Validation of Climate Models Using Ground-Based GNSS Observations

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Structure of presentation

• Introduction to global and regional climate models

• Ground-based GNSS provides the integrated water vapour (IWV) content in the atmosphere above each site — measured in kg/m²

• Correlation studies: trends in IWV vs. temperature trends

• Review of relevant error sources when monitoring IWV over long time scales

• Ongoing and planned work
Part 1: Introduction to global and regional climate models

GCM = General Circulation Model
or
Global Climate Model

RCM = Regional Climate Model

Weather Forecasts vs. Climate Models

- Both are based on similar models
- Forecasts starts at a given situation and calculates weather parameters for later time epochs
- The dynamics of the atmosphere implies that reliable deterministic forecasts cannot be made for time periods approaching ten days or longer
- Neither a weather forecast model nor a climate model can predict the weather at a specific time in the future
- However, the models can be applied to long time scales
- Climate models simulate and describe the statistics of the weather (parameters), often mean values over 30 years
In addition: cloud dynamics, droplets, aerosols, and radiation processes are modeled at scales down to $10^{-9}$ m.

Ongoing Warming

New records of high temperature occur often

2009 was one of the warmest years since the start of observations around 1860

2000–2009 was the warmest decade

Sources:
- Upper - Climate Research Unit at the University of East Anglia, Norwich
- Lower - NASA's Goddard Institute for Space Studies
How do the GCMs manage the 20th Century

Simulated annual global mean surface temperatures

(a) Natural
(b) Anthropogenic
(c) All forcings

IPCC, 2001

Continued increase of CO$_2$ in the atmosphere

Changes in the CO$_2$ concentration

Variations during the last 800,000 years

Sources: IPCC, CDIAC – Carbon Dioxide Information Analysis Center
Future Changes

Example: Model Results for Sweden

Temperature change in Northern Sweden using the scenario A1B for 2071–2100 compared to 1961–1990

The result is strongly depending on the choice of GCM!
Assessment of Climate Models

Today's GCMs reproduce much of the observed climate, both in terms of long term averages, variabilities, and extremes.

Weaknesses:
- Relatively coarse resolution (>100km),
- Do not include all relevant processes (e.g. feed-back mechanisms in the carbon cycle)
- All processes relevant to the climate system are not fully understood (in particular clouds)

Available observational data for validation?

- Ground based
  - Relatively long time series
  - Problems: homogeneity and coverage
- Radiosondes
  - Limited coverage
  - Available since the 50ies
- Satellite data
  - Global coverage
  - Available since the 70ies
- Re-analyses
  - Global coverage
  - Available since the 50ies
Limitations of a GCM

- All processes are not resolved: approximations for e.g. turbulence, clouds and precipitation, ...
- Parameterizations express small scale phenomena using large scale parameters
- GCMs (as well as NWPs) must compromise between resolution and computational speed

Regional Climate Modelling

GCM  RCM
GCM – RCM Comparison
Simulated winter (DJF) MSLP and precipitation (1961–1990)

Regional details are not captured by GCMs!

Global climate model (CCSM3)
Regional climate model (RCA3)
(with lateral boundary conditions from CCSM3)

Towards Higher Resolution

- GCMs is usually based on horizontal resolutions of 100–300 km
- Occasional test runs have used 25 km

- RCMs is usually based on horizontal resolutions of 25–50 km
- Occasional test runs have used 10 km
- The Rossby Centre has carried out comparisons using resolutions of 50, 25, 12.5 och 6.25 km
- The present models limits the resolution to approximately 5 km
- Operational NWP use 22, 11, and 5 km, and test as carried out using 2.5 km

- With a higher resolution large improvements are expected for precipitation and wind
Part 2:

Using Ground-Based GNSS for applications in climate research

The IWV data are fitted to the model:

\[
IWV = I_0 + At + B \sin(2\pi t) + C \cos(2\pi t) + D \sin(4\pi t) + E \cos(4\pi t)
\]

where \( t \) is the time in years and the coefficients \( I_0, A, B, C, D, E \) are estimated.

Both annual and semi-annual terms are used to describe the seasonal variations.

This is motivated from the Lomb-Scargle periodograms:
IWV trends over Sweden and Finland

- Analysis period: 10 years, November 16, 1996 – November 15, 2006
- IWV trends varies from -0.5 to +1.5 kg/m²/decade
- Uncertainties in the trends are ~0.4 kg/m²/decade (taking temporal correlations into account) (Nilsson and Elgered, JGR, 2008)

Estimating trends in ground temperature from observed monthly means

The temperature data are fitted to the same type of model as earlier used for the GPS IWV results:

\[ T = T_0 + At + B \sin(2\pi t) + C \cos(2\pi t) + D \sin(4\pi t) + E \cos(4\pi t) \]

where \( t \) is the time in years and the coefficients \( T_0, A, B, C, D, E \) are estimated.
Correlation between trends in ground temperature and IWV 1996–2006


GNSS Error Sources

- Ionospheric effects:
  including higher order terms => < 0.04 kg/m²

- Effects due to phase centre variations (PCVs):
  - transmitting antennas on satellites
  - receiving antennas on the ground
Effects due to antenna phase centre variations (PCVs)

PCVs as a function of the satellite nadir angle

PCVs as a function of the receiver elevation angle


During the period mid 2003 to mid 2008 the satellite type IIR-B/M is replacing type II/IIA

Real data from Onsala: elev. cutoff 10° Trend: 0.07 kg/m²/year

Simulated data: elev. cutoff 10° Trend: 0.06 kg/m²/year

Using sites at different latitudes and different elevation cut-off angles, simulations show that ignoring APC variations in the satellite can lead to an additional IWV trend of up to 0.15 kg/m²/year for regular GPS processing for the time period 2003–2008.
Effects due to antenna phase centre variations

The impact of the ECCOSORB: offset in the IWV decreases from 1.6 kg/m² to 0.3 kg/m² compared to results from the ONSA IGS site

No significant (< 0.4 kg/m² in IWV) impact detected due to the use of radome

(Ning et al., The impact of microwave absorber and radome geometries on GNSS measurements of station coordinates and atmospheric water vapour, Advances in Space Research, in press, 2010)

Conclusion: GNSS is capable of monitoring IWV with high accuracy over long time scales, but systematic errors cannot be ignored

Plans for 2010–2011:
- Process the GPS data from > 100 European sites from 1996–2009 (inclusive), GIPSY 5.0
- IWV comparisons to climate models used at SMHI
- Try to understand the differences …