Intermediate Scale Ionospheric Structure
A Done Deal or Neglected Topic?

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Structure Characterization

Dynamic observable

$$N(\mathbf{r},t) = \overline{N}(\bar{\mathbf{r}},\bar{t})(1 + \delta N(\Delta\mathbf{r} - \mathbf{v}\Delta t)/N_0)$$

Slowly varying average centered on $\bar{\mathbf{r}}$ & $\bar{t}$

Structure frozen within volume defining $\overline{N}(\bar{\mathbf{r}},\bar{t})$

Random component with mean zero over volume defining $\overline{N}(\bar{\mathbf{r}},\bar{t})$

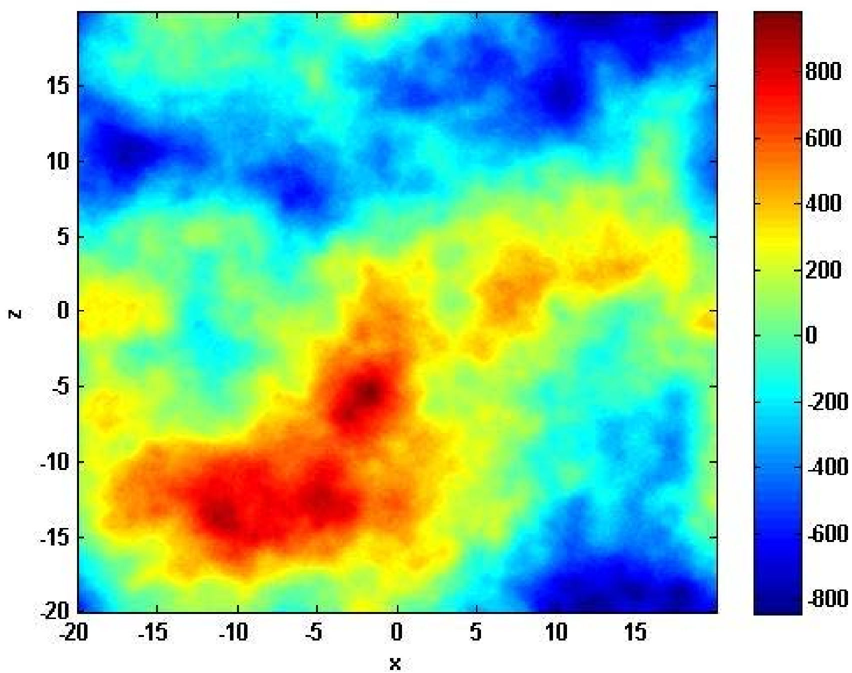
The $\delta N(\Delta\mathbf{r})/N_0$ structure range will be referred to as the *intermediate scale*

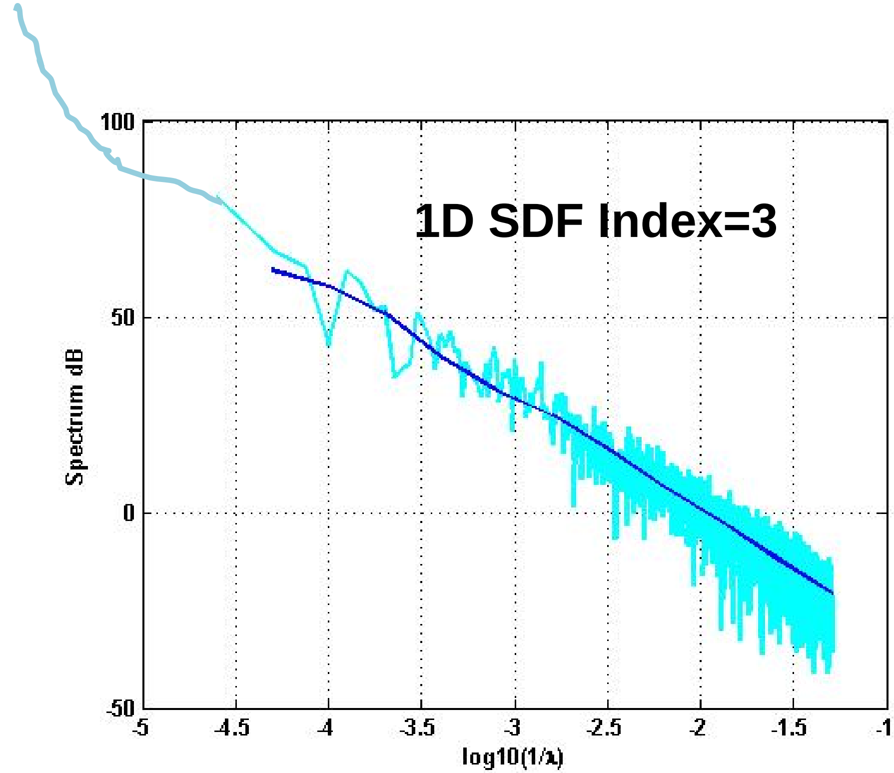
The key to separating background from structure is homogeneity

Turbulence as a Guide

- Classical turbulence theory predicts a scale-free inverse power-law spectral density function (SDF)
- An unbounded power-law process (e. g. Brownian motion) is not strictly homogeneous
- The formal resolution of the dilemma uses structure functions in place of covariance functions
- Benoit Mandelbrot introduced fractional Brownian motion (fBm) as a class of stochastic processes that support scale-free turbulence-like structure
- The fBm model is well suited to physical processes that admit no clear transition from trend-like to statistically homogeneous structure

2D Fractional Brownian Motion Index 4 (Kolmogorov=> 11/3)





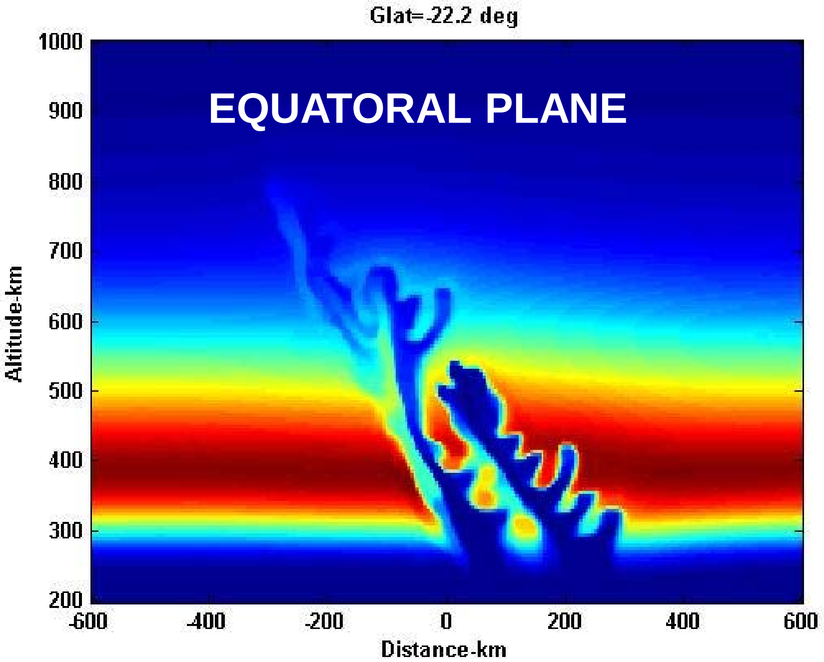
SDF $$\Phi(\boldsymbol{\kappa}) = Cq^{-p}$$

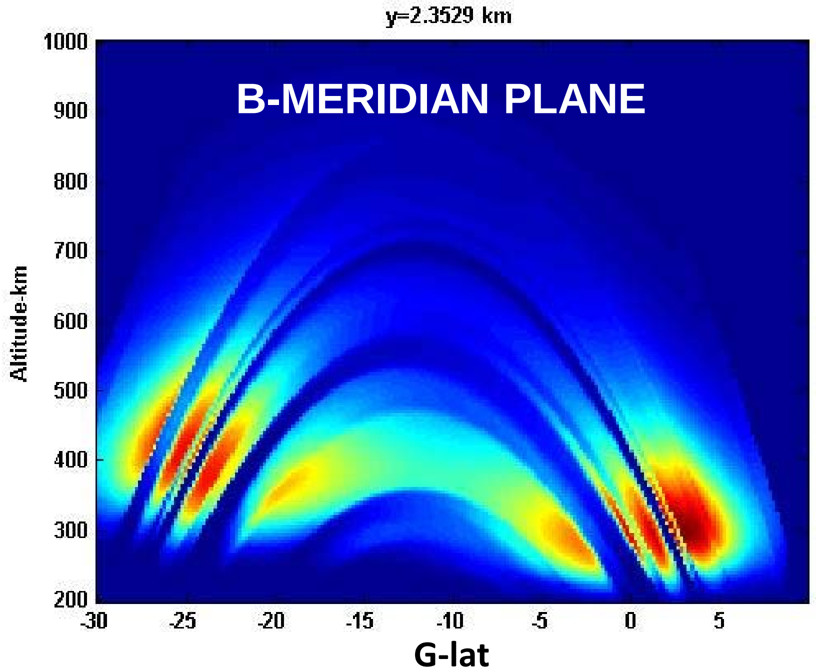
Scaling Law $$N(\mathbf{r}) \sim N(\alpha\mathbf{r})/\alpha^{p-2}$$

Locally homogeneous isotropic intermediate scale structure is completely characterized by two parameters, C and p

Inhomogeneity + Anisotropy

Equatorial Ionosphere



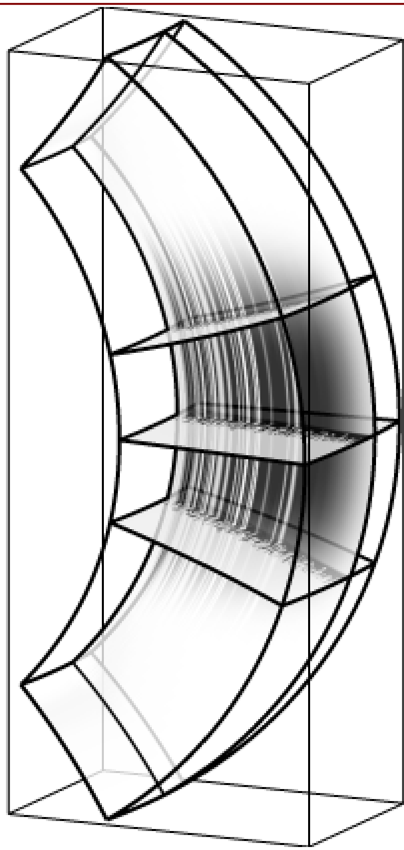


STRUCTURE CHARACTERISTICS

- **Inhomogeneous**
- **Anisotropic**
- **Current resolution limit of ~5 km excludes intermediate scale structure**

Simulations provided by John Retterer, Boston College

Striations



Numerical simulations of the ionospheric striation model in a non-uniform magnetic Field

By

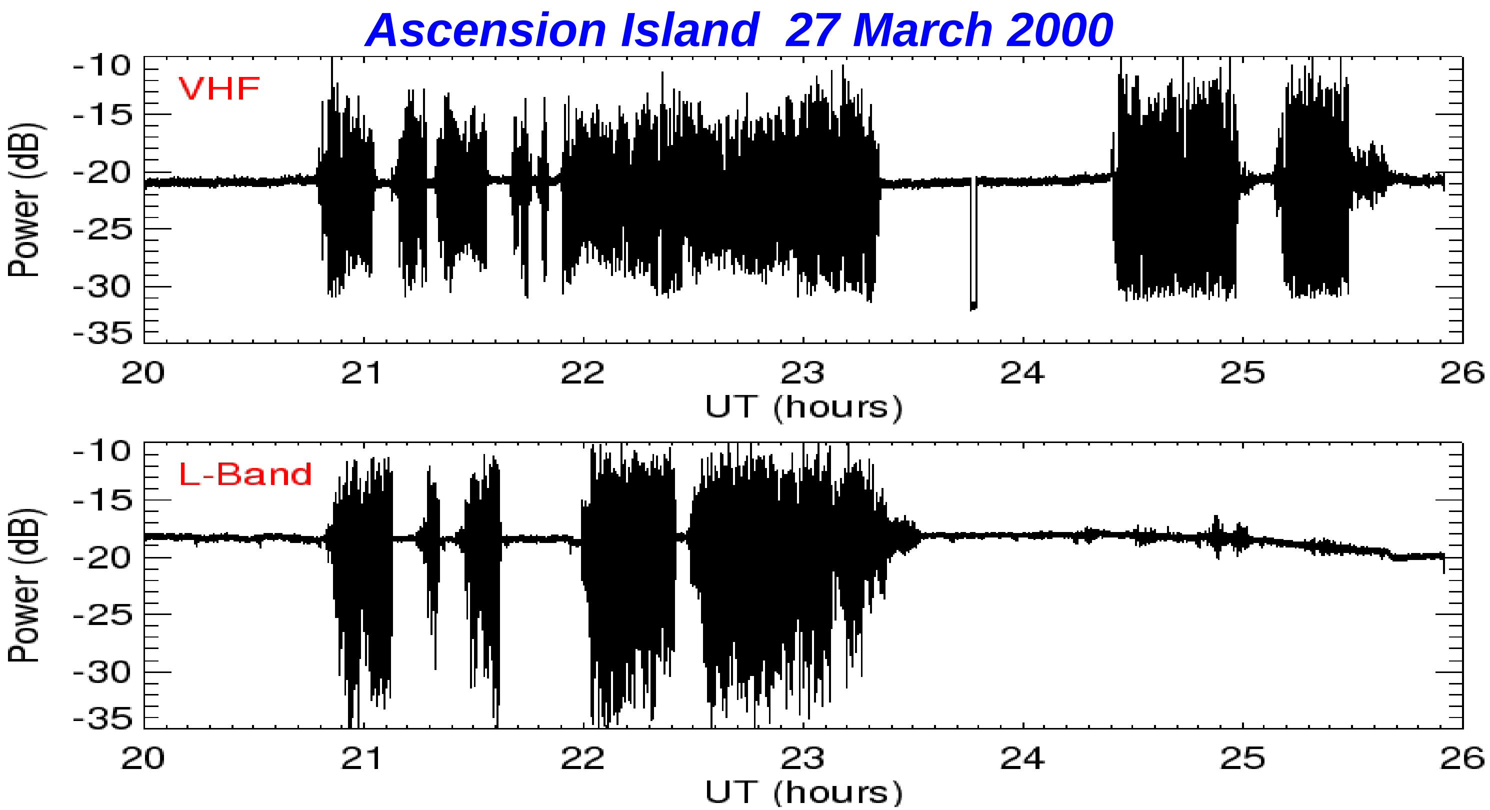
Christophe Besse, Jean Claudel, Pierre Degond, Fabrice Deluzet, G´erard Gallice, and Christian Tessieras

Configuration Space Model

$$\Delta N(\zeta_{\parallel},\zeta_{\perp}) = \sum_k N_k p_{\parallel}(\zeta_{\parallel} - \zeta_{\parallel}^k) \frac{\exp\left\{-(\zeta_{\perp} - \zeta_{\perp}^k)^2/(2\sigma_k^2)\right\}}{2\pi\sigma_k^2}$$

$$\left\langle |\Delta N(\zeta_{\parallel};\kappa_{\perp})|^2 \right\rangle = N\sum_k < N_k^2 > p_{\parallel}^2(\zeta_{\parallel} - \zeta_{\parallel}^k)\langle \exp\{-\sigma_k^2 \kappa_{\perp}^2/2\}\rangle$$

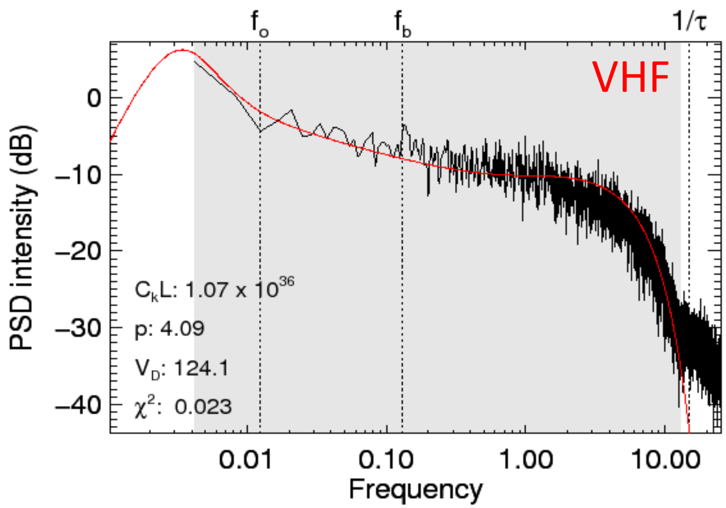
Geosynchronous Satellite Scintillation Data
AFRL Campaign

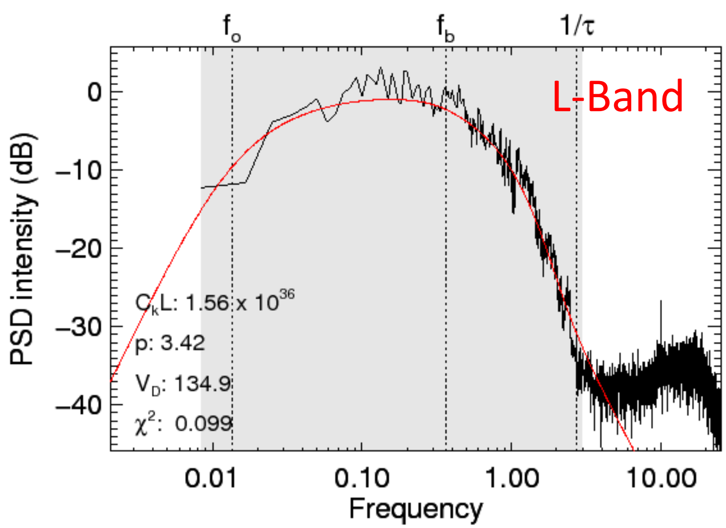


Iterative Parameter Estimation

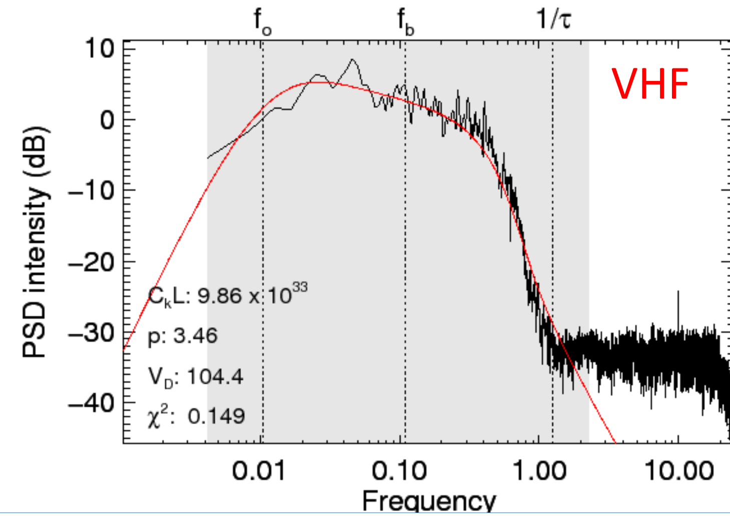
by Charles Carrano

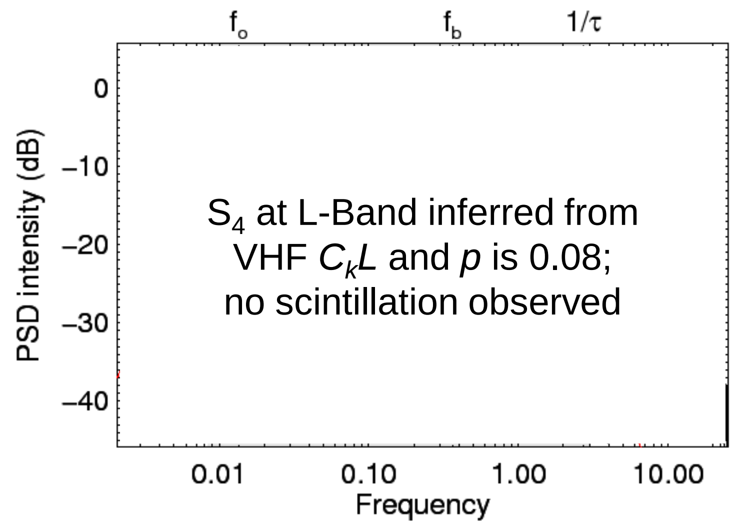
Early Evening (22:02 UT)





Post Midnight (25:20 UT)





Conclusions

- **It is well established that intermediate scale ionospheric structure (100 km - 100 m) is characterized by a multi-component inverse power-law SDF**
  - **Supporting measurements emphasize cross-field geometries with data segments no larger than 10 km as interpreted with models that implicitly assume 3D homogeneity**
- **Reconciliation of models and data will require some rethinking of both the theory of ionospheric structure formation and stochastic models that can accommodate the results**
- **The effort is timely because physics-based global models and supporting data derived from satellite and ground TEC measurements will soon accommodate the intermediate-scale**

Thank you for your attention

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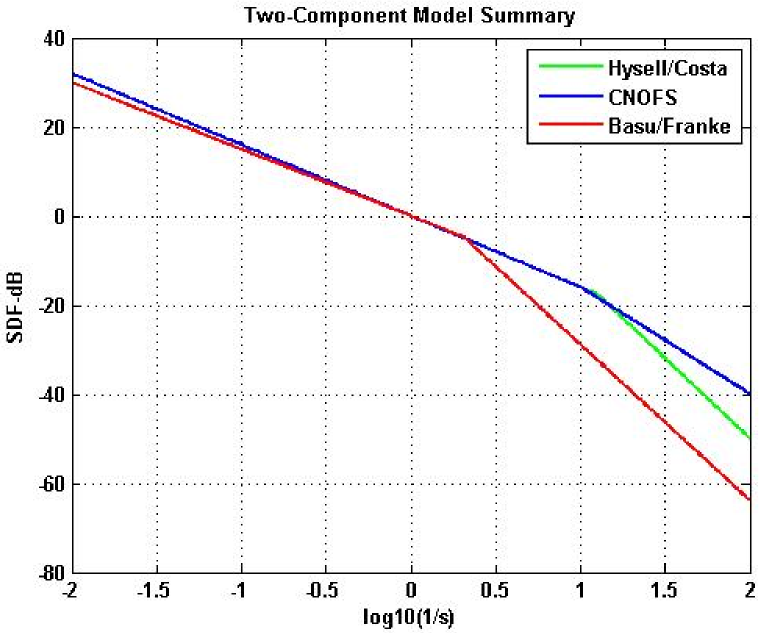
Ionospheric Structure <= Observation



- Basu et. al reported two-component power-law spectra from AEE RPA data
- More recent results by Costa and earlier by Hysell reported two-component spectra with break scales below 100 m
- The most recent scintillation results suggest changing ESF structure although early analyses by Franke showed that the Basu results could explain the frequency dependence of equatorial scintillation for VHF to S-band