Earth System Science

One of the great scientific challenges of the 21st century is to forecast the future of planet Earth. As human activities push atmospheric carbon dioxide (CO_2) and methane concentrations far beyond anything seen for nearly half a million years (prompting the strongest statement yet from the Intergovernmental Panel on Climate Change that human activities are warming the world), we find ourselves, literally, in uncharted territory, performing an uncontrolled experiment with planet Earth that is terrifying in its scale and complexity.

Wrestling to understand these challenges is the young, and still emerging, discipline of Earth System Science (ESS). Polar-ice and ocean-sediment cores (the Vostok ice core from Antarctica, for example) provide a picture of the last half-million years of Earth's history unimaginable even two decades ago, and mark the emergence of ESS as the discipline that deals with our planet as a complex, interacting system. ESS takes the main components of planet Earth—the atmosphere, oceans, freshwater, rocks, soils, and biosphere—and seeks to understand major patterns and processes in their dynamics. To do this, we need to study not only the processes that go on within each component (traditionally the realms of oceanography, atmospheric physics, and ecology, to name but three), but also interactions *between* these components. It is the need to study and understand these between-component interactions that defines ESS as a discipline in its own right.

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Physicists have long understood the "Goldilocks effect"—why, in general terms, Earth's natural blanket of atmospheric CO_2 and distance from the Sun make the planet "just right" for life, neither too hot (like Venus) nor too cold (like Mars). James Lovelock's penetrating insights that a planet with abundant life will have an atmosphere shifted into extreme thermodynamic disequilibrium, and that Earth is habitable because of complex linkages and feedbacks between the atmosphere, oceans, land, and biosphere, were major stepping-stones in the emergence of this new science. We still do not understand all these feedbacks and cannot, yet, build a model that reproduces changes in Earth's temperature and atmospheric composition revealed by the Vostok ice core, but these problems now hold center stage in ESS.

There are also numerous other interrelated challenges for this emerging discipline. Do species' identities matter in biosphere-geosphere interactions, or is life simply "green slime"? What are the main feedbacks influencing planetary inorganic–organic carbon dynamics? How does human domination of the global nitrogen cycle, or rapid urbanization, impact on other components of the Earth system? How do we link models of geophysical processes to those describing human socioeconomic activities? The time scales involved in such questions range from hundreds to hundreds of millions of years, and involve processes that are highly nonlinear, presenting considerable challenges for modelers.

The greatest challenge for the new discipline, however, is to provide prescriptions that will reverse current human abuse of planet Earth, signposting routes to a sustainable future. The biggest barriers to rapid progress are institutional. Comparisons between ESS and medical science are telling. Scientists and engineers from many disciplines routinely work together within institutions and organizations to improve human health. We would be startled if it were not so. The health of the planet is a different story. Although a few pioneering individuals and institutions around the world recognize the need for the strong interdisciplinary work that defines ESS, in the main we lack the organizations to nurture this new discipline. There are, as far as I am aware, no undergraduate degree courses in ESS. A mere handful of U.S. and European institutions (including Penn State, the University of California at Irvine, the University of Maryland, the Danish Centre for Earth System Science, the Potsdam Insitute, and ETH in Zurich) offer graduate programs and the kind of interdisciplinary working environments that are essential for the rapid development of ESS. The International Geosphere-Biosphere Programme (IGBP) serves as a pioneering focus for ESS, but lacks the resources to do more. Funding agencies, compartmentalized into traditional disciplines, are ill-equipped to rise to the new challenges posed by ESS.

It is hard to imagine a more important discipline than Earth System Science. We urgently need to overhaul our thinking and rejig our institutions to allow this crucial new science to flourish.

John Lawton

John Lawton is a professor at the Centre for Population Biology, Imperial College, Silwood Park, and chief executive of the UK Natural Environment Research Council.