GOCE Gravity Gradients for Solid Earth Sciences

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with contributions from Mirko Reguzzoni

Many thanks to our GOCE HPF colleagues:
Sophie Fiorot, Thomas Gruber, Ejo Schrama,
Christian Tscherning, Pieter Visser, …
ESA support is acknowledged (GOCE HPF, STSE)

From L1b to User Gradients

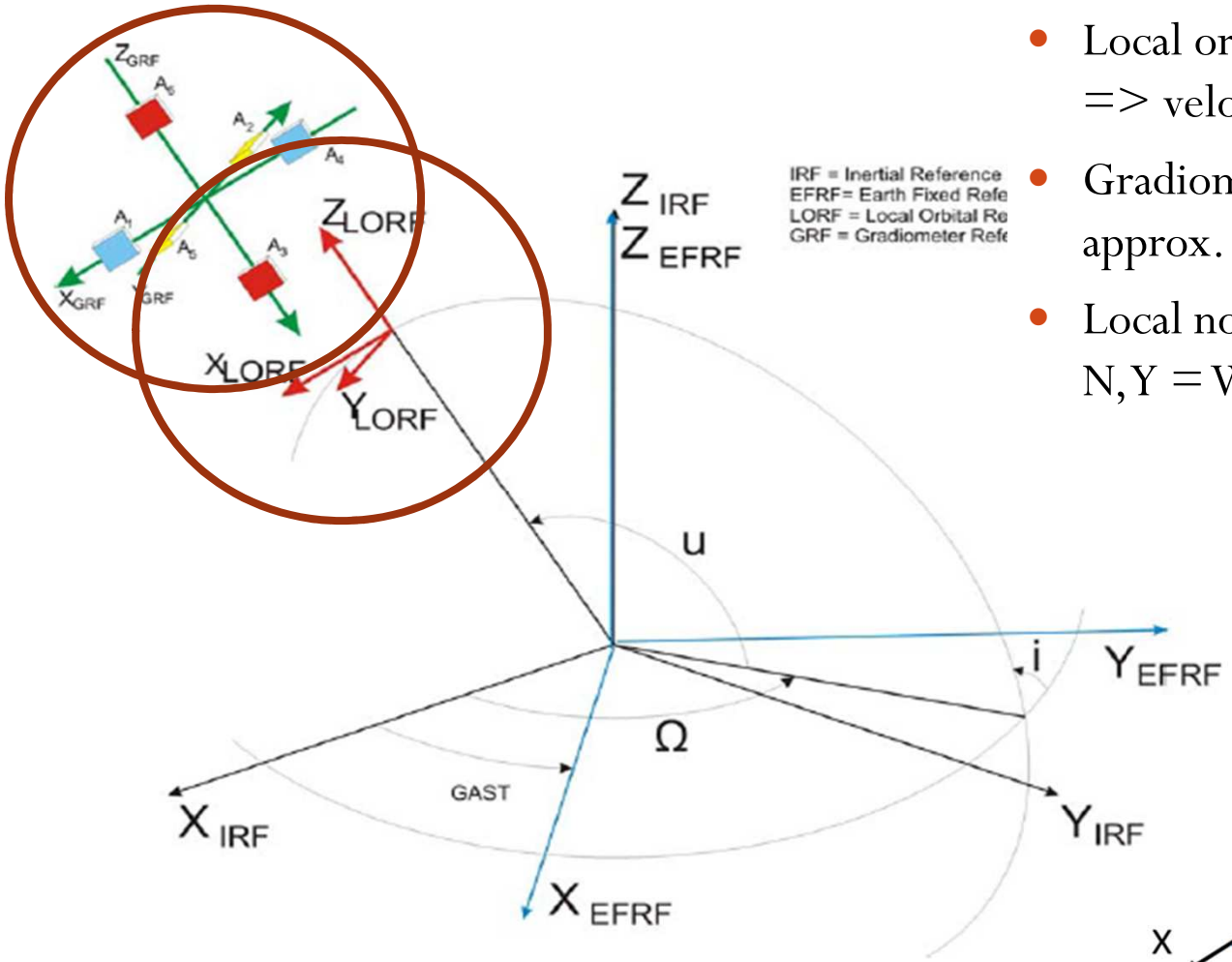
- Part I: gradients along the orbit
  - Gradients in instrument and north-oriented frame
  - Data processing & quality
- Part II: gradients in grids
  - Mean orbital altitude and close to Earth
  - Data processing
- Where to get the data?
- Summary

Part I: Gradients along the orbit

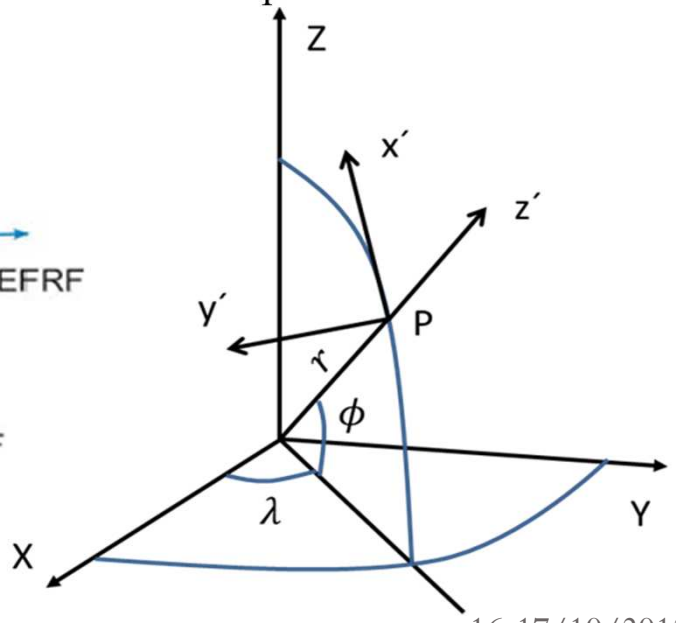
GOCE HPF

GOCE+ GeoExplore

Reference frames: GRF, LORF and LNOF

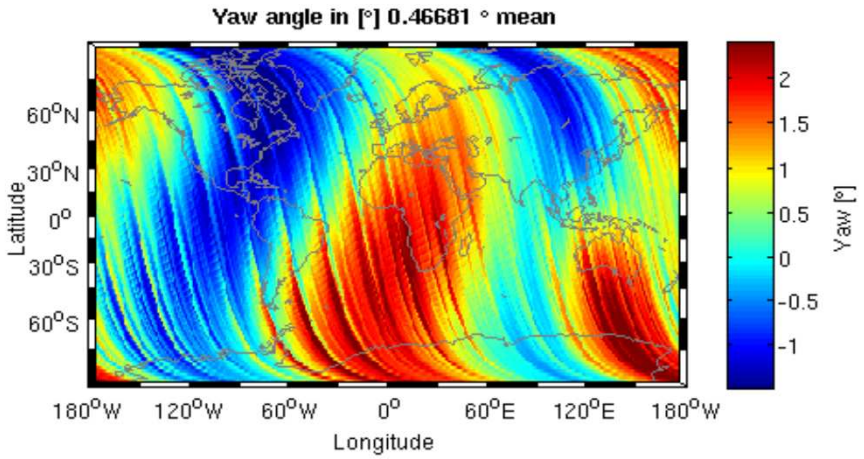


- Local oribital reference frame (LORF): X => velocity vector
- Gradiometer reference frame (GRF): approx. LORF
- Local north-oriented frame (LNOF): X = N, Y = W, Z = Up

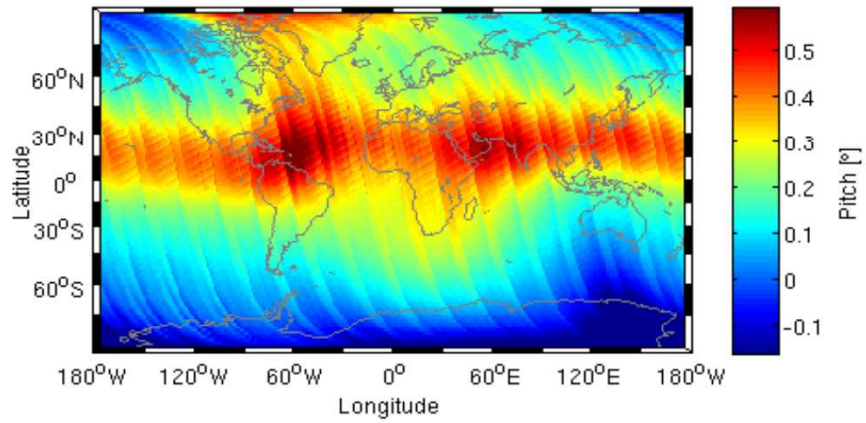


Example: rotation around Z- and Y-axis

GRF to LORF

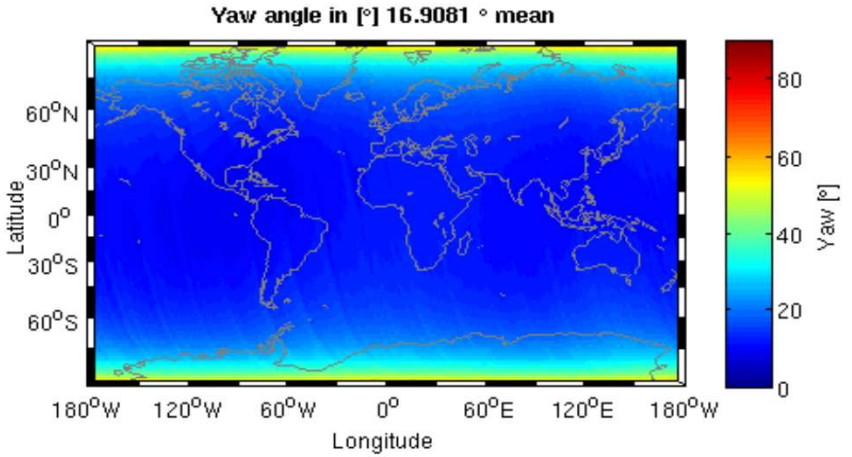


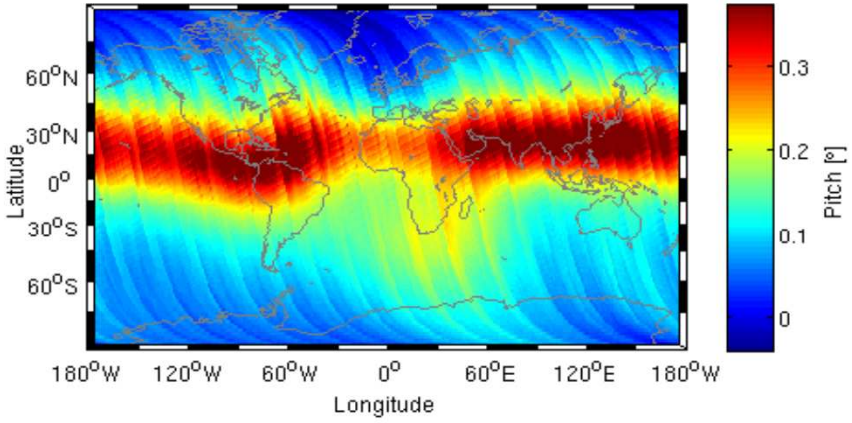
Z



Y

GRF to LNOF





Gravity gradients along the orbit

- Time series of gravity gradients $V_{XX}, V_{YY}, V_{ZZ}, V_{XY}, V_{XZ}, V_{YZ}$

1. **Given in GRF (instrument frame)**
   - X ≈ velocity direction
   - Y ≈ cross-track direction
   - Z ≈ radial direction
2. **Given in LNOF (Earth related)**
   - X = North
   - Y = West
   - Z = Up

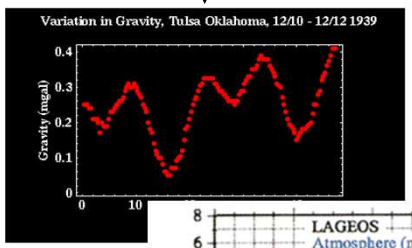
- Note: Z in GRF and LNOF almost equal, X and Y very different

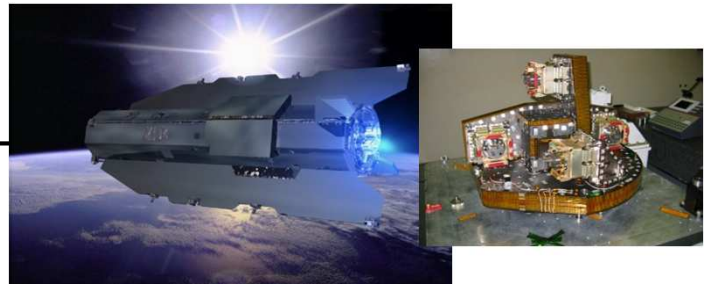
Two classes of products

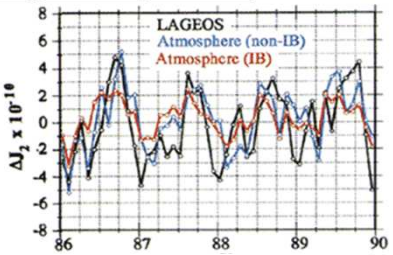
- Computed by GOCE HPF: "GOCE-only"
  - GRF: EGG_NOM_2
  - LNOF: EGG_TRF_2
- Computed in context of GOCE+ GeoExplore: GOCE/GRACE gradients
  - GRF: GGC_GRF
  - LNOF: GGC_NWU

- How are these products computed?

Gravity Gradient Processing

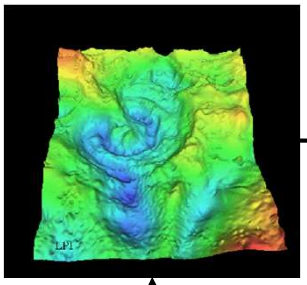






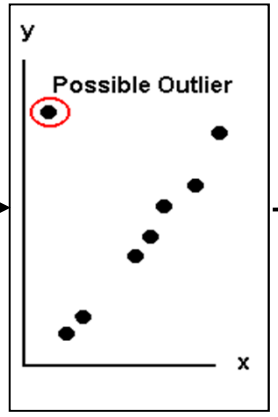
Temporal corrections

Frame transformation

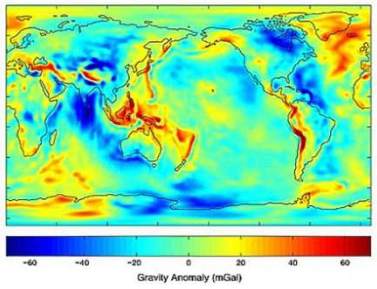


EGG_TRF_2

CGG_NWU



Outliers

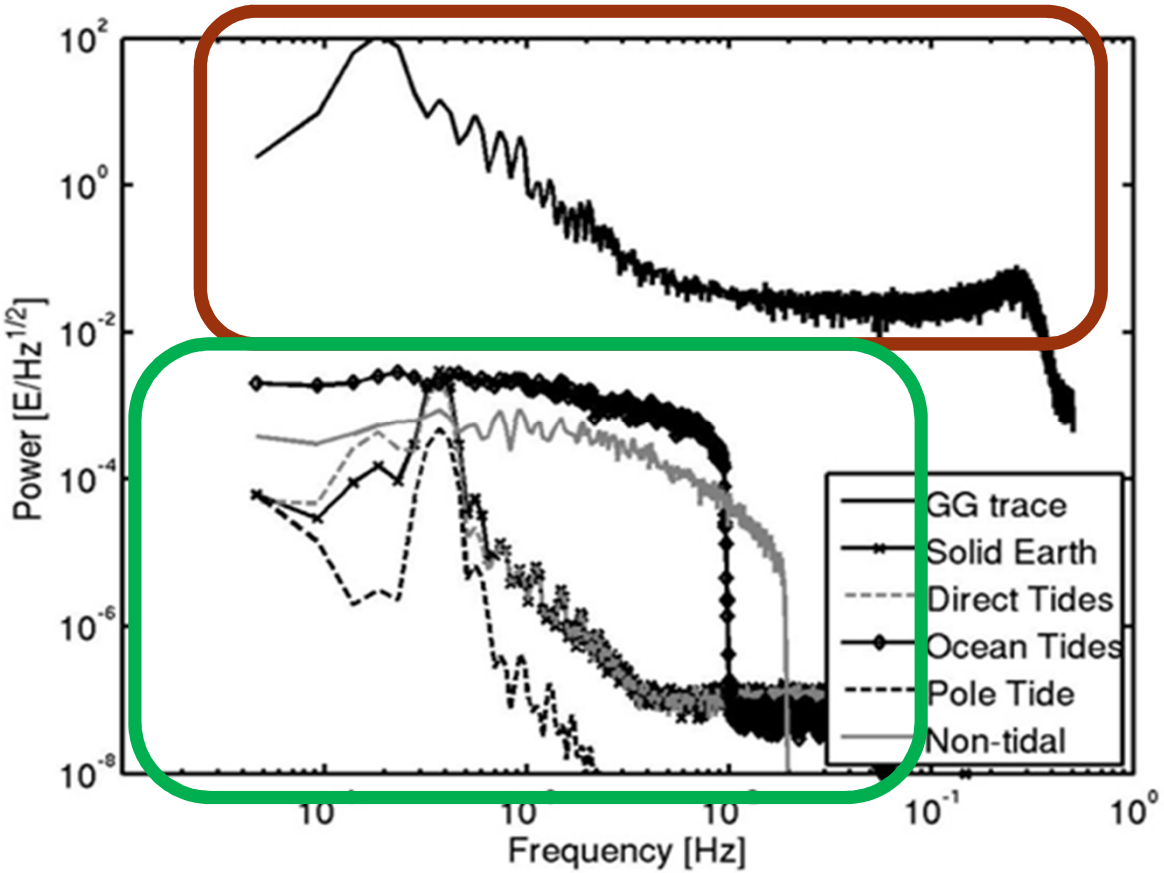


External calibration

EGG_NOM_2

GGC_GRF

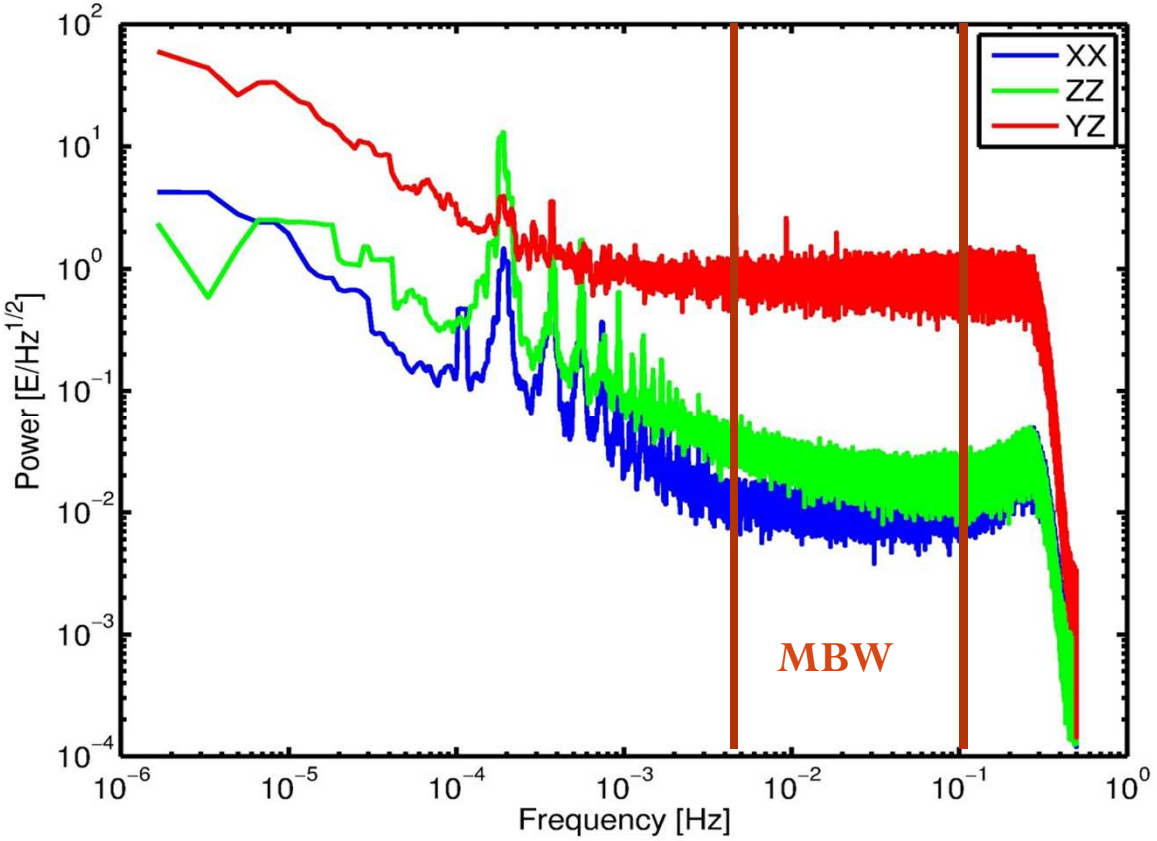
Tidal and non-tidal temporal corrections



GG trace

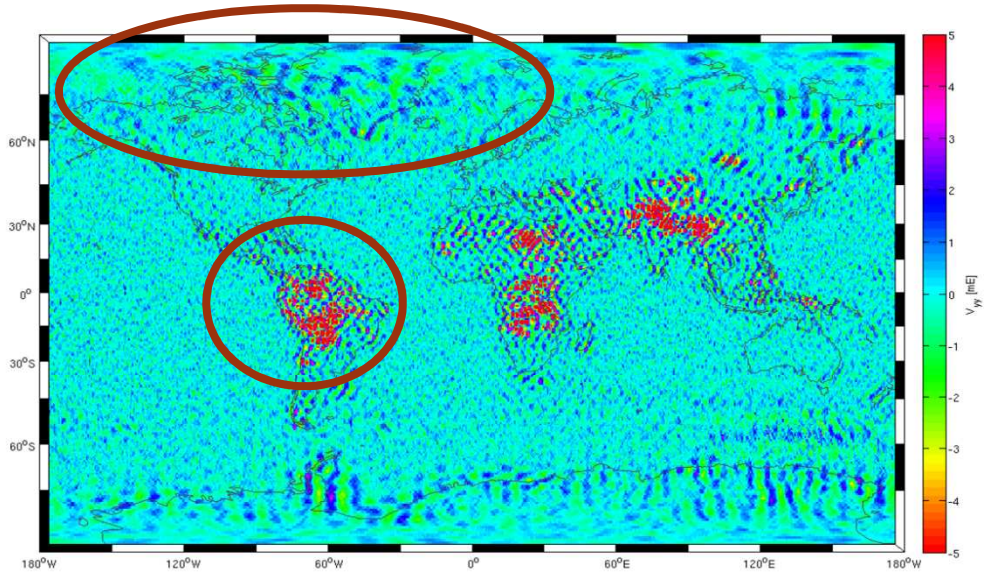
Temporal corrections

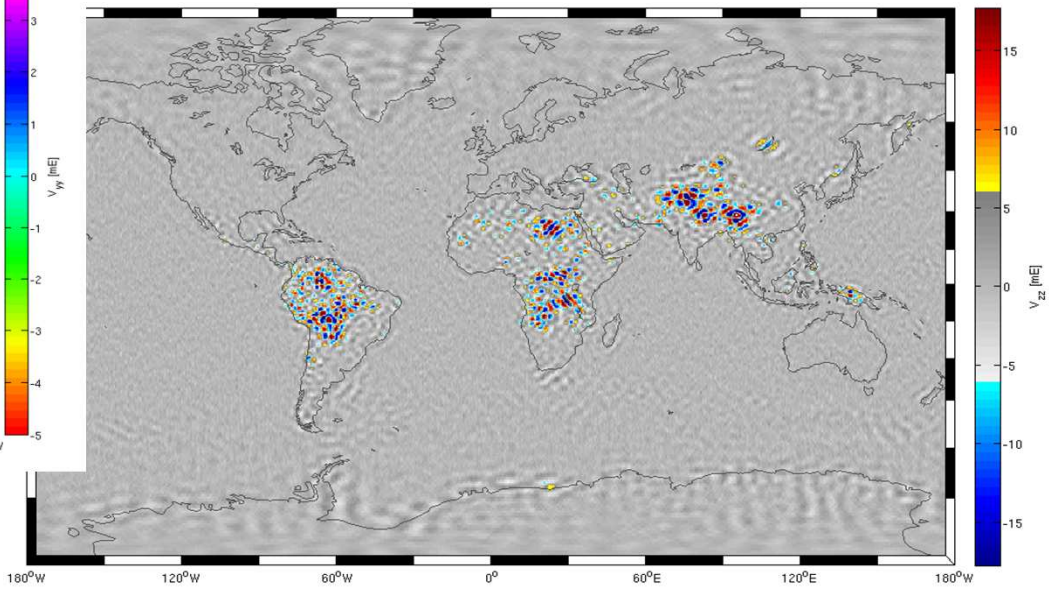
PSD GG errors



- High accuracy:
  - XX, YY, ZZ, XZ
  - XX, YY two times more accurate in MBW than ZZ, XZ
- Less accurate:
  - XY and YZ
- All gradients:
  - Error increase below MBW

Comparison with EGM2008, YY, ZZ

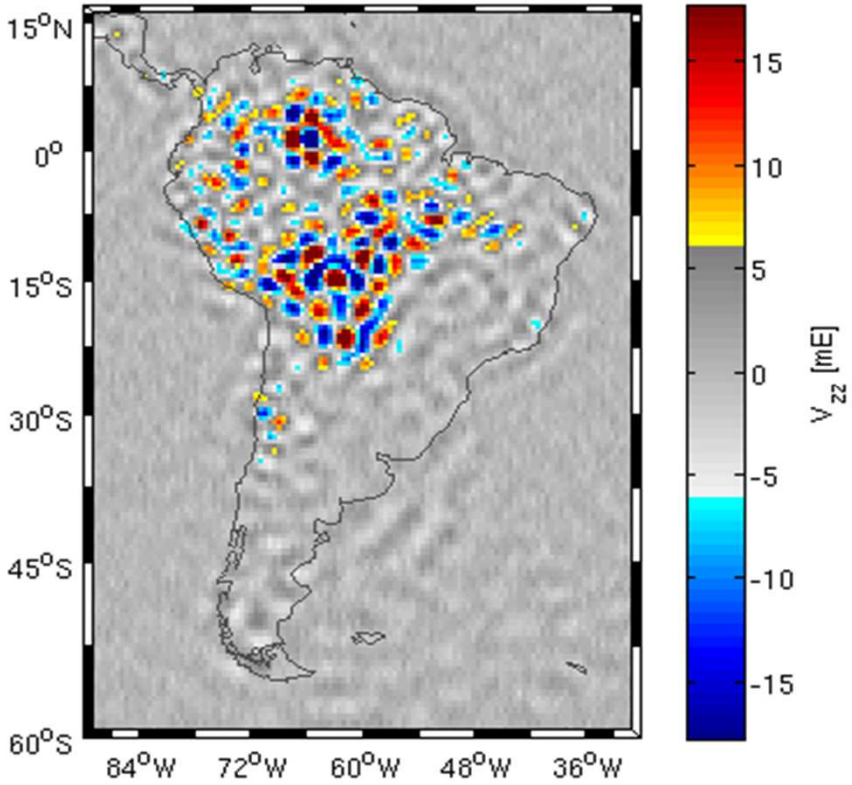




Large differences in regions where terrestrial data in EGM2008 is poor

Small anomalous signal close to magnetic poles in YY (not in XX, ZZ and XZ)

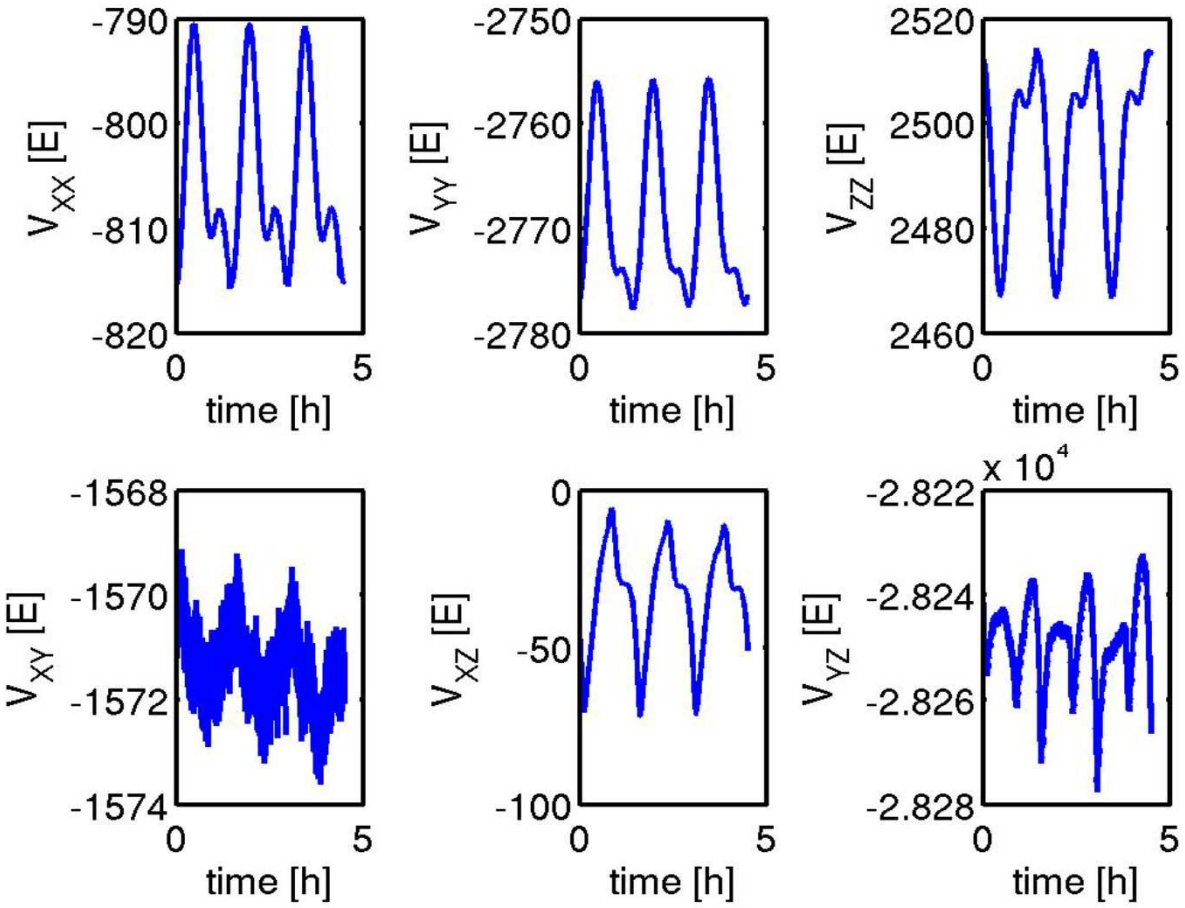
Comparison with EGM2008, YY



Characteristics EGG_NOM_2

- EGG_NOM_2:
  - Given in instrument frame (GRF)
  - Accurate: $V_{XX}, V_{YY}, V_{ZZ}, V_{XZ}$; less accurate: V_{XY}, V_{YZ}
  - Error increase at long wavelengths
  - Temporal corrections applied
  - Outliers flagged
  - Original EGG_NOM_1b can be restored
  - GRF – LNOF rotation also requires orbit product (SST_PSO)

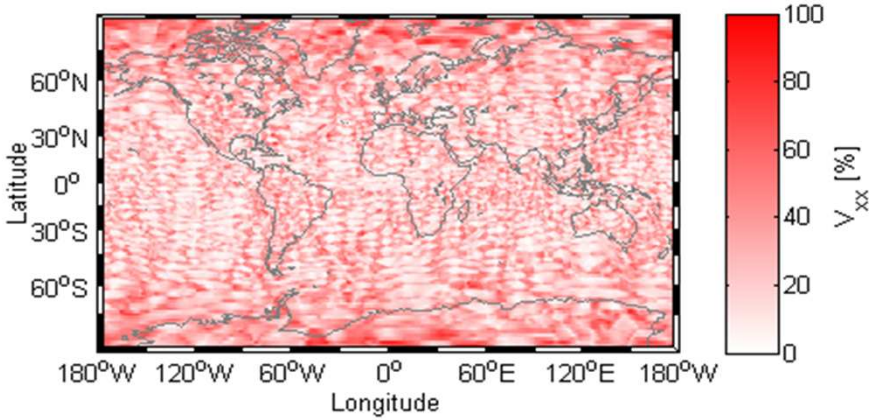
EGG_NOM_2:
3 revolutions November 1, 2009



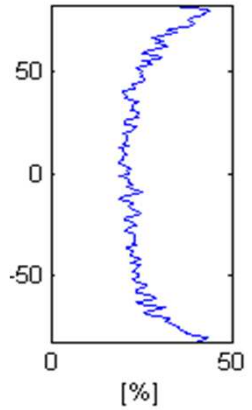
Gradient tensor rotation

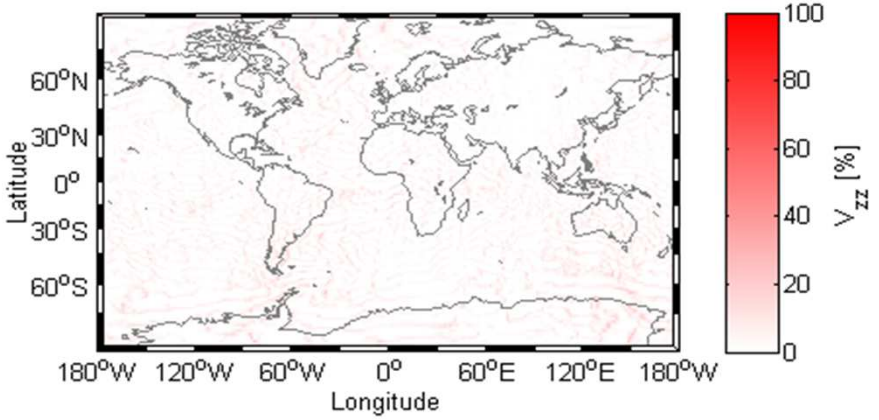
- Tensor rotation from GRF to any other frame
  - XY and YZ error projects onto accurate GGs
  - Error increase below MBW for all GGs leaks to MBW after rotation
- Use information from GOCE-only global gravity field model
  - Completely replace XY and YZ
  - Replace signal below MBW of XX, YY, ZZ and XZ in EGG_NOM_2 with model information
  - Current release of EGG_TRF_2 uses TIM R3 model
- GGs in EGG_TRF_2 mix GOCE and model information

Model information in MBW in EGG_TRF_2

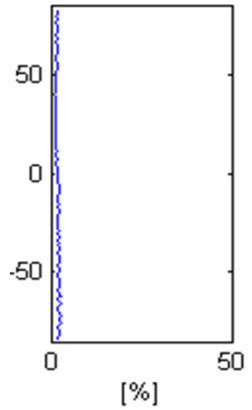


XX

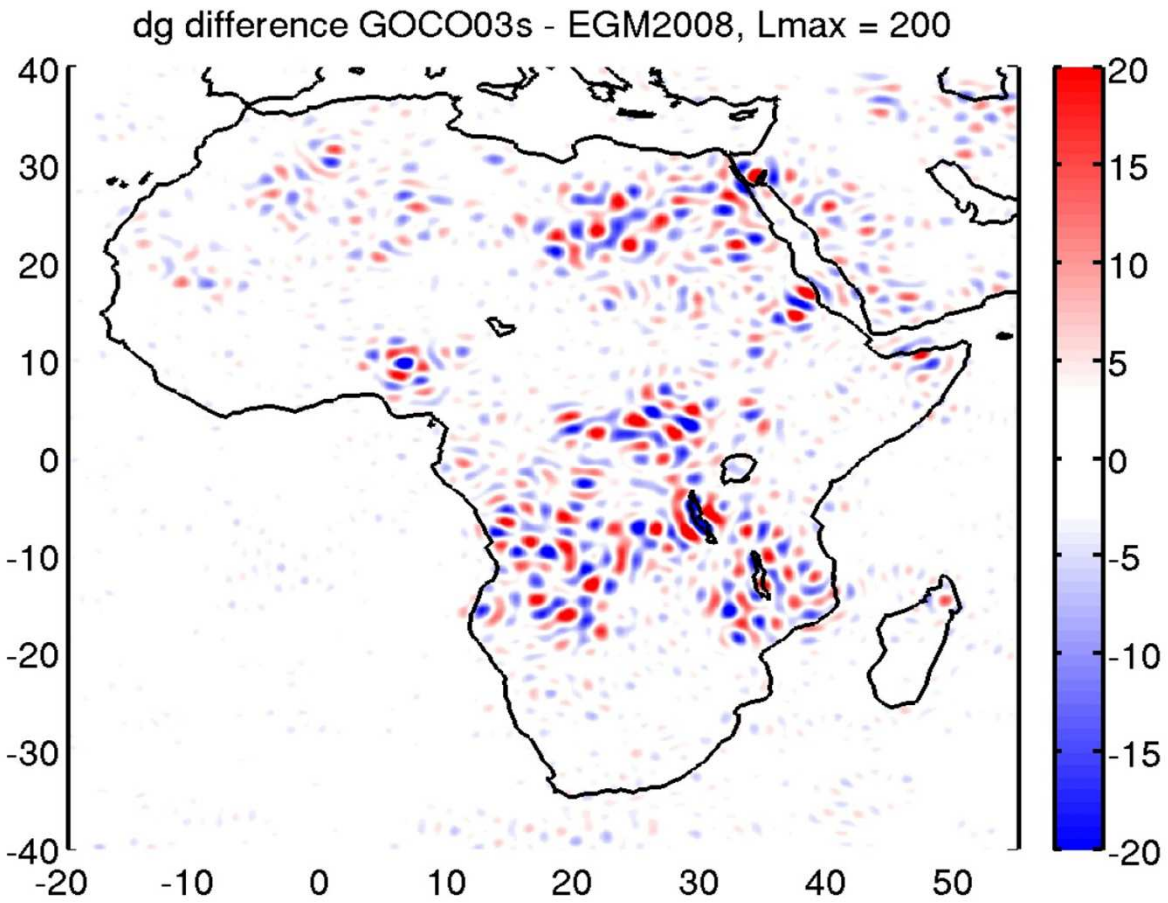




ZZ



Gravity anomaly difference GOCO03s – EGM2008, Lmax = 200

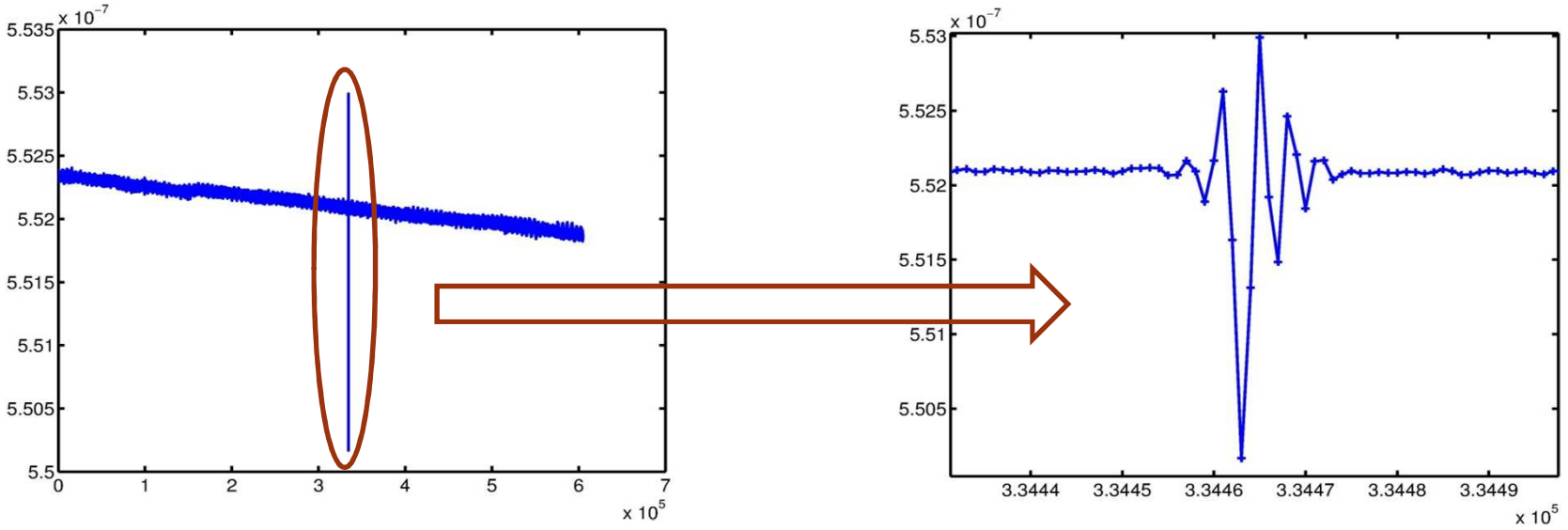


Characteristics EGG_TRF_2

- EGG_TRF_2:
  - Given in local north-oriented frame (LNOF)
  - GGs V_{XY}, V_{YZ}: GOCE TIM R3 gravity field model
  - Long wavelength GG signal: GOCE gravity model
  - GG error more homogeneous
  - Temporal corrections applied
  - Outliers flagged
  - Original EGG_NOM_1b cannot be restored

Gradients from GOCE+ GeoExplore

- GGC_GRF: like EGG_NOM_2 but
  - Long wavelengths below MBW in all gradients from GOCE/GRACE model (GOCO03s)
  - Tailored outlier detection, whereas EGG_NOM_2 production is almost completely automized => more ourliers flagged in GGC_GRF
  - Rotation matrix GRF – LNOF included



Gradients from GOCE+ GeoExplore

- GGC_NWU
  - Similar to EGG_TRF_2
  - Computed from GGC_GRF
  - Contains information from GOCE/GRACE gravity field model

Part II: Gradients in grids

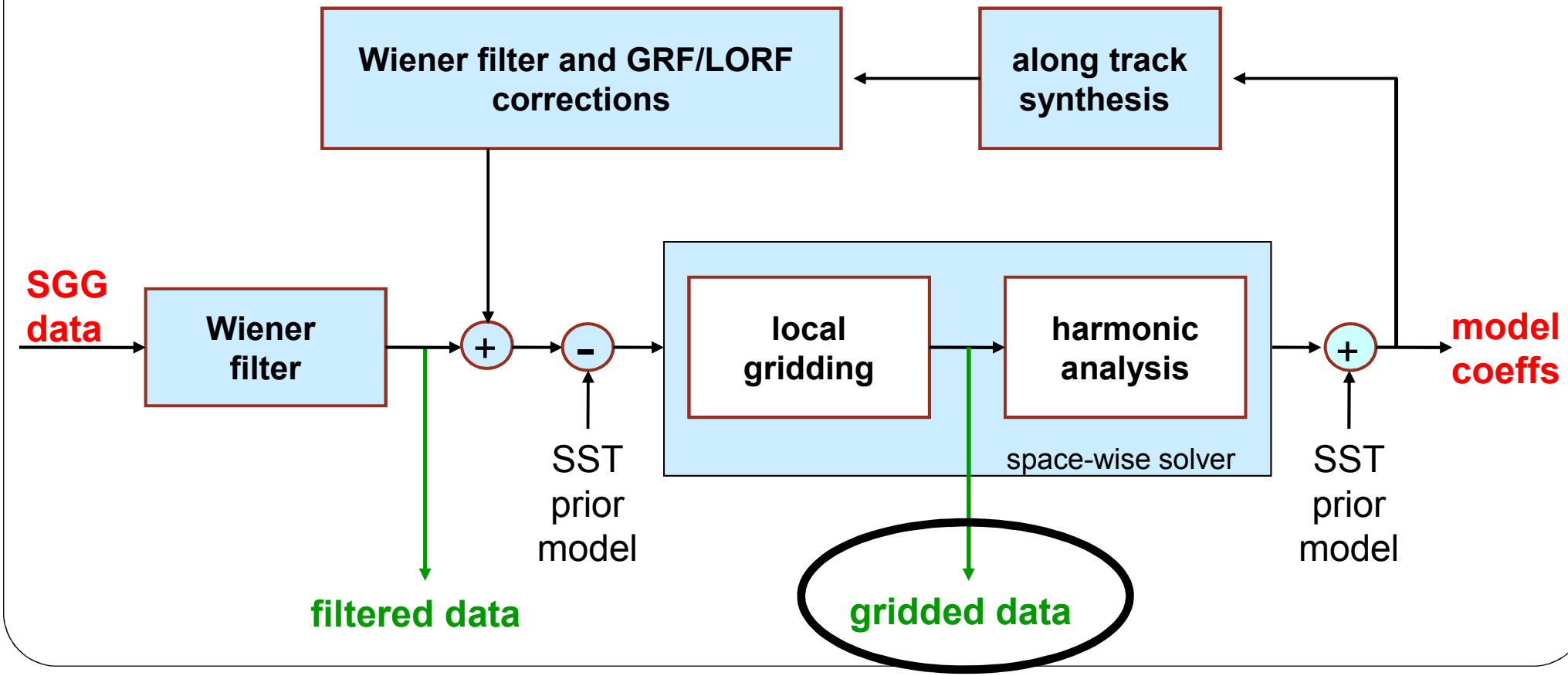
Politecnico di Milano

UCPH, Copenhagen

GOCE-only space-wise scheme

The space-wise approach is a multi-step collocation procedure:

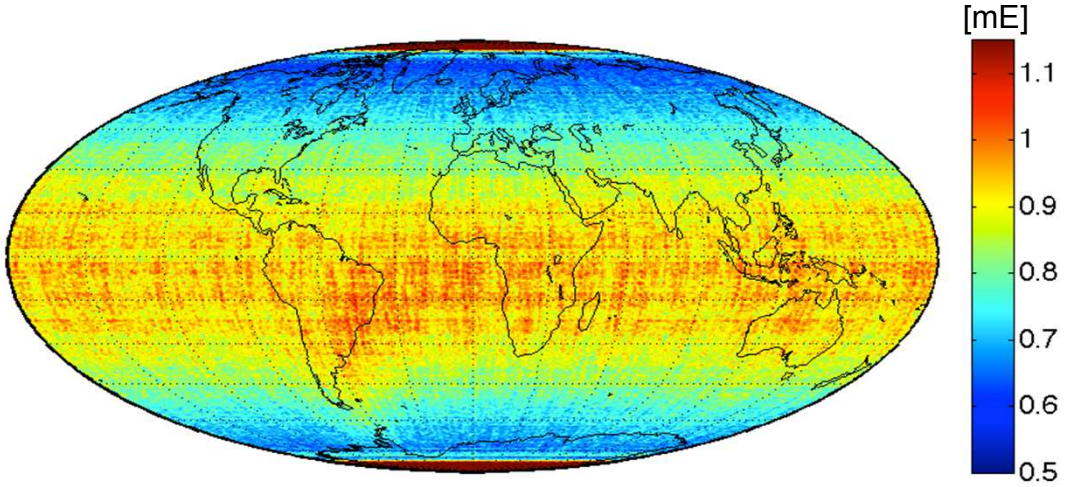
- data filtering along the orbit (Wiener filter) with iterative corrections,
- data gridding at satellite altitude (LS collocation),
- spherical harmonic analysis (numerical integration).



GOCE-only space-wise grids

Currently 0.5° x 0.5° grids of potential T and second radial derivatives Trr
Error estimates based on Monte Carlo simulations.

Predicted error std of Trr - R3 solution
(based on 500 Monte Carlo samples)



Trr [mE] $\lvert\varphi\rvert<90°$	Trr [mE] $\lvert\varphi\rvert<80°$
19.1	0.9

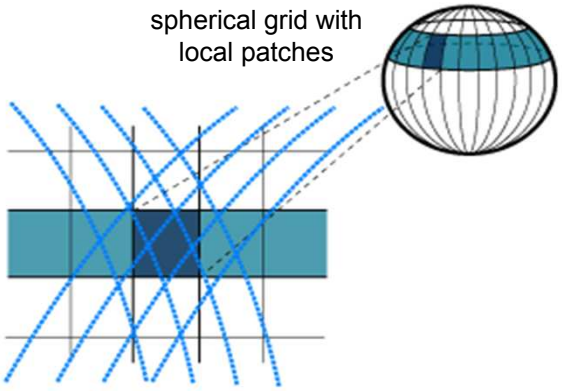
Error below the mE level !!

Future releases:

- increase grid resolution 0.2° x 0.2°
- compute not only Trr but also other gravity gradients (e.g. T_{NN})

How are grids computed?

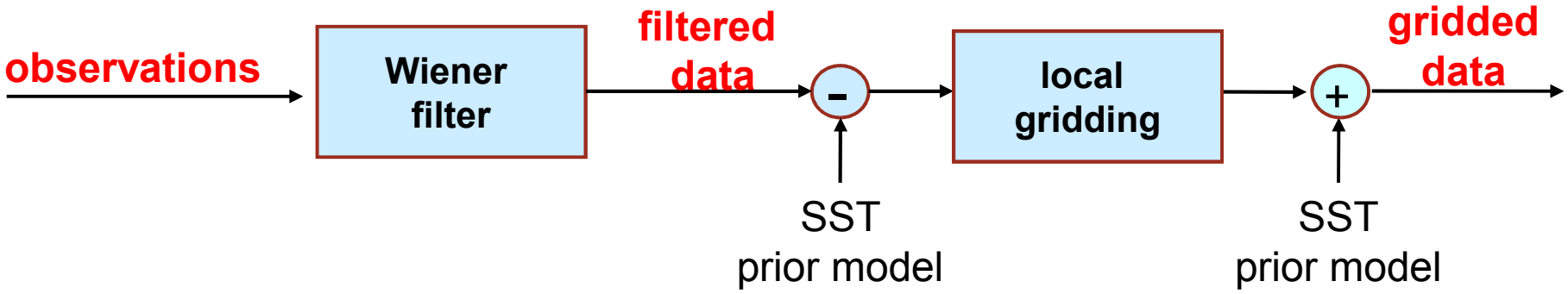
A unique collocation is computationally unfeasible due to the huge amount of GOCE data.



➡ A collocation gridding applied to local patches of data is used with locally adapted covariance functions

➡ To implement the local gridding:

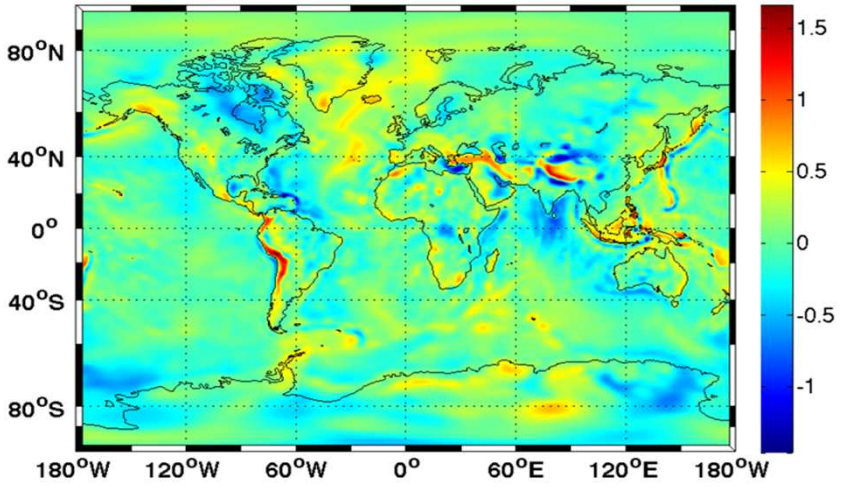
- a Wiener orbital filter is used to reduce the strongly time correlated noise of the gradiometer
- a GOCE-only prior model (SST model) is used to reduce the spatial correlation of the signal



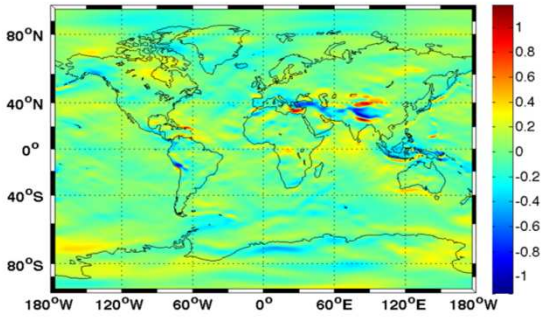
New grids (from POLIMI)

High resolution grids at satellite altitude:

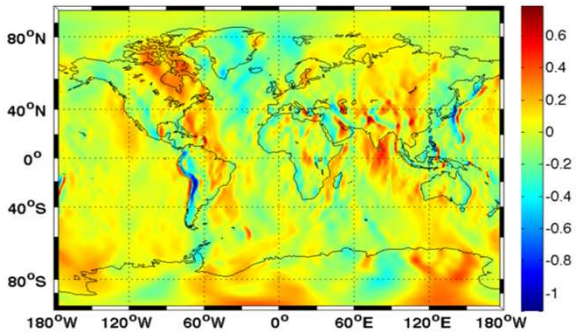
Trr [E]



T_{NN} [E]

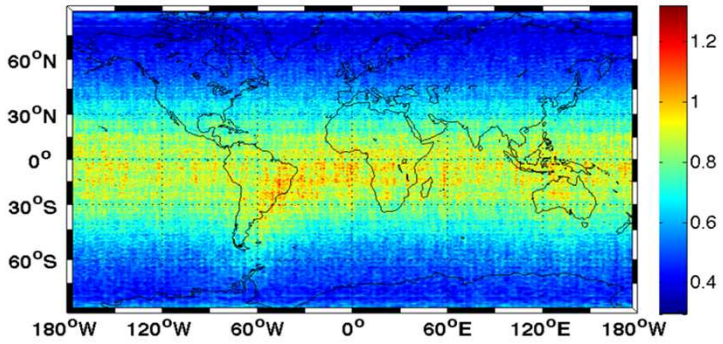


T_{EE} [E]



Symmetric cylindrical error covariance + pointwise error variances, both computed from Monte Carlo samples

$$C(\vartheta, \vartheta', \Delta\lambda) \qquad +$$



σ^2_{Trr} [mE^2]

New grids (from UCPH)

- High resolution grids (6' x 6') at almost ground level (fixed altitude of 10 km) will be computed.

- They are not GOCE-only grids:
  - GRACE model is used as prior model
  - airborne and/or ground gravity data over polar areas

- The GOCE input are Wiener filtered data coming from the space-wise processing scheme plus their auto- and cross-covariance functions.

- The processing is based on LSC using the GEOCOL software.

- The output are grids of:
  - gravity anomalies Δg
  - 2nd order radial derivatives T_{rr}
  - optionally, some "horizontal" 2nd order derivatives, such as T_{NN}

  all of them with the corresponding error standard deviations.

Where to get the data?

GOCE gravity gradient data

- ESA Earthnet Online
- See also
  - goce4interior.dgfi.badw.de
  - gocedata.como.polimi.it
- Not all gradient products available yet

Summary

- Gradients in instrument frame
  - EGG_NOM_2 (pure GOCE)
  - GGC_GRF (GOCE/GRACE below MBW)
- Gradients in local north-oriented frame
  - EGG_TRF_2 (GOCE-only)
  - GGC_NWU (from GGC_GRF)
- Gradient grids
  - At satellite altitude 0.5° x 0.5° vertical gradient
  - In future
    - Higher resolution, also other gradients
    - At satellite altitude and 10 km altitude