GPS measurement strategies

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GPS measurement strategies
Pseudorange vs. phase

- Using **pseudorange** measurements only:
  - C/A code: 10 m (100 m if S/A on)
  - P code: 1 m
  - Real time possible
  - One receiver is sufficient

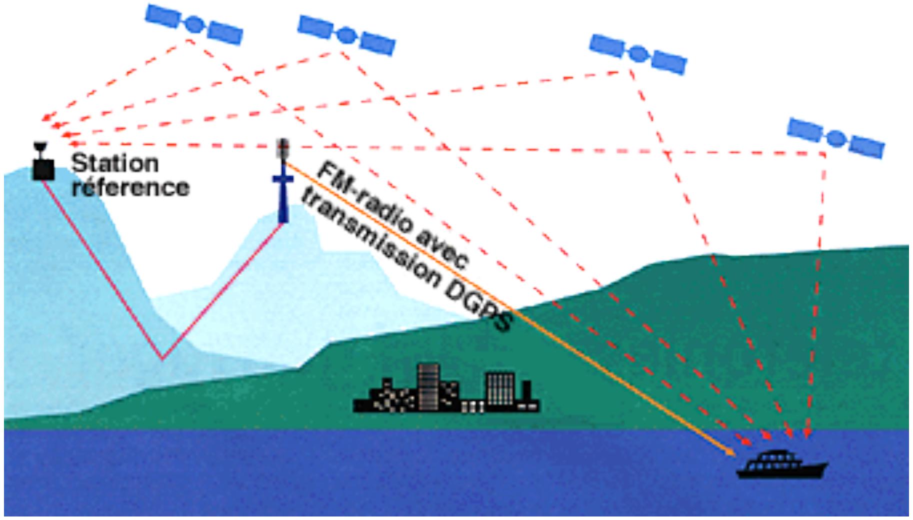
- Using **phase** measurements:
  - Precision varies from 1 mm to 10 cm, depending on the processing strategy (orbits, troposphere, ionosphere)
  - 2 receivers (at least) are necessary in order to produce double differences…! => need for a reference station
  - Latency: depends on communication with reference station
    - Real time if communication link between reference station and rover
    - Post-processed otherwise

GPS measurement strategies

- Bottom line when using phase data: many errors sources must be corrected, such as propagation errors
- Corrections can be computed externally and provided by radio link = differential GPS
- Corrections can be computed “internally” if data from a reference station is available:
    - In real-time -- receiver computes phase solution
    - Post-processed -- data is first downloaded to a computer, the processed.
- Positions can be obtained:
    - At each measurement epoch = kinematic GPS
    - For a longer time span = static GPS

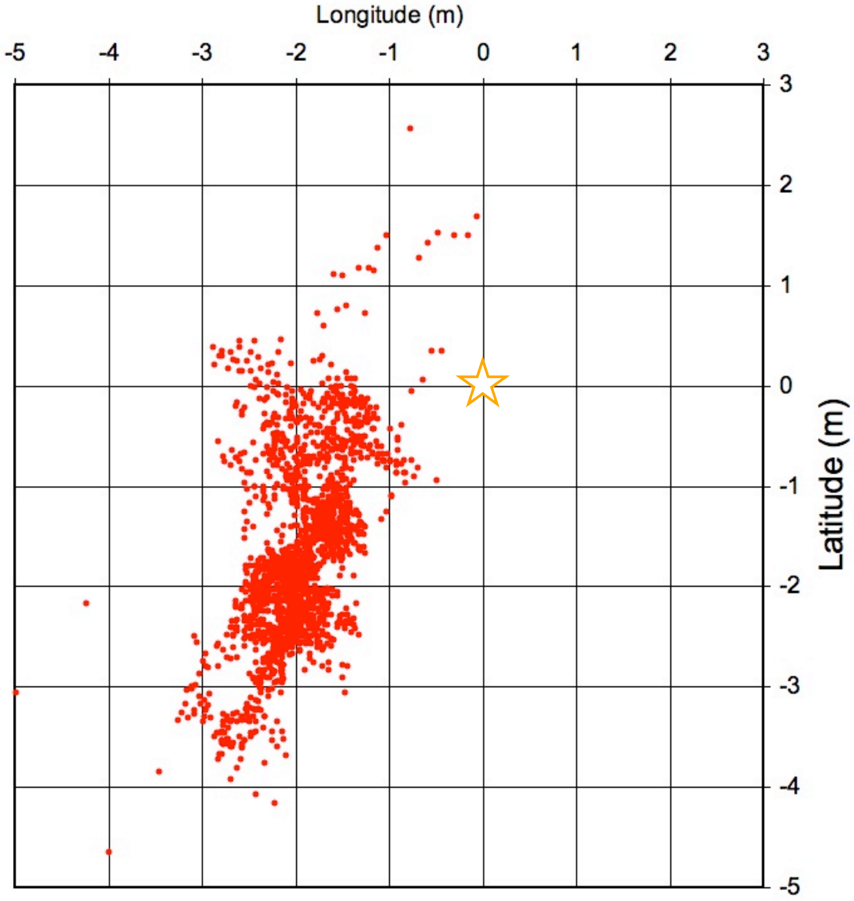
Differential GPS

- A reference station whose position is precisely known:
  - Computes its position using available GPS satellites
  - Compares it with its “true” position
  - Computes a pseudorange correction for each satellite = **differential corrections**
  - Broadcasts these corrections on radio frequencies
- The user:
  - Has a radio antenna attached to his GPS receiver
  - Receives differential corrections from reference station
  - Measures and correct pseudoranges
  - Computes a position using these more accurate pseudoranges
- Interests:
  - Pseudorange receivers
  - Meter-level accuracy, even with S/A on
  - Corrects for sat. orbit errors, propagation errors
- Limitations:
  - Sat. orbit errors valid everywhere but propagation errors only valid in the vicinity of the reference station
  - Propagation of the differential correction radio signal
  - S/A off since May 2000.



Mapping a dump with DGPS

Differential GPS



☆ « True » position

● DGPS positions

- Comparison between precise positioning (GAMIT, phase processing, etc.) and differential GPS (DGPS Omnistar)
- The “true” position (from several 24-hour static sessions) is set at 0,0 for comparison = star
- DGPS measurements were acquired during 1 hr 30 min = red dots
  - DGPS average:
    - ⇒ X=-1.93m
    - ⇒ Y=-1.61m
  - DGPS standard deviation:
    - ⇒ Xstd=0.97m
    - ⇒ Ystd=1.17m

Kinematic positioning

- The GPS antenna is mobile
- Need for a reference station if phase processing
- Real-time:
  - Easy if using pseudorange only
  - If using phase: need for a communication link with reference station (=> short distance)
- Precision:
  - Peudorange, real-time: 1-10 m
  - Phase:
    - < 5 cm if **phase ambiguities** are solved
    - 10-50 cm if **phase ambiguities** are not solved
- Applications:
  - Navigation s.l., precision farming, fleet management
  - Cartography, SIG

Mapping dry river beds in Arizona

Bathymetry mapping in the Everglades

Static positioning

- GPS antenna fixed (tripod, spike mount, etc)
- The longer the session, the more precise the result
- But logistical contingencies:
  - Safety
  - Battery life (use solar!)
  - Access to site
- Usually associated with phase measurements
- Used when high-precision is needed: e.g. crustal deformation

Typical GPS campaign setup using a "spike mount", Dominican Republic

Mapping street intersections in Buenos Aires

Rapid-static positioning

- GPS antenna put on benchmark for a few minutes, then moved to next benchmark without loss of lock => phase ambiguities are kept the same from benchmark to benchmark
- Slightly better precision than kinematic

Mapping fire hydrants in California

High accuracy static GPS surveying

- *E.g.*: crustal deformation measurements
- Field strategy:
  - Network of geodetic benchmarks perfectly attached to bedrock
  - Separation typically 10-100 km
  - Dual frequency GPS receivers
  - 2 to 3 measurement sessions of 24 hours, sampling at 30 sec
  - Then move to next site. Usually several crews operate simultaneously.
  - Download GPS measurements from receiver memory into computer daily, quality control, backups
- In the lab, after the campaign:
  - Data post-processing using phase measurements
  - Precision 1-3 mm horizontal, 5-7 mm vertical
- Important issues:
  - Monumentation
  - Antenna setup


Benchmark


Receiver + laptop


Antenna on tripod

A typical GPS campaign schedule

			Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	
			15	16	17	18	19	20	21	22	23	24	25	26	27	28	1	2	3	
#	**FULL NAME**	**CODE**	046	047	048	049	050	051	052	053	054	055	056	057	058	059	060	061	062	Problems
1	Puerto Tortuguero	TORT	Arrival in the evening, meeting at the Cervantes	Meeting at Instituto Cartografico Militar and Mineria, obtain work authorisations, get equipment from customs	Rent cars, shopping for small equipment, training session, install SDOM	15:47	x	x	x	14:18									Departure	
2	Barahona	BARA				17:57	x	x	13:42											
2	Cabo Rojo	ROJO							19:44	x	x									
3	Puerto Escondido	ESCO								18:58	x	x								
4	La Colonia	COLO										10:55	x	15:07						
5	Banica	BANC											16:25	x	x					
6	Tierra Nueva	TIER												18:41	x	x	15:05			
7	San Juan	SANJ														11:15	x	11:52		
8	Santiago	SANT				17:37	x	x	12:57											
9	Camp David	CAMP				19:43	x	x	14:16											40% of expected data in rinex files
10	Los Hidalgos	HIDA							21:45	x	x	15:50								
11	La Reunion	REUN								15:19	x	13:14								Delay due to permission to access site
12	Moncion	MONC										18:22	x	x	13:40					
13	Capotillo	CAPT										21:39	x	x	15:28					
14	Capotillo	CAPO											21:43	13:35						Survey of CAPO-CAPT tie
15	Monte Cristi	CRIS													18:29	4:21				Power disconnected
16	Pepillo Salcedo	PEPE													16:43	x	x	14:04		
17	Villa Altagracia	VILL				15:43	x	x	14:43											
18	Constanza	CONS				20:39	x	x												
19	La Vega	LAVE							22:07	x	x	12:30								
20	Moca	MOCA							18:46	x	x									
23	Las Terranas	TERR										20:16	x	x						
24	Arroyo Barril	ARRO										17:06	x	x	21:50					Antenna moved during session 057
21	Cabo Frances	FRAN													14:57	x	x			
22	Castillo	CAST													23:51	x	x	12:35		
25	Las Americas	AMER				17:40	x	x	14:42											
26	Bayaguana	BAYA				21:21	x	x	12:58											
27	Boca de Yuma	BOCA							22:33	x	x	12:45								
28	La Romana	ROMA							20:22	x	x	14:39								
29	Punta Cana	PUNT										19:22	x	x	13:36					
30	Higuey	HIGU										22:37	x	x	11:37					
31	Sabana la Mar	SMAR													19:27	x	x	0:24		
32	El Seibo	SEIB													16:10	x	x	12:27		
33	Santo Domingo	SDOM			21:21	x	x	x	02:16		19:43	x	x	x	x	x	8:05			Power failures
			Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	
			15	16	17	18	19	20	21	22	23	24	25	26	27	28	1	2	3	
			046	047	048	049	050	051	052	053	054	055	056	057	058	059	060	070	071	

Team 3	Andy Eby, Rosaida Ortiz, 2ndo Teniente Nicadil Suero	🟥	24h session

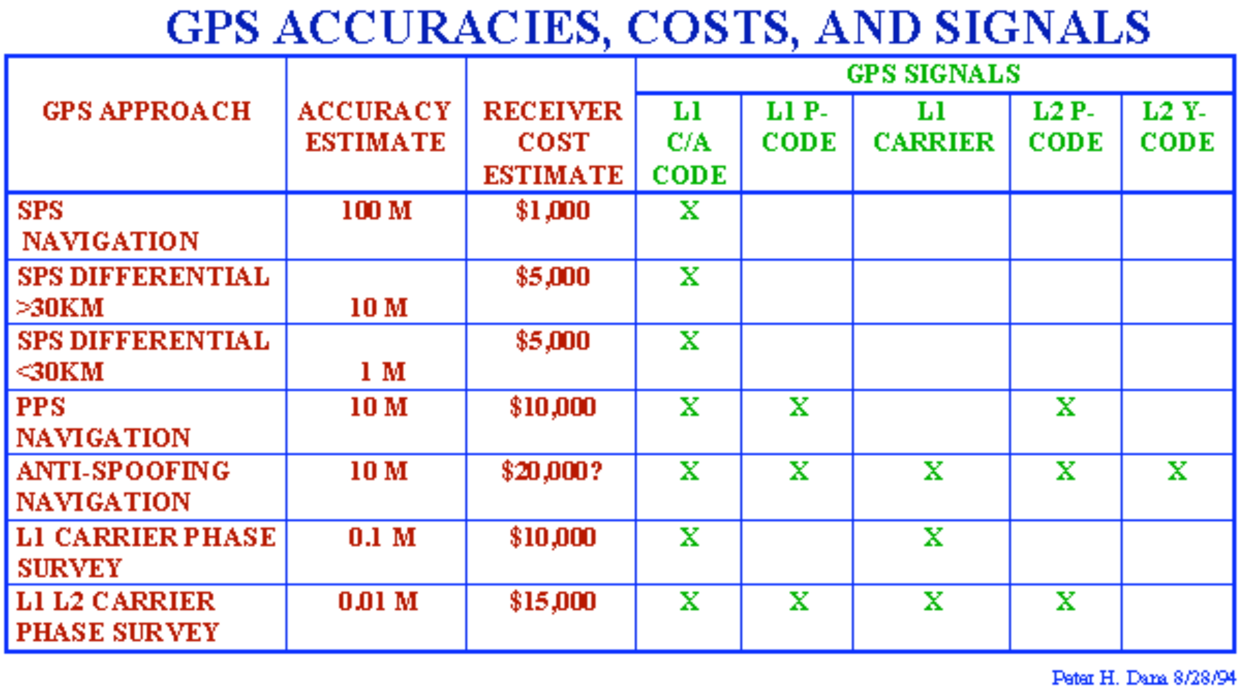
High accuracy static GPS surveying with continuous permanent GPS stations

- Typical setup:
  - Dual frequency GPS receivers
  - Phase and pseudorange measurements at 30 sec rate, continuously, 24h/day, 365 days/year
  - GPS antenna mounted permanently on a stable geodetic monument
  - Site protected and unattended
  - Receiver, power supply and modem in a shelter by the antenna
  - Data downloaded daily or more frequently if needed (and if possible)
- Interests:
  - Continuous position time series
  - Better detection of transient signals
- Problems:
  - Power supply
  - Lightning
  - Vandalism
  - Sites not as stable as originally thought…

Permanent GPS site, antenna on concrete pillar anchored in bedrock

Shelter with GPS receiver, solar panels

Accuracies, cost, and signals

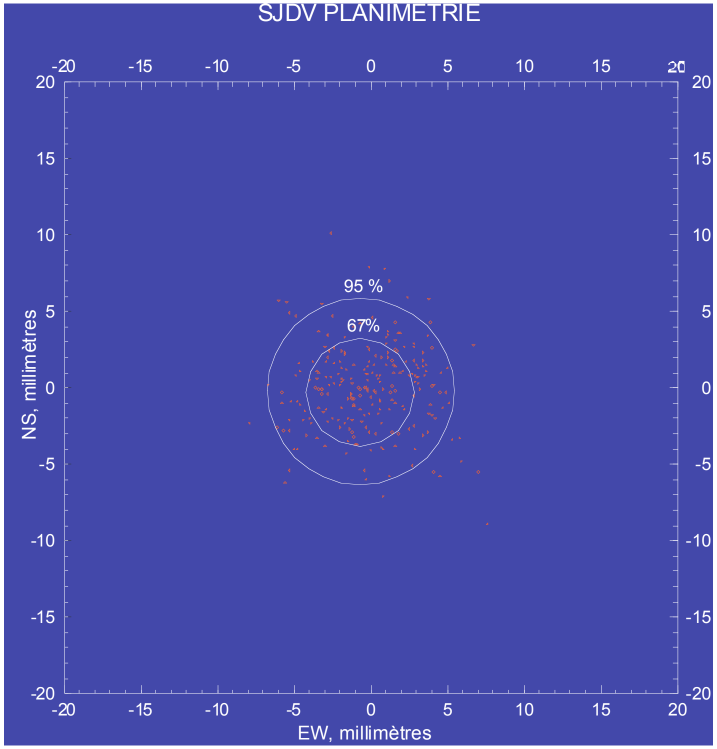


GPS ACCURACIES, COSTS, AND SIGNALS

GPS APPROACH	ACCURACY ESTIMATE	RECEIVER COST ESTIMATE	GPS SIGNALS				
			L1 C/A CODE	L1 P-CODE	L1 CARRIER	L2 P-CODE	L2 Y-CODE
SPS NAVIGATION	100 M	$1,000	X				
SPS DIFFERENTIAL >30KM	10 M	$5,000	X				
SPS DIFFERENTIAL <30KM	1 M	$5,000	X				
PPS NAVIGATION	10 M	$10,000	X	X		X	
ANTI-SPOOFING NAVIGATION	10 M	$20,000?	X	X	X	X	X
L1 CARRIER PHASE SURVEY	0.1 M	$10,000	X		X		
L1 L2 CARRIER PHASE SURVEY	0.01 M	$15,000	X	X	X	X	

Peter H. Dana 8/28/94

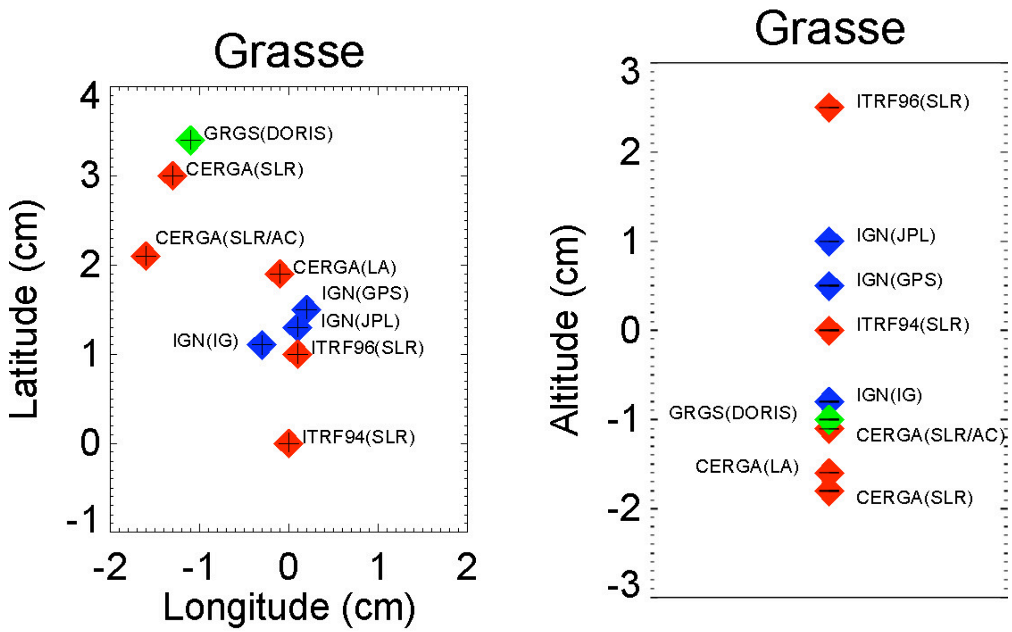
Precision and accuracy



Daily positions (NE) for SJDV over a 6 month time period

The scatter of a series of measurements made using the same technique is an indicator of the **precision** of the position estimate

Precision = internal control



Comparison of the position of site Grasse (right panel: NE, left panel: Up) obtained using 2 different geodetic techniques (GPS, SLR) and different processing strategies

The scatter of a series of measurements made using independent techniques is an indicator of the **accuracy** of the position estimate

Accuracy = external control

Quantifying Precision

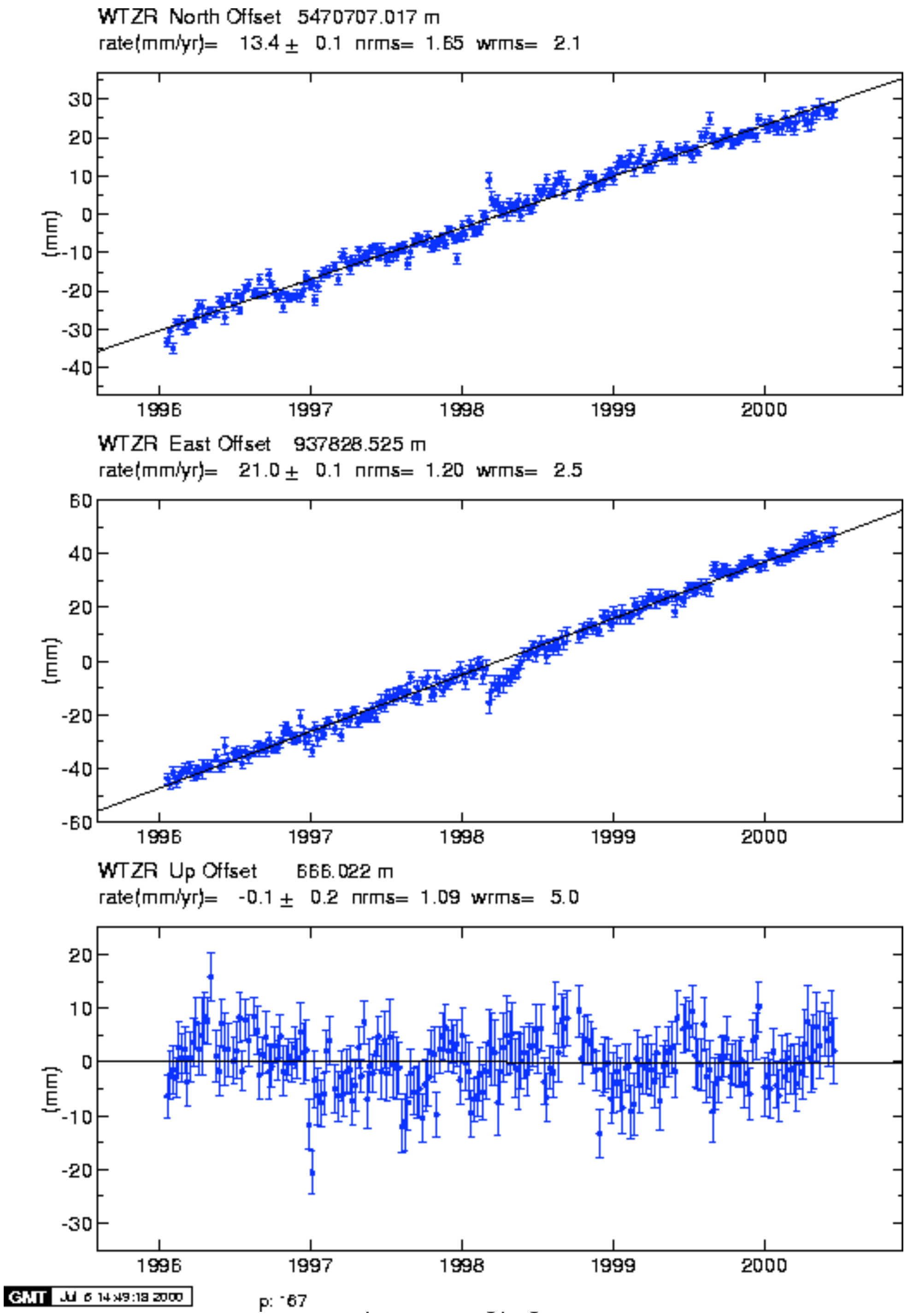
- One position: least squares solution provides formal error (cf. GPS parameter estimation).
- Several positions at static site => time series can be plotted.
    - Scatter of daily positions to the weighted mean of the entire time series = a measure pf precision
    - Called repeatability, defined by:

$$wrms = \sqrt{\frac{\frac{N}{N-1}\sum_{i=1}^{N}\frac{(y_i-(a+bt_i))^2}{\sigma_i^2}}{\sum_{i=1}^{N}\sigma_i^2}}$$

y_i and σ_i = position and associated formal error from the inversion

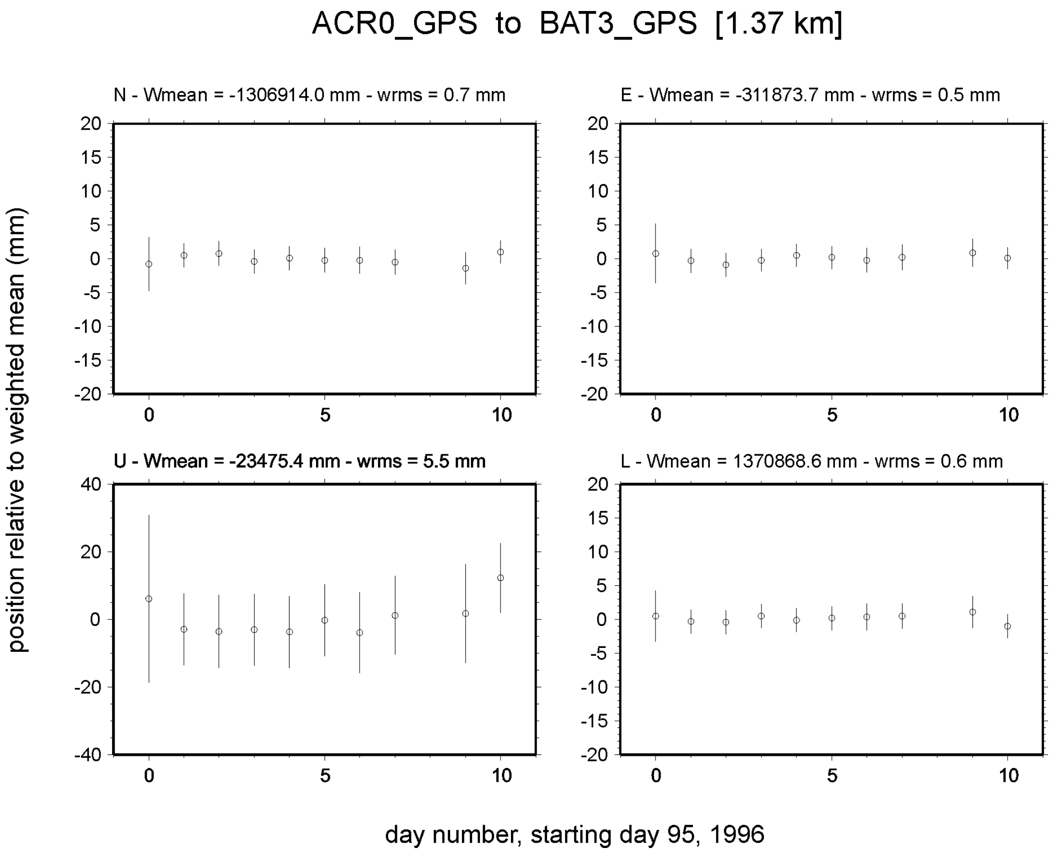
N = number of data points

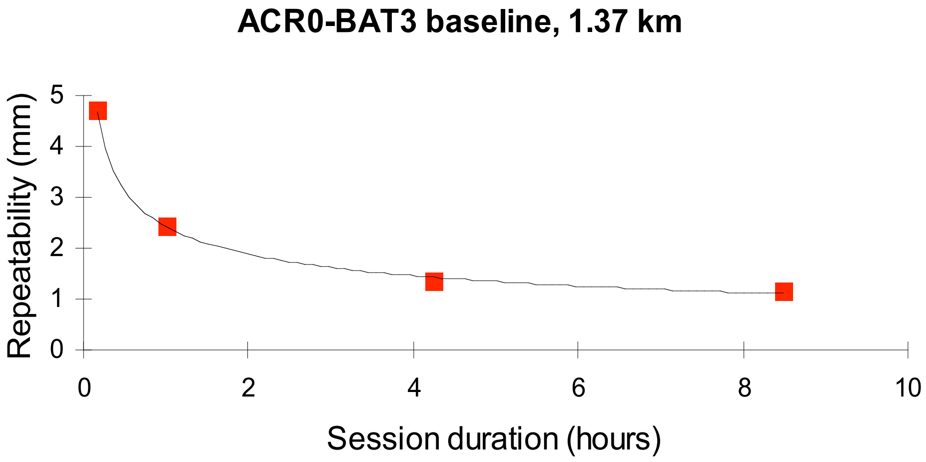
- Repeatability leads to a more conservative result than the formal errors from the least squares solution



A short baseline

- 1.3 km long baseline continuously observed during 10 days
- Processing of GPS phase data (on L1) with research software
- Repeatability, horizontal components:
  - 24 hr sessions: < 1 mm
  - 15 min sessions: ~ 5 mm





Influence of baseline length

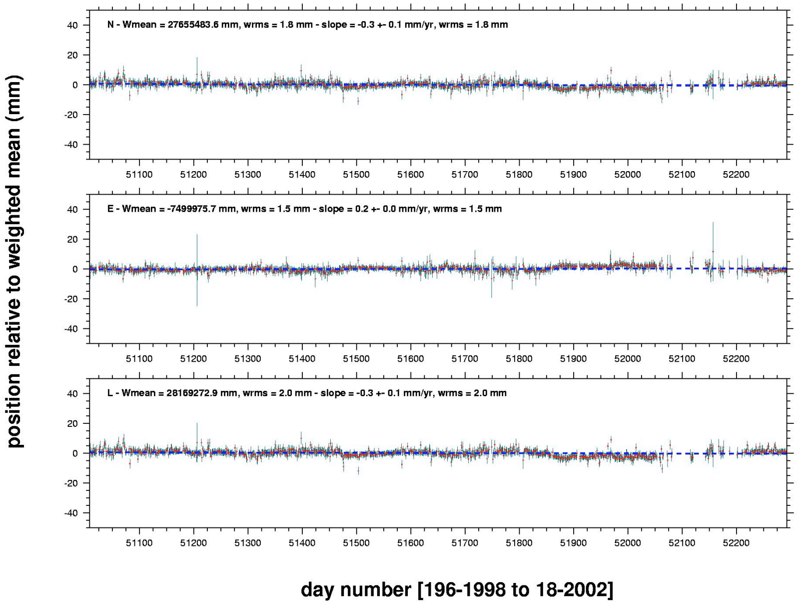
- Next slide compares 4 different baseline length, from 30 to 2300 km:
  - Permanents GPS sites (IGS network)
  - 1 to 2 years of continuous measurements
  - Plots show time series -- how can we compare precision for these 4 baselines?

- Repeatability, or WRMS (horizontal components):
  - ⇒ Short baseline (28 km) = 2.0 mm
  - ⇒ Medium baseline (160 km) = 2.3 mm
  - ⇒ Long baseline (870 km) = 7.3 mm
  - ⇒ Very long baseline (2300 km) = 10.0 mm

30 km

GINA_GPS to MICH_GPS [28.17 km]

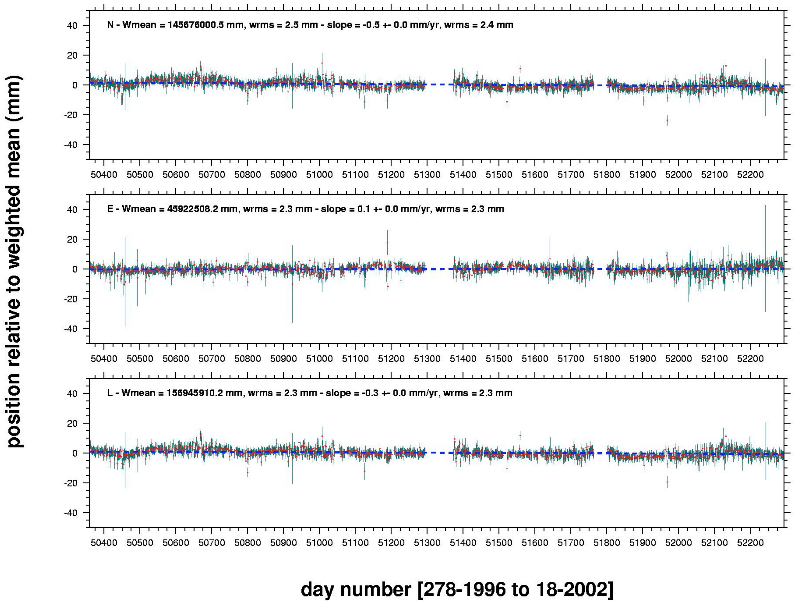
cleaned time series, maxsig=100 mm, maxdev=100 mm



160 km

GRAS_GPS to TORI_GPS [156.95 km]

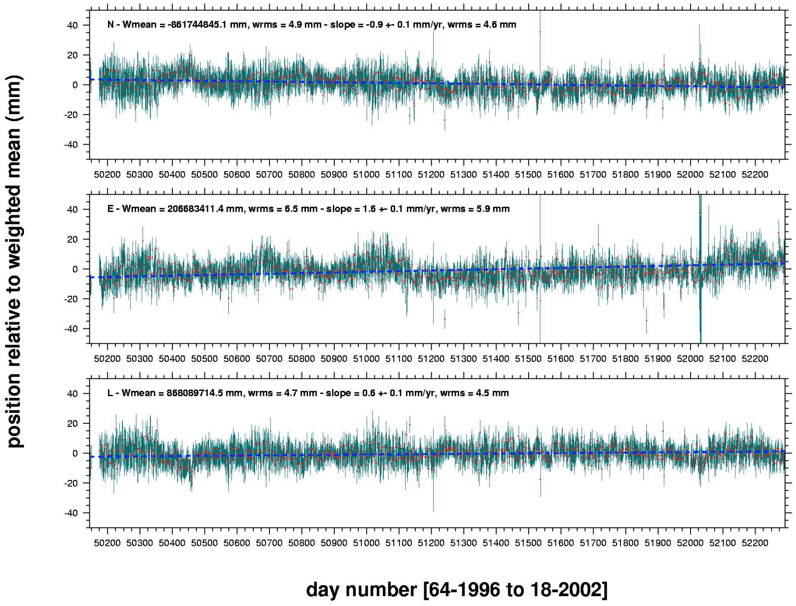
cleaned time series, maxsig=100 mm, maxdev=100 mm



870 km

CAGL_GPS to ZIMM_GPS [868.09 km]

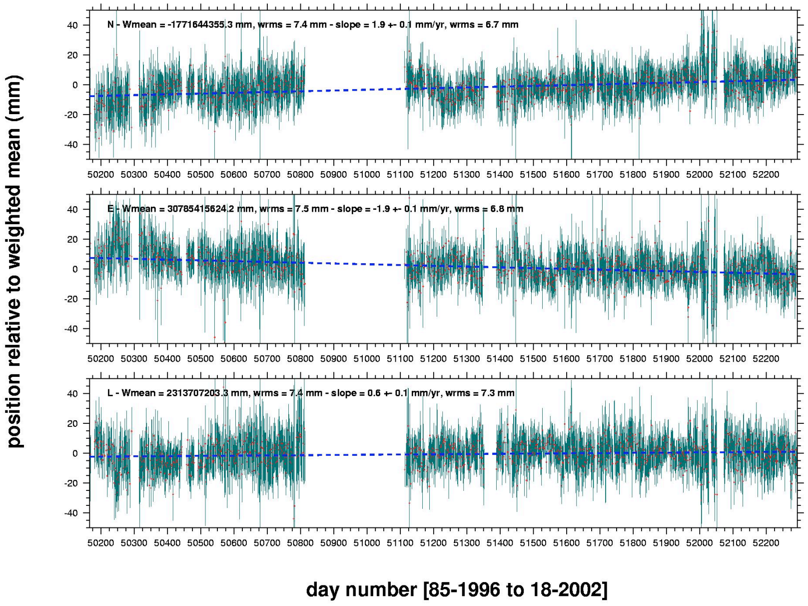
cleaned time series, maxsig=100 mm, maxdev=100 mm



2300 km

SFER_GPS to POTS_GPS [2313.71 km]

cleaned time series, maxsig=100 mm, maxdev=100 mm



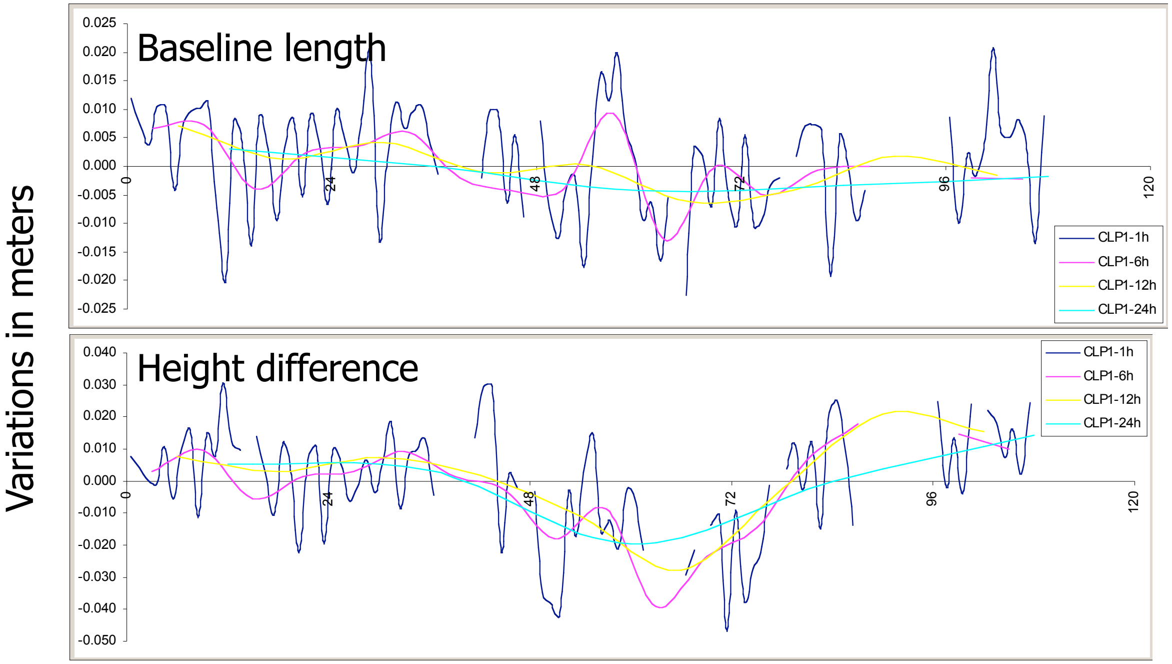
Influence of session duration

The La Clapiere landslide in the French Alps (50×10^6 m^3). Circles show location of GPS sites

- Reference site outside of the landslide + 3 sites on the landslide => baselines ~ 1 km
- Continuous observations during 6 days
- Processing of the phase data (L1 only - why?), using 24hr, 12hr, 6hr, 1hr sessions

⇒ Shorter sessions are affected by a high-frequency noise

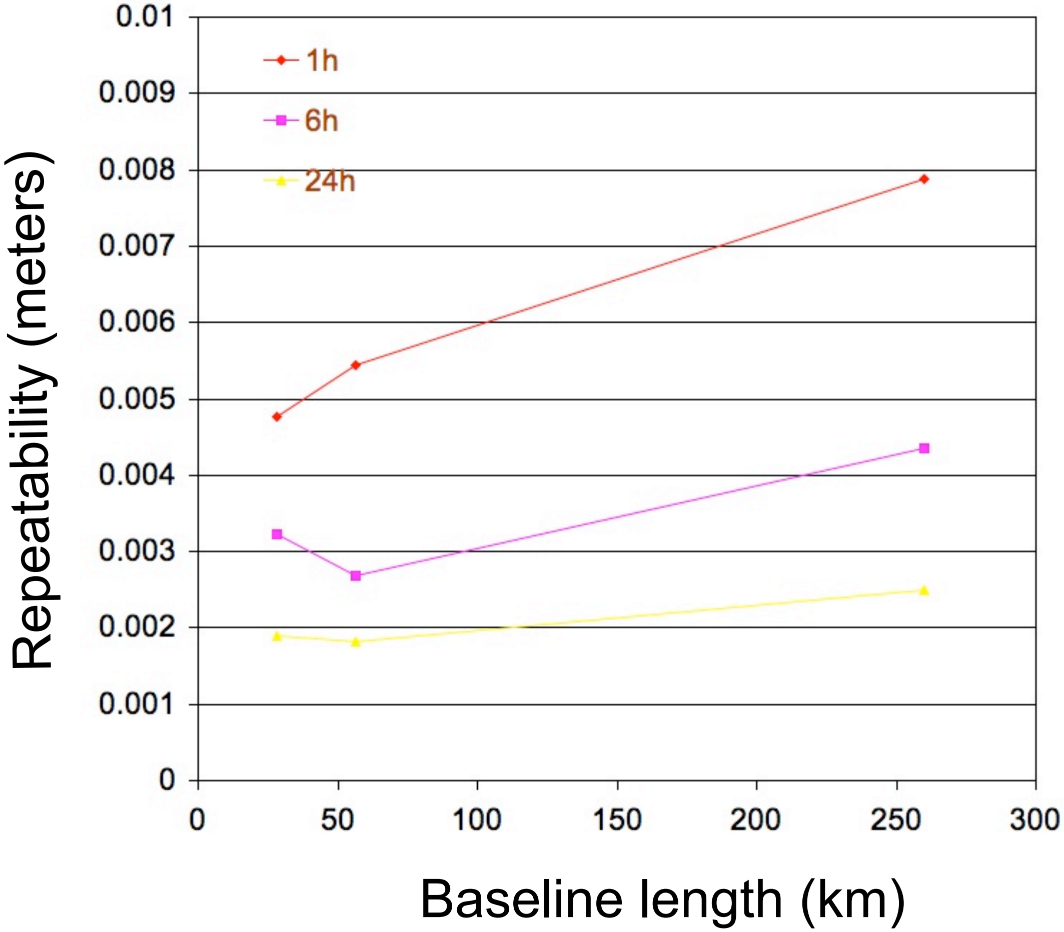
⇒ HF noise is correlated with PDOP variations and multipath (enhanced by topo + snow).



Baseline length and height difference between reference site and site CLP1

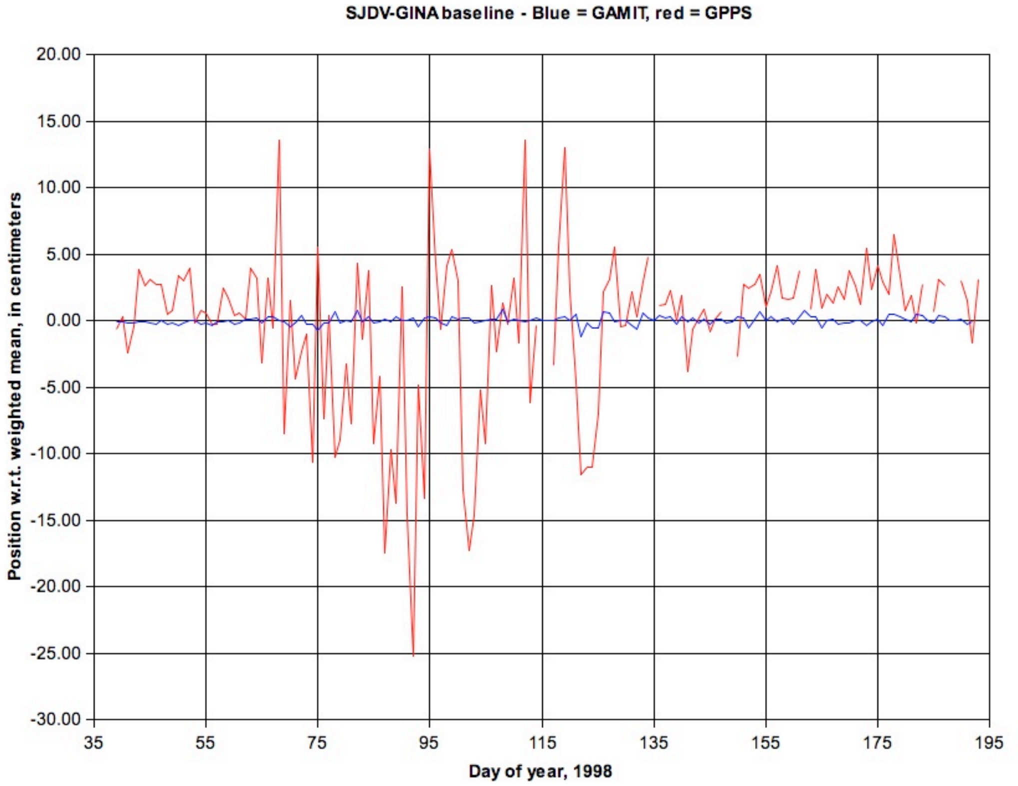
Influence of session duration

- Three baselines observed continuously during 30 days
- Length = 30, 60 and 260 km
- Sophisticated processing of the phase data (LC)
  - 1, 6, and 24 hr sessions
  - Research software (GAMIT)
  - Precise IGS IGS, estimation of tropospheric parameters, etc…



Influence of processing strategy

- 260 km long baseline observed continuously during 160 days
- Processing of the phase GPS data (LC) using 24 hour sessions with:
  - A commercial software (GPPS), broadcast orbits, no tropospheric estimation, etc.
  - A research software (GAMIT), IGS precise orbits, tropospheric estimation, etc.



Result:

- GPPS: wrms = 6 cm
- GAMIT: wrms = 3 mm
- But mean length differ by 0.6 mm only!

The quest for millimeter precision… The recipe

- Receivers:
  - Record phase and pseudorange data
  - Dual frequency
- Antennas:
  - Design that minimizes multipath
  - Calibrated + phase diagram known
- Measurements:
  - Long sessions (24 hours), repeated 2-3 times (=> power!)
  - Or continuous recording at permanent sites
  - Sampling rate 30 seconds, elevation cut-off 10°
- Sites: stable, secure, and perennial
- Reliable field operators!
- Post-processing of phase data:
  - Ionosphere-free combination LC
  - Double differences (eliminate clocks) => need for at least 2 stations
  - Models:
    - Antenna phase center variations
    - Tropospheric zenith delays (+ horizontal gradients)
    - Solid-Earth tides, ocean loading (+ atmospheric and hydrological loading…)
    - Orbit perturbations: solar radiation pressure, yaw
  - A priori tables:
    - Earth orientation parameters for accurate conversions between inertial and Earth-fixed frames
    - Lunar and solar ephemerides (tidal effects)
    - Precise GPS orbits (from IGS)
    - Accurate terrestrial reference frame (ITRF)

⇒ Research software (GAMIT, BERNESE, GIPSY, etc.)

Precision and accuracy of phase-derived GPS positions

At this point in the semester, you have to be able to answer these questions

- Why should baseline length matter?
- Why should session duration matter?
- Why should type of software matter?
- What else should matter?
- What should my measurement strategy be if the requirements are X cm precision?