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Scintillation Modeling at CCMC

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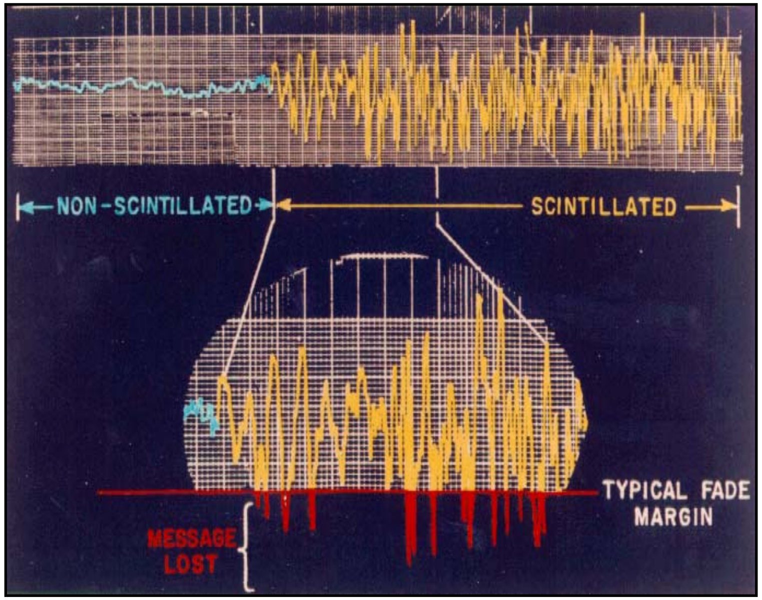
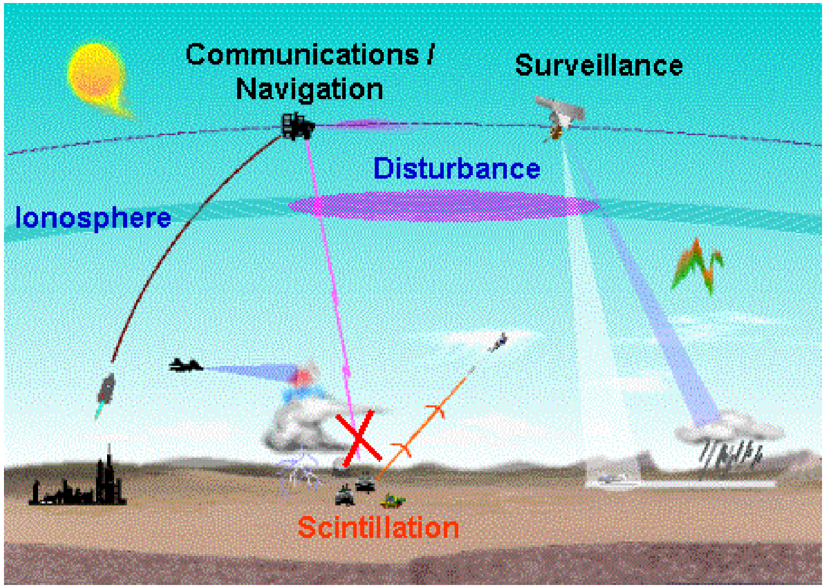
Scintillation Modeling at CCMC

- Radio Scintillation: importance and relevance
  - Space-weather impacts
  - Basic-science community
- The PBMOD Model for Scintillation
  - What is it?
  - What can it do?
- Transition of model to CCMC
  - Model requirements
  - Interface for the community user

Scintillation

Scintillation: Rapid fluctuations of the amplitude & phase of radio signals to/from space due to ionospheric turbulence

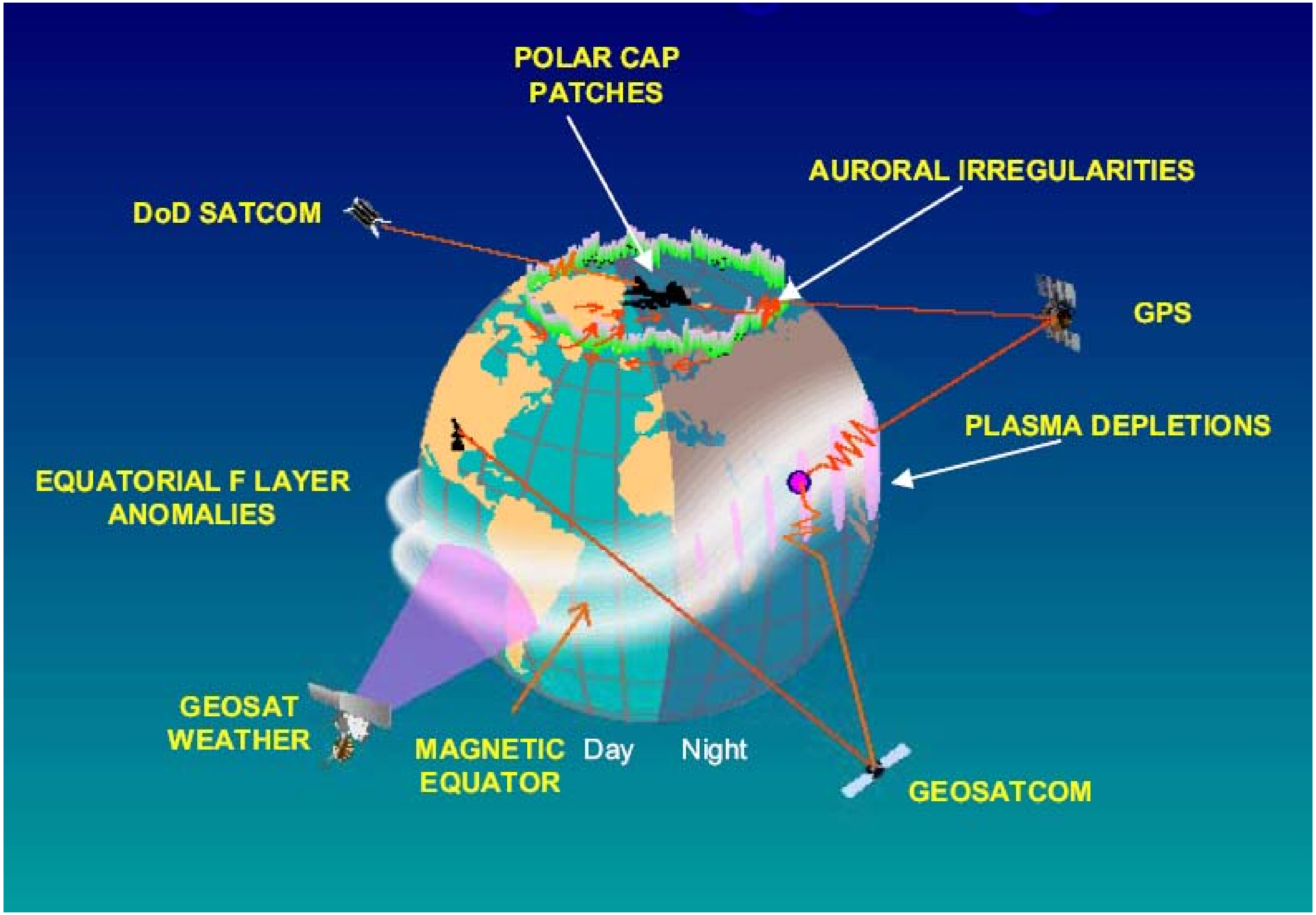




Scintillation causes outages of communication and navigation systems

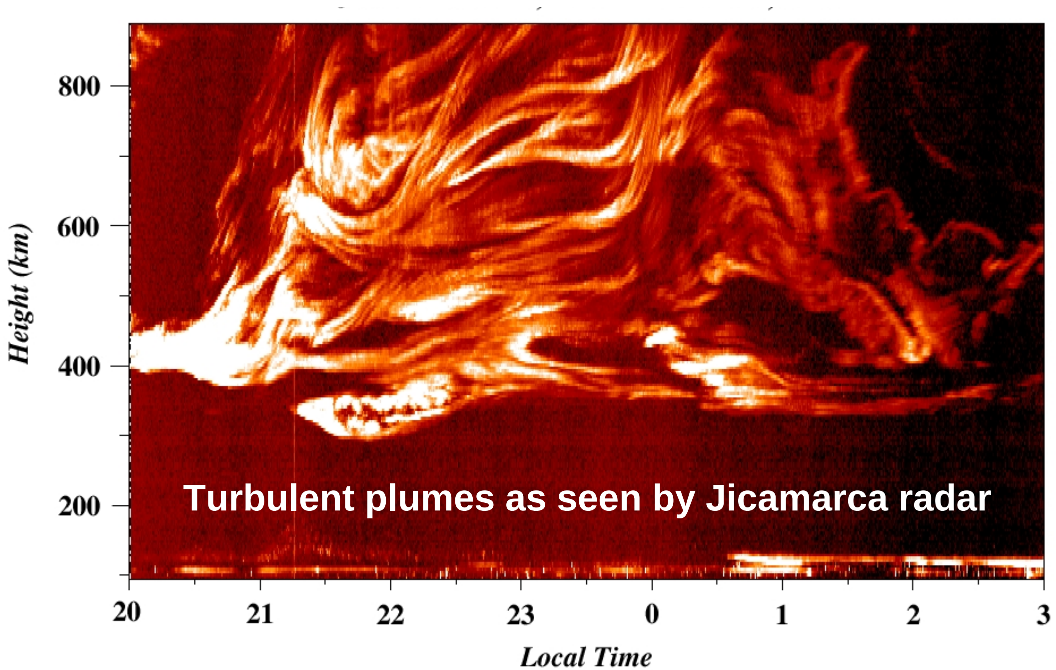
Scintillation Regions

polar and equatorial



Low Latitude Scintillation

Scintillation at low magnetic latitudes is associated with the development of plasma turbulence within plumes of uplifting low-density plasma triggered by the Rayleigh-Taylor instability near the lower edge of the ionospheric F layer



(Woodman and LaHoz 1976)

Spectrum of density irregularities from rocket fly-through density measurements

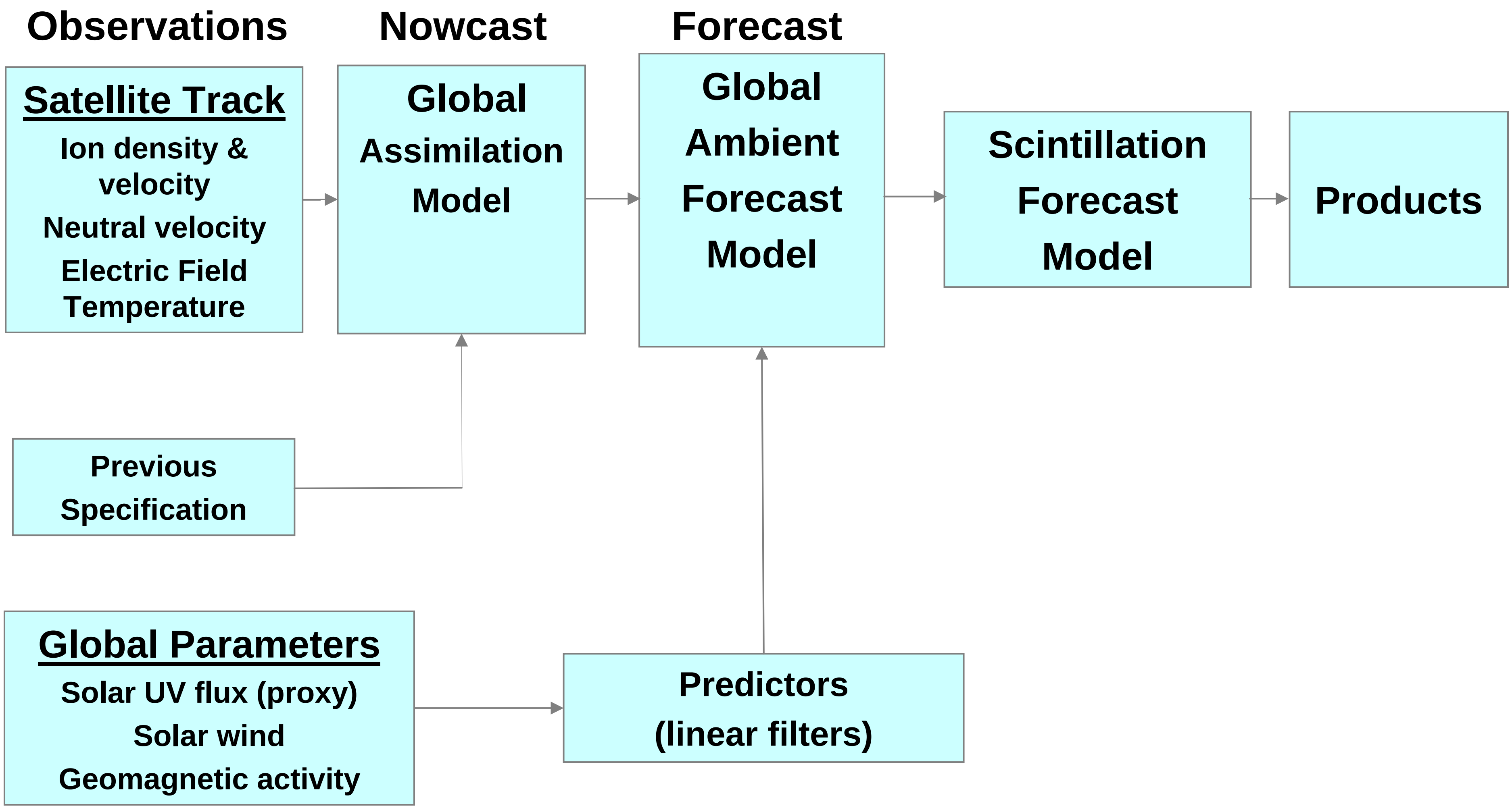
(Kelley and Livingston 2003)

Scintillation Modeling at CCMC

- Radio scintillation calculations require a multi-scale chain of models of low-latitude ionospheric phenomena:
  - Ambient (global-scale) plasma-density modeling
  - Rayleigh-Taylor plasma-instability calculation
  - Plasma plume/bubble calculation
  - Scintillation calculation using resulting turbulence
- PBMOD is the model of these processes developed for the AF/NASA C/NOFS program by John Retterer (AFRL)
- PBMOD is being installed at CCMC for community use

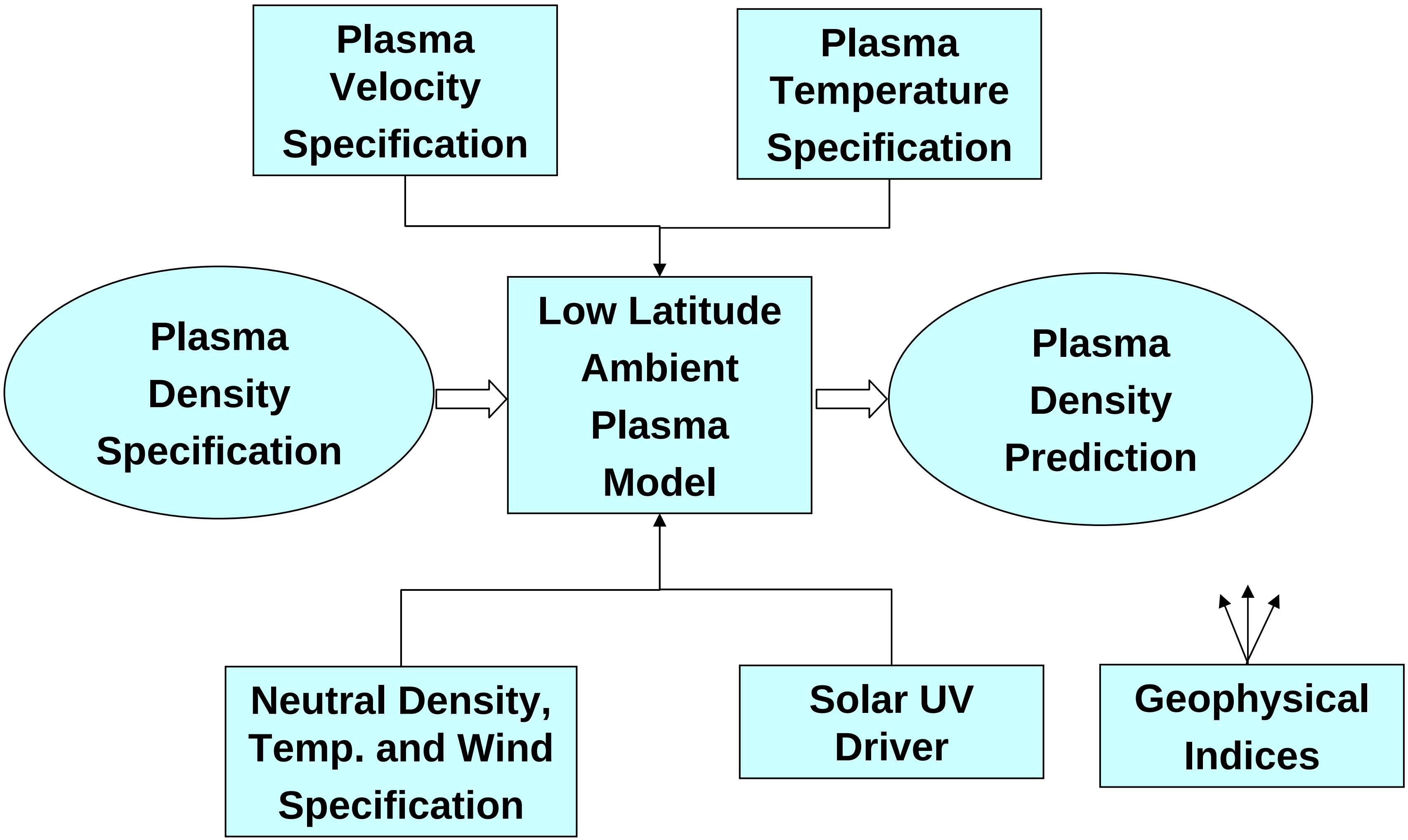
C/NOFS Scintillation Forecasting

PBMOD System Architecture

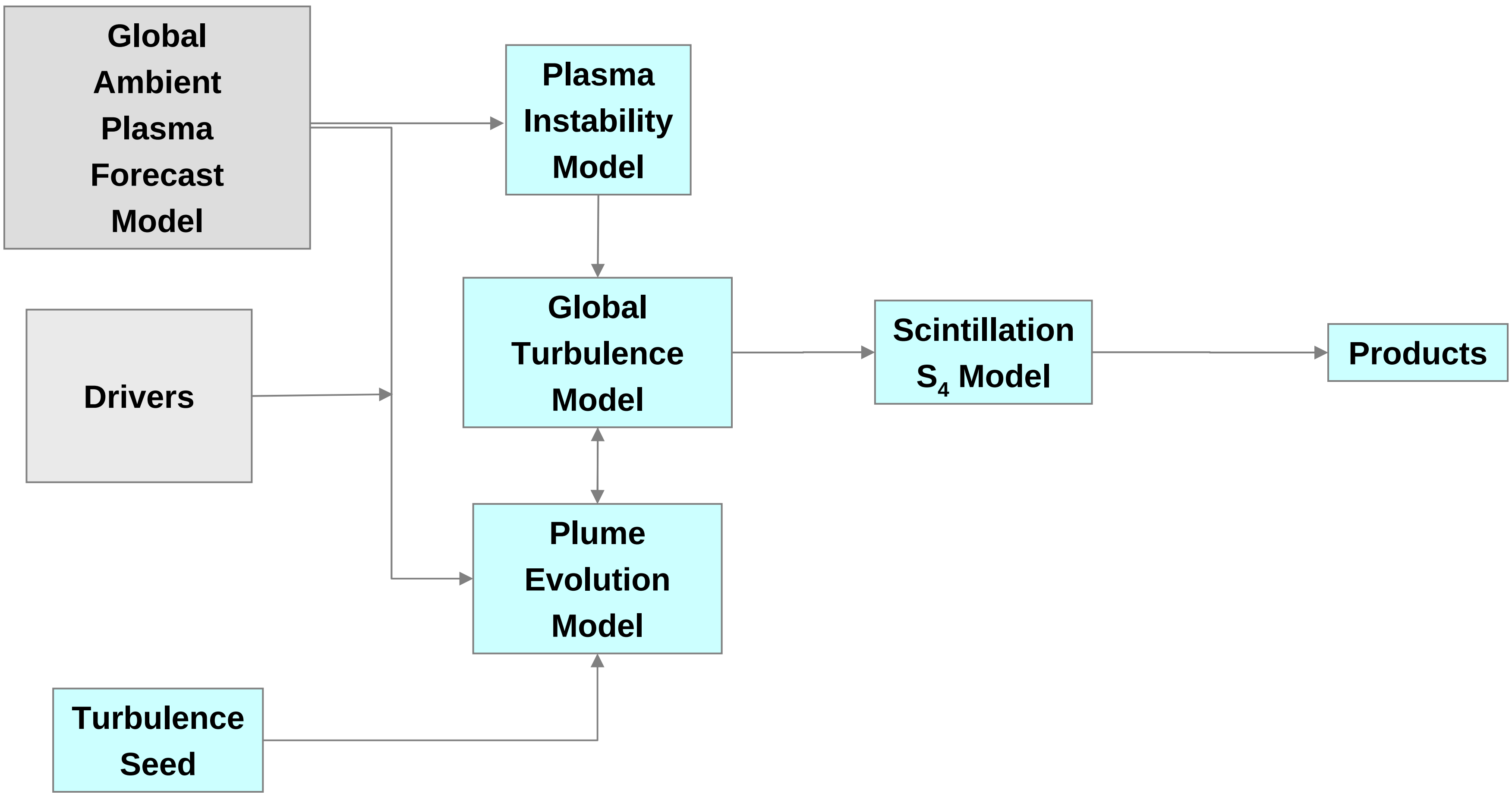


Ambient Ionosphere Model

Inputs



Scintillation Forecast Model



Scintillation Forecast Model

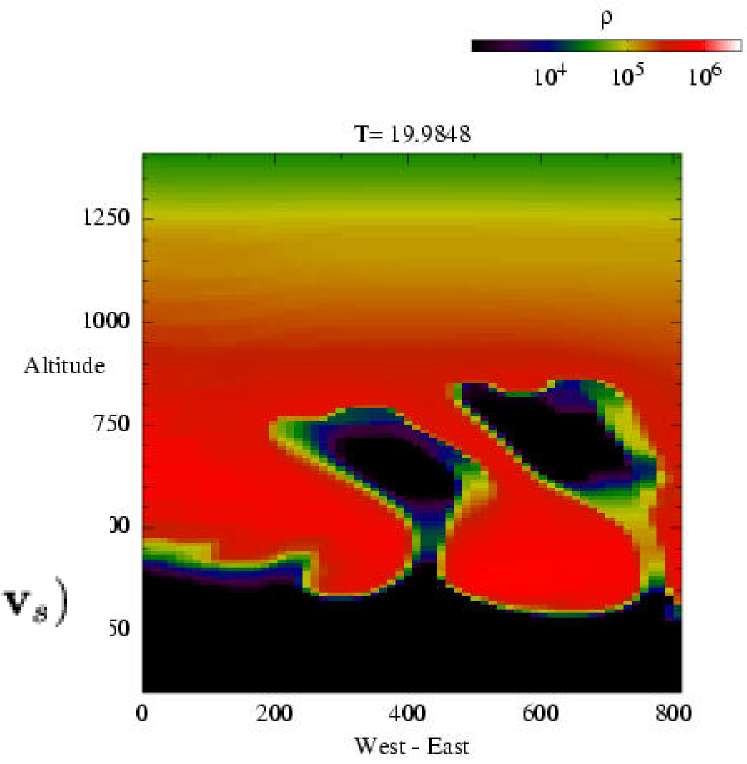
Plume Evolution Model Algorithms

Model describes temporal development of mesoscale plasma structure & turbulence

Uses nonlinear continuity and momentum equations

$$\frac{\partial n}{\partial t} + \nabla_\perp \cdot (n\mathbf{v}_\perp) = 0$$

$$\frac{d\mathbf{v}_s}{dt} = \frac{q_s}{m_s}\mathbf{E} + \mathbf{g} + \Omega_s \mathbf{v}_s \times \hat{\mathbf{B}} - \frac{1}{n_s}\nabla_\perp P_s + \nu_s(\mathbf{U} - \mathbf{v}_s)$$



Perpendicular electric fields:

global-scale fields from ambient model +

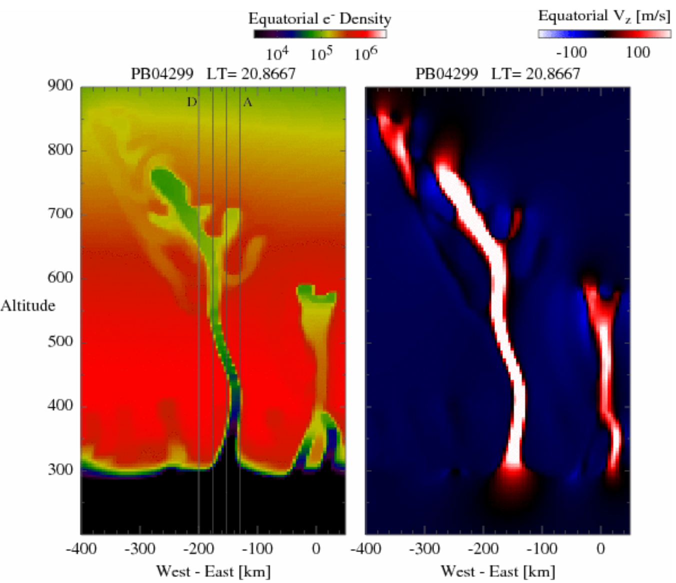
self-consistent fields determined by current-continuity condition

Start with small perturbation; if unstable plasma, perturbation will quickly grow

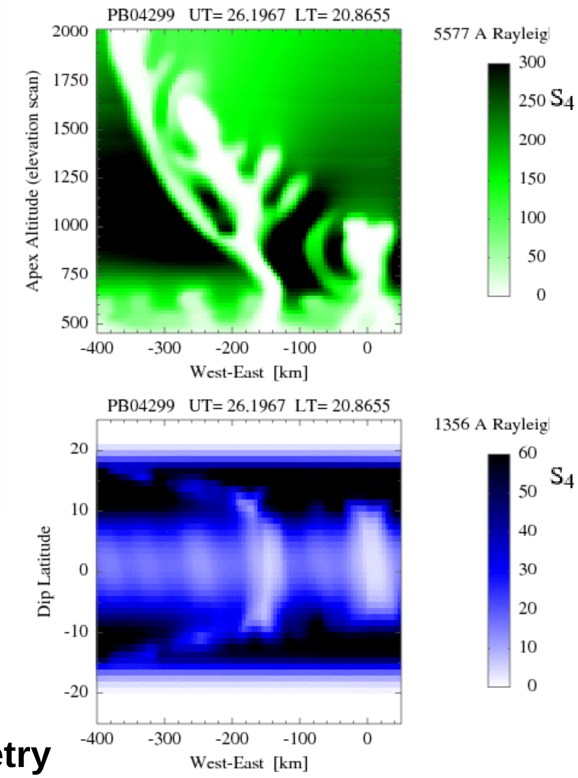
PBMOD includes two-dimensional and three-dimensional plume models

Scintillation Modeling by PBMOD

geomagnetically quiet conditions

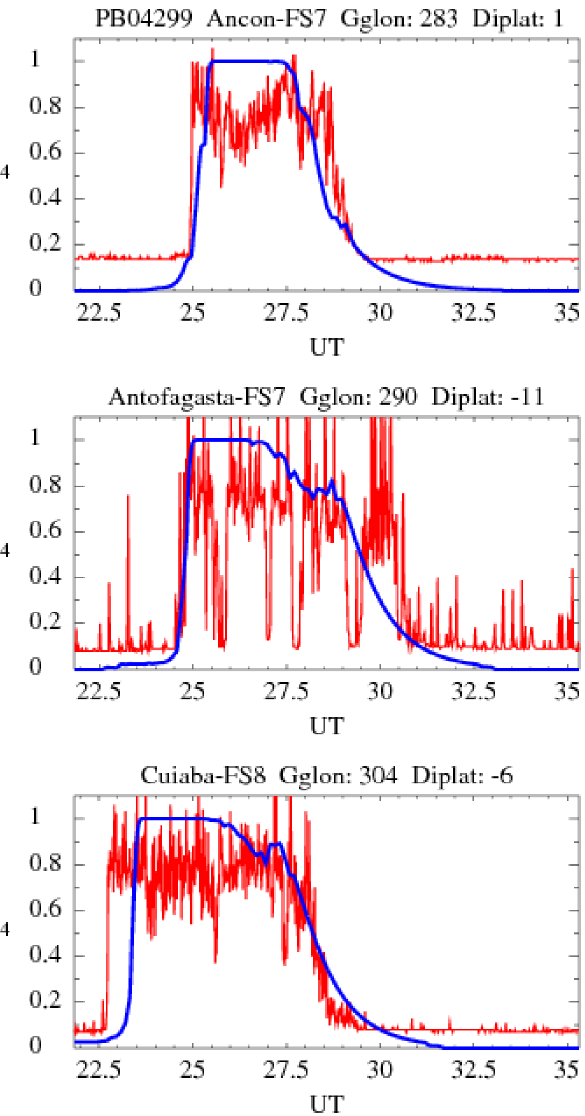


Plume structure in density (left) and vertical velocity (right)



Airglow images of plumes: geometry of Cornell Hawaii camera (looking south toward plume) in 5577 A (top) and GUVI nadir sensing in 1356 A (bottom)

(Retterer 2009a,b)



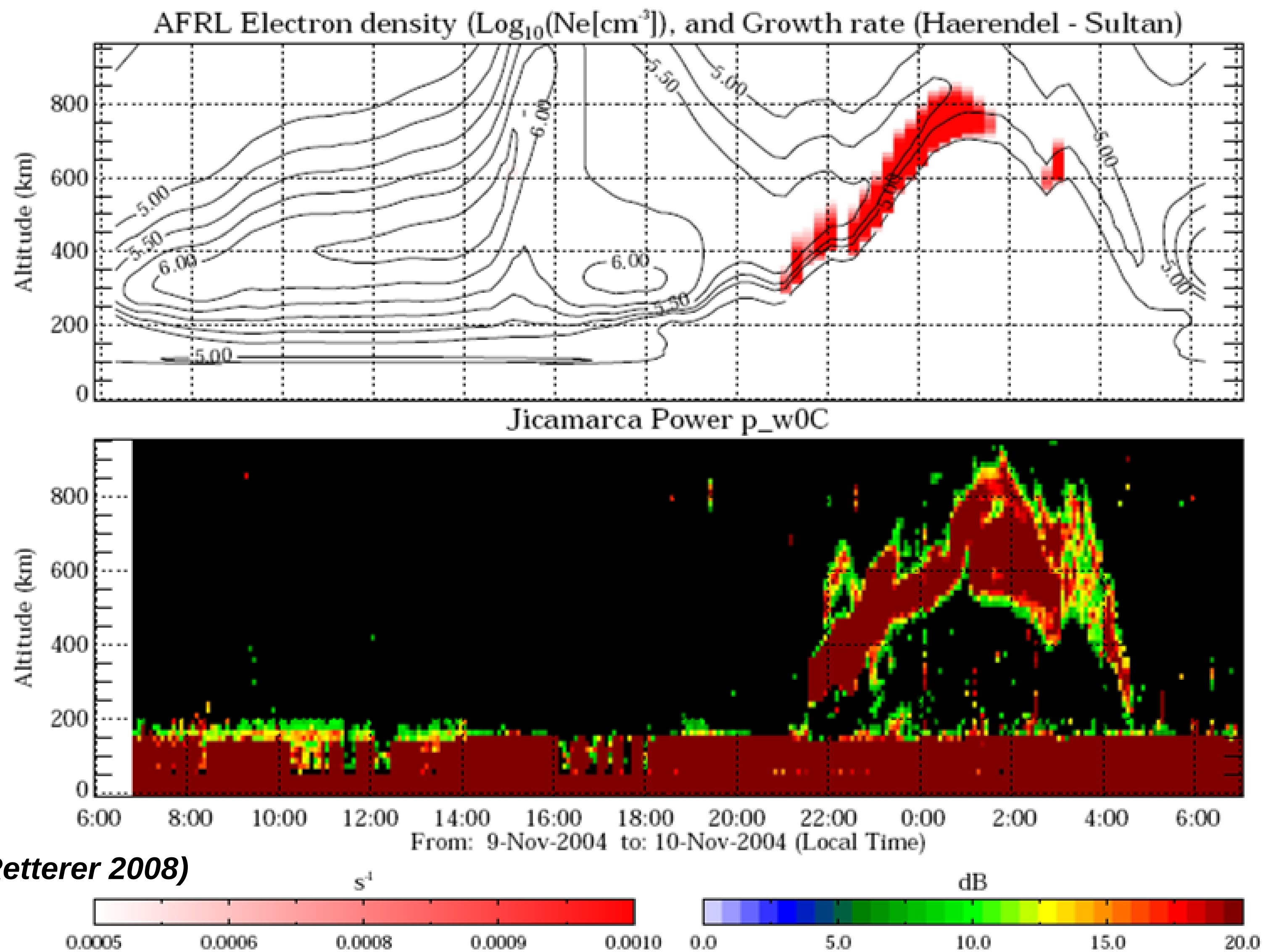
Scintillation observed at 3 SCINDA stations (red) compared with PBMOD predictions (blue)

Scintillation Modeling

geomagnetic storm conditions (November 2004)

Density contours & RT growth shading from PBMOD using plasma drifts from Jicamarca

Jicamarca RADAR coherent returns - indicating presence of turbulence



(Kelley and Retterer 2008)

Modeling Requirements

- The basic PBMOD calculation gives the low-latitude structure in one longitude sector; global calculation is done using multiple sectors
  - longitude coupling is weak because E-W drift is slow relative to time scales of plume development
- Driver options:
  - Climatological specification using Hedin, Fejer, etc. models (parameterized by geophysical indices)
  - Output of NCAR TIEGCM thermospheric model
  - Custom specification (input files of drifts and winds)

Modeling Requirements

- PBMOD now on a private CCMC host (ono4) for test runs
- Execution time for a 24-hour run of one sector
  - Ambient plasma: approx 5 minutes
  - for TIEGCM drivers: add 30 min
  - Medium-resolution 2-d plume model: approx 25 min
  - High-resolution 3-d plume model: 10 hours
- Storage space for output files
  - Ambient model + med-res plume: 300 MB per run-day
  - TIEGCM : 3 GB per run-day for global specification
  - High-res 3d plume: 24 GB

User Interface

User choices and options

- Recommend using PBMOD to explore effect of various drivers on instability of the ionosphere and the resulting plume development
- Recommend studies on dependence of plume development on initial conditions of the plume (its ‘seeding’)
- Initial user run choices:
  - Local or global calculation
  - Climatological, TIEGCM, or custom drivers
  - 2-d or 3-d plume model

User Interface

User choices and options

- Climatological runs
  - User needs to provide only date and location (PBMOD incorporates recent history database of F10.7, Ap, Kp, Ace solar-wind, and NOAA auroral power input data)
- Custom runs
  - User provides history of a driver parameters (e.g., plasma drift or neutral wind)
    - suggest a text box on the web input screen, initialized by the climo values of the parameter, into which the user can edit or paste values

User Interface

Output

- **PBMOD output files**
  - ASCII files for low-dimensional quantities
  - Netcdf files for higher-dim quantities (e.g., densities); compact binary format, but host-architecture agnostic

- **Graphical display**
  - Postscript files generated by internal plotting utility
  - Animations to show the ionospheric evolution that the model is designed to describe

Summary

- Radio scintillation is a space-weather phenomenon with important implications for the basic science of the ionosphere and consequences for operational systems (satcom, radar, GPS)
- PBMOD is a model of the chain of phenomena that lead to scintillation, developed for the USAF/NASA C/NOFS program, which has been tested and improved under a variety of circumstances
- Implementing PBMOD at CCMC will enable community users to explore a number of meaningful aspects of the scintillation phenomena using the model and a limited web interface