Global Ionosphere Maps and Related Products Generated by CODE

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The Center for Orbit Determination in Europe (CODE)

CODE is a joint venture of the following four institutions:

- the Federal Office of Topography (L+T), Wabern, Switzerland,
- the Federal Agency of Cartography and Geodesy (BKG), Frankfurt, Germany,
- the Institut Géographique National (IGN), Paris, France, and
- the Astronomical Institute of the University of Berne (AIUB), Switzerland.

The actual analysis center is located at the AIUB.

CODE has been contributing to the International GPS Service (IGS) since the beginning (1992) with products meeting high quality standards.

Since 1999, the IGS orbit and clock combinations are computed at CODE/AIUB.

Topics

- Overview of parameter types regularly solved for at CODE
- CODE global ionosphere maps (GIM) in IONEX (IONosphere map EXchange) format
- Discussion of selected SH coefficients of our GIM representation
- Modified SLM mapping function (approximating the JPL ESM mapping function)
- Relevance of P1-P2 and P1-C1 differential code biases (DCB) for GPS ionosphere analyses
- Reducing CODE IONEX data into daily sets of “Klobuchar-style” ionospheric coefficients
- Summary and outlook

Parameter Types Regularly Solved for at CODE

- Station coordinates (and velocities), geocenter coordinates
- Orbital parameters, solar radiation pressure parameters
- HR Earth rotation parameters (ERPs), nutation parameters
- Site-specific tropospheric zenith delay and gradient parameters
- Satellite antenna offset parameters with respect to L3 as well as L4 LC
- Implicitly stochastic ionosphere parameters in the course of DD ambiguity fixing using the QIF strategy; (unresolved) initial carrier phase ambiguities
- Global, regional, and site-specific ionosphere model parameters (based on about 150 ground stations)
- P1-P2 as well as P1-C1 differential code bias (DCB) parameters for the satellite constellation (and all stations)
- Phase-consistent satellite and receiver clock corrections

CODE GIM (IONEX) Description

Global ionosphere maps (GIM) are generated on a daily basis at CODE using data from about 150 GPS sites of the IGS and other institutions.
The vertical total electron content (VTEC) is modeled in a solar-geomagnetic reference frame using a spherical harmonics expansion up to degree and order 15. The time resolution considered for the VTEC maps is 2 hours.
Instrumental biases, so-called differential code biases (DCB), for all GPS satellites and ground stations are estimated as constant values for each day, simultaneously with the 12 times 256, or 3072 parameters used to represent the global VTEC distribution. The DCB datum is defined by a zero-mean condition imposed on the satellite bias estimates.
To convert line-of-sight TEC into vertical TEC, a modified single-layer model mapping function approximating the JPL extended slab model mapping function is adopted. The mapping function is evaluated at geodetic satellite elevation angles. For the computation of the ionospheric pierce points, a spherical layer with a radius of 6821 km is assumed, implying geocentric, not geodetic IONEX latitudes.

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Web site: `http://www.aiub.unibe.ch/ionosphere.html`
Data archive: `ftp://ftp.unibe.ch/aiub/CODE/`

Modified Single-Layer Model Mapping Function

SLM mapping function:

$$F(z) = \frac{1}{\cos z'} \quad \text{with} \quad \sin z' = \frac{R}{R+H} \sin z$$

R and H are set typically to 6371 and 450 kilometers, respectively.

“Modified” SLM (MSLM) mapping function:

$$F(z) = \frac{1}{\cos z'} \quad \text{with} \quad \sin z' = \frac{R}{R+H} \sin(\alpha\, z)$$

Best fit with respect to the JPL extended slab model (ESM) mapping function is achieved at $H = 506.7$ km and $\alpha = 0.9782$ (when using $R = 6371$ km and assuming a maximum zenith distance of 80 degrees).

Relevance of P1-P2 and P1-C1 Differential Code Biases (DCB) for GPS Ionosphere Analyses

- Geodetic GPS receivers may provide P1 and/or C1 $=$ C/A and P2 or C2 $=$ C/A $+$ (P2 $-$ P1) code observables.

- Instrumental satellite (and receiver) biases are present for all code observables: B_{C1}, B_{P1}, B_{P2}.

- For ionosphere analyses, the "geometry-free" linear combination, L1 $-$ L2, is commonly formed.

- The following three code combinations are possible:
  - P1 and P2 (and C1)—leading to $B_{P1} - B_{P2} = B_{P1-P2}$
  - C1 and C2—leading to $B_{C1} - (B_{C1} + (B_{P2} - B_{P1})) = B_{P1-P2}$
  - C1 and P2—leading to $B_{C1} - B_{P2} = B_{P1-P2} - B_{P1-C1} \neq B_{P1-P2}$

- Remark: τ_{GD}, the "group delays" broadcast by the GPS system, are related to B_{P1-P2} as follows: $\tau_{GD} = -1.55 \cdot B_{P1-P2}$.

How to Use P1-P2 and P1-C1 Satellite DCB Information

The following table gives the corrections due to satellite-specific DCBs for the most important linear combinations derived from various combinations of code observable types:

LC	P1/P2	C1/C2		C1/P2	
L1	$+1.55 \cdot B_{P1-P2}$	$+1.55 \cdot B_{P1-P2}$	$+B_{P1-C1}$	$+1.55 \cdot B_{P1-P2}$	$+B_{P1-C1}$
L2	$+2.55 \cdot B_{P1-P2}$	$+2.55 \cdot B_{P1-P2}$	$+B_{P1-C1}$	$+2.55 \cdot B_{P1-P2}$	
L3	0		$+B_{P1-C1}$		$+2.55 \cdot B_{P1-C1}$
L4	$-B_{P1-P2}$	$-B_{P1-P2}$		$-B_{P1-P2}$	$+B_{P1-C1}$
L5	$-1.98 \cdot B_{P1-P2}$	$-1.98 \cdot B_{P1-P2}$	$+B_{P1-C1}$	$-1.98 \cdot B_{P1-P2}$	$+4.53 \cdot B_{P1-C1}$

L3, L4, and L5 denote the ionosphere-free, geometry-free, and wide-lane LC, respectively (following the notation used in the Bernese GPS Software).

The factors involved are computed as $\nu_2^2/(\nu_1^2 - \nu_2^2) = 1.546$, $\nu_1^2/(\nu_1^2 - \nu_2^2) = 2.546$, $\nu_1\,\nu_2/(\nu_1^2 - \nu_2^2) = 1.984$, and $\nu_1/(\nu_1 - \nu_2) = 4.529$, where ν_1 and ν_2 are the basic carrier frequencies.

Determining Klobuchar-Style Ionospheric Coefficients Best Fitting our GIM Information

- Input: 12 2-hourly global ionosphere maps (GIMs) in IONEX format
- Adjustment method: Least-squares method treating the individual TEC values of the IONEX grid maps as pseudo-observations; adequate a-priori information in conjunction with an iterative adjustment are indispensable
- Output: Eight coefficients—four alphas and four betas
- Data interface: RINEX navigation data format
- Possible options:
  - Consider a-priori variance information in form of IONEX RMS maps
  - Restrict analysis to pre-defined area
  - Determine coefficients for n TEC maps each

Summary

- CODE's GPS-derived global ionosphere map information is available, without any gaps, as of 1995, namely in Bernese ionosphere format, in IONEX format, and also in "compressed" form of Klobuchar-style ionospheric coefficients (RINEX format). The CODE data archive is accessible through anonymous ftp at `ftp://ftp.unibe.ch/aiub/CODE/`.

- Since June 1998, CODE has been contributing to the IGS ionosphere service, together with EMR/NRCan, ESA, JPL, UPC. Corresponding TEC and (P1-P2) DCB combinations are made at ESA/ESOC.

- At CODE, a *final*, a *rapid*, and a *predicted* GIM product are generated.

- Automatically updated ionosphere-related website: `http://www.aiub.unibe.ch/ionosphere.html`

- CODE P1-C1 satellite DCB values are recommended to be adopted for use with the IGS official products.

- For GPS data analysis, we use the Bernese GPS Software, currently the development version 5.0.

Outlook—Planned Improvements

- Consider simultaneously P1-P2 and P1-C1 DCB corrections in both ionosphere and clock estimation
- Refine TEC parameterization in terms of time-dependence
- Connect daily TEC/DCB results at day boundaries by means of normal equation manipulation
- Combine GPS-based TEC results with TOPEX-based TEC results in a correct way (on the normal equation level)
- Tests concerning use of low-elevation data (down to 3 degrees)
- Improving data screening scheme
- Ultra-rapid products (?)
- Model higher-order ionospheric terms (RRE corrections) by taking into account (three) additional "global" parameters in the geodetic, "ionosphere-free" DD analysis