SF2A 2003
F. Combes, D. Barret and T. Contini (eds)

THE GREEN VEGETATION AS A BIOSIGNATURE ON EARTH AND EARTH-LIKE PLANETS: POLDER DATA AND EARTHSHINE OBSERVATIONS

Arnold, L.[1], Bréon, F.M.[2], Brewer, S.[3], Guiot, J.[3], Jacquemoud, S.[4] and Schneider, J.[5]

Abstract. The vegetation signal measured from the integrated Earth reflectance spectrum derived from Moon Earthshine observations is compared with data from Earth-observing POLDER-1 satellite. The vegetation signal 24-h variation is computed from POLDER data for different Earth phases and observer positions (equator, pole).

1 Introduction

In June 2001, two groups obtained low resolution visible spectra of the Moon Earthshine (Arnold et al. 2002, Woolf et al. 2002) and extracted the integrated reflectance spectrum of the Earth. They both detected an increase (≈ 0 to 10%) of reflectance around 700nm attributed to the Earth green vegetation which reflectance significantly increases in the near infrared, after 700nm (the so-called Vegetation Red Edge, or VRE). The conclusion of these works is that vegetation, i.e. life, could be detected in a low resolution spectrum of an unresolved Earth. In this paper, we analyse the VRE obtained from Earth daily maps acquired by the POLDER-1 satellite (Deschamps et al. 1994) in June 1997 in the red and the near infra-red and compare it to Earthshine observations results.

2 Analysis of POLDER maps

We define the VRE by the reflectance ratio $VRE = (r_I - r_R)/r_R$, where r_I and r_R are the near-infrared (NIR, 865nm) and red (670nm) reflectances, respectively

[1] Observatoire de Haute-Provence, CNRS, 04870 Saint-Michel-l'Observatoire
[2] CEA/DSM/LSCE - 91191 Gif sur Yvette
[3] CEREGE, Europôle Méditerranéen de l'Arbois, BP 80, 13545 Aix en Provence Cedex 04
[4] Lab. Environnement et Développement, Univ. Paris 7, 2 P. Jussieu 75251 Paris Cedex 05
[5] Observatoire de Paris-Meudon, 92195 Meudon Cedex

(Arnold et al. 2002). The VRE quantifies the reflectance variation between the red absorption peak and the NIR plateau from the vegetation reflectance spectrum. This definition is close to the $NDVI = (r_I - r_R)/(r_I + r_R)$ routinely used for vegetation remote-sensing (note that global NDVI maps which are often available cannot be used to derive a global value because r_I and r_R are unknown locally, while an integrated NDVI would require the knowledge of the visible and NIR reflectance of each pixel, as done hereafter for the VRE). The NIR and red images are projected on a sphere, then multiplied by a lambertian mask to simulate the scene (figure 1). Although several assumptions have been made, none of them

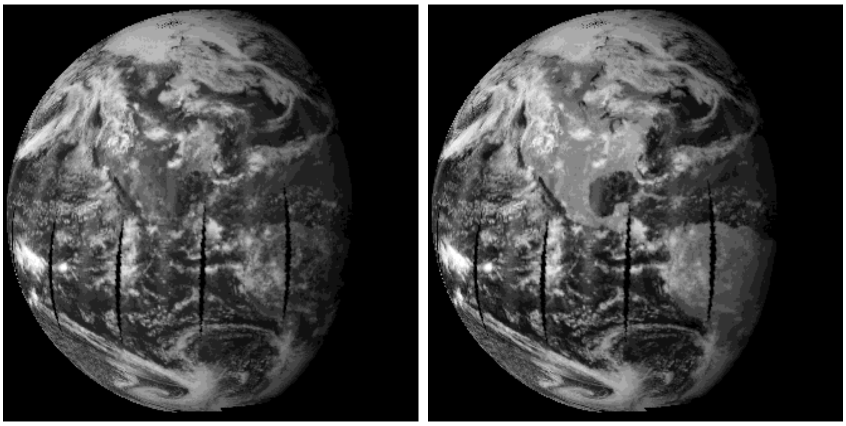

Fig. 1. Scenes reconstructed from POLDER-1 red (left) and NIR (right) images acquired in June 12, 1997. Small strips of data are missing. The Amazon forest looks brighter on the infrared map. The observer is above Central America, reproducing the Earth as seen from the Moon the day of Earthshine observation on 24th June 2001. The VRE was $7 \pm 3\%$ in 2001 while here POLDER 1997 data give 6%.

should influence the results at the first order level: for instance, we do not take into account the anisotropy of the bidirectional reflectance distribution functions of the Earth surfaces (vegetation, deserts, oceans, clouds). We do not add any specular Sun reflexion on the oceans, which would slightly decrease the VRE. On the other hand, POLDER daily data give a real map with clouds, and it would be possible to use series of images to estimate the 'noise' due to the cloud cover fluctuation. A one-year series would indicate whether seasonal variations are significant or not.

3 Discussion: VRE from POLDER maps and Moon Earthshine

Figure 2 shows the variation of the VRE estimator while the Earth rotates in front of an observer located above Equator, for three different Earth phases. How effective is a 2-lambda-based VRE estimator to detect vegetation ? The lowest curve simulates a desert Earth: all continents pixels have the optical properties of the Sahara, while oceans are unchanged. We see that the POLDER-data-based VRE estimator is biased, and for Earth seen at a phase angle of 90°, it shows vegetation if its value is greater than $\sim 8\%$, while negative values indicate the presence of oceans.

For a planet with only Sahara-like deserts, the POLDER-data-based VRE would be a constant versus planet rotation and equal to $\sim 13\%$, while a 100% vegetation-covered planet would show a VRE of $\sim 35\%$. But vegetation needs water, thus it is likely that a large ocean and clouds are present and decrease the VRE: A planet only covered by oceans and clouds would show a VRE of $\sim -3\%$. Thus in the extreme case of a planet with one hemisphere of water and the other one of desert, we would observe a VRE ranging from $\sim -3\%$ to $\sim 13\%$. Only higher values may indicate vegetation unambiguously. A value below 13% could be a false negative detection (ocean+desert, instead of ocean+vegetation), and a full spectrum obviously would be more consistent.

When the observer sees the Earth from the North pole (figure 3), the VRE reaches 12%: No vegetation is unambiguously detected, if one considers the discussion above, due to the high reflectivity of the Pole (ice, snow and clouds) which reduces the relative contribution of the northern vegetation. It is thus foreseen that during the last glaciations in Earth history, the vegetation signal was lower than today. On the other hand, warmer and wetter periods may suggest a greener Earth, if the cloud cover was not too important.

June 2001 Moon earthshine observations gave values of 7 ± 3 (evening) and $10 \pm 5\%$ (morning, Arnold et al. 2002), while June 12, 1997 POLDER maps give 6 and 11% respectively for the same simulated Earth and Moon configuration. Observations by Woolf et al. (2002) gave 6%, maybe only $\sim 3\%$ (Jucks 2002, private communication) while POLDER gives 6%. The VRE derived from POLDER seems in good agreement with the Earthshine observation. But we observe that Rayleigh scattering is well visible in Polder blue image which has a global reflectance $\sim 30\%$ higher than the red image. Rayleigh scattering thus makes the red image brighter than the NIR one, probably implying an underestimate red edge with POLDER data. The NIR and red bands used for POLDER and Earthshine also were not exactly the same.

4 Conclusion

The POLDER images allowed us to compute the integrated VRE for different simulated phases and observer latitudes, with several assumptions as discussed above. We obtain values in correct agreement with the VRE extracted from the Earthshine observations. For the Earth, the VRE estimator based on POLDER data indicates the presence of large oceans (negative values) and lands covered by vegetation (VRE $\geq\sim 8\%$ for the Earth seen from equator - figure 2 -, or $\geq\sim 13\%$ for a planet without ocean). A value below 13% would not allow a unambiguous detection of vegetation (ocean+desert or ocean+vegetation ?), and a full spectrum obviously would be more consistent to identify the vegetation red edge around 700nm.

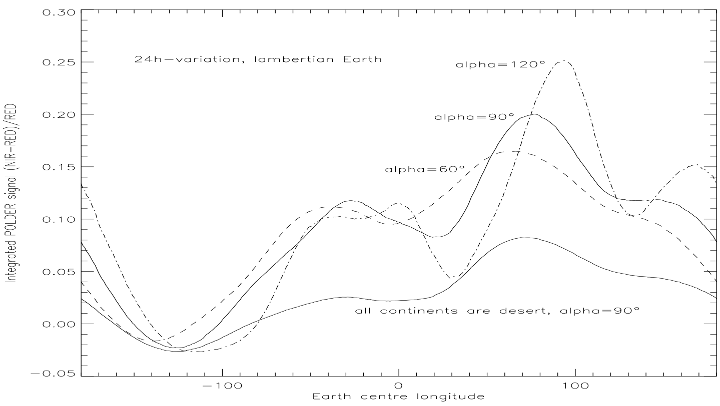

Fig. 2. VRE 24-hour variation. The observer is above latitude 0° and measures the VRE while the Earth rotates, for three different Earth phases. The lowest curve simulates a desert Earth: all continents pixels have the properties of the Sahara, oceans are unchanged. The figure shows that the POLDER-data-based VRE estimator is biased: for the Earth seen at a phase angle of 90° and from equator, it shows vegetation if it is $\geq\sim 8\%$, while negative values indicate the presence of oceans.

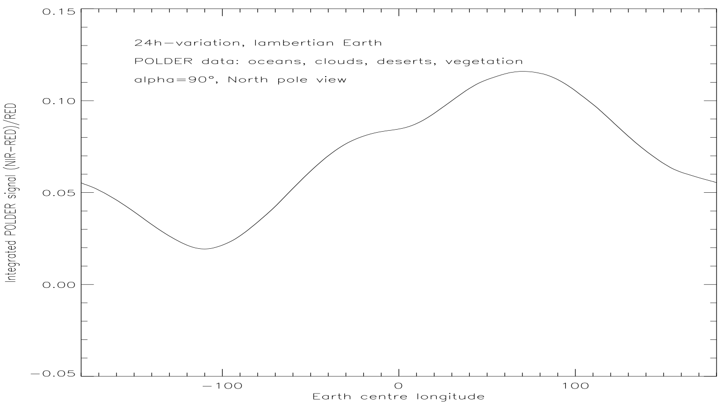

Fig. 3. VRE 24-hour variation when the observer is above latitude 67°, June 12, 1997. The observer sees the Earth at a phase angle of 90°.

References

Arnold L., Gillet S., Lardière O., Riaud P., Schneider J., A&A 2002, 392(1), 231-237

Deschamps P.Y., Bréon F.M., Leroy M., Podaire A., Bricaud A., Buriez J.C., Sèze G., IEEE Trans. Geosc. Rem. Sens. 1994, 32(3), 598-615

Woolf N.J., Smith P.S., Traub W.A., Jucks K.W., ApJ 2002, 574, 430-433