Towards Real-time Geometric Orbit Determination of Low Earth Orbiters

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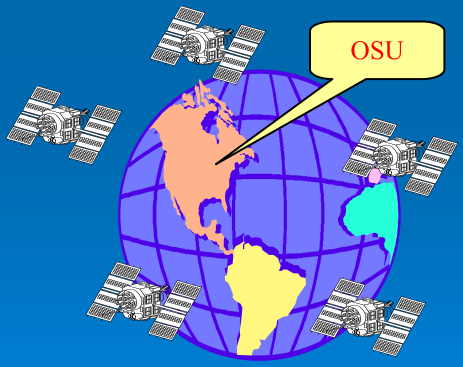

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Outline

- Precise Kinematic Orbit Determination (P-KOD) with triple differences
- Performance analysis: CHAMP
- Data screening (CS detection)
- Orbit smoothing
- Achievable accuracy
- Summary

Kinematic POD

- Advantages
  - No force model error affects the solution
  - Fast (potential for near real-time)
  - Quality solution for good PDOP
- Disadvantages
  - No dynamics to compensate for weak geometry
  - No solution or weak solution for weak geometry
  - Requires correct coordinates for a starting epoch (forward solution only)

Triple Difference POD

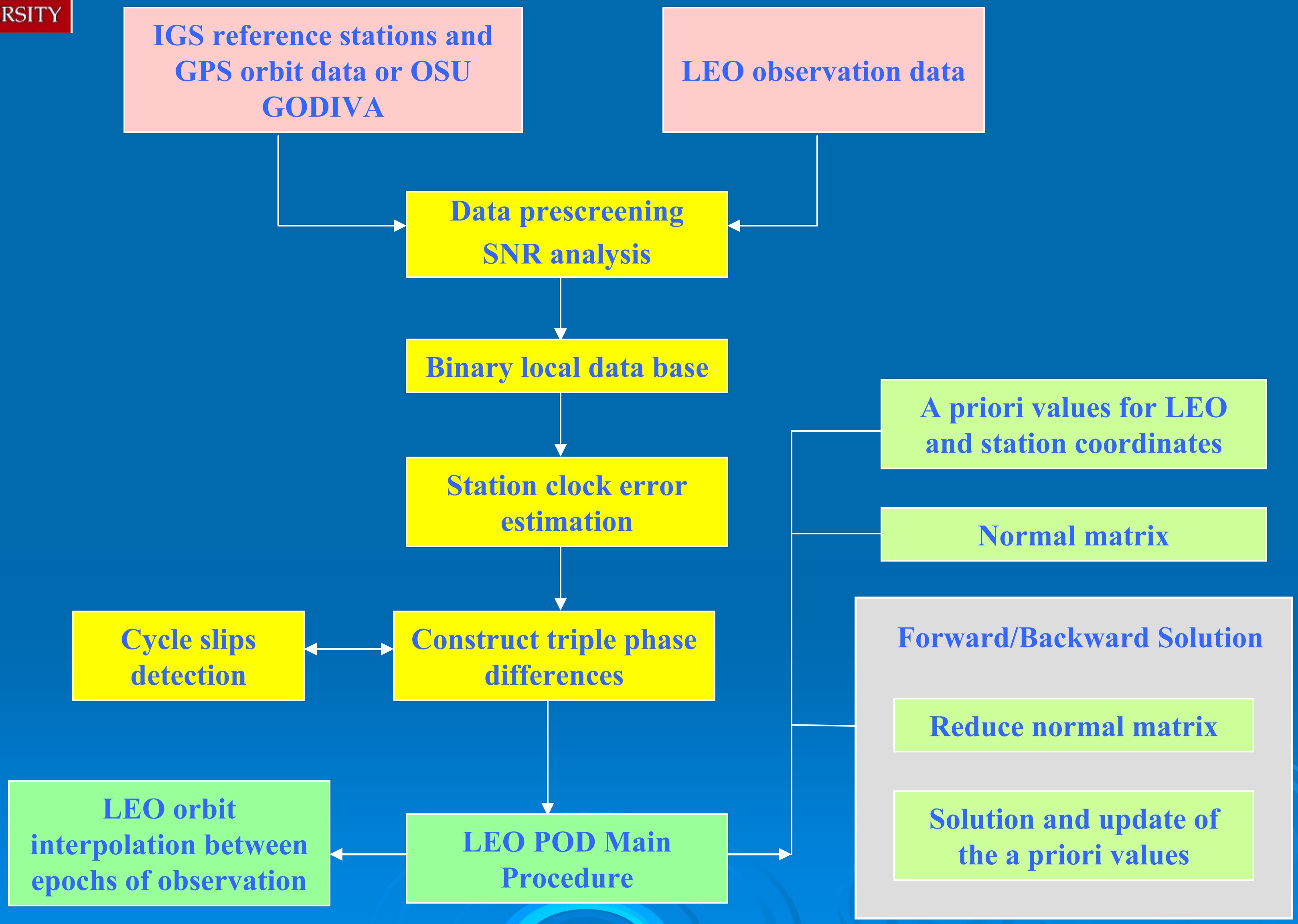
- Primary advantage: fast, no ambiguity fixing
- Disadvantage: epoch-to-epoch correlation (non-diagonal variance-covariance matrix)
  - Cholesky decomposition and decorrelation scheme
- Requires good approximated orbit to detect CS (large residuals)
- Equivalent to double difference with float ambiguities

P-KOD Data Processing: CHAMP

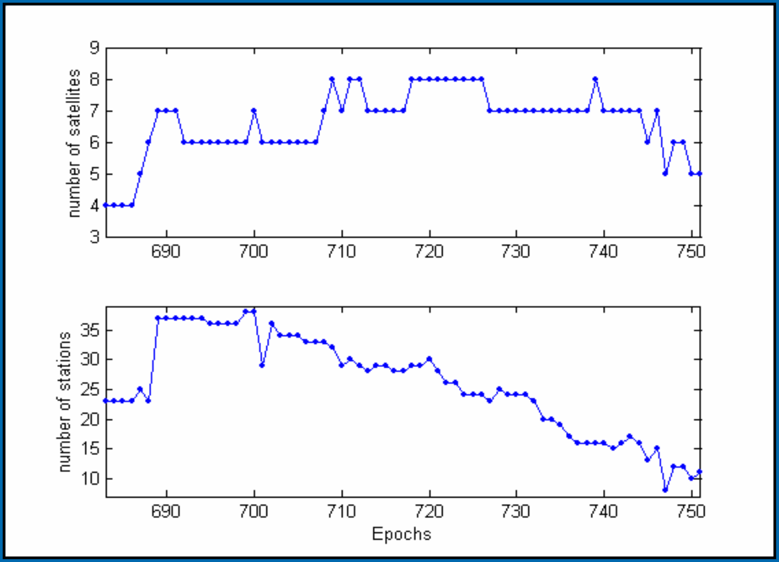
- 24 hour data sets processed
  - 65 IGS tracking stations
  - 30-s data sampling rate
  - Elevation cut off angle 0º (CHAMP) and 10º (stations)
- CS detection based on initial SNR prescreening,

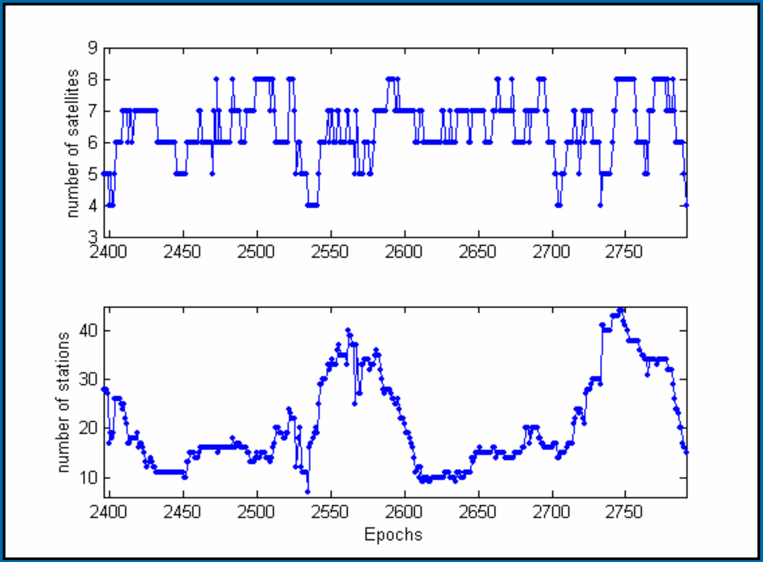
  and triple difference residual analysis
- Normal matrix is accumulated until a singularity point is reached (too few observations or bad geometry)
- Initial epoch released (forward/backward filter)

P-KODE Processing Flowchart



Examples of Weak Geometry





Epochs	RMS_x [m]	RMS_y [m]	RMS_z [m]	RMS_{3D} [m]	No. of Iterations
0683:0751 (068)	0.111	0.075	0.266	0.298	13
2396:2791 (395)	0.265	0.179	0.351	0.475	2

Statistics of Singularities

No.	Duration	# of epochs
1	0253 ~ 0255	3
2	0678 ~ 0682	5
3	0752 ~ 0753	2
4	1080 ~ 1080	1
5	1314 ~ 1314	1
6	1392 ~ 1392	1
7	1904 ~ 1904	1
8	2394 ~ 2395	2
9	2792 ~ 2792	1
SUM		17

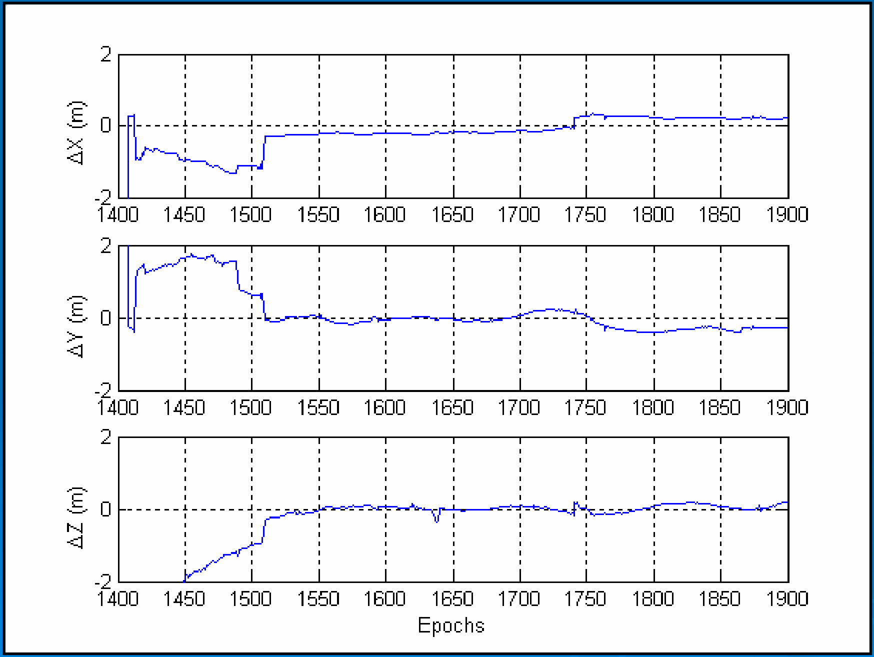
Example Results : June 15, 2001

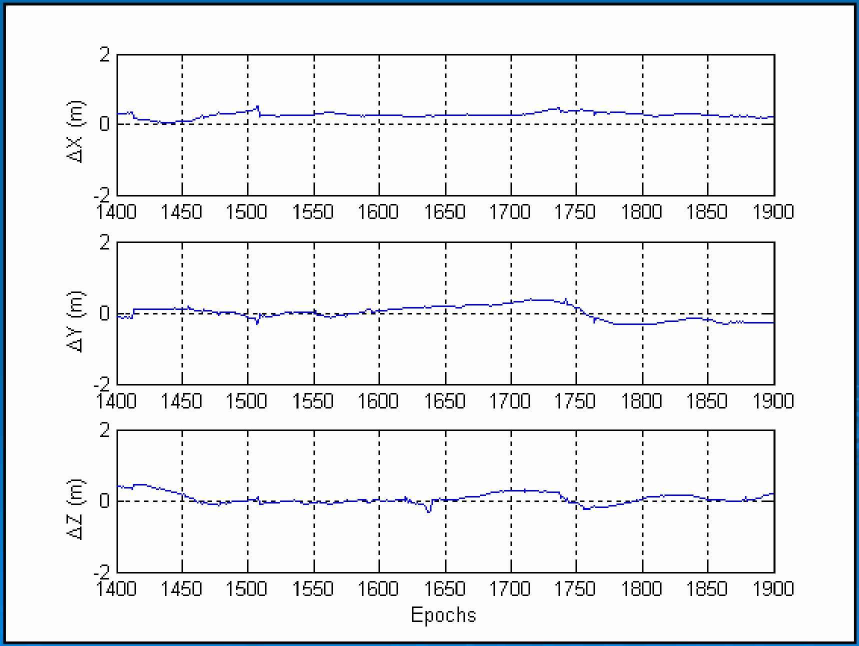
Forward filter solution

RMS_x = 0.513 m
RMS_y = 0.865 m
RMS_z = 1.059 m
RMS_{3D} = 1.460 m

Backward filter solution

RMS_x = 0.079 m
RMS_y = 0.202 m
RMS_z = 0.155 m
RMS_{3D} = 0.266 m





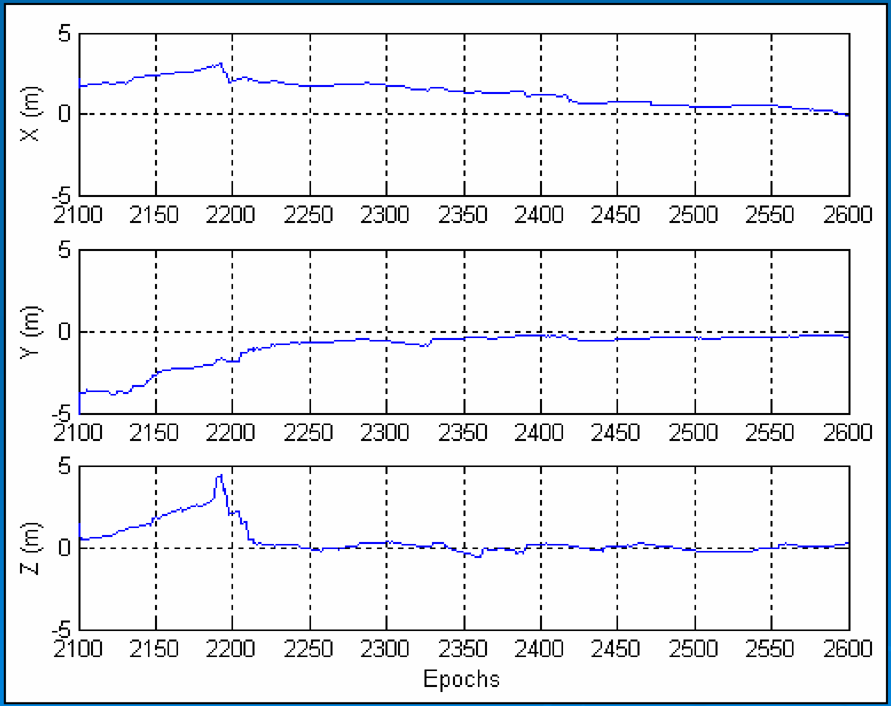
Example Results: October 3, 2001

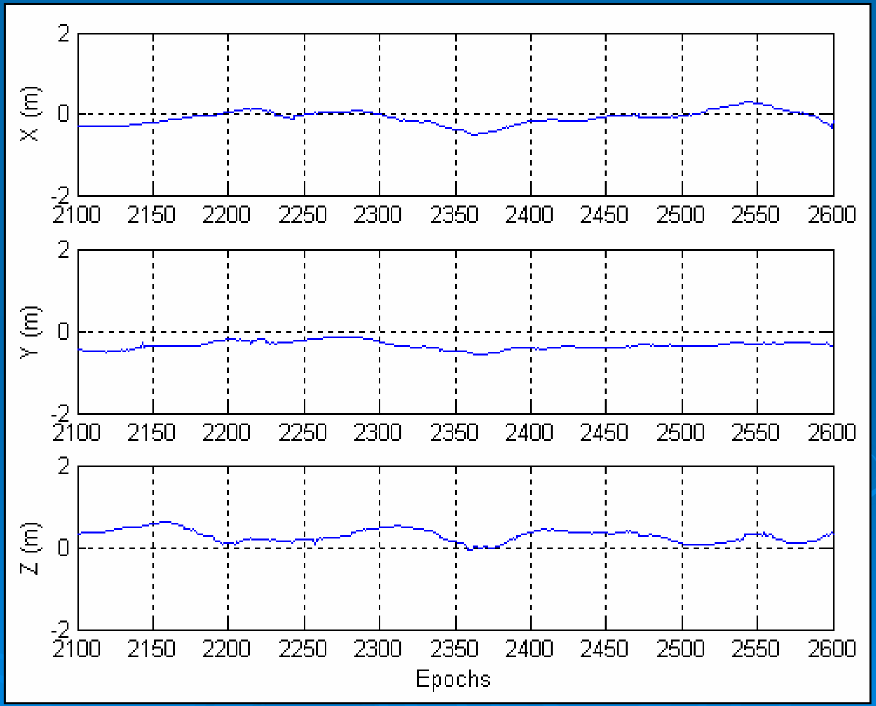
Forward filter solution

$RMS_x = 0.745$ m
$RMS_y = 1.029$ m
$RMS_z = 0.866$ m
$RMS_{3D} = 1.537$ m

Backward filter solution

$RMS_x = 0.173$ m
$RMS_y = 0.098$ m
$RMS_z = 0.154$ m
$RMS_{3D} = 0.252$ m

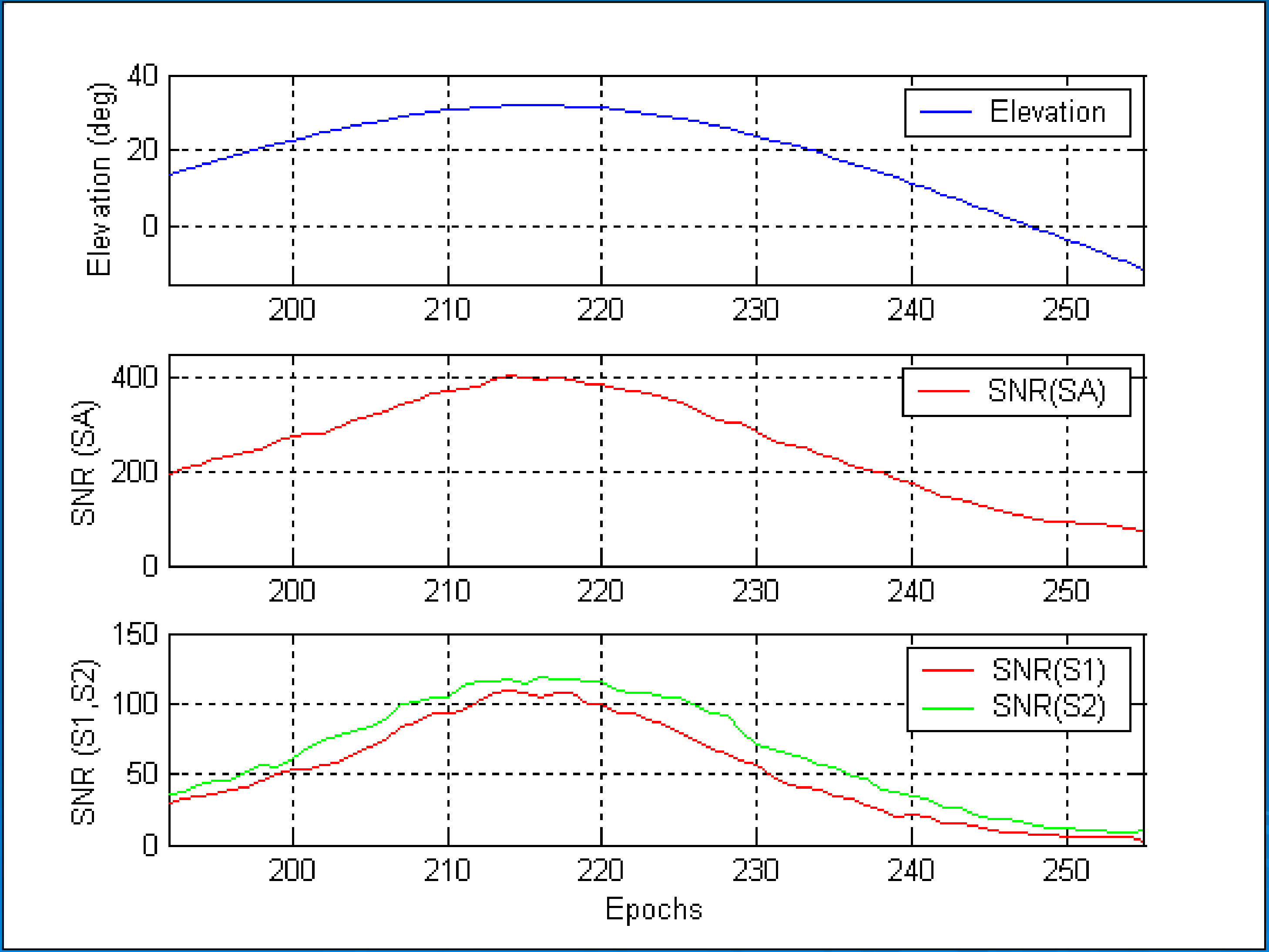




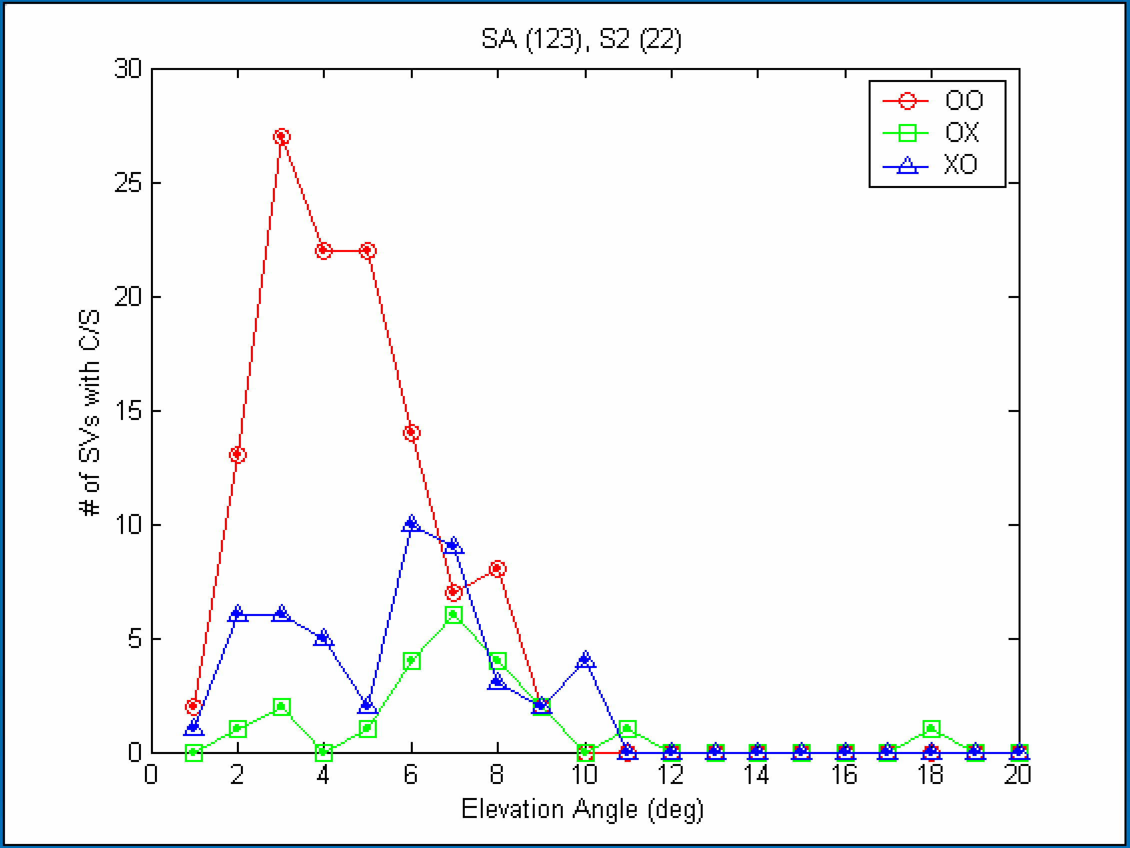
SNR for CS Detection

- CS caused by low SNR due to bad ionospheric conditions, multipath, high receiver dynamics or low elevation angle
- Raw signal strength
- 3 types of SNR
  - S1, S2 : L1, L2 phase observations
  - SA : SNR for C/A channel (CHAMP ext.)
- Related to the elevation angle

SNR vs. Elevation



Cycle Slip Detection Using SNR: CHAMP



- OO – C/S detected by both methods (TD residual and SNR)
- 0X – C/S indicated by TD residual only
- X0 – C/S indicated by SNR only

Cycle Slip Detection Using SNR: CHAMP

SA	S2	# of C/S	# of matched C/S
120	22	1708 (5.0%)	1336 (80.6%)
121	22	1817 (5.3%)	1354 (81.7%)
122	22	1910 (5.7%)	1372 (82.8%)
123	22	1938 (5.6%)	1395 (84.2%)
124	22	1984 (5.8%)	1415 (85.4%)
125	22	2099 (6.1%)	1417 (85.5%)

- **Number of C/S in TD residuals: 1657**
- **Total number of TD: 34374**
- **500 epochs tested, all PRNs included**

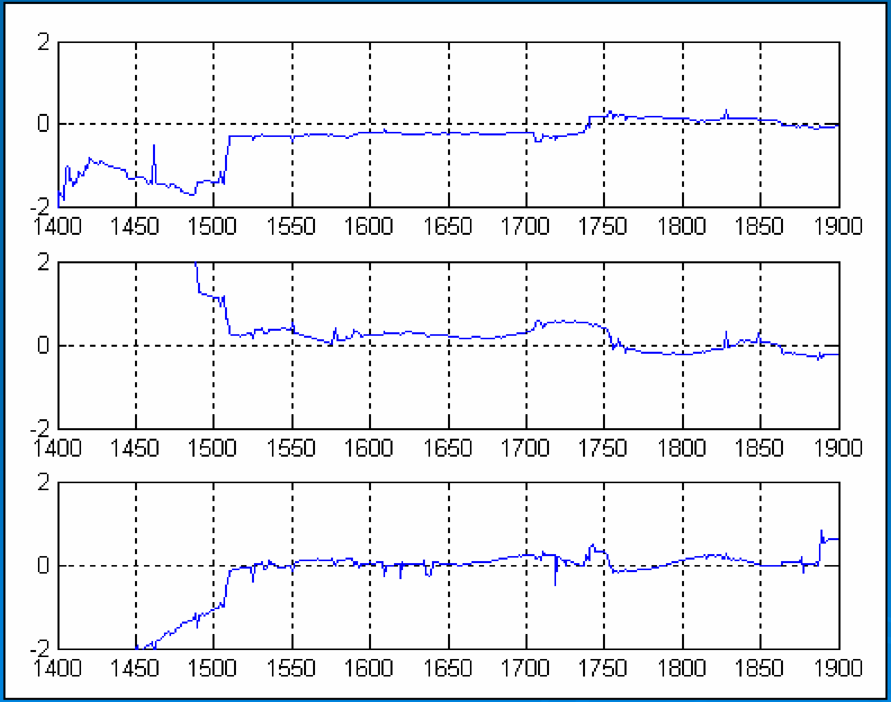
Corresponding Orbit Solution: initial approximation good to ~ 5 m

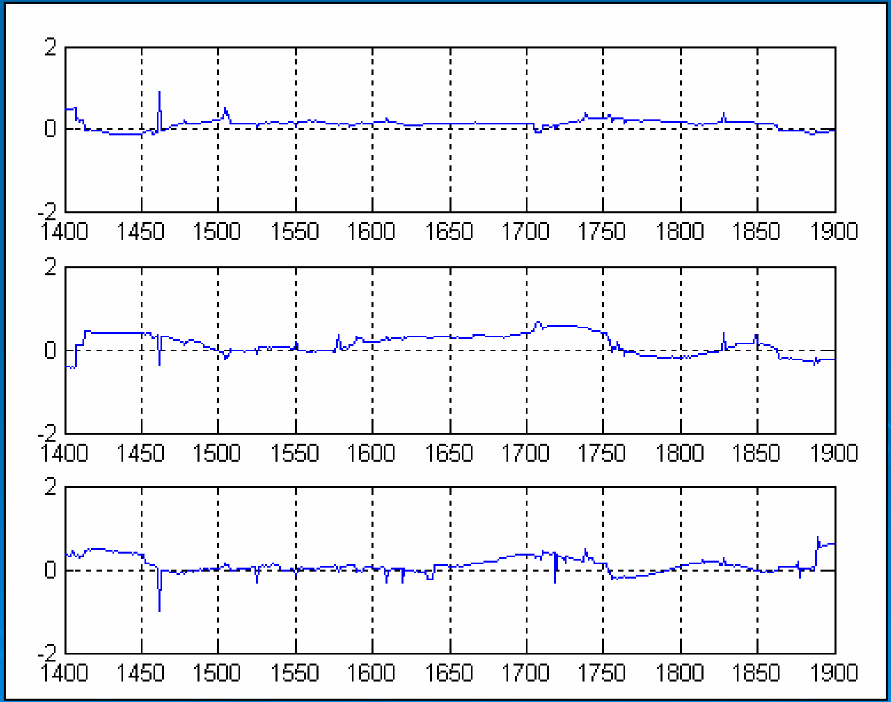
Forward filter solution

$RMS_x = 0.538$ m
$RMS_y = 1.014$ m
$RMS_z = 1.223$ m
$RMS_{3D} = 1.677$ m

Backward filter solution

$RMS_x = 0.120$ m
$RMS_y = 0.245$ m
$RMS_z = 0.193$ m
$RMS_{3D} = 0.334$ m





SA(123), S2(22)

Orbit Smoothing

- Guerra and Tapia (1974)
  - built-in FORTRAN function
  - works for the data with less than 25% error
- Moving averaging window
  - average of 20 data points
- Polynomial Fitting
  - 9^{th} order

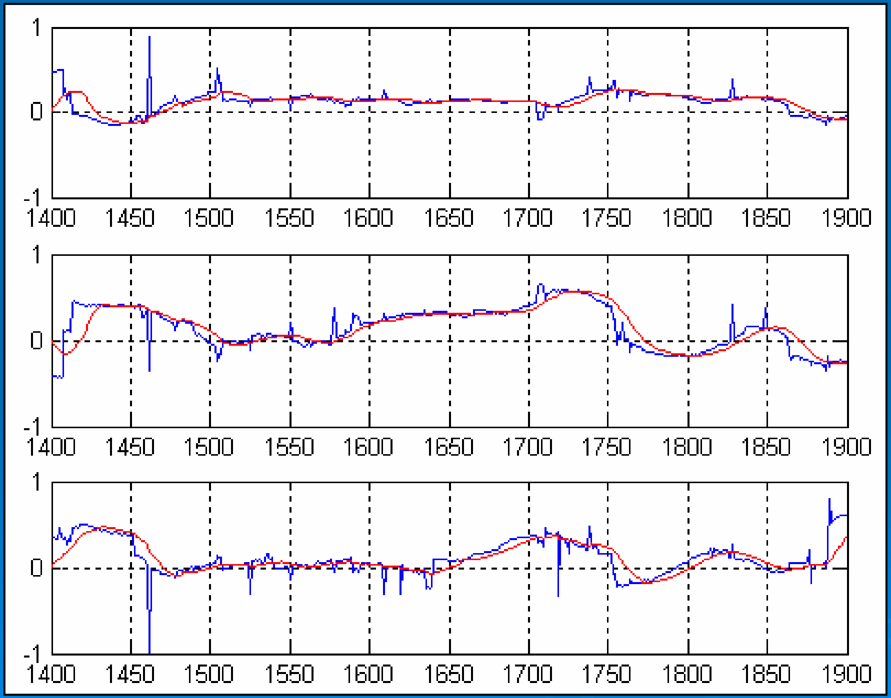
Orbit Smoothing

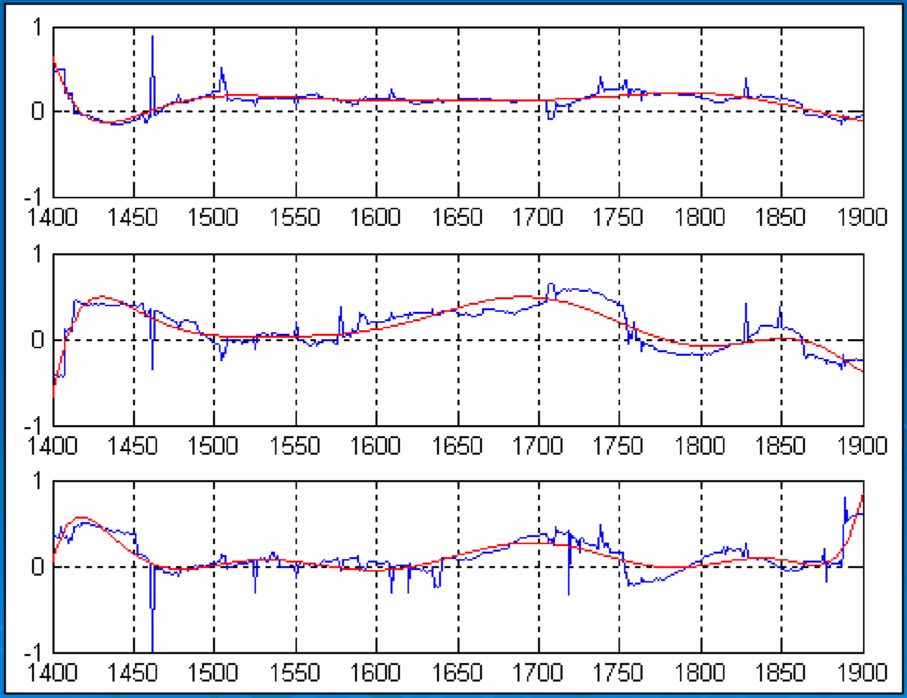
Direct Form II Transposed

RMS_x = 0.092 m
RMS_y = 0.220 m
RMS_z = 0.154 m
RMS_{3D} = 0.283 m

Polynomial fitting (n=9)

RMS_x = 0.099 m
RMS_y = 0.213 m
RMS_z = 0.154 m
RMS_{3D} = 0.280 m





Summary

- Kinematic triple difference POD works well for good geometry
- Short processing time (less than 2 h, forward and backward, on 1.8 GHz Pentium processor)
- Problems with weak geometry
- CS cleaning is not easy (high dynamics, LEO in the middle of the ionospheric layer)
  - SNR plus orbit smoothing give promising results
  - More work needs to be done on SNR threshold selection
- Gaps in the solution – reduced dynamics needed for orbit continuity and balance between geometry and force model