Response to Reviewer #2

We are very grateful to the reviewer for the insightful and careful review. These comments are very helpful to improve the quality of the manuscript. All comments were answered in below, and the manuscript was revised according to these comments. The comments from the reviewers are kept in regular font with underlines and our responses in blue color.

Referee 2

The dataset provides a MODIS-derived annual surface water frequency dataset, which can help analyze the dynamics of surface water. The manuscript is well structured and written! My major comments are:

(1) I agree with the authors that the daily MODIS observations have value in capturing the variations of surface water; however, its limitation is also obvious. The 500-m resolution is too coarse for capturing the abundant small water bodies as well as the subtle changes of surface water. Moreover, the Sinusoidal projection of MODIS caused a considerable distortion in high latitudes, worsening this omission, particularly in North America and Eastern Russia, where a large portion of the global small water bodies are located. (2) It seems that the authors have been mainly focused on China and a few low-mid latitudes, but did not assess the performance in high latitudes, which seems to require more attention during validation.

Response: (1) As you pointed out, it is difficult for the dataset to capture small water bodies and the subtle changes of surface water due to the coarse spatial resolution of MODIS, especially in high latitudes in the Northern Hemisphere where a large number of small water bodies are located. The Sinusoidal projection of MODIS distorts shape and angles, but it can preserve the size of features true to their real area as an equal area projection. We think that the main problem at high latitudes is the limitation of coarse resolution of MODIS in the identification of small water bodies.

Satellite data often has certain advantages in terms of temporal or spatial resolution, time coverage, etc., but it is difficult to take into account all of these aspects. MODIS provides daily spectral measurements of the Earth surface since 2000. Its long-term high-frequency observations have unique advantages in monitoring of the seasonal and interannual changes in surface water. The relevant discussion has been added in lines 601-606 in Section 5 in the revision.

(2) We added four validation sites to demonstrate the performance of the dataset at high and mid latitudes, including Lake Winnipegosis in Canada (99.91° W, 52.61° N), lakes in western Russia (31.00° E, 64.10° N), Lake Maggiore in Italy (8.65° E, 45.90° N), and Lake Wakatipu in New Zealand (168.55° E, 45.10° S). The first two sites are located in high latitudes of the Northern Hemisphere, where concentrated a large number of small water bodies. The last two sites are located in the middle latitudes of the northern and southern Hemispheres, respectively. Figure 6 and the relevant description were revised (lines 160-187 in Section 2.4 and lines 366-400 in Section 4.3). It is complex and requires a lot of work to validate a global product. We selected eight sites as examples to demonstrate the performance of the dataset for different surface water types, permanent and seasonal waters, different latitudes, as well as with presence of frequent cloud cover. We will further analyze the dataset in future work.

The authors reported the areas of global inland surface water, including permanent and maximum areas; however, I think the numbers could be biased by failing to capture the small water bodies as commented in the above paragraph. As many much finer surface water datasets have already been produced, I would suggest the authors clarify the conditions of these reported areas, such as water bodies larger than a certain size; otherwise, the areas would not be valid.

Response: Since the spatial resolution of MODIS is 500 meters, only water bodies with a spatial range greater than 500 m × 500 m can be detected. In addition, to reduce the influence of noise, the water bodies with an area less than 2×2 pixels were removed for the generated SWF maps. Thus, the dataset provides maps of inland water bodies larger than 1 km×1 km open to the sky. The relevant description was edited in lines 278-280 in Section 4.1, and the post-processing procedures were supplemented in lines 237-238 in Section 3.1 in the revision.

I am not convinced why the authors did not compare the results to the global water dataset produced by Pekel et al. and the GLAD (Pickens et al., 2020), which all provide permanent and seasonable water cover that can be comparable to this dataset.

Response: We added the comparison with two high-resolution surface water products derived from Landsat observations, including Global Land Analysis & Discovery (GLAD) global surface water dynamics dataset from Pickens et al. (2020) and global surface water dataset from Pekel et al. (2016). The areas of global maximum, permanent and intermittent surface water were compared (lines 236-243 in Section 4.1 in the revision). The generated SWF maps were also compared with the annual water percent dataset of GLAD and seasonality dataset of GSW in three demonstration regions, including Taihu Lake, lakes in northeastern Tibetan Plateau and Qarhan Salt Lake. Considering the time of available data for the five datasets (GLOBMAP, GLAD, GSW, GSWCD and ISWDC), the year for the comparison of the three regions was changed to 2015, and the results was similar to that in 2016. Figure 3-5 and the relevant description in Section 4.2 were revised (lines 296-363), and description about the two datasets were added in Section 2.3 (lines 114-118, 139-156). In general, the spatial pattern of GLOBMAP SWF maps agrees with that of the two high-resolution products in the three comparison regions. The two Landsat-based products can represent more spatial details and extract larger area of permanent and maximum surface water with their fine spatial resolution, while our dataset captures more intermittent surface water and successfully reduces the influence of clouds and frozen water. Please see details in Section 4.1 and 4.2.

Specific comments:

I would suggest removing "for change analysis of inland water bodies" in the title.

Response: The title has been edited according to your suggestion. This product can not only be used to analyze the changes of inland water bodies, but also can characterize their spatial distribution and seasonal characteristics.

Line 172, why six observations?

Response: We selected six observations by weighing available clear-sky observations and possible noise observations, such as shadows, burned areas and occasional water cover. In the tropics, subtropics, and high latitudes of the northern hemisphere, the number of available clear-sky snow-free observations is usually limited due to frequent cloud and snow/ice covers as well as the polar night in winter (see details in discussion about available clear-sky observations in lines 561-585 in Section 5 in the revision). On one hand, selecting too many observations may include cloud or snow/ice observations in the determination of the maximum surface water extent. On the other hand, choosing too few observations may be interfered by possible noises in maximum surface water mapping. For example, shadows and burned areas greatly reduce the reflectance in the NIR band, and heavy rain and flood would cause occasional water cover, which may be included in the selected observations with the lowest NIR reflectance. Through extensive tests across the globe, we selected six observations with the lowest NIR reflectance during a year to map the maximum surface water extent. There are more than six clear-sky snow-free observations for 99.9992% (99.98%) of the total terrestrial surface (inland water bodies), which can ensure to obtain reliable clear-sky observations in most regions of the world. Those pixels with water count ≥ 3 were used to create the maximum surface water extent map to exclude the occasional water cover and residual shadows and burned areas. The relevant description was edited in lines 209-214 in Section 3.1 to make it clearer.

Line 179, does the slope criteria also remove water in a sloppy area that is outside of shadow? Also, did the variation of solar angles along latitudes and seasons considered in estimating shadows?

Response: The variation of solar angle along latitudes and seasons was not considered in the slope criteria for shadows estimation, which may cause water that is outside of shadow to be removed in mountainous areas. Here, the slope criteria was mainly used to exclude large areas mountain shadows, such as shadows in the margin of the Tibetan Plateau. Underestimation of lakes in these regions should have limited impacts on large scale. For mountain shadows with a small range, since the local time when MODIS passes changes among days, the distribution of shadows will change due to different solar and viewing geometry. MOD09A1 selects the best possible observation during an 8-day composition period, and its spatial resolution is coarse (500 m), which helps to reduce the effects of mountain shadows with a small range. As you suggested, consideration of solar angle variation would help to improve the identification of terrain shadows. We supplement the related discussion in Section 5 (lines 587-595 in the revision).

Line 200, please clarify what resample method was adopted.

Response: The Sentinel-1 SWF maps were resampled to 500 m resolution by averaging the valid SWF estimations from Sentinel-1 data within the MODIS 500 m grid. The resample method has been revised in lines 247-248 in the revision to make it clearer.

Line 427-448, I am not fully agreeing with the novelty of the method as mentioned here. The method still identifies water cover as explained in the methodology, so the statement of the advancement here does not seem to be a valid point. Also, the method seems to be a very simple one without considering calculating water index or machine learning-based models. I am honestly surprised that it was robust enough for producing a reasonable global result.

Response: We mean that the algorithm does not directly identify water cover to estimate surface water cover frequency (SWF). The water observations count was estimated by subtracting the land observations count from clear-sky observations (land and water) count, and then divided clear-sky observations count to estimate the SWF. As you pointed out, we identified water pixels in mapping the maximum surface water extent. But this procedure used six observations with the lowest reflectance in the NIR band (R_{NIR}). Since cloud and snow/ice generally show much higher R_{NIR} than that of land and water, cloud and snow/ice observations should be excluded in these six observations, thus water can be separated from land reliably. The relevant description has been edited to make it clearer (lines 527-527 in Section 5).

In generation of global water datasets, it is not only needed to propose good water cover extraction algorithm, but also need to consider data quality, noise and applicability of the algorithm in different regions. Indeed, we also tried various methods such as water index and classification. But it is difficult to distinguish water from clouds and snow/ice in some cases, and variation of characteristics of water body and surface background may also result in confusion in water extraction, making it challenging to establish a globally applicable algorithm.

We found a reliable and robust method to separate land from water, cloud and snow/ice. The reflectivity of the red band (R_{Red}) of the former is generally lower than that of the SWIR band (R_{SWIR}), while it is opposite for the latter three. If the SWF were estimated indirectly by identifying land, the interference of cloud and snow/ice in water identification would be avoided. Here, three procedures were implemented to extract the SWF indirectly. (1) In mapping of the maximum surface water extent, cloud and snow/ice observations were excluded automatically through selecting several observations with the lowest R_{NIR} during a year, which helps to determine the possible surface water extent reliably. (2) The land identification method ($R_{Red} < R_{SWIR}$) was robust and applicable for major types of water bodies and surface background, and can exclude cloud and snow/ice observations. (3) The water count was estimated by subtracting the land observations count from clear-sky observations count, which avoids directly distinguishing water from cloud and snow/ice. The above methods are ubiquitous for various water bodies and surface background types, and reduce the interference of cloud and snow/ice, which helps to improve the applicability of the algorithm across the globe. The relevant description was revised (lines 539-555 in Section 5).

Figure 8 is hard to interpret because most of the pixels showing positive trends also show negative trends. I think that the authors need to come up with a better way of presenting the results.

Response: Figure 8 was revised to present the fraction and rate of the dominant change trend of surface water cover frequency in 10 km resolution (Fig. 2.1 in this file). For visualization, the linear trend of surface water cover frequency was aggregated to 10 km resolution and selected to display the fraction of positive slopes or negative slopes ($p < 0.05$), whichever is larger in each 10 km grid, to represent the dominant monotonic change type of surface water. Grids with dominantly positive (negative) slopes were labeled as inundation frequency increasing (decreasing) areas (positive (negative) fraction). Similarly, we compared the average rate of positive slopes and negative slopes within each 10 km grid, and chose the faster change rate to represent the intensity of surface water changes. Grids with positive (negative) slope rate mean that the water occurrence is increasing (decreasing) rapidly. Figure 8 and related descriptions have been revised (lines 427-453 in Section 4.4 in the revision).

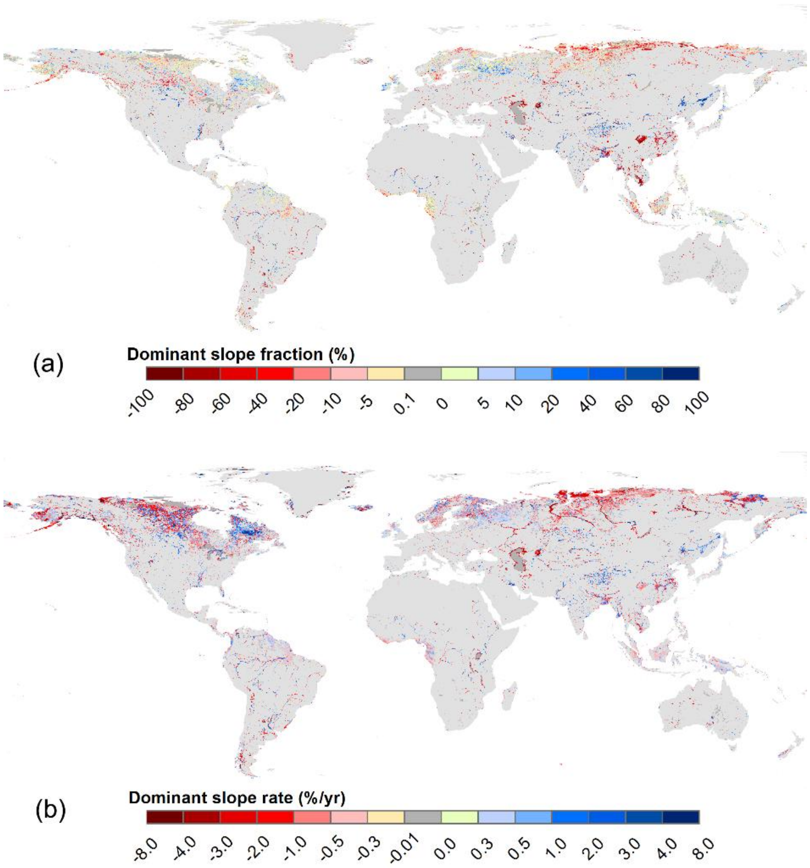

Figure 2.1. Linear trends of surface water cover frequency (SWF) during 2001 and 2020. The trend maps were aggregated to 10 km resolution for visualization. (a) Dominant SWF slope fraction (%). The positive (negative) fraction means that the fraction of pixels with increasing (decreasing) SWF ($p < 0.05$) in each 10 km grid, indicating whether the inundation frequency is dominantly increasing (decreasing). (b) Dominant SWF change rate (%/yr). The positive (negative) slope rate means that the mean linear slope rate of pixels with increasing (decreasing) SWF ($p < 0.05$) in each 10 km grid, whichever is faster, indicating whether the inundation frequency is increasing (decreasing) rapidly. The light grey refers to non-water covered areas.

Reference:

Pekel, J. F., Cottam, A., Gorelick, N., and Belward, A. S.: High-resolution mapping of global surface water and its long-term changes, Nature, 540, 418-+, 10.1038/nature20584, 2016.

Pickens, A. H., Hansen, M. C., Hancher, M., Stehman, S. V., Tyukavina, A., Potapov, P., Marroquin, B., and Sherani, Z.: Mapping and sampling to characterize global inland water dynamics from 1999 to 2018 with full Landsat time-series, Remote Sens. Environ., 243, 10.1016/j.rse.2020.111792, 2020.