HOW ULF/ELF WAVES GENERATED IN UPPER IONOSPHERE BY HAARP CAN PROPAGATE OVER LONG DISTANCE

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Generation of ELF and ULF electromagnetic waves by modulated heating of the ionospheric F2 region

B. Eliasson, C.-L. Chang and K. Papadopoulos,

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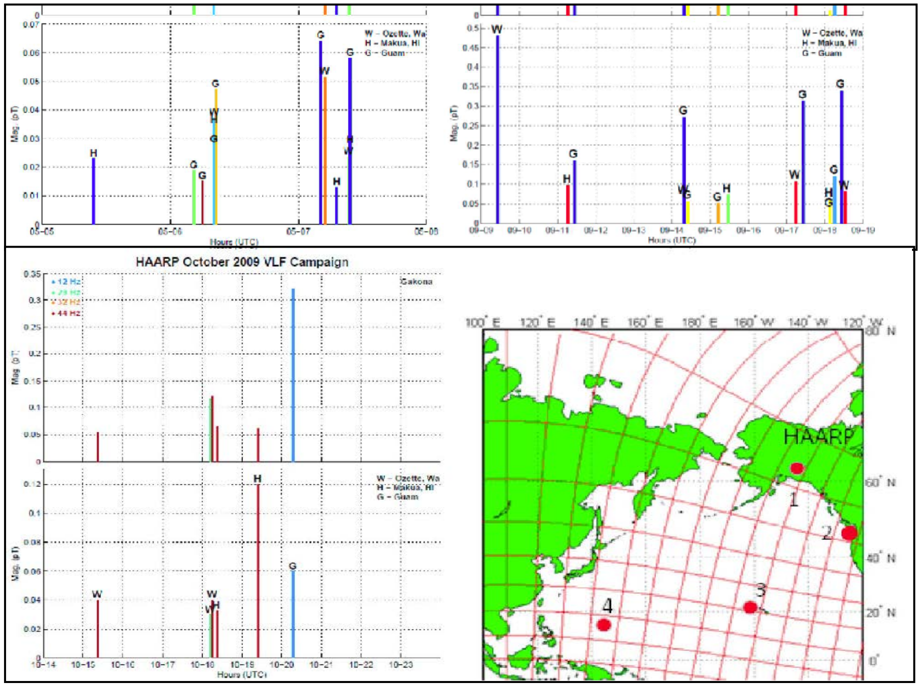
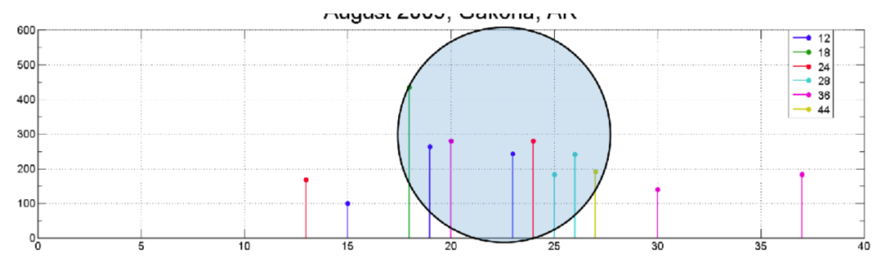
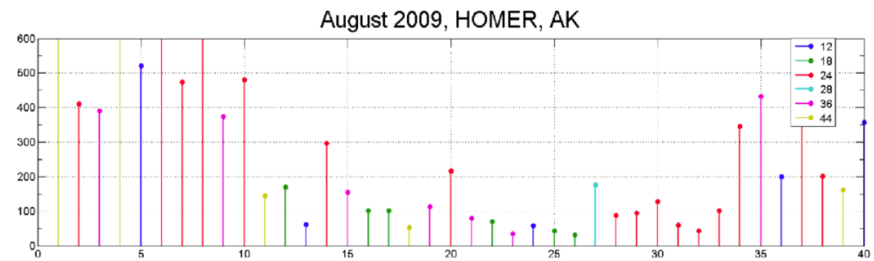
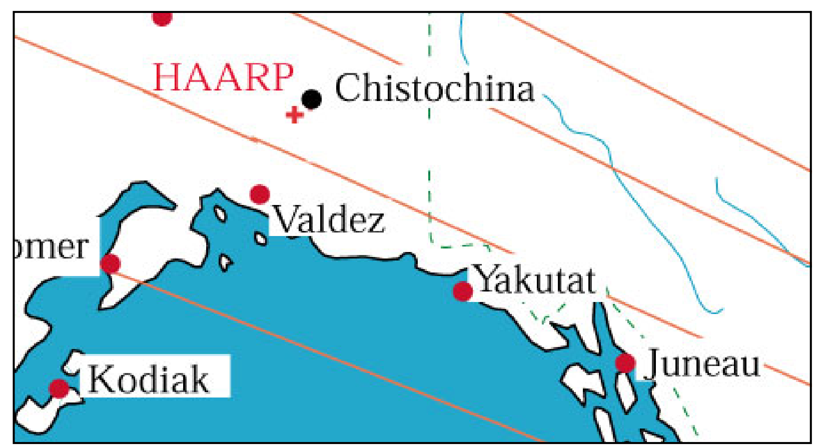


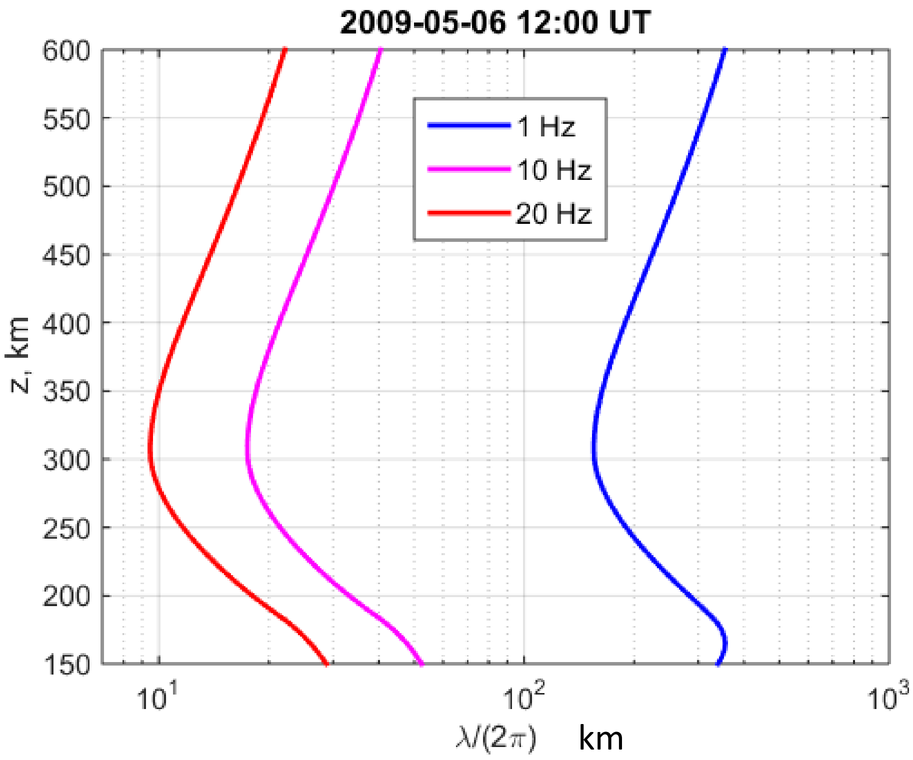


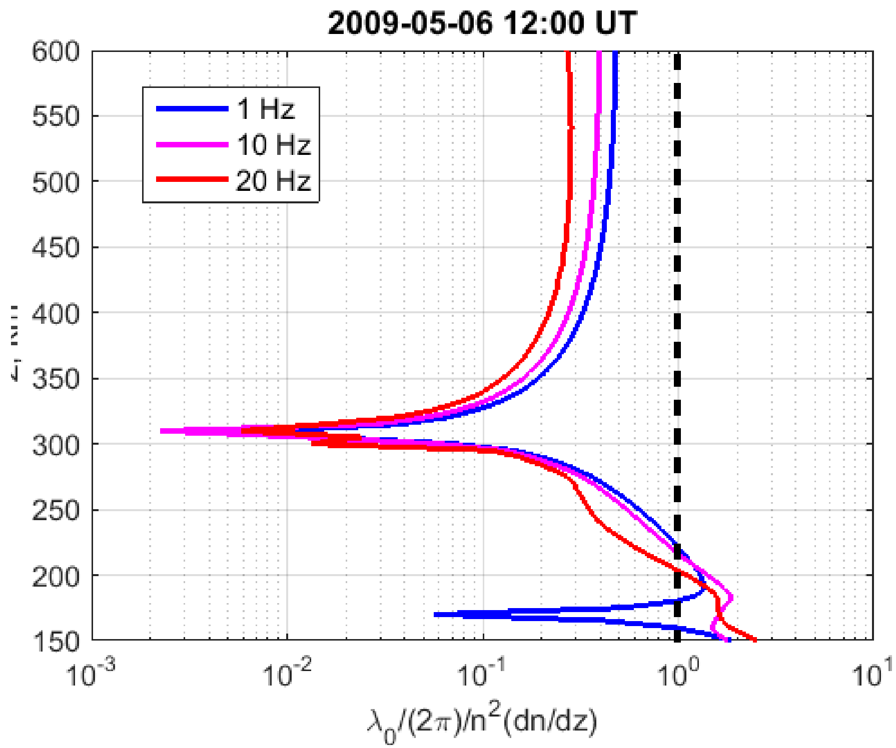




ICD generated ELF waves measured at 1. Gakona, Alaska, 2. Lake Ozette, WA (2100 km), 3. Hawaii (4700 km) and 4. Guam (7700 km) during three campaigns conducted in 2009. Notice that in many cases the waves were detected only at the far sites and not in Gakona. A number of times the waves were measured at two or three sites.

Validity of geometrical optic approach





Basic equations

$$\frac{dr}{d\tau}=\frac{1}{n^2}\left(n_r-\frac{1}{2}\frac{\partial n^2}{\partial n_r}\right);$$

$$\frac{d\vartheta}{d\tau}=\frac{1}{rn^2}\left(n_\vartheta-\frac{1}{2}\frac{\partial n^2}{\partial n_\vartheta}\right);$$

$$\frac{d\varphi}{d\tau}=\frac{1}{r\sin\vartheta n^2}\left(n_\varphi-\frac{1}{2}\frac{\partial n^2}{\partial n_\varphi}\right);$$

$$\frac{dn_r}{d\tau}=\frac{1}{2n^2}\frac{\partial n^2}{\partial r}+n_\vartheta\frac{d\vartheta}{d\tau}+\sin\vartheta n_\varphi\frac{d\varphi}{d\tau};$$

$$\frac{dn_\vartheta}{d\tau}=\frac{1}{r}\left(\frac{1}{2n^2}\frac{\partial n^2}{\partial\vartheta}-n_\vartheta\frac{dr}{d\tau}+r\cos\vartheta n_\varphi\frac{d\varphi}{d\tau}\right);$$

$$\frac{dn_\varphi}{d\tau}=\frac{1}{r\sin\vartheta}\left(\frac{1}{2n^2}\frac{\partial n^2}{\partial\varphi}-\sin\vartheta n_\varphi\frac{dr}{d\tau}-r\cos\vartheta n_\varphi\frac{d\vartheta}{d\tau}\right)$$

Here *n*- the refractive index of the wave, The refractive indices of normal waves in a magnetoactive plasma satisfy the dispersion equation

$$An^4+Bn^2+C=0,$$

$$A=\varepsilon_\perp\sin^2\theta+\varepsilon_{||}\cos^2\theta;$$

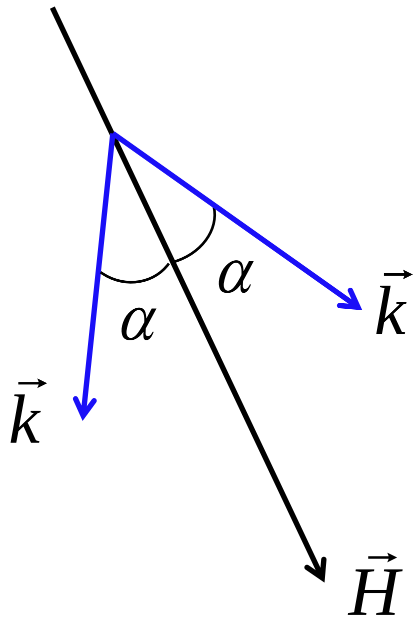
$$B=-\varepsilon_\perp\varepsilon_{||}\left(1+\cos^2\theta\right)-\left(\varepsilon_\perp^2-g^2\right)\sin^2\theta;$$

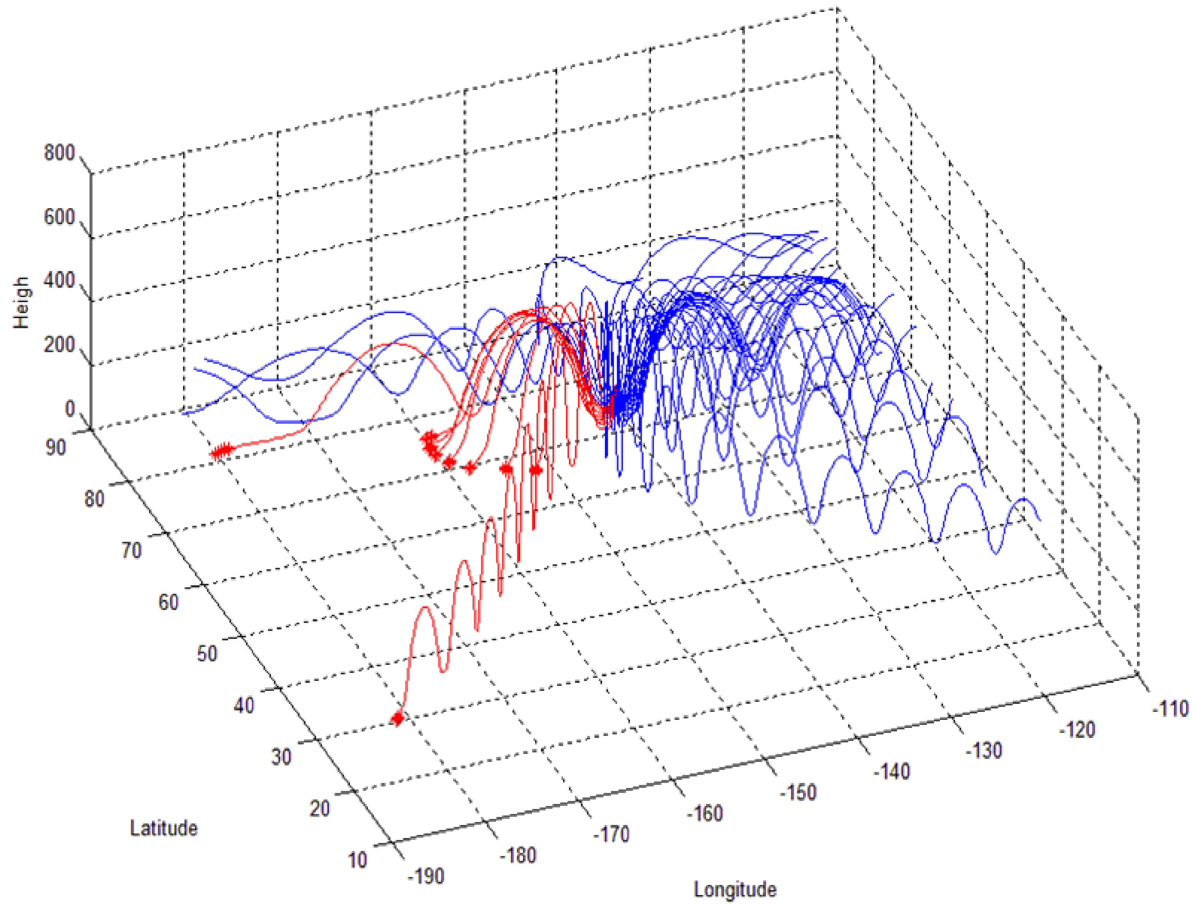
$$C=\varepsilon_{||}\left(\varepsilon_\perp^2-g^2\right).$$

$n_r, n_\vartheta, n_\varphi$ - the projection of the wave normal vector on the axis of the spherical coordinate system.

It should be noted that we constantly monitor the applicability of the geometric optic approximation during the calculations.

Results of numeric simulations





Blue rays are trapped in the MHD waveguide , red one came to the lower ionosphere and have possibility to get the Earth surface

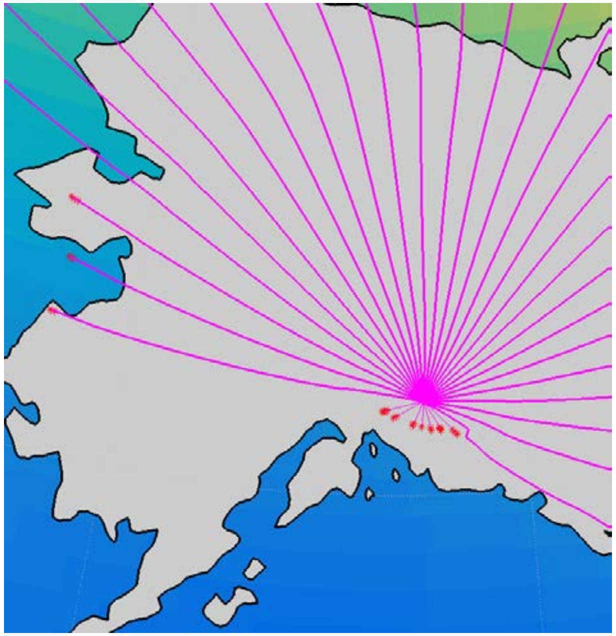
Projections of the ULF trajectories on the Earth surface (examples)

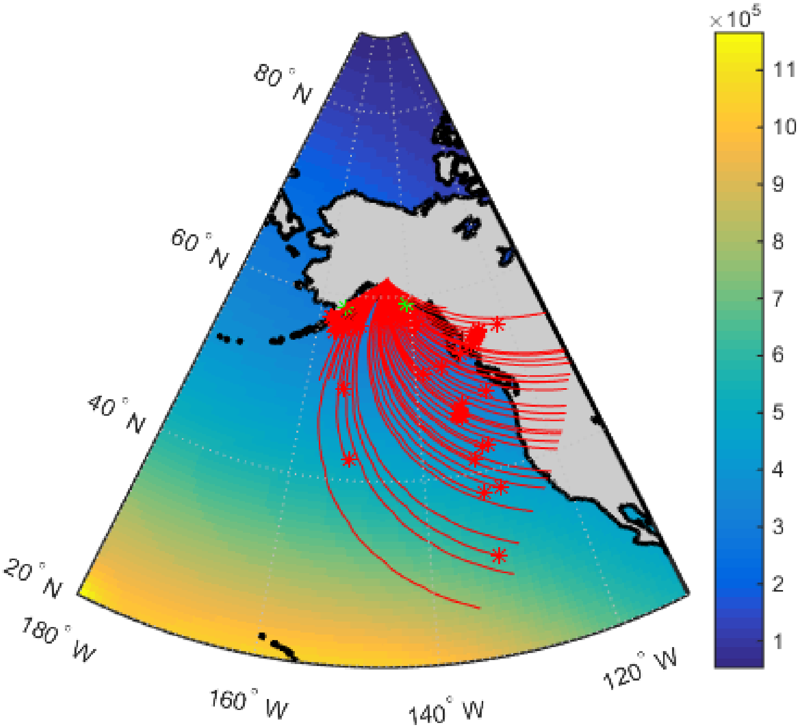
2009.05.06 12.00UT
f = 10 Hz

Z_s = 300 km $\alpha = 35^o$

2009.10.18 00.00UT
f = 20 Hz

Z_s = 230 km $\alpha = 155^o$





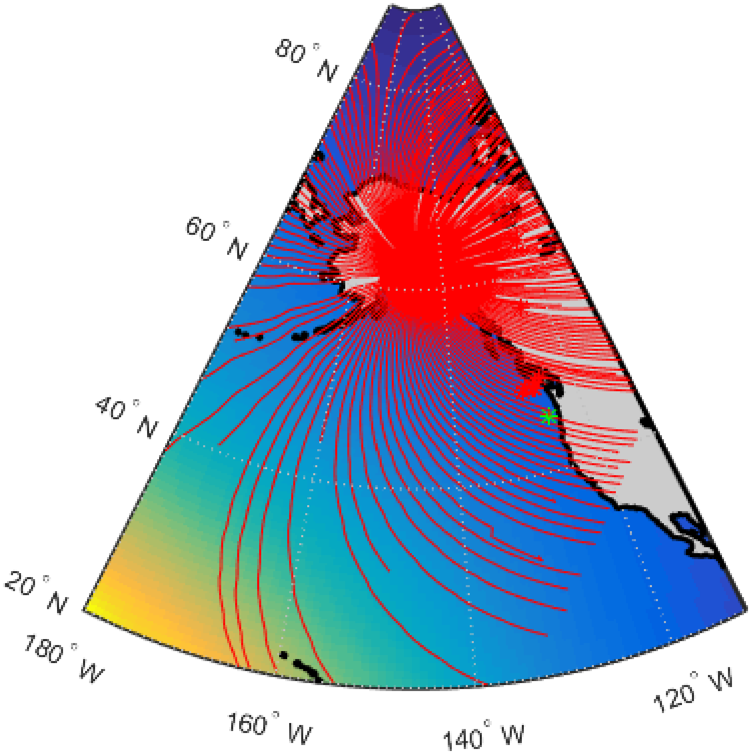
The color bar shows the distribution of electron density at 300 km altitude

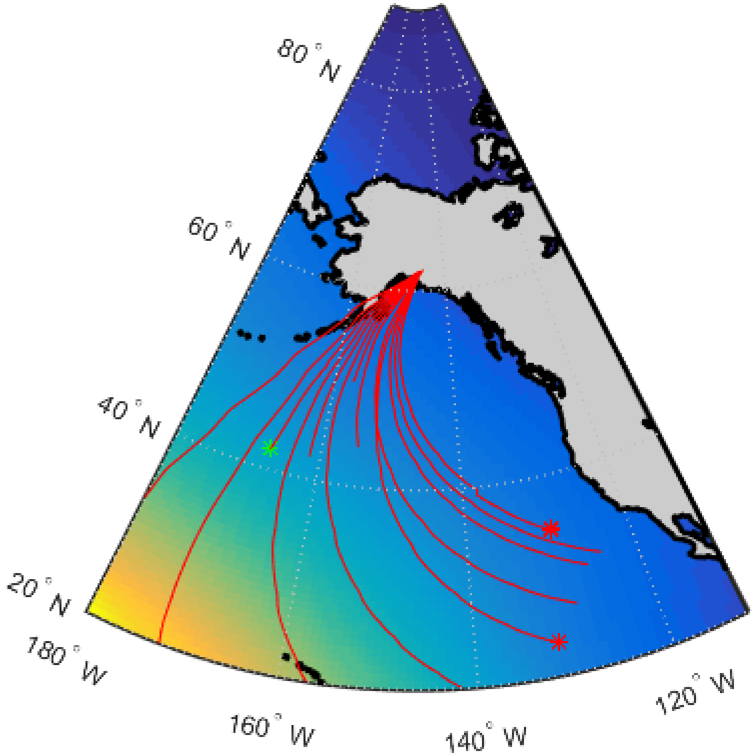
Projections of the ULF trajectories on the Earth surface

2009.10.18   02.00UT

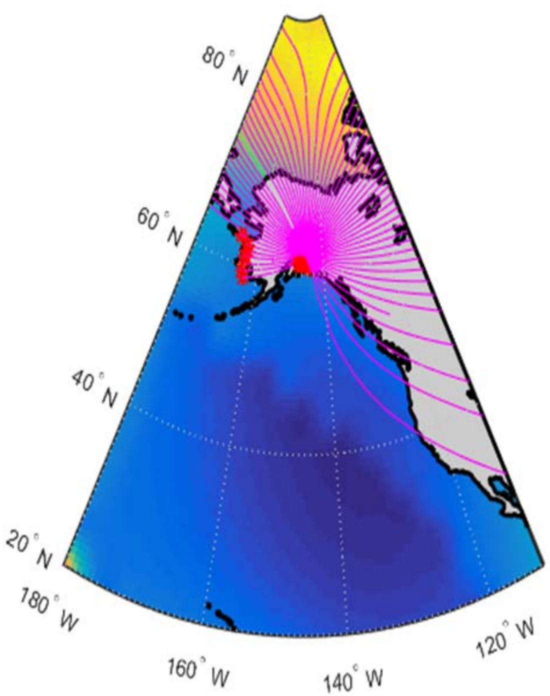
f = 20 Hz

Z_s = 250 km $\alpha = 55^o$ Z_s = 230 km

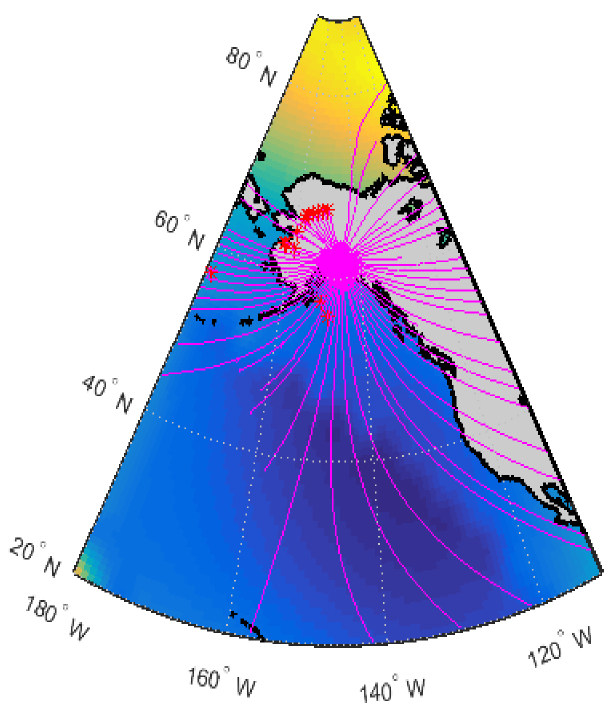




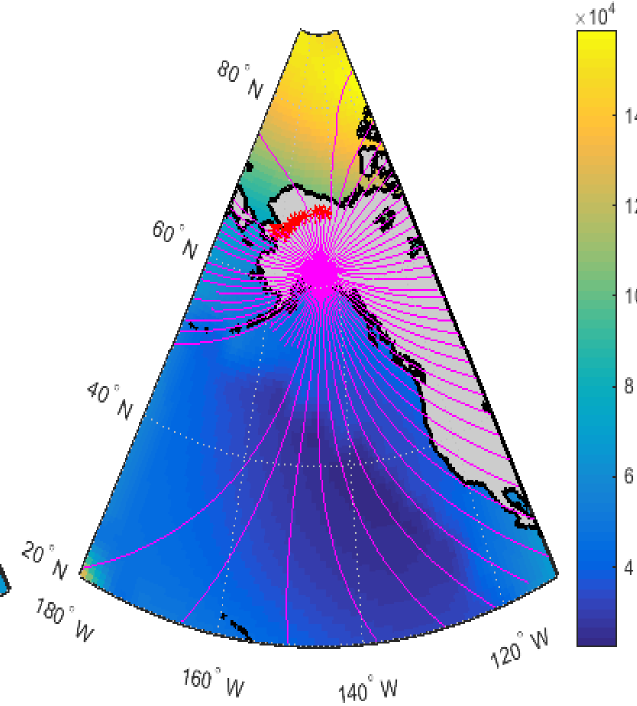
More examples for 2009.05.06 at 12:00 UT for 10 Hz in presence of the ionospheric throat



Z_S = 300 km
α=140



Z_S = 250 km
α=45



Z_S = 300 km
α=45

Conclusions

- **The lateral gradients of the plasma parameters like on the terminator or main ionospheric trough responsible for driving the ULF rays traces to the lower ionosphere. It could be emphasize existing of two kinds of rays deducing the ULF waves from MHD waveguide in the E-layer from which they can reach the surface of the earth. One group of rays come out at a distances of 100-500 km from the source, and the other at a considerable large distance in the middle of the Pacific Ocean.**

Thank you

for attention