Towards a better understanding of variability and long-term evolution of stratospheric aerosol load

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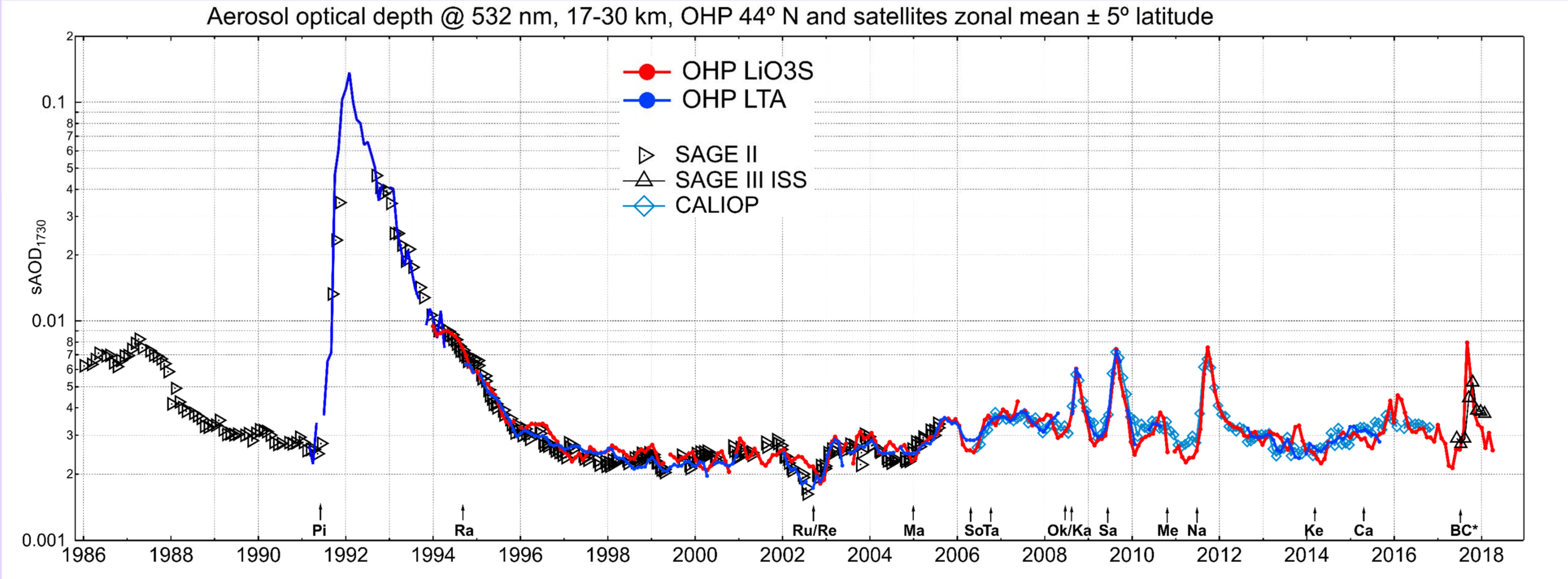
With contributions from *J.-P. Vernier, A. Bourassa, C. Bingen, M. DeLand, P.K. Bhartia*

3 decades of stratospheric aerosol observations by OHP lidars and satellites



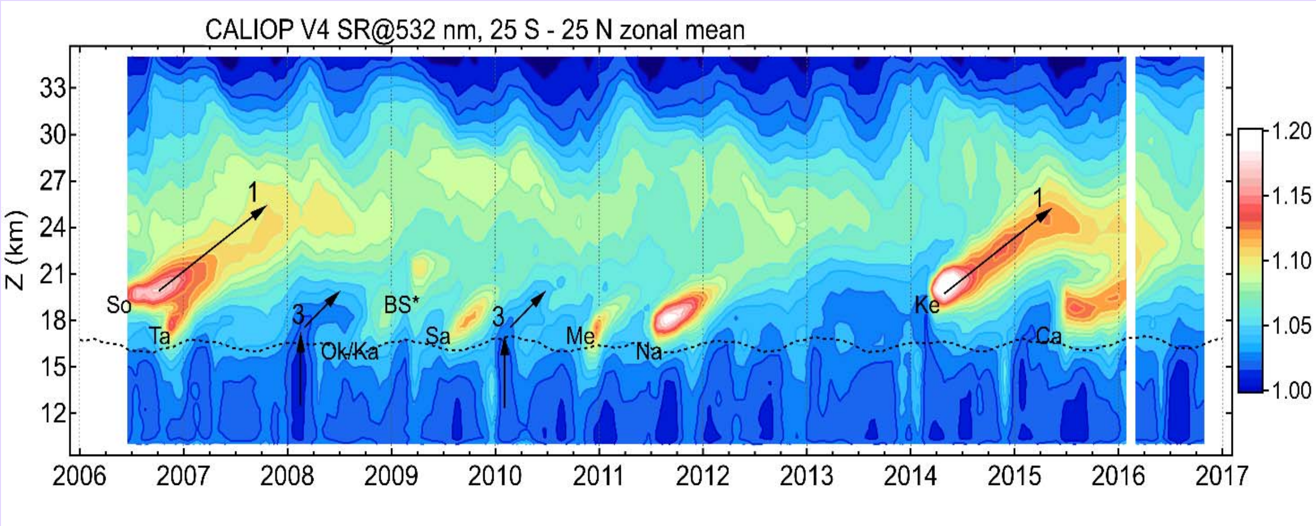
The sAOD record can be segregated into 3 periods

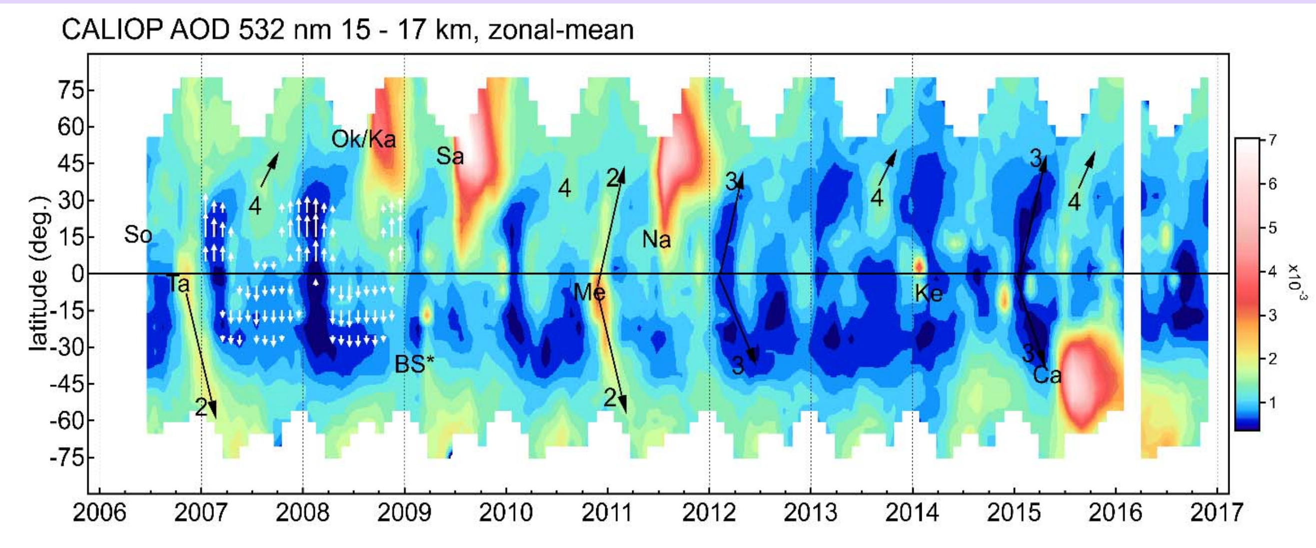
1) Pinatubo period spanning nearly 6 years since mid-1991;

2) volcanically-quiescent period 1997 – 2002, during which sAOD remains at background levels;

3) period of relatively frequent moderate eruptions at different latitudes in both hemispheres since 2002 with short interludes between the eruptions when sAOD attains background levels.

Processes controlling global distribution of stratospheric aerosol

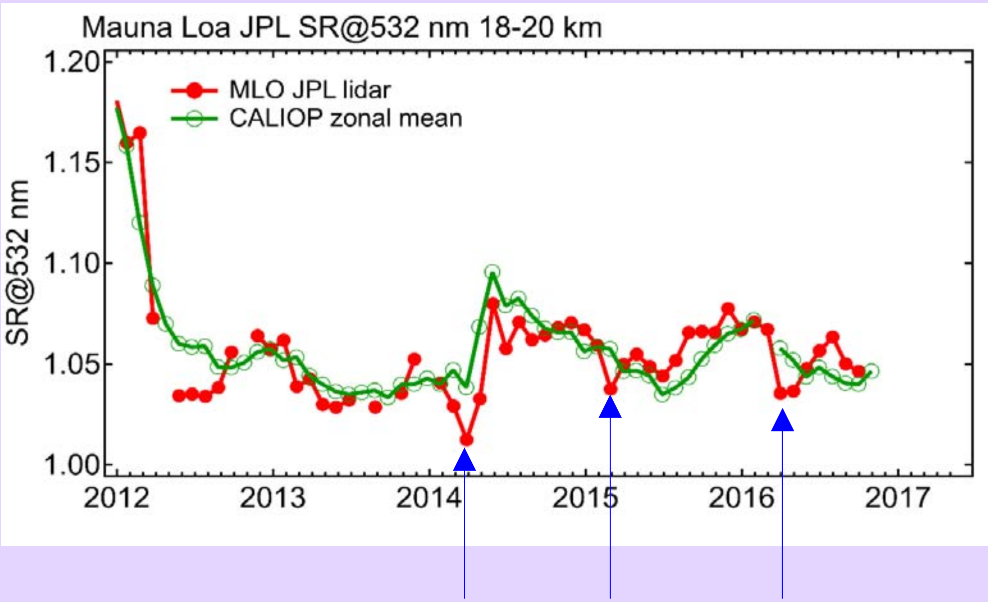


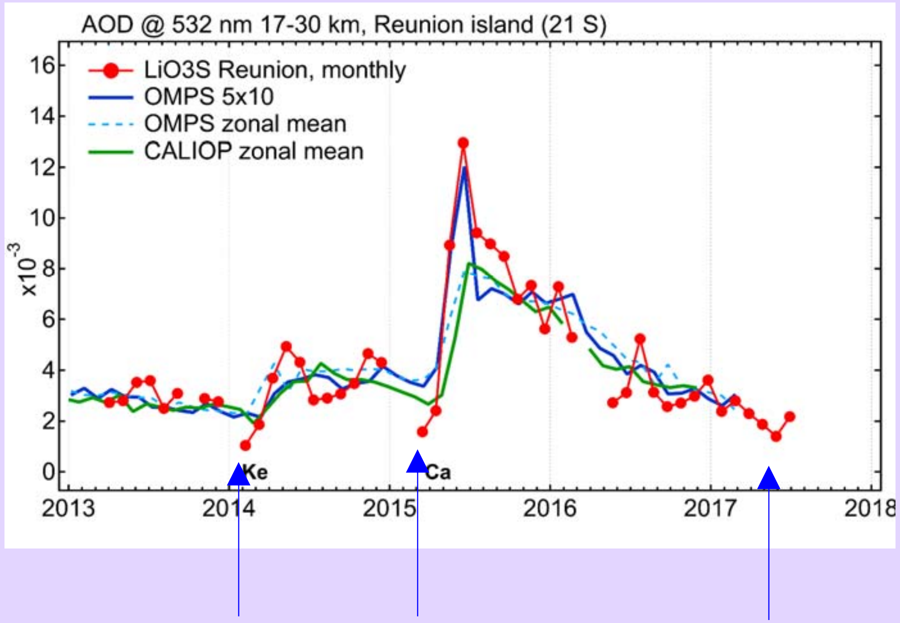


1. Slow uplift of volcanic plumes in the upward branch of the BDC
2. Two-way meridional transport of volcanic plumes and its modulation by QBO
3. Rapid cleansing of the TTL during Austral summer followed by further ascent of clean air in the stratosphere and its poleward transport
4. Asian Tropopause Aerosol Layer (ATAL) occurring during boreal summer and propagating northward

Processes controlling global distribution of stratospheric aerosol

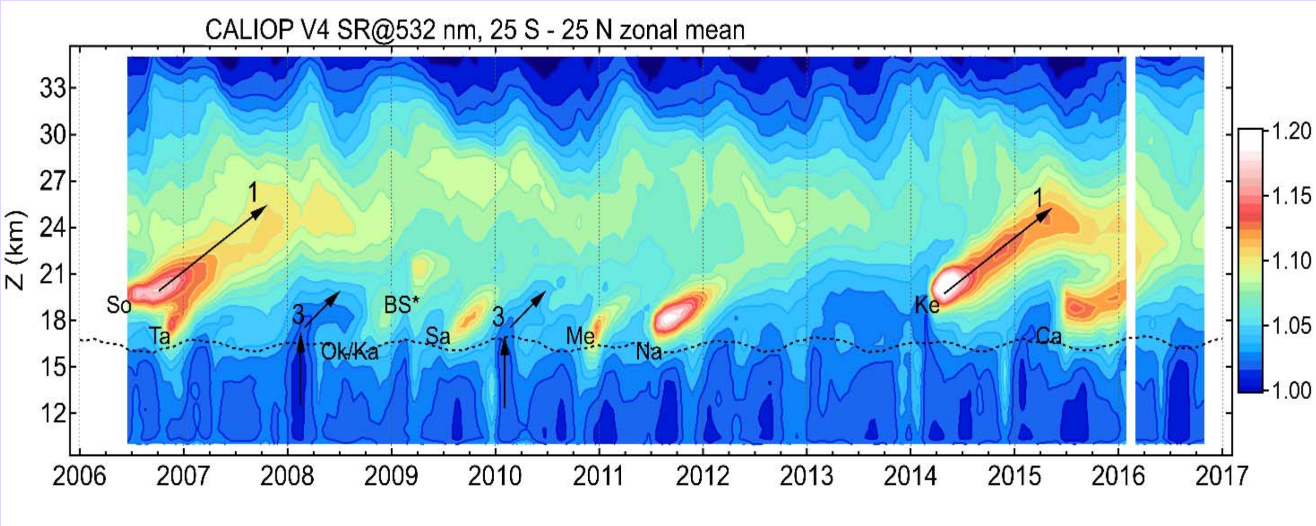
Aerosol observations at two tropical NDACC sites: Mauna Loa and Maido

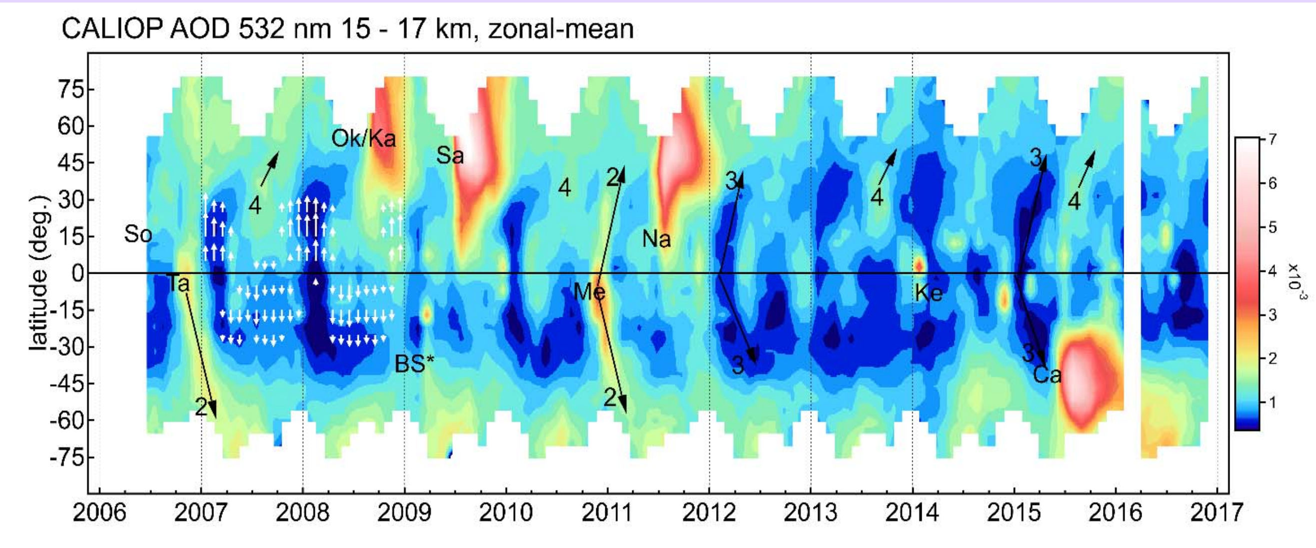




Systematic aerosol minimum in Austral summer due to convective cross-tropopause transport of clean air (cleansing)

Processes controlling global distribution of stratospheric aerosol





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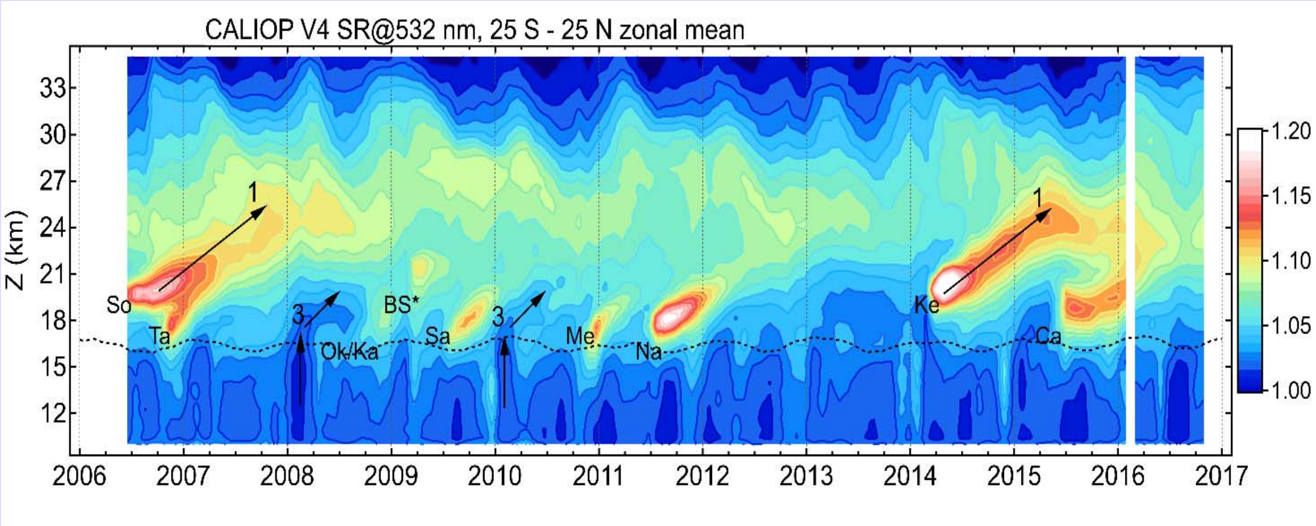
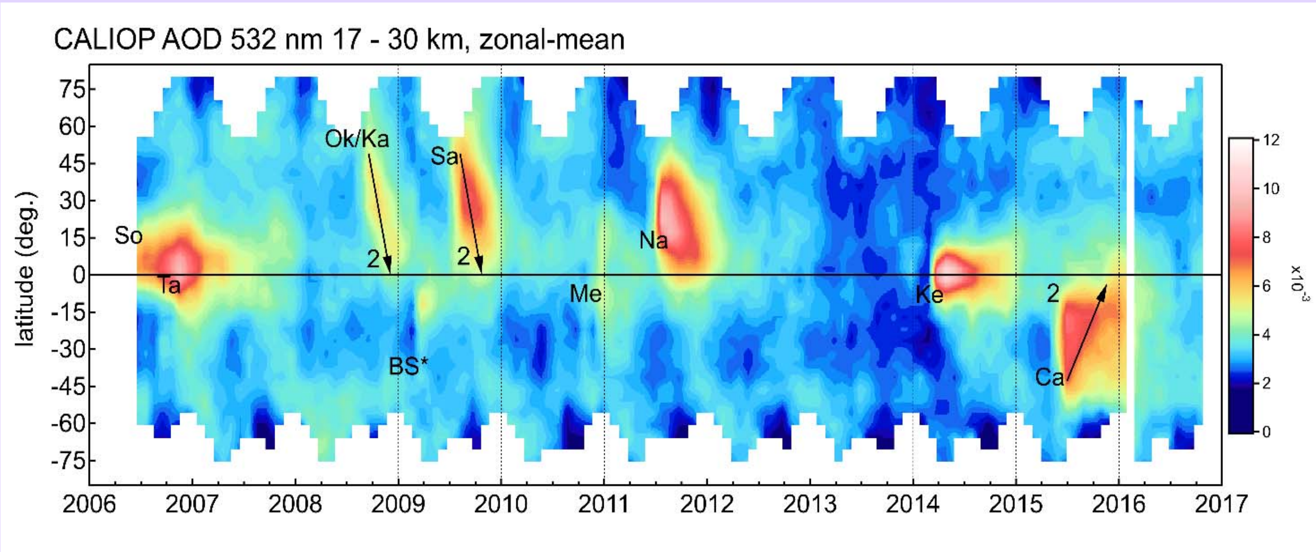
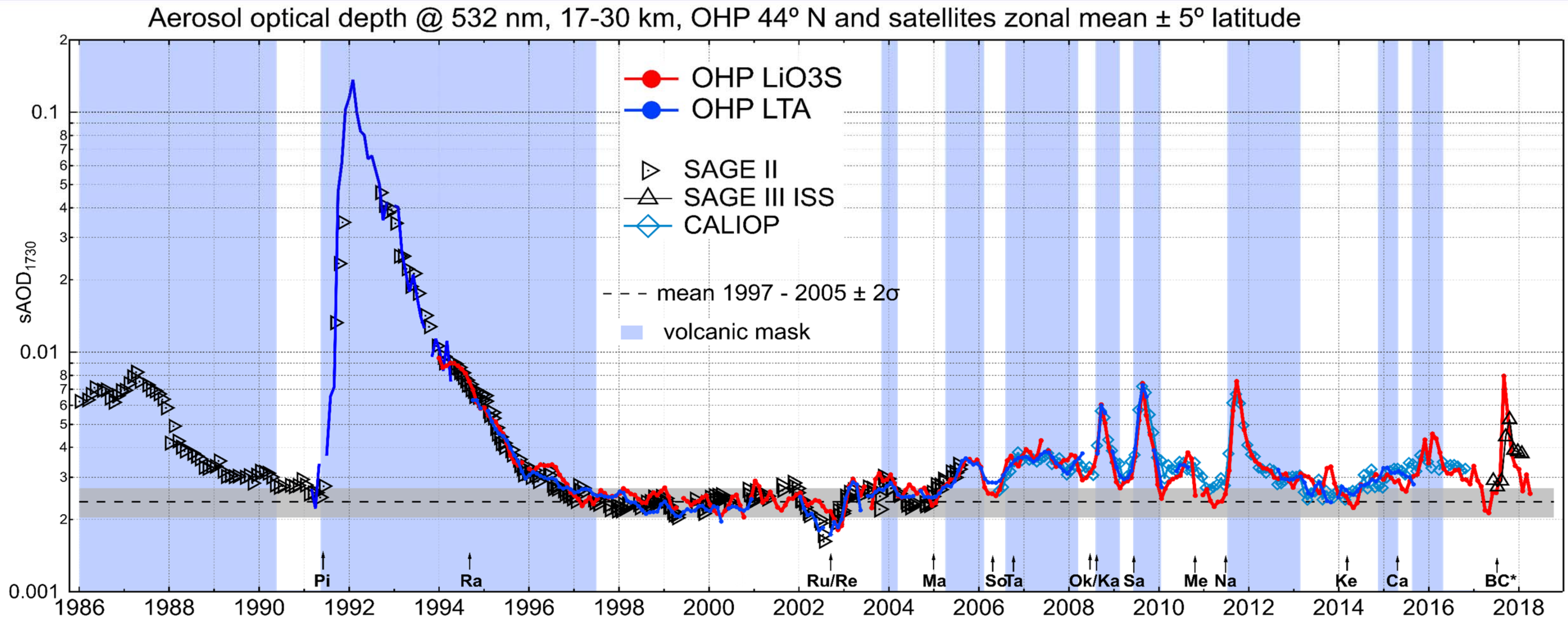
Processes controlling global distribution of stratospheric aerosol





1. Slow uplift of volcanic plumes in the upward branch of the BDC (e.g. Vernier et al., 2009)
2. Two-way meridional transport of volcanic plumes and its modulation by QBO (e.g. Trepte and Hitchman, 1992)
3. Rapid cleansing of the TTL during Austral summer (Vernier et al., 2011b) followed by further ascent of clean air in the stratosphere and its poleward transport (Khaykin et al., 2017a)
4. Asian Tropopause Aerosol Layer (ATAL) occurring during boreal summer (Vernier et al., 2011c) and propagating northward (Khaykin et al., 2017a)

3 decades of stratospheric aerosol observations by OHP lidars and satellites

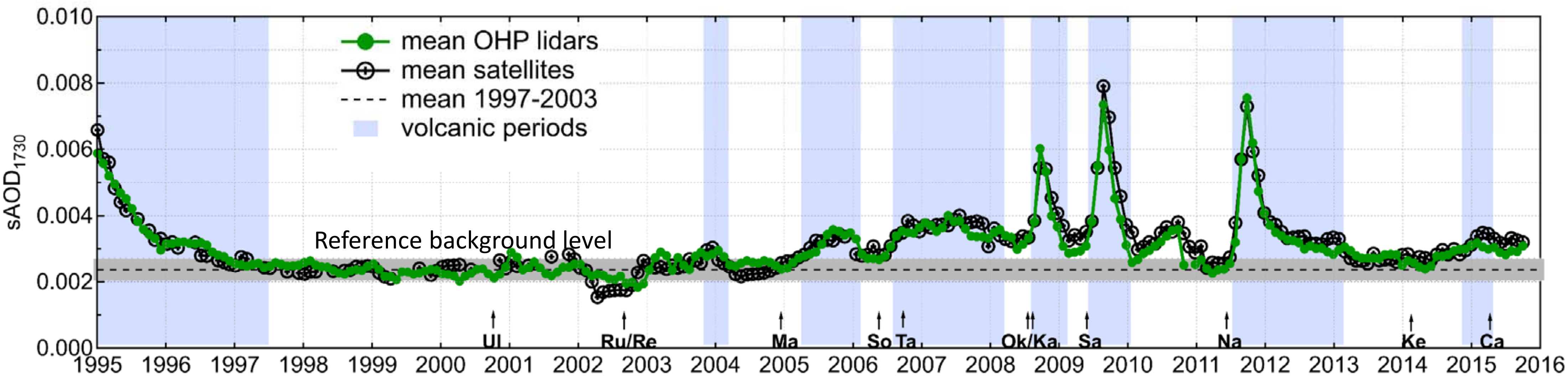


- ✓ A combination of local and global observations was used to separate between volcanically-perturbed and quiescent periods
- ✓ No satellite records both the 1996-2003 quiescent period and a variable post-2003 period
- ✓ Accurate detection of background levels of stratospheric aerosol is challenging

OHP lidar observations: detection of quiescent periods

Stratospheric Aerosol Optical Depth 17-30 km ($sAOD_{1730}$) @ 532 nm

Mean of 2 **OHP lidars** and 5 **satellites** (SAGE II, GOMOS, OSIRIS, CALIOP, OMPS)

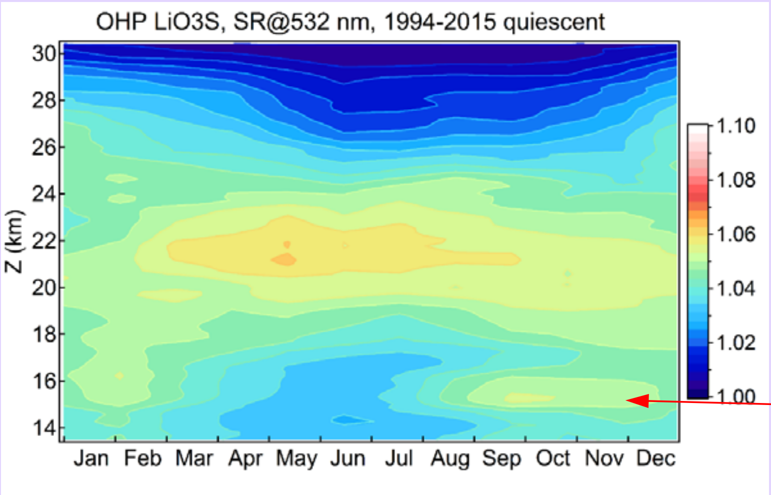


- ✓ "Reference" background level of sAOD at mid-latitudes accurately determined
- ✓ Is there a change a long-term change in background aerosol level ?

Khaykin et al., ACP, 2017

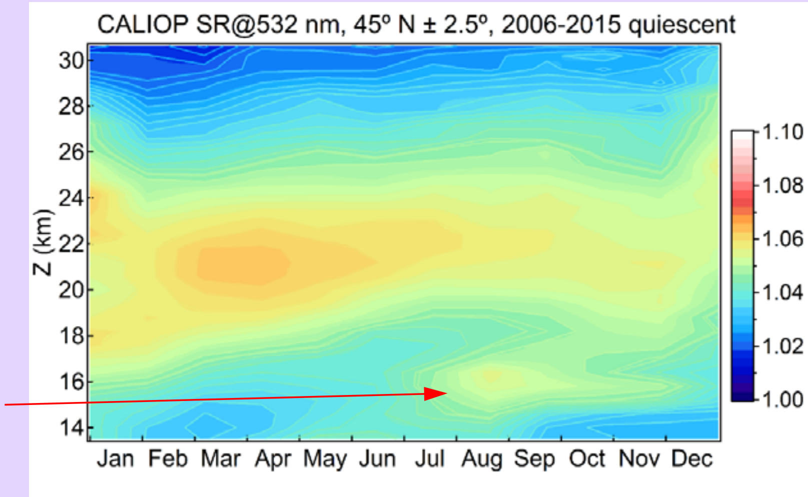
Aerosol annual cycle and long-term change

OHP lidar, volcanoes cleared

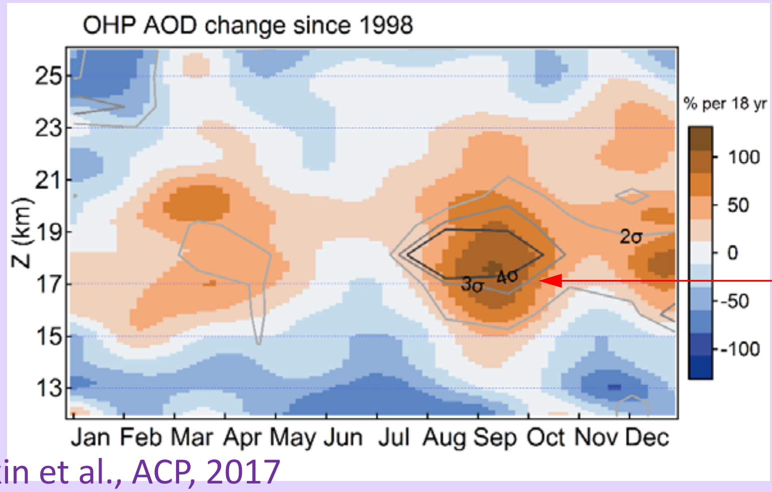


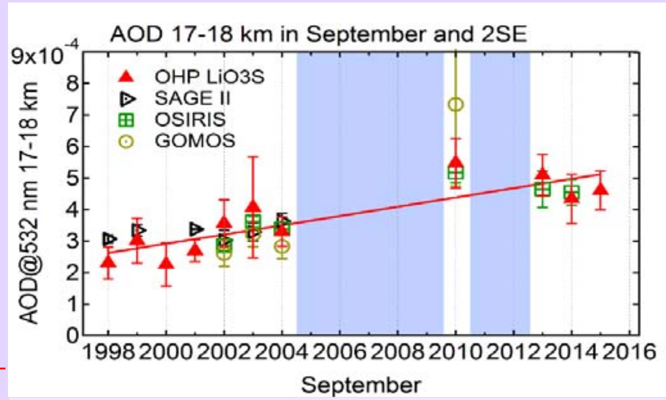
ex-ATAL

CALIOP, 40-50°N volcanoes cleared



Background aerosol long-term change

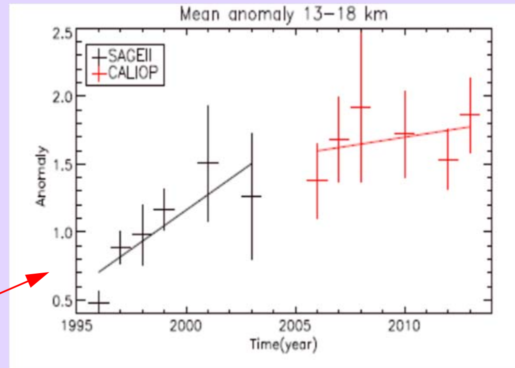




Statistically significant 2 times increase of midlatitudes LS AOD in early Fall

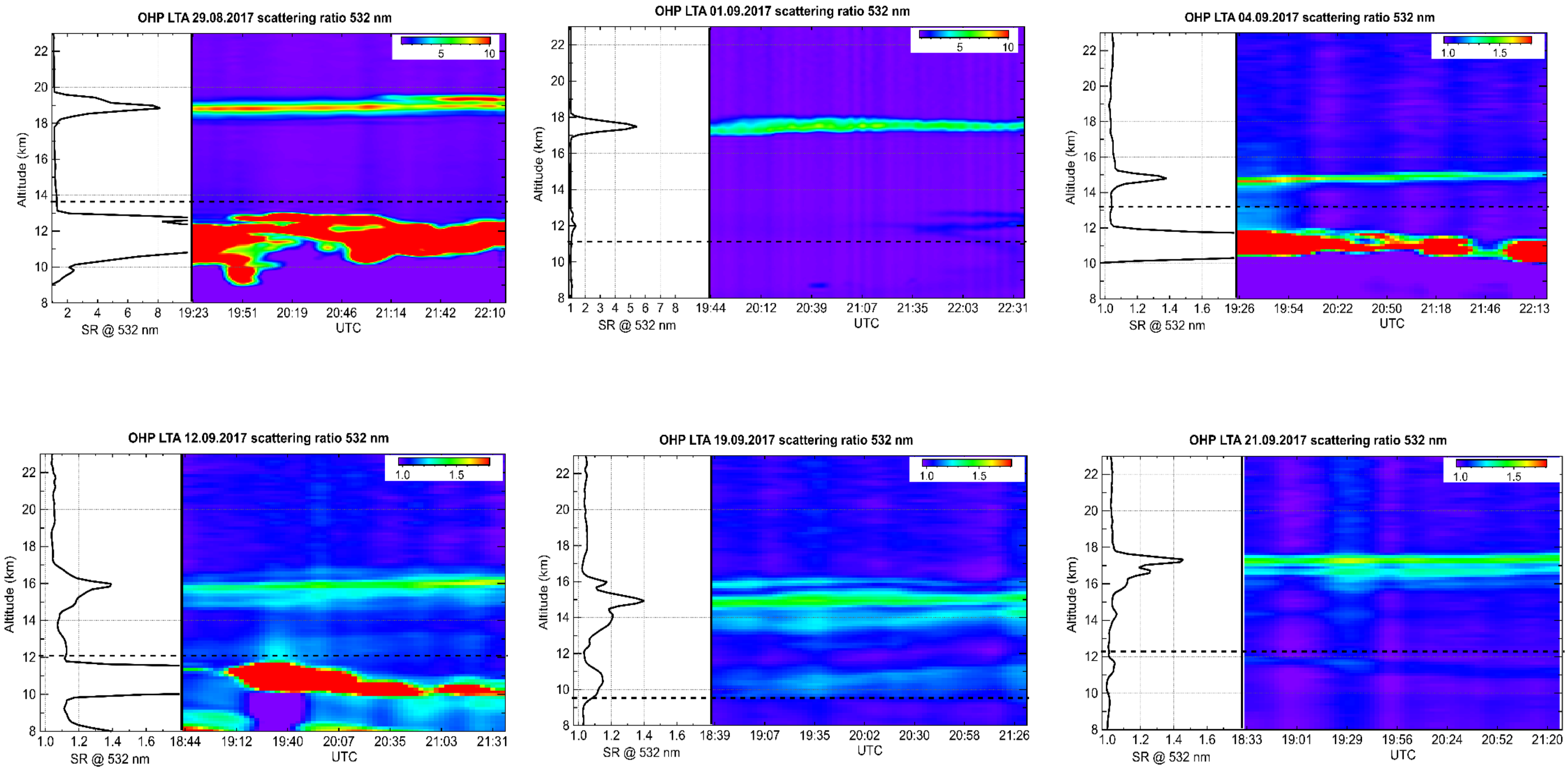
Consistent with 3 times increase of ATAL AOD reported by Vernier et al., 2015

Summer/winter ratio of AOD 13-18 km above Eastern Mediterranean

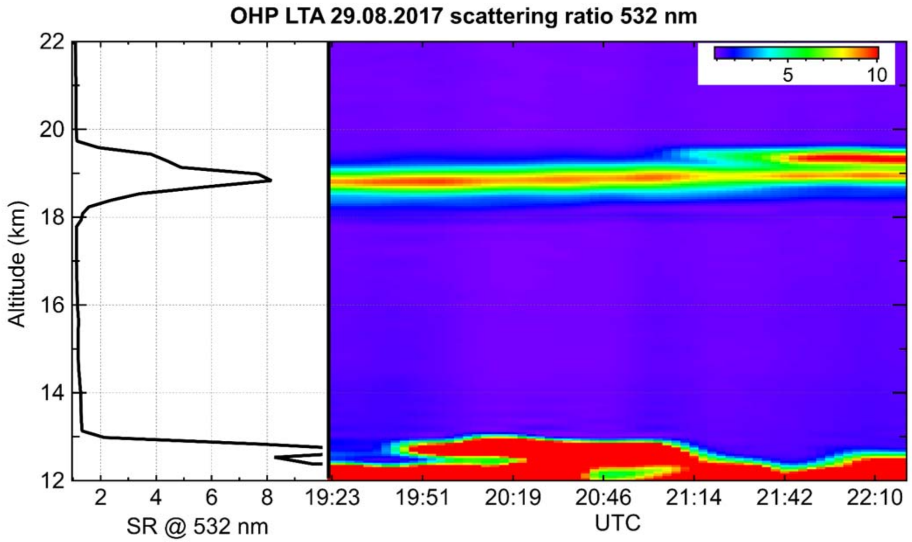


Khaykin et al., ACP, 2017

Detection of stratospheric smoke plumes at OHP



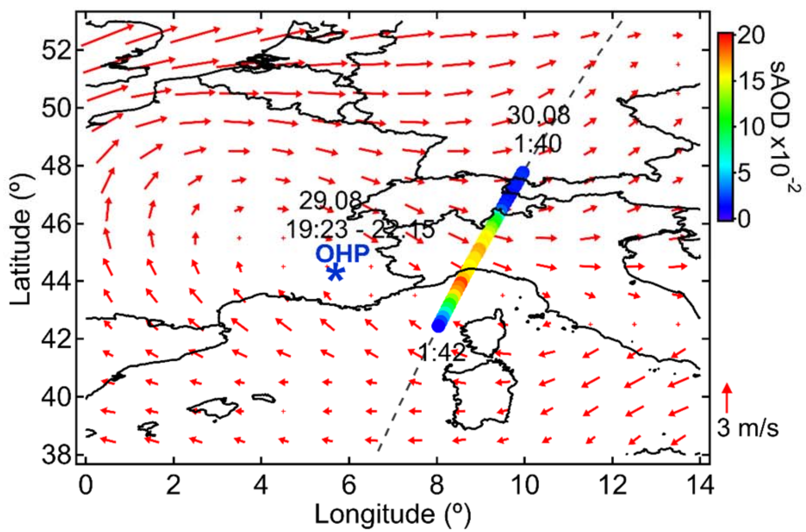
Impact of August 2017 NA wildfires on stratospheric aerosol load

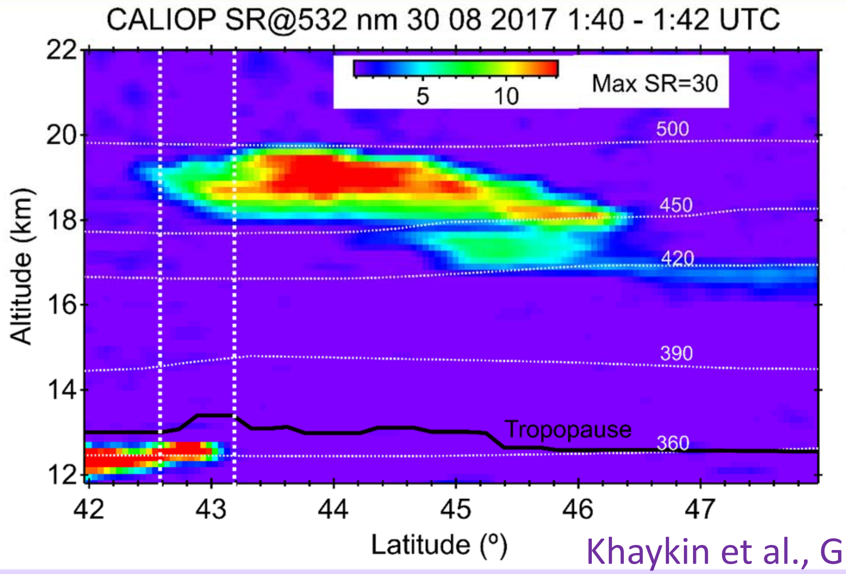


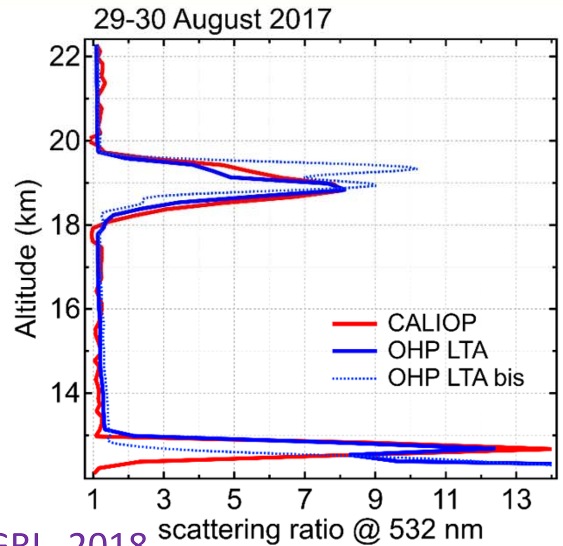
- Stratospheric smoke plumes with unprecedentedly high SR detected at OHP in August-September 2017
- Plumes are traceable to PyroCBs in North America
- Smoke plumes at different levels above OHP through November

Cross-sampling of the same smoke cloud by OHP lidar and CALIOP

Excellent agreement between GB and space lidars



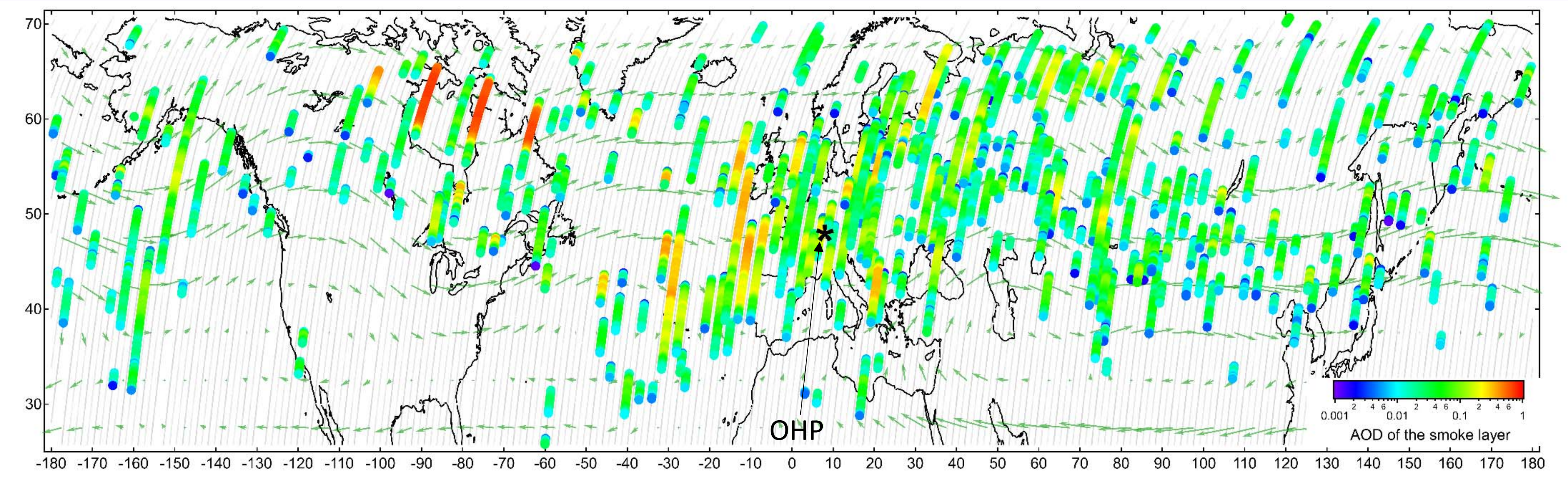




Khaykin et al., GRL, 2018

Impact of August 2017 NA wildfires on stratospheric aerosol load

Locations of stratospheric smoke layer detected by CALIOP nighttime observations (16 Aug – 03 Sep)

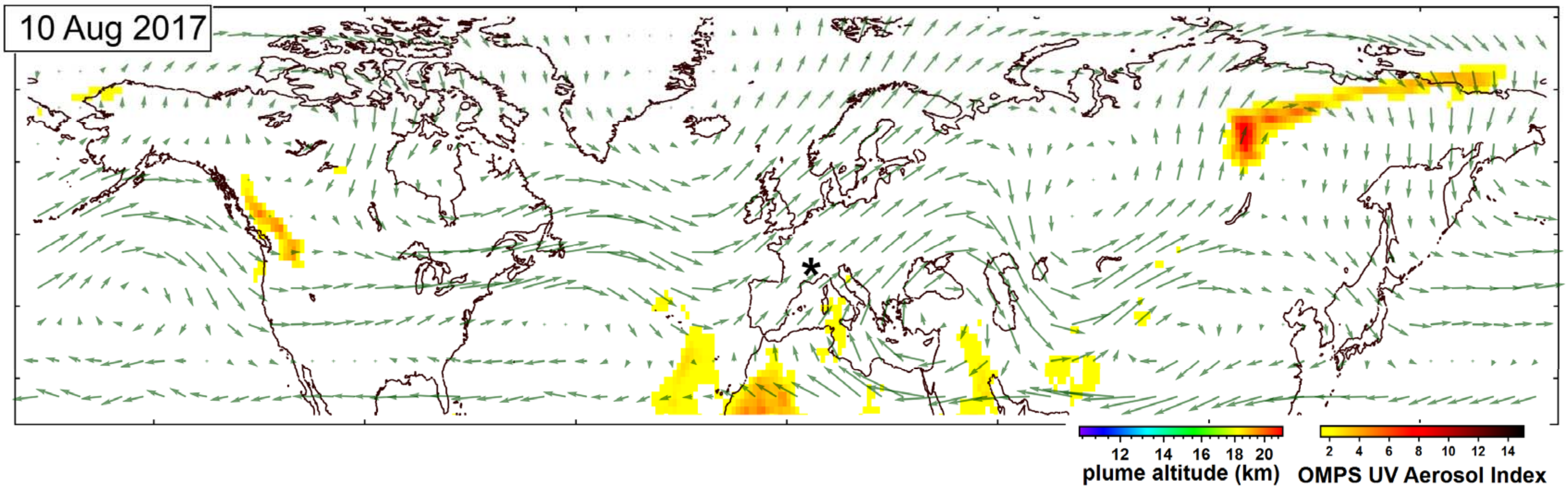


- AOD of the stratospheric smoke plume reaching 1 (0.2 – 0.5 above Europe)
- Rapid hemispheric dispersion and entrainment by Asian monsoon

Khaykin et al., GRL, 2018

Impact of August 2017 NA wildfires on stratospheric aerosol load

OMPS UV aerosol index and CALIOP smoke detections



- Several patches of plumes at different levels travelling at different speed
- Forefront plume reaches Europe in a few days
- Smoke plume crossed the globe in about two weeks and dispersed at hemispheric scale
- Additional injections by PyroCbs in Northwest USA in late August

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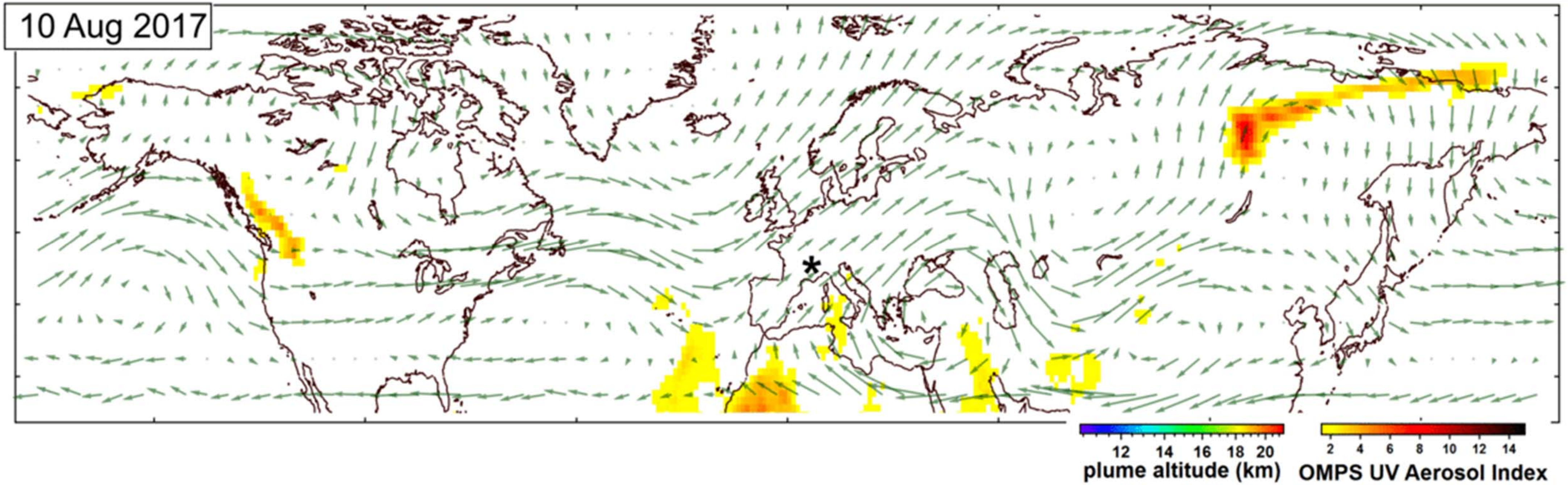

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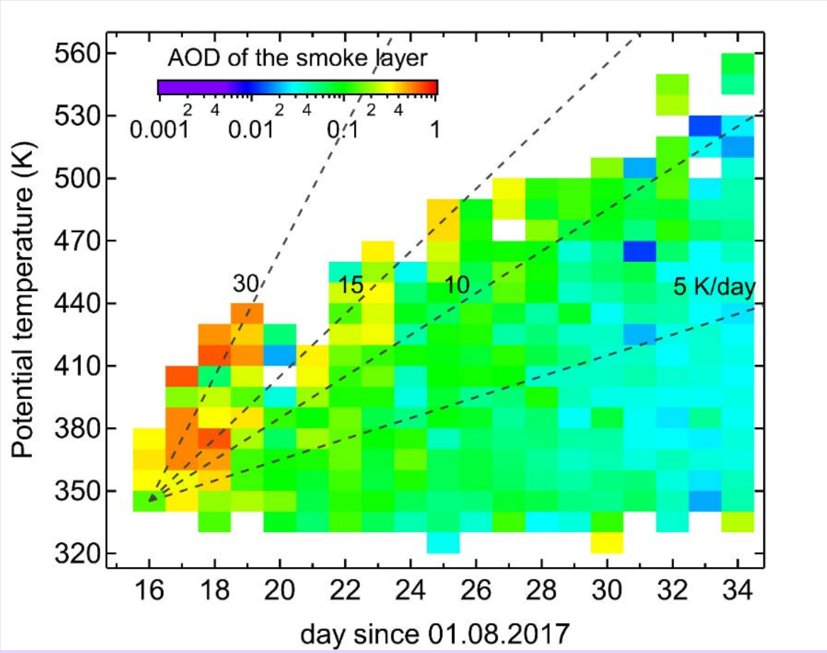
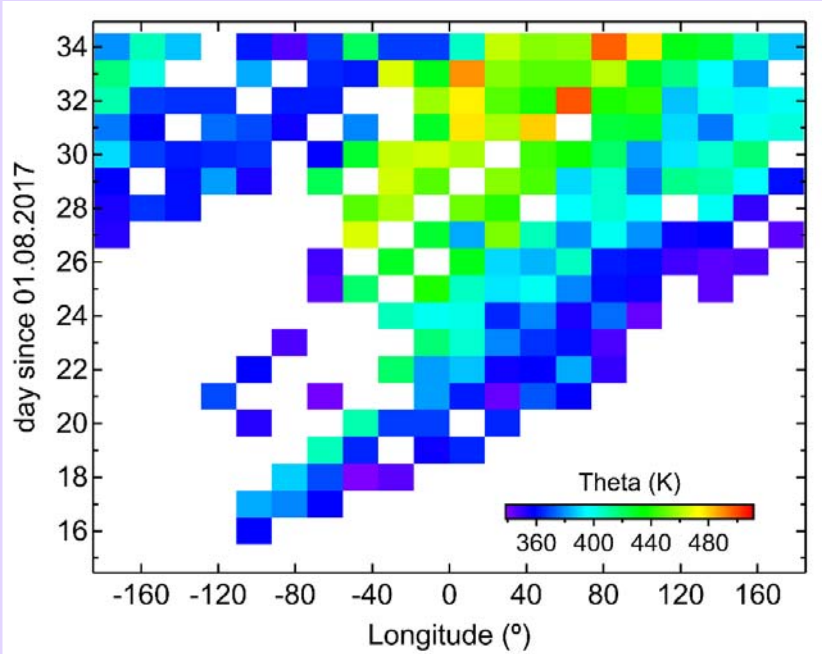
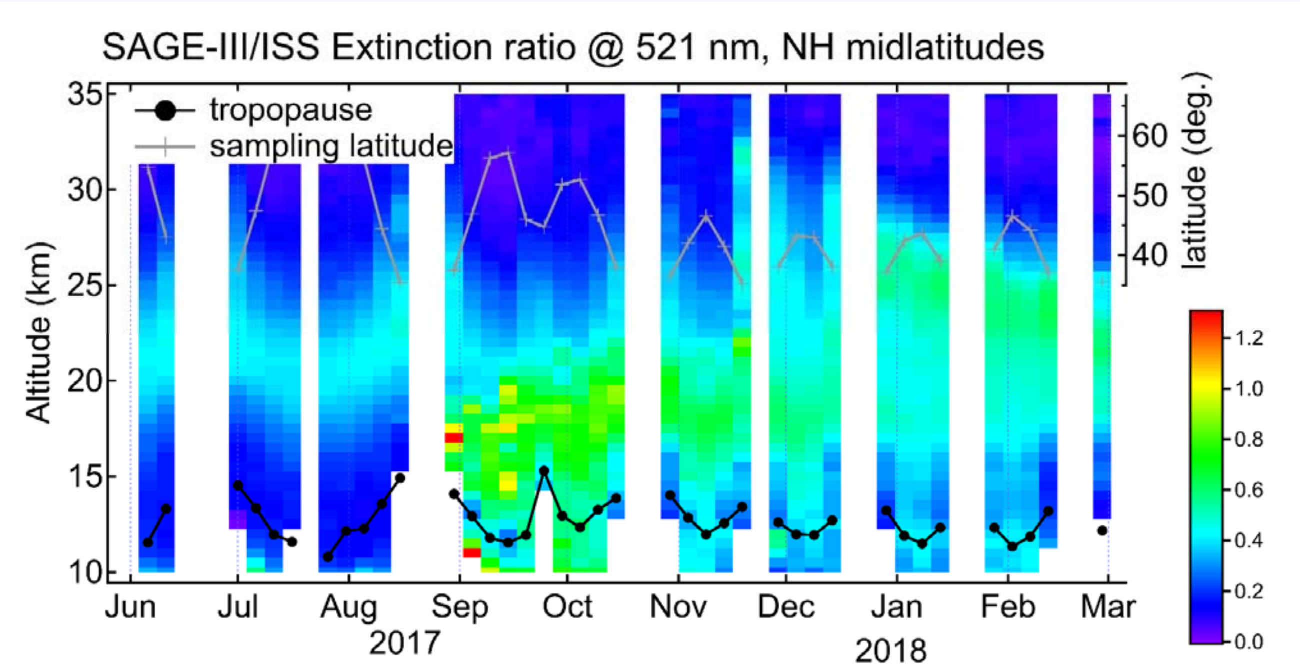


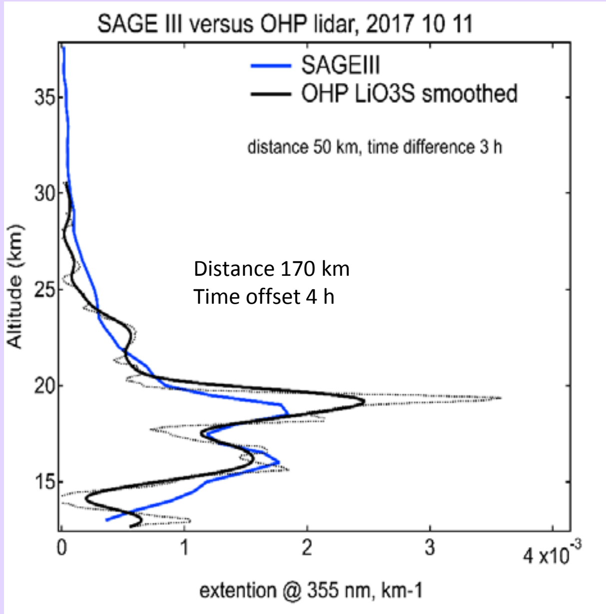


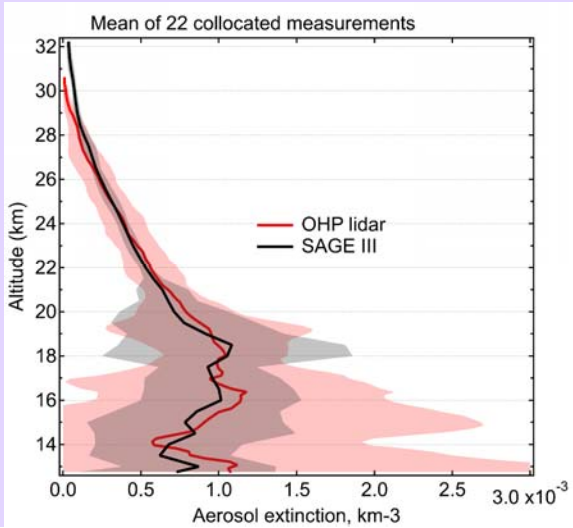
- Rapid ascent of the smoke plumes through radiative heating by up to 30 K/day
- Vertical excursion of up to 12 km (340 to 560 K)

Zonal-temporal evolution of the smoke plume detected by CALIOP with color coding by potential temperature of maximum SR within the smoke layer.

SAGE III observations of smoke

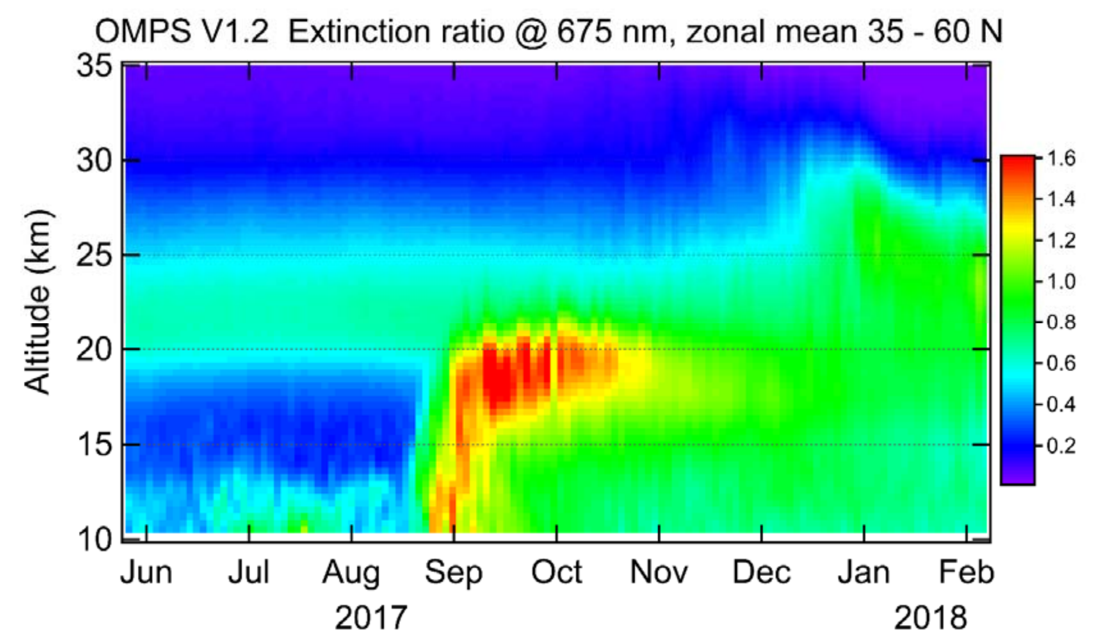


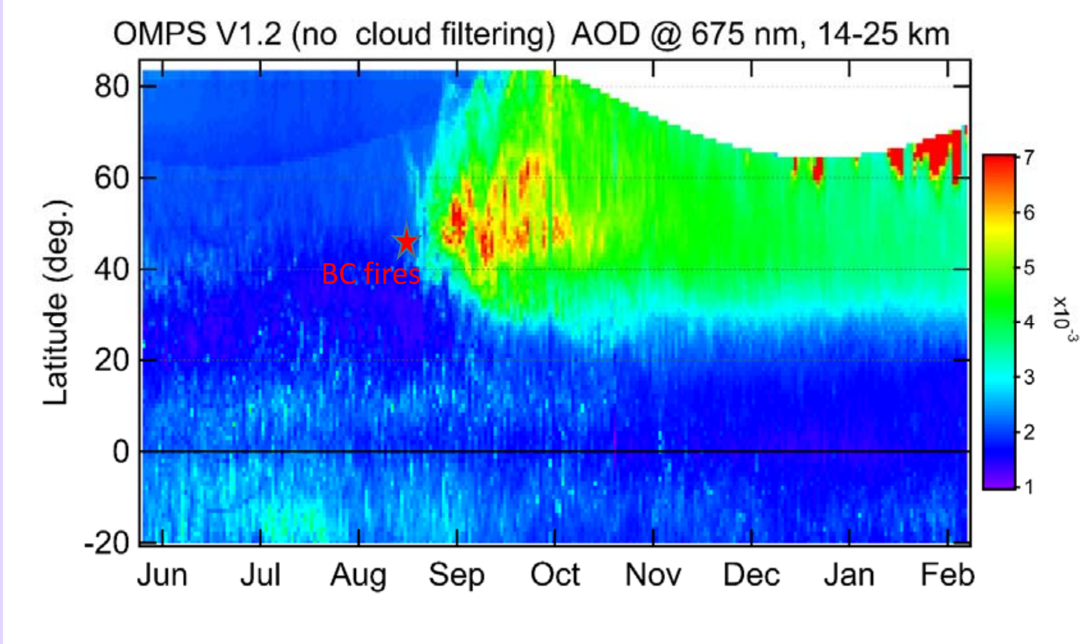




- **Radiative ascent of the smoke seen by SAGE III**
- **Collocated observations of smoke plumes by SAGE III and OHP lidars**
- **Good agreement and constraint for lidar ratio**

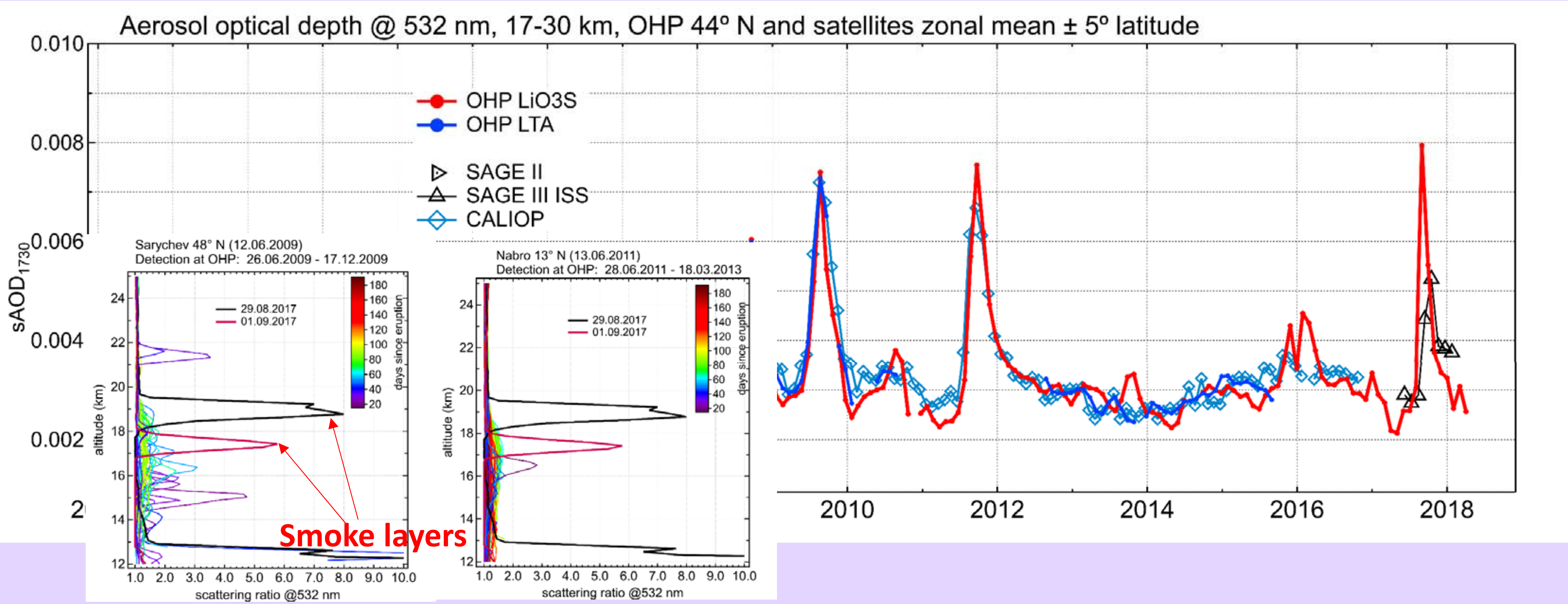
OMPS LP V1.2 (unfiltered) observations of smoke





- **Radiative ascent and hemisphere-scale dispersion of the smoke seen by OMPS**
- **Smoke has been most certainly entrained in the Arctic vortex but did not penetrate into the tropics**
- **Smoke persisted in the stratosphere for 6+ months**

Impact of August 2017 NA wildfires on stratospheric aerosol load



- On a monthly scale, the stratospheric AOD perturbation caused by PyroCb events in British Columbia is similar to that of moderate volcanic eruptions
- Stratospheric smoke plumes detected by OHP lidars had stronger scattering than volcanic plumes from Sarychev and Nabro eruptions

Summary

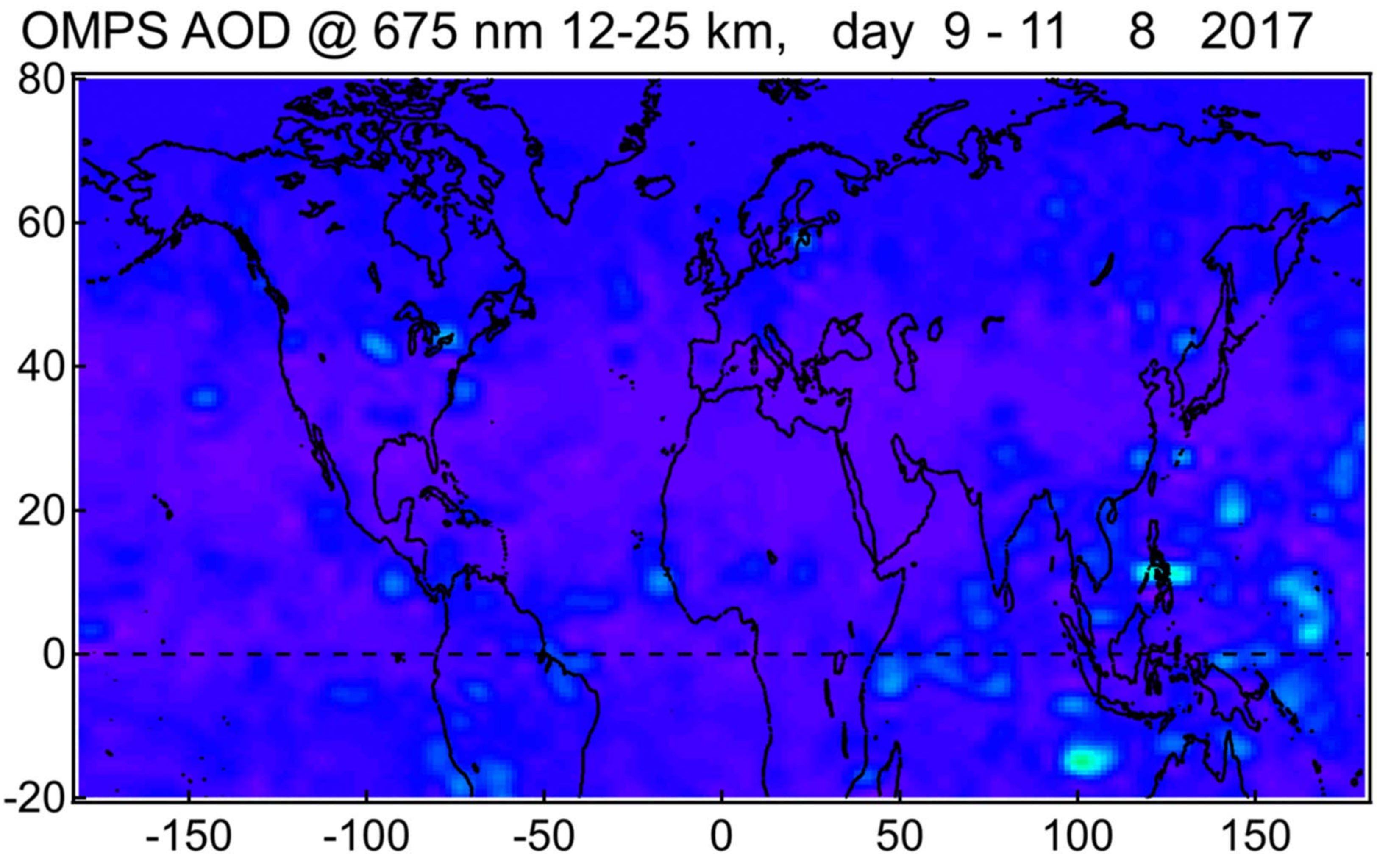
- ✓ **Combination of GB lidar and satellite observations allowed identifying the drivers of background SA and its long-term evolution**
- ✓ **Annual cycle of LS mid-latitude background SA is modulated by poleward transport of clean air from the deep tropics and polluted air from ASM**
- ✓ **Doubling of ex-ATAL AOD detected by OHP lidars**
- ✓ **Stratospheric smoke plumes detected by ground-based and spaceborne lidars featured unprecedentedly high backscatter and aerosol optical depth**
- ✓ **Summer 2017 wildfires had a hemisphere-scale impact on SA load similar to that of moderate volcanic eruptions**
- ✓ **Long-term lidar observations by ground-based are indispensable for ensuring the continuity of stratospheric aerosol climate record**
- ✓ **Further effort is required to secure high quality of NDACC aerosol data records : systematic and rigorous quality control, cross-validation, use of satellite data…**

Further information:

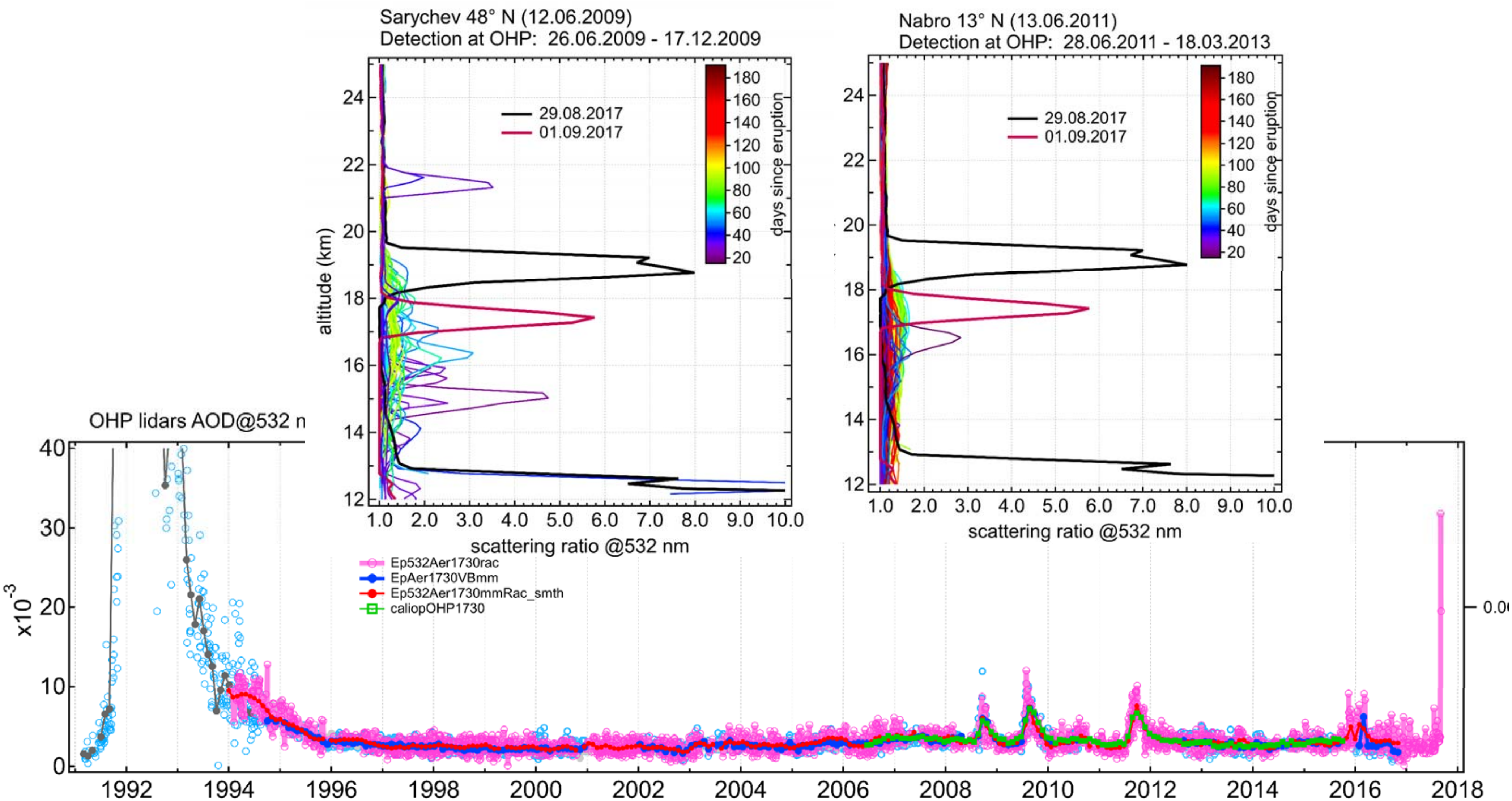
Khaykin et al., *Variability and evolution of the midlatitude stratospheric aerosol budget from 22 years of ground-based lidar and satellite observations*, Atmos. Chem. Phys., 2017

Khaykin et al., *Stratospheric smoke with unprecedentedly high backscatter observed by lidars above southern France*, Geophys. Res. Lett., 2018

OMPS LP V1.2 (unfiltered) observations of smoke



Supplementary material



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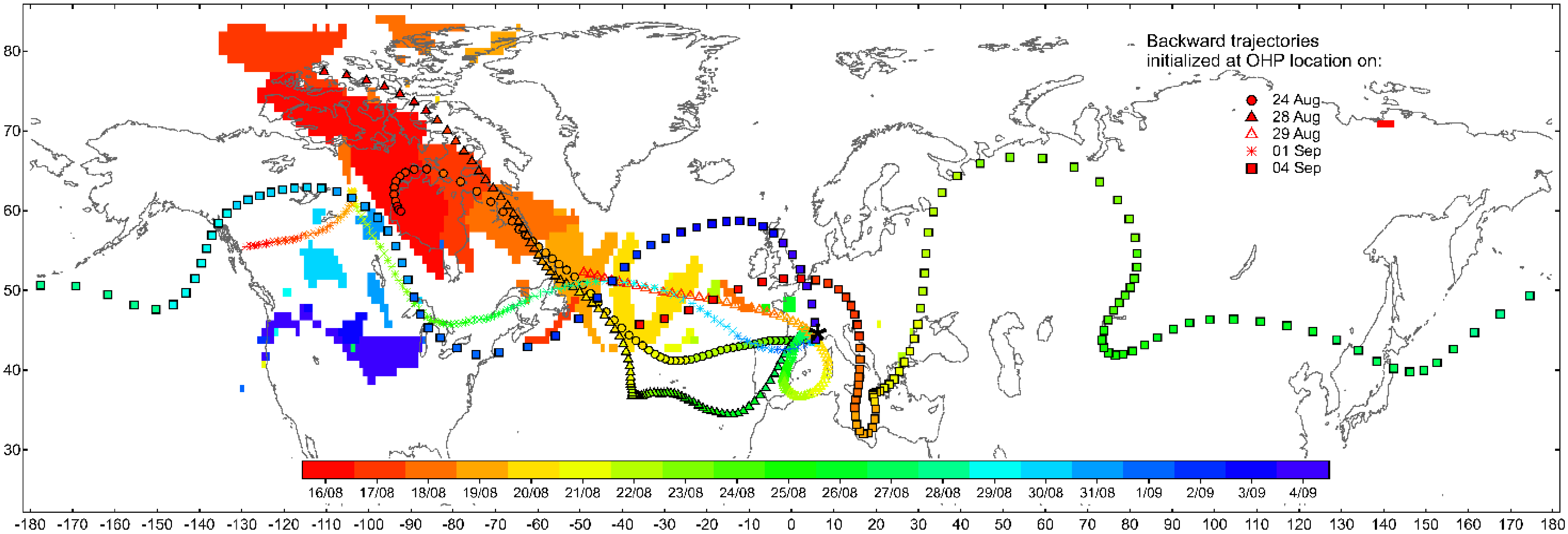
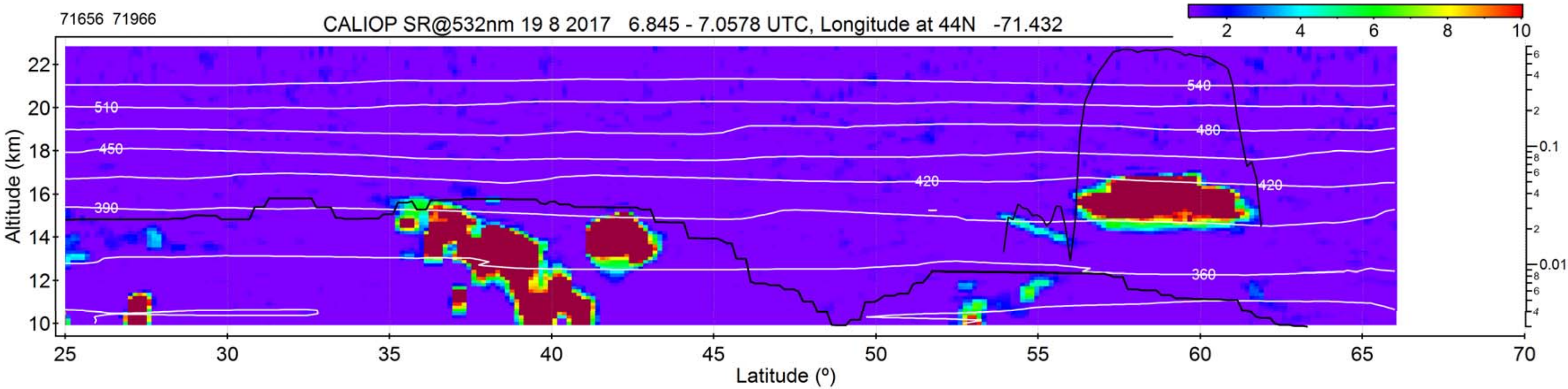
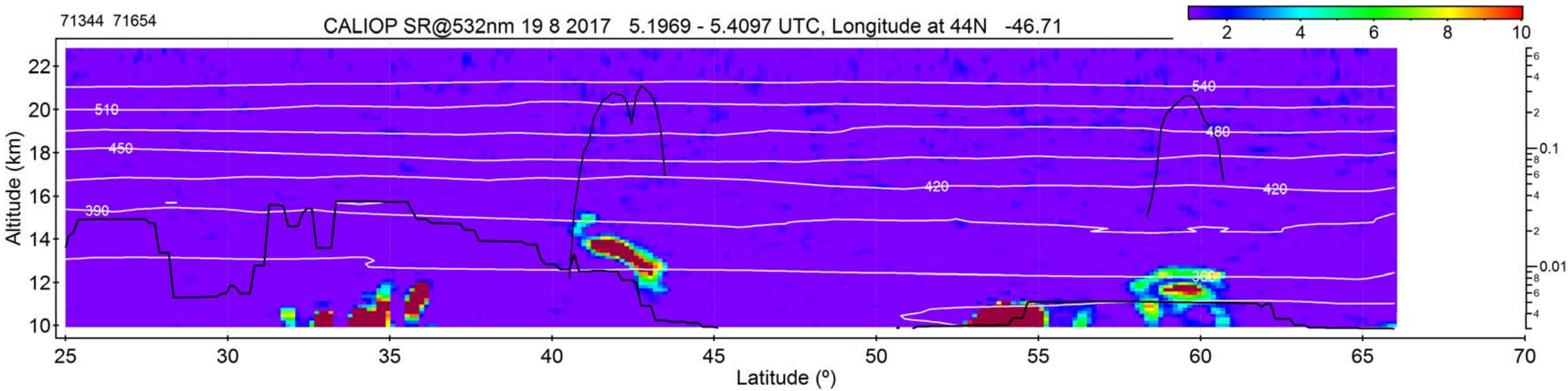


. Backward trajectories initialized at OHP (black asterix) on the dates of lidar detections of stratospheric smoke at the level of layer's SR maximum. Shaded areas indicate the locations where OMPS recorded AI exceeding 7. Trajectories and AI>7 areas are color–coded by date.

Supplementary material





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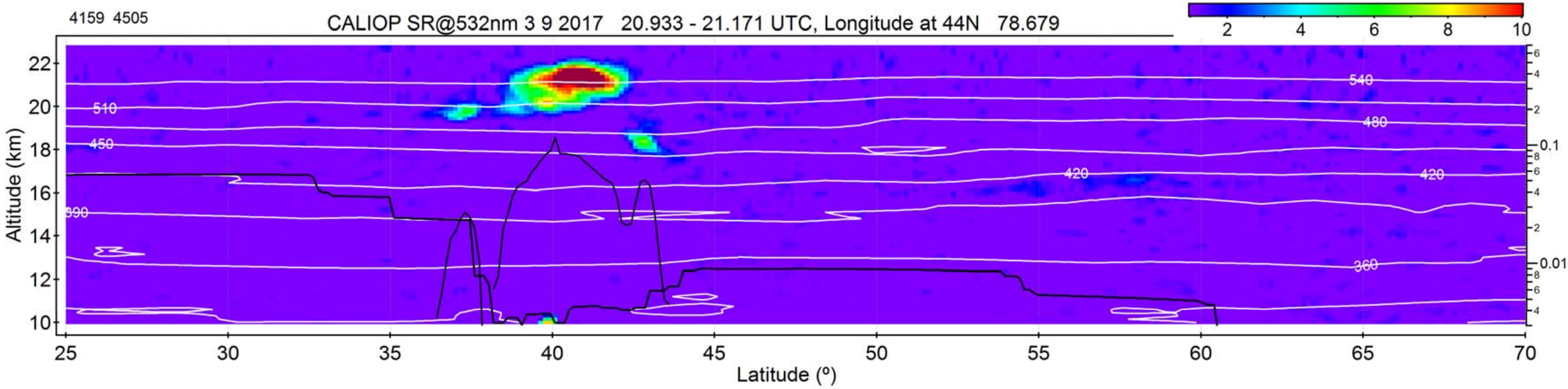

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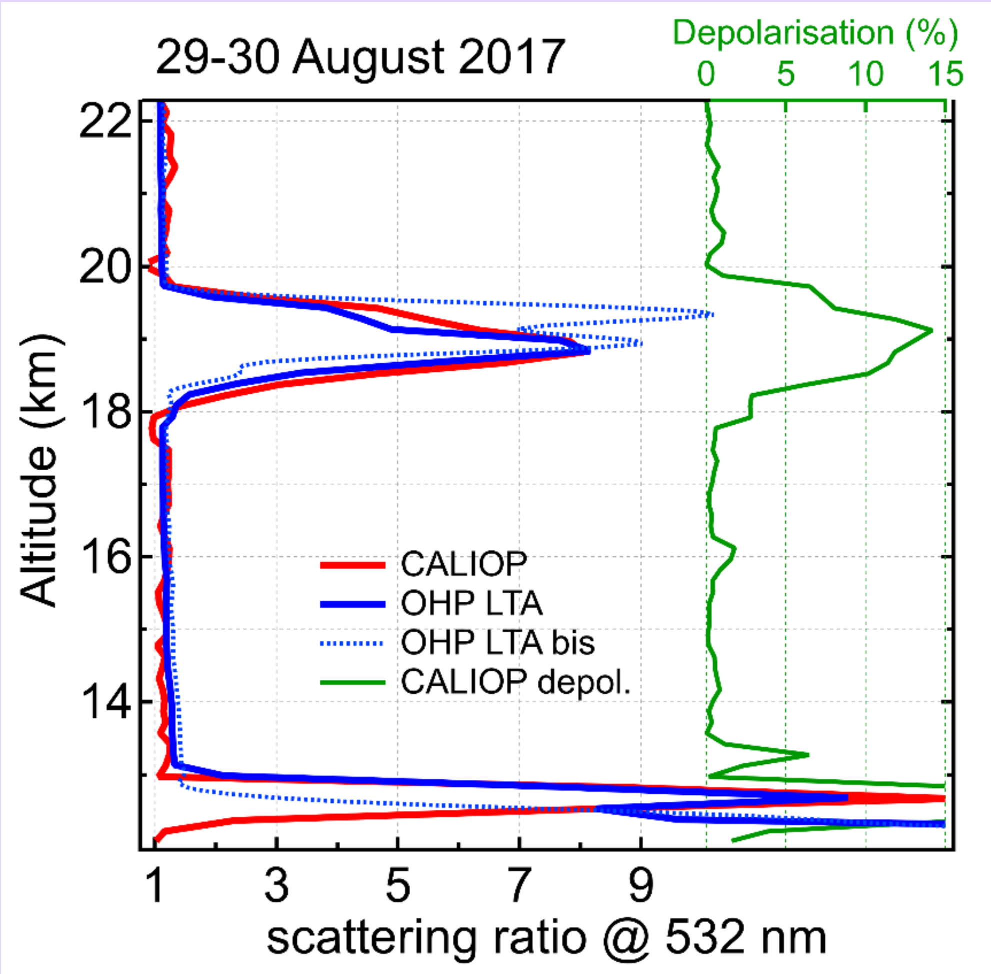
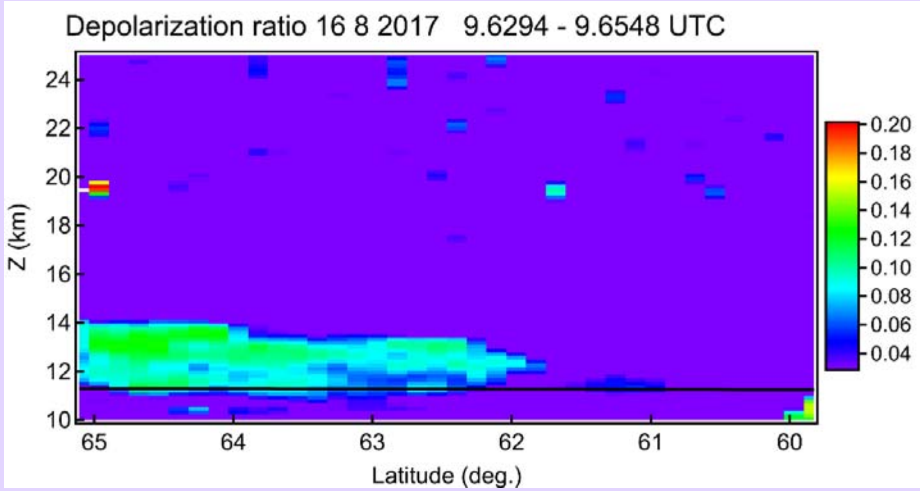
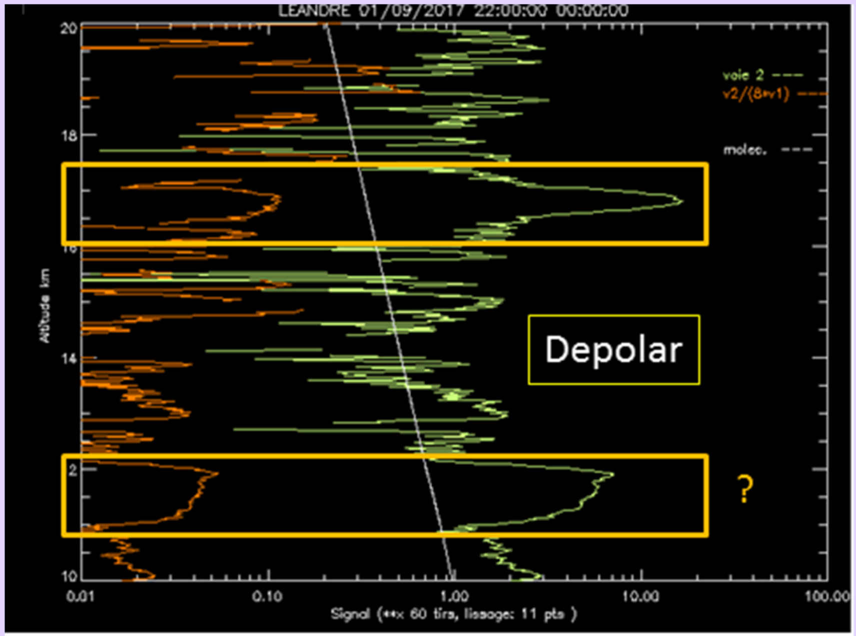


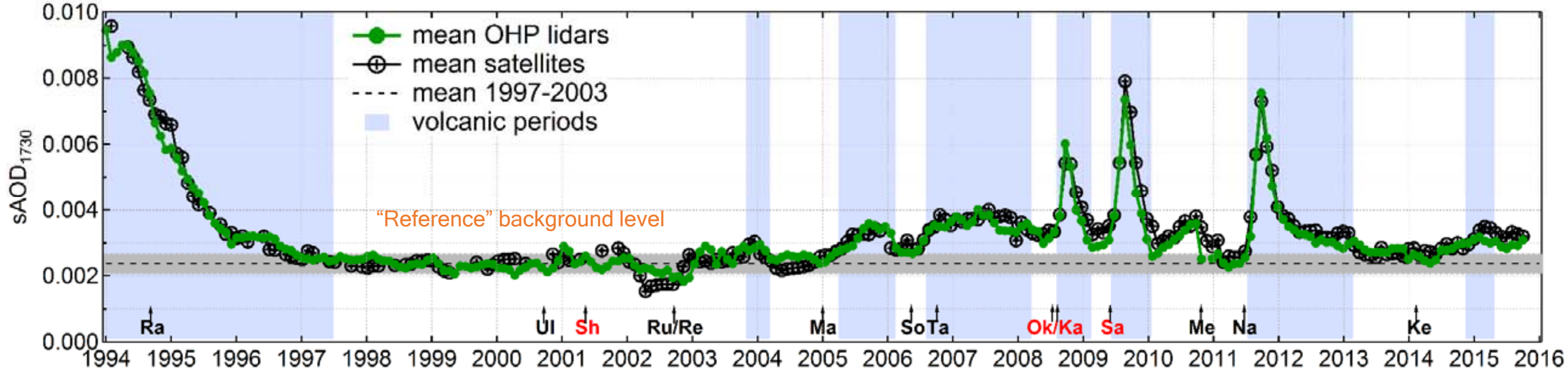




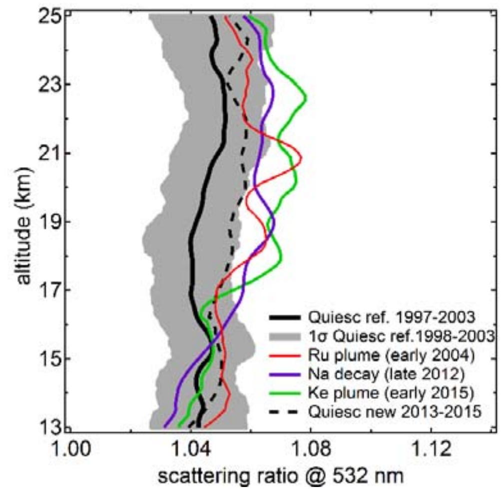
OHP lidar observations: detection of quiescent periods

Stratospheric Aerosol Optical Depth 17-30 km ($sAOD_{1730}$) @ 532 nm

Mean of OHP lidars and satellites



- "Reference" background level of sAOD at mid-latitudes accurately determined
- A combination of concurrent local and global observations was used to separate between volcanically-perturbed and quiescent periods
- Volcanically-perturbed periods identified using global satellite and OHP lidar data on the base of a set of criteria



Khaykin et al., ACP, 2017

Supplementary material