UNIVERSITY OF CALGARY

Energetic Particles Precipitation Model

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Acknowledgments:

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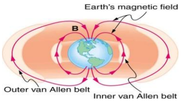
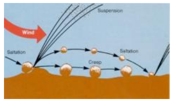
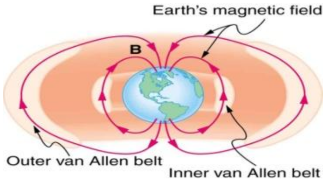
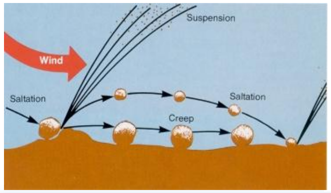
Model’s Main Components:

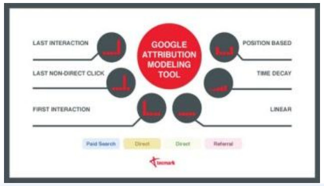



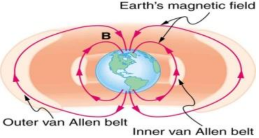
Sources of Atmospheric Ionization Caused by Energetic Charged Particles



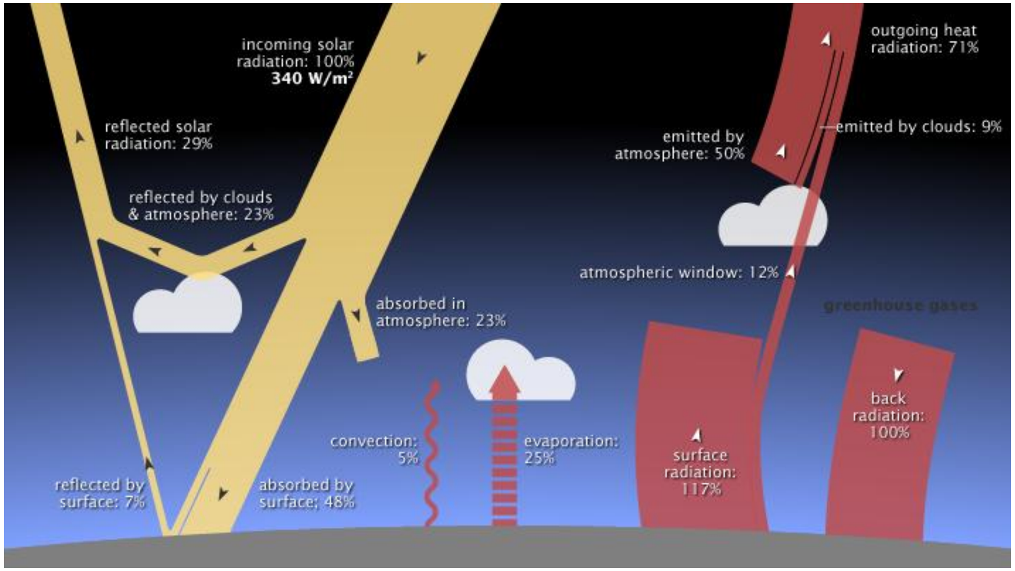
Charged Particles Transport in Earth Atmosphere



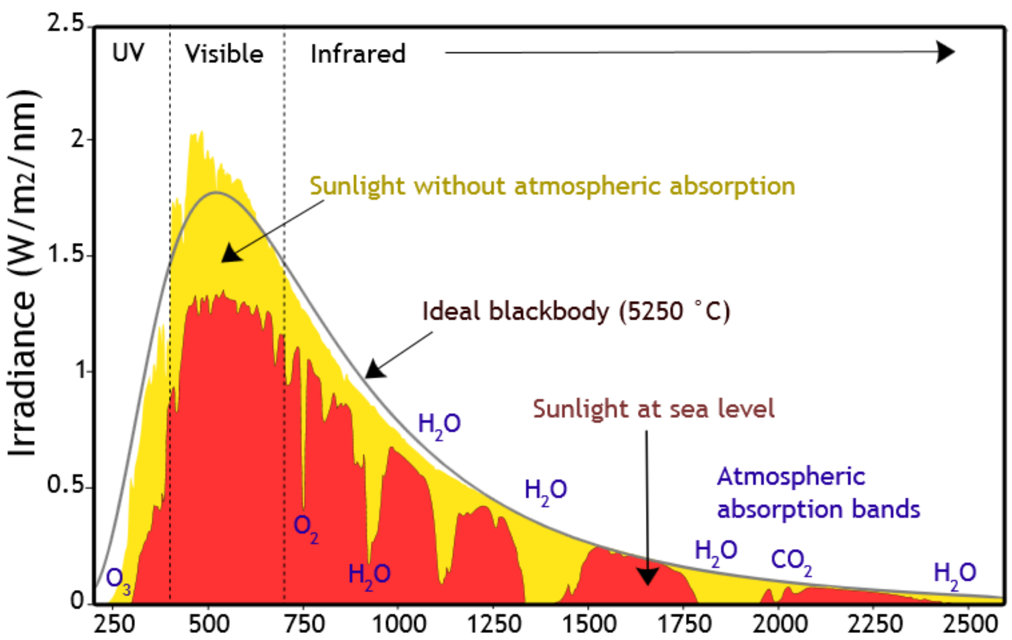
Modeling of Detector Responses



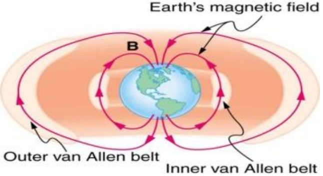
Atmosphere Energy Budget



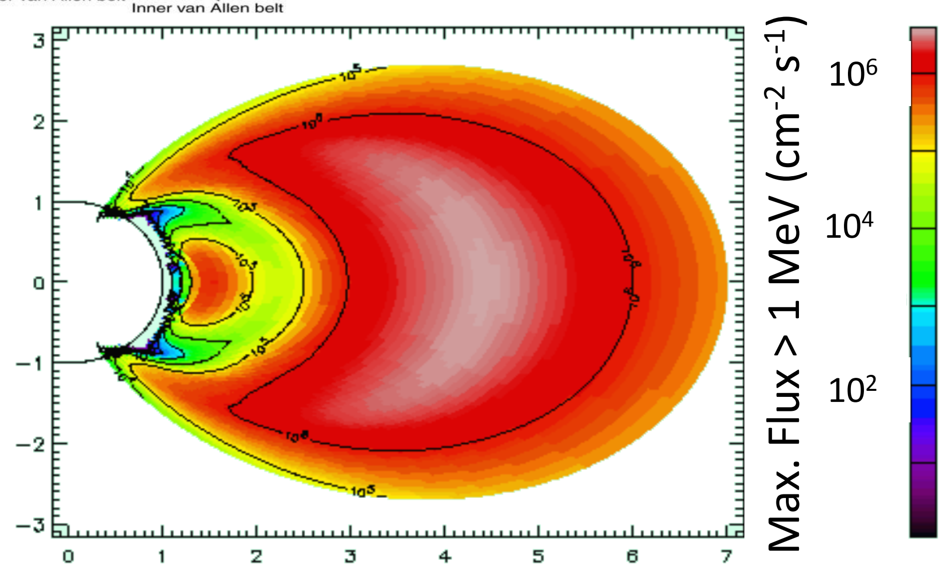
- The value of the **solar constant** (total radiative energy incident on a plane perpendicular to the rays, at distance 1 AU from the sun) ~**1373** W/m^2;
- **On average**, ~ **25%** arrives at the top of the atmosphere;
- Changes by about **0.1%** over the course of the solar cycle.



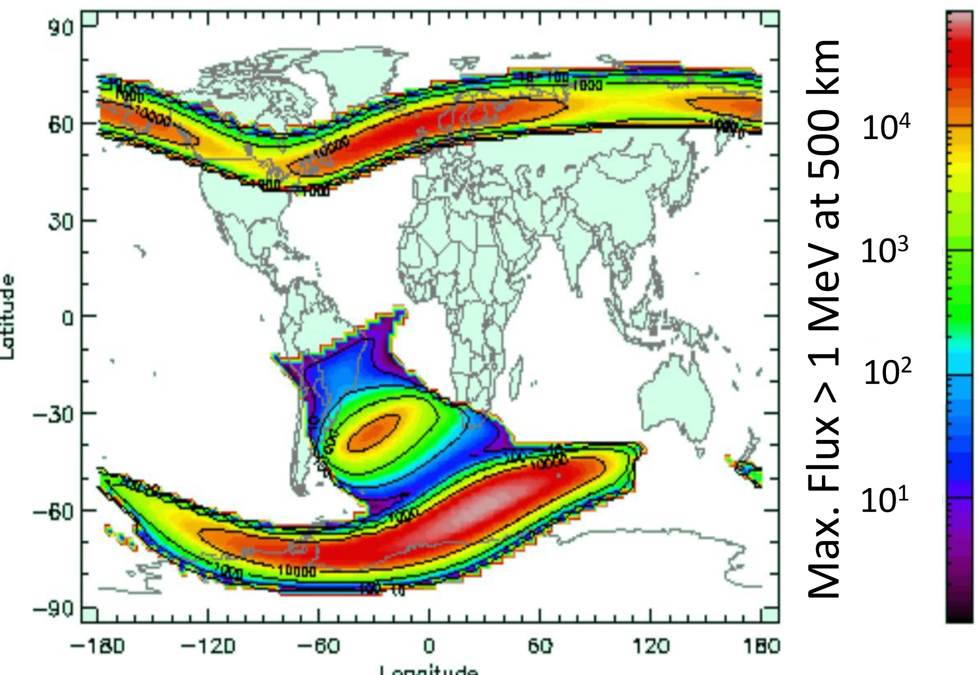
- **Lyman-alpha** (**121** nm), the **EUV strongest line**, causing **ionization** and governing the chemistry of the upper stratosphere and mesosphere;
- Its Ionization of "**NO**" is responsible for the formation of the ionospheric **D region**;
- Lyman alpha energy flux at solar minimum ~**3.8** mW/m^2;
- Its irradiance may varies by more than **50%**.



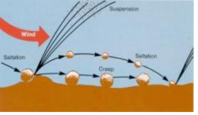
Van Allen Electron Radiation Belts



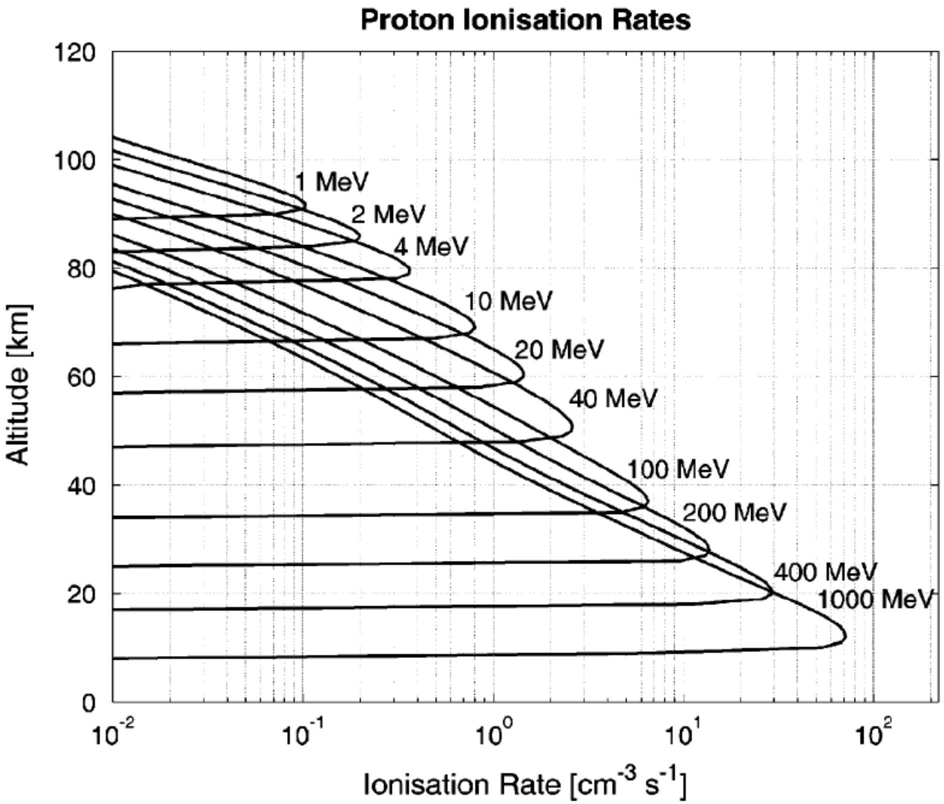
- Invariant coordinate map of the AE-8 MAX integral electron flux >1 MeV;
- Conservative figures indicate a maximum energy in trapped radiation of **6 x 10^{15}** Joules.
"Maximum Total Energy of the Van Allen Radiation Belt", Dessler, A. J.
- Energetic precipitation modulates the **NAM/SAM** modes which causes changes in the surface temperature over North America;



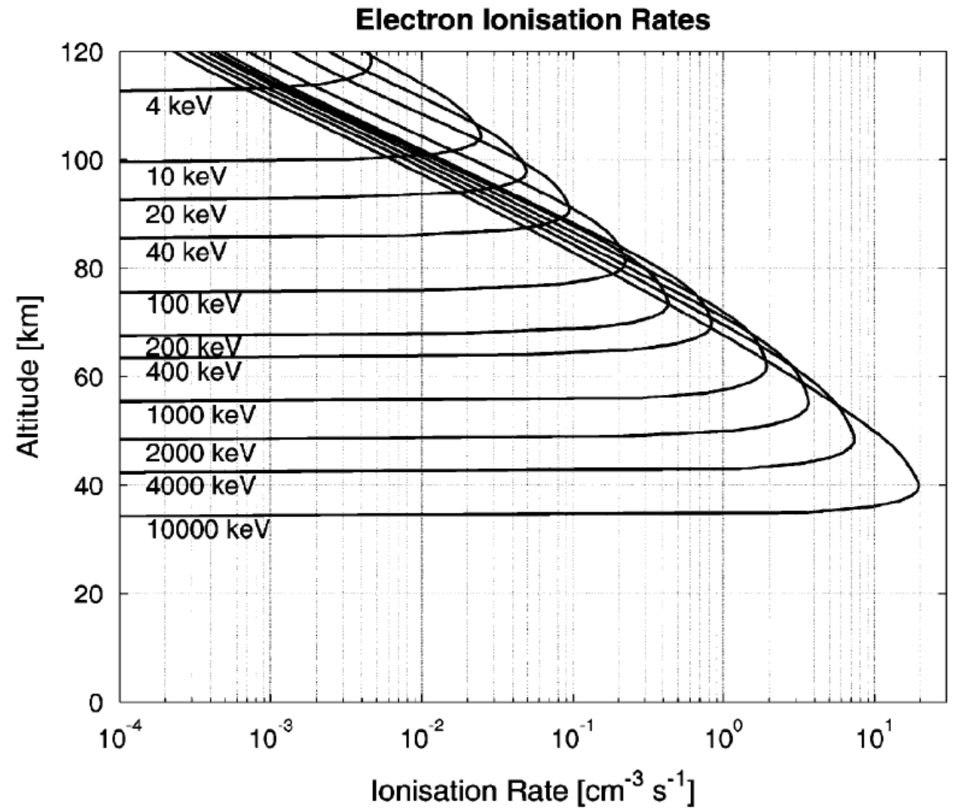
- World map of the AE-8 MAX integral electron flux >1 MeV at 500 km altitude;
- Energy flux from the flux of 10^5 1 MeV electrons/cm^2/sec ~**0.16** mW/m2;
- During geomagnetic storms the electron flux >1 MeV in the radiation belts can vary by up **to five orders of magnitude**;



Charged Particles Transport in Earth Upper Atmosphere

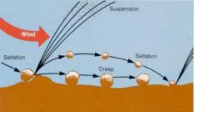


Altitude profiles of the ionization rate produced by monoenergetic beam of protons with initial energy, identified on each curve.
A flux of **1 proton cm^{-2} s^{-1} sr^{-1}** is assumed at every initial proton energy.

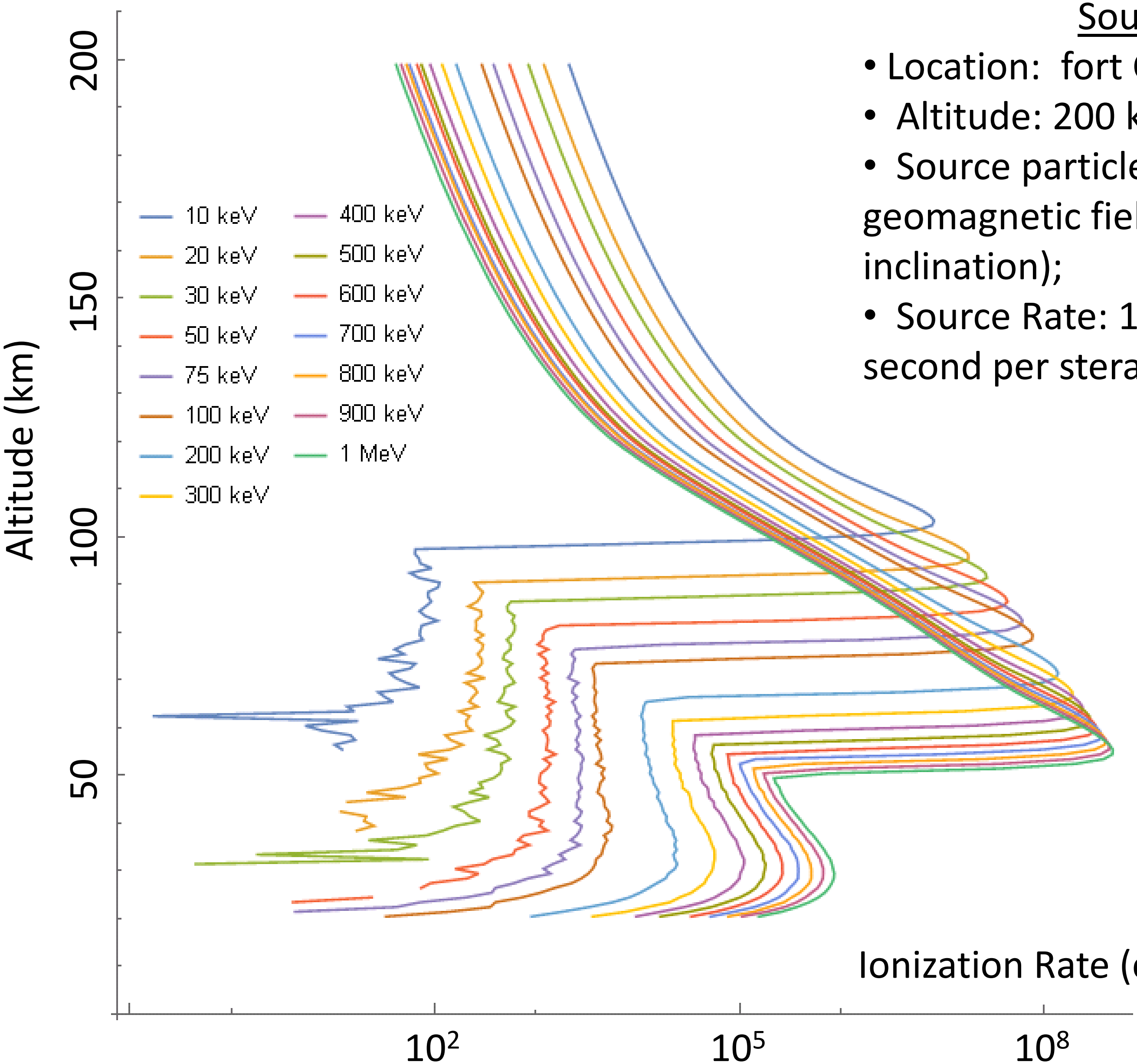


Altitude profiles of the ionization rate produced by monoenergetic beam of electrons with initial energy, identified on each curve.
A flux of **100 electrons cm^{-2} s^{-1} sr^{-1}** is assumed at every initial electron energy.

Impact of different energies of precipitating particles on NOx generation in the middle and upper atmosphere during geomagnetic storms; Esa Turunen at al. 2008

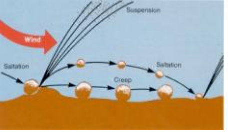


Electron Ionization Rates Energy Series

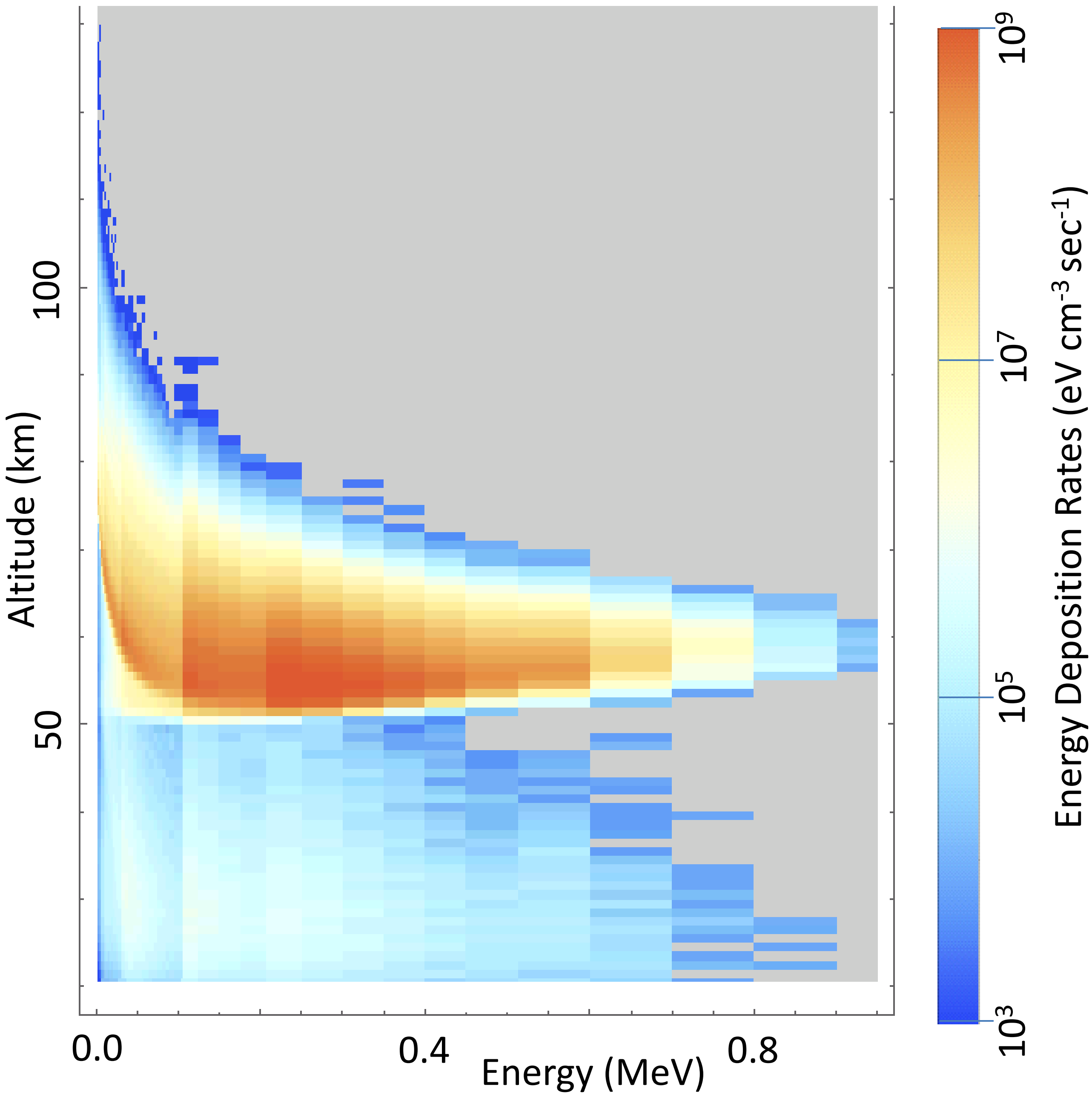


Source Parameters:

- Location: fort Churchill (58.75^{0}N, 94.9^{0}W);
- Altitude: 200 km;
- Source particles direction aligned with geomagnetic field line (~80^0 field inclination);
- Source Rate: 10^{10} electrons per cm^2 per second per steradian per MeV.

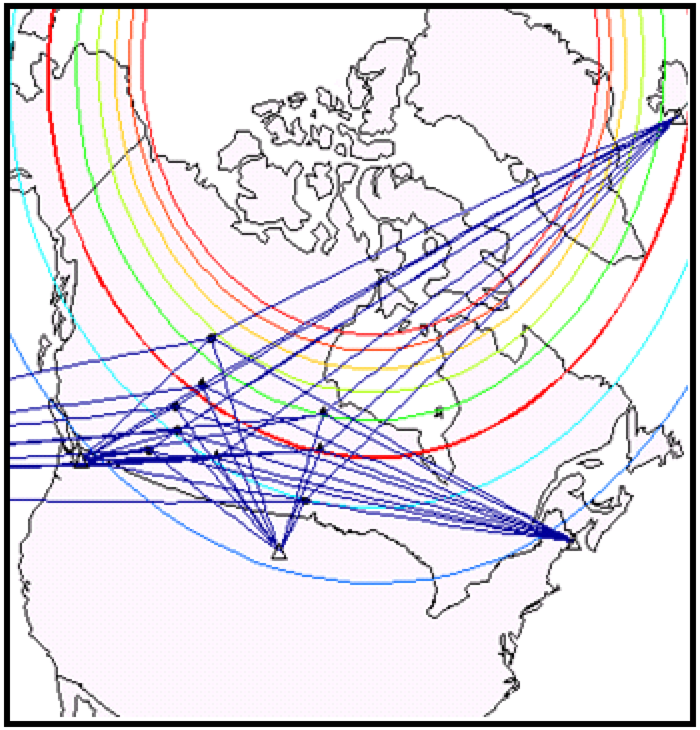


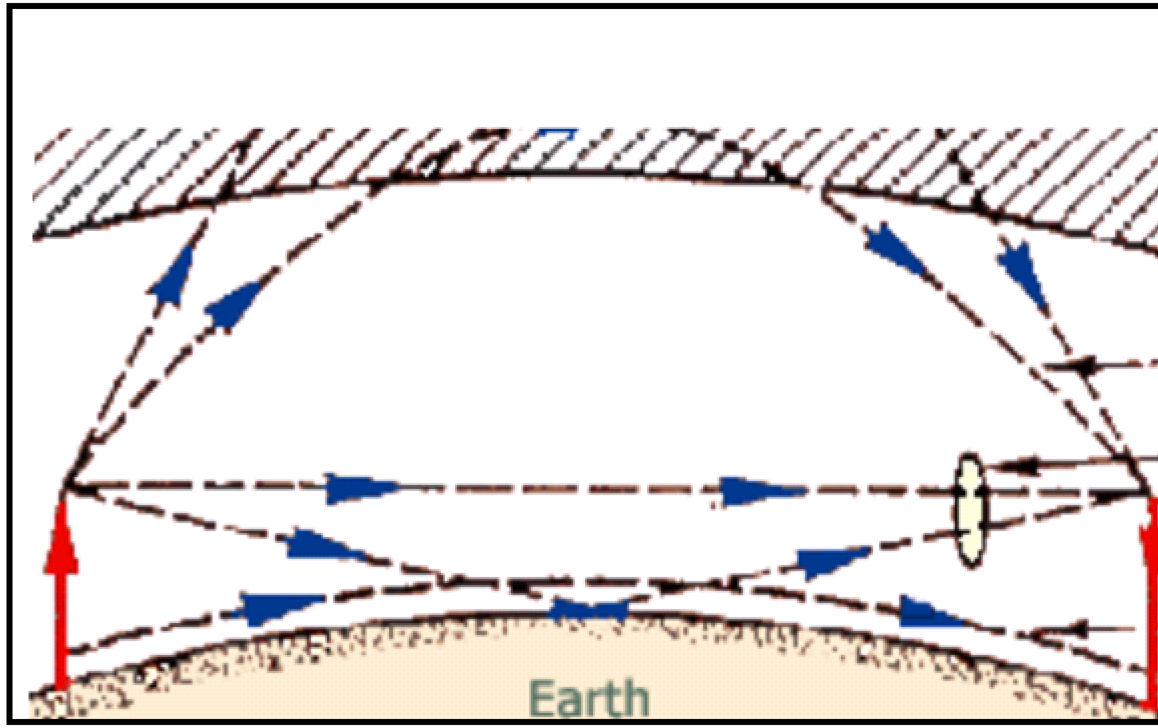
MCNP Calculations of Electron Energy Deposition Rates



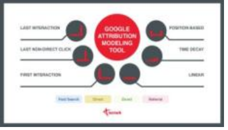
- Calculated energy deposition rates for 1 MeV electrons;
- Grey areas in the plot indicate regions of zero energy depositions.

Energetic Precipitation Monitoring with VLF Instrumentation

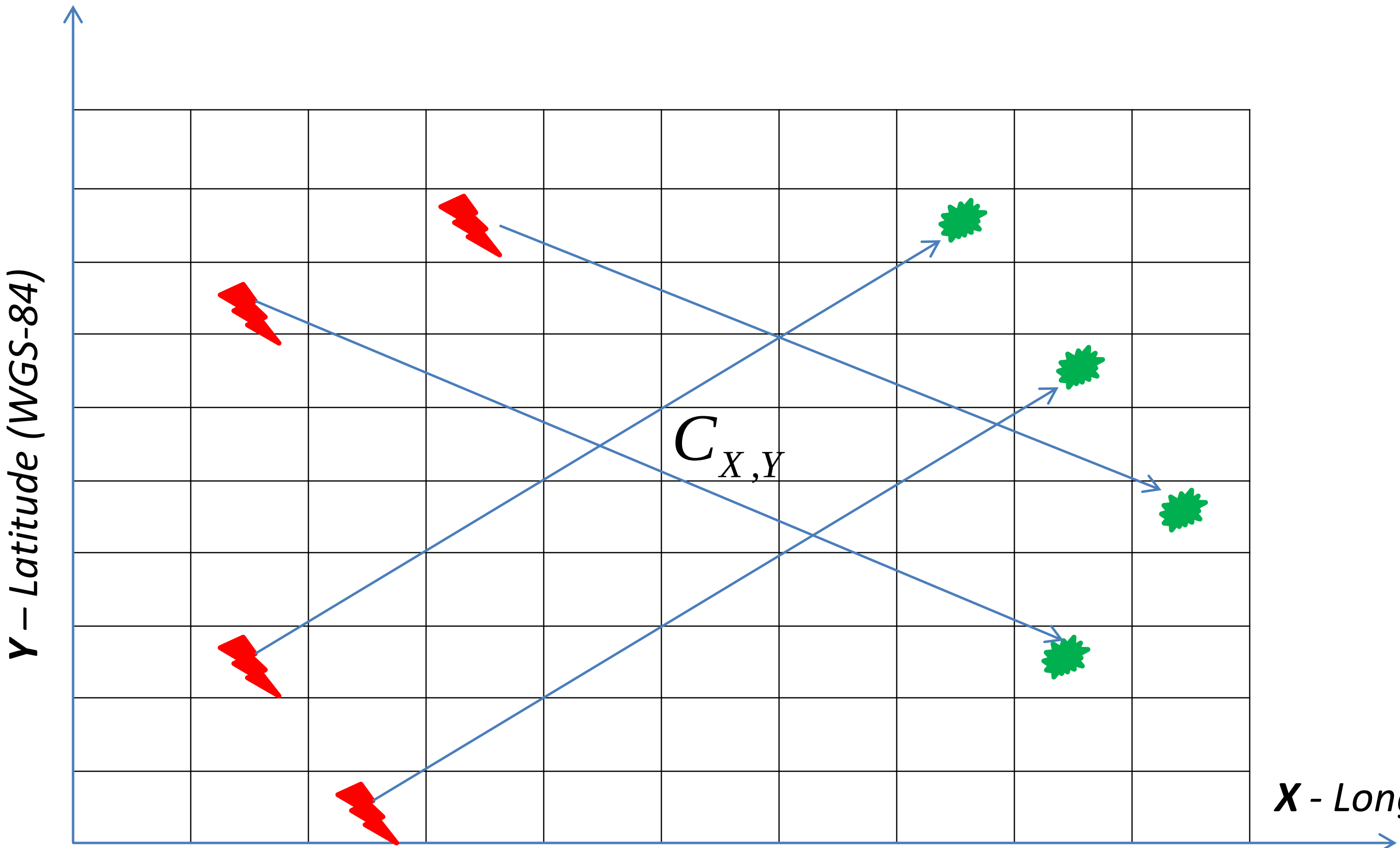




- VLF waves are trapped in the Earth-Ionosphere waveguide;
- Energetic electrons lower slightly the bottom edge of the D- region changing effective path length (signal phase) along the propagation path;
- Changes in signal phase monitors precipitation along the transmitter-receiver path;

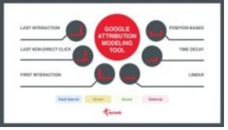


The Model: Main Principles



<u>“**WGS-84 Grid**” upper level object:</u>

- Combines **models** responsible for the physics of VLF propagation;
- Estimate physical parameters along propagation paths by splitting path into segments with the similar properties (Forward Modeling);
- Restore cell’s physical parameters by means of responses of devices deployed in the grid space (Inverse or Backward Modelling).



Grid Cell Indexes

Index of Model's implementation:

1 - NRLMSISE-00 – neutral atmosphere density;

2 - IRI-2012 – Ionosphere free electron density;

3 - AURIC – atmosphere ionization by EUV photons;

4 - MCNP 6 - Coupled electron-photon transport in atmosphere;
- Electron production rates;
- Electron & Ion collision profiles;

5 - Analytical models of Ionosphere - based on the effective reflection height and the sharpness of the ionospheric transition;

6 – Earth's conductivity model.

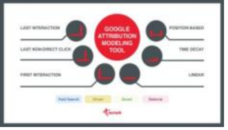
$$\left(C_{X,Y}\right)^{M,L}_{Z,T(Annual),T(Diurnal)}$$

Index of Model's Parameter:

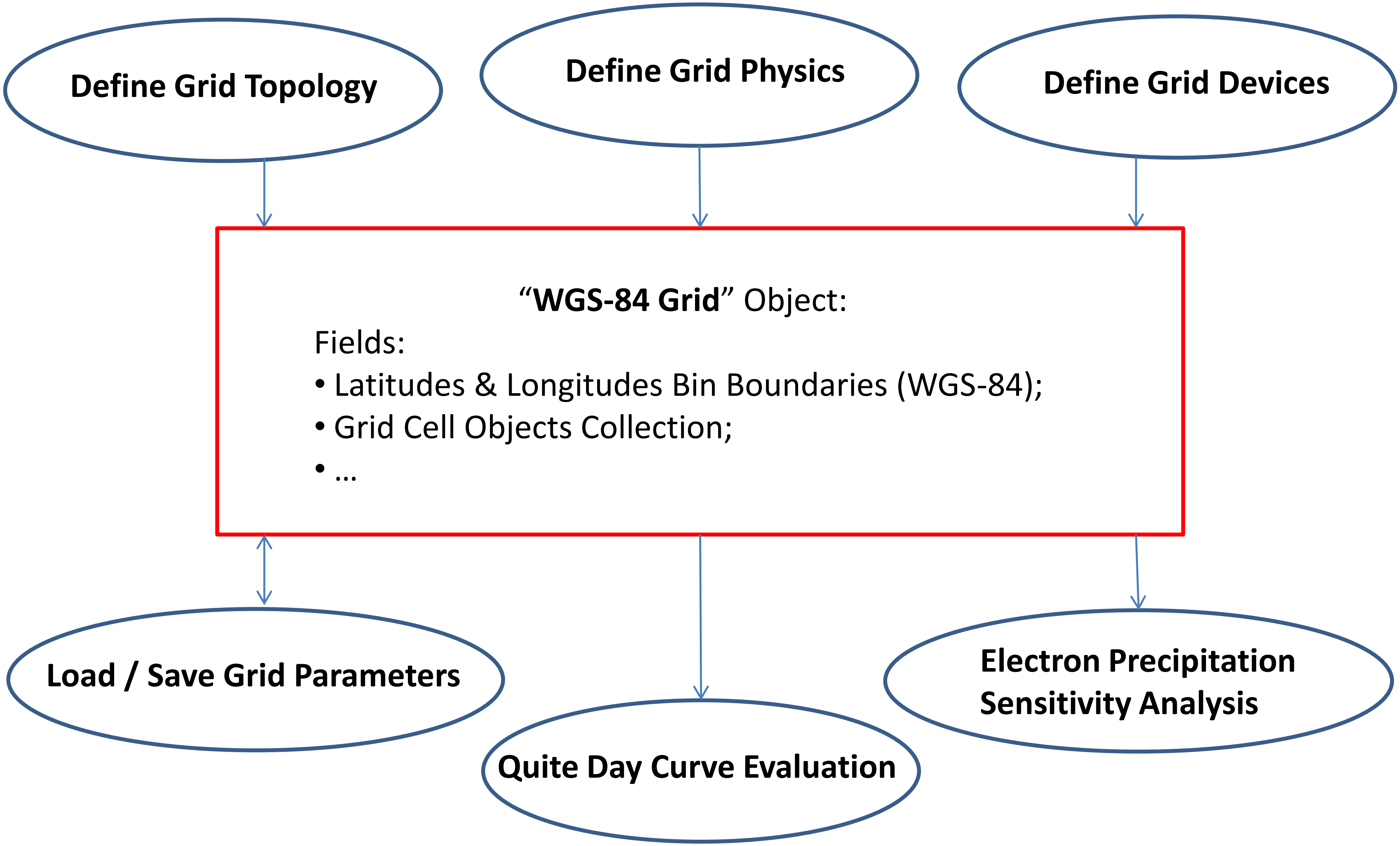
Index of Parameter's altitudinal profile

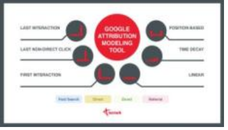
Index of Parameter's seasonal time dependence (Slow)

Index of Parameter diurnal time dependence (Fast)



Forward Modeling





LWPC Software

• Simple model of the ionosphere used in the LWPC produces an **exponential increase in conductivity with height** specified by the set of slopes and reference heights;

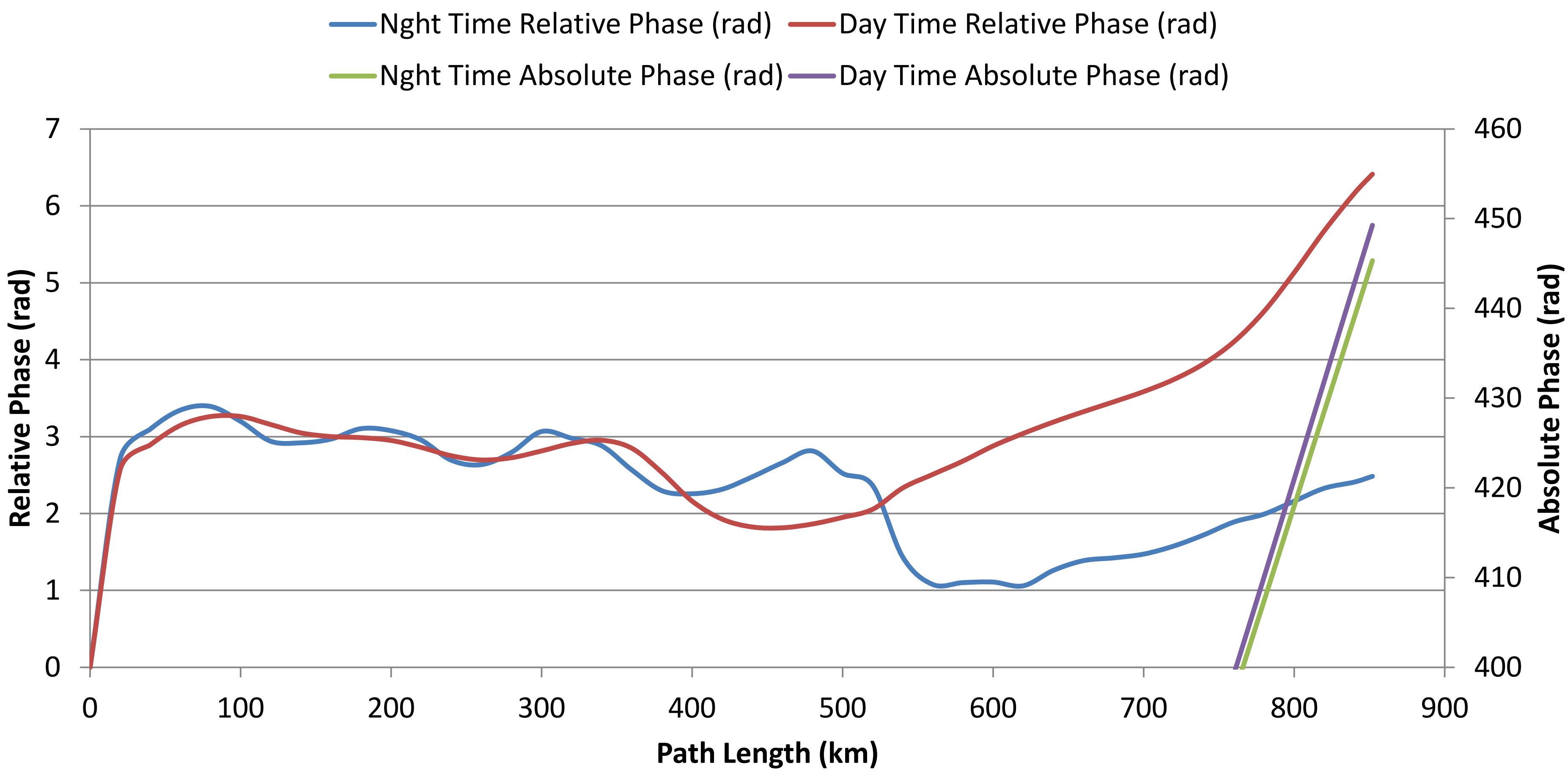
• Transition occurs in the nighttime between **middle geomagnetic latitudes** (starting with dip angle of **70°**) and polar latitudes (starting with dip angle of **74°**) are treated by implying additional segments of a transmitter - receiver path.

• The transition is strongly influenced by injections of solar particles guided there by the earth's geomagnetic field and causing additional ionization of atmosphere.

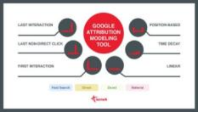
• The most time-consuming process in the LWPC is the generation of the mode parameters along propagation paths;

• Ionospheric external model option allow arbitrary input of electron and ion density profiles and collision frequencies averaged over the chosen path segments (grid cells).

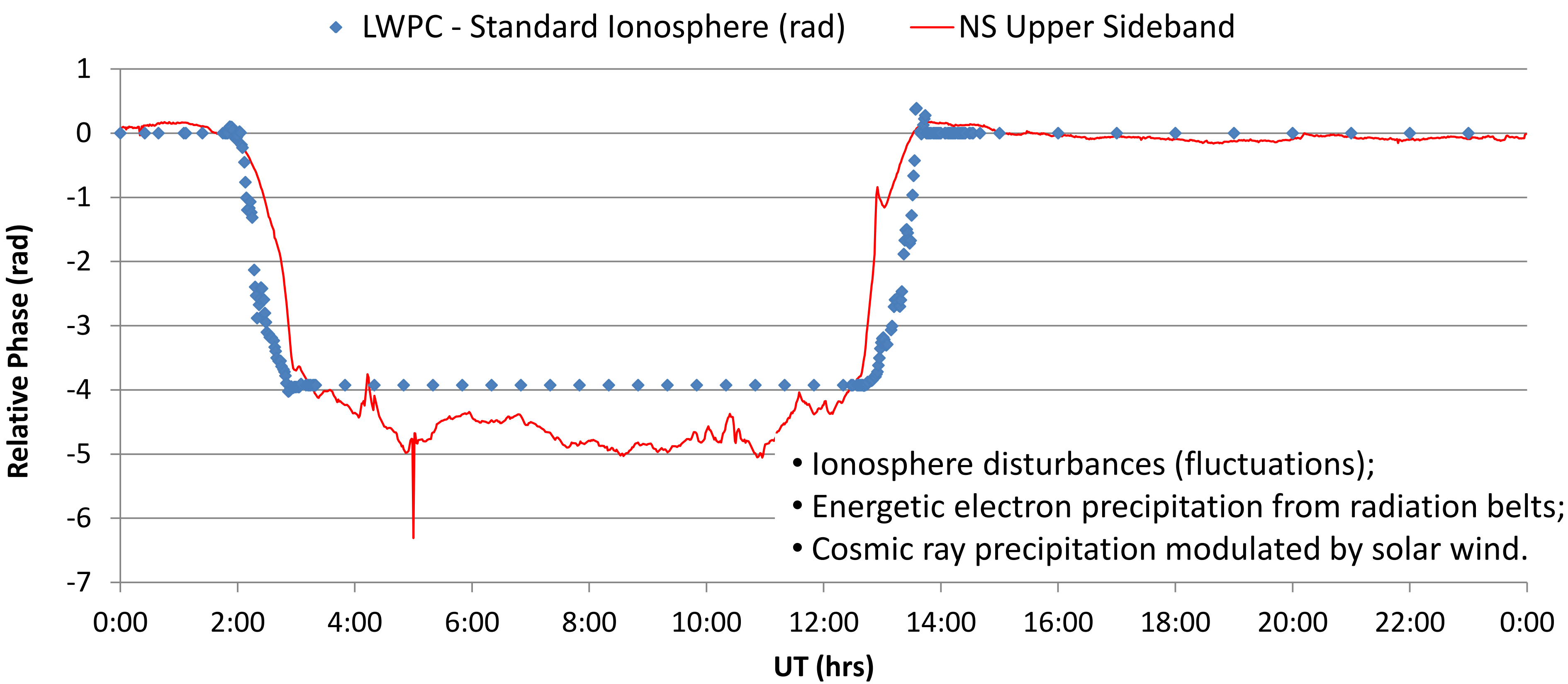
Phase Variation in VLF Propagation in the middle geomagnetic latitudes



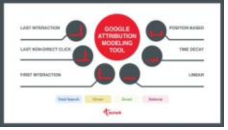
Phase variation in VLF Propagation between Jim Creek(WA, Transmitter, **69°42’** dip angle) and Camrose (AB, Receiver, **75°06’** dip angle) pair of stations.



Quite Day Curve



- Comparison of the observed phase to the estimated quiet time (undisturbed) phase relative to the Free-Space Delay (known as the quiet day curve - **QDC**) calculated by **LWPC** software;
- Date of observation: **September 12, 2014**;
- Receiver: **Camrose** (AB); Dip angle: **75°06'** ;
- Transmitter: **Jim Creek**(WA); Dip angle: **69°42'**; Carrier Frequency : **24.8** kHz;
- Guiding Day Curve: **NS Upper Sideband**.



Conclusions

- Numerous existing models describing atmosphere ionization and VLF propagation are needed to be combined in a frame of a single **Unified Model**;

- The **Unified Model** manages simultaneous run of an unique model combinations by means of organizing models inputs – outputs, namely:
    - Passing calculated parameters between models and
    - Saving final parameters along propagation paths;

- **Iterative process** over different models - **starting with the simplest one** - is the only reliable way to get an adequate description of VLF propagation in complicated propagation environments;

- **Approval models** and their **parameters** is the **output** of the **Unified Model**.


Answers
Questions?