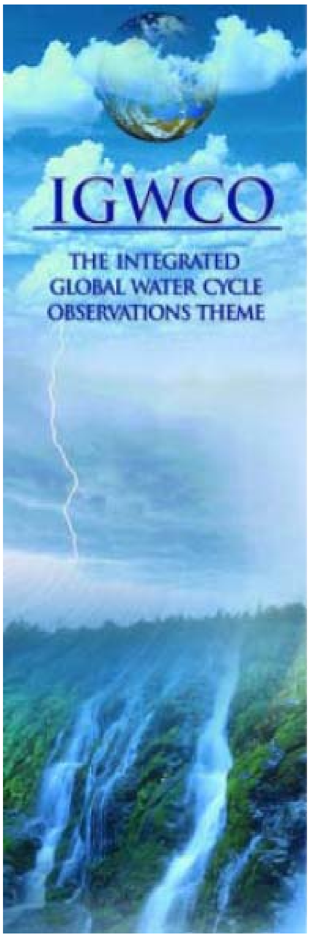

THE INTEGRATED GLOBAL WATER CYCLE OBSERVATION (IGWCO) THEME

ASSESSMENT REPORT

FINAL DRAFT, 23 MAY 2007

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1. INTRODUCTION

1.1. IGOS-P Background

The Integrated Global Observing Strategy Partnership (IGOS-P) is a partnership of international organizations concerned with providing strategic guidance and coordination for world-wide efforts to monitor the global environment. It seeks to as link research, long-term monitoring, and operational programs by bringing together producers of global observations related to the environment, and the users that require them to respond to needs in the science and policy communities. Its principal objective is to develop a strategy for integrated observations to monitor the state of the global environment, with a particular interest in climate change. Additional objectives include making available integrated datasets from diverse platforms, such as satellite, airborne, and *in-situ* observation systems, and promote their use in research and water resource management.

The IGOS Partners recognize that a comprehensive global Earth observing system is best achieved through a step-wise process focused on practical results. This strategy led to the concept of concentrating on individual “Themes,” centered on the major components of the Earth-atmosphere-ocean ensemble. The IGOS Themes allow for the definition and development of a global strategy for the observation of selected environmental issues that are of common interest to the IGOS Partners as well as to user groups. Current IGOS Themes include the Oceans, the Carbon Cycle, Geohazards, the Cryosphere, and the Water Cycle.

1.2. Inception of the IGWCO

The IGOS Global Water Cycle Theme was initiated by the World Climate Research Programme (WCRP), and supported by the Japan Aerospace Exploration Agency (JAXA), the National Aeronautics and Space Administration (NASA), and the National Oceanic and atmospheric Administration (NOAA) at the November 2000 IGOS-P meeting in Brazil. A writing team co-chaired by WCRP and the Committee on Earth Observation Satellites (CEOS)/JAXA (including Professor Toshio Koike, Don Carson, and Rick Lawford), and an advisory team chaired by WCRP were subsequently established to develop a theme proposal. The proposal was accepted by IGOS-P in 2001, at which point a writing team again co-chaired by WCRP and JAXA, and an advisory team chaired by WCRP, developed a comprehensive report after holding three regional workshops. A draft report was submitted to the 10th IGPS Plenary in June 2003 for comment, and a subsequent version was approved for implementation at a special IGOS-P meeting held in Colorado, USA, during November 2003. A tri-partite secretariat structure was envisaged for the maintaining the IGWCO, in which WCRP/GEWEX would provide scientific guidance, the WMO executive resources and assistance, and JAXA providing logistical and financial support, including organizing water management workshops and joint CEOP-IGWCO meetings, providing travel funds, producing IGWCO information brochures, and handling teleconferencing needs for the IGWCO.

Within the framework of the IGOS objectives, the IGWCO contributes to critical social issues dealing with the hydrologic cycle by addressing concerns about the long-term sustainability of safe water globally. Simultaneously, it addresses environmental issues and the need to detect and understand climate change through the observation and analysis of trends in atmospheric water vapor, precipitation, streamflow and other water cycle variables. With respect to these various concerns, the primary objective of the IGWCO is to provide a framework for guiding decisions regarding priorities and strategies for the maintenance and enhancement of water cycle observations. From this perspective of providing guidance strategy, the IGWCO is active in the following areas:

- monitoring climate variability and change.
- facilitating effective water management and sustainable development of the world’s water resources.
- fostering societal applications for resource development and environmental management.

- providing specification for numerical weather and water forecasts, and for intraseasonal-to-interannual climate predictions.
- promoting research directed at priority water cycle questions, such as defining the role of water in the Earth system, and cloud and land feedback effects on the climate system.

A second main objective of the IGWCO is to promote strategies that facilitate the acquisition, processing, and distribution of data products needed for effective management of the worlds water resources. To achieve these goals, the initial activities will rely on space-based systems and *in-situ* networks that are currently in place or planned. Furthermore, it will engage the global community through multiple linkages to global programs and internationally coordinated activities.

The unique characteristic of the IGWCO is that it sets up strategies, identifies partners, and then attempts to foster collaboration between them. Thus, it is important to note that the IGWCO is a "best efforts" enterprise, which means that it does not undertake activities in its own right. Rather, it relies on the good will and cooperation of the agencies it is involved with to accomplish agreed-upon goals. As such, projects conceived by the IGWCO are ends in themselves. This means that once a suitable agent/initiative has been identified to lead a particular project, that group is allowed to autonomously shoulder responsibility for carrying the project through to completion.

With this perspective in mind, in the nearly 4 years since the IGWCO has been in existence, the IGWCO has expanded and accomplished several of its initial objectives. In particular, the advent of the Group on Earth Observations (GEO), in conjunction with already well-established initiatives such as WCRP's Global Energy and Water Cycle Experiment (GEWEX) and the Global Terrestrial Network-Hydrology (GTN-H), has opened up avenues for the IGWCO in terms of accomplishing its objectives by allowing the IGWCO to dovetail many of its activities into the GEWEX, GEO and GTN-H implementation plans. Further, oversight of the IGWCO has been reinforced thanks to the secretariat services provided from the outset by the Japan Aerospace Exploration Agency (JAXA) for the Science Advisory Group (SAG), and the accommodation of the Executive Committee Secretariat by the World Meteorological Organization (WMO) since the summer of 2006.

1.3. GEO and IGWCO

IGWCO activities have been strongly linked with GEO from the outset. Indeed, one of the earliest successes of the IGWCO was that it led in the writing of the water chapter of the GEO Ten-year Implementation plan. This strong connection has been further enhanced interactions and contributions of the IGWCO to GEO Water Tasks. To cite a few specifics:

- **WA-06-01:** In the context of GEO's organization of workshops on water observations, the IGWCO (Steve Greb) has developed a proposal for a water quality workshop. The IGWCO has submitted this proposal to GEOSEC and GEOSEC is now coordinating the next steps with Dr. Greb. The IGWCO has been working with GEOSEC to establish the workshop dealing with the surface and atmospheric water cycle issues, which is slated to take place 27-29 March 2007 at the GEO Secretariat (WMO, Geneva).
- **WA-06-02:** Working with GEO towards establishing a demonstration project highlighting the value of hydrological ensemble forecasts in water resource management, the IGWCO will develop a strategic plan through the Hydrologic Ensemble Prediction Experiment (HEPEX) project, operate nine testbed projects, prepare several scientific articles and sessions at science conferences and develop plans for a Chapman conference on hydrological ensembles. These activities are intended to help assess the value of ensemble forecasts in water resource management.
- **WA-06-05:** Assisting GEO in its task of establishing a coordination mechanism for global *in-situ* water observations, the IGWCO and GTN-H are initiating the development of the Hydrological Applications and Run-Off Network (HARON). The goal of this project in its intial phase is to upgrade and sustain the operations of the existing global network of major runoff stations. This is to be followed by a second phase in which *in-situ* measurements from this network will be integrated with satellite altimetry observations to determine water levels in rivers, lakes/reservoirs, and estuaries with as much accuracy as possible.

- **WA-06-06:** Promote best practices in Earth observation application for integrated water resource management in developing countries by supporting a series of workshops in South America, Asia, Africa, and a Small Island nation.
    - IGWCO interested in sponsoring a Terrestrial Initiative in Global Environmental Research (TIGER) workshop as part of African capacity building.
- **WA-06-07:** Capacity Building Program for Water Resource Management This Task is led by IGOS-P/IGWCO. Initiate capacity building programs to develop tools for using remote sensing data in support of water management, and to show the value of Earth observations generally in water resource management. The program will be initiated in Latin America and will then be extended to Asia and Africa. Linkages with existing efforts of GEO Members and Participating Organisations will be made.
    - the IGWCO sponsored Asian Water Cycle Initiative has already emerged, which will lead in capacity building and hydrologic studies in Asia.
    - the goals and needs have evolved since the report was written
    - according to the pattern of IGOS-P there will be a review of the plan after 5 years.

1.4. GTN-H and IGWCO

Most networks of the GTN-H are directly relevant to objectives of the IGWCO water cycle. As can be seen from Figure 1 below, GTN-H networks such as Groundwater, Soil Moisture, Water Quality, Evapotranspiration, and Precipitation all have identical counterparts within the IGWCO water cycle variables. These are just a few of the strong linkages between the objectives of both initiatives (from Project 1.2: Inventory of Existing Data Products, Databases, and Organizations; *Report of the 2nd GTN-H Coordination Panel Meeting, July 2005*).

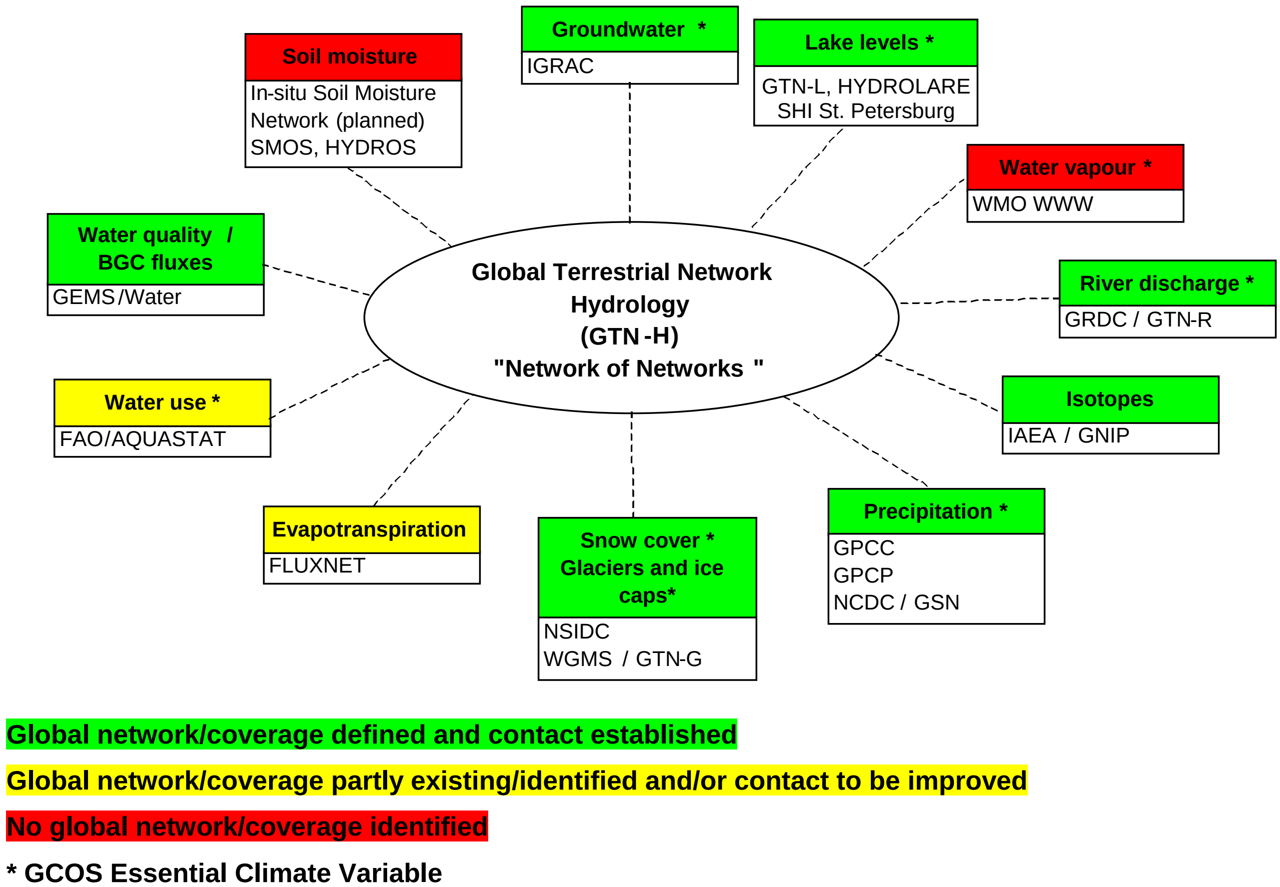

Figure 1: Inventory of Networks comprising the GTN-H Configuration.

There are several additional aspects of GTN-H projects that intersect with IGWCO interests. Drawing upon the GTN-H July 2005 report, some of those projects include:

- Project 1.1: Cross-linkage between the GTN-H website and the IGWCO website.

- Project 1.3 GTN-H provides the technical framework for implementation of IGWCO objectives (metadata constitute a backbone for access to data from networks related to the IGWCO).
- Project 2.1: Development of GTN-H gridded runoff datasets are related to the Streamflow and Surface Water Storage variables of the IGWCO.
- Project 2.2: Real-time hydrological conditions mapping related to IGWCO runoff and soil moisture water cycle variables.
- Project 3.1: Biogeochemical flux mapping related to IGWCO water quality monitoring objectives.
- Project 4.1: Reference hydrological dataset linked to IGWCO runoff objectives, as well as the WCP-Water observation directive to obtain data field from pristine basin research to detect climate change signal in time series of runoff.
- Project 4.2: GTN-H networks fit within overarching IGWCO objectives of improving access to data, identifying existing networks, and promoting common metadata standards.

1.5. Goal of IGWCO Assessment Report

Much has changed since the inception of the IGWCO. Using the April 2004 Integrated Global Observing Strategy (IGOS) publication, *The Integrated Global Water Cycle Observations Theme: For the Monitoring of our Environment from Space and from Earth* as a reference guide (hereafter, the IGWCO Guide), the IGWCO Report to IGOS-P (May 2006), and the IGWCO Report to IGOS-13bis (November 2006), this goal of this report is to produce a cross-referenced overview of activities within the IGWCO, focusing on the status of the stated objectives of the water cycle variables. In the intervening 3 years since the report was written, it is timely to review those objectives to determine those that have been met, those that have not, those that are in the process of being met, and those that have taken a different track due to opportunities of convenience. The report also aims to provide a perspective on the future orientation of the IGWCO in terms of tasks that remain outstanding.

Using the outline of Chapter 4 in the IGWCO Guide as a template, an assessment of the accomplishments in each of the IGWCO water cycle arenas follows. For a quick overview, Table 1 (page 19) reproduces all of the recommended objectives for each of the water cycle variables from the IGWCO Guide, indicates the mechanism or agency responsible for implementation of a given objective, and provides a measure of progress towards the stated objective (within the scope of the IGWCO) using the following key: “A” for Accomplished with tangible output; “C” for Commenced with activity ongoing; and “N” for no discernible activity.

2. PRECIPITATION (IGWCO Water Cycle Variable 4.1)

2.1. Main Objective

- To produce a time series of accurate gridded precipitation fields (all hydrometeor phases) with fine spatial and temporal resolution for nearly all land areas of the world, including those regions where rain gauges are sparse, inappropriately distributed, or non-existent.

The centerpiece of this effort is the Program to Evaluate High Resolution Precipitation Products (PEHRPP), which aims to devise a “hypothesis-based assessment” for providing the best way to combine data from disparate sources such as *in-situ* rain gauge networks, passive microwave sensing, and precipitation radar. After an initial quality assessment with respect to the high-resolution global precipitation products currently available, the IGWCO will pursue development of a fully integrated system via the PEHRPP.

Participants: International Precipitation Working Group (IPWG), Global Energy and Water Cycle Experiment (GEWEX)
Point of Contact: Phil Arkin (University of Maryland)

2.2. What has been accomplished

The PEHRPP has been launched and is in its second year of existence:

- PEHRPP presented to IPWG October 2004.
  - Coordination Group for Meteorological Satellites (CGMS) agrees to sponsorship.
- Goals:
  - Characterize errors in various HRPP, on diverse spatial and temporal scales.
  - Enable developers of HRPP to improve products, and users to understand relevant characteristics.
  - Define data requirements/computing resources for retrospective HRPP processing.
- Preliminary results discussed at World Weather Research Program (WWRP), Boulder 2005.
- Interim results discussed at 3rd IPWG Workshop, Melbourne 2006.
- Validation/intercomparison precipitation datasets from regional campaigns now available:
  - http://www.bom.gov.au/bmrc/SatRainVal/validation-intercomparison.html

Gridded precipitation datasets from the Coordinated Enhanced Observation Period (CEOP) are also available:

- http://www.gewex.org/ceop.htm

2.3. Currently Ongoing

4 Suites of Activity

- Suite 1: statistical comparisons, validating data from 8 sites against national rain gauge and radar networks.
- Suite 2: comparison studies focusing on high quality fine resolution time series over select limited regions from CEOP and TAO/TRITON rain gauges.
- Suite 3: analysis of high quality datasets from NAME and KWAJEX, combining radar (from NCAR S-Pol and INEMET) and rain gauge data.
- Suite 4: “big picture” analysis:
  - validation of large-scale precipitation quantities
  - evaluation of GPCP and CMAP
  - observations of stream flow and water budgets
  - identify artifacts not evident in statistics of Suites 1-3
- HRPP Workshop planned for late 2007.

2.4. Other Objectives Remaining

- Internationally agreed-upon set of procedures/protocols for collecting/correcting snowfall measurement.

2.5. New Directions to explore

- Plans to address need for high resolution frozen hydrometeor measurements (in PEHRPP or other project)?
- Incorporate SNOTEL snow measurement data from network in Western USA? (http://www.wcc.nrcs.usda.gov/snow/index.html)
- Incorporate high-resolution hydrometeor data from Community Collaborative Rain, Hail, and Snow Network (CoCoRaHS) ? (http://www.cocorahs.org/).
- Incorporate Atmospheric Radiation Measurement (ARM) high-resolution hydrometeor, cloud cover, radar, and passive microwave data from SGP, TWP and NSA sites? (http://www.arm.gov).
- Research on mobile phone signal interference and precipitation intensity. (http://www.sciencemag.org/cgi/content/abstract/312/5774/713) (http://news.bbc.co.uk/2/hi/science/nature/4974542.stm) (http://www.newscientist.com/article/dn9113-cellphone-masts-can-measure-rainfall.html)

- Proposal for a new IGWCO project: Using data from the HRPP initiative as well as available high resolution satellite precipitation data, develop a project on global, high resolution precipitation estimation from satellite data, updated every 6 hours in support of the International Flood Network (IFNET) and the International Flood Initiative of UNESCO, WMO, the International Centre for Water Hazard and Risk (ICHARM; Japan), and others.

3. Soil Moisture (IGWCO Water Cycle Variable 4.2)

3.1. Main Objective

- The production of an integrated soil moisture product, optimally combining the best available *in-situ* and remotely sensed data with the modeling and data assimilation capabilities of numerical weather and climate forecasting operations.

In order to better understand global water and energy cycles, improve the prediction of precipitation, and provide advice to water resource managers at the local level, adequate soil moisture information is essential. However, at present, no global *in-situ* network for soil moisture exists. Thus, the IGWCO has set improved global observations and model estimates of soil moisture as a priority.

Participants: ISMWG, GCOS, ESA (SMOS)
Point of Contact: Peter van Oevelen (ESA), Tom Jackson (Hydrology and Remote Sensing Laboratory)

3.2. What has been accomplished

- The International Soil Moisture Working Group (ISMWG) was established in 2005 to handle the main objectives of this IGWCO water cycle variable.
- The first ISMWG Workshop was held in March 2006. Outcomes included:
  - standardization of measurement protocols
  - cross-validation among temperature, soil texture/bulk density, gravimetric soil moisture, sensor density/depth, units of representation
  - network design, density, linkages, availability of metadata
  - formation of task group
- Additionally, the European Space Agency (ESA) Soil Moisture and Ocean Salinity Mission (SMOS) Workshop held in May 2006, addressed ways in which this initiative could support the IGWCO. Further, the European Centre for Medium-Range Forecasting (ECMWF) expressed interest in collaborating by providing model analyses/assimilation products.

3.3. Currently Ongoing

- GCOS has named soil moisture as one of its emerging Essential Climate Variables (ECV) and thus is placing an emphasis on developing an experimental soil-moisture product from existing networks and satellite observations, in collaboration with the IGWCO (Action T37 [TF1], GCOS Implementation Plan).
  - Goal is development of quasi-operational integrated global soil moisture product by 2011.
- GCOS's Ocean Observations Panel For Climate (OOPC) through the WCRP endorses research efforts to demonstrate the feasibility of measuring salinity from space, in particular the current efforts through the Soil Moisture and Ocean Salinity project (SMOS) and Aquarius (Action O16 [OF6], GCOS Implementation Plan).
- Development of a Global *In-situ* Soil Moisture Network by the ISMWG.
- Publication of the March 2006 Workshop report forthcoming.
- Website/newsletter development to foster research discussion.
- Improve quality of satellite products and promote use of data.

- Coordinate SMOS with other relevant missions.
- Encourage current field experiment participation/data sharing.
- White paper development.
- ISMWG workshop planned for Spring 2007, Asia.
- HYDROS no longer operational due to NASA funding curtailment.

3.4. Other Objectives Remaining

- Operational soil moisture product.
- Research to remove vegetation effects from moisture signal.
- Stronger participation in GTN-H.
- Coordinated plan for soil moisture networks. (Whitepaper?)
- Program/network of supersites identified to provide comprehensive datasets for sensor evaluation/calibration, provide basis for developing soil wetness/moisture algorithms for satellite measurements. (ARM?)

3.5. New Directions to explore

Possible linkages with other programs dedicated to remote sensing of soil moisture could be reviewed, such as:

- Baseline Solar Radiation Network (BSRN) latent heat flux data (http://www.gewex.org/bsrn.html)
- Soil Climate Analysis Network (SCAN) data (http://www.wcc.nrcs.usda.gov/scan/)
- Oklahoma Mesonet soil moisture data (http://ams.confex.com/ams/Annual2006/techprogram/paper_101610.htm)
- Global Hydrology & Climate Center (GHCC) Surface Hydrology & Remote Sensing project (http://www.ghcc.msfc.nasa.gov/surface_hydrology/)

4. STREAMFLOW AND SURFACE WATER STORAGE (RUNOFF) (IGWCO WATER CYCLE VARIABLE 4.3)

4.1. Main Objective

- The establishment of an integrated stream/lake/reservoir database, comprised of *in-situ* and remotely-sensed capacity/flow monitoring in real time.

Given that water resource managers need timely and accurate information with respect to river flow and water storage in lakes and reservoirs to prevent, among other things, water-related disasters, the IGWCO has emphasized the development of a Global Runoff Monitoring Project. The objective of this initiative is to provide temporal observations and analyses of surface runoff and lake/reservoir storage variations and variability, by means of integrated *in-situ* and remotely sensed real-time monitoring. In the year since it was first proposed, the project has expanded to include participants such as the ESA, GEO and GTN-H.

Participants: GEO, GTN-H/GTN-R, ESA, De Monfort University, WHYCOS, WMO, NASA
Point of Contact: Michael Rast (GEO Secretariat), Wolfgang Grabs (WMO)

4.2. What has been accomplished

- Participation of ESA encouraged, following success of “River-Lake” project with ENVISAT altimetry products, in conjunction with Water Elevation Recovery Missions (WatER) Initiative.
    - Development of River Lake Hydrology (RLH) and River Lake Altimetry (RLA) data products. (http://earth.esa.int/riverandlake/description.htm)

- In response to the Decadal Survey, NASA has established the WATER Mission, which aims to determine where water is stored on Earth's land surfaces, and how this storage varies in space and time, by tracking fresh water from space (including surface water runoff).
    - a component of this initiative is the use of satellite-borne Ka-Band Radar Interferometer (KaRIN) to measure water elevation.
    - Arctic freshwater discharge now being estimated due to GRACE.
- The Global Runoff Monitoring Project first proposed at CEOP/IGWCO Workshop (March 2006).
    - Project subsequently renamed Hydrological Applications and Runoff Network (HARON) with participation of GEO and GTN-H.

Currently Ongoing

- HARON:
    - Phase I: GEO/GTN_H establishment of HARON project:
        - upgrade 300+ *in-situ* monitoring stations
        - provide data to modelers as input for model calibrations
        - GEO expertise for integration of diverse observing platforms
    - Phase II: formalize cooperation between ESA and WMO (with Memorandum of Understanding by early 2007).
        - ESA to support WHYCOS and GTN-H with real-time altimetry observational data over select basins (Africa, Asia, Latin America).
        - Calibrate discharge data via algorithm development; then distribute via website.
    - Phase III: establishment of the International Hydrological Database on Lakes and Rivers (HYDROLARE) Center, Russia.
        - monitor fluxes and residence times for 200 largest freshwater lakes

- Formation of Task Team to prepare implementation plan.
- Focus on calibration/rating curves for select rivers.
- Calculate storage volume changes for large lakes/reservoirs, based on bathymetric information.
- WHYCOS conducting country-by-country inventory of stream flow measurement status, and data transfer issues.
- WHYCOS evaluations of status and decrease of hydrometric measurements. (e.g. http://www.whycos.org/IMG/pdf/WHYCOS_EVALUATION_REPORT_-_VERSION_8_APRIL_2005_1.pdf)
- WMO to develop and set standards for data formats, algorithm development, etc., with *Communities of Practice* document.

4.3. New Directions to explore

- Establish threshold for sustainable withdrawal from boreholes/aquifers.
- Use of stable isotope ratios in river flow to measure impact of land use changes in basin hydrology. (e.g. CEOP Newsletter No. 10, August 2006)
- Use of Doppler lidar to measure river surface velocity.
- How to combine *in-situ* with complementary altimetry data to provide bi-weekly river data for forecasting purposes.
- How to strengthen observational capacities.
- Exploit other capabilities of remote sensing.

5. CRYOSPHERIC VARIABLES (IGWCO Water Cycle Variable: 4.4)

5.1. Main Objective

- To provide comprehensive, integrated measurements of cryospheric variables (snowfall and snow depth, snow water equivalence, permafrost depth/distribution, freeze/thaw state of the surface, glacier status) via remotely sensed and *in-situ* monitoring.

The cryosphere was initially identified as a water cycle variable of interest to the IGWCO due to the vast amounts of fresh water it contains stored in glaciers, ice sheets, and seasonal snow cover. Additionally, the high albedo of snow and ice expanses plays a dominant role in albedo variability of the Earth's surface, while seasonal snow cover and ground ice regulate the depth of permafrost and extent of freeze/thaw cycles, respectively. In the intervening time since the IGWCO Reference Guide was written, however, the Cryosphere became identified, and approved, as an IGOS-P Theme in its own right (see: http://stratus.ssec.wisc.edu/igos-cryo/). Therefore, as of this writing, none of the objectives set out for the IGWCO in relation to the Cryosphere has been pursued. Indeed, the way forward may be to allow the Cryosphere Theme to take the lead, with the IGWCO closely collaborating to both accomplish its goals and foster cross-cutting activity among IGOS themes.

5.2. New Directions to explore

- The relationship to IGOS-P Cryosphere Theme needs to be explored, defined, and differentiated.
- Alternatively, the IGWCO should explore ways to collaborate with Climate and Cryosphere (CliC) project, as an example of cross-cutting integration amongst IGOS-P Themes.

6. CLOUDS AND WATER VAPOR (IGWCO Water Cycle Variable: 4.5)

6.1. Main Objective

- The production of vertical water vapor profiles and cloudiness databases, based on radiosonde and remotely sensed measurements.

The 2004 IGWCO Reference Guide highlighted the fact that the inadequate representation of radiation processes in the cloudy atmosphere is currently one of the greatest sources of uncertainty in efforts to model atmospheric circulation. Given the major role that clouds play in modifying radiative forcing, in conjunction with the efficient absorption and re-emission of infrared radiation by water vapor in the atmospheric column, it is critical that these components of the hydrologic cycle be accurately quantified globally in order to ameliorate model simulations of the general circulation. As of this writing, however, none of the objectives of the IGWCO have been brought to fruition.

6.2. New Directions to explore

It is perhaps timely to re-evaluate the extent to which the IGWCO wishes to pursue global integration efforts in this area. It may be decided that, given the breadth of this topic and the number of international initiatives already working on it (e.g. GEWEX, CMMAP, CLOUDSAT), the objectives set out for the clouds and water vapor variables are no longer pertinent nor manageable, and should thus be discarded. If, on the other hand, the objective of providing a global integration strategy for these variables is to be retained, then it would be beneficial to revisit the objectives, redefine where necessary, and explore how they can be achieved through collaboration with existing initiatives. In particular:

- To what extent should GEWEX take a lead role in fulfilling IGWCO's objectives in this area? If it does, what would this leadership look like, how would it be implemented, and which mechanisms would it use? It may be expedient to look for synergistic linkages in this area with:

- collaboration with GCOS should be enhanced
- collaboration with the Integrated Land Ecosystem – Atmosphere Processes Study (iLEAPS) should be explored
- the Atmospheric Radiation Measurement (ARM) Program (http://www.arm.gov)
- the CloudSat Program (http://cloudsat.atmos.colostate.edu/home)
- the Global Hydrology Resource Center (GHRC) (http://ghrc.msfc.nasa.gov/ghrc.html)

7. Evaporation and Evapotranspiration (IGWCO Water Cycle Variable: 4.6)

7.1. Main Objective

- To provide comprehensive water vapor flux measurement data from evaporation/evapotranspiration sources, including *in-situ* and eddy-correlation methods from flux towers, and estimates from models based on the energy balance equation.

Atmospheric water vapor is replenished through evaporation of liquid water over both ocean and land surfaces, and through transpiration from vegetation. As previously mentioned, accurately determining the amount of water vapor in the atmosphere is crucial for improving numerical weather prediction and global climate model simulations. The IGWCO has identified the measurement of total evaporation/evapotranspiration, especially over land, as particularly problematic both in terms of methods and extent. Aside from routine US National Weather Service (NWS) evaporation pan measurements and eddy correlation sensors at (non-heterogeneously spaced) flux towers (FLUXNET), there is an ongoing paucity of data for this water cycle variable. Thus, IGWCO objectives for water vapor included not only expanding existing initiatives, including adaptation of the CO_2-oriented FLUXNET to emphasize evaporation/evapotranspiration measurements, but also exploring ways in which evaporation/evapotranspiration might be measured by remote sensing means. As of this writing, however, none of the objectives set out in the IGWCO Reference Guide have been met.

7.2. New Directions to explore

As with the previous water cycle variable, Clouds and Water Vapor, it would be expedient to re-evaluate the objectives set forth in relation to evaporation and evapotranspiration. A question to consider is where the current objectives as stated are perhaps beyond the scope of what can be accomplished through the IGWCO. Additionally, it may be that there is considerable overlap with the objectives of the previous water cycle variables, Clouds and Water Vapor, such that the objectives here may be folded in with them for the sake of efficiency.

8. ENERGY-WATER INTERACTIONS AND CLIMATE (IGWCO Water Cycle Variable: 4.7)

8.1. Main Objective

- The development of comprehensive sensible and latent heat flux databases for ocean and land surfaces, based on research and operational satellite measurements, *in-situ* networks and reanalysis products.

Forced by differential solar heating, weather and climate are the response of the Earth atmosphere system as it seeks to establish thermodynamic equilibrium. Added to this, increasingly, are forcings due to anthropogenic activities. In order to better understand the global distributions of energy in all of its forms, and the exchanges that occur between them on the disparate time and space scales, it is important that accurate observations and analyses of the various forms of atmospheric energy, mass, and momentum be conducted. For example, as noted in the IGWCO Reference Guide, incoming solar energy is partitioned into latent and sensible heat at the land-air interface. How this partitioning takes place is dependent on moisture in the upper layers of the soil and ultimately induces land-atmosphere feedbacks that affect cloud development, which in turn influences climate. The IGWCO Guide outlines the various objectives designed to provide and integrated measurement of energy-water interactions, such as the development of sensors and mission strategies to measure cloud profiles and indirect aerosol effects on cloud development and radiation budget. However, once again as of this writing, none of these objectives has been carried out.

8.2. New Directions to explore

By its very name, the activities of the Global Energy and Water Cycle Experiment (GEWEX) project are principally directed towards examining energy-water interactions. GEWEX is therefore perhaps the entity is best suited to direct the accomplishment of IGWCO objectives, should indeed the IGWCO wish to continue global integration efforts with respect to this water cycle variable. Moreover, given the interplay between clouds, water vapor, evaporation and the energy cycle, it might be advantageous to merge the objectives of the previous two water cycle variables (4.4 and 4.5) with those of the Energy-Water Interactions variable to streamline efforts and create a single variable dealing with clouds, water vapor, and energy interactions. As before, some further food for thought would be to consider how the IGWCO could find partnership opportunities with the CMMAP, CloudSAT, ARM, and GHRC initiatives.

9. GROUNDWATER (IGWCO Water Cycle Variable: 4.8)

9.1. Main Objective

- Conducting an integrated global monitoring of groundwater (including aquifers and other underground storage), based on *in-situ* monitoring and perturbations in Earth's gravity field as measured by satellite observations.

The importance of groundwater management has become increasingly apparent as demands for drinking water and agricultural irrigation continue their upward trend. As the IGWCO Guide points out, in many regions of the world, groundwater usage has reached a rate where withdrawal from a large number of aquifers globally exceeds its annual replenishment and leads to depletion of aquifer storage with undesirable side effects. This has negative implications for water and soil quality, and ultimately the quality of life for the entire ecosystem, including humans.

Participants: UNESCO/FAO (ISARM), GRACE, IGRAC
Point of Contact: Alice Aureli, Matt Rodell, Jay Famiglietti

9.2. What has been accomplished

The International Groundwater Assessment Centre (IGRAC) and the UNESCO International Hydrological Programme (IHP) have been identified as promising partners in the IGWCO effort to assist with strategy for integrated global groundwater monitoring. In particular:

- IGRAC is fully supported by the government of The Netherlands, with funding through 2009.
- IGRAC is working to establish a sustainable Global Groundwater Monitoring System (GGMS), using aggregated information from existing networks to provide changes in groundwater at regional scales over the globe.
- Within GGMS, IGRAC is exploring possibilities of using Gravity Recovery and Climate Experiment (GRACE) satellite observations for groundwater monitoring.

In addition to IGRAC, a joint working group has been launched comprised of the United Nations Environmental Scientific and Cultural Organization (UNESCO), the Geological Application of Remote Sensing (GARS) project, and the IGWCO.

In addition to IGRAC, a Groundwater Working Group has recently been established, comprised of GARS, UNESCO, TIGER, and the IGWCO. Among other things, priority needs for the group to address include:

1. inventory of needs for groundwater information for applications;
2. review existing groundwater information systems and to develop and promote initiatives that will address the gaps;
3. propose and develop observing system plans and strategies for international programs and national agencies responsible for groundwater;
4. identify opportunities for applying remote sensing data in the identification, mapping and management of groundwater resources;
5. assist IGOS-P Global Water Cycle and Geohazards Observations themes in responding to GEO targets that have implications for groundwater observational systems, including activities related to capacity building.

A Groundwater Workshop is being planned by the new IGWCO-GARS-UNESCO Groundwater Working Group, with the probable venue being the Netherlands, autumn 2007. The leaders include Matt Rodell (NASA), Jay Famiglietti (UCI) and a representative from UNESCO. The Workshop would be aimed at participants such as groundwater resource managers, academics, remote sensing experts, industry users, agricultural users, data providers and hydrologic services, representatives from regions that are highly dependent on groundwater, and policy experts. The proposed purposes of the Workshop include:

- remote sensing technologies that may be useful and how to promote these to the various national space agencies;
- review ground based well observation networks in existence, and how, if possible, to make data from these networks available for scientific studies;
- role of an intensive groundwater field campaign.

In view of the slow advancement in this area, it is essential that the Groundwater Working Group liaise in the very near future via a teleconference call to finalize the planning of this workshop.

Determine extent of groundwater monitoring networks change globally and identify regions of particular human and natural stress and vulnerability to climate change. Implementation via: GGMS (IGRAC), GWES, GRAPHIC.

9.3. New Directions to explore

Linkages with other groundwater research programs, such as Australia's Centre for Groundwater Studies (CGS) could be beneficial. (http://groundwater.com.au/home/). Additionally, avenues of collaboration with UNESCO's International Hydrological Programme (IHP) should be explored, in particular with respect to the GWES (Groundwater for Emergency Situations) and GRAPHIC (Groundwater Resources Assessment under the Pressures of Humanity and Climate Change) projects. The goals of these projects are, among other things, to identify groundwater resources resistant to natural disasters, and to explore the impact of various human activities and climatic changes on groundwater fluxes, storage, and quality.

10. WATER QUALITY (IGWCO Water Cycle Variable: 4.9)

10.1. Main Objective

- In order to quantify the linkages between water quality and health, the IGWCO has identified a globally integrated strategy to monitoring water quality as another of its water cycle objectives. Both *in-situ* and remotely sensed monitoring are essential components of this approach.

Participants: GEO, University of Wisconsin

Point of Contact: Michael Rast (GEO Secretariat), Steven Greb (University of Wisconsin)

10.2. What has been accomplished

GEO has been pivotal in bringing together expert technical advice on water quality issues via remote sensing. In particular:

- GEO has planned an Inland and Nearshore Coastal Water Quality Remote Sensing Workshop (27-29 March 2007, Geneva), which will cover the following topics:
    - inland waters and coastal land influenced waters
    - data reception, preprocessing, distribution
    - remote sensors (spatial, temporal, spectral resolutions)
    - processing algorithm issues
        - atmospheric correction
        - air-water interface corrections
        - optical water quality variables
        - derived variables (i.e. eutrophication index)
    - calibration/validation issues

At the same time, the University of Wisconsin (UW) has been active in pursuing the objectives of the IGWCO, including the launch of two initiatives:

- the Freshwater Color Coordination Group
- the Multisensor Space-borne Monitoring of Global Large Lakes: Towards an Operational Assessment of Trends in Water Quantity and Quality. The goals of this initiative are to:
    - produce satellite-derived map showing water level fluctuations over 40 large lakes worldwide
    - evaluate the ability of Ice, Cloud, and land Elevation Satellite (ICES) / Geoscience Laser Altimeter System (GLAS) to provide accurate lake level measurements, for the same 40 lakes
    - use field observations from Global Environment Monitoring Program (GEMS) database and corrected satellite imagery to classify second set of lakes
    - derive basic operational algorithms
    - quantify remote sensing costs and data processing issues

10.3. New Directions to explore

Biogeochemical fluxes for a number of large rivers of the world should be established on the basis of a joint ongoing project between GRDC and GEMS/Water, based on Google Earth visualization techniques (see paragraph 1.3, GTN-H Project 3.1).

11. OBSERVATIONAL SYSTEMS AND DATABASES TO SUPPORT SOCIETAL APPLICATIONS AND SUSTAINABLE RESOURCE DEVELOPMENT (IGWCO Water Cycle Variable: 4.10)

11.1. Main Objective

- Adequately addressing socio-economic concerns and sustainable water development requires a comprehensive dataset built upon a broad range of data types, sources, and collection methodologies. Application-specific data (relating to demographics or economic development factors, for example) in combination with products derived from the IGWCO water cycle variables is intended to form such a comprehensive database.

Participants: Global Water System Project (GWSP)
Point of Contact: Charles Vorosmarty

11.2. Currently Ongoing

The Global Water System Project (GWSP) is a cross-cutting initiative that has been established and produced several reports and newsletters (http://www.gwsp.org/products.html). The ultimate goal of the GWSP is to provide an "end-to-end data evaluation" study for water resources, linking the geophysics of water, governance, vulnerability and supply limitations in the context of climate change, erosion, pollution and salinization. To that end, the GWSP along with GEWEX and the IGWCO are assembling a digital atlas for water and water indicators. Additional future GWSP projects include the development of models capable of defining scenarios for the global water system.

12. THE COORDINATED ENHANCED OBSERVATION PERIOD (CEOP)

12.1. Main Objective

- The overarching goal for the IGWCO with CEOP is that the datasets it produces will satisfy the needs of environmental policymakers while supporting scientific and operational environmental programs.

The Coordinated Enhanced Observation Period (CEOP) is the IGWCO's "first element," designed to demonstrate the concept of a fully integrated dataset in terms of range of instruments (*in-situ* and remote sensing), spatial and temporal domains, and levels of international cooperation. Several campaigns have been successfully carried out, producing datasets that are comprehensive in nature and global, regional, and national in scope.

Participants: CEOS, GEWEX, WCRP

12.2. What has been accomplished

Phase 1 had been carried out to completion, including the execution of 3 Enhanced Observation Periods (EOPs). Datasets from these EOPs are currently available via the CEOP website. In particular:

Phase 1 has been completed. Major achievements include:

- EOP-1 (July-September 2001)
- EOP-3 (October 2002-September 2003)
- EOP-4 (October 2003-December 2004)
- Convergence of Observations:
    - 35 terrestrial reference centers
    - 12 NWP/Data assimilation centers
    - 9 satellite projects
- Inter-operability agreement:
    - ISO TC/211 19115 metadata standard
- Data management:
    - online since June 2005
    - *in-situ* data archiving: National Center for Atmospheric Research (NCAR), USA
    - model output data archiving: World Data Center for Climate, Max-Planck Institute for Meteorology, Germany
    - data integration/archiving: University of Tokyo and Japan Aerospace Exploration Agency (JAXA), Japan
- Publications in CEOP/WCRP Newsletter, Journal of Meteorological Society of Japan.
- Water and Energy Cycle Simulation and Prediction (WESP) model output/intercomparison studies.

- CEOP Inter Monsoon Studies (CIMS): model monsoon simulations/intercomparison studies.
- Satellite development:
    - algorithm development/validation (soil moisture, snow)
    - data assimilation for land hydrology (soil moisture, surface fluxes)

12.3. Currently Ongoing

CEOP Phase II has been initiated:

- Proceeding in two stages; 2005-2007 and 2007 – 2010.
- First Pan-GEXEW meeting recently held (Frascati, Italy, 9-12 October 2006):
    - close cooperation with GEOSS emphasized
    - close cooperation with GEWEX/WCRP core projects emphasized
        - GEWEX Hydrometeorology Panel (GHP)
    - commitments to IGWCO emphasized

13. Opportunity-driven Accomplishments

As mentioned in the Introduction, some of the objectives of the IGWCO have expanded or been accomplished through unexpected means, while others have taken a different tack than originally envisaged. This section examines several instances where this has occurred.

13.1. Capacity Building

Contact point: Chu Ishida (JAXA), Rick Lawford (GEWEX), Ana Medico (CONAE)

Thanks to the leadership of *Comision Nacional de Actividades Espaciales* (CONAE), GEWEX, and JAXA, in order to augment the efforts of water managers around the world, particularly those in lesser-developed nations, the IGWCO has taken on the objective of capacity building in addition to global integration efforts in the water cycle variables mentioned above. More specifically, the IGWCO wishes to foster the potential for increasing the efficiency of water use through better monitoring and prediction of pertinent water cycle variables. To that end, the IGWCO has organized several workshops in order to provide a suitable environment where data users (water resource managers, hydrological and agricultural services) and data providers (universities, international/regional meteorological programs, and space agencies) can discourse with respect to experiences, achievements, and specific needs in the sphere of water management. One such workshop was conducted in conjunction with CONAE and took place in Buenos Aires in 2005.

More recently, the International Workshop on Earth Observation in Water Management Services was held in Bangkok, in September 2006, involving the co-sponsorship of GEWEX, JAXA, GEO, WMO, and UNESCO. A key result was that 3 working groups were established to focus on Groundwater and Water Quality, Flood Management, and Drought Management issues. From these working groups it became evident that data quality and availability is a major concern to stakeholders, as well as the need for streamlining remotely-sensed/satellite data integration with *in-situ* data. It was suggested that GEO could play a role in addressing these issues. Additionally, Bangladesh is keen to advance on water contamination issues, a task to be assigned to the GEO Asian Water Quality Project.

In November 2006, the Buenos Aires Capacity Building Development Proposal took place. The workshop included people drawn from JAXA, the Canadian Space Agency, NOAA, NASA, IRI, UNESCO, IAI, and UMETSAT, as well as interested parties from water resource management groups in Argentina, Colombia, and Peru. A plan was assembled centering on a proposal similar to the Terrestrial Initiative in Global Environmental Research (TIGER), but more open. Specifically, high-interest projects will be identified to make use of satellite data, in which results can be tracked and documented. The goal is to provide feedback to experts who can then tailor data to fit needs of regional populations. It is hoped that CONAE will take the lead with this effort.

13.2. Flood and Drought Management

Of special importance is the fast-track development of a GEO Water Cycle Community of Practice. A first draft outline of a proposal for a Community of Practice is planned to be available for the next GEO Users Interface Committee meeting. A number of new topics will also be advanced in 2007. These include:

- The development of a flood project to fill an apparent gap in the Integrated Global Observing Strategy–Partners (IGOS-P) themes and possibly the GEO plan. A planning workshop will be proposed in collaboration with the International Centre for Water Hazard and Risk Management (ICHARM) Program (Japan) and other organizations.
- IGWCO will consider Drought as a possible demonstration project of how to link remote sensing and socioeconomic data. The formation of a UNESCO-IGWCO-GARS Working Group on groundwater and the establishment of an initial task list are also envisaged.

13.3. IGWCO Visibility

13.3.1. Website

An IGWCO-specific website has been developed and is online. The IGWCO website provides a main focal point from which reports, minutes, and other documents may be downloaded, powerpoint presentations viewed, and relevant meetings announced. The site is structured such that content flows sequentially from the general to the specific, is rich in links to partner websites and contains a private sector for communication within the SAG. The URL link for the website is:
http://www.wmo.int/web/homs/igwco/igwco.index.shtml

13.3.2. Promotional Material

Further activities relate to the production of an IGWCO information brochure (JAXA) to promote the concepts of the IGWCO/IGOS strategy planning for the hydrological cycle. In addition, information tables were set up at both the 4^{th} World Water Forum and the UN Commission for Sustainable Development (CSD).

14. CONCLUSIONS

14.1. General Comments

As is evident from this report, much has been, or is being, accomplished in terms of the objectives set out for the IGWCO at its inception. The water cycle variables of Precipitation, Soil Moisture, Streamflow and Surface Water Storage (Runoff), Groundwater, and Water Quality, as well as the CEOP initiative, have seen much activity with tangible output available in some instances. At the same time, there are many objectives that have not been met, particularly with respect to the water cycle variables of the Cryosphere, Clouds and Water Vapor, Evaporation/Evapotranspiration, and Energy-Water Interactions. Still other objectives have been, or are being, realized that were not necessarily within the IGWCO scope, such as Capacity Building and Flood/Drought Management.

Realizing the ever-present strong budget restrictions that hamper the fulfillment of certain objectives, now is the time to reconsider whether those objectives should remain within the scope of IGWCO activities. Perhaps a new set of objectives needs to be drawn in order to guide the near-future of the IGWCO. Or perhaps some objectives should be modified or expanded, drawing upon the expertise of GEWEX, GEO, GTN-H and other programs to reach fulfillment. If these agencies are to contribute to the goals of the IGWCO, specific mention should be made as to how contributions will be made, what those contributions will look like, and through which mechanisms they will be implemented.

14.2. Summary of Findings

- A number of IGWCO activities have been opportunity-driven (as opposed to objective-driven).

- A review of the IGWCO visibility and outreach strategy is in order.
- A proactive search for project funding needs to be undertaken.
- There is a need to improve linkages between GTN-H projects and IGWCO objectives.
- There is a need to improve linkages between GEWEX projects and IGWCO objectives.
- There is a need to decide how much, and what type, of guidance to provide to GEO in accomplishing both its tasks, and those of the IGWCO.
- There is little apparently being done in terms of cross-cutting within the IGOS-P family of themes. Perhaps this could be initiated through IGOS-P itself.
- This report is a call for review of the 2004 IGWCO Reference Guide, to update it and keep it “living.”

15. ACRONYMS

ARM	Atmospheric Radiation Measurement
BSRN	Baseline Solar Radiation Network
CEOP	Coordinated Enhanced Observing Period
CEOS	Committee on Earth Observation Satellites
CGMS	Co-ordination Group for Meteorological Satellites
CGS	Centre for Groundwater Studies
CliC	Climate and Cryosphere Project
CMAP	CPC (Climate Prediction Center) Merged Analysis of Precipitation
CMMAP	Center for Multi-Scale Modeling of Atmospheric Processes
CoCoRaHS	Community Collaborative Rain, Hail, and Snow Network
CONAE	*Comision Nacional de Actividades Espaciales*
ECMWF	European Centre for Medium-Range Forecasting
ESA	European Space Agency
ECV	Essential Climate Variable (GCOS)
GARS	Geological Application of Remote Sensing
GCOS	Global Climate Observing System
GEMS	Global Environment Monitoring Program
GEO	Group on Earth Observations
GEWEX	Global Energy and Water Cycle Experiment
GHCC	Global Hydrology & Climate Center
GHP	Hydrometeorology Panel
GHRC	Global Hydrology Resource Center
GGMS	Global Groundwater Monitoring System
GLAS	Geoscience Laser Altimeter System
GPCP	Global Precipitation Climatology Project
GPM	Global Precipitation Mission
GRACE	Gravity Recovery and Climate Experiment
GRAPHIC	Groundwater Resources Assessment under Pressures of Humanity and Climate Change
GTN-H	Global Terrestrial Network Hydrology
GTN-R	Global Terrestrial Network Rivers
GWES	Groundwater for Emergency Situations)
GWSP	Global Water System Project
HARON	Hydrological Applications and Run-Off Network
HEPEX	Hydrologic Ensemble Prediction Experiment
HRPP	High Resolution Precipitation Products
HYDROLARE	International Hydrological Database on Lakes and Rivers
HYDROS	Hydrosphere State mission
ICES	Ice, Cloud, and land Elevation Satellite
ICHARM	International Centre for Water Hazard and Risk
IFNET	International Flood Network
IGOS-P	Integrated Global Observing Systems Partnership
IGRAC	International Groundwater Resources Assessment Centre
IGWCO	Integrated Global Water Cycle Observations Theme
IHP	International Hydrological Programme (UNESCO)
iLEAPS	Integrated Land Ecosystem – Atmosphere Processes Study
INEMET	Instituto Nacional de Meteorología
IPWG	International Precipitation Working Group
ISMWG	International Soil Moisture Working Group
JAXA	Japan Aerospace Exploration Agency
KWAJEX	Kwajalein Experiment
NAME	North American Monsoon Experiment
NWS	National Weather Service
PEHRPP	Proposal to Evaluate High Resolution Precipitation Products
RLA	River Lake Altimetry
RLH	River Lake Hydrology
SAG	(IGWCO) Science Advisory Group
SCAN	Soil Climate Analysis Network
SMOS	Soil Moisture and Ocean Salinity Mission
TIGER	Terrestrial Initiative in Global Environmental Research
UNESCO	United Nations Environmental Scientific and Cultural Organization
UW	University of Wisconsin
WatER	Water Elevation Recovery Missions
WCRP	World Climate Research Programme
WHYCOS	World Hydrological Cycle Observing System
WMO	World Meteorological Organization
WWRP	World Weather Research Programme

TABLE 1: INVENTORY OF OBJECTIVES FOR IGWCO HYDROLOGIC VARIABLES

Progress Status key:

A = Accomplished (finished product available)
C = Commenced (activity ongoing)
N = No discernible activity

Water Cycle Variable: 4.1 Precipitation

Expected Results	Implementation via	Progress Status
a) Improved instruments (higher spatial and spectral resolution) to enhance sampling required on more satellites.		N
b) Enhanced coverage of space-borne radar, with improvements in sensitivity to light rain and solid precipitation.		N
c) Improved algorithms to combine/blend observations from disparate platform sources.	PEHRPP	A
d) Execution of specifically targeted field campaigns using satellite, aircraft and novel *in-situ* instruments (i.e. profilers).	PEHRPP/CEOP	A
e) Agreement among nations concerned on protocols for collecting/correcting snowfall measurements.		N
f) Strengthening of national networks for snowfall measurements and data collection.		N

Water Cycle Variable: 4.2 Soil Moisture

Expected Results	Implementation via	Progress Status
a) Development of coordinated plan for soil moisture networks, at national and international levels.	ISMWG, GCOS	C
b) Conduct studies to determine most useful products from missions such as SMOS (HYDROS discontinued).	ISMWG	C
c) Understand/quantify relationship between surface soil wetness and deep soil moisture profiles.	ISMWG	C
d) Conduct research to determine best way of removing vegetation effect from soil moisture signal.		N
e) Establishment of supersite network to provide comprehensive datasets for sensor evaluation and calibration; basis for developing soil wetness/moisture algorithms for satellite measurements; basis for evaluation of climate model outputs.	ISMWG	C

Water Cycle Variable: 4.3 Streamflow and Surface Water Storage (Runoff)

Expected Results	Implementation via	Progress Status
a) Document extent and causes of decrease in hydrometric measurements globally.	WHYCOS/GEO	A
b) Conduct review of streamflow measurement status and distribution, by country, and determine transferability of data to global databases.	WHYCOS/GTN-H	C
c) Conduct research to gain streamflow/surface water distribution information through exploitation of altimetry data from existing satellite observations.	ESA	A
d) Explore, evaluate, develop, and implement non labor-intensive alternative options for streamflow measurement.	GEO	C
e) Establish system for routine collection and distribution of any and all water level information from satellite and aircraft observations.	GEO/ HYDROLARE	C
f) Explore remote sensing feasibility of streamflow via proof of concept studies of rivers with known widths and slopes.	GEO	C
g) Promote free and open streamflow data exchange globally via international program membership in GEO.	GTN-H GRDC/WHYCOS	C
h) Establish/upgrade 380 *in-situ* river and lake run-off stations, and combine with remotely-sensed data.	HARON (GTN-H/GEO/ ESA/GCOS)	C

Water Cycle Variable: 4.4 Cryospheric Variables

Expected Results	Implementation via	Progress Status
a) Development of new sensors and algorithms to measure SWE on the ground, under wide range of vegetation conditions.		**N**
b) Capitalize on cold-season satellite measurements/field projects to plan optimized mission for measuring cold-season processes/variables from space.		**N**
c) Plan field project focussing on snow, ice, and snowmelt measurement in mountainous region.		**N**
d) Encourage development of multispectral sensors to provide freeze/thaw patterns under various vegetation conditions.		**N**
e) Supplement current network of snow-depth observations from manual climate-observing stations and global, daily snow-depth analyses with weekly measurements of SWE.		**N**
f) Establish research-quality dataset of climatology of snow properties, integrating *in-situ*, microwave, and visible snow measurements for select stations.		**N**

Water Cycle Variable: 4.5 Clouds and Water Vapor

Expected Results	Implementation via	Progress Status
a) Establish high-calibre radiosonde network in equatorial regions to accurately capture vertical distribution of water vapor, a critical factor in radiation budget research.		**N**
b) Consolidate datastreams from current GPS network into a global operational network.		**N**
c) Development of higher vertical resolution water vapor sensors for inclusion on satellites.		**N**
d) Coordinate satellite missions field experiments to measure cloud properties.		**N**
e) Provide measurement-based estimates of radiation flux-divergence through development of techniques to determine vertical distribution and optical properties of cloud particles in atmospheric column.		**N**
f) Development of integrated analysis approach to assessing cloud aerosol detection from “A-Train” sensors.		**N**
g) Addition of cloud aerosol sensor to GPM core satellite.		**N**
h) Promotion of new methods and technology development for observing profile microphysics and vertical motion.		**N**

Water Cycle Variable: 4.6 Evaporation and Evapotranspiration

Expected Results	Implementation via	Progress Status
a) Research into new satellite sensors and algorithms, data assimilation systems and modelling to provide more accurate picture of areal evapotranspiration.		**N**
b) Methodology development to correct flux measurements under difficult conditions (high elevation, cold-season) to maintain energy budget balance.		**N**
c) WMO establishment of standards for collection , processing and archiving of flux data.		**N**
d) Establish plans to transform FLUXNET and related observational systems into operational network.		**N**
e) Integrate CEOP reference sites into real-time, operational observing network.		**N**
f) Investigate methodologies for using stable isotope data as complementary tool for land surface evaporation estimates.		**N**

Water Cycle Variable: 4.7 Energy/Water Interactions and Climate

Expected Results	Implementation via	Progress Status
a) Complete radiation budget (ERBE, SRB with atmospheric radiative flux profiles) to be combined with atmospheric circulation reanalyses to diagnose variability of global energy and water exchanges at weather-scales over 20-30 year period.		**N**
b) Separate forced and unforced climate variations through examination of energy and water exchanges together with observed forcing changes.		**N**
c) Conduct systematic, detailed comparison of old-style versus new-style observational data, supplemented by surface-based measurements.		**N**
d) Development of sensors and mission strategies to measure cloud profiles and indirect aerosol effects on cloud development, radiation budget.		**N**
e) Improvement of water vapor and temperature profile retrievals through combination with sounding data, ISCCP cloud fields, and long-term dataset reprocessing.		**N**
f) Development of surface and latent heat fluxes for ocean and land surfaces, based on research and operational satellite measurements, *in-situ* networks and reanalysis products.		**N**

Water Cycle Variable: 4.8 Groundwater

Expected Results	Implementation via	Progress Status
a) Explore the use of data from GRACE, GOCE and related satellites to inventory groundwater resources and monitor short-term variability.	**GARS GGMS (IGRAC)**	**C**
b) Conduct inter-comparison of groundwater availability/variability measurement techniques, in order to optimize and standardize procedures.	**GGMS (IGRAC)**	**C**
c) Determine extent of groundwater well change globally, and identify regions of particular stress and vulnerability to change.	**GGMS (IGRAC)**	**C**
d) Determine extent of groundwater monitoring networks change globally and identify regions of particular human and natural stress and vulnerability to climate change.	**GGMS (IGRAC), GWES, GRAPHIC**	**C**

Water Cycle Variable: 4.9 Water Quality

Expected Results	Implementation via	Progress Status
a) Review GEMS water quality database to determine frequency and distribution of key remotely-sensed parameters.	**GEO**	**C**
b) Development of empirical models of water quality through merger of satellite imagery (MERIS, MODIS, Landsat) and regression analysis with GEMS data.	**GEO/UW**	**C**
c) Development of universal algorithms for water-quality variables based on application of analytical model algorithms.	**GEO/UW**	**C**
d) Establishment of *in-situ*, automated sensor network to continuously monitor optical metrics at water surface, in concert with field campaigns to ascertain inherent optical properties of waters studied.	**GEO**	**C**

Water Cycle Variable: 4.10 Observational Systems and Databases to Support Societal Applications and Sustainable Resource Development

Expected Results	Implementation via	Progress Status
a) Establishment of task group to review data needs of users related to water usage, socioeconomic factors, and man-made reservoirs, and recommend strategy for IGWCO to facilitate collection/dissemination data pertaining to these needs.	**GWSP**	**C**

CEOP : The first element of the IGWCO Theme

Expected Results	Implementation via	Progress Status
a) Production of comprehensive, global, regional and national datasets to satisfy the environmental information needs of policymakers as well as support scientific and operational environmental programs as a demonstration of the global/international integration concept.	**CEOS, GEWEX, WCRP**	**A**