
Atmospheric model in Python (manual)

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Introduction

This short document explains how to use the atmospheric refraction and dispersion model that I've constructed. For a detailed look into the different formula's that are used, as well as possible derivations and diagrams, I'd recommend you to look at the *MICADO_Sources_of_uncertainty_in_atmospheric_dispersion.pdf* document. This manual is meant to be an introduction in how to use my Python code. For a complete overview of all the functions I recommend looking at the source code. The *atmosphericModel.py* code has to be imported (preferred) or modified to be used. Importing it can be done by creating a new Python script in the same root folder and using

```
import atmosphericModel
```

or by adding it to your PATH environment temporarily, e.g.:

```
import sys
sys.path.insert(0, '<LOCATION_OF_ATMOSPHERICMODEL.PY>'),
```

where everything between the '' is the folder where *atmosphericModel.py* is located.

Requirements

- Python 2 or 3
- Numpy and Scipy packages

A quick example

Below is a simple example showing how to call and calculate the index of refraction, the atmospheric refraction and atmospheric dispersion for H-band at Cerro Armazones.

```
from atmosphericModel import *

T      = 279.65      # k
P      = 71200       # Pa
H      = 0.22
xc     = 450         # ppm
lat    = -24.5983    # degrees
h      = 3064        # m
l1     = 1.49        # micron
l2     = 1.78        # micron
zenith = 30          # degrees

# Initiate Ciddor model
at = Ciddor1996(p=P, T=T, H=H, xc=xc)

# Calculate density of air
rho = at.rho(p=P, T=T, RH=H, xc=xc)

# Calculate index of refraction at wavelength 1 and 2
n1 = at.n_tph(l=l1, T=T, p=P, RH=H, xc=xc)
n2 = at.n_tph(l=l2, T=T, p=P, RH=H, xc=xc)

# Initiate refraction and dispersion object
ref = refraction(lat, h, P, rho)
disp = dispersion(lat, h, P, rho)

print('Cassini refraction: %s arc sec' %(ref.cassini(n1, n2, zenith) * 3.6e3))
print('Cassini dispersion: %s mas' %(disp.cassini(n1, n2, zenith) * 3.6e6))
```

The index of refraction is calculated following Ciddor's 1996 paper *Refractive index of air: new equations for the visible and near infrared* (Applied Optics, 35:1566).

The atmospheric refraction can be calculated using any of the following methods, all of which are described in either *Understanding astronomical refraction* by Young (2006) or in *On the importance of astronomical refraction for modern solar astrometric measurements* by Corbard et al. (2019);

1. Plane-parallel atmosphere (Young, 2006)
2. Cassini's homogenous spherical atmosphere (Young, 2006; Corbard et al., 2019)
3. Oriani's theorem (Young, 2006; Corbard et al., 2019), up to the third order term.
4. Expanded version of Oriani's theorem (Corbard et al., 2019), including the fifth order term.
5. Formula based on the error function as described in Corbard et al., 2019.

All models require input of zenith in degrees and return an output in degrees.

Range of validity and input units

The validity of this model is only determined by the transmission of the atmosphere, i.e. Snell's law must be valid, and the conditions for which the Ciddor model is able to return correct values of the index of refraction. For typical, realistic values at ground based observing sites, this model will give good results in the wavelength range between 0.4 and 2.5 μm .

For longer wavelengths an index of refraction has to be supplied by the user.

The input parameters and corresponding units are given below.

Input parameter	Unit
Temperature	K
Pressure	Pa
Humidity	Unit fraction (i.e. a humidity of 22% is 0.22)
CO ₂ content	Parts per million (ppm)
Latitude	Degrees
Height above sea level	m
Wavelength	μm
Zenith angle	Degrees