Review of "A net decrease in the Earth's cloud plus aerosol reflectivity during the past 33 yr (1979–2011) and increased solar heating at the surface", by Herman et al., Atmos. Chem. Phys. Discuss., 12, 31991–32038, 2012

I have five major concerns with this study:

1) This study claims that the downwelling broadband solar radiation at the surface could be estimated from satellite TOA LER measurements. Based on reading the abstract multiple times I am unsure whether the authors claim only the TOA reflectance is changing due to clouds and aerosols at one wavelength, or whether they imply that LER can actually be used as a surrogate for broadband downwelling surface flux. Please clarify. If the regional trends noted in the paper can be used to estimate the change in surface downwelling at the surface, I have the following concern.

It would appear from this review that the title did not describe the goals of the paper. I have changed the title to stay closer to the paper's goals. "**A Net Decrease in the Earth's Cloud, Aerosol, and Surface 340 nm Reflectivity During the Past 33 Years (1979-2011)".** The purpose of this data paper is to show the change in 340 nm reflectivity measured by a series of satellites with a common calibration. A calculation was added assuming that Trenberth's cloud+aerosol reflectivity could be perturbed by a small amount based on the 340 nm LER change to estimate the effect on Trenberth's shortwave energy estimate absorbed at the surface. The 340 nm LER data are not used to estimate shortwave energy over an extended wavelength range. To remove the confusion, a new subsection title was added as follows,

"7.0 A Perturbation to Trenberth et al., [2009] Estimate of Shortwave Surface Absorption"

This paper does not claim that "the downwelling broadband solar radiation at the surface could be estimated from satellite TOA 340 nm LER measurements". The perturbation to Trenberth's estimate is in the spirit of evaluating one term in a differential function of multiple variables with everything else held constant.

The abstract has also been changed slightly,

"Applying a similar perturbation to the energy balance partitioning given by Trenberth et al., [2009], a 3.6% change in cloud plus aerosol reflectivity corresponds to an increase of 2.7 W/m^2 of solar energy reaching the Earth's surface (an increase of 1.4% or 2.3 W/m^2) absorbed by the surface, which is partially offset by an increase in longwave cooling to space."

Actual ground based measurements are sparse in both spatially and temporally, limited mainly over land, with various degrees of quality. The quality of surface fluxes have increased dramatically over time, for example, the BSRN (Baseline Surface Radiation Network) frequently has meetings to standardize surface fluxes and has set up guidelines for best practices. Global surface flux datasets from GCMs, assimilated (ECMWF) and observed (ISCCP-FD) compute the surface fluxes from cloud properties and may be biased spatially and temporally depending on the quality of the input. These global datasets validate their surface fluxes with ground observations and contribute to projects that evaluate the quality of long-term flux and cloud climate datasets such as GEWEX

(http://www.gewex.org/). It seems conspicuous that the LER fluxes are not compared to any existing ground based surface measurements, which standard practice with global surface flux datasets. Due to the large size of the SBUV/2 footprint, it may be difficult to validate the SW down with a surface site not representative of the larger surrounding domain, such as coastal or terrain sites. However, the surface community has introduced ground sites over uniform regions. For example, Long et al 2009 has derived large domain 12-year fluxes over the US using ARM-SGP. An important validation is make sure that the ground based surface flux natural variability is consistent with the SBUV/2 over the same time period. If this were performed it would bring about much more confidence that the LER can be used to derive the surface downwelling fluxes.

Since this paper does not estimate the SW radiation, but rather the change in 340 nm LER, there is no quantitative way to compare with the ARM data. Qualitatively, the ARM data is showing an increase in radiation reaching the ground. This is consistent with the 340 nm LER, which shows a general decrease in LER that corresponds to an increase in surface radiation (proportional to $(1 - LER)/(1-R_G)$). Converting the 340 nm LER results for the US (0.97 RU/decade) to percent change gives about a 3% per decade increase in 340 nm surface radiation over the US. Long et al., Figure 15, shows a 2.3% per decade in decrease in cloud cover. Performing a least squares fit to Long et al., Figure 15 aggregate average gives 2.3±2.3% per decade, which is within the range of the LER 3% per decade.

Long, C. N., E. G. Dutton, J. A. Augustine, W. Wiscombe, M. Wild, S. A. McFarlane, and C. J. Flynn (2009), Significant decadal brightening of downwelling shortwave in the continental United States, J. Geophys. Res., 114, D00D06, doi:10.1029/2008JD011263.

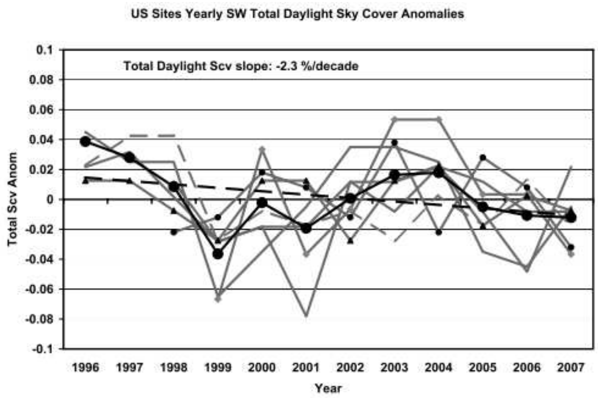


Figure 15. Yearly averages of SW total daylight sky cover (Scv) anomalies (gray) for the ARM SGP Central Facility and SURFRAD sites used in this study (see Table 1) as well as the aggregate average (black curve with dots) and the corresponding least squares linear fit. Individual sites discussed in text denoted as gray diamonds (Penn State), black dots (Desert Rock), black triangles (Table Mountain), and gray dashed curve (Bondville).

Augustine, J. A., and E. G. Dutton (2013), Variability of the surface radiation budget over the United States from 1996 through 2011 from high-quality measurements, J. Geophys. Res. Atmos., 118, 43–53, doi:10.1029/2012JD018551.

Augustine and Dutton [2013] estimate a decrease in downward SW of 7.2 ±1.5 W/m2/decade (their Table 2). If 155 W/m2 is used as a reference value for downward SW radiation reaching the Earth's surface at 40N, then this represents a decrease of 4.6±1%/decade, which is approximately consistent with the 340 mn LER decrease of 3% per decade over the US. As mentioned before, there is no expectation that the numbers agree exactly because of the differences between SW and the narrow 340 nm channel and because of the differences in the nature of the measurement (satellite vs ground)

If the authors of this study were confident of their results, would it not be appropriate for the SBUV/2 team to archive the data of this study and release it to the community? The ISCCP, AVHRR-Patmos, CERES, ECMWF, assimilated, GCM, and ground based surface site datasets are all freely available to public. If two or more independent methods provide the same natural variability and trends will greatly enhance the claims of this study.

These data are archived at the NASA DISC facilty in HDF format as was stated in the acknowledgement, "**Acknowledgement: This research is supported by the NASA MEaSUREs Project. The data and documentation are available at the DES-DISC (http://mirador.gsfc.nasa.gov/** enter keyword LER)", and is now in the introduction. Note: I have changed the original link to make access easier.

2) This study claims that LER can provide an alternative estimation of the change in the broadband SW downwelling flux due to the cloud plus aerosol cover. For wavelengths less than 0.5µm the ground reflectivity is less than 10% LER, making these wavelengths advantageous to monitor cloud cover change. Again the abstract is not clear whether the increase in the SW absorbed at the surface is broadband or for one wavelength.
If this is the case then what is not evident, is how LER can monitor over time the changes in cloud SW fluxes in other frequencies such as the in the near IR in the water vapor absorption bands, where the water vapor associated with increases or decreases in clouds may impact the total SW downwelling flux.

Hopefully, the changes in the paper now indicate clearly that this paper does **not** claim that LER can provide an alternative estimation of the change in the broadband SW downwelling flux due to the cloud plus aerosol cover. Rather, we use Trenberth's estimate of SW radiation and simply estimate the effects of a perturbation to one of the parameters in his estimate while holding all the others constant.

Simply applying a scaling factor based on some broad assumptions presented on page 32009 and 32010 using Trenberth's energy balance diagram to the LER and assuming that the surface reflectivity has remained constant over time and atmospheric absorption has not changed are bold assumptions. This simply implies that the change in TOA reflectance is only due to clouds and aerosol variation, not surface reflectance changes. If this statement is actually made, then it can be verified by comparing LER with the well calibrated and diurnally corrected CERES broadband SW TOA reflected dataset over the last ten years. The regional trends should be consistent.

For the 340 nm UV wavelengths, the surface reflectivity is low, except over snow and ice. Changes in the UV surface reflectivity (land, vegetation, oceans) are negligible compared to the clouds. The observed LER changes are mostly associated with clouds and aerosols (60S to 60N), with the changes dominated by the mid-latitudes and equatorial regions. The Trenberth exercise is to show the effect of reflectivity change with everything else held constant. There was no implication in the perturbation calculation that the surface reflectivity and atmospheric absorption in the visible and near-IR did not change over 33 years. I have rewritten the introduction to the Trenberth perturbation exercise to state this.

The section now reads

"The shortwave SW portion of the Earth's energy balance model of Trenberth et al. [2009] contains five major factors: 1) energy reflected to space by aerosols and clouds, 2) energy reflected by Rayleigh scattering, 3) energy absorbed in the atmosphere, 4) energy reflected by the Earth's surface, and 5) energy absorbed by the Earth's surface. In the following calculation, all physical properties (e.g., surface reflectivity and atmospheric absorption) of the atmosphere and surface are held constant except for cloud reflectivity.

To estimate the effect of a 3.6% decrease in cloud plus aerosol reflectivity in terms of shortwave energy change ΔE absorbed by the surface, we assume as starting values Trenberth et al. [2009] estimate of 341.3 W/m^2 average solar energy at the top of the atmosphere, 78 W/m^2 absorbed by the atmosphere, 79 W/m^2 reflected by the atmosphere plus clouds and aerosols, and 23 W/m^2 reflected by the surface (Figure 10). Rayleigh scattering is assumed to be 6% of the incident radiation or 4.74 W/m^2. Of the incoming radiation, 79-4.74=74.26 W/m^2 are reflected by clouds and aerosols giving a fractional cloud plus aerosol reflectivity of 74.26/341.3=0.2176. The estimated broadband reflectivity value is close to the fractional 340 nm LER estimate of $<R> = 0.219$. The radiation heading toward the surface is 341.3-78-79=184.3 W/m^2, of which 23 W/m^2 is reflected from the surface yielding 102 W/m^2 of total reflected radiation and 161.3 W/m^2 absorbed by the surface. The effective fractional surface reflectivity based on Trenberth et al. is $R_G = 23/184.3 = 0.1248$, which is held constant. To make a simplified calculation of the shortwave change ΔE in solar energy absorbed by the surface from the change in reflectivity $\Delta<R>$, Trenberth's 78 W/m^2 estimate of atmospheric absorption is held constant.

For calculating energy change ΔE, the exact starting numbers (i.e., Trenberth et al.) do not make a significant difference. Extra significant figures are retained only for ease in checking the calculations.

The 3.6% decrease in average cloud plus aerosol reflectivity gives a reduced cloud plus aerosol fractional reflectivity of 0.2176*(1-0.036) = 0.2098 giving 341.3*0.2098 = 71.60 W/m^2. Then the clouds and atmosphere reflect 71.60+4.74 = 76.34 W/m^2, and 341.3-76.34-78 = 186.96 W/m^2 reaches the surface. The amount reflected from the surface is now 23.33 W/m^2 and 186.96-23.3 = 163.66 W/m^2 is absorbed by the surface. The total reflected solar radiation is now 76.34+23.33 = 99.67 W/m^2. The difference is 99.67-102 = -2.33 W/m^2, which is the same as the difference absorbed by the surface, ΔE = 163.63-161.3 = 2.33 W/m^2, or a change of 1.4%."

3) Several regional LER trends are given in the last part of the abstract. There is no distinction made in the paper if these are trends by simply placing a trend over the natural variability of clouds and aerosols over the last 30 years. Since the cloud and aerosol natural variability is dominated by the ENSO cycle as claimed by the authors, simply placing a trend line over the natural variability is dangerous and highly dependent on beginning and end points of the ENSO events, of which the magnitude has been rather small over the last decade. Is putting a trend over the natural variability meaningful? However if the point of the paper is to imply that these trends are outside of the normal annual, AO, ENSO, MJO, NAO, oscillations and volcanic eruptions, then an uncertainty factor must be given in order to give confidence to these trends and is absent in this study.

Reply:

All of the trends were computed by deseasonalizing the data in a manner shown in Figure 7 as well as applying a linear least squares fit to the original data. Deseasonalization removes the annual cycle, but leaves the ENSO and volcanic eruption effects in the time series. The 33-year time series is composed of complete years starting on January 1 and ending on December 31. The exact starting and ending day made no significant difference in trend estimation, since there was no major ENSO event in the starting and ending years (1979 and 2011). This paper was meant to be a data paper and include all changes in reflectivity. Another paper is being written that performs EOF analysis to separate the effects.

The following has been added to the paper, "In the following section, all trends are computed for deseasonalized data and plotted over the original daily LER data. The trends for the original daily data are almost identical to the daily deseasonalized data. An exception was made for Greenland, where the winter months are missing because of darkness above the Arctic circle."

In addition, the figures now have either monthly average (30-day low-pass filter for zonal average data) or 300-day average (300-day low pass filter from 10-day average gridded LER product). The computed trends are approximately the same. The only change is in the estimated error bars, which are larger for the daily or 10-day average time series than for the low-pass filter time series. The paper quotes the larger error bars.

These papers provide the confidence level given a trend and the natural variability.
Weatherhead, E. C., G. C. Reinsel, G. C. Tiao, X.-L. Meng, D. Choi, W.-K. Cheang, T. Keller, J. DeLuisi, D. J. Wuebbles, J. B. Kerr, A. J. Miller, S. J. Oltmans, J. E. Frederick, 1998: Factors affecting the detection of trends: Statistical considerations and applications to environmental data, Journal of Geophysical Research, 103, 17149-17161.
Leroy, S. S., J. G. Anderson, and G. Ohring, 2008: Climate Signal Detection Times and Constraints on Climate Benchmark Accuracy Requirements. Journal of Climate, 21, 841-846.

Page 32013 does mention that the ENSO cycle is removed from the mid Pacific Ocean in 7.1. I do not know what the intent of this paper is with revealing these LER trends. Careful studies must be performed to verify these trends above natural variability and the physics behind these trends and corroborating these with other independent datasets.

Reply:
I agree with the reviewer in principle about the desirability to discuss the physics behind these trends. In this data paper, the purpose is to simply show that the long-term trends with and without the ENSO effects are nearly the same. The underlying physics is outside the scope of the paper. It would require a good coupled atmosphere-ocean model constrained by available data. The implied conclusion from the data is that the ENSO effect is not causing the observed trends.

The LER trends are Figures 14 and especially 16 are not convincing as statistically significant, when overlaid with daily? measurements. Fig 9 does make an attempt with an annual low pass filter.

Reply: All trends, except for Greenland, were computed by deseasonalizing the data as in figures 7 and 9. The results were nearly identical (see figure 9) between the original and deseasonalized versions. Using an annual low-pass filter or a 30-day low pass filter gives the same trends, but it reduces the uncertainty. The 30-day low pass filter has an error estimate that is approximately 3 times lower than the daily error estimate. All of the figures and trends have error estimates that show that the trends are statistically significant. The figures have been modified to include a 30-day low pass filter for daily zonal averages and a 300-day filter for the regional time series composed of 10-day averages.

4) Zonal diurnal corrections are performed to remove the diurnal cycle regionally. Figure 11.

The LER trends over 30 years are highly correlated with regions with large diurnal cycles, such as off of the Peruvian and California coast (positive trends) with clouds in the morning, and land afternoon convective regions such as South America and the USA (negative trends). Page 32004 line 25. The Labow et al. paper describes a 5° zonal land and ocean diurnal corrections. Applying a mean land/ocean zonal correction does not remove all the diurnal variation in regions with large (maritime stratus) amplitude diurnal variations, based on other zonal regions with weak diurnal cycles. How can the authors be sure that the maritime stratus regions, in Figure 11 top panel, have been properly removed with a zonal ocean correction, where most of the ocean does not have a diurnal cycle?

Reply:
I agree. With the available data it is not possible to remove all of the diurnal variation in a small coastal region. The paper now contains sentences stating this limitation.

"For coastal regions that have large diurnal variations in cloud amount, application of the zonal average correction does not properly remove the diurnal variation of the observations caused by the changing equator crossing time of the SBUV-2 instruments. Since similar negative trends occurred using the shorter time series from N7-TOMS (1979 – 1992), which had a nearly constant near-noon equator crossing time [Herman et al., 2001 Plate 1], it suggests that the negative trend is not caused by aliasing from diurnal variation."

A new figure has been added to the paper showing noon normalized trends with the appropriate land-only or ocean-only correction applied.

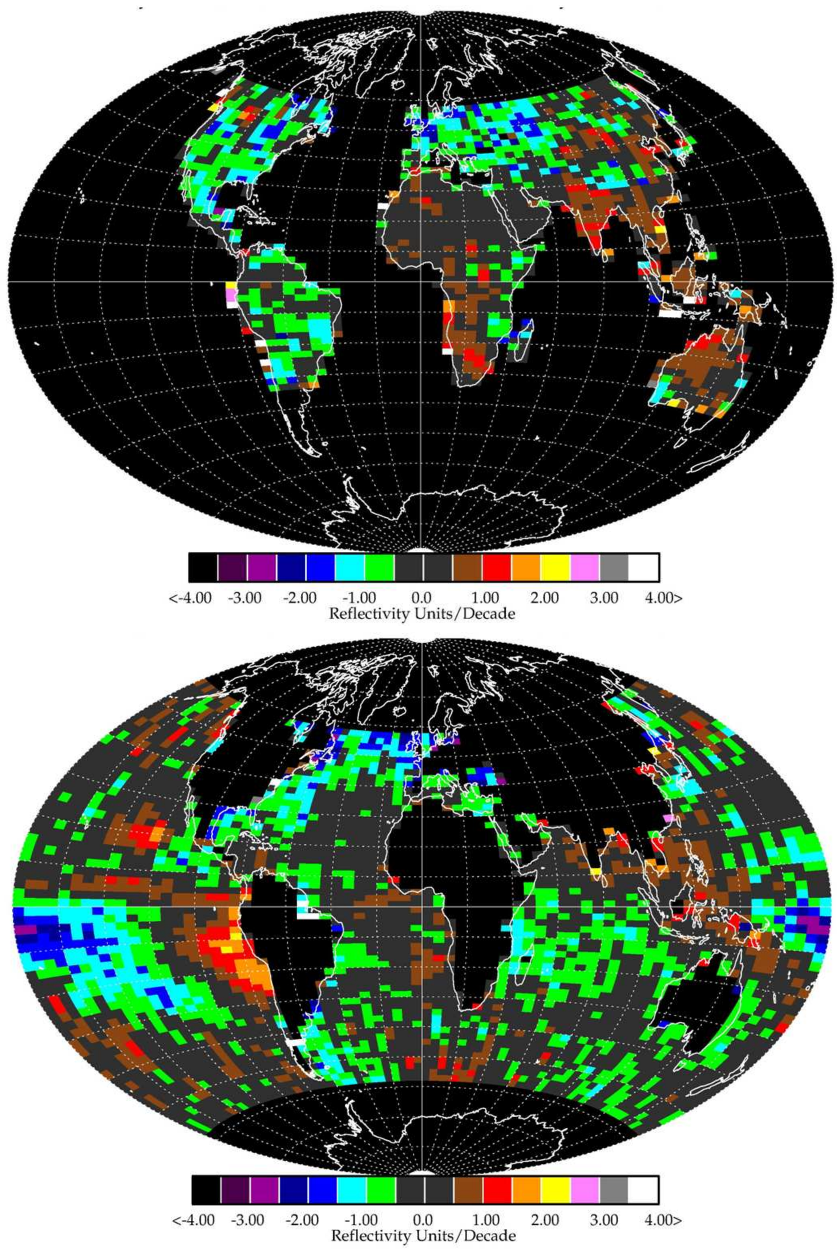


Figure 11B LER linear trends $\Delta LER(\theta,\phi)$ as a function of latitude θ and longitude ϕ. The upper panel has land only noon normalization correction applied to the data, while the lower panel is based on ocean only noon normalization correction applied The noon normalization was not applied to latitudes > 60^{O} because of a lack of measured radiances at different local times.

As mentioned in the paper that the ENSO activity is small in the 2000-2010 decade compared to previous decades and Figure 9 does illustrate that. The 2000-2010 decade is also the time period that multiple LER datasets were used in the dataset. If the only one LER dataset were available would the same results have been obtained in figure 7, especially the degrading orbits of NOAA-14 as it cycle through the terminator? This would be an excellent validation of the diurnal correction. It seems that all the regional trends during this time are flat after 2000. Most of the trends are really the difference of the first decade compared with the last decade. The first decade of results relies solely on one dataset from Nimbus-7, indicating that the calibration of the instrument is most crucial in all of regional trends.

It is true, that the first decade is dominated by one instrument, Nimbus-7 SBUV, while the 2nd and 3rd decades have multiple instruments with some overlapping data. This is the same situation as all of the existing cloud data sets that extend back to 1979. The calibration of N7-SBUV was carefully redone as explained in the calibration section of the paper. The SBUV-2 data sets were not used when the instrument got near the terminator.

5) The authors claim that the reflectivity of Greenland is changing over time. The summit of Greenland has been use by many to calibrate imager visible channels, similar to Antarctica. The calibration of AVHRR and ATSR over Greenland and Antarctica were consistent with the studies listed below. The summit and Antarctica are both at 3-km in elevation, where very few clouds are found. Are clouds brighter than snow surfaces, since the authors state that cloud cover changes could be the cause? I can only imagine maybe the snow surface is changing due to water ponding or soot. In order to convince the reader I would like to see an added figure showing the Antarctica LER variability similar to Fig 15. The noise of which should be much smaller than Greenland and be very flat.
S. J. MASONIS and S. G. WARREN, Gain of the AVHRR visible channel as tracked using bidirectional reflectance of Antarctic and Greenland snow, int. j. remote sensing, 2001, vol. 22, no. 8, 1495–1520
WILLIAM R. TAHNK AND JAMES A. COAKLEY JR., Improved Calibration Coefficients for NOAA-12 and NOAA-15 AVHRR Visible and Near-IR Channels, JTECH, 2002, pg 1826
Dave L. Smith, Chris T. Mutlow, and C. R. Nagaraja Rao, Calibration monitoring of the visible and near-infrared channels of the Along-Track Scanning Radiometer-2 by use of stable terrestrial sites, January 2002 ! Vol. 41, No. 3 ! APPLIED OPTICS

Reply:

Additional trends are now computed for regions near Greenland, but over the oceans (see below).

Minor concerns • The intent of this paper is not well outlined in the abstract.
The abstract and title have been changed.

Is it to scale the LER to derive an actual SW downwelling flux?
The intent is not to scale the 340 nm LER

Then the following regional trends are still in RU. Are the regional trends that are given in the abstract the regions that are responsible for the overall global change?

The global change was computed for all of the available data

I have added some changes related to the Greenland location as follows:

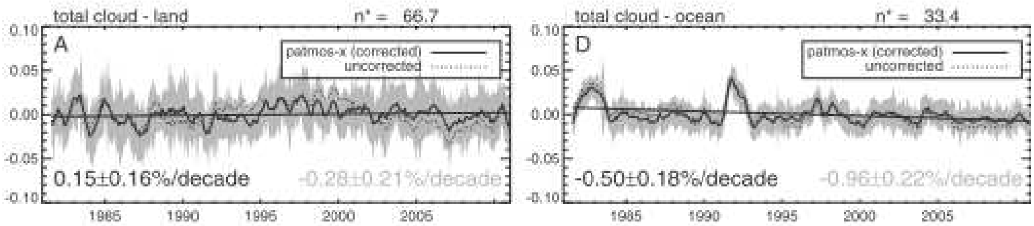
"The LER trend over Greenland (Figure 15) shows that a significant decrease in scene reflectivity (0.3 ±0.03 RU/decade) may be partly composed of changes in surface ice reflectivity and changes in the cloud cover over the ice. Three adjacent regions to Greenland over the dark ocean (70^{O}-74^{O}N 5^{O}-10^{O}W), (60^{O}-64^{O}N 25^{O}-35^{O}W), and (54^{O}-58^{O}N 40^{O}-50^{O}W) show even stronger decreases in LER (-1.3 ± 0.3 RU/Decade), (-1.6 ± 0.3 RU/Decade), and (-1.1 ± 0.3 RU/Decade) than over the Greenland ice. Clouds over ice and snow have a lower scene reflectivity than a clear-sky scene over the same ice and snow. This is because of the multiple reflections between the clouds and the surface that causes absorption of more photons. In contrast to the low reflectivity ocean areas, the high reflectivity ice sheet provides a surface that limits the amount of change in LER that can be observed to changes in the ice reflectivity plus changes in cloud cover. A decrease in cloud cover over unchanging Greenland ice and snow should cause an increase in LER. However, the adjacent areas show decreased reflectivity over the nearby oceans, suggesting that more summer sunlight is reaching the ice surface in recent years, causing it to darken because of melting. Most of the data shown in Figure 15 is from the summer because of the high latitude, where sunlight disappears after the September equinox."

• Page 31992 line 7, "much higher reflectivity of clouds plus aerosols" I believe not all aerosols are weighted equally with LER measurements. Rayleigh scattering probably obscures the aerosols close to the surface, where as the effects of stratospheric aerosols are properly monitored.

Most of the Rayleigh scattering is removed as part of the LER estimation. Non absorbing aerosols (other than smoke and dust) tend to brighten a scene compared to clouds over the ground, particularly, if the optical depth of the clouds is not too large. For high optical depth clouds, the presence of aerosols below the clouds can be neglected. Non-absorbing aerosols above thick clouds have a negligible effect on LER. Absorbing aerosols, above or within clouds, decrease the LER. The statement refers to the reflectivity of aerosols plus clouds compared to the ground or ocean surfaces. As such, it is correct.

• Page 31994, line17. "Two other long-term cloud data sets exist, AVHRR and HIRS, which have diurnal cloud variation from drifting orbits." The AVHRR and HIRS are on the same NOAA platforms as SBUV/2. There have been many algorithms developed to remove the diurnal variations of cloud properties and radiances due to the sampling time of the degrading NOAA orbits. These datasets have the advantage of smaller footprints than the SBUV/2 and therefore can resolve the diurnal cycle over small regions, unlike the zonal ocean/land diurnal adjustments used in this paper. Here are some references.

The 340 nm LER agrees qualitatively with Foster and Heidinger as to the magnitude and direction of the change. However, the quantities measured are quite different. Their measurement is of cloud fraction (cloud cover), while the LER is a measure of reflected energy (a combination of cloud fraction and cloud optical depth plus a small surface and aerosol contribution). For thick clouds, the cloud fraction and LER are highly correlated. This correlation is weaker for thin clouds and multi-layer cloud structures where optical depth is a factor contributing to the LER. Also, the diurnal variation of effective cloud fraction is not the same as diurnal variation of LER. Comparing the result of Foster and Heidinger's Figure 8 (page 10 of this reply) with our new Figure 8 (see page 12 of this reply), where land and ocean are separated, we have a very small trend between 30S and 30N for land and a much larger trend for ocean. This agrees with Foster and Heidinger. Our new figures are now included in the paper



Foster, M., and A. Heidinger, 2012: PATMOS-x: Results from a Diurnally-Corrected Thirty-Year Satellite Cloud Climatology. J. Climate. doi:10.1175/JCLI- D-11-00666.1, in press.

Lee, Hai-Tien, Arnold Gruber, Robert G. Ellingson, Istvan Laszlo, 2007: Development of the HIRS Outgoing Longwave Radiation Climate Dataset. J. Atmos. Oceanic Technol., 24, 2029–2047.

MacKenzie, Ian A., Simon F. B. Tett, Anders V. Lindfors, 2012: Climate Model–Simulated Diurnal Cycles in HIRS Clear-Sky Brightness Temperatures. J. Climate, 25, 5845–5863

• Figure 2 Only LER should be plotted; the MODIS clear-sky map should be removed. The reader would want to see the relative magnitude of LER over various cloud types. To make a more convincing argument that the 340nm channel is a good substitute for cloud variations.

Reply:
The graph is meant to be qualitative, showing mostly that the LER pattern resembles clouds. There is a coarse grey scale given for LER over the color MODIS map. On this particular day, the storm in the Gulf of Mexico is clearly brighter (whiter) than the mid-latitude clouds. The figure caption has been changed.

"Figure 2: The 340 Δ 1.1 nm LER from AURA/OMI for 10 September 2008. The hurricane in the Gulf of Mexico is a Category 4 Hurricane named Ike. The LER (black, grey, and white, scale lower left) is superimposed on a MODIS clear-sky color map. The high altitude storm cloud in the Gulf of Mexico is clearly brighter (whiter) than mid-latitude clouds."

Also, the following text now applies to Figure 2 in the paper:

"LER represents the *combined* cloud, aerosol (including haze) and surface scene reflectivity as observed from space. Changes in LER are mostly caused by clouds and, to a lesser extent, aerosols, except in regions covered by snow/ice (e.g., Greenland). While the local details vary from day to day, the global patterns of cloud cover are present every day. Most of the regional cloud patterns repeat seasonally, but with small shifts in latitude and longitude. An example of LER from a single day, 10 September 2008, is shown in Figure 2 using the daily imaging capabilities of OMI. The LER in Figure 2 is scaled from 0 to 80 RU showing some bright high clouds in the equatorial region, a bright hurricane cloud in the Gulf of Mexico (a category 4 hurricane named Ike), and the geographic distribution of cloud cover. The main patterns are from cloud cover showing higher area averaged LER towards the polar regions, an equatorial band of clouds at about 5^{O}N, and local minima (more cloud-free) at about 20^{O}N and 20^{O}S. Some of the smaller features are frequently recurring, such as the cloud plumes going south-eastward from Argentina, southern Africa, and Australia. Significant sulfate aerosols, which typically rise to an altitude of 3-5 km when well away from their sources, can sometimes increase the nadir-viewing LER of a scene up to 15 RU relative to a clear-sky background. Soot, smoke, desert dust, volcanic ash, black carbon and organic aerosols absorb in the NUV and can decrease the scene reflectivity."

• Is the LER magnitude wavelength dependent? The 412nm wavelength SeaWIFS LER has some very different trends over Peruvian stratus regions and over the Amazon, than that of 331nm SBUV/2 LER in Fig. 13 in Herman et al. 2009, which resembles the 340nm SUB/2 LER regional trend figure 11 in this study. Is this due to a difference in the wavelength being used or is it improper calibration of the data?

Reply:
The LER is somewhat wavelength dependent, but this does not account for the differences observed by SeaWiFs. We simulated the 412 nm SeaWiFs channel using OMI data and the SeaWiFs filter function. The results were clearly different than the 412 nm SeaWiFs LER. This may be because the SeaWiFs radiances are vicariously calibrated only over clear-sky ocean scenes using the MOBY station (and similar stations) and not over bright cloud covered or ice/snow scenes. Unlike SBUV and SBUV/2 we have no way of recalibrating SeaWiFs.

Herman, J. R., G. Labow, N. C. Hsu, and D. Larko (2009), Changes in cloud and aerosol cover (1980–2006) from reflectivity time series using SeaWiFS, N7-TOMS, EP-TOMS, SBUV-2, and OMI radiance data, J. Geophys. Res., 114, D01201, doi:10.1029/2007JD009508.

• How can the authors be sure that the zonal trends from 30 to 60° North latitude are not a result of the variations of the winter snow time periods in figure 8? Could the figure be replaced with a land and ocean trends separated?

Reply:
We have added a separate land and ocean figures for trends and the annual zonal average. The the annual zonal average results are shown in Figure 5A (see below). Next, we calculated the trends for oceans and land using separate time corrections derived from ocean data and land data. The separate trends are shown in Figures 8B and 8C. While not conclusive, the decrease over oceans (no snow and ice) are consistent with the decrease over land.

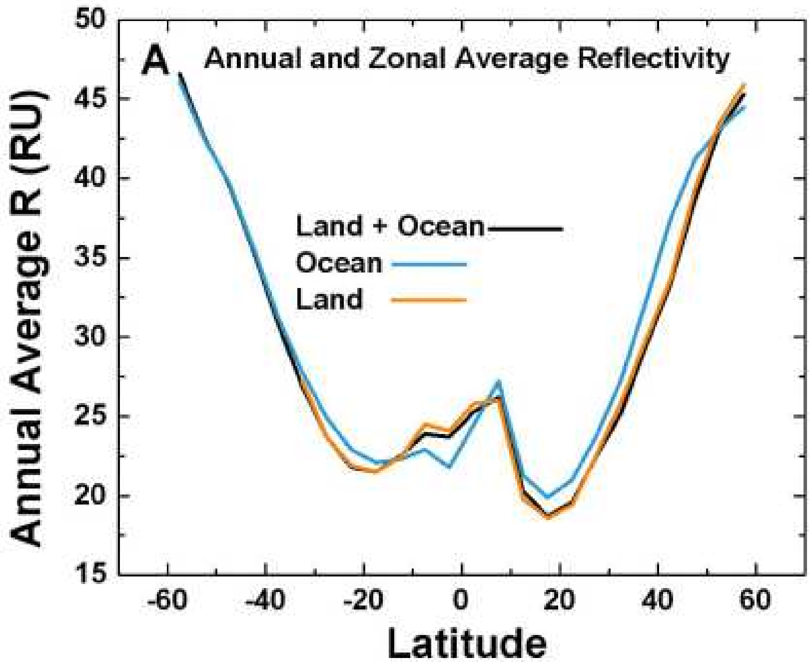


Figure 5A Thirty-three year average of the zonal average time series as a function of latitude from the SBUV series of instruments separated in to land only, ocean only, and combined.

At high latitudes the decrease over land would also influenced by a decrease in snow cover. For regions that are covered almost permanently by snow and ice below the Arctic circle, decreasing cloud cover could cause an increase in LER. For latitudes above 60N, most of the data in the LER time series comes from non-winter months when the ground starts to darken as the snow ages and melts. For cases where the surface reflectivity reduced, a decrease in cloud cover would produce a decrease in LER. The transition region between increasing and decreasing LER is complicated by the sub-pixel cloud fraction and the subpixel distribution of surface reflectivity.

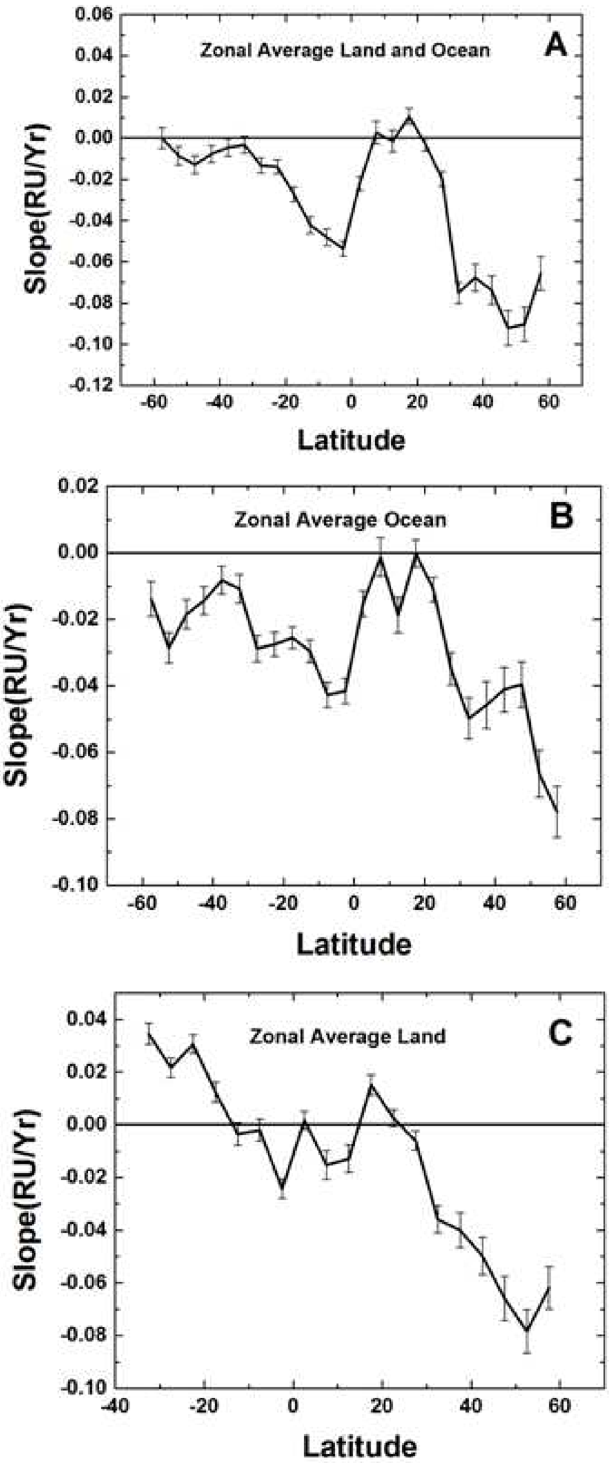


Figure 8 Zonal average trends (RU/Year) 1979 to 2011. (A) Land and Ocean, (B) Ocean, (C) Land

New Figure 8