The efficient detection of cloud scenes by Radiance Enhancement (RE) and with their impact on earth global energy budget due to Short Wave upwelling Radiative Flux (SWupRF) within NIR spectral range of space-orbiting Argus1000 micro-spectrometer

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Abstract

The Radiance Enhancement (RE) and integrated absorption technique is applied to develop a clouds model by enhancement in radiance due to cloud and no cloud phenomena. The Shortwave upwelling Radiative Flux (SWupRF)$_{W/m^2}$ within NIR of Argus 1000 for O_2, H_2O, CO_2 and CH_4 has also been quantifies. This new model is used to estimate the magnitude variation for RE and SWupRF over spectral range of 1100nm to 1700nm by varying surface altitude, mixing ratios and surface reflectivity. In this work we employ satellite real observation of space orbiting Argus 1000 along with line by line GENSPECT radiative transfer model for the efficient detection of clouds with their impact on surface energy budget due to SWupRF effects. We calculate and compare both the synthetic and real measured observed data set of different week per pass of Argus flight. Results are found to be comparable for both the approaches, after allowing for the differences with the real and synthetic technique. The methodology based on RE and (SWupRF)$_{W/m^2}$ of the space spectral data can be promising for the instant and reliable detection of the cloud scenes with their impact on earth climate.

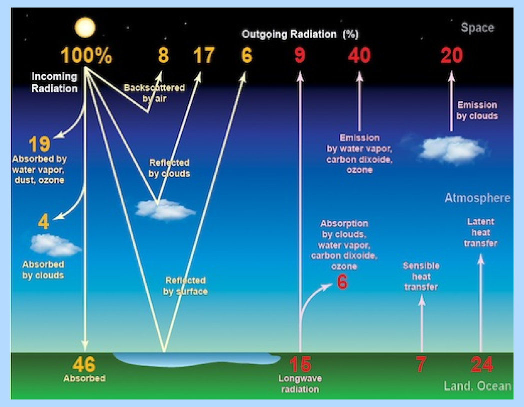

Fig. 1. Earth and its atmosphere maintain an energy balance by either absorbing incoming radiation or reflecting it energy back into space.

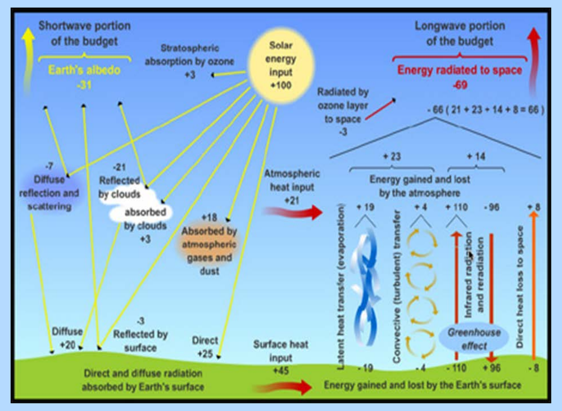

Fig. 2. The short wave and long wave component of the energy budget.

Fig. 3. Canadian Advanced Nanosatellite eXperiment-2 (CanX-2) with Argus 1000, an atmospheric-spectrometer within the spectral range of 900-1700 nm.

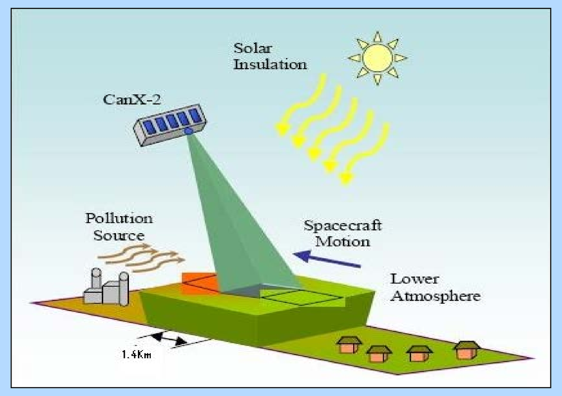

Fig. 4. CanX-2-Argus1000 observation geometry for the detection of different atmospheric features.

Introduction

- Clouds are central phenomena to provide a link between the two key energy exchange processes that determine the earth climate, namely solar and terrestrial radiance exchanges and water exchanges.
- Clouds play a very important role in controlling earth's climate and directly change the cooling or heating of the surface below.
- Identification of clouds by radiance enhancement(RE) and shortwave upwelling radiative flux *SWupRF* (W/m²) in remote sensing dataset are a key issue particularly in the case of sensors working in the visible and near infrared range of electromagnetic spectrum due to severe absorption of cloud constituent's.
- The incoming solar radiation is attenuated as it penetrates the atmosphere, reflects from the surface and travels back to space.
- In real atmosphere, the attenuation includes the molecular (Rayleigh) scattering, absorption by CO_2, CH_4, CO and water vapor in a form of clouds. The most popular greenhouse gas H_2O plays a very important part for clouds analysis.
- Clouds with radiation energy usually play a very important role through absorption and scattering of photonic radiance within different atmospheric layers specially water vapor, carbon dioxide, oxygen and aerosols.
- Clouds effect the path of photons through the atmosphere and therefore change the interpretation of the depth of an absorption band. In cloud retrievals from a satellite, it is very important to have a good estimate of the surface albedo. The reason is that the cloud detection is usually performed by comparing the measured reflectance with expected reflectance from cloud scene
- Measurements acquired from the space orbiting Argus 1000 provide vital information related to long term changes in atmospheric composition and clouds scenes in terms of their radiative effects.
- In this study a new RE & *SWupRF* techniques are applied to space based dataset of Argus1000 micro-spectrometer along with GENSPECT line-by-line radiative transfer model to detect cloud scene.

Argus 1000 spectrometer

- The Argus 1000 is a micro-spectrometer, launched on aboard on the 28th of April 2008 on the Canadian Advanced Nano space eXperiment 2 (CANX-2).
- Argus 1000 has 136 channels in the near infrared spectrum 1100 – 1700 nm with a spectral resolution of 6 nm and an instantaneous spatial resolution of 1.4 km at 640 km orbit.
- Monitor radiation absorption by major atmospheric trace greenhouse gases including Oxygen (O_2), Water Vapor (H_2O), Carbon Dioxide (CO_2) and Methane (CH_4).
- The Argus 1000 spectrometer is capable of monitoring ground-based sources and sinks of anthropogenic pollution. The instrument was designed to take nadir observations of reflected sunlight from Earth's surface and atmosphere. The nadir viewing geometry of Argus is of particular utility as this observation mode provides the highest spatial resolution on the bright land surfaces and returns more useable soundings in regions that are partially cloudy or have significant surface topography.
- York University has been working with the spacecraft operations at the University of Toronto Institute for Aerospace Studies Space Flight Laboratory (UTIAS-SFL) to process the science data and the related spacecraft telemetry, principally measurement timing and spacecraft pointing, in order to properly interpret the Argus Observations.

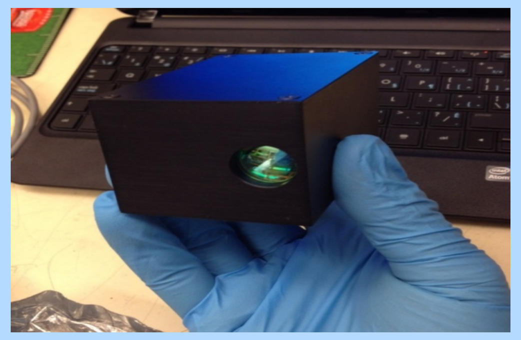

Fig. 5. Argus 1000 qualification model (image courtesy of Thoth Technologies, Inc.).

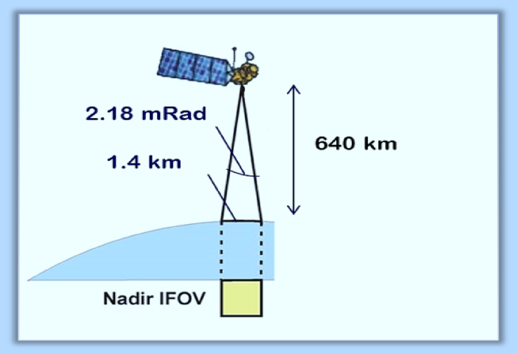

Fig. 6. Argus Field-of-view

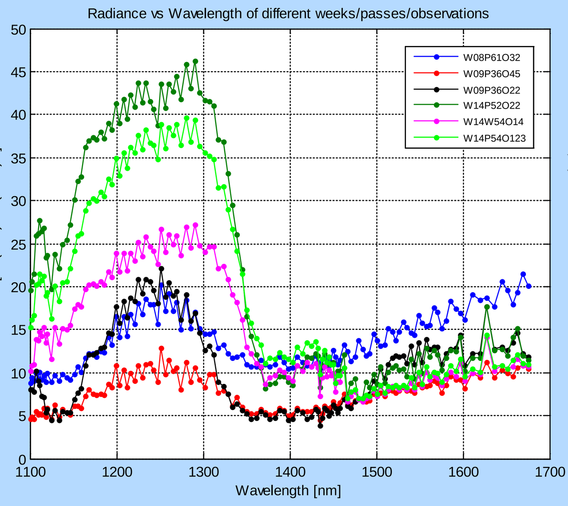

Fig. 7. Argus spectra- radiance vs wavelength of weeks per passes with selected observation numbers (week08/09/14, pass61/36/52/54, obs32/45/22/14/123).

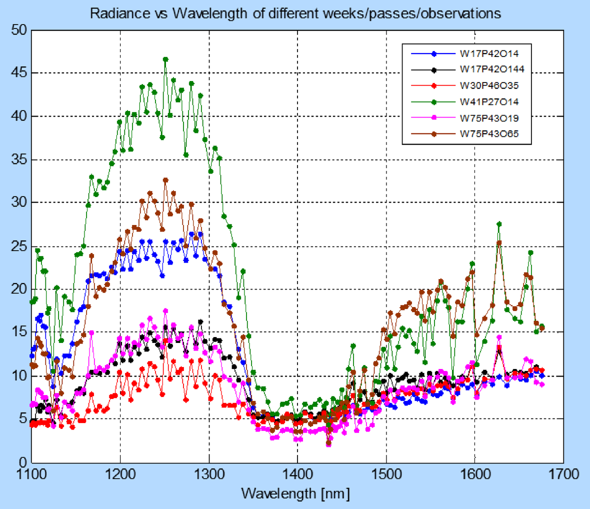

Fig. 8. Argus spectra- wavelength vs radiance of different weeks per passes with selected observation numbers week17/30/41/75, pass42/46/27/43, obs14/144/35/19/65).

Table I : Typical Argus week per pass - Parameters for sampling of calculating RE & SWupRF.

Week No. _Pass No.	Date	Observation Numbers (OBS)	Packet Length	Observations number with satellite Sun angle, Nadir angle, Lat. & Long.	Location
Week08_Pass61	2009October30	32-121	276	OBS32: Sat. nadir angle = 6.2240 Sat. sun angle = 35.4821 Lat. = 8.6388, Long. = 61.2715 OBS121: Sat. nadir angle = 4.9744 Sat. sun angle = 33.0354 Lat. = 3.0414, Long. = 60.2615	Arabian Sea & Seychelles
Week09_Pass36	2009November04	22-45	69	OBS22: Sat. nadir angle = 5.0968 Sat. sun angle = 35.5000 Lat. = 6.8350, Long. = -35.4025 OBS45: Sat. nadir angle = 5.4026 Sat. sun angle = 33.9916 Lat. = 3.7837, Long. = -36.0342	North Atlantic Ocean
Week14_Pass52	2010March04	22-125	125	OBS22: Sat. nadir angle = 24.7152 Sat. sun angle = 58.1136 Lat. = 47.3740, Long. = -77.7286 OBS125: Sat nadir angle = 21.8777 Sat. sun angle = 54.5434 Lat. = 42.2893, Long. = -79.9453	Toronto/ Kitcisakik (Canada)
Week14_Pass54	2010March04	14-123	123	OBS14: Sat. nadir angle = 4.1527 Sat. sun angle = 62.7967 Lat. = 53.1442, Long. = -124.6127 OBS123: Sat nadir angle = 17.2101 Sat. sun angle = 57.9201 Lat. = 47.0893, Long. = -126.6271	Vancouver (Canada)
Week17_Pass42	2010April28	14-144	144	OBS14: Sat. nadir angle = 18.2065 Sat. sun angle = 51.0290 Lat. = 64.8690, Long. = 177.4778 OBS144: Sat nadir angle = 1.2381 Sat. sun angle = 43.9990 Lat. = 55.5832, Long. = 172.3671	Magadan (Russia)
Week30_Pass46	2010December 16	35-460	460	OBS35: Sat. nadir angle = 2.6513 Sat. sun angle = 32.3060 Lat. = -26.7341, Long. = 43.2740 OBS460: Sat nadir angle = 2.2886 Sat. sun angle = 45.0506 Lat. = -55.4500, Long. = 33.7905	Indian Ocean
Week41_Pass27	2011September08	14-198	198	OBS14: Sat. nadir angle = 4.5387 Sat. sun angle = 56.8632 Lat. = -37.5321, Long. = -72.0149 OBS198: Sat nadir angle = 3.0990 Sat. sun angle = 67.1288 Lat. = -50.2686, Long. = -76.2329	Patagonia (South America)
Week75_Pass43	2013August14	19-65	65	OBS19: Sat. nadir angle = 1.8888 Sat. sun angle = 38.6809 Lat. = 31.7593, Long. = 148.2136 OBS65: Sat nadir angle = 1.6877 Sat. sun angle = 38.1652 Lat. = 19.9247, Long. = 145.5481	North Pacific Ocean

Table II: Input parameters for GENSPECT Synthetic calculations.

Types of parameter	Significance values and ranges
Mixing Ratios of gases	refmod 95_ O_2.mxr, refmod 95_ CO_2.mxr, refmod 95_ CH_4.mxr, refmod 95_ H_2O.mxr (1976 U.S. Standard Atmospheric Model)
Gases in %	O_2 (0-100) , CO_2 (1-200), CH_4 (1-100), H_2O (1 to 100)
Height from surface to top of clouds	2km to 50 km
Surface Type	Lambertian
Satellite sun angle*	Argus geo location (Ave. of obs no.)
Satellite nadir angle*	Argus geo location (Ave. of obs no.)
Reflectivity	0.01 to 0.3 (over oceans) 0.3 (over generic vegetation and bare soil) 0.1 to 0.9 (over snow, clouds, and ice)
Scattering Type	Rayleigh

Methodology (RE vs. SWupRF)

- An integrated technique have been developed to calculate the Short Wave upwelling Radiative Flux (SWupRF) in term of W/m² both for Synthetic and Argus observed spectra by using GENSPECT line by line radiative transfer model.
- The detection of cloud scene can be found by the difference of the ratio of the observed data with simulated data for the selected week/pass of Argus flight with single or multiple scan (RE technique).
- SHARCNET (SAW & ORCA) clusters are used to run many GENSPECT-Synthetic jobs both in series and parallel mode.
- 'Lsqnonlin' non-linear optimization technique is applied on different GENSPECT jobs along with Argus dataset.
- The relationship of RE and SWupRF are as follows:

$$RE_i = \frac{1}{N}\sum_{i=1}^{N}\left\{\frac{OBS[j]-SYN[j]}{SYN[j]}\right\}$$

$$(SWupRF)syn, (SWupRF)obs = \int_{\lambda 1}^{\lambda max} S(\lambda)d\lambda$$

$$(SWupRF) \cong \sum_{i=1}^{N} S(\lambda i)d\lambda$$

$$((SWupRF))_{\Omega} = (SWupRF) \times 2\pi\int_0^{\frac{\pi}{2}} sin\theta cos\theta d\theta = \pi(SWupRF)$$

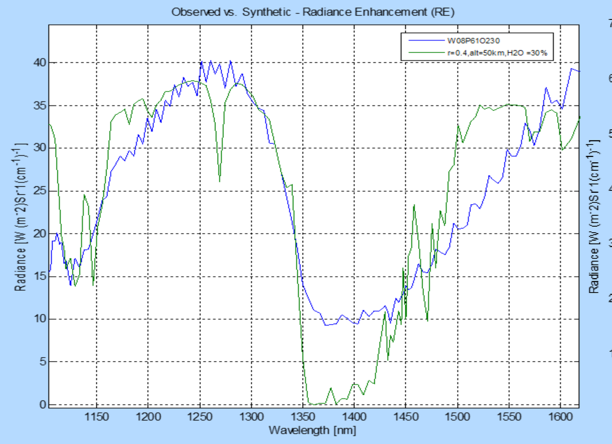

Fig. 9. Argus spectra- wavelength vs radiance of different weeks per passes with selected observation numbers week17/30/41/75, pass42/46/27/43, obs14/144/35/19/65).

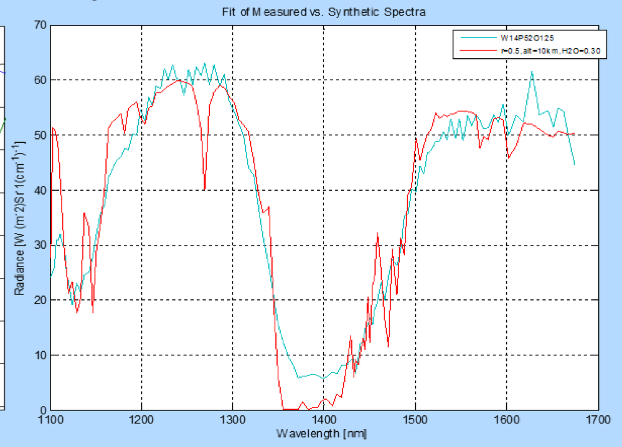

Fig. 10. Argus spectra- wavelength vs radiance of different weeks per passes with selected observation numbers week17/30/41/75, pass42/46/27/43, obs14/144/35/19/65).

GENSPECT line-by-line radiative transfer code

- The GENSPECT is a line-by-line radiative transfer algorithm for absorption, emission, and transmission for a wide range of atmospheric gases.
- GENSPECT can compute synthetic spectra for comparison with data collected by Earth observing instruments. The radiative transfer characteristics of gases have been extensively analyzed and are commonly modeled by examination of the energy transitions between different vibrational states of a gas molecule.
- The loader input parameters includes gas file, specific gas name, run time, wavenumber, air broadening, self-broadening, temperature coefficients etc.
- Each atmospheric species has a unique absorption cross section spectrum, which is used widely to identify the species in atmospheric spectral measurements.
- GENSPECT has been used to compute synthetic spectra for comparison with data collected by Earth observing instruments.

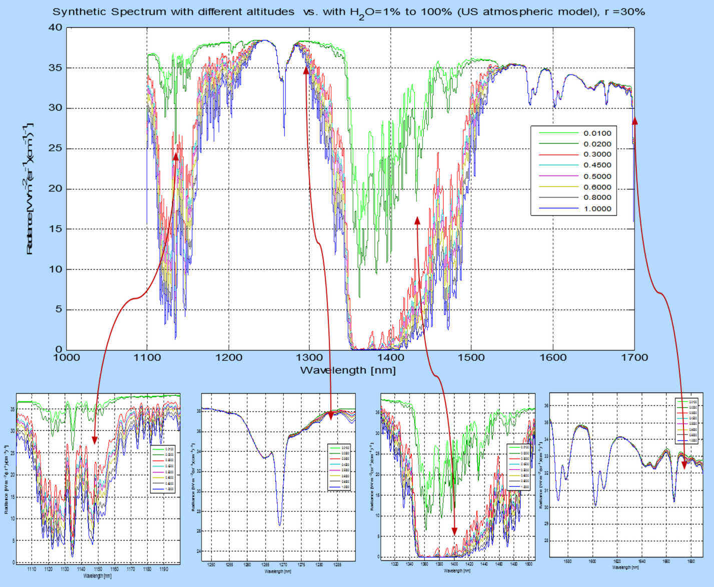

Fig. 11. GENSPECT-Synthetic model from 0% to 100% of H_2O concentration (by using US atmospheric model) .

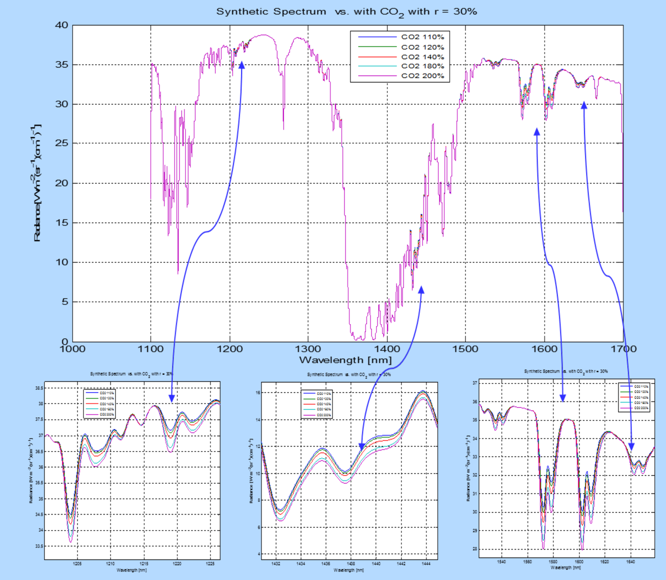

Fig. 12. GENSPECT-Synthetic model from 0% to 100% of CO_2 concentration (by using US atmospheric model) .

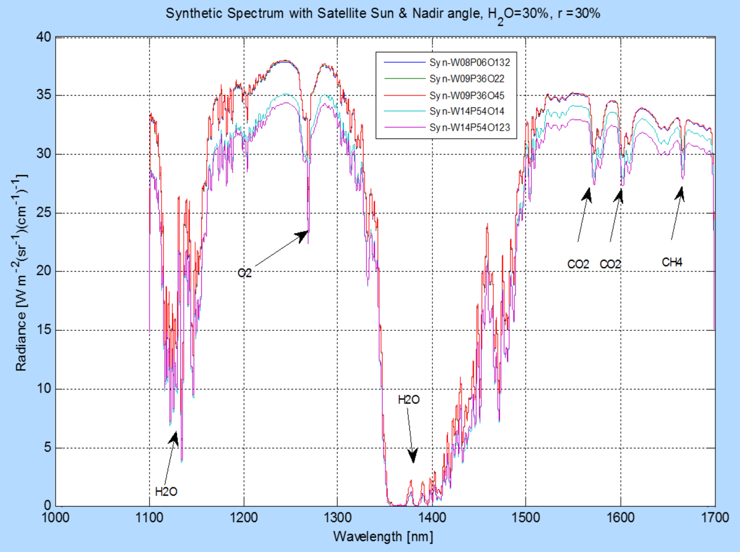

Fig. 13. GENSPECT-Synthetic model with Argus 1000 – Solar zenith & sun angle.

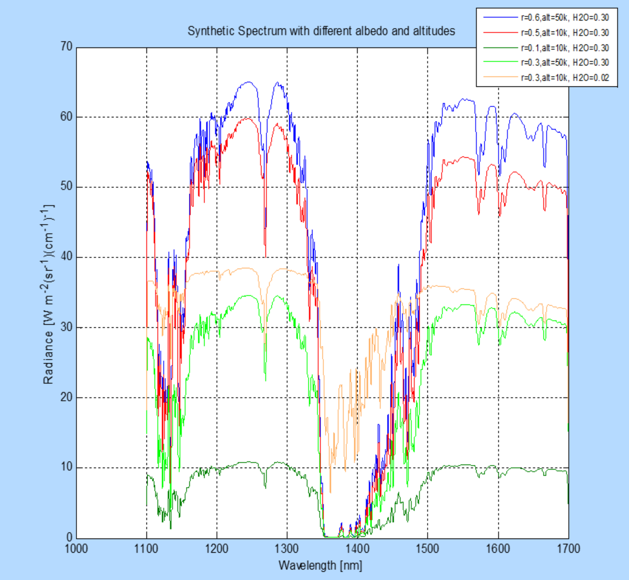

Fig. 14. GENSPECT-Synthetic model with Argus 1000 – Albedo and Altitudes variations.

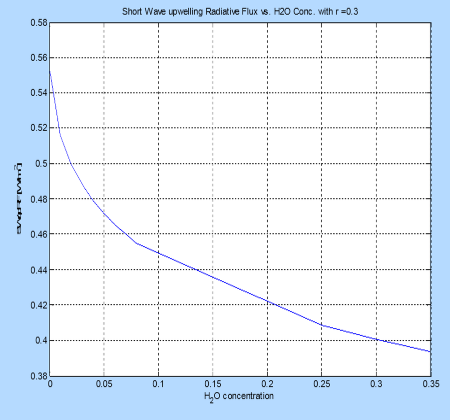

Fig. 15. GENSPECT from 0% to 35% of H_2O concentration, albedo = 0.3 show $SWupRF_{syn}$ range from 0.4725 [0.3950 to 0.5500] W/m²

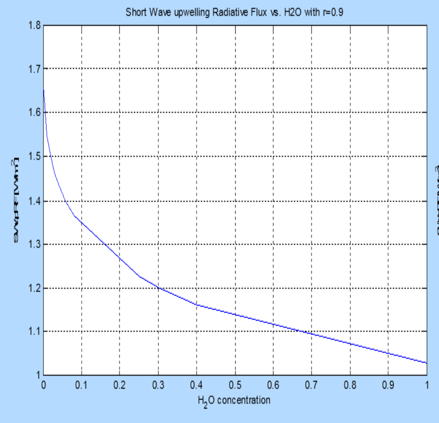

Fig. 16. GENSPECT from 0% to 35% of H_2O concentration, albedo 0.9 show $SWupRF_{syn}$ range from 1.340 [1.030 to 1.650] W/m²

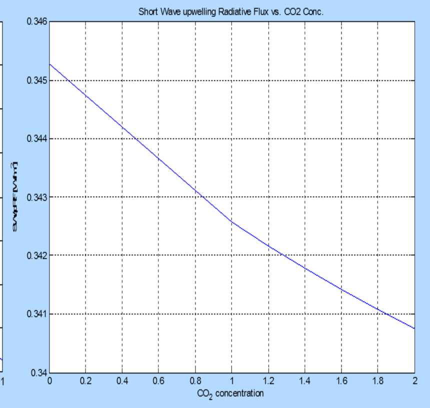

Fig. 17. GENSPECT from 0% to 200% of CO_2 concentration, show $SWupRF_{syn}$ range from 0.3430 [0.3407 to 0.3454] W/m²

Conclusion

The space orbiting Argus 1000 micro-spectrometer continuously monitors the sources and sinks of the trace gases. The efficient detection of cloud scenes are instigated by applying radiance enhancement (RE) technique with shortwave upwelling radiative flux (SWupRF) within spectral range of 1100 nm to 1700 nm using the Argus dataset over different locations of globe during the period of 2010 to 2013 under different atmospheric concentrations. Four wavelength bands of greenhouse gases has been chosen for RE & SWupRF technique i.e. O_2, H_2O, CO_2 and CH_4 gas species. The synthetic model gives $(SWupRF)_{syn}$ within the range of [0.3950 to 1.650] W/m² and the selected Argus observed model gives $(SWupRF)_{Obs}$ within the range of [0.01 to 3.15] W/m². The simulated results of $(SWupRF)_{syn}$ with the same set of solar sun and zenith angles were compared with the few measured results of $(SWupRF)_{Obs}$ of the Argus satellite data over Arabian sea, North Atlantic Ocean, Canada, Russia etc. Both the models has given the minimum difference of SWupRF within the selected wavelength of each gas. The comparisons show that the total surface $(SWupRF)_{total}$ contributed by all the greenhouse gases within the IPCC range. The detailed investigation has been required to add cloud features by comparing the radiance enhancement over different spatial locations with the radiative effect of SW. This will definitely reduce the quantification process of detection of cloud scenes and its relationships with concentrations of water vapor and CO_2 and will also helpful to extrapolate the consequence of full SW wavelength range in contrast with the climate behavior. With more than 7 years heritage in space, Argus 1000 demonstrates that the new generation of the light, small and inexpensive micro-spectrometers categorically increase the process of efficient detection of cloud scenes and can also be helpful to global monitoring climate change due to clouds within SWupRF range.

RE & SWupRF results

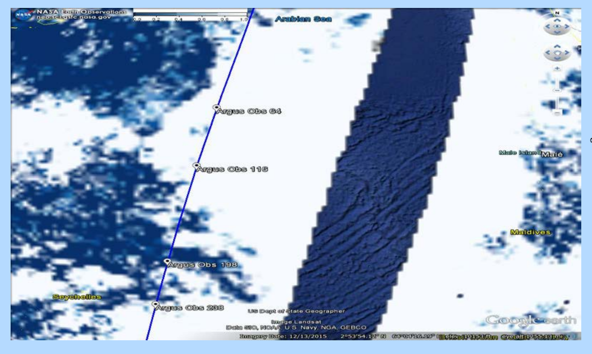

Fig. 18. Argus observed spectra of week 8 pass 61 (October 30th, 2009) over Arabian sea with observation numbers 64 to 238.

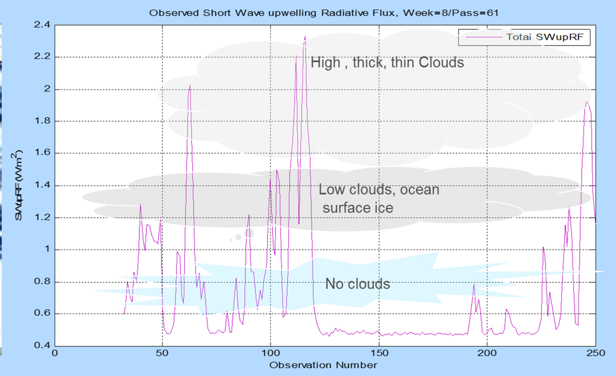

Fig. 19. Argus week 8 pass 61 (October 30th , 2009) with $SWupRF_{obs}$ (0.42- 2.35 W/m²) and variability factor 5.6

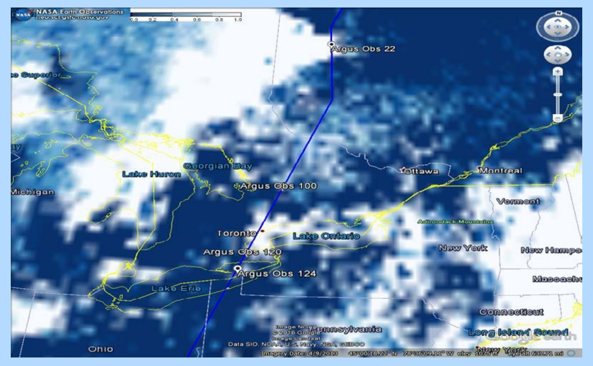

Fig. 20. Argus observed spectra of week 14 pass 52 (March 4th, 2010) over Toronto/Kitcisakik (Canada) with observation numbers 22 to 125.

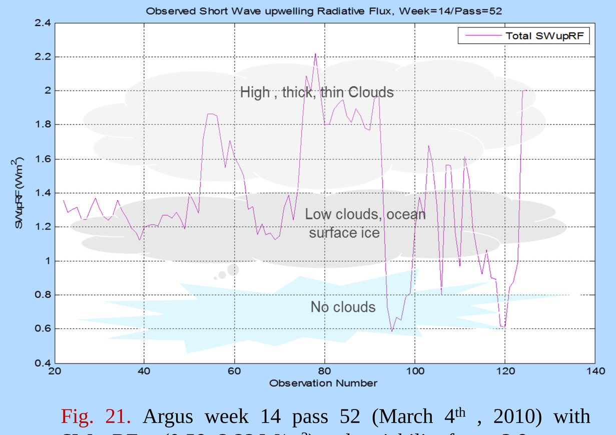

Fig. 21. Argus week 14 pass 52 (March 4th , 2010) with $SWupRF_{obs}$ (0.58- 2.22 W/m²) and variability factor 3.8

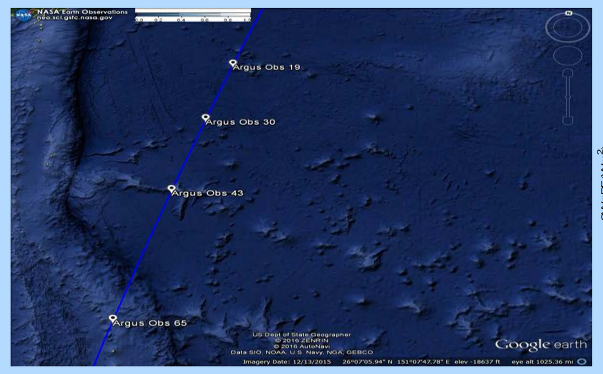

Fig. 22. Argus observed spectra of week 75 pass 43 (August 14th , 2013) over North pacific ocean with observation numbers 19 to 65.

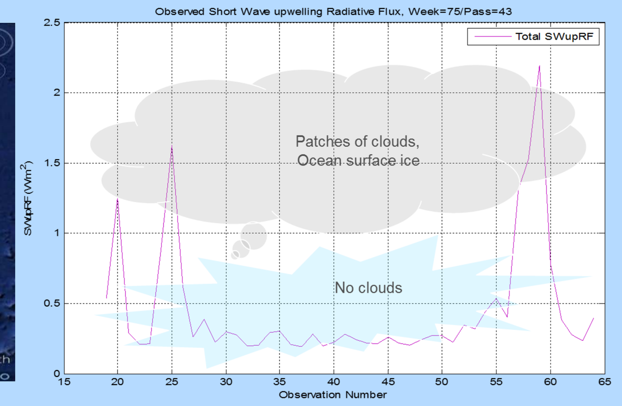

Fig. 23. Argus week 75 pass 43 (August 14th , 2013) with $SWupRF_{obs}$ (0.20- 2.22 W/m²) and variability factor 11.0

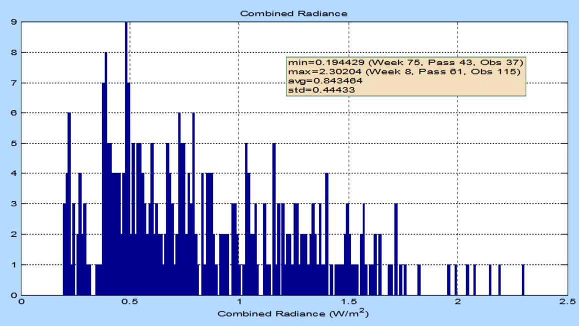

Fig. 24. Histogram of the selected Argus weeks/passes/observations with max = 2.30 w/m2, min = 0.194 W/m2, Ave. = 0.84 W/m2 & Sigma = 0.44 (approximately).

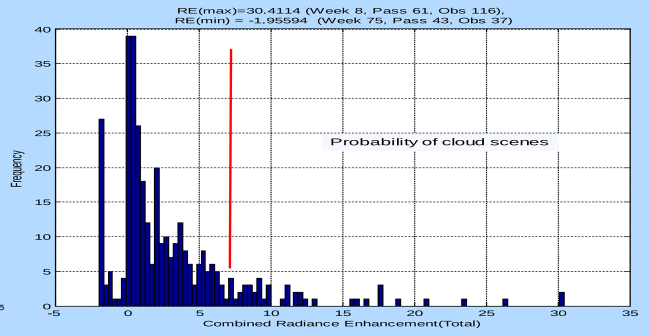

Fig. 25. Histogram of the subsequent probability of cloud and no cloud scenes.

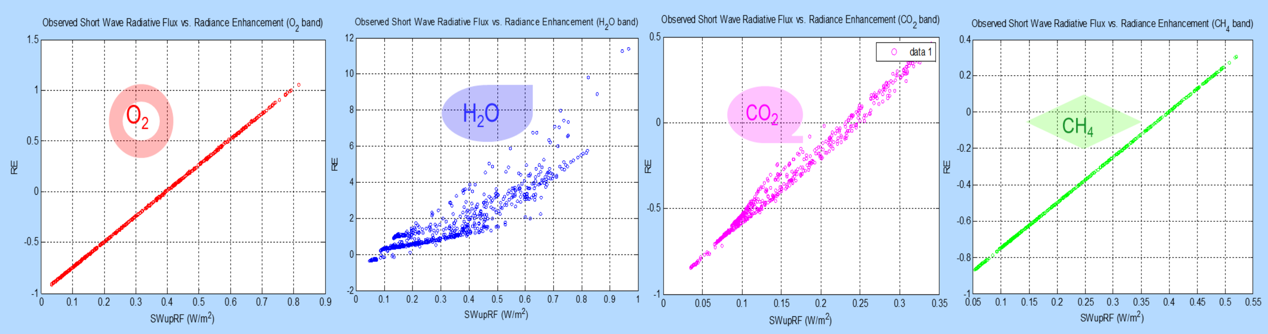

Fig. 26 (a), (b), (c) & 9d). Scattered plots of O_2, H_2O, CO_2 & CH_4 between RE and SWupRF of Argus data set for the efficient detection of cloud and no cloud scenes.

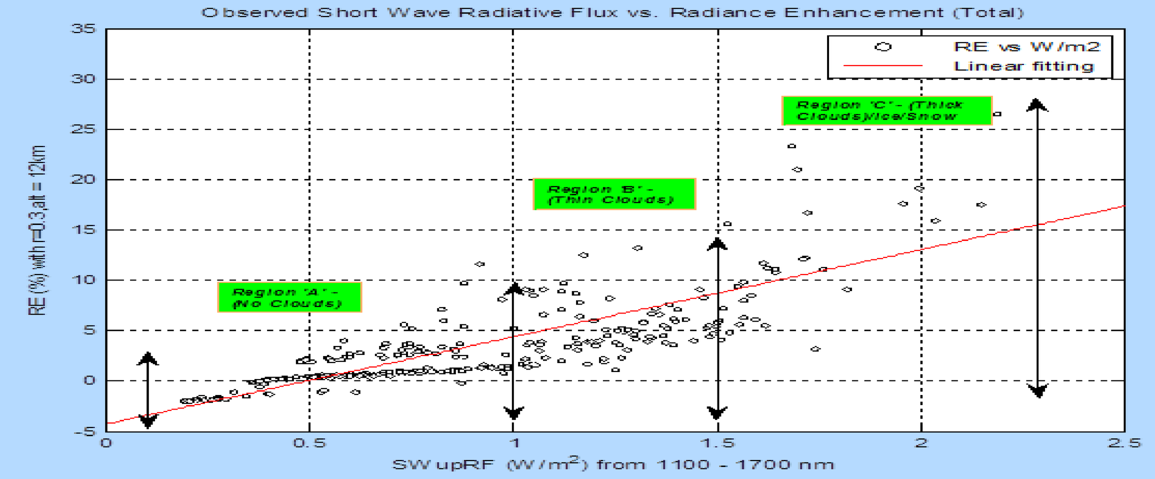

Fig. 27. Scattered plot between RE and SWupRF of Argus data set.

Key References

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