Satellite-based Estimates of Groundwater Depletion

NASA

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Groundwater Monitoring







Inadequacy of Surface Observations



Global Telecommunication System meteorological stations. Air temperature, precipitation, solar radiation, wind speed, and humidity only.



River flow observations from the Global Runoff Data Centre. Lighter circles indicate greater latency in the data record.



Eight countries make groundwater data publicly available through the Global Groundwater Monitoring Network.



USGS Groundwater Climate Response Network.

Issues include coverage gaps, delays, measurement continuity and consistency, data format and QC, political restrictions

NASA GSFC







NASA GSFC

Gravity Recovery and Climate Experiment (GRACE)



 \bullet Two identical satellites flying in tandem, near-polar orbit, ${\sim}200$ km apart, 500 km initial altitude

- Distance between satellites tracked by K-band microwave ranging system
- Launched 17 March 2002





Top: 23 year time series of snow, soil moisture, and groundwater storage in Illinois, USA (right)



TWS variations are dominated by: Soil moisture in temperate regions; Snow in polar and alpine regions; Surface water in wetlands.

GRACE Terrestrial Water Storage Anomalies, 2003-2013

Top: Monthly terrestrial water storage anomalies (equivalent height of water in cm), derived from GRACE CSR RL05 data with 300 km smoothing (unscaled), available from http://grace.jpl.nasa.gov (Landerer and Swenson, *Wat.*

Resour. Res., 2012).

Bottom: Same as top, with seasonal cycle removed.





- "Trends" in GRACE derived terrestrial water storage, 2002-2014.
- Best fit linear rate of change of TWS (cm/yr).
- Based on land hydrology product from GRACE Tellus (CSR RL05).
- Which apparent trends are real and likely to continue?





Groundwater Depletion in Northern India





GW = TWS - SM - SWE

Groundwater continues to be depleted in the Indian states of Rajasthan, Punjab, and Haryana by about 16.0 km³/yr, reduced slightly from our previous (2002-08) estimate of 17.7 \pm 4.5 km³/yr (Rodell, Velicogna, and Famiglietti, 2009).

Growth of Irrigation in Saudi Arabia



Landsat images prepared by Aries Keck, NASA/GSFC



Groundwater Depletion in Saudi Arabia





Preliminary estimate of groundwater depletion rate: 2.6 km³/yr. This includes the impact of a persistent drought in the region, as indicated by the soil water time series.



Preliminary estimate of groundwater depletion rate: 4.9 km³/yr. Estimate likely would increase if properly scaled to account for leakage.

Emerging Trends in Global Freshwater Storage

Trends in terrestrial water storage (cm/yr), including groundwater, soil water, lakes, snow, and ice, as observed by GRACE during 2003-13



GRACE observes changes in water storage caused by natural variability, climate change, and human activities such as groundwater pumping

Land Surface Models (LSMs)

prec

Water

Balance

Runof

SCHEME

LSMs solve for the interaction of energy, momentum, and mass between the surface and the atmosphere in each model element (grid cell) at each discrete time-step (~15 min) SURFACE



Input - Output = Storage Change $P + G_{in} - (Q + ET + G_{out}) = \Delta S$ $R_n - G = L_n + H$

System of physical equations: Surface energy conservation equation Surface water conservation equation Soil water flow: Richards equation **Evaporation: Penman-Monteith equation** etc.

terception Reser

Leaf Drip

Snow

Percolation

Drainage

Reflected and

Longwav

Radiation

Energy Balance

Root Laye

Recharge Lave

Longwave

Radiation

LSM Input and Output Fields

Input Parameters:

vegetation class vegetation greenness/LAI soil type elevation

Required Forcing Fields:

total precipitation convective precipitation downward shortwave radiation downward longwave radiation near surface air temperature near surface specific humidity near surface wind speed (U & V) surface pressure

Summary of Output Fields:

soil moisture in each layer snow water equivalent soil temperature in each layer surface and subsurface runoff evaporation transpiration latent, sensible, and ground heat fluxes snowmelt snowfall and rainfall net shortwave and longwave radiation



GRACE Data Assimilation for Drought Monitoring

GRACE terrestrial water storage anomalies (cm equivalent height of water) for June 2007.



New process integrates data from GRACE and other satellites to produce timely information on wetness conditions at all levels in the soil column, including groundwater. For current maps and more info, see http://www.drought.unl.edu/MonitoringTools.aspx



U.S. Drought Monitor product for 26 July 2007.



Drought indicators from GRACE data assimilation (wetness percentiles relative to the period 1948-present) for 26 June 2007.



Indicators of Drought Based on GRACE Data Assimilation





http://svs.gsfc.nasa.gov/vis/a030000/a030100/a030177/

Summary and Future Prospects

• Due to the incompleteness of ground-based observations, space-based observation of global freshwater resources is critical.

• NASA's GRACE satellite mission is unique in its ability to monitor all forms of water at all depths, including groundwater.

• Emerging trends in terrestrial water storage observed by GRACE during 2002-14 can be categorized as natural variations, climate change impacts, or direct consequences of human activities, particularly irrigation.

• The value of GRACE and other satellite data for applications such as drought monitoring can be enhanced by combining them within a land surface model.

• The GRACE Follow-On mission is scheduled to launch in August 2017.

Data, Visualization, Educational Materials



http://www.csr.utexas.edu/grace/education/ - GRACE educational materials

<u>http://gracetellus.jpl.nasa.gov/data/gracemonthlymassgridsland/</u> - GRACE data, images, and animations

http://smap.jpl.nasa.gov/ - Soil Moisture Active Passive Mission

http://trmm.gsfc.nasa.gov/ - Tropical Rainfall Measurement Mission

http://pmm.nasa.gov/GPM/ - Global Precipitation Measurement Mission

<u>http://www.pecad.fas.usda.gov/cropexplorer/global_reservoir</u> - Satellite based monitoring of lake and reservoir levels

<u>http://disc.sci.gsfc.nasa.gov/giovanni/overview/index.html</u> - Giovanni Earth science data visualization tool

http://drought.unl.edu – National Drought Mitigation Center

<u>http://wmp.gsfc.nasa.gov/international/collaborations.php</u> - NASA/GSFC Water Resources Applications Projects

<u>http://www.nasa.gov/topics/earth/features/india_water.html</u> - Feature on Indian groundwater depletion detected by GRACE