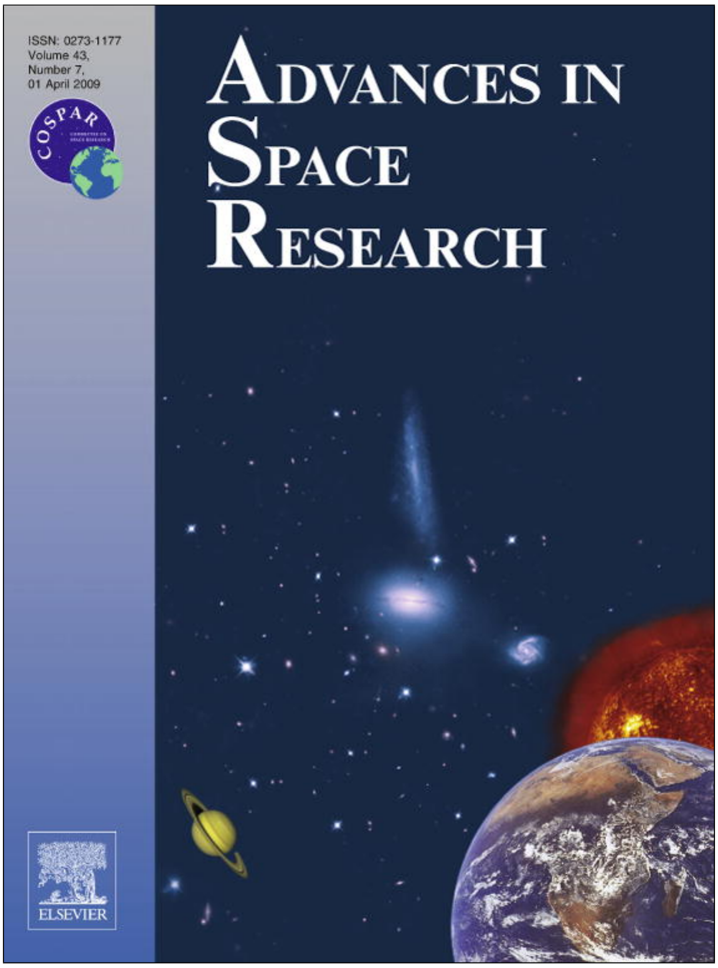

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The Lunar Terrestrial Observatory: Observing the Earth using photometers on the Moon's surface

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Abstract

The Earth's albedo is one of the least studied fundamental climate parameters. The albedo is a bi-directional variable, and there is a high degree of anisotropy in the light reflected from a given terrestrial surface. However, simultaneously observing from all points on Earth at all reflecting angles is a practical impossibility. Therefore, all measurements from which albedo can be inferred require assumptions and/or modeling to derive a good estimate. Nowadays, albedo measurements are taken regularly either from low Earth orbit satellite platforms or from ground-based measurements of the earthshine from the dark side of the Moon. But the results from these different measurements are not in satisfactory agreement. Clearly, the availability of different albedo databases and their inter-comparisons can help to constrain the assumptions necessary to reduce the uncertainty of the albedo estimates. In recent years, there has been a renewed interest in the development of robotic and manned exploration missions to the Moon. Returning to the Moon will enable diverse exploration and scientific opportunities. Here we discuss the possibility of a lunar-based Earth radiation budget monitoring experiment, the Lunar Terrestrial Observatory, and evaluate its scientific and practical advantages compared to the other, more standard, observing platforms. We conclude that a lunar-based terrestrial observatory can enable advances in Earth sciences, complementary to the present efforts, and to our understanding of the Earth's climate.

Keywords: Albedo; Climate; Longwave radiation; Satellites; Earthshine

1. Introduction

In recent years, there has been a renewed interest in the development of robotic and manned exploration missions to the Moon. Returning to the Moon will enable diverse exploration and scientific opportunities. Here we propose to use lunar exploration to set up a lunar observatory designed to better understand our own planet, Earth. The first such observatory was brought to the Moon by Apollo 16, which deployed a small far-UV telescope in a shady area to make spectral observations of the Earth's upper atmosphere. The astronauts returned the film from the observations to Earth.

The Earth's climate is driven by the amount of energy absorbed from the Sun, dominated by the solar luminosity and the Earth's albedo, and the amount of energy emitted to space in the form of infrared radiation, mainly controlled by atmospheric greenhouse gases. Considerable effort has been made in the past to characterize and model both solar irradiance and greenhouse gases. The Earth's albedo remains the least studied fundamental climate parameter. Most climate studies assume the albedo to be nearly constant in time, but recent monitoring of the albedo, from different techniques, show that this is certainly not the case.

It is also important to notice that the albedo is a bi-directional property, and there is a high degrees of anisotropy in the reflected light from a given surface. Thus, to derive ideal estimates of the Earth's true Bond albedo

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(reflectance at all wavelengths in all directions), it would be necessary to observe reflected radiances from the Earth, from all points on the Earth and at all angles. Therefore, all measurements from which albedo can be inferred require assumptions and/or modeling to derive a meaningful estimate.

Nowadays, albedo measurements are taken regularly either from Low Earth Orbit (LEO) satellite platforms or from ground-based measurements of the earthshine on the dark side of the Moon. But the results from these different measurements are not always in satisfactory agreement (Pallé et al., 2005, 2004; Wielicki et al., 2002; Pinker et al., 2005; Wild et al., 2005). Further, there are discrepancies of up to 7% among the mean albedo estimates of different global circulation models (Charlson et al., 2005).

Apart from these discrepancies, all the observational estimates of the Earth reflectance are broadly consistent in suggesting changes in the Earth's shortwave forcing, both at the surface and at the top of the atmosphere, that will have a large impact on the planet's radiation budget (Gilgen et al., 1998; Stanhill and Cohen, 2001; Liepert, 2002). Thus, the availability of different albedo databases and their inter-comparisons are essential to constraining the assumptions necessary to reduce the uncertainty of the albedo estimates.

Global measurements of the infrared radiation emitted from Earth are only taken from LEO satellites, and are subject to the same limitations discussed for the albedo.

Here we propose a lunar-based Earth radiation budget monitoring experiment, and evaluate its scientific and practical advantages over other, in use or proposed, techniques for Earth's Radiation Budget monitoring. Long-term monitoring of both variables (reflected shortwave and emitted longwave radiation), with detailed geographical resolution, would provide valuable information for the study of the Earth's global energy budget, cloud macro- and micro-physics, the interactions of clouds and aerosols, and the role of greenhouse gases (especially those non-well mixed in the atmosphere such as water vapor) in climate change.

2. A Moon-based Earth's radiation budget monitoring

The Lunar Terrestrial Observatory (LTO) proposed in this paper would consist of a two (four) small telescopes, one (two) in the visible range and one (two) in the infrared, continuously monitoring the Earth. Photometric images of the full Earth disk would be taken continuously, and would provide a continuous record of the reflected shortwave flux from the Earth's surface and atmosphere, and the emitted flux of outgoing longwave radiation (OLR). In Fig. 1, an illustration is shown of the two views of the Earth (one in the visible and one in the infrared) that LTO would continuously record. Note that the OLR flux can be measured continuously over the full Earth disk.

Here we focus on the scientific value of the LTO, rather than its specific nature (manned or robotic) or technical details, as they will be highly dependent on the evolution of the diverse national space programs. Consider however, that viewed from the Moon, the angular size of the Earth is large (about 2° in diameter). A fine geographical resolution will be needed to support the science objectives of LTO, but as an example, suppose that we wish to image the Earth in 100 × 100 pixels (equivalent to a geographical resolution of about 100 km). Then, if each pixel is 25 μm in size, and the imaging beam is *f*/4, conservation of etendue (geometric optical throughput) requires that the telescope size be only about 2 cm in diameter. This illustrates that a very modest (and low mass) LTO telescope is needed to completely capture the full image of the Earth. Moreover, the flux rates are large: in the visible we expect that the Earth at quadrature will produce about 10^5 electrons per second per image pixel per 1000 Å band, making the exposure times very short. Several feasibility studies and research proposals support the possibility of such a low mass/size LTO (Smith et al., private communication; Ruzmaikin et al., private communication; Traub et al., private communication).

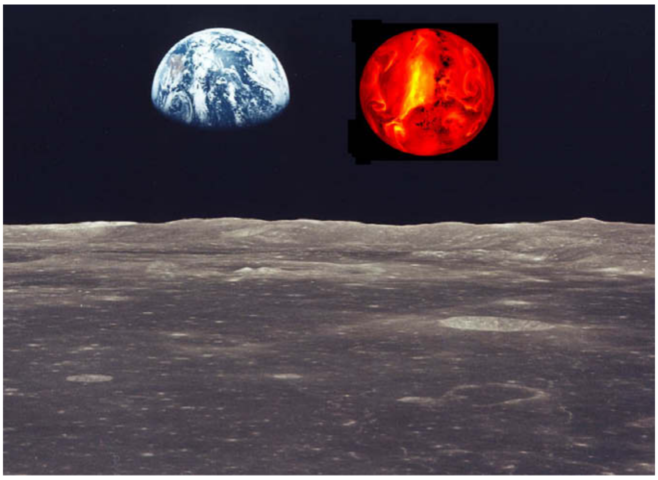

Fig. 1. Earth views from the Moon. The picture illustrates a real image of the Earth, in the visible, taken by the Apollo 11 astronauts in 1969. Overplotted is a global composite of the water vapor in the atmosphere, mapped in the IR range, by the GOES satellites. LTO would obtain continuous observations of the Earth both in the visible and infrared. Note that the two images correspond to different dates, seasons and geometries so the weather patterns do not correspond to each other, but are plotted for illustration only. In reality, the IR emission from the Earth as seen from the Moon, will be slightly brighter from the sunlit part of the Earth than from the night side.

We note that LTO would benefit from the inclusion of a side-by-side solar observatory to look for correlations between changes in the full solar radiation spectrum and reflectance, for example. However, we will not further discuss solar observations here.

2.1. Scientific objectives

There are several primary scientific objectives that could be met by measuring the earthshine from the Moon:

- To monitor and characterize the diurnal, seasonal and inter-annual variability of the Earth's reflectance. One of the most crucial climate parameters, and at same time one of the least well-known.
- The Earth's reflectance and OLR are tightly related to cloud amount and other cloud properties, and the high geographical resolution provided by LTO would help to characterize the role of clouds in the Earth's radiation balance. It will also help to constraint climate model parameterizations on regional scales.
- To monitor and characterize the diurnal, seasonal and inter-annual variability of the Earth's infrared emission.
- To obtain globally-integrated measurements, by degrading the detectors resolution to a single point, of the Earth's shortwave and longwave light curves. This will serve as very valuable input for future missions aiming at the detection and characterization of extrasolar planets. Among the most interesting things to study are: determining the magnitude of the albedo changes on global scales at all time scales; determining the changes in the observed Earth's light curve as a function of phase; determining the photometrical precision needed to retrieve the Earth's rotational rate; determining the importance/detectability of glint scattering signaling the presence of oceans; trying to derive the presence of tracers (clouds) in the Earth's atmosphere by observing changes in the rotational rate, etc.

3. Inter-comparison of Earth's radiation budget observing platforms

There are five primary, distinct ways in which one can measure the Earth's albedo: from a satellite(s) in LEO, from a satellite(s) in Geosynchronous Earth Orbit (GEO), from a satellite sitting at the L1 Sun–Earth Lagrangian point, from a telescope sitting on the Moon and from ground-based observations of the earthshine in dark side of the Moon.

Currently LEO, GEO and earthshine observations are routinely carried out. In LEO, the ERBE (Earth Radiation Budget Experiment) instrumentation, and the more recent CERES (Clouds and the Earth's Radiant Energy System) instruments have monitored the Earth's reflectance and OLR since early 1980's in the tropical regions (Chen et al., 2002), and globally since 2000 (Wielicki et al., 2002). A more diversified set of experiments, including GERB (Geostationary Earth Radiation Budget) and MODIS (The Moderate Resolution Imaging Spectroradiometer), to cite some examples, are also currently gathering data. The Earthshine Project, has continuous measurements of the earthshine since 1999 from BBSO in California, and is currently expanding to a global network (Pallé et al., 2005).

Several proposals have been made to place an Earth observing satellite at the Lagrange L1 point. The US-led TRIANA mission, lately renamed as DSCVR (Valero et al., 2000), was built but never launched, and its European counterpart, the Earth–Sun–Heliosphere Interactions Experiment (Earthshine), is still in its design phase (Wall et al., 2003).

In this section, we will review and compare the observing parameters and retrieved information of the existing and planned albedo/OLR missions to those of LTO.

3.1. Sampling

Observing all points on Earth from all reflecting angles is a practical impossibility. Thus, for our purposes, we define a coverage, C, of 100% if all points on Earth were observed from at a least one angle at all times. Thus, to compare the spatial and temporal coverage of the different observing methodologies we define our coverage factor, C, as

$$C = \frac{\Delta T}{T}\frac{\Delta A}{A} = \frac{N_h}{12(24)}\frac{N_d}{365}\frac{\Delta A}{A} \tag{1}$$

where, $\frac{\Delta T}{T}$ and $\frac{\Delta A}{A}$ are the fractional temporal and geographical coverage of the sunlit half of the Earth reflectance, respectively. As some of the observing techniques cannot be used at all times, to do a fair comparison, we need to estimate the coverage over a relatively long period of time (a year for example). Thus, N_h and N_d are the number of hours per day and number of days per year in which observations take place. For albedo the number of hours/day is divided by 12 (average daylight duration), and for the OLR, it would be divided by 24.

In the upper part of Table 1, the coverage is given for the several albedo observing techniques that have been proposed. The calculated coverage omits, in all cases, losses in duty cycle due to overhead time. The maximum coverage (100%) is only achieved by locating a satellite at the Sun–Earth Lagrangian point. This ensures that the whole sunlit half of the Earth faces the detector at all times, and the telescope can be operated continuously.

A satellite in GEO and the LTO come in second and third place, with a coverage of roughly 40% and 25%, respectively. The abrupt decrease in coverage from a Lagrangian observing system is due to the fact that, as seen from the Moon (or from geosynchronous orbit), the Earth presents phases that occult part of the sunlit Earth. Also LTO cannot operate if the Sun is above the horizon, although it is not clear where the limiting angle would be if the telescope is appropriately shielded (Smith, private communication). If LTO could observe when the Sun is lower than, for example, 45° above the horizon, the coverage would be larger (as indicated within parentheses in Table 1). Coverage could be further enlarged by locating LTO at a high lunar latitude, so that the Sun is always relatively low on the horizon, inside a crater permanently in the shadows, or even inside a pipe pointing to Earth.

A network of earthshine observatories, mainly limited by lunar phase and the short duration of the observations, is fourth in coverage, followed by a LEO satellite, with a very poor temporal sampling at each location.

Table 1
Comparison of the coverage parameters for different albedo measurements techniques. For OLR measurements, the number will be the same, except for an L1 satellite where coverage C, I_c and I_{ck} would be half the values here. For earthshine observations OLR measurements are not possible.

	LEO Sat.	GEO Sat.	ES (8-stat.)	L1 Sat.	LTO
N_h	0.5	12	3.0	12	6.0
N_d	365	365	182	365	182 (273)
$\Delta A/A$	1	0.4	1	1	1
C	4.2	40.0	12.5	100.0	25 (37.5)
Geo. Resol.	1 km	1 km	Continental	10 km	10 km
$\Delta R/R$	2×10^{-9}	2×10^{-9}	0.3	2×10^{-8}	2×10^{-8}
I_c	2.1×10^{9}	2.0×10^{10}	45	5×10^{9}	1.25×10^{9} (1.87×10^{9})
$\Delta K/K$	0.15	1	0.8	0.05	0.9
I_{ck}	3.15×10^{8}	2.0×10^{10}	36	2.5×10^{8}	1.125×10^{9} (1.68×10^{9})

3.2. Geographical resolution

The results in the previous paragraph are however misleading. Not only is it essential to have a wide geographical coverage, but also the geographical resolution of that coverage is critical for subsequent detailed climate studies. A satellite in LEO fares quite poorly when the crude space/time coverage of the observations, C, is considered. But at the same time the geographical resolution of the satellite observations is unmatched.

A detailed geographical resolution is needed to establish the links between surface and atmospheric small-scale components and their radiative properties. Resolution is also invaluable for the validation of the observations with other complementary datasets (such as ground-based weather observatories or balloon measurements), and the modeling of the results at regional scales.

Again LTO, with a resolution of about 10 km, features second place in effective geographical resolution, one order of magnitude worse than a LEO or GEO satellite data (see Table 1), and similar to a satellite at L1. It is also noteworthy that the ground-based earthshine observations have no geographical resolution. Although, in the case of a network of earthshine stations, a very large-scale resolution (of a few hundred to a thousand kilometers) could be achieved with overlapping observations (Pallé et al., 2004, 2005).

We note that the geographical resolution of 1 km is not met by all operating LEO satellites, but it will probably be met routinely in future instrumentation. The 10 km geographical resolution from L1 or the Moon, can be lowered down to 1 km too, but it would require larger instrumentation (telescopes) and substantially increase the cost of such missions, without providing a crucial incremental scientific return. Thus, we select 10 km resolution as the most probable scenario for such missions.

One can define what we call the "information content index", I_c, as

$$I_c = C \Big/ \frac{\Delta R}{R}. \qquad (2)$$

where $\frac{\Delta R}{R}$ is the angular fraction of the Earth's radius resolved in any one observation. It is very similar to $\frac{\Delta A}{A}$ in Eq. 1, but here we are not considering the amount of area covered over the course of one year of observations, but the angular fraction of the Earth's diameter covered by a single observation.

While the index I_c has no real physical meaning, it takes into account not only the space/time coverage of the observations, but also their detailed resolution, and it serves to illustrate the amount of information that a given technique produces. Information that can be used for inter-calibration with other datasets, model validation, etc.

The information content index is very similar for all observing platforms, except for ground-based earthshine. In the I_c index, the lower temporal coverage of the whole sunlit Earth of LEO satellites, as compared to the other platforms, is compensated by their very fine geographical resolution. Satellites in GEO or at L1, with both fine geographical resolution and large coverage, retrieve the most information without considering the scattering angle.

3.3. Scattering angle

As mentioned in the introductory section, the albedo is a bi-directional property, and there is a high degrees of anisotropy in the reflected light from a given terrestrial surface. Thus, radiance retrievals at different angles are critical in order to retrieve the true Bond albedo of the Earth. To determine the Bond albedo, A, which is the fundamental reflection parameter for climate studies, one needs to integrate the measured radiances, or albedos, $p(\theta)$, over all observing angles,

$$A = \frac{2}{3} \int_{-\pi}^{\pi} d\theta p(\theta) f_L(\theta) \sin\theta, \qquad (3)$$

where θ is the observing (phase) angle, $f_L(\theta)$ is the Earth's Lambert phase function and p is the apparent albedo in one direction. The kernel of the integrand, $f_L(\theta)\sin\theta$, is plotted in Fig. 2, and its coverage by the different observing platforms are compared.

LEO satellites have a fixed geometry in the sense that they measure every point of the Earth from a nadir point of view (perpendicular to each Earth surface element), or,

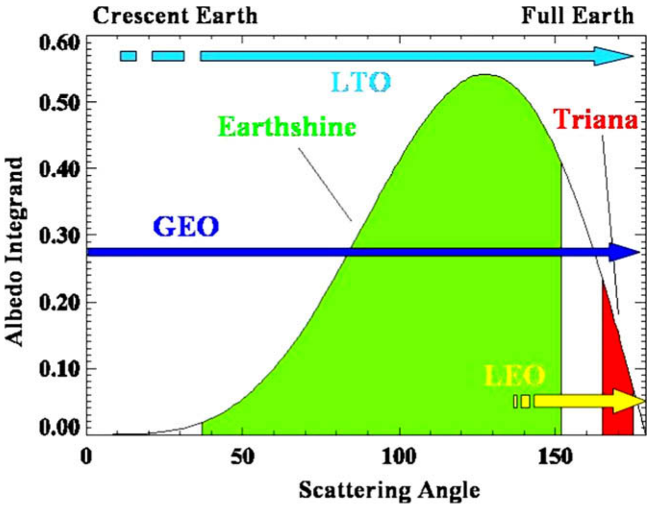

Fig. 2. The kernel ($f_L(\theta)\sin(\theta)$) from which the Bond albedo is determined, shown as a function of observing angle. Its behavior is dominated by the Lambert phase function for small phase angles and by $\sin(\theta)$ for large phase angles. The kernel coverage by the ground-based earthshine observations (green), a satellite orbiting about L1 assuming the proposed orbit of Triana or DSCVR (red), a satellite in LEO (yellow), a satellite in GEO (dark blue) and the proposed LTO (light blue), is shown. Adapted from (Palle et al., 2005). (For interpretation of color mentioned in this figure the reader is referred to the web version of the article.)

if several detectors are used, a limited set of angles can also be measured.

In this sense, DSCVR and LEO satellites are limited to a small range of scattering angles, which means one has to assume a linear relationship in the changes of reflectance properties at all scattering angles, or rely on modeling to derive estimates of changes in the Earth's Bond albedo. Contrariwise, the LTO observations would sample almost the full range of scattering angles, as the GEO satellites do, but for a more limited region of the Earth.

A further weight, that takes into account the angular coverage of the measurements, can be introduced in the I_c calculations, in the form of,

$$I_{ck} = I_c \Big/ \frac{\Delta K}{K} \tag{4}$$

where $\frac{\Delta K}{K}$ is the fraction of the kernel covered by each method. This kernel-weighted index is also given in Table 1.

3.4. Observational geometry and the diurnal cycle

The geometry of the observations is also an important parameter. Complete longitudinal coverage of the Earth could be achieved using 5 of the current GEO satellites, which would cover about 96% of the planet, leaving out the polar regions. However, because of the curvature of the Earth, only data up to latitudes of about 50–60° are commonly used (Valero et al., 2000). LEO satellites have a more homogenous sampling, as they have the same (nadir) viewing geometry for each point of the Earth once a day.

Fullest longitudinal coverage is also a problem for observations from L1 or from the Moon. Observations from an L1 satellite, will have a full hemispheric view of the whole illuminated Earth. This geometry will change only slightly with seasons, and because of the spherical shape of the Earth, the regions near the center of the disk will be geographically better sampled than the outer regions. For the tropical and inter-tropical regions, this differential sampling becomes uniform as the Earth rotates, but it is never properly solved for the polar regions.

This is important because, although the polar regions are small in area, they are very susceptible to climate change, through changes in snow/ice thickness and extent, leading to strong changes in albedo and OLR (Davies, 2007). However, for the DSCOVR mission, algorithms have been developed to work up to about 80° in either solar zenith angle or satellite viewing angle. Unlike GEO satellites, for Triana the two angles would be approximately equal, which permits viewing closer to the poles (Valero et al., 2000). From the Moon, despite being four times closer to the Earth than the L1 point, the same geometrical advantages hold, and retrieval algorithms such as those planned for the TRIANA/DSCVR missions could be developed for LTO.

Thus, with respect to useful geographical coverage, an LEO satellite is the best option for an homogeneous sampling, followed by LTO or an L1 satellite, with GEO satellites having the worst "useful" coverage (note that this "usefulness" of the observations is not incorporated into Table 1).

Another key issue of Earth's radiation measurements is for the collected data to be able to characterize the diurnal cycle of reflected and emitted radiances. LEO satellite cannot do that and must rely on modeling or inter-calibration with other datasets to correct the data. One of the greatest advantages of GEO is to be able to characterize this diurnal cycle, albeit only for part of the planet. An L1 satellite or the suggested LTO would also be able to characterize the diurnal cycle of the albedo for virtually each point on the planet, daily or monthly.

3.5. Calibration and instrument lifetime

One of the most difficult problems in the study of climate variability is the construction of long-term, well-calibrated time series of the essential climate parameters. This is often the Achilles heel of satellite data compilations.

Because satellite observation have to rely on absolute measurements of radiances from different points on Earth, they are bound to have calibration errors. Space is an unforgiving environment, and compiling reliable long-term observations is not an easy task. When observing from space, orbits and altitudes change, instrumentation degenerates, and gaps in the observations are inevitably produced because of the finite lifetime of the missions.

Moreover, when a new satellite is launched, it carries improved instrumentation yielding data from which it is not easy to compare with data from previously launched instrumentation, as the scientific goals change with time. This remains true for all satellite data, whether at LEO, GEO or L1.

Moreover, satellites have a finite lifetime, sometimes very short. In the case of DSCVR, for example, the nominal mission lifetime is two years (Valero et al., 2000). Even though this missions would provide some unique climate data, they are not so useful for decadal to centennial scale climate changes studies. Thus, in order to compile a long-term series, one needs to link together data from different satellites.

Observations from the Moon with LTO, offer some advantages for the long-term calibration of the data, that are denied to LEO, GEO or L1 satellites. A simple LTO can be developed as a robotic mission, but frequent manned visits or settlements in the Moon may allow the recharging of dead batteries, complex repairs and precise in-situ calibrations, as well as basic maintenance that can substantially extend the lifetime of the instrumentation. Moreover, the possibility exists for retrieving the instrumentation back to Earth where post facto calibration tests can be performed. In-situ calibration is also possible using the well-known astronomical technique of observing standard stars. The small size/mass of the instrumentation could also be used to argue for redundant instrumentation, two visible and two infrared LTO telescopes, for calibration purposes. With this continuous support, the lifetime of simple instrumentation can be extended for decades. And if new instrumentation is developed, it can always be installed next to the old instrumentation, and provide a smooth, well-calibrated, transition.

Ground-based observations of the earthshine are based on relative measurements between the dark and bright sides of the Moon. Thus, they are insensitive to systematic long-term changes in the instrumentation, and are also insensitive to changes in solar irradiance or local atmospheric conditions. Despite the low information content of these kind of globally-integrated measurements, their strength relies in their simplicity, and can provide a very useful complement to satellite or LTO measurements. The cost of such ground-based instrumentation, about two orders of magnitude cheaper than any of the alternative methodologies, is also a good argument for continuing observations.

3.6. Environment

The lunar environment is much harsher than our normal environment below the Earth's atmosphere. About 30,000 zap pits (micro-craters) per year will be formed on a given square meter of the lunar surface (Taylor, 1989). The exposed surfaces of any instrumentation placed on the Moon must be protected from this type of bombardment for the duration of the mission. Moreover, the electronic components must be able to withstand the high energy solar flare particles with fluxes of about 100 $\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$. This will be especially harsh if the mission is being conducted, as it will be, for measurements lasting more than a few years, and during periods of high solar flare activity. The instrumentation will also need thermal protection to cope with extreme hot and cold temperatures along a lunar day, and rapid change from one to the other.

Lunar dust is another potential danger for LTO. The lunar regolith is composed largely of angular agglutinate fragments, which are highly abrasive and adhere electrostatically. Deposited on optics, the dust would compromise the imaging performance and increase the emissivity of the telescopes, which would add background noise to thermal IR measurements (Lester, 2006). However, lunar robotic missions so far have not encountered this problem (Lowman, 2006). The Apollo 12 mission retrieved components from the Surveyor 3 spacecraft that had been on the Moon for 31 months and operated with little dust problems (NASA SP-284).

On the other hand, satellites in LEO do not find a more comfortable environment. Objects in LEO encounter atmospheric drag, from the thermosphere or exosphere, depending on the orbital altitude. In LEO, the instrumentation is exposed to a radiation field composed of galactic cosmic rays, solar particles, particles in the Earth's radiation belts and neutrons and protons from the Earth's atmosphere (Zhou et al., 2004; Shin and Kim, 2004). Higher orbits are subject to early electronic failure because of intense radiation and charge accumulation. Finally, orbital debris are also becoming a major concern for those planning spacecraft missions in Earth orbit, either in low Earth orbit or in higher geosynchronous orbits.

As a summary of all the previous discussions, a comparison of the strengths of each Earth radiation budget observing technique is given in Table 2.

4. Conclusions

The principal advantage of observing the earthshine from the Moon is the compromise between the different measurements techniques. While the proposed LTO may not have the high resolution of the LEO satellite instrumentation, a resolution of tens of km, depending on the instrumentation, is good enough for global climate models and regional climate changes assessments. The coverage, *C*, is smaller than what a satellite in the Lagrangian point would have, but it is larger than the retrieved coverage from any of the remaining techniques. Observations from LTO will also sample a wide range of scattering angles that will contribute to the determination of the Earth's Bond albedo. On top of that, LTO has the potential for unprecedented precision for a calibrated long-term time series, which is a crucial factor in climate change studies, and depending on the intensity of future robotic and manned lunar expeditions, the lifetime of such a mission could be extended for much longer than a satellite mission either in LEO, GEO or L1.

Table 2
A comparison table of the typical characteristics and advantages of each albedo/OLR observing platform. An 'x' symbol means that the particular technique meets the requirement formulated in the left column. The techniques that has the most "ideal" result for each requirement is marked with a bold capital **X**. Note that LTO does not meet this last case for any of the requirements. However it meets almost all the listed requirements, except for homogeneous latitudinal sampling and cheap cost.

Requierement	LEO Sat.	GEO Sat.	ES (8-stat.)	L1 Sat.	LTO
Homog. sampl. long	x		x	x	x
Homog. sampl. long + lat	**X**				
Scattering angle sampling		**X**	x		x
Detailed Geo. Res.	**X**	x		x	x
Decadal lifetime			**X**		x
Diurnal cycle		**X**	x	x	x
Calibration			**X**		x
Low cost			**X**		

Some authors have expressed their fears that the new NASA vision of lunar exploration may divert resources from the Earth sciences (Leovy et al., 2005), which are greatly needed for the characterization and evaluation of the current global warming. It is not the authors suggestion in this paper that the LTO should be implemented instead of any of the other Earth sciences missions. However, if future, more intensive, lunar exploration and exploitation are to take place regardless, the LTO can offer an invaluable contribution to Earth sciences, by providing a better understanding of the Earth's radiation budget and ultimately, Earth's climate. Most especially if the LTO data is combined with other, independent, Earth radiation budget datasets.

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