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Evaluating the simulated radiative forcings, aerosol properties, and stratospheric warmings from the 1963 Mt Agung, 1982 El Chichón, and 1991 Mt Pinatubo volcanic aerosol clouds

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1 Converting Backscatter Ratio to Extinction

The wavelength exponent of aerosol backscatter (κ_b) and the 532nm extinction-to-backscatter ratio (EBR_{532}) are necessary coefficients for calculating 532nm aerosol extinction from the 694nm aerosol backscatter ratio (BSR) measured by the Lexington lidar. From co-analysing mid-latitude lidar and balloon measurements, Jäger and Deshler (2002) provide monthly timeseries at 3 vertical levels for both of these coefficients for the Pinatubo aerosol cloud, (see Figures 2 and 4, and note the published correction in Jäger and Deshler, 2003). Although these coefficients will be different for the Agung eruption cloud, we use the Pinatubo values for January 1993 to September 1994 (from 19 months after the eruption) as representative for the January 1964 to Septmber 1965 period of the Lexington measurements, when the optical depth of the clouds were similar and at similar point in the seasonal cycle in stratospheric circulation. Although both of the coefficients are dependent on the particle size distribution, we consider this temporal offset to give a reasonable approximation in the Agung case. In addition to the temporal offset, with the Pinatubo cloud at higher altitude than the Agung cloud, we used the 15-20km, 20-25km and 25-30km values from Jäger and Deshler (2003) to generate the Lexington extinction timeseries at 15 km, 20 km and 24 km, respectively.

The calculation for molecular backscatter is from Vega et al. (2017):

$$\beta_{Rayleigh(\lambda,z,\theta)} = 2.938 \times 10^{-32} \frac{P_{(z)}}{T_{(z)}} \cdot \frac{1}{\lambda^{4.0117}} (m^{-1} sr^{-1}) \tag{1}$$

where P is pressure (hPa), T is temperature (K), z is altitude (m), λ is wavelength (m) and $\beta_{Rayleigh}$ is the backscatter coefficient (angular).

The backscatter ratio (BSR) is defined as:

$$BSR = \frac{\beta_{mol} + \beta_{aer}}{\beta_{mol}} \tag{2}$$

where β_{mol} and β_{aer} are molecular and aerosol backscatter, respectively.

In general, the steps used to convert the lidar backscatter to extinction are as follows:

1. Calculate molecular backscatter using $\beta_{Rayleigh}$ for a given pressure. Here, we use values from US standard atmosphere (Table S1).

2. Calculate the aerosol backscatter (β_{aer}) using:

$$\beta_{aer694} = (BSR - 1) \times \beta_{mol694} \tag{3}$$

   where, βaer_{694} and βmol_{694} are aerosol and molecular backscatter at 694 nm, respectively.

3. Convert aerosol backscatter at 694 nm to 532 nm using:

$$\beta_{aer532} = (\frac{694}{532})^{kb} \times \beta_{aer694} \tag{4}$$

   where β_{aer532} is aerosol backscatter at 532 nm or, more generally, from wavelength λ_2 to λ_1:

$$\beta\lambda_1 = (\frac{\lambda_2}{\lambda_1})^{kb} \times \beta\lambda_2 \tag{5}$$

4. Calculate extinction at 532 nm using:

$$EXT_{532} = \beta_{aer532} \times EBR_{532} \tag{6}$$

   where EXT_{532} is the aerosol extinction at 532 nm and EBR_{532} is the the 532nm extinction-to-backscatter ratio.

Table S1. Standard atmosphere values of pressure, altitude and temperature.

Pressure (hPa)	Altitude (m)	Temperature (°C)	Temperature (K)
120.4	15000	-56.5	216.65
47.5	20900	-55.6	217.55
25.1	25000	-51.5	221.65

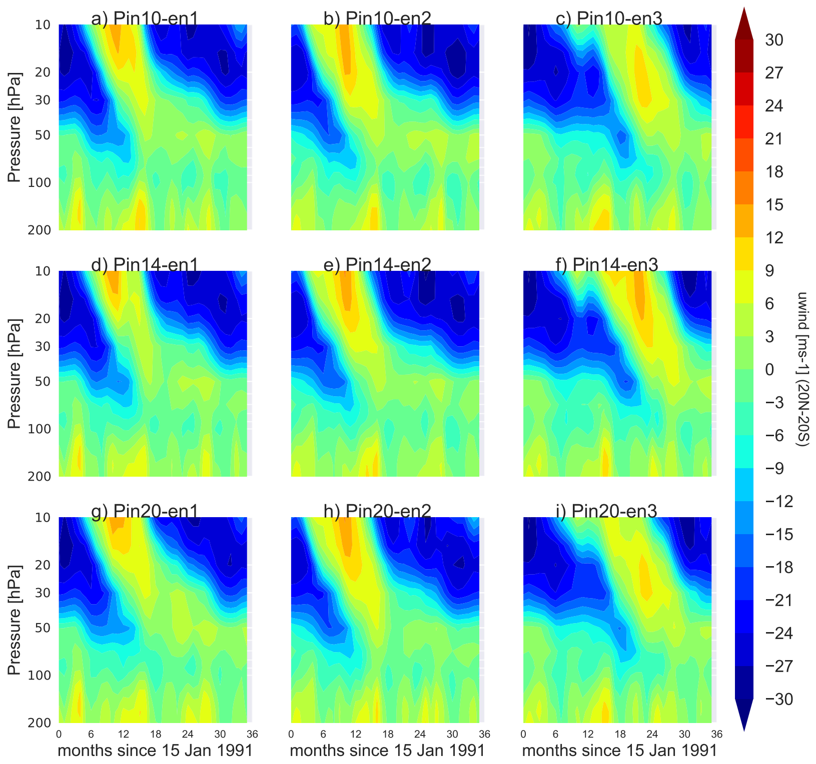

Figure S1. Monthly mean zonal mean wind in the tropical stratosphere (averaged between 20° S and 20° N) from individual members from **Pin10** (top), **Pin14** (middle) and **Pin20** (bottom) simulations.

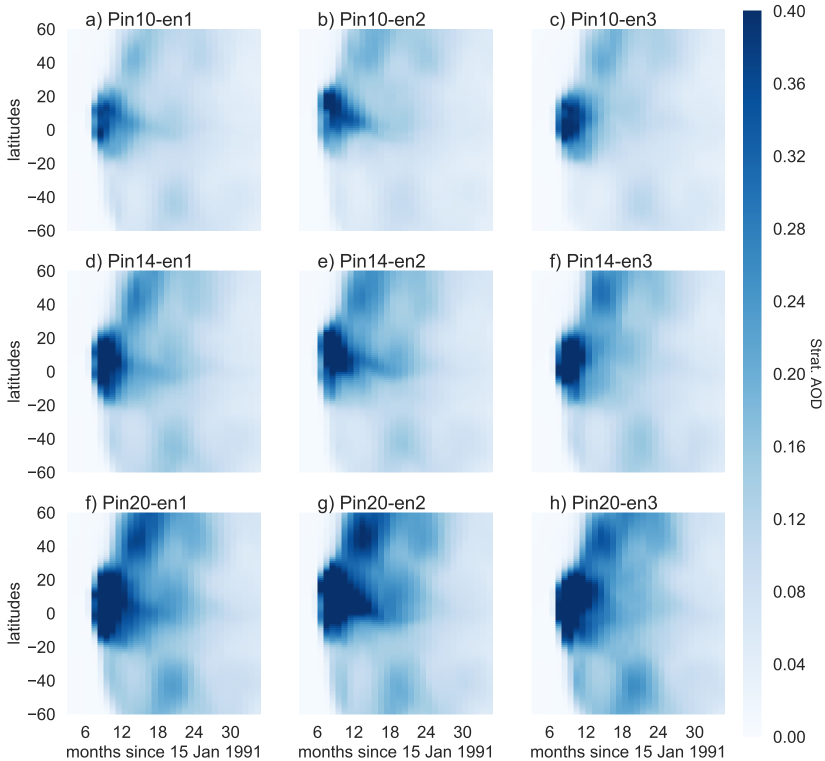

Figure S2. Monthly mean stratospheric Aerosol Optical Depth (sAOD) from individual members of the **Pin10** (top), **Pin14** (middle) and **Pin20** (bottom) simulations.

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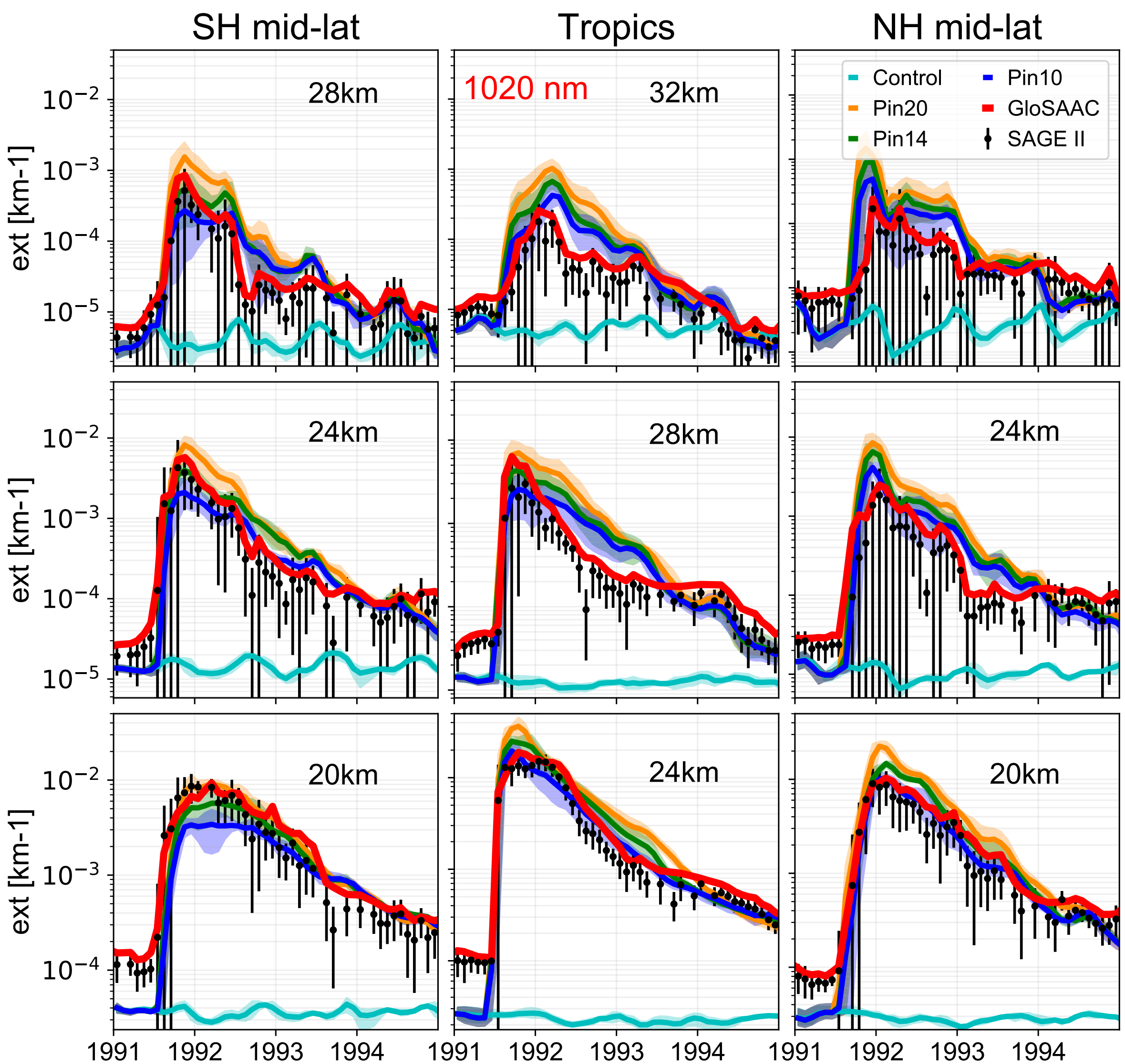

Figure S3. Ensemble mean extinctions (1020 nm) from simulations **Pin00** (aqua), **Pin10** (blue), **Pin14** (green), and **Pin20** (orange). The shaded regions indicate the variability among ensemble members. Extinctions for SH mid-latitudes (35°S – 60°S), tropics (20°S – 20°N), and NH mid-latitudes (35°N – 60°N) are shown in left, middle and right panels, respectively. Mid-latitude extinctions are shown for 20, 24 and 28 km, whereas tropical profiles are shown for 24, 28 and 32 km. Monthly mean extinction from SAGE II v7.2 measurements for a given latitude band are shown with black filled circles and vertical lines indicate standard deviation from all the measurements for a given month. Gap-filled extinctions from the GLoSSAC V2 dataset (Kovilakam et al., 2020) are shown with a red line.

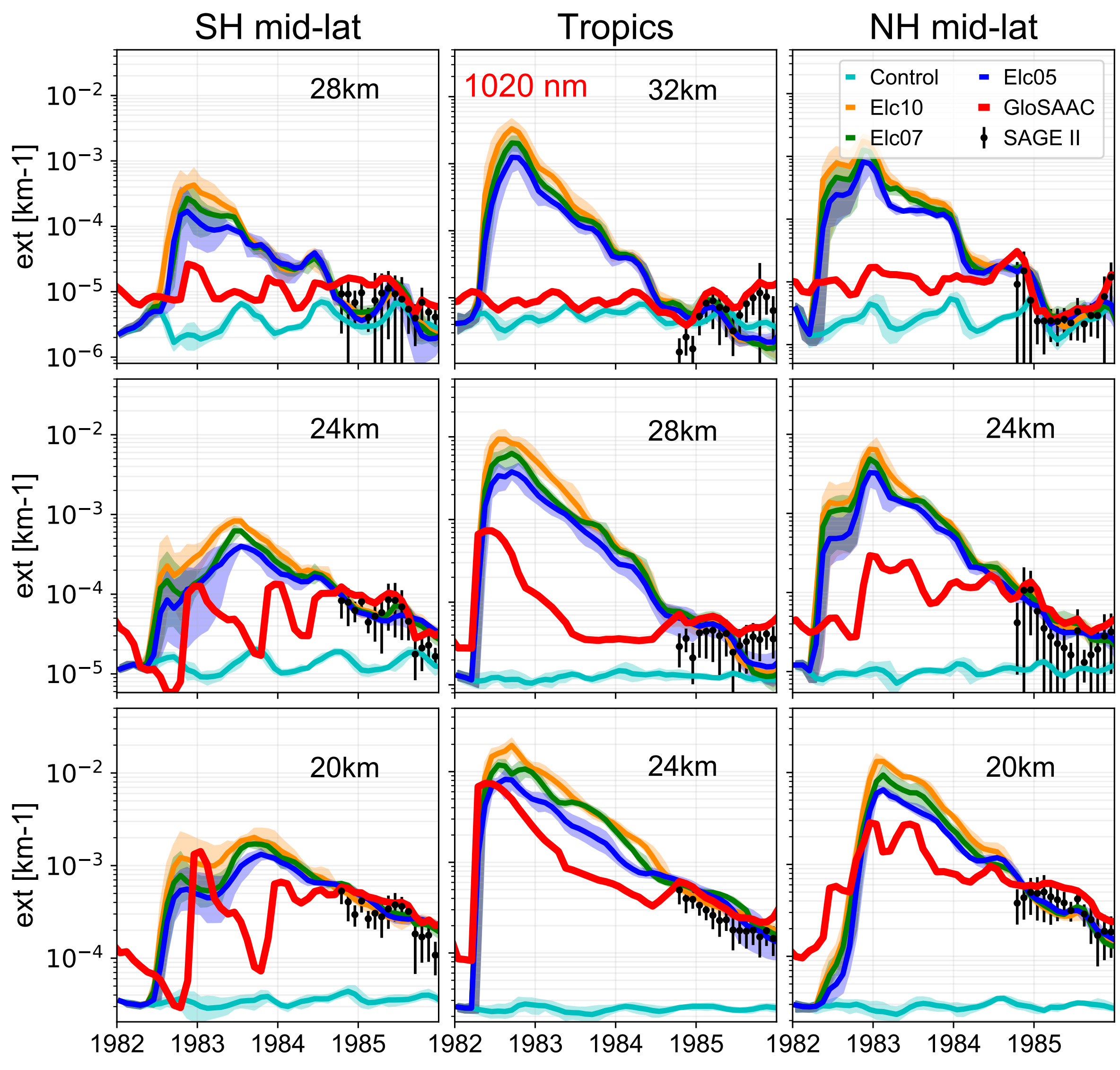

Figure S4. Same as Figure S1 but for the El-Chichon eruption

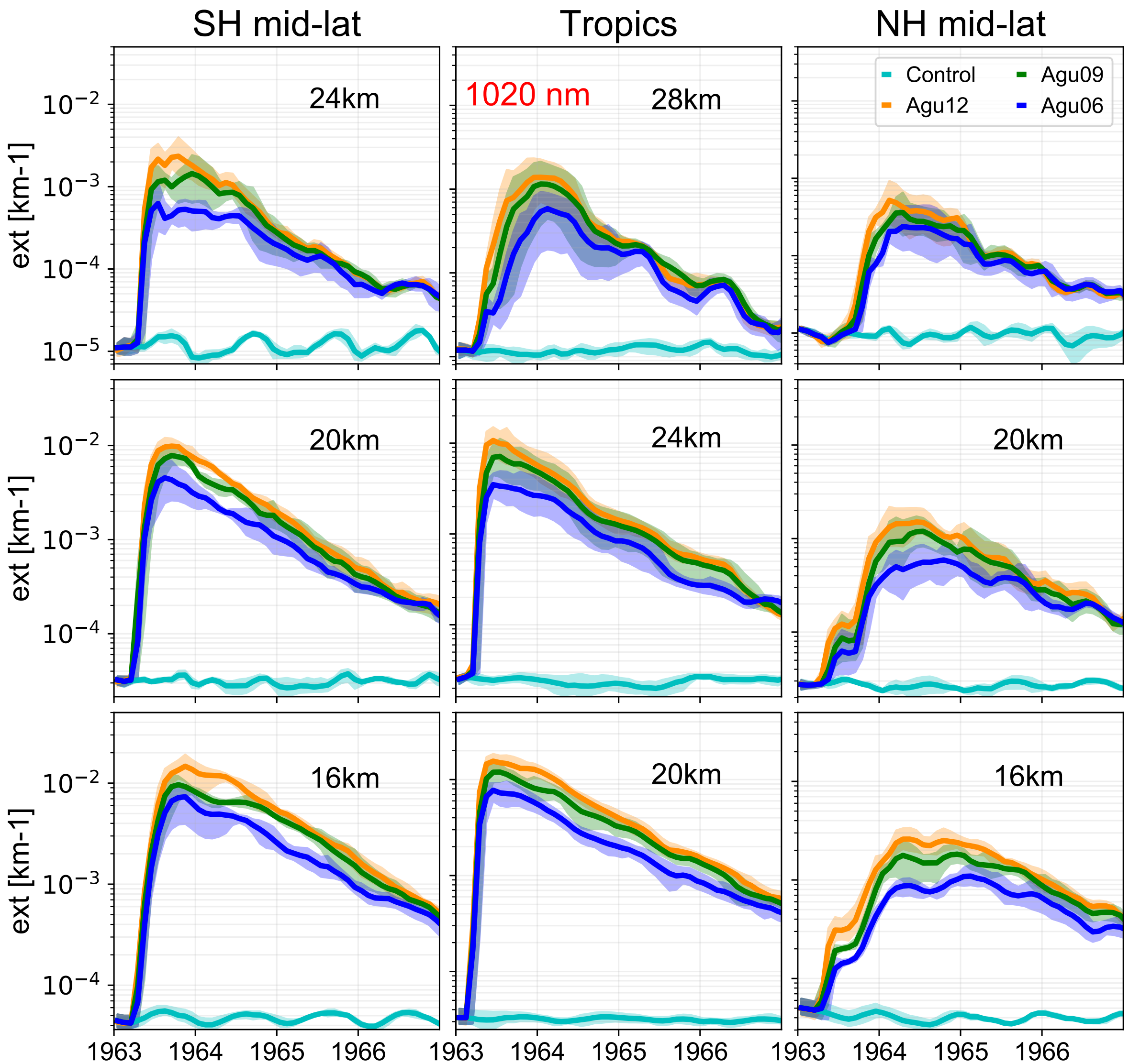

Figure S5. Same as Figure S1 but for the Agung eruption. Extinction at 1020 nm is not available in the evaluation datasets, hence only simulated extinctions are shown.

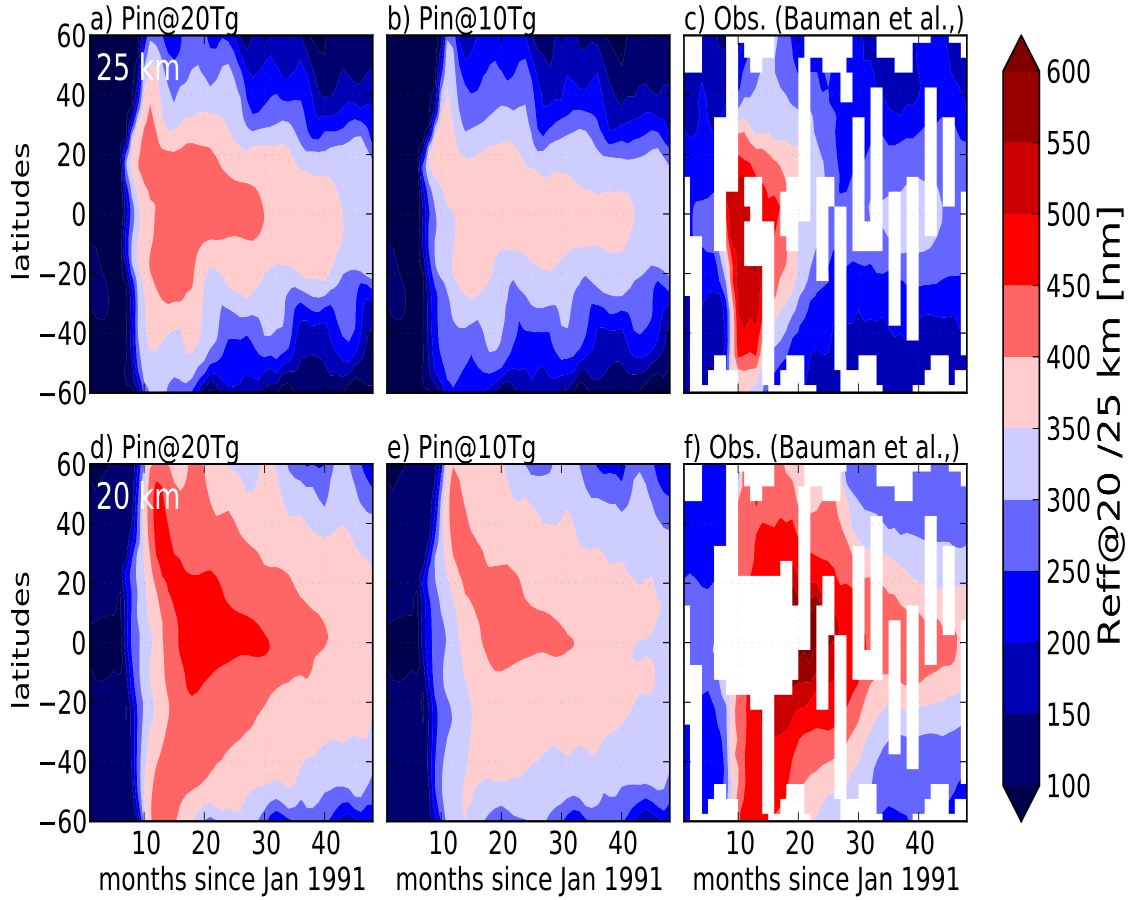

Figure S6. Modelled (from simulations **Pin10** and **Pin20**) and observation-derived (from Bauman et al., 2003) effective radii (R_{eff}, in μm) at (a)-(c) 25 km and (d)-(f) 20 km.