

The Simulation of a Disturbed HF Channel

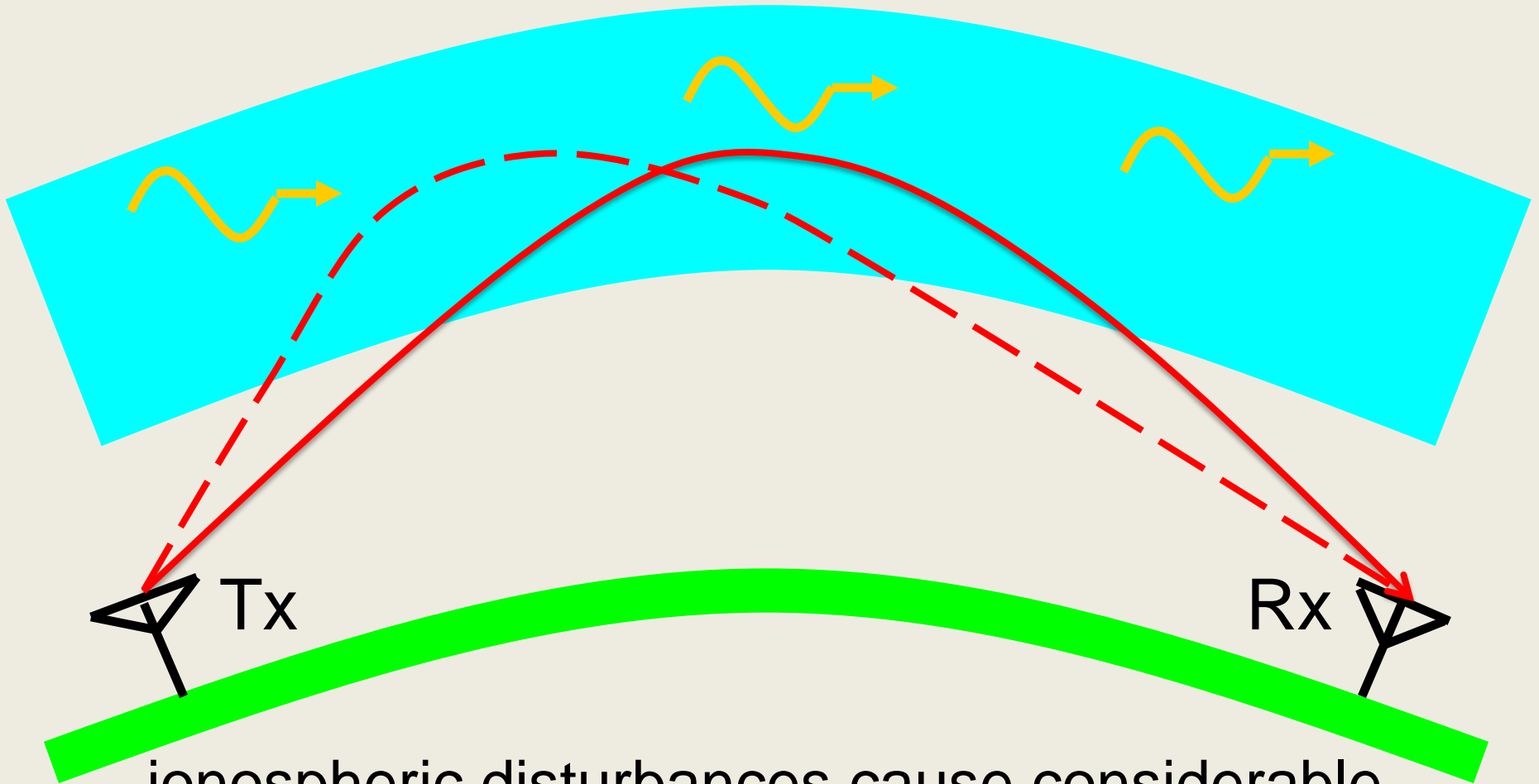
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Effect of TID's upon propagation



ionospheric disturbances cause considerable variations in propagation paths

HF Channel

Simulation and Modelling

Modelling for:

- 1) investigating fading
- 2) investigating direction of arrival

Simulations for:

- 3) testing strategies for low power HF comms
- 4) testing algorithms for direction finding

Requires:

- 1) realistic background ionospheres that includes TIDs
- 2) accurate full 3D point to point ray tracing that includes magneto-ionic effects
- 3) effects of antennas and losses

Ionospheric Modelling

Background Ionosphere:

Chapman layers with layer parameters provided

by IRI and a simple model of the auroral zone

Ionospheric disturbances:

Hook (1968) model of ionisation driven along Earth's field lines by gravity waves

Gravity wave velocity

$$\underline{U} = U_0 \exp(i(\omega t - k_x x - k_y y))$$

causes electron density perturbation

$$\delta N = \Re \left\{ \frac{\hat{\underline{\ell}}_H \cdot \underline{U}}{\omega} \left(\underline{k} \cdot \hat{\underline{\ell}}_H N + i \hat{\underline{\ell}}_H \cdot \nabla N \right) \right\}$$

where $\hat{\underline{\ell}}_H$ is a unit vector along the field lines.

NB for realistic gravity waves all components of \underline{k} are complex

Gravity Wave Modelling

- Gravity waves have a dispersion relation

$$\frac{\omega^4}{C^2} - \omega^2 \left(\left(\frac{2\pi}{\lambda_x} \right)^2 + \left(\frac{2\pi}{\lambda_y} \right)^2 + \frac{\omega_A^2}{C^2} \right) + \omega_B^2 \left(\frac{2\pi}{\lambda_x} \right)^2 = 0$$

where C is the speed of sound, ω_A is the acoustic frequency and ω_B is the Brunt Vaisala frequency .

The wave vector is complex

$$k_x = 2\pi/\lambda_x - i/L_x \quad \& \quad k_y = -2\pi/\lambda_y + i/L_y$$

Modelling by Friedman (1966) and Francis (1973) suggests ducted modes at distinct phase speeds.

A model has been developed to calculate these modes.

$L_x \cong 4\lambda_x$ due to leakage of energy upwards.

$L_y = 2H$ below F layer peak but then decreases due to diffusion.

Ray Tracing

Rays satisfy Fermat's principle

$$\delta \int_A^B \frac{\mu}{u} \underline{u} \cdot d\underline{r} = 0$$

where

$$\mu^2 = 1 - \frac{2X(1-X)}{2(1-X) - (Y^2 - Y_p^2) \pm \sqrt{(Y^2 - Y_p^2)^2 - 4(1-X)^2 Y_p^2}}$$

Fermat's principle implies the Haselgrove equations

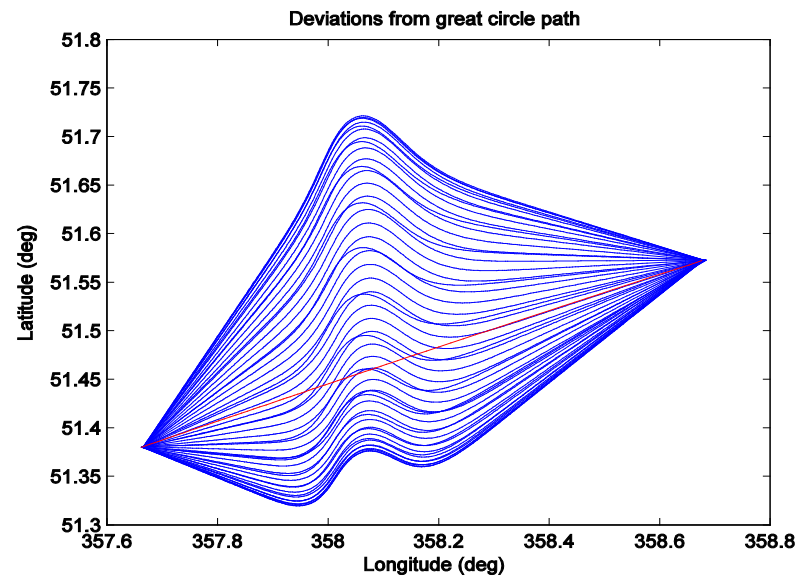
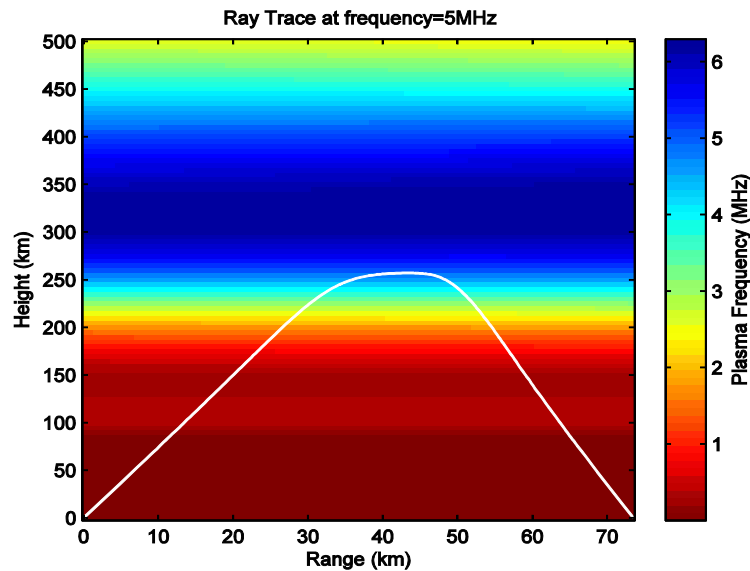
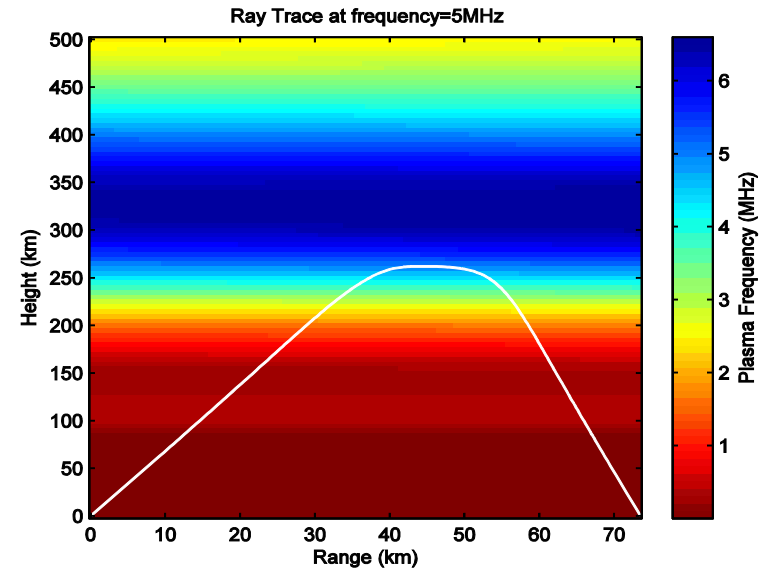
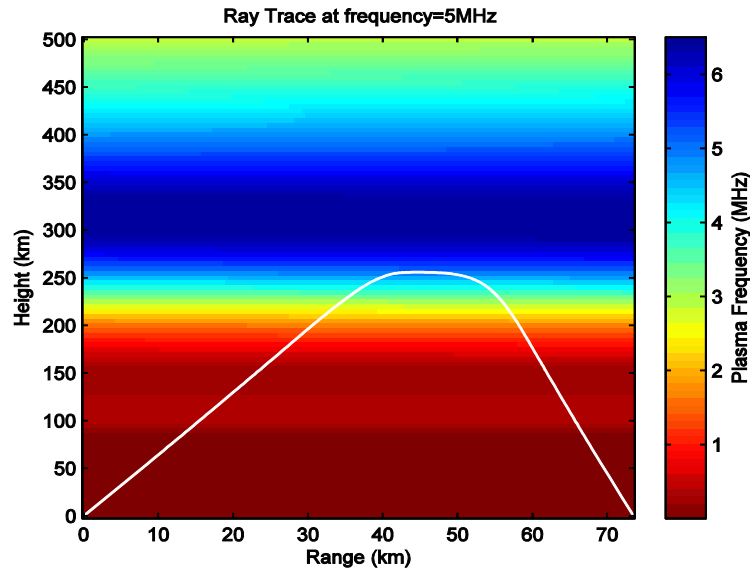
$$\frac{dx_i}{dt} = u_i - \mu \frac{\partial \mu}{\partial p_i} \quad \text{and} \quad \frac{du_i}{dt} = \mu \frac{\partial \mu}{\partial x_i}$$

Solution of point to point Tracing Problems

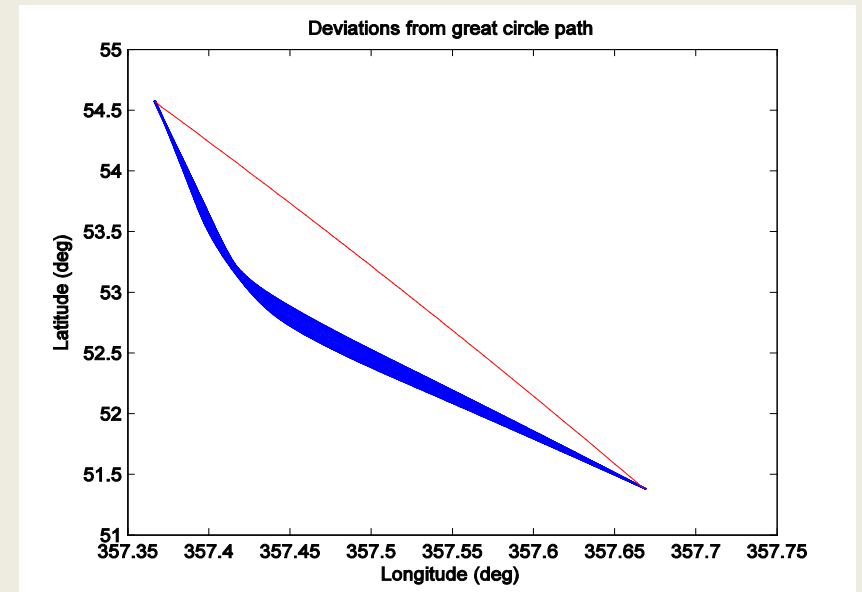
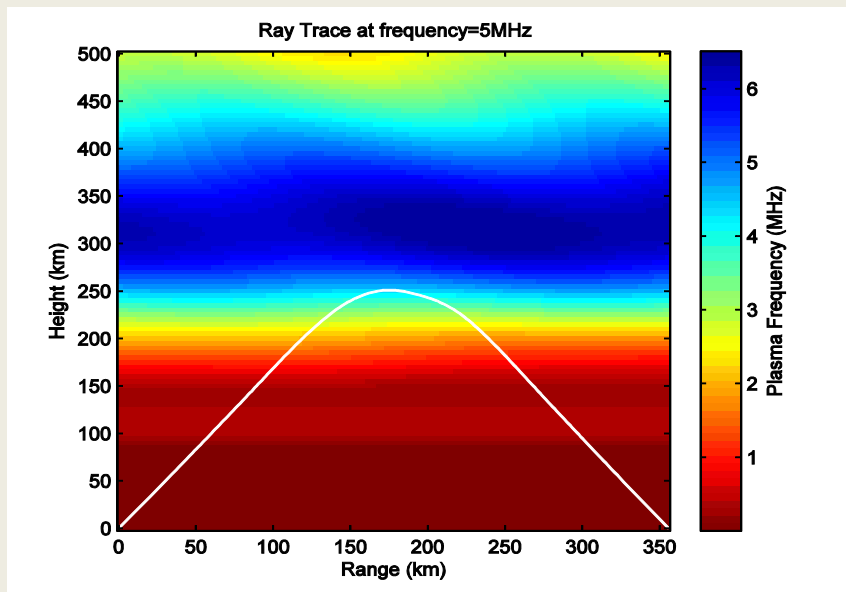
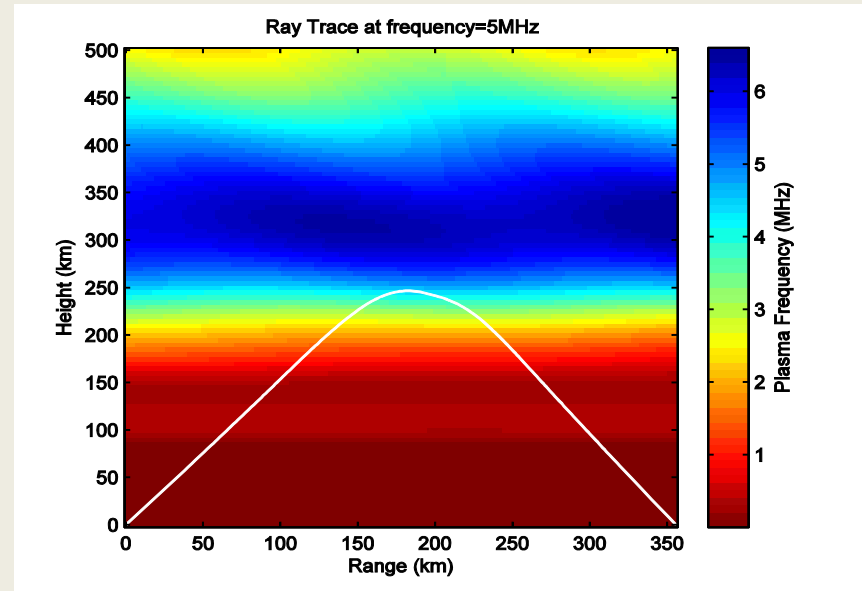
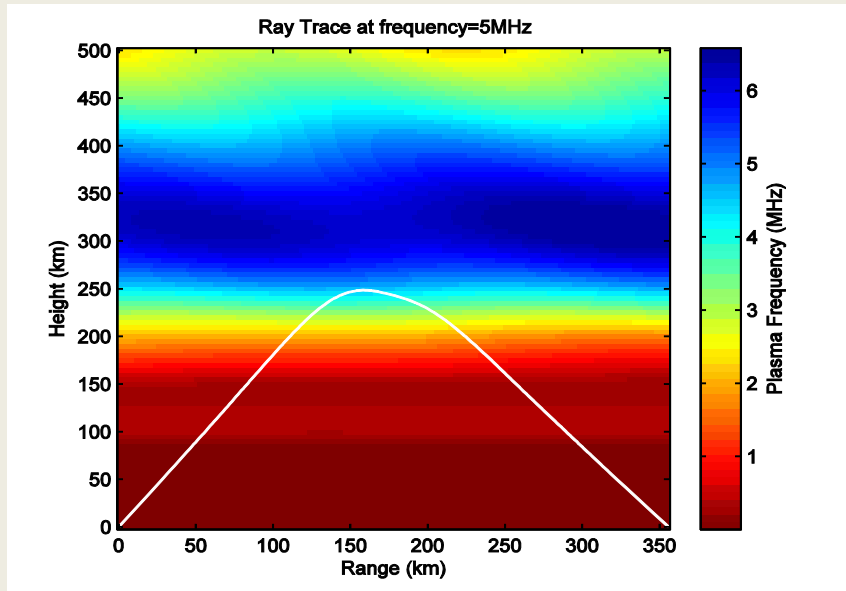
- 1) We can solve Fermat's Principle directly by means of a finite element technique.
- 2) We can solve the Haselgrove equations by means of a shooting method (also known as homing).

NB For both approaches we need a good initial approximation that can be provided by a suitable 2D ray tracing method.

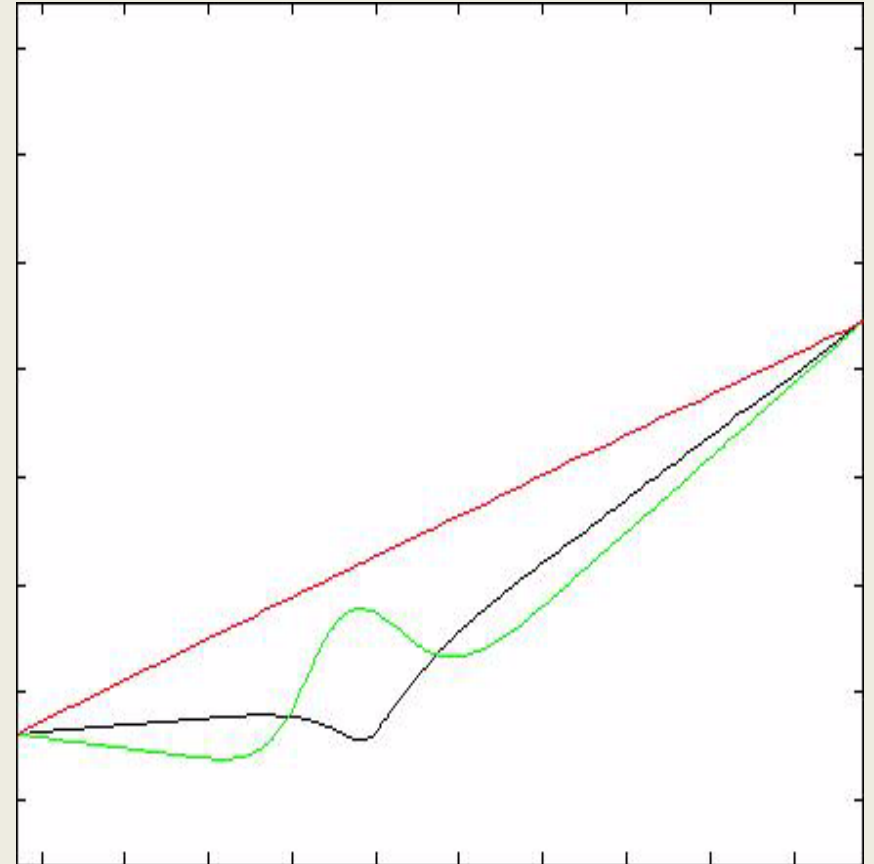
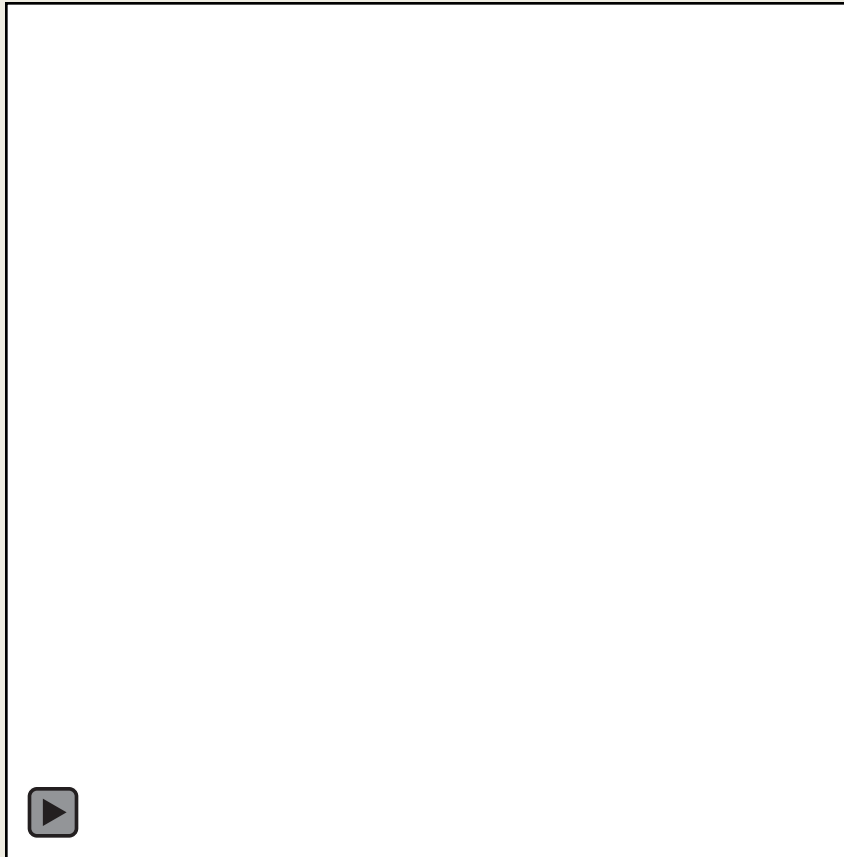
Bath to RAL on 5MHz (0 ray)



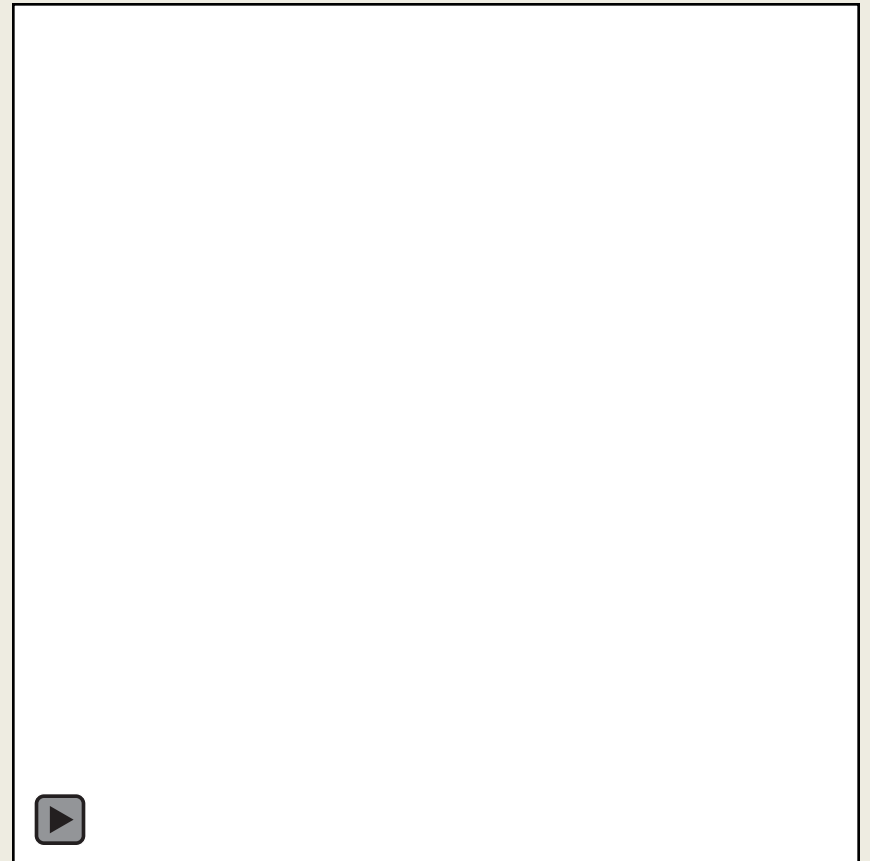
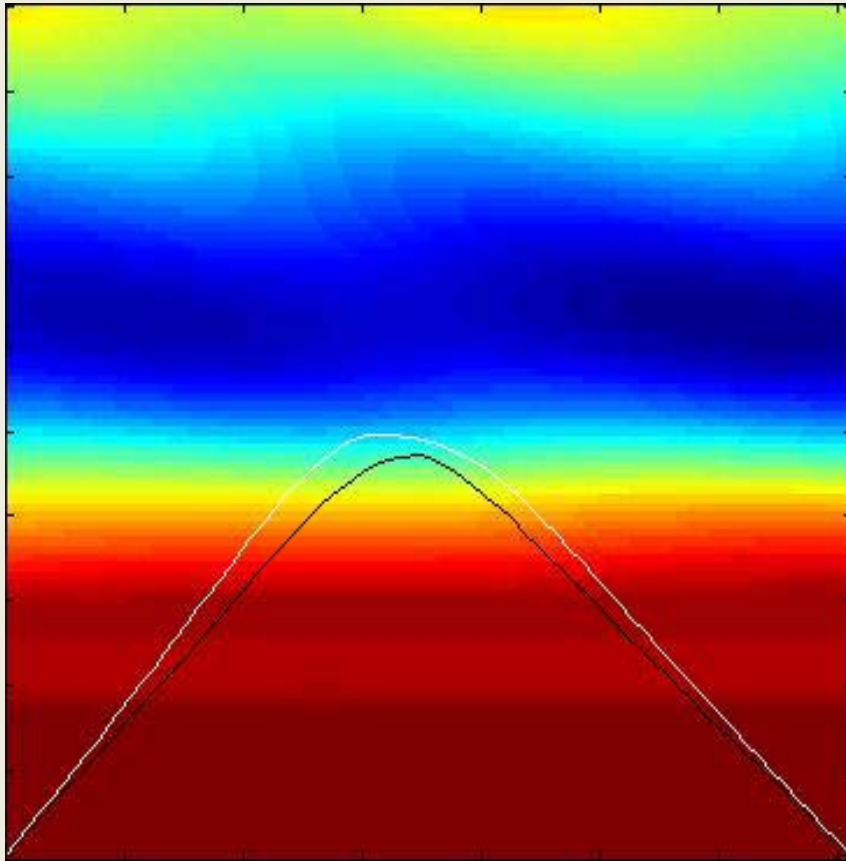
Bath to Westmorland on 5MHz (0 ray)



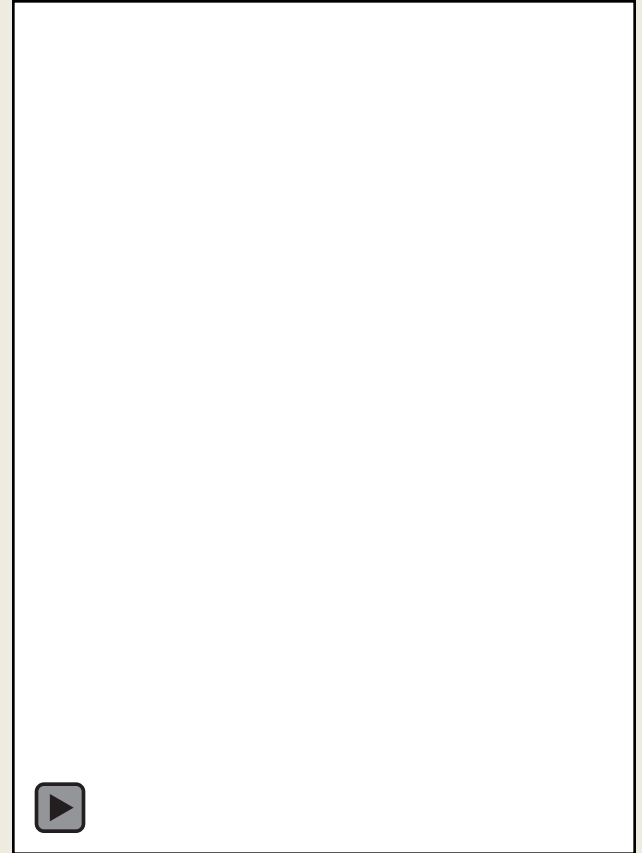
Bath to RAL on 5MHz



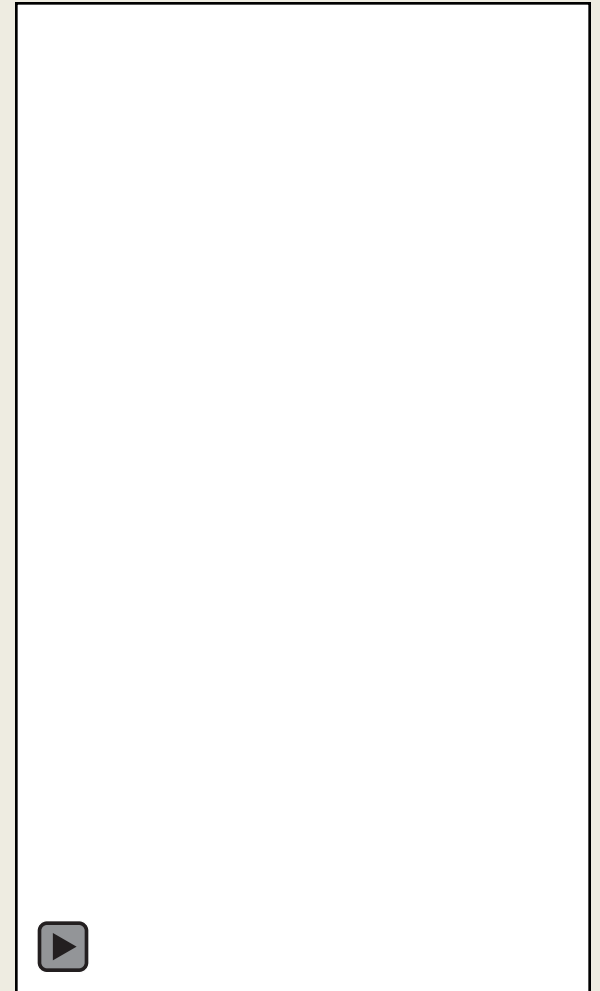
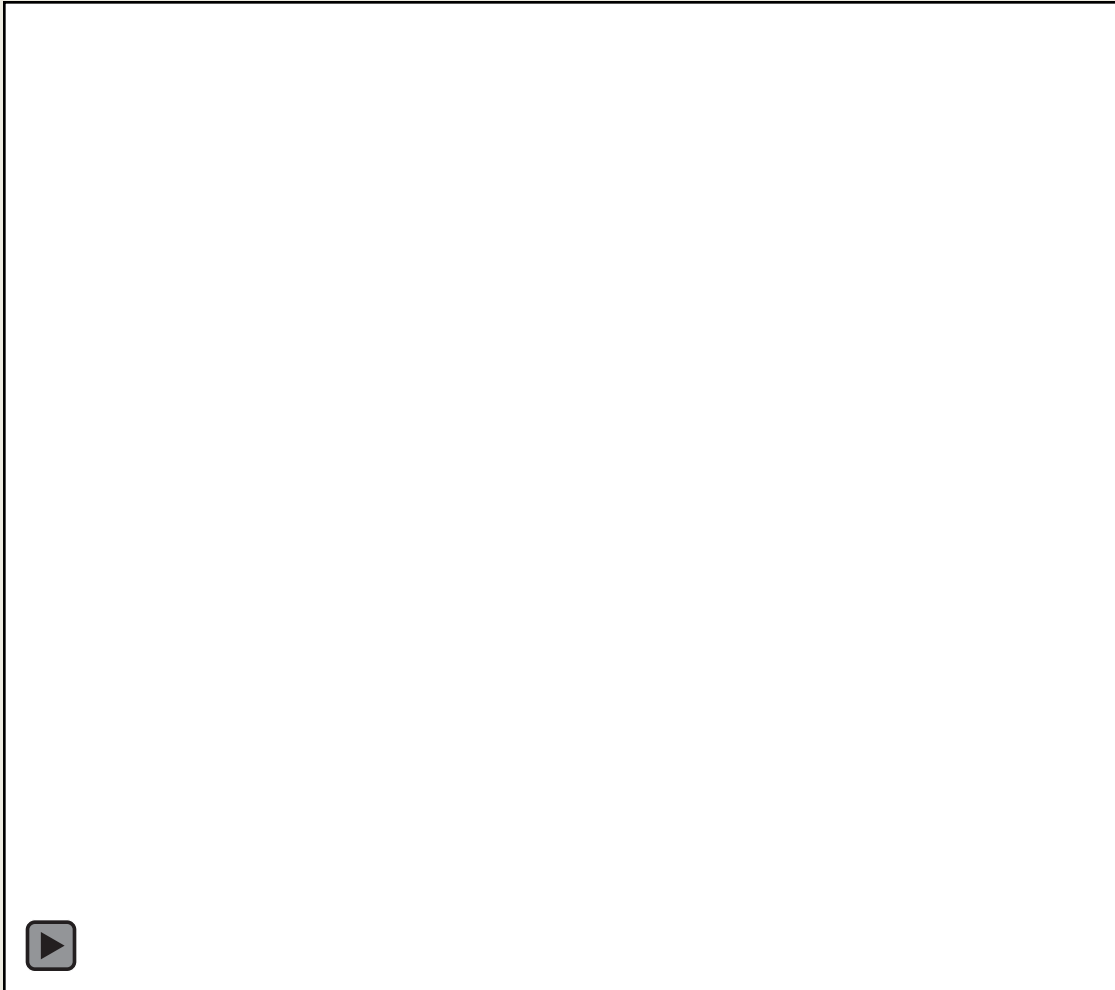
Bath to Westmorland on 5MHz



Alice Springs Northwards on 15MHz



Shorter wavelength TID



Conclusions

- We have established that effective modelling of a disturbed HF channel requires full 3D ray tracing that includes magneto-ionic effects.
- We have developed a realistic model of a TID disturbed ionosphere.
- We have developed suitable 3D point to point ray tracing, based on both homing and direct variational techniques.
- We have developed software that can study an HF channel and, in particular, the DOA.