pwv_kpno: *A Python Package for Modeling PWV transmission using SuomiNet GPS*

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University of Pittsburgh

DESC Photometric Calibration
2018/10/04

Project Goal

"Use dual band GPS measurements of localized PWV to simulate the atmospheric absorption due to H_2O as a function of date and time."

Project deliverable must also be:

1. Easily extensible to user definable locations
2. Intuitive and simple to use
3. Conducive to a collaborative effort

Dual Band GPS

- Dual band signals pick up phase shift
  - Clock shift
  - Doppler effect
  - Atmospheric contribution

  } Frequency Independent

- Zenith Total Delay (ZTD)
  - Zenith Hydrostatic Delay (ZHD)
  - Zenith Wet Delay (ZWD)

- PWV = Q(T) * ZWD

Calculating Transmission

- Optical depth of material

$$T \equiv e^{-\tau} \quad s.t. \quad \tau = \sum_{i=1}^{N} \tau_i = \sum_{i=1}^{N} \tau_i = \sum_{i=1}^{N} \sigma_i \int_0^l n_i(z) dz$$

- In terms of PWV:

$$\tau_{PWV} = \sigma \frac{(N_a \cdot \rho_{PWV})}{\mu_{PWV}} PWV_z \, \mathrm{X}^{.6}$$

N_a= 6.02 E23 *(1 / mol)*
μ_{PWV} = 18.0152 *(g / mol)*
ρ_{PWV}= 0.99997 *(g / cm^3)*

version 1.0.0 python 2.7, 3.5+ license GPL v3.0 build passing coverage 73% astro-ph.im arXiv:1806.09701

What is pwv_kpno?

pwv_kpno is a science focused Python package that provides access to models for the atmospheric absorption due to H_2O. The strength of H_2O absorption features are strongly correlated with measurements of localized PWV column density. By measuring the delay of dual-band GPS signals traveling through the atmosphere, it is possible to determine the PWV column density along line of sight. **pwv_kpno** leverages this principle to provide atmospheric models for user definable sites as a function of date, time, and airmass.

How it Works

The SuomiNet project is a meteorological initiative that provides semi-hourly PWV measurements for hundreds of GPS receivers worldwide. The **pwv_kpno** package uses published SuomiNet data in conjunction with MODTRAN models to determine the modeled, time-dependent atmospheric transmission. By default, the package provides access to the modeled transmission function at Kitt Peak National Observatory. However, the package is designed to be easily extensible to other locations within the SuomiNet Network. Additionally, **pwv_kpno** provides access to atmospheric models as a function of PWV, which is independent of geographical location. Default atmospheric models are provided from 3,000 to 12,000 Angstroms at a resolution of 0.05 Angstroms.

Contributing and Attribution

pwv_kpno is open source software released under the GNU General Public License. Issues raised on GitHub and pull requests from contributors are welcome. Additionally, pull requests introducing dafault configuration files for new sites are also welcome.

If you use **pwv_kpno** as part of any published work or research, we ask that you please cite Perrefort, Wood-Vasey et al. 2018 If the publisher allows, you can also include a footnote with a link pointing to this documentation page.

Acknowledgements

This work is based in part on observations taken at Kitt Peak National Observatory, National Optical Astronomy Observatory (NOAO Prop. IDs: 2011B-0482 and 2012B-0500; PI: Wood-Vasey), which is operated by the Association of Universities for Research in Astronomy (AURA) under a cooperative agreement with the National Science Foundation.

This work was supported in part by the US D
Energy Office of Science under DE-SC000791

Additional Resources

1. An up time monitor for the SuomiNet web server can be found here.

2. To learn more about the SuomiNet project, see suominet.ucar.edu.

3. For an additional example on the correlation between GPS signals and atmospheric modeling, see Blake and Shaw,

https://mwvgroup.github.io/pwv_kpno/

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We gratefully acknowledge support from the Simons Foundation and member institutions

arXiv.org > astro-ph > arXiv:1806.09701

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Astrophysics > Instrumentation and Methods for Astrophysics

pwv_kpno: A Python Package for Modeling the Atmospheric Transmission Function due to Precipitable Water Vapor

Daniel Perrefort, W. M. Wood-Vasey, K. Azalee Bostroem, Kirk Gilmore, Richard Joyce, Charles Corson

(Submitted on 25 Jun 2018)

We present a Python package, pwv_kpno, that provides models for the atmospheric transmission due to precipitable water vapor (PWV) above Kitt Peak National Observatory (KPNO). Using the package, ground based photometric observations taken in the *ugrizy* bands ($3,000 < \lambda < 12,000$ \AA) can be corrected for atmospheric effects due to PWV. Atmospheric transmission in the optical and near-infrared is highly dependent on the PWV column density along line of sight. By measuring the delay of dual-band GPS signals through the atmosphere, the SuomiNet project provides accurate PWV measurements for hundreds of locations around the world. We installed a dual-band GPS system at KPNO in the spring of 2015. The pwv_kpno package uses published SuomiNet data in conjunction with MODTRAN models to determine the modeled atmospheric transmission function at Kitt Peak. In addition, we demonstrate that we can successfully predict the PWV at KPNO from nearby dual-band GPS stations on the desert floor. We thus can provide atmospheric transmission functions for observations taken from 2010 onward. This software is modular and is intended to be extensible to other observatories.

Subjects: **Instrumentation and Methods for Astrophysics (astro-ph.IM)**
Cite as: **arXiv:1806.09701 [astro-ph.IM]**
(or **arXiv:1806.09701v1 [astro-ph.IM]** for this version)

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- NASA ADS

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pwv-kpno 0.12.1

```
pip install pwv-kpno
```

Latest version

Last released: Sep 3, 2018

Models the atmospheric transmission function for KPNO

Navigation

Project description

Release history

Download files

Project links

Homepage

Project description

Overview

pwv_kpno is a Python package for modeling the atmospheric absorption due to H_2O at Kitt Peak National Observatory. It provides atmospheric models from 3,000 to 12,000 Angstroms for years 2010 onward. Understanding atmospheric effects is important when calibrating ground based astronomical observations. Traditionally, determining the detailed atmospheric transmission function at a given date and time required performing dedicated spectrographic observations. **pwv_kpno** provides an alternative that can be performed at the user's convenience.

Package Features

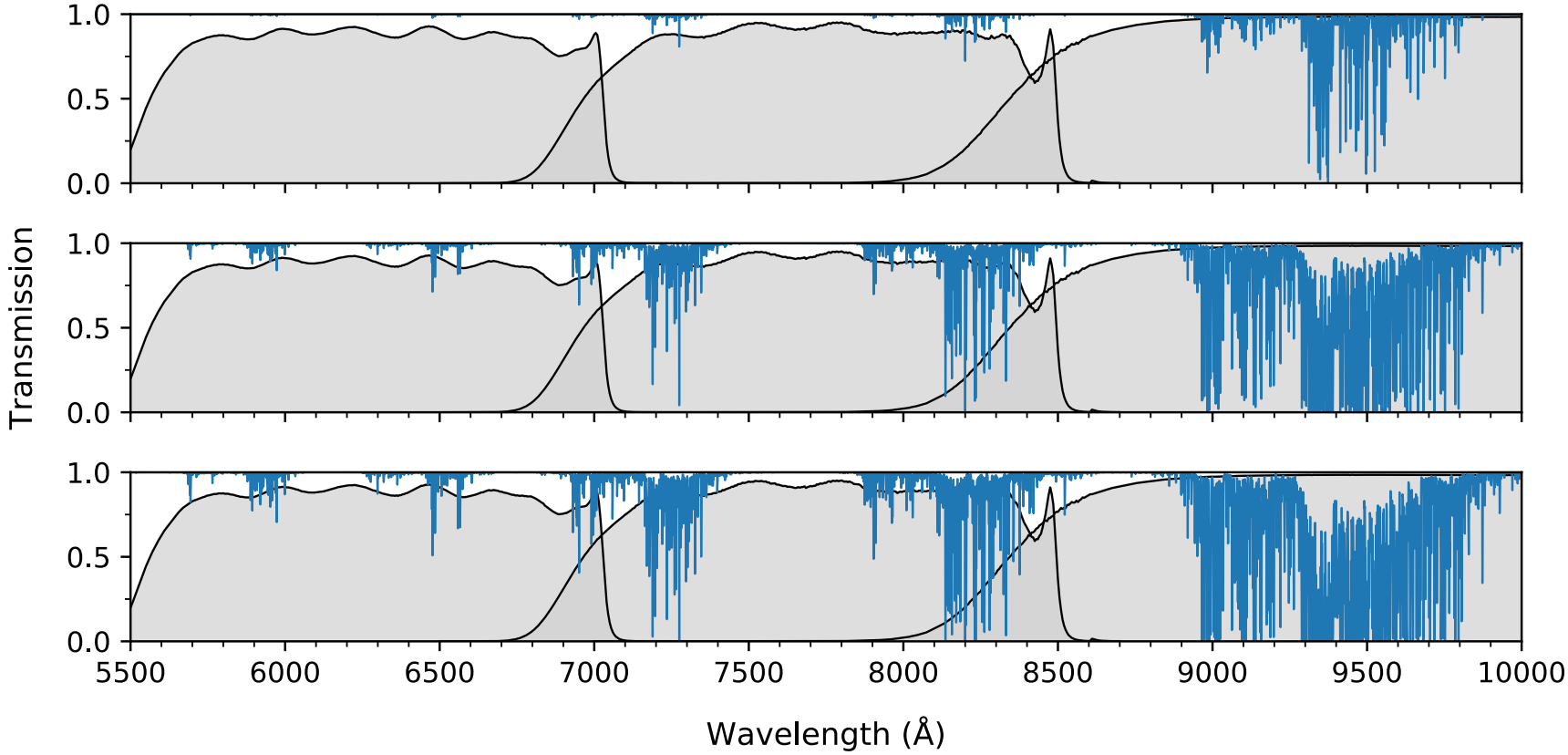
- Automatic download and parsing of new SuomiNet Data
- Access to full set of (downloaded) SuomiNet data
- PWV transmission model for given date, time, and airmass
  - 3,000 to 12,000 Å at 0.5 Å resolution
- PWV transmission model for given PWV
- Transmission models can be easily binned
- Guided process for extending to user defined sites
- Sharable config files for each site
- Black body spectral energy distribution with atmospheric features
- Full, online documentation, examples, and validation overview

Download Data from SuomiNet:

```
>>> from pwv_kpno import pwv_atm
>>> pwv_atm.update_models()
```

Model the Atmosphere:

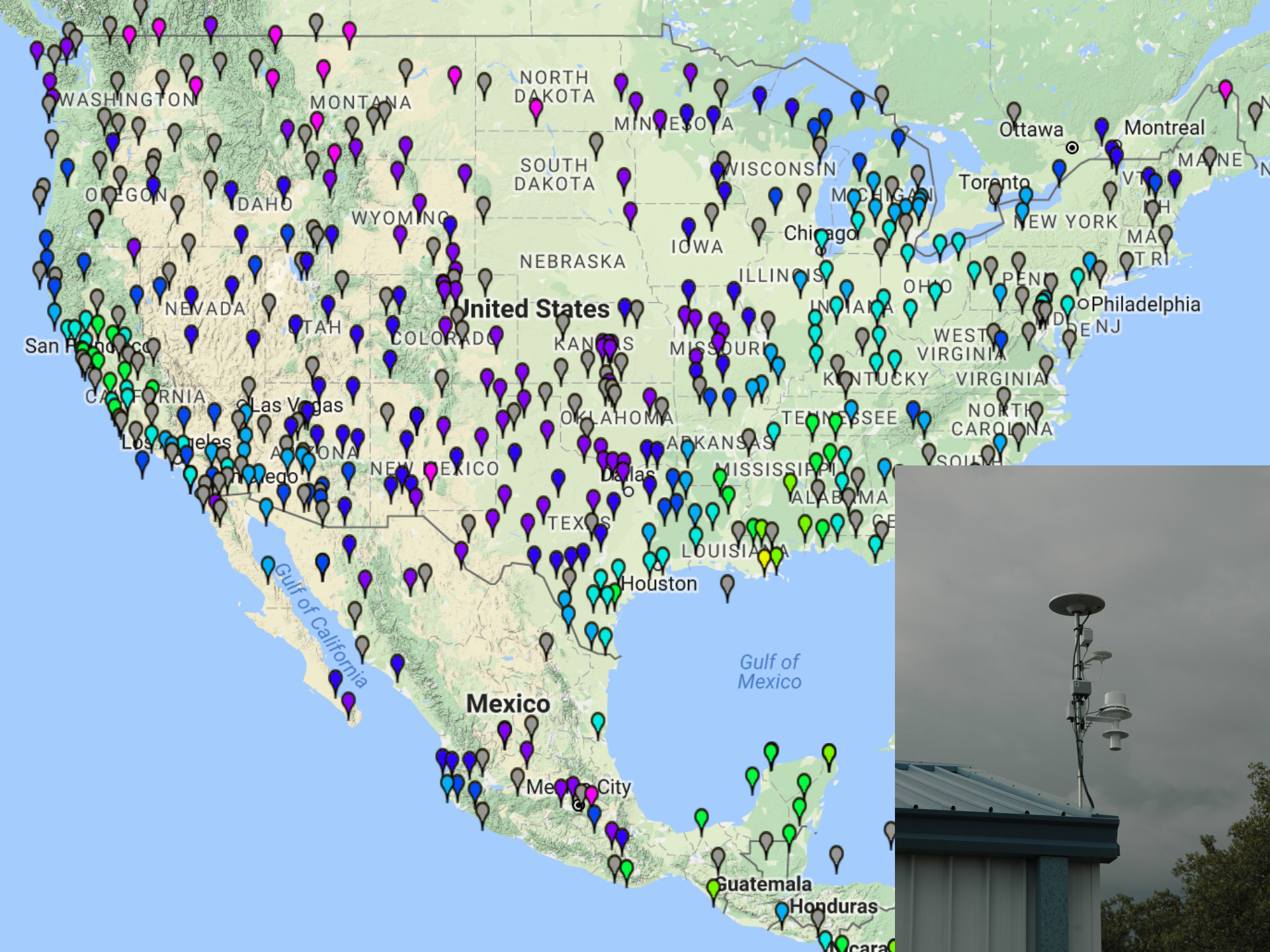
```
>>> from datetime import datetime
>>> from pwv_kpno import pwv_atm
>>> import pytz
>>>
>>> obsv_date = datetime(year=2013,
>>>                      month=12,
>>>                      day=15,
>>>                      hour=5,
>>>                      minute=35,
>>>                      tzinfo=pytz.utc)
>>>
>>> pwv_atm.trans_for_date(date=obsv_date, airmass=1.2)

  wavelength  transmission  transmission_err
   Angstrom
  ---------- -------------- ----------------
     3000.00 0.999999991637 1.3506621821e-08
     3000.05 0.999999991637 1.3507332141e-08
     3000.10 0.999999991637 1.3507963636e-08
         ...            ...              ...
```



From install to transmission function in minutes.

So how does it work?

And how well?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IOWA
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Philadelphia
NEW YORK
MAINE
San Francisco
Las Vegas
Los Angeles
San Diego
Dallas
Houston
United States
Mexico
Gulf of California
Gulf of Mexico
Guatemala
Honduras

```
>>> from pwv_kpno import pwv_atm
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```
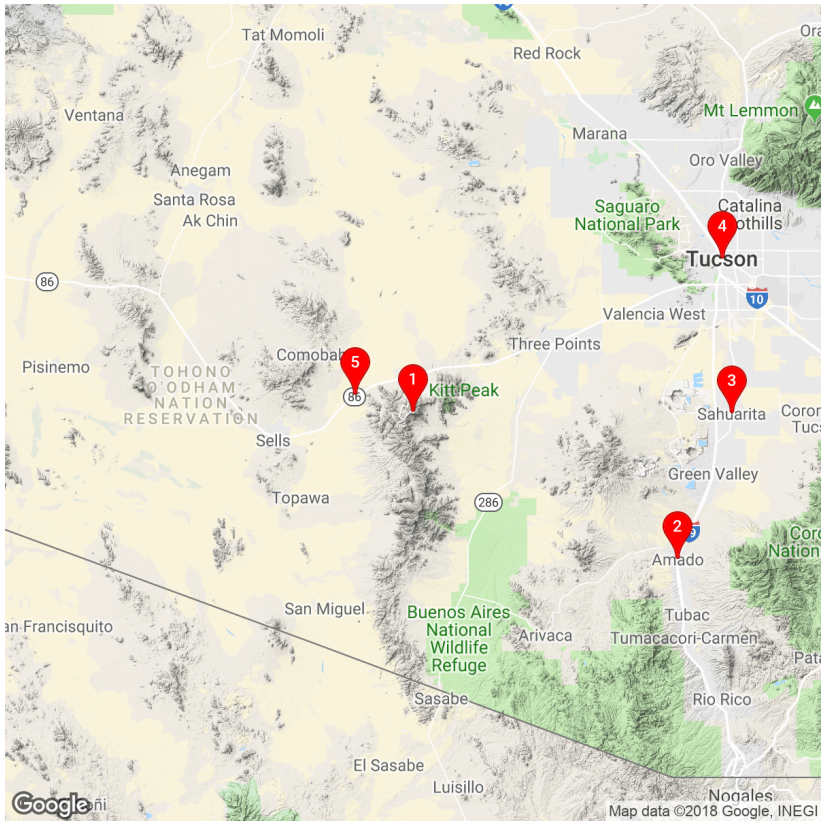
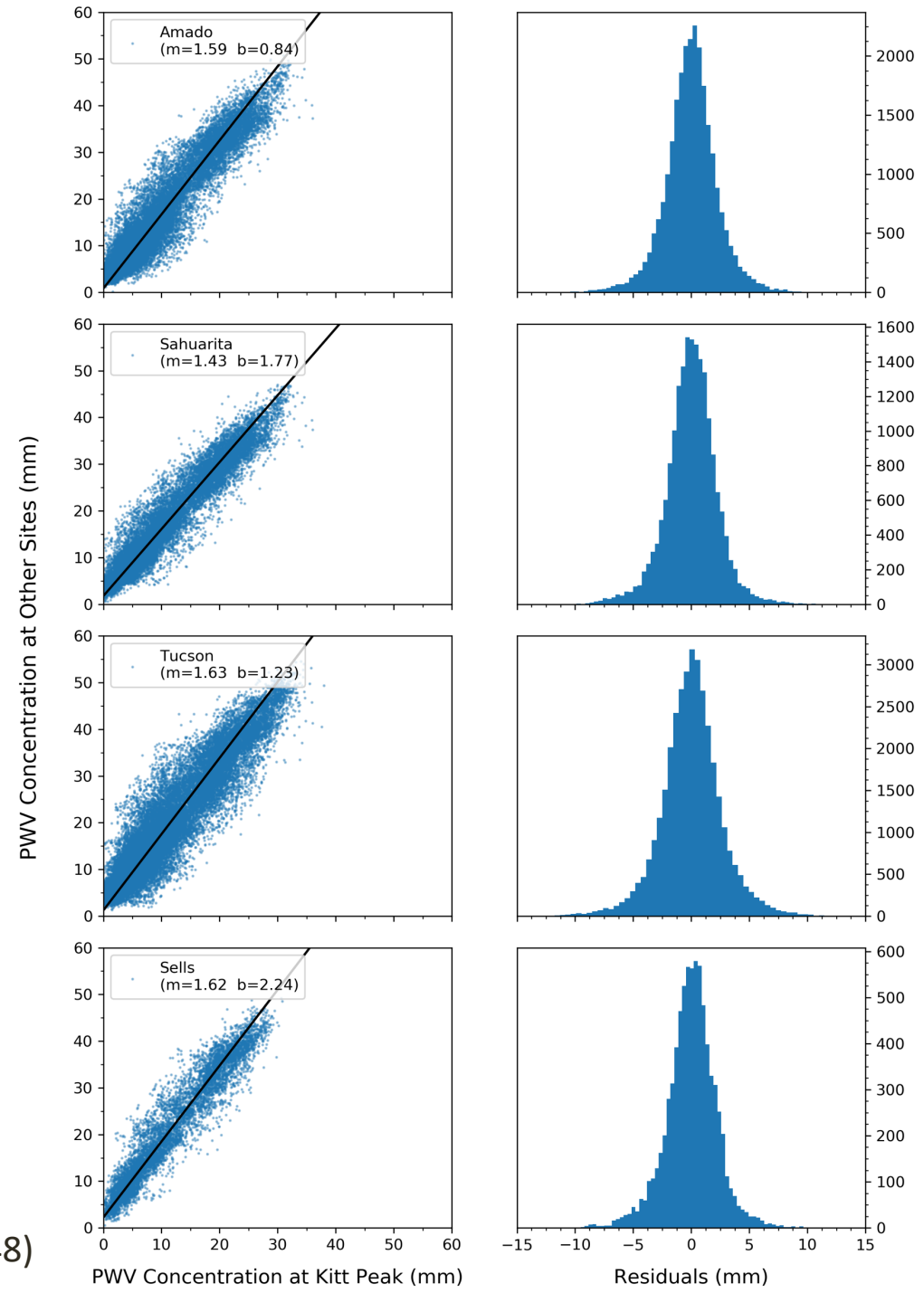
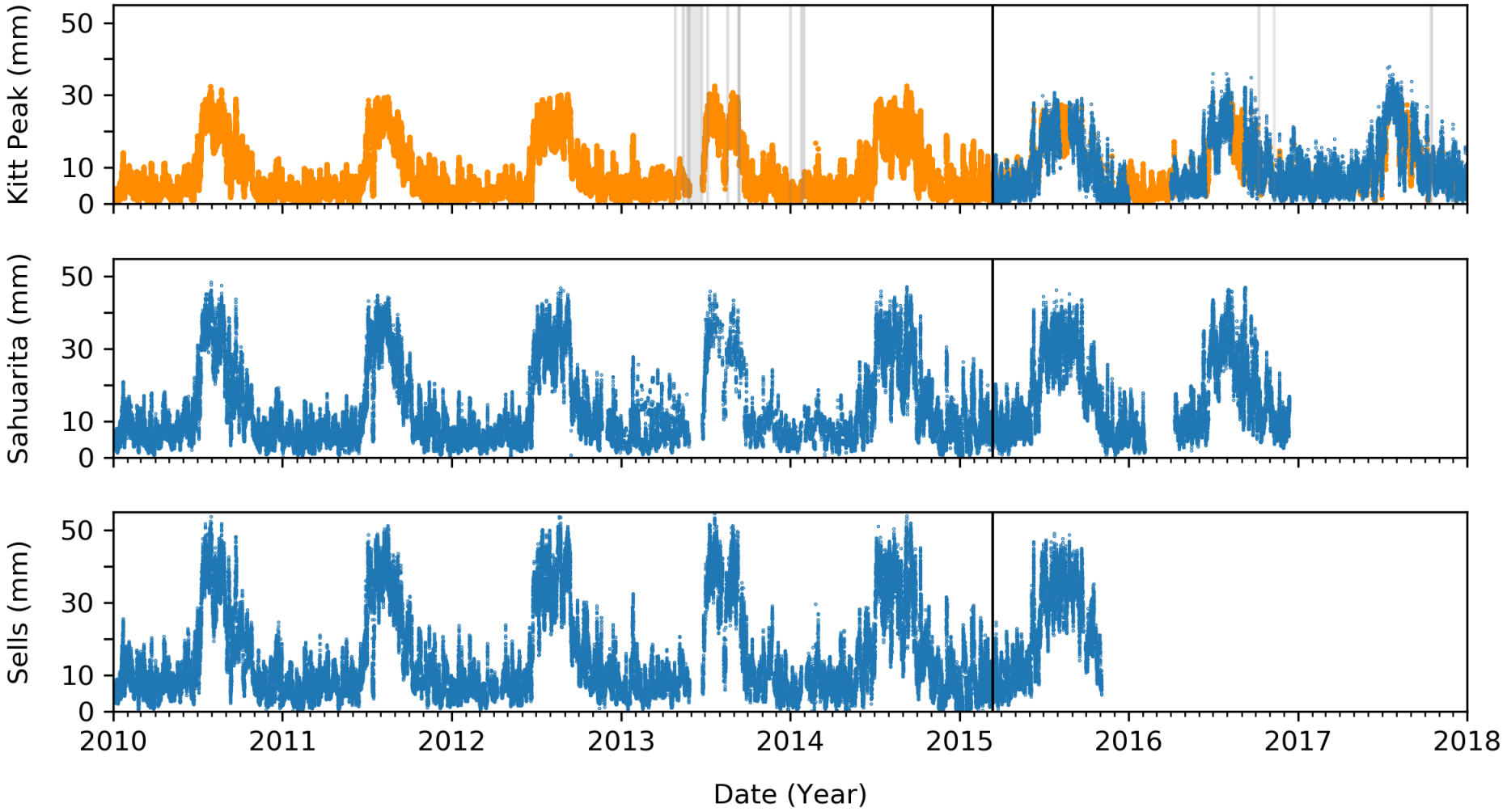



1. Kitt Peak National Observatory (KITT)
2. Amado Arizona (AZAM)
3. Sahuarita Arizona (P014)
4. University of Arizona (SA46)
5. Tohono O'odham Community College (SA48)

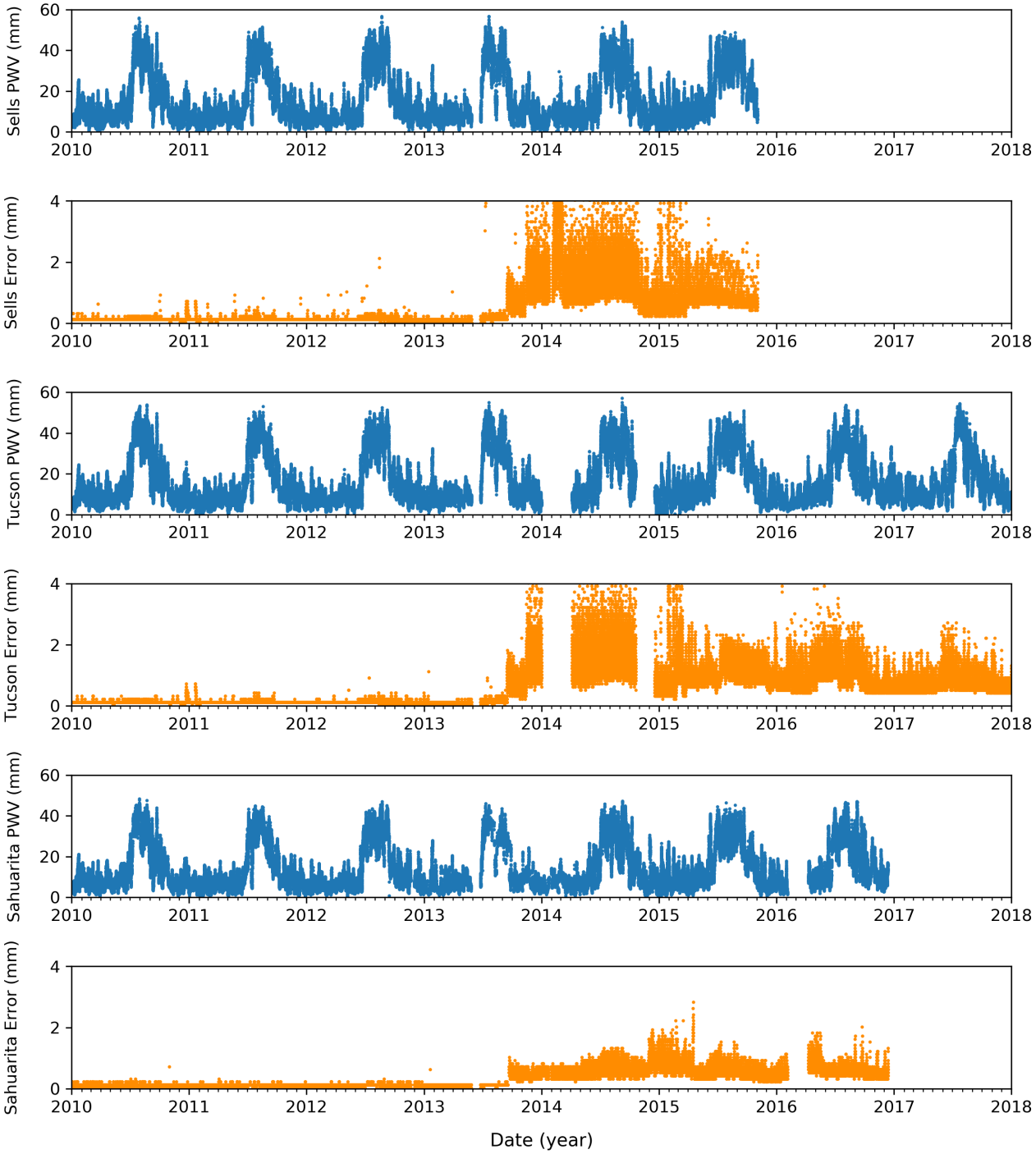




- Atmospheric Models for each site are averaged together
- Users can include as many or as few supplementary sites as desired
- No modeling for data gaps of 1 day or longer

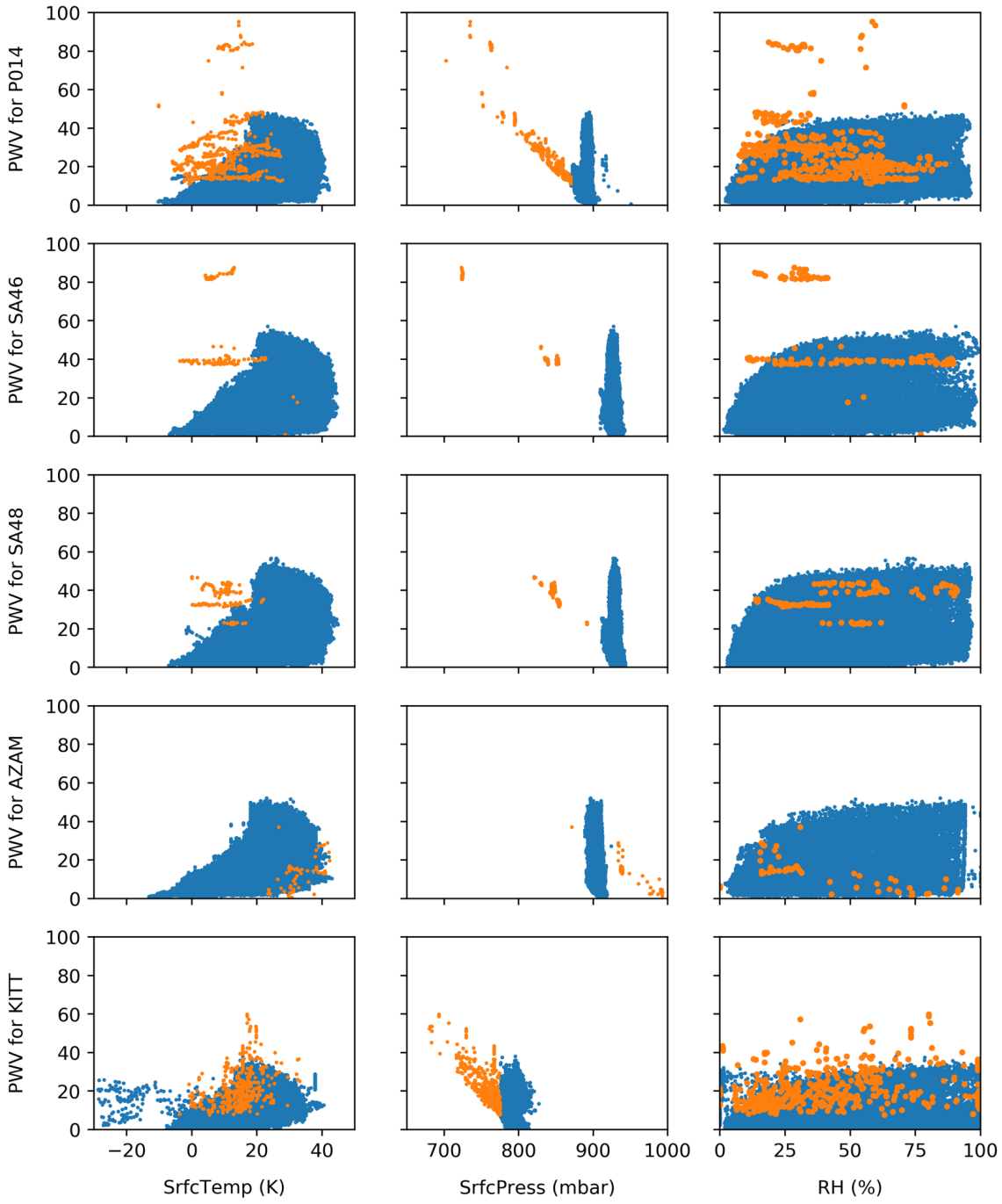
SuomiNet Data Isn't Perfect

- Rounding Error in public data
  - Add *0.025* to all reported errors
- Unidentified error increase in 2013
- Duplicate data records (uncommon)
  - Isolated to specific instance
  - Ignore disagreements, keep agreements
- Hourly data for Conus, but daily for international
- Subject to PWV spikes for hardware malfunctions



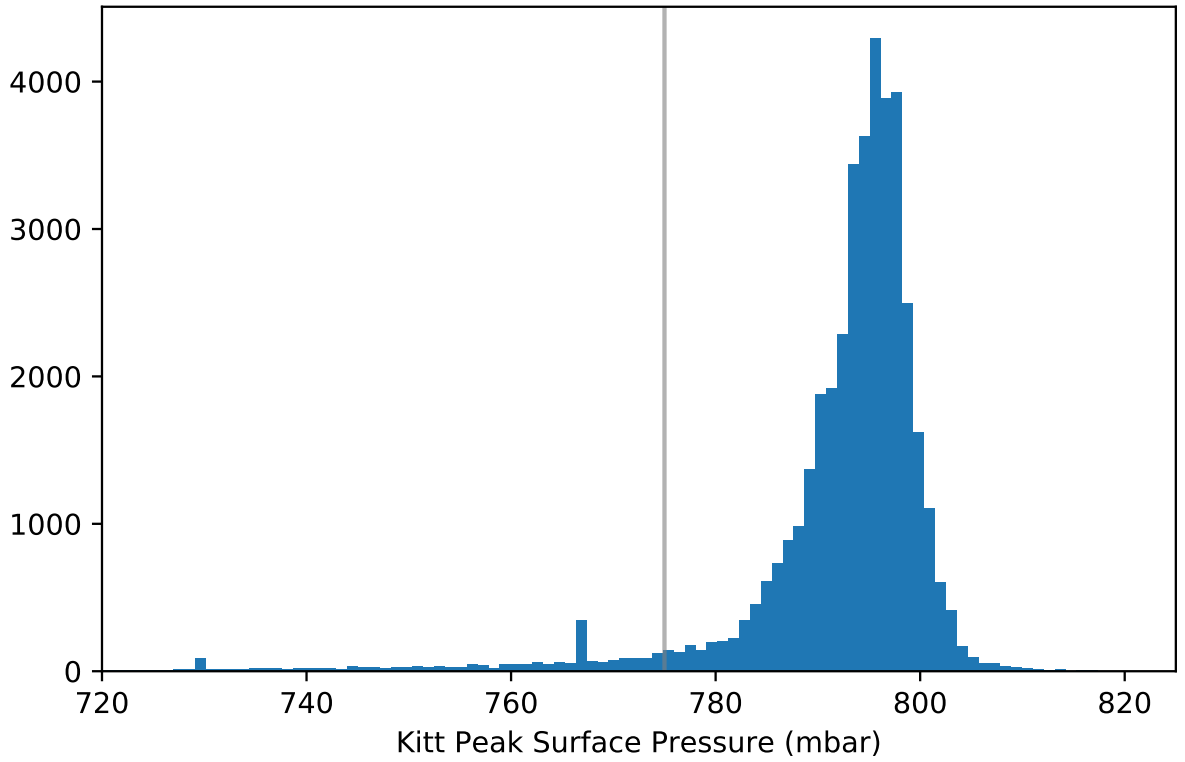
Unexplained error increase occurs across multiple sites

Likely a change in SuomiNet pipeline error propagation

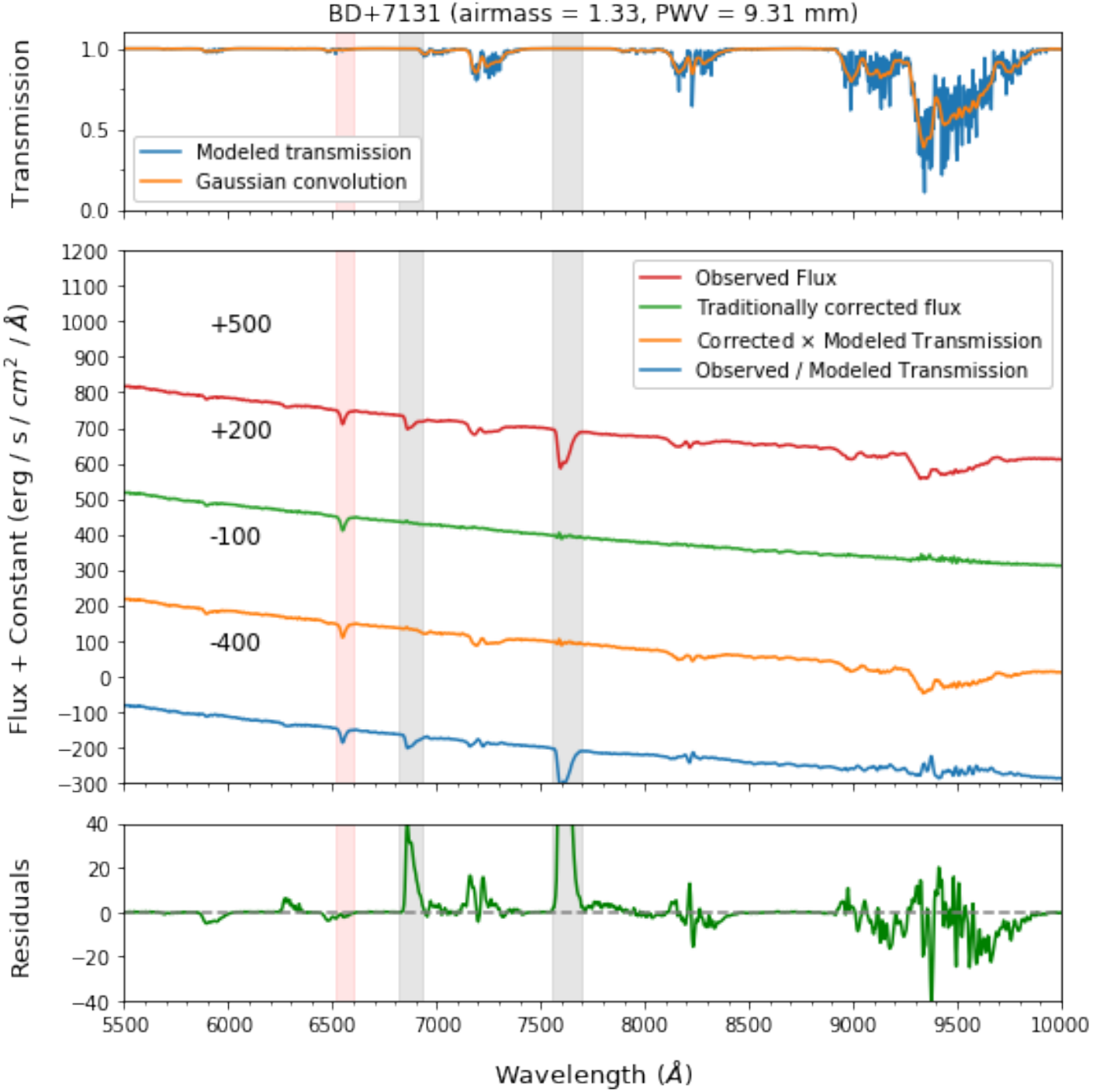


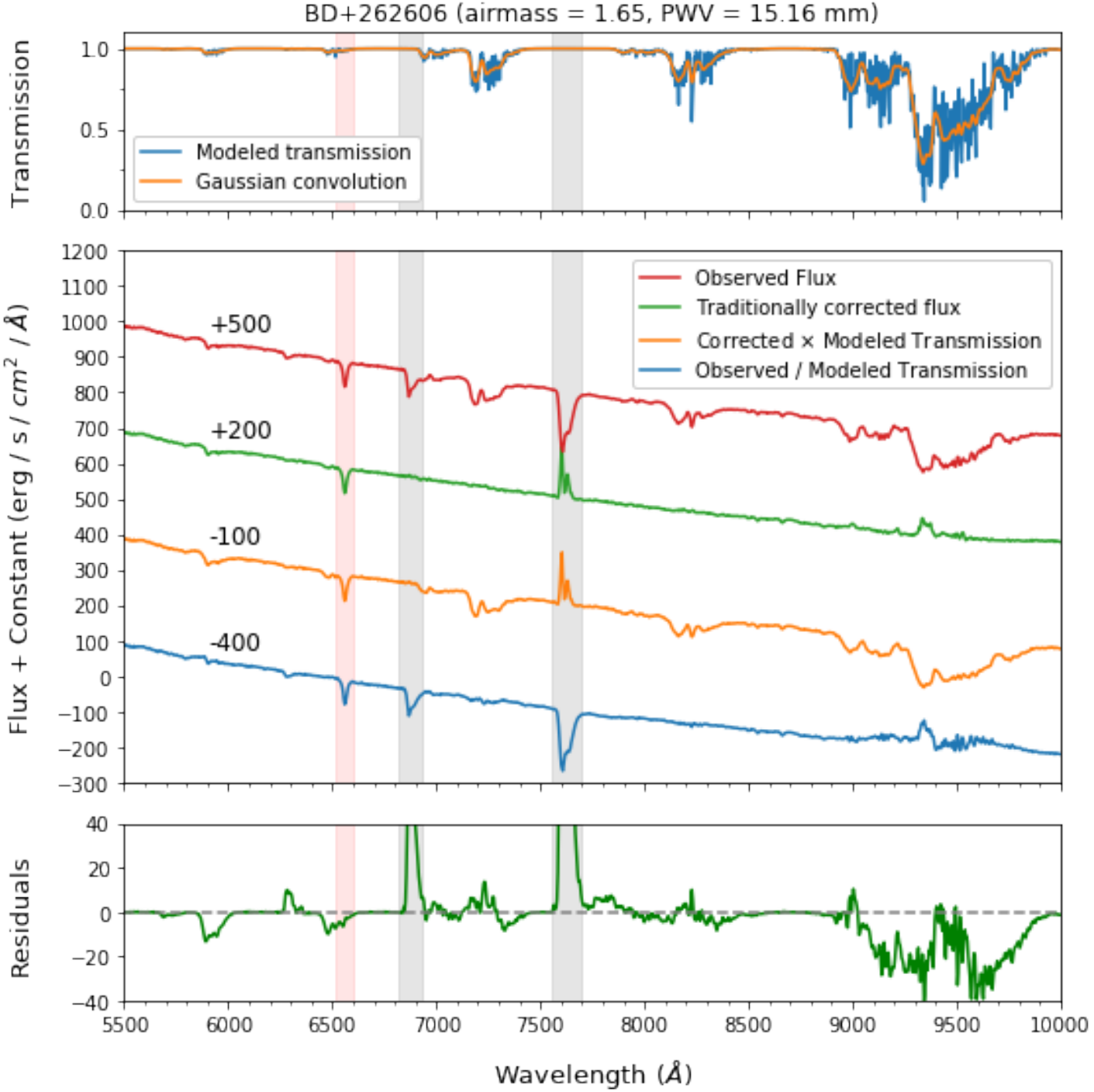
Available Parameters:

1. Date
2. PWV
3. PWV Error
4. Zenith Delay
5. Temperature
6. Pressure
7. Relative Humidity



Site Name	Receiver ID Code	Lower Pressure Cut	Upper Pressure Cut
Kitt Peak Az	KITT	775 mbar	1000 mbar
Amado Az	AZAM	880 mbar	925 mbar
Sahuarita AZ	P014	870 mbar	1000 mbar
Tuscon Az	SA46	900 mbar	1000 mbar
Sells Az	SA48	910 mbar	1000 mbar


BD+7131 (airmass = 1.33, PWV = 9.31 mm)
Transmission
Modeled transmission
Gaussian convolution
Flux + Constant (erg / s / cm² / Å)
Observed Flux
Traditionally corrected flux
Corrected × Modeled Transmission
Observed / Modeled Transmission
+500
+200
-100
-400
Residuals
Wavelength (Å)


BD+262606 (airmass = 1.65, PWV = 15.16 mm)
Transmission
Modeled transmission
Gaussian convolution
Flux + Constant (erg / s / cm^2 / Å)
Observed Flux
Traditionally corrected flux
Corrected × Modeled Transmission
Observed / Modeled Transmission
+500
+200
-100
-400
Residuals
Wavelength (Å)

Custom Site Modeling

```
>>> from pwv_kpno.package_settings import ConfigBuilder
>>>
>>> new_config = ConfigBuilder(
>>>     site_name='cerro_tololo',
>>>     primary_rec='CTIO',
>>>     sup_rec=[]
>>> )
>>>
>>> new_config.save_to_ecsv('./cerro_tololo.ecsv')
```

Includes options for:

1. Site name (Site ID)
2. Primary and supplemental receivers
3. H_2O cross sections
4. Data Cuts

Custom Site Modeling

```
>>> from pwv_kpno.package_settings import ConfigBuilder
>>>
>>> new_config = ConfigBuilder(
>>>     site_name='cerro_tololo',
>>>     primary_rec='CTIO',
>>>     sup_rec=[],
>>>     wavelength=custom_wavelengths, # Array of wavelengths in Angstroms
>>>     cross_section=custom_cross_sections # Array of cross sections in cm^2
>>> )
>>>
>>> new_config.save_to_ecsv('./cerro_tololo.ecsv')
```

Add your new site to the package:

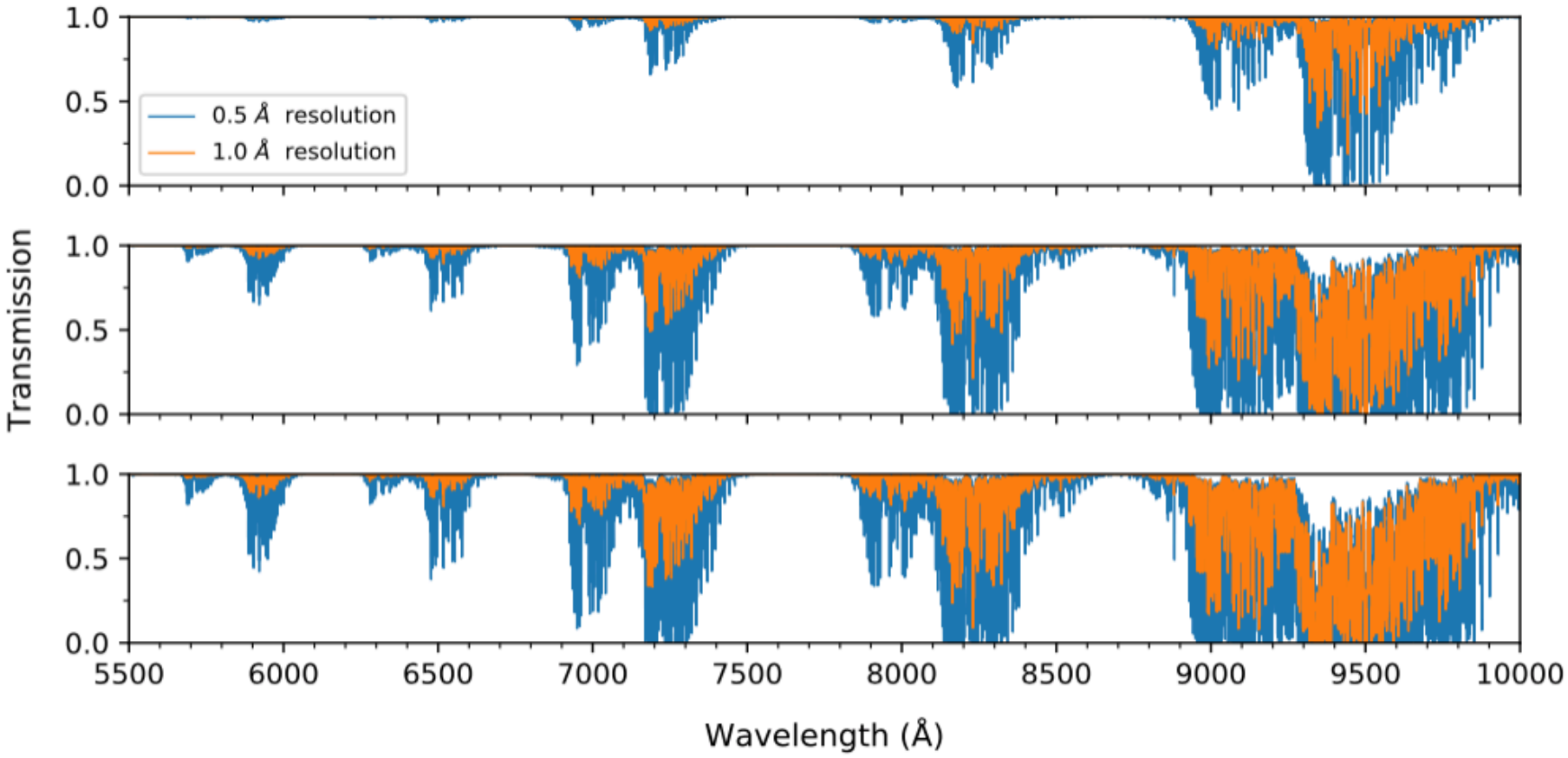
```
>>> from pwv_kpno.package_settings import settings
>>> settings.import_site_config('./cerro_tololo.ecsv')
```

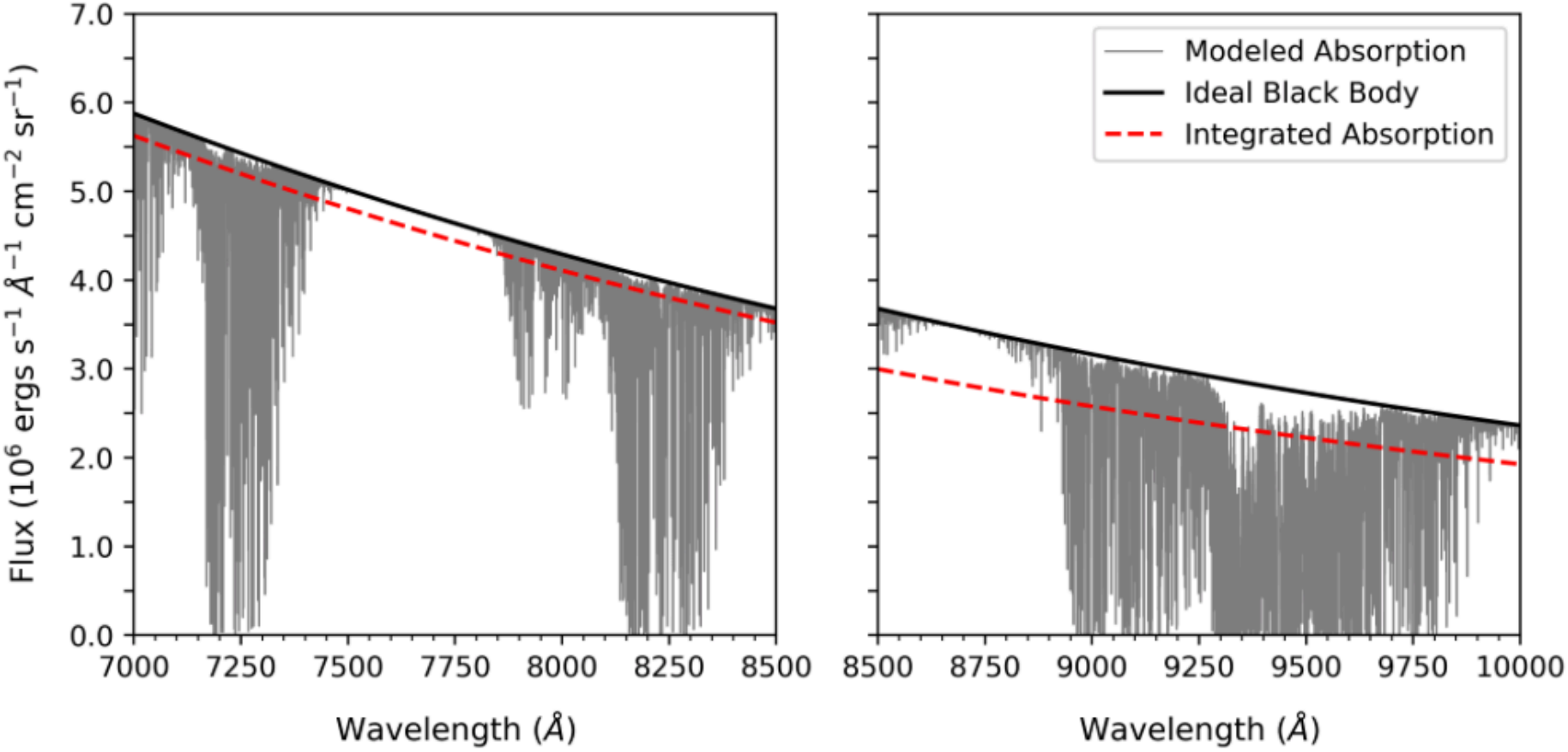
Easily switch between different sites:

```
>>> settings.set_site('cerro_tololo')
>>> print(settings.site_name)
```

Moving Forward

- Version 1.0 coming soon! (Public release ~1.5 weeks away)
- Improved modeling of PWV between sites
  - Machine learning favored over meteorological models
- Further investigation into effects of line saturation (>9,000 Å)
  - Fit EW of observations to compare PWV
- Additional validation on real world observations
- Fine tuning of airmass dependence


0.5 Å resolution
1.0 Å resolution
Transmission
1.0
0.5
0.0
5500
6000
6500
7000
7500
8000
8500
9000
9500
10000
Wavelength (Å)


Flux (10^6 ergs s^{-1} Å^{-1} cm^{-2} sr^{-1})
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
7000
7250
7500
7750
8000
8250
8500
Wavelength (Å)
8500
8750
9000
9250
9500
9750
10000
Wavelength (Å)
Modeled Absorption
Ideal Black Body
Integrated Absorption