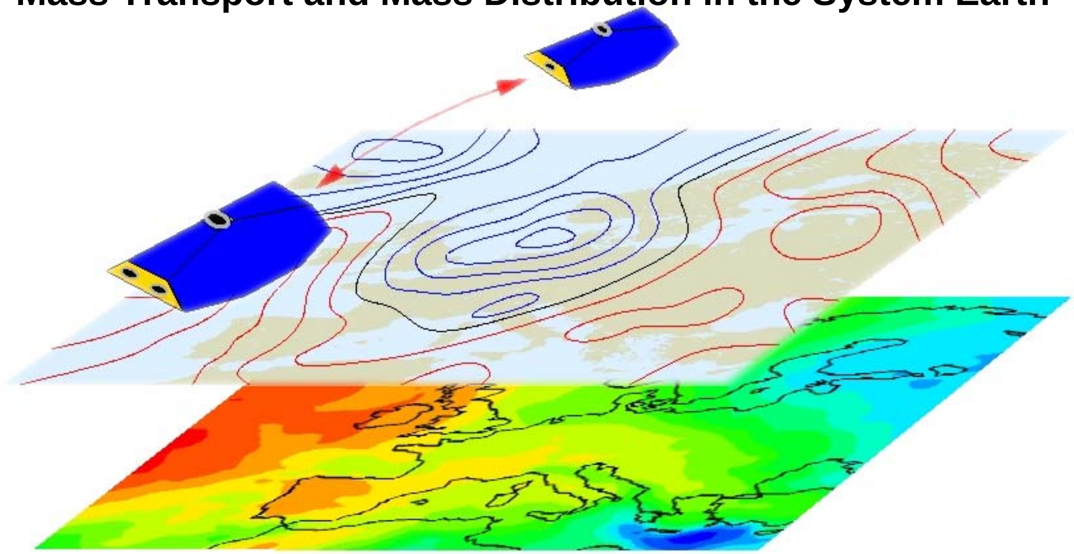
Improved DE-ALiasing for Gravity Field Modeling with GRACE
(IDEAL-GRACE)

A Project within the DFG Priority Program SPP1257
Mass Transport and Mass Distribution in the System Earth



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Comments/Questions on GRACE De-Aliasing (1)

1. What was the idea?

   → Remove known mass variation signal. It was thought that we know it for the atmosphere and the oceans.

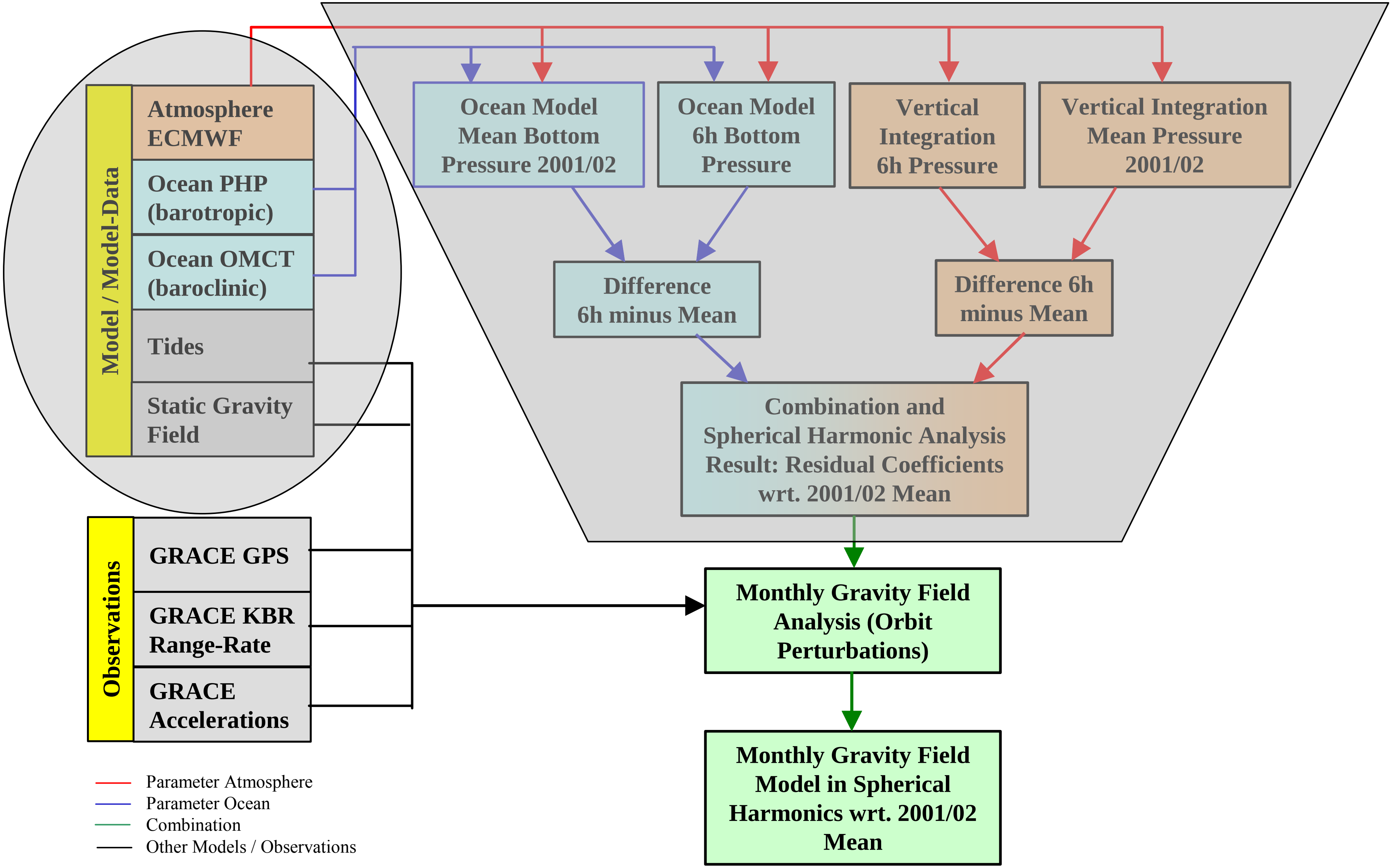
2. Implementation:

   Mass variations of the atmosphere and the oceans with respect to a multi year mean are corrected during gravity field estimation procedure by updating the force model (vertical integration required). Both data sets are regarded as error-free. Result: Gravity potential correction SHS (GAA, GAB, GAC, GAD).

Comments/Questions on GRACE De-Aliasing (2)

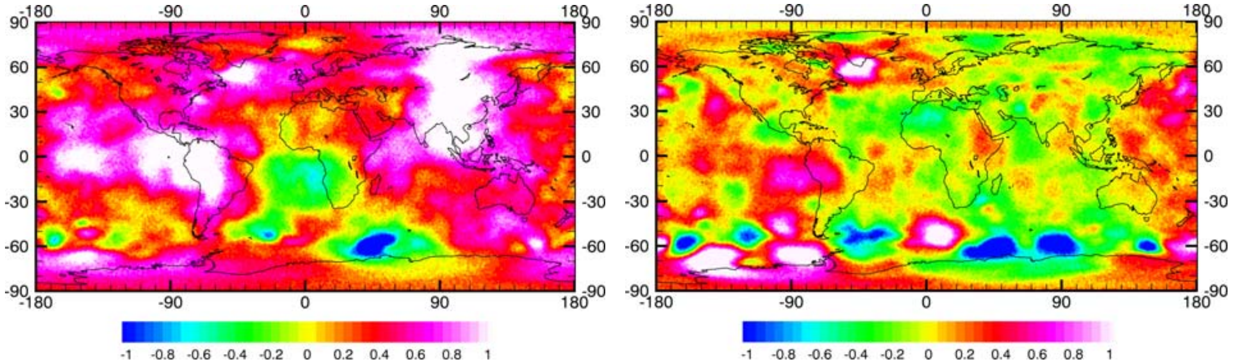
3. My questions without answers:
   - Why was the non-mass conserving OMCT implementation regarded as not applicable for GRACE de-aliasing, even if ocean mass variations are corrected wrt. a multi year mean ?
   - Is it allowed to add back monthly mean de-aliasing products regarding that the gravity field estimation step in between is a non-linear process ?
   - For ocean applications: Why not adding back bottom pressure values directly taken from the OMCT model (which includes the atmosphere) on a grid instead of going via spherical harmonics with all its problems at coastal areas?.
4. Possible answer for some of the questions: Perform de-aliasing wrt. to monthly mean instead to multi-year mean. Regard GRACE as an observation system for total monthly mass variation signal instead assuming known long period signals.

Current GRACE De-Aliasing Process



Overall Project Goals

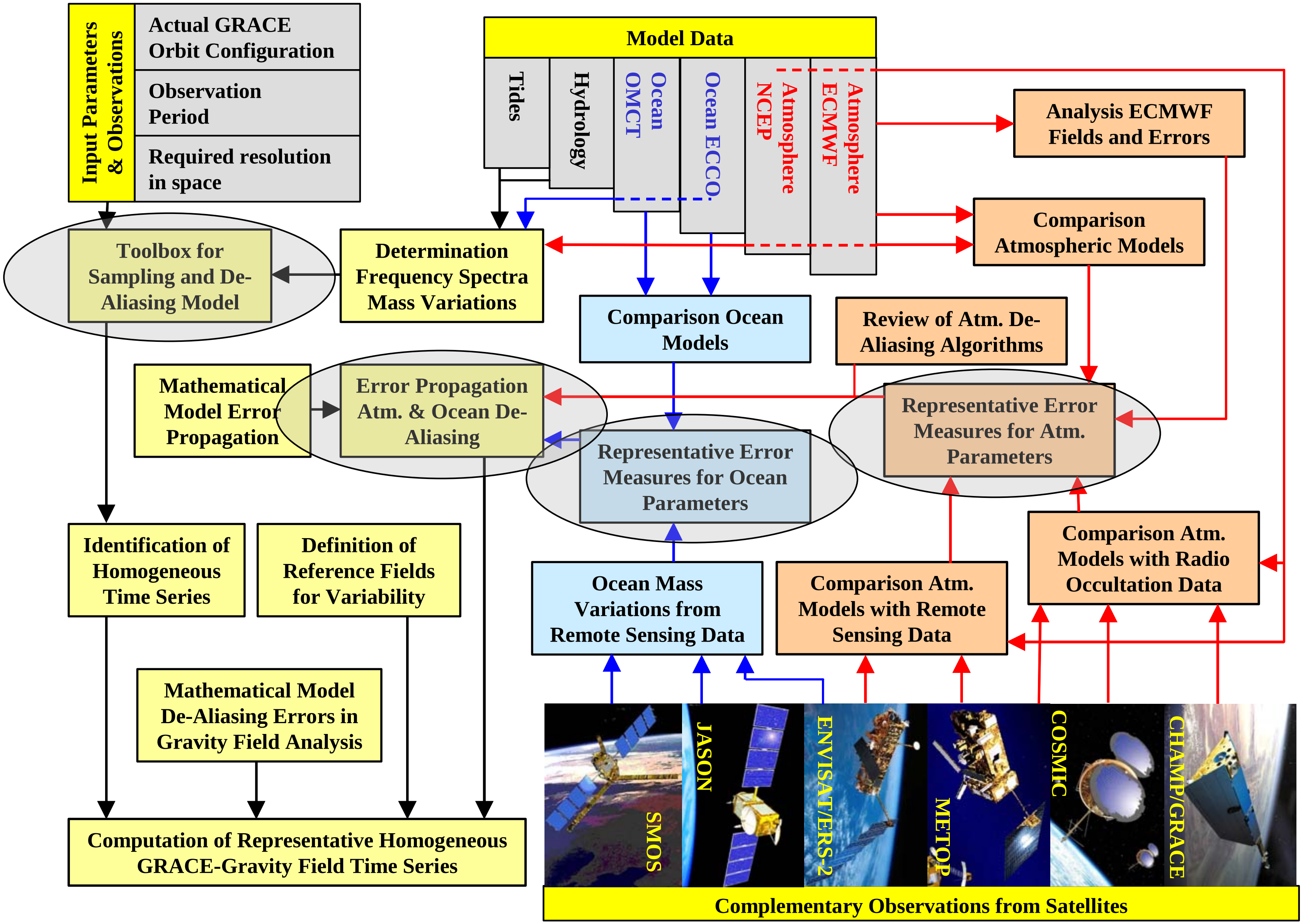
1. The assumption of error free atmospheric and oceanic input parameters shall be reviewed by independent data and representative error measures for them shall be determined.



Differences of geoid height variations in [mm] between NCEP re-analysis and ECMWF operational analysis for two different time stamps (left: 23.2.2001 18:00, right 23,2,2001 24:00).

2. The de-aliasing concept shall be improved by:
   - developing a full mathematical sampling and aliasing model for identification of homogeneous time series.
   - developing an error propagation for the de-aliasing.

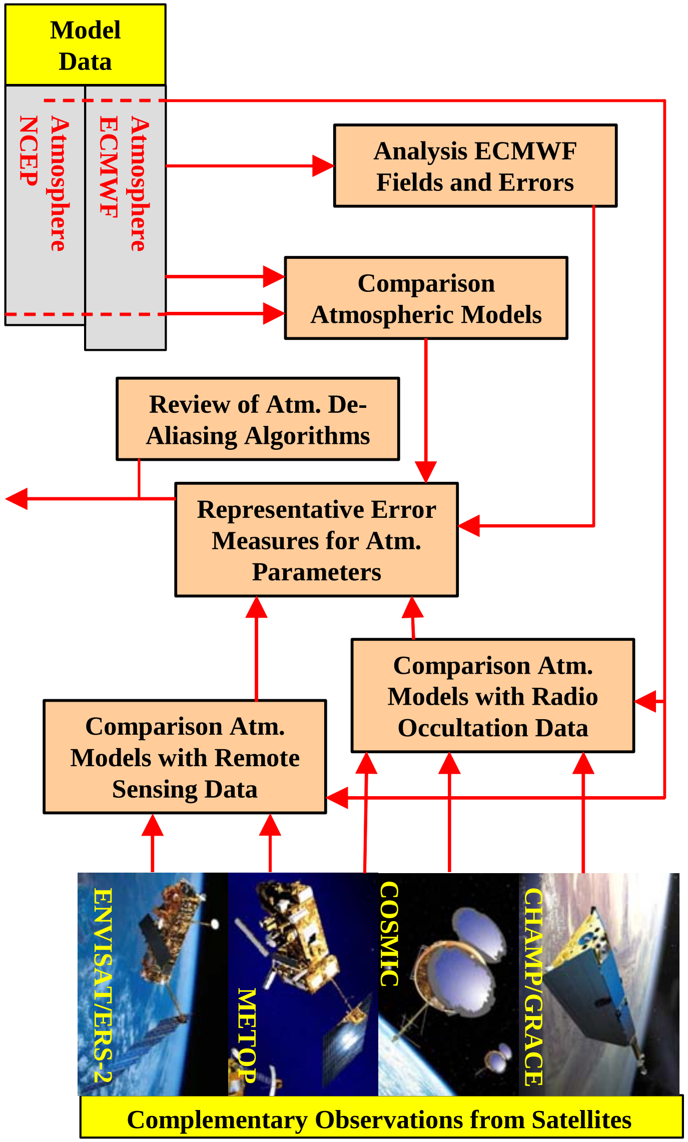
Project Layout



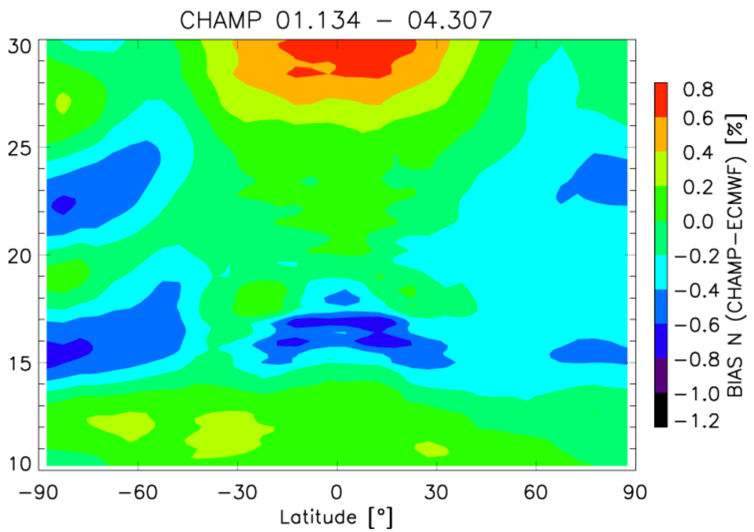
Work Packages - Atmosphere

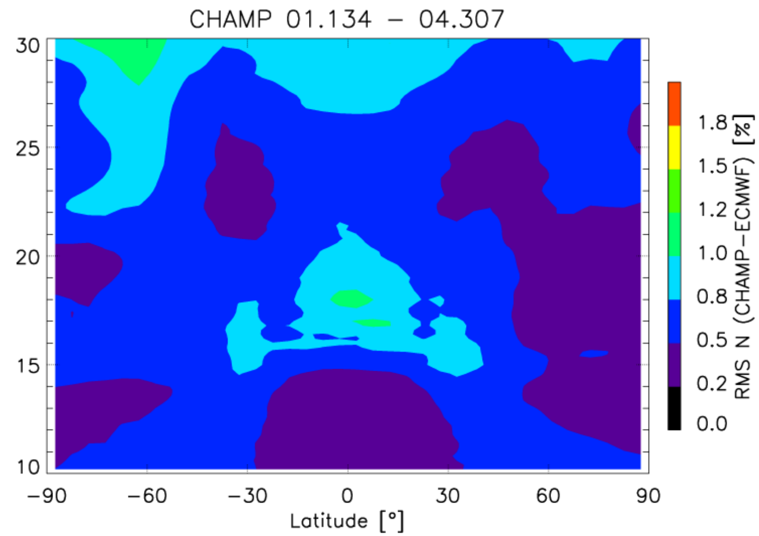
- Analysis of global meteorological fields and error information from ECMWF (GFZ). Determination of spatial and temporal mean values.
- Comparison between different atmospheric models (GFZ). Determination of error characteristics of ECMWF fields.
- Comparison ECMWF analyses with radio occultation data (GFZ).
- Comparison of model output with satellite observations (remote sensing and atmosphere sounding missions) (DLR).
- The algorithms applied for atmospheric de-aliasing are reviewed (DLR)

➢ Main outcome atmosphere:
Determination of representative error measures for atmospheric parameters to be further used in de-aliasing.

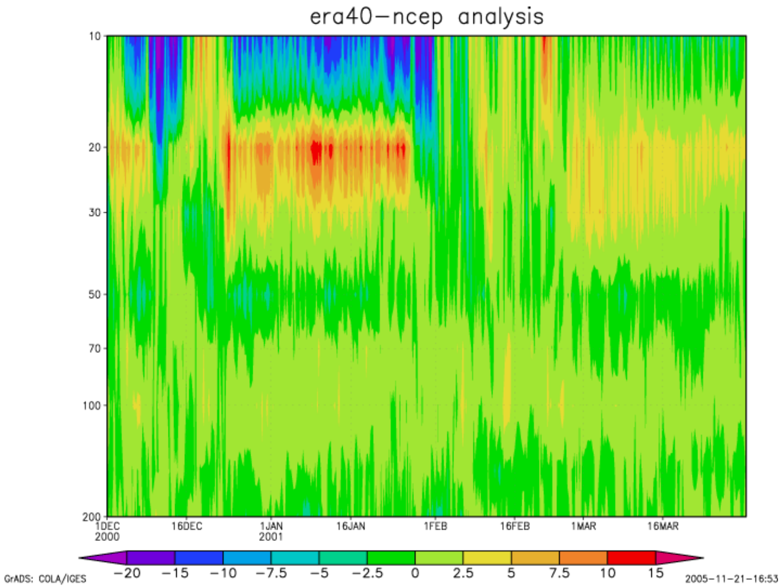


Examples - Atmosphere





<u>Above:</u> Comparison of CHAMP refractivity data with corresponding ECMWF analyzes (CHAMP-ECMWF) in the upper troposphere/stratosphere (left: bias; right: rms) between May 14, 2001 and June 8, 2005 (~ 200, 000 profiles). The refractivity of the occultation can be derived without meteorological "background" data. The different patterns above the northern and southern hemisphere are related to weaknesses of the ECMWF data.

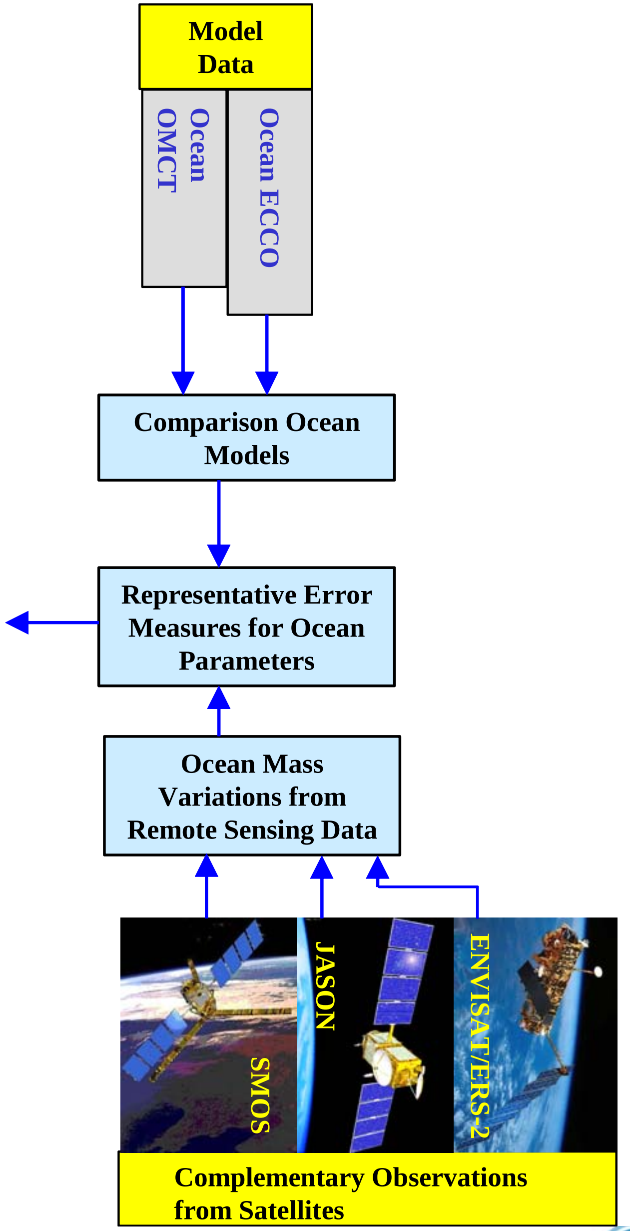


<u>Left:</u> Height-Time cross section (200-10 hPa) of temperature difference between ECMWF (ERA40) and NCEP reanalysis between Dec. 1, 2000 and March 31, 2001 at Ny Aalesund, Spitzbergen (78°12N). The differences can reach up to 20 K.

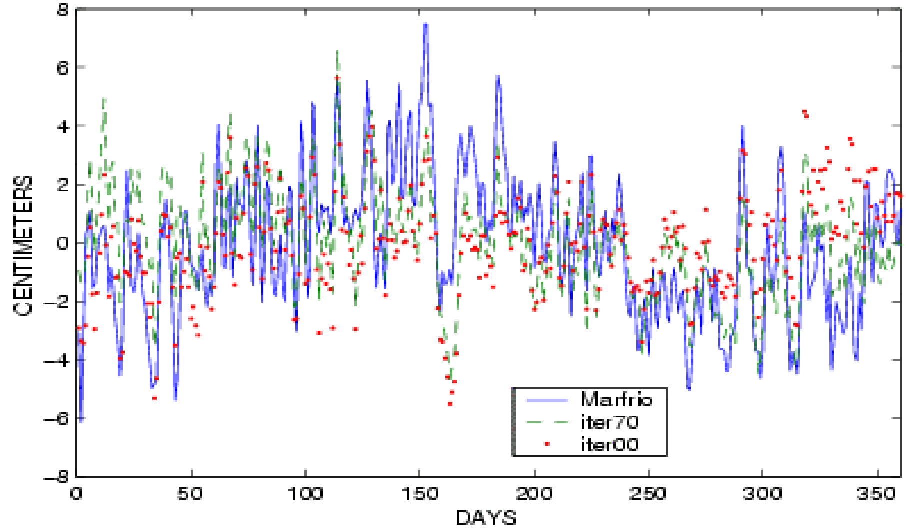
Work Packages - Ocean

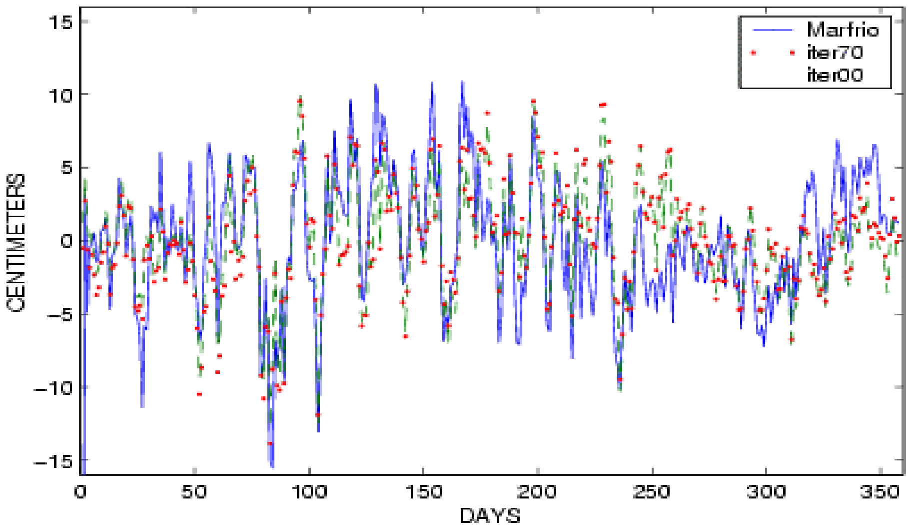
- Ocean model inter-comparison study (UNI-HH). RMS and time mean differences in bottom pressure and surface elevation.
- Comparison of ocean mass variations from ocean model and remote sensing data (UNI-HH). RMS and time mean differences between model solution and satellite data.

➢ <u>Main outcome ocean:</u>
Determination of representative error measures for ocean bottom pressure data to be further used in de-aliasing.



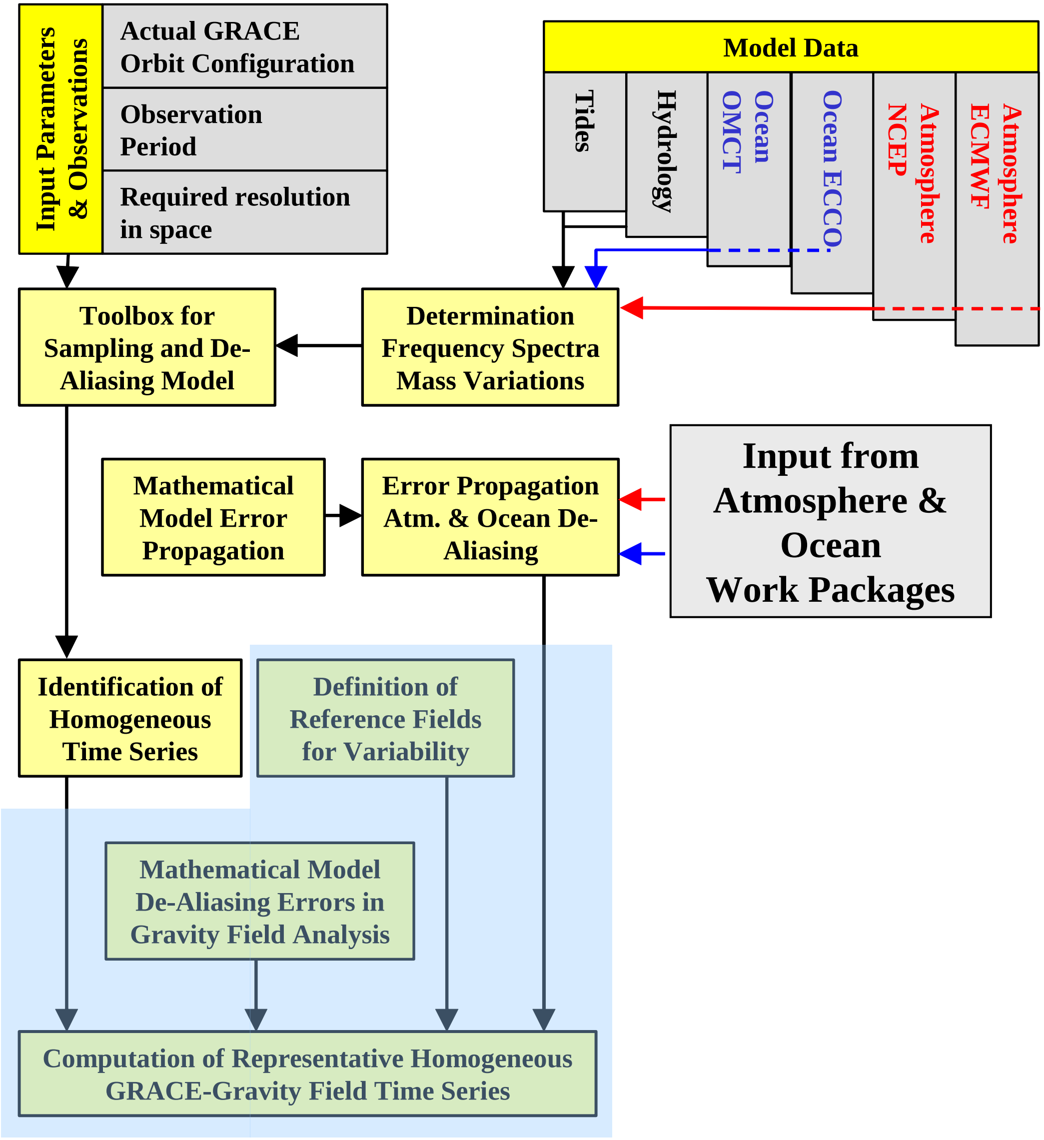
Examples - Ocean





Comparison of ocean bottom pressure variations from data with an unconstrained model (labelled iter 0), with a constrained one (after 70 iterations).
Upper panel is for an instrument at 31degree S, 36 degree W, 2604m depth, and
Lower panel is for an instrument at 46 degree 52' S, 52 degree 28' E in 3600m of water (from Wunsch and Stammer, 2003).

Work Packages - Geodesy



- Mathematical model for error propagation of de-aliasing and implementation in source code according to GRACE software standards (IAPG).
- Spectral analysis of mass variation phenomena (IAPG).
- Development of a toolbox for the analysis of the sampling and aliasing characteristics for satellite missions observing mass variations (IAPG).
- Applying the toolbox for GRACE time series in order to identify homogeneous GRACE time series (IAPG).
- Further application of de-aliasing errors, definition of reference fields for variability and reprocessed GRACE time series planned for second project phase (GFZ)

Examples - Geodesy

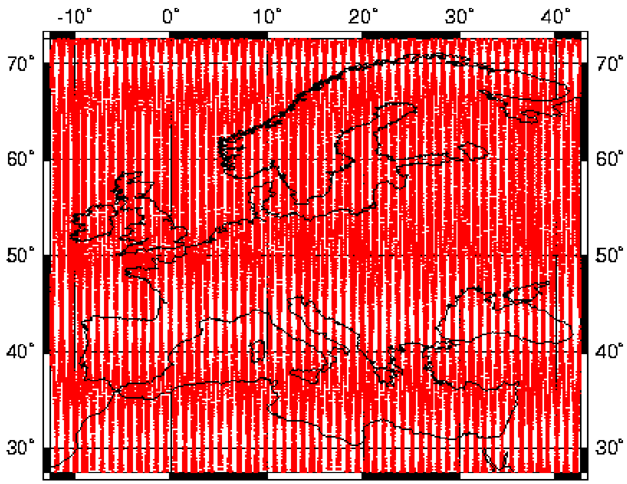
$$T_v = (1+0.608S)T \quad ; \quad P_{k+1/2} = a_{k+1/2} + b_{k+1/2} P_S$$

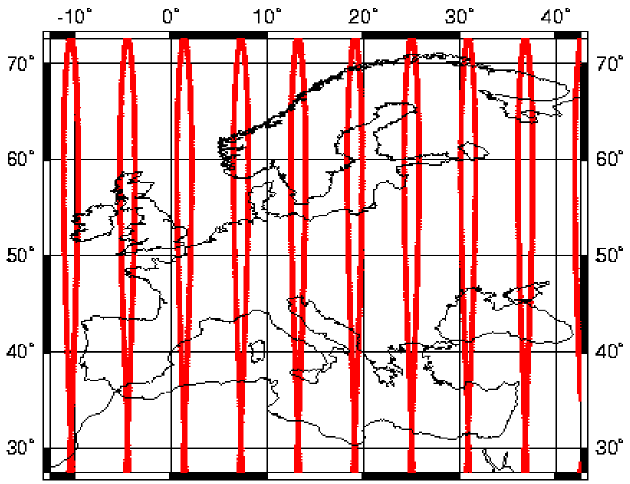
$$\Phi_{k+1/2} = \Phi_S + \frac{1}{g}\sum_{j=k+1}^{N_{level}} R_{dry} T_v \ln \frac{P_{j+1/2}}{P_{j-1/2}}$$

$$C_{nm} = -\frac{a^2(1+k_n)}{(2n+1)Mg} \iint_{Earth} \left[\int_{P_S}^{0} \left(\frac{a}{a-\Phi} + \frac{\xi}{a} \right)^{n+4} dP \right] P_{nm}(\cos\theta)\cos m\lambda \sin\theta d\theta d\lambda$$

$$S_{nm} = -\frac{a^2(1+k_n)}{(2n+1)Mg} \iint_{Earth} \left[\int_{P_S}^{0} \left(\frac{a}{a-\Phi} + \frac{\xi}{a} \right)^{n+4} dP \right] P_{nm}(\cos\theta)\sin m\lambda \sin\theta d\theta d\lambda$$

<u>Error Propagation De-Aliasing:</u>
Formulas for which error propagation has to be developed





<u>Sampling & Aliasing Problem:</u>
GRACE sampling characteristics for two specific months (extreme cases)

Conclusions

- **We expect to get a much deeper insight into the problem of de-aliasing of GRACE, which might be one of the main remaining uncertainty sources in the GRACE data analysis.**

- **Sampling and aliasing toolbox could be used for the mission planning of future gravity field mission targeting on the detection of mass variations.**

- **Project is funded for 2 years. Extension planned to include the remaining work packages.**