Towards A Globally-Focused Earth Simulation Centre

ICES FOUNDATION

Helping guide the successful transformation of human society
in an era of rapid climate change and frequent natural disasters.

The key to solving problems in weather, climate and environmental science is high performance computing. Nature can only be accurately described and computed from equations that take account of complex, non-linear interactions between multiple natural systems, i.e. rivers, lakes, oceans, mountains, forests, dust, pollution, cloud cover, snow cover, ice, polar regions, etc. Such equations of motion are so interconnected and intertwined that they can only be managed when all aspects are held in big memory and computed simultaneously. Only then can we begin to address the systemic risks associated with natural disasters and planetary change.

- Bob Bishop, Founder & President of the ICES Foundation

As our familiar climate disappears, we will have to rely more on computationally-intensive integrated Earth system simulations to chart the possible future paths of our new planet.

- Larry Smarr, Founder & Director of the California Institute of Telecommunications and Information Technology

The Scope and Vision of the ICES Foundation

Our vision is to create an *international resource centre* dedicated to simulating the dynamic *Earth System as a Whole*. We have set out to build a hub for *global innovation and public good,* using deep scientific understandings combined with advanced modelling, simulation and visualization technologies.

To do this we will:

1) Install and continually upgrade one of the world's fastest supercomputers;
2) Improve the numerical models for the various dynamic natural subsystems of the planet;
3) Assimilate and synthesize data sets from regional and national research partners;
4) Harmonize satellite and in situ data sets with scientific models of the Earth Sciences;
5) Return useful simulation outputs and interactive visualizations to our partner networks;
6) Provide support to developing nations which do not have the necessary resources themselves;
7) Build a training environment for integrative thinkers to specialize in *Earth Systems Modelling*.

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Executive Summary

In the 21st Century, humanity must grapple with the greatest convergence of global challenges in our history—*the difficulty of living in balance with our fast changing Earth*. Now, more than ever, as society grapples with the multiple challenges of climate change, resource depletion, economic development, and human security, a leadership capability is needed that tackles the full complexity of the Earth and its many coupled systems head-on.

Policy makers, community planners, emergency responders, and scientists need to have at their disposal the expert assistance of an advanced capability *Earth Simulation Centre that is able to operate at a global level*. Such a centre would assist in the analysis of global climate and environment, and provide policy guidance for future large-scale shocks and emergencies. It would *complement local and national planning and prediction capabilities by offering an integrated global picture.* As such it would be an invaluable tool for decision support that improves science-based decision making around the world.

We envision that such a centre will include a fully dedicated high-performance computing capability and an appropriate complement of expert technical and scientific staff. The centre will be capable to assimilate all available world data relating to the *dynamic state of the planet*, and provide risk analysis for human security. It will be heavily networked with associated local, national and regional facilities and will access various *Citizen Science Networks* that have recently come on the scene.

When completed, this **International Centre for Earth Simulation** will achieve financial sustainability as a *public private partnership* that works closely with government agencies, international NGO's, and private corporations to provide comprehensive insights into planetary change while generating operational revenue through professional services contracts, patent licensing and leasing compute cycles, while also receiving in-kind contributions from partner organizations.

The ***International Centre for Earth Simulation (ICES) Foundation***, together with its Board of Directors, Expert Committee, and companion website, has already been created and is ready to step up and obtain the necessary high-performance computing equipment, software expertise and visualization technologies to make this vision a reality.

We are seeking strategic partners and financial supporters to build out these vital ICES capabilities in the form of a ***Swiss-based, not-for-profit NGO that uniquely contributes to the public good.***

Learn more at www.icesfoundation.org.

A String of Disasters

Open a newspaper today and you are likely to discover another earthquake has struck somewhere in the world, that threatening wildfires have consumed precious forests and spread beyond control, or that a new “100 Year Storm” is inundating some region, causing flash floods and mudslides. Events like these are more likely in the present century, due to natural variations and the accumulated effects of our encroaching civilization, altered landscapes, burgeoning industry and global warming.

Indeed, we can expect these events to be more impactful in future times than they were in the past—it was once the case that smaller and more resilient communities could avoid harmful impacts when disaster struck—but not anymore, for in a highly urbanized world of multiple mega-cities, and with the world’s population mostly clustered along coastlines, waterways and fault-lines, the geography of risk has profoundly changed.

A brief survey of the last decade is enough to cause alarm—earthquakes in Haiti, Italy, Turkey, Chile, New Zealand and Japan; tsunamis in both the Indian and Pacific Oceans; the Fukushima nuclear reactor meltdown; tornadoes across the Central and Southern United States; wildfires in Australia, California, Chile and Europe; multi-year droughts in the U.S. Southwest, Mexico and the Horn of Africa; heat waves in Russia and Europe; massive flooding in Asia and Latin America; disruption of international travel by Icelandic and Chilean volcanoes; the list goes on.

In fact, we have come through a string of recent disasters that were neither accurately predicted, nor properly assessed for their severity—mostly because of the limited forecasting tools available, and our limited understanding of how Nature’s various systems work in unison. Yet the frequency of such harmful events will most likely increase in the decades ahead, not decrease. And a rise of sea-level around all our coastlines will most certainly exacerbate this situation.

The challenges associated with the management of natural disasters are compounded by the intensification of human activities and their impacts on the planet. Groundwater supplies are drawing short as demand for food production and manufacturing increases. Deforestation and urban development continue to alter the cycling of water, nutrients, and energy—disrupting natural balances that were in place for millennia before industrialization began.

The need for detailed knowledge of planetary change has never been greater. ICES will address this critical need for better and more integrated information, analysis and simulation in dealing with the difficult task of decision-making in these complex and increasingly turbulent times.

Now is the Time

We stand at the nexus of possibilities. Just when the need for synthesis is greatest, the essential elements that could lead to powerful new insights and breakthroughs are within reach. Recent decades have seen the emergence of innovative *new tools and sensor networks* that weave together the strengths of specialized disciplinary knowledge — climate science, geophysics, environmental studies and public health, for example. Furthermore, giant leaps in the power of computing, mathematical modelling capabilities, and data collection and analysis methods have enabled the diverse research communities of the world to run numerical simulations of the most complex processes in their respective domains, with higher and higher accuracy.

And yet the pinnacle of these technologies is not currently applied to the systemic threats of planetary change. Indeed, top-tier supercomputers have thus far been primarily dedicated to the industrial-military complex, while the greatest threats to civilization of all—namely, climate change, natural disasters, environmental contamination, ecological collapse, together with the likelihood of social chaos—have not received the dedication of resources that such a predicament demands. A quick glance at the *Top500 Supercomputing Sites* worldwide shows that none of the ten most powerful machines is dedicated to the Earth Sciences.

It is time to start planning for a truly international climate prediction facility, on a scale such as ITER or CERN. Such a centre would not replace existing national climate centres. Rather, it would allow them to do the sort of research experimentation that is currently impossible.

- Tim Palmer, President, Royal Meteorological Society

Without doubt, our present day world is in immediate need of a continuously updated, fully dedicated, leading-edge supercomputer meta-hub facility that coordinates the global view and brings together the complex simulations and sciences of this dynamic planet on which we live.

The power of simulation-based research within the industrial-aerospace-military complex has been well demonstrated over the last decades, and also demonstrated within manufacturing in general as a design and development tool. Now is surely the time to *'stand up'* such a facility for the world at large, and tackle the most difficult simulation of them all—that of the entire *Earth System*.

A Global Synthesis of Knowledge

The last two centuries are a story of knowledge specialization and splintering. Today, nearly 100 research fields grapple with different aspects of our *Earth System*—each with their own aca-demic departments, peer-review processes, professional journals, and research conferences.

Researchers, scholars and government officials must overcome many obstacles to keep abreast of develop-ments in neighbouring fields. Insights are quite often funneled through parallel stovepipes and silos, with very few major institutions focusing on the *Earth as a Whole*; knowledge integration is not an agenda item! As a result, many great advances of the last century have come at the expense of the whole.

Today, no institutional centre exists that has the capability to model the *Entire Earth System*.

There was an early attempt by Japan however, to fill this void with its *Yokohama Earth Simulator*—launched in 2002 and still active today. It was a great first attempt, making history by using the most powerful supercomputer of the day (an NEC SX-6), with its entire capacity dedicated to planetary dynamics. Sadly, even though this machine was upgraded in performance by a factor of 3 in 2009, it has nevertheless fallen to the 94th position in the November 2011 edition of *Top500 Super computing Sites,* and struggles to remain competitive at a time of severe governmental funding challenges; a subject we will return to later in this document.

And here we should point out that *knowledge synthesis* delivers more than the sum of existing fragments of knowledge. So-called "edge effects" that are found at the boundaries of knowledge domains are fertile ground for both breakthrough insights and new discoveries. There is much more to learn about the complexities of the *Total Earth System* than we comprehend today, all lying in wait for us, but which will only be revealed through the application of advanced modelling methods, enhanced compute power, and extensive efforts to integrate the multiple sciences of the Earth.

ICES will provide this *global platform for knowledge integration and synthesis*, and will encourage strong partnership ties with relevant government agencies, research labs, NGO's and Citizen Science groups around the world.

Yokohama Earth Simulator

Our approach will adhere to the principles of *open coding, open data filing, and open access publishing,* so that information can flow freely and rapidly between the many specialized domains and national geographies that exist today, and in the future.

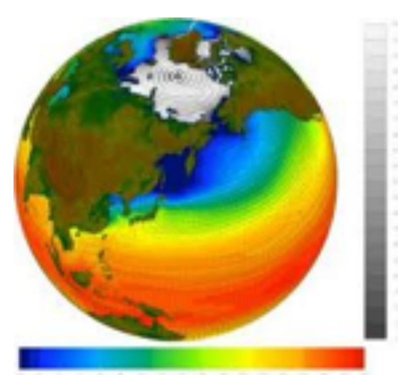
Modelling & Simulation as Platform for Collaboration

For 50 years or more, computer-based simulation has proven to be a robust approach for the study of complex dynamic systems in industrial and scientific research. It offers a powerful extension beyond what theoretical and experimental methods alone are able to deliver. Simulation is now commonly used to explore time-evolution of complex systems where experimentation is not feasible or, in many cases, where it is simply unsafe.
The formation of galaxies, solar systems, stars and planets, for example, cannot be studied experimentally because such systems form on spatial and temporal scales that are far too large for experimentation.

Likewise, *geoengineering* is an area of speculative science and engineering, with potential for unintended consequences with the Earth. Numerical simulations however, enable such ideas to be *safely tested, investigated and studied in minute detail*, and with multiple experts looking on, either at desktop or at an auditorium level.

Today's advanced simulation methods also provide an effective platform for *collaboration between specialists in differing areas of expertise*—it is one of the few methodologies with a track record of success for bringing together deep background knowledge from different fields.

Numerical models could be used to combine global warming, soil erosion, and load-shifting, for example, to examine the combined effect they may potentially have for triggering earthquakes. Such intractable topics as earthquake prediction would benefit from the comprehensive integration



of these three processes and more, into a single model. *Our point is that modelling, simulation and visualization provides the methodological platform to achieve major advances in difficult areas.*

In fact, we are convinced that *Simulation-based R&D can be used as an integrating platform for all Earth Sciences*, and that by building and maintaining a leading-edge scientific super computing and simulation centre, *sufficiently networked to the rest of the world and continuously integrating diverse data sets as they arise*, we can develop new mathematical algorithms and models to great advantage. This obviously calls for ICES to actively participate in the design of global modelling standards across the entire Earth Science community.

We are also committed to providing compute cycles in the case of extra-territorial disaster management and response, as needed in the case of global shocks and emergencies—the need for international collaboration being considerably greater when disaster strikes. It is during these times that the nations of the world will benefit most from a dedicated analysis and prediction centre with global capabilities.

One further point should be emphasized: because of its non-govermental nature, ICES will not compete with existing research centres in their quest for national government funding. Nor will ICES attempt to duplicate their various data collection efforts. Our role is to integrate and synthesize what is already known, to build next-generation models of the *Whole Earth System*, and to educate the *next generation of holistic thinkers and policy makers*.

We will act as a research facility, compute resource, and knowledge bank that *leverage local, national, and regional efforts to the planetary scale*.

Despite tremendous progress in climate modeling and capability of high-end computers in the past 30 years, our ability to provide robust estimates of the risk to society, particularly from possible catastrophic changes in regional climate, is constrained by limitations in computer power and scientific understanding.

- Jagadash Shukla, President, Institute of Global Environment and Society

Advances in High Performance Computing

Because of Moore's Law, technological advances in the semiconductor industry produce a 1000-fold improvement every decade in the price/performance ratio for computing. This means the highest performing machines today are a million times more powerful than the best machines built just 20 years ago.

Today's top computers achieve *multi-petaflop*[1] performance—they can perform trillions of calculations *every second*—and such compute power has brought a number of previously intractable problems within reach of current numerical modelling and simulation techniques.

The complex dynamics of ecosystems, atmospheric and oceanic circulation and many of the complex aggregation processes involved in the formation of galaxies, stars and planets for example, have been successfully simulated on present day high-performance computers.

High-performance computing facilities are very expensive to maintain however, and only a few governments can afford to invest in the infrastructure and expertise necessary to attempt simulations of the Earth *on a global-scale*—with USA, Japan, China, Germany, France, UK being exceptions to the rule—but the complexity of global simulation is so great that even these governmental efforts are very limited in scope.

We firmly believe that the only way to move forward so as to understand and successfully predict global-scale Earth system and ecological threats is to pool resources globally, as well as to collaborate across national borders in this effort.

[1] One petaflop equals 10 to the power of 15, or 1000 trillion floating-point operations per second.

Just as CERN was expensive and above the budget and knowledge limits of any single national government to build and maintain, the same *raison d'être* exists for having only one globally chartered Earth Simulator capable of staying at the crest of all the component technology curves and being the ***meta-node*** of a global network. *It is here that we seek to place ICES.*

In addition, just as CERN hosts an expert community of technical talent, so will ICES provide a resource pool available to assist the various national scientific communities in tackling the most complex and difficult challenges within various components of *Earth Science*

Our goal for ICES is to build a supercomputing facility, annually ranked in the top ten machines of the world, and to dedicate its capabilities to combining all sciences of the Earth: a global centre that complements the limited capabilities currently available at the local, national and regional levels, and a centre operating under open access, not-for-profit principles. The simultaneous threats of climate destabilization, ecological disaster and resource depletion *surely demand the very best response we can muster as a prosperous civilization.*

Creating Value from Massive Data Pools

We live today in an information age, but we can easily be overwhelmed by the deluge of data around us. Smart devices such as mobile phones, laptops and tablets proliferate and have rapidly become ubiquitous. Indeed, Internet access is essentially available to all, and as a consequence, many data streams have become truly astronomical in scale to feed this community of users—storing and forwarding peta-bytes[2] and even exabytes[3] of data per year.

Immense amounts of data are generated each day by Earth Observations from space, land and ocean. Harmonization of practices and procedures for their use, through an international effort, is one of the key challenges and priorities to advance understanding of the Earth System and planetary change.
- Michael Rast, Head of Science Strategy, Coordination & Planning Office, ESA

Emerging from this data-rich environment is the science of ***big data analytics***—that is, the practice of mining huge volumes of data to reveal important patterns and insights.

Of particular interest to ICES are the pools of data recorded minute-by-minute by *sensor networks* that monitor surface weather, ocean currents, seismic activity and many other aspects of our planet's behaviour, since every nation gathers information about the Earth in some fashion, either from in-situ, ocean or space-based devices.

The existence of such data pools is critically important to ICES, as we will require access to them for use as input to our modelling and simulation efforts. Toward this end, *we strongly support the efforts of all national governments to build portals that make their data archives open access, and freely available.*

The use of data of global scope in fact already hints at substantial improve-ments in forecasting of local extreme weather. Severe weather is known for wreaking havoc on many areas of the world, at very high cost to life and limb. The price of more accurate weather modelling and fore-casting capability pales in comparison to the damages caused by unforeseen weather events. Improve-ments in storm track forecasting have a rapid ROI, but they require access to the full panoply of world data, not just local data.

For example, the cost of hurricane evacuation on the US Atlantic seaboard exceeds $1 million per coastal mile, or $100 million in the case of a hurricane that cannot be predicted to come ashore within one hundred miles. A

[2] One petabyte equals 10 to the power of 15 bytes
[3] One exabyte equals 10 to the power of 18 bytes

50% improvement in forecast accuracy would lower this cost by $50 million, provided it could be accomplished in a timely manner; enough to recover the cost of much high performance computing equipment in a single event, and more importantly, saving lives along the way. The economic impacts of this one scenario make ICES a highly desirable investment.

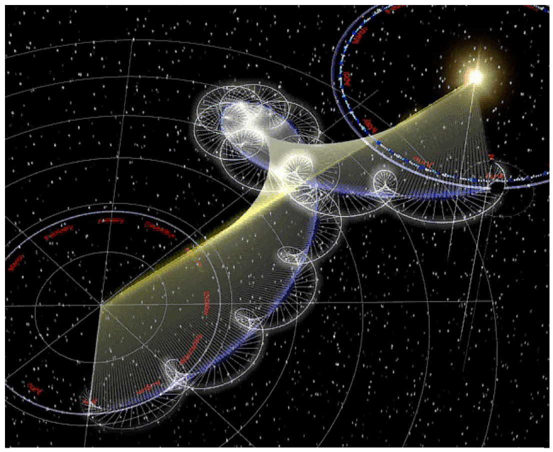
In addition to *big data analytics*, ICES will also provide HPC consultation and compute cycles to developing nations and regions which do not have the necessary resources themselves—*devoting 25% of our total computing capacity to less developed nations that cannot afford research facilities of their own.*

Interactive and Immersive 3D Visualizations

Critical to *big data analytics* is the ability to extract, manipulate and visualize any information under investigation. Policy makers, elected leaders, journalists and indeed the general public will need *compelling visual narratives* that convey important insights about our changing planet in order to convince them to take action at the local level.

Researchers themselves will need increasingly sophisticated visual representations of the physical processes they are studying, especially as model complexity increases and more processes of Nature are introduced.

One important advantage for visualization-based analysis is that computer simulation output can be presented as *multiple layers of data for every time-step in a key process*. Although the underlying physics and chemistry must always be calculated by the brute force of numerical computation, visual output enables the human mind to understand Nature's fundamental processes quicker and more deeply.



Visual Representation of Earth spiraling around the Sun

Furthermore, such *'visual computing'* allows any number of viewers to explore *these virtual worlds with precision and rigor*, either locally or remotely, either individually or in an auditorium setting. In this respect, we have all witnessed the remarkable comprehension that Google Earth, IMAX theatre and daily televised weather reporting has brought to us.

Even in the arena of children's entertainment, modern video consoles demonstrate just how powerful immersive and interactive visualization can be. The image realism rendered within game worlds like 'SimCity' and 'Second Life' is an essential ingredient for meaningful engagement today—and it cultivates millions of young players, as a result. Similarly, we believe that when scientific simulation is combined with photo-realistic imagery in Earth Sciences, it will encourage a wider community of individuals to explore the dynamic Earth in ways that go beyond what is possible today. We all understand that *seeing is believing*—and, in this case, *'believing' opens the gate to broad and constructive engagement!*

Reasons such as these have caused *visual simulation* to be routinely employed as a professional training tool in recent decades—from *flight simulation* training for pilots to *surgical simulation* training for medical specialists.

Virtual worlds allow people to learn from their mistakes in a low-impact environment before moving on to the real world. In a similar way, ICES will emphasize the importance and training value of *intuitive, interactive and immersive visualization for understanding Nature's complex systems*.

We will provide this capability via the Internet to our clients as a valuable part of our simulation output. Decision-makers and emergency responders alike will benefit from interactive simulations of global or localized scenarios, *providing the ability to minimize their risks and avoid potentially catastrophic harm through practice at zero cost in a virtual world and without causing damage.*

Leveraging the Many Layers of Computing

Supercomputing is regarded as the pinnacle of computing capability, and clearly ICES will make extensive use of it to accomplish its mission. Yet there is a hierarchy of machine power leading up to this level, all of which may find relevance in our operations.

The nearest layer below supercomputing is *Grid Computing*, where several machines of lesser performance are networked together, and where an overlaying software architecture allows users to break their work into multiple segments, and then scatter the work over the distributed machine network for execution.

If the machine network can be *'metered'* for usage and the various costs charged out to individual users, it is often labeled *Cloud Computing*. Recent advances in 'virtualization' and database access have led to the widespread adoption of *Cloud Computing* in the business world. This same method however, is finding its way into the world of science.

In a complex world where divergent interests are in competition, simplistic solutions are not successful—and are probably unworkable in the real world.

- Martin Beniston, Director, Institute for Environmental Sciences, University of Geneva

Grid Computing or *Cloud Computing* will work nicely if the calculations at hand do not require intensive communications between the scattered software segments, but such methods will experience massive bottlenecks when references across the network become intense.

Attempting to calculate the vast array of parallel and contemporaneous physical processes in a full *Earth Simulation* will obviously suffer such latency effects, and the bottlenecks will negatively impact the availability of final results. As such, *Grid Computing is less capable of delivering on-time critical simulations compared to a single consolidated system of equal horsepower—which is the hallmark strength of supercomputing*.

At a level below Cloud Computing we have the Internet itself, and below that, individual desk-tops, lap-tops, tablets and smart phones, most of which today can be connected to the Internet, and which can be viewed as *access devices* for downloading data from *'the Cloud'*, or sending data up to it.

It is the intention of ICES to use whatever level of the computing hierarchy works best, decided case-by-case, for each of its component software developments. However, when it comes to modelling, simulating and visualizing the most complex of its global challenges, there is no doubt that *communication considerations between each of the multiple job segments will force the work onto a centralized supercomputer that is fully dedicated and able to produce high-resolution results in a usable time-frame.*

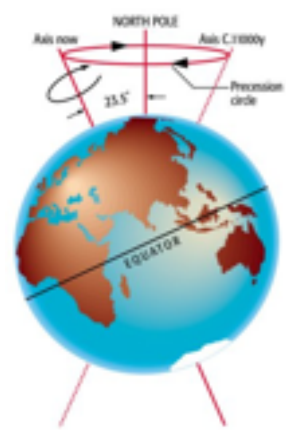
Distributing results from the supercomputer to others will be possible via the public Internet however, sometimes with the intermediate support of Cloud Computing. Through such a digital infrastructure, it will be possible for clients to access ICES visual simulations via the Internet that are both immersive and interactive. In this manner, ICES will make use of the many layers of computing at its disposal.

Getting A Complete Picture of the Whole Earth

When looked upon from space, the Earth is seamlessly integrated—a borderless swirl of land mass and oceans—yet our knowledge about the Earth is neither seamless, nor borderless, nor integrated. To understand it, science has sliced the Earth into various time-periods and subsystems. Three centuries of reductionist thinking has advanced by separating the world into manageable pieces—a process of *dis-integration* that has resulted in the academic silos and stovepipes we see today.

A brief survey of present day research fields illustrates the fragmented picture: the solid globe beneath our feet is categorized into the elementary layers of core, mantle, crust, asthenosphere and lithosphere. Then special phenomena within these layers become sub-fields, such as *fault lines, subduction zones, geysers, and glaciers,* to name but a few. Likewise, in atmospheric science we have the elementary layers of troposphere, stratosphere, mesosphere, thermosphere, exosphere, ionosphere, and plasmasphere and then the recognition of special phenomena such as *radiative transfer, aerosol chemistry, cloud formation, convection*, etc—all of this just a small sampling of the *complex research fields and sub-fields that make the study of the Earth System possible today.*

Were we to also segment the oceans (which occupy more than 70% of the Earth's surface), or divide up the Earth's biological systems along similar lines, the number of research fields would explode exponentially, and reach well over one hundred independent, but somewhat overlapping fields. Thus the intrinsic complexity of the Earth is manifest by this vast array of specialized research domains which has been formed to analyze the intricacies of its constituent pieces.



Yet even this is insufficient, for another dimension of knowledge organization is needed to speak of *cyclic effects* and the *time dynamics* of certain processes. There is a ***hydrological cycle*** for clouds and rain, rivers and oceans, plant respiration, and erosion of the land, for example. ***Carbon and nitrogen cycles*** combine geology with life—tracking the profoundly malleable atoms chemically embodied in all living things, while also constituting the various forms of air pollution, rock formation, and atmospheric heat-trapping**.** And other major cycles on Earth entail ***atmospheric circulation and seasonal change***. At an even larger scale, we have the ***Milankovitch Cycles***, *describing orbital parameters of the Earth-Sun System, which dictate the coming and going of ice ages.*

In order to understand these many aspects of our changing Earth—a pre-requisite for civilization to become sustainable—*many specialized fields and sub-fields must be brought back together into an integrated whole****, which is the key priority of the ICES mission.***

Influence of the Solar System

At this point, we should point out that any effort to model and simulate the *Whole Earth System* will need to include the physics of *larger cosmological influences*. *The Earth is not a closed system; for it is constantly bombarded by radiation and high-energy particles from the Sun*. This activity warms the planet, feeds the photosynthetic process, and alters the chemistry of our atmosphere.

Just as studies of the Earth have traditionally been fragmented into multiple domains, so has the larger Solar System in which the Earth is embedded. Embracing the complexities of our changing planet requires that we include the physics of relevant cosmological forces in all of our simulation studies. State-of-the-art climate models in use today do not include many of the dynamic interactions that actually occur between Earth and Sun. The Sun is often simplified in these models as a static and constant energy source, despite the fact that ***coronal mass ejections*** from its surface routinely collide and interact with the upper atmosphere of the Earth and interrupt its chemistry as well as the magnetic field that shields all land-based life from deadly radiation.

On longer time scales, the *'many body'* gravitational effects of our neighboring planets produce both tilting in the Earth's axis, as well as variations in Earth-Sun orbital distance, which in turn produce both ice ages and warmer periods on Earth. Such factors are often included in *advanced* astrophysics simulations, but remain yet to be combined with other physics in computational modelling of the Earth System itself. In addition to this omission, the interior of our Sun is in constant and violent flux, and this must also be taken into account as to its effects on Earth, if we want to arrive at accurate future projections.

A multitude of less identified space objects constitute a further subject for inclusion. Indeed, the prevalence of comets, asteroids, and meteorites in our Solar System regularly threatens our home planet; and even our own self-created space junk from 50 years of national space programs is a continuous hazard for all of society's communication satellites and future space projects. One theory even has it that the age of dinosaurs was brought to an end by a massive asteroid that struck the tip of the Yucatan peninsula some 65 million years ago.

Clearly, a comprehensive study of Earth Systems requires us to bring all of these considerations together, and to combine a much wider plethora of *interacting factors than currently embraced*. ICES will thus incorporate solar physics and astronomical phenomena into its modelling, and be sure that the associated risks are fully quantified.

Prediction & Uncertainty of Extreme Events

A major contribution to social well-being that ICES will make is in the domain of *extreme weather prediction* and *natural disaster risk assessment*.

The challenges of predicting the behaviour of complex systems are well known, namely that intricate feedbacks create a sensitivity to unknowns that tends to be both subtle and dramatic. The most sensitive of all being those processes that are *non-linear* in nature—whereby small changes of input lead to extremely large changes in output.

It is striking to note that these processes are the very ones that are least understood and most poorly characterized in the best computer models we have today.

As for climate change, uncertainty is *the* major issue, because the potential harms of global change have a broad range of possibilities, many of which can be dramatic in their impact. One critical aspect of climate change is the issue of *sea level rise*. If major ice sheets in Antarctica and Greenland melt more quickly than current climate models predict, there will be significant raising of ocean levels worldwide.

Current model outputs give a conservative estimate of roughly one meter sea level rise by the year 2100. Incorporation of non-linear *land-ice feedbacks* however, will likely increase this by several meters, with obvious catastrophic effects on coastal populations, world wide.

Incorporating all relevant feedbacks in our *Earth System Models* however, will require a substantial enhancement in the sophistication of the numerical models themselves, as well as a strong boost of underlying compute power.

Current global models have a horizontal resolution accuracy of around one hundred kilometers at best, whereas we will need to improve resolution accuracy down to at least 10 kilometers going forward. Vertical resolution, on the other hand, will need to be taken to the single kilometer resolution level. Available compute capacity is a major limiting factor that slows progress on improving resolution accuracy, and indeed model development in general—and these factors argue strongly for building the ICES facility as soon as possible, so as to enable fine-grain atmospheric phenomena such as cloud physics, convection, and vorticity, as well as eddy currents in the ocean, to be taken into account.

Further complicating Earth System prediction efforts today is the deep inter-connectedness of natural systems with our socio-economic systems—*we have learned the hard way that the propagation of risk across adjacent domains can trigger Multiple Synchronous Collapse*: that is, disruption in one system spreading to disrupt others around it.

A striking example was witnessed in the March 2011 Fukushima nuclear meltdown in Japan that arose through an unanticipated series of system linkages. In this case, the major slippage of a subduction zone on the ocean floor near Japan produced a magnitude 9.0 earthquake, creating multiple tsunami waves that were 10 meters high or more when they reached the shoreline of the Tohoku region some 30 minutes later. Water poured into the narrowing valleys, increasing the wall of water to heights of 40 meters or more at the inland end of those valleys.

On the coastline itself, waves broke over the protective barriers and inundated the various cooling systems of the Fukushima Daiichi nuclear energy plant, causing the meltdown of three reactors and producing several explosions that shook the neighbouring villages.

Three weeks later, a radiation cloud and leaked radioactive water reached foreign shores, giving this event its ultimate global impact. More than 20,000 people lost their lives in the combined earth-quake, tsunamis and nuclear meltdown, with over 400,000 people dislocated—all of which was unanticipated—but all due to the tight coupling of so many adjacent natural and socio-economic systems.

Fukushima is a wake-up call, and we should all realize how serious the phenomenon of risk propagation and Multiple Synchronous Collapse can be. It cannot be approached in a piecemeal manner. Only through synthesis and integration can the systems in close proximity to one another be simulated as a whole. It is in this capacity that ICES will be uniquely useful. A global effort to bring coupled systems of the Earth together as a seamless whole is needed to even begin the difficult work of ***Disaster Risk Reduction*** *in the 21st Century.*

The Role of ICES for Cities and Bioregions

Many of the most significant actions pertaining to sustainability are now underway at the local level—principally at municipal and bioregional scales. It is almost a truism to say that ecological risks are irrevocably bound to urban issues. Whether dealing with water quality, air pollution, access to a stable food supply, or increasingly constrained material inputs for industry, the majority of solutions are being crafted and implemented by city managers, regional planners, and their affiliated local institutions.

Drainage basin for the Amazon River

The recent disaster in Japan reminds us that global threats arise from local disturbances. The same is true in reverse—localized risks are contingent on the larger-scale drivers that influence and constrain them. In the parlance of numerical models, the key issue is *the characterization of boundary conditions* that represent what flows into a region and how changes in the region flow outward to impact other locales.

Currently there are many efforts to simulate the dynamic linkages for specific bioregions, one example being the Amazon River watershed where vast forests intersect with numerous waterways to cycle water and nutrients across the South American continent. Efforts such as this depend on highly detailed sensor networks to gather sufficiently precise data to describe all of the key physical processes. And yet the large-scale energy fluxes from atmospheric circulation, ocean mixing, and plate tectonics all contribute significantly to what happens locally.

It is here that ICES can play a critical role for cities and bioregions—tuning the performance of global Earth System models to the point where *downscaling* can reliably inform boundary conditions for local and bioregional simulations. Downscaling involves finer spatial and temporal resolution than that used by the global model to form a mathematical bridge across scales. No global-scale climate model in use today is able to characterize localized weather patterns well enough for regional planning purposes.

Contributing to model improvement goes both ways. Global models can increase the effectiveness of high-resolution local and bioregional simulations by strengthening linkages between large-scale patterns and local boundaries. In a similar manner, high-resolution data sets from local and bioregional sensor networks can be used as inputs to train global models. This virtuous cycle allows for the intricacies of local contexts to be combined with the global patterns that arise at the whole-system level.

Neither can succeed on its own. While the appropriate scales for policy implementation are municipal and bioregional, the flows coming in from global systems are necessary for planning purposes. Continual improvements can be made for modelling efforts at both scales through ongoing dialogue and collaboration. ICES will provide an international platform with sufficient neutrality to accelerate this discourse so that model improvements come more quickly.

Two other challenges for regional planning comprise the yawning gap between short term weather forecasting and longer-term climate modelling, as well as precipitation forecasting accuracy. Both of these challenges remain unresolved at this time. ICES will add its integrative skills to these problem areas.

Towards Urban Resilience

A global movement is now underway that focuses on carbon neutral urban landscapes, regional food safety, green building construction, and the recycling of waste products—spearheaded by the world's major cities.

Increasing emphasis is placed on transportation systems, energy distribution, public health, and quality of life for people within these cities.

Every *State of the World* report published by the Worldwatch Institute since 2006 has focused on urbanism to draw attention to the remediation of severe ecological deterioration using improved design of cities, old and new.

In a recent TED Talk, reknowned innovator Stewart Brand described how we are in the midst of a great migration of people from rural areas to squatter cities and urban slums in many regions of the world. Nearly all population growth in this century will take place in these new urban dwellings, with mega-cities emerging rapidly throughout Africa, Asia, and Latin America.

Cities are both the progenitors of development pressure contributing to environmental harm and the cultural incubators of technological and social innovation. The latter increasingly paving the way to a sustainable future. They are where the action is for policy implementation, as well as being the economic engines of the future.

Ecological design principles are being used to apply *biomimicry*—inspiration from biological and living systems—to plan urban development through the lens of ecosystem science.

The same principles apply here as they do at the bioregional level. Local systems must incorporate global fluxes into their development models. It is here that ICES, once again, can play a contributing role.

As cities grapple with economic and environmental issues, they will increasingly depend upon dynamic modelling to identify hazards and reveal opportunities. Urban planners extensively use *geographic information systems (GIS)* to analyze layers of information that overlap within the same landscape. They build up detailed databases for utility grids, storm water and sewage systems, transportation networks, etc.—often enabling them to run simulations of their interconnected systems in order to develop *smart city* architectures.

Of particular concern is the balance between urban density and hinterland agriculture, where the rural areas become closely coupled with city planning. Again this is an area where whole-system integration of larger-scale processes becomes essential for synergistic outcomes.

The impact of land use changes and water depletion often jeopardizes the productivity of agricultural lands. Conflict is a major source of frustration for urban development in such cases, exacerbated in part by the lack of adequate foresight and understanding of these interlocking issues.

City managers and regional planners would benefit from an integrated picture of complex interlocking issues in order to do their jobs more effectively.

Who are some of ICES Clients?

A diverse global portfolio of government agencies, NGO's, research institutions, and corporations stand to benefit directly from the outputs of ICES. The ICES Foundation has been very well received at recent international conferences, and during presentations given to academic institutions and corporate research labs. Endorsements in hand confirm the need for an ICES-type institution, and acknowledge the possible ongoing benefits it could create for a wide community of international organizations. And as these organizations absorb and pass on their increased knowledge and awareness to the public, the public in turn will benefit.

Drs. Ghassem Asrar, Director of the World Climate Research Programme (WCRP), and Antonio Busalacchi, Chairman of the Joint Scientific Committee of WCRP make the case for ICES in their letter of support written on December 22nd, 2010. They articulate the following benefits for ICES partner organizations around the globe:

- Understanding the causes and assessment of consequences for low frequency but high impact extreme events in a changing climate;
- Inclusion of additional complexity in existing climate models to account for interactions among interconnected biological, geophysical, socio-economic and other factors;
- Significant increases in the spatial resolution of simulated fields from thousands of kilometers for model projections;
- Addressing the urgent need for sub-seasonal, seasonal, decadal and long-term predictions as a continuum from weather-to-climate time scales.

Our best chance for delivering these benefits is to dedicate a top performance computing facility to the effort, providing open access for national and regional partners to contribute their numerical models, data sets, and extensive expertise. *Citizen Science organizations will also have an increasing engagement with ICES, especially as these entities grow and become more sophisticated in the years ahead.*

Technology partners say the same thing. Dr. Matthias Kaiserswerth, Director and VP at *IBM's Nobel-Prize winning Research, Switzerland*, put it succinctly when he said *"the mission behind ICES is very complementary with IBM's vision of a smarter planet—and your timing couldn't be more relevant."* The need to push computing to the '*exascale*' level in the next decade and to address grand challenges such as the ICES mission is widely recognized within the computing industry.

ICES will be a conduit through which world data is incorporated from local, national and regional sources, and returned as simulation outputs back to this network of recipients. The scientific rationale for establishing a *global hub* is almost identical to that for CERN and ITER—achieving pinnacle performance through consolidation of resources, whilst tying in a global network of collaborators. Such an act of consolidation is necessary to scale up the compute power and model complexity necessary to reach the levels of a viable, robust and fully integrated *Earth Simulator*, as has been already described. However, in our case, we do envision ICES as a *public-private partnership*, rather than simply a government controlled organization.

Yet it is those organizations operating at the coalface that stand to benefit most: *the vast community of international NGO's which exist to promote human safety, well-being, and economic development*. These organizations incorporate a global communication infrastructure which will be useful for distributing the scientific findings that will derive from ICES simulations, and translating them into a myriad of local contexts where the daily need for risk management and reduction exists.

In this manner, *ICES is designed to operate as a community resource that raises the entire global network of practitioners and participants to new levels.*

Making the Business Case for ICES

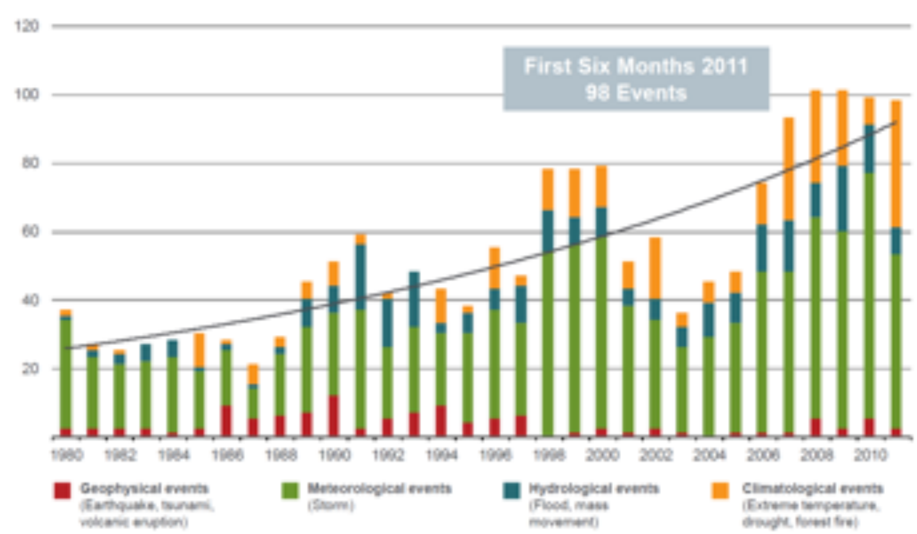
Many industries depend upon robust insights about environmental futures for market analysis and business strategy as they strive to increase their profitability in a changing world. As such, the business world stands to benefit considerably from the outputs of ICES simulations.

The insurance industry is a classic example, where increasing costs from natural disasters threaten the business model of many insurance companies. In 2011 alone, a total of $380 billion US was incurred in global losses from some 820 loss-relevant events,[4] breaking previous record highs for the third time in the last decade.

The rationale for improving predictability of natural disasters is clear: insurance companies will need in-depth knowledge about changes in the geography of risk, including the dynamic nature of planetary processes, for they must pay out claims for loss of life and property when *built-costs* alone are sharply escalating in a densely populated world.

Implications for energy production are equally clear. In the past, petroleum companies depended heavily on geologic surveys to assess market scalability for oil, coal, and natural gas extraction. Now as the pressures for alternative clean energy grow daily, the ability to forecast where the winds will blow and how much cloud cover to expect are essential to the estimation of ROI for wind and solar power investments. In the fossil fuel industries, CCS (*Carbon Capture and Storage)*—an approach that may become essential for staving off the worst impacts of climate change—requires accurate knowledge about geologic forces to deter-mine where carbon stores might be lo-cated, and how long they are likely to remain secure.

The global challenges for food production make ICES outputs invaluable yet again. Agricultural productivity is contingent on water supply, soil quality and sunshine, and also the year-to-year stability of such factors—all of which are deeply entangled in the web of cycles mentioned earlier, namely: the



[4] http://www.munichre.com/en/media_relations/press_releases/2012/2012_01_04_press_release.aspx

potential increase in flooding that washes away top soils, or in other instances, suppresses rainfall and creates extended drought and desertification of formerly productive lands. Access to *globally integrated, high resolution modelling* is going to be essential for agribusiness companies to provide food for the estimated 9 billion people who will populate the planet by mid-century.

We have already alluded to the coastline uncertainties associated with sea level rise, uncertainties which have strong implications for the valuation of nearby real estate. Add to this the complications from inland wildfires, flash flooding, earthquakes, and the serious possibility of widespread climate-induced migration, and the need for better simulation outputs with an integrated perspective becomes great indeed. Urban planners, construction companies and real estate developers therefore make up another business category that will need to accurately estimate the future economic value of land resources.

The business case for ICES is thus deep and strong. And with the rapid rise of *sustainable business practices* across the globe—a trend that most likely will continue into the foreseeable future—the value of having an international research and policy guidance facility to demonstrate this necessary competence is both pervasive and profound.

The ICES Network of Participants

The partner network we envision for ICES includes a broad spectrum of scientific bodies, humanitarian organizations, government agencies, citizen science networks and private corporations. An expansive list has been compiled on our website. However, the following is illustrative of organizations that would stand to benefit from ICES.

First and foremost is the Geneva-based World Meteorological Organization (WMO) and its member network of highly competent national weather services. The WMO itself does not have, nor does it plan to have, a central simulation capability of its own in the future, and therefore depends solely on computing facilities controlled by local, national and regional agencies. Hence a dedicated, high performance computing facility in nearby physical proximity such as ICES, which could be directed toward globally significant events as needed, would be a major complementary asset for the WMO.

Of course, the significance of the WMO and its network cannot be overstated, since it provides data collection and synthesis worldwide, and has broad analytical and communication capability, with a 100-year history of operational success.

In the humanitarian realm, there are groups like the Geneva-based World Health Organization (WHO), International Strategy for Disaster Reduction (ISDR), International Committee of the Red Cross (ICRC), UN High Commissioner for Refuges, (UNHCR), and the World Bank.

Struggling to keep pace with global change, organizations such as these will need to map out the geography of risk for human populations in many parts of the world. They lack the modelling and simulation capabilities necessary to bring the full force of science and technology to bear on their attempts to promote long-term human security.

And, of course, there are the institutions that have already built a limited amount of global climate and environmental understanding, such as: the UK Hadley Centre, Germany's Climate Services Centre, Max Planck Institutes, DKRZ, the US National Center for Atmospheric Research (NCAR), and the European Environment Agency, as well as the United Nations Environment Programme (UNEP), World Wildlife Fund (WWF), Nature Conservancy, Global Earthquake Model and Global Carbon Project.

Such organizations depend extensively on integrated scientific research to guide their policies and inform their constituencies.

ICES intends to be seen as a key infrastructural element and partner for assisting these organizations in policy and knowledge development, by delivering a globally integrated picture of Nature and the entire Earth System.

Training a Legion of Integrative Thinkers

In the passages above, we have drawn attention to the technological and scientific challenges that will be involved with global modelling and simulation efforts. No less important is the need for human leadership to tackle these challenges—locally, nationally and regionally.

ICES will play a vital role in cultivating leaders of tomorrow who can articulate and evaluate the broad set of issues facing the planet at large. And in addition, while the need for specialized technical and scientific expertise continues, there is a growing recognition that more resources for cultivating transdisciplinary expertise are essential if we wish to deal with the enormous complexities of integrative modeling at any level.

In this respect, the next generation of leaders and decision makers will require a far deeper level of *integrative thinking* than permeates our society today. Those efforts in the academic world to synthesize fields of research across disciplinary boundaries, laudable as they are, have been very limited to date, due to the absence of institutional resources. ICES will fill this gap by operating as a research base, a policy guidance forum, and an open access network for graduate students, postdoctoral researchers, professional scientists and policy makers alike.

In summary, ICES will be an immediate contributor to building integrative frameworks for Earth Systems Science:

- including computer modelling, algorithm development, and big data analytics;
- including computer systems architecture, data assimilation, and reanalysis;
- including interactive data visualization and communication technologies.

And in its future phase, understanding the linkage of socio-economics with Earth Science, especially in the areas of health, food & agriculture, pollution, sustainability, transportation, and in guiding public policies for risk mitigation and disaster management.

ICES will provide research facilities, scholarship opportunities, and educational tools for the rising wave of scholars and researchers who bridge the traditional knowledge boundaries. Nurturing this human capacity is a major part of our mission.

Why we need a Non-Governmental Player

The positioning of ICES outside the public sector also deserves special commentary, and in what follows we will explain our motivation to do so, since the current landscape of *Earth Systems Science* is comprised almost entirely of government departments and their sponsored academic institutions and agencies.

Perhaps most prominently, there is the case of Japan and its *Yokohama Earth Simulator (YES)* that was mentioned earlier, which started out as a highly competitive facility with the most powerful machine of the day. Yet it was unable to maintain this position, we believe, because it depended solely on funding from the Japanese government. Housed within the Japan Agency for Marine-Earth Science & Technology (JAMSTEC), YES resided within a structure that was not designed specifically for *globally integrative cross-border work*. Both these factors have negatively impacted the efficacy of their attempt.

Of course, we are delighted that Japan had the brilliance to lead the way and to get their scientists to first base. Yet the outcome of their experiment makes the case for a truly global effort—exactly what we seek to achieve through ICES—all the more clear. *Building a global simulation capability goes beyond national borders and budgets. It is too expensive for all but a few countries, each having its own political realities that complicate earnest attempts.* And, as the 2008~2012 global economic downturn has shown, big projects can be significantly undermined when national government budgets get squeezed.

At yet another level, the Intergovernmental Panel on Climate Change (IPCC), sponsored by the United Nations, is a very well known organization driving nations of the world to cooperate around a global ecological challenge. While the IPCC has performed admirably at establishing a strong consensus among scientists about the impacts of human activity on global change, it adopts a political process of broad inclusivity (for example, giving all submitted models equal weighting, regardless of merit), and this creates some potential distortion in the results of greatest relevance to policymakers such as *sea-level rise and climate sensitivity to* CO_2 *doubling.*

Clearly, participating countries seek to politically influence the IPCC with national interests in mind. Failure of the 1997 Kyoto Protocol, and delays with COP15/16/17 at Copenhagen, Can Cun, and Durban, respectively, demonstrate the enormity of this challenge, as national priorities stand to gain and international consensus proves elusive. *There is indeed tremendous need for independence, integrity and neutrality to allow this vital effort to progress on behalf of the entire international community*.

Similar political dynamics can be found within the machinations of a single nation, where national government agencies compete for legitimacy and expense budgets, making it difficult for research staff to collaborate in a sustained manner across departmental silos. In the United States for example, the operational domains of NOAA, NASA, NSF, USGS, EPA, DOC, DOI, DOE and the DOD significantly overlap, but there is no clear path to integrating their vast Earth science research systems without threatening livelihoods and creating an overall political backlash from vested interests.

I am a huge believer in public-private partnerships. They are hard to do, but when they are successful, they are extremely successful.

- John T. Chambers, Chairman and CEO of Cisco Systems

For all these reasons, ICES is not approaching government agencies for direct cash funding—for fear of contributing even more to these conflicts. Instead, ICES will operate as *an independent, not-for-profit, non-governmental enterprise* where philanthropic contributions can be applied directly—avoiding the conflicting concerns commonly experienced within the public sector that have proven to be barriers to cross-border and cross-departmental scientific integration. But because, on the other hand, ICES will be highly dependent on government data and scientific inputs, it is choosing to position itself as a ***Public-Private-Partnership***.

A Lesson from the Private Space Industry

Of course, we aren't the first to deploy this strategy. The emergence of a vibrant space industry in the private sector shows how non-governmental entities can drive technological advancement to meet an ambitious set of global objectives. Decades of government sponsorship seeded an industrial ecosystem out of which many *for-profit commercial ventures* have recently sprung, including the formation of companies that provide low orbit satellites, spacecraft, launch facilities, and a host of specialized space solutions.

Often working in close partnership with government agencies, these private compan-ies bring an agility and focus to complement public efforts while adding synergistic tech-nology developments. The X Prize Foundation has become pivotal as an innovation incu-bator for next-generation tech-nologies, made famous by its role in seeding the private *space tourism industry*. Richard Bran-son's *Virgin Galactic* now offers the experience of space travel to broader audiences than public sector space programs were able to. Future supply convoys for maintaining the *International Space Station* are most likely to be operated by private enterprise for the remainder of this decade

It is the network of non-governmental activity having deep linkages to public agencies where the *'secret sauce'* develops. We see ICES operating in an analogous fashion, by positioning itself outside the public sector but with significant connectedness across government agencies—bringing flexibility, agility, and fast response in an era of multiple global shocks, challenges and threats.

Our Model for Public-Private Partnership

The ICES Foundation plans to operate as a ***not-for-profit, Public-Private-Partnership (PPP)***, physically based in or near Geneva, Switzerland. It will effectively be the *'CERN of Sustainability'—a world-class research and policy-interface facility that is available to partner with scientists and decision makers globally.* Switzerland itself is renowned for an international outlook and humanitarian consciousness, but perhaps most of all, it is known for its *long-standing neutrality*. Hence it makes an ideal home base for ICES operations.

We have chosen the ***PPP*** structure as a means to help us establish close ties with public institutions, while at the same time seeking private funding sources. The Swiss Federal Government has rigorous protocols regarding the public accountability of Swiss-based foundations, which requires for ICES to operate with the utmost integrity in achieving its mission on behalf of the international community and donors. Working with other government agencies across the globe, surveillance by the Swiss authorities will be valuable for building trustful relationships abroad.

Strategic partnerships are currently forming around the grand vision of ICES, with institutions such as the WCRP, University of Geneva, Institute of Global Environment and Society (IGES), Ecole Polytech Federal Lausanne (EPFL), CERN and the Swiss-based IBM Research Laboratory fully supportive. We have spent the last two years building the case for ICES at many international conferences, universities, and research centers, and now we are ready to launch ICES as a functioning platform.

It is indeed a propitious time to launch the next step of the ICES journey and we are ready to receive funding and build out the full network of primary partners. *In the early part of 2012, we are planning to reach out to founding donors and raise the seed capital for operational stand-up*. This will be a modest step in a long march, and by the end of this decade, we envision ICES having a US $50 million annual operating expense budget and employing a total scientific and technical staff of roughly 200, many of whom will have been seconded from partnering organizations. This operating expense budget will

How ICES will achieve Financial Sustainability

Our income stream will not be limited solely to philanthropic donations throughout the duration of our long-term mission. Many avenues for creating revenues will be available to ICES, for example through sponsorships, professional service contracts, patent licensing, and selling compute cycles as a service bureau. We envision diverse revenue streams that result from delivery of timely, high-value knowledge in the midst of turbulent global change, even while ICES maintains an open code, open data, open access publishing philosophy. We anticipate that these revenue streams will eventually offset one third of our annual operating expenses.

The second one-third of our expenses we hope to cover by means of a 'pay-for-success social impact bond'. Although this is a rather new financial instrument for financing NGOs, it holds great promise in the years ahead.

Of course, first and foremost, the ICES entity has a mission to serve the public good. We will preserve the integrity of this mission through executive oversight, high standards of financial auditing, and Swiss federal surveillance. That said, we do recognize entire economic sectors can be devastated by unanticipated natural disasters, and where alignment of values and vision occur with the private sector, ICES will stake out opportunities to be of service such as to create value for impacted economies while returning support back to our core operations.

What You Can Do To Help

Now is the time to act swiftly on this bold vision. The ICES Team will be forging strategic alliances with financial supporters, technology providers, and research partners throughout 2012. You can get involved by bringing potential funding sources to our attention, drafting letters of support on our behalf, and leveraging your networks to attract the critical mass of people and resources necessary to make the ICES centre a reality.

Never before have the needs been greater and the opportunities so near at hand. The world demands a new-born institution to operate on the same global scale as its converging threats, and to confront the complex challenges today, and in the decades ahead. The world needs ICES—an International Centre for Earth Simulation.

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Front Cover Graphic

The ICES logo includes the Anasazi petroglyph known as the *Sun Dagger* which is carved into the side of Fajada Butte in Chaco Canyon, New Mexico. This ancient calendar is comprised of three vertical stones that shine sunlight onto a spiral carved into the rock to mark the passage of time, with unique positions for the solstices and equinoxes. The Sun Dagger was used to track the changing seasons and guide agricultural practices for an advanced civilization that depended on in-depth knowledge of the changing planet for its survival. In the same spirit, ICES seeks to be a conduit for shedding light on the hidden patterns that shape our evolving Earth.

Back Cover Graphic

The ICES Montage was created by Tony and Bonnie DeVarco for the ICES Foundation with use of satellite imagery courtesy of NASA's Earth Observatory. The inset diagram is a simplified version of the *Tree of Life*, showing common names of the major groups. This version of the tree is based on the *Tree of Life appendix in Life: The Science of Biology*, 8th ed., by D. Sadava, H. C. Heller, G. H. Orians, W. K. Purves, and D. M. Hillis (Sinauer Associates and W. H. Freeman, 2008). Other insets include the Sun Dagger and the Analemma. The constellation Pleiades peeks through in the background.

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1. Full Earth Disk - Eastern Hemisphere, Source: *NASA* (inside cover)
2. Japanese Tsunami 2011, Source: http://www.thesun.co.uk/ (page 2)
3. Tornado, Source: http://www.sema.dps.mo.gov/plan_and_prepare/tornadoes.asp (page 2)
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5. Visualization of the Earth-Sun System, Metanoiaa ©2006-2012 (page 7)
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13. Graph of Natural Disaster Occurence, Source: MunichRE (page 15)
14. ICES Building, Source: Burckhardt + Partner SA (page 20)


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