Modeling of Geomagnetically Induced Currents (GICs) – Computational Challenges

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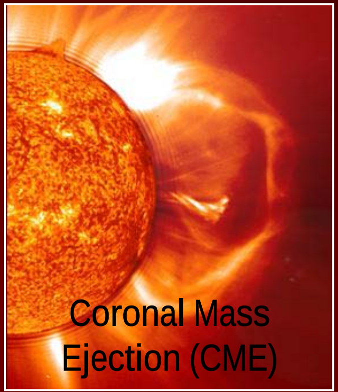
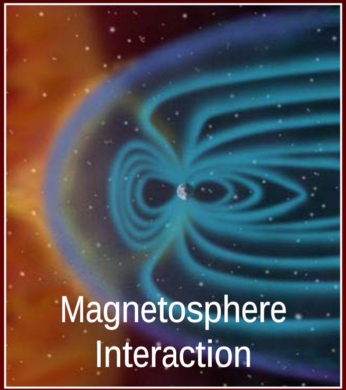
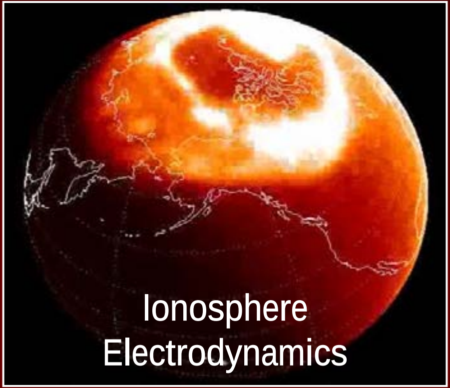
Complete GIC Physics – Model Components and Inputs







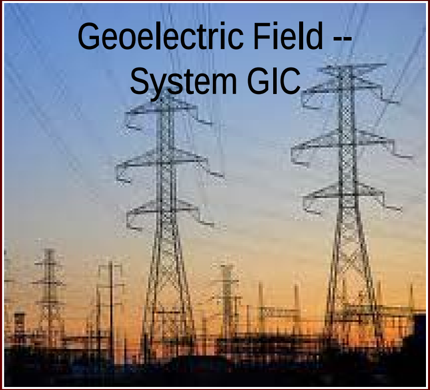


Image source – http://www.nasa.gov

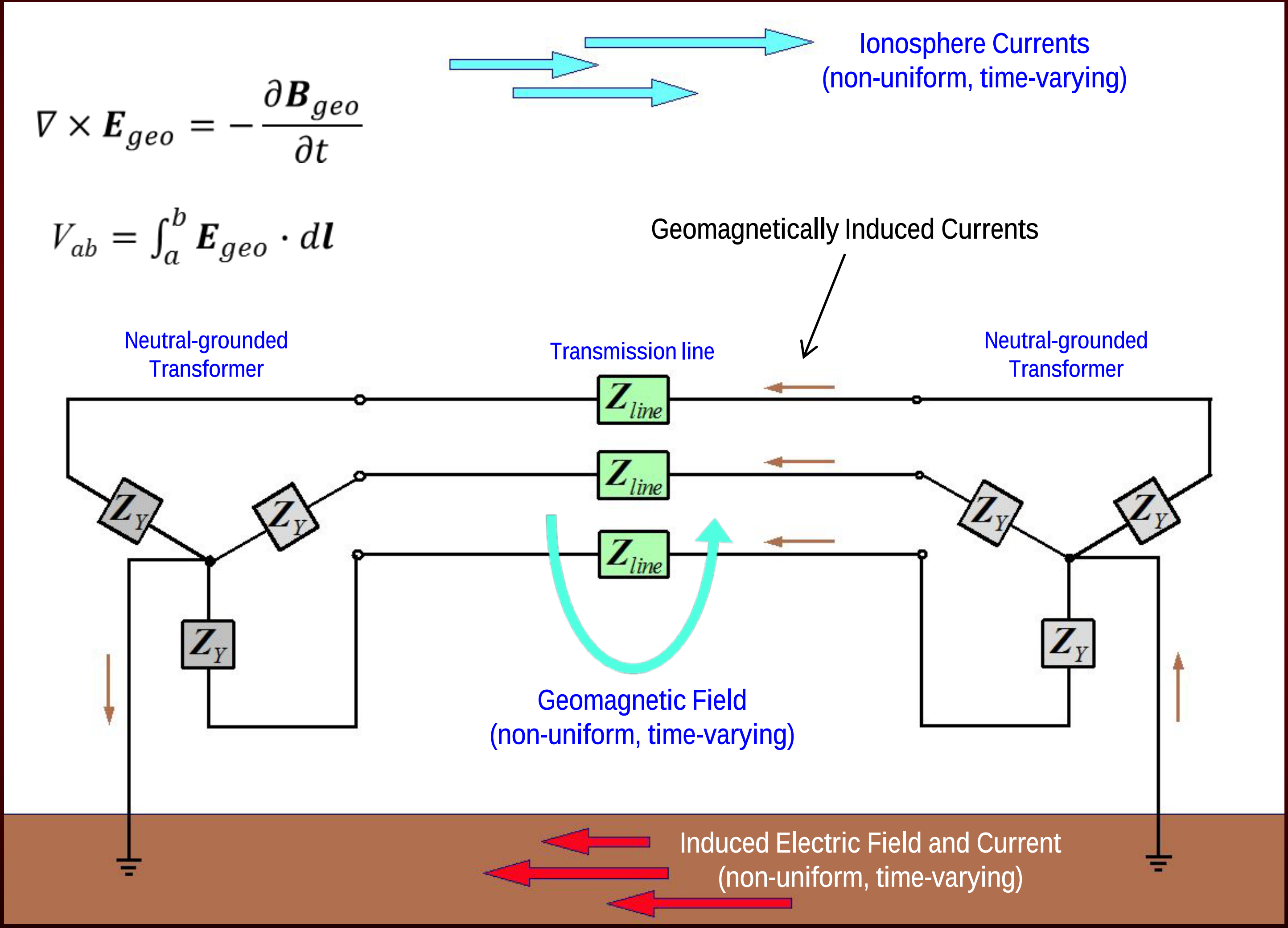
Ground-based sensors

- Magnetometers
- Radars
- Solar observatories

Satellite-based sensors

- Magnetometers
- Electric field sensors
- Radars
- Imagers (optical, UV, X-ray, etc.)
- Particle detectors, mass spectrometers

GIC Physics – Coupling of Geomagnetic Disturbances to Power Systems



Overall Model for Accurate GIC Prediction - Requirements

- Ionosphere current model
  - The proximity of ionosphere currents to the earth surface make these currents the dominant source of the GIC-producing geoelectric field
- Magnetosphere current model
  - The effects of magnetosphere currents can be neglected at higher latitudes, but are more significant at lower latitudes
- Earth environment (ground conductivity)
- Transmission System

Modeling Ionosphere Currents

- Equivalent ionosphere currents can be determined through an inverse problem using ground magnetometer data sets.
- The ionosphere convection velocities can be measured using HF radar, from which currents can be determined given accurate characterization of charge distributions.
- Ground magnetometer data can be combined with HF radar data to enhance the accuracy of the ionosphere current model.

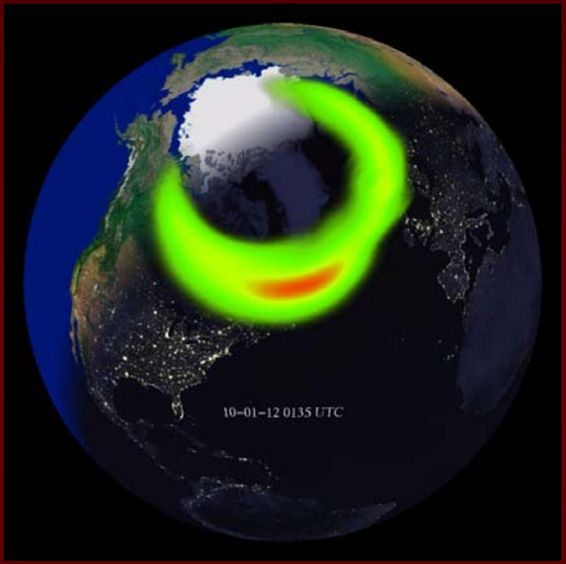
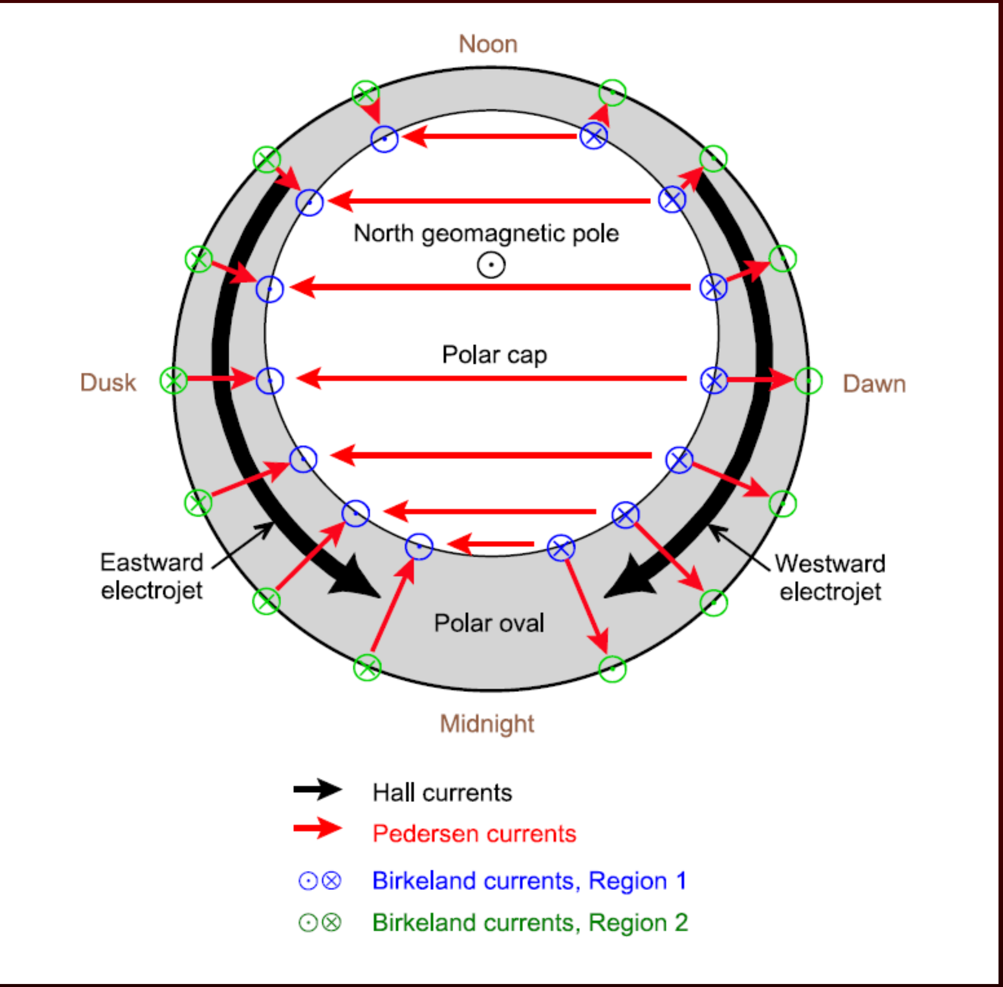


Image source – http://www.noaa.gov

Auroral Oval



Magnetosphere - Ionosphere Current System

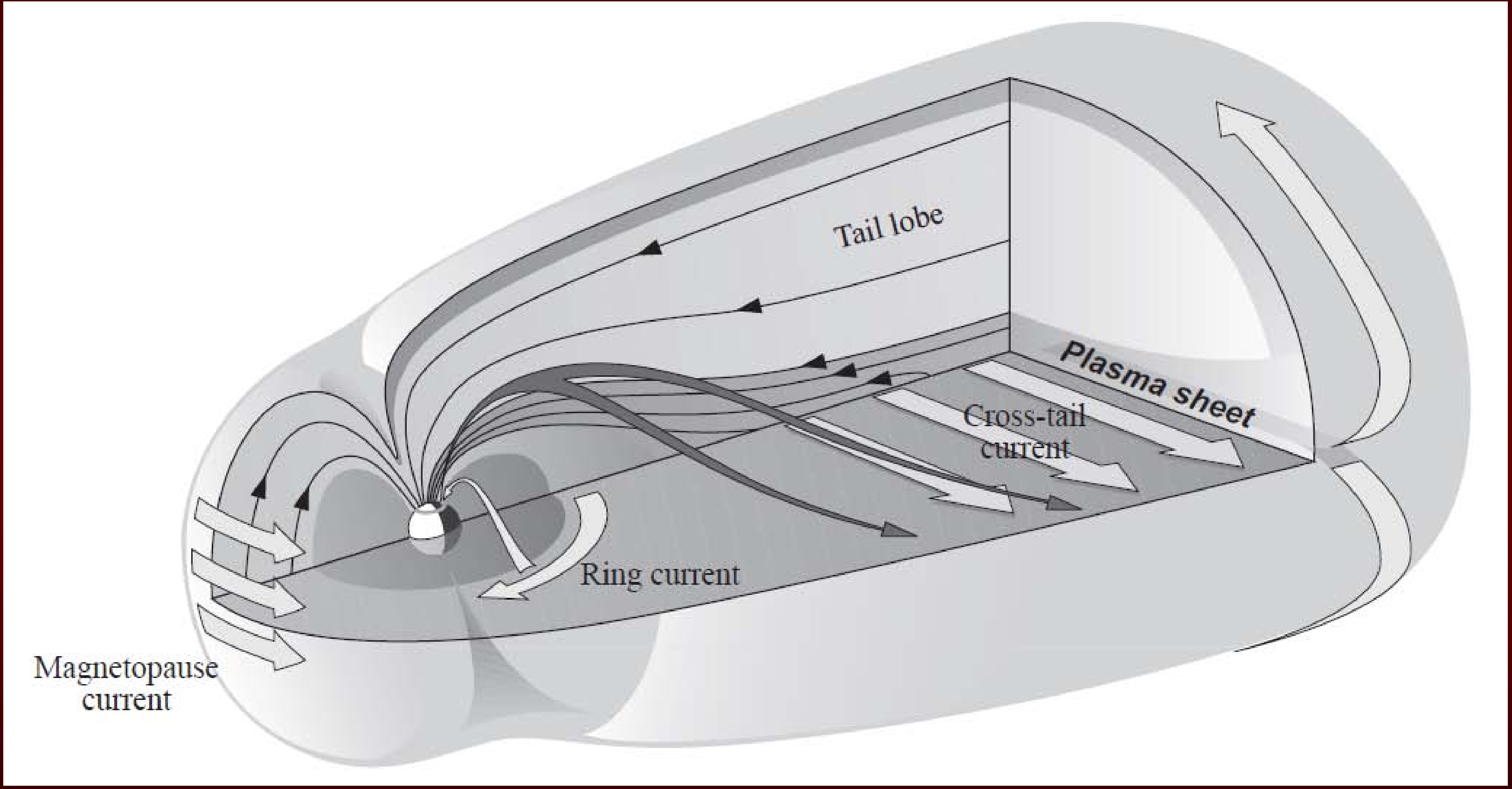
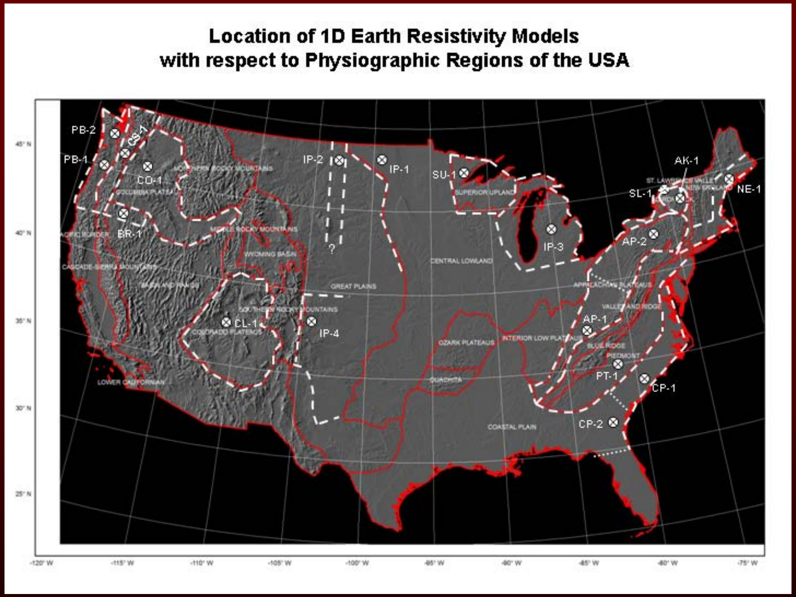


Image source – Vanhamaki, H., *Theoretical modeling of ionospheric electrodynamics including induction effects*, 2007.

Importance of Accurate Ground Conductivity Models

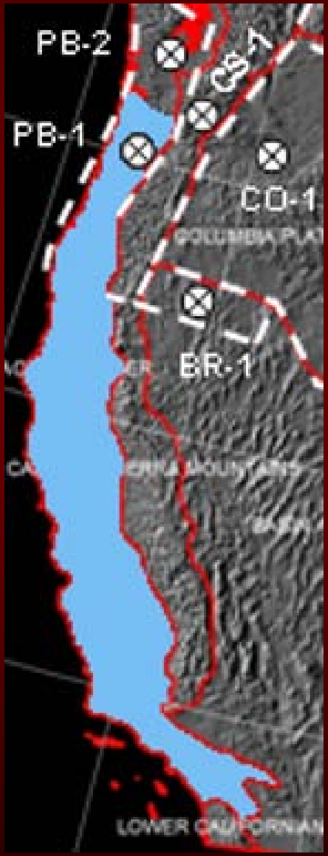
- The geoelectric field and resulting GICs are proportional to dB/dt and characterized as quasi-DC at sub 1 Hz frequencies.
- The typical skin depth of a multilayered earth is on the order of 100's of kilometers at GIC frequencies.
- Conductivity models at depth are necessary to accurately determine the resulting geoelectric field produced by the ionosphere currents.

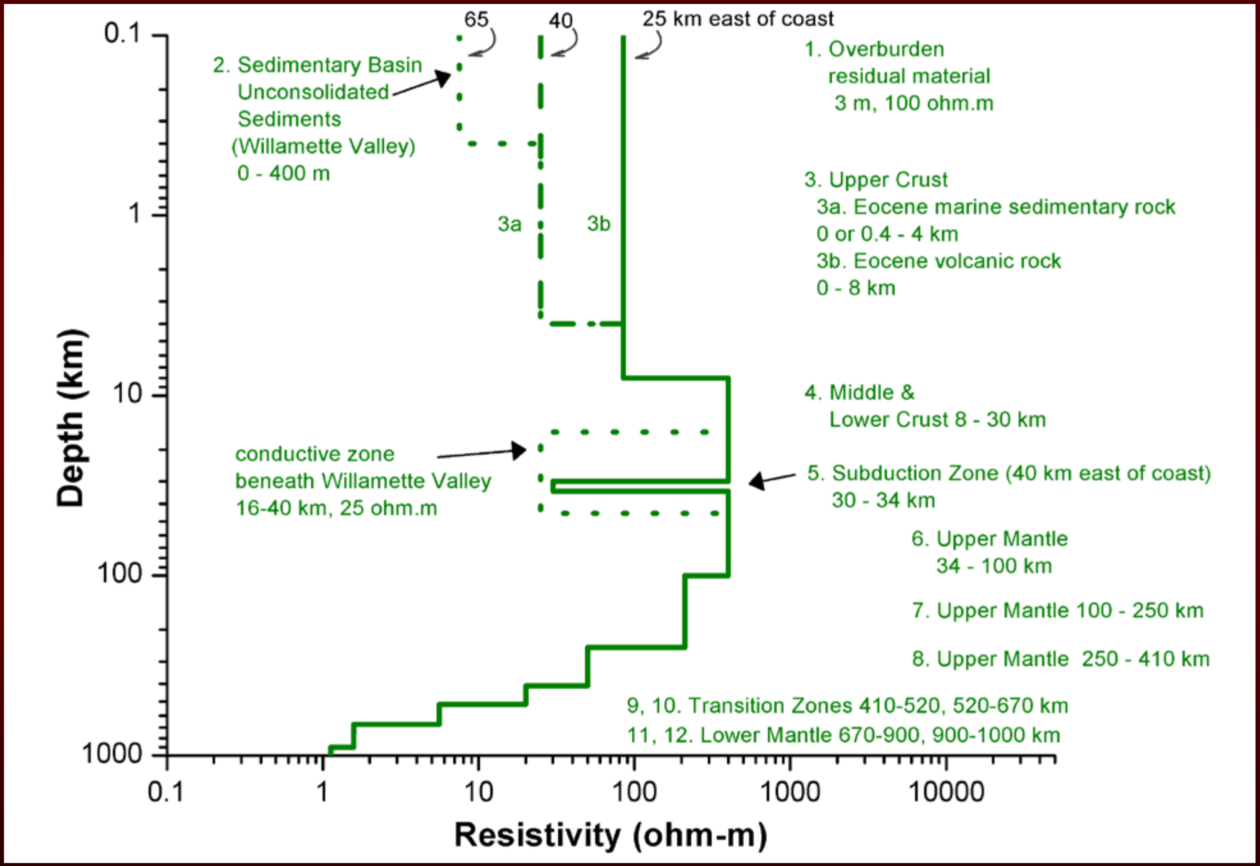


source – http://geomag.usgs.gov/conductivity/

Ground Conductivity Data

1D Resistivity Model for Pacific Border Model PB-1

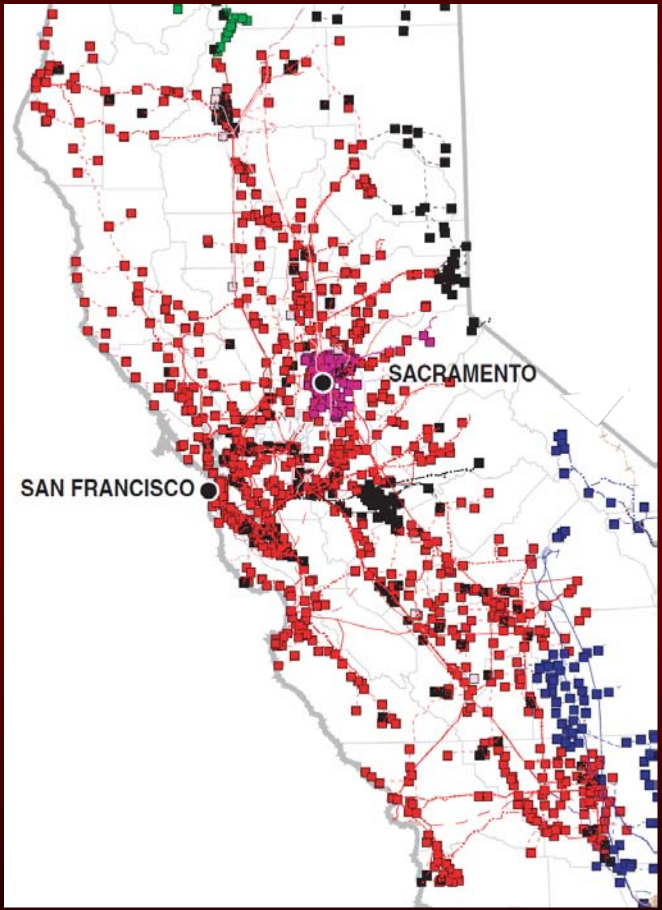




source – http://geomag.usgs.gov/conductivity/

Transmission System Model - Geometry and Connectivity

- GIC calculations performed at DC based on induced voltages determined from geoelectric field
- Line resistances
- Ground points and grounding resistances
- Component grounding configurations
- Component internal resistances



Source: http://www.energy.ca.gov

Overall GIC Computational Model - Challenges

- Complex geometry:
  - Coronal mass ejection
  - Magnetospheric interaction
  - Magnetosphere - Ionosphere current distributions
  - 3D ground conductivity models
  - Transmission system
- Complex physics:
  - Coronal mass ejection
  - Magnetospheric interaction
  - Determination of magnetosphere - ionosphere currents
  - Multilayer ground field penetration
  - Interaction of transmission system with complex vector field

Overall GIC Computational Model – Typical Simplifications

- Determine ionosphere currents from magnetometer data / HF radar
  - o Bypasses the coronal mass ejection and magnetospheric interaction geometry/physics
  - o Magnetosphere currents are not included explicitly
- Simplified equivalent ionosphere current distributions
- Simplified ground conductivity models
  - o Uniform (1D) layered ground conductivity model (so-called “coastal effect” is neglected)
  - o Planar layered ground conductivity model
- Simplified interaction of geoelectric field with transmission system
  - o Geoelectric field magnitude is assumed to be uniform
  - o Geoelectric field is assumed to be unidirectional

A Significant Step Forward

Increased accuracy in ionosphere – magnetosphere current models using a more realistic environment

Computational Tools – Key Requirements

- Complete Maxwell's equations solution
- Accurate modeling of complex geometries
- Efficient modeling of multiple media
- Capable of simulating non-sinusoidal low frequency excitation
- Practical simulation of very large models

Finite-Difference Time-Domain (FDTD) Method

- Complete solution of the time-dependent Maxwell’s equations
  - General FDTD scheme is inefficient at low-frequency
  - Special quasi-magnetostatic FDTD solver is efficient at low frequencies
- Computational grid allows accurate modeling of complex geometries
- Each grid cell can be assigned unique electrical properties (**μ**,**ε**,**σ**)
- Low-frequency time-varying ionosphere/magnetosphere source currents can be modeled efficiently
- FDTD solvers can utilize parallel computing hardware (graphics processing units – GPUs) for efficient simulation of large problems

Conclusions

- Accurate simulation of GIC levels in power systems requires a large model incorporating complex geometry and complex physics.
- Determination of accurate ionosphere - magnetosphere model currents require a significant amount of input data. The determination of accurate model currents is the most significant challenge in GIC modeling.
- The simulation accuracy of GIC levels can be improved by utilizing a simulation tool that eliminates many of the simplifying assumptions typically implemented (quasi-magnetostatic FDTD scheme).

Questions?