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*Supplement of*

## **Stratospheric aerosol radiative forcing simulated by the chemistry climate model EMAC using Aerosol CCI satellite data**

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## Model setup

**Table S1:** Lower mode boundaries (dry) and distribution width  $\sigma$  in EMAC for stratospheric/tropospheric (L90) and tropospheric only (L31) setups.

|            |                     | Nucleation | Aitken | Accumulation | Coarse |
|------------|---------------------|------------|--------|--------------|--------|
| L90,strat. | Rmin, $\mu\text{m}$ | 0.0005     | 0.006  | 0.07         | 1.6    |
|            | $\sigma$            | 1.59       | 1.59   | 1.49         | 1.7    |
| L31,trop.  | Rmin, $\mu\text{m}$ | 0.0005     | 0.006  | 0.06         | 1.0    |
|            | $\sigma$            | 1.59       | 1.59   | 1.59         | 2.0    |

**Table S2:** Sea salt composition, %

| Mode   | Na <sup>+</sup> | K <sup>+</sup> | Ca <sup>++</sup> | Mg <sup>++</sup> | SO <sub>4</sub> <sup>-</sup> | Cl <sup>-</sup> | Bulk  |
|--------|-----------------|----------------|------------------|------------------|------------------------------|-----------------|-------|
| Coarse | 7.11            | 0.47           | 0.06             | 2.18             | 0.52                         | 8.47            | 81.18 |
| Accum. | 21.34           | 0.94           | 0.06             | 4.37             | 1.03                         | 25.42           | 46.83 |

**Table S3** Volcanic SO<sub>2</sub> injections into the stratosphere, derived from MIPAS and OMI/TOMS (Brühl et al., 2015). Updated on the basis of GOMOS and new MIPAS data including the ones in UTLS mode (Bingen et al., 2017). SO<sub>2</sub> masses above 14 km in low latitudes, above 13 km in midlatitudes and above 12 km in high latitudes. Listed altitudes and latitudes refer to the maxima in MIPAS ‘plumes’. The given time refers to the center of the first MIPAS 5day-period selected and not the beginning of the eruption. The eruption of Kanlaon in July 2006 is difficult to separate from the Soufriere Hills plume. Integration done after interpolation to ECHAM-grid in resolution T42L90 with simplified conversion from altitude to pressure. Data typically from a 10 day period, for Sarychev and Kasatochi from 30 days (with scaling). If only Vanuatu (or Van.) is mentioned means that several volcanoes there erupt simultaneously. Some names are abbreviated after the first occurrence, a ‘+’ means that the volcanoes cannot be separated. The last column is a scaling factor to be applied for SO<sub>2</sub> masses and mixing ratios if resolution T63L90 instead of T42L90 is used. M: monsoon influence, \* SO<sub>2</sub> estimated from GOMOS extinctions (Bingen et al., 2017).

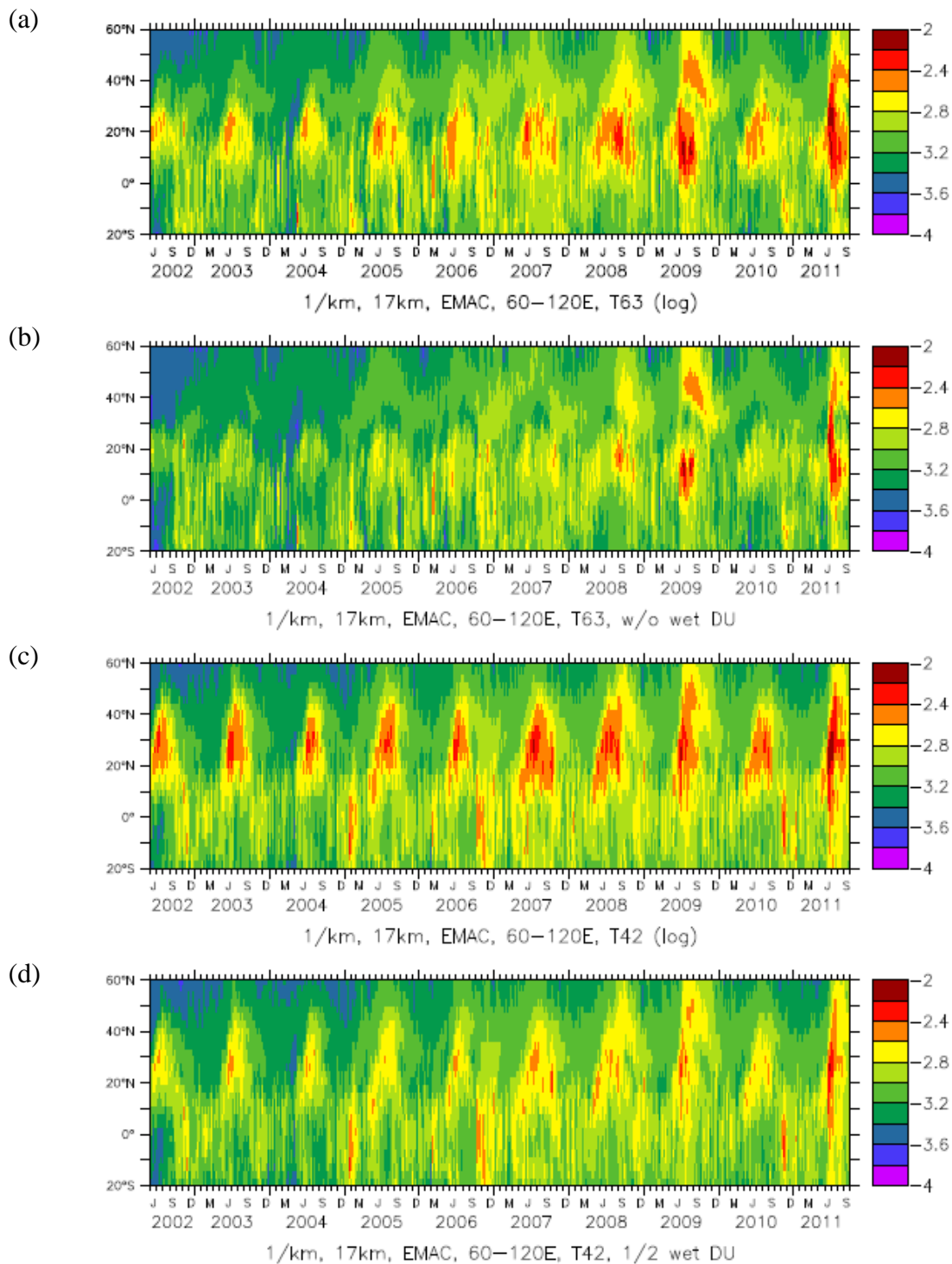
| Volcano or region         | Time        | Latitude   | Longitude   | Height     | SO <sub>2</sub> 3D str (kt) | Fact. T63 |
|---------------------------|-------------|------------|-------------|------------|-----------------------------|-----------|
| Nyamuragira               | 23 Jul 2002 | -1         | 30          | 15         | 23                          | 1         |
| Witori                    | 2 Aug 2002  | -6         | 150         | 14         | 18                          | 1         |
| Ruang                     | 26 Sep 2002 | 2          | 125         | 18         | 71                          | 1         |
| El Reventador             | 5 Nov 2002  | 0          | -78         | 17         | 77                          | 1         |
| Nyiragongo, Lokon         | 9 Jan 2003  | -1, 1      | 30, 125     | 15, 16     | 20, 17                      | 0.6       |
| Nyirag., Lokon (Rabaul?)  | 5 Mar 2003  | -5, 1      | 30, 125     | 17, 15     | 17, 19                      | 0.7       |
| Anatahan, Nyirag., Ulawun | 14 May 2003 | 16, -1, -5 | 143, 30,150 | 16, 16, 17 | 13, 21, 9                   | 0.7       |
| Lewotobi, Kanlaon         | 13 Jun 2003 | -8, 10     | 123,123     | 15, 15     | 13, 21                      | 0.7       |
| Soufriere Hills           | 13 Jul 2003 | 16         | -62         | 17         | 59                          | 0.7       |
| Gamalama, Japan, M        | 17 Aug 2003 | 1, 33      | 128, 131    | 16, 16     | 15, 13                      | 0.5       |
| Bezymianny or Klyuchev.   | 6 Sep 2003  | 56         | 160         | 14         | 8                           | 1         |
| Lokon, Soufr.H.(+Masaya)  | 26 Sep 2003 | 2, 15      | 125, -62    | 16, 16     | 12, 9                       | 0.6       |
| Rabaul                    | 10 Nov 2003 | -5         | 150         | 16         | 24                          | 0.7       |
| Rabaul                    | 5 Dec 2003  | -5         | 150         | 16         | 19                          | 0.7       |

|   |             |                      |                       |                 |               |      |
|---|-------------|----------------------|-----------------------|-----------------|---------------|------|
| Rabaul, Nyiragongo?                           | 9 Jan 2004  | -5, -1               | 150, 30               | 17, 15          | 15, 13        | 0.7  |
| Langila, Nyiragongo?                          | 3 Feb 2004  | -5, -1               | 150, 30               | 17, 17          | 16, 4         | 0.7  |
| Soufriere Hills                               | 4 Mar 2004  | 10                   | -62                   | 17              | 28            | 0.8  |
| Nyamu., Awu+Tengger C.                        | 12 Jun 2004 | -1, 4, -8            | 30,125,112            | 17, 15          | 25, 22 *      | 0.8  |
| Pacaya, Galeras                               | 17 Jul 2004 | 15, 1                | -91, -77              | 17, 17          | 16, 15 *      | 0.7  |
| Galeras                                       | 11 Aug 2004 | 1                    | -77                   | 16              | 21 *          | 0.7  |
| Vanuatu, Rinjani+Kerinci                      | 30 Sep 2004 | -16, -8, -2          | 168,116,101           | 15,15,17        | 10, 21 *      | 0.7  |
| Manam, Sopotan                                | 30 Oct 2004 | -4, 1                | 144, 125              | 16, 16          | 11, 16 *      | 0.7  |
| Manam, Nyiragongo                             | 24 Nov 2004 | -4, -1               | 144, 30               | 17, 15          | 22, 14 *      | 0.8  |
| Nyiragongo, Reventador                        | 4 Dec 2004  | 0, 0                 | 30, -77               | 16, 16          | 31, 8 *       | 0.6  |
| Vanuatu, Sopotan                              | 24 Dec 2004 | -16, 1               | 168, 125              | 17, 15          | 22, 23 *      | 0.7  |
| Manam   | 28 Jan 2005 | -4                   | 144                   | 18              | 144           | 0.9  |
| Anatahan, (+)                                 | 3 Apr 2005  | 16                   | 143                   | 15              | 21            | 0.7  |
| Anatahan, Soufriere Hills                     | 23 Apr 2005 | 16, 16               | 143, -62              | 16,16           | 30, 30        | 0.7  |
| Anatahan, Fernadina, Van.                     | 18 May 2005 | 16, 0, -16           | 143,-91,168           | 15,15,15        | 11, 15, 8     | 0.7  |
| Anatahan, Santa Ana                           | 12 Jun 2005 | 16, 14               | 143, -90              | 15,15           | 17, 13        | 0.7  |
| Anatahan, Soufriere Hills                     | 12 Jul 2005 | 16, 16               | 143, -62              | 15,15           | 18, 13        | 0.8  |
| Anatahan, Ruang                               | 6 Aug 2005  | 16, -8               | 143, 113              | 15,15           | 19, 28        | 0.7  |
| Anatahan, Ruang                               | 16 Aug 2005 | 16, -8               | 143, 113              | 15,15           | 25, 31        | 0.55 |
| Santa Ana                                     | 5 Oct 2005  | 14                   | -90                   | 17              | 46            | 0.7  |
| Sierra Negra, Dabbahu                         | 25 Oct 2005 | -1, -13              | -91, 40               | 15,15           | 20, 27 *      | 0.8  |
| Karthala, Galeras                             | 24 Nov 2005 | -10, -2              | 43, -80               | 16,16           | 16, 14        | 0.8  |
| Sopotan, Lopevi                               | 24 Dec 2005 | 1, -16               | 125, 168              | 16,16           | 33, 18        | 0.7  |
| Rabaul +                                      | 23 Jan 2006 | -5                   | 152                   | 16              | 31            | 0.8  |
| Manam, Chile                                  | 4 Mar 2006  | -5, -40              | 144, -70              | 17,16           | 72, 7         | 0.81 |
| Cleveland                                     | 14 Mar 2006 | 53                   | -170                  | 13              | 8             | 1    |
| Ecuad., Tinakula, Lascar                      | 18 Apr 2006 | -5,-10, -23          | -78,166,-68           | 17,17,17        | 16, 21, 3     | 0.8  |
| Soufriere Hills                               | 23 May 2006 | 16                   | -62                   | 19              | 156           | 0.8  |
| Kanlaon                                       | 2 Jul 2006  | 10                   | 123                   | 20              | 70            | 0.6  |
| Tungurahua, Rabaul                            | 16 Aug 2006 | -2, -4               | -78, 150              | 19, 17          | 44, 22        | 0.9  |
| Rabaul  | 10 Oct 2006 | -4                   | 150                   | 17              | 172           | 0.76 |
| Ubinas, Vanuatu                               | 25 Oct 2006 | -20,-20              | -70, 168              | 17, 15          | 14, 41        | 0.6  |
| Ambrym  | 9 Nov 2006  | -10                  | 160                   | 17              | 45            | 0.6  |
| Nyamuragira, Mexico                           | 29 Nov 2006 | 5, 5                 | 30, -90               | 17, 15          | 40, 30        | 0.7  |
| Bulusan, Sopotan, Vanuatu                     | 24 Dec 2006 | 13, 1, -16           | 125,125,168           | 18, 16, 15      | 10, 10, 18    | 0.75 |
| 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 | 0.9  |
| Nev. d Huila, Kartha., Van.                   | 22 Feb 2007 | 0, -10, -16          | -70, 43, 168          | 16,15,16        | 11, 14, 11    | 0.7  |
| Etna, Reventador, Ambrym                      | 24 Mar 2007 | 38, 0, -16           | 15, -78, 160          | 15,16,17        | 11, 24, 20    | 0.7  |
| Pit.Fourn.Reunion, Reventador +               | 8 Apr 2007  | -20, 0               | 57, -80               | 16, 16          | 31, 15        | 0.7  |
| Ulawun, Vanuatu, N.d. Huila                   | 3 May 2007  | -5, -25, 3           | 150,160,-70           | 15,15,15        | 15, 7, 9      | 0.7  |
| Papua, Kamchatka, Nyira., Ubinas+Lascar       | 13 May 2007 | -10, 50, 0, -20      | 150,150,30, -75       | 16,16,16, 16    | 8, 1, 13, 8   | 0.8  |
| Llaima, Vanuatu, Bulusan                      | 23 May 2007 | -30,-15, 13          | -70,160,125           | 18,15,17        | 14, 8, 10     | 0.7  |

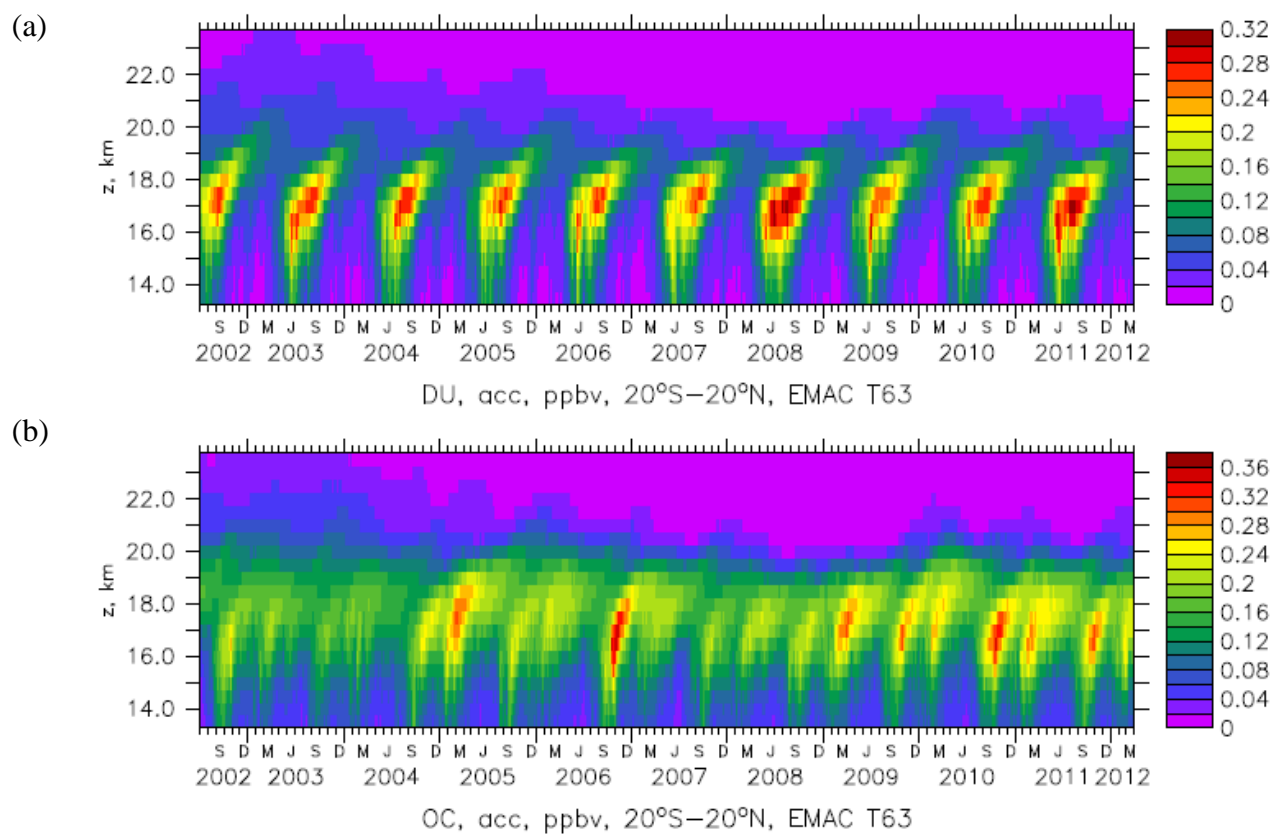
|   |             |                 |                    |                |             |     |
|---|-------------|-----------------|--------------------|----------------|-------------|-----|
| Soputan,Bezym.,Telica                     | 12 Jun 2007 | 1, 56, 13       | 125,160,-87        | 16, 14,15      | 19, 10, 13  | 0.7 |
| Lengai, Mexico, M                         | 2 Jul 2007  | 2, 20           | 29, -90            | 16, 15         | 17, 11      | 0.8 |
| Raung, Japan, M (+)                       | 27 Jul 2007 | -5, 35          | 110, 130           | 15,15          | 14, 14      | 0.7 |
| Manda Hararo, Java, M                     | 11 Aug 2007 | 12, -5          | 40, 115            | 17, 15         | 21, 18      | 0.6 |
| Vanuatu, Mexico, M                        | 20 Sep 2007 | -5, 20          | 180, -90           | 16,16          | 11, 18      | 0.7 |
| Jebel al Tair, Galeras                    | 5 Oct 2007  | 16, 1           | 42, -80            | 16,16          | 68, 13      | 0.6 |
| Galeras, Jebel, Soputan                   | 4 Nov 2007  | -2, 15, -5      | -80,42,110         | 16,16,16       | 10, 7, 12   | 0.7 |
| Soputan or Krakatau, Galeras, Chikurachki | 14 Nov 2007 | -5, -1, 50      | 110,-75,155        | 16,16, 15      | 13, 12, 14  | 0.7 |
| Talang, Galeras                           | 9 Dec 2007  | 0, 0            | 100, -75           | 16,16          | 13, 15      | 0.8 |
| Ulawun?                                   | 19 Dec 2007 | 1               | 150                | 17             | 29          | 0.6 |
| Nevado del Huila, Llaima                  | 3 Jan 2008  | 1, -35          | -75,-71            | 17, 15         | 32, 5       | 0.8 |
| Galeras, Anatahan                         | 23 Jan 2008 | -3, 15          | -80, 145           | 16,16          | 24, 12      | 0.6 |
| Tungurahua, Papua                         | 12 Feb 2008 | -5, -5          | -80, 155           | 16, 17         | 19, 14      | 0.7 |
| TaraBatu (+)                              | 13 Mar 2008 | -5              | 125                | 16             | 33          | 0.8 |
| Lengai, Andes, Kerinci                    | 28 Mar 2008 | -5, 5, -2       | 36, -80, 101       | 16,16,16       | 10, 7, 11   | 0.6 |
| Egon, Nev.d.Huila                         | 12 Apr 2008 | -5, 5           | 122, -76           | 15, 17         | 20, 13      | 0.7 |
| Mexico, Ibu, Chaiten                      | 27 Apr 2008 | 15, -35         | -90, 125, -70      | 16,16,16       | 13, 15, 4   | 0.7 |
| Mexico, Barren I., Chaiten                | 12 May 2008 | 10,10, -35      | -90, 90, -70       | 14,16, 14      | 13, 18, 6   | 0.8 |
| Soputan, Nicaragua/C.R.                   | 16 Jun 2008 | 1, 15           | 125, -85           | 16,16          | 32, 10      | 0.8 |
| Okmok, Soputan                            | 21 Jul 2008 | 53, 1           | -168, 125          | 16,16          | 57, 30      | 0.9 |
| Kasatochi                                 | 15 Aug 2008 | 52              | -175               | 17             | 390         | 0.7 |
| Dallafilla,N.d.Huila,Rev.                 | 13 Nov 2008 | 14, 3           | 40, -78            | 17,17          | 55, 40      | 0.7 |
| Karangetang, Galeras, Jap.                | 18 Dec 2008 | 3, 0, 30        | 125,-80,130        | 17, 17, 15     | 19, 13, 11  | 0.8 |
| Barren Island, Galeras                    | 2 Jan 2009  | 10, 3           | 90, -80            | 17, 15         | 16, 16      | 0.6 |
| Indonesia?, Galeras                       | 27 Jan 2009 | -5, 0           | 100, -80           | 16,16          | 15, 13      | 0.8 |
| Galeras, Villarrica, Karangetang, Vanuatu | 16 Feb 2009 | -2, -35, 3, -16 | -78, -75, 100, 168 | 16, 15, 16, 17 | 12, 7, 7, 8 | 0.9 |
| Redoubt, Galeras                          | 28 Mar 2009 | 60, 0           | -155, -75          | 13, 15         | 61, 43      | 1   |
| Fernandina, Nyira.                        | 12 Apr 2009 | 0, 0            | -90, 30            | 16,16          | 12, 16      | 1   |
| Galeras+Reventador                        | 7 May 2009  | 0               | -75                | 15             | 31          | 0.8 |
| Rinjani, Vanuatu, Revent.                 | 22 May 2009 | -5, -15, 3      | 116,165,-80        | 16,16,16       | 5, 6, 18    | 0.7 |
| Sarychev, MandaHararo                     | 21 Jun 2009 | 48, 12          | 153, 40            | 16,16          | 496, 91     | 0.9 |
| Vanuatu, Mayon, Galeras                   | 4 Oct 2009  | -15, 13, 2      | 165,120,-80        | 17,17,17       | 6, 9, 14    | 0.7 |
| Tungurahua, Hawaii, Van.                  | 19 Oct 2009 | 5, 20, -16      | -76,-155, 165      | 16,16,16       | 11, 8, 9    | 0.6 |
| Galeras, Karkar, Vanuatu                  | 3 Dec 2009  | 0,-5,-16        | -78,146,165        | 17,17,17       | 15, 12, 5   | 0.8 |
| Mayon, Nyamuragira, Van.                  | 2 Jan 2010  | 13, 0, -15      | 120, 30, 168       | 16,16,16       | 12, 12, 13  | 0.7 |
| Turrialba, Vanuatu                        | 17 Jan 2010 | 5, -15          | -82, 168           | 16,16          | 15, 15      | 0.6 |
| Soufriere Hills                           | 16 Feb 2010 | 16              | -62                | 17             | 45          | 0.8 |
| Arenal, Indon., Van.                      | 2 Apr 2010  | 9, 0, -16       | -84,120,168        | 15,15,15       | 18, 15, 6   | 0.8 |

|                                      |             |             |               |            |            |      |
|--------------------------------------|-------------|-------------|---------------|------------|------------|------|
| Tungurahua, Dukono, Van.             | 2 May 2010  | -5, 2,-16   | -78,128,168   | 16,16,16   | 20, 14, 10 | 0.7  |
| Pacaya, Ulawun, Sarigan              | 6 Jun 2010  | 15, -5, 16  | -91,150,145   | 17, 16, 15 | 38, 8, 6   | 0.7  |
| Ulawun, Costa Rica,<br>Miyakejima, M | 16 Jul 2010 | -5, 15, 35  | 150, -87, 140 | 16,16,16   | 11, 18, 8  | 0.7  |
| Karanget., Nicaragua, Van.           | 15 Aug 2010 | 3, 15, -16  | 125,-85,168   | 16,16,16   | 17, 17, 9  | 0.7  |
| Galeras, Sinabung M                  | 30 Aug 2010 | 5, 5        | -77, 100      | 16,16      | 16, 20     | 0.6  |
| Karangetang?, Barren Isla.           | 4 Oct 2010  | 3, 12       | 125, 94       | 16, 16     | 28, 19     | 0.7  |
| Merapi                               | 8 Nov 2010  | -7          | 110           | 17         | 108        | 0.9  |
| Tengger C., Tungu., Chile            | 23 Dec 2010 | -8, -3, -40 | 110, -78,-75  | 17,17,17   | 23, 19, 12 | 0.7  |
| Tengger C.                           | 7 Jan 2011  | -8          | 110           | 16         | 40         | 0.6  |
| Lokon-Empung, Planchon,<br>Bulusan   | 26 Feb 2011 | 1, -35, 13  | 125,-75,125   | 16, 15, 16 | 19, 5, 17  | 0.7  |
| Karangetang, Sangay,<br>Planchon     | 23 Mar 2011 | 2, -2, -35  | 125, -78,-75  | 15,15,15   | 12, 12, 6  | 0.8  |
| Galeras?, Karangetang                | 12 Apr 2011 | 5, 5        | -77, 128      | 16,16      | 14, 13     | 0.7  |
| Tungurahua, Dukono, Van.             | 2 May 2011  | 2, 2, -16   | -78,128,160   | 16, 16, 15 | 18, 13, 7  | 0.7  |
| Grimsvötn, Lokon                     | 27 May 2011 | 65, 1       | -20, 125      | 14, 16     | 20, 30     | 0.9  |
| Puyehue                              | 11 Jun 2011 | -41         | -71           | 13         | 23         | 1    |
| Nabro                                | 21 Jun 2011 | 13          | 41            | 18         | 446        | 0.91 |
| Soputan, Marapi                      | 20 Aug 2011 | 1, 0        | 125, 100      | 18, 16     | 15, 5      | 0.6  |
| Manam, Tungurahua                    | 19 Oct 2011 | -4, -3      | 144, -78      | 16,16      | 14, 14     | 0.6  |
| Nyamuragira                          | 18 Nov 2011 | -2          | 29            | 16         | 39         | 0.8  |
| Gamalama, Nyamuragira                | 18 Dec 2011 | 1, -1       | 128, 29       | 16, 15     | 27, 19     | 0.7  |
| Vanuatu, Nyamuragira                 | 12 Jan 2012 | -16, -1     | 168, 29       | 16, 14     | 20, 17     | 0.7  |
| Vanuatu, Nyamuragira                 | 11 Feb 2012 | -16, -1     | 168, 29       | 17,17      | 23, 22     | 0.7  |
| N.Ruiz, Marapi                       | 12 Mar 2012 | -3, 0       | -76, 100      | 16, 17     | 17, 21     | 0.7  |

## Stratospheric dust and organic carbon



**Figure S1:** (a) Logarithm of extinction at 550 nm simulated by EMAC in resolution T63L90, (b) Same without contribution by wet dust, (c) Extinction by EMAC in resolution T42L90, (d) same with contribution of wet dust halved. Results correspond to Fig. 2 concerning geographic region, the altitude of 17 km and the observations.



**Figure S2:** Simulated volume mixing ratio of dust (DU, (a)) and organic carbon (OC, (b)) in the tropics, accumulation mode.