Global Energy and Water Exchanges
Helmholtz Alliance: Remote Sensing and Earth System Dynamics – Hydrosphere Presentation

GEWEX Organization, Science Questions & Imperatives

Version: 2.0.0 (October 7, 2013)

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Some Acronyms

- **GEWEX**: Global Energy and Water Exchanges Project of the World Climate Research Programme (WCRP)
- **WCRP**: World Climate Research Programme
- **GDAP**: GEWEX Data Assessments Panel
- **GHP**: GEWEX Hydroclimatology Panel
- **GLASS**: Global Land Atmosphere System Studies Panel
- **GASS**: Global Atmospheric System Studies Panel
Hydrosphere

- Goal to present the view of GEWEX as a user representative in the Helmholtz Alliance on the Hydrosphere
- Explain the purpose of GEWEX as organization
- Showcase research results and approaches in the GEWEX and WCRP context
Outline

- Personal Background
- GEWEX and WCRP, history and overview
- GEWEX Organization
- GEWEX Science
  - GEWEX Science Questions
  - GEWEX Imperatives
  - GEWEX Science Activities per Panel
  - Showcase the Science – Global Freshwater Availability
- Conclusion
Overstroming

Bron: PBL (2009)
GEWEX and WCRP

Some background information
World Climate Research Programme

Sponsored by the World Meteorological Organization, the International Council for Science and the Intergovernmental Oceanographic Commission of UNESCO.

- **The WCRP Mission**: to facilitate analysis and prediction of Earth system variability and change for use in an increasing range of practical applications of direct relevance, benefit and value to society.
GEWEX
A brief history

- Born out of the realization that the Earth observational systems at that time (the early 1980’s) needed to be improved on if more progress was to be made on the meteorology and global climate research.

- Two feasibility workshops were held in 1987 and 1988 and in the first part of 1990 a science plan was finalized.

- In December of 1990 the Global Energy and Water cycle Experiment (GEWEX) was approved by WMO and ICSU as a core project of the World Climate Research Programme (WCRP).
What We Do

The Global Energy and Water EXchanges (GEWEX) project of the World Climate Research Programme (WCRP) facilitates, enables, coordinates international climate and related research activities with an emphasis on land – atmosphere processes and interactions.
Water
Energy
The Subject
The Earth – Global to Local Studies
The Subject
The Earth’s Water and Energy Cycle
Phase I: 1990 - 2002

Science Objectives

- Determine the hydrological cycle and energy fluxes by means of global measurements of atmospheric and surface properties.
- Model the global hydrological cycle and its impact on the atmosphere, oceans and land surfaces.
- Develop the ability to predict the variations of global and regional hydrological processes and water resources, and their response to environmental change.
- Advance the development of observing techniques, data management, and assimilation systems for operational application to long-range weather forecasts, hydrology, and climate predictions.
In addition to the Phase I Science Objectives GEWEX in Phase II addresses the following principal scientific questions:

- Are the Earth's energy budget and water cycle changing?
- How do processes contribute to feedback and causes of natural variability?
- Can we predict these changes on up to seasonal to interannual scales?
- What are the impacts of these changes on water resources?
Phase III: 2013 ~ 2022
Science Objectives & Imperatives

・ Building upon the results and experience from Phase I and II the GEWEX community for Phase III has developed through an open and interactive process:

・ A new **Vision** and **Mission** Statement

・ An **Imperatives** document describing the framework of necessary activities

・ The **GEWEX Science Questions** to be address in the next 5 to 10 years and which contribute directly to the WCRP Grand Challenges
GEWEX Vision

Water and energy are fundamental for life on Earth. Fresh water is a major pressure point for society owing to increasing demand and vagaries of climate.

Extremes of droughts, heat waves and wild fires as well as floods, heavy rains and intense storms increasingly threaten to cause havoc as the climate changes. Other challenges exist on how clouds and aerosols affect energy and climate. Better observations and analysis of these phenomena, and improving our ability to model and predict them, will contribute to increasing information needed by society and decision makers for future planning.
GEWEX Mission

To measure and predict global and regional energy and water variations, trends, and extremes (such as heat waves, floods and droughts), through improved observations and modeling of land, atmosphere and their interactions; thereby providing the scientific underpinnings of climate services.
World Climate Research Programme

Sponsored by the World Meteorological Organization, the International Council for Science and the Intergovernmental Oceanographic Commission of UNESCO.

- **The WCRP Mission**: to facilitate analysis and prediction of Earth system variability and change for use in an increasing range of practical applications of direct relevance, benefit and value to society.

- The two overarching objectives of the WCRP are:
  1. *to determine the predictability of climate*, and
  2. *to determine the effect of human activities on climate*

- Progress in understanding climate system variability and change makes it possible to address its predictability and to use this predictive knowledge in developing adaptation and mitigation strategies. Such strategies assist the global communities in responding to the impacts of climate variability and change on major social and economic sectors including food security, energy and transport, environment, health and water resources.
Six WCRP Grand Challenges

To inspire the community to become involved. They are specific and focused while identifying barriers and ways to advance the science, and they should capture the imaginations of funding agencies, science program managers, and the public.

<table>
<thead>
<tr>
<th></th>
<th>Challenge</th>
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<tbody>
<tr>
<td>1</td>
<td>Action-oriented regional climate information</td>
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<tr>
<td>2</td>
<td>Regional sea level</td>
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<tr>
<td>3</td>
<td>Cryosphere in a changing climate</td>
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<td>4</td>
<td>Cloud and climate sensitivity</td>
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<td>5</td>
<td>Changes in water resources</td>
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<td>6</td>
<td>Prediction and attribution of extreme events</td>
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</table>
WCRP Organization

Joint Scientific Committee
Joint Planning Staff
Modeling Advisory Council
Data Advisory Council

Working Groups on: Couple Modeling (WGCM), Region Climate (WGRC), Seasonal to Interannual Prediction (WGSIP), Numerical Experimentation (WGNE)

- CliC
  - Cryosphere-Climate Interactions
  - Ocean-Atmosphere Interactions

- CLIVAR
  - Cryosphere in a Changing Climate
  - Changes in Water Availability
  - Aerosols, Precipitation & Cloud Systems
  - Climate Extremes

- GEWEX
  - Actionable Regional Climate Information
  - Regional Sea-Level Rise

- SPARC
  - Land-Atmosphere Interactions
  - Troposphere-Stratosphere Interactions

- Ghp
- G
- G
- G

World Climate Research Programme
GEWEX Science Questions

‣ Are these questions actionable/action-oriented?
  • I.e. are they tractable, and is there a way forward?

‣ What new opportunities have arisen that relate to observations (such as new satellites; proposed field projects), models (computers, better resolution, new models like CMIP5), ideas?

‣ What benefits might accrue? What are the impacts? Why does it matter? Are there links to food, water, health, energy, biodiversity...?
### Four GEWEX Science Questions
For the next 5 to 10 years

<table>
<thead>
<tr>
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<th>Observations and Predictions of Precipitation</th>
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<tr>
<td>2</td>
<td>Global Water Resource Systems</td>
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<td>3</td>
<td>Changes in Extremes</td>
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<td>4</td>
<td>Water and Energy Cycles and Processes</td>
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</table>
1. Observations and Predictions of Precipitation

How can we better understand and predict precipitation variability and changes?

- How well can precipitation be described by various observing systems and what basic measurement deficiencies and model assumptions determine the uncertainty estimates at various space and time scales?

- How do changes in climate affect the characteristics (e.g., distribution, amount, intensity, frequency, duration, type) of precipitation, with particular emphasis on extremes of droughts and floods?

- How much confidence do we have in global and regional climate predictions of precipitation?
2. Global Water Resource Systems

How do changes in land surface and hydrology influence past and future changes in water availability and security?

- How do changes in land surface and hydrology influence past and future changes in water availability and security?
- How do changes in climate affect terrestrial ecosystems, hydrological processes, water resources and water quality, especially water temperature?
- How can new observations lead to improvements in water management?
3. Changes in Extremes

How does a warming world affect climate extremes, esp. droughts, floods, and heat waves, and how do land area processes, in particular, contribute?

- What are the short-term, mid-term and strategic requirements for the existing observing systems and data sets, and which observations are needed to accurately quantify trends in the intensity and frequency of extremes on different space/time scales?

- How can models be improved in their simulation and predictions or projections of the magnitude and frequency of extremes?

- How can the phenomena responsible for extremes be better simulated in models?

- How can we promote development of applications for improved tracking and warning systems arising from extremes?
4. Water and Energy Cycles and Processes

How can understanding of the effects and uncertainties of water and energy exchanges in the current and changing climate be improved and conveyed?

- Can we balance the energy budget at the top-of-atmosphere?
- Can we balance the energy budget at the surface of the Earth?
- Can we further track the changes over time?
- Can we relate the changes in surface energy budget with atmospheric-oceanic processes and long-term variability?
- Can we improve confidence in feedbacks associated with cloud-aerosol-precipitation interactions in the climate system?
Local Land-Atmosphere Interactions

1. incoming solar
2. wind
3. relative humidity
4. moisture flux
5. canopy conductance
6. soil moisture
7. reflected solar albedo
8. emitted longwave

- positive feedback for C3 & C4 plants, negative feedback for CAM plants
- negative feedback above optimal temperature

- positive feedback
- negative feedback

Land-surface processes: surface layer & ABL, radiation

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GEWEX Imperatives

The Imperatives – things that must be done - provide a strategic view of GEWEX activities for 15 years beyond 2013. They form the framework for a more focused set of GEWEX Science Questions (GSQs) whose main focus is on the 5-10 year period from 2013-2022.
## GEWEX Imperatives

<table>
<thead>
<tr>
<th>Category</th>
<th>Number</th>
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<tbody>
<tr>
<td>Datasets</td>
<td>1</td>
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<tr>
<td>Analysis</td>
<td>2</td>
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<tr>
<td>Processes</td>
<td>3</td>
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<tr>
<td>Modeling</td>
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<td>Applications</td>
<td>5</td>
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<tr>
<td>Technology Transfer</td>
<td>6</td>
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<tr>
<td>Capacity Building</td>
<td>7</td>
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</table>
GEWEX: Major Components

[Diagram showing the major components of the Earth's water cycle, including GDAP, GASS, GLASS, and GHP.]
GEWEX achieves its goals through data set development and analysis, process studies and model improvement.
GEWEX Data and Assessments Panel

- Radiative processes and understanding
  - Develop and improve of radiative transfer codes, comparisons

- Global Data sets
- Global In-situ observational networks, development and standardization (radiation, soil moisture)
- Reprocessing of datasets
- Assessment and intercomparison studies
- http://www.gewex.org/GDAP.html

Global datasets
Aerosols
Clouds
Radiation
Water Vapor
Precipitation
Surface fluxes
Soil Moisture
A GRP product is endorsed by GEWEX/GRP to conform to a high standard of production and documentation. It consists of a blend of available satellite and in-situ observations and is periodically compared and assessed against other products in an open and transparent fashion. It is openly available to everyone without restrictions.
Data Rescue Efforts
ISCCP B1 Data Product (basically a ‘raw’ product: 10km)

B1 Status - 2003
17 satellites

B1 Status - 2006
22 satellites

B1 Status - 2007
29 satellites
GEWEX Integrated Products

Common Ancillary Data

ISCCP

GACP

Common Output w. Uncertainty

Validation

BSRN

Validation

Buoys/Ships

Validation

Towers

LandFLUX

+
Global Energy Budget

Reflects Solar Radiation 101.9 W m⁻²
Reflects by Clouds and Atmosphere 79
Reflects by Surface 23

Incoming Solar Radiation 341.3 W m⁻²

Outgoing Longwave Radiation 238.5 W m⁻²

Emission by Atmosphere 169

Atmospheric Window 40

Greenhouse Gases

Absorbed by Atmosphere 78

Latent Heat 80

Thermal Evaporation 80

Surface Radiation

Net absorbed 0.9 W m⁻²

Absorbed by Surface

GEMEX

166 Trenberth et al 2011 J Climate 344
A recent revision by Stephens et al., 2012

Incoming solar \(340.2\pm0.1\)

Reflected solar \(100.0\pm2\)

TOA imbalance \(0.6\pm0.4\)

Clear-sky emission \(266.4\pm3.3\)

Outgoing longwave radiation \(239.7\pm3.3\)

Atmospheric absorption \(75\pm10\)

Clear-sky reflection \(27.2\pm4.6\)

Surface shortwave absorption \(165\pm6\)

Surface reflection \(23\pm3\)

Sensible heating \(24\pm7\)

Latent heating \(88\pm10\)

Surface emission \(345.6\pm9\)

All-sky emission to surface \(-187.9\pm12.5\)

Longwave cloud effect \(26.7\pm4\)

Clear-sky emission to surface \(319\pm9\)

All-sky longwave absorption \(-187.9\pm12.5\)

Shortwave cloud effect \(47.5\pm3\)
Global Data Sets – Climate Data Records

› Continuity
  • Grace follow on, GPM, TIR?,
  • What about new missions such as SWOT?

› Consistency
  • Product development centered vs sensor development
  • Calibration/sensor stability etc.
To assess climate variability and change, consistent long-term data records are needed.

Some activities:

1. GCOS -- Global Climate Observing System.
   - This activity has defined “Essential Climate Variables: ECV”.
   - As part of GCOS, the Global Terrestrial Observing System: GTOS and the Global Terrestrial Network – Hydrology: GTN-H were established.

2. Given needed global consistency in observations, and the relatively long (operational) satellite records, studies were funded on developing Climate Data Records (CDR) using operational and "experimental" (e.g., NASA EOS) satellite observations for climate studies.

**Climate Data Records from Environmental Satellites: Interim Report**

**WHAT ARE CDRs?**

The National Research Council (NRC) defines a CDR as a time series of measurements of sufficient length, consistency, and continuity to determine climate variability and change. ([National Research Council, 2004](http://www.nap.edu/catalog/10644.html)).
New Technology
In a climate research context

- Progress is needed / New type of observations
- New technology is desirable
- When properly managed!
  - i.e. not at the cost of continuity!
  - A paradigm shift is necessary from sensor focus to product development

Currently not properly managed...
- Regional hydroclimate projects
- Globally distributed extensive **regional data sets**: water and energy cycle observations (in situ and space borne and modeling data)
- **Global Data Centers**: data management system / GEO Prototype for Water Cycle Observations
- Regional climate and hydrological modeling and **process Descriptions**
- **Hydrological Applications** and Forecasting (Drought monitoring, Hydrological Ensemble Predictions...)
Global Atmosphere System Study

- Atmospheric processes, esp. clouds, convection, microphysics
- Model Parameterization evaluation and development
- Data sets and tools, intercomparisons
- Atmospheric Boundary Layer
- Strong cooperation with NWP via WGNE

[http://www.gewex.org/gass_panel.html](http://www.gewex.org/gass_panel.html)

**Projects**
- Boundary Layer clouds
- Polar clouds
- Convection, clouds
- GABLS3
- MJO
- Single Column Models
- Cloud Resolving Models
- GASS-GHP links
GEWEX Modeling: GLASS

Global Land Atmosphere System Study
- Land surface modeling
- Model Parameterization and development from land surface process
- Data sets and tools, intercomparisons
- Land-atmosphere coupling
- Model Data Fusion
- Strong cooperation with NWP via WGNE
- http://www.gewex.org/glass_panel.html

Local Land-Atmosphere Interactions

Ongoing:
- ALMIP2 – Links to GHP
- GLACE2-CMIP
- LoCo Working Group
- LUCID2 – Links to iLEAPS

Launching in next “12” months:
- GSWP3 – Links to carbon community
- PILDAS – Links to WGNE
- DICE – GLASS/GABLS diurnal cycles
- PALS/Benchmarking (PLUMBER) – Links to GHP
- LoCo/SGP testbed
Hot spots of soil moisture-temperature coupling

Analysis for local *hottest month* (i.e. valid in all regions ≠ JJA)

NHD: Number of hot days (ERA-interim)
SPI: Standardized precipitation index (in 3-month preceding hottest month)

Surface moisture deficits are a necessary condition for the occurrence of hot days in a large fraction of the globe

(Mueller and Seneviratne 2012, PNAS)
The grand environmental challenges facing human society involve the changing of Earth's water cycle.

With a warming planet, perhaps the two most pressing questions facing us are:

- Will the availability of fresh water change and how?
- By how much will sea level rise?

and our challenge is to develop an understanding that can provide quantitative answers to them.
Note to the challenges

- Those two questions are not independent
- Water availability is a (re)distribution issue (global available water is constant) -> hydrological cycle
- Is the hydrological cycle changing – intensifying?
- Focus on fresh water
Availability of Fresh Water
Surface Water balance

$$\Delta S = P - Q - ET$$

- **Precipitation (P)**
  - Rain gauges, RS (TRMM, CloudSat, AMSR-E, IR, ...)

- **Change in storage ($\Delta S$)**
  - Groundwater recharge/flow, soil moisture, standing water
  - Wells, RS (GRACE, SWOT, AMSR-E $\rightarrow$ SMOS $\rightarrow$ SMAP)

- **Runoff (Q)**
  - Stream gauges, Global Runoff Data Center, Dai/Trenberth, RS (SWOT)

- **Evaporation/Evapotranspiration (ET)**
  - RS Quickscat, AMSR-E, MODIS, ACOS/OCO, ...
  - (RS of ET also requires surface net radiation)

- Global accuracy/consistency/ability?
A challenge for Hydrology:
Creating Climate Data Records for the terrestrial water budget using in-situ, remote sensing observations and LSM?

\[
\frac{dS}{dt} = P - ET - Q
\]

What the budget should look like?
(from off-line modeling, forced closure)

Potential Remote Sensing Datasets

- \(dS/dt\) from GRACE
- \(ET\) from SRB/ISCCP \(\rightarrow\) LandFlux
- \(P\) from TRMM/CMORPH \(\rightarrow\) GPM
- \(Q\) from TOPEX/POSEIDON/JASON \(\rightarrow\) SWOT
### Potential global water cycle data sources

<table>
<thead>
<tr>
<th>Variable/Source</th>
<th>Type</th>
<th>Period</th>
<th>Resolution</th>
<th>Reference</th>
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<tbody>
<tr>
<td><strong>p</strong></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>CPC</td>
<td>In-situ</td>
<td>1950-</td>
<td>1º</td>
<td>Chen et al., 2002</td>
</tr>
<tr>
<td>CRU</td>
<td>In-situ</td>
<td>1901-</td>
<td>0.5º</td>
<td>Mitchell &amp; Jones, 2005</td>
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<tr>
<td>WM</td>
<td>In-situ</td>
<td>1900-</td>
<td>0.5º</td>
<td>Willmott &amp; Matsuura, 2010</td>
</tr>
<tr>
<td>GPCC</td>
<td>In-situ</td>
<td>1900-</td>
<td>0.5º</td>
<td>Schneider et al., 2008</td>
</tr>
<tr>
<td>GPCP/TMPA</td>
<td>RS/in-situ</td>
<td>1998-</td>
<td>0.25º-1º</td>
<td>Huffman et al.</td>
</tr>
<tr>
<td><strong>e</strong></td>
<td></td>
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<tr>
<td>ET (LandFlux)</td>
<td>RS</td>
<td>1984-2006</td>
<td>1º</td>
<td>Vinukollu et al., 2010; Ershadi et al., 2013</td>
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<tr>
<td>ERA-Interim</td>
<td>Reanalysis</td>
<td>1989-</td>
<td>T255</td>
<td>Simmons et al., 2006</td>
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<td>MPI</td>
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<td>1989-</td>
<td>T255</td>
<td>Jung et al (2009)</td>
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<tr>
<td>VIC</td>
<td>LSM</td>
<td>1948-</td>
<td>1/2ºx1/3º</td>
<td>Sheffield &amp; Wood, 2007</td>
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<tr>
<td><strong>q</strong></td>
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</tr>
<tr>
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<td>In-situ</td>
<td>1900-</td>
<td>basin</td>
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<td>LSM</td>
<td>1948-</td>
<td>1º</td>
<td>Sheffield &amp; Wood, 2007</td>
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<td><strong>Δs</strong></td>
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<tr>
<td>GRACE</td>
<td>RS</td>
<td>2002-</td>
<td>basin</td>
<td>Swenson &amp; Wahr, 2002</td>
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<tr>
<td>VIC</td>
<td>LSM</td>
<td>1948-</td>
<td>1º</td>
<td>Sheffield et al., 2008</td>
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Precipitation

- Direct EO Measurements e.g. GPCP, TRMM, GPM
- Understanding clouds and precipitation processes e.g. Cloudsat
- Aerosols and water vapor
- Rain gauge data e.g. GPCC
- Global Climate Models precipitation representation
Global Precipitation Climatology Project (GPCP)

Robert Adler, U. of Maryland-College Park, USA
Synergy

CloudSat Radar
- Precipitation

CALIPSO 532 nm
- Tropical Thin Cirrus
- Mixed Phase Cloud
- Aerosol

MODIS 11 μm
Challenges - Precipitation

- **Models** - global models have biases that point to problems in the way precipitation (and cloud) physics is represented. Global models also miss major storm types (e.g. MCSs) that for example deliver large fractions of precipitation to real Earth.

- **Process perspective** - We still do not know the extent to which the water cycle is influenced by aerosol but anecdotal evidence is building.

- **Observations** - we still have a way to go and need to approach the problem in a more integrated way (tie clouds, aerosol and precipitation and then link to soil moisture, etc.) - globally our capabilities to address water cycle processes, while improved, seriously lag behind the science and model development.
Change in Storage
Earth Observation

- **Snow**
  - GRACE, GPM

- **Ground water and soil moisture**
  - GRACE, ASCAT, AMSR-E, SMOS, SMAP, Tandem-L?

- **Lakes and rivers**
  - TOPEX/Poseidon, SWOT
Conclusion

The successful implementation of the WCRP Grand Challenges and associated science questions described here depend significantly upon the GEWEX Imperatives: observations and data sets, their analyses, process studies, model development and exploitation, applications, technology transfer to operational results, and research capacity development and training of the next generation of scientists.

They involve all of the GEWEX Panels and will benefit greatly from strong interactions with other WCRP projects such as CLIVAR, SPARC, and CliC and other sister global environmental change research programs such as the IGBP, the International Human Dimensions Programme (IHDP), and DIVERSITAS.
7th International Scientific Conference on the Global Energy and Water Cycles

World Forum
The Hague, The Netherlands
14-17 July 2014
Acknowledgement

The Global Energy and Water Exchanges project (formerly Global Energy and Water cycle Experiment) and its panels are driven by primarily voluntary contributions by scientists around the world.

The programmatic support by the International GEWEX Project Office is made possible through NASA.
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