# Validation of Climate Models Using Ground-Based GNSS Observations

Gunnar Elgered[1], Jan Johansson[1,2], Erik Kjellström[3], Ragne Emardson[2], Per Jarlemark[2], Tobias Nilsson[1,4], Tong Ning[1], Ulrika Willén[3]

*[1]Dep. of Earth and Space Sciences, Onsala Space Observatory, SE-43992 Onsala*
*[2]SP Technical Research Institute of Sweden, SE-50115 Borås*
*[3]Swedish Meteorological and Hydrological Institute, SE-60176 Norrköping*
*[4]Institute of Geodesy and Geophysics, Vienna Univ. of Technol., AT-1040, Vienna*





## 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/m$^2$
- 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

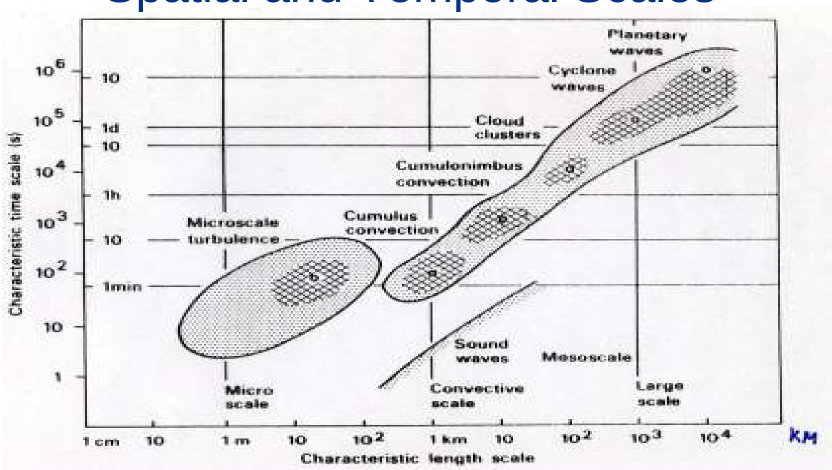




## Weather Forecasts vs. Climate Models

- 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

# Spatial and Temporal Scales




In addition: cloud dynamics, droplets, aerosols, and radiation processes are modeled at scales down to $10^{-9}$ m





# Ongoing Warming

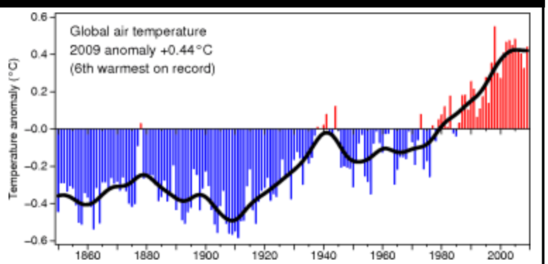
New records of high temperature occur often

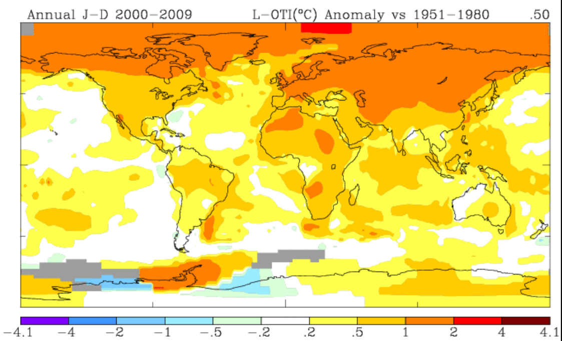
2009 was one of the warmest years since the start of observations around 1860

2000–2009 was the warmest decade

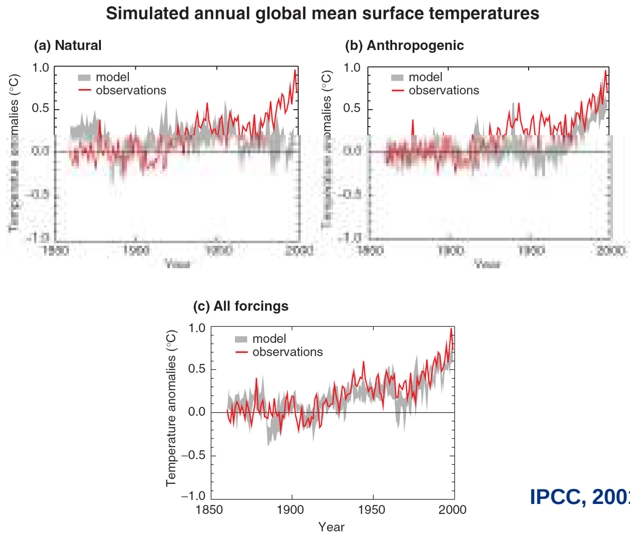
Sources:
Upper - Climate Research Unit at the University of East Anglia, Norwich

Lower - NASA's Goddard Institute for Space Studies



# How do the GCMs manage the 20th Century

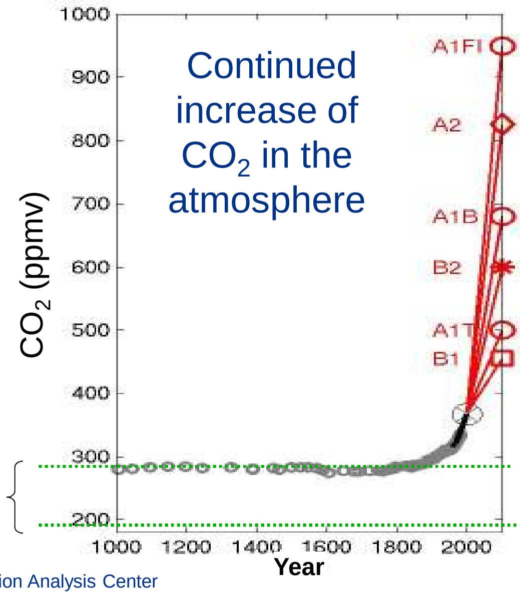



**IPCC, 2001**





# Changes in the $CO_2$ concentration

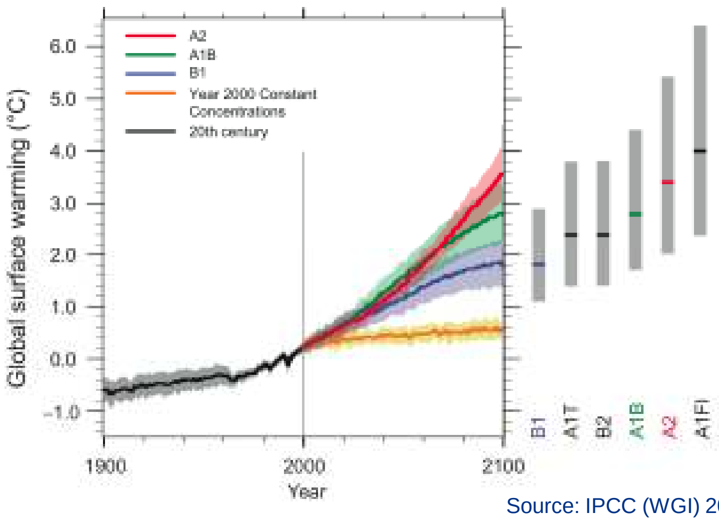



Variations during the last 800,000 years

Sources: IPCC, CDIAC = Carbon Dioxide Information Analysis Center

# Future Changes

0 defines the mean value for the period 1980-1999




Source: IPCC (WGI) 2007

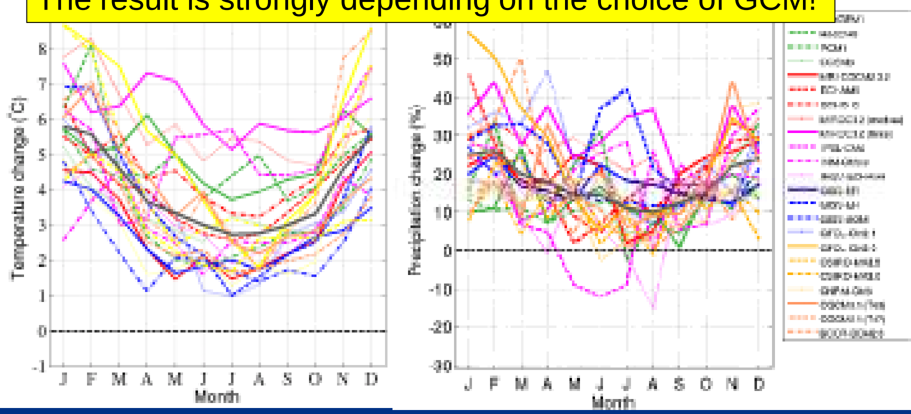




# Example: Model Results for Sweden

Temperature change in Northern Sweden using the scenario A1B for 2071–2100 compared to1961–1990

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.

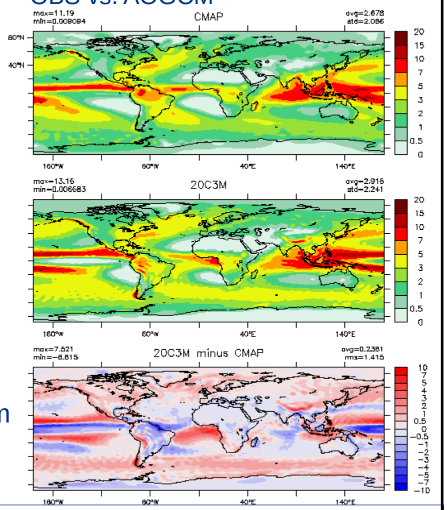
Weaknesses:

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)

Annual mean precipitation (mm/day): OBS vs. AOGCM



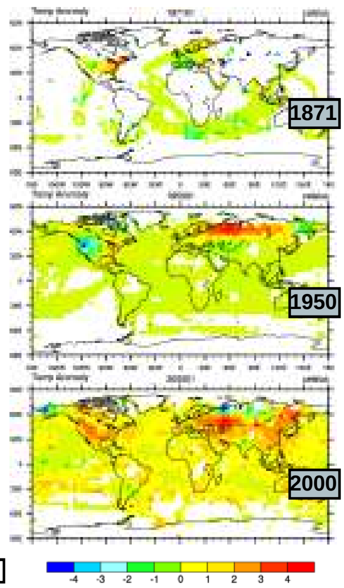

OBS = CMAP = CPC (climate prediction centre) Merged Analysis of Precipitation
AOGCM = atmosphere-ocean coupled general circulation model
20C3M = 20th century forcing, i.e. Greenhouse gases increasing as observed during the 20th century





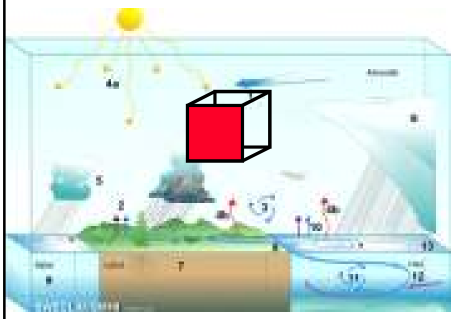
# Available observational data for validation?

- 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




Gridded temperature anomalies from CRU

# Limitations of a GCM

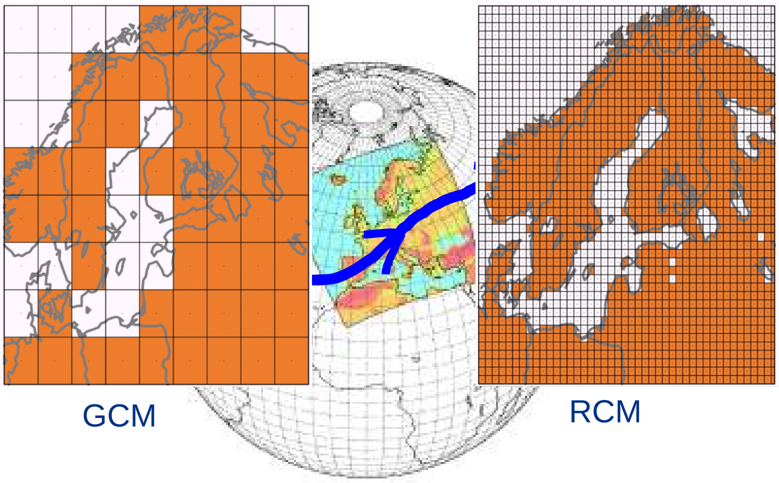


- All processes are not resolved: approximations for e.g. turbulence, clouds and precipitation, …
- Parameterizations express small scale phenomena using large scale parameters
- GCMs (as well as NWPs) must compromise between resolution and computational speed



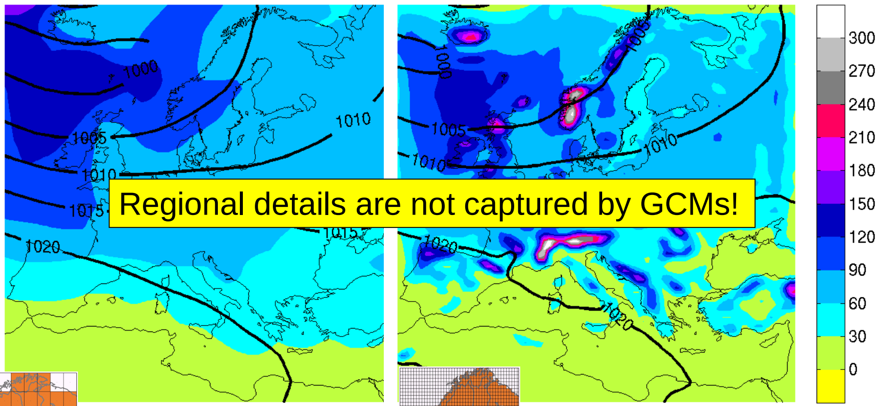


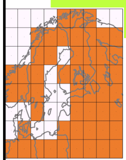
# Regional Climate Modelling



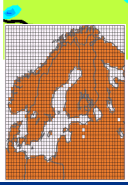
# GCM – RCM Comparison

## Simulated winter (DJF) MSLP and precipitation (1961–1990)



**Global climate model (CCSM3)**



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

CCSM3 = Community Climate System Model version 3





# Towards Higher Resolution

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

- RCMs is usually based on horisontal 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:

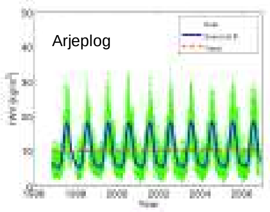
# Using Ground-Based GNSS for applications in climate research

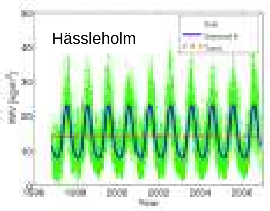




# Estimating IWV trends from ten years of GPS data

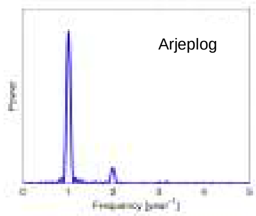
Lidberg et al., J. Geod., 2007

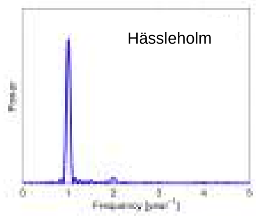



Both annual and semi-annual terms are used to describe the seasonal variations.

This is motivated from the Lomb-Scargle periodograms:



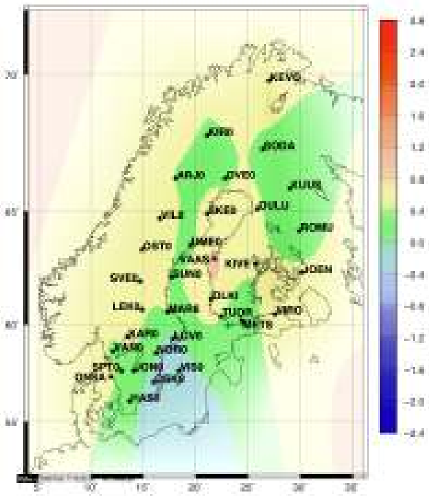




The IWV data are fitted to the model:

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

where *t* is the time in years and the coefficients $I_0$, *A, B, C, D, E* are estimated.

# IWV trends over Sweden and Finland



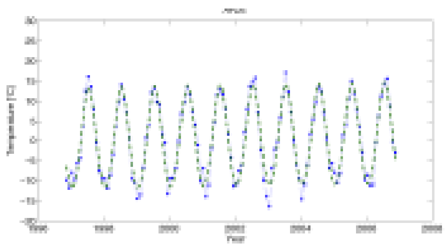
(Nilsson and Elgered, JGR, 2008)

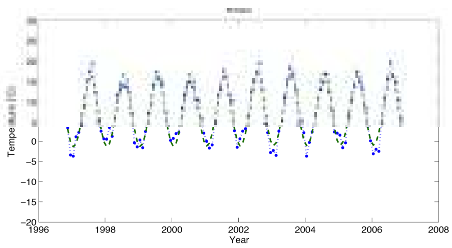
- Analysis period: 10 years, November 16, 1996 – November 15, 2006
- IWV trends varies from –0.5 to +1.5 kg/m$^2$/decade
- Uncertainties in the trends are ~0.4 kg/m$^2$/decade (taking temporal correlations into account)





# Estimating trends in ground temperature from observed monthly means



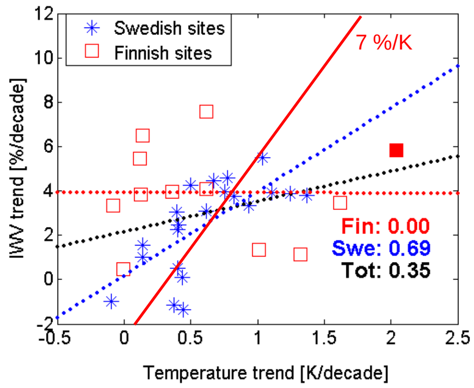


The temperature data are fitted to the same type of model as earlier used for the GPS IWV results:

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

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




Assuming conservation of relative humidity [Trenberth et al., Bull. Am. Meteorol. Soc., 2003] we obtain for the IWV ~ 7 [%/K].





# GNSS Error Sources

- Ionospheric effects:

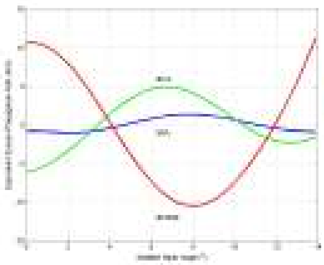
  including higher order terms => < 0.04 kg/m$^2$

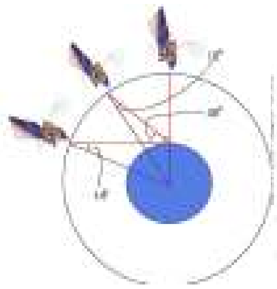
- Effects due to phase centre variations (PCVs):
  - transmitting antennas on satellites
  - receiving antennas on the ground

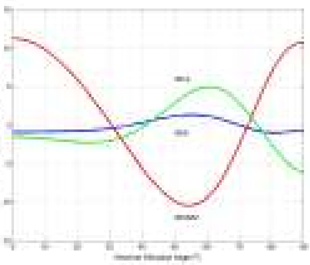
# Effects due to antenna phase centre variations (PCVs)

PCVs as a function of the satellite nadir angle

PCVs as a function of the receiver elevation angle







Jarlemark et al., Ground-Based GPS for Validation of Climate Models: the Impact of Satellite Antenna Phase Center Variations, IEEE Trans. Geosci. Rem. Sens., in press, 2010.

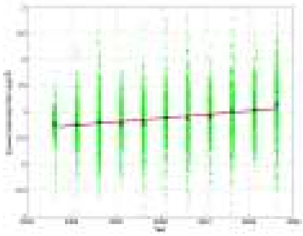




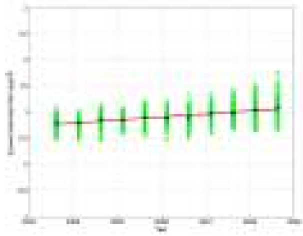
# Effects due to antenna phase centre variations (cont.)

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/m$^2$/year



Simulated data:
elev. cutoff 10°
Trend: 0.06 kg/m$^2$/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/m$^2$/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/m$^2$ to 0.3 kg/m$^2$ compared to results from the ONSA IGS site

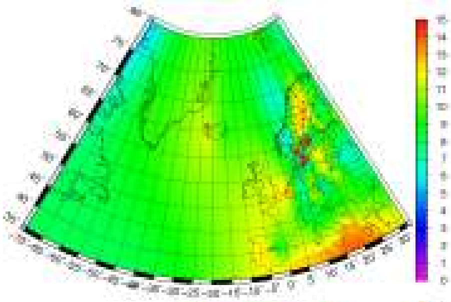
No significant (< 0.4 kg/m$^2$ in IWV) impact detected due to the use of radome

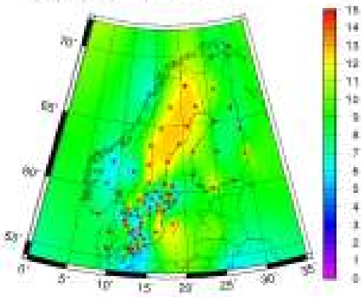
(Ning et al., The impact of microwave absorber and radome geometries on GNSS measurements of station coordinates and atmospheric water vapour, Advances in Space Research, in press, 2010)





## 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 …