Davies et al. GigaScience (2016) 5:14
DOI 10.1186/s13742-016-0118-5

GigaScience

COMMENTARY

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Simulating social-ecological systems: the Island Digital Ecosystem Avatars (IDEA) consortium

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Abstract

Systems biology promises to revolutionize medicine, yet human wellbeing is also inherently linked to healthy societies and environments (sustainability). The IDEA Consortium is a systems ecology open science initiative to conduct the basic scientific research needed to build use-oriented simulations (avatars) of entire social-ecological systems. Islands are the most scientifically tractable places for these studies and we begin with one of the best known: Moorea, French Polynesia. The Moorea IDEA will be a sustainability simulator modeling links and feedbacks between climate, environment, biodiversity, and human activities across a coupled marine–terrestrial landscape. As a model system, the resulting knowledge and tools will improve our ability to predict human and natural change on Moorea and elsewhere at scales relevant to management/conservation actions.

Keywords: Computational ecology, Biodiversity, Genomics, Biocode, Earth observations, Social-ecological system, Ecosystem dynamics, Climate change scenarios, Predictive modeling

Background

High-throughput data collection techniques and large-scale computing are transforming our understanding of ecosystems, making convergent scientific frameworks a research priority [1]. As human activities increasingly impact ecosystem processes, we need new approaches that focus on how whole communities of organisms interact with people and the physical environment at the scale of landscapes or catchments [2]. This requires an e-infrastructure for data intensive science that enables the integration of computational physics, chemistry, biology, ecology, economics and other social sciences. Such an advance would allow researchers to (1) characterize the multidisciplinary functional attributes of social-ecological systems; (2) quantify the relationships between those functional attributes under historic and current conditions; and (3) model the trajectories of goods and services under a range of policy-driven scenarios and future environmental conditions. The resulting knowledge would improve our ability to predict human and natural change at scales relevant to management/conservation actions.

Unlike some aspects of climate change, processes related to biodiversity and ecosystem services are "typically place-based and many of the effects are seen at sub-global scales" [3]. Inspired by successes in modeling complex systems at other scales of organization, notably the cell [4], the Island Digital Ecosystem Avatars (IDEA) Consortium aims to build computer simulations ('avatars')

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to the scale of whole social-ecological systems. With a common boundary constraining their physical, ecological, and social networks, islands have long been recognized as model systems for ecology and evolution [5]. Their geography sets clear limits on the species to inventory, space holders (ground cover) to measure, organisms to count, physical–chemical contexts to characterize, and natural–human interactions to consider. The knowledge and cyberinfrastructure developed for island avatars, and complementary efforts targeting major cities like Singapore [6] and New York [7], will eventually scale to countries and regions, including their associated coastal waters. Island avatars are built from the genome up, while at the same time downscaling regional models to establish boundary conditions. They address many of the challenges faced by macrosystems ecology [8], and general ecosystem models [9]. Indeed, an Earth Avatar would converge on the Global Earth Observation System of Systems (GEOSS) [10] and Future Earth [11]. The IDEA approach, however, avoids overwhelming complexity, instead concentrating effort on the simplest social–ecological systems that include most of the data types covered by GEOSS, and many of the processes found globally.

Moorea IDEA

The small island of Moorea (134 km^2) in French Polynesia is well placed for a proof-of-concept study. About 15 km northwest of Tahiti with a population of ~17,000, Moorea is perhaps the best studied island in the world [12] thanks to several decades of activity at its two research stations (CNRS-EPHE CRIOBE [13], and the University of California (UC) Berkeley Gump Station [14]), which respectively house France's Center of Excellence for Coral Reef Research (LabEx CORAIL [15]), and the US National Science Foundation's only coral reef Long-Term Ecological Research (MCR LTER) site [16], which is administered by UC Santa Barbara. Additionally, the Moorea Biocode Project [17] has characterized every species (>1 mm) on the island, including genetic sequences, museum specimens, and digital photographs [18]. While there is still much more to learn, especially concerning the vastly diverse microbes [19] and human systems, the existing physical and biotic databases provide a powerful foundation for whole system ecological modeling. Combined with a wealth of data on the resilience of Moorea's ecosystems, including the response of its coral reefs to large-scale perturbations [20] and the evolution of Polynesian society [21], Moorea has many of the characteristics needed to advance systems ecology and sustainability science [22].

The Moorea IDEA aims to understand how biodiversity, ecosystem services, and society will co-evolve over the next several decades depending upon what actions are taken. Specifically, we ask: (1) what is the physical, biological, and social state of the island system today? (2) How did it get to this point? (3) What is its future under alternative scenarios of environmental change and human activity, including conservation efforts? These questions are addressed through a place-based data science infrastructure and computational platform (Fig. 1). The Moorea Avatar is the best digital representation of the island; a three-dimensional visualization of Moorea that looks similar to the one on Google Earth, but which includes the dimension of time and enables researchers to zoom into a location, access data, and run simulations. Today's island represents the key baseline because the majority of the modeling data needed are not available for historic time periods. The Avatar computational platform allows other versions of Moorea to be generated and visualized *in silico* for a range of purposes. This involves the integration of physical, biological, and social data [12–21], and drawing on best-available scientific knowledge to show what the island looked like in the past (using historic baselines to explore particular issues), and to predict how it might look in the future. Unlike video games, our projections are constrained by reality and are intended not only for research and education, but also to support scenario-based planning; helping

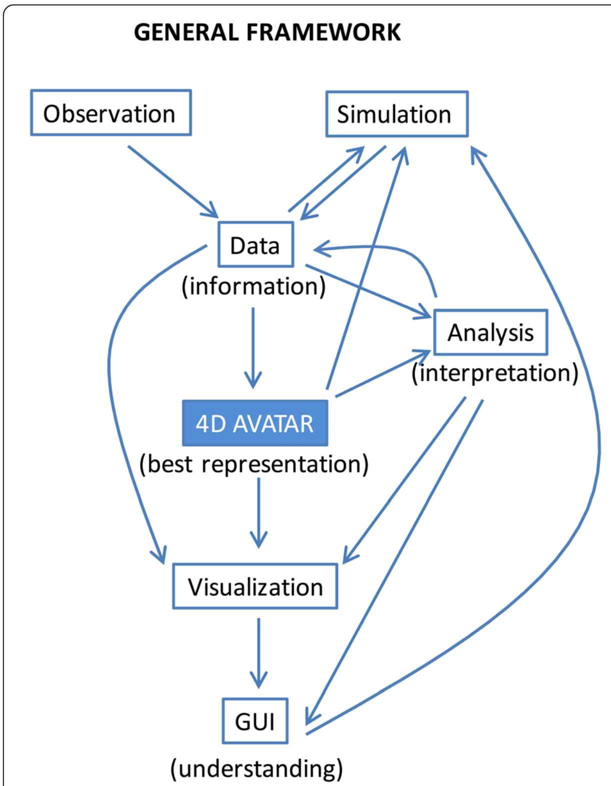

Fig. 1 The data-driven avatar communicates knowledge through a Graphical User Interface (GUI) customized for different stakeholders. Their improved understanding in turn generates new hypotheses to test and new simulations to run, thus driving further data collection

local communities adapt to environmental change and maximize ecological resilience. Our goal is to emulate P4 Medicine, extending to social–ecological–physical systems the Predictive, Preventive, Personalized, and Participatory approach that promises to revolutionize the biomedical field [23].

Working with the local population to co-develop island avatars as "boundary objects" [24] is critical to ensuring that the simulations are useful, credible and legitimate. Non-scientist stakeholders take joint ownership of their avatar by prioritizing the policies to simulate (e.g., conservation plans), and by contributing traditional/local knowledge and data. The participatory approach includes citizen science, taking advantage of newly affordable technologies and helping reconnect people with natural processes through observation and experiential learning.

Organization

The Moorea IDEA was initiated by researchers associated with the UC Berkeley Gump Research Station and CRIOBE, through a workshop at the Pauli Center for Theoretical Studies, ETH Zurich, in November 2013. The Consortium now includes more than 80 scientists from around the world, representing the physical, biological, social, computer and information sciences. Institutional nodes (more than 20) form its governing body, which is currently led by an Executive Committee representing the founding institutions. The Consortium addresses convergent research questions across areas of societal interest (energy, water, nutrients, biodiversity, food and nutrition, and health) through five overlapping and interlinked working groups (Table 1). The Moorea IDEA has gained support from the Municipality of Moorea and the territorial government of French Polynesia. In the future, other islands could join to form a network that shares the generally applicable tools and approaches generated by the IDEA Consortium. For example, the nearby atoll Tetiaroa constitutes a worthwhile comparison to Moorea. Further afield, and reflecting the ambition to scale to larger places, scientists and government officials from Crete have expressed a strong interest in the project.

Table 1 Research priorities of the IDEA Consortium

Working group	Task
1. Data science	Integrating diverse data sources, coupling models, and visualizing information
2. Physical modeling	Oceanic and atmospheric forcing, and physical-chemical properties and fluxes
3. Genes to ecosystems	Biodiversity dynamics, evolutionary processes, and ecological interactions
4. Social-ecological systems	Coupling past, present, and future ecosystems to human activities
5. Simulations, synthesis, and service	Use-oriented avatar as a platform for data exploration, scenario-based planning, and education

Conclusions

The new Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) has prioritized an assessment on the "Modeling of Biodiversity and Ecosystem Services" [25]. Addressing this grand challenge will require computational models of place that are able to simulate alternative scenarios and visualize likely outcomes for scientists, policymakers, and the public [26]. Big data, computational ecology, and sophisticated simulation platforms cannot solve all of the world's problems, but harnessing scalable technology addresses the lack of capacity in local knowledge management systems, and can help illuminate pathways to sustainability. In an era in which society is seeking to transition to clean energy and sustainable economic growth, knowledge of the pathways to these futures is needed, along with showcases demonstrating that such change is possible. At least initially, examples are more likely to come from islands and cities than large regions and countries. Islands are disproportionately affected by global change and epitomize the coastal zones where most of humanity lives. They serve as models for continental regions and, ultimately, for our common island home: planet Earth.

Abbreviations

CRIOBE: Centre de Recherches Insulaires et Observatoire de l'Environnement (Center for Island Research and Environmental Observatory); GEO: Group on earth observations; GEOSS: Global Earth Observation System of Systems; IDEA: Island Digital Ecosystem Avatars; IPBES: International panel on biodiversity and ecosystem services; LTER: Long Term Ecological Research.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

ND drafted the original text with DF, DG, SH, SP and MT (representing the five founding institutions of the IDEA Consortium). Other co-authors contributed to the text and/or participated in Consortium workshops that developed the concepts presented here. JLH developed the first draft of Fig. 1. A full list of IDEA Consortium members supporting the concepts described herein can be found on the Moorea IDEA website [27]. All authors read and approved the final manuscript.

Funding

This paper is a contribution of CRIOBE and the Gump South Pacific Research Station (#213). Work was supported in part by: the Institute of Theoretical Physics and the Pauli Center at ETH Zurich; the US National Science Foundation (NSF Moorea Coral Reef Long Term Ecological Research Site, OCE-1236905; Socio-Ecosystem Dynamics of Natural-Human Networks on Model Islands, CNH-1313830; Coastal SEES: Adaptive Capacity, Resilience, and Coral Reef State Shifts in Social-ecological Systems, OCE-1325652, OCE-1325554); the Gordon and Betty Moore Foundation (Berkeley Initiative in Global Change Biology; Genomic Standards Consortium); Courtney Ross and the Ross Institute; UC Berkeley Vice Chancellor for Research; CRIOBE; and the France Berkeley Fund (FBF 2014-0015).

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Received: 12 December 2015 Accepted: 21 February 2016

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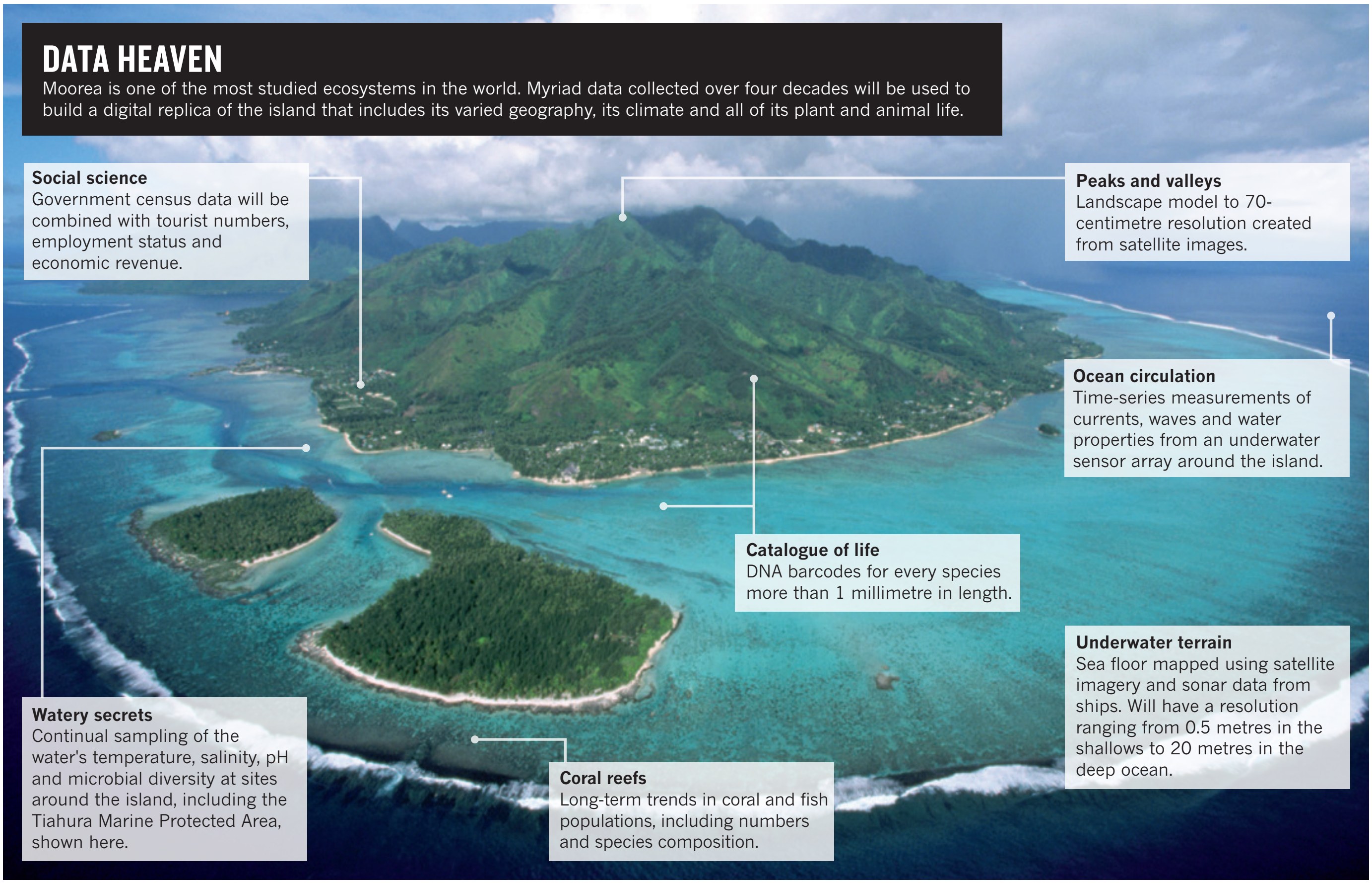


YANN ARTHUS-BERTRAND/CORBIS

ENVIRONMENT

Tropical paradise inspires virtual ecology lab

Digital version of Moorea will provide a way to experiment with an entire ecosystem.

BY DANIEL CRESSEY

A paradise on Earth could soon become the first ecosystem in the world to be replicated in digital form in painstaking detail, from the genes of its plants and animals to the geography of its landscape.

An international team is preparing to create a digital avatar of the Pacific island of Moorea, which lies off the coast of Tahiti and is part of French Polynesia. Moorea is already one of the most studied islands in the world; the team plans to turn those data into a virtual lab that would allow scientists to test and generate hypotheses about the impact of human activities.

Ecologists have used models for years to tease out the relationships between different facets of nature, such as temperature and population or predators and prey. But much of that modelling is relevant only to specific species or research questions, and some scientists want a holistic view. As human activity and natural variations combine to alter the environment, researchers need to know how mitigating steps — such as setting up protected areas, or attempts to curb fossil-fuel use — might affect an entire ecosystem.

"We know the world's changing. Yet the decisions we're making, we're making them in the dark," says Neil Davies, one of the people behind the Moorea IDEA (Island Digital Ecosystem Avatars) project and director of Gump Station, the University of California, Berkeley's marine-science base on the island. "We're not going to have precise predictions ever, but we need to have a way of modelling different scenarios." For example, if a hotel is built at a certain location, how does that change the ecosystem? If a species disappears from a river, what happens downstream?

Moorea is an ideal place to start, says Davies, because the island is about 16 kilometres across and has just 17,000 people living on it, making it easier to model than larger ecosystems and those that are more connected to the rest of the world. In addition, French researchers have been there since the 1970s, and Gump Station has been operating since the 1980s. Both efforts have collected myriad data on the island's waters, with decades-long studies of coral and fish numbers (see 'Data heaven').

These traditional surveys of marine life are now being linked up with the Moorea Biocode Project, which aims to characterize every species larger than a millimetre in length on the island and allocate them a 'DNA barcode' — snippets of DNA that can be used as a unique identifier. Species can thus be identified quickly and easily even when they are in places or states that would otherwise be difficult ▶

to recognize, such as in the contents of another organism's stomach, or in seed or larval form.

The avatar would combine insights gleaned from the Biocode project — such as which species are present at certain ocean spots, or which species are eaten by another — with data on weather, ocean currents and society such as population density and real-estate prices. It would provide a three-dimensional visualization of the island and its surrounding waters that might look something like those on Google Earth, but would enable researchers to zoom into a location, access data and run simulations.

"The first stage will be a framework to integrate the data we have. To collate them, combine them, and to make the data accessible to scientists," says project member Matthias Troyer, a computer scientist at the Swiss Federal Institute of Technology in Zurich. "Then, based on that, one can start on modelling."

EXPANDING PROJECT

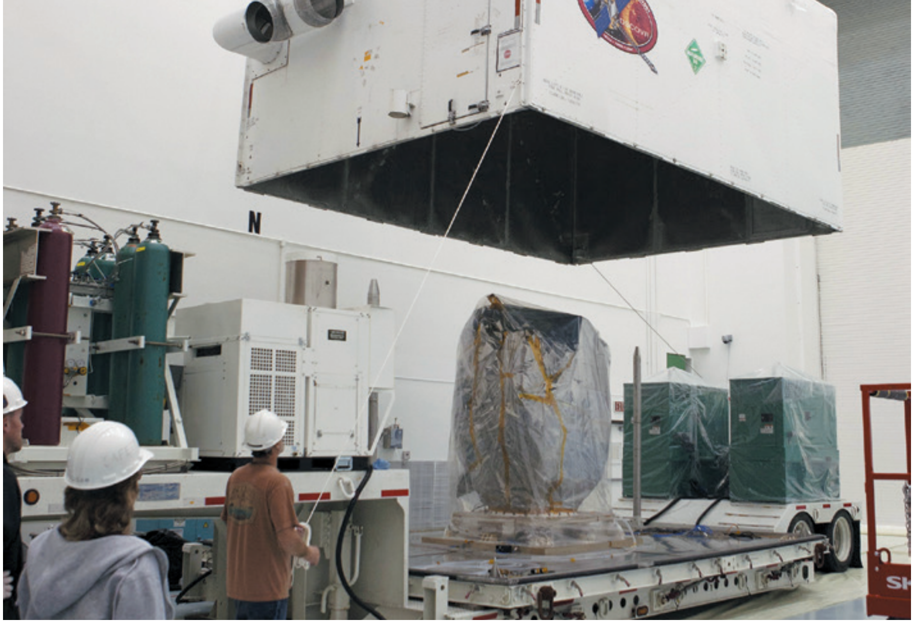
The IDEA project was born in 2013, the brainchild of Davies, Troyer and three other marine scientists: Dawn Field at the University of Oxford, UK; Sally Holbrook at the University of California, Santa Barbara; and Serge Planes from the French research base on Moorea. The consortium now has more than 80 participants.

At meetings late last year, the IDEA team discussed how to combine existing data with those coming from the latest technologies. Some of the framework for the avatar is already under construction, and Davies says that the team is seeking funding of around US$5 million over three years to pursue a pilot project.

The project is "really novel in the modelling community", says Mike Harfoot, an ecosystem modeller at the United Nations Environment Programme's World Conservation Monitoring Centre in Cambridge, UK, because it will integrate societal data with physical and biological components. And, he adds, the computational power required to take a holistic approach to modelling ecosystems has only recently become available.

> *"It's impressive the amount of data going into it."*

"It's impressive the amount of data that's going in it," says Rick Stafford, a computational ecologist at Bournemouth University, UK. Getting the different data sets to talk to each other will be a challenge, but the time is ripe for such an ambitious undertaking, says Davies. And it if works on Moorea, the approach could be rolled out to other parts of the world. Although ambitious, says Davies, "it's not a pipe dream". ■



The DSCOVR craft is removed from a container in Cape Canaveral, Florida.

KIM SHIFLETT/NASA

SPACE

Mothballed NASA craft to launch

Proposed by former US vice-president Al Gore in 1998 to image Earth, DSCOVR probe will monitor space weather.

BY MARK ZASTROW

After nearly 14 years in limbo, an Earth-monitoring spacecraft built by NASA is finally set to fly.

The Deep Space Climate Observatory (DSCOVR), scheduled to launch as soon as 29 January, will constantly observe Earth's sunlit side from a distance of 1.5 million kilometres. It will track daily weather patterns and seasonal vegetation changes, monitor atmospheric pollution and make the most precise measurements yet of how much energy Earth throws out into space — crucial data for the improvement of global climate models.

DSCOVR's resurrection is thanks to renewed interest in what was originally its secondary mission: monitoring space weather. From a point between the Sun and Earth at which the bodies' gravitational pulls cancel out, the probe will be able to detect approaching solar storms — bursts of charged particles and powerful radiation that pose a threat to astronauts, orbiting satellites and power grids on the ground. Such storms are of interest to the US Air Force, which is funding the satellite's launch, and the National Oceanic and Atmospheric Administration (NOAA), which will operate it.

DSCOVR was the brainchild of former US vice-president Al Gore. He imagined a probe that would beam down a live image of Earth's illuminated side that could be available online. Just as the famous 'blue marble' image of Earth taken by the *Apollo 17* crew had inspired people, Gore said in 1998 that DSCOVR would "awaken a new generation to the environment and educate millions of children around the globe".

To Gore's critics in Congress — particularly Republicans sceptical of his environmental advocacy — those were fighting words. The mission was nothing more than "a multimillion-dollar screen saver", said representative Dave Weldon (Republican, Florida). It acquired the unflattering nickname 'GoreSat'.

"The worst thing that can happen to science is to get mixed up in politics," says Francisco Valero, a retired climate scientist who was at the Scripps Institution of Oceanography in La Jolla, California, and led the satellite's original Earth-science team. "That is what happened to us."

Although Gore intended the project to be mostly educational, NASA formulated a complementary science mission by soliciting proposals from the community. Valero's winning pitch was a probe to measure how much radiation Earth reflects back into space, a crucial variable for untangling the web of processes that influence the planet's climate. Clouds, for example, are a perennial conundrum for climate models because they both reflect incoming sunlight and trap outgoing heat. Valero proposed two instruments: a camera called EPIC to image clouds and other climate-influencing factors such as pollution, volcanic ash and seasonal