Comparison of Travel-Time Definitions

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Three travel-time definitions

Gabor Wavelet (Kosovichev & Duvall, 1997):

$G = A \exp[-\delta\omega^2/4\ (\tau-\tau_g)^2] \cos[\omega_0(\tau-\tau_p)]$

Gizon & Birch (2002):

$X_\pm(\mathbf{r_1},\mathbf{r_2},t) = \int dt\ f(t')\ [C(\mathbf{r_1},\mathbf{r_2},t) - Cref(\Delta,t'-t)]^2$

$\tau_\pm(\mathbf{r_1},\mathbf{r_2}) = \mathrm{argmin}_t\ \{X_\pm(\mathbf{r_1},\mathbf{r_2},t)\}$

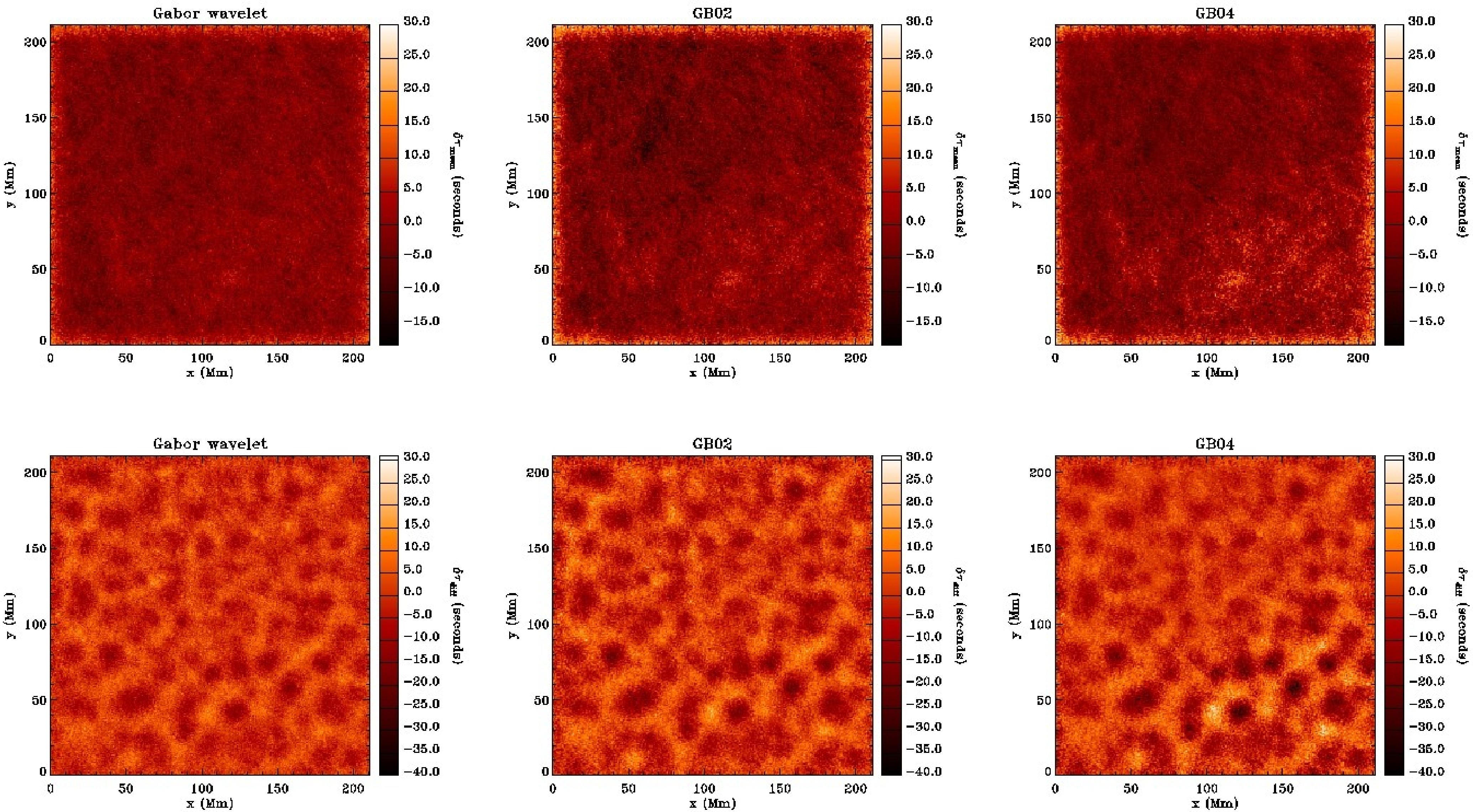
Gizon & Birch (2004):

$\tau_\pm(\mathbf{r_1},\mathbf{r_2}) =$

$\int dt\ f(\pm t)\ \dot{C}_{ref}(\Delta,t)\ [C(r_1,r_2,t) - C_{ref}(\Delta,t)]\ /\ \int dt\ f(\pm t)\ [\dot{C}_{ref}(\Delta,t)]^2$

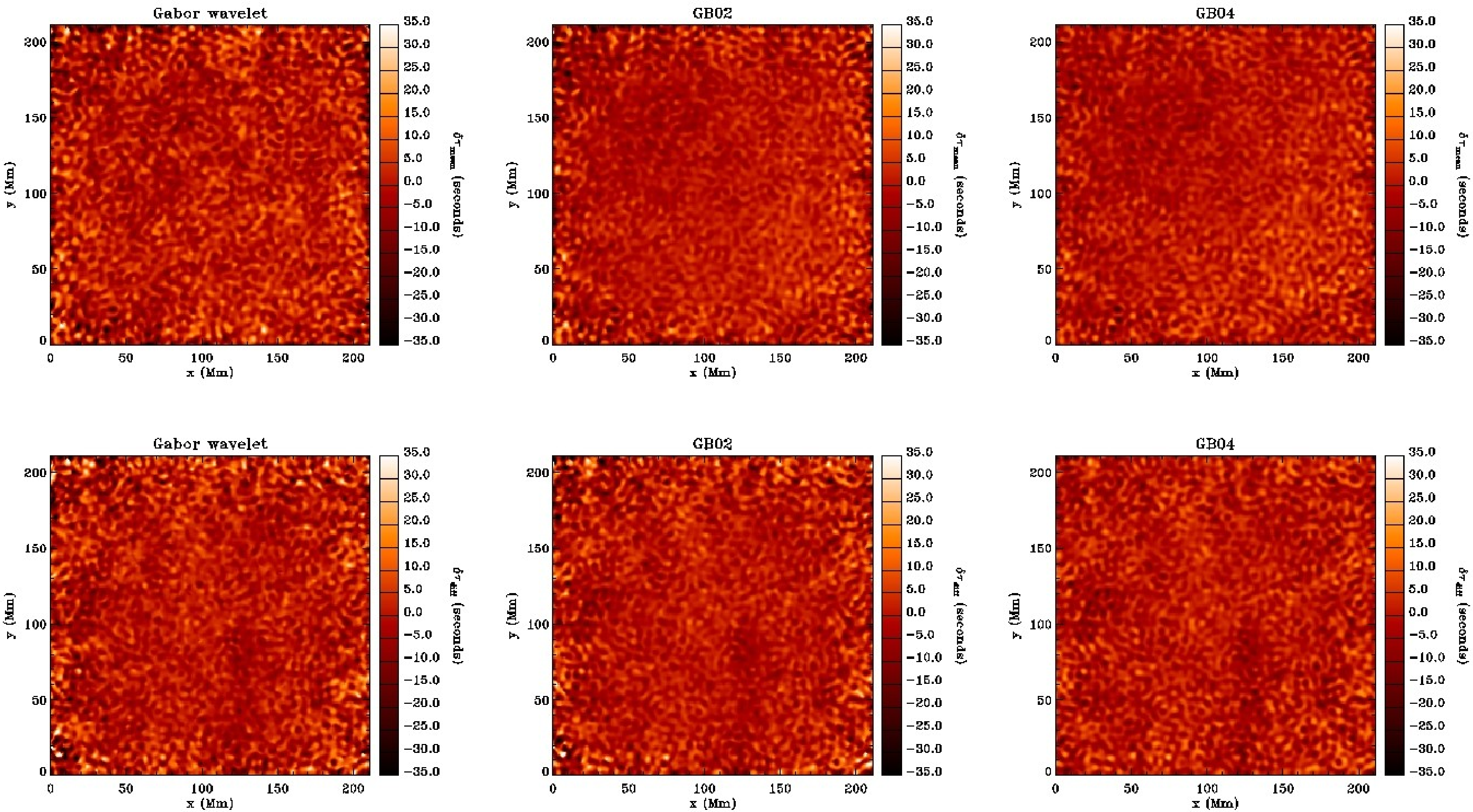
Mean and Difference Travel Times in Quiet Sun (I)

Δ= 6.2 Mm



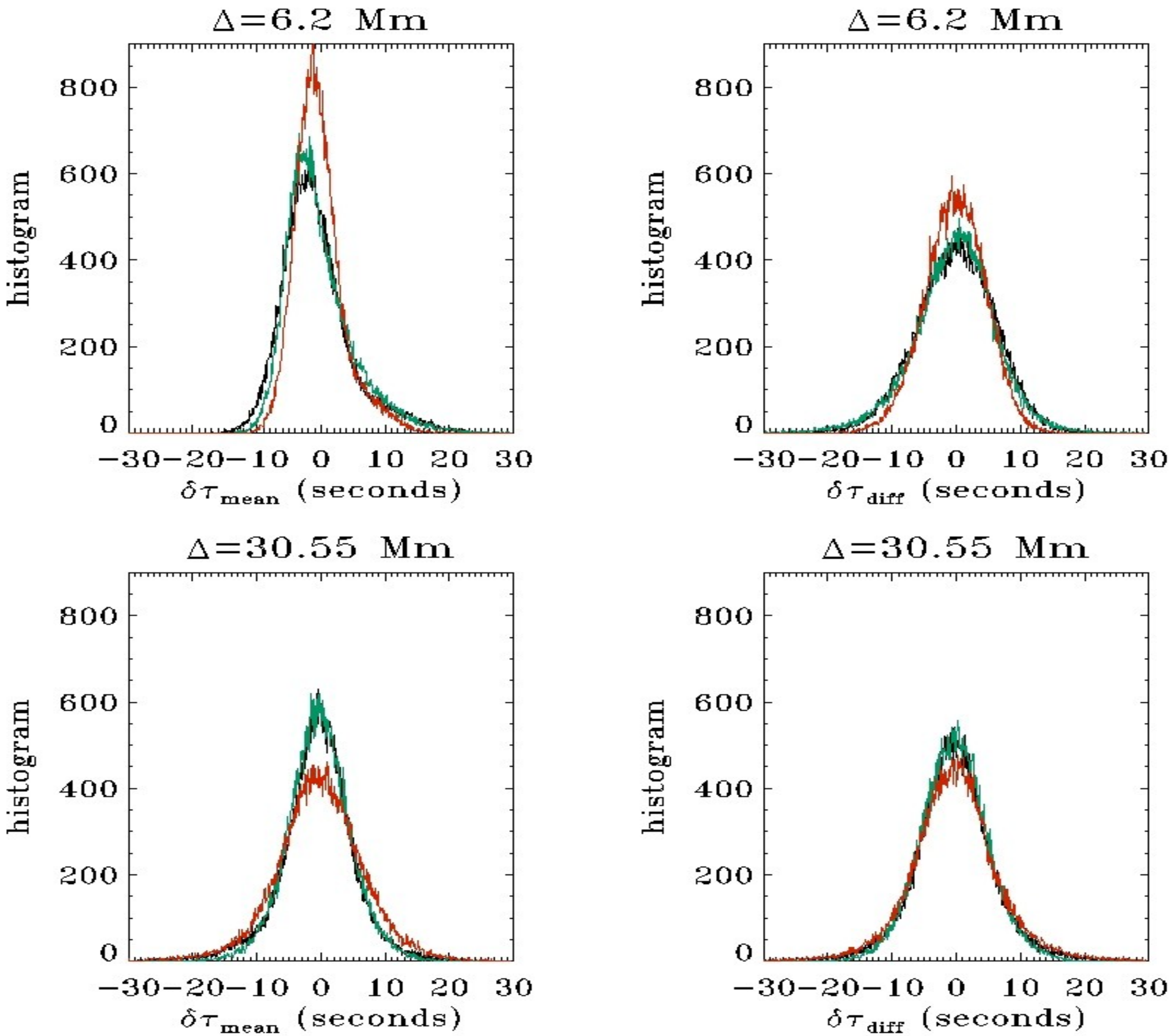
Mean and Difference Travel Times in Quiet Sun (II)

Δ= 30.55 Mm

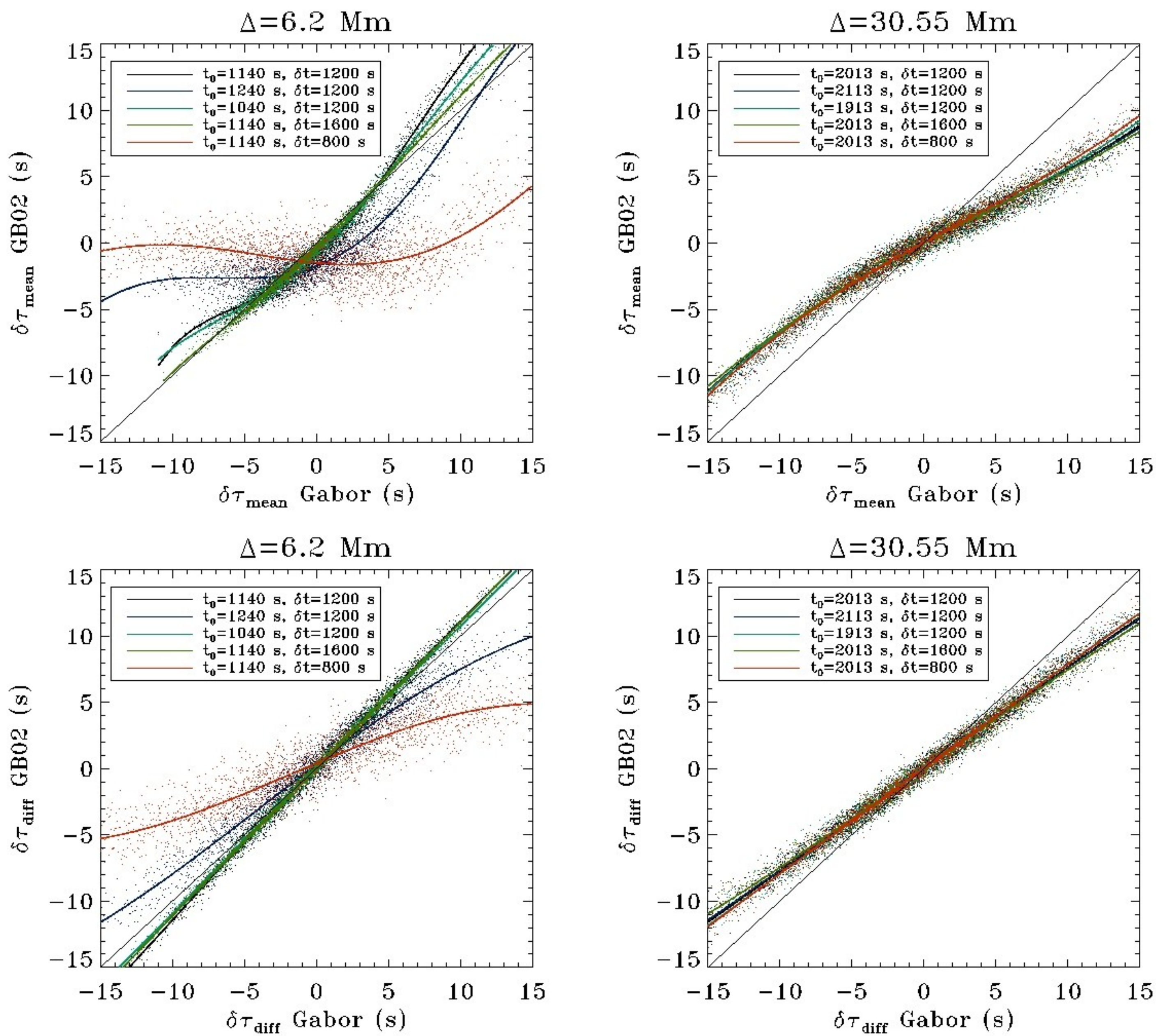


Mean and Difference Travel Times in Quiet Sun (III)

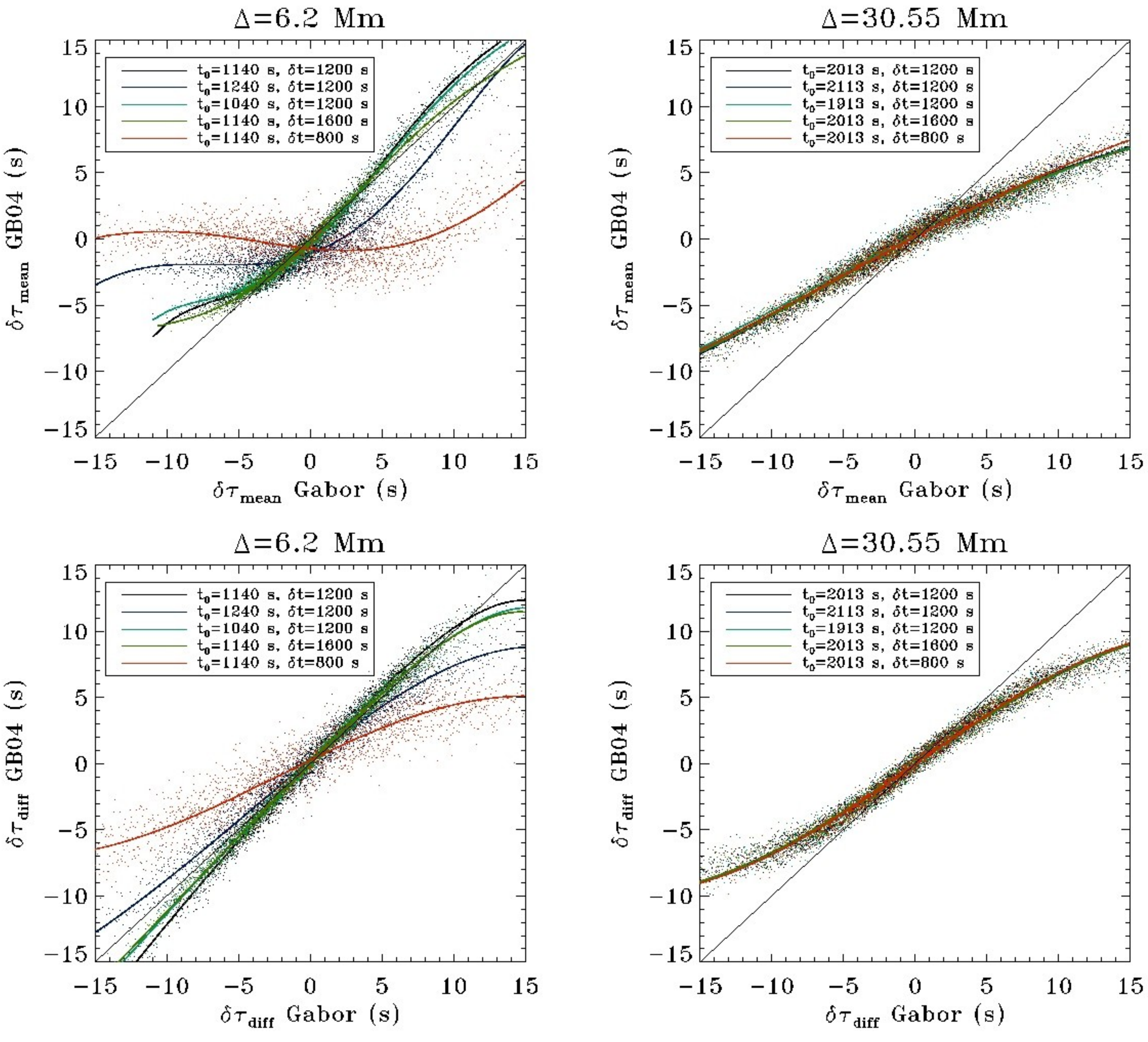
Black = GB02,
Green= GB04,
Red= Gabor



Mean and Difference Travel Times in Quiet Sun (IV)

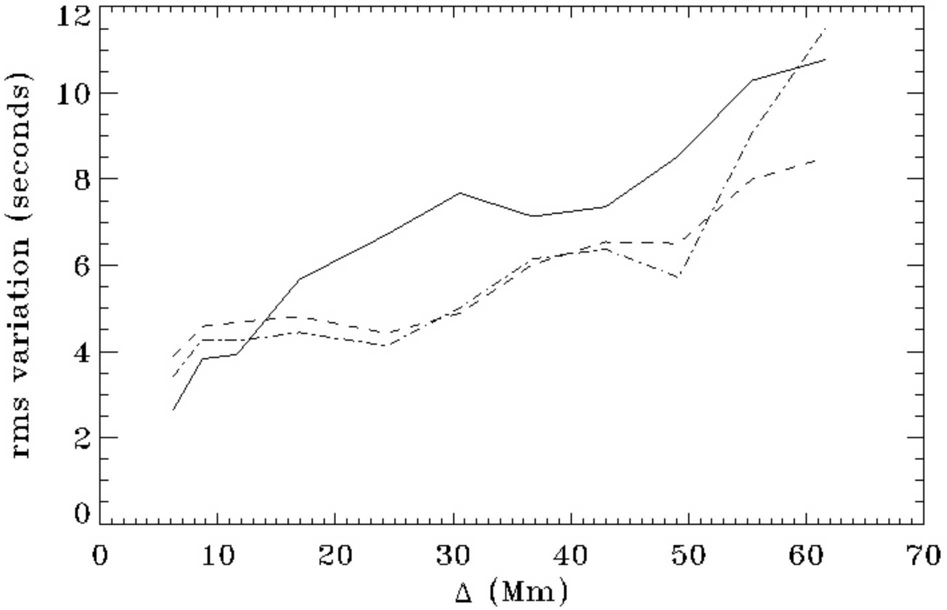


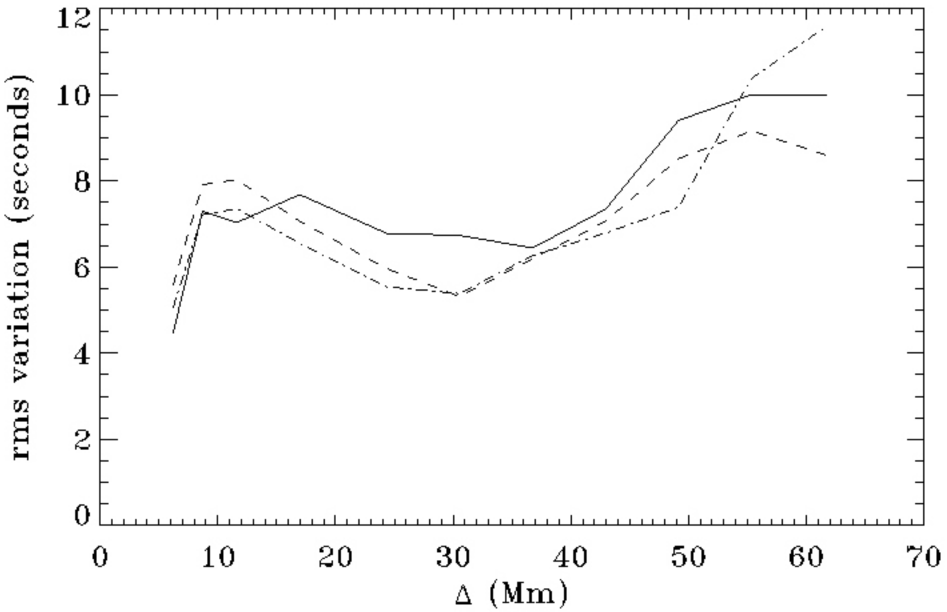
Mean and Difference Travel Times in Quiet Sun (V)



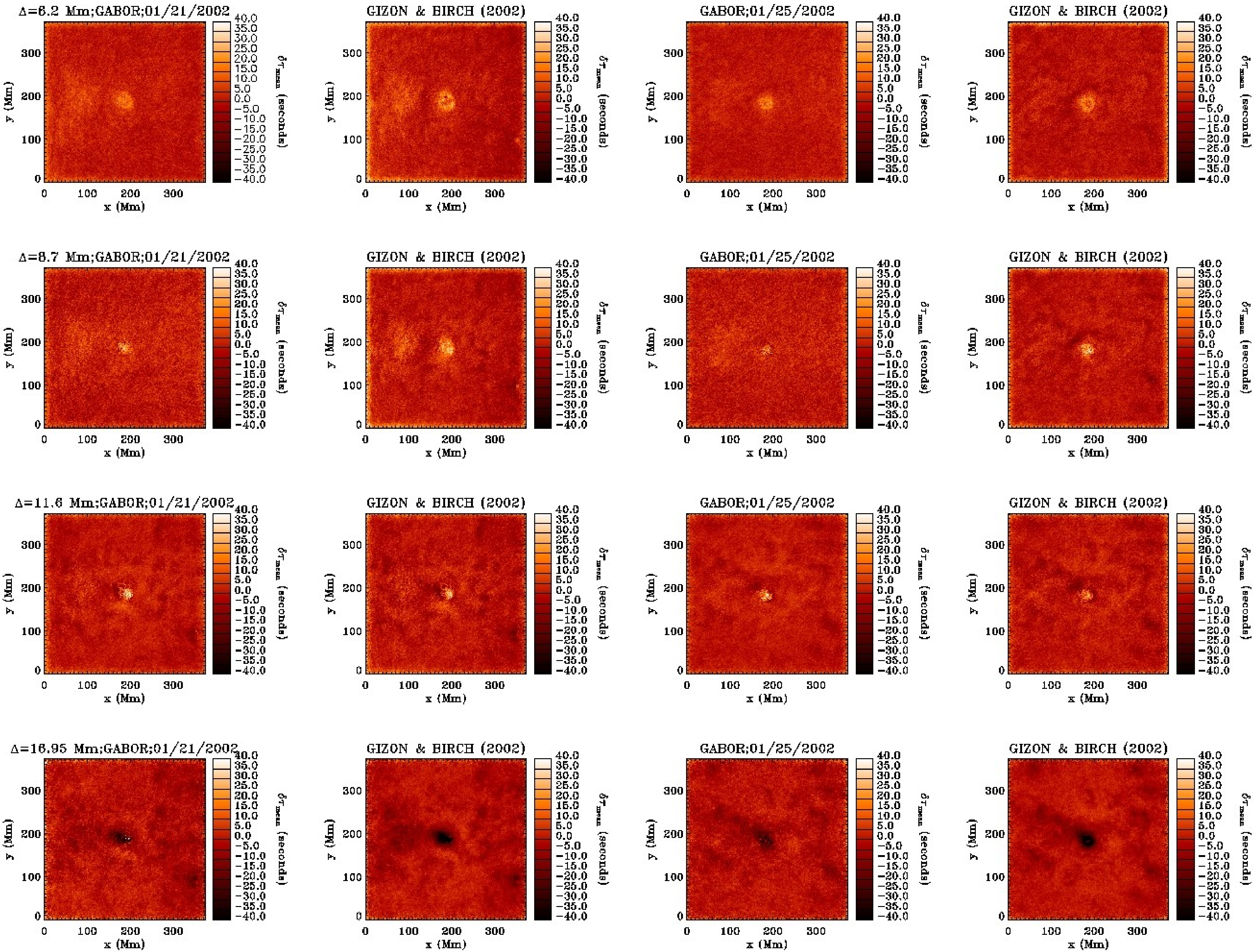
Mean and Difference Travel Times in Quiet Sun (VI)

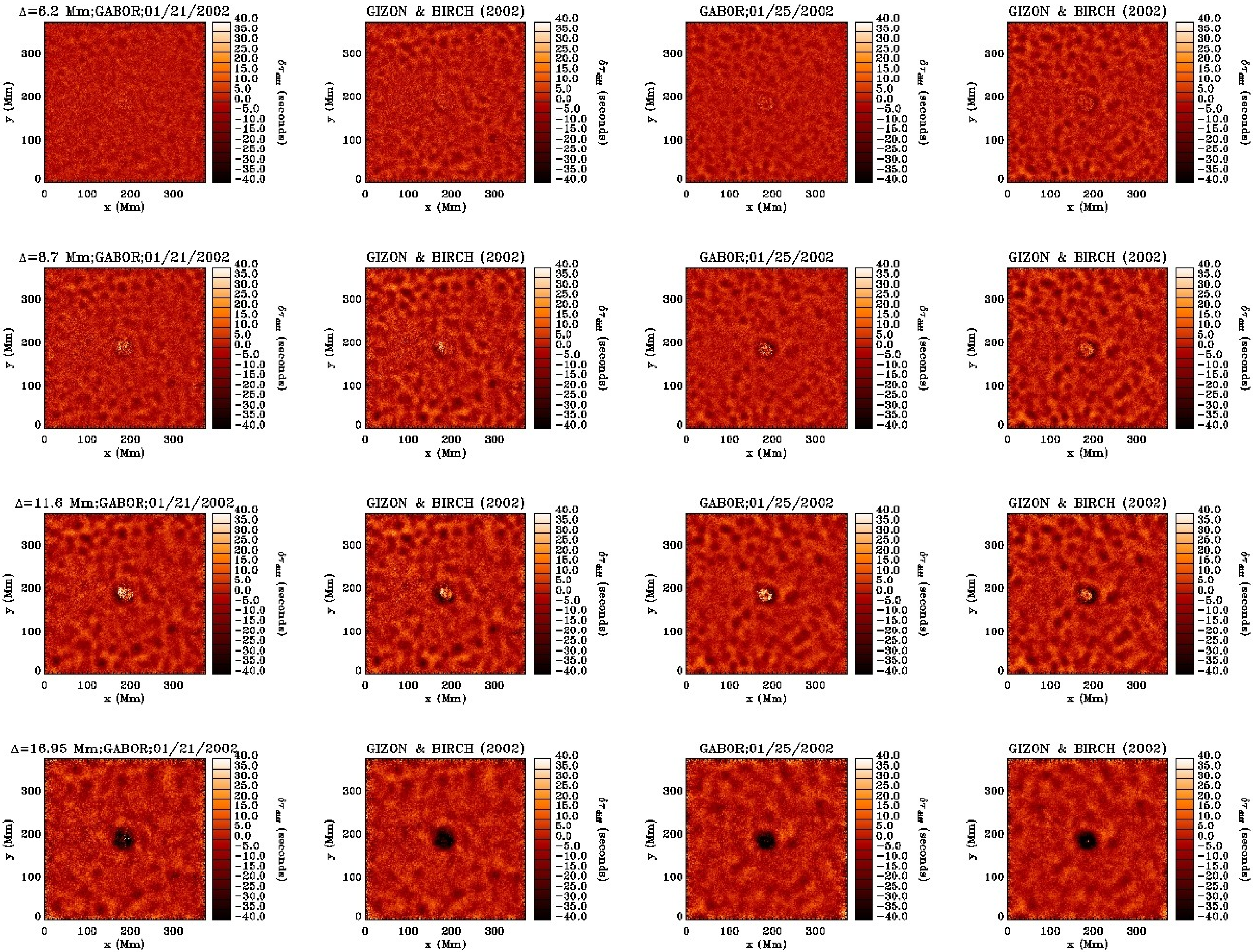
Solid = Gabor,
dashed= GB02,
dash-dotted= GB04
upper=mean,
lower=difference



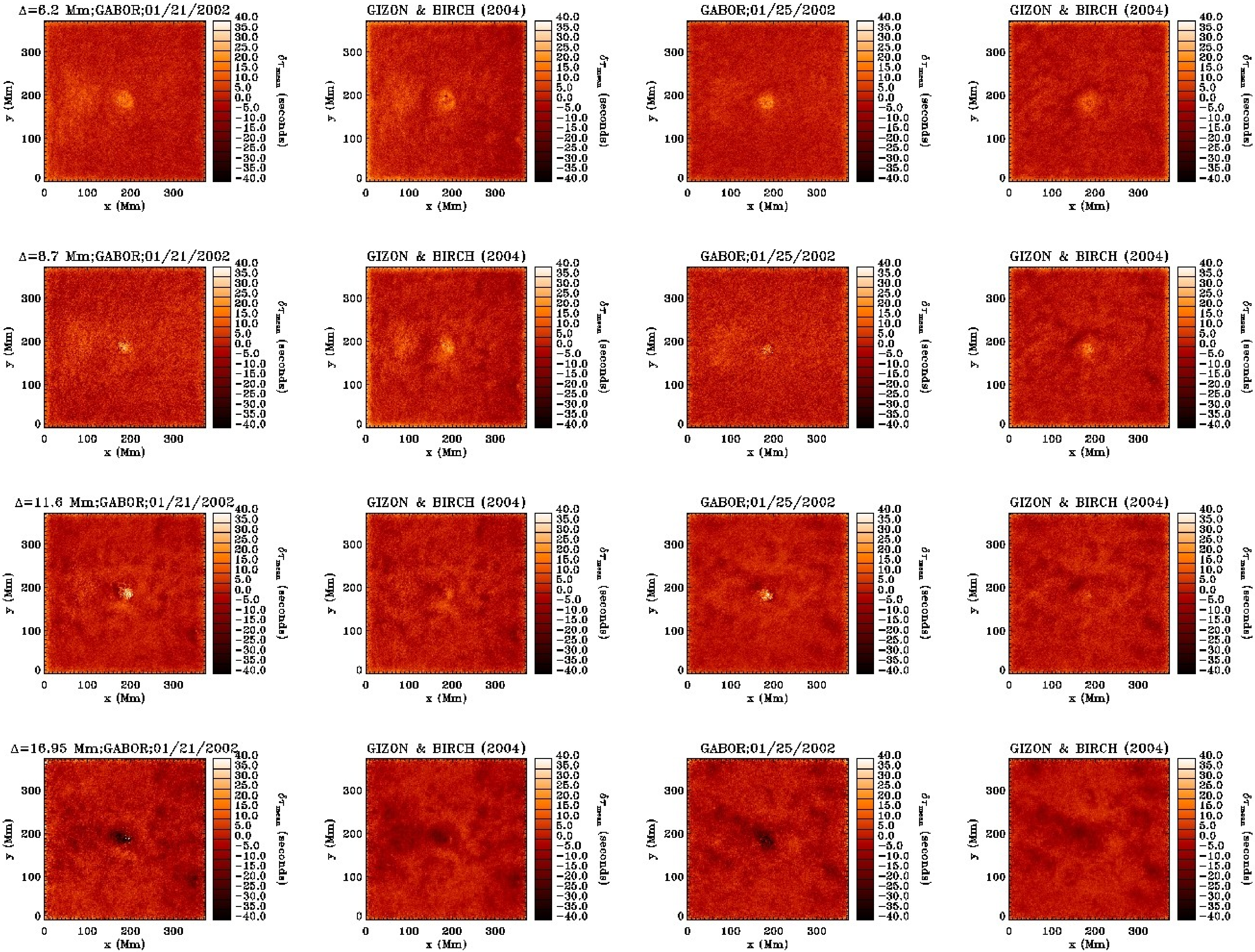


Mean and Difference Travel Times in Active Region NOAA 9787 (preliminary results)

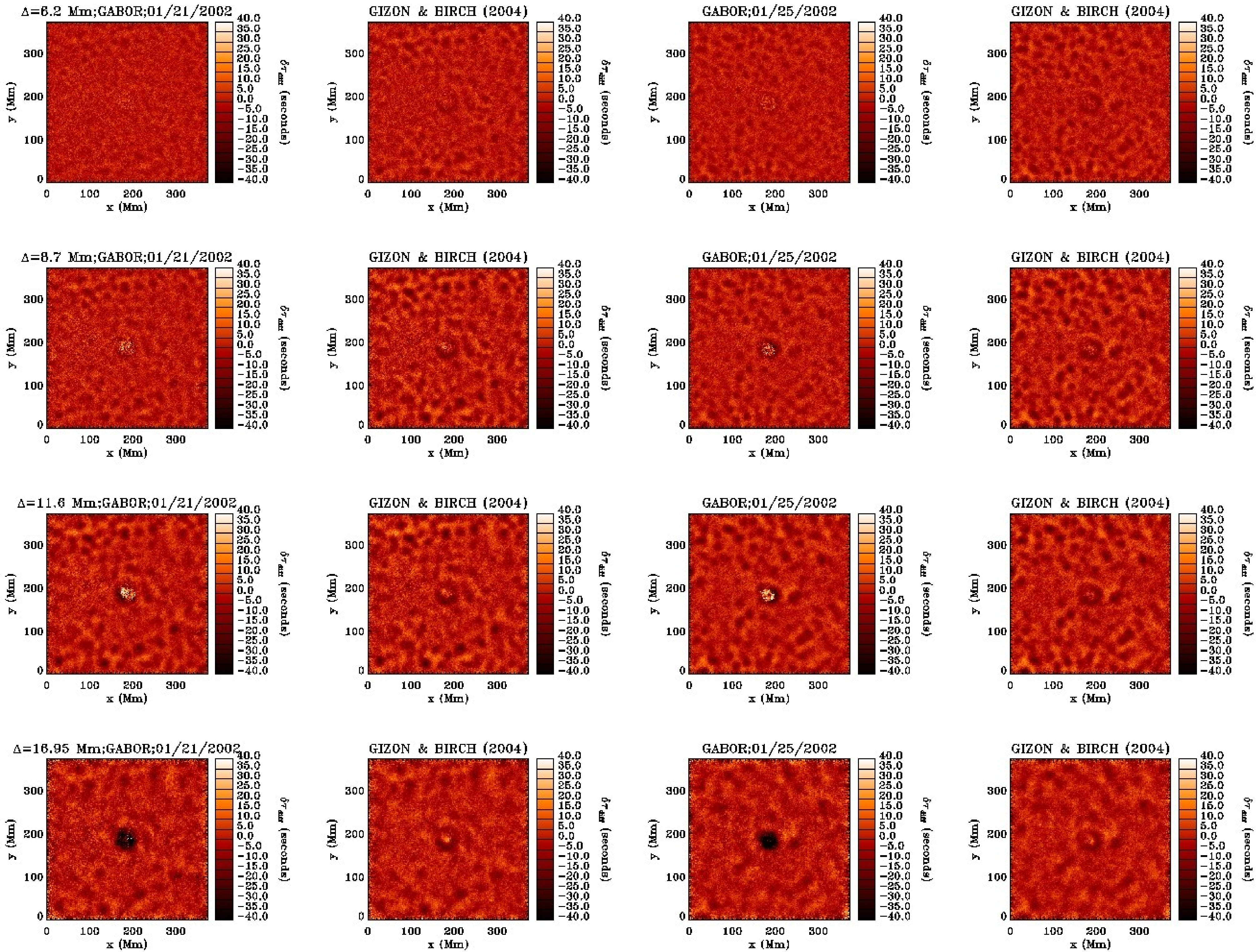

Δ=6.2 Mm;GABOR;01/21/2002
GIZON & BIRCH (2002)
GABOR;01/25/2002
GIZON & BIRCH (2002)
Δ=8.7 Mm;GABOR;01/21/2002
GIZON & BIRCH (2002)
GABOR;01/25/2002
GIZON & BIRCH (2002)
Δ=11.6 Mm;GABOR;01/21/2002
GIZON & BIRCH (2002)
GABOR;01/25/2002
GIZON & BIRCH (2002)
Δ=16.95 Mm;GABOR;01/21/2002
GIZON & BIRCH (2002)
GABOR;01/25/2002
GIZON & BIRCH (2002)
x (Mm)
y (Mm)
δτ_mean (seconds)
0
100
200
300
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
−5.0
−10.0
−15.0
−20.0
−25.0
−30.0
−35.0
−40.0



Δ=6.2 Mm;GABOR;01/21/2002
GIZON & BIRCH (2002)
GABOR;01/25/2002
GIZON & BIRCH (2002)
Δ=8.7 Mm;GABOR;01/21/2002
Δ=11.6 Mm;GABOR;01/21/2002
Δ=16.95 Mm;GABOR;01/21/2002
x (Mm)
y (Mm)
δτ_diff (seconds)



Δ=6.2 Mm;GABOR;01/21/2002
GIZON & BIRCH (2004)
GABOR;01/25/2002
GIZON & BIRCH (2004)
Δ=8.7 Mm;GABOR;01/21/2002
GIZON & BIRCH (2004)
GABOR;01/25/2002
GIZON & BIRCH (2004)
Δ=11.6 Mm;GABOR;01/21/2002
GIZON & BIRCH (2004)
GABOR;01/25/2002
GIZON & BIRCH (2004)
Δ=16.95 Mm;GABOR;01/21/2002
GIZON & BIRCH (2004)
GABOR;01/25/2002
GIZON & BIRCH (2004)
x (Mm)
y (Mm)
$\delta\tau_{mean}$ (seconds)



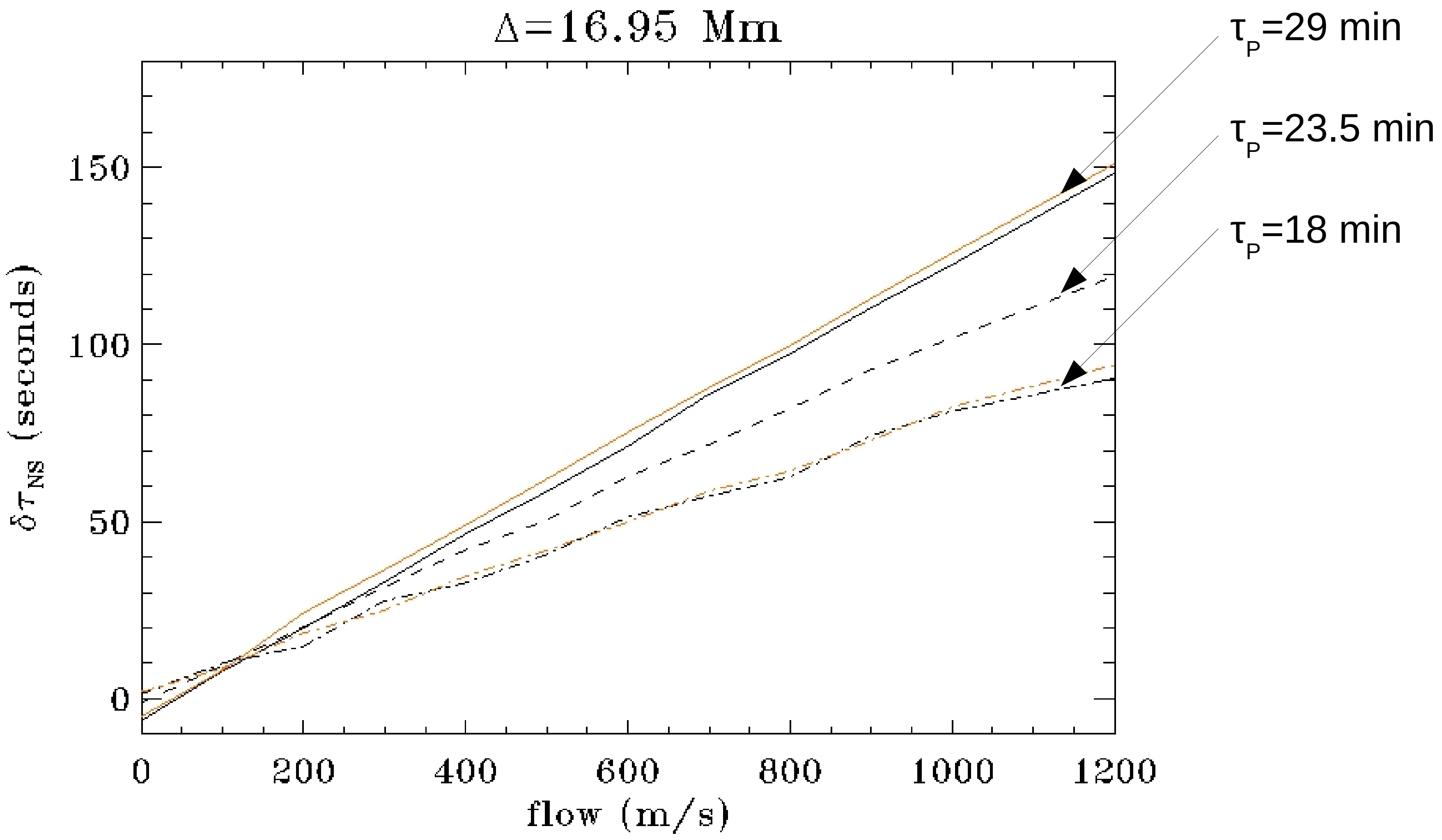
Δ=6.2 Mm;GABOR;01/21/2002
GIZON & BIRCH (2004)
GABOR;01/25/2002
GIZON & BIRCH (2004)
Δ=8.7 Mm;GABOR;01/21/2002
GIZON & BIRCH (2004)
GABOR;01/25/2002
GIZON & BIRCH (2004)
Δ=11.6 Mm;GABOR;01/21/2002
GIZON & BIRCH (2004)
GABOR;01/25/2002
GIZON & BIRCH (2004)
Δ=16.95 Mm;GABOR;01/21/2002
GIZON & BIRCH (2004)
GABOR;01/25/2002
GIZON & BIRCH (2004)
x (Mm)
y (Mm)
(seconds)

Comparison of north-south difference travel times through horizontal flows added to a simulation of the solar convection

(S. Couvidat & A. Birch)

- Simulation of Stein, Nordlund, Georgobiani, & Benson (already used in local helioseismology by, e.g., Braun et al. (2007), Zhao et al. (2007), Georgobiani et al. (2007)
- power spectrum close to MDI
- 96x96x20 Mm^3
- 8.5 hours of data
- dx=0.384 Mm, dt=60 s
- added steady southward uniform flows to the vertical velocity maps, using shift theorem in Fourier domain; 12 flow velocities
- worked with acoustic modes only (Jackiewicz et al., 2007, studied f-mode case)
- time-distance analysis performed with 2 kind of filters ("standard" ---values from T. Duvall--- and "broad" ---FWHM x4---) for 4 distances source-receiver

Uncertainty in the difference travel time with the phase time of the Gabor wavelet (I)



Uncertainty in the difference travel time with the phase time of the Gabor wavelet (II)

At Δ=8.7 Mm

with a 200 m/s southward flow

τ_{ref} = 12.85 min

τ_{North} = 12.917 min

τ_{South} = 12.781 min

$\delta\tau_{NS}$ = 8.15 s

τ_{ref} = 12.85+2π/ω_{ref}= 16.95 min

τ_{North} = 12.917+2π/ω_{North}= 17.074 min

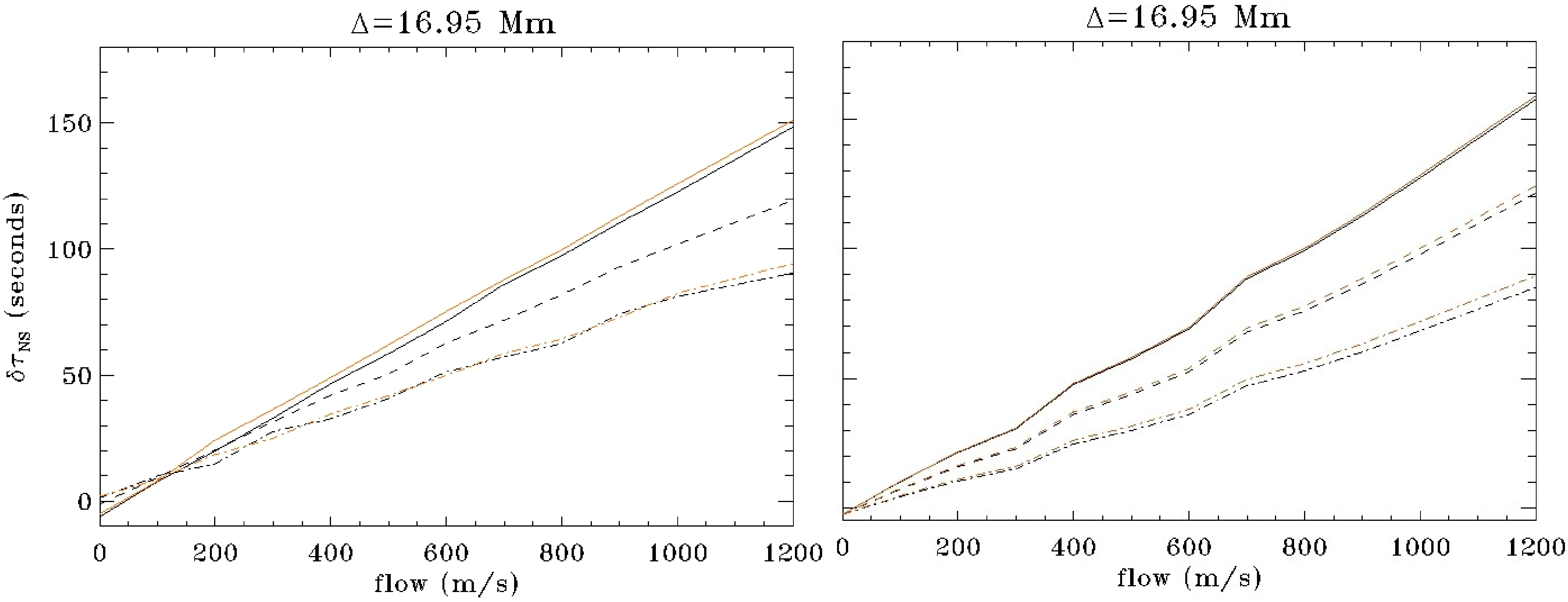
τ_{South} = 12.781+ 2π/ω_{South}= 16.794 min

$\delta\tau_{NS}$ = 16.79 s

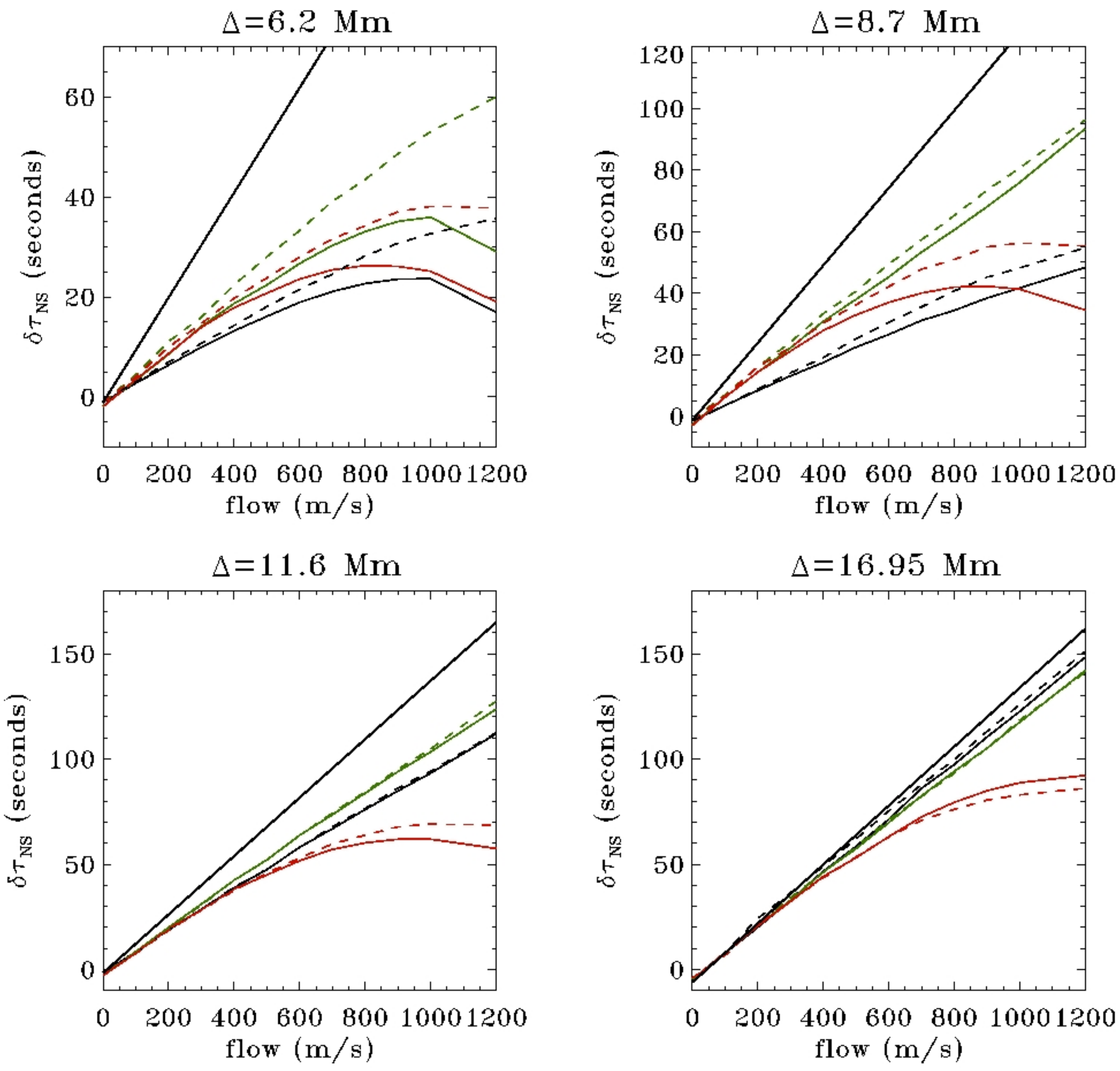
➡ $\delta\tau_{NS}$ not unique because $\omega_{North} \neq \omega_{South}$

Uncertainty in the difference travel time with the phase time of the Gabor wavelet (III)

Ray-path kernels can be corrected to include this dependence on the reference phase time: $\delta\tau_{NS} \sim -2 \int \mathbf{nU}/c^2 \, ds + (\delta\omega_S - \delta\omega_N)/\omega \;\; \tau_p$



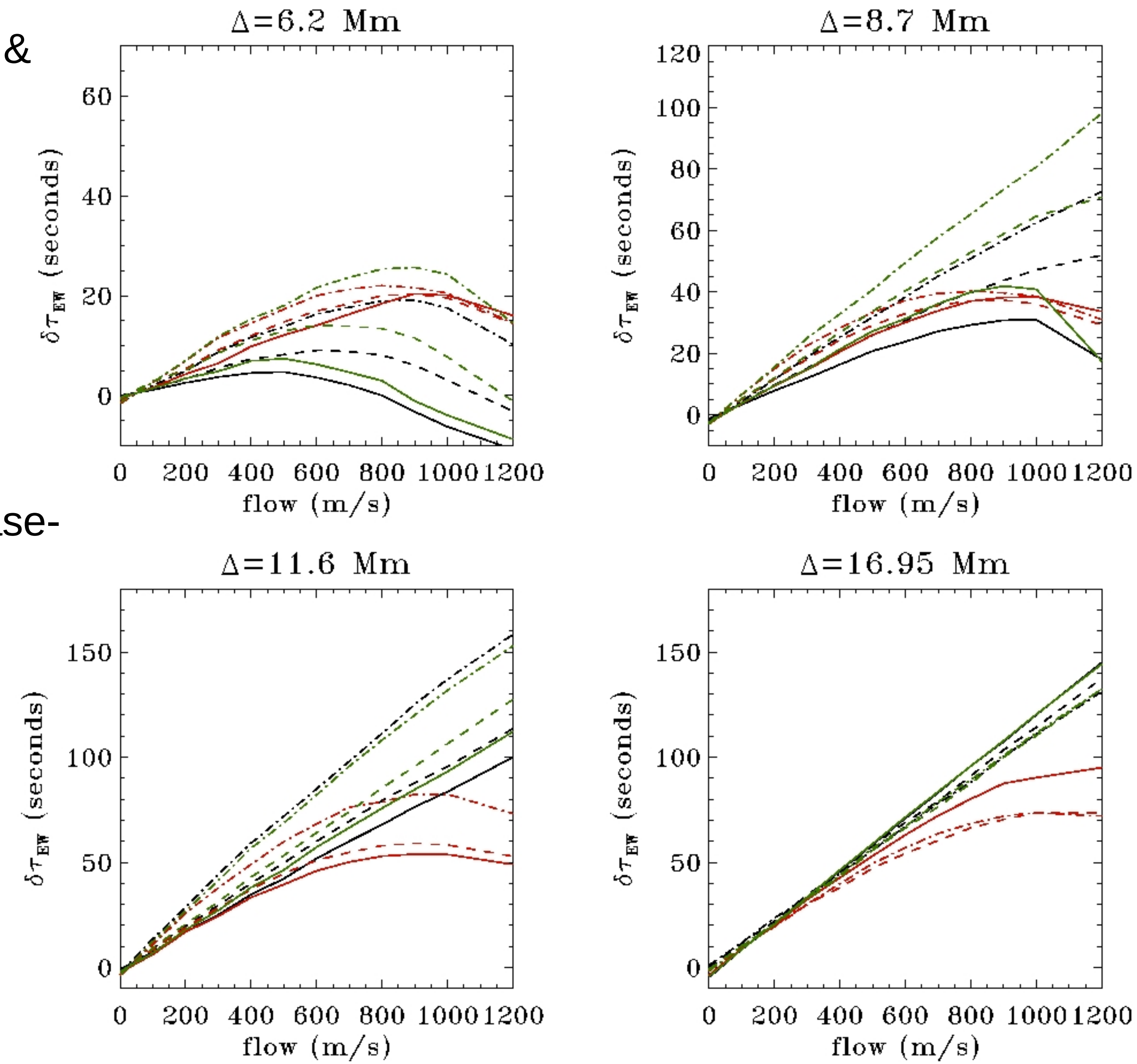
North-South travel-time difference in presence of flows (I)



North-South travel-time difference in presence of flows (II) : frequency dependence

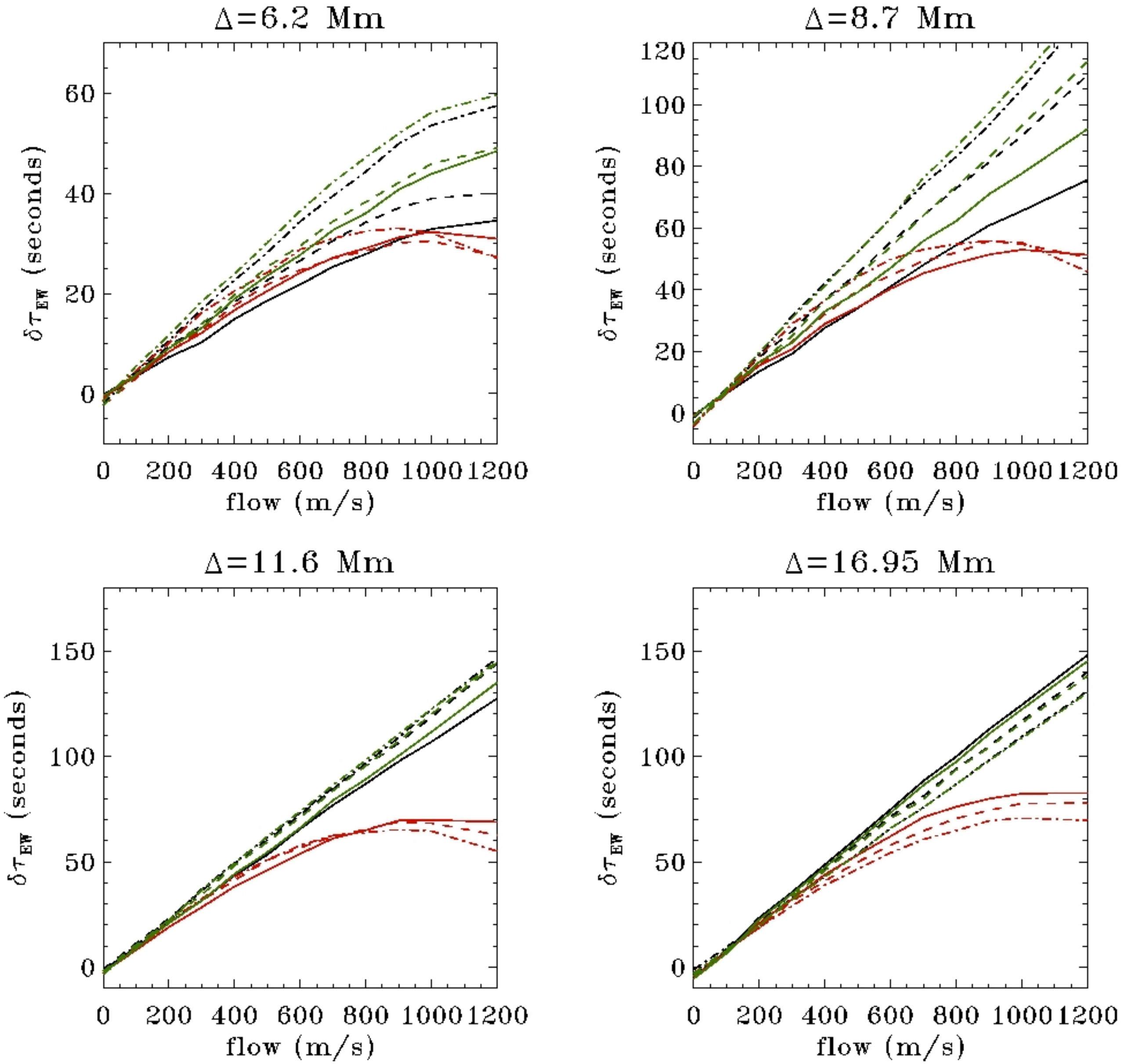
Following Braun & Birch (2006)

Standard phase-speed filters



North-South travel-time difference in presence of flows (III) : frequency dependence

Broad phase-speed filters



Conclusion

- in quiet Sun the three definitions give very similar results
- in active region, Gabor and GB02 give similar results after cross-covariances have been normalized
- GB04, even with normalization, seems inadequate for active regions
- lack of uniqueness of phase travel time returned by Gabor wavelet can be problematic: the reference phase time used should always be mentioned
- if phase-speed filters are too narrow, Gabor and GB02 can return time differences not linear in the flow strength
- GB04 is never linear in the flow strength