Journal of Quantitative Spectroscopy & Radiative Transfer 216 (2018) 6–16

Contents lists available at ScienceDirect

Journal of Quantitative Spectroscopy & Radiative Transfer

journal homepage: www.elsevier.com/locate/jqsrt

Cloud information content in EPIC/DSCOVR's oxygen A- and B-band channels: An optimal estimation approach

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A R T I C L E I N F O

Article history:
Received 28 November 2017
Revised 7 May 2018
Accepted 8 May 2018
Available online 16 May 2018

Keywords:
Oxygen A-band
Oxygen B-band
Multiple scattering
Radiative transfer
Remote sensing
Cloud top height
Geometrical cloud thickness
DSCOVR
EPIC
Optimal estimation theory
Information content analysis

A B S T R A C T

We use computational 1D radiative transfer modeling and the formalism of optimal estimation to quantify the cloud information content in the oxygen A- and B-band channels of the Earth Polychromatic Imaging Camera (EPIC) on the Deep Space Climate ObserVatoRy (DSCOVR) platform. EPIC/DSCOVR images the sunlit hemisphere of our planet from ≈1,500,000 km away with ≈8 km pixels at the center of the disc. EPIC pixel-scale spectral data is used to estimate in-band/continuum radiance ratios for O_2's A- and B-bands, from which one can derive, in principle, both cloud top height and cloud geometrical thickness. We use the general framework of optimal estimation theory to show that in practice, once measurement error is factored in, only cloud top height can be reliably inferred. With that limitation in mind, we discuss the ramifications for retrieval algorithm development.

1. Introduction & overview

The Deep Space Climate ObserVatoRy (DSCOVR) mission [1] is blazing a new path for Earth observation, and leaving behind an interesting history [2–7]. This instrument platform is on a Lissajous orbit around the Sun–Earth "L_1" Lagrangian point, at c. 1,500,000 km from our planet in direction of the Sun. The primary instruments on DSCOVR are sampling its magnetic, plasma and radiation environment for space science purposes. However, from that unique vantage point, DSCOVR also looks back at the sunlit hemisphere of Earth with two complementary sensors. The National Institute of Standards and Technology Advanced Radiometer (NISTAR) measures radiance from the whole hemisphere in three broadband channels: total reflected and emitted radiation (0.2–100 µm), total reflected solar radiation (0.2–4 µm), and reflected NIR and SWIR (0.7–4 µm). In contrast, the Earth Polychromatic Imaging Camera (EPIC) [8] images the Earth with a 2,048 × 2,048 pixel camera, yielding ≈8 km pixels at the center of the disc, every 60 to 100 minutes [9]. EPIC's filter wheel carries 10 narrowband channels sampling the UV–VIS spectral range. Among these channels, those at 680, 688, 764, and 780 nm are dedicated to forming two in-band/out-of-band radiance ratios for di-oxygen's A- and B-bands. Fig. 1 shows calibrated [10] EPIC images in these four O_2 channels on Nov. 19, 2017, 02:24:37 UTC when the (New) Moon happened to be between DSCOVR and Earth (more precisely, DSCOVR and Australia).[1]

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https://doi.org/10.1016/j.jqsrt.2018.05.007
0022-4073/© 2018 Published by Elsevier Ltd.

[1] Data is available from the Atmospheric Science Data Center (ASDC) at NASA Langley Research Center's Distributed Active Archive Center (DAAC): URL is https://search.earthdata.nasa.gov/search; granule ID is epic_1a_20171119022437_02.h5. Note that this is Level 1a (calibrated but not geolocated) data, and therefore not viewable at the EPIC website [9].

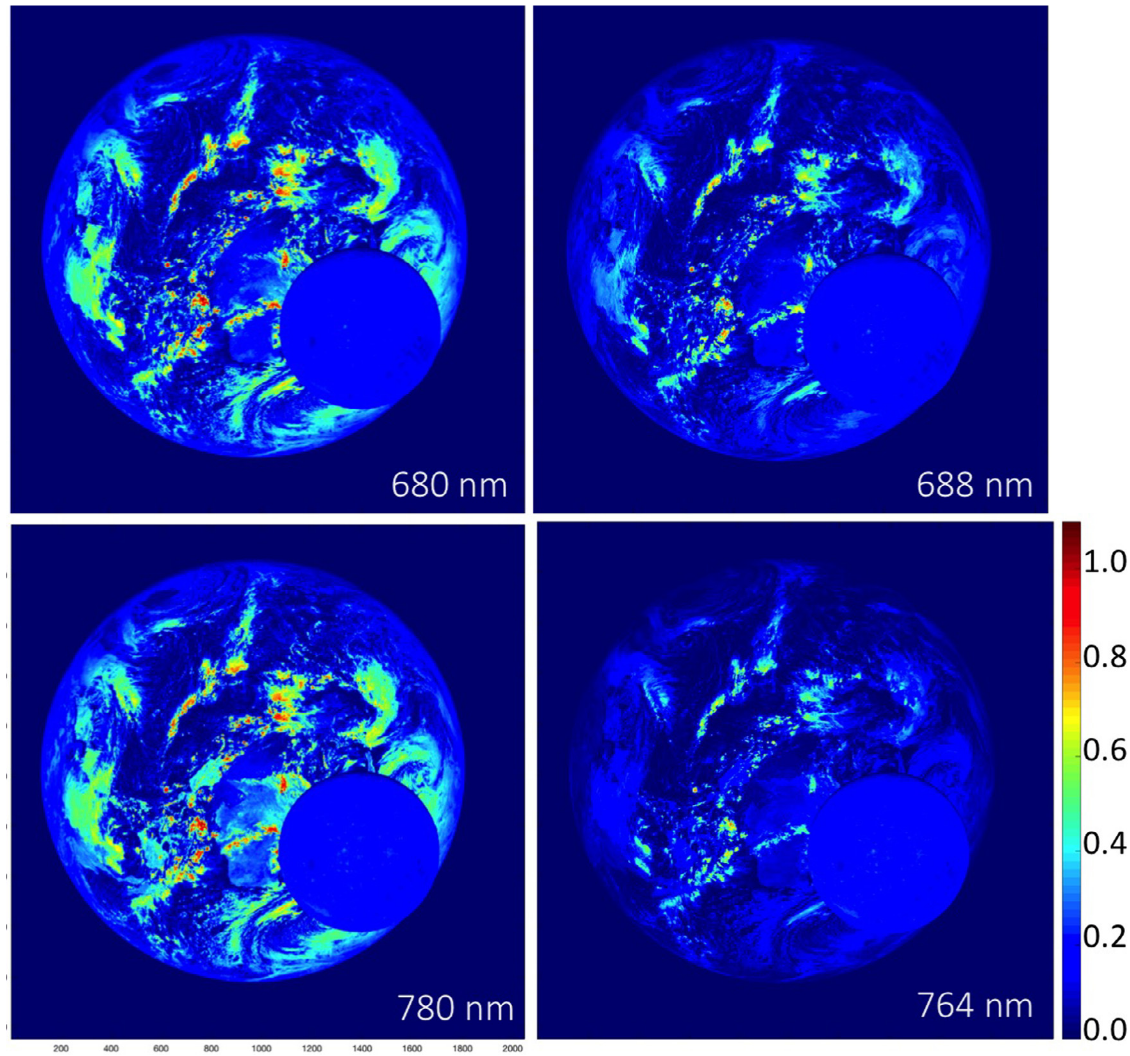

Fig. 1. *Earth-and-New-Moon EPIC images captured on 19-11-2017 at 02:24:37 UTC.* Clockwise, from top left: TOA radiance $I_{\text{TOA}}(\lambda)$ spectral bands at λ = 680, 688, 764, and 780 nm in reflectance form $\pi I_{\text{TOA}}(\lambda)/F_0(\lambda)$, with $F_0(\lambda)$ being the incoming spectral solar irradiance at TOA. Left panels are reference channels while right ones are in-band counterparts; B-band is on top, A-band is on bottom, and the same color scale was used for all the panels. Notice that Australia partially covered by the Moon. For lack of any O_2 absorption in the line of sight, the Moon itself is almost equally reflective in both in-band and reference channels at both A- and B-bands—a fact used in EPIC channel cross-calibration (along with the 10% increase in the lunar albedo going from B- to A-band wavelenths). North is to the upper left, and the equator runs lower-left to upper-right. The tropics are characteristically laced with relatively small bright cloud masses typical of deep convection regimes with similar brightness in all 4 channels, as expected for the highest CTHs reaching the stratopause since there is little O_2 above them. In contrast, the mid-latitude cloud systems are characterized by expansive stratus layers that are not as bright in the reference purely reflecting channels as tropical systems, and are markedly darker in the absorbing channels, as expected for lower CTHs, especially for the A-band since effective O_2 absorption optical thickness in (1) is significantly larger in the A-band EPIC filter than in its B-band counterpart.

The original[2] purpose of EPIC's multi-spectral O_2 absorption observations is basically to gain access to the 3$^{\text{rd}}$ dimension of the Earth's cloudy atmosphere without leaving the realm of passive remote sensing in the solar spectrum. Cloud top heights (CTHs) and, if possible, cloud geometrical thicknesses (CGTs) are targeted, and maybe discrimination between single- and multiple cloud layers. This is vital information in climate studies since it is a well-known fact that low clouds cool the climate by increasing planetary albedo while high-level clouds warm the climate by trapping thermal IR radiation, as do greenhouse gases.

EPIC has inherently mono-directional viewing geometry, and we will argue that this limits retrieval from O_2 A-band absorption observations to just CTH in the presence of realistic instrumental noise levels. This is consistent with the findings of Xu et al. [12] in a recent study of dust plume heights using EPIC A- and B-band data.

In contrast, multi-angle O_2 absorption measurements open up the possibility of retrieving CGT as well as CTH, even with the strict minimum of two channels, as demonstrated empirically by Ferlay, Desmons and co-authors [13,14] for POLDER-3/PARASOL [15]. Future multi-angle polarimetric sensors such as those on EUMETSAT's committed 3MI (Multi-view/Multi-channel/Multi-polarization Imager) mission [16] and NASA's proposed MAIA (Multi-Angle Imager for Aerosols) investigation [17] will have that same capability. That was indeed demonstrated theoretically by Merlin and coworkers [18] who compared the anticipated performances of 3MI and MSPI (Multi-angle Spectro-Polarimetric Imager) [19], a NASA airborne sensor that is, among other things, a precursor to MAIA.

Physically, the multi-angle bi-spectral retrieval of CGT works because the signal from the more oblique views probe more shallow layers than their more normal counterparts. Another way of

[2] Marshak and Knyazikhin [11] recently uncovered another application of EPIC's O_2 B-band channel in vegetation health monitoring.