

Interactive comment on “The Future of Earth Observation in Hydrology” by Matthew F. McCabe et al.

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Received and published: 19 April 2017

This paper is an admirably comprehensive overview of how changes in sensing platforms, data providers of spaceborne applications, enable new data sources, and thus, presumably, new breakthroughs in hydrology. No single paper can be expected to comprehensively cover the entire possible ‘future of hydrology’ and thus this provides a somewhat biased view (about which a caveat in the text would be useful). Nevertheless, the authors have done a remarkably thorough job in terms of capturing the various exciting opportunities available. I particularly appreciate the high number of references across such a diverse paper. Nevertheless, some increased focus and streamlining would significantly improve the paper and is necessary. Many of the points made in the current paper are likely to be lost on the reader without it.

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[Response]. We thank the reviewer for their thoughtful comments and obvious attention to detail in reviewing this paper. We agree that there are specific aspects of the paper that may require some refining during the revision process, and your comments will help in directing this activity.

Specific Comments:

1) Section 2 isn't clearly tied to the rest of the paper. Section 2.1 is a haphazard mix of challenges that can be addressed by using a wider diversity of platforms, commercial or otherwise, highlighted in Sections 3 and 4 (e.g. the risk of launches and focusing on single large instruments), and ones that are unrelated (e.g. greater multi-mission integration could be achieved also with space agencies and traditional large LEO or geostationary satellites), and ones that may even be made worse if traditional EO platforms break down (e.g. the perception that remote sensing data are magic and ignorance about reliance on retrieval algorithms may become worse with people using more commercial solutions that, for reasons of competition with other companies, are far more likely to keep their technological and retrieval details secret). Additionally, the challenges and opportunities mentioned for each variable in Section 2.2 are somewhat haphazard. It would be useful to specifically link each of the variables to opportunities mentioned in the rest of the paper.

[Response]. The paper seeks to provide an overview of the current state of EO, offer a perspective on outstanding challenges and knowledge gaps, and highlight the opportunities (and limitations) of emerging sensing platforms that have the potential to advance the EO field. Section 2 is a central element of this purpose, reflecting both on the capabilities for hydrological retrieval, which is deliberately concise and largely satellite focused, as well as identifying some of the broader EO "Problems, Challenges and Knowledge Gaps" (Section 2.1). We would disagree that these are a haphazard collection: the listed challenges, while not exhaustive, are certainly relevant, pertinent and in some instances, present as immediate roadblocks to furthering progress in the field. It is important to clarify that Section 3 and 4 are not presented as solutions to

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the challenges and issues outlined in Section 2. We are not advocating that simply providing more observations is the answer to these challenges. As such, providing a direct link to the variable specific issues outlined in Section 2 to these later sections is not the intent or purpose of our work. However, we appreciate the comment that further effort is needed to better integrate the different elements of this paper into a cohesive and self-contained manuscript, and will attempt to address this in a revised version.

2) Section 4 comes across too much as an advertisement for EO start-ups in Silicon Valley and a list of problems with space agency-built sensors (as also mentioned in Josh Fisher's non-reviewer comment). The challenges associated with commercial data are mentioned either as an aside that belies the serious nature of the issue (unknown and most likely lacking calibration relative to scientific standards in most cases), or not at all (data continuity, data costs, the fact that Cubesat orbits aren't always perfectly predictable a priori because of the way in which they are launched). The lower budgets of these startups are presented as being due to the nimbleness of commercial industry, but don't reflect the fact that launching lots of small satellites is inherently cheaper, or that SpaceX has relied on massive amounts of capital investments and has a high failure rate. This is a dis-service not only to government agencies as a source of EO data, but also to the points raised in Section II (which are lost in the process) and to the fact that, in reality, and the fact that future models and analyses efforts are likely to be best aided by a combination of both single-sensor satellites that provide reliable data at perhaps coarser spatial resolution and high resolution data from Cubesats. This section would be significantly aided by a summary table of pros and cons for a) government vs. commercial observing systems. The enormous potential of commercial systems (rightfully highlighted) would go to waste if the community cannot also think and overcome their related challenges. If space is an issue, such a table would therefore be more useful than e.g. table I, which summarizes established knowledge.

[Response]. We thank the reviewer for their perspective on this. As is detailed in our response to Dr Fisher (see <http://www.hydrol-earth-syst-sci-discuss.net/hessd>

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2017-54/hess-2017-54-AC2-print.pdf), we are certainly not seeking to present the commercial sector as the panacea of all problems related to EO. As noted in that response, the opportunities presented by the commercial sector represent just one of a large number of emergent EO technologies that are discussed in our paper, which include advances in UAVs, citizen science, balloons, opportunistic sensing, in addition to important government space-agency driven missions. In terms of the issues associated with commercial systems, we clearly identify calibration limitations (p.36 l. 18-20 and elsewhere) and explicitly refer to the issue of data continuity and data costs (in the title of Section 4.3 as well as throughout p.36 last paragraph and p.37). That commercial are cheaper, is reflected in the type and quality of the product: a point that can perhaps be reiterated. Further effort to highlight these very real challenges can be made in the revised version. However, as we are not advocating an “us versus them” approach to EO between the government and commercial spheres, and considering that the pro’s and con’s are already well stated throughout Section 4.3, the need for a table will require some consideration. Likewise, we will carefully review the paper for perceived bias, while also being mindful that such pointed discussions of both commercial and agency based EO are somewhat rare in the literature, and while being a potentially sensitive topic, may also represent as an important agent of change.

Relatedly, the authors may also want to consider renaming the paper “Opportunities and challenges for the future of remote sensing” to further highlight that a world where hydrologists predominantly use data from the start-ups and new platforms identified in this paper would be great but is not guaranteed if the challenges mentioned throughout are overcome.

[Response]. We appreciate the reviewers’ suggestion and will consider the most appropriate title for the paper upon revision. But again, we are not advocating this particular vision of the future: the best outcome, as the reviewer notes, is likely the one that combines available systems and sensing platforms.

3) Section 3.2 only has one subheading, and it is unclear why UAVs deserve their own

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subheading but balloons and solar planes do not.

[Response]. Noted. This was a formatting mistake made during final edits. 3.2 should be UAVs alone and there will be no subsequent sub-heading, as Balloons and Solar Planes are detailed in Section 3.3.

4) It would be useful to have a short summary section somewhere that explicitly summarizes challenges to the community and how it operates. E.g. the need to move towards cloud more, publish processed datasets to the same cloud platform rather than keeping them behind user accounts, think about how to engage with commercial agents, building data ingestion systems that are based on more haphazard temporal and spatial coverage, etc. Such issues are now mentioned as asides throughout and may seem less important, although they are arguably among the most potentially actionable results of the paper.

[Response]. As has been noted by many of the reviewers, the paper is already quite long and exhaustive, so we are reticent to add additional sections to the manuscript. However, as this reviewer rightly states, this may be an important missing element. We have tried to steer away from prescriptive action and instead provide an overview of challenges, limitations and opportunities. Perhaps a paragraph in the conclusion section would suffice to draw attention to these important actions.

5) Several sections have noticeably lower added value than others and may be best deleted to keep the paper length manageable and make the rest of the paper clearer. For example, the historical introduction about ground measurements in Section 3.6 (p. 25) only barely links up to the rest of the section (except maybe through the “Internet of Things” reference, but even that is only useful to someone who has already spent time thinking about the IoT and will grasp the connection immediately). Similarly, discussion of the declining trend in ground observations in Section 2.1 breaks the flow and is somewhat out of place. The section on potential new airborne measurements for commercial aircraft (p. 27) is far too vague – what variables could possibly be easily

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added? Airborne instrumentation for radar, fluorometry or even optical measurements requires extensive retrofitting of the aircraft and e.g. instrument protection in the form of a radome. By contrast eddy covariance measurements are difficult to calibrate.

[Response]. Noted. We will attempt to streamline some of these discussions while maintaining the intent of the underlying message. The decline of in-situ networks (Sect 2.1) is an important issue that often gets lost in the excitement of new satellite missions and emerging technologies: we will consider how best to phrase and place this in the context of the paper; likewise the introduction to Section 3.6. In terms of airborne sensing, this is a deliberately brief section that has some pertinent examples (the AMDAR system), which we will provide a clearer reference to. There are also efforts to install IR based sensors as early warning systems that have a range of potential applications (see Nature 502, 422–423, 2013 doi:10.1038/502422a): but the reviewer is correct in that there are challenges to do this, which can also be mentioned.

Minor Specific Comments:

* Section 3 title: It would be useful to include the phrase “data sources” or “platforms” somewhere in this section title, as that is the focus of many of the sub-headings.

[Response]. Noted and we will examine this in the revision of the paper.

* Page 4, Line 9: The A-Train efforts and large number of sensors aboard Aqua have been useful so some care with phrasing is needed here.

[Response]. Noted, and an excellent example that should be highlighted.

* Page 7, Point 4: The first sentence here provides far too limiting a view of the possible uses of hydrological data. It does not include, for example, the use of hydrologic earth observation data (without further assimilation) in carbon-cycle or biogeochemical studies, epidemiological ones, or even ones on social science implications of variations in water availability (e.g. Muller et al, PNAS, 2016 "Impact of the Syrian refugee crisis on land use and transboundary freshwater resources"). It would be more correct to delete

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the first sentence and rephrase that the ability to have long-term trends is useful for many studies instead of being so definitive.

[Response]. We agree and the reviewer has provided several appropriate examples to broaden this perspective.

* Page 7, Line 19: Su et al, Geophysical Research Letters, 2016 (“Homogeneity of a global multi-satellite soil moisture climate data record”) may be a helpful citation in the discussion of multi-sensor merging

[Response]. Noted and we appreciate the reference to highlight this important aspect of research.

* Page 12, Line 3: Note that e.g. Konings and Gentine, Global Change Biology, 2017 (“Global variations in ecosystem-scale isohydricity”) is a notable exception here.

[Response]. Thanks for providing this interesting reference.

* Page 15, line 14: NASA/DLR rather than NASA/German

[Response]. Noted

* Page 36, Line 13: The Chinese WCOM mission may be worth mentioning as an exception here, though it is still in the early phases

[Response]. Noted. WCOM is discussed on pg. 15 lines 20-26. While this is a strong hydrological focused mission proposal, it does not cover the full range of variables needed for closure.

* You may want to mention that Planet was recently sold

[Response]. To our knowledge, Planet has not been sold. They acquired Blackridge (operators of RapidEye) and are negotiating the purchase of Google’s Terra Bella satellite imaging capability.

* The 220 MB multimedia supplement may not be worth its large file size. Although it is

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difficult to note the cars moving unless looking for it. If the authors really want to include it, it may be worth cropping to a smaller area that focuses more on the highways.

[Response]. Noted. We will consider the value of this supplementary material.

* A few informal abbreviations have slipped in throughout: tech rather than technology, 'till, jet Propulson lab rather than laboratory, etc..

[Response]. Noted. A careful editing will ensure these are removed during the revision process.

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., doi:10.5194/hess-2017-54, 2017.

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