DIRECT WATERBALANCE

An interdisciplinary approach towards the determination of large scale actual evapotranspiration and the evaluation of atmospheric moisture flux

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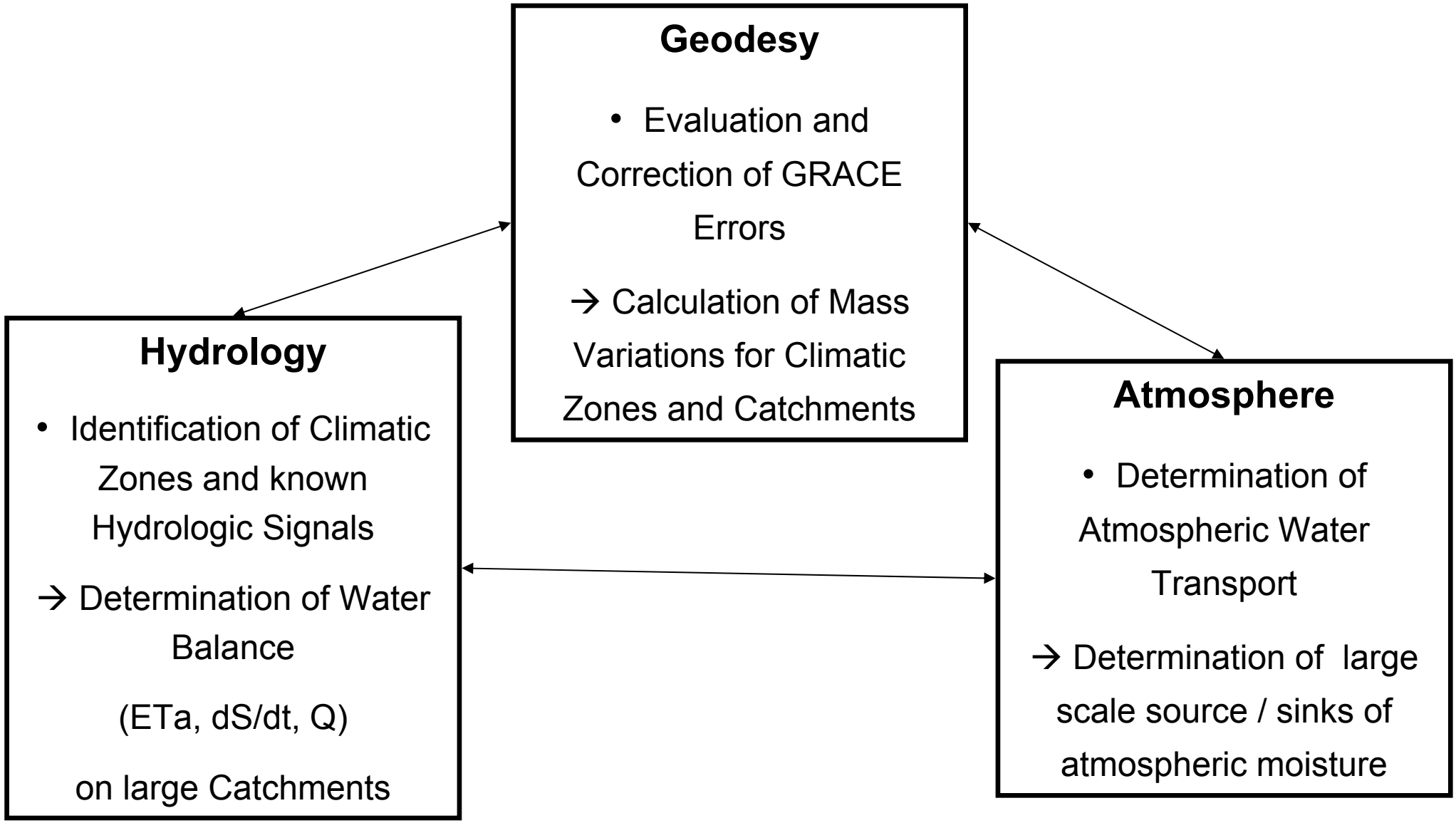
Project Structure



Evaluation Approach

Large Scale Water Balance for Catchments :

$$\underbrace{P - ET_a - R = \frac{\partial S}{\partial t}}_{\text{Hydrology}} \leftrightarrow \underbrace{\frac{\partial M}{\partial t}}_{\text{GRACE}} \leftrightarrow \underbrace{\frac{\partial S}{\partial t} = -\vec{\nabla} \cdot \left(q\vec{u}\right) - R}_{\text{Atmosphere}}$$

Hydrology :

- Meteorology : $P = P_{adv} + P_{conv}$ and ET_a (Soil, Vegetation)
- Catchment Runoff R

GRACE :

- Total Mass Change dM/dt

Atmospheric Input :

- Moisture Flux Divergence (MFD) $-\vec{\nabla} \cdot \left(q\vec{u}\right)$

Main Aims

<u>Direct</u> Determination of large scale actual Evapotranspiration

← Quantification of mass errors :

- Hydrology (*P, ETa, R*)
- GRACE (*dM/dt*)

Evaluation of Atmospheric Moisture Flux

- Hydrology, GRACE

→ Improved <u>Global</u> Waterbalance and Discharge from Land Masses

Development of Local methods for Satellite Gravimetry

by use of corrections from known terrestrial signals

Steps

Evaluation Phase :

1.) GRACE ←→ Hydrology : $\frac{\partial M}{\partial t} \leftrightarrow P - ET_a - R$

- ET_a *negligible* → for certain areas (Deserts, Boreal, High Altitude)
  → for certain times (Winter, Dry Season)
- $R \sim 0$ → Dischargeless Basins

- Hydrology = most accurate known mass changes on large areas

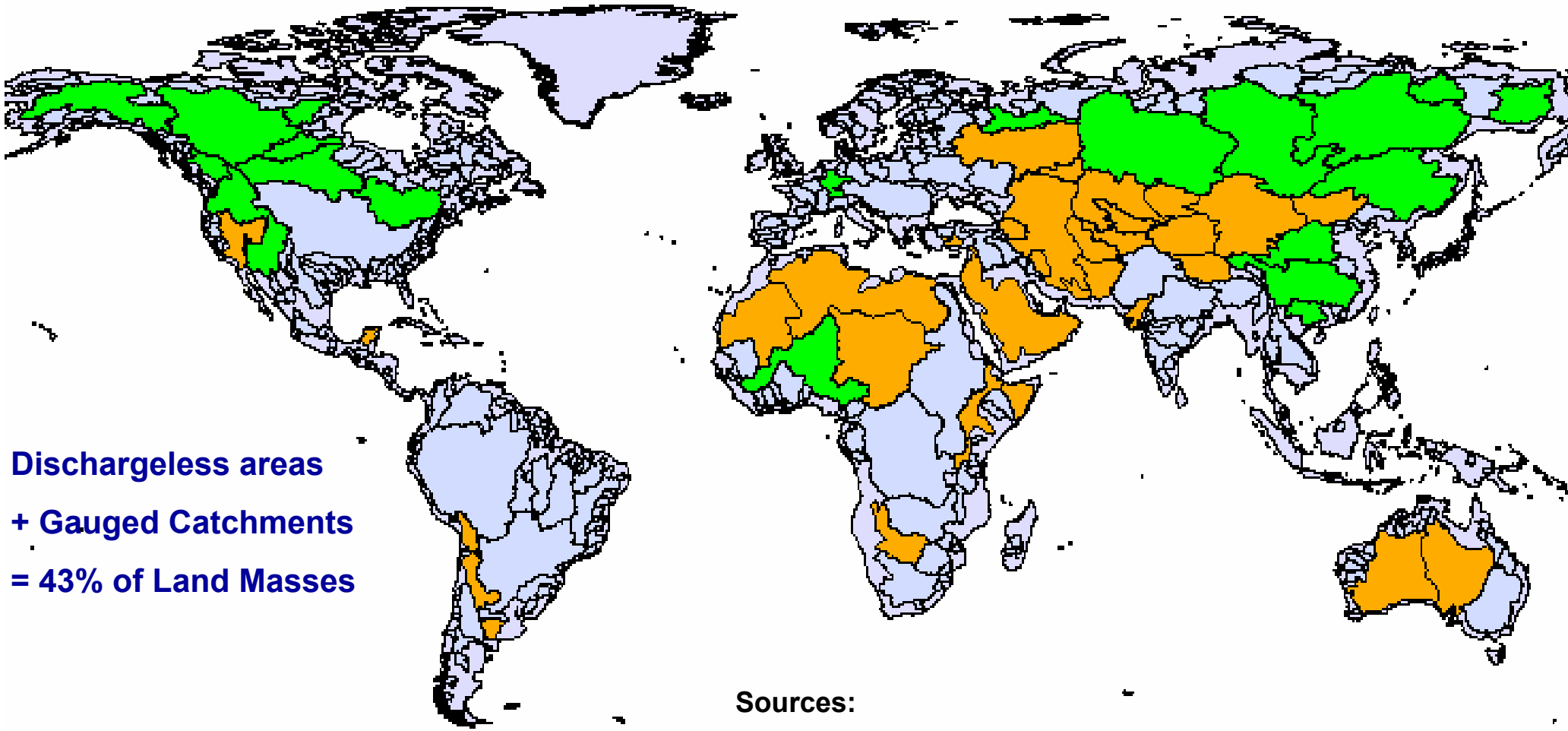
2.) Atmospheric Moisture Flux ←→ GRACE : $-\vec{\nabla} \cdot (q\vec{u}) - R \leftrightarrow \frac{\partial M}{\partial t}$

Application Phase

- Direct ETa $ET_a = P - R - \frac{\partial M}{\partial t}$
- Discharge from ungauged Catchments $R = -\vec{\nabla} \cdot (q\vec{u}) - \frac{\partial M}{\partial t}$

Data Situation : Space

Global Distribution of recent Discharge Data until 2004



Dischargeless areas

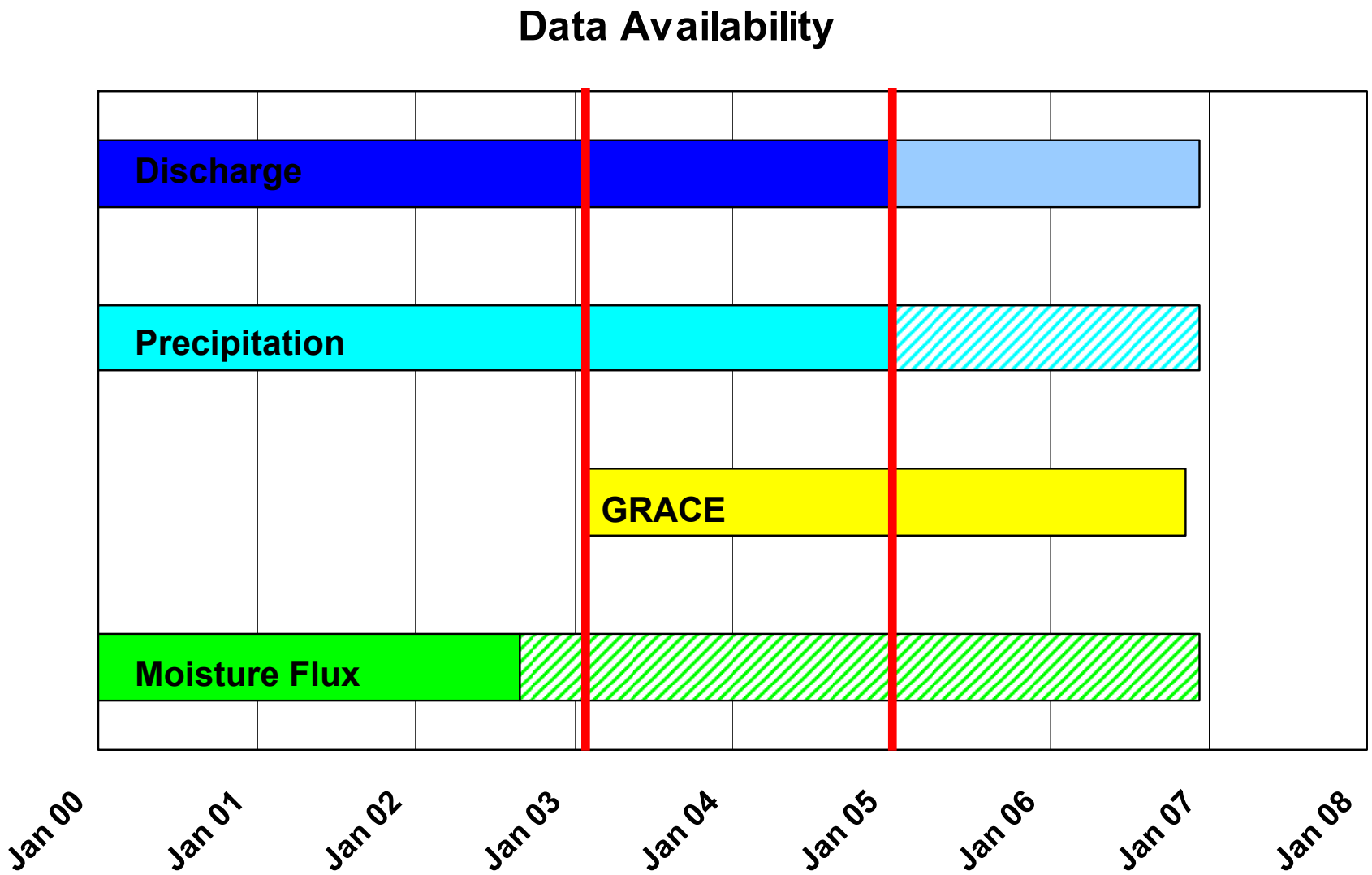
+ Gauged Catchments

= 43% of Land Masses

Sources:

- GRDC, USGS, ArticRims Project, Water Survey Canada,
- Mainly Daily Values

Data Situation : Time



Data Situation : Consequences

Availability of Precipitation and Moisture Data until 2004

→ Direct Water Balance with GRACE for only 2 years

→ Limited possibilities for Error Quantification

Use of Statistical Data from longer Time Periods (GPCC, GRDC, ERA40)

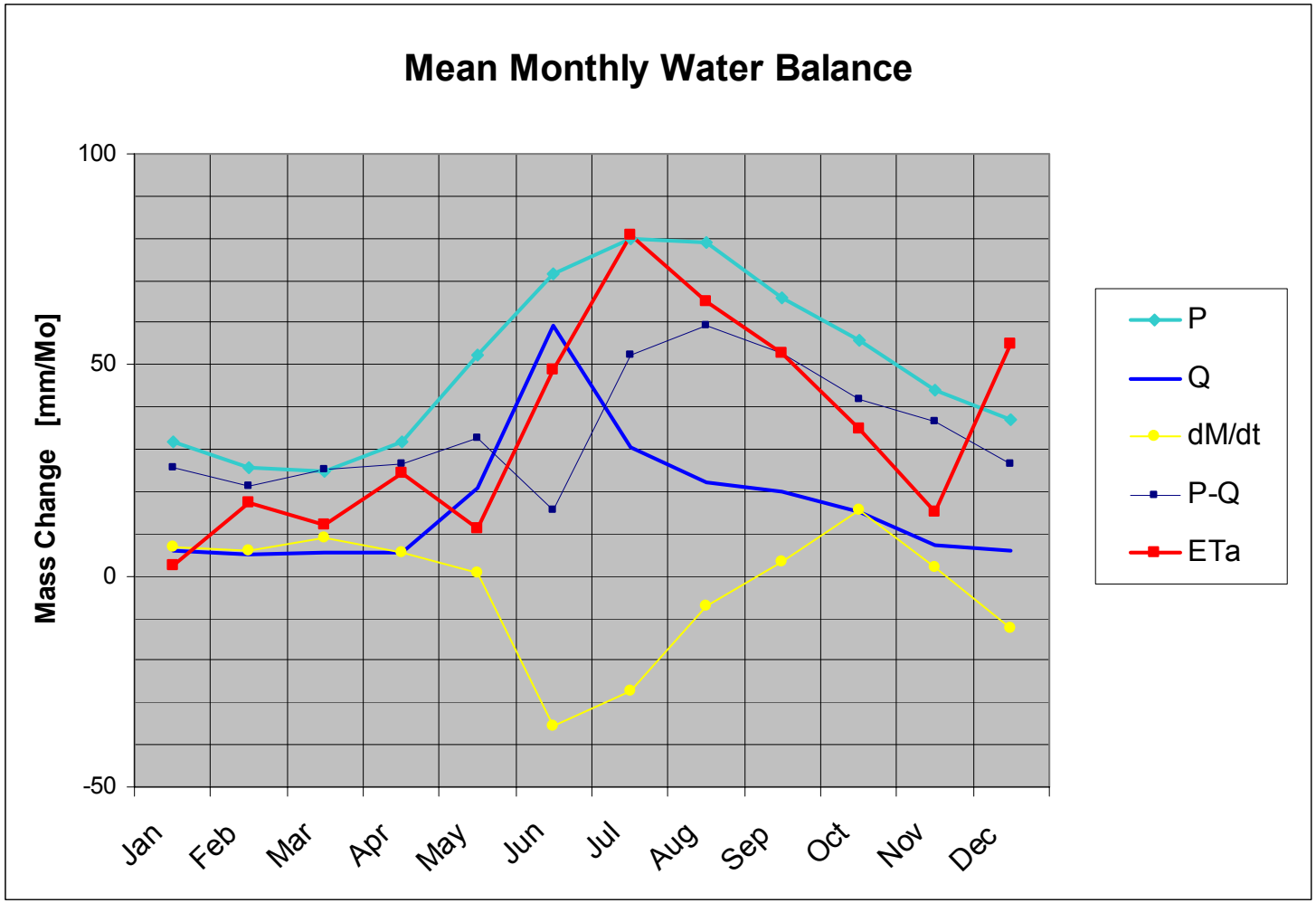
→ Investigations on Mean Monthly Behaviour
(different length of available time periods)

→ Investigations on spatial Characteristics of Catchments

Water Balance

Mean Monthly Behaviour

Siberian Tundra

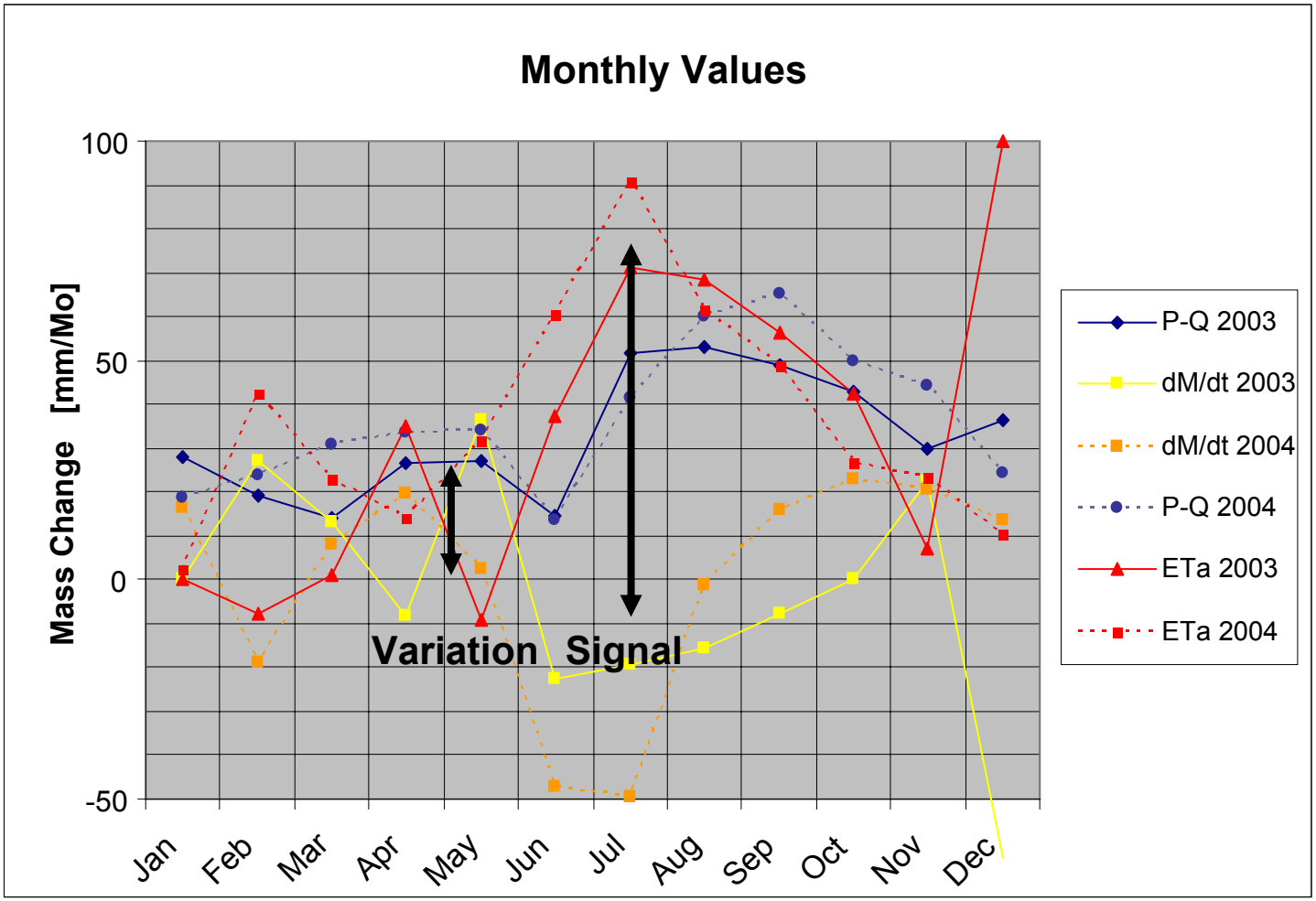


→ **Reasonable Annual Behaviour**

Water Balance

Monthly Behaviour

Siberian Tundra



→ **Variations +/- 20% - 30% of Annual Amplitudes**

Signal Variations

Variations = Physical Fluctations (Hydrology, GRACE) **+** Error ε

Quantification of Variations :

Focus on Interannual Monthly Deviations from Mean Annual Behaviour = **Residuals**

→ Elimination of Annual Behaviour

- Residuals of Hydrology (wet / dry year) :

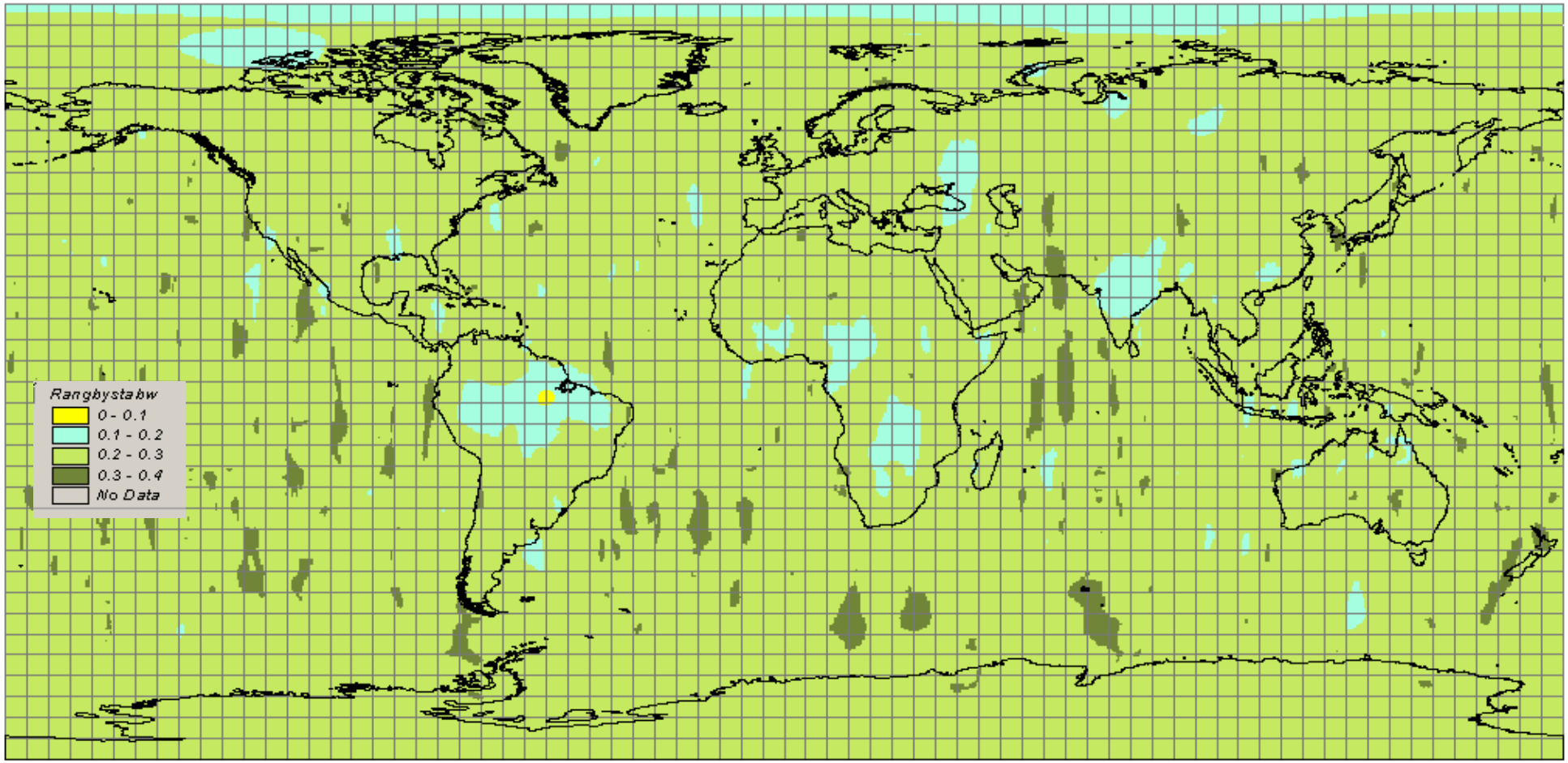
  $dS/dt \sim P - R$ (where $ETa \sim 0$ for Tundra, Winter, High Elevation)

  $dS/dt < P$ (where $ETa <\sim P$ for Deserts)

- Residual of GRACE Mass Change Rates : dM/dt

Variation / Signal for GRACE

Stdev of GRACE Residual / GRACE Mean Annual Range



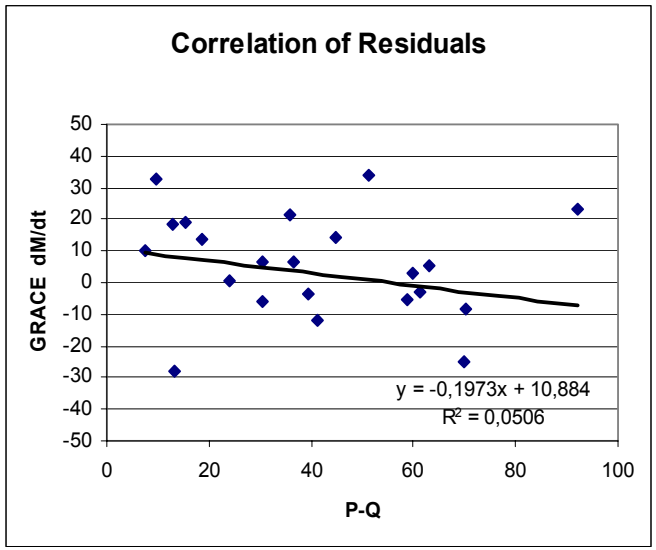
→ Mean Variation / Signal GRACE ~25%

→ Smaller for large, tropical Catchments

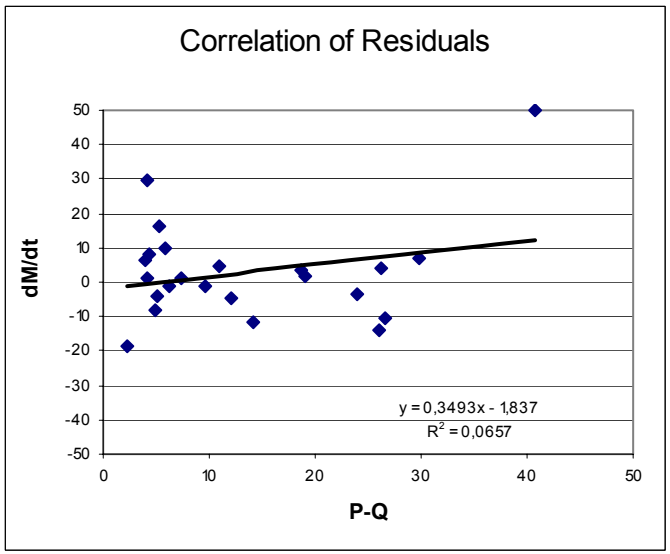
Correlation : GRACE ←→ Hydrology

Correlation of Residuals between Hydrology and GRACE

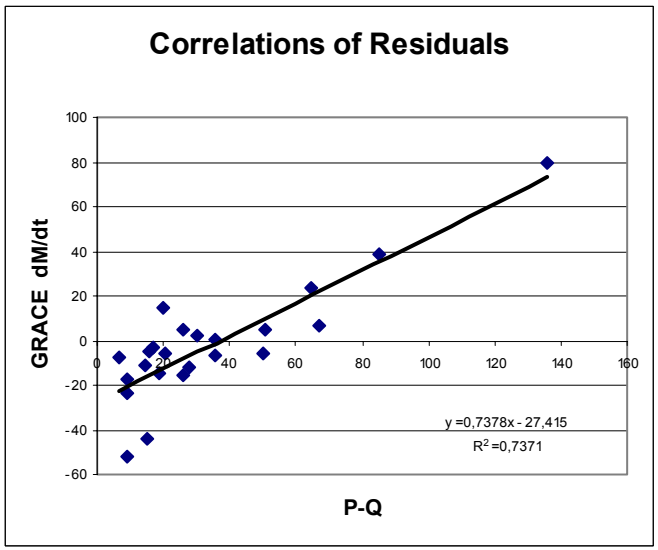
(for different catchments, for 2003-2004, where $dS/dt = P - R > 0$ with $ETa < 15mm/mo$)



Nelson – Thelon



Gobi



Australia West

→ No systematic Correlation of Residuals between Hydrology and GRACE

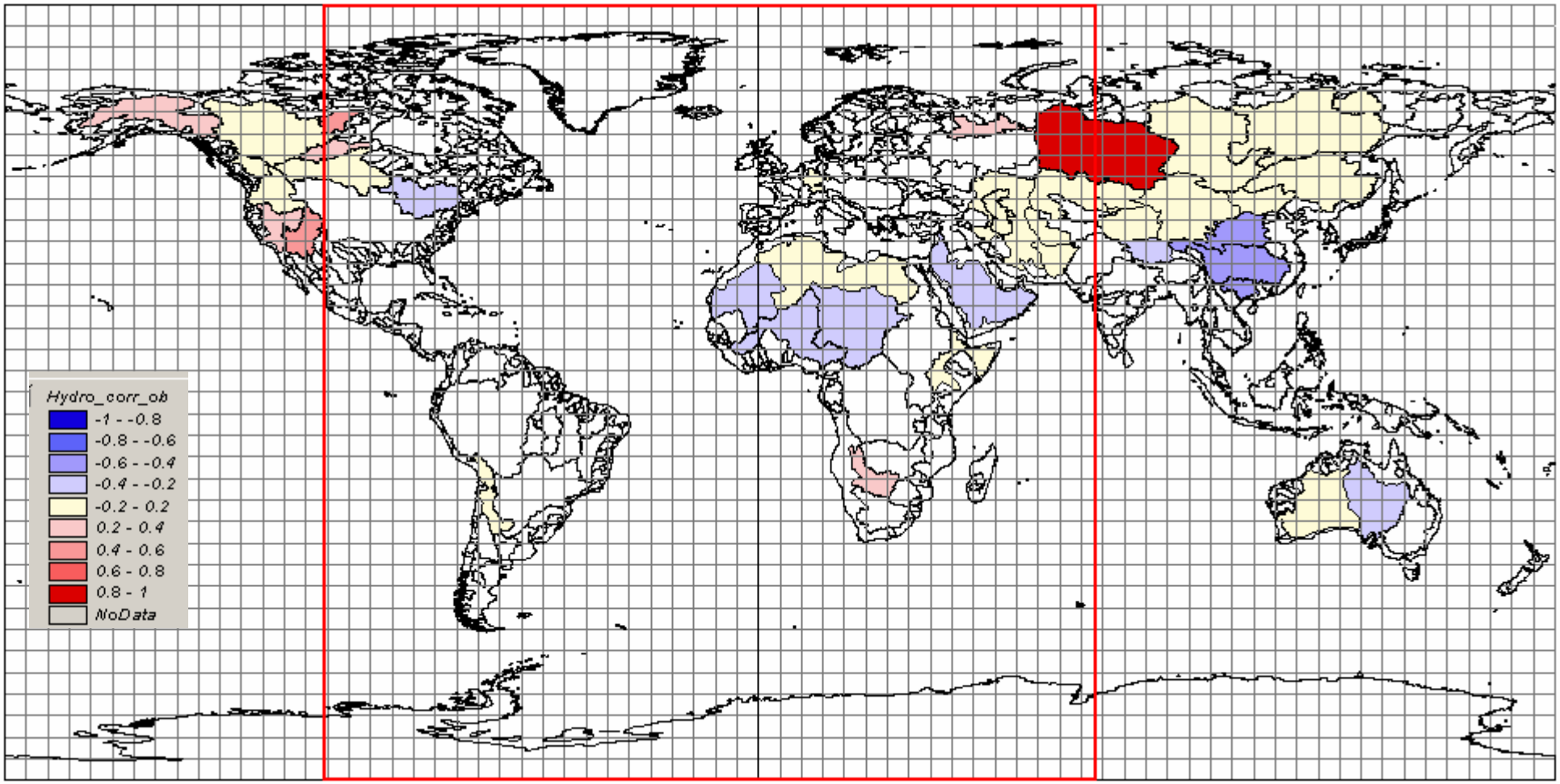
Hydrological Experience → Hydrological Residuals ~ Climatic Fluctuations > Error ε

→ Need for High Accuracy Quantification of Hydrological Uncertainty

Correlation : Hydrology ←→ Hydrology

Spatial Distribution of Temporal Correlation of Residuals between Catchments

(River **OB** versus different catchments, for time periods where *ETa <~ 15mm/mo*)



Correlation : GRACE ←→ GRACE

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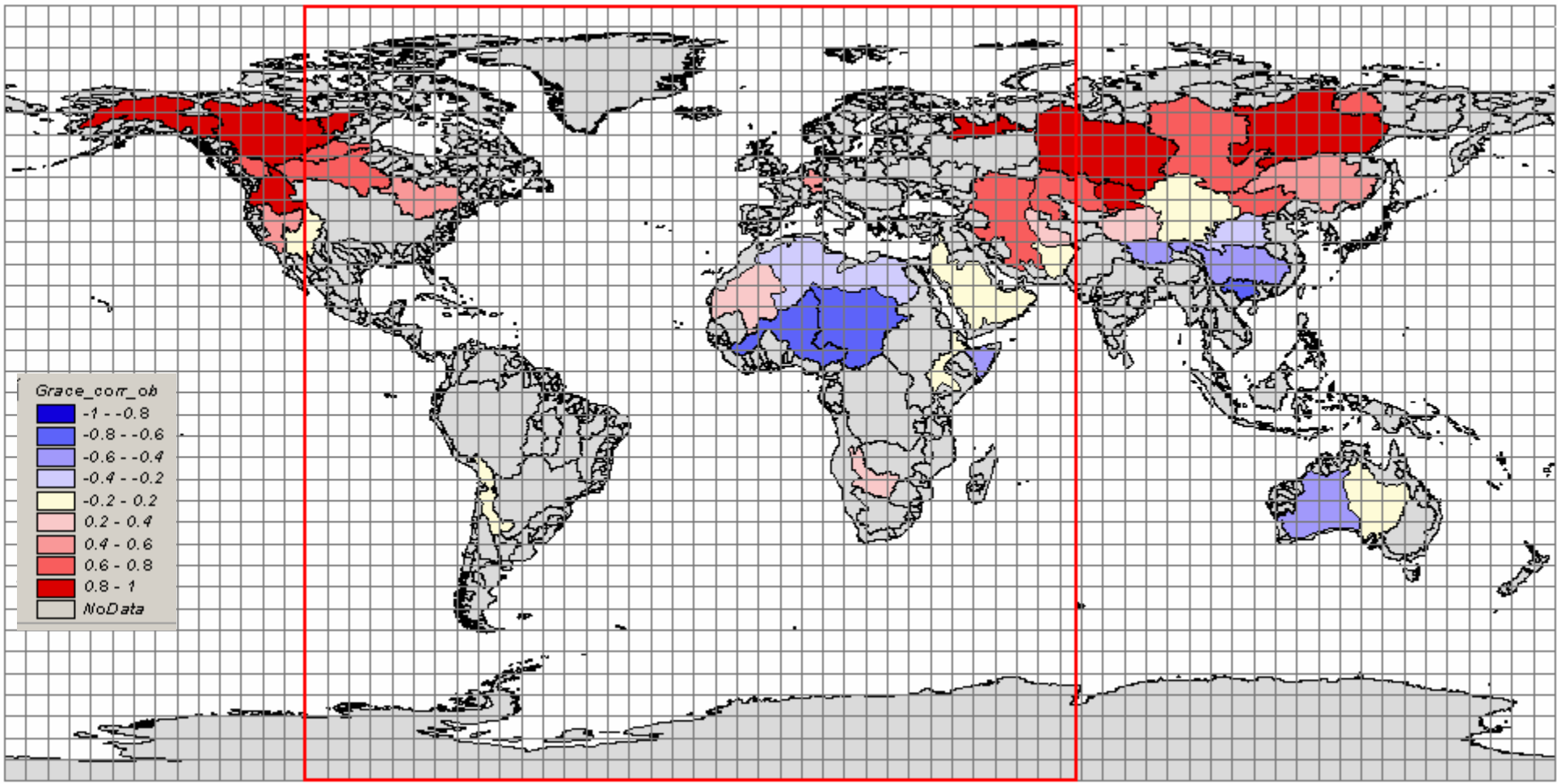
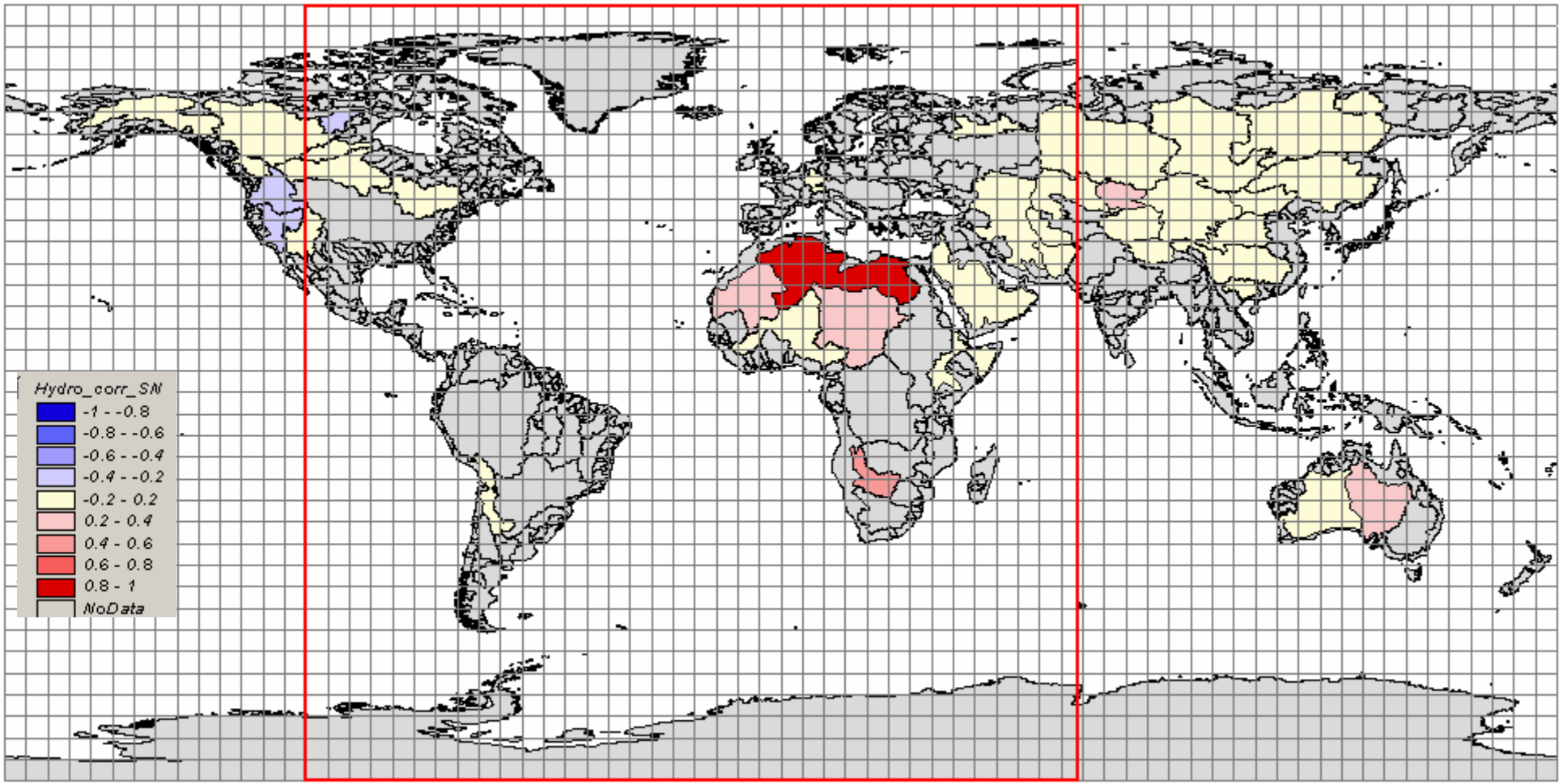


Correlation : Hydrology ←→ Hydrology

Spatial Distribution of Temporal Correlation of Residuals between Catchments

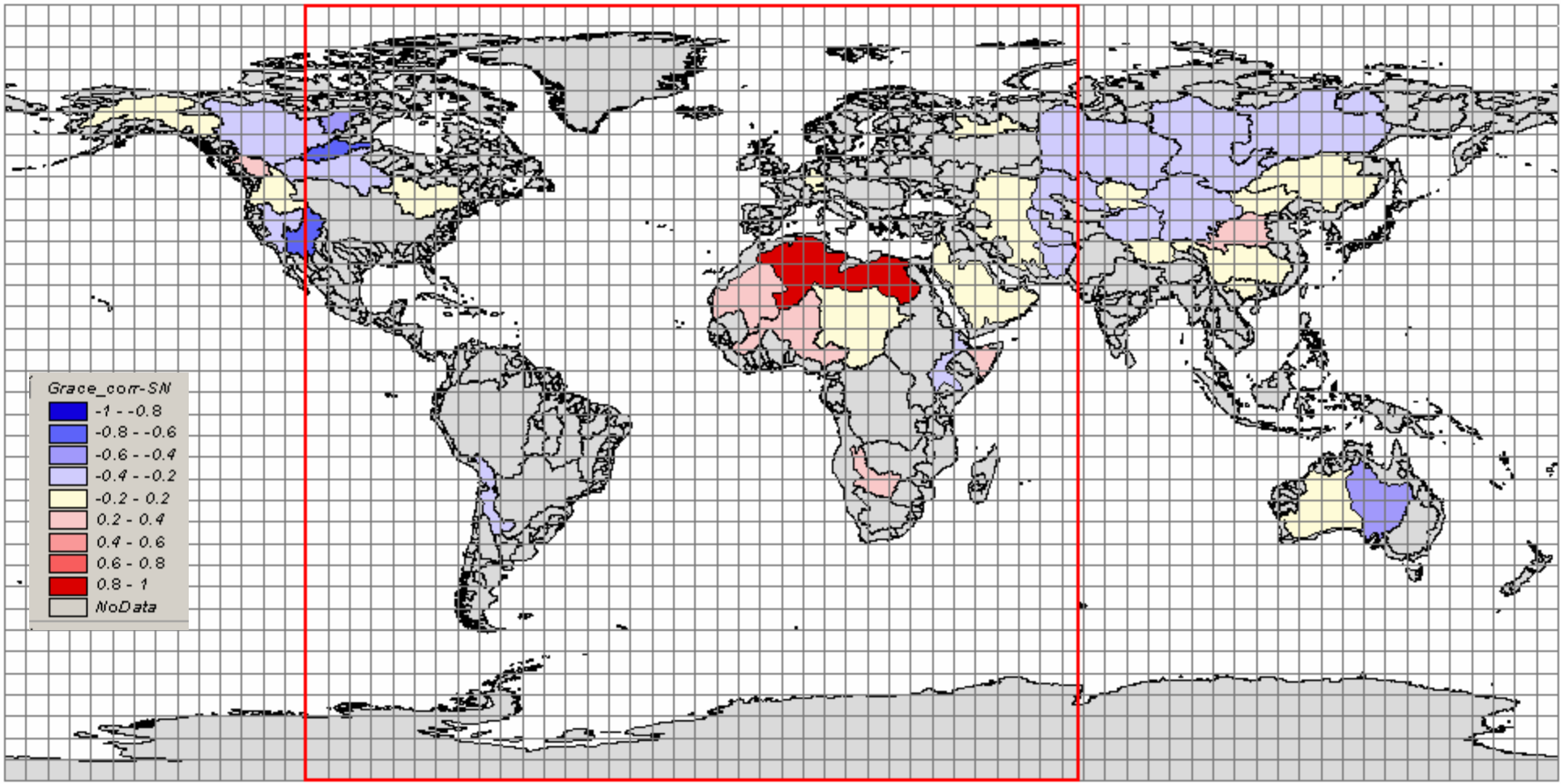
(**Sahara_N** versus different catchments, for time periods where *ETa <~ 10mm/mo*)



Correlation : GRACE ←→ GRACE

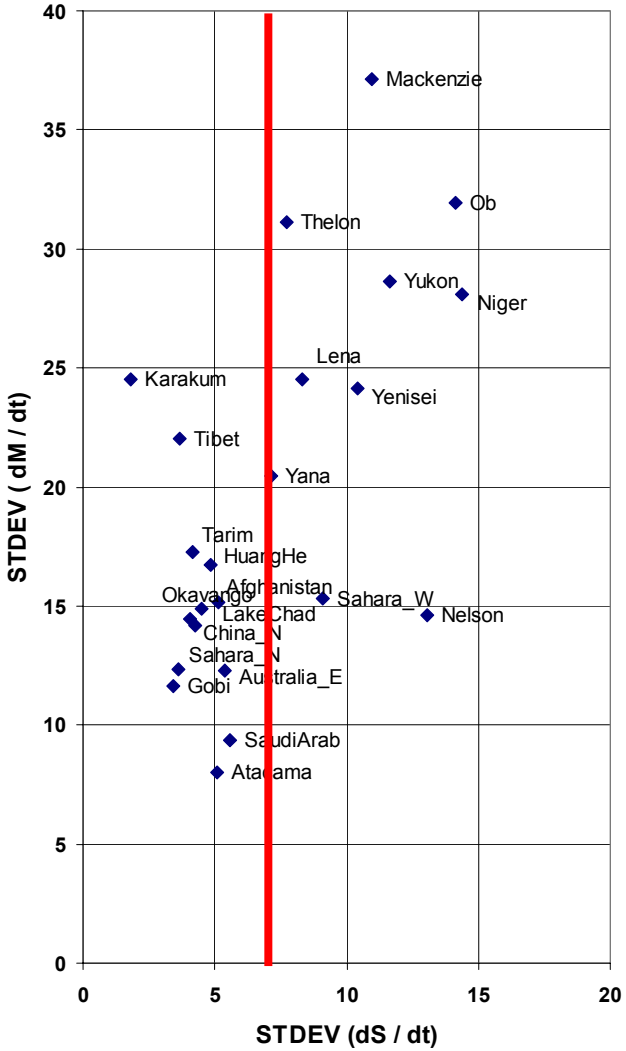
Spatial Distribution of Temporal Correlation of Residuals between Catchments

(**Sahara_N** versus different catchments, for time periods where *ETa <~ 10mm/mo*)

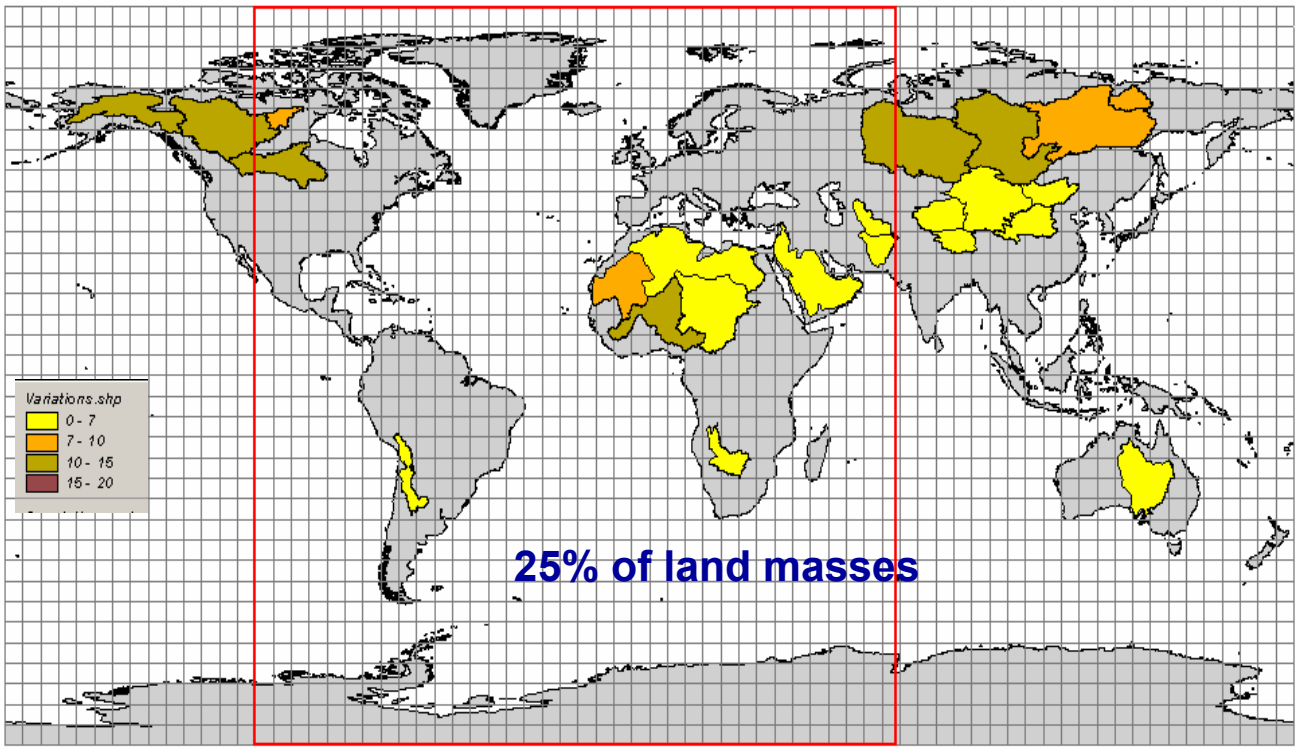


Comparison of Signal Variations

GRACE ←→ Hydrology



- for catchments
- for long time series when *ETa <~ 15mm/mo*

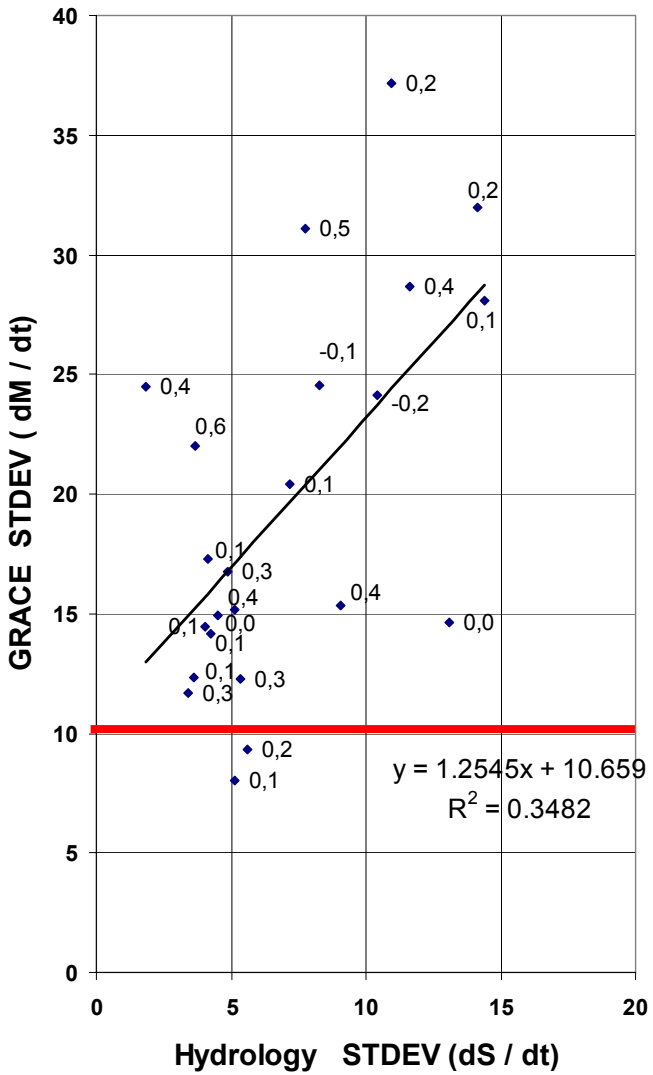


→ many catchments with STDEV(dS/dt) < 7mm/mo

→ Hydrological Reference Areas

GRACE Signal Variations

GRACE ←→ Hydrology



- for catchments
- for long time series when *ETa <~ 15mm/mo*

GRACE variations

→ Threshold = 10mm

= Atmospheric Error (J. Wahr et al.) ???

(1 mbar = 10mm)

→ **Task for Atmosphere Research**

Improvement in Atmospheric Pressure Distribution by Regional Modelling

Evaluation of Atmospheric Moisture Flux ←→ GRACE, Hydrology

→ Improved Global Waterbalance

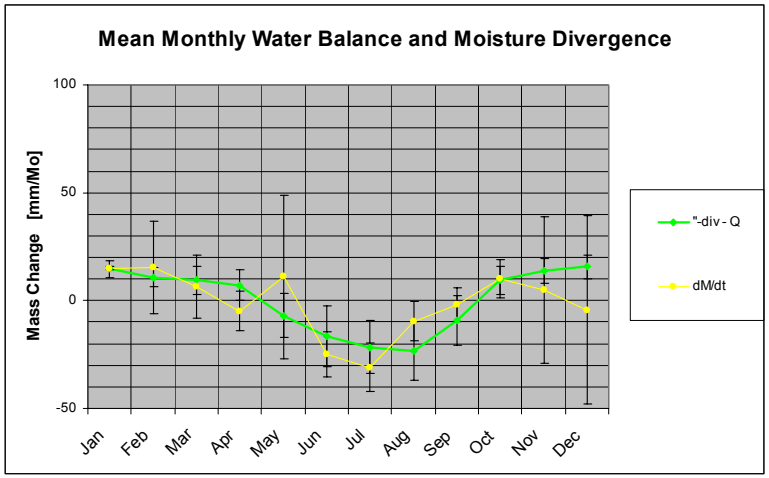
→ Discharge from Ungauged Catchments

→ First Approach of a Comparison with Statistical (Historical) Data

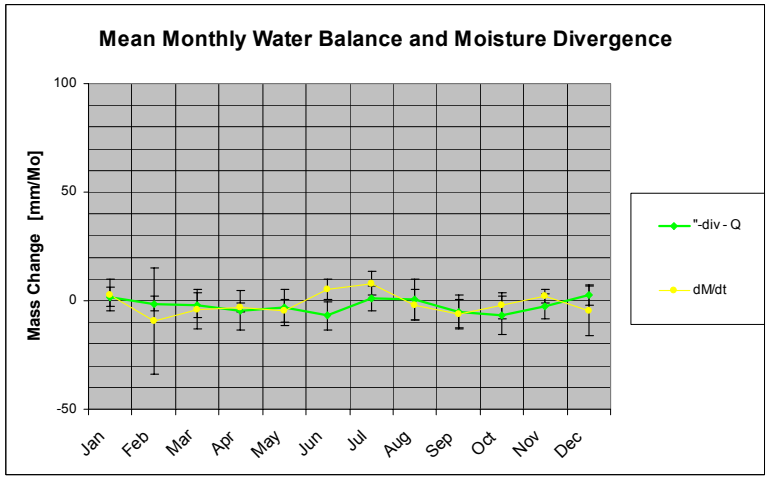
- 15 years of (*–MFD – R*) $-\vec{\nabla}\cdot(q\vec{u})-R=\frac{\partial S}{\partial t}$
- 4 years GRACE

Atmospheric Water Balance ←→ GRACE

Mean Monthly Values (Statistical Comparison)

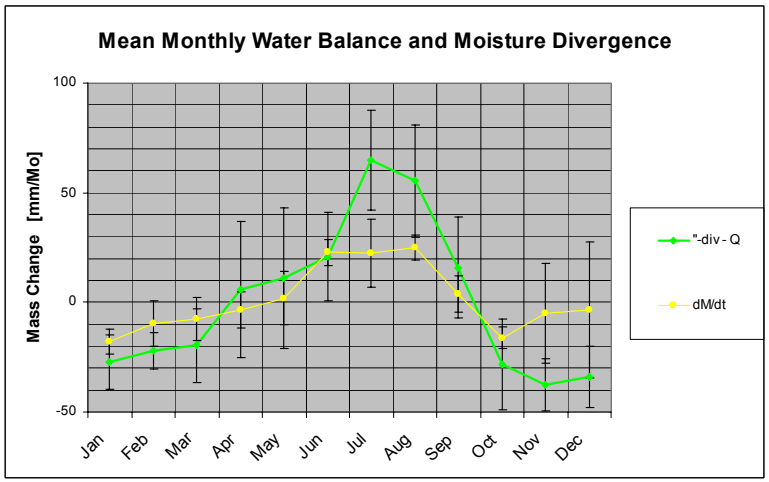


Mackenzie, Yukon, Nelson

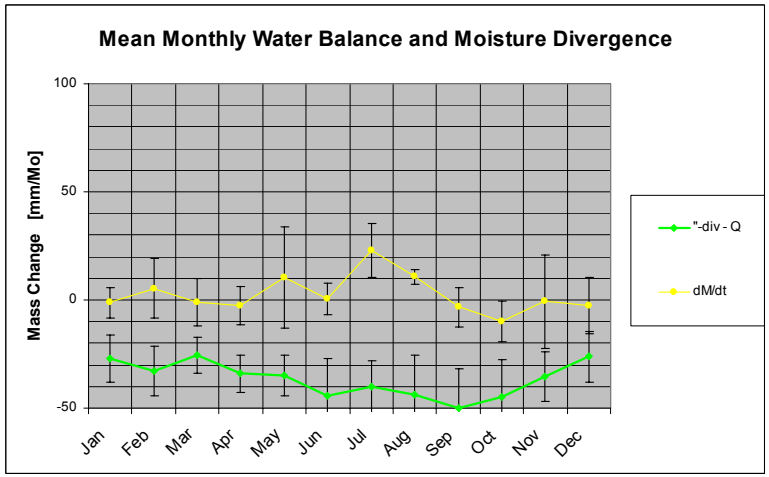


Sahara_N

Fits well



Lake Chad



Sahara_W

Deviations; unphysical results

Atmosphere

Deviations and unphysical Behaviour in Atmospheric Moisture Flux from :

- **Uncertainties and Differences in Atmospheric Data Sets**
- **Atmospheric Model Type / Physics**
- **Different Spatial Resolutions**

→ **Improved atmospheric moisture fluxes & air masses by Regional Atmospheric Modelling**

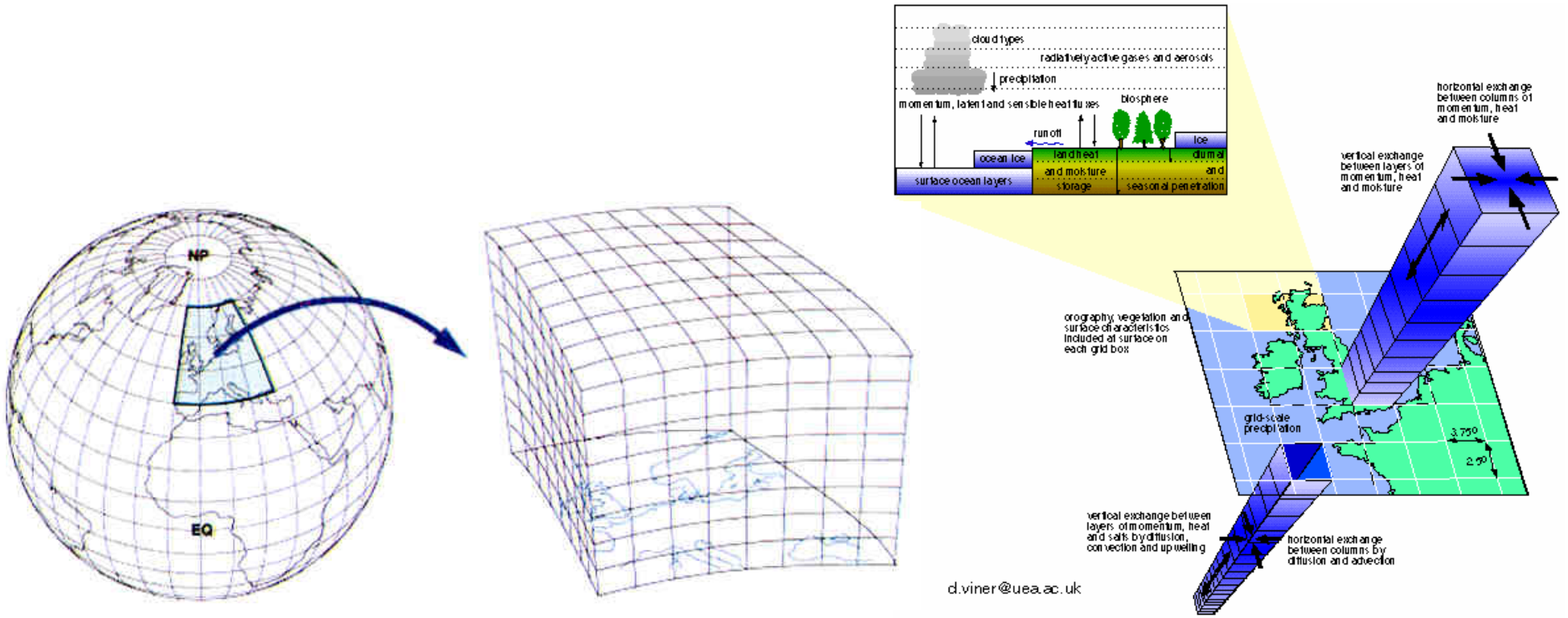
- **Global** fields vs. **regionalized WRF** fields
- Impact of global driving (**ECMWF vs. GFS**)
- Impact of time stepping

1) MFD vs. ET-P (Exemplarily analyzed for Australia, January 2002)

2) air masses

Regional atmospheric modeling

Downscaling of global atmospheric model fields to regional scales:

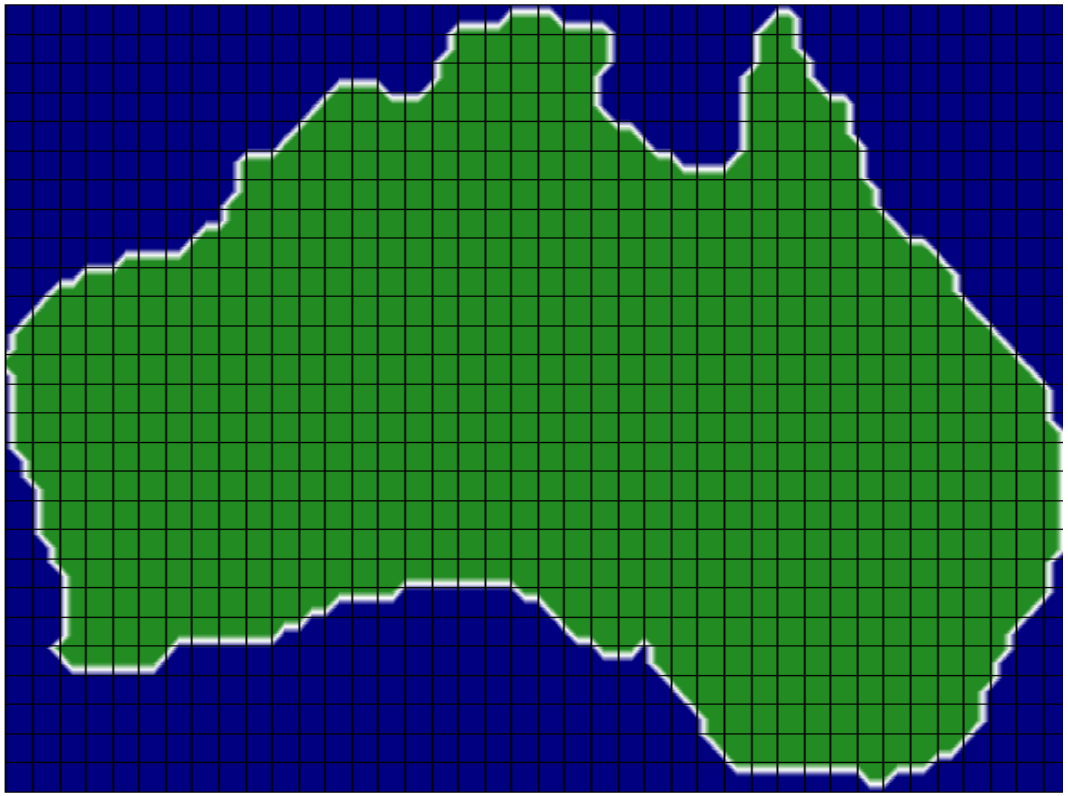


⇒ Δx ≈ 30 km e.g. in this study

Regional atmospheric modeling

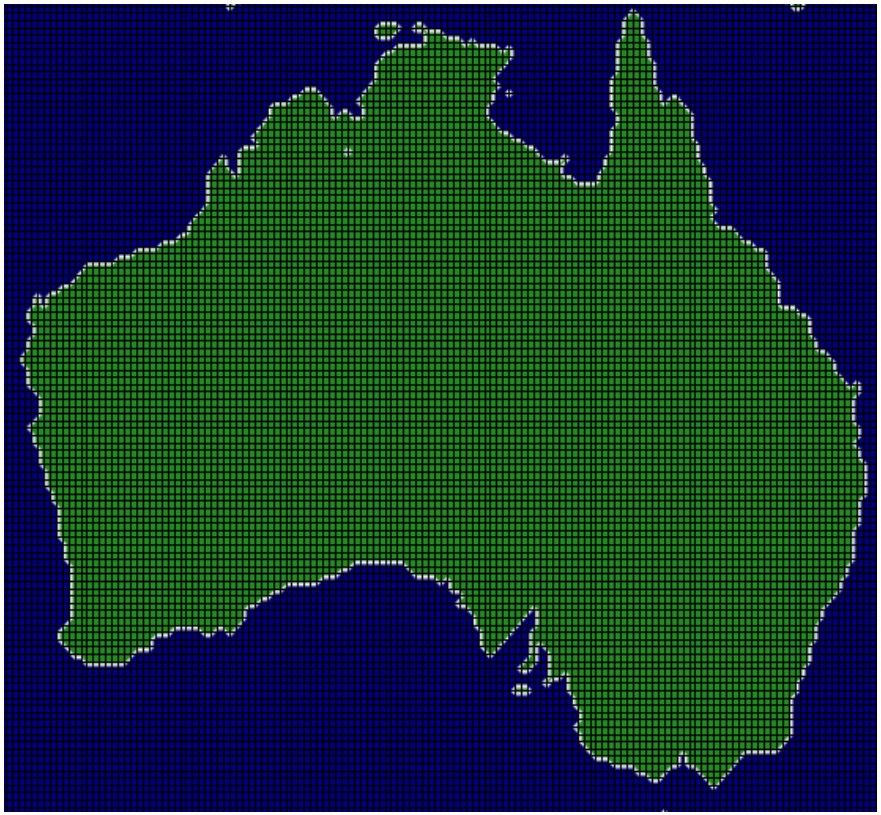
Global atmospheric model ≅ 90 x 90 km² (ECMWF)

Timestep (output) 6 hours

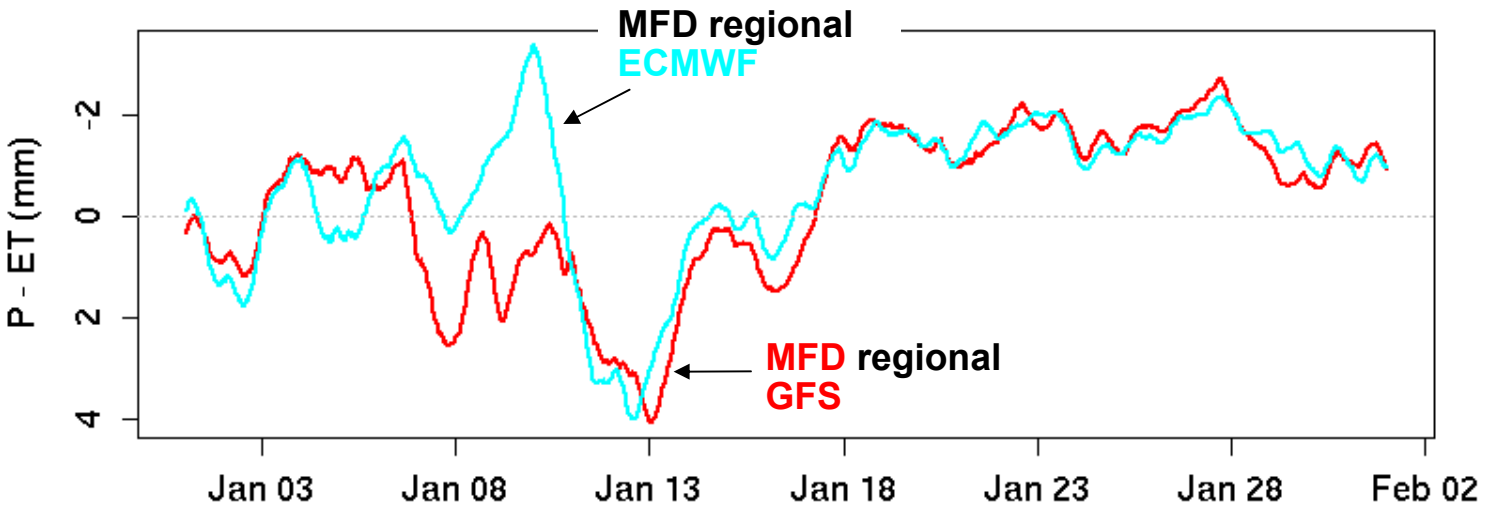


Regional atmospheric model 30 x 30 km² (WRF)

Timestep 180 seconds, 27 vertical layers



MFD vs. P-ET & global vs. regional models



MFD:

Global driving data set impacts MFD (rather than P-ET)

Australian mean JAN 2002

6 hours resolution

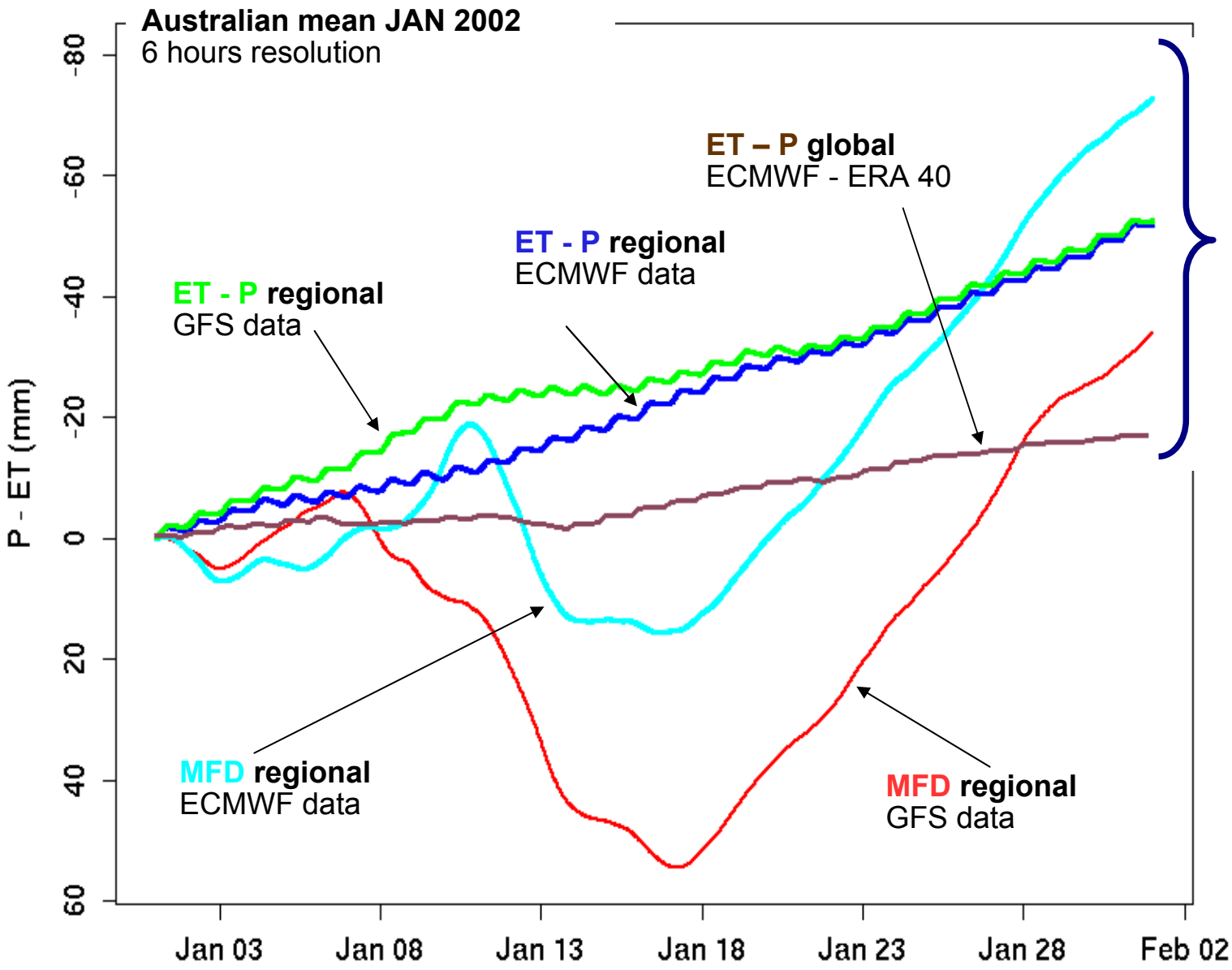
Runoff neglected

P-ET:

Regionalisation gives higher amplitudes

Little impact of driving on regionalisation

P-ET vs. MFD cumulative



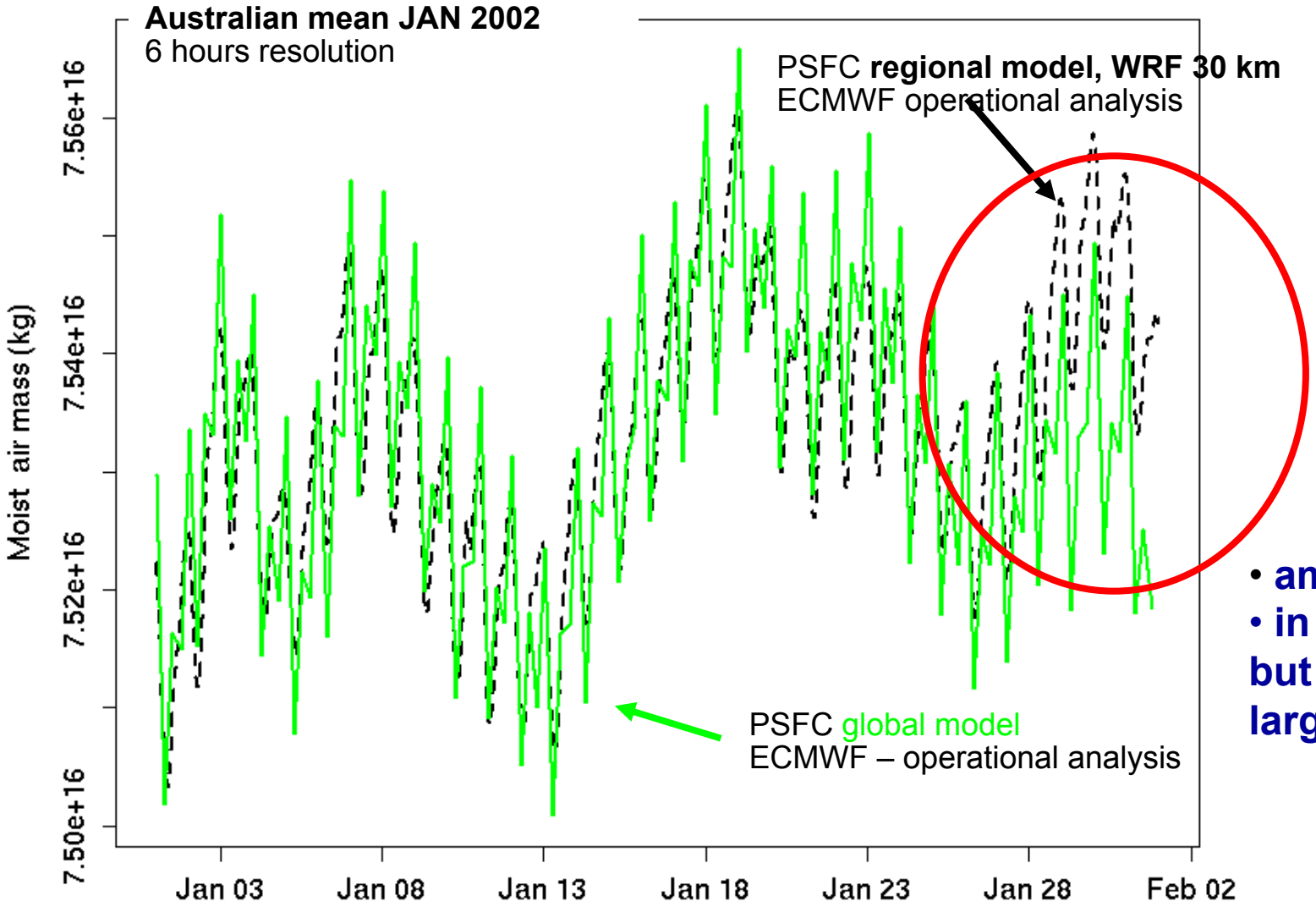
Significant differences between cumulated values of

MFD vs. ET-P

and

regional vs. global models !

Modelled Atmospheric Mass Variations

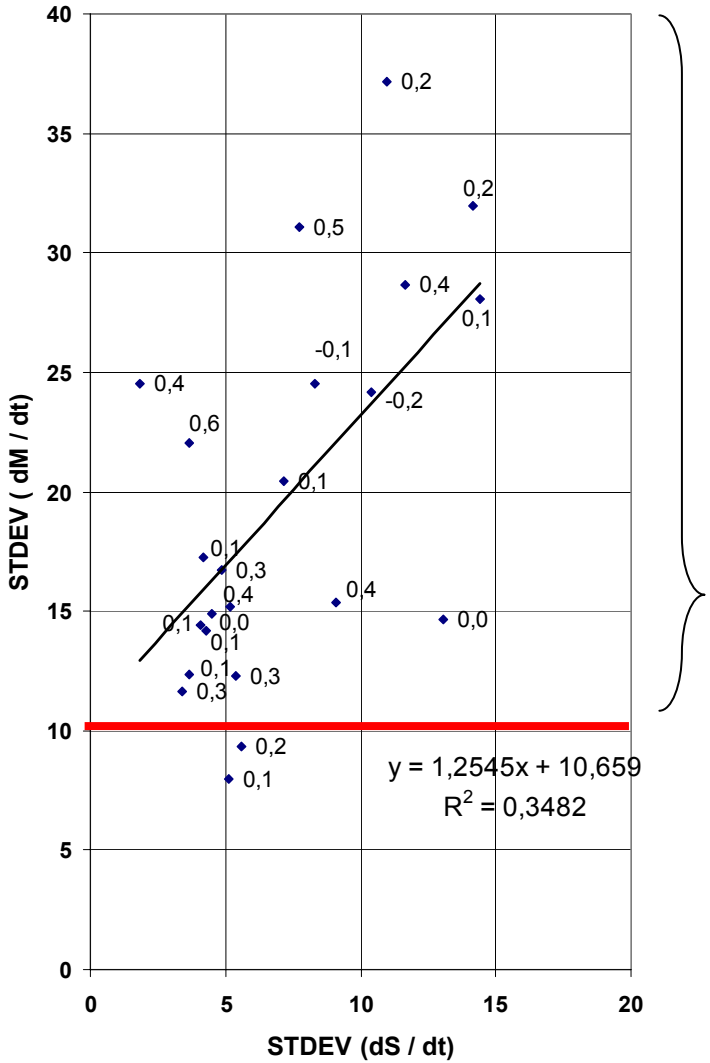


- **amplitudes differ**
- **in general congruence but for selected periods large differences possible**

Geodesy

GRACE Signal Variations

GRACE ←→ Hydrology



- for catchments
- for long time series when *ETa <~ 15mm/mo*

GRACE variations

→ Threshold = 10mm

→ Task for Atmosphere Research

→ **Task for Geodesy**

Geodesy Tasks

Effect of filters: attenuation, biased estimation

- functional vs. stochastic
- isotropic vs. anisotropic — e.g. Han et al.
- filter parameter choice (e.g. cap radius) — e.g. (Chen, Wilson, Famiglietti, Rodell; 2007)
- destriping or not — e.g. (Swenson, Wahr; 2006)
- omission and commission errors — e.g. (Gunter, Ries, Bettadpur, Tapley; 2006)

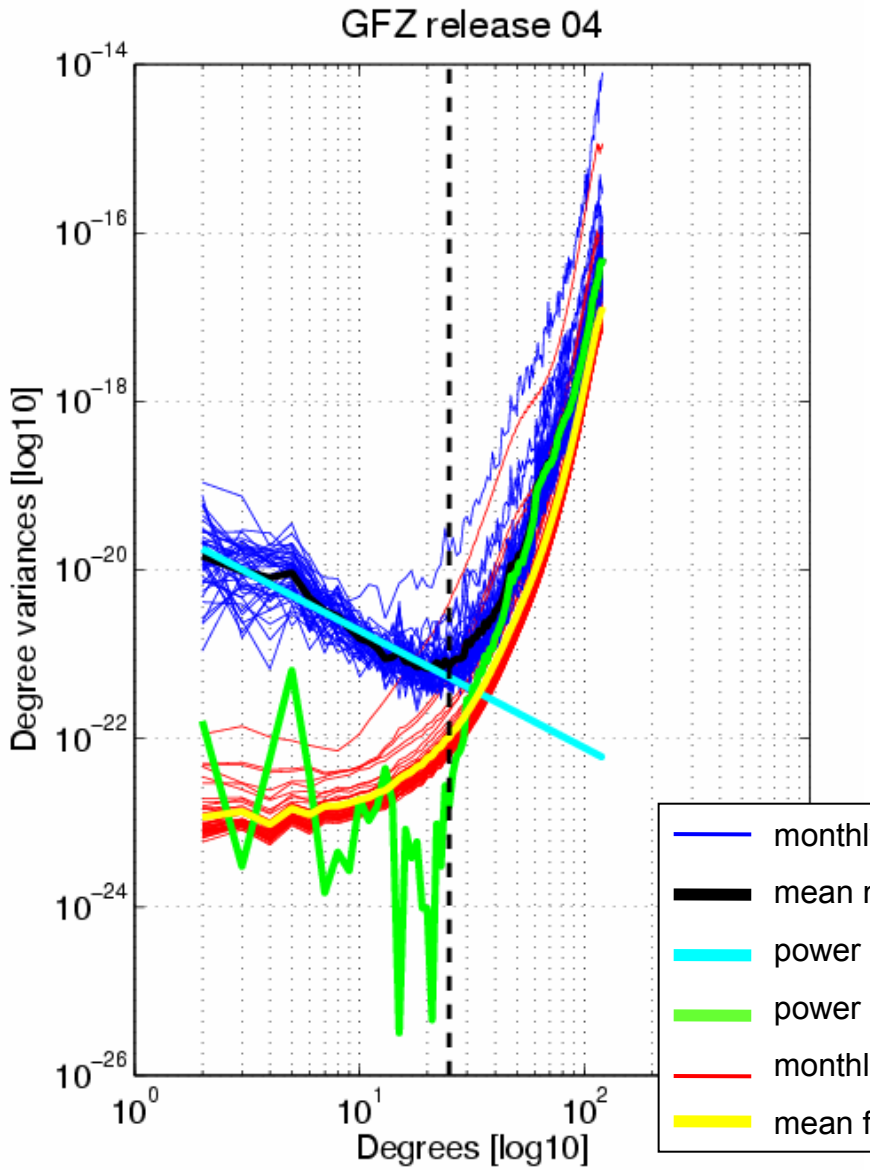
Effect of correlation/decorrelation

- propagation of full error VC matrix — e.g. Schrama
- simulation of normal matrix structure — e.g. Kusche

Effect of basin function

e.g Wilson et al.

Error Budgets: Wiener Filtering



$$w_l = \frac{s_l^2}{s_l^2 + n_l^2}$$

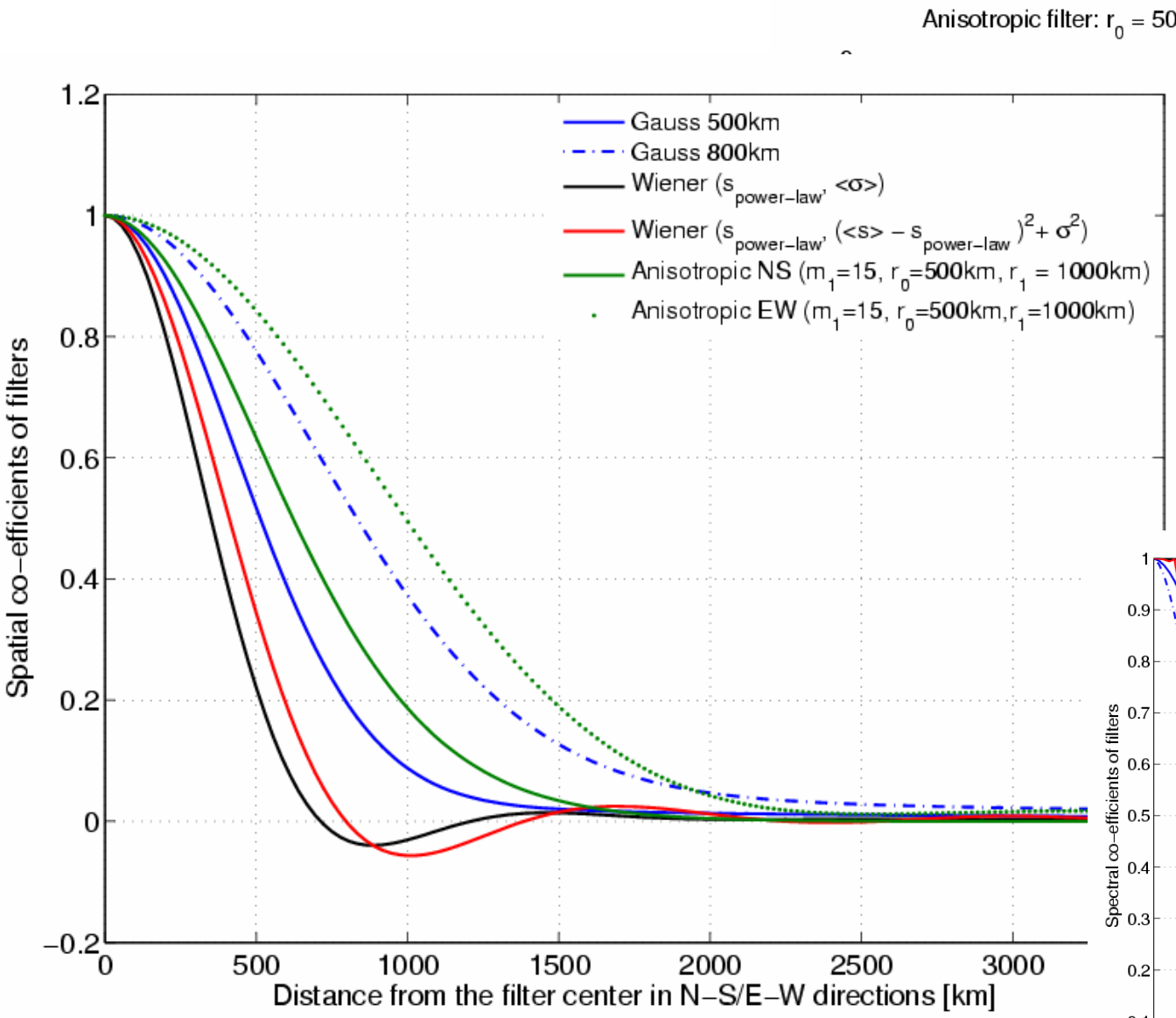
But:

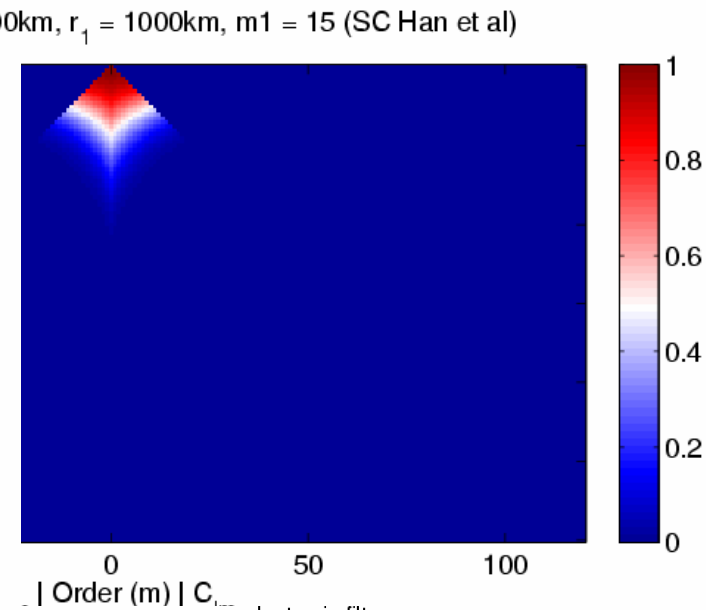
- when is signal really signal?
- what is noise?
- anisotropic?

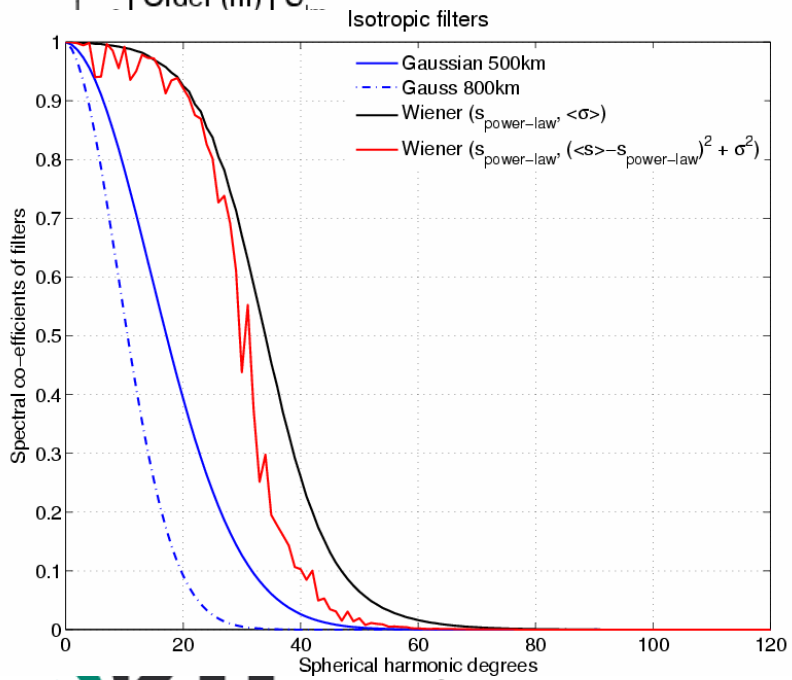
s_l

n_l

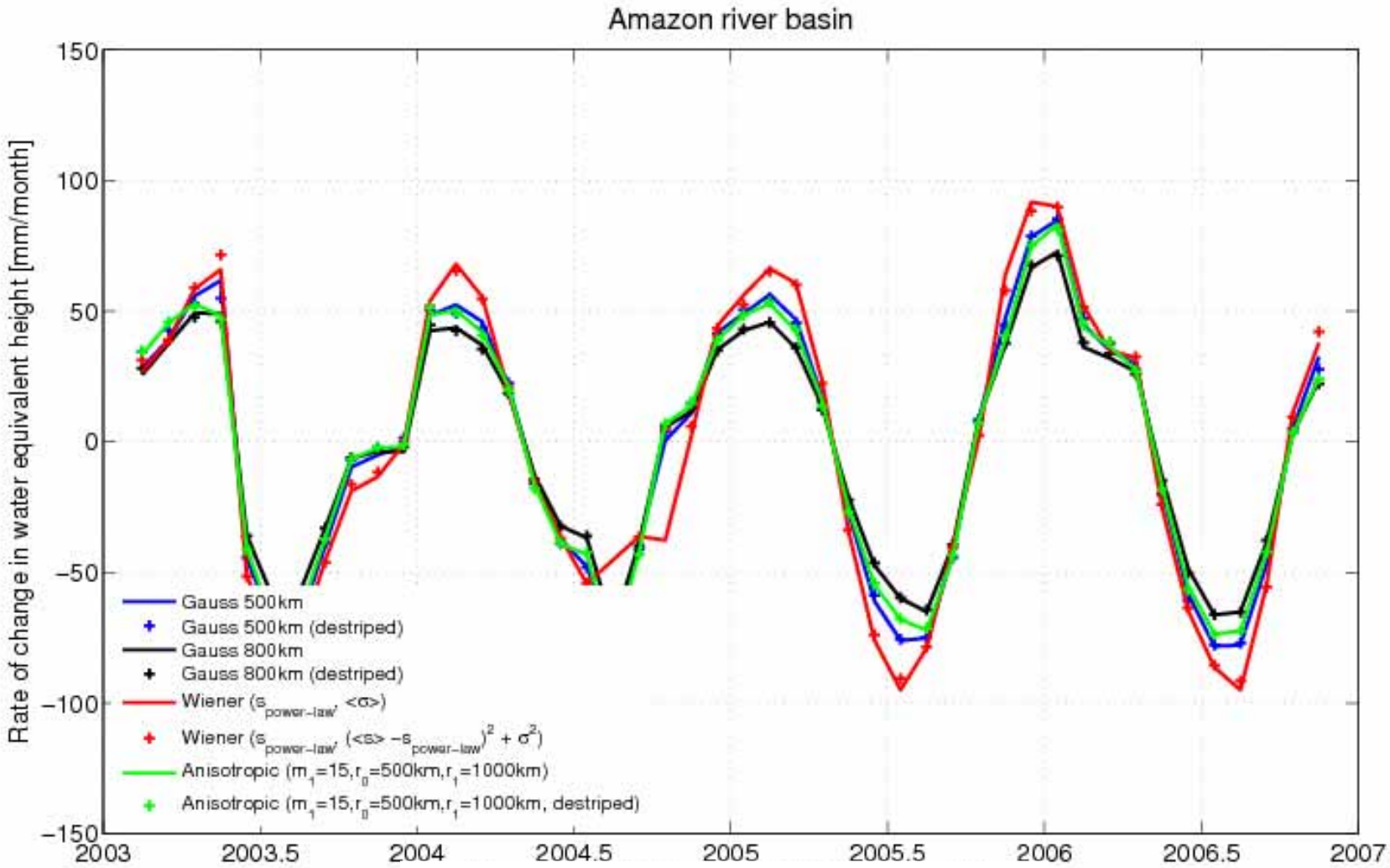
filters and windows







some filtering effects



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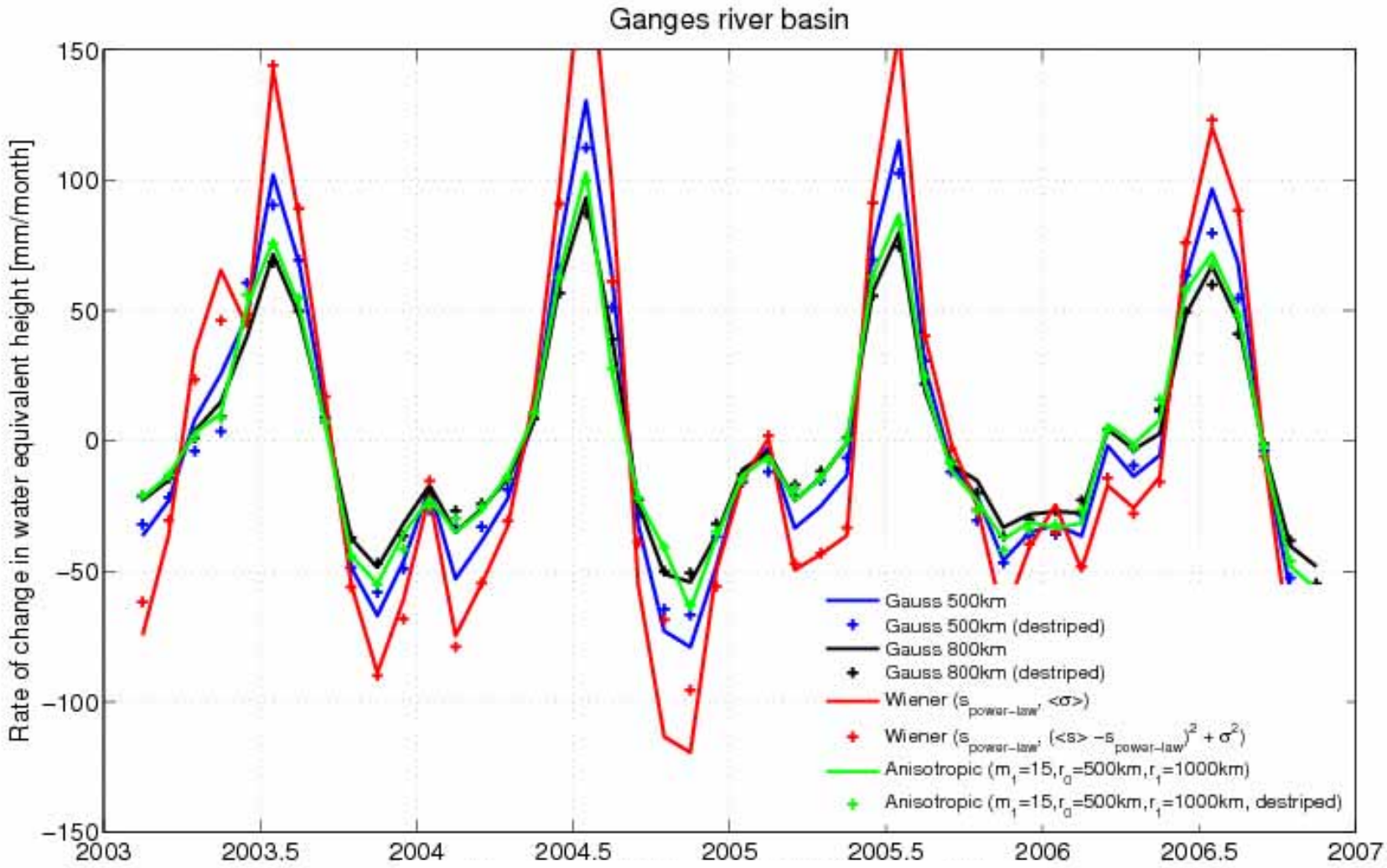


Summary

No systematic Correlation between **Residuals** of
GRACE Mass Changes and Hydrologic Storage Changes

Significant Impact of Global Atmospheric Driving Data and
Spatial Resolution on MFD and Atmospheric Masses

Significant Impact of Filter Choice (and Spectral Correlations)
on Mass Estimates and their Uncertainties

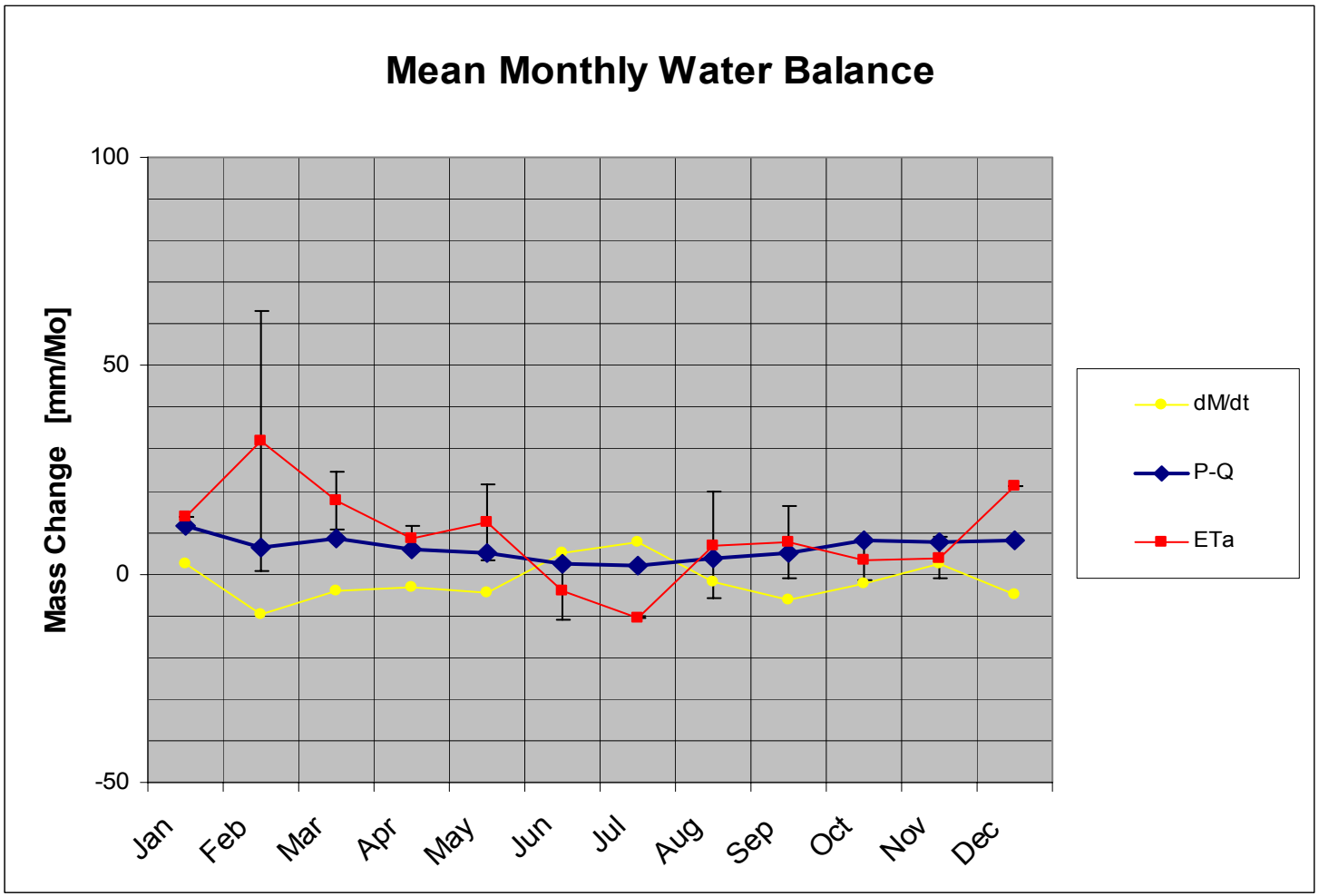
Use of Mass Constraints from Hydrology as Reference for GRACE
(25% area of land masses)

End

Water Balance

Mean Monthly Behaviour

Northern Sahara

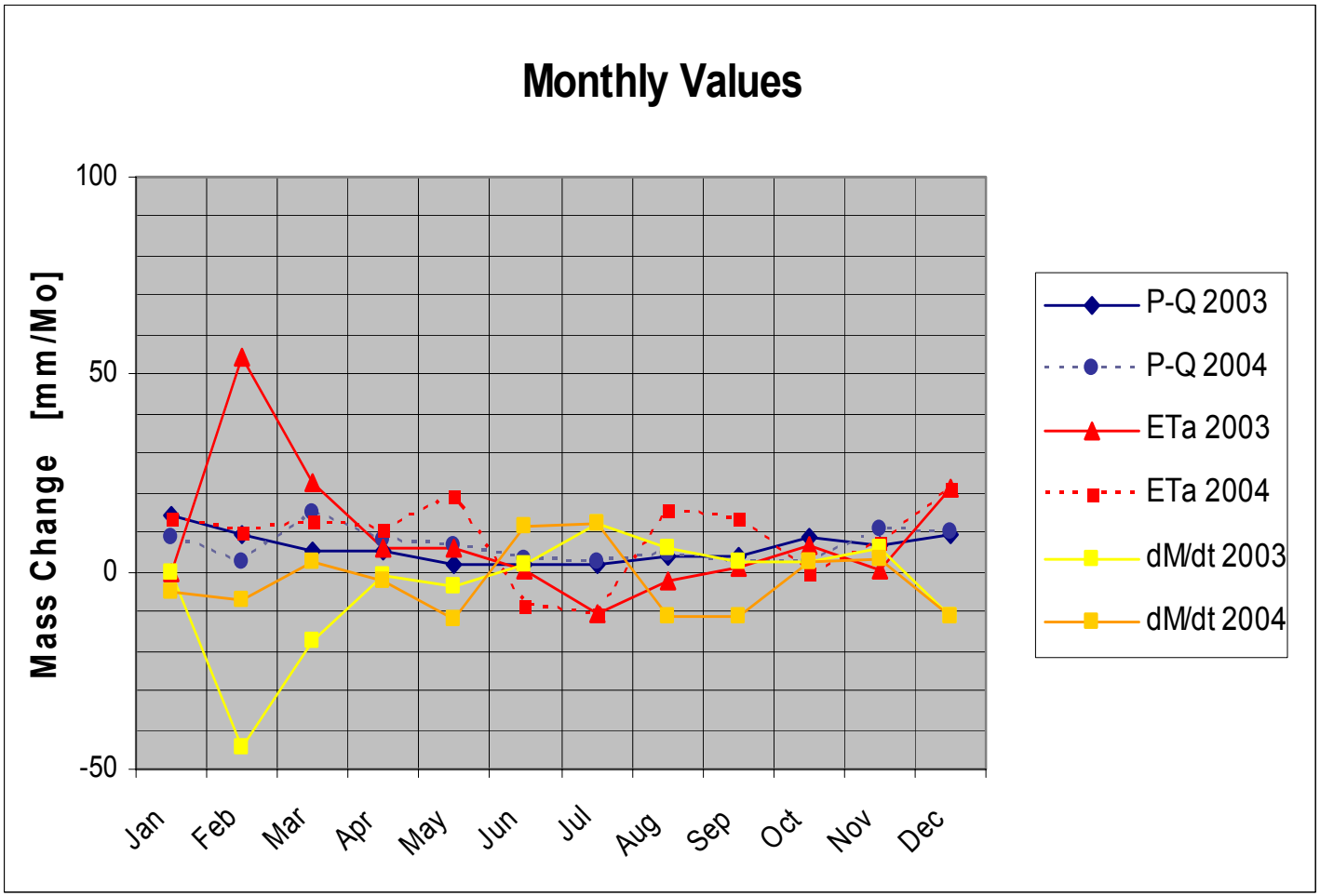


→ **Reasonable Annual Behaviour**

Water Balance

Monthly Behaviour

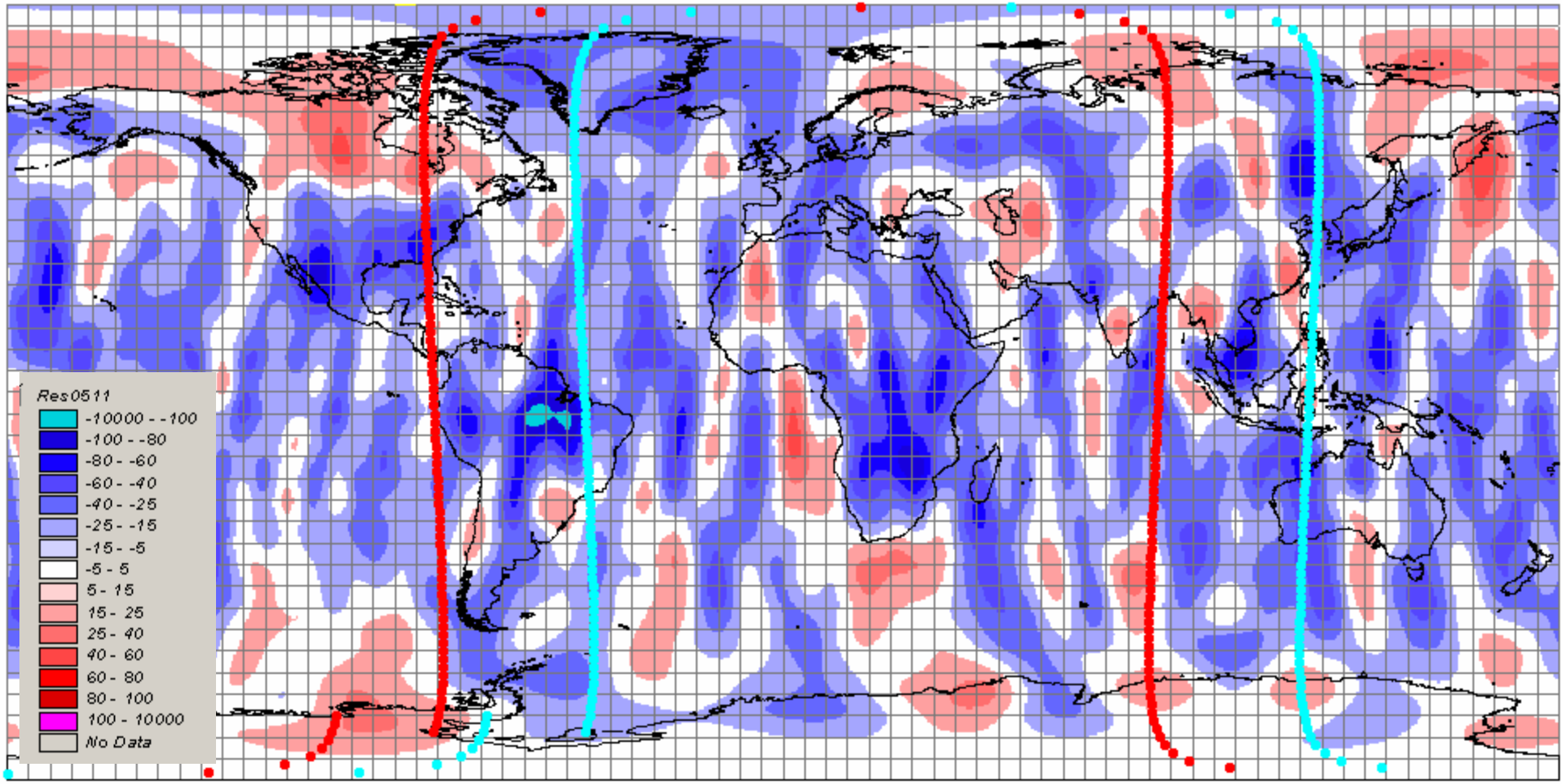
Northern Sahara



→ **Variations +/- 20% - 30% of Annual Amplitudes** (for Tundra)

GRACE Residuals

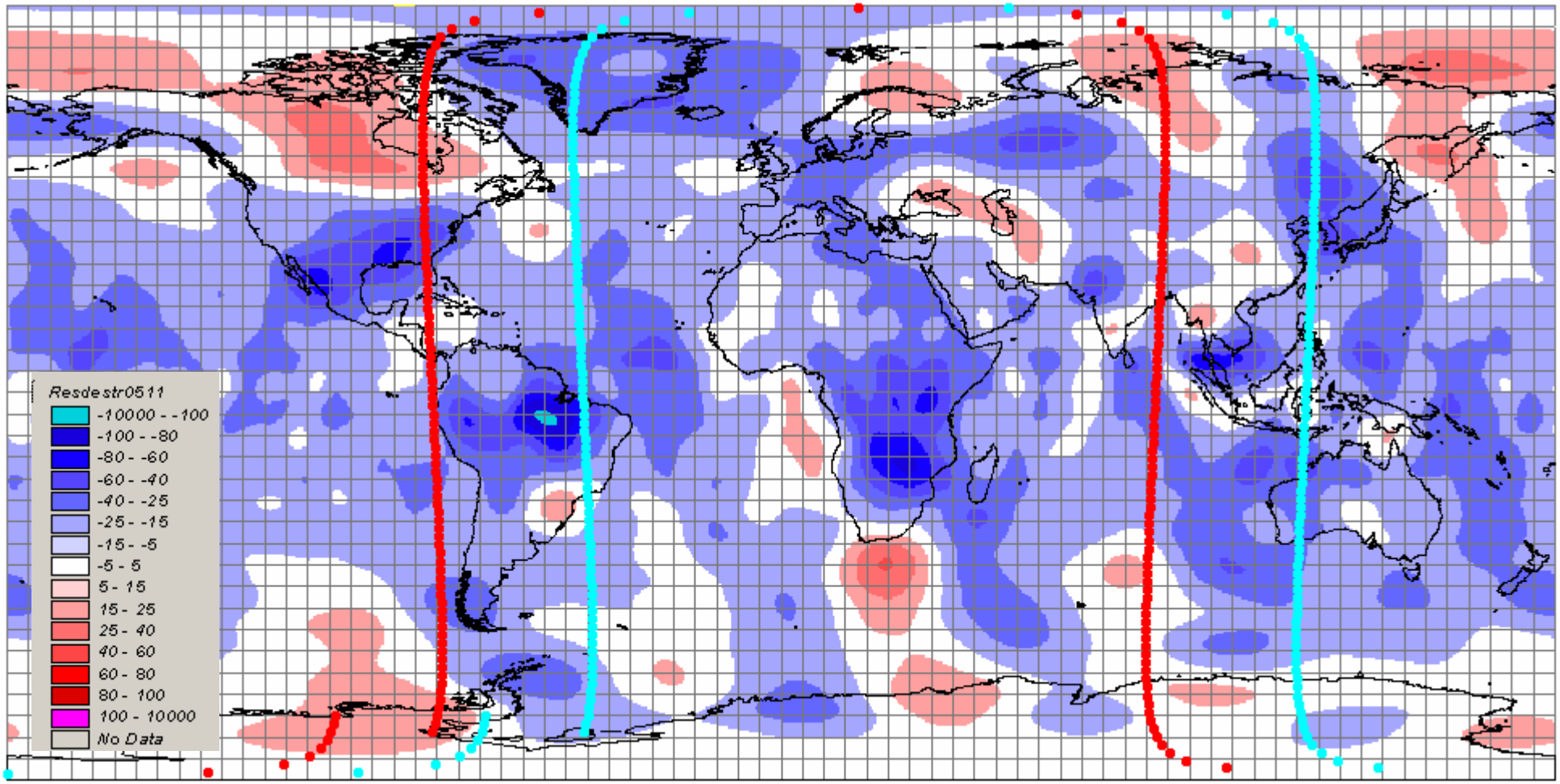
Monthly Residual of GRACE Global Solutions Release IV Nov 05



Relationship to Orbits ?

GRACE Residuals

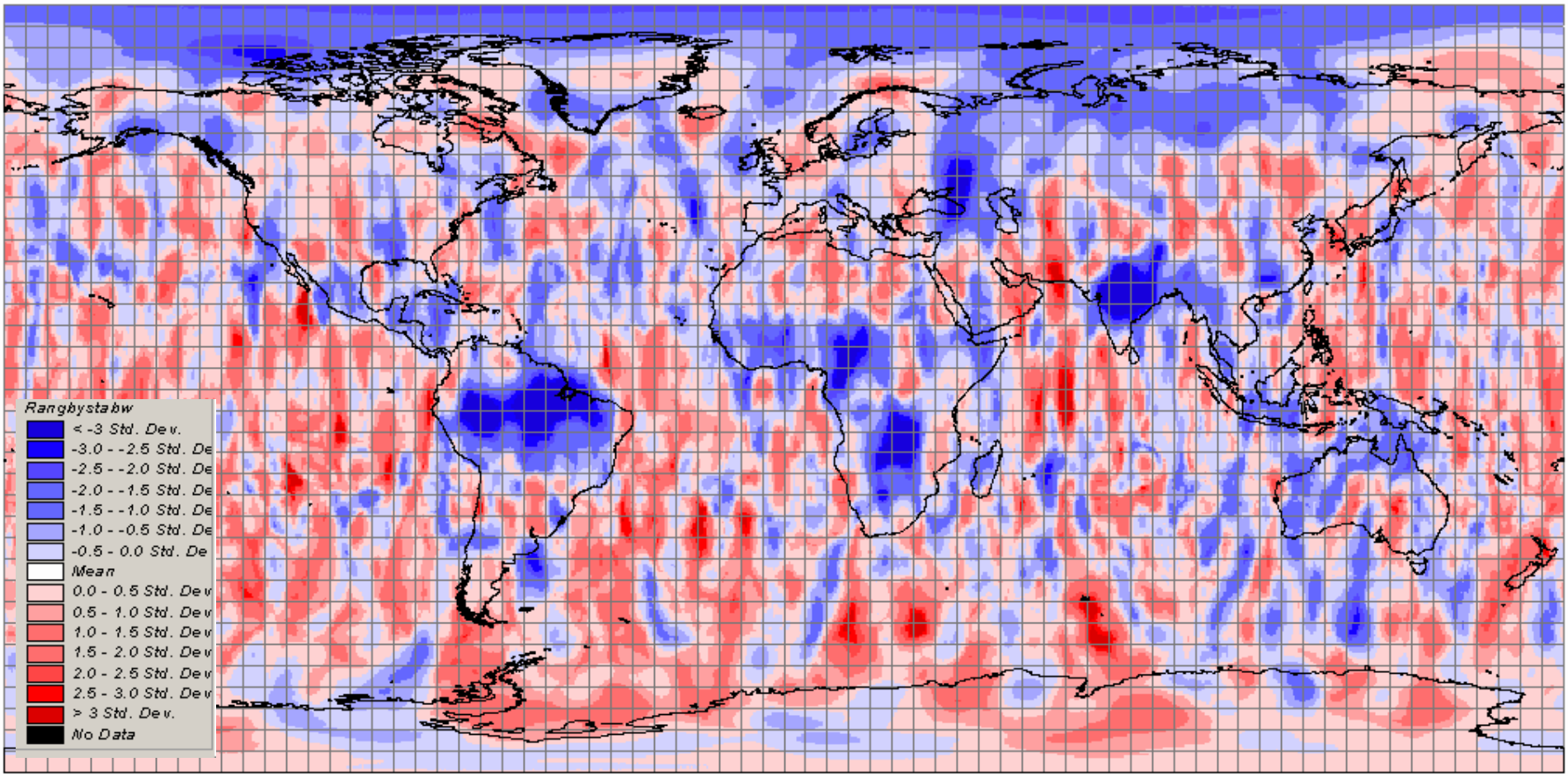
Monthly Residual of GRACE Global Solutions Release IV Destriped Nov 05



Relationship to Orbits ?

Noise / Signal for GRACE

Stdev of GRACE Residual / GRACE Mean Annual Range



Stdev from 25% Mean

Next Steps

Hydrology :

- Quantification of Hydrological Uncertainties
- Selection of appropriate Reference Areas (dS/dt<10mm/mo)
- Correlations Hydrology - GRACE

Atmosphere :

- Evaluation of Moisture Flux on Regional Scales
- Evaluation of Regional Pressure Distrubutions

Geodesy :

- filter optimization
- improved error budgets
- Investigation of correlations
- functional modeling of residual signal with radial base functions
- Correlations spatial vs. spectral
- developing mass correction models for hydrological constraints (25% of land masses)
- incorporating regional atmospheric constraints