1. In lines 188-189, you mention that the Bayesian approach introduces an approximating PDF for the parameters. Is the PDF chosen by the algorithm or by the authors? If the PDF is chosen by the authors as an input to the vbICA, does changing that PDF significantly change the output?

The PDF of each variable is a priori chosen. Note though that to approximate the PDF of the sources (i.e., of the independent components) we are using a Mix of Gaussians (MoG). Given a sufficient number of Gaussians, it is possible to approximate any desired PDF. We restrain the number of Gaussians to 4 because in past research this number of Gaussians was sufficient to properly model the data retrieving accurate results (for the accuracy of the results, tests were performed on synthetic simulations for which the ground truth was known, see for example Gualandi et al., 2016, J. of Geodesy, and references therein). The final posterior PDF will thus be a MoG, and it can approximate multimodal distributions. What we can control, apart from the number of Gaussians in the mix, is the a priori on the Gaussians which govern their mean and precision (i.e., inverse of the variance). The results obtained using different a priori are overall similar, with differences in the variance explained of less than 0.07%.

Among the tested a-priori parameters we choose those that maximize the Negative Free Energy. This is equivalent to maximizing the independence of the sources according to the variational approach adopted that minimizes the Kullback-Leibler (KL)-divergence between the true (unknown) posterior and the modeled one.

2. For the NTAL and HDYL models, why are you modeling them at a grid interval rather than at the specific points of the GNSS stations?

GNSS data do not evenly cover the study region, while NTAL and HYDL models do. By using all the NTAL and HYDL data, it is easier to show the spatial patterns of the atmospheric and hydrological loading.

When you compare the ICs from the models to the GNSS stations (eg Figure 7), are you using the closest grid point or interpolating them to the GNSS station position?

When we compare the ICs from the models to the GNSS station we use the closest grid point, as we say in lines 349-351.

Would it not more consistent to just use the NTAL and HYDL models at the GNSS points and then apply the vbICA?

We agree that if we had used NTAL and HYDL models to remove the sources of loading from the GNSS time series, we could have considered only the data at the GNSS stations. Nonetheless, for the purpose of interpreting the spatial features of the GNSS results, it is preferable to use all the available data from the loading models, so that the spatial cover of the study area is as dense as possible.

3. This may be out of the scope of this paper, but I'm still wondering why the authors wouldn't remove known sources of loading, like NTAL, NTOL and HYDL and then apply a vbICA to see if there are any consistent patterns in the data not attributed to those well known signals? This could then highlight additional signals that cannot easily be removed from the data or are missed by the models (eg reference frame jitters). To me, this seems like a preferred method to use the vbICA since it would remove signals we know exist first and then diagnose the resulting signals. Otherwise, your ICs are likely to contain the known signals (NTAL and HYDL) as well as contributions from other signals that have similar temporal or spatial patterns – which the authors acknowledge when explaining why they combine multiple IC from

different sources. Thus, the ICs are likely dominated by the loads you are attributing them to but also likely contain other signals that might be more apparent if you removed the known signal first.

While we know that GNSS data are affected by hydrological and atmospheric loading, precisely quantifying their contribution is not an easy task. A mismodeling of the loading signal can lead to residuals in GNSS time series that may be very difficult to interpret; the residuals might also be temporal and/or spatially correlated, making even harder to see if there are any consistent patterns in the data not attributed to loading signals.

We then prefer not to correct the GNSS time series with any model, that by definition cannot be perfect, but let vbICA extract the signals associated with the loading.

4. I still think the authors are overstating the temperature relationship in IC4. In lines 394, you state that it is well correlated with temperature, but couldn't you find a similar correlation with another annual signal, like NTAL for example or even HDYL? I think the added discussion in line 600 is helpful but still do not provide a strong enough case to be mentioned in the abstract and in the conclusion. Yes, IC4 has a strong annual signal but that does not necessarily mean that it is due to temperature fluctuations especially given that majority of the stations this component explains less then 1% of the data variance as stated in lines 618. Also, the mechanisms provided for temperature would be highly site specific and would be dependent on the type of monumentation (eg is the monument located in bedrock vs unconsolidated soil monuments)? Additionally, the mechanisms provided are more related to hydrology and site characteristics then temperature. I think the relationship of IC4 to temperature is overstated especially since it is mentioned in the abstract and conclusion and multiple times throughout the text even though the IC is only prevalent in a few stations and the mechanisms provided do not support the claim.

Following your advice we have eliminated the mention of the temperature in the abstract and in the summary. In line 618-619 we now say that IC4 might also be influenced by systematic errors in GNSS observations and in their modeling. In the conclusion, and in general over the manuscript, we present IC4 as a seasonal signal which is in phase with the temperature, but that is not necessarily caused by temperature itself.

5. Additionally, when calculating the reduction in the standard deviation, you only use the first 3 ICs (lines 477) and not IC4. Why?

In our interpretation atmospheric and hydrological loading are associated with IC1, IC2 and IC3. Since we do not have any clear evidence that IC4 is associated with hydrological or atmospheric loading, while studying the reduction of the standard deviation when removing the atmospheric and hydrological loading contribution, we decide to remove only the contribution of the first 3 ICs (in line 477 we say four, it was a mistake that we have now corrected).

6. You state the ICs likely contain a larger component of power-law noise. When you are comparing the different filtering approaches (line 477-479) when you remove the modelled GFZ NTAL and HYDL are you also estimating a noise model for those series as well?

In the following figures we show the Spectral Index (Fig. 1) and the white noise percentage (Fig. 2) of the IGb14-time series minus the displacements due to HYDL+NTAL. The white noise percentage of the resulting time series is smaller than what is obtained performing the

ICs filtering (Fig. 12b). We added this information in Sect. 5.1 and added Fig. 1 and Fig. 2 in the Supplementary material (Fig. S19).

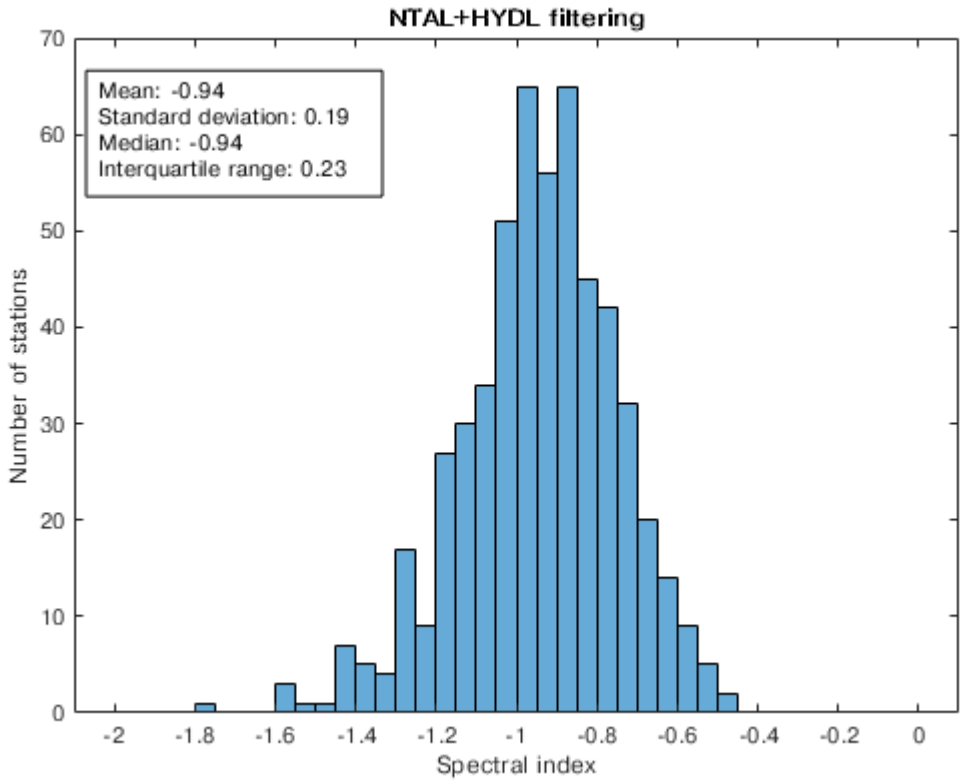

Figure 1: Histograms of the spectral index in the filtered time-series. The filtering is done by subtracting the displacements due to HYDL+NTAL from IGb14-time series.

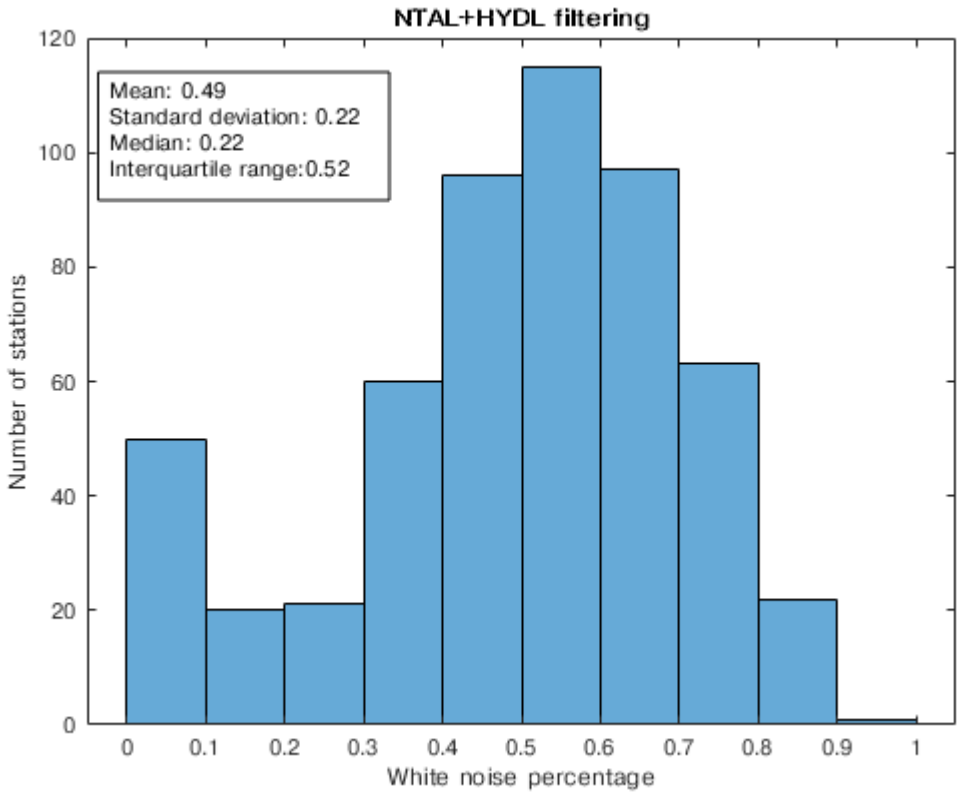

Figure 2: Histograms of the white noise percentage in the filtered time-series. The filtering is done by subtracting the displacements due to HYDL+NTAL from IGb14-time series.

7. Lines 433-435 are a touch confusing. Are you assuming that removing the ICs completely removes all the annual signal? Could there not be other processes that have annual signals that are not captured by the ICs?

We are assuming that the majority of the seasonal signals are captured by the ICs. As a result, we assume that there is no need to include annual and semi-annual terms in the time series modeling used to estimate the GNSS station vertical velocities.

It is worth noting that the inclusion of the annual and semi-annual terms in the time series modeling does not change much the estimation of the GNSS stations velocities, as you can see in the Fig. 3: the variation of the velocity estimates change less than 0.05 mm/yr for 479 of the 545 stations.

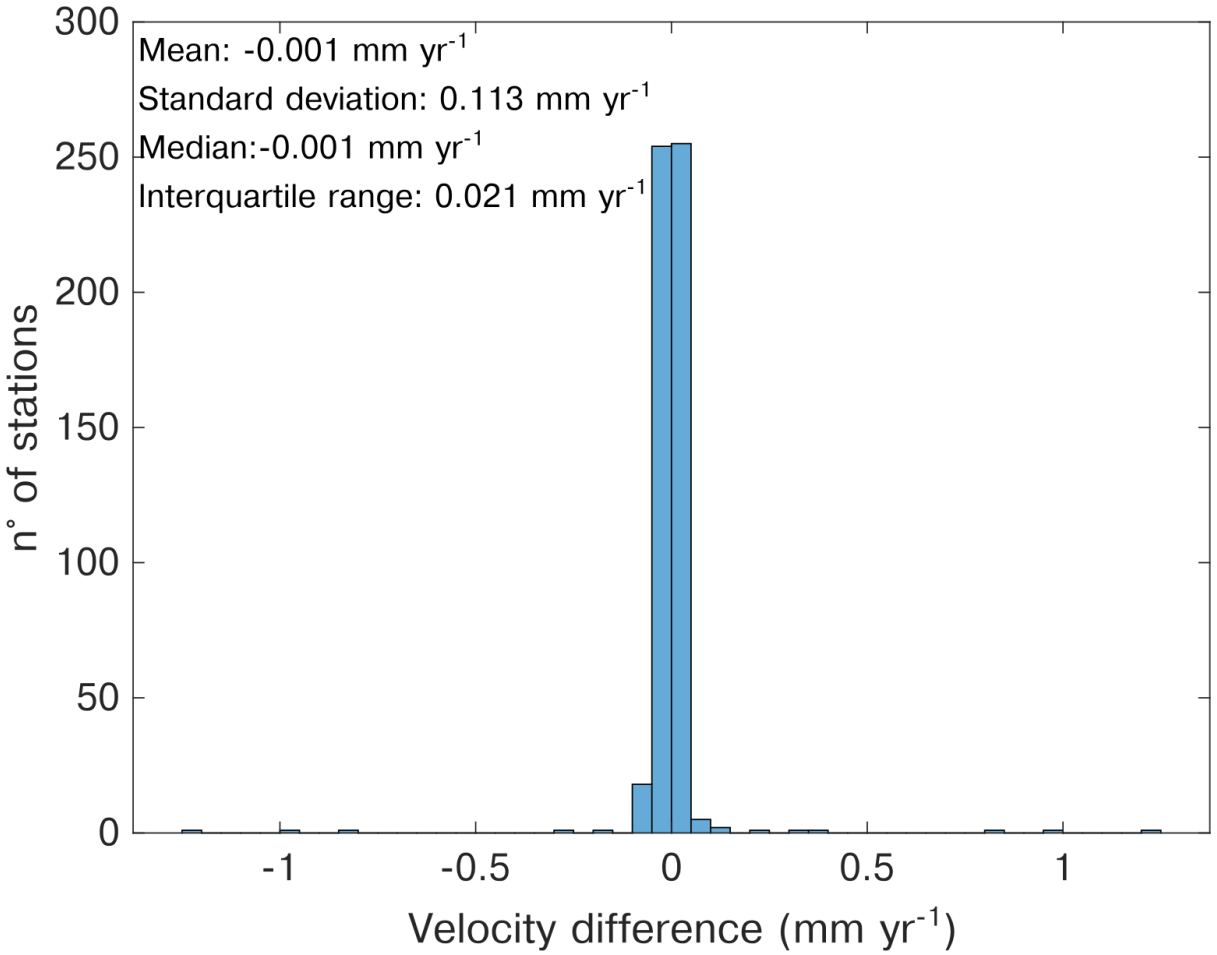

Figure 3: difference between GNSS vertical velocity estimation with and without considering annual and semi-annual terms in the time series modeling.

8. Figure 6 might be improved by consistent axes.
Ok, done.

9. Maybe I missed it, but what precipitation data are you using (lines 557).
The precipitation data we use are provided by the NASA Goddard Earth Sciences Data and Information Services Center (Huffman et al., 2019), they are daily with a spatial resolution of 0.1°. This information is reported in Section 3.2 (lines 252-253); we also added the link to the data in the “Code and data availability” section (line 702).