

PBMOD Scintillation Modeling at CCMC

John Retterer
Boston College



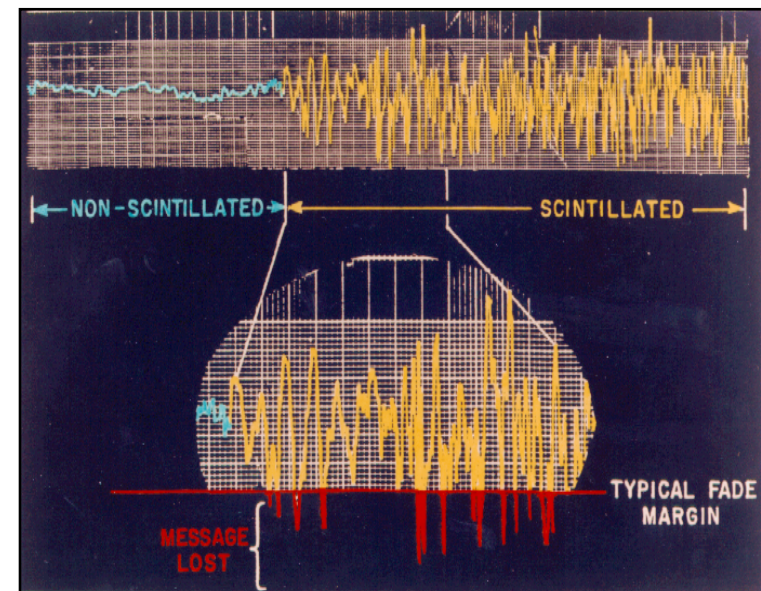
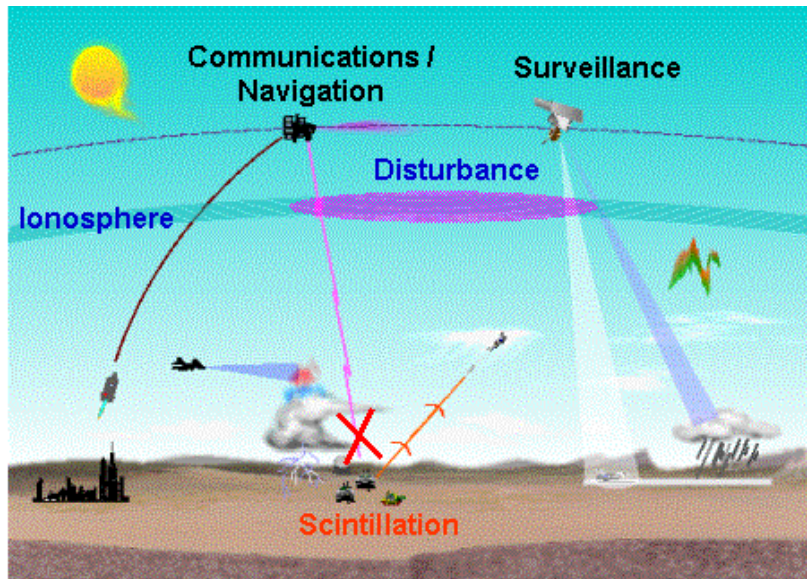
The 7th CCMC Community Workshop

Annapolis, MD

March 31 – April 5, 2014

- **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**
 - Interfaces for the community user

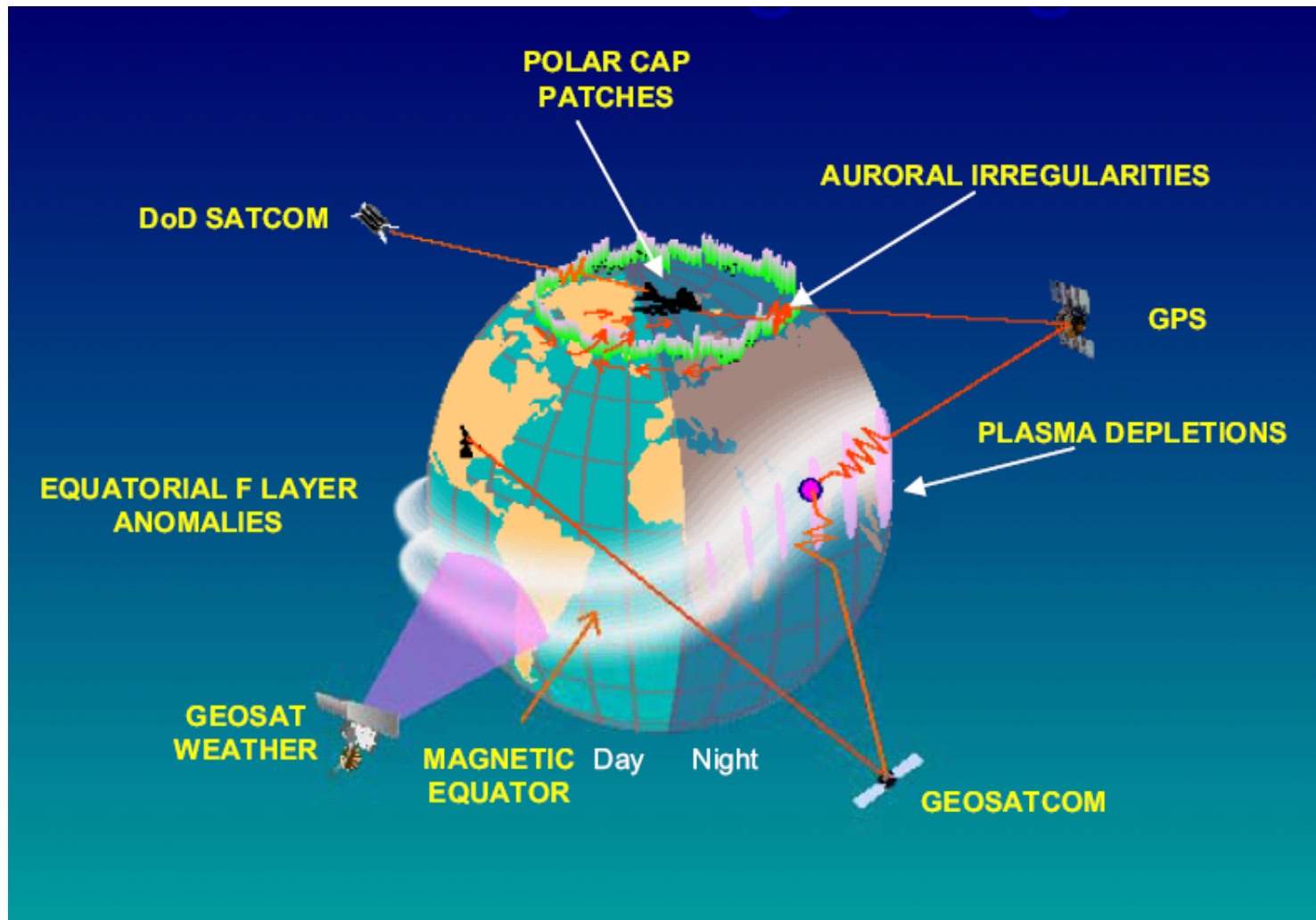
Scintillation: Rapid fluctuations of the amplitude & phase of radio signals from space due to ionospheric turbulence



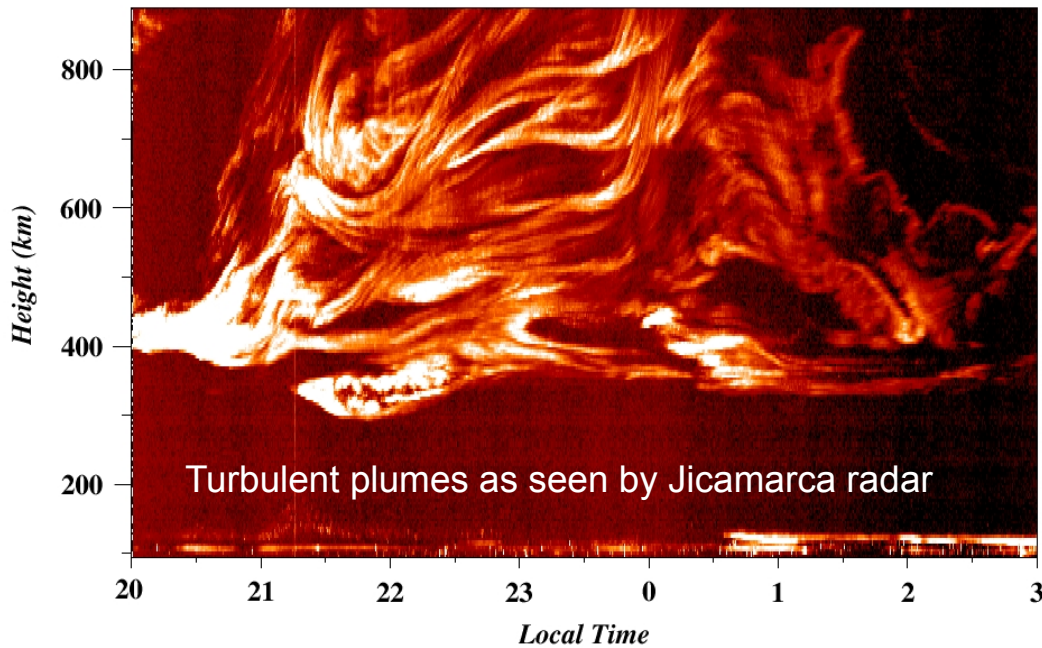
Scintillation causes outages of communication and navigation systems

Scintillation Regions

polar and equatorial

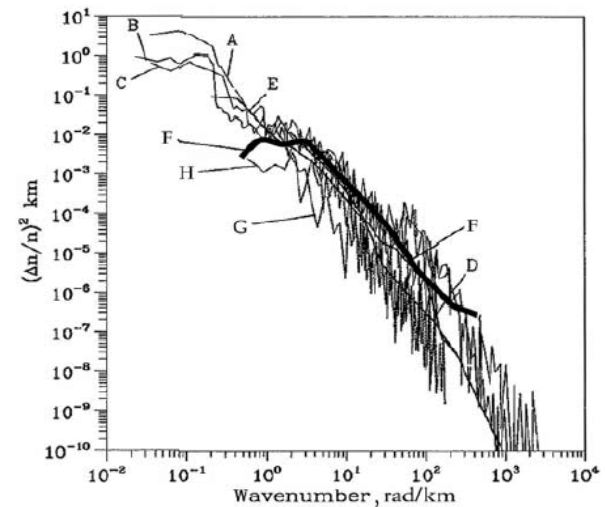


Scintillation at low magnetic latitudes is associated with the development of plasma turbulence within plumes of uplifting low-density plasma triggered by the Rayleigh-Taylor instability near the lower edge of the ionospheric F layer



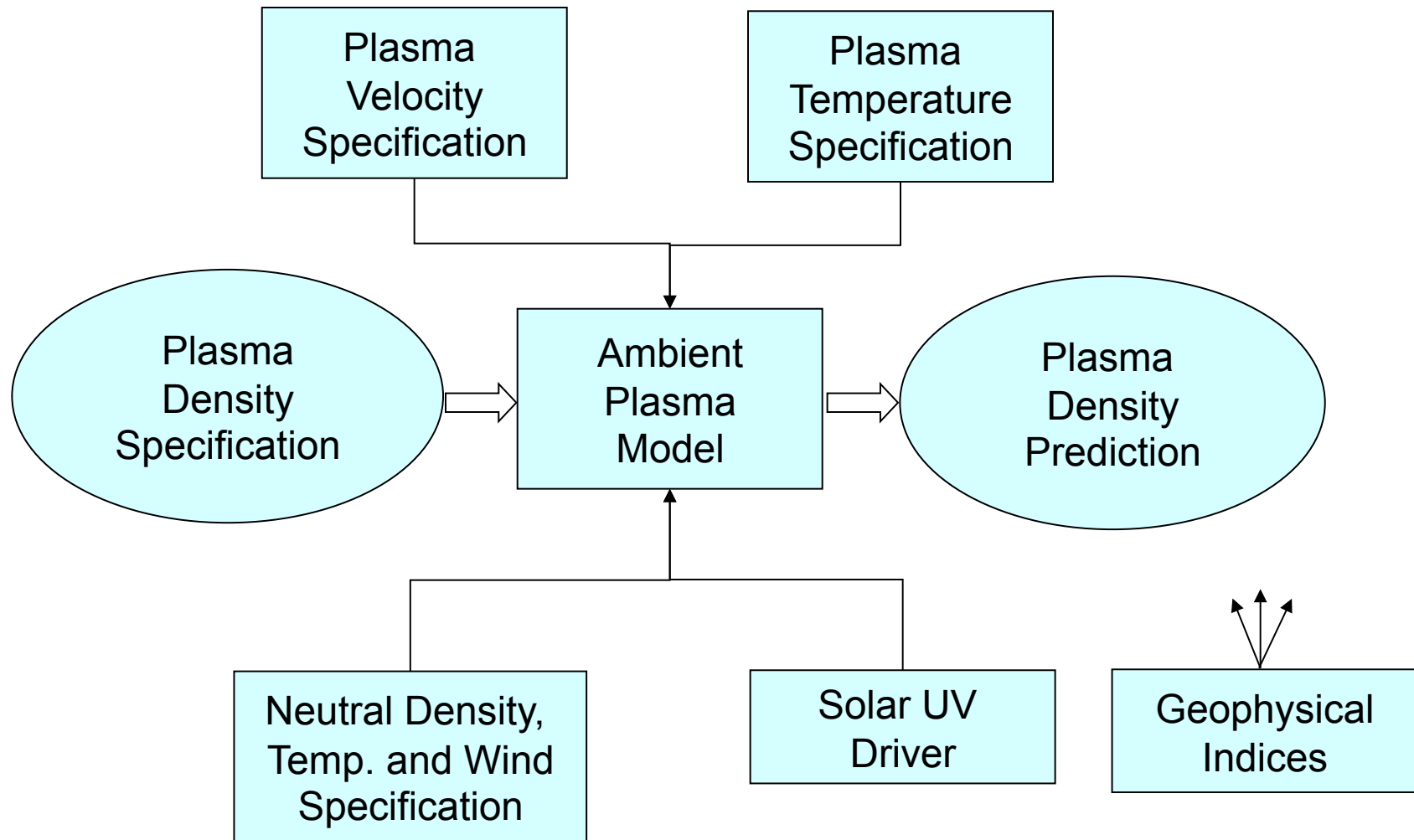
(Woodman and LaHoz 1976)

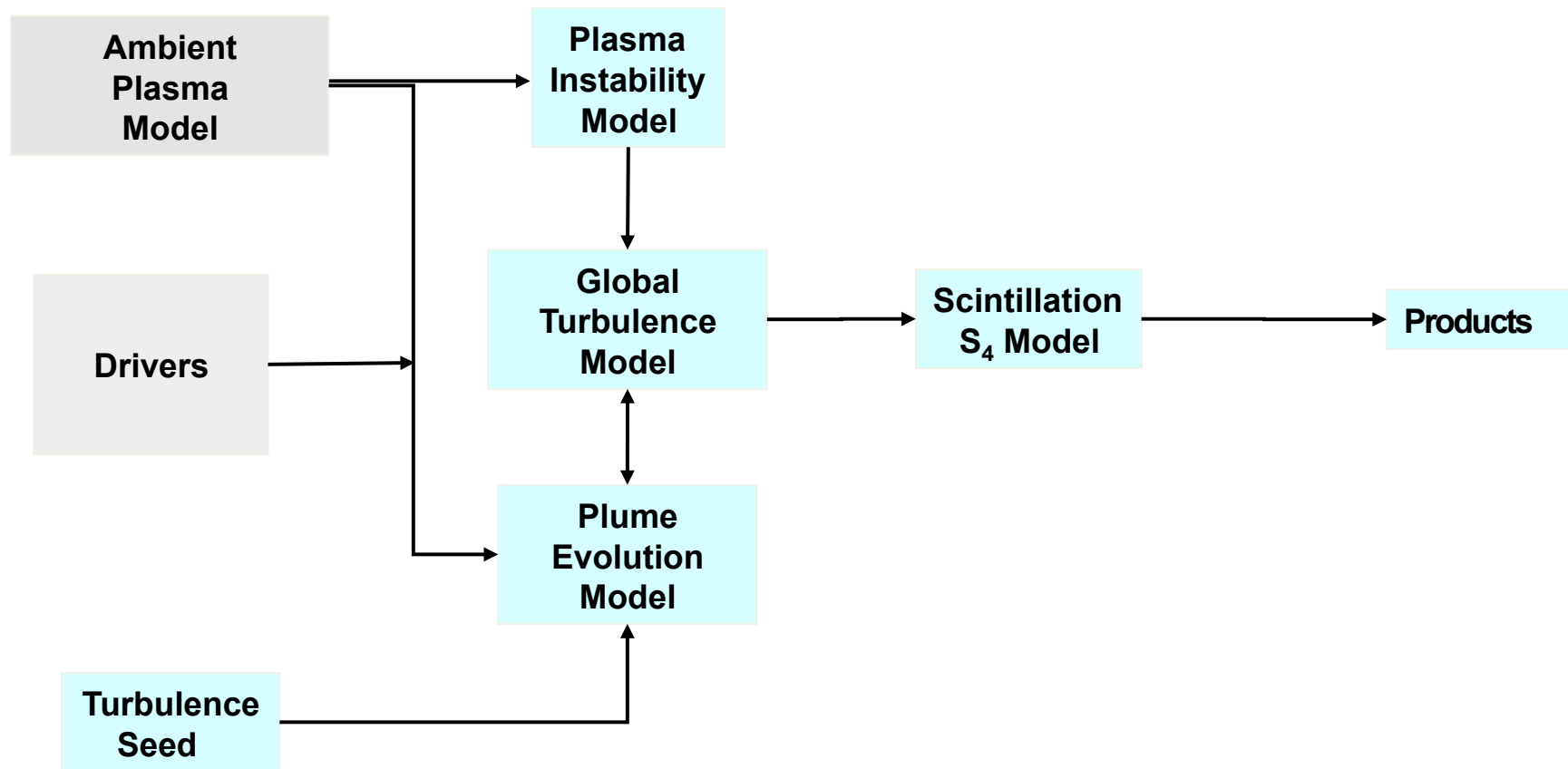
Spectrum of density irregularities from rocket fly-through density measurements



(Kelley and Livingston 2003)

- 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 has been installed at CCMC for community use





Model describes temporal development of mesoscale plasma structure & turbulence

Uses nonlinear continuity and momentum equations

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

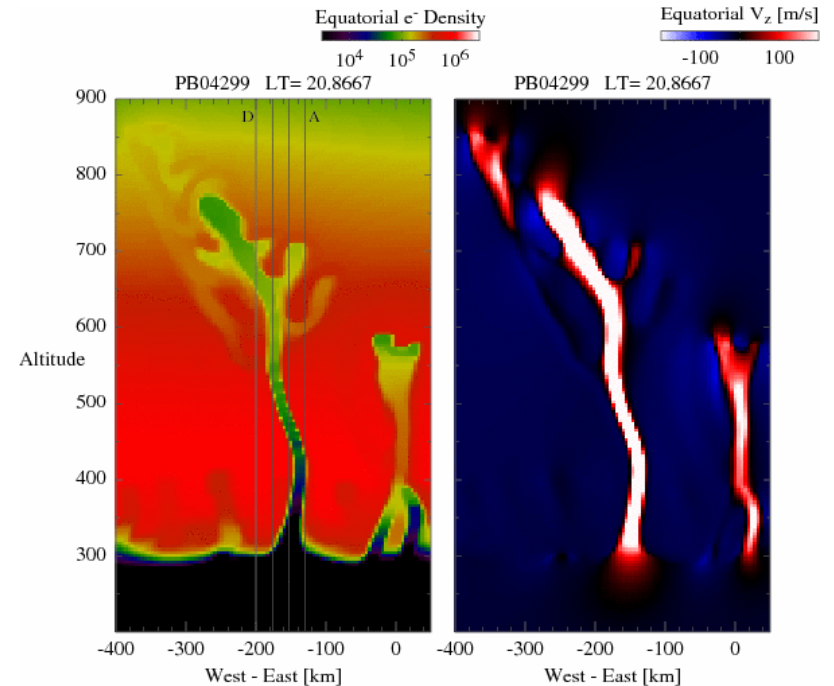
$$\frac{d\mathbf{v}_s}{dt} = \frac{q_s}{m_s} \mathbf{E} + \mathbf{g} + \Omega_s \mathbf{v}_s \times \hat{\mathbf{B}} - \frac{1}{n_s} \nabla_{\perp} P_s + \nu_s (\mathbf{U} - \mathbf{v}_s)$$

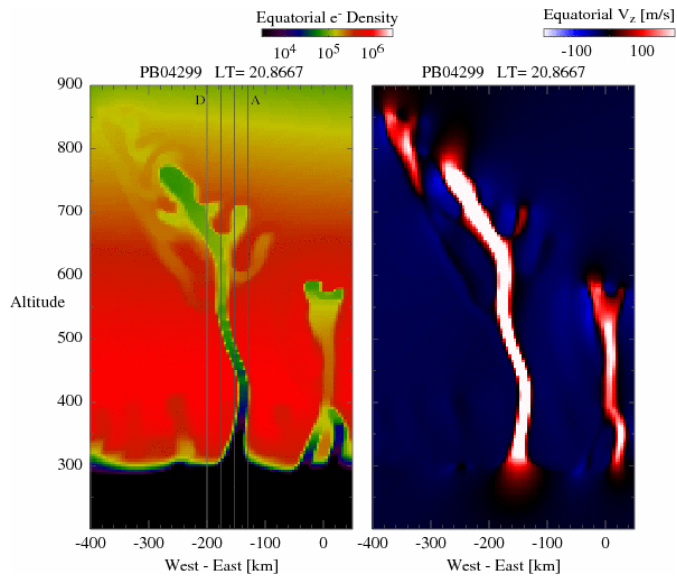
Perpendicular electric fields:

- 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

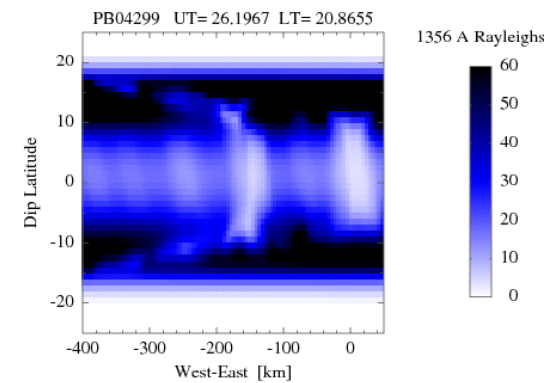
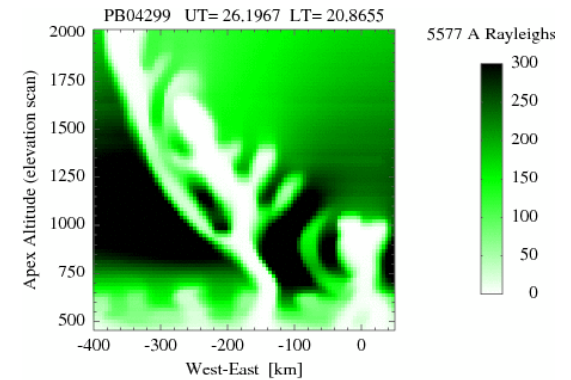
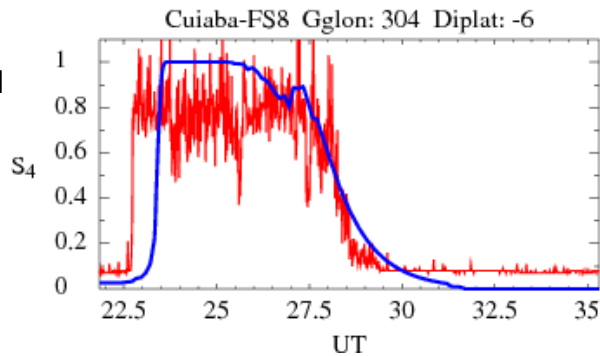
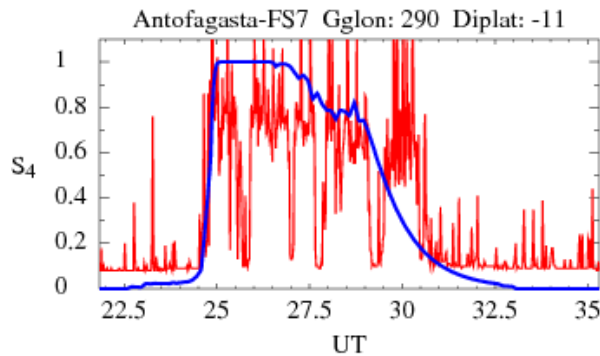
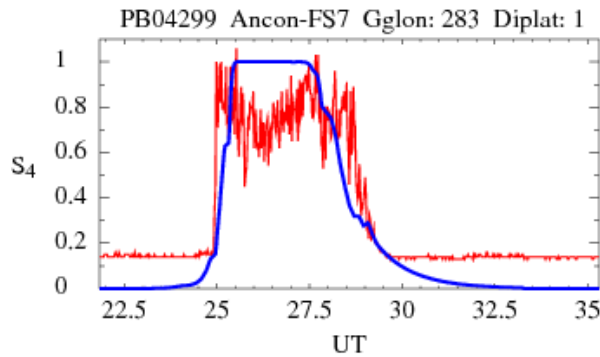
PBMOD includes two-dimensional and three-dimensional plume models





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

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

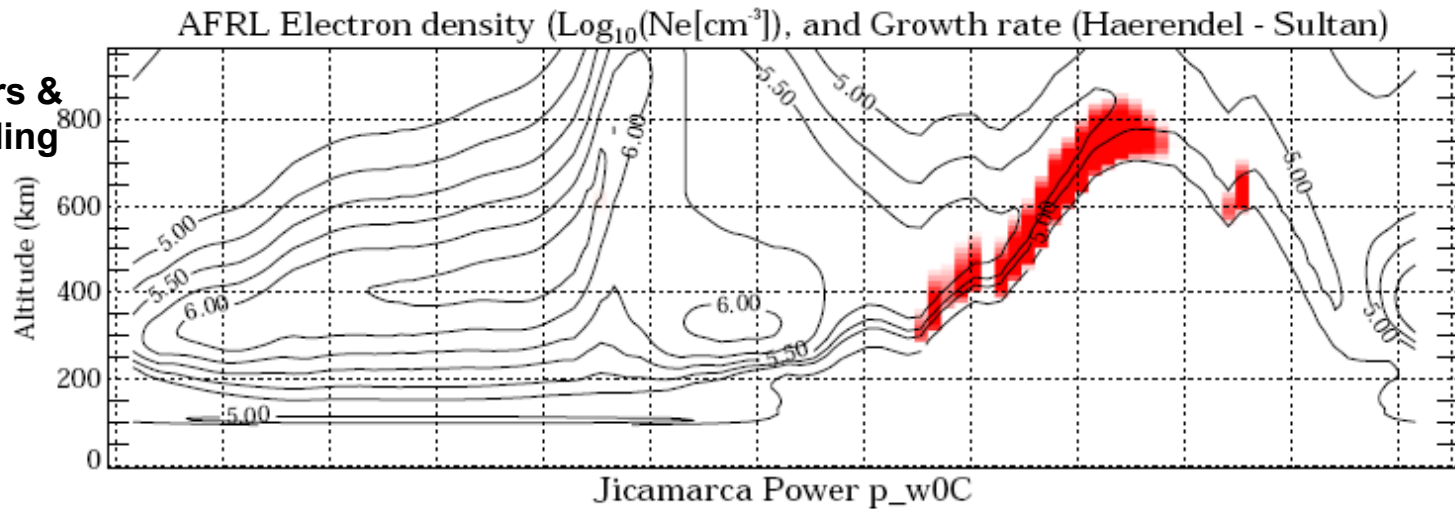


Airglow images of plumes: geometry of Cornell Hawaii camera (looking south toward plume) in 5577 A (top) and GUVI nadir sensing in 1356 A (bottom)

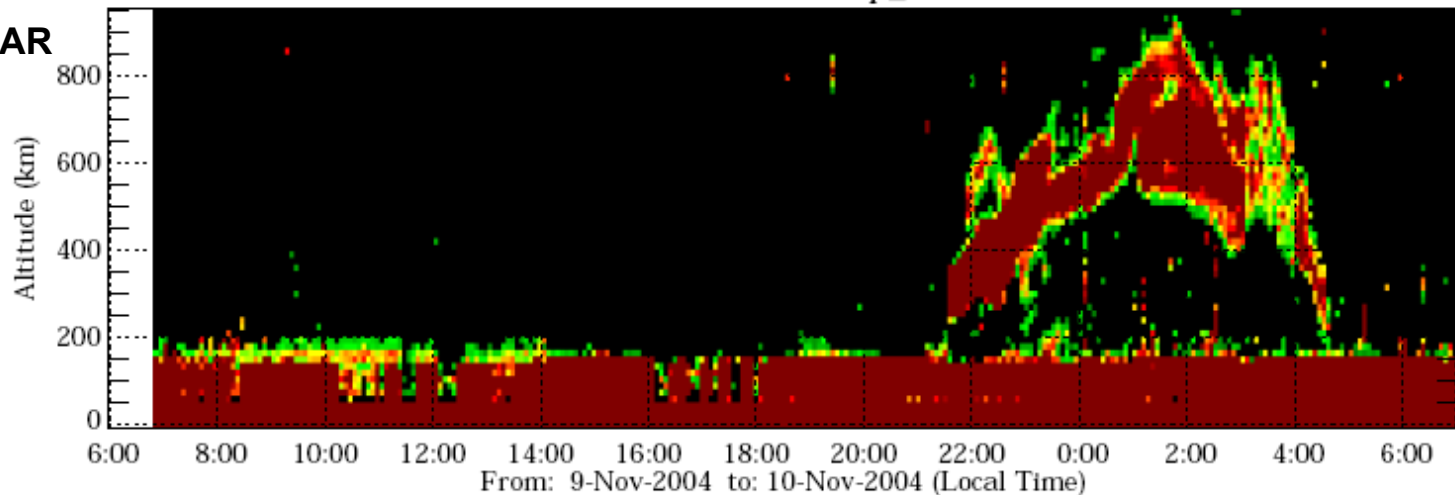
Scintillation Modeling

geomagnetic storm conditions (November 2004)

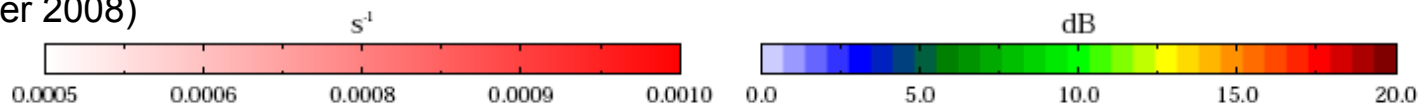
Density contours & RT growth shading from PBMOD using plasma drifts from Jicamarca



Jicamarca RADAR coherent returns - indicating presence of turbulence



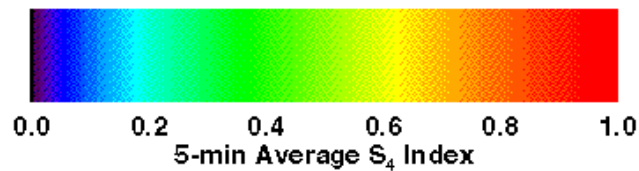
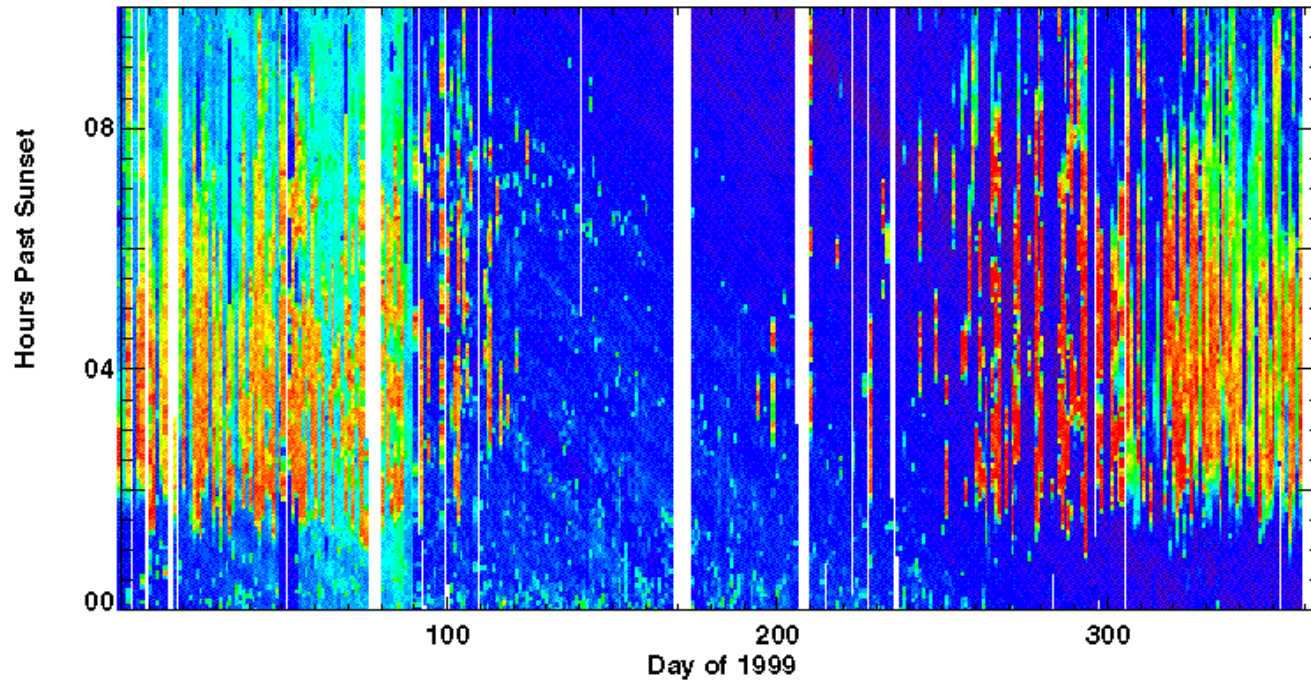
(Kelley and Retterer 2008)



Scintillation Variability

SCINDA Station at Antofagasta, Peru

Antofagasta West
UHF Scintillation Index : 1999



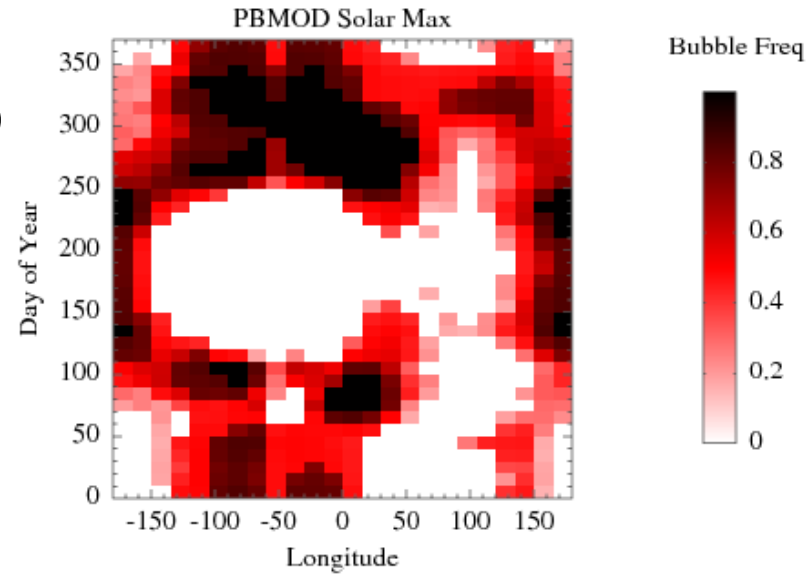
Courtesy
Keith Groves

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

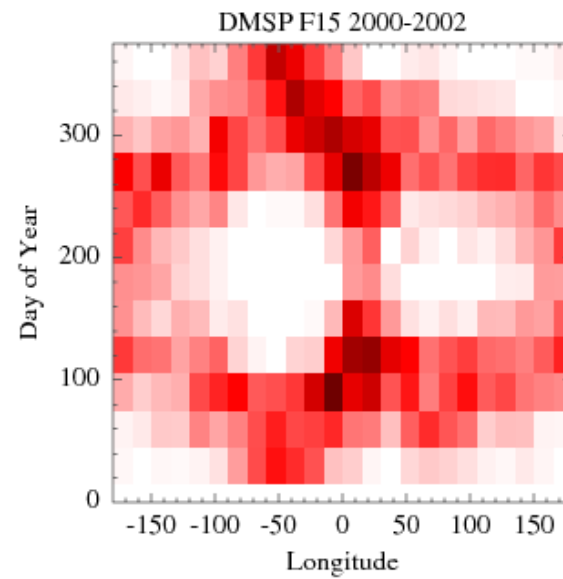
Plasma Bubble Climatology

solar max

PBMOD

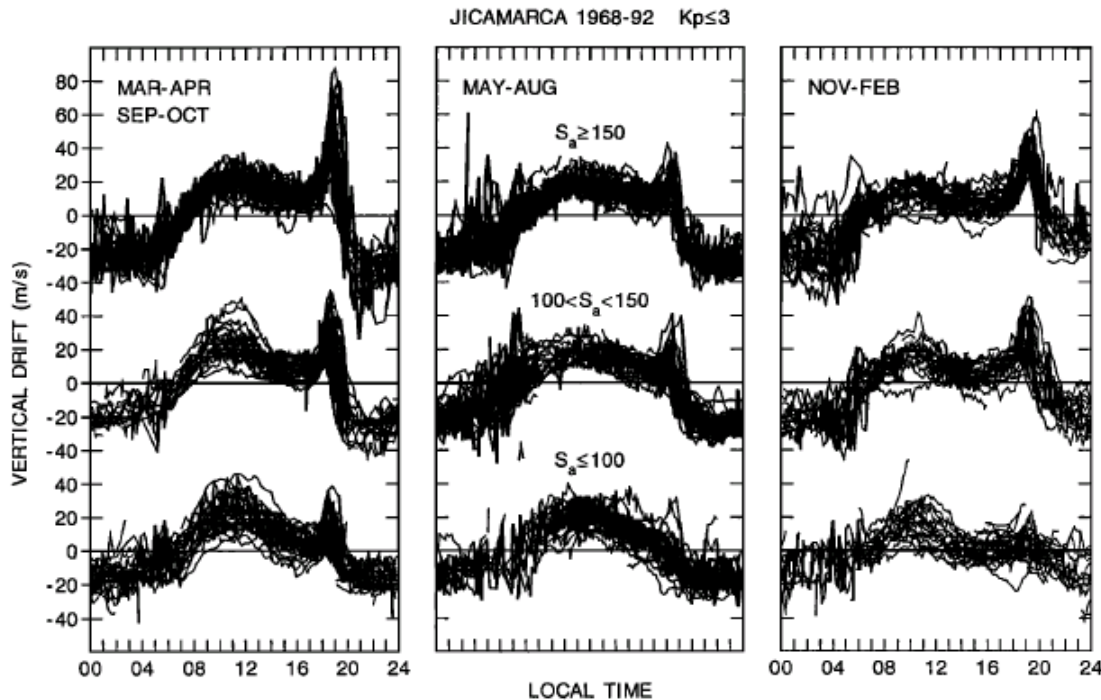


DMSP

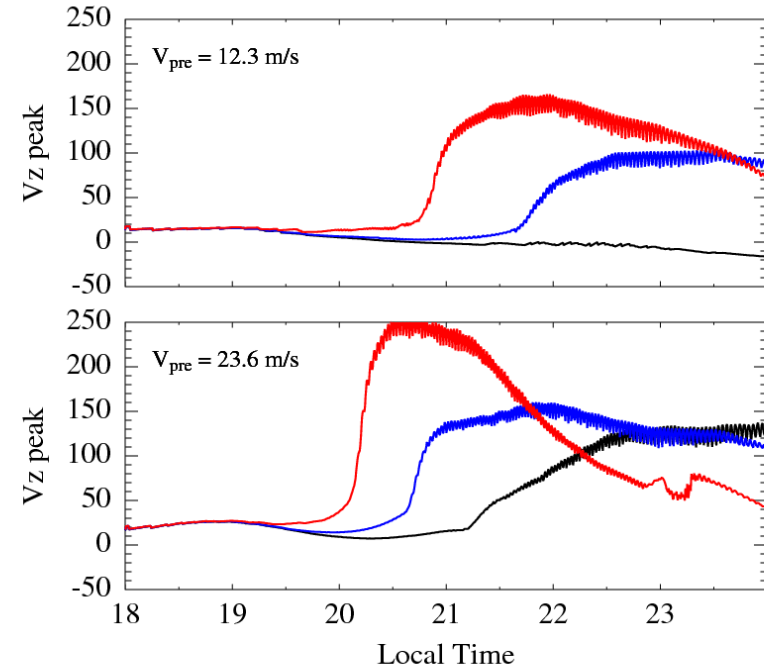
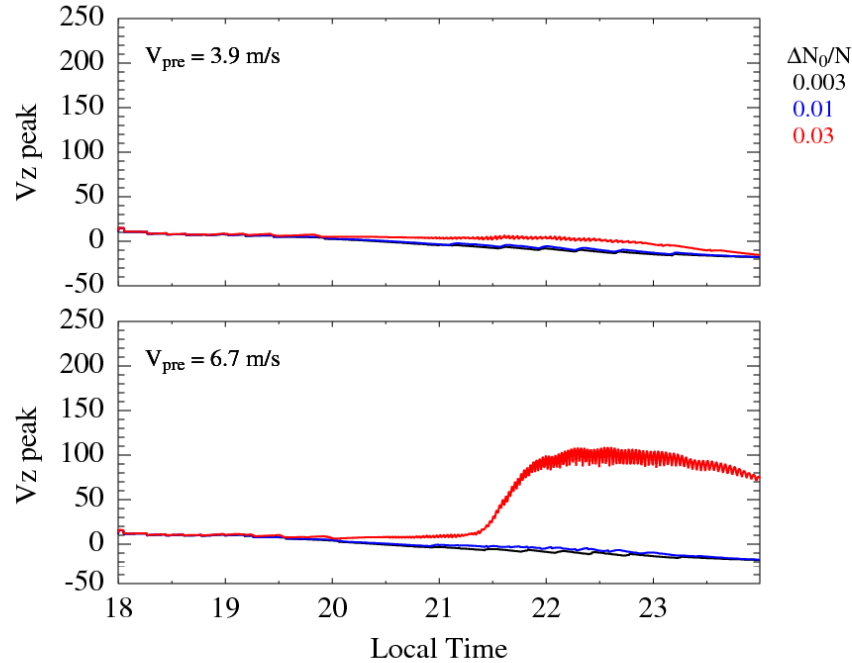


The natural variability in scintillation is caused by the variability of geophysical conditions controlling the instability of the ionosphere

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



Jicamarca ISR data (Scherliess & Fejer) illustrates the natural scatter of velocities



Scintillation variability due to the interplay between the variabilities of the strength of the Rayleigh-Taylor instability growth rate and the strength of the seed density perturbation



CCMC PBMOD Webpages



R2O (Research to Operations) Support

Ionospheric Experimental Real-time Simulations:

[Real-time Ionosphere/Irregularity/Scintillation Calculation \(Model: PBMOD\)](#)

[Retrospective run of PBMOD](#) | [PBMOD simulations archive](#)

- PBMOD is being run daily at CCMC
- Execution start timed so that scintillation calculation can serve as a forecast
- The job is rerun later when geophysical indices are known, to provide a 'retrospective'
- Calculations are done with two drift-velocity histories
 - Expected drift (50th percentile) for plasma densities
 - 85th 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

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)

[Parameters](#) [run_db](#)

[Geophysical Indices](#)

Thermospheric Drivers

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

Plasma Drivers

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

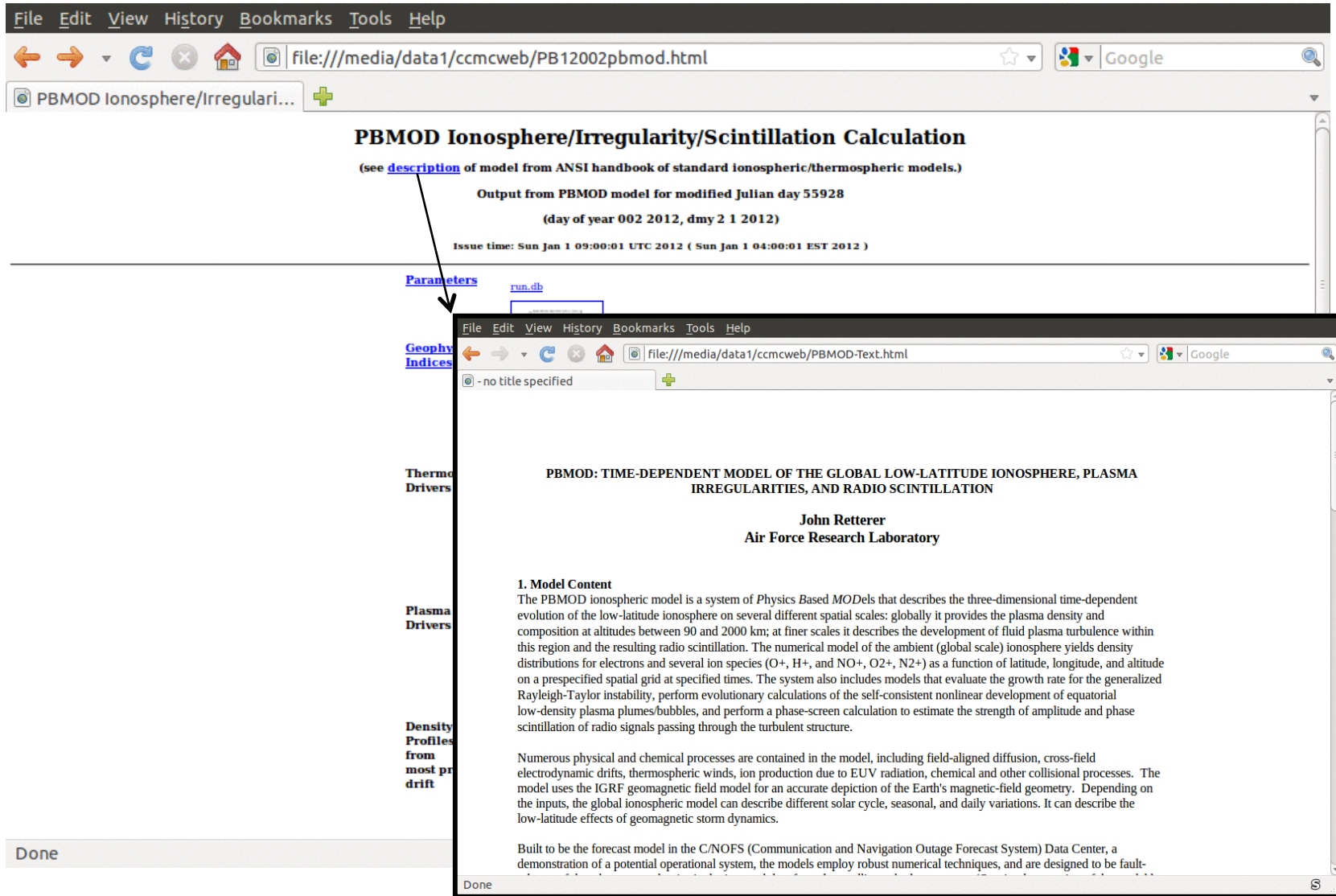
Density Profiles from most probable drift

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

Done

Top of page

- Geophysical indices
- Driver quantities



The image shows a web browser window displaying the PBMOD model interface. The main window title is "PBMOD Ionosphere/Irregulari...". The page content includes:

- Parameters** (with a link to `run.dib`)
- Geophy Indices**
- Thermo Drivers**
- Plasma Drivers**
- Density Profiles from most pr drift**

An inset window shows the file `file:///media/data1/ccmcweb/PBMOD-Text.html` with the following text:

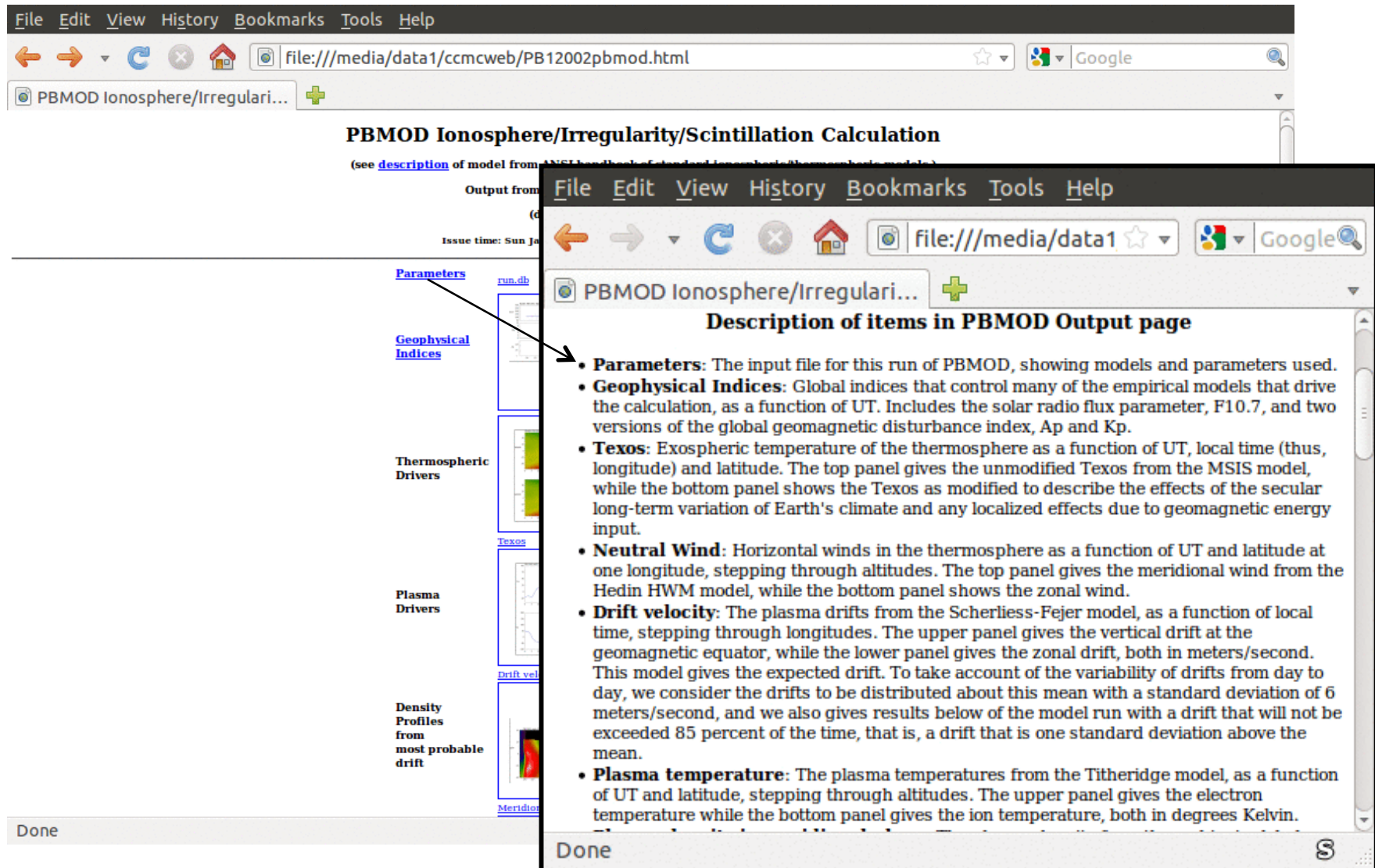
PBMOD: TIME-DEPENDENT MODEL OF THE GLOBAL LOW-LATITUDE IONOSPHERE, PLASMA IRREGULARITIES, AND RADIO SCINTILLATION

John Retterer
Air Force Research Laboratory

1. Model Content
The PBMOD ionospheric model is a system of Physics Based MODels 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⁺, H⁺, and NO⁺, O₂⁺, N₂⁺) 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 Ionosphere/Irregularity/Scintillation Calculation

(see [description](#) of model from [ANSI Handbook of Ionospheric Parameters and Models](#))

Output from
(G
Issue time: Sun J

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

[Geophysical Indices](#)

Thermospheric Drivers

[Texos](#)

Plasma Drivers

[Drift vel](#)

Density Profiles from most probable drift

[Meridians](#)

Done

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

File Edit View History Bookmarks Tools Help

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

PBMOD Ionosphere/Irregulari...

from most probable drift

Profile Parameters from most probable drift, by time

Profile Parameters from most probable drift, by longitude

Meridional plane

Equatorial profiles

NmF2

HmF2

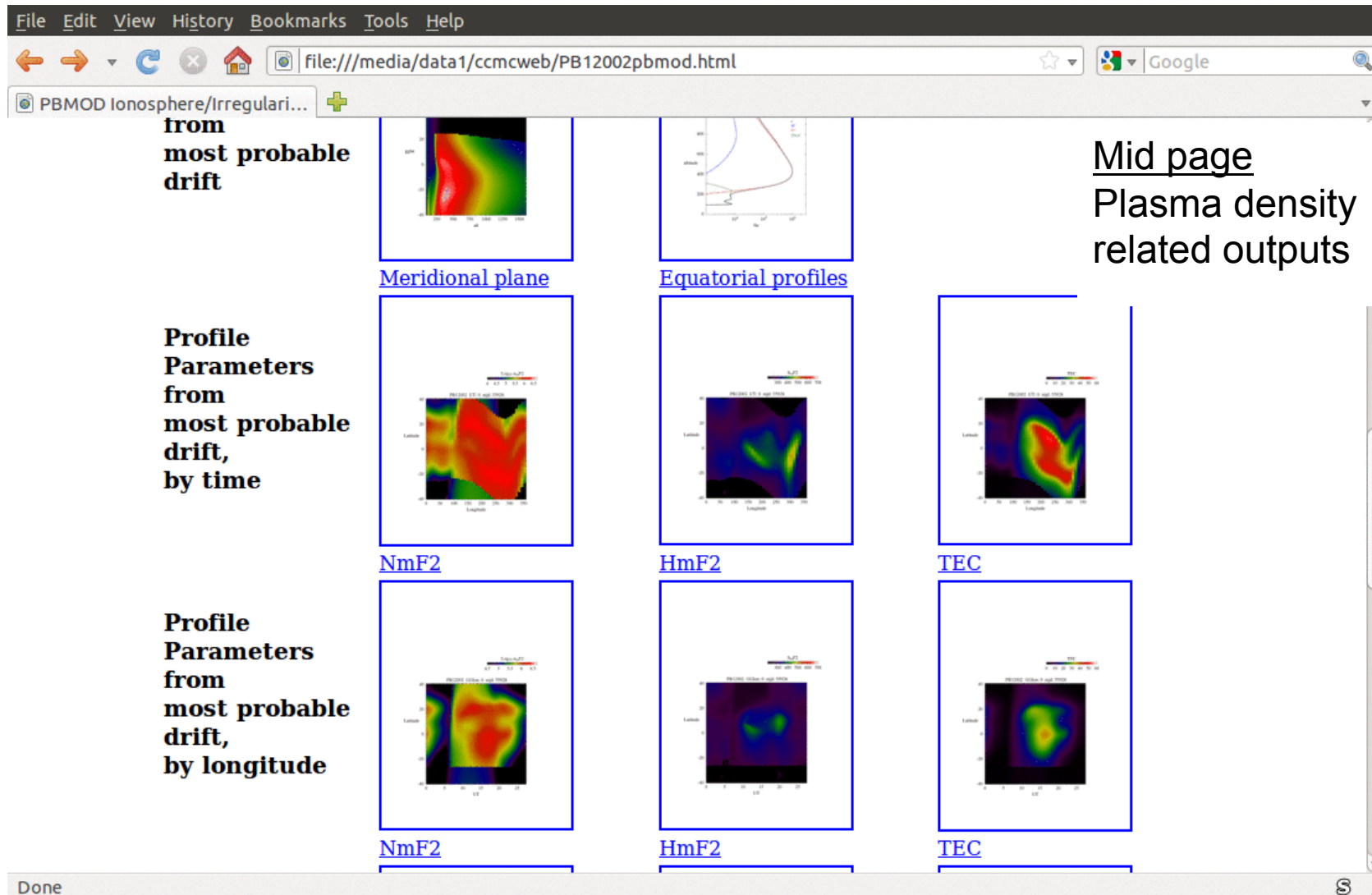
TEC

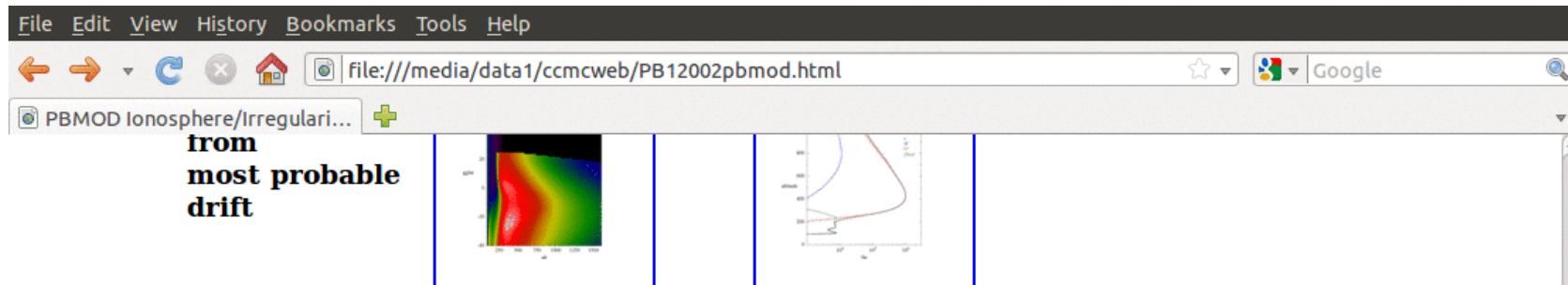
NmF2

HmF2

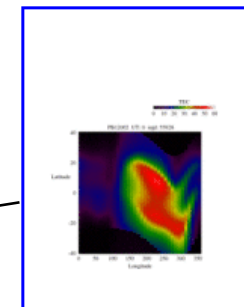
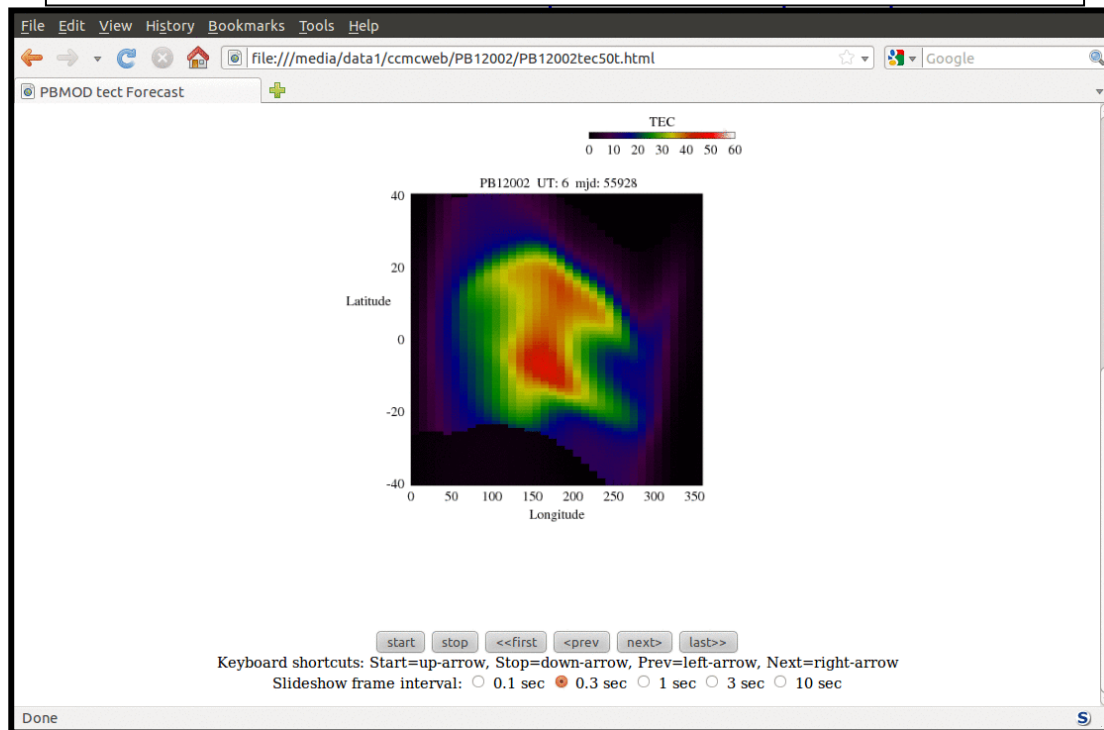
TEC

Mid page Plasma density related outputs

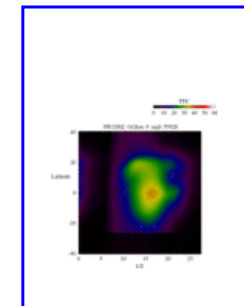




Animations of TEC and other quantities



TEC



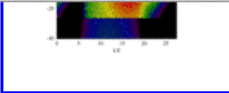

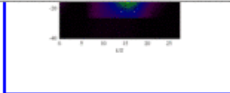
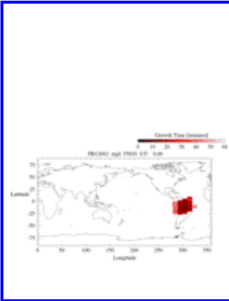
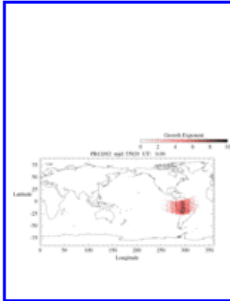
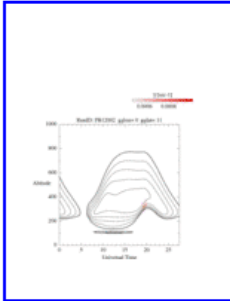
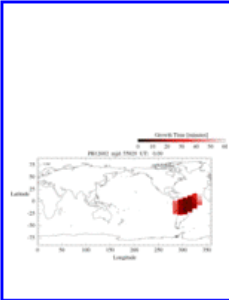
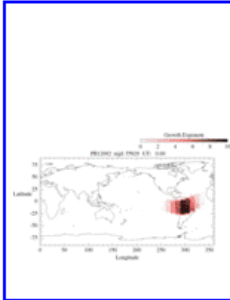
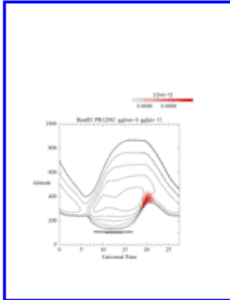
TEC

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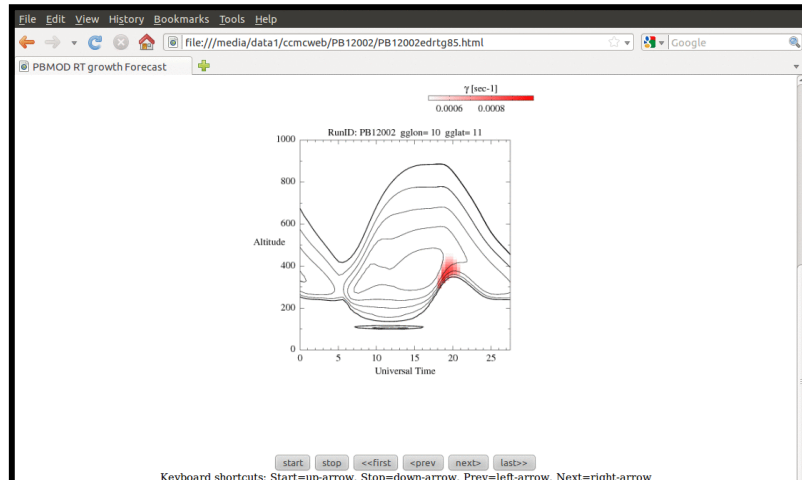
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PBMOD Ionosphere/Irregulari...

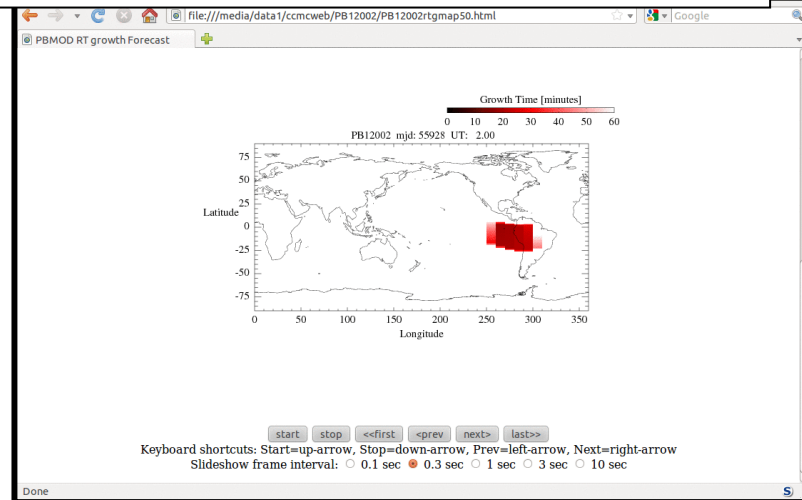
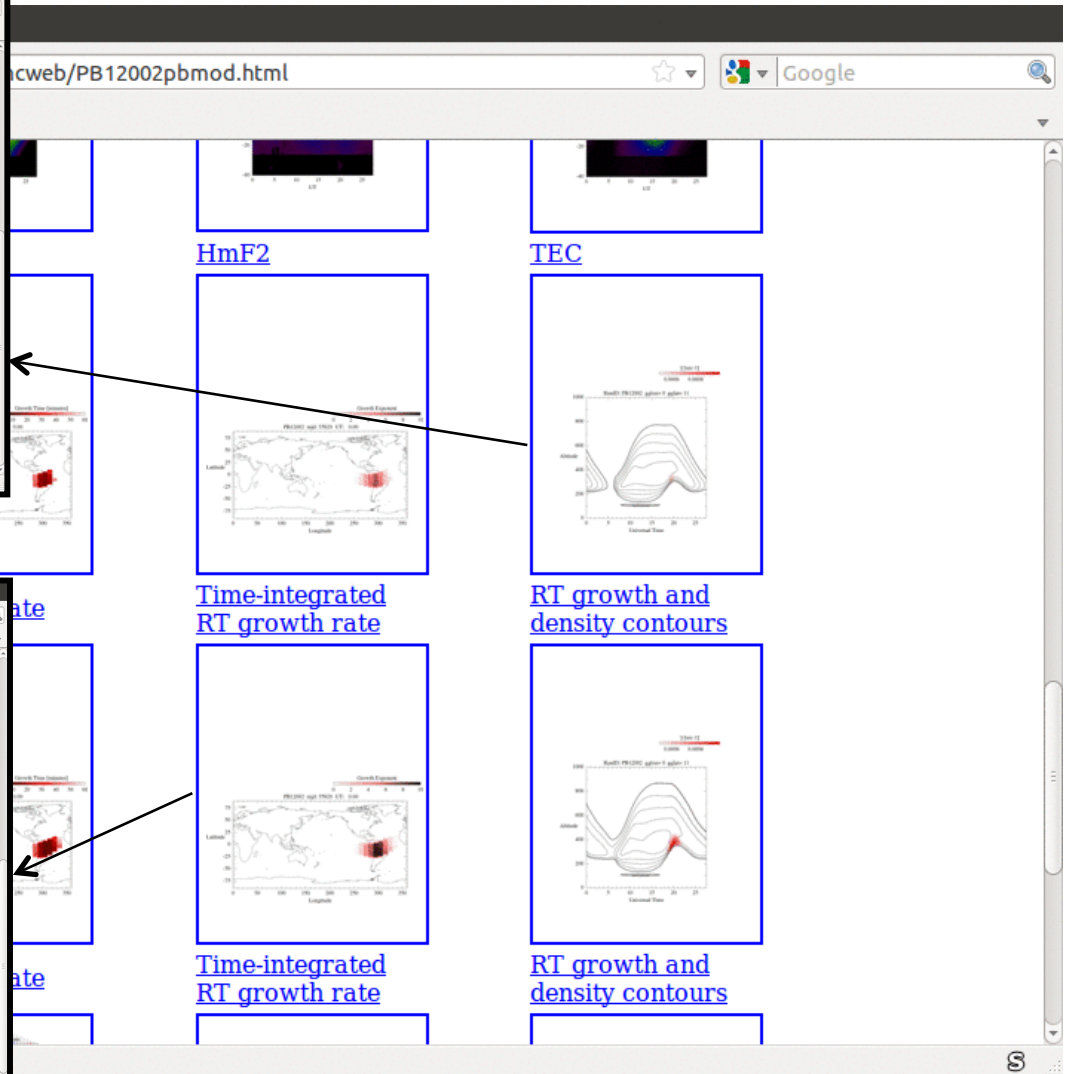
by longitude

			
	NmF2	HmF2	TEC
Rayleigh-Taylor Growth Rate from most probable drift			
	RT growth rate	Time-integrated RT growth rate	RT growth and density contours
Rayleigh-Taylor Growth Rate from 85th-percentile drift			
	RT growth rate	Time-integrated RT growth rate	RT growth and density contours

Done



Animations of Rayleigh-Taylor growth rate

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

HmF2

TEC

Time-integrated RT growth rate

RT growth and density contours

Time-integrated RT growth rate

RT growth and density contours

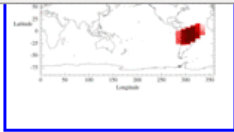
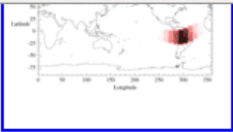
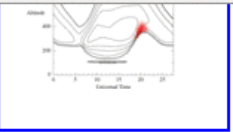
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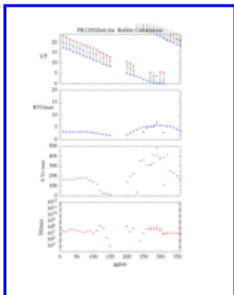
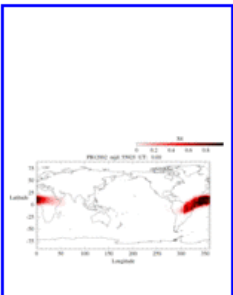
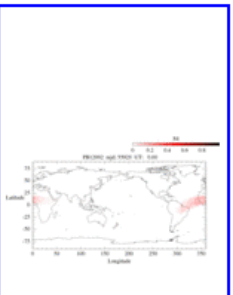
PBMOD Ionosphere/Irregulari...

50th percentile drift

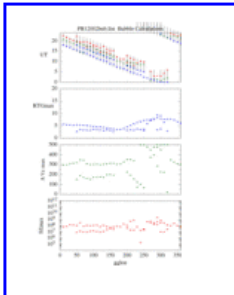
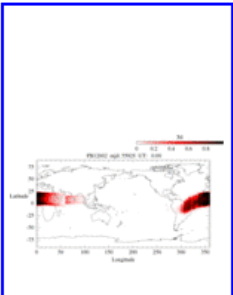
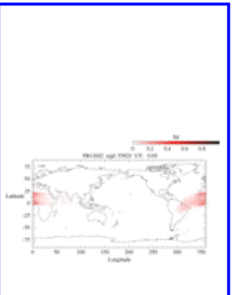
[RT growth rate](#) [Time-integrated RT growth rate](#) [RT growth and density contours](#)

Bubbles and Scintillation from most probable drift

[Bubble list](#) [UHF S4](#) [L-band S4](#)

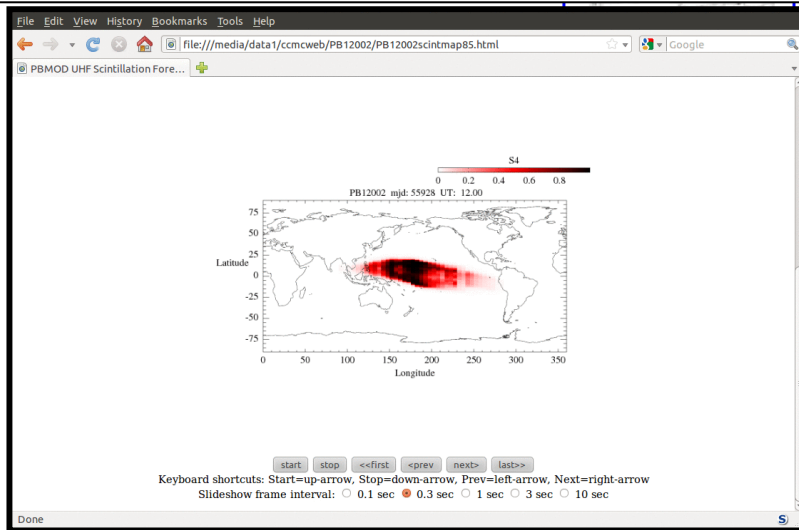
Bubbles and Scintillation from 85th-percentile drift

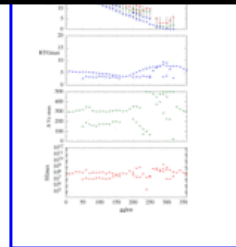
[Bubble list](#) [UHF S4 at 85 pc](#) [L-band S4 at 85 pc](#)

Done

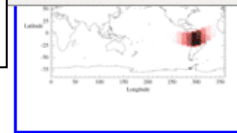
Animations of scintillation strength



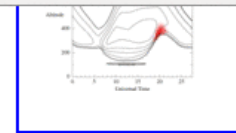
Bubbles and Scintillation from 85th-percentile drift



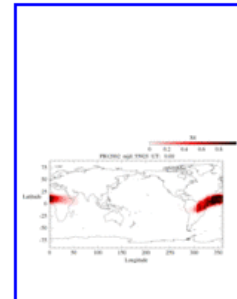
Bubble list



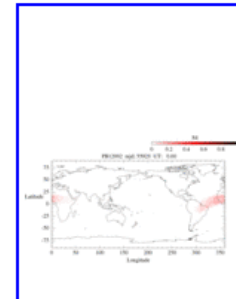
Time-integrated RT growth rate



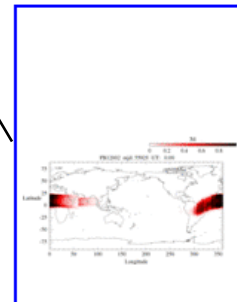
RT growth and density contours



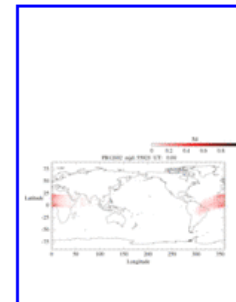
UHF S4



L-band S4



UHF S4 at 85 pc

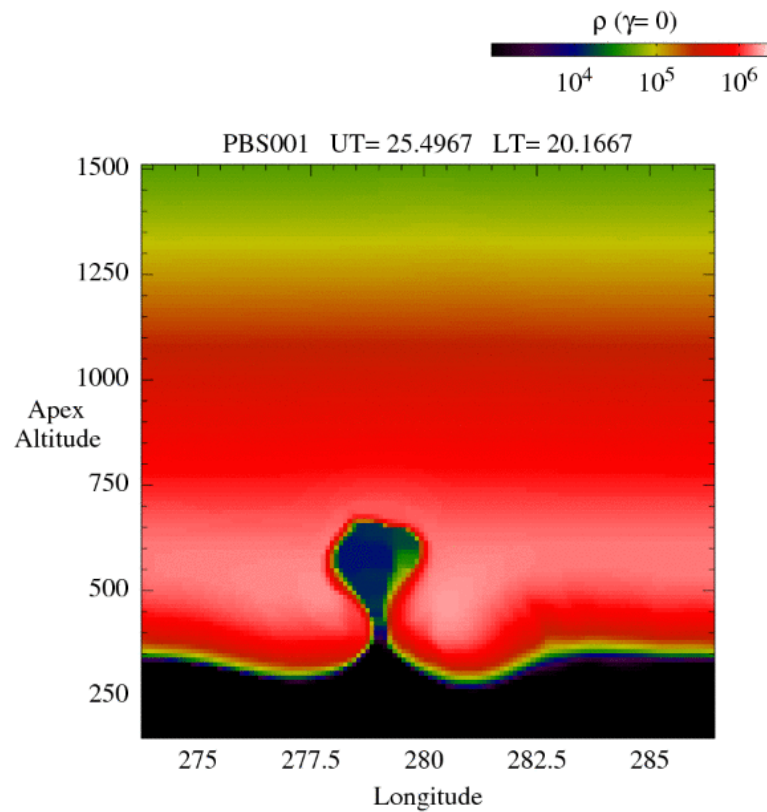


L-band S4 at 85 pc

Animations of bubble quantities

PBMOD at CCMC

Animation controls



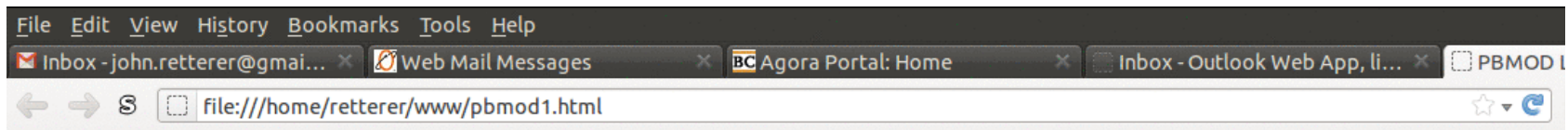
start stop <<first <prev next> last>>

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

- **Laboratory for exploring low-latitude ionospheric phenomena (density structure, Rayleigh-Taylor instability development, scintillation formation)**
- **User can enter plasma drift and other parameters**
- **Local mode – one longitude sector**
- **Under development**

Inputs

- **Choice of driver sets: empirical models or TIEGCM outputs**
- **User can specify/modify histories of**
 - **F10.7**
 - **Kp**
 - **Neutral-wind scaling and offset parameters**
 - **Plasma drift**
- **User can specify plume-model**
 - **Density Seed**
 - **other parameters**



PBMOD Model Run on Demand for the Low-Latitude Ionosphere, Plasma Turbulence, and Radio Scintillation

- Longitude (deg E)
- Date (day month year)
- Drivers: Climatological TIEGCM
 - Climatological Drift Model: Scherliess-Fejer (1999) CNOFS Climo
- Ambient density calculation
- Rayleigh-Taylor growth rate calculation
- Bubble calculation
 - Seed Model: ad hoc CNOFS Climo
 - Seed fractional density magnitude
 -
 -
 -
- Scintillation calculation
 - Radio signal frequencies [MHz]
- Email address for notification of job completion

File Edit View History Bookmarks Tools Help


PBMOD Ionosphere/Scintillati... +

file:///home/retterer/www/PBpbmod.html

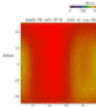
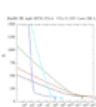
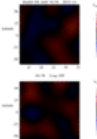
PBMOD Ionosphere/Scintillation Forecast

Output from PBMOD model
for modified Julian day 56738
(day of year 081 2014, dmy 22 3 2014)
in longitude sector 280 ° E (at geomagnetic equator)
Issue time: Sun Mar 30 00:32:37 UTC 2014 (Sat Mar 29 20:32:37 EDT 2014)

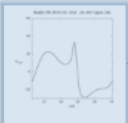
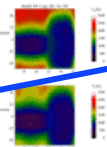
Parameters [run.db](#)

Geophysical Indices 

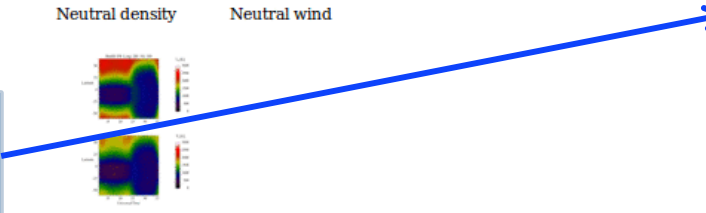
Thermospheric Drivers

Texos  Neutral density  Neutral wind 

Plasma Drivers

Drift velocity  Temperature 

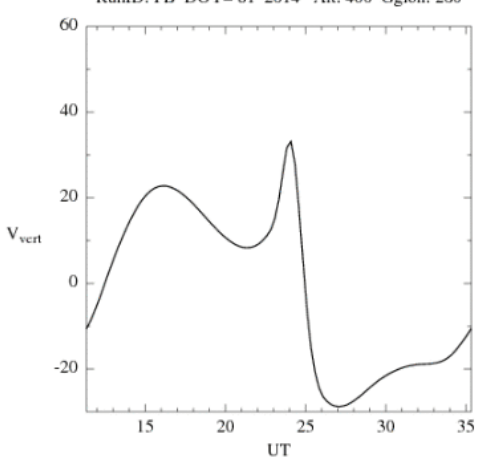
Just the top of the page ...



File Edit View History Bookmarks Tools Help

PBMOD Plasma Drifts

file:///home/retterer/www/PBiv.html



RunID: PB DOY= 81 2014 Alt: 400 Gglon: 280

[Edit drifts](#)
[Download drifts](#)

[About PBMOD](#)
[CCMC Realtime PBMOD Page](#)
[John Retterer](#)
[Boston College, Institute for Scientific Research](#)

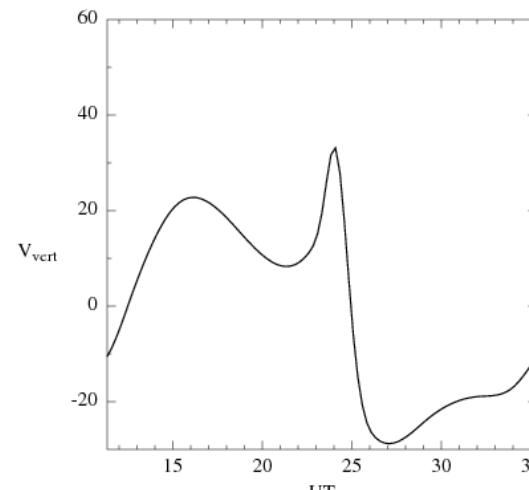
File Edit View History Bookmarks Tools Help

PBMOD Low-Latitude Ionosph...

file:///home/retterer/www/vedit.html

PBMOD Ion Velocity Model
Date: 56744 87 2014 3 28
Gglon: 280.0
LUTobs: 1
Sigvv: 1.0

UT	Vvert
11.333	-10.5
11.433	-9.8
11.533	-9.1
11.633	-8.3
11.733	-7.5
11.833	-6.6
11.933	-5.7
12.033	-4.7
12.133	-3.7
12.233	-2.6
12.333	-1.6
12.433	-0.5
12.533	0.6
12.633	1.6
12.733	2.7
12.833	3.7
12.933	4.7
13.033	5.7
13.133	6.7
13.233	7.6
13.333	8.6
13.433	9.5
13.533	10.4
13.633	11.3
13.733	12.1



RunID: PB DOY= 81 2014 Alt: 400 Gglon: 280

home cancel refresh submit changes

Outputs

- Just like CCMC daily-run output page
- Plasma density, TEC, & profile parameters (hmF2, NmF2)
- Rayleigh-Taylor growth rate
- Plume evolution animations
- Scintillation strength (S_4)

- 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
- PBMOD daily runs at CCMC provide climatological maps of scintillation and a wide variety of other parameters of the low-latitude ionosphere that illuminate the conditions there
- PBMOD Run on demand: permit the community user to explore a variety of aspects of the scintillation phenomenon using the model with the web interface

