IGS phase center model igs08.atx - Current status and future improvements

Ralf Schmid

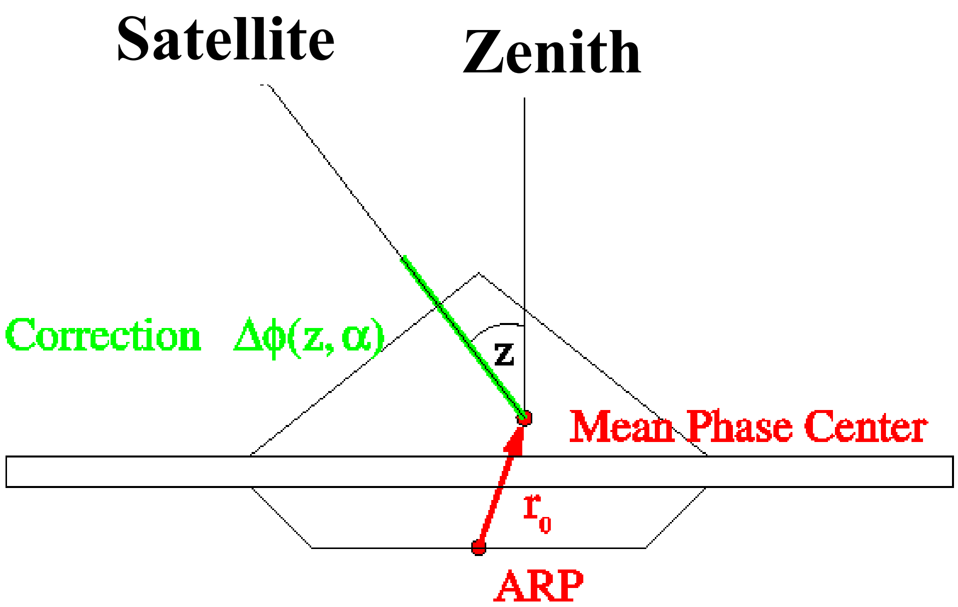
Institut für Astronomische und Physikalische Geodäsie
Technische Universität München

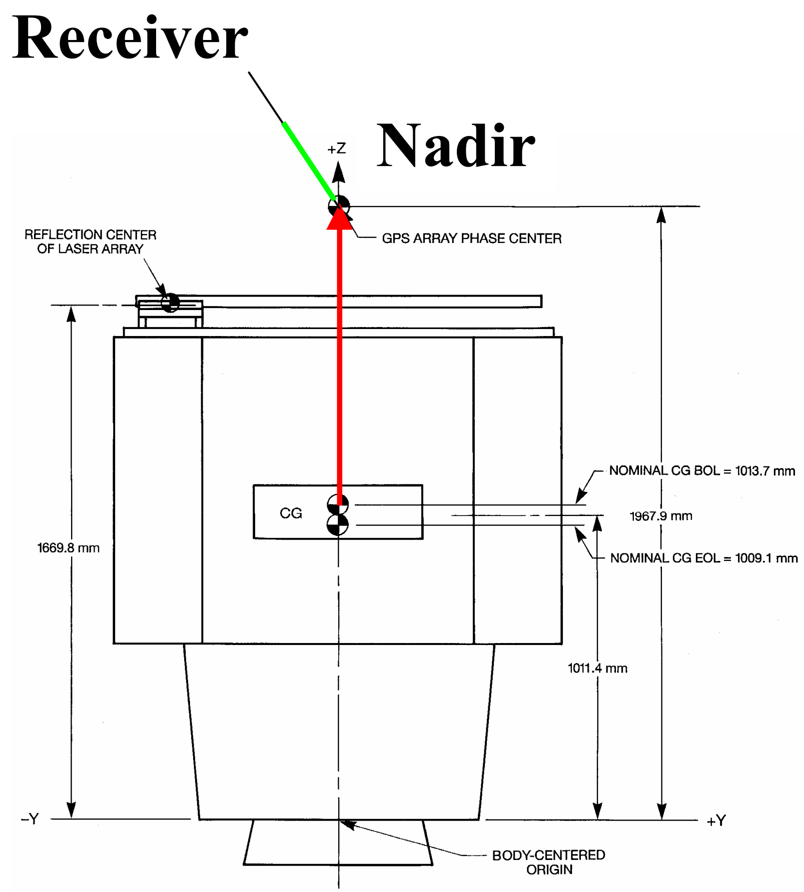
Many thanks to all the members of the IGS Antenna Working Group!

Outline

- **Background**
  - Antenna phase center modeling
  - Phase center calibration: absolute vs. relative
- **Benefit** from first absolute IGS model igs05.atx
  - Global terrestrial scale
  - Troposphere parameters
- From igs05.atx to **igs08.atx**
- **Deficiencies** of igs08.atx
  - Azimuth-dependent satellite antenna PCVs
  - PCVs for big nadir angles
  - Dependence on the ITRF scale

Antenna phase center modeling

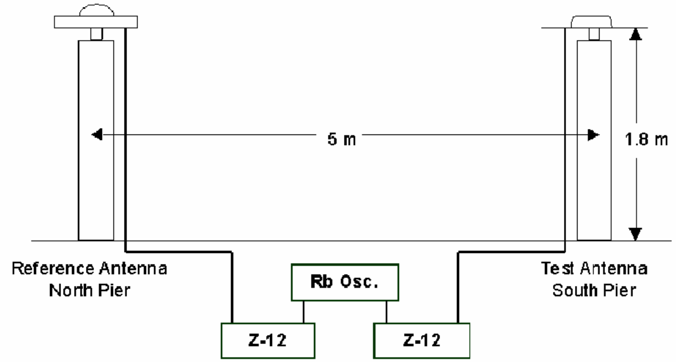




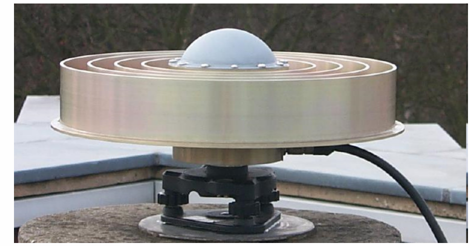
Phase center offset (PCO): from ARP/CoM to mean phase center

Phase center variations (PCVs): elevation- and azimuth-dependent corrections

Relative field calibration

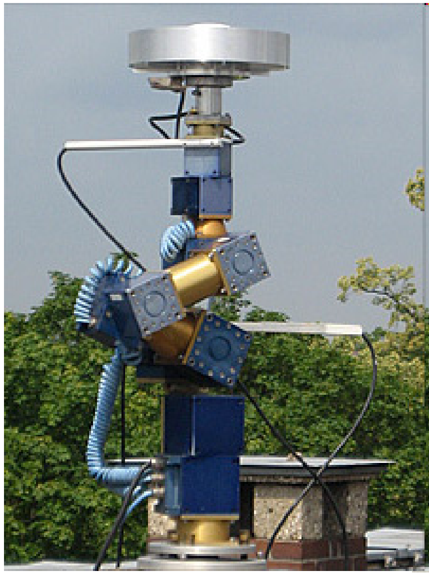


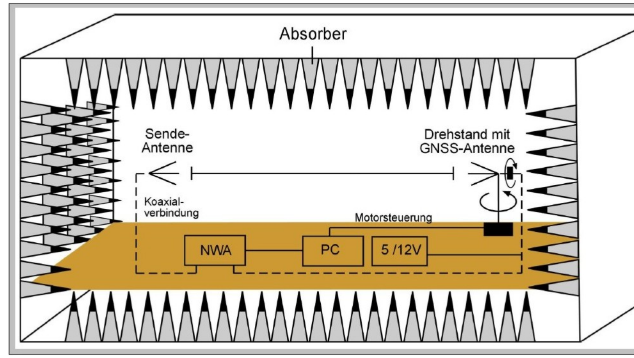
Mader (1999)



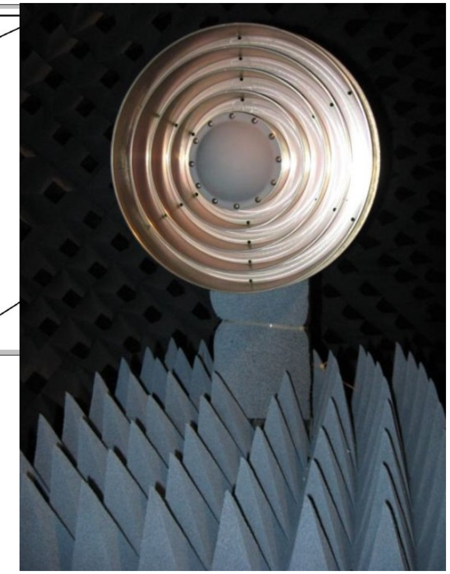
- PCVs relative to the **reference antenna AOAD/M_T** (Dorne Margolin chokering antenna)
- Arbitrary assumption: **PCV (AOAD/M_T) = 0**
- Systematic errors on **long baselines** as identical satellites appear at different elevations at the two tracking stations
- In use within the IGS from June 1996 until November 2006

Absolute receiver antenna calibration



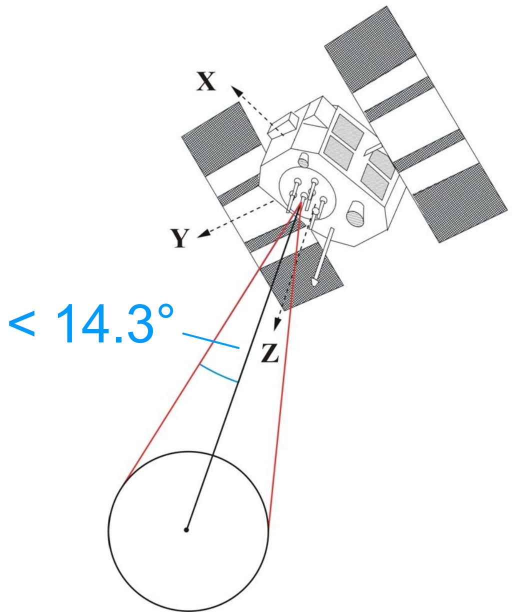


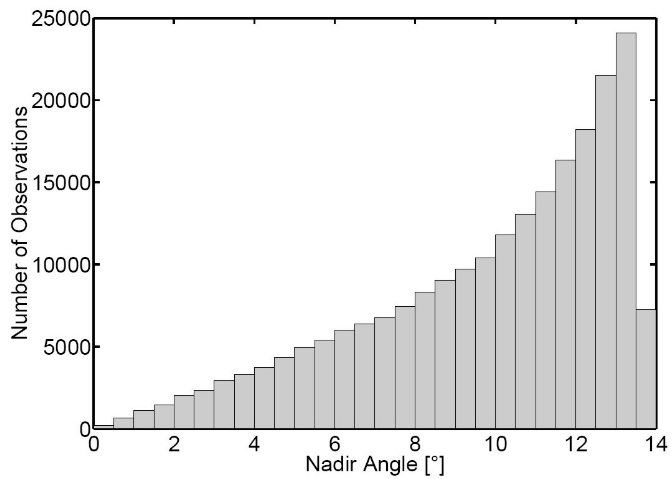
Zeimetz (2010)

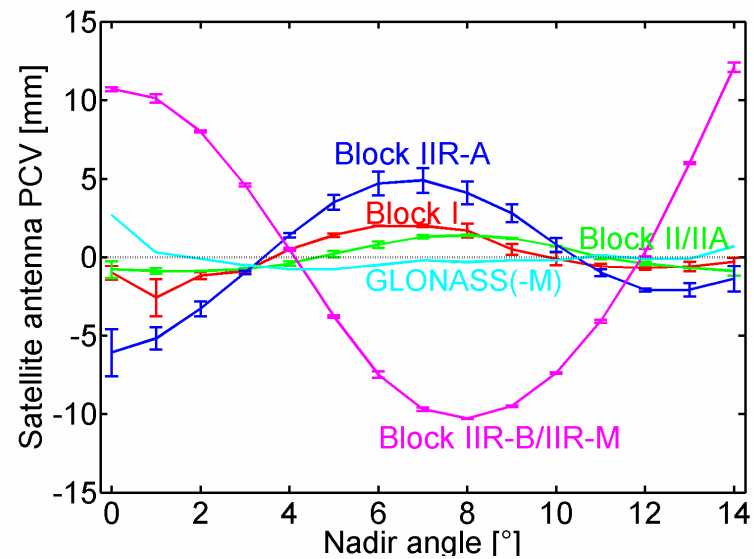


- Robot (using real GNSS signals) or anechoic chamber (artificial signals) approach
- PCVs **down to 0° elevation** for different **azimuth** angles
- The two independent approaches **agree on the 1 mm level**
- Cause large terrestrial scale bias, if satellite antennas unconsidered
- In use within the IGS since November 2006

Satellite antenna phase center modeling



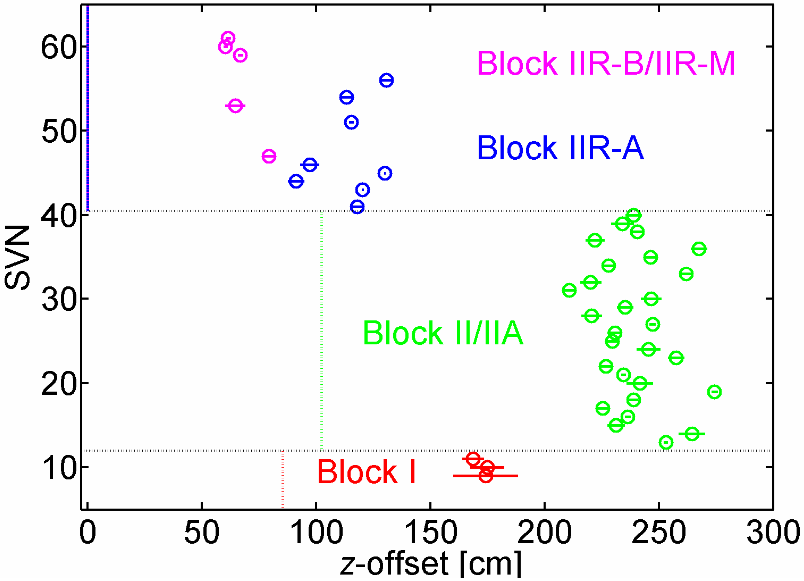




- **maximum nadir angle is small**: < 14.3° in the GPS case
- **uneven distribution** of observations w.r.t. the nadir angle
- PCO and PCVs cannot be estimated simultaneously
- if terrestrial data is used, **receiver antenna calibrations and station coordinates (global scale) have to be fixed**
- absolute PCV level cannot be separated from the clock

IGS transition to absolute phase center modeling

Model	Receiver antenna			Satellite antenna	
	PCO	PCV	Radome	PCO	PCV
igs01.pcv (1996-2006)	**relative** to reference antenna **AOAD/M_T**		**ignored**	block-specific	**ignored**
igs05.atx (2006-2011)	**absolute**, i.e., independent of a reference antenna		considered, if calibration available	satellite-specific	block-specific

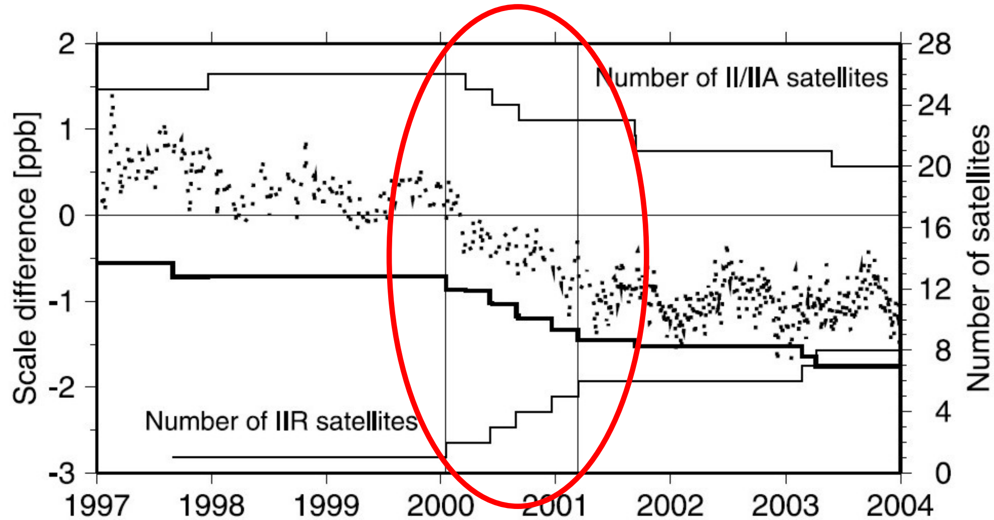


Benefit from absolute model igs05.atx

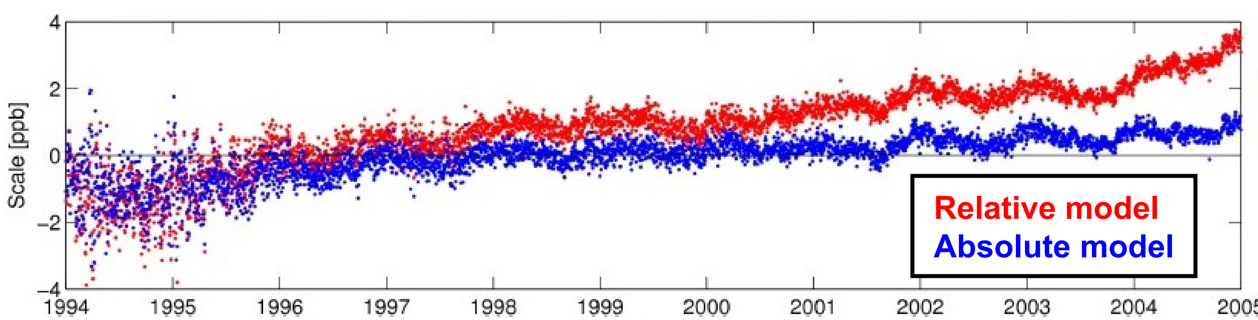
- G. Beutler (1998): "The *Bermuda Triangle* troposphere, station heights, GPS antennas is the final destination for many GPS analysts."
- As with absolute phase center corrections one of the elevation-dependent effects could be improved, other, highly correlated, **elevation-dependent effects should benefit**:
  - **station heights**: better stability of the global scale, smaller height biases w.r.t. other space geodetic techniques, smaller coordinate jumps due to antenna changes, etc.
  - **troposphere parameters**

Benefit for the terrestrial scale rate

Ge et al. (2005): Changes in the satellite constellation cause changes in the global terrestrial scale, if satellite antenna *z*-offsets are incorrect



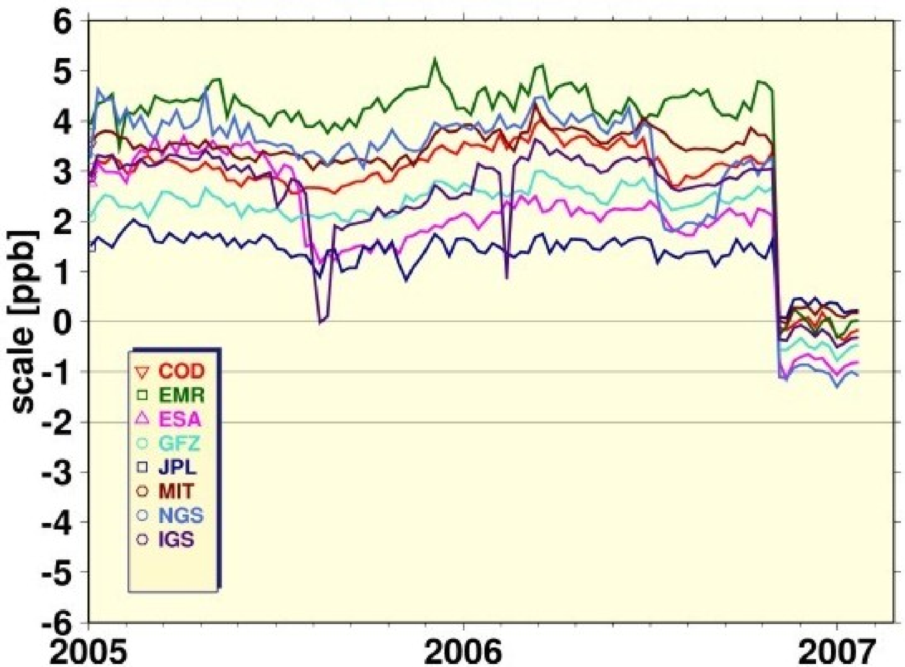
Gendt et al. (2007): Absolute phase center corrections reduce IGS scale rate



Scale rate (ppb/y) to RF:

	IGb00	IGS05
Ant rela	0.35	0.24
Ant abs	0.15	0.04

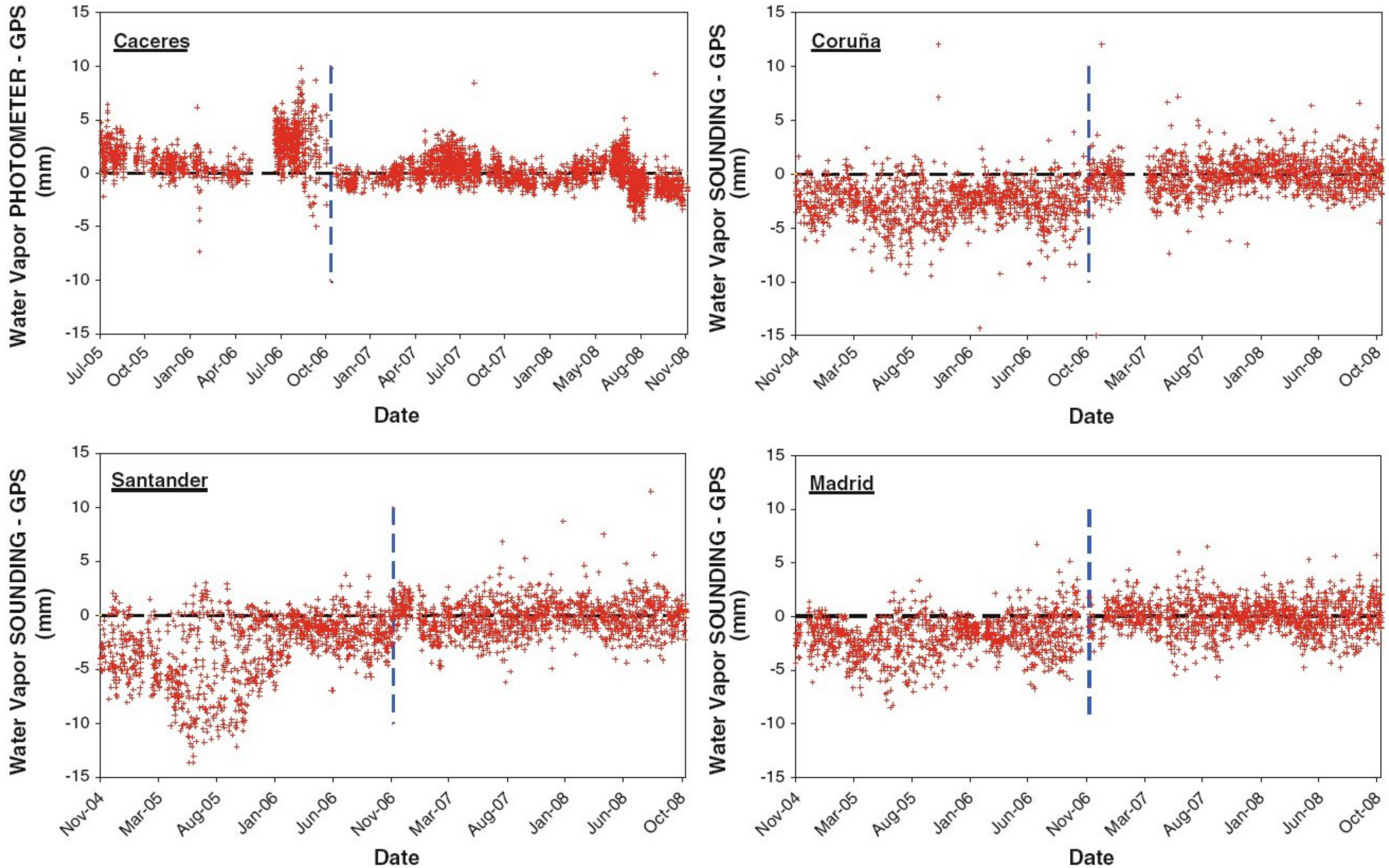
Benefit for the global terrestrial IGS scale



Gendt et al. (2007)

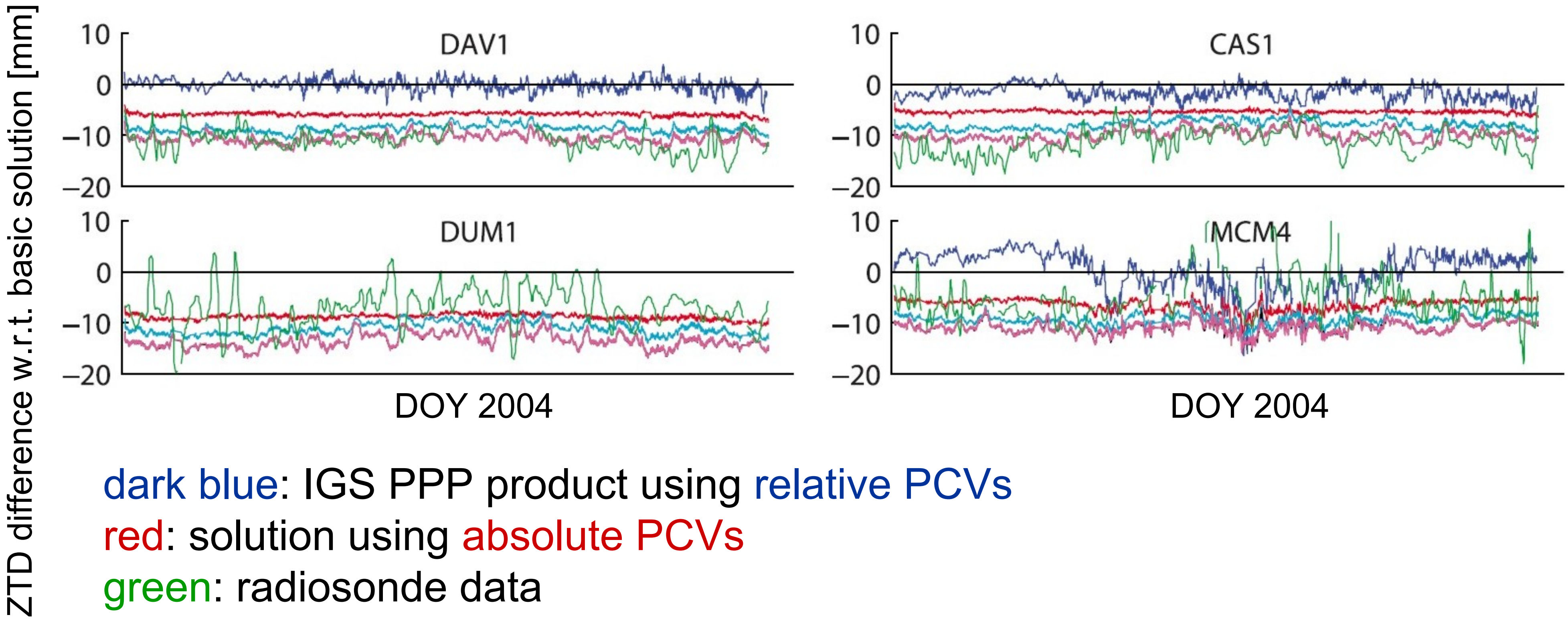
- **better scale consistency between ACs**, as identical satellite antenna corrections are used (not the case before November 2006!)
- **better agreement with ITRF scale**, as the latter was fixed for the estimation of satellite antenna corrections

Benefit for troposphere parameters (I)



Ortiz de Galisteo et al. (2010): "Before November 6, 2006, the data calculated with the GPS ground receivers contained a systematic error, overestimating the precipitable water vapor in 2-3 mm. After November 6, 2006, this **wet bias practically decreases to zero**."

Benefit for troposphere parameters (II)



dark blue: IGS PPP product using relative PCVs
red: solution using absolute PCVs
green: radiosonde data

Thomas et al. (2011): "Our conclusion is that, in Antarctica at least, a proportion of the widely observed **bias** between GPS and radiosonde measurements **can be explained by earlier GPS analysis deficiencies**."

Why igs08.atx?

- **igs05.atx** was approximately consistent with **IGS05** (IGS realization of ITRF2005)
- Altamimi et al. (2011): **scale difference** between ITRF2008 (released end of May 2010) and ITRF2005 of **-0.94 ppb**
- Zhu et al. (2003): Δz [m] ≈ -0.13 · Δscale [ppb]
  -0.94 ppb correspond to about **+12.2 cm** (too big to ignore!)

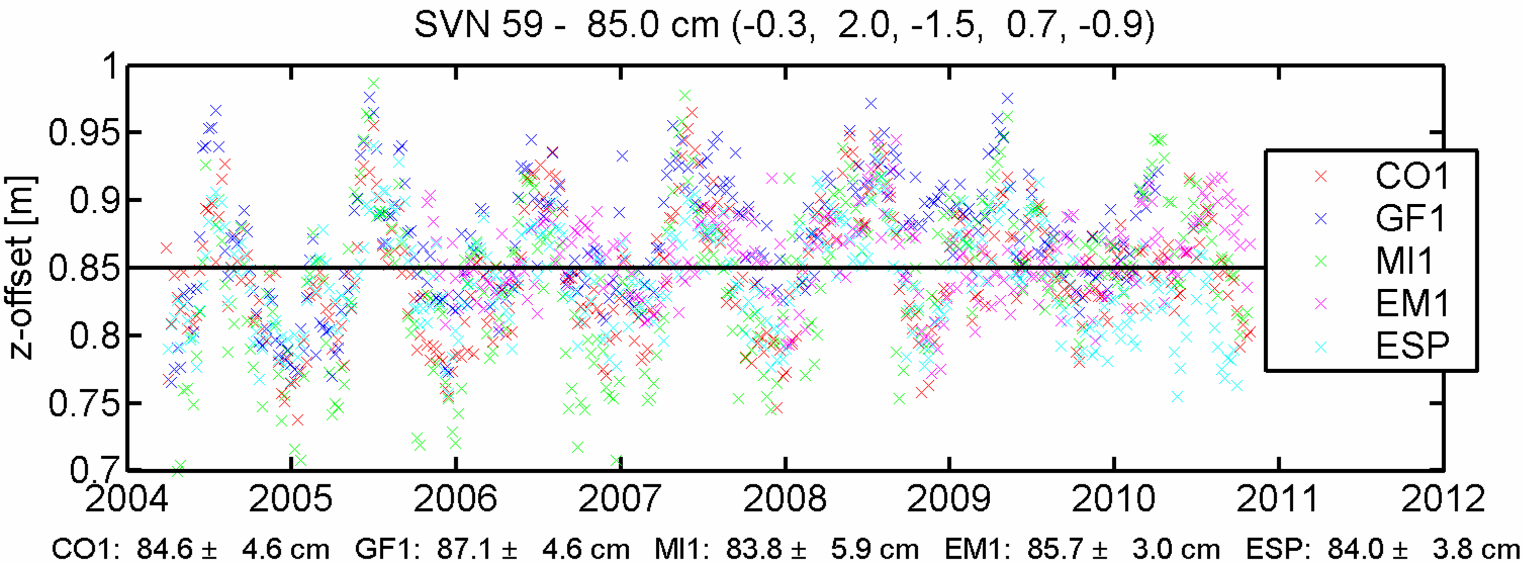
Problems to be solved at the same time:

- igs05.atx only contained block mean values for satellites launched between 2006 and 2010, i.e., no satellite-specific estimates
- especially important for GLONASS, as the constellation completely changed since 2006
- receiver antenna calibrations had not been updated since 2006 for consistency reasons

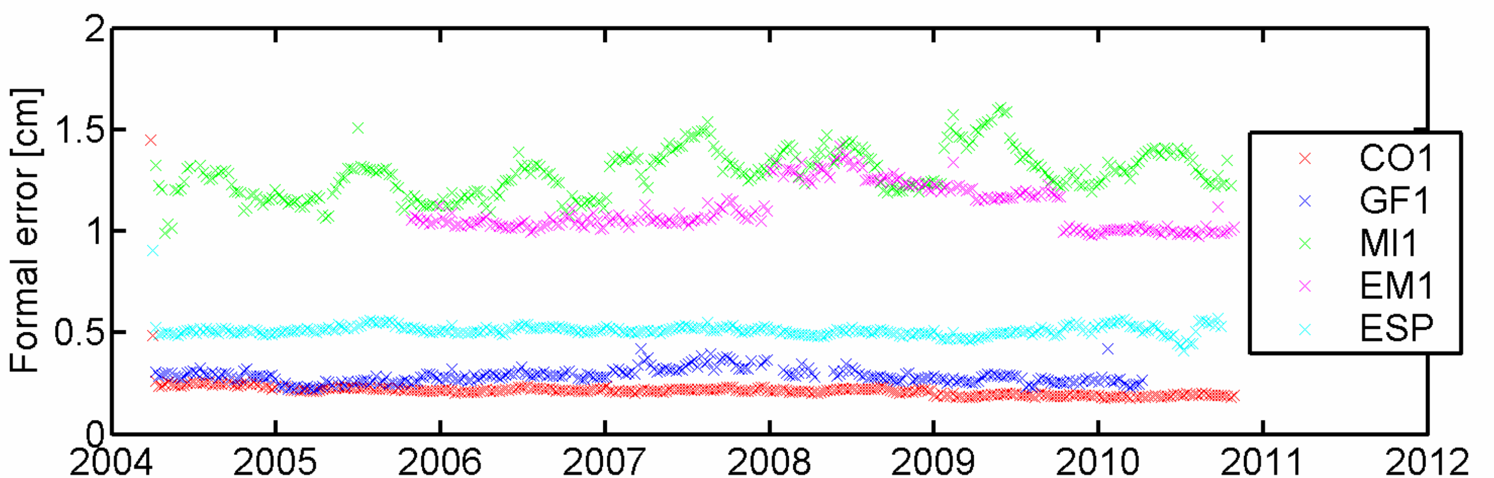
Strategy to derive igs08.atx

1) Update of **receiver antenna calibrations**:
   - get latest mean calibration results for each antenna type from Geo++
   - include corrections for the GLONASS frequencies, if available
   - correct known inconsistencies
2) Correction of IGS station coordinates to account for calibration updates: ITRF2008 → IGS08
3) Estimation of **GPS satellite antenna *z*-offsets** from reprocessed (1994-2007) and operational (2008-2010) weekly SINEX files of five ACs with ITRF2008/IGS08 and igs05.atx PCVs kept fixed
4) Estimation of **GLONASS satellite antenna corrections** from separate long-term solutions of CODE and ESOC with GPS satellite antenna corrections kept fixed
5) Common release of IGS08 and igs08.atx

GPS satellite antenna *z*-offset time series (I)

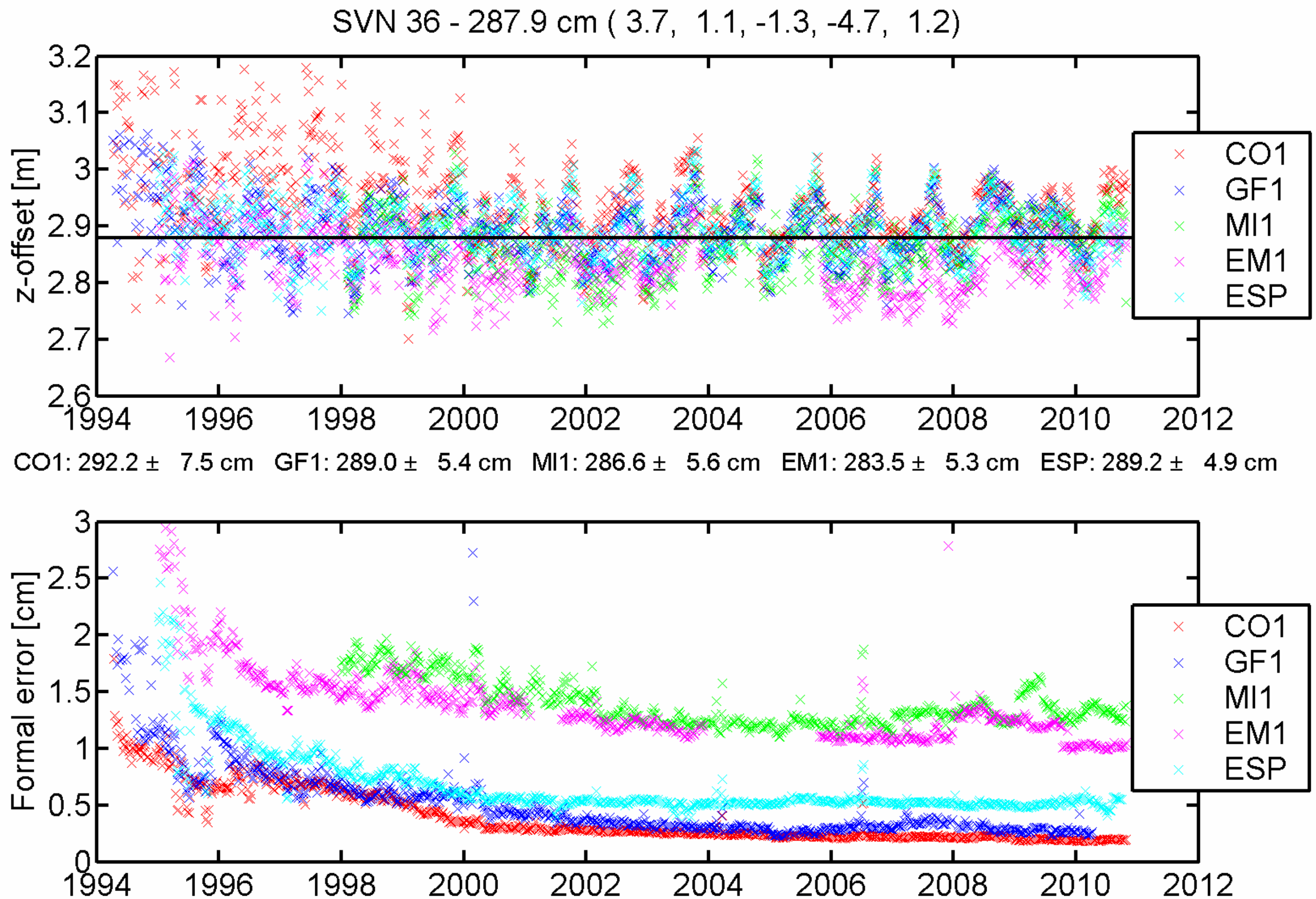


only small biases between ACs



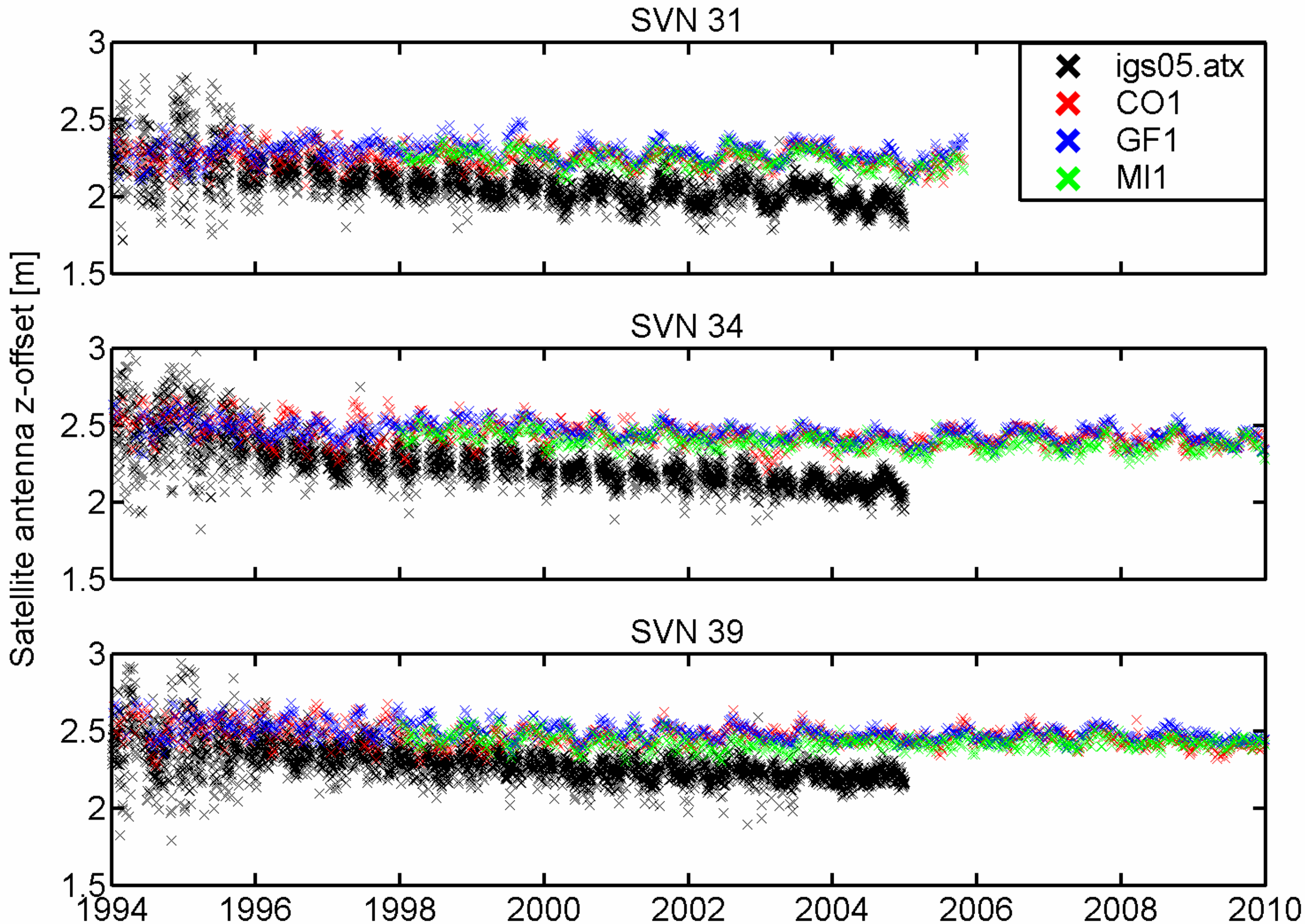
formal errors by far too optimistic

GPS satellite antenna *z*-offset time series (II)



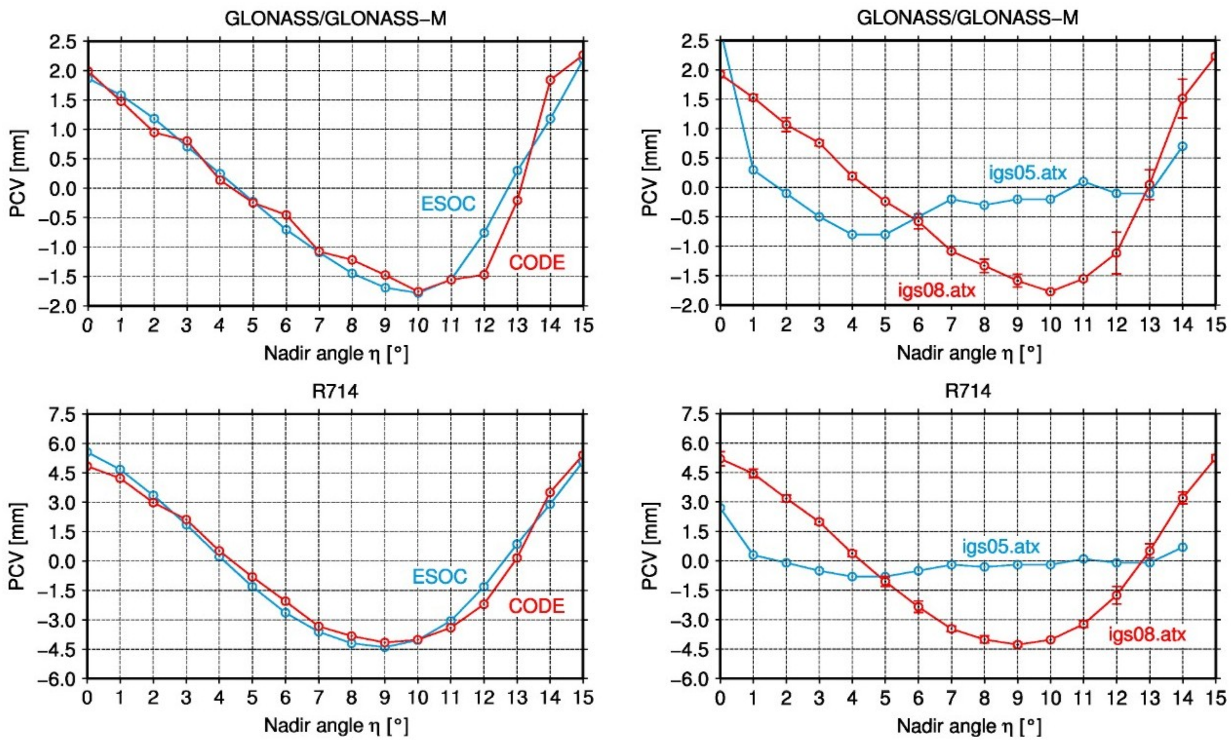
"Annual" signal in *z*-offset time series probably connected to **deficiencies in the modeling of orbits** ("draconitic period") **and station coordinates** (aliased loading effects)

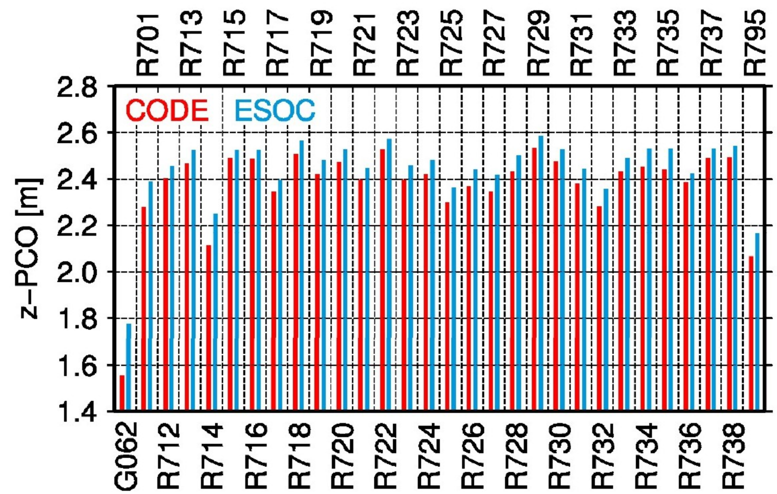
Trends in z-offset time series



Significant trend in igs05.atx time series (due to error in the mean vertical velocity of IGb00) has disappeared with igs08.atx

GLONASS estimates by CODE and ESOC





Dilssner & Dach et al. (2011)

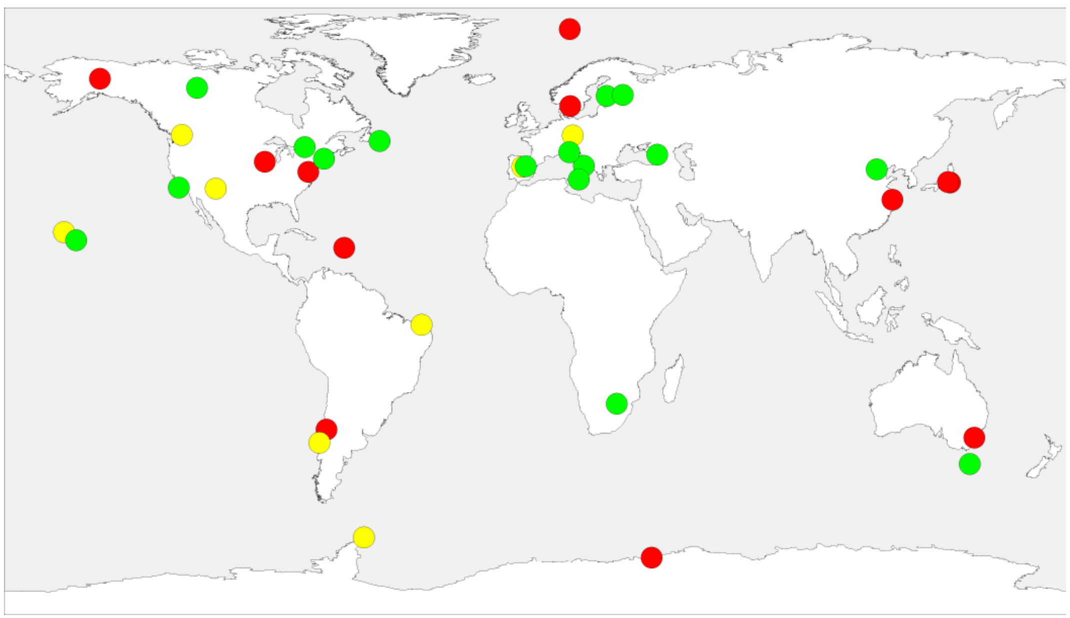
Considerable improvement compared to igs05.atx: more ACs, more data, more satellites, more tracking stations, extension w.r.t. nadir angle

IGS network: receiver antenna calibration status

Statistics for stations in the IGS network (December 2009):

Model	**absolute** calibration	**converted** field calibration	**uncalibrated** antenna/ radome combination
igs05.atx	62%	18%	20%
igs08.atx	**69%**	**11%**	**20%**

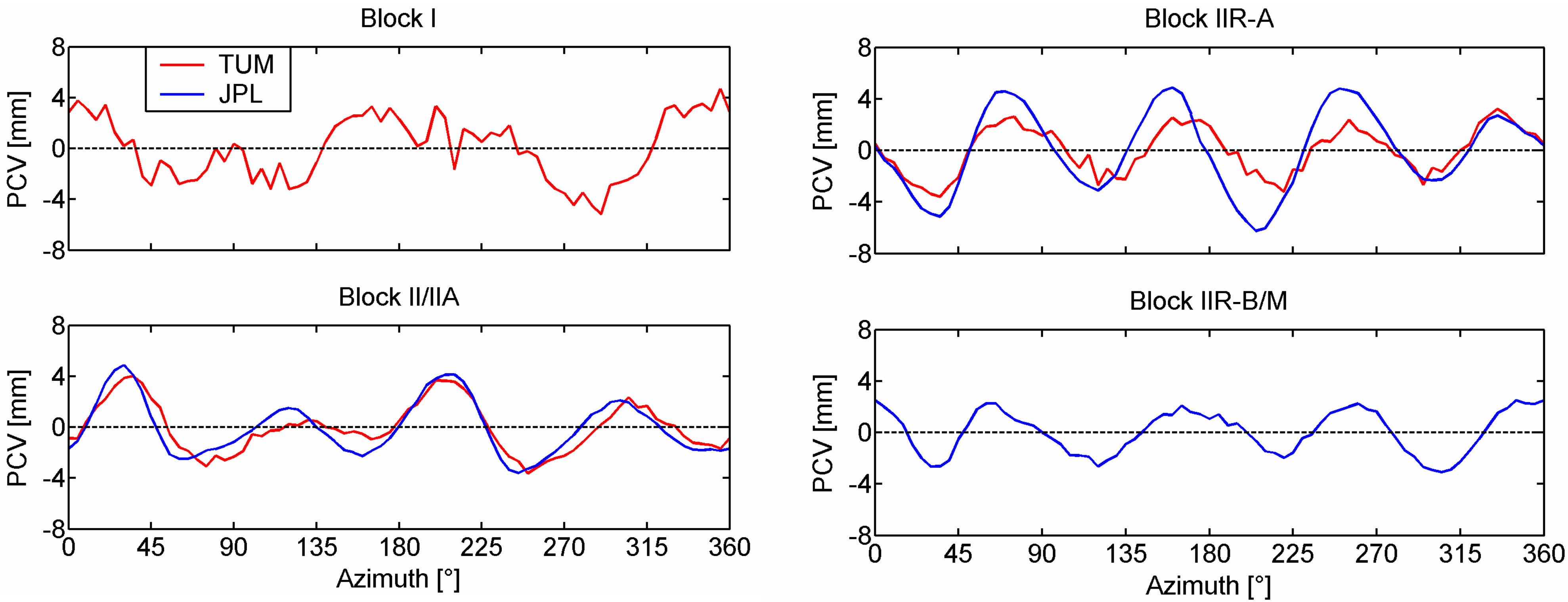
Local ties between GPS and VLBI:



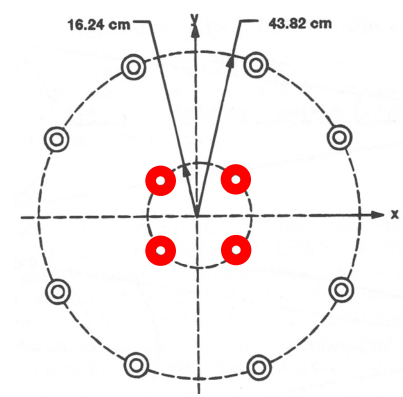
igs05.atx vs. igs08.atx

	igs05.atx	igs08.atx
GPS satellite antennas	11 years of data, 2 ACs	16 years of data, 5 ACs
	solutions aligned to IGb00 (based on relative phase center corr.)	solutions aligned to IGS08, i.e., full consistency with reference frame
	trend-correction due to error in mean vertical velocity of IGb00	no common z-offset trend
	radome calibrations not considered	available radome calibrations applied
	block mean values for satellites launched since 2006	satellite-specific estimates for 8 latest satellites
GLONASS sat. ant.	15 months of data, 1 AC	7/2.5 years of data, 2 ACs
Receiver antennas	robot calibrations for about 60% of the IGS stations	robot calibrations for about 70% of the IGS stations
	GPS-specific corrections only	GPS- and GLONASS-specific corrections

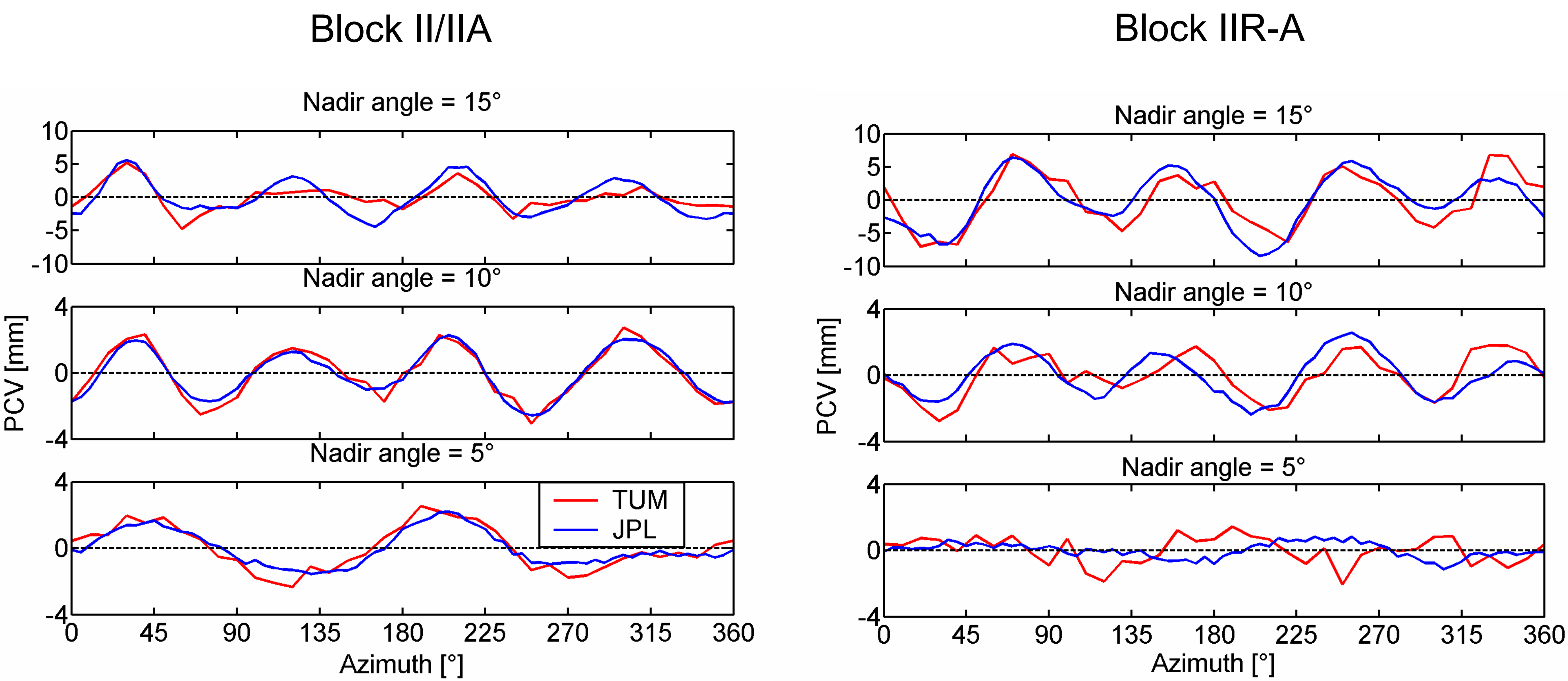
Azimuth-dependent PCVs (nadir angle = 14°)



- TUM results based on a few days of data only (Schmid et al., 2005)
- JPL values shifted by 90° in azimuth direction
- different resolution in nadir: 14° (TUM), 1° (JPL)

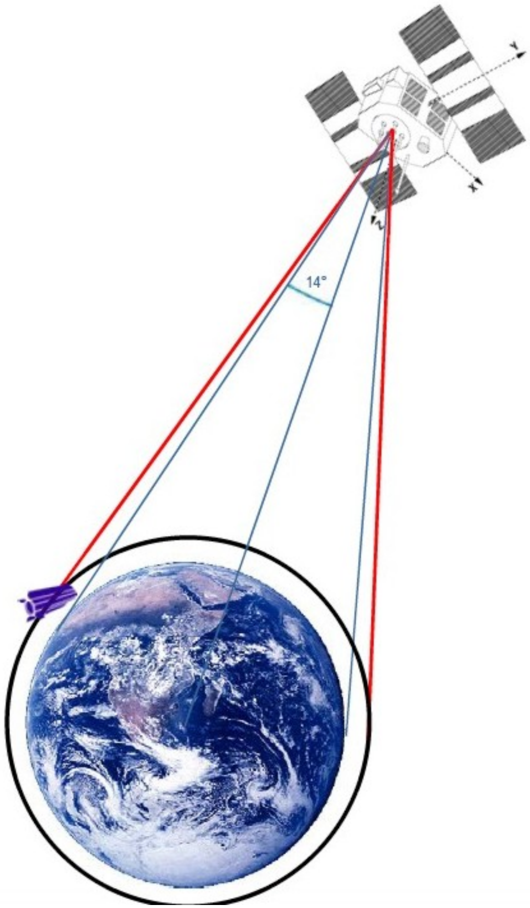


Azimuth-dependent PCVs (different nadir angles)

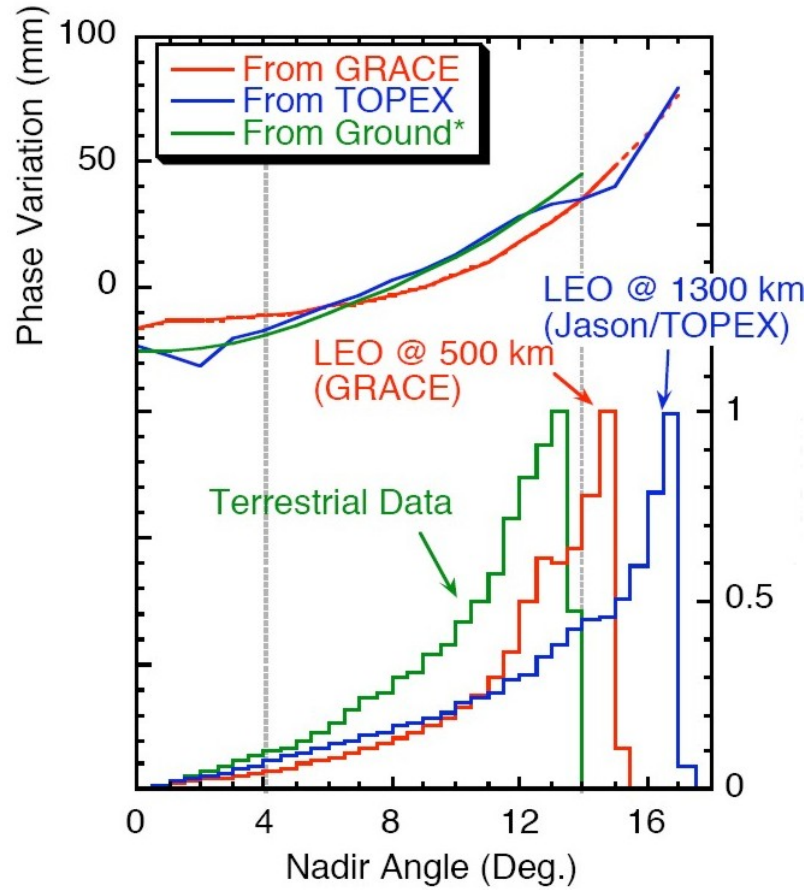


- different resolution in nadir: 5° (TUM), 1° (JPL)
- nearly perfect agreement in amplitude and phase

PCV values for big nadir angles (I)



Jäggi et al. (2011)



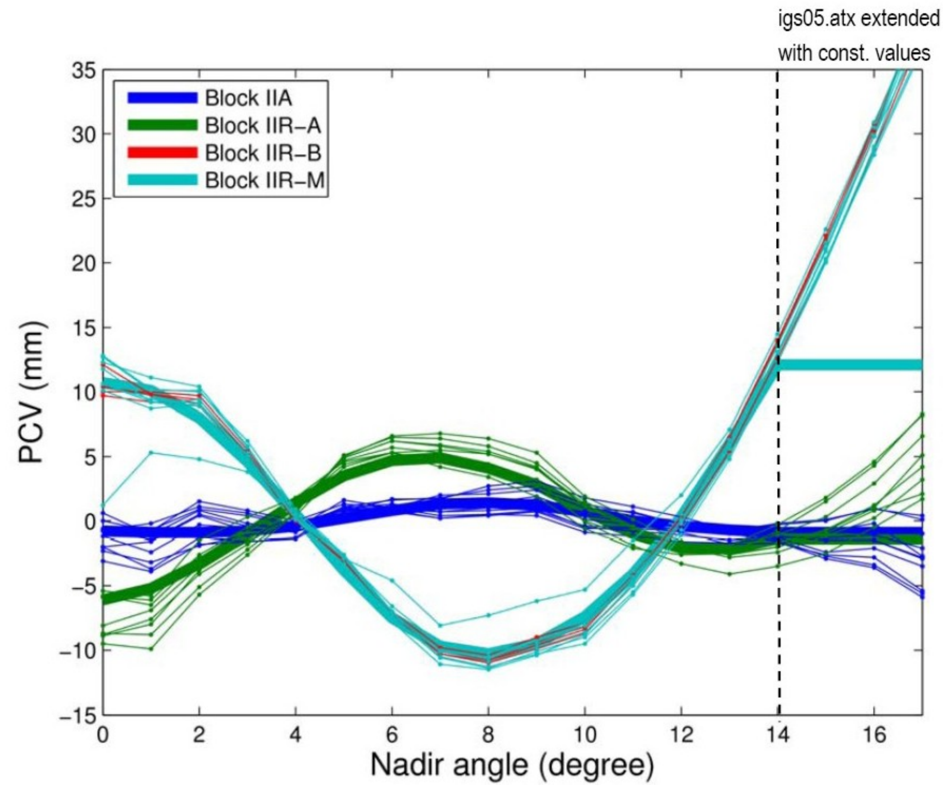
Haines et al. (2010)

Most LEO observations are taken at nadir angles for which the IGS does **not** provide phase center corrections so far

PCV values for big nadir angles (II)

Jason-2 solution (CODE):

- GPS and LEO PCVs estimated **simultaneously**
- certain set of GPS PCVs has to be **fixed to a priori values** (2 Block IIA satellites for the example on the right)
- significant PCV signal beyond a nadir angle of 14°

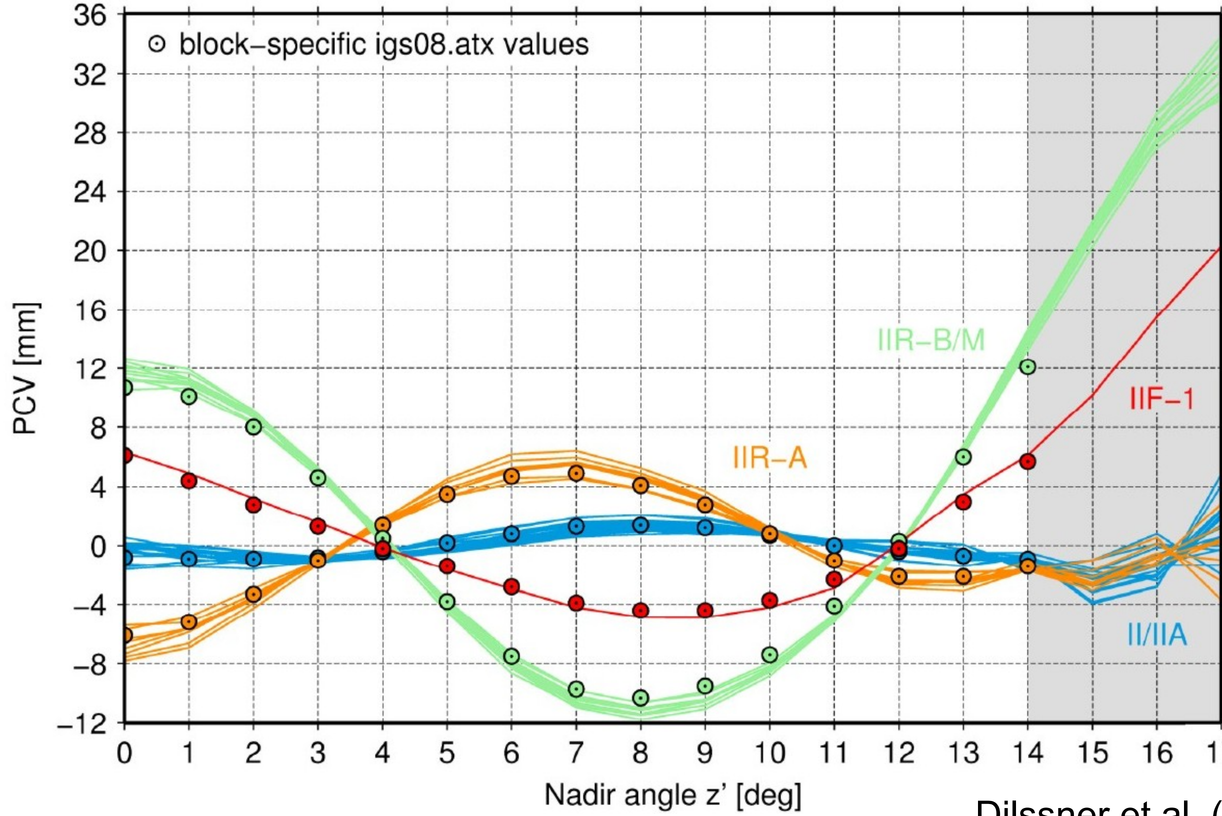


Jäggi et al. (2011)

- biggest PCV signal for latest satellite generation
- strengthened PCV estimates possible by **combining the data of several LEO missions**

PCV values for big nadir angles (III)

Jason-1/2-solution (ESOC):

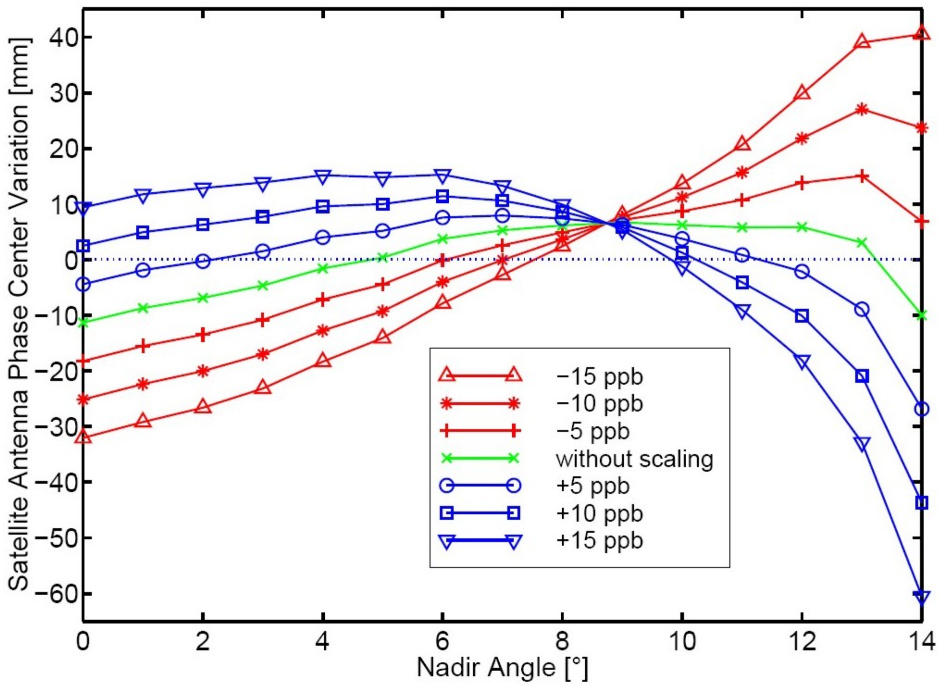


Dilssner et al. (2011)

- simultaneous processing of LEO and ground data: sufficient to fix ground antenna calibrations
- PCVs for nadir angles ≤ 14° should be fixed to igs08.atx values in order to include remaining estimates into the IGS model

Dependence on the ITRF scale (I)

Collilieux et al. (2010): "Although the [GPS] scale drift compared to VLBI and SLR mean scale is smaller than 0.4 mm/year, we think that it would be premature to use that information in the **ITRF scale definition** due to its strong dependence on the GPS satellite and ground antenna PCVs."

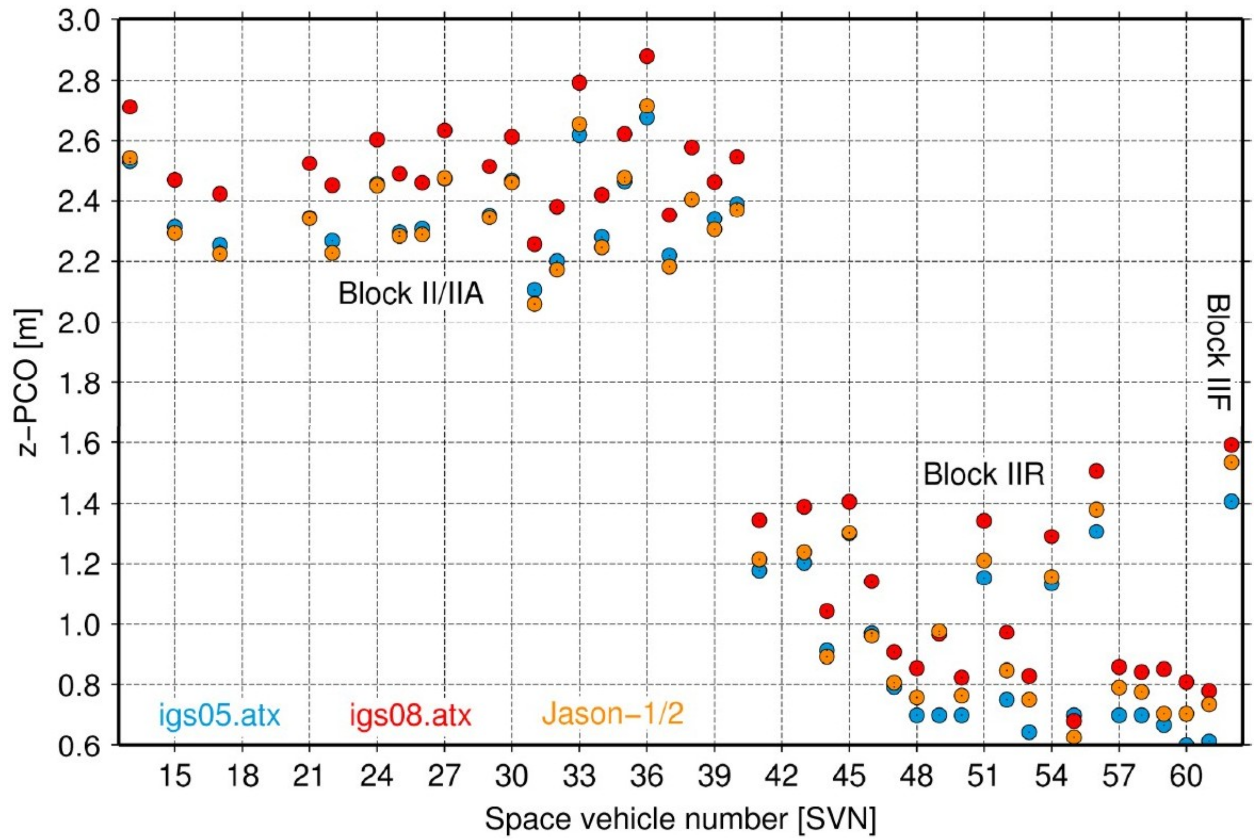


Zhu et al. (2003):
Δz [m] ≈ -0.13 · Δscale [ppb]

(scale difference of 1 ppb corresponds to z-offset difference of 13 cm)

Dependence on the ITRF scale (II)

Jason-1/2-solution (ESOC):

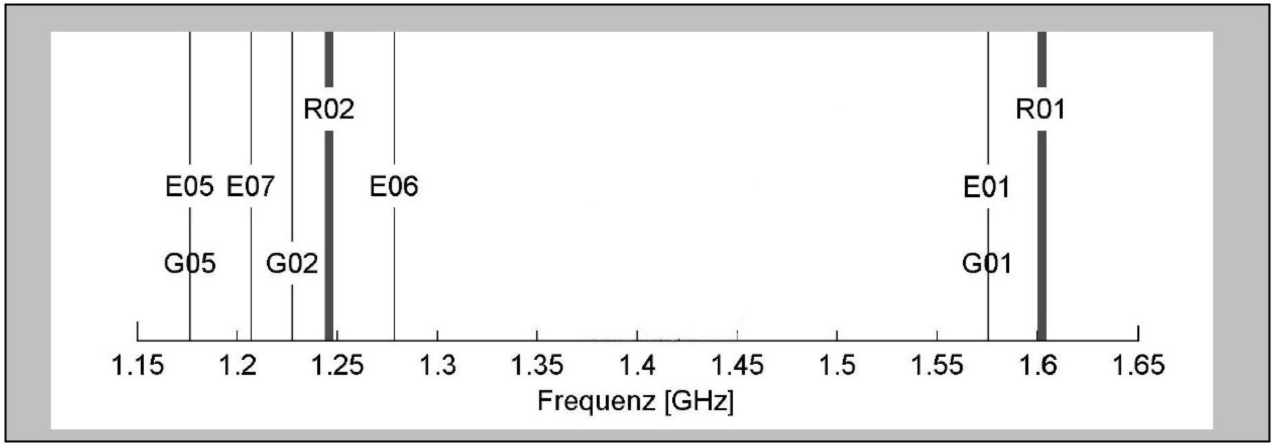


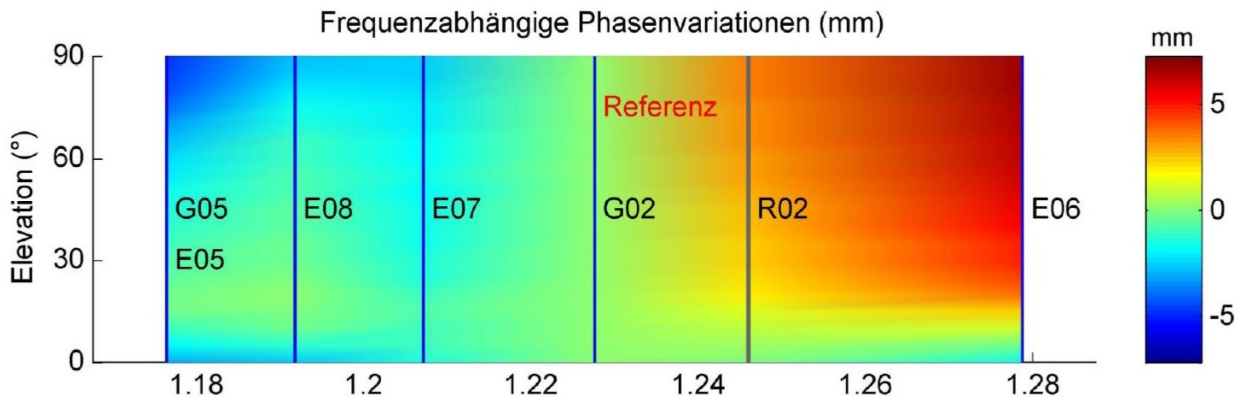
Dilssner et al. (2011)

- "JPL approach": scale constraint from satellite force models (GM)
- GPS scale closer to ITRF2005 scale (VLBI-based) than to ITRF2008 scale (VLBI- and SLR-based)
- independent GNSS scale achievable

Upcoming new signals

Zeimetz (2010)





- chamber calibration (using artificial signals) could provide phase center corrections for any signal
- when and how to incorporate these results into the IGS model?

Conclusions

- Awareness of antenna issues could be considerably improved during the last decade (5 years ago, e.g., the impact of radomes as well as satellite antenna effects were still ignored within the IGS)
- High consistency achieved between reference frame and antenna model: ITRF2008/IGS08 and igs08.atx much more consistent than IGS05 and igs05.atx
- Theoretical solutions for lots of open antenna issues available, the question is how and when to consider them in practice:
  - PCV extension to bigger nadir angles should be easy
  - independent IGS scale with upcoming reprocessing campaign repro2?
  - azimuth-dependent PCVs??
- Beutler's vision from 1998 could become reality:
  Antennas could really be the "final destination"!


Thanks for
your attention!
Leica
MUEJ, Munich