Ionospheric Models

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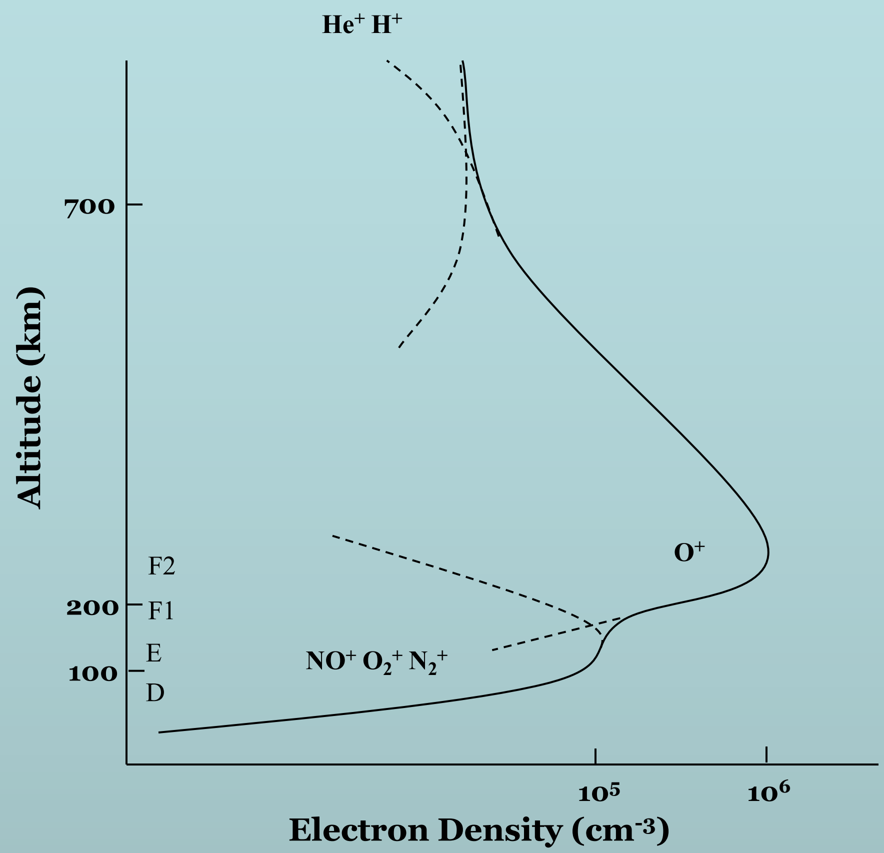
CEDAR-GEM Student Workshop, June 26, 2011

Earth's Ionosphere



Typical daytime midlatitude Ionosphere.

- **Ionosphere has layered structure**
- **Ion composition varies with altitude**
- **Different processes dominate at different regions**

  D, E: chemical processes

  F: plasma transport

- **Ionosphere density varies with**

  Latitude,

  Longitude,

  Universal Time,

  Season,

  Solar Cycle,

  Geomagnetic Activity.

Earth's Ionosphere

- Ionosphere displays large variability due to various processes in the ionosphere-thermosphere system.
- It is influenced by solar, interplanetary, magnetospheric and mesospheric processes.
- Ionosphere is characterized by background state (climatology) and disturbed state (weather).
- Ionosphere influences on military and civilian communication, surveillance and navigation systems, satellite operation, etc.
- It has very interesting physics.

Importance

- Model studies are alternatives of direct measurements.
- They help to test our knowledge and improve our understanding of the system.
- Can get parameters that are not always accessible to measurements.
- Numerical experiments are cheaper and convenient to study various processes.

Characteristics of Ionospheric Models

- Outputs of Ionospheric models are electron density along with other parameters (T_e, T_i, ion composition, drifts, etc.).
- Models might be global or regional.
- There are no all-purpose ionospheric models.
- All ionospheric models need some type of input data.
- Current ionospheric models are constantly undergoing improvements and validations.

Types of models

- **Empirical**
  (IRI)
- **Parameterized**
  (PIM, SLIM, FAIM, ICED)
- **Physics-Based** (stand-alone)
  (USU-TDIM, IPM, IFM, FLIP, SAMI2, SAMI3)
- **Data Assimilation**
  (GAIM-FP, GAIM-GM, JPL/USC GAIM)
- **Coupled Physics-Based**
  (TIE-GCM, CTIM, CTIP, GTIM, SUPIM, CMIT)

Empirical Models

- Empirical models attempt to model systematic ionospheric variation from the historic data records.

- **Data sources:** Ionosondes, topside sounders, incoherent scatter radars, rockets and satellites.

- **Model construction:** Data are synthesized, binned with appropriate indices and fitted with either analytic expressions or orthogonal functions.

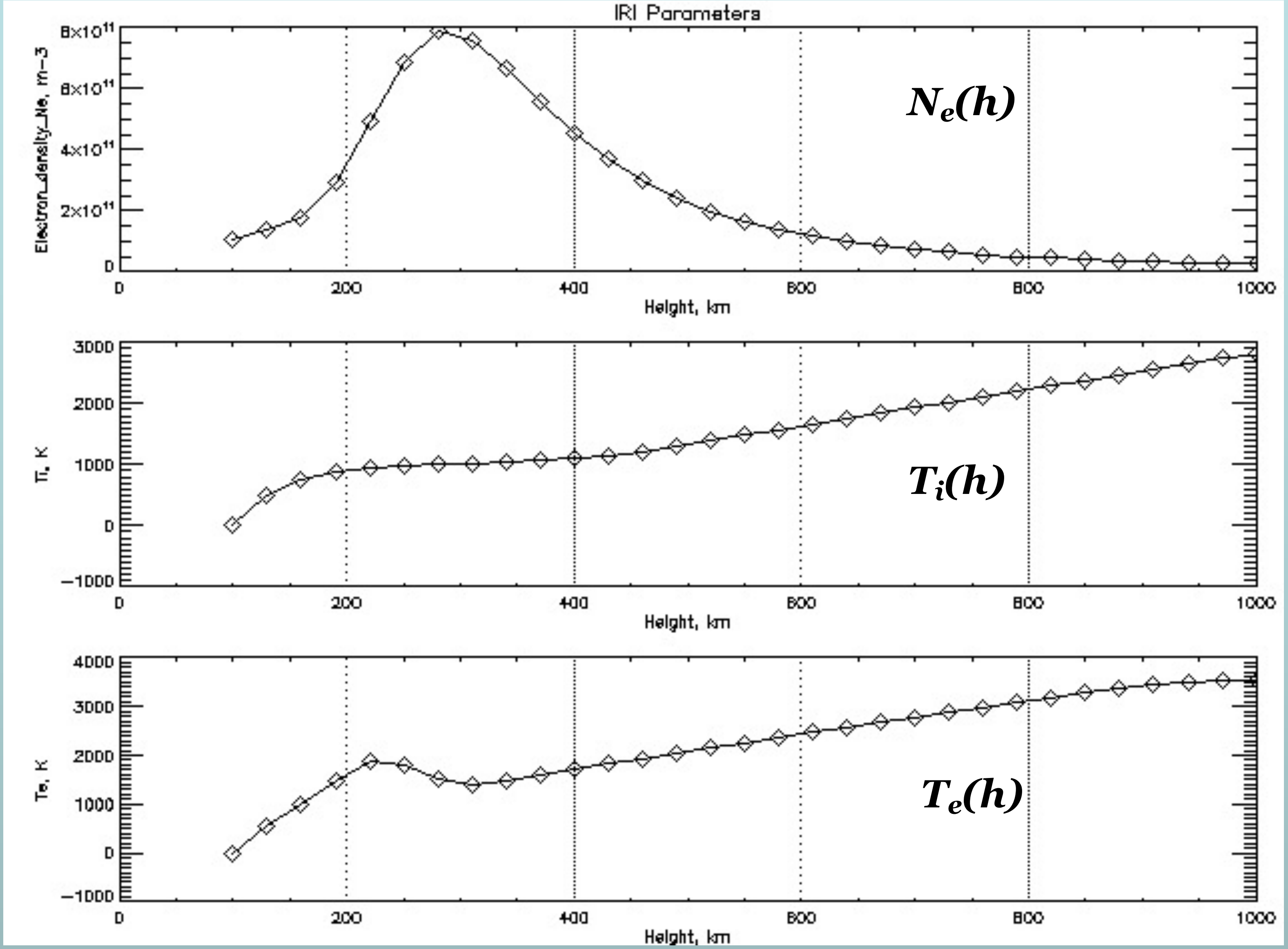
Empirical Models

Purpose and limitations:

- Models are mainly used for specification and forecasting purposes.
- Empirical models describe average conditions.
- Models are realistic in the areas sufficiently covered by observations.
- Easy to use.

Empirical Models

Example:



Parameterized Models

- Parameterized models simplify the theoretical models by expressing them in terms of solar-terrestrial parameters and geographic locations.

- They are based on orthogonal function fits to data that are output of physics-based models.

- Theoretical model runs are performed for various helio-geophysical conditions and parameterization is usually done in terms of solar activity, geomagnetic activity and season.

Parameterized Models

Purpose and limitations:

- Parameterized models describe the climatology of the ionosphere.

- They are suitable only for well-specified geophysical problems.

- Parameterized models cannot accurately reproduce specific situations.

- They are computationally fast still retaining physics of theoretical models.

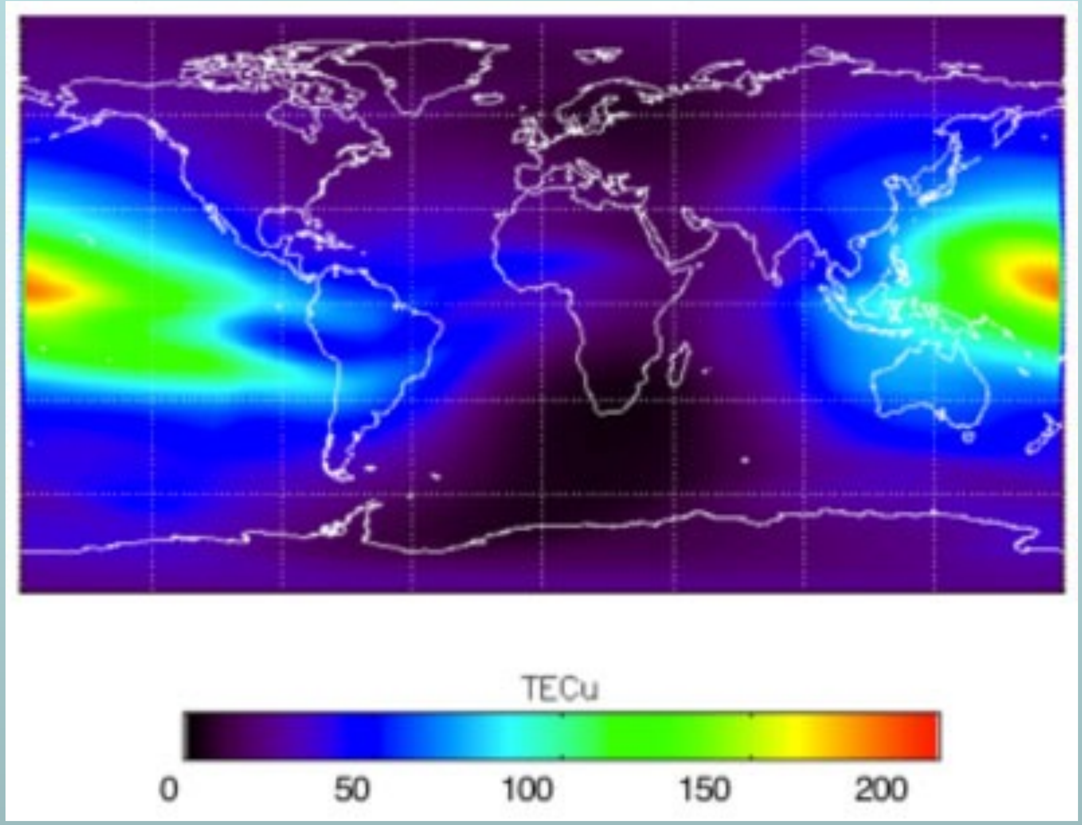
Parameterized Models

Example:

PIM-Parameterized Ionosphere Model (90-25000 *km*)

Input: *UT,DOY,F10.7,Kp*

Output: $N_e(h)$, *foF2, foE, hmF2, hmE, TEC*



TEC

September 22

UT=1:39

F10.7= 200.

Physics-Based Models
(stand-alone ionosphere)

- The models solve 3-D time dependent equations of continuity, momentum and energy for the electrons and ions (mainly NO^+, O_2^+, N_2^+, N^+, O^+, He^+, H^+) numerically.

- All important chemical and transport processes are taken into account (solar production, chemical production and loss, ambipolar and thermal diffusion, *i-i, i-n* and *e-n* collisions, etc.).

- Requires:

Magnetospheric input - (convection electric field and particle precipitation)
Atmospheric input - (neutral densities, temperatures and winds)
Dynamo and storm-time electric field at low latitudes.

Geomagnetic field (fixed, no time variations)

These are usually specified by corresponding empirical models.

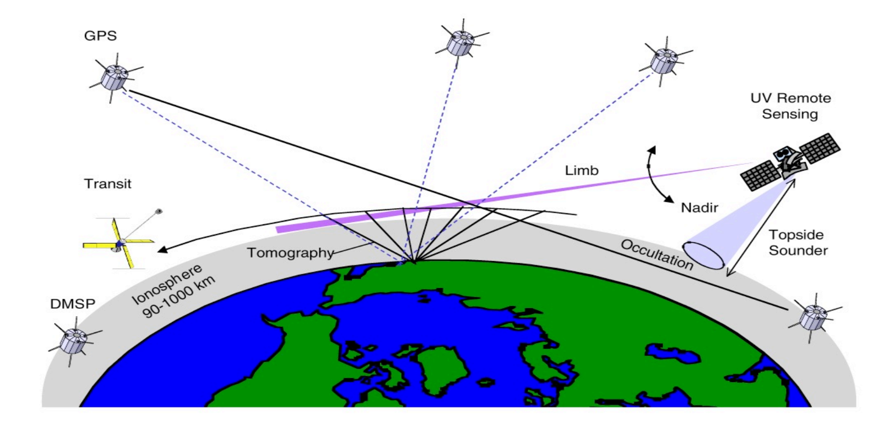
Physics-Based Models

Purpose and limitations:

- Physics-based models are mainly used for scientific studies.
- Uncertainty in the input parameters is the main limitation of using theoretical models for prediction and forecasting.
- An extensive preparation of inputs is needed to obtain meaningful results.

Data Assimilation Models

- Models combine measurements from observing system with the information obtained from theoretical model trough the data assimilation technique.
- The outputs of 3-D ionosphere have parameters closer to the observations.
- They estimate physical drivers (neutral wind, neutral composition, electric field, etc.) that are self-consistent with the calculated ionospheric parameters.
- Assimilated data may have different sources.



Data Assimilation Models

Purpose and limitations:

- Models can be used for the studies of both, ionospheric climatology and ionospheric weather.

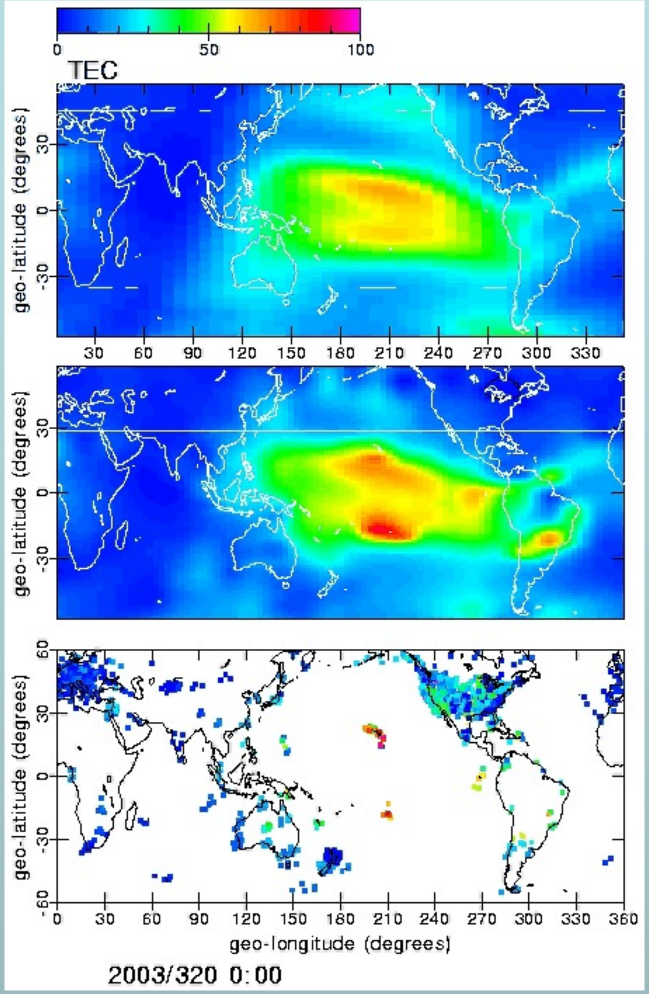
- The accuracy of the reconstructed ionosphere depends on the amount of assimilated data, the diversity of the data types and the quality of the data.

- Very little data results in the output that is primarily background theoretical model.

Data Assimilation Models

Example:

GAIM-FP Global Assimilation of Ionospheric Measurements-Full Physics (90-20,000 *km*)



Physics-Based

Data assimilation

Global TEC data

Coupled Physics-Based Models

- Such models do not need atmospheric and/or magnetospheric input.

- They include coupling processes, time delays and feedback mechanisms inherent in the near Earth environment.

- Currently there are ionosphere-thermosphere, ionosphere-polar wind, ionosphere-thermosphere-mesosphere and ionosphere-thermosphere-plasmasphere coupled global models.

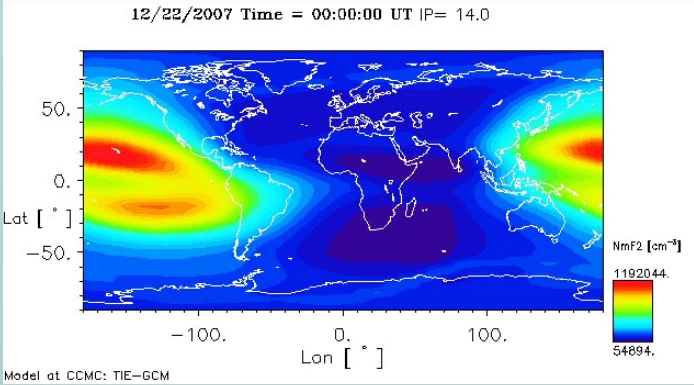
- More recently, work began to couple global ionosphere/thermosphere models to MHD models of global magnetosphere.

Coupled Physics-Based Models

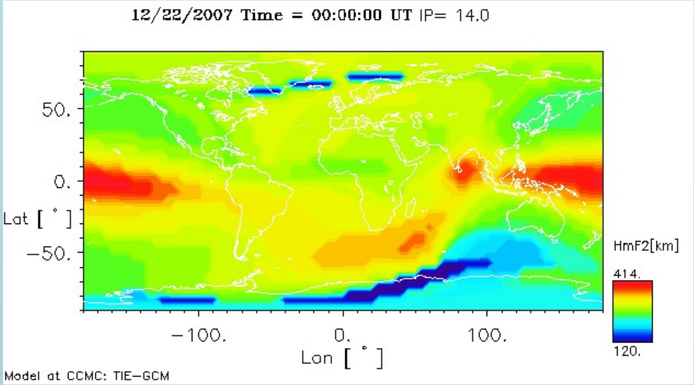
Example:

TIE-GCM Thermosphere-Ionosphere Electrodynamics General Circulation Model (70-600 *km*)

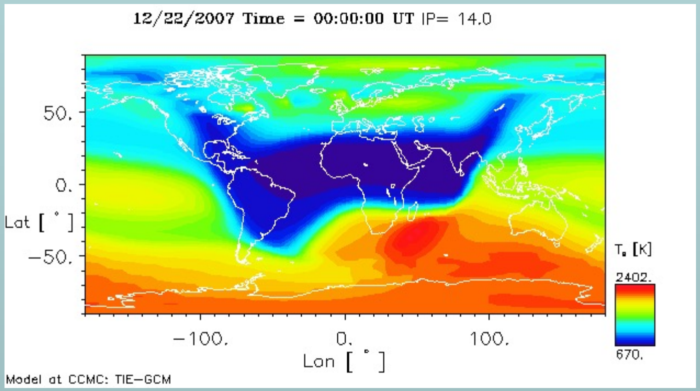
NmF2



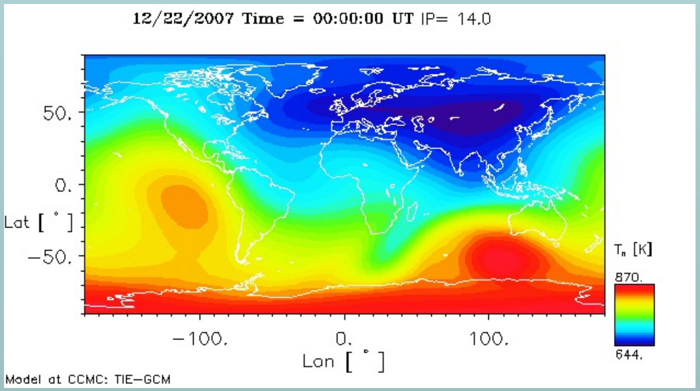
hmF2



T_e



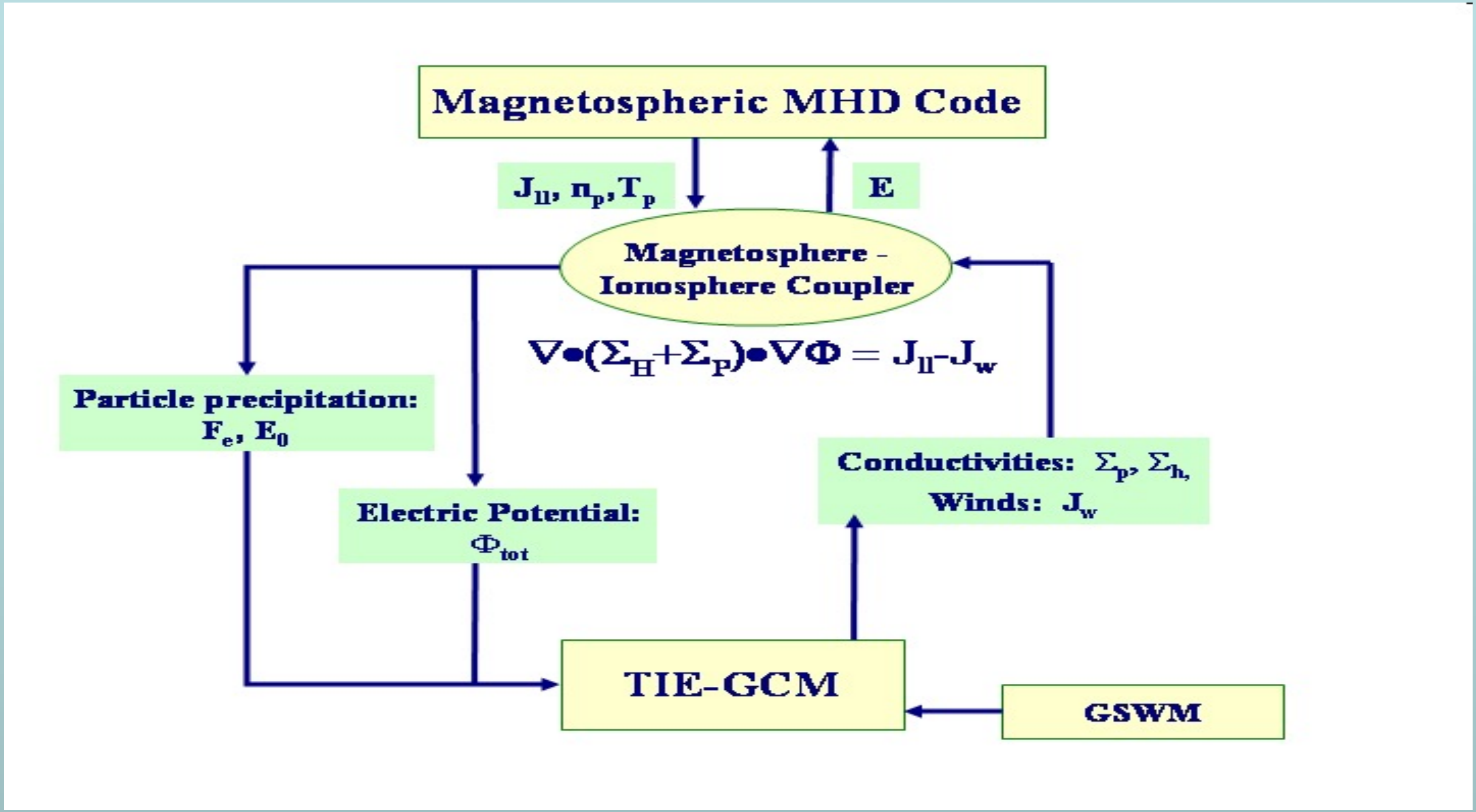
T_n



Coupled Physics-Based Models

Example:

CMIT - Coupled Magnetosphere Ionosphere Thermosphere model



Questions?