Second, to foster creativity, we plan to support people who want to work in new areas — especially young researchers setting up their own labs. Most scientists do their most creative work at this early stage of their careers. But — understandably — it's often hard to obtain funding unless you can demonstrate expertise in a particular area. The Chan Zuckerberg Initiative could fill a niche by taking on more risks than other funders. That risk is worthwhile if it brings people into biomedical areas in which the need is great but current research is narrowly directed. Unfortunately, disease-relevant fields can be some of the hardest to break into for someone with a new idea or approach. Certain disease foundations, such as the Hereditary Disease Foundation for Huntington's disease or the Simons Foundation Autism Research Initiative, have done this well in the past. But we think that there is room to scale up this model to many other biomedical problems.

Finally, on openness. We believe that research advances when people build on each others' work. So our principles include making data, protocols, reagents and code freely available for other scientists to use. As an example of this approach, the HCA has committed to making its reference data publicly available after quality-control checks. Indeed, the Chan Zuckerberg Initiative engineering team and our HCA collaborators are building all of the software for the 'data coordination' arm of the project on the open-source platform Github.

We're also supporting external groups that share these values and goals. For instance, we're funding bioRxiv, the largest and fastest-growing preprint repository for the biological sciences — and a leader in bringing biology towards the level of sharing that's expected in the physical and computer sciences.

The Chan Zuckerberg Initiative is just starting, and we have a lot to learn. But I've been lucky to work in areas in which the free exchange of ideas and results is the norm. In my experience, such an approach creates the most dynamic fields. Now I have the chance to lead a new funding venture, and to explore whether openness or dynamism comes first. After all, as scientists we do experiments; as funders, we can do experiments too. ■

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JUHO AALTO

An enclosure for measuring gas exchange between plants and the atmosphere at a station in Finland.

Build a global Earth observatory

Markku Kulmala calls for continuous, comprehensive monitoring of interactions between the planet's surface and atmosphere.

Climate change. Water and food security. Urban air pollution. These environmental grand challenges are all linked, yet each is studied separately.

Interactions between Earth's surface and the atmosphere influence climate, air quality and water cycles. Changes in one affect the others. For example, increasing carbon dioxide enhances photosynthesis. As they grow, plants withdraw greenhouse gases from the atmosphere, but they also release volatile organic compounds such as monoterpenes. These speed up the formation of aerosol particles, which reflect sunlight back into space. Our actions — such as emission-control policies, urbanization and forestry — also affect the atmosphere, land and seas[1–5].

Satellites and stations on the ground track greenhouse gases, ecosystem responses, particulate matter or ozone independently of each other. Coupled observations are occasionally performed, but in intensive bouts. Vast areas of the globe — including Africa, eastern Eurasia and South America — are barely sampled.

The result is a cacophony of information that yields little insight. It is like trying to forecast weather in November with spotty measurements of rain, wind, temperature or pressure from June.

The answer is a global Earth observatory — 1,000 or more well-equipped ground stations around the world that track environments and key ecosystems fully and continuously. Data from these stations would be linked to data from satellite-based remote sensing, laboratory experiments and computer models.

Researchers could find new mechanisms and feedback loops[6] in this coherent data set. Policymakers could test policies and their impacts. Companies could develop environmental services. Early warnings could be provided for extreme weather, and quick responses initiated during and just after chemical accidents.

A global observatory has been discussed for more than a decade, but is only now feasible[7]. Instruments have matured; for example, today's mass spectrometers ▶

can measure thousands of atmospheric chemicals at once. My team and our collaborators have shown how a rounded set of environmental measurements can be obtained at one station, called SMEAR II (Station for Measuring Ecosystem-Atmosphere Relationships), in the boreal forests of Finland.

Regional initiatives to combine and broaden space- and ground-based monitoring are established well enough to roll out similar stations globally. These include PEEX (the Pan Eurasian Experiment) and the DBAR (Digital Belt and Road), a research initiative related to China's One Belt and One Road Initiative — a development strategy covering a swathe of 65 countries between China and Europe that reaches as far south as Kenya. The World Meteorological Organization (WMO) is taking steps to establish a global observatory. And the urgency is here: carbon emissions must decline after 2020 (ref. 8).

The scale of the enterprise remains daunting. It requires a wholesale shift in how environmental data are collected and disseminated.

AN INTEGRATED NETWORK

Incomplete coverage from ground stations is the main limit to observations of Earth's conditions. Satellites can continuously monitor some compounds, such as CO_2, ozone and aerosols, almost planet-wide. But they cannot resolve processes or fluxes, or trace the hundreds more compounds of interest. Satellite data must be 'ground-truthed'. Models need data to validate them.

Current networks of ground stations have been set up without considering the big picture. Each discipline or team designs and builds stations to suit its purpose. Greenhouse gases, atmospheric chemicals and ecosystems are monitored at different sites. Funding agencies focus on national interests.

The SMEAR II station takes a more integrated approach. Using state-of-the-art atmospheric mass spectrometers, cloud radars and lidars (light detection and ranging instruments), it observes more than 1,000 variables. These include greenhouse gases, trace gases and aerosols, as well as indicators of photosynthesis, soil temperature, moisture and nutrient gradients.

The challenge is to set up similar stations around the world — and to incorporate local expertise. Good places to start would be the three global regions where coverage is sparse, and in megacities.

HOT SPOTS

The Arctic and boreal regions. Former Soviet Union countries, including Russia and Kazakhstan, are crucial laboratories for global change. They are rich with minerals, oil and natural gas: Siberia contains 85% of Russia's prospected gas reserves, 75% of its coal and 65% of its oil reserves. And climate change is rapidly altering their environments. There is much we don't know. How rapidly will permafrost disappear? Does Arctic greening sequester carbon or produce aerosols? Will methane emissions increase drastically, and so ramp up global warming?

In this region, as elsewhere, researchers need to observe aerosols together with greenhouse gases (such as CO_2 and methane) and other trace gases (volatile organic compounds, nitrogen oxides, ozone, sulfur dioxide, carbon monoxide and ammonia). Two stations are starting to increase the range of observations that they can make: the Tiksi Hydrometeorological Observatory in the River Lena delta in eastern Russia and the Zotino Tall Tower Observatory (ZOTTO) in southwest Siberia, 500 kilometres from Tomsk. Ideally, to cover the region, around 30 comprehensive stations will be needed, spaced 1,000 kilometres apart. A global observatory must appear on the agendas of upcoming meetings of the Russian government and the Arctic Council.

Africa. The continent's population is increasing fast — it has doubled since 1987, and it reached 1.2 billion people in 2015. Meanwhile, once-fertile areas have become dry, challenging water and food supplies and requiring strategies to store rainwater and retain soil moisture[9]. Water and other biogeochemical cycles need to be understood better. But monitoring in Africa is limited mainly to short-term observations of carbon sinks and sources (by the global network FLUXNET) and to some air-quality observations that measure about a dozen variables.

A minimum of 30 stations should be built in Africa. These must comprise at least one in each main ecosystem that is relevant to food and water, including rainforests, savannahs and semi-deserts. Prime sites should be identified with local organizations and scientists. United Nations organizations, development banks and private foundations that work in Africa should add their support.

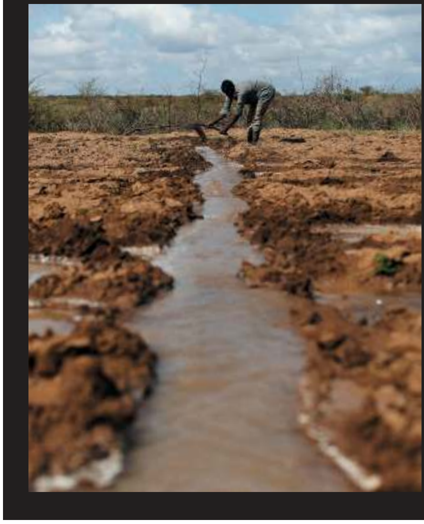
South America. The Amazon basin is a crucial place to monitor, owing to its vast area and influence on global carbon and hydrological cycles. It forms its own climate system, which is changing[10] as a result of agricultural expansion and deforestation. These disturbances, together with climate shifts, will affect carbon storage and water cycles. Yet there is little information available, and no combined observations. Only the Amazon Tall Tower Observatory (ATTO), located about 150 kilometres northeast of Manaus, Brazil, is taking steps to increase the range and continuity of data obtained.

South America needs at least 20 such stations: 7 should be located in the Amazonas region. The exact sites need to be identified with local scientists and organizations.

Four hot spots

Setting up stations to monitor air, soil and ecosystems across Eurasia, Africa, South America and in major cities would fill crucial gaps in a global observatory network.

1 African nations such as Somalia need better monitoring of water cycles to improve strategies that help to retain soil moisture.



Cities. Urban areas are growing: the urban population has tripled since 1970. More than 55% of the global population lives in urban areas. Better data on air quality is a particularly pressing need. Currently, fewer than 15 variables are typically observed at sites in urban areas, and the data quality is often poor.

More than 30 megacities worldwide each contain greater than 10 million people, and hundreds of cities have populations in the millions. Each large metropolis should have at least one comprehensive observatory and a suite of simpler local stations. The Global Mayors' Forum should put the global observatory on its agenda, as should the G20 countries.

COST EFFECTIVE

A global observatory, comprising a network of 1,000 super stations, needs to be established within 10–15 years. Costs would be around €10 million (US$11.8 million) to €20 million per station, or €10 billion

2 Deforestation in the Amazon basin is changing its climate system.

3 Greenhouse-gas measurements in Siberia will help to reveal the effects of melting permafrost.

4 Megacities such as Lagos need better data on air quality.

SOMALIA: SIEGFRIED MODOLA/REUTERS; AMAZON: UESLEI MARCELINO/REUTERS; SIBERIA: JEREMY NICHOLL/EYEVINE; LAGOS: PIUS UTOMI EKPEI/AFP/GETTY

to €20 billion for the whole thing. This is comparable to the construction cost of the Large Hadron Collider near Geneva, Switzerland, or that of US President Donald Trump's proposed Mexican wall.

Stations should be constructed or upgraded using a modular approach. The different modules would target atmospheric chemistry, micrometeorology and soil chemistry, for example. Each block would cost around €500,000 to €2 million to develop and install. Annual servicing would add about 3–6% per year to these costs.

The instruments will need to be harmonized, calibrated and standardized. They must be developed and upgraded as techniques improve. Data sharing must be considered — information must be reliable and open. Data scientists will be needed to analyse data and develop products that flow from the stations to users and archives. Professional staff will be needed to run the stations.

Existing networks need to coordinate their practices. These include scientific programmes such as PEEX, the DBAR initiative and FLUXNET; global organizations such as the WMO and Future Earth; private global foundations and companies; and municipal, governmental and UN bodies.

Complementary infrastructures such as the following should be combined: the Integrated Carbon Observation System (ICOS); the WMO's Global Atmosphere Watch; the Aerosols, Clouds, and Trace gases Research Infrastructure network (ACTRIS); Europe's Long-term Ecosystem Research (LTER); and the infrastructure for Analysis and Experimentation on Ecosystems (AnaEE). The first step would be the open exchange of data between them, which is already starting to happen in Europe. Next, the networks should establish joint stations across other continents, especially in the hot spots mentioned. SMEAR II proves that this is feasible and need not be expensive.

Once we establish the global observatory, we will have the tools to understand how the Earth system works. ■

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