PBMOD Scintillation Modeling at CCMC

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The 7th CCMC Community Workshop

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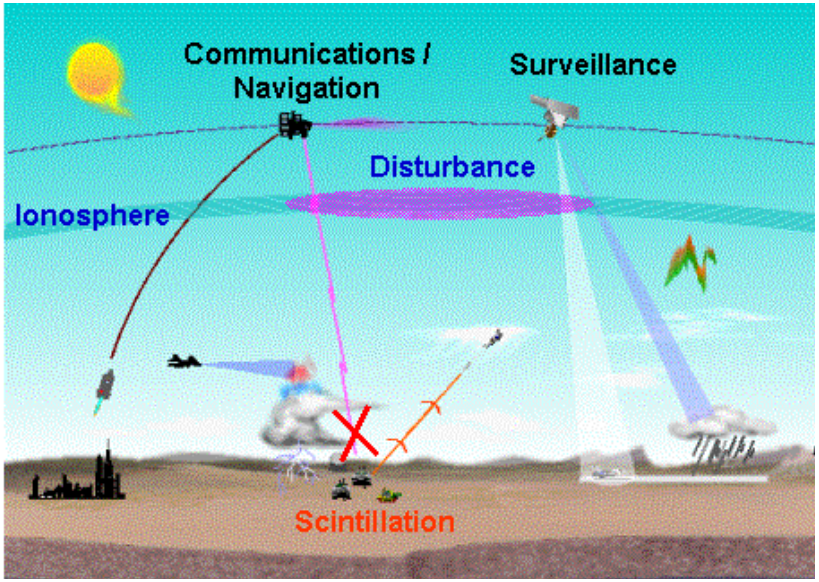
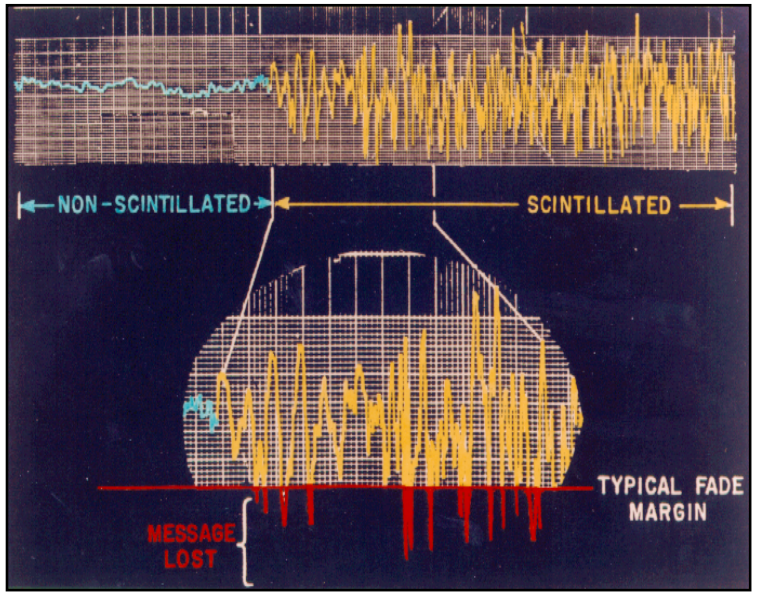
Scintillation Modeling at CCMC

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

Scintillation

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

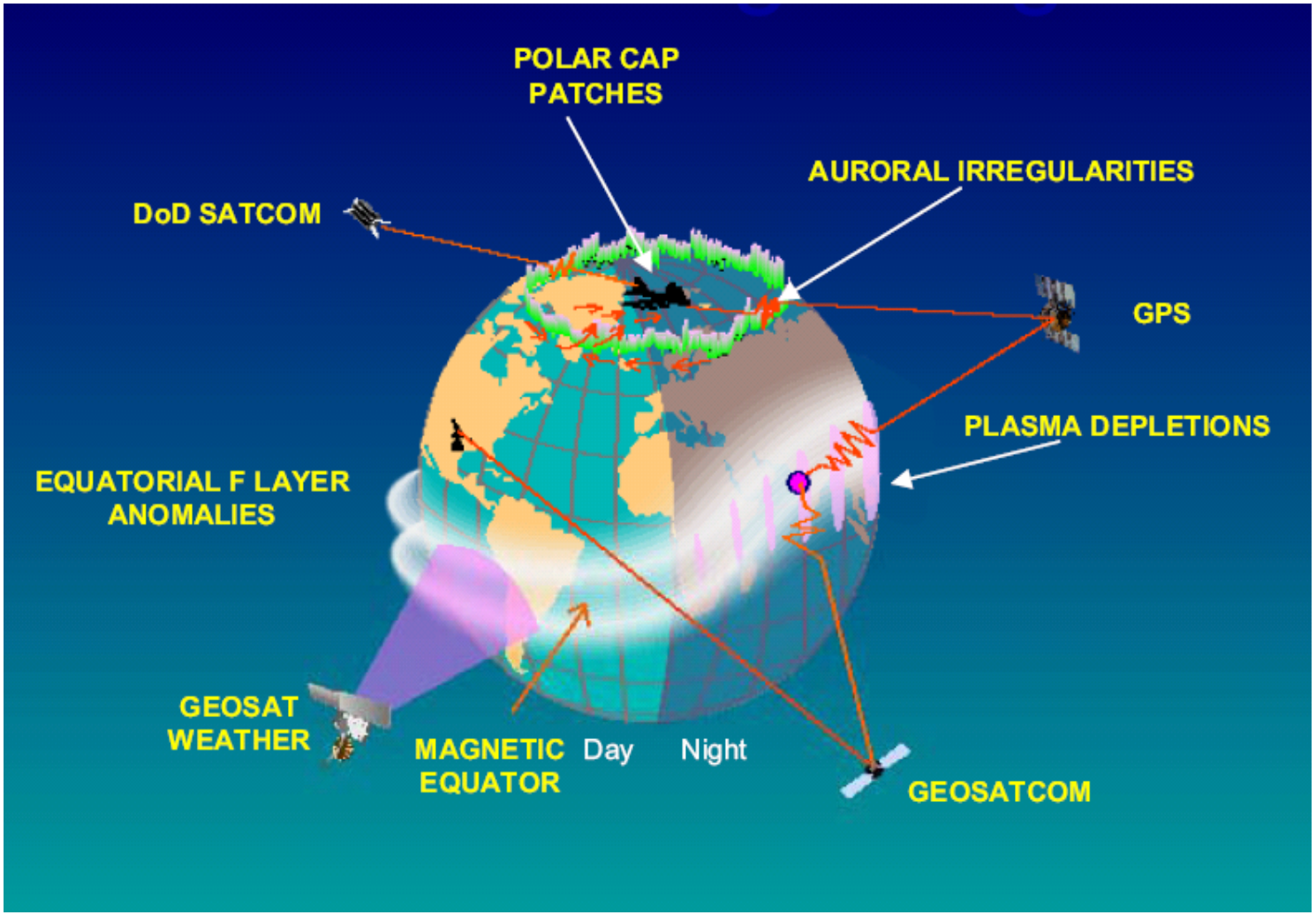




Scintillation causes outages of communication and navigation systems

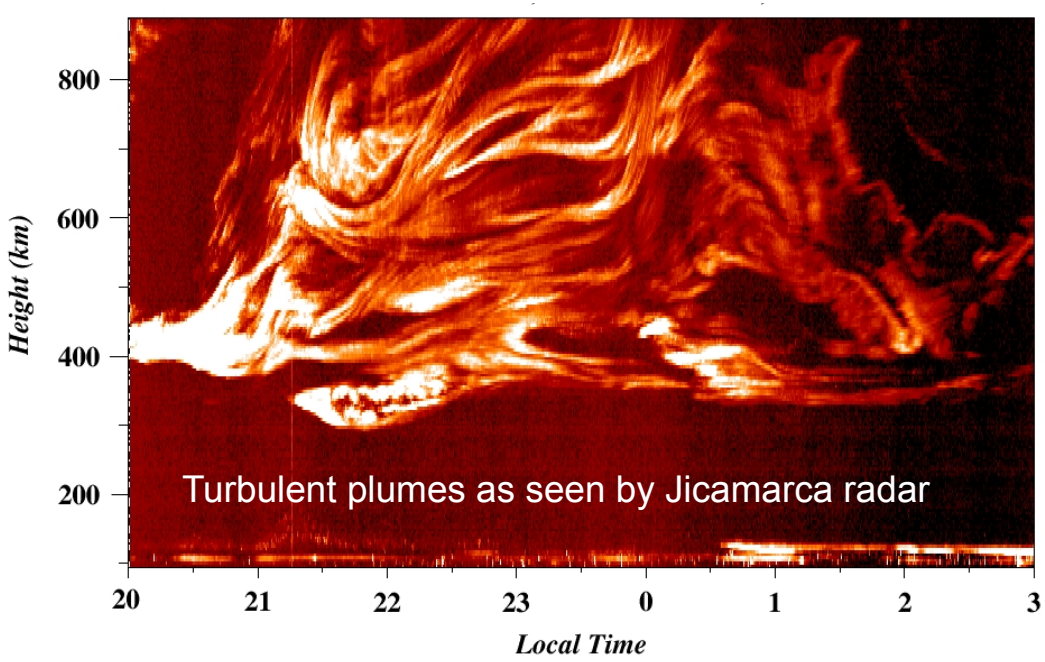
Scintillation Regions

polar and equatorial



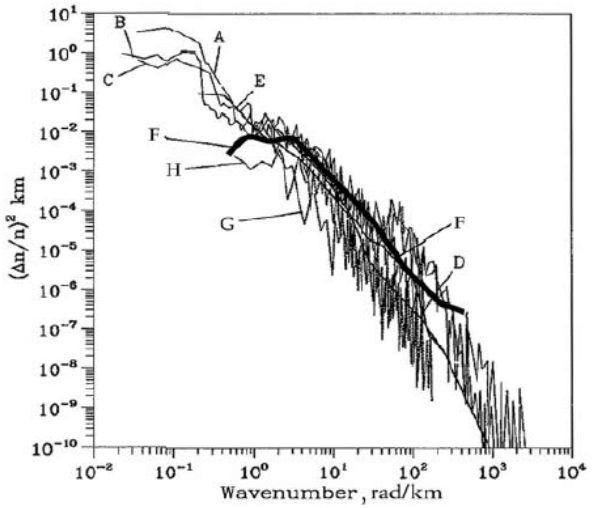
Low Latitude Scintillation

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

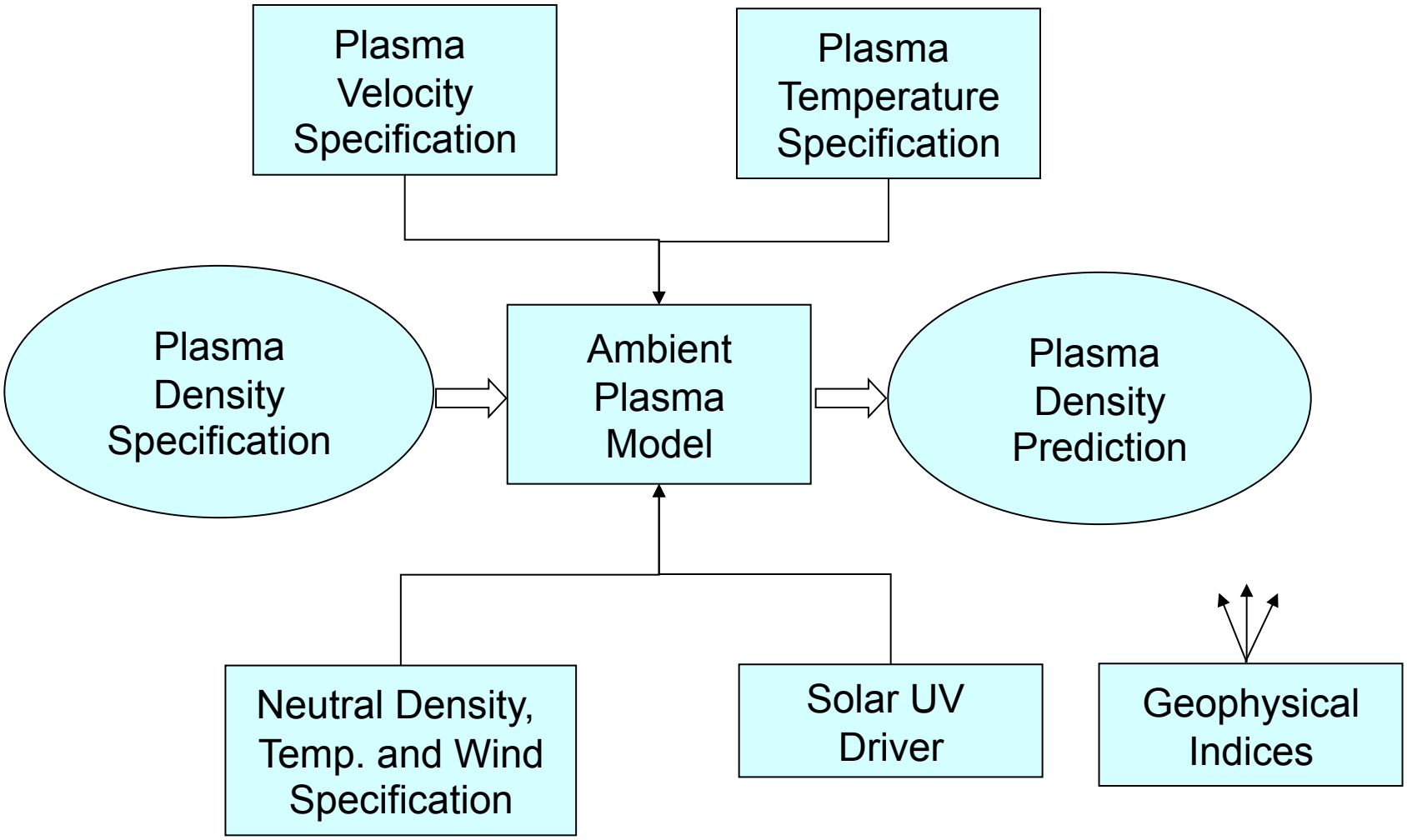


(Kelley and Livingston 2003)

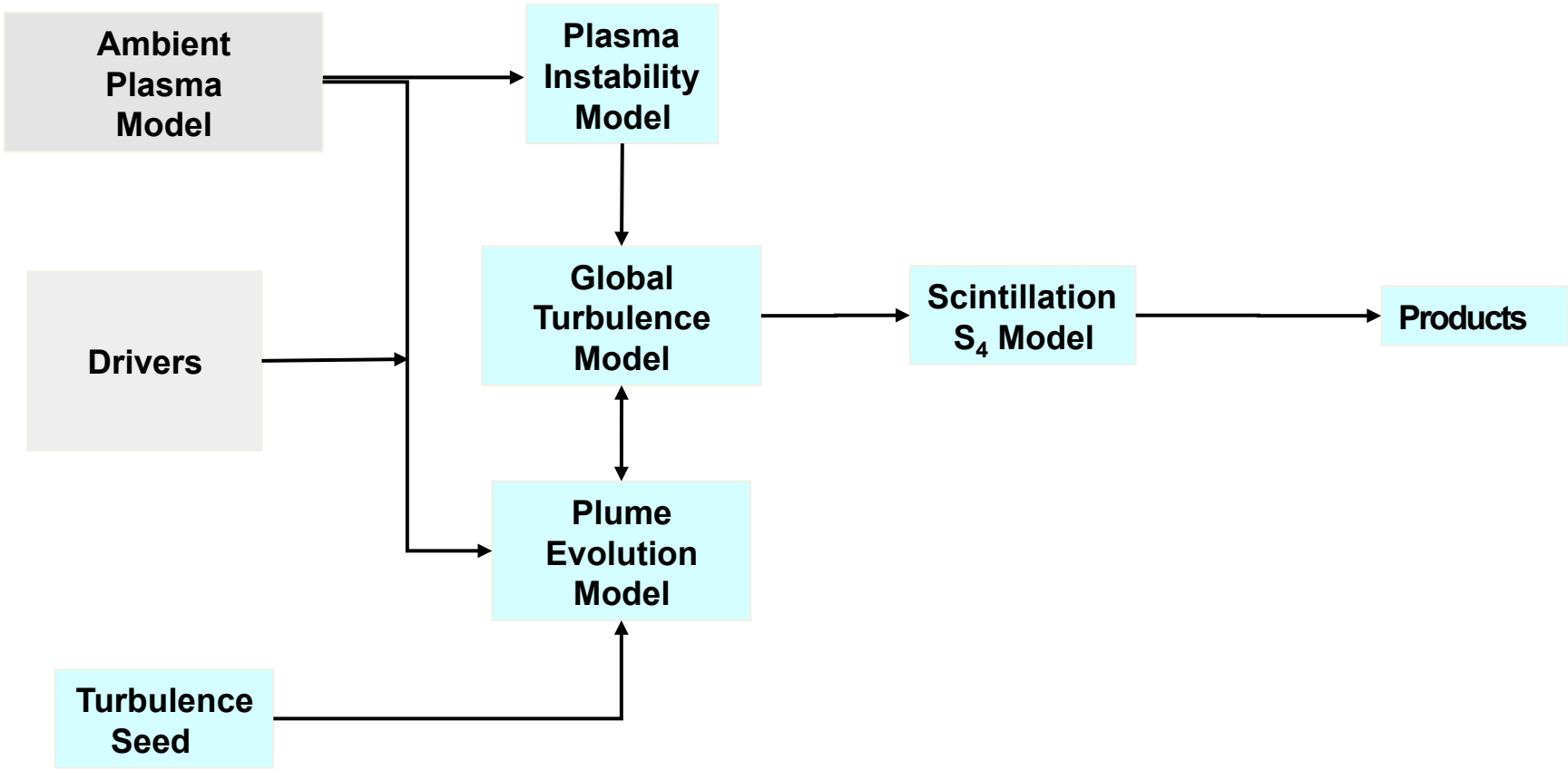
Scintillation Modeling at CCMC

- 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 has been installed at CCMC for community use

PBMOD Ambient Ionosphere Model



PBMOD Scintillation Forecast Model

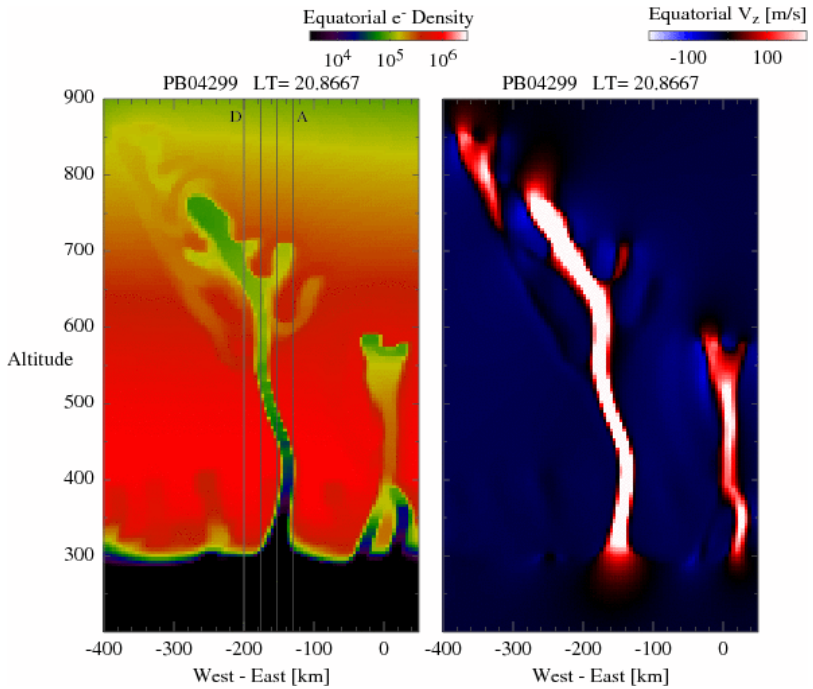


Scintillation Forecast Model

Plume Evolution Model Algorithms

Model describes temporal development of mesoscale plasma structure & turbulence

Uses nonlinear continuity and momentum equations



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

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

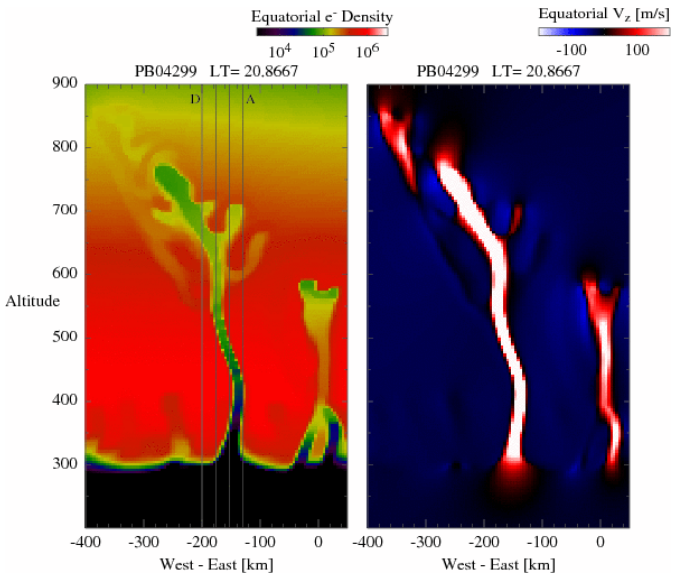
Perpendicular electric fields:
- global-scale fields from ambient model +
- self-consistent fields determined by current-continuity condition

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

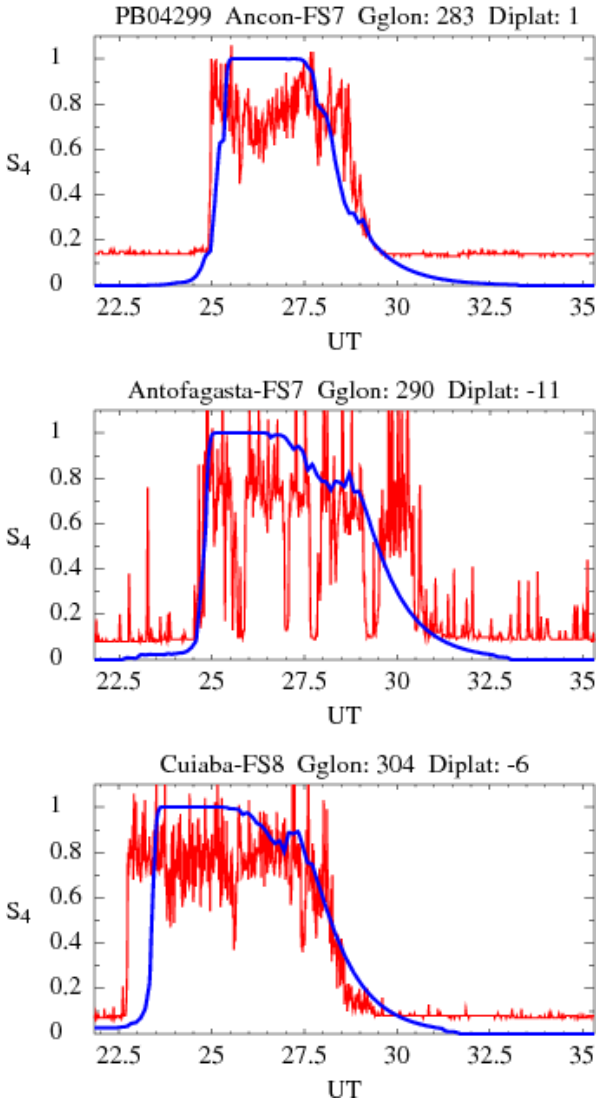
PBMOD includes two-dimensional and three-dimensional plume models

Scintillation Modeling by PBMOD

geomagnetically quiet conditions

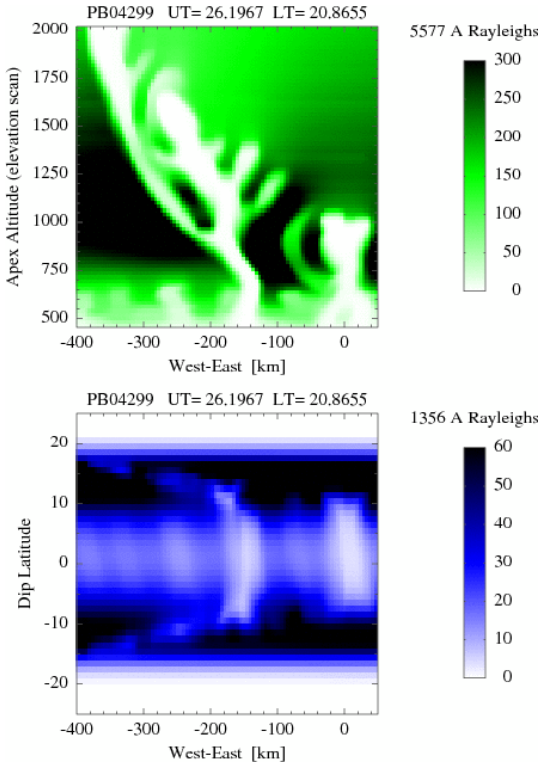


Plume structure in density (left) and vertical velocity (right)



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

(Retterer 2010a,b)

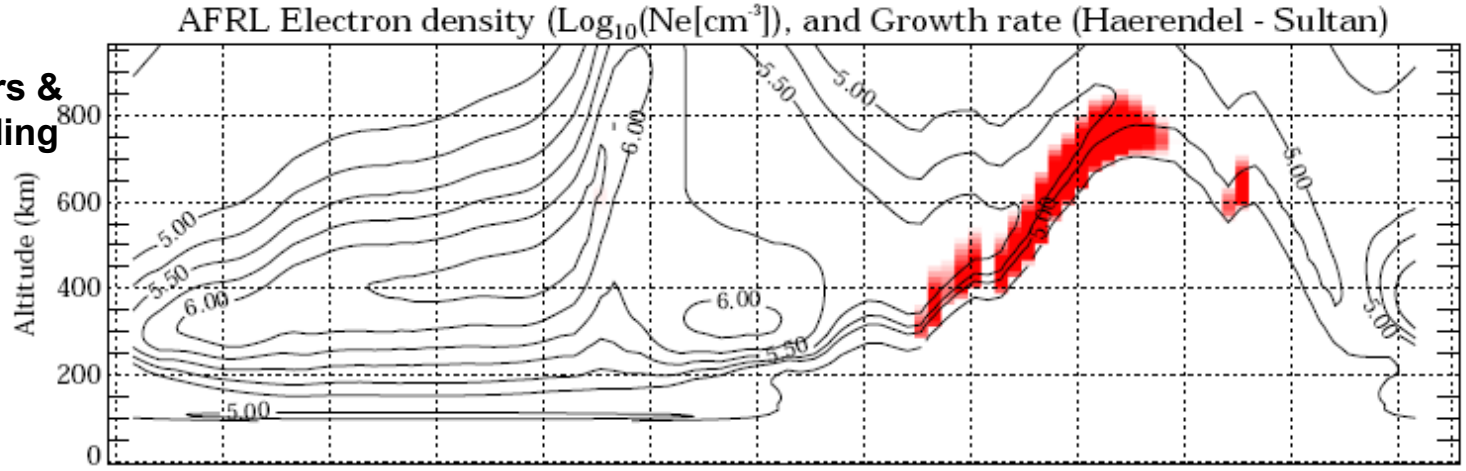


Airglow images of plumes: geometry of Cornell Hawaii camera (looking south toward plume) in 5577 A (top) and GUVI nadir sensing in 1356 A (bottom)

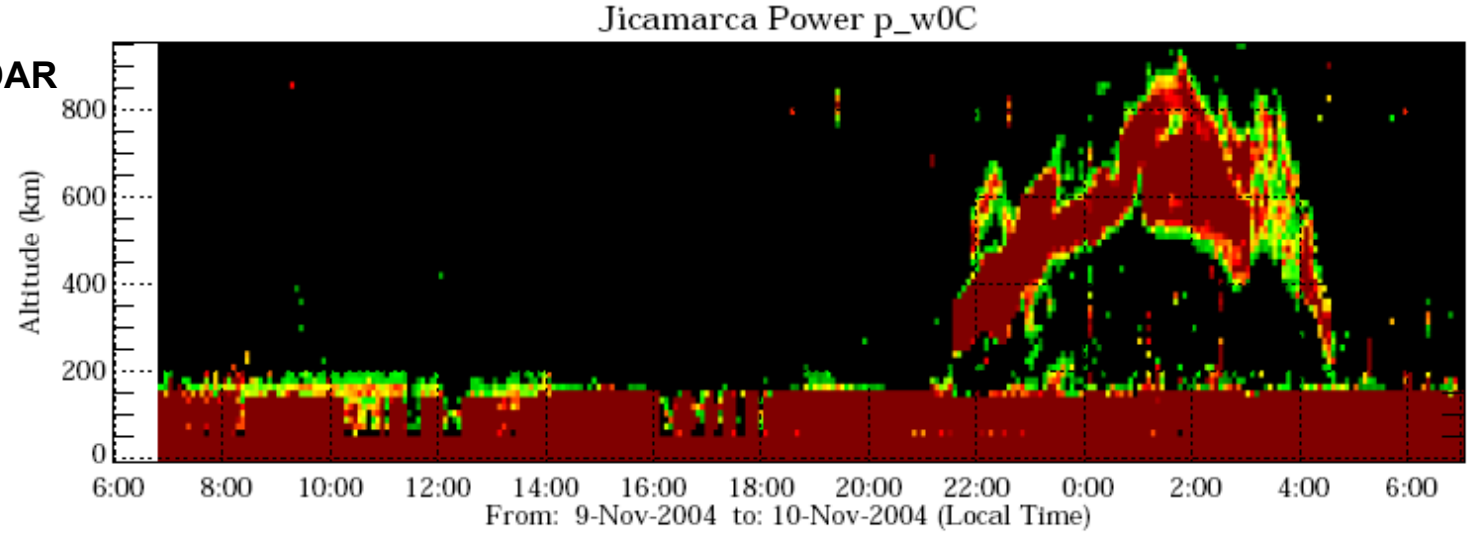
Scintillation Modeling

geomagnetic storm conditions (November 2004)

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



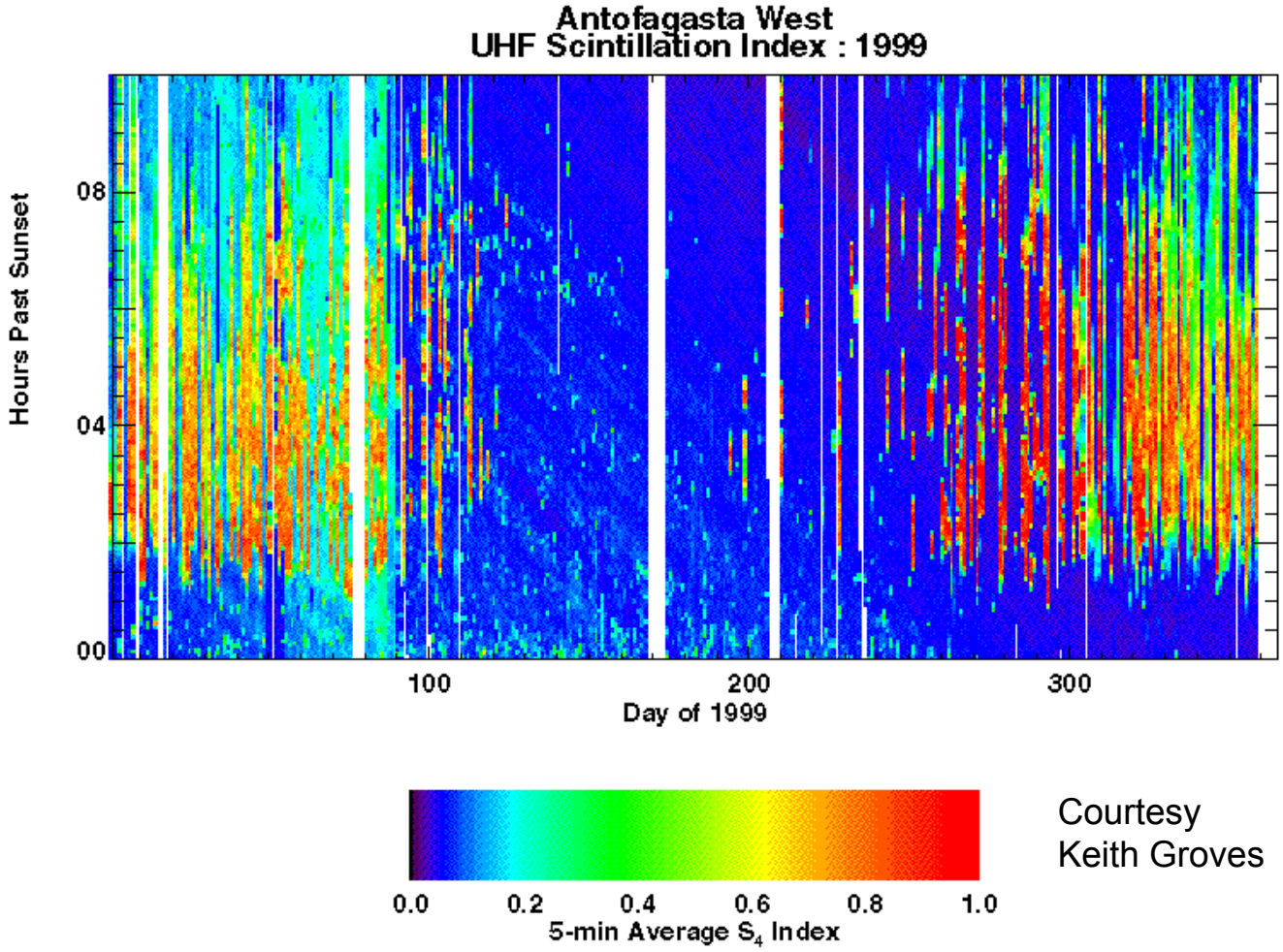
Jicamarca RADAR coherent returns - indicating presence of turbulence



(Kelley and Retterer 2008)

Scintillation Variability

SCINDA Station at Antofagasta, Peru



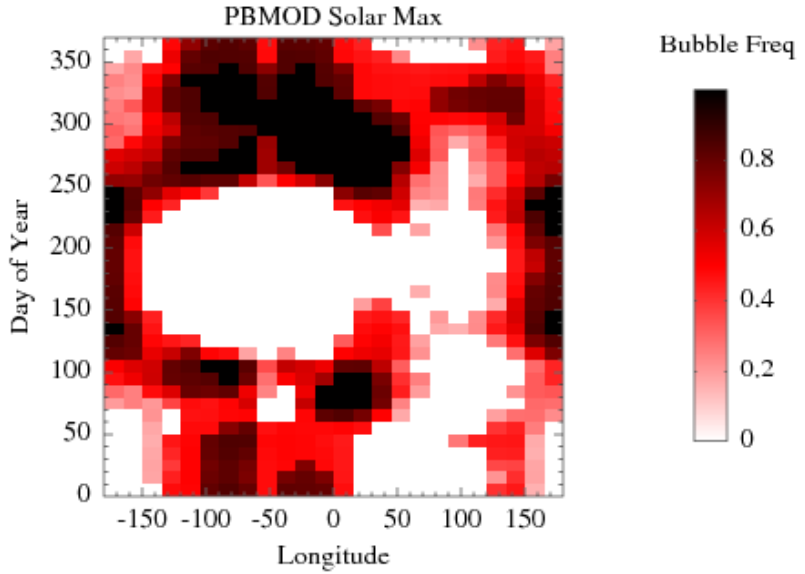
Courtesy
Keith Groves

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

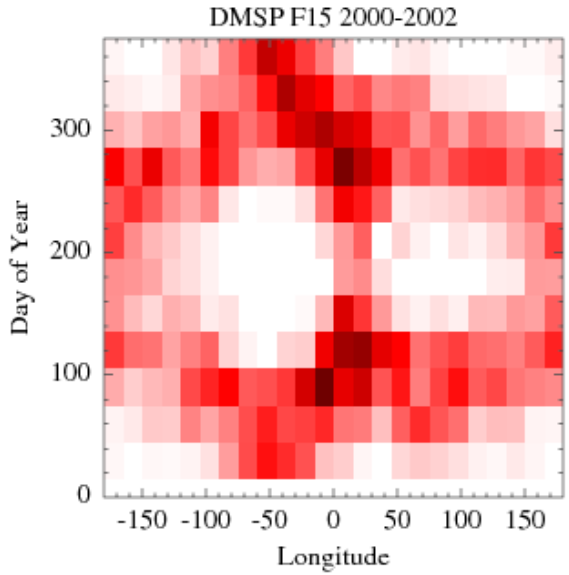
Plasma Bubble Climatology

solar max

PBMOD



DMSP

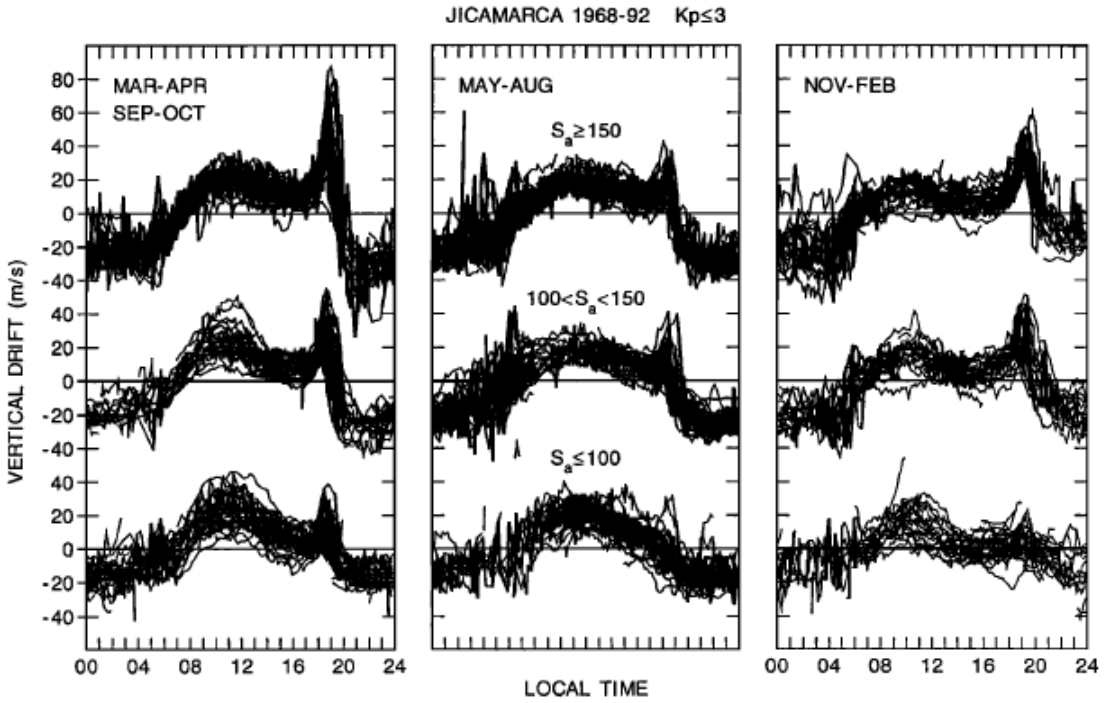


Retterer and Gentile 2010

Natural Geophysical Variation

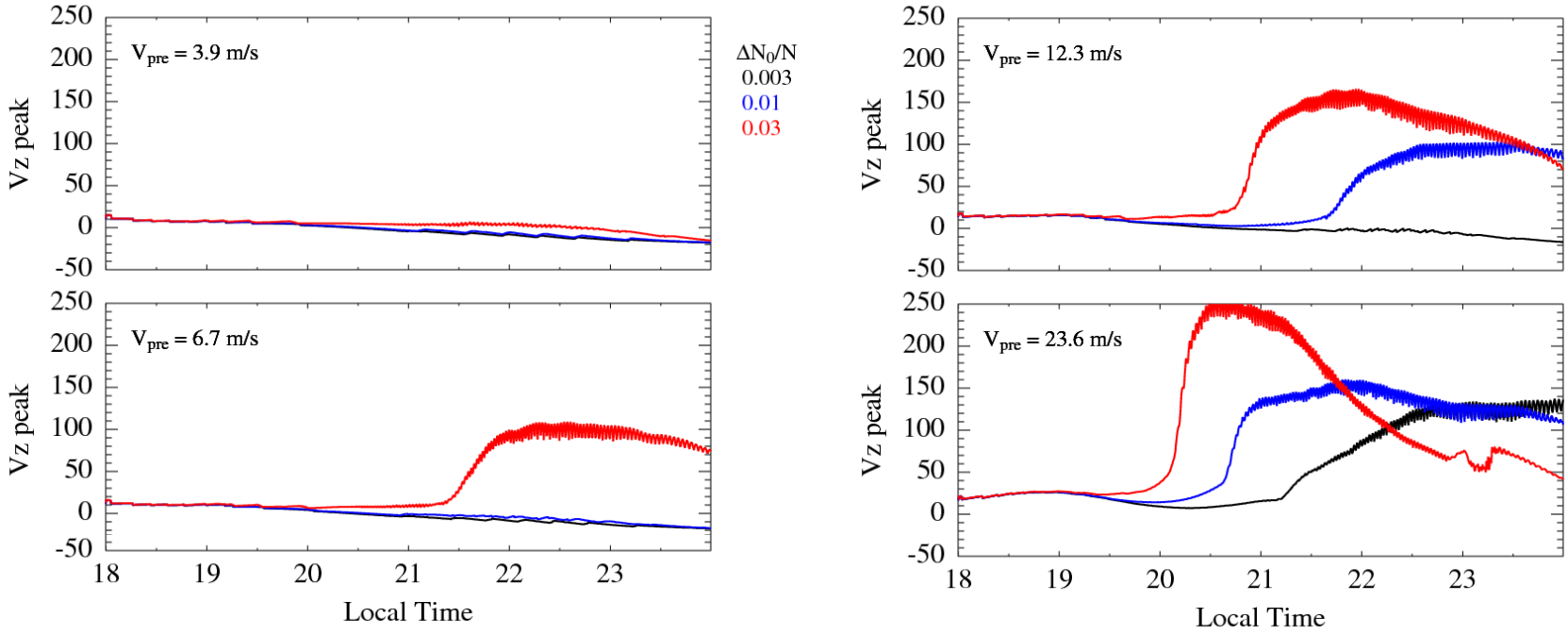
The natural variability in scintillation is caused by the variability of geophysical conditions controlling the instability of the ionosphere

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



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

Scintillation Variability



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

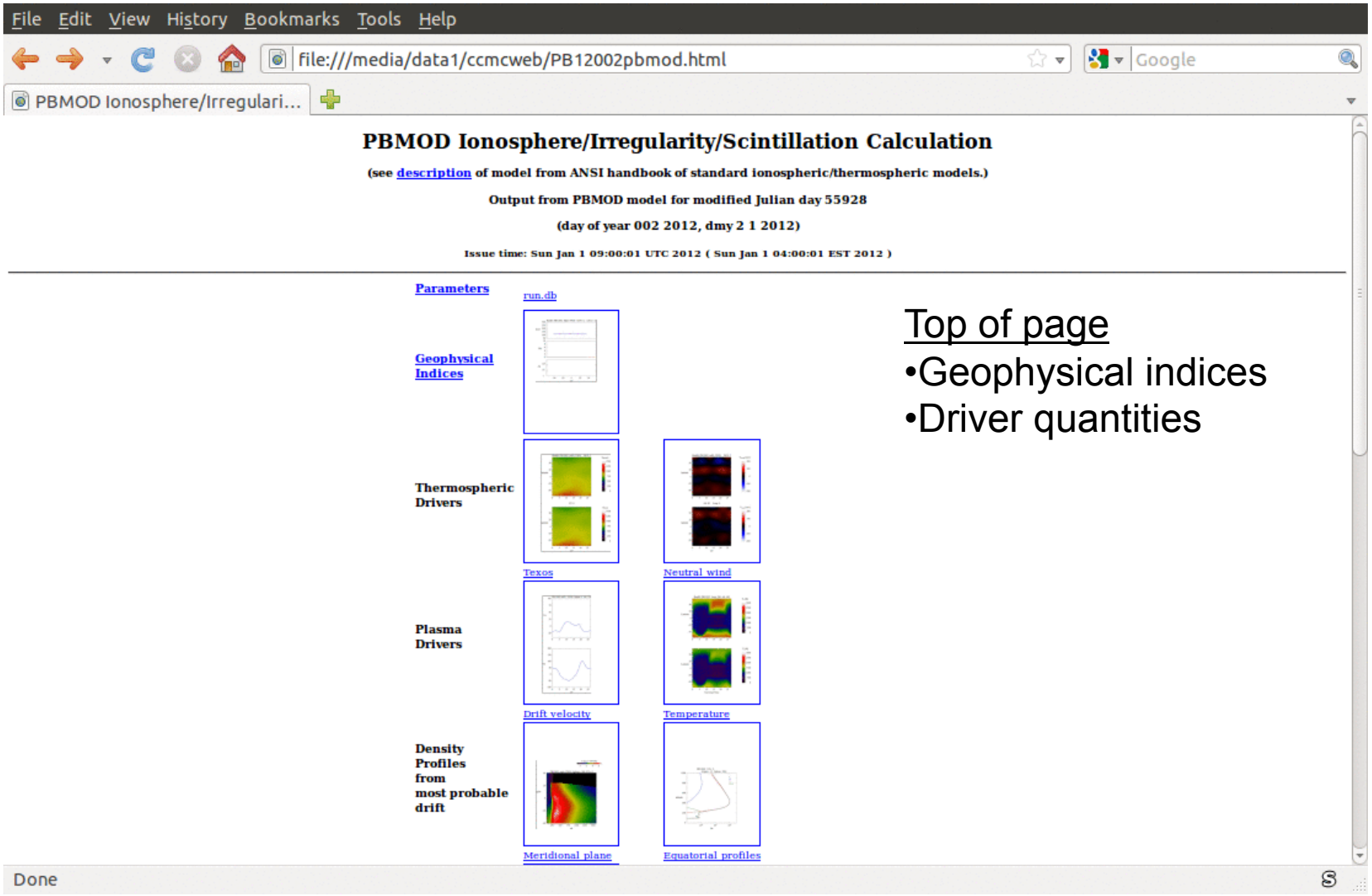
R2O (Research to Operations) Support

Ionospheric Experimental Real-time Simulations:
Real-time Ionosphere/Irregularity/Scintillation Calculation (Model: PBMOD)
Retrospective run of PBMOD | PBMOD simulations archive

CCMC PBMOD Daily Run

- 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

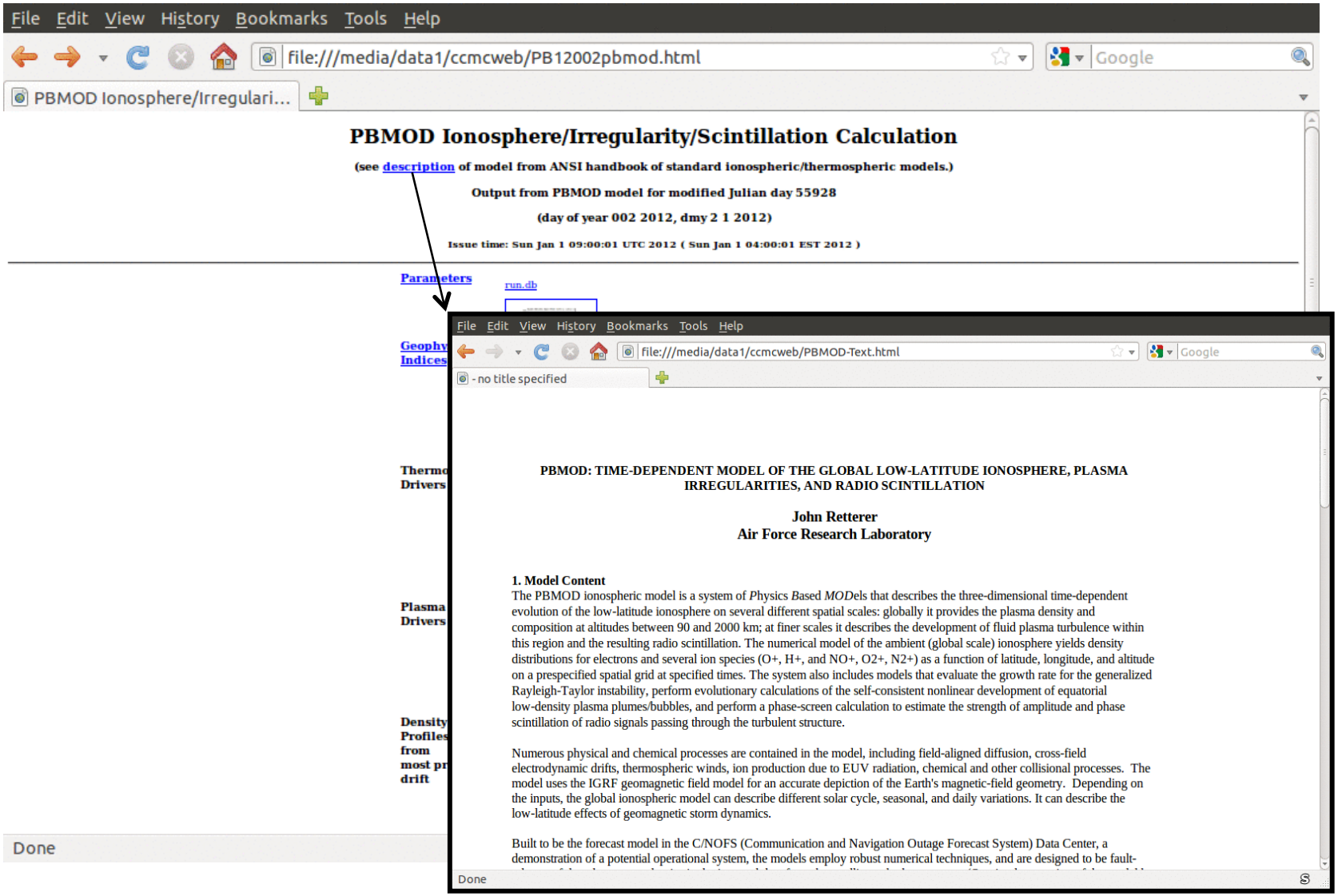
PBMOD at CCMC



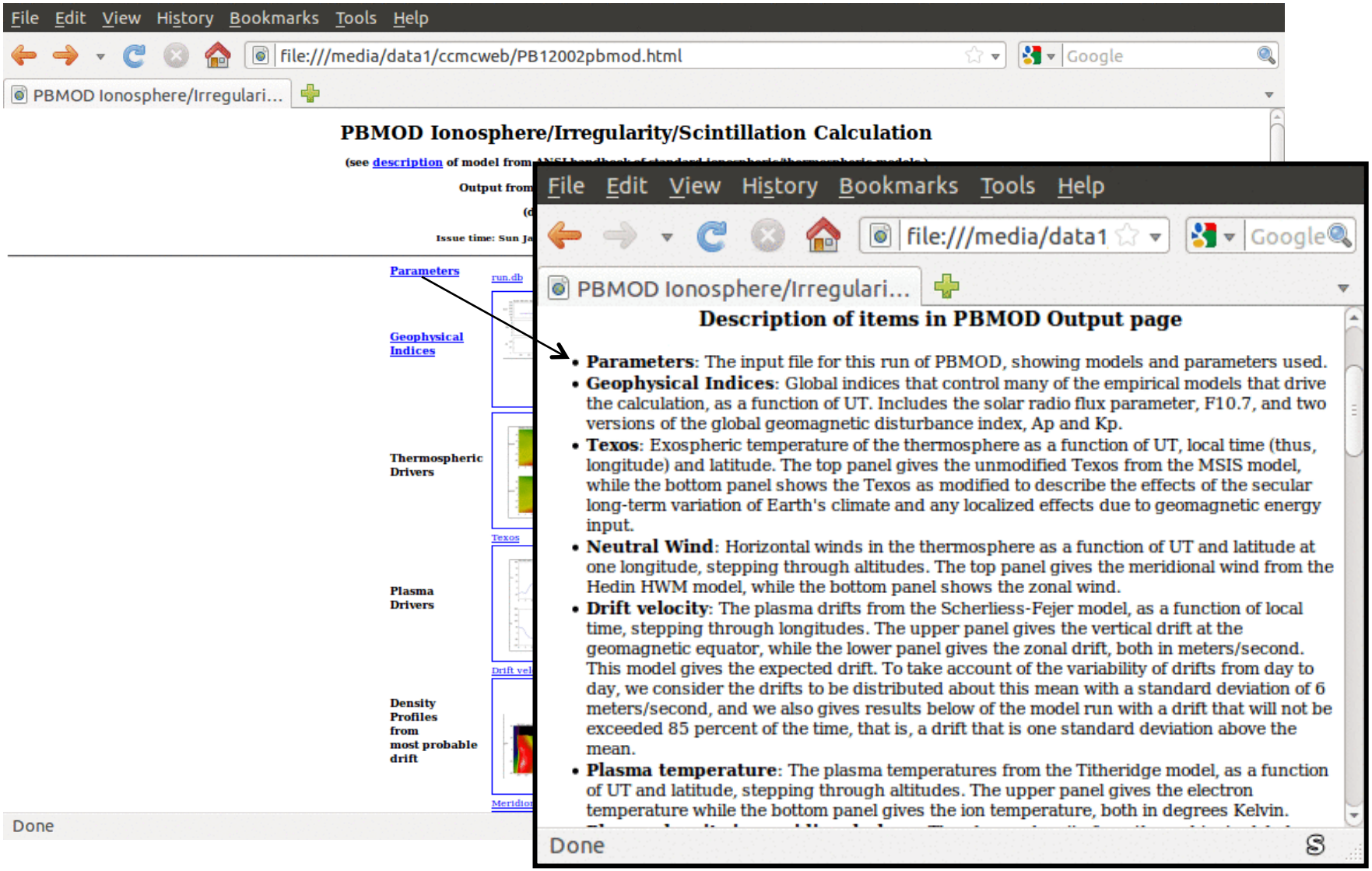
Top of page

- Geophysical indices
- Driver quantities

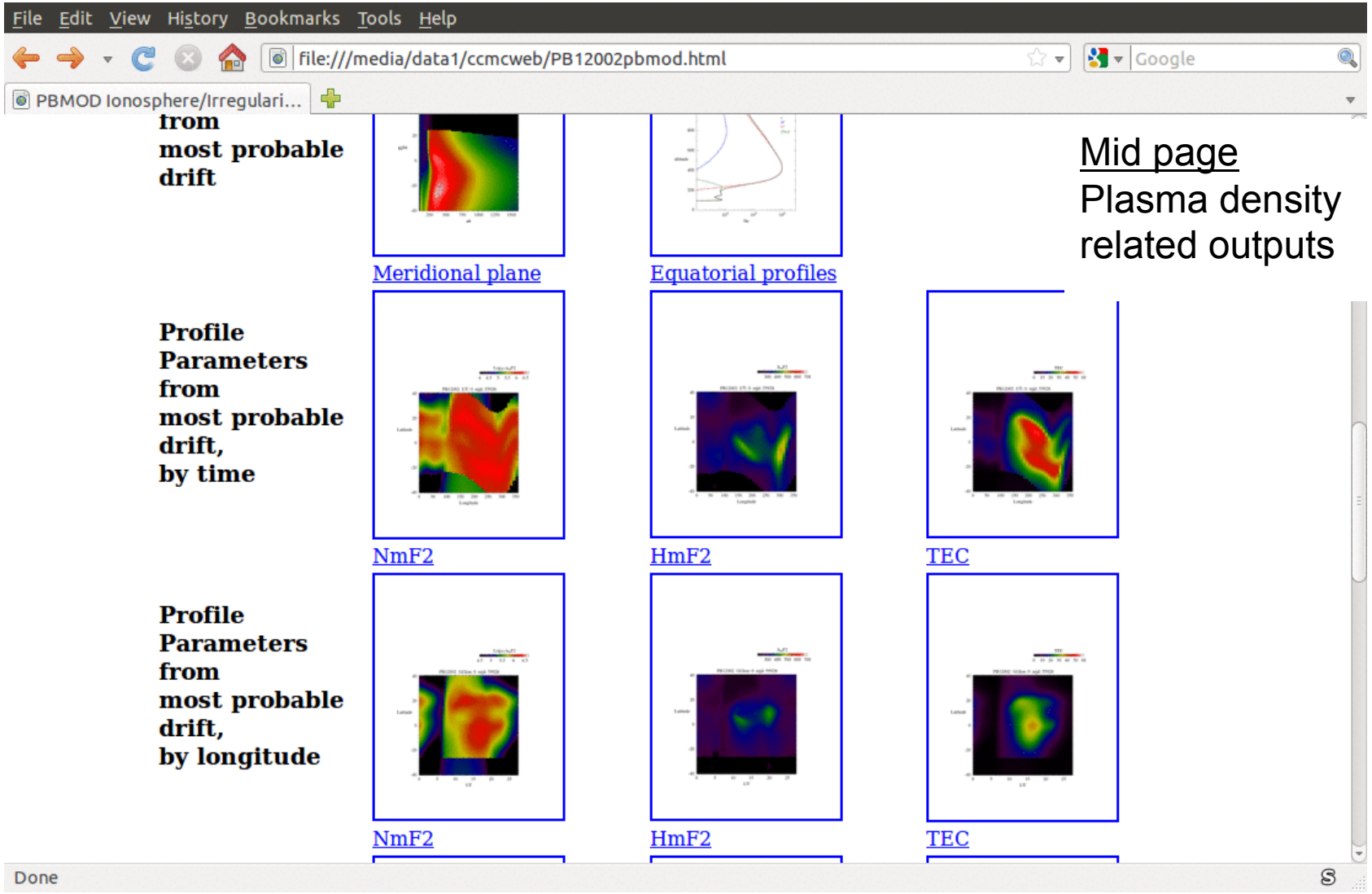
PBMOD at CCMC



PBMOD at CCMC

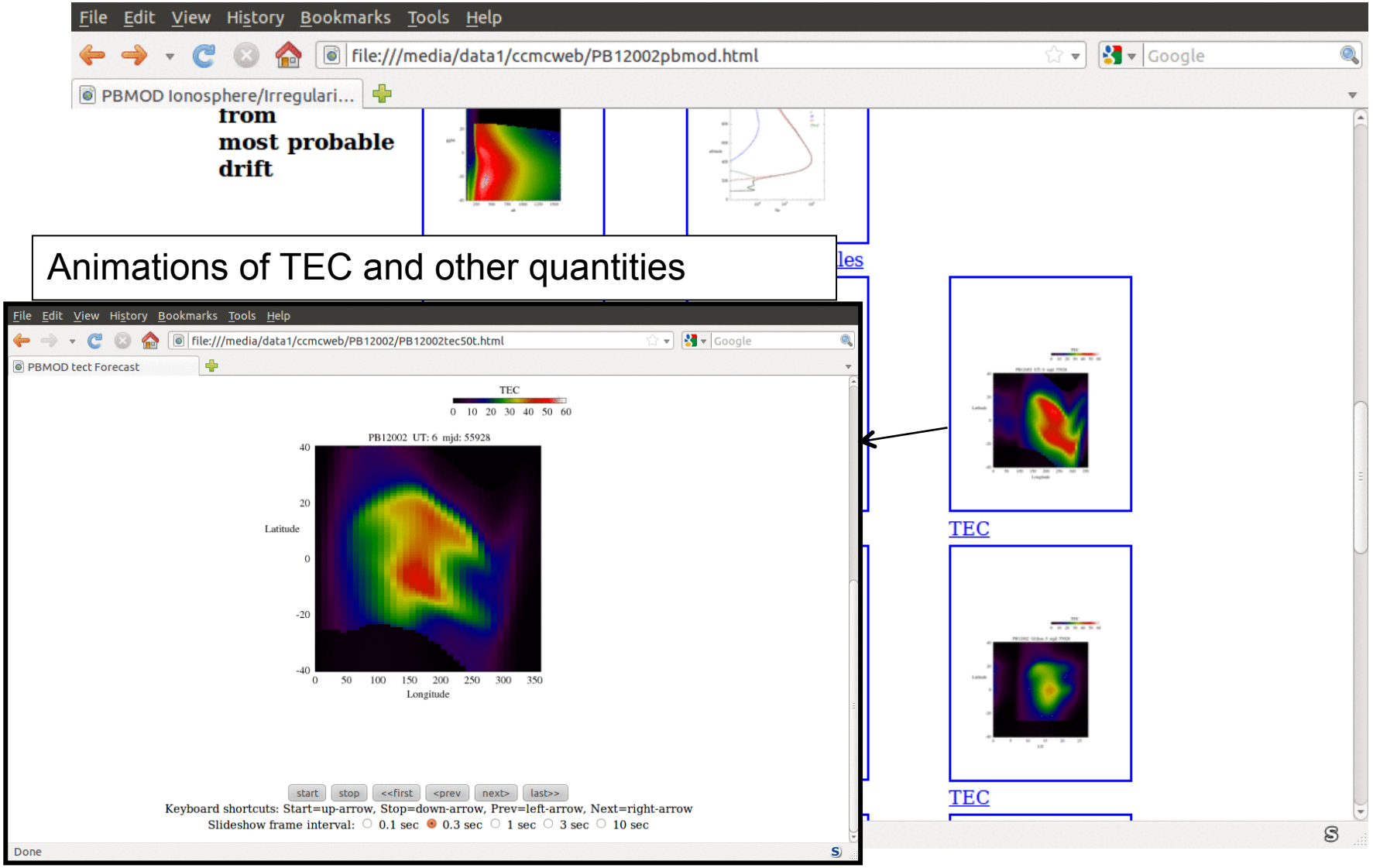


PBMOD at CCMC

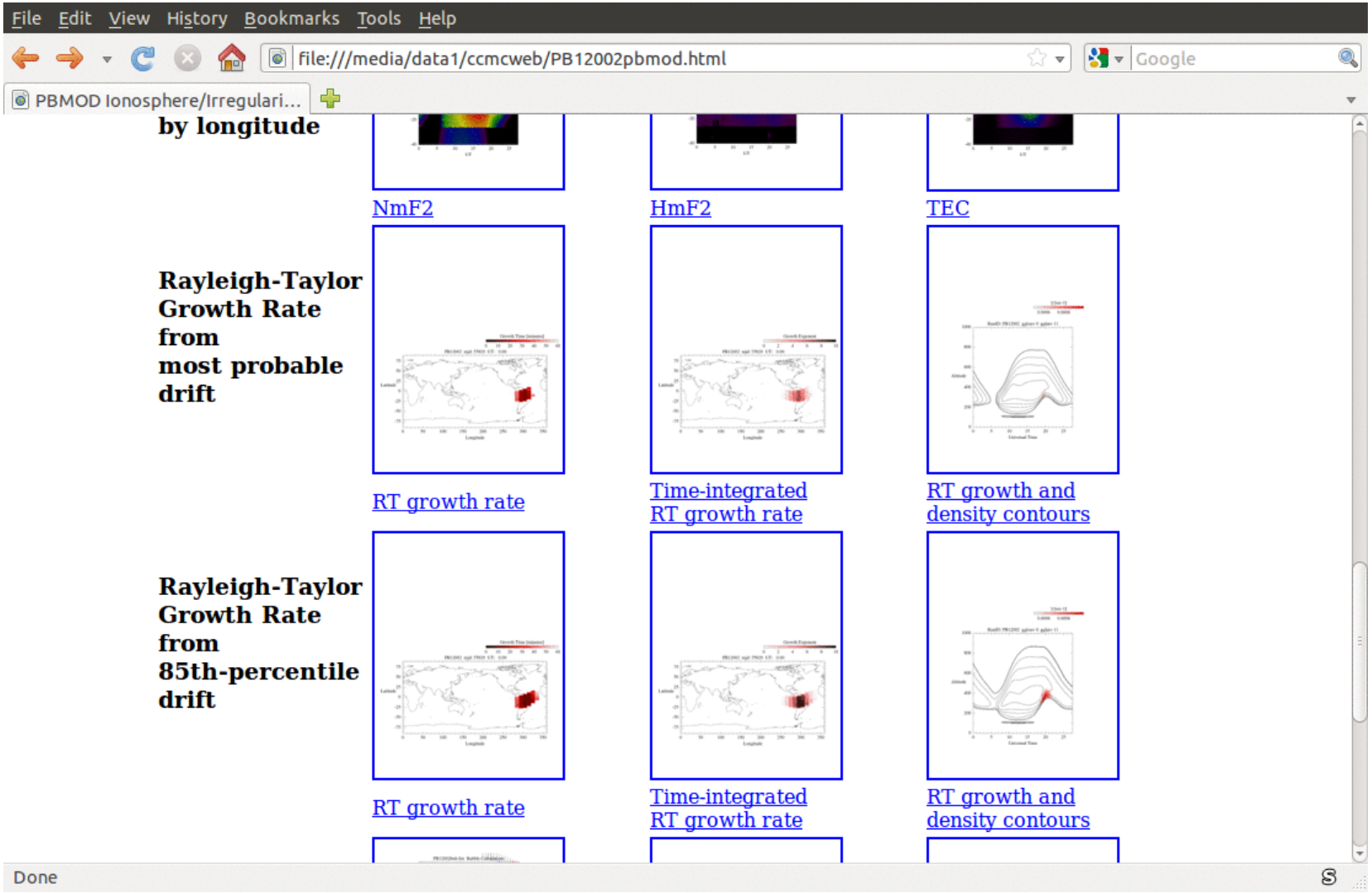


Mid page
Plasma density related outputs

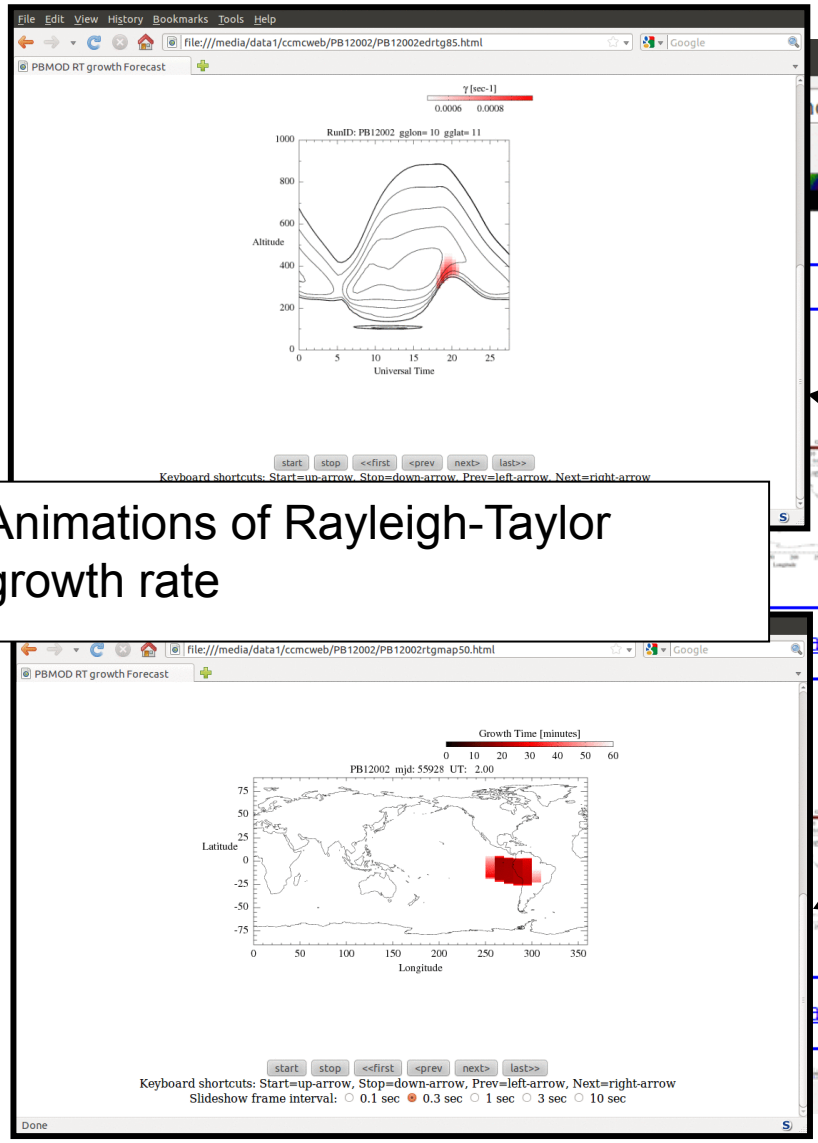
PBMOD at CCMC



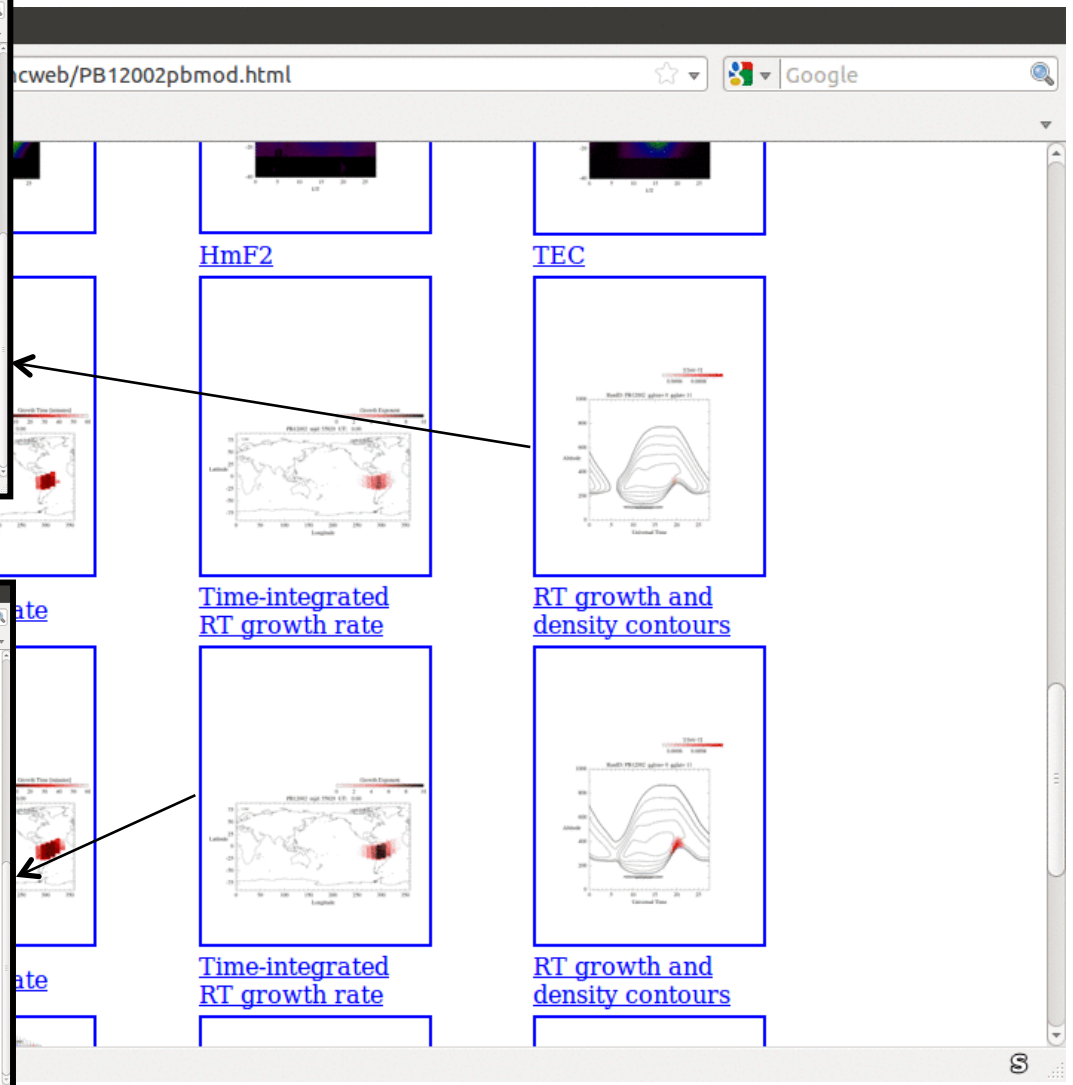
PBMOD at CCMC



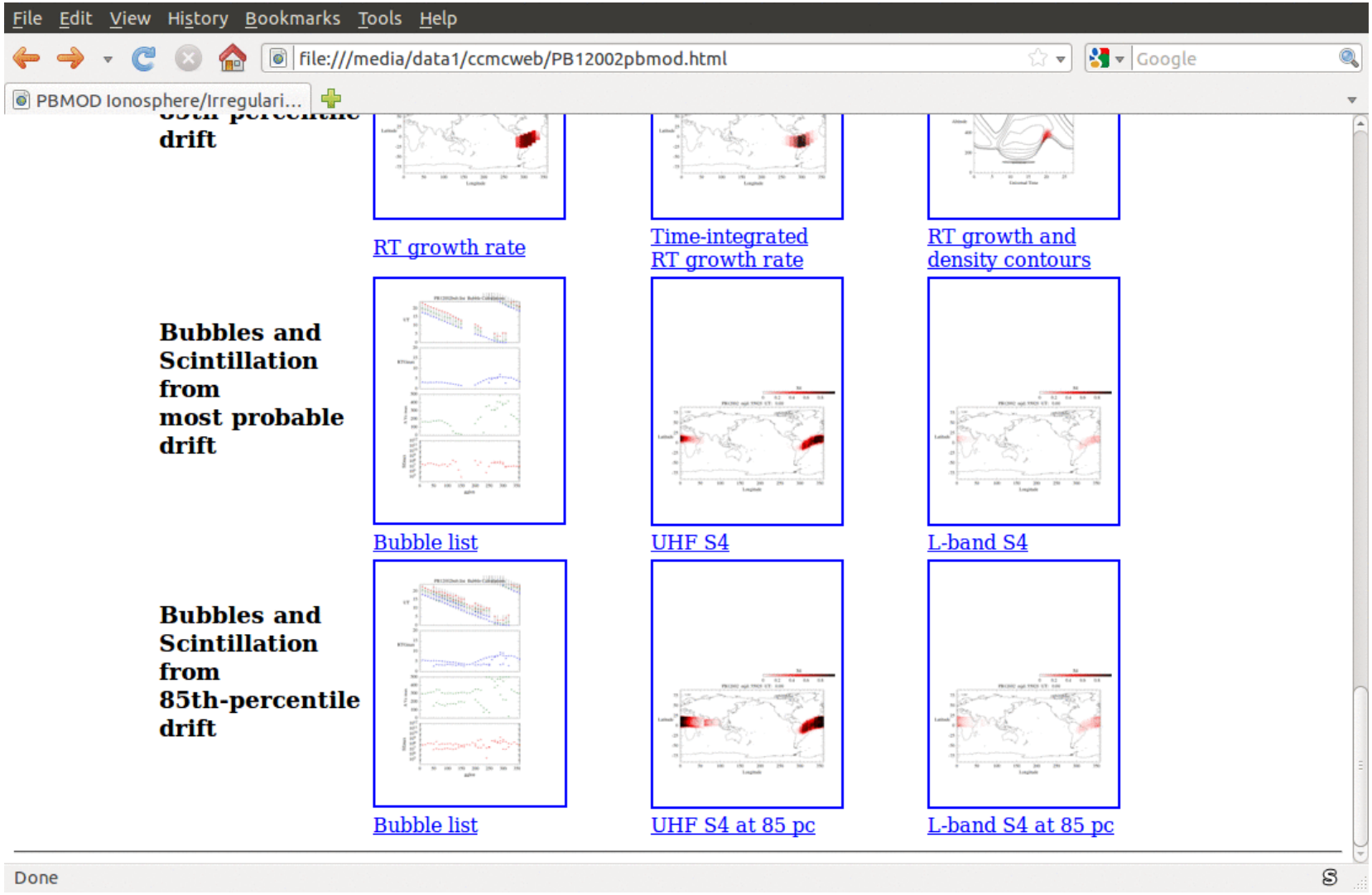
PBMOD at CCMC



Animations of Rayleigh-Taylor growth rate

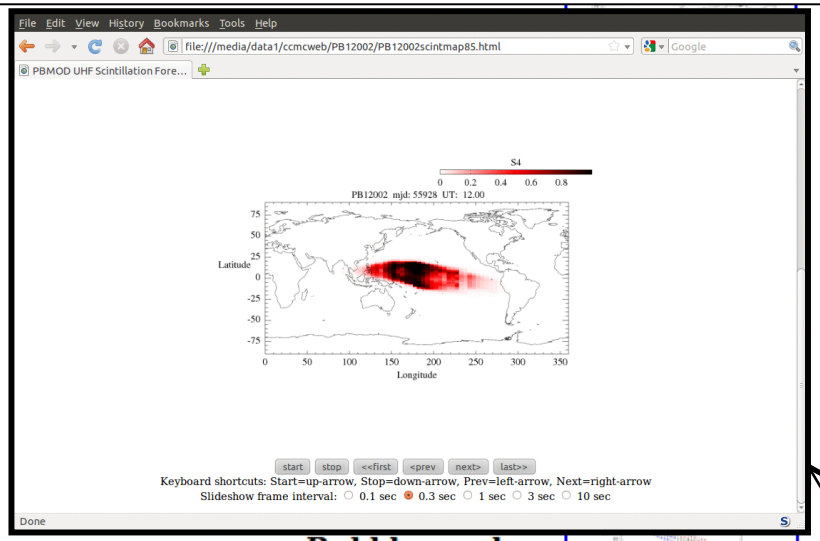


PBMOD at CCMC



PBMOD at CCMC

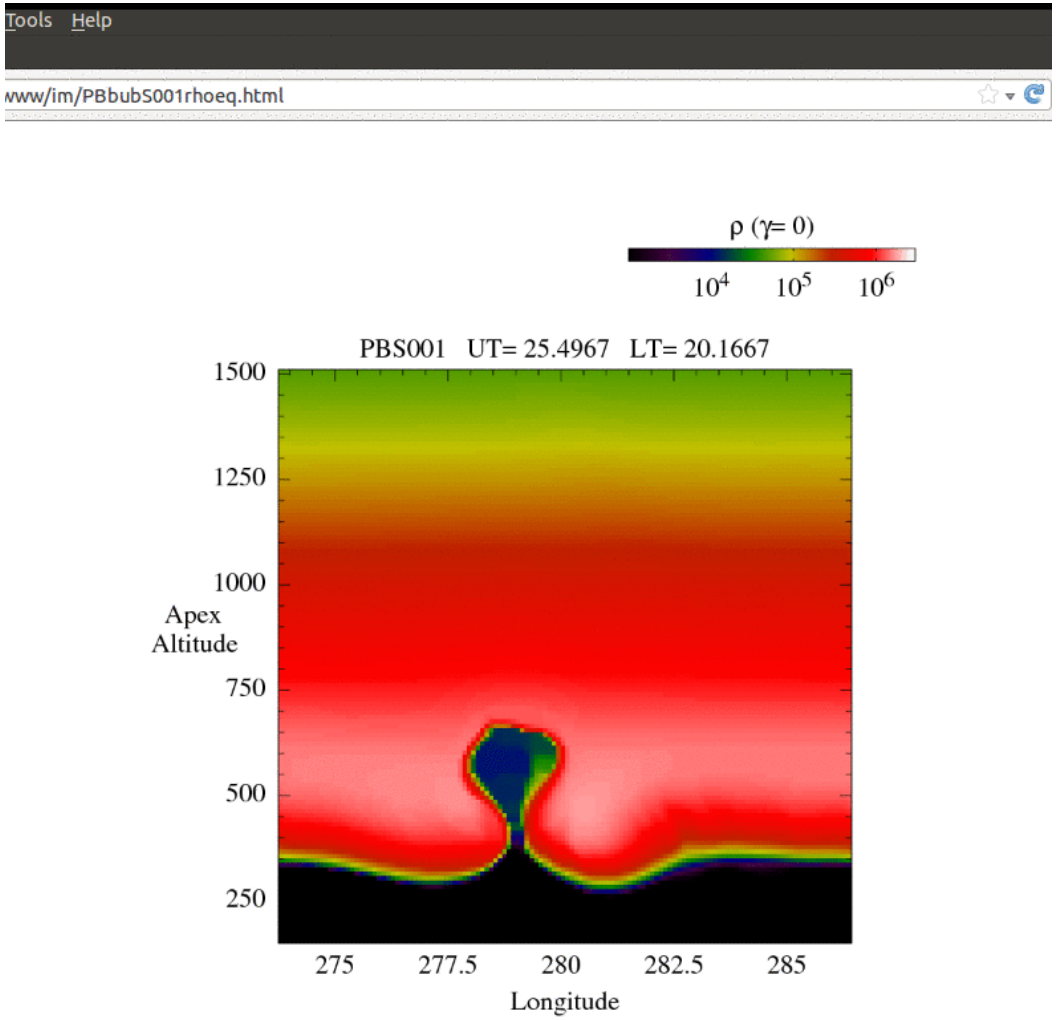
Animations of scintillation strength



Animations of bubble quantities

PBMOD at CCMC

Animation controls



PBMOD Run on Demand

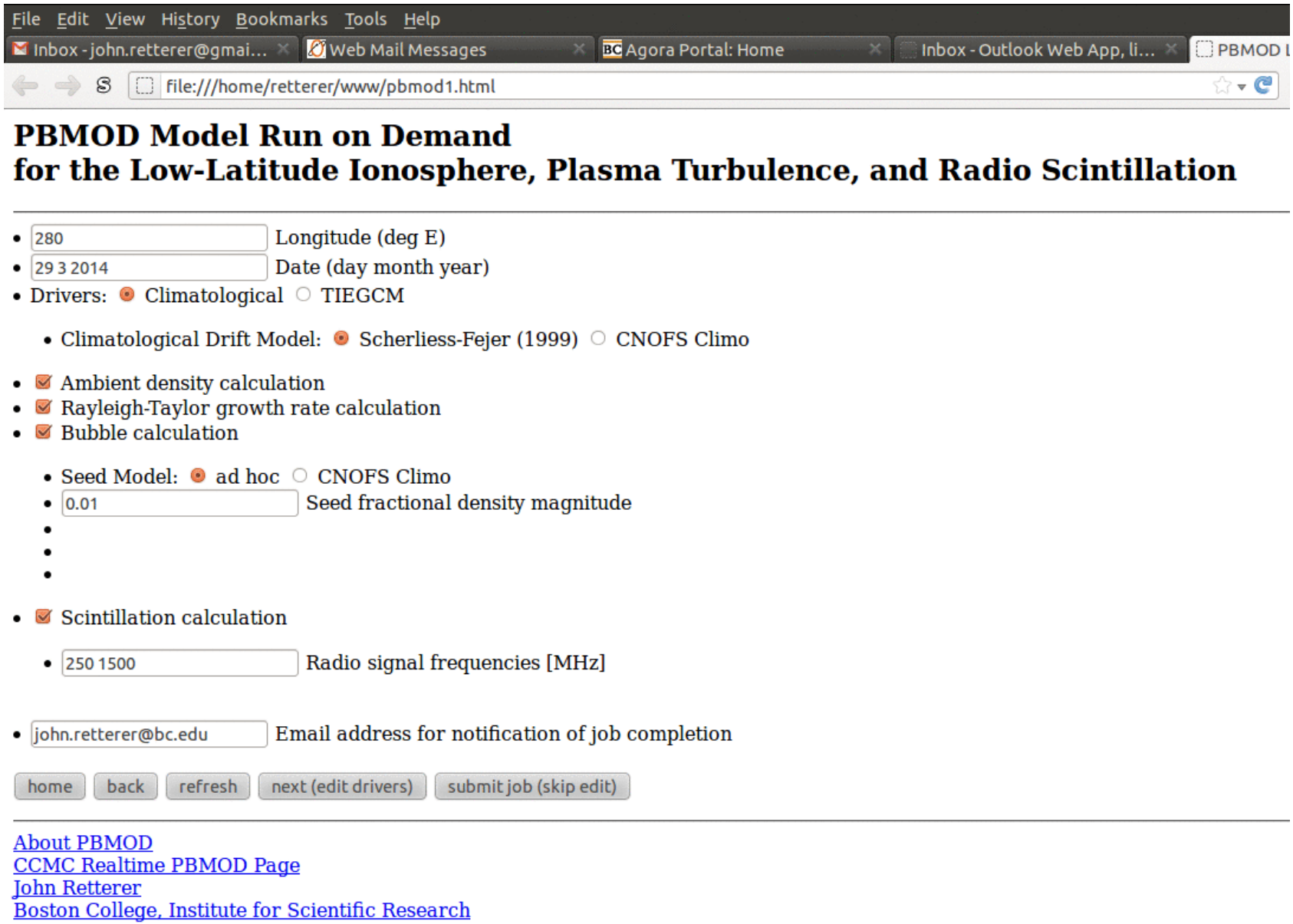
- Laboratory for exploring low-latitude ionospheric phenomena (density structure, Rayleigh-Taylor instability development, scintillation formation)
- User can enter plasma drift and other parameters
- Local mode – one longitude sector
- Under development

PBMOD Run on Demand

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 Run on Demand



PBMOD Run on Demand

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

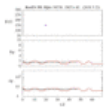
(day of year 081 2014, dmy 22 3 2014)

in longitude sector 280 ° E (at geomagnetic equator)

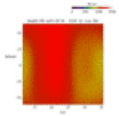
Issue time: Sun Mar 30 00:32:37 UTC 2014 (Sat Mar 29 20:32:37 EDT 2014)

Parameters run.db

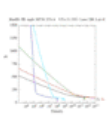
Geophysical Indices



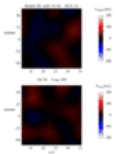
Thermospheric Drivers



Texos

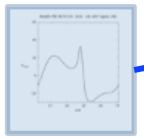


Neutral density

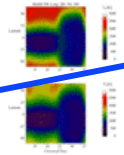


Neutral wind

Plasma Drivers



Drift velocity



Temperature

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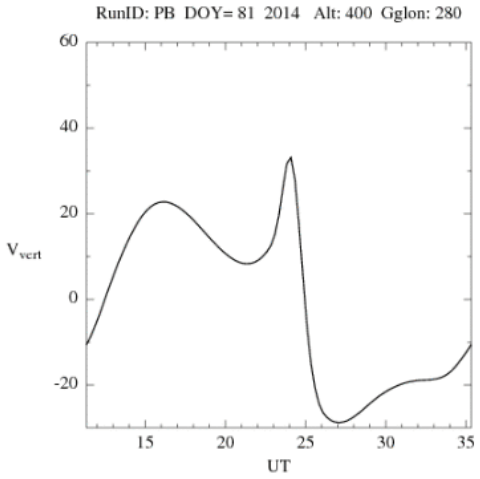
PBMOD Run on Demand

File Edit View History Bookmarks Tools Help

PBMOD Plasma Drifts

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



Edit drifts
Download drifts

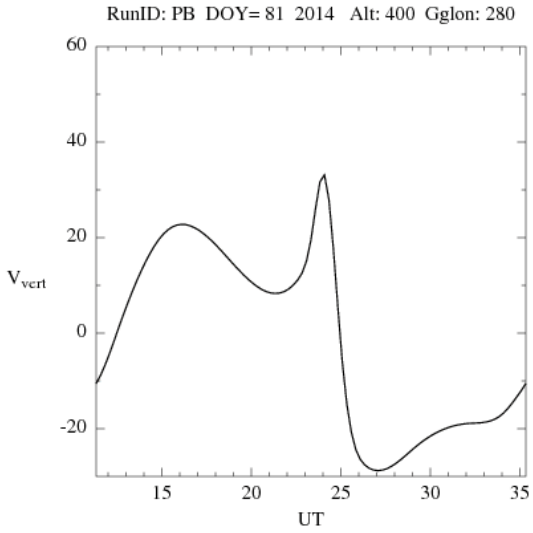
About PBMOD
CCMC Realtime PBMOD Page
John Retterer
Boston College, Institute for Scientific Research

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
```



home | cancel | refresh | submit changes

PBMOD Run on Demand

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)

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
- 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