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Retrieving total ozone column over snow using Sentinel-3 Ocean and Land Colour Instrument

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*Abstract*— In this Letter, spaceborne measurements performed by Ocean Land and Colour Instrument (OLCI) onboard the Sentinel-3 mission are used to derive total ozone column data over snow fields. The results of the retrievals are compared with those performed by the Ozone Monitoring Instrument on board the Aura satellite. Good correspondence of the derived total ozone column is found. This work opens a door for fast ozone retrievals using high spatial resolution imagery with frequent re-visit time over polar areas covered by snow and ice.

*Index Terms*—radiative transfer, remote sensing, ozone, snow

# INTRODUCTION

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paceborne ozone total column amount (total ozone) retrievals have been performed for nearly half a century with first results derived from the BUV instrument on Nimbus-4 in 1971[1]. Currently, the algorithms to retrieve total ozone have reached a high level of maturity providing relative errors similar to those of ground-based instrumentation (1-2%). The errors are somewhat larger (about 3-5%) for polar regions covered by snow and ice, where solar zenith angles are often large. It is common practice to use the UV-visible part of the measured spectrum to derive not only total ozone but also the vertical ozone concentration profiles [2, 3]. High spatial resolution imagers, such as MERIS onboard Envisat, have also been used to retrieve total ozone with enhanced accuracy in polar regions, where a strong ozone signature in the registered spectrum exists [4]. In this work we develop a new robust and simple technique to derive total ozone column data using spaceborne measurements over snow at the following wavelengths: 620, 865, and 1020nm. The two longer wavelengths are used to assess the surface reflectance outside gaseous absorption bands and the wavelength at 620nm is used to derive the total ozone. The technique is based on the analytical solution of the inverse problem. The method is very fast and can be applied to any instrument performing measurements at the triplet of wavelengths (or in their vicinity) mentioned above. Unlike [4], we do not use the look-up-table approach and we do not use a polynomial fit of the absorption-free spectrum. Instead the physical modelling of the snow reflectance spectrum free of gaseous absorption is performed [5,6]. Therefore, the technique is only applicable to snow-covered polar areas, where the accuracy of total ozone retrieved from spectrometers is reduced (see Fig.9 in [7]).

In Section 2 we present a description of the retrieval theory. Section 3 is aimed at the validation of the technique applied to Sentinel-3 OLCI images over Antarctica, using measurements from the Ozone Monitoring Instrument (OMI) onboard the AURA satellite.

# THEORY

We assume that the top-of-atmosphere reflectance over clean polar regions covered by snow can be presented in the following form:

(1)

where *t* is the atmospheric transmittance and is the snow reflectance. It is assumed that spectral channels are selected in such a way that atmospheric scattering effects are weak and can be ignored compared to the contribution from the bright snow surface. It is known that clean snow reflectance can be presented in the following form [5,6]:

). (2)

Here, is the reflectance of an ideal nonabsorbing snow, α is the bulk ice absorption coefficient, is the effective absorption length[5], is the cosine of the viewing zenith angle, is the cosine of the solar zenith angle. It follows that the clean snow spectral reflectance is determined by just two parameters: and . They can be derived from bi-spectral reflectance measurements in the near -infrared, where errors of Eq. (1) for clean polar atmosphere are low. This enables the determination of the transmittance *t* at the wavelengthfrom Eq. (1):

. (3)

The value of is calculated using Eq.(2) with the following analytical inversion for the parameters present in this formula:

, , (4)

where and indices (*2,3*) signify the near -infrared wavelengths used (). We shall assume that the wavelength is selected in such a way that the measurements at this channel are influenced mostly by ozone absorption processes with other atmospheric influences of minor importance. Then it follows:

, (5)

where is the ozone vertical optical density (VOD) at the wavelength and *A* is the air mass factor [8]. We shall use the following simple approximation for the air mass factor:

. (6)

Eq. (3), (5) can be used to derive the value . On the other hand, it follows for the VOD by definition:

(7)

Here is the ozone absorption cross section at the height *z* and the wavelength is the concentration of the ozone molecules at the height *z*. Using the theorem about average, we can derive from Eq. (7):

(8)

where

(9)

is total ozone and is the ozone absorption cross section at the wavelength and generally unknown height . The value of can be estimated performing the calculations of VOD at a given wavelength for a given value of taking into account vertical profiles of pressure, temperature ( for the calculations of and also . Clearly, the value of will depend on the profiles assumed in such a calculation. Generally, this dependence is weak and will be ignored in this work. Then one can derive for the effective absorption cross section (EACS):

(10)

We note that one should account for the instrument spectral response function because the measurements are usually performed not at a single wavelength but in narrow spectral range Therefore, the value of will differ for different instruments even if measured at the same central wavelength.

Summing up, we propose the following equation to derive the total ozone over snow fields in polar regions (see Eqs. (2), (3), (5), (8)):

*c* (11)

where and parameters are found from Eq. (4). The value of *c* is usually measured in Dobson Units (DU). The bulk ice absorption coefficient is derived using the following equation: , where the imaginary part of ice refractive index has been tabulated in [9]. Eq. (11) can be simplified taking into account that the exponent in Eq. (11) is close to one due to small value of bulk ice absorption coefficient in the visible. Then it follows:

*c* (12)

where we accounted for Eq. (4) and indices signify the wavelengths used. This simple equation can be used to estimate the total ozone using the analyticaL Ozone Retrieval Algorithm (LORA) described above.

# Validation

We have validated the LORA applied to OLCI[10] on board Sentinel-3A using Ozone Monitoring Instrument (OMI) [11] onboard Aura measurements. OMI provides near-daily highly accurate ozone retrievals around the globe [12]. Here, we used the Level-3 OMI total ozone column data derived from the Differential Optical Absorption Spectroscopy (DOAS) retrieval algorithm [13]. The data were selected to overlap the Dome C research station in Antarctica (75.1S,123.35E). The study site is located at 3233m a.s.l. and temperatures above freezing point have never been observed. We applied the algorithm to x collocated OLCI and OMI measurements over the time period October 1, 2016 - February 27, 2017. After a visual inspection of the OLCI images, only cloudless days were selected for the inter-comparison. During this period the total ozone column varied drastically (150 – 400 DU) due to the presence of the ozone hole.

The following OLCI wavelengths have been used: 620nm, 865m and 1020nm.The first wavelength corresponds to the maximum of ozone absorption in the OLCI spectrum. We have found that the value of EACS at this wavelength is equal to *inverse DU.* The calculations of EACS (see Eq. (10)) have been performed at the fixed total ozone value equal to 405DU for the pre-defined vertical profiles of pressure, temperature, and ozone concentration. Because the value of total ozone is inversely proportional to EACS, the uncertainty in the calculation of EACS propagates to the calculation of total ozone (see Eq. (12)) leading to overall positive or negative biases. In future the correspondent uncertainty could be reduced by taking into account the relevant European Centre for Medium-Range Weather Forecasts (ECMWF) atmospheric profiles for a given location and time.

The wavelengths 865nm and 1020nm have been selected because they are least affected by atmospheric effects [6]. The imaginary part of ice refractive index was assumed to be equal to 2.4 and 2.25 at 865nm and 1020nm, respectively, as reported in [9]. This leads to the value of The ice is almost non-absorbing at the OLCI channel located at 620nm ().

The inter-comparison of Level 3 OMI total ozone derived using DOAS retrieval algorithm and LORA OLCI retrievals is given in Fig.1. OMI and OLCI have multiple paths in the vicinity of Dome C. Diurnal variations in total ozone were neglected in the comparisons, since OLCI and OMI measurements were performed at a different time of day. The OMI retrievals for a given day correspond to the satellite path providing the best quality total ozone. The OLCI total ozone results have been averaged taking onto account all retrievals for a given day. It follows that the retrievals as performed by LORA capture well the temporal changes of total ozone over an austral winter season at Dome C. The correlation coefficient with respect to OMI results is extremely high (0.92, see Fig.2). Therefore, one can conclude that LORA can be used to derive high spatially resolved maps of total ozone over Antarctica. The spatial resolution of OLCI is 0.3\*0.3 as compared to the 13\*24 OMI resolution. Therefore, there are about 2800 OLCI pixels inside one OMI ground scene. Such a high spatial resolution can be of importance in areas where ozone undergoes rapid spatial changes. For this study, we have ignored the ozone sub-pixel variations in the OMI data and have directly compared OLCI retrievals for a single pixel over Dome C with collocated OMI pixel. Therefore, some of differences reported in Fig.1 are not only due to various approximations used in the development of the OLCI retrieval algorithm but also due to the difference in the scale of measurements. We have found that differences are below 5% for most of cases.

![A screenshot of a cell phone

Description automatically generated]()

Figure 1. The temporal dependence of total ozone at the Dome C for the period October 2016 – February, 2017 derived from OLCI and OMI measurements. The data on total ozone derived from the EMCWF reanalysis at this location (as provided in OLCI metadata files) is also given.

![A close up of a map

Description automatically generated]()

Figure 2. The correlation of OLCI and OMI total ozone retrievals for the collocated 78 clear sky days in the period October, 2016 - February, 2017. The correlation coefficient is 0.92 and the standard deviation is 20.4 DU.

# Conclusions

We have presented a simple algorithm to derive total ozone over snow using a high spatial resolution spectral imager performing measurements at three wavelengths. The measurements at the first wavelength (620nm) are strongly affected by the ozone absorption. Two other wavelengths must be located at the near – infrared and are used to determine the reflectance of underlying surface. The technique has been applied for the OLCI total ozone retrieval over Dome C (Antarctica). A good correspondence of the retrieved total ozone derived from a low spatial resolution sensor such as OMI has been found. Although the described technique is only valid for pollutant-free snow, it could be extended for the cases of polluted snow. In that case, instead of Eq. (12) one must use Eq. (11) with substituted by the corresponding value of the scaled absorption coefficient of pollutants as described in [5,6]. The developed algorithm can be used to study the dynamics of ozone around the South Pole and also at other snow – covered areas that benefit from high spatial and temporal observations, such as the current OLCI/Sentinel -3A, B and also future Sentinel – 3C, D missions.

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