Global Measurements of Optically Thin Ice Clouds Using CALIOP

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Overview

Optically thin ice clouds have been shown to have a net warming effect on the globe but, because passive instruments are not sensitive to optically thin clouds, the occurrence frequency of this class of clouds is greatly underestimated in historical passive sensor cloud climatology. One major strength of CALIOP (Cloud-Aerosol Lidar with Orthogonal Polarization), onboard the CALIPSO (Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations) spacecraft, is its ability to detect these thin clouds, thus filling an important missing piece in the historical data record. This poster examines the full mission of CALIPSO Level 2 data, focusing on those CALIOP retrievals identified as thin ice clouds according to the definition shown to the right. Using this definition, thin ice clouds are identified and counted globally and vertically for each season. By examining the spatial and seasonal distributions of these thin clouds we hope to gain a better understanding these thin ice clouds and how their global distribution has changed over the mission. This poster showcases when and where CALIOP detects thin ice clouds and examines a case study of the eastern pacific and the effects seen from the El Niño–Southern Oscillation (ENSO).

The Data

- Full mission, June 2006 - July 2017
- CALIPSO level 2 version 4.10, 5km merged layer product
- Day and Night
- Thin ice clouds
  - $0.03 \leq \tau \leq 0.3$
  - High Confidence ROI
  - $T_C \leq -40$ °C
  - Isolated (not vertically adjacent)
- Bin Size
  - Longitude: 5°
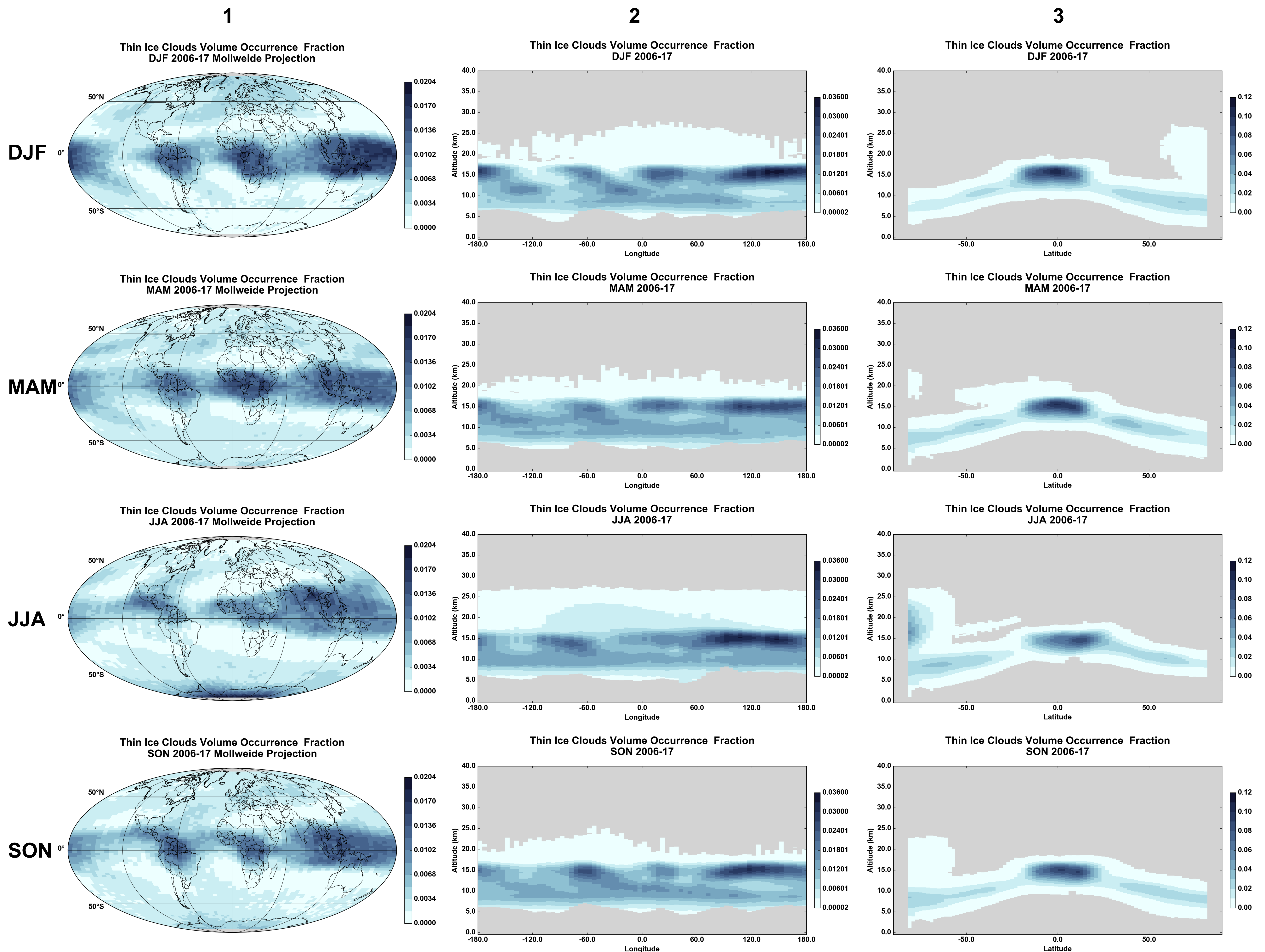 - Latitude: 2°
  - Altitude: 30m

Figure 1: Volume occurrence frequency of optically thin ice clouds identified by CALIOP over the span of the CALIPSO mission. The data is shown in vertical, horizontal and altitude bins for the period of June, 2006 to July, 2017. Volume occurrence fraction is defined as the number of occurrences of thin ice clouds detected in the bin, normalized by the number of observations in that bin. On the maps, values of zero are shaded white so that true zero volume occurrence can be separated from no data values. In the latitude/longitude vs altitude plots, bins with less than the observation outlier outer fence value (Q1 - (3*IQ)) as well as bins with a volume occurrence fraction < 0.05% of the maximum value have been removed and are considered no data.

Changes Over Time

With such a long running data record, we can begin to look at trends in optically thin clouds over the course of the CALIPSO mission. While the 11 years of data aren't enough to give us confidence on a climatological time scale, we can begin to study the trends in the data for shorter time scale effects and begin to examine what may be happening.
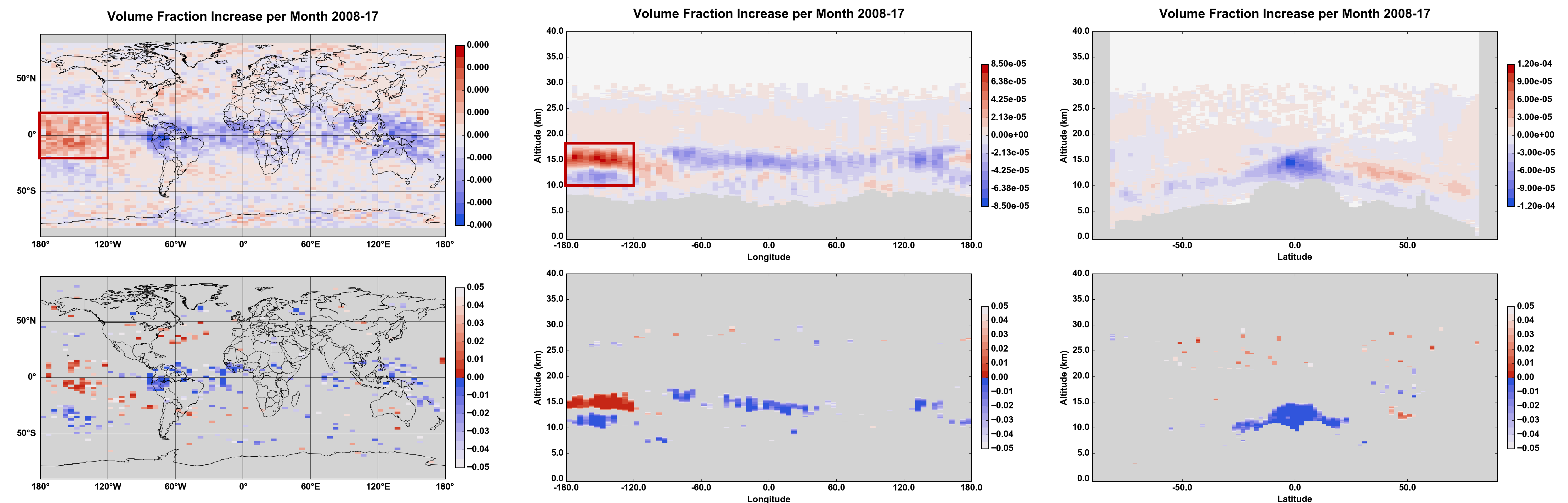

Figure 2: Linear regression slopes (top) and p-values (bottom) for monthly average volume occurrence frequencies per bin. The data is a sub-sample from from Jan, 2008 to Jul, 2017 averaged along the z-axis. The p-values have been given the sign of the slope and are calculated for a null hypothesis of slope equaling zero. A |p-value| < 0.05 denotes a 95% confidence that resampling the data would not produce a slope as extreme as zero.

Case Study: Eastern Pacific

The eastern Pacific Ocean, highlighted by the red box in the Figure 2, shows an increase in thin ice clouds near the equator. However, the trend appears to be decreasing in other equatorial regions. Because all longitudes, latitudes, and altitudes contribute to the figures above, and regional trends are difficult to discern. Below we consider specific longitude, latitude, and altitude regimes.
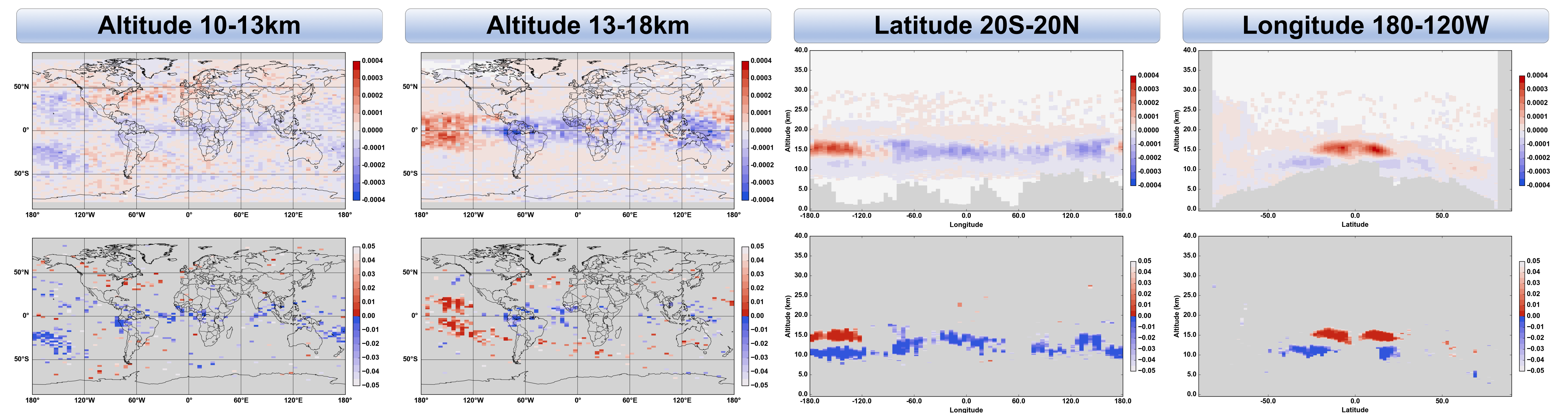

Figure 3: Eastern Pacific Ocean linear regression slopes (top) and p-values (bottom) for monthly average volume occurrence frequencies per bin limiting the z-axis to the values in the labels above the individual plots.

A Connection to ENSO

Avery et. al. 2017 have found that the increase in ice clouds seen at 13-18km on the above plots is tied to the El Niño–Southern Oscillation (ENSO) [1]. The time series of the average slope for the region described above compared to the Oceanic Niño Index (ONI) shows a relationship between the ENSO and the increase in optically thin ice clouds from 13-18km. However, from 10-13km there is a statistically significant decrease in thin ice which does not appear to be related to ENSO. This decrease and the decrease seen in other regions near the equator deserves further investigation and will be examined in future work.
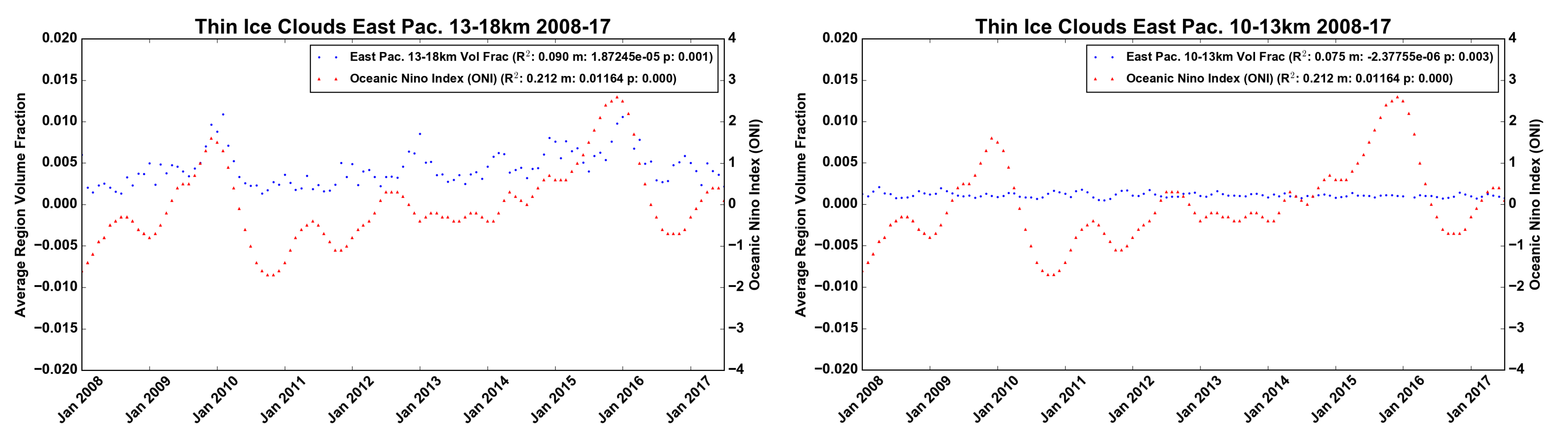

Figure 4: Average monthly eastern Pacific Ocean volume fraction plotted on the left y-axis and Oceanic Niño Index plotted on the right y-axis. The plot to the left shows 13-18km for the region and the plot to the right shows 10-13km for the region.

Conclusion

Optically thin ice clouds are important constituents of the atmosphere and cannot be detected by passive or cloud profiling radar instruments. CALIOP detects these clouds and has a valuable long running dataset which allows trends to be discovered in hard to detect optically thin ice clouds. On a climatological time scale, relatively short trends can be detected in the CALIPSO data record. An example of one such trend is the ENSO sea surface temperature increase being related to an increase in thin ice clouds in the eastern pacific. Other statistically significant changes in these clouds have been detected and leave much more work to be done in the future on this rich and valuable dataset.

[1] Melody A. Avery, Sean M. Davis, Karen H. Rosenlof, Hao Ye, and Andrew E. Dessler. Large anomalies in lower stratospheric water vapour and ice during the 2015–2016 el niño. Nature Geoscience, 10:405 EP –, 05 2017.