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Measurement Report: Observed Increase in Southern Hemisphere Reflected Energy from Clouds During December 2020 and 2021

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Atmospheric Chemistry and Physics Discussions

Abstract

Measured backscattered UV radiances at 388±1.5 nm are converted to Lambert Equivalent Reflectivity (LER) are from EPIC (Earth Polychromatic Imaging Camera) onboard the DSCOVR spacecraft (Deep Space Climate Observatory) orbiting about the Sun-Earth Lagrange-1 (L_1) gravitational balance point. The average percent of reflected solar energy in the 388±1.5 nm band is 29.2% of the global incident solar energy in that band. Maximum reflected 388 nm solar energy R_{SE}, mostly from clouds, occurs during summer solstice in each hemisphere, December in the Southern Hemisphere SH and June in the Northern Hemisphere NH. The global average R_{SE} (90^{O}S to 90^{O}N) has a maximum in December and a minimum in June showing that the SH cloud reflected energy is greater than that in the NH. Backscattering from land and oceans at 388 nm is small, since the average clear-sky reflectivity of the Earth's surface free of snow and ice is about 0.05. Calculations of R_{SE} based on the 388 nm LER show a 7% increase during December 2020 in R_{SE} at 40^{O}S to 50^{O}S when the backscatter angle B_A was 178.05^{O}, and 6% at 30^{O}S to 40^{O}S in November 2021 when B_A = 177.5^{O} compared to previous years, 2015-2019, with a smaller B_A. Comparison of 380 nm R_{SE} at 40^{O}S to 50^{O}S during December 2020 from the low Earth polar orbiting nadir mapper in the Ozone Mapping and Profiler Suite (OMPS-NM) near 13:30 local solar time suggest that there has been a 5% increase in SH cloud reflection during December 2020 compared to previous years. This suggests that the observed increase by EPIC is mostly from an increase in cloud cover and not from enhanced backscatter. In the NH R_{SE} values at large EPIC B_A (177.5^{O} in June 2020 and 178.2^{O} in June 2021) between 30^{O}N to 60^{O}N show a percent decrease 4.8% in R_{SE} at 45^{O}N during June 2021 and a 6% increase during June 2020 at 55^{O}N compared to the previous 4 years. This also suggests that the increase and decrease in R_{SE} are probably related to changes in cloud cover and not backscatter angle effects. Annual integrals of percent reflected solar energy over complete years are almost constant at all latitudes.

https://doi.org/10.5194/acp-2022-481
Preprint. Discussion started: 10 August 2022

Atmospheric Chemistry and Physics Discussions

1.0 Introduction

The EPIC satellite instrument (Earth Polychromatic Imaging Camera) onboard the DSCOVR (Deep Space Climate Observatory) observed almost the full illuminated Earth's disk since June 2015 from an orbital position near the Earth-Sun L_1 point (Lagrange-1 point) approximately 1.5×10^6 km from the Earth. The spacecraft orbit consists of an approximately 6-month non-repeating tilted Lissajous figure about L_1 that varies in distance from the Earth ($\pm 1 \times 10^5$ km). The changing orbit causes variations in the instrument's small satellite viewing angle from the Sun-Earth line (SEV) (Marshak et al., 2021). Recently (2020-2021), the SEV minimum has decreased from $4^{O} – 6^{O}$ to slightly less than 2^{O} (backscatter angle $B_A = 178^{O}$), which might cause the observation of reflected radiances to increase compared to observations from smaller backscattering angles (Marshak et al., 2021, Penttila et al., 2021). The largest enhanced backscatter effects for small SEV arise in the Near IR (NIR) from vegetation with smaller effects from clouds in the visible and NIR (Marshak et al., 2021).

This paper will examine the cloud-reflected energy in the narrow band 388±1.5 nm where there is Rayleigh scattering but almost no atmospheric absorption or seasonal dependence of the low surface reflectivity from land, vegetation, or oceans. Data obtained from two observational platforms will be compared, one from the EPIC instrument at L_1 and the second from the nadir mapper in the Ozone Mapping and Profiler Suite (OMPS) onboard the joint NASA/NOAA Suomi National Polar-orbiting Partnership (Suomi NPP) satellite in an Earth inclined low Earth polar orbit crossing the equator at about 13:30 local solar time. OMPS-NM occasionally observes at large backscattering angles in the equatorial region but never at higher latitudes.

The EPIC instrument observes the Earth in 10 narrow band filter channels from 317.5 nm to 780 nm (317.5, 325, 340, 388, 443, 551, 680, 688, 764, and 780 nm) using a 30-cm aperture telescope imaging on a 2048x2048 hafnium coated CCD (Charge Coupled Detector) with a field of view of 0.62^{O} viewing the Sun illuminated Earth with a nominal angular size of 0.5^{O}. Instrument details and calibration are discussed in Herman et al. (2018) and Marshak et al. (2018). EPIC obtains between 13 to 22 images per 24 hours depending on the amount of time during a day the receiving antenna at Wallops Island, Virginia (38^{O}N latitude) is in view of the spacecraft.

The OMPS suite of instruments consists of three spectrometers, a spatial nadir mapper OMPS-NM, a nadir looking ozone profiler, and a limb viewing profiler. Of the three, this paper uses the data from the downward looking spatial mapper OMPS-NM at 380±0.55 nm. The OMPS-NM side-to-side looking nadir mapper spectrometer (side-swath of 2000 km) has a spectral range of 300 to 380 nm with a spectral resolution of 1.1 nm and a nadir spatial resolution of 50 x 50 km^2 (Jaross et al., 2012; McPeters et al., 2019).

Unlike the visible and near-IR channels of EPIC, the 380 nm and 388 nm UV reflectivities of clear-sky snow/ice-free scenes are very low over both land and oceans for both EPIC and OMPS-NM. The average clear-sky Lambert Equivalent Reflectivity (LER) (Bhartia et al., 1993, Krotkov et al., 1998, 2001; Herman et al., 2001, Herman et al., 2018) of the snow/ice free Earth's surface is about 0.05 (Herman and

https://doi.org/10.5194/acp-2022-481
Preprint. Discussion started: 10 August 2022

Celarier, 1997) after the calculated Rayleigh scattering amount from the surface to the top of the atmosphere TOA has been subtracted. The observed UV reflectivity is almost independent of seasonal surface vegetation effects and shadowing effects from the terrain and vegetation and comes mostly from clouds (Herman et al., 2018).

This paper will examine the reflected solar energy R_{SE} in the EPIC narrow band 388±1.5 nm and the OMPS-NM 380±0.55 nm band. Other than Rayleigh scattering the sources of reflection are from the clouds, snow/ice, aerosols, land and oceans. The main interest here is the relative year-to-year change in R_{SE} from 388±1.5 nm or 380 ± 0.55 nm solar irradiance reflected from the illuminated portion of the Earth as seen by EPIC and OMPS during the period June 2015 to June 2021. This includes the period (2020-2021) when the minimum EPIC SEV angles were near 2^O (B_A near 178^O), compared to previous years 2015-2019 when the minimum SEV angles were larger (4^O- 6^O). The goal is to see which latitude bands contribute to the apparent increased back reflection observed by EPIC in June and December 2020 and 2021, and to compare changes in percent reflected energy with SEV angles and the corresponding measurements from OMPS-NM.

The values of reflected energy for OMPS-NM have less point-to-point variation than those for EPIC since the OMPS-NM is observing mid-day zonal average reflected radiances while EPIC observes spatially resolved reflected radiances from near sunrise to near sunset. The quantities of interest are the relative values for each observing instrument during each summer maxima for June and December 2020 and 2021 as a function of latitude compared to the maxima in previous years, 2015-2019.

The 1 AU solar flux at 388 nm is approximately 1.04 W $m^{-2}nm^{-1}$ (Thuillier et al., 2003) and at 380 nm is 1.3 W $m^{-2}nm^{-1}$. The EPIC filter has an almost rectangular Full Width Half Maximum band pass of $\Delta\lambda$ = 3 nm (Herman et al., 2018) yielding a solar irradiance at 1 AU at the top of the atmosphere of E_{TOA} = 3.12 Wm^{-2}. For NPP-NM at 380±0.55 nm, E_{TOA} is 1.43 Wm^{-2}. All of the following results will be expressed as a percent reflected energy incident on the area of a flat disk of radius R_E, πR_E^2, $P_{SE}(t,\theta)$ weighted by the area of each latitude band and the cosine of the solar zenith angle SZA appropriate for the latitude θ, longitude, and time t from start of the EPIC ozone data on 17 June 2015 18:44:39 GMT. The EPIC $P_{SE}(t,\theta)$ are corrected for the change in the amount of illuminated Earth seen by EPIC caused by changes in orbit observing angles during 2021-2022 compared to previous years.

2.0 Reflected Solar Energy R_{SE} and P_{SE}

The intensity of the solar irradiance $F_{SUN}(t)$ at a given Greenwich Mean Time (GMT) on the Earth's surface is reduced in proportion to the cosine of the solar zenith angle SZA = $\zeta(\theta,\phi,\delta)$, where ϕ = longitude, θ = latitude, and δ = the Earth's declination angle $-23.45^O \le \delta \le 23.45^O$, Eqs. 1-9. Further variation is given by the changing Sun-Earth distance caused by the approximately elliptic orbit of the Earth about the Sun. The illuminated Earth of mean radius R_E= 6371 km is divided into latitude by longitude grids of 0.25^O x 0.25^O. The reflected energy $E_i(\theta_i,t)$ contribution of each latitude band θ_i is approximately proportional to the illuminated latitude-band area A_i on the Earth (Eqs. 1-5) from M illuminated grid points. For convenience, the small ($2\Delta\theta = 0.25^O$) latitude band contributions can be summed into 18 ten-degree latitude bands $-90^O < \theta < 90^O$ using Eq. 6 with the energy reflected in each

https://doi.org/10.5194/acp-2022-481
Preprint. Discussion started: 10 August 2022

Atmospheric Chemistry and Physics
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Discussions

band in Watts (Eq. 8), or in percent of R_{SE} appropriate for a given latitude band (Eq. 9). This is followed by a correction for the changing orbit in 2020-2021.

From Eqs. 1-9, the EPIC sunrise to sunset 388±1.5 nm reflected energy (90^{O}S to 90^{O}N) from clouds, aerosols, the surface, and snow/ice is P_{SE} = 29.2% of the incident solar energy including the surface contribution. Annual integrals of reflected energy are almost constant.

For OMPS-NM, the spatial grid is $\Delta\theta$ = 0.5^{O} and $\Delta\phi$ = 0.5^{O} corresponding to its coarser spatial resolution and the summation in Eq. 5 is over 360^{O} since OMPS-NM makes 1 measurement per 24 hours for a given grid point at fixed solar time near 13:30 local solar time. N = 40 for EPIC in Eq. 7 and 20 for OMPS-NM.

$$A_i(\theta,\varphi,\Delta\theta) = 2\pi R_E^2\left[\mathrm{Sin}(\theta_i+\Delta\theta) - \mathrm{Sin}(\theta_i-\Delta\theta)\right]\frac{\Delta\varphi}{2\pi} \tag{1}$$

$$A_i(\theta_i,\varphi,\Delta\theta) = R_E^2 B_i(\theta_i,\Delta\theta)\Delta\varphi = \text{Area of one grid box} \tag{2}$$

$$\text{where} \qquad B_i(\theta_i,\Delta\theta) = 2\,\mathrm{Cos}(\theta_i)\,\mathrm{Sin}(\Delta\theta) \tag{3}$$

$$\text{and } \Delta\varphi = 0.25\pi/180 \text{ and } \Delta\theta = 0.125\pi/180 \tag{4}$$

$$E_i(\theta_i,t) = R_E^2 F_{Sun}(t)\sum_{j=1}^{M}\left[\cos(\zeta(\theta_i,\varphi_j,t))L_{ER}(\theta_i,\varphi_j,t)\right]B(\theta_i,\Delta\theta)\Delta\varphi \tag{5}$$

$$E_i(\theta_i,t) = R_E^2 F_{Sun}(t,\Delta\lambda)G_i(\theta_i,t) \qquad \text{(Watts)} \tag{6}$$

$$G_k(\theta_k,\Delta\theta) = \sum_{j=1}^{N} G_{j,k}(\theta_{j,k}) \text{ for } k = 1, 18 \text{ for the band width } \Delta\theta = \frac{\pi}{18} \tag{7}$$

$$I(t,\theta_k,\Delta\theta) = F_{Sun}(t,\Delta\lambda)R_E^2 G_k(\theta_k,\Delta\theta) \qquad \text{(Watts)} \tag{8}$$

$$P_{SE}(t,\theta_k,\Delta\theta) = 100\frac{G_k(\theta_k,\Delta\theta)}{\pi} \qquad \text{(Percent)} \tag{9}$$

The global percent reflected energy P_{SE} appears to increase in the SH during December 2020 (SEV = 1.95^{O}) (Table 1) compared to previous years (2015-2019) when the SEV angles are larger. Part of the 2020 - 2021 increase may be caused by enhanced backscatter (Marshak et al., 2021) from clouds and part from the Earth's surface. There are also small SEV angles in June 2021 that corresponds to the maximum reflected energy in the NH that do not show and enhanced P_{SE}. Sections 2.1 and 2.2 will show which latitude bands contribute to the global (90^{O}S to 90^{O}N) increased reflected energy during 2020 – 2021 shown in Fig. 1.

https://doi.org/10.5194/acp-2022-481
Preprint. Discussion started: 10 August 2022

Atmospheric Chemistry and Physics Discussions

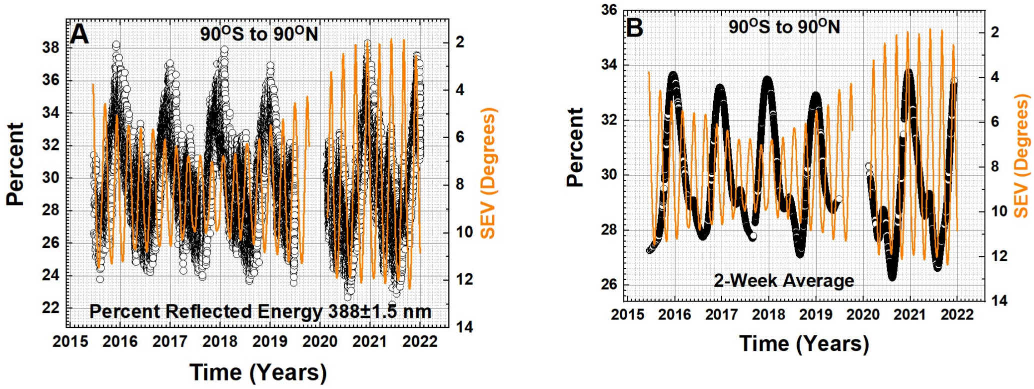

Fig.1 Panel A: Percent reflected solar energy P_{SE} for the Earth from 90^{O}S to 90^{O}N in the narrow band 388±1.5 nm (black circles one for each EPIC scene) from clouds, aerosols, and surface as a function of time and SEV angle (orange curve – right axis). There are about 6000 points per year. Panel B: 2-week running average to more clearly show the December and June peaks.

Table 1 Minimum SEV angles

Date	SEV (Deg)
19 March 2020	3.25
16 June 2020	2.46
15 September 2020	2.10
11 December 2020	**1.95**
7 March 2021	2.05
3 June 2021	**1.83**
2 September 2021	1.88
29 November 2021	2.53

Most of the apparent scatter of data points for EPIC in Fig. 1 is not measurement noise but instead is the result of obtaining multiple measurements of the rotating Earth every day. Figure 2 contains a small subset of data points obtained from 20 March 2016 to 30 March 2016 showing the successive maxima occurring over the Pacific Ocean and the minima over Africa. This is opposite of the behavior for the visible and NIR channels that have much higher surface reflectivity, especially over Africa and over vegetation. Since the data are from March, the NH winter cadence applies for 13 points per 24 hours compared to the NH summer cadence of 21 points per 24 hours. The same interpretation of apparent scatter in EPIC data points applies to every figure. The summer/winter difference in cadence is caused by the location of the data receiving antenna at Wallops Island, Virginia (37.9^{O}N) changing the number of hours the spacecraft is in view.

https://doi.org/10.5194/acp-2022-481
Preprint. Discussion started: 10 August 2022

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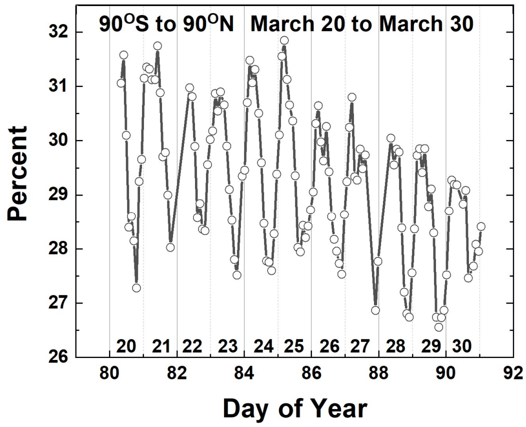

Fig. 2 EPIC's daily variation of P(t) caused by the Earth's rotation for $\Delta\theta$ = 90°S to 90°N from 20 March 2016 to 30 March 2016 corresponding to the grey circles in Figure 1A. The numbers 20 to 30 represent the dates in March 2016.

2.1 Southern Hemisphere

The maximum percent reflected energy P_{SE} in each hemisphere occurs during their respective summer months corresponding to the minimum SZA at a given latitude caused by the varying solar declination angle ±23.45° during the earth's annual orbit about the sun. In the SH there is a clear P_{SE} increase (Fig.3) in December 2020 (SEV=1.95°) for latitudes greater than 30° compared to previous years. A smaller increase in P_{SE} occurs at the end of November 2021 (SEV = 2.53°). In the NH there are also correspondences of the summer P_{SE} maxima with minimum SEV angle (1.83°) in June 2021 and June 2020 (2.46°). As shown later, NH P_{SE} values do not show an increase compared to previous years.

The SH quantity of interest is the peak during December 2020 when the SEV angle was about 1.95° compared to the average peak of the preceding years when the SEV angle was 6° to 7° (Figs. 1 and 3). Because of the small SEV angle, EPIC observes more of the illuminated disk at SEV=2° than at SEV=6°. The missing area near the Earth's limb rotates east and west and north and south with the satellite orbit. The worst case for mid-latitudes is when the orbit is aligned with the latitude of interest. After cosine weighting for reflected energy from the Earth's edges, there is an increase in observed reflected energy at mid-latitudes when the SEV angle is 2° compared to 6° from just the observing geometry.

Figure 3 shows ratio of observed cosine weighted illuminated areas as a function of month of the year for four SH latitude bands as observed by EPIC during 2020-2021 with SEV ≈ 2° to that during the years 2015-2019 when SEV was 4°-6°. The ratios of the observed areas in December, A_C = Area in 2020/<Area 2015-2019>, are 1.03 for 35°S, 55°S, and 65°S, and 1.04 for 45°S, where <…> denotes average. To compare the reflected energy from 2015-2019 to that from 2020 Eqs. 8 and 9 for 2020 must be divided by A_C. for this purpose, the smoothed Loess(2-months) data are used (Cleveland, 1981). The results are shown in Fig.4 for four latitude bands.

https://doi.org/10.5194/acp-2022-481
Preprint. Discussion started: 10 August 2022

Atmospheric Chemistry and Physics Discussions

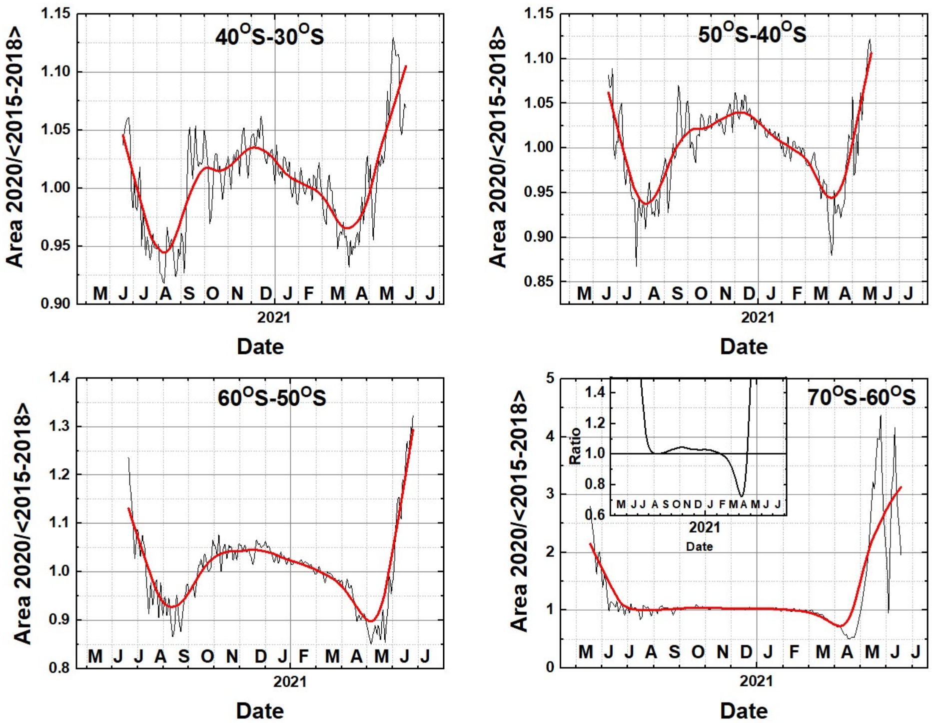

Fig. 3 The ratio The ratio $R_A = A(2020)/\langle A(2015\text{-}2018)\rangle$ of the Earth's area within the specified latitude bands seen by EPIC in 2020 to that seen during the years 2015-2019. In December 2020, the ratio is 1.03 for 35°S, 55°S, and 65°S, and 1.04 for 45°S. The red curve is Loess(2-months). The inset in 70°S-60°S shows the details near December 2020.

Figure 4 shows SH EPIC percent reflected energy P_{SE}(388±1.5 nm) for six 10° wide latitude bands compared to the SEV angles with $R_A = A(2020)/\langle A(2015\text{-}2018)\rangle$ applied. The dates of the minimum SEV angles are shown in Table 1 with a clear minimum SEV angle match on 11 December 2020 and 29 November 2021 (Fig. 3 and Appendix Fig. 1A), except at latitudes poleward from 70°S where the peak P_{SE} occurs just after the SEV minimum. At mid-latitudes, 30°S to 70°S the SEV December minimum and the P_{SE} maximum match closely. For lower latitudes 0 – 20, the P_{SE} peaks do not show and increase and are significantly wider.

The approximate equivalent of a seven-day least-squares running average (Cleveland, 1981), Loess(f), where f= fraction of data points in the entire time series, is performed on the data set corresponding to approximately 13 illuminated Earth views per 24 hours in December using Loess(0.035). For the 7 days surrounding the minimum SEV=1.96° on 10 December the range of SEV angles that are included in the averaged P_{SE} spans 1.96° to 2.43°. The specific day of the December peak P_{SE} varies with latitude so that it occurs slightly after the 10 December minimum SEV at latitudes 90°S to 70°S but closely matches the minimum SEV time for latitudes 70°S to 10°S with lower latitudes 10°S to 40°S having a wider peak (Fig. 4).

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Preprint. Discussion started: 10 August 2022

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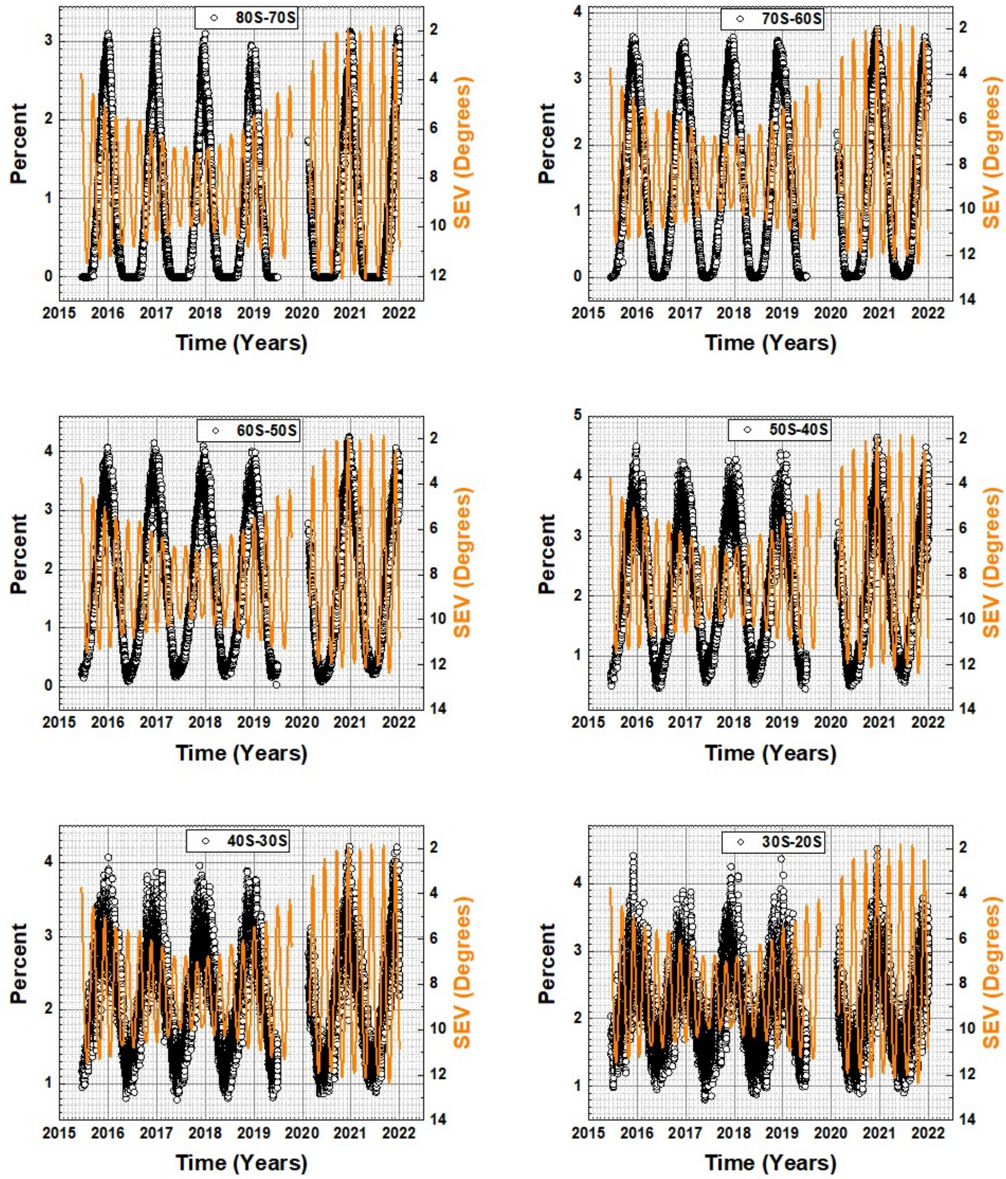

Fig. 4 EPIC SH percent reflected solar energy in the P_{SE}(388±1.5 nm) band (grey circles), the SEV angles (orange). Magnified details are shown in the Appendix Fig. A1.

An alternate graph comparing different years is shown in monthly average P_{SE} (Fig. 5) for the SH showing that the largest effect is in the 40^{O}S to 50^{O}S latitude band centered in December 2020 (orange curve).

https://doi.org/10.5194/acp-2022-481
Preprint. Discussion started: 10 August 2022

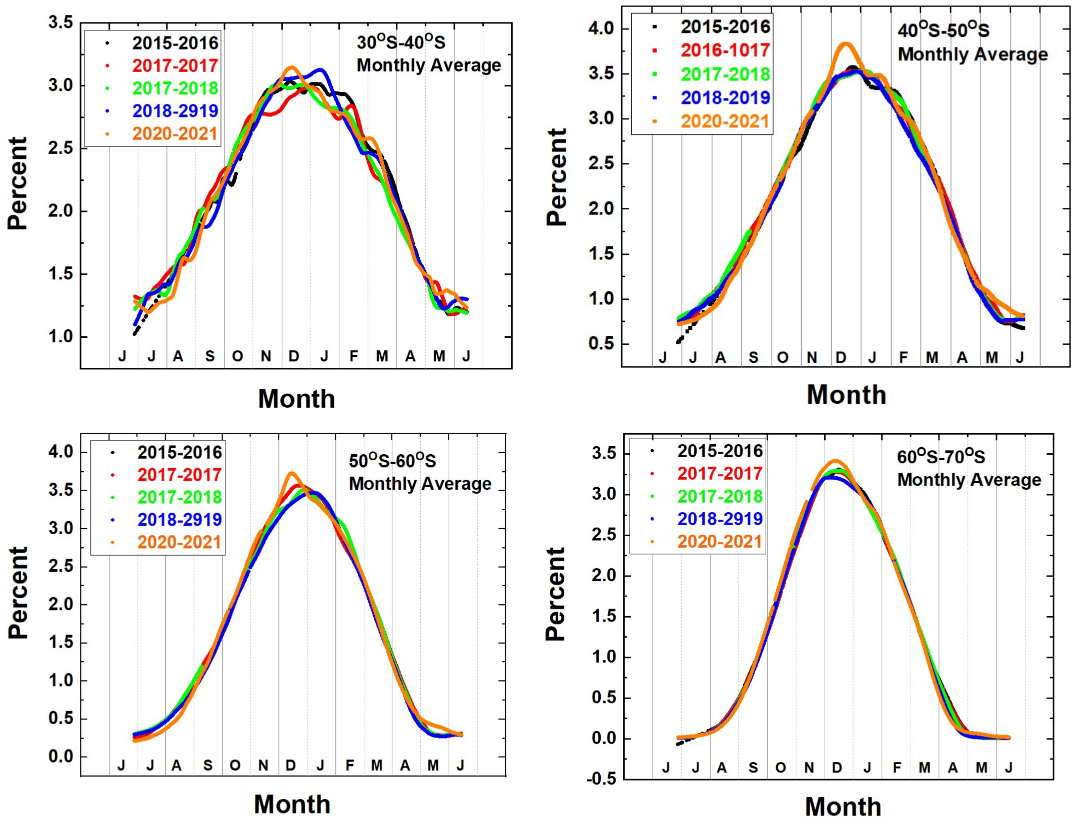

Fig. 5 Monthly average of SH annual time series of percent reflected energy at 388±1.5 nm for 5 years, 2015 – 2021 for 4 latitude bands.

The results of Figs. 4 and 5 are summarized in Fig. 6 as a function of latitude showing comparisons of the P_{SE} peak values in December 2020 and November 2021 compared to previous years. The maximum P_{SE} is at 45°S during December 2020 (4.19%, orange curve) compared to the 4-year average (3.77%). Similar data from November 2021 shows almost no difference (3.89%) compared to the 4-year average (3.77%).

https://doi.org/10.5194/acp-2022-481
Preprint. Discussion started: 10 August 2022

Atmospheric Chemistry and Physics
Discussions

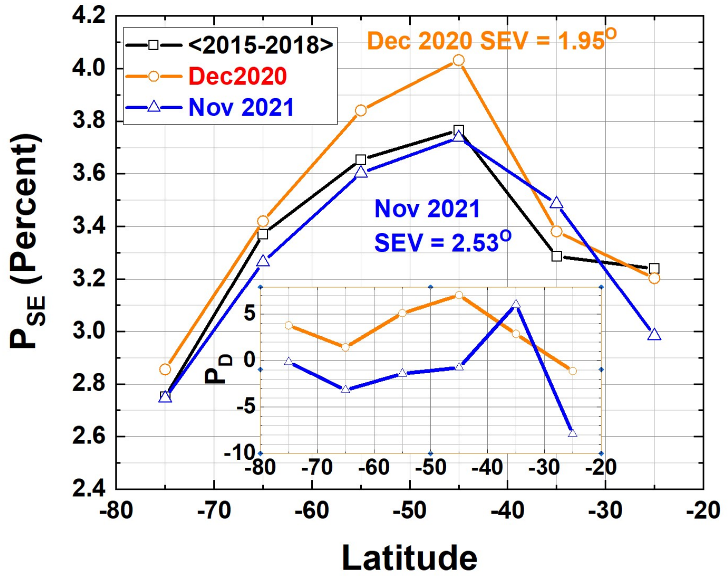

Fig. 6 One-week least squares running averages Loess(0.035) of P_{SE} values from Fig. 3 as a function of latitude for the periods Dec 2020 (SEV = 1.95^{O}) and November 2021 (SEV = 2.53^{O}) compared to the average of the preceding 4 years, 2015-2018 (4^{O} < SEV < 6^{O}). The symbols <A-B> denote average. The inset shows the percent difference P_D as defined in Eq. 10.

$$P_D = 100\left(\frac{P_{SE}^{Y} - P_{SE}^{Avg}}{P_{SE}^{Avg}}\right) \qquad Y = 2020 \text{ or } 2021 \tag{10}$$

Figure 7 shows the EPIC-view hemispheric zonal average for OMPS-NM for the latitude band 50^{O}S-40^{O}S compared to 1 to 2 hour time-dependent P_{SE} from EPIC . The peak values for the December solstice maxima are in close agreement while the June solstice minima do not agree P_{SE}(EPIC, June) < P_{SE}(OMPS, June) since P_{SE}(OMPS, June) are computed from a zonal average that always includes more clouds than the minimum values of P_{SE}(EPIC, June) occurring over Africa (Fig. 2).

The EPIC SH cloud peak reflected energy aligns with the small SEV angle (1.96^{O}) in December 2020 and the percent difference P_D (Eq. 10) is P_D = 5.4% compared to the preceding 4 years. The OMPS-NM December 2020 peak also exceeds the average of the preceding 5 years by P_D = 5%. This suggests that the increase in December 2020 is from increased cloud cover and not from enhanced backscatter when SEV = 1.96^{O}.

https://doi.org/10.5194/acp-2022-481
Preprint. Discussion started: 10 August 2022

Atmospheric Chemistry and Physics
Discussions

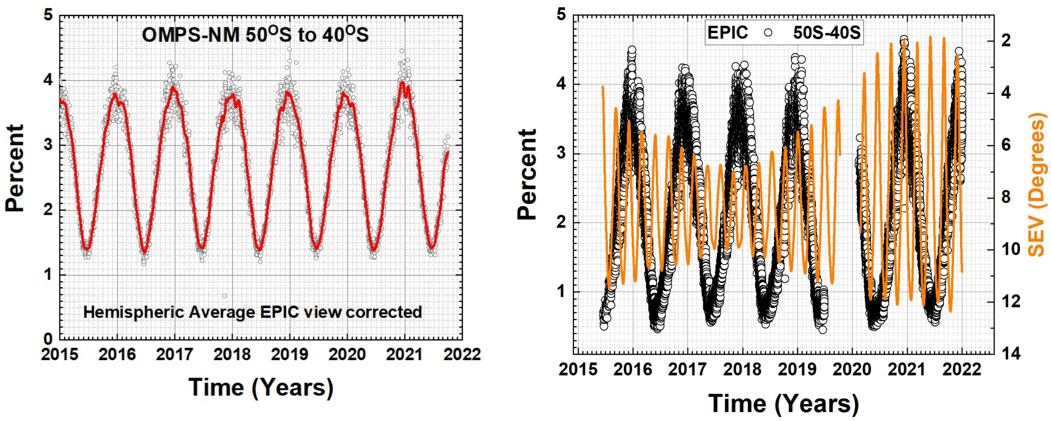

Fig. 7. A time series of OMPS-NM hemispheric zonal average P_{SE} (1 point per day grey circles) 2015-2021.5 and a 1-week average (red curve) for the band 40°S to 50°S compared to EPIC P_{SE}. The red-curve is a 1-week running average Loess(0.028).

Table 2 Summer Solstice Area Ratios (Figs 3 and 8)
$R_A = A(2020)/<A(2015\text{-}2018)>$

Latitude	R_A	Latitude	R_A
65S	1.03	65N	0.97
55S	1.03	55N	0.97
45S	1.04	45N	0.99
35S	1.03	35N	0.99
25S	1.04	25N	1.00
15S	1.02	15N	0.95
5S	1.02	5N	1.01

2.2 Northern Hemisphere

The NH June peaks in P_{SE} coincide with the SEV minima of 16 June 2020 (2.46°) or 3 June 2021 (1.83°) in 5 of the 6 latitude bands shown (Fig. 8). Exceptions are for 0 to10°N, 10°N to 20°N, and 20°N to 30°N. For the latitude bands where there is coincidence between the maxima in $P(t,\theta,10)$ and minima SEV one might expect enhanced backscattering corresponding to the June minimum SEV compared to previous years as there is in the SH. However, this is not the case (Figs. 8, 9, 10).

https://doi.org/10.5194/acp-2022-481
Preprint. Discussion started: 10 August 2022

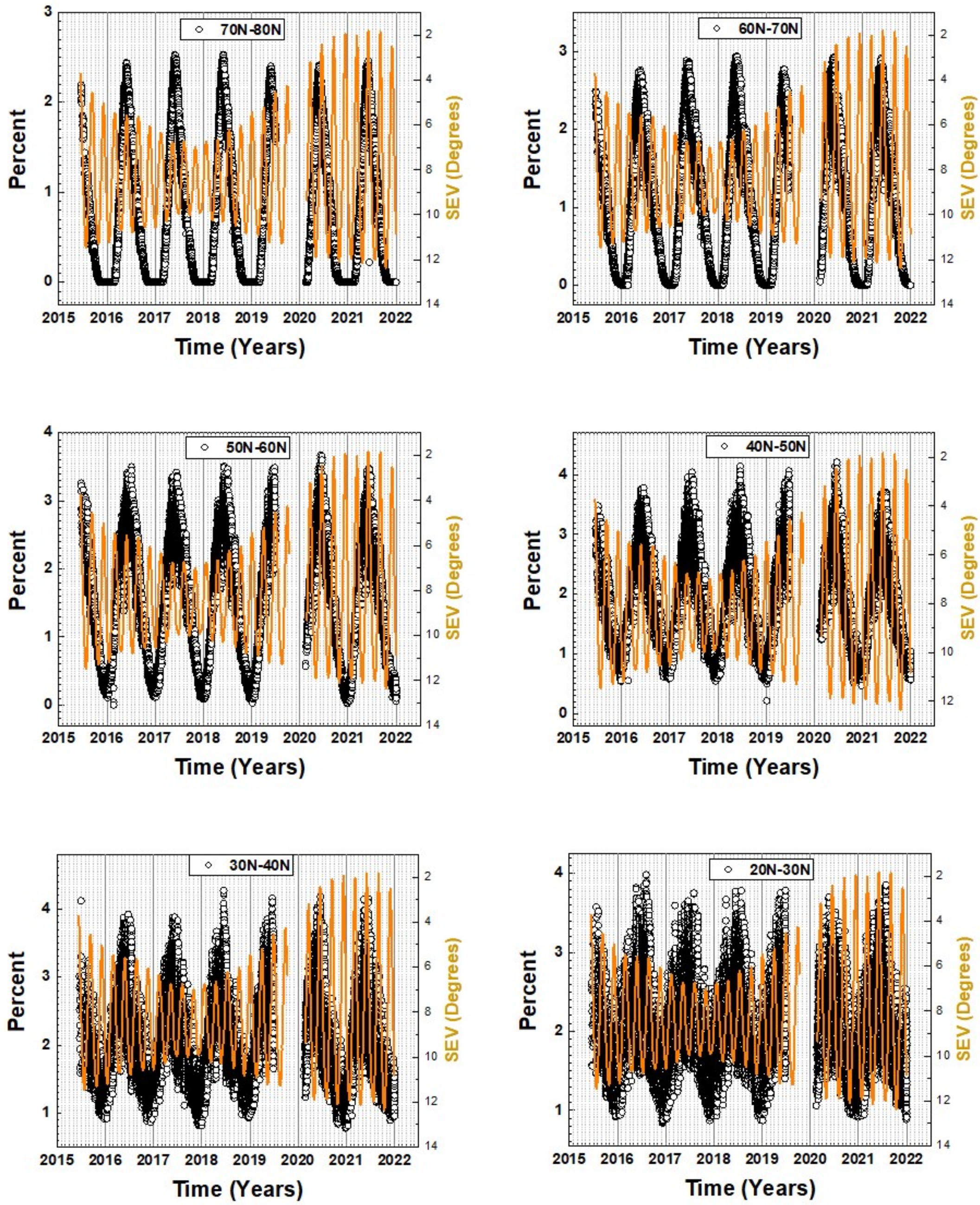

Fig. 8 EPIC NH percent reflected solar energy in the P_{SE}(388±1.5 nm) band (grey circles), the SEV angles (orange). Magnified details are shown in the Appendix Fig. A1.

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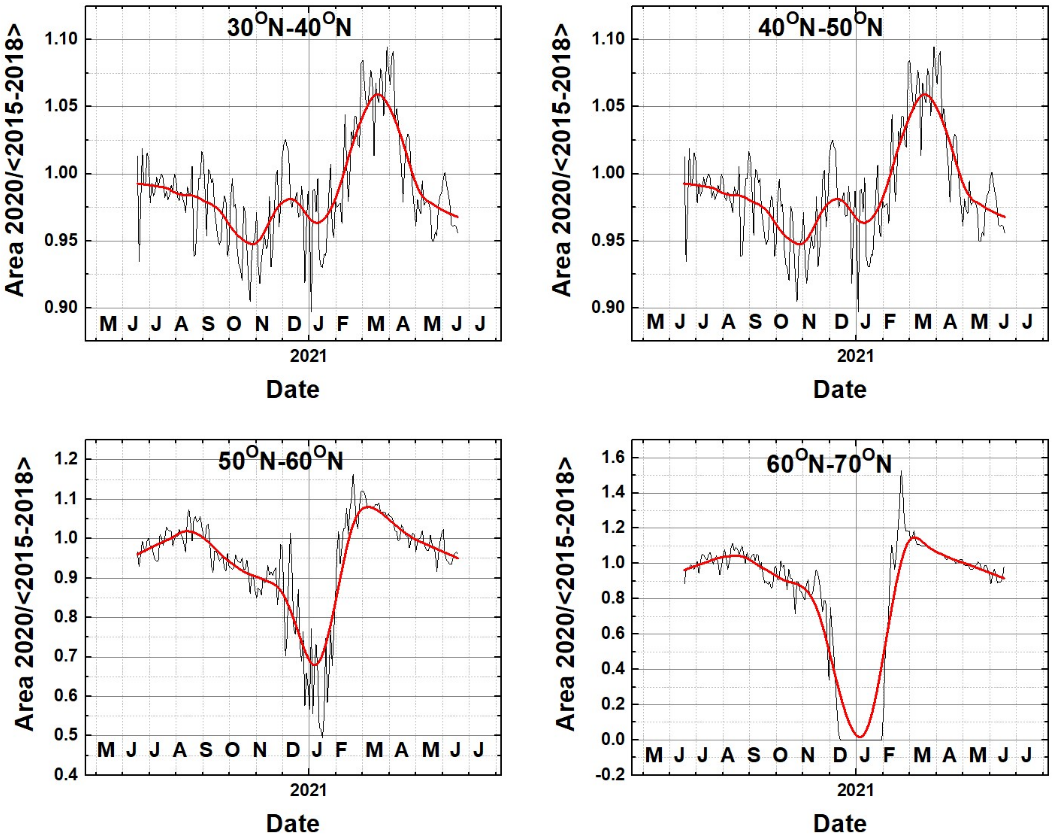

Fig. 9 The ratio $R_A = A(2020)/\langle A(2015\text{-}2018)\rangle$ of the Earth's area within the specified latitude bands seen by EPIC in 2020 to that seen during the years 2015-2019. In June 2020, the ratio is 0.96 for 35^{O}N, 0.96 for 45^{O}N 0.97 for 55^{O}N, 0.93 for 65^{O}N. The red curve is Loess(2-months).

Because the DSCOVR orbit about L_1 has an approximately six-month period superimposed on a longer period of about 5 years when the orbit shape changes from an ellipse to a circle and back to an ellipse, the observed area effect in the NH was different than in the SH when the SEV angles became small. The June solstice area ratio values are closer to 1.

https://doi.org/10.5194/acp-2022-481
Preprint. Discussion started: 10 August 2022

Atmospheric Chemistry and Physics
Discussions
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A 1-week average analysis (Fig. 10) is done for the NH June maxima with 23 views per 24 hours and a Loess(0.006) that is similar to that for the SH (Fig. 5) based on the data shown in Fig. 8.

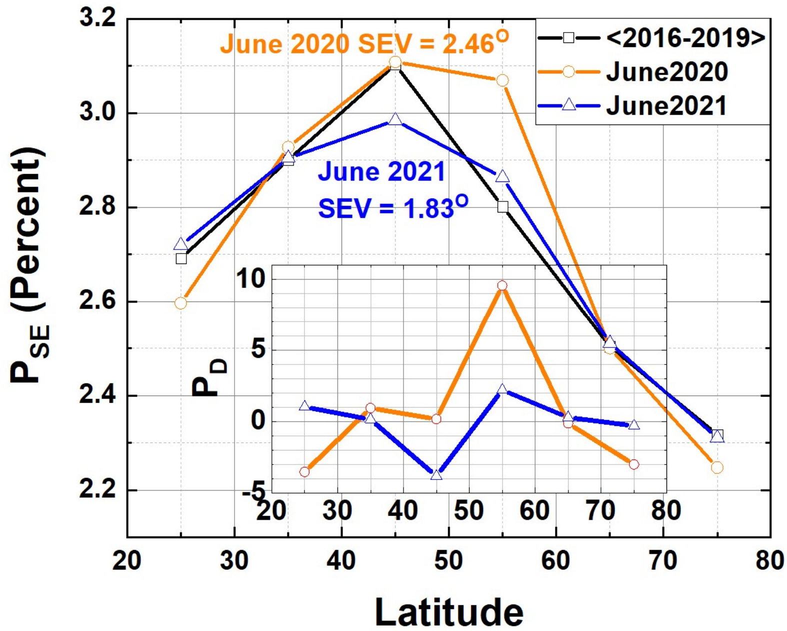

Fig. 10 Peak 1-week least squares running averages Loess(0.006) of P_{SE} values from Fig. 8 as a function of latitude for the periods June 2020 (SEV = 2.46°) and June 2021 (SEV = 1.83°) compared to the average of the preceding 4 years, 2016-2019 (4° < SEV < 6°). The symbols <A-B> denote average. Inset is Percent Difference P_D vs Latitude as in Eq. 10.

The June 2021 peak P_{SE} data (SEV = 1.83°) shows a decrease (P_D = -4.8%) at (40°N – 50°N) relative to the preceding 4 years (2016-2019) suggesting that there was no significant backscatter effect and that the cloud amount decreased. The period June 2020 (SEV = 2.46°) shows no significant change at 45°N and an increase at 55°N of P_D = 9%, which is probably due to increased cloud amount since the SEV angle is 2.46°. The NH time monthly average time series for each year (Fig. 11) can be compared in a manner similar to Fig. 4 showing that the small SEV period during 2021 (blue curve) does not show an enhanced backscatter effect, but instead a decrease in reflected energy compared to <2016-2019>.

https://doi.org/10.5194/acp-2022-481
Preprint. Discussion started: 10 August 2022

Atmospheric Chemistry and Physics
Discussions

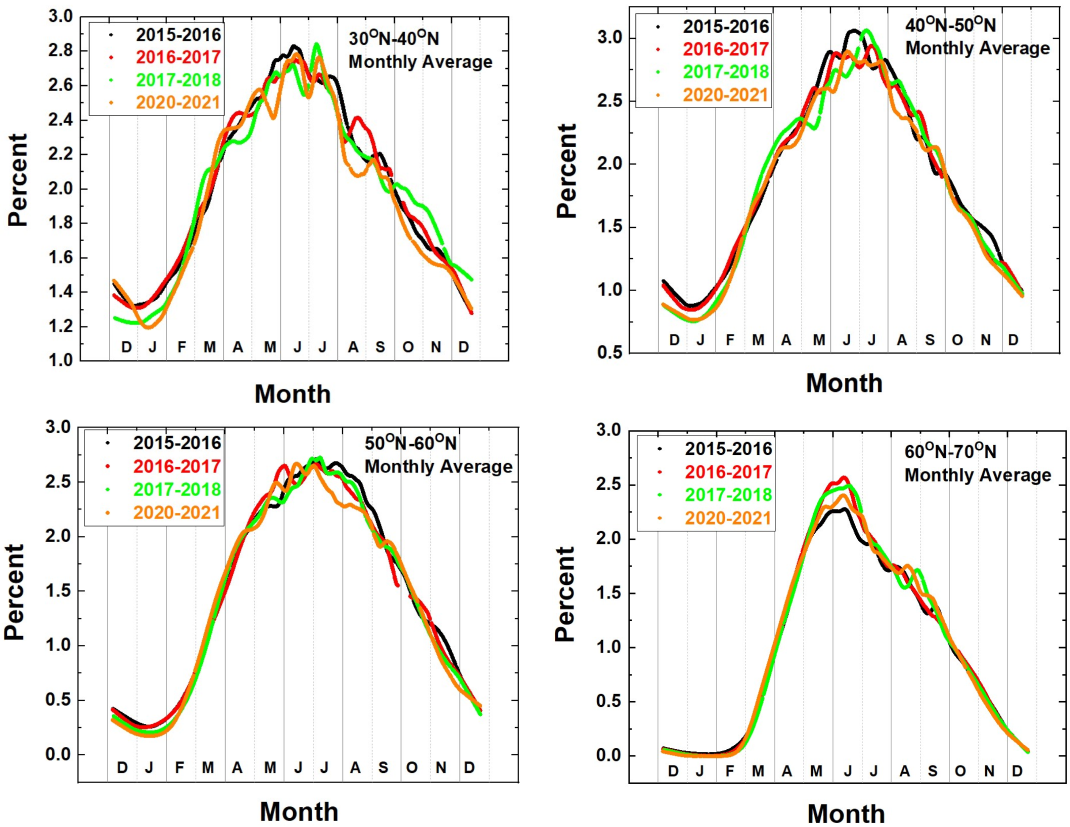

Fig. 11 Monthly average of NH annual time series of percent reflected energy at 388±1.5 nm for 4 years, 2015 – 2021.

3.0 Summary

EPIC observed 388±1.5 nm backscattered irradiances are mostly from clouds since the average 388 nm reflectivity of the Earth's snow/ice-free surface is small, approximately 0.05. At all non-equatorial latitudes, the maximum reflected energy occurs during the summer solstice (minimum SZA). During the period 2020 to 2021, the backscatter angle became close to 178° in December 2020 compared to 174° – 176° in prior years (2015 – 2019), which might lead to enhanced reflected energy. The analysis of showed that there was a significant increase in reflected energy, P_D = 7%, in the latitude band 40°S - 50°S during December 2020 with smaller effects at other SH latitudes P_D = 3% at 35°S and 5% at 55°S and none near the equator. If the increases were due to enhanced backscatter, one would have expected the same enhanced backscatter in the NH during June 2021 from P_{SE} peaks that coincide with the SEV minimum (SEV = 1.83°). Instead, there was a decrease at 45°N and almost no increase at 55°N. The P_D = 8% increase at 55°N (SEV = 2.46°) shown in Fig. 11 suggests that the increase was from change in cloud cover in the NH with backscatter effects being small. Comparison with the polar orbiting OMPS-NM (SEV greater than 40° – 23.45° = 16.55°) percent reflected energy at 380±0.55 nm showed a 5%

https://doi.org/10.5194/acp-2022-481
Preprint. Discussion started: 10 August 2022

Atmospheric Chemistry and Physics Discussions

December 2020 increase at 45^{O}±5^{O}S implying there was an increase in cloud cover seen by both EPIC and OMPS-NM. However, the global annual integral of reflected 388±1.5 nm energy is almost constant.

Two recent papers, Marshak et al., (2021) and Penttilä et al. (2021) suggested that the increase in observed reflected sunlight might be from enhanced backscattering in the SH when the SEV angle was close to 2^{O}. The increase seen by Marshak et al., was mostly from land surfaces in the visible wavelength ranges. The analysis of Penttilä et al. (2021) suggested that about half might be caused by increased cloud cover. The results of the current analysis (EPIC observed increase of P_D = 7% at 45^{O}S and 5% at 55^{O}S and 5% observed from OMI-NM at 45^{O}S) suggest that most of the increase in reflected energy in December 2020 comes from an increase in cloud amount.

https://doi.org/10.5194/acp-2022-481
Preprint. Discussion started: 10 August 2022

Atmospheric Chemistry and Physics Discussions

4.0 Appendix

Figure A1 shows magnified details for 2 latitude bands each in the NH and SH along with the coinciding minimum SEV data.

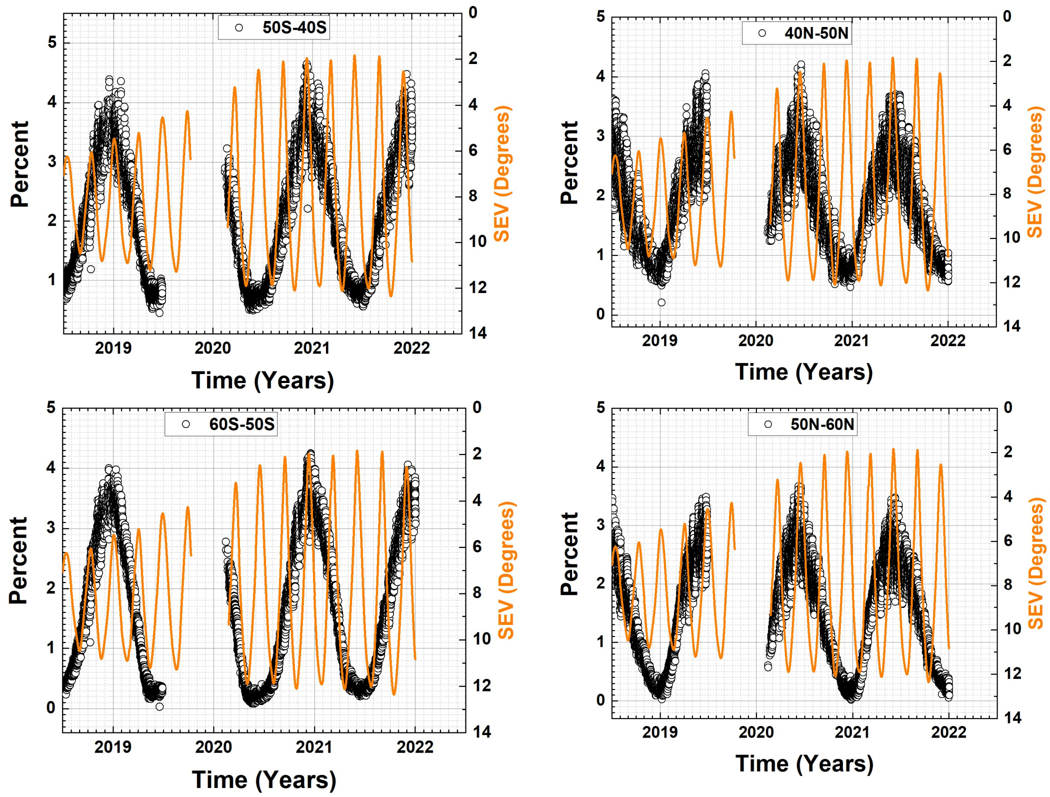

Fig. A1 Magnified samples from Figs. 3 and 7 showing SEV minimum coincidences with P_{SE} maxima in the SH and NH. The SEV are colored orange.

https://doi.org/10.5194/acp-2022-481
Preprint. Discussion started: 10 August 2022

Atmospheric Chemistry and Physics Discussions

Author contribution:

Jay Herman is responsible for writing the text, calculations in the paper, and all the figures. Liang-Kang Huang is responsible for supplying the available EPIC LER data as a function of latitude, longitude and time. He also suggested many technical improvements. Dave Hafner also helped supply the LER data and the OMPS-NM data. Adam Szabo suggested the original idea for the paper.

Data Availability

The data used are publicly available in an Excel and Zip format at Open Science Framework

https://osf.io/r3xpt/

Competing interests:

The authors declare that they have no conflict of interest.

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Preprint. Discussion started: 10 August 2022

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https://doi.org/10.5194/acp-2022-481
Preprint. Discussion started: 10 August 2022

Atmospheric Chemistry and Physics Discussions

Figure Captions

Fig.1 Panel A: Percent reflected solar energy PSE for the Earth from 90OS to 90ON in the narrow band 388±1.5 nm (black circles one for each EPIC scene) from clouds, aerosols, and surface as a function of time and SEV angle (orange curve – right axis). There are about 6000 points per year. Panel B: 2-week running average to more clearly show the December and June peaks.

Fig. 2 EPIC's daily variation of P(t) caused by the Earth's rotation for $\Delta\theta$ = 90^{O}S to 90^{O}N from 20 March 2016 to 30 March 2016 corresponding to the grey circles in Figure 1A. The numbers 20 to 30 represent the dates in March 2016.

Fig. 3 The ratio The ratio R_A = A(2020)/<A(2015-2018)> of the Earth's area within the specified latitude bands seen by EPIC in 2020 to that seen during the years 2015-2019. In December 2020, the ratio is 1.03 for 35^{O}S, 55^{O}S, and 65^{O}S, and 1.04 for 45^{O}S. The red curve is Loess(2-months). The inset in 70^{O}S-60^{O}S shows the details near December 2020.

Fig. 4 EPIC SH percent reflected solar energy in the P_{SE}(388±1.5 nm) band (grey circles), the SEV angles (orange). Magnified details are shown in the Appendix Fig. A1.

Fig. 5 Monthly average of SH annual time series of percent reflected energy at 388±1.5 nm for 5 years, 2015 – 2021 for 4 latitude bands.

Fig. 6 One-week least squares running averages Loess(0.035) of P_{SE} values from Fig. 3 as a function of latitude for the periods Dec 2020 (SEV = 1.95^{O}) and November 2021 (SEV = 2.53^{O}) compared to the average of the preceding 4 years, 2015-2018 (4^{O} < SEV < 6^{O}). The symbols <A-B> denote average. The inset shows the percent difference P_D as defined in Eq. 10.

Fig. 7. A time series of OMPS-NM hemispheric zonal average P_{SE} (1 point per day grey circles) 2015-2021.5 and a 1-week average (red curve) for the band 40^{O}S to 50^{O}S compared to EPIC P_{SE}. The red-curve is a 1-week running average Loess(0.028).

Fig. 8 EPIC NH percent reflected solar energy in the P_{SE}(388±1.5 nm) band (grey circles), the SEV angles (orange). Magnified details are shown in the Appendix Fig. A1.

Fig. 9 The ratio R_A = A(2020)/<A(2015-2018)> of the Earth's area within the specified latitude bands seen by EPIC in 2020 to that seen during the years 2015-2019. In June 2020, the ratio is 0.96 for 35^{O}N, 0.96 for 45^{O}N 0.97 for 55^{O}N, 0.93 for 65^{O}N. The red curve is Loess(2-months).

Fig. 10 Peak 1-week least squares running averages Loess(0.006) of P_{SE} values from Fig. 8 as a function of latitude for the periods June 2020 (SEV = 2.46^{O}) and June 2021 (SEV = 1.83^{O}) compared to the average of the preceding 4 years, 2016-2019 (4^{O} < SEV < 6^{O}). The symbols <A-B> denote average. Inset is Percent Difference P_D vs Latitude as in Eq. 10.

https://doi.org/10.5194/acp-2022-481
Preprint. Discussion started: 10 August 2022

Atmospheric Chemistry and Physics Discussions

Fig. 11 Monthly average of NH annual time series of percent reflected energy at 388±1.5 nm for 4 years, 2015 – 2021.