CLIMATE SCIENCE

A bright side of precipitation

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During the period 1986–2000, the world — or at least its terrestrial parts — became wetter. On average, the increase in precipitation over this time was 3.5 mm yr^{-1}. In other words, the hydrological cycle intensified, and Martin Wild and his colleagues set themselves the task of investigating the factors responsible (M. Wild, J. Grieser and C. Schär *Geophys. Res. Lett.* **35,** L17706, doi:10.1029/2008GL034842; 2008).

The strength of the main engine that powers the hydrological cycle depends on the balance of radiative energy at Earth's surface. That balance in turn depends, first, on the amount of solar radiation absorbed by the surface, and second, on the difference between the amount of thermal radiation being transmitted upwards into the atmosphere (upward radiation) and that being re-radiated back (downward radiation, which is controlled by the greenhouse capacity of the atmosphere). The sum of these fluxes determines the amount of energy that is available for the latent heat of evaporation, which drives precipitation. Any change in these fluxes induces changes in evaporation and precipitation, and thus in the intensity of the hydrological cycle.

For their calculations, the authors drew from two sources: the Global Energy Balance Archive and the Baseline Surface Radiation Network. The latter provides more sophisticated data, but started up only in the 1990s. Another consideration in the calculations was the serious but temporary effects on radiation balance of the huge emissions from the 1991 eruption of Mount Pinatubo in the Philippines, which lasted for several years.

After accounting for those effects, Wild *et al.* conclude that there has been a steady rise in net surface radiation of 0.2 W m^{-2} yr^{-1} between 1986 and 2000. They mention two possible causes. One is 'solar brightening' — a rise in surface radiation resulting from a more transparent atmosphere caused by a decrease in anthropogenic aerosols. The other is a more powerful greenhouse effect, increasing downward radiation.

As the authors point out, their study cannot provide a truly global picture because of the lack of data from the oceans. But their calculated rise in net surface radiation fits well with the estimate of energy flux required to drive the rise in precipitation. This provides a satisfying first-order numerical link between the changes in precipitation and radiation, recorded in independent data sets, over the 15-year period of their study.

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collaboration (Fig. 1). For all their promise, the LCLS and XFEL are large and expensive; the LCLS is about 2 kilometres long, and XFEL will be even longer. The construction cost for the LCLS, which uses an existing particle accelerator, is about €300 million ($450 million), and XFEL will cost about €1 billion.

Shintake and colleagues are part of a team designing a Japanese X-FEL called the SPring-8 Compact Self-Amplified Spontaneous Emission Source (SCSS), which is planned for construction in the near future[4]. The work they now describe[1] uses a smaller-scale FEL, working at UV wavelengths, to show that cheaper and smaller X-FELs can be made by taking advantage of advances in the physics and technology of electron beams.

FELs operate by combining the technology of lasers and electron accelerators (Fig. 2). A particle accelerator produces electrons moving at close to the speed of light. These pass through a magnet, which causes them to follow a sinusoidal trajectory. The acceleration due to the bending of the electrons by this 'undulator' magnet produces electromagnetic waves. These have a wavelength that is proportional to the oscillation period of the sinusoidal path and inversely proportional to the square of the electron energy. Typically, the oscillation has a period of a few centimetres, and therefore, to produce X-rays with a wavelength of about 10^{-10} metres (1 ångstrom, the typical size of an atom), electrons are required that have energies of up to 15 gigaelectronvolts. For comparison, the energy of electrons produced by medical electron linear accelerators — used in many hospitals for radiation therapy — is 1,000 times smaller than this value. Medical accelerators are about a metre long; if an X-FEL accelerator were to be constructed using the same technology, it would need to be around a kilometre long. The length of the undulator magnet alone would be about 100 metres, and so, including space for X-ray diagnostic and manipulation equipment, the entire X-FEL would measure a few kilometres.

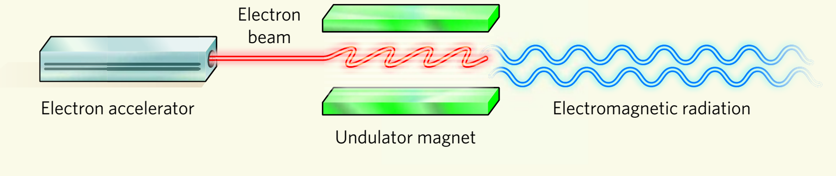

Figure 2 | X-ray specs. A free-electron laser (FEL) consists of a linear accelerator producing a beam of high-energy electrons that then pass through an 'undulator' magnet. This magnet bends the electrons into a sinusoidal path, causing them to emit electromagnetic radiation whose frequency depends on the energy of the electrons and the wavelength of their undulations. Using current technology, a FEL that emits X-rays would be several kilometres long, but the approach tested by Shintake *et al.*[1] on an ultraviolet-emitting device could reduce the size two- to threefold.

One way to make X-FEL sources more manageable would be to reduce the electron-beam energy but to force the electrons into tighter undulations. This would have the effect of making both the accelerator and undulator shorter. Shintake *et al.*[1] show that the accelerator length can be reduced by using a 'C-band' high-frequency accelerator, a technology developed for the construction of high-energy electron–positron linear colliders[5]. Other advances involved are an improved electron source and an undulator magnet with smaller period and shorter length. When combined in the SCSS design, these advances would lead to a more compact X-FEL.

An even more advanced instrument under consideration[6,7] is a high-gradient accelerator driven by a phenomenon known as a laser-plasma wakefield, which is created by passing a brief laser pulse through a plasma of charged particles. Whereas Shintake and colleagues' approach can decrease the length of the accelerator to around a half or a third of that possible now, the laser-plasma accelerator could provide a 100-fold reduction. However, it is still at the exploration and proof-of-principle stage.

The size and cost of an X-FEL could also be reduced by using sources that produce electron beams with higher electron density and smaller variation in momentum than are currently available; together, these properties are described as the beam emittance. Smaller-emittance electron beams would allow the use of lower electron energies, and shortened accelerators and undulators. Emittance could