A new climatology of stratospheric aerosol volume densities from MIPAS

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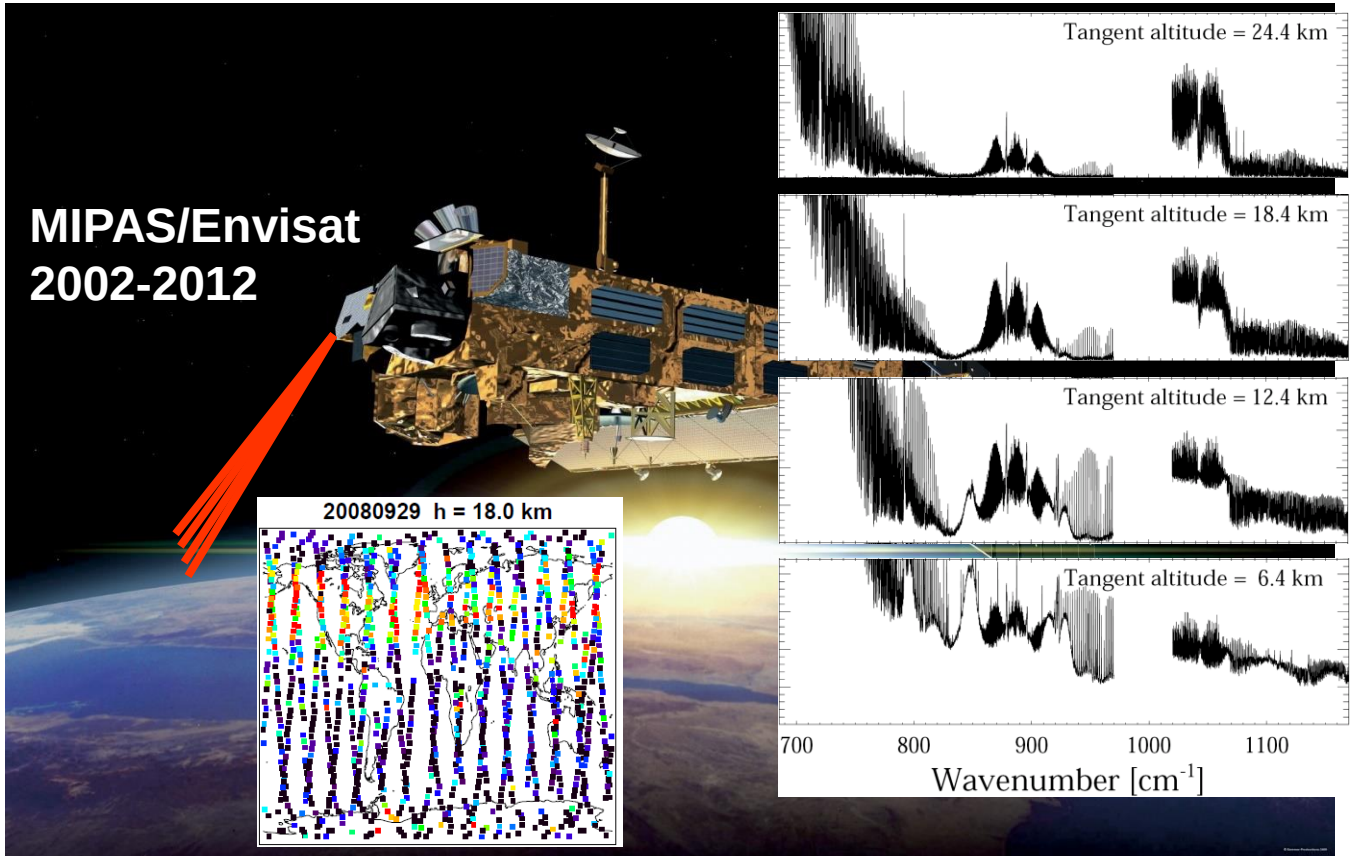
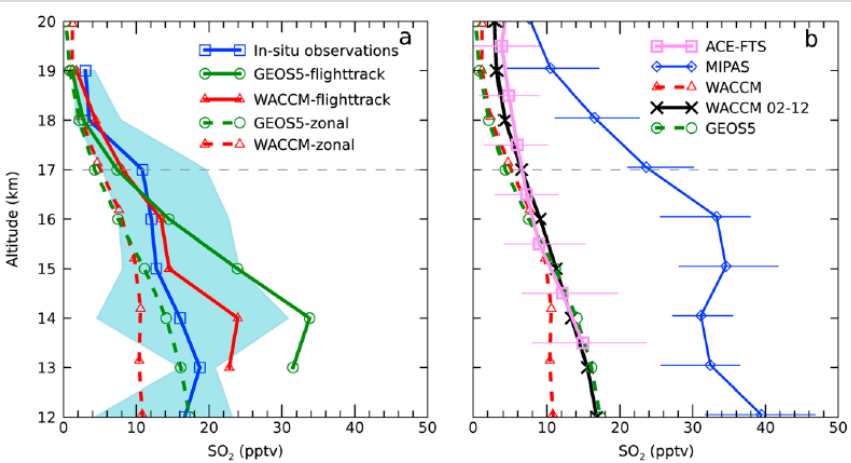

MIPAS/Envisat
2002-2012
20080929 h = 18.0 km
Tangent altitude = 24.4 km
Tangent altitude = 18.4 km
Tangent altitude = 12.4 km
Tangent altitude = 6.4 km
700
800
900
1000
1100
Wavenumber [cm-1]

MIPAS ‚sulfur datasets‘

- **SO_2 volume mixing ratio profiles (2 datasets)**
  - Retrieval from mean spectra: 15-45 km, monthly+zonal averages,18 profiles/month (Höpfner et al., ACP, 2013)
  - Retrieval from single limb-scans: 8-20 km, high temporal and horizontal resolution, up to 2000 profiles/day (Höpfner et al., ACP, 2015)
- **OCS volume mixing ratio profiles (1 dataset)**
  - Retrieval from single limb-scans: 8-35 km, high temporal and horizontal resolution, up to 2000 profiles/day (upper troposphere: Glatthor et al., GRL, 2015, stratosphere: Glatthor et al., ACP, 2016)
- **H_2SO_4 aerosol volume density profiles (1 dataset)**
  - Retrieval from single limb-scans: 8-~33 km, high temporal and horizontal resolution, up to 2000 profiles/day (Günther et al., ACPD, 2017)



(23.6 pptv). It is important to note that the MIPAS $\pm 2\sigma$ uncertainty range (−7.4 pptv to 54.6 pptv, not shown in Figure 3 [see *Höpfner et al.*, 2015]) and the variability at shorter time scales do include the WACCM value. As discussed in *Höpfner et al.* [2015], the MIPAS systematic uncertainties are quite significant relative to background SO_2 mixing ratios. In addition, the potential influence of volcanic SO_2 emissions during the MIPAS

Rollins et al., GRL, 2017

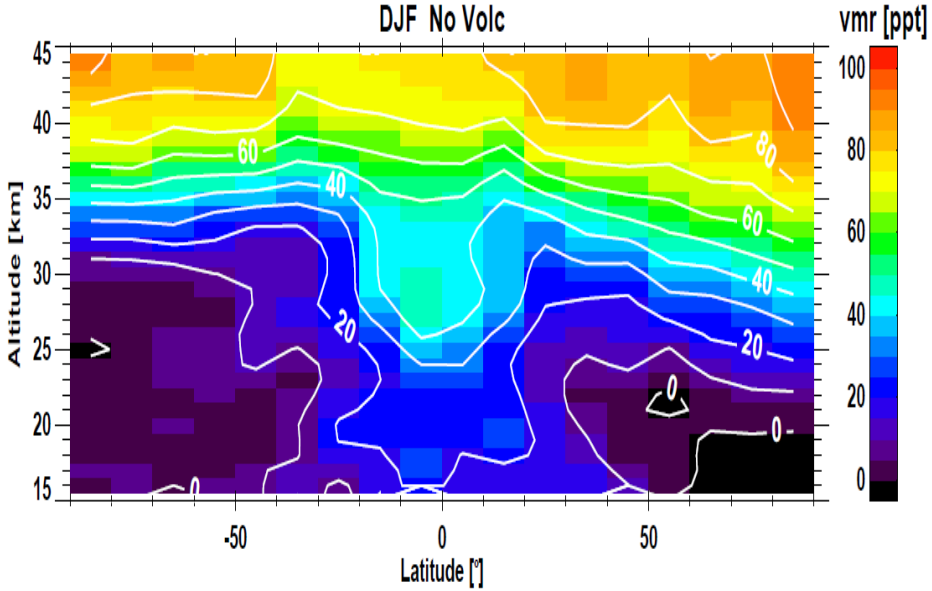
MIPAS SO_2: two datasets

ACP 2013

Retrieval from mean spectra: 15-45 km, monthly+zonal averages,18 profiles/month

→ **More suited for high altitudesand background studies (but: monthly means may contain volcanic signals)**

→ **Not suited to look at volcanic eruptions**

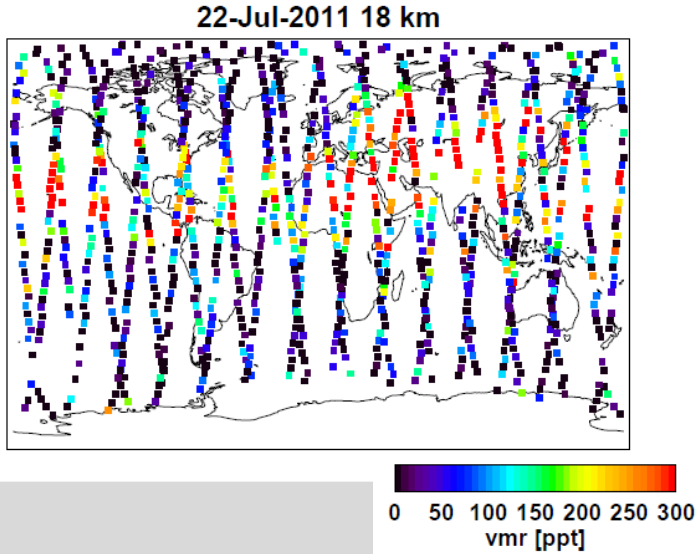


ACP 2015

Retrieval from single limb-scans: 8-20 km, high temporal and horizontal resolution, up to 2000 profiles/day

→ **Don‘t use for background studies**

→ **Suited for enhanced SO_2 conditions and variability**



Volcano or region	Time	Latitude	Longitude	Height (km)	SO_2 3D str (kt)	Obs
Nyamuragira	23 Jul 2002	−1	30	15	23	M
Witori	2 Aug 2002	−6	150	14	18	M
Ruang	26 Sep 2002	2	125	18	71	MG
El Reventador	5 Nov 2002	0	−78	17	77	MG
Nyiragongo, Lokon	9 Jan 2003	−1, 1	30, 125	15, 16	20, 17	MG
Nyirag., Lokon (Rabaul?)	5 Mar 2003	−5, 1	30, 125	17, 15	17, 19	MG
Anatahan, Nyirag., Ulawun	14 May 2003	16, −1, −5	143, 30,150	16, 16, 17	13, 21, 9	M
Lewotobi, Kanlaon	13 Jun 2003	−8, 10	123	15	13, 21	MG
Soufriere Hills	13 Jul 2003	16	−62	15–18	59	MG
Gamalama, Japan, M	17 Aug 2003	1, 33	128, 131	16	15, 13	MG
Bezymianny or Klyuchev.	6 Sep 2003	56	160	14	8	G
Lokon, Soufr.H.(+Masaya)	26 Sep 2003	2, 15	125, −62	16	12, 9	MG
Rabaul	10 Nov 2003	−5	150	16	24	MG
Rabaul	5 Dec 2003	−5	150	16	19	MG
Rabaul, Nyiragongo?	9 Jan 2004	−5, −1	150, 30	17, 15	15, 13	MG
Langila, Nyiragongo?	3 Feb 2004	−5, −1	150, 30	17	16, 4	MG
Soufriere Hills	4 Mar 2004	10	−62	17	28	MG
Nyamu., Awu + Tengger C.	12 Jun 2004	−1, 4, −8	30,125,112	17, 15	25, 22	G
Pacaya, Galeras	17 Jul 2004	15, 1	−91, −77	17	16, 15	G
Galeras	11 Aug 2004	1	−77	16	21	G
Vanuatu, Rinjani + Kerinci	30 Sep 2004	−16, −8, −2	168,116,101	15,15,17	10, 21	G
Manam, Soputan	30 Oct 2004	−4, 1	144, 125	16	11, 16	G
Manam, Nyiragongo	24 Nov 2004	−4, −1	144, 30	17, 15	22, 14	G
Nyiaragongo, Reventador	4 Dec 2004	0	30, −77	16	31, 8	G
Vanuatu, Soputan	24 Dec 2004	−16, 1	168, 125	17, 15	22, 23	G
Manam	28 Jan 2005	−4	144	18	144	MG, M
Anatahan, (+)	3 Apr 2005	16	143	15	21	M
Anatahan, Soufriere Hills	23 Apr 2005	16	143, −62	16	30, 30	M
Anatahan, Fernadina, Van.	18 May 2005	16, 0, −16	143, −91,168	15	11, 15, 8	M
Anatahan, Santa Ana	12 Jun 2005	16, 14	143, −90	15	17, 13	M
Anatahan, Soufriere Hills	12 Jul 2005	16	143, −62	15	18, 13	M
Anatahan, Ruang	6 Aug 2005	16, −8	143, 113	15	19, 28	M
Anatahan, Ruang	16 Aug 2005	16, −8	143, 113	15	25, 31	MG
Santa Ana	5 Oct 2005	14	−90	17	46	M
Sierra Negra, Dabbahu	25 Oct 2005	−1, −13	−91, 40	15	20, 27	G
Karthala, Galeras	24 Nov 2005	−10, −2	43, −80	16	16, 14	MG
Soputan, Lopevi	24 Dec 2005	1, −16	125, 168	16	33, 18	MG
Rabaul+	23 Jan 2006	−5	152	16	31	MG
Manam, Chile	4 Mar 2006	−5, −40	144, −70	17	72, 7	MG
Cleveland	14 Mar 2006	53	−170	13	8	G
Ecuad., Tinakula, Lascar	18 Apr 2006	−5,-10, −23	−78,166, −68	17	16, 21, 3	M
Soufriere Hills	23 May 2006	16	−62	19	156	MG
Kanlaon	2 Jul 2006	10	123	20	70	M
Tungurahua, Rabaul	16 Aug 2006	−2, −4	−78, 150	19	44, 22	MG
Rabaul	10 Oct 2006	−4	150	17	172	M
Ubinas, Vanuatu	25 Oct 2006	−20	−70, 168	17, 15	14, 41	M
Ambrym	9 Nov 2006	−10	160	17, 15	45	M
Nyamuragira, Mexico	29 Nov 2006	5	30, −90	17, 15	40, 30	MG
Bulusan, Soputan, Vanuatu	24 Dec 2006	13, 1, −16	125,125,168	18, 16, 15	10, 10, 18	MG
Karthala, Bulusan, Lascar, Shiveluch, Vanuatu	23 Jan 2007	−10, 13, −23, 57, −16	43, 125,-68, 160, 168	17,17,15, 15,15	6, 5, 7, 8, 6	MG
Nev. d Huila, Kartha., Van.	22 Feb 2007	0, −10, −16	−70, 43, 168	16,15,16	11, 14, 11	MG
Etna, Reventador, Ambrym	24 Mar 2007	38, 0, −16	15, −78, 160	15,16,17	11, 24, 20	MG
Pit.Fourn.Reunion, Reventador +	8 Apr 2007	−20, 0	57, −80	16	31, 15	MG
Ulawun,Vanuatu,N.d.Huila	3 May 2007	−5, −25, 3	150,160, −70	15	15, 7, 9	MG
Papua, Kamchatka, Nyira., Ubinas + Lascar	13 May 2007	−10, 50, 0, −20	150,150,30, −75	16	8, 1, 13, 8	MG
Llaima,Vanuatu, Bulusan	23 May 2007	−30, −15, 13	−70,160,125	18,15,17	14, 8, 10	MG
Soputan,Bezym.,Telica	12 Jun 2007	1, 56, 13	125,160, −87	16, 14,15	19, 10, 13	MG
Lengai, Mexico, M	2 Jul 2007	2, 20	29, −90	16, 15	17, 11	M
Raung, Japan, M (+)	27 Jul 2007	−5, 35	110, 130	15	14, 14	M
Manda Hararo, Java, M	11 Aug 2007	12, −5	40, 115	17, 15	21, 18	M
Vanuatu, Mexico, M	20 Sep 2007	−5, 20	180, −90	16	11, 18	M
Jebel al Tair, Galeras	5 Oct 2007	15–40(16), 1	42, −80	16	68, 13	M
Galeras, Jebel, Soputan	4 Nov 2007	−2, 15, −5	−80,42,110	16	10, 7, 12	MG
Soputan or Krakatau, Galeras, Chikurachki	14 Nov 2007	−5, −1, 50	110, −75,155	16,16, 15	13, 12, 45	M
Talang, Galeras	9 Dec 2007	0	100, −75	16	13, 15	M
Ulawun?	19 Dec 2007	1	150	17	29	MG
Nevado del Huila, Llaima	3 Jan 2008	1, −35	−71	17, 15	32, 5	M

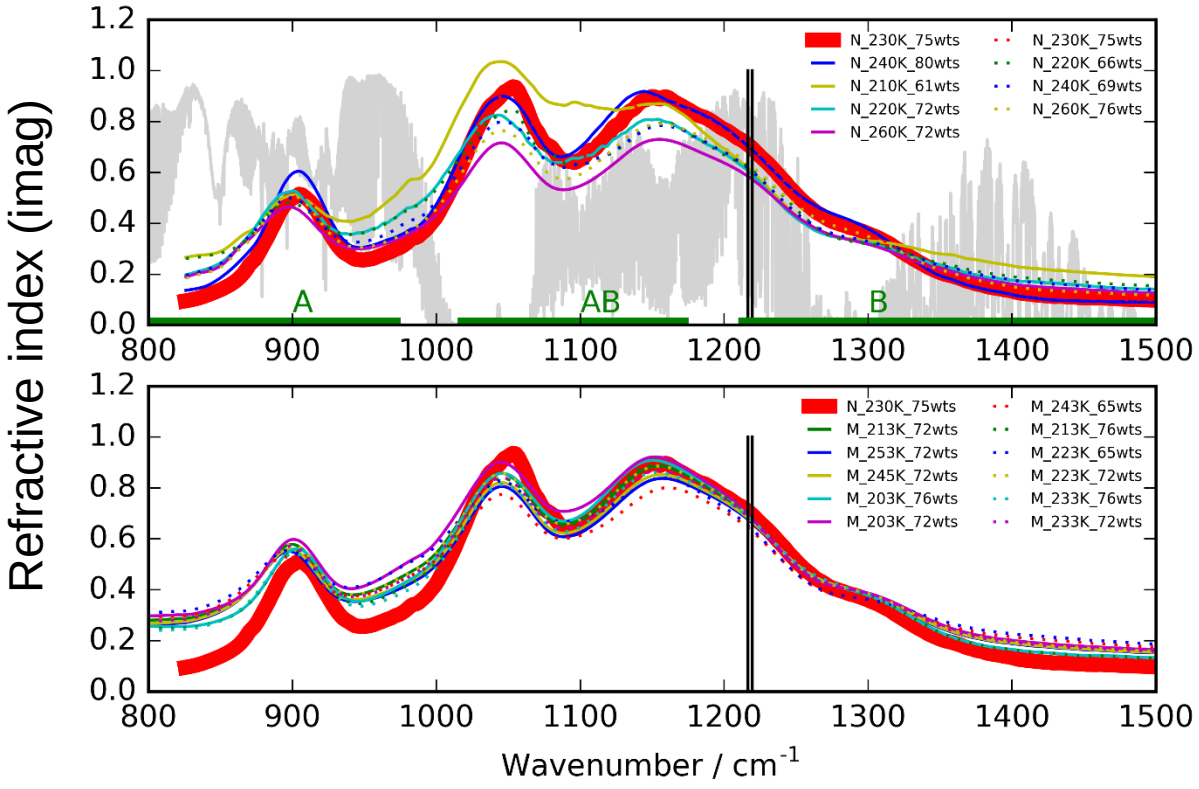
Volcano or region	Time	Latitude	Longitude	Height (km)	SO_2 3D str (kt)	Obs
Galeras, Anatahan	23 Jan 2008	−3, 15	−80, 145	16	24, 12	M
Tungurahua, Papua	12 Feb 2008	−5	−80, 155	16, 17	19, 14	M
TaraBatu (+)	13 Mar 2008	−5	125	16	33	MG
Lengai, Andes, Kerinci	28 Mar 2008	−5, 5, −2	36, −80, 101	16	10, 7, 11	M
Egon, Nev.d.Huila	12 Apr 2008	−5, 5	122, −76	15, 17	20, 13	M
Mexico, Ibu, Chaiten	27 Apr 2008	15, −35	−90, 125, −70	16	13, 15, 4	M
Mexico, Barren I., Chaiten	12 May 2008	10, −35	−90, 90, −70	16, 14	13, 18, 6	M
Soputan, Nicaragua/C.R.	16 Jun 2008	1, 15	125, −85	16	32, 10	M
Okmok, Soputan	21 Jul 2008	53, 1	−168, 125	16	57, 30	M
Kasatochi	15 Aug 2008	52	−175	13–18	390	MG
Dallafilla,N.d.Huila,Rev.	13 Nov 2008	14, 3	40, −78	17	55, 40	M
Karangetang, Galeras, Japan	18 Dec 2008	3, 0, 30	125, −80,130	17, 17, 15	19, 13, 11	MG
Barren Island, Galeras	2 Jan 2009	10, 3	90, −80	17, 15	16, 16	M
Indonesia?, Galeras	27 Jan 2009	−5, 0	100, −80	16	15, 13	M
Galeras, Villarrica, Karangetang, Vanuatu	16 Feb 2009	−2, −35, 3, −16	−78, −75, 100, 168	16, 15, 16, 17	12, 7, 7, 8	M
Redoubt, Galeras	28 Mar 2009	60, 0	−155, −75	13, 15	61, 43	M
Fernandina, Nyira.	12 Apr 2009	0	−90, 30	16	12, 16	M
Galeras + Reventador	7 May 2009	0	−75	15	31	M
Rinjani, Vanuatu, Revent.	22 May 2009	−5, −15, 3	116,165, −80	16	5, 6, 18	M
Sarychev, MandaHararo	21 Jun 2009	48, 12	153, 40	16	496, 91	MG
Vanuatu, Mayon, Galeras	4 Oct 2009	−15, 13, 2	165,120, −80	17	6, 9, 14	M
Tungurahua, Hawaii, Van.	19 Oct 2009	5, 20, −16	−76, −155, 165	16	11, 8, 9	MG
Galeras, Karkar, Vanuatu	3 Dec 2009	0,-5,-16	−78,146,165	17	15, 12, 5	M
Mayon, Nyamuragira, Van.	2 Jan 2010	13, 0, −15	120, 30, 168	16	12, 12, 13	M
Turrialba, Vanuatu	17 Jan 2010	5, −15	−82, 168	16	15, 15	M
Soufriere Hills +	16 Feb 2010	16	−62	16–18	46	M
Arenal, Indon., Van.	2 Apr 2010	9, 0, −16	−84,120,168	15	18, 15, 6	M
Tungurahua, Dukono, Van.	2 May 2010	−5, 2,-16	−78,128,168	16	20, 14, 10	M
Pacaya, Ulawun, Sarigan	6 Jun 2010	15, −5, 16	−91,150,145	17, 16, 15	38, 8, 6	M
Ulawun, Costa Rica, Miyakejima, M	16 Jul 2010	−5, 15, 35	150, −87, 140	16	11, 18, 8	MG
Karanget., Nicaragua, Van.	15 Aug 2010	3, 15, −16	125, −85,168	16	17, 17, 9	M
Galeras, Sinabung M	30 Aug 2010	5	−77, 100	16	16, 20	M
Karangetang?, Barren Isla.	4 Oct 2010	3, 12	125, 94	16	28, 19	M
Merapi	8 Nov 2010	−7	110	17	108	M
Tengger C., Tungu., Chile	23 Dec 2010	−8, −3, −40	110, −78, −75	17	23, 19, 12	M
Tengger C.	7 Jan 2011	−8	110	16	40	M
Lokon-Empung, Planchon, Bulusan	26 Feb 2011	1, −35, 13	125, −75,125	16, 15, 16	19, 5, 17	M
Karangetang, Sangay, Planchon	23 Mar 2011	2, −2, −35	125, −78, −75	15	12, 12, 6	M
Galeras?, Karangetang	12 Apr 2011	5	−77, 128	16	14, 13	M
Tungurahua, Dukono, Van.	2 May 2011	2, 2, −16	−78,128,160	16, 16, 15	18, 13, 7	M
Grimsvötn, Lokon	27 May 2011	65, 1	−20, 125	14, 16	20, 30	M
Puyehue	11 Jun 2011	−41	−71	13	23	G
Nabro	21 Jun 2011	10–55 (13)	41	16–19	446	MG
Soputan, Marapi	20 Aug 2011	1, 0	125, 100	18, 16	15, 5	MG
Manam, Tungurahua	19 Oct 2011	−4, −3	144, −78	16	14, 14	M
Nyamuragira	18 Nov 2011	−2	29	16	39	M
Gamalama, Nyamuragira	18 Dec 2011	1, −1	128, 29	16, 15	27, 19	M
Vanuatu, Nyamuragira	12 Jan 2012	−16, −1	168, 29	16, 14	20, 17	M
Vanuatu, Nyamuragira	11 Feb 2012	−16, −1	168, 29	17	23, 22	M
N.·Ruiz, Marapi	12 Mar 2012	−3, 0	−76, 100	16, 17	17, 21	M

Bingen et al., 2017

MIPAS aerosol volume density: retrieval, bias handling, filtering

- Retrieval of aerosol volume density profiles *(scattering can be neglected in the thermal IR (~10 µm) for particles with r <~ 1 µm)*
- Tikhonov constraint on profile smoothness
- Zero a-priori profile
- Instrumental offset from upper tangent views (> 35 km)
- Correction of altitude-dependent bias (in-situ comparisons)
- Assume 75wt% H_2SO_4
- Filter for cirrus (Spang et al., 2004) before retrieval
- Filter for subvisual cirrus (Griessbach et al., 2016), ash (Griessbach et al., 2016) and PSCs (temp/date/lat criteria) in retrieved profiles

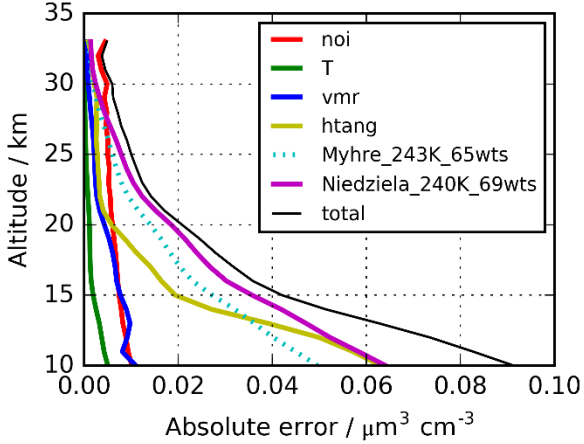
IR refractive indices

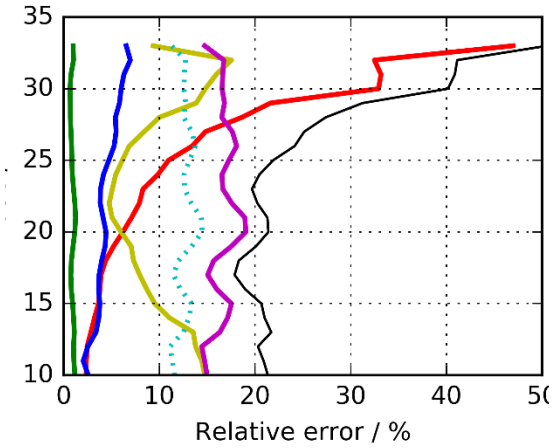


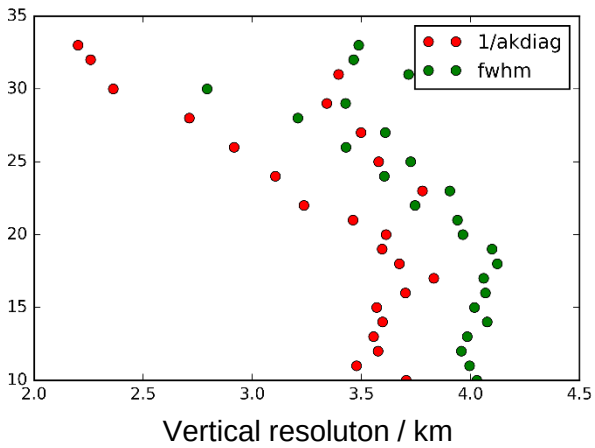
N: Niedziela et al., 1999
M: Myhre et al., 2003

Günther et al., ACPD, 2017

Error estimation and resolution







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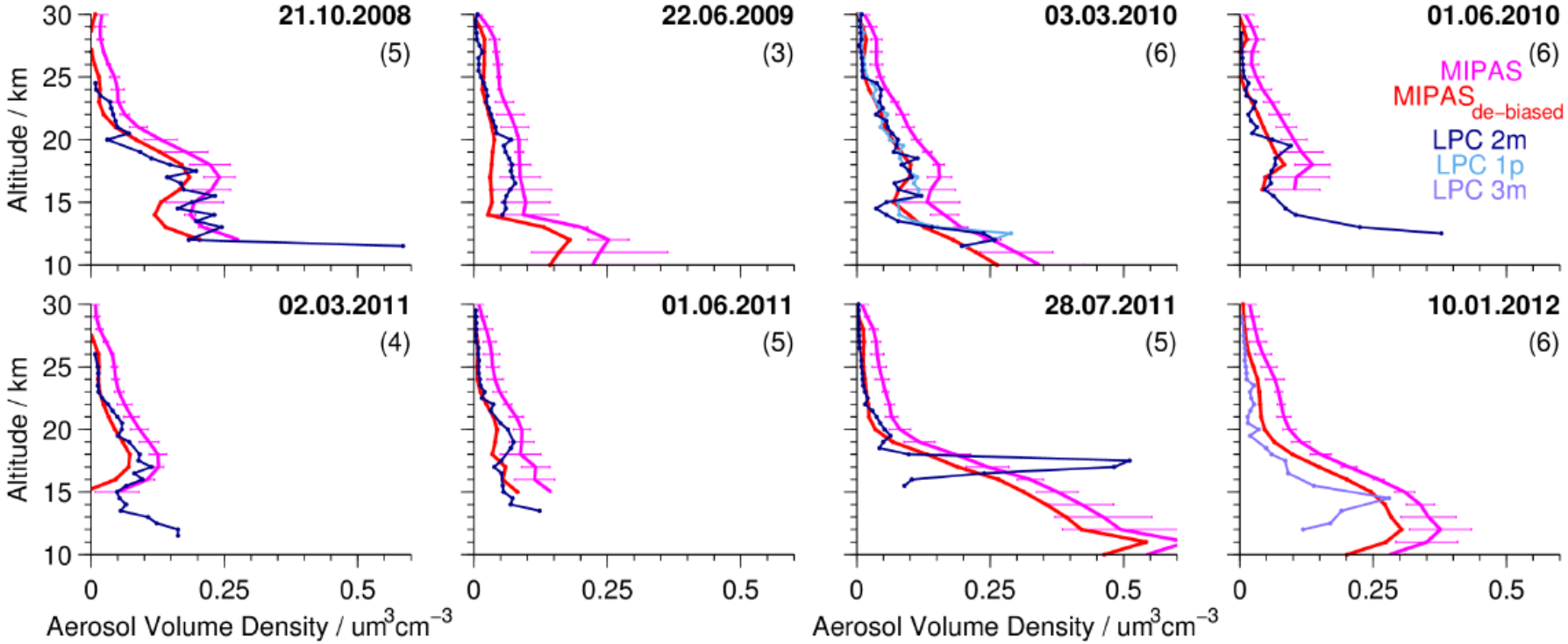
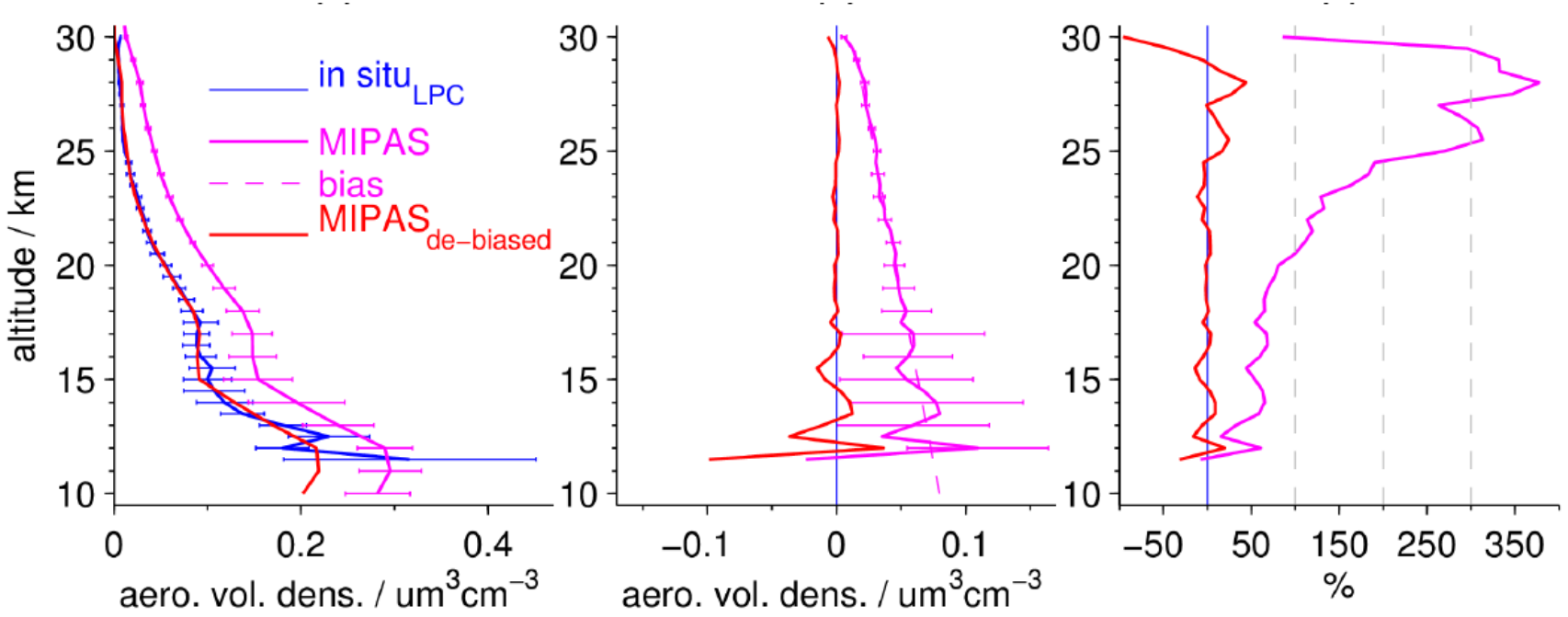
Comparison with Laramie balloon flights



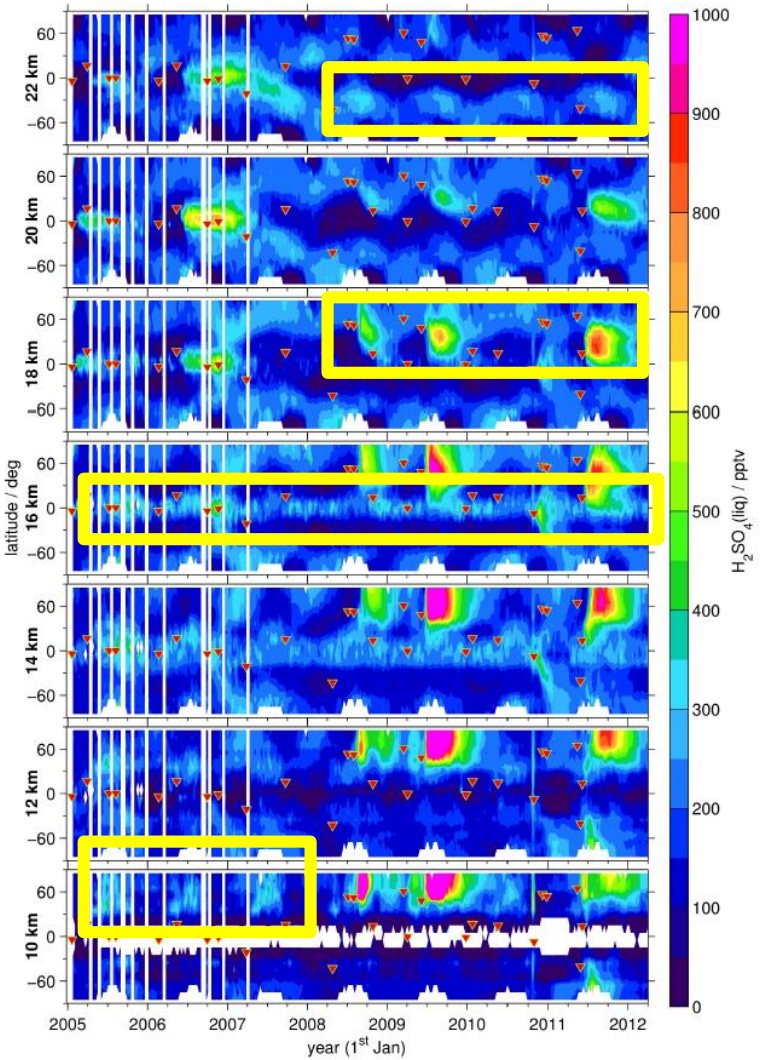
Günther et al., ACPD, 2017

MIPAS bias correction

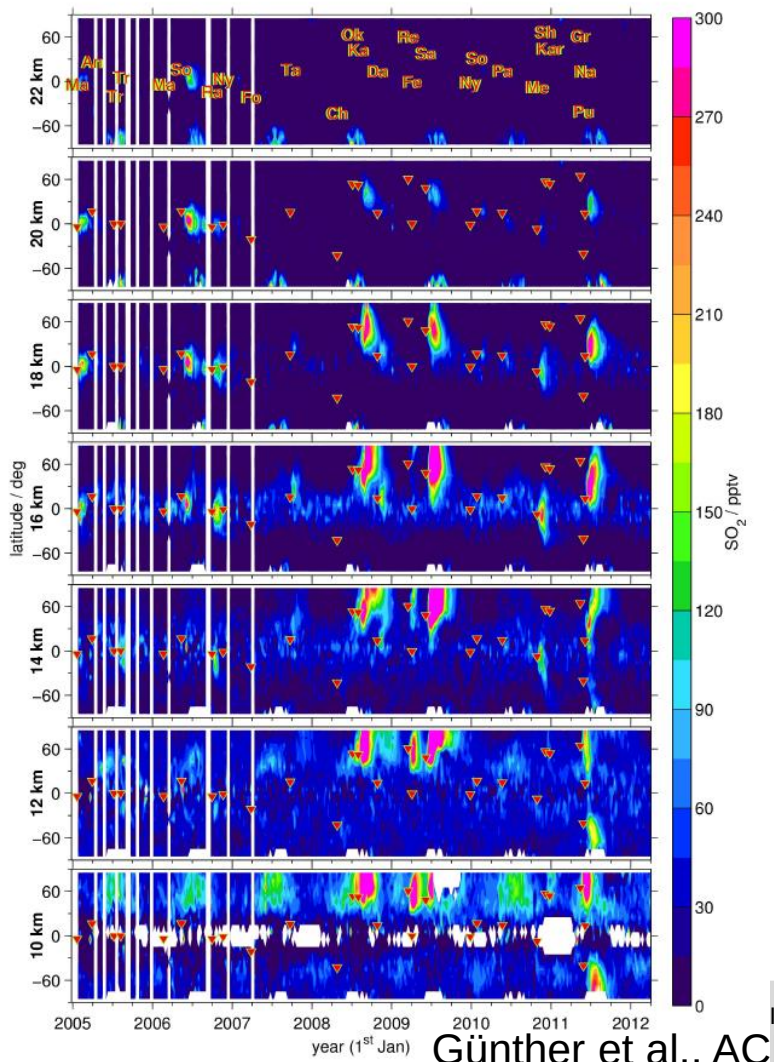


Günther et al., ACPD, 2017

H_2SO_4 (ppt)

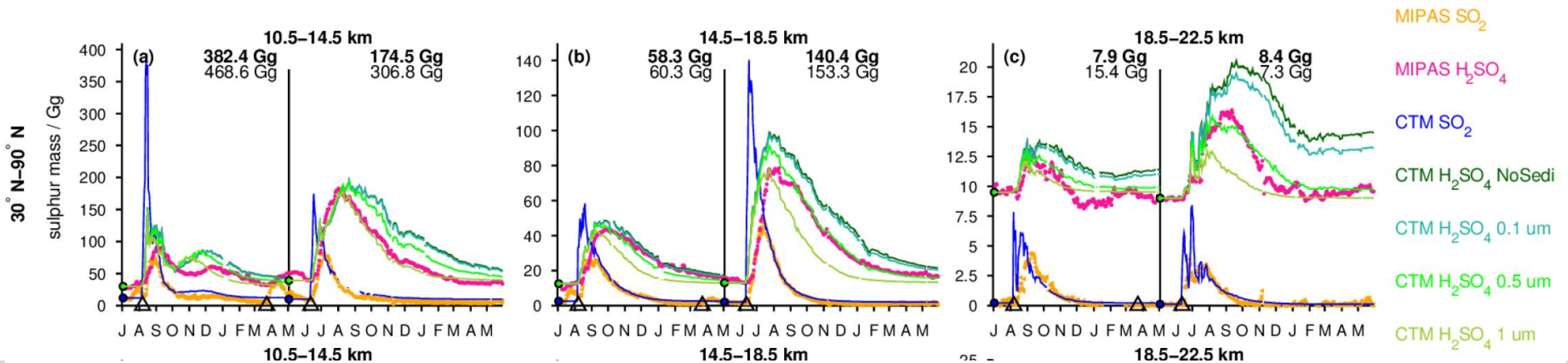


SO_2 (ppt)



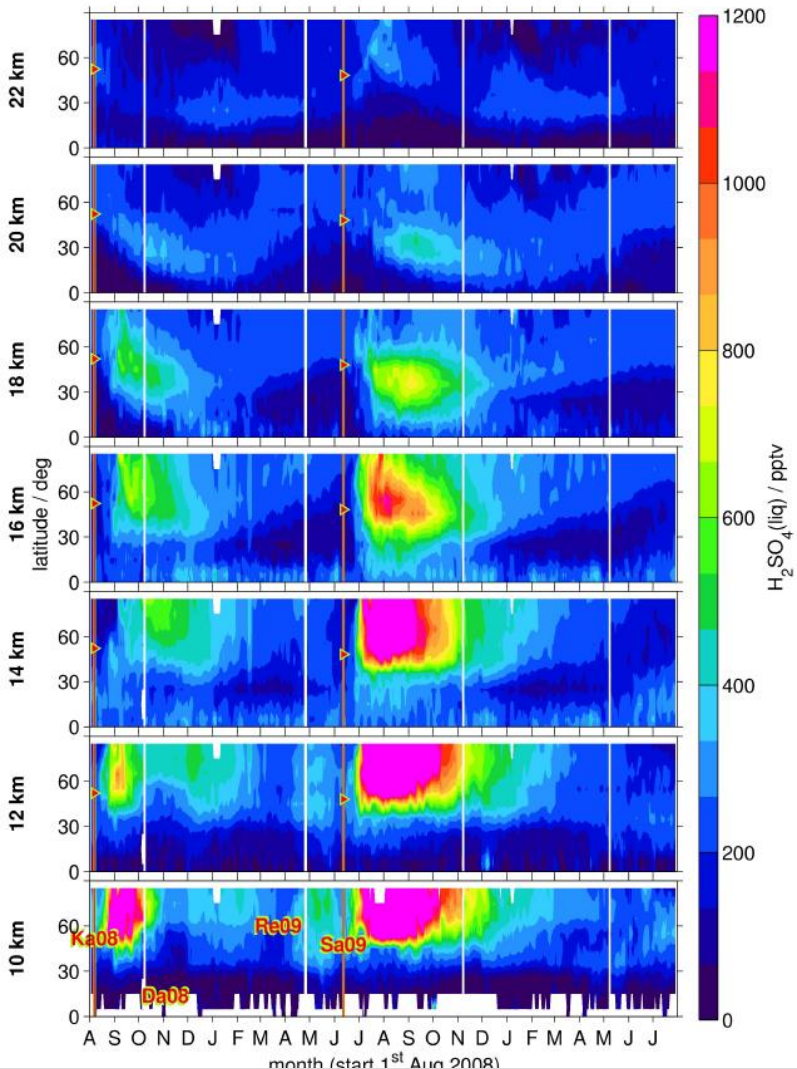
Günther et al., ACPD, 2017

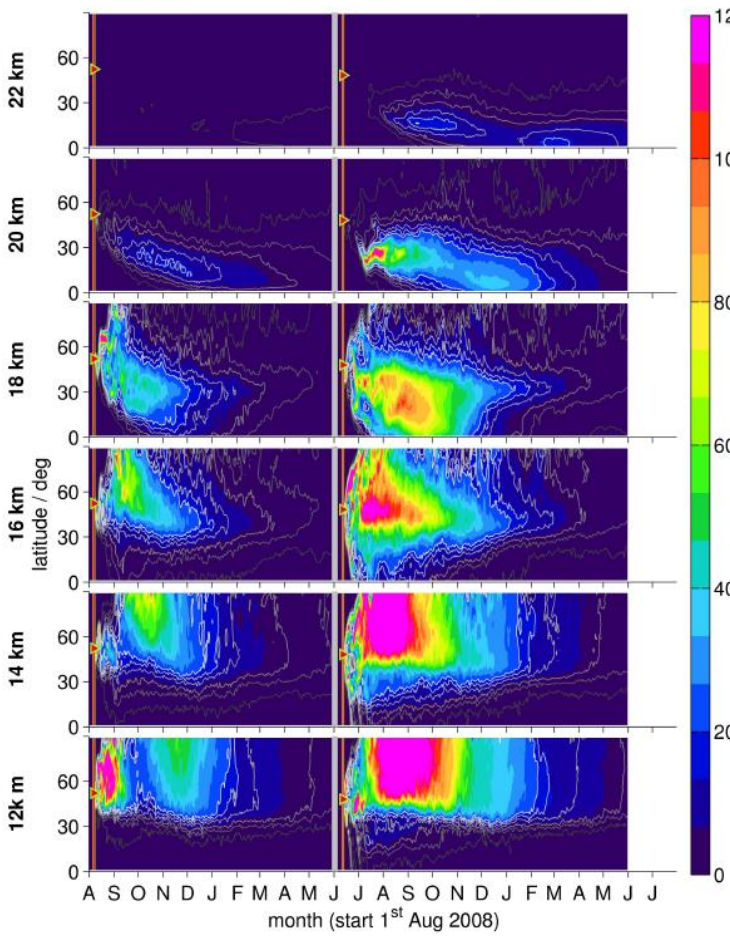
Sulfur mass budget after Kasatochi and Sarychev



Günther et al., ACPD, 2017

Transport into the tropics





Günther et al., ACPD, 2017

(see also Wu et al., ACPD, 2017)

Summary

- Whole budget of sulfur species from MIPAS available: OCS, SO_2, H_2SO_4(liq.)
- Sulfate aerosol volume density retrieval: altitude depedent bias corrected by use of in-situ data
- Quantitative analysis of Kasatochi and Sarychev
- Transport into tropics
- In work: analysis of OCS-conversion and transport at 20-30 km