Global Energy and Water Cycle Experiment

Phase I

GEWEX

WCRP

WORLD CLIMATE RESEARCH PROGRAMME

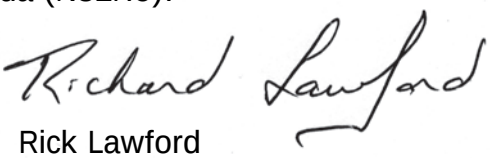
Foreword

The Global Energy and Water Cycle Experiment (GEWEX) of the World Climate Research Programme (WCRP), sponsored by the World Meteorological Organization (WMO), the International Council for Science (ICSU), and the Intergovernmental Oceanographic Commission (IOC) of the United Nations Educational, Scientific and Cultural Organization (UNESCO), has amassed an outstanding record of accomplishments during the first phase of its planned program. From bringing hydrology, land surface, and atmospheric sciences communities together, to showing the importance of understanding soil moisture/atmosphere and cloud/radiation interactions and their parameterization within prediction models, GEWEX has been on the leading edge of science since its inception. Pulling together the global data sets necessary for validation of our predictive models and fostering direct applications with water resources user groups have also provided significant advances in climate research.

This brochure provides just a sample of the numerous accomplishments that GEWEX has achieved during its build-up phase (Phase I). This prepares the stage for many more advances in Phase II, when the community will exploit the new fleet of environmental satellites and build upon the newly implemented model upgrades developed in Phase I.

The authors would like to recognize the very critical support of national agencies in making this program possible. Although the list is very long, special recognition must be given to the U.S. National Aeronautics and Space Administration (NASA), the U.S. National Oceanic and Atmospheric Administration (NOAA), the Japan Aerospace Exploration Agency (JAXA), the Japanese Meteorological Agency (JMA), the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT), Meteo France, the German Association of Natural Resources, the European Space Agency (ESA), the European Community, the Meteorological Service of Canada, and the Natural Sciences and Engineering Research Council of Canada (NSERC).

Moustafa Chahine
Past Chair, Scientific Steering Group



Rick Lawford
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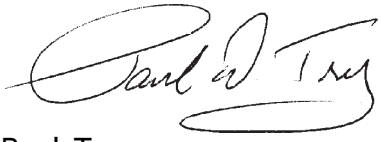

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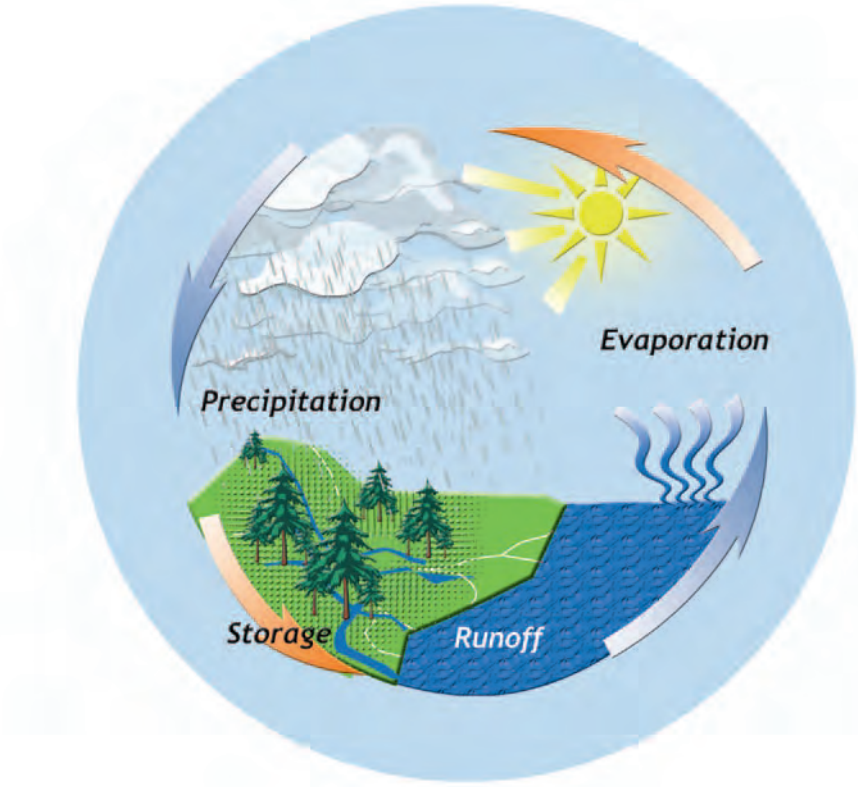
Global Energy and Water Cycle Experiment (GEWEX)

Water in its various forms plays a dominant role in nearly all aspects of the Earth's climate system. As vapor, it is the Earth's strongest and most plentiful greenhouse gas and a primary carrier of atmospheric energy. Clouds play competing roles in both warming and cooling the atmosphere depending on their composition and altitude. Precipitation controls soil moisture and runoff to the oceans. The cycle is closed by evaporation from both the land and the ocean to the atmosphere. The highest scientific priority for predicting climate change and the goal of GEWEX is to understand the full cycle of evaporation, cloud formation, and precipitation.



From the beginning, GEWEX has been a phased project, initially conceived to take advantage of the development of the new series of environmental satellites [i.e., Terra, Aqua, Tropical Rainfall Measuring Mission (TRMM), European Space Agency Environmental Satellite (ENVISAT), and the Advanced Earth Observation Satellite I (ADEOS I)]. The first phase was designed as a build-up phase maximizing the climate use of the current operational and research satellite data, prior to the new satellites becoming operational. The second phase is designed to begin the scientific exploitation of the data from the new satellite sensors.

Primary Phases of GEWEX

Phase I: 1990-2002 Build-Up Phase

Phase II: 2003-2012 Full Implementation – Exploit New Capabilities (New Generation of Satellites and Upgraded Models)

To define the influence of water and energy in climate change, GEWEX has the following objectives:

- Determine the Earth's hydrologic cycle and energy fluxes using global measurements.
- Model the global hydrologic cycle and assess its impact on the atmosphere, oceans, and land surfaces.
- Develop the ability to predict variations in global and regional hydrologic processes and water resources as well as their responses to environmental change.
- Foster the development of observing techniques, data management, and assimilation systems for operational application to long-range weather forecasts, hydrology, and climate predictions.

GEWEX activities will extend into the next decade and will build upon the latest developments in surface-based meteorological and hydrological observing systems as well as Earth observing satellite missions.

The primary activities of GEWEX include:

a) Global data set development,

b) Process studies, and

c) Model development support.

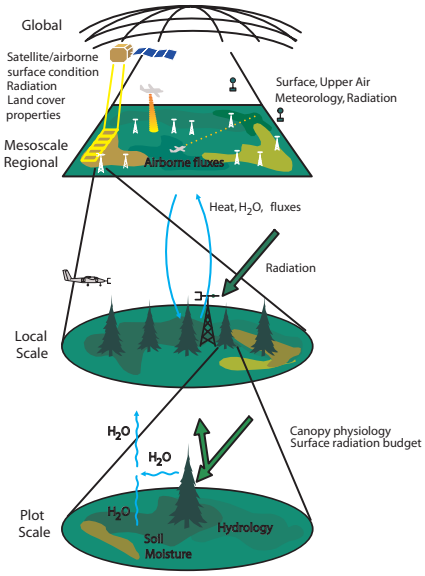
To accomplish the objectives, GEWEX has formed projects to address the critical elements in the energy and water cycles. The global data projects focus on global distribution and variability of clouds, water vapor, aerosols, surface radiation, precipitation, and the features of the land surface and near-surface meteorology that couple the land to the atmosphere. The modelling projects focus on the cloud, land-atmosphere, and boundary layer parameterizations necessary to drive our regional and global prediction models. Coupling the land-atmosphere at the mesoscale has been the initial strategy for the hydrometeorology projects of GEWEX. Five major continental-scale campaigns provide new process understanding and improved model representation in the Amazon, Baltic Sea, Mississippi River Basin, Mackenzie River Basin and four basins in Asia (Thailand, Tibet, Siberia and Eastern China).

GEWEX: A Proven and Successful Research Strategy

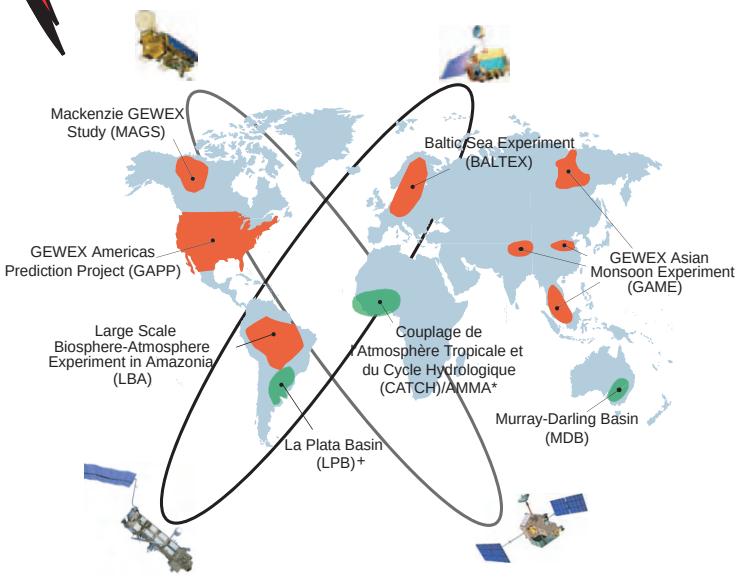
The GEWEX strategy throughout Phase I has been to observe the key energy and water cycle elements globally; to achieve improved understanding and upgraded parameterizations of land surface coupling and cloud processes within mesoscale models through regional process studies; to upscale to global models for prediction; and to downscale for local water resource applications. Phase I, with a broad global strategy (see below) supported by regional field campaigns and multiscale modelling, is now producing critical results necessary for improved climate change prediction and water resource applications.

Observe Globally

Upscale for Prediction



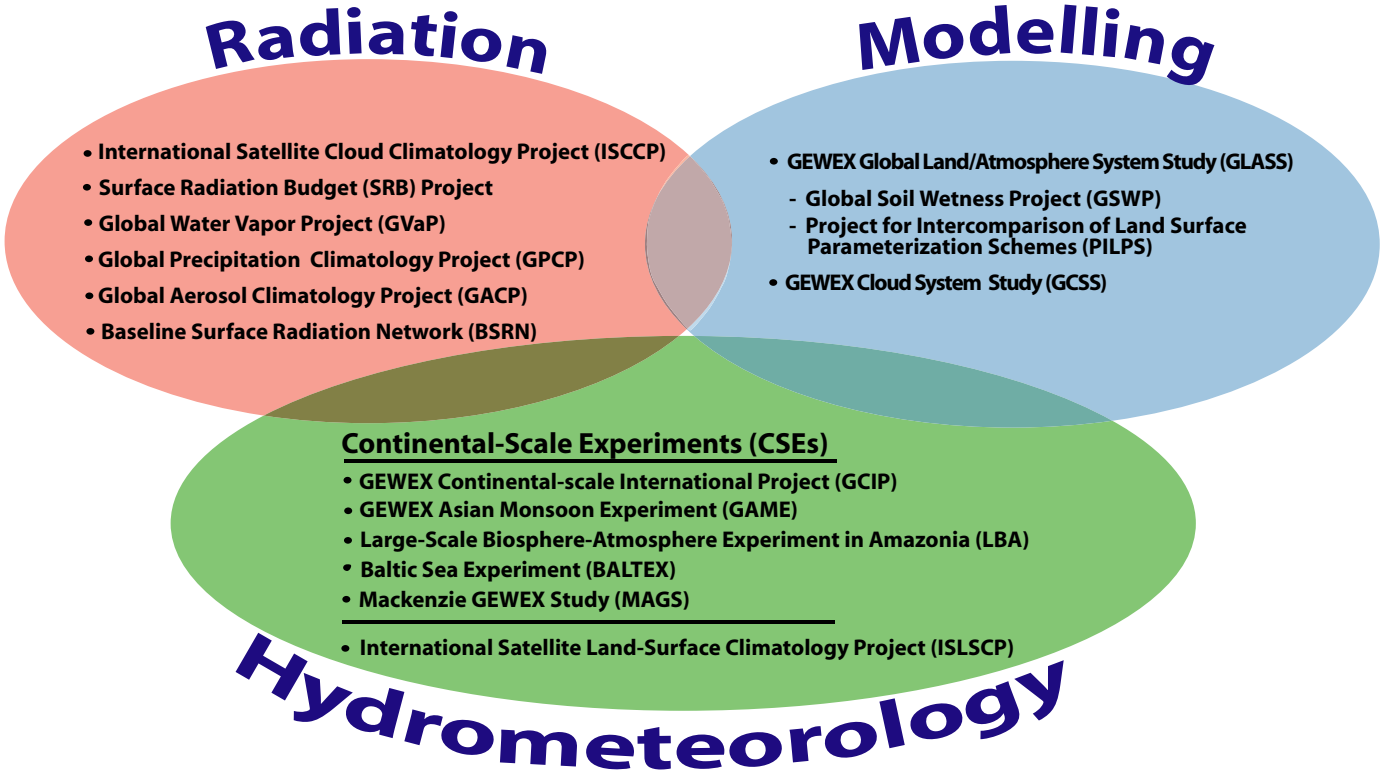
Couple Land-Atmosphere on a Continental Scale (mesoscale modelling)



Downscale for Application

GEWEX Components

GEWEX is composed of three research focus areas with projects designed to address the key elements of the global energy and water cycle — **Radiation** Projects; **Hydrometeorology** Projects; and **Modelling and Prediction** Projects. The figure below shows the distribution of GEWEX projects in Phase I.



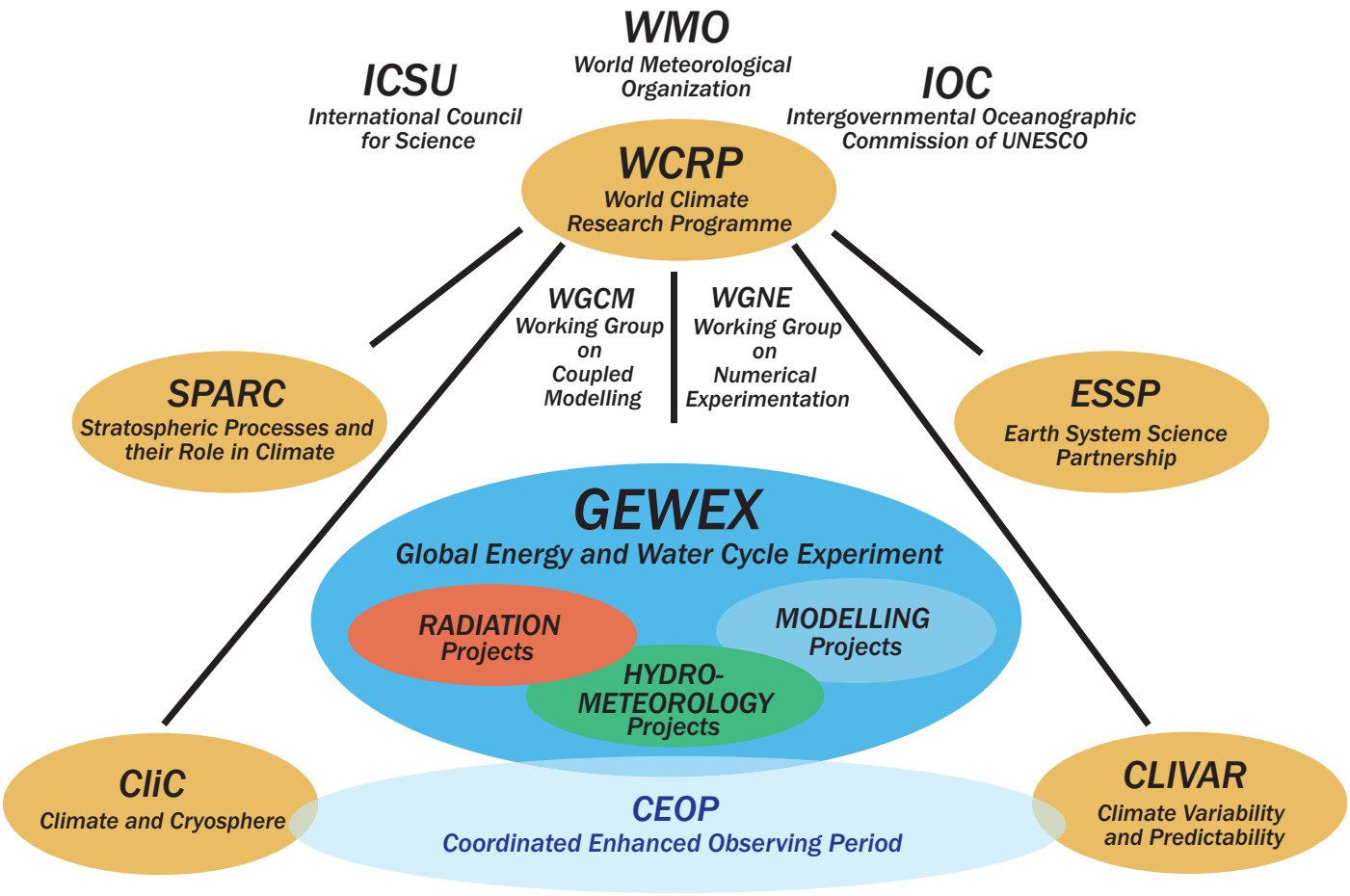
The activites under each research foci are coordinated and guided by their respective panels:

- **GEWEX Radiation Panel (GRP):** Exploit satellite and ground-based remote sensing, together with key long-term *in situ* measurements, to determine global atmospheric and surface radiation and water fluxes with the precision needed to diagnose the causes of forced and unforced climate variations on decadal time scales.

- **GEWEX Hydrometeorology Panel (GHP):** Demonstrate skill in predicting changes in water resources and soil moisture on time scales up to seasonal and annual as an integral part of the climate system, building upon distributed and intensive process studies in the Continental-Scale Experiments (CSEs) and the Coordinated Enhanced Observing Period (CEOP).

- **GEWEX Modelling and Prediction Panel (GMPP):** Develop accurate global model information on the energy and water budget and demonstrate predictability of their variability and response to climate forcing, focusing on cloud and land surface process representation.

GEWEX Organization within WCRP



GEWEX is a core program in WCRP concerned with studying the dynamics and thermodynamics of the atmosphere and interactions with the Earth's surface. By virtue of this central role, GEWEX has links with all other WCRP projects, in particular, the Climate Variability and Predictability (CLIVAR) Project, the Stratospheric Processes and their Role in Climate (SPARC) Project, and the Climate and Cryosphere (CliC) Project.

Note: Access to further information on GEWEX and all data sets is available through http://www.gewex.org.

Summary of Key Results from Phase I

- Completed 15-25 year global data sets of water cycle elements showing global changes, including regional and interannual variations and trends.

- Produced first global analyses of indirect aerosol effects needed for use by the Intergovernmental Panel on Climate Change (IPCC)—determined that improved aerosol data and process understanding were needed for accurate surface radiation and precipitation prediction.

- Produced first compilation of co-registered global data sets for modellers and educational outreach use.

- Reduced significant uncertainties in the understanding and simulation of key water cycle variables through improvements in global observations and land-surface and cloud process parameterizations derived through regional studies and model intercomparisons.

- Improved understanding of regional and global water and energy budgets. Regional budget closure, however, needs further research and improved data accuracy.

- Greatly improved national and international capabilities to undertake large-scale field campaigns, interdisciplinary research, and the management of large data sets involving data from many disciplines and data systems.

- New research, data, and analyses demonstrated the critical importance of land-surface interactions, soil moisture, and global high resolution precipitation data.

- Major new land-surface scheme upgrades resulted in improved prediction capabilities.

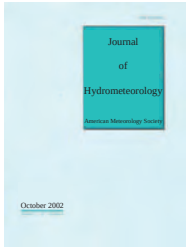
- Regional/Continental-Scale Experiment site data and modelling has proven to be very effective in improving understanding of local processes; however, modelling of diurnal processes must be improved.

Phase I Significant Accomplishments are summarized by results and impact as well as by projects on the following pages.

Results and Global Impact of GEWEX Phase I Activities

New Hydrology-Atmosphere Sciences Linkages

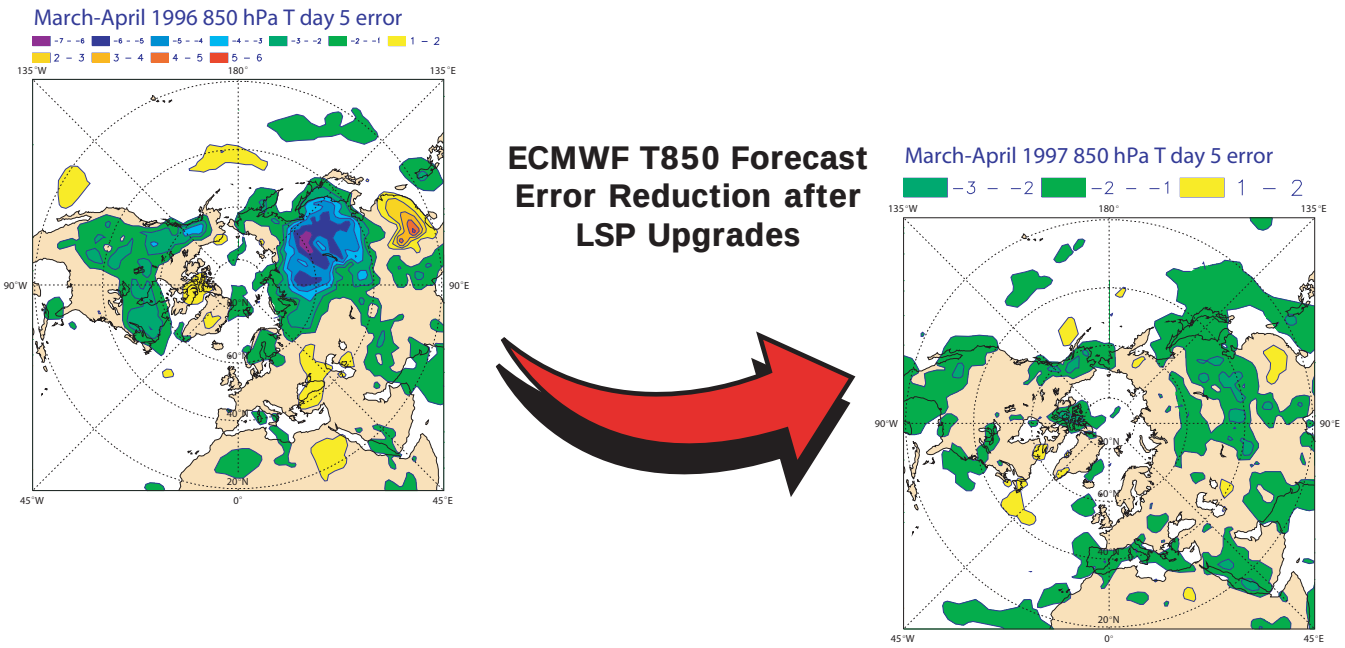
The development of a new interdisciplinary relationship between the hydrologic and atmospheric sciences, with a focus on coupled land surface-atmosphere interactions, led to the initiation of the *Journal of Hydrometeorology*.



During Phase I, the breadth and richness of GEWEX research results led to:

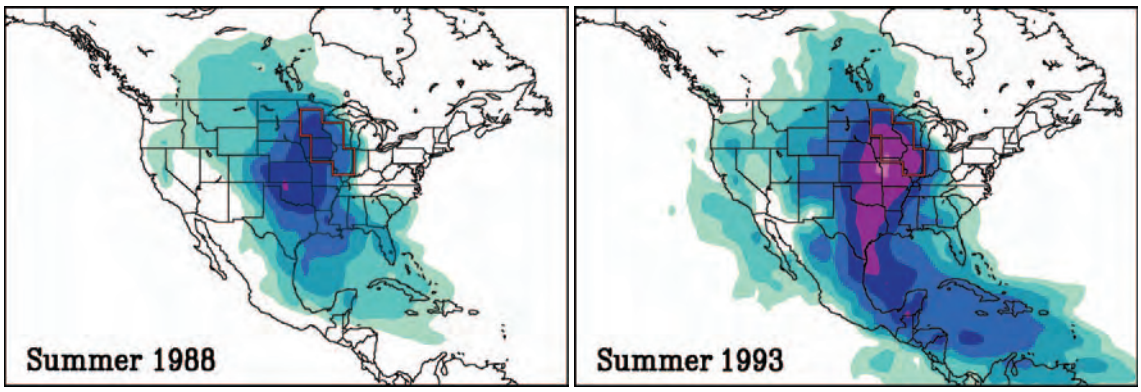
- **Over 20 special journal issues**
- **Over 15 review articles**
- **Distribution of 15,000 data CD-ROMs**
- **Participation of over 2,000 scientists in GEWEX projects**
- **Over 5,000 citations referring to GEWEX results**

Land-Surface Parameterization (LSP) Upgrades Improve Prediction



Providing new field data and the initiation of a new series of land-surface parameterization upgrades in regional and global models worldwide have led directly to improved weather and climate prediction capabilities as displayed above.

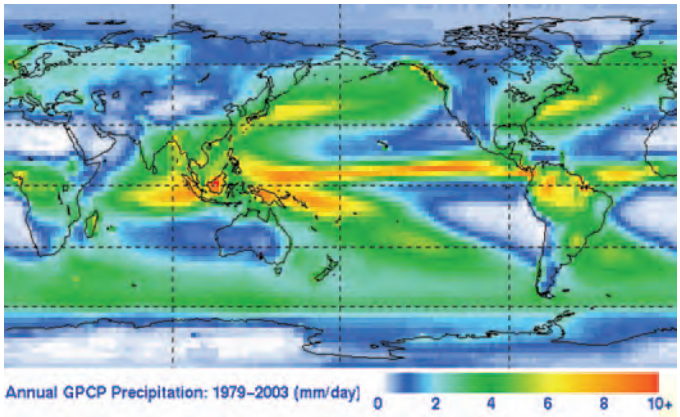
Importance of Soil Moisture: Measurements and Modelling



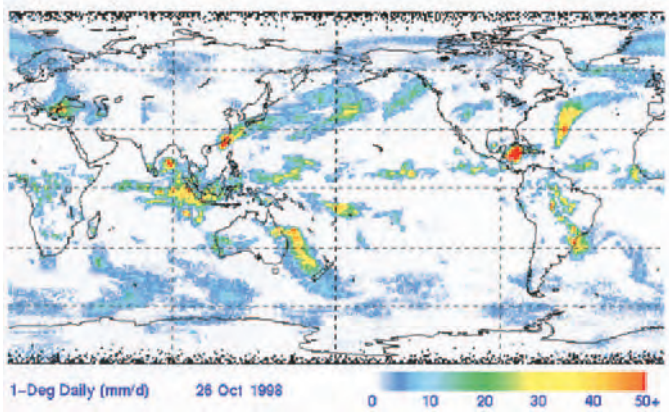
Upstream soil moisture and five-fold increase in Gulf of Mexico moisture flow fuels 1993 flooding.

The GEWEX Continental-scale International Project (GCIP) provided new *in situ* instrumentation programs, new investigations, and new results showing the importance of soil moisture in the modelling and prediction of the regional and global water cycle.

Higher Spatial/Temporal Resolution Global Data Sets

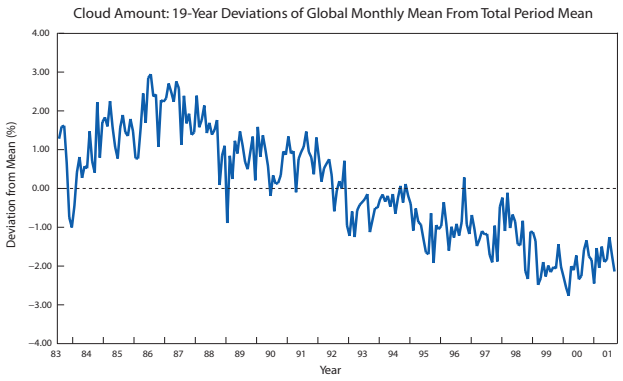


Annual and Daily Global Precipitation from the Global Precipitation Climatology Project (GPCP)



New global and regional precipitation measurements with higher spatial and temporal resolution provided more accurate prediction of regional hydrology and the water cycle (providing 1x1 degree, 3-hourly data sets).

Extended Global Measurements of Water and Energy Cycle



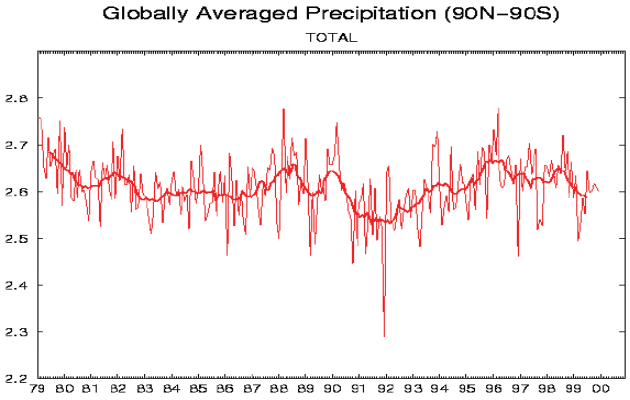
ISCCP (Clouds)

GVaP (Water Vapor)

SRB (Surface and TOA Radiation)

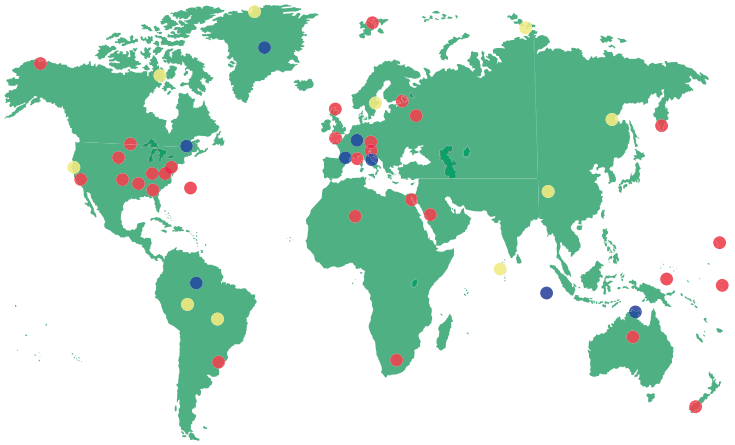
GACP (Aerosols)

GPCP (Precipitation)



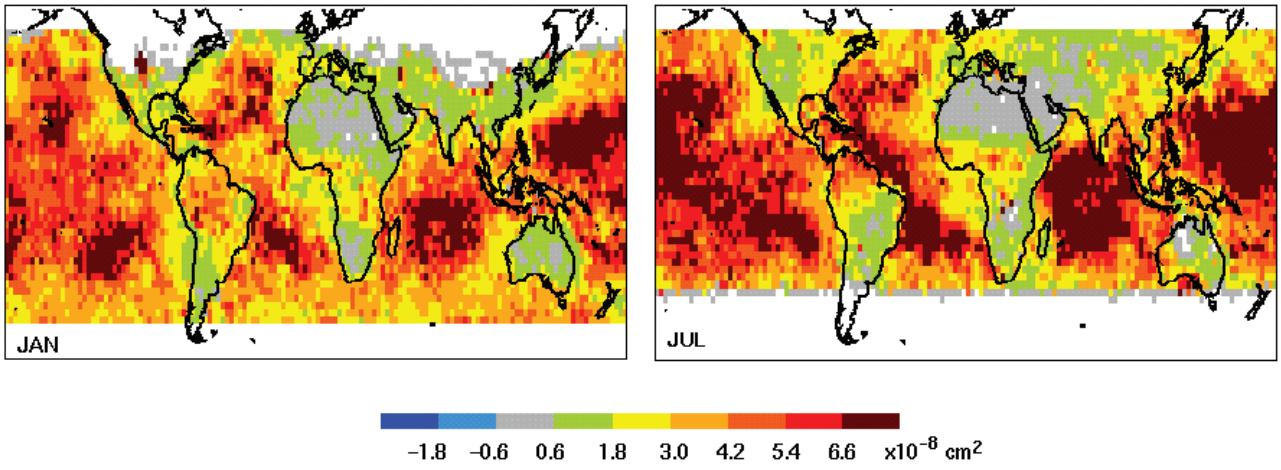
GEWEX undertook the first systematic effort to produce the basic and integrated elements of the global energy cycle with a 15-25 year observationally based view of the Earth, providing cloud, water vapor, precipitation, surface and top-of-the-atmosphere radiation budget, aerosol, and land-surface characteristics at 1.0-2.5 degree and 3-hourly-daily resolution. With the exception of total cloud cover, data showed little or no global trends, but significant regional, interannual and internal atmospheric variations are occurring.

Baseline Surface Radiation Network (BSRN)



The BSRN established worldwide, cross-calibrated observing stations providing long-term total short-wave and longwave flux measurements with accuracies of +/- 10 Wm^2 and +/- 5 Wm^2 respectively. Over 36 stations were operating in 2004.

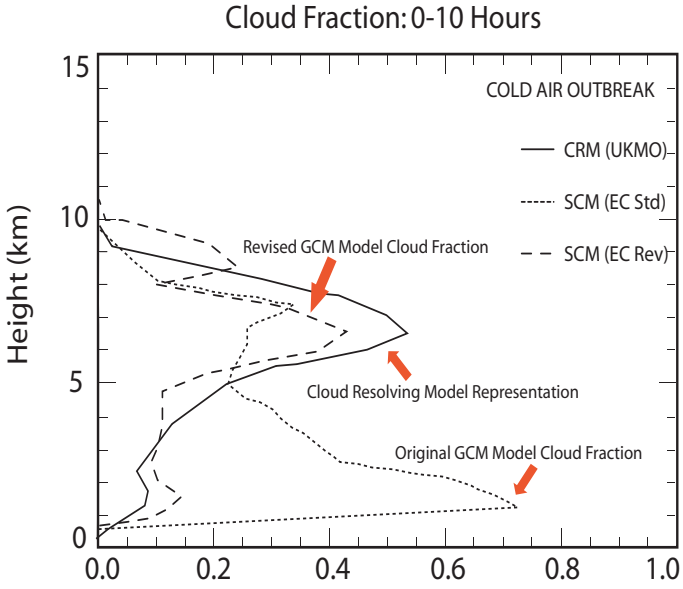
Indirect Aerosol Effect: Key IPCC Issue



Cloud albedo change due to variations of aerosol loading using data from the International Satellite Cloud Climatology Project (ISCCP).

ISCCP made the first global measurements of the indirect aerosol effect. The Twomey effect is a key uncertainty issue for the Intergovernmental Panel on Climate Change (IPCC) showing significant albedo changes over oceans, but little over land areas.

Intercomparison of Cloud Models and GCM Parameterizations



Coordinated development and intercomparisons of cloud resolving models, large eddy simulations (LES) and single column models (with regional cloud system data sets to support upgraded cloud parameterizations in weather and climate prediction models) were initiated. The GEWEX Cloud System Study (GCSS) found radiative processes were consistent between observations and models, but significant problems in cloud top entrainment, ice crystal fall velocities, boundary layer treatment, and precipitation generation mechanisms exist in weather and climate predictive model parameterizations.

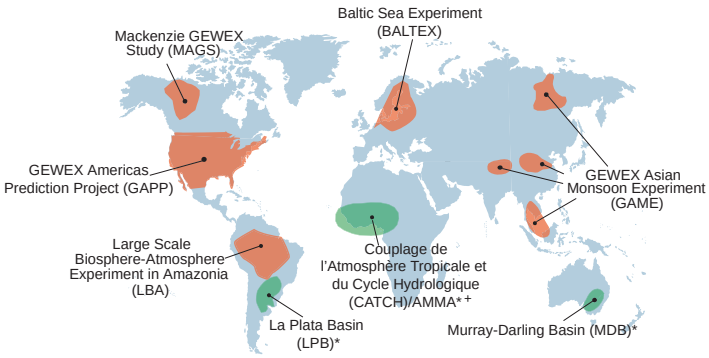
Global and Regional Closure of Water and Energy Budgets

GEWEX Continental-Scale Experiments (CSEs)

Successfully Characterizing the Energy and Water Budgets Over a Wide Range of Climate Regimes

The GEWEX CSEs contributed to closing energy and water budgets at both continental and global scales illustrating a possible global closure of the water budget within 10 percent; however, significant problems remain with regional closures within 15 to 50 percent.

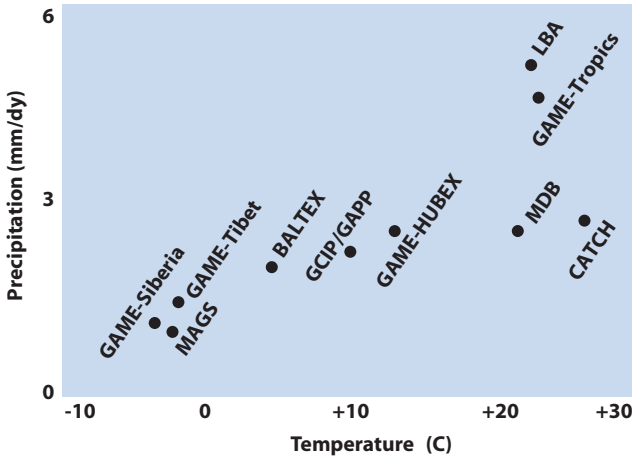
Continental-Scale Experiments



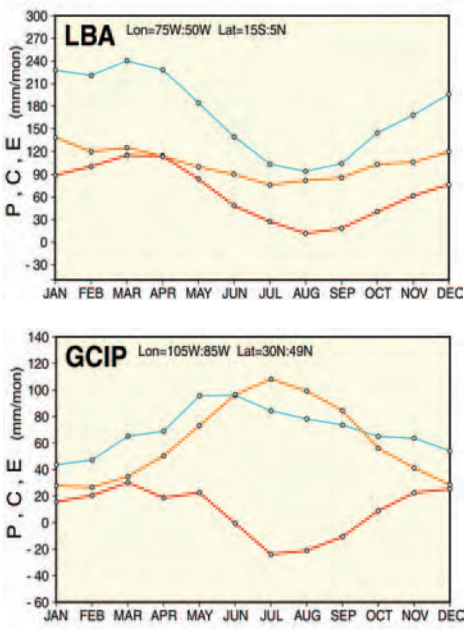
* CSEs that were developed in Phase II.

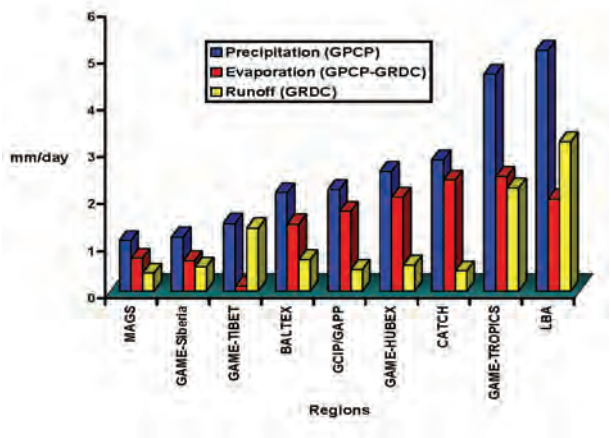
+ The African Monsoon Multidisciplinary Analysis (AMMA) extended the regional coverage and replaced CATCH in 2003.

Climate Range of GEWEX CSEs



Regional Process Measurement and Understanding





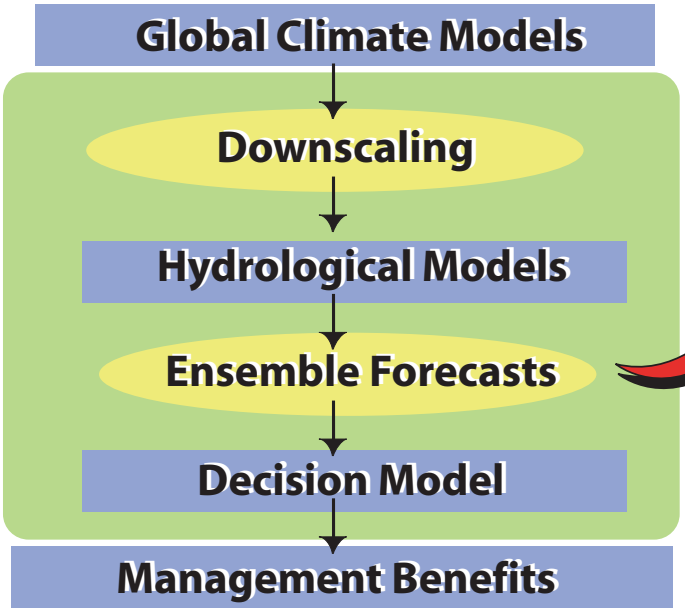
Seasonal cycles of monthly mean precipitation – P (blue), convergence – C (red), and evapotranspiration – E (orange) for GEWEX regions help illustrate water balance and feedback processes.

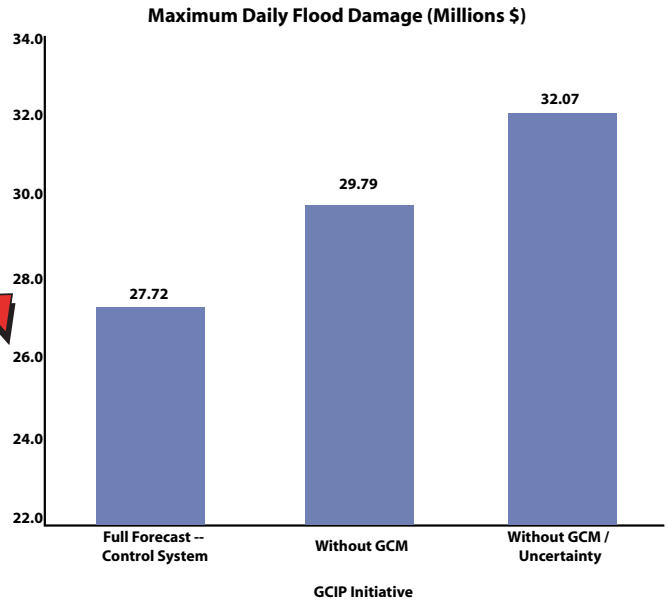
Major improvements in understanding and measuring continental-scale processes (including moisture recycling rates) from multiple field campaigns in different climate regimes on all major continents were achieved .

New Collaborative Relationships with Water Resource Applications Groups

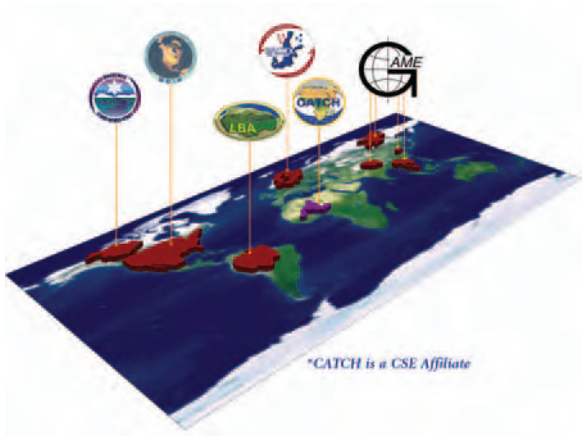
Phase I Results Have Real Impact:

- End-to-end assessments of the benefits of using climate forecasts in water resource decisions show major advatages.
- Using ensemble and forecast uncertainty showed average annual benefits of $2 million for one medium sized Iowa Basin.



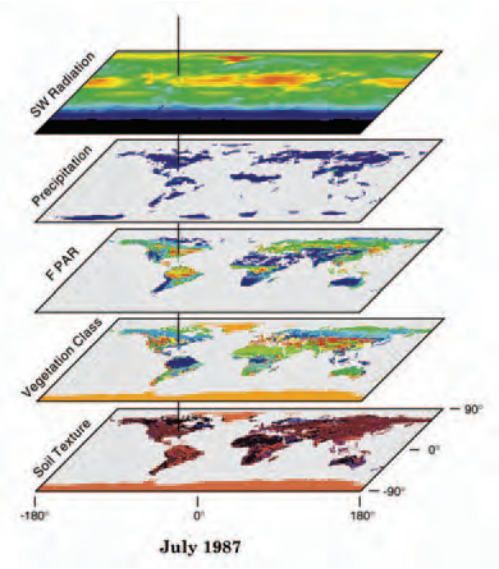


Major new collaborative relationships with water resource applications groups on several continents were initiated to assess the societal benefits resulting from GEWEX research.



Major international data policy changes occurred, leading to the release of research network and field campaign data, as well as model output.

Co-located Global Near-Surface Data Set Compilation

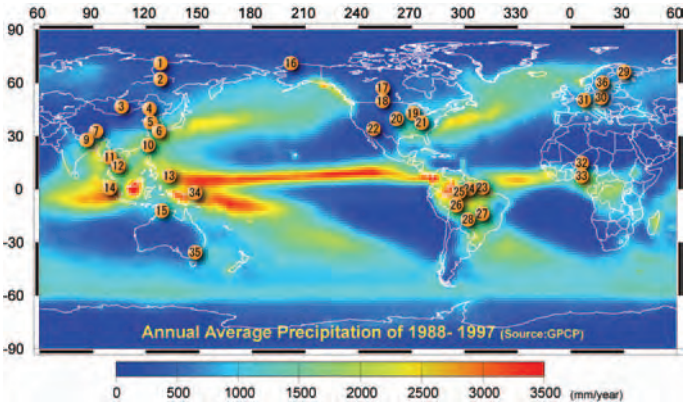


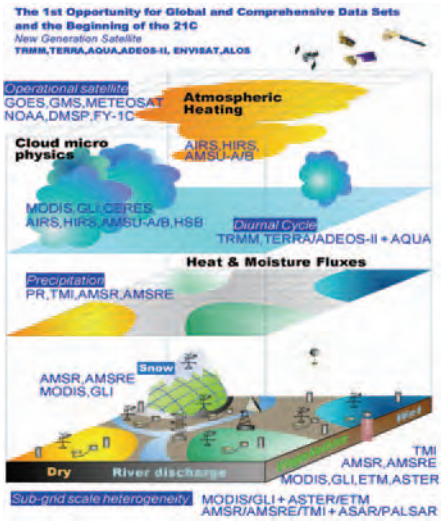
International Land Surface Satellite Climatology Project (ISLSCP) Data Sets

The first implementation of co-located 1x1 degree observational data sets of all available elements for modelling the Earth's water and energy cycles for 2- and 10-year data sets was achieved. As well as supporting the research community, these data sets support a major new broad educational user community.

Coordinated Enhanced Observing Period (CEOP)

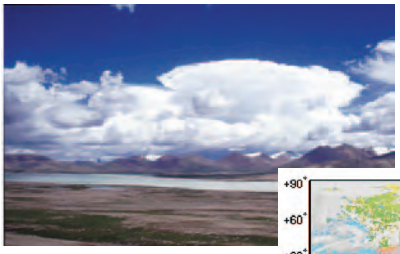
CEOP Reference Sites and Model Data Merged with New Satellite Data





CEOP, a major new global international project, was initiated to provide new prototype land-ocean monsoon and water cycle closure as well as budget data sets and studies. Initial results show the value of CEOP reference site data for model and satellite evaluation, calibration, and validation.

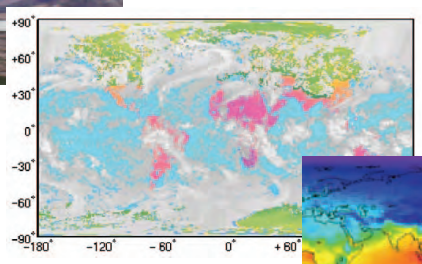
GEWEX Radiation Panel

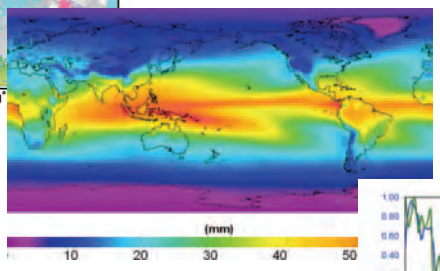


BSRN (Surface Validation Measurements)

SRB (Surface Radiation)

GVaP (Water Vapor)

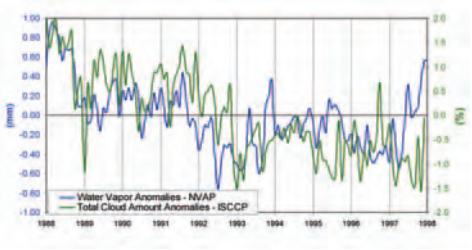




ISCCP (Clouds)

GPCP (Precipitation)

GACP (Aerosols)



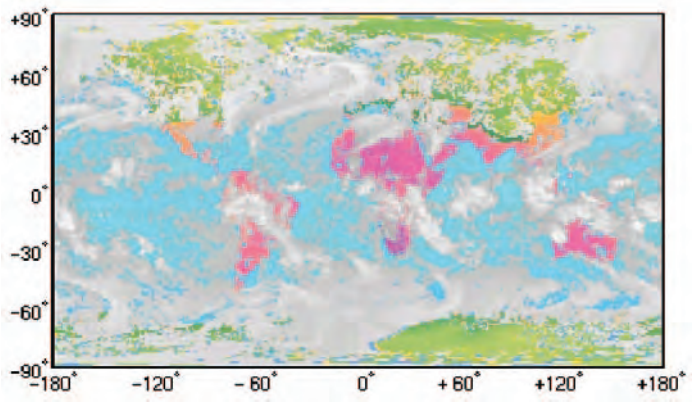
The GEWEX Radiation Panel (GRP) brings together leading experts to provide insights into the radiative interactions and climate feedbacks associated with atmospheric water processes. Changes in atmospheric water vapor, precipitation, clouds, and aerosols affect the energy balance of the Earth, and these processes are intertwined, complex, and simultaneous. For phenomenological studies, satellite observations are used to provide global basin data with sufficient resolution to address the large range of space and time scales involved. Projects under GRP combine *in situ* and satellite measurements to address globally the key components of the energy and water cycle and their relationships.

Key Results:

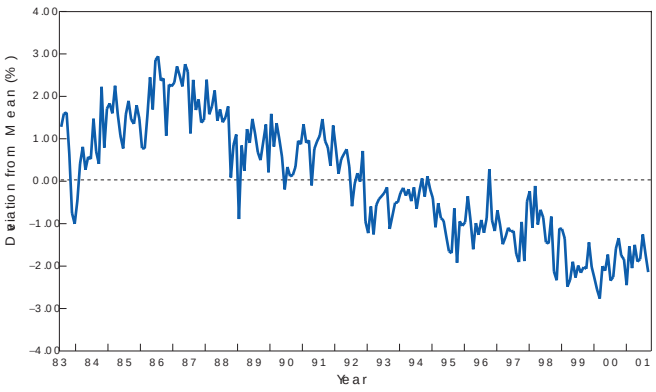
- Demonstrated that the existing three-dimensional radiative transfer models can accurately represent atmospheric radiative processes.
- Managed the development of the 15-25 year global data sets of key water and energy cycle elements (clouds, precipitation, water vapor, aerosols, and surface radiation).
- Provided a focus on calibration and validation that resulted in significant increased accuracy in surface radiation measurements.

International Satellite Cloud Climatology Project (ISCCP)

ISCCP Global Cloud Distribution



Cloud Amount: 19-Year Deviations from Global Monthly Means from Total Period Mean



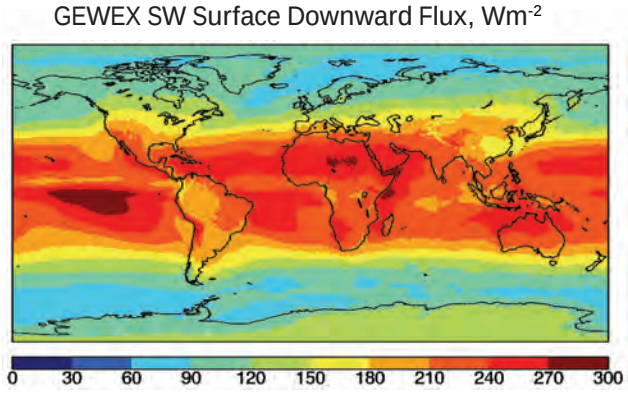
ISCCP has produced a 19-year (1983-2001) cloud and related parameter data set that is now available on CD-ROM or ftp from the Web site at http://isccp.giss.nasa.gov. These data sets and analysis products are being used to understand cloud dynamical behavior (especially as part of the GCSS Data Integration for Model Evaluation—http://gcss-dime.giss.nasa.gov), to determine cloud effects on the radiation budget, to examine cloud processes in the hydrological cycle, and to elucidate cloud-climate feedbacks.

Key Results:

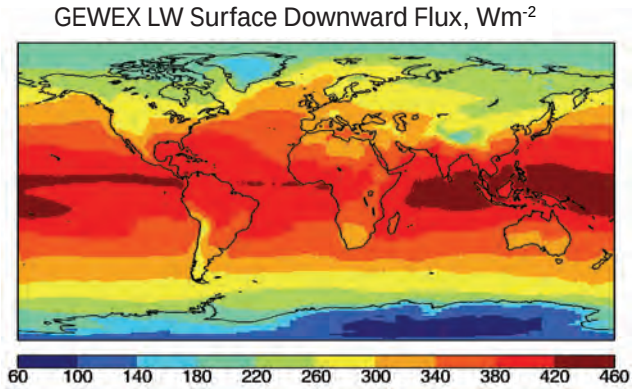
- Established and maintained common radiance calibration standards for the entire weather satellite constellation.
- Produced the first, globally complete, diurnally resolved cloud climatology.
- Provided the first global measurements of cloud optical thicknesses.
- Developed the global cloud properties used to reconstruct the complete radiation budget, showing that clouds reinforce the mean atmospheric circulation and damp the oceanic circulation.

Surface Radiation Budget (SRB) Project

Global Annual Averages
July 1983 - October 1995



Shortwave



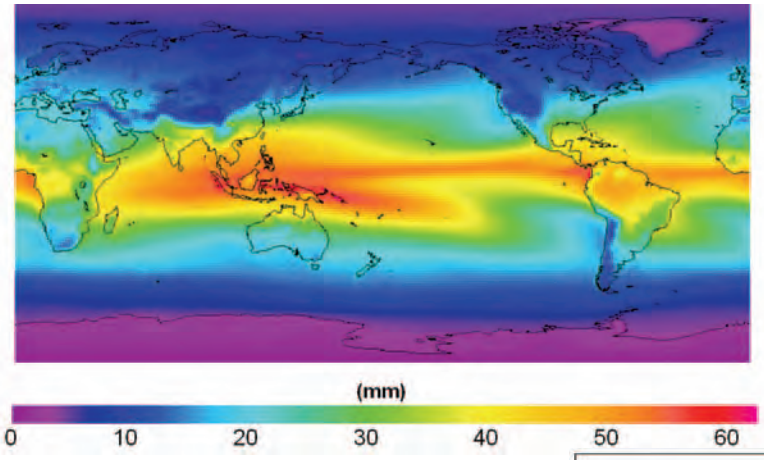
Longwave

SRB has completed processing 12+ years (1983-1995) of surface radiation data. Using the ISCCP 3-hourly parameters as input, SRB results generated 3-hourly surface radiation data and temporal averages of daily, monthly 3-hourly, and monthly radiation. Global annual means show good agreement (+/- 3 Wm^{-2}) with other satellite methods but show reduced shortwave downward flux (-12 Wm^{-2}) and increased longwave downward flux (+20 Wm^{-2}) relative to conventional estimates. Monthly averaged shortwave and longwave RMS differences relative to the Baseline Surface Radiation Network flux measurements were 20 Wm^{-2} for shortwave and 15 Wm^{-2} for longwave radiation, showing that more progress is still needed to achieve the objective of 10 Wm^{-2} RMS differences. Year-to-year global annual mean variability was about +/- 2 Wm^{-2}, and largest at the poles. Aerosol interference still remains a significant problem in improving accuracy.

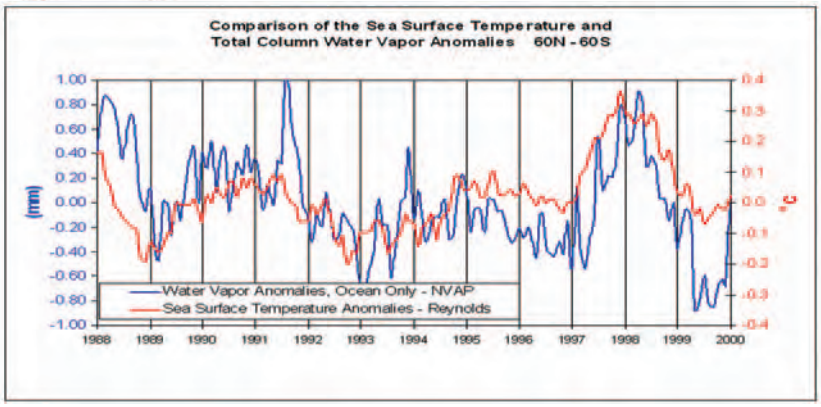
Key Results:

- Produced 12+ years of SRB parameters at 1x1 degree resolution.
- Results for global annual means indicate less shortwave energy and more longwave energy arriving at the surface than conventional estimates.
- Found that long-term monthly deseasonalized anomalies provided variability ranges of 3-5 Wm^{-2} short wave and 2-3 Wm^{-2} longwave.
- Determined that Pinatubo eruption produced maximum perturbation of 10 Wm^{-2} in surface shortwave averaging between 20° N and 20° S.

Global Water Vapor Project (GVaP)



NASA Water Vapor Project (NVAP) Total Column Water Vapor (1988-2001)



Comparison of Total Column Water Vapor and Sea Surface Temperature Anomalies from Global Means

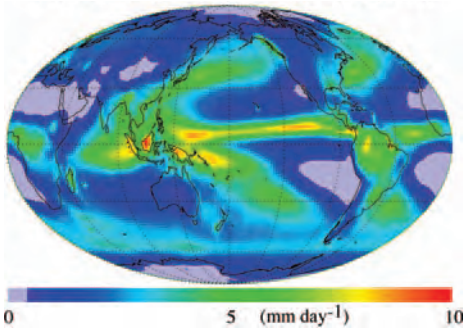
GVaP produced the NASA Water Vapor Project (NVAP) data set and has successfully encouraged and participated in field campaigns to evaluate water vapor measurement systems. NVAP combined retrievals of precipitable water from ground-based radiosondes, microwave data from Special Sensor Microwave Imager (SSM/I), and infrared data from the TIROS Operational Vertical Sounder. Cross-comparisons with cloud (ISCCP) and precipitation (Global Precipitation Climatology Project) data show strong internal consistency within the observationally based GEWEX Radiation Panel data sets.

Key Results:

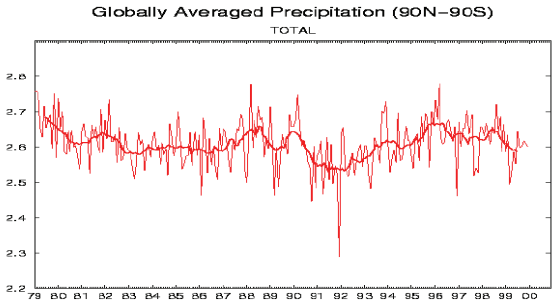
- Developed a key global water vapor data set (NVAP) combining 14 years (1988-2001) at 1x1 degree, 4-layers in a daily, pentad, and monthly time scale.
- Fostered and participated in an international water vapor science assessment and implementation plans.
- Demonstrated that remote sensing of water vapor provides better accuracy than conventional measurement techniques.

Global Precipitation Climatology Project (GPCP)

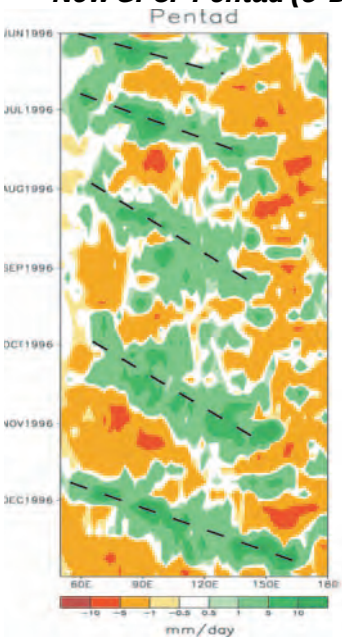
GPCP Annual Average Over 23 Years



Few Global, but Many Regional Changes in 23-Year Record



New GPCP Pentad (5-Day) Product Shows MJO



Time-longitude plots of estimated precipitation anomalies during June-December 1996 in mm/day units. Dashed lines on the panel indicate periods of increased convective precipitation associated with Madden-Julian Oscillation (MJO) activity.

The GPCP data set has produced a blended data set from rain gauge and satellite data including NOAA polar orbiting infrared data and Defense Meteorological Satellite Program microwave data. More than 23 years of data from over 6,000 rain gauges [provided by the Global Precipitation Climatology Center (GPCC)] and satellite measurements have been merged to estimate monthly, pentad, and daily rainfall on a 2.5 and 1.0 degree global grid from 1979 (1997 for daily 1 degree) to the present. Little or no long-term trend is observed globally (in contrast to climate model predictions), but significant changes are found regionally. The El Niño/Southern Oscillation (ENSO), the Madden-Julian Oscillation (MJO) and other climate features were tracked using these data. Cross-calibration/comparison with new Earth Observing System/Tropical Rainfall Measuring Mission data led to modifying algorithms and reanalysis to help place newer, more accurate satellite sensor data into a larger context (longer term) for improved climate analysis.

Key Results:

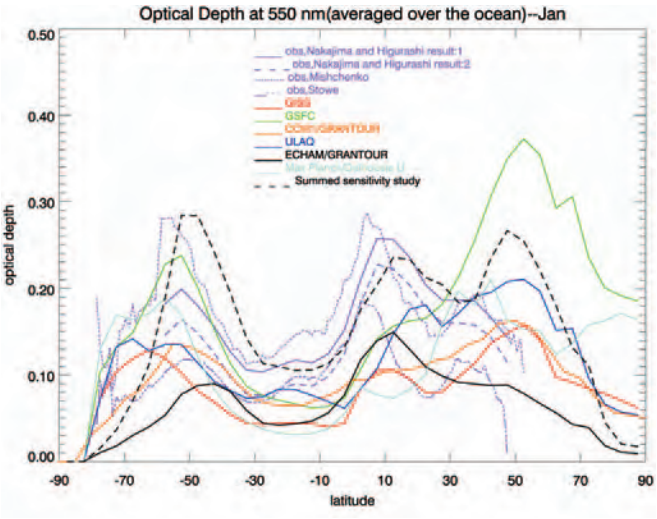
- Achieved significant international cooperation on data collection, retrievals and analysis.
- Developed advanced techniques for merging different satellite and gauge data.
- Developed and produced monthly, pentad, and daily global precipitation data sets maximizing use of both satellite and *in situ* measurements.
- Determined that the data show no detectable global trend in precipitation although regional changes can be identified.
- Used data for model validation and a thorough description of the precipitation response to ENSO.

Global Aerosol Climatology Project (GACP)

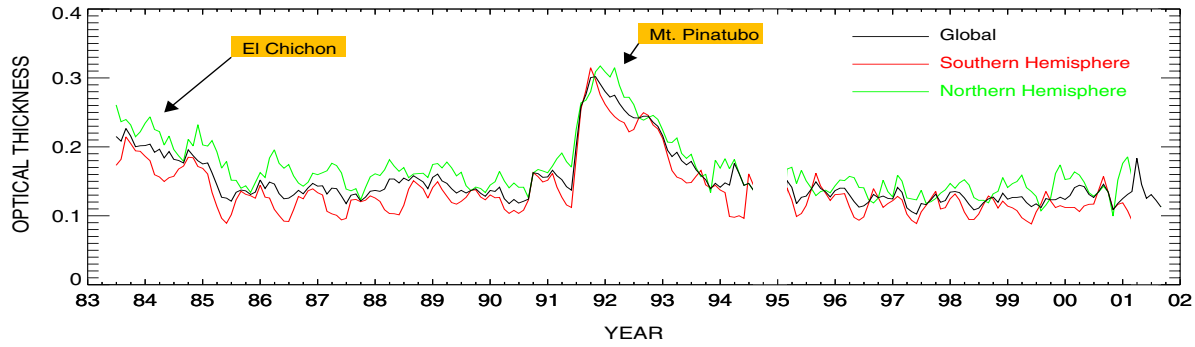
GACP has analyzed satellite radiance observations and field measurements to infer the global distribution of aerosol properties and their seasonal and interannual variations, and performed advanced modelling studies of the aerosol formation, processing, and transport. It has produced more than 18+ years of global 1x1 degree data sets using 2-wavelength Advanced Very High Resolution Radiometer (AVHRR) based aerosol retrieval over ocean optical depth and Ångström exponent data.

Extensive comparisons of GACP and Moderate Resolution Imaging Spectroradiometer aerosol retrievals have been performed. The optical thickness data agree reasonably well, both in overall trends in the global average value of optical thickness and the regional/seasonal distributions.

IPCC Intercomparison of Eleven Aerosol Models Compared with GACP Observations



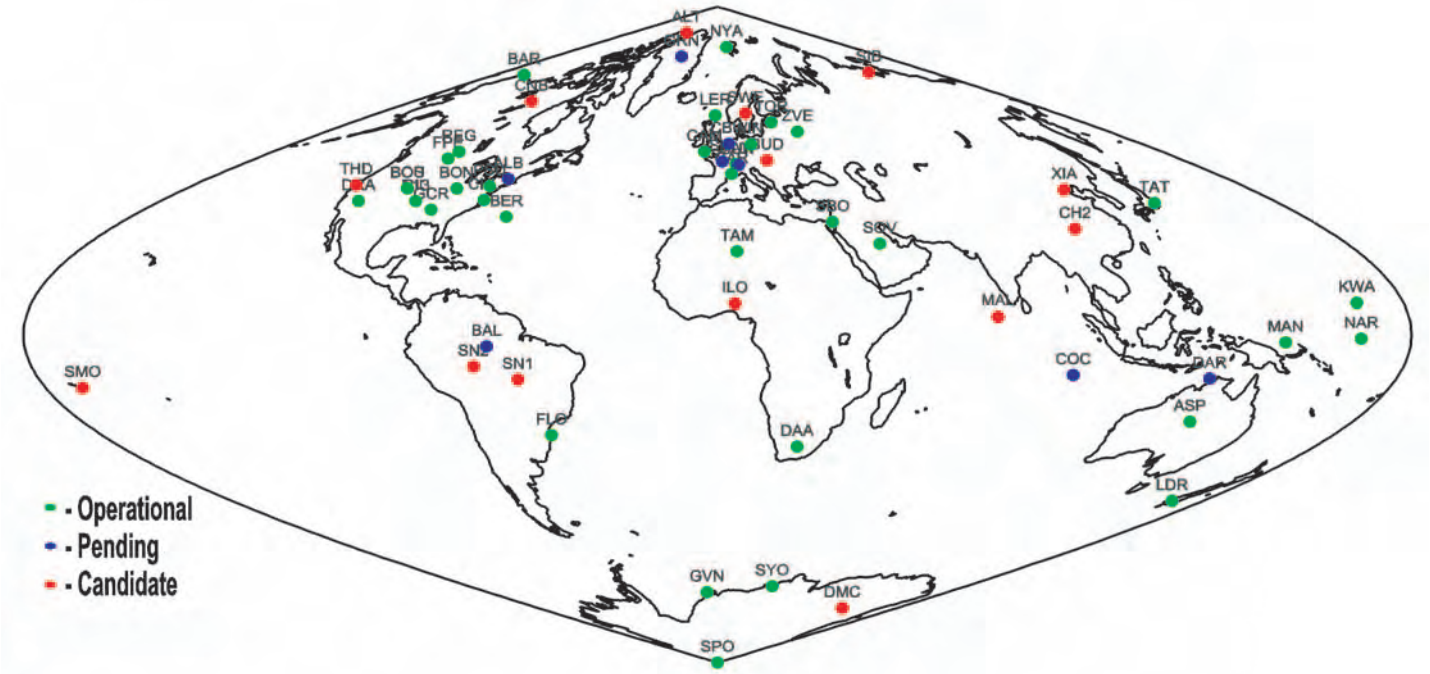
12-18 Year Aerosol Data Set Shows No Significant Trend



Key Results:

- The global monthly mean optical thickness and Ångström exponent show no significant trends between the periods affected by major volcanic eruptions, and oscillate around the average values 0.14 and 0.75, respectively.
- The optical thickness maxima and minima for the Southern Hemisphere occur around January-February and June-July, respectively. The Northern Hemisphere exhibits a similar pattern, but with maxima in February-April.
- The Northern Hemisphere mean optical thickness systematically exceeds the global average over the Southern Hemisphere.
- The results of AVHRR retrievals during the period affected by the Mt. Pinatubo eruption are consistent with the Stratospheric Aerosol and Gas Experiment (SAGE) retrievals of the stratospheric aerosol optical thickness.

Baseline Surface Radiation Network (BSRN)



BSRN Station Status, 2004

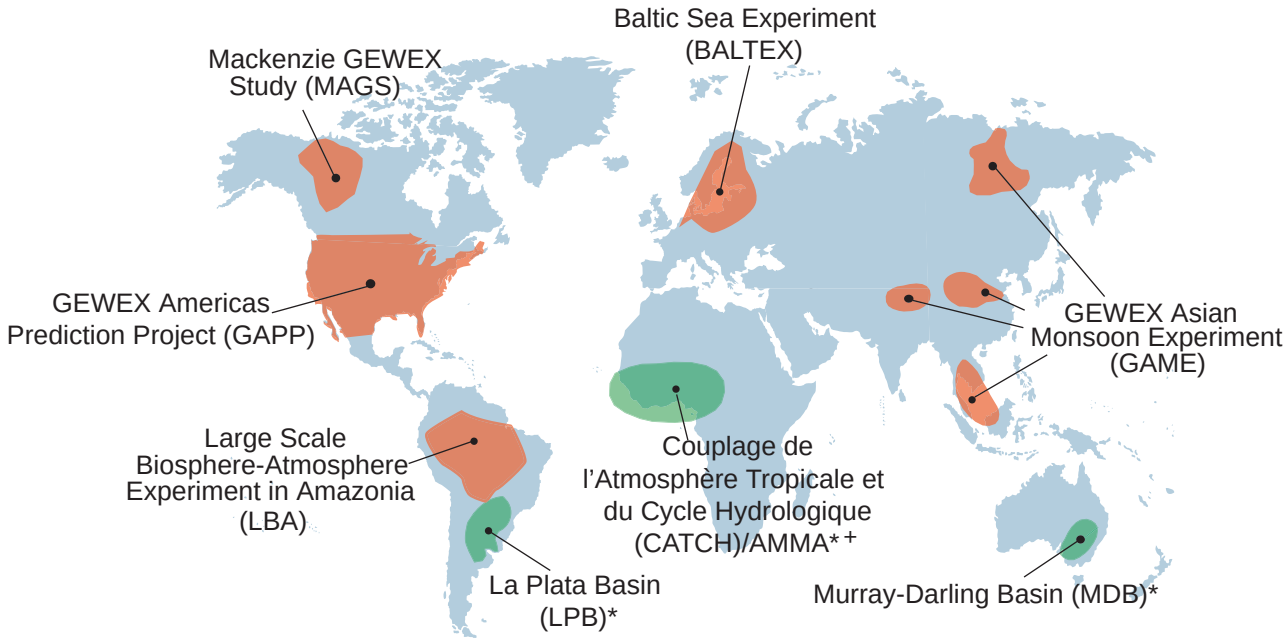
BSRN provides a worldwide network of surface radiation sensors to continuously measure radiative fluxes at the Earth's surface, measuring direct, diffuse shortwave, and longwave radiation. More than 2,500 data-months are now available from the central archives, representing an average of 6 years of data from 36 functioning sites in 19 countries. Many of these sites began operation in 1992 and each year more are added to the network. Data with accuracies of +/- 5 Wm^{-2} longwave and +/- 5-8 Wm^{-2} shortwave are currently available.

Key Results:

- Coordinated and developed significant advances in basic surface irradiance measurement techniques.
- Developed the international measurement reference standards for surface infrared and solar diffuse radiation.
- Developed an internationally recognized state-of-the-art surface irradiance measurement capability for climate research applications.
- Established an archive of surface radiation measurements for applications in GCM modelling and satellite retrieval of surface energy budget.
- The Global Climate Observing System (GCOS) has adopted BSRN as its reference surface radiation network.

GEWEX Hydrometeorology Panel (GHP)

Continental-Scale Experiments



* CSEs that were developed in Phase II.

+ The African Monsoon Multidisciplinary Analysis (AMMA) extended the regional coverage and replaced CATCH in 2003.

The goal of the GHP is to closely coordinate Continental-Scale Experiments (CSEs) along with other key hydrometeorology projects such as the Global Runoff Data Center and the International Satellite Land-Surface Climatology Project. Some of the important GHP integrated efforts include the Water and Energy Budget Study, the Water Resources Applications Project and the GHP Data Management Working Group.

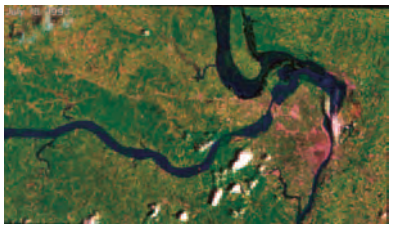
Key Results:

- Coordinated five CSEs and affiliated global projects that resulted in hundreds of refereed contributions by scientists from over 50 countries.
- Established free and open access to hydroclimatological research data from different countries for the international scientific community.
- Developed a scientific basis for characterizing and closing water and energy budgets on a continental scale, initiated global transferability studies, and developed global/regional budget closure intercomparisons.
- Carried out assessments of the value of climate predictions in water resource decisions.

GEWEX Continental-scale International Project (GCIP)

GCIP Mississippi River Basin Area

Drought Stage 1988



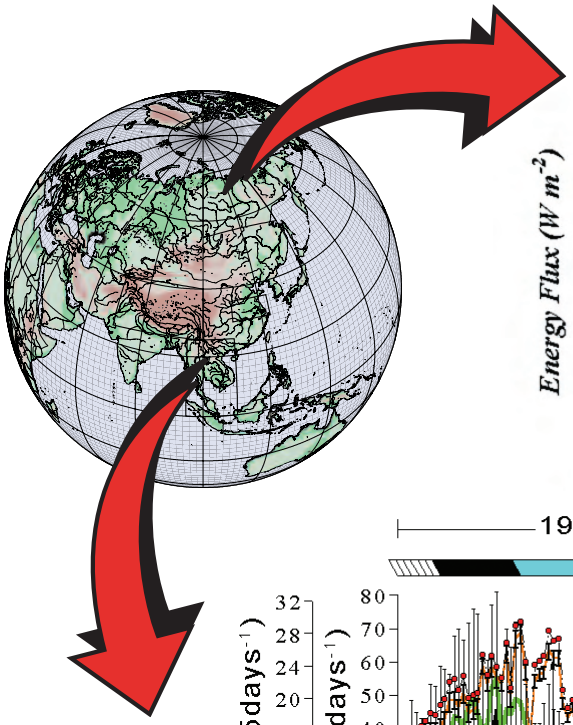
Flood Stage 1993

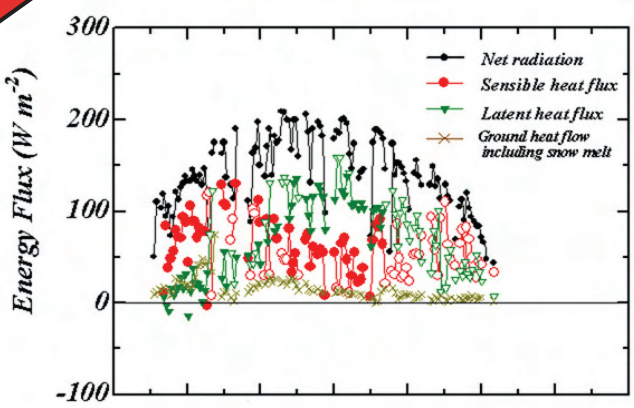
GCIP established the CSE concept as the first international project to bring together the hydrologic and meteorological science communities for a common research goal. GCIP was launched in 1995 in the Mississippi River Basin to take advantage of the extensive meteorological and hydrological networks existing there. The motivation for GCIP came from recognition of the need to close regional water and energy budgets and to improve parameterization of land-atmosphere interactions and land-surface hydrology in climate models. The GCIP mission was to demonstrate skill in predicting changes in water resources on time scales up to seasonal and annual as an integral part of the climate system. In 2001 GCIP expanded to become the GEWEX Americas Prediction Project (GAPP). This new project is building upon and extending GCIP results.

Key Results:

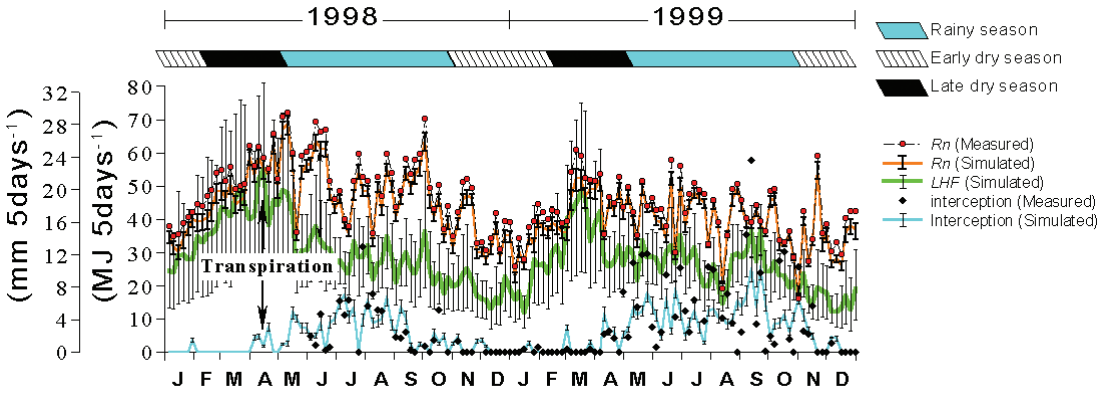
- Developed GCIP legacy data sets including high resolution, precipitation and radiation, and a comprehensive data delivery system.
- Reduced the uncertainty in the closure of the water budget for the Mississippi River Basin and produced a CD-ROM of water and energy budgets for the basin.
- Delivered significant improvements to the NOAA operational forecast systems through the understanding and better representation of land surface processes (e.g., snow, ground ice, soil moisture, vegetation).
- Initiated demonstration projects showing the use and benefits of climate forecasts in water management.
- Developed and implemented a national land data assimilation capability that led to the initiation of a number of model intercomparisons (Project for Intercomparison of Land-Surface Parameterization Schemes/Project to Intercompare Regional Climate Situations) and model development activities (Model Parameter Estimation Experiment).

GEWEX Asian Monsoon Experiment (GAME)





Seasonal change of latent and sensible heat balance is controlled by the coupled snow cover, permafrost vegetation system of the Taiga forest in west Siberia.



Maximum evapotranspiration appears in the midst of the late dry season in the evergreen forests of northern Thailand through memory effect of vegetation and soil moisture.

GAME research is directed at understanding the role of the Asian monsoon in the Earth's climate system and improving the simulation and seasonal prediction of Asian monsoon patterns and regional water resources. The scientific strategy of GAME includes monitoring by satellites and *in situ* surface observations, process studies based on the four regional experiments located in distinctive climate regions (Tropics, Sub-tropics, Tibetan Plateau and Siberia), and modelling of hydrometeorological processes in the climate system.

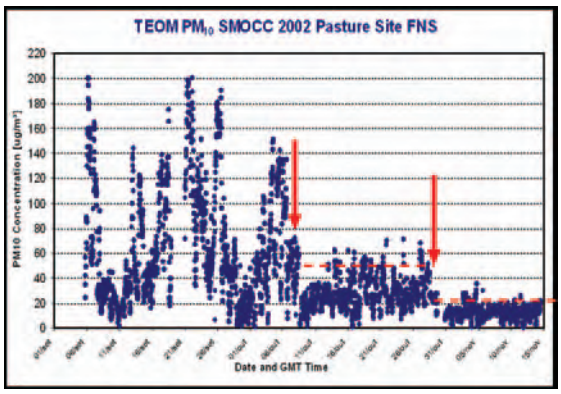
Key Results:

- Documented the role of the diurnal cycle in energy and water cycle processes revealed in the tropical and subtropical regions in monsoon Asia, including the Tibetan Plateau.
- Quantified the role of large-scale vegetation and soil moisture in the seasonal cycle of energy and water cycle processes, particularly in Northern Eurasia and the humid tropics in Asia.
- Clarified the impact of land cover/use changes (e.g., deforestation, rice paddies) on atmospheric boundary layer and cloud/precipitation systems in the tropical/subtropical region in Asia through intensive observation and modelling.

Large Scale Biosphere-Atmosphere Experiment in Amazonia (LBA)

LBA Field Campaign Areas

LBA Flux Towers



LBA Shows Impact of Aerosols on Clouds (arrows show onset of significant precipitation)

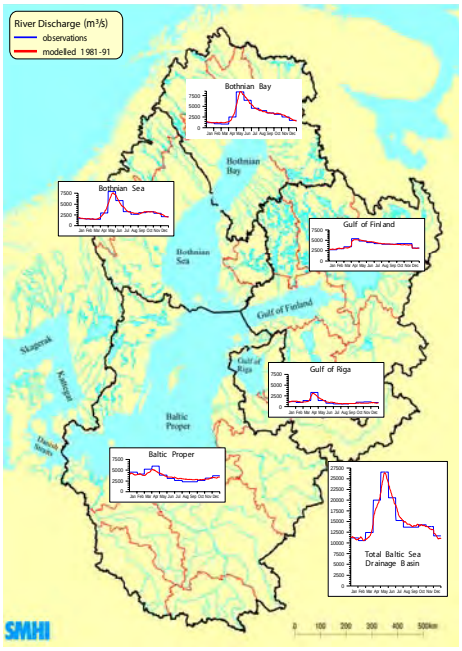
The hydrometeorology aspects of the multidisciplinary LBA have been directed at understanding the role of tropical forests and the consequences of deforestation for regional energy and water budgets. Phase I field experiments, modelling and analyses have shown a 44 percent imbalance of the water cycle in the Amazon Basin. The recently completed installation of 13 flux towers, 13+ upper air stations and 10 new Doppler radars will now assist in reducing this imbalance. LBA has had a strong capacity building component, having provided training for more than 40 graduate students and developed expertise in planning and implementing field activities and leading to the enhancement of operational services.

Key Results:

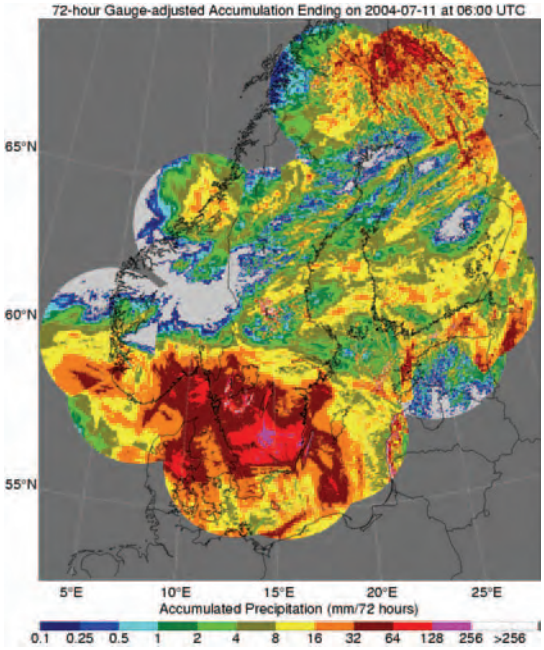
- Quantified the interannual variability of the Amazon Basin as a source/sink of carbon dioxide and moisture.
- Identified a major impact of biomass burning in the physics of rainfall.
- Used cloud condensation nuclei and aerosol concentration as indicators of the onset of the rainy season.
- Determined the transport of moisture from Amazonia to southern Brazil via the low level jet east of the Andes.
- Developed river routing schemes and hydrological modelling for instrumented pilot and macroscale basins.

Baltic Sea Experiment (BALTEX)

Modelling River Discharge



Precipitation from Radar Network



BALTEX is a multinational program to explore and model the various mechanisms determining the space and time variability of energy and water budgets of the Baltic Sea and its entire drainage basin. Episodic hydrometeorological events not only produce flooding in densely populated areas but they lead to important ecological processes in the Baltic Sea. The BALTEX region covers roughly 20 percent of the European continent and shows large seasonal, interannual and regional variations in climate. In Phase I, two major enhanced observing periods (PIDCAP 1995, and BRIDGE 1999 to 2002) with dedicated observational and modelling activities were conducted.

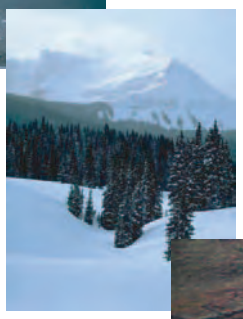
Key Results:

- Produced a compilation of unprecedented basin-wide observational data including both *in situ* and remotely sensed data for the major water and energy cycle parameters, such as precipitation, runoff, clouds, and radiation.
- Improved understanding of the processes controlling in and outflow situations in the Danish Straits, which constitutes the “river mouth” of the region.
- Improved understanding of air/land surface and air/sea/sea-ice exchange processes obtained through numerous field experiments and high-resolution modelling.
- Established two major coupled model systems and conducted model runs for the entire BALTEX region.
- Extended modelling studies to decadal time scales for analysis of both past (1800-2000) and projection of future (21st Century) climate conditions in the region.

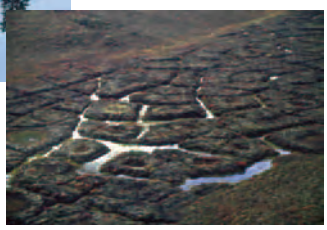
Mackenzie GEWEX Study (MAGS)

Mackenzie River Basin

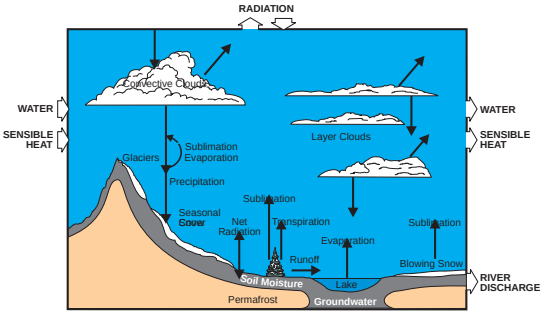
Rivers



Snow



Permafrost



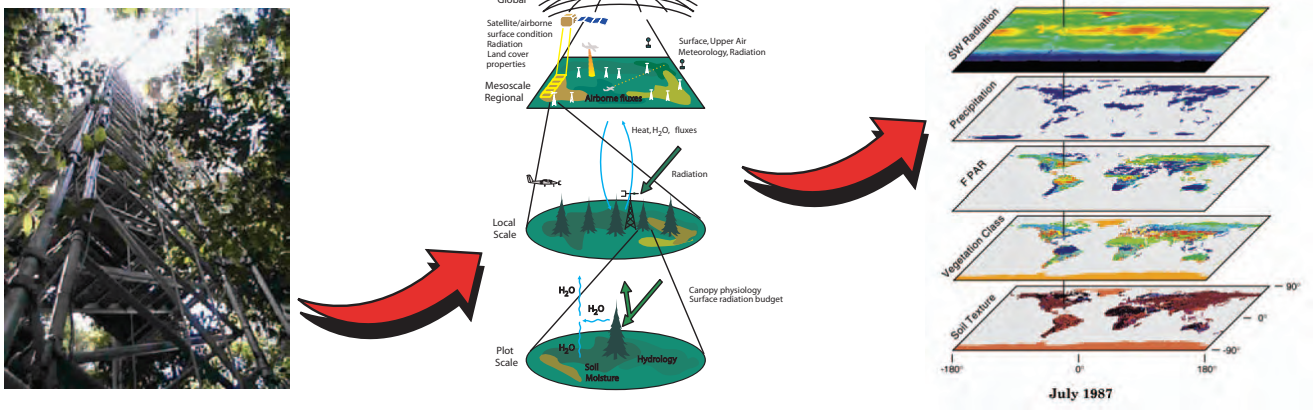
Water and Energy Flows of the Mackenzie River Basin

MAGS is a multidisciplinary project to understand and model the response of the energy and water cycle in northern Canada to climate variability and change, to define the impacts of its atmospheric and hydrologic processes and feedbacks on the regional and global climatic systems, and to apply our predictive capabilities to climate, water resource and environmental issues in the cold regions. During Phase 1 of MAGS (1996-2000), MAGS provided a new understanding of the atmospheric and hydrologic processes that influence the cold regions, and improved insights into the energy and water system of the Mackenzie Basin. Building on these results, Phase 2 (2001-2005) concentrates on modelling all major components of the physical system and application of unified knowledge and prediction tools to water resource problems in the Mackenzie basin and other parts of Canada.

Key Results:

- Developed comprehensive observational and synthetic climate data sets for the Mackenzie Basin.
- Identified sublimation in blowing snow as one of the main causes for the “missing surface water storage.”
- Quantified evaporative losses from large northern lakes and improved understanding and model representation of runoff processes in the northern regions.
- Carried out assessments of basin scale water budgets and precipitation recycling for the Mackenzie Basin and elucidated the roles of the Mackenzie Basin in global energetics and dynamics.

International Satellite Land-Surface Climatology Project (ISLSCP)



During its early stages, ISLSCP sponsored large-scale field experiments to develop and test satellite algorithms and associated climate and ecosystem models. ISLSCP also develops global, interdisciplinary data collections, including satellite-generated data series for use in investigating the impact of land-surface change on climate. The Global Soil Wetness Project (GSWP) produces large-scale data sets of soil moisture, temperature, runoff, and surface fluxes.

Field Experiments

The First ISLSCP Field Experiment (FIFE): Konza Prairie, Kansas, 1987 and 1988.

The Boreal Ecosystems-Atmosphere Study (BOREAS): Canadian boreal forest, 1994 to 1996.

Interdisciplinary Data Collections

Initiative I (1987-1988). The first interdisciplinary Earth Science data collection included global, monthly surface meteorology, vegetation, soils, surface routing and runoff, atmospheric radiation data and clouds at a 1-degree spatial resolution.

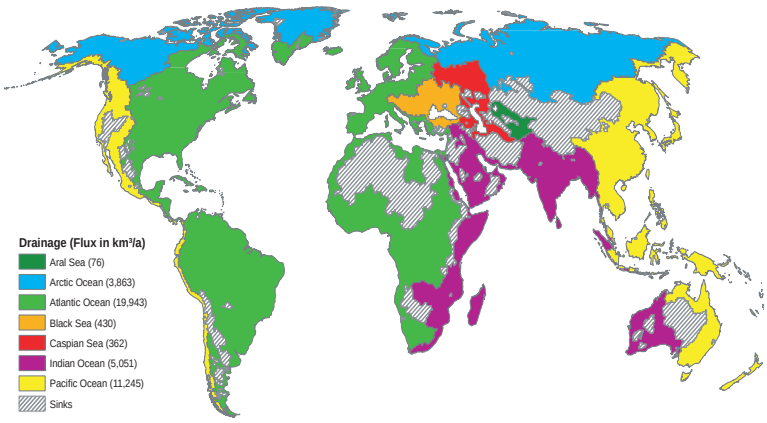
Initiative II (1986-1995). This data collection provides increased spatial resolution (from 1-degree to 1/2- and 1/4-degree) and a number of new data series such as topography, carbon-related data series and human dimensions data.

Key Results:

- Initiative I: Distributed, upon request, over 13,000 CD-ROM data sets and 267,000 files downloaded by users. Over 500 citations from a wide variety of users reference these data.
- Initiative II: Initiated a follow-on 10-year collection of 47 data sets for distribution both online and by DVD.
- Quantified the importance of land processes to climate and in the development of land-surface models using results from the data initiatives, FIFE, BOREAS, and GSWP.

Global Runoff Data Centre (GRDC)

GRDC is a GEWEX-affiliated global data center for river discharge, located in Koblenz, Germany and supported by the Federal Institute of Hydrology, operating under the Federal Ministry for Transport, Building and Housing. It collects and disseminates discharge data from countries around the world and produces data products for support of global hydroclimate analysis. GRDC provides daily and monthly discharge data for over 7,200 gauging stations in river basins located in 153 countries to users worldwide.

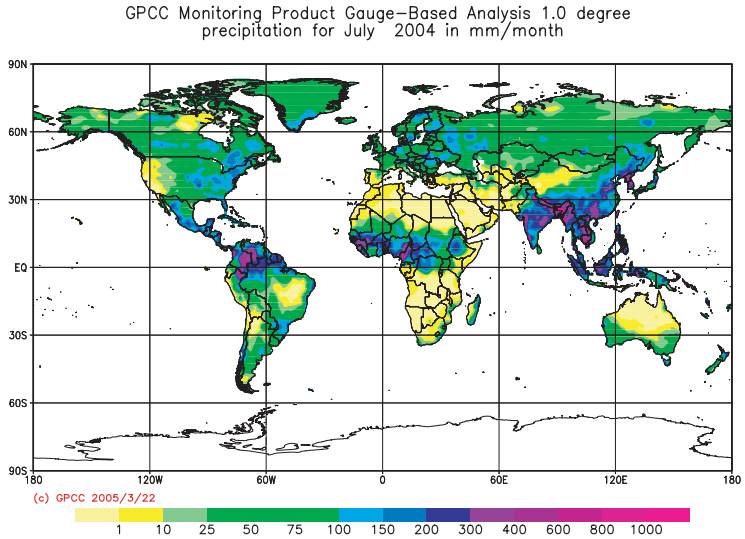


Drainage basins of oceans and seas and associated aggregations of GRDC estimated long term mean annual freshwater influx from rivers.

Key Results:

- Produced, in collaboration with the University of New Hampshire, the first globally gridded runoff field on a 0.5° grid available as long-term mean monthly values.
- Developed estimates of long term mean annual fresh water surface water flux estimates into the world oceans on a 0.5° resolution of the continental coastlines.

Global Precipitation Climatology Centre (GPCC)

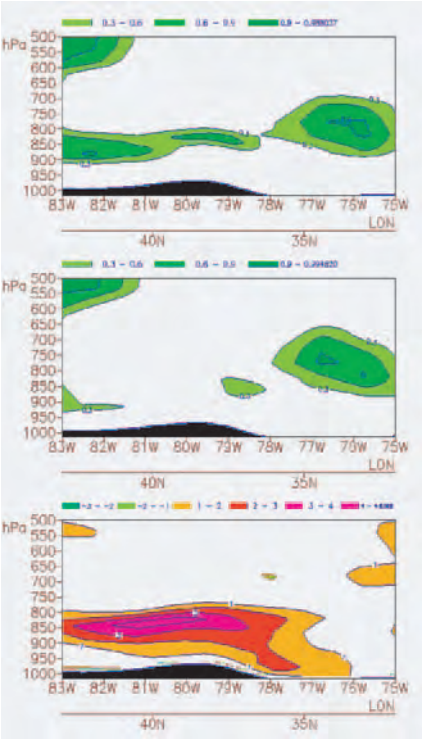


GPCC is a GEWEX-affiliated data center operating in the National Meteorological Service of Germany, that provides global precipitation data products for monitoring and researching the Earth's climate. During Phase I of GEWEX, GPCC delivered gridded data products of monthly precipitation for the global land-surface based on: 1) near-real time gauge data from 7,000 stations worldwide for 1986-present; and 2) gauge data from over 40,000 stations in 176 countries for 1986-1995.

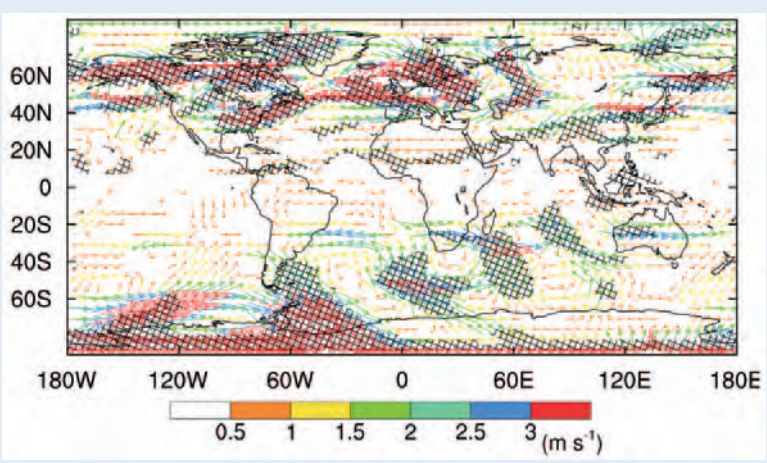
Key Results:

- Produced a system for monitoring anomalies on a near-real time global basis.
- Produced a new global 50-year precipitation climatology (1951-2000), based on time-series from 9,343 selected stations.

GEWEX Modelling and Prediction Panel (GMPP)



Model Treatment of Cloud Ice Leads to Large Forecast Errors - *(Figure at left) Vertical Cross Section (top panel) where a fraction of condensate is assumed to exist as water below 0 °C. The middle panel forecast treats all clouds below 0 °C as ice. The bottom panel is the resulting temperature difference.*



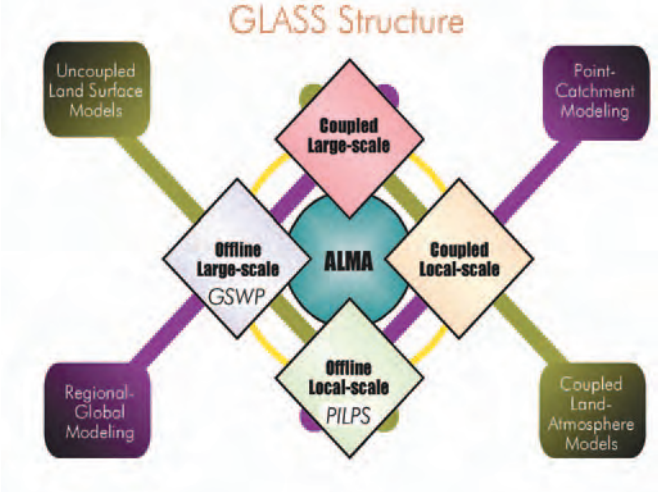
Northward shift of Northern Hemisphere jet stream results from changes in the treatment of subgrid vegetation information. *Red areas show maximum changes in 300 mb wind vectors.*

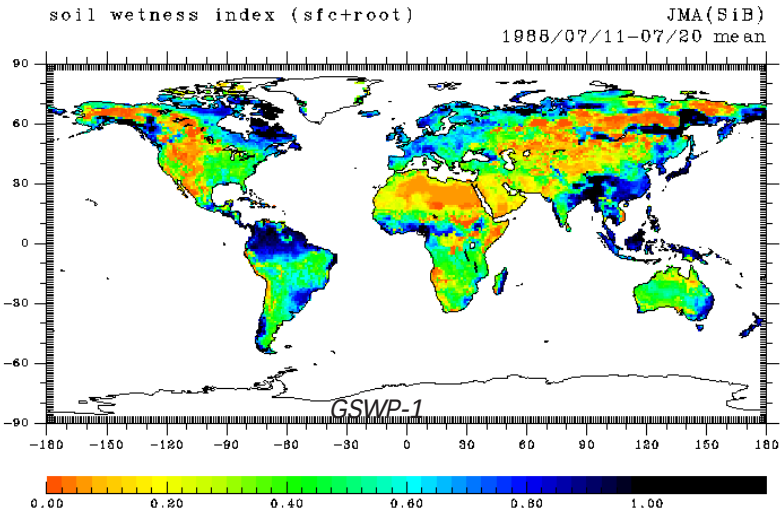
The GMPP oversees development and improvement of cloud and land-surface parameterization schemes to ensure their successful integration into Global Circulation Models (GCMs) and coordinates these activities with the priorities of the Working Group on Numerical Experimentation (WGNE). The major Phase I components of GMPP include the GEWEX Cloud Study System (GCSS) and Global Land-Atmosphere System Study (GLASS) with its primary subprojects: Project for Intercomparison of Land-Surface Parameterization Schemes (PILPS) and the Global Soil Wetness Project (GSWP). GCSS develops new cloud parameterizations based on cloud resolving models of different cloud systems for numerical weather prediction and climate models. Also, GCSS developed models using existing and planned campaign data sets; conducted intercomparison workshops; and provided blueprints of cloud data requirements for new campaigns. In early Phase I activities, the major driving force in demonstrating the importance of land-atmosphere coupling was PILPS and its many subprojects. GLASS, initially through the PILPS, has coordinated the development of improved land-surface schemes for coupled land-atmosphere models at all scales.

Key Results:

- Demonstrated the importance of land-atmosphere coupling—defined and helped implement the model upgrades needed for both regional and global prediction models.
- Established the need for both coupled and off-line local and large scale evaluations to achieve needed improvements in Land Surface Schemes (LSSs).
- Demonstrated how cloud resolving models and single column models can significantly improve GCM cloud parameterizations and resulting prediction capabilities.

Global Land/Atmosphere System Study (GLASS)





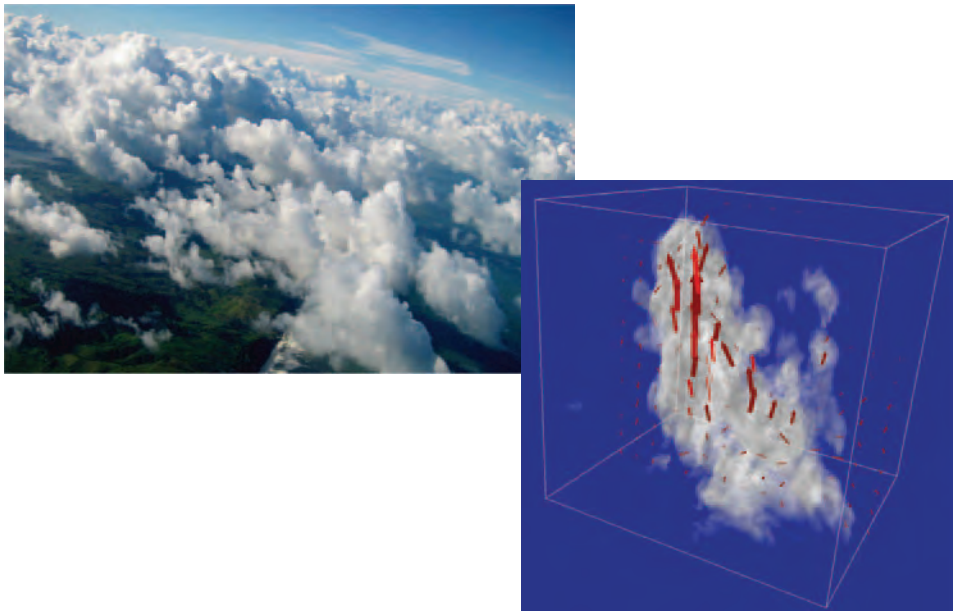
Adequate representation of land-surface processes in climate and weather prediction models is essential for these models to produce reliable predictions. GLASS fosters the development and evaluation of the next generation of LSSs. GLASS carries out multi-institutional experiments of both stand-alone LSSs and coupled land-atmosphere models at local (point, plot and catchment) and large (continental to global) scales, including PILPS, GSWP, and the Global Land Atmosphere Coupling Experiment (GLACE). GLASS pursues multi-model experiments to avoid model dependent results and reveal the current range of uncertainty.

The goal of GLASS is to incorporate improved understanding of the physical processes at the land-surface into models and to identify and understand the important components of land-atmosphere interaction.

Key Results:

- Accelerated the development of land-surface schemes by model and data intercomparisons for different climate regimes (PILPS).
- Improved the simulation of soil wetness by uncoupled LSSs and showed that its use as a specified boundary condition in global circulation models (GCMs) can significantly improve their simulation of climate anomalies (GSWP).
- Combined coupled LSSs and GCMs to assess their wide range of climate sensitivity, which can greatly affect their ability to simulate climate predictability (GLACE).
- Developed a critical set of standards for the exchange of forcing data for land-surface schemes [Assistance for Land-Surface Modelling Activities (ALMA)].

GEWEX Cloud System Study (GCSS)



Large-Eddy Simulation Model of a Cumulus Cloud

Insufficient understanding of cloud processes and feedbacks is one of the most critical deficiencies in climate models that produce climate scenarios and in numerical weather prediction models that produce precipitation forecasts. GCSS activities have led to improved parameterizations of clouds in climate models by providing a better understanding of the physical processes at work within the following types of cloud systems: Boundary Layer; Cirrus; Extra-tropical Layer; Precipitating Convective; and Polar. GCSS works with global climate modellers to identify the most important deficiencies of cloud parameterizations in global climate models. The GCSS approach relies on a combination of high quality, integrated cloud-scale and large-scale observational data sets, state-of-the-art cloud resolving models, and single-column versions of global climate models.

Key Results:

- Developed an online library called the Data Integration for Model Evaluation (DIME) (http://gcss-dime.giss.nasa.gov) of observationally based single-column model test cases for many cloud systems, including shallow cumulus, stratocumulus, cirrus, frontal, and precipitating convective to facilitate involvement of the world research community in the study of cloud processes.
- Produced a series of peer-reviewed papers that document the deficiencies of cloud parameterizations in GCMs as revealed by the GCSS single-column model tests, and provide benchmark results obtained with cloud-resolving models.
- Evaluated the representation of specific cloud systems in GCMs.

GEWEX is in Phase II, which in the context of the original objectives, is addressing the following principal scientific questions:

- Are the Earth's energy budget and water cycle changing?
- How do water and energy cycle processes contribute to feedback and causes of natural climate variability?
- Can we predict these changes for seasonal to interannual?
- What are the impacts of these changes on water resources?

In Phase II of GEWEX there is increasing interaction with the water resource and applications communities to ensure the usefulness of GEWEX results. This requires the development and use of a wide range of modelling tools ranging from the full global climate models to regional and mesoscale models, and to downscaling methods suitable for the smaller spatial and temporal scales generally associated with hydrological models used in local water resource management.

One of the primary elements of Phase II is the Coordinated Enhanced Observing Period (CEOP). CEOP is developing a 2-year data set of *in situ*, satellite and model data for the period of 2003-2004 to support research objectives in the climate prediction and monsoon system studies. CEOP has been endorsed as the first element of the new Integrated Global Water Cycle Observation Theme approved by the Integrated Global Observing System Partnership (IGOS-P). In addition, GEWEX is addressing a new set of objectives approved for its second phase by the Joint Scientific Steering Committee for WCRP.

Phase II Objectives:

- Produce consistent research quality data sets complete with error descriptions of the Earth's energy budget and water cycle and their variability and trends on interannual to decadal time scales, and for use in climate system analysis and model development and validation.
- Enhance the understanding of how energy and water cycle processes function and quantify their contribution to climate feedbacks.
- Determine the geographical and seasonal characteristics of the predictability of key water and energy cycle variables over land areas and through collaborations with the wider WCRP community determine the predictability of energy and water cycles on a global basis.
- Develop better seasonal predictions of water and energy cycle variability through improved parameterizations encapsulating hydrometeorological processes and feedbacks for atmospheric circulation models.
- Undertake joint activities with operational hydrometeorological services and hydrological research programmes to demonstrate the value of new GEWEX prediction capabilities, data sets and tools for assessing the consequences of global change.

Acronyms

ADEOS I	Advanced Earth Observation Satellite I
ALMA	Assistance for Land-Surface Modelling Activities
AVHRR	Advanced Very High Resolution Radiometer
BALTEX	Baltic Sea Experiment
BOREAS	Boreal Ecosystems-Atmosphere Study
BRIDGE	Major Enhanced Observation Period within BALTEX
BSRN	Baseline Surface Radiation Network
CEOP	Coordinated Enhanced Observing Period
CIRA	Cooperative Institute for Research in the Atmosphere
CliC	Climate and Cryosphere Project
CLIVAR	Climate Variability and Predictability Project
CMDL	NOAA Climate Monitoring and Diagnostics Laboratory
COLA	Center for Ocean-Land-Atmosphere Studies
CSE	Continental-Scale Experiment
DIME	Data Integration for Model Evaluation
DMSP	Defense Meteorological Satellite Program
ECMWF	European Centre for Medium-Range Weather Forecasts
ENSO	El Niño/Southern Oscillation
ENVISAT	European Space Agency Environmental Satellite
ESA	European Space Agency
ESSP	Earth System Science Partnership
EUMETSAT	European Organization for the Exploitation of Meteorological Satellites
FIFE	First ISLSCP Field Experiment
GACP	Global Aerosol Climatology Project
GAME	GEWEX Asian Monsoon Experiment
GAPP	GEWEX Americas Prediction Project
GCIP	GEWEX Continental-scale International Project
GCM	Global Circulation Model
GCOS	Global Climate Observing System
GCSS	GEWEX Cloud System Study
GEWEX	Global Energy and Water Cycle Experiment
GHP	GEWEX Hydrometeorology Panel
GISS	NASA Goddard Institute for Space Studies
GLACE	Global Land Atmospheric Coupling Experiment
GLASS	Global Land-Atmosphere System Study
GMPP	GEWEX Modelling and Prediction Panel
GPCC	Global Precipitation Climatology Centre
GPCP	Global Precipitation Climatology Project
GRDC	Global Runoff Data Centre
GRP	GEWEX Radiation Panel
GSFC	NASA Goddard Space Flight Center
GSWP	Global Soil Wetness Project
GVaP	Global Water Vapor Project
ICSU	International Council for Science
IGOS-P	Integrated Global Observing Strategy – Partnership
IGPO	International GEWEX Project Office
IOC	Intergovernmental Oceanographic Commission of UNESCO
IPCC	Intergovernmental Panel on Climate Change
ISCCP	International Satellite Cloud Climatology Project
ISLSCP	International Satellite Land-Surface Climatology Project
JAMSTEC	Japan Agency for Marine-Earth Science and Technology Center
JAXA	Japan Aerospace Exploration Agency
JMA	Japanese Meteorological Agency
LaRC	NASA Langley Research Center
LBA	Large-scale Biosphere Atmosphere Experiment in Amazonia
LES	Large Eddy Simulations
LSP	Land-Surface Parameterization
LSS	Land-Surface Scheme
MJO	Madden-Julian Oscillation
MAGS	Mackenzie GEWEX Study
MOPEX	Model Parameter Estimation Experiment
NASA	National Aeronautics and Space Administration
NOAA	National Oceanic and Atmospheric Administration
NSERC	Natural Sciences and Engineering Research Council of Canada
NVAP	NASA Water Vapor Project
PIDCAP	Pilot Study for Intensive Data Collection and Analysis of Precipitation
PILPS	Project for the Intercomparison of Land-Surface Parameter Schemes
RMS	Root Mean Square
SAGE	Stratospheric Aerosols and Gas Experiment
SPARC	Stratospheric Processes and their Role in Climate Project
SRB	Surface Radiation Budget
SSM / I	Special Sensor Microwave Imager
TRMM	Tropical Rainfall Measuring Mission
UNESCO	United Nations Educational, Scientific and Cultural Organization
WCRP	World Climate Research Programme
WGCM	Working Group on Coupled Modelling
WGNE	Working Group on Numerical Experimentation
WMO	World Meteorological Organization

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