GHOST

Global Hierarchical Observing Strategy

IOC

FAO

ICSU

UNESCO

UNEP

WMO

GCOS/GTOS

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NOTE

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FOREWORD

Few issues have captured the attention of the world as dramatically as global change. This poses two major challenges to humankind. The first is to understand the nature and causes of these global changes, their extent, and the rate at which they are occurring. The second is to determine the consequences of such change upon people and their well-being. The understanding of these challenges lies in the coupling of a set of long-term observations over a range of temporal and spatial scales with process studies and models. The Global Climate Observing System (GCOS), the Global Terrestrial Observing System (GTOS) and the Global Ocean Observing System (GOOS) were created by the World Meteorological Organization (WMO), the United Nations Environment Programme (UNEP), the Food and Agricultural Organization of the United Nations (FAO), the United Nations Educational, Scientific and Cultural Organization (UNESCO) and the International Council of Scientific Unions (ICSU) to provide the required observations.

Successful execution of the GCOS and GTOS programmes requires both local observations, often measured in situ, and broader scale data frequently obtained by remote sensing. Such data sets are necessary to achieve the GCOS objectives such as climate change detection, assessment of seasonal and interannual variability, model validation; and the GTOS objective of detecting and assessing the impact of climate change on terrestrial ecosystems, among others. To obtain the data sets typically implies that each variable is measured at many locations around the world with the necessary temporal frequency, accuracy and consistency so that the global data sets can be generated from these measurements. Since most variables of interest vary both in time and in space, often quite rapidly, this poses a formidable challenge. The success of this integrated system is highly dependent on the sampling strategies employed. It is therefore necessary to design an optimal sampling system which still retains adequate spatial and temporal resolution, but is also affordable and practical. A hierarchical strategy, in which, at the one extreme a few variables are measured regularly in a large number of places, and at the other extreme a large number of variables are measured for a limited period in a few locations, meets these requirements.

On behalf of the organizations co-sponsoring GCOS and GTOS, I am happy to introduce this booklet which describes a sampling strategy for obtaining the observations that are required for a better understanding of global change.

(G.O.P. Obasi)
Secretary-General

INTRODUCTION

This brochure briefly describes a proposed strategy to be shared between the Global Terrestrial Observing System (GTOS) and the Global Climate Observing System (GCOS), and to be linked to the Global Ocean Observing System (GOOS), for collecting reliable, representative, long-term data about the world's land and freshwater ecosystems. A more complete description can be found in Version 2.0 of The GCOS/GTOS Plan for Terrestrial Climate-related Observations, which is available from the GCOS Joint Planning Office (GCOS-32). This information is needed to guide rational manage- ment of the environment. It is needed for the whole world because many of the processes affecting the quality of the environment occur at scales larger than the individual nation; global climate change, desertification and trans-boundary pollution are examples. It is needed over the long term because the processes involved may be slow, but cumulatively very dangerous. The need for a long observation period and global coverage means that the measurements must be made very consistently if they are to be comparable. The scope of the effort requires that the observing system be designed for maximum efficiency.

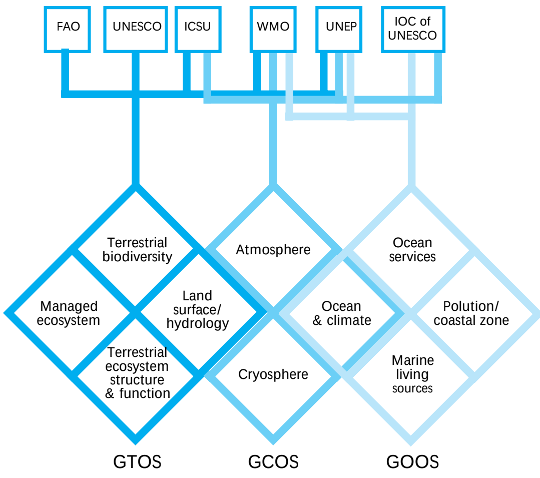


Figure 1. Relationship between the international global observing systems.

THE CONCEPT

It is not possible to know everything, everywhere, all the time. It is therefore necessary to design an optimal sampling system which still retains adequate spatial and temporal resolution, but is affordable and practical. A hierarchical strategy in which at the one extreme a few variables are measured regularly in a large number of places, and at the other extreme a large number of variables are measured in a few locations for a limited period, meets these requirements. The hierarchy divides fairly naturally into five tiers, each with more-or-less unique characteristics and roles (Table 1), although existing facilities often straddle more than one tier. The concept is applicable to the three main areas which GHOST is concerned with — the land surface, freshwater ecosystems and ice surfaces — each of which would have their own hierarchy, but sharing tier 5. The observing system could be built largely out of existing national and international observation systems, research centres and stations, with modest additions of stations and sites where representation is inadequate. A major effort towards methodological consistency and data management is needed.

The proposed hierarchy is incompletely nested. In other words, research centres (tier 2) are not necessarily made up of research stations (tier 3), stations by sites, and so on; but in most cases there are strong linkages between the tiers. Within the hierarchies for the land, freshwater and cryosphere, there is a balance between different types of systems: for instance between natural, agricultural and urban ecosystems on the land; between rivers, lakes, estuaries and ground water in freshwater systems; and between ice sheets, ice caps, glaciers and permafrost in the cryosphere. There is

Table 2. Recommended variables.

Tier	*Role*	*Characteristics*	*Indicative Numbers*
1. Large area experiments e.g., IGBP transcets, large catchment studies.	Understanding of spatial structure and processes.	Cover a linear dimension of >100 km, very intensive sampling, highly integrated data sets.	10
2. Research centres e.g., large LTERS, large agricultural research stations.	Understanding processes, experimentation, method development, data synthesis.	Fundamental research on a crop, ecosystem or cryosphere type, one per major type. Generally expensive complex instruments.	100[a]
3. Stations e.g., Biosphere reserves, smaller national agricultural and ecosystem research sites, research catchments, small polar stations.	Long-term measurement of variables which vary over periods from weeks to years. Calibration and validation of remotely-sensed variables. Trends of variables.	Secure existence, representative of the range within a type, but not statistically unbiased. Frequent measurement of variables.	1000[a]
4. Sample sites e.g., US EMAP programme, UK country survey.	Direct measurement of variables not observable by remote sensing, calibration and validation of remotely-sensed variables, status and trends of biome health.	Infrequently visited (once per year to once per decade), large sample, statistically unbiased.	10000[a]
5. Remote sensing e.g., AVHRR, SPOT, Landsat.	Spatial and temporal interpolation at scales down to 1 day and 30 metres. Extent of biome, ice sheets, etc., status and trends of a biome health.	Frequent, complete coverage, variables mostly indirectly observed.	Not applicable

Note:

a. The numbers indicated are estimates only and may vary significantly especially at tier 3. Approximately in the ratios: 35 natural ecosystems; 35 agroecosystems; 10 rivers; 10 lakes; 10 cryosphere.

Table 1. Roles and characteristics of the tiers.

Proposed Climate-related Variables

Vegetation
Leaf Area Index (2,3,5)
Net Primary Productivity (2,3)
Net Ecosystem Productivity (2)
Above-ground Biomass (3)
Below-ground Biomass (3)
Necromass (3)
Surface Roughness (2,3)
Spectral Vegetation Greenness Index (5)
Plant N, P and S Content (3,4)
Maximum Stomatal Conductance (2,3)

Land Cover/Use and Disturbance
Fire (5)
Land Cover (5)
Land Use (4)

Soil Properties
Moisture Content (2,3)
Organic C, N, P and S (3,4)
Total C, N, P and S (3,4)
Bulk Density (3,4)
Particle Size Distribution (3,4)
Surface State (3,4)
95% Rooting Depth
Available P (3,4)
Cation Exchange Capacity (3,4)
pH (3,4)

Radiation
Aerosol Thickness (2)
Incoming Total Short-wave Radiation(2,3)
Reflected Short-wave Radiation(2,3)
Photosynthetically Active Radiation (2,3)
Outgoing Long-wave Radiation (2,3)
Cloud Cover (3)
Tropospheric Ozone Thickness (2)

Hydrology
Air Temperature (2,3)
Vapour Pressure Deficit (2,3)
Wind Speed (2,3)
Evapotranspiration (2,3)
Discharge (2,3)
Surface Water Storage Fluxes (2,3)
Ground Water Storage Fluxes (2,3)
Precipitation (2,3)
Runoff to the Ocean (1,2,3)

Biogeochemistry
Rain Chemistry (2,3)
Dissolved Organic C, N and P in Water (2,3)
Leaf Biomass BNF Plants (2,3)
Volcanic S Emissions (2)
Fossil Fuel CO_2, N and S (2)
N & P Fertiliser Use (2)

Cryospheric Properties
Glaciers and Ice Caps (3,4)
Ice Sheet Mass Balance (3,5)
Ice Sheet Surface Balance (3)
Ice Sheet Extent and Topography (3,4,5)
Permafrost Active Layer -Thickness (2,3,4)
Permafrost Thermal State (3,4)
Sea Ice Concentration (5)
Sea Ice Motion (5)
Sea Ice Extent (5)
Sea Ice Thickness (4)
Snow Depth (2,3,)
Snow Water Equivalent (2,3,4)
Snowfall (3)
Snow Cover Area (5)
Time of Lake and River Freeze and Thaw (3)

Trace Gases
Methane Fluxes (2)
Carbon Dioxide Fluxes (2)

Note: Numbers in brackets refer to the tier where the variable would be measured.

also a geographical balance, which ranges from broad representation at tiers 1 and 2, detailed representation at tier 3, unbiased sampling at tier 4 and complete coverage at tier 5.

Variables

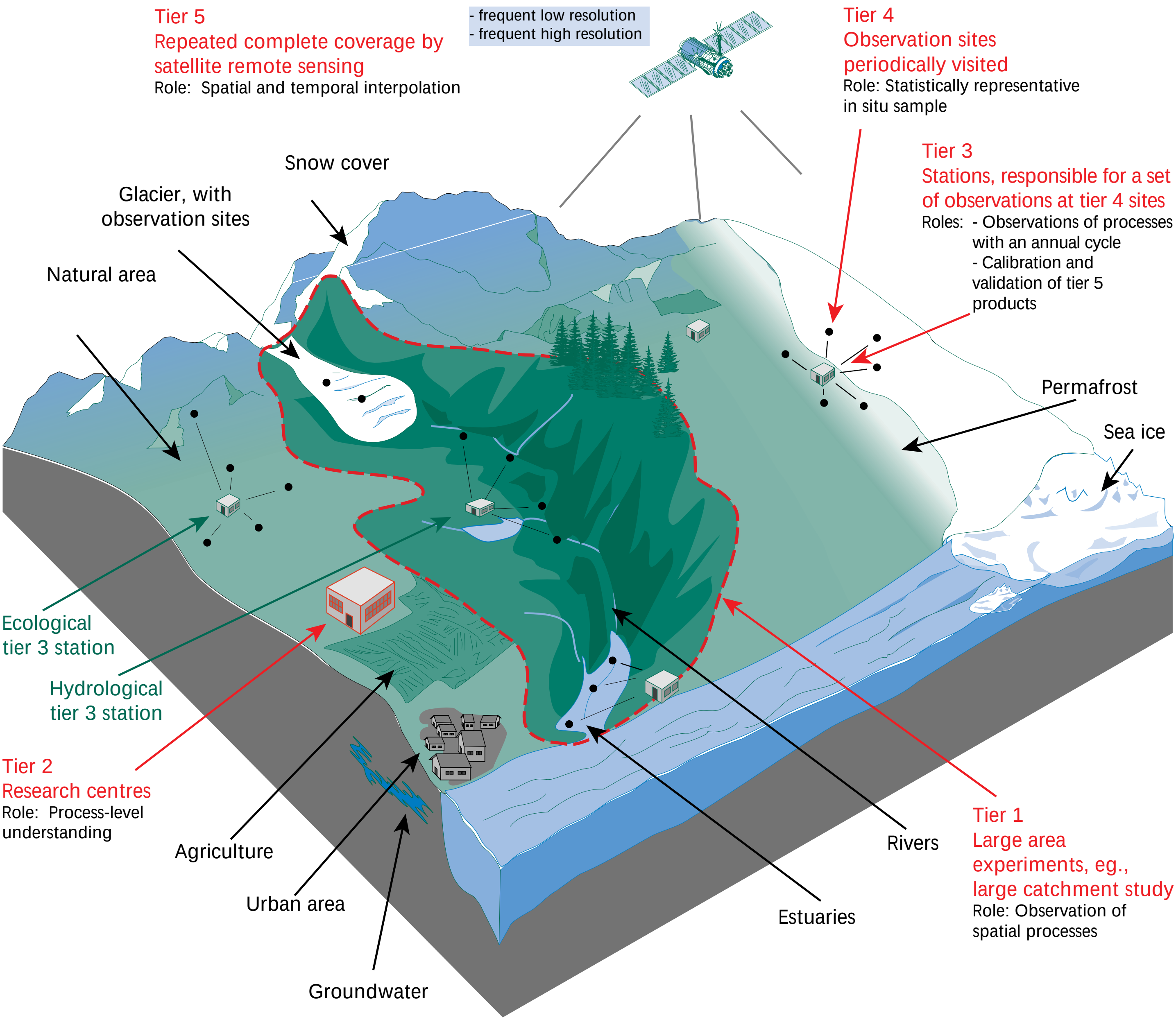
The proposed variables (Table 2) have been selected to be:

- the minimum set needed to observe, understand and predict changes in critical life supporting processes;
- integrated internally consistent and mutually supporting and enhancing;
- globally applicable and standardisable as possible;
- linked to related variables in higher and lower tiers via models, permitting interpolation in space and time to cover gaps in the system.

Models will play an essential role in filling the gaps in space and time unavoidably left by an incomplete sampling system. In general, tiers 1 and 2 generate models, which are run, validated and interpolated using data from tiers 3, 4, and 5.

Organizations joining the GCOS/GTOS will choose the tier at which they should operate. They must collect all the variables appropriate to the system which they study within, to allow integrated data sets to be developed. In a few cases this is not efficient, and a specialized agency may be responsible globally for certain variables within one or more tiers. For example, sulphur aerosols emitted from volcanoes are important for the global radiation balance, but the emissions are localised and intermittent, and therefore best measured by volcanologists.

The variables are specified in terms of definition, units of measurement, spatial resolution, temporal frequency and required accuracy. In most cases, the methods to be


Tier 5
Repeated complete coverage by satellite remote sensing
Role: Spatial and temporal interpolation
- frequent low resolution
- frequent high resolution
Tier 4
Observation sites periodically visited
Role: Statistically representative in situ sample
Tier 3
Stations, responsible for a set of observations at tier 4 sites
Roles: - Observations of processes with an annual cycle
- Calibration and validation of tier 5 products
Snow cover
Glacier, with observation sites
Natural area
Permafrost
Sea ice
Ecological tier 3 station
Hydrological tier 3 station
Tier 2
Research centres
Role: Process-level understanding
Agriculture
Urban area
Groundwater
Rivers
Estuaries
Tier 1
Large area experiments, eg., large catchment study
Role: Observation of spatial processes

used to obtain them are not prescribed, although harmonisation of methods will form part of the programme. This is because the surface of the world is so heterogeneous that a single method is seldom globally applicable. However it is important to assure that methods are comparable and compatible.

The area of the global surface sampled at tiers 1 and 2 is very small, and cannot be statistically unbiased. The approach is for tier 1 to span major global environmental gradients, and for tier 2 to have at least one centre in each major crop, terrestrial biome, freshwater system and cryosphere system. The number of locations at tier 3 is approaching a statistically useful sample within broad types, but because it is to be made up largely of existing facilities, does not represent an unbiased sample. It does define the range of variation within a type. Tier 4 provides a statistically unbiased sample. The sample design for this tier is left to individual participating nations, and may be systematic or stratified. Tier 5, where the coverage is complete, provides a globally consistent basis for stratification.

The temporal frequency of sampling is defined by the rate of change of the variable. Tier 2 centres are equipped with automatic data loggers, which can record very rapid events, such as the eddies which carry trace gases between the earth's surface and the atmosphere. Tier 3 has permanent staff, who can record events on a daily to monthly basis, such as snow depth, lake level or leaf cover. Tier 4 is visited once a year to once a decade, and is used for observations of variables such as soil organic carbon content, ice sheet thickness, and depth to the water table.

The required accuracy is determined by what is needed for useful interpretation, and what is possible with affordable current technology.

Figure 2. Diagrammatic representation of GHOST.

Data management

There is a clear requirement for systems that will promote and facilitate the access by individuals, institutions and national entities to relevant global and regional level information. Especially for the land, observations are often scattered and need to be assembled from a large number of sources and locations and may often require substantial analysis to create internally consistent databases.

There needs to be explicit links with a variety of different existing data systems. At the heart of any data system is a requirement for high quality meta-data describing data sets, including attributes such as location, time of collection and data reliability and quality. Rather than any sort of centralized system, a highly dispersed system is envisaged.

Another essential aspect of data and information distribution is to ensure agreement to, and implementation of, data policy that leads to free and open access to the data sets.

To the fullest extent possible, the GCOS/GTOS data and information systems will rely upon existing national and international programmes. Systems operated by these programmes, such as the ICSU World Data Centres, World Weather Watch (WWW) of the WMO, GOOS, UNEP's GRID and many others, should be enhanced as necessary to meet data requirements rather than creating new entities. Tasks necessary to implement the system will be performed by the existing world and national observing systems, telecommunications networks, and data and processing centres. GCOS and GTOS should act to ensure data are collected, validated, processed and archived to the exacting standards necessary. They should also review, monitor and coordinate activities between groups to ensure proper data are being collected and can be exchanged easily.

Questions which GHOST could answer

It is impossible to foresee all the critical environmental issues of the future. Who could have predicted the depletion of the ozone layer, or the effect of DDT on birds of prey? It is clear that other issues will become increasingly important: the global climate, the supply of safe drinking water, the diversity of living organisms and the potential of the land surface to yield sufficient food and fibre for its population, are examples. GHOST is designed to satisfy both the known needs, and to have sufficient richness and flexibility to adapt to emerging needs. Here is a sample of vital questions which can only be addressed with an integrated global system such as GHOST:

- Is the carbon balance of the terrestrial biosphere shrinking or growing? Since this is the major location of the 'missing sink' of global carbon, this question is central to understanding the limits of carbon dioxide emissions under the Framework Convention on Climate Change.
- Is the productive potential of arid lands decreasing? The countries of the world have committed themselves to combatting desertification. This is a matter of life and death for millions of people.
- Is the tundra permafrost melting? If it does, millions of tons of carbon dioxide and methane could be released into the atmosphere, leading to runaway global warming.
- How much habitat exists for endangered species? Plant and animal populations are not aware of political boundaries, and must be conserved on a global basis. This is recognised in the Convention on Biodiversity.
- How much sediment, nitrogen and phosphorus is flowing from river basins into the coastal zone? This question affects the fisheries on which millions of people depend.

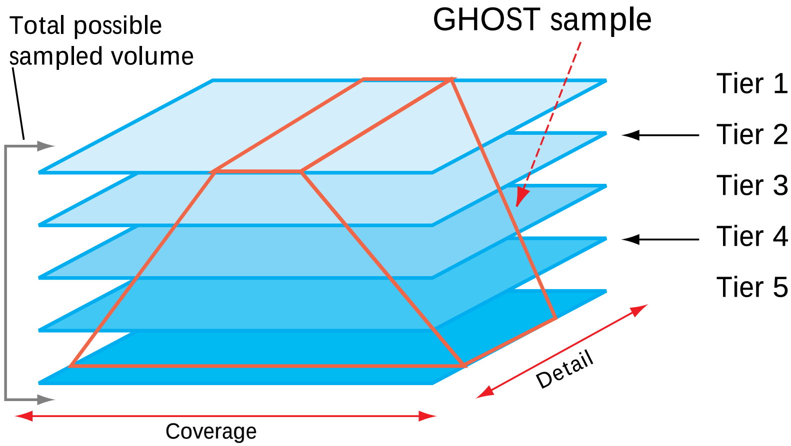


Figure 3. Relationship between GHOST sample and total possible samples.

Participation

GHOST participation is by voluntary association. Participating organizations determine the tier(s) at which they choose to operate, and would commit themselves to:

- providing all of the applicable variables at that tier within one of the hierarchies (terrestrial, freshwater or cryosphere);
- accepting the other responsibilities associated with the tier.

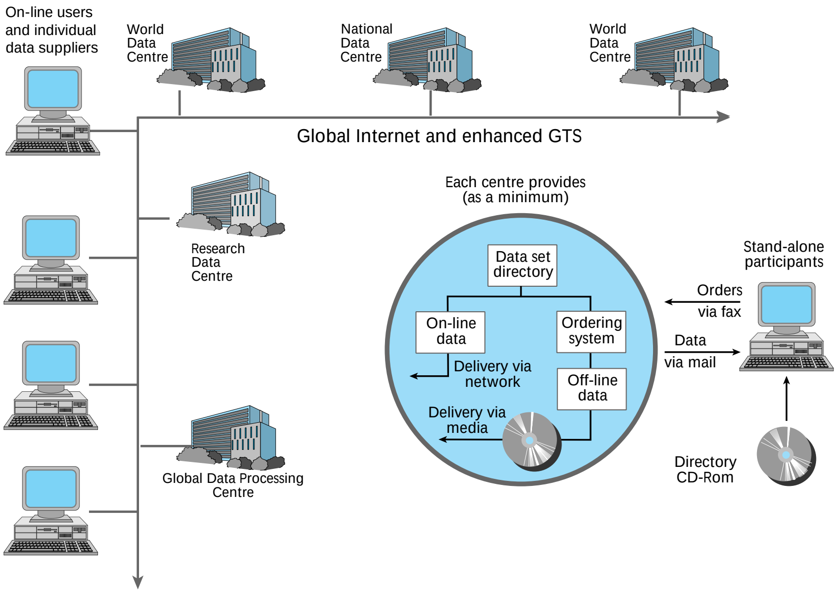


Figure 4. Characteristics of the GCOS/GTOS Data Management System.

At the central level, international and national support will be coordinated to ensure at least one tier 3 site per country, to provide national contact points. Where central resources are involved, major unsampled systems would take precedence over systems already represented. Once all major systems are represented, sample intensity proportional to the area (or volume) involved will be the guiding criterion. All else being equal, a long-term record, ease of access, and the presence of equal active research at the location are advantages.

Governance

The GHOST system is steered by a Terrestrial Observation Panel, which is a committee of distinguished scientists drawn from a range of disciplines and various parts of the world. The panel is a joint activity of the Global Terrestrial Observing System and the Global Climate Observing System, which share the responsibility for appointing its members and implementing its recommendations. GTOS and GCOS have different key stakeholders and governance structure, but are linked by both being components of the Global Observing System.

The sample network will not ‘belong’ to GHOST. It will belong to the national governments, and research organizations which support it. In the case of the tier 1 experiments, GHOST will mainly provide a mechanism for long-term archiving of data, and the continuation of some key variables beyond the life of the campaigns.

Funding

Since the bulk of the operational part of the GHOST system consists of existing satellites, research sites, stations, centres and campaigns, most of the operational funding for the system would come from the existing sources which support these activities. New funding would be directed towards stimulating the development of new observing sites and variables where there are critical deficiencies and to data exchange and harmonisation mechanisms. This additional expenditure is justified in terms of the value added to existing measurements by making their scope global and the synergies resulting from an integrated data set.

Further information

If you are interested in further documents, or wish to propose a site or observation system as a GHOST partner, please contact:

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