



# Scintillation Modeling at CCMC

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**Air Force Research Laboratory  
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**Ja Soon Shim**

**CCMC**

**NASA Goddard Space Flight Center**



# Scintillation Modeling at CCMC



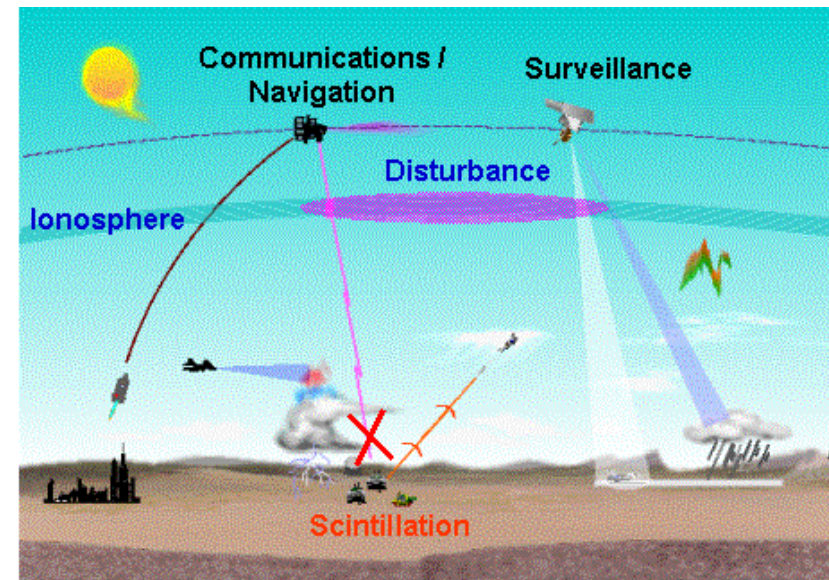
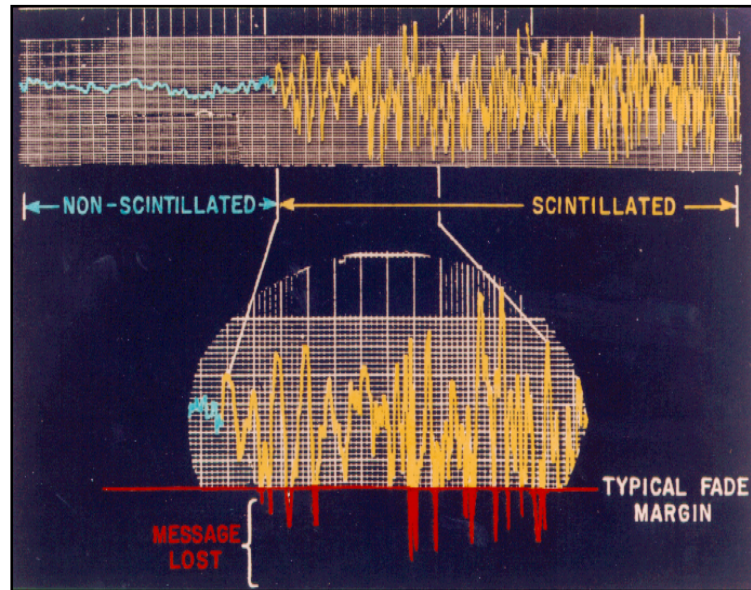
- **Radio Scintillation: importance and relevance**
  - **Space-weather impacts**
  - **Basic-science community**
- **The PBMOD Model for Scintillation**
  - **What's in it?**
  - **What can it do?**
- **Transition of model to CCMC**
  - **Interface for the community user**



# Scintillation



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

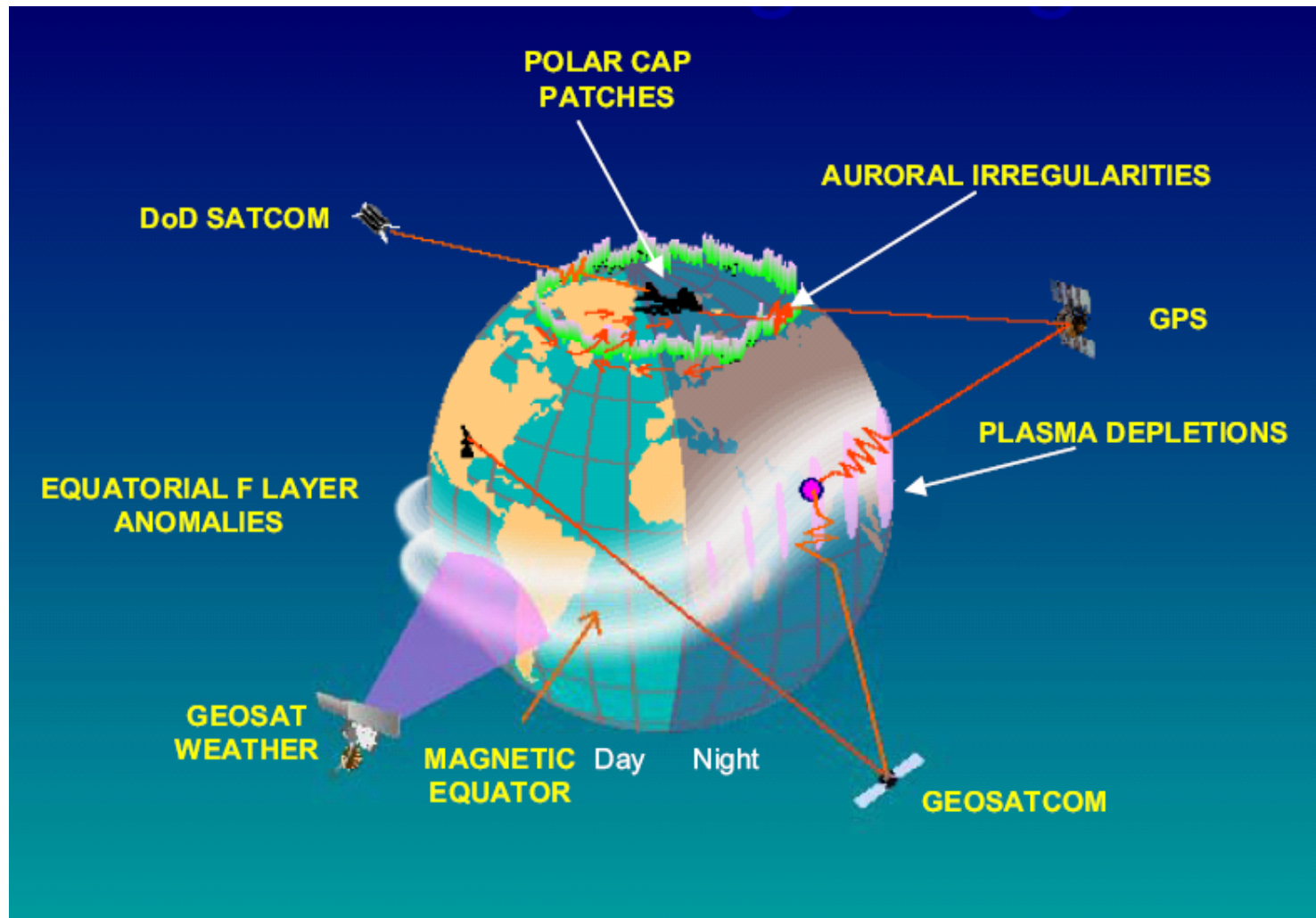


***Scintillation causes outages of communication and navigation systems***



# Scintillation Regions

## polar and equatorial

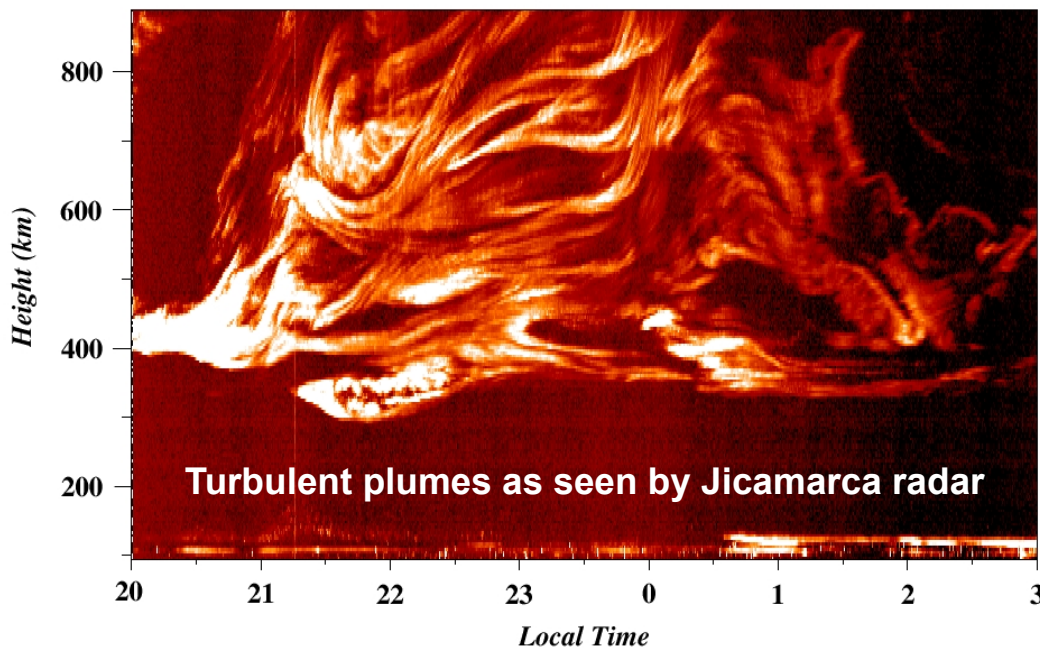




# Low Latitude Scintillation

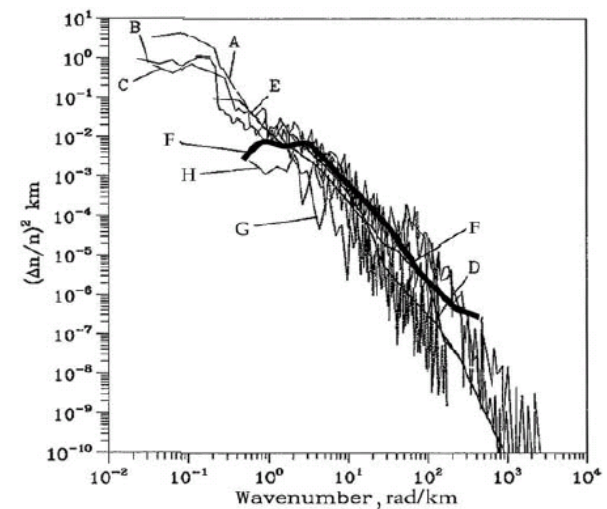


***Scintillation at low magnetic latitudes is associated with the development of plasma turbulence within plumes of uplifting low-density plasma triggered by the Rayleigh-Taylor instability near the lower edge of the ionospheric F layer***



(Woodman and LaHoz 1976)

**Spectrum of density irregularities from rocket fly-through density measurements**



(Kelley and Livingston 2003)



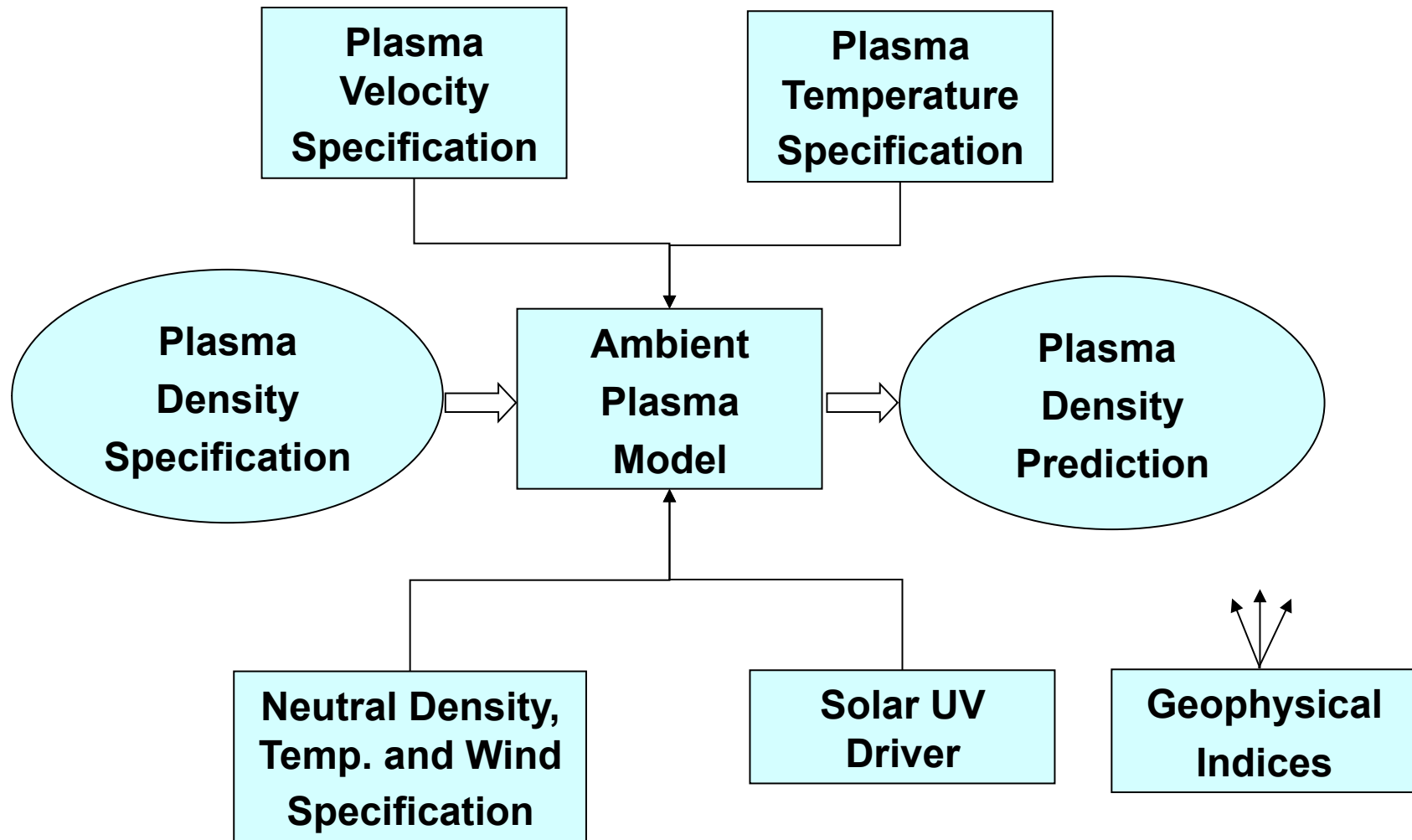
# Scintillation Modeling at CCMC



- **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 system of models of these processes developed for the Air Force/NASA C/NOFS program by John Retterer (AFRL/BC)**
- **PBMOD is being installed at CCMC for community use**

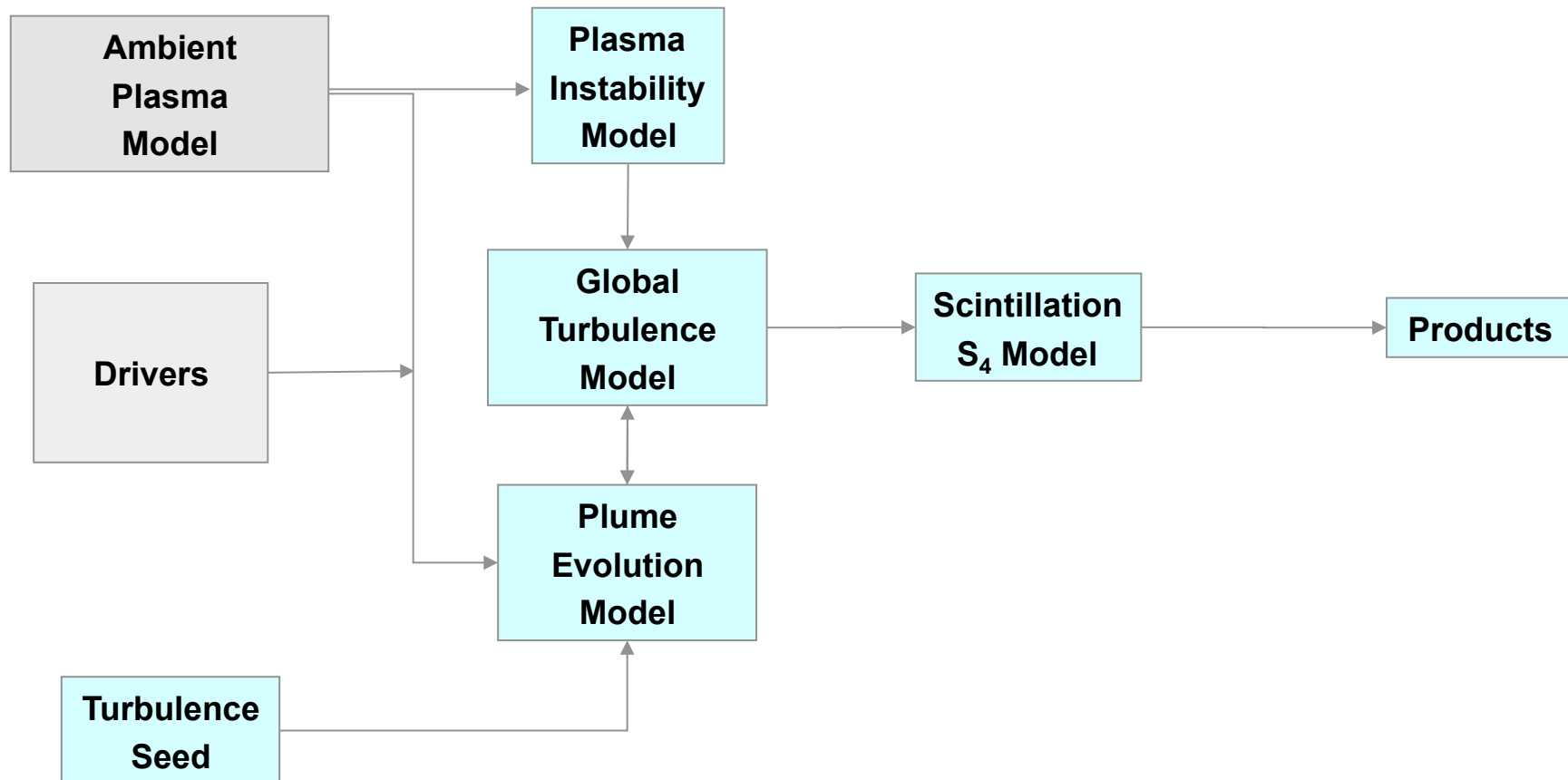


# PBMOD Ambient Ionosphere Model





# PBMOD 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

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

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

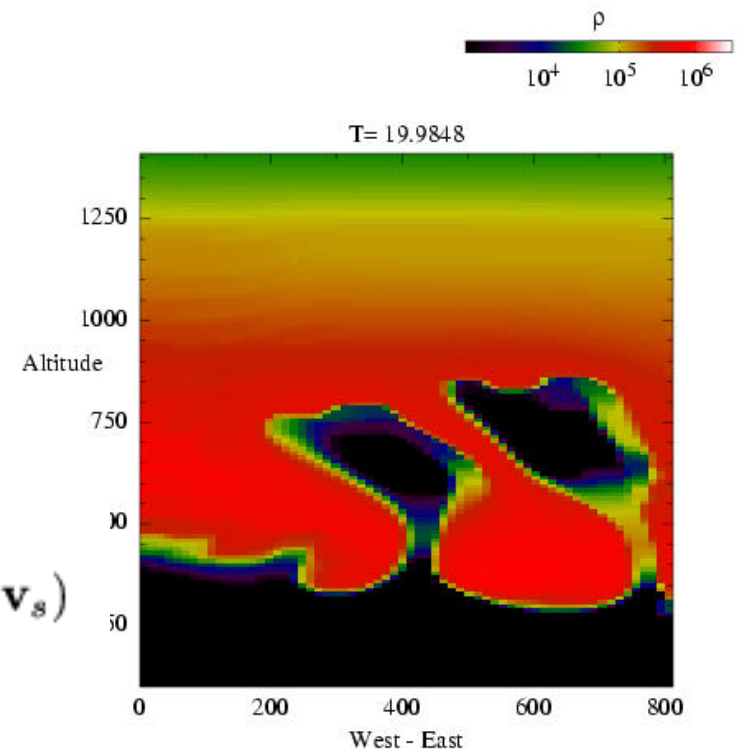
Perpendicular electric fields:

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

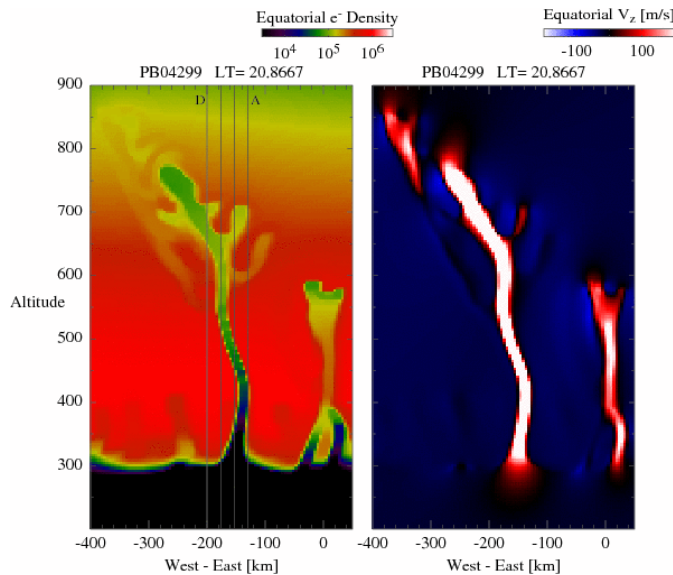
PBMOD includes two-dimensional and three-dimensional plume models



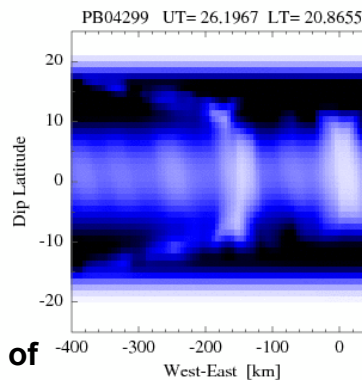
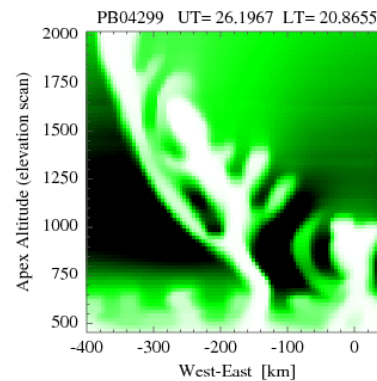


# Scintillation Modeling by PBMOD

geomagnetically quiet conditions



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

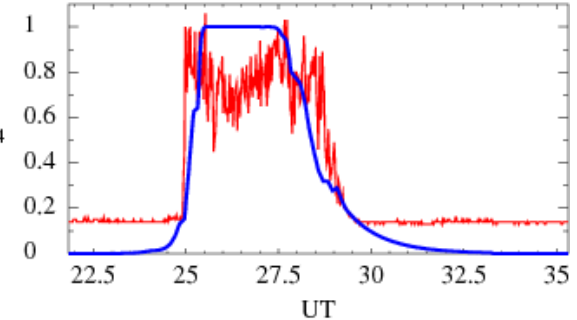


Airglow images of plumes: geometry of Cornell Hawaii camera (looking south toward plume) in 5577 A (top) and GUVI nadir sensing in 1356 A (bottom)

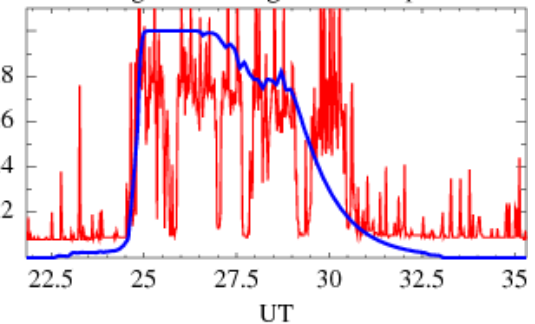
(Retterer 2010a,b)

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

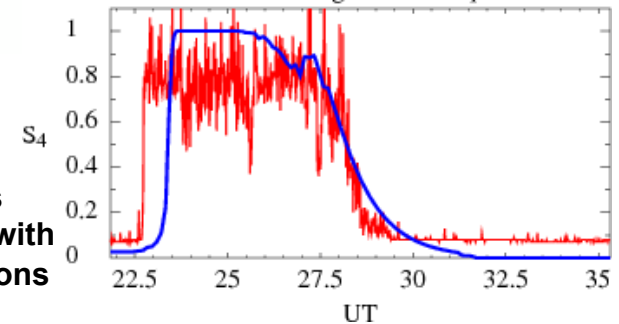
PB04299 Ancon-FS7 Gglon: 283 Diplat: 1



Antofagasta-FS7 Gglon: 290 Diplat: -11



Cuiaba-FS8 Gglon: 304 Diplat: -6



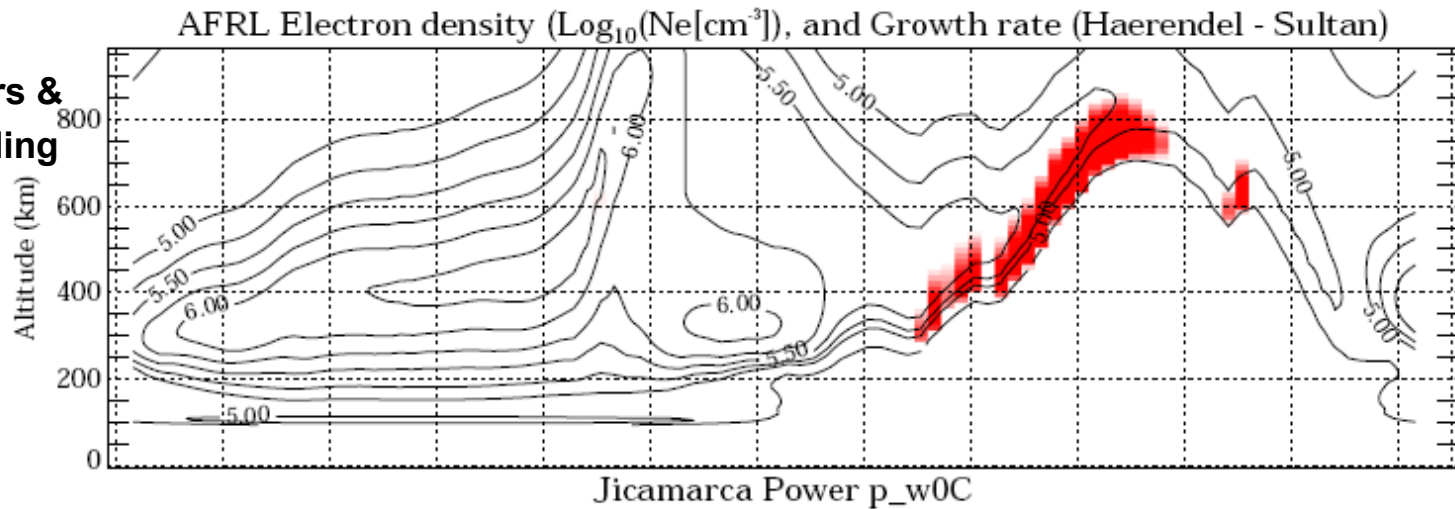


# Scintillation Modeling

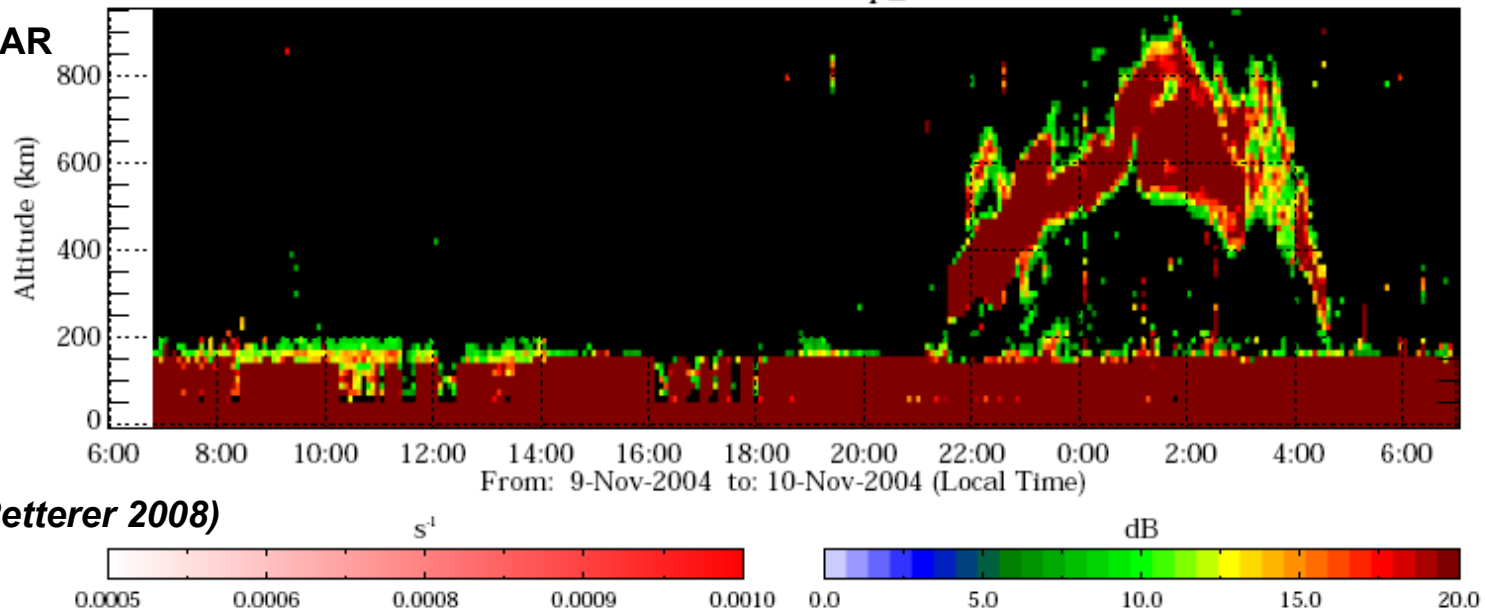
geomagnetic storm conditions (November 2004)



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



Jicamarca RADAR  
coherent  
returns -  
indicating  
presence of  
turbulence

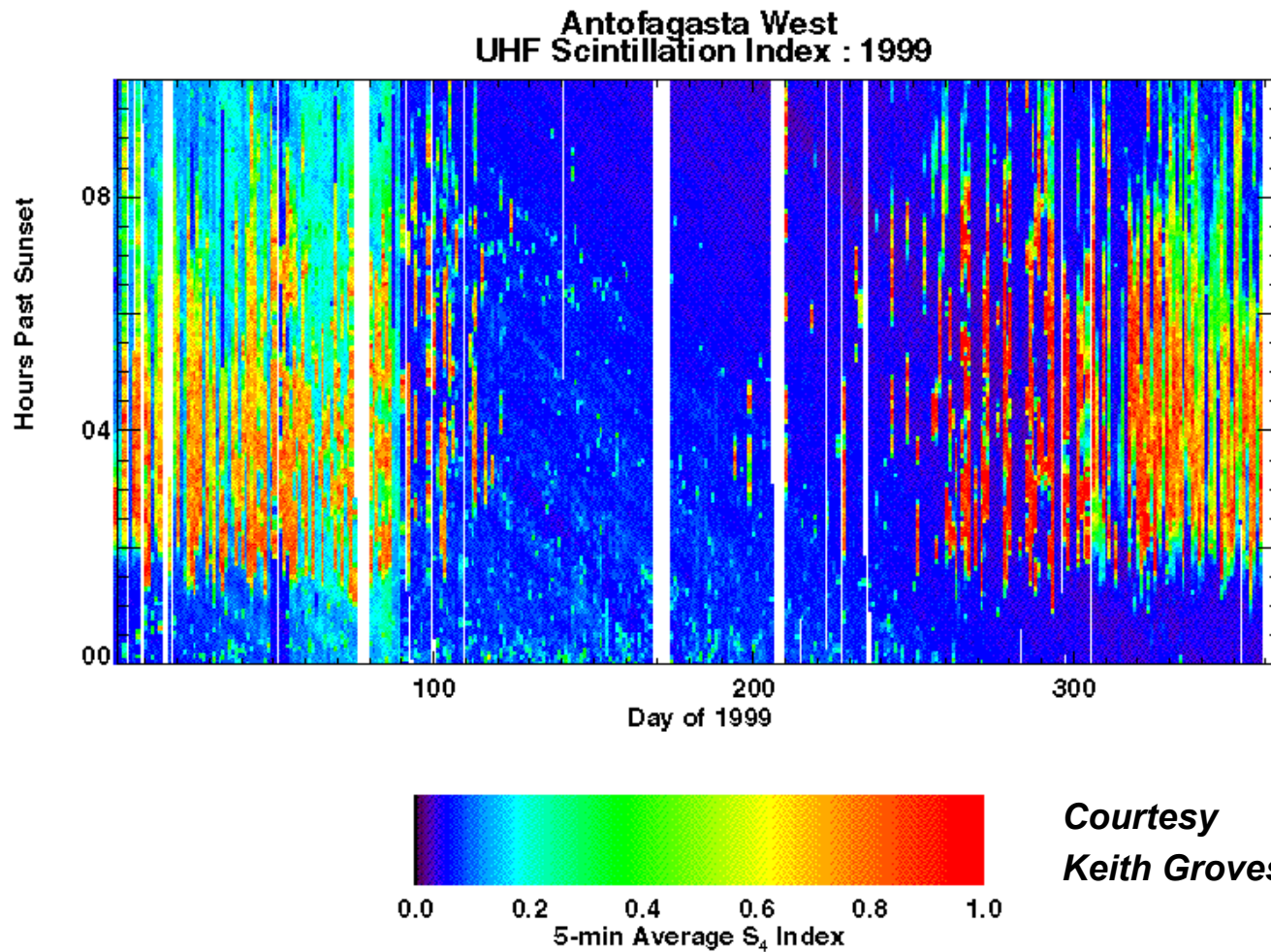


(Kelley and Retterer 2008)



# Scintillation Statistics

## SCINDA Station, Antofagasta, Peru



***Definite seasons of occurrence, but high day-to-day variability***

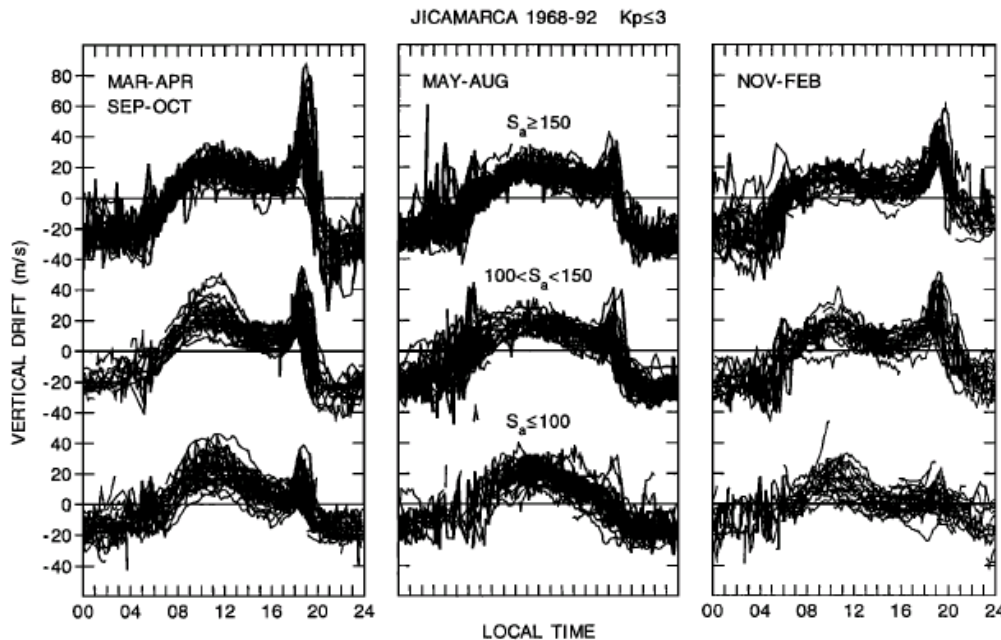


# Natural Geophysical Variation



The natural variability in scintillation is caused by the variability of geophysical conditions controlling the instability of the ionosphere

The major variable factor is the vertical plasma drift (Fejer et al., 1999)



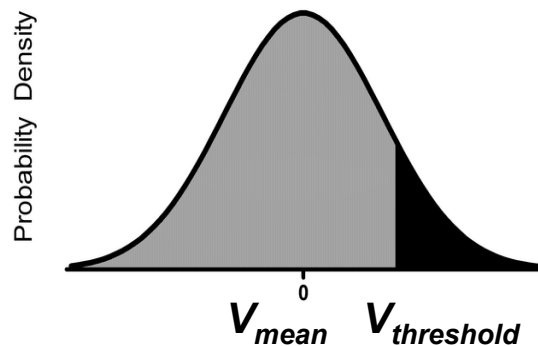
**Jicamarca ISR data**  
(Scherliess & Fejer) suggest that the natural scatter of velocities: is +/- 10 m/s



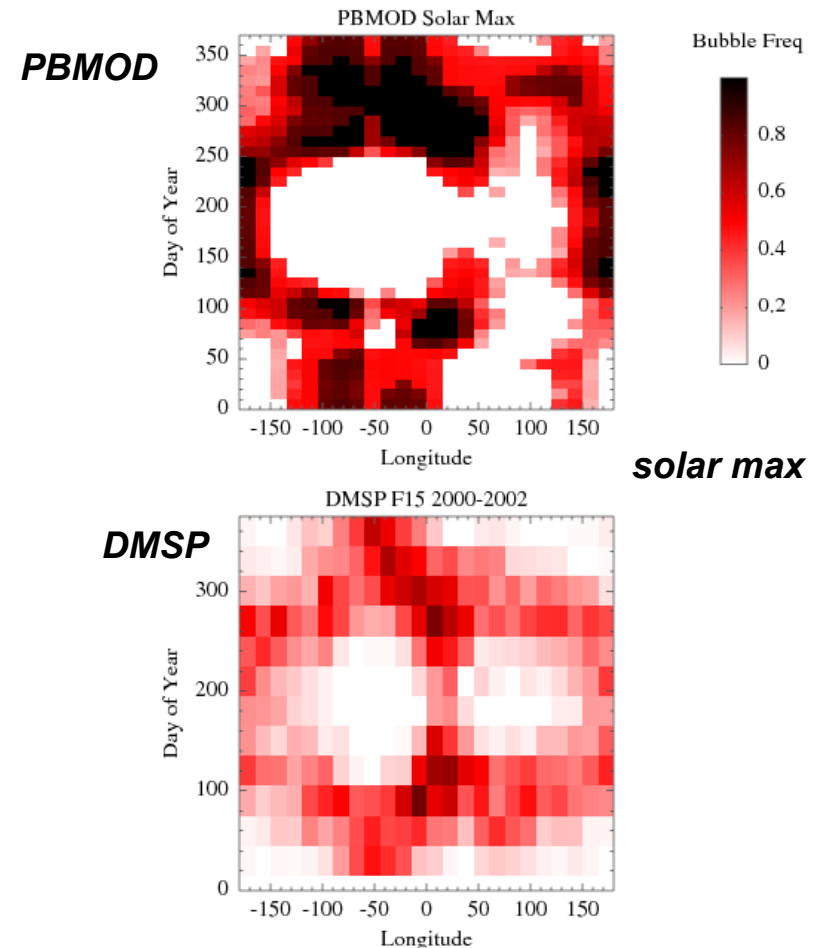
# Plasma Bubble Probability



To test the idea that the statistics of bubble/scintillation formation can be described using the statistics of the vertical plasma drift, we estimated the bubble frequency at DMSP altitude from the ensemble statistics of several PBMOD runs with different plasma velocities to determine the threshold. The probability is then determined from the fraction of the population exceeding the threshold. We found general agreement in the patterns of occurrence (the differences in detail could be fixed by adjusting other parameters).



## Plasma Bubble Probability



Retterer and Gentile 2010



# PBMOD Daily Run at CCMC



- **Daily run of PBMOD currently being performed at CCMC**
- **Execution start timed so that scintillation calculation can serve as a forecast**
- **Calculation done with two drift-velocity histories**
  - **Expected drift (50<sup>th</sup> percentile) for plasma densities**
  - **85<sup>th</sup> percentile drift envelope to find near-worst-case scintillation strength**
- **Output webpage**
  - **Wide variety of output quantities, described in links**
  - **Model documentation included for reference**



# PBMOD Daily Run Webpage



File Edit View History Bookmarks Tools Help

file:///media/data1/ccmcweb/PB12002pbmod.html

PBMOD Ionosphere/Irregulari...

### PBMOD Ionosphere/Irregularity/Scintillation Calculation

(see [description](#) of model from ANSI handbook of standard ionospheric/thermospheric models.)

Output from PBMOD model for modified Julian day 55928  
(day of year 002 2012, dmy 2 1 2012)

Issue time: Sun Jan 1 09:00:01 UTC 2012 ( Sun Jan 1 04:00:01 EST 2012 )

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**Parameters** [run\\_db](#)

**Geophysical Indices**

**Thermospheric Drivers**

**Plasma Drivers**

**Density Profiles from most probable drift**

[Texos](#) [Neutral wind](#)

[Drift velocity](#) [Temperature](#)

[Meridional plane](#) [Equatorial profiles](#)

Top of page

- Geophysical indices
- Driver quantities





# PBMOD Daily Run Webpage



**PBMOD Ionosphere/Irregularity/Scintillation Calculation**  
(see [description](#) of model from ANSI handbook of standard ionospheric/thermospheric models.)

Output from PBMOD model for modified Julian day 55928  
(day of year 002 2012, dmy 2 1 2012)

Issue time: Sun Jan 1 09:00:01 UTC 2012 ( Sun Jan 1 04:00:01 EST 2012 )

[Parameters](#) [run.dtb](#)

**PBMOD: TIME-DEPENDENT MODEL OF THE GLOBAL LOW-LATITUDE IONOSPHERE, PLASMA IRREGULARITIES, AND RADIO SCINTILLATION**

John Retterer  
Air Force Research Laboratory

**1. Model Content**  
The PBMOD ionospheric model is a system of Physics Based *MOD*els that describes the three-dimensional time-dependent evolution of the low-latitude ionosphere on several different spatial scales: globally it provides the plasma density and composition at altitudes between 90 and 2000 km; at finer scales it describes the development of fluid plasma turbulence within this region and the resulting radio scintillation. The numerical model of the ambient (global scale) ionosphere yields density distributions for electrons and several ion species (O<sup>+</sup>, H<sup>+</sup>, and NO<sup>+</sup>, O<sub>2</sub><sup>+</sup>, N<sub>2</sub><sup>+</sup>) as a function of latitude, longitude, and altitude on a prespecified spatial grid at specified times. The system also includes models that evaluate the growth rate for the generalized Rayleigh-Taylor instability, perform evolutionary calculations of the self-consistent nonlinear development of equatorial low-density plasma plumes/bubbles, and perform a phase-screen calculation to estimate the strength of amplitude and phase scintillation of radio signals passing through the turbulent structure.

Numerous physical and chemical processes are contained in the model, including field-aligned diffusion, cross-field electrodynamic drifts, thermospheric winds, ion production due to EUV radiation, chemical and other collisional processes. The model uses the IGRF geomagnetic field model for an accurate depiction of the Earth's magnetic-field geometry. Depending on the inputs, the global ionospheric model can describe different solar cycle, seasonal, and daily variations. It can describe the low-latitude effects of geomagnetic storm dynamics.

Built to be the forecast model in the C/NOFS (Communication and Navigation Outage Forecast System) Data Center, a demonstration of a potential operational system, the models employ robust numerical techniques, and are designed to be fault-



# PBMOD Daily Run Webpage



File Edit View History Bookmarks Tools Help

file:///media/data1/ccmcweb/PB12002pbmod.html

PBMOD Ionosphere/Irregulari...

## PBMOD Ionosphere/Irregularity/Scintillation Calculation

(see [description](#) of model from [AMSU handbook for total ionospheric parameters model](#))

Output from  
(G  
Issue time: Sun Ja

[Parameters](#) [run.db](#)

[Geophysical Indices](#)

Thermospheric Drivers

Plasma Drivers

[Drift vel](#)

Density Profiles from most probable drift

[Meridion](#)

Done

File Edit View History Bookmarks Tools Help

file:///media/data1

PBMOD Ionosphere/Irregulari...

### Description of items in PBMOD Output page

- **Parameters:** The input file for this run of PBMOD, showing models and parameters used.
- **Geophysical Indices:** Global indices that control many of the empirical models that drive the calculation, as a function of UT. Includes the solar radio flux parameter, F10.7, and two versions of the global geomagnetic disturbance index, Ap and Kp.
- **Texos:** Exospheric temperature of the thermosphere as a function of UT, local time (thus, longitude) and latitude. The top panel gives the unmodified Texos from the MSIS model, while the bottom panel shows the Texos as modified to describe the effects of the secular long-term variation of Earth's climate and any localized effects due to geomagnetic energy input.
- **Neutral Wind:** Horizontal winds in the thermosphere as a function of UT and latitude at one longitude, stepping through altitudes. The top panel gives the meridional wind from the Hedin HWM model, while the bottom panel shows the zonal wind.
- **Drift velocity:** The plasma drifts from the Scherliess-Fejer model, as a function of local time, stepping through longitudes. The upper panel gives the vertical drift at the geomagnetic equator, while the lower panel gives the zonal drift, both in meters/second. This model gives the expected drift. To take account of the variability of drifts from day to day, we consider the drifts to be distributed about this mean with a standard deviation of 6 meters/second, and we also gives results below of the model run with a drift that will not be exceeded 85 percent of the time, that is, a drift that is one standard deviation above the mean.
- **Plasma temperature:** The plasma temperatures from the Titheridge model, as a function of UT and latitude, stepping through altitudes. The upper panel gives the electron temperature while the bottom panel gives the ion temperature, both in degrees Kelvin.

Done



# PBMOD Daily Run Webpage

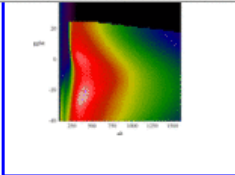


File Edit View History Bookmarks Tools Help

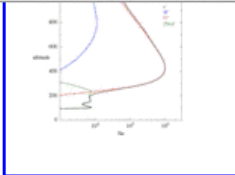
file:///media/data1/ccmcweb/PB12002pbmod.html

PBMOD Ionosphere/Irregulari...

**from most probable drift**

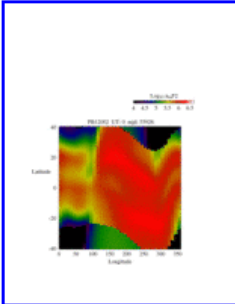


[Meridional plane](#)

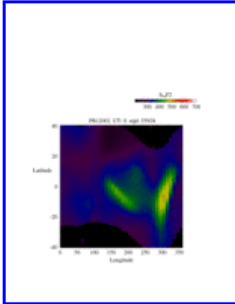


[Equatorial profiles](#)

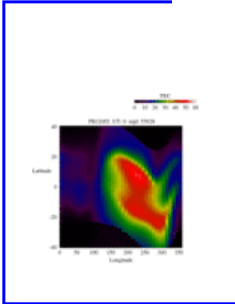
**Profile Parameters from most probable drift, by time**



[NmF2](#)

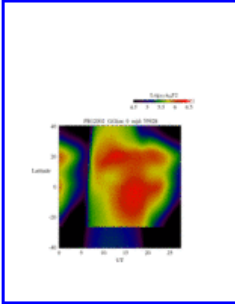


[HmF2](#)

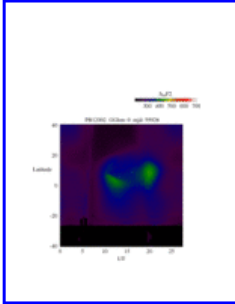


[TEC](#)

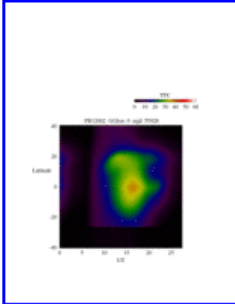
**Profile Parameters from most probable drift, by longitude**



[NmF2](#)



[HmF2](#)



[TEC](#)

**Mid page Plasma density related outputs**

Done



# PBMOD Daily Run Webpage




File Edit View History Bookmarks Tools Help

file:///media/data1/ccmcweb/PB12002pbmod.html

PBMOD Ionosphere/Irregulari...

**from most probable drift**



## Animations of TEC and other quantities

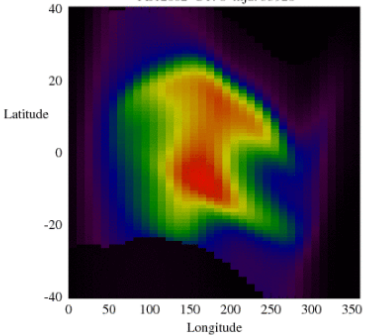
File Edit View History Bookmarks Tools Help

file:///media/data1/ccmcweb/PB12002/PB12002tec50t.html

PBMOD tect Forecast

TEC  
0 10 20 30 40 50 60

PB12002 UT: 6 mjd: 55928



Latitude

Longitude

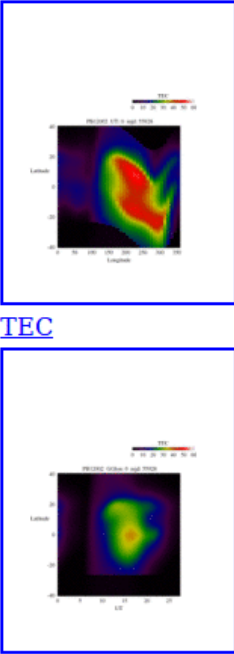
start stop <<first <prev next> last>>

Keyboard shortcuts: Start=up-arrow, Stop=down-arrow, Prev=left-arrow, Next=right-arrow

Slideshow frame interval:  0.1 sec  0.3 sec  1 sec  3 sec  10 sec

Done

les



TEC

TEC



# PBMOD Daily Run Webpage



File Edit View History Bookmarks Tools Help

file:///media/data1/ccmcweb/PB12002pbmod.html

PBMOD Ionosphere/Irregulari...

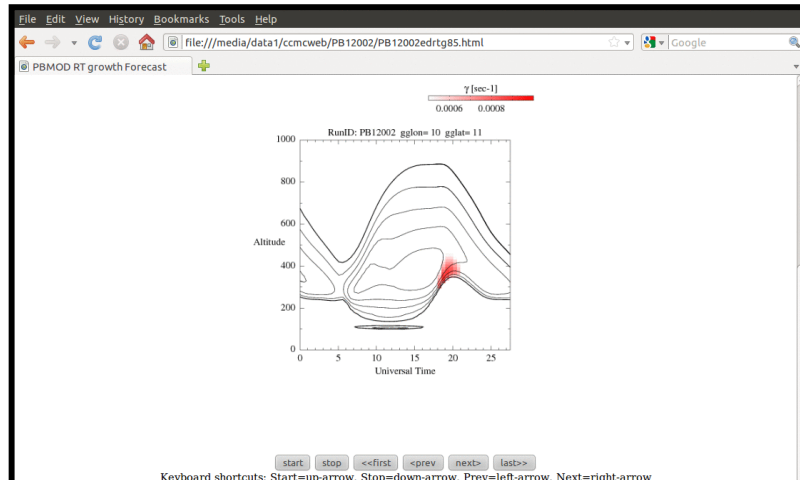
**by longitude**

	NmF2	HmF2	TEC
<b>Rayleigh-Taylor Growth Rate from most probable drift</b>			
	<a href="#">RT growth rate</a>	<a href="#">Time-integrated RT growth rate</a>	<a href="#">RT growth and density contours</a>
<b>Rayleigh-Taylor Growth Rate from 85th-percentile drift</b>			
	<a href="#">RT growth rate</a>	<a href="#">Time-integrated RT growth rate</a>	<a href="#">RT growth and density contours</a>

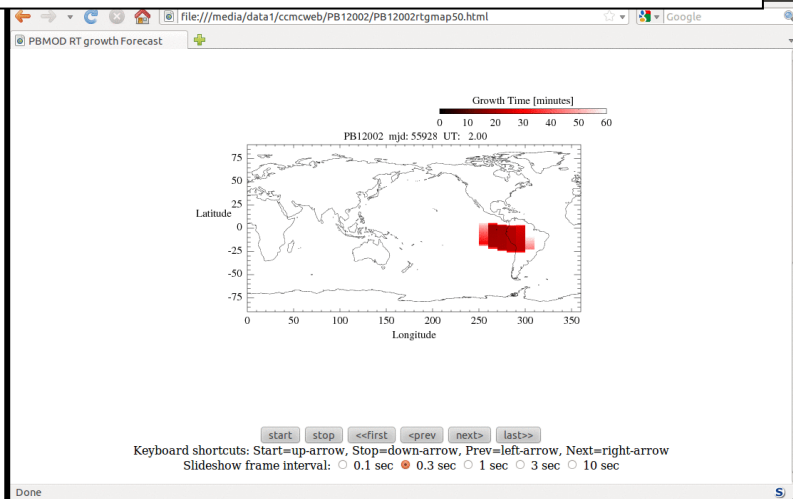
Done



# PBMOD Daily Run Webpage



**Animations of Rayleigh-Taylor growth rate**



The webpage displays a grid of plots for the PBMOD Daily Run. The plots are arranged in a 2x2 grid for each of two different runs. The labels for the plots are:

- HmF2
- TEC
- Time-integrated RT growth rate
- RT growth and density contours

Arrows from the text box point to the 'Time-integrated RT growth rate' and 'RT growth and density contours' plots in both the top and bottom rows.



# PBMOD Daily Run Webpage

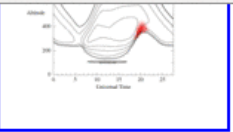
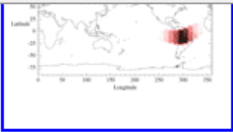
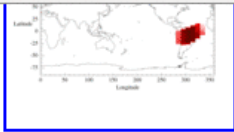


File Edit View History Bookmarks Tools Help

file:///media/data1/ccmcweb/PB12002pbmod.html

PBMOD Ionosphere/Irregulari...

**50th percentile drift**

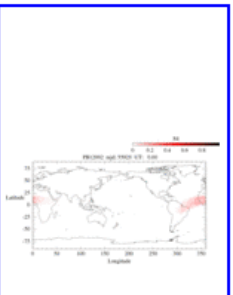
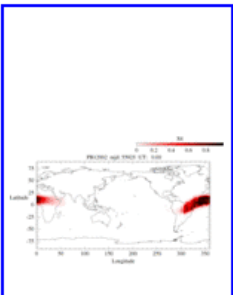
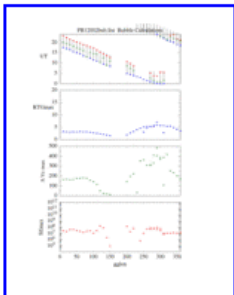


[RT growth rate](#)

[Time-integrated RT growth rate](#)

[RT growth and density contours](#)

**Bubbles and Scintillation from most probable drift**

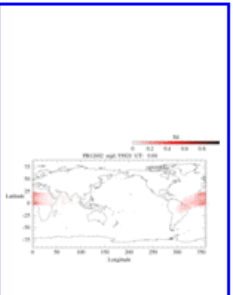
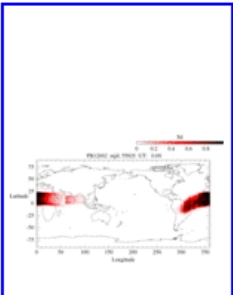
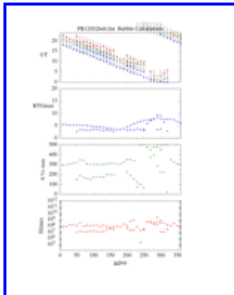


[Bubble list](#)

[UHF S4](#)

[L-band S4](#)

**Bubbles and Scintillation from 85th-percentile drift**



[Bubble list](#)

[UHF S4 at 85 pc](#)

[L-band S4 at 85 pc](#)

Done

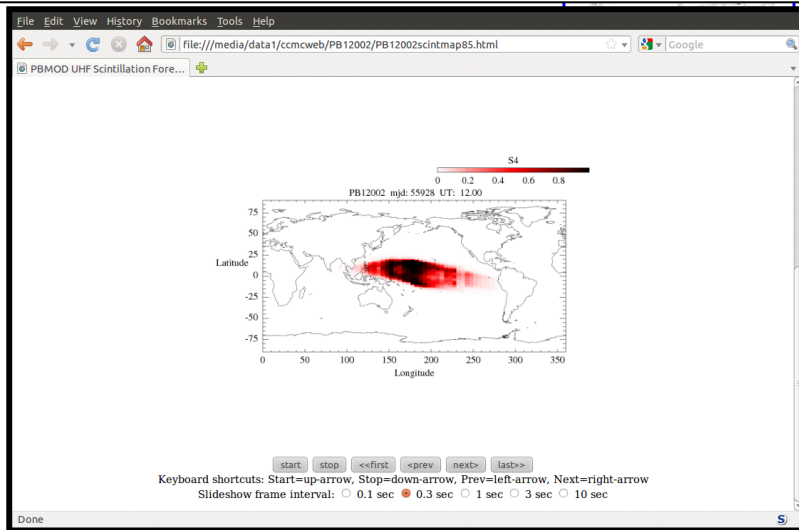
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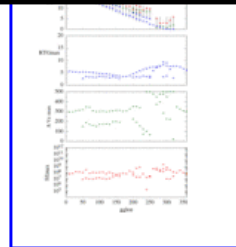
# PBMOD Daily Run Webpage



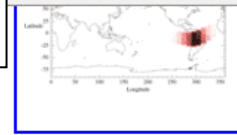
## Animations of scintillation strength



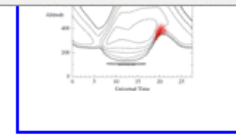
**Bubbles and Scintillation from 85th-percentile drift**



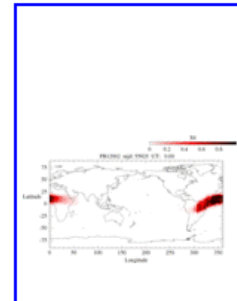
Bubble list



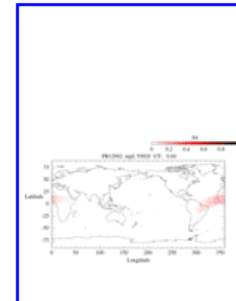
Time-integrated RT growth rate



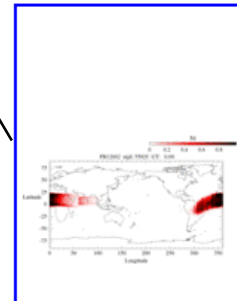
RT growth and density contours



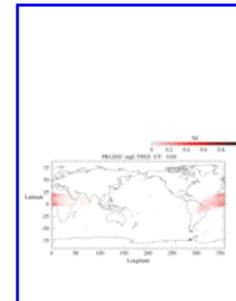
UHF S4



L-band S4



UHF S4 at 85 pc



L-band S4 at 85 pc

## Animations of bubble quantities





# To Be Added



- **Run PBMOD on Demand**
  - User entry of plasma drift (local mode – one longitude sector)
- **Couple PBMOD with other models at CCMC**
  - TIEGCM for winds
  - Penetration fields and other storm effects



# Summary



- **Radio scintillation is a space-weather phenomenon with important implications for the basic science of the ionosphere and consequences for operational systems**
- **PBMOD is a model of the chain of phenomena that lead to scintillation that was developed for the Air Force/NASA C/NOFS program, which has been tested and refined under a variety of circumstances**
- **Good reason to implement PBMOD at CCMC: there are a number of meaningful aspects of the scintillation phenomena that the community user will be able to explore using the model with the web interface**