The Earthshine project:

Measuring Earth's albedo from Earth

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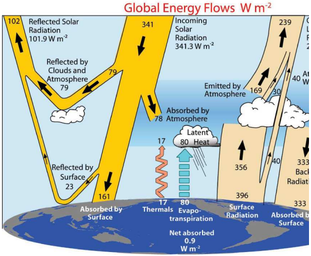
VINNOVA 2008

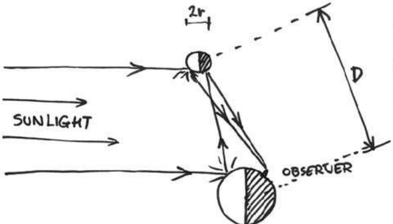
Energy Budget I



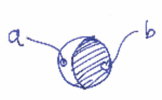
LW flux can be observed well (better than 1%). SW fluxes can *NOT* be measured that well. (Tech reasons)

Basics

- Terrestrial albedo is basic factor in climate system; radiative balance. Albedo can be measured and modelled: give climate insights.
- Developed a telescope system, on Mauna Loa Hawaii, to measure albedo via Earthshine
- 4 to 6 telescopes around the world; global-mean coverage: NJIT/BBSO/IAC collaboration.



Equations I

a on BS, b in DS 

$$
\begin{aligned}
I_a &\sim I_0 \times \frac{1}{D^2} \times \alpha_a \times \rho_a \\
I_b &\sim I_0 \times \frac{R^2}{D^2} \times \alpha_E \times \rho_E \times \alpha_b \times \frac{1}{D^2} \times \rho_b \\
\frac{I_a}{I_b} &= \frac{I_0 \times \frac{1}{D^2} \times \alpha_a \times \rho_a}{I_0 \times \frac{R^2}{D^2} \times \alpha_E \times \rho_E \times \alpha_b \times \frac{1}{D^2} \times \rho_b} \\
\alpha_E &= \frac{I_b}{I_a} \times f(radii, distances) \times g(reflectances)
\end{aligned}
$$

Historical & Modern work on Earthshine I

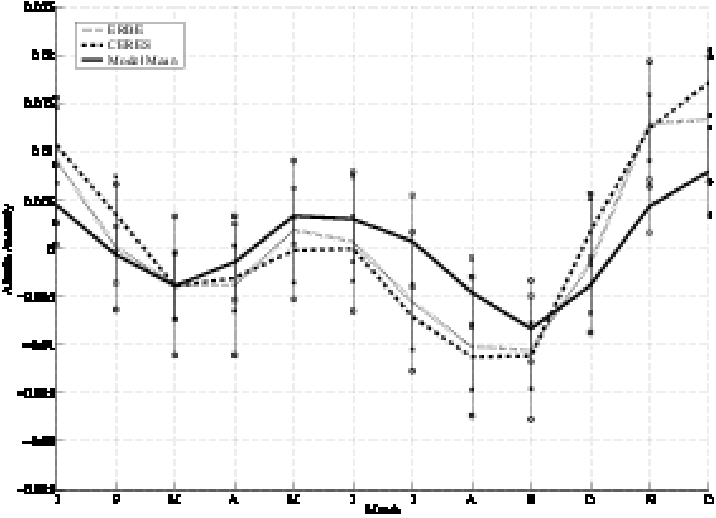
Historical references from [Longshaw, 2010]

- da Vinci (1508)
- Michael Mästlin, and Kepler (1604)
- Galileo (1610)
- Alexander von Humboldt noted that Lambert in 1774 saw 'green earthshine'; reference to meteorology.
- Quantitative Albedo estimates
  - [Very, 1915] A=0.89
  - [Russell, 1916] found A=0.45/0.43, and arguing for Very: A=0.41; Zöllner: A=0.41; and Abbott gets A=0.37

Historical & Modern work on Earthshine II

- [Aldrich, 1919] A=0.43 (balloon pyranometry)
- [Danjon, 1936] (1926 – 1935), Dubois (1940 – 1960); $<A>=0.40$ [0.25 - 0.56]
- [Fritz, 1949]: A=0.35 - first meteorologist.
- [Dzhasybekova et al., 1960]; $<A>=0.391\pm0.014$ [0.31 - 0.48]
- Bakos (1960, 1964): A=0.41/0.42
- ERBE: $A\sim0.3$
- BBSO (1990s -): [Goode et al., 2001] $A=0.297\pm0.005$ (1.8% err).

Annual cycle & Variability I



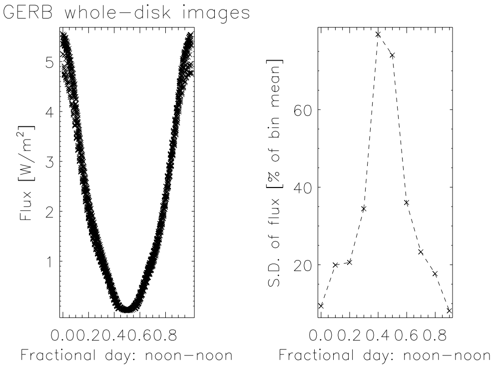
Errors and uncertainties I

- Intrinsic variability of global mean albedo:
  - Seasonal: max/min $= \pm$ 1%.
  - Monthly anomaly: 1σ=0.8% [Bender et al., 2006].
  - Simulated: Daily: 1σ=1.3% [for τ= 3 days] - 1.1% at 2 days - 1.8% at 5 days

(Statistical) Experimental design I

Q: Given properties of the natural variability, at what level can trend-like global-mean albedo changes be detected?
A: Simulating correlated noise, and using
H_0 **: "Albedo is stationary"**,
and assuming 10 years of observations at 100 nights per year, we can, at the 90% level rule out that observed trends above $\pm 0.23\%$ are erroneous.

GERB data: Earth (segment) variability I



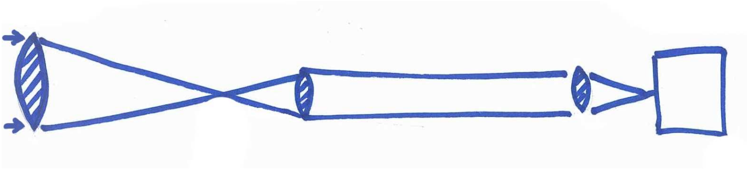
Common Mode Rejecting Principle I

Terrestrial albedo is proportional to intensity ratio DS/BS.

Two avenues:

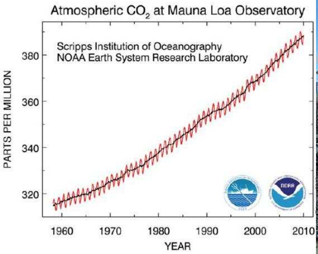
1. Measure DS and BS separately
    - Optimize use of detector linearity
    - but, must know shutter speeds precisely
2. Measure DS and BS simultaneously, and have Common Mode Rejection:
    - Detector sensitivity variations cancel
    - Atmospheric transparency issues cancel
        - Different airmasses
        - Transient thin clouds
    - Independent of shutter accuracy
    - Solar constancy not required

Methods: Telescope Optics and Mechanisms I



- First focus: blank out regions of image - occultators here
- Collimated beam: reduce intensity uniformly - colour filters and shutters here
- CCD is 16-bit

Observatory site



Telescope I

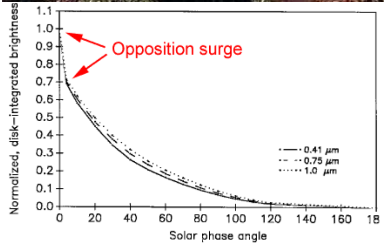
Data Reduction: Principles

- Determine terrestrial albedo by matching synthetic models of the Moon to Observed images
- Synthetic model: of Sun-Earth-Moon system, based on albedos and reflectance theory

Parametrized Moon images I

- Lunar albedo map
- Lunar reflectance model
- Earthshine generator
  - Terrestrial albedo model
  - Terrestrial reflectance model
- Solar irradiance model
- Ephemeris-driven geometry model

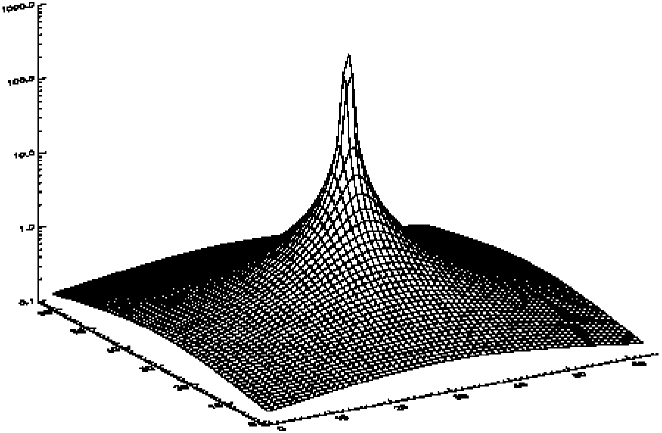
Reflectance: Opposition Surge or Gegenschein I



Methods: Point Spread Function I

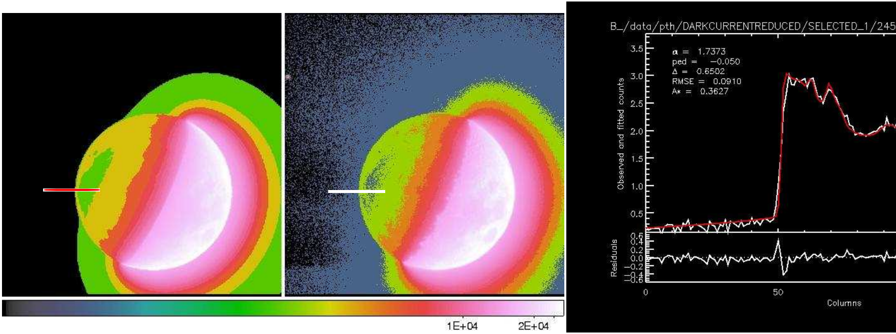
- PSF generated by optics and atmosphere
- The PSF describes how a point source is rendered in the image plane
- Empirically, telescopic PSFs are power-laws: $P(\alpha) \sim \frac{1}{r^{\alpha}}; \alpha$ is *max* 3
- Since $P(\alpha \times \beta) = (P(\alpha))^{\beta}$, can generate all PSFs from one base-function.
- Studied Stars, Jupiter and Moon halos to generate base-PSF.
- Halo around any extended object generated by convolution (multiplication in Fourier domain).

Methods: Point Spread Function II

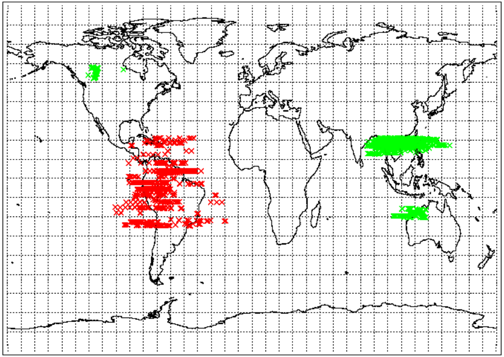


Limb intensity profiles I

Profiles fitted

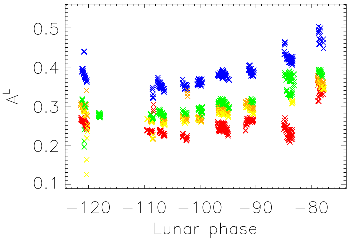


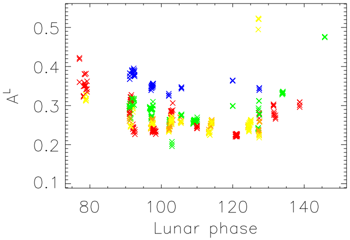
Results: Inventory I



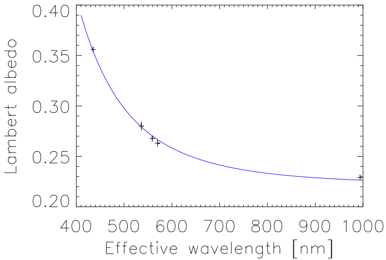
518 individual albedo determinations over 6 months (Jan - June) in 2012. During observations at MLO approx 65000 Moon images were taken + 15000 tech frames.

Results: All nights I



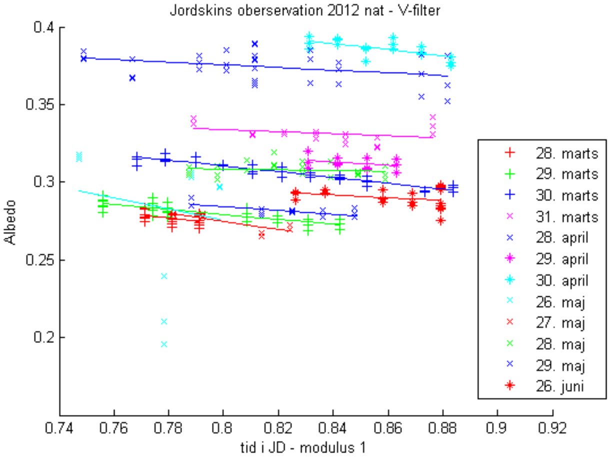


- We see a phase dependency over W. Pac./Australasia
- Rayleigh scattering colour:



Results: Single nights I

Johanne Øelund's student project



Perspectives I

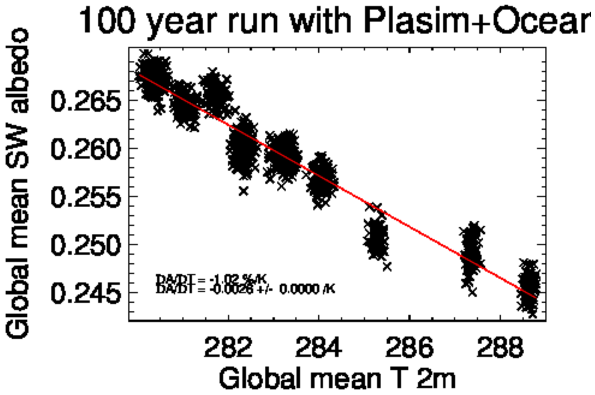
- Incorporate within a network of telescopes
- Direct data analysis
- Complement to satellite data
  - Assimilation?
  - Sat. data adjustments?
- Reflectance work
- Method development
  - Conservative image, or 2-D field, interpolation
  - Field co-location
- Automation - Software integration

Albedo vs Temperature I

Climate is more than mean temperature - but using T as the main variable: What are the expectations for the Albedo vs. Temperature relationship?

- Simple EBM - equating net incoming SW energy to outgoing LW - gives -1%/K.
- Coupled GCMs give similar results:
  - For extra points: Why are they the same?

Albedo vs Temperature II



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