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The changing water cycle

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Overview

- Water vapour is the main component of the Earth's natural greenhouse effect, which keeps the surface of the planet about 33°C warmer than it would be otherwise.
- The availability of water is critical for agriculture and is one of the greatest pressures on freshwater resources. Extremes in precipitation – either high or low – can be hugely damaging.
- With climate change, warming of the lowest part of the atmosphere allows the maximum level of water vapour there to increase. This in turn acts to amplify the greenhouse gas warming, as does the melting of ice and snow in a warmer climate.
- The net impact of warming on clouds depends on many detailed aspects of changes to the atmospheric circulation and has so far been one of the main uncertainties in projections of climate change. The IPCC's Fifth assessment Report (AR5) says that the feedback from clouds is likely to be positive.
- Global precipitation is expected to increase as the climate warms, perhaps by between 1-3 per cent per degree Celsius of warming. The contrast in precipitation between wet and dry regions and between wet and dry seasons will increase, although there may be regional exceptions.
- Globally for short-duration events, AR5 expects a shift to more intense individual storms and fewer weak storms as temperatures increase. Extreme precipitation events over land will very likely be more intense and more frequent.
- Regional to global-scale decreases in soil moisture and increased risk of drought in presently dry regions are expected by the end of the century in a high emissions scenario. Soil moisture drying would likely be most prominent in the Mediterranean, Southwest US and southern African regions.
- Monsoons are likely to affect greater areas and the monsoon season is likely to lengthen in many regions, with a likely intensification of monsoon precipitation.

Role of water in the climate system

Water is critical in keeping Earth habitable, quite apart from the direct role it plays in living organisms. Its ability to exist in all three phases of matter – liquid, gas or vapour and solid (snow and ice) – means that its effects on the climate system are far-reaching and diverse. Water vapour is the main component of the Earth's natural greenhouse effect, which keeps the surface of the

planet about 33°C warmer than it would otherwise be.

It takes energy to evaporate water from the liquid state. As temperature increases, more water vapour is evaporated from liquid water surfaces; on Earth, this is overwhelmingly from the ocean. The maximum amount (technically the saturated partial pressure) of water vapour in the atmosphere also increases by about 7 per cent more for every degree of warming in typical atmospheric conditions. This means a 50 per cent increase in water vapour for a 6°C rise in temperature. The relative humidity of the atmosphere - a measure of the actual amount of water compared to its saturated level - affects cloud formation at higher, cooler levels of the atmosphere and therefore precipitation which occurs when the condensed water droplets become large enough. The relative humidity varies depending on the large-scale atmospheric circulation.

Important movements of latent energy in the climate system occur through the transport of water vapour by the wind, this energy being released when condensation occurs. The transport of latent energy towards the poles helps reduce the temperature contrast between the equator and the polar regions. It also provides much of the moisture for the higher latitudes. The dynamical balance of the atmosphere leads to a tropical circulation with deep convection and heavy precipitation close to the equator and dry subtropical regions, where relatively dry air from high in the atmosphere descends to the lower atmosphere. Latent heat is also the engine for tropical cyclones and is important for mid-latitude cyclones.

Clouds have ambiguous effects on the Earth's energy balance depending on the relative magnitude of two opposing effects: they increase the amount of sunlight reflected back into space (tending to cool the surface) and they enhance the trapping of infrared radiation reflected back from the Earth's surface (producing a warming tendency). For high clouds, the positive feedback usually wins, whereas for low clouds, the negative feedback tends to dominate, moderating the warming effect.

Snow and ice are very good reflectors of sunlight and therefore have a cooling effect on the climate by reducing the amount of the Sun's energy absorbed by the Earth.

Role of water in the impacts of weather and climate

The availability of water is critical for agriculture and constitutes one of the greatest pressures on freshwater resources. Irrigated agriculture, which represents 20 per cent of the total cultivated land and around 70 per cent of global freshwater withdrawals, produces 40 per cent of the world's food.

Extremes in precipitation – either high or low – can be hugely damaging for both agriculture and the rest of the economy, including through loss of life. Extreme rainfall and flooding in the Himalayas during the 2013 Indian Monsoon is thought to have resulted in the deaths of several thousand people. The year-long US Midwest/Plains drought in 2012 was estimated to have cost US\$35 billion and resulted in 123 deaths as estimated by US reinsurance firm, Aon Benfield.

Importance of water-related changes in a changing climate

With climate change, the lower troposphere warms and this warmer environment allows the maximum level of water vapour in this part of the atmosphere to increase. This in turn acts to amplify the warming due to greenhouse gases. The net impact of warming on clouds is expected to depend on many detailed aspects of changes to the atmospheric circulation and has so far been one of the main uncertainties in climate modelling. Melting of ice and snow in a warmer climate

reduces the reflectivity of the Earth's surface, allowing more of the Sun's energy to be absorbed and amplifying the temperature response.

Global precipitation is expected to increase but by a smaller amount than water vapour in the atmosphere as the climate warms, perhaps by about 2 per cent per degree Celsius. When it rains, the episodes are expected to be more intense with an increased risk of floods. The sub-tropics are expected to dry while the tropics are expected to become wetter in a warmer climate due to changes in tropical circulation.

Poleward transport of latent energy by the atmosphere is expected to increase as the planet warms and the air becomes moister. Consistent with this, high latitudes are also expected to become wetter because of warming. Reductions in sea ice extent and thickness will affect the transfer of energy and moisture between the ocean and the atmosphere, with potentially significant impacts on ocean circulation and regional weather.

Model simulations show that, as the climate warms, there is a poleward shift in the extra-tropical storm tracks. A recent analysis of AR4 models by Woolings et al (2012) finds that the North Atlantic storm track strengthens and extends further east, with a rise in storminess in Europe. Zappa et al (2013) have found that the AR5 models also suggest a slight increase in the number and intensity of cyclones associated with strong wind speeds over the UK and central Europe.

What does the IPCC Fifth Assessment Report (AR5) say about observed changes to the water cycle?

AR5 finds new evidence of a likely human influence on the water cycle since 1960 and notes that:

- Patterns of sea surface salinity, which are strongly dependent on precipitation and evaporation (as well as ocean currents), are very likely caused by an intensification of the water cycle.
- Contrary to AR4, AR5 reports that average runoff has not changed in the majority of rivers.

On atmospheric water vapour, AR5 reports:

- It is very likely that water vapour levels (i.e. specific humidity) near the surface and in the lower part of the atmosphere (i.e. the troposphere) have increased globally since the 1970s.
- Coincident with greater warming over land relative to the oceans, there have been fairly widespread decreases in relative humidity near the surface over the land areas recently.

On precipitation, changes are harder to measure. AR5 finds:

- A significant influence on global scale changes in precipitation patterns (with medium confidence) including increases in northern hemisphere mid to high latitudes.
- With medium confidence that human emissions have contributed to a global-scale intensification of heavy precipitation over the second half of the twentieth century.
- Overall, little change in land-based precipitation since 1900, contrasting with AR4, which reported that global precipitation averaged over land areas had increased.

On clouds, AR5 reports:

- Low confidence in observations of global-scale cloud variability and trends. Changes in the types, properties and extent of clouds are likely to enhance the warming but quantification remains difficult.

On sea-ice, AR5 notes that:

- The strong and significant decrease in Arctic sea ice extent reported in AR4 has continued. In Antarctica, there was an increase in annual mean sea ice extent of between 1.2-1.8 per cent per decade between 1979 and 2012, with some regions increasing and some decreasing.

On droughts and floods, AR5 says that:

- In land regions with sufficient observational coverage, there is medium confidence that climate change has contributed to a global-scale intensification of heavy precipitation over the second half of the 20th Century.
- The AR4 conclusions regarding global increasing trends in hydrological droughts since the 1970s are no longer supported. There is low confidence in the attribution of changes in drought since the mid-20th Century to human influence.
- There continues to be a lack of evidence and thus low confidence regarding the sign of trend in the magnitude and/or frequency of floods on a global scale.

On changes in circulation and cyclones, AR5 says that:

- Large variability makes it difficult to draw robust conclusions. But it is likely that circulation features have moved poleward since the 1970s, involving a widening of the tropical belt, a poleward shift of storm tracks and jet streams and a contraction of the northern polar vortex. Evidence is more robust for the northern hemisphere.
- Globally there is low confidence in the attribution of changes in tropical cyclone activity to human influence.

What does AR5 say about projected changes to the water cycle?

The projected near-term changes (2016-35) in the water cycle in AR5 include:

- Increased near-surface specific humidity (very likely). It is likely there will be an increase in evaporation in many regions.
- Increased mean precipitation averaged over latitude bands in the high (and some of the mid) latitudes (very likely) and reductions in the sub-tropics (more likely than not). Changes at regional scales may differ depending on natural climate variability, volcanic forcing and atmospheric aerosols.
- A likely increase in the frequency and intensity of heavy precipitation events over land (likely). Regional changes will be strongly affected by natural variability and will also depend on future aerosol level (emissions and volcanic) and land use change.

In the longer-term, with a warmer climate AR5 projects changes including:

- Increased global precipitation (virtually certain), with the likely rate of increase between 1 to 3 per cent per degree of warming for all scenarios except RCP2.6¹, where there is a wider estimate of 0.5 to 4 per cent per degree of warming.

¹ The Fifth Assessment Report uses new greenhouse gas emissions scenarios known as representative concentrations pathways (RCPs). They are each named after the amount of radiative forcing in W per square metre in 2100. They include some element of mitigation. They are (low to high forcing, where high radiative forcing means high greenhouse gas concentrations): RCP2.6, RCP4.5, RCP6.0 and RCP8.5.

- Substantial spatial variation of changes in average precipitation under the high emissions RCP8.5 scenario and increased contrast between wet and dry regions and wet and dry seasons. High latitudes and the equatorial Pacific Ocean are very likely to experience more precipitation.
- Globally for short-duration events, a shift to more intense individual storms and fewer weak storms as temperatures increase is likely. Extreme precipitation events over most of the mid-latitude land masses and over wet tropical regions will very likely be more intense and more frequent.
- Regional to global-scale decreases in soil moisture and increased risk of drought in presently dry regions by the end of the century in RCP8.5 is likely. Soil moisture drying is most prominent in the Mediterranean, Southwest US and southern African regions (likely with high confidence).
- Globally, the areas encompassed by monsoon systems will likely increase over the 21st Century, with a lengthening of the monsoon season in many regions. Monsoon precipitation is likely to intensify, while monsoon winds are likely to weaken.

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