DERIVING HYDROLOGICAL DROUGHT INDICATORS BASED ON A GRACE-ASSIMILATED GLOBAL HYDROLOGICAL MODEL

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DROUGHT FACTS

- Global impacts on agriculture, society and economic losses
- 11 million people died of drought, 2 billion affected since 1900 (published 2013)
- Drought affected more people worldwide than any other natural hazard
- Danger: Slow-onset nature, lack of visible physical damage, blurred temporal boundaries

(FAO, 2013, 2017 & 2018)

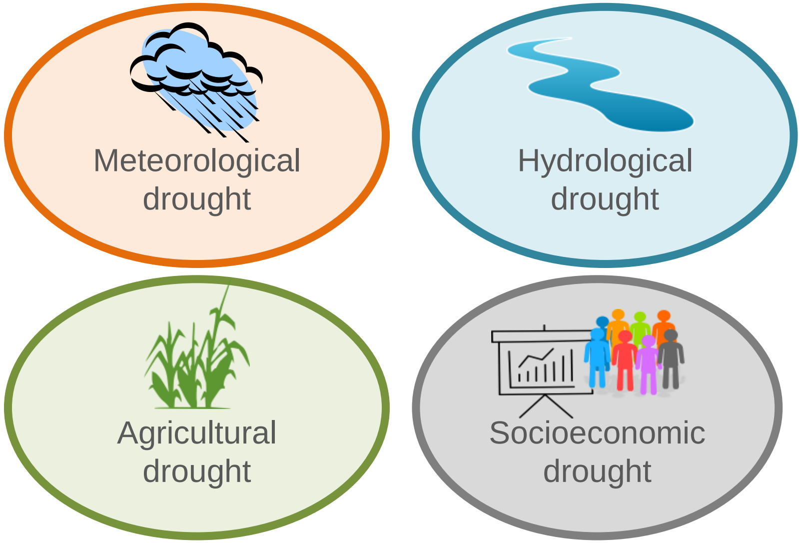


HOW TO DEFINE DROUGHT?

- Multiple definitions of drought exist in the literature
- In most cases drought is defined as deficit compared to the 'normal' and assigned with four drought types

E.g. precipitation deficit, increased temperature

Effect of precipitation deficit on surface/subsurface water, phase shift to meteorological droughts



Deficit of soil moisture, damage on biomass and crops

Imbalance of supply and demand of economic goods associate with other drought types

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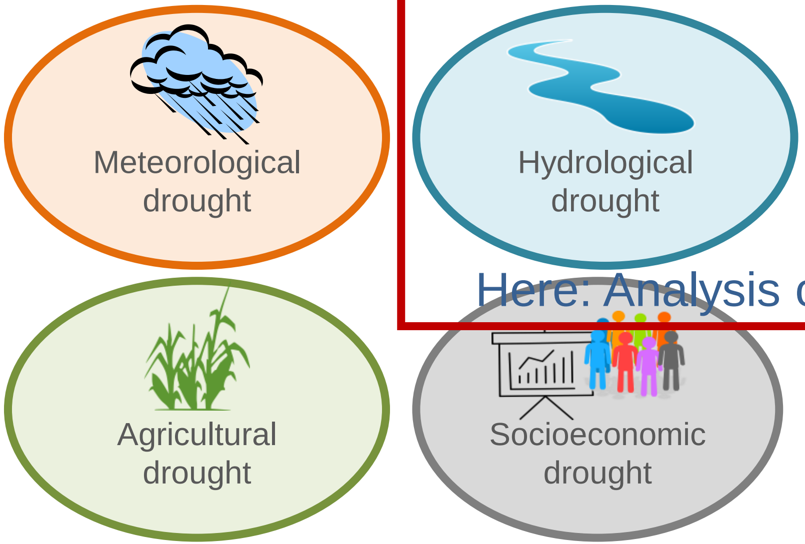
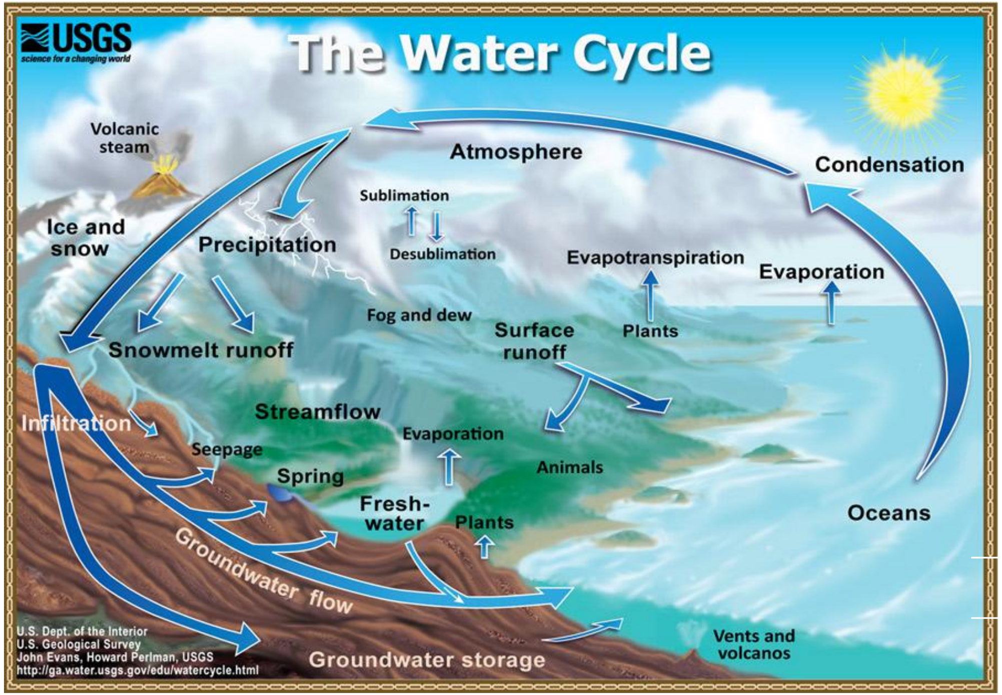


Here: Analysis of hydrological drought

Deficit of soil moisture, damage on biomass and crops

Imbalance of supply and demand of economic goods associate with other drought types

ANALYZING HYDROLGICAL DROUGHT: THE GLOBAL WATER CYCLE

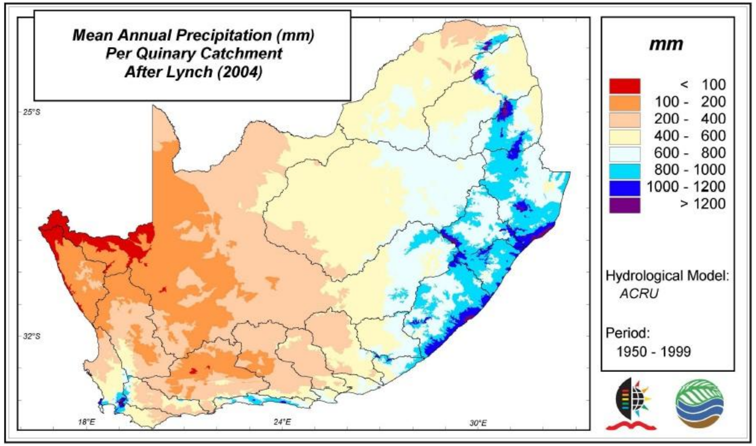


- In-situ observations are sparse
- Analyzing single storage might be insufficient for drought detection
- Opportunity: The satellite mission **GRACE** offers a great possibility to observe changes in all storages with global resolution derived as **total water storage anomalies**


Credit: NASA JPL/Caltech

CHALLENGES OF USING GRACE ONLY

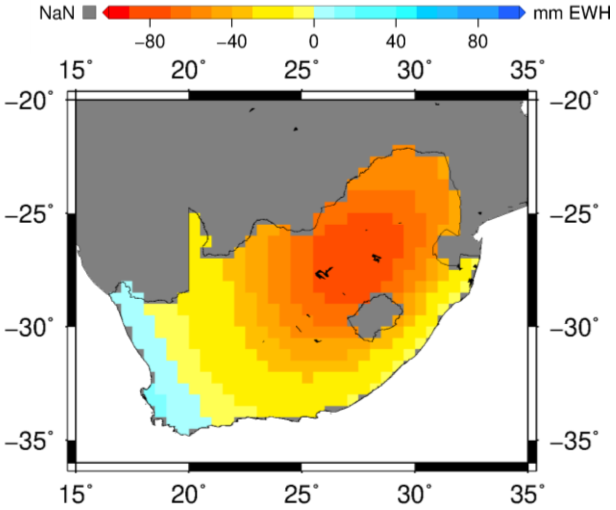
- Study region: South Africa



Credit: Schulze (2012)

- Precipitation is very local

→ drought can be local

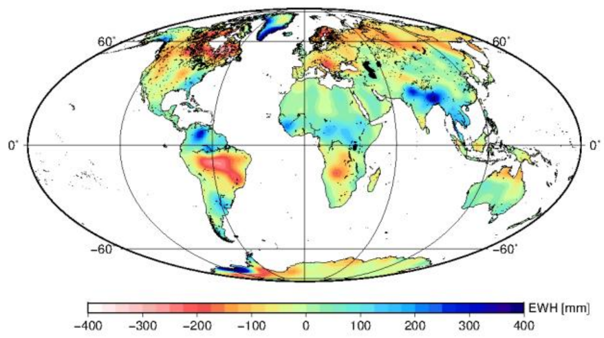


- GRACE resolution (~300 km) too coarse for use in drought monitoring and forecasting system

ADDRESS CHALLENGE:

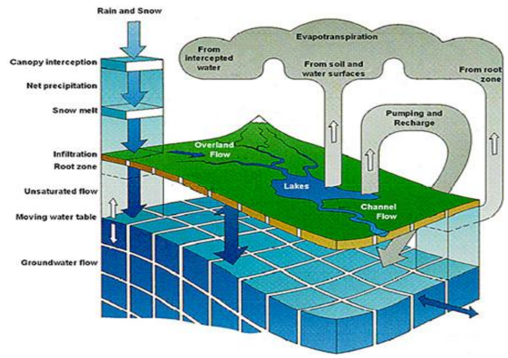
COMBINATION OF REAL OBSERVATIONS WITH MODEL OUTPUT

GRACE – Real observation

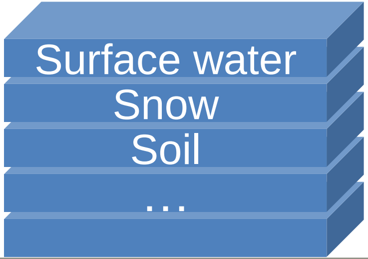


Spatial resolution ~300 km; monthly
Vertical:

WGHM – Hydrological model



Spatial resolution ~50 km; daily
Vertical:



Combine both sources to improve analysis by

Data assimilation

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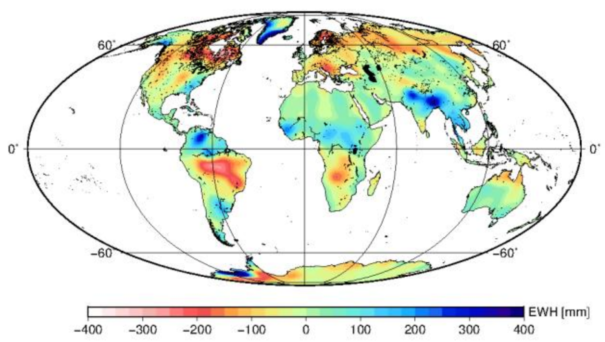
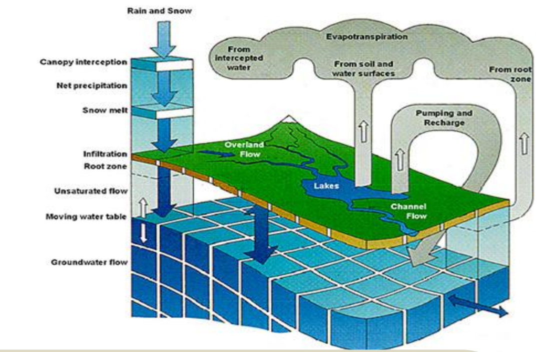


WGHM – Hydrological model



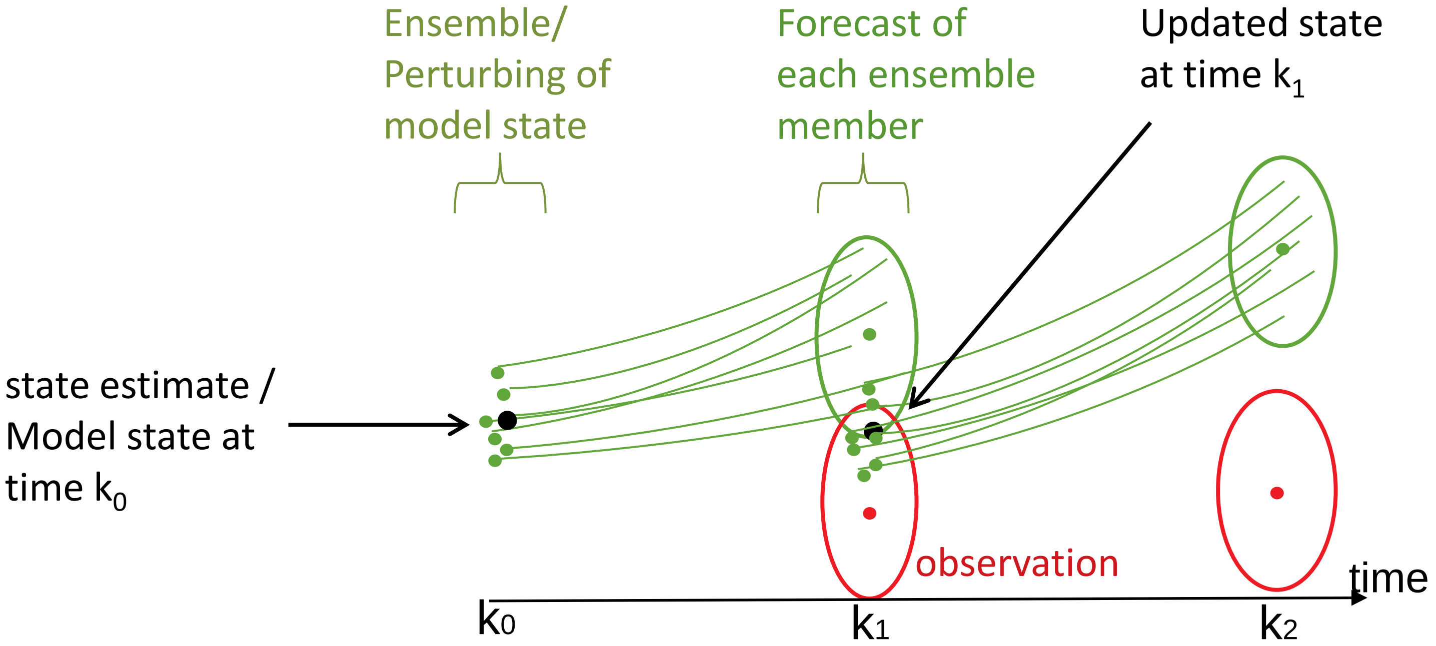
Spati
Vertic

By assimilating GRACE into WGHM …

… the model gets closer to reality
... the spatial resolution of GRACE is increased
... the vertical resolution of GRACE is increased

DATA ASSIMILATION CONCEPT

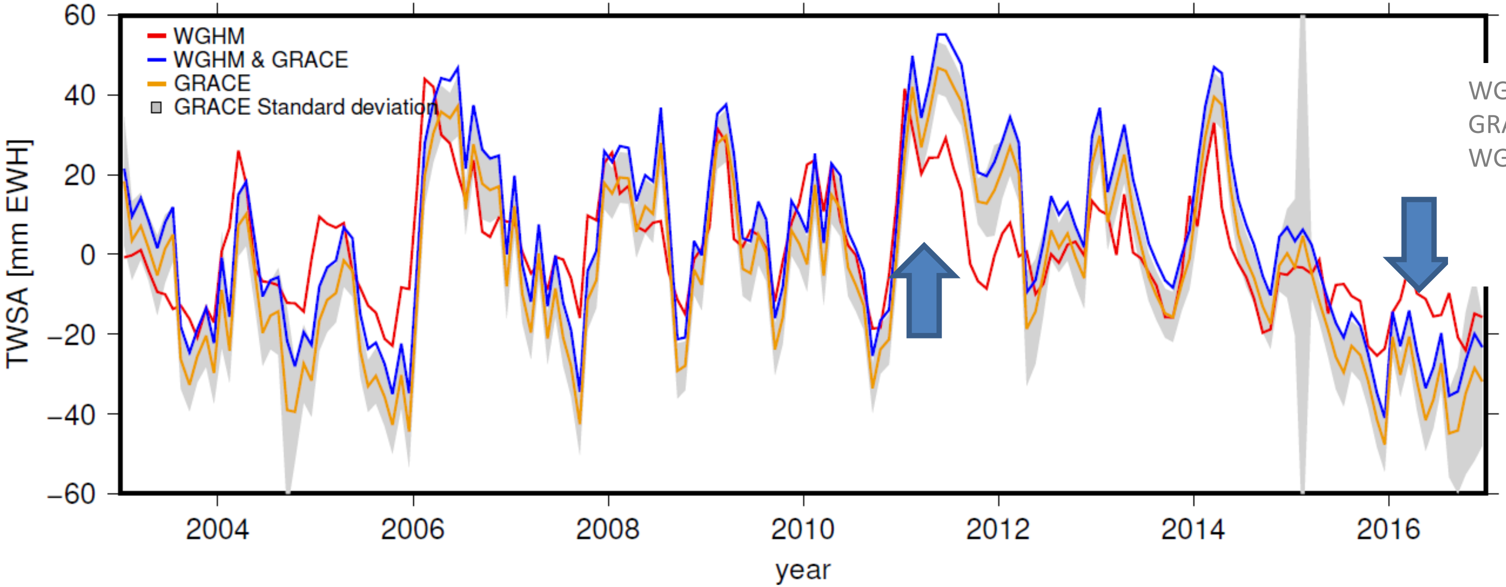
OPTIMAL STATE ESTIMATION USING ENSEMBLE-BASED KALMAN FILTER



More about EnKF: Evensen, J. Geophys. Res. (1994)

DATA ASSIMILATION **SOUTH AFRICA**: TOTAL WATER STORAGE ANOMALIES

- **Preliminary results,** shown: spatial average TWSA in South Africa derived by the model WGHM, the observations GRACE, and by assimilating GRACE into WGHM
- GRACE & WGHM drier than WGHM in 2015/2016 (and 2004/2005)
- GRACE & WGHM wetter than WGHM in 2011



WGHM = Model
GRACE = Observation
WGHM & GRACE = Observation assimilated into model

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CONCLUSION 1/2

Main points up to now:

1) Drier period in 2016 in South Africa
2) In most months, the assimilation (WGHM & GRACE) is closer to the real observations (GRACE) than the model (WGHM)

What comes next:

- How to identify droughts in South Africa?
- Usage of drought indicators for hydrological drought

DROUGHT INDICATORS

INDICATORS FOR HYDROLOGICAL DROUGHT

- Characterization (retroperspective), monitoring and triggering management plan for drought
- Describe severity, location, timing and duration of drought
- Are often categorized into severity classes to enable e.g. faster policy making
- Usually based on single fluxes (e.g. streamflow, reservoir levels)
  - Streamflow indicators are no representative indicators for lager units (e.g. countries)
- Problem: No validation of drought indicators

GRACE-BASED DROUGHT INDICATORS: TWO EXAMPLES

Basics

GRACE-based Drought Severity Indicator (DSI)

- Used in Zhao et al. (2017)
- Standardization wrt. climatology

Accumulated Drought Severity Indicator (DSIA)

- Used in Gerdener et al. (2020)
- Modification of Zhao et al. (2017) by using accumulated TWSA instead

→ Temporal smoothing, less noise

Equation

$$DSI_{i,j} = \frac{TWSA_{i,j} - \overline{TWSA_j}}{\sigma_{TWSA_j}}$$

‘Climatological’ mean of TWSA of month i over all years

‘Climatological’ standard deviation of TWSA of month j over all years

j … month, i … year

$$DSIA_{i,j} = \frac{TWSA^{+}{}_{i,j} - \overline{TWSA^{+}{}_{i}^{j}}}{\sigma_{TWSA^{+}{}_{i}^{j}}}$$

- Accumulation of TWSA over scale period

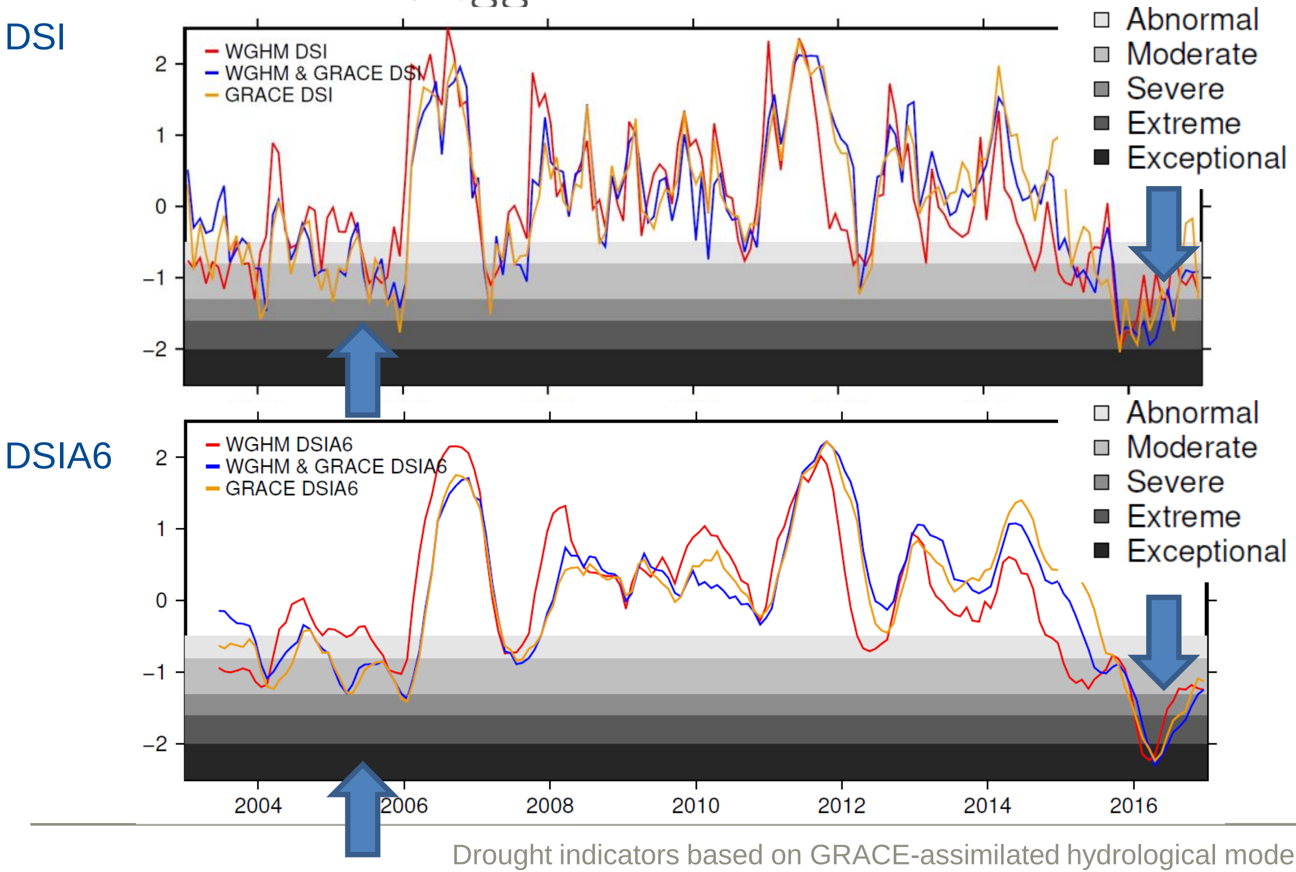
$$TWSA^{+}_{i,j,q} = \sum_{k=1}^{q} TWSA(t_{i,j+1-q})$$

q … scale period, e.g. 6 months

t … time referring to month j and year i

DATA ASSIMILATION SOUTH AFRICA:

TEMPORAL COMPARISON OF TWSA-DSI AND TWSA-DSIA6



- The assimilation (WGHM & GRACE) identifies a slightly more intense drought in 2016 than the model
- Drought in 2004/2005 more intense with WGHM & GRACE than with WGHM only
- Both indicators identify dry periods, but each indicator has its advantages and disadvantages

→ Detailed comparison of multiple indicators in Gerdener et al. (2020)

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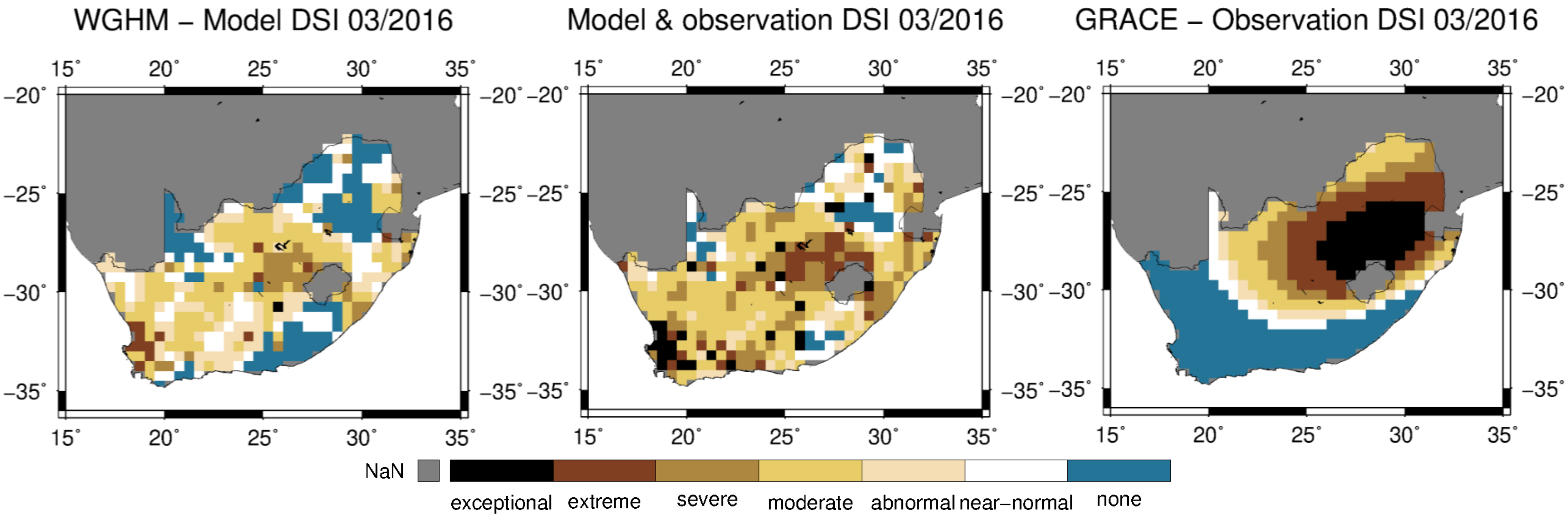
DATA ASSIMILATION SOUTH AFRICA:

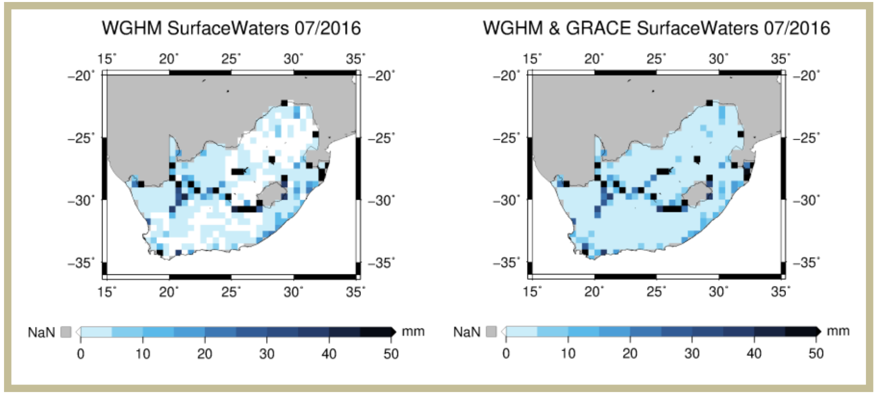
SPATIAL DOWNSCALING OF GRACE FOR THE EXAMPLE TWSA-DSI

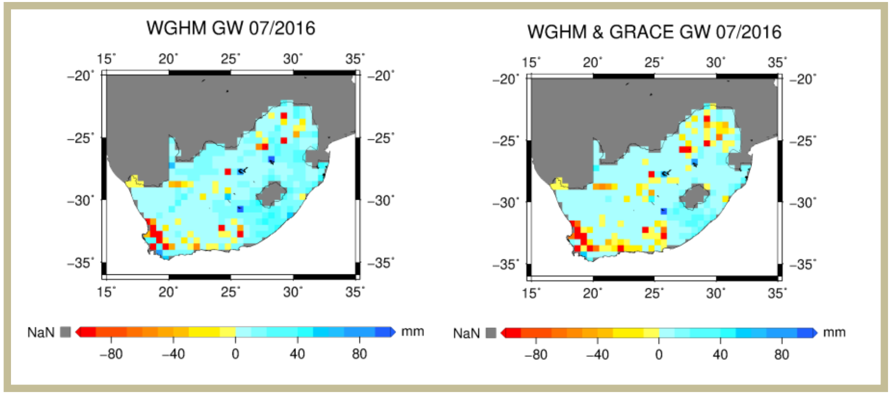


- Spatial downscaling of total water storage changes/DSI
- No 'simple' downscaling → varying spatial information
- Assimilation helps expanding knowledge of drought region
- EM DAT database: known drought event in 2016

DATA ASSIMILATION SOUTH AFRICA:

VERTICAL DOWNSCALING OF GRACE - SURFACE WATERS & GROUNDWATER





WGHM = Model
WGHM & GRACE = Observation assimilated into model

Surface waters= Global lakes, local lakes, global wetlands, local wetlands, river, reservoir

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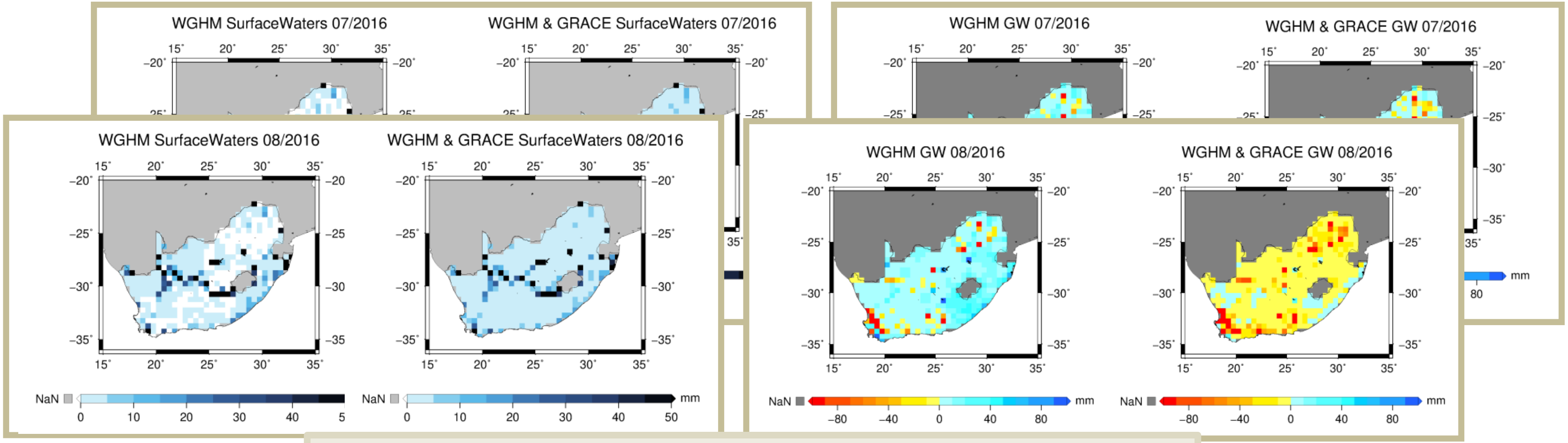

Vertical downscaling of GRACE-TWSA:

- Data assimilation enables vertical disaggregation
- Less changes in surface waters compared to groundwater
- Assimilation shows high variation in groundwater storage, e.g. in August 2016

WGHM = Model
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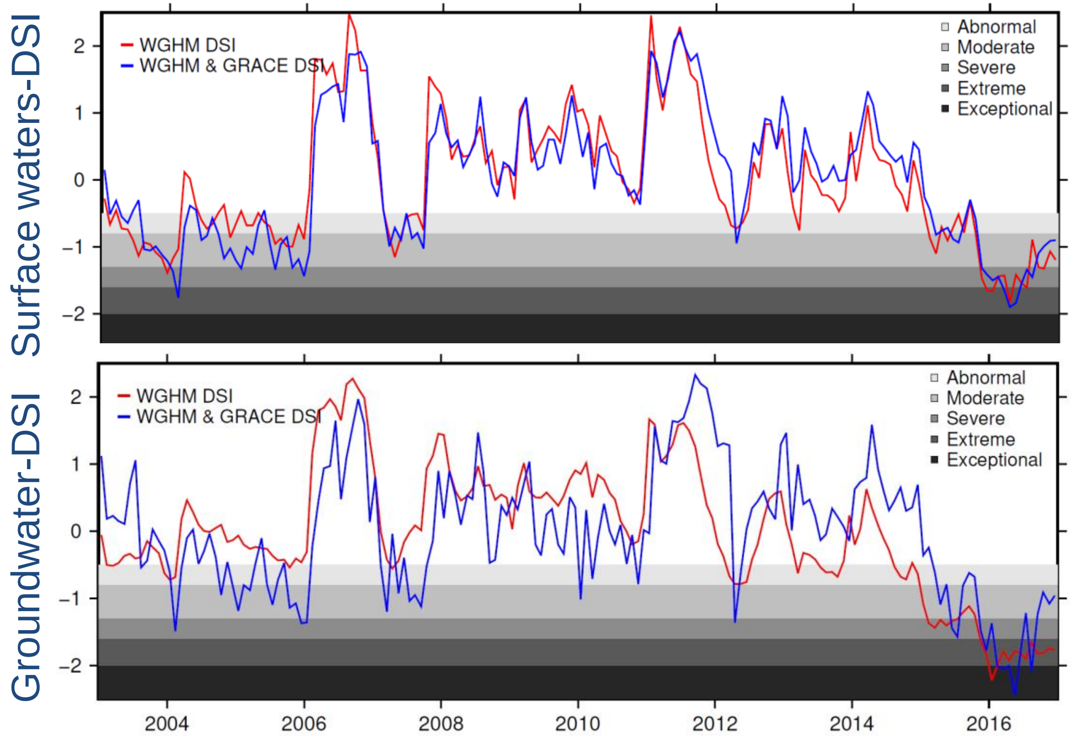
Surface waters= Global lakes, local lakes, global wetlands, local wetlands, river, reservoir

DATA ASSIMILATION SOUTH AFRICA:

IS THE DROUGHT DOMINANT IN A SPECIFIC STORAGE?



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- Applying same methodology of DSI to groundwater and surface waters
- Drought in 2015/2016 more present in groundwater storage than in surface storages

Assimilation of GRACE into WGHM allows new insights into detecting hydrological droughts

→DA improves GRACE coarse spatial resolution

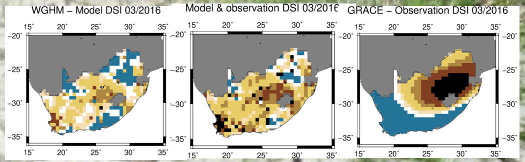
→Improves vertical resolution of GRACE for detecting, e.g. groundwater droughts

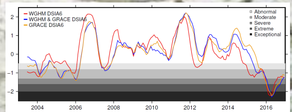
CONCLUSION 2/2 & OUTLOOK

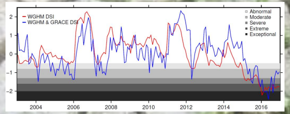
1) Assimilation enables a more realistic drought detection compared to the model, while spatially and vertically downscaling GRACE

2) Drought indicators and data assimilation facilitate identification of - and deeper insight into - droughts in South Africa

3) Identification of drought in South Africa in 2015/2016 is mainly apparent in groundwater storage





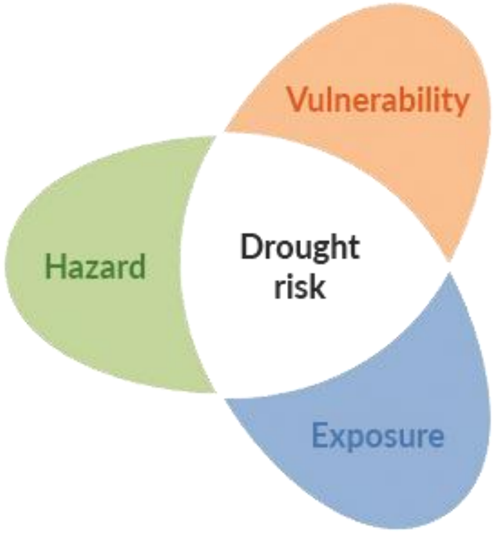


OUTLOOK:

- Validation of model and assimilation results against in-situ data
- Integration of GRACE-FO data into the framework

GLOBE DROUGHT PROJECT

- This work is part of the GlobeDrought project funded by BMBF
- Aim: Developing a web-based drought information system
- Components hazard, vulnerability, and exposure are combined to derive drought risk
- Use GRACE for considering hydrological drought, which is part of drought hazard



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