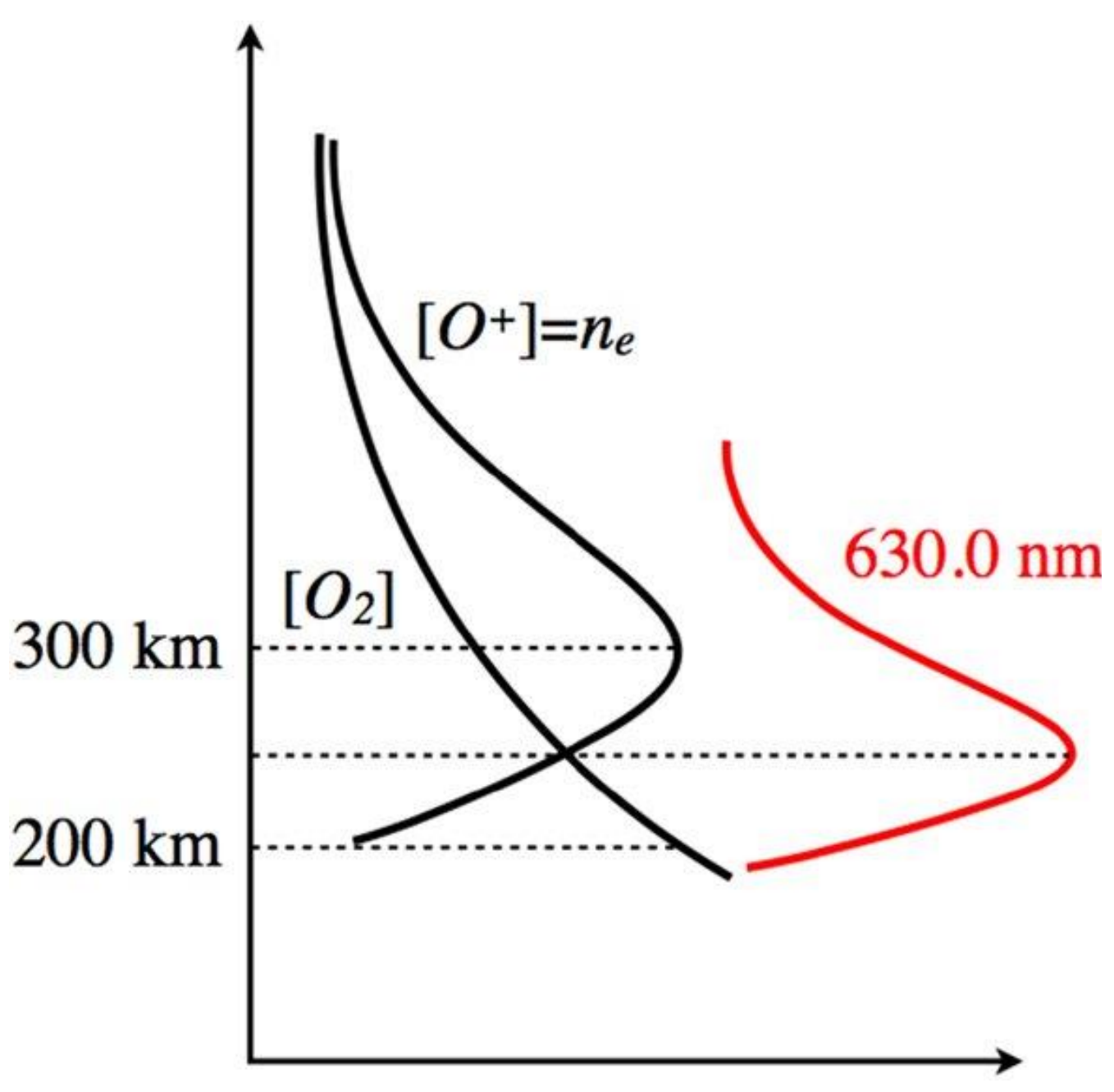
Comparison and validation of photochemical models for atomic oxygen ion retrieval from ground-based observations of 630.0 nm airglow near Irkutsk

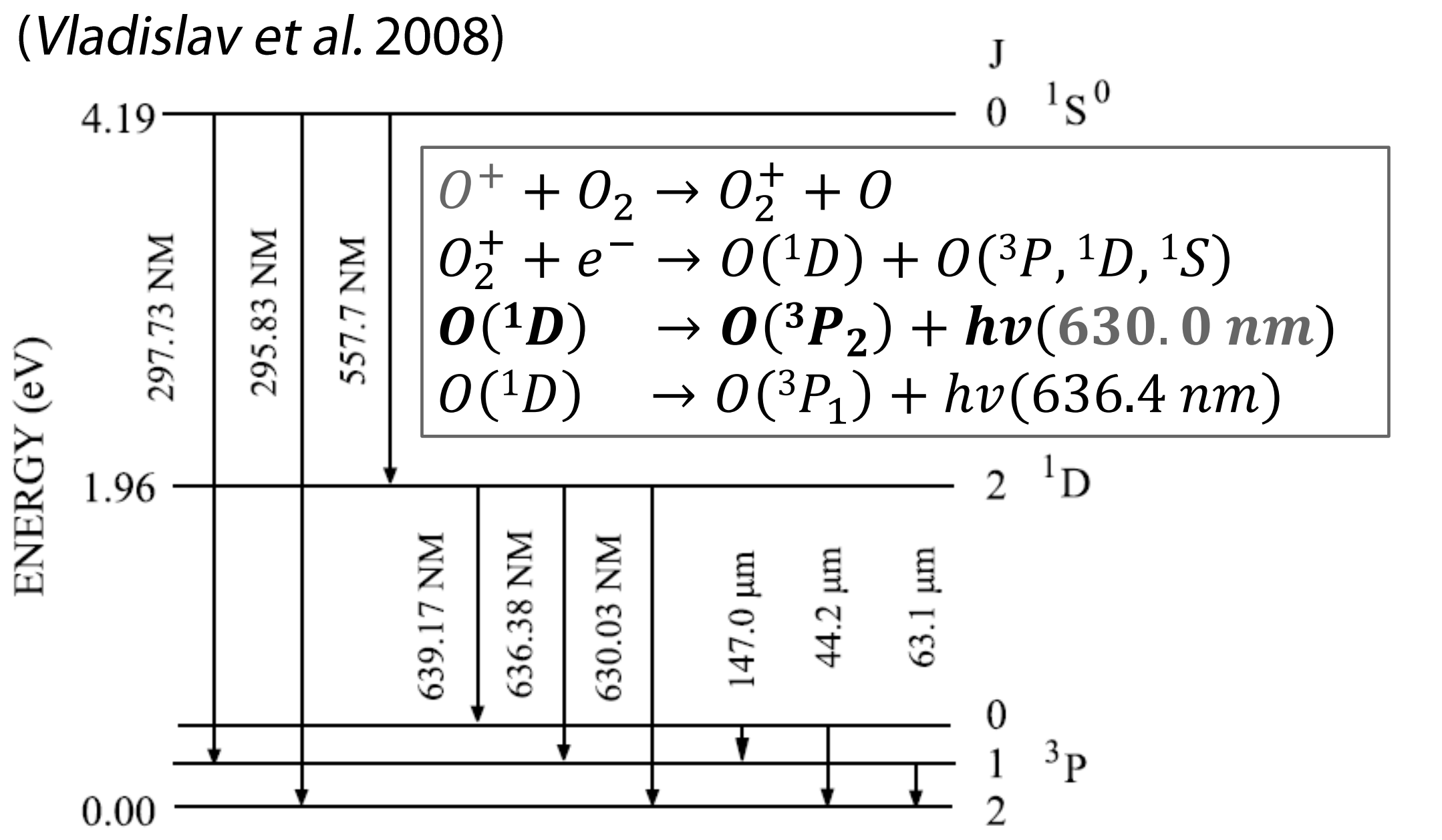
Y. Duann*[1,2], L. C. Chang[1,2], Y. -C. Chiu[1,2], C. C. J. H. Salinas[1,2], A. V. Dmitriev[1,2], K. G. Ratovsky[3],
I. V. Medvedeva[3], R. Vasilyev[3], A. V. Mikhalev[3], J. Y. Liu[1,2], C. H. Lin[4], T. -W. Fang[5,6,7]
[1] Graduate Institute of Space Science, National Central University, Taoyuan, Taiwan
[2] Center for Astronautical Physics and Engineering, National Central University, Taoyuan City, Taiwan.
[3] Institute of Solar-Terrestrial Physics SB RAS, Irkutsk, Russia
[4] Department of Earth Science, National Cheng Kung University, Tainan, Taiwan
[5] Cooperative Institute for Research in Environmental Sciences, University of Colorado Boulder, U.S.A
[6] Space Weather Prediction Center, National Oceanic and Atmospheric Administration, Boulder, CO, USA
[7] Satellite Research Centre, Nanyang Technological University, Singapore
* Email: cntwtpe@gmail.com

Introduction

(Hosokawa *et al.*, 2019)



Structure of the metastable levels and the wavelengths of the transitions between these levels for a neutral oxygen atom. (*Vladislav et al.* 2008)



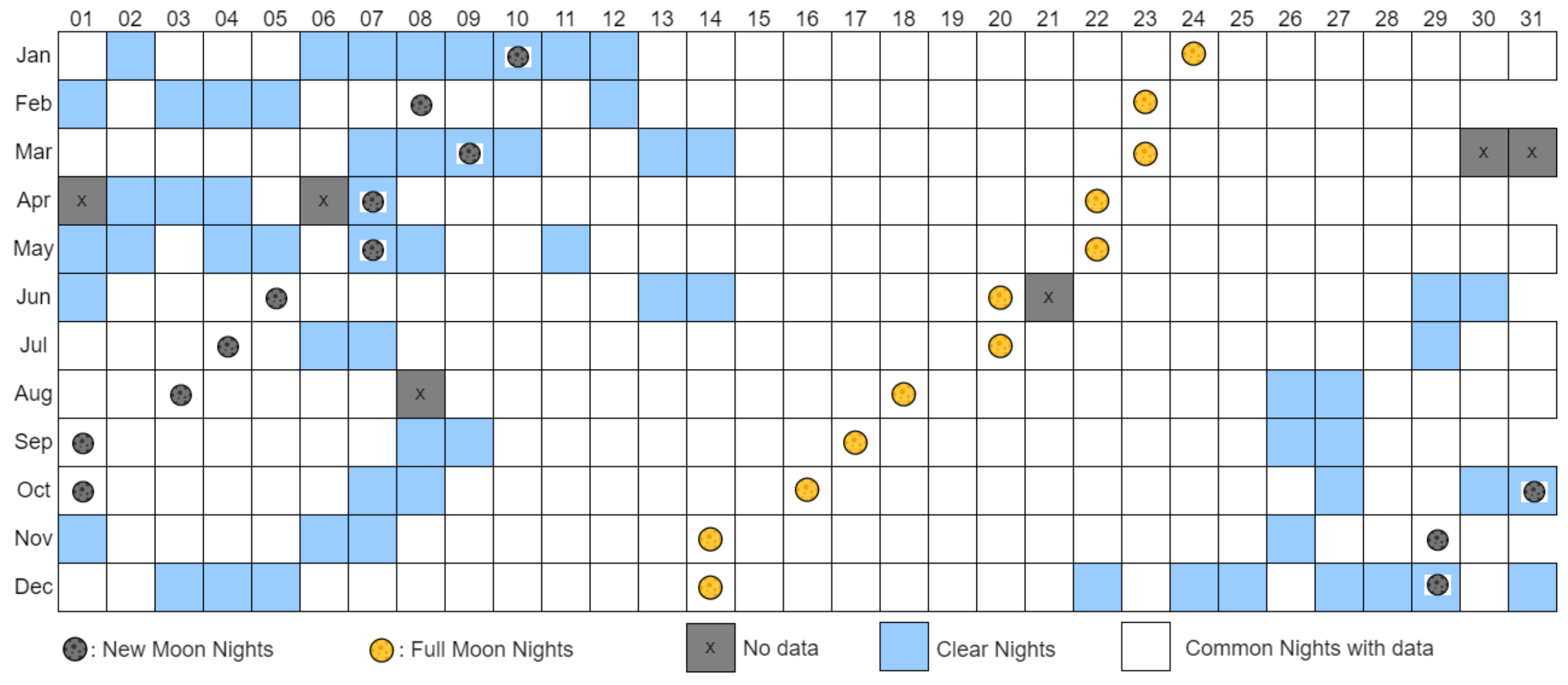
$O^+ + O_2 \rightarrow O_2^+ + O$
$O_2^+ + e^- \rightarrow O(^1D) + O(^3P, ^1D, ^1S)$
$\boldsymbol{O(^1D) \rightarrow O(^3P_2) + h\nu(630.0\ nm)}$
$O(^1D) \rightarrow O(^3P_1) + h\nu(636.4\ nm)$

Atomic oxygen ions (O^+) have been identified as the main plasma component in the *F*-region of the ionosphere, and the density of O^+ ($[O^+]$) can be considered almost equivalent to the electron density (Ne) in the F_2 layer (*Aladjev et al.*, 2001).

Datasets

1. The Geophysical Observatory of the Russian Academy of Sciences Siberian Branch, Institute of Solar-Terrestrial Physics (ISTP-SB-RAS) Ground-based 630.0 nm Airglow Observations
2. Irkutsk Station IR352 DPS-4 Digisonde
3. FORMOSAT-3/COSMIC Observations
4. National Center for Atmospheric Research (NCAR) Thermosphere-Ionosphere-Electrodynamics General Circulation Model (TIE-GCM)
5. The International Reference Ionosphere Model (IRI-2012)
6. US Naval Research Laboratory Mass Spectrometer Incoherent Scatter Radar (NRLMSISE-00) Empirical Atmospheric Model

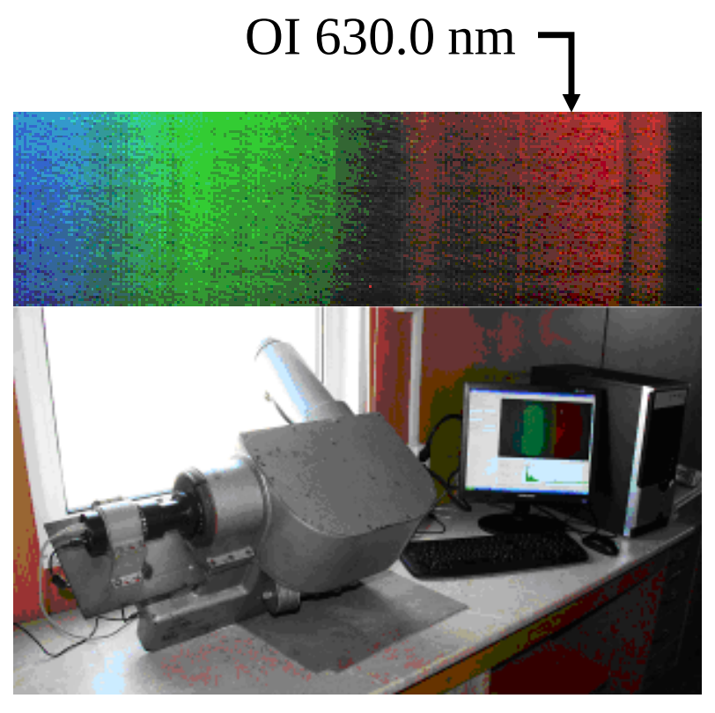
2016 ISTP Geophysical Observatory Observation Conditions



There were only 63 clear nights with data in 2016, and 6 of them are new moon clear nights. In this study, we utilized data from all 360 days when observations were possible.

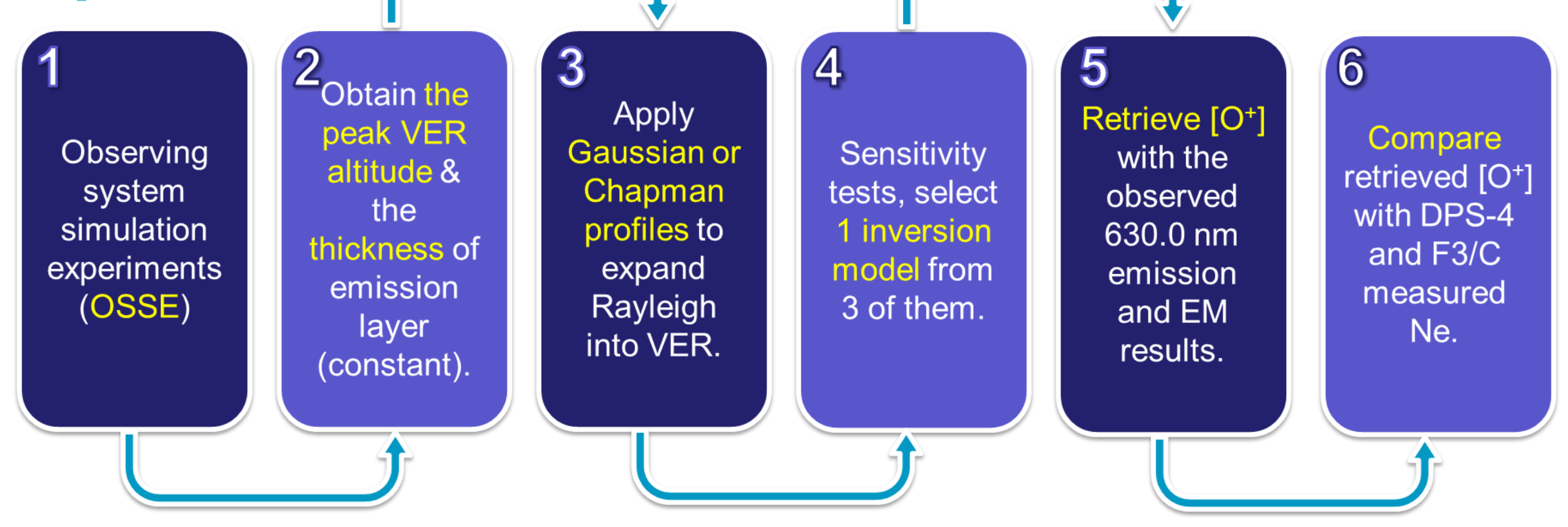
VIDEOSKAN-285

SATI-1M spectrograph
CCD (SONY ICX285AQ) mounted on the base of the LOMO developed ISP-51 spectrograph

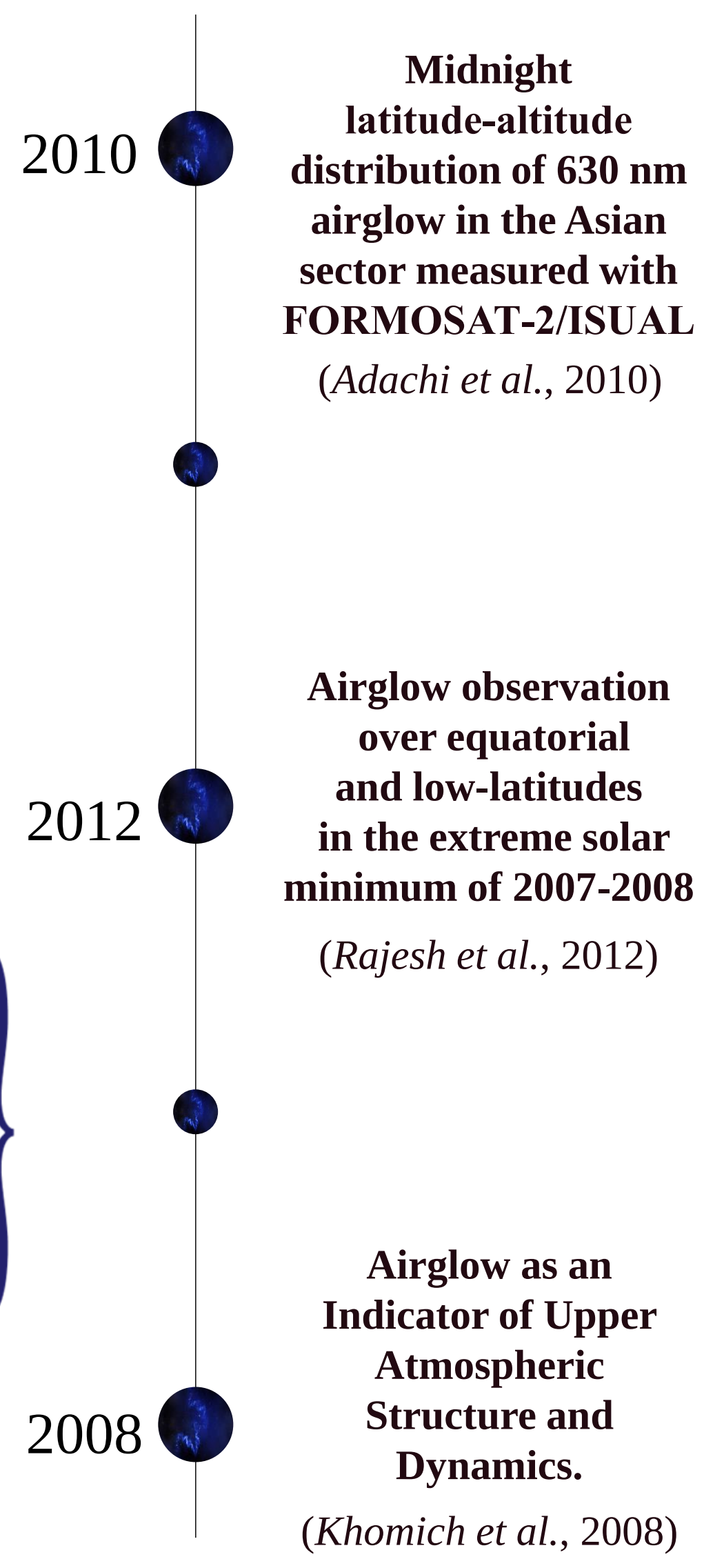


Methodology

Steps



1. Observing system simulation experiments (OSSE)
2. Obtain the peak VER altitude & the thickness of emission layer (constant).
3. Apply Gaussian or Chapman profiles to expand Rayleigh into VER.
4. Sensitivity tests, select 1 inversion model from 3 of them.
5. Retrieve $[O^+]$ with the observed 630.0 nm emission and EM results.
6. Compare retrieved $[O^+]$ with DPS-4 and F3/C measured Ne.

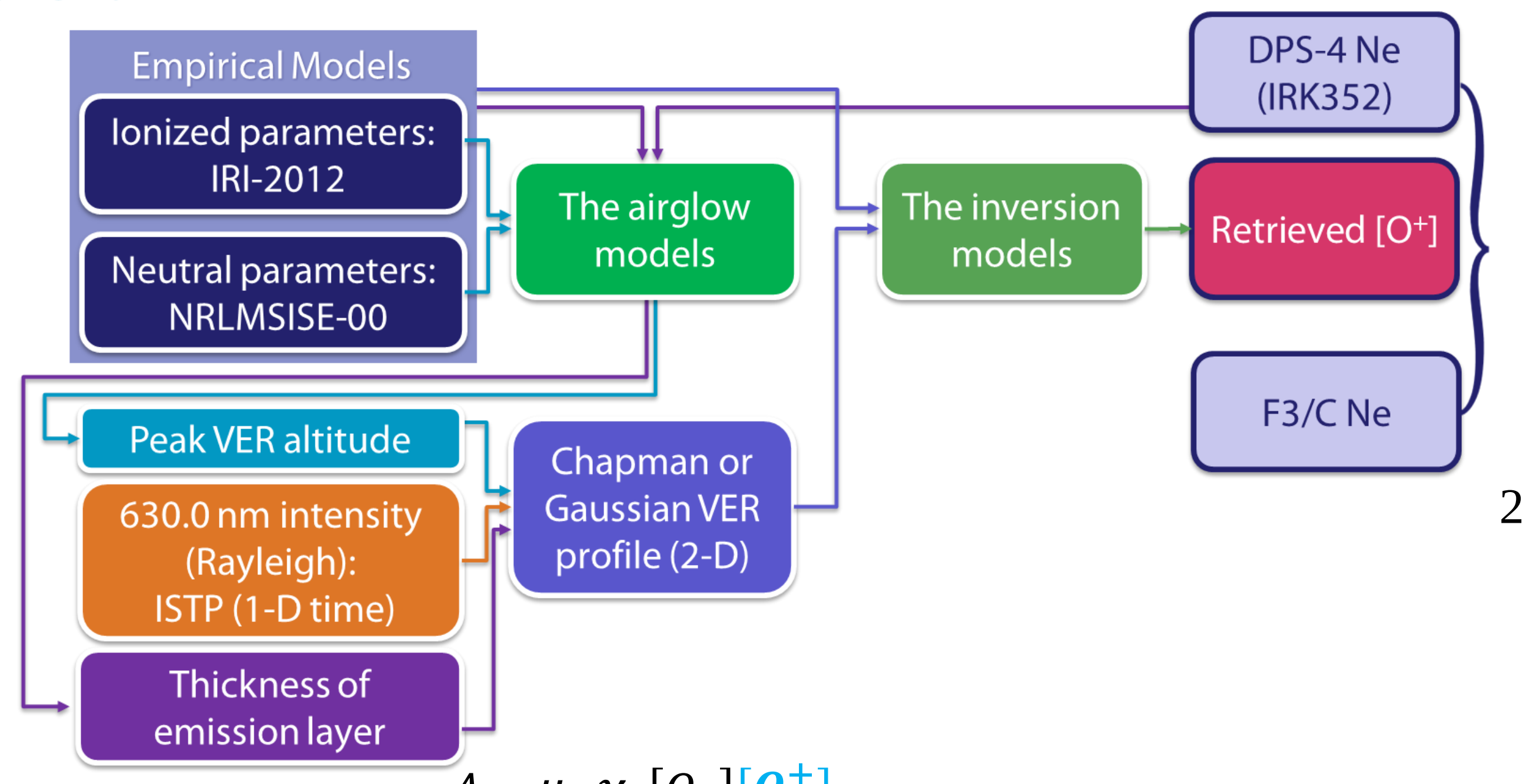


2010 — Midnight latitude-altitude distribution of 630 nm airglow in the Asian sector measured with FORMOSAT-2/ISUAL (*Adachi et al.*, 2010)

2012 — Airglow observation over equatorial and low-latitudes in the extreme solar minimum of 2007-2008 (*Rajesh et al.*, 2012)

2008 — Airglow as an Indicator of Upper Atmospheric Structure and Dynamics. (*Khomich et al.*, 2008)

Retrieval



Empirical Models
Ionized parameters: IRI-2012
Neutral parameters: NRLMSISE-00
The airglow models
The inversion models
DPS-4 Ne (IRK352)
Retrieved $[O^+]$
F3/C Ne
Peak VER altitude
630.0 nm intensity (Rayleigh): ISTP (1-D time)
Thickness of emission layer
Chapman or Gaussian VER profile (2-D)

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

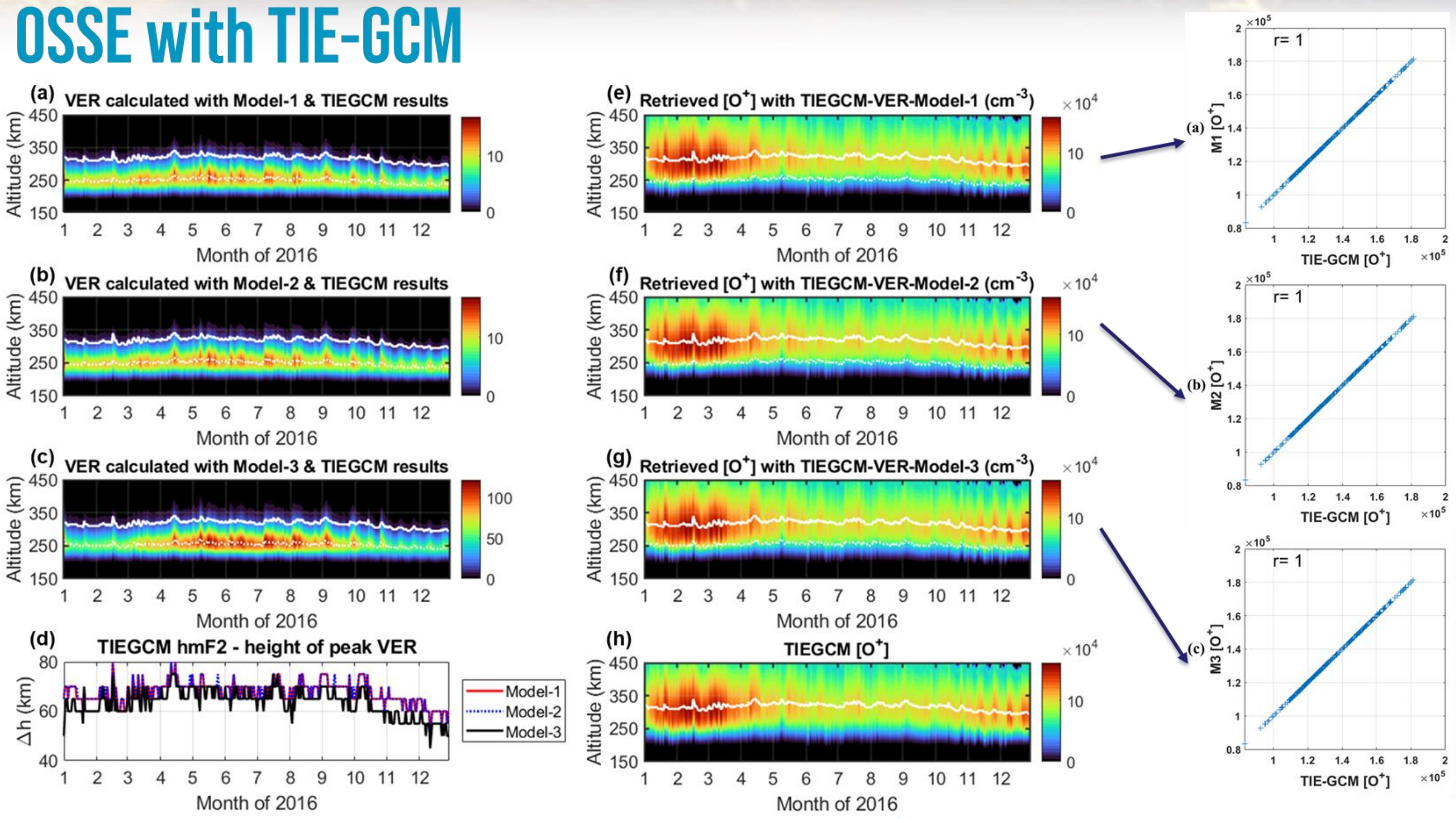
2. $$V630.0 = \frac{0.756\,\mu_D k_3[O_2][O^+]}{1+(k_2[N_2]+k_5[O_2]+k_6[e^-]+k_7[O])/A_{1D}}$$

3. $$V630.0 = \frac{A_{630.0}\cdot\alpha_{O+O_2}\cdot[O^+]\cdot[O_2]+A_{520.0}\cdot\alpha_{NO+eS}\cdot[NO^+]\cdot n_e+\alpha_{NO+eD}\cdot\alpha_{NDO_2}\cdot[NO^+]\cdot[O_2]\cdot n_e}{\{A_{520}+\alpha_{NDO_2}\cdot[O_2]+\alpha_{NDO}\cdot[O]+\alpha_{NDe}\cdot n_e\}\cdot\left\{1+\frac{\beta_{N_2}\cdot[N_2]+\beta_{O_2}\cdot[O_2]+\beta_O\cdot[O]+\beta_e\cdot n_e}{A_{630}+A_{636.4}}\right\}}$$

The inversion models are derived from the airglow models 1-3, to retrieve VER into $[O^+]$. The 630.0 nm airglow intensities observed from the ground are in units of Rayleighs. The brightness is extended into a vertical profile by applying Chapman or Gaussian distribution. A general thickness of the emission layer was then defined based on DPS-4 measured Ne profiles at Irkutsk as both true data and inputs for the airglow models 1 – 3. The profile expansion method is validated well with Riemann Sum.

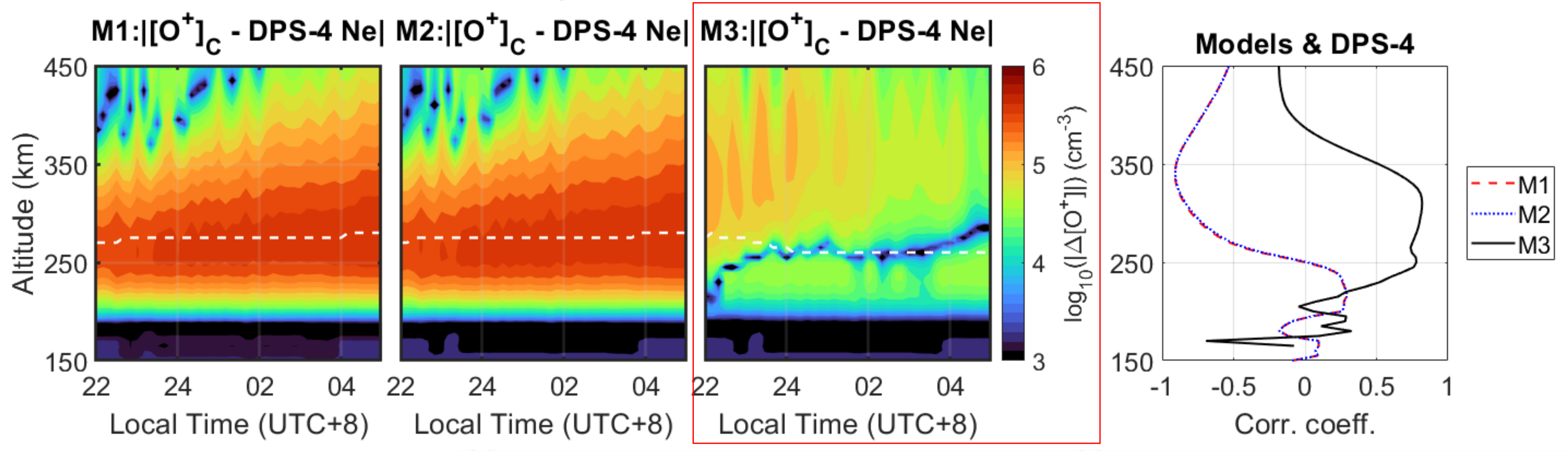
Results

OSSE with TIE-GCM



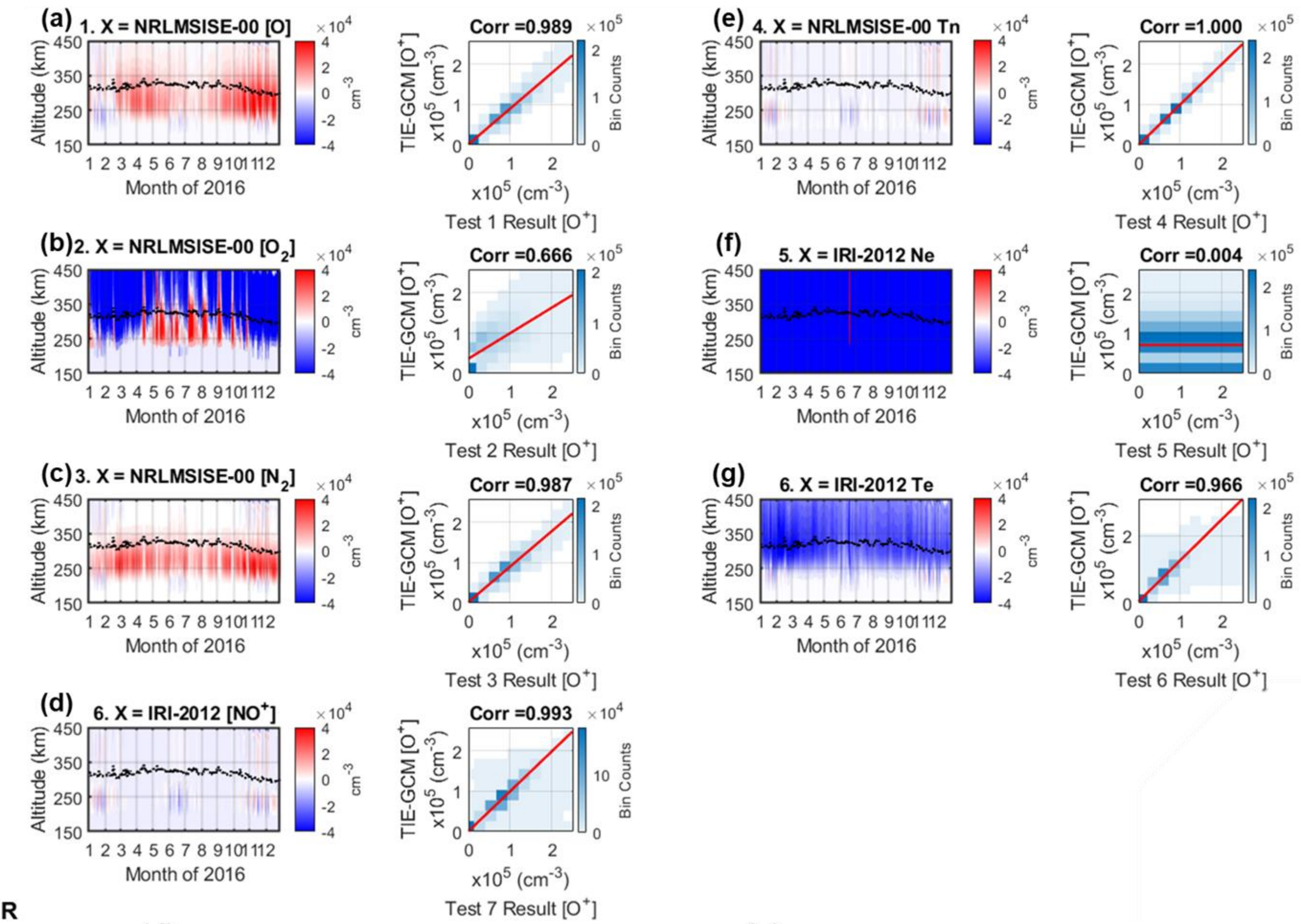
Validation with Empirical models and DPS-4 Ne

The absolute difference of the DPS-4 Ne & the inversion models derived $[O^+]$ w/ the Chapman distributed VER on 2016-Mar-9th

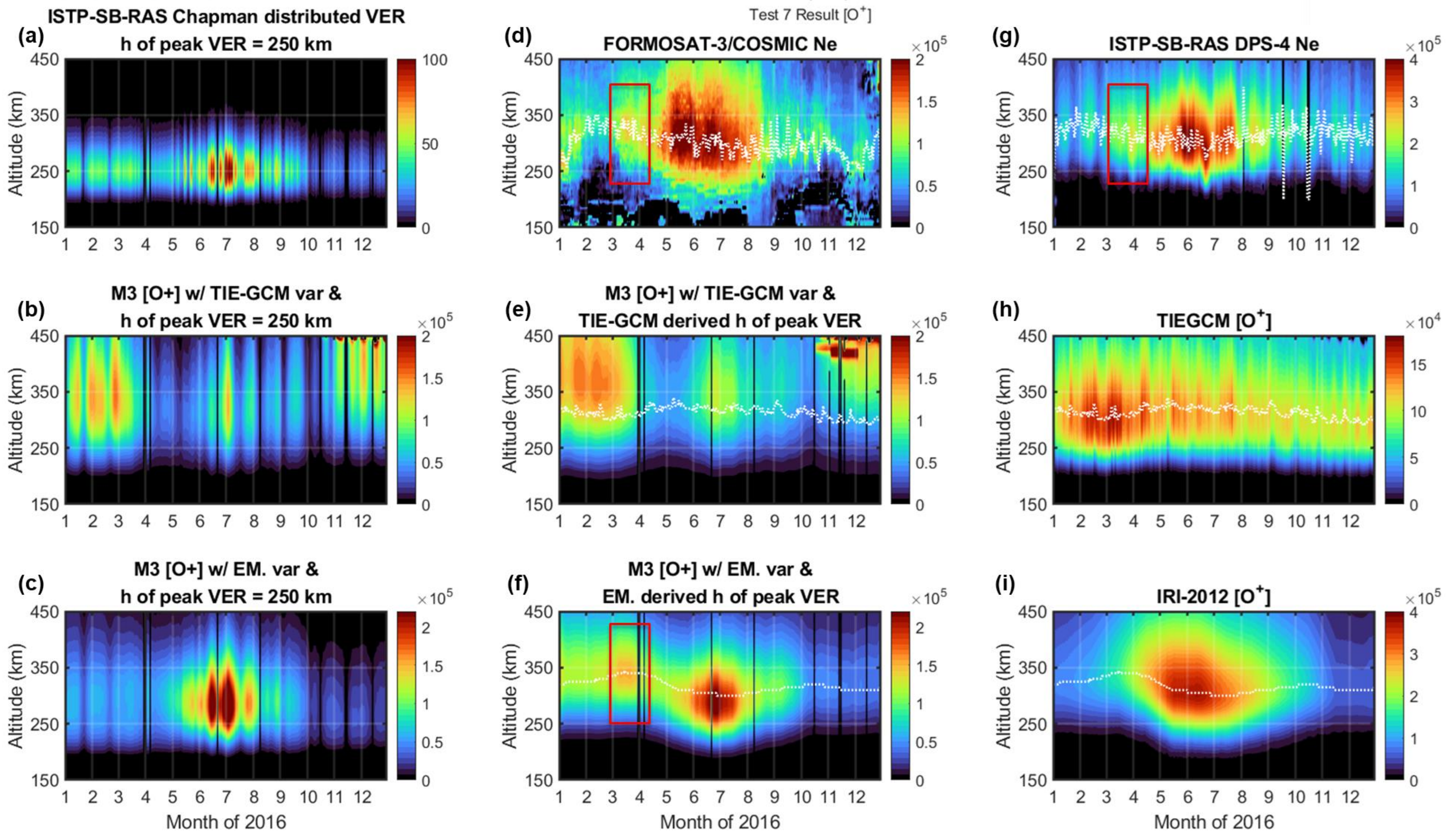


Sensitivity Tests

The correlation and the residual between the TIE-GCM $[O^+]$ and the sensitivity testing results of the inversion Model 3 $[O^+]$ by switching the TIE-GCM components with X: The inversion Model 3 (switch X) – TIE-GCM $[O^+]$.



Retrieval



Conclusions

The Inversion model 3 performs results which is the closest to the observations than the others. The peak VER height has a significant impact to the seasonal pattern of the retrieved [O+]. The sensitivity test manifests that the [O+] generated from the inversion models are sensitive to the variations of the [O2] and Ne especially.

The retrieved [O+] with observed 630.0 nm intensity and EM provided variables is capable of revealing a result similar to both F3/C and DPS-4 observations, and the secondary peak can be manifested more clearly by applying with the airglow model 3 derived peak VER height than in the observations.