Earthshine vs CERES for 2000 to 2004

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E. Palle (for Earthshine data)

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BACKGROUND

- A recent paper in Science by Palle et al. (2004) claims that the Earth's reflected SW flux has increased 6 W m^{-2} between 2000 and 2003.

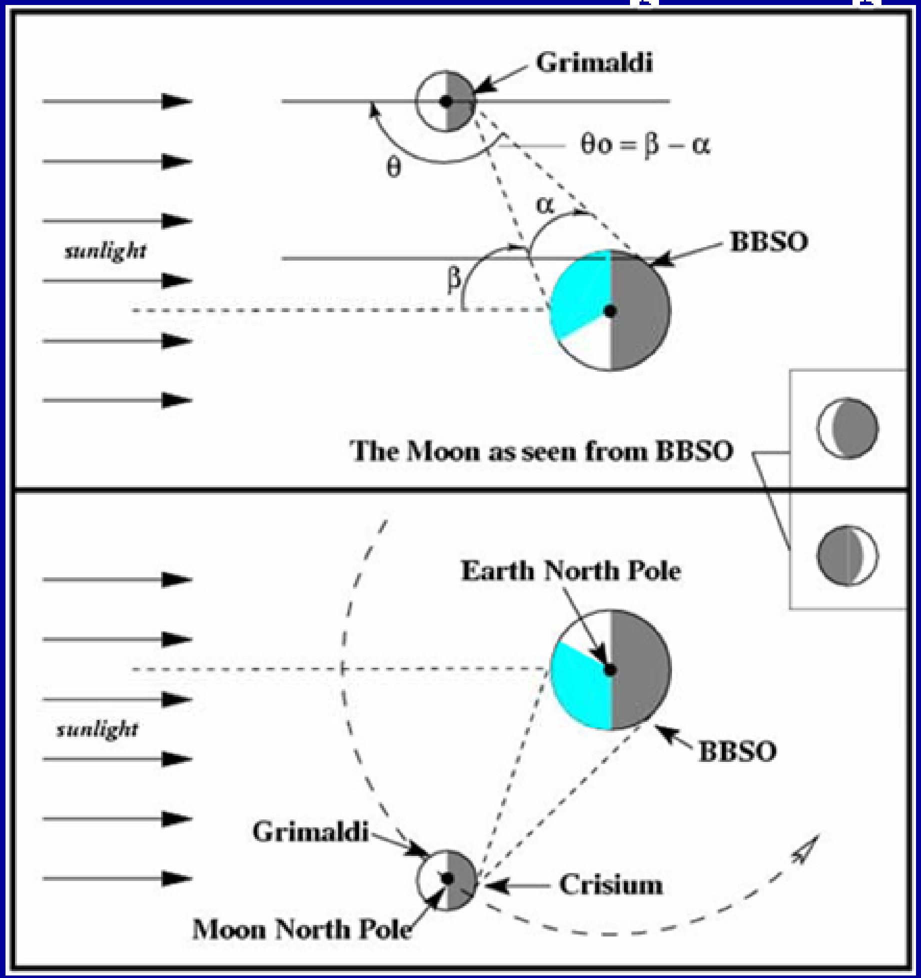
- CERES shows a ≈2 W m^{-2} decrease in SW flux over the same period. Approximately half is believed to be caused by spectral darkening of the optics when in RAP mode.

- The lead author of the Science paper, Enric Palle, visited LaRC in August 2004. We agreed to work together to sort out the reason for the difference.

Earthshine measurements of the Earth's large-scale reflectance

- The Earthshine is the ghostly glow on the dark side of the Moon
- Origin of Earthshine first explained by Leonardo da Vinci
- First measured by Danjon beginning in 1927-34 and by Dubois 1940-60.
- ES/MS = albedo (+ geometry and moon properties)
- ES intensity varies during the month
  - Largest at crescent Moon (full Earth)
  - Smallest near full Moon (crescent Earth)

Waning / morning

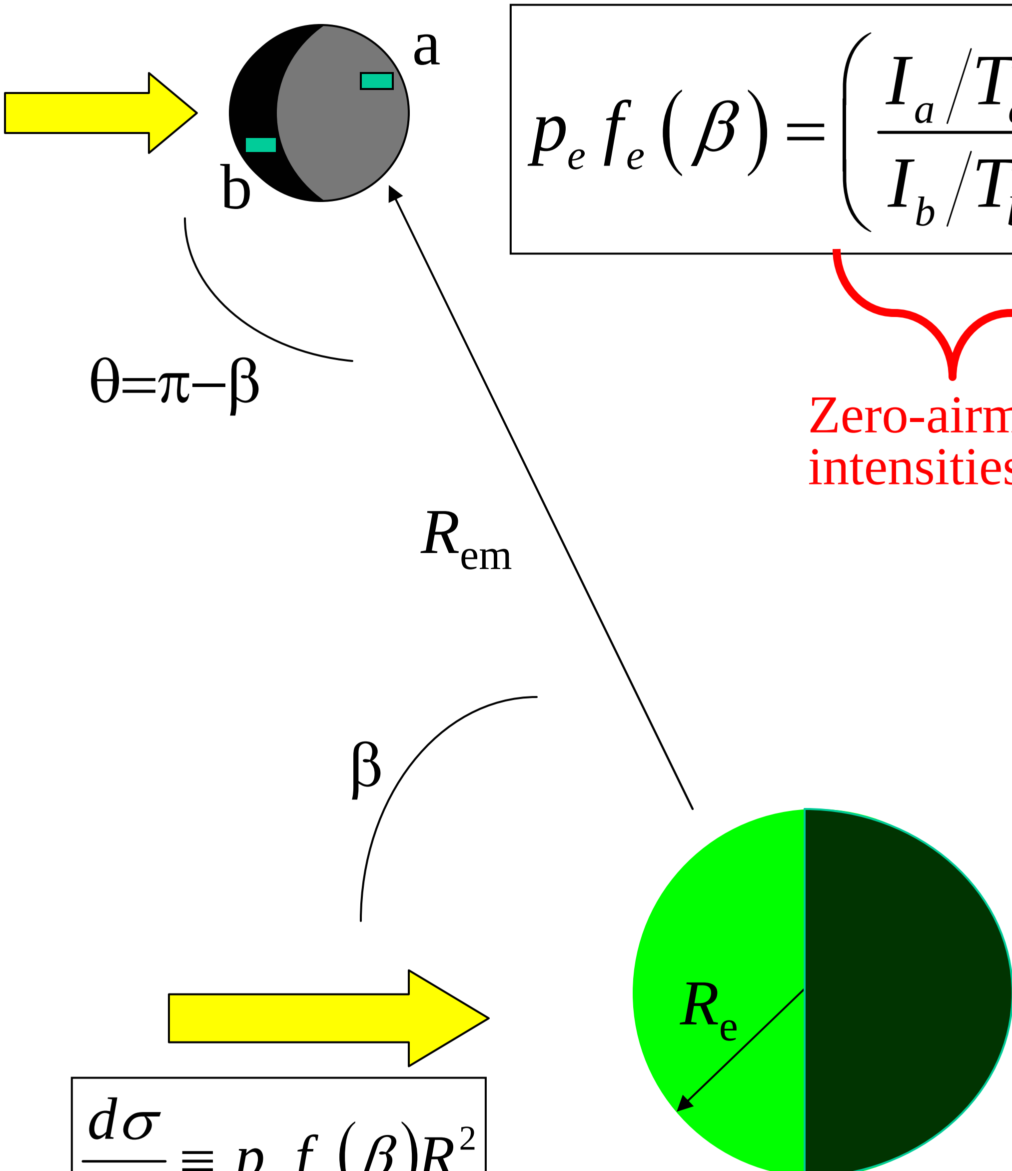


$$p_e f_e(\beta) = \left(\frac{I_a / T_a}{I_b / T_b}\right)\left(\frac{p_b f_b(\theta)}{p_a f_a(\theta_0)}\right)\left(\frac{R_{em}}{R_e}\right)^2\left(\frac{R_{es}}{R_{ms}}\right)^2$$

Zero-airmass intensities

Lunar reflectivities $\theta_0 \sim 1^o$

Geometry



$$\frac{d\sigma}{d\Omega} \equiv p_e f_e(\beta) R_e^2$$

$$f(0) \equiv 1$$

$$A = \frac{\sigma}{\pi R_e^2} = \int_{-\pi}^{\pi} p_e f_e(\beta) |\sin\beta| d\beta$$

Apparent Albedo:

$$A^* \equiv \frac{3}{2}\frac{p_e f_e(\beta)}{f_L(\beta)}; \; [A^*] \equiv -2.5 \log A^*$$

$$f_L(\beta) = \frac{(\pi - |\beta|)\cos\beta + \sin|\beta|}{\pi}$$

$A^* \to p^*$ for historical reasons

APPARENT ALBEDO (p^*)

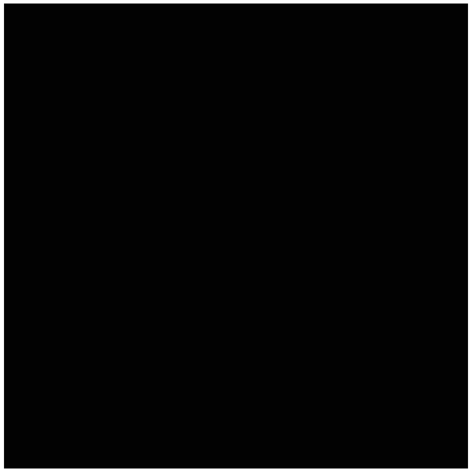
- Albedo of a Lambert sphere that would give the same instantaneous reflectivity as the true Earth at the same phase angle.

- If p^* did not change with phase angle, that would imply a Lambertian Earth.

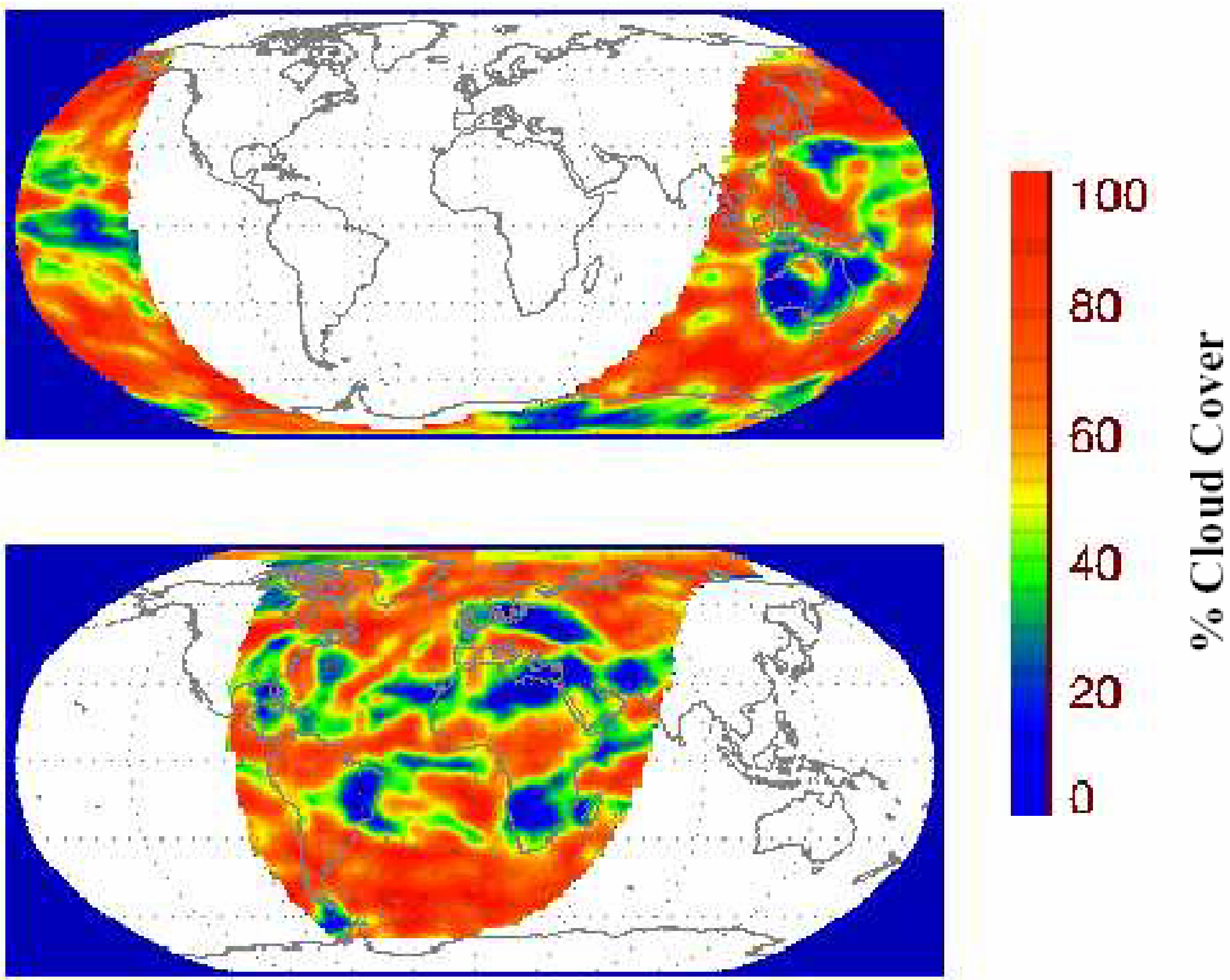
The Effective and Bond Albedos

- On any one night, the apparent albedo (p^*) is measured in 1 direction.
- To obtain the Bond albedo, A, integrate over all phases of the moon at monthly/yearly time scales

$$A = \frac{2}{3} \int p^* f_L(\theta) \sin(\theta) d\theta$$



Coverage during one night



15/10/99
Phase = -116

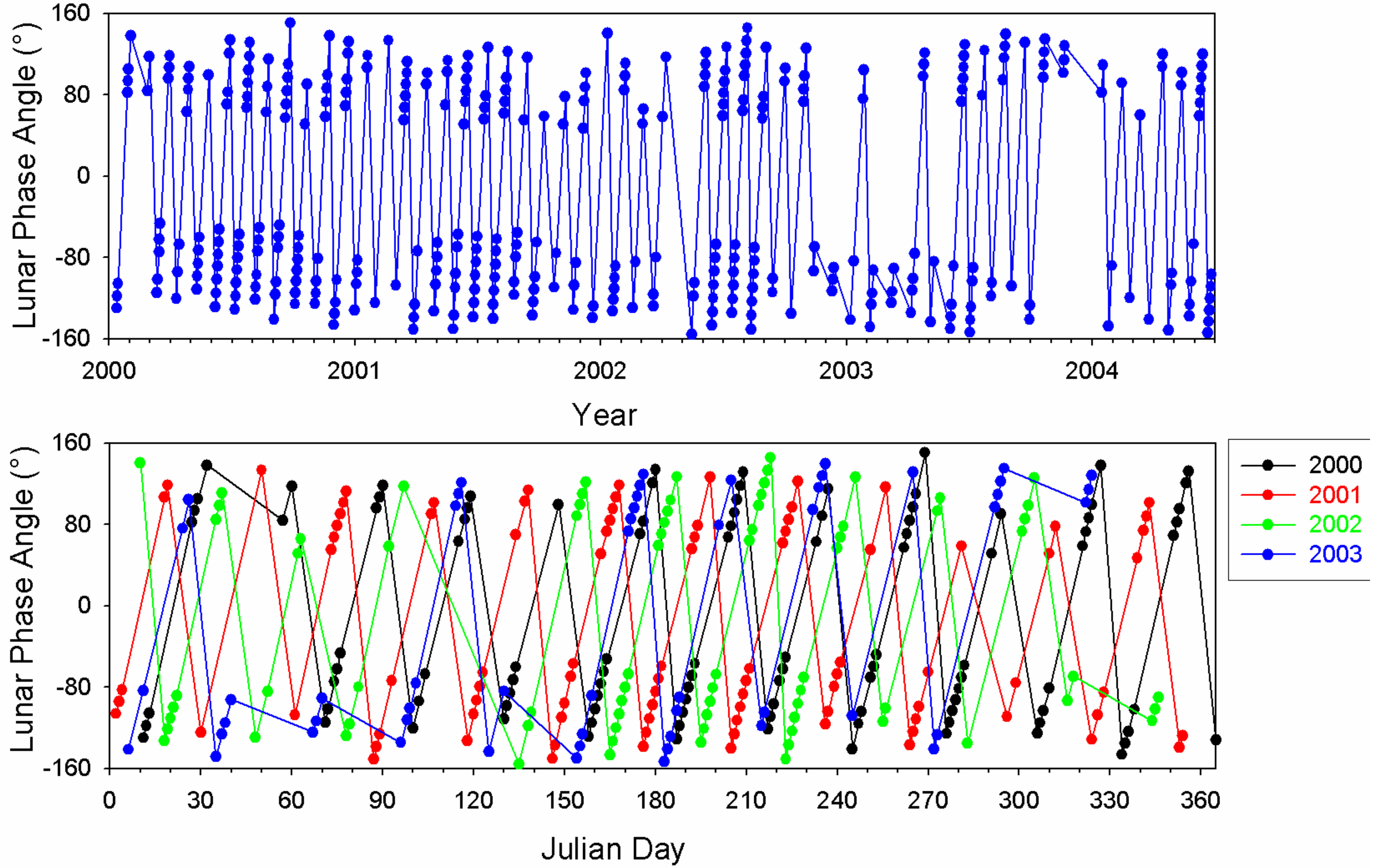
Evening

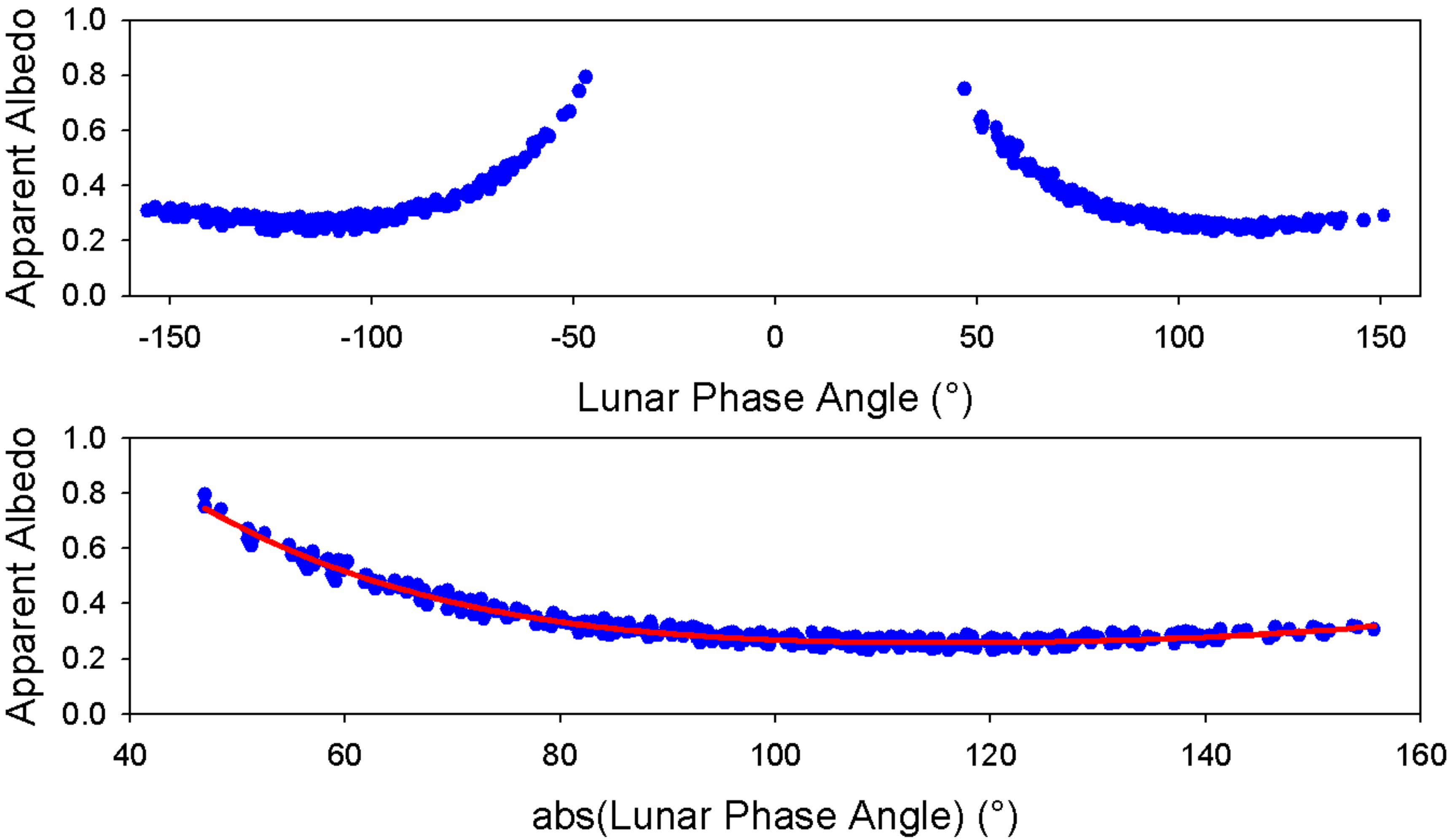
In the sunlight &
Visible from the Moon

04/09/99
Phase = +110

Morning

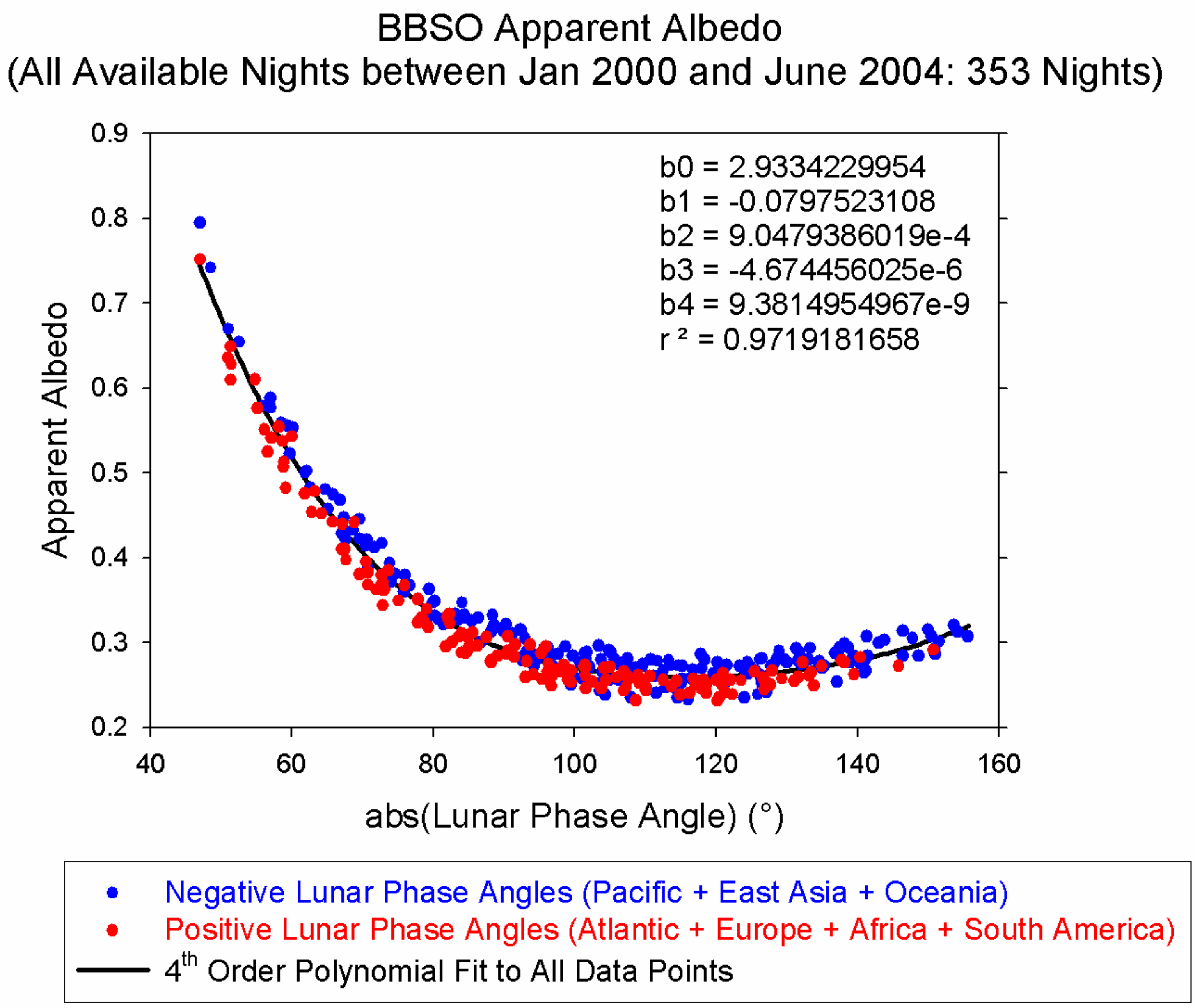
Lunar Phase Angle Sampling (353 Nights)



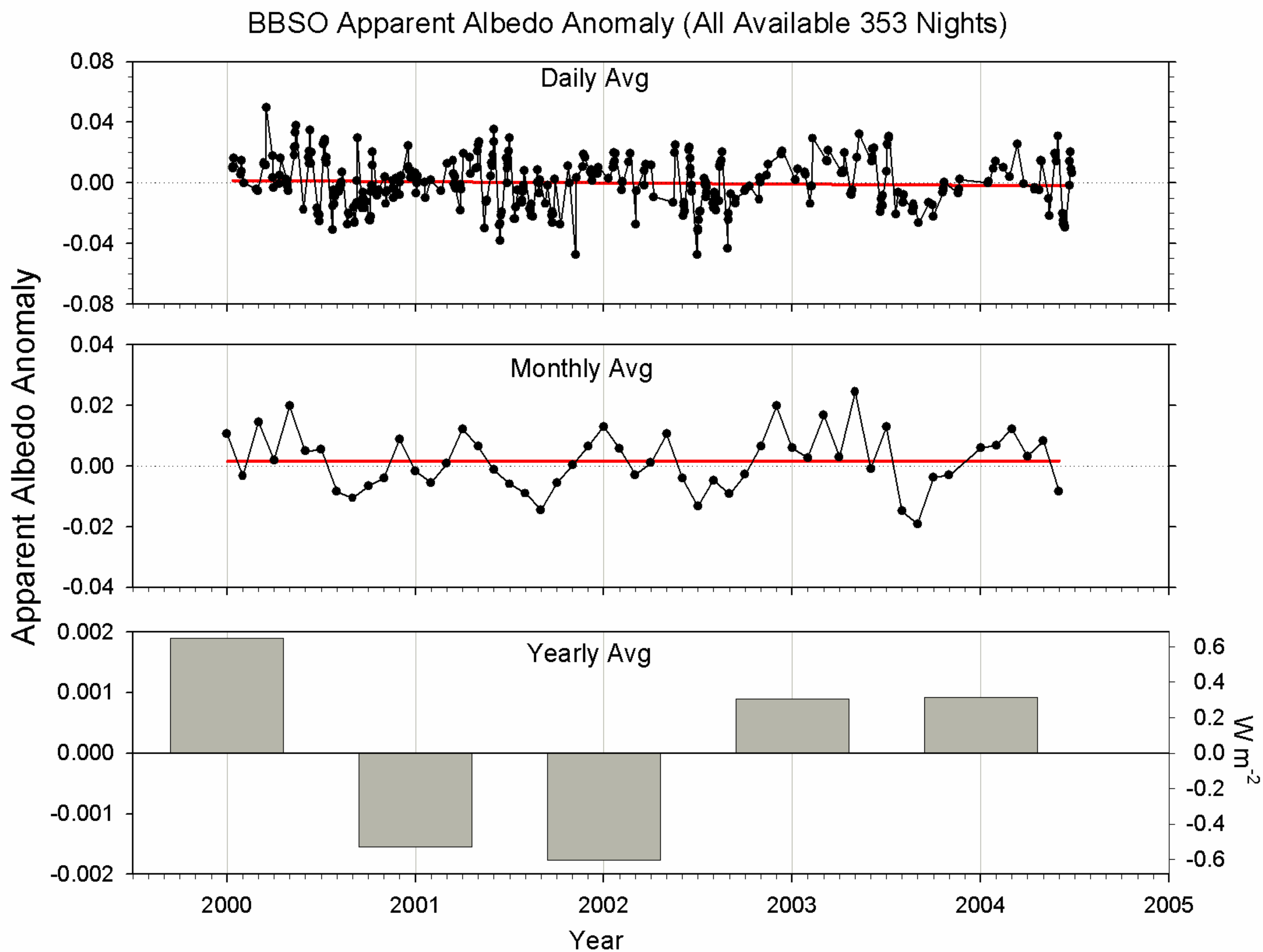


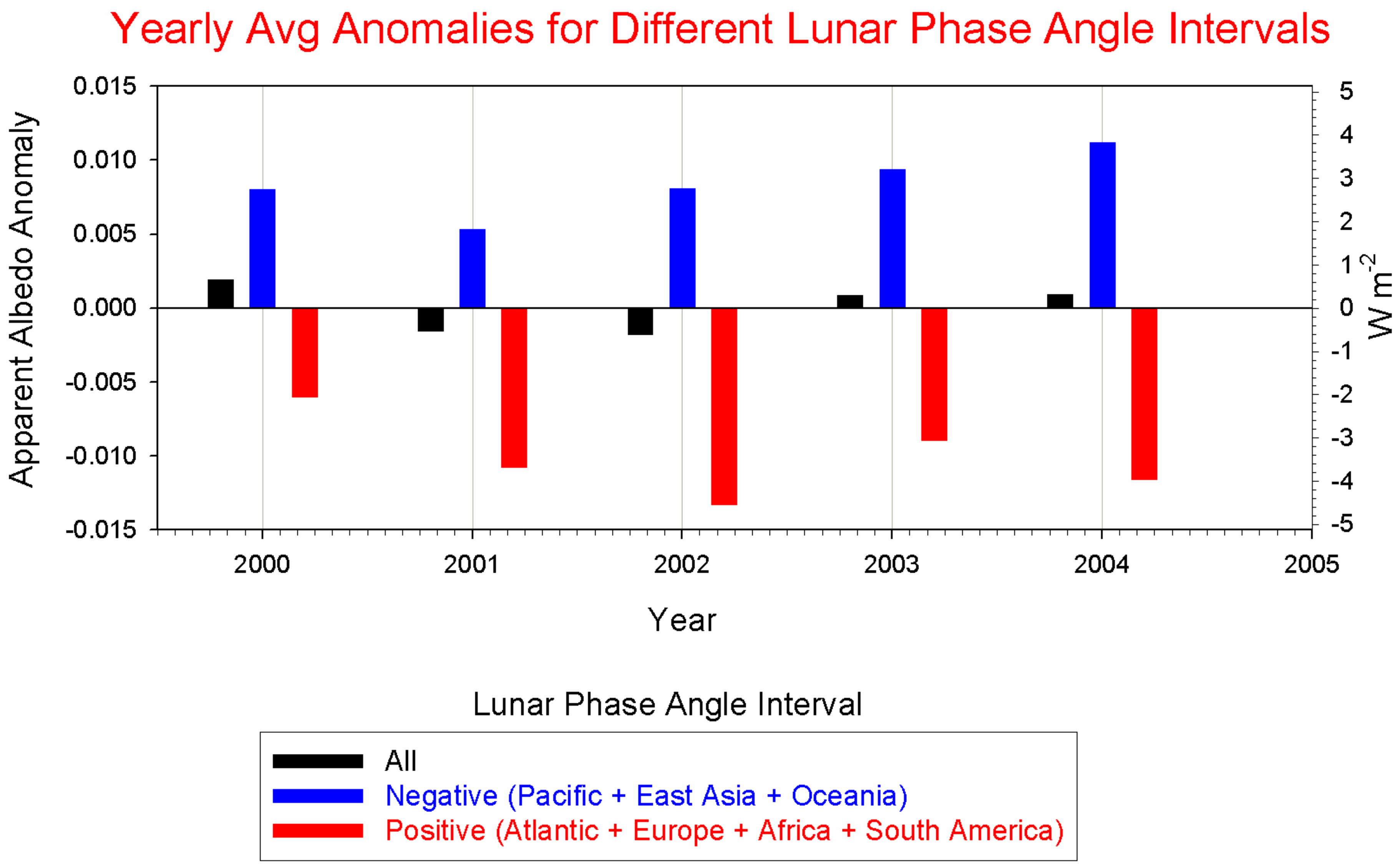
Apparent Albedo Anomaly:

$$\Delta p^*(t) = p^*(t,\theta) - \hat{p}^*(\theta)$$



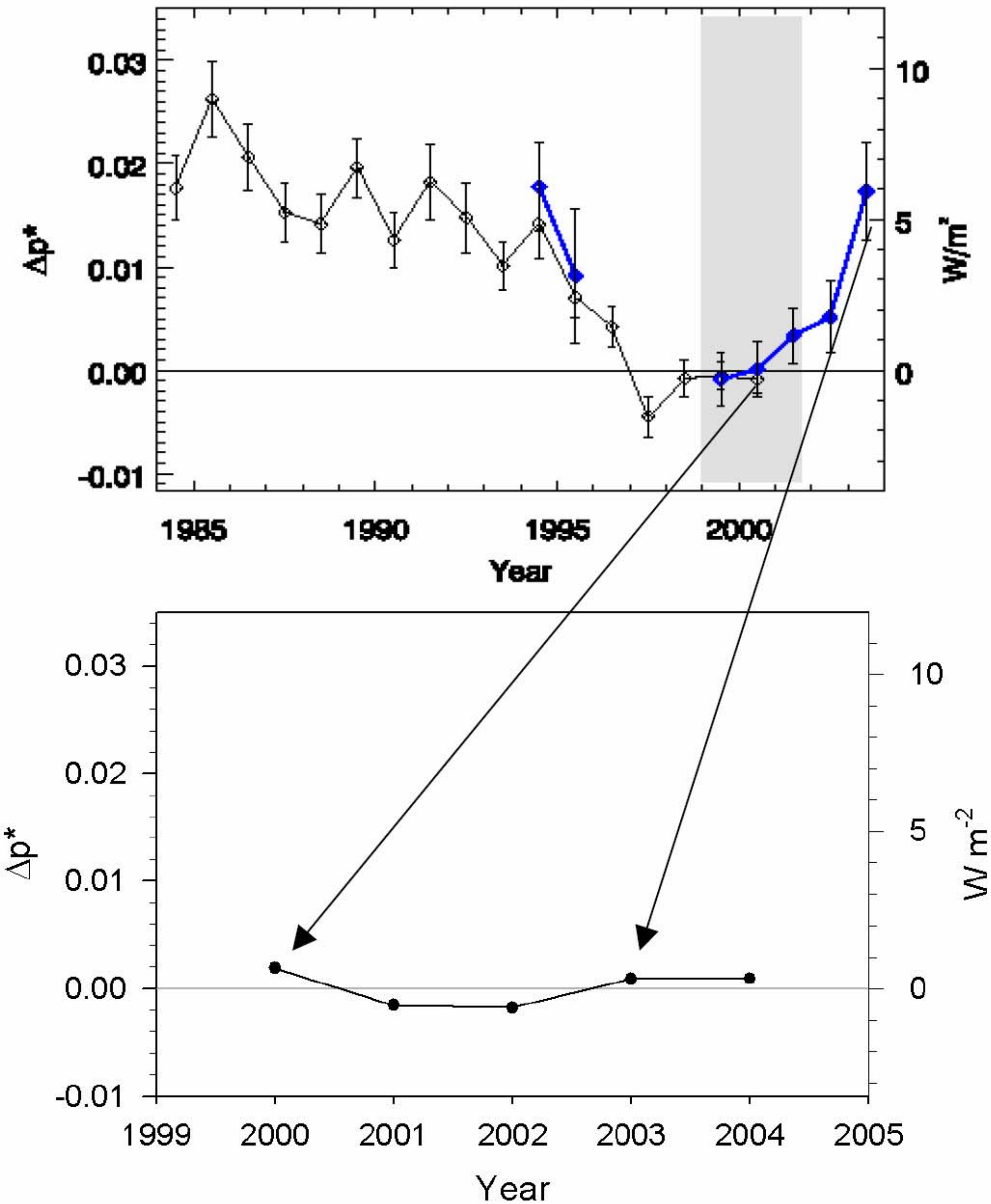
BBSO Apparent Albedo
(All Available Nights between Jan 2000 and June 2004: 353 Nights)
b0 = 2.9334229954
b1 = -0.0797523108
b2 = 9.0479386019e-4
b3 = -4.674456025e-6
b4 = 9.3814954967e-9
r ² = 0.9719181658
Apparent Albedo
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
40
60
80
100
120
140
160
abs(Lunar Phase Angle) (°)
Negative Lunar Phase Angles (Pacific + East Asia + Oceania)
Positive Lunar Phase Angles (Atlantic + Europe + Africa + South America)
4th Order Polynomial Fit to All Data Points


BBSO Apparent Albedo Anomaly (All Available 353 Nights)
Daily Avg
Monthly Avg
Yearly Avg
Apparent Albedo Anomaly
0.08
0.04
0.00
-0.04
-0.08
0.04
0.02
0.00
-0.02
-0.04
0.002
0.001
0.000
-0.001
-0.002
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
W m-2
2000
2001
2002
2003
2004
2005
Year



Yearly Avg Anomalies for Different Lunar Phase Angle Intervals
0.015
0.010
0.005
0.000
-0.005
-0.010
-0.015
Apparent Albedo Anomaly
5
4
3
2
1
0
-1
-2
-3
-4
-5
W m-2
2000
2001
2002
2003
2004
2005
Year
Lunar Phase Angle Interval
All
Negative (Pacific + East Asia + Oceania)
Positive (Atlantic + Europe + Africa + South America)

BBSO Yearly Mean Apparent Albedo Anomalies

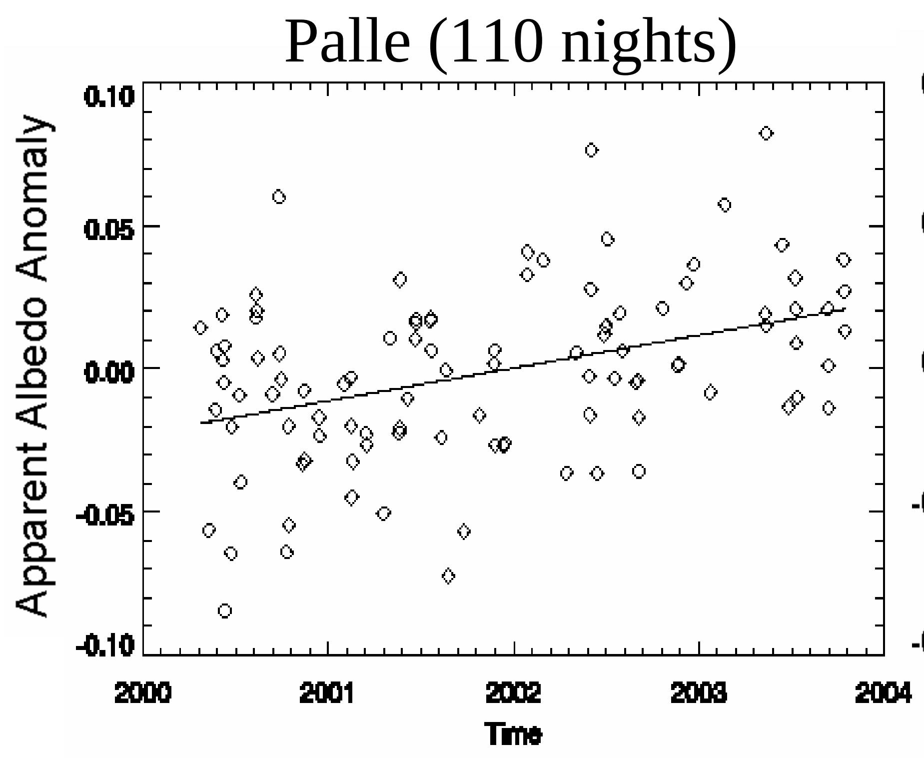


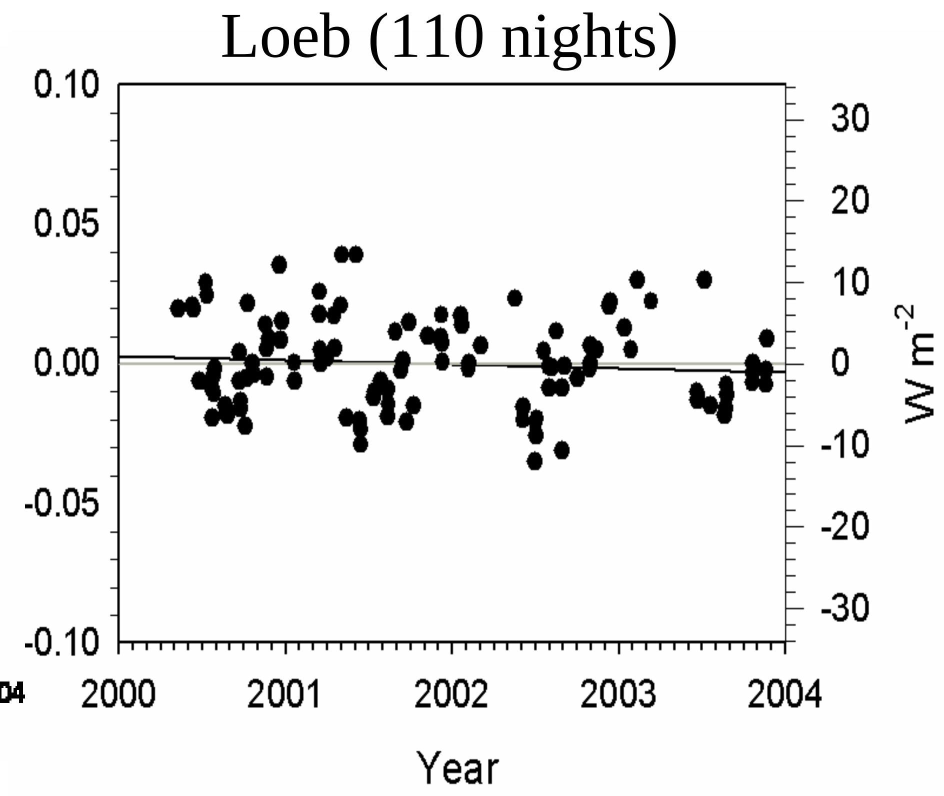
Palle et al.

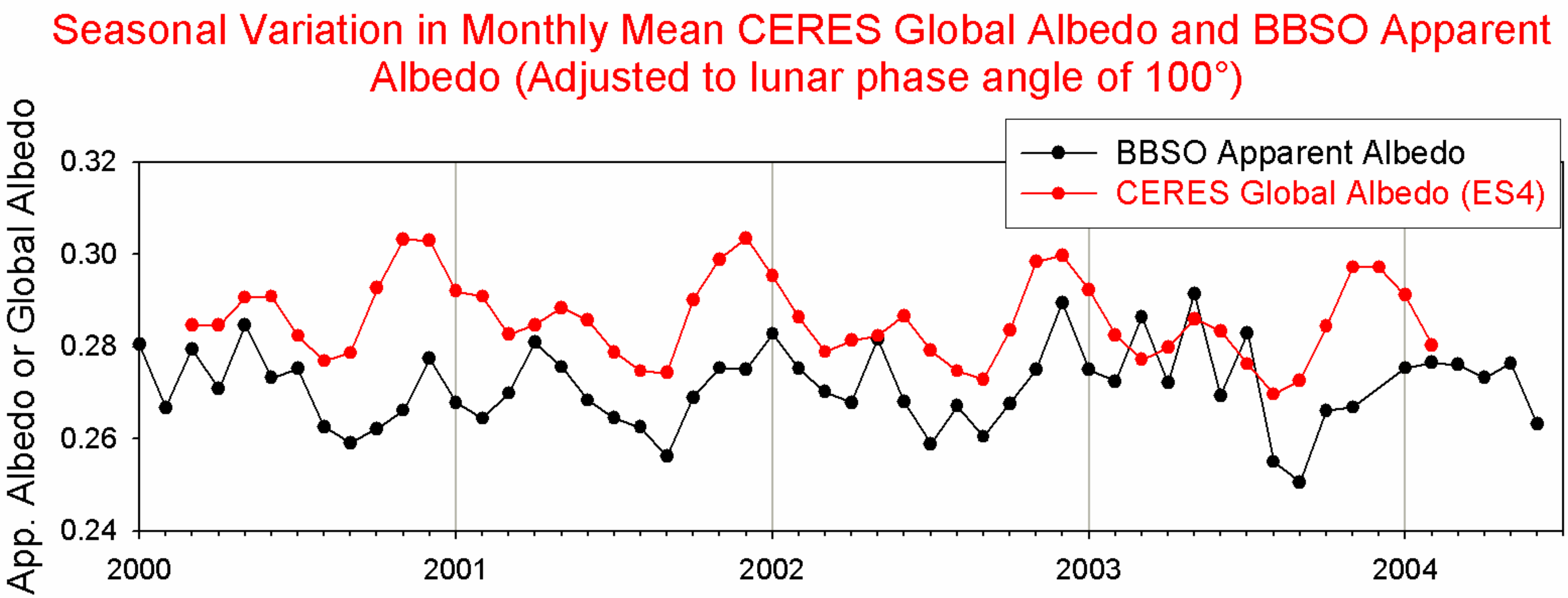
?

Loeb

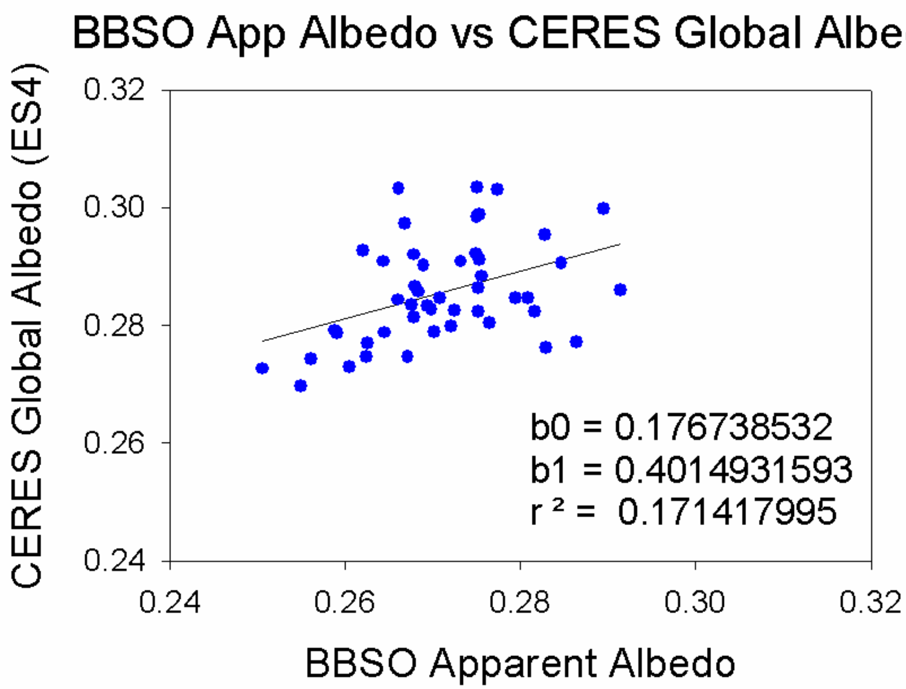
Daily Avg Apparent Albedo Anomalies for BBSO Data





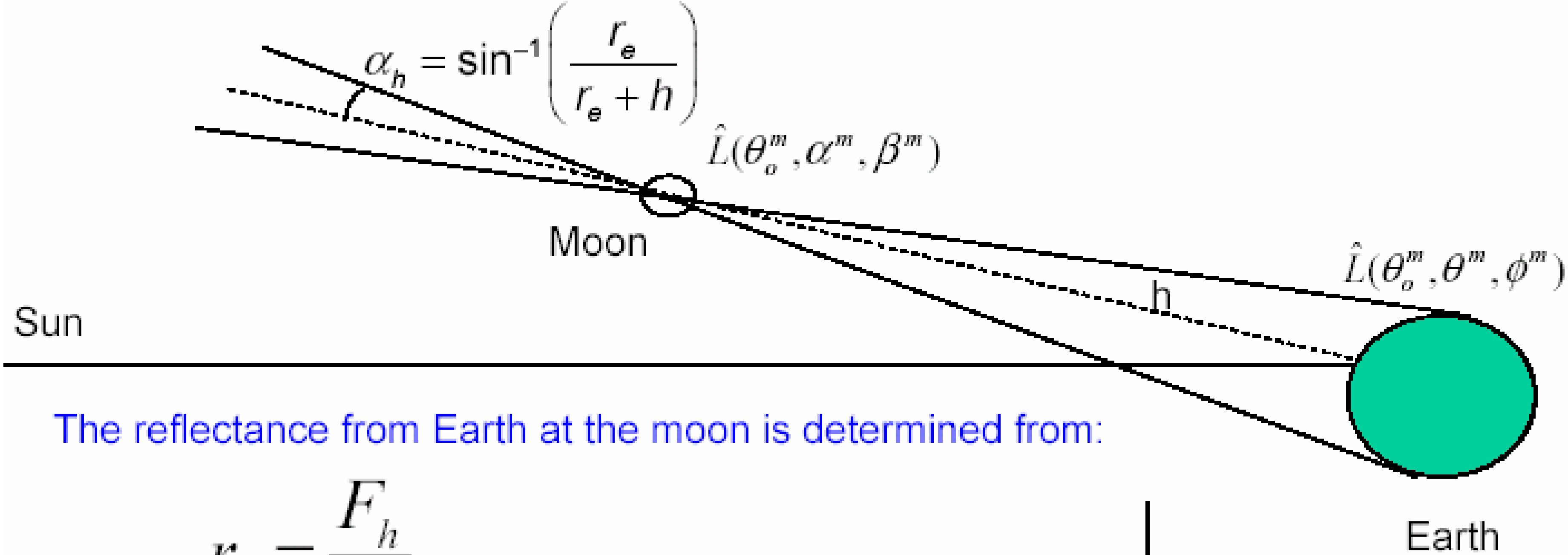


Seasonal Variation in Monthly Mean CERES Global Albedo and BBSO Apparent Albedo (Adjusted to lunar phase angle of 100°)
BBSO Apparent Albedo
CERES Global Albedo (ES4)
App. Albedo or Global Albedo
0.32
0.30
0.28
0.26
0.24
2000
2001
2002
2003
2004



BBSO App Albedo vs CERES Global Albedo
CERES Global Albedo (ES4)
0.32
0.30
0.28
0.26
0.24
b0 = 0.176738532
b1 = 0.4014931593
r ² = 0.171417995
0.24
0.26
0.28
0.30
0.32
BBSO Apparent Albedo

Inferring Earthshine From CERES



The reflectance from Earth at the moon is determined from:

$$r_h = \frac{F_h}{S_h}$$

$$F_h = \int_0^{2\pi} \int_0^{\alpha_h} \hat{L}(\theta_o^m, \alpha, \beta) \cos\alpha \sin\alpha \, d\alpha \, d\beta$$

$$S_h = \int_0^{2\pi} \int_0^{\alpha_h} \frac{\mu_o E_o}{\pi} \cos\alpha \sin\alpha \, d\alpha \, d\beta$$

$$\sin\alpha = \frac{r_e}{r_e + h} \sin\theta^m$$

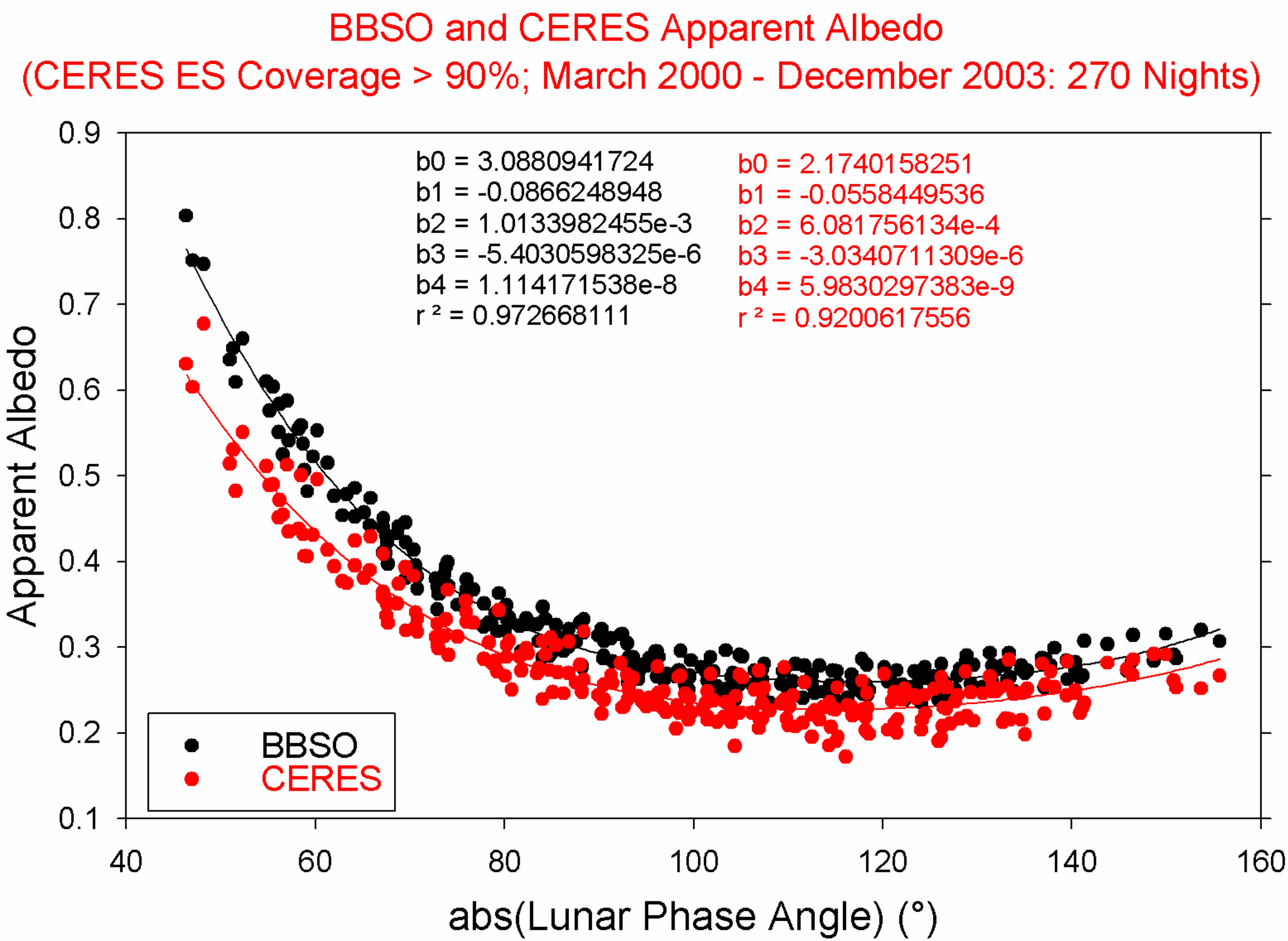
h=Earth-moon dist

$$\beta = \phi$$

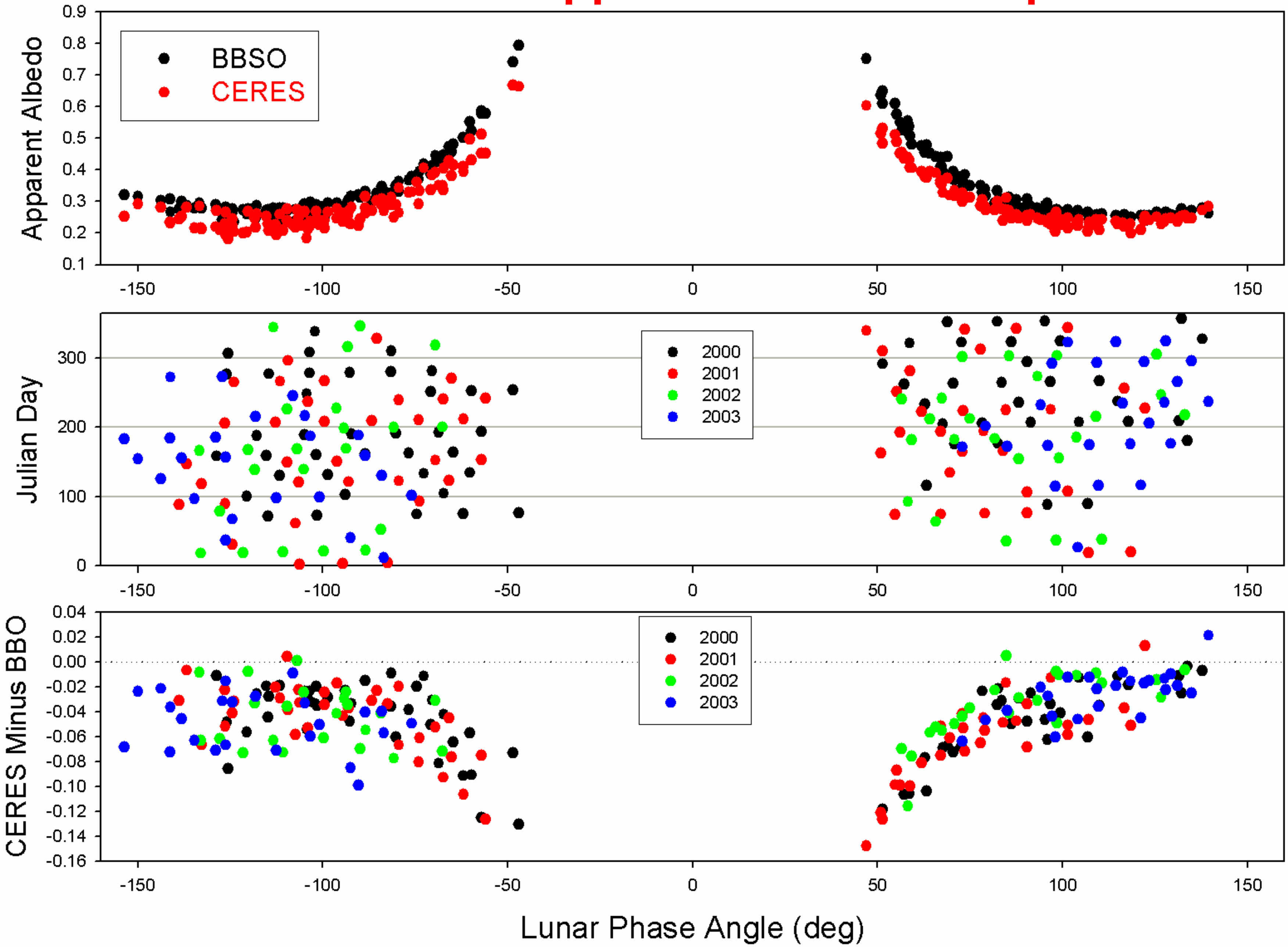
$$\mu_o = \cos(\theta_o^m)$$

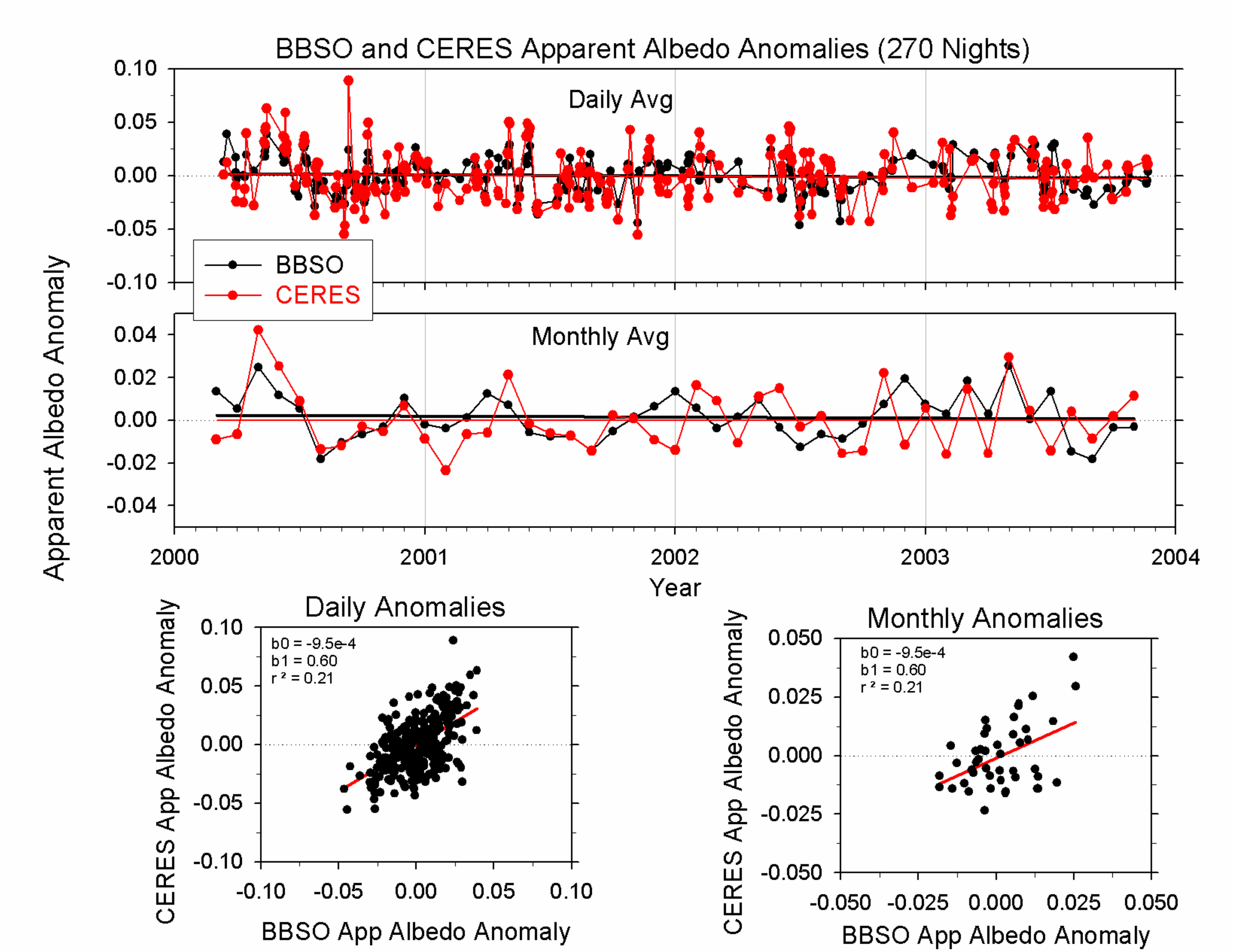
$$E_o = 1365 \text{ W m}^{-2}$$

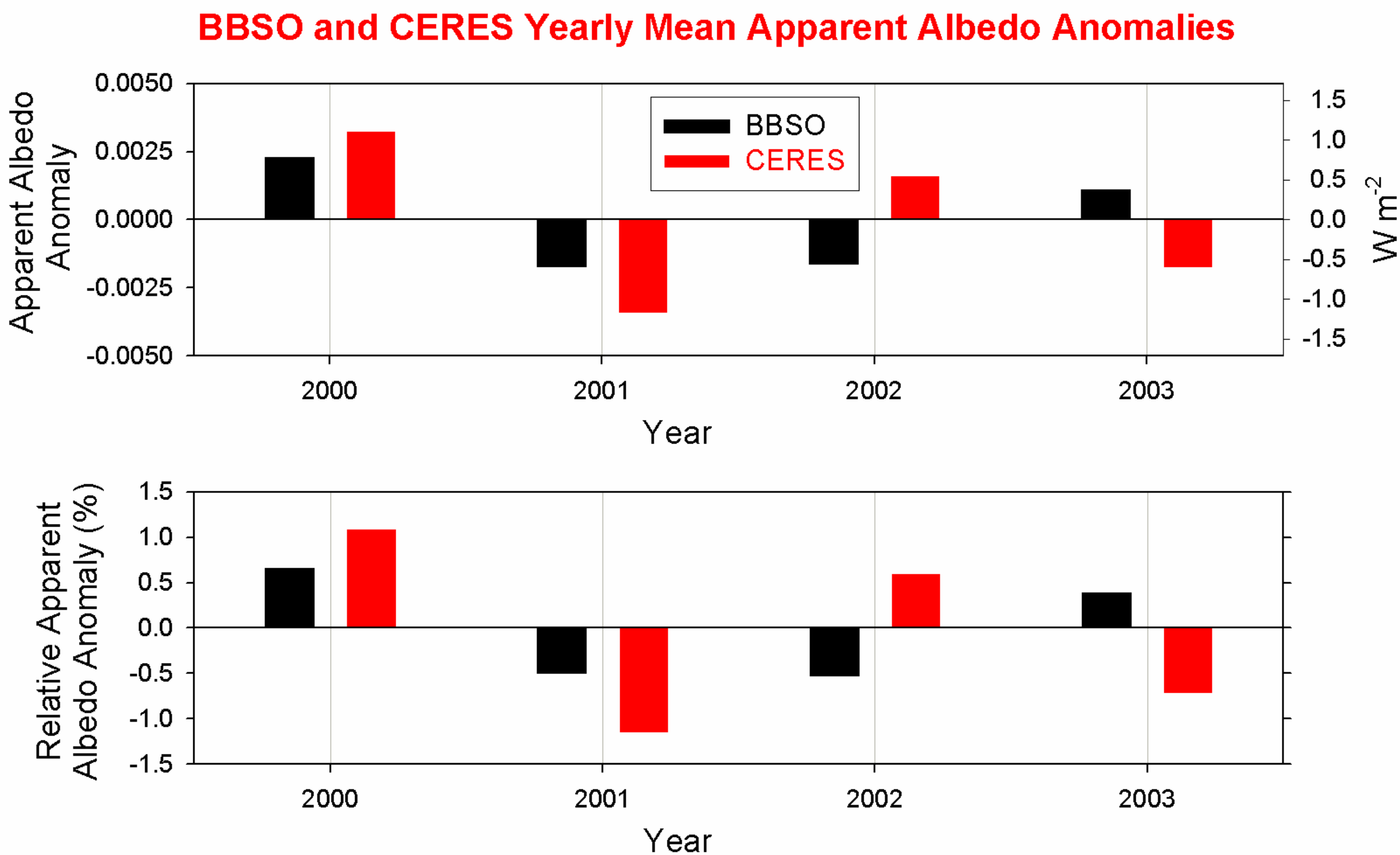
To determine above integrals, consider only regions that contribute to Earthshine.


BBSO and CERES Apparent Albedo
(CERES ES Coverage > 90%; March 2000 - December 2003: 270 Nights)
b0 = 3.0880941724
b1 = -0.0866248948
b2 = 1.0133982455e-3
b3 = -5.4030598325e-6
b4 = 1.114171538e-8
r ² = 0.972668111
b0 = 2.1740158251
b1 = -0.0558449536
b2 = 6.081756134e-4
b3 = -3.0340711309e-6
b4 = 5.9830297383e-9
r ² = 0.9200617556
Apparent Albedo
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
40
60
80
100
120
140
160
abs(Lunar Phase Angle) (°)
BBSO
CERES

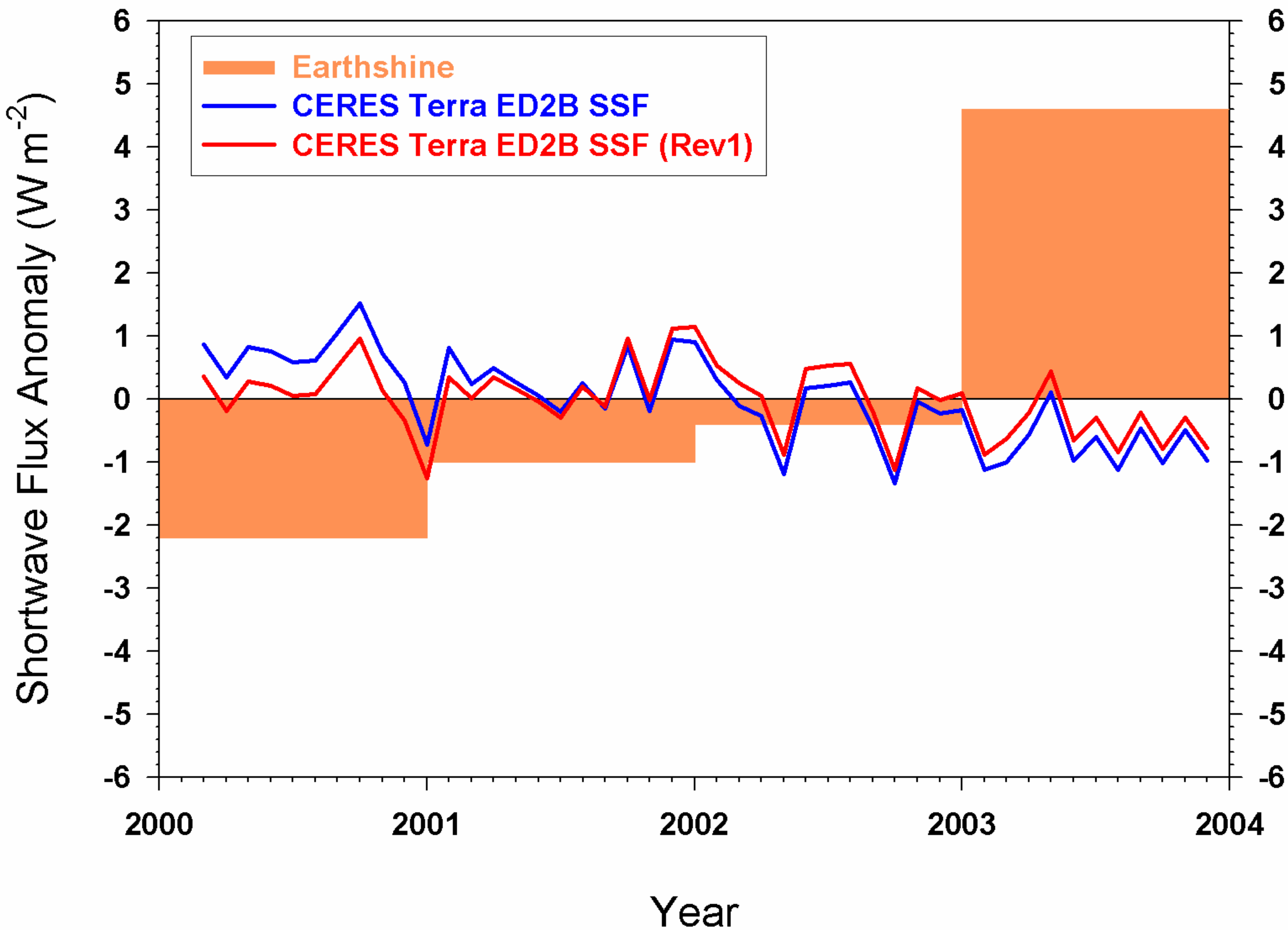
CERES and BBSO Apparent Albedo Comparison




BBSO and CERES Apparent Albedo Anomalies (270 Nights)
Daily Avg
Monthly Avg
BBSO
CERES
Apparent Albedo Anomaly
Year
2000
2001
2002
2003
2004
Daily Anomalies
b0 = -9.5e-4
b1 = 0.60
r ² = 0.21
CERES App Albedo Anomaly
BBSO App Albedo Anomaly
Monthly Anomalies
b0 = -9.5e-4
b1 = 0.60
r ² = 0.21
CERES App Albedo Anomaly
BBSO App Albedo Anomaly



BBSO and CERES Yearly Mean Apparent Albedo Anomalies
BBSO
CERES
Apparent Albedo Anomaly
0.0050
0.0025
0.0000
-0.0025
-0.0050
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
W m-2
2000
2001
2002
2003
Year
Relative Apparent Albedo Anomaly (%)
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
2000
2001
2002
2003
Year



Earthshine
CERES Terra ED2B SSF
CERES Terra ED2B SSF (Rev1)
Shortwave Flux Anomaly (W m-2)
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
2000
2001
2002
2003
2004
Year

Summary

- From our own analysis of Earthshine data, we cannot reproduce the large increase in Earth reflectance reported in Palle et al. (Science, 2004).

- The methodology used to analyze Earthshine data is questionable:

  => Assumes no difference between apparent albedos from –ve and +ve lunar phase angles (e.g. Pacific vs Atlantic regions).

  => Irregular year-to-year sampling of apparent albedo due to length of lunar month and data gaps due to cloud cover at BBSO.

- Seasonal cycle of apparent albedo is inconsistent with seasonal cycle of global albedo (e.g., from CERES)