An Assessment of Atmospheric Turbulence for CONT05 and CONT08

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Introduction

- Fluctuations in the atmospheric delay due to turbulence is a significant error source in geodetic VLBI.
- Simulations are used to investigate the influence of the atmosphere onthe VLBI results.
- Problem: find appropiate station specific values for the parameters needed for the simulations (e.g. the refractive index structure constant C_n^2).
- We perform simulations using different methods for obtaining C_n^2. We then compare the baseline repeatabilities from the simulations with those observed during CONT05 and CONT08.

Simulation of tropospheric delays

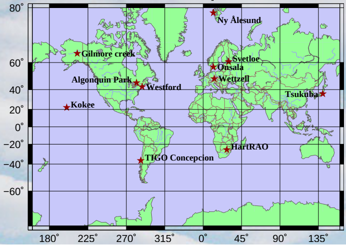
- According to the theory of atmospheric turbulence fluctuations in the refractive index can be described by:

$$\left\langle [n(\mathbf{r}_1, t_1) - n(\mathbf{r}_2, t_2)]^2 \right\rangle = C_n^2 \left\| \mathbf{r}_1 - \mathbf{r}_2 - \mathbf{v}(t_1 - t_2) \right\|^{2/3} \quad (1)$$

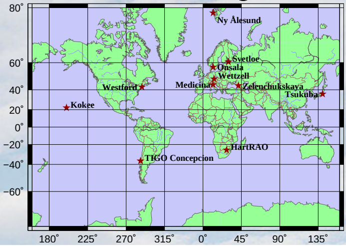
  where $\mathbf{r}$ is the position, t time, $\mathbf{v}$ wind velocity, and C_n^2 is the *refractive index structure constant*.
- Using this equation, atmospheric delays can be simulated [see *Nilsson et al., Proc 18:th EVAG meeting, 2007*; *Nilsson and Haas, Proc. 5:th IVS General Meeting, 2008*].
- For this we need to know the structure constant C_n^2.
- C_n^2 can vary from between less than 10^{-16} m$^{-2/3}$ up to more than 10^{-12} m$^{-2/3}$.
- Typically, large C_n^2 can be expected when the temperature and/or the humidity is high.

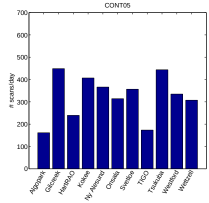
CONT05 and CONT08

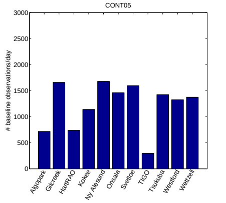
CONT05, 12–27 September 2005

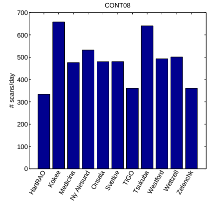


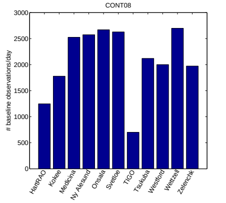
CONT08, 12–26 August 2008







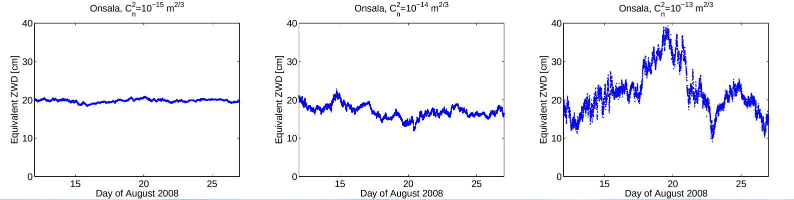




Simulations

- We have made simulations for both CONT05 and CONT08.
- Clock errors were simulated as random walk processes plus integrated random walks plus integrated integrated random walks.
- The observation noise was simulated as a white noise process with standard deviation of 30 ps.
- First we make simulations with the same C_n^2 for all stations.
- For these simulations C_n^2 is assumed constant up to 2 km, and zero above. Three different values of C_n^2 was used:
  - $C_n^2 = 10^{-15}$ m$^{-2/3}$. Most likely too low for all stations.
  - $C_n^2 = 10^{-14}$ m$^{-2/3}$. Probably a little bit too low for most stations.
  - $C_n^2 = 10^{-13}$ m$^{-2/3}$. Probably a bit too high for most stations.
- Actual wind velocities from ECMWF were used.
- The simulated VLBI observations were analyzed with the VLBI processing software SOLVE.

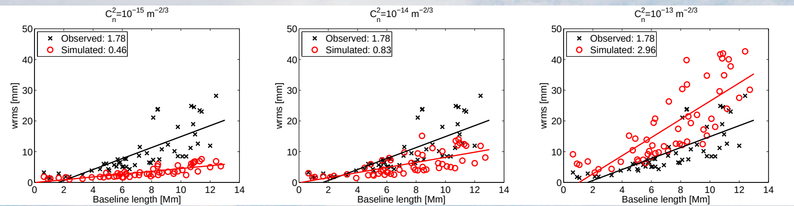
Examples of simulated wet delay



Examples of time series of simulated equivalent zenith wet delays (Onsala, CONT08).

CONT05 Simulations

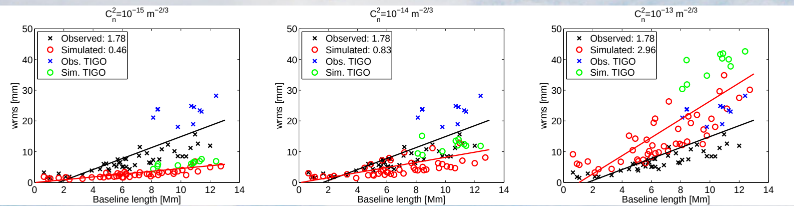
Same C_n^2 for all stations.



- $C_n^2 = 10^{-14}\ \mathrm{m}^{-2/3}$ give too small and $C_n^2 = 10^{-13}\ \mathrm{m}^{-2/3}$ too large baseline repeatabilities compared to observed data. Typical C_n^2 for the CONT05 stations and period probably somewhere in between these values.
- $C_n^2 = 10^{-15}\ \mathrm{m}^{-2/3}$ gives baseline repeatabilities much lower than the observed ones. This indicates that the atmosphere is the dominating error source.

CONT05 Simulations

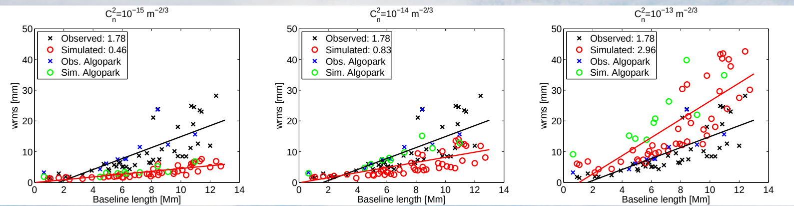
Same C_n^2 for all stations.



- Large wrms for baselines containing the station TIGO in observed data. Seen also in simulated data.
- The reason is that TIGO aquires very few observations compared to most other station.

CONT05 Simulations

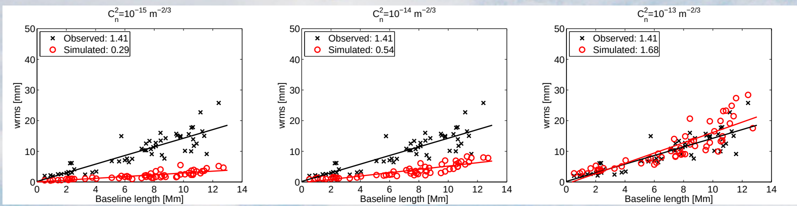
Same C_n^2 for all stations.



- Simulations also give large wrms for baselines containing the station Algonquin Park. This is not seen in observed data.
- This could indicate that the atmosphere above Algonquin Park was relatively stable (low C_n^2) during CONT05.

CONT08 Simulations

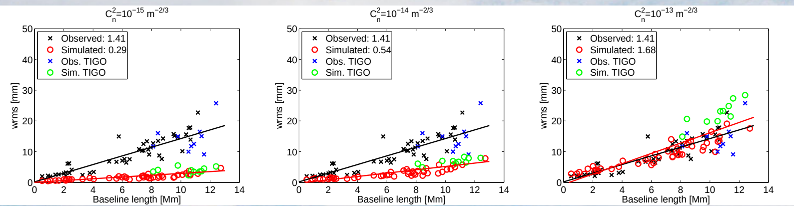
Same C_n^2 for all stations.



- Better repeatabilities compared to CONT05. Most likely a consequence of a larger number of observations.
- $C_n^2 = 10^{-13}$ m$^{-2/3}$ gives the similar baseline repeatabilities as the observed ones.
- This indicates that that C_n^2 generally was higher for CONT08 compared to CONT05.

CONT08 Simulations

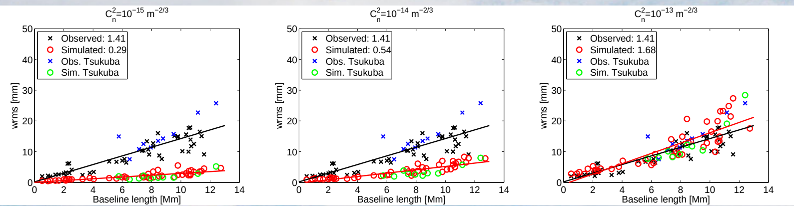
Same C_n^2 for all stations.



- Repeatabilities for TIGO baselines not worse than other baselines.
- Probably mostly due to more observations are aquired by TIGO in CONT08 compared to CONT05.

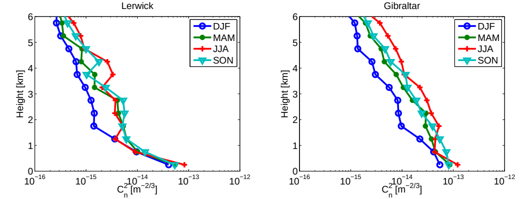
CONT08 Simulations

Same C_n^2 for all stations.



- Large wrms observed for baselines involving Tsukuba.
- Indicates large C_n^2 for Tsukuba during CONT08.

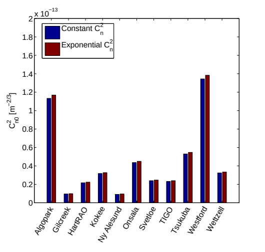
Estimation of C_n^2 from high resolution radiosonde data



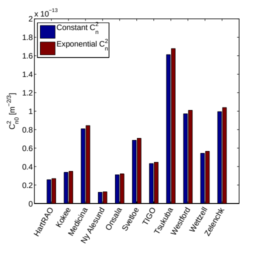
- Mean C_n^2 profiles can be estimated from radiosonde data (obtained from British Atmospheric Data Archive (BADC)).
- Figures shows mean profiles for different seasons estimated using radiosonde data from 2003–2006.
- For simulations, the C_n^2 profile were take from the radiosonde station closes in latitude.
- CONT05: mean profiles for September–November (SON).
- CONT08: mean profiles for June–August (JJA).

Estimation of C_n^2 from GPS

CONT05

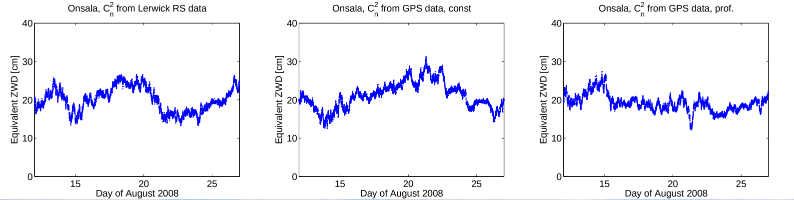


CONT08



- C_n^2 can be estimated using the one day variance of the zenith delay [*Treuhaft and Lanyi, Radio Sc.i, 1987*].
- We have used zenith delays estimated from GPS data at the different VLBI station to estimate station specific C_n^2 for the CONT05 and CONT08 periods.
- Two shapes of the C_n^2 profile were tested:
  - $C_n^2(z) = C_{n0}^2$ up to z =2 km and zero above.
  - $C_n^2(z) = C_{n0}^2 \cdot \exp\left[-\frac{2z}{2\text{ km}}\right]$

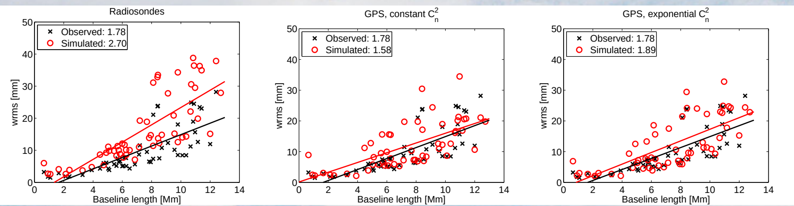
Examples of simulated wet delay



Examples of time series of simulated equivalent zenith wet delays (Onsala, CONT08).

CONT05 Simulations

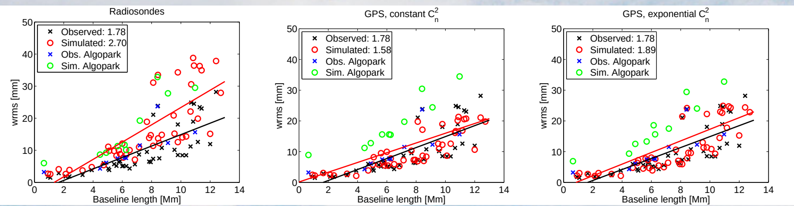
Station specific C_n^2 values.



- C_n^2 from radiosonde data gives larger repeatabilities compared to observations.
- Could be due to the fact that the radiosonde stations and VLBI station are at different locations.
- C_n^2 estimated using zenith delay from GPS gives repeatabilities mostly agreeing well with observations.
- No large difference between using constant C_n^2 and using a C_n^2 profile.

CONT05 Simulations

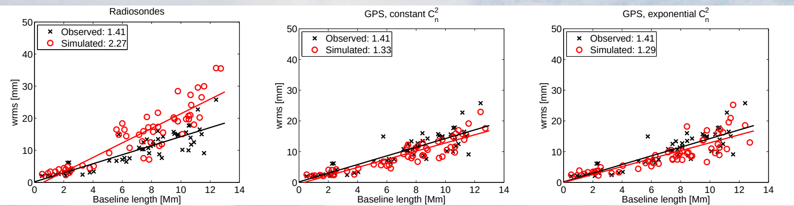
Station specific C_n^2 values.



- For C_n^2 estimated from GPS repeatabilities for baselines containing Algonquin Park are overestimated.

CONT08 Simulations

Station specific C_n^2 values.



- Also here C_n^2 from radiosonde data gives larger repeatabilities compared to observations.
- Simulations with C_n^2 from GPS gives repeatabilities agreeing with the observed ones.

Conclusions

- Fluctuations in the atmospheric delay due to atmospheric turbulence is the most important error source in geodetic VLBI.
- Generally, C_n^2 was higher in CONT08 than in CONT05.
- Better baseline repeatabilities for CONT08 compared to CONT05. Having more observations gives more accurate results.
- Determining C_n^2 from variance of the zenith delay (obtained e.g. using GPS) seems to give realistic C_n^2 values for simulations.

Thank you for listening