Photochemical model for atomic oxygen ion retrieval from ground-based observations of airglow

Y. Duann*[1,2], L. C. Chang[1,2], Y. C. Chiu[1,2], Alexei V. Dmitriev[1,2], K. G. Ratovsky[3], I. V. Medvedeva[3] and A. V. Mikhalev[3]

[1] Graduate Institute of Space Science, National Central University, Taoyuan, Taiwan

[2] Center for Astronautical Physics and Engineering, National Central University, Taoyuan City, Taiwan.

[3] Institute of Solar-Terrestrial Physics SB RAS, Irkutsk, Russia

* Email: cntwtpe@gmail.com

NCU SPACE SCIENCES

Abstract

To study the chemistry and composition of the upper atmosphere, we can utilize airglow emissions from the photochemical reactions of the ions in this region. When the atomic oxygen ions distributed in the ionospheric F region experience an energy level transition, visible light with a wavelength of 630 nm is released. We used the photometer system built by our team at NCU to perform ground-based observations of airglow over the sky of Taiwan at Lulin Observatory (23.46°N, 120.87°E) during selected nighttimes. Ground-based airglow photometer observations throughout 2016 from the Institute of Solar-Terrestrial Physics (ISTP) in Irkutsk, Russia (51.8°N, 103.1°E) are also utilized. [22] We combined the mean values of our observations every 10 minutes with a photochemical model based on the formula derived from the theories of R. Link and L. L. Cogger (1988), Sobral et al (1993), and Vladislav Yu. Khomich et al. (2008). With these different methods, we can estimate how the density of oxygen atomic ions varies with time and altitude and compare the results from empirical models with satellite-based observation data from FORMOSAT-3/COSMIC. The airglow brightness values simulated (Unit: Rayleighs) by the empirical GLOW model v0.98 by Solomon (2017) are also applied to validate the effectiveness of the three inversion models used in this research.

The tendency and variation of the atomic oxygen ion density calculated by our photochemical models is compared to the ground-based time variation of airglow radiance, electron density observations of FORMOSAT-3/COSMIC, and input variables from GLOW. Similarities and differences are discussed. The pattern of atomic oxygen ion variation resolved by our inversion model, will be

Introduction

1. The main purpose of observing the variation of atomic oxygen ion density, is that lifetime of atomic ions is longer than that of molecular ions. If atomic oxygen ion density is higher, the lifetime of the plasma will be longer, affecting the physical structure of the ionosphere.
2. The airglow of 630 nm is released from OII photochemical reaction occurring at about 250 km, which is the altitude of F-layer ionosphere.
3. With a ground-based photometer system, we get the illuminance data as counts, and transform it into volume emission rate (photons cm^{-3} s^{-1}).
4. The wavelength 630 nm is also same as OH emissions occurring between 80~90 km. To determine the intensity of OII emission more accurately, Gaussian fitting was applied in the calculation.

Models

1. $V630.0 = \frac{A_{1D}\mu_D\gamma_1[O_2][O^+]}{k_1[N_2]+k_2[O_2]+k_3[O]+A_{1D}+A_{2D}}$

2. $V630.0 = \frac{0.756\,\mu_D\gamma_1[O_2][O^+]}{1+(k_2[N_2]+k_5[O_2]+k_6[e^-]+k_7[O])/A_{1D}}$

3. $V630.0 = \frac{\alpha_{O+O_2}\cdot[O^+]\cdot[O_2]+\alpha_{NO+eS}\cdot[NO^+]\cdot n_e+\alpha_{NO+eD}\cdot\alpha_{NDO_2}\cdot[NO^+]\cdot[O_2]\cdot n_e}{\{A_{520}+\alpha_{NDO_2}\cdot[O_2]+\alpha_{NDO}\cdot[O]+\alpha_{NDe}\cdot n_e\}\cdot\left\{1+\frac{\beta_{N_2}\cdot[N_2]+\beta_{O_2}\cdot[O_2]+\beta_O\cdot[O]+\beta_e\cdot n_e}{A_{630}+A_{636.4}}\right\}}$

A_{1D}: Transition probability of 630.0 nm emission.

A_{2D}: Transition probability of 636.4 nm emission.

μ_D : The quantum yield of production of O(1D) state.

γ_1 : The rate of the charge exchange process between O^2 and O^+, producing O_2^+.

k : The reaction rate coefficients.

α : The reaction rate of the dissociative recombination.

β : The rates of the processes of deactivation of excited states.

Conclusions

1. According to IRI model, we can see that in Northern hemisphere high latitude, V630 had a peak value during Summer.
2. Applied to Median V630 values of Irkutsk in 2016, model 3 has a similar variation as IRI model, there is a peak in June, while models 1 and 2 show peaks at Spring equinox, Summer solstice and Winter solstice.
3. Comparing with the results of Toru Adachi et al. in 2007 and 2008, there was a significant discrepancy in peak values of V630.0. It might be caused by solar maximum and minimum.
4. Future work: Figure out the way to calibrate light intensity magnitude affected by peak height distance from the ground, and thickness variation of airglow.

Data Analysis

FORMOSAT-3 Data retrieve: Data are mostly saved as format in amplitude and phase.

$$N_e = \sum \hat{A}(\Phi,z)\cos[\omega t_{UT} - s\lambda + \hat{\psi}(\Phi,z)] + \bar{A}(\Phi,z)$$

$$TEC = \sum \hat{A}(\Phi)\cos[\omega t_{UT} - s\lambda + \hat{\psi}(\Phi)] + \bar{A}(\Phi)$$

$\omega = \frac{2\pi}{T}$

T is period 24, 12, 8, 0 hr. $\omega = 0$ when $T = 0$ hr.

$s = -4 \sim +4$, zonal wave number.

t_{UT} is UT time. [hr]

z is altitude. [km]

$\hat{A}$ is amplitude. $[cm^{-3}]$

$\bar{A}$ is DC term, zonal mean amplitude. $[cm^{-3}]$

Φ is latitude. [degree North]

λ is longitude. [degree]

$\hat{\psi}$ is phase. [rad]

Photochemical reactions:

- $O^+ + O_2 \rightarrow O_2^+ + O$
- $O_2^+ + e^- \rightarrow O(^1D) + O(^3P, ^1D, ^1S)$
- $O(^1D) \rightarrow O(^3P_2) + h\nu(630.0\ nm)$
- $O(^1D) \rightarrow O(^3P_1) + h\nu(636.4\ nm)$
- $Counts \times 0.69 = Rayleigh$
- $Rayleigh = 10^6\ photons \cdot sec^{-1} \cdot cm^{-2} \cdot column^{-1}$
- The thickness of airglow : ~40 km = $4 \times 10^6\ cm$
- $\boldsymbol{Data \times 0.69 \times 10^6 \times 4 \times 10^{-6} photons \cdot sec^{-1} \cdot cm^{-3}} \cdot column^{-1}$
- OI airglow and OH airglow are included in 630 nm. To expand the vertically integrated values into a vertical profile, we assume a **Gaussian Distribution**.

$$I(z) = I_p \times \exp\left(-\left(\frac{(z-z_p)^2}{2\sigma^2}\right)\right)$$

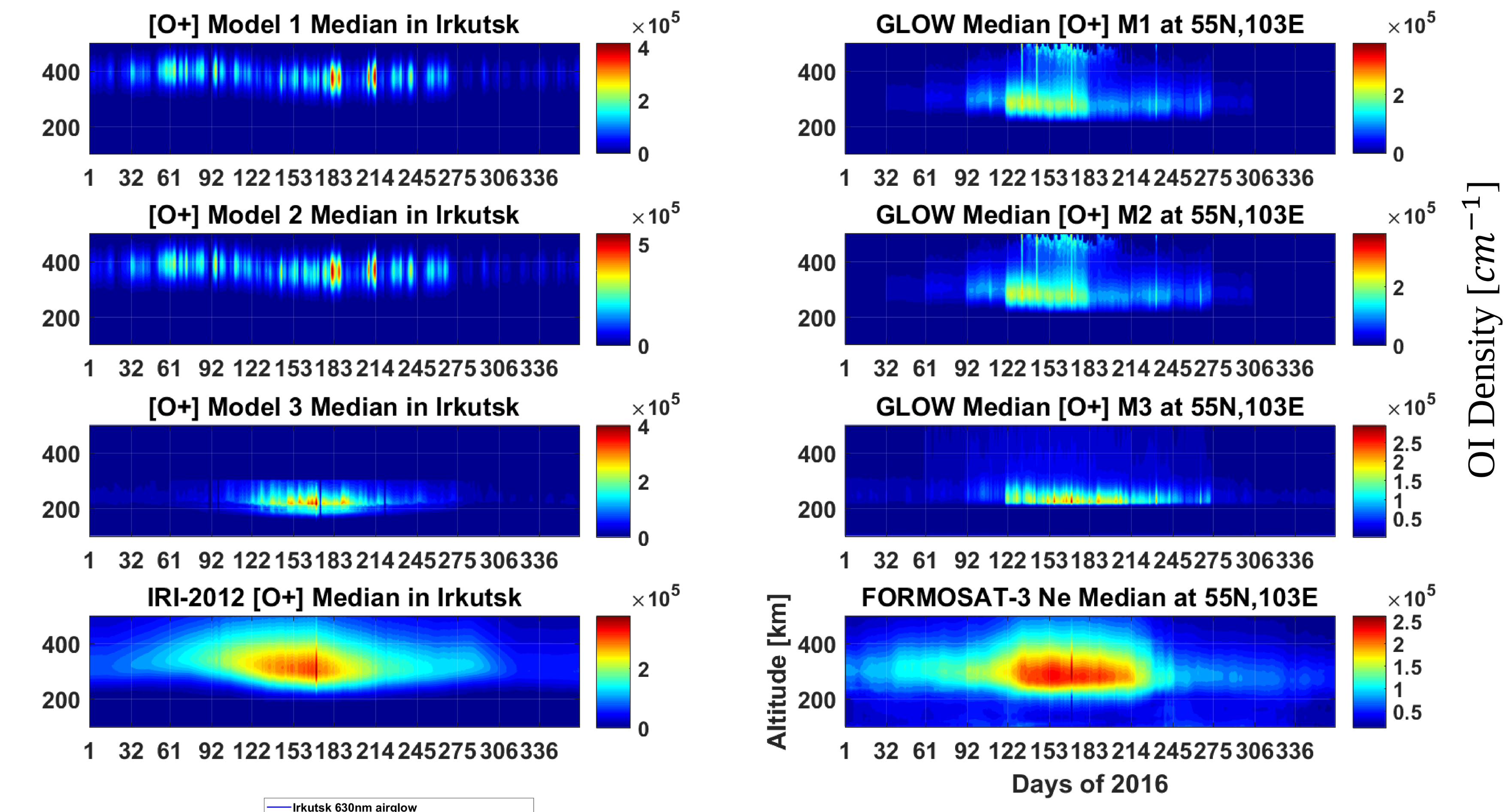
$$V630.0 = Rayleigh \times 10^6 = V_0\int_0^\infty \exp\left(-\left(\frac{(z-z_p)^2}{2\sigma^2}\right)\right)dz$$

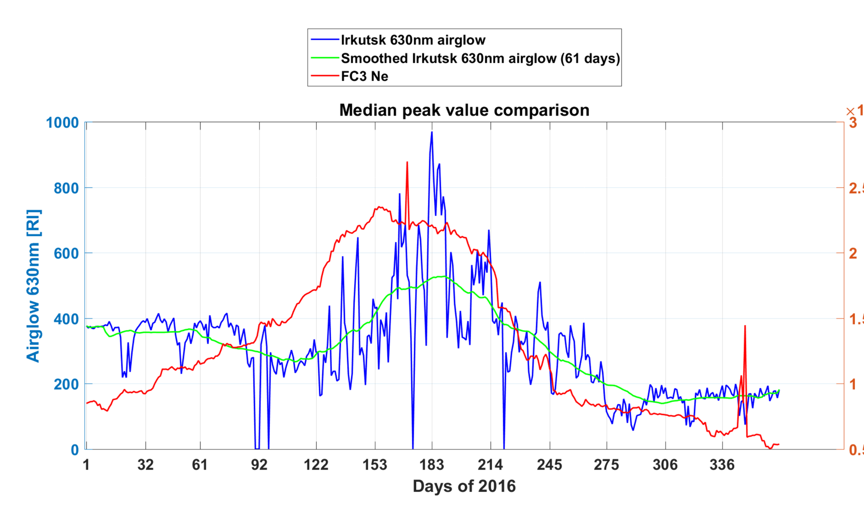
$$\rightarrow V_0 = \frac{2 \times V630.0}{\sigma\sqrt{2\pi}}$$

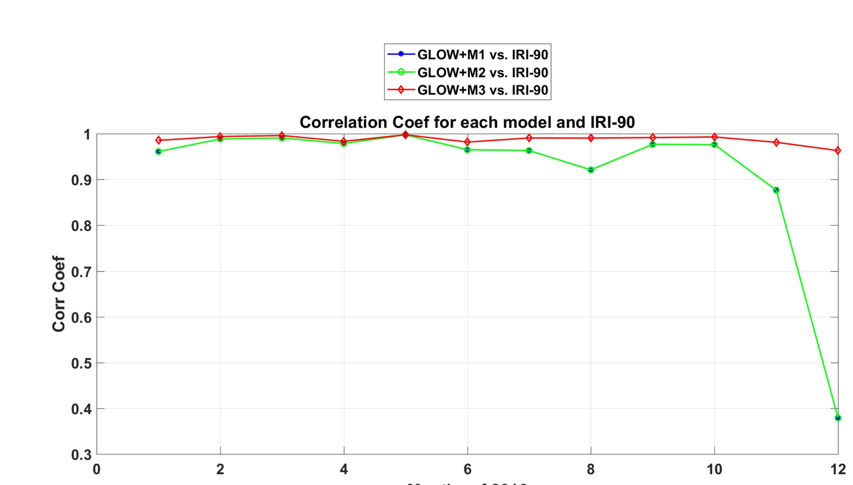
$$\boldsymbol{V630.0' = \frac{2 \times V630.0}{\sigma\sqrt{2\pi}} \times exp\left(-\left(\frac{(z-z_p)^2}{2\sigma^2}\right)\right)}$$

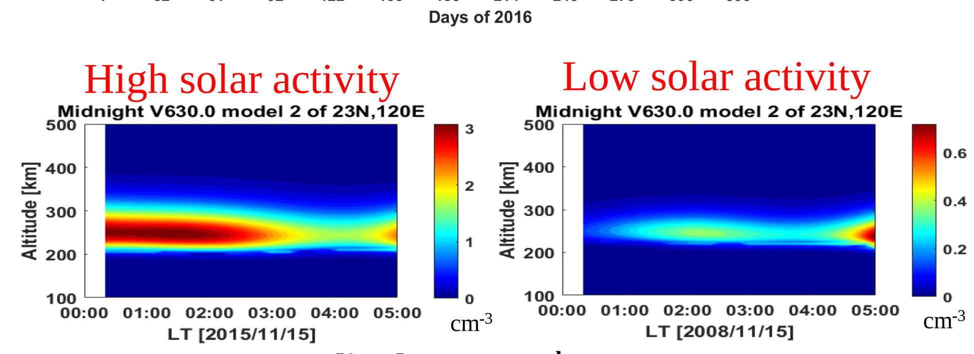
Comparisons

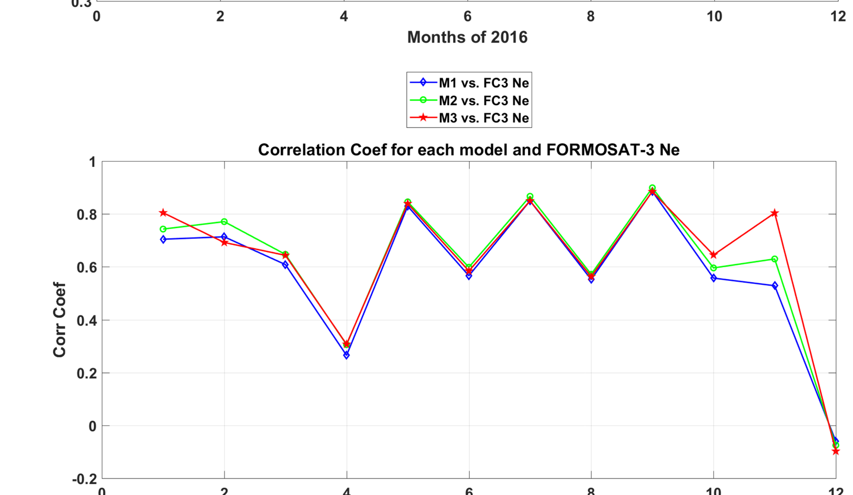
With Median V630 values



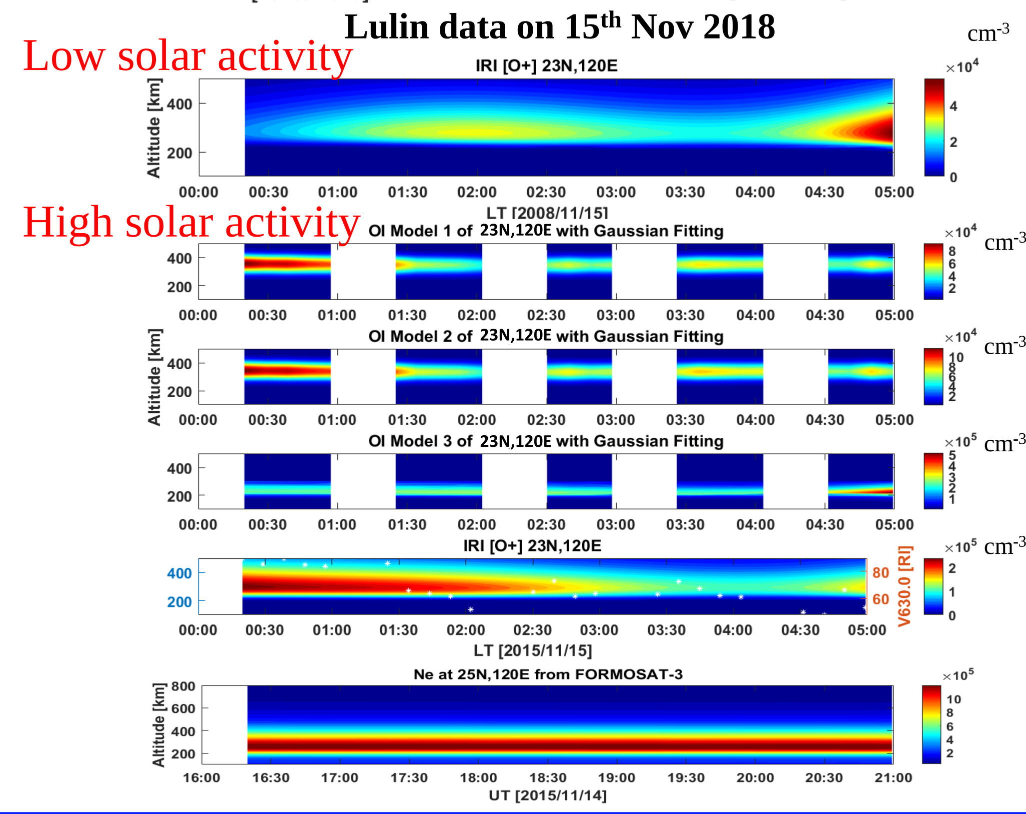




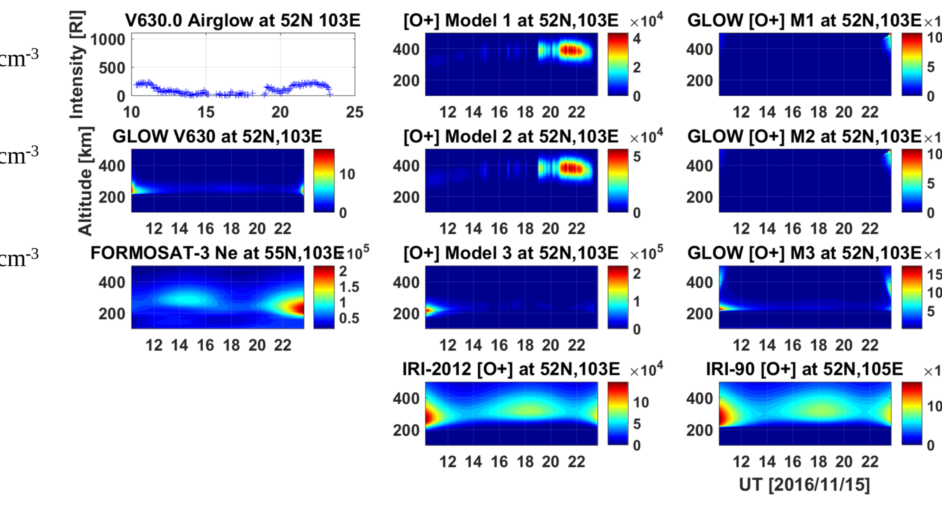




Lulin data on 15th Nov 2018



Irkutsk data on 15th Nov 2018



Reference

[1] P K Rajesh[1,S,*], J Y Liu[1], C H Lin[2], A B Chen[3], R R Hsu[3] & H T Su[3]. (2012. Feb. 23). "Airglow observation over equatorial and low-latitudes in the extreme solar minimum of 2007-2008". *Indian Journal of Radio & Space Physics*. Vol 41, April 2012, pp. 148-154.

[2] Toru Adachi,[1,2] Masashi Yamaoka,[1] Mamoru Yamamoto,[1] Yuichi Otsuka,[3] Huixin Liu,[1] Chun-Chieh Hsiao,[4] Alfred B. Chen,[5] and Rue-Ron Hsu[5]. (2010. Sep. 18). "Midnight latitude-altitude distribution of 630 nm airglow in the Asian sector measured with FORMOSAT-2/ISUAL". *JOURNAL OF GEOPHYSICAL RESEARCH*. Vol. 115, A09315, doi:10.1029/2009JA015147, 2010.

[3] Vladislav Yu. Khomich, Anatoly I. Semenov, Nikolay N. Shefov (2008). Airglow as an Indicator of Upper Atmospheric Structure and Dynamics. Springer-Verlag Berlin Heidelberg. ISBN: 978-3-540-75832-7.