A NEW TECHNIQUE FOR GPS-BASED ORBIT DETERMINATION OF GEOSCIENCE SPACECRAFT

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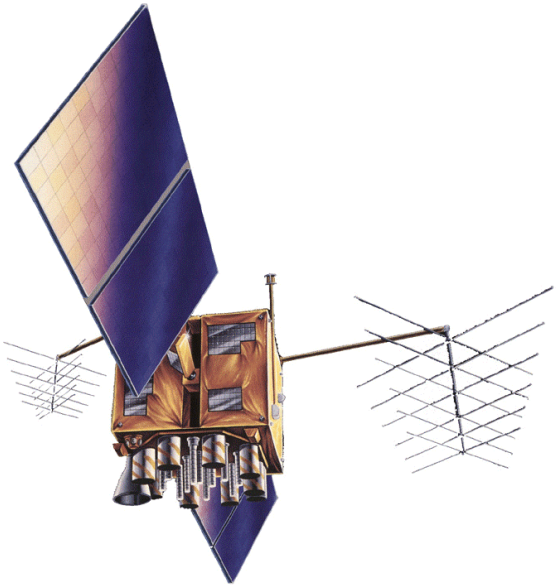
OVERVIEW

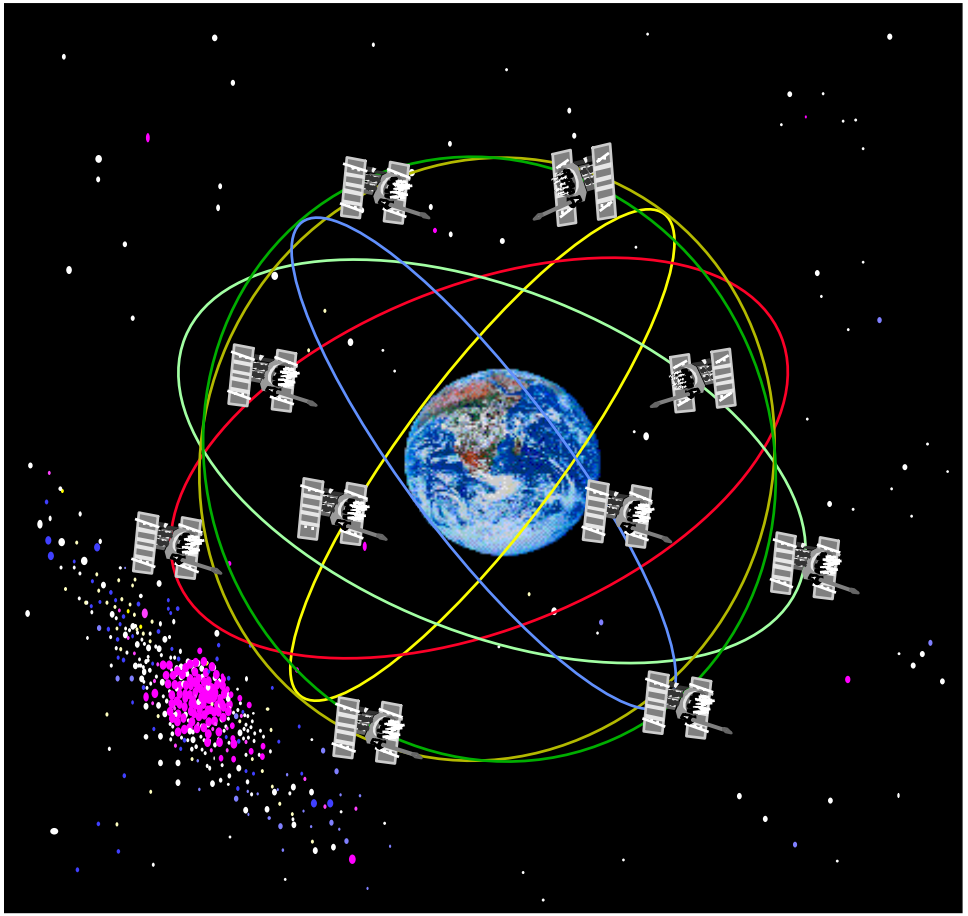
- Principles of the Global Positioning System.
- Uses of GPS data collected onboard geoscience spacecraft.
- Developed GPS data infrastructure.
- An implementation of the infrastructure:

  The geometric orbit determination technique.
- Preliminary results.
- Conclusions.
- Acknowledgements.

THE GLOBAL POSITIONING SYSTEM



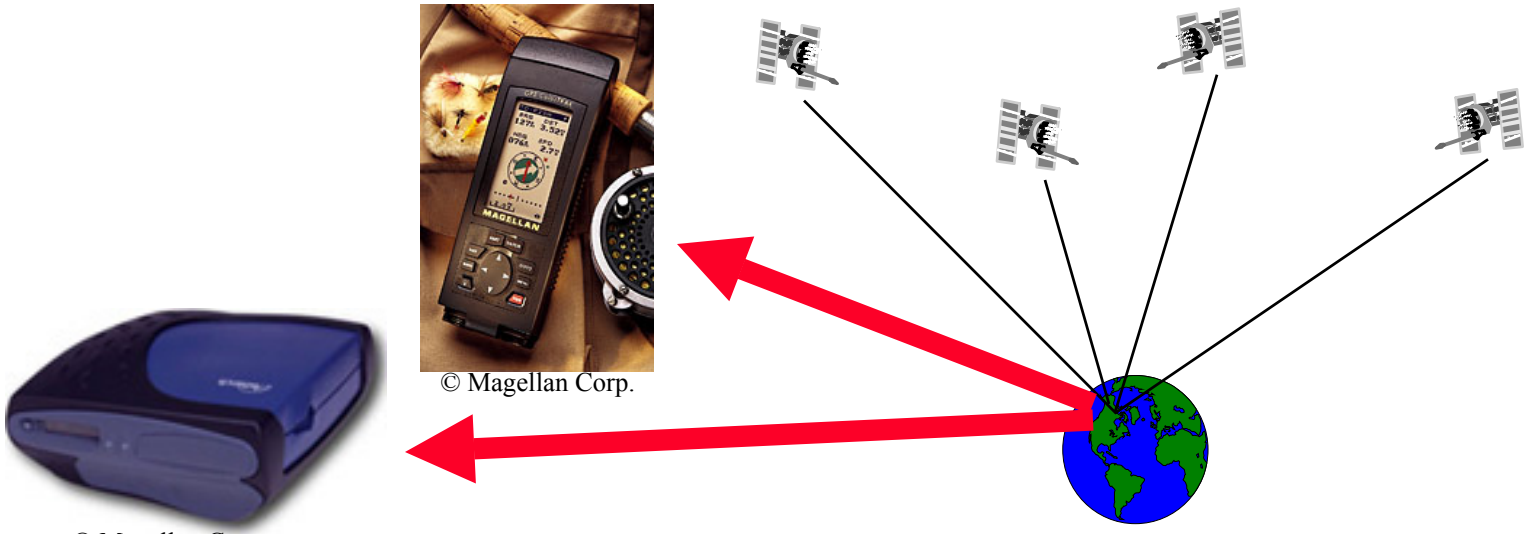
Block II-R satellite



Schematic of the GPS constellation

IT'S ALL ABOUT TIME

- GPS is possible for many reasons, the most important of which is precise, accurate timing.
- Atomic clocks on the GPS satellites and crystal clocks in GPS receivers are used to compute the travel time of electromagnetic waves, hence range.
- The combination of range measurements in a mathematical filter allows for receiver position and time to be estimated.



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GPS MEASUREMENT PRECISION DEPENDENCIES

GPS measurement	low precision (10s of cm), unambiguous *pseudoranges*	high precision (sub-mm), ambiguous *carrier phases*
measurement constituents which must be estimated or eliminated	• satellite position error • satellite clock • receiver clock • troposphere • ionosphere • multipath • receiver noise • …	• satellite position error • satellite clock • receiver clock • troposphere • ionosphere • multipath • receiver noise • carrier-phase ambiguity • … • …

PSEUDORANGE POINT POSITIONING

GPS measurement

low precision (10s of cm), unambiguous *pseudoranges*

few-metre accuracy

measurement constituents which must be estimated or eliminated

- **satellite position error** ×
- **satellite clock** ×
- **receiver clock** ×
- **troposphere** ×
- **ionosphere** ×
- **multipath**
- **receiver noise**
- **…**

× partially addressed
×× fully addressed

CARRIER-PHASE RELATIVE POSITIONING

GPS measurement

high precision (sub-mm), ambiguous *carrier phases*

centimetre accuracy

measurement constituents which must be estimated or eliminated

- **satellite position error ××**
- **satellite clock ××**
- **receiver clock ××**
- **troposphere ××**
- **ionosphere ××**
- **multipath**
- **receiver noise**
- **carrier-phase ambiguity ××**
- **…**
- **…**

× partially addressed
×× fully addressed

BENEFITS OF SPACEBORNE GPS

- The following data can be collected by placing a GPS receiver modified for spaceflight (a *spaceborne* GPS receiver) aboard a Low Earth Orbiter (LEO) spacecraft:
  - **Orbit determination** (position and velocity).
    - Real-time [few-metre-level].
    - Post-processed [decimetre-level].
  - **Attitude determination** [sub-degree-level].
  - **Timing** [sub-microsecond-level].
  - **Ranging information** between spacecraft and GPS satellites for GPS signals transiting the atmosphere.

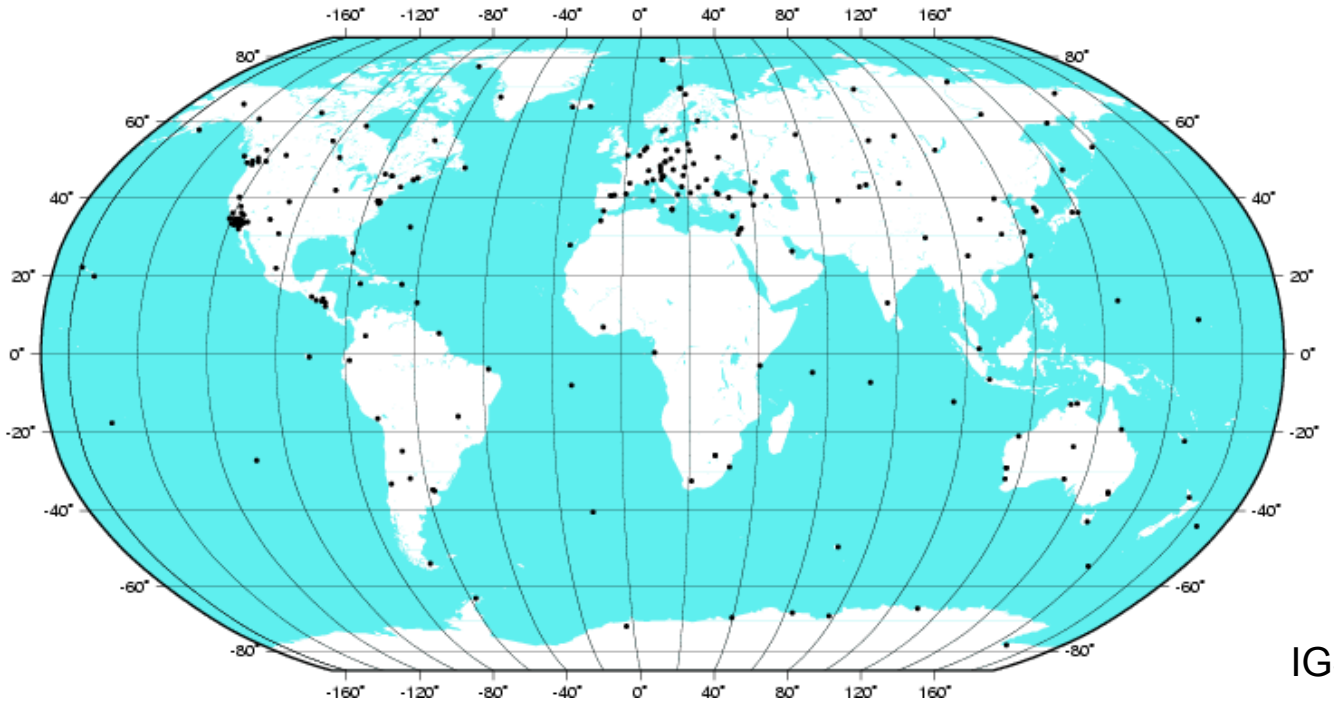
BENEFITS OF GPS-EQUIPPED GEOSCIENCE SPACECRAFT

- Gravity field recovery and geoid determination.
- Radar and laser altimetry.
- Interferometric Synthetic Aperture Radar positioning.
- Other remote sensing instrumentation positioning.
- Time-tagging and synchronization of scientific sensor measurements.
- Ionospheric limb sounding.
- Tropospheric limb sounding.
- Sea-surface profiling.

SPATIAL DATA INFRASTRUCTURE PROVIDED BY THE INTERNATIONAL GPS SERVICE (IGS)

- The IGS is an association of worldwide scientific organisations:
  - Promoting:
    - International standards for GPS data acquisition and analysis.
    - Deployment and operation of a common, comprehensive global tracking system.
  - Providing:
    - GPS orbits.
    - Tracking data.
    - Other high-quality GPS data and data products on-line, in near-real-time.

IGS TRACKING NETWORK AND PRODUCTS OF INTEREST



IGS tracking network

- IGS data products of interest:
  - Precise GPS satellite orbits.
  - Precise GPS satellite clock corrections.

GEOMETRIC ORBIT DETERMINATION STRATEGY

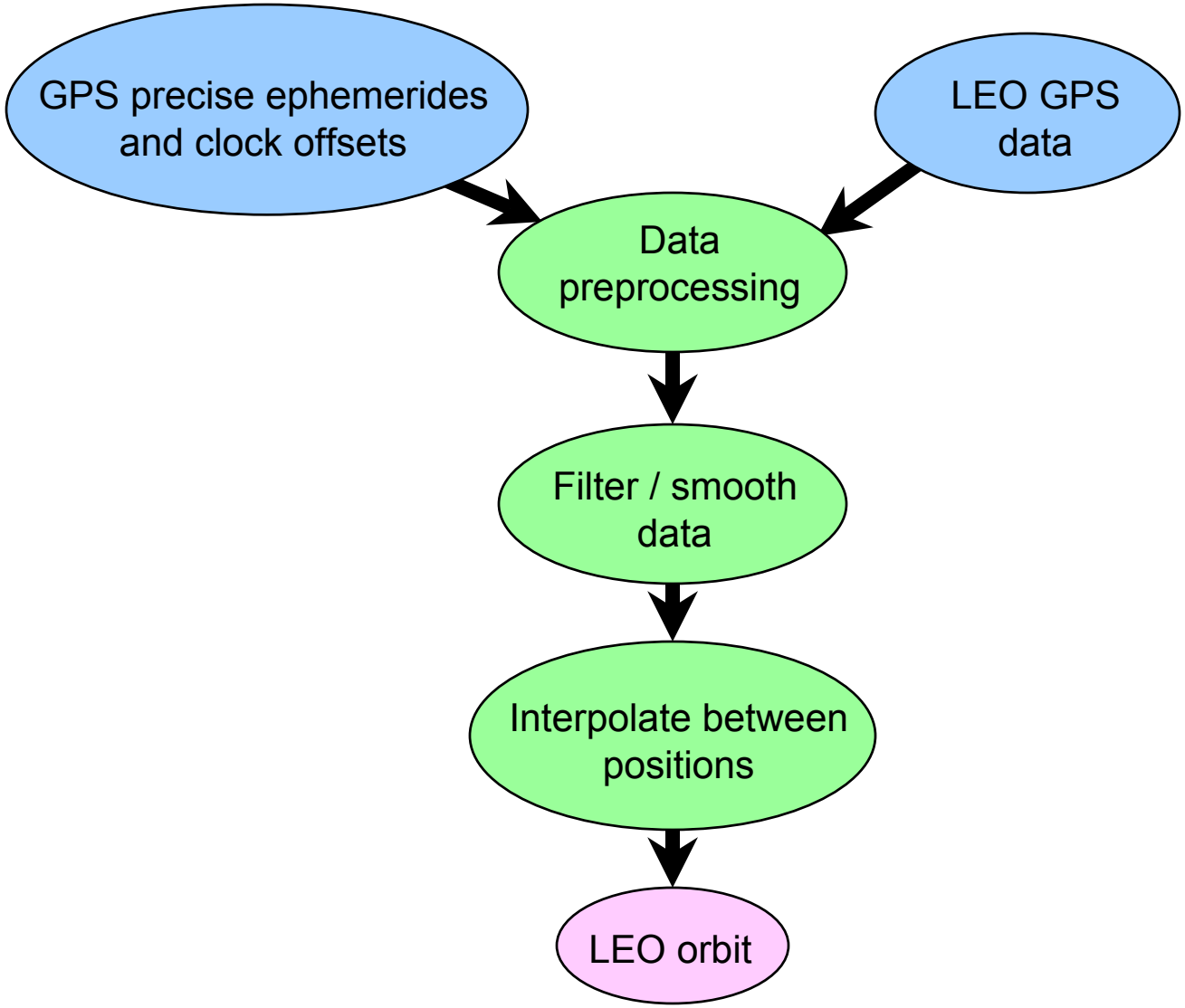
- Purely *geometrical*, GPS-based solution.
- Simultaneously:
  - Utilize *code* data to compute LEO *position,*
  - and *carrier* data to compute LEO *position change,*
  - in a kinematic sequential least squares filter/smoother.
- Inputs (all *readily available* aside from LEO data):
  - Dual-frequency code and carrier measurements from LEO receiver.
  - Precise GPS constellation ephemerides.
  - Precise GPS constellation satellite clock offsets from GPST.
- Interpolate GPS-determined positions for LEO state throughout orbit.

CARRIER-PHASE-CONNECTED, PSEUDORANGE POINT POSITIONING

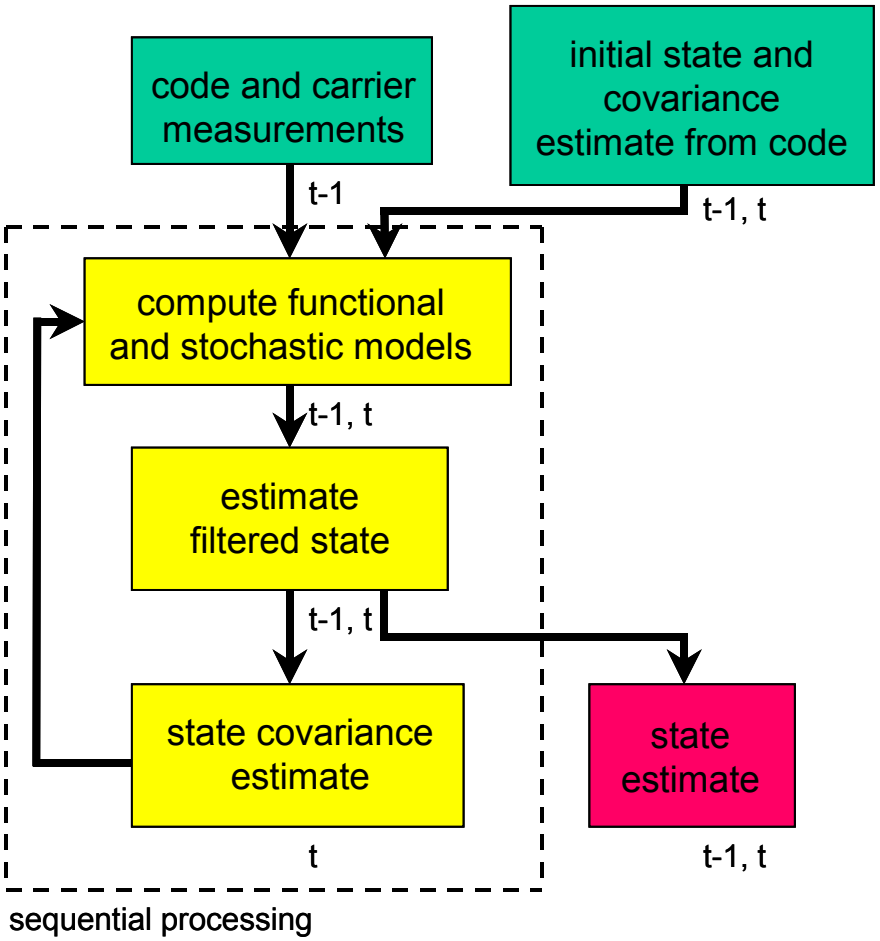
GPS measurement	low precision (10s of cm), unambiguous *pseudoranges*	high precision (sub-mm), ambiguous *carrier phases*
decimetre accuracy		
measurement constituents which must be estimated or eliminated	• satellite position error ×× • satellite clock ×× • receiver clock ×× • troposphere ×× • ionosphere ×× • multipath × • receiver noise × • …	• satellite position error ×× • satellite clock ×× • receiver clock ×× • troposphere ×× • ionosphere ×× • multipath • receiver noise • carrier-phase ambiguity ×× • … • …

× partially addressed
×× fully addressed

FLOW OF GEOMETRIC PROCESSING STRATEGY



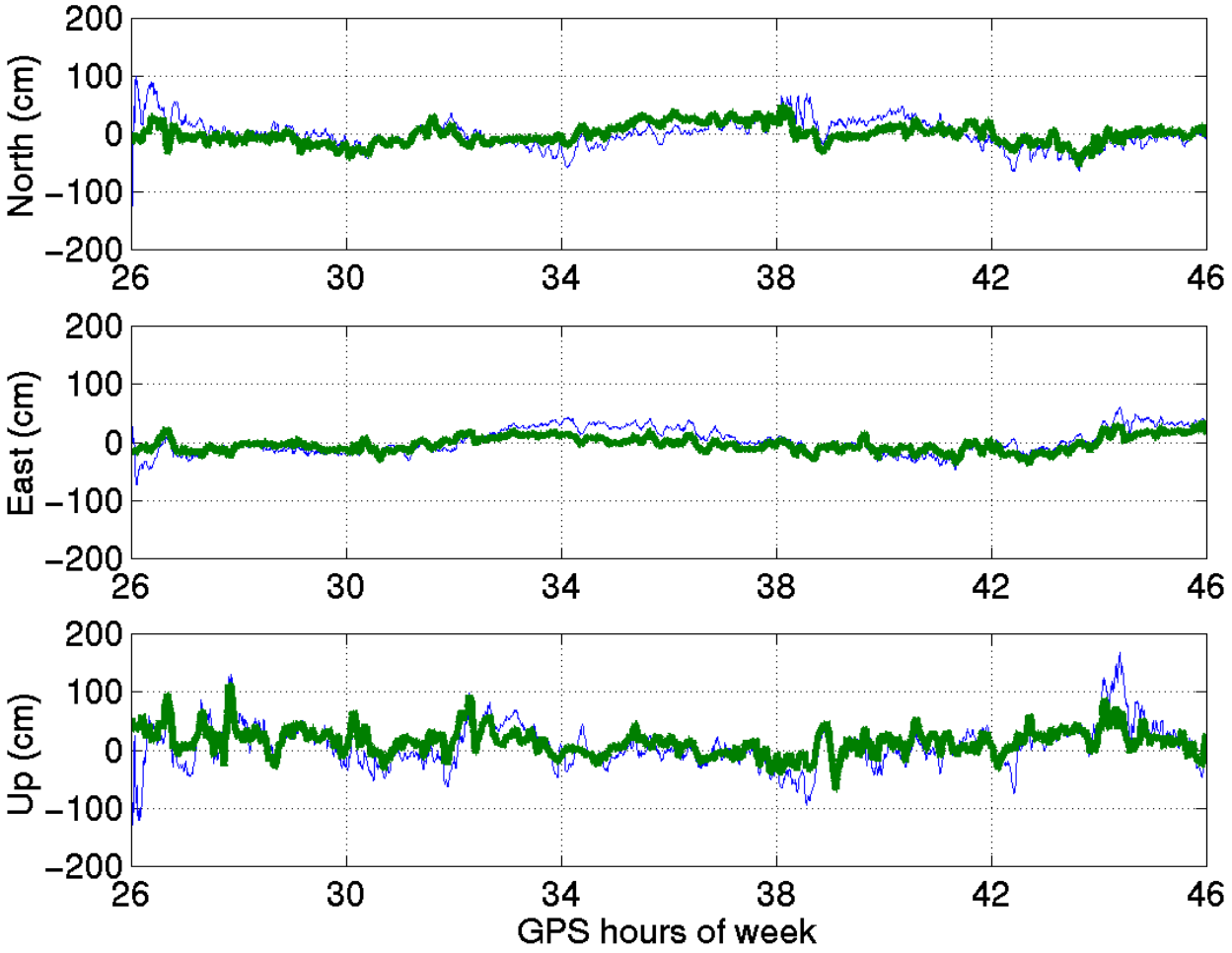
KINEMATIC, SEQUENTIAL, LEAST-SQUARES FILTER



PRELIMINARY STATIC, TERRESTRIAL DATA TESTING

- Data description:
  - One day of dual-frequency data from station Algonquin (ALGO) located at 45. 96° N, 78.07° W in central Ontario, Canada.
  - 7 August 2000.
  - 30 second data interval.
  - 5° elevation angle mask.
  - IGS precise GPS satellite orbits and clock offsets.
- Processing:
  - Use of UNB3 tropospheric prediction model; residual delay not estimated.
  - Investigate repeatability of position computations.
  - Test performance of technique against most accurate geodetic techniques.

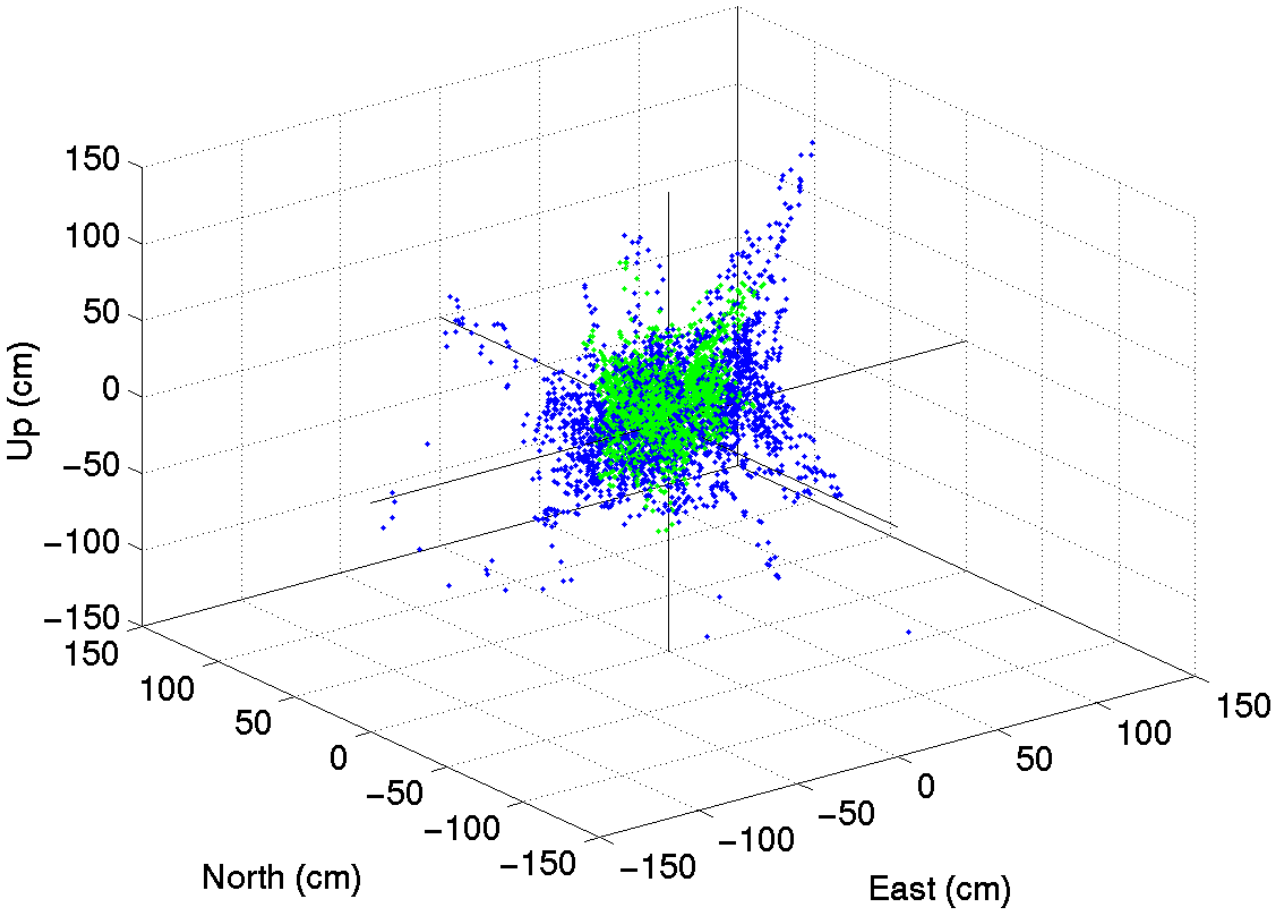
FILTER / SMOOTHER RESULTS



r.m.s. (cm)	Filter	Smoother
North	24.5	16.8
East	21.9	13.3
Up	37.2	26.7
Hor.	32.9	21.4
3-D	49.6	34.2

Filter
Smoother

AVERAGING RESULTS VERSUS PUBLISHED POSITION



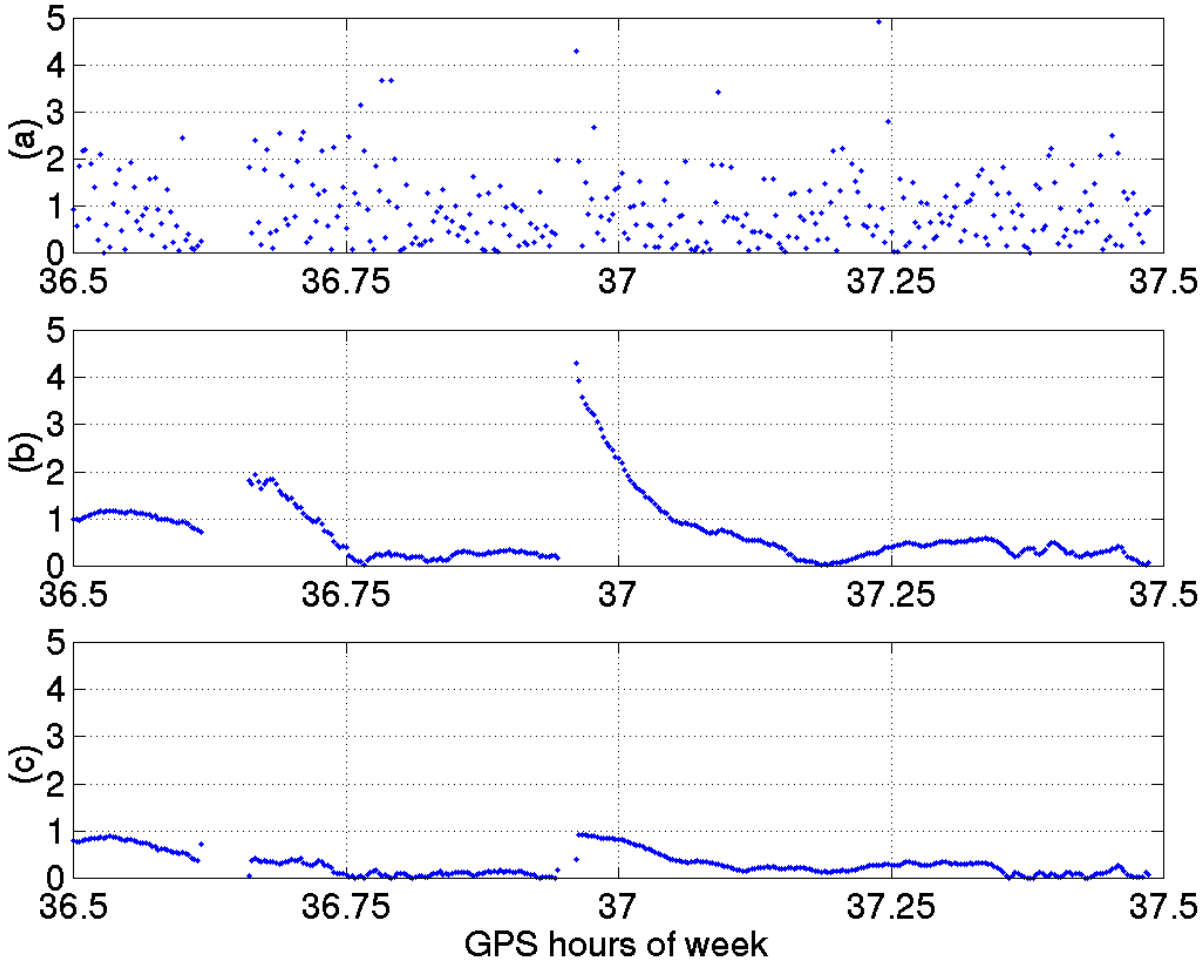
Bias (cm)	Filter	Smoother
North	0.8	-1.1
East	1.6	-3.5
Up	7.3	13.7
Hor.	1.8	3.7
3-D	7.5	14.2

Filter
Smoother

PRELIMINARY SPACEBORNE DATA TESTING

- Data description:
  - One day of single-frequency data from Topex/Poseidon (altitude 1335 km).
  - 13 November 2000.
  - 300 second data interval.
  - No elevation angle mask.
  - IGS precise GPS satellite orbits and clock offsets.
- Processing:
  - Investigate the geometric strength of measurements.
  - Test practicality and performance of technique against JPL high-quality orbit.

TOPEX/POSEIDON SATELLITE ORBIT ERROR



sol'n (cm)	3dr.m.s.
(a) code	154
(b) filter	43
(c) smoother	33

CONCLUSIONS

- Geometric orbit determination strategy proposed.
- Kinematic, sequential least-squares filter described.
- Static, terrestrial state testing indicates few-decimetre position component r.m.s. and few-centimetre overall position bias. Promising results.
- Preliminary spaceborne data testing indicates few-decimetre total displacement r.m.s. Envisage decimetre-level position component r.m.s.
- Dynamics-free nature of filter allows for application of technique to any platform.

GPS PROCESSING EVOLUTION

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POINT POSITIONING

IGS DATA PRODUCTS


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POINT POSITIONING

ACKNOWLEDGEMENTS

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