Water Resilience to Climate Change and Human Development

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24 – 26 June 2014

Sustainable Resource Development in the Himalaya
The Grand Dragon Hotel, Leh, India

Acknowledgements

- *Institute of Energy Research and Training (IERT), University of Jammu*
- *Geological Society of London*

- *Professor Richard Taylor (UCL Department of Geography)*
- *Dr. William Burgess (UCL Department of Earth Sciences)*
- *Dr. Alan MacDonald (British Geological Survey)*
- *Professor Kazi Matin Ahmed (University of Dhaka)*
- *Dr. Anwar Zahid (Bangladesh Water Development Board)*

Outline

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- Global distribution of water resources
- Freshwater use: focus on the Himalayan region
- Impacts of intensive pumping for irrigation
- Impacts of climate change on water resources
- Summary

Distribution of water on Earth

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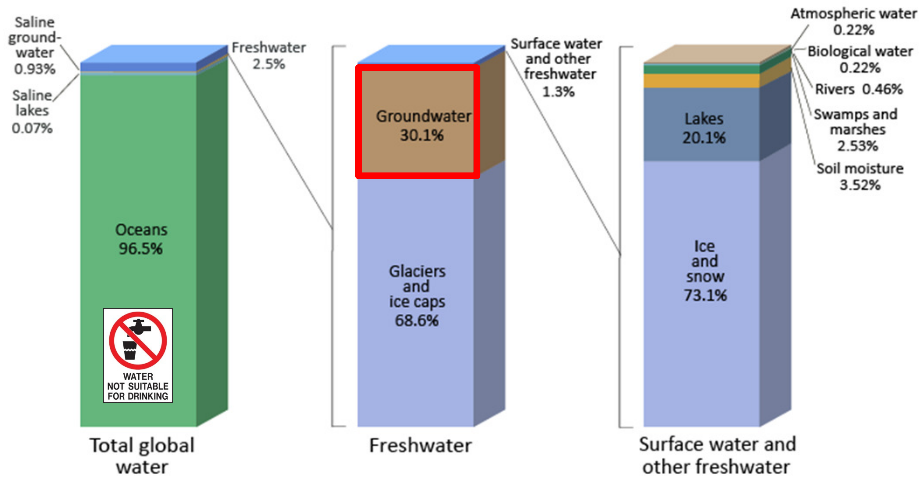
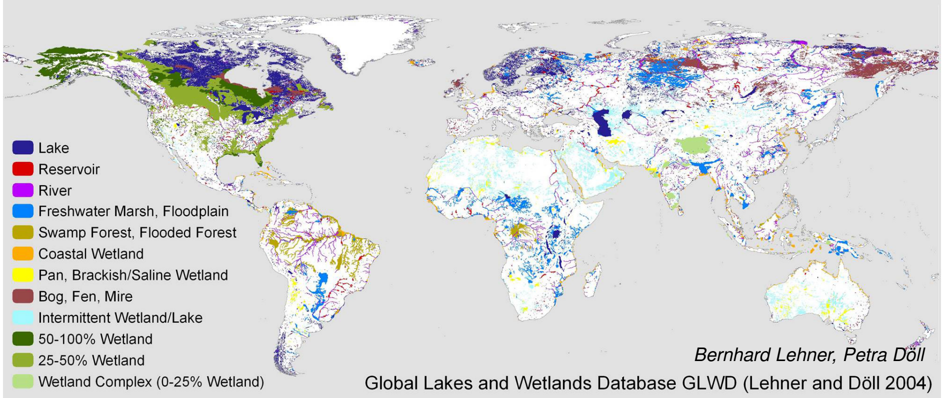


Source: Igor Shiklomanov's chapter "World fresh water resources" in Peter H. Gleick (editor), 1993, Water in Crisis: A Guide to the World's Fresh Water Resources.

Global distribution of surface water



Bernhard Lehner, Petra Döll
Global Lakes and Wetlands Database GLWD (Lehner and Döll 2004)

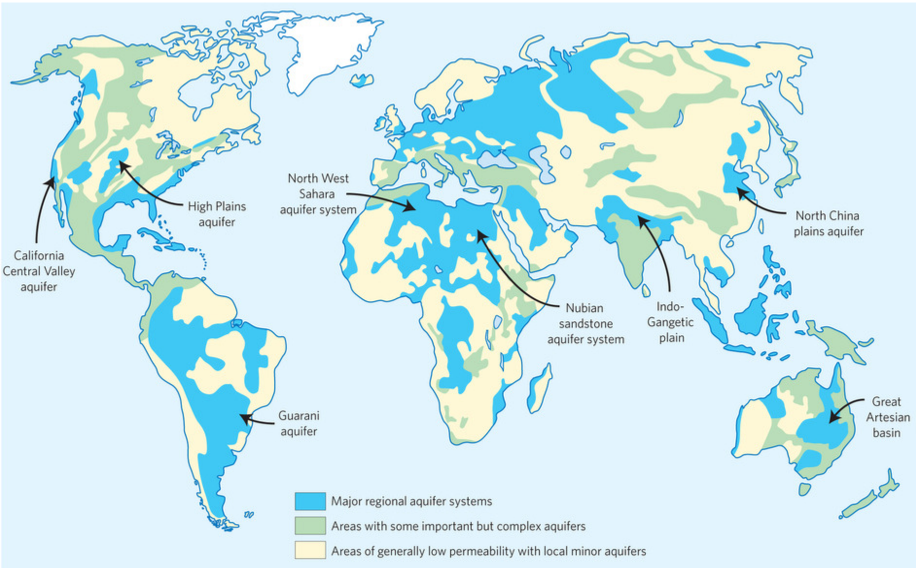
Surface water represents ~1% freshwater

Global Lakes and Wetlands Database:

- Total lakes and reservoirs: ~2.7 million km^2 (2% of total land area)
- Total lakes: 250,000 (lake area ~2.4 million km^2)
- Total rivers: 360,000 km^2 (0.3% of total land area)
- Total wetlands (including rivers): 8–10 million km^2 (6.2–7.6% of total land area)

Global distribution of groundwater

Groundwater represents ~30% freshwater



Taylor et al. (2013a), Nature Climate Change 3, 322–329

Global use of freshwater (e.g. groundwater)

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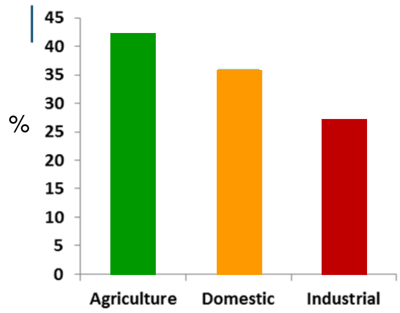
Agricultural water supply

Domestic water supply

Industrial water supply

Groundwater: 1/3[rd] of all global freshwater withdrawal



Taylor et al. (2013a), Nature Climate Change 3, 322–329

Freshwater use in the Himalayan countries

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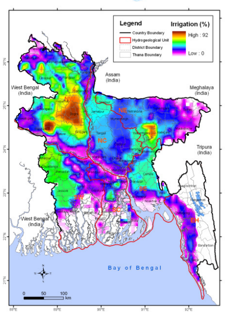
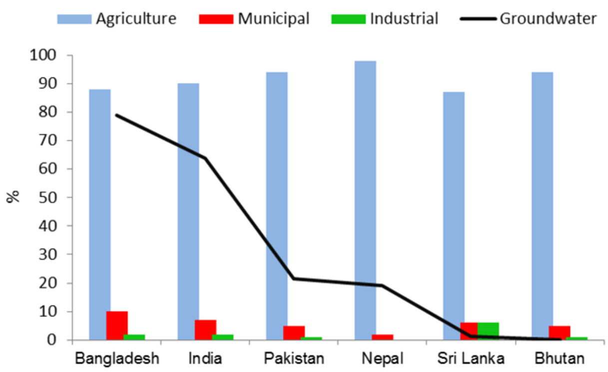
How resilient are these water supplies to climatic and anthropogenic stresses?



Bangladesh: population of 150 million

Groundwater-fed drinking water: **90%**

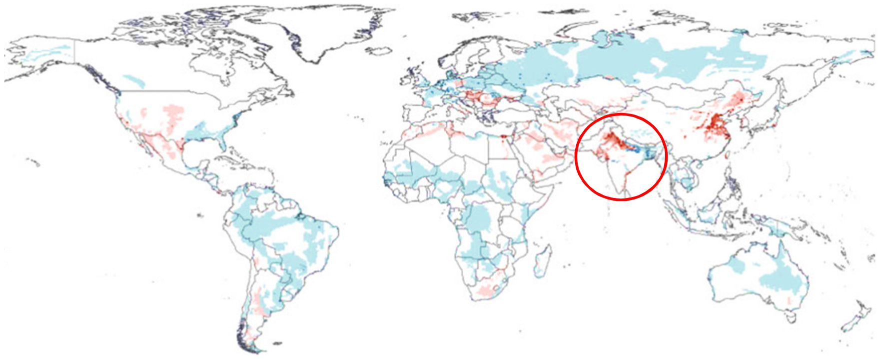
Groundwater-fed irrigation: **80%**



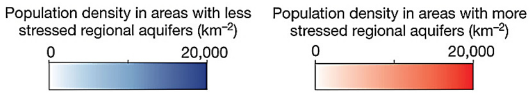
Shamsudduha (2013)

Groundwater security – global-scale stress

- Groundwater stress may be affecting ~1.7 billion people and could limit the potential to increase agricultural production



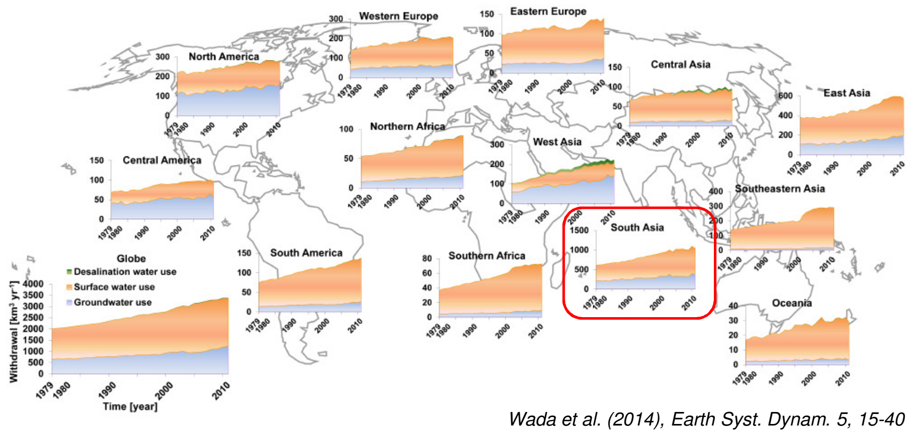
More water use and climate change will further increase these stresses



Gleeson et al. (2012) Nature 488, 197–200

Impacts of intensive pumping on freshwater

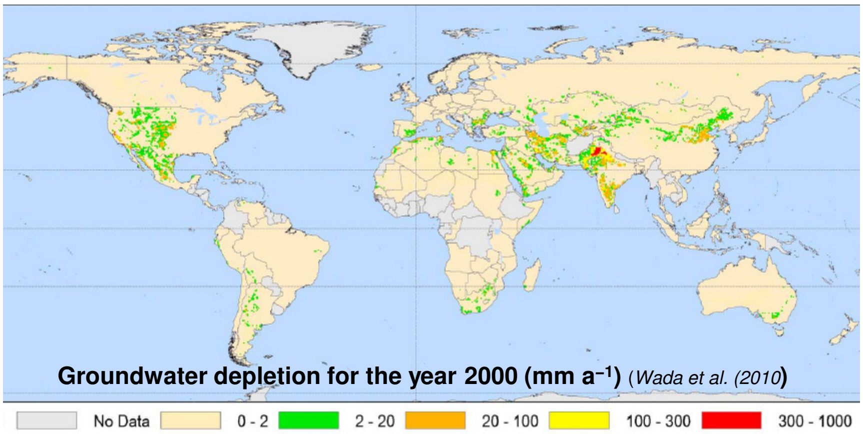
- Globally, Irrigation accounts for 70-80% of the total freshwater use
- Surface water withdrawals increased from **1,350** km^3 yr^{-1} in 1979 to **2,100** km^3 yr^{-1} in 2010 (**56% increase**)
- Groundwater withdrawals increased from **650** km^3 yr^{-1} in 1979 to **1,200** km^3 yr^{-1} in 2010 (**85% increase**)



Wada et al. (2014), Earth Syst. Dynam. 5, 15-40

Impacts of intensive pumping on groundwater

- Total global groundwater depletion increased from **126(±32) km^3 a^{-1}** in 1960 to **283(±40) km^3 a^{-1}** in 2000
- This depletion equals 39(±10)% of the global yearly groundwater abstraction, 2(±0.6)% of the global yearly groundwater recharge and a considerable amount of **0.8 (±0.1) mm a^{-1}** to current sea-level rise



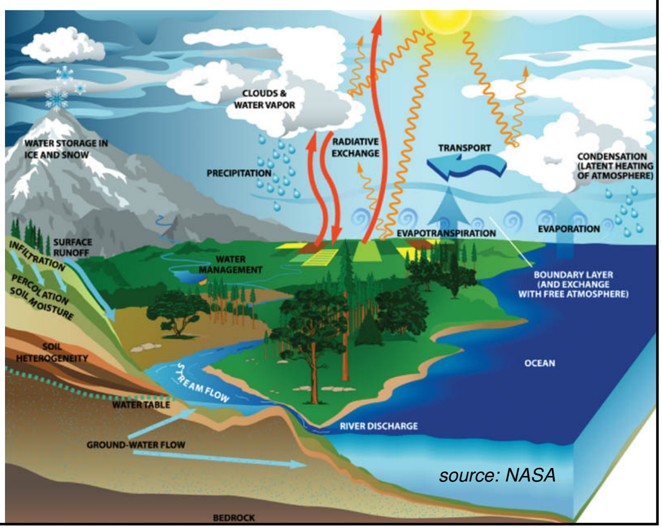
Groundwater depletion for the year 2000 (mm a^{-1}) (*Wada et al. (2010*))

Climate change: impacts on water storage

Climate change manifests itself mainly through changes in the Earth's hydrological systems

Higher Temperatures
Changing Rain and Snow Patterns
More Droughts
Warmer Oceans
Rising Sea Level
Wilder Weather
Increased Ocean Acidity
Shrinking Sea Ice
Melting Glaciers
Less Snowpack
Thawing Permafrost

US EPA (2013)

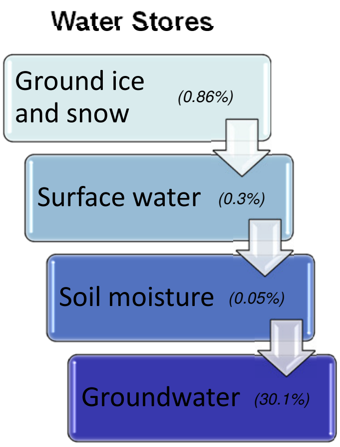


source: NASA

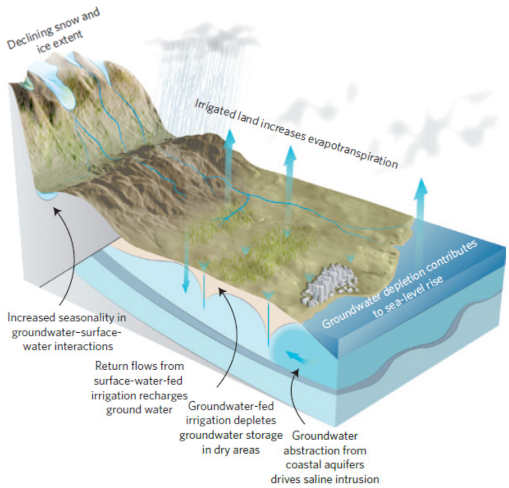
Climate change impacts on water stores

Global warming intensifies the hydrological system through:

- *Net transfer of freshwater from ice and snow*
- *Higher saturation vapour pressures that enhance precipitation and evapotranspiration*



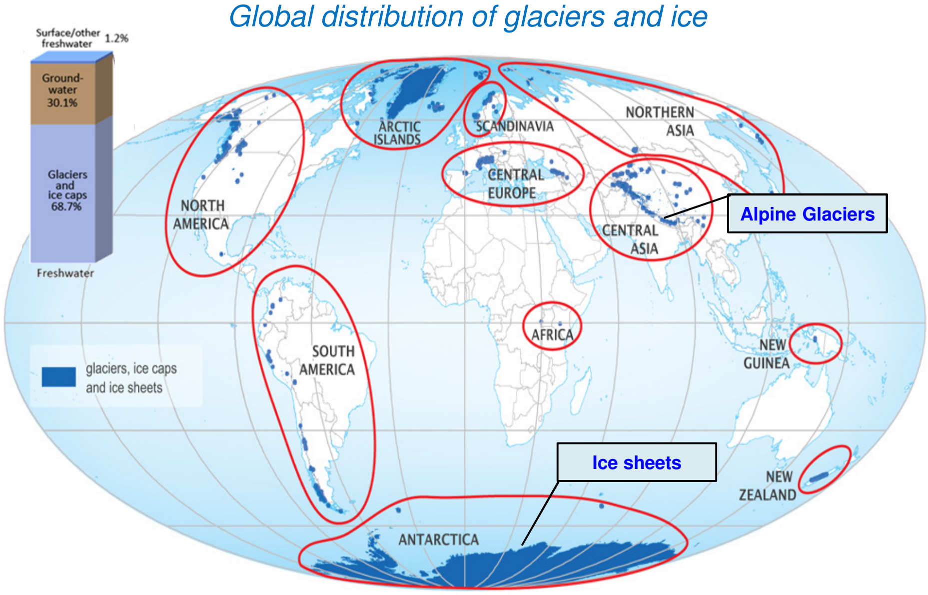
Note: % of total freshwater



Taylor et al. (2013), Nature Climate Change 3, 322–329

• *Net transfer of freshwater from ice and snow*

Global distribution of glaciers and ice

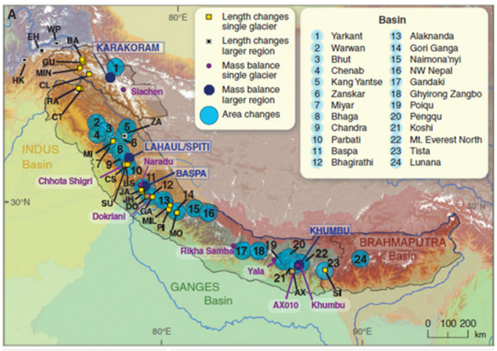


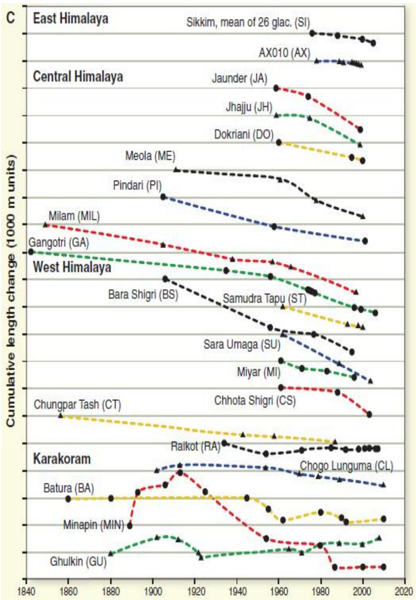
http://www.grid.unep.ch/glaciers/img/6-1.jpg

Recent alpine glacial recession in the Himalaya

	Total	Fresh
Ice sheets and glaciers	**1.74%**	**68.7%**
Antarctic ice sheet	1.62%	64.2%
Greenland ice sheet	0.17%	6.70%
Glaciers	0.02%	0.69%

http://en.wikipedia.org/

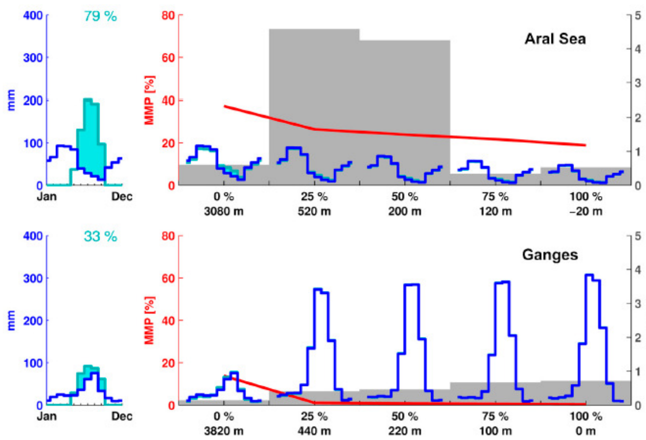




Bolch et al. (2012), Science 336, 310-314

Glacial recession and river flow

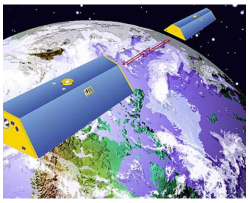
Contribution of melt-water discharges from snow and alpine glaciers to river flow is major in very dry basins, moderate in most mid-latitude basins, and minor in monsoon climates



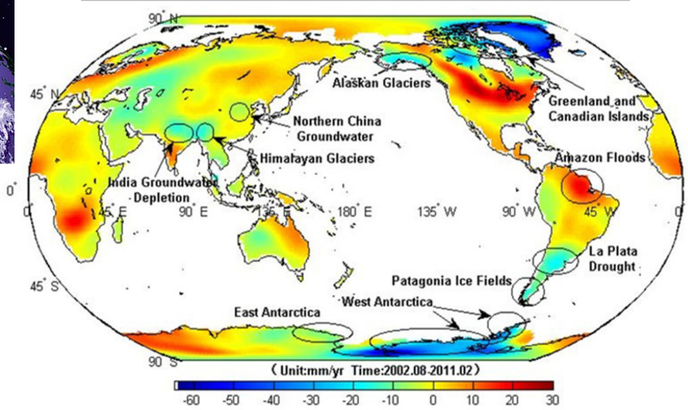
Kaser et al. (2010), PNAS 107, 20223-20227

Recent terrestrial water mass losses

Trends in terrestrial water mass anomalies from 2002 to 2011 observed by NASA's GRACE satellite mission - negative signals dominate over Greenland, Alaska and Antarctica



Trends in GRACE terrestrial water mass (2002-2011)



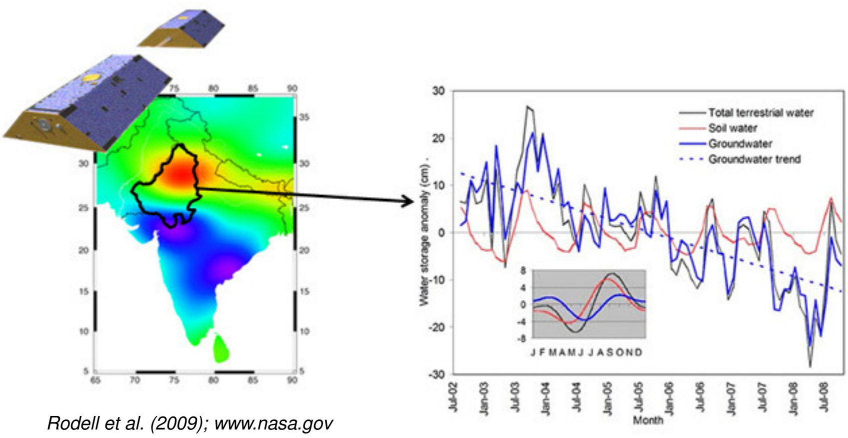
NASA's GRACE satellite mission (Gravity Recovery And Climate Experiment)

Jin and Feng (2013), Global and Planetary Change 106, 20-30

Groundwater depletion in NW India

Groundwater depletion detected from in situ and GRACE satellite data in California Central Valley, North China Plain, High Plains Aquifer, NW India and Bangladesh

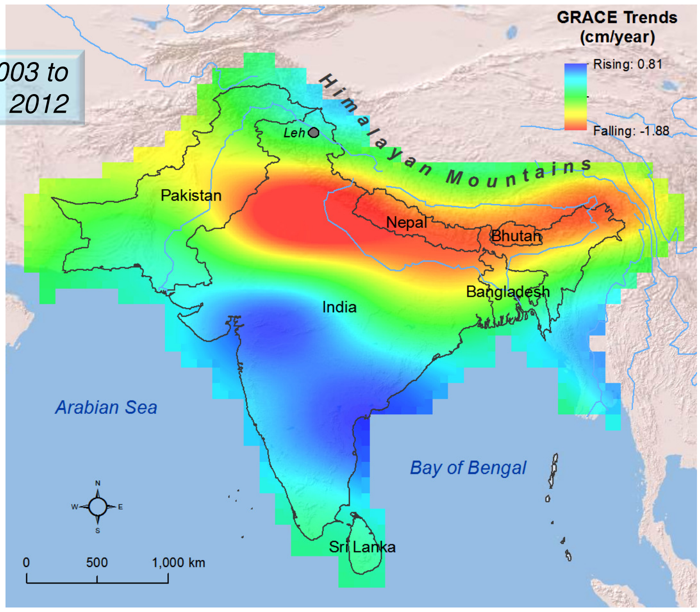
Rodell et al. (2009); Chen et al. (2010); Longuevergne et al. (2010); Famiglietti et al. (2011); Scanlon et al. (2012); Shamsudduha et al. (2012)



Rodell et al. (2009); www.nasa.gov

Recent water losses in the Himalayan region

January, 2003 to December, 2012



Contribution of GW depletion to sea-level rise

Groundwater depletion contributes to sea-level rise through a net transfer of freshwater from long-term terrestrial groundwater storage to active circulation near the earth's surface and its eventual transfer to oceanic stores

REVIEW ARTICLE NATURE CLIMATE CHANGE DOI: 10.1038/NCLIMATE1744

Table 1 | Estimates of global- and continental-scale groundwater depletion.

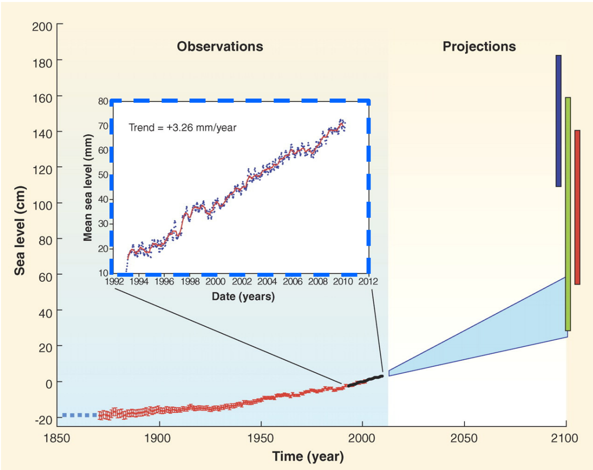
	Flux-based method[91]*		Volume-based method[92]†	
Region	Groundwater depletion	Sea-level rise	Groundwater depletion	Sea-level rise
World	204 ± 30	0.57 ± 0.09	145 ± 39	0.40 ± 0.11
Asia	150 ± 25	0.42 ± 0.07	111 ± 30	0.31 ± 0.08
Africa	5.0 ± 1.5	0.014 ± 0.004	5.5 ± 1.5	0.015 ± 0.004
North America	40 ± 10	0.11 ± 0.03	26 ± 7	0.07 ± 0.02
South America	1.5 ± 0.5	0.0042 ± 0.0014	0.9 ± 0.5	0.002 ± 0.001
Australia	0.5 ± 0.2	0.0014 ± 0.0006	0.4 ± 0.2	0.001 ± 0.0005
Europe	7 ± 2	0.02 ± 0.006	1.3 ± 0.7	0.004 ± 0.002

Flux-based and volume-based estimates of global and continental-scale groundwater depletion ($km^3 yr^{-1}$) and their contributions to global sea-level rise ($mm yr^{-1}$). *Year 2000. †Period between 2001 and 2008.

Taylor et al. (2013a), Nature Climate Change 3, 322–329

Trends in global sea levels – overall rise

Recent increase in the mean rate of sea-level rise, 3.3 mm/year, relative to 20th C average:1.7 mm/year

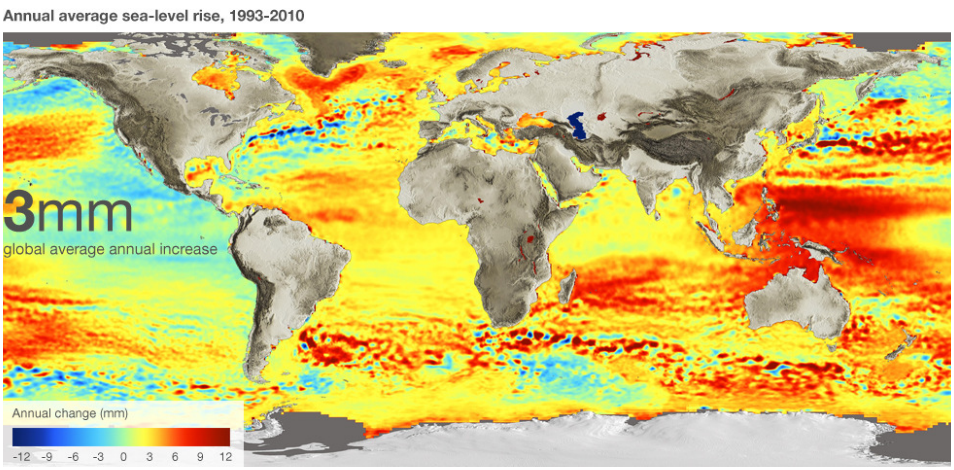


- *Red curve - tidal gauge record*
- *Black curve - altimetry record*
- *Shaded light blue zone - IPCC AR4 projections for the A1FI scenario*
- *Blue, green & red bars - semi-empirical projections (various studies)*

Nicholls and Casenave (2010), Science, vol. 328, 1517-1520

Spatial variations in global sea levels

Substantial variations in global sea levels derived from satellite altimetry data – vulnerable coastal ecosystems



Data source: National Centre for Space Studies (CNES) at http://www.aviso.oceanobs.com/

• *Higher vapour pressure enhances precipitation*

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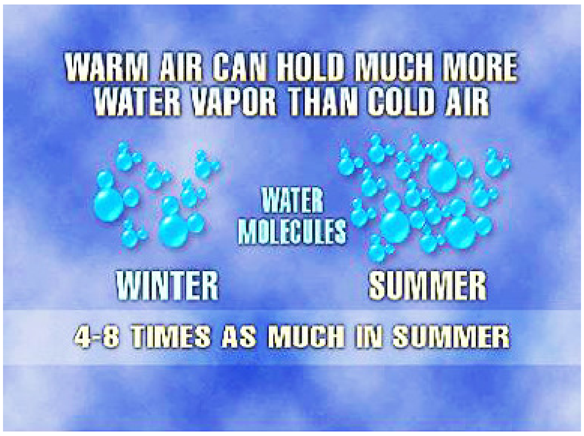
Warmer air holds more moisture…



The increased moisture in the atmosphere is driving the shift to heavier but less frequent rains — "when it rains, it pours."

www.cksimpsonwx.blogspot.co.uk/ and www.climatecommunication.org/

Theoretical basis for the intensification of rainfall

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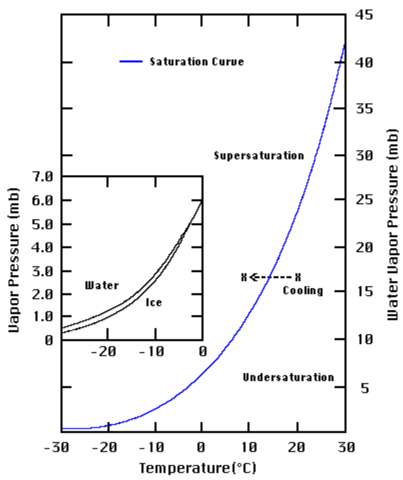
1. Warmer air holds more water
   – *amount rises exponentially with temperature*
   4.5 g·m^{-3} @ 0℃
   30 g·m^{-3} @ 30℃
2. Heavy rainfalls tend to deplete the available moisture in air

As air temperature rises in the tropics it leads to greater increases in water-holding capacity so in the tropics intensification of rainfall is projected to be greatest under a warmer climate

Clausius-Clapeyron relation

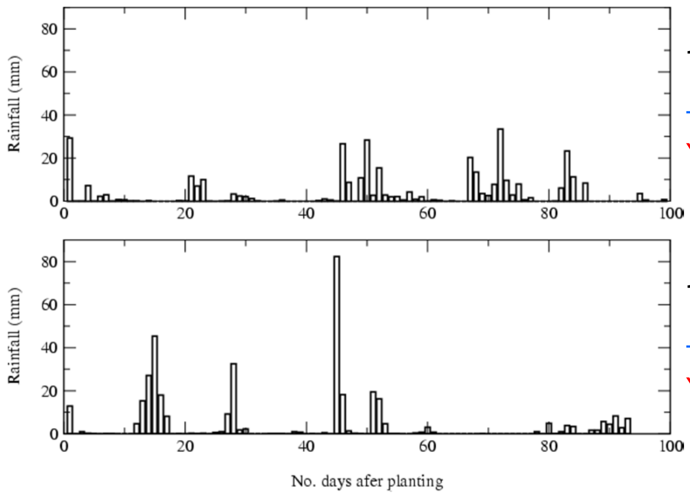
The vapor pressure of ice and water between -30° and 30° (mb = millibar). (Berner and Berner 1987)



Negative effect of rainfall intensity on crop

More variable precipitation (soil moisture) reduces crop yields

Example: groundnut crop in Andhra Pradesh (India)



1975:

Total rainfall: 394 mm

Yield = 1360 kg/ha

1981:

Total rainfall: 389 mm

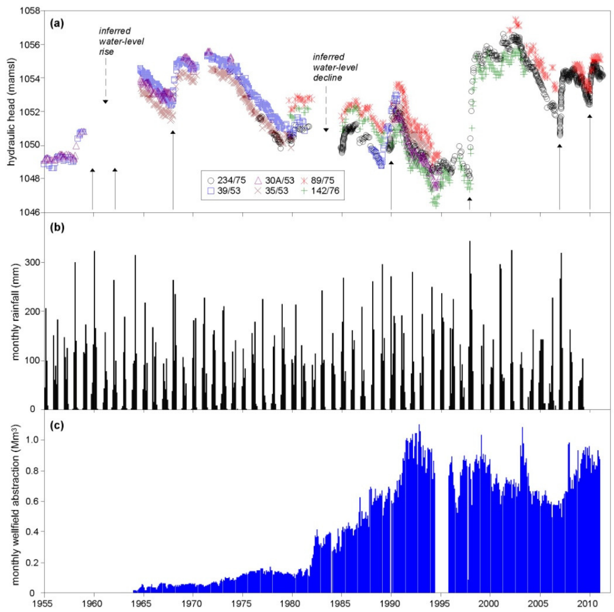
Yield = 901 kg/ha

Challinor et al. (2006), "Avoiding Dangerous Climate Change", 187-194

Positive effect of rainfall intensity on groundwater

Longest, observed record of groundwater levels in the tropics:

Makutapora well field in Tanzania

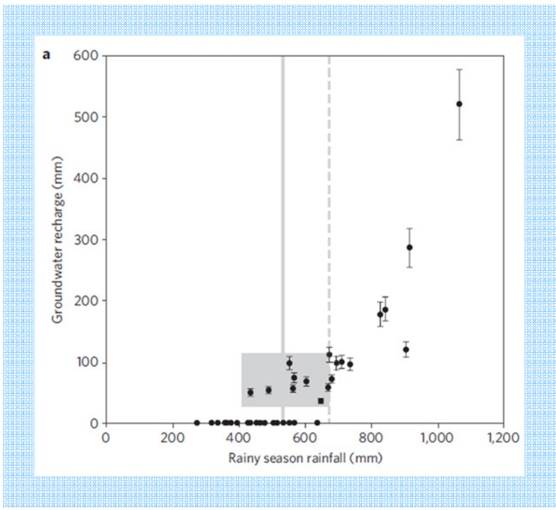


Taylor et al. (2013b), Nature Climate Change 3, 374-378

Positive effect of rainfall intensity on groundwater

Groundwater recharge results disproportionately from very intense, extreme seasonal rainfalls

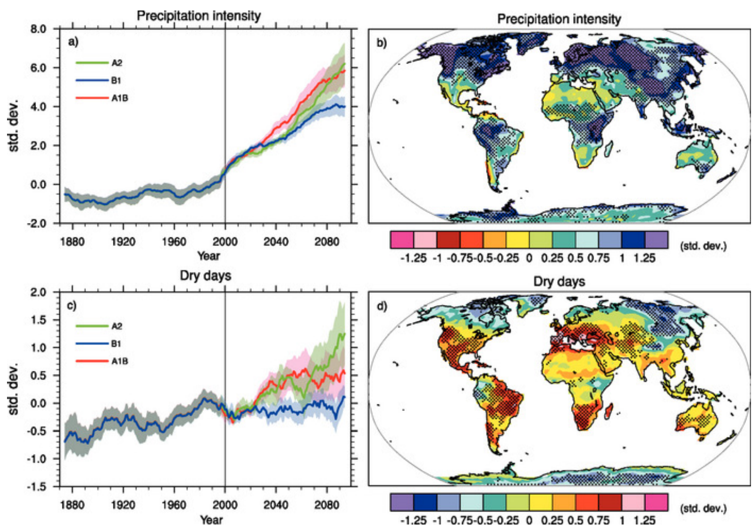
http://berkeley.edu/



Taylor et al. (2013b), Nature Climate Change 3, 374-378

Projected changes in precipitation intensity

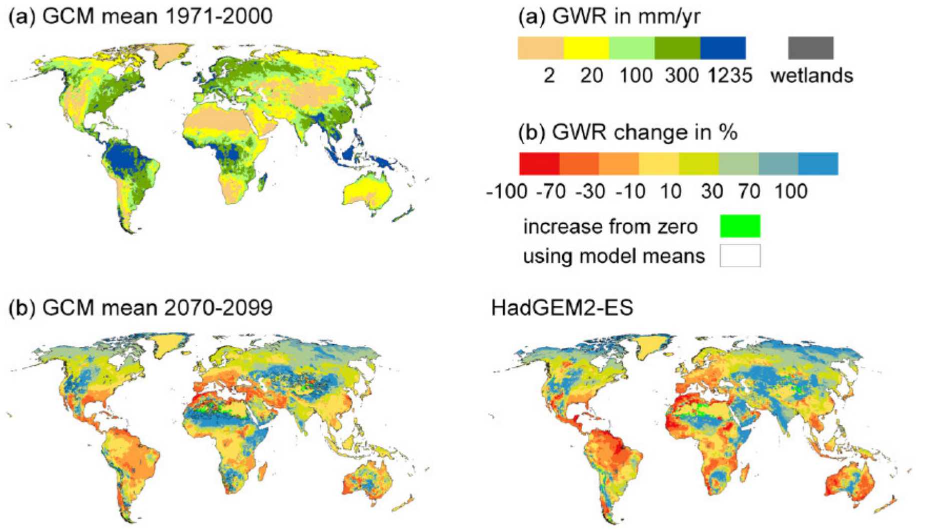
More variable & intensive rainfall – widespread signal



IPCC AR4 (2007)

Climate change and groundwater recharge

IPCC 5th AR - Coupled Model Intercomparison Project (CMIP5), RCP 8.5



Debate on focused versus diffuse recharge

Portmann et al. (2013), Environ. Res. Lett. 8, 024023

Summary:

1. Groundwater is the largest store of global freshwater (30.1%); groundwater contributes 1/3rd of all freshwater withdrawal; groundwater use in South Asia is high
2. Global water withdrawal increased by more than 60% from 2000 $km^3\ yr^{-1}$ in 1979 to 3300 $km^3\ yr^{-1}$ in 2010
3. Climate change and variability will affect the global distribution of freshwater stores, particularly in the Himalaya
4. Groundwater recharge results disproportionately from very intense, extreme seasonal rainfalls in the tropics
5. Groundwater depletion from land has contributed to the global sea-level rise in recent time (global average: 0.4 to 0.57 m depending on the methods applied)