Characteristics and long term trends in tropopause parameters obtained from US high resolution rawinsonde data

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Introduction

Tropopause is the boundary between troposphere and stratosphere. It acts as a lid restricting the stratosphere troposphere exchange processes.

Tropopause Definitions!

- ❖ Thermal Tropopause (WMO)

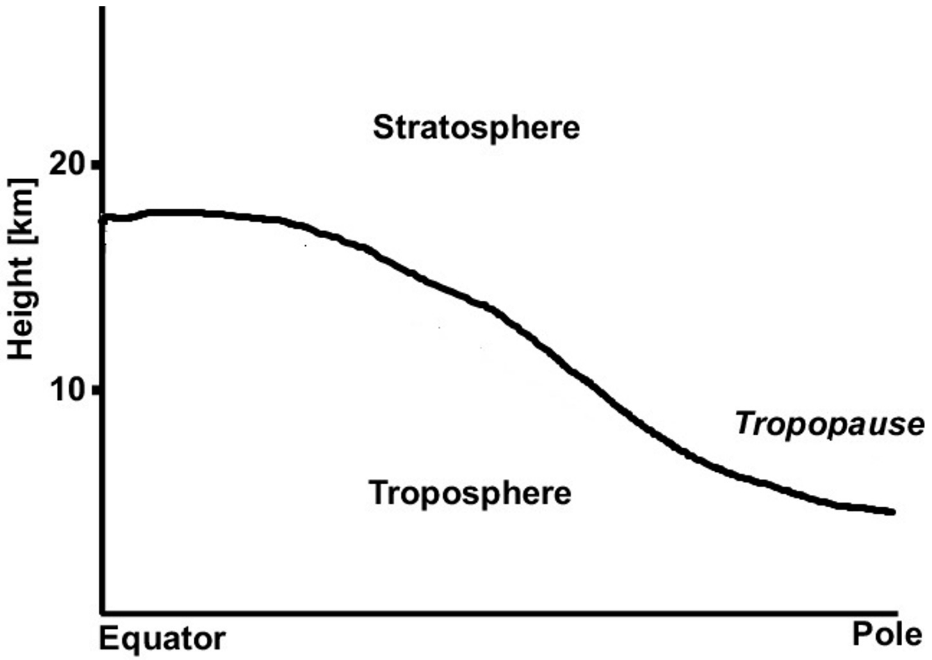
Tropopause based on thermal lapse rate.

- ❖ Dynamical Tropopause

Tropopause based on potential vorticity.

- ❖ Cold Point Tropopause

Tropopause based on minimum temperature altitude.



Why to study tropopause?

- Tropopause is a natural limit between the troposphere and the stably stratified stratosphere.
- Tropopause acts as a barrier that suppresses the stratosphere-troposphere exchanges (STE).
- Understanding of STE is dependent on the ability to quantify tropopause structure and variability.
- Also tropopause is located in a minimum temperature region, making the altitude a robust indicator of climate change as it is sensitive to the concentrations of radiatively active species in the upper troposphere lower stratosphere(UTLS) region.
- Long term trends in tropopause altitude is also an indicator of climate change.

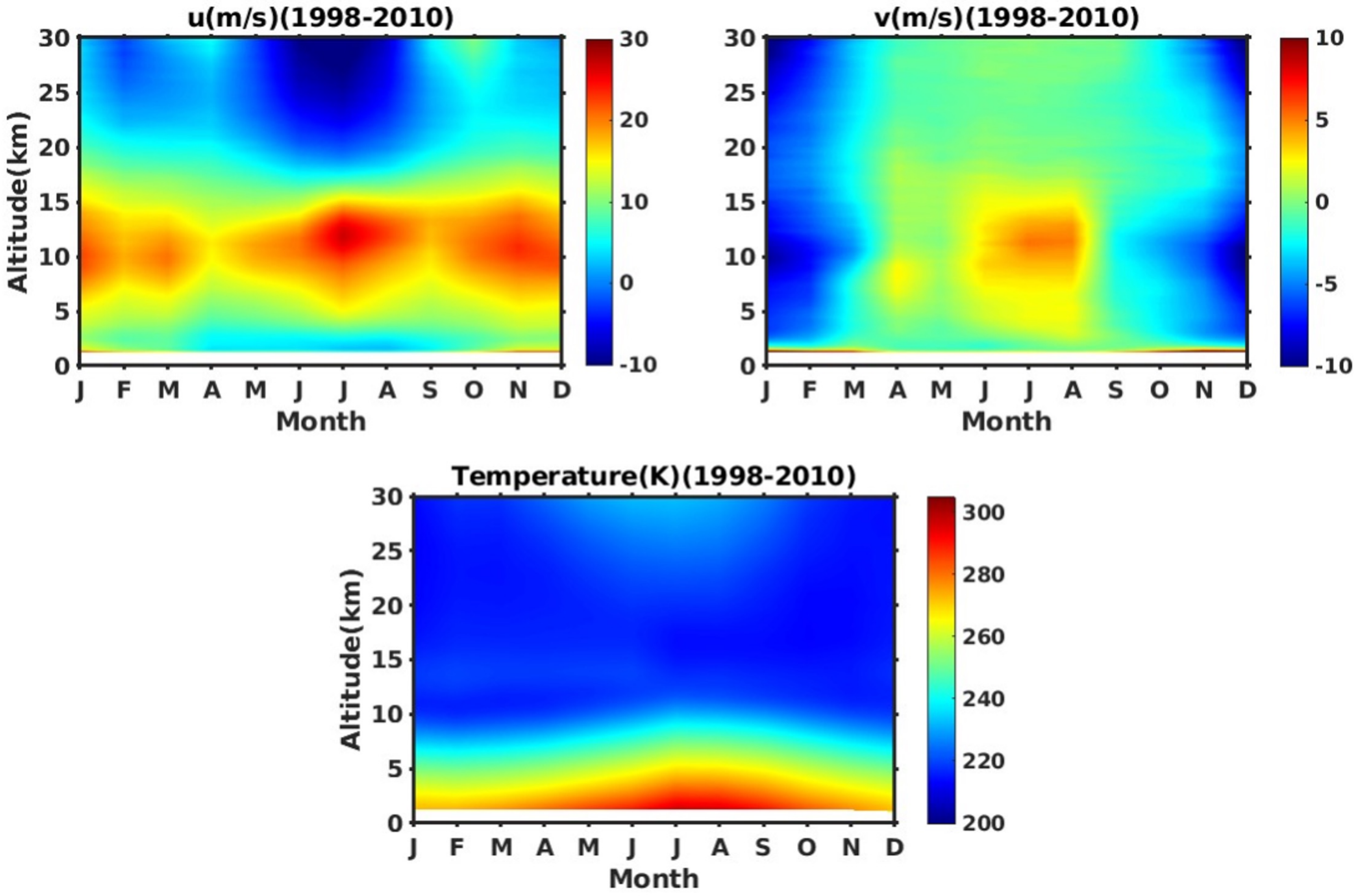
Objectives

- ❖ Study the latitudinal variations of tropopause altitude and temperature using high resolution radiosonde data.
- ❖ Compare the tropopause altitude with an existing empirical model.
- ❖ Analysing the long term trends in tropopause parameters with a multivariate linear regression model using proxy data from open sources.

Data used for the present study

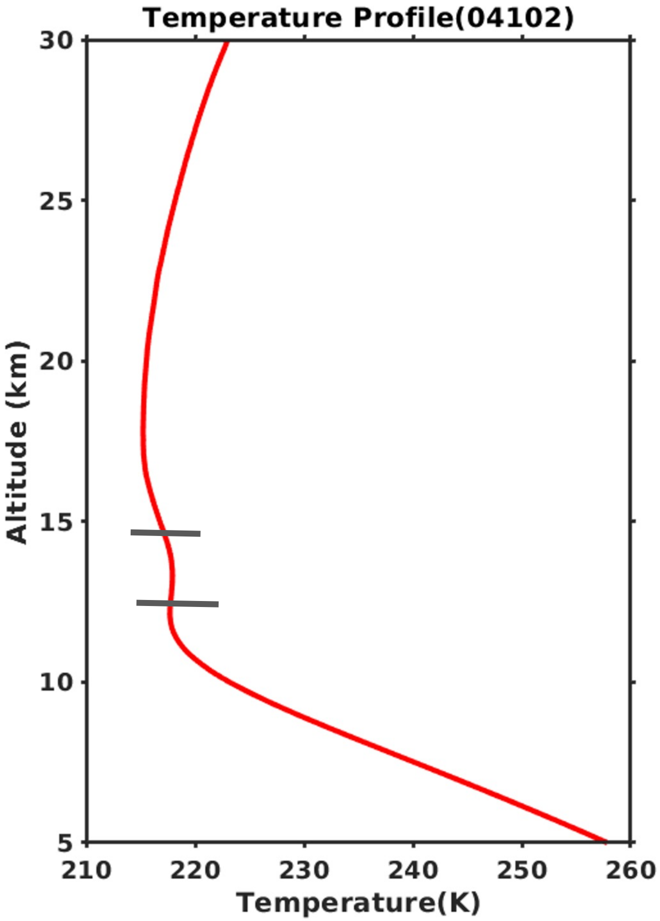
- ❖ US high resolution rawinsonde 6-second data have been downloaded from https://www.sparc-climate.org/data-centre/data-access/us-radiosonde/
- ❖ Upper-air observations are usually made twice daily at 00 UTC and 12 UTC hours and archived as TD6211.
- ❖ The station network consists of 96 observing sites from which 66 stations with more than 85% data points have been selected.

Background atmosphere (04102,Great Falls, MT)

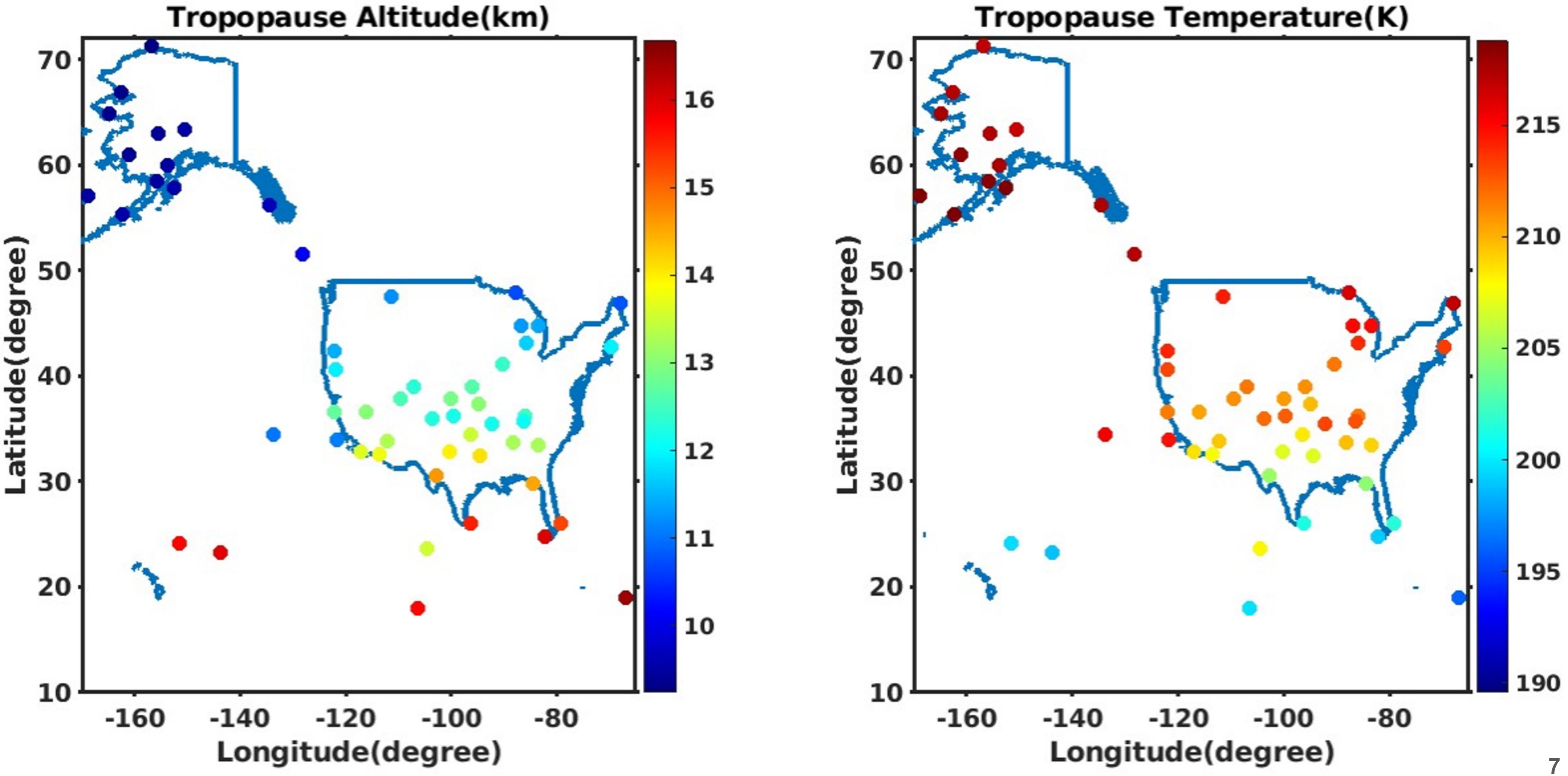


Methodology used to find tropopause altitude and temperature

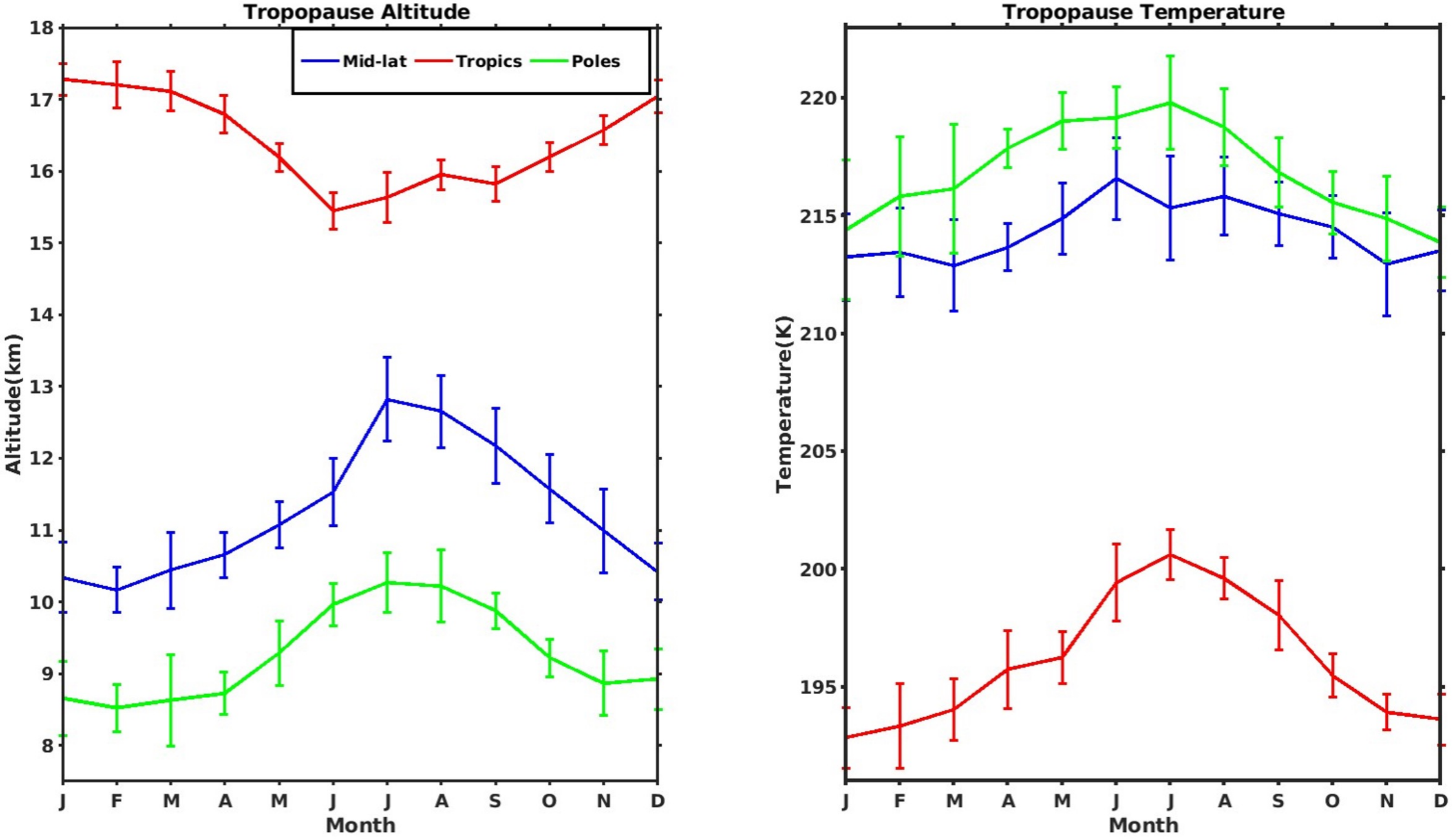
- Raw data is interpolated to 150m height interval.
- Applied 3σ rule to discard the outliers.
- Calculated the lapse rate (LR) for altitude range 7 to 22 km and lowest level with LR less than 2 K/km is identified as tropopause if the condition is satisfied for the next 2 km.
- If the LR exceeds 3 K/km within 1 km of the first tropopause,a second tropopause is identified satisfying the above condition.
- The tropopause temperatures are also identified from the data.



Mean tropopause altitude and temperature

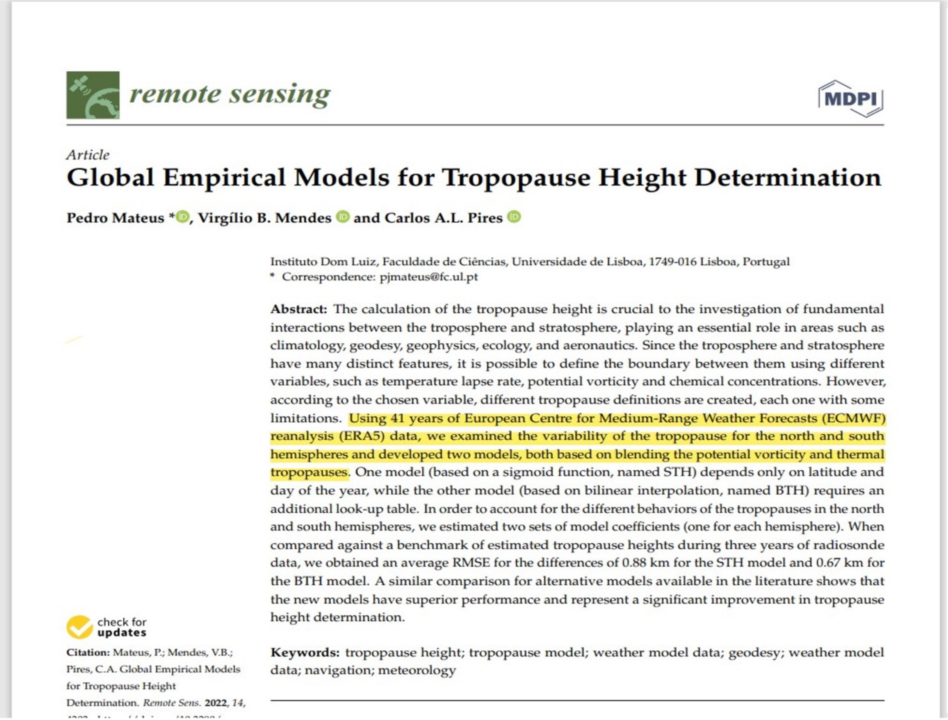


Monthly tropopause altitude and temperature(1998-2012)



Monthly and latitudinal variations of tropopause altitude and temperature.

Comparison with empirical model



remote sensing
MDPI

Article

Global Empirical Models for Tropopause Height Determination

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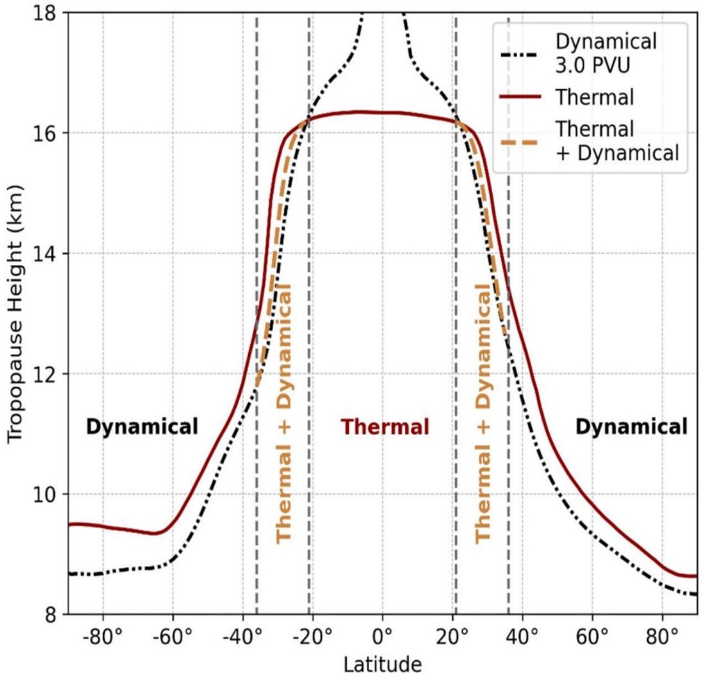
Abstract: The calculation of the tropopause height is crucial to the investigation of fundamental interactions between the troposphere and stratosphere, playing an essential role in areas such as climatology, geodesy, geophysics, ecology, and aeronautics. Since the troposphere and stratosphere have many distinct features, it is possible to define the boundary between them using different variables, such as temperature lapse rate, potential vorticity and chemical concentrations. However, according to the chosen variable, different tropopause definitions are created, each one with some limitations. Using 41 years of European Centre for Medium-Range Weather Forecasts (ECMWF) reanalysis (ERA5) data, we examined the variability of the tropopause for the north and south hemispheres and developed two models, both based on blending the potential vorticity and thermal tropopauses. One model (based on a sigmoid function, named STH) depends only on latitude and day of the year, while the other model (based on bilinear interpolation, named BTH) requires an additional look-up table. In order to account for the different behaviors of the tropopauses in the north and south hemispheres, we estimated two sets of model coefficients (one for each hemisphere). When compared against a benchmark of estimated tropopause heights during three years of radiosonde data, we obtained an average RMSE for the differences of 0.88 km for the STH model and 0.67 km for the BTH model. A similar comparison for alternative models available in the literature shows that the new models have superior performance and represent a significant improvement in tropopause height determination.

Keywords: tropopause height; tropopause model; weather model data; geodesy; weather model data; navigation; meteorology

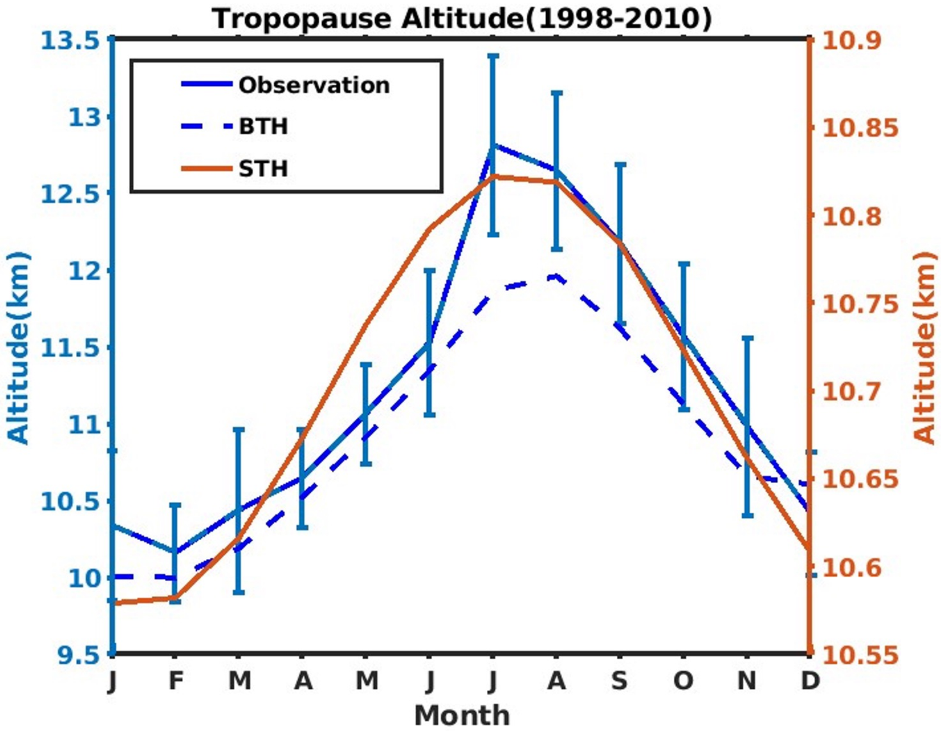
Citation: Mateus, P.; Mendes, V.B.; Pires, C.A. Global Empirical Models for Tropopause Height Determination. *Remote Sens.* **2022**, *14*,



Calculating tropopause altitude with two models based on blending potential vorticity and thermal tropopause, Mateus et al,2022.

Model equation

$$f(\varphi, doy) = a_0 + \frac{a_1}{\left(1 + exp\left(-\frac{\varphi - a_2}{a_3}\right)\right)^{a_4}} + a_5 . \cos\left(\frac{2\pi(doy - 28)}{365.25}\right)$$

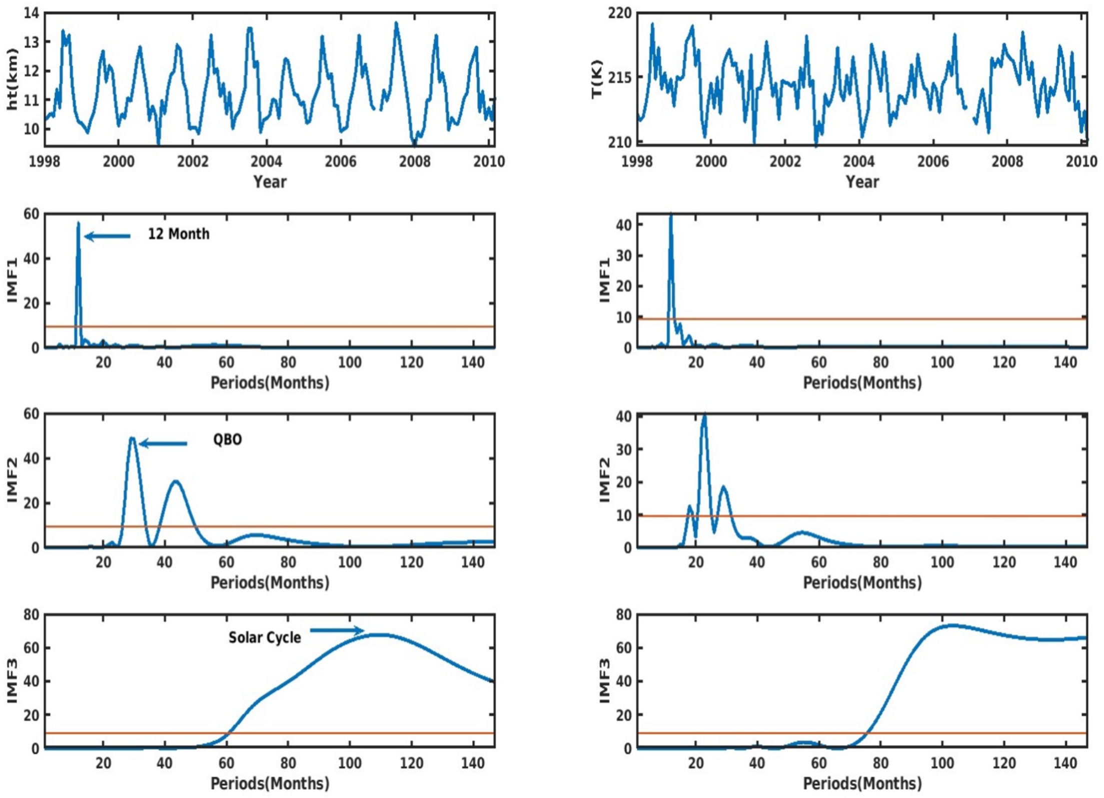


Seasonal term

Mateus et al, 2022

Models and Observation show a similar monthly variation.

Multivariate Linear Regression



$$T(t,z)=\alpha(z) + \beta(z)t + \Upsilon(z)\mathrm{Solar}(t) + \delta(z)\mathrm{QBO}(t) + \mathrm{resid}(t)$$

Where α , β , Υ , δ are calculated as

$$\alpha(z) = A_o + \sum_{i=1}^{3}[A_i \times \cos\omega_i t + B_i \times \sin\omega_i t]$$

where $\omega_i = 2\pi i/12$.

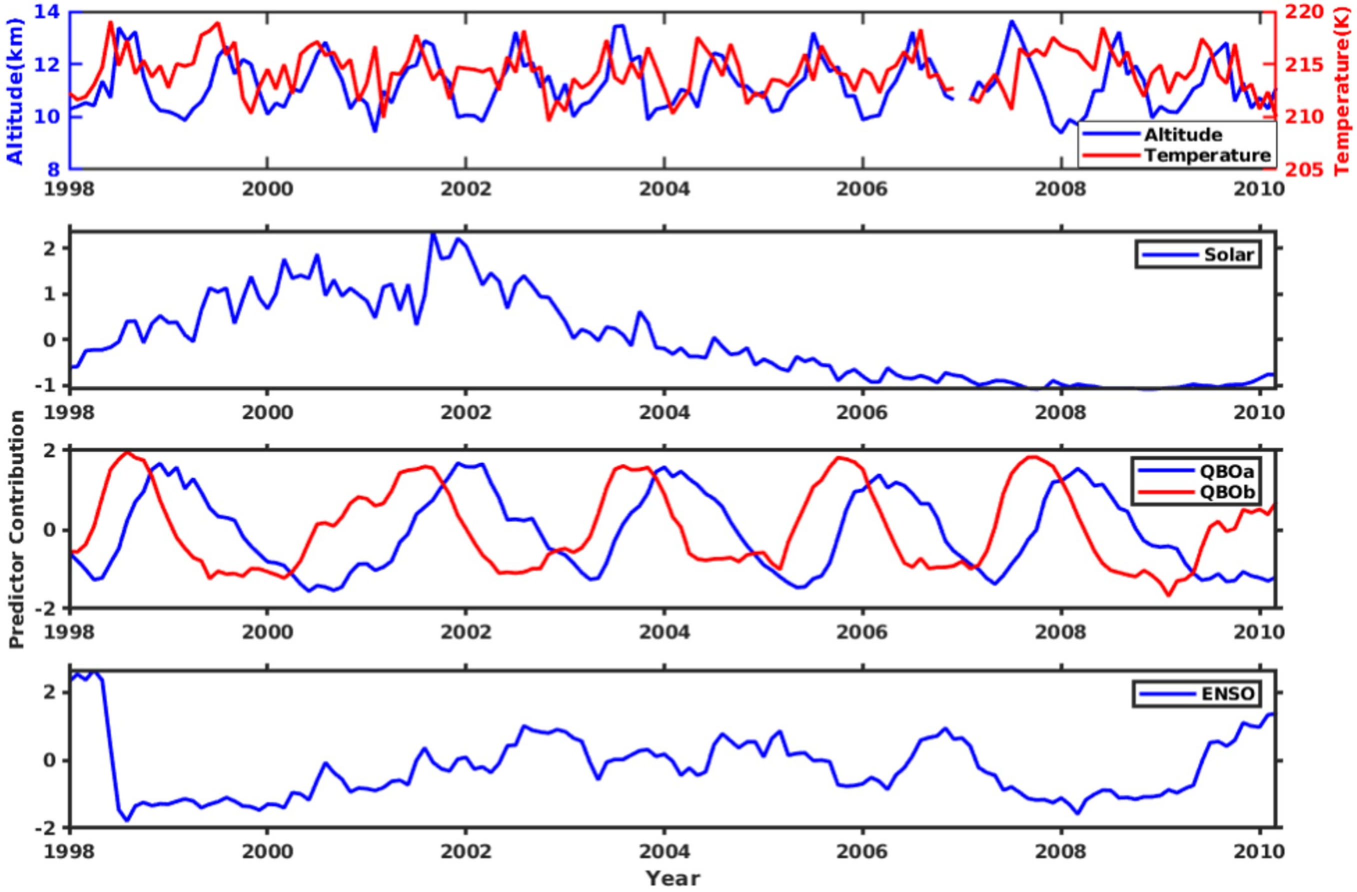
Error estimate

$$\sigma = \sqrt{\frac{S}{N-M}(X^T X)^{-1}}$$

S is the sum of squares of residuals, N is the length of data, and M is the total number of regression constants (N > M)

Randell and Cobb,1994

Predictors contribution



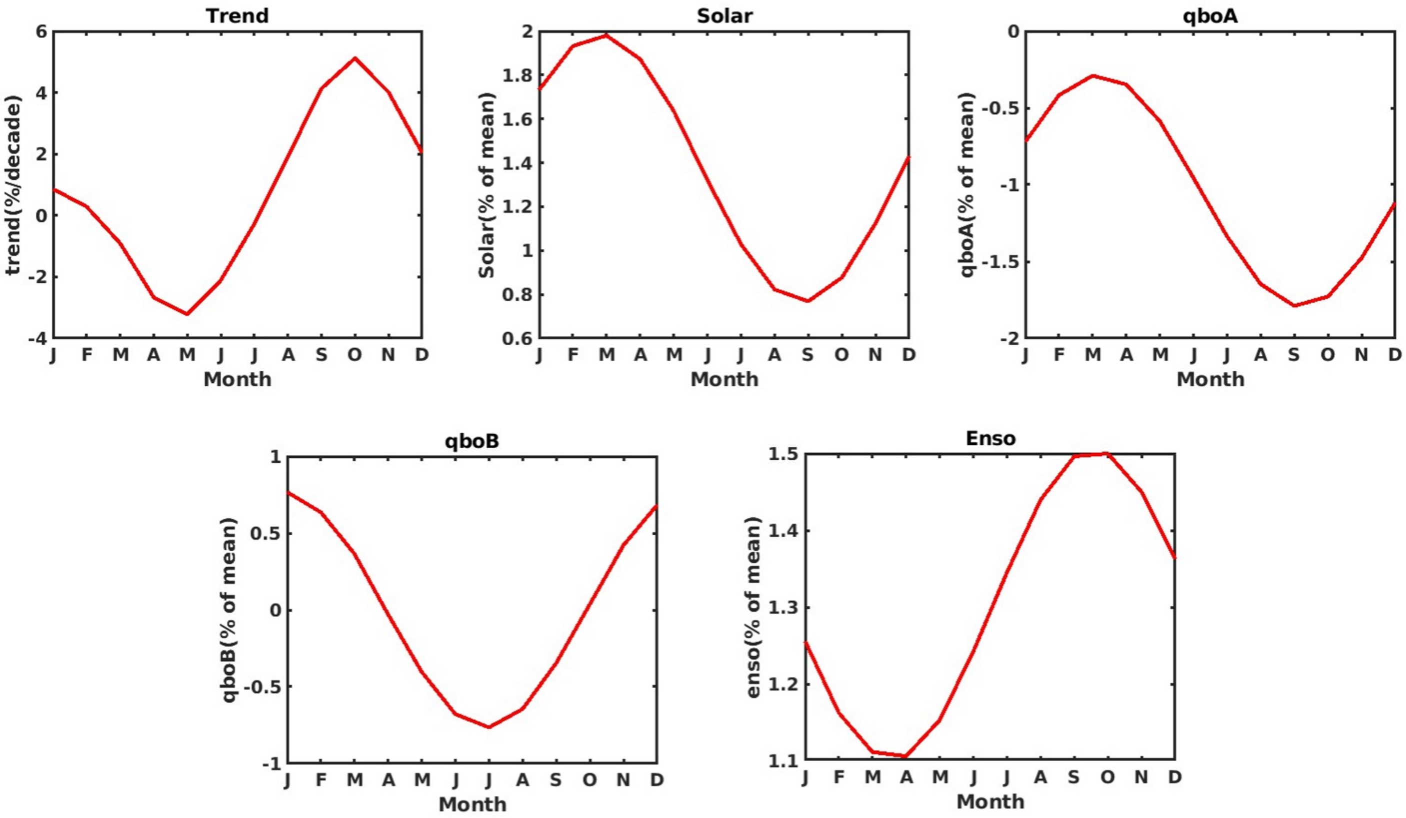
Correlation between the predictors

	ENSO	SOLAR	QBOA	QBOB	AOD
ENSO	1	0.04	0.12	-0.02	0.37
SOLAR	0.04	1	-0.04	0.06	0.12
QBOA	0.1084	-0.04	1	0.002	0.04
QBOB	-0.02	0.06	0.0025	1	0.09
AOD	0.37	0.12	0.04	0.09	1

Significance has been tested with p value of 0.05

AOD has significant correlation with most of the predictors and thus is not a good choice of predictor.

Trend in tropopause altitude (Station code-04102)



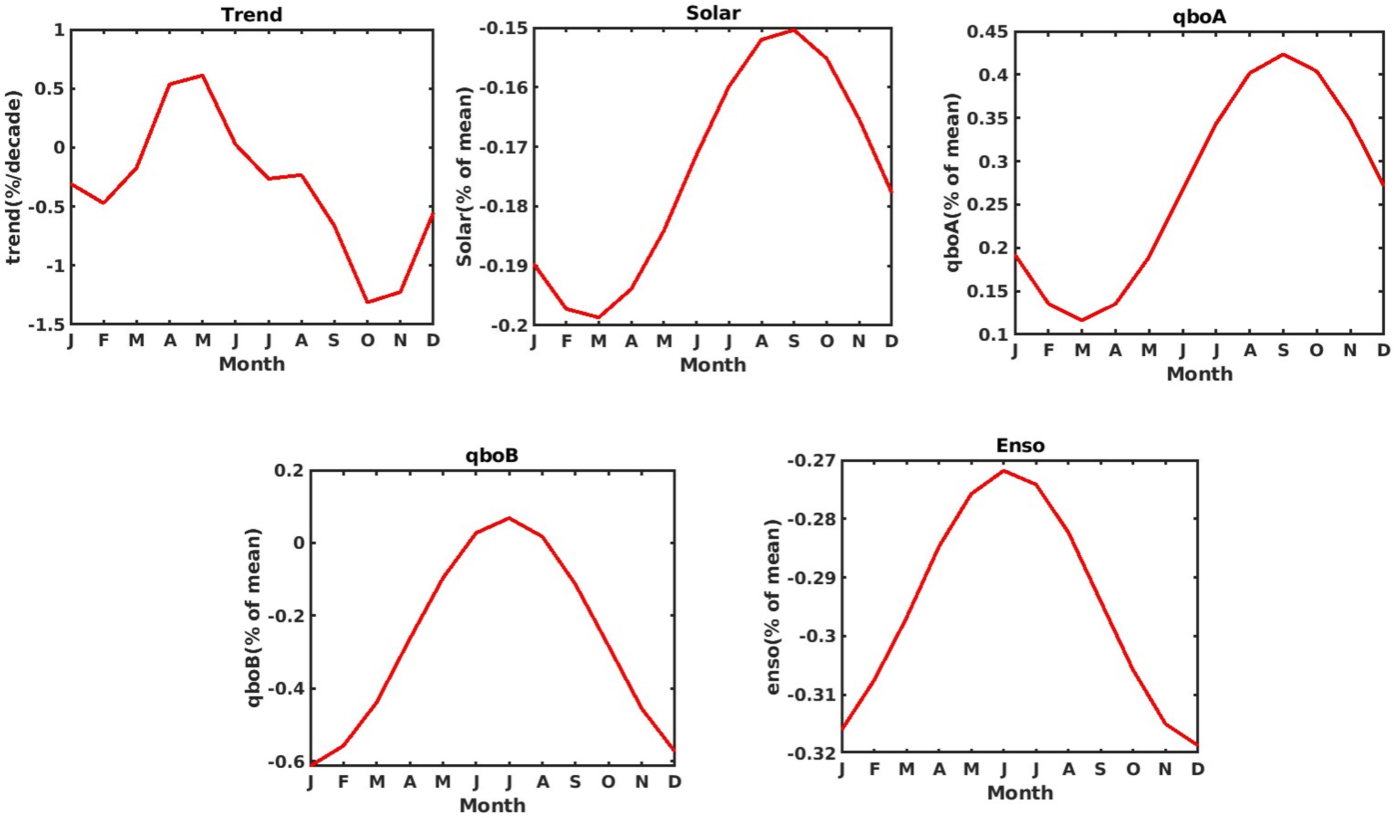
There is a negative trend during MAM and a positive trend during SON.

Trend in tropopause altitude

Station	Trend±2σ (%/decade)	Solar±2σ (% of mean)	qboA±2σ (% of mean)	qboB±2σ (% of mean)	ENSO±2σ (% of mean)
26510(P)	3.8±1.6	0.5±1.2	0.1±0.9	-0.9±0.8	1.2±0.8
04102(M)	1.6±2.2	1.3±1.3	0.3±0.9	0.5±0.7	-0.2±0.9
25501(M)	2.7±2	-0.3±1.4	-0.6±1.1	-0.1±0.9	0.5±0.9
40505(T)	1.2±0.9	0.2±0.3	-0.003±0.2	0.5±0.2	0.4±0.2
41406(T)	1.2±0.8	0.003±0.3	-0.2±0.2	0.4±0.2	0.5±0.2

14% of stations show a significant positive trend in the tropopause altitude, while 48% showed a positive trend though not significant. 4% showed a significant negative trend.

Trend in tropopause temperature (Station code-04102)



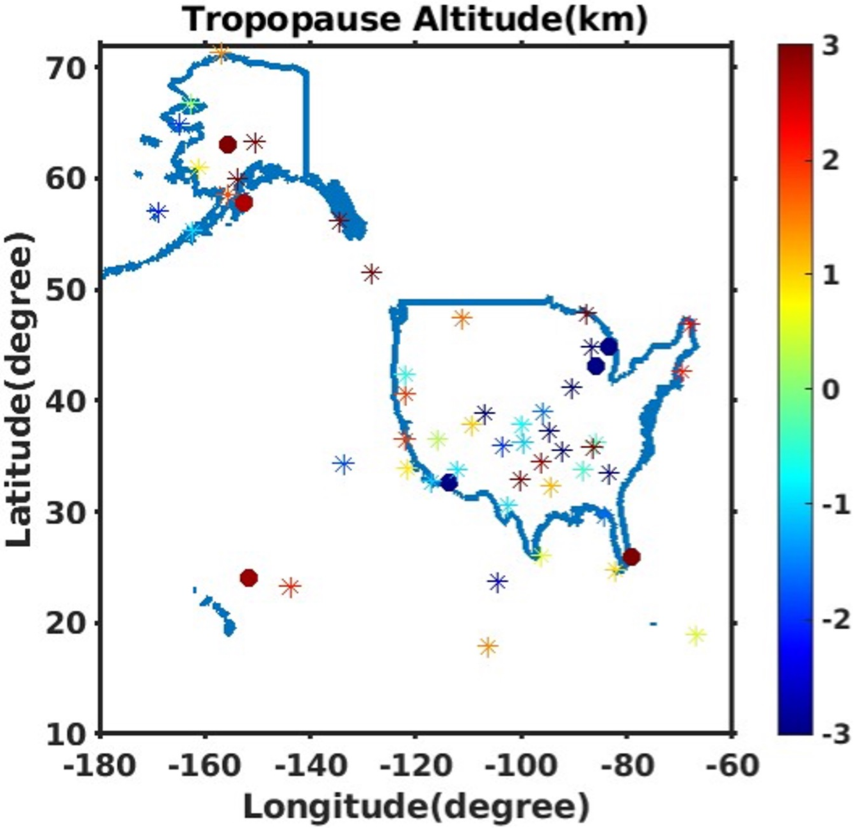
There is a positive trend during MAM and a negative trend during SON.

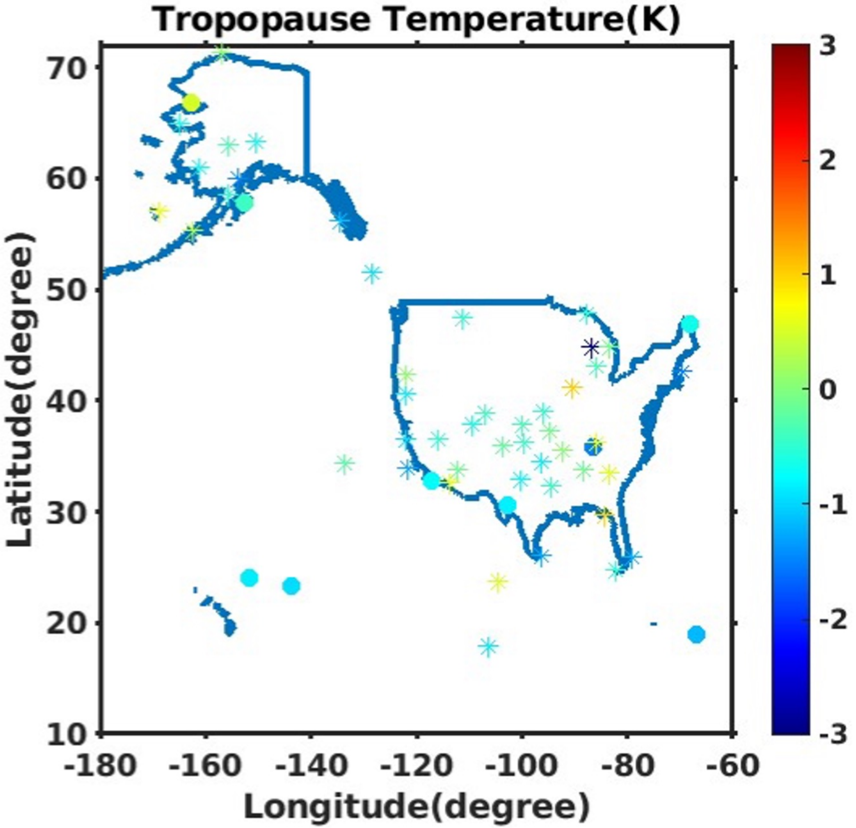
Trend in tropopause temperature

Station	Trend±2σ (%/ decade)	Solar±2σ (% of mean)	qboA±2σ (% of mean)	qboB±2σ (% of mean)	ENSO±2σ (% of mean)
26510(P)	-0.3±0.3	-0.1±0.2	0.1±0.2	0.1±0.2	-0.2±0.2
04102(M)	-0.5±0.7	-0.2±0.2	0.01±0.1	-0.1±0.1	-0.1±0.2
25501(M)	-0.4±0.4	0.1±0.3	0.1±0.2	0.04±0.1	-0.1±0.2
40505(T)	-0.1±0.3	0±0.2	0.1±0.1	-0.3±0.1	0.1±0.1
41406(T)	0.1±0.3	0.2±0.2	0.2±0.1	-0.2±0.1	0.1±0.1

76% of stations show a negative trend in tropopause temperature but only 10% was significant.

Trend in tropopause altitude and temperature





Summary

- US High resolution rawinsonde over 96 stations has been used to study the tropopause characteristics over 66 stations.
- Lapse rate tropopause and second tropopause has identified based on WMO definitions.
- Mean tropopause height for the mid latitude station is identified to be of 11.2±1 km, and is maximum during summer.
- Mean tropopause temperature is found to be 214.3±2K.
- Identified tropopause values are compared with that of the global empirical model developed by Mateus et al,2022.
- LOTUS multivariate linear regression model is applied to the tropopause temperature and height for the 66 relevant stations by including predictors as QBO,ENSO and solar cycle.
- Trend in tropopause altitude is 1.6±2.2 (%/decade), and tropopause temperature is -0.5±0.8 (%/decade) for the station 04102.
- Tropopause temperature and altitude are showing opposite trends as expected in 68% of the stations.

THANK YOU