# *TROPESS Atmospheric and Surface Temparature Level 2 Standard Data Product User Guide*

Authors: Kevin Bowman, John Worden, Robert Herman, Susan Kulawik, Ming Luo, Karen Cady-Pereira, Vivienne Payne, Kristal Whitten and Kristen Fahy

# 1 Table of Contents

# 1 Introduction

## 1.1 Overview and Document Scope

This document is the User Guide for the TROPESS AIRS and CrIS TATM and Tsur Level 2 Standard Product Files. This document is intended to be used with the README, which describes the variables included in the data products.

## 1.2 Dataset Description

This user guide describes the TROPESS AIRS and CrIS Level 2 Standard Product Files for atmospheric temperature (TATM) and surface temperature (Tsur).

Table 1. Dataset Description

| Product Information | Description |
|---|---|
| Parameters | TATM profile |
| Data Product Provenance | MUSES Version 1.11 |
| Approximate file size | 130MB |
| Spatial coverage | Regular collections have global coverage:<br>Nominal latitude range: 70 N to 50 S<br>Nominal longitude range: -180 to 180<br><br>Special collections: Spatial coverage varies by collection |
| Temporal coverage | Each L2 Standard file contains 1 day of data. |
| File format | netcdf |
| Vertical sensitivity | Estimates of atmospheric temperature typically have the greatest sensitivity between 825 hPa and 100 hPa, with significant sensitivity in the stratosphere. However, sensitivity depends on observed scene parameters such as thermal contrast and can be variable. Users should assess individual retrieval sensitivity using the averaging kernel (AK) for TATM profiles and degrees of freedom for signal (DOFS). |
| Data quality | The L2 Standard data products have undergone a pre-quality check, which involves checks for retrieval convergence and measurement sensitivity. There are no checks for clouds or land versus ocean as we do not find these to substantively affect the quality of the retrieval as long as the retrieval has converged. Note that retrievals over thick clouds will not be sensitive to TATM below the clouds. |
| Uncertainty | Profiles levels have approximately 0.5 K observational error (does not include vertical smoothing error). |
| Validation Stage | Stage 2 according to NASA guidelines<br>https://science.nasa.gov/earth-science/earth-science-data/data-maturity-levels |
| Retrieval Levels | 31 levels: from surface to top-of-atmosphere |
| Fill Values | -999 |

### 1.3 Filename

The Level 2 Standard Products adhere to the following filename convention:

```
[TROPESS]_
[Instrument-Platform]_[ProductLevel]_[ProductType]_[ProductName]_[DateSt
amp]_[AlgorithmName]_[AlgorithmVersion]_[ProcessingStrategy]_[FormatVers
ion].nc
```

**Example:**

```
TROPESS_CrIS-SNPP_L2_Standard_TATM_20200912_MUSES_R1p10_FS_F01.nc
```

# *2* Product File Contents and Parameter Description

### 2.1 Variables included in the L2 Standard Product

Please see the README for a list of variables included in the L2 Standard Product Files

# 3 References

**Citing these data**
The following references were also used in the development of this documentation and should be cited for model/data comparisons.


Bowman, K.W.; Rodgers, C.D.; Kulawik, S.S.; Worden, J.; Sarkissian, E.; Osterman, G.; Steck, T.; Lou, M.; Eldering, A.; Shephard, M.; Worden, H.; Lampel, M.; Clough, S.; Brown, P.; Rinsland, C.; Gunson, M.; Beer, R., Tropospheric Emission Spectrometer: Retrieval Method and Error Analysis, **IEEE Trans. Geosci. Remote Sensing**, **44**, 1297- 1307, May 2006.

Rodgers, C. D., and B. J. Connor (2003), Intercomparisons of remote sounding instruments, ***J. Geophys. Res***., **108**(D3), 4116, doi:10.1029/2002JD002299

Worden, H. M. et al., Predicted errors of tropospheric emission spectrometer nadir retrievals from spectral window selection, ***J. Geophys. Res.***, 109, D09308, doi:10.1029/2004JD004522, 2004.

Worden, J., Kulawik, S., Frankenberg, C., Payne, V., Bowman, K., Cady-Pereira, K., Wecht, K., Lee, J.-E., and Noone, D.: Profiles of $CH_4$ , HDO, $H_2O$, and $N_2O$ with improved lower tropospheric vertical resolution from Aura TES radiances, **Atmos. Meas. Tech.**, **5**, 397–411, https://doi.org/10.5194/amt-5- 397-2012, 2012.

# 4. Extended User Guide: L2 Standard Product

This extended user guide shows how to compare these fields to aircraft or model fields and calculate uncertainties.

*How to Compare TROPESS TATM profiles to aircraft or model fields*
All comparisons between remotely sensed data an *in situ* measurements or high resolution model fields must account for the sensitivity of the remotely sensed measurement and any regularization used with the remotely sensed measurements. Otherwise *large* errors will be incurred with the comparisons.

The validation technique of comparing retrievals of TATM from satellites to radiosondes has been demonstrated many times. For TATM, the observation operator is linear with x and xa. This is in contrast to species volume mixing ratio (VMR) for chemical species retrieval, which performs the observation operator on log(VMR). We first construct an observation operator that is used for comparison of the TROPESS TATM data to models or vertical profile measurements such as from aircraft:

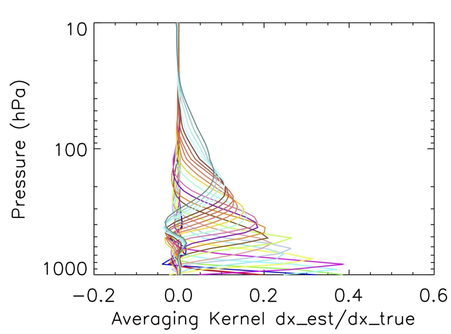
1) Calculate the TATM profile using the model or radiosonde fields (for the purpose of this demonstration we will call this $\boldsymbol{x}\_{true}$).
2) Construct the operation operator as the following :
$$H(\cdot) = x_a + A((\cdot) - (x_a))$$
3) Apply observation operator to the TATM profile:
$$\hat{x} = H(x_{true})$$

In the netcdf product file and in the equation $x_a$ is the constraint vector used to regularize the retrieval. The $H(\cdot)$ is the observation operator, where the $(\cdot)$ represents the model or *in situ* profile. A is the Averaging kernel matrix and must be matrix multiplied by $(x_{true}) - (xa)$**.**

After this operation one can compare the modified TATM profile ($\hat{x}$**)** to the retrieved "x" variable in the netcdf product file. Note that the averaging kernel matrix (**A**) is not symmetric so getting the row/column order of A correct is critical. You can check your work by using the above equation with the zeroth entries for the averaging kernel, $x_a$ and using the zero$^{th}$ entry for x as $x_{true}$. If your
test operation (steps 1-3) matches the variable x_test then the operation is correct.

Figure 1 shows an example of the averaging kernel rows for an AIRS TATM retrieval over a typical scene.

***Figure 1. Averaging Kernel (A) rows in the troposphere for a cloud-free AIRS TATM TROPESS retrieval. Colors indicate the pressure level corresponding to each row.***



### 4.1 Calculation of the Degrees of Freedom for Signal (DOFS)

The DOFS is the number of independent pieces of information that can be resolved and is therefore a useful diagnostic of the retrieval. The Averaging kernel matrix (see previous section) is the sensitivity of the estimate to the true state. The DOFS is defined as the trace of the averaging kernel matrix. To determine if the estimate is sensitive to a particular altitude a good place to check is the DOFS. The expected range of DOFS varies by species. For good retrievals of TATM the total DOFS is typically between 6 and 8.

A value of zero means no sensitivity to the retrieved profile. The typical range of DOFS for thermal infrared (TIR) spectral TATM observations over cloud free ocean is 6 to 8, (except in polar regions).

### 4.2 Error Derivation Used for Process Studies and Model or Aircraft Comparisons

Errors are calculated based on the derivation in Bowman *et al*. (2006). The TROPESS AIRS product files provide the averaging kernel (or AK) **A** in order to compare the TATM estimates with either aircraft data or models or some other constructed profile.

The uncertainties can be calculated by taking the expectation of the difference between the estimate and the true state.

$$E(\hat{x} - \underline{x})((\hat{x} - \underline{x})^{T} = \left(I - A\right)S_{a}\left(I - A\right)^{T} + S^{meas} + S^{int}$$

The first term represents the smoothing error and covariances, $S^{obs} = S^{meas} + S^{int}$ are provided with the TROPESS product files. The smoothing error terms are not needed for comparisons since aircraft or model profiles are smoothed by the averaging kernel before comparing. The product files provide the following error diagnostic terms:

$\boldsymbol{A}$ = AVG_KERNEL
$S^{obs}$ = OBS_ERROR

# *5* Validation Summary

Based on the NASA Validation criteria listed subsequently, we list the validation level of the TROPESS L2 TATM product as Level 1. TATM accuracy has been validated by comparison with radiosondes. Figure 2 below shows the difference between AIRS TATM profile and radiosonde in situ temperatures with the observation operator (averaging kernels) applied. It is seen that AIRS TATM has a mean bias within +/- 1 K throughout the troposphere.

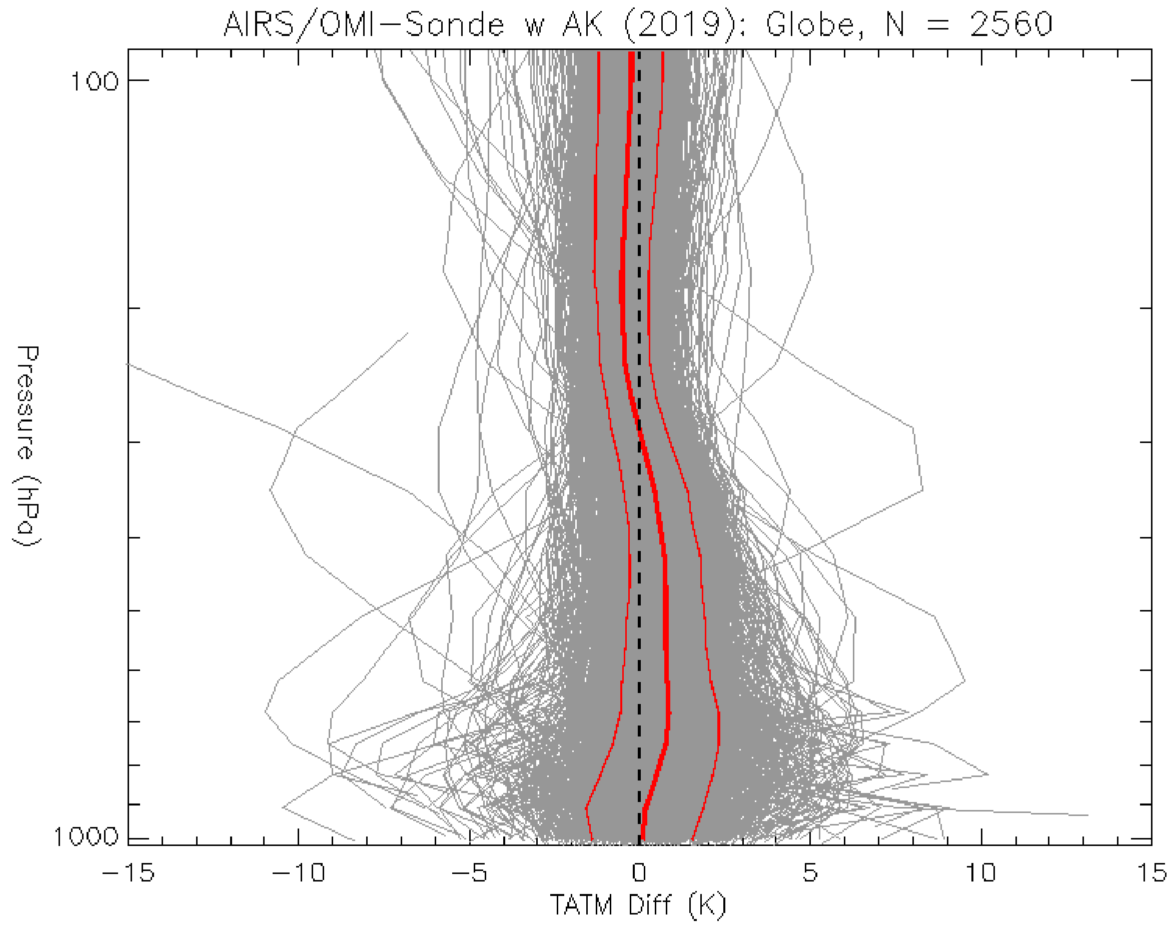



**Figure 2.** AIRS-Only TATM minus radiosonde temperature with averaging kernel applied for 2560 global matches within 50 km and +1.5 / -0.5 hours. Also shown are mean difference (thick red line) and mean+/-rms (thin red lines).

## Appendix A. Retrieval levels

The table below contains the nominal retrieval levels. For each sounding, the surface pressure level is inserted into the retrieval levels set. Any retrieval levels below the surface pressure level are omitted.

| Index | Pressure [hPa] |
|---|---|
| 1 | 1040.0000 |
| 2 | 1000.0000 |
| 3 | 908.5140 |
| 4 | 825.4020 |
| 5 | 749.8930 |
| 6 | 681.2910 |
| 7 | 618.9660 |
| 8 | 510.8980 |

| | |
|---|---|
| 9 | 421.6980 |
| 10 | 348.0690 |
| 11 | 287.2980 |
| 12 | 237.1370 |
| 13 | 177.8290 |
| 14 | 133.3520 |
| 15 | 100.0000 |
| 16 | 74.9896 |
| 17 | 56.2339 |
| 18 | 42.1696 |
| 19 | 31.6229 |
| 20 | 23.7136 |
| 21 | 17.7828 |
| 22 | 13.3352 |
| 23 | 10.0000 |
| 24 | 8.2540 |
| 25 | 6.8129 |
| 26 | 5.1090 |
| 27 | 2.6102 |
| 28 | 1.6156 |
| 29 | 1.0000 |
| 30 | 0.3831 |
| 31 | 0.1000 |

## Acknowledgement

The research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.