Model Strengths and Weaknesses

Recent Developments

Non-Self-Consistent Models

Model	Output	Altitude Range (km)	Resolution	Magnetic Coordinate	Photoionization
IFM	N_i (O^+, H^+, NO^+, O_2^+), N_e, T_i, T_e	90 – 1600	Long. 5˚-15˚ Lat. 2˚-5˚	Best-fit IGRF dipole for each longitude	EUVAC
IPM	N_i (O^+, H^+, NO^+, O_2^+, He^+, N_2^+, N^+), N_e, T_i, T_e	90 – 20000	Long. 3.75 ˚ Lat. < 1˚ at low-latitude	IGRF dipole	EUVAC
LLIONS	N_i (O^+, H^+, NO^+, O_2^+), N_e, T_i, T_e	90 – 10000	Single longitude Lat. 2˚	Best-fit IGRF dipole for each longitude	EUVAC
PBMOD	N_i (O^+, H^+, NO^+, O_2^+, N_2^+), N_e, T_i, T_e	90 – 4000	Long. 7.5˚ Lat. 1˚	IGRF Apex	Hinteregger Fluxes Jasperse CSD (1977)
GIP	N_i (O^+, H^+, NO^+, O_2^+, N_2^+, N^+), N_e, T_i, T_e	90 – 20000	Long. 4.5˚ Lat. 1˚	IGRF Apex	Fluxes (Tobiska model) Cross sec. (Torr and Torr, 1982)
SAMI2	N_i (H^+, O^+, He^+, N^+, NO^+, N_2^+, O_2^+), N_e, T_i (H^+, O^+, He^+), T_e	90 – 20000	Single longitude Lat. 1˚	IGRF-like	EUVAC

IFM (Ionospheric Forecast Model)

Strengths	Weaknesses
✓ Fast solution to the ionosphere on a single magnetic meridian closely aligned with the IGRF field in the low latitude ionosphere. ✓ Each meridian is a best-fit dipole to the IGRF for the chosen longitude. ✓ Solve the ion densities along closed magnetic field lines for low and mid latitude ionosphere. ✓ Uses Titheridge temperature model for ion and electrons, which remains an excellent low and mid-latitude temperature representation. ✓ Drivers of neutral densities and winds and plasma drifts are easily altered for sensitivity studies or data assimilation.	x H+ is provided by a physics-based formula instead of solved simultaneously with the O+. x The magnetic field lines are begin to depart from IGRF field lines as you move away from the dip equator. x Temperatures are not calculated but are empirically determined. x Output is only provided up to 2000 km even though the calculation is made on field lines with apex altitudes of 10,000 km. x No He+ x No interhemispheric flow at mid latitudes x Upper limit of 1500 km. Need to specify topside flux at upper boundary

IPM (Ionospheric-Plasmasphere Model)

Strengths	Weaknesses
✓ Fast solution to the ionosphere on a single magnetic meridian. ✓ Parallel execution of individual magnetic meridional planes. ✓ Solves for ion densities along closed magnetic field lines for low and mid latitude ionosphere. ✓ Designed for ensemble Kalman filter data assimilation. ✓ Neutral densities, winds, and plasma drifts are easily adjustable. ✓ Uses Titheridge temperature model for ion and electrons, which remains an excellent low and mid-latitude temperature representation. ✓ Use of IGRF magnetic field ✓ Rigorous calculation of H+ and He+ ✓ Interhemispheric flow is included	x Temperatures are not calculated but are empirically determined. x Without data assimilation the winds, neutral densities and e-fields are given by empirical models.

LLIONS (Low Latitude IONosphere Sector model)

Strengths	Weaknesses
✓ Fast solution to the ionosphere on a single magnetic meridian closely aligned with the IGRF field in the low latitude ionosphere. ✓ Each meridian is a best-fit dipole to the IGRF for the chosen longitude. ✓ The solves the O+ along closed magnetic field lines for low and mid latitude ionosphere. ✓ Uses Titheridge temperature model for ion and electrons, which remains an excellent low and mid-latitude temperature representation. ✓ Drivers of neutral densities and winds and plasma drifts are easily altered for sensitivity studies or data assimilation. ✓ Many LLIONS runs in parallel can be used to generate the global low-latitude ionosphere.	x H+ is provided by a physics-based formula instead of solved simultaneously with the O+. x The magnetic field lines are begin to depart from IGRF field lines as you move away from the dip equator. x Temperatures are not calculated but are empirically determined. x Output is only provided up to 2000 km even though the calculation is made on field lines with apex altitudes of 10,000 km. Note that LLIONS is essentially the same code as the IFM for the low latitude ionosphere.

PBMOD (Physics Based MODel)

Strengths	Weaknesses
✓ Solves transport along complete flux tube (low & mid mag. Lats)	x Not closely coupled with a dynamo model to provide drifts
✓ Uses IGRF magnetic field model	x Not self-consistently coupled with a thermosphere model
✓ Built to accept numerous sources of driver	x Uses old solar EUV flux (Hinteregger)
✓ Validated density profiles	
✓ Output in standard netcdf format permits coupling to other models • RT growth rate • 3D EPB/radio scintillation models	

GIP (Global Ionosphere and Plasmasphere model)

Strengths	Weaknesses
✓ 1st principles model which solves transport along complete flux tube.	x Temperatures are not calculated but are empirically determined.
✓ Physics are based on the CTIPe	x Somewhat unstable
✓ Close flux tubes between +/- 60 deg mag lat and open flux tubes with upper boundary at 10,000 km in high latitudes.	x No He+ and hydrogen is specified according to MSIS.
✓ Adopt the Apex Coordinates	
✓ Built to accept numerous sources of driver	
✓ somewhat flexible, i.e., can add more ions relatively easily, can use different EUV models	

SAMI2 (Sami2 is Another Model of the Ionosphere)

Strengths	Weaknesses
✓ 1st principles model ✓ covers +/- 60 deg mag lat ✓ uses IGRF-like field ✓ seems to be robust ✓ uses empirical neutral models and E x B drifts (although drifts can be specified analytically or by data) ✓ includes ion inertia along B ✓ somewhat flexible, i.e., can add more ions relatively easily, can use different EUV models	x Photoelectron heating model is 'weak' note: Roger Varney has developed a physics based photoelectron heating model for sami2 but it is very computationally expensive. x small time step so it is more computationally intensive than other ionosphere models

Self-Consistent Models

Model	Output	Lower Boundary Condition	Altitude Range (km)	Ionosphere Resolution	Mag. Coord.	Photo-ionization
SAMI3	H^+, O^+, He^+, N^+, NO^+, N_2^+, O_2^+, N_e, T_i (H^+, O^+, He^+), T_e, Φ	HWM93	85 – 20000	Long. 3.75° Mag. Lat. 1°	Tilt Dipole	EUVAC
TIEGCM	Neutral Composition, U_n, V_n, T_n, T_i, T_e, N_e, O^+, NO^+,O_2^+, Z, Φ	GSWM02 migrating diurnal and semidiurnal tides	97 to 450 – 600	Long. 5° Lat. 5°	IGRF Apex	EUVAC for <1050 Woods & Rottman [2002] for >1050A
TIMEGCM	Neutral Composition, U_n, V_n, W, T_n, T_i, T_e, N_e, O^+, O_2^+, NO^+, N_2^+, N^+, Z, Φ	GSWM migrating diurnal and semidiurnal tides	30 to 450 – 600	Long. 5° Lat. 5°	IGRF Apex	EUVAC for <1050 Woods & Rottman [2002] for >1050A
GITM	Neutral Composition, U_n,V_n,W_n,T_n, V_i, T_i, O^+, O_2^+, NO^+, N_2^+, N^+, T_e, N_e, Φ	GSWM migrating diurnal and semidiurnal tides	100 – 700	Long. 5° Mag. Lat. 1°	IGRF Apex	EUVAC Hinteregger's SERF1 model
CTIPe	Neutral Compositions, U_n,V_n,T_n, T_i, O^+, H^+, O_2^+, NO^+, N_2^+, N^+, N_e, Φ	migrating semidiurnal tides	Thermosphere 80 – 500 Ionosphere 80 –10000	Long. 18° Lat. 2°	Tilt Dipole	EUVAC for <1050 Woods & Rottman [2002] for >1050A

SAMI3 (SAMI3 is Also a Model of the Ionosphere)

Strengths	Weaknesses
✓ 1st principles model ✓ covers +/- 88 deg mag lat ✓ uses IGRF field but only for low- to mid-latitude ✓ seems to be robust ✓ can use empirical neutral models and TIMEGCM for neutral data ✓ includes ion inertia along B ✓ somewhat flexible, i.e., can add more ions relatively easily, and different EUV models ✓ solves for neutral wind dynamo ✓ can use volland/stern, Weimer, and RCM for high latitude convection potential ✓ can model ionosphere/plasmasphere system	x Photoelectron heating model is 'weak' note: Roger Varney has developed a physics based photoelectron heating model for sami2 but it is very computationally expensive. x small time step so it is more computationally intensive than other ionosphere models (e.g., TIEGCM) x E region needs improvement x too much ion heating at high latitude/ altitude x electron density/TEC may be too high at very large F10.7 (> 200)

TIEGCM (Thermosphere Ionosphere Electrodynamics General Circulation Model)

Strengths	Weaknesses
✓ Fully coupled neutral dynamics and ionospheric electrodynamics	X At the lower boundary the prescribed background atmosphere is simplified
✓ Accurate treatment of solar EUV and photoelectron processes, including capability of using EUV measurements	X At the upper boundary a simple LT-varying O+ flux is specified and no plasmasphere is included.
✓ Comprehensive photochemistry and thermodynamics	X Possible mismatch of the auroral precipitation pattern with the ion convection pattern at high latitude.
✓ Choice of high latitude inputs: Heelis, Weimer, AMIE, or coupling to magnetospheric models (CISM/CMIT)	X Predefined region for the high latitude ion convection pattern is independent of the geophysical conditions which leads to non-physics based penetration electric fields.
✓ Tidal and wave perturbations can be specified at the lower boundary	

GITM (Global Ionosphere-Thermosphere Model)

Strengths	Weaknesses
✓ Ease of use and ease of programming. This makes it so it is very easy to swap in and out new features to experiment with different physics. ✓ Flexibility. GITM can be run at just about any resolution and with all sorts of different electric fields, magnetic configurations, auroral precipitation models and waves at the lower boundary. It can be run in 1D, 3D global and 3D regional modes. ✓ Chemistry does not assume steady-state. ✓ Neutrals are non-hydrostatic, so it can capture acoustic waves and other small-scale structures that other models can't.	x Newness / Lack of user base. With only a few people using it all of the time, it is hard to validate it and tune it correctly. Therefore, there are obvious things that should be fixed, but are not really being worked on. (Send money.) x Very small time-step. In order to resolve acoustic waves, the time step is 2-3 seconds. Code still runs at around 20 times real-time, but you have to use ~32 processors to run at the same resolution as the TIEGCM (5x5) or more for high resolution. x Altitude limited, so that it doesn't solve along a magnetic field-line. So, when there are large vertical flows, the ion density can squirt out the top. That is very bad. Boundary conditions at the top are poorly specified.

CTIPe (Coupled Thermosphere Ionosphere Plasmasphere Electrodynamics Model)

Strengths	Weaknesses
✓ Includes fully coupled global thermosphere, high-latitude ionosphere, mid- and low-latitude ionosphere/plasmasphere, and electrodynamics calculation of the global dynamo electric field. ✓ Includes the topside ionosphere and plasma transport so does not require an artificial boundary condition ✓ 1-min time step ✓ Continuously being improved and validated using satellite and ground-based observations ✓ Short time forecast (20 min ahead of real-time) are available	x Longitude resolution is 18° (to be improved) x Vertical resolution for thermosphere is 1 scale height (currently being improved to 1/4 scale height) x Use tilted dipole, instead of International Geomagnetic Reference Field (IGRF) magnetic field x Plasma transport perpendicular to the magnetic field not seamless between the high and mid/lower latitude ionosphere components