Numerical Fluid Dynamics Project

2020

Python Tools & INCAA Projections

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CLEMSON PHYSICS AND ASTRONOMY

Young, C. Alex. “Aurora.” The Sun Today with C. Alex Young, Ph.D., 1 July 2019, www.thesuntoday.org/space-weather/aurora/.

Numerical Fluid Dynamics Project

Project Description & Details

- Accessing Atmospheric models with Python (pyglow)
- INCAA Measurement Projections (PI Kaeppler)

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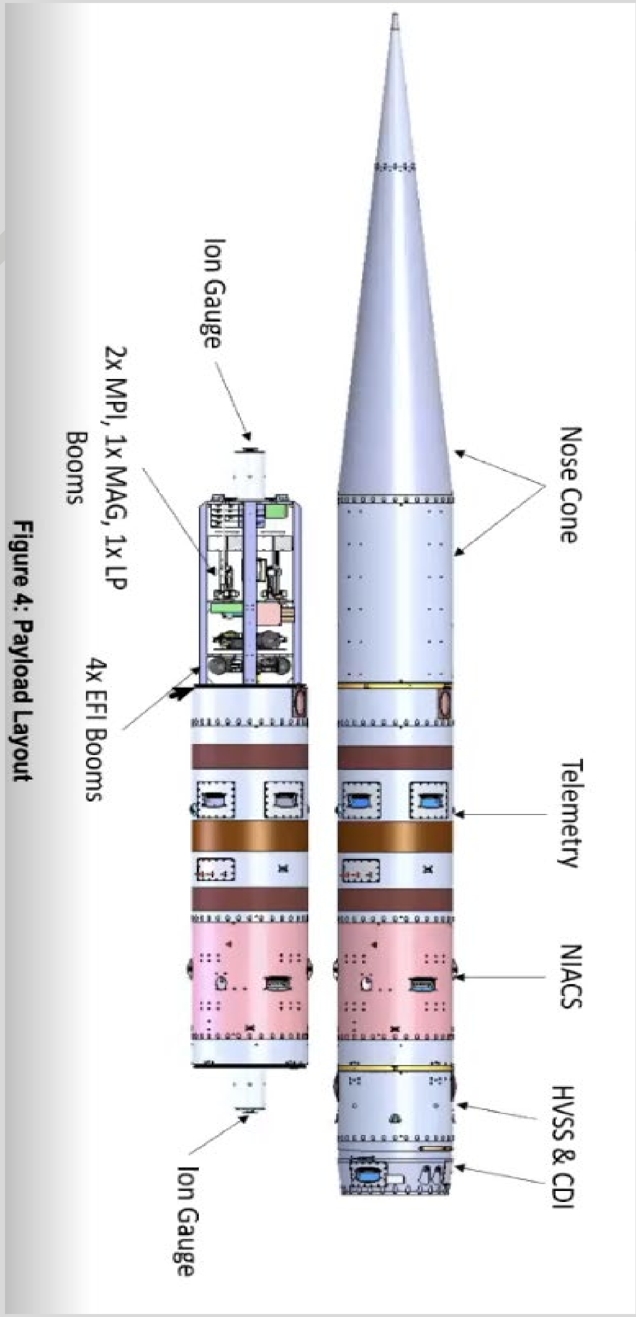


Figure 4: Payload Layout

Atmospheric Model Utility

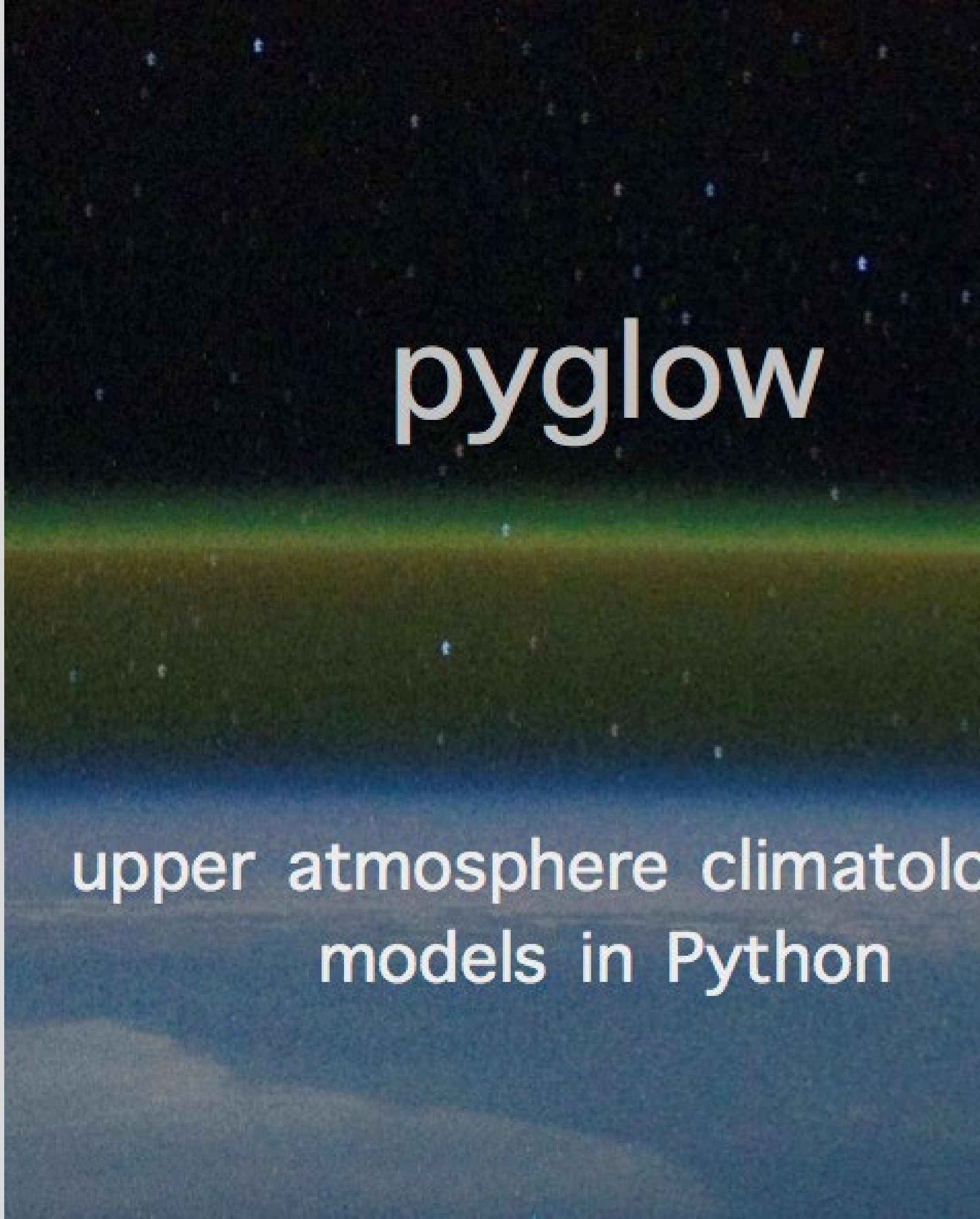
Vast majority of atmospheric models written in FORTRAN, but python is irreplaceable for most applications.

Pyglow is a python module developed by Tim Duly (and contributors) helps alleviate the issue.

Some of the supported Models:

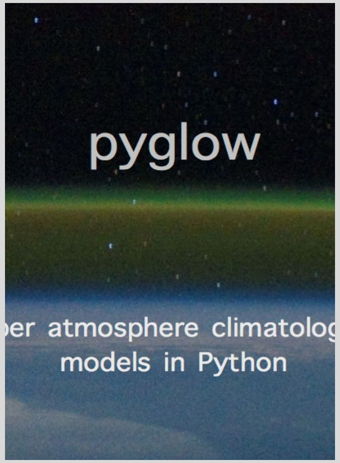
- IGRF (11, 12)
- IRI (2012, 2016)
- MSIS (2000)
- HWM (1993, 2007, 2014)

https://github.com/timduly4/pyglow



Pyglow Demo

- Quick overview
- MSIS projections
- Python-FORTRAN bridge!



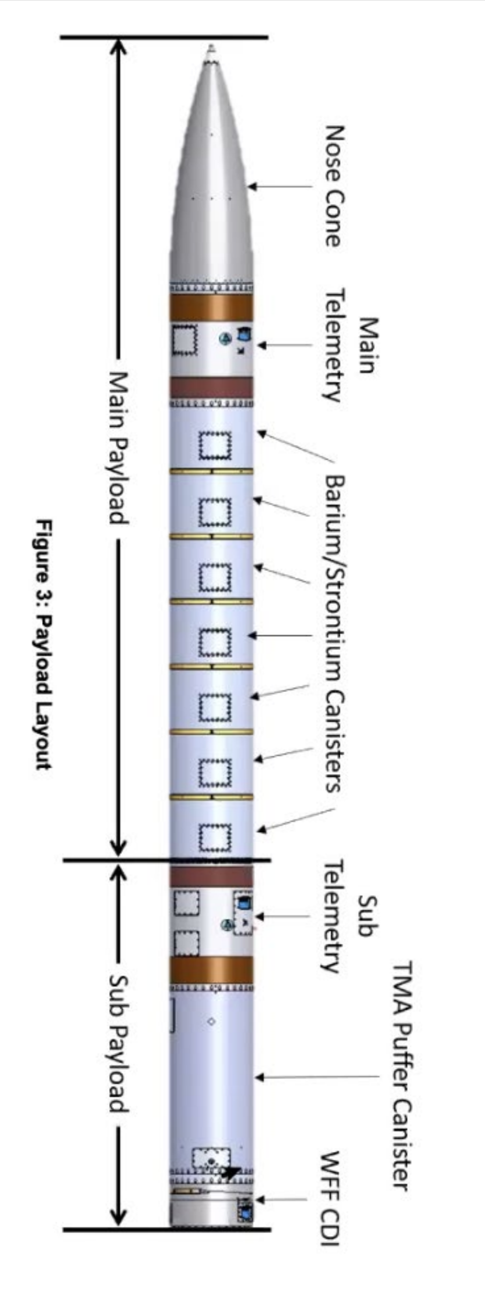


Figure 3: Payload Layout

INCAA Projections

Sounding rocket campaign due to launch Spring 2022

- Ion demagnetization altitude (κ)
- Ion velocity, neutral winds, DC electric fields (2D), DC magnetic fields (3D), neutral mass density and temperature, and electron density
- How can models help?

$$\kappa = \frac{\Omega_i}{\nu_{in}} = \frac{q_i}{m_i \nu_{in}} = \frac{|\mathbf{v_i} - \mathbf{u_n}|}{\left| \frac{\mathbf{E}}{|B_0|} + \frac{\mathbf{v_i} \times \mathbf{B_0}}{|B_0|} \right|}$$

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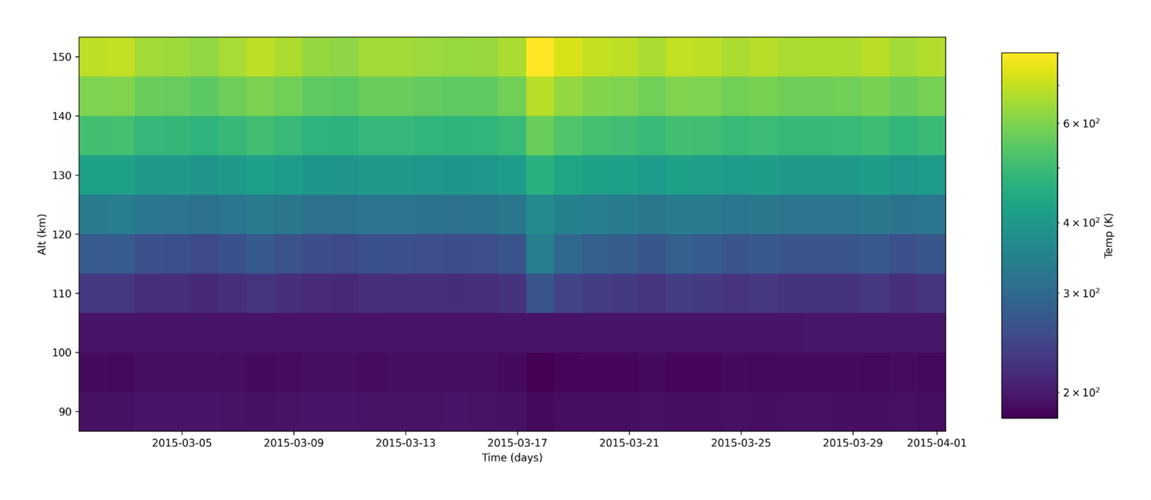
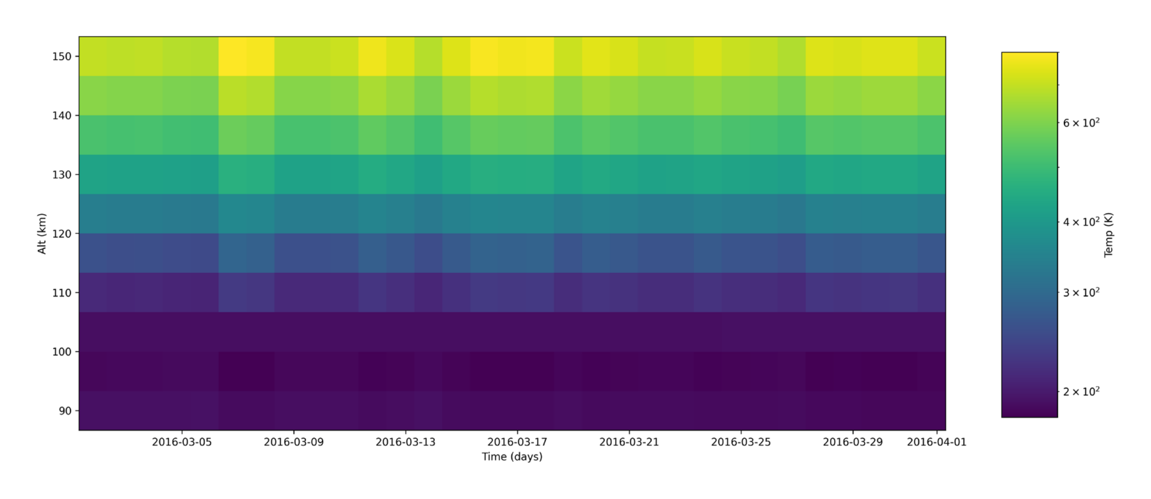
NRLMSISE Projections[1]

Model inputs:

- 2015-2018, March
- Altitude: typical E-region
- Poker Flats, Alaska





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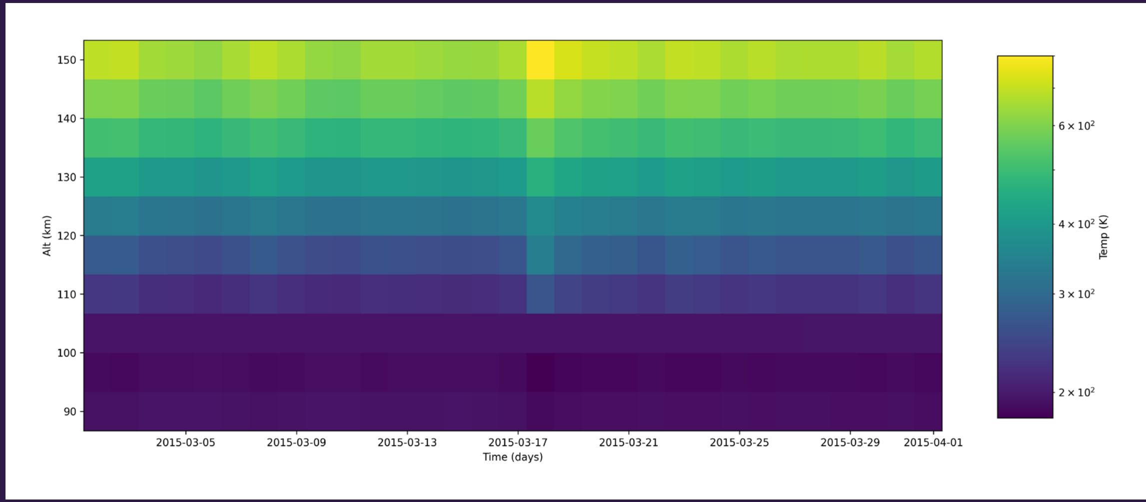

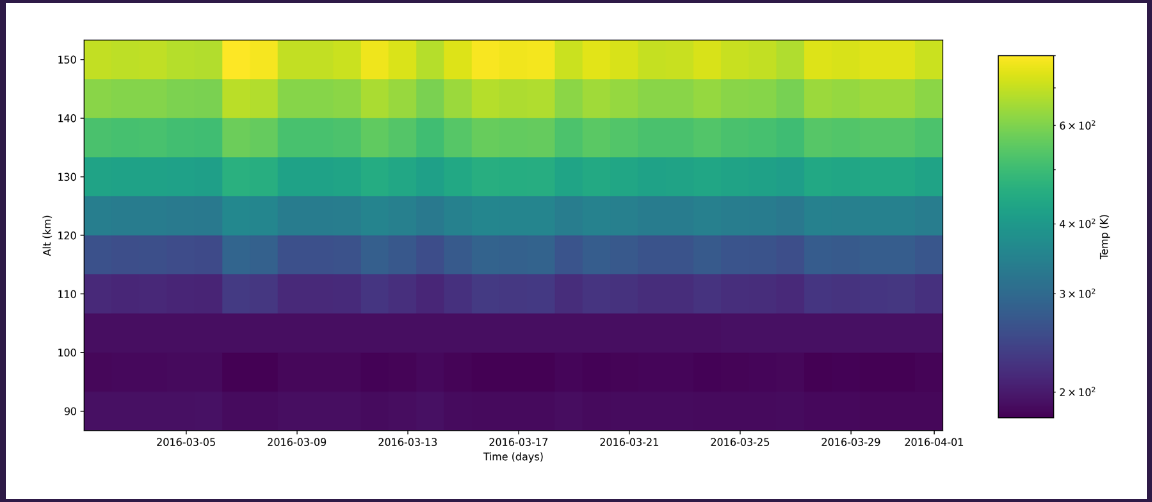

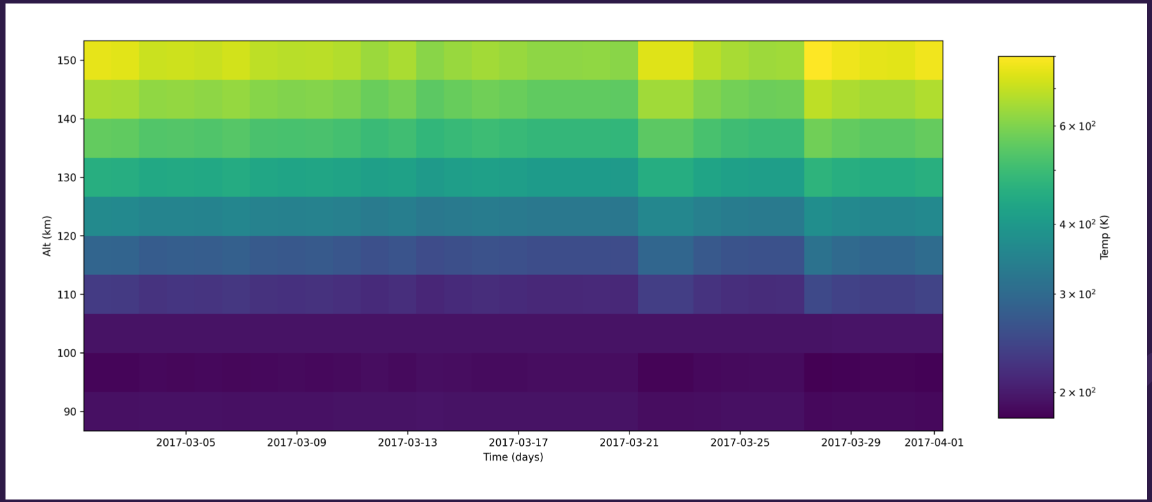

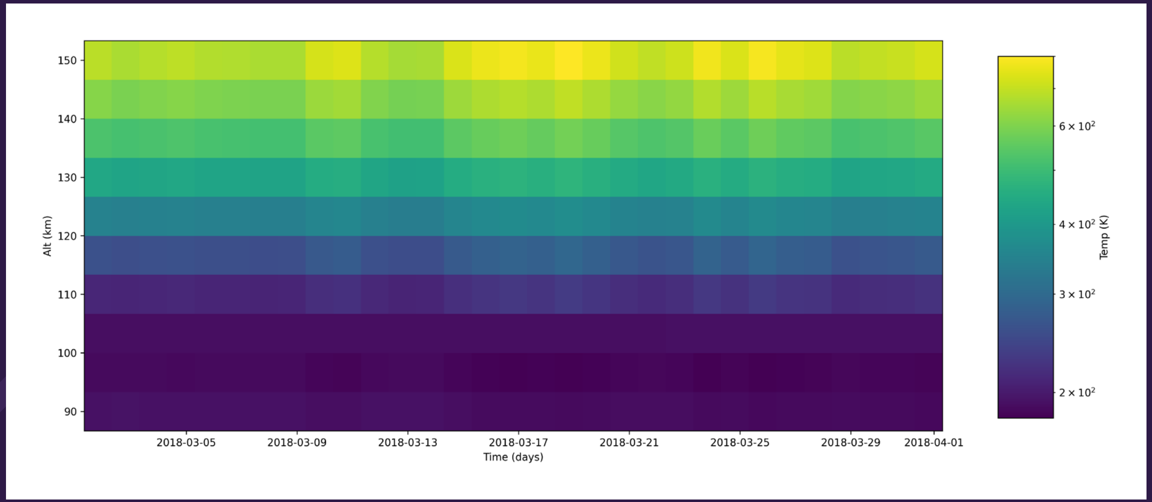

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NRLMSISE 2.0[4]

Vertical Temperature Profile:

- Linear combination of cubic B-spines (below 122 km) and Bates thermospheric temperature profile (above 122 km)

$$\frac{1}{T(\zeta)} = \begin{cases} \left\{T_{ex} - (T_{ex} - T_B)\exp\left[-\sigma(\zeta - \zeta_B)\right]\right\}^{-1} & ; \ \zeta \ge \zeta_B \\ \sum_{i=0}^{N_S - 1} \alpha_i S_i(\zeta) & ; \ \zeta < \zeta_B \end{cases} \tag{1}$$

$T(\zeta)$	Temperature profile as a function of geopotential height
$\zeta_B = 122.5$ km	Bates profile reference height and joining height
T_{ex}	Exospheric temperature (fitting parameter)
$T_B = T(\zeta_B)$	Temperature at ζ_B (fitting parameter)
$\sigma = T'_B / (T_{ex} - T_B)$	Shape parameter
$T'_B = \left.\frac{dT}{d\zeta}\right\vert_{\zeta=\zeta_B}$	Temperature gradient at ζ_B (fitting parameter)
$N_S = 24$	Number of B-spline basis functions
α_i	Coefficients on B-spline basis functions (fitting parameters)
S_i	Cubic B-splines with nodes at heights $\zeta_{S,i}$; $i = 0$ to $N_S + 3$

$$\zeta_{S,i} = \{-15, -10, -5, 0, 5, \ldots, 80, 85, 92.5, 102.5, 112.5, 122.5, 132.5, 142.5, 152.5\} \text{ km}$$

Vertical Density Profile:

- Hydrostatic balance in lower and middle atmosphere, and essentially a diffusive (hydrostatic) equilibrium in upper atmosphere

$$\ln n(\zeta) = \ln n_0 - \frac{g_0}{k}\int_{\zeta_0}^{\zeta} \frac{M(\zeta')}{T(\zeta')} d\zeta' - \ln\frac{T(\zeta)}{T(\zeta_0)} - Ce^{-(\zeta-\zeta_C)/H_C} + R\left[1 + \tanh\left(\frac{\zeta - \zeta_R}{\gamma(\zeta) H_R}\right)\right]$$

$n(\zeta)$	Number density of a particular species
$n_0 = n(\zeta_0)$	Reference density (defined below)
ζ_0	Reference geopotential height
g_0	Reference gravitational acceleration (see equation (A3))
k	Boltzmann constant
$M(\zeta)$	Effective mass profile (defined below)
C, ζ_C, H_C	Chemical loss term parameters
R, ζ_R, H_R	Chemical/dynamical correction parameters

$$\gamma(\zeta) = \frac{1}{2}\left\{1 + \tanh\left(\frac{\zeta - \zeta_\gamma}{H_\gamma}\right)\right\} \tag{2}$$

$\zeta_\gamma = 70$ km

$H_\gamma = 40$ km

IRI Projections[2]

- Still in progress
- Kernel error?
- Any help is appreciated!

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International Reference Ionosphere[3]

"For given location, time and date, IRI provides monthly averages of the electron density, electron temperature, ion temperature, and ion composition in the ionospheric altitude range…."

Primary ISR used: Jicamarca, Arecibo, Millstone Hill, Malvern and St. Santin

Height Ranges:

- Ne: daytime (65-2000km) / nighttime (80-2000km)
- Te/Ti: 60-2500km
- Ion composition: 75-2000km

"Arecibo Message." SETI Institute, 2018, www.seti.org/arecibo-message.

References

1. A. E. Hedin, Extension of the MSIS Thermospheric Model into the Middle and Lower Atmosphere, J. Geophys. Res. 96, 1159, 1991.
2. Bilitza, Dieter. “International Reference Ionosphere Model - IRI (2016).” *NASA*, NASA, ccmc.gsfc.nasa.gov/models/modelinfo.php?model=IRI.
3. Bilitza, Dieter. “International Reference Ionosphere Model - IRI (2016).” NASA, NASA, ccmc.gsfc.nasa.gov/models/modelinfo.php?model=IRI.
4. Emmert, J. T., Drob, D. P., Picone, J. M., Siskind, D. E., Jones, M., Mlynczak, M. G., et al. (2020). NRLMSIS 2.0: A whole-atmosphere empirical model of temperature and neutral species densities. Earth and Space Science, 7, e2020EA001321. https://doi.org/10.1029/2020EA001321

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