Radiative forcing by volcanic and mineral dust aerosol in the stratosphere, a transient simulation from 1990 to 2017 with the CCM EMAC using satellite data

C Brühl, K. Klingmüller, J. Lelieveld, MPI for Chemistry, Mainz, Germany

L. Rieger, University of Saskatchewan, Saskatoon, Canada

L. Clarisse, Université Libre de Bruxelles, Brussels, Belgium

C. Bingen, BIRA, Brussels, Belgium

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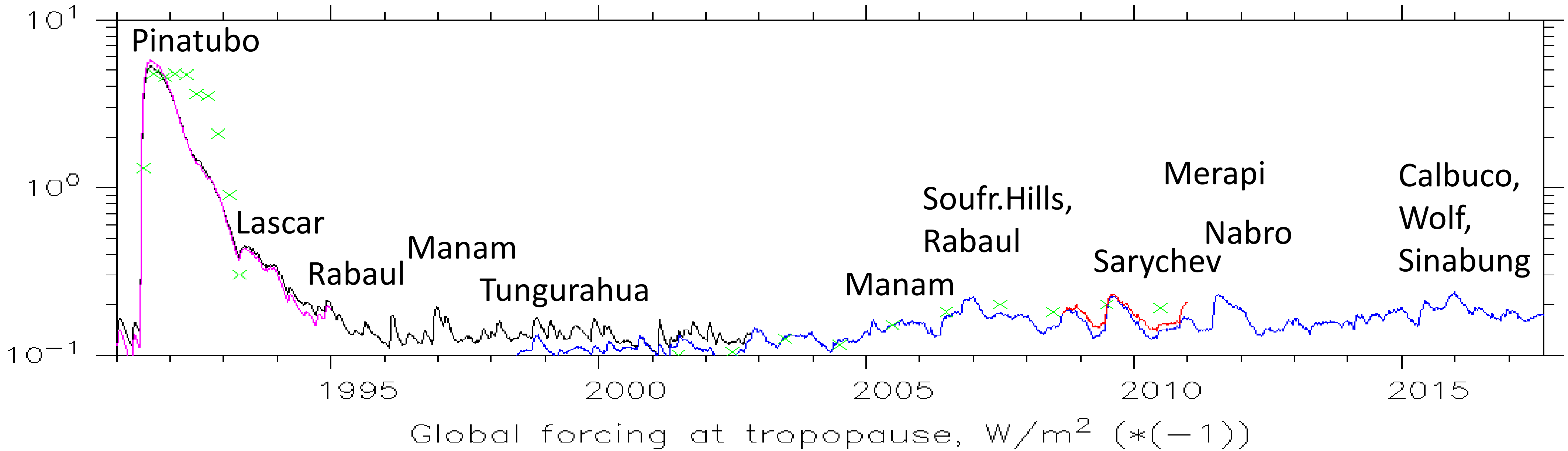
Model EMAC (V2.52, Jöckel et al., 2010 GMD; Brühl et al., 2018, ACP)

- GCM ECHAM5, Resolution T63/L90 (1.9° up to 1 Pa with internal Quasi-Biennial Oscillation, slightly nudged), meteorology nudged to ERA-Interim in troposphere (below 100hPa), observed transient SST.
- MECCA1 chemistry module with sulfur chemistry, scavenging by clouds.
- GMXE aerosol module (4 soluble and 3 insoluble modes with EQSAM or ISORROPIA chemistry, $\sigma_{nuc,ait}$=1.59, σ_{acc}=1.49, σ_{cs}=1.7; lower mode boundaries (r) nucleation 0.0005, aitken 0.006, accum 0.07, coarse 1.6 µm). Interactive with dynamics and chemistry.
- Radiative forcing calculated online, aerosol types: dust, organic and black carbon, sulfate, sea salt and aerosol water.

- Emissions: CO, NO_x, OC, BC, NH_3, sulfur: DLR-MACCity, Biomass burning based on ACCMIP-MACCity and GFEDv2, OC-SOA: AEROCOM_UMZ1 (see Jöckel et al., 2016, GMD), dust: Astitha et al., 2012, ACP. Increase of sulfur emissions after 2012 in South Asia as in Lelieveld et al., 2018, Science.
- OCS: updated Montzka surface observations, CFCs, CH_4, N_2O: ALEGAGE data
- About 230 explosive volcanic eruptions 2002-2012 (see Bingen et al. 2017, Rem.Sens.Env. and SSIRC), 33 eruptions 1998-2002, 42 eruptions 1990-1997 including Pinatubo, 157 eruptions 2012-2017 (**see handout**). SO_2 derived as 3D plumes from MIPAS (Höpfner et al, 2015, ACP) and GOMOS on ENVISAT, SAGE (using Grainger et al., 1995, JGR), OSIRIS, the Smithsonian volcano database and added to the model SO_2 at eruption time. Volcanoes degassing into the troposphere (Diehl et al., ACPD 2012, truncated at 200hPa) and DMS oxidation included.

SSIRC SO_2-database: doi: 10.1594/WDCC/SSIRC_1

Global radiative forcing by stratosp. aerosol



EMAC, SAGE, updated; EMAC, SSIRC database for input of SO_2, after Mar 2012

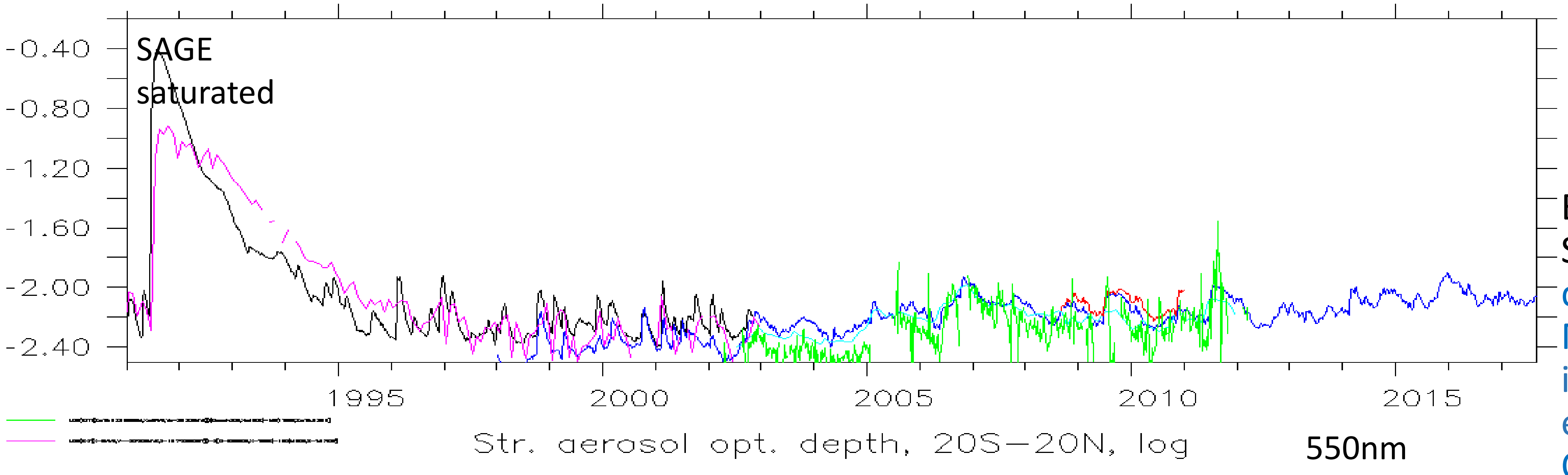
OSIRIS; EMAC, more volcanoes from OSIRIS.

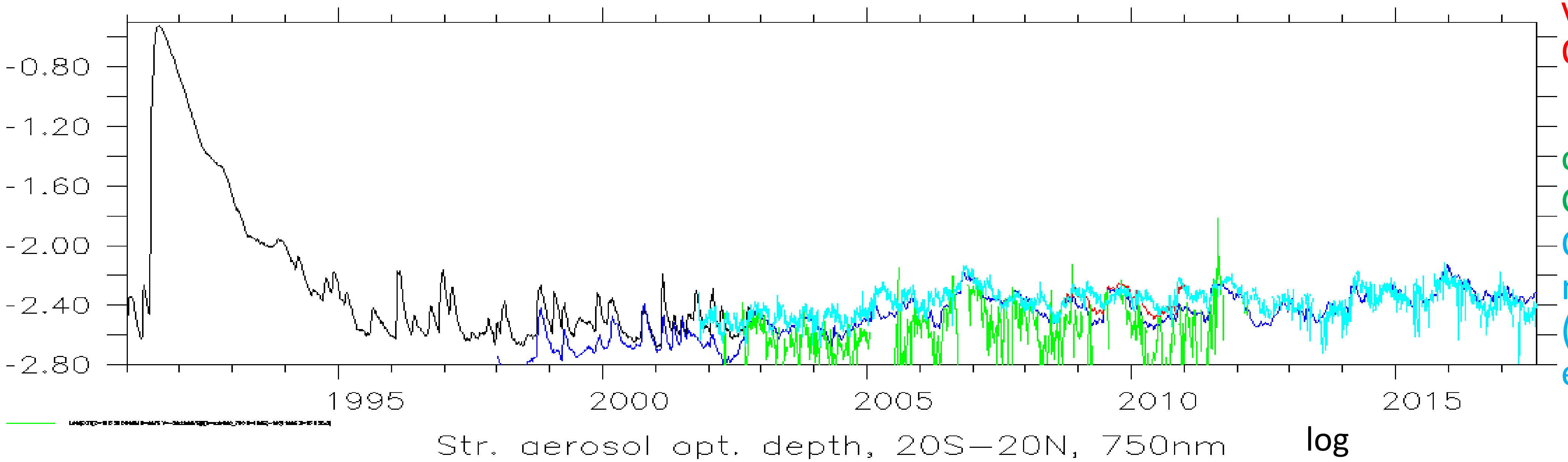
From observations: ERBE (Wong, 2006) and Solomon et al 2011 (ann.av., Science).

EMAC solar forcing at Top of Atmosphere, 60S-60N.

SAGE: Stratospheric Aerosol and Gas Experiment, Thomason et al., 2008, ACP; OSIRIS: Optical Spectrograph and InfraRed Imager, Bourassa et al., 2018, AMT; GOMOS: Global Ozone Monitoring by Occultation of Stars

Stratospheric aerosol optical depth, 550 and 750nm

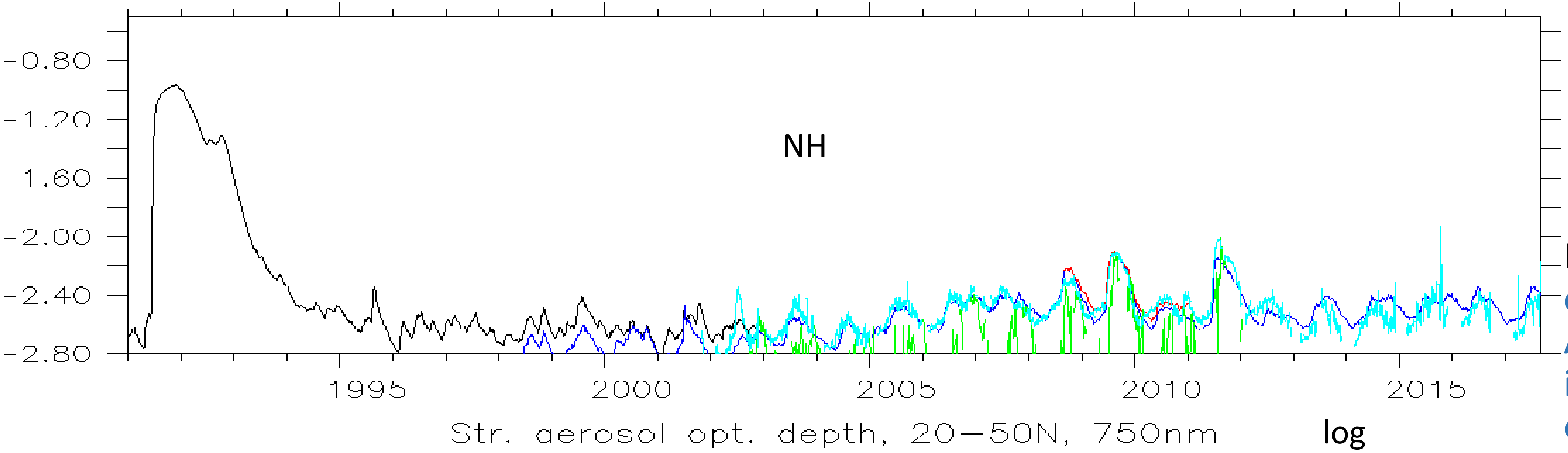


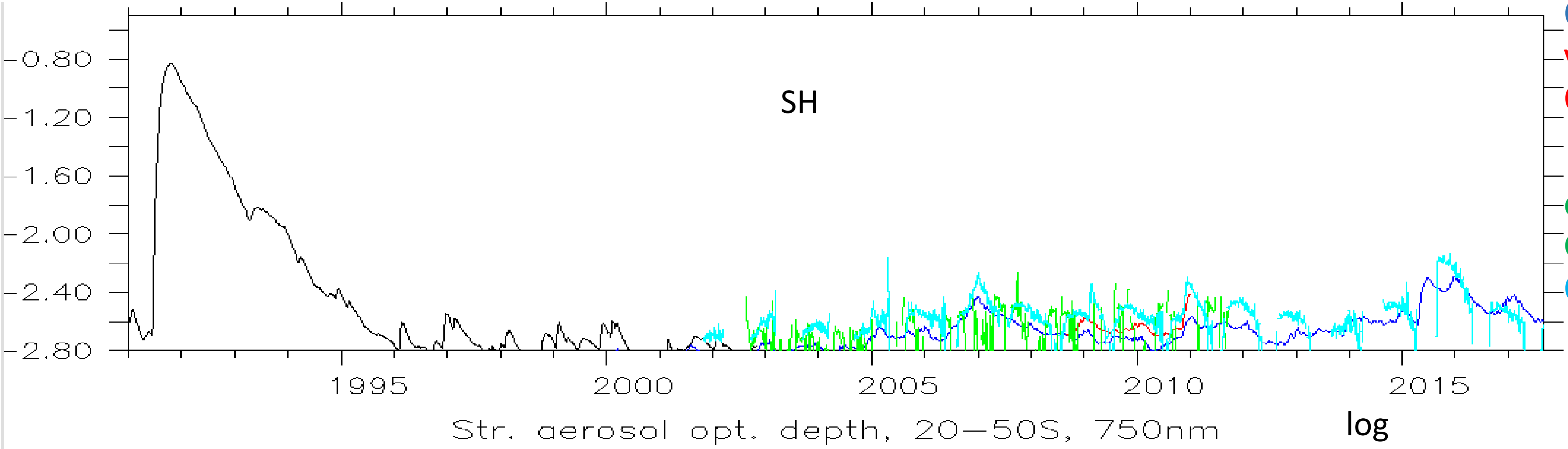


EMAC (updated SAGE, SSIRC database, after Mar 2012 SO_2 injections estimated from OSIRIS, more volcanoes from OSIRIS).

From observations: GOMOS, SAGE II, OSIRIS (750nm), multisatellite (550nm, Santer et al., 2014).

Stratosph. aerosol optical depth, subtropics and midlatitudes

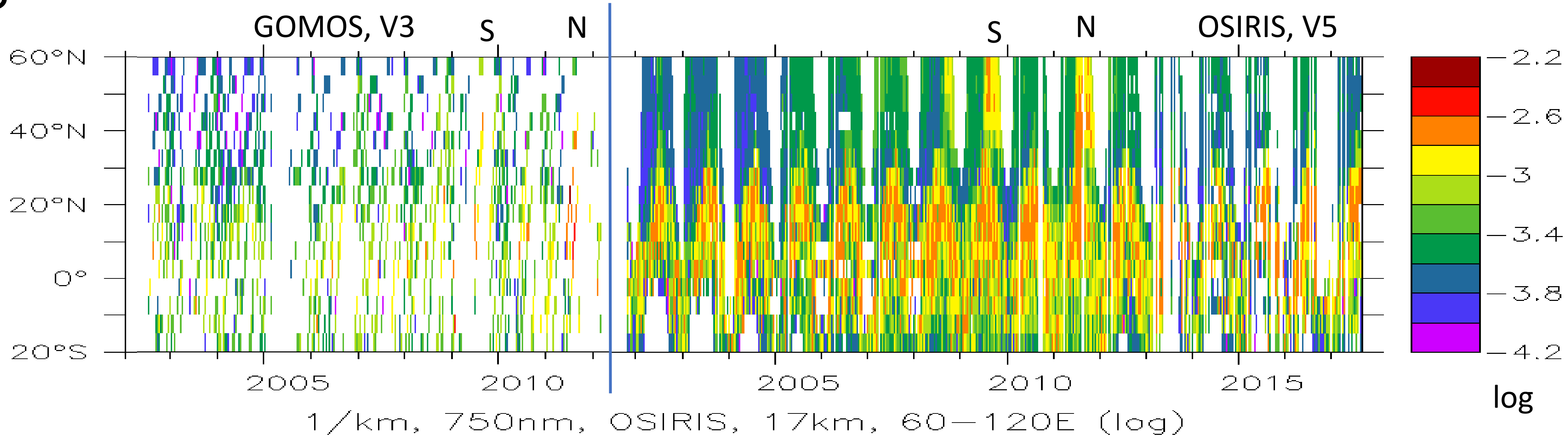




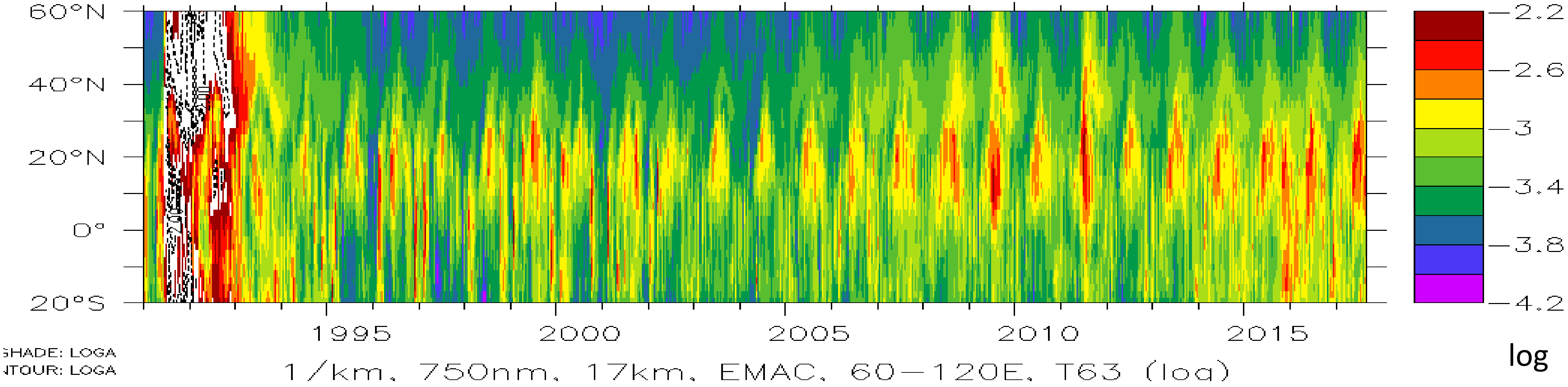
EMAC (SSIRC database, after Apr 2012 SO_2 injections estimated from OSIRIS, more volcanoes from OSIRIS).

From observations: GOMOS, OSIRIS

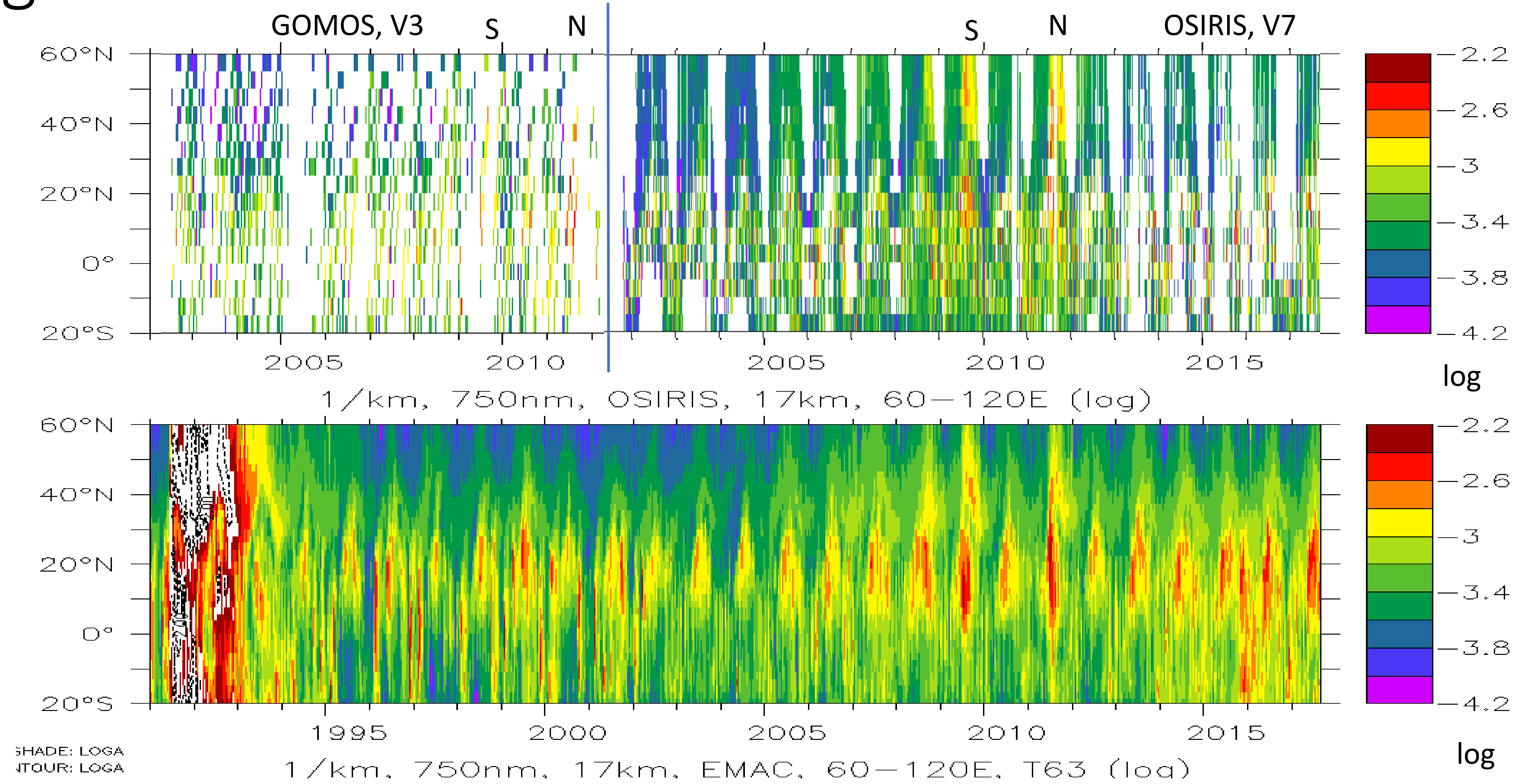
Extinction: GOMOS, OSIRIS, EMAC, Asian monsoon region



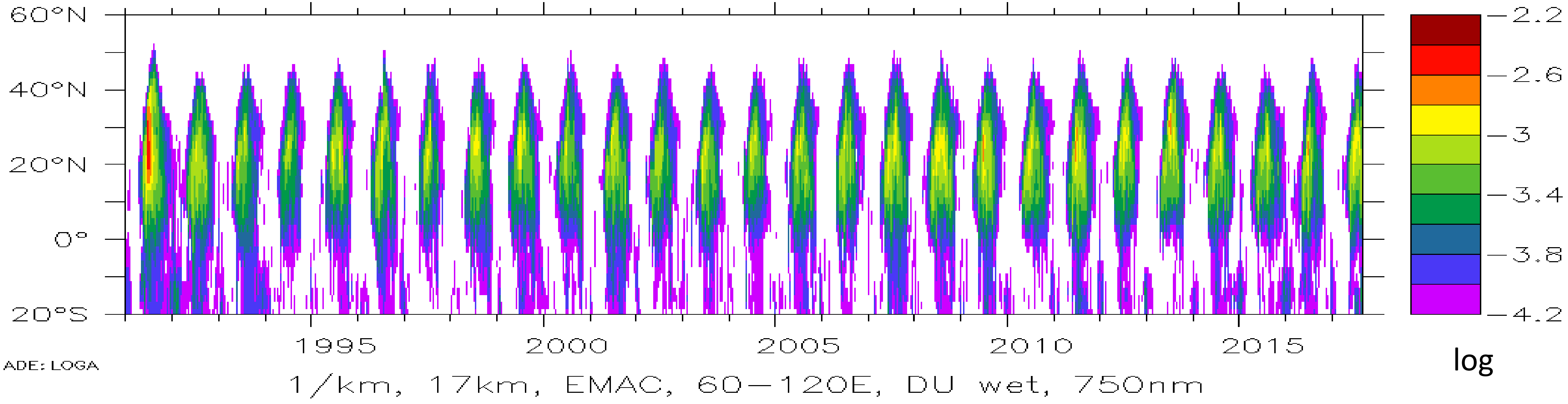
17km
(asl)

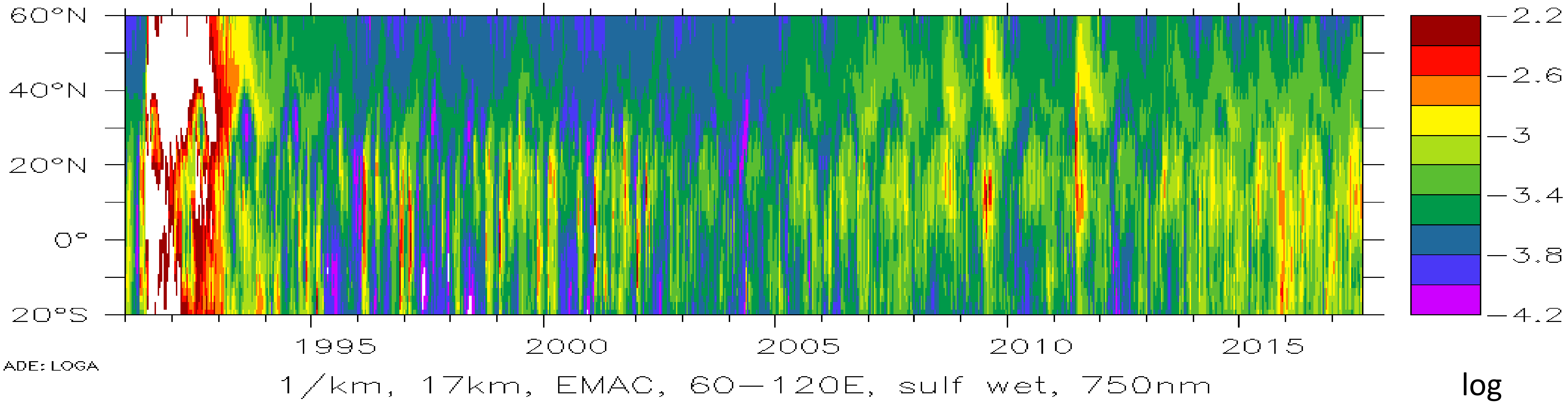


Extinction: GOMOS, OSIRIS, EMAC, Asian monsoon region



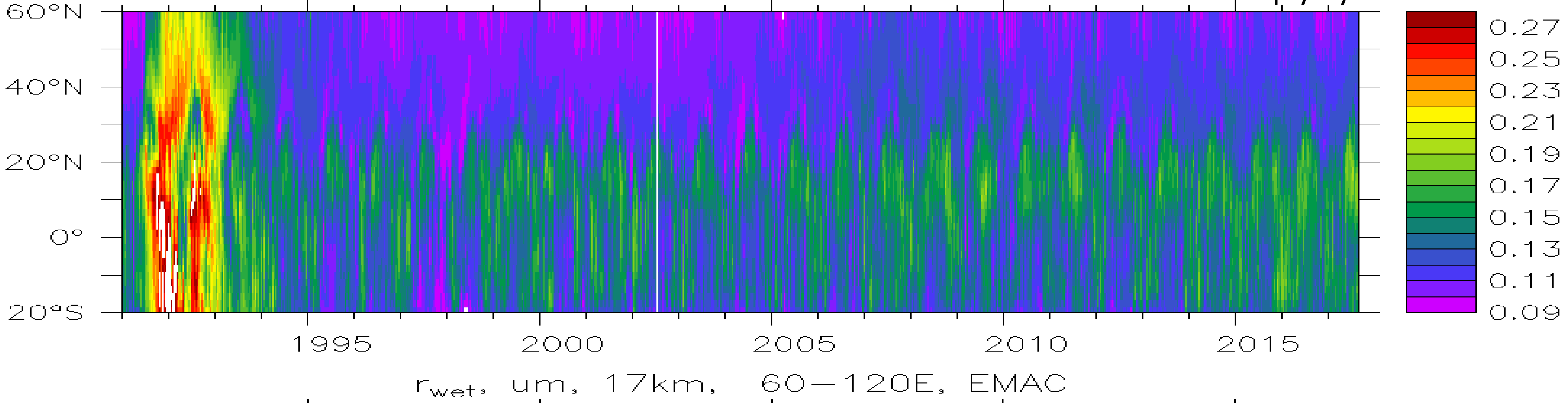
Extinction of wet dust and sulfate in monsoon area

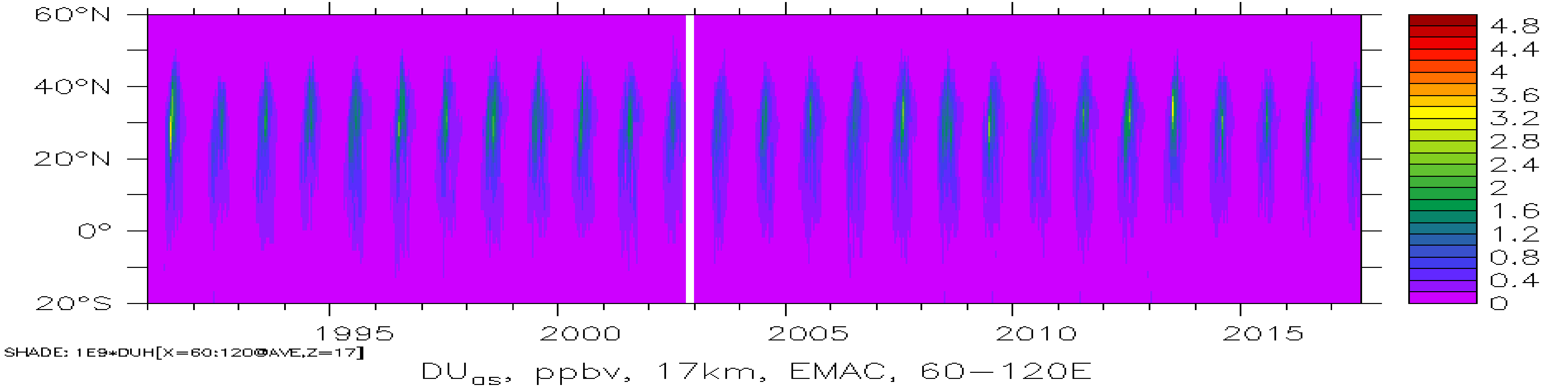




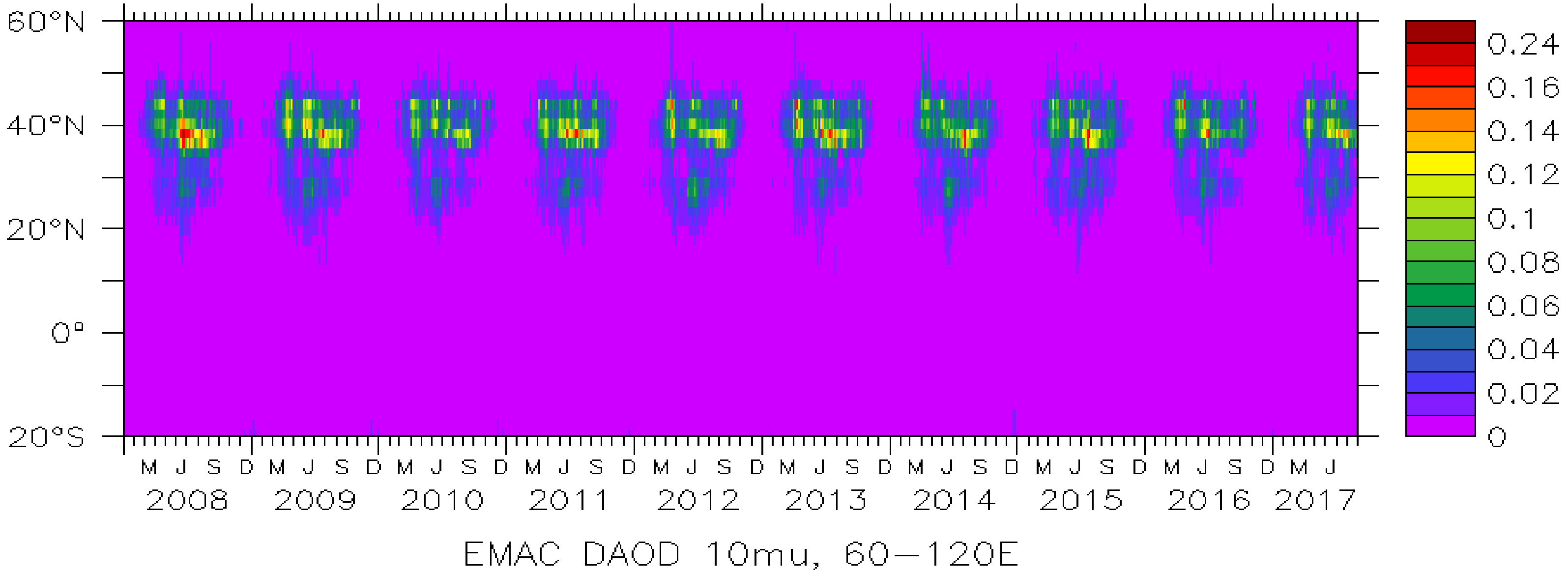
Accumulation mode median wet radius, monsoon region

For effective radius multiply by 1.4

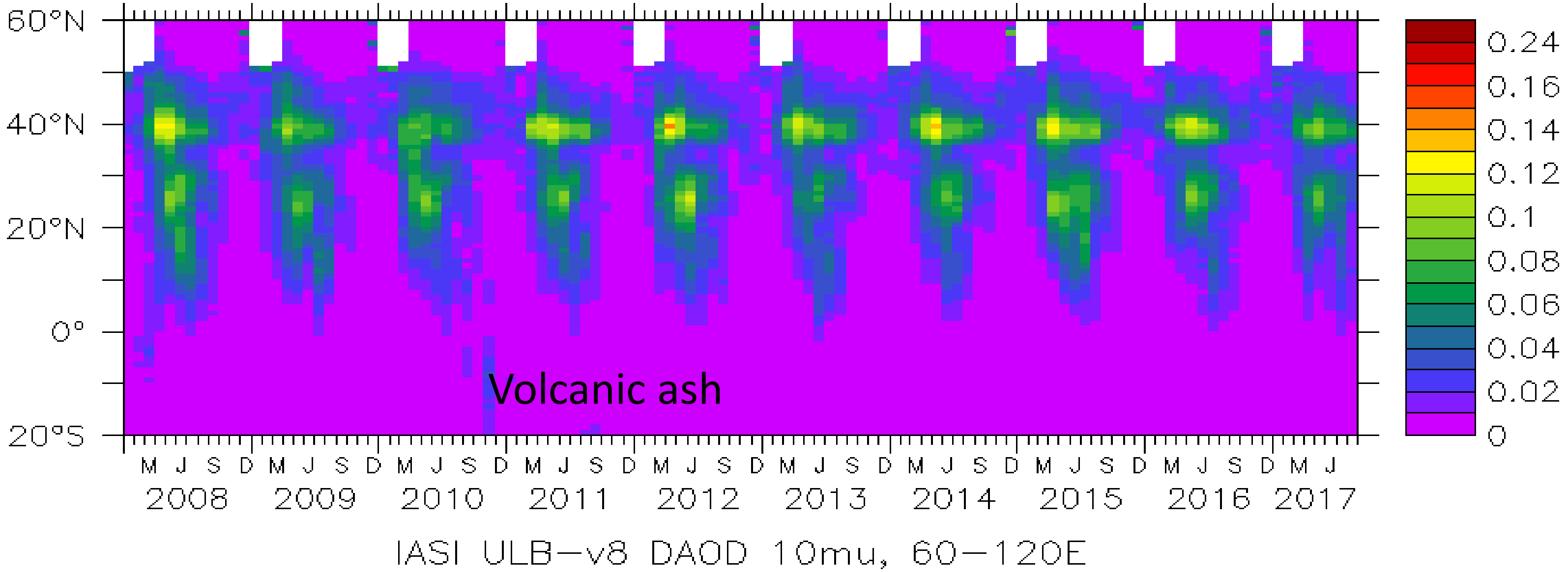




Dust AOD at 10μm, EMAC and IASI, Asian monsoon region



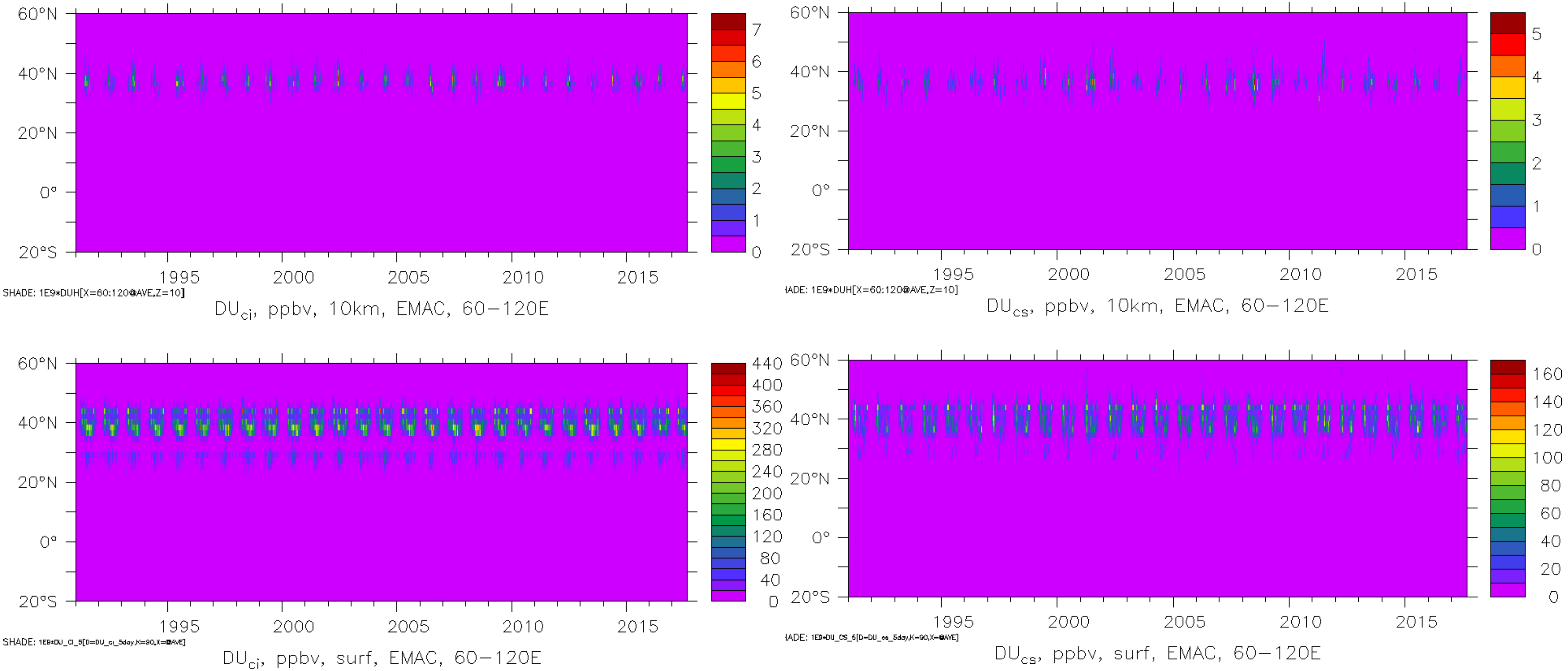
IASI: Infrared Atmospheric Sounding Interferometer, Clarisse et al., 2019, JGR-A



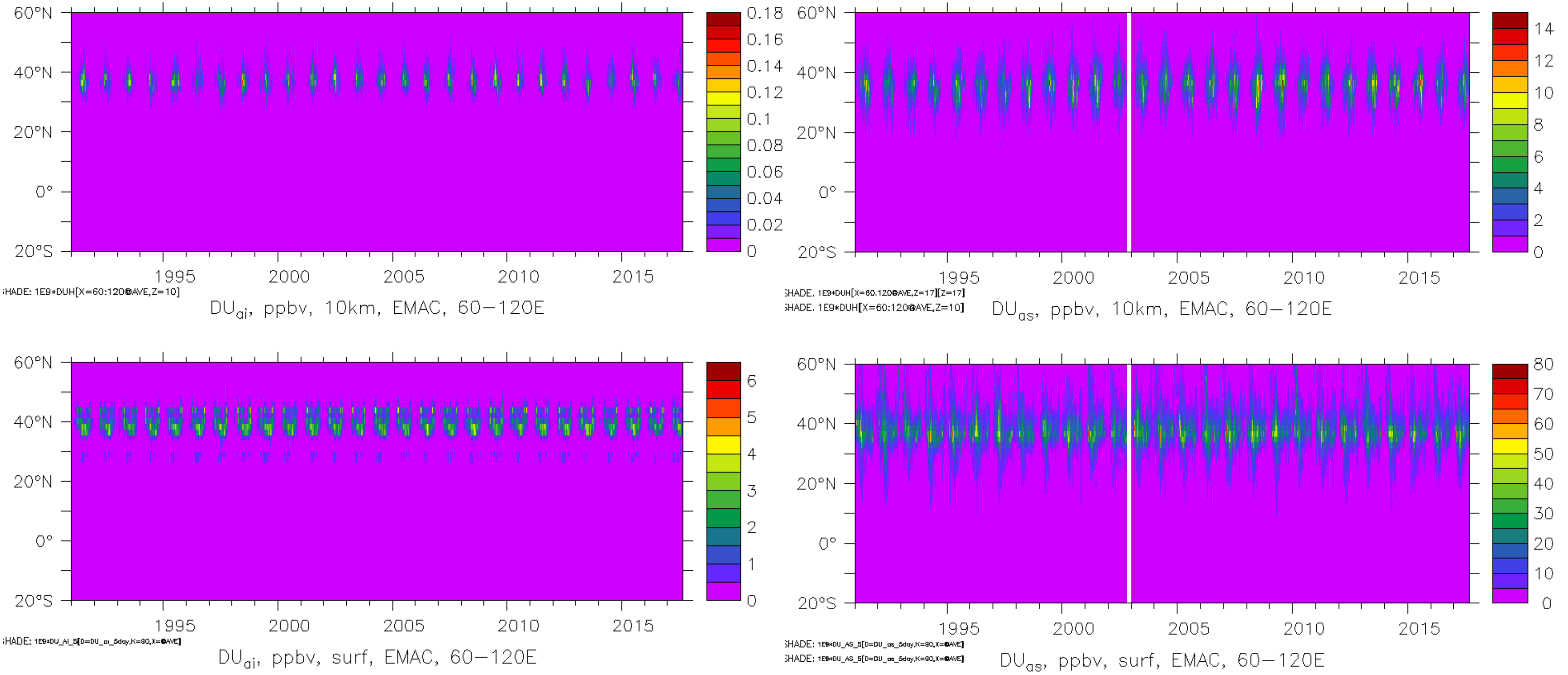
Taklamakan

West India

Insoluble and soluble coarse mode dust particles at surface and 10km (asl)



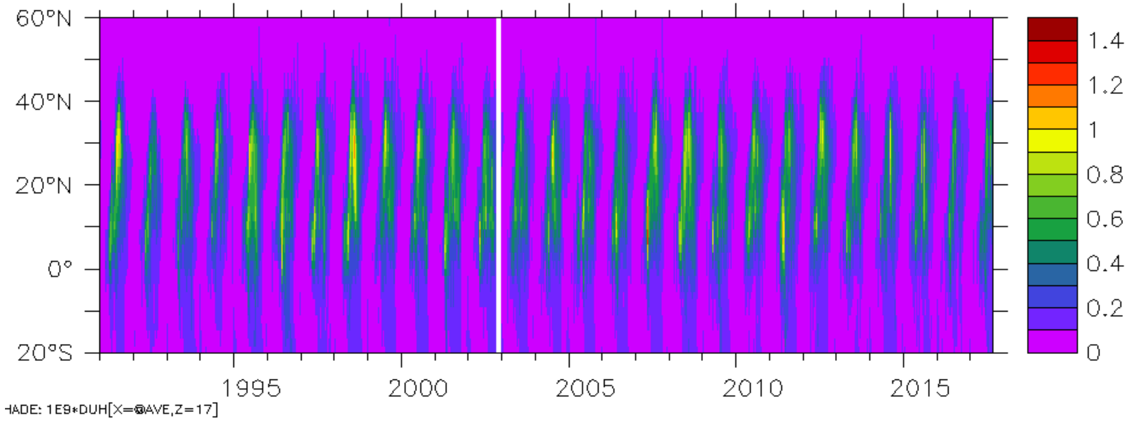
Insoluble and soluble accumulation mode dust, surface and 10km (asl)



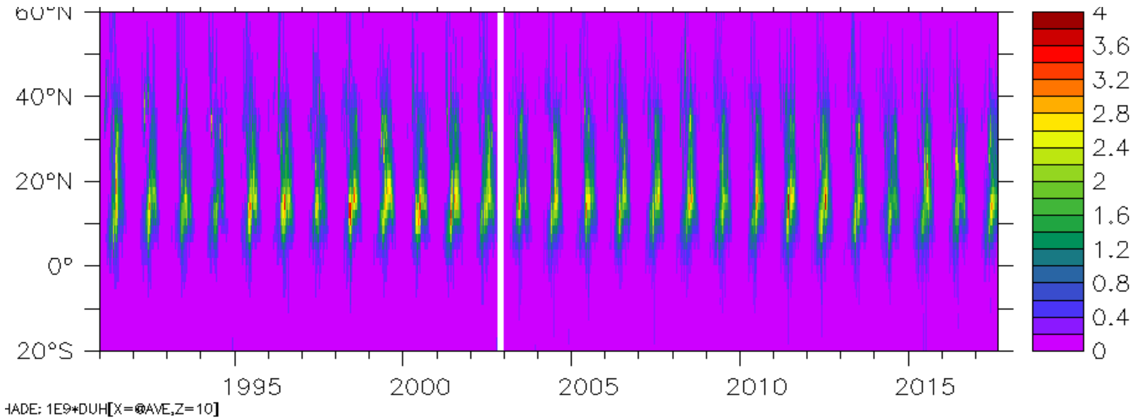
Conclusions

- From the wavelength dependence in observations and simulations, aerosol in the UTLS with enhanced particle size due to water uptake can be identified as aged dust in the Asian monsoon region (see also Brühl et al., 2018). This is responsible for a seasonal signal in total and stratospheric AOD in northern subtropics and midlatitudes.
- Total DAOD in IR is dominated by insoluble coarse aerosol in the lower troposphere, SAOD (vis.) by soluble accumulation mode aerosol in LS.
- As seen for 2015, also a sulfate accumulation from a lot of consecutive smaller tropical and subtropical volcanic eruptions matters for radiative forcing.
- Largest forcing after Pinatubo in 2006 (Soufr.Hills/Rabaul), 2009 (Sarychev), 2011 (Nabro) and 2015 (Calbuco/Sinabung/Wolf)

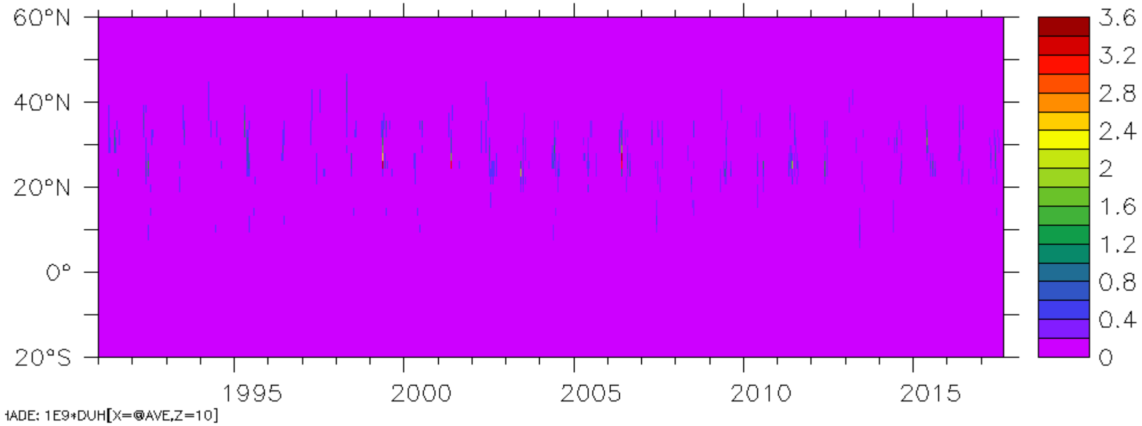
Dust aerosol of Sahara



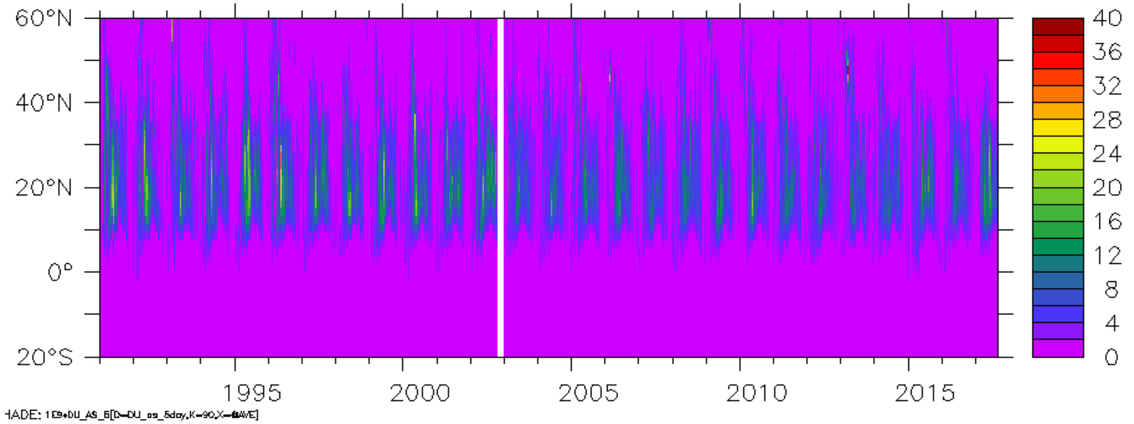
DU as , ppbv, 17km, EMAC, −20:40 E



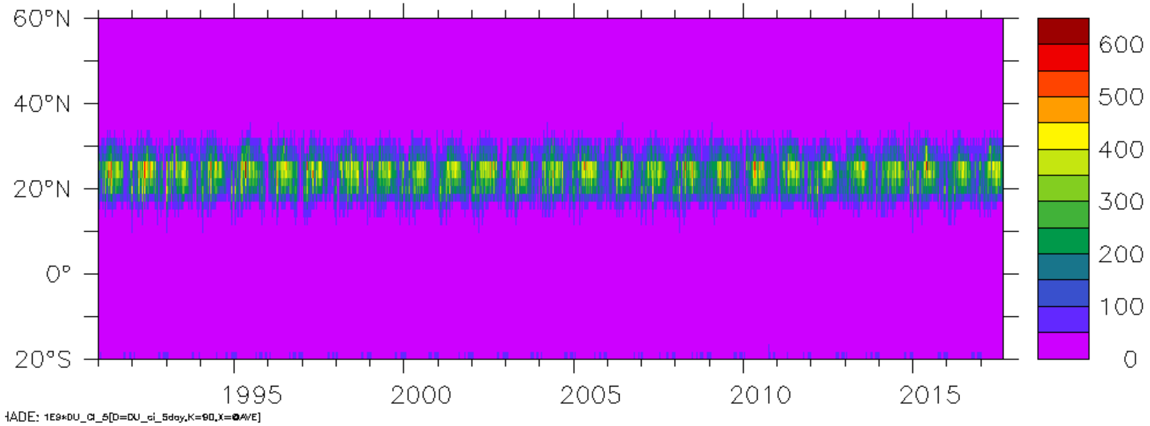
DU as , ppbv, 10km, EMAC, −20:40 E



DU ci , ppbv, 10km, EMAC, −20:40 E

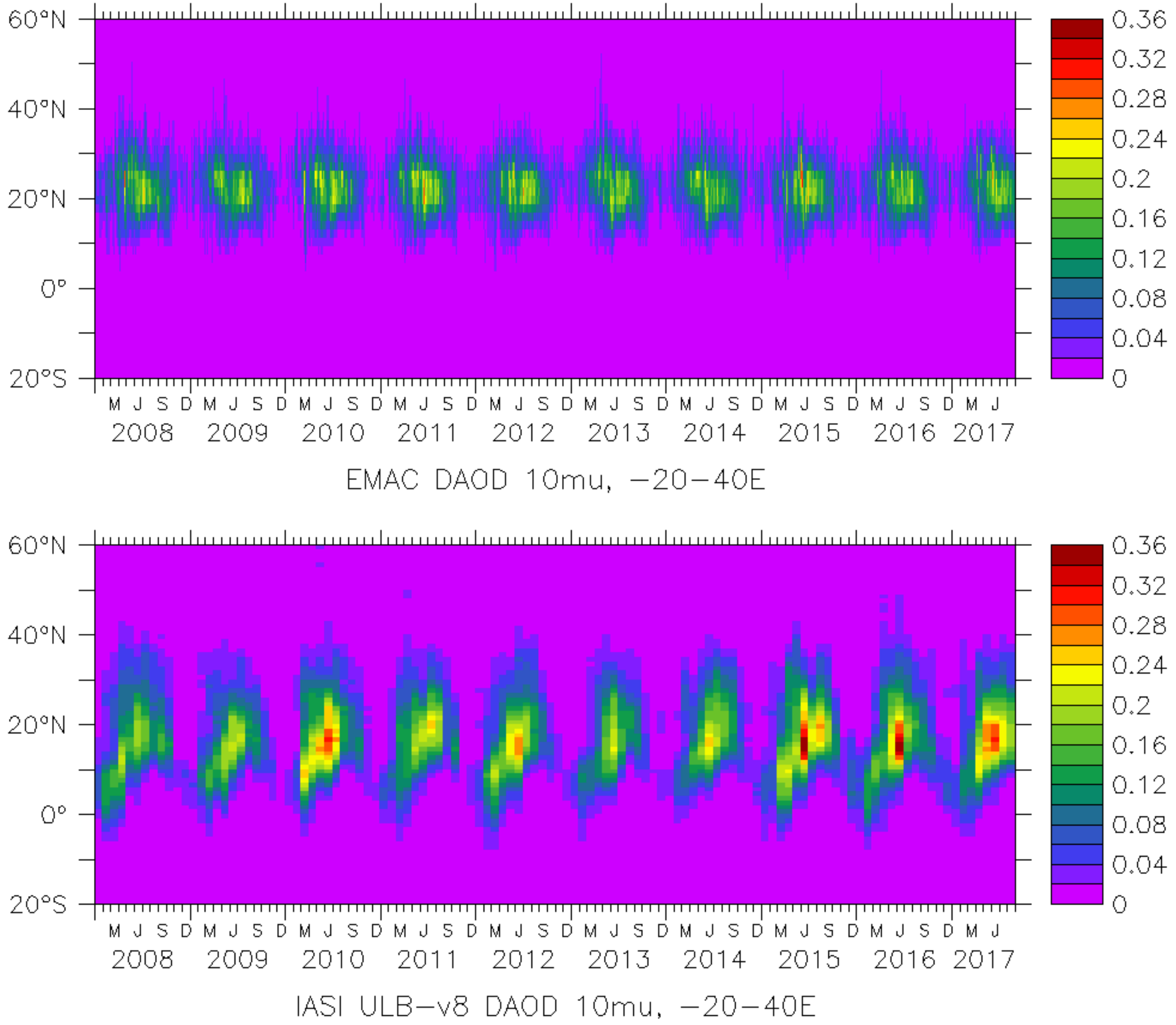


DU as , ppbv, surf, EMAC, −20:40 E



DU ci , ppbv, surf, EMAC, −20:40 E

Sahara dust AOD, EMAC and IASI



Extinction at 17km, EMAC and OSIRIS, v5 and v7, 10yrs