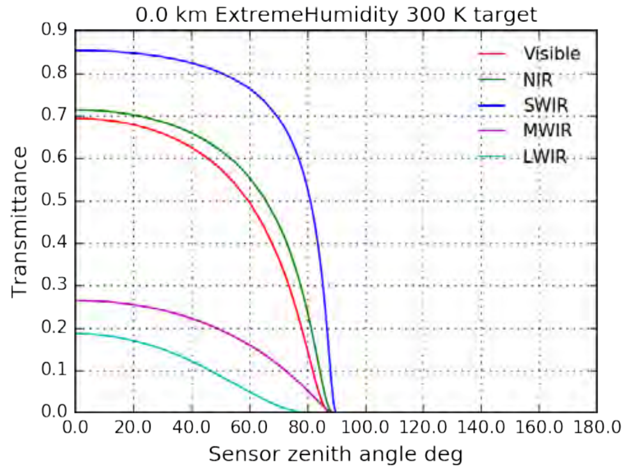

0.0 km ExtremeHotLowHumidity 6000 K target
Visible
NIR
SWIR
MWIR
LWIR
Transmittance
Sensor zenith angle deg

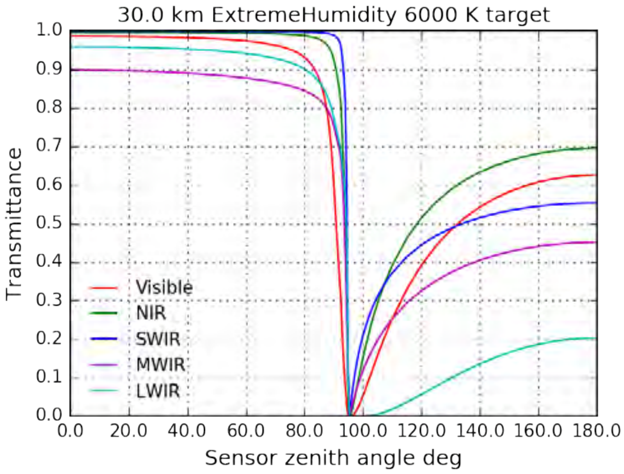

0.0 km ExtremeHotLowHumidity 300 K target
Visible
NIR
SWIR
MWIR
LWIR
Transmittance
Sensor zenith angle deg

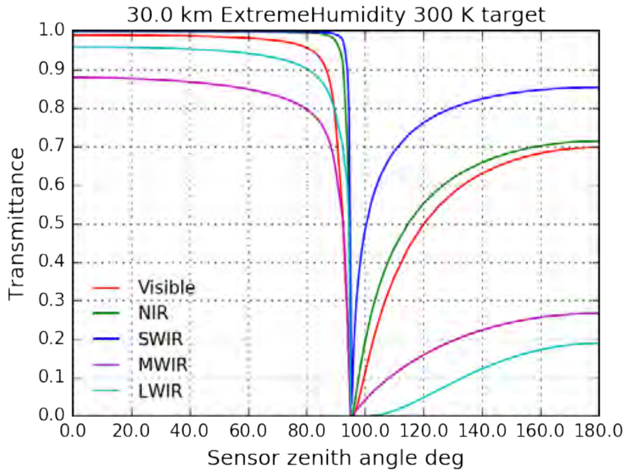

30.0 km ExtremeHotLowHumidity 6000 K target
Visible
NIR
SWIR
MWIR
LWIR
Transmittance
Sensor zenith angle deg

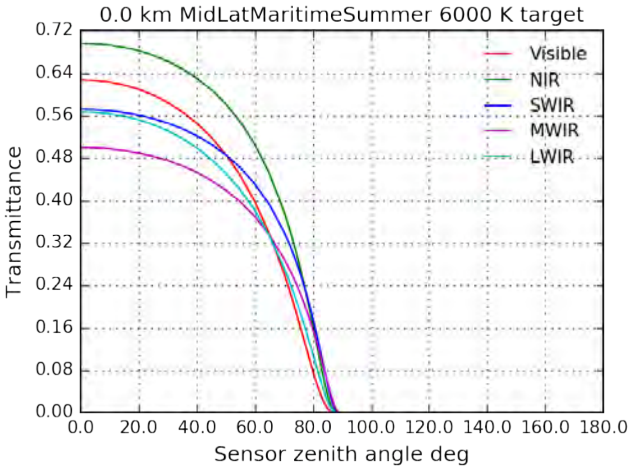

30.0 km ExtremeHotLowHumidity 300 K target
Visible
NIR
SWIR
MWIR
LWIR
Transmittance
Sensor zenith angle deg

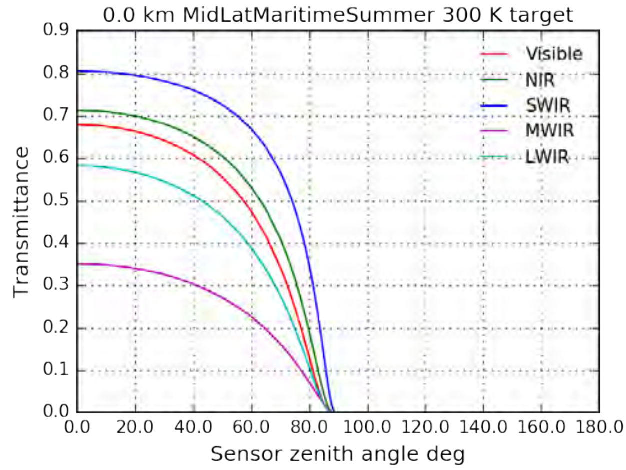

0.0 km ExtremeHumidity 6000 K target
Visible
NIR
SWIR
MWIR
LWIR
Transmittance
Sensor zenith angle deg

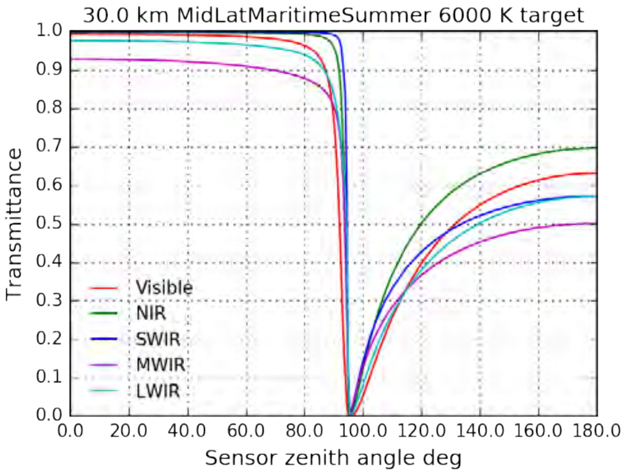

0.0 km ExtremeHumidity 300 K target
Visible
NIR
SWIR
MWIR
LWIR
Transmittance
Sensor zenith angle deg

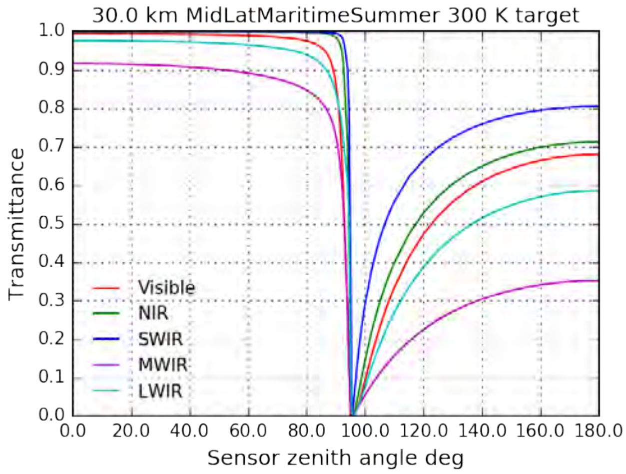

30.0 km ExtremeHumidity 6000 K target
Transmittance
Sensor zenith angle deg
Visible
NIR
SWIR
MWIR
LWIR

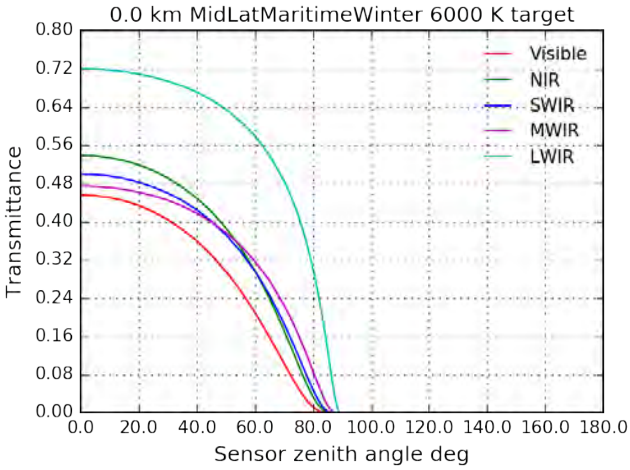

30.0 km ExtremeHumidity 300 K target
Transmittance
Sensor zenith angle deg
Visible
NIR
SWIR
MWIR
LWIR

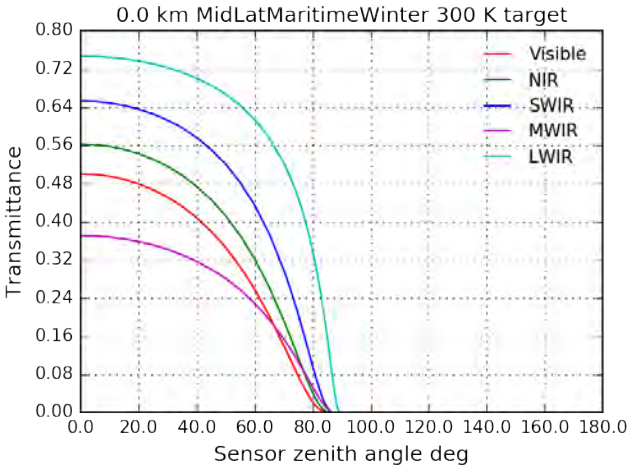

0.0 km MidLatMaritimeSummer 6000 K target
Transmittance
Sensor zenith angle deg
Visible
NIR
SWIR
MWIR
LWIR

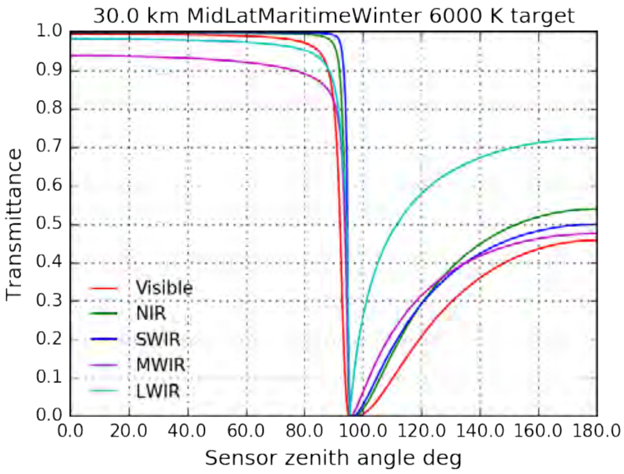

0.0 km MidLatMaritimeSummer 300 K target
Transmittance
Sensor zenith angle deg
Visible
NIR
SWIR
MWIR
LWIR

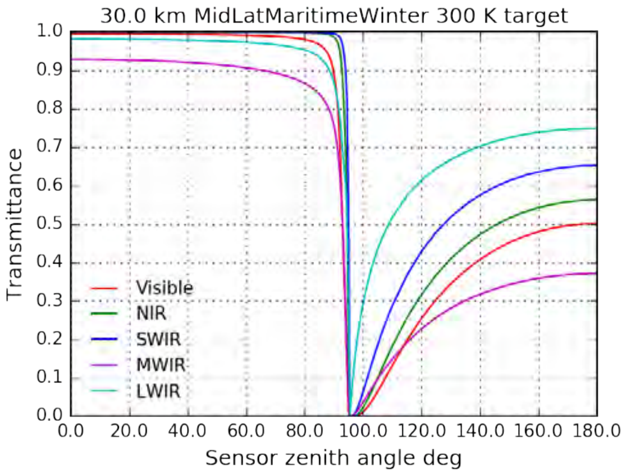

30.0 km MidLatMaritimeSummer 6000 K target
Transmittance
Sensor zenith angle deg
Visible
NIR
SWIR
MWIR
LWIR

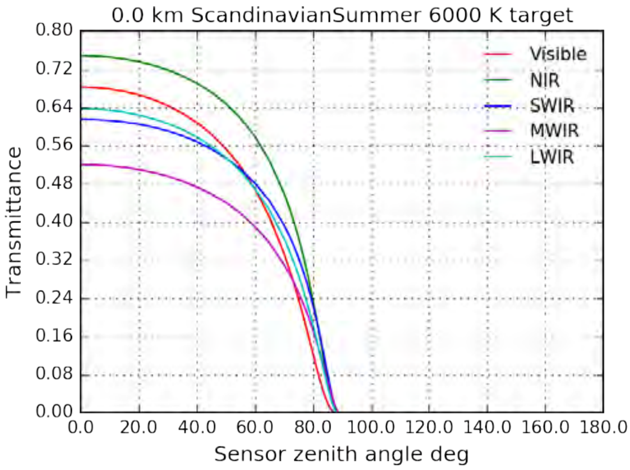

30.0 km MidLatMaritimeSummer 300 K target
Transmittance
Sensor zenith angle deg
Visible
NIR
SWIR
MWIR
LWIR

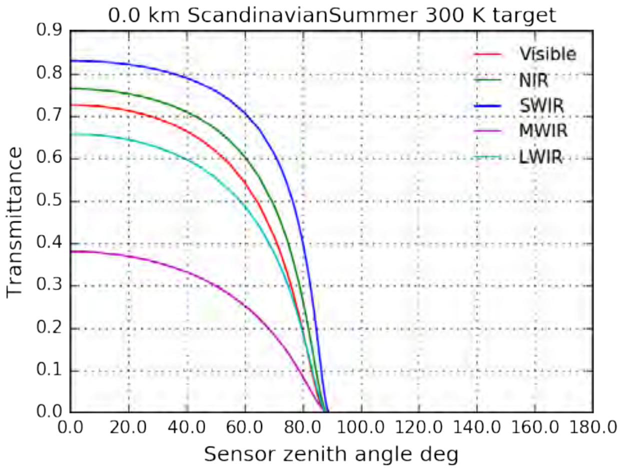

0.0 km MidLatMaritimeWinter 6000 K target
Transmittance
Sensor zenith angle deg
Visible
NIR
SWIR
MWIR
LWIR

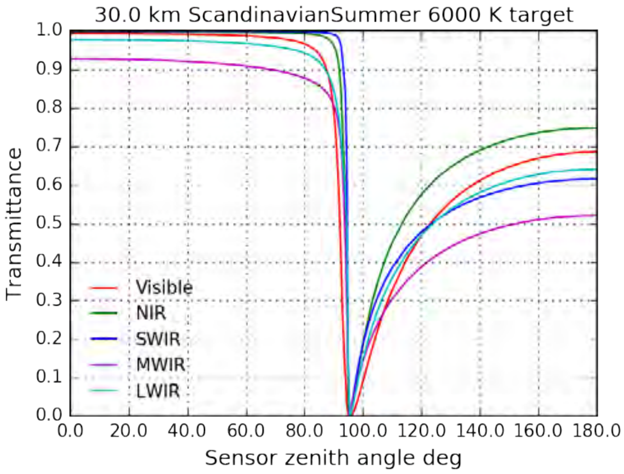

0.0 km MidLatMaritimeWinter 300 K target
Transmittance
Sensor zenith angle deg
Visible
NIR
SWIR
MWIR
LWIR

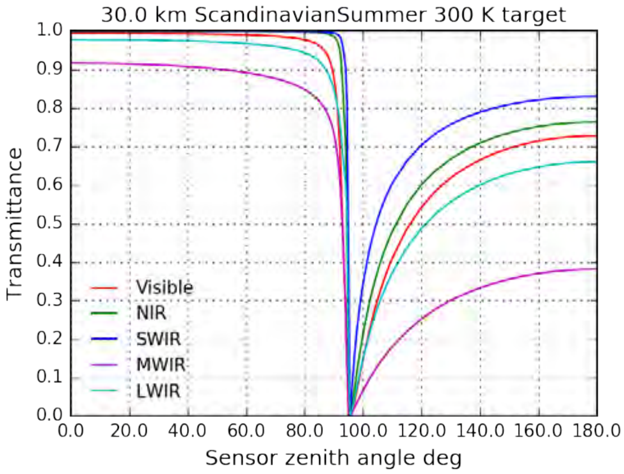

30.0 km MidLatMaritimeWinter 6000 K target
Transmittance
Sensor zenith angle deg
Visible
NIR
SWIR
MWIR
LWIR

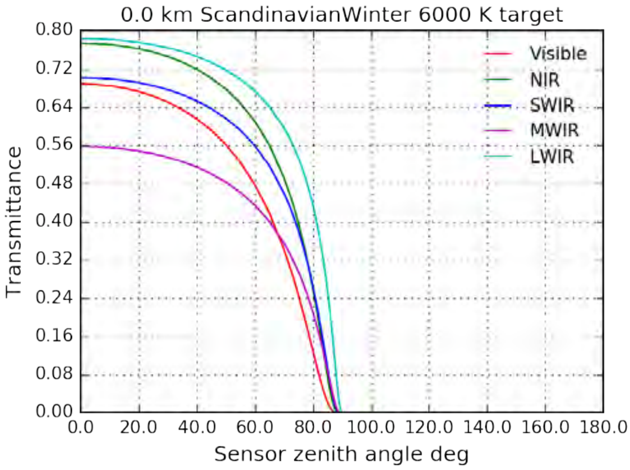

30.0 km MidLatMaritimeWinter 300 K target
Transmittance
Sensor zenith angle deg
Visible
NIR
SWIR
MWIR
LWIR

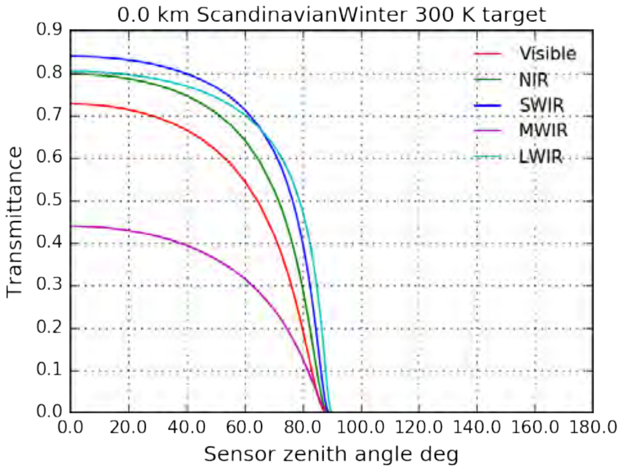

0.0 km ScandinavianSummer 6000 K target
Transmittance
Sensor zenith angle deg
Visible
NIR
SWIR
MWIR
LWIR

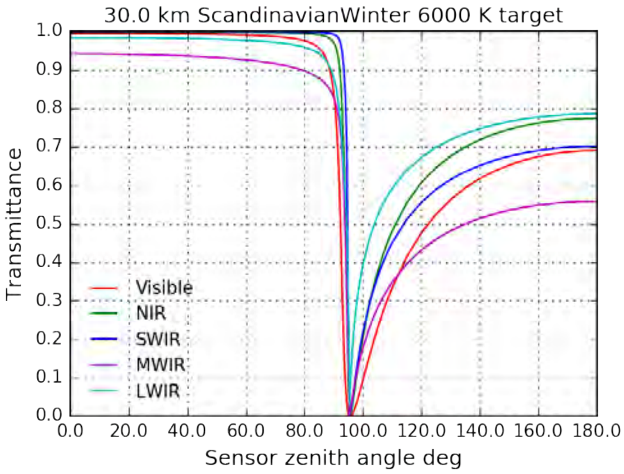

0.0 km ScandinavianSummer 300 K target
Transmittance
Sensor zenith angle deg
Visible
NIR
SWIR
MWIR
LWIR

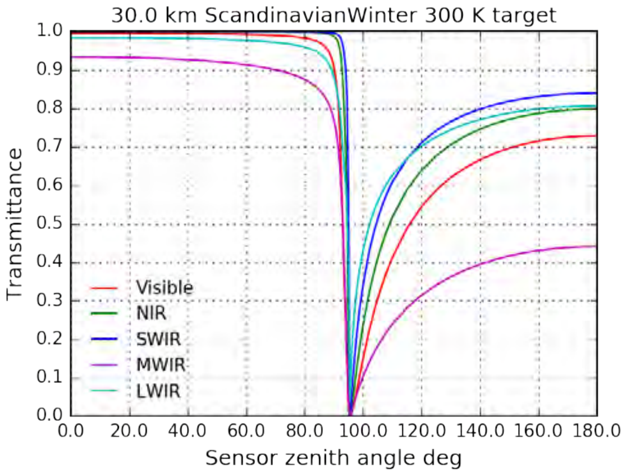

30.0 km ScandinavianSummer 6000 K target
Transmittance
Sensor zenith angle deg
Visible
NIR
SWIR
MWIR
LWIR

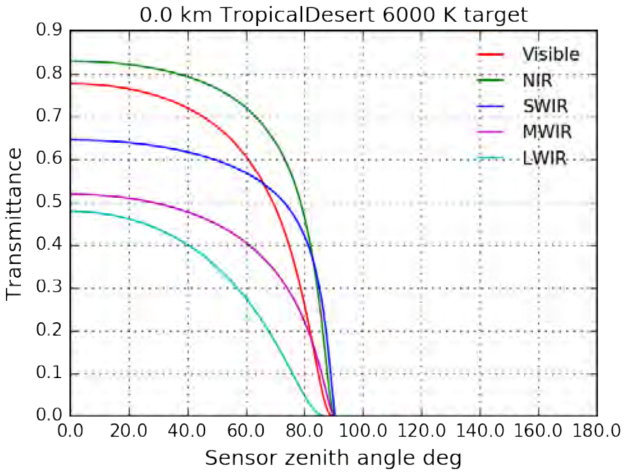

30.0 km ScandinavianSummer 300 K target
Transmittance
Sensor zenith angle deg
Visible
NIR
SWIR
MWIR
LWIR

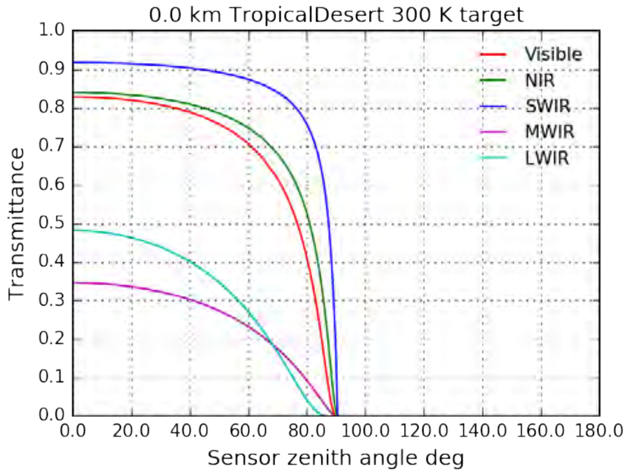

0.0 km ScandinavianWinter 6000 K target
Transmittance
Sensor zenith angle deg
Visible
NIR
SWIR
MWIR
LWIR

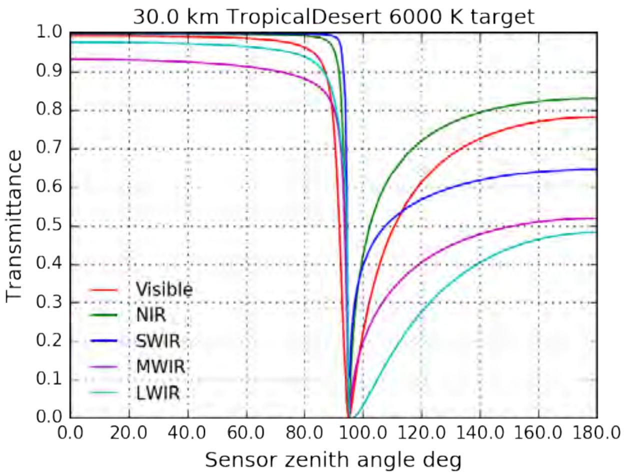

0.0 km ScandinavianWinter 300 K target
Transmittance
Sensor zenith angle deg
Visible
NIR
SWIR
MWIR
LWIR

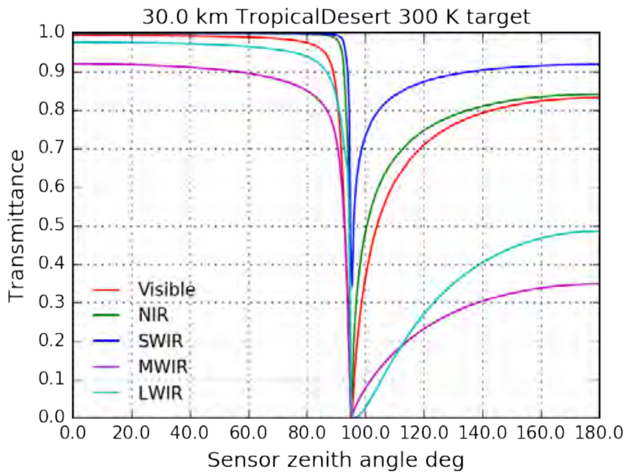

30.0 km ScandinavianWinter 6000 K target
Transmittance
Sensor zenith angle deg
Visible
NIR
SWIR
MWIR
LWIR

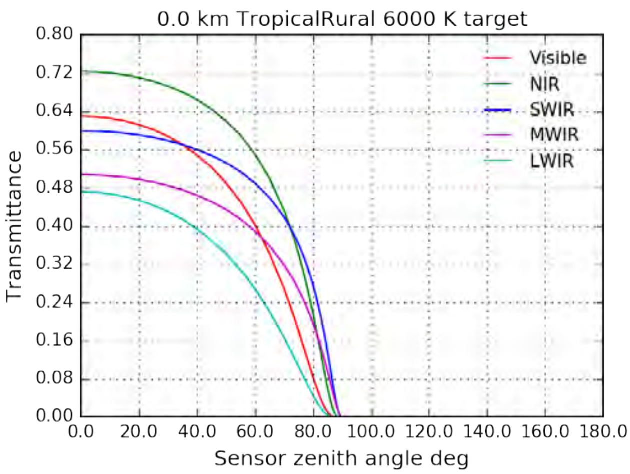

30.0 km ScandinavianWinter 300 K target
Transmittance
Sensor zenith angle deg
Visible
NIR
SWIR
MWIR
LWIR

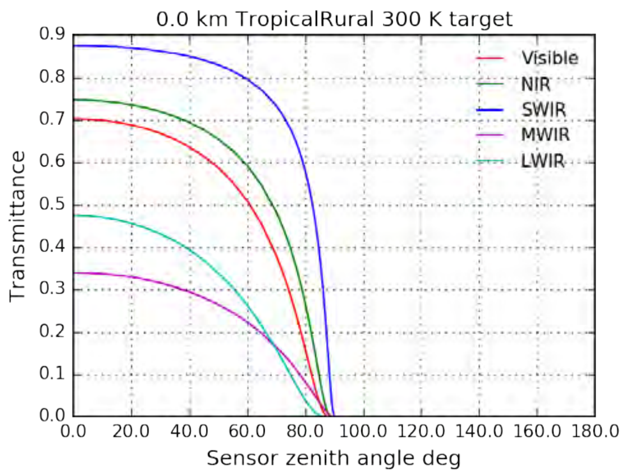

0.0 km TropicalDesert 6000 K target
Transmittance
Sensor zenith angle deg
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9
0.0 20.0 40.0 60.0 80.0 100.0 120.0 140.0 160.0 180.0
Visible
NIR
SWIR
MWIR
LWIR

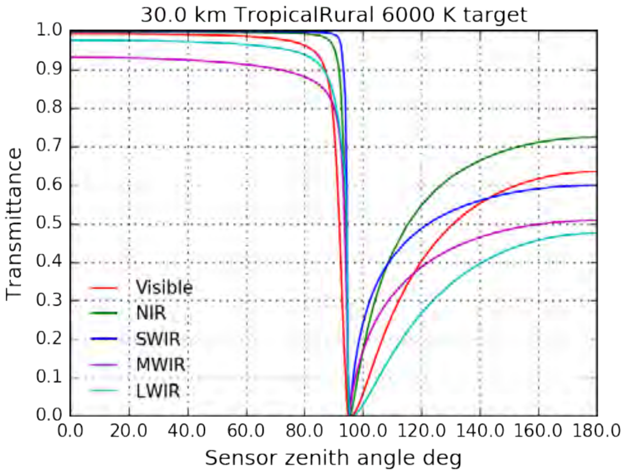

0.0 km TropicalDesert 300 K target
Transmittance
Sensor zenith angle deg
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0
0.0 20.0 40.0 60.0 80.0 100.0 120.0 140.0 160.0 180.0
Visible
NIR
SWIR
MWIR
LWIR

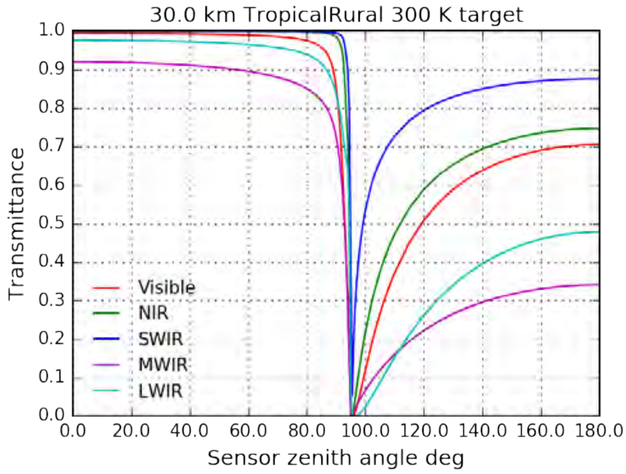

30.0 km TropicalDesert 6000 K target
Transmittance
Sensor zenith angle deg
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0
0.0 20.0 40.0 60.0 80.0 100.0 120.0 140.0 160.0 180.0
Visible
NIR
SWIR
MWIR
LWIR

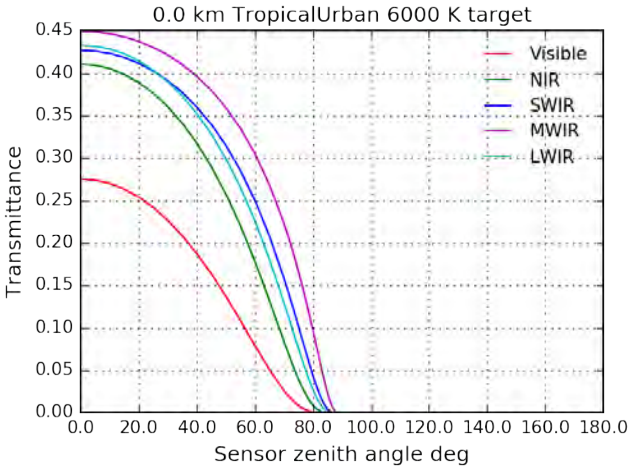

30.0 km TropicalDesert 300 K target
Transmittance
Sensor zenith angle deg
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0
0.0 20.0 40.0 60.0 80.0 100.0 120.0 140.0 160.0 180.0
Visible
NIR
SWIR
MWIR
LWIR

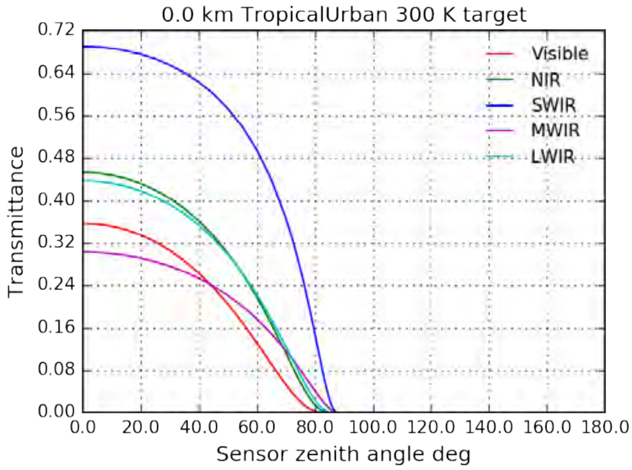

0.0 km TropicalRural 6000 K target
Transmittance
Sensor zenith angle deg
0.00 0.08 0.16 0.24 0.32 0.40 0.48 0.56 0.64 0.72 0.80
0.0 20.0 40.0 60.0 80.0 100.0 120.0 140.0 160.0 180.0
Visible
NIR
SWIR
MWIR
LWIR

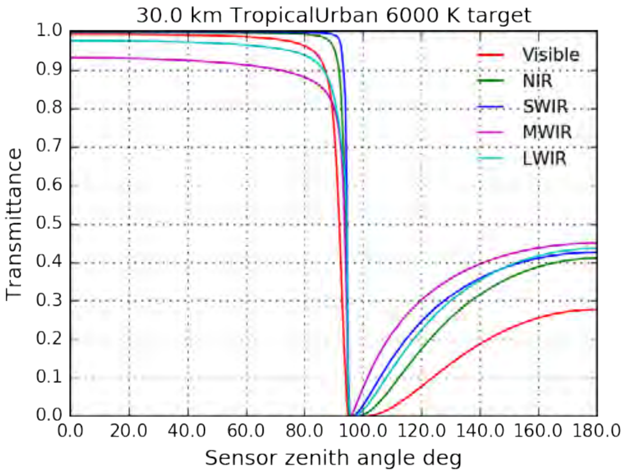

0.0 km TropicalRural 300 K target
Transmittance
Sensor zenith angle deg
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9
0.0 20.0 40.0 60.0 80.0 100.0 120.0 140.0 160.0 180.0
Visible
NIR
SWIR
MWIR
LWIR

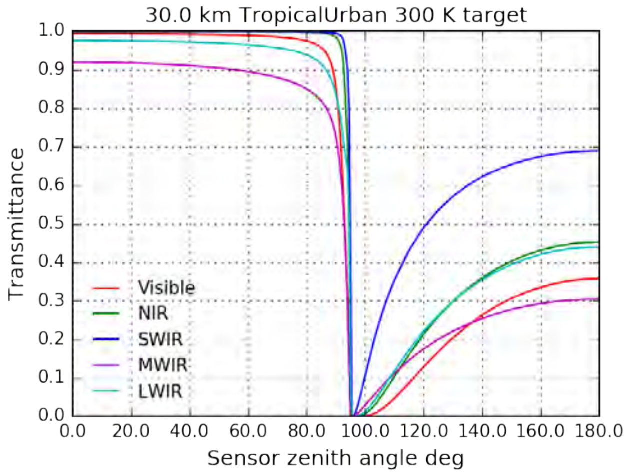

30.0 km TropicalRural 6000 K target
Transmittance
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.0 20.0 40.0 60.0 80.0 100.0 120.0 140.0 160.0 180.0
Sensor zenith angle deg
Visible
NIR
SWIR
MWIR
LWIR

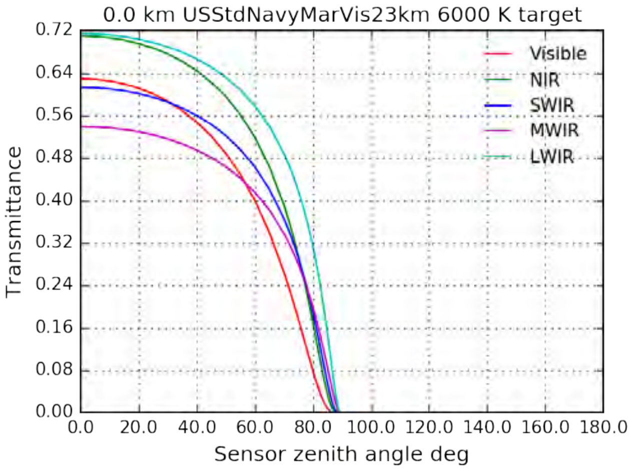

30.0 km TropicalRural 300 K target
Transmittance
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.0 20.0 40.0 60.0 80.0 100.0 120.0 140.0 160.0 180.0
Sensor zenith angle deg
Visible
NIR
SWIR
MWIR
LWIR

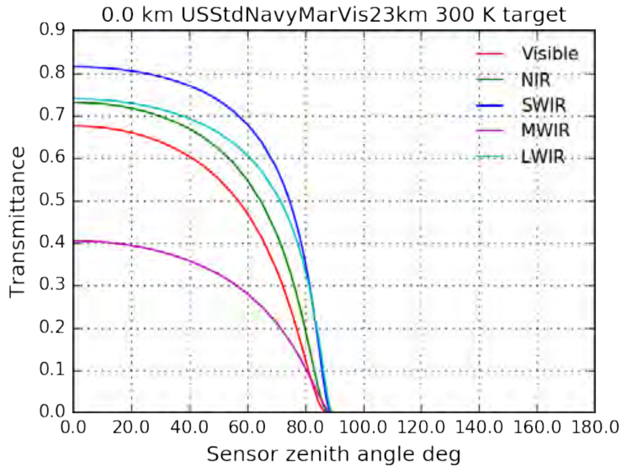

0.0 km TropicalUrban 6000 K target
Transmittance
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0.0 20.0 40.0 60.0 80.0 100.0 120.0 140.0 160.0 180.0
Sensor zenith angle deg
Visible
NIR
SWIR
MWIR
LWIR

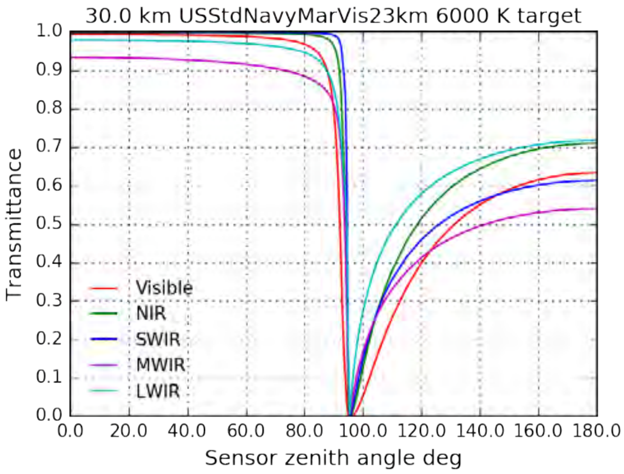

0.0 km TropicalUrban 300 K target
Transmittance
0.72
0.64
0.56
0.48
0.40
0.32
0.24
0.16
0.08
0.00
0.0 20.0 40.0 60.0 80.0 100.0 120.0 140.0 160.0 180.0
Sensor zenith angle deg
Visible
NIR
SWIR
MWIR
LWIR

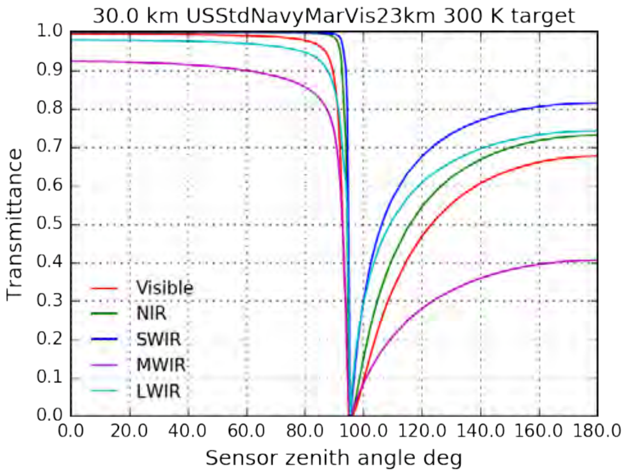

30.0 km TropicalUrban 6000 K target
Transmittance
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.0 20.0 40.0 60.0 80.0 100.0 120.0 140.0 160.0 180.0
Sensor zenith angle deg
Visible
NIR
SWIR
MWIR
LWIR


30.0 km TropicalUrban 300 K target
Transmittance
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.0 20.0 40.0 60.0 80.0 100.0 120.0 140.0 160.0 180.0
Sensor zenith angle deg
Visible
NIR
SWIR
MWIR
LWIR

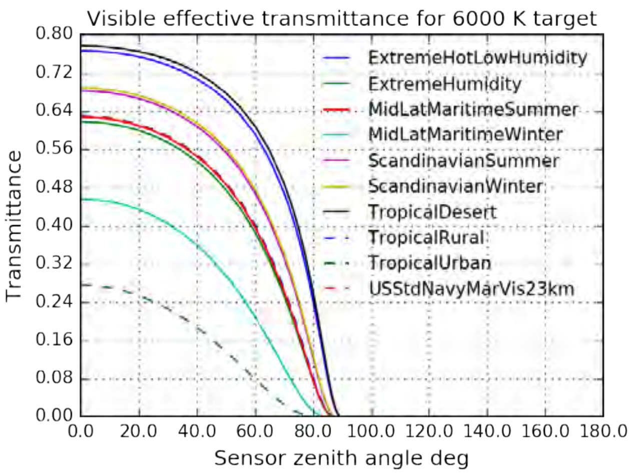


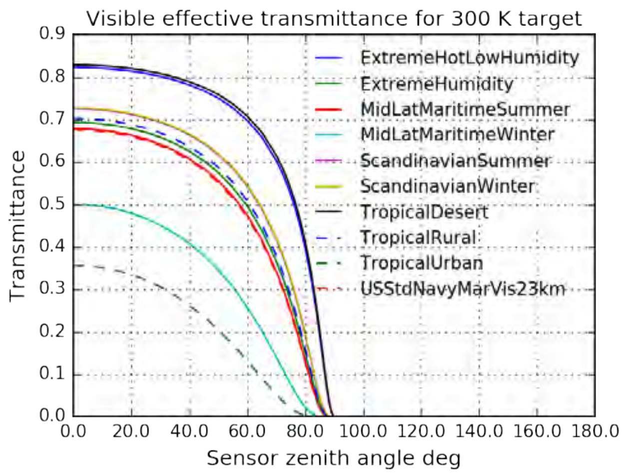


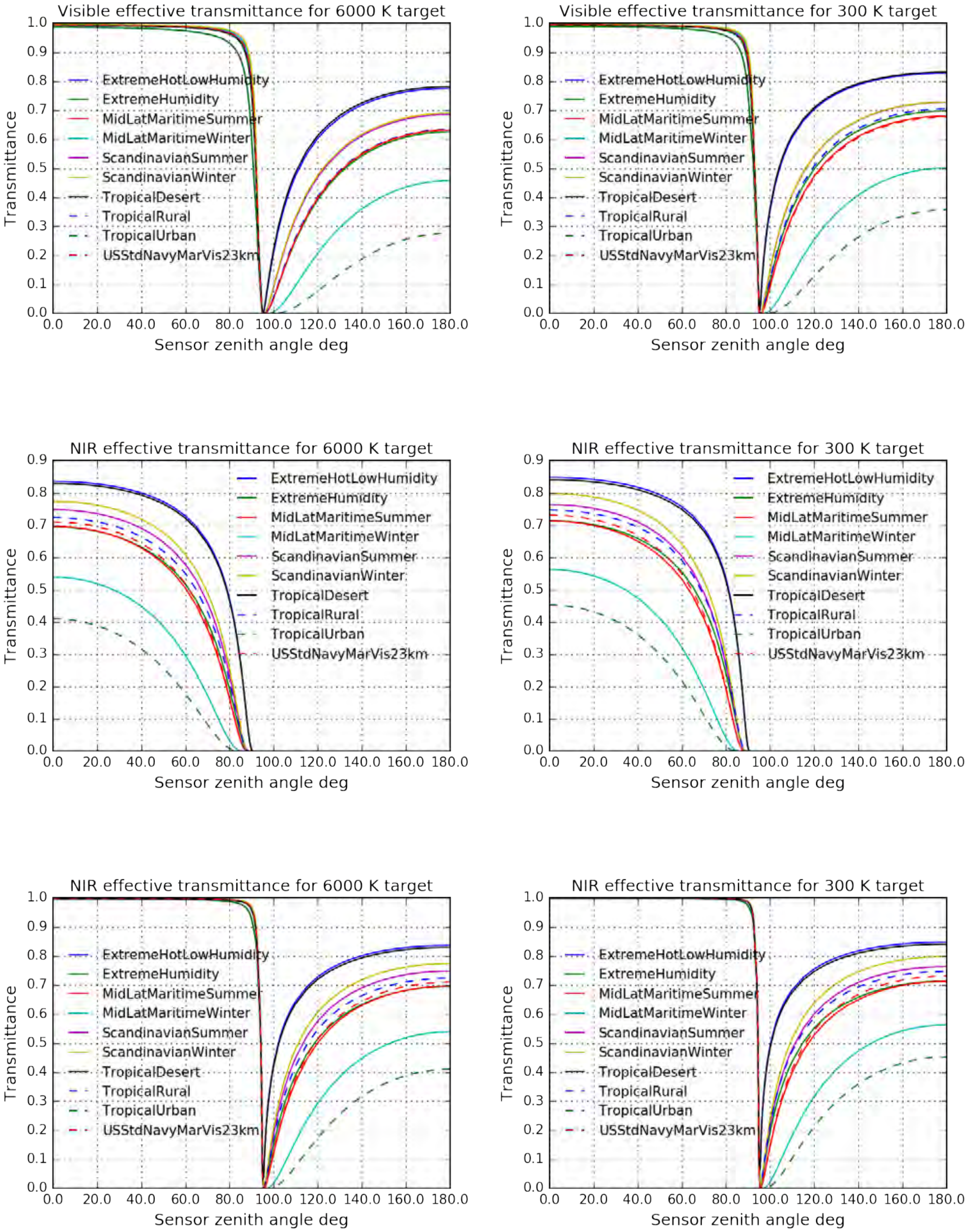


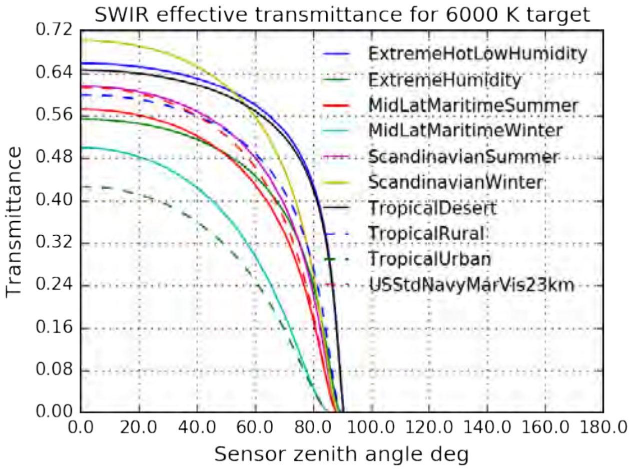


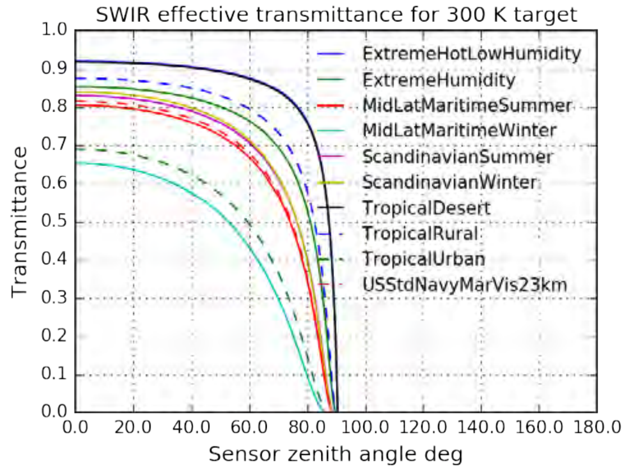
See Listing 5.19 for the code to plot the effective transmittance for the different spectral bands.

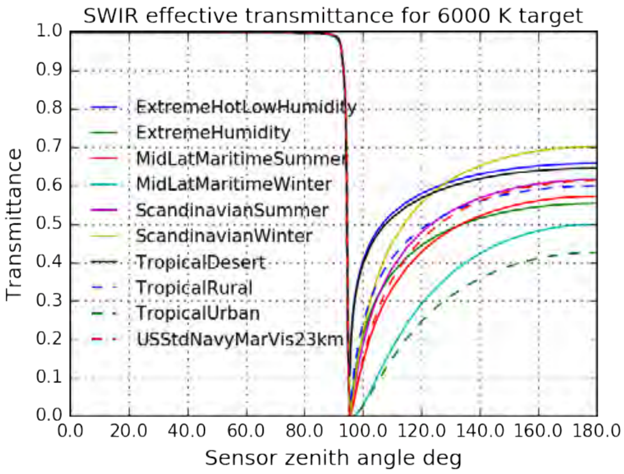


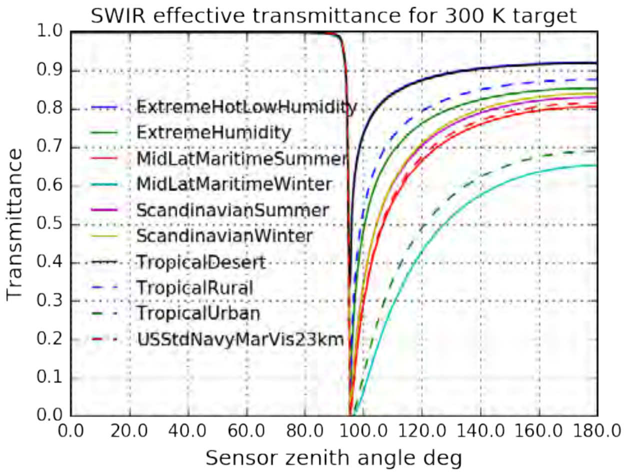


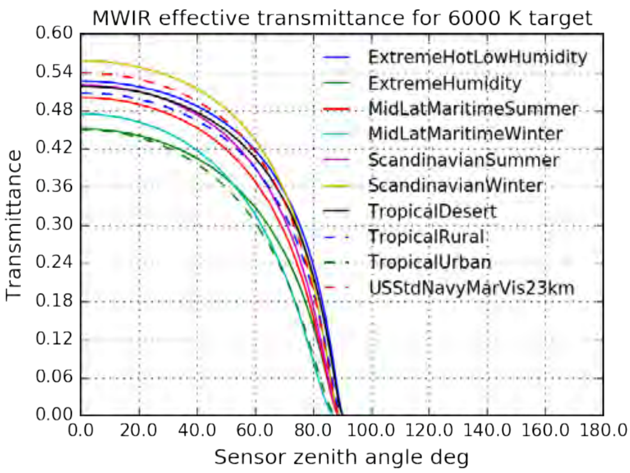

Visible effective transmittance for 6000 K target
Visible effective transmittance for 300 K target
NIR effective transmittance for 6000 K target
NIR effective transmittance for 300 K target
NIR effective transmittance for 6000 K target
NIR effective transmittance for 300 K target
Transmittance
Sensor zenith angle deg
ExtremeHotLowHumidity
ExtremeHumidity
MidLatMaritimeSummer
MidLatMaritimeWinter
ScandinavianSummer
ScandinavianWinter
TropicalDesert
TropicalRural
TropicalUrban
USStdNavyMarVis23km

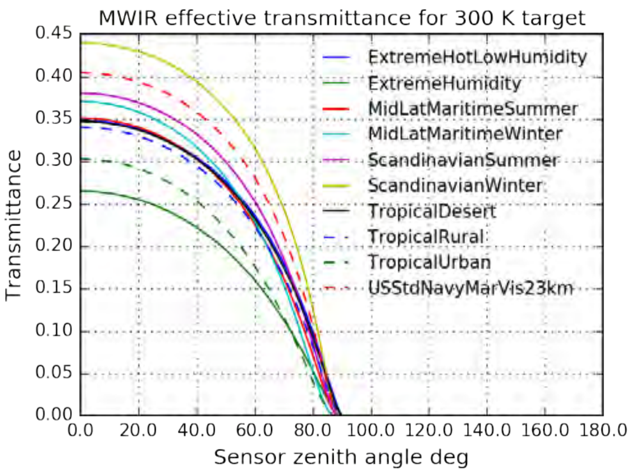

SWIR effective transmittance for 6000 K target
Transmittance
Sensor zenith angle deg
ExtremeHotLowHumidity
ExtremeHumidity
MidLatMaritimeSummer
MidLatMaritimeWinter
ScandinavianSummer
ScandinavianWinter
TropicalDesert
TropicalRural
TropicalUrban
USStdNavyMarVis23km

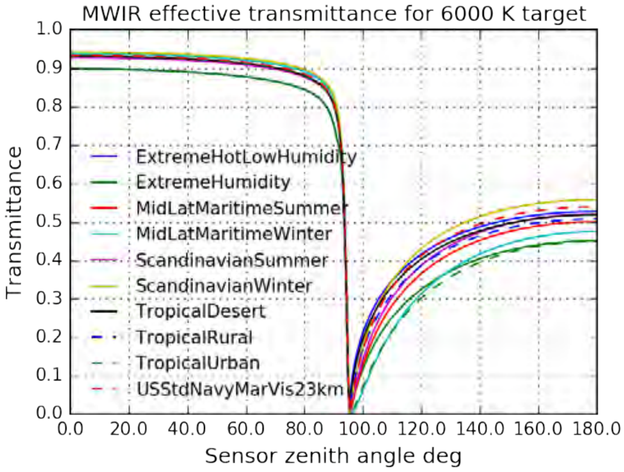

SWIR effective transmittance for 300 K target
Transmittance
Sensor zenith angle deg
ExtremeHotLowHumidity
ExtremeHumidity
MidLatMaritimeSummer
MidLatMaritimeWinter
ScandinavianSummer
ScandinavianWinter
TropicalDesert
TropicalRural
TropicalUrban
USStdNavyMarVis23km

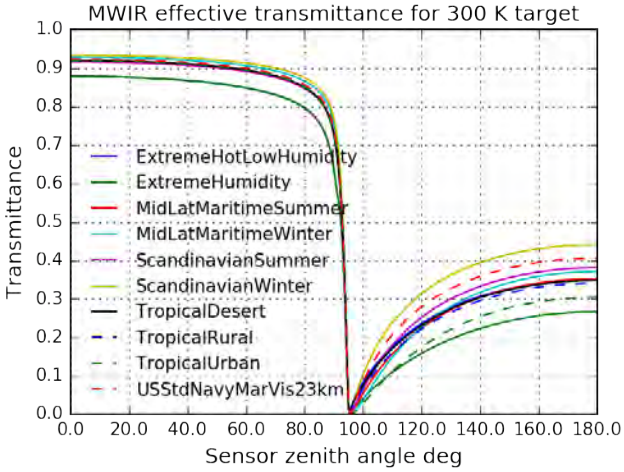

SWIR effective transmittance for 6000 K target
Transmittance
Sensor zenith angle deg
ExtremeHotLowHumidity
ExtremeHumidity
MidLatMaritimeSummer
MidLatMaritimeWinter
ScandinavianSummer
ScandinavianWinter
TropicalDesert
TropicalRural
TropicalUrban
USStdNavyMarVis23km

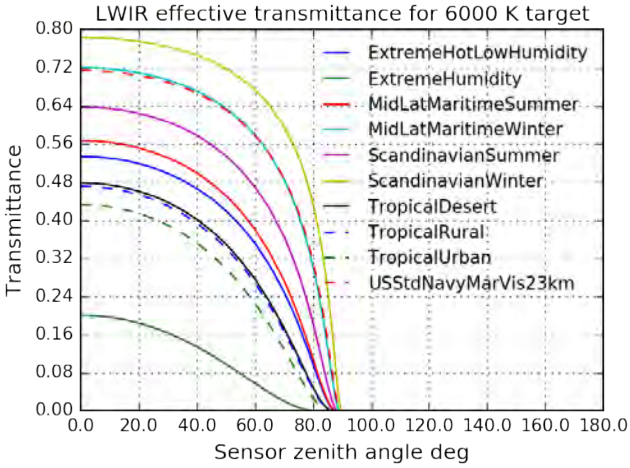

SWIR effective transmittance for 300 K target
Transmittance
Sensor zenith angle deg
ExtremeHotLowHumidity
ExtremeHumidity
MidLatMaritimeSummer
MidLatMaritimeWinter
ScandinavianSummer
ScandinavianWinter
TropicalDesert
TropicalRural
TropicalUrban
USStdNavyMarVis23km

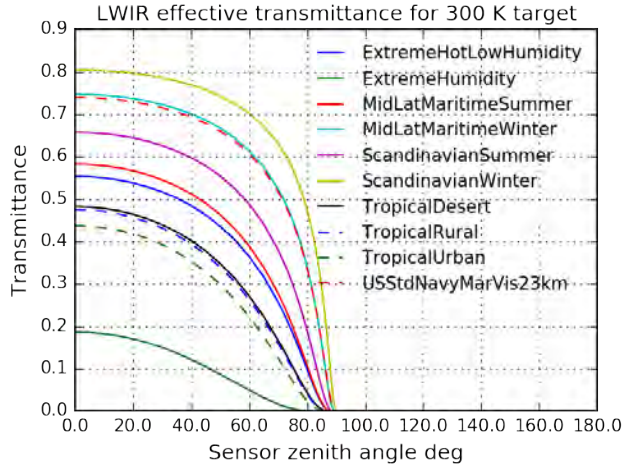

MWIR effective transmittance for 6000 K target
Transmittance
Sensor zenith angle deg
ExtremeHotLowHumidity
ExtremeHumidity
MidLatMaritimeSummer
MidLatMaritimeWinter
ScandinavianSummer
ScandinavianWinter
TropicalDesert
TropicalRural
TropicalUrban
USStdNavyMarVis23km

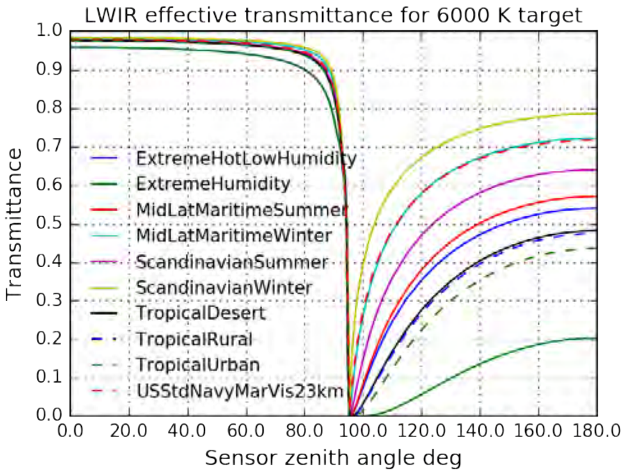

MWIR effective transmittance for 300 K target
Transmittance
Sensor zenith angle deg
ExtremeHotLowHumidity
ExtremeHumidity
MidLatMaritimeSummer
MidLatMaritimeWinter
ScandinavianSummer
ScandinavianWinter
TropicalDesert
TropicalRural
TropicalUrban
USStdNavyMarVis23km

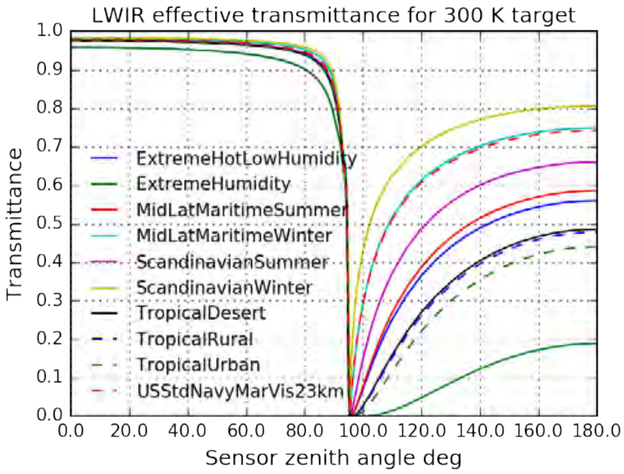

MWIR effective transmittance for 6000 K target
Transmittance
Sensor zenith angle deg
ExtremeHotLowHumidity
ExtremeHumidity
MidLatMaritimeSummer
MidLatMaritimeWinter
ScandinavianSummer
ScandinavianWinter
TropicalDesert
TropicalRural
TropicalUrban
USStdNavyMarVis23km


MWIR effective transmittance for 300 K target
Transmittance
Sensor zenith angle deg
ExtremeHotLowHumidity
ExtremeHumidity
MidLatMaritimeSummer
MidLatMaritimeWinter
ScandinavianSummer
ScandinavianWinter
TropicalDesert
TropicalRural
TropicalUrban
USStdNavyMarVis23km


LWIR effective transmittance for 6000 K target
Transmittance
Sensor zenith angle deg
ExtremeHotLowHumidity
ExtremeHumidity
MidLatMaritimeSummer
MidLatMaritimeWinter
ScandinavianSummer
ScandinavianWinter
TropicalDesert
TropicalRural
TropicalUrban
USStdNavyMarVis23km


LWIR effective transmittance for 300 K target
Transmittance
Sensor zenith angle deg
ExtremeHotLowHumidity
ExtremeHumidity
MidLatMaritimeSummer
MidLatMaritimeWinter
ScandinavianSummer
ScandinavianWinter
TropicalDesert
TropicalRural
TropicalUrban
USStdNavyMarVis23km


LWIR effective transmittance for 6000 K target
Transmittance
Sensor zenith angle deg
ExtremeHotLowHumidity
ExtremeHumidity
MidLatMaritimeSummer
MidLatMaritimeWinter
ScandinavianSummer
ScandinavianWinter
TropicalDesert
TropicalRural
TropicalUrban
USStdNavyMarVis23km


LWIR effective transmittance for 300 K target
Transmittance
Sensor zenith angle deg
ExtremeHotLowHumidity
ExtremeHumidity
MidLatMaritimeSummer
MidLatMaritimeWinter
ScandinavianSummer
ScandinavianWinter
TropicalDesert
TropicalRural
TropicalUrban
USStdNavyMarVis23km

3 α, β AND γ FITS TO STANDARD ATMOSPHERES

Clients sometimes use simple equations to model atmospheric transmittance with range. These models are not suitable for wideband spectral ranges. This section investigates the goodness of fit of two such models. Both these models apply for a uniform atmospheric path. Slant paths from any height above 2 km would not be accurately modelled.

The (α, β) extinction model is as follows:

$$\tau = \exp\left[-\alpha R\left(\frac{10}{R}\right)^{\beta}\right] \tag{3.1}$$

The (γ) or Beer (Bouguer) extinction model is as follows:

$$\tau = \exp\left[-\gamma R\right] \tag{3.2}$$

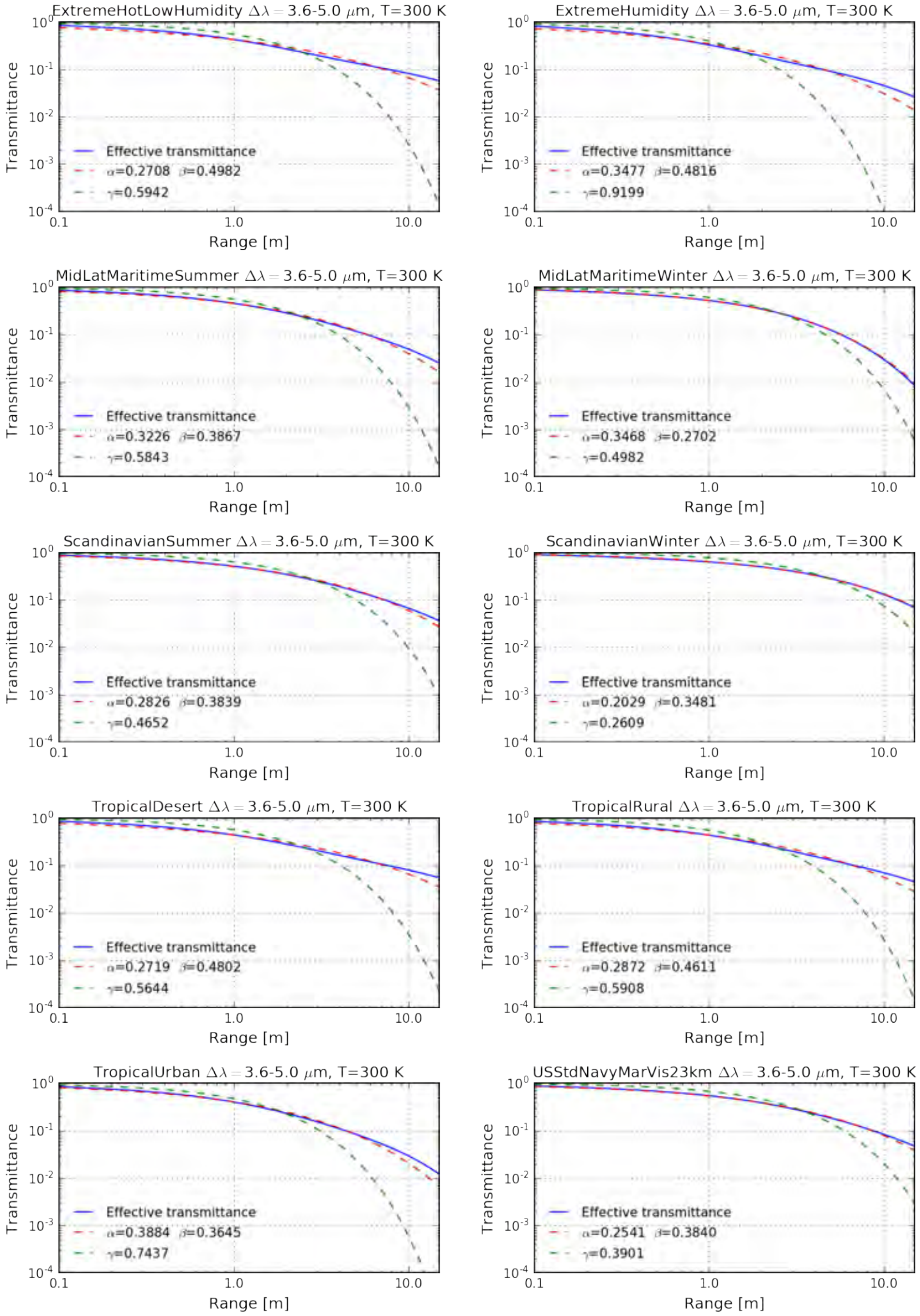
In the graph below the curves labelled 'Effective Transmittance' are the true transmittance variation against range. The sets of curves labelled 'α/β and γ are the approximation curve fits.

It is quite evident that the approximation curves are not very good approximations. For the data shown here the (α, β) extinction model gives a reasonable fit over the distances considered (0.1 to 15 km), but beyond 15 km the error grows very quickly. The (γ) model only fits reasonably for a path length shorter than about 2 km.

See Listing 5.20 for the code to model the approximations.

See Listing 5.21 for the code to collect list of atmospheres.

See Listing 5.22 for the code to plot the approximations vs true results..



See Listing 5.23 for the code to prepare tables.

	Atmosphere	α	β	γ
0	ExtremeHotLowHumidity: 44 C, 30% RH (18.1), 77 km Vis Desert	0.270773	0.498202	0.594155
1	ExtremeHumidity: 35 C, 95% RH (37.9), 23 km Vis Rural	0.347705	0.481553	0.919896
2	MidLatMaritimeSummer: 21 C, 76% RH (14), 23 km Vis Maritime	0.322575	0.386728	0.584343
3	MidLatMaritimeWinter: -1 C, 77% RH (3), 10 km Vis Maritime	0.346758	0.270231	0.498239
4	ScandinavianSummer: 14 C, 75% RH (9), 31 km Vis Maritime	0.282606	0.383870	0.465228
5	ScandinavianWinter: -15.9 C, 80% RH (1), 31 km Vis Maritime	0.202865	0.348069	0.260869
6	TropicalDesert: 26.6 C, 75% RH (18), 75 km Vis Desert	0.271947	0.480195	0.564427
7	TropicalRural: 26.6 C, 75% RH (18), 23 km Vis Rural	0.287227	0.461126	0.590823
8	TropicalUrban: 26.6 C, 75% RH (18), 5 km Vis Urban	0.388425	0.364487	0.743685
9	USStdNavyMarVis23km: 15 C, 46% RH (5.9), 23 km Vis Nav.Mar, SS4	0.254076	0.383958	0.390133

4 PYTHON AND MODULE VERSIONS, AND DATES

See Listing 5.24 for the code.

Software	Version
Python	2.7.11 64bit [MSC v.1500 64 bit (AMD64)]
IPython	4.1.2
OS	Windows 7 6.1.7601 SP1
numpy	1.10.4
scipy	0.17.0
matplotlib	1.5.1
pyradi	0.2.3
pandas	0.18.0
Mon Sep 26 09:20:16 2016 South Africa Standard Time	

```
Software versions
Python 2.7.11 64bit [MSC v.1500 64 bit (AMD64)]
IPython 4.1.2
OS Windows 7 6.1.7601 SP1
numpy 1.10.4
scipy 0.17.0
matplotlib 1.5.1
pyradi 0.2.3
pandas 0.18.0
Mon Sep 26 09:20:16 2016 South Africa Standard Time
```

5 LISTINGS

Listing 5.1: Code Listing in cell 10

```
#to prepare the environment
import numpy as np
import scipy as sp
import pandas as pd
import pyradi.ryplot as ryplot
import os.path
from scipy.optimize import curve_fit

%matplotlib inline

# %reload_ext autoreload
# %autoreload 2

import pyradi.ryplot as ryplot
import pyradi.ryplanck as ryplanck
import pyradi.ryfiles as ryfiles
import pyradi.rymodtran as rymodtran

# import xlsxwriter

from IPython.display import HTML
from IPython.display import Image
from IPython.display import display
from IPython.display import FileLink, FileLinks

#make pngs at 150 dpi
import matplotlib as mpl
mpl.rc("savefig", dpi=150)
mpl.rc('figure', figsize=(10,8))
# %config InlineBackend.figure_format = 'svg'

pd.set_option('display.max_columns', 80)
pd.set_option('display.width', 200)
pd.set_option('display.max_colwidth', 150)
```

Listing 5.2: Code Listing in cell 12

```
#to define the atmospheres
"""This file provides Python-style definitions of the standard atmospheres.
This file can be included in other python scripts
"""

#each base tape5 file is in its own directory
dirs = ['ExtremeHotLowHumidity', 'ExtremeHumidity',
        'MidLatMaritimeSummer','MidLatMaritimeWinter',
        'ScandinavianSummer','ScandinavianWinter',
        'TropicalDesert','TropicalRural',
        'TropicalUrban','USStdNavyMarVis23km']

#altitudes  (in m)
alts = [305, 1524, 3048, 4572, 6096, 7620, 9144, 10668, 12192, 13716, 14326, 15240]

atmospheres = {
    u'ExtremeHotLowHumidity':['44 C, 30% RH (18.1), 77 km Vis Desert'],
    u'ExtremeHumidity'      :['35 C, 95% RH (37.9), 23 km Vis Rural'],
    u'MidLatMaritimeSummer' :['21 C, 76% RH (14), 23 km Vis Maritime'],
    u'MidLatMaritimeWinter' :['-1 C, 77% RH (3), 10 km Vis Maritime'],
    u'ScandinavianSummer'   :['14 C, 75% RH (9), 31 km Vis Maritime'],
    u'ScandinavianWinter'   :['-15.9 C, 80% RH (1), 31 km Vis Maritime'],
    u'TropicalDesert'       :['26.6 C, 75% RH (18), 75 km Vis Desert'],
    u'TropicalRural'        :['26.6 C, 75% RH (18), 23 km Vis Rural'],
    u'TropicalUrban'        :['26.6 C, 75% RH (18), 5 km Vis Urban'],
    u'USStdNavyMarVis23km'  :['15 C, 46% RH (5.9), 23 km Vis Nav.Mar, SS4'],
    }
```

Listing 5.3: Code Listing in cell 15

```
#to plot the vertical profiles
def plotProfiles(alts, dirs, atmospheres,maxalt):
    #first plot the different altitudes for each atmosphere
    pa = ryplot.Plotter(4, 1, 1, figsize=(6,6));
    pp = ryplot.Plotter(1, 1, 1, figsize=(6,6));
    pt = ryplot.Plotter(2, 1, 1, figsize=(6,6));
    ph = ryplot.Plotter(3, 1, 1, figsize=(6,6));

    for i,directory in enumerate(dirs):
        for alt in alts:
            if alt == 305:
                datadir = os.path.join('.',directory,'{}'.format(alt))
                filename = os.path.join(datadir,'tape6')
                with open(filename,'rt') as fin:
                    lines = fin.readlines()
                    cntProfiles = 0
                    linecnt = 0
                    doLines = True
                    while(doLines and linecnt < len(lines)):
                        if 'ATMOSPHERIC PROFILES' in lines[linecnt]:
```

```
                            linecnt += 2 # discard empty line and read next
                            acclines = []
                            if 'RH (%)' in lines[linecnt]:
                                linecnt += 2 # discard header lines
                                for i in range(36):
                                    acclines.append((lines[linecnt]).split())
                                    linecnt += 1
                                arr = np.asarray(acclines, dtype=np.float)
                                arr[0,1] = .1
                                #write profile to disk
                                profile = np.hstack((arr[:,1].reshape(-1,1),arr[:,2].reshape(-1,1),arr[:,3].reshape(-1,1),arr↲
                                    [:,10].reshape(-1,1)))
                                profilepath = os.path.join('.',directory,'{}-profile.txt'.format(directory))
                                np.savetxt(profilepath, profile)
                                #process
                                arrdf = pd.DataFrame(arr)
                                arrdf = arrdf[arrdf[1] <= maxalt]
                                arr = arrdf.values
                                aero = np.sum(arr[:,4:8], axis=1)
                                pa.logLog(1,aero,arr[:,1],label=[directory])
                                pp.semilogY(1,arr[:,2],arr[:,1],label=[directory])
                                pt.semilogY(1,arr[:,3],arr[:,1],label=[directory])
                                ph.semilogY(1,arr[:,10],arr[:,1],label=[directory])
                                doLines = False
                        linecnt += 1

    cpa = pa.getSubPlot(1)
    cpp = pp.getSubPlot(1)
    cpt = pt.getSubPlot(1)
    cph = ph.getSubPlot(1)

    for falt in [1000, 5000, 30000]:
        malt = 0.3048 * falt / 1000.
        pa.logLog(1,np.asarray([1e-4,1e0]),np.asarray([malt,malt]),plotCol='k')
        cpa.text(0.2,0.9*malt, '{:.0f} kft'.format(falt/1000.), horizontalalignment='left', fontsize=8)
        pp.semilogY(1,np.asarray([240,1040]),np.asarray([malt,malt]),plotCol='k')
        cpp.text(960,0.9*malt, '{:.0f} kft'.format(falt/1000.), horizontalalignment='left', fontsize=8)
        pt.semilogY(1,np.asarray([210,330]),np.asarray([malt,malt]),plotCol='k')
        cpt.text(318,0.9*malt, '{:.0f} kft'.format(falt/1000.), horizontalalignment='left', fontsize=8)
        ph.semilogY(1,np.asarray([10,100]),np.asarray([malt,malt]),plotCol='k')
        cph.text(92,0.9*malt, '{:.0f} kft'.format(falt/1000.), horizontalalignment='left', fontsize=8)

    for ext in np.logspace(-2,0, 20):#[1e-2, 1e-1, 1]:
        cpa.text(ext,0.105, '{:.0f} km vis'.format(3.91/ext), verticalalignment='bottom', horizontalalignment='center', ↲
             fontsize=8, rotation=90)

    cpa.set_xlabel('Extinction [km$^{-1}$]')
    cpa.set_ylabel('Altitude [km]')
    cpa.set_title('Vertical 550 nm Extinction Profiles')
    cpp.set_xlabel('Pressure [mBar]')
    cpp.set_ylabel('Altitude [km]')
    cpp.set_title('Vertical Pressure Profiles')
    cpt.set_xlabel('Temperature [K]')
    cpt.set_ylabel('Altitude [km]')
    cpt.set_title('Vertical Temperature Profiles')
    cph.set_xlabel('Relative humidity [%]')
    cph.set_ylabel('Altitude [km]')
    cph.set_title('Vertical Humidity Profiles')
#     pa.saveFig('profiles-aerosol.png')
#     pp.saveFig('profiles-pressure.png')
#     pt.saveFig('profiles-temperature.png')
#     ph.saveFig('profiles-humidity.png')

plotProfiles(alts, dirs, atmospheres, 10.)
```

Listing 5.4: Code Listing in cell 17

```
#to plot the spectral transmittance
def plotTau(alts, dirs, atmospheres):
  #first plot the different altitudes for each atmosphere
  for i,directory in enumerate(dirs):
    p = ryplot.Plotter(i, 1, 1, figsize=(12,6))
    for alt in alts:
      datadir = os.path.join('.',directory,'{}'.format(alt))
      filename = '{}-{}m.1km'.format(directory, alt)
      data = np.loadtxt(os.path.join(datadir,filename), skiprows=1)
      p.plot(1, data[:,0], data[:,1],
        '{} {} 1 km transmittance, 135 deg zenith'.format(directory, atmospheres[directory][0]),
        'Wavelength $\mu$m','Transmittance', label=['{} m'.format(alt)],legendAlpha=0.5)
#     p.saveFig(os.path.join('.',directory,'{}.png'.format(directory)))

  #now plot the different atmospheres for each altitude
  for j, alt in enumerate(alts):
    p = ryplot.Plotter(j+len(dirs), 1, 1, figsize=(12,6))
    for i,directory in enumerate(dirs):
      datadir = os.path.join('.',directory,'{}'.format(alt))
      filename = '{}-{}m.1km'.format(directory, alt)
      data = np.loadtxt(os.path.join(datadir,filename), skiprows=1)
      p.plot(1, data[:,0], data[:,1],
        '{} m altitude, 135 deg zenith 1 km transmittance'.format(alt),
        'Wavelength $\mu$m','Transmittance', label=['{} {}'.format(directory, atmospheres[directory][0])],
        legendAlpha=0.5)
#     p.saveFig(os.path.join('.','AllScen-{}m.png'.format(alt)))

plotTau(alts, dirs, atmospheres)
```

Listing 5.5: Code Listing in cell 20

```
#to return Placnk radiator radiance
def lpathfunc(nu,tbb):
    return  ryplanck.planck(nu,tbb, 'en') / np.pi
```

Listing 5.6: Code Listing in cell 21

```
#to calculate and plot atmospheric temperature
files = ryfiles.listFiles(root=r'.',
                patterns=r'.*tape7', recurse=1, return_folders=0, useRegex=True)

#remove the files with elev in the name
fileslist = []
for filen in files:
    if 'elev' not in filen:
        fileslist.append(filen)


dfAtmoTempCols = ['Atmosphere','Altitude','TmpLoTau','TmpHiTau','3.5-4.8','8.3-12','TmpAve','TmpAll']
dfAtmoTemp = pd.DataFrame(columns=dfAtmoTempCols)

# for i,filename in enumerate([r'C:\WorkA\TAPM\Atmospheres\Standard\ExtremeHotLowHumidity\305\tape7',
#                              r'C:\WorkA\TAPM\Atmospheres\Standard\ExtremeHotLowHumidity\15240\tape7']):
for i,filename in enumerate(fileslist):
    filesplit = filename.split('\\')
    colselect = ['FREQ', 'TOT_TRANS','PTH_THRML']
    tape7 = rymodtran.loadtape7(filename, colselect )
    tape7[:,2] *= 1e4

    genericbands = {
        '10-12,5':[12.5, 10.],  # generic
        '8.33-9.34':[9.34, 8.33],  # generic
        '4.5-5.0':[5.0, 4.5],  # generic
        '3.2-4.5':[4.17, 3.2],  # generic
        }
    camerabands = {
        '8.33-12.0':[12.0, 8.33], # this is the 8-12 band including
        '3.5-4.8':[4.8, 3.5], # this is the 3-5 band including CO2
        }

    #prepare selection for generic bands
    selectHiTau = np.zeros(tape7[:,0].shape)
    for key in genericbands:
        selectHiTau = np.logical_or(selectHiTau,
            np.all([ tape7[:,0] >= 1e4/genericbands[key][0], tape7[:,0] <= 1e4/genericbands[key][1]], axis=0))

    selectLoTau = np.logical_not(selectHiTau)
    select3to5 = np.all([ tape7[:,0] >= 1e4/camerabands['3.5-4.8'][0], tape7[:,0] <= 1e4/camerabands['3.5-4.8'][1]], axis=0)
    select8to12 = np.all([ tape7[:,0] >= 1e4/camerabands['8.33-12.0'][0], tape7[:,0] <= 1e4/camerabands['8.33-12.0'][1]], axis↵
        =0)

    popt, pcov = curve_fit(lpathfunc,tape7[selectHiTau,0], tape7[selectHiTau,2]/(1-tape7[selectHiTau,1]), p0=(250.) )
    tmpHiTau = popt[0]
    popt, pcov = curve_fit(lpathfunc,tape7[selectLoTau,0], tape7[selectLoTau,2]/(1-tape7[selectLoTau,1]), p0=(250.) )
    tmpLoTau = popt[0]
    tmpAve = (tmpHiTau + tmpLoTau) / 2.
    popt, pcov = curve_fit(lpathfunc,tape7[:,0], tape7[:,2]/(1-tape7[:,1]), p0=(250.) )
    tmpAll = popt[0]
    popt, pcov = curve_fit(lpathfunc,tape7[select3to5,0], tape7[select3to5,2]/(1-tape7[select3to5,1]), p0=(250.) )
    tmp3to5 = popt[0]
    popt, pcov = curve_fit(lpathfunc,tape7[select8to12,0], tape7[select8to12,2]/(1-tape7[select8to12,1]), p0=(250.) )
    tmp8to12 = popt[0]

    dfAtmoTemp = dfAtmoTemp.append(pd.DataFrame([[filesplit[-3], float(filesplit[-2]), tmpLoTau, tmpHiTau,
                            tmp3to5, tmp8to12, tmpAve, tmpAll]], columns=dfAtmoTempCols))

    if filesplit[-3] =='ExtremeHotLowHumidity' and (filesplit[-2]=='305' or filesplit[-2]=='15240') :

        p = ryplot.Plotter(i, 2,2,'{} - {} m'.format(filesplit[-3],filesplit[-2]),figsize=(10,10))
        p.plot(1, tape7[:,0],selectHiTau * .2, plotCol='m',label=['High $\\tau$ selection'], linestyle='--', )
        p.plot(1, tape7[:,0],select3to5 * 0.4, plotCol='y',label=['3.5-4.8 $\\mu$m'], linestyle='--', )
        p.plot(1, tape7[:,0],select8to12 * 0.4, plotCol='c',label=['8.3-12 $\\mu$m'], linestyle='--', )
        p.plot(1, tape7[:,0],tape7[:,1],colselect[1],'Wavenumber cm$^{-1}$','Transmittance',
                plotCol='r',maxNX=5,pltaxis=[0,4000,0,1])

        p.plot(2, tape7[:,0],tape7[:,2],colselect[2],'Wavenumber cm$^{-1}$','Radiance W/(m$^2$.sr.cm$^{-1}$)',
                plotCol='r',label=['$L_\\mathrm{path}$'])
        p.plot(2, tape7[:,0],tape7[:,2]/(1.-tape7[:,1]),plotCol='b',label=['$L_\\mathrm{path}$ / $(1-\\tau)$'],
                maxNX=5)
        p.plot(2, tape7[:,0],selectHiTau * 0.05, plotCol='m',label=['High $\\tau$ selection'], linestyle='--', )
        p.plot(2, tape7[:,0],select3to5 * 0.1, plotCol='y',label=['3.5-4.8 $\\mu$m'], linestyle='--', )
        p.plot(2, tape7[:,0],select8to12 * 0.1, plotCol='c',label=['8.3-12 $\\mu$m'], linestyle='--', )
        p.plot(2, tape7[:,0],ryplanck.planck(tape7[:,0],tmpHiTau,'en')/np.pi,
            plotCol='g',label=['$L_\\mathrm{bb}$'+'({:.1f}) K (high $\\tau$)'.format(tmpHiTau)])
        p.plot(2, tape7[:,0],ryplanck.planck(tape7[:,0],tmpAll,'en')/np.pi,
            plotCol='k',label=['$L_\\mathrm{bb}'+'$({:.1f}) K (all)'.format(tmpAll)])
        p.plot(2, tape7[:,0],ryplanck.planck(tape7[:,0],tmpLoTau,'en')/np.pi,
            plotCol='c',label=['$L_\\mathrm{bb}$'+'({:.1f}) K (low  $\\tau$)'.format(tmpLoTau)],
                maxNX=5,pltaxis=[650,2500,0,0.15])

        p.semilogY(3, tape7[:,0],tape7[:,1],colselect[1],'Wavenumber cm$^{-1}$','Transmittance',
                plotCol='r',maxNX=5,pltaxis=[0,16000,1e-9,1e0])
        p.semilogY(4, tape7[:,0],tape7[:,2],colselect[2],'Wavenumber cm$^{-1}$','Radiance W/(m$^2$.sr.cm$^{-1}$)',
                plotCol='r',label=['$L_\\mathrm{path}$'])
        p.semilogY(4, tape7[:,0],tape7[:,2]/(1.-tape7[:,1]),plotCol='b',label=['$L_\\mathrm{path}$ / $(1-\\tau)$'],
                maxNX=5,pltaxis=[0,16000,1e-30,1e0])
        p.semilogY(4, tape7[:,0],ryplanck.planck(tape7[:,0],tmpHiTau,'en')/np.pi,
                plotCol='g',label=['$L_\\mathrm{bb}$'+'({:.1f}) K (high  $\\tau$)'.format(tmpHiTau)])
        p.semilogY(4, tape7[:,0],ryplanck.planck(tape7[:,0],tmpAll,'en')/np.pi,
                plotCol='k',label=['$L_\\mathrm{bb}$'+'({:.1f}) K (all)'.format(tmpAll)])
        p.semilogY(4, tape7[:,0],ryplanck.planck(tape7[:,0],tmpLoTau,'en')/np.pi,
```

```
                    plotCol='c',label=['$L_\\mathrm{bb}$'+'({:.1f}) K (low  $\\tau$)'.format(tmpLoTau)],
                    maxNX=5,pltaxis=[0,16000,1e-30,1e0])
```

Listing 5.7: Code Listing in cell 22

```
#to process and print atmospheric transmittance
dfAtmoTempk = dfAtmoTemp.sort_values(by=['Atmosphere','Altitude']).copy()

writer = pd.ExcelWriter('./StandardAtmoTemperatures.xlsx', engine='xlsxwriter')
dfAtmoTempk.to_excel(writer, sheet_name='Temperatures', startrow=0, startcol=0, header=True, index=False)

trimCols = ['TmpLoTau','TmpHiTau','3.5-4.8','8.3-12','TmpAve','TmpAll']
for col in trimCols:
    dfAtmoTempk[col] =  ((10*dfAtmoTempk[col]).astype(int))/10

atmolist = np.unique(dfAtmoTempk['Atmosphere'])
string = ''
for atmo in atmolist:
    dfAtmo = dfAtmoTempk[dfAtmoTempk.Atmosphere==atmo]
    dfAtmo = dfAtmo.set_index('Atmosphere')
    string += dfAtmo.to_html()
HTML(string)
```

Listing 5.8: Code Listing in cell 23

```
#to plot atmospheric temperature
r = ryplot.Plotter(1,1,1,'',figsize=(10,5))
atmoUnique = dfAtmoTempk['Atmosphere'].unique()
for atmos in atmoUnique:
    atmprofile = dfAtmoTempk[dfAtmoTempk.Atmosphere==atmos]
    r.plot(1, atmprofile['Altitude'], atmprofile['3.5-4.8'],xlabel='Altitude [m]',
           ylabel='Apparent temperature [K]',ptitle='Down-looking atmospheric temperature 3.5-4.8 $\mu$m',label=[atmos])
for alt in [1000, 5000, 30000]:
    malt = 0.3048 * alt
    r.plot(1,np.asarray([malt,malt]),np.asarray([240,320]),plotCol='k')

    cp = r.getSubPlot(1)
    cp.text(malt, 317, '{:.0f} kft'.format(alt/1000.),
                 horizontalalignment='left', fontsize=8)
```

Listing 5.9: Code Listing in cell 25

```
#to define the spectral bands
specranges = {}
with open('StandardSpectralRanges.txt','rt') as fin:
    lines = fin.readlines()
    for line in lines:
        linelst = line.rstrip().split()
        specranges[linelst[0]] = [float(linelst[1]),float(linelst[2])]
print(specranges)
import operator
specrangesSorted = [x[0] for x in sorted(specranges.items(), key=operator.itemgetter(1))]
print(specrangesSorted)
```

Listing 5.10: Code Listing in cell 27

```
#to calculate effective transmittance
def analyseTau(alts, dirs, atmospheres,specranges, reflect = 0.3, rangekm=5):
    """for specified atmospheres and altitudes calculate the effective transmittance
    for specified spectral bands, for sunlight radiance and 300K radiance
    at the specified distance.
    Results are returned in a pandas dataframe
    """

    #prepare to create the data frame
    columns=['Atmosphere','Altitude','SpecRange','EffTauSlant','PathLenSlant','EffTauRange','PathLenRange','effGamma']
    aTau = pd.DataFrame(columns=columns)
    doPlot = True
    for i,directory in enumerate(dirs):
        for j, alt in enumerate(alts):
            #load data from file
            datadir = os.path.join('.',directory,'{}'.format(alt))
            filename = '{}-{}m.1km'.format(directory, alt)
            data = np.loadtxt(os.path.join(datadir,filename), skiprows=1)

            #calculate source radiance for sun and terrain
            LSun = ryplanck.planck(data[:,0],6000.,'el')
            L300 = ryplanck.planck(data[:,0],300.,'el')
            LEff = (1-reflect) * L300 + reflect * 2.1e-5 * LSun
            if doPlot:
                doPlot = False
                p = ryplot.Plotter(1,1,1,'Source Spectrum for Effective Transmittance Calculation',figsize=(12,5))
                p.logLog(1,data[:,0],LEff,'','Wavelength [$\mu$m]',
                         'Radiance [W/(m$^2$$\cdot$sr$\cdot$$\mu$m)]')#,pltaxis=[0.3,14,1,1000])

            for k, spec in enumerate(specranges.keys()):
                #select a smaller spectral integration range according to spectral band definition
                select = np.zeros(data[:,0].shape)
                select = np.where(((data[:,0]>=specranges[spec][0]) & (data[:,0]<=specranges[spec][1])), 1.0, 0.0)
                # the following two lines check spectral selection
        #         seldiff = np.where(np.diff(select) != 0)
        #         print(specranges[spec][0], specranges[spec][1], data[seldiff,0])

                #get slant path distance
```

```
                rangesl = ((alt/1000.) / (np.cos(45.0 * np.pi / 180.)) )

                taukm = np.exp( rangekm * np.log(data[:,1]))
                tausl = np.exp( rangesl * np.log(data[:,1]))
                effTaukm = np.trapz(select *LEff * taukm,data[:,0]) / np.trapz(select * LEff, data[:,0])
                effTaukm = int(1000.*effTaukm) / 1000.
                effTausl = np.trapz(select *LEff * tausl
                                ,data[:,0]) / np.trapz(select * LEff, data[:,0])
                effGamma = -np.log(effTausl)/rangesl
                effTausl = int(1000.*effTausl) / 1000.
                aTau = aTau.append(pd.DataFrame([[directory,alt,spec,effTausl,rangesl,effTaukm,rangekm, effGamma]], columns=↲
                    columns))
    return(aTau)
```

Listing 5.11: Code Listing in cell 29

```
#to define atmospheric conditions
rangekm = 5
reflect = 0.3
limAlts = alts
# limAlts = [305, 1524, 3048, 4572,  10668, 15240]
# limAlts = [4572]
aTau = analyseTau(limAlts, dirs, atmospheres, specranges, reflect, rangekm)
# print(aTau)
```

Listing 5.12: Code Listing in cell 30

```
#to sort and process the data
#first set up the dataframe to sort spectral range by the low wavelength, rather than alpha
# http://stackoverflow.com/questions/23482668/sorting-by-a-custom-list-in-pandas
specrangesSorted = sorted(specranges, key=lambda key: specranges[key][0])
aTau.SpecRange = aTau.SpecRange.astype("category")
aTau.SpecRange.cat.set_categories(specrangesSorted, inplace=True)
```

Listing 5.13: Code Listing in cell 32

```
#to build the result tables
string = ''
for alt in limAlts:
    filData = aTau[aTau['Altitude']==alt]
    filData = filData.drop('Altitude', axis=1)

    pathType = ['PathLenSlant', 'PathLenRange']
    effTType = ['EffTauSlant', 'EffTauRange']

    for i in [0,1]:
        redData = filData
        #get appropriate range and drop the original rangecolumns
        pathlen = 1000. * np.unique(redData[[(pathType[i])]].values)[0]
        redData = redData.drop('PathLenSlant', axis=1)
        redData = redData.drop('PathLenRange', axis=1)
        redData = redData.drop('effGamma', axis=1)
        if i == 0:
            redData = redData.drop('EffTauRange', axis=1)
        else:
            redData = redData.drop('EffTauSlant', axis=1)

        #build a long description of the atmosphere
        redData.Atmosphere = redData.Atmosphere.map(lambda x: ' '.join((x, atmospheres[x][0])))
        #first create the mulitindex row-wise
        redData = redData.set_index(['Atmosphere', 'SpecRange'])
        #then unstack the deepest row-indexes into columns and select the target sze and concept
        redData =  redData.unstack(('SpecRange'))
        redData.reindex_axis(sorted(redData.columns), axis=1)

        if i == 0:
            string += r'<P>\newpage'
            string +=  '<P>\nAltitude {} m, slant path length {:.0f} m, (recalculated from 1 km data set)'.format(alt,pathlen)
        else:
            string +=  '<P>\nAltitude {} m, fixed path length {:.0f} m, (recalculated from 1 km data set)'.format(alt,pathlen)
        string += redData.to_html()

HTML(string)
```

Listing 5.14: Code Listing in cell 35

```
#to load the data and print the column headings
dfEff = pd.read_excel('atmos-elevation-angles.xlsx')
print(dfEff.columns)
# print(dfEff.Zenith.unique())
```

Listing 5.15: Code Listing in cell 37

```
#ro print the spectral ranges
print(specranges)
```

Listing 5.16: Code Listing in cell 40

```
#to plot the direct irradiance on ground level for the different spectral bands
atmodirs = dfEff.Atmo.unique()
altitudes = dfEff.Altitude.unique()
```

```
specBands = specrangesSorted
ipl = 0
for ic,specBand in enumerate(specBands):
    for il,alt in enumerate([altitudes[0]]):
        ipl += 1
        p = ryplot.Plotter(ipl,1,2,figsize=(12,4))
        for ip,lradu in zip([1,2],['W/m2','q/(s.m2)']):
            p.resetPlotCol()
            for ia,atmodir in enumerate(atmodirs):
                dft = dfEff[ (dfEff.Atmo==atmodir) & \
                             (dfEff.Altitude==alt) & \
                             (dfEff.SpecBand==specBand)  \
                ].copy()

                dft = dft.sort_values(by='Zenith')
                plotVal = dft.BoaWatt if lradu=='W/m2' else dft.BoaQ
                p.plot(ip, dft.Zenith, plotVal, '{} km {} sun zenith {} deg '.format(alt/1000.,specBand, -23),
                       'Sensor zenith angle deg','Apparent irradiance {}'.format(lradu), label=[atmodir] )
```

Listing 5.17: Code Listing in cell 42

```
#to plot the path radiance for the different spectral bands
atmodirs = dfEff.Atmo.unique()
altitudes = dfEff.Altitude.unique()
specBands = specrangesSorted
ipl = 0
for ic,specBand in enumerate(specBands):
    for il,alt in enumerate(altitudes):
        ipl += 1
        p = ryplot.Plotter(ipl,1,2,figsize=(12,4))
        for ip,lradu in zip([1,2],['W/(m2.sr)','q/(s.m2.sr)']):
            p.resetPlotCol()
            for ia,atmodir in enumerate(atmodirs):
                dft = dfEff[ (dfEff.Atmo==atmodir) & \
                             (dfEff.Altitude==alt) & \
                             (dfEff.SpecBand==specBand)  \
                ].copy()

                dft = dft.sort_values(by='Zenith')
                plotVal = dft.LpathWatt if lradu=='W/(m2.sr)' else dft.LpathQ
                p.plot(ip, dft.Zenith, plotVal, '{} km {} sun zenith {} deg '.format(alt/1000.,specBand, -23),
                       'Sensor zenith angle deg','Path radiance {}'.format(lradu), label=[atmodir] )
```

Listing 5.18: Code Listing in cell 43

```
#to plot the effective transmittance for the different atmospheres
atmodirs = dfEff.Atmo.unique()
specBands = specrangesSorted
altitudes = dfEff.Altitude.unique()
ipl = 0
for ia,atmodir in enumerate(atmodirs):
    for il,alt in enumerate(altitudes):
        ipl += 1
        p = ryplot.Plotter(ipl,1,2,figsize=(12,4))
        for specBand,plotCol in zip(specBands,['r','g','b','m','c',]):
            dft = dfEff[ (dfEff.Atmo==atmodir) & \
                         (dfEff.Altitude==alt) & \
                         (dfEff.SpecBand==specBand)  \
            ].copy()
            dft = dft.sort_values(by='Zenith')
            p.plot(1, dft.Zenith, dft.effTauSun, '{} km {} {} K target'.format(alt/1000., atmodir,6000),
                   'Sensor zenith angle deg','Transmittance', label=[specBand], plotCol=plotCol )
            p.plot(2, dft.Zenith, dft.effTau300, '{} km {} {} K target'.format(alt/1000.,atmodir,300),
                   'Sensor zenith angle deg','Transmittance', label=[specBand], plotCol=plotCol )
```

Listing 5.19: Code Listing in cell 44

```
#to plot the effective transmittance for the different spectral bands
atmodirs = dfEff.Atmo.unique()
specBands = specrangesSorted
altitudes = dfEff.Altitude.unique()
ipl = 0
for ic,specBand in enumerate(specBands):
    for il,alt in enumerate(altitudes):
        p = ryplot.Plotter(ipl,1,2,figsize=(12,4))
        ipl += 1
        for ip,targ in zip([1,2],[6000,300]):
            p.resetPlotCol()
            for ia,atmodir in enumerate(atmodirs):
                dft = dfEff[ (dfEff.Atmo==atmodir) & \
                             (dfEff.Altitude==alt) & \
                             (dfEff.SpecBand==specBand)  \
                ].copy()

                dft = dft.sort_values(by='Zenith')
                plotVal = dft.effTauSun if targ==6000 else dft.effTau300
                p.plot(ip, dft.Zenith, plotVal, '{} effective transmittance for {} K target'.format(specBand,targ),
                       'Sensor zenith angle deg','Transmittance', label=[atmodir] )
```

Listing 5.20: Code Listing in cell 46

```
#to model the approximations
def tauAB(prange, alpha, beta):
    tau = np.exp(-alpha * prange * (10/prange) ** beta)
```

```
    return tau

def tauG(prange, gamma):
    tau = np.exp(-gamma * prange)
    return tau
```

Listing 5.21: Code Listing in cell 47

```
#to collect list of atmospheres
wlLo = 3.6 # um
wlHi = 5.0 # um
tempTarg = 300 # K
strScenario = r'$\Delta\lambda=${}-{} $\mu$m, T=300 K'.format(wlLo, wlHi, tempTarg )
fileslist = ryfiles.listFiles(root=r'.',
                patterns='.*\.1km', recurse=1, return_folders=0, useRegex=True)
#filter only 305 m
filelist = []
for item in fileslist:
    if '305' in item:
        filelist.append(item)
```

Listing 5.22: Code Listing in cell 48

```
#to plot the approximations vs true results.
prange = np.linspace(0.1,15,100)
p = ryplot.Plotter(1,len(filelist)/2,2, figsize=(12,18))
alphabetagamma = []
for i,filename in enumerate(filelist):
    #do this for horizontal path (homogeneous atmosphere)
    atmotype = os.path.basename(filename).replace('-305m.1km','')
    atmosphere = '{}: {}'.format(atmotype,atmospheres[atmotype][0])
    atmo = np.loadtxt(filename, skiprows=1)
    # select only the limited spectral range
    atmo = atmo[np.all([ atmo[:,0]<=wlHi, atmo[:,0]>=wlLo], axis=0),:]
    gamma = -np.log(atmo[:,1]) / 1.0
    tau = np.exp(-gamma.reshape(-1,1) * prange.reshape(1,-1) )

    radtau = ryplanck.planck(atmo[:,0], tempTarg, 'el')
    tauEff = np.trapz(radtau.reshape(-1,1) * np.exp(-gamma.reshape(-1,1) * prange.reshape(1,-1) ),
                    atmo[:,0],axis=0) / np.trapz(radtau ,atmo[:,0],axis=0)

    popt, pcov = curve_fit(tauAB, prange, tauEff, p0=(0.5, 0.5) )
    alpha = popt[0]
    beta = popt[1]
    alfabetaL = r'$\alpha$={:.4f}  $\beta$={:.4f}'.format(alpha,beta)

    popt, pcov = curve_fit(tauG, prange, tauEff, p0=(0.5) )
    gamma = popt[0]
    gammaL = r'$\gamma$={:.4f}'.format(gamma)
    alphabetagamma.append([atmosphere, alpha,beta,gamma ])

    title = '{} {}'.format(atmotype,strScenario)
    p.logLog(i+1,prange, tauEff,'','','', linestyle=['-'],plotCol='b',
            label=['Effective transmittance'])
    p.logLog(i+1,prange, tauAB(prange,alpha, beta),'','','',
            linestyle=['--'],plotCol='r',label=[alfabetaL])
    p.logLog(i+1,prange, tauG(prange,gamma),title,
            'Range [m]','Transmittance', linestyle=['--'],plotCol='g',
            label=[gammaL],pltaxis=[0,15,1e-4,1])
#     cp = p.getSubPlot(i+1)
#     cp.text(0.15, 2e-3, strScenario,
#                   horizontalalignment='left', fontsize=10)
```

Listing 5.23: Code Listing in cell 49

```
#to prepare tables
string = ''
string += r'$(\alpha,\beta)$ parameters for a horizontal homogeneous path '
string += 'under conditions: {}. '.format(strScenario)
string += r'Data fitted over path range of 0.1 to 15 km. '
abdf = pd.DataFrame(alphabetagamma, columns=['Atmosphere',r'$\alpha$',r'$\beta$',r'$\gamma$'])
string += abdf.to_html()
HTML(string)
```

Listing 5.24: Code Listing in cell 51

```
%load_ext version_information
%version_information numpy, scipy, matplotlib, pyradi, pandas
```

Listing 5.25: Code Listing in cell 52