GPS measurements in the field

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Material from R. King, T. Herring, M. Floyd (MIT) and S. McClusky (now ANU)

Outline

- Survey setups
- Potential errors
  - Human error
  - Monument error
  - Seasonal error
  - System error
- Hands-on equipment

Survey setups

- May be done with:
  - Tripod
  - Spike mount
  - Pole
- Intentions:
  - Set antenna horizontal
  - Ensure antenna is centered above survey mark (necessarily requires that the antenna mount is set horizontal)
  - Align antenna conventional mark to true north

Surveyor's tripod

- Advantages:
  - Easily portable
  - Stable on flat ground
- Disadvantages:
  - Inconsistent height setup (variable multipath)
  - Easily disturbed

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Fixed-height mast (e.g. Tech2000)

- Advantages:
  - Automatically centered
  - Fixed height (reduces human error)
  - Stable
  - Identical multipath environment each setup
- Disadvantages:
  - Difficult first-time placement due to anchor installation (also requires large, hard surface)

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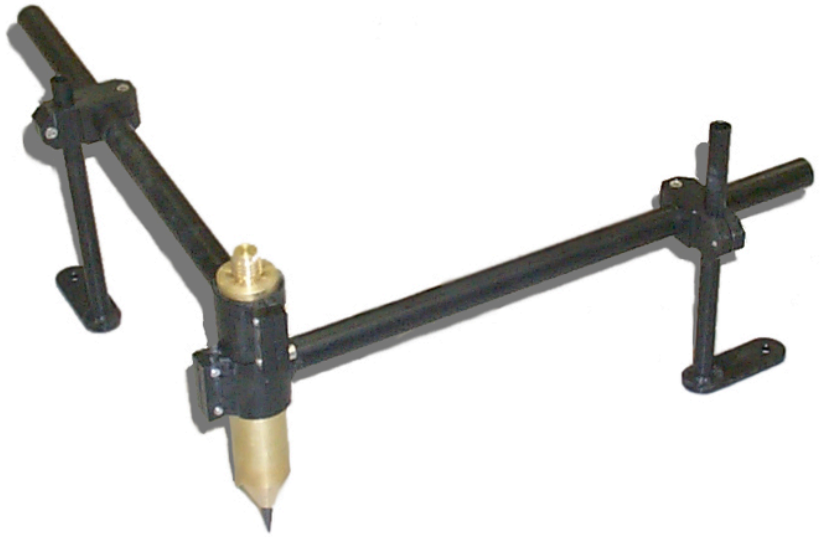
Spike mounts

- Advantages:
  - Fixed height (reduces human error)
- Disadvantages:
  - Awkward to level precisely and orientate antenna
  - Proximity to ground may increase direct multipath signal



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Basic rules for any setup

- Know how well your equipment is calibrated, and how to calibrate or verify its accuracy if necessary
  - A 1-D level is a very useful tool to have!
- Iterate using finer and finer adjustments
  - It's a rare day that the best of us find an acceptably accurate setup the first time
- Always work upward from the base of a tripod setup
  - Fix the legs once an approximate (within a few cm) position is achieved
  - Work exclusively with the tribrach on the platform thereafter
- Always level the (optical) plummet before assessing the centering, especially after making adjustments

Human error

Location errors

Photograph by M. Floyd

Photograph by M. Floyd

Photograph by M. Floyd

Setup errors

- Episodic survey setups can mean that measurements are not centered perfectly over a mark or the antenna height not measured accurately
- These measurements tend to exhibit an independent and random nature

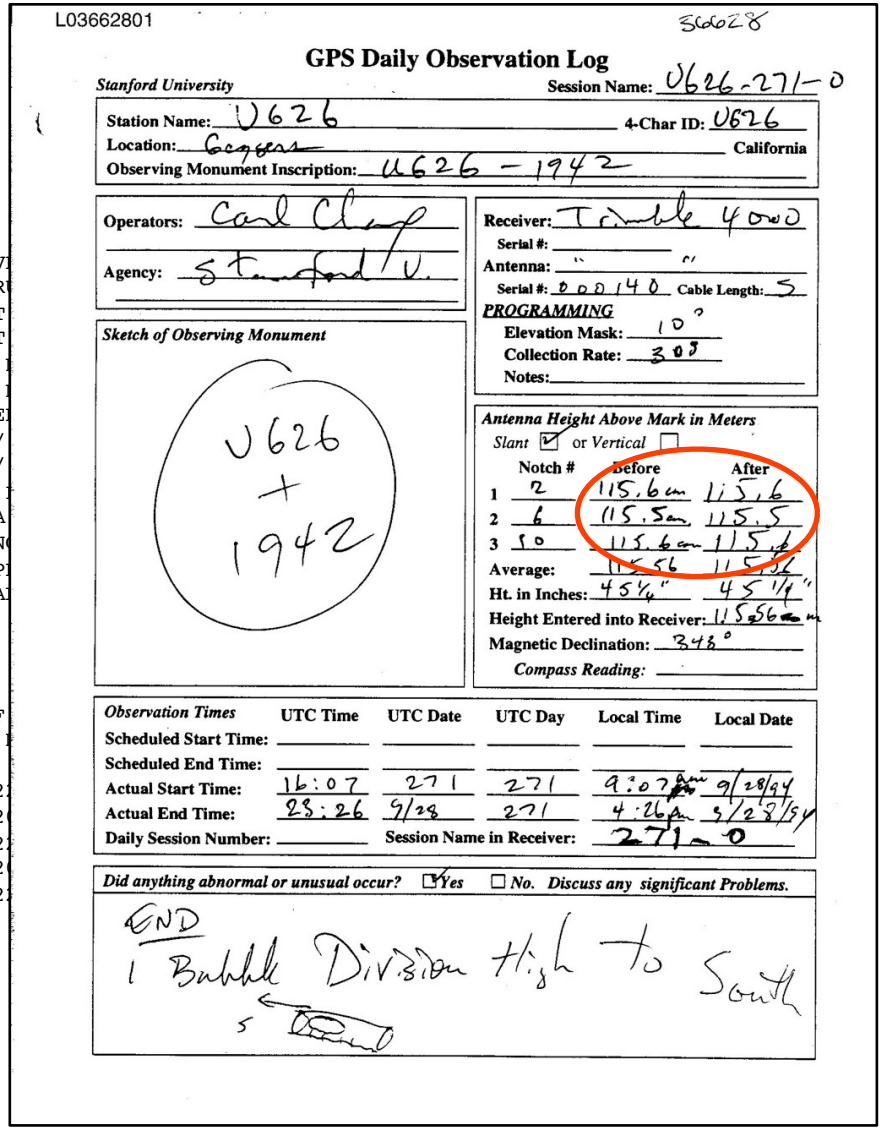
Archive errors

```
     2.10           OBSERVATION DATA    G (GPS)             RINEX V
teqc  2006Jul20     UNAVCO Archive Ops  20060725 16:48:29UTCPGM / R
Solaris 5.9|UltraSparc IIi|cc -xarch=v9 SC5.5|=+-|*Sparc    COMMENT
BIT 2 OF LLI FLAGS DATA COLLECTED UNDER A/S CONDITION       COMMENT
U626                                                        MARKER
U626                                                        MARKER
UNKNOWN             Stanford University                     OBSERVE
3414A05687          TRIMBLE 4000SSE     NP 5.71 / SP 1.26   REC # /
3015A00136          TRM14532.00                             ANT # /
 -2683218.3014 -4185018.7102  3983204.9361                  APPROX
       1.4755        0.0000        0.0000                   ANTENNA
     1     1                                                WAVELEN
     5    L1    L2    C1    P1    P2                        # / TYP
    30.0000                                                 INTERVA



  1994     9    28    16     7    30.0000000     GPS         TIME OF
                                                            END OF

 94  9 28 16  7 30.0000000  0  5G 5G 6G17G20G24
   2437477.48856   1792564.39355  22428902.4774              2
   -548226.77657   -402556.82256  20834866.1484              2
   -567509.56556   -371824.37155  22860949.9614              2
   1203057.74657    883752.12057  20612879.2734              2
    793138.12755    501650.82355  22928979.6334              2
```



L03662801

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GPS Daily Observation Log

Stanford University

Session Name: U626-271-0

Station Name: U626 — 4-Char ID: U626

Location: Geysers — California

Observing Monument Inscription: U626 - 1942

Operators: Carl Clapp

Agency: Stanford U.

Receiver: Trimble 4000

Serial #:

Antenna: "

Serial #: 000140 Cable Length: 5

PROGRAMMING

Elevation Mask: 10°

Collection Rate: 30s

Notes:

Sketch of Observing Monument

U626 + 1942

Antenna Height Above Mark in Meters

Slant ☑ or *Vertical* ☐

Notch #	Before	After
1 2	115.6cm	115.6
2 6	115.5cm	115.5
3 10	115.6cm	115.6
Average:	115.56	115.56
Ht. in Inches:	45¼"	45 1/4"

Height Entered into Receiver: 115.56cm

Magnetic Declination: 348°

Compass Reading:

Observation Times	UTC Time	UTC Date	UTC Day	Local Time	Local Date
Scheduled Start Time:					
Scheduled End Time:					
Actual Start Time:	16:07	271	271	9:07a	9/28/94
Actual End Time:	23:26	9/28	271	4:26p	9/28/94
Daily Session Number:		Session Name in Receiver:		271-0	

Did anything abnormal or unusual occur? ☑ *Yes* ☐ *No. Discuss any significant Problems.*

END

1 Bubble Division high to South

5

Monument error

Survey marks

Monuments for tectonics (best)

Drilled monuments

- Attached to solid bedrock
- Very stable
- Must be secured somehow

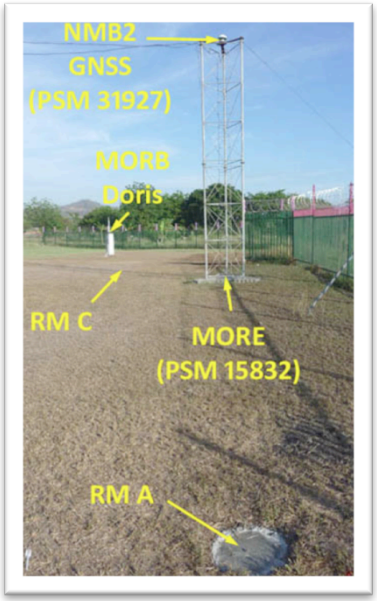
Shallow rod in bedrock

- Attached to solid bedrock
- Cheap and easy to install
- Must be secured somehow

Monuments for tectonics (other)

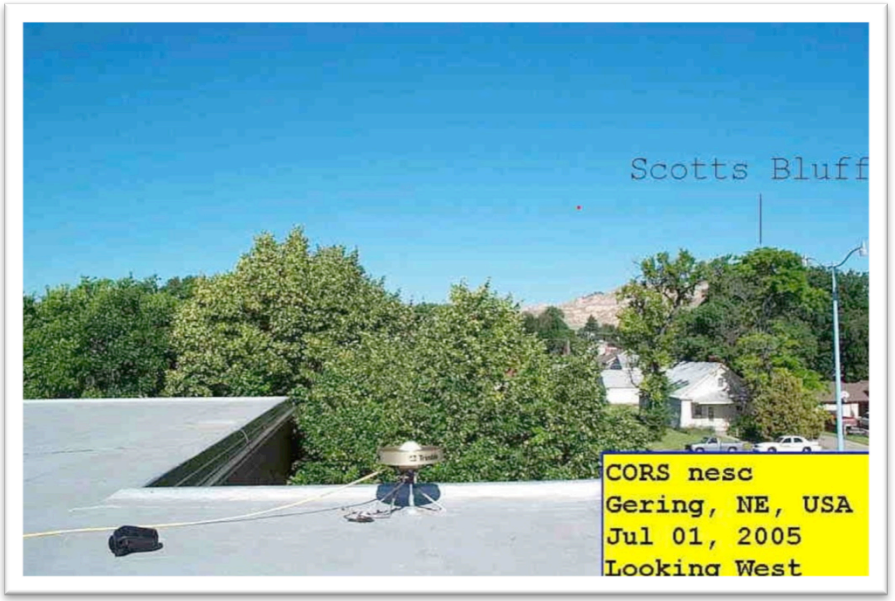
High metal masts

- Generally secure
- Suffer from heat expansion and contraction
- May suffer from unstable foundation



Roofs of buildings

- Easily accessible
- Generally secure
- No knowledge of building foundation stability

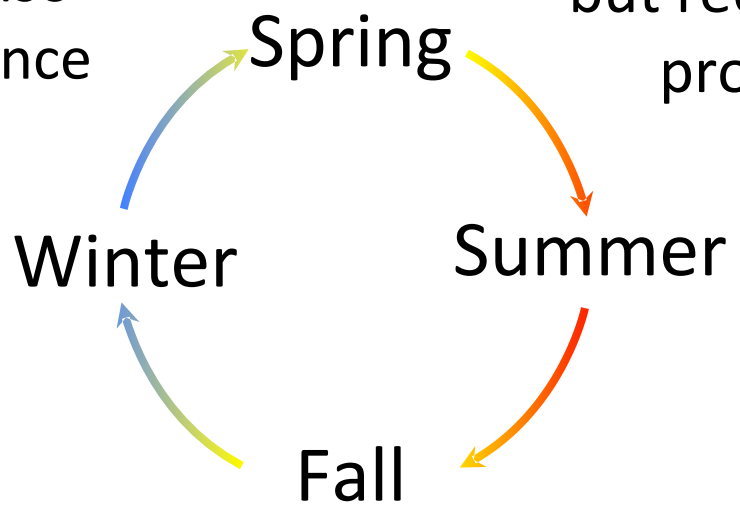


Seasonal error

Groundwater variations

Wet ground may expand and uplift but additional load also produces subsidence

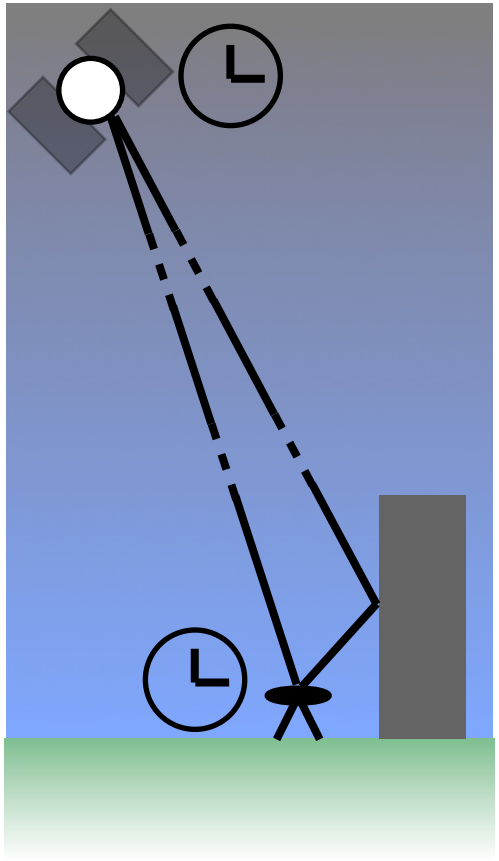
Dry ground may contract and subside but reduced load also produces uplift



System error

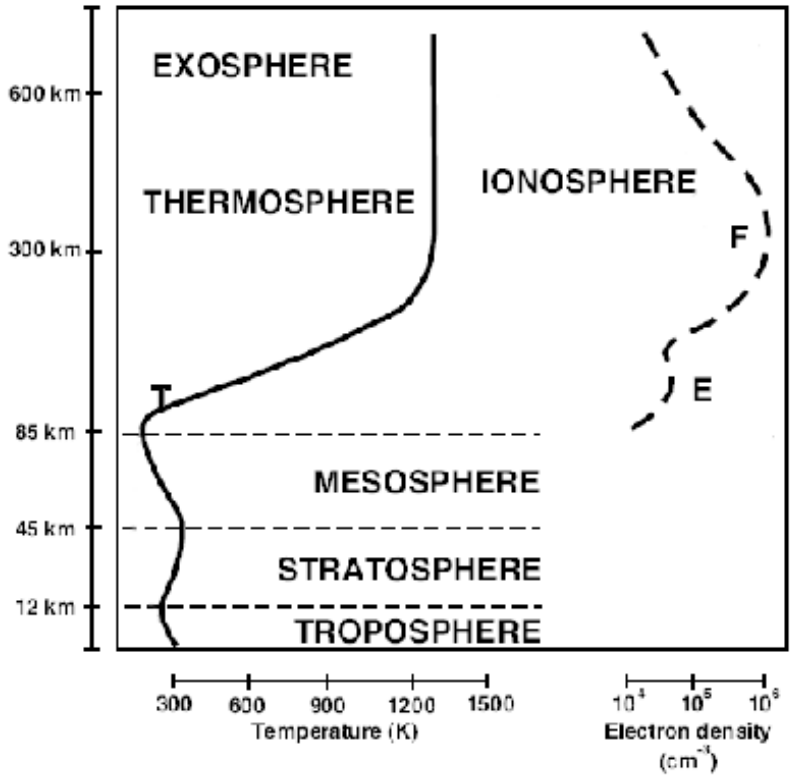
Propagation effects

- Ionosphere
  - Frequency-dispersive layer causes differential delay of L1 and L2 as a function of (unknown) total electron content (TEC)
- Troposhere
  - Delay through medium, especially water in atmosphere
- Clock errors
  - Offsets and drift of receiver and satellite clocks affects time, and therefore phase/distance, measurement
- Multipath
  - Back-scattering of signal interferes with direct signals
  - Random: no good method for mitigation or modeling



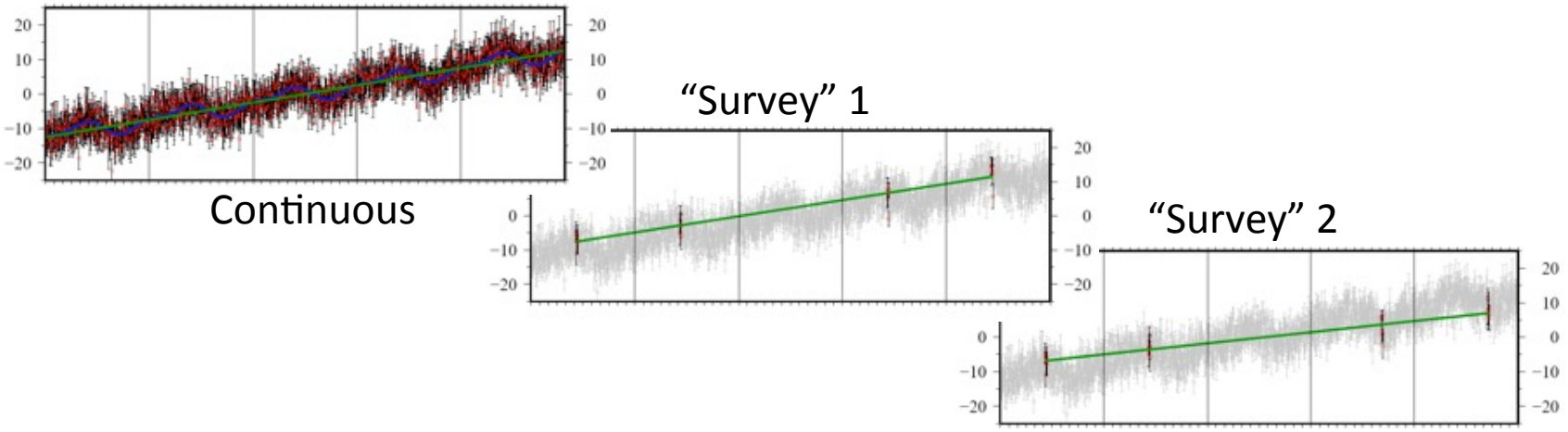
Atmospheric effects

- Ionosphere
  - delay $\propto 1/f^2$
- Troposphere
  - “Dry” delay
  - “Wet” delay



Time series noise characteristics

Survey timing



	x_0	***v***	A_0	τ_0	A_1	τ_1	ε
Input	−12.5 mm	**5 mm/yr**	2 mm	1.88 (0.3 yr)	1 mm	5.65 (0.45 yr)	3 mm
Continuous *	−12.41 mm	**4.93 mm/yr**	1.82 mm	1.93 (0.31 yr)	0.91 mm	5.48 (0.44 yr)	3.07 mm
"Survey" 1	−9.55 mm	**4.72 mm/yr**	-	-	-	-	-
"Survey" 2	−8.21 mm	**3.21 mm/yr**	-	-	-	-	-

* Maximum likelihood estimation of velocity and periodic terms, given a noise model

“Unknown” error?

- A potential error is anything that is not accounted for by a modeled or estimated parameter