A comparison of stratospheric smoke events seen by SAGE II (1984-2005) and SAGE III (2017-2021)

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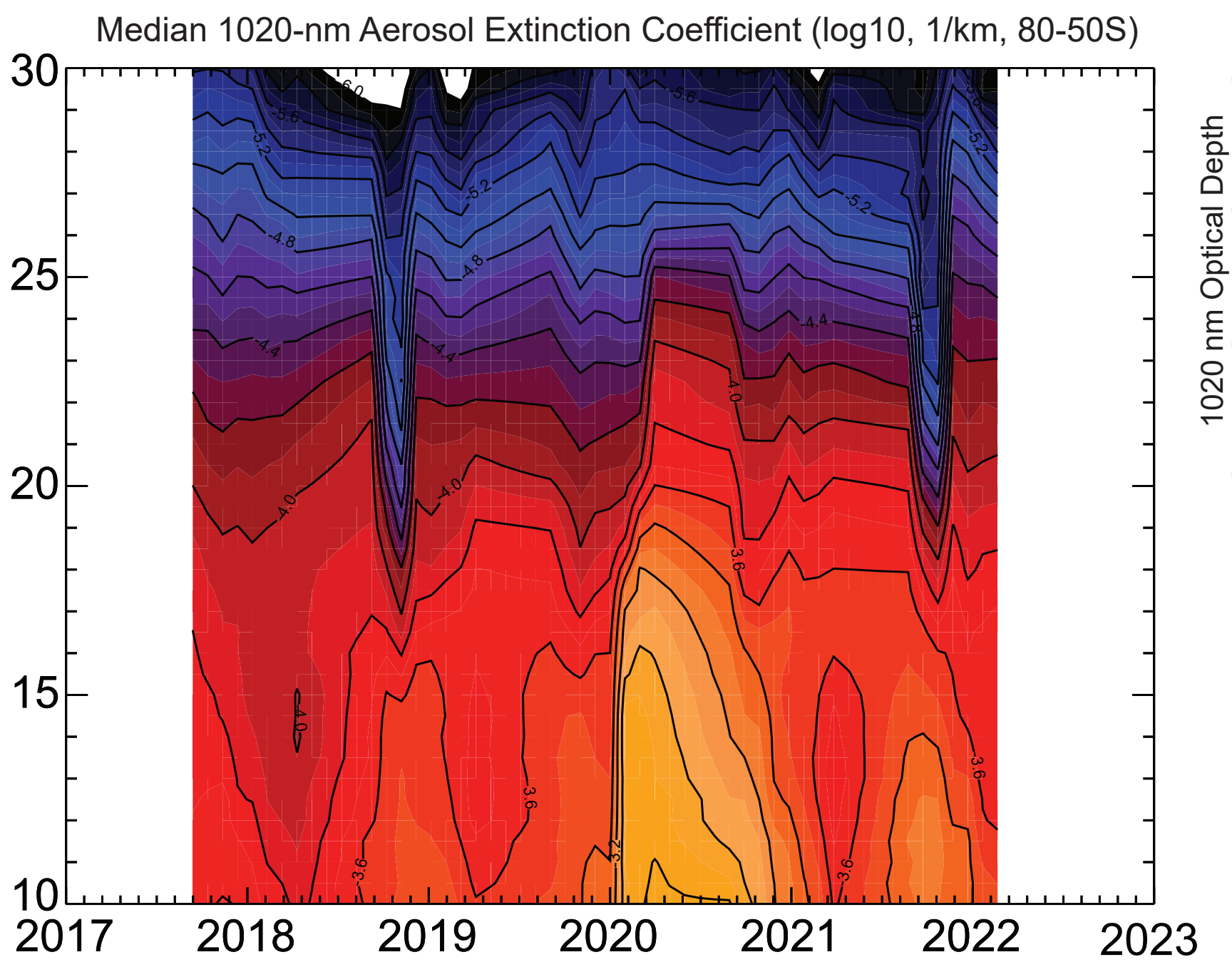
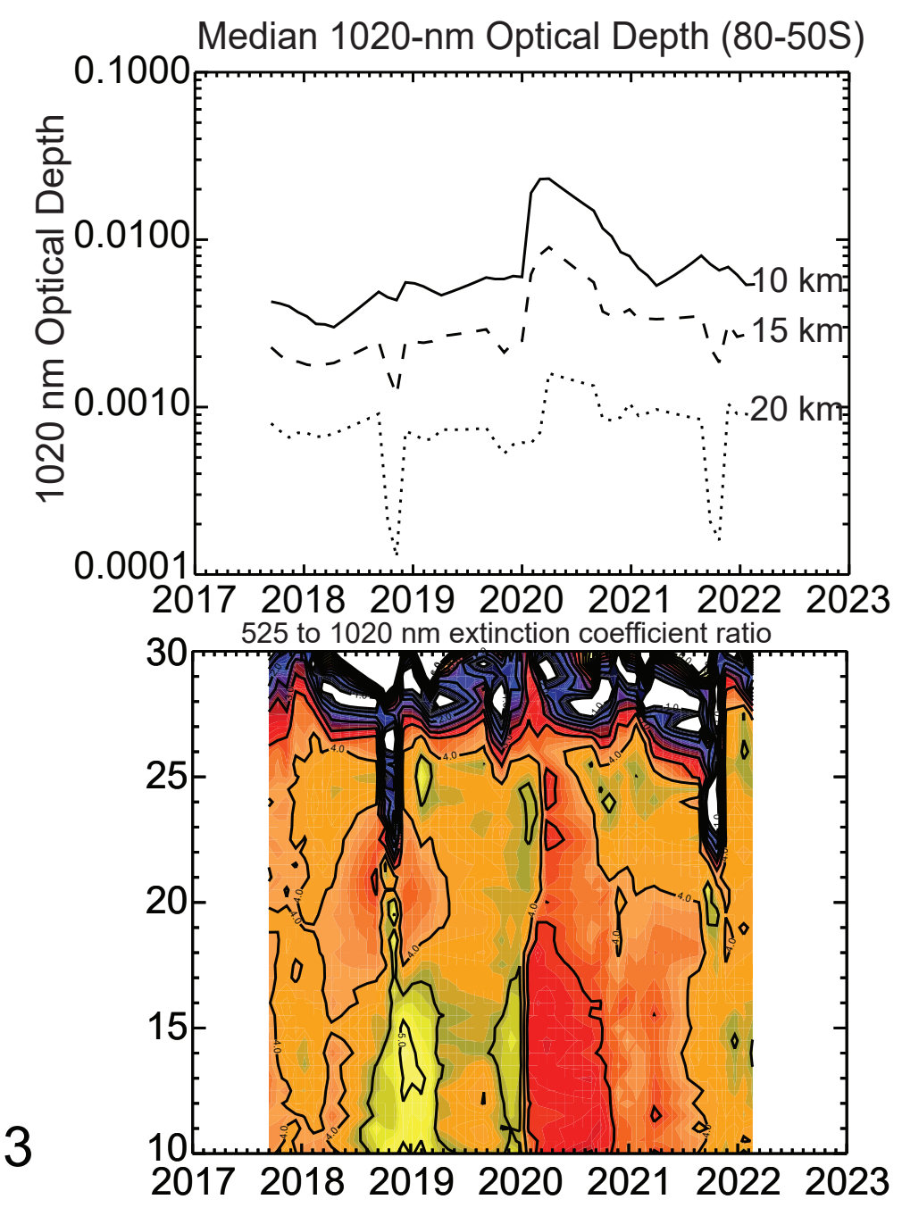
Focus

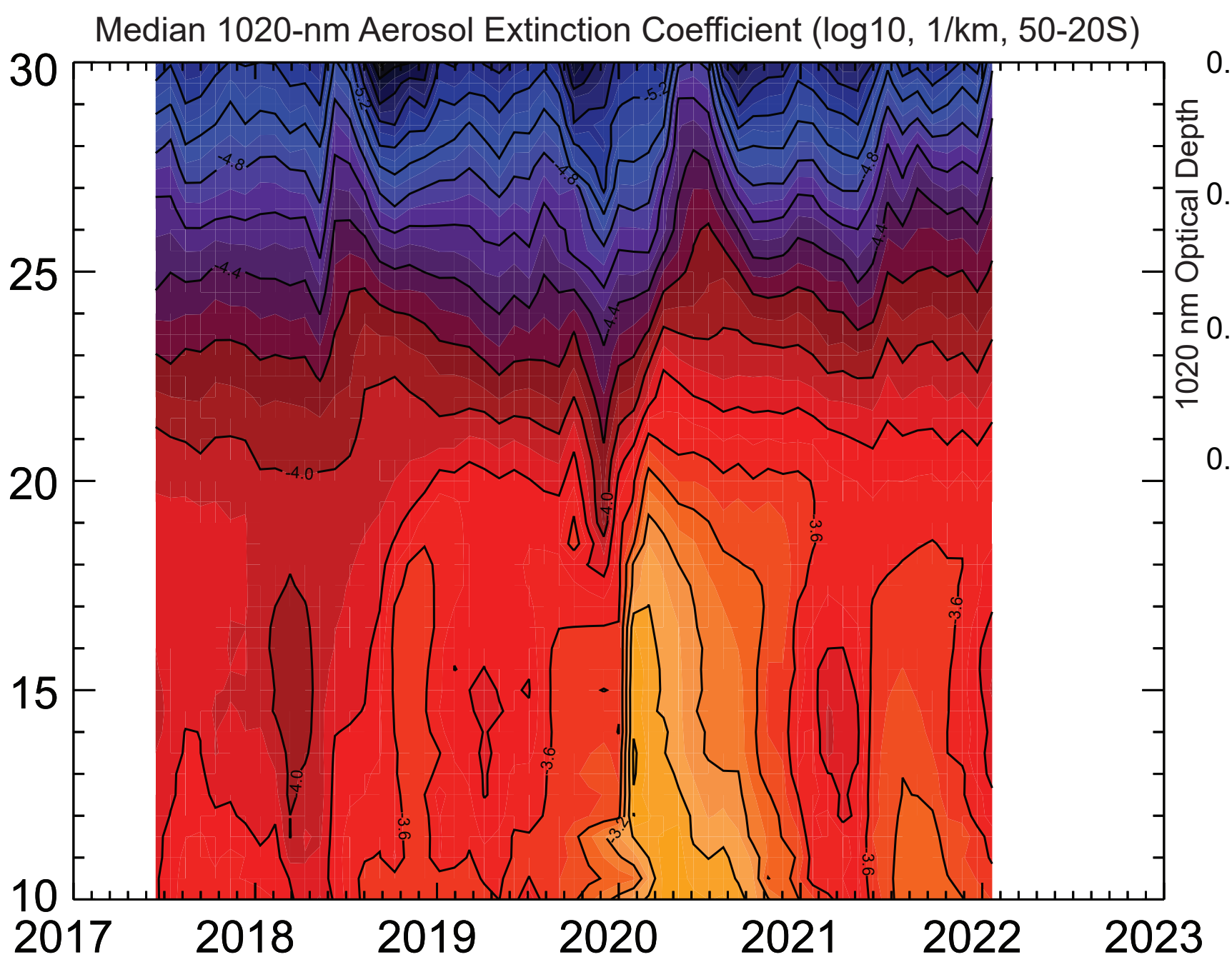
Herein, we compare smoke events that appear in the SAGE II and SAGE III/ISS data records. Stratospheric aerosol variability during these mission lifetimes are quite different. The SAGE II data record (1984-2005) is dominated by the Mt. Pinatubo eruption (1991) and a few much smaller volcanic events and smoke is not generally considered a major component. The SAGE III/ISS stratospheric aerosol record (2017-present) has been remarkably complex with a number of volcanic eruptions, particularly Hunga Tonga and Raikoke, and several smoke events among which the BC fire of 2017 and Australian fires of 2019/2020) are particularly noteworthy. These two smoke events produced are generally considered the largest stratospheric smoke events observed by spaceborne sensors. The hope is to provide context for these large events by comparing with the extended record from SAGE II, an instrument that provides fundamentally similar measurements and by using the same analysis approach. Given the comparative rarity of smoke events in the stratosphere, we do not expect to conclude anything with regard on ongoing climate changes, however illustrating the substantial differences of these periods is noteworthy.

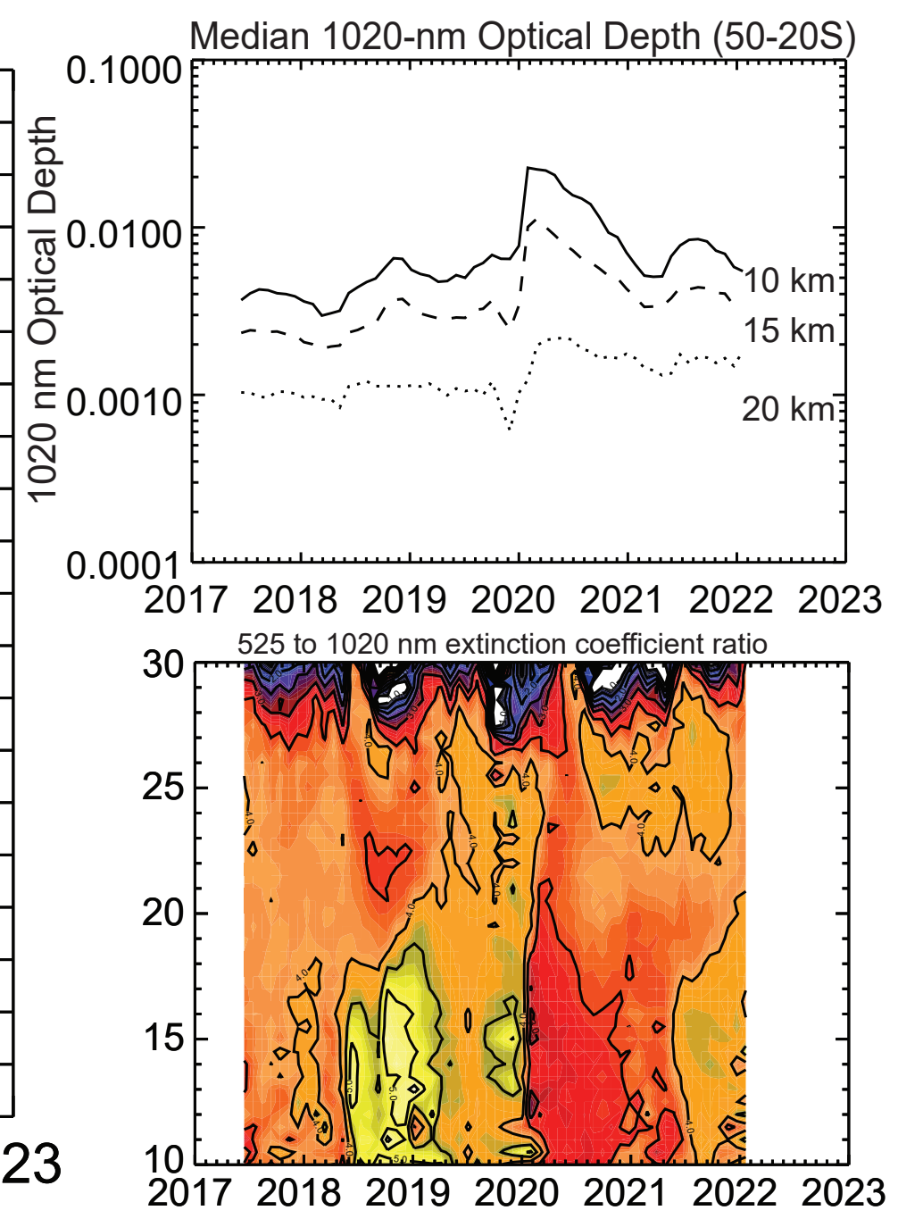
SAGE III

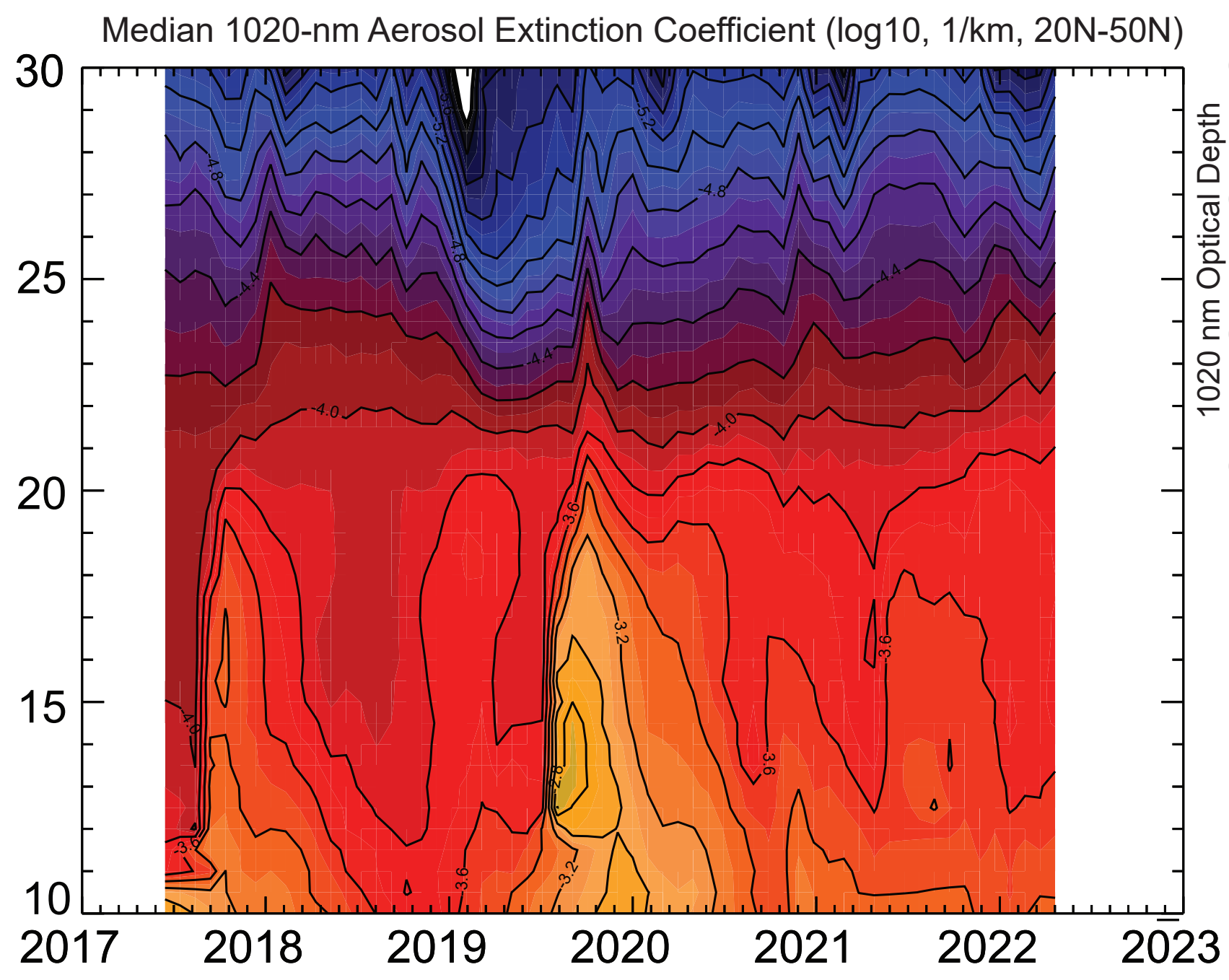
In the figures below, we show mid and high latitudes depicts of SAGE III/ISS aerosol extinction coefficient data. With a focus on smoke, we exclude all data within 2 km of the tropopause since smoke and clouds have similar spectral signatures and separating between the two is difficult. Data is binned in 5 latitude ranges (80-50S, 50-20S, 20S-20N , 20-50N, and 50-80N) by month and altitude and the median value selected. Median monthly optical depth is reported above certain fixed altitudes (e.g., >10 km) for individual events, we also report values at the 85th percentile given the highly inhomogeneous conditions that typically follow these events. In the SAGE III record, we find 2 additional (but much smaller) smoke events (by applying the method described on the right for SAGE II analysis) associated with the California fires of 2020 and 2021. Volcanic events that appear in this record are not a focus of further discussion. SAGE III/ISS smoke-derived optical depth enhancements are shown in the table to the right. Nominally, optical depth enhancements can be inferred at about the 0.001 level though ambient aerosol levels, seasonal variability and other factors can influence how well these can be inferred.

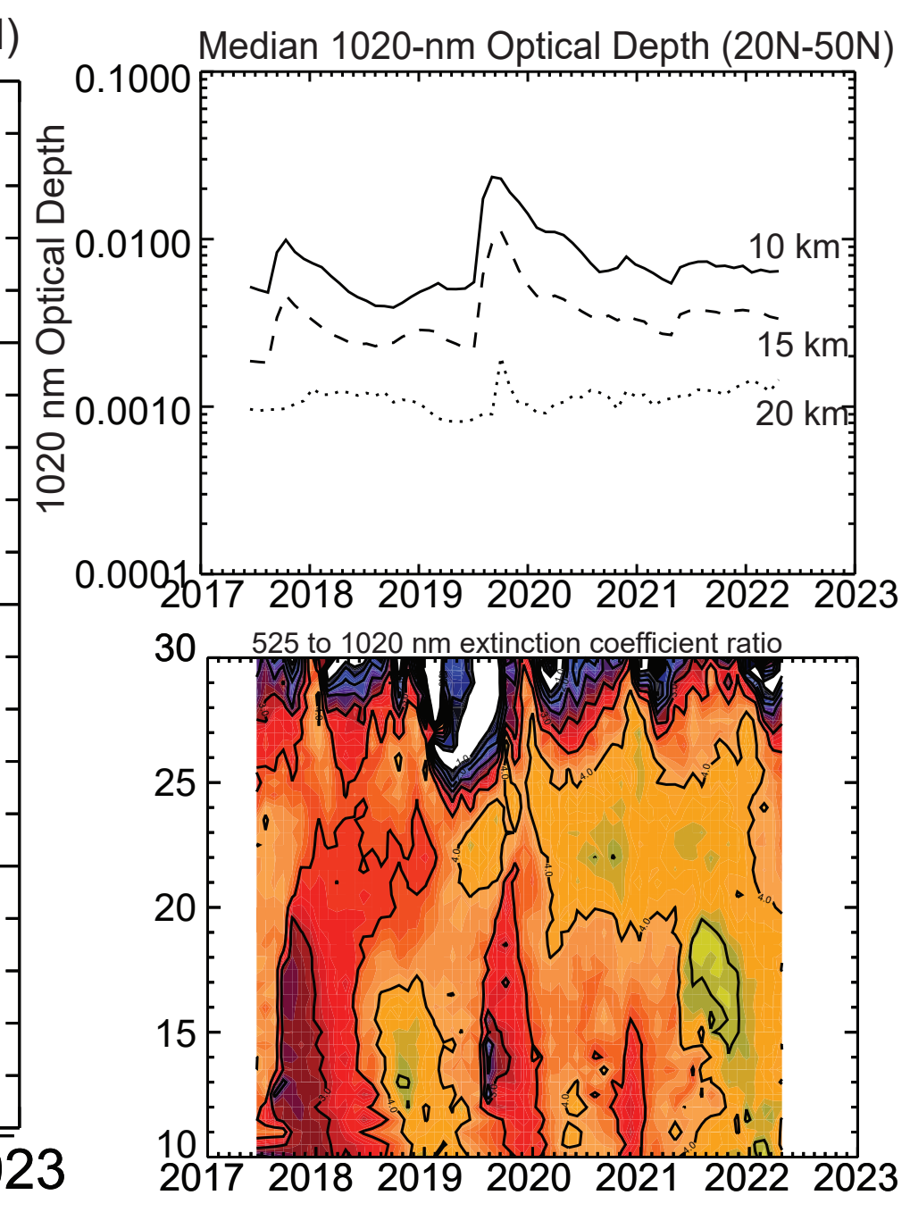


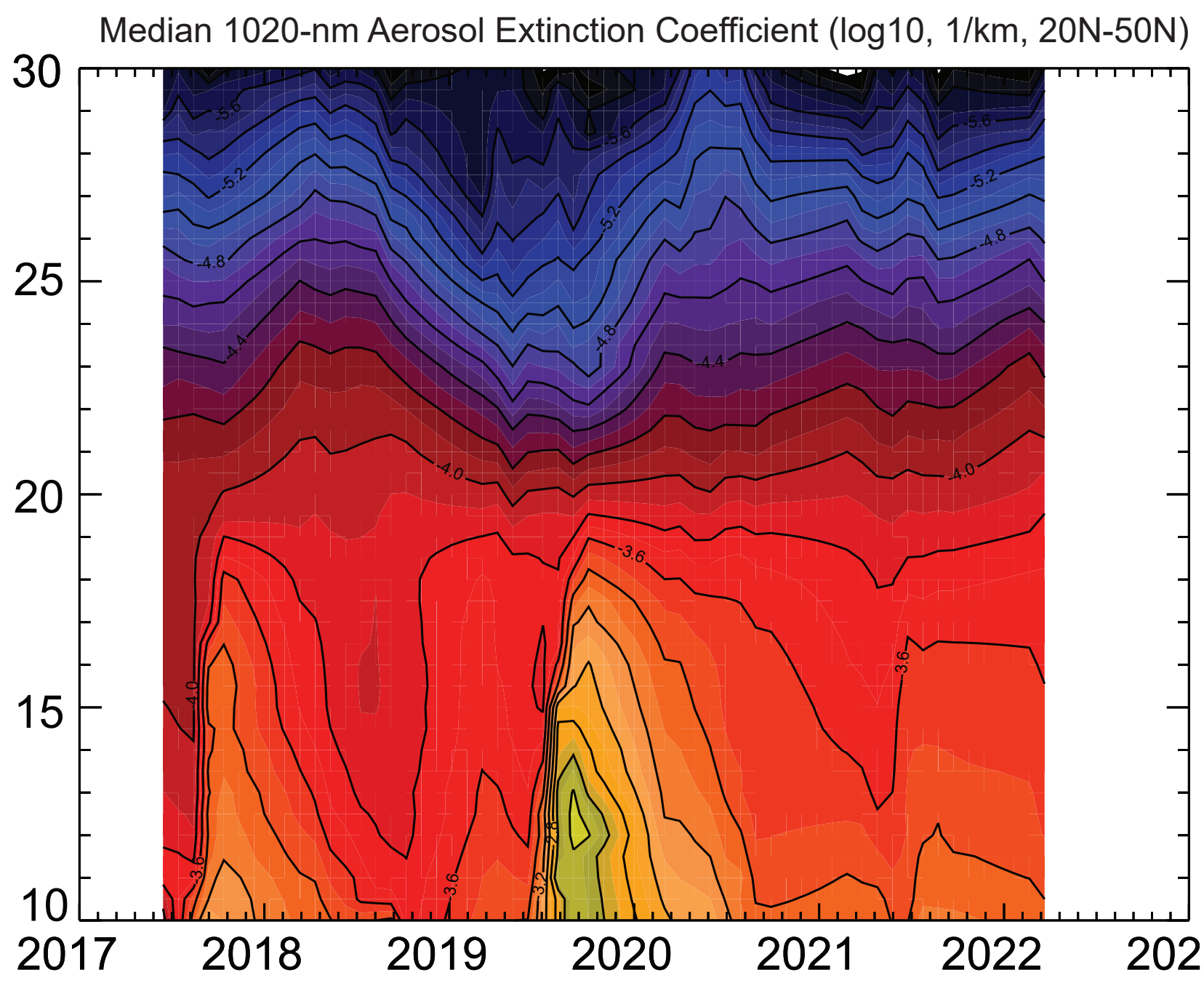


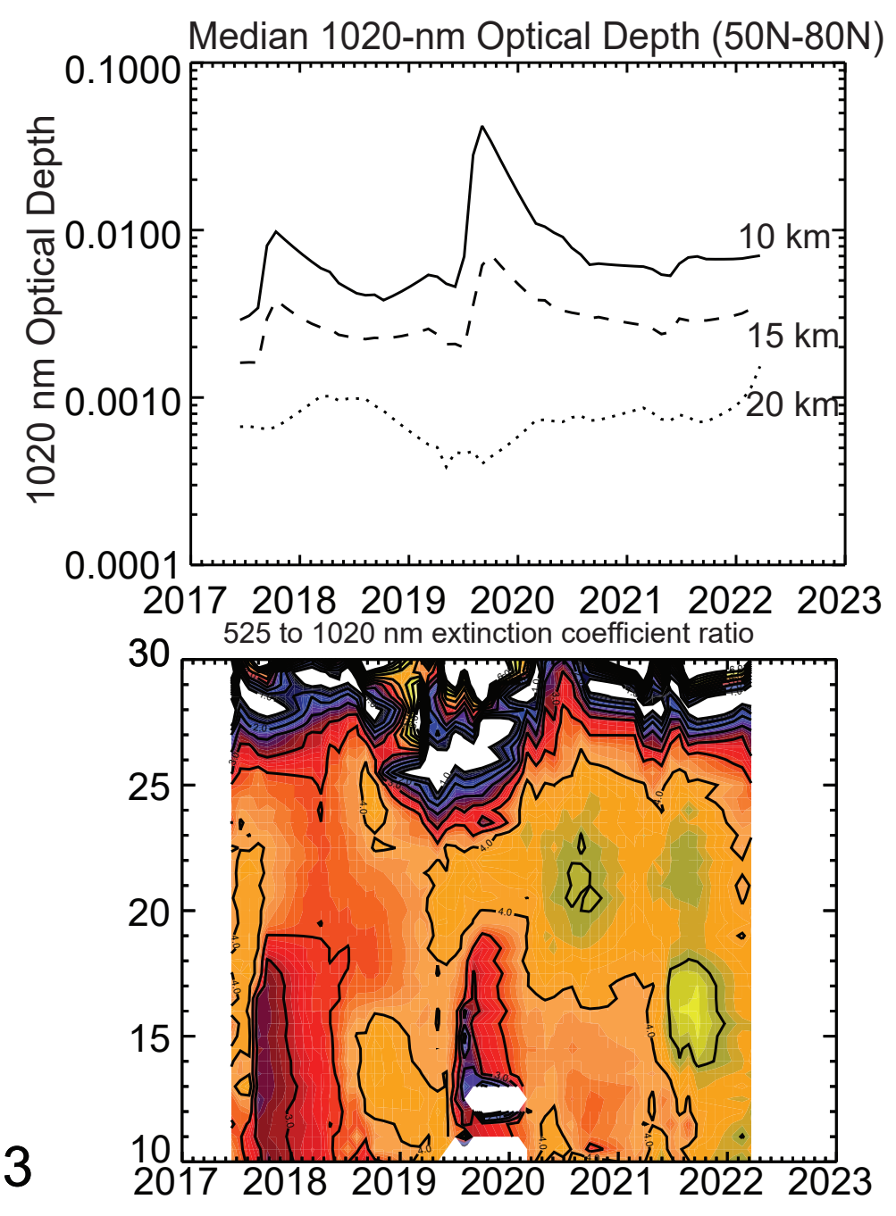












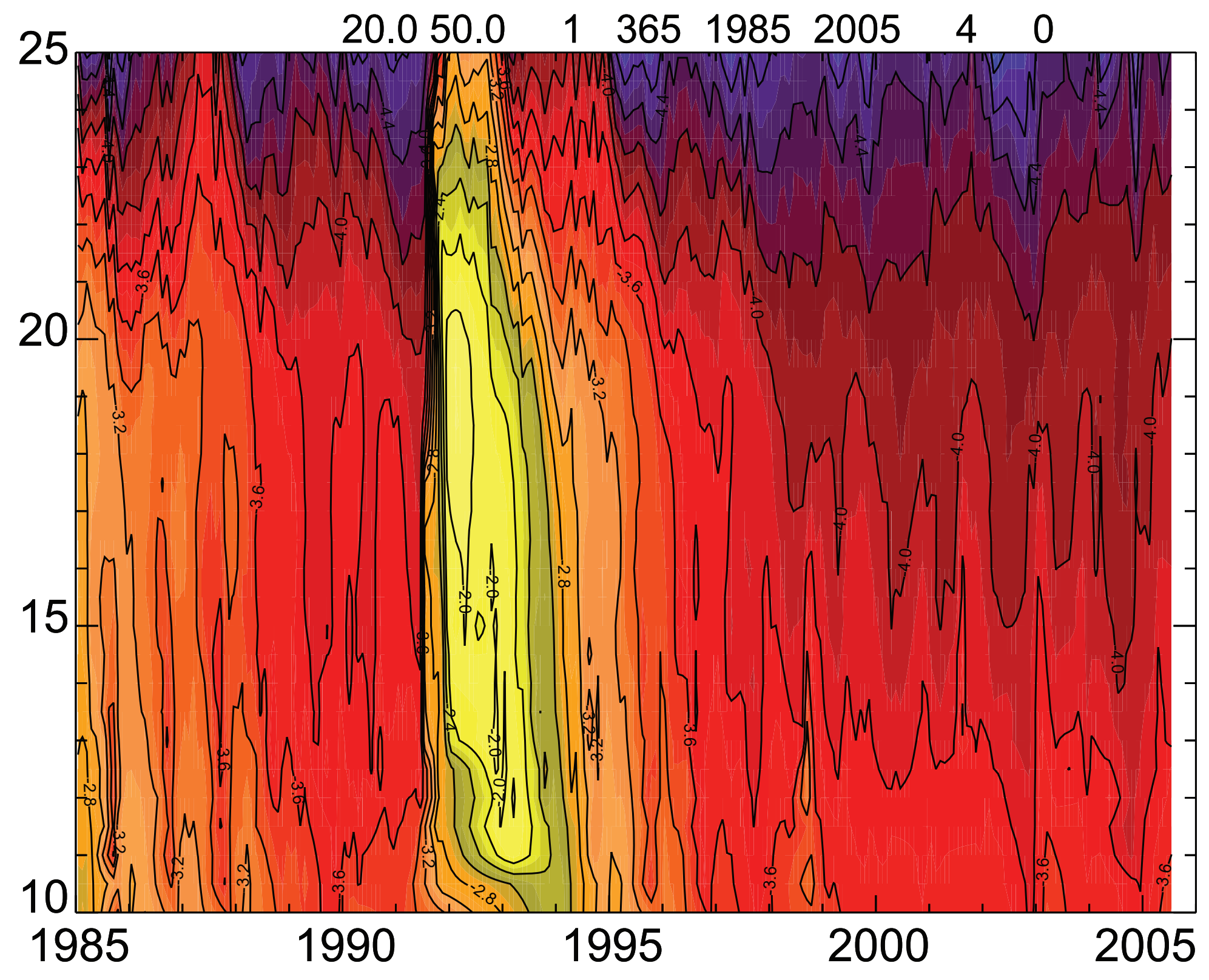
Some Conclusions

We have used a outlier finder to identify smoke and small volcanic events in the SAGE II record. In this, we have found 6 distinct smoke events and 2 small (one very small!) volcanic events. Using similar analysis techniques, we find that the largest smoke event in the SAGE II record (Norman Wells in 1998) is about half the magnitude of the BC fire of 2017 and almost an order of magnitude less than the Australian Fires of 2019/2020. This event is the only event which can be observed as some of the material reaches the tropics and is caught up in the B-D circulation. Most SAGE II smoke events are comparable to the two California events in 2020 and 2021. Overall, SAGE II observed 6 events in 14 years of analysis or about 1 every 2 years. Whereas, SAGE III/ISS has seen 4 in about 5 years or a rate of almost 1 a year. Such events are sufficiently infrequent that we hesitate to suggest a difference between the SAGE II and SAGE III/ISS time periods, though the differences appear quite dramatic.

SAGE II

As shown below, the SAGE II record is dominated by the 1991 eruption of Mt. Pinatubo and to a lesser extent by small eruptions spread throughout the record and the recovery from the 1981 eruption of El Chichon. Impacts by pyrocumulus injections of smoke are generally seen as a minor component of the overall record though there presence has been noted in the past. Below, we identify SAGE II outlier events and attempt to attribute them to volcanic and smoke events, leaning on this and previous analyses. We will identify potential events using an outlier method based on the IQR approach modified to account for strong asymmetry in the distribution of aerosol extinction coefficient values. As with the SAGE III analysis, data is analyzed in 5 latitude bins and only data at or above the tropopause +2 km is used to avoid the impact of clouds. Only those events that produced at least 10 outliers at within a contiguous altitude band are considered so some very minor events may be excluded. At the end, we find 6 smokes events in the 21-year SAGE II record and 2 minor volcanic events that often not included in list of SAGE II volcanic events. The ability to identify outliers in the SAGE II record is influenced by the background aerosol level so that during the peak of the Pinatubo period, small smoke events may be missed. While we have made some attempt to evaluate all years, we focus below on the lowest aerosol loading periods (1986-1990 and 1997-2005) so only 14 of 21 possible years. The summary of optical depth enhancements for these events is shown in the table below.

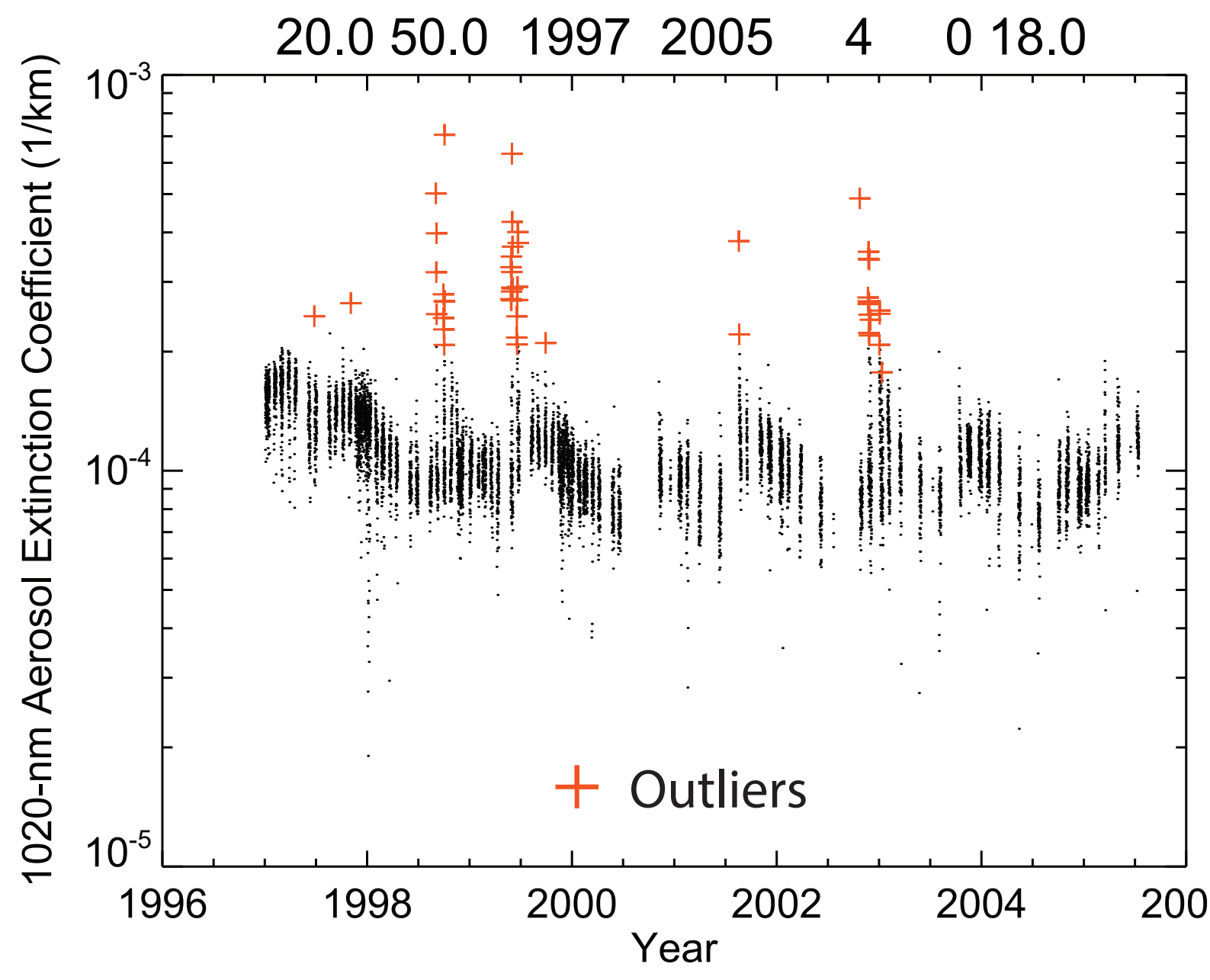
SAGE II 1020-nm aerosol extinction coefficient for 20 to 50N in monthly median, 0.5 km altitude bins. The record is dominated by the 1991 eruption of Mt. Pinatubo. By contrast the largest smoke event in this record can be seen between 10 and 15 km in 1999.

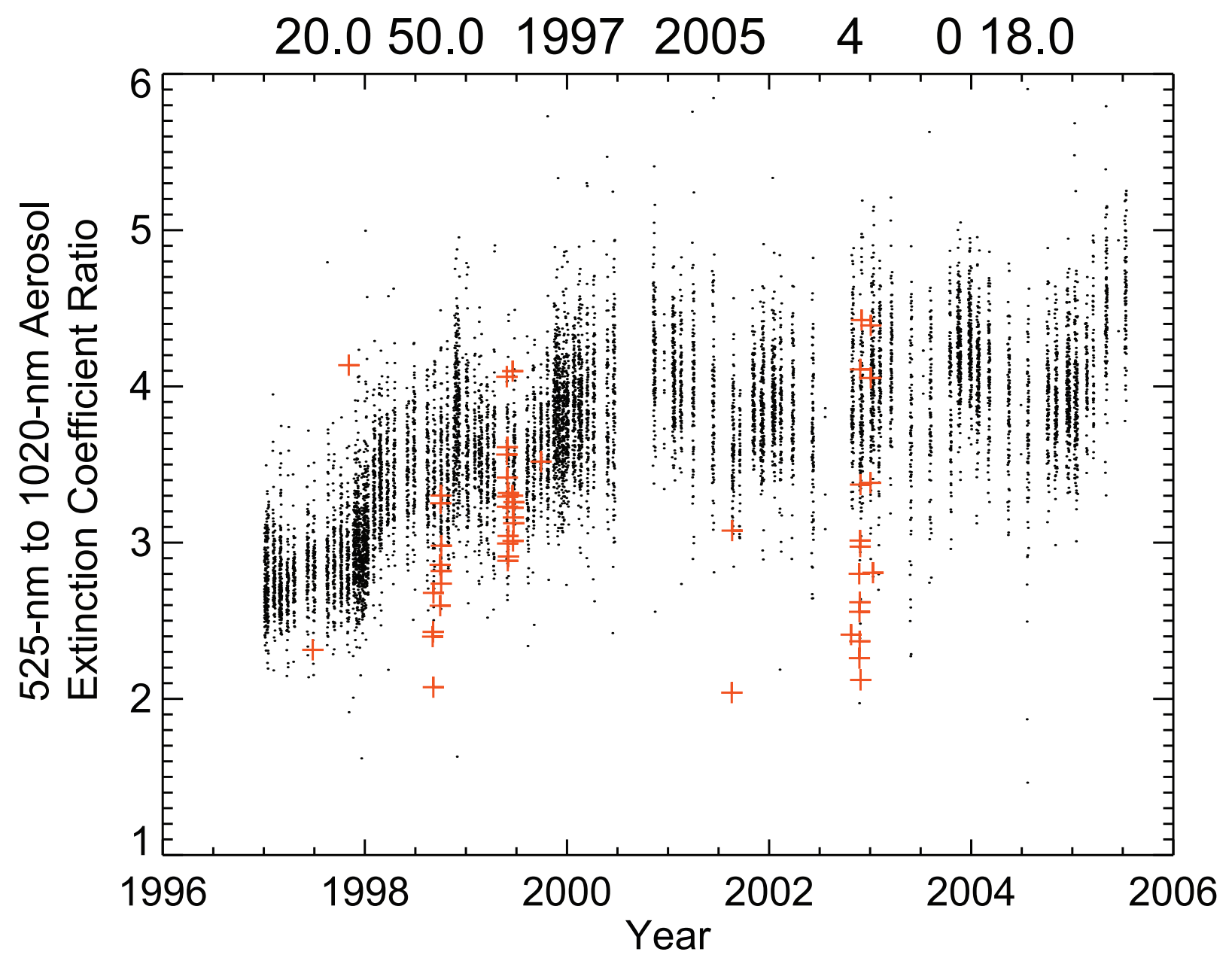


Year	Altitude range (km)	Latitude Band	Source	Source origin date	85-Percentile 1020-nm Optical Depth	Median 1020-nm Optical Depth
1987	12-14	50-80N	Tahe, China	May 13	0.003	0.0015
	12-14	20-50N			0.003	<0.0005
1990	18-22	tropics	Kelut, Indonesia	February 10	0.002	0.001
	17-22	20-50S			0.0015	0.001
	17-22	50-80S			<0.001	0.001
1990	12-16	50-80N	Circle, Alaska, US	July 7	0.002	0.001
	12-17	20-50N			<0.001	<0.0005
1998	13-14	50-80N	Sheveluch, Russia	May 30	<0.001	-
1998	17-19	Tropics	Norman Wells, Canada	August 3-4	**0.001**	**-**
	12-19	20-50N			**0.0025**	**0.0015**
	12-16	50-80N			**0.004**	**0.003**
1999	12-17	50-80N	Shishaldin, US	April 19	<0.001	-
	12-19	20-50N			0.0005	-
	18-19	Tropics			<0.0002	-
2001	12-18	20-50N	Chisholm, Canada	May 29	0.003	0.0003
	12-17	50-80 N			0.0015	0.001
2003	12-15	50-80S	Canberra, Australia	January 18-22	0.0005	0.0003
	17-19	20-50S			<0.0004	<0.0003
2003	12-17	20-50N	Conibear, Canada	August 17	<0.001	-
	12-13	50-80N			<0.001	-
2017	10-22	50-80N	British Columbia, Canada	August 12	**0.012**	**0.0035**
	13-24	20-50N			**0.009**	**0.004**
2020	13-18	20-50N	California Creek, US	September 1	0.002	0.0008
	11-17	50-80N			<0.001	-
2019/2020	12-30+	20-50S	(a lot of) Australia	December/January	**0.039**	**0.016**
	10-30+	50-80S			**0.025**	**0.018**
2021	12-15	20-50N	McKay Creek, US	June 29	0.002	0.002
	11-14	50-80N			0.001	<0.001

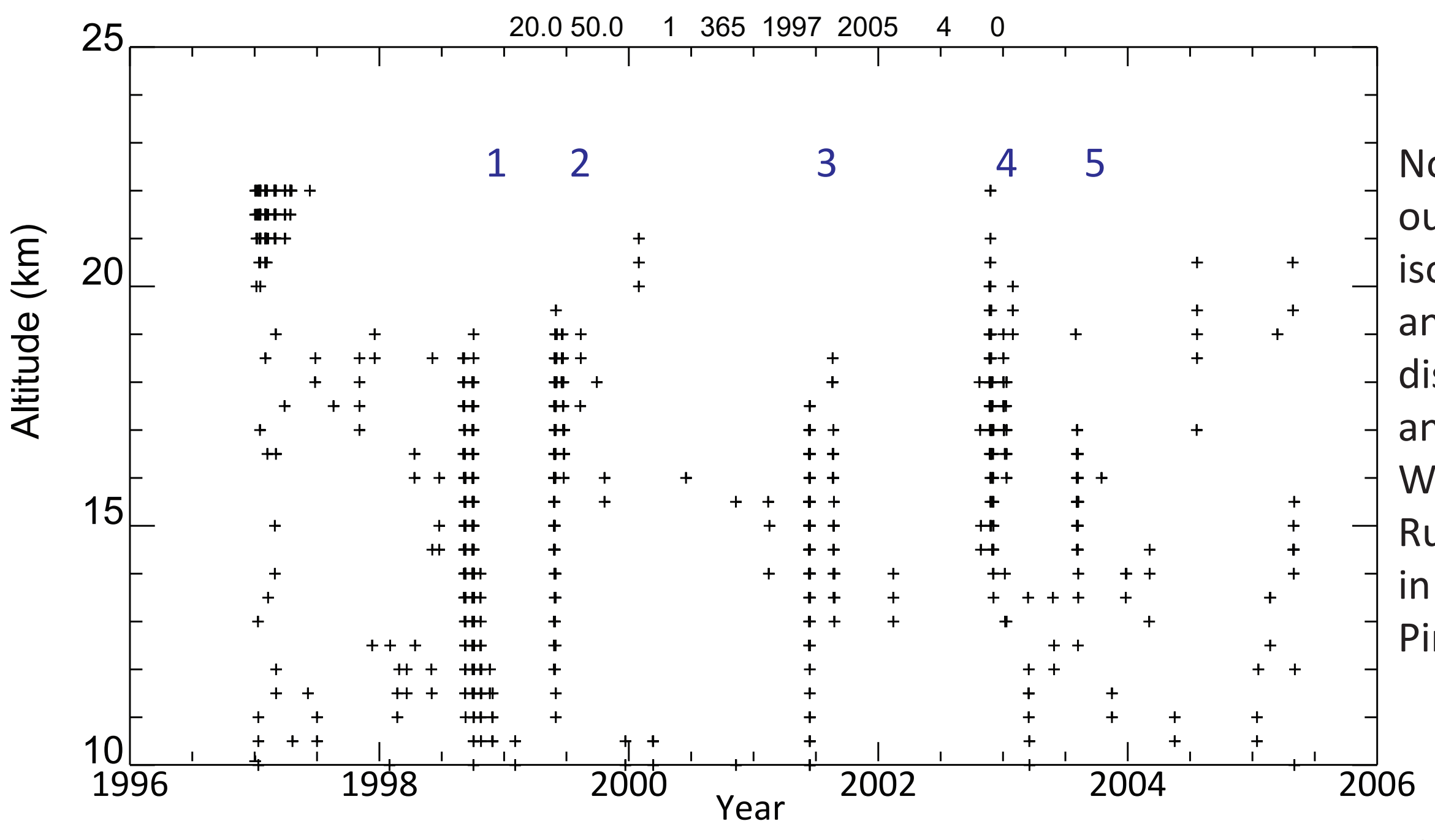
A tabulation of SAGE II and SAGE III/ISS smoke events in median and 85-th percentile impacts on >10 km stratospheric aerosol optical depth.

Outliers





The extinction positive outlier bound is given by median+1.5*IQR*k where k accounts for the symmetry of the extinction coefficient data. The value for k is generally larger than 1. Outlier events are considered to occur when the individual outliers occur in spatial/temporal clusters.



Not surprisingly, for a statistical outlier test, there are a number of isolated outliers in the NH mid latitude analysis to the left. However, several distinct cluster are readily available and have been associated with Norman Wells (1), Shishaldin (2), Chisholm (3), Ruang (4), and Conibear (5). The cluster in 1997 above 20 km is a remnant from Pinatubo.