Data assimilation with plasmaspheric density measurements from VLF whistlers: preliminary results

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Abstract

AWOddNet is a global network for monitoring the plasmasphere. It consists of 13 ground stations automatically detecting VLF whistlers and performing automatic inversion on GPS. The algorithm yields real-time plasmaspheric electron densities. Another source of data used here is s ground based measurements of magnetic field line resonances (FLE), obtained from magnetometer arrays, such as the European quasi-Meridional Magnetometer Array (EMMA). These data are fed into a data assimilation process which combines models and observations, to arrive at the most probable model of the plasmasphere. This paper presents an event study of a specific storm event from 2012.

Electron Densities from Whistlers

- Whistlers are VLF (3-30 kHz) impulses generated by lightning, traveling along magnetospheric field lines, observable on the earth and/ or in space.
- Through propagation in the plasma content of the magnetosphere, they acquire a frequency-time signal with a characteristic shape.
- The time delay depends on the plasma density along the propagation path. It is also frequency dependent, causing their typical curved shape, see Fig. 1.
- Therefore, whistler measurements can tell us about the plasma density in the plasmasphere.

Whistlers have been regarded as cheap and effective tools for plasmasphere diagnostics since the early years of whistler research, but have never been routinely used, since the extraction of equatorial densities was very labour intensive. Recently (between 2002 and 2014) an Automatic Whistler Detector and Analyzer Network (AWOddNet) was developed which is capable of automatically detecting and analyzing whistlers [1].

Data assimilation combines models and observations to arrive at the best representation of a state. Data assimilation is the de-facto standard approach to conditioning weather models for weather prediction, e.g. weather forecasting.

Assimilative Model of the Plasmasphere

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Assimilative Run for 2012 July Event

26 July 2012

Data sources used so far:
- EMMA magnetometer array
- NHAMA magnetometer array (Central America west coast)
- InMac magnetometer array (North America central)
- AWDANet VLF stations

Result of the model runs

Fig. 9 Data coverage for the analyzed event

Mass Densities from Magnetometer Arrays

Field line resonances (FLE) are terrestrial standing waves of the magnetic field lines fixed into the atmospheres at their ends, caused by compressive MHD waves. From the detected resonance frequency the equatorial plasma mass densities can be inferred.

The European quasi-Meridional Magnetometer Array (EMMA) was established in 2012 with the main goal of monitoring plasmaspheric mass densities based on the detection of geomagnetic FLEs. FLEs are detected by applying the phase gradient technique [2] to data obtained at low-latitude stations (150-300 km) stations.

Ensemble Kalman Filter – Monte Carlo approximation to KF (used in this study)

Data assimilation does not forecast, but it can be used to constrain the state from which a prediction is run with known (or more often guessed) model drivers.

Data assimilation is expressed in Bayesian way: a probability distribution evolves through time, determined by:
- (i) The range of possible evolution, taking into account the probability distribution of unknown physics and drivers which are not measured.
- (ii) Measurements which partially constrain the model and thus eliminate some possible evolutionary paths.

Example:
- A plasmasphere model might represent quiet and storm-time behavior, and without other knowledge (e.g. solar wind or observations in the plasmosphere) all scenarios are included in the probability distribution.
- A satellite at 1 RE observes it is not in the plasmosphere, so all evolution which places the plasmasphere at or beyond 1 RE can be eliminated.

Useful data assimilation narrows the probability distribution.

Bayesian calculations are computationally intensive so in practice we choose simplifications
- Kalman Filter – when the models known and noise is Gaussian
- Ensemble-Kalman Filter – Monte Carlo approximation to KF (used in this study)
- Particle Filter – Monte Carlo approximation to Bayesian

Conclusions

- Data assimilation is the correct approach to obtaining the plasmasphere state from limited observations. By definition, combining all available information gives best results. It is a way to combine direct observations of plasma density, boundaries, images, empirical and statistical models, etc. Differences, bad data or calculation bias the results, model uncertainty and data scarcity must be well understood, model must be sufficiently flexible to represent real plasmasphere evolution. Practical problems to be addressed before improving models and assimilation procedures: inter-calibration and weighting of different data types, studying and adjust saturation and inflow/outflow. Also, event studies (looking larger data sets).

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References