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SCIENCE REQUIREMENTS FOR A GLOBAL CHANGE TECHNOLOGY INITIATIVE ARCHITECTURE TRADE STUDY

by

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SUMMARY

Science requirements for a Global Change Technology Initiative (GCTI) Architecture Trade Study have been established by reviewing and synthesizing results from recent studies. A scientific rationale was adopted and used to identify a comprehensive set of measurables and their priorities. Spatial and temporal requirements for a number of measurement parameters were evaluated based on results from several working group studies. Science requirements have been defined using these study results in conjunction with the guidelines for investigating global changes over a time scale of decades to centuries. Requirements are given separately for global studies and regional process studies. For global studies, temporal requirements are for sampling every 1 to 12 hours for atmospheric and radiation parameters and 1 day or more for most Earth surface measurements. Therefore, the atmospheric measurables provide the most critical drivers for temporal sampling. Spatial sampling requirements vary from 1 km for land and ocean surface characteristics to 50 km for some atmospheric parameters. Thus, the land and ocean surface parameters have the more significant spatial variations and provide the most challenging spatial sampling requirements.

INTRODUCTION

Global observations of the physical parameters required to detect and quantify changes in global climate, composition of the atmosphere, surface properties, and the biosphere can only be accomplished using sophisticated instruments on orbiting spacecraft. Defining such a mission is a formidable task involving several essential elements. First, the overall goals of the effort must be defined and the associated science requirements established. Next, goals and

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Table 2 shows the measurables and ESSC priorities for Earth science studies on the time scale of decades to centuries. The measurables are broken down into categories relating to the atmosphere, the Earth land and ocean surfaces, and the energy components of the solar and Earth radiation. While this list of measurables is widely accepted, the priorities are subject to debate. For example, the priority framework of the U. S. Global Change Research Program shown in table 3 (from ref. 5, a report by the Federal Coordinating Council on Science, Engineering, and Technology (FCCSET)), gives all the measurables in table 2 as high priority, but places much higher relative importance on clouds and water vapor than does the ESSC. At a recent meeting, the Investigator Working Group of the Earth Observing System (EOS) found substantial agreement with the priorities in table 3, but voiced the need for a relative measure of importance to give proper perspective to the separation between the highest and lowest priorities.

It seems prudent at this point to examine some parameters that are excluded by adopting the rationale stated above. To this end, the measurables for the time scale of thousands to millions of years are shown in table 4. Several items on this list warrant comment. Although given low priority by the FCCSET, two measurables were given the highest priority by the ESSC: seismic properties (including plate motions and deformations), and gravity and geoid. The seismic properties are presently being measured to high accuracy by in situ techniques supplemented by precise position information from the Global Positioning System (GPS). Some monitoring improvements can be achieved by the Geodynamic Laser Ranging System (GLRS). The gravity measurable is pertinent to this study, particularly as it relates to satellite position determination for analysis of altimetry measurements. This is an indirect requirement, and the GPS can provide the needed information. Therefore, based on the low priority for the adopted science rationale and the existing capabilities for these two measurables, we feel justified in not including these parameters. Also included on the list in table 4 is the lightning measurable, even though it was not included in the ESSC science discussions. Lightning has been included in several measurement system studies, however, so it was included for completeness. With regard to lightning, we have not found any specific scientific requirement for this measurement, and, therefore, it is not included in our study.

INITIAL MEASUREMENT REQUIREMENTS

Numerous scientific groups have undertaken to establish spatial and temporal requirements for Earth science measurements. Results of the most relevant studies are given in table 5 for temporal requirements and in table 6 for spatial requirements. The Science and Mission Requirements Working Group for the Earth Observing System (EOS) defined scientific requirements for a wide variety of measurements of atmospheric, radiative, and Earth surface parameters

Based on current climate model characteristics, the spatial resolution for data products must be 100-250 km (horizontal) and have a vertical resolution equivalent to 9-17 pressure levels. Resolution requirements for instantaneous measurements should, therefore, be in the range of 10-25 km.

The best estimates of temporal resolution for data products range from less than 1 day to 1 month. For adequate temporal sampling, some variables such as cloud cover and associated radiation parameters require measurements across the entire diurnal cycle to avoid aliasing daily and longer-term variations. Other physical properties change at a much slower rate. Some examples are sea ice distribution and land surface properties.

Regional Process Studies are crucial to understanding the Earth as a system and to evolving improved models. These studies require the highest possible temporal and spatial resolutions, but are of limited time and space extent. They involve satellite, aircraft, and ground-based measurements used together in an intensive field study. Some of the important existing regional climate process studies are listed in table 8 for the Physical Climate System and for the Biogeochemical Cycles. These are the programs that must be continued and expanded upon in order to adequately understand regional processes and develop accurate models.

FINAL SCIENCE REQUIREMENTS

The requirements recommended for the GCTI Architecture Trade Study are shown in table 9. The requirements are given separately for Global Change Studies and Regional Process Studies. The requirements are to be interpreted as instantaneous measurement requirements, and the appropriate data products are given as a footnote. Parameters for which measurements over the diurnal cycle are critical are so noted. Where a range of values is given, the lower value is an ideal to provide an objective while the upper value is an adequate level or minimum requirement.

For Global Change Studies, temporal requirements are for sampling every 1 to 12 hours for atmospheric and radiation parameters and 1 day or more for most Earth surface measurements. For temporal variations, the most rapidly changing parameters are those related to the Earth's atmosphere. For this reason, these measurables provide the most critical drivers for temporal sampling. Spatial sampling requirements vary from 1 km for land and ocean surface characteristics to 90 km for atmospheric parameters. Thus, the land and ocean surface parameters have the more significant spatial variations and provide the most challenging spatial sampling requirements.

TABLE 1. GUIDELINES FOR SCIENCE REQUIREMENTS

- CONCEPTUAL AND NUMERICAL MODELS

    THOUSANDS TO MILLIONS OF YEARS - EARLY EARTH, CORE AND MANTLE, PLATE-TECTONICS, AND SOLAR-DRIVEN

    DECADES TO CENTURIES - PHYSICAL SYSTEMS (ATMOSPHERE, OCEANS, LAND SURFACES), BIOGEOCHEMICAL CYCLES, WATER CYCLE

- OBSERVATIONAL REQUIREMENTS

    REMOTE SENSING VS. IN SITU OBSERVATIONS

    INSTANTANEOUS MEASUREMENTS VS. ANALYZED DATA PRODUCTS

- SCIENTIFIC STUDIES

    GLOBAL VARIABLES (SURVEYS)

    PROCESSES (CASE STUDIES)

TABLE 3. U.S. GLOBAL CHANGE RESEARCH PROGRAM PRIORITY FRAMEWORK

SCIENCE PRIORITIES

INCREASING PRIORITY

Climate and Hydrologic Systems	Biogeochemical Dynamics	Ecological Systems and Dynamics	Earth System History	Human Interactions	Solid Earth Processes	Solar Influences
Role of Clouds Ocean Circulation and Heat Flux Land/Atm/Ocean Water & Energy Fluxes Coupled Climate System & Quantitative Links Ocean/Atm/ Cryosphere Interactions	Bio/Atm/Ocean Fluxes of Trace Species Atm Processing of Trace Species Surface/Deep Water Biogeochemistry Terrestrial Biosphere Nutrient and Carbon Cycling Terrestrial Inputs to Marine Ecosystems	Long-Term Measurements of Structure/ Function Response to Climate and Other Stresses Interactions between Physical and Biological Processes Models of Interactions, Feedbacks, and Responses Productivity/ Resource Models	Paleoclimate Paleoecology Atmospheric Composition Ocean Circulation and Composition Ocean Productivity Sea Level Change Paleohydrology	Data Base Development Models Linking: Population Growth and Distribution Energy Demands Changes in Land Use Industrial Production	Coastal Erosion Volcanic Processes Permafrost and Marine Gas Hydrates Ocean/Seafloor Heat and Energy Fluxes Surficial Processes Crustal Motions and Sea Level	EUV/UV Monitoring Atm/Solar Energy Coupling Irradiance (Measure/ Model) Climate/Solar Record Proxy Measurements and Long-Term Data Base

INCREASING PRIORITY

SOURCE: COMMITTEE ON EARTH SCIENCES
FEDERAL COORDINATING COUNCIL ON SCIENCE, ENGINEERING, AND TECHNOLOGY

TABLE 5. TEMPORAL REQUIREMENTS FOR EARTH SCIENCE MEASUREMENTS

REGIME/ CATEGORY	MEASURABLE	TEMPORAL REQUIREMENTS (D=DAY, H=HOUR, M=MINUTE) EOS	JPL	LaRC	GEO-EOS
SOLAR	SPECTRAL RADIATION	NA	1D	1D	1 SEC
ATMOSPHERE	PRESSURE (SURFACE)	NA	30M	1-3H	NA
	TEMPERATURE PROFILE	1D	1D	1-3H	15M
	STRATOSPHERIC GASES	1D	12H	3-12H	30M
	AEROSOLS & PARTICULATES	1D	1D	3-12H	15-60M
	TROPOSPHERIC WATER VAPOR	12H	12H	3-12H	30-60M
	CLOUD COVER & HEIGHT	6H	3H	1-3H	1-3H
	TROPOSPHERIC GASES	1D	3H	1-3H	1H
	WIND FIELDS	12-24H	30M-12H	1-3H	NA
RADIATION BUDGET	REFLECTED SW & EMITTED LW FLUX	6-24H	12H	1-3H	1-3H
EARTH (LAND/ OCEAN)	SURFACE TEMPERATURE	12H	6-24H	1-3H	15-60M
	PRECIPITATION	1D	3H	1-3H	15-60M
	VEGETATION COVER/TYPE	3-30D	3-30D	3-30D	1-3H
	SOIL MOISTURE	2-7D	12H-3D	12H-3D	30-60M
	BIOMASS INVENTORY	2-7D	7D	2-7D	1H
	OCEAN COLOR (CHLOROPHYLL)	2D	2D	2D	NA
	OCEAN CIRCULATION	2D	Hs-Ds	1D	15-60M
	SEA LEVEL RISE	NA	2D	2D	NA
	SEA ICE COVER/DEPTH	7D	7D	7D	NA
	OCEAN CO_2	NA	2D	2D	NA
	SNOW COVER/DEPTH/WETNESS	7D	1-7D	1D	NA

NA = NOT AVAILABLE

TABLE 7. GLOBAL CLIMATE CHANGE STUDIES

- MODELS ARE REQUIRED TO UNDERSTAND VERY COMPLEX EARTH SYSTEM
- GLOBAL OBSERVATIONS ESSENTIAL TO MODEL DEVELOPMENT, VERIFICATION, AND IMPROVEMENT
- HIGH ABSOLUTE ACCURACY FOR OBSERVATIONS IS ESSENTIAL TO DETECTION OF LONG-TERM TRENDS
- BEST GUIDES FOR OBSERVATIONAL REQUIREMENTS ARE GLOBAL CLIMATE MODEL CHARACTERISTICS:

- SPATIAL RESOLUTION*	100-250 KM (HORIZONTAL) 9-17 PRESSURE LEVELS
- SPATIAL COVERAGE	GLOBAL EXTENT
- TEMPORAL RESOLUTION*	1 DAY - 1 MONTH
- TEMPORAL COVERAGE	DECADES

* VALUES ARE RESOLUTIONS FOR DATA PRODUCTS, MEASUREMENT RESOLUTION REQUIREMENTS MAY BE HIGHER

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* VALUES ARE RESOLUTIONS FOR DATA PRODUCTS, MEASUREMENT RESOLUTION REQUIREMENTS MAY BE HIGHER

TABLE 9. REQUIREMENTS* FOR EARTH SCIENCE MEASUREMENTS

REGIME/ CATEGORY	MEASURABLE	DIURNAL CYCLE CRITICAL	GLOBAL CHANGE STUDIES		REGIONAL PROCESS STUDIES	
			TEMPORAL	SPATIAL	TEMPORAL	SPATIAL
SOLAR	SPECTRAL RADIATION	NO	1D	SUN DISK	1D	SUN DISK
ATMOSPHERE	PRESSURE (SURFACE)	NO	3-12H	10km		
	TEMPERATURE PROFILE	YES	1-3H	10-50km	15M-1H	5km
	STRATOSPHERIC GASES	NO	3-12H	50km	30M	5-10km
	AEROSOLS & PARTICULATES	NO	3-12H	10km	15M-1H	0.1-1km
	TROPOSPHERIC WATER VAPOR	NO	3-12H	10km	30M-1H	10km
	CLOUD COVER & HEIGHT	YES	1-3H	1km	15M-1H	1km
	TROPOSPHERIC GASES	YES	1-3H	10km	30M-1H	10-50km
	WIND FIELDS	YES	1-3H	10km	30M-1H	
RADIATION BUDGET	REFLECTED SW & EMITTED LW FLUX	YES	1-3H	10-30km	30M-1H	1-30km
EARTH (LAND/ OCEAN)	SURFACE TEMPERATURE	YES	1-3H	1-4km	6M-24H	30m-200km
	PRECIPITATION	YES	1-3H	1-30km	3M-3H	1-200km
	VEGETATION COVER/TYPE	NO	7D	1km	1-30D	30m-10km
	SOIL MOISTURE	NO	2D	1-10km	12H-7D	30m-10km
	BIOMASS INVENTORY	NO	7D	1km	1-30D	1-10km
	OCEAN COLOR (CHLOROPHYLL)	NO	2D	1-4km	2D	30m-4km
	OCEAN CIRCULATION	NO	2D	1-4km	1D	30m-4km
	SEA LEVEL RISE	NO	2D	10km	2D	10km
	SEA ICE COVER/DEPTH	NO	7D	1-20km	1-3D	1-25km
	OCEAN CO_2	NO	2D	0.5km		
	SNOW COVER/DEPTH/WETNESS	NO	7D	1km	12H-3D	1-10km

* SAMPLING REQUIREMENTS ARE GIVEN; DATA PRODUCTS FOR GLOBAL CHANGE STUDIES ARE DAILY MEANS AND 100-250km MEANS, DATA PRODUCTS FOR REGIONAL PROCESS STUDIES ARE HIGHLY VARIABLE.