Importance of leakage analysis for trend studies

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1. Motivation

The GRACE satellites have been observing the mass changes on and within the Earth's surface for more than a decade. The GRACE observations are noisy and thus filtering is necessary. Filtering reduces noise but also changes the signal (Klees et al., 2007; Longuevergne et al., 2010). The trend estimates for mass change over glaciers, ice-caps and hydrological catchments alarmed mankind. The quantitative aspect of observations suffer high uncertainity due to leakage (King et al., 2012; Long et al., 2015). Thus leakage analysis of filtered GRACE dataset is inevitable.

The effect of filtering on trend estimates from GRACE have never been investigated before. In this contribution we discuss the need and importance of leakage analysis for trend studies. We suggest a methodology to treat discrepancies in the trend, due to filtering. We demonstrate the method in a closed-loop environment first and then apply it to GRACE.

2. Breaking the filtering process

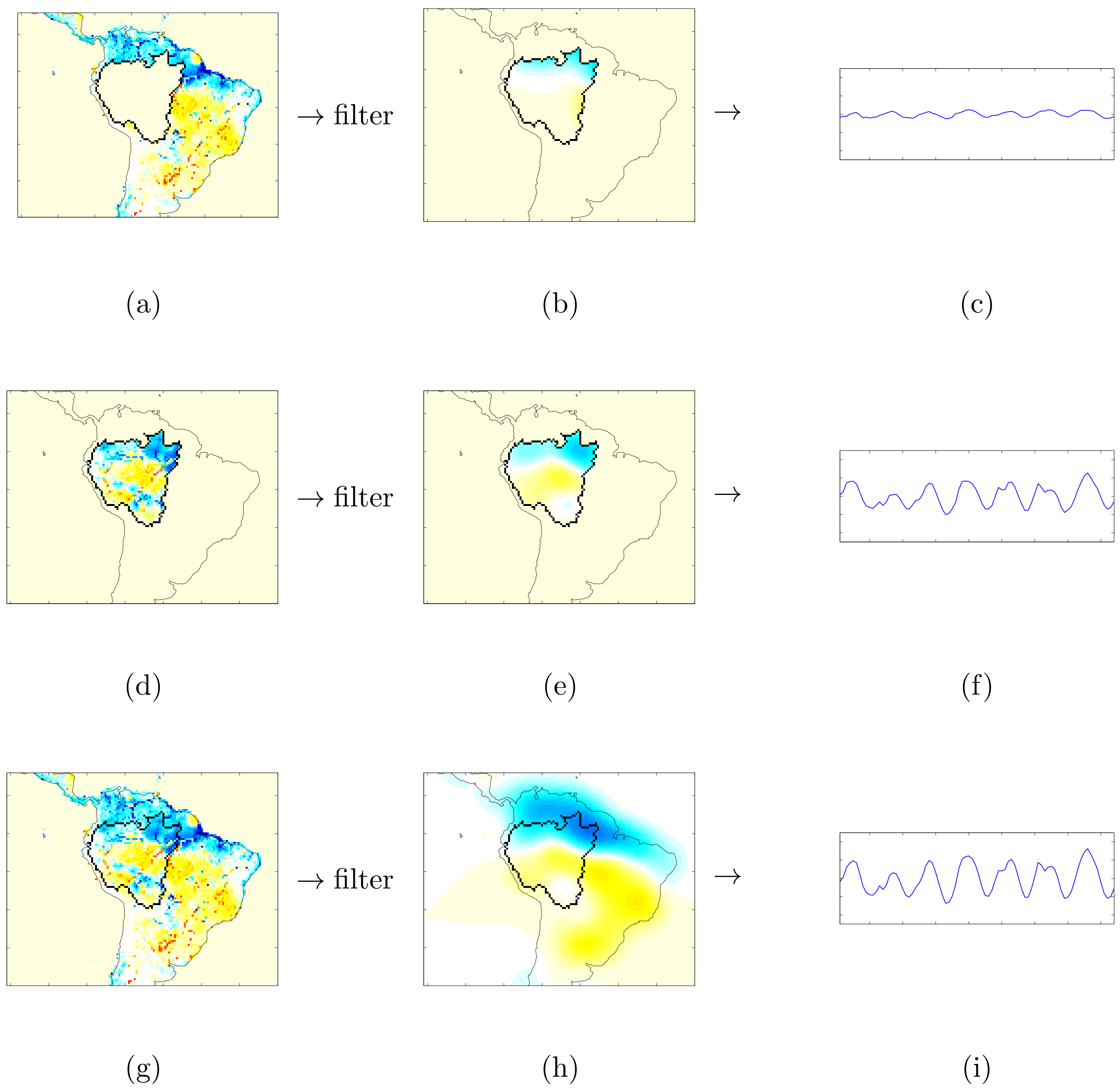

Figure 1: *An illustrative example. (a) shows a field only outside the catchment. Filtering (a) gives us (b), which is aggregated over the catchment for every month to get leakage time-series (c). (d) is a field only inside the catchment, filtering it only inside catchment gives (e), the corresponding time-series is (f). (g) is a global field,(h) is filtered version, from which we get the time-series (i). The time-series in (i) is summation of time-series in (c) and (f).*

For a catchment c described by a characteristic function $R(\theta,\lambda)$, we denote the true time-series by f_c, time-series from filtered global field by $\bar{f_c}$, leakage time-series by l_c and the scale factor for the region and a filter kernel by s then,

$$\bar{f_c} = \frac{1}{s} f_c + l_c, \qquad \text{where } s \approx \frac{\int\limits_{\Omega} R(\theta,\lambda)\mathrm{d}\Omega}{\int\limits_{\Omega} \bar{R}(\theta,\lambda)R(\theta,\lambda)\mathrm{d}\Omega}. \tag{1}$$

The time series f_c can be written as $\alpha\sin(\omega t+\phi)+T(t)$, similarly $\bar{f_c}$ can be written as $\bar{\alpha}\sin(\omega t+\bar{\phi})+\overline{T}(t)$ and leakage time-series as $\alpha_l\sin(\omega t+\phi_l)+T_l(t)$. The corresponding α is the amplitude, ϕ is the phase, $T(t)$ is the trend component. Putting the time-series in (1) and solving for the relation between the trends, we get

$$\overline{T}(t) = \frac{T(t)}{s} + T_l(t). \tag{2}$$

Thus the trend from filtered data equals a scaled down true trend followed by a shift due to leakage. So isolated catchments with no trend nearby will suffer only from a scaling effect, while catchments with several strong trend signals nearby can have complicated behaviour.

3. Validation in a closed-loop environment

We use WGHM model data and assume the trend $T(t)$ to be linear, characterized by slope k.

	Indus	Ganges	Brahmaputra	Highland of Tibet	Aravalli	Mahanadi
k_{true}	-0.81	-2.59	-0.91	-0.02	-1.50	0.36
$\bar{k}$	-0.95	-1.57	-1.06	-0.55	-1.02	-0.64
k_{rec}	-0.89	-2.53	-0.87	-0.02	-1.66	0.32
$k_{\text{true}} - \bar{k}$	0.14	-1.02	0.15	0.53	-0.48	1.00
$k_{\text{true}} - k_{\text{rec}}$	**0.08**	**-0.06**	**-0.03**	**-0.00**	**0.16**	**0.04**

Table 1:*Validation in a closed-loop environment. k_{true} represents the true trend, $\bar{k}$ is the trend of the time-series obtained from filtered model, and k_{rec} is the trend computed from (2). All values are in* mm/yr.

4. Results and conclusion

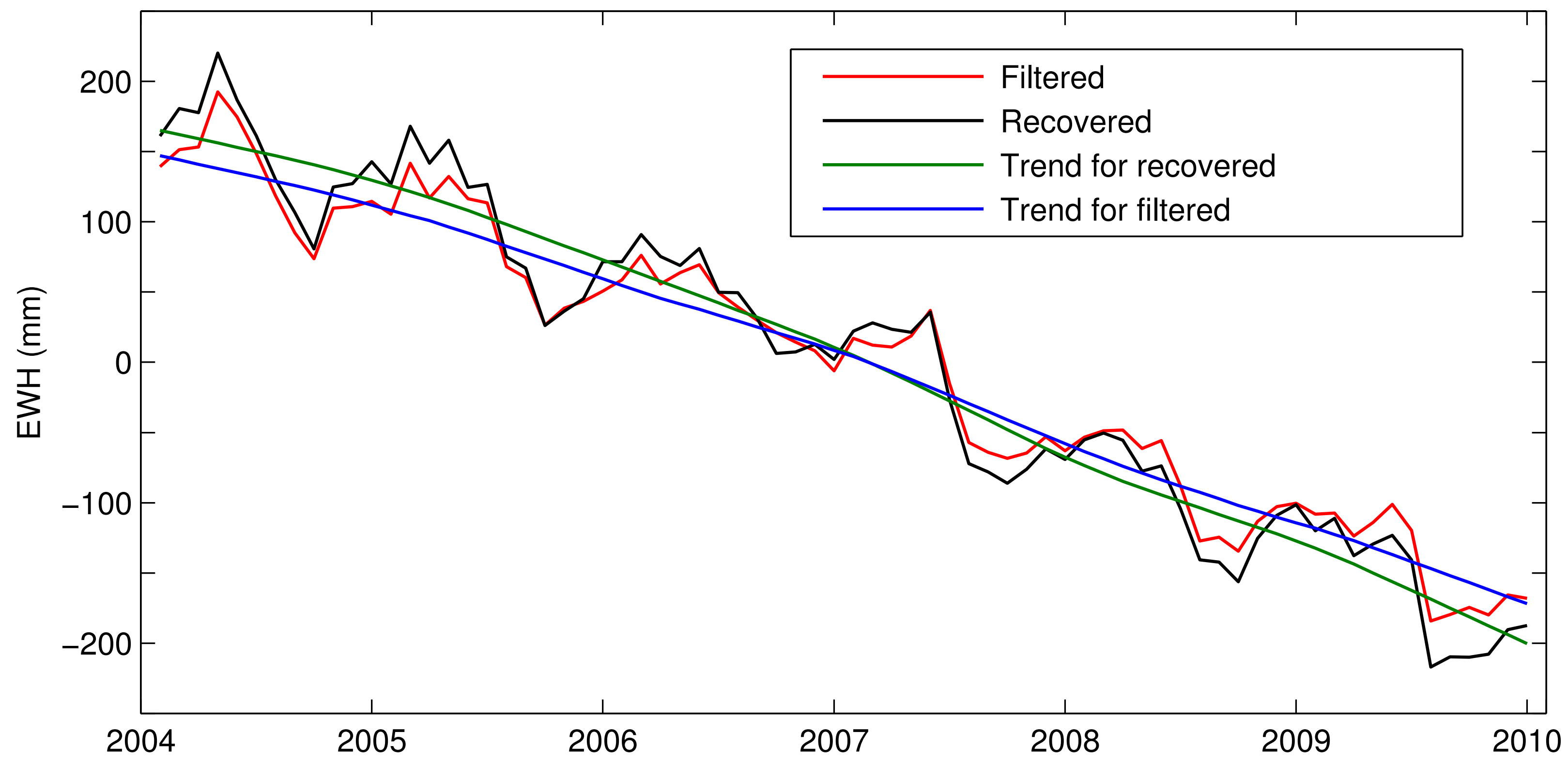

Figure 2: *Trend analysis with GRACE data over Greenland. We use STL (Seasonal-Trend decomposition procedure based on Loess) to extract trend (Cleveland et al., 1990). A Gaussian filter with averaging radius of* 400 km *was used.*

- The trend estimates are affected due to filtering.
- Isolated catchments need only scaling, no need of leakage analysis.
- Non-isolated catchments have shift due to leakage from surroundings. Thus the trend signal might be over or under estimated.
- Minimizing effects of filtering is essential for better trend estimation.
- Average rate of mass change over Greenland from filtered GRACE data is −48 mm/yr and after minimizing the effects of filtering is −53 mm/yr.

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