USE OF THE SWARM IONOSPHERIC GRADIENT PRODUCT TO MODEL SCINTILLATION AT HIGH LATITUDES

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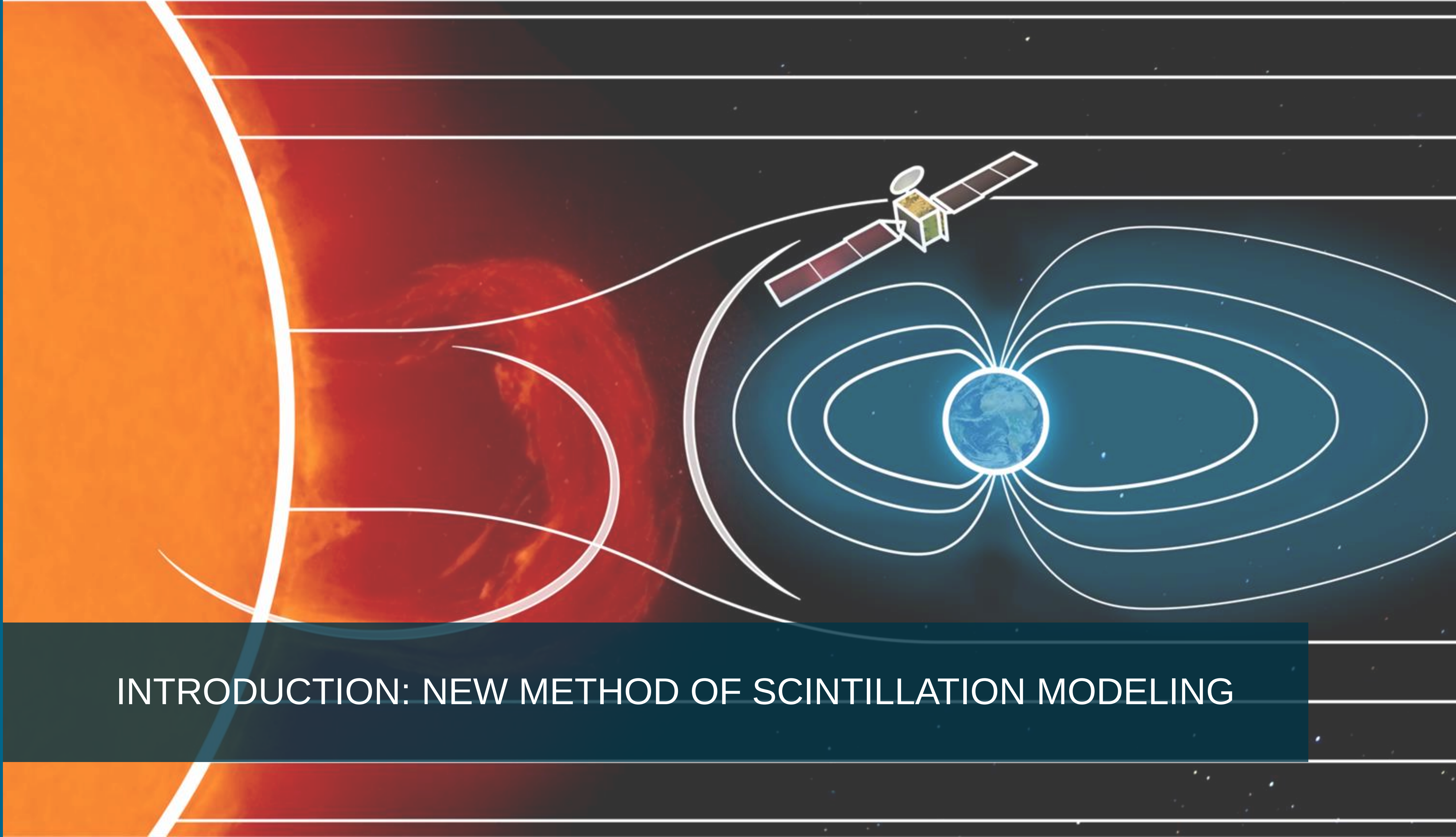
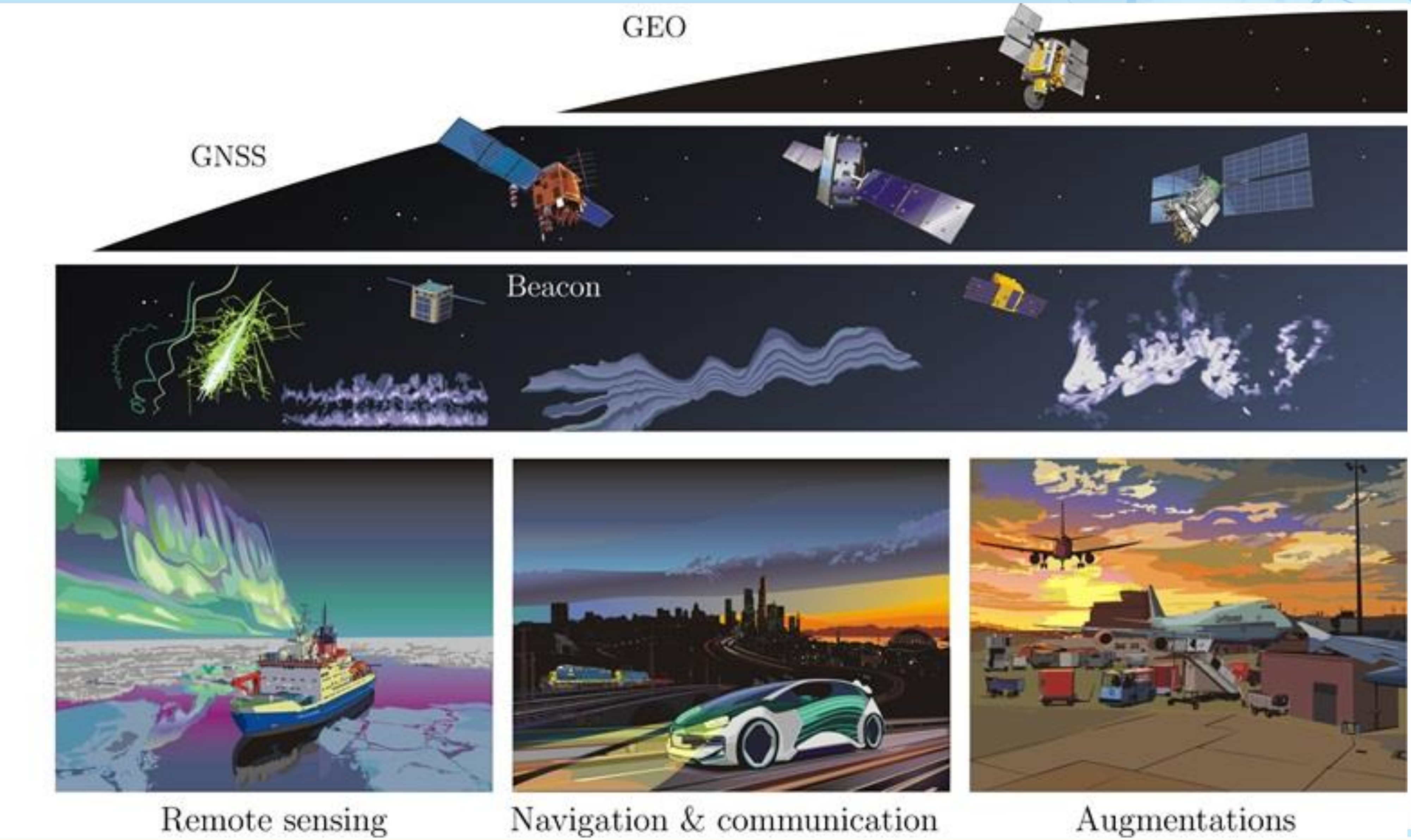


INTRODUCTION: NEW METHOD OF SCINTILLATION MODELING

Ionospheric irregularities



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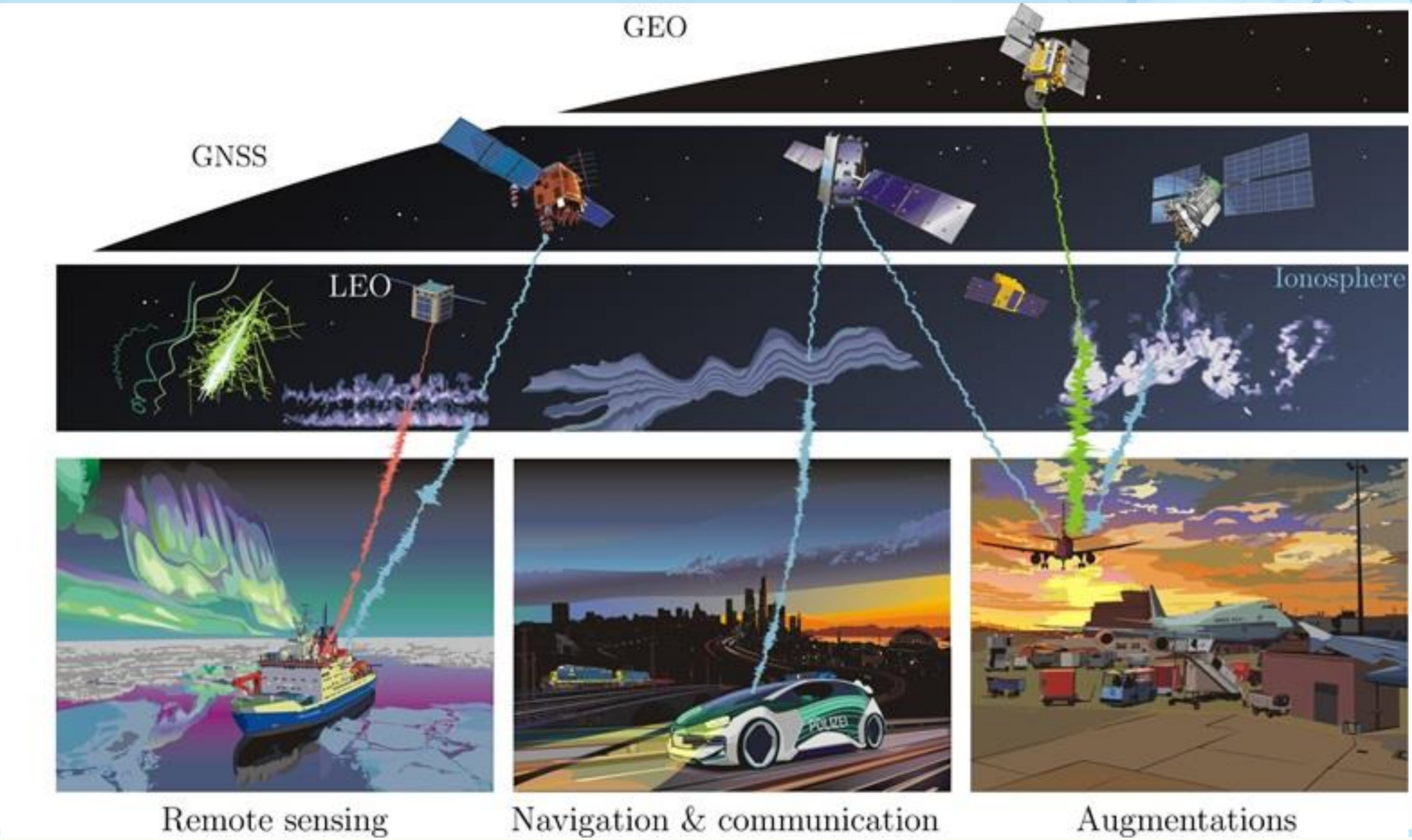
Ionospheric scintillation



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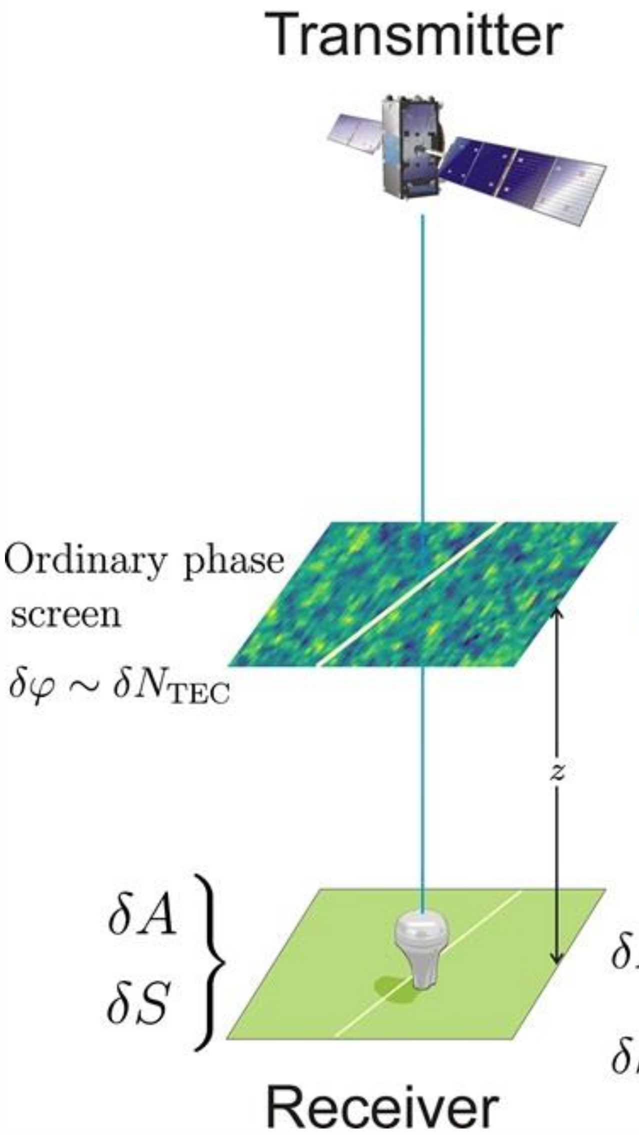
Phase screen model for estimation of scintillation strength



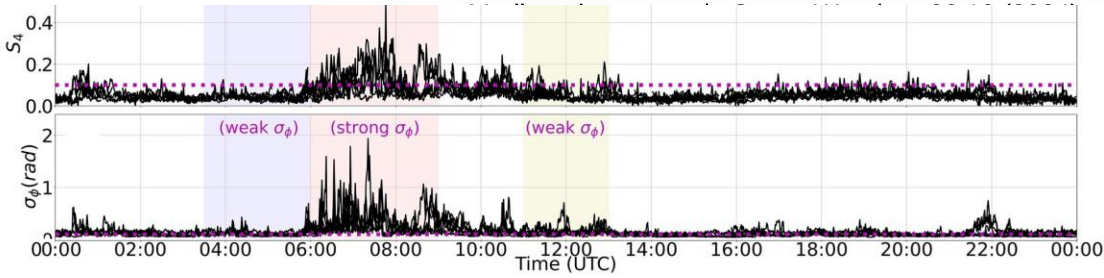
SCINTILLATION INDICES:

- Amplitude fluctuations δA:

$$S_4^2 = \frac{\langle|\delta A(0)|^4\rangle - \langle|\delta A(0)|^2\rangle^2}{\langle|\delta A(0)|^2\rangle^2}$$

- Phase fluctuations δS:

$$\sigma_{\delta S} = \sqrt{\langle \delta S(0)^2 \rangle}$$



Phase screen realization:

$$\delta\varphi(\boldsymbol{r}_\perp) = -r_e\lambda \int \delta N_e(\boldsymbol{r})\mathrm{d}z = -r_e\lambda\ \delta N_{\mathrm{TEC}}(\boldsymbol{r}_\perp)$$

Statistical properties of the screen are related to those of the electron density fluctuations.

C. Rino, Radio Sci., 14, 6 (1979)

Fresnel filtering

$$\delta A = \frac{ik}{2\pi z}\int A_0(\boldsymbol{r}'_\perp)\left(e^{-i\delta\varphi(\boldsymbol{r}'_\perp)} - 1\right)\underbrace{e^{-i\frac{k}{2z}|\boldsymbol{r}_\perp - \boldsymbol{r}'_\perp|^2}}_{\text{Fresnel filtering}}\mathrm{d}^2\boldsymbol{r}'_\perp$$

$$\delta S \approx \delta\varphi$$

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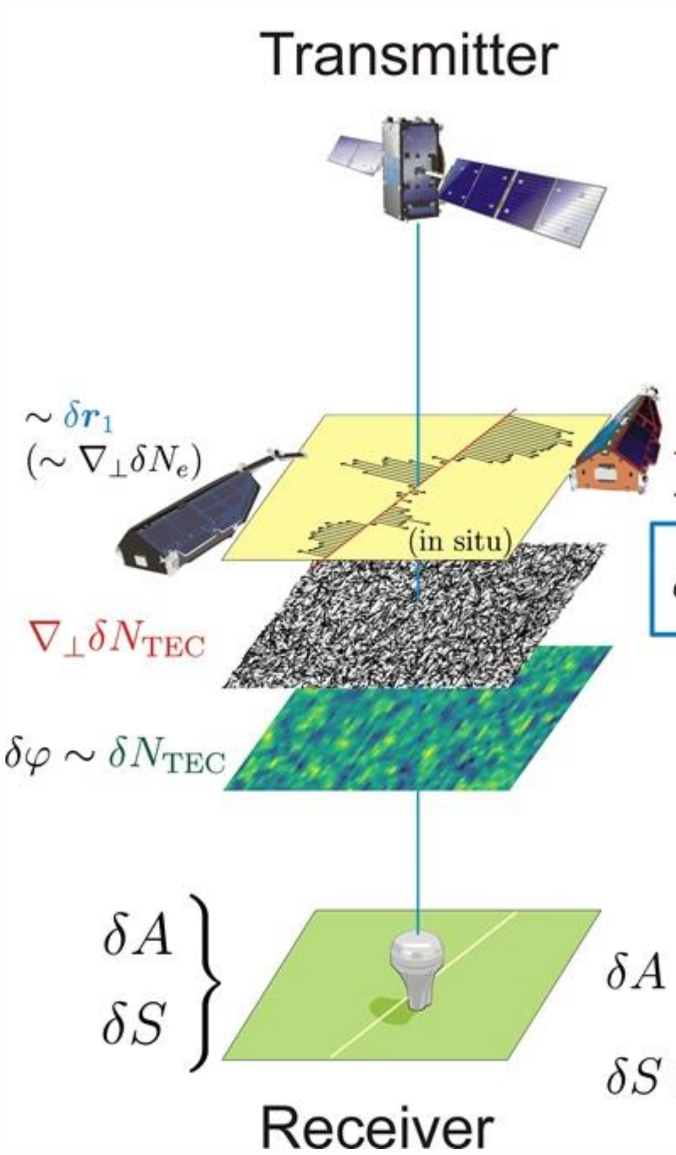
Phase screen model for estimation of scintillation strength



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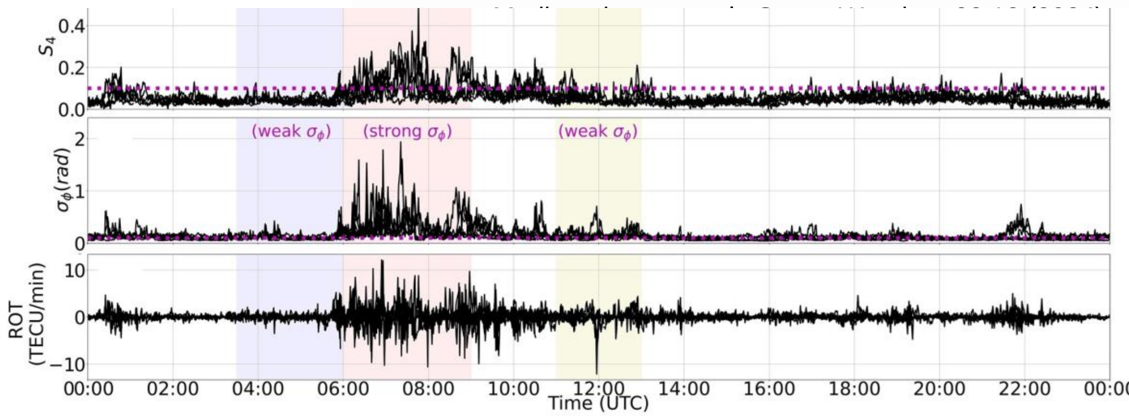

Phase gradient screen realization:

$$\delta\varphi(\boldsymbol{r}_\perp) = -r_e\lambda\, \delta N_{\rm TEC} + r_e\lambda\, \delta\boldsymbol{r}_1 \cdot \nabla_\perp \delta N_{\rm TEC}$$

Statistical properties of the screen are related to those of the electron density fluctuations.

D. Vasylyev et al., JSWSC, 14, 29 (2024)

Fresnel filtering

$$\delta A = \frac{ik}{2\pi z}\int A_0(\boldsymbol{r}'_\perp)\left(e^{-i\delta\varphi(\boldsymbol{r}'_\perp)} - 1\right)\overbrace{e^{-i\frac{k}{2z}|\boldsymbol{r}_\perp - \boldsymbol{r}'_\perp|^2}}\mathrm{d}^2\boldsymbol{r}'_\perp$$

$$\delta S \approx \delta\varphi$$

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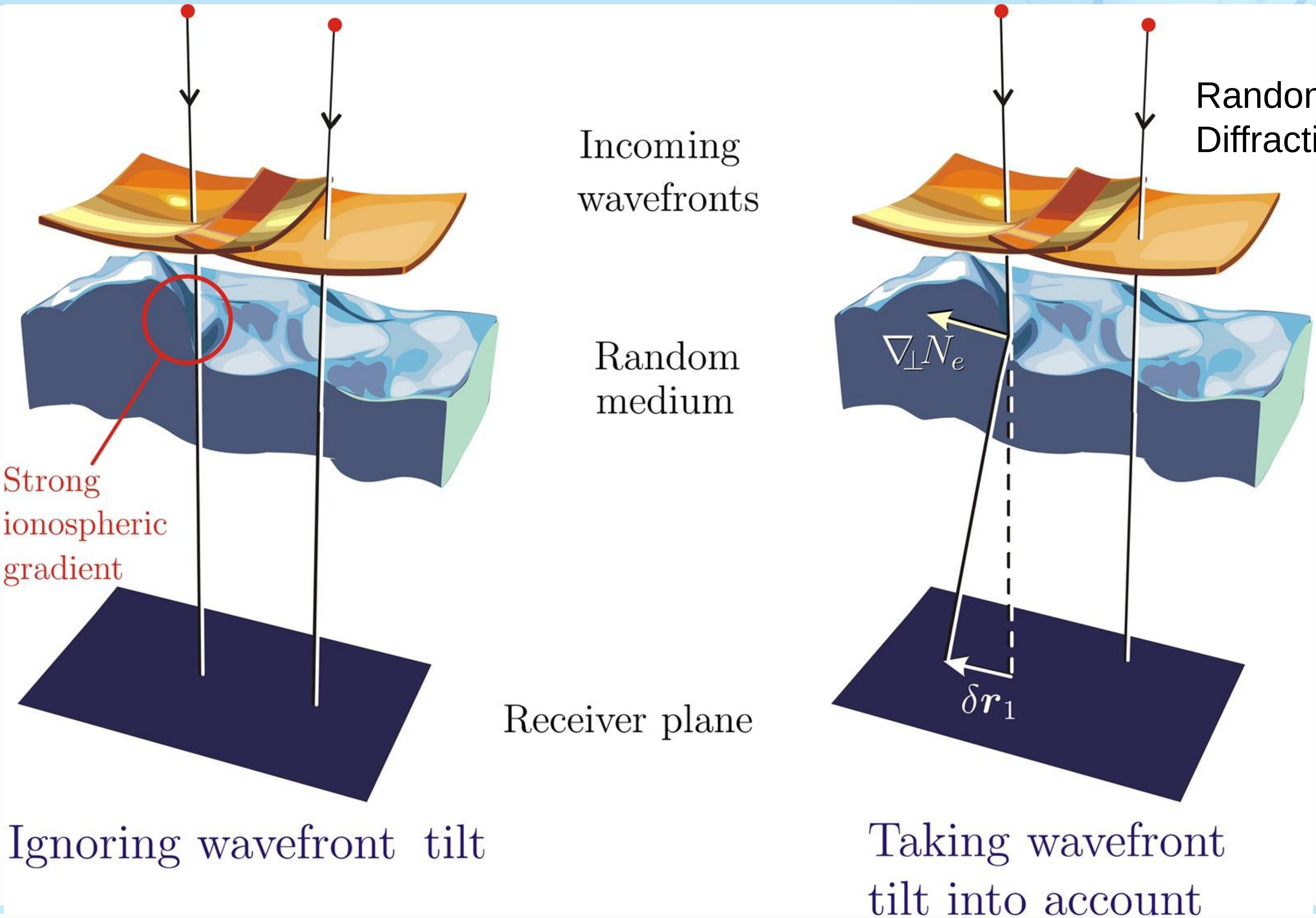
Physics behind the gradient dependent correction

Random Diffraction

Random Diffraction+Refraction



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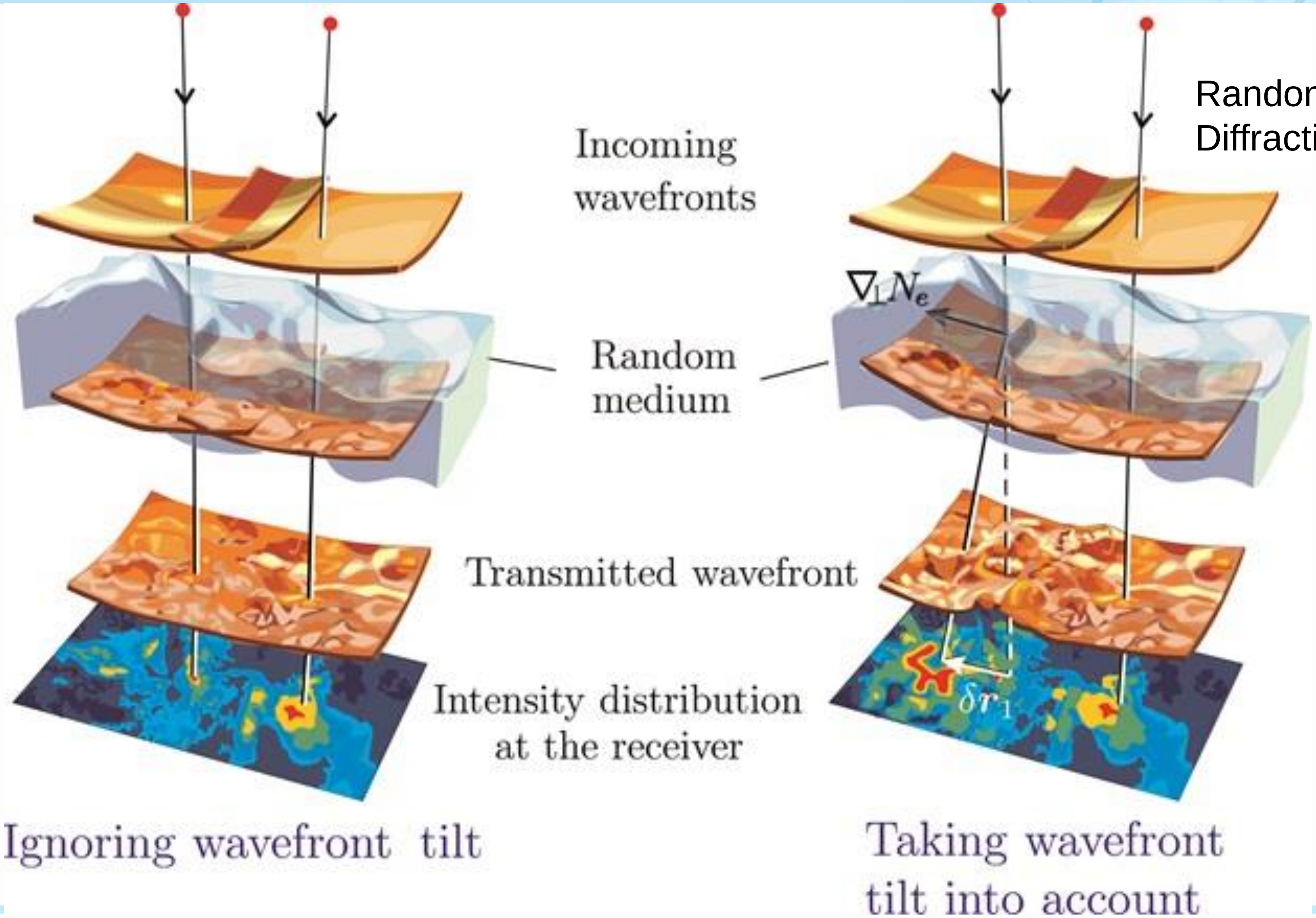
Physics behind the gradient dependent correction

Random Diffraction

Random Diffraction+Refraction



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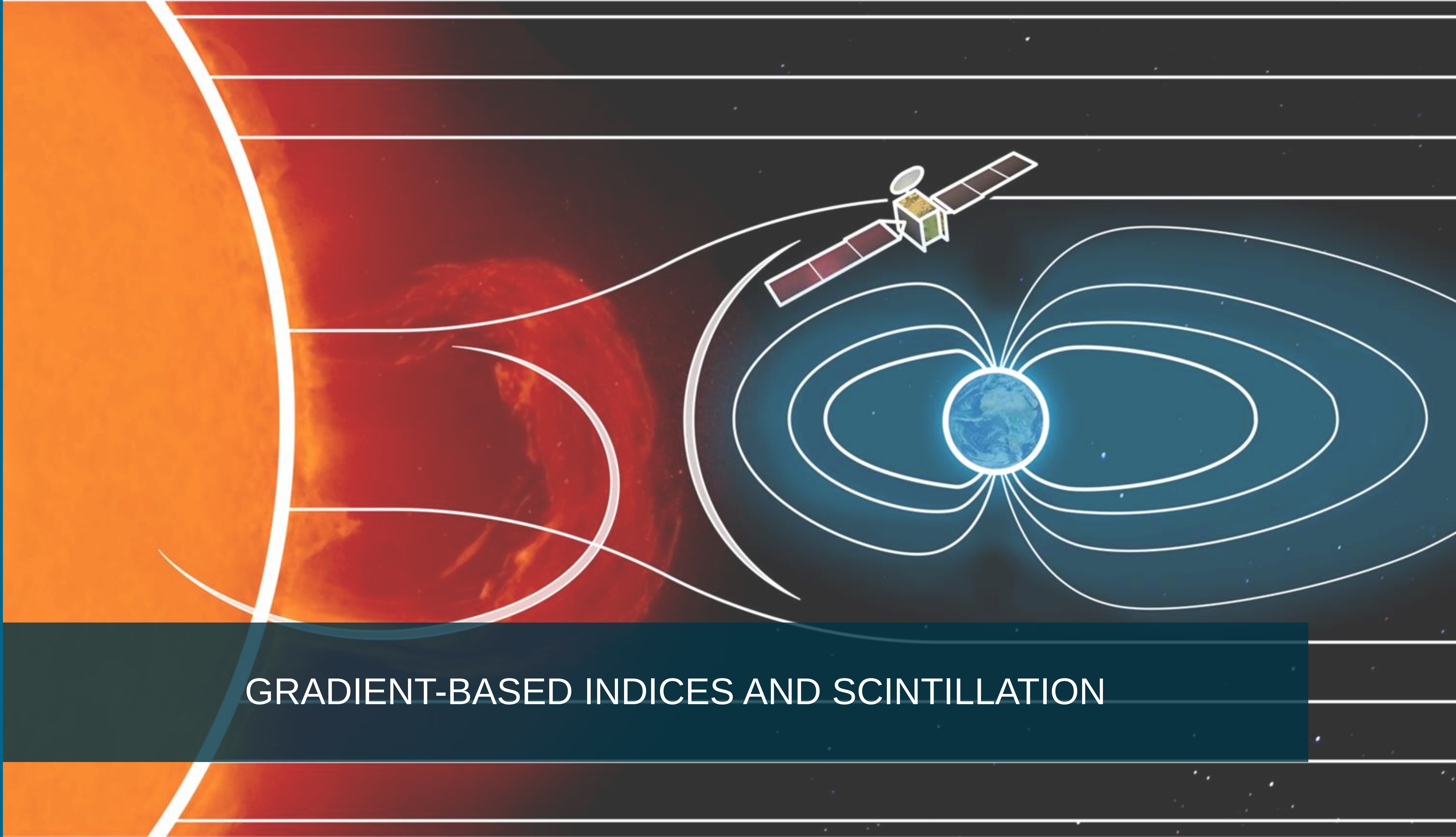


GRADIENT-BASED INDICES AND SCINTILLATION

1st component: Total Electron Content gradient (related to ROTI)

Pi et al., Geophys. Rev. Lett. 24, 2283 (1997)

$$ROTI = \sqrt{\frac{\sum_i^n (ROT_i)^2}{n} - \left(\frac{\sum_i^n ROT_i}{n}\right)^2}$$

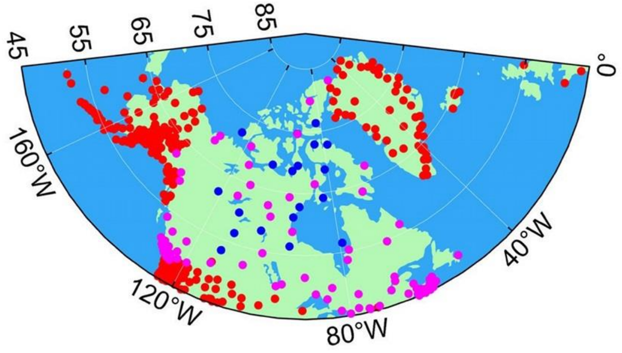
$$ROT_i \equiv \frac{TEC\left(t+(i-n/2)\delta t\right) - TEC\left(t+(i-n/2-1)\delta t\right)}{\delta t}$$

TEC gradient derived from ROTI:

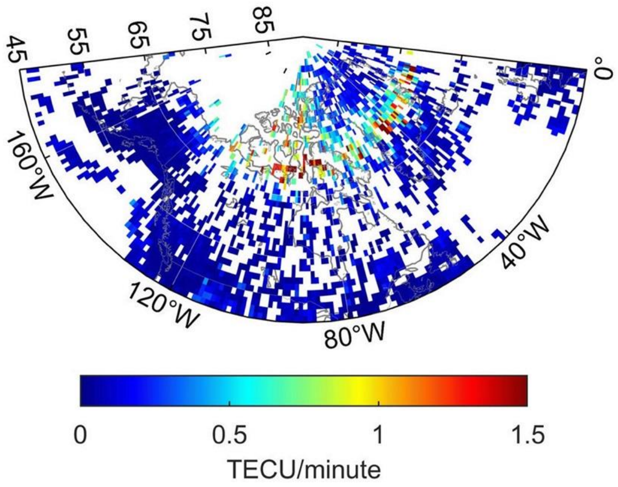
$$\nabla TEC = \frac{\overline{\boldsymbol{V}_{drift}}}{\overline{(V_{drift})}^2} ROTI,$$

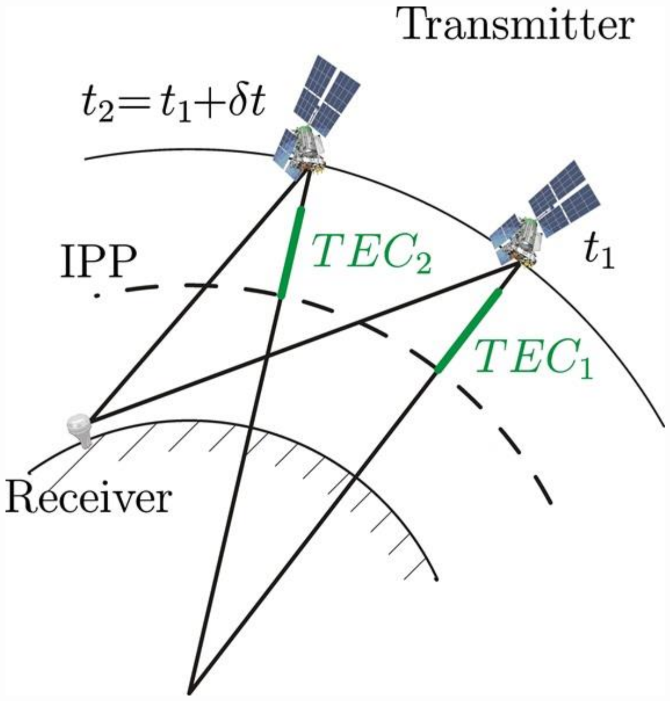
where $\overline{\boldsymbol{V}_{drift}}$ is the plasma drift velocity averaged over the time $n\delta t$.

L.Liu, Y. Morton, Y. Liu, Geophys. Res. Lett. (2021)

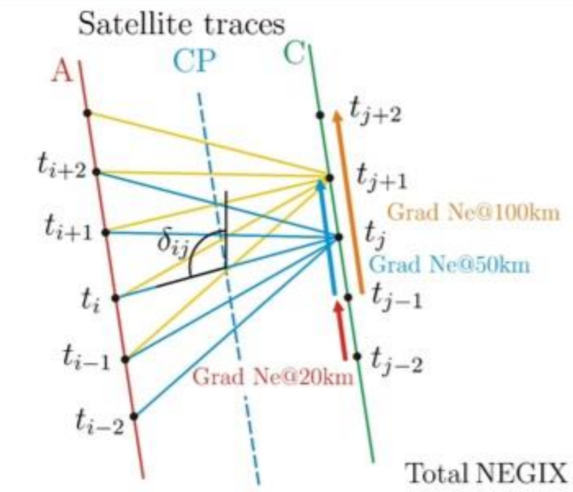


Global navigation satellite system stations





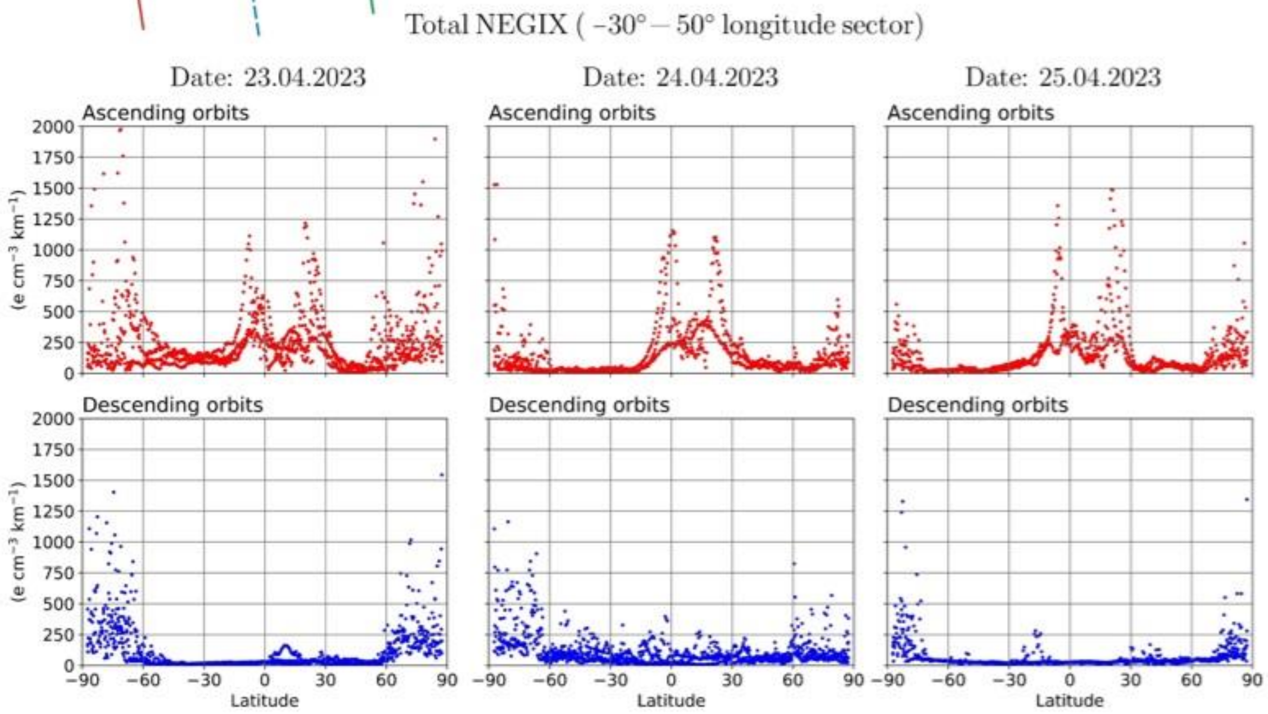
2nd component: Electron density gradient index NeGIX (SWARM)



$$\langle \nabla Ne_x \rangle = \frac{1}{N_D} \sum^{N_D} \nabla Ne_{ij} \sin \delta_{ij} \quad = NeGIX_x$$

$$\langle \nabla Ne_y \rangle = \frac{1}{N_D} \sum^{N_D} \nabla Ne_{ij} \cos \delta_{ij} \quad = NeGIX_x$$

$$\text{NeGIX} = \sqrt{\langle \nabla Ne_x \rangle^2 + \langle \nabla Ne_y \rangle^2}$$



Project:

Monitoring of Ionospheric Gradients At Swarm (MIGRAS)

J. A. Cahuasqui, et al., *"New Swarm products NeGIX and TEGIX for monitoring ionospheric gradients",* submitted to JSWSC

1st component: Model for TEC gradient/ROTI

EOF model by Y. Jin et al., Space Weather (2023)

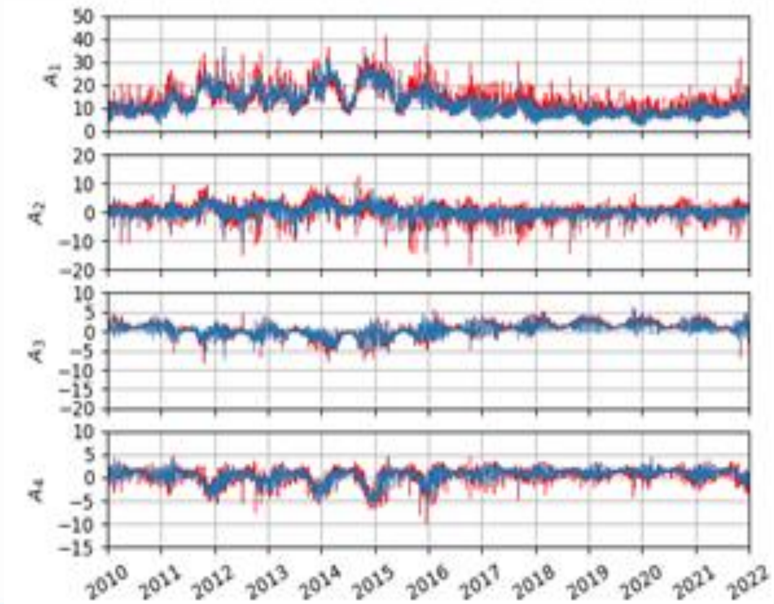
Geophysical parameters: $F_{10.7}, K_p, IMF, \ldots$

$$ROTI = \sum_i^4 \text{coefficients}_i \cdot \text{functions}_i$$

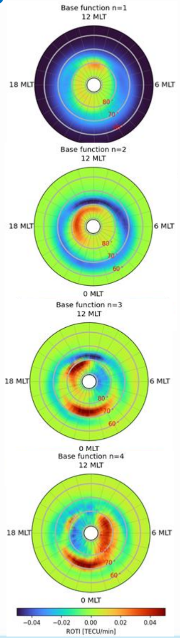
(red:truth
blue:model)

coefficients

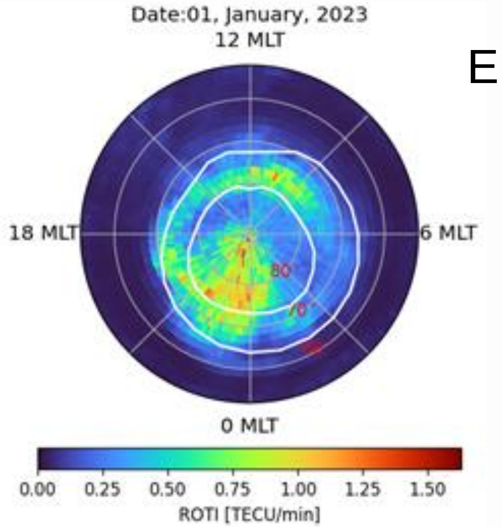
orthogonal functions



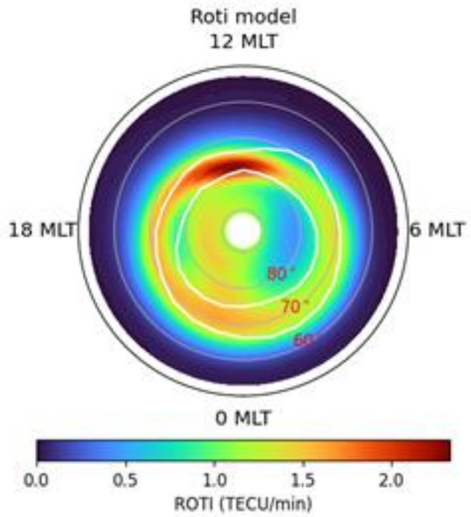
x +
x +
x +
x



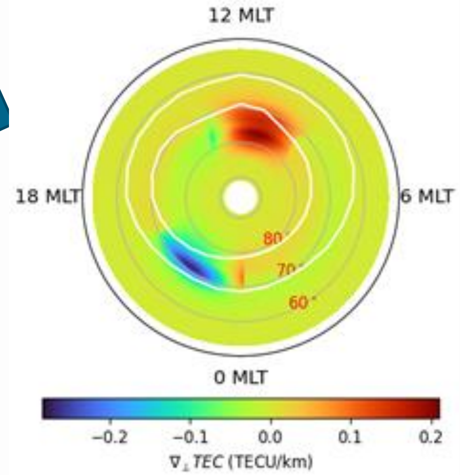
Empirical ROTI



Model ROTI



Gradient TEC
E-W component



2nd component: Model for SWARM NeGIX

Geophysical parameters: $F_{10.7}, K_p, IMF, \ldots$

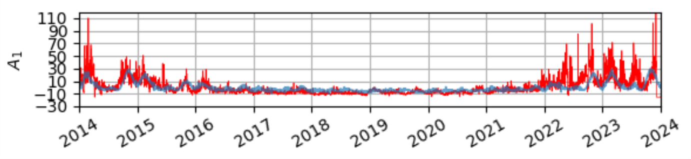
$$NeGIX = \text{coefficient} \cdot \text{function}$$

Negative component of NeGIX_x

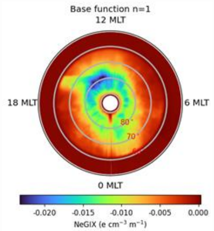
(red:truth, blue:model)

coefficient

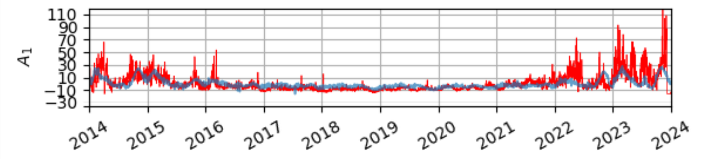
orthogonal function



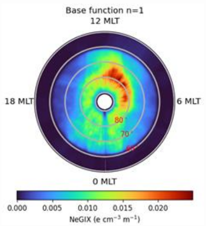
x

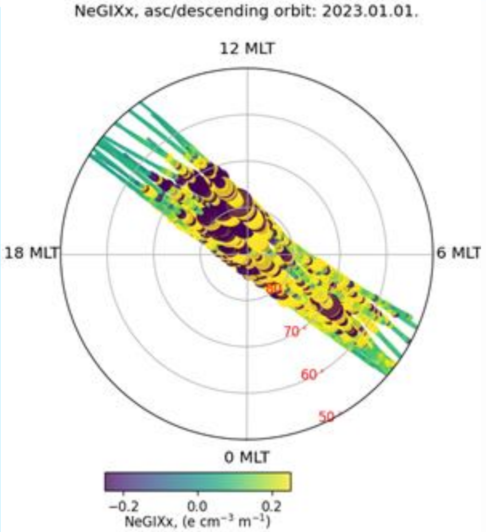


Positive component of NeGIX_x



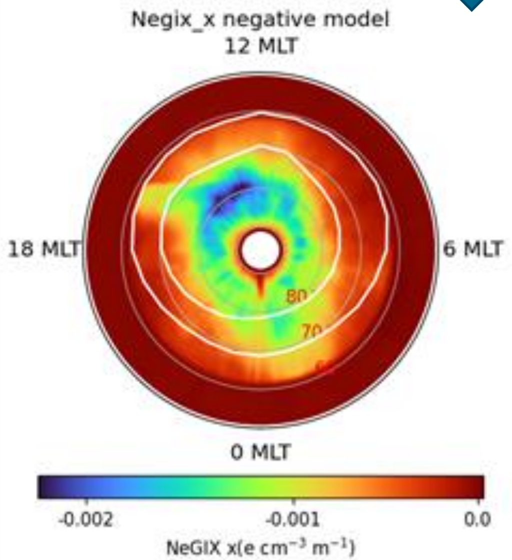
x

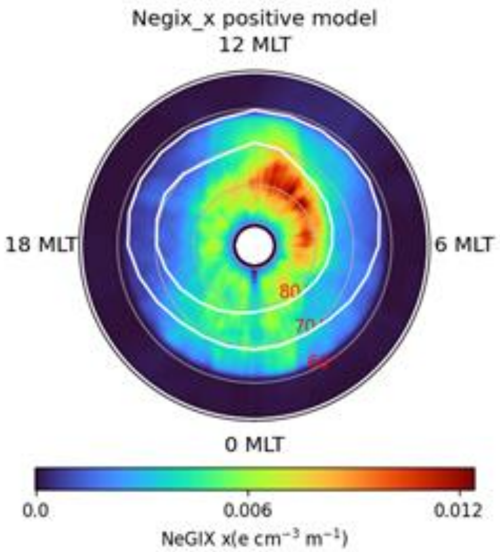




Empirical NeGIX_x
(East-West component of gradient)

Model NeGIX_x
(negative & positive components)





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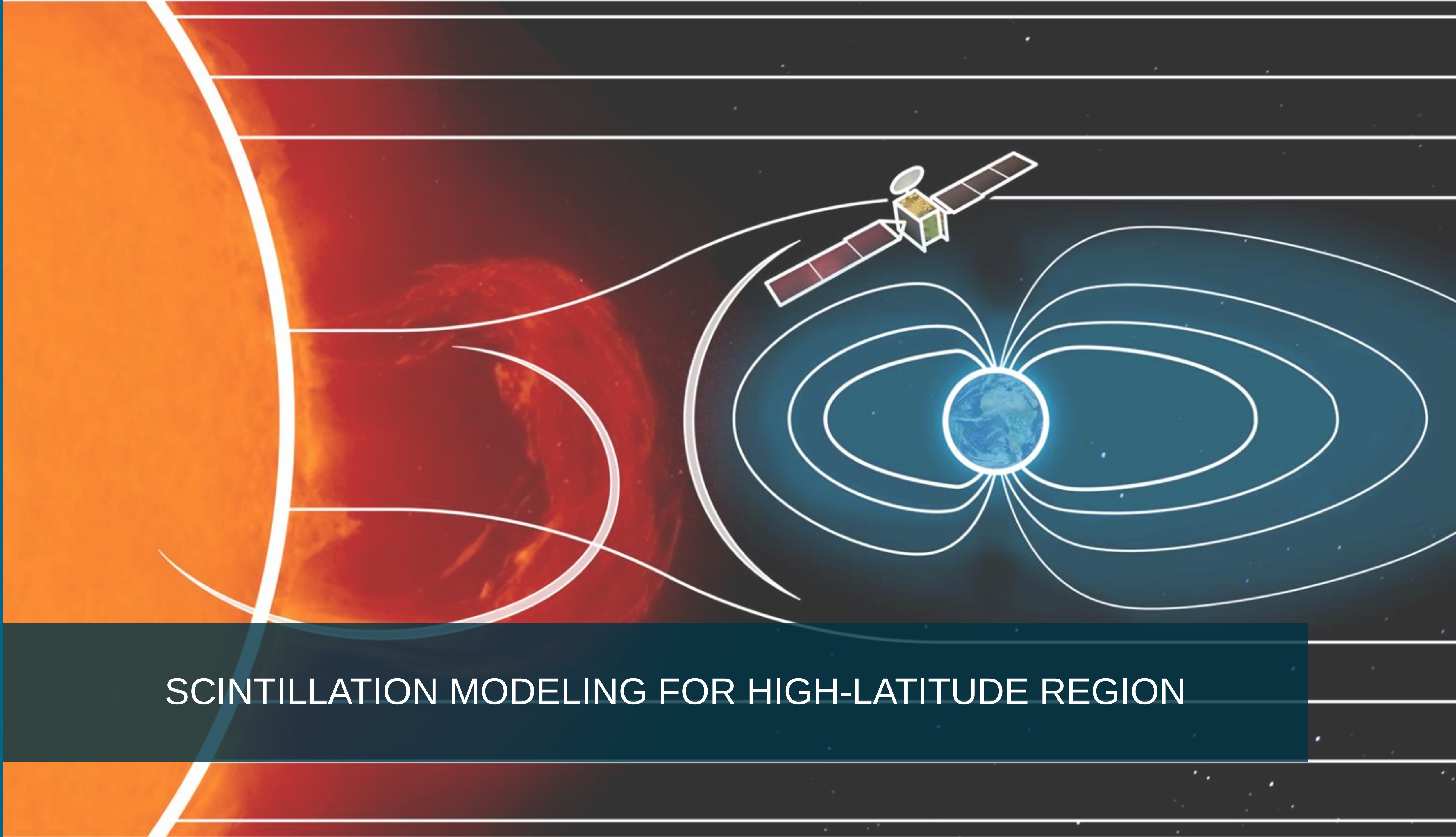
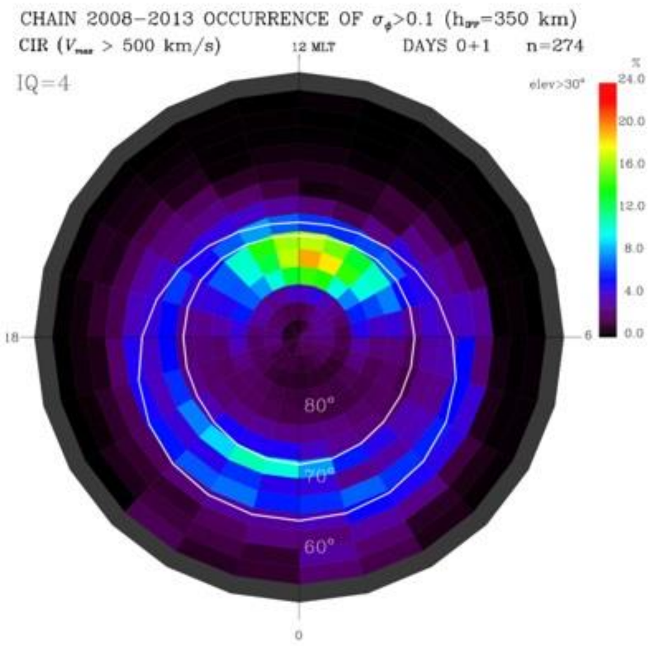


SCINTILLATION MODELING FOR HIGH-LATITUDE REGION

High-latitude scintillation model for GISM

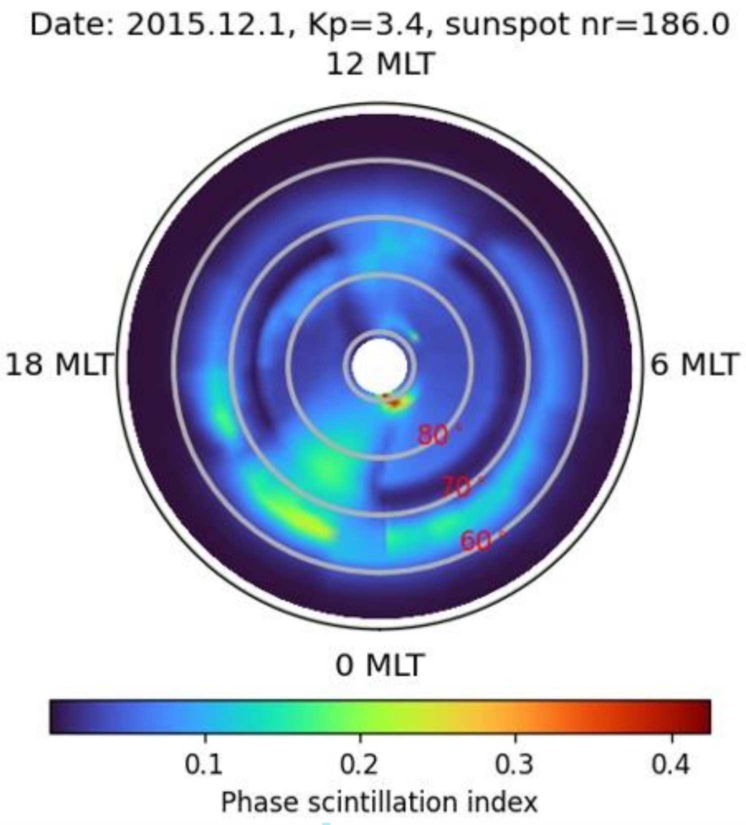
Empirical probability of occurrence of $\sigma_\varphi > 0.1$



Prikryl et al., Ann. Geophys. 33, 531 (2015)

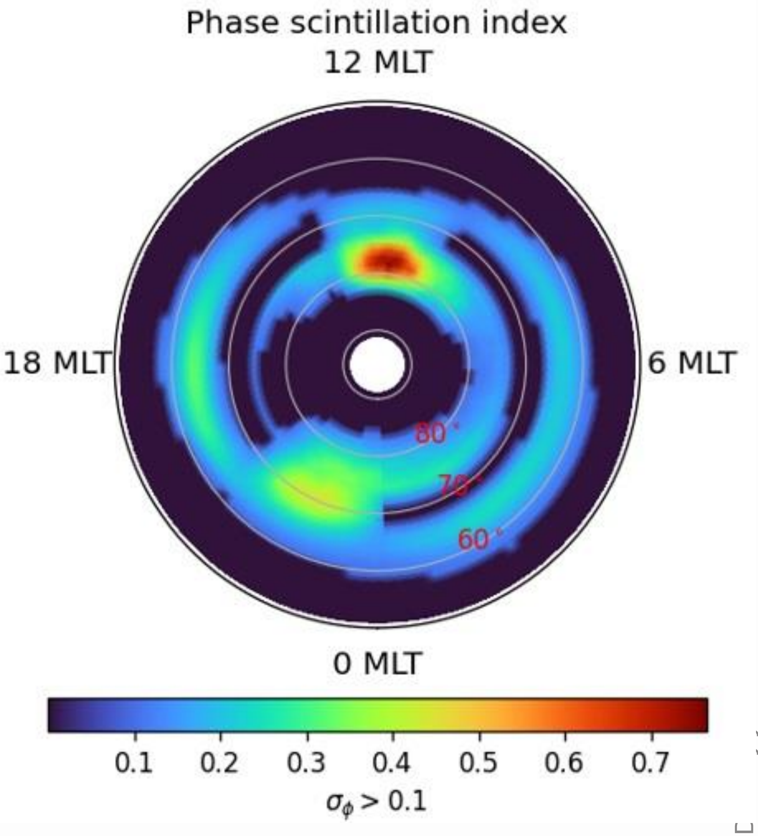
Example of scintillation map realisation with $\sigma_\varphi > 0.1$

WBMOD



Diffractive scintillation

GISM

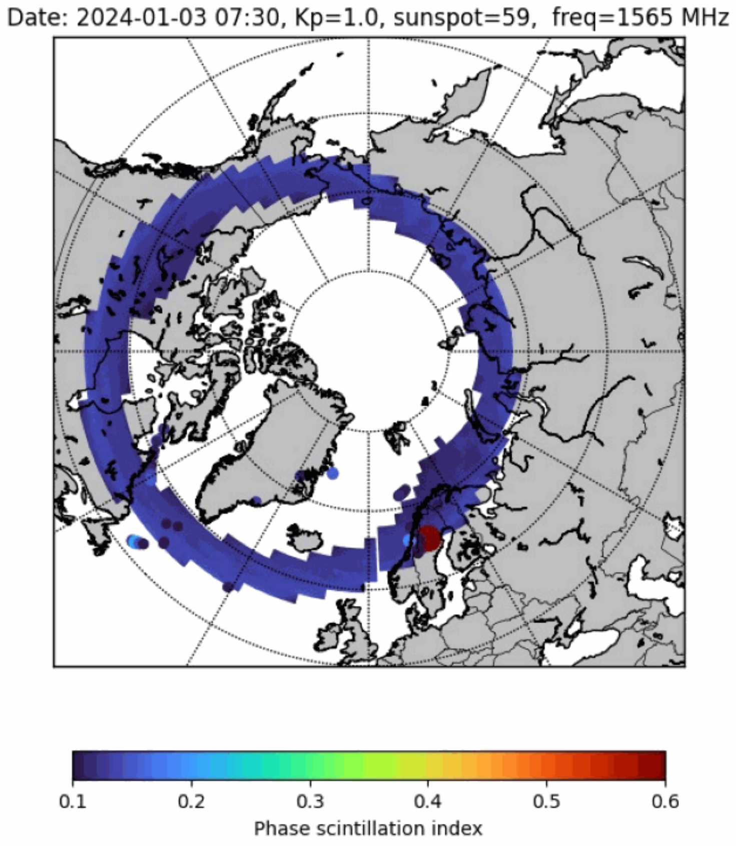


Diffractive+ refractive scintillation

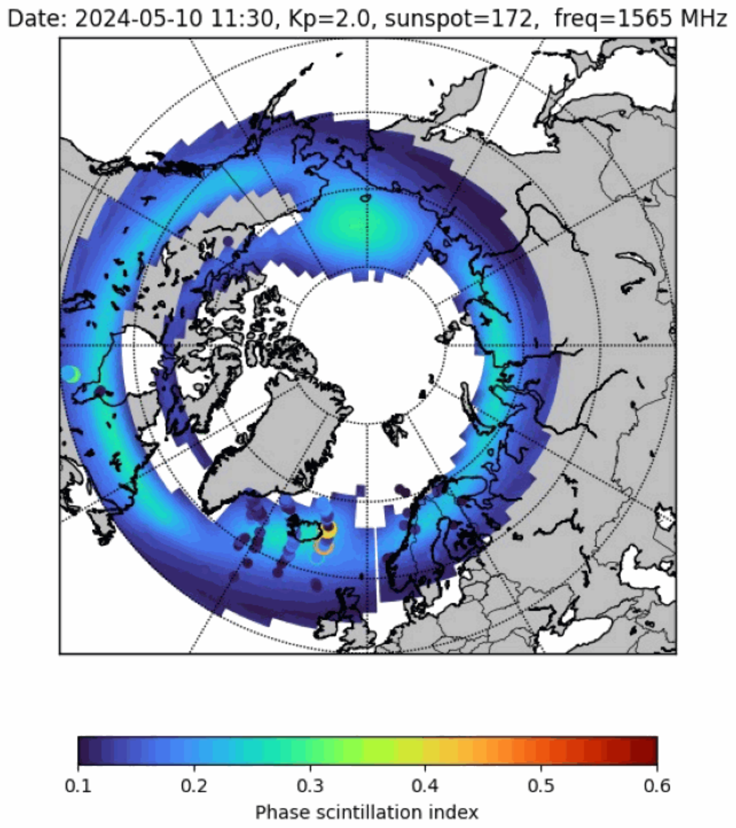
High-latitude scintillation model for GISM

Empirical scintillation from CHAIN and DLR stations: points
Current model: colored area

Quite geomagnetic conditions



Disturbed geomagnetic conditions



Conclusions and outlook

- Strong ionospheric gradients may cause intense refractive scintillation (primarily phase scintillation)
- Phase gradient screen approach is bale to incorporate such type of scintillation
- Electron density gradients derived from SWARM (NeGIX) productsalong with ROTI are valuable input for scintillation modeling
- Climatological model for NeGIX has been constructed by using empirical orthogonal function in similar footing as it was done for ROTI
- The resulting high-latitude scintillation model is capable to explain the enchanced scintillation activity at magnetic noon sector.

SWARM DISC

DLR SWEET

project