Application of Kohonen maps to the GPS Stochastic Tomography of the Ionosphere

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Summary: The adaptative classification of the rays received from a constellation of geodetic satellites (GPS) by a set of ground receivers is performed using neural networks. This strategy allows to improve the reliability of reconstructing the Ionospheric electron density from GPS data. As an example, we present the evolution of the radially integrated electron density (Total Electron Content, TEC) during the day 18th October 1995, coinciding with an important geomagnetic storm. Also the problems in the vertical reconstruction of the electron density are discussed, including the data coming from one Low Earth Orbiter GPS receiver: the GPS/MET. Finally is proposed as main conclusion a new strategy to estimate the ionospheric electron distribution, using GPS data, at different scales —the 2-D distribution (TEC) at Global scale and the 3-D distribution (Electron density) at Regional scale—.

1. Introduction

about the Problem:

As it is well known, the Ionosphere is the part of the Earth Atmosphere containing free ions and causes a frequency-dependent delay in the propagated EM-signals, being proportional to the columnar density of electrons (TEC) (see for instance Davies 1990, page 73).

This is a *distorting* physical effect for Space Geodesy and Satellite Telecommunications activities, that can be used in a *positive sense* to estimate the global 3-D distribution of the free-electrons in the Atmosphere, from dual frequency delay observations, i.e. for the *Stochastic Tomography of the Ionosphere.*

about the Data:

To achieve this objective, we need during a certain time interval, a high *sampling rate* of the Atmosphere, with so many rays in so many orientations as possible. Nowadays, the unique system that provides so many observations, continuously and on a planetary scale, is the *Global Positioning System* (GPS). Its space segment contains a constellation with more than 24 satellites emitting continuously carrier and code phases in two frequencies L1 ($\simeq$1.6 GHz) and L2 ($\simeq$1.2 GHz) (see for instance more information in Seeber 1993, pages 209-349). In the GPS user segment, it is possible to get *few hours later* the public domain data gathered from a global network of permanent receivers, such as International GPS Service for Geodynamics (IGS, Zumberge et al. 1994), with more than 100 stations worldwide distributed, mainly concentrated in the Northern Hemisphere, in North America and Europe. Also the *Low Earth Orbiters* containing GPS receivers (LEO), are becoming usual. Hajj et al. (1994) conclude than the GPS/MET LEO observations, are important to resolve the vertical structure of the Ionosphere.

C. Hayashi et al. (eds.), *Data Science, Classification, and Related Methods*

about the Model and Goals:

But the amount of data implied (more than $1.5\,10^6$ delays/day collected in the IGS network) jointly with its inhomogeneous distribution, makes it difficult to solve the problem, so that new algorithms and strategies must be considered to perform the tomography of the Ionosphere.

In this paper we mainly discuss the different data analysis problems encountered in the estimation of the ionospheric electron distribution using mainly ground data from the IGS network, and the solutions adopted, emphasizing three points:

1. The adaptative clustering of the rays, using the Kohonen neural network algorithm. This technique will be applied for bidimensional modeling (TEC) of the overall Ionosphere, i.e. at Global scale, generating cells adapted in size to the variable sparsity of the data.
2. The problems coming from the bad geometry to solve the vertical structure of the Ionosphere using data coming solely from ground receivers are also discussed. We will adopt the model using regular cells instead of the adaptative one, due to the better performance related with the lower discretization error in presence of high correlations.
3. The inclusion of a set of GPS/MET data, consisting on *orthogonal* rays to the ground data rays, improve the estimation of the ionospheric vertical structure.

2. The Model

The Scenario:

We have the following situation:

- From each ground station (see figure 1) we simultaneously measure with a certain sampling rate (i.e. 1 time/30 sec) the ionospheric delays experienced by the rays received from the visible satellites (i.e. 4-8).
- This rays cross different parts of the *nearby* Ionosphere to the respective station.
- Between observation epochs the Earth rotates, and the part of the sounded Ionosphere has changed.
- We assume that the Ionosphere is *stationary* in a Sun-fixed reference system[1].
- Then, we have chosen an Geocentric Equatorial pseudo-Inertial reference system (GEI), where the X-Axis points towards the Vernal Equinox and the Z-Axis points towards the Geographic North Pole; the XY plane is the celestial equator. In the GEI the Sun is only *moving* 1 degree/day. The associated spherical coordinates are the right ascension α (*azimuthal* angle) and the declination δ (angle referred to the equator).

The General Model:

Not taking into account the *bending-effect* of the ray, we have to solve the following

[1]This is not true in *second order*, due to the magnetic field effects and the variability of geomagnetic conditions (see for example Sanz el al., 1996)