

# How the recent Anak Krakatau eruption affected the atmospheric structure?

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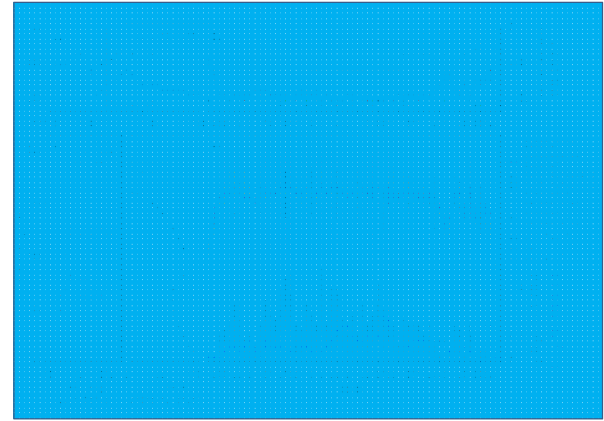
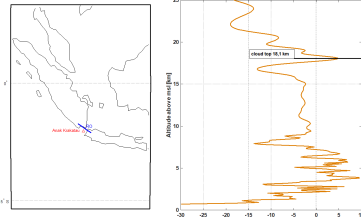
## Abstract

The Anak Krakatau (Child of Krakatau) volcano is part of the Pacific Ring of Fire, one of the most active volcanic areas of the world. The Anak Krakatau experienced a large explosive eruption, in December 2018, which collapsed the southwestern side of the mountain, generated a tsunami and triggered strong convection and a volcanic thunderstorm lasting for six days.

The eruption injected gas and ash up to the upper troposphere and lower stratosphere regionally affecting the atmospheric structure for a few months.

Despite the complexity of the area, which is often characterized by volcanic eruptions, strong convection and sometimes “touched” by the tropical cyclones rainbands, the Anak Krakatau eruption left a clear signature in the atmospheric structure with large temperature variation around the tropopause layer and very likely overshooting the stratosphere. The zonal temperature residuals, after removing the QBO and ENSO, show a cooling of UTLS of about 2°C for 6 months after the eruption.

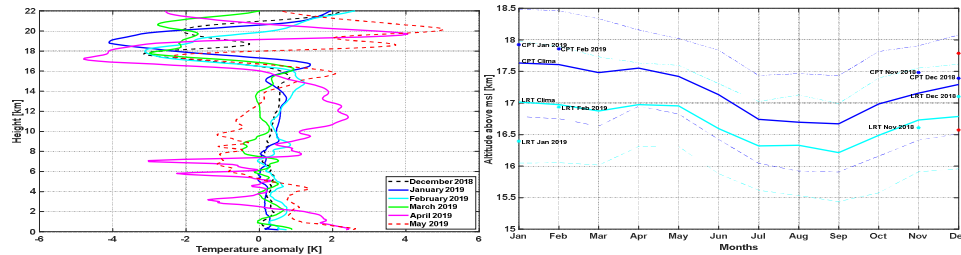
## Background



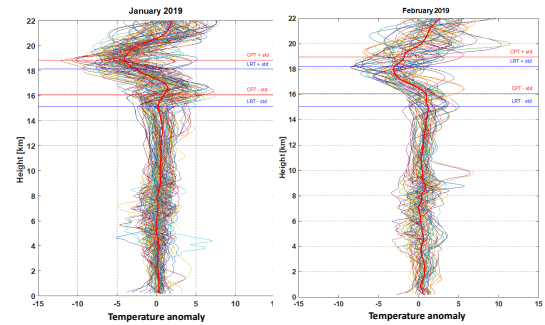
Volcanic activity in tropical atmospheres can trigger deep convection and so called volcanic thunderstorms. The heating at ground surface and entrainment of moist air creates positive buoyancy, which transport volcanic gases and ash particles to the Upper Troposphere and Lower Stratosphere (UTLS). This type of deep convection is rarely observed to last continuously for more than one day and so it is difficult to study the dynamics, microphysics and electrification processes. The Anak Krakatau eruption was one of the rare cases with deep convection lasting for six days. The volcano erupted for the first time the 22<sup>nd</sup> of December 2018 with a second phase at the beginning of January 2019. Cloud-top temperatures hovered around -80 °C and a large lightning activity was found into the cloud. During the eruption, a deep convective plume formed over the volcano, the anvil was ice-rich and ash-poor and, according to different algorithms, reached 16-18 km above sea level and. The bending angle anomaly method (please attend the presentation of V. Cigala on Tuesday at 16.30 for details), applied to the closest RO, shows a cloud top altitude of 18.1 km suggesting a likely overshooting top.

Figure from A. Prata, A. Folch, A. J. Prata, R. Biondi, H. Brenot, C. Cimarelli, C. Corradini, J. Lapierre and A. Costa, “Fire and ice: Anak Krakatau triggers volcanic freezer in the upper troposphere”, Scientific Reports, in press, 2019.

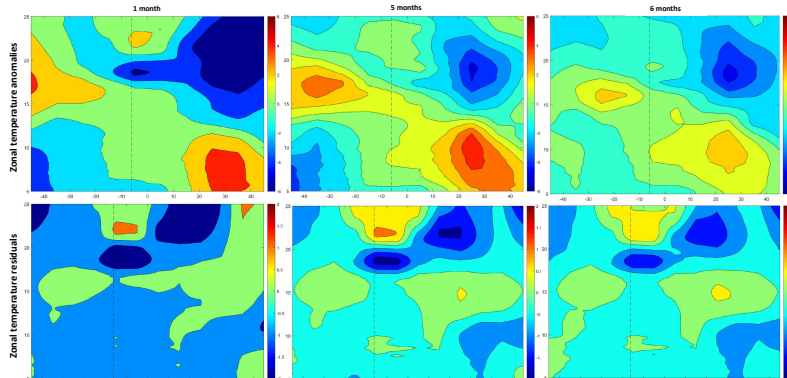
## Methodology and Results



The temperature anomaly in the UTLS within a 5°x5° box around the volcano became negative already the day of the eruption and the cooling persisted in the area for about 7 months reaching the maximum amplitude in April. The climatological values were computed using all the profiles from 2006 to 2018 in a box of 5° latitude and 5° longitude around the volcano. The climatological Coldest Point Tropopause (CPT) altitude in December around the Anak Krakatau is 17.29 km while the climatological Lapse Rate Tropopause (LRT) is 16.78 km with a standard deviation of 0.8 km. In January the CPT slightly rises to 17.63 km and the LRT to 17.01 km. In December 2018, before the Anak Krakatau eruption, the tropopause altitude was consistent with the climatological values (CPT 17.24 km and LRT 17.02 km) but the eruption changed the atmospheric conditions and the CPT and LRT altitudes diverged reaching respectively 18.7 km and 15.9 km in January 2019.

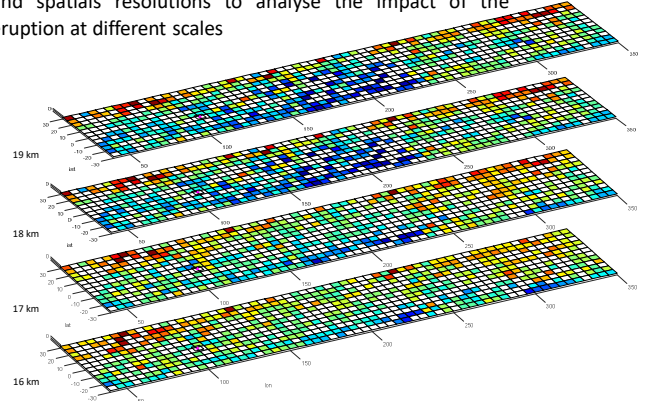


The RO temperature anomalies in the Krakatau area during the eruption, show a warming of the upper troposphere (15,5 km – 17 km) with an averaged peak amplitude of about 4K, and a cooling of the lower stratosphere (18 km – 20,5 km) with amplitude up to -4K. After the eruption the tropospheric warming persisted just for 1 month.



Zonal mean temperature anomalies associated with Anak Krakatau eruption. The anomalies are estimated as the difference between the averaged value of 1-5-6 months after December 2018 and the average value of 24 months before the eruption. Top panels without removing the QBO and ENSO, bottom panel removing them.

Anomaly maps removing QBO and ENSO. We have made them with 100 meter vertical sampling, different temporal and spatial resolutions to analyse the impact of the eruption at different scales



This study is part of the Volcanic clouds dEtection and monitoring for Studying the eRuption impact on climate and aVlatiOn (VESUVIO) project, funded within the Programme Supporting TALENt in ReSearch (STARS) @ University of Padova. Website <http://biondiriccardo.it/BR/vulcano/indexvesuvio.htm>

## Bibliography

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- V. Cigala et al., GNSS radio occultation advances the monitoring of volcanic clouds: the case of the 2008 Kasatochi eruption, *Remote Sensing*, in press, 2019.
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