

# Revisiting non-tidal ocean loading corrections for high precision terrestrial gravimetry

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## ► Intro. – Loading effects in high precision gravity time series

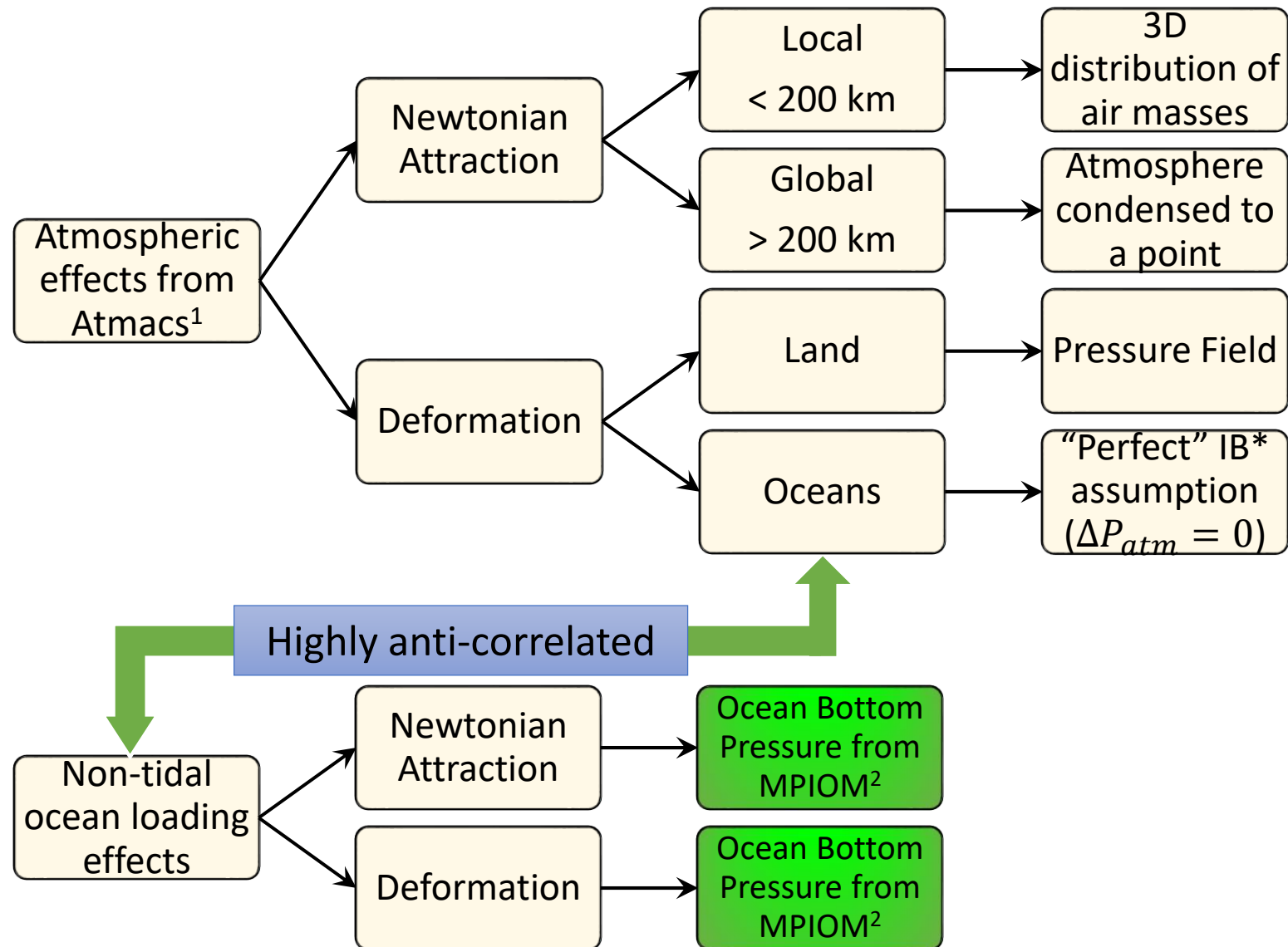
Loading effects (Newtonian attraction + deformation) commonly applied in high precision gravity time series:

- Atmospheric loading ( $\sim 50$  to  $100 \text{ nm/s}^2$ ):
  - Air pressure admittance;
  - Numerical weather models, usually assuming an Inverse Barometer response of the oceans.
- Ocean Tide Loading (tens of  $\text{nm/s}^2$ ).

And not that common with a smaller magnitude ( $10\text{-}20 \text{ nm/s}^2$ ):

- Non-tidal ocean loading effects (NTOL):
  - Local storm surge models;
  - Large-scale barotropic models;
  - General ocean circulation models.

## ► Intro. – Atmospheric and non-tidal ocean loading effects



<sup>1</sup>Atmospheric attraction computation service (BKG; Klügel and Wziontek, 2009)

<sup>2</sup>Max Planck Institute Ocean Model (Jungclaus et al., 2013)

\*Inverse Barometer

## ► New method to account for atmospheric and non-tidal ocean loading effects

|                                                                                                                                                                                                                                          |                                                                                                                                                                                                                                           |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Current modelling approach:                                                                                                                                                                                                              | A new strategy: <b>separate atmospheric and oceanic contributions.</b>                                                                                                                                                                    |
| <ul style="list-style-type: none"><li>Atmospheric effects over the oceans:<ul style="list-style-type: none"><li>➤ Newtonian attraction;</li><li>➤ <b>No deformation, mostly assuming “perfect” or “modified” IB.</b></li></ul></li></ul> | <ul style="list-style-type: none"><li>Atmospheric effects over the oceans:<ul style="list-style-type: none"><li>➤ Newtonian attraction;</li><li>➤ <b>Include deformation effects (abandoning the IB assumption).</b></li></ul></li></ul>  |
| <ul style="list-style-type: none"><li>Non-tidal ocean effects: <b>OBP includes a contribution of the atmosphere.</b><ul style="list-style-type: none"><li>➤ Newtonian attraction;</li><li>➤ Deformation.</li></ul></li></ul>             | <ul style="list-style-type: none"><li>Non-tidal ocean effects: <b>account only for ocean dynamics, no atmospheric loading.</b><ul style="list-style-type: none"><li>➤ Newtonian attraction;</li><li>➤ Deformation.</li></ul></li></ul>    |
| <b>Problems:</b> <ul style="list-style-type: none"><li>× Newtonian contributions from the atmosphere accounted twice;</li><li>× The IB hypothesis is not always valid;</li></ul>                                                         | <b>Advantages:</b> <ul style="list-style-type: none"><li>✓ Newtonian effects not accounted twice;</li><li>✓ No need to include the IB hypothesis;</li><li>✓ No need of using land-sea mask for atmospheric loading computation.</li></ul> |

The aim is then to compare both approaches...

## ► Comparison between both approaches

### Processing of gravity time series

- Earth and ocean tides;
- Atmospheric effects from Atmacs;
- Polar motion;
- Instrumental drift.
- Gravity residuals are dominated by seasonal hydrological effects:
  - ✓ Butterworth high-pass filtering with a corner frequency of 150 cpd to remove seasonal variations and trend-like features.

### Ocean Bottom Pressure

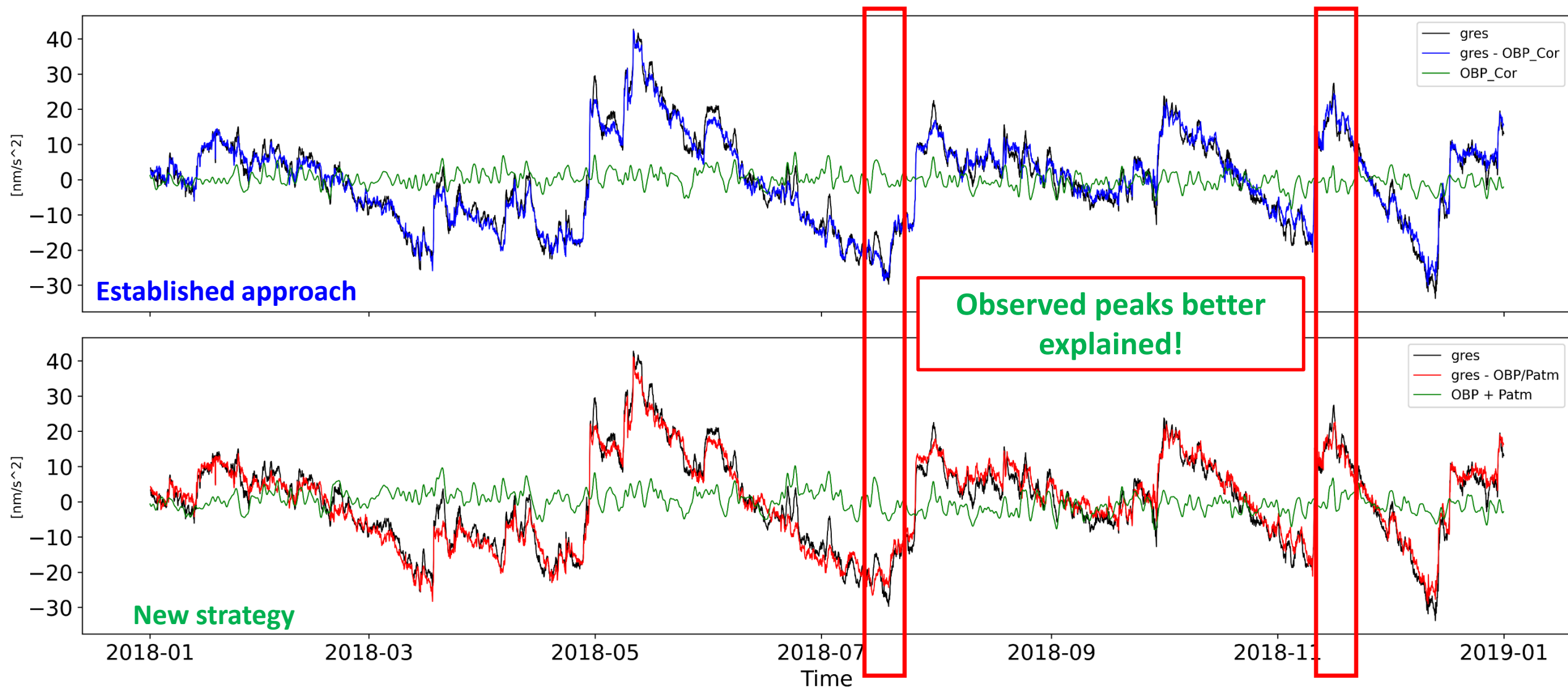
- Ocean Bottom Pressure anomalies from MPIOM, run by H. Dobsław at GFZ;
  - Forced by Operational ECMWF;
  - Grid resolution of  $0.5^{\circ} \times 0.5^{\circ}$ ;
  - Temporal resolution of 3 hours;
  - Pressure variations converted to water heights.
- Loading effects computed with SPOTL software (Agnew, 2012).

### Analysis of five SG stations:

- AGGO (Argentina): local storm surge model (Oreiro et al., 2018) applied.
- Medicina (Italy);
- Membach (Belgium);
- Yebes (Spain);
- Wettzell (Germany).

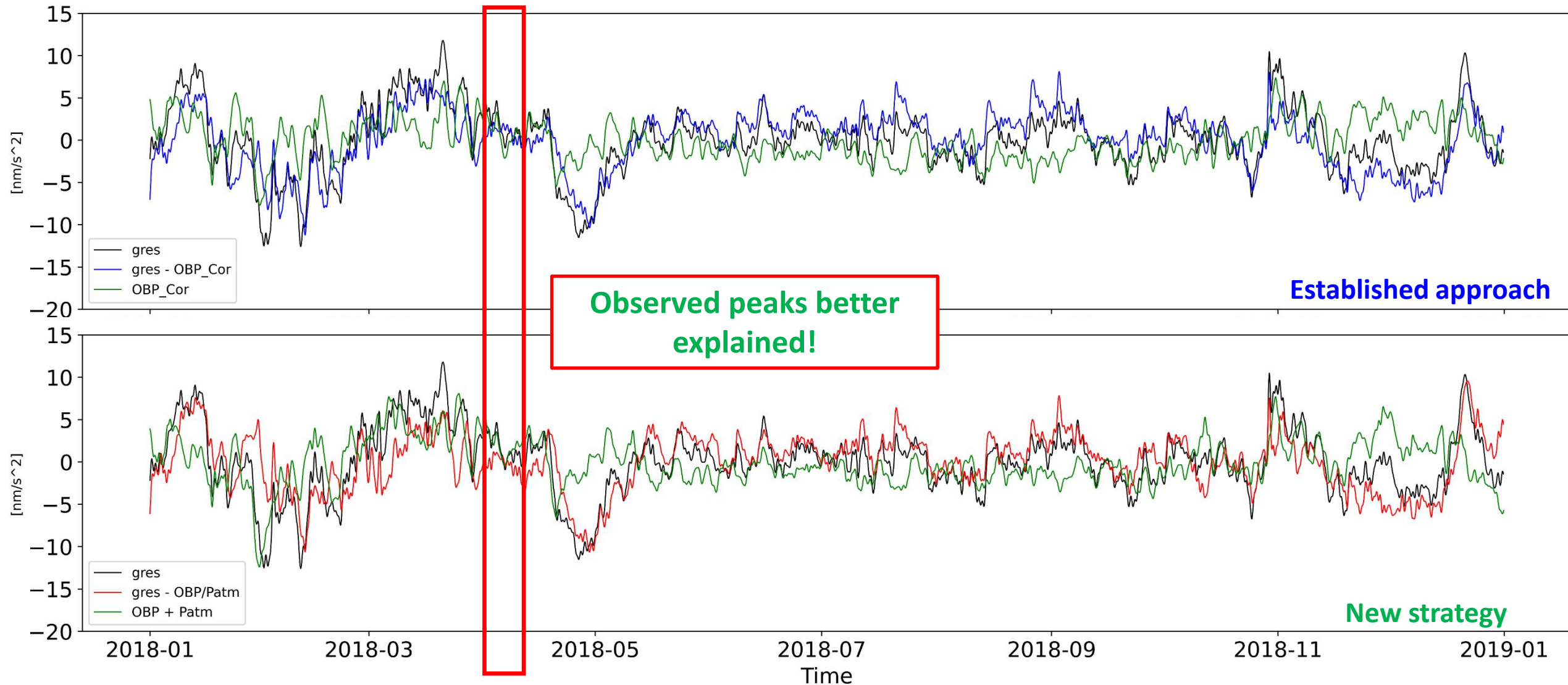
## ► Comparison between both approaches: time series

AGGO



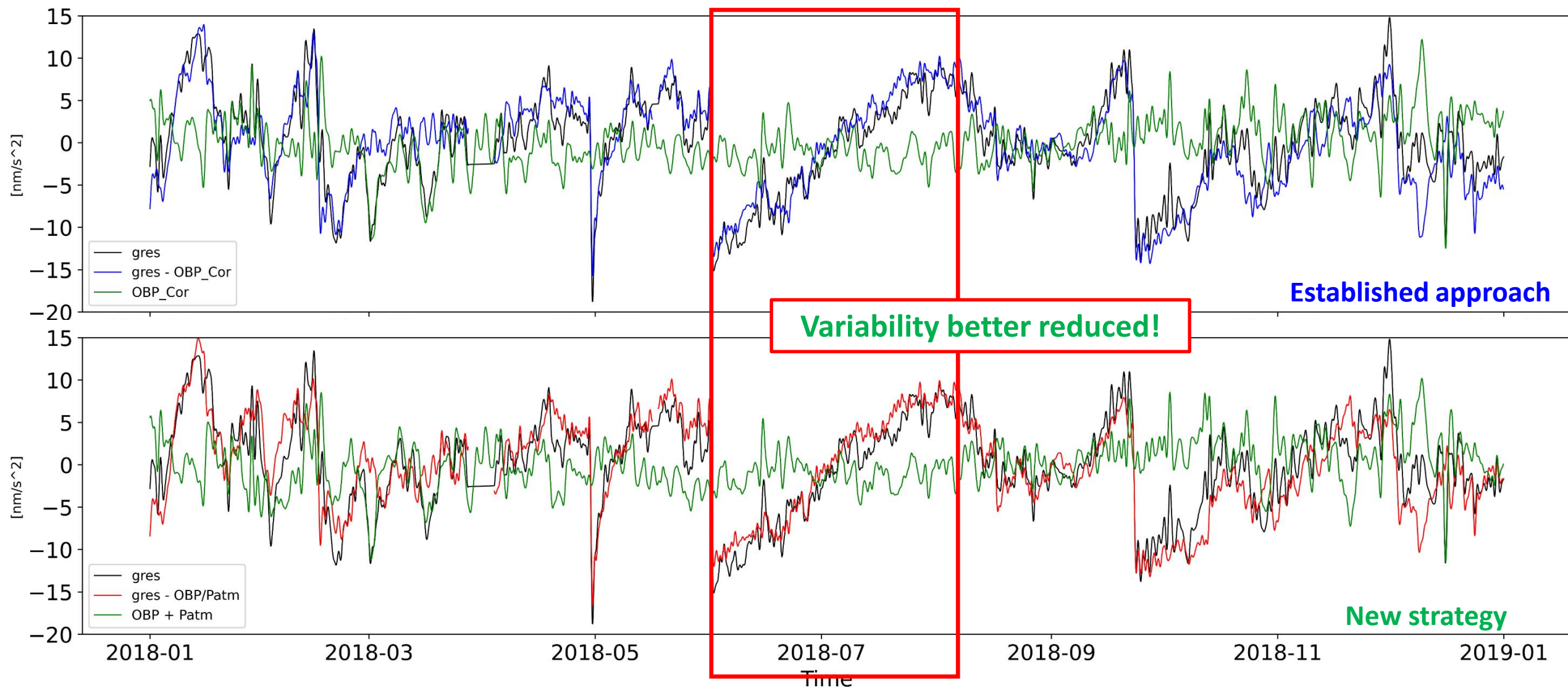
## ► Comparison between both approaches: time series

Medicina



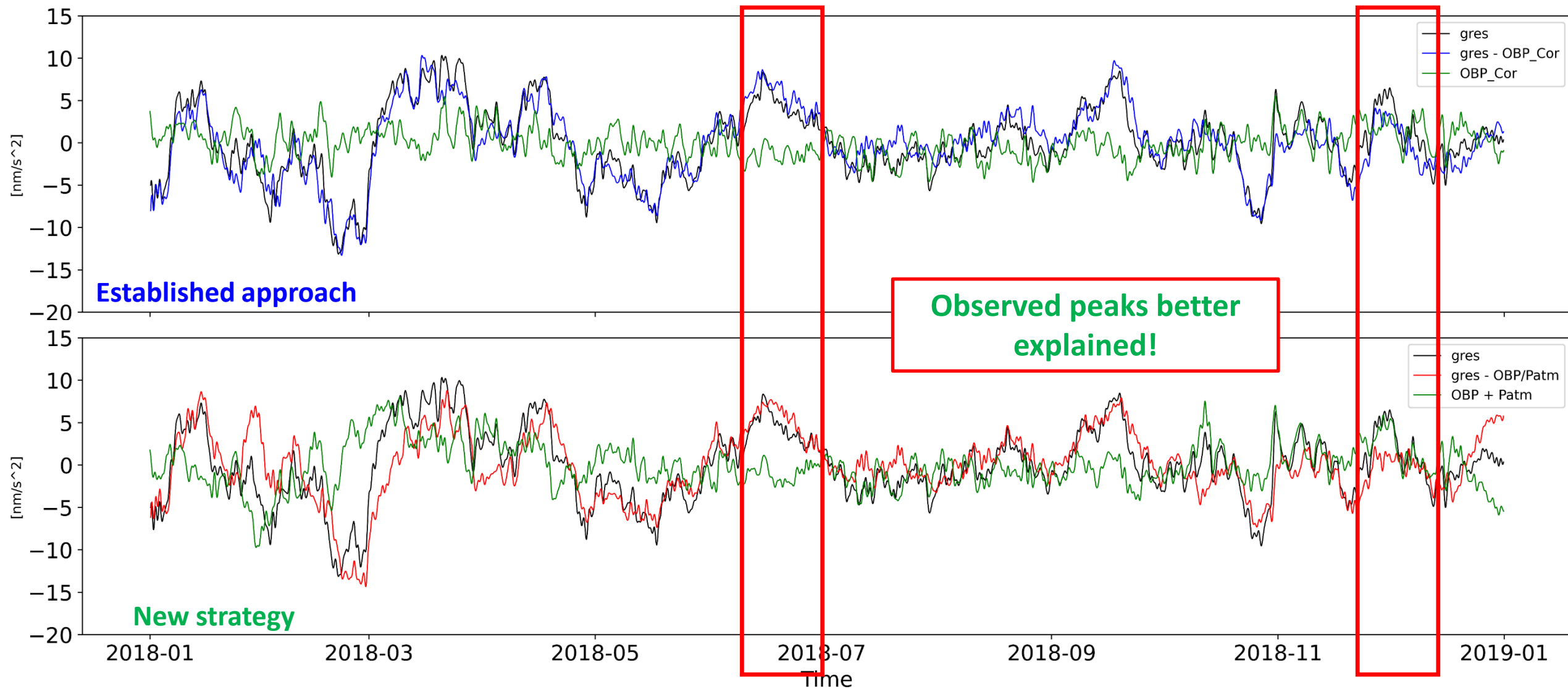
## ► Comparison between both approaches: time series

Membach



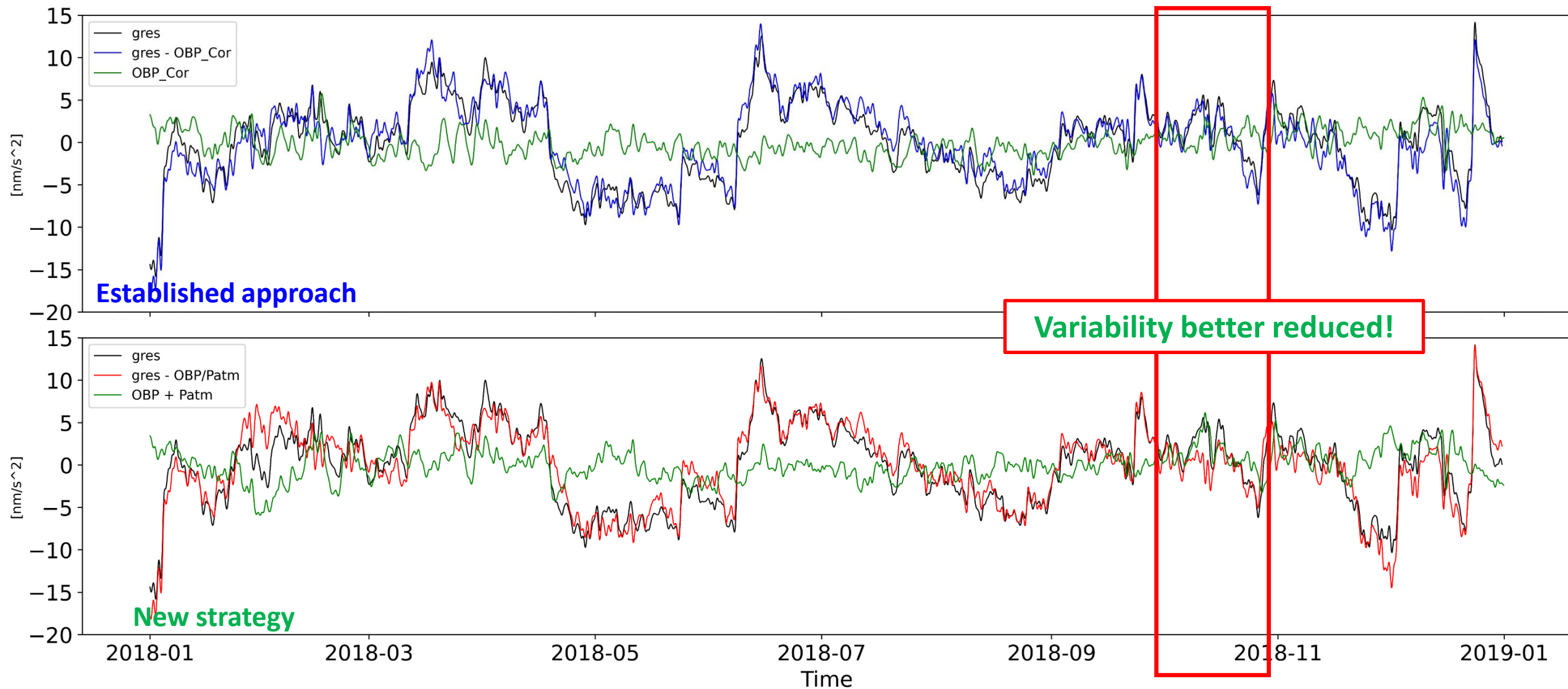
## ► Comparison between both approaches: time series

Yebes



## ► Comparison between both approaches: time series

Wettzell



## ► Comparison between both approaches: correlation coefficient and RMS

Gravity residuals are dominated by seasonal hydrological effects:

- Butterworth high-pass filtering with a corner frequency of 150 cpd to remove seasonal variations and trend-like features:
  - Pearson correlation coefficient;
  - RMS variability.

| Station  | Cor. Coef |          | RMS  |                |                 |
|----------|-----------|----------|------|----------------|-----------------|
|          | OBP_Cor   | OBP/Patm | gres | gres - OBP_Cor | gres - OBP/Patm |
| AGGO     | 0.18      | 0.22     | 12.6 | 12.4           | 12.2            |
| Medicina | 0.48      | 0.55     | 4.0  | 3.5            | 3.3             |
| Membach  | 0.23      | 0.24     | 5.5  | 5.6            | 5.5             |
| Wettzell | 0.12      | 0.17     | 4.7  | 4.8            | 4.7             |
| Yebes    | 0.25      | 0.41     | 4.3  | 4.2            | 4.0             |

Established approach

New strategy

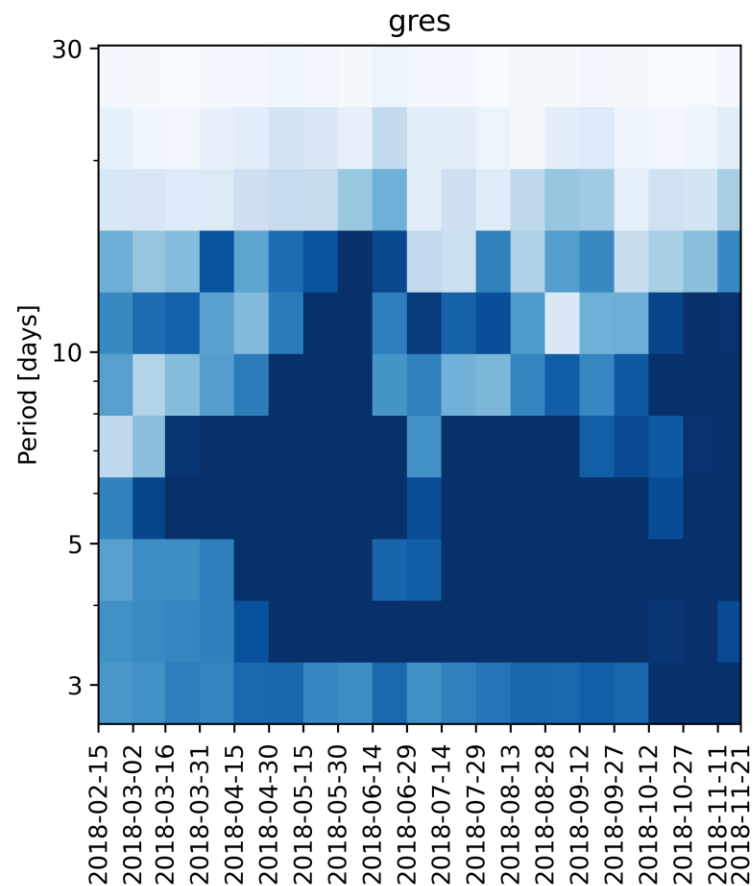
For all stations there is a better agreement with the new approach, as well as a larger RMS reduction after applying the corrections!

## ► Comparison between both approaches: analysis for different periods

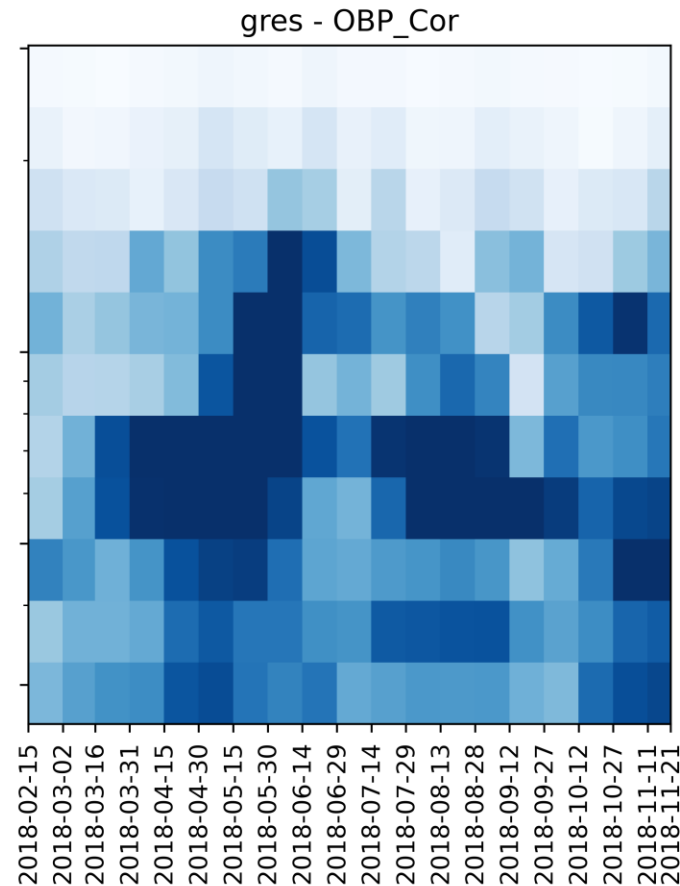
Variability of the signal with different corrections:

- Sliding window variance analysis: window length of 90 days and shift of 15 days;
- Butterworth band-pass filtering.

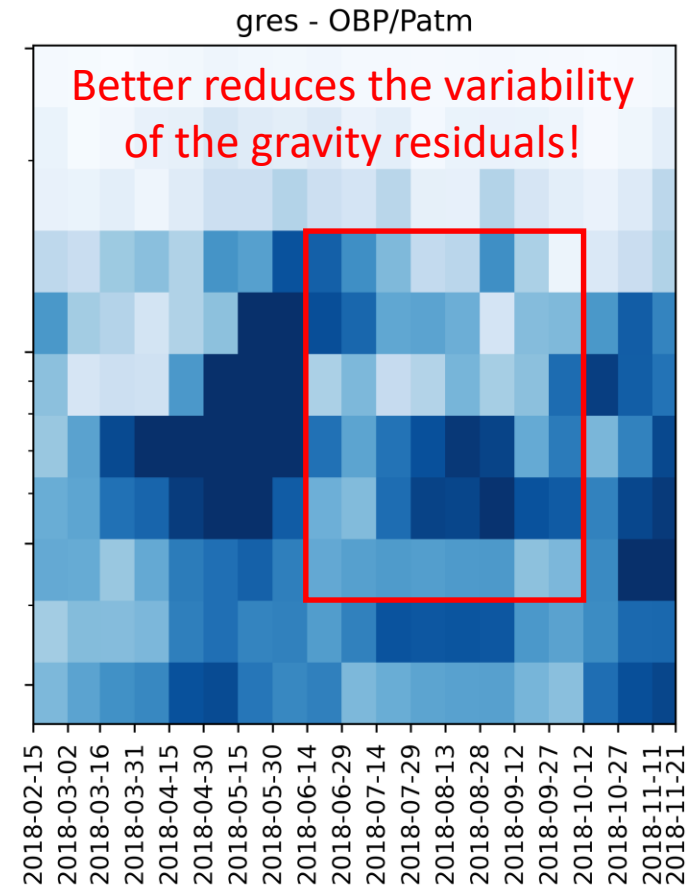
AGGO



Established approach



New strategy

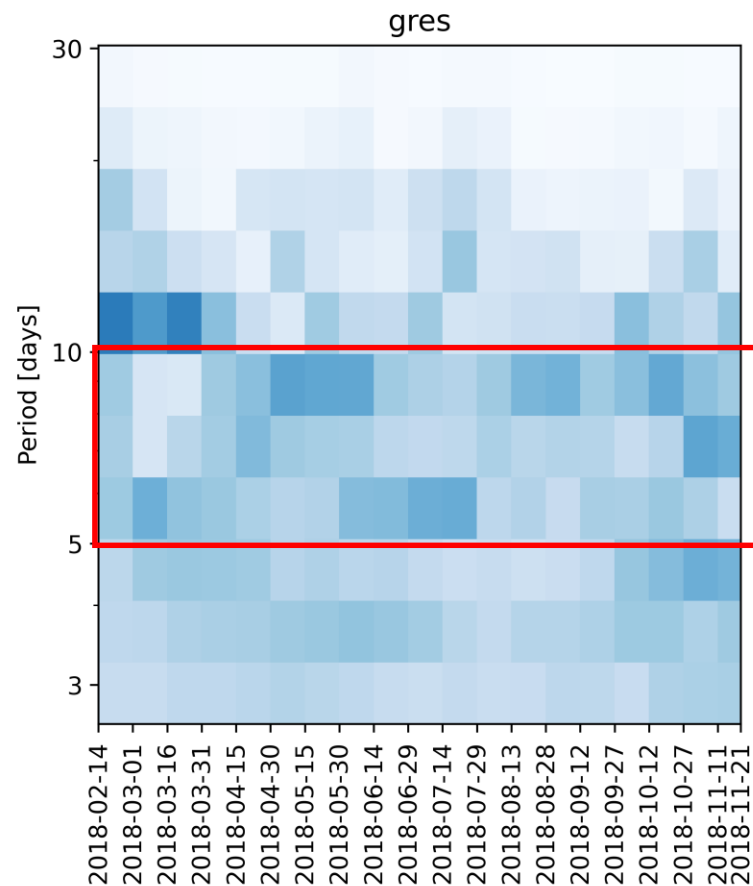


## ► Comparison between both approaches: analysis for different periods

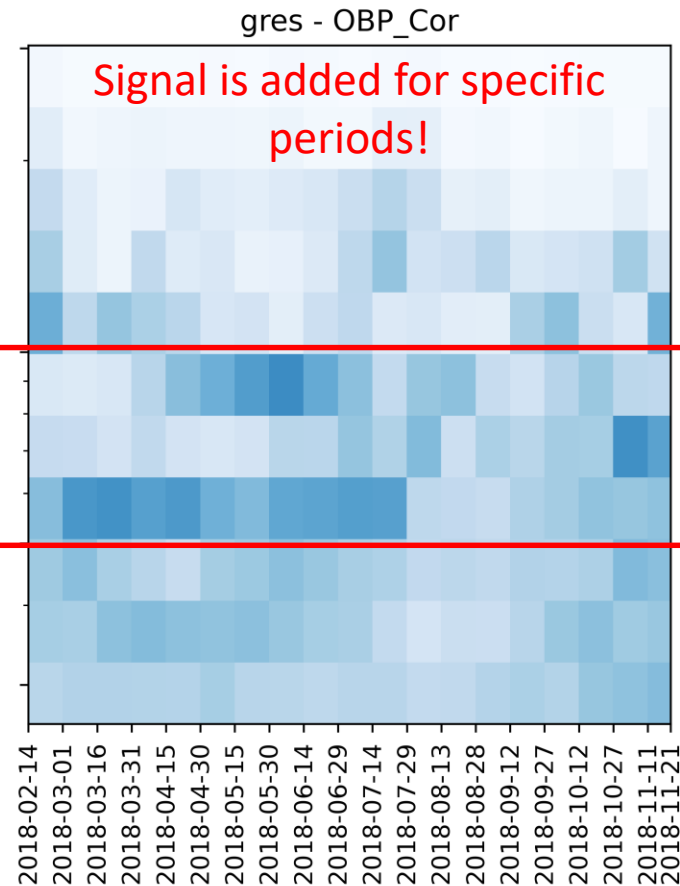
Variability of the signal with different corrections:

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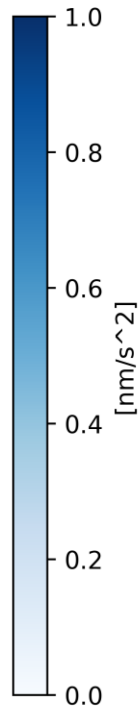
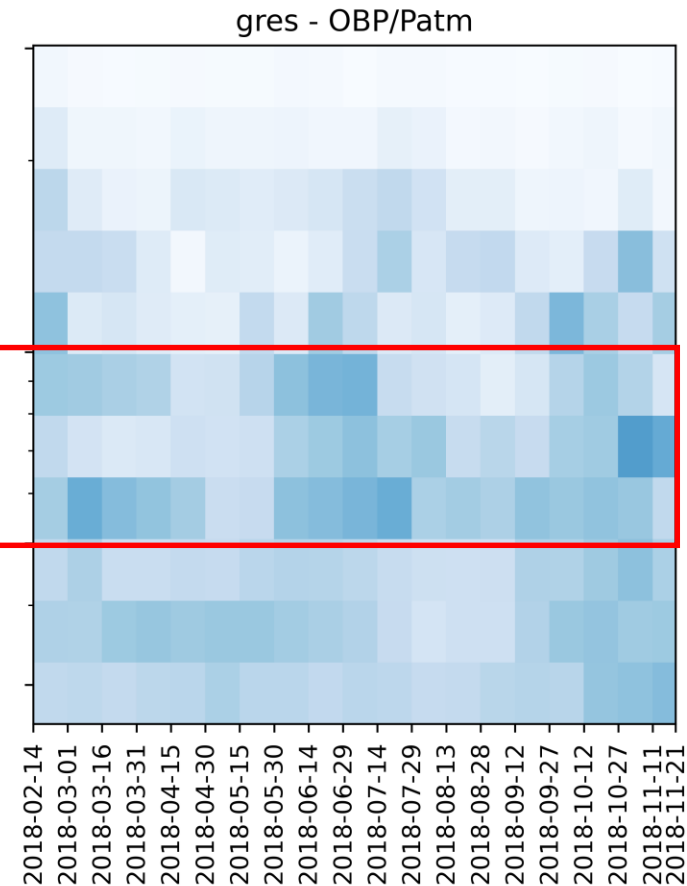
Wettzell



Established approach

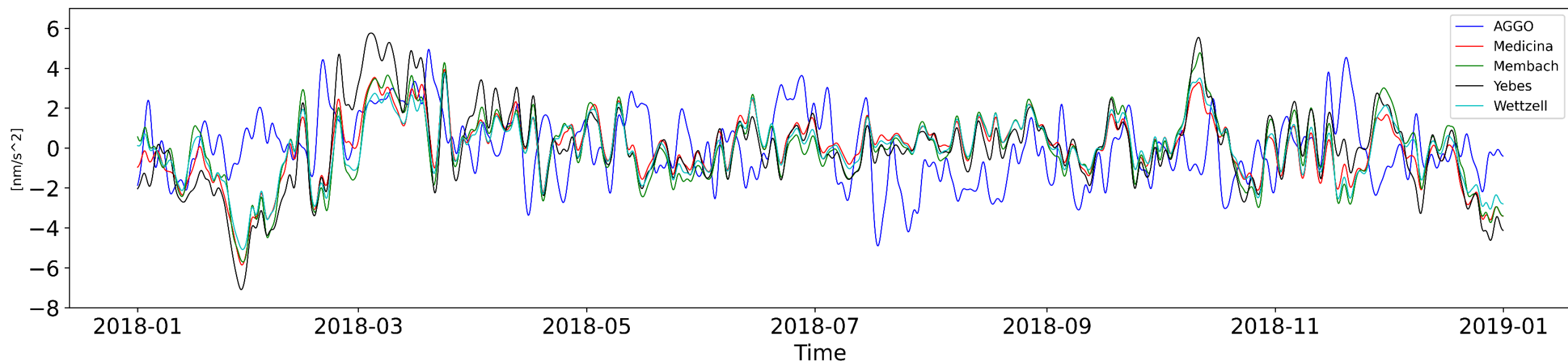


New strategy



► Comparison between both approaches: differences

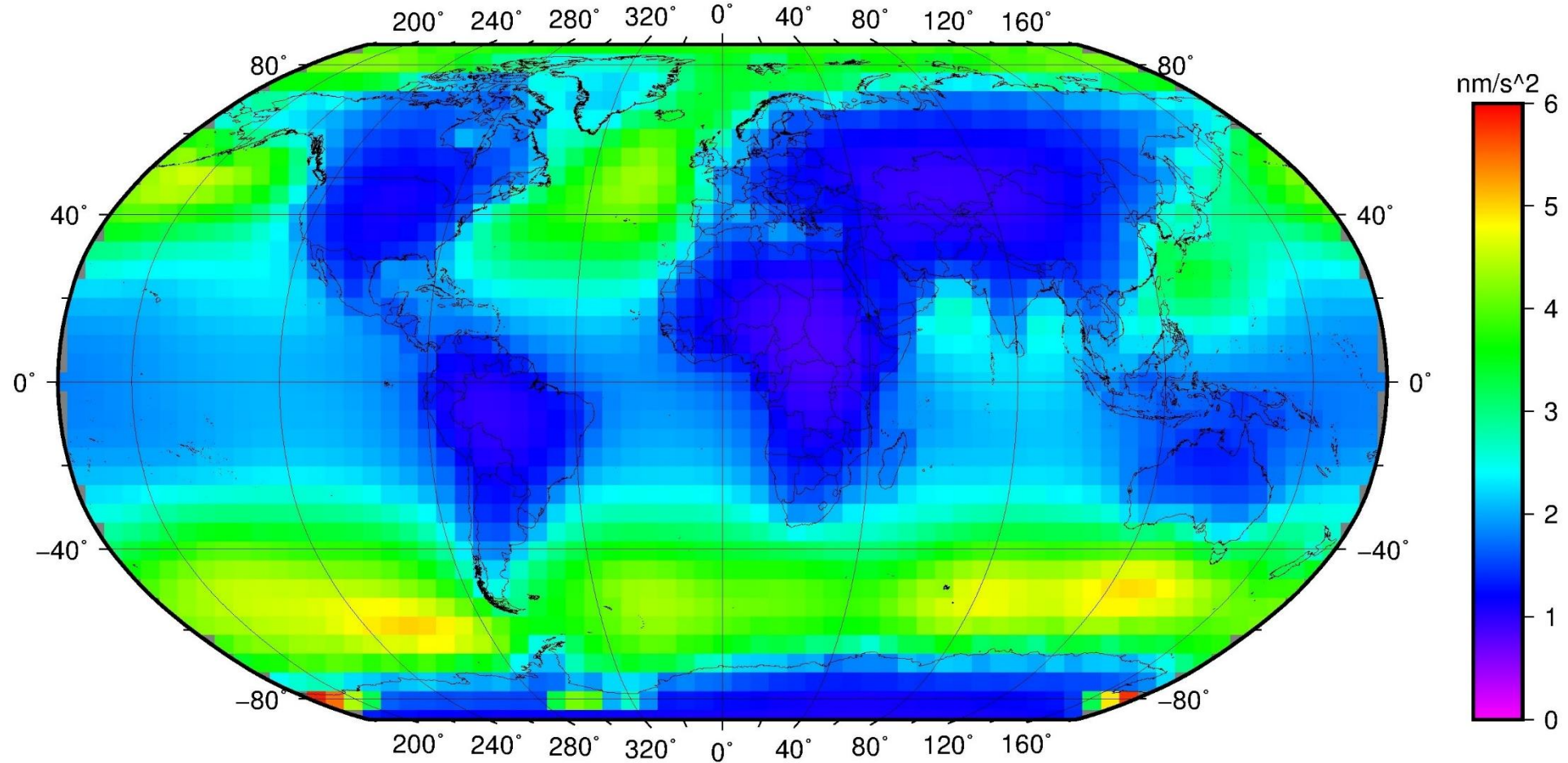
$OBP_{cor}$  vs.  $OBP/P_{atm}$



Differences can rise  $10 \text{ nm/s}^2$  ( $1 \mu\text{Gal}$ ) peak-to-peak!

► Comparison between both approaches: differences

RMS of the differences globally – Period 2018



Deviations become larger for stations close to the coast!

## ► Summary and conclusions

- A new strategy for modelling atmospheric together with non-tidal ocean loading effects is proposed.
  - Advantages:
    - ✓ Newtonian effects are not accounted twice;
    - ✓ No need to include the IB hypothesis for the atmospheric effects over the oceans;
    - ✓ No need of using land-sea mask for atmospheric loading computation;
    - ✓ Keep the 3D atmospheric mass distribution over oceans (relevant for coastal stations) from Atmacs.
- Variability of the gravity residuals recorded at five SG stations decreased;
- Possible simplifications for operational application in existing services (e.g. Atmacs) using AODB\* products:
  - a) Restore the Newtonian attraction in the atmospheric computation scheme;
  - b) Replace the “perfect” IB assumption by a “modified” IB in the atmospheric deformation computation over oceans.

### References:

- Agnew, D. C. (2012). SPOTL: Some programs for ocean-tide loading.
- Dobslaw, H., Bergmann-Wolf, I., Dill, R., Poropat, L., & Flechtner, F. (2017). Product description document for AOD1B release 06. GFZ German Research Centre for Geosciences Department, 1.
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