Time-Distance Measurements of the Solar Diameter

1. Solar diameter measurements are important for understanding solar irradiance variation and for comparison with value used in solar model.

2. We present method of solar radius measurements based on 2D cross-correlation analysis with multiple bounce time-distance method.
Method of Multiple Bounces
Travel-Time for Each Packet (GONG data)
(different colors for different phase velocity filters)
2D CCF for Different Wave Packets
GONG 12 Hour Data Set

N = 9
N = 10
N = 11
2D CCF of the N=11 Wave Packet
GONG 12 H. Data Set
Spatial Profile
(for N=8, 3 Different GONG 12 H. Data Sets)
Temporal Profile (CCF + Gabor fitting) for N=8
GONG 12 h. data set
Precision of the method

Solar radius fluctuation is $\sim \delta R \leq 2 - 3 \text{ km/year}$ (W.A.Dziembowski, P.R.Goode, J.Schou 2001; Antia et al. 2000).

$\Rightarrow \delta R/R \sim 3 - 4.5 \times 10^{-6}$

$\delta \Delta = \frac{\delta R}{R} \sim 360^\circ \sim 1.1 - 1.6 \times 10^{-3}^\circ$

from the real GONG - classic (low resolution) data we have a precision (preliminary computations) $\sim 2.8 \times 10^{-2}$ degree

(for 12 hours data set, for single wave packet).

We have $\sim 200$ sets in 1996 $\Rightarrow (2.8 \times 10^{-2})/\sqrt{200} \sim 2 \times 10^{-3}$

Using 4 wave packets we will have $(2 \times 10^{-3})/\sqrt{4} = 1 \times 10^{-3}$ degree

or $3 \times 10^{-6} \frac{\delta R}{R}$ for precision of the method with GONG data

With GONG+, MDI and especially with HMI we can increase the precision
Radius difference measurement (temporal variation or difference with model)

Propagation time for an individual wave packet:

$$\tau \approx \frac{s}{c}, \text{ where } s = \text{travel distance}, \ c = \text{sound speed}$$

$$\delta \tau \approx \frac{1}{c} \delta s - \frac{\delta c}{c} \frac{s}{c}$$

for each wave packet, $\frac{1}{c} \propto \text{const} \equiv a$, and $\frac{\delta c}{c} \propto \text{const} \equiv b \Rightarrow \delta \tau \approx \delta s + b$

we can measure $\delta \tau$ and $\delta s$ and interpret $\delta s$ as radius change after removing

$b \propto \frac{\delta c}{c}, \quad \delta \tau = \tau_{\text{obs}} - \tau_{\text{theory}}$
Conclusions and future work

- Precision of multiple-bounce method can allow us to measure radius difference at a level $1 \times 10^{-5}$ (temporal variation or difference from model)
- To increase the precision, we need higher resolution images (GONG+, MDI, HMI)
- We need to extend our computations for higher-N wave packets (up to $N=15$ is possible, taking into account lifetime) and longer period of observations (1996-1997)