NASA ENERGY AND WATER CYCLE STUDY

NEWS

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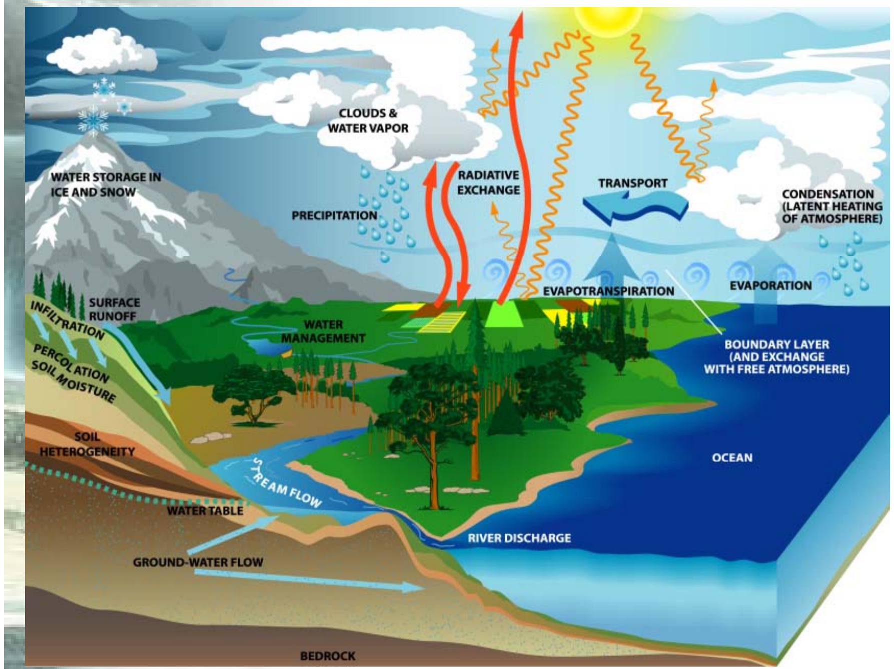
Project Scientist: P. Houser (GMU/CREW),
Program Manager: J. Entin (NASA-HQ)
Program Coordinator: D. Belvedere (CREW)
NEWS Integration Team: W. Rossow (CCNY), W. Lapenta (MSFC), B. Lin (LaRC), E. Njoku (JPL), C. Schlosser (MIT), R. Schiffer (UMBC/GEST)

NEWS PIs: Famiglietti, Betts, Roads, Olson, Leung, Koster, Schubert, Denning, Wentz, Liu, Soden, Bosilovich, L'Ecuyer, Adler, Fetzer, Wielicki, Curry, Sorooshian, Peters-Lidard, Rodell, Dong, Hu, Lettenmaier, McFarlane, Waliser

NEWS Challenge:

Document and enable improved, observationally-based, predictions of water and energy cycle consequences of Earth system variability and change.

The Water and Energy Cycle



Water in the climate system functions on all time scales: From hours to centuries

Why study the water & Energy cycle?

1. *Water exists in all three phases in the climate system and the phase transitions are a significant factor in the regulation of the global and regional energy balances*

2. *Water vapor in the atmosphere is the principal greenhouse gas and clouds at various levels and composition in the atmosphere represent both positive and negative feedback in climate system response*

3. *Water is the ultimate solvent and global biogeochemical and element cycles are mediated by the dynamics of the water cycle*

4. *Water is the element of the Earth system that most directly impacts and constraint human society and its well-being.*

Presentation Objectives

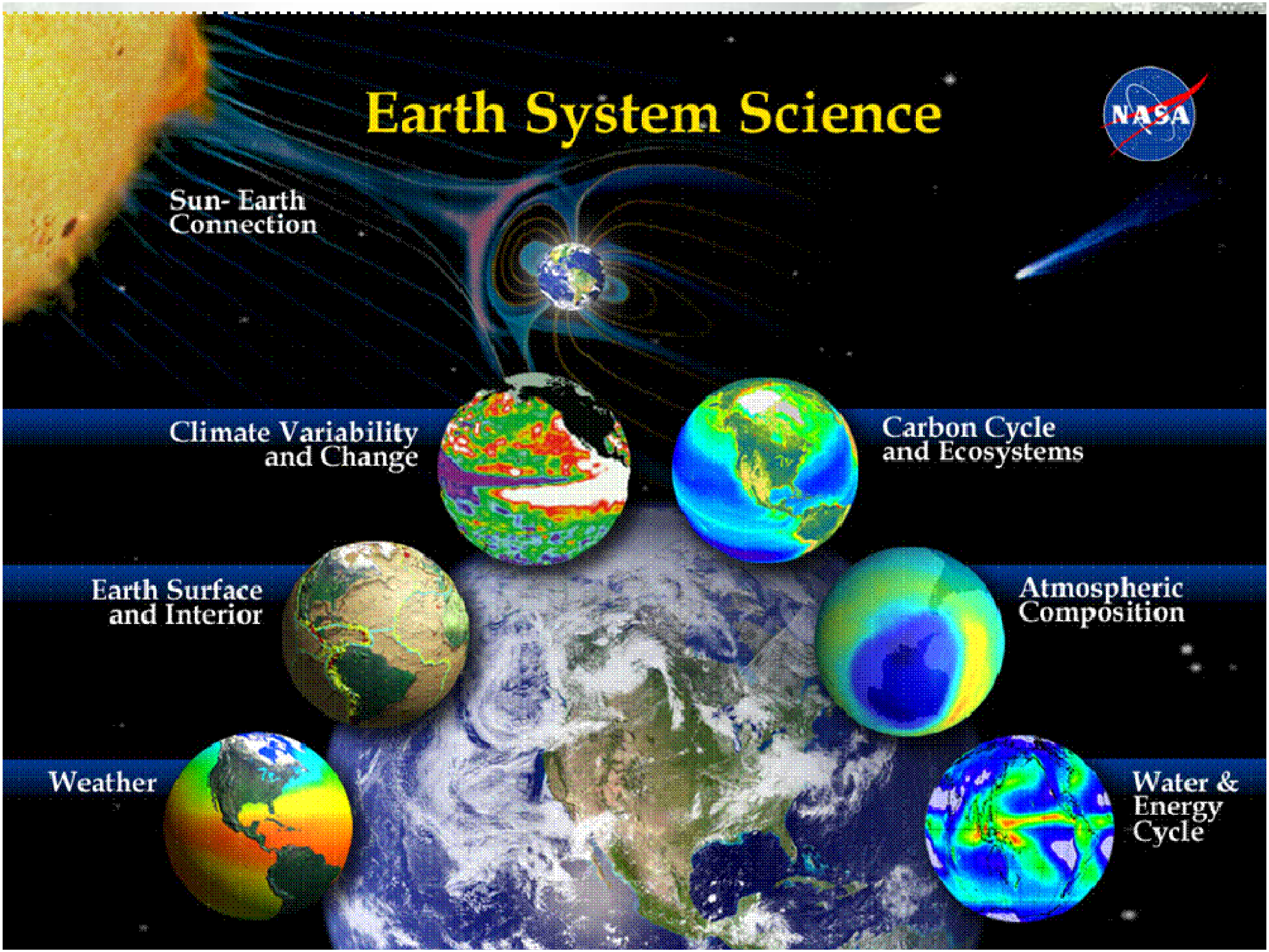
The NASA Energy and Water- Cycle Study (NEWS) long-term grand challenge:

document and enable improved, observationally-based, predictions of water and energy cycle consequences of Earth system variability and change.

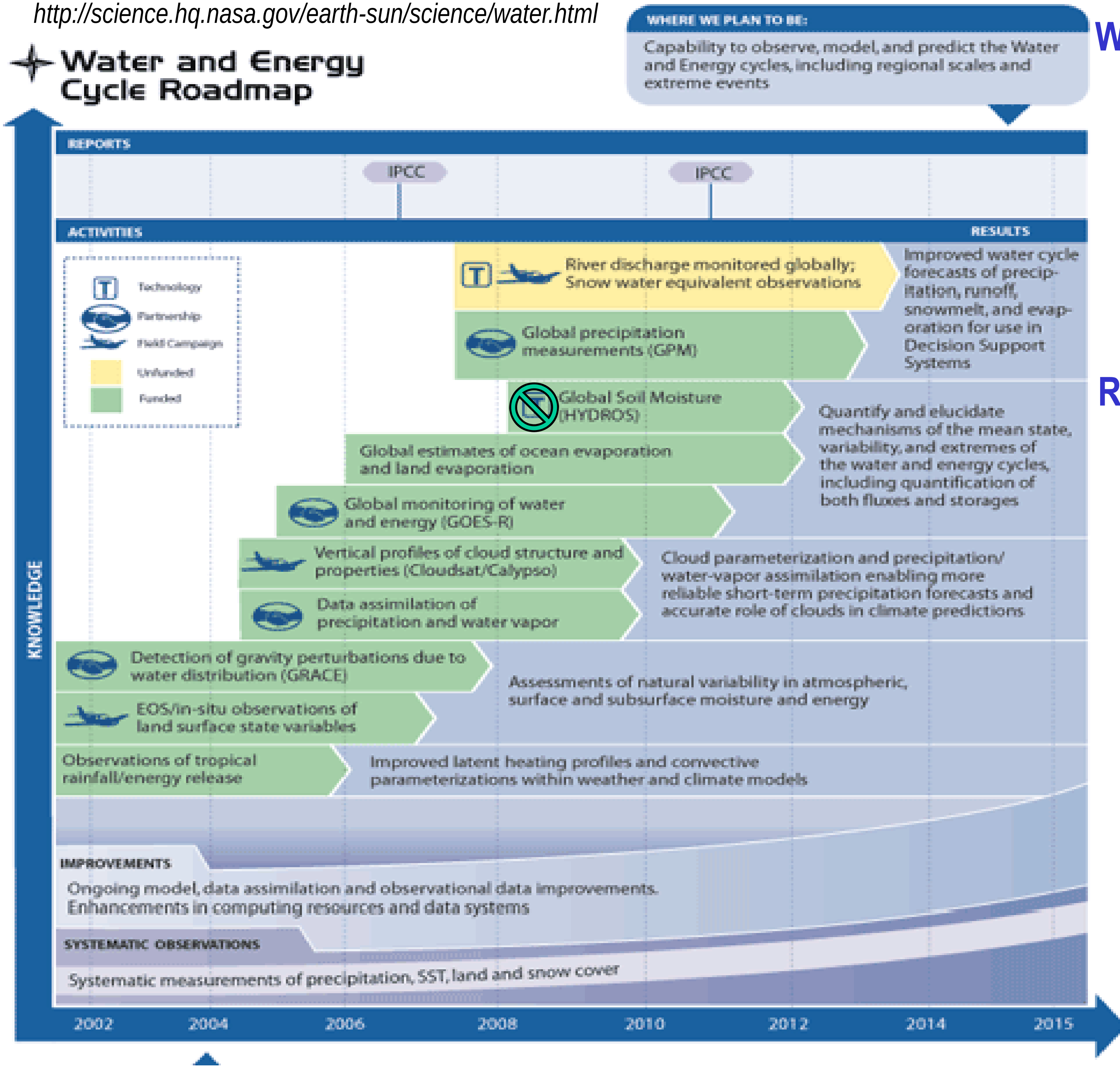
To make decisive advances in water and energy cycle prediction, we must:

- **Develop a discipline of prediction and verification through the integration of water and energy cycle observations and models.**
- **Develop climate quality, globally complete observations of the key water- and energy-cycle rates and storages (e.g. assess and fill gaps).**
- **Provide an accurate accounting of the key reservoirs and fluxes associated with the global water and energy cycle, including their spatial and temporal variability.**

NEWS is envisioned to make critical linkages (integration) between NASA research programs and satellite missions, other agencies, and international efforts (not just integrate amongst its members).


Earth System Science
NASA
Sun- Earth Connection
Climate Variability and Change
Carbon Cycle and Ecosystems
Earth Surface and Interior
Atmospheric Composition
Weather
Water & Energy Cycle

http://science.hq.nasa.gov/earth-sun/science/water.html



WEC Programs:

- + Terrestrial Hydrology
- + Precipitation Sciences
- + LCLUC
- + NEWS
- + Modeling (MAP)
- + Cloud Modeling
- + Water Management

Related Missions:

- + ACRIMSAT
- + Aqua
- + Aquarius
- + ERBS
- + GPM
- + GRACE
- + ICESat
- + Jason-1
- + OSTM
- + SORCE
- + Terra
- + TOPEX-Poseidon
- + TRMM
- + Cloudsat & CALISPO
- + Decadal Survey

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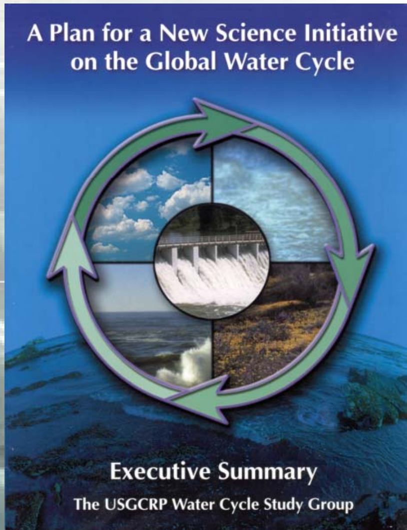

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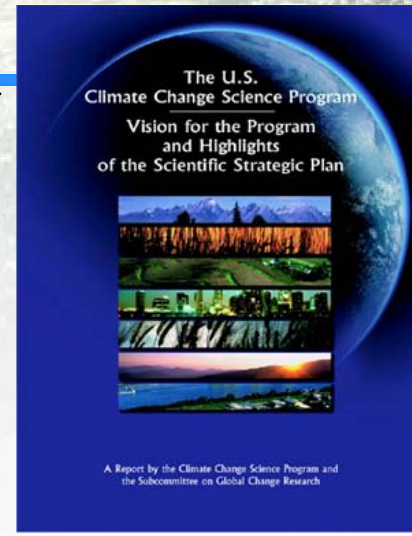


What are the causes of water cycle variations?

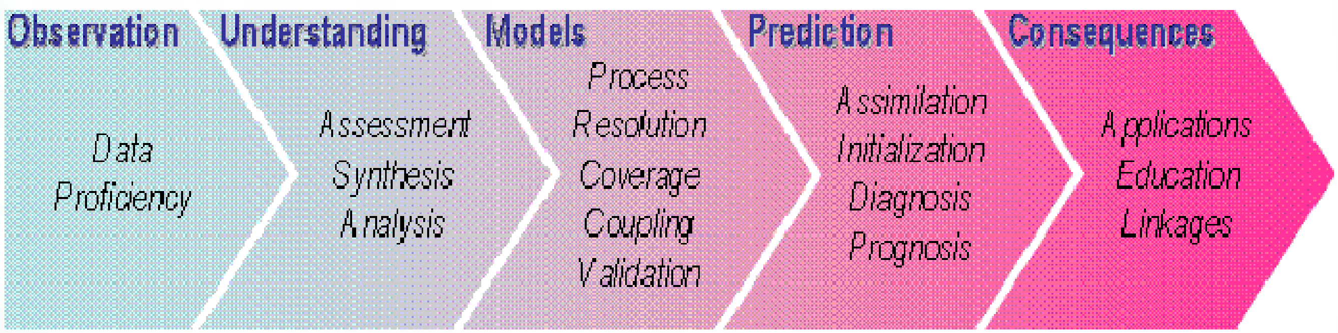
Are variations in the global and regional water cycle predictable?

How are water and nutrient cycles linked?

NEWS Integrated Water and Energy Cycle Research Challenge:

Document and enable improved, observationally-based, predictions of water and energy cycle consequences of Earth system variability and change.

The NEWS challenge is **global** in scale and requires the integration of NASA **system components** to **make decisive progress toward the NEWS challenge** in an **end-to-end program**



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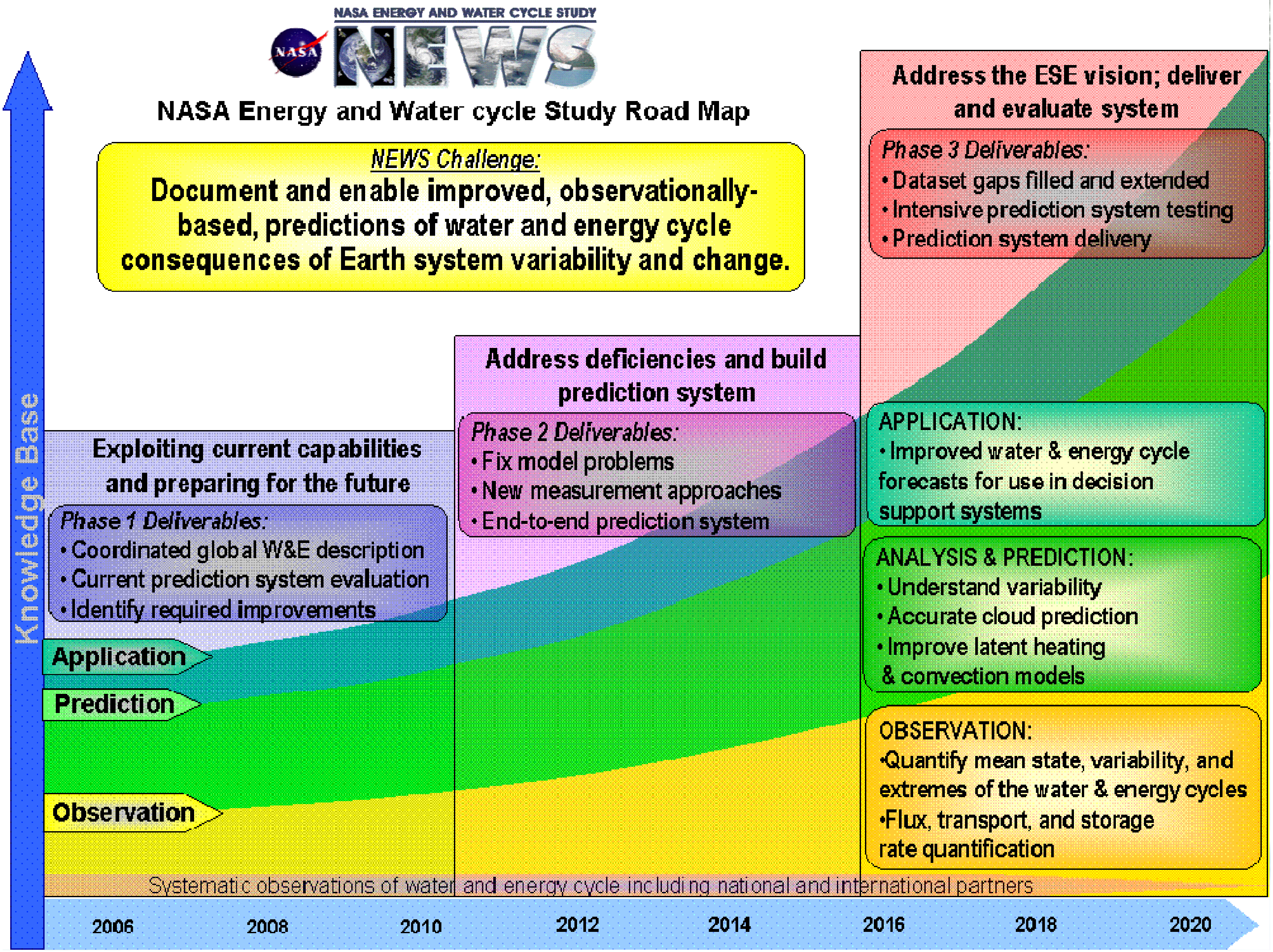

NASA ENERGY AND WATER CYCLE STUDY
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NASA Energy and Water cycle Study Road Map
NEWS Challenge:
Document and enable improved, observationally-based, predictions of water and energy cycle consequences of Earth system variability and change.
Knowledge Base
Exploiting current capabilities and preparing for the future
Phase 1 Deliverables:
• Coordinated global W&E description
• Current prediction system evaluation
• Identify required improvements
Address deficiencies and build prediction system
Phase 2 Deliverables:
• Fix model problems
• New measurement approaches
• End-to-end prediction system
Address the ESE vision; deliver and evaluate system
Phase 3 Deliverables:
• Dataset gaps filled and extended
• Intensive prediction system testing
• Prediction system delivery
APPLICATION:
• Improved water & energy cycle forecasts for use in decision support systems
ANALYSIS & PREDICTION:
• Understand variability
• Accurate cloud prediction
• Improve latent heating & convection models
OBSERVATION:
•Quantify mean state, variability, and extremes of the water & energy cycles
•Flux, transport, and storage rate quantification
Application
Prediction
Observation
Systematic observations of water and energy cycle including national and international partners
2006
2008
2010
2012
2014
2016
2018
2020

NEWS Components

NEWS Constraints

- Focus on water and energy processes and dynamics in the climate system.
- The NEWS challenge is a **global scale** objective
- Integrate water and energy cycle system components (observations and predictions)
- NEWS elements: **Observation, Understanding, Models, Prediction and Consequences**
- Make **decisive progress** toward NEWS challenge
- NASA administers the water and energy cycle focus area as an **end-to-end program**
- NEWS is an **experiment** in the power of coordination, integration and teamwork

NEWS Objectives:

- Develop and deploy experimental **E&WC global observing system**
- **Document the global E&WC** by obtaining complete observational record of all associated relevant geophysical properties
- Build **fully interactive global climate model** that encompasses process-level E&WC forcings and feedbacks – *Climate models that can predict weather-scale extremes*
- Create global surface and atmosphere **data assimilation system for E&WC variables**
- **Assess variability of the global E&WC** on time scales ranging from seasonal to decadal, and space scales ranging from regional to continental to global
- Support the **application of climate prediction capabilities** for estimating the impact of climate variability and change on water resources

NEWS Science and Integration Team (NSIT)

NEWS Science Integration Team: Support NEWS investigations and integrate their research results to address NASA-ESE science questions. The NEWS integration group will work with NEWS investigations to implement their results into a larger coordinated product, such as a NASA model, data system, etc.

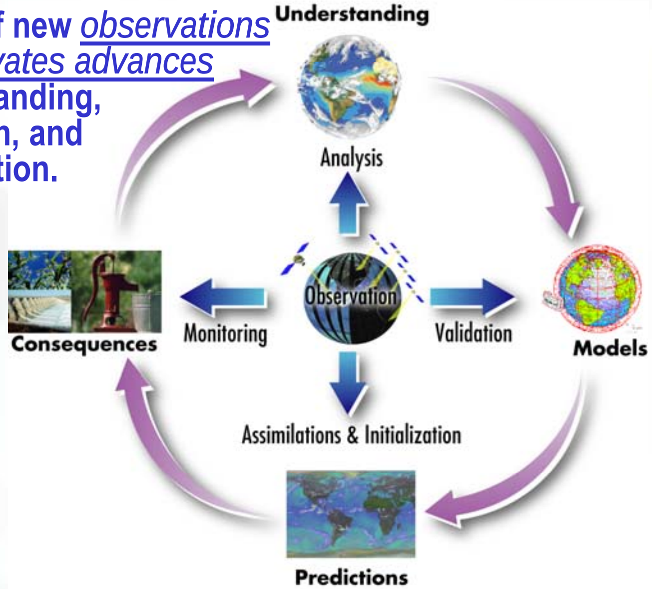
-Established by the Associate Administrator for Earth Science
-Will address all elements of WEC research and technology requirements and mission development.
-Provides a liaison with the other NASA Earth Science research focus areas.
-Serves as an interface to NASA system components.
-Focuses, coordinates and integrates the results of the NEWS investigations.

Current Members:
Bing Lin, Bill Rossow, Adam Schlosser, Bob Schiffer, Bill Lapenta, Eni Njoku, Paul Houser

NSIT Activities:
(1) **NEWS science integration:** Data product integration, PI coordination, Linkages to NASA system components, Interdiciplinary science
(2) **NEWS science gap filling:** Doing science that must be done, but was not proposed and/or funded
(3) **NEWS administration:** Organize meetings, NEWS planning & vision, POC responsibilities, Implementation plan updates, Representing NEWS to national and international partners

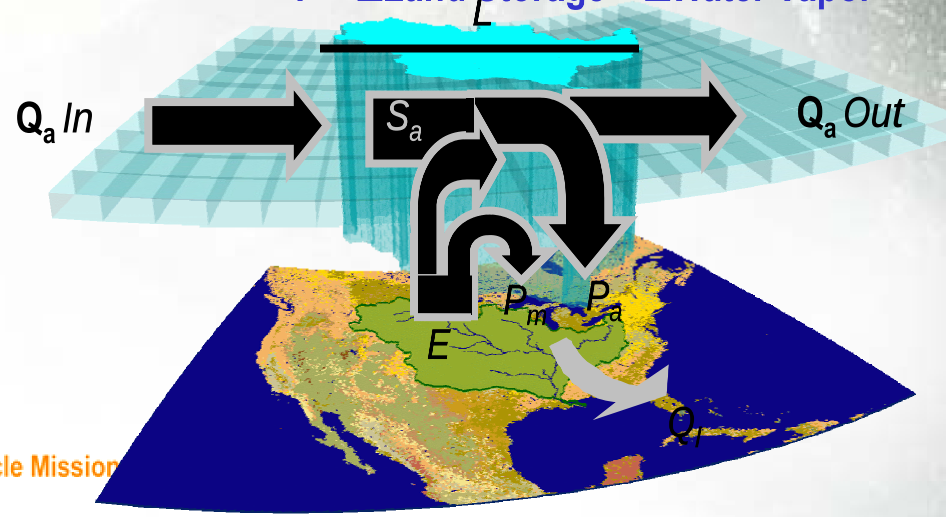
NEWS Observation Strategy

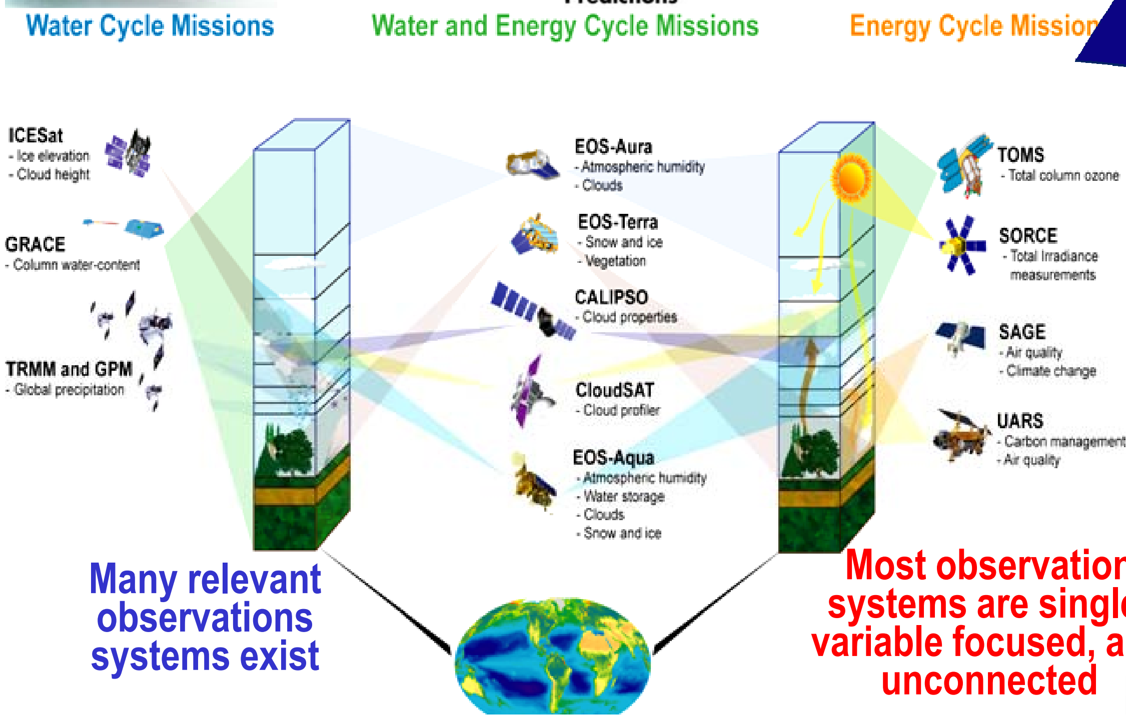
The availability of new *observations strongly motivates advances* in understanding, prediction, and application.



Input - Output = Storage Change

Transport + Evaporation - Precipitation – Runoff - P = ΔLand Storage + ΔWater Vapor





Many relevant observations systems exist

Most observation systems are single-variable focused, and unconnected

We must define and develop an integrated user-focused water observation system that can not only detect climate trends but also local variation of extremes

We must preserve critical *in-situ* benchmark observations that enable us to detect trends & extremes.

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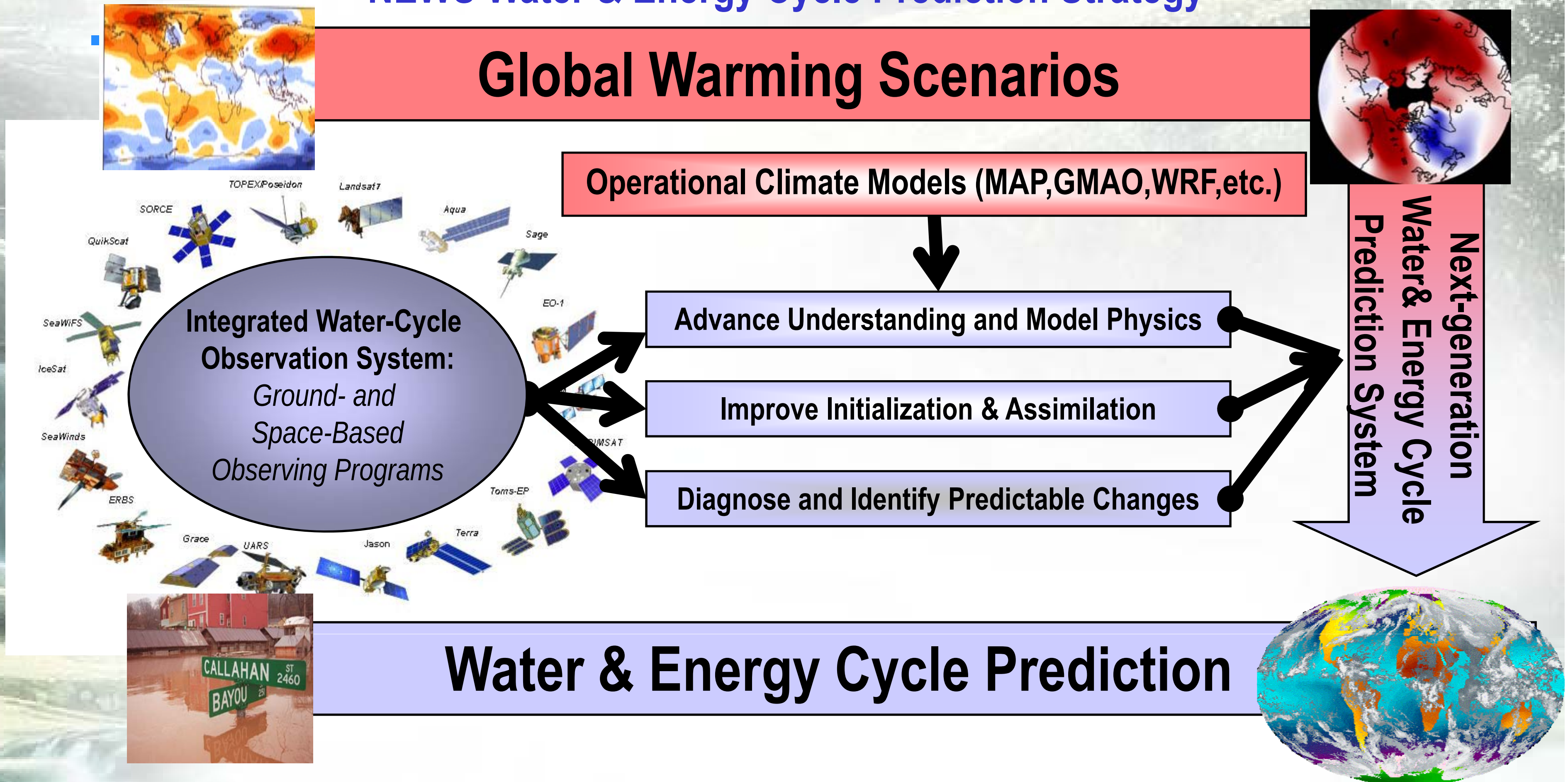
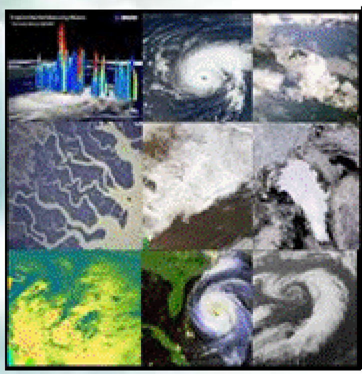
NEWS Water & Energy Cycle Prediction Strategy





- Useful prediction is critical – it is the link to stakeholders.
- Need a new paradigm of climate models that produce useful weather-scale, process-scale, and application-scale prediction of local extremes.
- More fully constrain climate models with observations, to improve their realism and believability.

NASA Energy and Water cycle Study - Phase 1 Summary

	Summary of Key Phase 1 Milestones
Observations and Retrieval	• Enhance global measurements of clouds and aerosols, radiation vertical profiles • Assess methods for quantifying snowfall and mixed precipitation • Evaluate and invest in technology for observing land/water storage • Evaluate global dataset adequacy and quality • Develop improved multi-sensor multivariate geophysical retrieval methods • Quantify NEWS data requirements
Analysis	• Reduce uncertainties in describing the global water/energy budget components • Improve accuracy of precipitation and evaporation estimates • Develop new climate data products (e.g., latent and radiative heating profiles) • Quantify predictability of energy and water cycle variations (all spatial scales) • Diagnose how multiple feedback processes affect climate responses to forcings
Modeling and Prediction	• Improve models of clouds, precipitation, hydrology, boundary layer and ocean mixing • Develop stand-alone ultra-high resolution cloud process and land hydrology models • Develop high resolution models for coupled clouds, radiation and hydrology • Test embedded process models in general circulation models • Develop and test advanced energy and water data assimilation methods • Quantify/evaluate causes/differences in precipitation predictions • Establish performance metrics for energy and water predictions
Applications	• Identify currently available data and analysis products useful for applications • Conduct selective demonstrations of usefulness of current data • Link weather & climate predictions to demonstrate their use in assessments • Identify observation and prediction system requirements for water management applications

Earth Science Mission Priorities

Initiated

- NPOESS Preparatory Project
- Landsat Data Continuity Mission
- Ocean Surface Topography Mission
- Glory
- Orbiting Carbon Observatory
- Aquarius
- Global Precipitation Measurement

*Future**

- Earth System Science Pathfinder (2014)
- *Future Representative Mission Elements:*

Changes in Earth's Ice Cover

Global Ocean Carbon, Ecosystems & Coastal Processes

Global Soil Moisture

Global Wind Observing Sounder

Multi-spectral Atmospheric Composition

Sea Surface & Terrestrial Water Levels

Vegetation 3-D Structure, Biomass & Disturbance

Wide-Swath All-weather Geodetic Imaging

** Future mission concept definitions and priorities to be reassessed now that the NRC decadal survey "Earth Science and Applications from Space" is available.*

Water Cycle Integration – How to achieve the desired integrated products?

What is integration?

- Integrating observations to establish a more complete system description
- Integrating model components to build a earth modeling system
- Integrating research results to establish end-user solutions

Data Integration: Spatial and temporal rectification to allow intercomparison and quality evaluation of disparate model and observation data;

Data-Model Integration: Physical rectification or constraint of data and its error using four dimensional data assimilation and modeling techniques.

Model Integration: Using component models to build a system model.

Solution Integration: Integrating components (research results) to develop solutions

Interpersonal Integration: Interconnection of disparate water cycle research teams.

Science Integration:

- Data integration
- Coordinate energy and water process modeling
- Water & energy cycle trend and variability assessments
- End-user decision support & solution network connections
- Program integration?

Water & Energy Cycle Data Integration

Water Cycle Data Integration: compile, diagnose and disseminate water and related energy cycle observations and predictions.

3 NEWS Integration projects:

1: Daily Time Scale (Leads: Rossow & Njoku)

- Do models handle coupling between land/atmosphere correctly?
- Local versus global scale diagnostics, synoptic and seasonal time scales.

2: Water Cycle Extremes; Two Golden Years, SGP 2006-2007 focus (Leads: Houser, Schiffer, Lapenta)

- How does diurnal cycle of WEC variables change in wet vs dry years?
- To what extend does the large scale dynamics play in controlling extremes, and are they predictable?
- Use an integrative analysis of observed extremes to improve our models' ability to predict extremes.

3: Annual and Longer time scales (Leads: Lin & Schlosser)

- How do we build on "zero-order" assessment done by Lin & Schlosser?
- Focus on recent years (2003+ to encompass "EOS-rich" measurements)
- What does "close the W & E cycle" really mean?

Key components of the WEC data integration include:

- Provide a "one stop", streamlined access to coordinated, geolocated, and integrated water & energy cycle data and visualizations from all sources.
- Identify and acquire global water and energy cycle observations and model predictions from all relevant sources, over the longest available period.
- Establish the products in consistent formats and access protocols.
- Develop an integrated re-processing plan.
- Assess the physical consistency of products.

State of the Water and Energy Cycle

Variable ↓ Sphere →	Ocean	Terrestrial	Atmosphere
Internal or State Variable	upper ocean currents (I/S) sea surface temperature (I/S) sea level/surface topography (I/S) sea surface salinity (I/S) sea ice (I/S) wave characteristics (I/S) mid- and deep-ocean currents (I) subsurface thermal structure (I) subsurface salinity structure (I) ocean biomass/phytoplankton (I/S) subsurface carbon(I), nutrients(I) subsurface chemical tracers(I)	topography/elevation (I/S) land cover (I/S) leaf area index (I) soil moisture/wetness (I/S) soil structure/type (I/S) permafrost (I) vegetation/biomass vigor (I/S) water runoff (I/S) surface temperature (I/S) snow/ice cover (I/S) subsurface temperature (I/S) subsurface moisture (I/S) soil carbon, nitrogen, phosphorus, nutrients (I)	wind (I/S) upper air temperature (I/S) surface air temperature (I/S) sea level pressure (I) upper air water vapor (I/S) surface air humidity (I/S) precipitation (I/S) clouds (I/S) liquid water content (I/S)
Forcing or Feedback Variable	ocean surface wind & stress (I/S) incoming SW radiation (I/S) incoming LW radiation (I/S) surface air temperature (I/S) surface air humidity (I/S) precipitation (I/S) evaporation (I/S) fresh water flux (I/S) air-sea CO_2 flux (I) geothermal heat flux (I) organic & inorganic effluents (I/S) biomass and standing stock (I/S) biodiversity (I) human impacts-fishing (I)	incoming SW radiation (I/S) incoming LW radiation (I/S) PAR radiation surface winds (I) surface air temperature (I/S) surface humidity (I/S) albedo (I/S) evapotranspiration (I/S) precipitation (I/S) land use (I/S) deforestation (I/S) land degradation (I/S) sediment transport (I/S) air-land CO_2 flux (I)	sea surface temperature (II/S) surface soil moisture (I/S) surface soil temperature (I/S) surface topography (I/S) land surface vegetation (I/S) CO_2 & other greenhouse gases, ozone & chemistry, aerosols (I/S) evapotranspiration (I/S) snow/ice cover (I/S) SW and LW surface radiation budget (I/S) solar irradiance (S)

BLUE=Water Cycle Variable; RED=Energy Cycle Variable; GREEN=Carbon/Chemistry Variable; BLACK=Boundary condition

$$\frac{d\langle Q\rangle}{dt} = \langle E\rangle - \langle P\rangle$$

$$R = P - E \pm \Delta G$$

$$P_o = E_o - D_o + D_l = E_o - R$$
$$P_l = E_l + D_o - D_l = E_l + R$$

$$\frac{\partial S}{\partial t} = -\nabla_H \cdot \vec{R}_o - (E - P).$$

$$P + R_o + \Delta O + G_{do} = E$$

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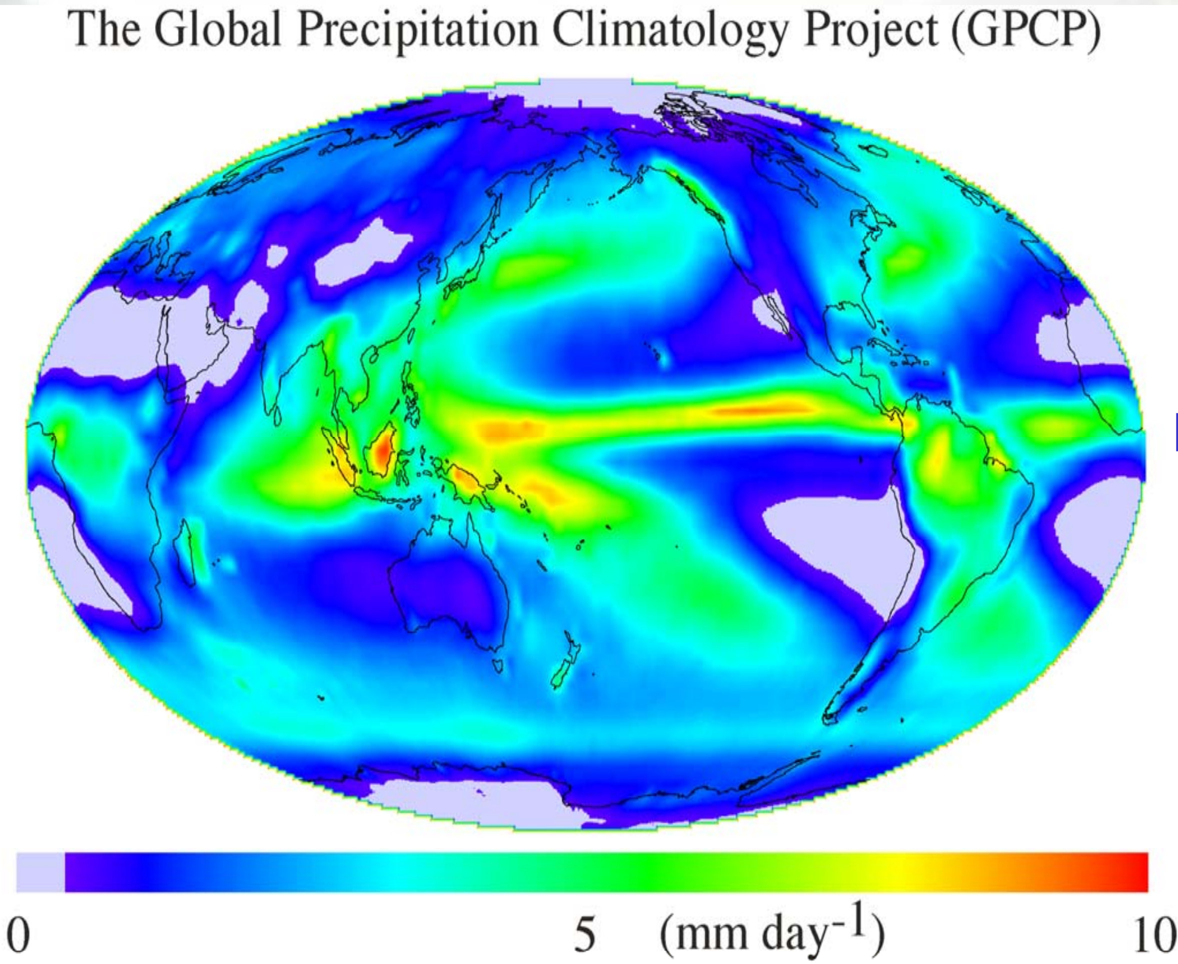
NEWS DATA Products

Adler (2008)

Global Precipitation Climatology Project (GPCP)

World Climate Research Program (WCRP)/GEWEX

Global total = 2.6 mm/d (Ocean [2.8 mm/d] Land[2.1 mm/d]



A merged monthly satellite/gauge analysis (1979-2007)

Input: SSM/I, Geo-IR, TOVS/AIRS, other data from NASA, NOAA, German Weather Service, universities-- final merged product produced by Goddard group

http://precip.gsfc.nasa.go v

Adler et al. (2003), J. Hydromet.

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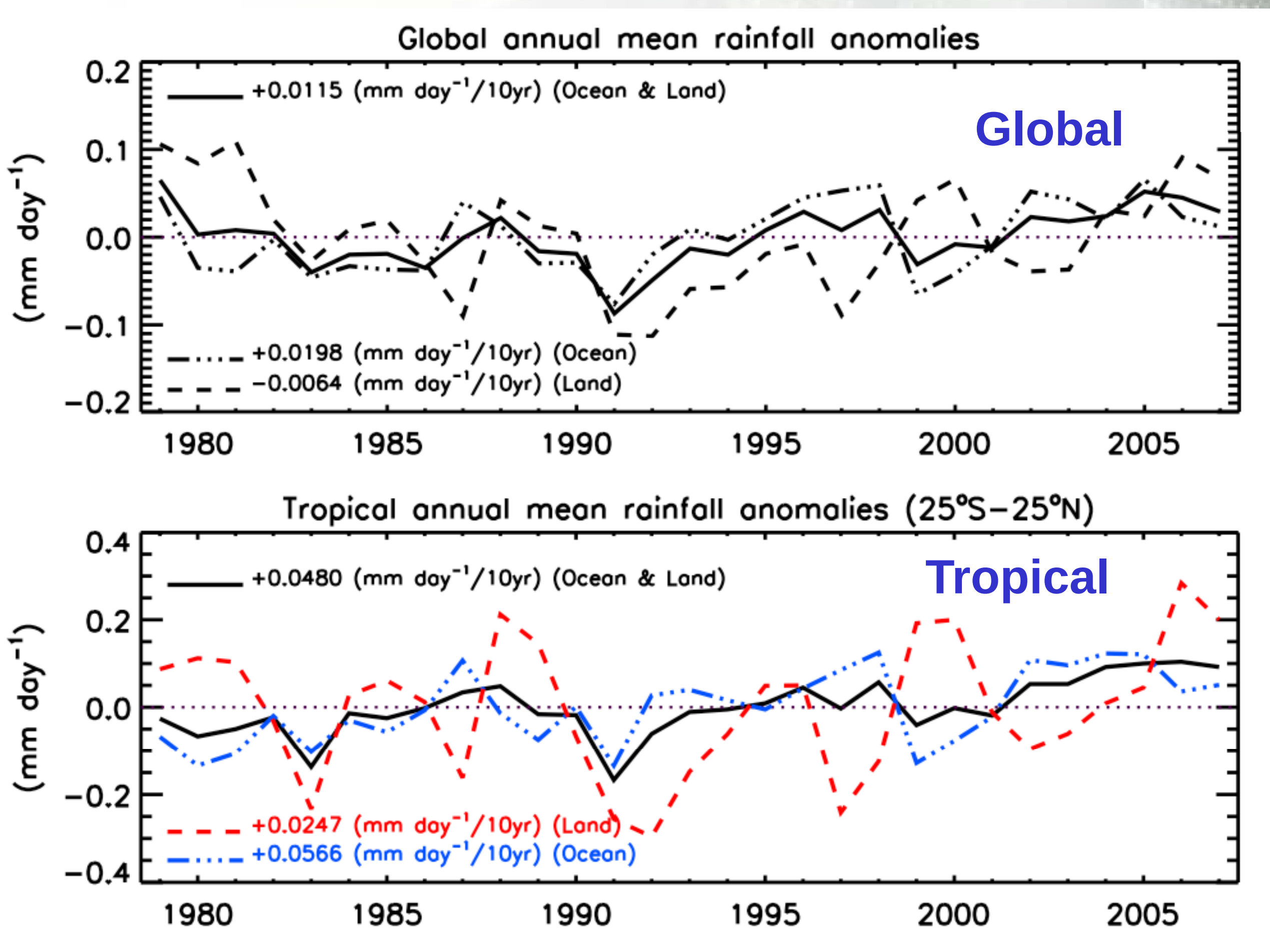
Adler (2008)

Global (and Tropical) Precipitation from 1979-2007 from Global Precipitation Climatology Project (GPCP) Analysis

Analysis from recent addition of 2007 to record (now 29 years) confirm results in Gu et al. (2007, J. Clim.) indicating little or no global trend, but significant upward trend in Tropics (especially over ocean). 2007 one of rainiest years in Tropics, especially over land.



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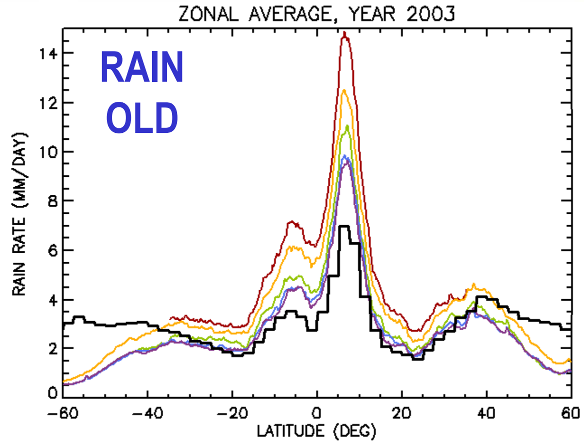
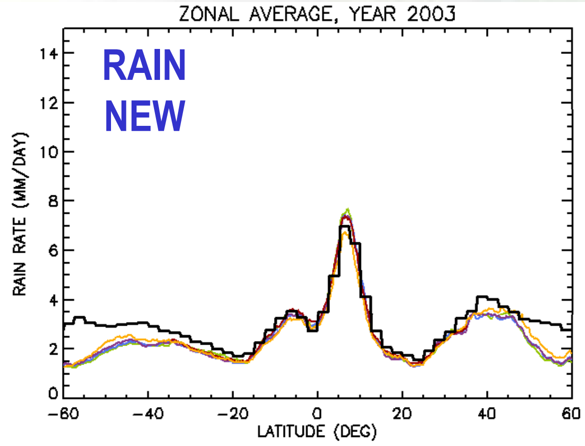
Rain Rate Intercalibration Completed

Hilburn & Wentz (2008)



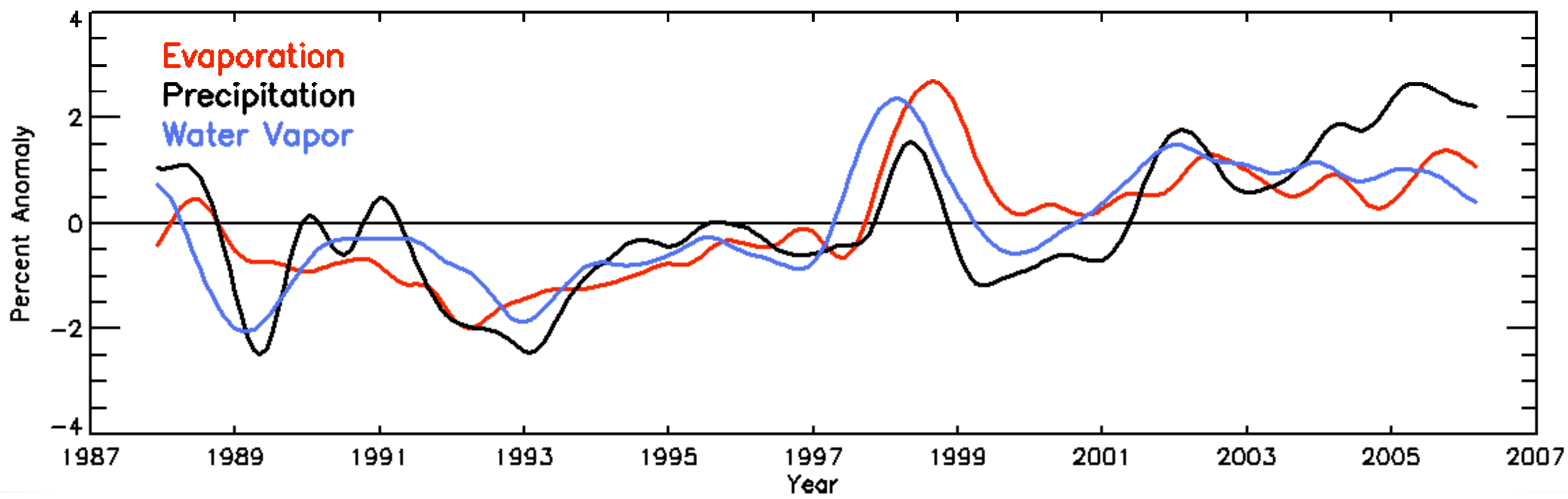


F13 (green), F14 (blue), F15 (purple), AMSR-E (orange), TMI (red),
Global Precipitation Climatology Project (black)

- Our new rain algorithm: **UMORA** (**U**nified **M**icrowave **O**cean **R**etrieval **A**lgorithm) is a modification of the Wentz and Spencer (1998) approach
  - Improved beamfilling: modeling saturation and resolution dependence (removed biases among different sensors)
  - Improved rain column height: constrained to data (removed tropical biases)
  - Improved calibration: 0.05K
- Hilburn and Wentz, 2008: Intercalibrated passive microwave rain products from the Unified Microwave Ocean Retrieval Algorithm (UMORA), *J. Appl. Meteor. Climatol.*, **47**, 778-794. (March 2008 Issue)

Hilburn & Wentz (2008)

Indirect Validation using Hydrological Consistency

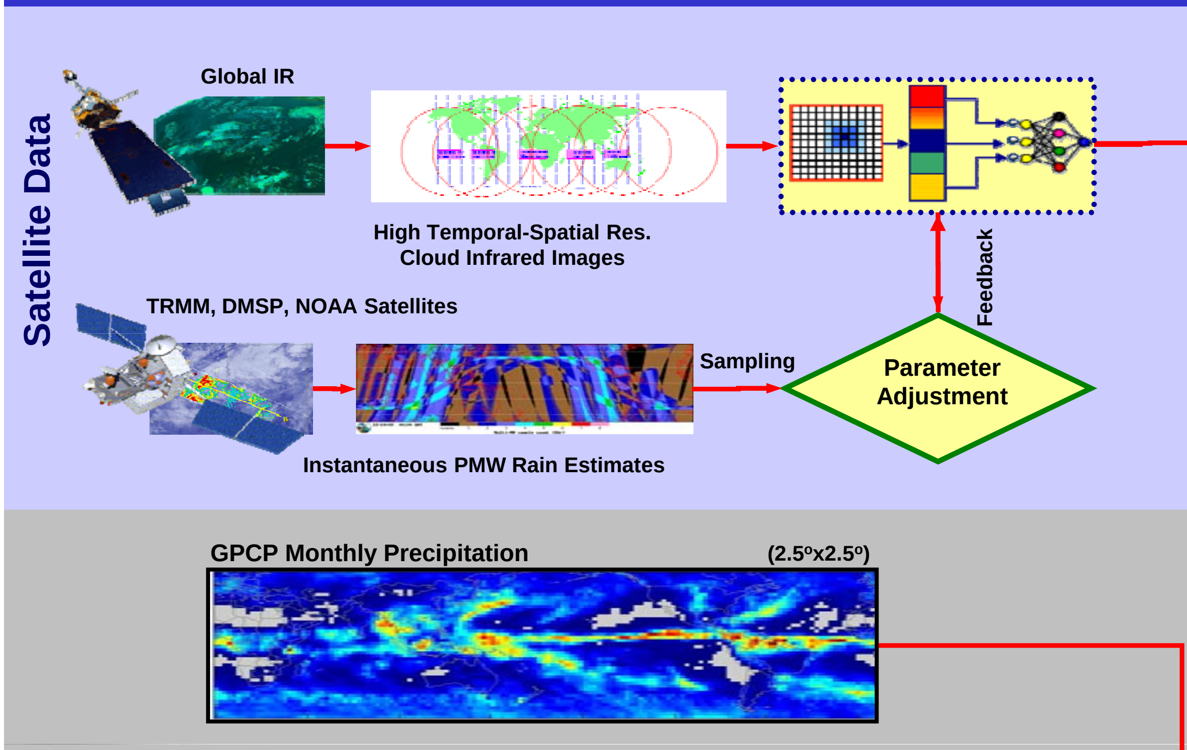


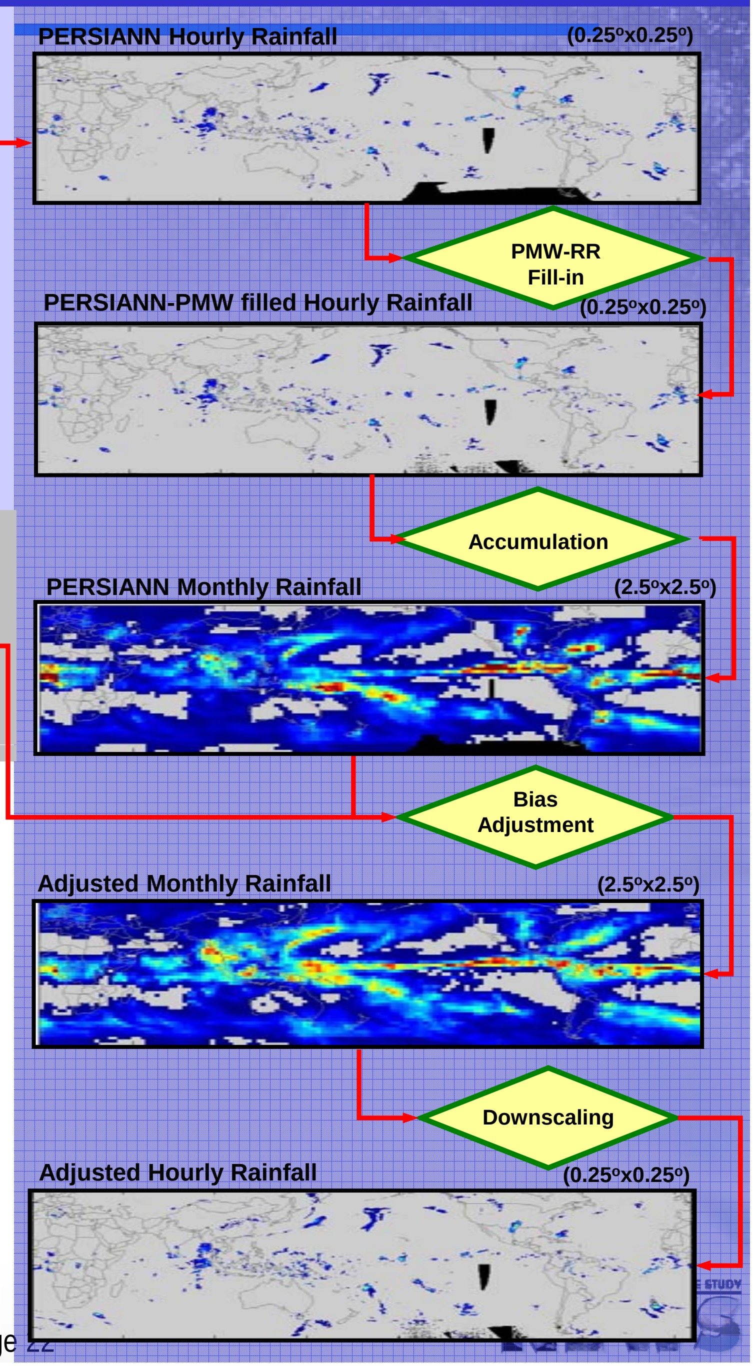
- Global evaporation balances global precipitation (with a static, latitude-dependent adjustment to rain)
  - Average evaporation: 962 mm/year
  - Average precipitation: 951 mm/year
  - Imbalance on the order of 1%

- Trends in evaporation and precipitation have the same magnitude as trends in water vapor, in contrast with climate models
  - Evaporation trend: + 1.3 % / decade
  - Precipitation trend: + 1.5 % / decade
  - Water Vapor trend: + 1.4 % / decade

Climate prediction models predict a muted response by precipitation see Wentz et al., 2007, *Science*.

Downscaling of GPCP Rainfall to High Spatio-temporal Scale Using PERSIANN





Bias adjustment of PERSAINN rainfall:

Stage I: Fill-in missing PERSIANN rainfall by PMW-rainfall.

Stage II: Accumulation and Adjustment of PERSIANN rainfall based on GPCP monthly rainfall measurement.

Stage III: Spatial and temporal downscaling of PERSAINN bias estimates from monthly rainfall at 2.5 degree to hourly at 0.25 degree.

Center for Hydrometeorology and Remote Sensing

NEWS DATA Integration

Data and Methods

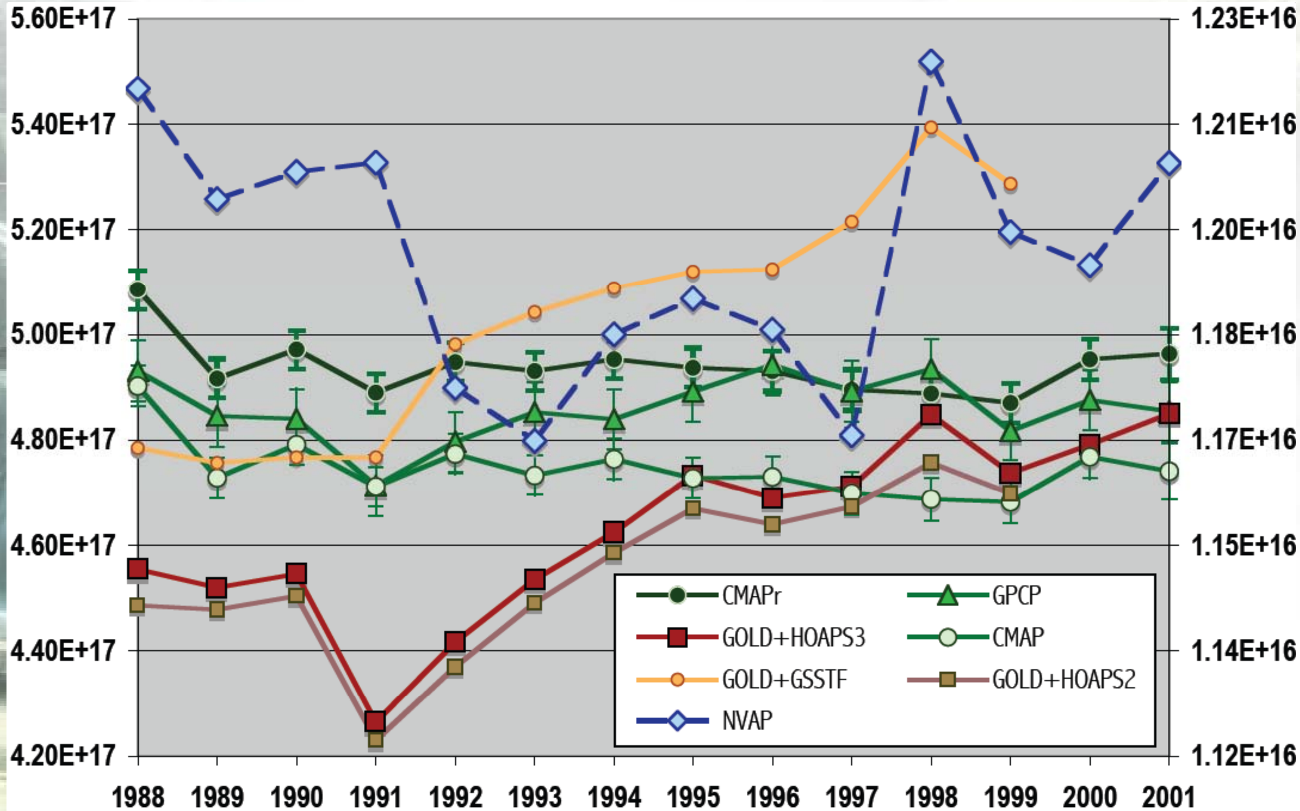
Extended Analyses (of Schlosser and Houser, J. Climate, 2007)

Fluxes	Product	Spatial	Temporal	Source & Primary Contact(s)
Precipitation	TMPA	60S ~ 60N; 180W ~ 180E (0.25°)	12Z29Jan2002 ~ present (3hr)	trmmopen.gsfc.nasa.gov (George J. Huffman)
	CMORPH	60S ~ 60N; 180W ~ 180E (0.25°)	00Z07Dec2002 ~ present (3hr)	ftp.cpc.ncep.noaa.gov (Robert Joyce & John Janowiak)
	PERSIANN	50S ~ 50N; 180W ~ 180E (0.25°)	00Z01Mar2000 ~ present (6hr)	hydis8.eng.uci.edu (Kuolin Hsu & Dan Braithwaite)
Evaporation	GLDAS (Land)	60S ~90N; 180W ~ 180E (1°)	Jan1979 ~ Aug2006 (Monthly)	hsbserv.gsfc.nasa.gov (Matthew Rodell)
	HOAPS (Ocean)	80S ~ 80N; 180W ~ 180E (1°)	00Z01Jan1987 ~ 12Z31Dec2005 (12hr)	www.hoaps.zmaw.de (Axel Andersson)
Storage	AIRS-AMSRE (Atmosphere)	90S ~ 90N; 180W ~ 180E (1°)	00Z01Jan2005 ~ 21Z31Dec2005 (3hr)	JPL (Eric Fetzer and Van Dang)
	GRACE (Terrestrial)	90S ~ 90N; 180W ~ 180E (1°)	CSR: Aug2002 ~ Dec2006 GFZ&JPL: Feb 2003 ~ Nov 2006 (Monthly)	podaac.jpl.nasa.gov (Don Chambers and Jay Famiglietti)
Moisture Transport	MOIS_TRANS	30S-30N; 180W-180E (0.5°)	07Jul1999 ~ 31Dec2005 (daily)	airsea.jpl.nasa.gov (Timothy Liu & Xiaosu Xie)

Atmospheric Budget: $dQ/dt = E - P - div(Q_t)$

Terrestrial Budget: $dS/dt = P - E - R$

Global Results: 1988-2001

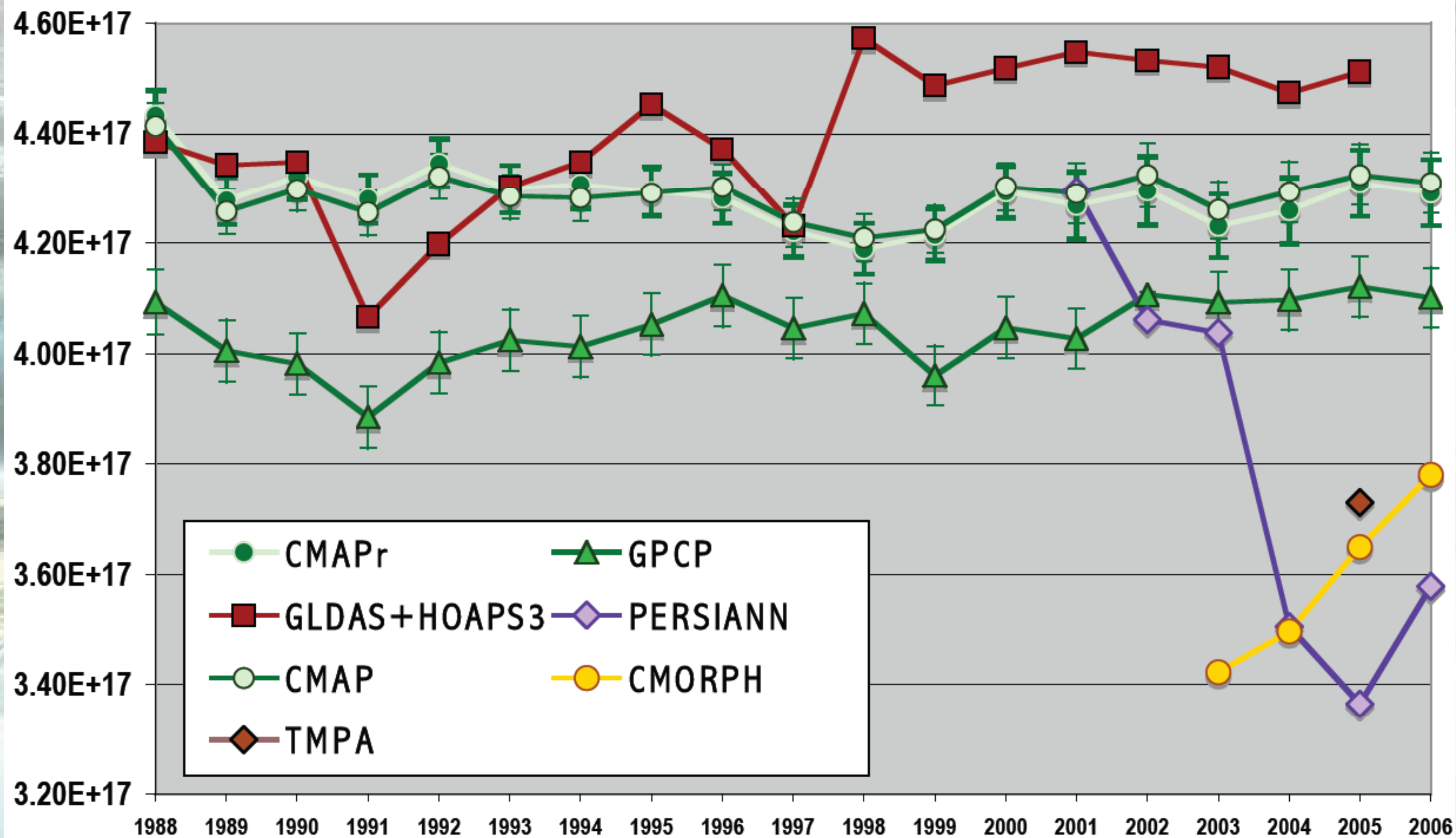


	GPCP	CMAP	CMAPr	HOAPS & GOLD
Land	1.07±0.02	9.98±0.01	1.00±0.01	0.684
Ocean	3.79±0.06	3.74±0.04	3.94±0.04	3.95
Global	4.86±0.06	4.75±0.04	4.94±0.04	4.63

Table 1. Global annual mean results of water budget terms for the period 1988-2001. Values are given in units of 10^{17} kg/yr.

- HOAPS (still) shows trend and Pinatubo plunge.
- GPCP/CMAP(r): The good, the bad, and the "split"
- Latter half of period, fluxes converging, really?
- Trend detection - need long monotic trend to verify GCMs (for low-risk detection).

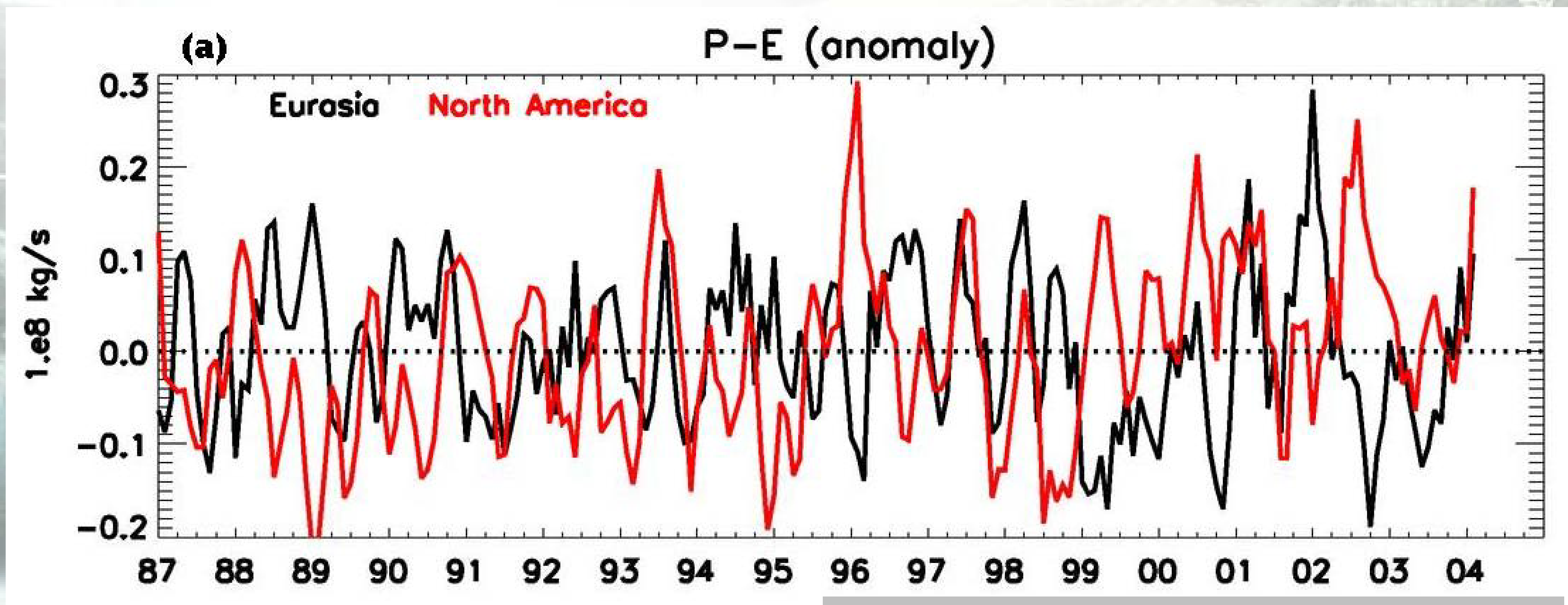
"Global" (50S-50N) Annual Timeseries of Legacy and Next-Generation Precipitation



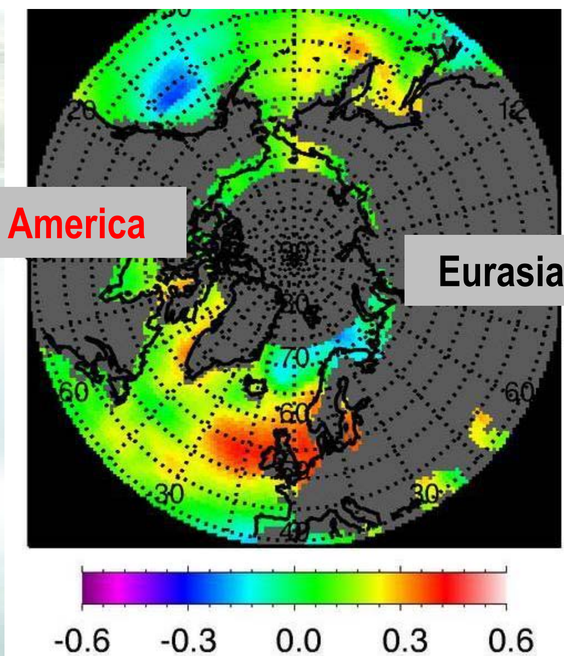
Not much consistency seen between legacy and next-generation estimates at the global scale... for now.

High-latitude water balance over two continents are connected by moisture transport in the Atlantic in the climatic scale (Liu &Tang)

Liu (2008)



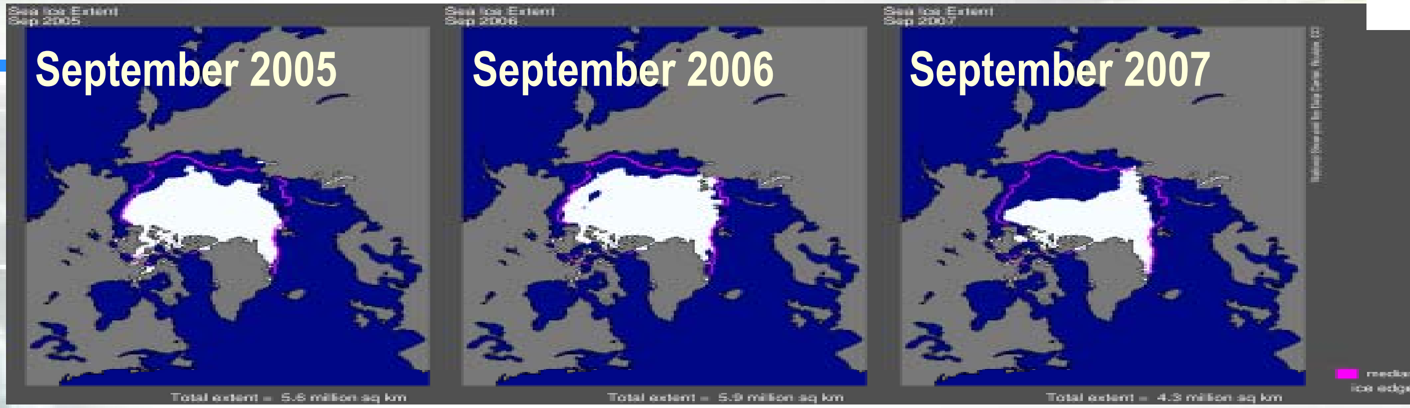
P-E interannual anomalies integrated over Eurasia and over North America from 50°N to 80°N (RIMS, UNH).

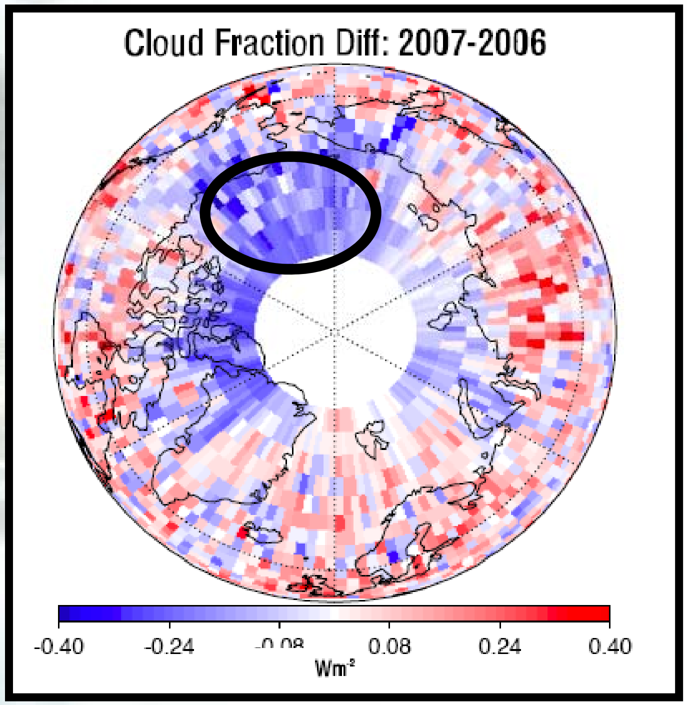


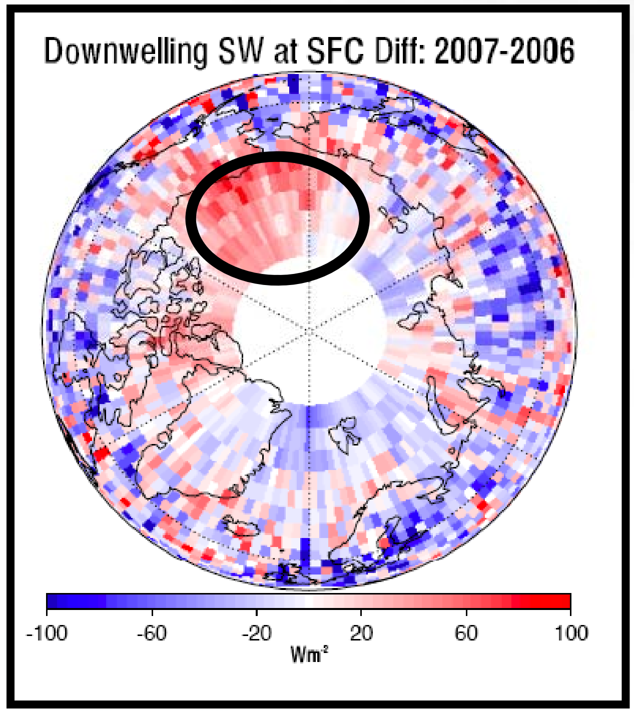
Correlation coefficients between the difference of the two time series (Eurasia-North America) and the zonal component of integrated moisture transport derived from SSM/I.

NEWS Data Analysis
&
Model Evaluation

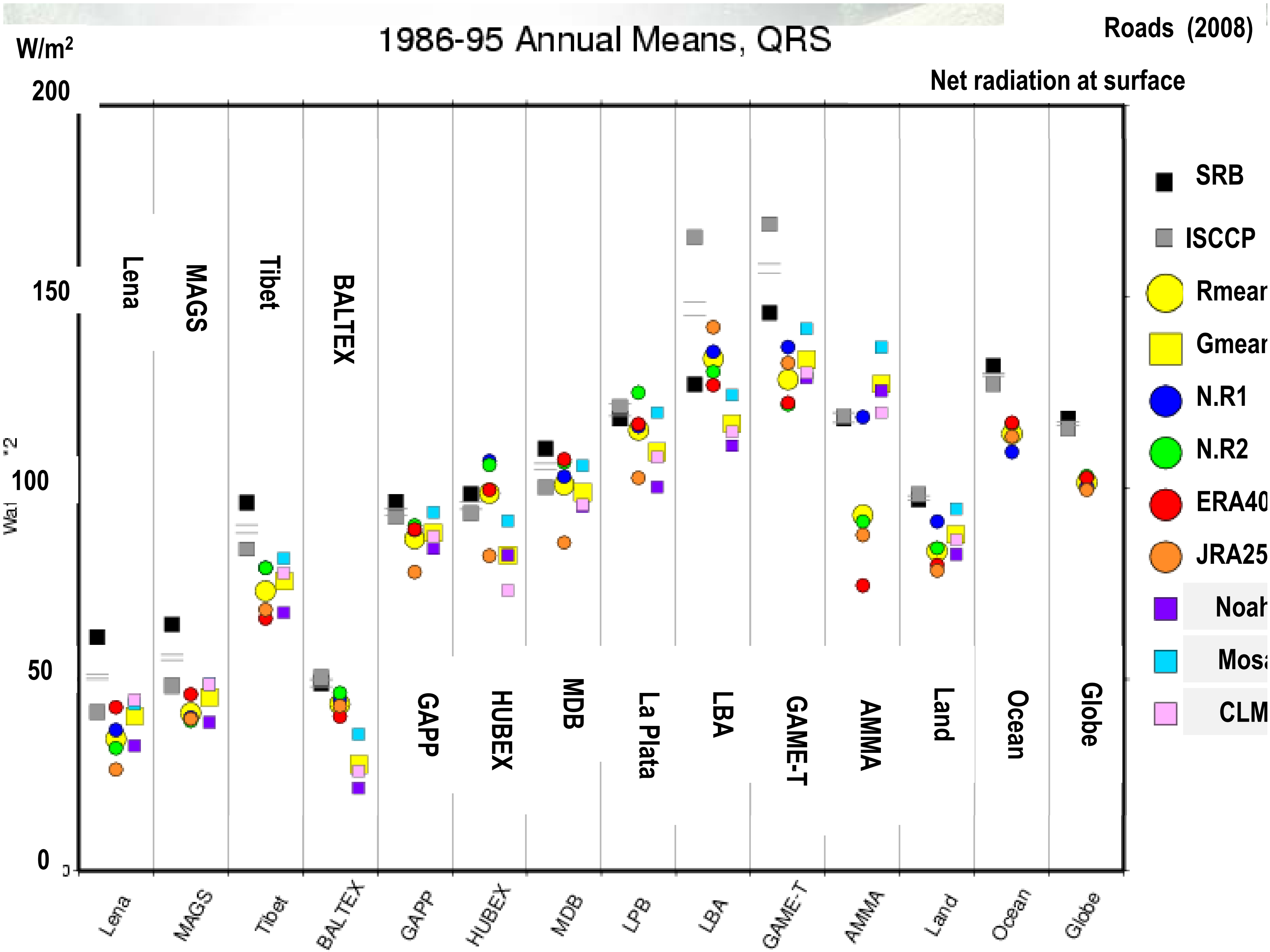
Lecuyer (2008)



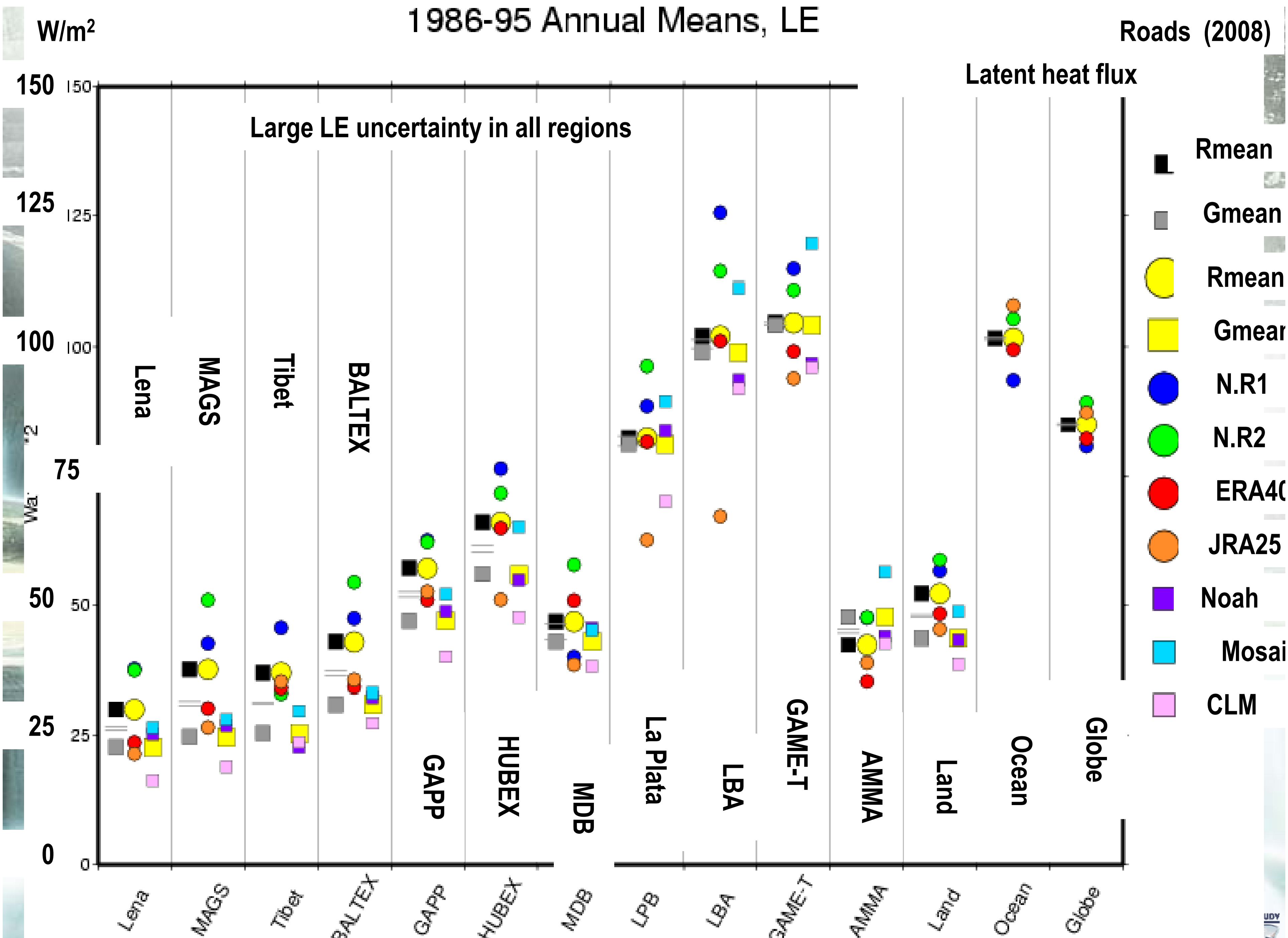




The observed (A-Train) 32 Wm^{-2} surface SW radiation anomaly during this 3 month period constitutes enough energy to warm a 20 m ocean mixed layer by more than 2 K or melt a 0.3 m layer of sea ice (Kay et al, 2008).



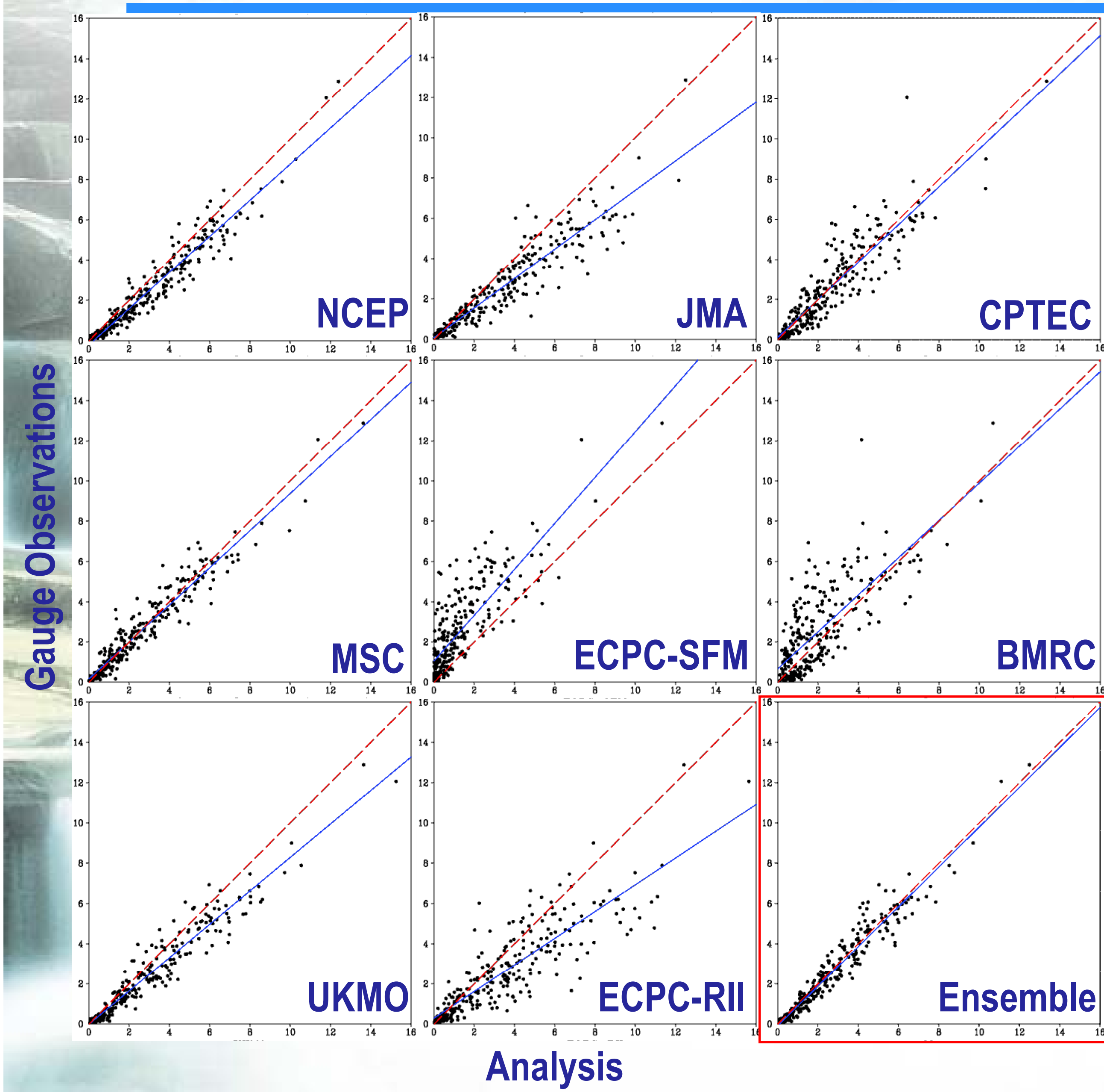
Roads (2008)
1986-95 Annual Means, QRS
Net radiation at surface
W/m²
200
150
100
50
0
Lena
MAGS
Tibet
BALTEX
GAPP
HUBEX
MDB
La Plata
LBA
GAME-T
AMMA
Land
Ocean
Globe
LPB
SRB
ISCCP
Rmear
Gmear
N.R1
N.R2
ERA40
JRA25
Noah
Mosa
CLM



W/m2
1986-95 Annual Means, LE
Roads (2008)
Latent heat flux
Large LE uncertainty in all regions
150
125
100
75
50
25
0
Lena
MAGS
Tibet
BALTEX
GAPP
HUBEX
MDB
La Plata
LBA
GAME-T
AMMA
Land
Ocean
Globe
LPB
Rmean
Gmean
Rmean
Gmear
N.R1
N.R2
ERA40
JRA25
Noah
Mosai
CLM

Bosilovich (2008)

Mississippi River Basin Precipitation



Jan-Sep 2004 Daily MRB Precipitation

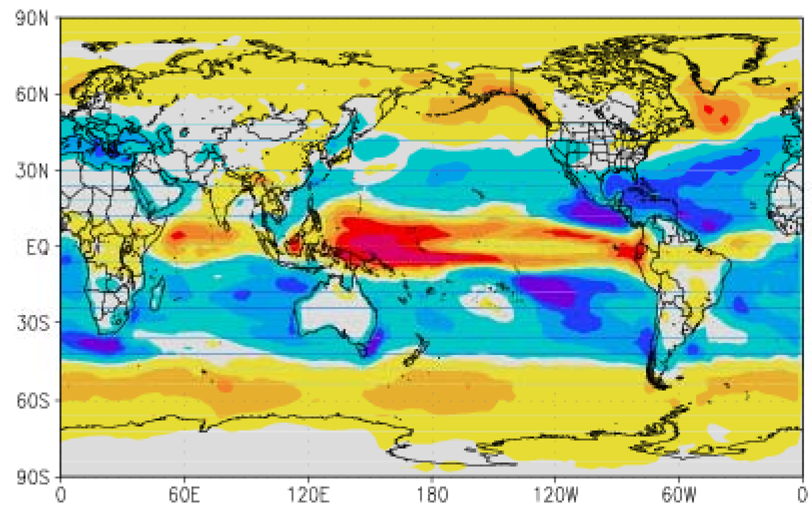
- MRB is in the heart of a data rich region for analyses
- Precipitation is independent (not assimilated)
- In general, Models have different characters
- Most overestimate high rain events
- BMRC excessively dry summer
- Ensemble fits well

Multi-model ensemble mean change from IPCC GCMs

Soden (2007)

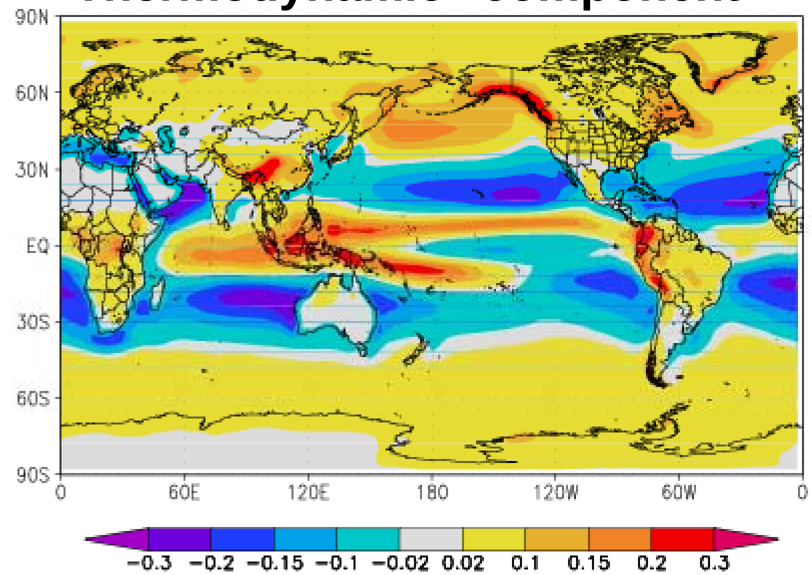
Change in (P-E) for 2100 minus 2000

“Dry regions get drier, wet regions get wetter”

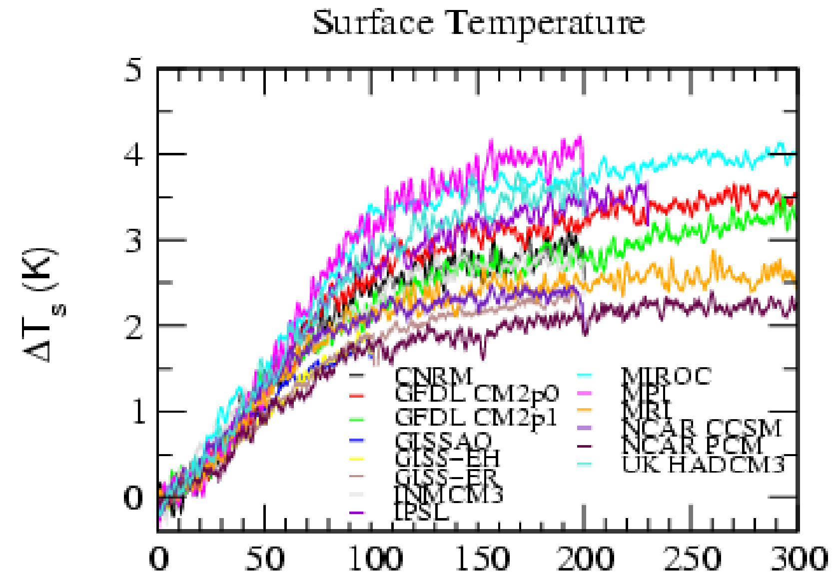


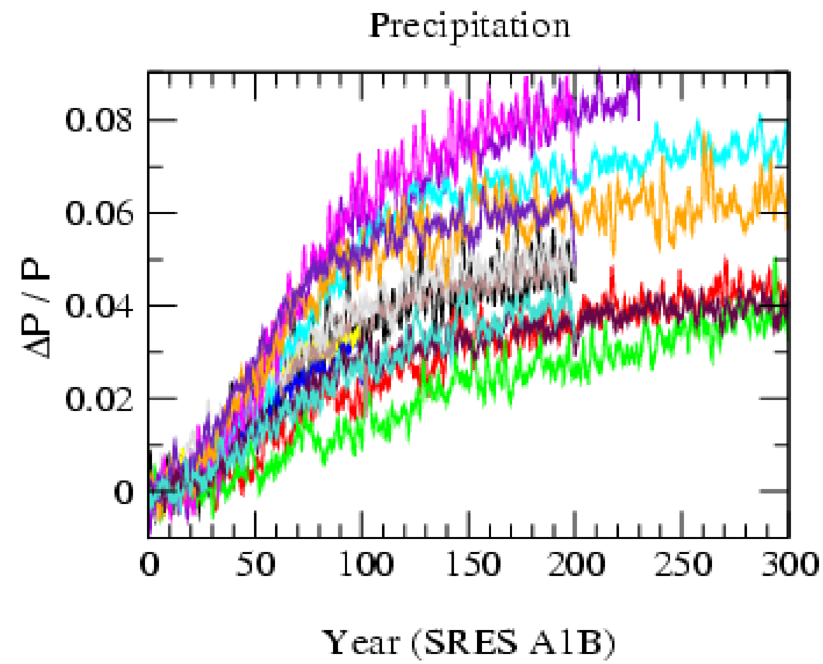
Held and Soden (2006)

“Thermodynamic” component



Δ(P-E) mr





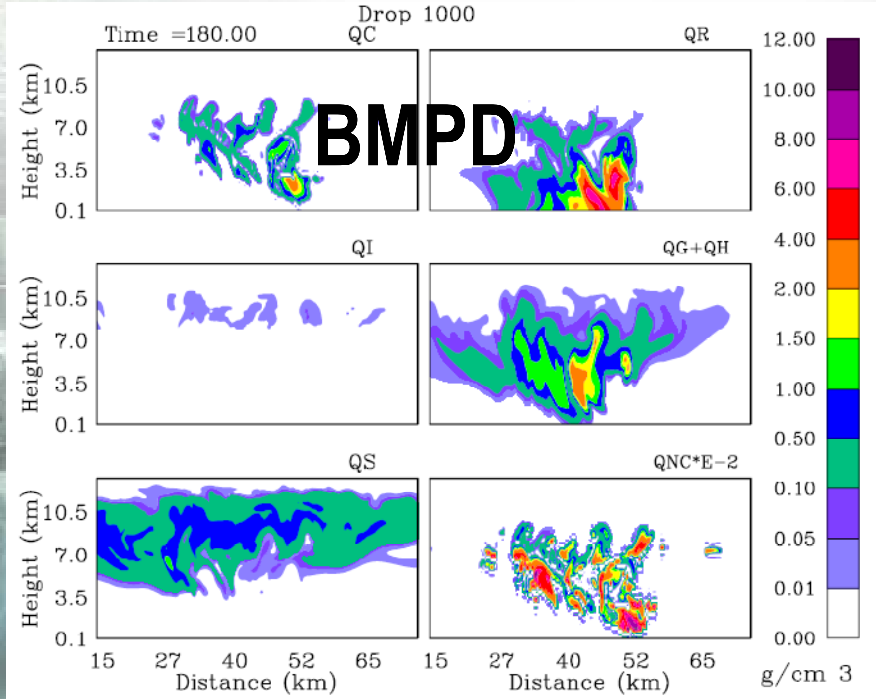
Paul R. Houser, November 3

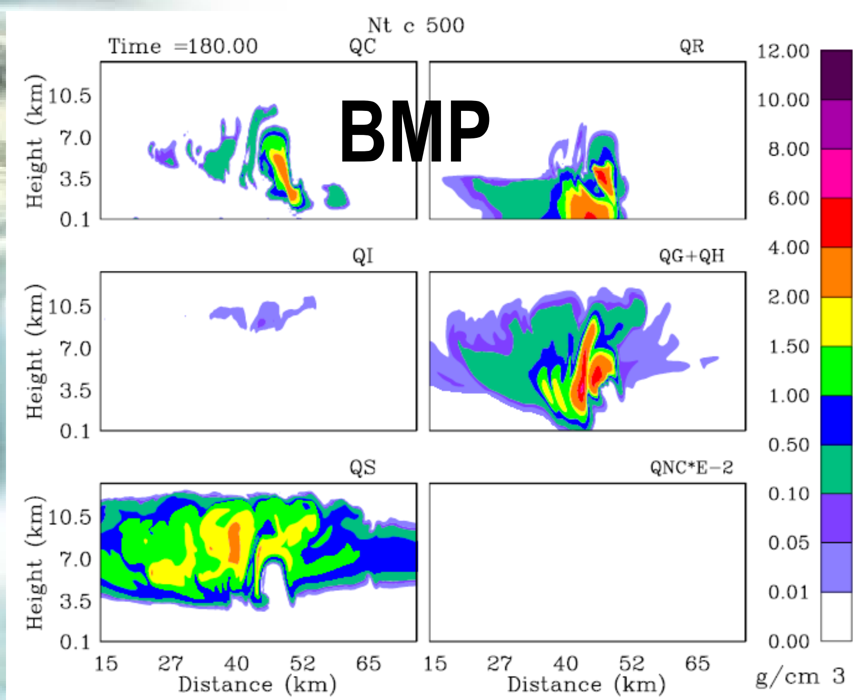
Vecchi and Soden (2007)

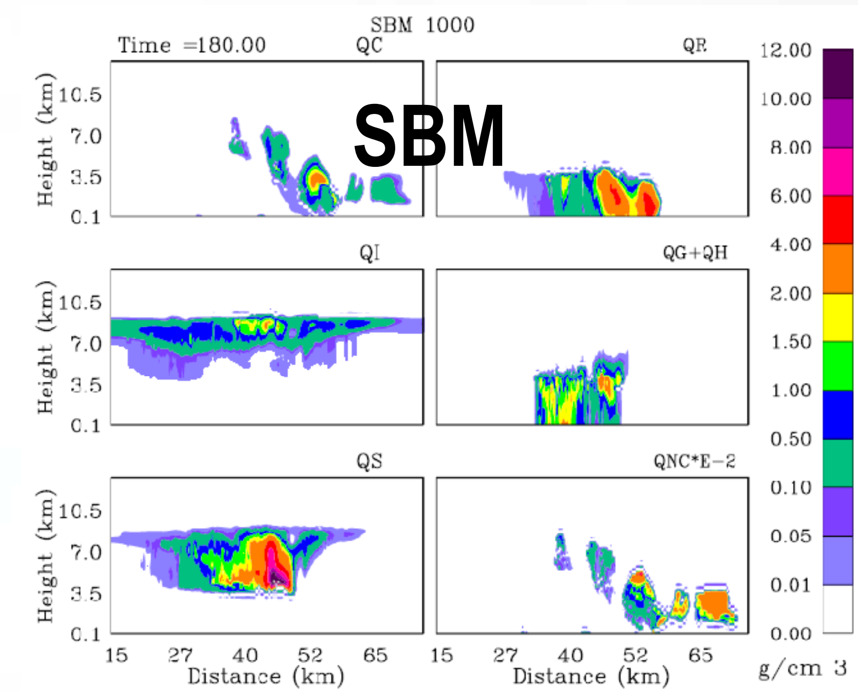
NEWS Modeling & Prediction

Leung (2008)

A Comparison of Three Different Cloud Microphysical Representations Implemented in WRF: Note the relatively large differences in the cloud structures simulated by the three methods

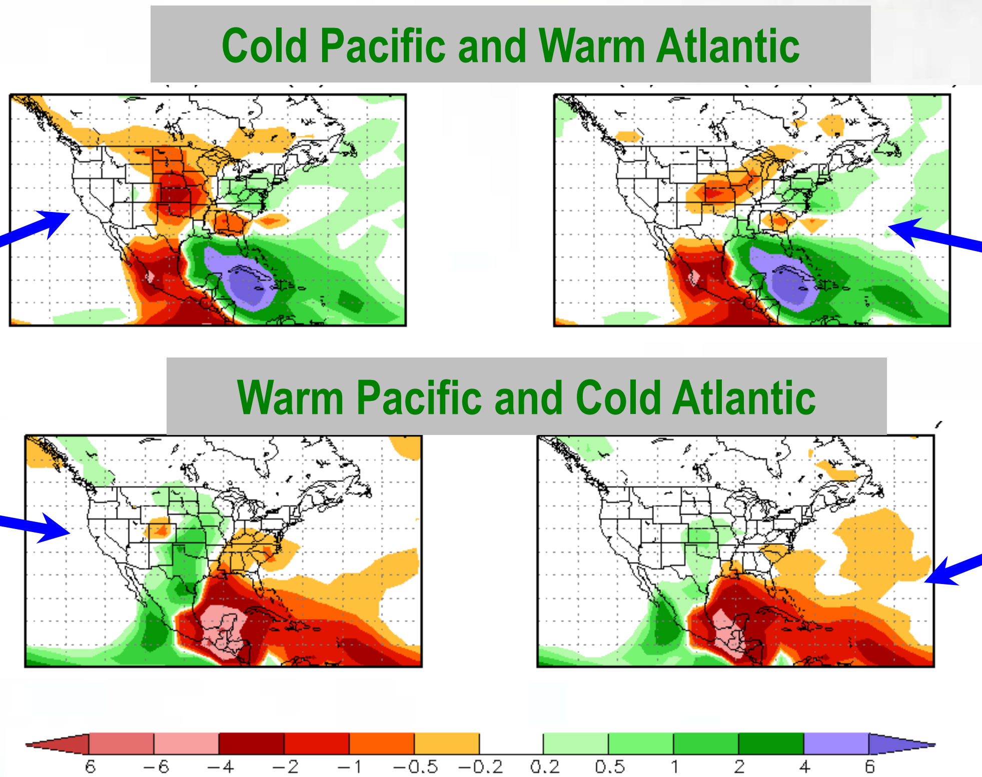






Schubert (2008)

Impact of Soil Moisture Feedbacks on JJA Precipitation



Interactive soil moisture

No soil moisture feedbacks

Summary

- The NEWS team is making great progress towards its goals on many fronts.

- PI Meeting Focus: Can we do better?
  - NSIT is retiring – what is next?
  - How can we see through the integration vision to include other NASA efforts, other agencies, other countries?
  - Can we adopt a new integration paradigm or business model?
  - What does the next 5 years of NEWS look like?

- NEWS Resources:
  - Web site: http://www.nasa-news.org
    - Implementation Plan, Quad Charts, Google Discussion Groups, Educational Materials, calendar of events
  - Data: ftp://crew.iges.org or http://crew.iges.org:9090 (GDS server)