GNSS Observations & Sea Level

Guy Wöppelmann
gwoppelm@univ-lr.fr

Outline: 1. Introduction
         2. The importance of Vertical Land Motions
         3. The GPS solution
         4. Spatial patterns of sea level change
         5. Concluding remarks

with contributions from:
- Marta Marcos
- Alvaro Santamaria
- ...
1. The Era of Recording Sea Level

- **1679** - Tide pole
- **1831** - Floating tide gauge
- **1960** - Pressure gauge
- **1985** - Acoustic & radar
- **1992** - Satellite

**Geocentric sea level**

- Climate contributions
- Land movements
- Sea Surface
- Bedrock crust
2. The importance of land movements at the coast

http://www.fgi.fi/fgi/themes/land-uplift

Vaasa weekly GPS positions

+8.46 ± 0.13 mm/yr

Sea level and prediction

Kahma, 2008
2. Gulf of Mexico & Grand Isle (Louisiana)

Maps by NOAA Climate.gov team (Stephen Gill)
Grand Isle weekly GPS positions

-8.0 ± 0.2 mm/yr
### Challenges

- Rates of sea-level change: ~2 mm/yr
- Standard errors: one order of magnitude less to be useful in LTT sea level studies!

### Determination

- **Modeling**: Only GIA
  - Uncertainties (viscosity profiles, lithosphere thickness, ice retreat)
- **Other processes?**
- **Monitoring**: Space Geodesy

### Diagram Description

- **Source PSMSL**: http://www.psmsl.org/train_and_info/geo_signals/
- **Sea Surface Tide Gauge Station**
- **Land movements**
- **Bedrock crust**
- **Co-seismic displacement**
- **Groundwater extraction**
- **Sedimentation**
- **Glacial isostatic adjustment**
- **No evidence of land motion**
- **Climate contributions**
3. Measure (if one can): The GPS solution

- Review of Geodetic Techniques
  Carter et al. (1989; 1993)

- **Campaign versus Continuous** GPS
  Zerbini et al. (1996)
  Neilan et al. (1998) – JPL (IGS/PSMSL)

- **Regional versus Global** GPS Processing
  Mazzotti et al. (2008)
  Legrand et al. (2010)

- International infrastructure (IGS)

- IGS pilot project: TIGA (OS, DC, AC)
  Launched in 2001

- **Cumulative** GPS processing *versus* Homogenous GPS reprocessing
  Wöppelmann et al. (2007) in GPC

Dedicated Data Storage: 7 To
“Lustre” Data File System

Altix ICE 8200 (SGI)
Cluster Linux (2008 → 2010)
128 processors → 392
3. GPS vertical velocities from the ULR consortium

Santamaria-Gomez et al. (2012) available at www.sonel.org

- Calculation of uncertainties on velocities taking into account time-correlated noise
- 326 GPS velocities, from which 201 co-located at or near a tide gauge (<15km)

Median = 0.3 mm/yr
3. GPS velocities at TG... How well do they work?

Tide gauge records

- Stavanger +0.4 mm/yr
- Copenhagen +0.5 mm/yr
- Nedre Gavle -6.0 mm/yr

Annual MSL (mm) in northern Europe

- Seattle +2.0 mm/yr
- Victoria +0.6 mm/yr
- Neah Bay -1.7 mm/yr

Annual MSL (mm) in northwestern America

- Key West +2.3 mm/yr
- Pensacola +2.2 mm/yr
- Grand Isle +9.1 mm/yr
- Galveston +6.4 mm/yr

Annual MSL (mm) in Gulf of Mexico

- Stavanger +1.5 mm/yr
- Copenhagen +0.6 mm/yr
- Nedre Gavle +0.7 mm/yr

GIA-corrected tide gauge records

- +1.5 mm/yr
- +0.6 mm/yr
- +0.7 mm/yr

RMS 0.5 mm/yr

GPS-corrected tide gauge records

- +2.2 mm/yr
- +1.7 mm/yr
- +1.9 mm/yr

RMS 0.3 mm/yr

RMS 3.4 mm/yr
4. Studying Spatial Patterns of Sea Level Change

**Douglas (2001)**

*Figure 3.16* Acceleration component of relative sea levels.

*Figure 3.11* RLR-site sea level trends corrected for glacial isostatic adjustment.

Local VLM are the most likely source of spatial variability

---

*Le Provost (2001)*

Variations dues aux marées, aux vents, tourbillons dans des zones très actives, tempêtes, cyclones

Oscillation de l'Atlantique Nord, du Pacifique, récurrence de phénomènes comme El Niño

Variations saisonnières

Variations des tourbillons typiques
Station selection criteria:

- Tide gauge records > 50 yr from 1900
  - 70% of valid data
- Regional grouping based on correlation coefficients
- Nearest robust GPS velocity estimate
  - Same land (Islands)
  - GIA gradient of TG-GPS stations < 0.4 mm/yr
- Active tectonic areas: co-location or redundant GPS data

76 records grouped into 17 regions
4. GPS velocities at TG... How well do they work?
4. GPS velocities at TG... How well do they work?

Dispersion has reduced to 0.5 mm/yr
4. Spatial Patterns of Sea Level Change
4. Spatial Patterns of Sea Level Change

Marcos et al. (2013)  
Hunter et al. (2003)  
Testut et al. (2006)  
Woodworth et al. (2010)  

Map showing spatial patterns of sea level change with markers for multi-station, single-station, and other studies. The color bar indicates millimeters per year (mm/yr) with values ranging from 0.8 to 2.4 mm/yr.
4. Hemispheric Sea Level Change

Northern Hemisphere: $2.0 \pm 0.2$ mm/yr
Southern Hemisphere: $1.1 \pm 0.2$ mm/yr

Global:
- Average from regions: 1.8 mm/yr
- Area-weighted from Hemispheres: 1.5 mm/yr
5. Concluding remarks

- Revisited study of global sea-level rise over the past 100 years
  - Updated datasets:
    - Number of stations, time series completeness and length
  - State-of-the-art methods and corrections
    - e.g., Grouping with “Virtual station” technique
    - Vertical land motion (VLM) with best GPS velocities

- Evidence for a differential sea-level rise between hemispheres
  - Robust observational evidence
    - within the limitations of the datasets, affecting any previous study

- Major consequences in terms of sea level research
  - Reconcile past estimates: the crucial role of geographic sampling
  - Striving to close the budget of 20th global sea level rise is an elusive goal
  - Research avenue for explaining the cause of this pattern…

- VLM are an important source of spatial variability of sea level trends
  - Masking the detection of climate-related signals and fingerprints
    - GIA models are limited by essence to the GIA process
    - VLM corrections are essential, from other sources e.g. GPS
    -GLOSS (IOC/Unesco) requires GPS at TGs and making the data available