

Palaeoclimatology

The woods fill up with snow

Michael N. Evans

Palaeoclimatological evidence covering the past millennium suggests that the global water cycle has changed in the past century. Agreement with climate models points to human activity as the main cause.

Two principal uncertainties in predicting climate change are the net effect of water in the climate system and the way in which water will be redistributed over the surface of the planet¹. On page 1179 of this issue, Treydte *et al.*² present a reconstruction of precipitation in central Asia for 826–1998 AD, developed from tree-ring data. Their results reveal a striking increase in snowfall over the past century compared with that over the previous millennium. This picture and other observations from around the world are concurring with predictions made by climate models, suggesting that the most pertinent aspects of the water cycle are adequately represented in the models. Furthermore, it seems that recent changes in precipitation patterns probably exceed the range of natural variability estimated for the past several hundred to one thousand years.

Resolving the influence of water on climate change is tricky, because the water cycle has interlinked effects on Earth's radiation budget, on the circulation of the atmosphere and ocean, and on the composition of any ecosystem. In turn, these processes combine to determine the distribution of moisture. The effects may occur on timescales from minutes to centuries, and on spatial scales from metres to hundreds of kilometres (Fig. 1)^{3–6}. Models incorporating the full richness of these processes and couplings could predict where, when and how climate change will manifest itself — for instance, as a change in the frequency of devastating droughts. Confirming that certain climatic features have changed in concert with the rise of greenhouse-gas emissions during the past century would improve our confidence in such models.

Monthly Hydrological Product Composite Derived from N-15 AMSU
Difference between Dec 2004 and Dec 2005

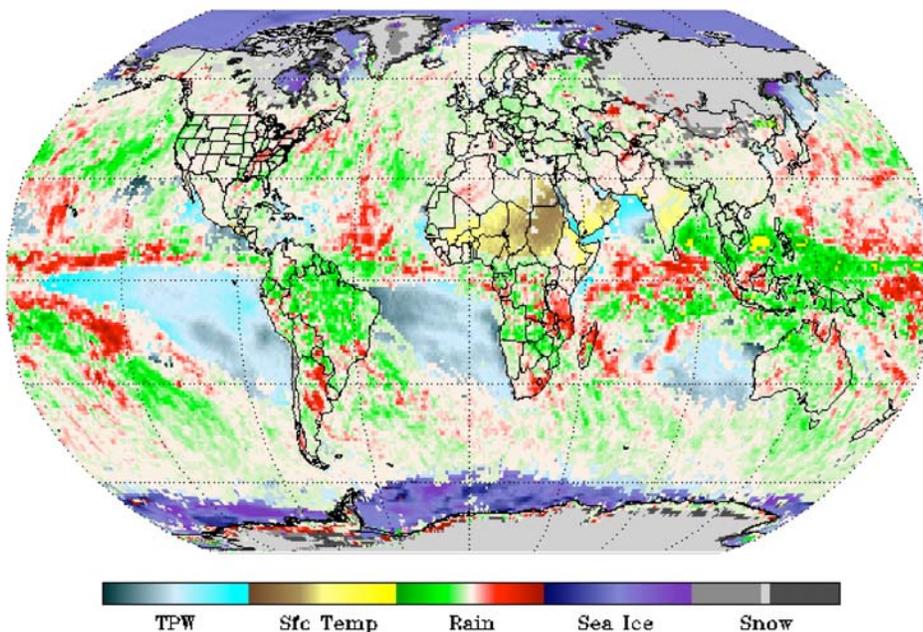


Figure 1 | Distribution of water in the climate system. Measurements are from the NOAA-15 Advanced Microwave Sounding Unit (AMSU) instrument⁶. The map shows the difference between December 2004, a weak El Niño/Southern Oscillation (ENSO) warm-phase event, and December 2005, a weak ENSO cold-phase event. ENSO events result in global redistributions of fresh water, which amplifies local, regional and global climate variability. Differences in total atmospheric precipitable water (TPW) range from 110 to +10 mm; in rainfall range from 11.0 to +1.0 mm per hour; in sea-ice concentration range from 150 to +50%; in snow cover range from 10.5 to +0.5 fraction of month for which snow cover was found in the grid box; and in surface temperature range from 110 to +10 K. (Courtesy of H. Meng and R. R. Ferraro, NOAA/NESDIS.)

In pursuit of this goal, Treydte *et al.*² developed a thousand-year estimate of the precipitation in central Asia — one of only a handful of well-dated, annually resolved reconstructions of climate variability on this timescale. Thanks to a series of laboratory, field and modelling studies⁷, the effects of environmental changes on the relative abundances of oxygen isotopes in the cellulose (cell-wall) component of wood are relatively well established (Fig. 2). About 70% of the variation in oxygen isotope composition of tree cellulose is determined by the isotopes in the source water taken up by the tree. The remainder is set by isotopic enrichment of water in the leaf or needles by evaporation before photosynthesis and the production of cellulose.

At high elevations in central Asia, precipitation is mostly snowfall. Treydte *et al.* use linear regression to demonstrate a link between the oxygen isotope composition in the cellulose of juniper trees in the region, and the average precipitation per water-year (from October to September) during the past century, observed at the handful of meteorological stations in the region. The authors show that greater precipitation is associated with lower concentrations of the oxygen isotope ¹⁸O. This is qualitatively consistent with the expected isotopic effects, and with observed global patterns in the stable isotopic composition of precipitation⁸.

The authors use the relationship between snowfall and oxygen isotope composition to reconstruct a time series of precipitation from tree-ring data. The data set has a high standard of intra- and inter-site replication that is rarely matched even in modern high-resolution isotopic palaeoclimate studies. Five records from one site share, on average, 36% of their variances; three twentieth-century records from three nearby sites share, on average, 25% of their variances. The time series of more than 1,100 years is composed of overlapping segments of pooled samples from at least 14 cores from seven trees for each year of record. It shows the same statistical relationship and quality of reconstruction as do the twentieth-century time series used by the authors to demonstrate the snowfall–isotope link. For palaeoclimate data from tree rings, these are very convincing results, and they indicate a common, interpretable signal of climate change.

In Treydte and colleagues' reconstruction, the greatest sustained increase in precipitation occurred in the past 150 years, which is roughly coincident with the Industrial Revolution and greenhouse-gas increases. As in the poem by Robert Frost, the woods have been filling up with snow.

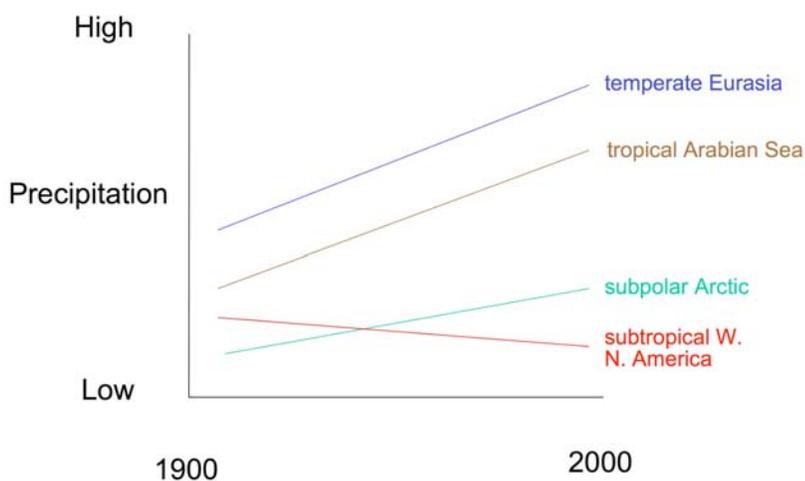


Figure 2 | Twentieth-century trends in palaeo-estimates of precipitation from around the world. The palaeo-observations used to deduce variations in precipitation show large changes over the twentieth century compared with the past several centuries². However, they are qualitatively consistent with predictions of the general circulation model⁹ for regional changes in the global water cycle in response to increases in greenhouse-gas concentrations. The plots are not to scale and are meant to indicate qualitative direction of change only. Data sources: subtropical western North America, tree-ring widths²³ in ²; temperate Eurasia, tree-ring widths and oxygen isotopes^{17, 24} in ²; tropical Arabian Sea, ocean sediments¹² in ²; subpolar Arctic, observed and modelled tree-ring widths¹⁰.

Does this agree with expectations based on model-derived climate-forecasting simulations that include realistic depictions of the effects of greenhouse-gas emissions? Roughly, yes. The authors review the

relevant literature and find that global precipitation increased by 1% per decade during the twentieth century. Furthermore, this and other palaeoclimate records (Fig. 2) suggest not only that the observed precipitation trends over the past century are unusual in the context of previous centuries, but also that observed drying in the subtropics and moistening in the tropics and high latitudes are consistent with model predictions⁹. The accuracy of climate-model predictions for trends in precipitation depends on whether the many interlinked roles of water in climate are correctly depicted. On the other hand, many uncertainties remain in interpreting long-term features in the palaeoclimate records. So agreement between the climate model and the estimates of rainfall deduced from various measures is compelling. A denser network of high-quality gauges of precipitation, created from a broad range of locations and biogeochemical data sources, will permit palaeoclimatologists to distinguish more clearly between the natural variability of the water cycle and alterations induced by greenhouse warming. This will in turn allow the uncertainties in data archives to be evaluated. It will also allow better definition of the spatial patterns in climate features during the past few centuries to millennia, and testing of climate-change hypotheses developed from simulations. All of these advances will assist the crucial work of climate-change detection and attribution¹.

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