Wave Properties and Diffusion Rates Associated with Alpha Transmitters

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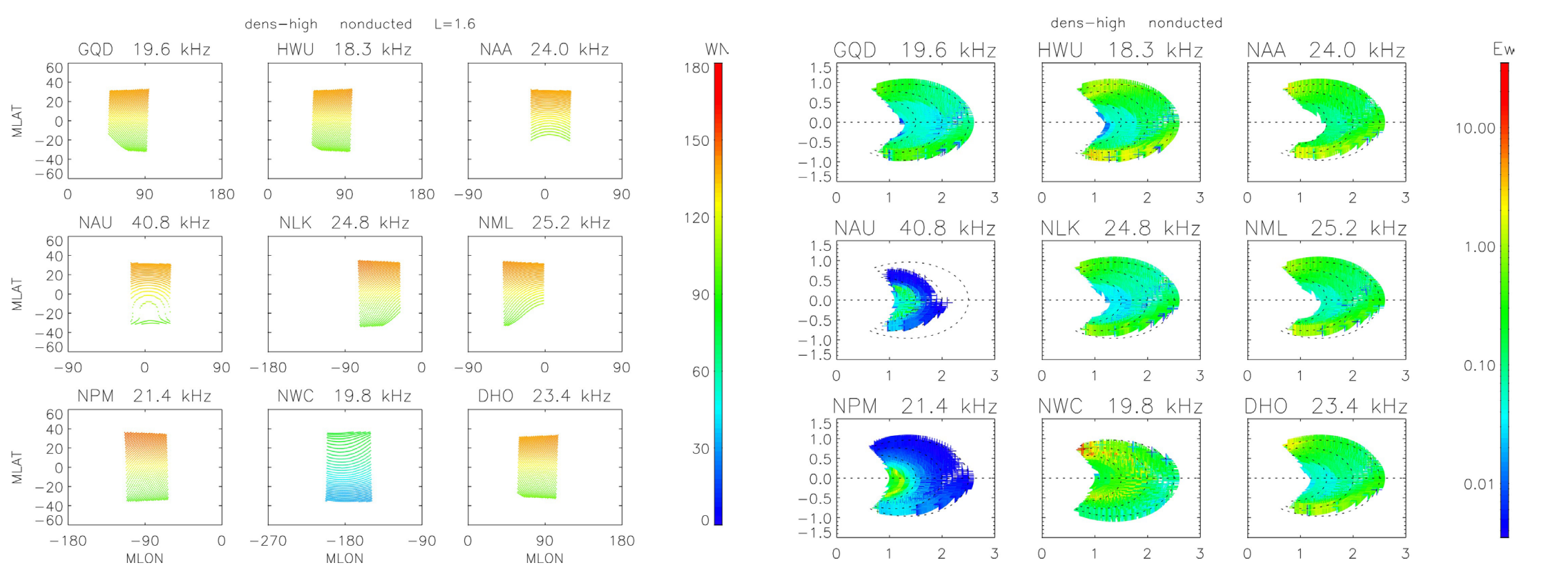
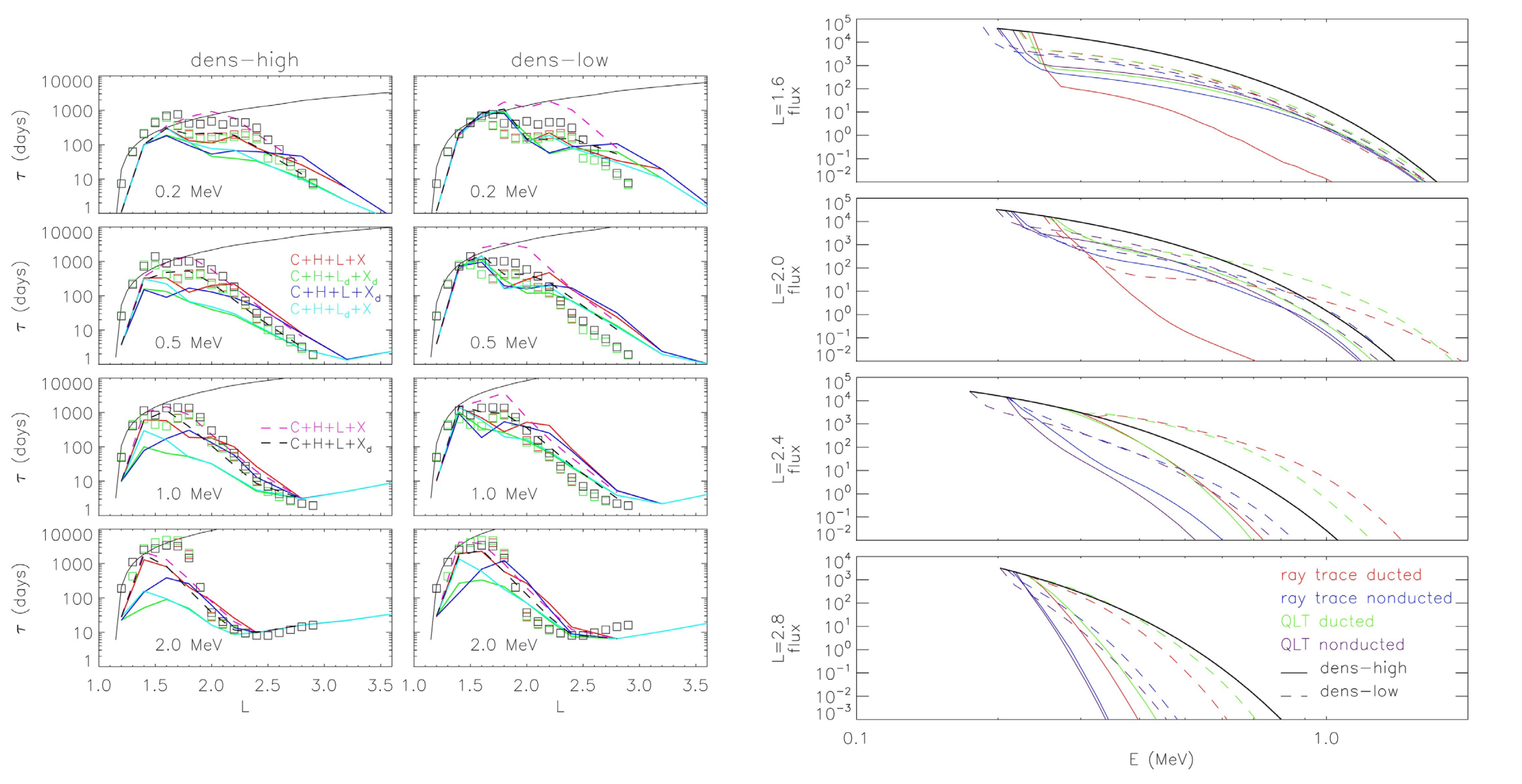
Inside the plasmasphere, pitch angle scattering of energetic electrons is driven by scattering from hiss, LGW, and VLF transmitters, as well as Coulomb collisions.

Starks+ (2020) and Albert+ (2020) modeled a set of ~20 kHz VLF transmitters (and LGW) from their sources through the ionosphere into space, obtaining realistic global wave patterns:



as well as QL diffusion coefficients, lifetimes, and steady-state flux distributions.



Claudepierre+ (2020): "we find significant quantitative disagreement at $L < 3.5$, where the theoretical lifetimes are typically a factor of ~10 larger than the observed, pointing to an additional loss process that is missing from current models."

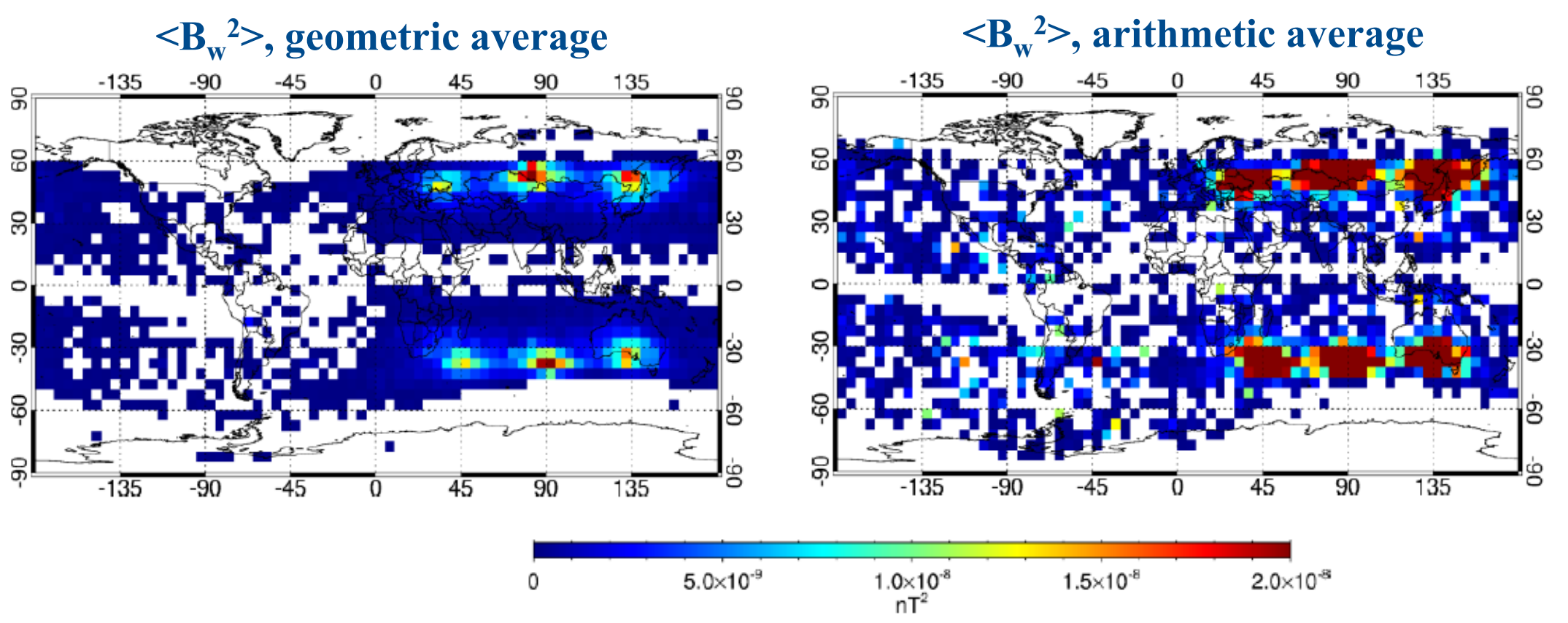
Or not: Broll+ (2023): "We conclude that nonequilibrium effects, rather than a missing diffusion or loss process, account for observed short decay rates."

Here we investigate some additional wave sources: the Russian Alpha (Alfa) transmitters (~12 kHz) and Power Line Harmonic Radiation (50/60 Hz).

Beyond the direct effects, this might shed light on the ducted/nonducted question.

Alpha transmitters as seen by RBSP/EMFISIS at 11.9 kHz, projected N and S along FLs to 110 km altitude.

(Also have 12.6 kHz and 14.9 kHz, 0.4/3.6 sec each)

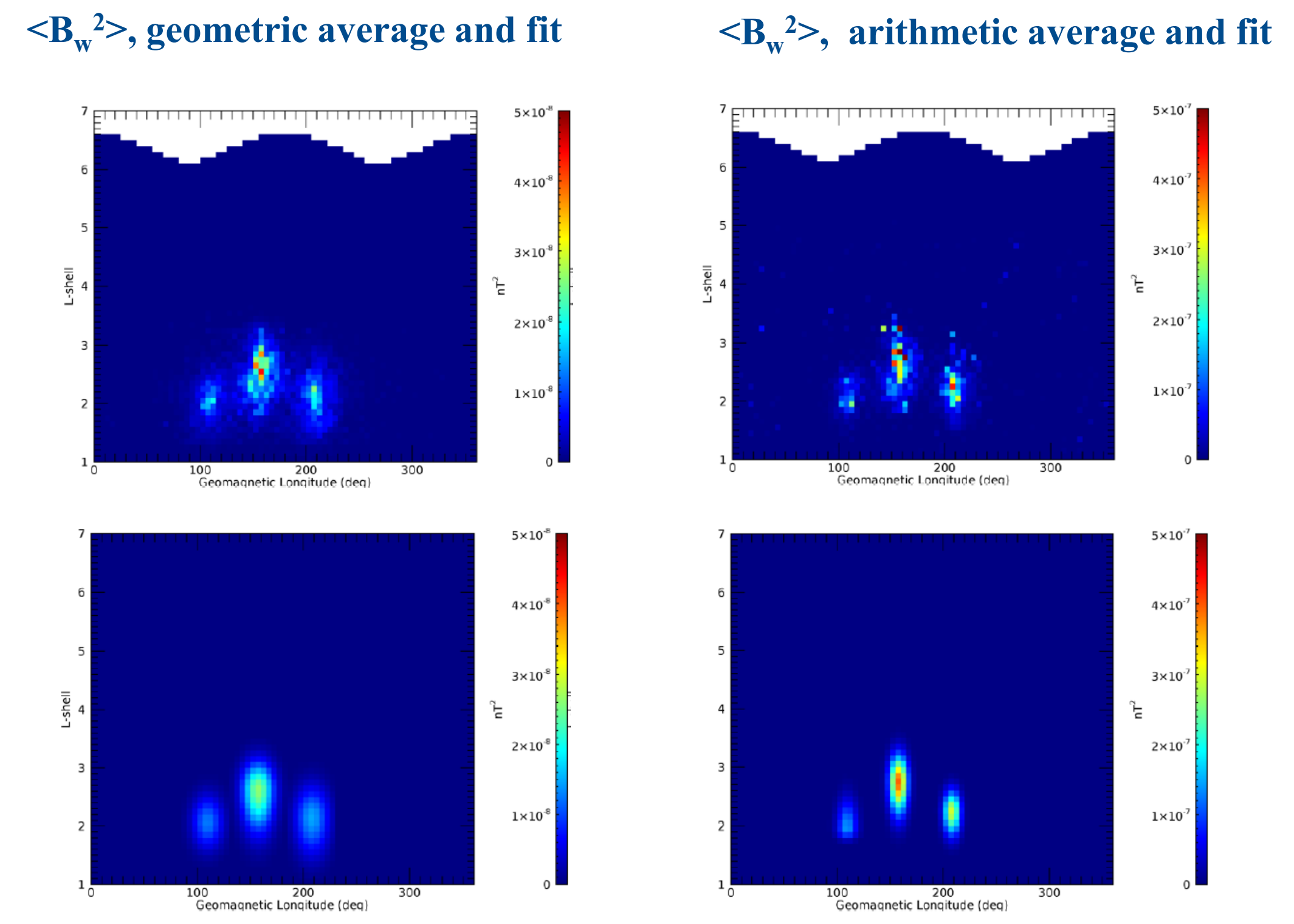

$\langle B_w^2\rangle$, geometric average

$\langle B_w^2\rangle$, arithmetic average

Fit B_w^2 for Alphas:

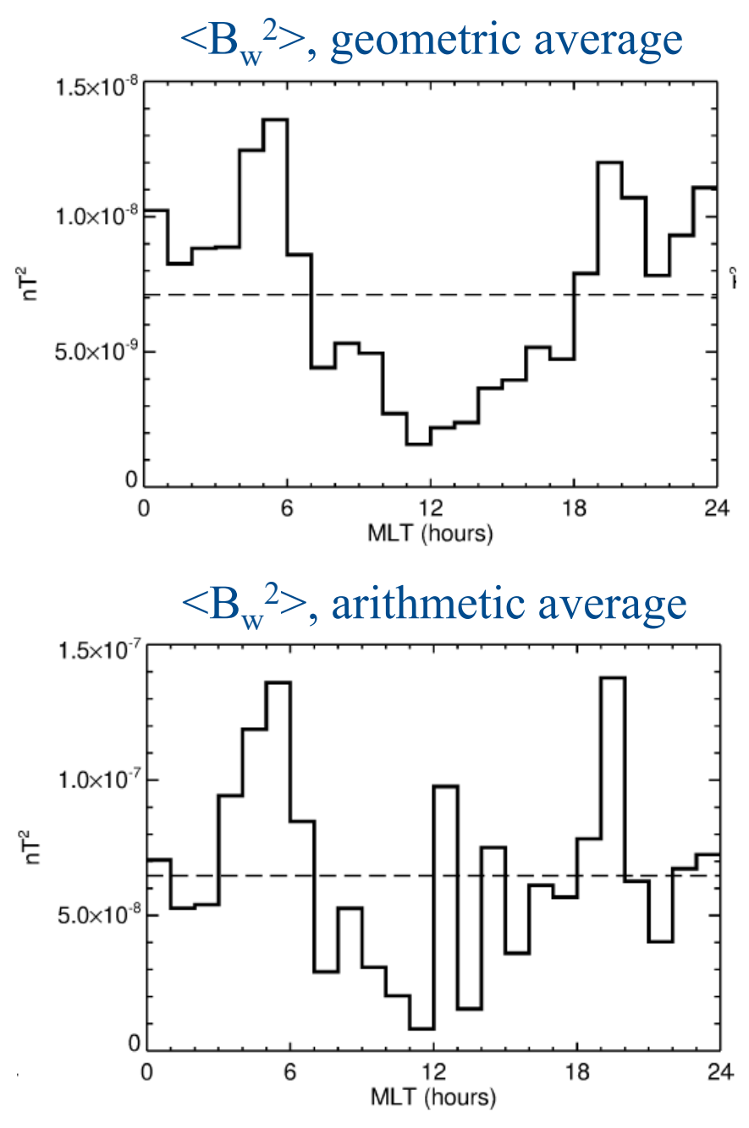
$$I = I_0 \exp\left(-\left(\frac{lon - lon_0}{X_{lon}}\right)^2\right) \exp\left(-\left(\frac{L - L_0}{X_L^{\pm}}\right)^2\right)$$

parameter	KRA geo	NOV geo	KOM geo	KRA ari	NOV ari	KOM ari
I_0 (nT^2)	1.27e-8	2.63e-8	1.48e-8	1.429e-7	3.966e-7	2.98e-7
lon_0 (deg)	109.66	157.34	208.12	109.44	157.92	208.35
L_0	2.067	2.633	2.149	1.946	2.753	2.238
X_{lon} (deg)	14.17	14.37	15.42	9.13	8.26	7.62
X_L^+	0.442	0.444	0.508	0.481	0.419	0.332
X_L^-	0.438	0.672	0.610	0.156	0.519	0.372


$\langle B_w^2\rangle$, geometric average and fit

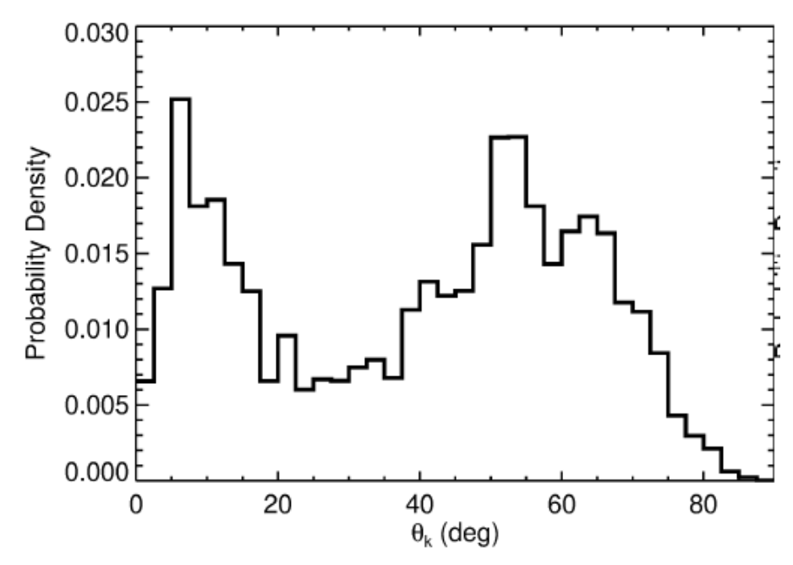
$\langle B_w^2\rangle$, arithmetic average and fit

$\langle B_w^2\rangle$ is larger at night than day, as expected (trans-iono absorption)


$\langle B_w^2\rangle$, geometric average

$\langle B_w^2\rangle$, arithmetic average

WN angle distribution (power-weighted)

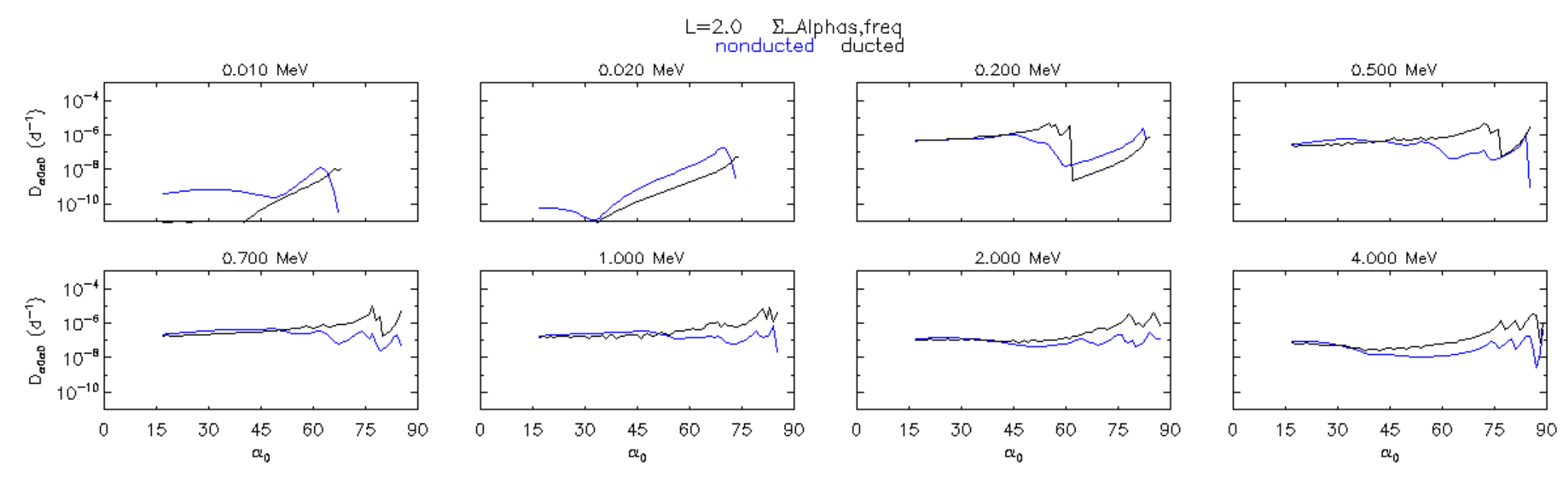


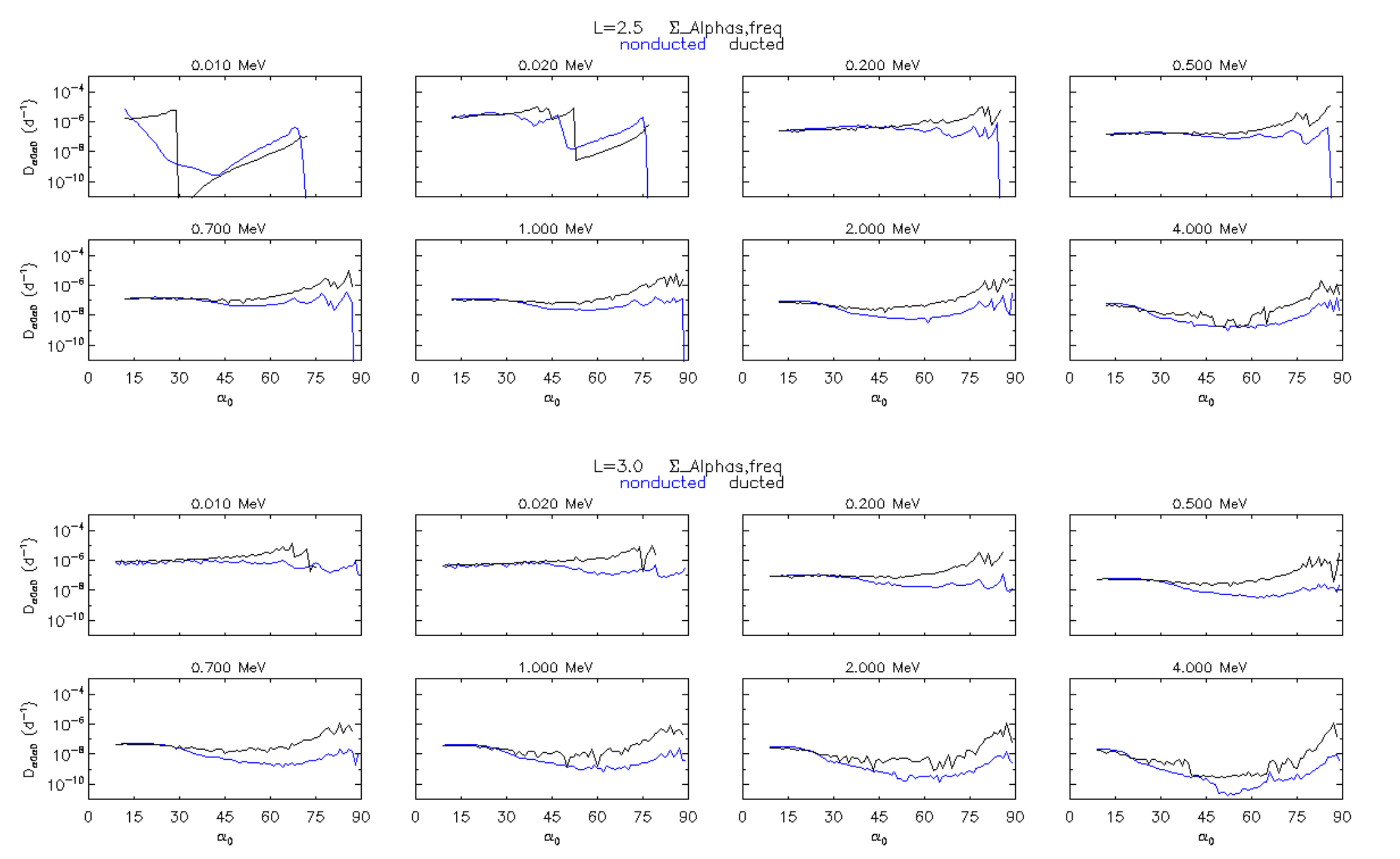
field-aligned ("ducted")

highly oblique (non-ducted)

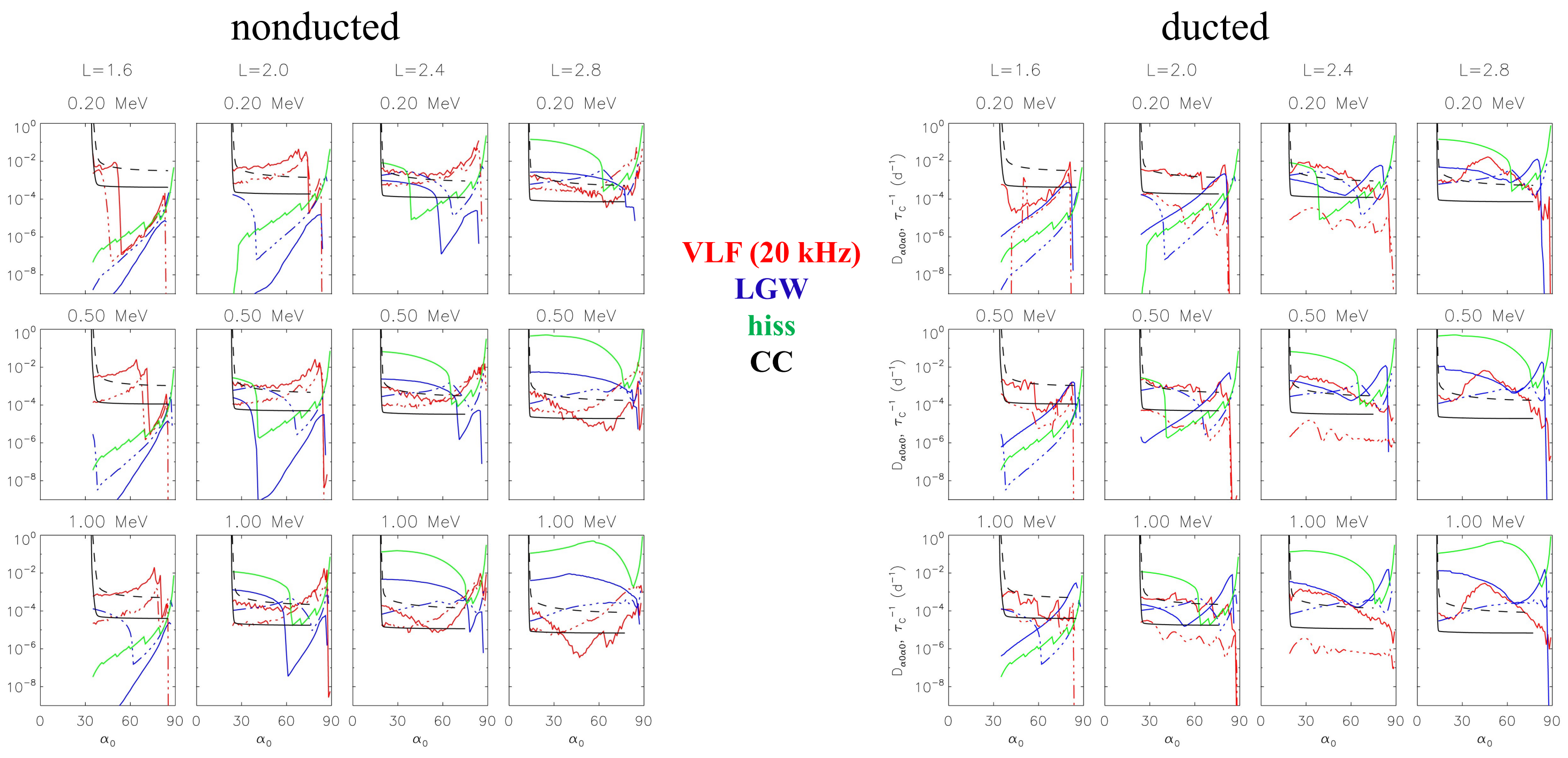
Diffusion coefficients, using simple b-av QLT

(amplitude and WN measured at equator and used all along FL)





These rates are small compared to other waves sources (Albert+, JGR 2020)



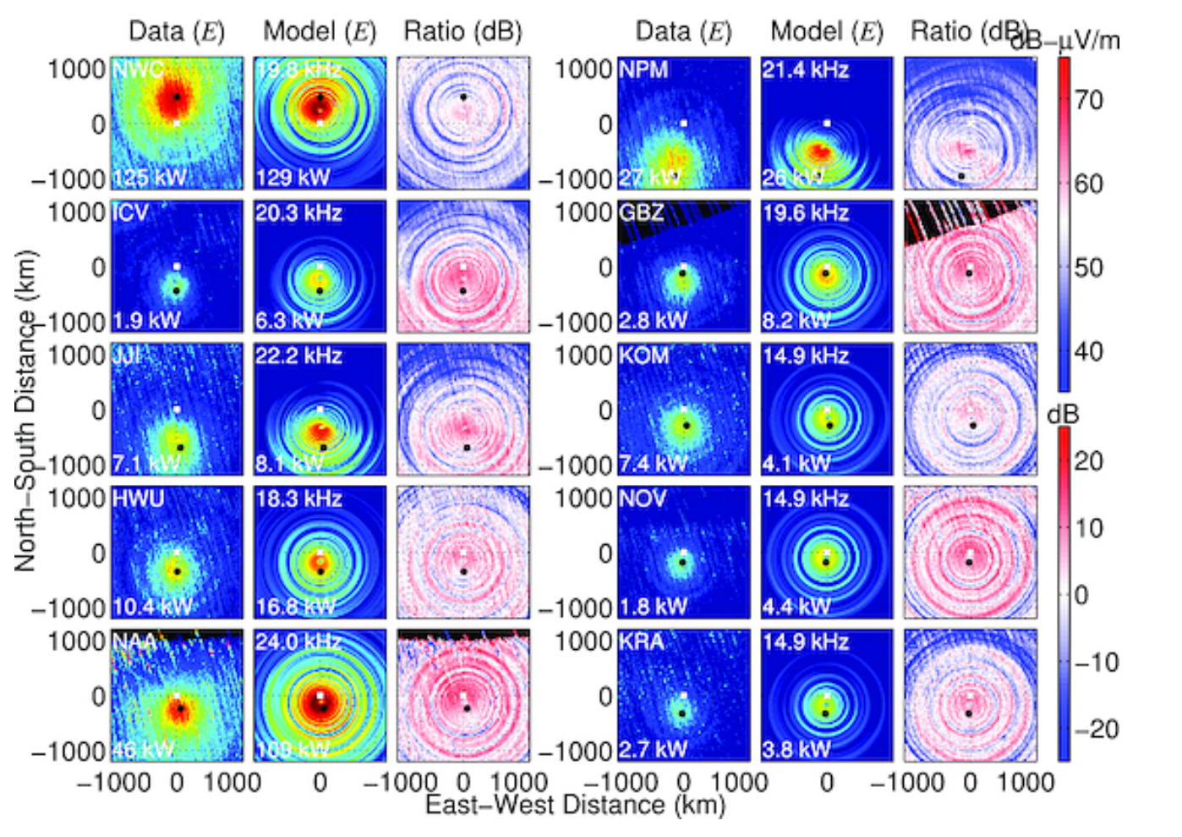
Not unexpected, since the measured wave amplitudes are small.

But the fields should be stronger at high latitude (closer to the source), and the WN varies with latitude.

End-to-end modeling can try to capture this.

As in earlier work for ~ 20 kHz transmitters (Starks et al., JGR, 2020), the Alphas were represented as dipoles in a full-wave model*, followed by ray+power tracing, with Landau damping.

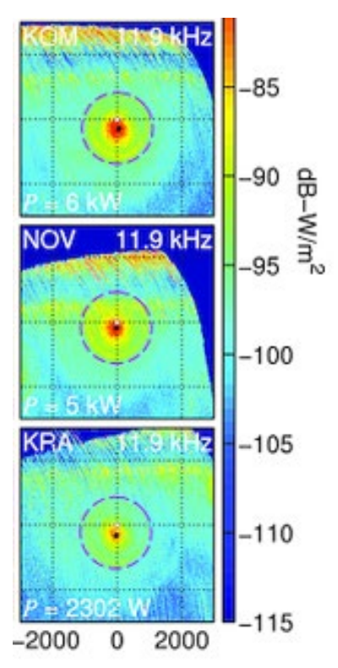
***The "Helliwell absorption curves" overestimate the trans-ionospheric propagation by about 20 dB (Starks et al., JGR 2008).**



From Cohen, Lehtinen, and Inan, GRL 2012: model agrees reasonably well with Demeter data.

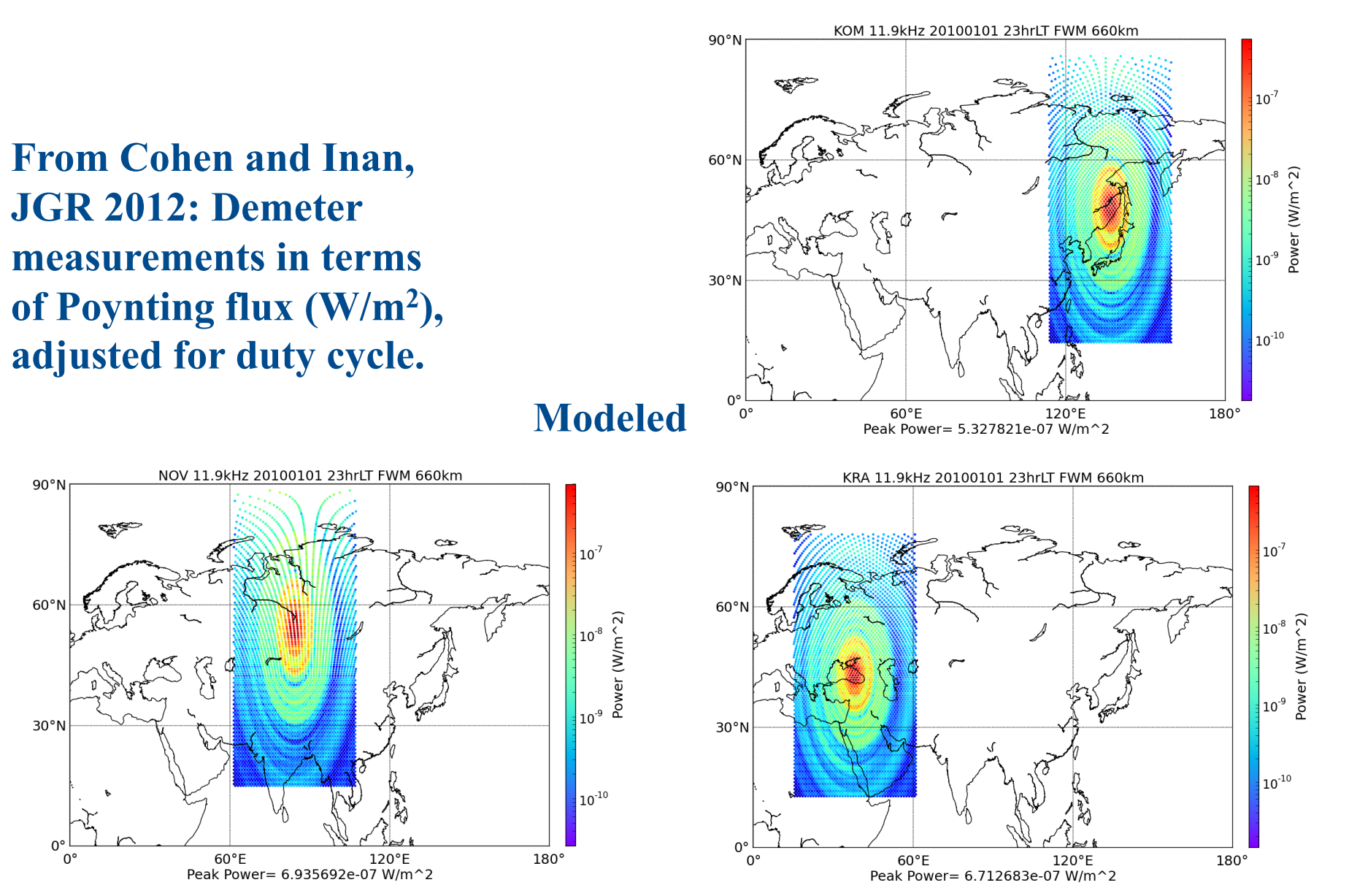
We've recently re-run the full-wave code for the Alpha transmitters, with similar results at Demeter altitude.

(Power at the source taken as 20 kW, not 500 kW as often quoted)

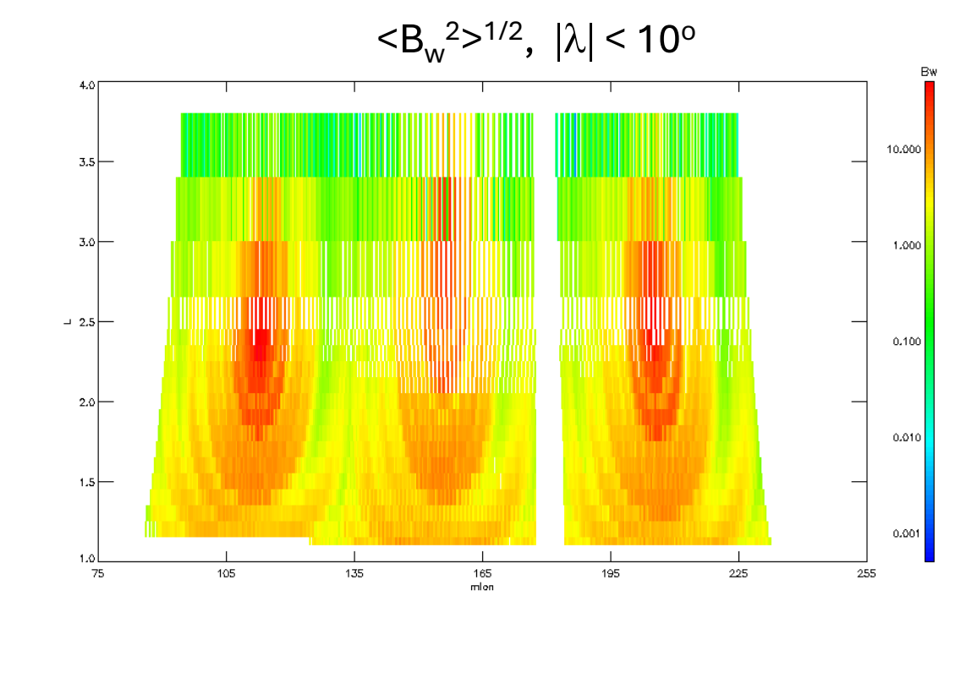


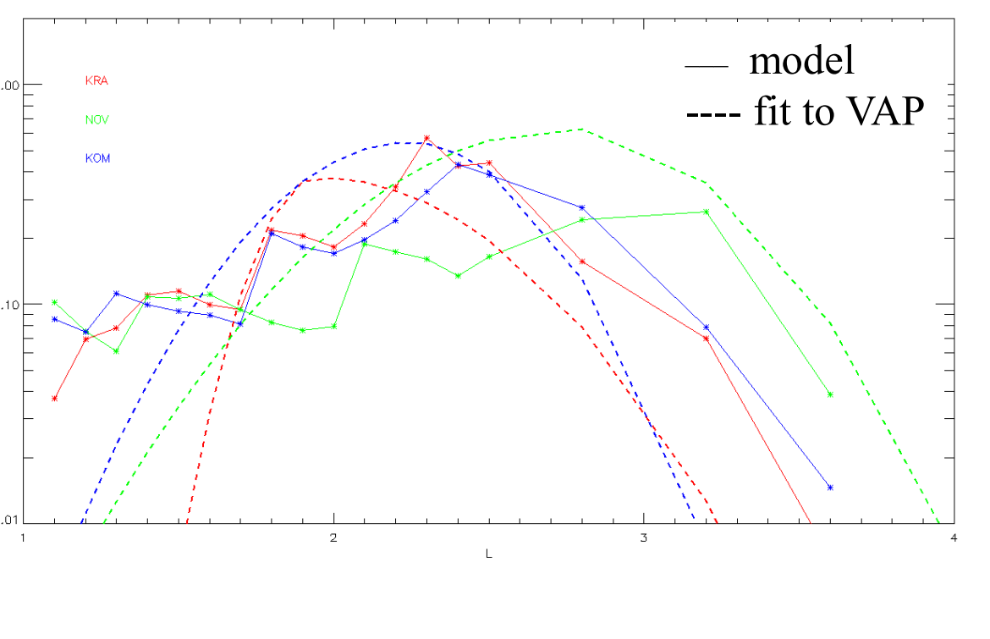
From Cohen and Inan, JGR 2012: Demeter measurements in terms of Poynting flux (W/m^2), adjusted for duty cycle.

Modeled



These values were used to drive our 3D ray-and-power tracer. Peak model results (high-den, nondducted, MLT-averaged) are comparable to EMFISIS measurements near the equator.





Next:

Find optimal mix of ducted/nonducted wave propagation

Assess implications for 20 kHz transmitters

Recompute diffusion coefficients

Reconsider electron lifetimes, PA and energy distributions