The Global Geodetic Observing System and the Global Geophysical Fluid Center

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with many contributions from other GGOS Activists

The Global Geodetic Observing System (GGOS) and the Global Geophysical Fluid Center (GGFC)

My Goal:
Underline the importance of the GGFC for GGOS

The Global Geodetic Observing System (GGOS) and the Global Geophysical Fluid Center (GGFC)

My Goal:

Underline the importance of the GGFC for GGOS

&

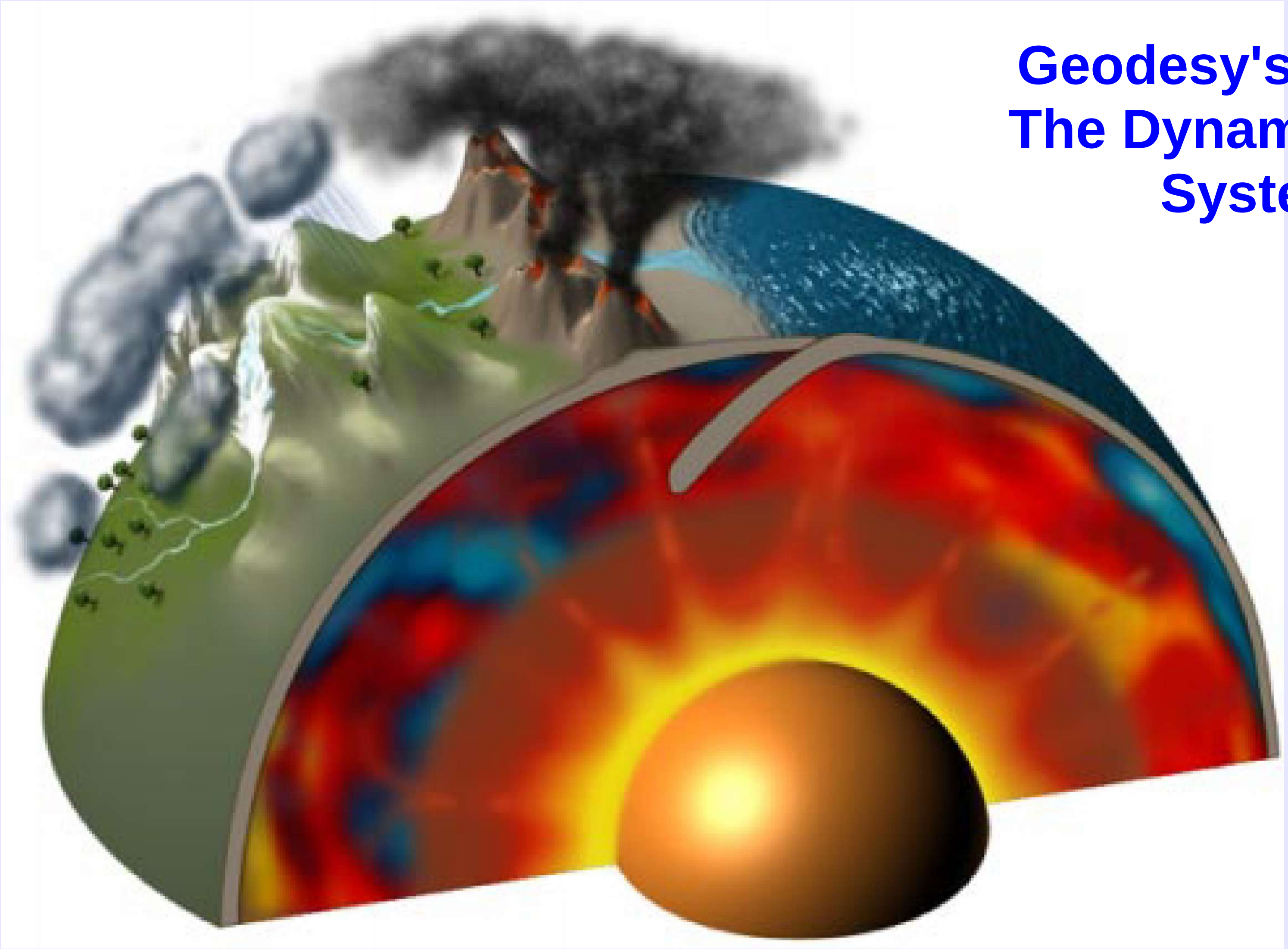
Develop a vision for the GGFC

- Brief historyof GGOS
- Geodesy's Contribution to Earth System Monitoring
- Concise introduction to the Global Geodetic Observing System
- Some words on interaction of GGOS with GEO and IGOS-P
- GGOS 2020: the strategy process
- The Earth System Dynamics Theme
- GGFC's role in and contribution to GGOS

Brief History of GGOS

- **First Steps** during IUGG **1995** in Boulder, USA.
- **Initial IAG Symposium in 1998** “Towards an Global Geodetic Observing System” in Munich, Germany.
- **IGGOS established** at 23-rd IUGG General Assembly, **2003** in Sapporo, Japan; supported by IUGG Resoution.
- Name changed to **GGOS** at first Meeting in April **2004**, Nice, France.
- IAG accepted as **Participating Organization in GEO** at EOS-II, April **2004**, Tokyo, Japan.
- First presentation of a geodetic **“Dynamic Earth” Theme** proposal at IGOS-P-12, June **2004**, Rome, Italy.
- **GGOS 2020** Strategy Process started in May **2006**.
- GGOS awarded **membership in IGOS-P** at IGOS-P-13, May **2006**, Geneva, Switzerland. Asked to prepare a “Earth System Dynamics” Theme

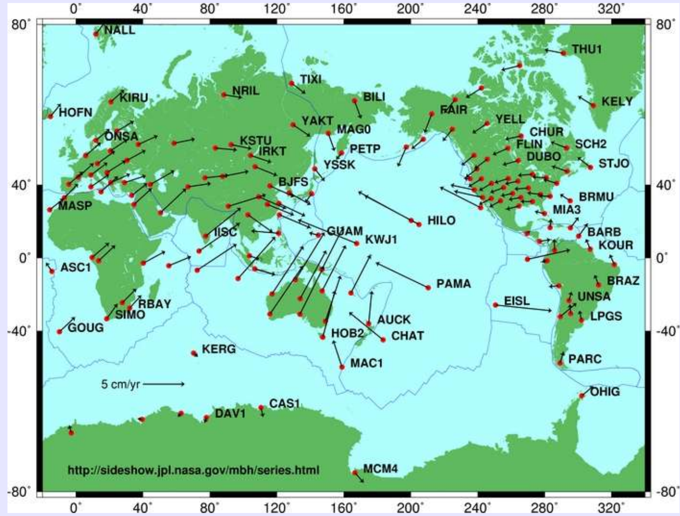
Geodesy's Contribution to Earth System Monitoring



Geodesy's Object: The Dynamic Earth System

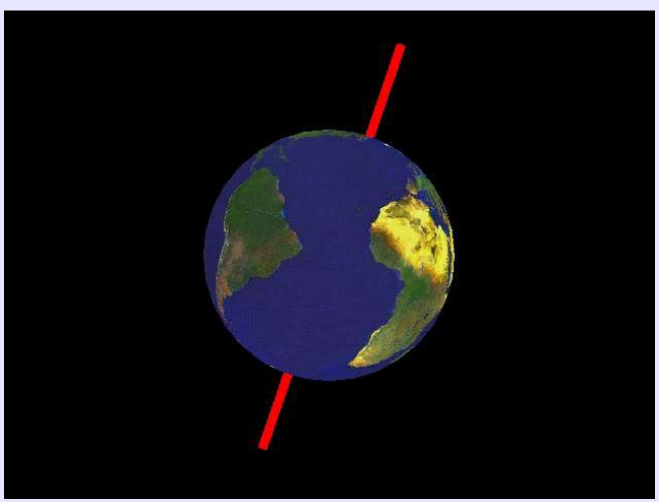
NASA Solid Earth Science Working Group report

Geodesy's Contribution to Earth System Monitoring

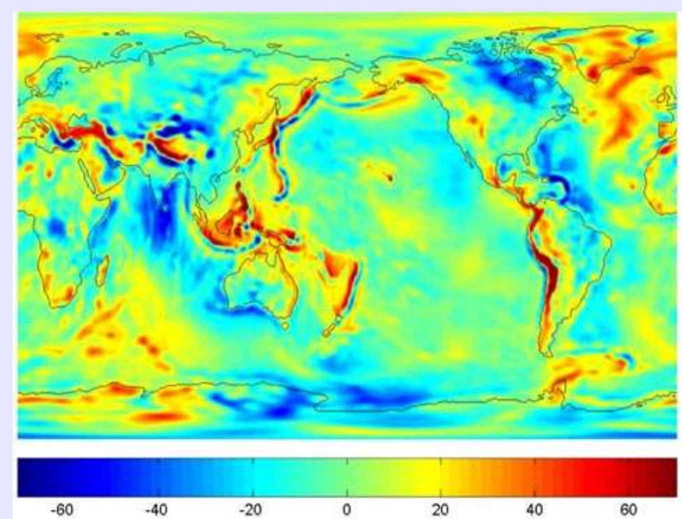


Shape & Deformation

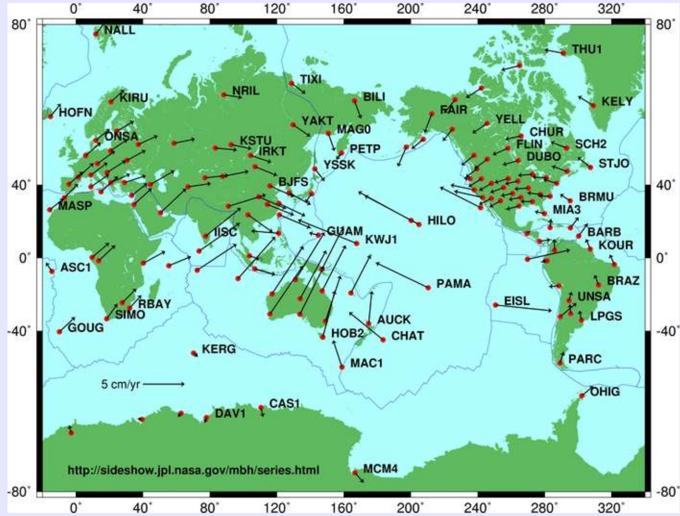
Earth Rotation



Gravity & Geoid



Geodesy's Contribution to Earth System Monitoring

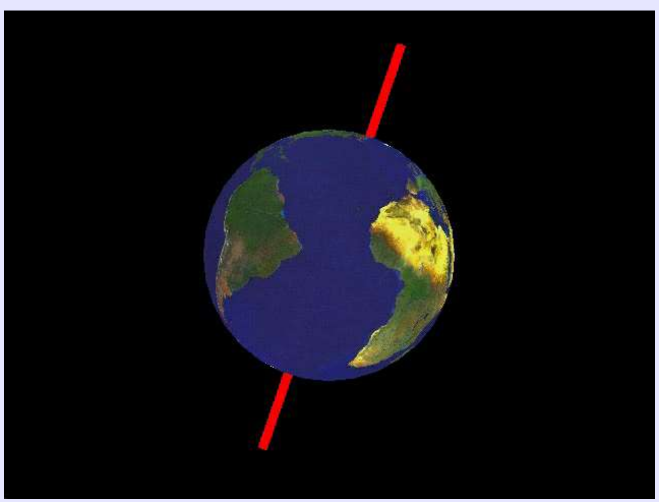


Shape & Deformation

The **three pillars of geodesy**:

- geometry
- gravity
- rotation

Earth Rotation



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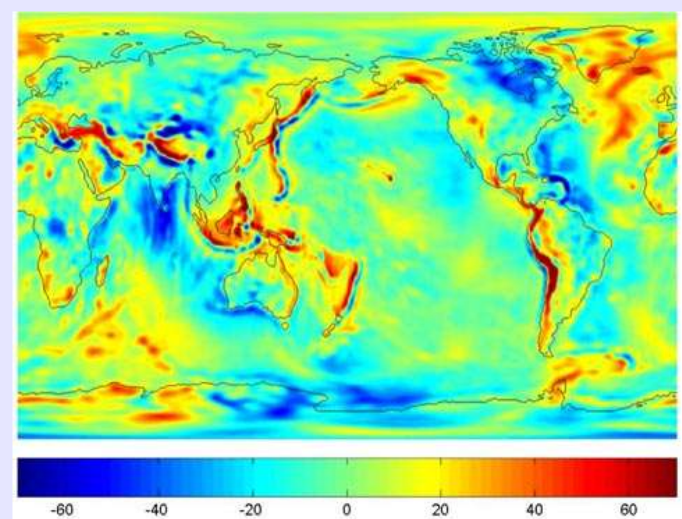


The Global Geodetic Observing System (GGOS)

Providing the Foundation for Earth Observation

“metrological basis”

Geometry, kinematics
GPS, altimetry, INSAR, mobile SLR
Remote sensing
Leveling
Tide gauges

Reference frame
VLBI, SLR, LLR, DORIS, PRARE, GPS

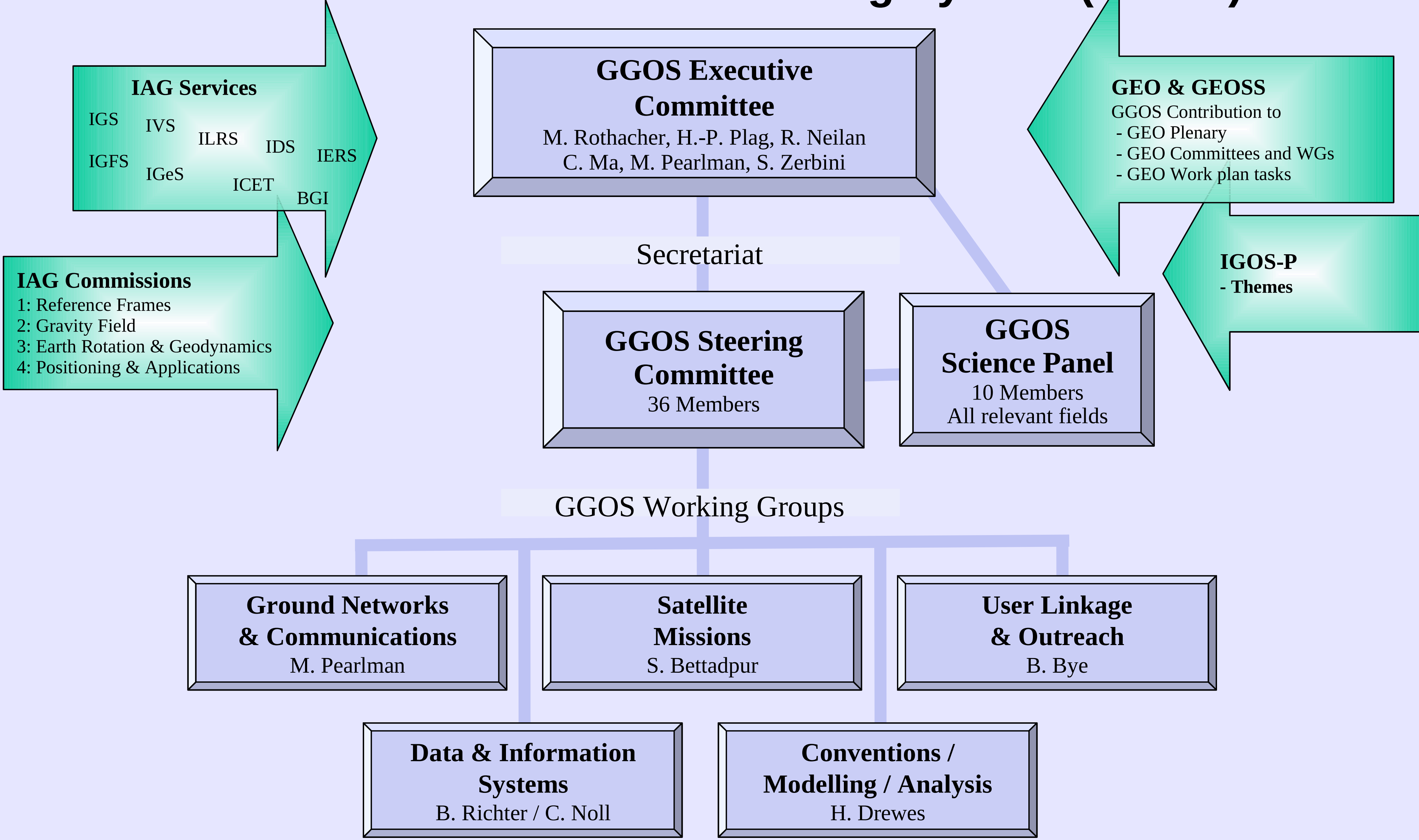
Earth Rotation
VLBI, LLR, SLR,GPS, DORIS
Classical: astronomy
Future: terrestrial gyroscopes

Gravitational field
Orbit analysis
Hi-lo & lo-lo SST
Satellite Gradiometry
Ship/air-borne gravimetry
Absolute gravimetry
Gravity-recording

Output: Reference Frame and Observations of the Shape, Gravitational Field and Rotation of the Earth

(modified from Rummel, 2000)

The Global Geodetic Observing System (GGOS)



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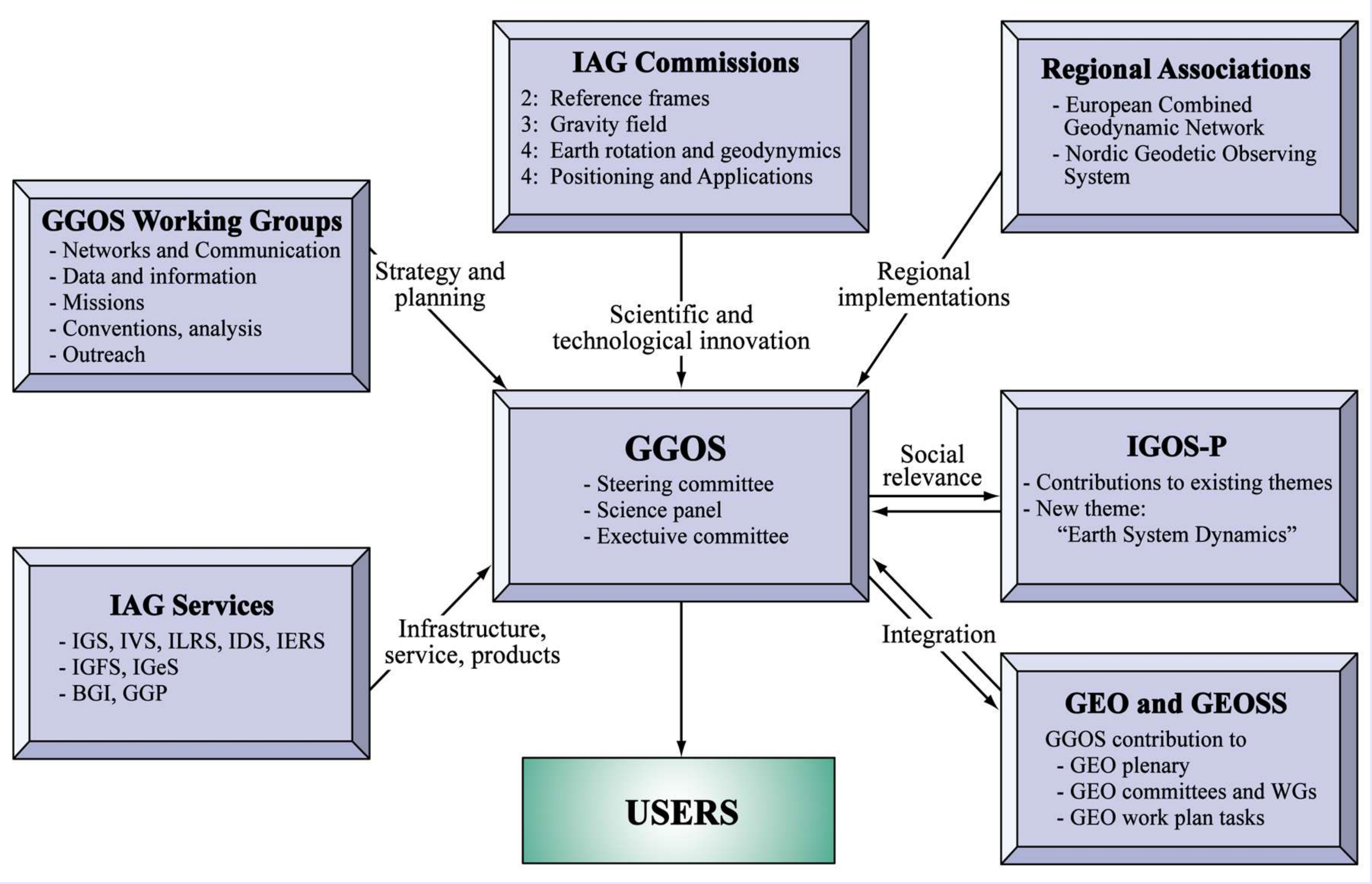

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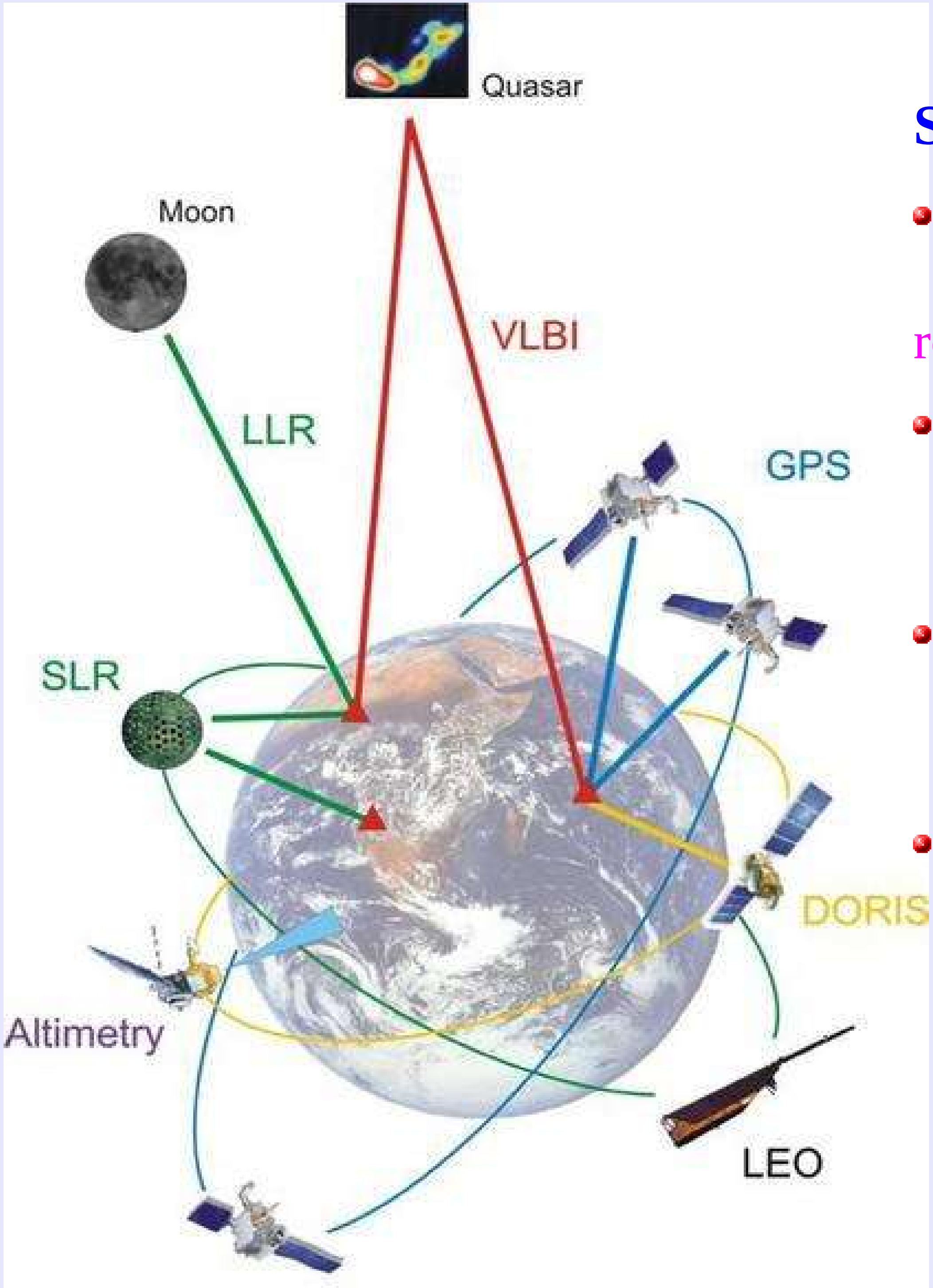


Scientific Vision:

- Unify observations
  - Integration of networks and reference frames
- Unify models
  - Same model used to predict all geodetic observations
- Unify observations with models
  - Assimilate geodetic observations into models
- Earth system dynamics
  - Surface change
  - Mass transport and exchange
  - Angular momentum exchange

The Global Geodetic Observing System (GGOS)

- The **accuracy level** targeted by GGOS for the three fundamental geodetic quantities (and their mutual consistency level) **is 10^{-9} or better**.

- At this level of accuracy, a big variety of mechanical **interactions between the different Earth system components** are relevant and need to be treated consistently.

- In this respect, **modern geodesy requires a system approach to the dynamics of the Earth** and **involves expertise from all Earth sciences** in the analysis and interpretation of the geodetic observations.

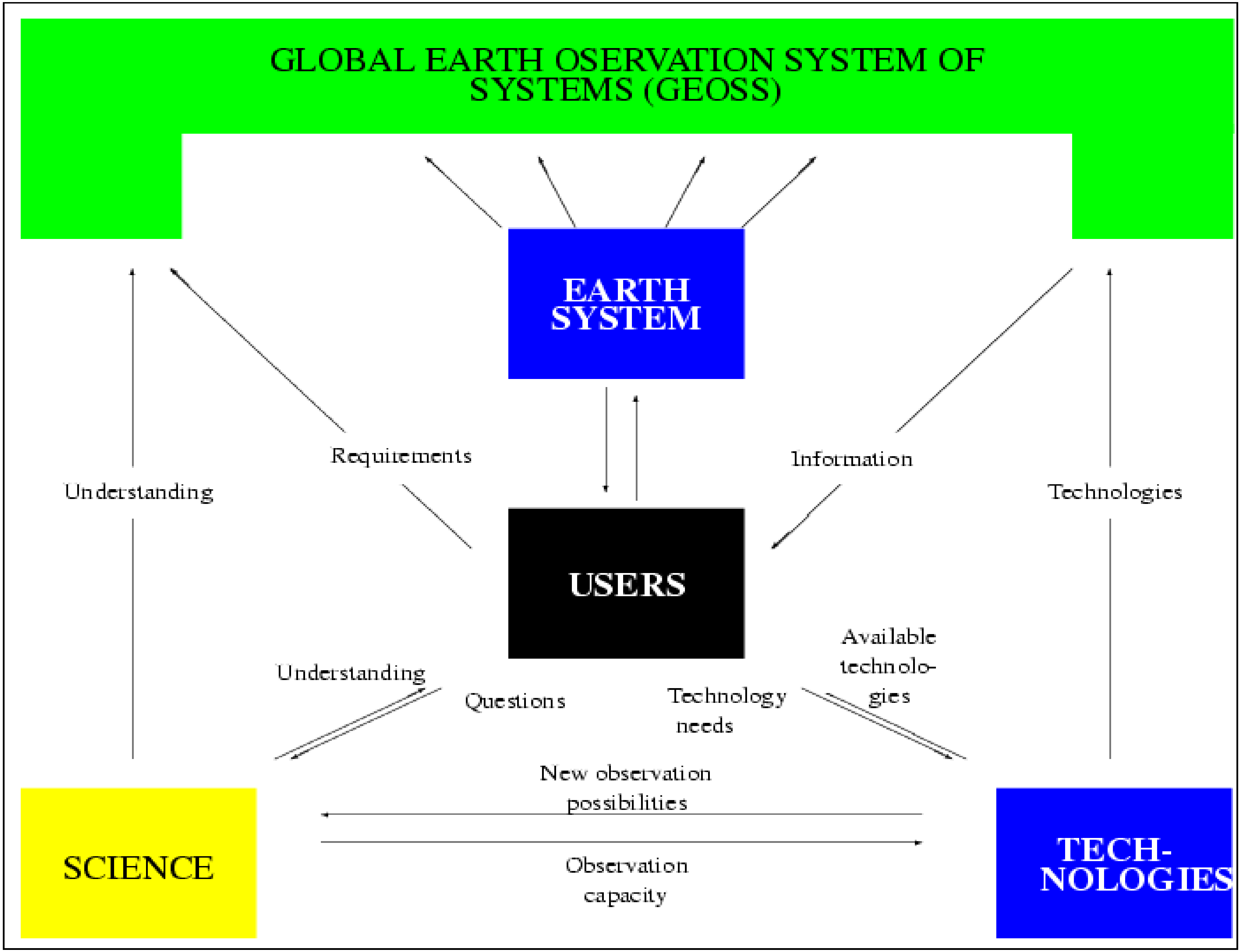
A GGFC-like approach (combined with a Science Panel) to the scientific challenge could be a way forward.

Interaction with GEO and IGOS-P

The GEO-APPROACH:

- Goal: Build a Global Earth Observation System of Systems that serves broad societal needs;
- as far as possible, built on existing systems;
- strategy described in a 10 Year Implementation Plan accepted on Ministerial Level
- currently nearly 70 member countries and about 40 Participating Organizations;
- Work Plan based on Task (more than 90 in 2006, about 70 in 2007-2009);
- strongly user-driven:

GEOSS: A System Ordered by the Users



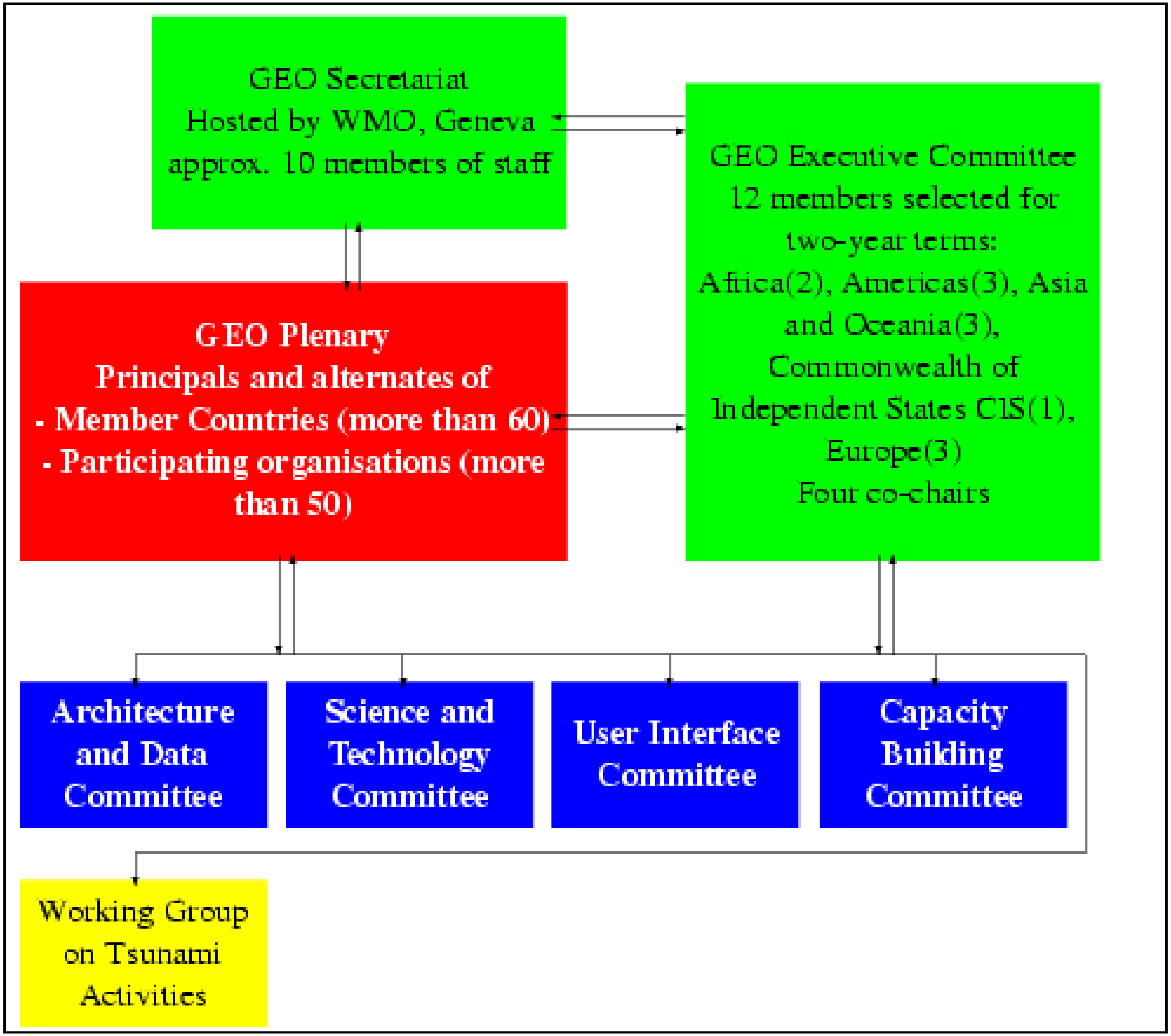
Interaction with GEO and IGOS-P

The GEO-APPROACH:

Address the needs of nine benefit areas of Earth observations identified by EOS-II:

- **Disaster:** reducing loss of life and property from natural and human-made disasters
- **Health:** understanding environmental factors affecting human health and well being
- **Energy resources:** improving management of energy resources
- **Climate:** understanding, assessing, predicting, mitigating, and adopting to climate variability and change
- **Water:** improving water resource management through better understanding of the water cycle
- **Weather:** improving weather information, forecasting, and warning
- **Ecosystems:** improving the management and protection of terrestrial, coastal, and marine ecosystems
- **Agriculture:** supporting sustainable agriculture and combating desertification
- **Biodiversity:** understanding, monitoring and conserving biodiversity

Interaction with GEO and IGOS-P



GGOS represents IAG in the GEO Plenary and all GEO Committees.

GGOS introduced a task “Global Geodetic Reference Frames” into the 2007-2009 Work Plan.

Interaction with GEO and IGOS-P

IGOS-P Approach:

- A small number of “Themes” focusing on a societal issue;
- Theme reports describe users, user requirements, and observation systems

GGOS is relevant for a number of these themes:

- **The Geohazards Theme**
- **The Ocean Theme**
- **The Water Cycle Theme**
- **The Coast Observation Theme**
- **The Cryosphere Theme**
- **The Land Theme**

GGOS and IGOS-P Themes

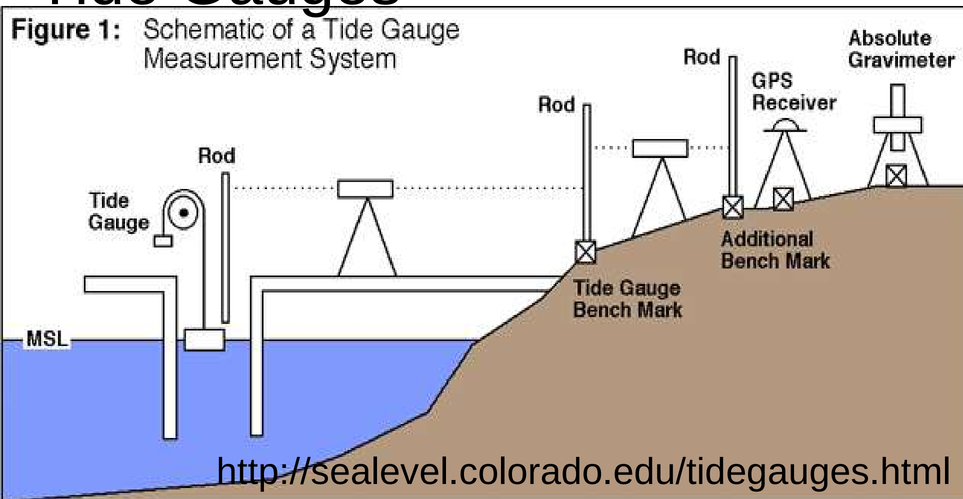
Example: Sea Level and Ice Sheets Trends

Relevant for:

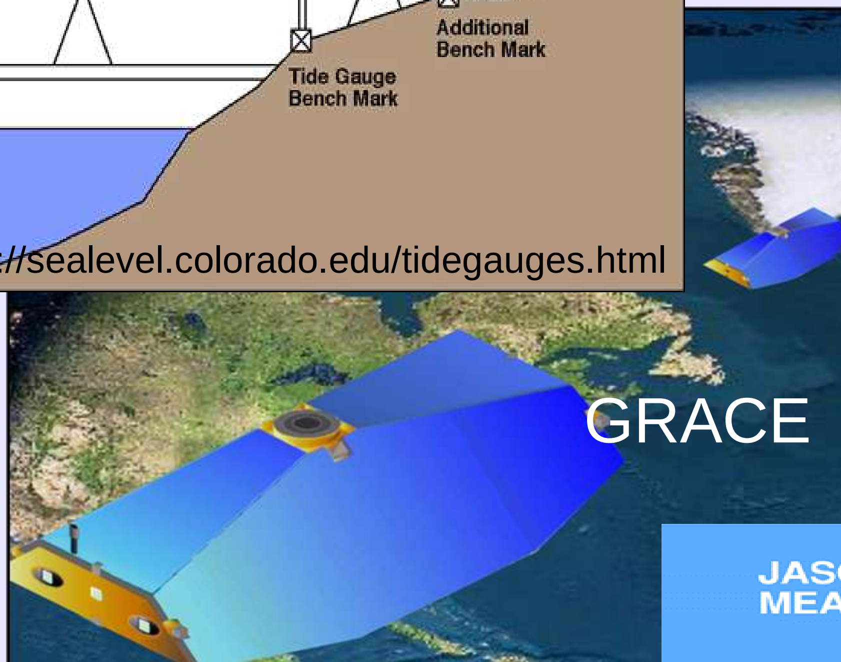
- Ocean Theme,
- Coast Observation Theme,
- Water Cycle Theme,
- Cryosphere Theme

GGOS and IGOS-P Themes

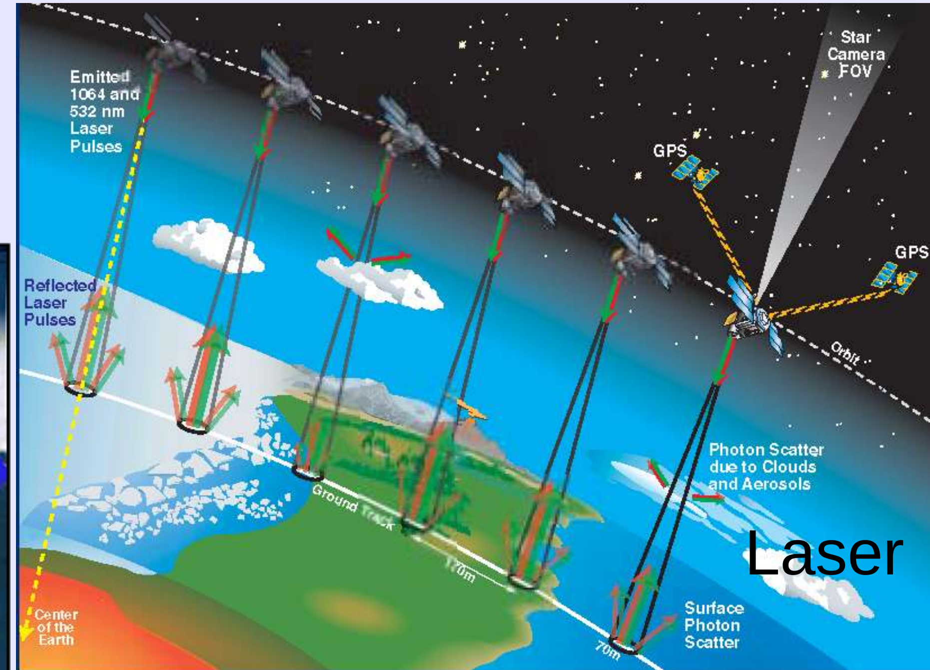
Tide Gauges



http://sealevel.colorado.edu/tidegauges.html



GRACE

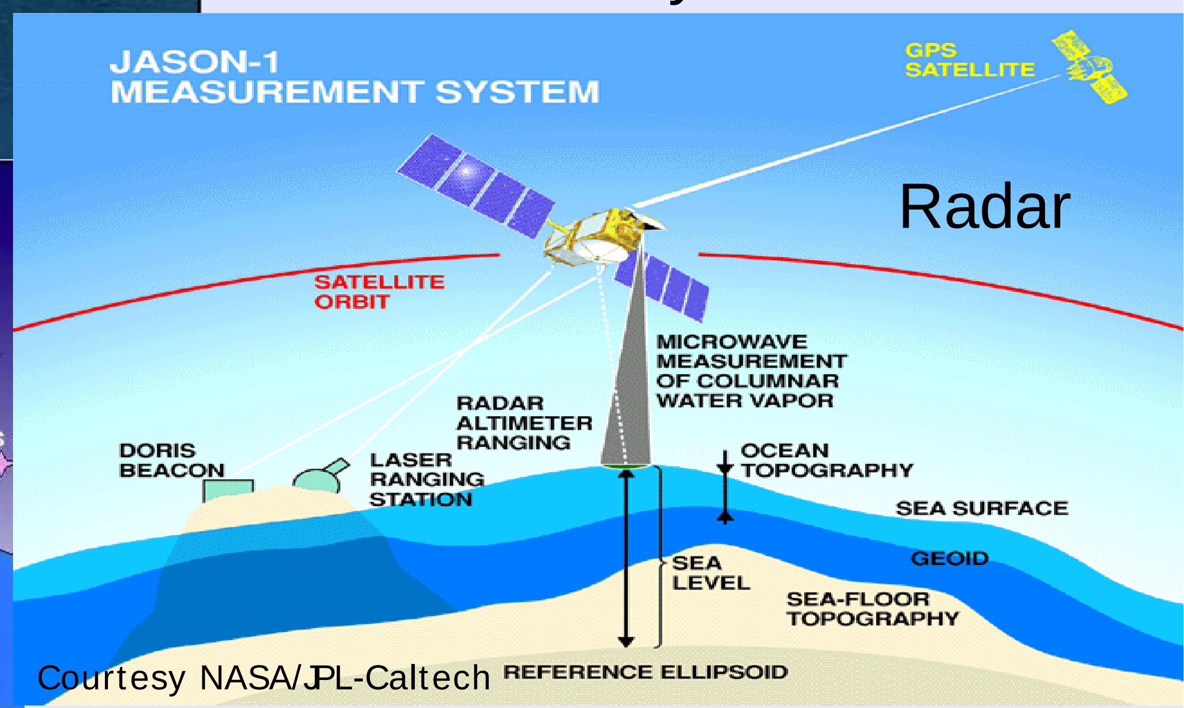


Laser

Satellite Altimetry http://icesat.gsfc.nasa.gov

GNSS Reflections

Zufada & Zavorotny (2004)



Radar

Courtesy NASA/JPL-Caltech

GGOS and IGOS-P Themes

GGOS Contribution:

- Terrestrial and celestial reference frames
- Precise positioning
  - Monuments on ground:
    Tide gauges
  - Satellites in space:
    Radar and laser altimeters
- Gravity measurements
  - Time variable:
    Ocean-bottom pressure
  - Static:
    Mean ocean circulation
- GNSS reflections

GGOS and IGOS-P Themes

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- Terrestrial and celestial reference frames
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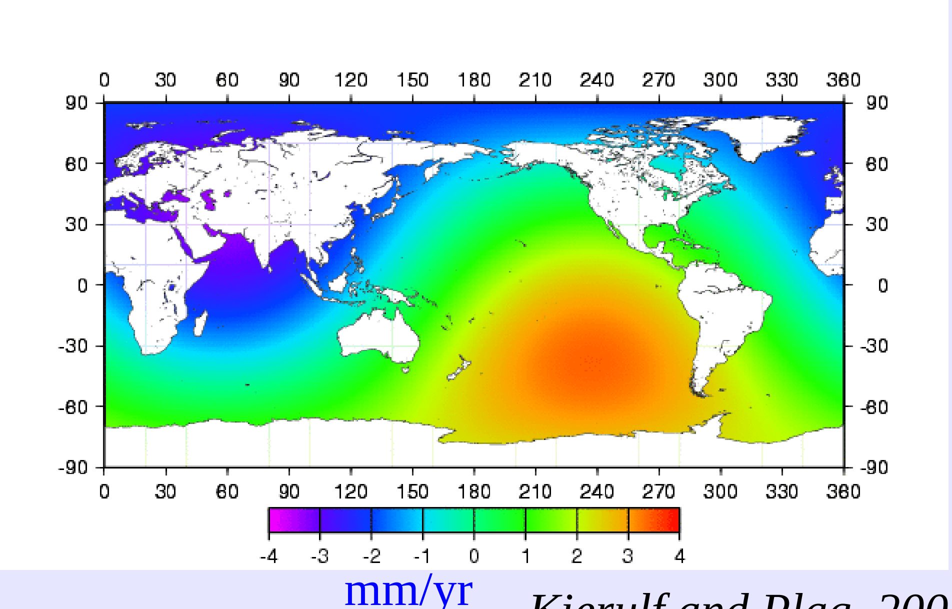
- GNSS reflections

Uncertainties in relation between Reference Frame Origin (RFO) and Center of Mass of Earth System (CM):

Uncertainty of 2 mm/yr affects:

- global sea level by 0.4 mm/yr
- ice sheet trends by 1.5 mm/yr
- local sea level by 2 mm/yr



Kierulf and Plag, 2005

GGOS Proposal to IGOS-P: Earth System Dynamics Theme

The Dynamics of the Earth system are strongly linked to mass transports in
- the atmosphere
- the water cycle
- the solid Earth

All these processes affect to certain levels:
- geometry of the Earth
- gravity field of the Earth
- Earth rotation

All these processes interact on global and regional scales.

Geodetic methods are inherently strong on regional to global scale.

Earth System Dynamics Theme

Geodetic quantities are relevant for several themes and benefit areas

Dynamic processes are a cross-cutting issue:

- climate
- geohazards
- water cycle
- ocean
- coastal zone
- sustainable development

Goals:

Design of the geodetic and geophysical observing system with focus on dynamic processes

Development of predictive capabilities

GGOS 2020
“The Global Geodetic Observing System: Meeting the Requirements of a Global Society on a Changing Planet in 2020”

Authors:

Hans-Peter Plag,

Reiner Rummel, Dork Sahagian, Chris Rizos, Jim Zumberge, Richard Gross,

Tom Herring, Markus Rothacher,

Gerhard Beutler

plus large Chapter Writing Teams

Time Schedule

- Request for Strategy paper of the GGOS Steering Committee in April 2006
- Draft Structure and Initial Strategy Writing Team (SWT) in June 2006
- First Meeting August 21-22, 2006, Washington, DC: Two documents (Strategy and Reference Doc.)
- First draft Reference document available on October 5, 2006
- GGOS Workshop 2006, October 8-9, Munich
- GGOS Retreat and GGOS 2020 SWT Meeting, February 19-22, 2007, Oxnard, California
- Strategy and Reference documents available in March 2007
- Hearing phase, including GEO, IGOS-P, IUGG, national authorities and space agencies
- Final documents available for IUGG, July 2-13, 2007, Perugia, Italy

Expected Output

- Two documents needed:
  - **Strategy document:** short document for politicians, decision makers, funding agencies
  - **Reference document:** long, comprehensive document with all the user requirements and details of GGOS in 2020 mainly for those actually doing the work
- First focus is on the Reference document
- Draft Reference document now available, about 130 pages, but not yet complete ...
- A lot of work still to be done: make it consistent, no repetitions, …
- Intensive and extensive discussions needed concerning the future structure and characteristics of GGOS (meetings and telecons)

Contents

Writing Team

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Chapter 8:	Tom Herring, Z. Altamimi, G. Blewitt, C. Ma, R. Neilan, R. Forsberg, J .Hinderer, D. Lavallee, D. Coulot, J.Ray
Chapter 9:	Markus Rothacher, G. Beutler, W. Bosch, A. Donnellan, C. Ma, M. Pearlman, D. Smith, *J. Hinderer, J. Ries, H. Schuh, F. Seitz, C.K. Shum, M. Thomas, I. Velicogna, J. Wahr, P. Willis*
Chapter 10:	Gerhard Beutler, M. Pearlman, H.-P. Plag., *R. Neilan, R. Rummel, M. Rothacher*
Chapter 11:	All lead authors

3. Science URs

A „the geodetic dimension“

==> Internal user requirements

B „the geo-scientific dimension“

==> External user requirements

3. Science URs

A „the geodetic dimension"

- Global change quanities and their temporal changes are small and difficult to detect
- Need to be derived from combination of complementary observation and sensor systems and from models
- Needs the combination of the three pillars of geodesy in one well defined reference system with one part per billion (nano-geodesy), consistent in space and time and stable over decades
- The space segment has to operate as one global instrument at 1 ppb-level
- Space-borne, air-borne and terrestrial techniques are to be combined
- Need for one self-consistent reference Earth System model (what is our model Earth?)

3. Science URs

GGOS 2020

A „the geodetic dimension“

Earth Rotation
Precession/ nutation
polar motion
and variations in l.o.d.

Geometry
3D+T: shape of
land surfaces
ice shields
oceans

Gravity/ Geoid
3D+T: detailed geoid
and gravity anomaly field

From space and terrestrial
Geodetic data to
Earth System Parameters
Consistent models
Data processing
Data combination
filtering

Oceanic transport
ocean circulation (quasi-static and time variation)
mass and heat transport,
eddies,
sea level: mass and volume change

Atmosphere and Ionosphere
Composition of ionoshere
Atmospheric sounding (T,H, P)
Tropospheric models
Mass balance

Continental hydrology
Continental water budget,
closure of water balance (global, regional)
water storage variation,
trends and climate change

Ice mass balance and sea level
ice surface: height change, velocities,
mass budget of ice sheets,
sea level rise from melting, dynamic ice models,
sea ice: coverage, thickness

Dynamics of mantle and crust
mantle dynamics and geoid signal,
time variation from global isostatic
adjustment, plumes, slabs, gravity signal of
crustal and lithospherie structures

Earth Deep Interior
Core-Mantle Coupling
Mantle anelasticity
ICB flattening

From Earth to Planets
Moments of Inertia
Fluid core?
Isostatic (un)equilibrium
Shape and gravity field

(after Ilk et al., 2005)

3. Science URs

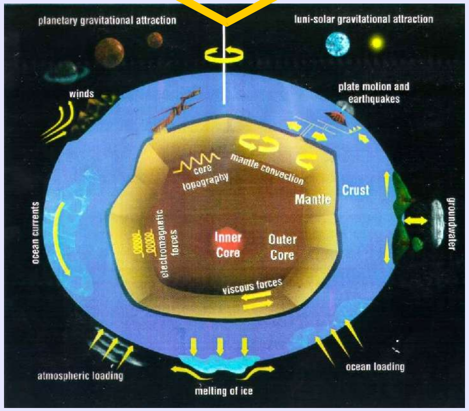
GGOS 2020

B „the geo-scientific dimension“

Earth rotation

Geometry

Gravity/ Geoid



Earth Deep Interior

Solid Earth processes

Cryosphere

Weather and Climate

Ocean and climate

Sea Level

Earth system dynamics

Mass Distribution and Transport

Earth system

Planets

4. EOS URs

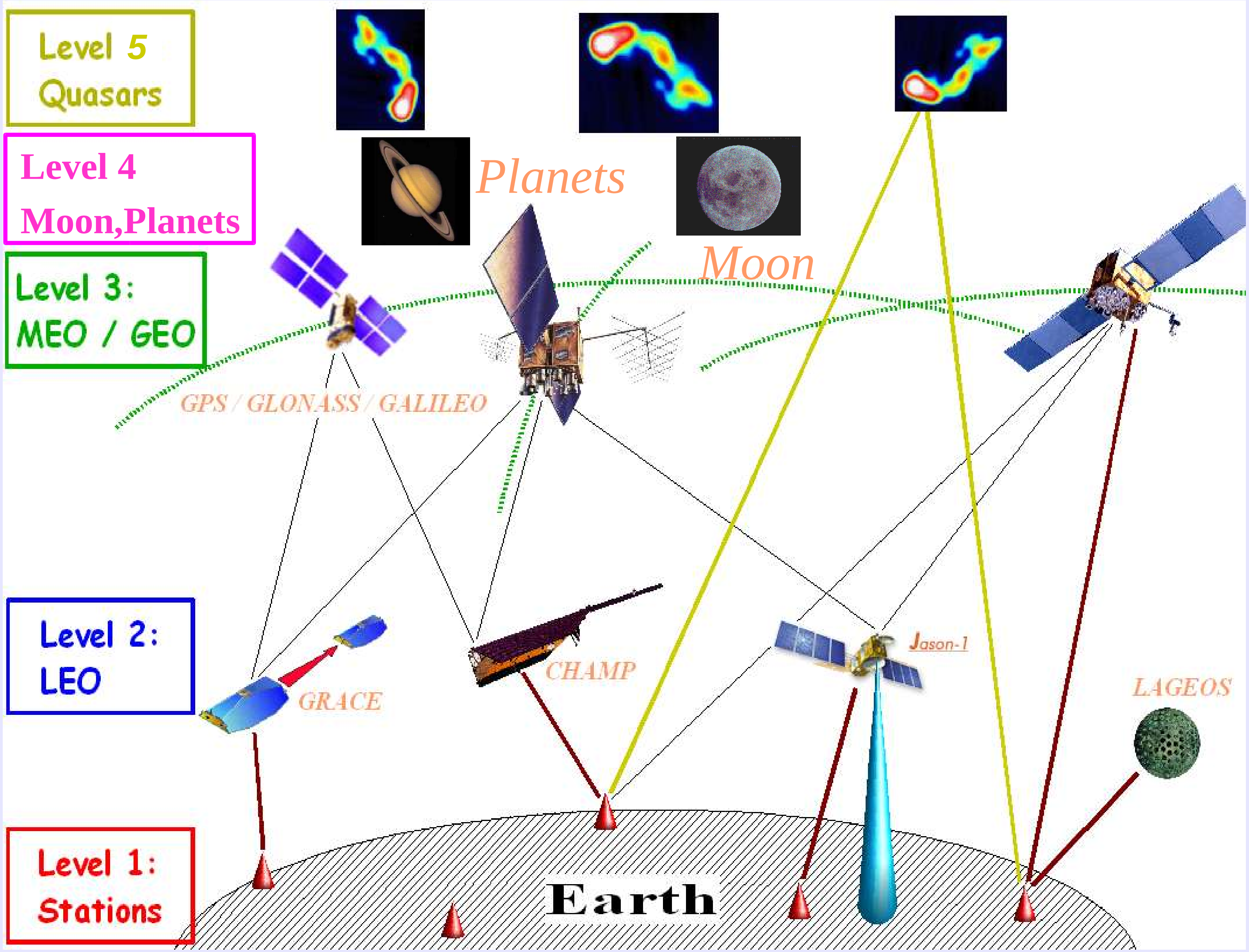
Chapter goal: Understand the requirements of

- the nine societal benefit areas of Earth observation
- GEO
- IGOS-P Themes

Topics addressed in the Chapter:

- **Disasters**: tsunamis, EQs, volcanoes, storms, landslides, creep, subsidence, floods
- **Energy resources**: wind, Oil pumping-induced subsidence, geothermal
- **Climate change**: ocean, atm. circulation, health
- **Water**: sea level, fresh water resources, lakes, streams, ground water, ice, dams, water mass redistribution, soil moisture
- **Weather**: enhancing prediction tools, extreme events, space weather
- **Ecosystems and Carbon cycle**: Land cover (forests, desertification), wetlands
- **Land use**: agriculture & irrigation, deforestation, desertification, erosion/deposition, urbanization

Integration of 5 Layers to a GGOS

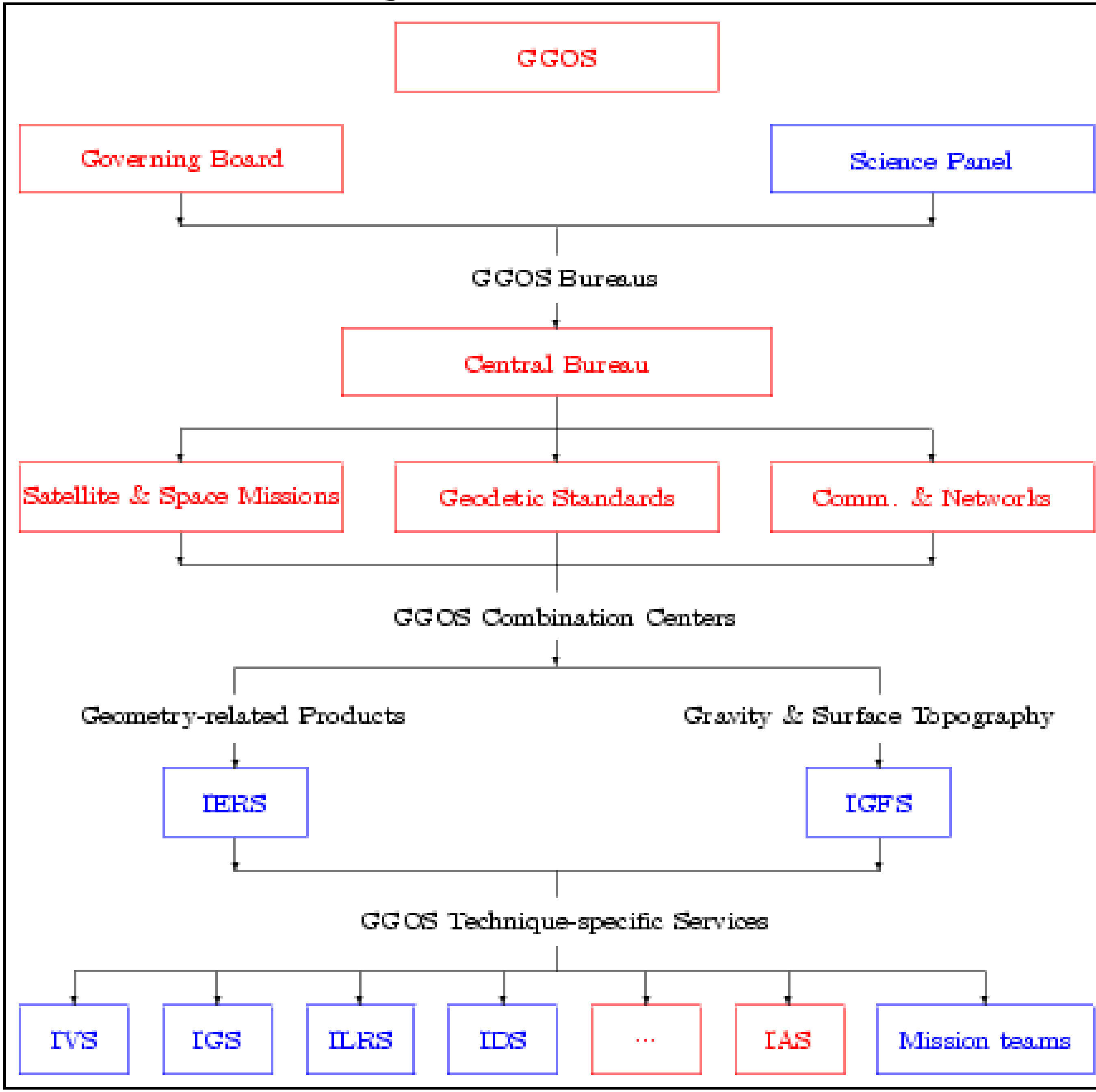


10. Way Forward

Chapter addresses:

- step for implementatio;
- international and intergovernmental background;
- internal organization.

10. Way Forward



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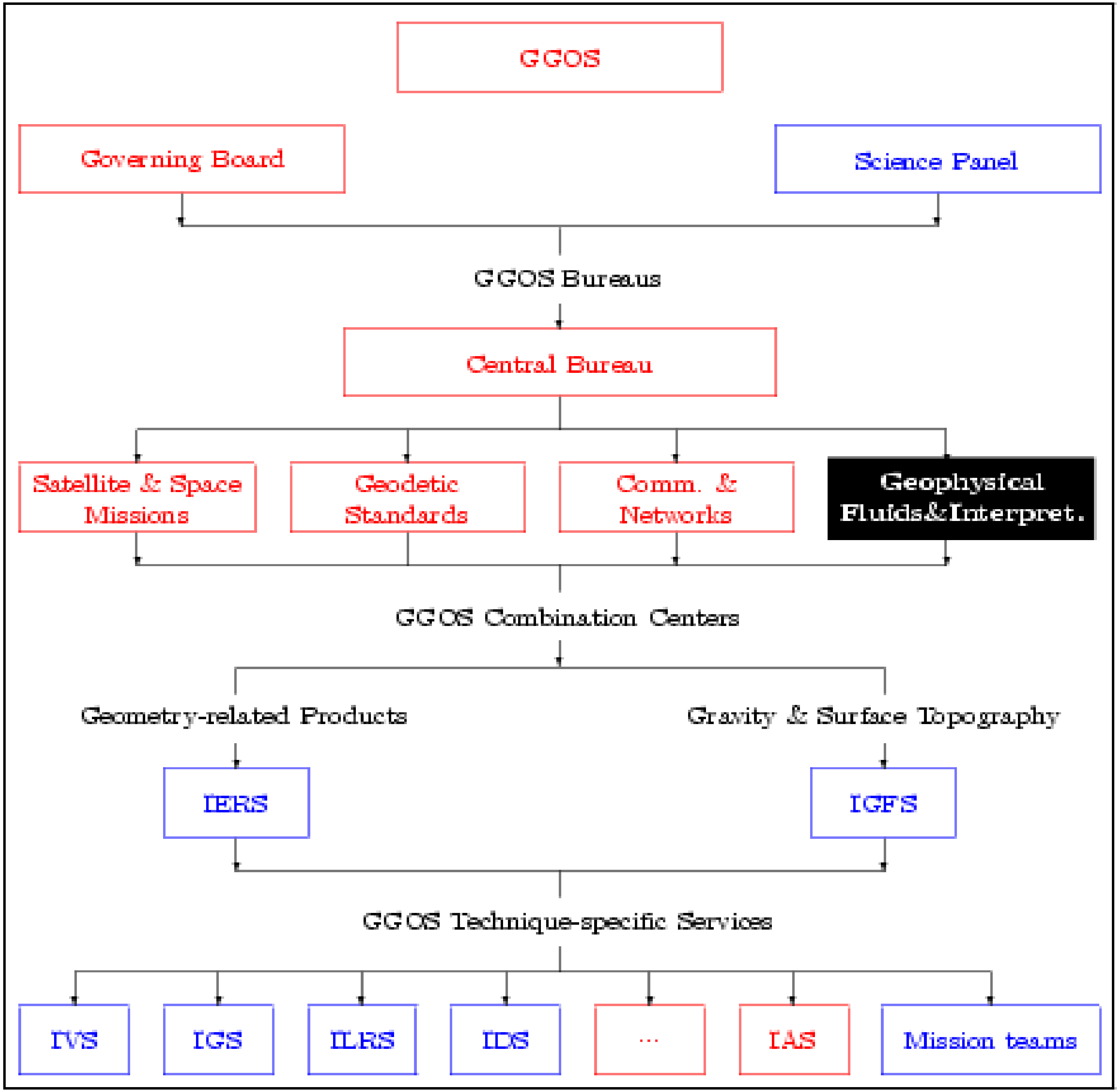

Conclusions

- Geodetic techniques are indispensable for Earth observation systems
- GGOS coordinates global networks for monitoring displacements, gravity variations and Earth's rotation variations
- GGOS provides the backbone for Earth observations: ITRF
- GGOS provides observations related to the dynamics of the Earth
- Users are (still) not fully aware of the potential of geodetic observations

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Can GGOS survive/continue at a high level without a visible service to society?

Example:

WMO provides more than observations of pressure, temperture, wind, ...;

WMO provides Earth system related information.

Conclusions

- To provide system-related information, GGOS needs an Earth system approach;
- To improve accuracy and consistency, GGOS needs an Earth System Dynamics theme or a similar approach
- Earth system dynamics are a cross-cutting issue for several themes/SBAs

Conclusions

The GGFC could/should

- provide fundamental support for the Earth System Dynamics approach,
- be a major component of GGOS,
- not be restricted to delivery of corrections.
- provide support for the quest for internal consistency,
- facilitate the interpretation of geodetic observations,
- support the development of an Earth system model.

The GGFC could be the geodetic Earth system service (in particular, mass transport).

The END

(*or the beginning?*)

GGOS and IGOS-P Themes

Water Cycle and Geodesy

- Gravity field variability measurements
- Degree-1 mass transport
- EOP as a constraint
- Ice sheets
- Sea Level & Circulation
- Radio Occultations
- Surface loading (geometry)

GGOS and IGOS-P Themes

Water Cycle and Geodesy

- Areas:
  - Ground Water Storage Changes
  - Climate/Weather Models
  - Snow-melt & run-off forecasts
- Current deficiencies are:
  - Latency (GGOS can solve this)
  - Data Gaps (GGOS can solve this)
  - Resolution (GGOS cannot solve this alone)

GGOS and IGOS-P Themes

Geodesy contribution to IGWCO Theme:

- Long-term changes in ground-water storage change
  - Even if geodetic spatial scales are too large, there is no other unified, practical & global measurement set available within hydrology
- Weather model boundary conditions
  - Large-scale P-E estimates
- Snow Cover Changes
- These contributions are of twofold importance:
  - Monitoring of the “state” of water cycle
  - Assimilating into models for calibration of models

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