Uncertainty Analysis of Model Output

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Outline

1. **Problems with Physics –Based Models**
2. **Uncertainty Analysis: Formal Procedure**
3. **Determining Uncertain Parameters**
4. **Ensemble Modeling**

1. Problems with Physics-Based Models

- **Relatively Simple Math Formulations**

  Diffusion, MHD, etc.

- **Uncertain Parameters**

  Chemical Rates, Collision Freq., etc.

- **Incomplete or Approximate Coupling**

  Kinetic & Fluid Formulations

- **Spatial & Temporal Resolutions are Coarse**
- **Missing Physics**

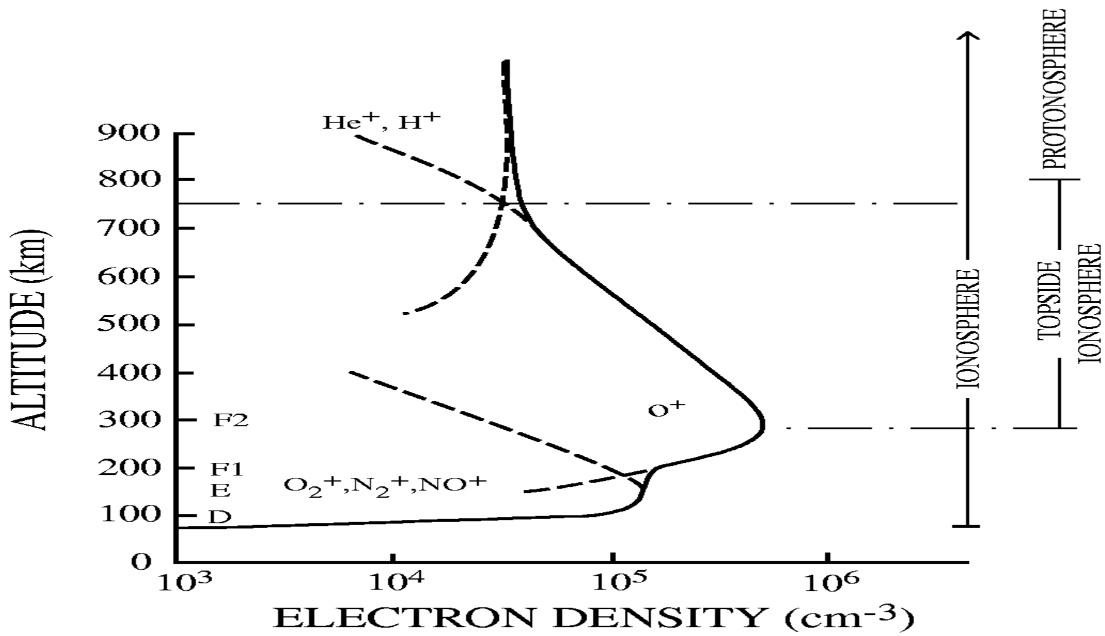
Photoionization

$$
\begin{array}{lll}
O + h\nu & \longrightarrow & O^+ + e \\
N + h\nu & \longrightarrow & N^+ + e \\
He + h\nu & \longrightarrow & He^+ + e \\
O_2 + h\nu & \longrightarrow & O_2^+ + e \\
N_2 + h\nu & \longrightarrow & N_2^+ + e \\
 & & \longrightarrow \quad N^+ + N + e \qquad 21\%
\end{array}
$$

$\lambda <$ 796 Å F-region

$\lambda \sim$ 796 – 1027 Å E-region

Ion Chemistry



F-Region

$$O + h\nu \rightarrow O^+ + e^*$$

$$O^+ + N_2 \rightarrow NO^+ + N$$

$$O^+ + O_2 \rightarrow O_2^+ + O$$

Topside

$$O^+ + H \Leftrightarrow H^+ + O$$

$$He^+ + N_2 \rightarrow N^+ + N + He$$
$$He^+ + N_2 \rightarrow N_2^+ + He$$
$$He^+ + O_2 \rightarrow O^+ + O + He$$

$$N_2^+ + O_2 \rightarrow O_2^+ + N_2$$
$$N_2^+ + O \rightarrow O^+ + N_2$$
$$N_2^+ + O \rightarrow NO^+ + N$$

Recombination

$$NO^+ + e \rightarrow N + O$$
$$O_2^+ + e \rightarrow O + O$$
$$N_2^+ + e \rightarrow N + N$$

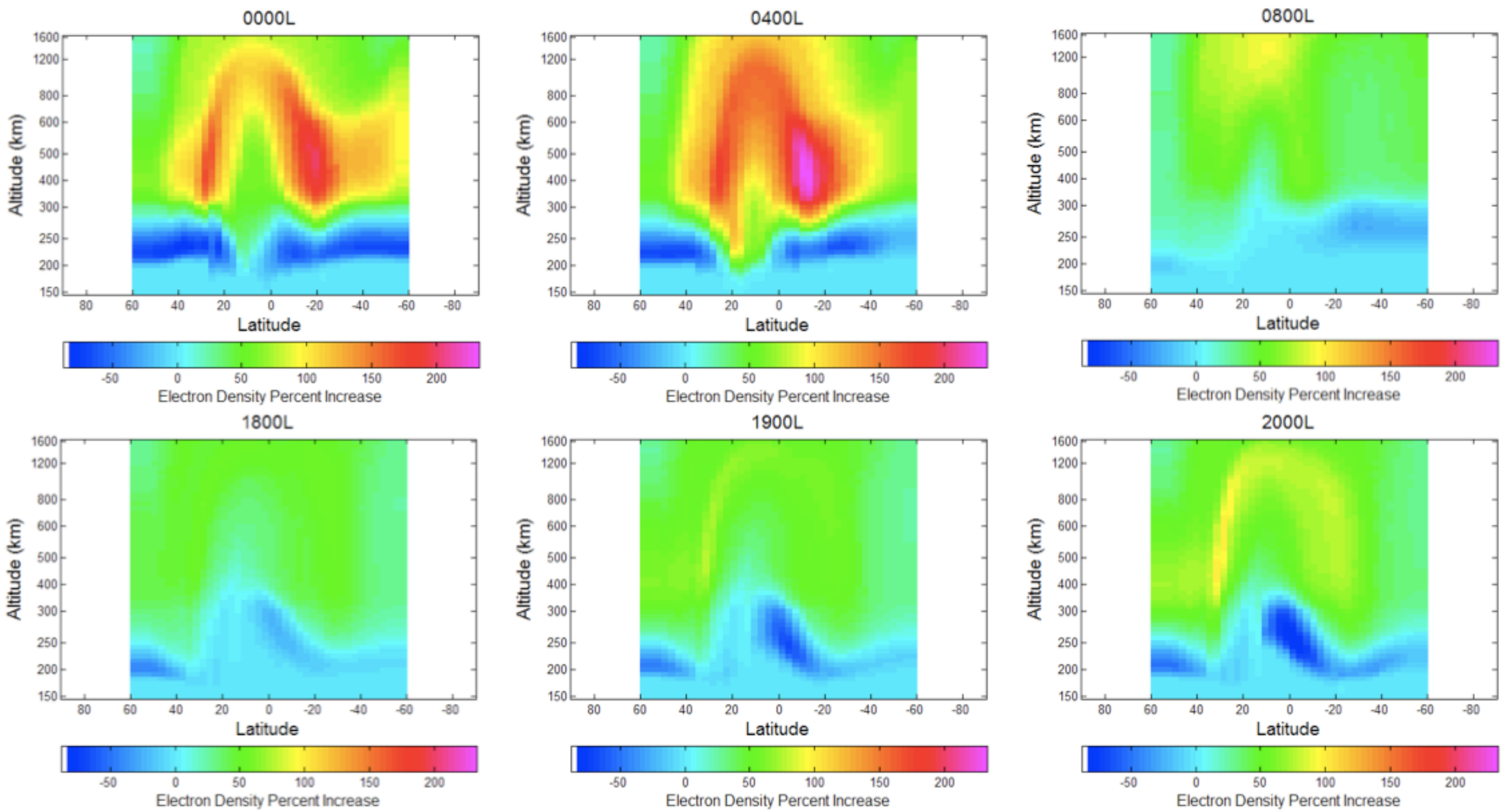
(fast process)

not important for density calculation

$$\begin{cases} O^+ + e \rightarrow O + h\nu \\ N^+ + e \rightarrow N + h\nu \\ He^+ + e \rightarrow He + h\nu \end{cases}$$

radiative recombination (slow process)

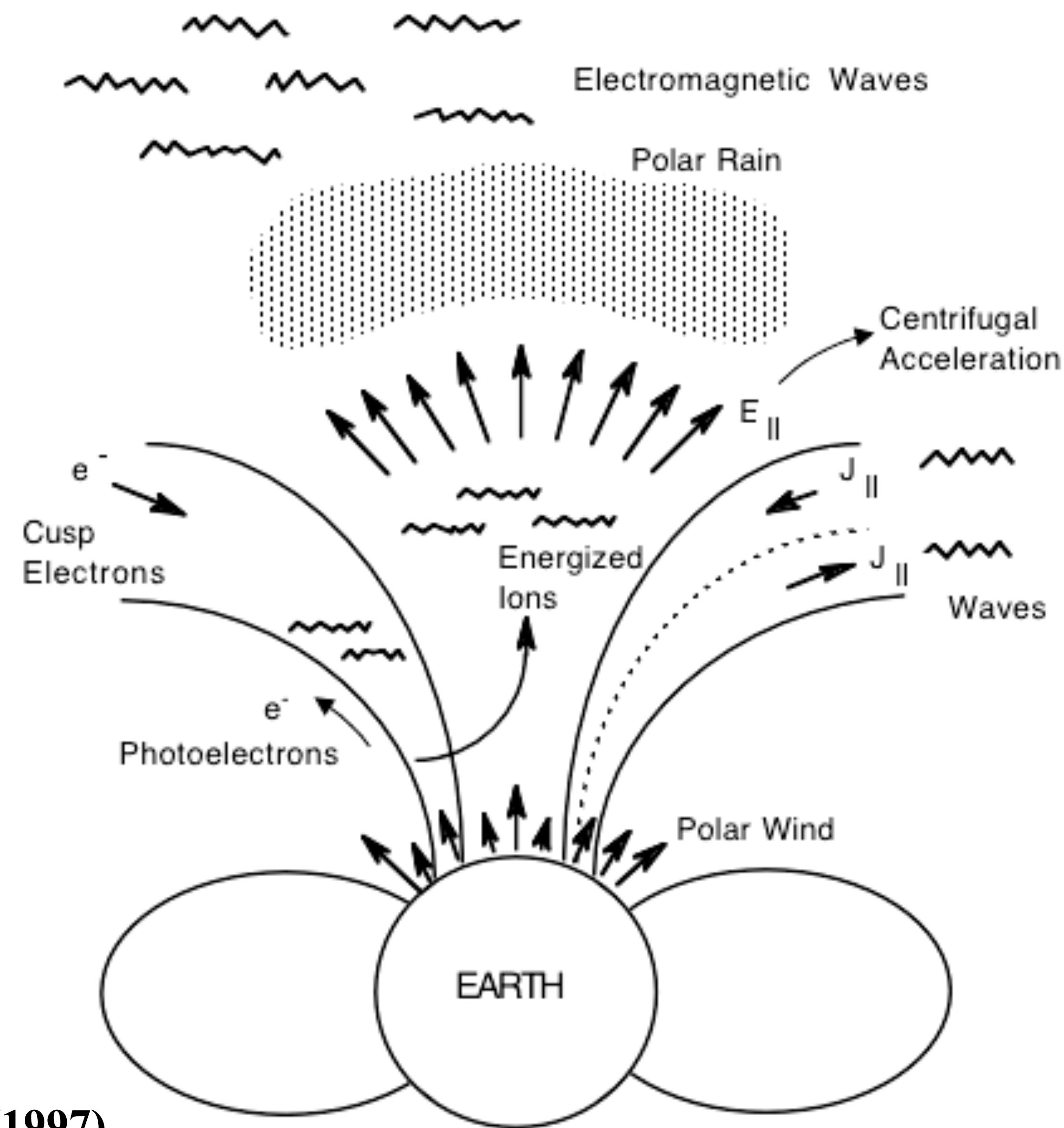
O^+ - O Collision Frequency
(Factor of 2 – Factor of 1)



% difference, 0º E, Solar Minimum, December, Low Kp

Jenniges et al (2010)

Downward Electron Heat Flow



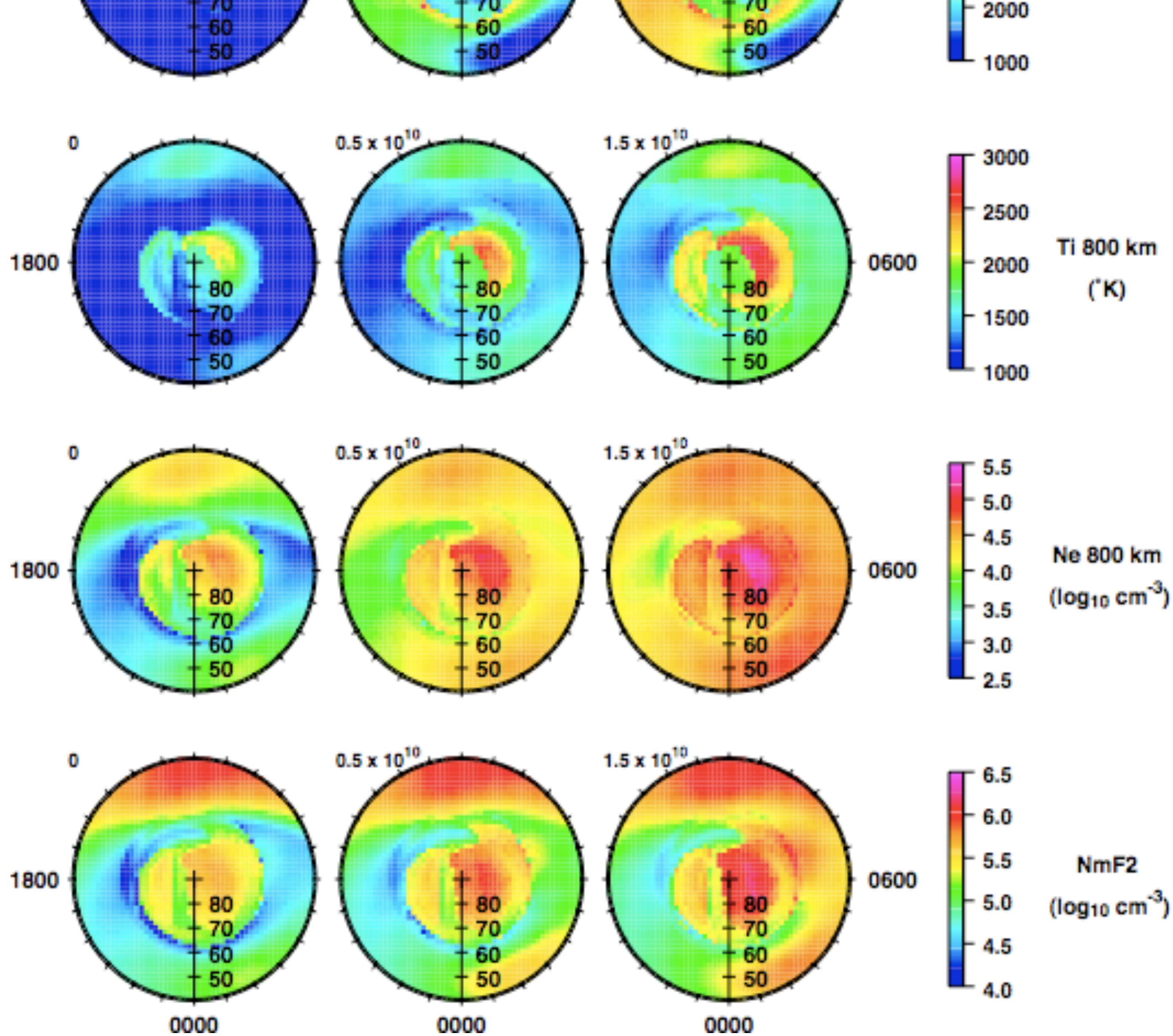
Schunk & Sojka (1997)

Winter
(day = 357)

Solar Medium
(F10.7 = 160)

Quiet
(Kp=2)

0500 UT



Q_T = 0.0 0.5 1.5 x 10^{10} eVcm^{-2} s^{-1}

David et al (2010)

2. Uncertainty Analysis: Formal Procedure

- List all Chemical Rates, Collision Freq., etc., with Uncertainties
- List Physics not Included in the Model and Estimate Effect
- Conduct two Simulations => One with Lower end of Uncertainties and one with Upper end of Uncertainties (including missing physics estimates and different spatial resolutions)
- Spread in Output is the Uncertainty

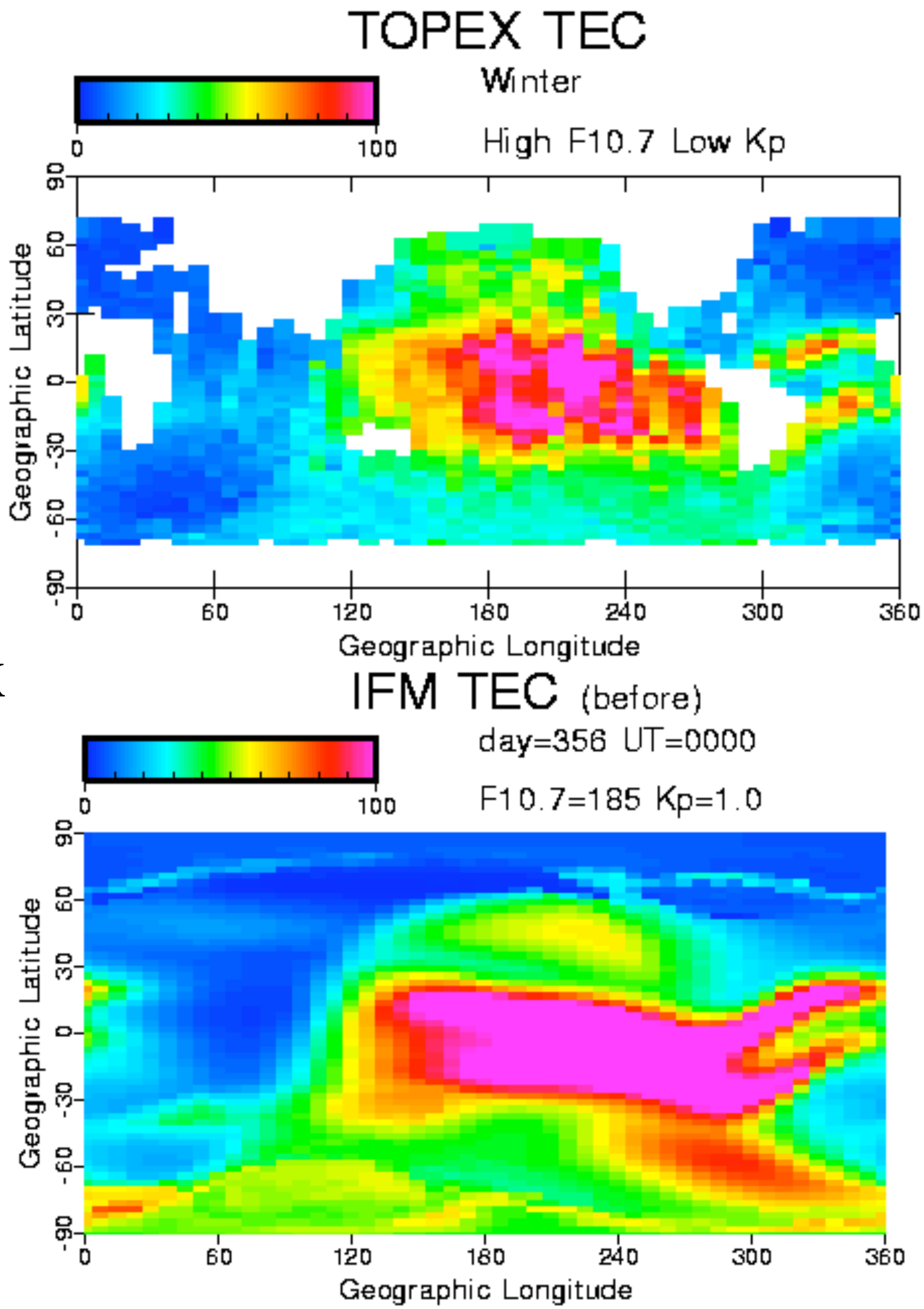
3. Determining Uncertain Parameters in IFM

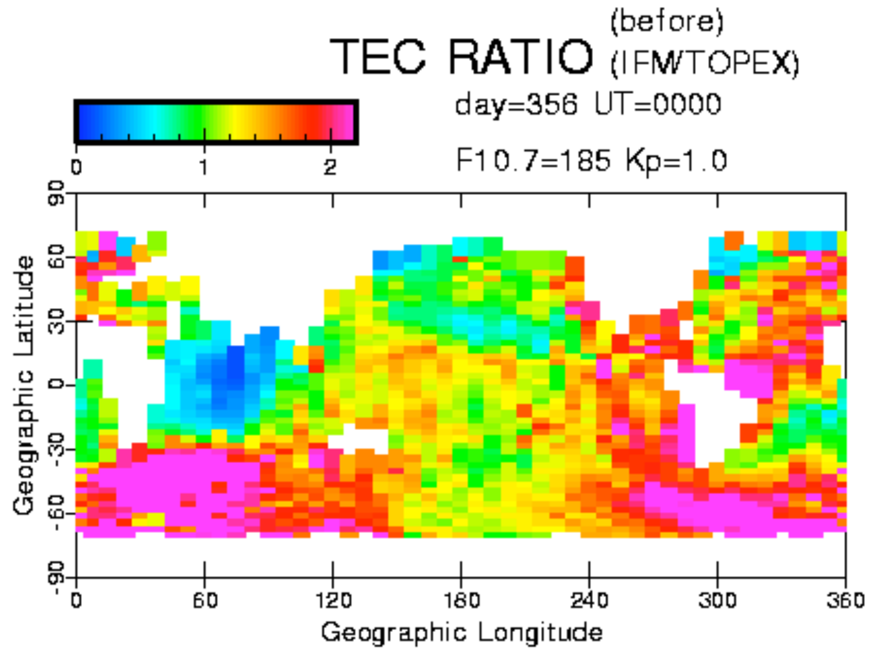
- IFM TEC Compared to TOPEX TEC
- TOPEX Measures Vertical TEC Over Oceans (1340 km)
- 10 - Year TOPEX Data Base (1992-2003)
- 18-Sec Averaged Data = 11 Million TEC Values
- Comparisons Covered Different Seasonal, Solar Cycle, and Magnetic Activity Conditions
- Uncertain Parameters in the IFM Adjusted to Bring IFM into Better Agreement with TOPEX TEC
- Also Compared to 10-year Ionosonde Dataset

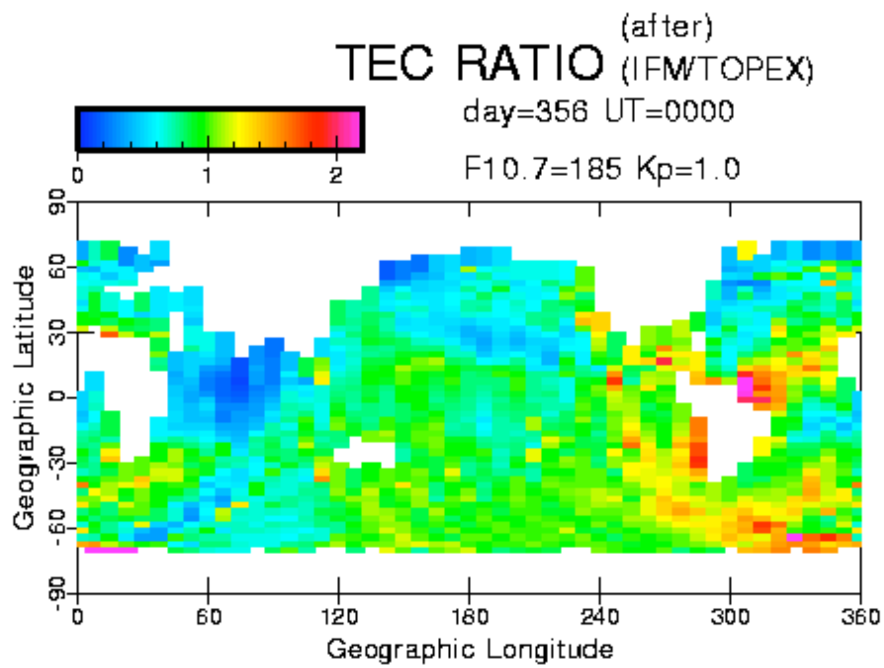
Winter

Low Kp

Solar Max




(before)
TEC RATIO (IFM/TOPEX)
day=356 UT=0000
F10.7=185 Kp=1.0
0
1
2
90
60
30
0
-30
-60
-90
Geographic Latitude
0
60
120
180
240
300
360
Geographic Longitude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IFM Parameters Adjusted

- O^+ - O Collision Frequency
- Secondary Electron Production
- Zonal Neutral Wind
- Equatorial Electrical Field

Order of Adjustment is Important

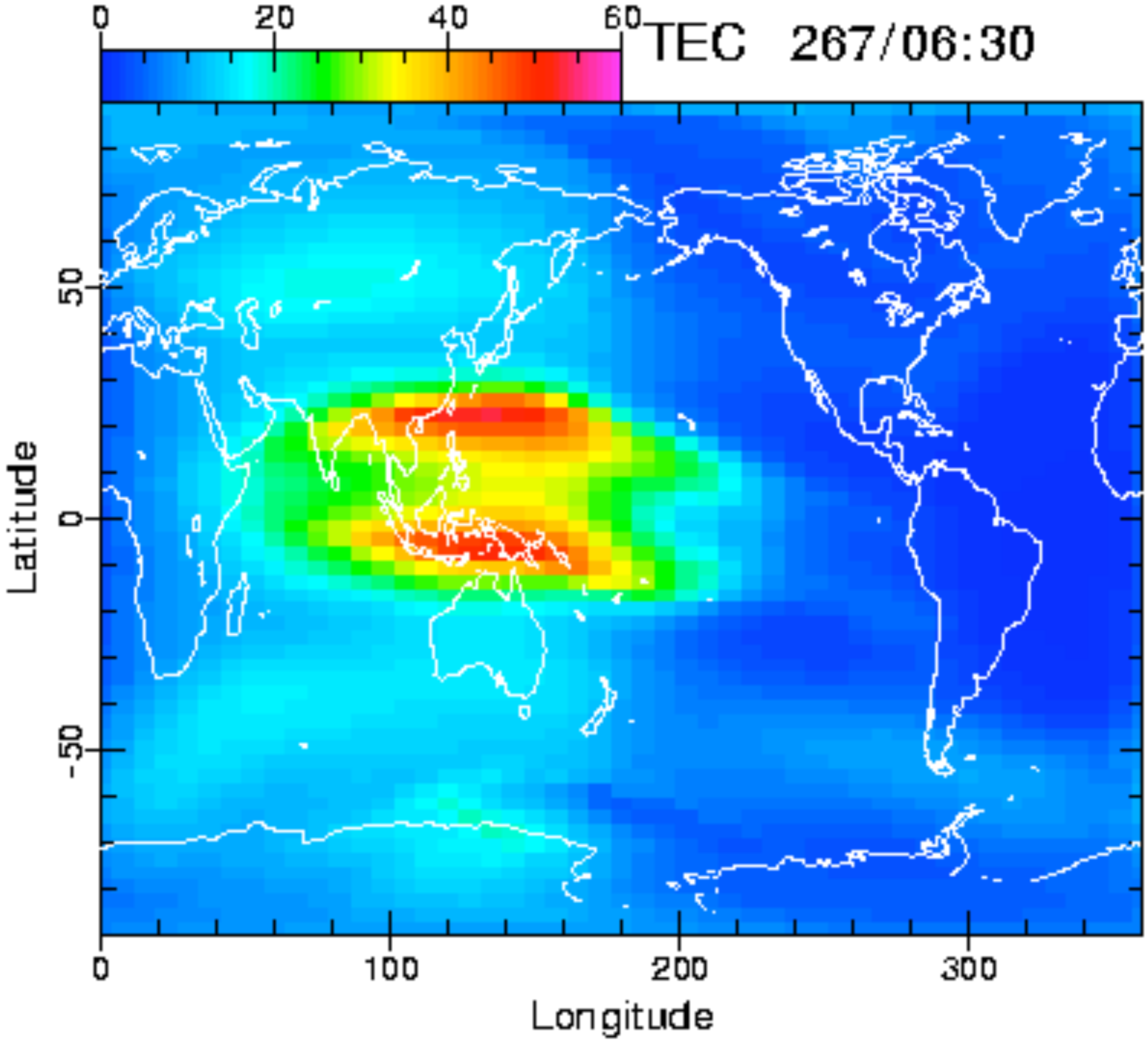
O^+ - O Collision Frequency Adjustment

- Mid-latitudes
- 0^o Declination
- Quiet Conditions
- Sunset N_mF_2 Decay verses Ionosonde Data

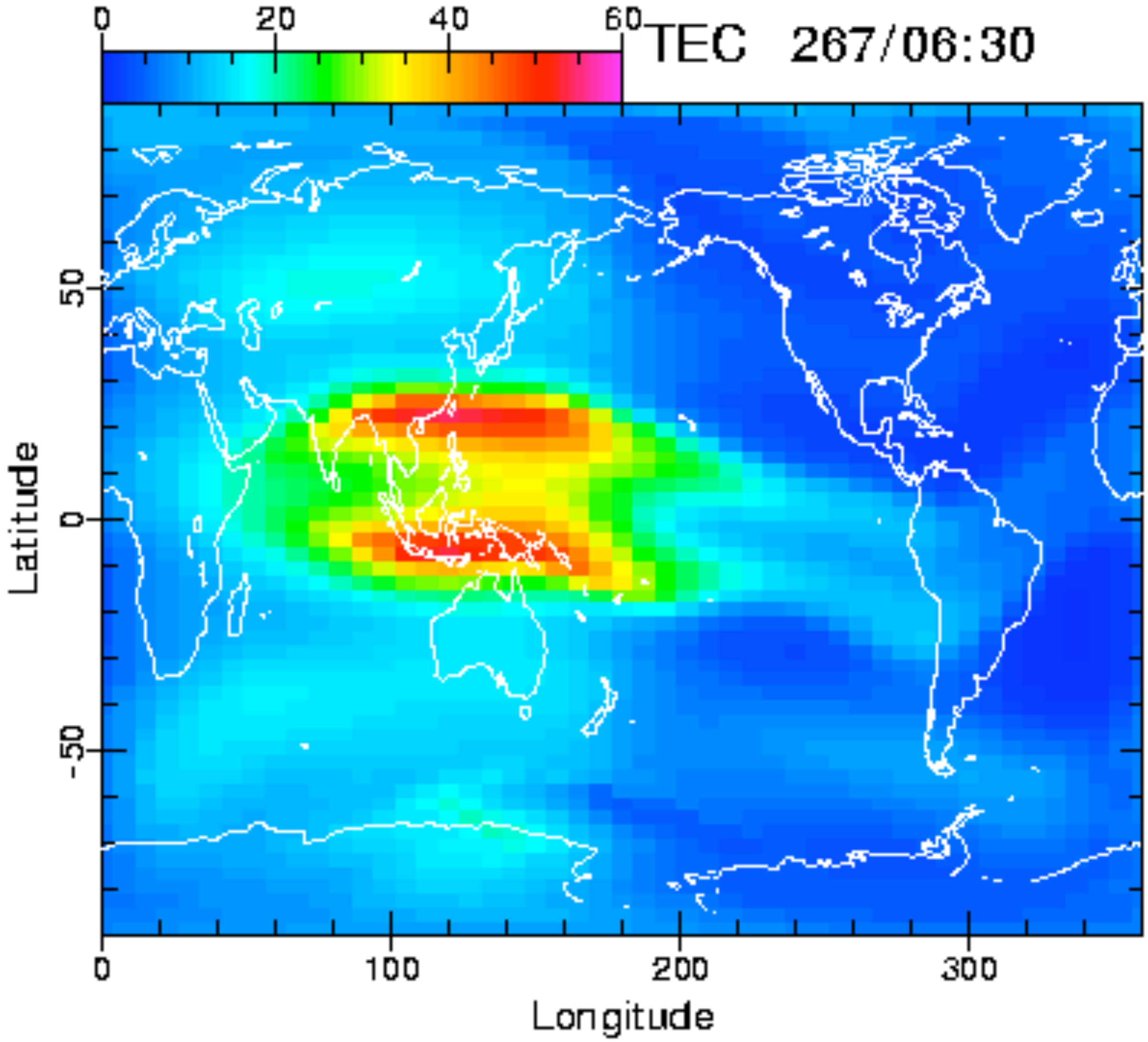
Example of E-Field Adjustment

- TEC in the equatorial region at night was typically too low when compared to the TOPEX data
- At times and in places the IFM could be too low by 5 - 10 TECU
- This problem has been corrected and extensive tests have been conducted for a wide range of solar, seasonal, and geomagnetic activity

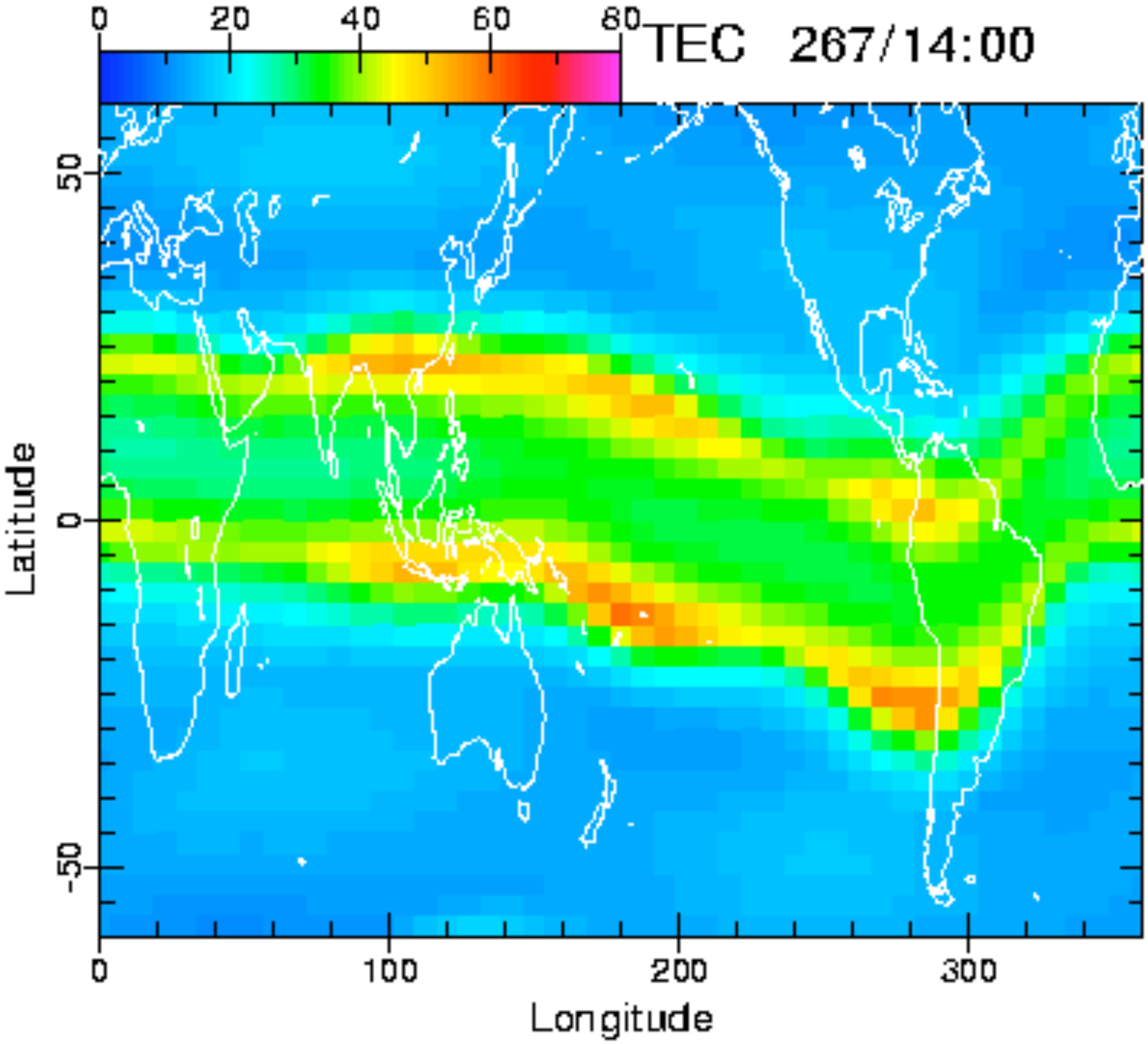
Original IFM, low F10.7, low Kp, color scale 0-60



Improved IFM, **low F10.7, low Kp, color scale 0-60**



4-Wave Signature Added



How Well Do Coupled Models Simulate Today's Climate?
By T. Reichler and J. Kim
AMS Article

- **Output from 3 different climate models**
- **Using equal weights, the multi-model mean usually outperforms any single model**
- **The use of multi-model ensembles is a common practice in weather and short-term climate forecasting**