The Instrument on NASA's GRACE Mission:

augmentation of GPS to achieve unprecendented gravity field measurements

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Gravity Recovery and Climate Experiment

- Purpose
  - Primary: Mapping the gravitational field of the Earth to at least an order of magnitude better than existing determinations. Detecting time-varying features in the field.
  - Secondary: Remote sensing of the Earth's atmosphere using GPS-based radio occultation

- Sponsors
  - NASA: Provided the twin satellites and instruments
  - DLR: Provided the launch vehicle and operations
  - Parallel science efforts in the US (U. Texas /CSR) and Germany (GFZ)

- Orbit
  - Launched on March 17, 2002, from Plesetsk, Russia
  - 500 km initial altitude, 89 deg. inclination, 0.001 eccentricity
  - Non-repeat ground track, 5 year lifetime
  - Satellite separation is maintained at 175 - 270 km

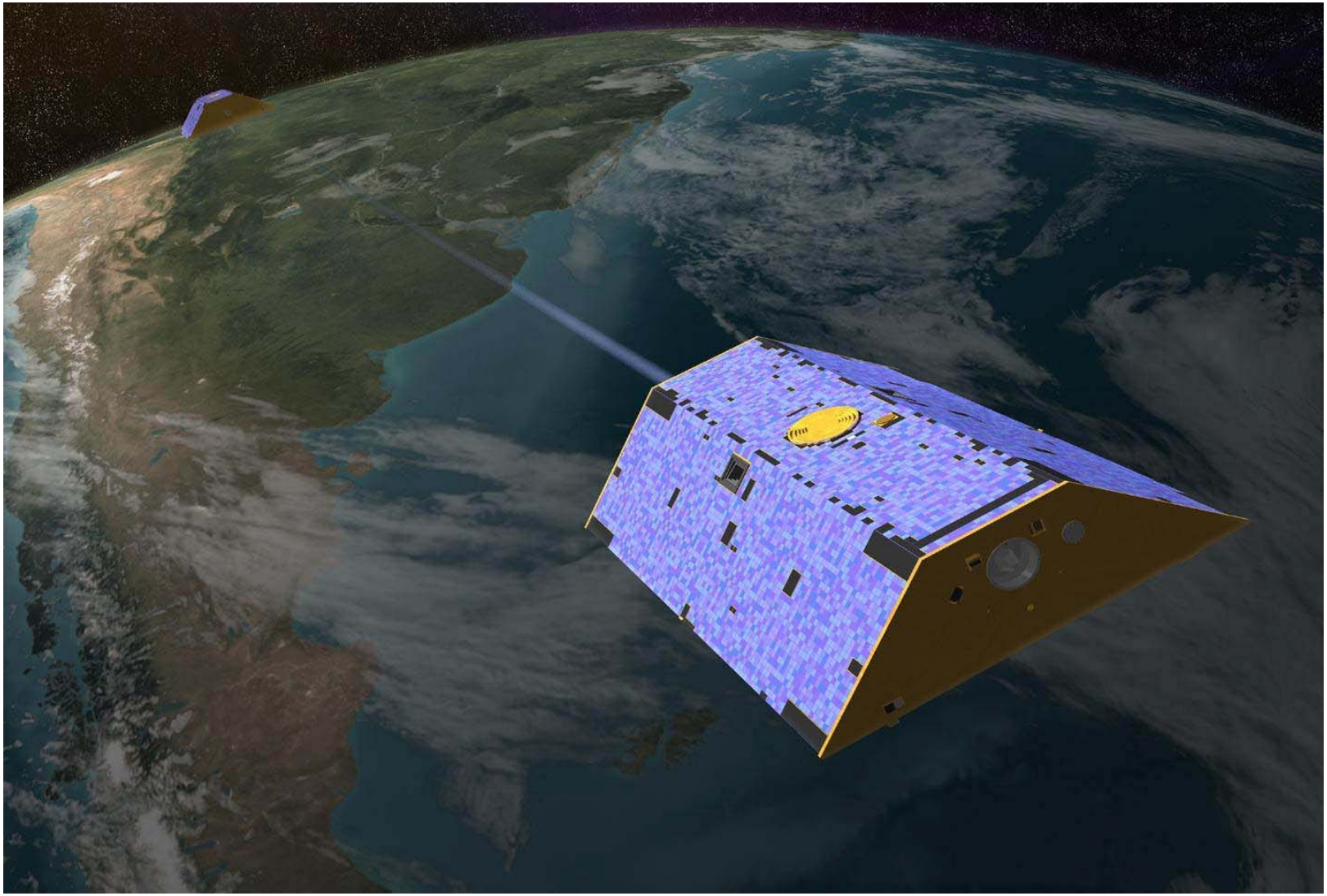
Measurement concept

The distance between the twin satellites constantly varies as they pass over Earth features. The satellites are the instruments:

- **Dual-One-Way Range (DOWR)**
  - The technique has been discussed for ~30 years
  - Each of two satellites transmits a carrier signal to the other satellite
  - Each satellite also measures the phase of the received signal
  - The sum of the Tx and Rx phases $\propto$ inter-satellite range change
  - By combining measurements from both satellites, clock errors with periods larger than the inter-satellite light time can be cancelled out (almost)

- **The role of GPS**
  - To meet science goals the range must be measured to a few microns
  - At K- (24 GHz) and Ka-bands (32 GHz) this is 1e-4 cycles
  - To combine measurements time-tags must be at the 150-200 ps level
    (from $\Delta t = \Delta\Phi / f_{bp}$, where f_{bp} = 502 or 670 kHz, the KBR difference frequencies)
  - This is most easily and cheaply provided by GPS, as opposed to on-board clocks
  - GPS also gives the usual precise orbit determination (and timing signals and…)

The GRACE satellites in orbit



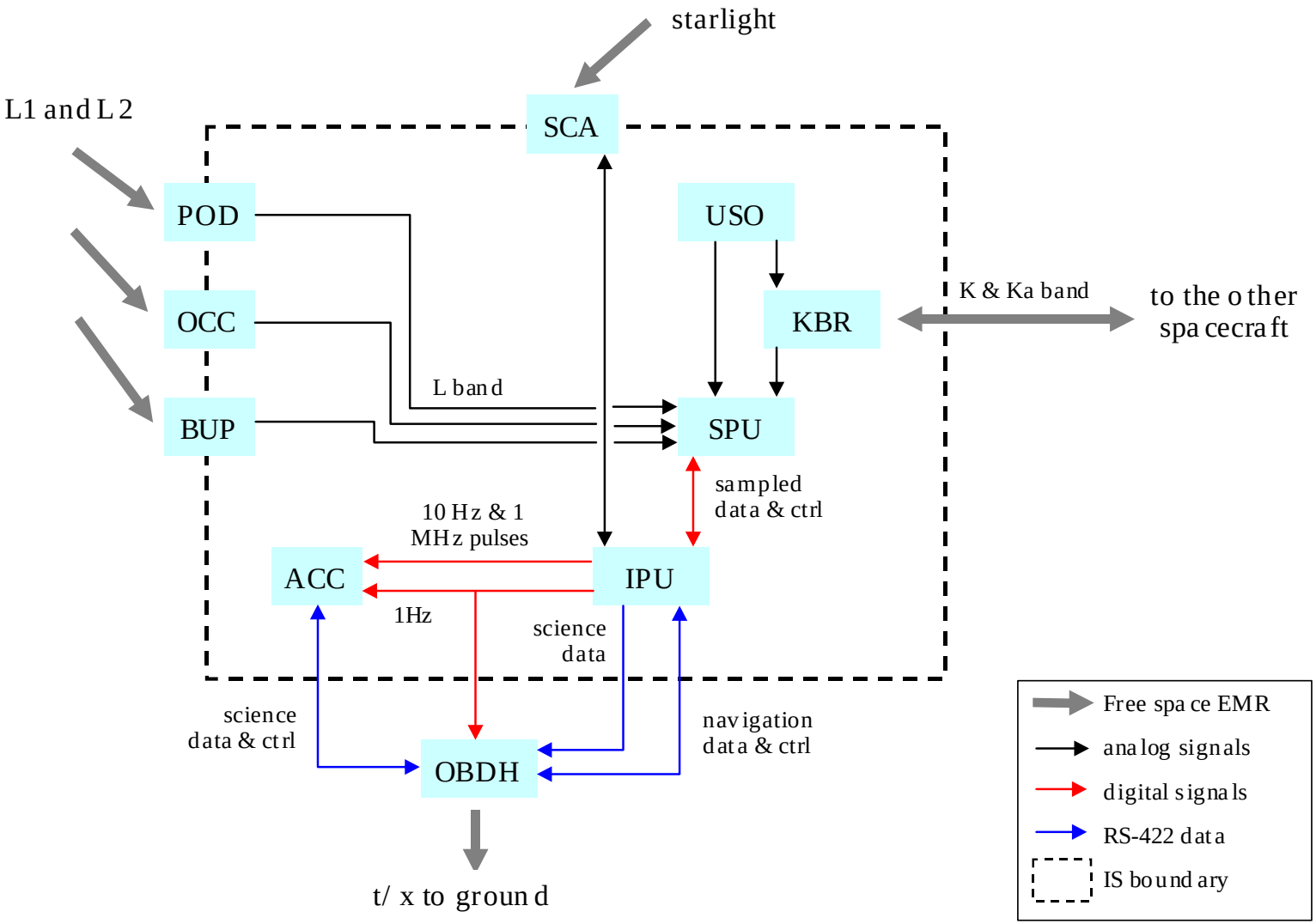
GRACE instrument system

Both satellites carry almost identical instrument suites (exception: the USO frequencies are slightly different, to offset the KBR signals).

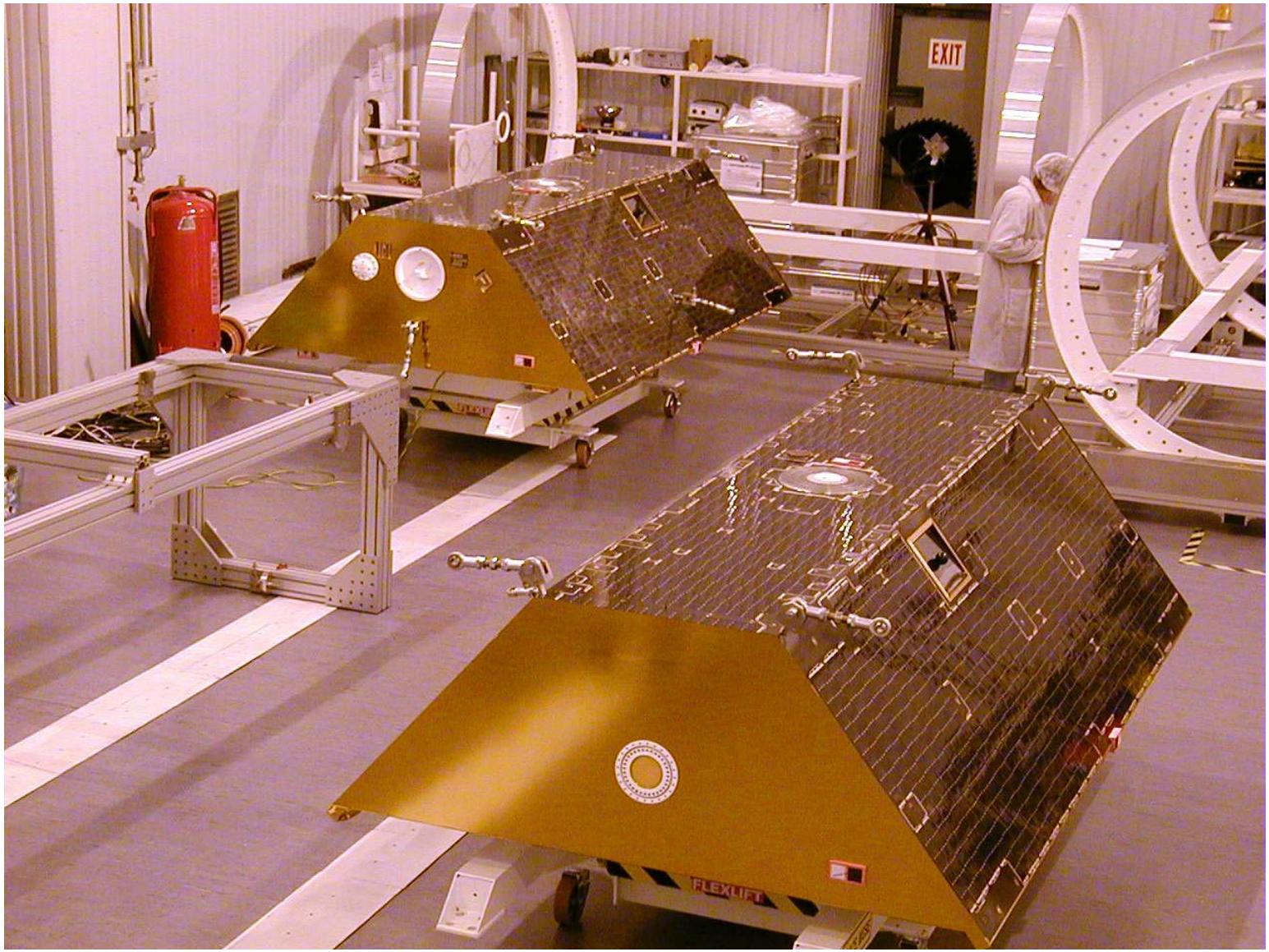
The instruments are redundant and cross-strapped (exception: ACC sensor unit and KBR horn are not redundant).

- Instrument Processing Unit (IPU)
  - Performs GPS signal processing; produces output observables; performs GPS signal processing processes SCA images; collects housekeeping data; outputs timing signals; selects KBR switches & cross-strapping
- Signal Processing Unit (SPU)
  - Downconverts RF signals from the 3 GPS antennas (POD, occultation, and back-up) and the KBR; digitizes data for the IPU
- K-Band Ranging system (KBR)
  - Satellite-to-satellite tracking at K- (24.5 GHZ) and Ka-band (32.7 GHz)
- Ultra-Stable Oscillator (USO)
  - Provides clock signals for the SPU and KBR
- Star Camera Assembly (SCA)
  - Attitude observations for KBR pointing and satellite attitude control
- Accelerometer (ACC)
  - Provides measurements to remove non-gravitational forces

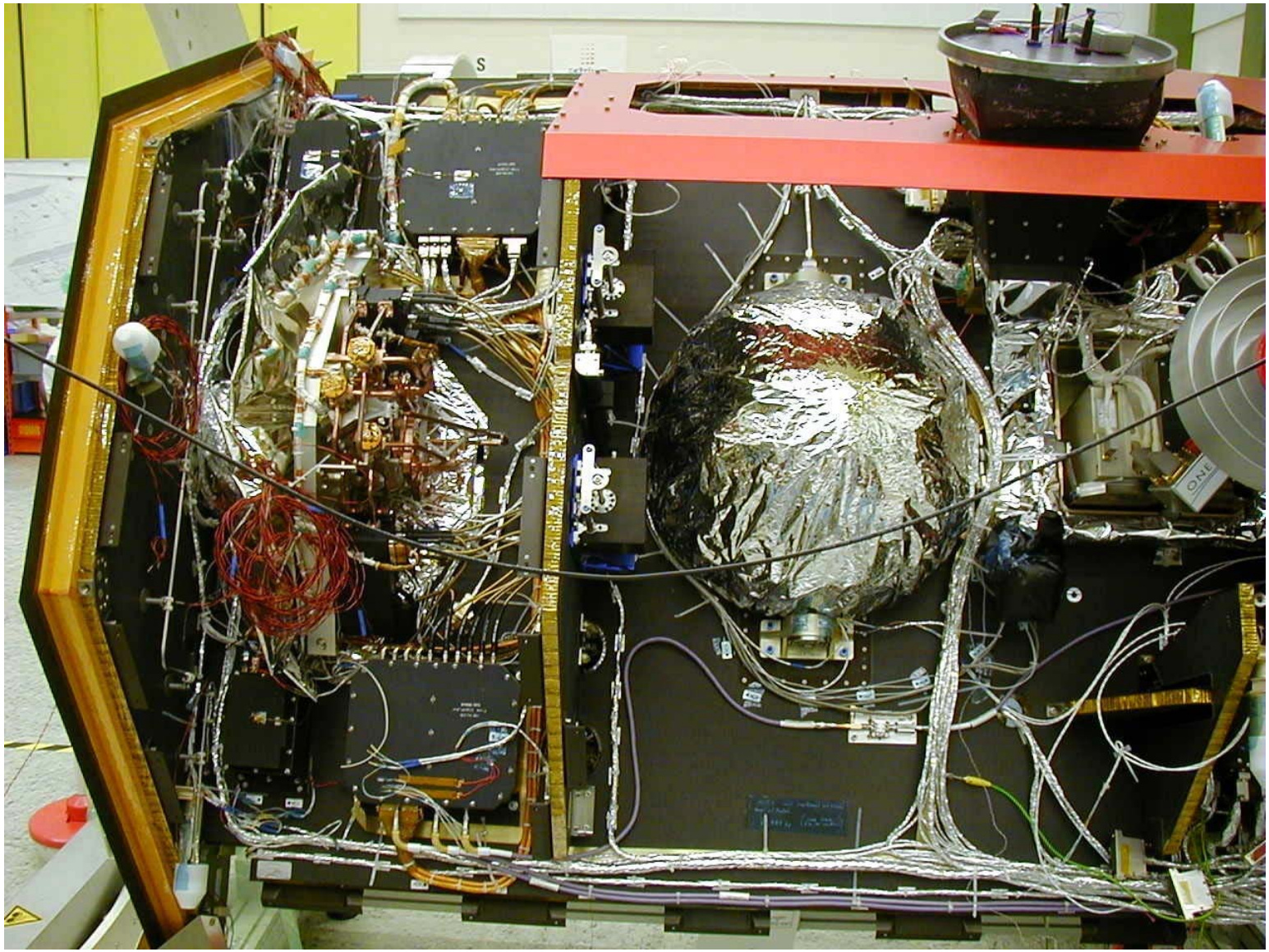
Instrument system dependencies



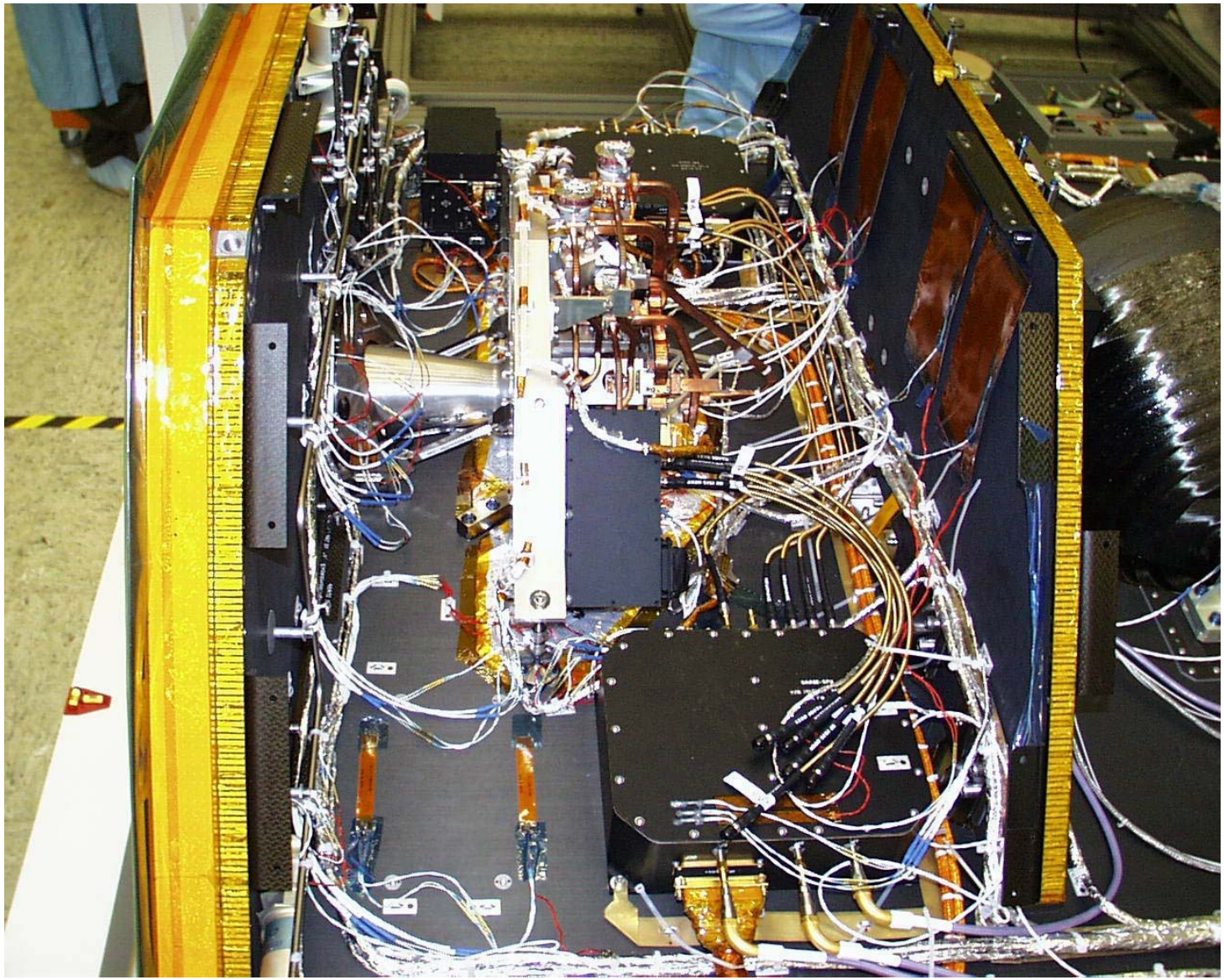
The GRACE satellites during pre-launch preparations



The instrument system during integration



Close-up of the IPU, SPU, KBR, and USOs



Design and testing philosophy

- **Design and development**
  - GRACE begun in the era of “faster, better, cheaper”
  - IPU not designed to resist Single-Event Upsets, just to recover quickly
  - Used mainly commercial parts in the IPU and SPU
  - Used traditional “space-approved” parts when possible (which wasn’t often)
  - Limited single-point failures
  - Retained proven BlackJack features whenever possible

- **Testing**
  - Used existing GPS testing infrastructure at JPL, e.g. simulator, data analyses
  - Performed extra “burn-in” testing because of commercial parts
  - Performed the usual suite of space qual. test, e.g. vibe, TVT, EMI/EMC, VTFMT
  - Dependence of most of the instrument system on the IPU required several formal functionality and performance verification tests, e.g. SCA testing

Operations

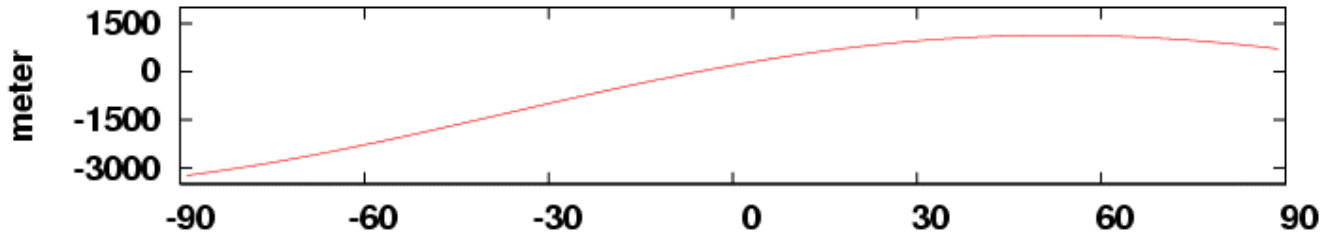
- **Anticipated events**
  - Main ground stations are Weilheim (up/down) and Neustrelitz (downlink only)
  - NASA's PGN used for early operations and non-routine events
  - Orbit maneuvers needed every ~50 days to maintain satellite separation
  - IPU reset frequency predicted at 1 per 6 days, due to known memory leak

- **Anomalies**
  - GRACE 1 IPU reset rate as expected; GRACE 2 IPU reset rate twice as frequent
  - IPU flash memory has been corrupted 3 times. Loss of configuration parameters has required operator intervention to resolve
  - Failures of some other instrument sub-systems on GRACE 1, i.e. USO, ACC-ICU, gyro

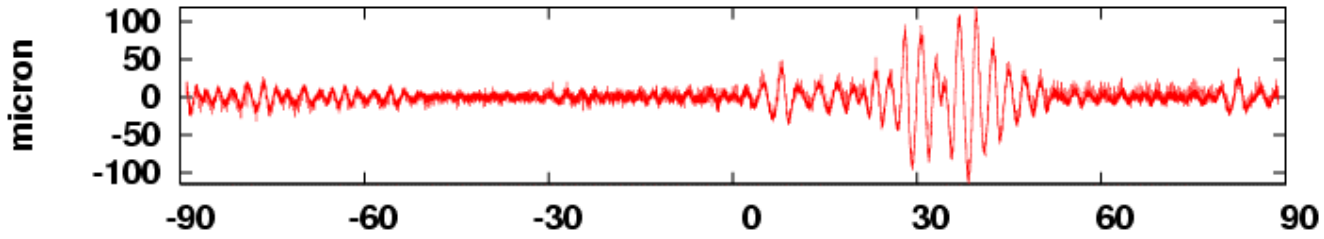
- **Future events**
  - IPU software upload in October
  - Finish KBR calibration

“Quick-look” data

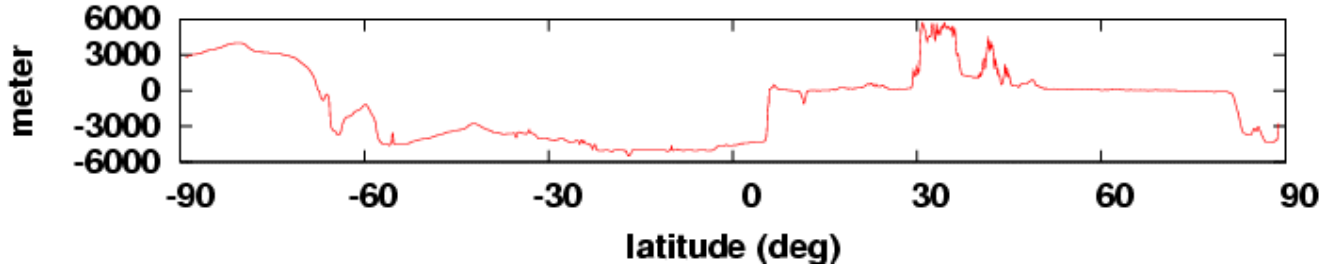
May 3, 2002 - 5s sampling of inter-satellite range, orbit errors and noise with period > 30s removed, non-gravitational forces ignored:



Full KBR
Range - Bias



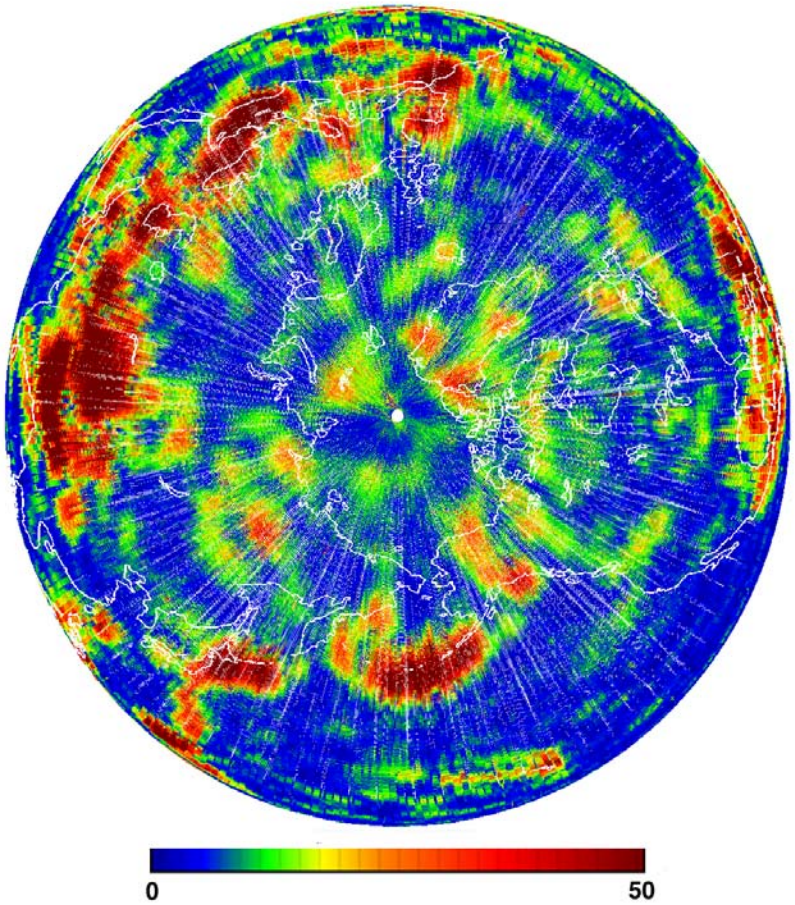
Cubic Spline Residual
(30 second knots)



Topography
Along Groundtrack

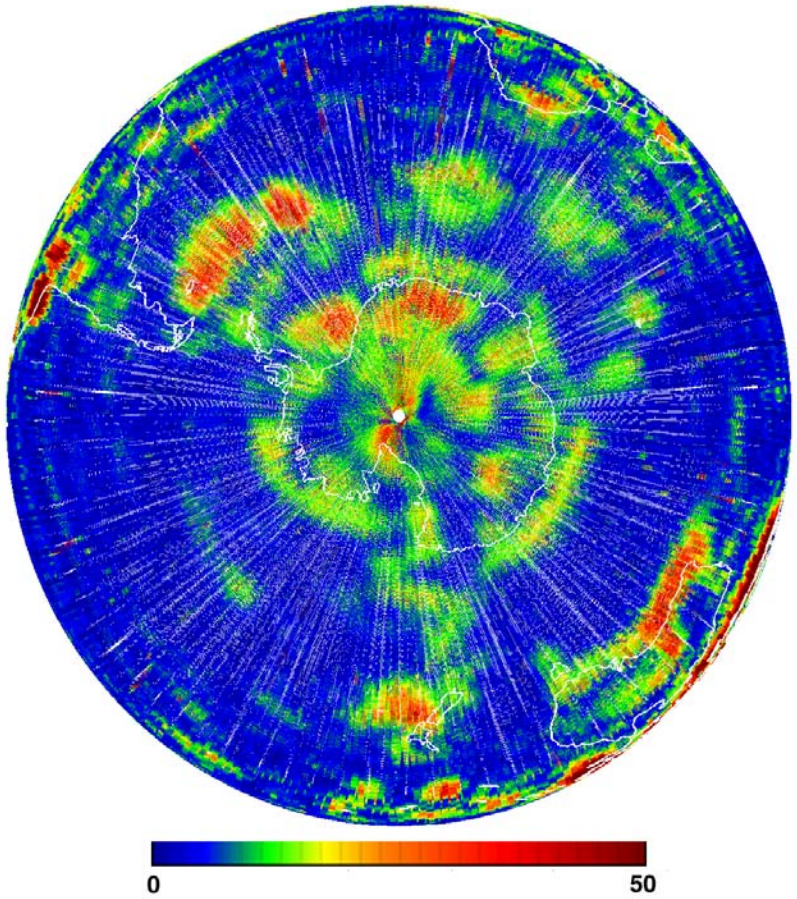
Geolocated inter-satellite range variations (1)

North Pole



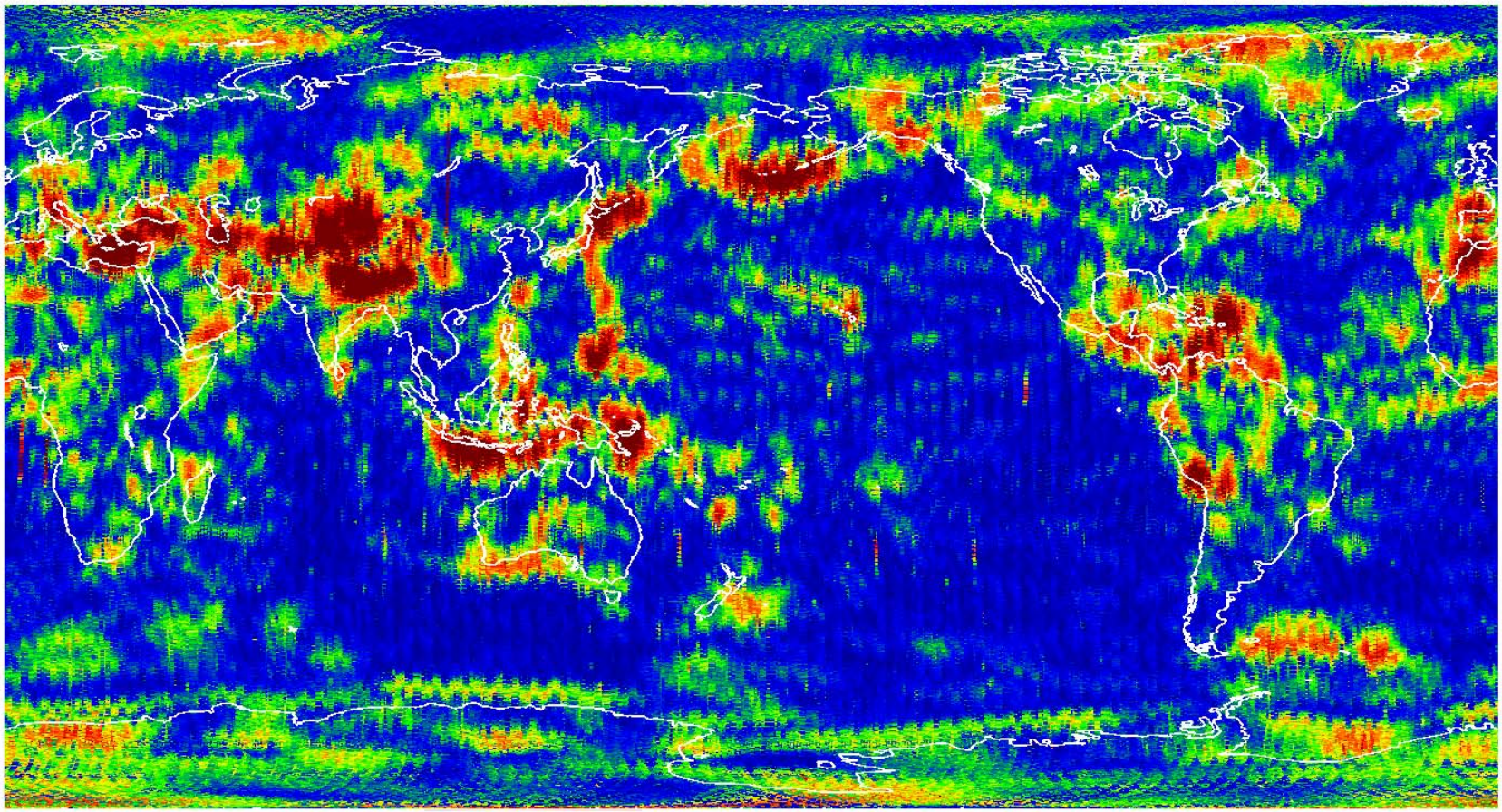
GRACE RANGE, ENVELOPE (30sec HI PASS), MICRONS_(GLK 2002-09-10)

South Pole



GRACE RANGE, ENVELOPE (30sec HI PASS), MICRONS_(GLK 2002-09-10)

Geolocated inter-satellite range variations (2)



GRACE RANGE, ENVELOPE (30sec HI PASS), MICRONS_(GLK 2002-09-10)