# GGOS 2020

## The Future GGOS as an Observing System

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# Remarks for a Common Understand

**GGOS** has two very different meanings, that should not be confused:

- **$GGOS_1$ :**

  The **actual infrastructure**, the actual observing system, different instrument types, satellite missions etc. and the

- **$GGOS_2$ :**

  The **organization GGOS**, components like Steering Committee, WGs, etc.

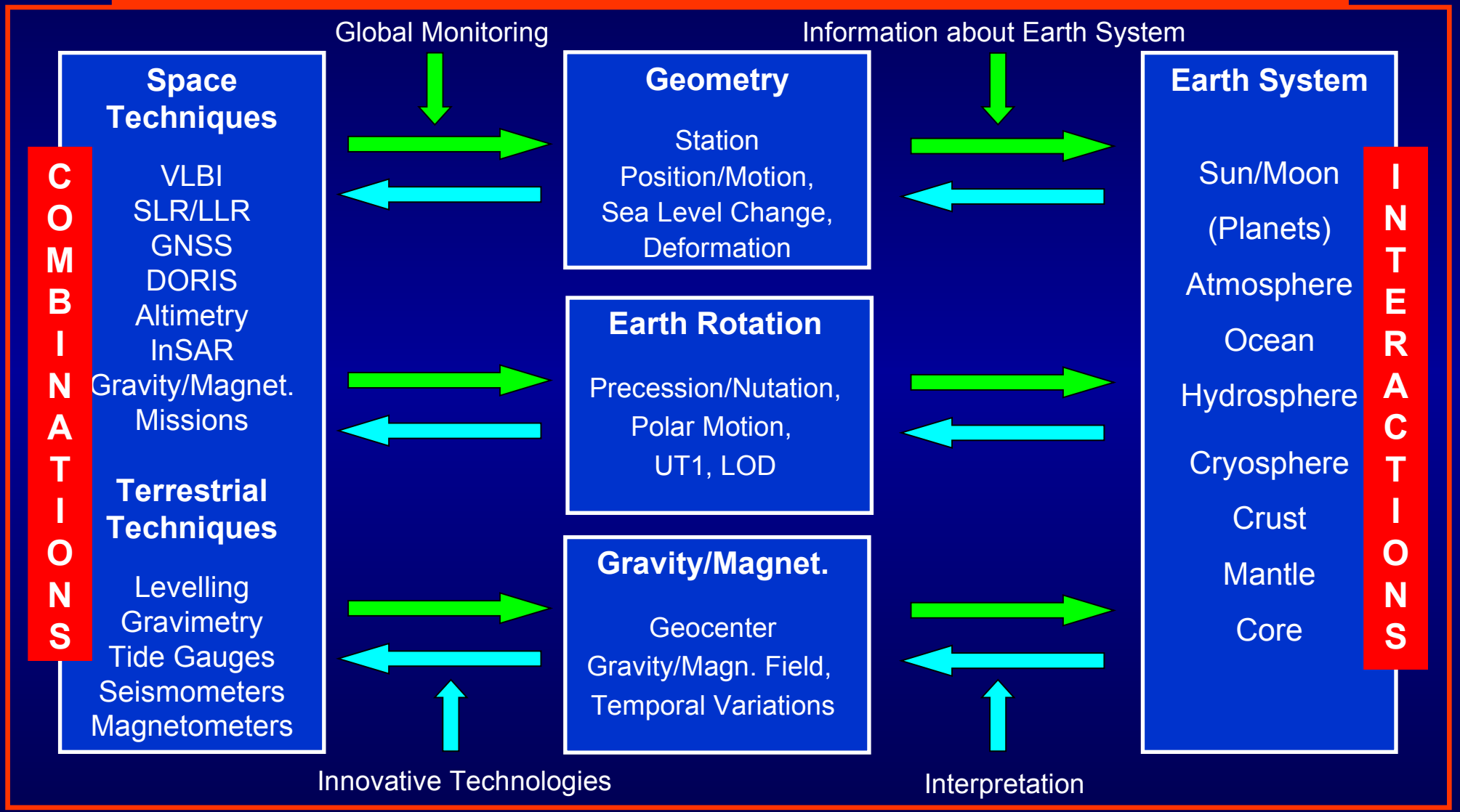
This presentation: **$GGOS_1$**, the actual observing system, i.e., an integration of observation technologies and operational processing chains into one system. The individual parts of the system are coordinated by various IAG Services.

**$GGOS_1$** : its core is the instrumental infrastructure, but it is much more:

- Instrumentation (ground- and space-based sensors)
- Data infrastructure (communication, archives, …)
- Operational data analysis and modeling chains
- GGOS Portal

# GGOS: Monitoring and Modelling the Earth's System

**Reference frames: highest accuracy and long-term stability**






GGOS

# Parts of the Future GGOS

- **Instrumentation:**

  Global terrestrial networks of observatories, Earth observing satellites and planetary missions

- **Data infrastructure:**

  Data transfer, communication links, data management and archiving systems, data and product dissemination centers, web pages, etc.

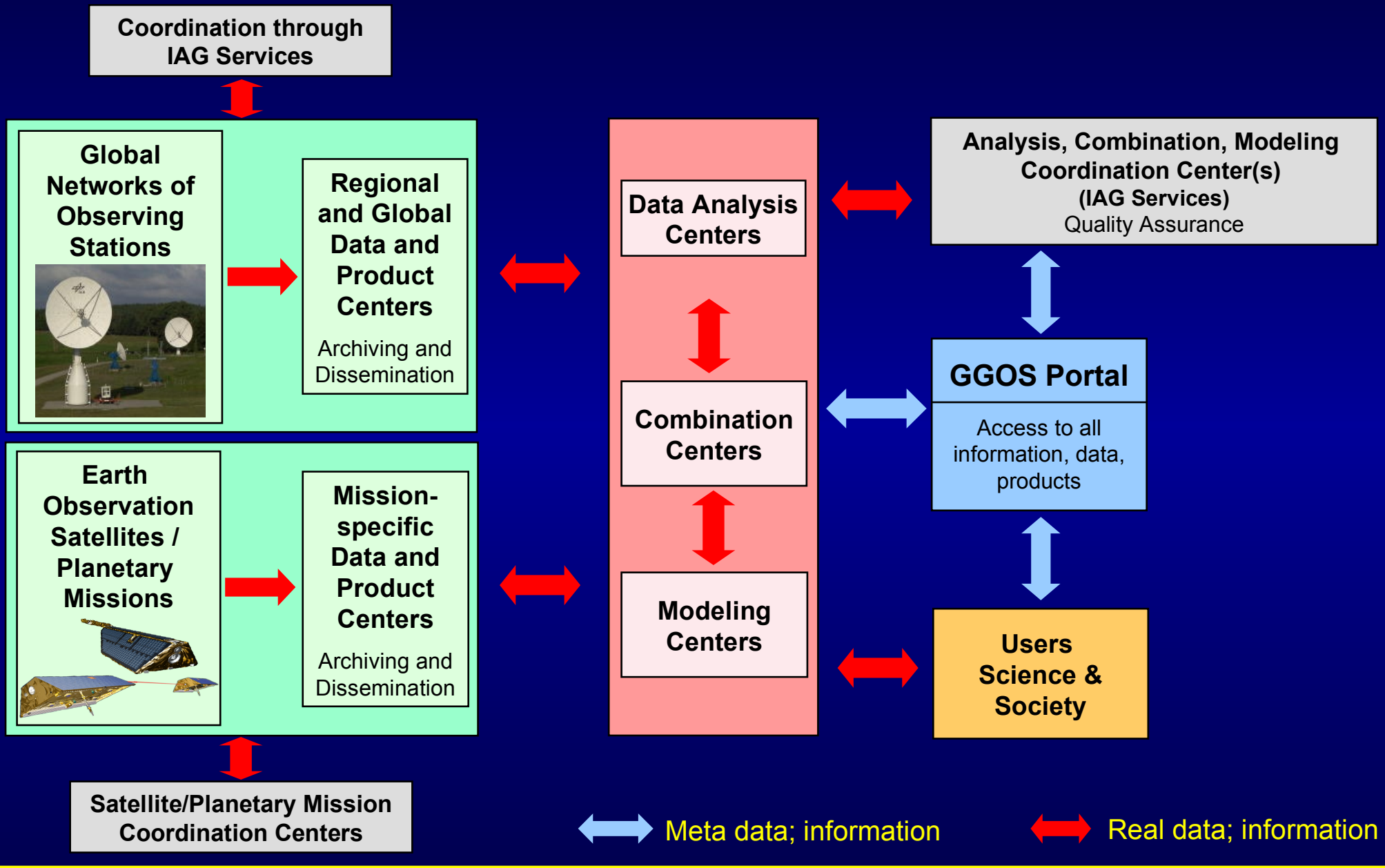
- **GGOS Portal:**

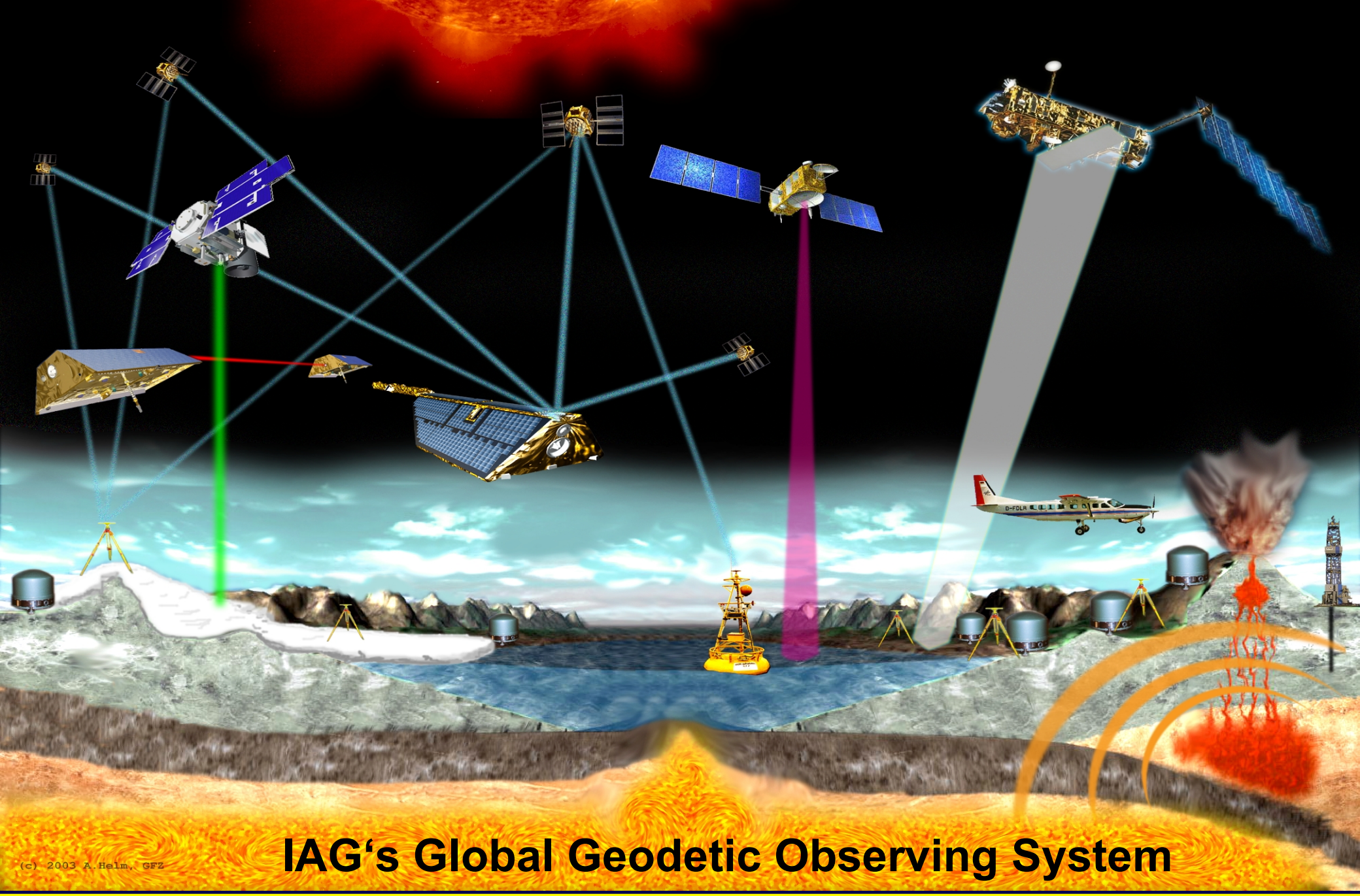
  A unique access point for all GGOS products with a database of relevant metadata according to international standards.

- **Data analysis, combination, modeling:**

  Complete and consistent data processing chains ranging from the acquisition and processing of vast amounts of observational data to its consistent integration and assimilation into complex numerical models of the Earth system.

# Structure of the Future GGOS





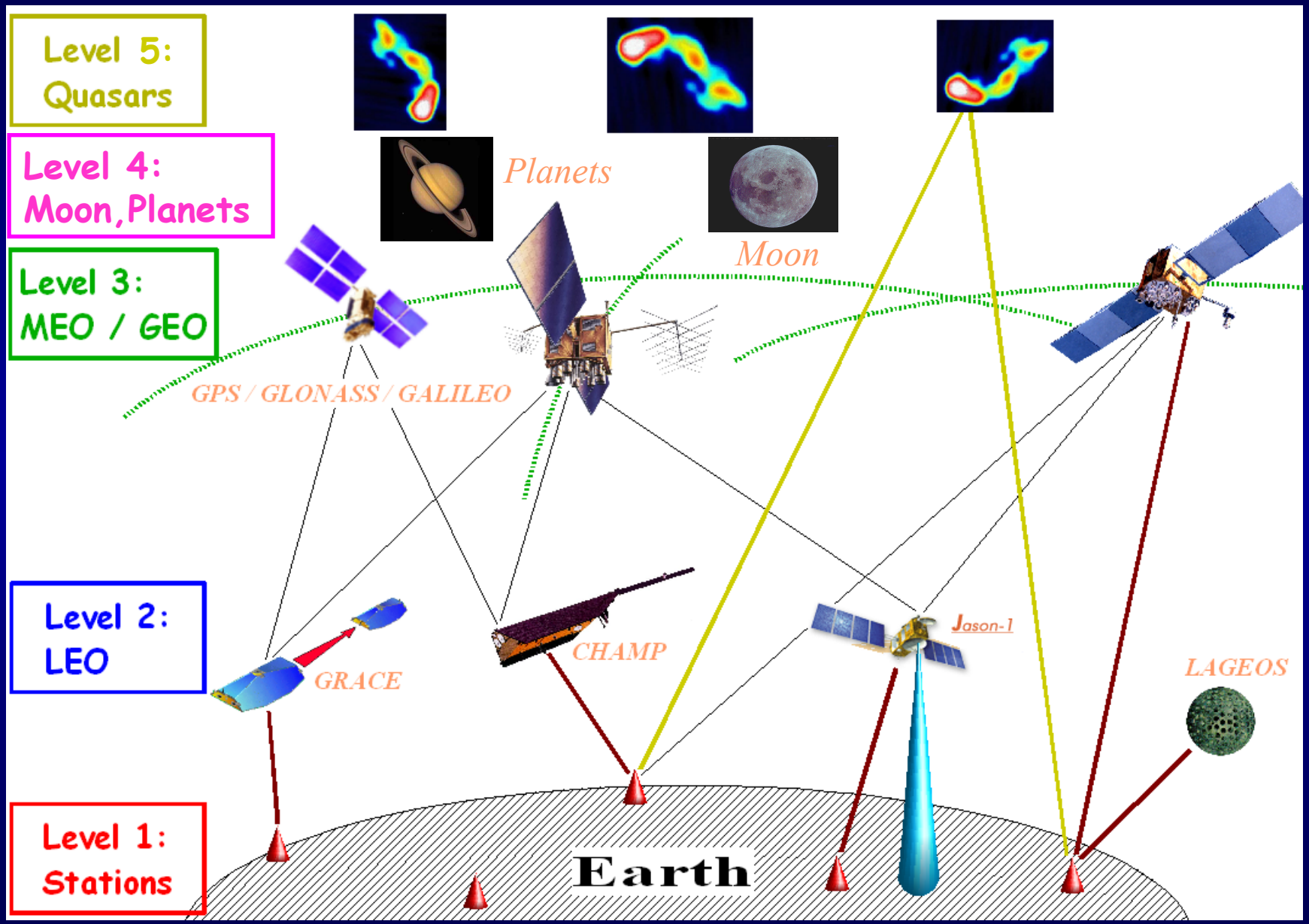

# IAG's Global Geodetic Observing System

# GGOS Instrumentation

**Five levels of objects** that are observing or are being observed in **GGOS**:

- **Level 1: the terrestrial geodetic infrastructure**
- **Level 2: the LEO (Low Earth Orbiter) satellite missions**
- **Level 3: the GNSS and the Satellite Laser Ranging (SLR) satellites**
- **Level 4: the planetary missions and geodetic infrastructure on planets**
- **Level 5: the stars and extragalactic objects**

# Integration of 5 Levels into a GGOS

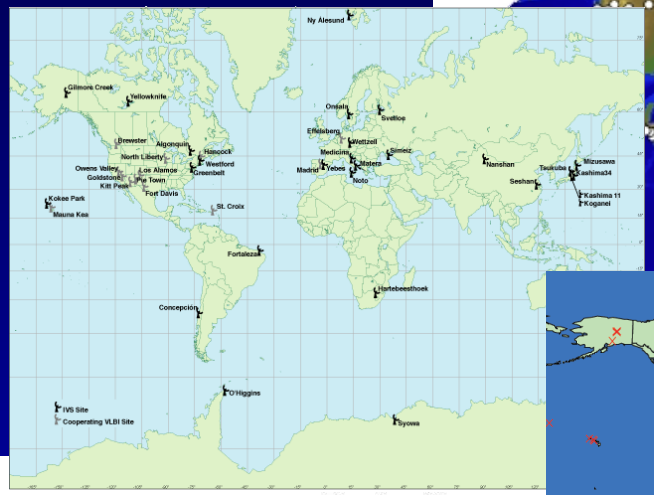




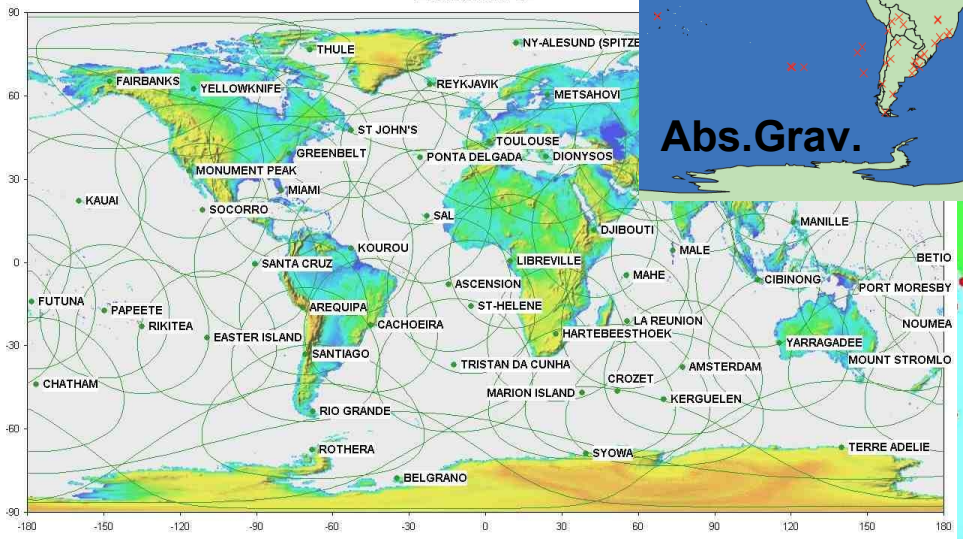

GGOS

# Level 1: Ground-Based Component

VLBI

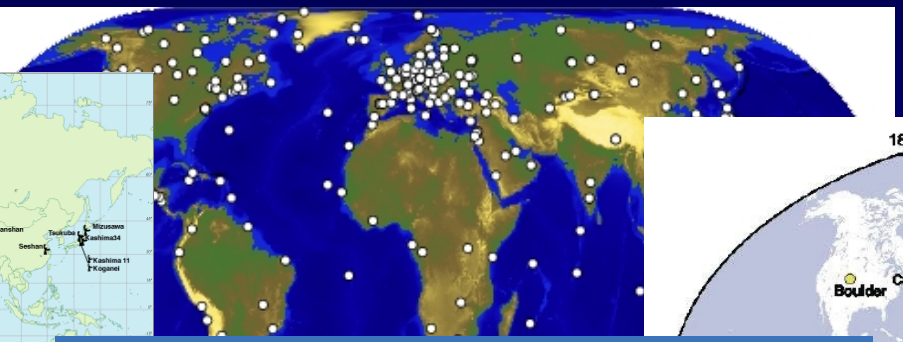



Elevation 12°

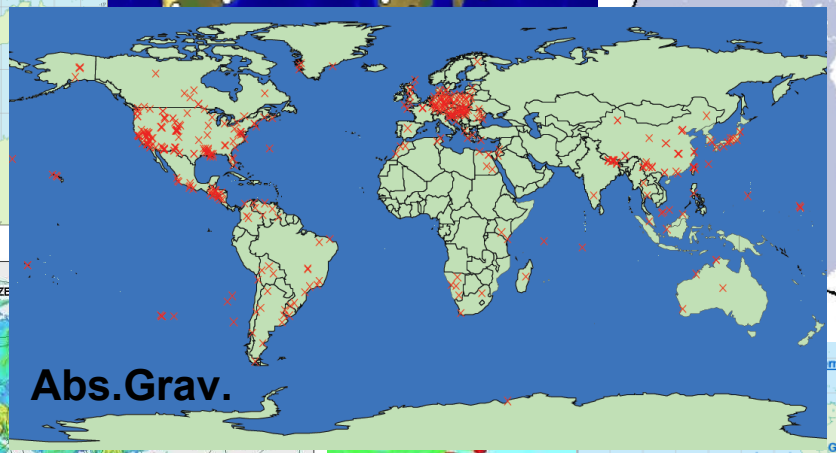



DORIS

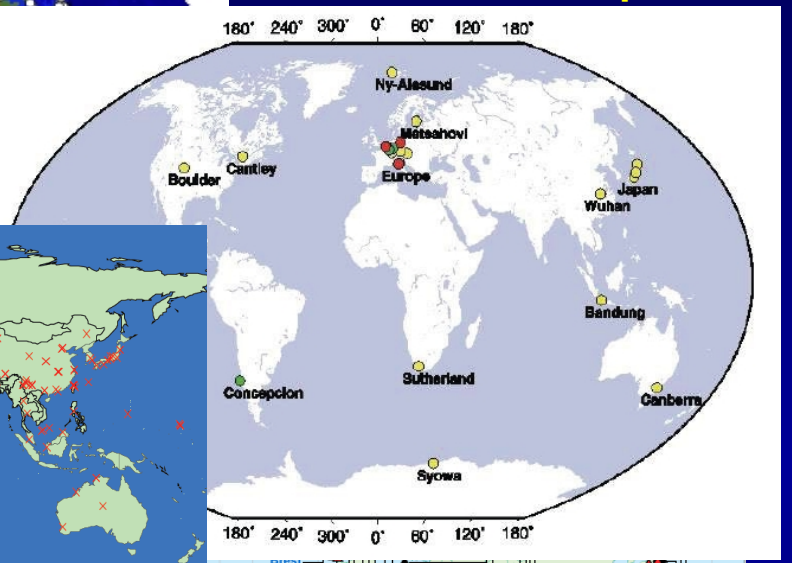
GPS

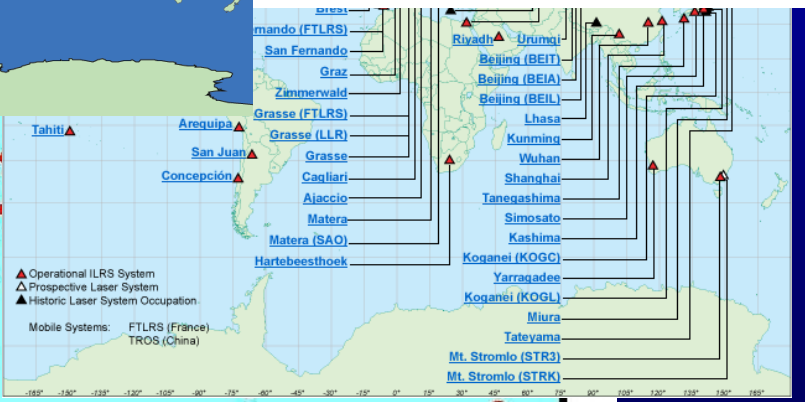


Abs.Grav.



Sup.Grav.




SLR/LLR






GGOS

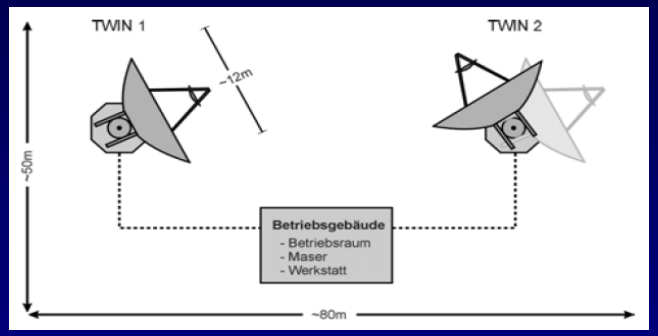
# Core Ground-Based Infrastructure

**Core Network (~ 40 Stations):**

- **2-3 VLBI telscopes** for continuous observations
- **SLR/LLR telescope** for trackoing of all major satellites
- At least **3 GNSS antennas and receivers** (controlled equipment changes)
- **DORIS beacon** of the most recent generation
- **Ultra-stable oscillator** for time and frequency keeping and transfer
- **Terrestrial survey instruments** for permanent/automated local tie monitoring
- **Superconducting** and **absolute gravimeter** (gravity missions, geocenter)
- **Meteorological sensors** (pressure, temperature, humidity)
- **Seismometer** for combination with deformation from space geodesy and GNSS seismology
- **Additional sensors**: water vapor radiometer, tiltmeters, gyroscopes, ground water sensors, …

**General Characteristics:** highly automated, 24-hour/365 days, latest technologies

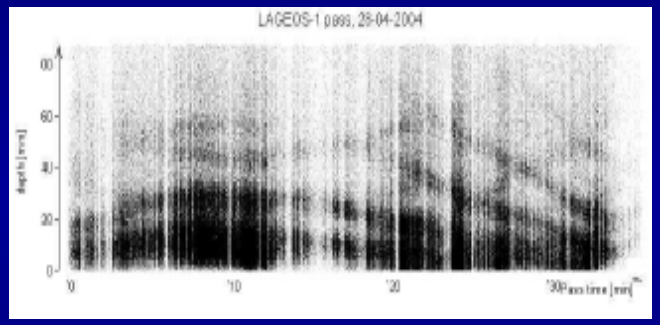
# Ground-Based Infrastructure: Innovation




**VLBI Twin Telescope (Wettzell)**

**VLBI:**

- High slew rates (> 5 deg/s)
- 1-3 small telescopes at a site
- Continuous frequency range (2-18 GHz)




**kHz Laser: Lageos Spin (Graz)**

**SLR:**

- kHz laser technology
- 2 frequency systems
- Higher quantum efficiency

**DORIS Beacon (Thule)**

**DORIS:**

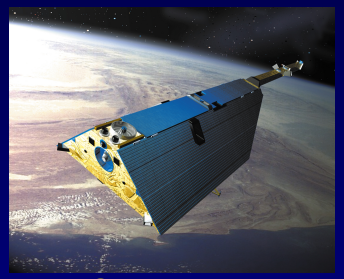
- 3rd generation DORIS systems

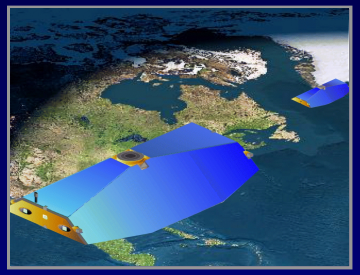
**Galileo Experimental Sensor Station (GESS)**

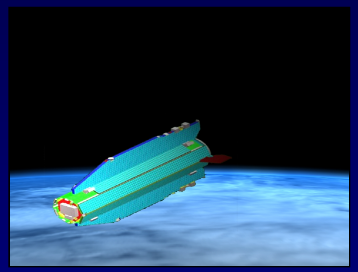
**GNSS:**

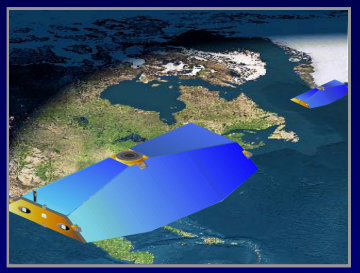
- GPS, Glonass,Galileo, Compass, …
- Sampling > 10 Hz
- Real-time
- 3 antennas/receivers

# Level 2: Satellite Mission Component

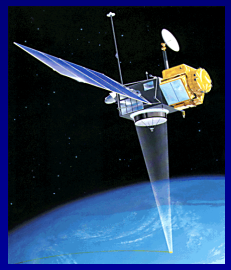

CHAMP

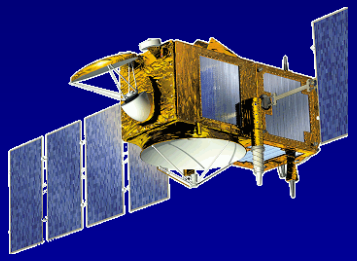

GRACE


GOCE


GRACE Follow-on ?

...

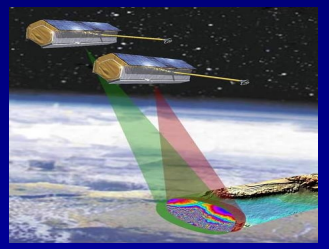

Topex/Pos.


JASON-1

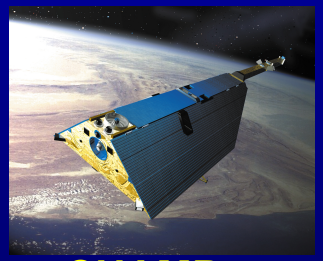

JASON-2

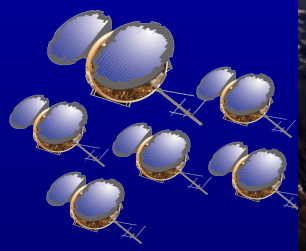
...


TerraSAR-X


TanDEM-X

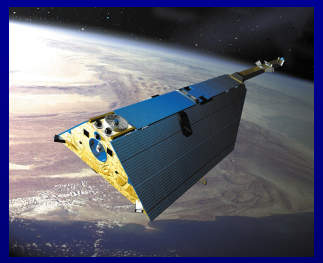
...


CHAMP


COSMIC


MetOp

...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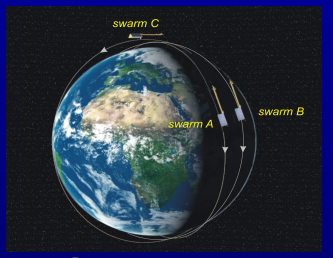
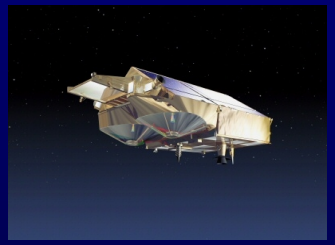


SWARM

...


IceSat-1

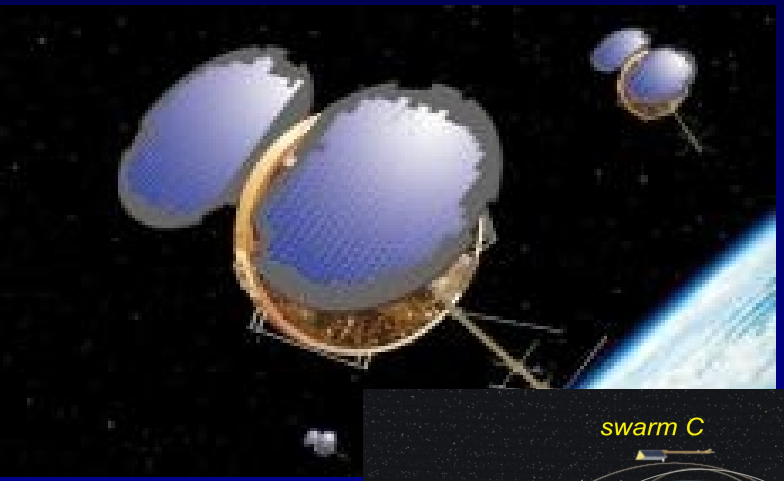

Cryosat-2

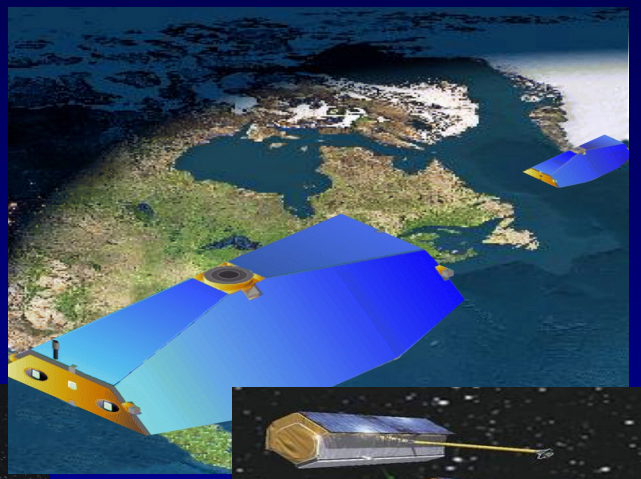

IceSat-2

...

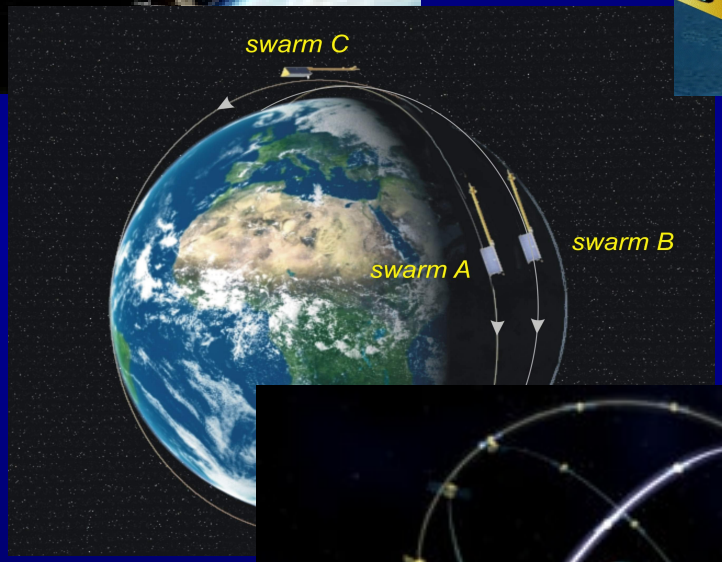
... and new mission concepts

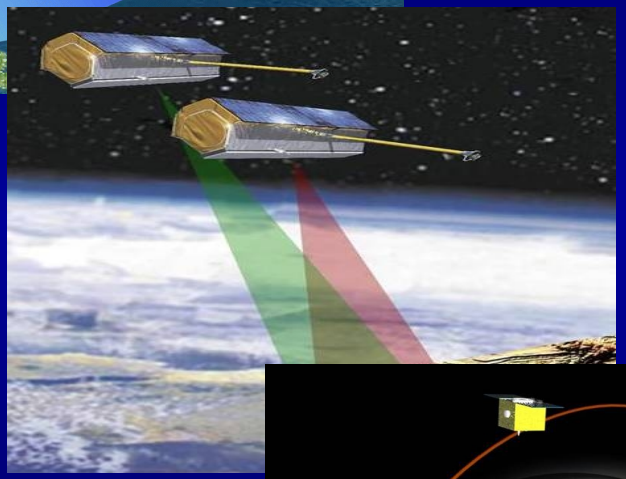
# New Mission Concepts: Constellations and Formations

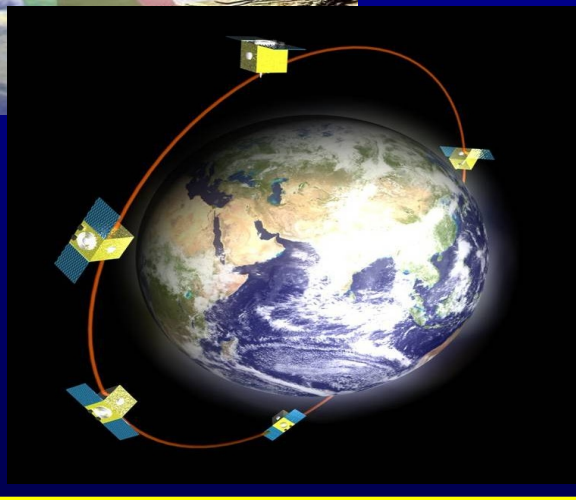




Formation flying, swarms

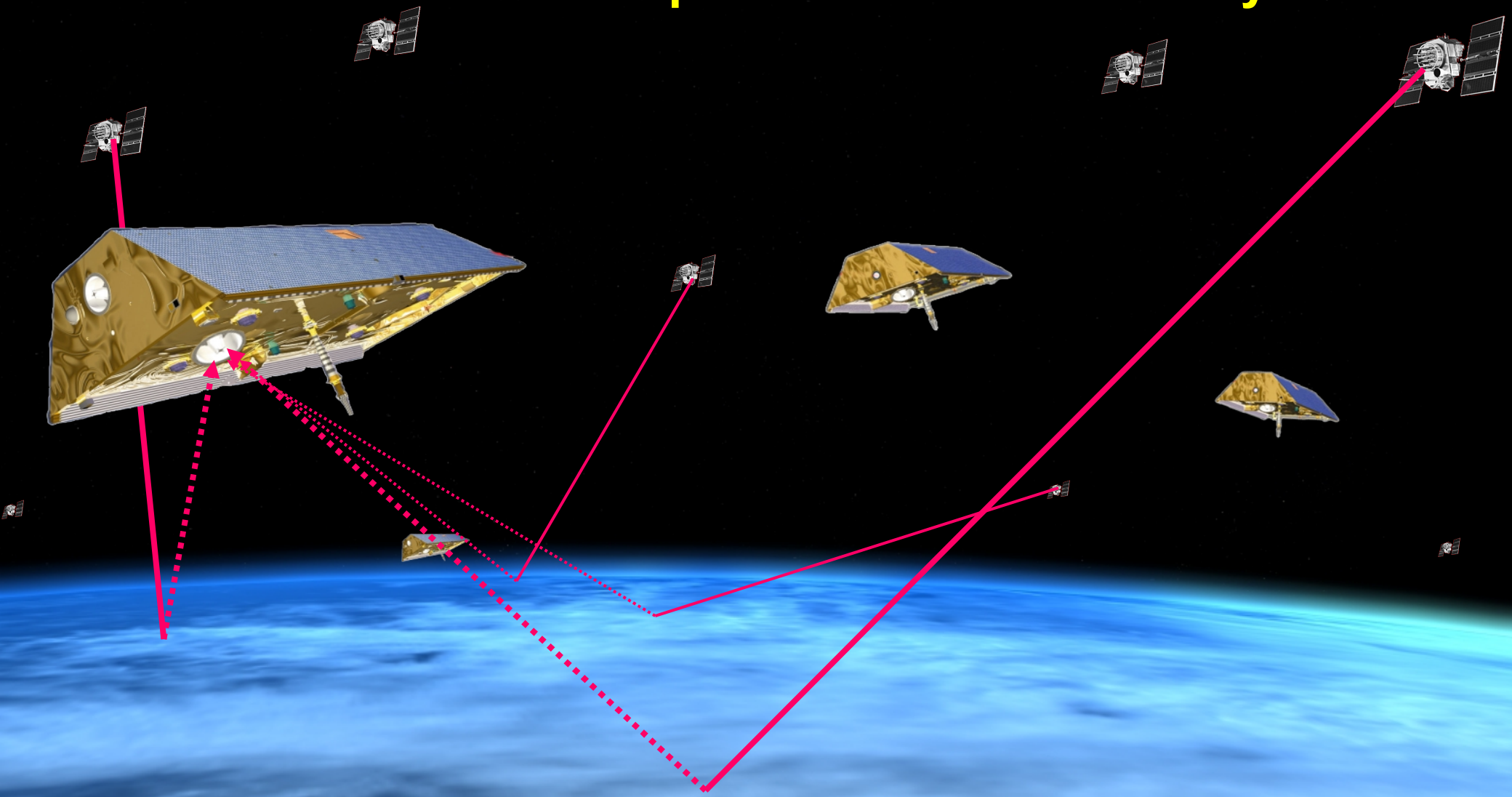




Satellite Constellations

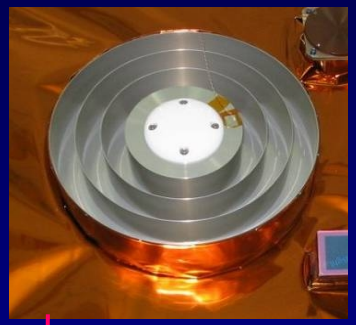
# New Mission Concepts: GNSS Reflectometry



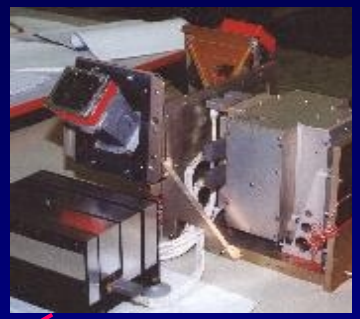
**Future satellite constellation as a component of a Multi-Hazard Early Warning System ?**

# New Mission Concepts: Co-location Micro-Satellite(s)

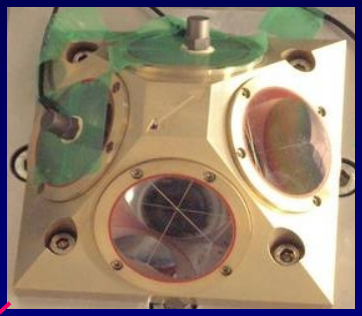

RO Antenna



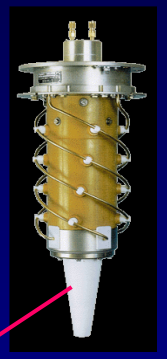
POD Antenna



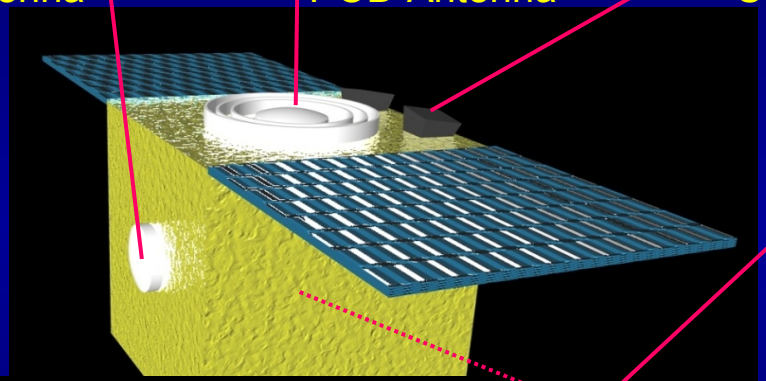
Star Sensors



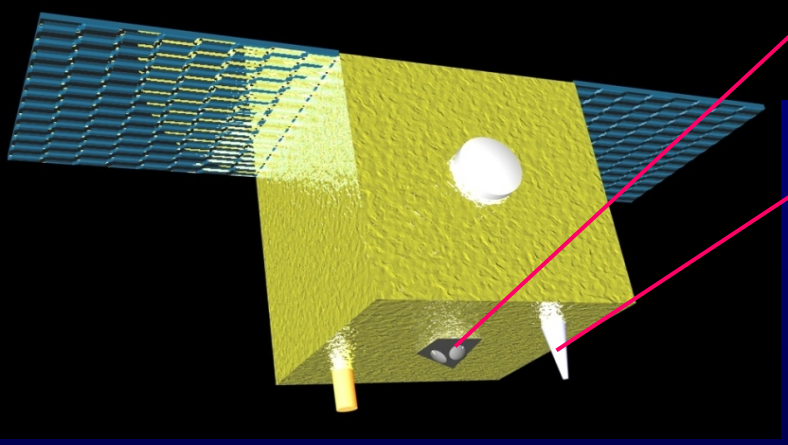
SLR Retro-Reflector

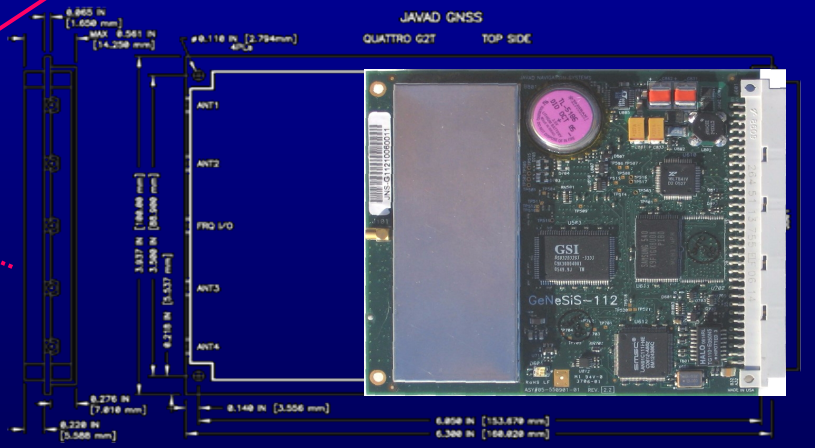


VLBI Sender



Mini-Satellite






3 GPS Receiver Board (Redundancy)



GGOS

# Level 2: LEO Satellite Missions

**Satellite Missions:**

- Continuous observations over **decades**, long time series (trends)
- **Chains of satellite missions** (altimetry, gravity, InSAR, …)
- **Constellations** of satellites (COSMIC, SWARM, …), micro- and nano-satellites
- **Formation flying**: several satellites forming “one large instrument”
- **Near real-time** data transfer (inter-satellite comm.) and analysis (early warning systems)
- Development of **new sensors** and technologies (e.g., GNSS reflectometry and scatterometry, laser interferometry between satellites with nm, ultra-stable optical clocks in space with $10^{-18}$)
- Satellites allowing **co-location** of space geodetic techniques (GNSS receiver , SLR retroreflector, VLBI emitter, gradiometer; SLR on GNSS satellites, VLBI in space, transponders on planets, …)

# Level 3, 4, 5: GNSS + Extraterrestrial

**GNSS and SLR Satellites:**

- More than 100 GNSS satellites in 2020: GPS (24/32) , GLONASS (24/19), GALILEO (30/1), QZSS (3), COMPASS (1), …
- Cheap LAGEOS-type satellites with laser retroreflectors and with GNSS receivers forming a network in space with internally 1 mm accuracy (distances up to 14’000 km)

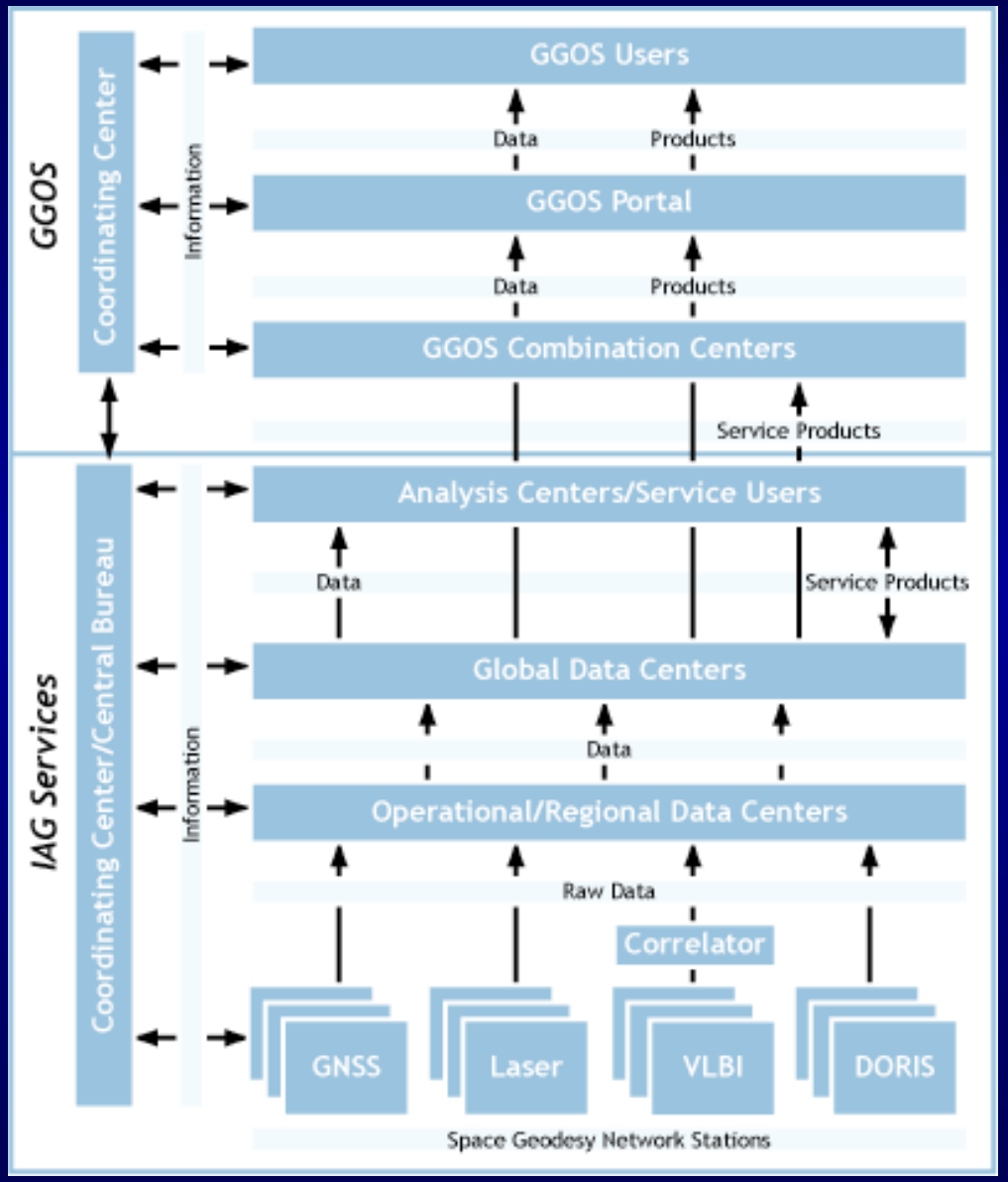
**Geodetic Planetary Missions:**

- Bepi Colombo, Mars missions, lunar exploration, …

**Stars** (observed with CCD cameras or in future with GAIA)

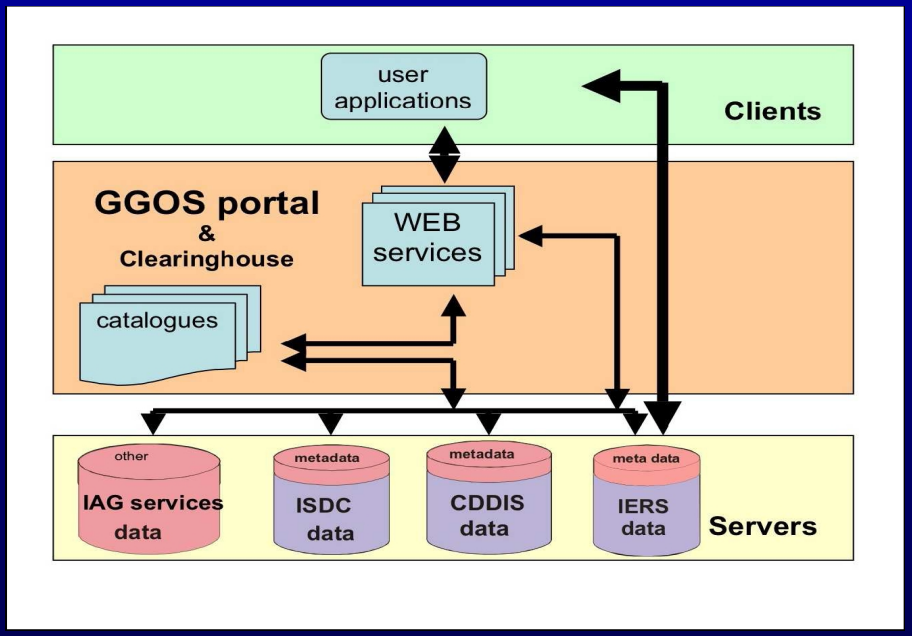
**Quasars**

# GGOS Data Flow and Portal

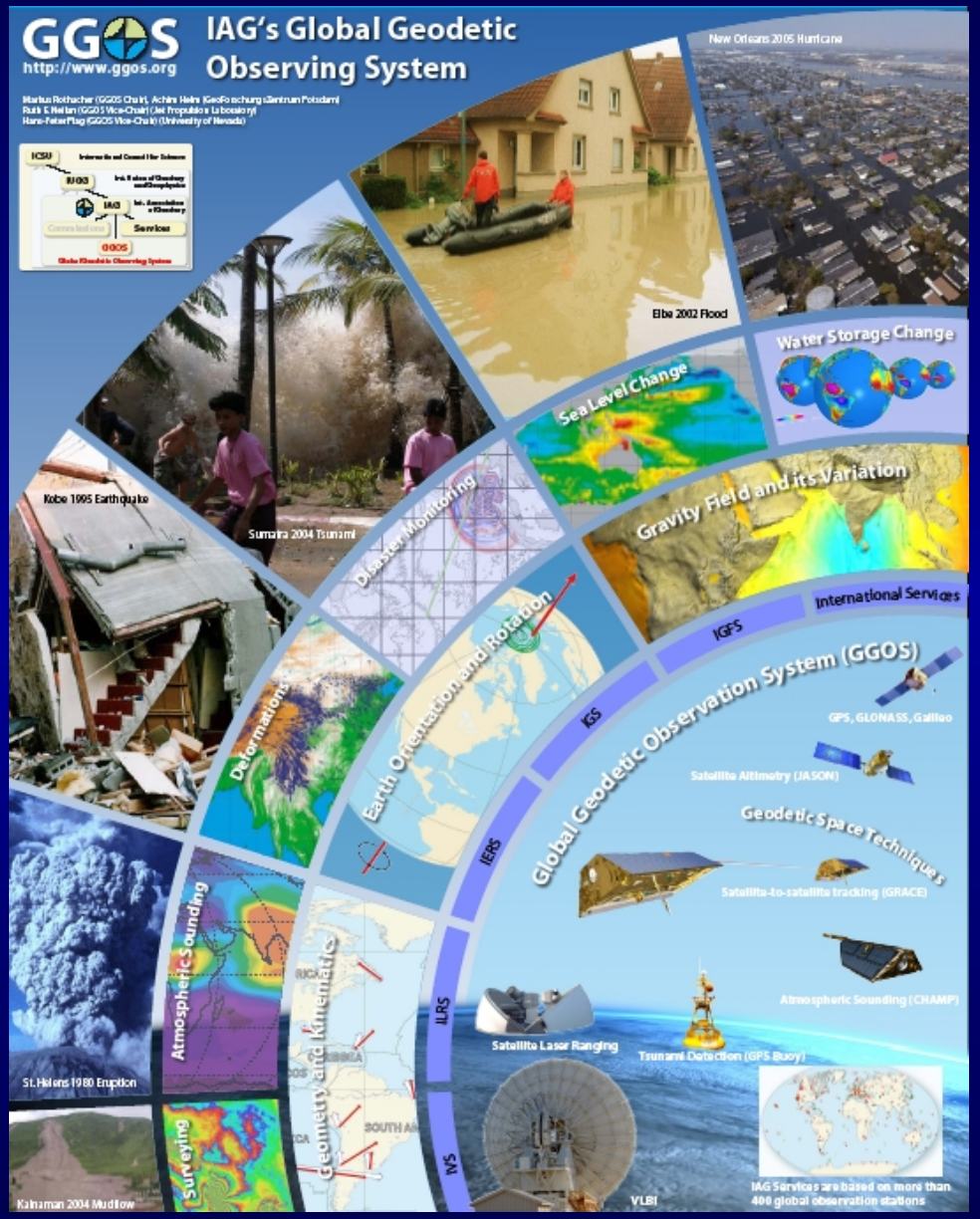



## Network Synergies:

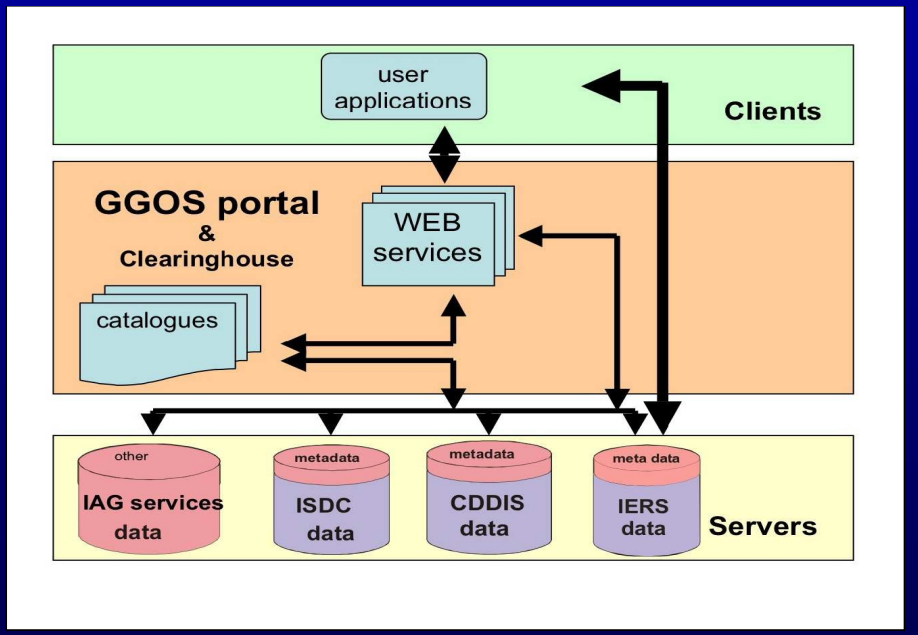
- Common data communica-tion and infrastructure for all techniques (archiving, …)
- Real-time data transfer
- New communication technologies for remote areas



# GGOS Portal




- One access point (entry door) for all geodetic products relevant in the frame work of GGOS
- Access not to the products themselves, but to the meta data. The products are available at the individual services data centers.
- Start with the burning questions of society and lead the way from there to the products, their characteristics, location, availability, latency, accuracy



# Processing, Analysis, Combination

**Processing and Analysis:**

- Fully automated processing in near real-time or even in real-time (early warning systems, GNSS seismology, atmosphere sounding, …)
- Full reprocessing capabilities for all data available, long consistent time series for long-term trends
- Combination of all data types on the observation level
- Combination with LEO data (co-location, gravity, geocenter, atmosphere, …)
- Combination with satellite altimetry data (and with InSAR ?)
- Combination with terrestrial data (e.g. gravity field, …)
- Combination of different analysis centers (redundancy, reliability, accuracy, …)

**Improvements in modeling, parameterization, conventions**

**Supercomputers, visualization**

# GGOS: Future Combination Space

**Parameter space for a rigorous combination:**

| Parameter Type | VLBI | GPS/ GLON. | DORIS/ PRARE | SLR | LLR | Alti-metry |
|---|---|---|---|---|---|---|
| Quasar Coord. (ICRF) | X | | | | | |
| Nutation | X | (X) | | (X) | X | |
| Polar Motion | X | X | X | X | X | |
| UT1 | X | | | | | |
| Length of Day (LOD) | | X | X | X | X | |
| Coord.+Veloc.(ITRF | X | X | X | X | X | (X) |
| Geocenter | | X | X | X | | X |
| Gravity Field | | X | X | X | (X) | X |
| Orbits | | X | X | X | X | X |
| LEO Orbits | | X | X | X | | X |
| Ionosphere | X | X | X | | | X |
| Troposphere | X | X | X | | | X |
| Time/Freq.; Clocks | (X) | X | | (X) | | |

ICRF

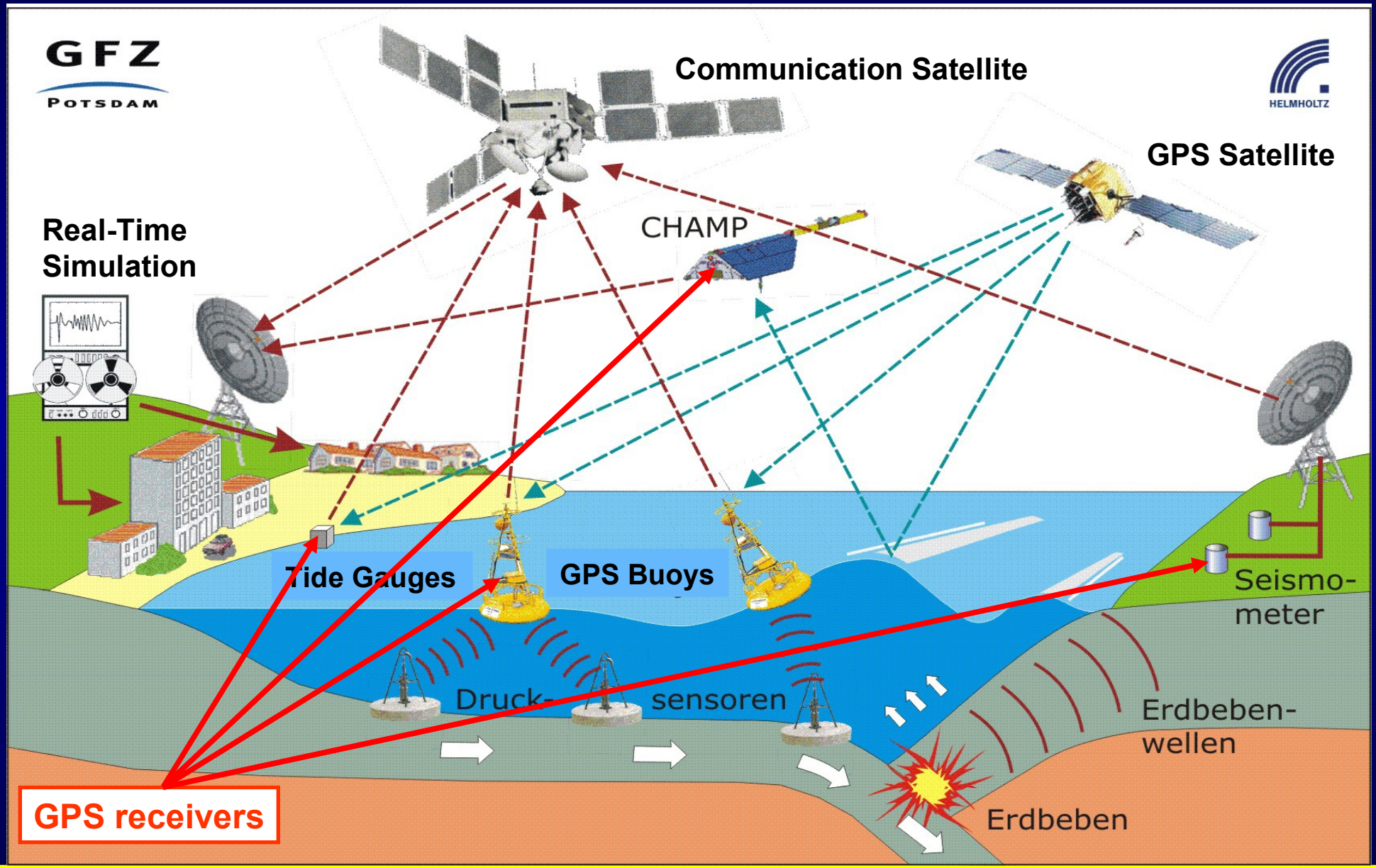
ITRF

Atmosphere

Earth Rotation

Gravity Field

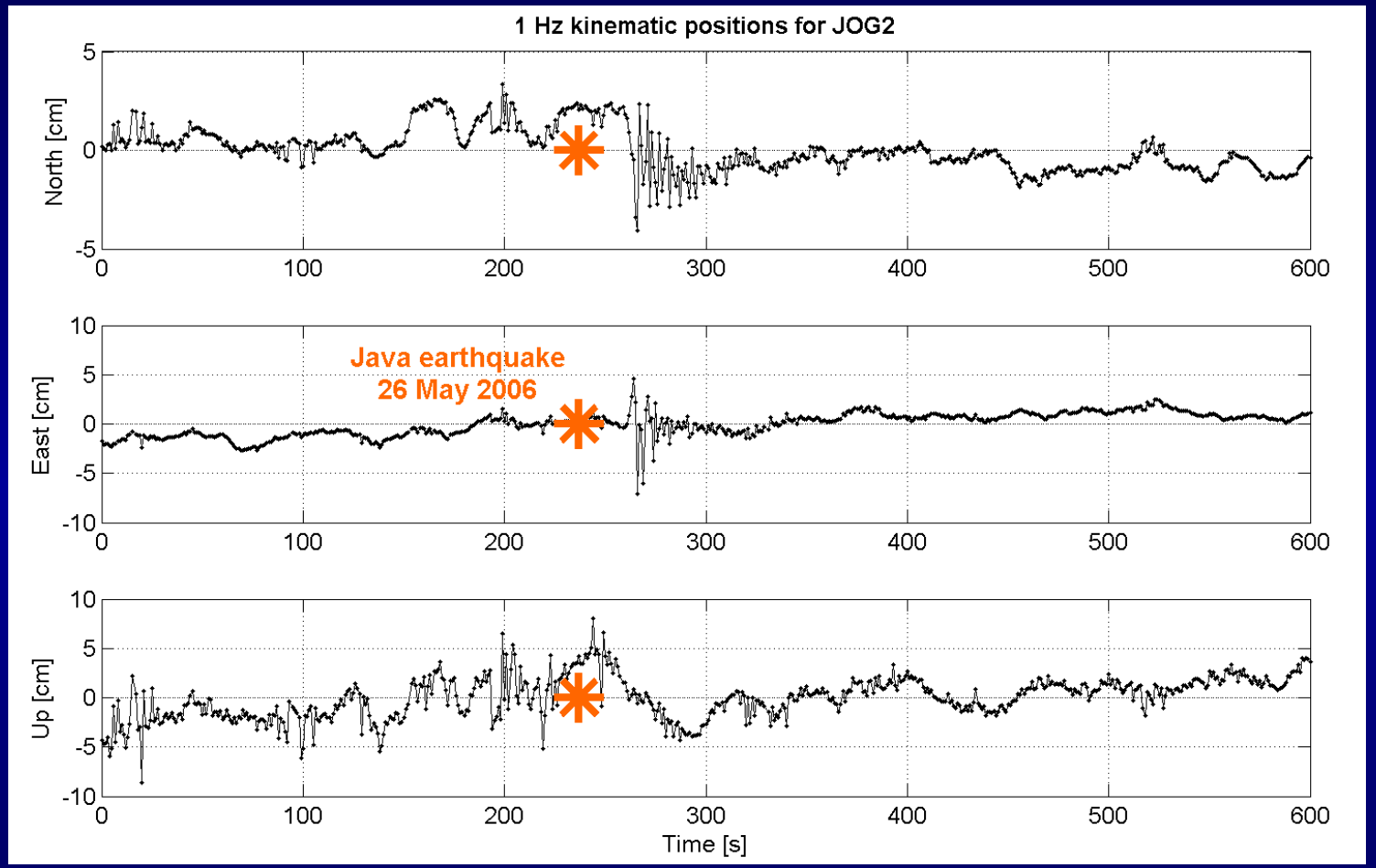
# Combination: Tsunami Early Warning System





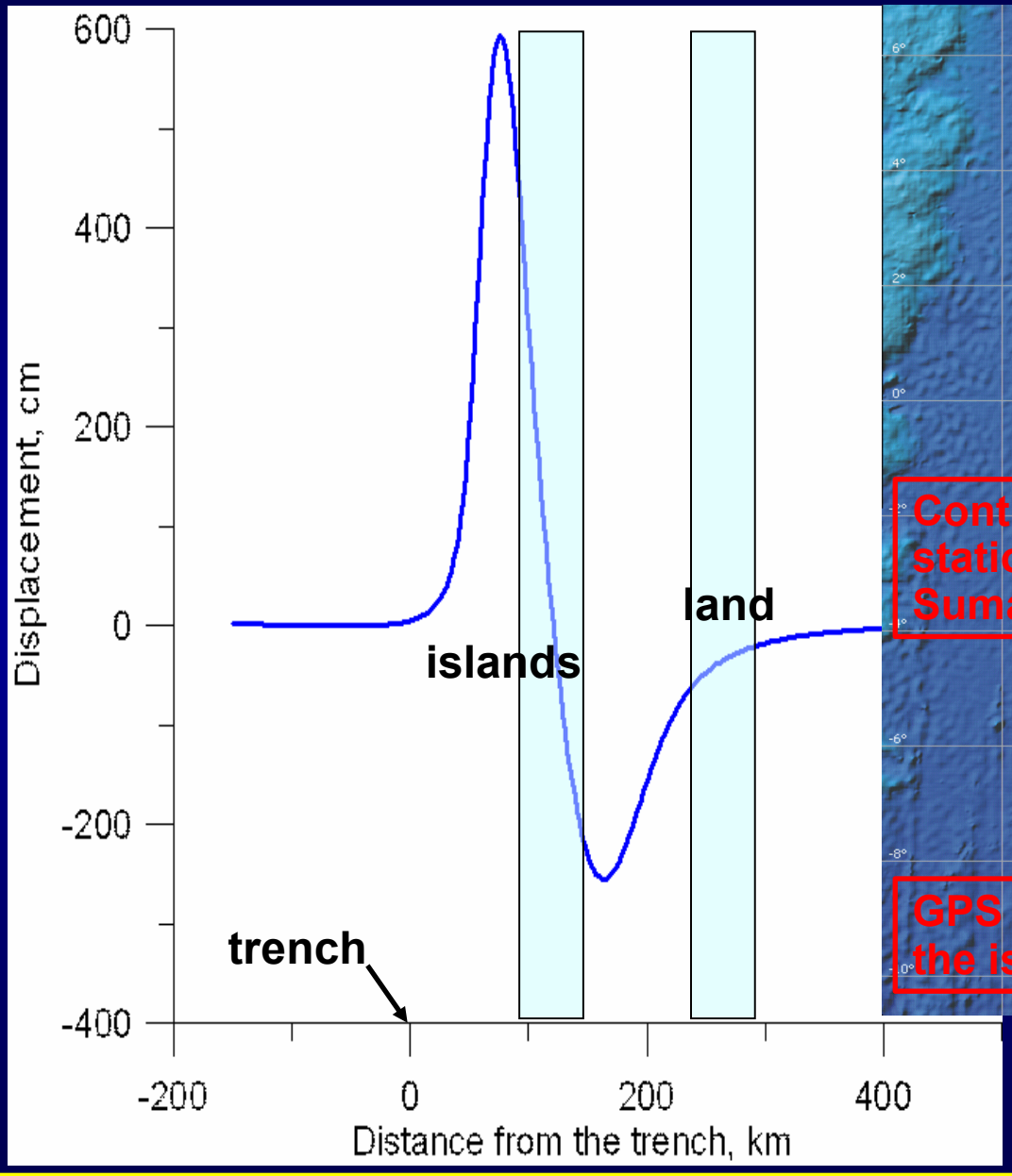

GGOS

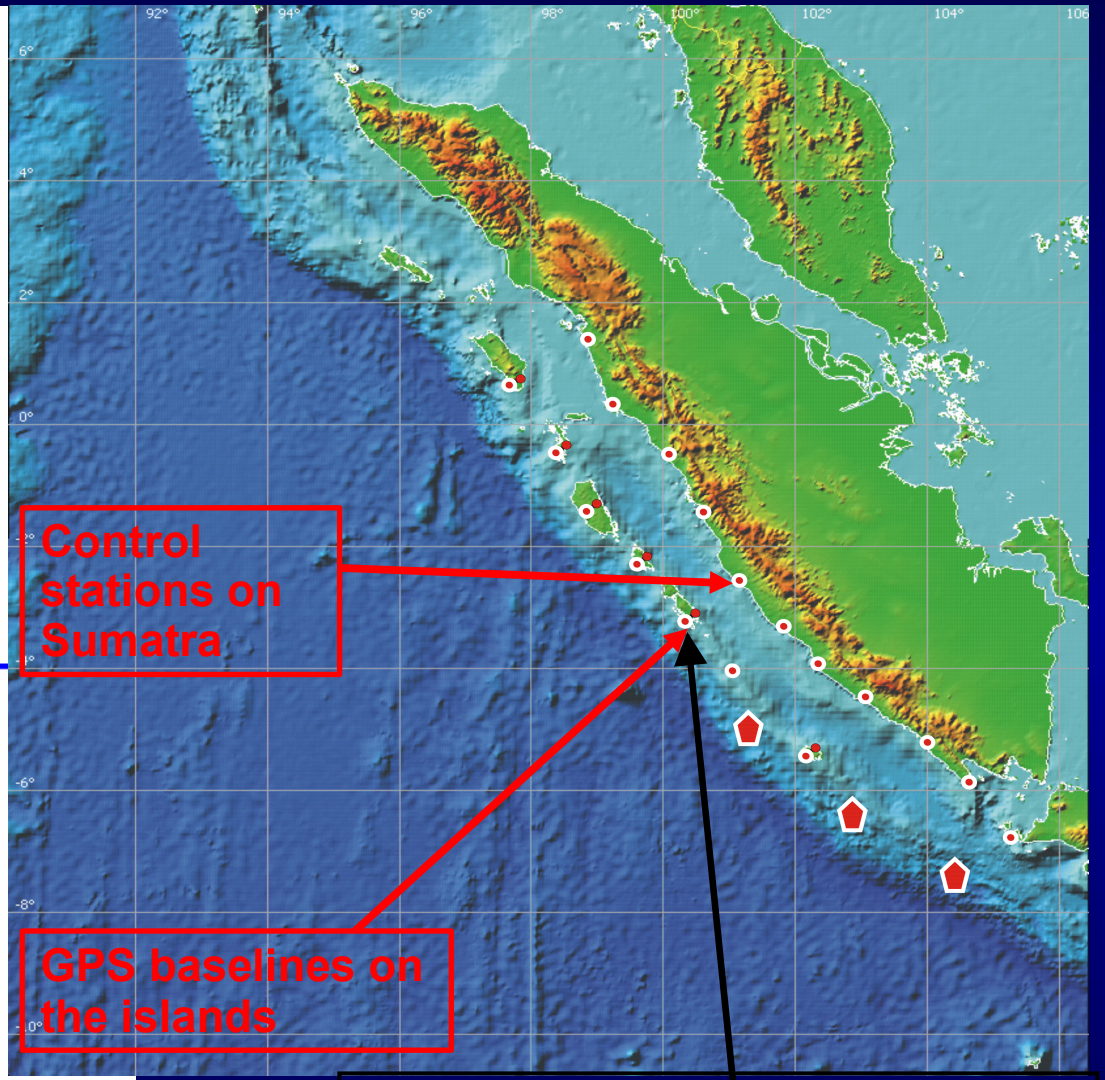
# Combination of Seismology / GNSS




- Earth`s motion during the earthquake
- Deformation due to the earthquake (magnitude determination, rupture process)

# Land Stations for a GPS Shield (Sobolev)



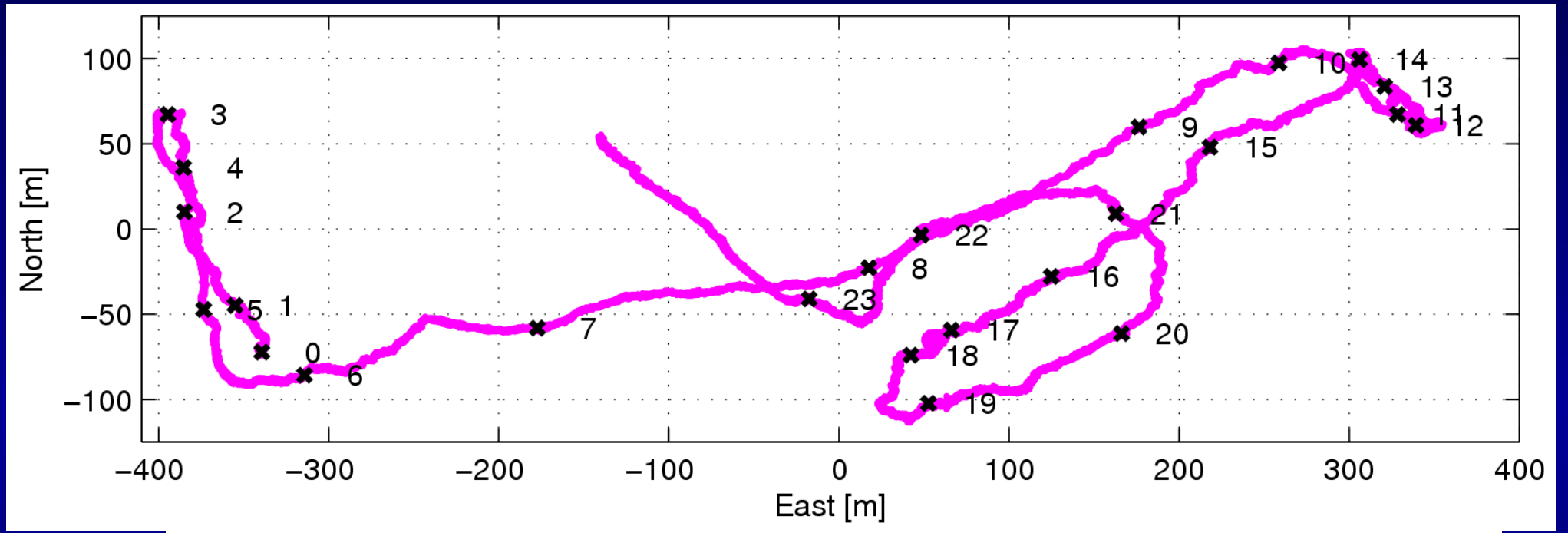



# Tsunami Buoy: GPS / OBPU / Seismometer

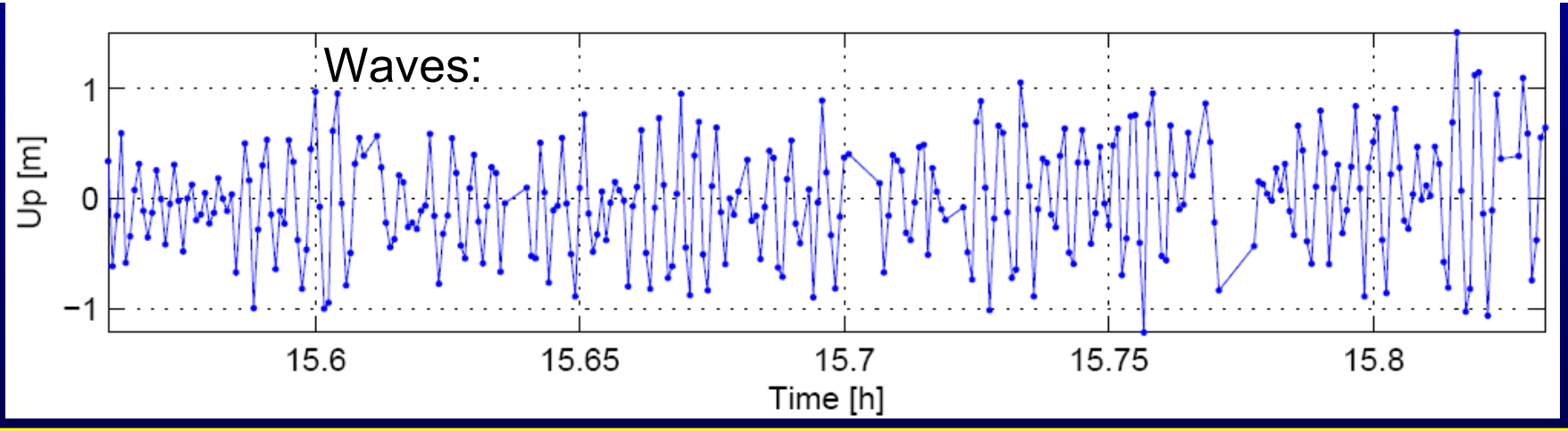


# GPS Tsunami Buoy: Motion

**Horizontal Position (Days):**




**Height:**



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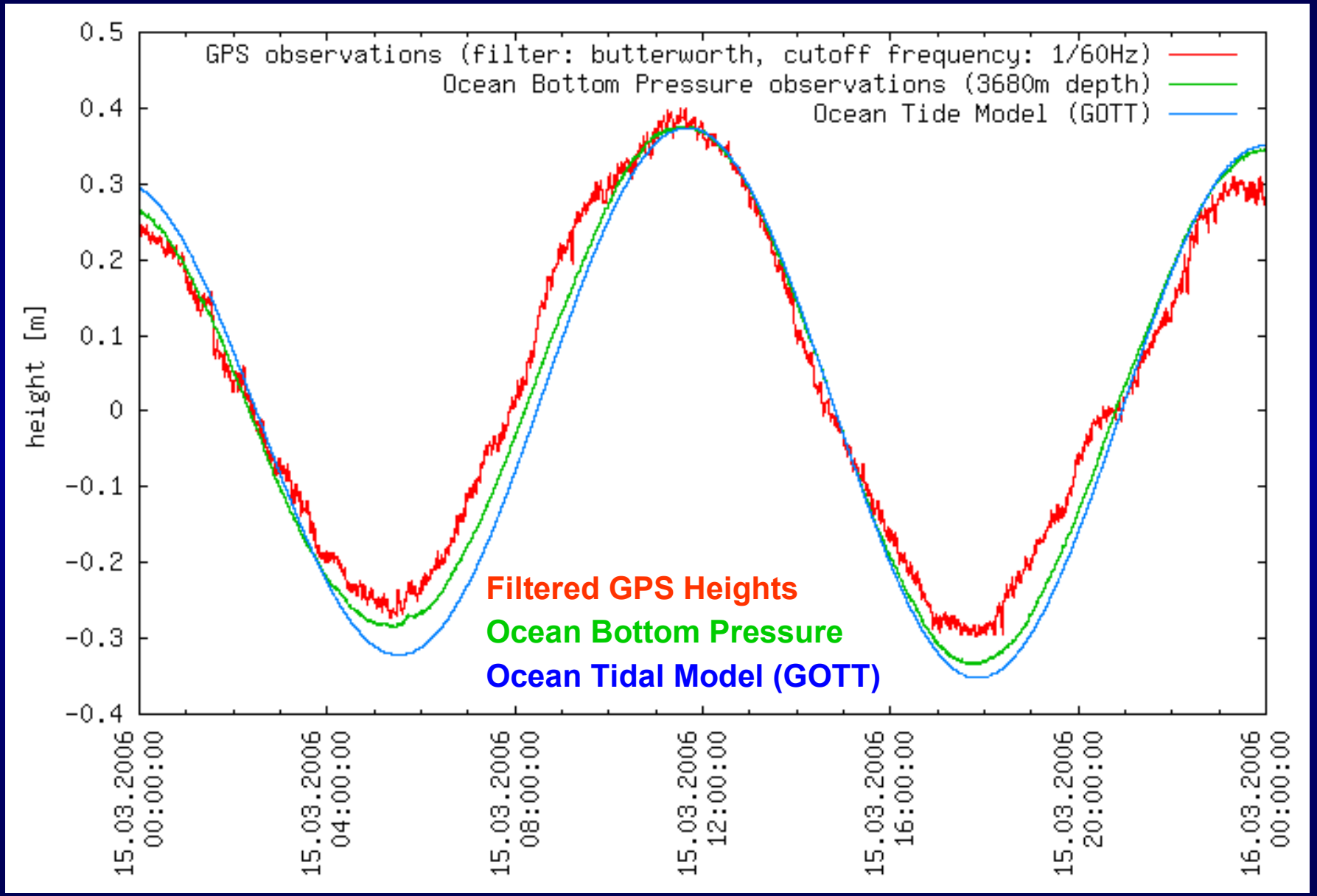
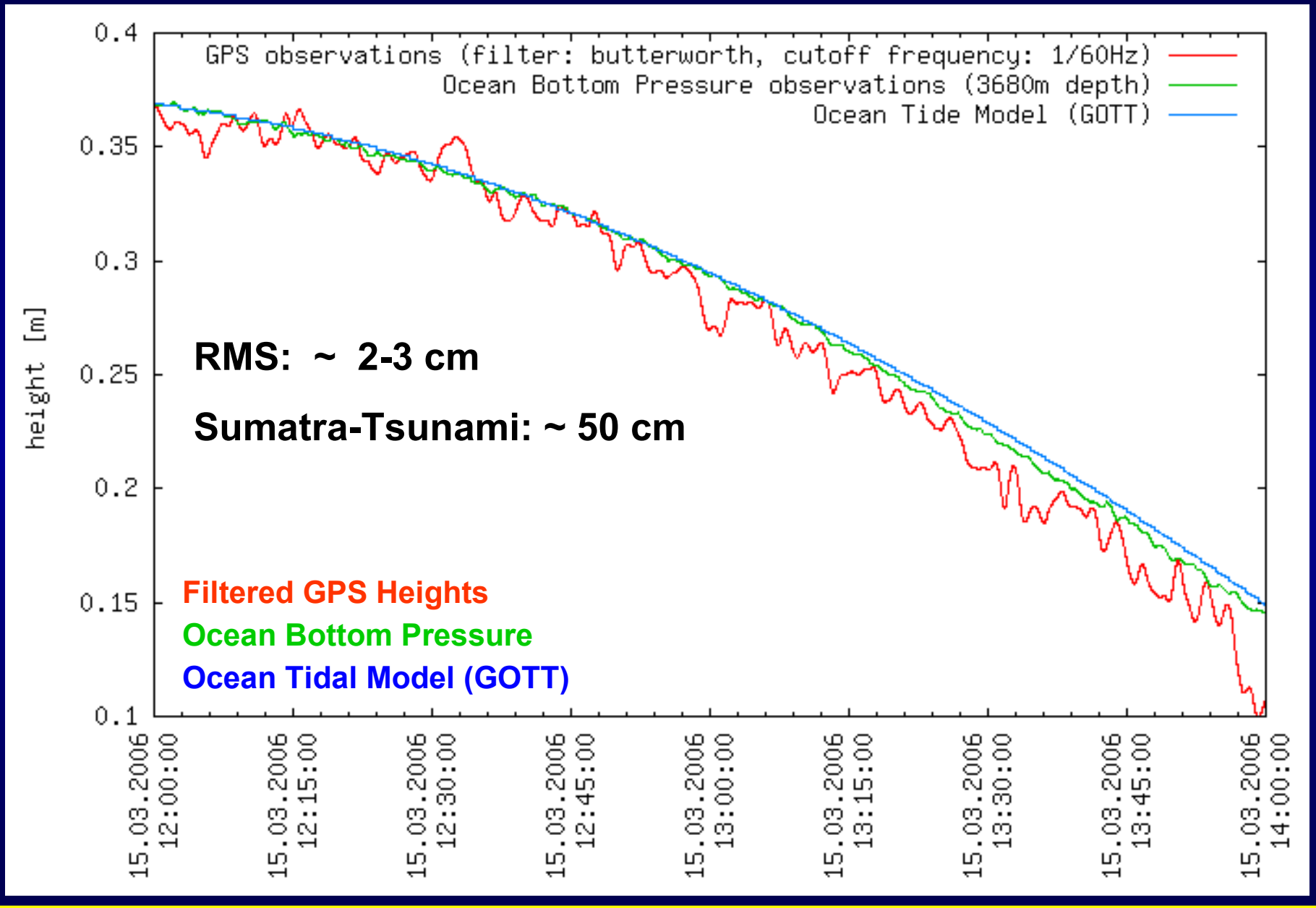
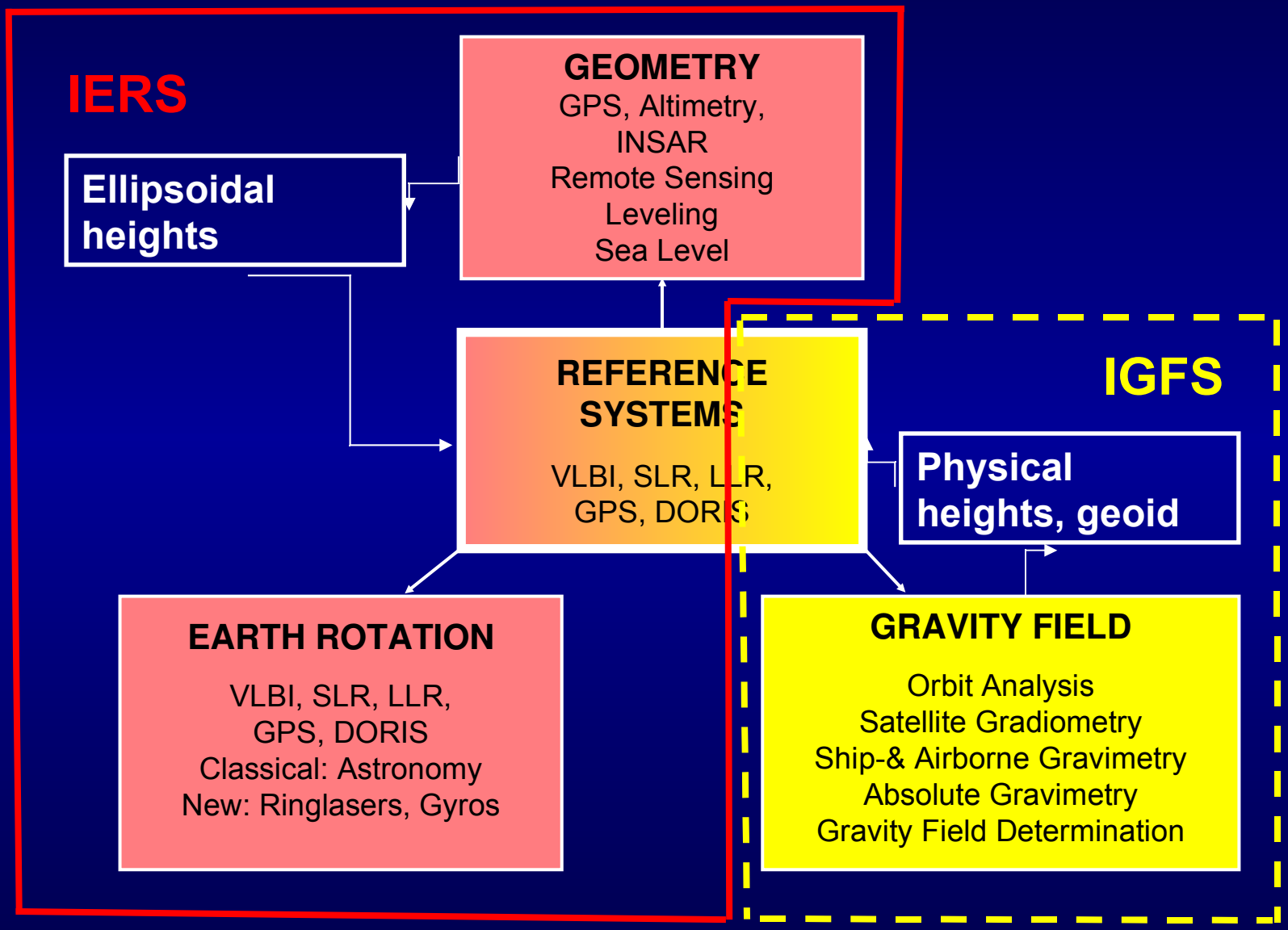
# Tsunami Buoy: Sea Level Height



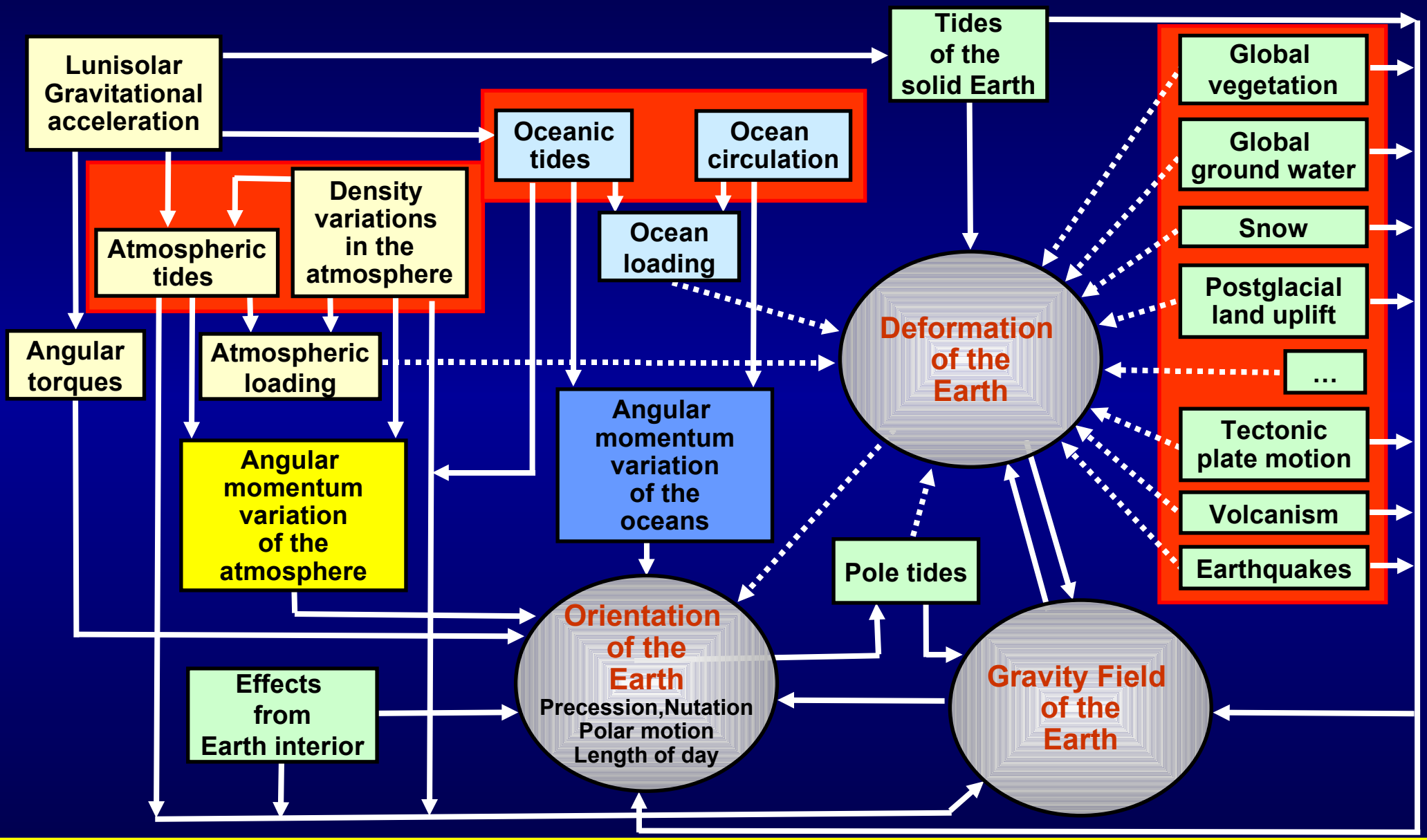
# GPS Tsunami Buoy: Sea Level Height



# Combination of Geometry and Gravity (IERS/IGFS)



# Earth System Modelling



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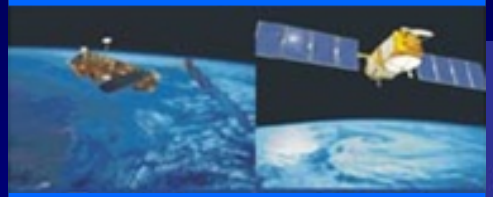
# Example: Sea-Level Change & Ice-Mass Balances

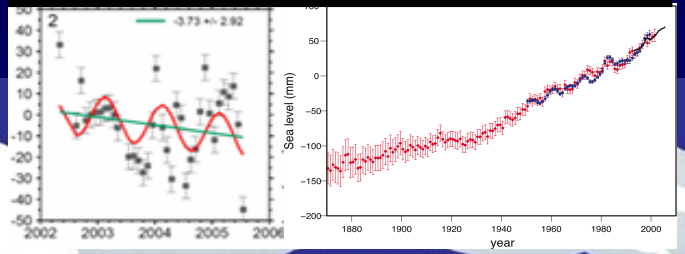
## Altimetry missions

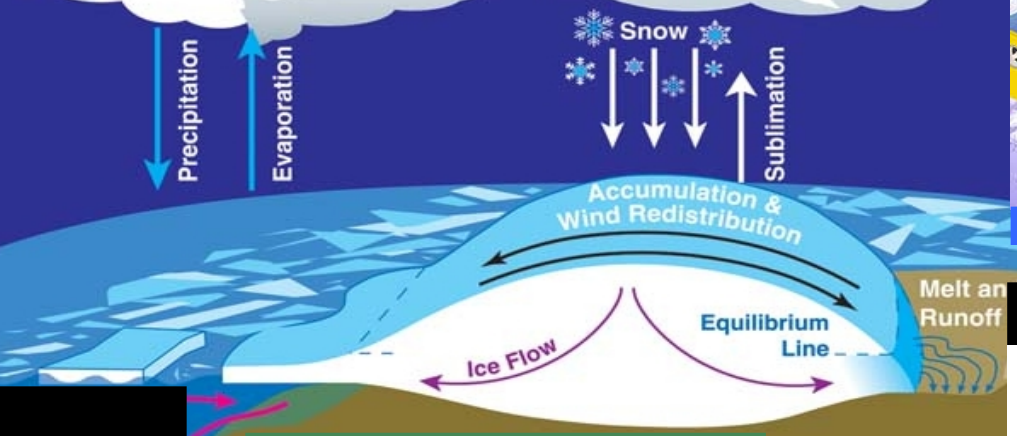


Envisat Jason-1

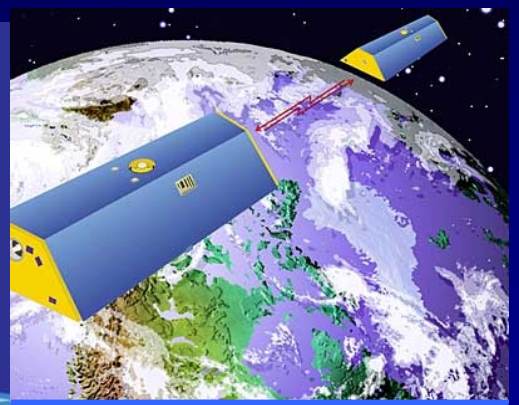
ICESat CryoSat II

## Data processing




## Gravimetry missions



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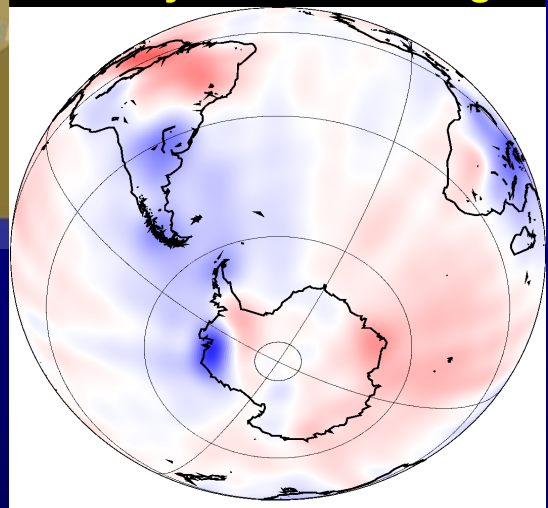
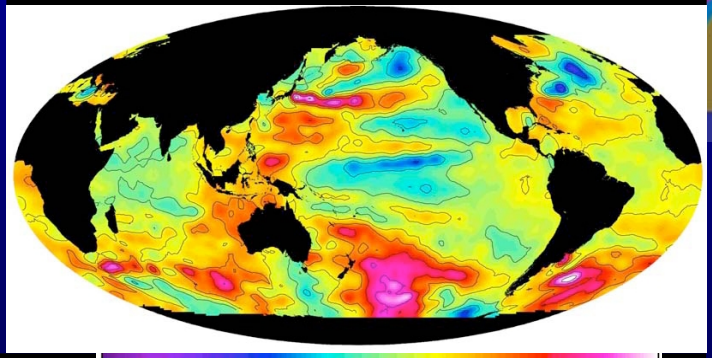
## Geodynamic modeling




Geoid change (mm/a)

## Ocean modeling




Sea-level change (mm/a)

## Terrestrial networks

Tide gauge GPS

Glacial-isostatic adjustment



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# Conclusions

- Geodesy can contribute significantly to the monitoring and understanding of the Earth system
- Integration of a multitude of different and innovative sensors on the ground and in space into a GGOS
- Complete and consistent data processing chains ranging from the acquisition to the processing of vast amounts of observational data
- Combination and assimilation of the geodetic/geophyiscal parameters into complex numerical models of the Earth system
- This will finally allow the understanding and prediction of the processes in the Earth system for the benefit of human society.