State-of-the-art physical models for calculating atmospheric pressure loading effects

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1. Introduction: The Project GGOS Atmosphere at TU Vienna

• Purpose and significance

Provide a detailed and comprehensive knowledge how the atmosphere affects observations of the three pillars of geodesy: geometry, gravity field & rotation

Contribute to a better understanding of the system Earth

• Main goals

Determine consistent and homogeneous models for

a) Atmospheric Propagation Delay (Delay) : Johannes Böhm (project leader)

b) Atmospheric Angular Momentum (AAM) : Michael Schindelegger

c) Atmospheric Gravity Field Coefficients (AGC) : Maria Karbon

d) Atmospheric Pressure Loading (APL) : Dudy D. Wijaya

http://ggosatm.hg.tuwien.ac.at/
1. Introduction: Atmospheric pressure loading (APL)

- The mechanism of atmospheric loading
- Characteristics of atmospheric loading

Global atmospheric pressure circulation

The Earth’s crust

Pressure variations → Deformation of the Earth’s crust

Onsala - Sweden (Lat: 57° N)

Boulder - USA (Lat: 40° N)

Pressure variations

van Dam & Wahr, 1987
1. Introduction: Atmospheric pressure loading (APL)

- Characteristics of atmospheric loading

  - Rule of thumb:
    
    \[10 \text{ hPa} \approx 3 \text{ mm radial displacement}\]

  - Temporal variations:
    
    annual, one to few weeks, diurnal, semidiurnal

- APL Service

  - van Dam & Gegout: [http://www.sbl.statkart.no/aboutloading/](http://www.sbl.statkart.no/aboutloading/)
  - TU Vienna: [http://ggosatm.hg.tuwien.ac.at/LOADING/VERSION1/](http://ggosatm.hg.tuwien.ac.at/LOADING/VERSION1/)
2. APL Modeling: The basic components of APL determination

• The IERS recommendation: Geophysical model

\[ U(\vec{r}, t) = \iint_{S} G_{R}(\psi) \left( P_{s}(\vec{r}_{p}, t) - P_{\text{ref}} \right) dS \]

The Green’s function (weight function)
Surface pressure
Reference pressure

• The basic components

Earth model
- geometry, mechanical properties, rheology

Theory & mathematical model
- elastic theory, boundary conditions, extension of load

Load Love Numbers

Global pressure data
- Atmospheric tides
- Oceanic response

The Green’s function & Pressure variations

Tidal & non-Tidal Surface displacements \( U \)
2. APL Modeling: Load Love Numbers and the Green's functions (a)

• Determination of Load Love Numbers \((h_n, l_n, k_n)\)

The SNREI Earth model: Preliminary Earth Reference Model (PREM), Gutenberg-Bullen Model (GB-model)

Fundamental theory: Free oscillations of the Earth & elastic-gravitation theory

Harmonic degree \(n\): 10000

• Definition of the radial Green's function \((G_R)\)

\[
U(\vec{r},t) = \int \int_S G_R(\psi) \left( P_s(\vec{r}_p,t) - P_{ref} \right) ds
\]

\[
G_R(\psi) = \sum_{n=0}^{+\infty} h_n P_n(\cos \psi)
\]

Formalism of the horizontal Green’s function \((G_h)\) is similar

![Graph showing comparison between PREM and GB models](image-url)
2. APL Modeling: Load Love Numbers and the Green’s functions (b)

- Effect of different Earth models on APL displacements

The difference of APL displacements for some VLBI sites (PREM minus GB model)

- The difference of the displacements due to the choice of a specific Earth model is small (< 1mm).
- We choose PREM model for our operational solutions.
2. APL Modeling : Definition of reference pressure

• Global Reference Pressure (GRP)

\[ U(\vec{r}, t) = \int \int_S G_R(\psi) \left( P_s(\vec{r}_p, t) - P_{ref} \right) ds \]

Reference pressure

GRP model:

• is based on the ECMWF 40 re-analysis (ERA-40) data (monthly means)

• provides a reference pressure value at any point

• is suitable for various applications

GRP memo, GRP data and MATLAB/Fortran codes can be found at http://ggosatm.hg.tuwien.ac.at/LOADING/REFPRES/

Schuh et al. (2010)
2. APL Modeling: Surface pressure & non-tidal displacements

- European Centre for Medium-range Weather Forecasts (ECMWF)

\[ U(\vec{r}, t) = \int \int_S G_R(\psi) \left( P_s(\vec{r}_p, t) - P_{ref} \right) ds \]

Surface pressure

- Temporal resolution: 00, 06, 12, 18 UTC
- Spatial resolution: 1° x 1°

- Problem of atmospheric pressure tides in the 6th fields

  - Representation of atmospheric tide signals is not accurate.
  - The 6th fields do not permit proper resolution of the S2 tide.
  - Atmospheric pressure signals S_1/S_2 should be removed and non-tidal APL displacements should be calculated (Ray & Ponte, 2003).
2. APL Modeling: Surface pressure & non-tidal displacements

- European Centre for Medium-range Weather Forecasts (ECMWF)

\[ U(\vec{r}, t) = \int \int_{S} G_{R}(\psi)(P_{s}(\vec{r}_{p}, t) - P_{ref}) \, ds \]

Surface pressure

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2. APL Modeling: Surface pressure & non-tidal displacements (b)

- Amplitude spectra of non-tidal displacements at WETTZELL

**Radial displacements**

- With (wrong) tide
- Tide free

**Eastward displacements**

- Spectra $\times 10^5 \text{ (mm}^2/\text{Hz})$
2. APL Modeling: Surface pressure & non-tidal displacements

- Non-tidal displacements at WETTZELL and ALGOPARK

Differences between Petrov & Boy and Vienna models are less than 10% of total displacements.
2. APL Modeling : Tidal displacements

- Three-hourly surface pressure from ECMWF (2005-2009)
  - Better representation of atmospheric tide signals
  - The 3\textsuperscript{h} fields permit proper resolution of \( S_2 \) and ter-diurnal \( S_3 \) tides

- Trigonometric model for tidal displacements
  - Pressure tide model:
    \[
    S_n^P(t) = B_n \cos(nt) + A_n \sin(nt)
    \]
  - Convoluted with Green’s functions
  - Tidal displacements model:
    \[
    S_n^l(t) = \tilde{b}_n \cos(nt) + \tilde{a}_n \sin(nt)
    \]
2. APL Modeling: Tidal displacements

- Tidal displacements at WETTZELL and ALGOPARK

![Graphs showing tidal displacements for WETT and ALGO](image)

Differences between three models are less than 50% of total displacements.
3. Status of APL service at TU Vienna

• Current status
  • Tidal and non-tidal displacements provided for all VLBI sites from 1980 till now.
  • Daily calculation (at 08:15 GMT+2).
  • Reference frame: Center of Mass (CM).

• Next plans
  • Recalculation of Love numbers and the Green’s functions.
  • Improvement of $S_1/S_2$ tide corrections and oceanic response.
  • Tidal and non-tidal displacements provided for the nodes of a global 1 degree grid.
  • Reference frame: Center of Mass (CM) & Center of the solid Earth (CE).

Download APL correction at
http://ggosatm.hg.tuwien.ac.at/LOADING/VERSION1/
4. Summary, conclusion and future investigations

• Summary and conclusion
  
  • State-of-the-art physical models for APL calculations have been presented and validated with results from other providers.
  
  • Differences between Petrov & Boy and Vienna results are very small, less than 10 % of the APL displacements (~20 mm)
  
  • Treatment of oceanic response was not discussed in this presentation. In the calculation we assume that the oceanic response follows the inverted barometer principle.
  
  • **REMARKS:** if the APL displacements remain uncorrected in the analysis of space geodetic data it can systematically affect other parameters as was shown by Dach et al. (2009) for GPS and Boehm et al. (2010) for VLBVI.

• Future investigations
  
  • Further improvements regarding theoretical and technical aspects will be done.
  
  • Thorough validations by VLBI observations and other space geodetic observations will be carried out.