Investigation on Inter Catchment / Cell Correlations of GRACE monthly solutions over the globe

M. J. Tourian\textsuperscript{1,2}, J. Riegger\textsuperscript{1}, B. Devaraju\textsuperscript{2} & N. Sneeuw\textsuperscript{2}

1. Institute of Hydraulic Engineering, University of Stuttgart, Germany
2 Institute of Geodesy, University of Stuttgart, Germany.

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Water Balance on Catchments

\[ \frac{dM}{dt} \leftrightarrow P - R - ET_a \]
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- \( dM/dt \) is the monthly mass rate aggregated over catchment, from GRACE

- \( P \) is the monthly precipitation aggregated over catchment

- \( R \) is the monthly runoff

- \( ET_a \) is monthly actual evapotranspiration over catchment which is difficult to measure and typically available from models only
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Water Balance — Amazon (Tropical wet)
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\[ ET_a = P - R - \frac{dM}{dt} \]
Water Balance – West Australia (Tropical dry)
Water Balance – West Australia (Tropical dry)

\[ ET_a = P - R - \frac{dM}{dt} \]
Water Balance — Ob (Boreal)
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\[ ET_a = P - R - \frac{dM}{dt} \]
Inter Catchment Correlation (ICC) – GRACE Signal

Amazon

West Australia
Inter Catchment Correlation (ICC) – GRACE Signal

Amazon

West Australia

Correlation : 0.76 ⇐ why?
Inter Catchment Correlation (ICC) – GRACE Signal

Reference catchment: Amazon

Reference catchment: West Australia

Reference catchment: Ob
Inter Catchment Correlation Matrix – GRACE Signal
Inter Catchment Correlation Matrix – GRACE Signal
Inter-Catchment Correlation Matrix – GRACE Signal

The graph shows a correlation matrix for catchments' latitudes, with a color gradient representing correlation values. The x-axis represents the catchments' latitude, while the y-axis also represents the catchments' latitude. The colors range from blue to red, indicating varying correlation strengths, with blue representing lower correlation and red representing higher correlation. Major catchments like Amazon and West Australia are marked with yellow lines for reference.
Inter Catchment Correlation Matrix – GRACE Signal

Reflecting the global circular pattern
GRACE Residual

![Graph showing GRACE Residual with time in months on the x-axis and dM/dt in mm/month on the y-axis between Jan 2003 and Jan 2008. The graph displays periodic variations in dM/dt.]
GRACE Residual

\[ \bar{x}_j = \frac{1}{\max(i)} \sum_{i=1}^{\max(i)} x_{i,j} \]
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GRACE Residual

How is the inter catchment correlation of residual?

\[
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\]

\[
r_t = x_{i,j} - \bar{x}_j
\]
Inter Catchment Correlation Matrix – GRACE Residual
Why are residual time series correlated like this?

Similar correlation matrix for $P - R - ET_a$ unfortunately not feasible due to runoff data limitation

Due to the poor distribution of catchments’ latitude, to find a real pattern grid based data is investigated
Mass Changes on Cell $5^\circ \times 5^\circ$

- For a better coverage over the globe we investigate on Inter Cell Corellation

- Mass changes (EWH) and rate of mass changes ($\frac{dM}{dt}$) is calculated $5^\circ \times 5^\circ$ over the globe
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Inter Cell Correlation - GRACE Residual

![Graph showing inter cell correlation with GRACE residual, with axes labeled as Cells' Latitude [degree] and Cells' Latitude [degree]. The color bar indicates correlation values ranging from -1 to 1.](image)
Inter Cell Correlation - GRACE Residual
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The diagram illustrates the inter cell correlation with GRACE Residual values, showing a color gradient from red to blue, indicating the strength of the correlation across different regions of the globe.
What we can see:

- High correlation between Polar Regions
- Anti correlation between polar and tropical region
- Correlation independent of landmasses or oceans

Where does it come from?
EOF Analysis

EOF analysis is performed on cell based EWH residual,
EOF Analysis

EOF analysis is performed on cell based EWH residual, singular value spectrum:
EOF Analysis

Mode 1 ($\sigma = 6883.92$)
EOF Analysis

Mode 2 ($\sigma = 4595.77$)
EOF Analysis

Mode 3 ($\sigma = 2636.24$)
EOF Analysis

Mode 4 \( (\sigma = 2090.17) \)

![Map with EOF Analysis](image)

![Graph with time series](image)
EOF Analysis

Mode 5 ($\sigma = 1889.53$)
Effect of Removing Mode on ICC

Inter Cell correlation **before** and **after** of removing
Effect of Removing Mode on ICC

Inter Cell correlation before and after of removing Mode 1
Effect of Removing Mode on ICC

Inter Cell correlation before and after of removing Mode 2
Effect of Removing Mode on ICC

Inter Cell correlation **before** and **after** of removing Mode 3
Effect of Removing Mode on ICC

Inter Cell correlation **before** and **after** of removing Mode 2&3

![Graphs showing correlation before and after removing Mode 2&3](image)

![Maps showing correlation before and after removing Mode 2&3](image)
What is mode 2?
Possible Reasons...

- Outliers?
Possible Reasons...

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Possible Reasons...

- Outliers?

Poster: **Outlier detection and correction for GRACE data to improve the continental water water balance**, Halls X/Y / Wed, 05 May, XY376
Possible Reasons...

- Outliers?
- Hydrology?
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How is the correlation of $dM/dt$ vs. $P - R$ changing after removing modes 2 & 3 for different catchment?
Possible Reasons...

- Outliers?
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Conclusion: no change
Possible Reasons...

- Outliers?
- Hydrology?
- De-aliasing models?
Possible Reasons...

- Outliers?
- Hydrology?
- De-aliasing models?

To assess the idea, GAC and GAD models provided by GFZ are added back to GSM data
Possible Reasons...

Computed ICC from GSM+GAD+GAC (Ref. $\phi = 87.5, \lambda = -177.5$)
Possible Reasons...

- Outliers?
- Hydrology?
- De-aliasing models?
- Effect of degree 1?
Possible Reasons...

- Outliers?
- Hydrology?
- De-aliasing models?
- Effect of degree 1? ICC from GRACE product corrected for degree 1 term
Possible Reasons...

ICC from GRACE product corrected for degree 1 term:

* JIGOG project team (Rietbroek, Kusche et al.)
Summary

- GRACE derived mass changes were analysed for inter catchment/cell correlation.
  - Residuals after removing the annual part of the signal were analyzed.
  - The peculiar behaviour in ICC is seen in different products (GFZ, ITG, CSR, JPL) (GFZ only shown in this presentation).
  - The possibility of outliers as source was tested and rejected.
  - Responsible EOF mode for the ICC pattern was identified.
  - Removing identified mode from GRACE signal does not lead to improving its correlation with hydrological signal.
  - Indication that degree-1 mass redistribution is causing pattern in ICC.
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Acknowledgments

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Thanks for your attention