Identification of Processing and Product Synergies for Gravity Missions in View of the CHAMP and GRACE Science Data System Developments

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http://www.csr.utexas.edu/grace

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Outline

- ***Mission Synergies***
  - ***Mission Scenarios and Synergies***
- ***Projects Synergies***
  - ***CHAMP Science Data System***
  - ***GRACE Science Data System***
  - ***Information System and Data Centers***
- ***Data Analysis Synergies***
  - ***Time Variable Gravity Field Corrections: High Frequency to Seasonal***
- ***Conclusions***

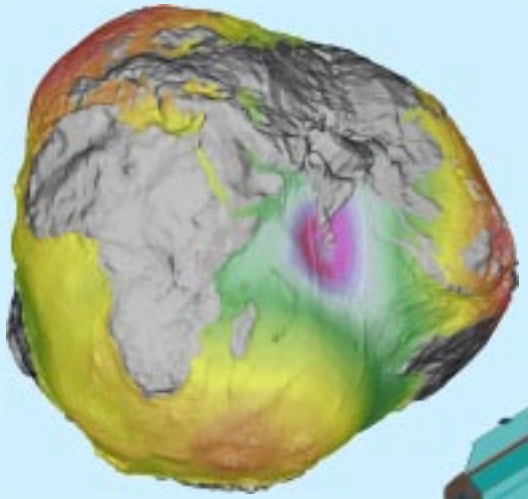
Mission Synergies

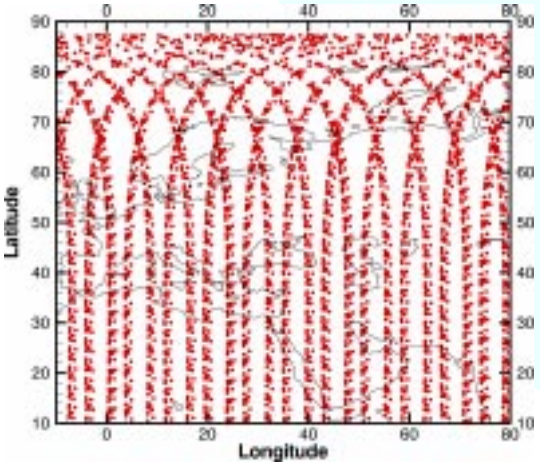
Mission Scenarios and Synergies

Mission Scenarios

CHAMP:

- t=7-2000 to 2005
- i=87.277^0
- e=0.004
- a=6823 km (initial)
- h=460-300 km
- GPS
- Accelerometer
- Objectives: Gravity & Magnetic Field
- Proc. & Archive: GFZ





CHAMP/GRACE 30 Days Sample Track Pattern

Sequence, Observation Periods and Spatial Sampling complementary for all 3 Missions

GRACE:

- T=11-2001 to 2006
- i=89^0
- e<0.005
- a=6843 km (initial)
- h=480/500-300 km
- GPS
- Accelerometer
- K-Band Ranging
- Objective: Gravity Field
- Processing & Archives: GFZ, UTCSR, JPL

GOCE:

- T=end 2005 to mid 2007
- i=96.5^0
- e<0.0045
- a=6613 km
- h=250 km
- GPS
- 3-Axis Gradiometer
- Objective: Gravity Field
- Processing & Archives: ESA, EGG-C

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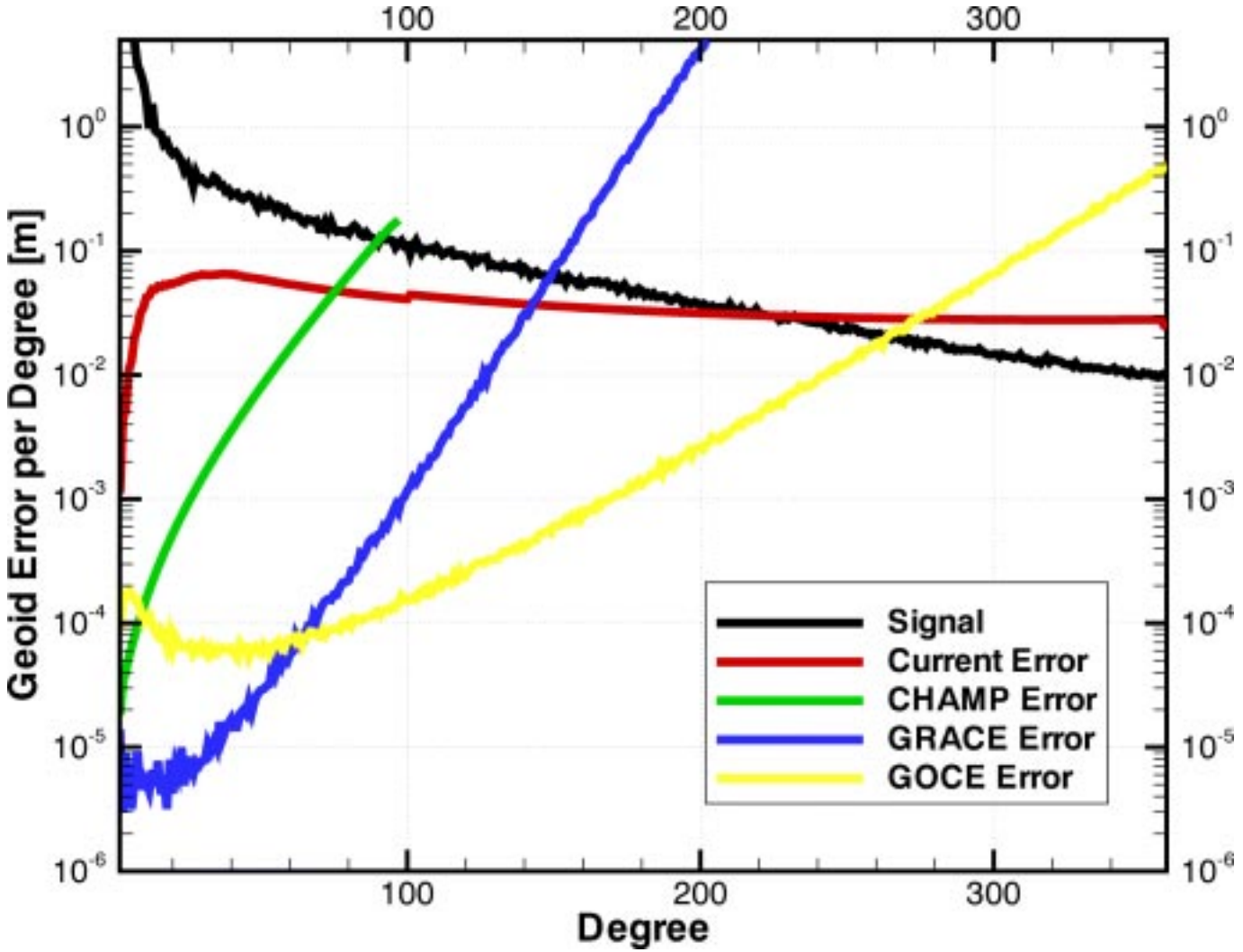
Mission Scenarios - Predicted Performance



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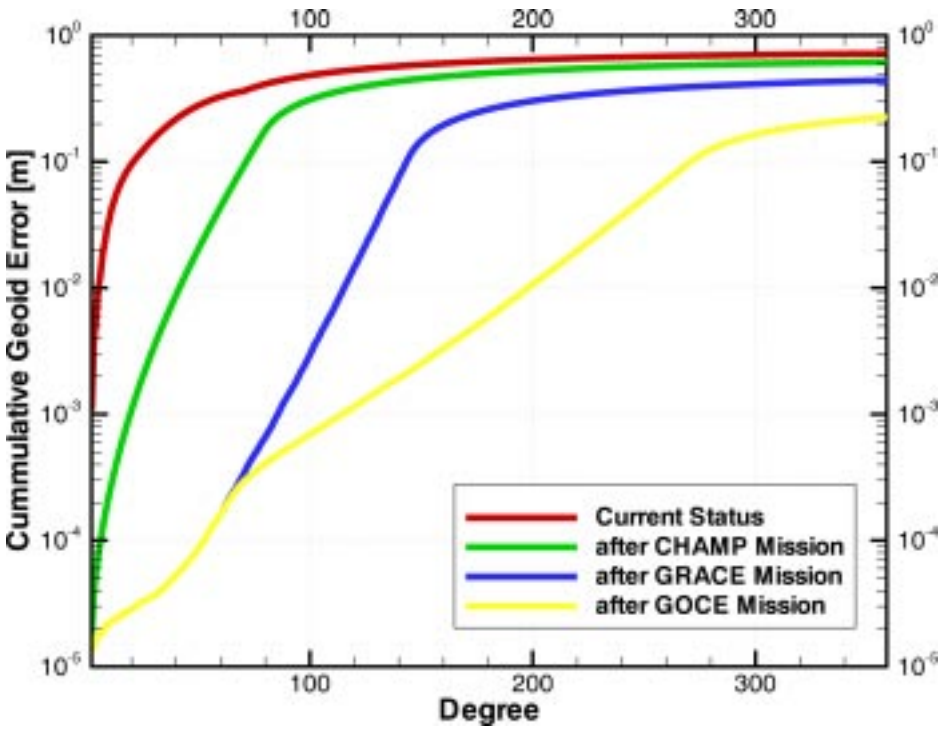
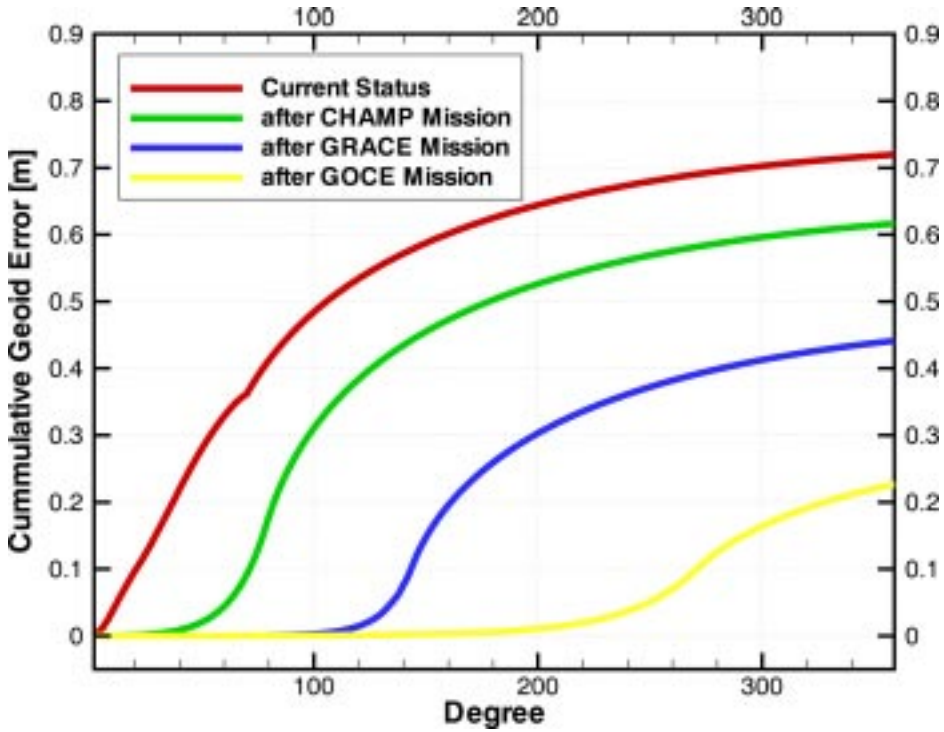
Mission Scenarios - Predicted Performance

Error Reduction for High Resolution Gravity Field Models by Inclusion of Gravity Field Missions in Sequence of their Launches

1. without new satellite missions
2. with CHAMP
3. with CHAMP & GRACE
4. with CHAMP & GRACE & GOCE



Logarithmic y-axis



Linear y-axis

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Mission Synergies

- Mission Sequence:
  - CHAMP is first operational high-low SST and accelerometer mission.
  - CHAMP will provide a strongly improved long wavelength gravity field as starting point for GRACE data analysis (iterative orbit perturbation analysis).
  - GRACE will provide a further improved medium wavelength gravity field as basis for GOCE data analysis.
- Observation Periods:
  - Overlapping GRACE and GOCE observations enable the reduction of monthly to seasonal gravity variations in GOCE observations by using monthly medium wavelength GRACE gravity solutions (seasonal bias in GOCE due to mission profile).
- Spatial Sampling:
  - CHAMP & GRACE gravity field model can fill the polar gap due to GOCE orbit configuration.

Projects Synergies

CHAMP Science Data System

GRACE Science Data System

Information System and Data Center

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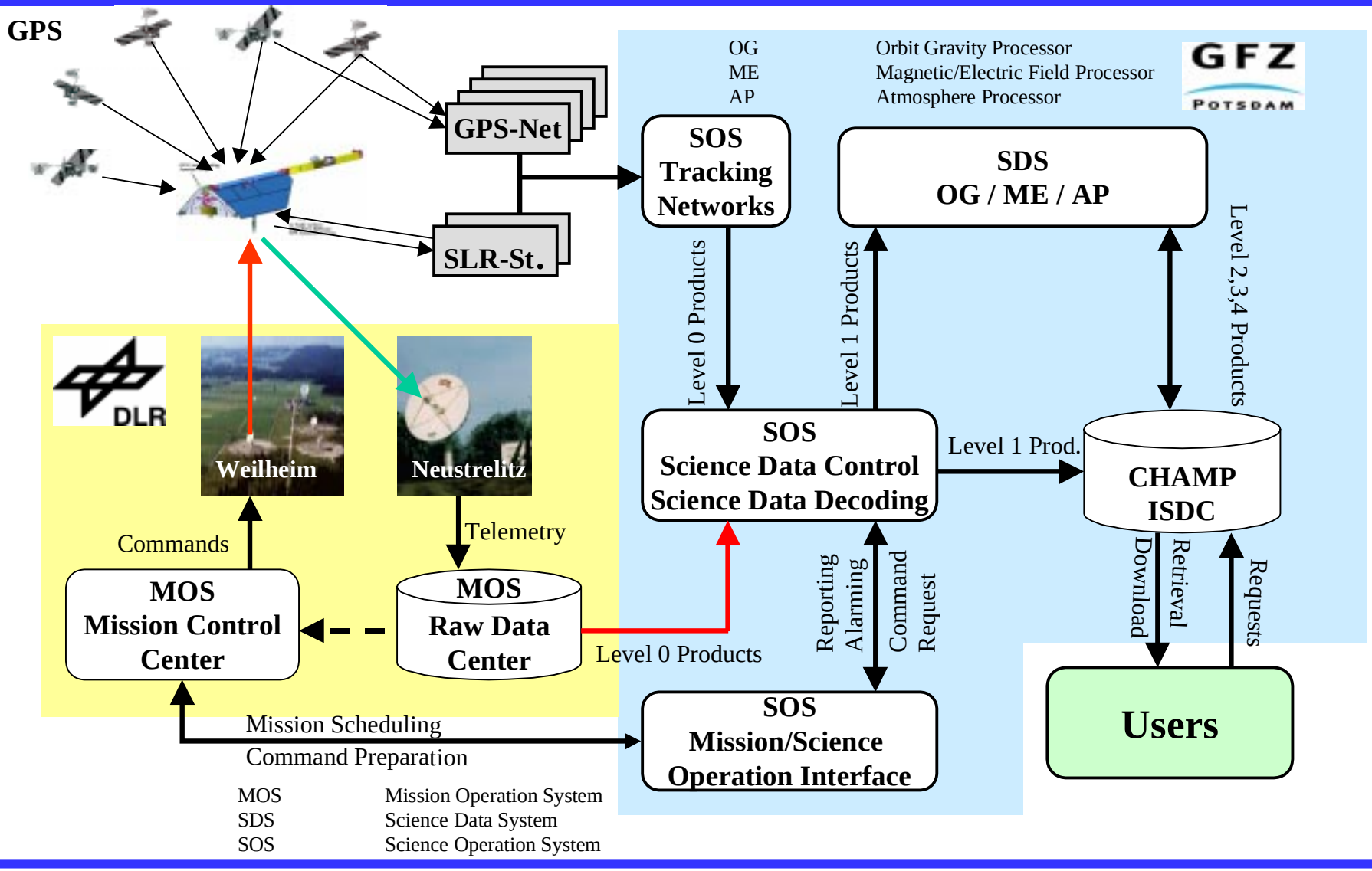
CHAMP Ground Segment



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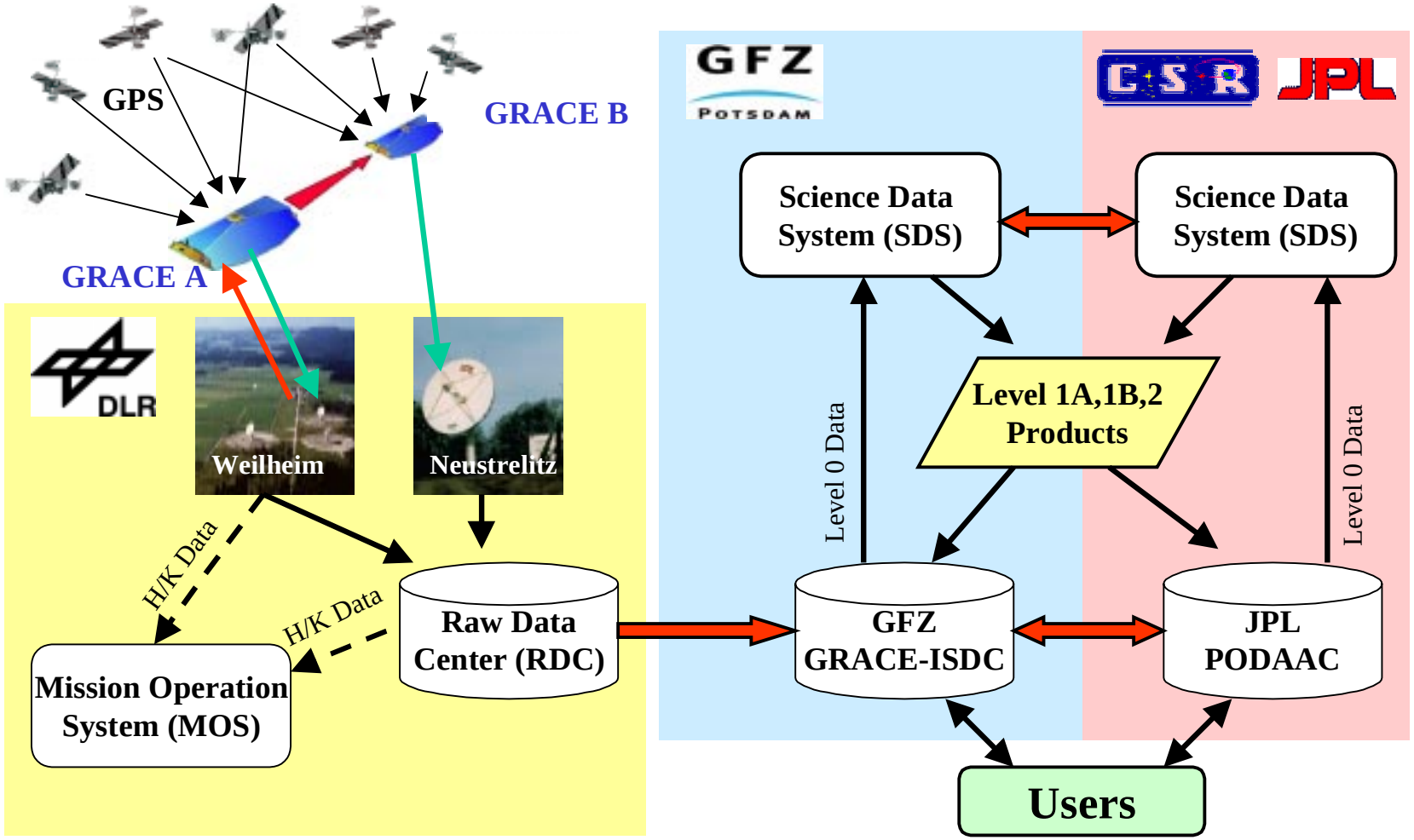
GRACE Ground Segment



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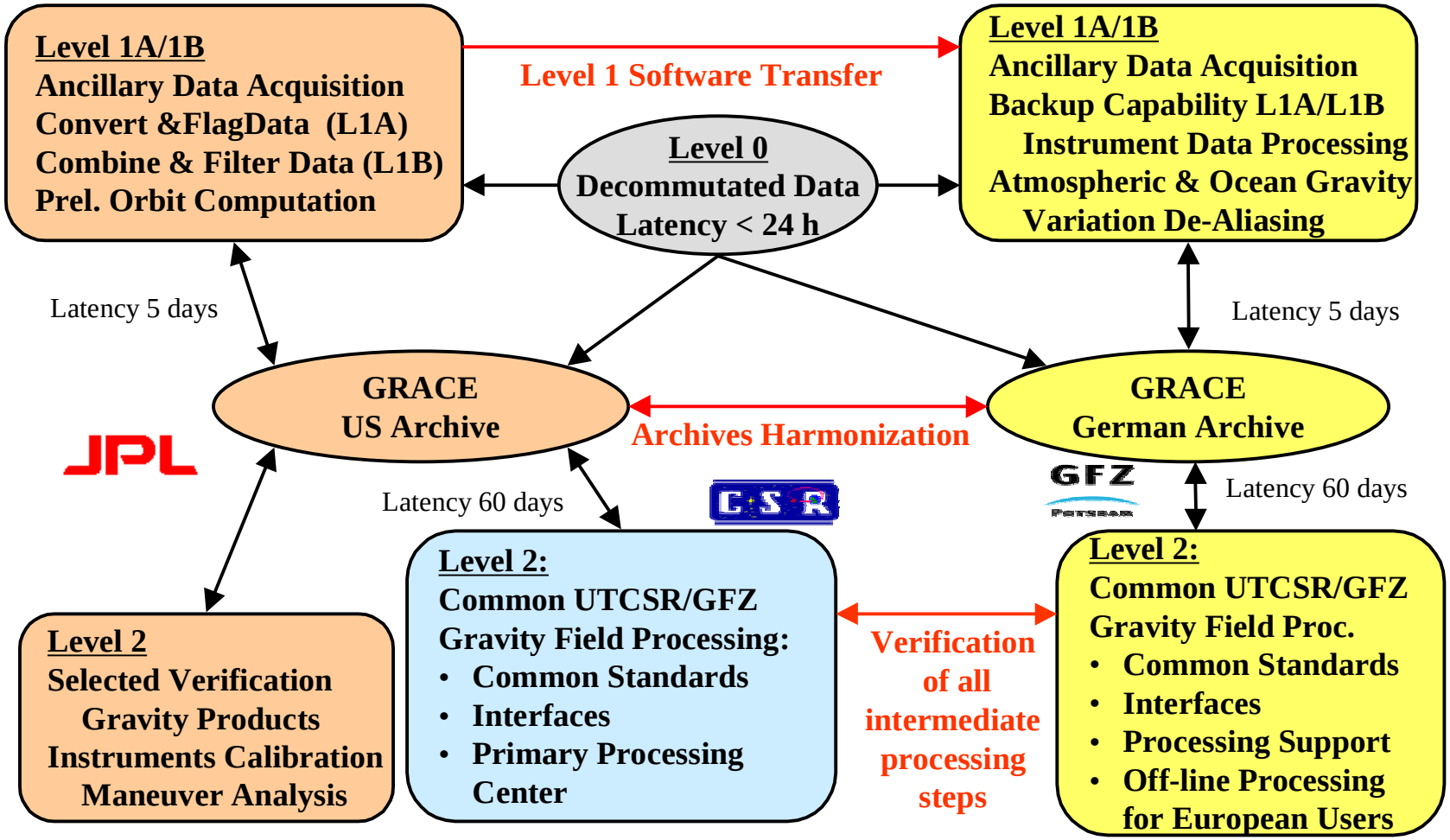
GRACE Science Data System



CHAMP Information System and Data Center (ISDC)

Requirements:

- Daily amount up to 1 GB, 2 TB/5 years
- Different product volumes and frequencies
- Platform independent access
- Data Policy: Partly online Access, Protected Access
- High data and operations security, low maintenance

Solution:

- Internet based Information System & Data Center
- Product Access via Retrieval (download) or FTP (download/upload), multistage authorizing
- Product Definition = Data File + Metadata File
  DIF: Directory Interchange Format
- Metadata Files define relationale database
- Product specific archiving (directory, media, backup)

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CHAMP Information System and Data Center (ISDC) - Authorization

- First Time Registration (Public Area Account)
- Public Area Users
  - Free Information and Data in Retrieval Section
- Restricted Area Users
  - Free and Restricted and Special User Dedicated Information and Data in the Retrieval and Download Section
  - No Access to Monitoring Section
- Internal Area Users
  - All Information and Data in the Retrieval and Download Section
  - Monitoring of Product Archiving Status
- Administration and Management of Users

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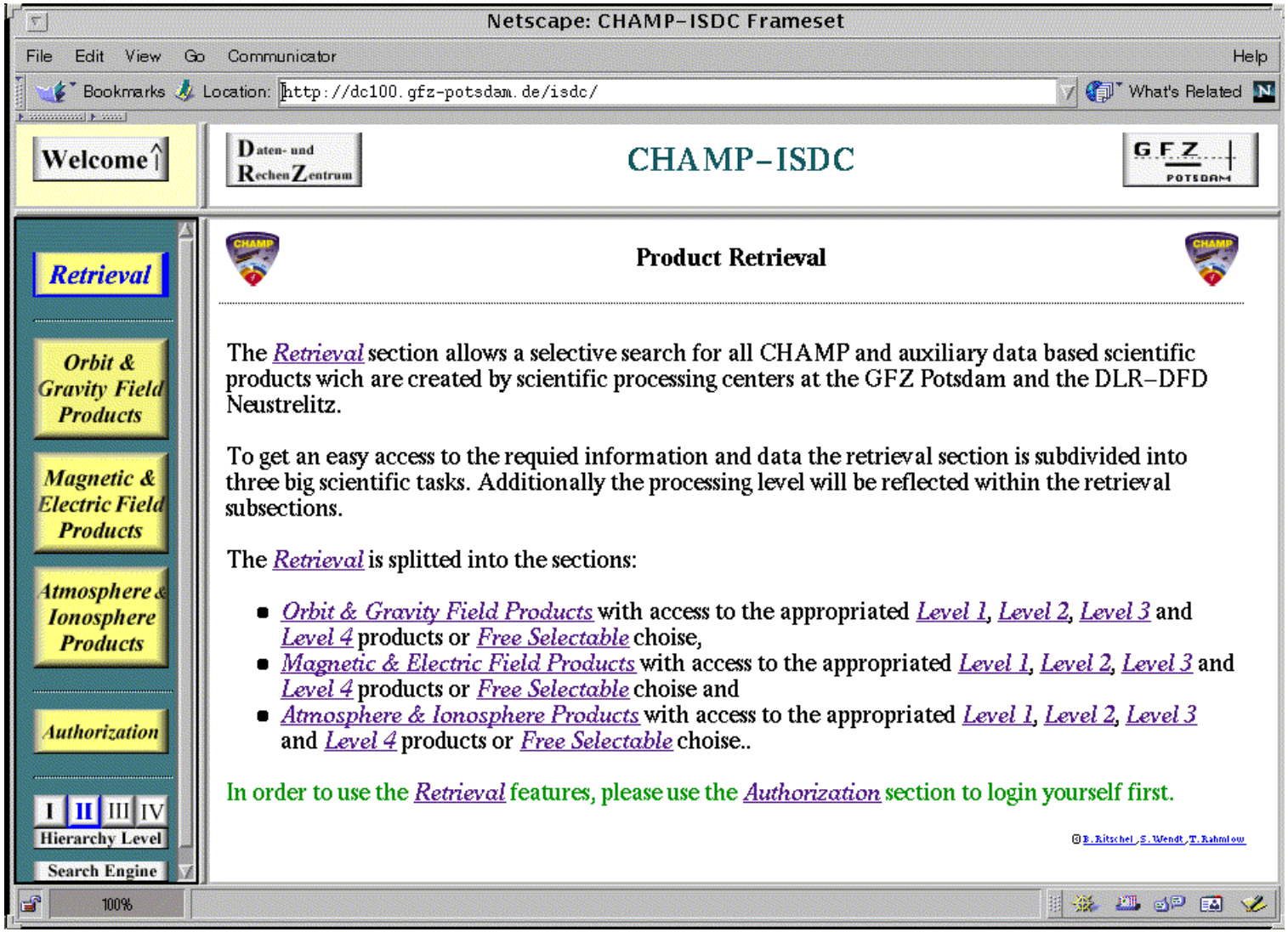
CHAMP Information System and Data Center (ISDC) - Retrieval



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Projects Synergies

Identified CHAMP & GRACE Project Synergies

- GRACE ISDC as copy of CHAMP ISDC. Archive Principles and Procedures are adopted to GRACE products and Access Rules.
- Future: Integration of both Systems into larger German Earth Science Information System foreseen.
- CHAMP Processing Strategies and Software (e.g. for high-low SST observations or accelerometer preprocessing) partly is adopted for GRACE Data Analysis.

Possible CHAMP, GRACE & GOCE Project Synergies

- Upgrade CHAMP/GRACE-ISDC for GOCE Products Archiving and User Interface.
- CHAMP/GRACE Processing Strategies and Software (e.g. for high-low SST observations or accelerometer preprocessing) partly can be adopted for GOCE Data Analysis.

➡ **Each Mission provides new Insights for Data-Analysis of Follow-on Mission. Close Link between Projects at GFZ**

Data Processing Synergies

Time Variable Gravity Field Corrections: High Frequency to Seasonal

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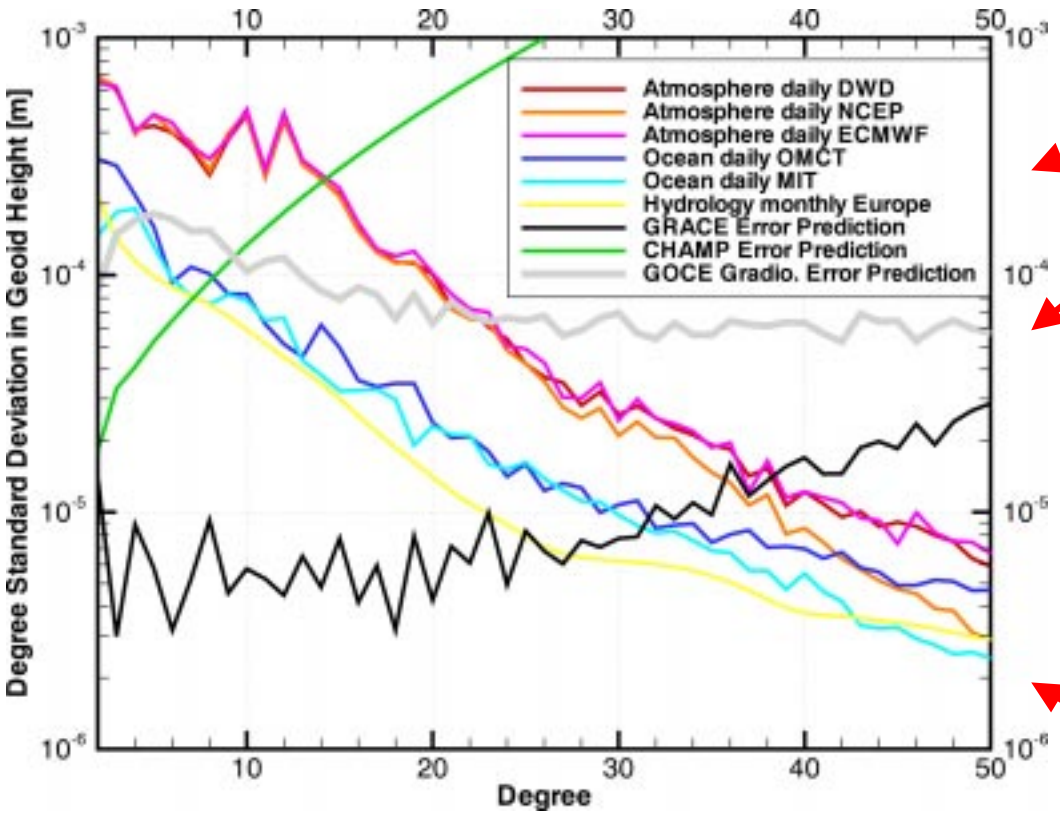
Sources of Gravity Field Variations

Selected Signals of Gravity Variations



Gravity field variations in terms of geoid heights estimated from surface pressure, ocean bottom pressure and continental water heights.

High Frequency Variations:

- Tides: Improved models necessary
- Atmosphere: Models available
- Oceans: Models available
- Continental Water: No data/model available

Seasonal Variations

- Atmosphere
- Oceans
- Continental Water
- Ice Mass

Detectable with GRACE monthly gravity models

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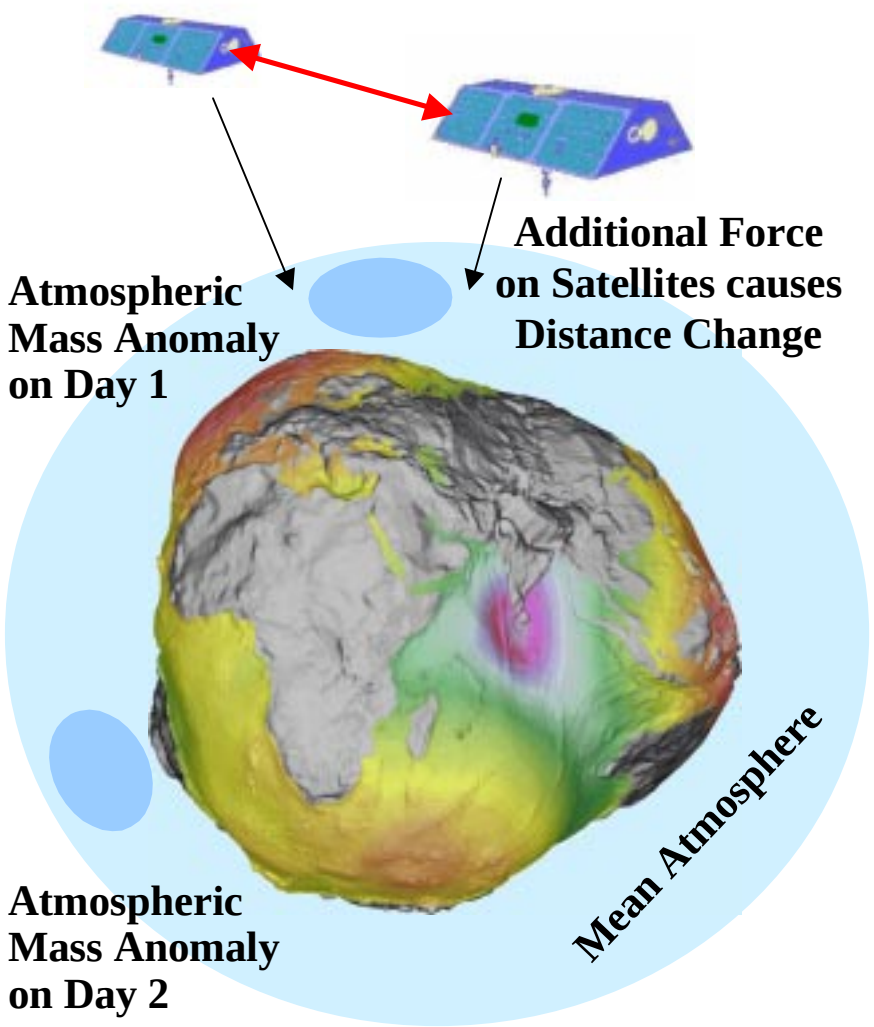
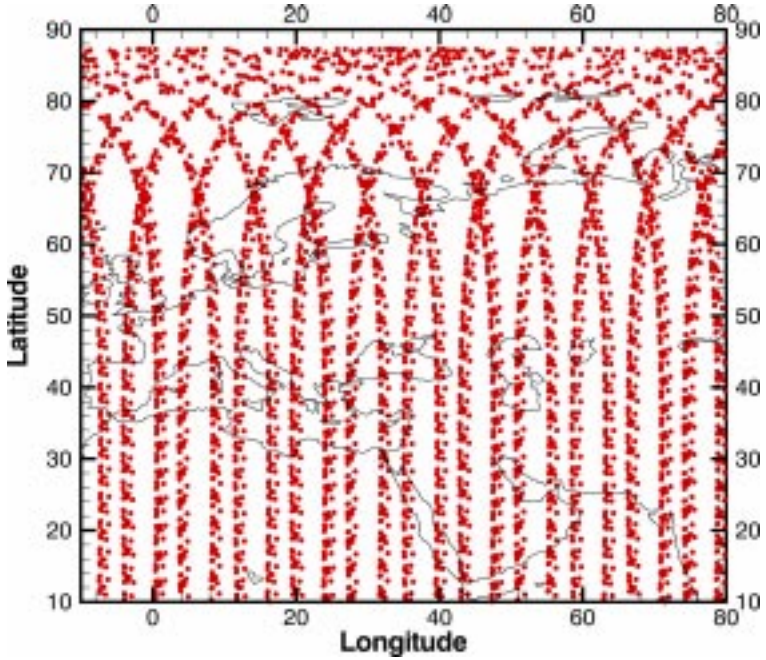
High Frequency Gravity Field Variations - Problem Definition



30 Days Sample Track Pattern



Due to variations in satellites space-time sampling no elimination of time dependent mass anomalies by repeated observations possible (e.g. altimetry). Correction during gravity field determination process necessary.

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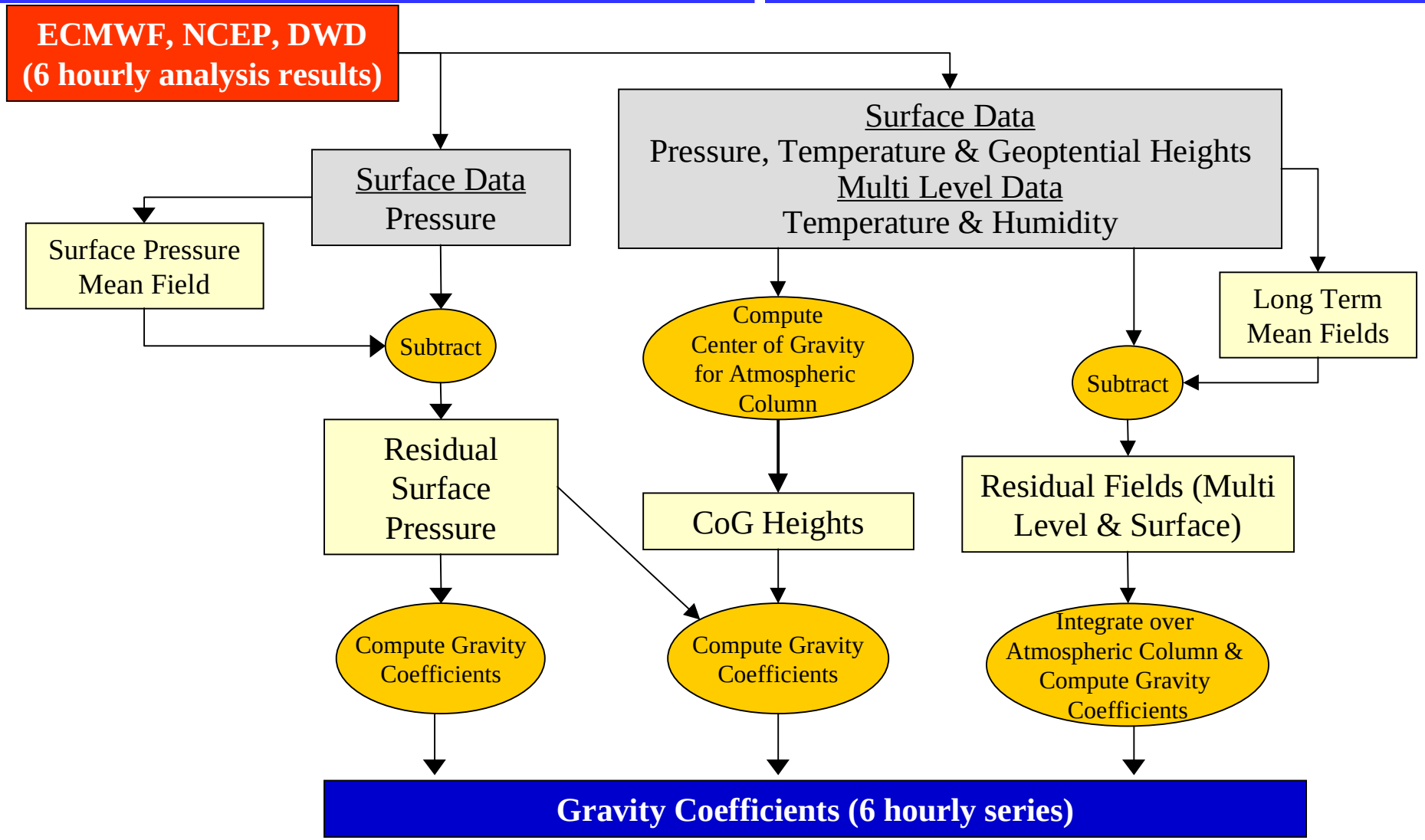
High Frequency Gravity Field Variations - Problem Definition

- **Mass variations cause time variant gravity field forces acting on the satellites**
- **Time varying gravity field forces have to be taken into account during orbit integration (for CHAMP & GRACE) or as correction to gradiometer measurements (for GOCE).**
- **Approach: Provision of gravity harmonics correction coefficients computed from external data to be applied to mean gravity field.**
- **Primary task: Computation of gravity coefficients corrections from different sources.**
- **Secondary task: Definition of mean gravity field with inclusion of mean atmosphere, ocean, ice and continental water.**

High Frequency Gravity Field Variations - Atmosphere



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High Frequency Gravity Field Variations - Atmosphere

$$V = \frac{kM}{r}\sum_{n=0}^{\infty}\sum_{m=0}^{n}\left(\frac{a}{r}\right)^{n} P_{nm}(\cos\theta)\left(C_{nm}\cos m\lambda + S_{nm}\sin m\lambda\right)$$

$$C_{nm} = \frac{1}{(2n+1)Ma^{n}}\iiint_{Earth} r^{n} P_{nm}(\cos\theta)\cos m\lambda\, dM$$

$$dM = \rho dV = \rho r^{2} dr\sin\theta d\theta d\lambda = r^{2} q\sin\theta d\theta d\lambda = r^{2} q dS \qquad q = \frac{P_S}{g} = \rho h \qquad \textit{(hydrostatic equation)}$$

Surface Pressure: *(on Earth surface r=a; k_n: load Love numbers for elastic deformation of Earth)*

$$C_{nm} = \frac{a^{2}(1+k_n)}{(2n+1)Mg}\iint_{Earth} P_S P_{nm}(\cos\theta)\cos m\lambda\, dS$$

Center of Gravity & Surface Pressure: *(r=a+z with z = center of gravity height)*

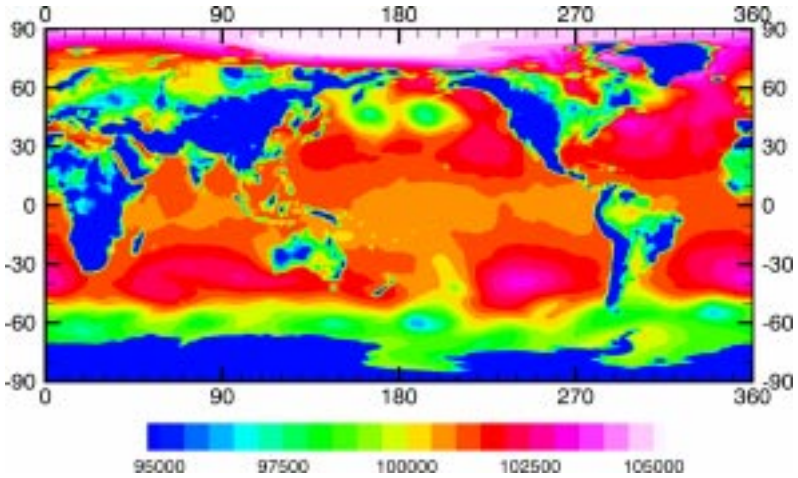
$$C_{nm} = \frac{(1+k_n)}{(2n+1)Ma^{n}g}\iint_{Earth} r^{n+2} P_S P_{nm}(\cos\theta)\cos m\lambda\, dS$$

Vertical Integration of Atmospheric Density:

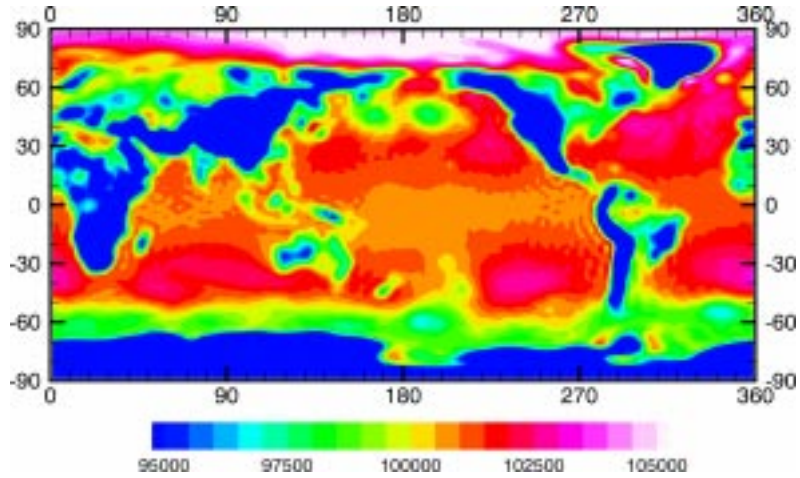
$$C_{nm} = \frac{(1+k_n)}{(2n+1)Ma^{n}}\iint_{Earth}\left[\int_{P_S}^{0}\frac{r^{n+2}}{g}dP\right] P_{nm}(\cos\theta)\cos m\lambda\, dS$$

High Frequency Gravity Field Variations - Atmosphere (Surface Pressure)

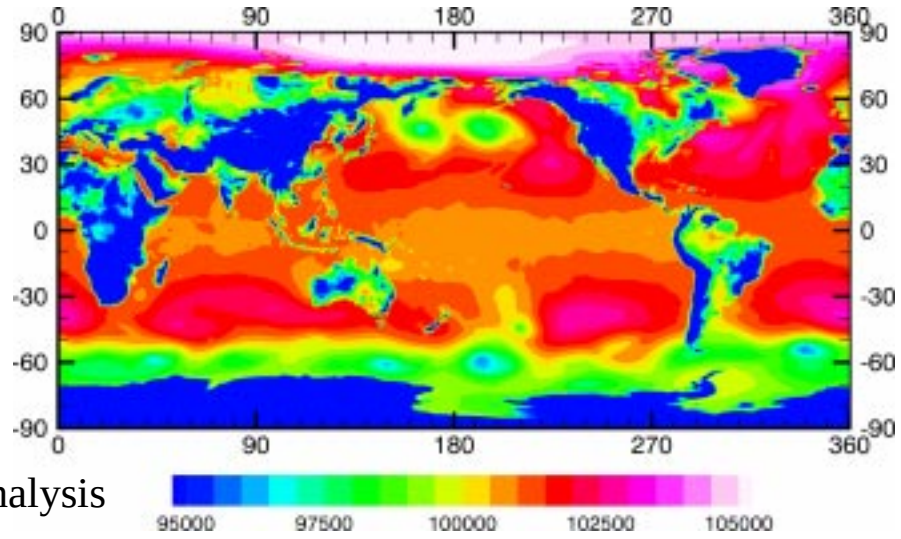
Surface Pressure from Different Analysis (23. Feb. 2001 00h)



DWD Analysis



NCEP Reanalysis



ECMWF Analysis

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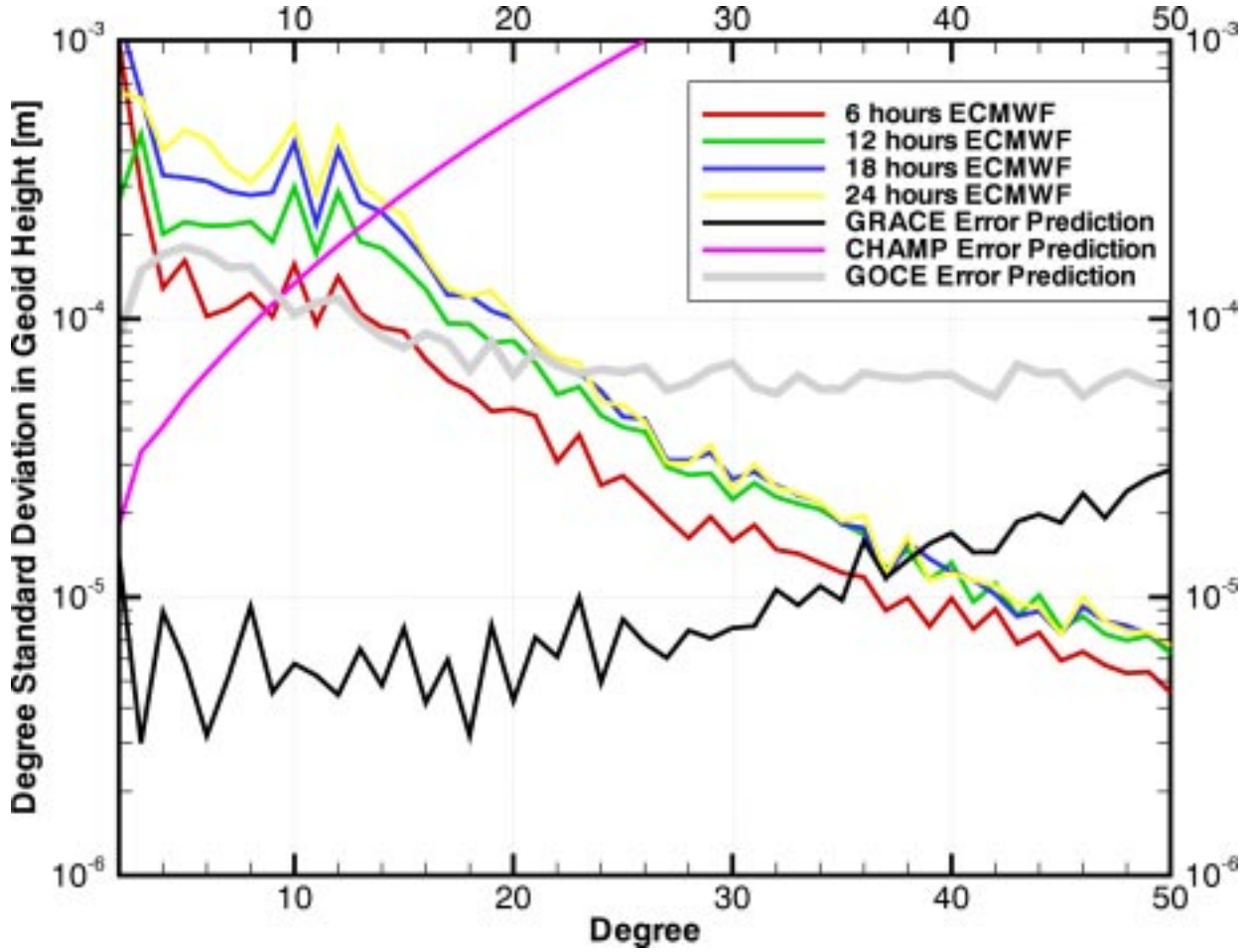
High Frequency Gravity Field Variations - Atmosphere (Surface Pressure)

Gravity Variations for Different Time Intervals (6, 12, 18, 24 hours) for ECMWF Surface Pressure Data (23.Feb. 2001)



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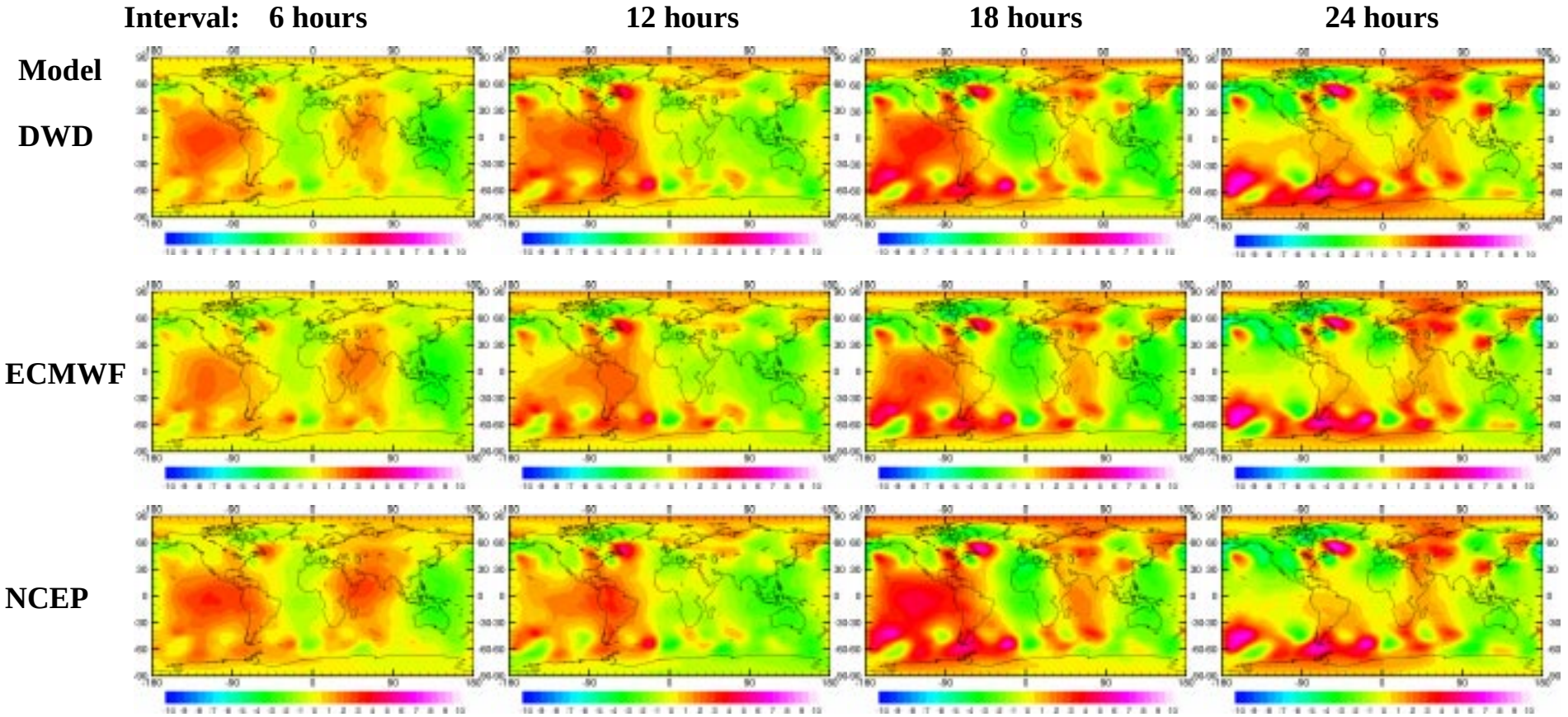
High Frequency Gravity Field Variations - Atmosphere (Surface Pressure)

Gravity Variations for Different Time Intervals for Different Atmospheric Analysis in Terms of Geoid Height Differences in mm (23. Feb. 2001)



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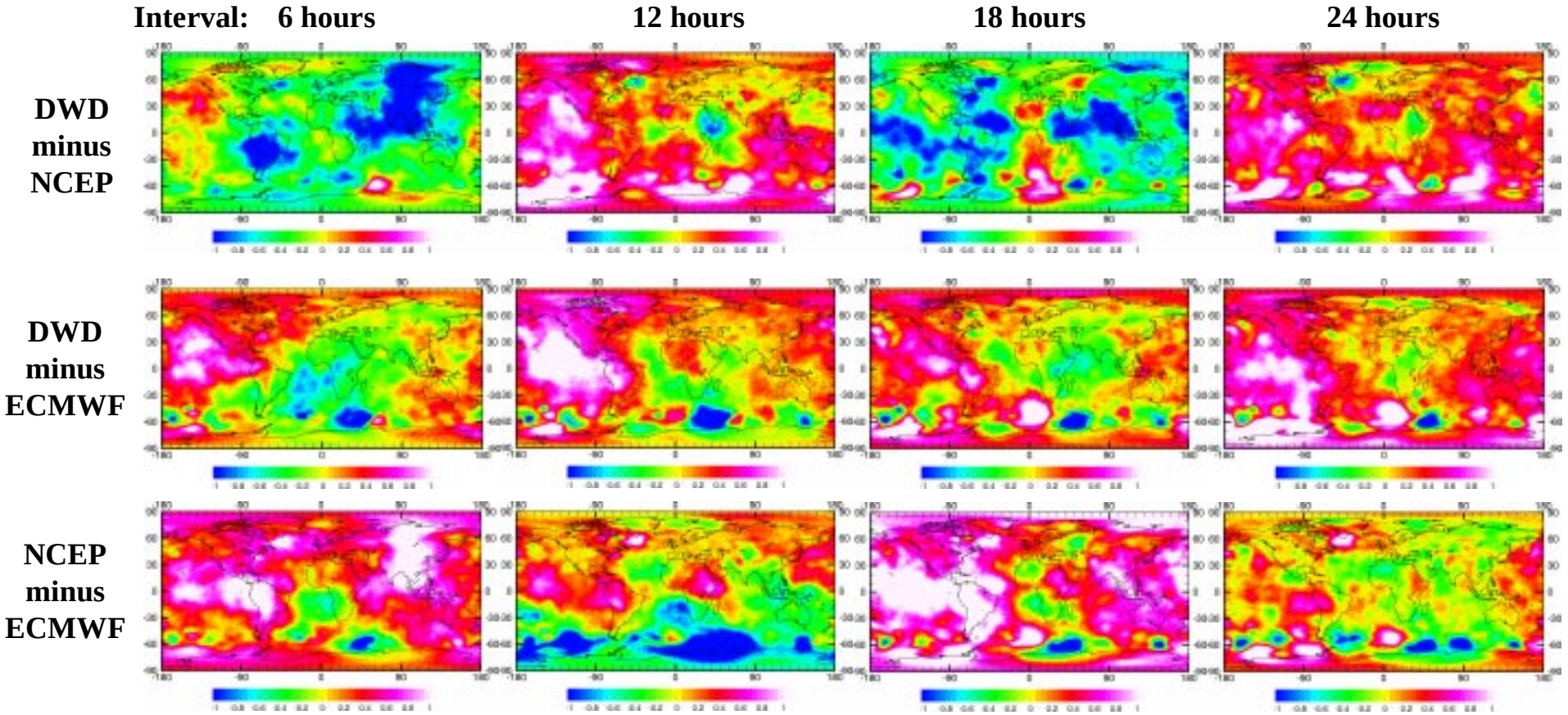
High Frequency Gravity Field Variations - Atmosphere (Surface Pressure)

Differences of Gravity Variations for Different Time Intervals for Different Atmospheric Analysis in Terms of Geoid Height Differences in mm (23. Feb. 2001)



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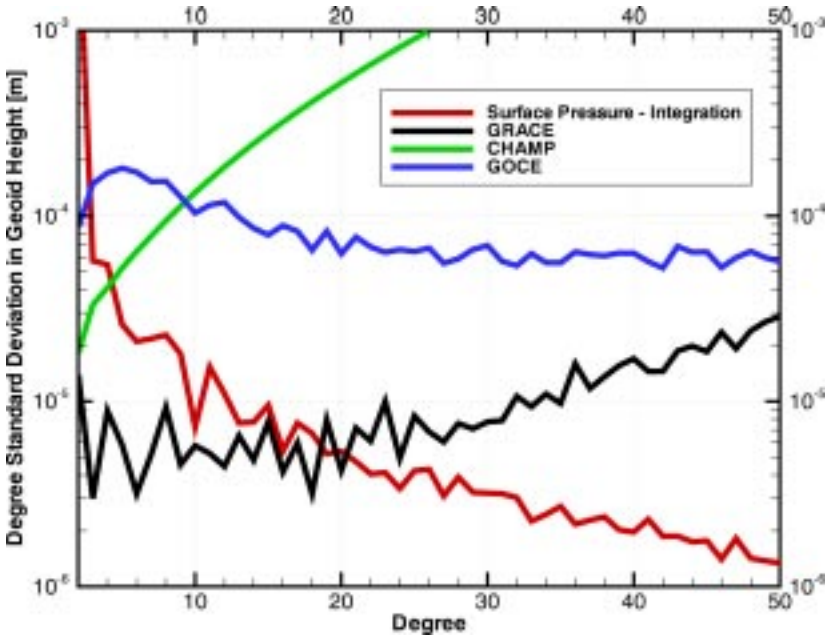
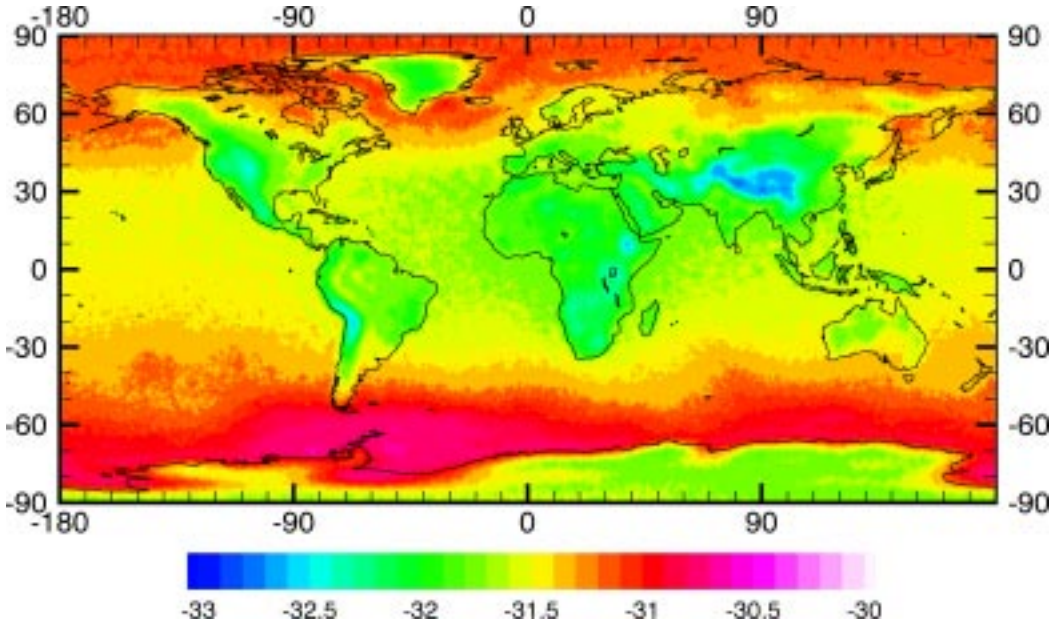
High Frequency Gravity Field Variations - Atmosphere (Vertical Integration)

Difference Surface Pressure - Vertical Integration





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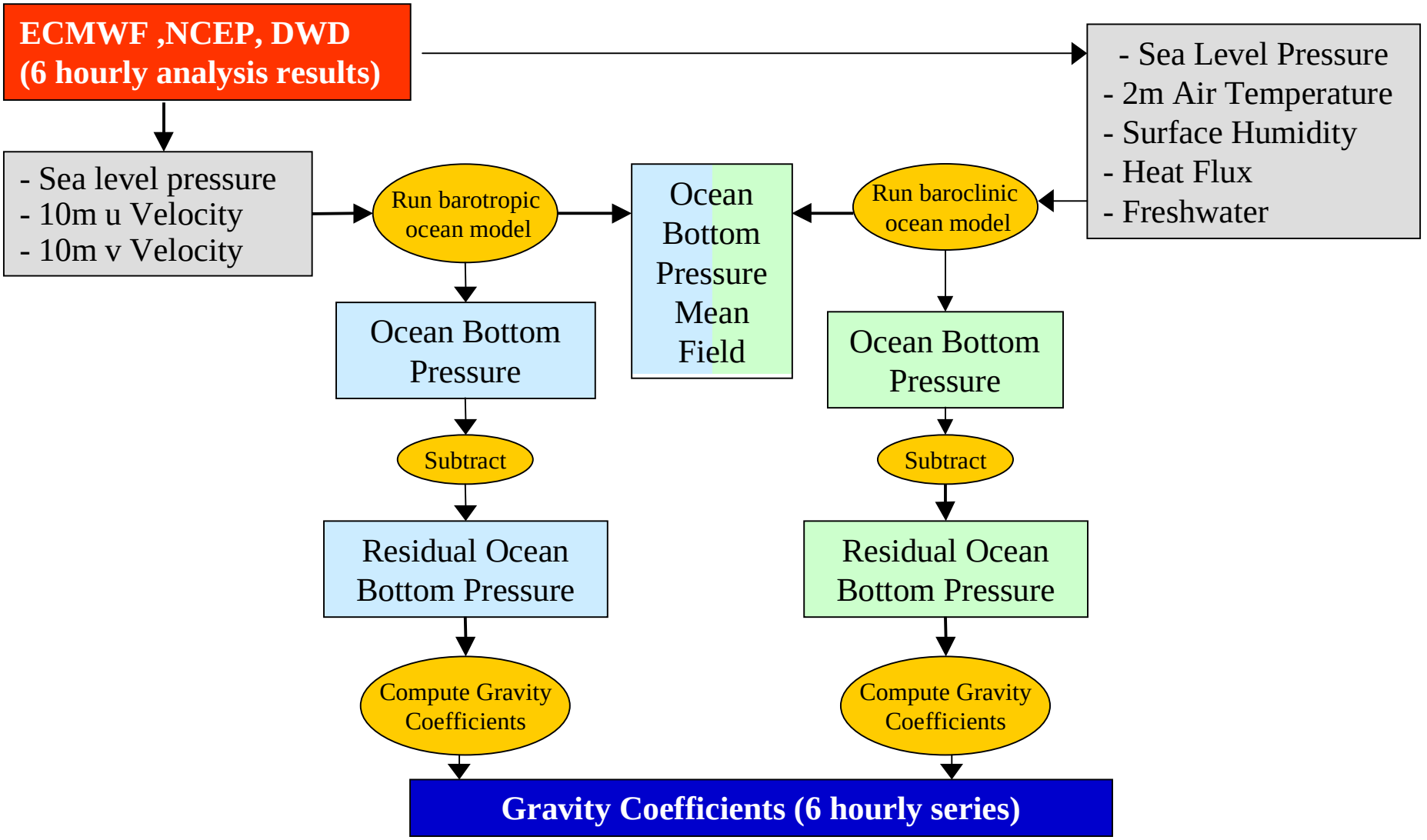
High Frequency Gravity Field Variations - Ocean



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High Frequency Gravity Field Variations - Ocean

Ocean Models available for GRACE Science Data System

Barotropic Model: Ponte-Hirose-Ali Version 1.1

Implemented at JPL by V. Zlotnicki

- 1.125 degree resolution, 1 hour time interval
- Global from 75S to 65N incl. Mediterranean. & smaller closed seas
- Forcing: Atmospheric pressure and 100 mbar winds converted to wind stress; Atmospheric thermal tides removed by filter.
- Bathymetry: ETOPO5 with modifications in shallow sea

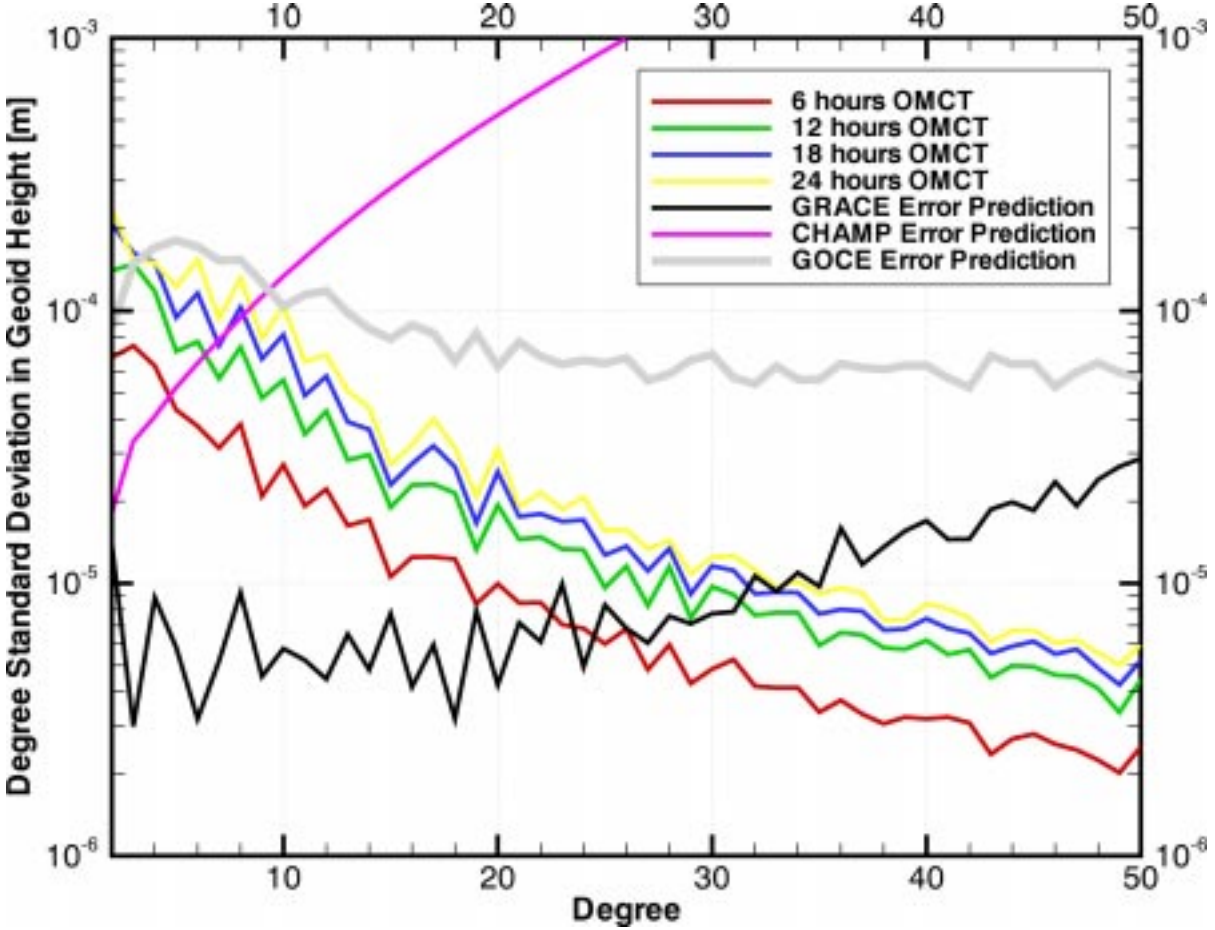
Baroclinic Model: Hamburg Ocean Model for Circulation and Tides

Developed and implemented by M. Thomas, J. Sündermann

- 1.875 degree resolution, 1 hour time interval, 13 layers
- Forcing: Atmospheric Pressure, wind vectors/wind stress, surface temperature, surface humidity, heat flux and freshwater desired
- Prognostic variables: Sea surface elevation, horizontal velocities, temperature, salinity, sea ice thickness and compactness

High Frequency Gravity Field Variations - Ocean

Gravity Variations for Different Time Intervals based on Hamburg OMCT Model (24. June 1994)



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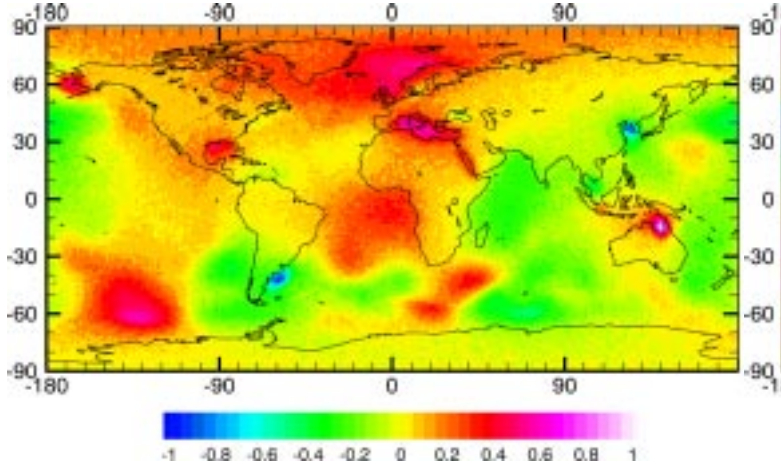
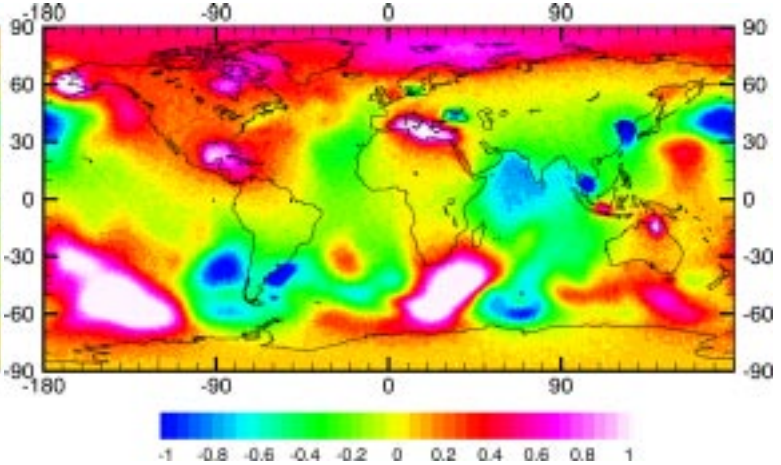
High Frequency Gravity Field Variations - Ocean

Gravity Variations for Different Time Intervals based on Hamburg OMCT Model

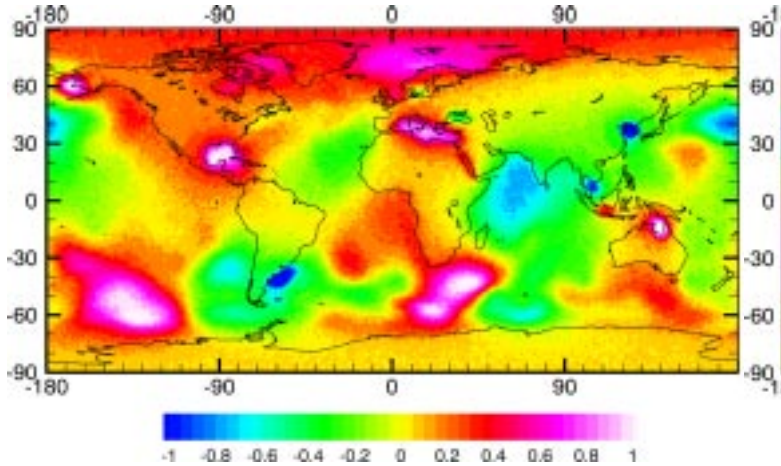
6 hours



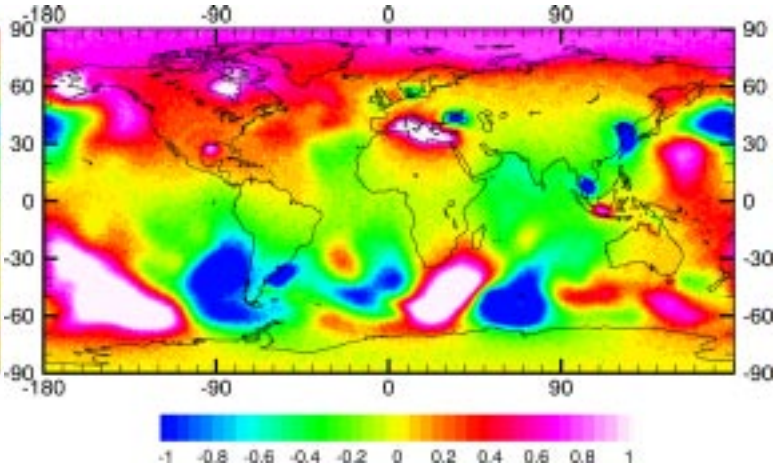
18 hours



12 hours



24 hours



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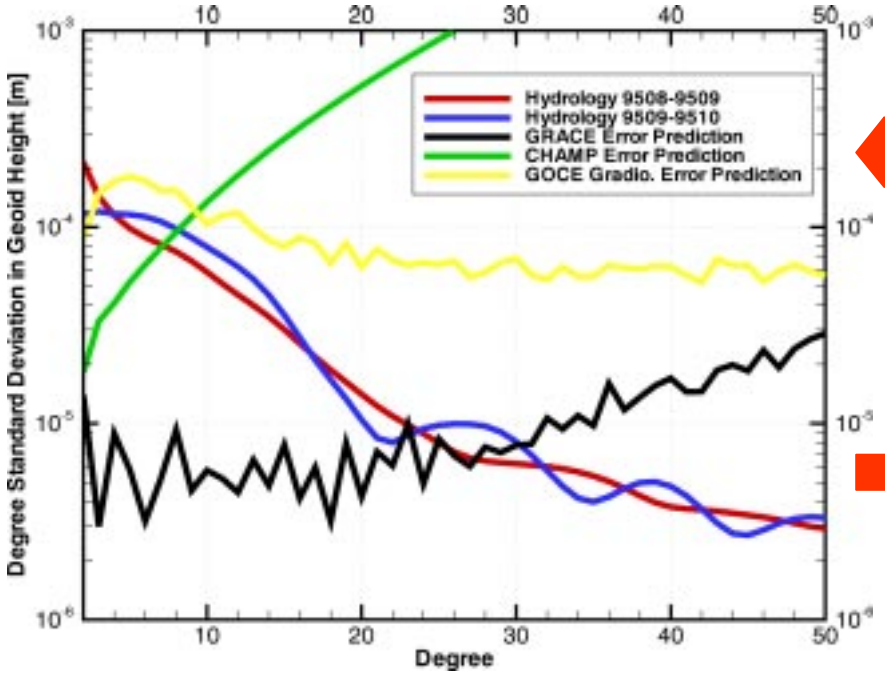
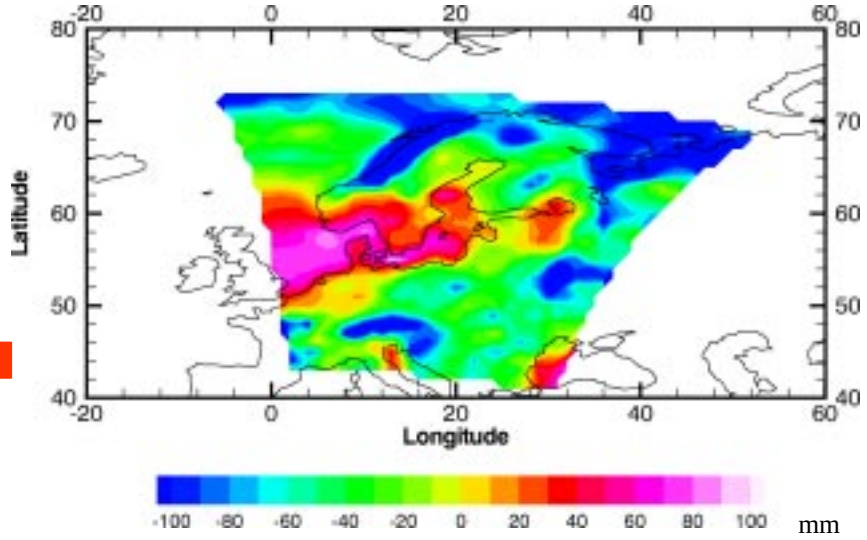
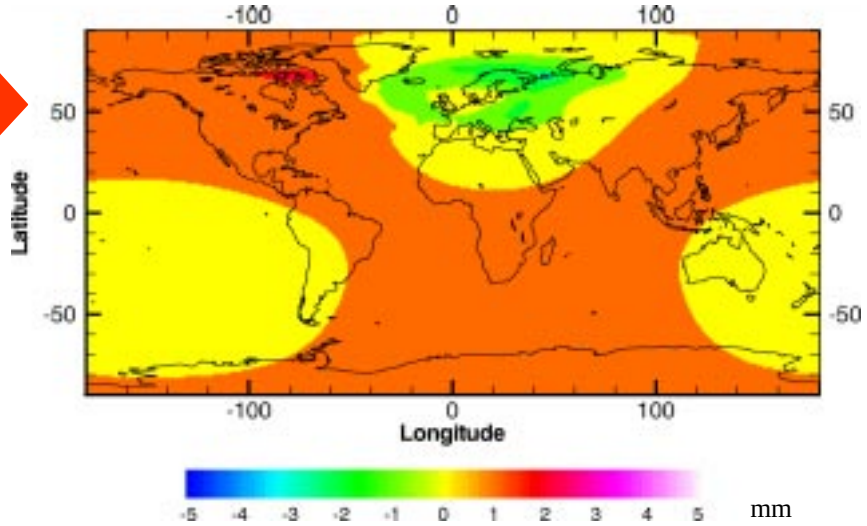
Seasonal Gravity Field Variations - Hydrology

Monthly Continental Water Redistribution over Europe (GKSS Model): Evaporation minus Precipitation







Gravity Coefficients Variations caused by Monthly Continental Water Mass Redistribution and Corresponding Geoid Variation

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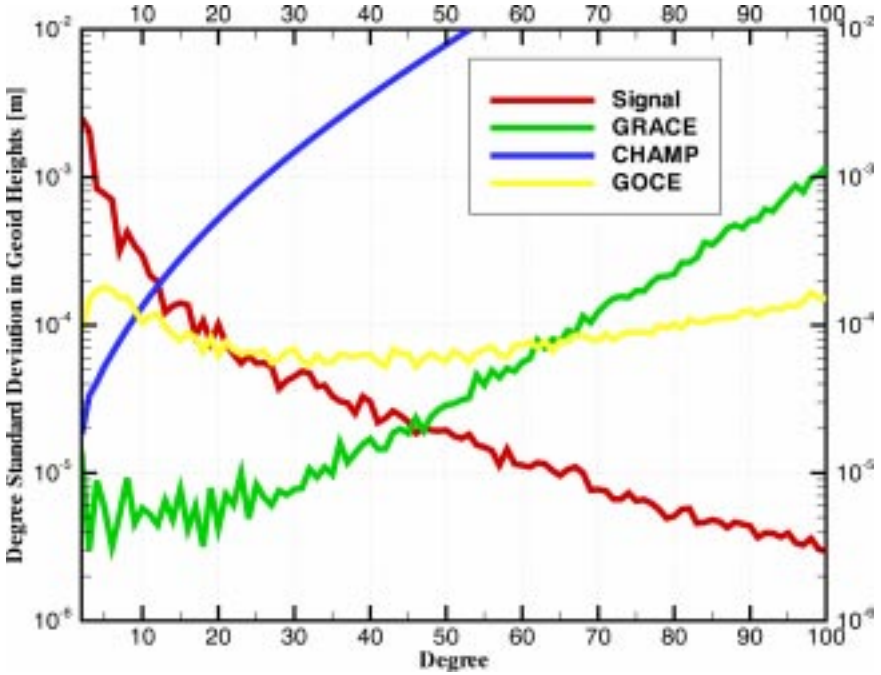
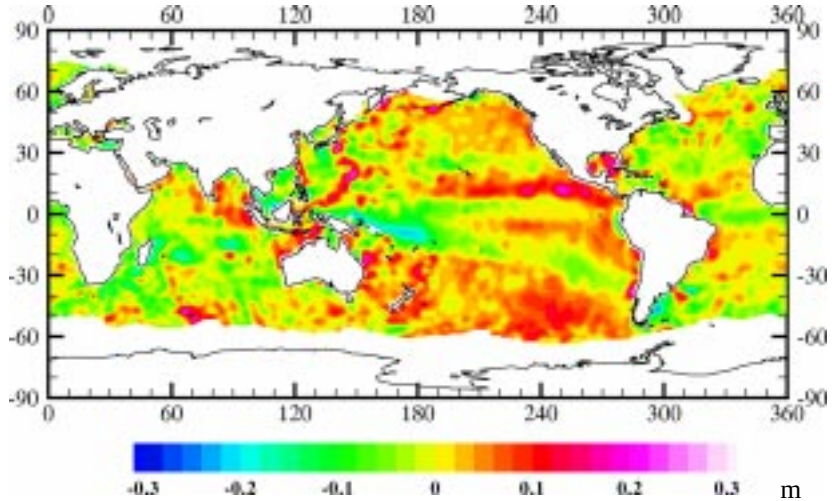
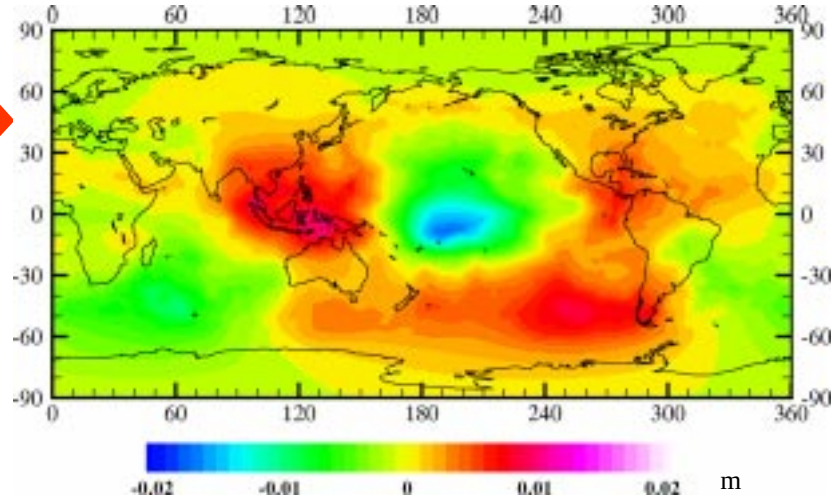
Seasonal Gravity Field Variations - Ocean

Monthly Sea Surface Height Variation wrt. 3 Years Mean Surface (Observed by Altimetry; Thermal Expansion Subtracted)







Gravity Coefficients Variations caused by Monthly Ocean Water Mass Redistribution and Corresponding Geoid Variation

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Data Processing Synergies

High Frequency Gravity Variation

- Tides: CHAMP and GRACE gravity field determination will include update of initial tidal model. In addition better initial model from altimetric/ hydrodynamic data analysis necessary. GOCE will profit from these developments significantly.
- Atmospheric/ Oceanic Variations: GRACE project will systematically produce gravity field correction coefficients from both sources based on best available models. Same corrections can also be used for GOCE observation corrections.

Seasonal Gravity Variation

- GRACE project will systematically provide monthly mean gravity field solutions. The analysis of this sequence of gravity field models can be used for reducing monthly effects as well as the seasonal bias in GOCE gravity field solution.

Conclusions

- **Mission Scenarios are Complementary in Sequence, Observation Period and Spatial Sampling.**
- **Combined Gravity Model (for all 3 Missions) can Enhance Single Mission Solutions.**
- **Significant Project Synergies within GFZ (and possibly with EGG-C Consortium) are obvious (e.g. Archives, Software, Processing Experience).**
- **High Frequency and Seasonal Time Variable Gravity Field De-Aliasing for GOCE will be based on GRACE Developments and Results.**
- **CHAMP, GRACE and GOCE should be commonly seen as one Tool for improving the Knowledge of the Earth Gravity Field.**