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BRISTOL

Data-driven estimate of past and present surface loading over North America: Bayesian Hierarchical Modelling approach applied to GPS and GRACE observations

Y. Ziegler, B. D. Vishwakarma, A. Brady, S. Chuter, S. Royston, R. Westaway, J. L. Bamber

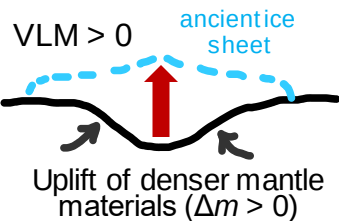
Attributing global sea level rise to its component parts



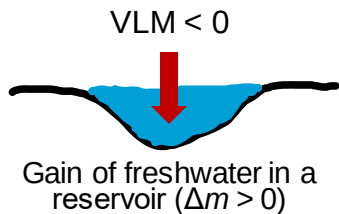
European Research Council
Established by the European Commission

Source separation for Vertical Land Motion

GIA-induced VLM
(viscous response)



Present-day hydrology-induced VLM
(elastic response)



BHM approach

Parameter:

$$\theta \sim p(\theta)$$

Latent process:

$$x|\theta \sim p(x|\theta)$$

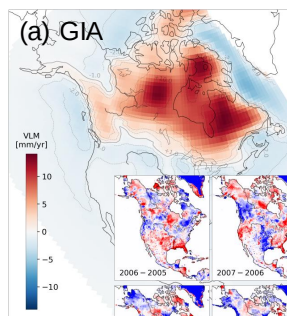
(VLM)

Observations:

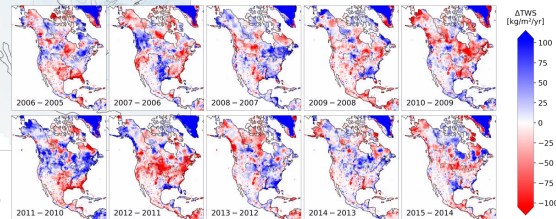
$$y|x, \theta \sim p(y|x, \theta)$$

(GRACE, GNSS)

Sources separation
based on the fields
spatio-temporal
characteristics



(b) ΔTWS



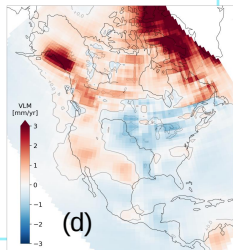
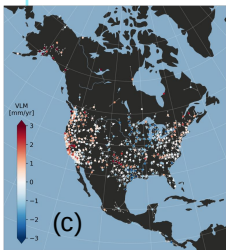
Observations/BHM input

GPS time series
from NGL +
corrections

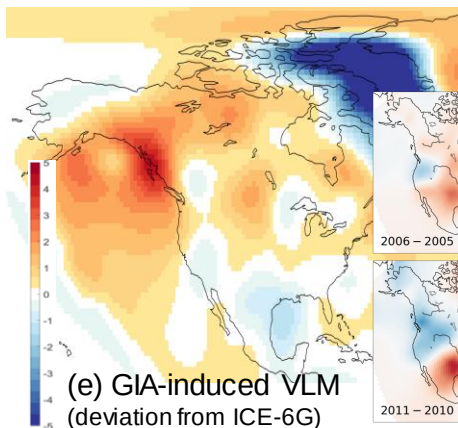
Pseudo-GRACE
product in terms
of VLM

2005-2015

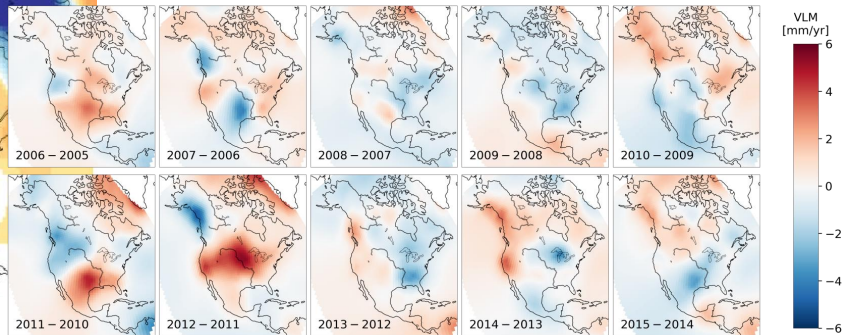
time-invariant
&
time-evolving
components



Results



(f) Hydrology-induced VLM



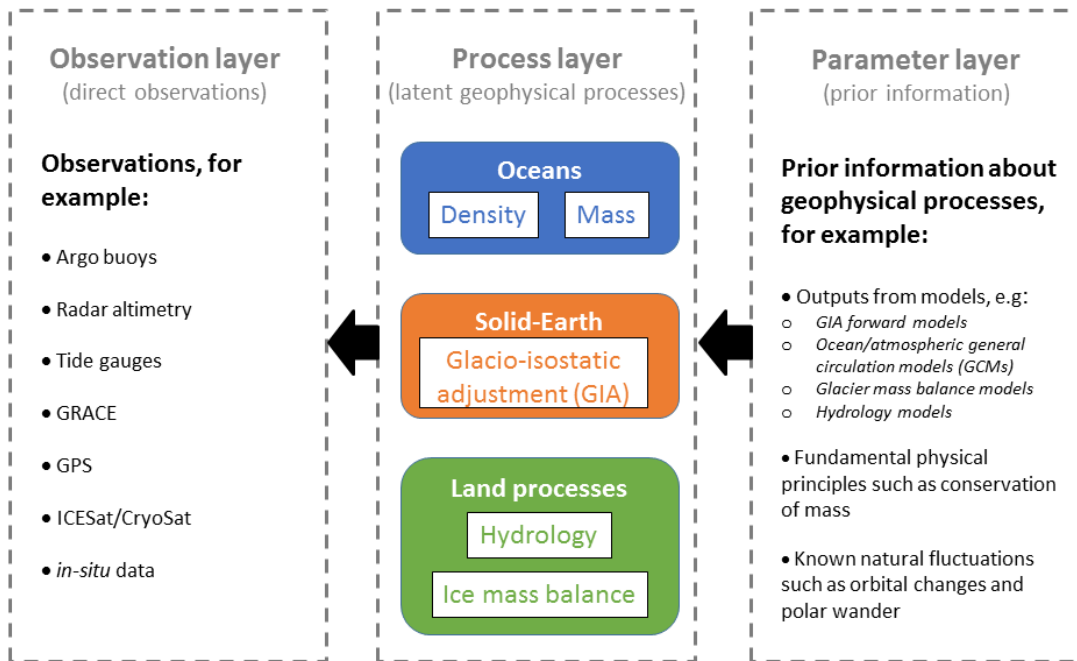
Data-driven estimate of past and present surface loading over North America: Bayesian Hierarchical Modelling approach applied to GPS and GRACE observations

Yann Ziegler, Bramha Dutt Vishwakarma,
Aoibheann Brady, Stephen Chuter, Sam Royston,
Richard Westaway, Jonathan Bamber

Attributing global sea level
rise to its component parts

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European Union's Horizon 2020 research and innovation
programme under grant agreement No 694188

The GlobalMass project



Main goal: attributing global sea level rise to its component parts

Method: Bayesian Hierarchical Modelling

Intermediate goal: estimate a data-driven global GIA solution



Bayesian Hierarchical Modelling (BHM)

Allows modelling of underlying latent processes and separation of sources (GIA vs hydrology)

Parameter: $\theta \sim p(\theta)$

spatio-temporal characteristics

Latent process: $x|\theta \sim p(x|\theta)$

VLM over the entire domain

Observation: $y|x, \theta \sim p(y|x, \theta)$

GRACE & GNSS data

Note: we subtract an implicit prior for GIA (e.g. ICE-6G) from the BHM input data to match the condition that the process x is modelled using a zero-mean Gaussian with variance $Q(\theta)$



Overcoming challenges in spatio-temporal modelling
of large-scale (global) data

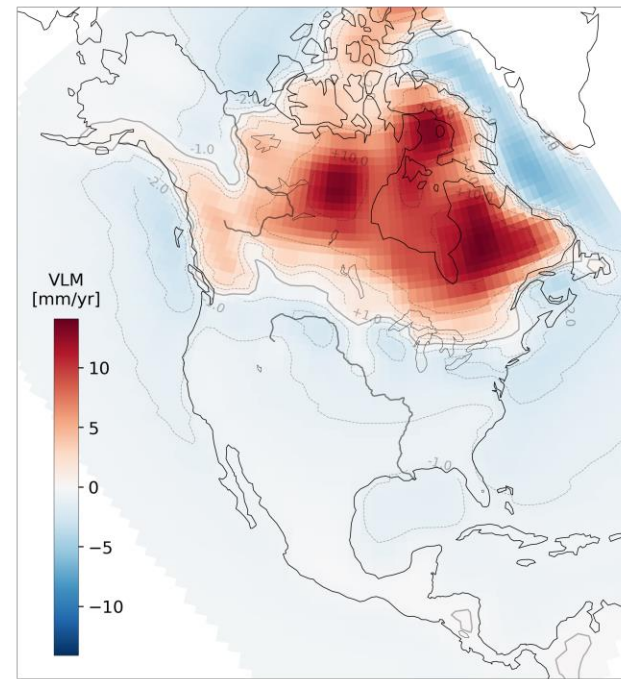
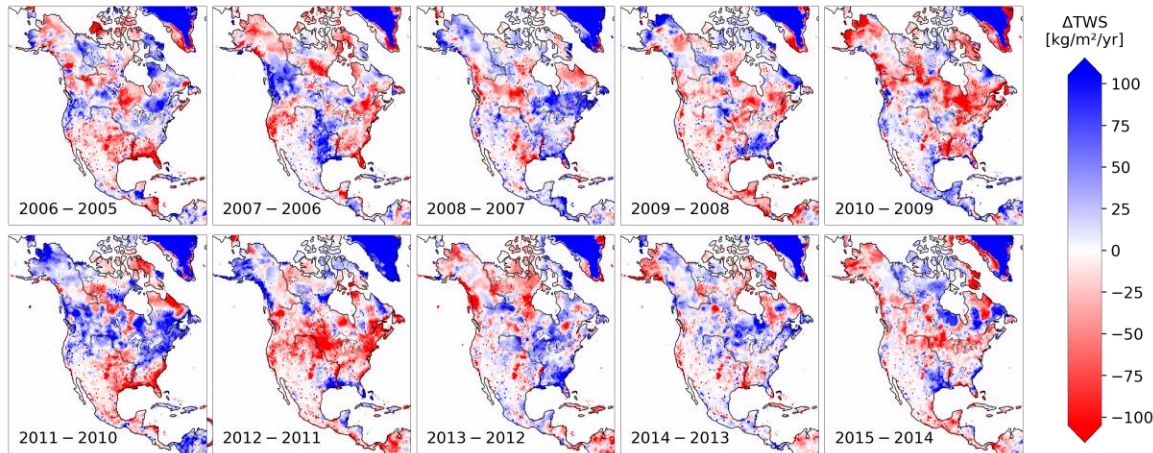
Aoibheann Brady *et al.*, EGU 2021 (Monday 26th, ESS11.6)

<https://meetingorganizer.copernicus.org/EGU21/EGU21-13357.html>

Focus on North America

Interesting region to validate GlobalMass approach:

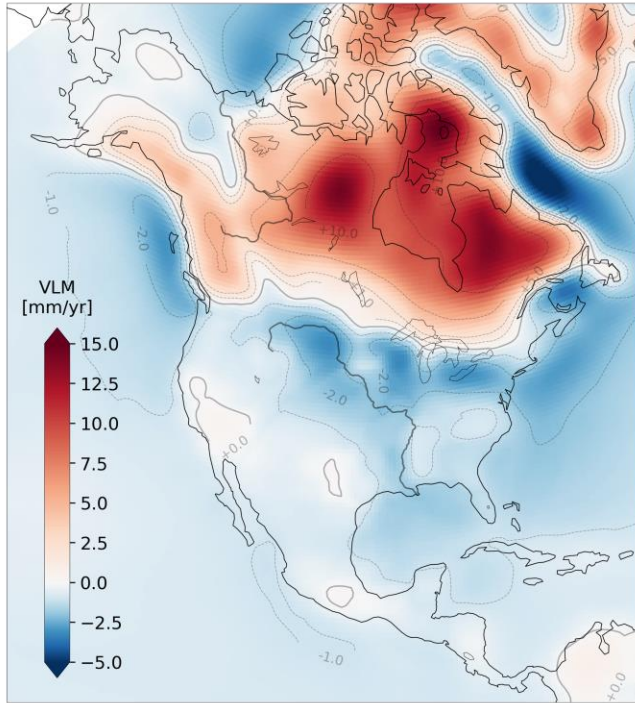
- Strong GIA signal (up to ~15 mm/yr)
- Hydrological signal (California, Great Lakes, 2012 drought ...)
- Thousands of observations (GPS time series)
- Many previous studies for reference/comparison
- A few challenges (tectonics? non-elastic hydrological signal?)



GIA: VLM from ICE-6G
(Peltier et al. 2015)

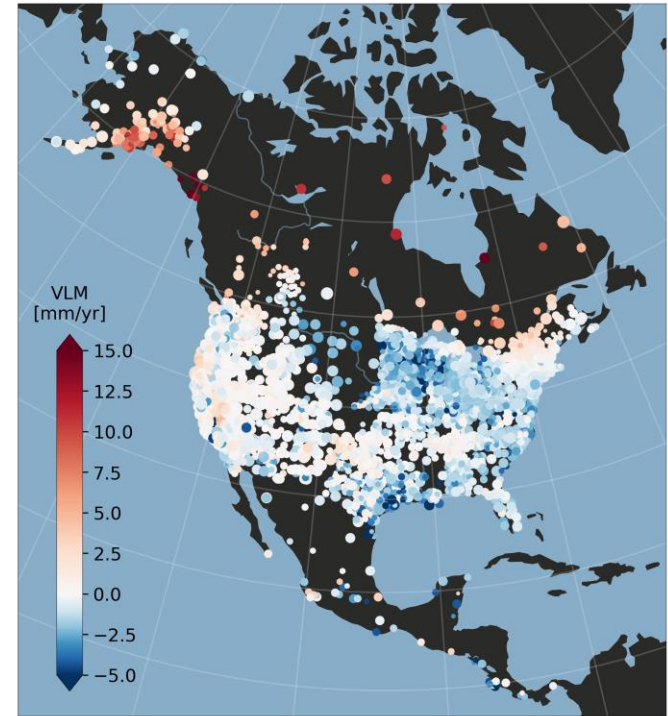
Hydrology:
annual change
of terrestrial
water storage
from WaterGAP
2.2d model
(Müller Schmied
et al. 2021)

Observations: GRACE and GNSS (2005-2015)



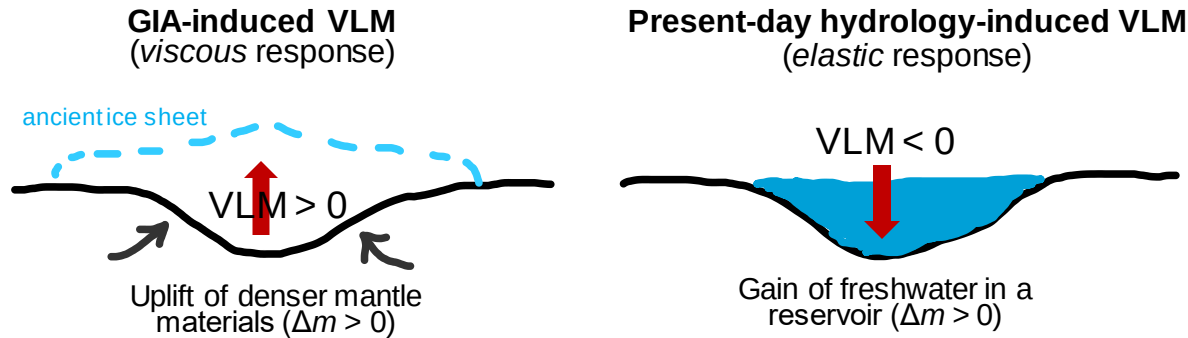
Mass change observed by
GRACE: JPL RL06
mascon solution
transformed into VLM for
the BHM, see next slides

Vertical displacements
observed by **GNSS**
technique: NGL dataset in
IGS14 (Blewitt et al. 2018),
offset detection/ correction,
atmospheric loading and
pole tide corrections applied



Present-day vs past surface loading

- Sea level is impacted by vertical land motion (VLM)
- Visco-elastic response of the Earth to surface mass loading induces VLM
- Observed mass change Δm (by GRACE) and VLM (by GNSS) are related differently (in sign and amplitude) depending on the geophysical process at play:



- Non-local relation between Δm and VLM: convolution with different Green's functions for elastic and viscous response (e.g. Farrell 1972, Purcell et al. 2011)

Challenge: how to combine mass change and VLM?

...in a data-driven BHM framework, without (wrongly) assuming that:

- the linear trend component of hydrology is negligible with respect to GIA
- GIA and hydrology processes induce the same relation between Δm and VLM
- the relation between Δm and VLM is local (no convolution)

Solution: pseudo-GRACE product approach

1. subtract a GIA model from GRACE observations Δm
2. transform remaining Δm into VLM assuming an elastic response
3. *BHM*: estimate a GIA field from GNSS observations and a pseudo-GIA (proxy) field from GRACE observations; the hydrology field is determined using both data sets
4. transform the pseudo-GIA field back to an actual GIA field assuming a viscous response
5. combine both GIA fields to get a single, physically consistent GIA field

For a new, alternative approach using least-squares method, see:



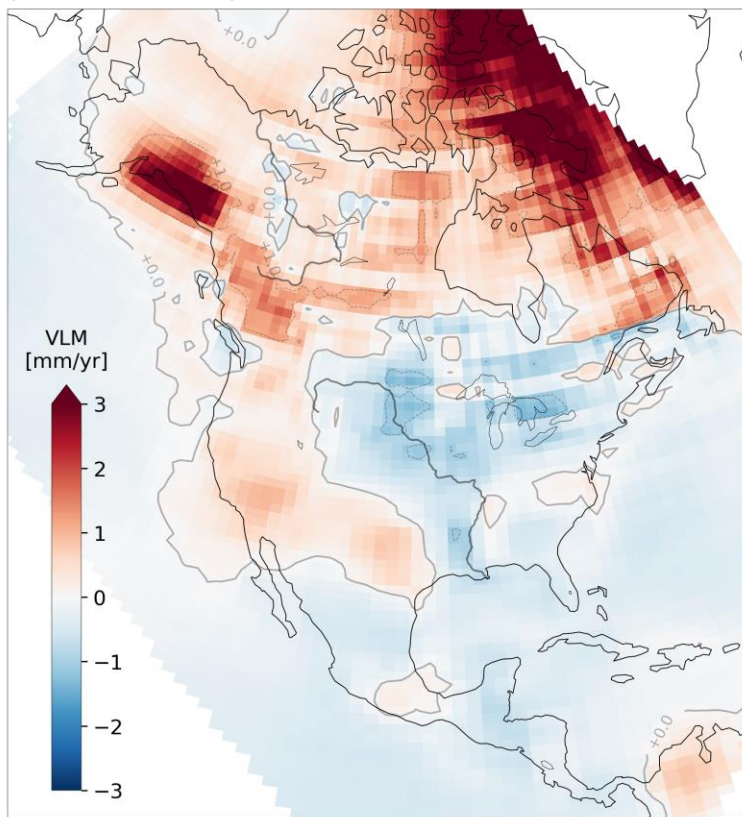
A novel data-driven method to estimate GIA signal from Earth observation data

Bramha Dutt Vishwakarma *et al.*, EGU 2021 (Wednesday 28th, G1.2)

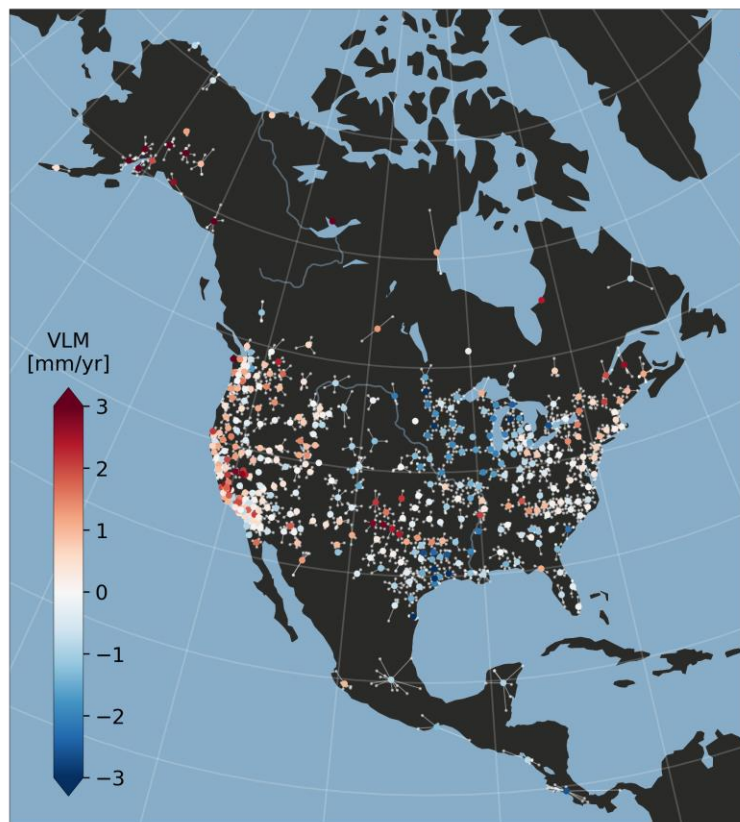
<https://meetingorganizer.copernicus.org/EGU21/EGU21-8876.html>

BHM input data (ICE-6G removed, no ice loading correction applied)

pseudo-GRACE product



GPS clusters and original stations used (small white dots)



Note: on these plots, only the linear trends (2005-2015) are shown; the data also contain a time-evolving component

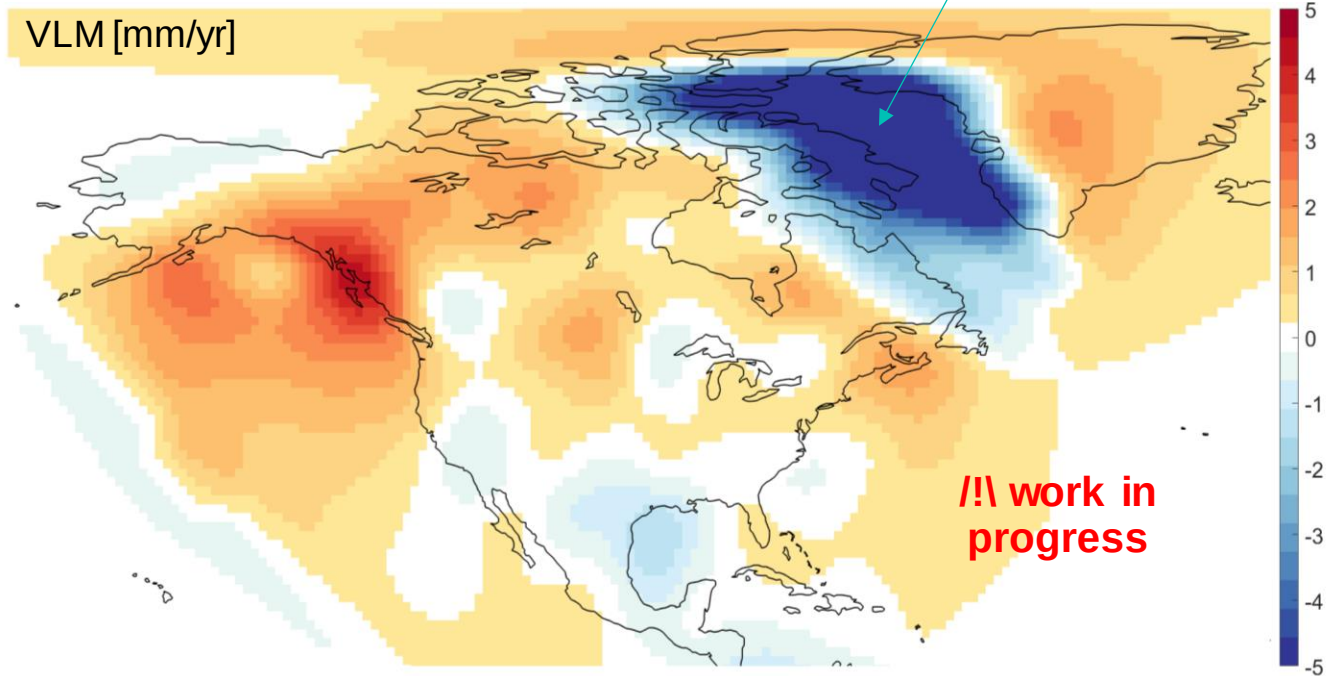
Preliminary results: time-invariant field – GIA

elastic rebound wrongly attributed to GIA (needs improvement on present-day ice loading correction)

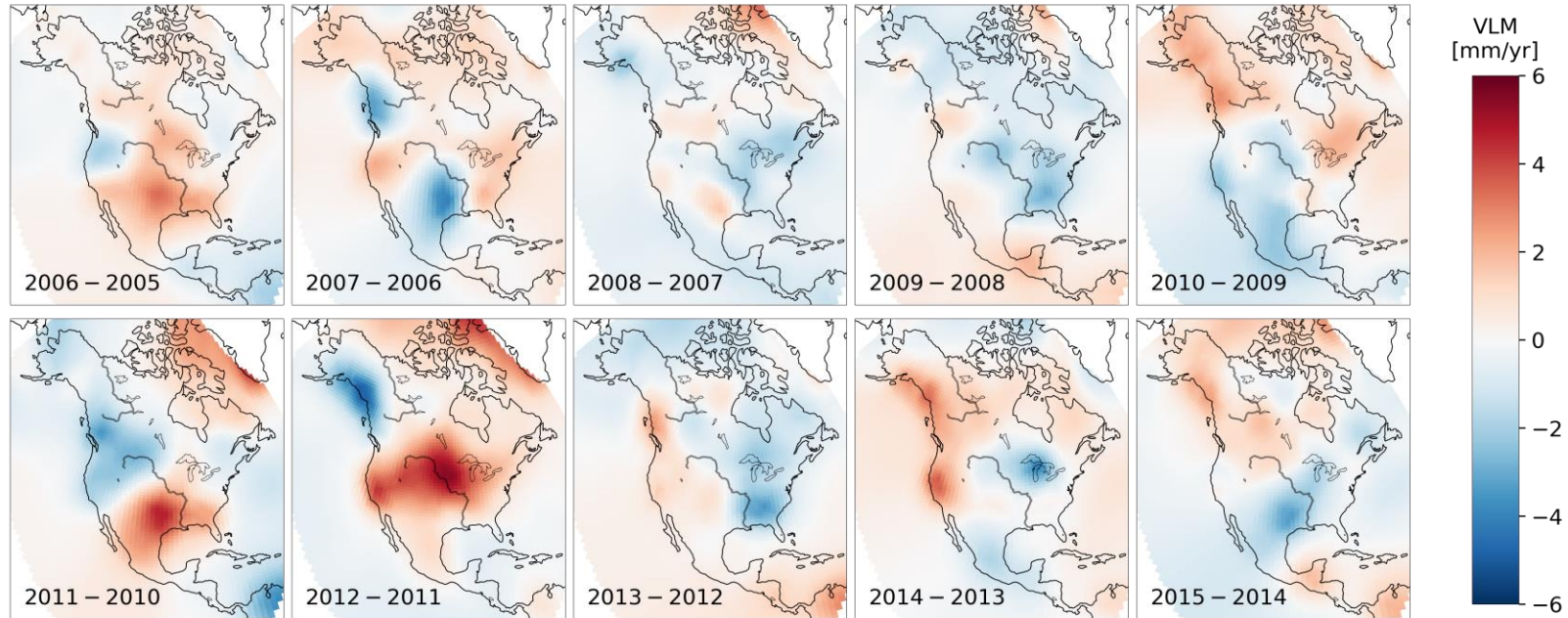
VLM [mm/yr]

Deviation
from ICE-6G

Underestimated
amplitude around
Hudson Bay and
in Alaska in
forward model?

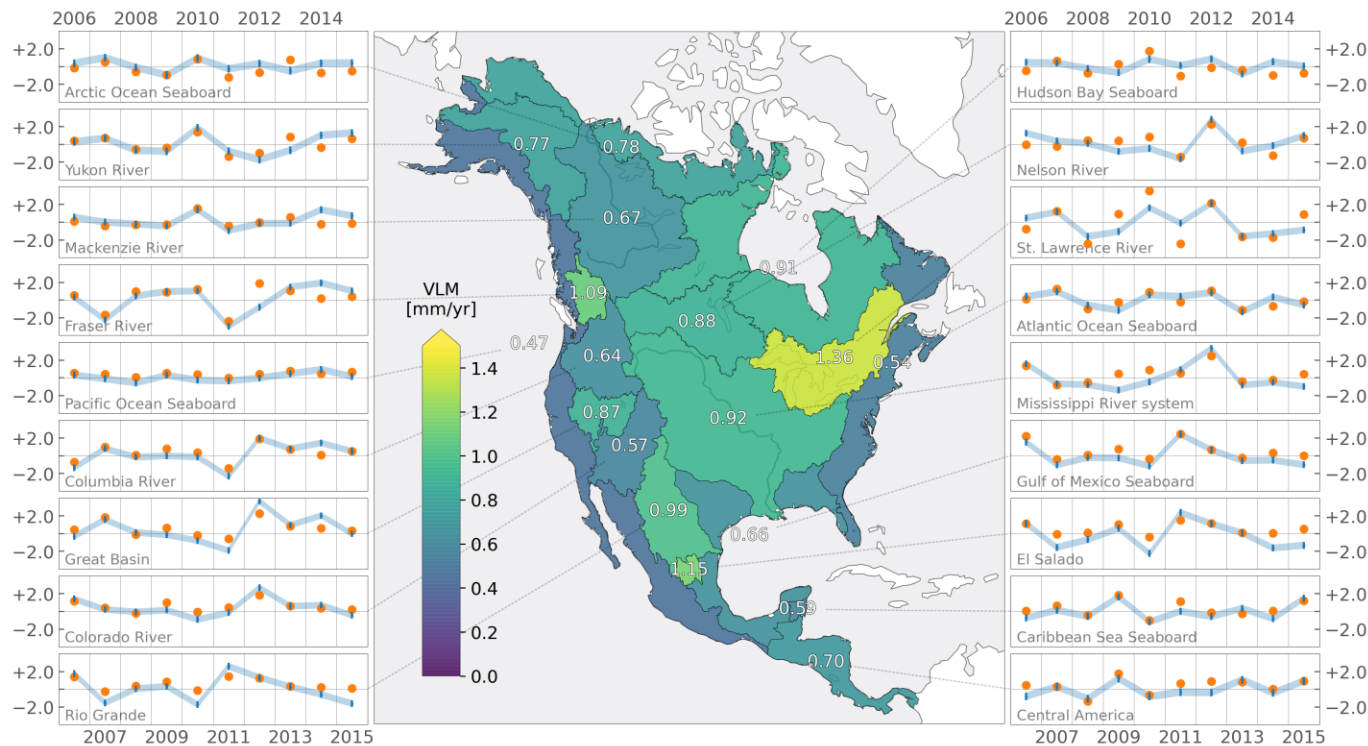


Results: time-evolving field – hydrology



Hydrology-induced VLM estimated by the BHM from GRACE and GPS data

Hydrology: comparison with WaterGAP



Time-evolving component of the VLM field estimated by the BHM, averaged over North America major basins

Map: RMS deviation of BHM estimate with respect to WaterGAP 2.2d model

Time series: WaterGAP in orange, BHM estimate with uncertainty in blue

Discussion and caveats

- We have recently improved our method to estimate the GIA field with the BHM from GRACE and GNSS observations
- The new results are preliminary but suggest that we can identify significant discrepancies with respect to recent GIA forward models such as ICE-6G and hydrological models such as WaterGAP
- Signals which are neither related to hydrology nor GIA may still be present in some areas; we are working on that to improve our data set (manual removal of GNSS stations...)

Conclusion and perspectives

- We use a data-driven but still physically consistent approach to estimate the VLM field over North America
- Using the BHM, we solve the source separation problem for GIA and hydrology relying only on assumptions on the spatio-temporal characteristics of each field
- We are now working on a global solution

Approaches and results discussed here soon available with data and code, stay tuned!



GlobalMass participation at vEGU21: Gather Online

26th to 30th April 2021



Monday 26 th	Tuesday 27 th	Wednesday 28 th	Thursday 29 th	Friday 30 th
ESSI1.6 Overcoming challenges in spatio-temporal modelling of large-scale (global) data Aoibheann Brady vPICO: 08:00 Chat: 08:34–09:30 HS2.5.2 Closing the water budget at the global scale using observations, remote sensing, and reanalyses Fanny Lehmann vPICO: 10:00 Chat: 10:30–11:30 G3.4 Coastal sea level change from Sentinel-3A SRAL over the U.S. Eastern seaboard Anrijs Abele vPICO: 10:28 Chat: 10:44–11:30		G1.2 A novel data-driven method to estimate GIA signal from Earth observation data Bramha Dutt Vishwakarma vPICO: 12:48 Chat: 12:56–13:15	CR2.1 Remote sensing of the cryosphere Stephen Chuter [co-convener] 08:00–11:30 G3.1 Data-driven estimate of past and present surface loading over North America: Bayesian Hierarchical Modelling approach applied to GPS and GRACE observations Yann Ziegler vPICO: 08:30 Chat: 08:32–09:30	HS2.4.3 Evaluating linear trends with respect to past decadal variability can help us assess the severity of GRACE observed water storage change Bramha Dutt Vishwakarma vPICO: 08:37 Chat: 08:43–09:30 CL4.1 How much of the decadal, coastal sea level variability can we describe by climate modes? Sam Royston Invited vPICO: 14:30 Chat: 15:20–16:00

All times are in UK BST



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Website: www.globalmass.eu
Twitter: [@GlobalMassTeam](https://twitter.com/GlobalMassTeam)

