Efficient detection of cloud scenes by Radiance Enhancement and Shortwave up Radiative Flux within the NIR wavelength bands of space orbiting Argus 1000 spectrometer.

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Abstract

The description, interpretation and imagery of cloud sciences by remote sensing datasets from Earth-orbiting satellites have become a great debate for several decades. Presently, there are many models for cloud detection and its classifications have been reported. However, none of the existing models can efficiently detect the clouds within the small band of shortwave upwelling radiative wavelength flux (SWupRF) band. Therefore, in order to detect the clouds more efficiently a method known as the radiance enhancement (RE) can be implemented (Siddiqui, R. et al. 2015; Siddiqui, R., 2017b). Satellite remote sensing database is one of the most essential parts of research for monitoring different atmospheric changes. This article proposes a new approach how with RE and SWupRF to distinguish cloud and non-cloud scenes by space orbiting Argus 1000 spectrometer utilizing the GENSPECT line-by-line radiative transfer simulation tool for space data retrieval and analysis (Quine, B. M. et al., 2002; Jagpal, R.K. et al. 2010, 2011; Siddiqui, R. et al. 2015; Siddiqui, R. et al. 2017a; Siddiqui, R., 2017b). This approach may be used within the selected wavelength band of
Argus 1000 spectrometer in the range from 1100 nm to 1700 nm to calculate the integrated SWupRF synthetic spectral datasets. We used the collected Argus observations starting from 2009 to investigate the radiative flux and its correlation with cloud and non-cloud scenes (Siddiqui, R. et al. 2015). Our results show that the both, RE and SWupRF model, are capable of identifying most of the cloudy scenes except for some thin clouds that cannot be identified reasonably with high confidence due to complexity of the atmospheric system. Based on our analysis, we suggest that the relative correlation between SWupRF and RE within a small wavelength band can be a promising technique for estimating the solar and thermal energy balance involving cloud layers.

1. Introduction

The World Climate Research Program (WCRP) was the first project established under the International Satellite Cloud Climatology Project (ISCCP) in 1982 to collect and analyze a globally uniform satellite radiance dataset to produce a new cloud climatology (Schiffer and Rossow, 1983). Clouds are central occurrences that provide a link between the two key energy exchange processes that determine the Earth climate, particularly the solar – terrestrial and solar – water radiance exchanges (Rossow and Garder, 1993). Cloud detection from remote sensing dataset continues to be one of the most perspective research areas since early 80’s (see e.g. Ebert, E.E. 1987, 1989, 1992, 2007; Curry, J.A. 1992; Li, Z. and Leighton 1991; Gao, B.C. et al. 1998; Kahn, B.H. et al. 2002; McNally, A.P. et al. 2003; Cutillo, L. et al. 2004; Song, X. et al. 2004; Minnis, P. et al. 2005; Chylek, P. et al. 2006; Jang, B. et al. 2006; Cheng, T et al. 2007; Li, W. et al. 2008; Li, D. et al. 2008; Krezel, A. et al. 2011; Ghosh, R.R. et al. 2012; Kazantzidis, A. et al. 2012; de Leeuw, G. et al. 2012; Escrig, H. et al. 2013; Tang, H. et al. 2013; Yordanov, G.H. et al. et al. 2013; Fisher, A. 2014; Wang, T. et al. 2014; Mateos, D. et al. 2014; Illingworth, A.J. et al. 2015; Guo, F. et al. 2015; Siddiqui, R. et al. 2015; Xu, D. et al. 2015; Menaka, E. et al. 2015; Xi, X. et al. 2015; Someya, Y. et al. 2016; Schreier,
Clouds are generally characterized by higher reflectance and lower temperature than the underlying Earth surface (Ackerman, S.A. et al. 1998). Clouds with radiation energy always play most important role through absorption and scattering of photonic radiance within different atmospheric layers due to water vapor, carbon dioxide, oxygen and aerosols. Knowledge and monitoring of the Earth radiation budget is essential for improving our understanding of the Earth climate and potential climate change (Hatzianastassiou, N. et al. 2005). The Earth surface net shortwave radiation, - the difference between the incoming and outgoing SW radiations, - represents the amount of solar radiation absorbed by surface (Inamdar, A.K. et al. 2005). Clouds are the main factor in modulating the Earth energy budget and the climate (Mitchell, D. L. et al. 2009). Furthermore, clouds are highly important in evolution and dynamics of the Earth climate as well as the environmental impact on the Earth by heat transfer process (Siddiqui, R. et al. 2015). In general, clouds take their ambient environment temperature that under normal lapse rate conditions usually decreases with increasing height in the atmosphere. Therefore, when emission is converted to equivalent black body temperature, it can be used to distinguish the presence of opaque clouds from warm surface with various threshold techniques (see e.g. Fournier, N. et al. 2006). According to Jagpal and coauthors (Jagpal, R. et al 2010) clouds and the other airborne particles absorbs or scatter a significant portion of the sunlight back to space (due to reflectance) before it transverse downwards the full atmospheric column, precluding full column of CO₂ measurements in the region occupied by opaque clouds.

The incoming solar radiation is attenuated as it penetrates into the atmosphere, reflects from the surface of the clouds and Earth, and travels back to space. In real atmosphere, the attenuation includes the molecular (Rayleigh) scattering, absorption by CO₂, CH₄, CO and water vapors and droplets in a form of clouds (Siddiqui, R. et al. 2016). The most abundant greenhouse gas H₂O is
particularly significant for clouds analysis. The attenuation also includes extinction (absorption as well as scattering) by aerosols and transmissive cirrus clouds, and partial reflection at components claimed by (Mao, J. et al. 2004). Clouds affect the path of photons through the atmosphere and, therefore, change optical depth within absorption band.

In cloud retrievals from a satellite, it is necessary to have a good estimate of the surface albedo (He, T. et. al. 2012). The reason is that the cloud detection is usually performed by comparing the measured reflectance with expected reflectance from the cloud scene (Li, W. et al. 2008). Cloud detection is a preliminary important step in most algorithms for processing radiance data that has been measured from satellites. In general, different clouds models are introduced in radiance transfer models and their influence on the radiance emitted from the Earth surface is estimated with respect to clear sky conditions at spectral regions as described by Cutillo and coauthors (Cutillo, L. et al. 2004).

One of the most efficient ways to represent accurately atmospheric variation with height is to divide the atmosphere into a large number of relatively thin homogeneous layers or cells where the required parametric values, assigned to each property of interest in each layer, are equal to the corresponding parametric values in the real atmosphere at each mid-point height of the specific layer (Quine, B.M. et al. 2002). The satellite instruments measures the radiances emitted or absorbed by the surface, atmosphere or clouds into the instruments line of sight captured by a small-size remote sensors. Radiance reflected by the top cloud layer depend on cloud thickness, cloud particle number density, size and shape (Mishchenko, M.I. et al. 1996; Fu, Q. et al. 1998; Yang, P. et al. 2005).

The Near Infrared (NIR) satellite instrument is one of the most efficient sources of detecting cloud scenes. The NIR cloud phase detection method developed by using MODIS algorithm (Pagano, T.S. et al. 1993; Chylek, P. et al. 2004). Along with the launch of multi spectral satellite e.g. TERRA, AQUA and MODIS (Xiong, X et al. 2009, Xiong, X et al. 2010), multispectral synthesis methods are
applied in cloud detection within NIR spectral region to detect cloud (Li, W. et al. 2008). Space orbiting Argus 1000 (Jagpal, R.K. et al. 2010, 2011; Siddiqui, R. et al. 2015; Chesser, H. et al. 2012) that covers the wavelength band of 1100 nm to 1700 nm that falls under the category of NIR shortwave radiation band, can also be adopted to detect efficiently the cloud scenes.

The work presented in this paper mainly covers the retrieval of Argus 1000 dataset for the calculation of RE and total SWupRF (Siddiqui, R. et al. 2017a) with help of the GENSPEC line by line radiative transfer model based on the different input parameters, such as cloud albedo, solar zenith angle (SZA), water vapor concentration, atmospheric concentration mixing ratios of O₂, CO₂ and CH₄ that significantly facilitates the procedure for efficient detection of the cloud scenes (Siddiqui, R., 2017b).

2. Instrument profile and radiative transfer model

2.1 Observational Pattern of Argus 1000 - a micro spectrometer

The Argus 1000 micro-spectrometer is shown in Fig.1 (Siddiqui, R. et al. 2017a; Siddiqui, R. et al., 2016). It was developed at York University, Canada in association with Thoth Technology Inc., is a part of the CanX-2 satellite’s payload (Sarda, K. et al., 2006) and launched into space in 2008.
CanX-2 orbits in a low Earth orbit (LEO), 640 km above the Earth surface where Argus field of view (FOV) provides a spatial resolution of 1.4 km.

Figure 2 shows the both front and backend of CanX-2 configuration in real time view during the assembly process. The Argus 1000 micro-spectrometer operates in the near infrared (NIR) covering overall region from 900 to 1700 nm with spectral resolution of about 4-6 nm (Jagpal, R. K. et al., 2010). The Argus instrument provides a means to make measurements of upwelling radiation reflected to space by the Earth surface and atmosphere. Reflection spectra of sunlight from the Earth surface contain significant absorption features associated with the molecular absorption by particular gas species that can be used to predict the composition of the atmosphere (Quine, B. M. et al., 2002; Jagpal, R.K., 2011).
Argus 1000 records the NIR signature of the surface-troposphere amounts of the significant greenhouse gases Oxygen $\text{O}_2$, carbon dioxide $\text{CO}_2$ and water vapour $\text{H}_2\text{O}$ in order to monitor anthropogenic pollution and to identify their sources including particulate matter PM$_{2.5}$ (Christopher, S. A and Gupta, P, 2010) in the atmosphere (Siddiqui, R. et al., 2015; Quine, B. M. et al., 2002). Methane (CH$_4$), Nitrous oxide (N$_2$O), carbon monoxide (CO) and hydrogen fluoride (HF) species also have absorption features in this spectral region of 900 nm to 1700 nm (Jagpal, R.K., 2011). The instrument operates from space to record IR spectra of reflected solar radiation using a linear photodiode array that records the incident radiant energy (Jagpal, R.K., 2011). The measured spectra can be compared with IR absorption signatures obtained by linear path forward modeling of the atmospheric absorption process for determination of the various concentrations of absorbing species. In the absence of saturation or scattering effects, the amount of absorption depends upon the density of the absorber gas along the path. Therefore, the primary measurement objective of the instrument is
to observe any changes in optical depth, associated with the variation of the following atmospheric
gas species in the spectral interval 900-1700 nm (11,111-5,882 cm\(^{-1}\)). Table 1 shows the observed
absorption in this spectral range and their typical absorption strengths (Jagpal, R.K., 2011; Siddiqui,
R., 2017b).

Table 1: Species observed by Argus

| Observed Target Gas          | Absorption wavelength (nm) | Comments                                    |
|------------------------------|-----------------------------|---------------------------------------------|
| Oxygen (O\(_2\))            | 1260                        | Very strong absorption due to O\(_2\) abundance |
| Water (H\(_2\)O)            | 900 1200 1400              | Dominant IR absorber 900-1700 nm           |
| Carbon Dioxide (CO\(_2\))   | 1240 1420 1570 1600        | 1600 nm features are well isolated         |
| Methane (CH\(_4\))          | 1660                        | Low abundance in this spectral band         |

The instrument was designed to take nadir observations of reflected sunlight from Earth
surface and atmosphere (Jagpal, R.K., 2011). The nadir viewing geometry of Argus 1000 is of
particular utility as this observation mode provides a useable probing data in regions that are partially
cloudy or have surface topography representing practical interest (Tsouvaltsidis, C. et al., 2015).

Argus team at the Space Engineering Laboratory at York University prepares the observation tables
for the desired targets around the globe using the Systems Tool Kits (STK) software. The Argus 1000
target list contains 35 global areas around the Earth. During the last seven years of Argus 1000 space
heritage, we have made over 300 reported observations over a series of land and ocean targets.
(Siddiqui, R. et al., 2015), few examples of the selected Argus dataset for the detection of cloud scene
are shown in Table 2 (Siddiqui, R., 2017b).

Table 2. Argus selected week per pass per observations with Geo-location

| Week No. Pass No. | Date              | Selected Observation Numbers | Observations number with satellite Sun angle, Nadir angle, Lat. & Long. | Location                    |
|------------------|-------------------|------------------------------|------------------------------------------------------------------------|-----------------------------|
| Week08_Pass61    | 2009October30     | 64,116,196,238               | OBS64: Sat. nadir angle = 5.7579, Sat. sun angle = 35.3047, Lat. = 6.5100, Long. = 60.9622 |
|                  |                   |                              | OBS116: Sat. nadir angle = 6.8112, Sat. sun angle = 32.3569, Lat. = 3.2055, Long. = 60.1266 |
|                  |                   |                              | OBS196: Sat. nadir angle = 3.4581, Sat. sun angle = 29.2728, Lat. = -1.5265, Long. = 59.2479 |
|                  |                   |                              | OBS238: Sat. nadir angle = 3.6066, Sat. sun angle = 29.1451, Lat. = -4.2681, Long. = 58.7476 |
|                  |                   |                              | Arabian Sea & Seychelles                                               |
| Week14_Pass52    | 2010March04       | 22,100,125                   | OBS22: Sat. nadir angle = 24.7152, Sat. sun angle = 58.1136, Lat. = 47.3740, Long. = -77.7286 |
|                  |                   |                              | OBS100: Sat. nadir angle = 23.8760, Sat. sun angle = 54.9109, Lat. = 42.8413, Long. = -79.7189 |
|                  |                   |                              | OBS125: Sat. nadir angle = 21.8777, Sat. sun angle = 54.5434, Lat. = 42.2893, Long. = -79.9453 |
|                  |                   |                              | Toronto/ Kiticsakik (Canada)                                           |
| Week75_Pass43    | 2013August14      | 30,43,65                     | OBS30: Sat. nadir angle = 1.7477, Sat. sun angle = 38.2453, Lat. = 28.9233, Long. = 147.5652 |
|                  |                   |                              | OBS43: Sat. nadir angle = 1.6689, Sat. sun angle = 37.9789, Lat. = 25.5822, Long. = 146.8083 |
|                  |                   |                              | OBS65: Sat. nadir angle = 1.6877, Sat. sun angle = 38.1652, Lat. = 19.9246, Long. = 145.5481 |
|                  |                   |                              | North Pacific Ocean                                                    |

Figures 3, 4 and 5 illustrate the Argus spectral profile of selected week per pass per observation numbers (Siddiqui, R. et al., 2017a). All these spectra show a high or low radiance in contrast with each other within their selected NIR wavelength bands of interest of O2, H2O, CO2 and CH4.
Figure 3. Argus spectra - radiance vs wavelength of week 08 pass 61 with selected observation numbers.

Figure 4. Argus spectra - radiance vs wavelength of week 14 pass 52 with selected observation numbers.
2.2 GENSPECT – a line by line radiative transfer model

The GENSPECT is a line-by-line radiative transfer algorithm for absorption, emission, and transmission for a wide range of atmospheric gases. GENSPECT uses a variable frequency grid to compute absorption parameters to a specified accuracy [Abrarov, S.M. et al., 2010a and 2010b]. HITRAN line strengths [Duggan, P. et al., 1993] are pre-adjusted for normal isotopic abundances and tabulated, to model an Earth atmosphere with natural abundance. Given information including gas types and amounts, pressure, path length, temperature, and frequency range for an atmosphere, the GENSPECT model computes the spectral characteristics of the gas. GENSPECT employs a unique computation algorithm that maintains a specified accuracy for the calculation by pre-computing where a line function may be interpolated without a reduction in accuracy (Quine, B. M. et al., 2002). The approach employs a binary division of the spectral range, and calculations are performed on a cascaded series of wavelength grids, each with approximately twice the spectral resolution of the
previous one. The GENSPECT error tolerances are 0.01%, 0.1%, and 1%, which may be selected according to the application (Quine, B. M. et al., 2002). GENSPECT has been used previously to compute synthetic spectra for data retrieval; collected by Earth observing instruments deployed in the air, in space and on the ground including MOPITT-A, MOPITT, ACE-FTS, and MAESTRO. [Quine et al., 2007, Jounot, L. J. et al., 2002, McKernan, E. et al., 2002, Drummond et al., 2002, Dufour et al., 2006, Dufour et al., 2005]. In order to corroborate satellite observational results, radiative transfer simulations are also performed by using GENSPECT model. The general input for the radiative transfer is the radiance enhancement and upwelling radiative flux in comparisons with Argus observational dataset taken out as different profile of temperatures, solar zenith angle, mixing ratio concentrations of O₂, H₂O, CO₂, CH₄ and surface albedos.

Figures 6 and 7 show the few spectral profile of GENSPECT-synthetic model with albedo 0.3 and 0.9 at different water level concentrations. Both the spectrum are in a reasonable agreement with absorption features of O₂, H₂O, CO₂ and CH₄ within their selected NIR wavelength bands of interest. Both figures also show the dominant increase of radiance shift by changing water vapor concentration, surface albedo and altitudes from surface to reflecting medium.
Figure 6. GENSPECT-Synthetic spectrums with H2O from 1% to 100% and albedo = 0.3.

Figure 7. GENSPECT-Synthetic spectrums with selected H2O level concentration and albedo = 0.9.

3. Radiance enhancement (RE) approach

Efficient detection of clouds or its surface features means detecting and recording of enhancement of radiant energy by clouds and their surface configuration at the border air–cloud. The detection of cloud or non-cloud scene is implemented by finding the maximum or minimum RE within selected NIR wavelength bands of O2, H2O, CO2 and CH4. (Siddiqui, R. et al., 2015). The RE approach is mainly based on the mean value of the ratio of the difference of the observed data with simulated data for the selected week per pass with single scan or multiple scan (Siddiqui, R., 2017b). In this model the cloud detection can found by selecting the sun elevation angle, satellite nadir angle, variable path length, atmospheric water vapor, variable reflectance, and cloud structure over land or sea (Siddiqui, R., 2017b). Table 3 shows the input parameters used for the efficient detection of cloud scene with geolocation of the Argus flight.
Table 3. Input parameters for RE model.

| Types of parameter | Significance values and ranges |
|--------------------|--------------------------------|
| Mixing Ratios of gases | $O_2$.mxr, $CO_2$.mxr, $CH_4$.mxr, refmod 95_ $H_2O$.mxr (1976 U.S. Standard Atmospheric Model) |
| Gases in % | $O_2$ (100), $CO_2$ (100), $CH_4$ (100), $H_2O$ (0 to 35) |
| Height from surface to top of clouds | 2km to 50 km |
| Surface Type | Lambertian |
| Reflectivity | 0.3 (over generic vegetation and bare soil), 01 to 0.9 (over snow, clouds, and ice) |
| Scattering Type | Rayleigh |

For the analysis of efficient detection of cloud scenes by using RE approach we have selected few retrieval datasets from Argus flight as shown in Table 2. The radiance enhancement approach for the selected GENSPECT-synthetic model with albedo 0.3 at different water level concentrations in contrast with Argus selected spectra of different week per pass per observation numbers are shown in Figs. 8, 9 and 10 (Siddiqui, R., 2017b).

Figures 8, 9 and 10 show the different selected observation numbers of weeks 08, 14 and 75 and passes 61, 52 and 43. Each observation number has been compared with synthetic model with albedo 0.3 and $H_2O$ concentration as 10% and 30%. The observation numbers 64, 116 and 238 of week 08 pass 61 and observation numbers 22 and 124 of week 14 pass 52 ranked as cloud signature. Similarly observation number number 196 of week 08 pass 61, observations number 100 and 120 of week 14 pass 52 and observations numbers 19, 30, 43 and 65 of week 75 pass 43 ranked as non-cloud scene by using RE values as shown in Table 4.
Figure 8. RE for Argus spectra in clear and cloudy sky of week 08 pass 61 with different observations number 64/116/196/238 vs. synthetic model spectra with ($r = 0.3$, $H_2O = 30\%$).

Figure 9. RE for Argus spectra in clear and cloudy sky of week 14 pass 52 with different observations number 22/100/120/124 vs. synthetic model spectra with ($r = 0.3$, $H_2O = 1\%$ & 30\%).
4. Shortwave upwelling radiative flux-approach

The integrated absorption technique is applied to develop a synthetic model to determine the magnitude of ShortWave upwelling Radiative Flux (SWupRF) within NIR wavelength bands of O₂, H₂O, CO₂ and CH₄ (Siddiqui, R. et al., 2017a). This new synthetic model is used to estimate the magnitude and expected magnitude variation over spectral range of 900 nm to 1700 nm by varying surface temperature to assess effect on outgoing (upwelling) forcing term (Siddiqui, R. et al., 2016).

In this approach, we employ satellite real observation of space orbiting Argus 1000 for O₂, H₂O, CO₂ and CH₄ with all the packets of the specified weeks, calibration, and background files to calculate the SWupRF. The SWupRF model loads a set of observed spectra for different week per pass per observation number and integrate each spectrum over the different spectral range of bands of interest to compute the (SWupRF)_{obs} (W/m²) as shown in Figs. 11, 12 and 13.
Figures 11, 12 and 13 show the SWupRF of the selected observation numbers of weeks 08, 14 and 75 and passes 61, 52 and 43. The higher the flux ($W/m^2$) of different observations of selected week per pass of Argus flight higher the chances of cloud scene. The lower flux profile at different observations demonstrates the clear sky or patches of clouds. The results of SWupRF shown in Table 6.

**Figure 11.** SWupRF of week 08 pass 61 of Argus observed data
Figure 12. SWupRF of week 14 pass 52 of Argus observed data

Figure 13. SWupRF of week 75 pass 43 of Argus observed data

5. Validations of cloud and non-cloud scenes

The performance of efficient detection of cloud scenes is usually based on by associations to the other satellites imagery (Jedlovec, G., 2010). In this study the validations have been carried out on the basis of MODIS-Aqua/Terra satellite imageries (MODIS web link). Figures 14, 15 and 16 (Siddiqui, R., 2017b) present the agreement of RE and SWupRF based results of Argus data set and the MODIS cloud images. The validation is splits into three types of scenarios of cloud scenes showing the variability of different types of cloud surface intensity.
Figure 14. Argus 1000 infrared space flight path with MODIS cloud masks of week 08 pass 61 for October 30, 2009 over Arabian Sea.

Figure 15. Argus 1000 infrared space flight path with MODIS cloud masks of week 14 pass 52 for March 04, 2010 over Ontario, Canada.
It is very important to compare the inside features of numerous clouds detection methodology because they are often used in different settings. Each cloud detection method may use different satellite sensors, different wavelength selections bands, and different geographical regions, different date and time etc. (G. Jedlovec, 2009). In our analysis all the three selected data set of Argus space flight showing a very good agreement in performance to detect efficiently the cloud scenes over different regions around the globe in comparisons with MODIS- Aqua/Terra satellite cloud masks. A quantitative analysis of all the selected data set of Argus 1000, as shown in Table 4, indicates that all the validations of cloud scenes ensured reasonably well in capturing the clouds and non-cloud scenes by the results of both RE and SWupRF techniques.
Table 4. Argus selected week per pass per observations with geo-location

| W/P/O     | Albedo | Altitude (Km) | Radiance (Max.) W/m²sr⁻¹(cm⁻¹)⁻¹ | Radiance (Min.) W/m²sr⁻¹(cm⁻¹)⁻¹ | RE    | SWupRF (W/m²) | Cloud/Type         |
|-----------|--------|---------------|----------------------------------|----------------------------------|-------|---------------|-------------------|
| 08/61/64  | 0.5    | 10            | 83                               | 17                               | 9.86  | 2.1           | Yes/Thick (full)  |
| 08/61/196 | 0.2    | 10            | 30                               | 09                               | 4.90  | 0.8           | Yes/Thin (partial) |
| 08/61/238 | 0.4    | 10            | 40                               | 09                               | 7.91  | 1.2           | Yes/Thick (full)  |
| 14/52/22  | 0.5    | 10            | 60                               | 12                               | 4.70  | 1.3           | Yes/Thin (full)   |
| 14/52/100 | 0.3    | 10            | 36                               | 06                               | 6.13  | 1.2           | Yes/Thin (partial) |
| 14/52/125 | 0.5    | 10            | 60                               | 06                               | 2.13  | 2.0           | Yes/Thin (partial) |
| 75/43/30  | 0.02   | 02            | 06                               | 0.5                              | -1.53 | 0.25          | No/nil (ocean)    |
| 75/43/43  | 0.1    | 02            | 13                               | 03                               | -1.52 | 0.25          | No/nil (ocean)    |
| 75/43/65  | 0.2    | 05            | 30                               | 04                               | 1.20  | 1.1           | No/nil (surface ice) |

6. Results & discussions

The results are assembled in Figs. 17, 18 and 19 to show snapshots for potential candidates of cloud non-cloud scenes from different Argus flight weeks per passes per observation by using RE & SWupRF models.
Figure 17. (a) RE for Argus week 08 pass 61 with observations number 64/116/198/238 vs. GENSPECT-synthetic model. (b) Argus flight vs. Terra/Aqua (MODIS cloud sat) with full and partial cloud scenes over Arabian Sea & Seychelles (c) SWupRF (0.47-2.30 W/m²) shows the high and low radiative flux intensity within the same range of Argus observation number.
Figure 18. (a) RE for Argus week 14 pass 52 with observations number 22/100/120/124 vs. GENSPECT-Synthetic model. (b) Argus flight vs. Terra/Aqua (MODIS cloud sat) with full and partial cloud scenes over Ontario, Canada (c) SWupRF (0.60- 2.20 W/m²) shows the high and low radiative flux intensity within the same range of Argus observation number.
Figure 19. (a) RE for Argus week 75 pass 43 with observations number 19/30/43/65 vs. GENSPECT-synthetic model. (b) Argus flight vs. Terra/Aqua (MODIS cloud sat) with full and partial cloud scenes over North Pacific Ocean (c) SWupRF (0.19- 2.20 W/m²) shows the high and low radiative flux intensity within the same range of Argus observation number.

Figures 20 and 21 (Siddiqui, R., 2017b) show the histograms of the obtained values of subsequent probability of cloud and non-cloud scenes. Both the results of RE and SWupRF for week 08 pass 61 with observation number 37 and week 75 pass 43 with observation number 115 & 116 are agreed for the efficient detection of cloud scenes.
Figure 20. Histogram of the Argus weeks/passes/observations with maximum flux intensity = 2.30 W/m², minimum flux intensity = 0.2 W/m², average of full spectral data set = 0.84 W/m².

Figure 21. Histogram of the subsequent probability of cloud and non-cloud scenes.
Higher the radiance enhancement for the full wavelength bands as well as for the wavelength bands of H$_2$O in contrast with the high intensity (W/m$^2$) signifies the more probability of cloud scenes.

Figure 22 illustrates a correlation between RE and SWupRF model by using scattered plot with linear fitting to check the validity of the both models for cloud and non-cloud scenes. The scatter plot shows that most points are distributed near the 0.2-1.0 (W/m$^2$):1-10 (RE), which is most probability of non-clouds scenes (or due to the reflection of aerosols with cluster of dust particles).

Figure 22 also illustrates that the higher the flux intensity in contrast with the radiance enhancement that signifies the higher probability of cloud scenes. The overall results of RE and SWupRF (W/m$^2$) show an excellent commitment for the efficient detection of cloud scenes (cite your previous works). There is some degree of data diversions because of number of errors i.e.:

(i) difference between satellite path and Argus boresight;

(ii) mixing of water vapor and carbon dioxide within atmospheric layers that affects calculation of the radiance enhancement;

(iii) selection of average number of satellite sun and nadir angle while comparing with each set of Argus data set.

Higher values indicates that a cloud reflects a large amount of solar radiation by different types of clouds, this can be justified by the variation of cloud albedo from 10% to more than 90% , with different concentration of liquid water, thickness of the atmospheric layers (by changing altitudes), and the satellite sun's and nadir angle. The smaller the droplets signify the greater liquid water content and the greater cloud albedo under assumption that all other factors are the same for using detection of the clouds (Kramer, H.J., 2002).
The scattered plot as illustrated in Fig. 22 gives the probability of different regions of cloud statistics. The higher the radiance with albedo from 0.7 to 0.9 with high altitudes, more the chances of low, thick clouds (such as stratocumulus) primarily reflecting most of the incoming solar radiation whereas with low albedo from 0.1 to 0.6 with high and low altitudes, more the chances of high, thin clouds (such as Cirrus) that tend to transmit it to the surface but then trap outgoing infrared radiation because of low albedo (Siddiqui, R., 2017b).

![Scattered plot between RE and SWupRF of Argus data set.](image)

**Figure 22.** Scattered plot between RE and SWupRF of Argus data set.

### 6. Conclusions

In this work, we have applied two new approaches, Radiance Enhancement (RE) and Shortwave upwelling Radiative Flux (SWupRF) approaches within NIR spectral range from 1100 nm to 1700
nm of space orbiting Argus micro-spectrometer over different spatial locations since 2009 for an improved cloud detection scenes. The two methods have been validated by real observations using collected MODIS data imagery. The RE-based method allows the efficient detection of the clouds through their higher spatial values in contrast with the GENSPECT line-by-line radiative transfer model within the high spectral resolution. This method mostly enables us to calculate the enhancement of reflectivity by different atmospheric concentrations of CO₂ and H₂O, range of albedos, satellite sun and nadir angle.

The second method tested is based on the SWupRF analysis within the same cluster of calculated radiances by the instrument. The cloud detection technique is applied on the high values of radiative flux intensity in terms of W/m² range of integrated spectral profile for the selected range of real observations as well in contrast with the RE results. Both results show in a good agreement with efficient detection cloud and non-cloud scenes by Argus FOV. Cloud detection at night is more challenging with described infrared measurements. The comprehensive investigation has also been required to add full range of Argus geo-located dataset. The presented methodology can reduce the quantification process of detection of cloud scenes and its relationships with the different atmospheric mixing ratios concentration, which is actively participated for the formation of clouds and will be helpful for the description of the climate change mechanism.

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