Manifestations of global climate change on accelerating the hydrological cycle:

Prospects for increases in extremes

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The presence of moisture affects the disposition of incoming solar radiation: Evaporation (drying) versus temperature increase.

Human body: sweats

Homes: Evaporative coolers (swamp coolers)

Planet Earth: Evaporation (if moisture available)
How should rainfall change as climate changes?

Usually only total **amount** is considered
- But most of the time it does not rain
- The **frequency and duration** (how often)
- The **intensity** (the rate when it does rain)
- The **sequence**
- The **phase**: snow or rain

The intensity and phase affect how much runs off versus how much soaks into the soils.

**Need at least hourly data.**
**Most analysis is of monthly means or at best daily means.**
Daily Precipitation at 2 stations

A

1  6  11  16  21  26

Drought  Wild fires  Local
Wilting plants  Floods

Amount: 75 mm
Frequency: 6.7%
Intensity: 37.5 mm

B

1  6  11  16  21  26

Soil moisture replenished
Virtually no runoff

Amount: 75 mm
Frequency: 67%
Intensity: 3.75 mm
**Why does it rain?**

If a parcel of air rises: it expands in the lower air pressure and cools, and therefore may condense moisture, producing a cloud, and ultimately rainfall or snowfall.

**Ingredients:**

1. **A storm of some sort to produce rising air (or orographic uplift):**
   - storm tracks, etc
2. **Microphysics of cloud droplets that matter for condensation and formation of droplets:**
   - affected by pollution
3. **Moisture**
Aerosols have multiple effects:

1. **Direct** - cooling
   - from sulfate aerosol:
     - milky white haze, reflects

2. **Direct** - absorbing
   - e.g. black carbon

3. **Indirect** - changes cloud
   1. Form cloud condensation nuclei, more droplets, brighter cloud;
   2. Less rain, longer lasting cloud;
   3. Absorption in cloud heats and burns off cloud
   4. Less radiation at surface means less evaporation and less cloud

**Lifetime only a week or so:** Very regional in effects

**Profound effects at surface:**
Short-circuits hydrological cycle

Ramanathan et al 2001
Why does it rain: where does the water come from?

Mean water amount (as water vapor) in atmosphere in mid-latitudes is 25 mm; but not all of this can be rained out: maybe 30% \( \Rightarrow \) 7.5 mm. Most of time it does not rain or snow.

So most of the water that rains out comes from winds that transport moisture into the rain region. On average, rain producing systems (e.g., extratropical cyclones; thunderstorms) reach out and grab moisture from distance about 3 to 5 times radius of precipitating area.
Extratropical Storms

Winds converging into the low, pull cold air from the poles toward the equator, and warm moist air from the subtropics to the poles.

Where they meet is where we find fronts, bringing widespread precipitation and significant weather, like thunderstorms.

Source: USA TODAY research by Chad Palmer, Graphic by Chuck Rose
Estimated frequency of occurrence (%) of non-drizzle precipitation either at time of observation or in the past hour from synops for December-January-February (left) and June-July-August (right). From Dai (2001).
Estimate of the annual mean recycling ratio of the percentage precipitation coming from evaporation within a length scale of 1000 km (adapted from Trenberth 1999).

For 500 km scales, global recycling is 10%. Mississippi basin: total area 21%: 500 km scales: annual 6.6%; 3.1% in DJF, 9.3% in JJA.
Water Holding Capacity

A basic physical law (the Clausius-Clapeyron equation) tells us that the water holding capacity of the atmosphere goes up at about 7% per degree Celsius increase in temperature.

This means that it rains harder (by about this amount) in warmer conditions owing to more moisture laying around to be gathered up.

It also means a greater delay between storms as the moisture is recharged:

Prospects for heavier but farther-between rain events: a recipe for drought and floods in different locations.
Global warming

Heating ↑

Temperature ↑ & Evaporation ↑

Water holding capacity ↑

Atmospheric moisture ↑

greenhouse effect ↑ & rain intensity ↑

Floods & Droughts
USA regional changes in surface humidity 1961-95

From Gaffen and Ross J. Clim 1999
Trends in annual mean surface water vapor pressure, 1975 to 1995, %. Blue areas have significant increasing trends and brown areas have significant decreasing trends, at 5% significance level. From New et al. (2000) and IPCC (2001).
Trends in atmospheric moisture 1973-93

From Ross and Elliot 1996
Best estimate of linear trends

0.41 mm/decade over global oceans
Much of the pattern of trend relates to changes in SST: 7% K\(^{-1}\). Precipitation and moisture convergence also important.
Trend (%/century) in Annual Precipitation
1900 - 1999
Changes in total, heavy, and very heavy precipitation over contiguous U.S.
Trends are up and significant at 1%: 7, 14, 20%/century

Linear trends %/100yrs over 2.5x3.5 grid 1900-2002
Groisman et al 2004
% Change per century in:
Intensity of precipitation

Light

Percentiles

Heavy
Percent of total seasonal precipitation for stations with $230\text{mm}\pm5\text{mm}$ falling into 10mm daily intervals based on seasonal mean temperature. Blue bar -3°C to 19°C, pink bar 19°C to 29°C, dark red bar 29°C to 35°C, based on 51, 37 and 12 stations.

As temperatures and $e_s$ increase, more precipitation falls in heavy (over 40mm/day) to extreme (over 100mm/day) daily amounts.

Karl and Trenberth 2003
Flood damages:

1. Local and national authorities work to prevent floods (e.g., Corp of Engineers, Bureau of Reclamation, Councils)
   - Build ditches, culverts, drains, levees
   - Can backfire!

2. Deforestation in many countries:
   - Leads to faster runoff, exacerbates flooding

3. Increased vulnerability to flooding through settling in flood plains and coastal regions
   - Increases losses.

Flooding statistics NOT useful for determining weather part of flooding!
Drought:

3 kinds of drought

1. Meteorological: absence of rain
2. Agricultural: absence of soil moisture
3. Hydrological: absence of water in rivers, lakes and reservoirs
Leading Modes of PDSI Variations

Trend

PC 1, 6.1% Temporal Patterns

PC 2, 4.9%, Darwin SLP (red) leads by 4 mon.

ENSO

$ r = 0.72$

Precipitation is dominant contributor

Warming contributes to increased drought

Dai et al 2004

J Hydromet
The Drought Monitor focuses on broad-scale conditions. Local conditions may vary. See accompanying text summary for forecast statements.

http://drought.unl.edu/dm
Observed changes in the timing of runoff from snow melt (center of mass of flow CT) in days for the 1948‐2000. Larger circles indicate statistically significant trends at the 90% confidence level.

From Stewart et al 2004 Climatic Change
20-year averages of PCM projected changes in runoff from snow melt [days] compared to average from 1951-80.

SNOW PACK: In Colorado, as in many mountain areas, global warming contributes to:

- more precipitation falls as rain rather than snow, especially in the fall and spring.
- snow melt occurs faster and sooner in the spring.
- snow pack is therefore less as summer arrives.
- soil moisture is less, and recycling is less.
- global warming means more drying and heat stress.
- the risk of drought increases substantially in summer.
- along with heat waves and wildfires.

The summer of 2002 may be a taste of what we will see much more of in the future?
Climate changes in both rainfall and temperature should be considered together. “It’s not the heat it’s the humidity!” Comfort depends upon both.

Water serves as the “air conditioner” of the planet.

There appear to be prospects for increases in extremes: More floods and droughts: both have adverse impacts.

Or more generally: changes are bigger in frequency and intensity, than amount.

Water management will be a key issue: How to save excesses in floods for times of drought?