GNSS observations of the land uplift in South Africa: Implication for water loss estimation

Christian Mielke, Makan Karegar, Helena Gerdener, Jürgen Kusche

University of Bonn

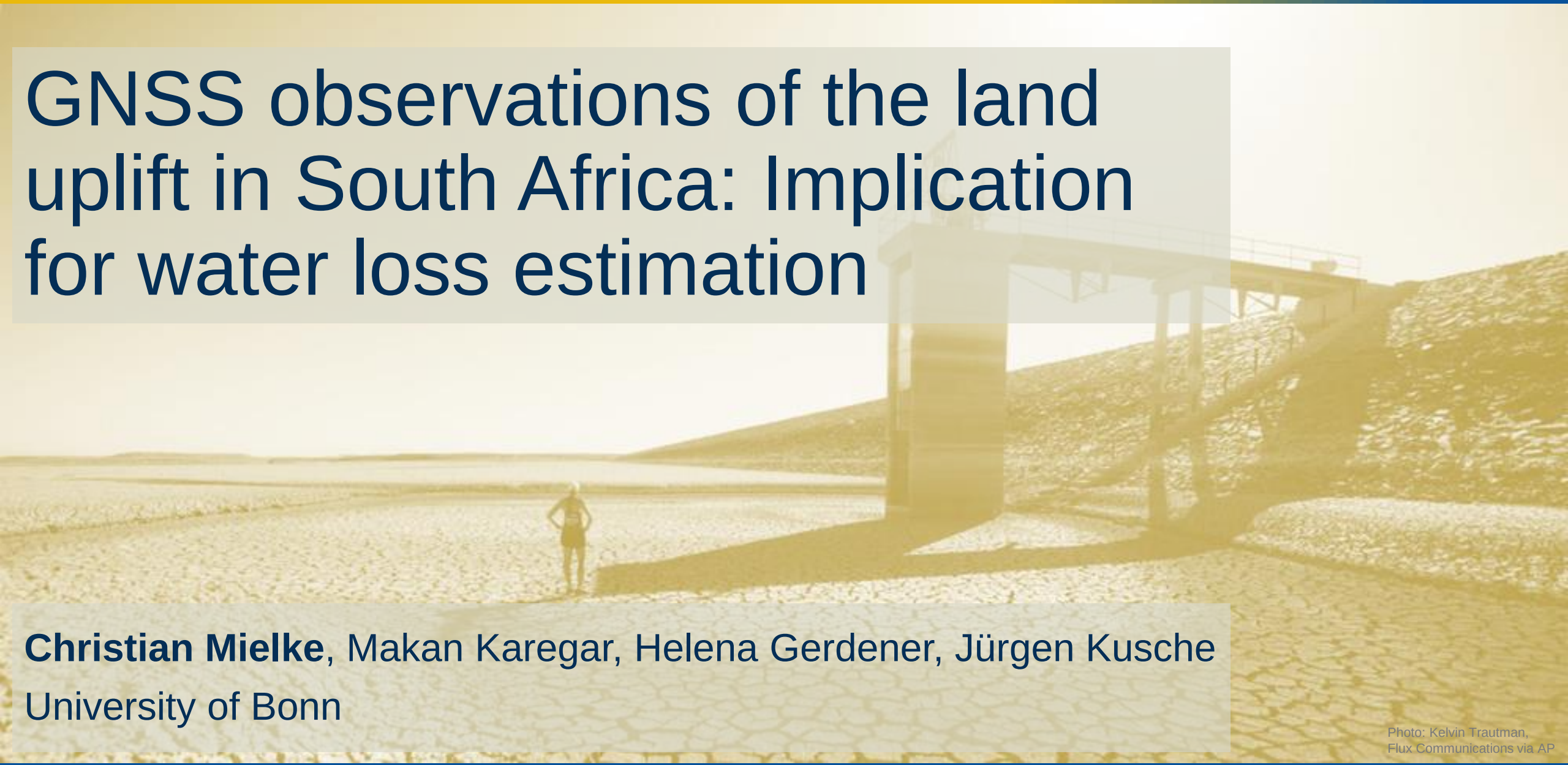


Photo: Kelvin Trautman, Flux Communications via AP

Land Uplift in South Africa

Motivation

GNSS networks indicate spatially coherent uplift

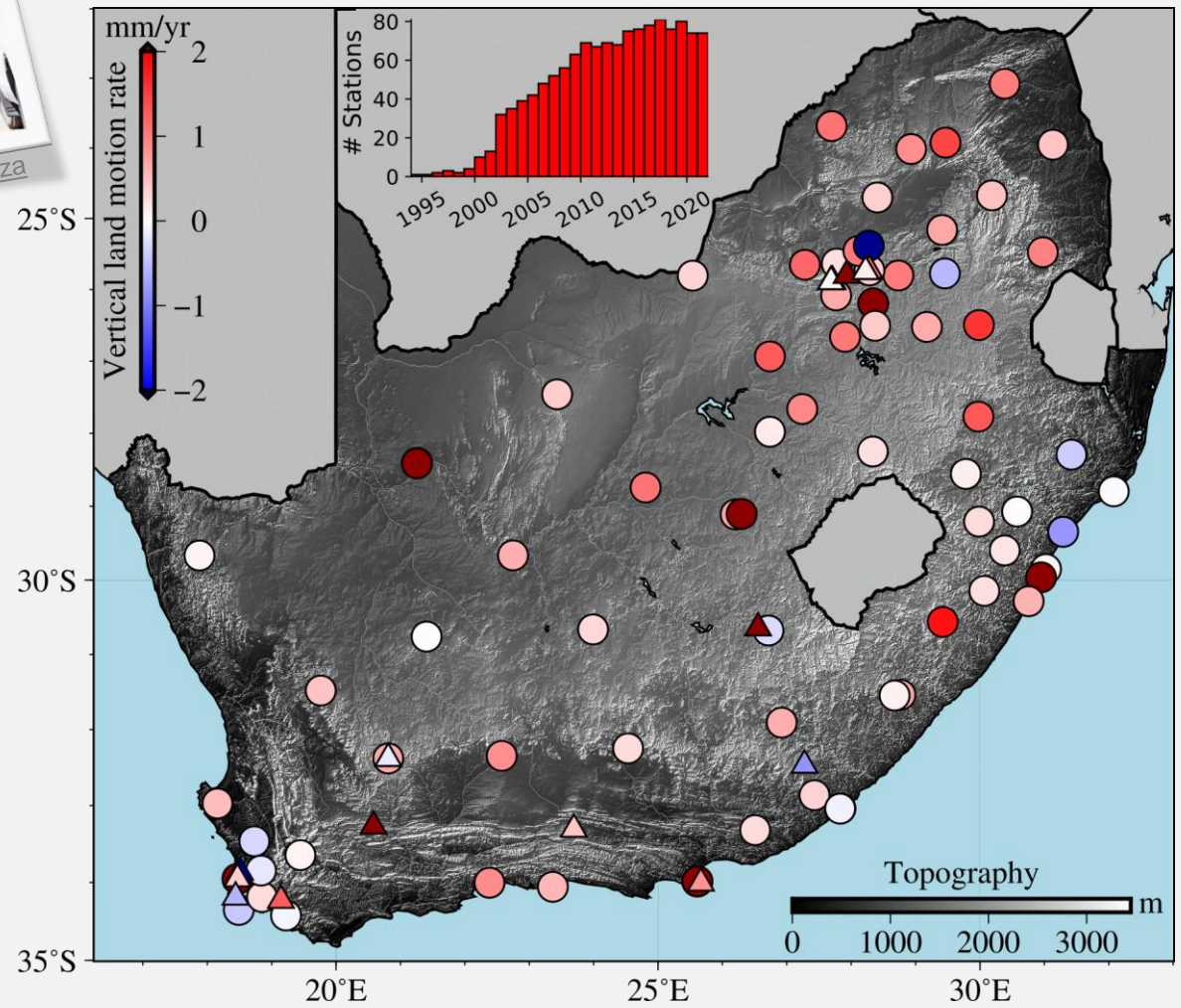
- cause of uplift not clear
- hypothesis by Hammond et al. (2021): mantle flow and dynamic topography

Droughts

- e.g. “Day Zero” drought in Cape Town (2015 – 2017)

Uplift related to water loss?

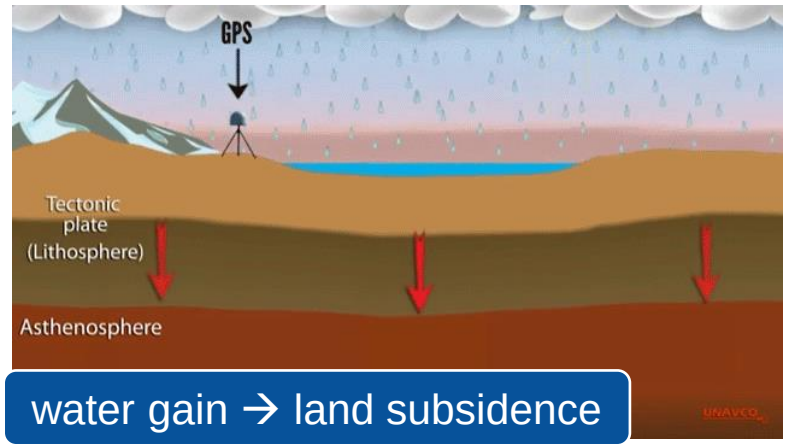
GNSS stations in South Africa and MIDAS[1] velocity fields



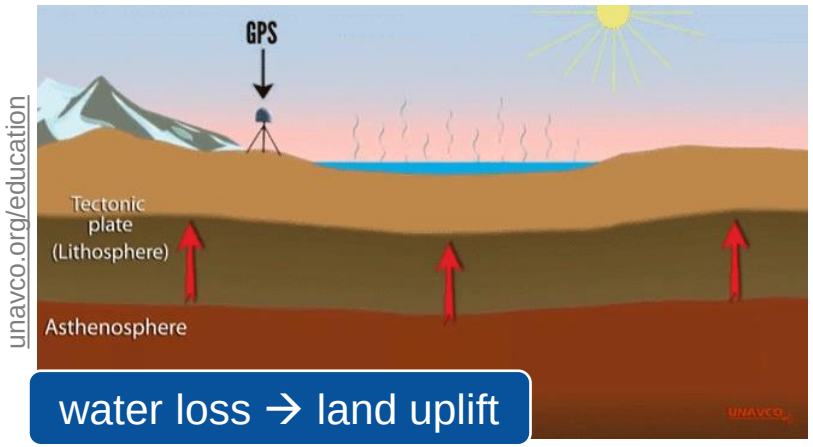
62 TrigNet[2] (●) + 40 additional (▲) continuously operating GNSS stations

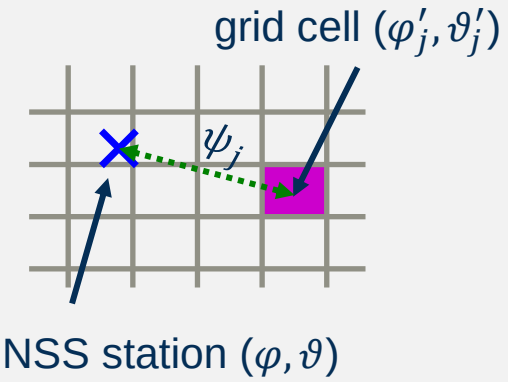
[1]robust trend estimator (Blewitt et al, 2016) | [2]countrywide network primary for survey applications

GNSS Inversion



unavco.org/education





derive TWS from GNSS uplift

- uplift as a function of area mass and Green's function
- Green's functions: elastic response of Earth's surface (we use PREM Earth model)

➢ we have to refine original GNSS time series!

ill-posed problem

- more grid cells (parameters) than GNSS stations (observations)
- unevenly distributed GNSS stations

➢ regularisation needed!

Radial displacement

$$\Delta u(\varphi,\vartheta) = \sum_j \Delta\sigma_j \underbrace{R^2 \Delta\varphi' \Delta\vartheta' \cos\varphi'_j}_{\text{grid area}} G(\psi_j)$$

Earth's radius R; *Green's function* G; $\Delta\sigma_j$: *area mass*

solve for entire grid using ...

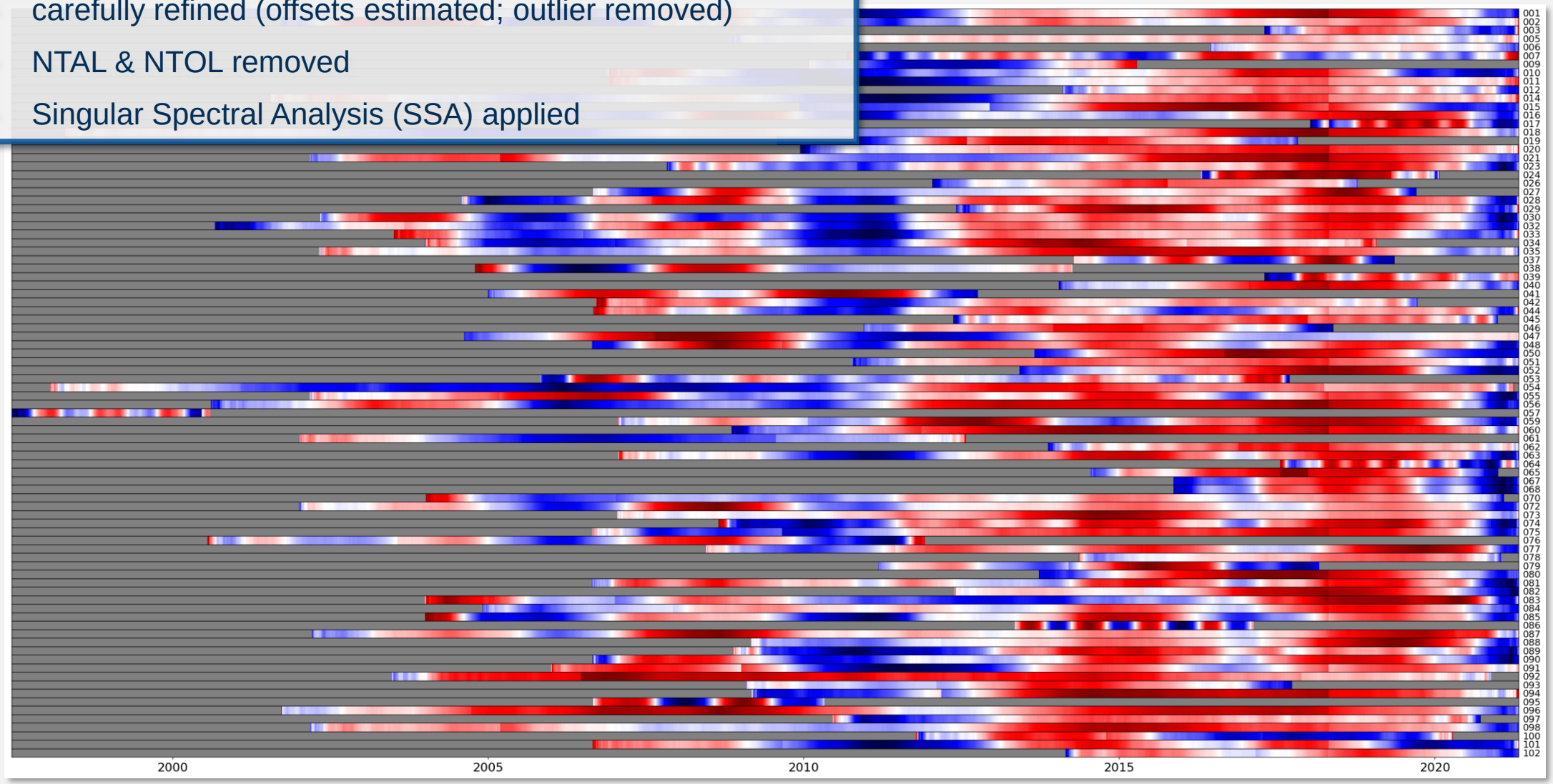
Tikhonov regularization

$$\min_{\boldsymbol{m}} \|\boldsymbol{G}\boldsymbol{m} - \boldsymbol{u}\|_2 + \alpha\|\boldsymbol{m}\|_2$$

GNSS Radial Displacements

- from Nevada Geodetic Laboratory (NGL; Blewitt et al, 2018)
- carefully refined (offsets estimated; outlier removed)
- NTAL & NTOL removed
- Singular Spectral Analysis (SSA) applied

Normalised[1] rates of GNSS long-term trend



[1]separately normalised between *-1* and *1*

TWS Spatial Correlations

- given the distribution of GNSS stations, best results are obtained for TWS retrieval on a 2° x 2° grid[1]
- seasonal signals show matching amplitudes
- “east-west-gradient” of humidity
- “phase shift” of rainy seasons
  - winter rainy season in the west
  - summer rainy season in the rest of the country

➢ high correlations with hydrological data

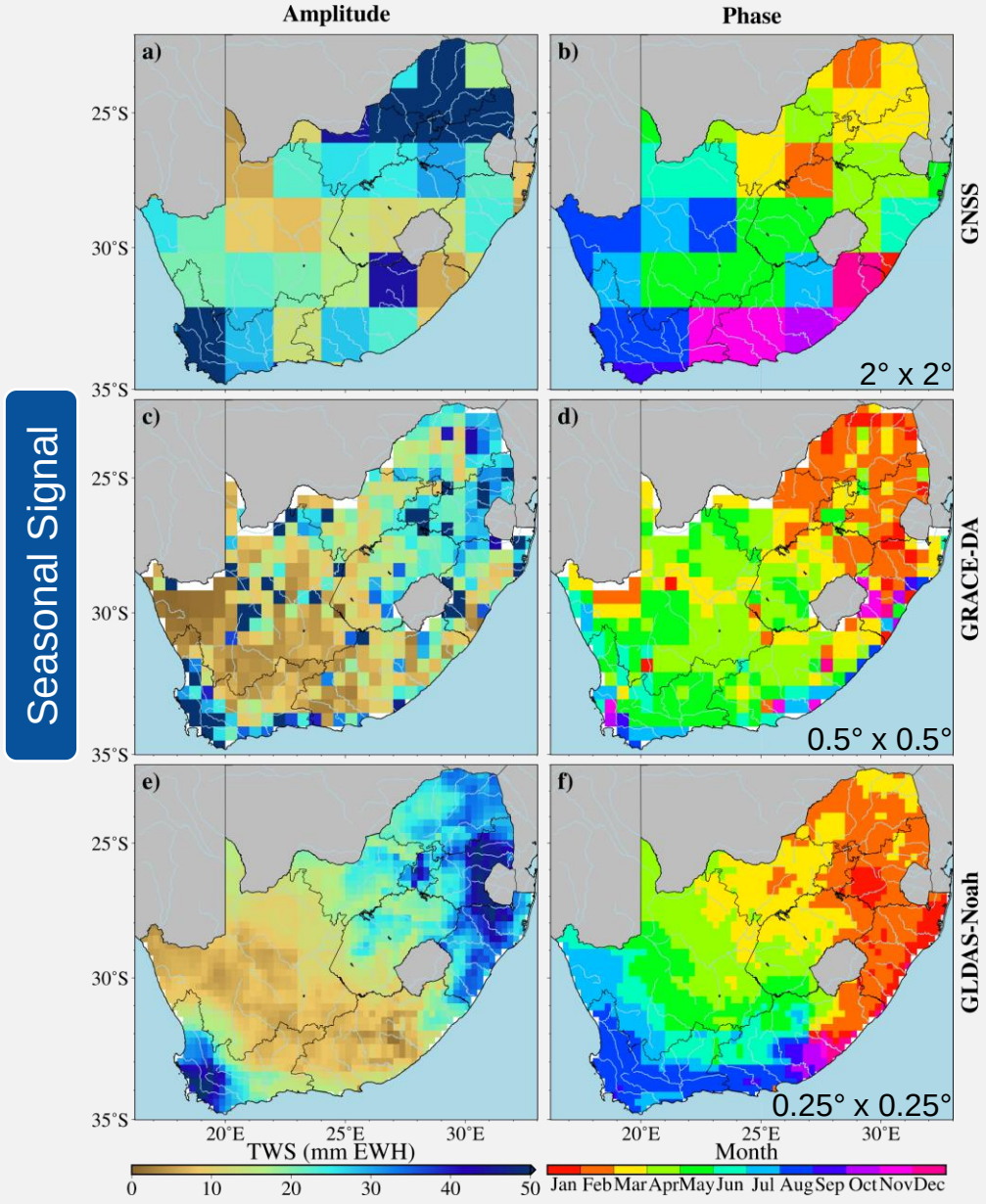
Comparison Data

GRACE assimilated data (GRACE-DA)

- local assimilation by Gerdener et al. (in preparation) from Uni Bonn, IGG
- assimilation of GRACE/-FO into WGHM

GLDAS-Noah 2.1 Land Surface Model

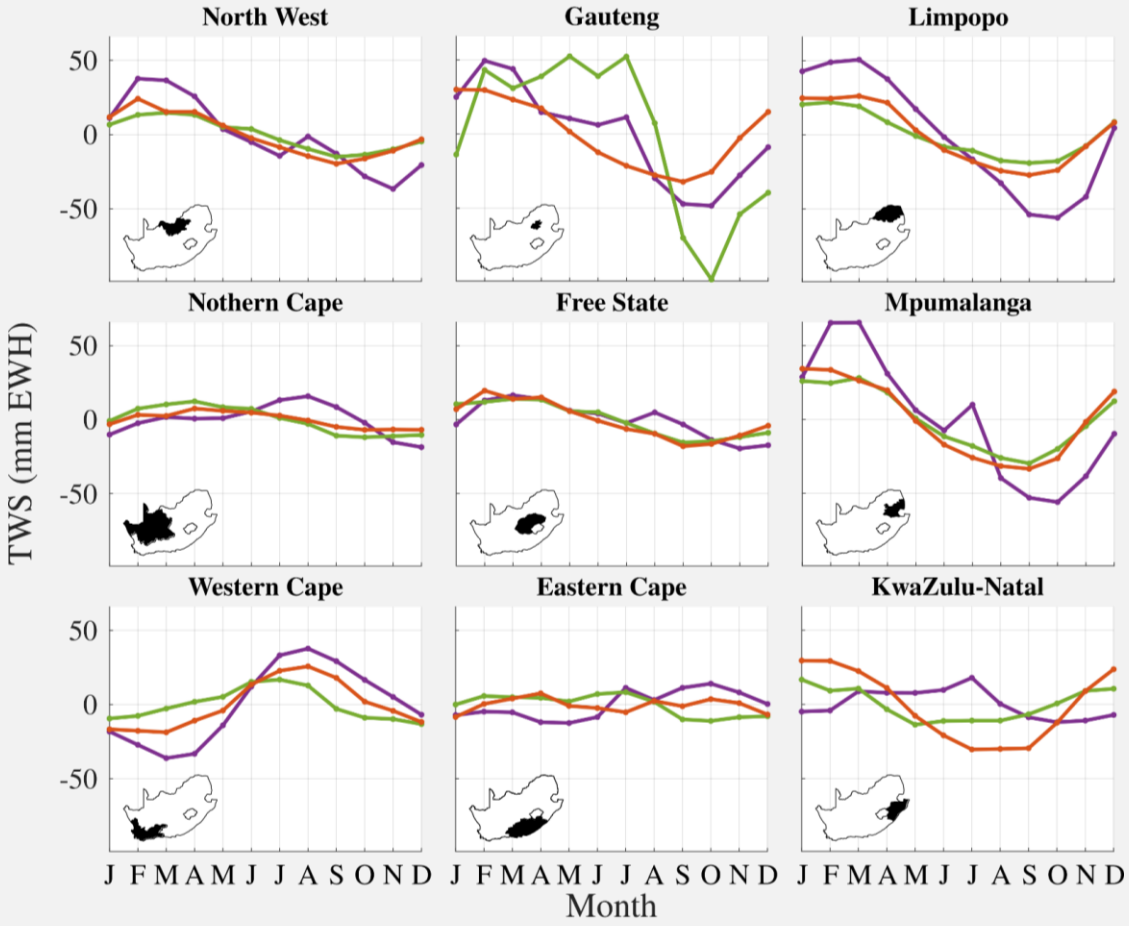
- Global Land Data Assimilation System Version 2 (Beaudoing et al. 2020, Rodell et al. 2004)



[1]experimentally found with checkerboard test

TWS Temporal Correlations

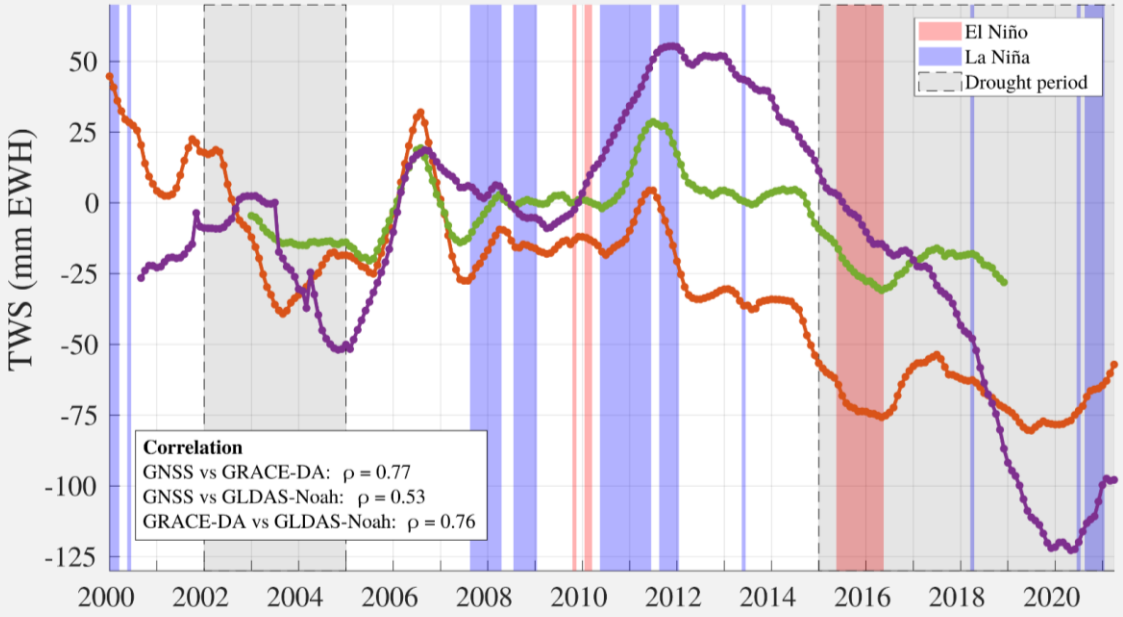
Monthly Climatology



- matching monthly climatology in multiple regions
- correlations with ENSO events
- negative trend in all data sets starting end 2011

➢ strong connection between GNSS, GRACE-DA and GLDAS-Noah trend

Long-Term Trend[1]



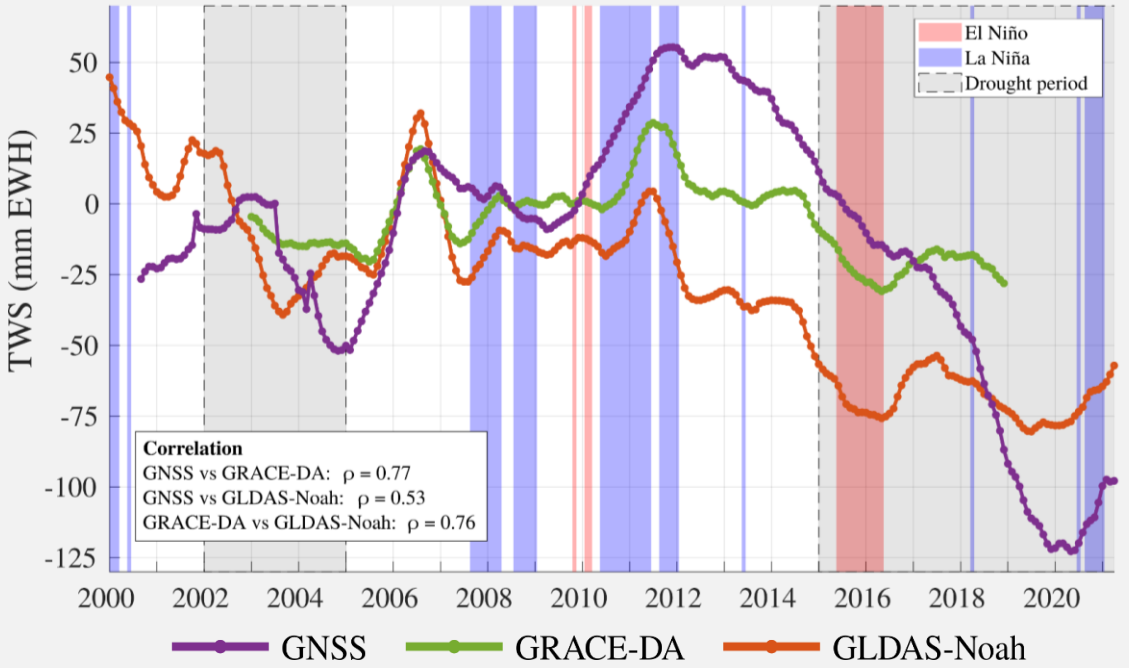
GNSS GRACE-DA GLDAS-Noah

[1]from 12-month moving average

Land Uplift in South Africa

- ✓spatial correlation of TWS
- ✓temporal correlation of TWS

Present-day land uplift in South Africa has a hydrological origin



GNSS observations of the land uplift in South Africa: Implication for water loss estimation

a pre-print will be available soon…

Questions?

Christian Mielke

mielke@geod.uni-bonn.de

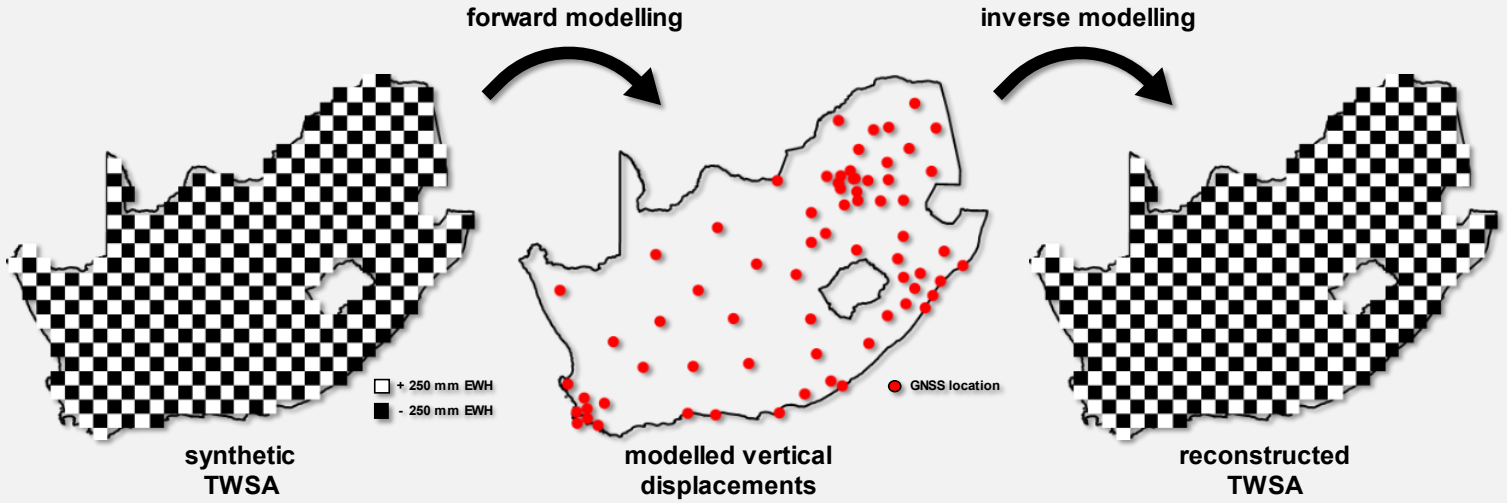
References

- Beaudoing, H., Rodell, M., & NASA/GSFC/HSL (2020). GLDAS Noah Land Surface Model L4 monthly 0.25 x 0.25 degree, Version 2.1. https://disc.gsfc.nasa.gov/datasets/GLDAS_NOAH025_M_2.1/summary?keywords=GLDAS. Last access: 14. September 2021.
- Blewitt, G., Hammond,W. C., & Kreemer, C. (2018). Harnessing the GPS Data Explosion for Interdisciplinary Science. Eos, 99. https://doi.org/10.1029/2018EO104623
- Blewitt, G., Kreemer, C., Hammond, W. C., & Gazeaux, J. (2016). MIDAS robust trend estimator for accurate GPS station velocities without step detection. Journal of Geophysical Research: Solid Earth, 121(3), 2054–2068. https://doi.org/10.1002/2015JB012552
- Hammond, W. C., Blewitt, G., Kreemer, C., & Nerem, R. S. (2021). GPS imaging of Global Vertical Land Motion for Studies of Sea Level Rise. Journal of Geophysical Research: Solid Earth, 126(7). https://doi.org/10.1029/2021JB022355
- Rodell, M., Houser, P. R., Jambor, U., Gottschalck, J., Mitchell, K., Meng, C.-J., Arsenault, K., Cosgrove, B., Radakovich, J., Bosilovich, M., Entin, J. K., Walker, J. P., Lohmann, D., & Toll, D. (2004). The Global Land Data Assimilation System. Bulletin of the American Meteorological Society, 85(3), 381–394. https://doi.org/10.1175/BAMS-85-3-381

Images

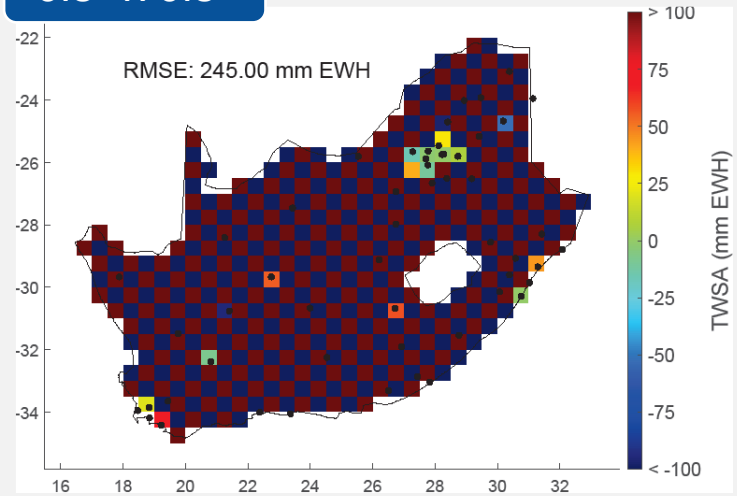
- https://gctca.org.za/city-bracing-for-day-zero/ (last access 23.05.2022)
- https://www.unavco.org/education/education-resources/videos-animations/ (last access 23.05.2022)

Checkerboard Test

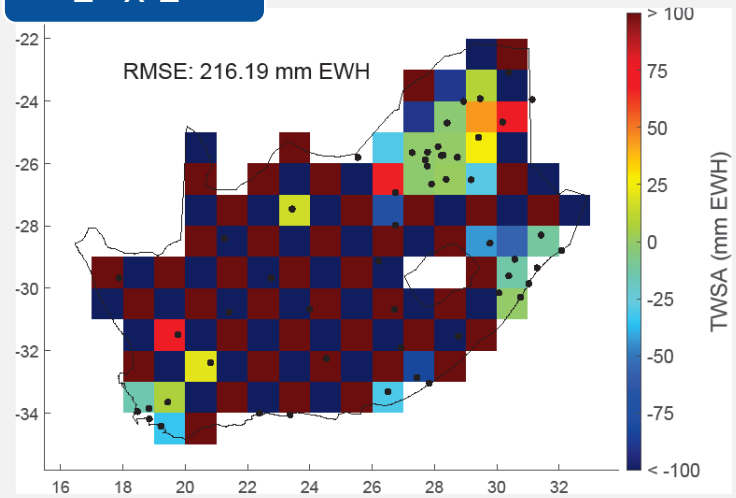


take difference (synthetic - reconstructed)

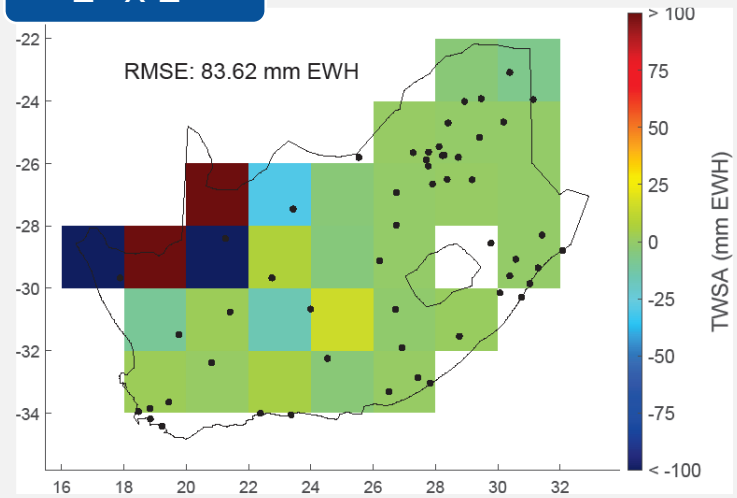
0.5° x 0.5°



1° x 1°



2° x 2°



3° x 3°