To What Extent Is The Cryosphere Taken Into Account In The Hydrological Loading Models?

Maylis de La Serve[1,2,3], Jeffrey T. Freymueller[3]

[1] Université Paris Cité, Institut de physique du globe de Paris, CNRS, IGN, F-75005 Paris, France [2] ENSG-Géomatique, IGN, F-77455 Marne-la-Vallée, France
[3] Department of Earth and Environmental Sciences, Michigan State University, East Lansing, MI, US

email : teyssendier@ipgp.fr , freymuel@msu.edu

A - Introduction

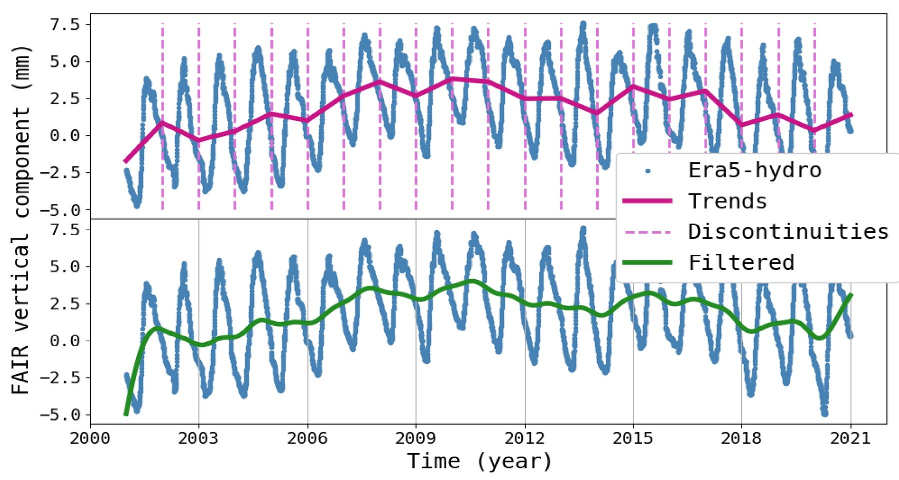
- Water mass redistribution, including melting of ice in glaciers and ice sheets and a variety of processes involving surface and groundwater, causes significant global deformation of the Earth's surface.
- Part of these deformation is non-linear and non-seasonal and is thus not fully taken into account in the latest realization of ITRF.
- One approach to this problem could be to use geophysical models to extend the current terrestrial reference frame model. But how accurate are these models?
- Due to the acceleration of the ice melt, it is necessary to consider a global cryospheric deformation model in addition to the customary loading deformation models (hydrological, oceanic and atmospheric).
- However, part of the deformation induced by glacier melt is most probably already accounted for by hydrological loading deformation models and prevents combined use of these models.
- To investigate this problem, we have compared Coulson's cryospheric deformation model [1] with a set of hydrological loading models and GNSS observations.

B – Datasets

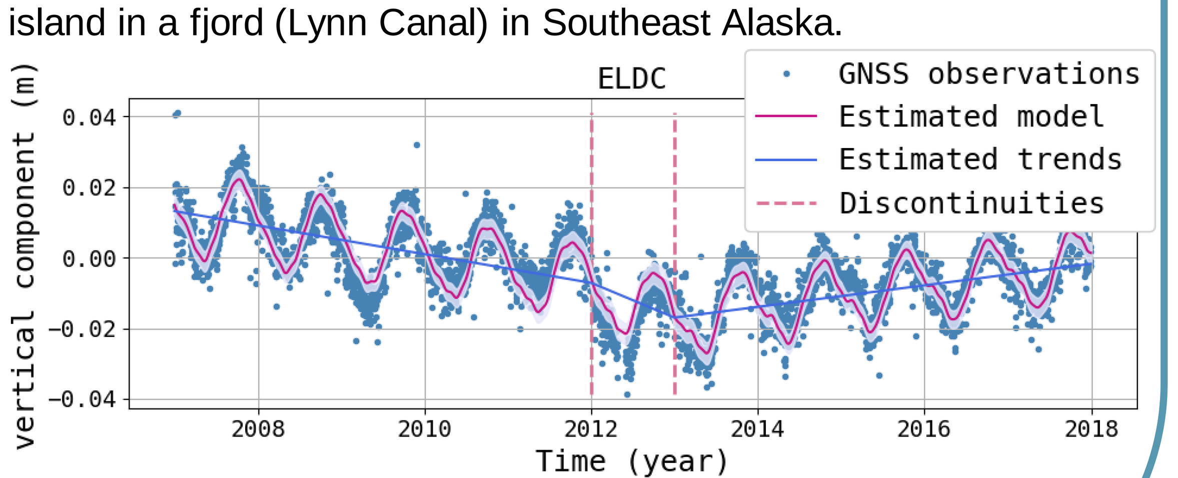
- Coulson et al (2021) cryospheric model [1] : global predictions of 3-D crustal motions in response to mass changes in Antartica and Greenland ice sheets and glaciers. Yearly grids of deformation rates, updated version running from 2002 to 2018.
- EOST ERA5_hydro model [2] : time series of displacements induced by hydrological load (soil moisture and snow) for 8845 stations from 1979 to 2023 with a 30 minutes sampling.
- GNSS observations processed at MSU with Gipsy goa-6.4 [3] in PPP mode, with the concatenated global solution aligned to ITRF2020 [4].

C – Preprocessing

- ERA5_hydro and GNSS times series have been preprocessed to obtain yearly trends to compare with Coulson's model.
- The adjusted modeling is composed of a linear part with discontinuities in velocities every year and annual and semi-annual sinusoids.
- The adjacent figure represents, for an ERA5_hydro time series, the comparison between the adjusted trends (in **violet**) and the filtered time series with a 0.5cpy cut-off frequency (in **green**) for validation.



- The same modeling has been adjusted on GNSS time series with a variable white plus flicker noise model in order to obtain realistic error bars.
- A multi-year average has been tested for the special case of ELDC, which is situated on a small island in a fjord (Lynn Canal) in Southeast Alaska.
- Only two discontinuities in velocities have been introduced in 2012 and 2013 both for ERA5_hydro and GNSS time series.

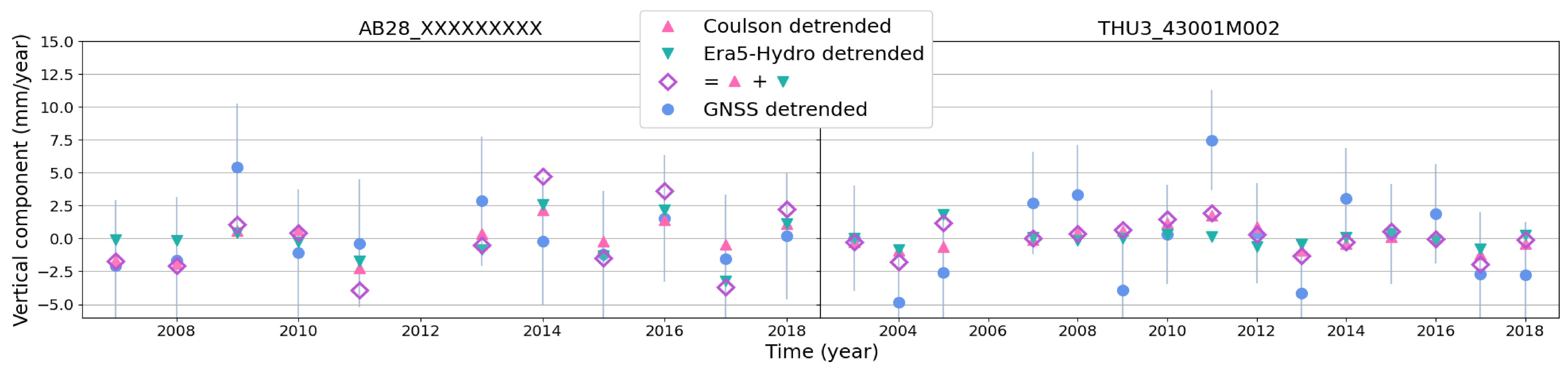


- In this particular case, Coulson's model has been averaged over the periods 2007-2012 and 2013-2018.

D – Comparison with GNSS

Two different methodologies have been used to compare the cryospheric models and the trends adjusted on ERA5_hydro times series to the trends adjusted on GNSS observations.

1

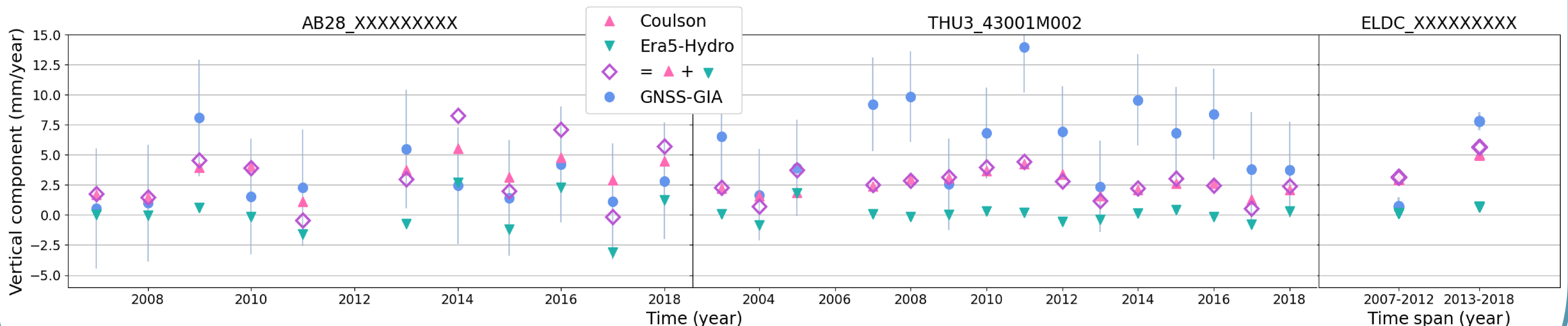


Yearly trend comparison on the sites AB28 (Alaska) and Thule (Greenland)

- Coulson: Each yearly grid has been **detrended** by using the mean value over the period.
- ERA5_hydro and GNSS: The model describe in C has been adjusted on the **detrended** time series before extracting yearly trends.

2

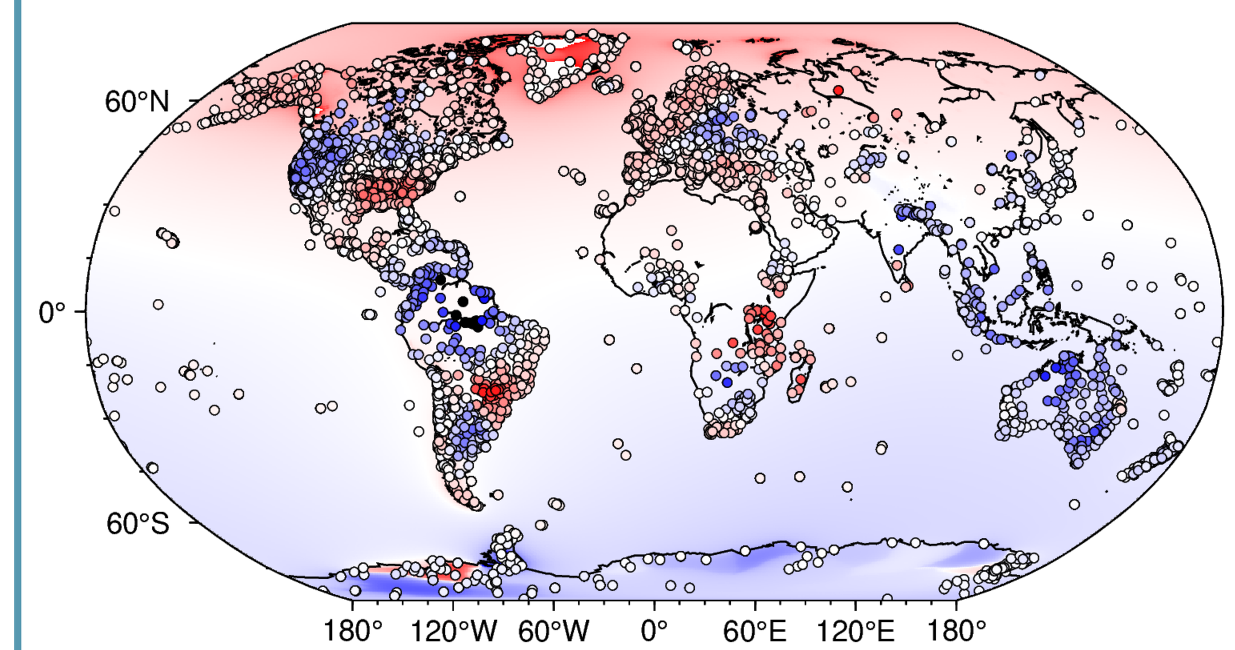
Yearly trend comparison on the sites AB28 (Alaska), Thule (Greenland) and ELDC (Southeast Alaska).



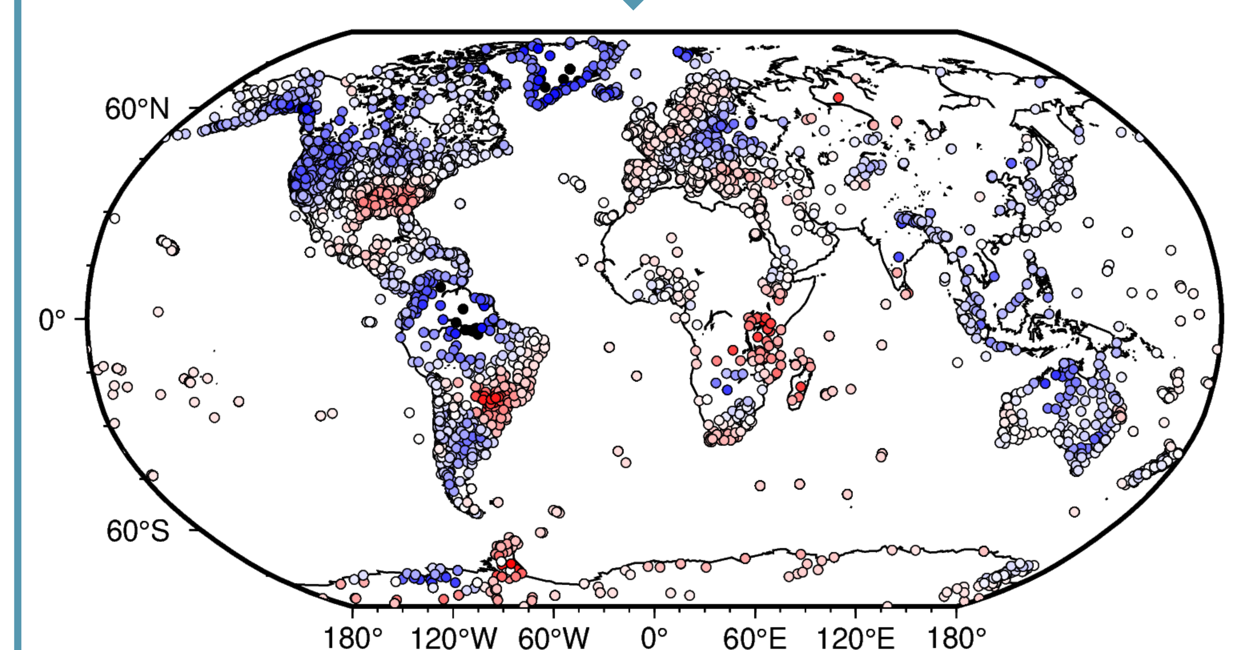
- A Glacial Isostatic Adjustment (GIA) model - ICE-6G_vm5 processed by Steffen [5] - has been used to correct the GNSS yearly trends from the Last Glacial Maximum (LGM).
- For sites AB28 and ELDC, an additional GIA correction for recent ice loss is made based on Hu and Freymueller [6].

E – Loading model comparison

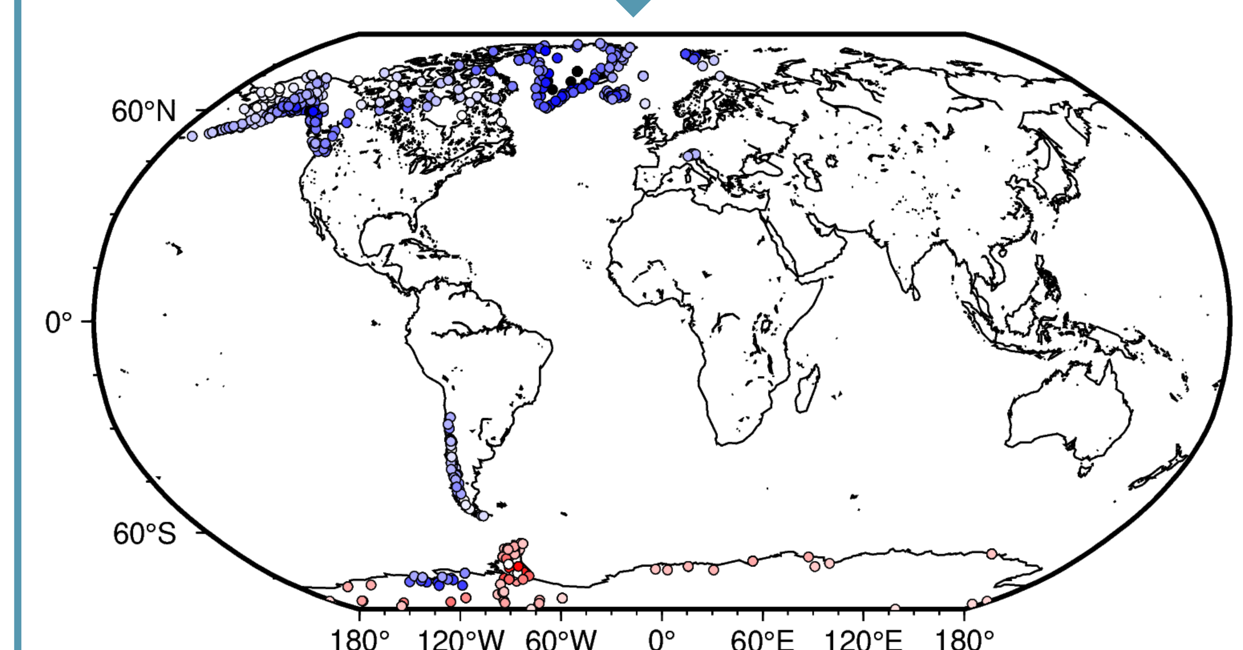
This comparison aims to identify areas where both models have significant signal. Far from glaciers and icecaps , we expect to see solely hydrological signal, whereas in their vicinity, we expect to see solely cryospheric signal.



Background: Coulson's cryospheric deformation model
Dots: Trends adjusted on ERA5_hydro times series



Difference between ERA5_hydro trends and Coulson's model. Big differences are expected in areas dominated by continental terrestrial water storage.



Filter to highlight areas where both ERA5_hydro and Coulson's model predict significant motion: the difference is close to neither of the models, with a 1mm threshold.

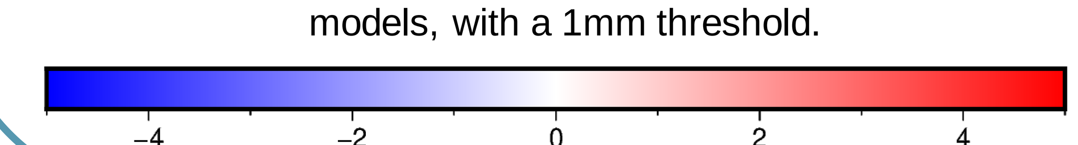


Illustration for year 2016, vertical component (mm/year)

F - Conclusion

- Comparison of the loading models (see E) was also carried out with the MERRA2_hyd and GLDAS2 datasets [2], showing similar results.
- Part of the differences observed in the comparison with GNSS (see D) is due to the underestimated correction of the GIA models, but also to the estimation of yearly trends that doesn't offer sufficient accuracy. Another part is certainly due to missing contribution both in the cryospheric and hydrological models.
- The continental hydrology models do not accurately represent the cryospheric mass changes but have significant mass variations in and near ice-covered areas. Especially in areas close to continental glaciers.
- Even when the ice-covered areas are masked out, there will be a substantial double-counting of mass if models of cryospheric change are summed with a model of continental hydrology.

G – References and acknowledgement

- We thank Paul Rebischung (IGN - IPGP) for providing the PyTRF software that we used for time series analysis.

[1] Coulson, S., Lubeck, M., Mitrovica, J. X., Powell, E., Davis, J. L., & Hoggard, M. J. (2021). The Global Fingerprint of Modern Ice-Mass Loss on 3-D Crustal Motion. Geophysical Research Letters, 48(16), e2021GL095477. doi: 10.1029/2021GL095477

[2] EOST loading service: http://loading.u-strasbg.fr/

[3] NASA JPL Gipsy goa-6.4 software: https://gipsyx.jpl.nasa.gov ; Bertiger W., Desai S.D., Haines B., Harvey N., Moore A.W., Owen S., Weiss J.P., 2010. Single receiver phase ambiguity resolution with GPS data, J. Geod., 84, 327–337. doi: 10.1007/s00190-010-0371-9.

[4] Altamimi, Z., Rebischung, P., Collilieux, X., Métivier, L., & Chanard, K. (2023). ITRF2020: An augmented reference frame refining the modeling of nonlinear station motions. Journal of Geodesy, 97(5), 47. doi: 10.1007/s00190-023-01738-w

[5] Steffen, H. (2021). Surface Deformations from Glacial Isostatic Adjustment Models with Laterally Homogeneous, Compressible Earth Structure (1.0) [Data set]. Zenodo. doi: 10.5281/zenodo.5560862

[6] Hu, Y., and J. T. Freymueller (2019), Geodetic Observations of Time-Variable Glacial Isostatic Adjustment in Southeast Alaska and its Implications for Earth Rheology. Journal of Geophysical Research Solid Earth, doi: 0.1029/2018JB017028.

Symposium 2024 - Bern

IGS INTERNATIONAL GNSS SERVICE

P2: 019