3. D2.1: Inventory of stratospheric layers related to extreme pyro-convective events.

3.1. Overview

Utilizing the Cloud Aerosol Lidar with Orthogonal Polarization (CALIOP) on board the Cloud Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO, see also D2.2), we were able to identify smoke aerosols from pyroCBs during intense wildfire events that reached into the stratosphere. CALIOP accurately measures the altitude of the event plumes with a very high vertical resolution in the stratosphere ranging between 60 - 300m. These are detailed in the following Table 1 as in Tackett et al. (2023). Although CALIOP has been taking measurements since 2006, we focus on the last decade to make sure that there is an overlap between various satellite and ground-based remote sensing products used for the purposes of WP2.

From the events listed in Table 1 below, we focus on the most recent two, demonstrating the degree of the impact of wildfire-associated pyroCb leading to enhanced stratospheric aerosol loading. The Pacific Northwest (PNW) event relates to smoke-infused thunderstorms coming about in the British Columbia, Canada as well as in the Washington state, United States on 12 August 2017, injecting between 0.1 -0.3 Tg of aerosol mass into the stratosphere (Peterson et al., 2018) and its plume was measured two days later from CALIPSO over north-east Canada at 12-14km. CALIPSO observations have shown that the smoke-infused plume reached Europe and circumnavigated the globe by the end of the month, affecting the entire Northern hemisphere stratosphere poleward of 30°N.

The most recent major wildfire event over the past decade took place in Southern Australia between 29 December 2019 – 4 January 2020 known as the Australian New Year (ANY) event. Multiple pyroCbs were developed over much of the continent leading to a massive injection of smoke into the stratosphere. The estimated mass of the aerosol injection is almost three times more than the PNW event ranging between 0.2 – 0.9 Tg (Khaykin et al., 2020). The smoke plumes during the first two weeks from the event were measured by CALIOP at 11-22 km, in much of the Southern Pacific Ocean, meaning that the plume was directed eastward, ultimately reaching altitudes of over 30km in February 2020. The smoke injection alongside water vapour deep into the stratosphere was accompanied by strong positive temperature anomaly due to enhanced absorption of solar radiation from the smoke particles. The impact of the ANY event highlighted the role of dynamics and heterogeneous chemistry to the observed mid-latitude and polar ozone depletion later that year (Solomon et al., 2022).

Event Name
Australian New Year (ANY) event, *Dec 2019–Jan 2020*
Pacific Northwest (PNW) event, *Aug 2017*
North American wildfires, *Jul 2014*
Australian bushfires, *Dec 2006*
Black Saturday Australian bushfires, *Feb 2009*
Siberian wildfires, *May 2012*

Siberian wildfires, *Jun 2007*	
Canadian wildfires, *Jul–Aug 2007*	

Table 1 Wildfire-associated smoke events reaching into the stratosphere as classified from the CALIOP v4.5 aerosol typing algorithm and sorted by the number (descending) of unique stratospheric aerosol layers in CALIOP.

Upon identifying the wildfire events that reach into the stratosphere, we use the Ozone Mapping and Profiler Suite Limb Profiler (OMPS-LP) on board the Suomi National Polar-orbiting Partnership (Suomi-NPP) measuring limb-scattered sunlight and provides aerosol extinction ratios at 6 different wavelengths spanning from mid-visible to near infrared as well as ozone profiles in 2012 (Pan et al., 2019). Additionally, we utilize the Aura Microwave Limb Sounder (MLS) version 5 (Livesey et al., 2006) which provides profiles of a suite of atmospheric trace gases, including ozone, water vapor, reservoir and reactive chlorine species, and several markers of biomass burning pollution.

In the section below we present some key figures pertaining to the two wildfire events detailed above. Figure 2 shows the Microwave Sounding Unit channel 4 (MSU4) vertical weighted average of the 745nm extinction ratio (aerosol/molecular) of the OMPS-LP for full available period 2012-2022 at the time of writing. Not accounting for the massive extinction ratio increase due to the Hunga Tonga–Hunga Haʻapai submarine volcanic eruption in February 2022, the ANY wildfires injection of sulphate aerosols into the stratosphere produces a longer-lived surge in the extinction ratio that is if not of a similar magnitude, stronger than the Calbuco eruption in mid-2015 and the Raikoke eruption in mid-2019.

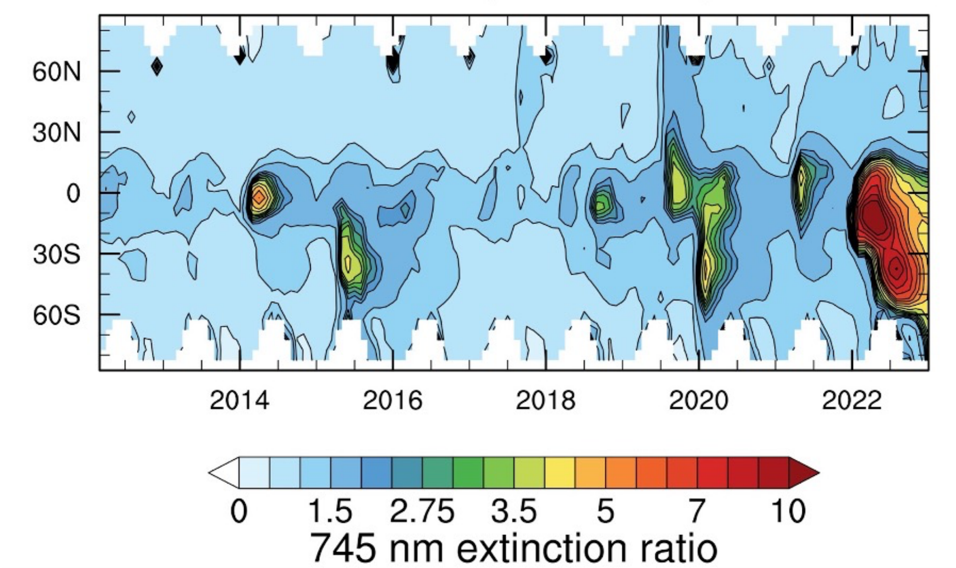

Figure 2 OMPS-LP level 3 monthly mean extinction ratio at 745 nm.

3.2. The Australian New Year event

A closer look to the ANY event as seen from the latitude/altitude cross sections of the extinction ratio at 745 and 510 nm in Figure 2, reveals that the plume at lower altitudes (up to ~13km) was confined in the mid-latitudes and then made its way towards the south pole by February/March 2020. However, higher up the sulphate plume moved equatorward within the first six months surpassing altitudes of 20km. The highest point of the plume impacts as measured by OMPS-LP was located at the same latitude of the initial injection at an altitude of ~31-32km.

The plume of the ANY massive pyroCbs injected into the stratosphere a large quantity of water vapour as seen in Figure 3. MLS data show that a positive anomaly of up to ~ 1ppm (~20-25%) was observed in altitudes below 20km that persisted for more than six months. This positive water vapour anomaly moved equatorwards soon after the event and crossed the tropics to reach the Northern Hemisphere (NH) mid-latitudes within six months of the event showcasing the climate impacts of wildfire stratospheric injections of this scale. The MLS data also show a minor O3 depletion in the lower stratosphere (LS) Southern Hemisphere (SH) mid-latitudes that was not-linked to transport processes; instead associated with enhanced and newly activated ClO concentrations albeit an unprecedented and prolonged HCL depletion (>50%) highlighting the impact of heterogeneous chemistry onto the smoke particles that reached the stratosphere (Santee et al. 2022).

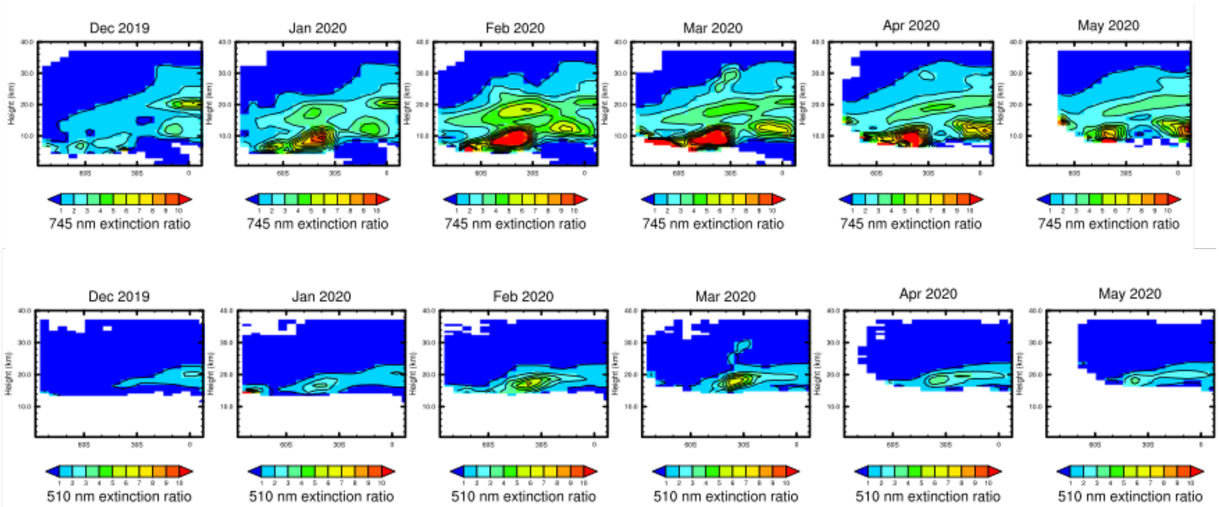

Figure 3 Latitude/altitude cross sections of OMPS-LP level 3 monthly mean extinction ratio at 745 nm (top row) and 510 nm (bottom row) for the first 6-months of the ANY wildfire event.

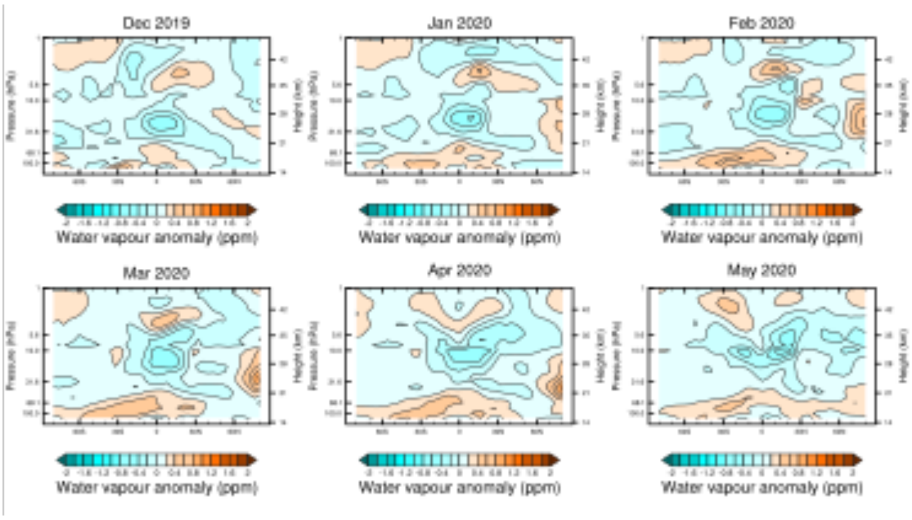

Figure 4 Latitude/pressure cross sections of MLS v5 level 3 monthly mean water vapor anomalies (wrt 2005-2019 climatology) for the first 6-months of the ANY wildfire event.

3.3. The Pacific NorthWest event

In a similar fashion to the analysis presented for the ANY wildfire event, Figure 5 shows the OMPS-LP extinction ratio for two wavelengths for the PNW event. The eruption in August 2017, injected smoke particles into the stratosphere at altitudes up to ~20km. The extinction ratio at 745 nm reached its maximum value (~2.5) in September 2017 as it moved upwards and polewards after a short period of time. The magnitude of this event is not quite comparable to ANY however, it showcases that even smaller scale pyroCbs exhibit the capacity to significantly impact the stratosphere across shorter time-scales. Finally, as seen in the MLS water vapour data in Figure 6, the water vapour anomaly amplitude reached values of 0.5 ppm which is roughly within the envelope of interannual variations in the lower stratosphere. Unlike ANY event the relatively enhanced water vapour in the vicinity dissipated rather quickly and it was well confined below the 20 km altitude level as expected due to the lower injection height of the smoke plume.

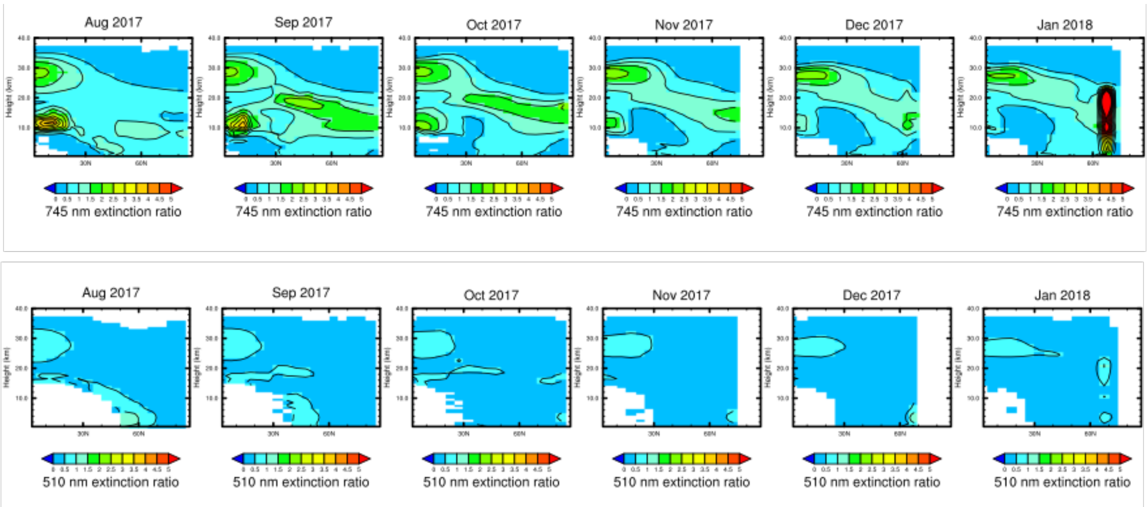

Figure 5 Latitude/altitude cross sections of OMPS-LP level 3 monthly mean extinction ratio at 745 nm (top row) and 510 nm (bottom row) for the first 6-months of the PNW wildfire event.

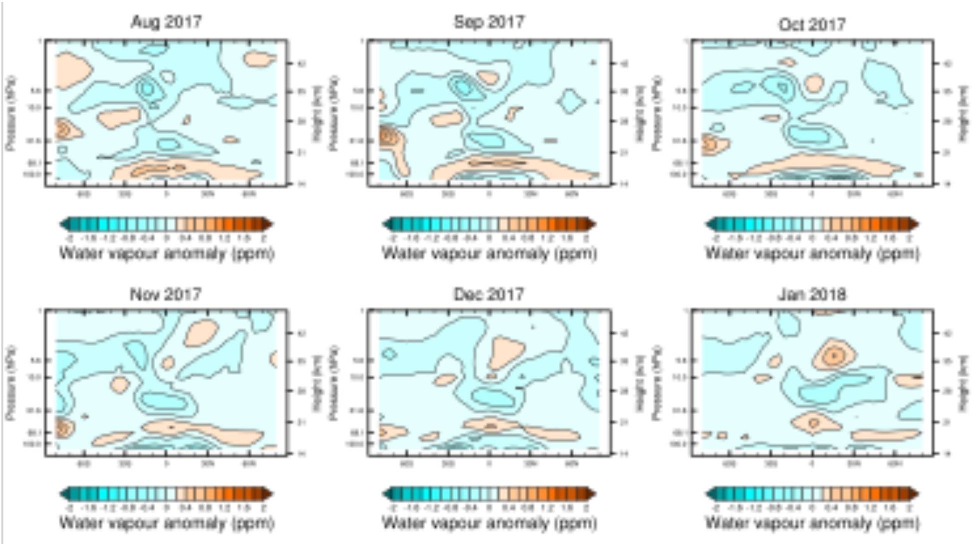

Figure 6 Latitude/pressure cross sections of MLS v5 level 3 monthly mean water vapor anomalies (wrt 2005-2019 climatology) for the first 6-months of the PNW wildfire even