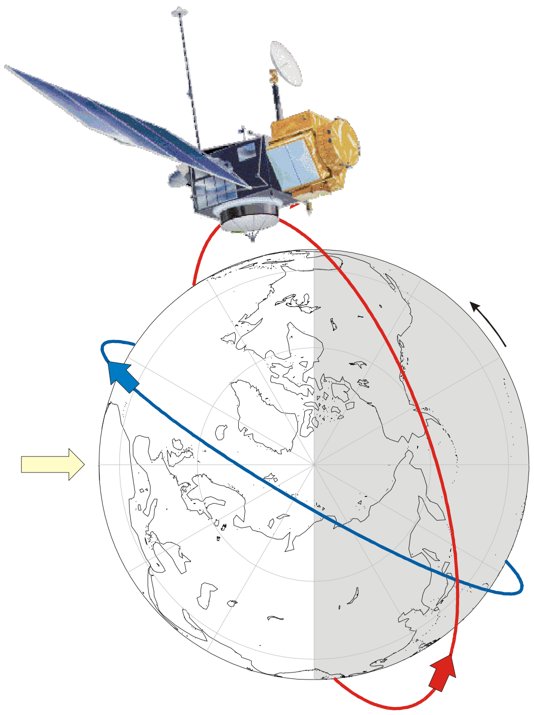
Issues in orbit tracking and orbit error reduction

Results of GAMBLE WP4

GAMBLE final meeting
Arles, 17 November 2003



Eelco Doornbos
Delft Institute for Earth-Oriented Space Research
Delft University of Technology

TU Delft
Delft University of Technology

DEOS

Workshop: Delft, November 8, 2002

Purpose

- Review the current state and future developments in the tracking systems and orbit determination in support of altimetry missions

Inputs

- Orbit requirements from GAMBLE workshops on sea-state and sea-height monitoring

Outputs

- Orbit and tracking recommendations, to be used in the GAMBLE Constellation Optimization work package

Workshop: Delft, November 8, 2002

Summary of requirements

- **Pierre-Yves Le Traon** (CLS): Sea-height
- **David Cotton** (SOS): Sea-state

Tracking systems

- **Ron Noomen** (DEOS): SLR
- **Patrick Vincent** (CNES): DORIS
- **Drazen Svehla** (TUM): GPS, cm-level POD
- **Max Meerman** (SSTL): GPS, SSTL receivers

Precise orbit determination

- **Phil Moore** (Univ. Newcastle): Aspects of POD
- **C.K. Shum** (OSU): Orbit choices and kinematic approach
- **Pieter Visser** (DEOS): Gravity field modeling
- **Eelco Doornbos** (DEOS): Non-gravitational forces

Discussion

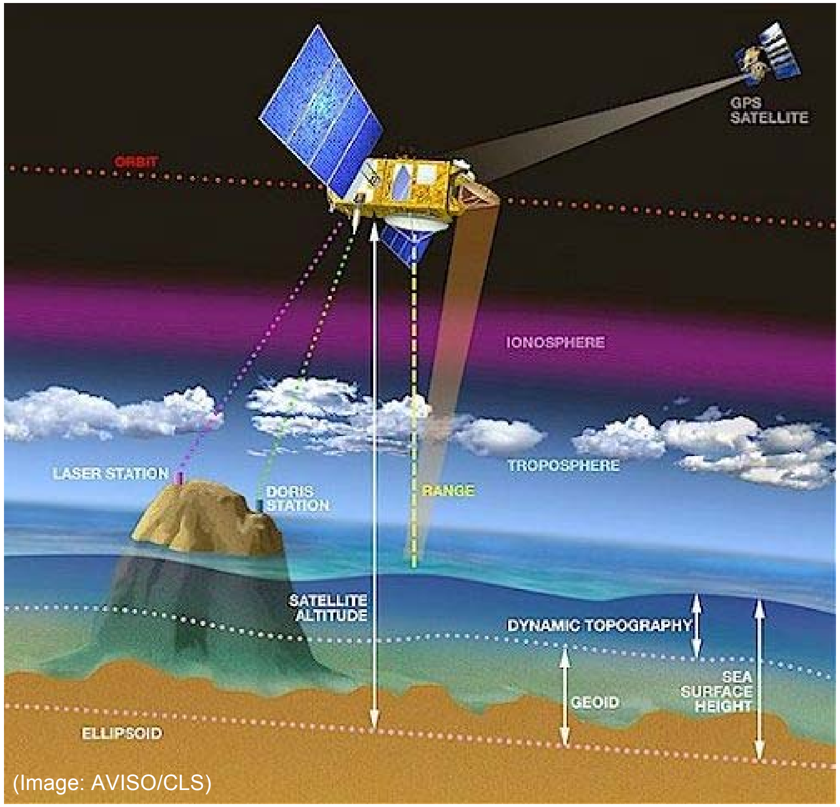
Precision Orbit Determination (POD)

Precision orbit determination

- Relates the altimeter range to a terrestrial reference frame

POD requirements:

- Tracking data
  - SLR
  - DORIS
  - GPS
- Measurement models
  - Station coordinates
  - Antenna offsets
  - Media corrections
- Force models
  - Gravity (static, tides, 3rd body)
  - Non-gravitational (drag, radiation pressure)



POD strategies

Orbit prediction

• Use of force models (gravity, drag, radiation pressure, etc.) to integrate orbit from initial state.

Dynamic / Reduced Dynamic POD

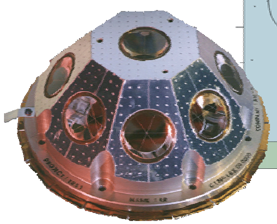
• Adjust initial state and force model parameters to obtain a best fit with the tracking data.

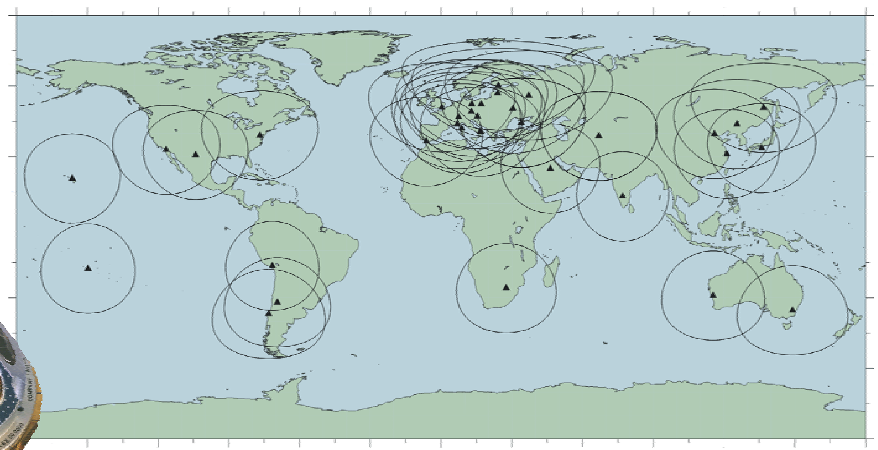
Kinematic POD

• Geometrical approach. Orbit follows (GPS) tracking data, force models have become irrelevant.

Precision satellite tracking systems 1

SLR: Satellite Laser Ranging



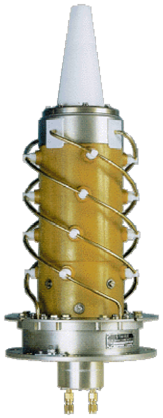


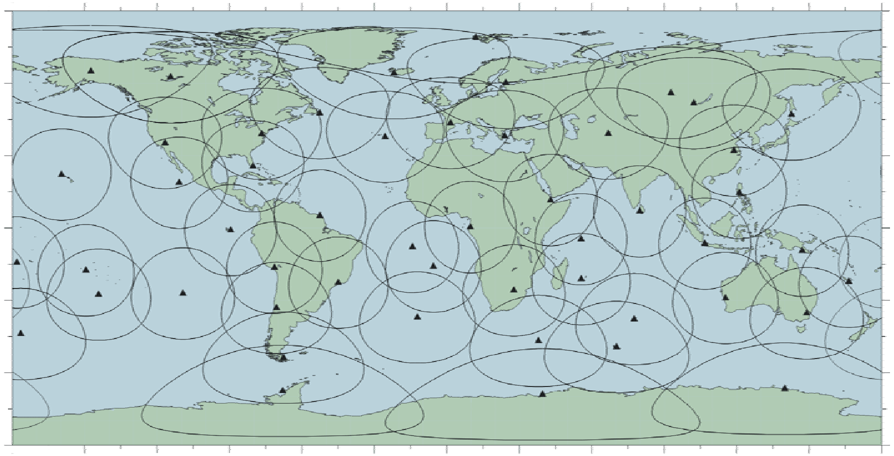
- Laser Retroreflector Arrays are relatively cheap
- The SLR community is very supportive of altimetry missions
- Operation of SLR stations is under threat of cuts in funding

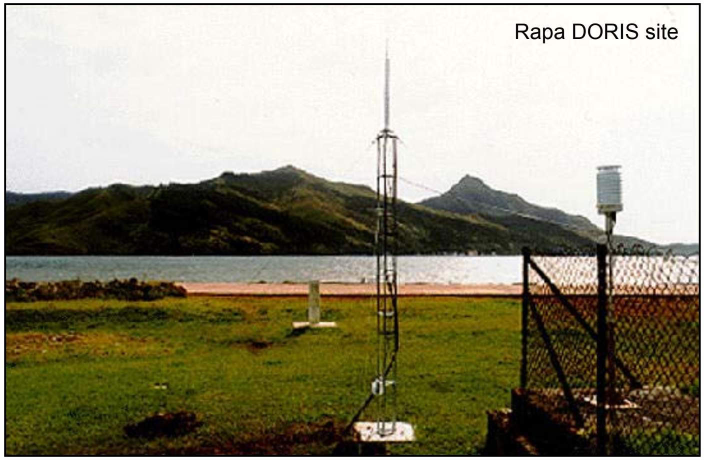
- Nevertheless, data quantity and quality is steadily increasing
- SLR is essential for Jason/Envisat-class orbits

Precision satellite tracking systems 2

DORIS: Doppler Orbitography and Radiopositioning Integrated by Satellite





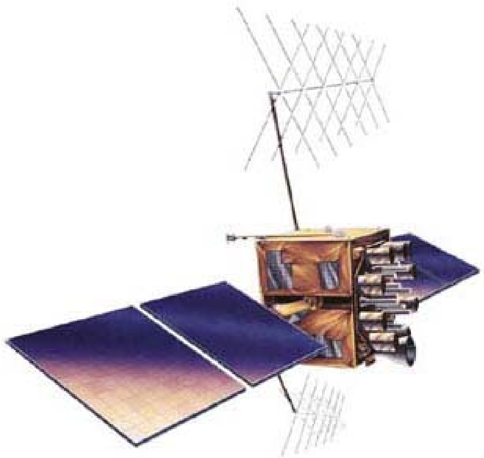


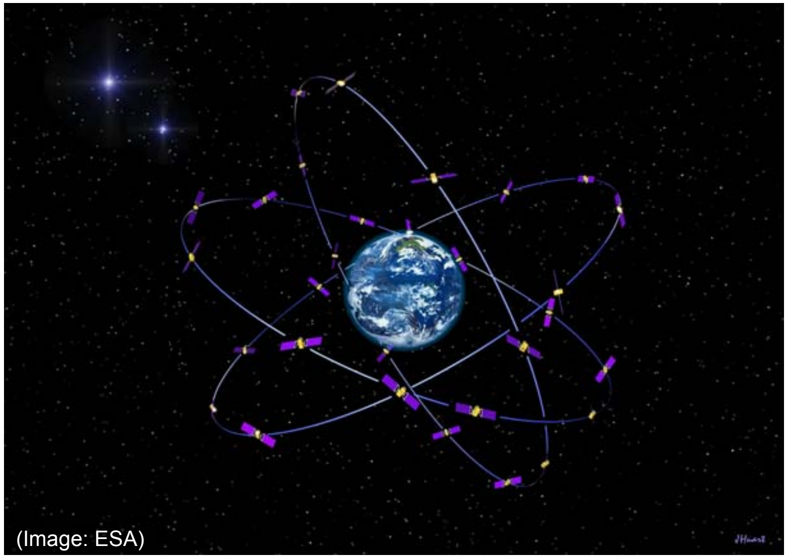
- 50-60 ground beacons
- Excellent global coverage, weather independent

- DORIS/DIODE Navigator provides real-time orbits with 30-cm radial precision: excellent for near real-time applications

Precision satellite tracking systems 3

GPS (and in the future: Galileo)





(Image: ESA)

- Miniaturized receivers without phase-measuring capabilities deliver orbits accurate to several meters on many micro-satellites

- Advanced receivers for cm accuracy
- Excellent tracking coverage and accuracy
- Complicated processing, research ongoing

Use of altimetry data in POD

Successfully applied to ERS-1, ERS-2 and GFO

Measurement types:

- Altimeter crossover differences (single or dual)
- Altimeter range measurements, corrected and referenced to a mean sea surface model

Alternatively…

- Correct inaccurate orbit using dual crossovers with reference-class mission, such as Jason

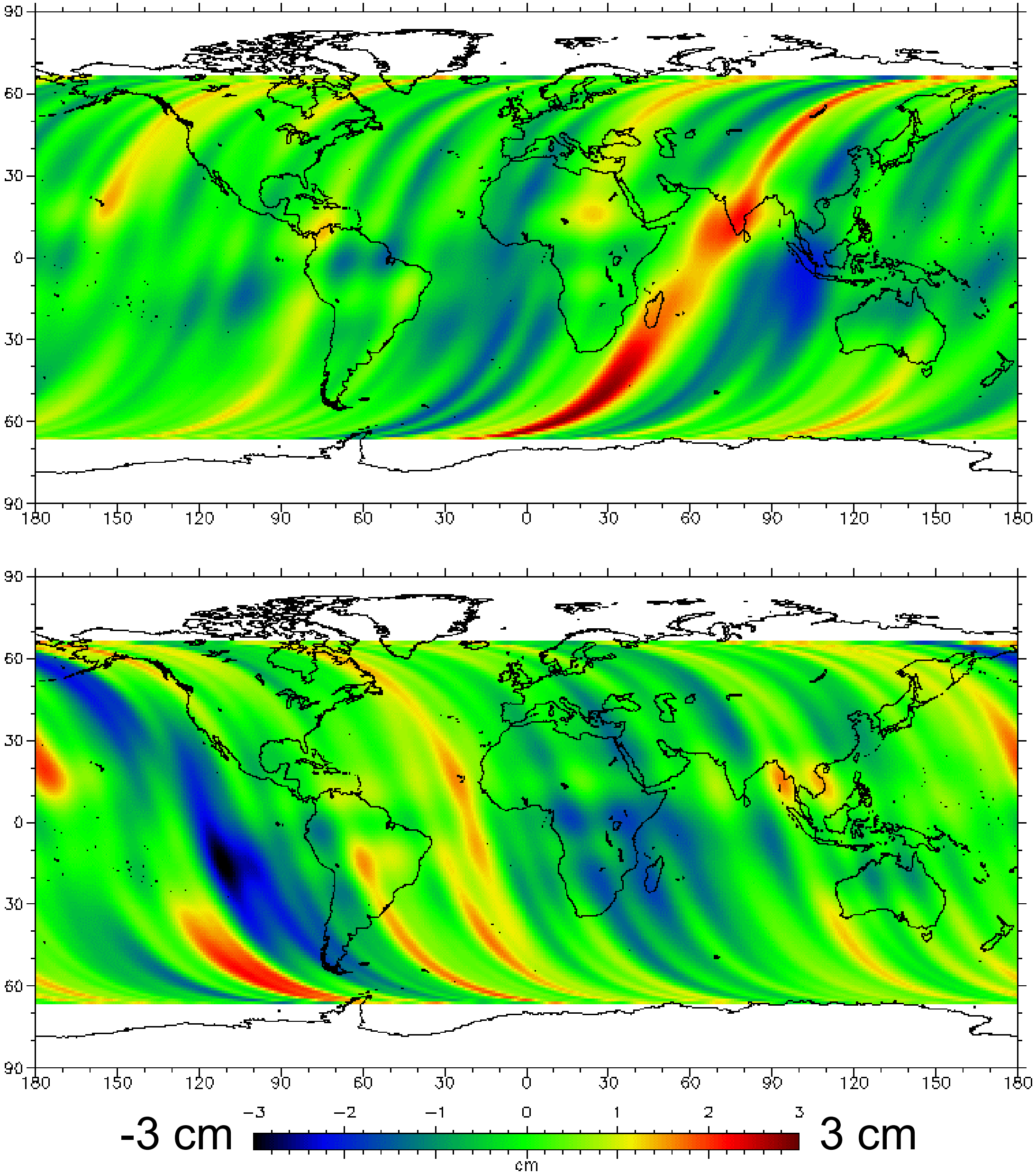
Pros:

- Supplies crucial information on radial position when other radiometric tracking is absent and SLR data is sparse

Cons:

- Danger of absorbing ocean signals in orbits

Force models: gravity



An illustration of inaccuracies in the reference frame:

Radial orbit differences
GRIM5-C1 – JGM-3
For T/P/Jason inclination and altitude

Force models: gravity

The first GRACE gravity solutions have recently become available

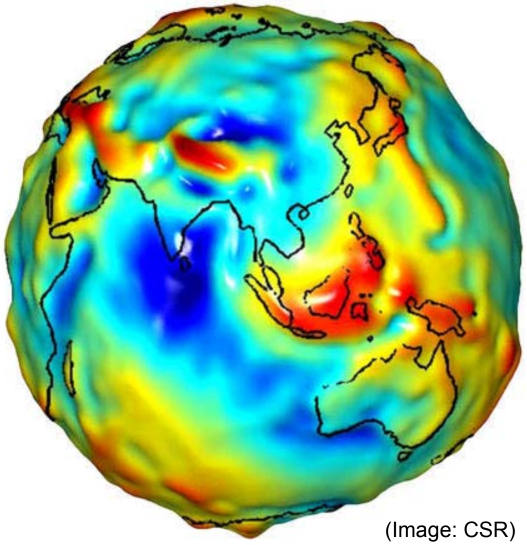
- CSR: GGM01
- GFZ: EIGEN-GRACE01

Result for POD:

- Equal or better results than the usual altimetry-tuned models

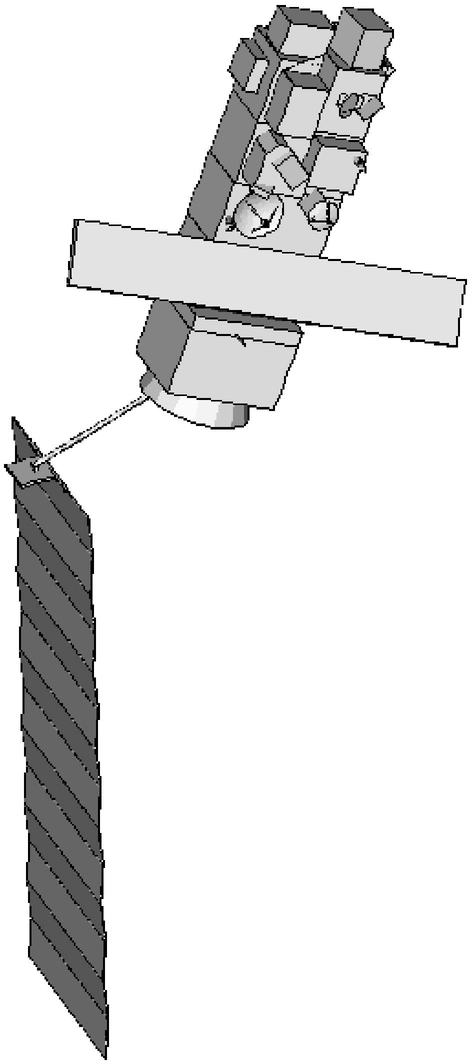
Future research

- Improve dynamic tide models
- Study effect of time-varying gravity and reference frame



(Image: CSR)

Force models: non-gravitational



(Image: TU Delft / ESOC)

Atmospheric drag and radiation pressure will soon be the only remaining major sources of force model error

Current and future research

- Highly detailed satellite geometry and interaction models
- Data assimilation in thermospheric density models

Other solutions

- Reduced dynamic or kinematic POD
- High altitude orbits
- Low area/mass ratio satellite design
- Include accelerometer on satellite

Accelerometer on altimetry satellites?

Advantages:

- Independent measurement of non-gravitational forces
- Improves POD
- Improves force model development

Disadvantages:

- Additional requirements on mission design
- Problem of decoupling accelerometer biases and scale factors

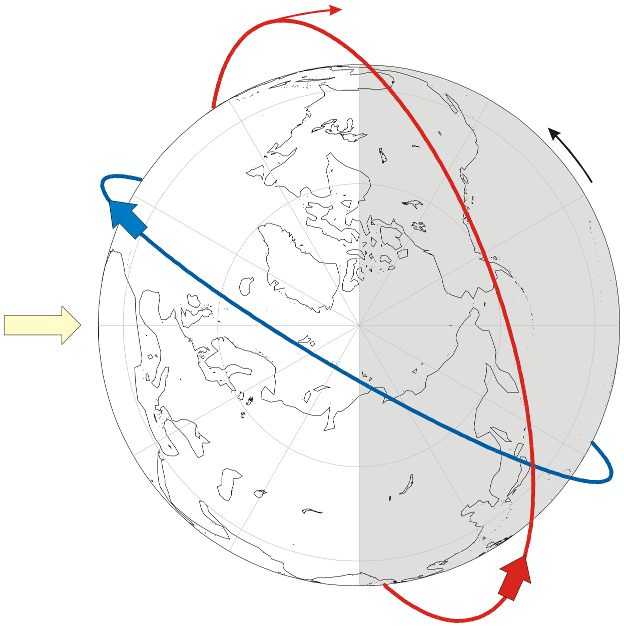
Orbit choice

- High altitude orbits are favourable for POD
  - Force models (gravity, drag)
  - Tracking coverage

- High altitude orbits reduce frequency of orbit maintenance maneuvers

- Impact on sampling of tides

- Continuation of the ERS/TP and Envisat/Jason configuration is highly recommended



Tracking requirements from WP2/3

Sea-state altimeter missions:

- No high-accuracy tracking system required.

Sea-height altimeter missions:

- Highest-accuracy altimeter-independent tracking and precise orbit determination required for reference missions
- For mesoscale studies, orbits adjusted using altimetry crossovers will be sufficient

Tracking system recommendations 1/2

Primary SSH reference missions (TP/Jason):

- The combination SLR, DORIS and Geodetic GPS is the recommended configuration.
- Highest achievable level of POD accuracy
- <2 cm radial RMS at 1336 km altitude
- Additional redundancy

Secondary SSH reference missions (Envisat, …):

- SLR plus either DORIS or Geodetic GPS is required
- <3-4 cm radial RMS accuracy at 800 km altitude
- Orbits that are completely independent from altimetry

Tracking system recommendations 2/2

Mesoscale SSH missions (wide swath or small constellations)

- <10 cm radial RMS accuracy (at 800 km altitude)
- a laser retroreflector is sufficient (but minimal) hardware
- POD using altimetry as additional tracking data (concept proven for ERS-1/2 and GFO)

Mesoscale SSH large constellations (>3 satellites)

- A large constellation might burden the SLR stations
- There will be many more crossover locations
- A non-geodetic GPS receiver instead of SLR will also provide stability in the along/cross-track directions

Wind/wave constellations

- No POD requirements

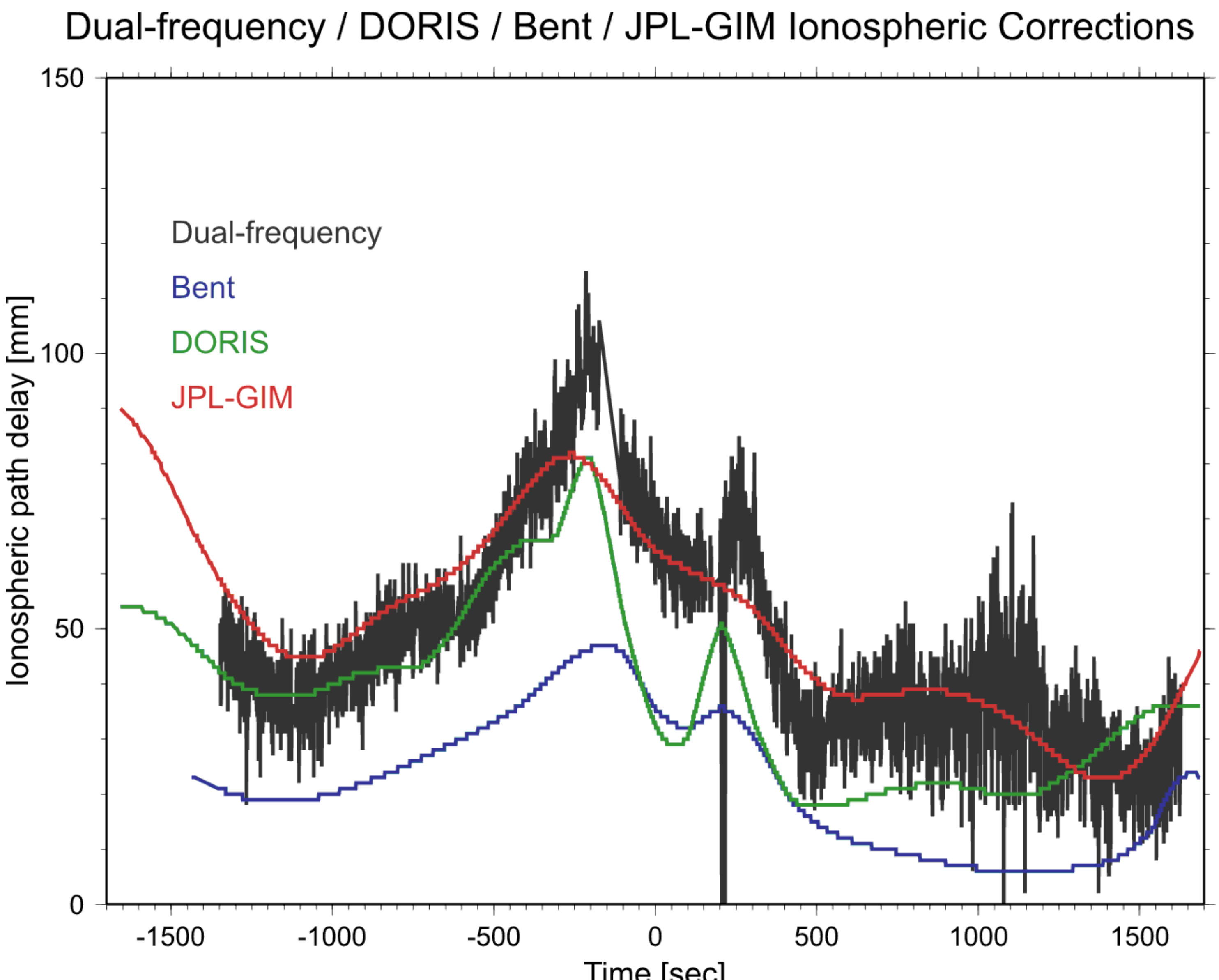
Conclusions and outlook

• Since ERS and TOPEX, POD is no longer a major limiting factor in altimetric system accuracy

• Current goal for Envisat: < 3 cm orbits
    • Mainly through force model improvement
• Current goal for Jason: < 1 cm orbits
    • Mainly through new tracking data processing techniques

• Low-cost tracking options for future mesoscale microsat missions are feasible (concept proven for ERS-1/2 and GFO)

Media corrections 1: Ionosphere



Media corrections 2: Wet troposphere