Geometric Approach to Position Determination in Space: Advantages and Limitations

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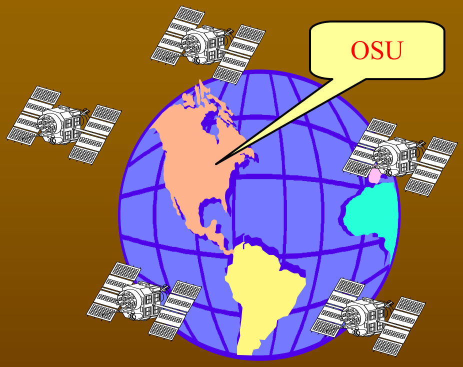

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Outline

- Kinematic POD with triple differences
- 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

- Triple difference kinematic precision orbit determination (POD)
  - OSU software GODIVA (1995): triple difference approach to GPS POD
  - OSU software P-KOD (Precision Kinematic Orbit Determination)
    - Extension of GODIVA to handle LEO (Low Earth Orbiter) POD in kinematic mode (2001)
  - UTX (Byun, S. H., 1998) LEO kinematic POD

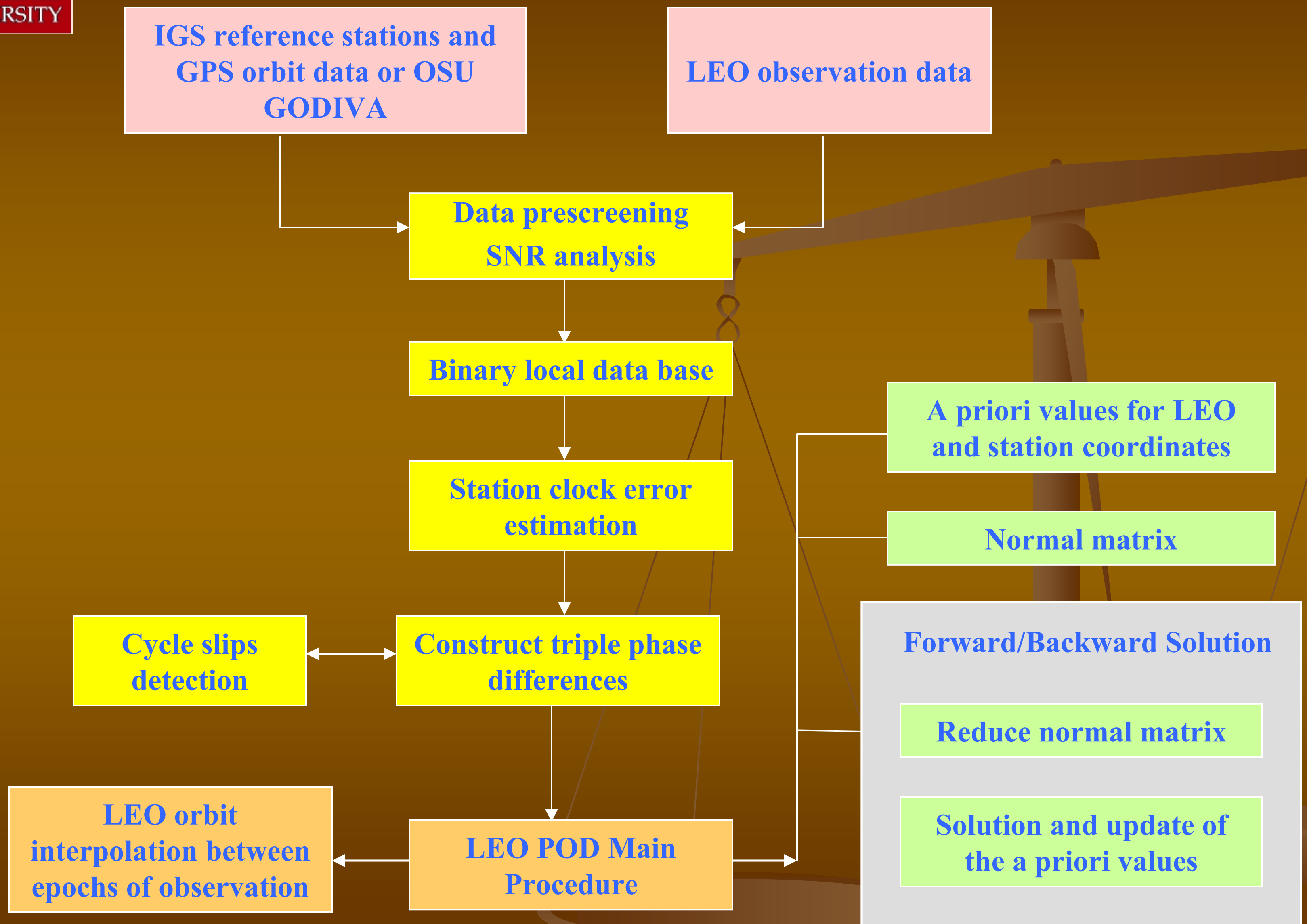
Triple Difference POD

- 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



Example Results

- Good orbit approximation available to clean (remove) CS as large triple difference residuals
- One iteration allows for convergence
- Forward filtering (batch least squares)
- Backward filtering
- Average percentage of CS in the data
  - CHAMP: 5-6
  - Tracking stations: <0.5

Distribution of Cycle Slips: 24 h Data Set, June 15, 2001

# of Epochs with no C/S	2007
# of Epochs with C/S	873
Total # of Epochs	2880

<table>
<tr><td>Total No. of Observations</td><td colspan="2">166495</td></tr>
<tr><td rowspan="4">Number of C/S</td><td colspan="2">Total = 9495 (5.7%)</td></tr>
<tr><td>CHAMP</td><td>Stations (65)</td></tr>
<tr><td>9226 (5.5%)</td><td>269 (0.2%)</td></tr>
<tr><td>97% of all CS</td><td>3% of all CS</td></tr>
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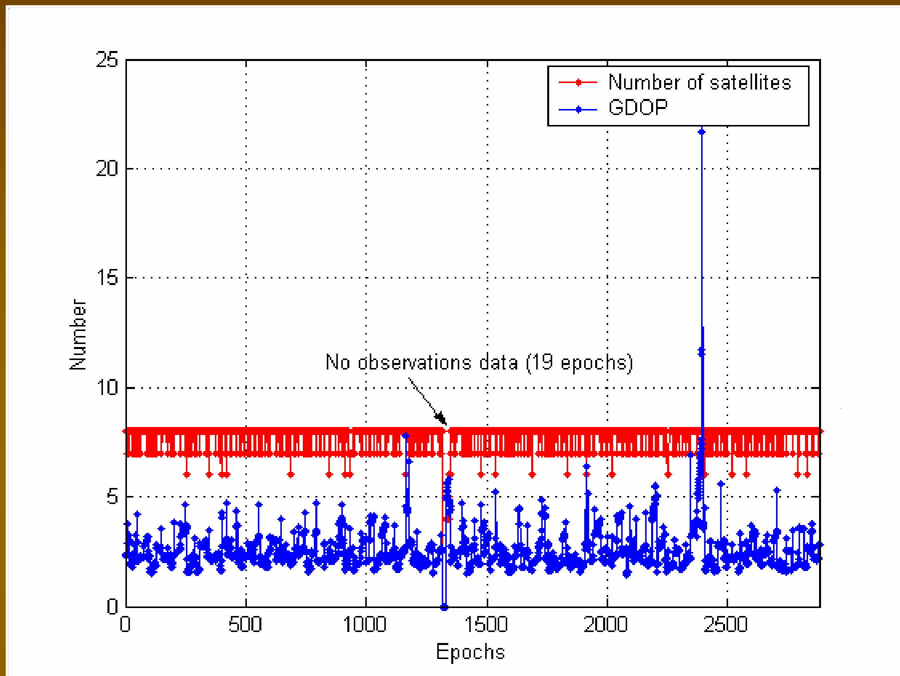
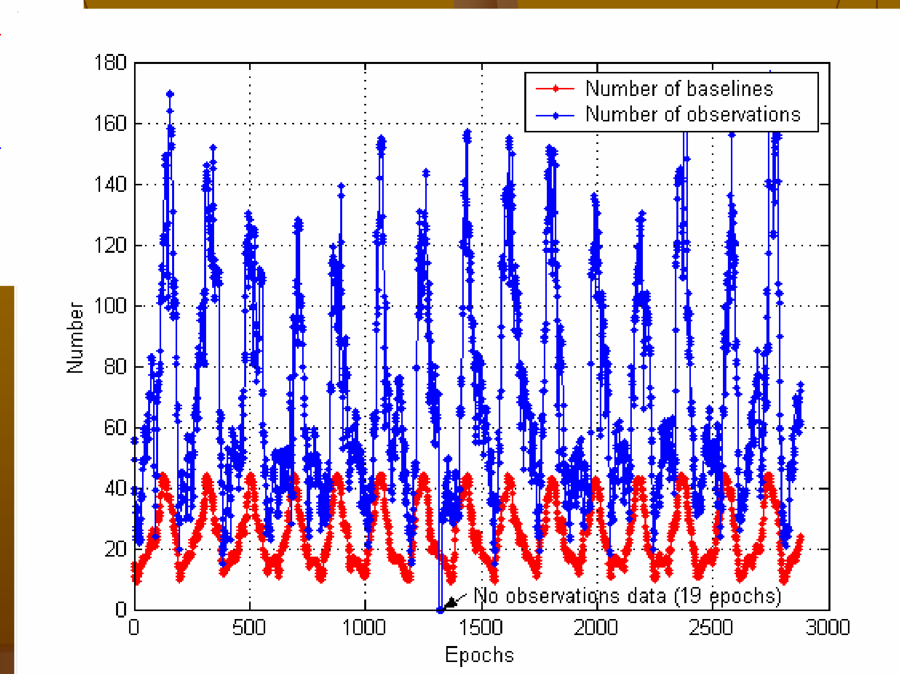
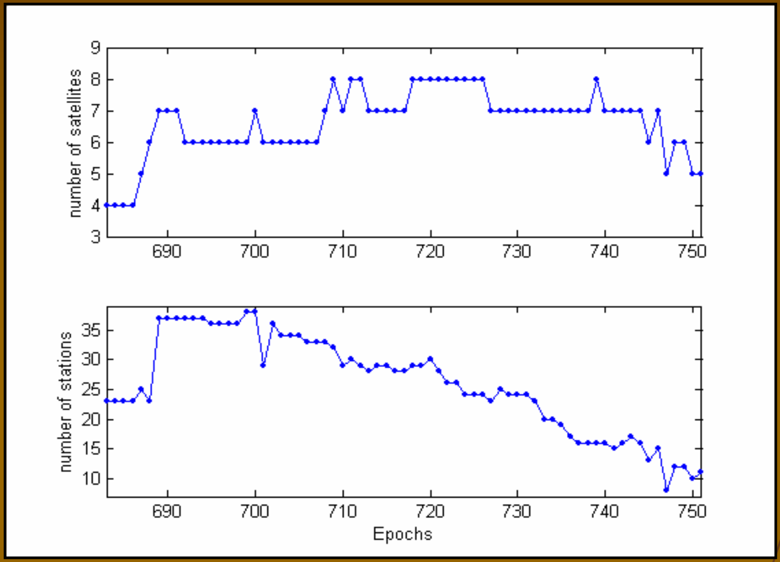
Number of Satellites and GDOP per Epoch

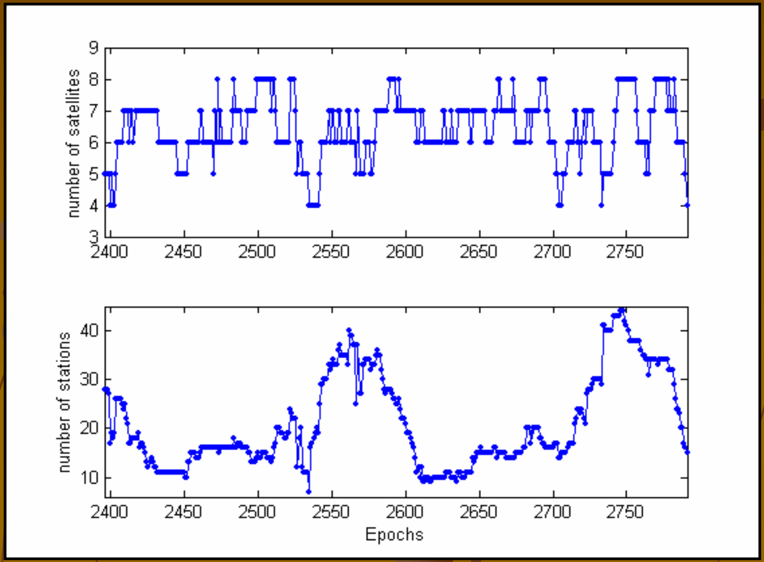


Observations and Baselines per Epoch



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

Singularity	Epochs	Duration
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

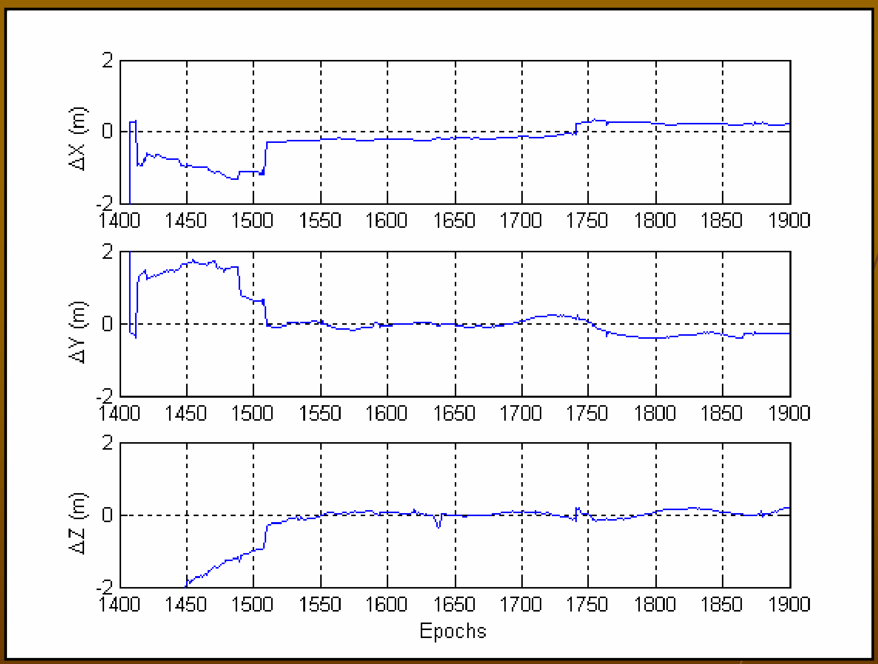
Example Results

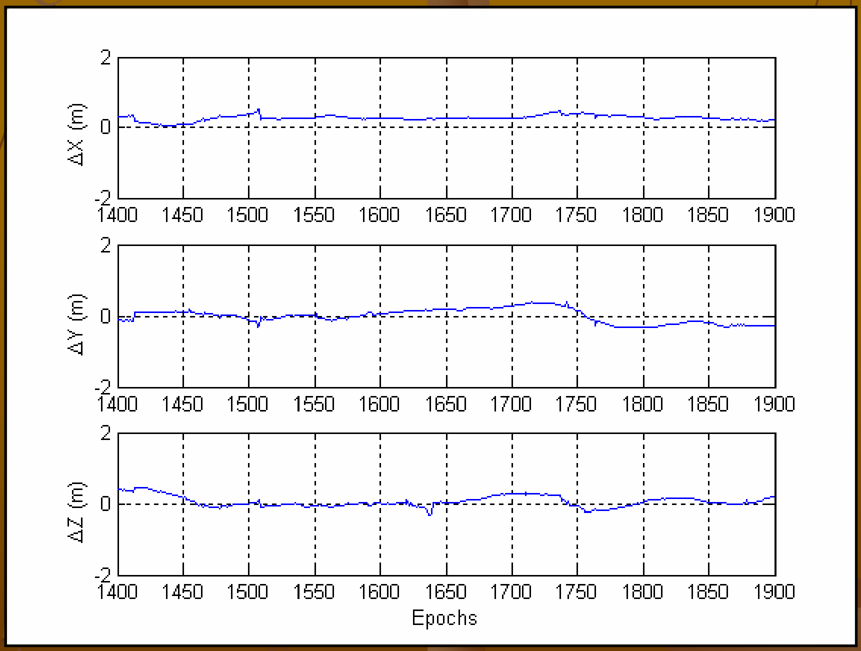
Forward filter solution

$RMS_x = 0.513$ 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

- Data missing
  - Data gap : 56 epochs
  - Large clock error: 221 epochs
- Singularity due to weak geometry or insufficient data
  - 15 epochs

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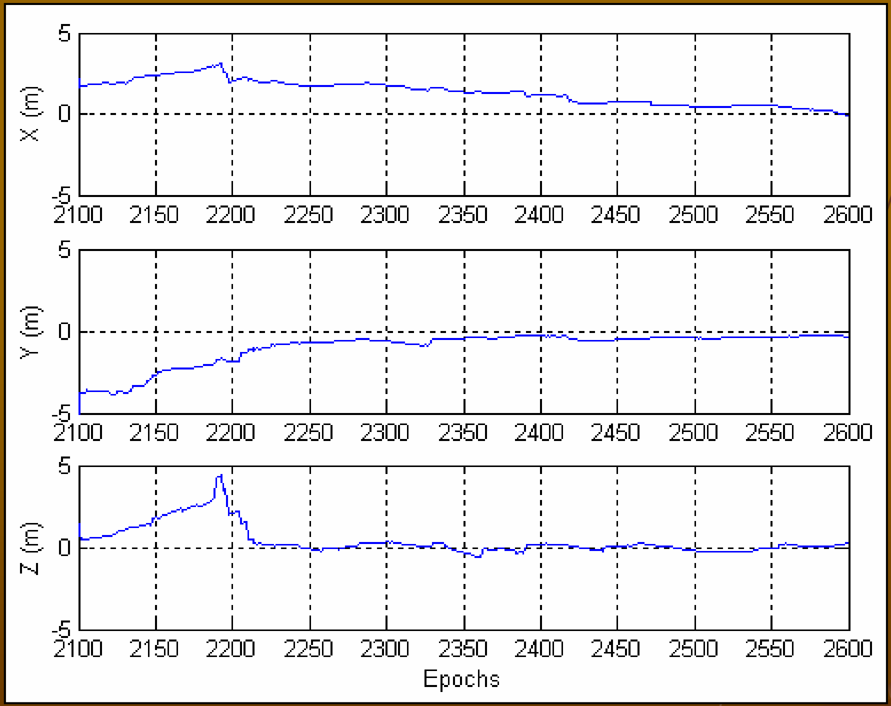
Example Results: October 3, 2001

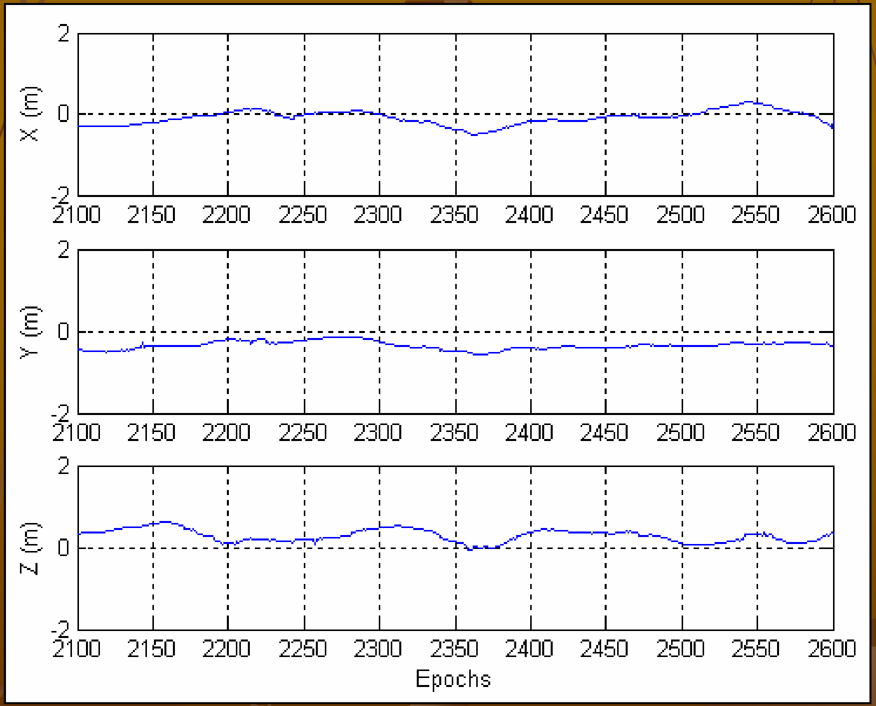
Forward filter solution

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

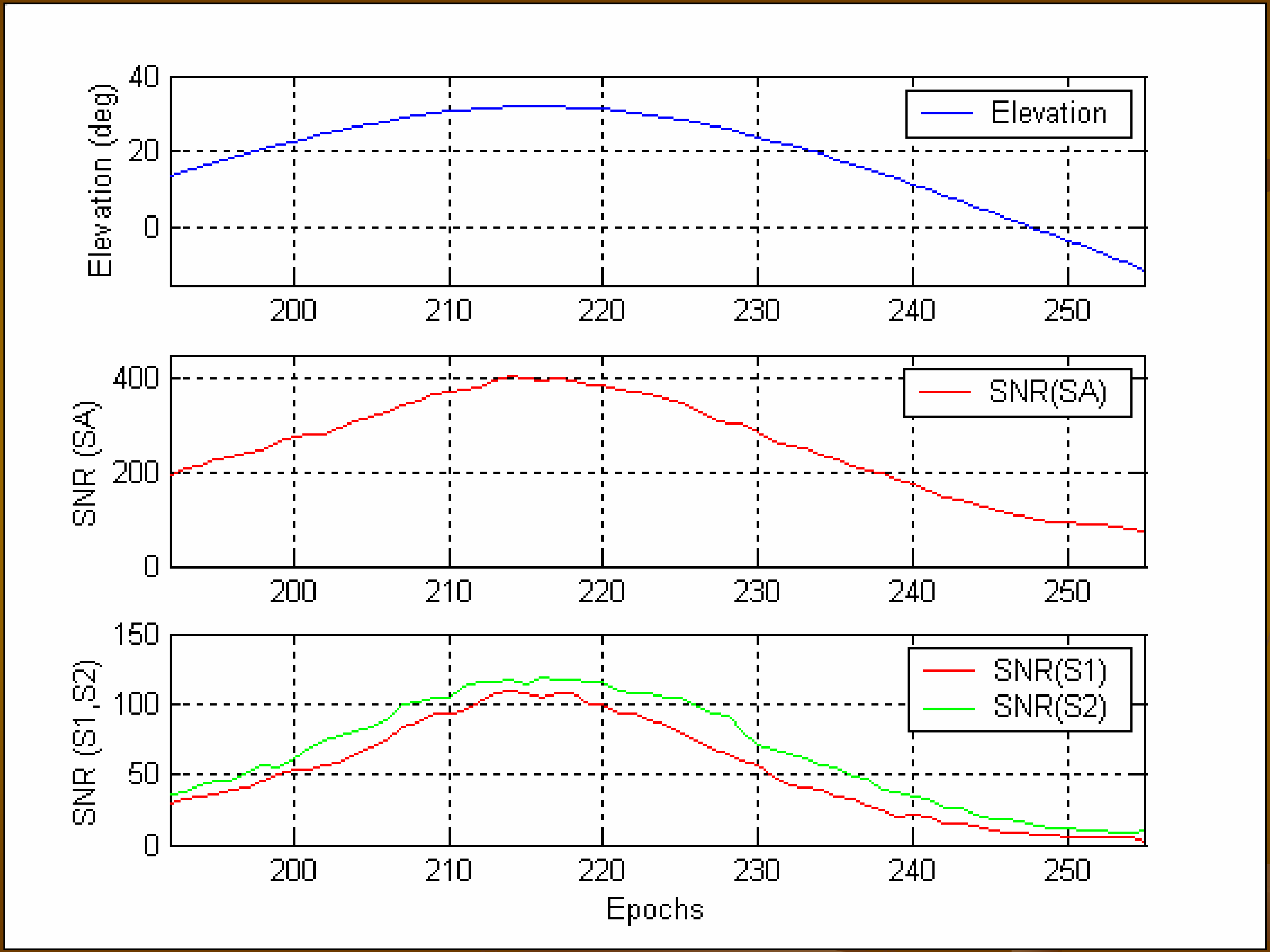




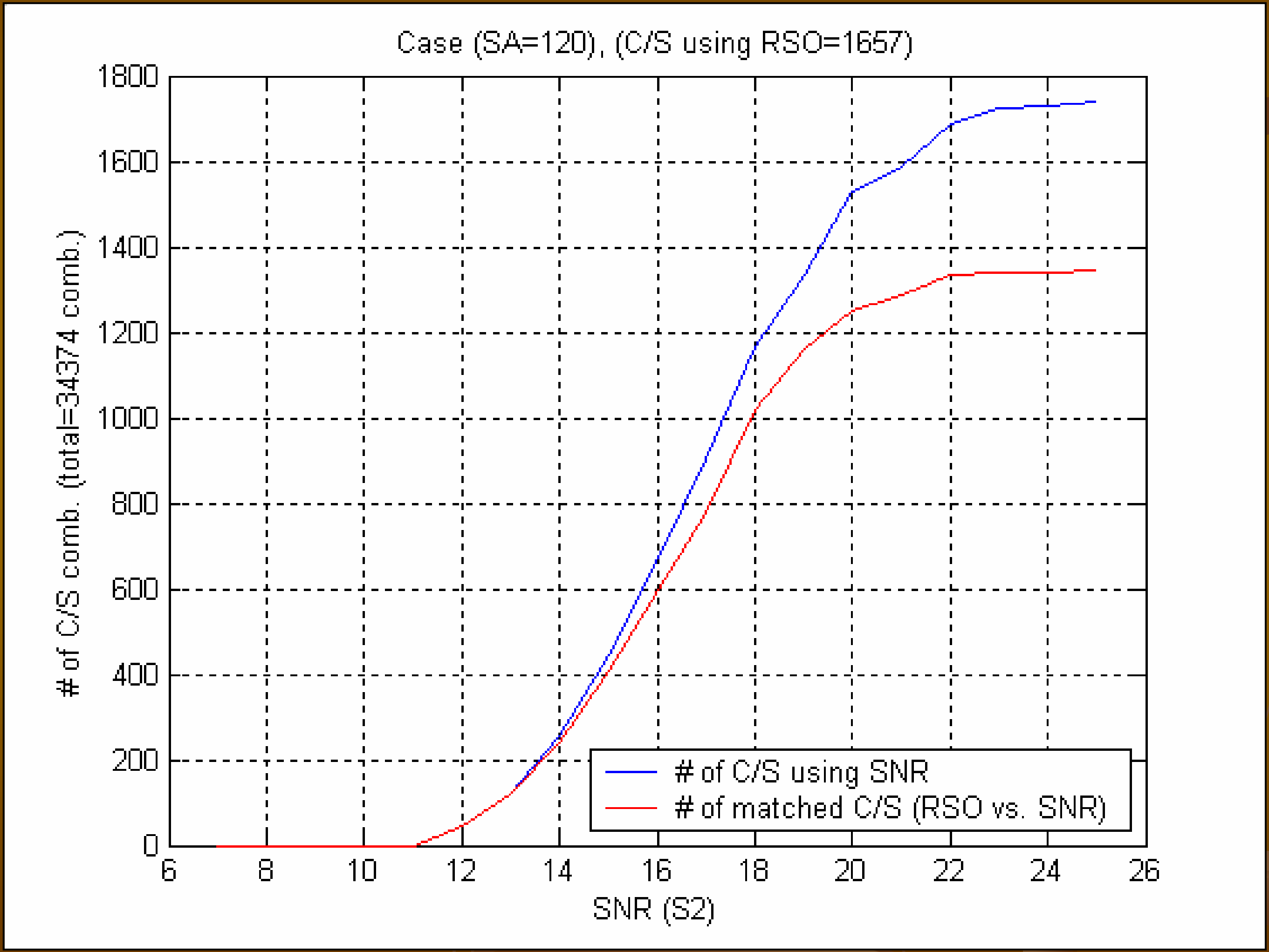
SNR for CS Detection

- 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



Cycle Slip Detection Using SNR: CHAMP

SA	S2	TD	SNR	0 – 5 deg	5 – 10 deg	10 – 15 deg	15 – 20 deg
120	22	O	O	80	29	0	0
		O	X	10	18	1	1
		X	O	17	21	0	0
121	22	O	O	83	30	0	0
		O	X	7	17	1	1
		X	O	19	25	0	0
122	22	O	O	84	31	0	0
		O	X	6	16	1	1
		X	O	20	27	0	0
123	22	O	O	86	31	0	0
		O	X	4	16	1	1
		X	O	20	28	0	0
124	22	O	O	87	32	0	0
		O	X	3	15	1	1
		X	O	23	28	0	0
125	22	O	O	87	33	0	0
		O	X	3	14	1	1
		X	O	28	29	0	0

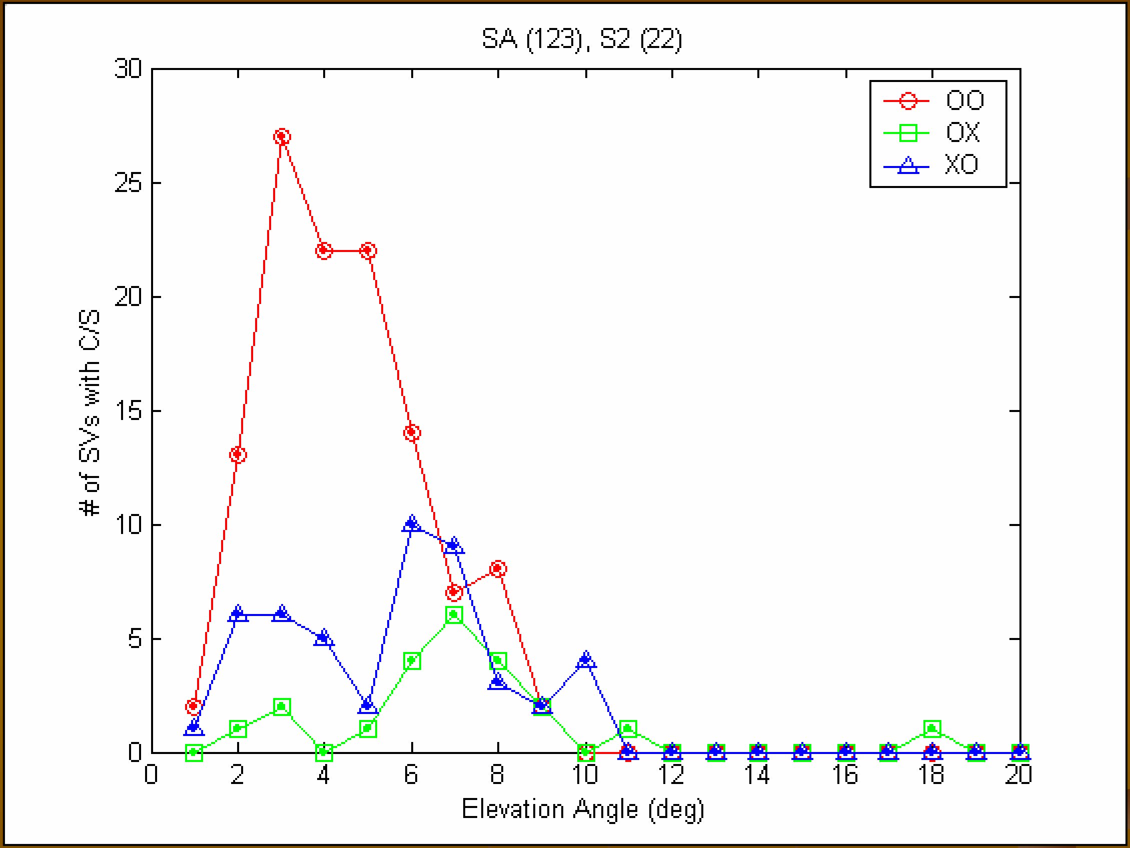
- **X – no C/S**
- **0 – C/S**
- **Total of 29 satellites tested over 500 epochs**

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**

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

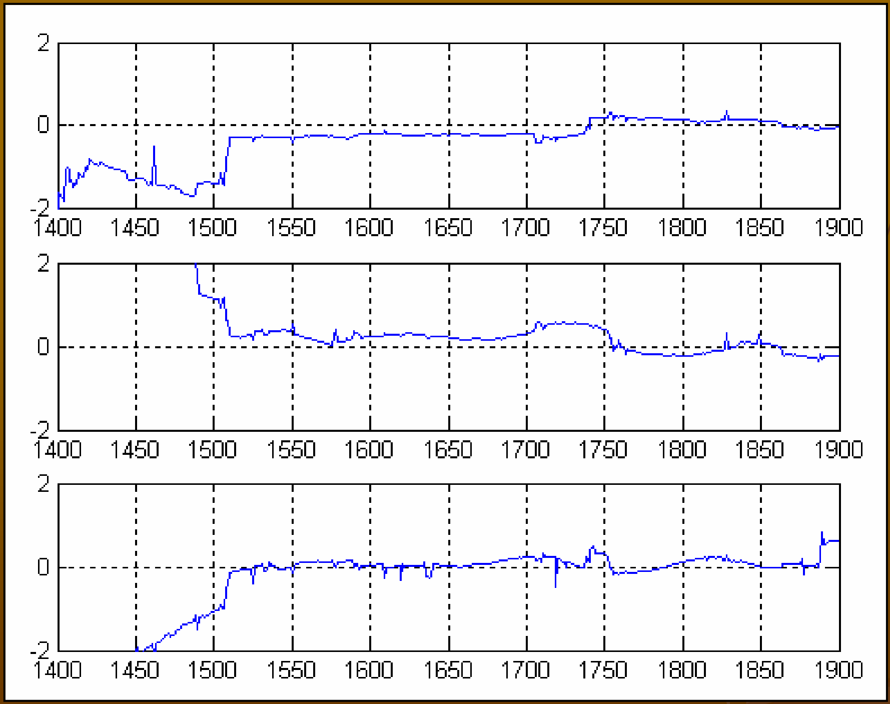
Corresponding Orbit Solution: initial approximation good to ~ 5 m

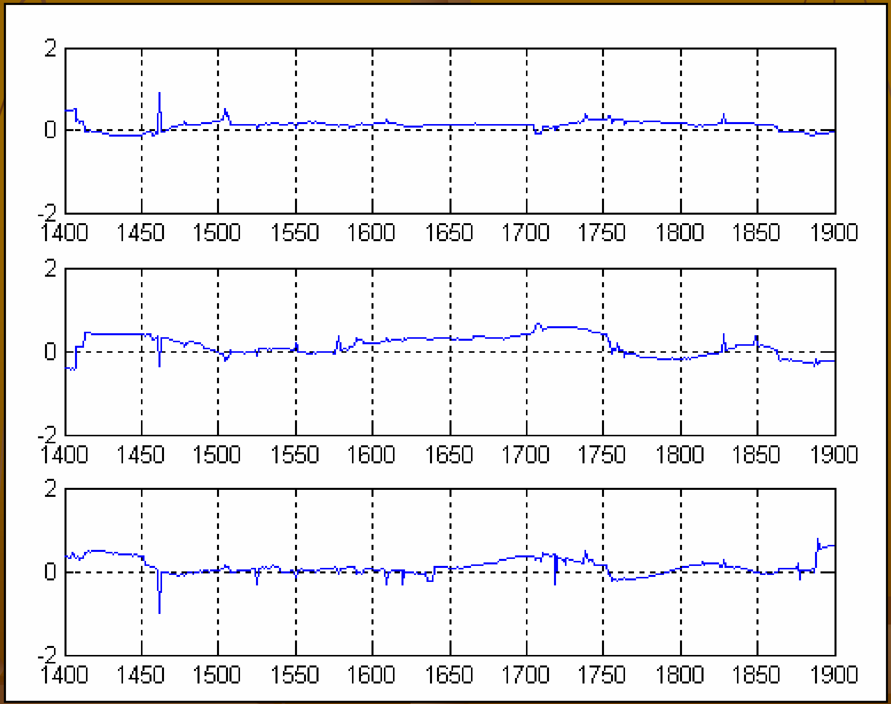
Forward filter solution

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

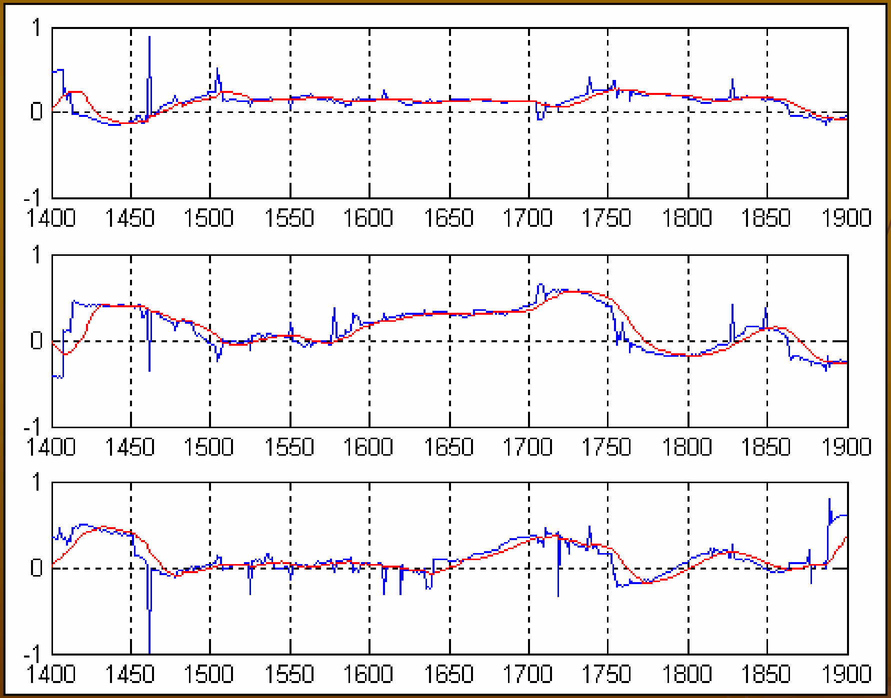
Orbit Smoothing

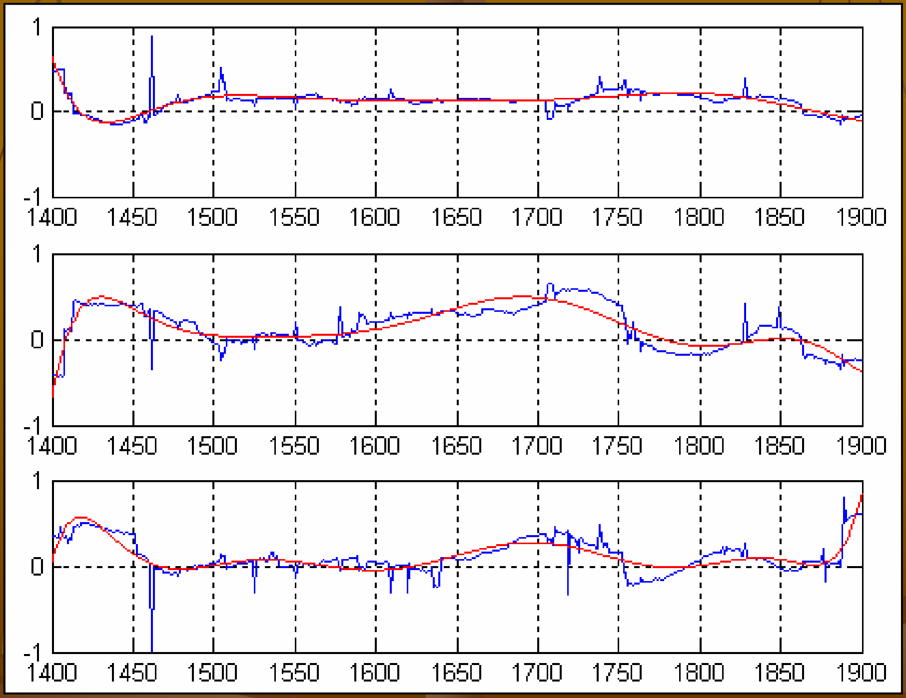
Direct Form II Transposed

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

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