WCRP Grand Challenge:

Changes in Water Availability

- Led by GEWEX
- *How can we better understand and predict precipitation variability and changes, and how do changes in land surface and hydrology influence past and future changes in water availability and security?*

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Water availability…

The questions focus on the exploitation of :

- *improved data sets of precipitation, soil moisture, evapotranspiration, and related variables, such as water storage and sea surface salinity*
- *Improved analyses to close the water budget over land*
- *Improved modeling capabilities: global climate models to regional hydro-climate models*
- *Improved information for products related to water availability and quality for decision makers and for initializing climate predictions from seasons to years ahead.*

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GEWEX Science Questions (GSQs)

"Water availability" will be addressed in all 4 GSQs, especially the first 2:

- Observations and Predictions of Precipitation
- Global Water Resource Systems
- Changes in Extremes
- Water and energy cycles and processes

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Challenges and Opportunities in Water Cycle Research: WCRP Contributions

Kevin E. Trenberth[1] and Ghassem R. Asrar[2]

Surveys in Geophysics (special issue)

Space Sciences Series of ISSI (Vol. TBD),

published by Springer.

Abstract

The state of knowledge and outstanding challenges and opportunities in global water cycle observations, research and modeling are briefly reviewed to set the stage for the reasons behind the new thrusts promoted by the World Climate Research Programme (WCRP) as Grand Science Questions (GSQs) to be addressed on a 5 to 10 year time frame. A number of GSQs are being brought forward within the WCRP under guidance of the Joint Scientific Committee (JSC) and those focused on water are led by GEWEX, the Global Energy and Water cycle Experiment. Here we describe what are some imperatives and opportunities for major advancements in observations, understanding, modeling, and product development for water resources and climate that will enable a wide range of climate services and inform decisions on water resources management and practices.

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Observations and Predictions of Precipitation- GSQ 1

- 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 (distribution, amount, intensity, frequency, duration, type) of precipitation – with particular emphasis on extremes of droughts and floods?
- *How do models become better and* how much confidence do we have in global and regional climate predictions of precipitation?

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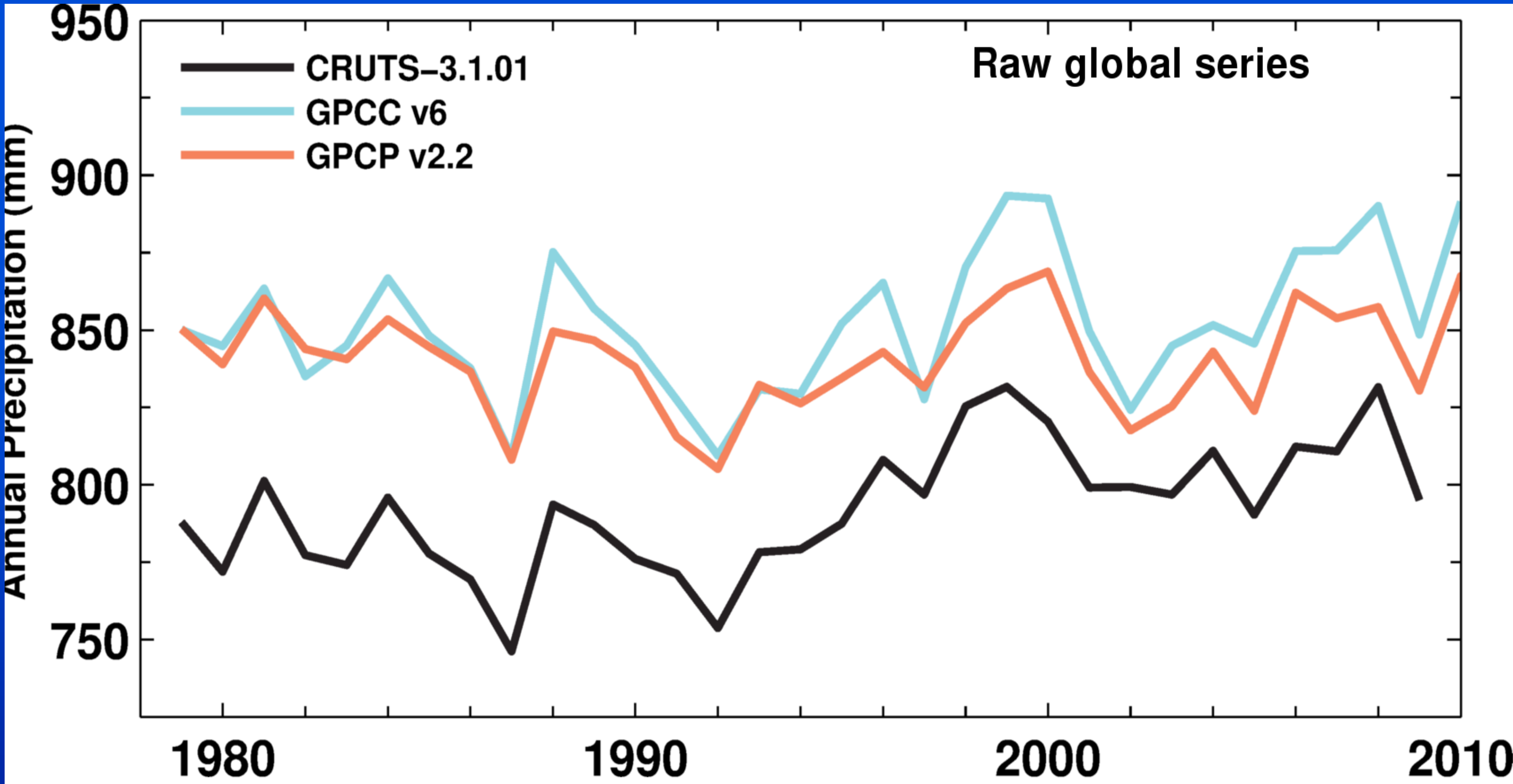
GEWEX Science Questions

How can we better understand and predict variations and changes in precipitation?

- use and development of expected improved **datasets** on: precipitation and soil moisture from ongoing and planned satellite missions, as well from in-situ observations;
- evaluation and **analysis** into various products;
- document the mean, variability, patterns, extremes and full probability density functions,
- **confront models** in new ways;
- improve understanding of atmospheric and land surface **processes** and their **modeling** that improve simulations of precipitation;
- employ new techniques of data assimilation and forecasts that improve predictions of the hydrological cycle.

These results should lead to improved climate services.

Global land precipitation



Differences not only in means but also trends. It turns out these account for the main discrepancies among drought indices, not ET.

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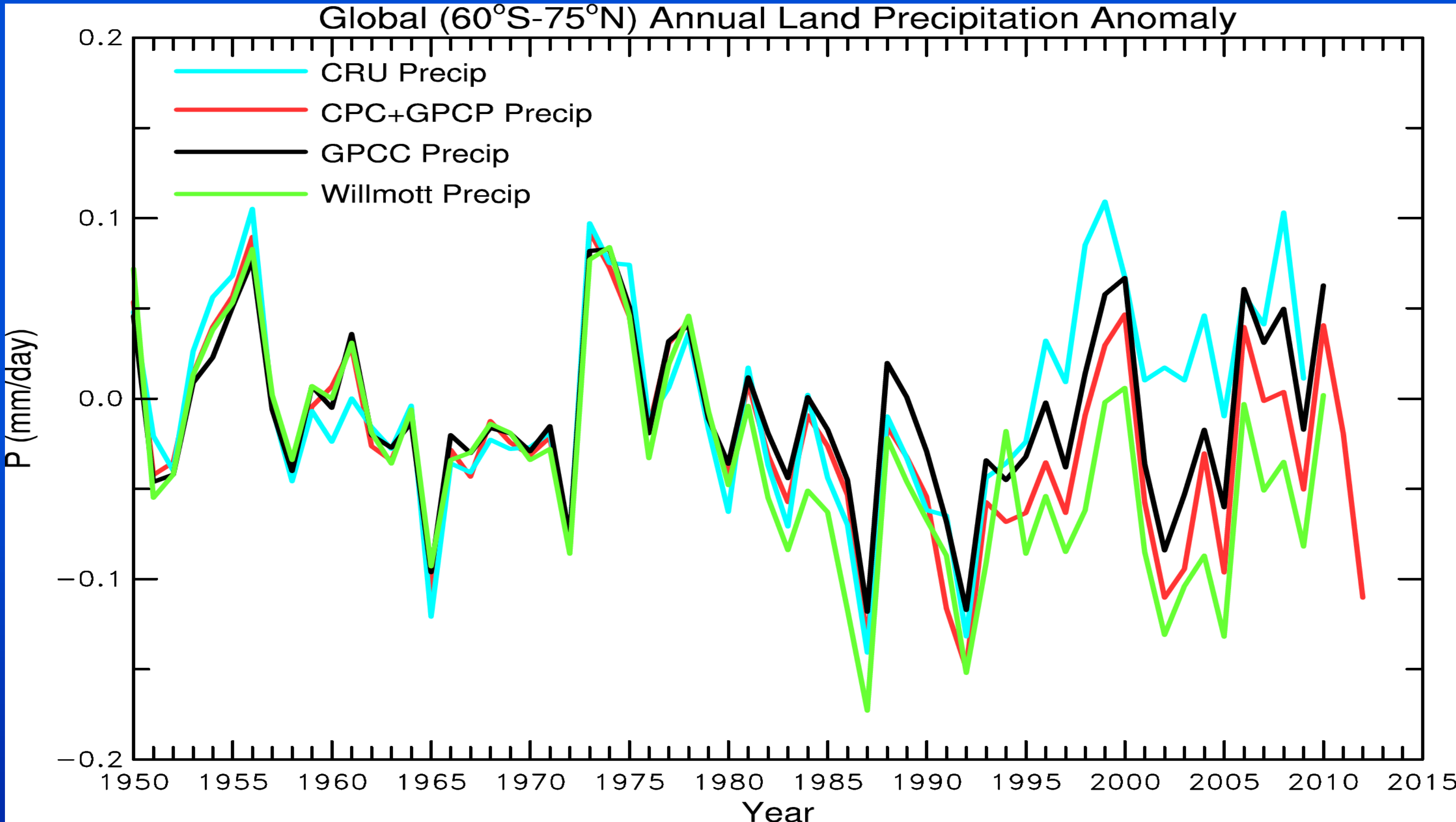
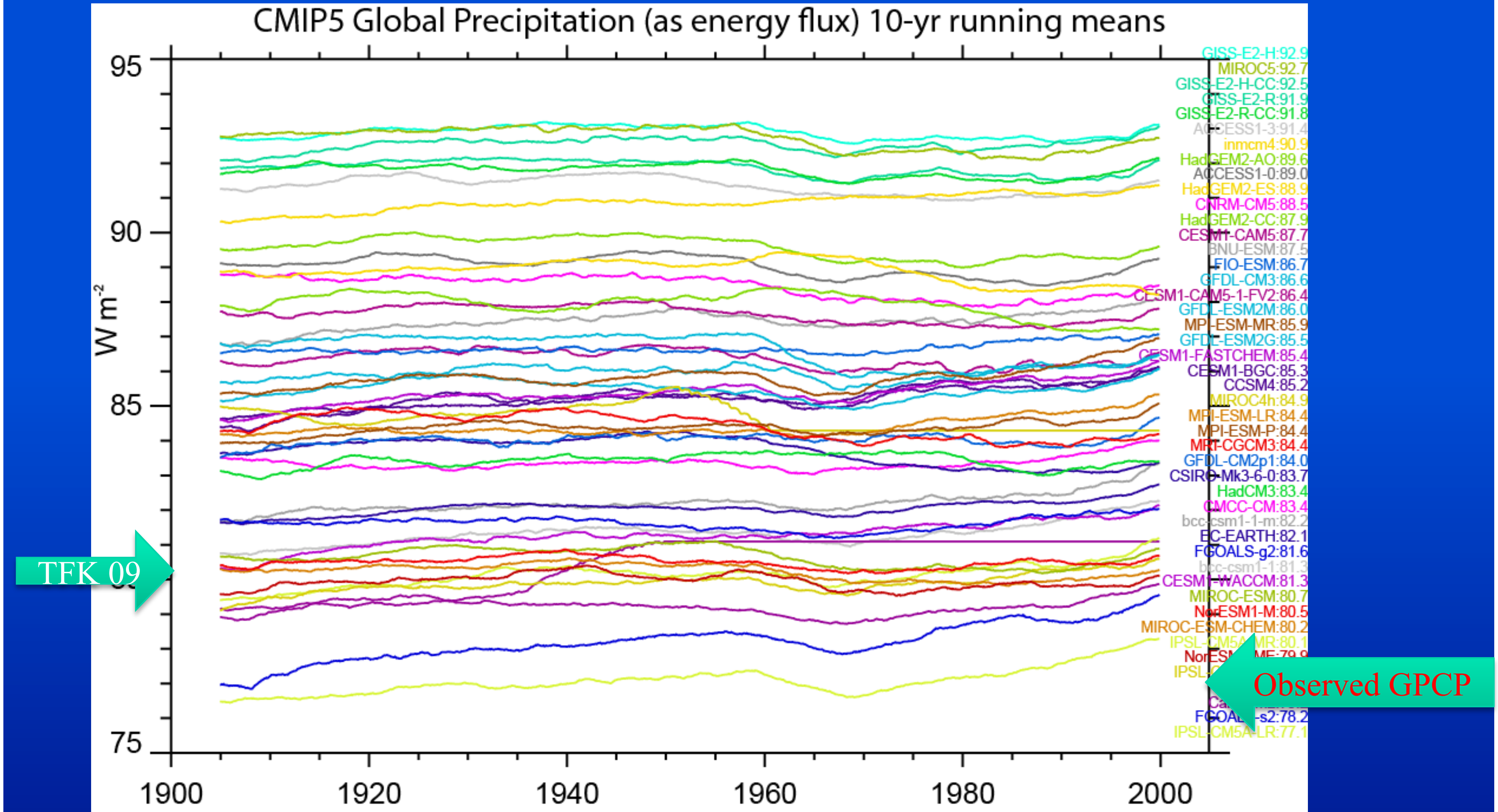
Global land precipitation



Differences in trends. It turns out these account for the main discrepancies among drought indices, not ET.

Courtesy A Dai

CMIP5 Precipitation



10-yr running means

A 22% spread! A major challenge.

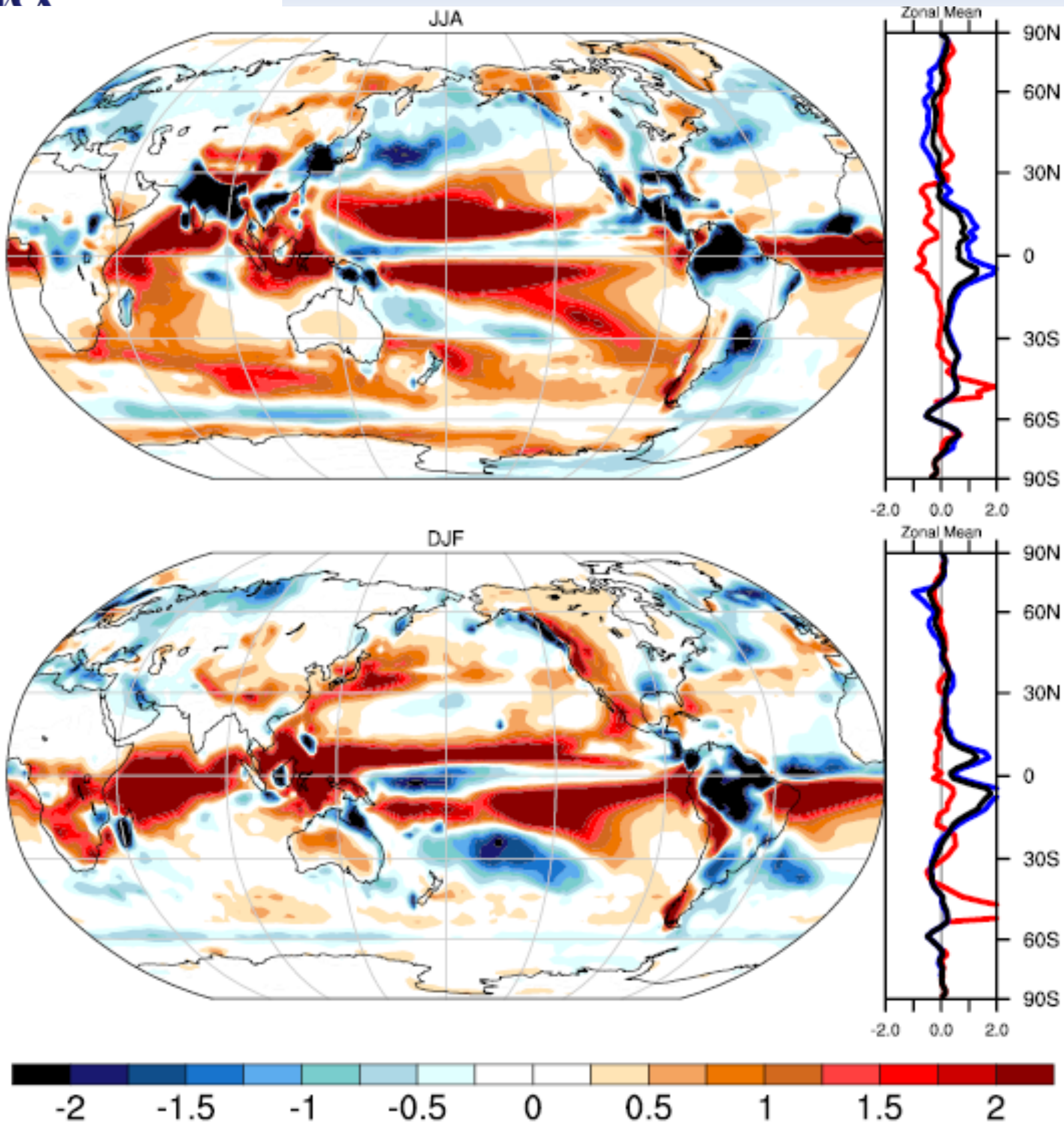
GDAP comments on Total Global Precipitation

- Estimated GPCP global climatology bias error is ~ 8%
- GPCC gauge analysis is adjusted upward for wind loss
- Snow is included over land (adjusted GPCC)
- Snow and light rain included over mid-high latitude ocean by use of TOVS/AIRS (Susskind) empirical relation—blend from passive microwave in low latitudes to TOVS/AIRS at higher latitudes—GPCP in middle/high latitude oceans tends to be higher than PMW estimates
- TRMM Composite Climatology (TCC) use TRMM V6 products approx match GPCP totals in deep tropics over ocean
- TRMM PR/Cloudsat comparisons by others indicate Cloudsat higher by ~5%, but were done with post-boost PR data.
- TCC and Japan colleagues use ~6% to adjust post-boost PR data to match means of pre-boost PR data

Adler et al 2012

GPM launch in 2014 will resolve most if not all of these issues

Errors in CMIP5: Mean bias



The main errors are in the tropics where TRMM gives good answers, and we know the models are not correct!

Note errors over Amazonia: not enough transport of moisture onto land in monsoons!

land
ocean
total

Precipitation in models:
"all models are wrong, some are useful"

A challenge:

Amount: distribution:
double ITCZ

Frequency: too often

Intensity: too low

Runoff: not correct

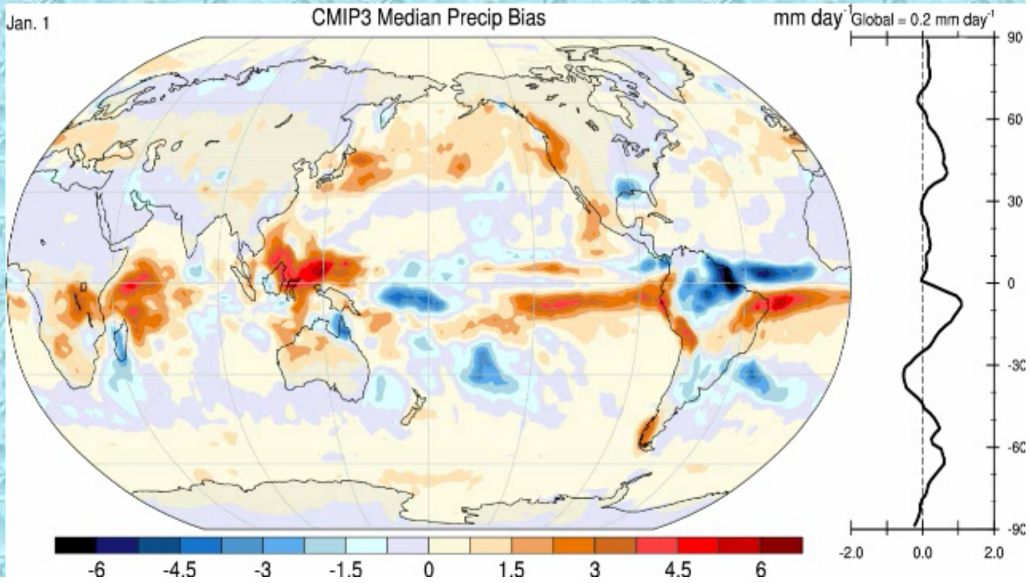
Recycling: too large

Diurnal cycle: poor

Lifetime: too short
(moisture)

Issues:

Tropical transients too weak
- Hurricanes
- MJOs
- Easterly waves
- MCCs

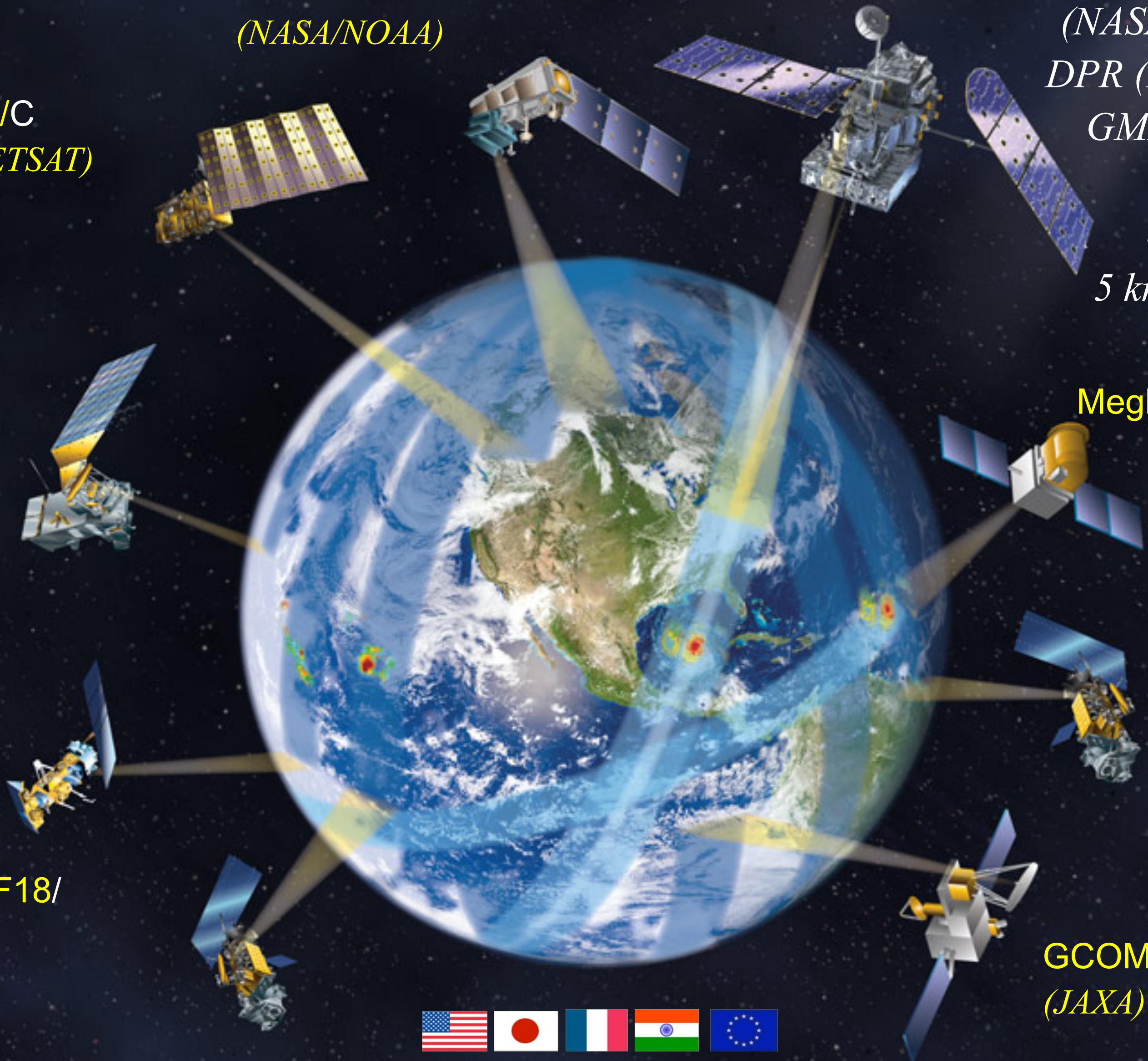


New observations:

Global Precipitation Mission: 3 hr sampling (2014)

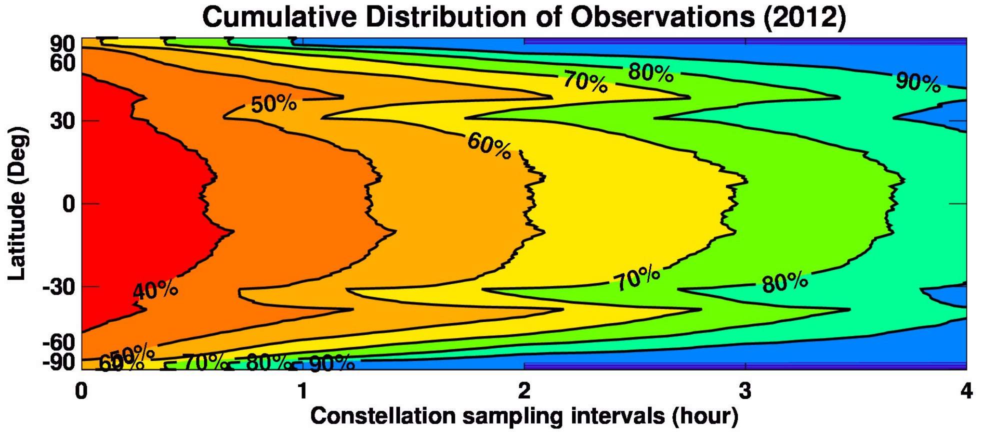
Cloudsat, Earthcare: clouds, aerosols (2015)

GPM Constellation Concept



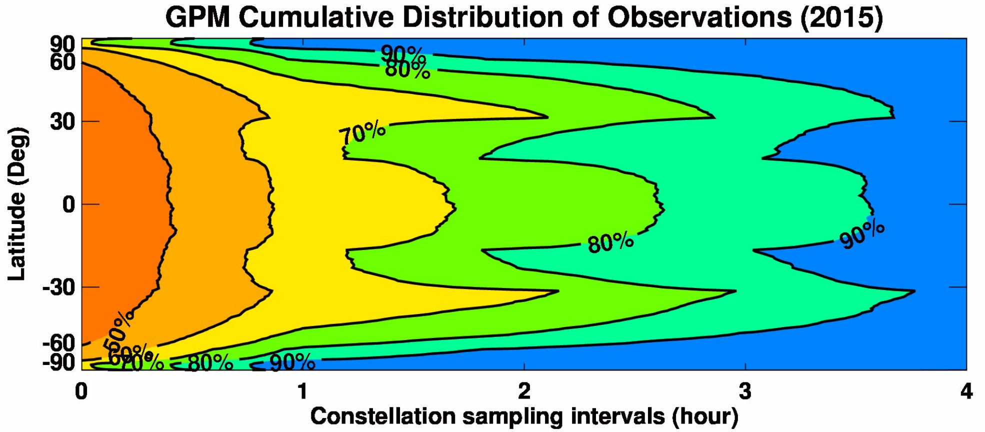
Next-Generation Unified Global Precipitation Products Using GPM Core Observatory as Reference

GPM Constellation Sampling Relative to Current Capability



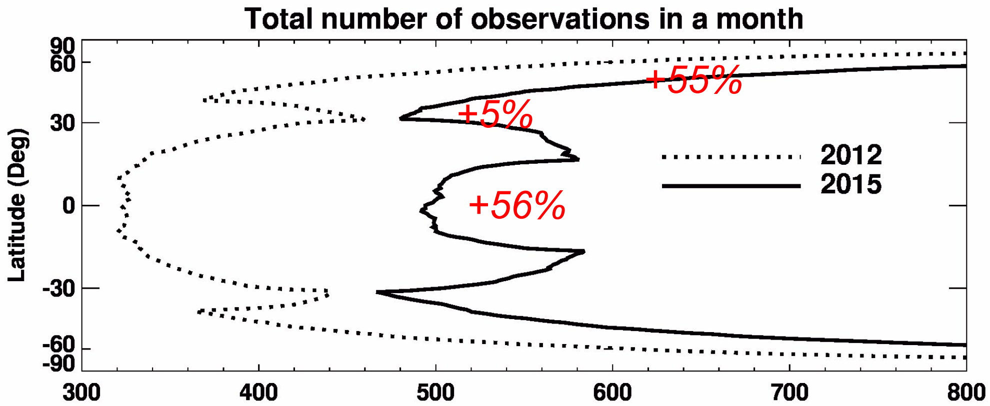
Current (2012)

- Less than 50% of observations are less than 1 hr apart
- 70-80% are less than 3 hr apart



GPM (2015)

- More than 60% of observations less than 1 hr apart
- 80-90% are less than 3 hrs apart at all latitudes



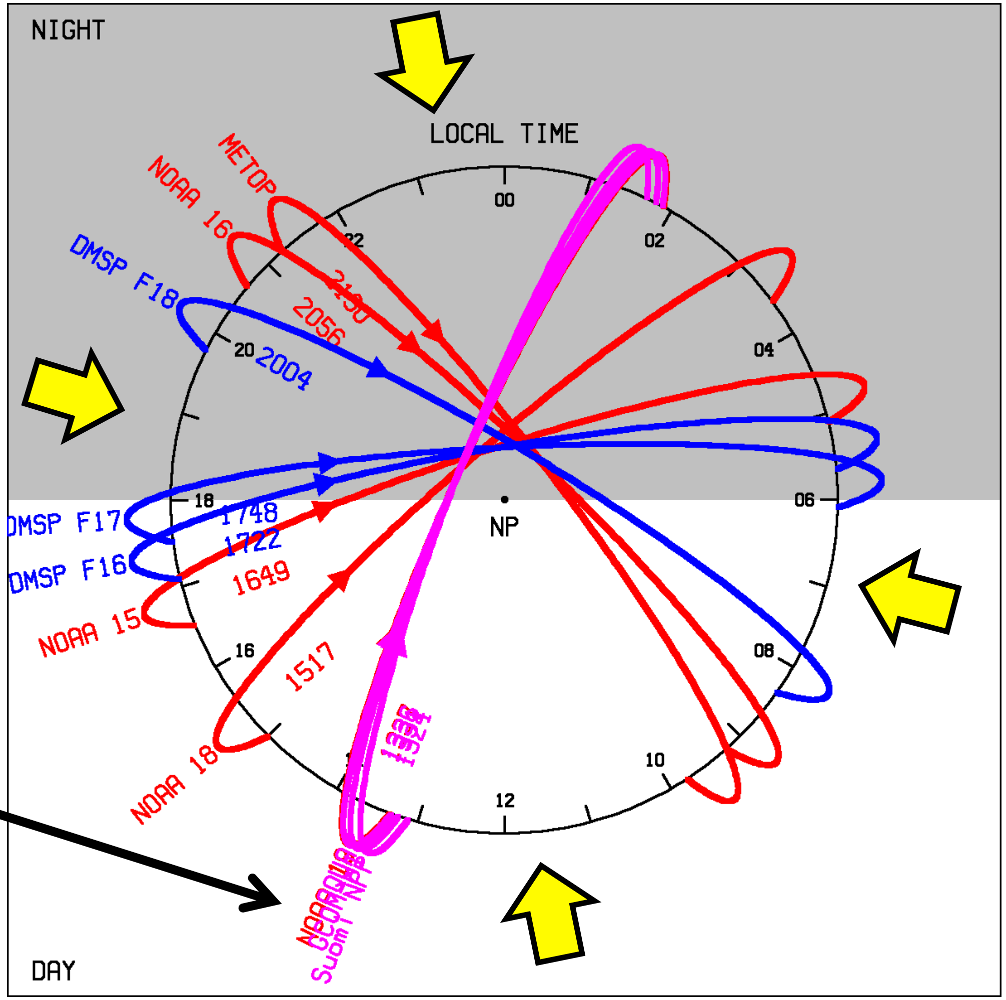
- Greater number of observations relative to 2012

2012: TRMM, F16, F17, F18, NOAA-18, NOAA-19, MetOp-A

2015: GPM Core, F17, F18, F19, MT, GCOM-W1, NPP, NOAA-18, NOAA-19, MetOp-B

Stan Kidder

Current Water-Cycle Satellites



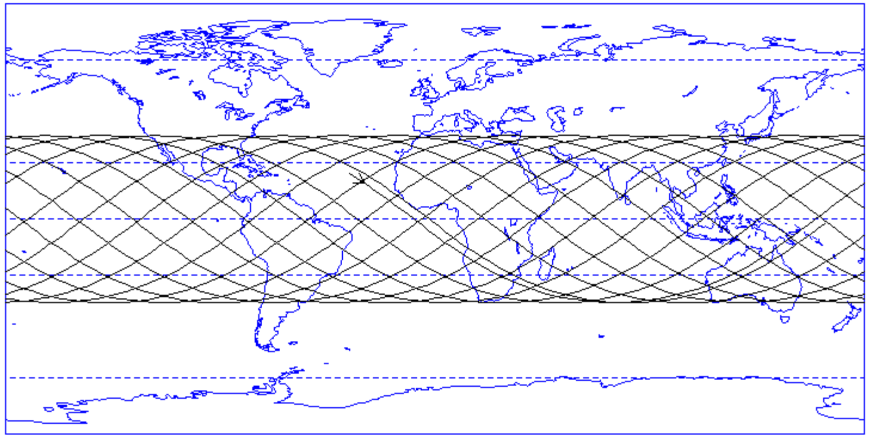
Gaps

Traffic Jam at 1330
Aqua
NOAA 19
Suomi NPP
GCOM-W1

Non-Sun-synchronous Satellites

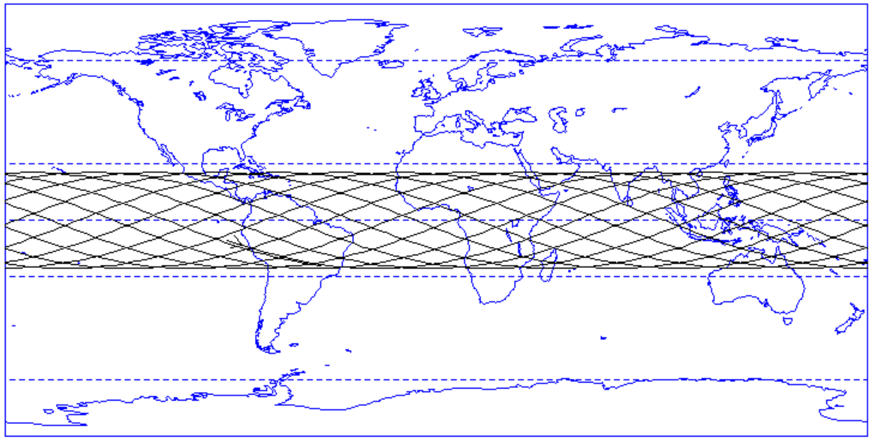
GLOBAL PRECIPITATION MEASUREMENT

TRMM



Inclination = 35°

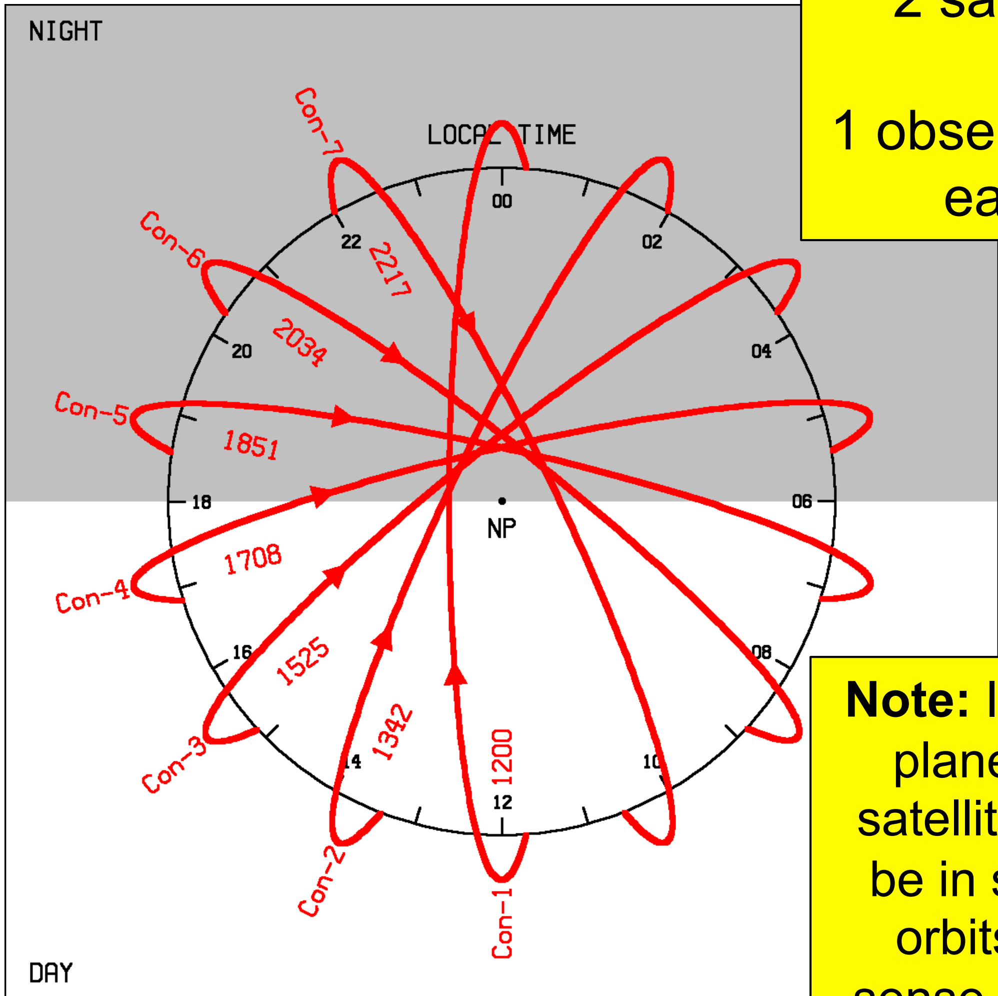
Megha-Tropiques



Inclination = 20°

Important, but still only two observations per day

Regularly Spaced Constellation



7 orbital planes
2 satellites per plane

1 observation everywhere each 50 minutes

Note: If regularly spaced planes are used, the satellites do not have to be in sun synchronous orbits, just ones that sense the polar regions.

Workshop on GSQ 1:

Fort Collins (host Kummerow)

June 27-28, 2013

- Format: 4 half day sessions
- 2 presentations each session
- discussion w moderator and rapporteur
- Feature topic in joint GDAP/GHP Sept mtg in Rio
- Feature topic at GEWEX Science Conference:
  - Sessions to be convened
- Role of panels? WGs?
- Is there an exec. group in charge? Who?
- Written report on recommendations

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Workshop on GSQ 1:

Fort Collins (host Kummerow)
June 27-28, 2013

- 1A: How well can precipitation probability distributions and accumulations be described by various observing systems, what defines the uncertainty estimates at various space and time scales and how can it be improved in the future? Y. Takayabu, P. O'Gorman, (Adler, Zolina)
- 1B: How can observations of water and energy related quantities be used to better understand relationships among these variables and how they influence observed precipitation at various scales? B. Wielicki, R. Roca, (Levizani, Loeb)
- 1C: How much confidence do we have in the physics of models used to predict long-term climate changes in precipitation and what metrics can be applied to track progress in the model representations of precipitation physics? R. Leung, J. Backmeister, (Moncrieff, Carbone)
- 1D: What is the role of data assimilation in bridging the gap between observations and models and how can we advance diagnostic methods that can deal more directly with the physics and parameterization of convection - and what planned and new observing systems could improve knowledge going forward? M. Bosilovich, G. Stephens, (vonder Haar; Seneviratne)

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Global Water Resource Systems -GSQ 2

- How do changes in the 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?

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GEWEX Science Questions:
Global water resources

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

- *Address terrestrial water storage changes*
- ***Close the water budget over land***
- *Exploit new datasets, data assimilation, improved physical understanding and modeling skill across scales,*
- *Catchments to regional to global to the entire hydrological cycle including hydrogeological aspects of ground water recharge.*
- *Use of **realistic land surface** complexity with all anthropogenic effects included instead of a fictitious natural environment.*
- *Includes all aspects of **global change:** water management, land use change and urbanization; water quality and especially water temperature (affected by industrial and power plants use); later nutrients.   cont…*

GEWEX Science Questions:
Global water resources

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

- *The* ***ecosystem response*** *to climate variability and responsive vegetation must be included.*
- *Cryospheric changes such as permafrost thawing and changes in mountain glaciers must be included.*
- *Feedbacks, tipping points, and extremes are of particular concern.*

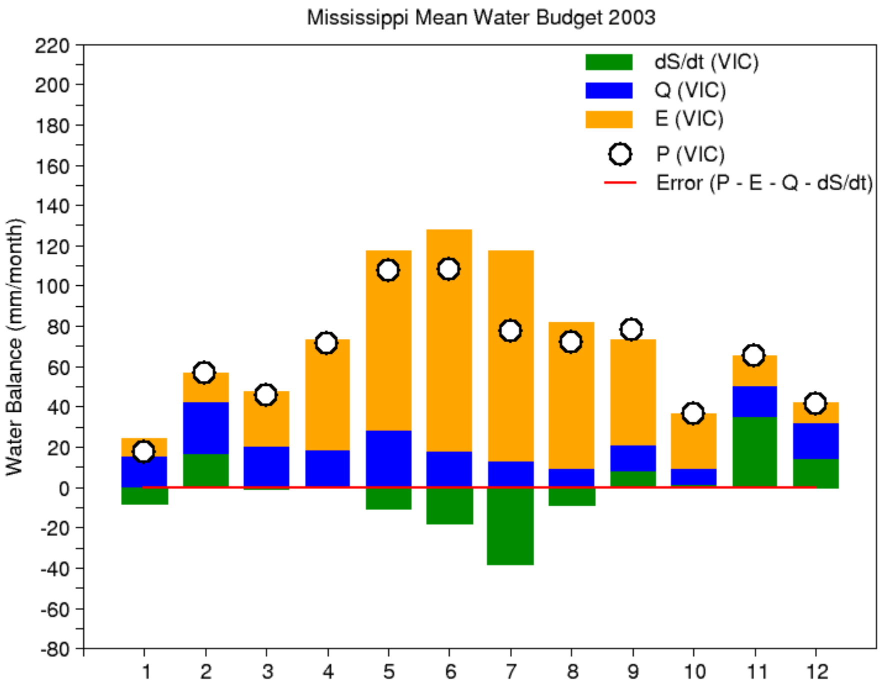
The results should enhance the evaluation of the vulnerability of water systems, especially to extremes, which are vital for considerations of water security and can be used to increase resilience through good management and governance.

A challenge for Hydrology:

Creating Climate Data Records for the terrestrial water budget using in-situ, remote sensing observations and LSM?

$$\frac{dS}{dt} = P - ET - Q$$

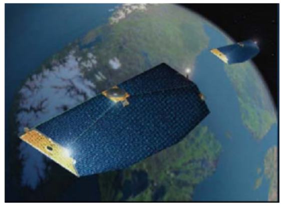
What the budget should look like?
(from off-line modeling, forced closure)



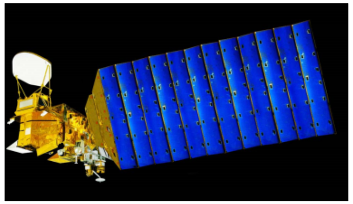
EGU 2010, HS4.8, 10234, 11:45am, May 5

Potential Remote Sensing Datasets

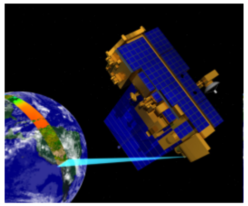
dS/dt from GRACE



ET from
SRB/ISCCP → LandFlux



P from TRMM/CMORPH
PERSIANN → GPM



Q from
TOPEX/POSEIDON/JASON
→ SWOT

Courtesy Eric Wood

Potential global water cycle data sources

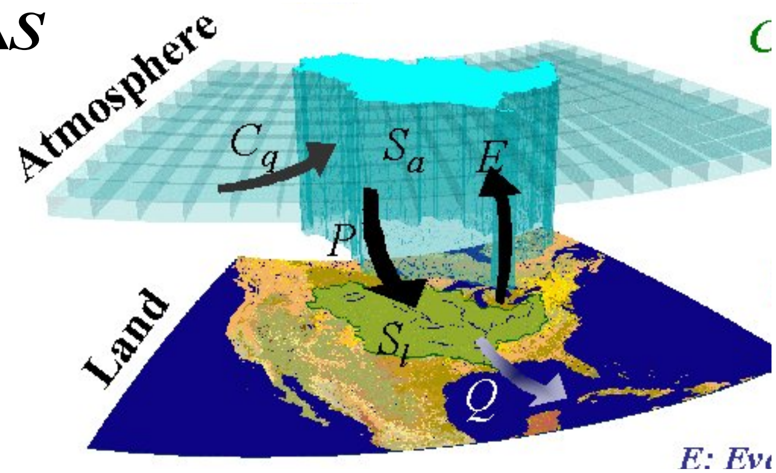
Variable/Source		Type	Period	Resolution	Reference
p	CPC	In-situ	1950-	1º	Chen et al., 2002
	CRU	In-situ	1901-	0.5º	Mitchell & Jones, 2005
	WM	In-situ	1900-	0.5º	Willmott & Matsuura, 2010
	GPCC	In-situ	1900-	0.5º	Schneider et al., 2008
	GPCP/TMPA	RS/in-situ	1998-	0.25º-1º	Huffman et al
e	ET (LandFlux) (4 algorithms)	RS	1984-2006	1º	Vinukollu et al., 2010; Ershadi etal., 2013
	ERA-Interim	Reanalysis	1989-	T255	Dee et al., 2011
	MPI	In-situ	1989-	T255	Jung et al (2009)
	VIC	LSM	1948-	1/2ºx1/3º	Sheffield &Wood, 2007
q	GRDC	In-situ	1900-	basin	GRDC, 2010
	VIC	LSM	1948-	1º	Sheffield &Wood, 2007
Δs	GRACE	RS	2002-	basin	Swenson &Wahr, 2002
	VIC	LSM	1948-	1º	Sheffield et al., 2008

Courtesy Eric Wood

Making the products consistent

Closing the water budget

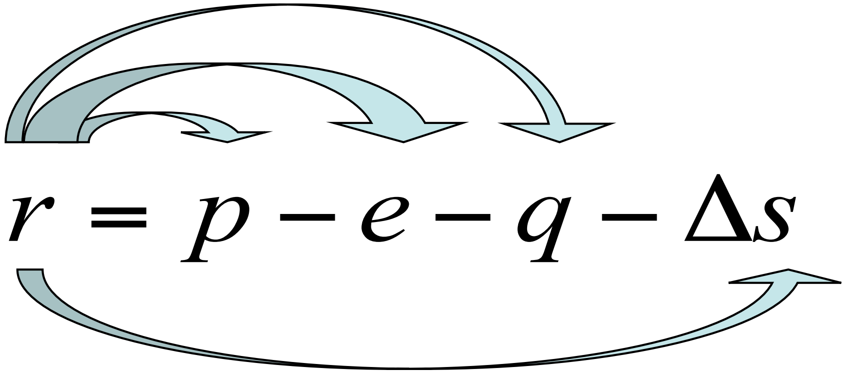
The closed water budget: $p = e + q + \Delta s$



Various errors lead to an unclosed budget with a residue term:

$$r = p - e - q - \Delta s$$

Force closure by redistributing the residue?



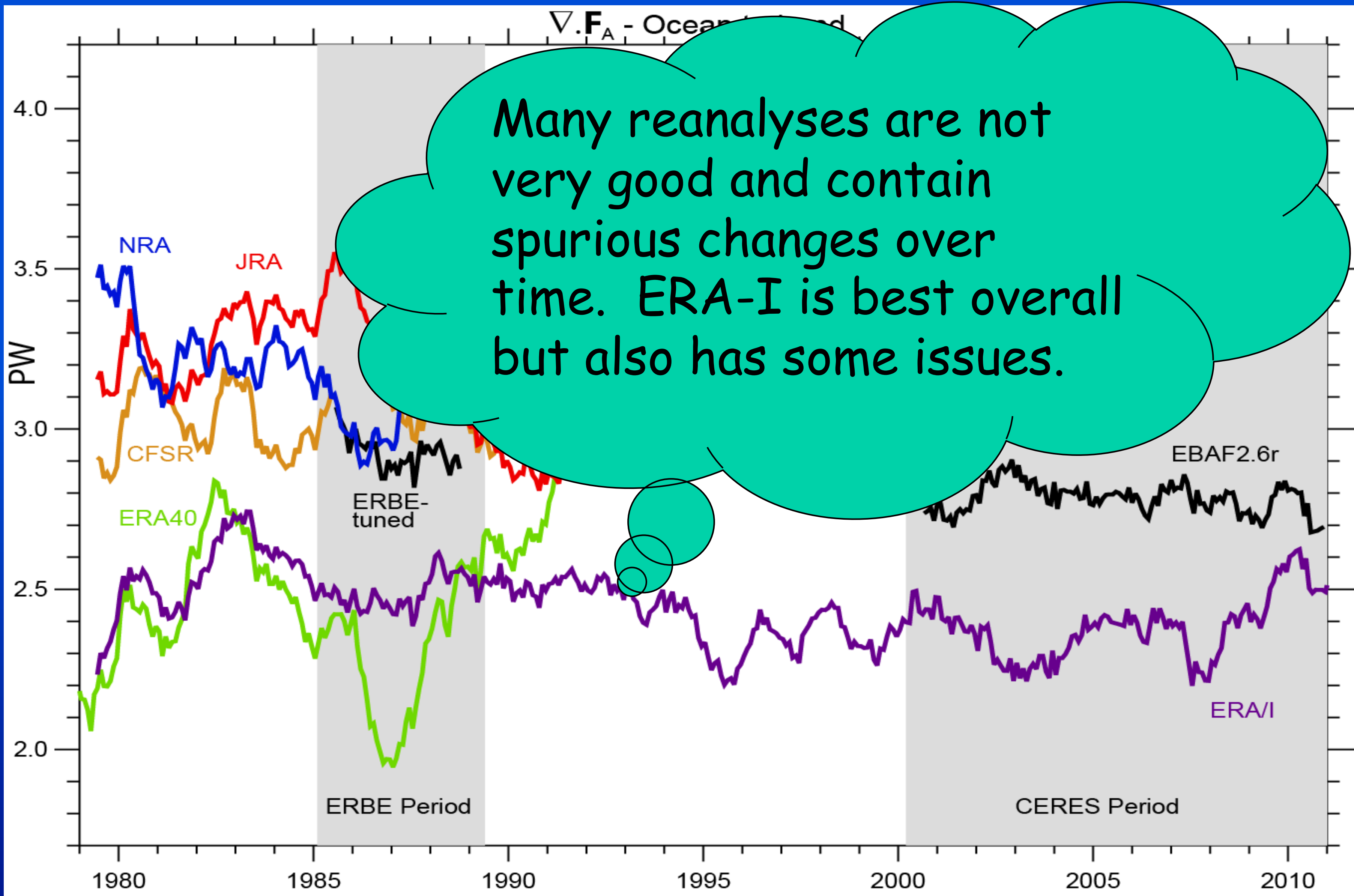
$$r = p - e - q - \Delta s$$

HOW? The Princeton group does this by estimating the errors for each term and passing the estimates through a Kalman filter where the closure constraint is introduced as an error free observation.

Courtesy Eric Wood

Transport of energy: Ocean to land

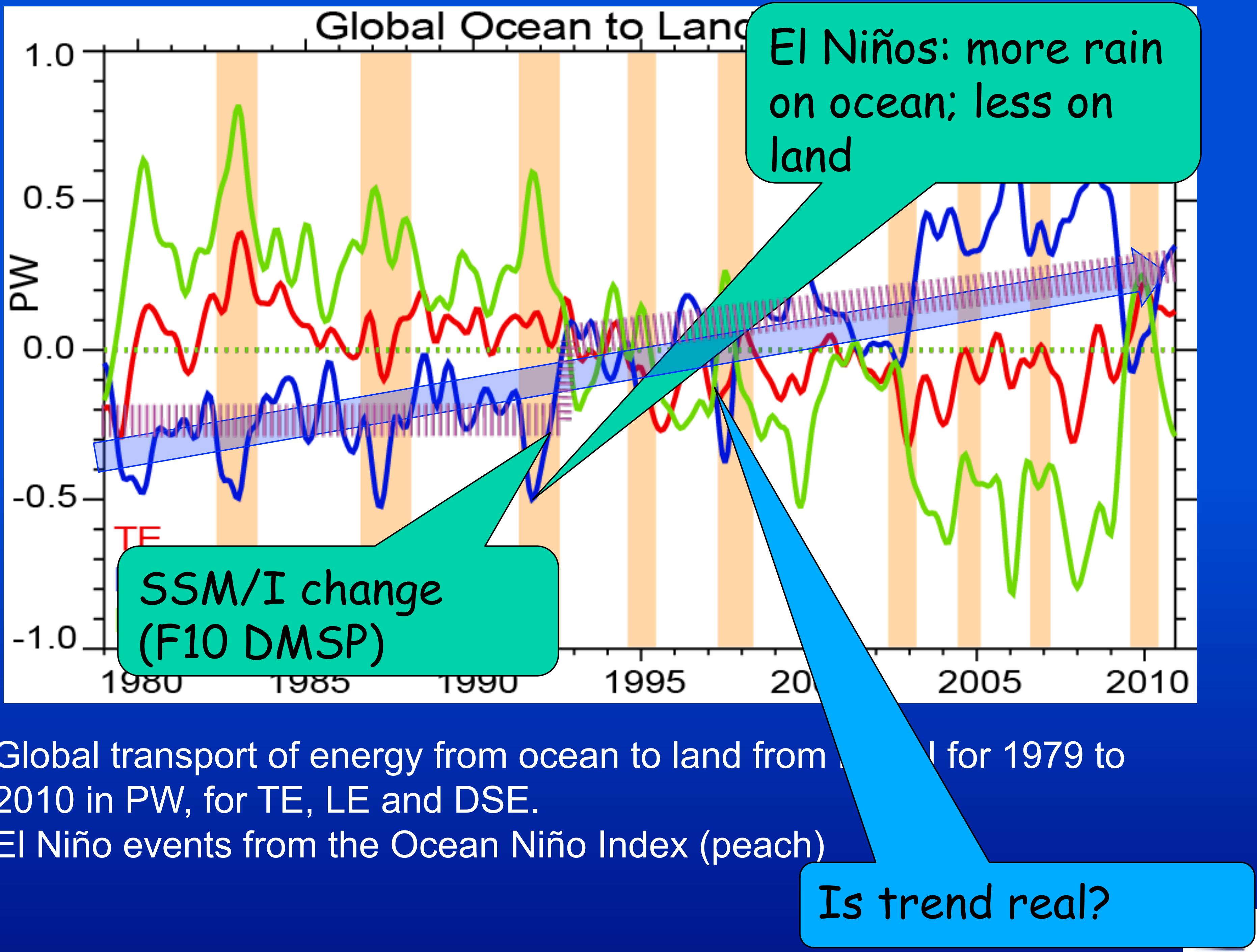
Global PW



-3.9
5.7
-6.5
-3.7
-0.8

Many reanalyses are not very good and contain spurious changes over time. ERA-I is best overall but also has some issues.

Trenberth et al 2013



Global transport of energy from ocean to land from ... I for 1979 to 2010 in PW, for TE, LE and DSE.
El Niño events from the Ocean Niño Index (peach)

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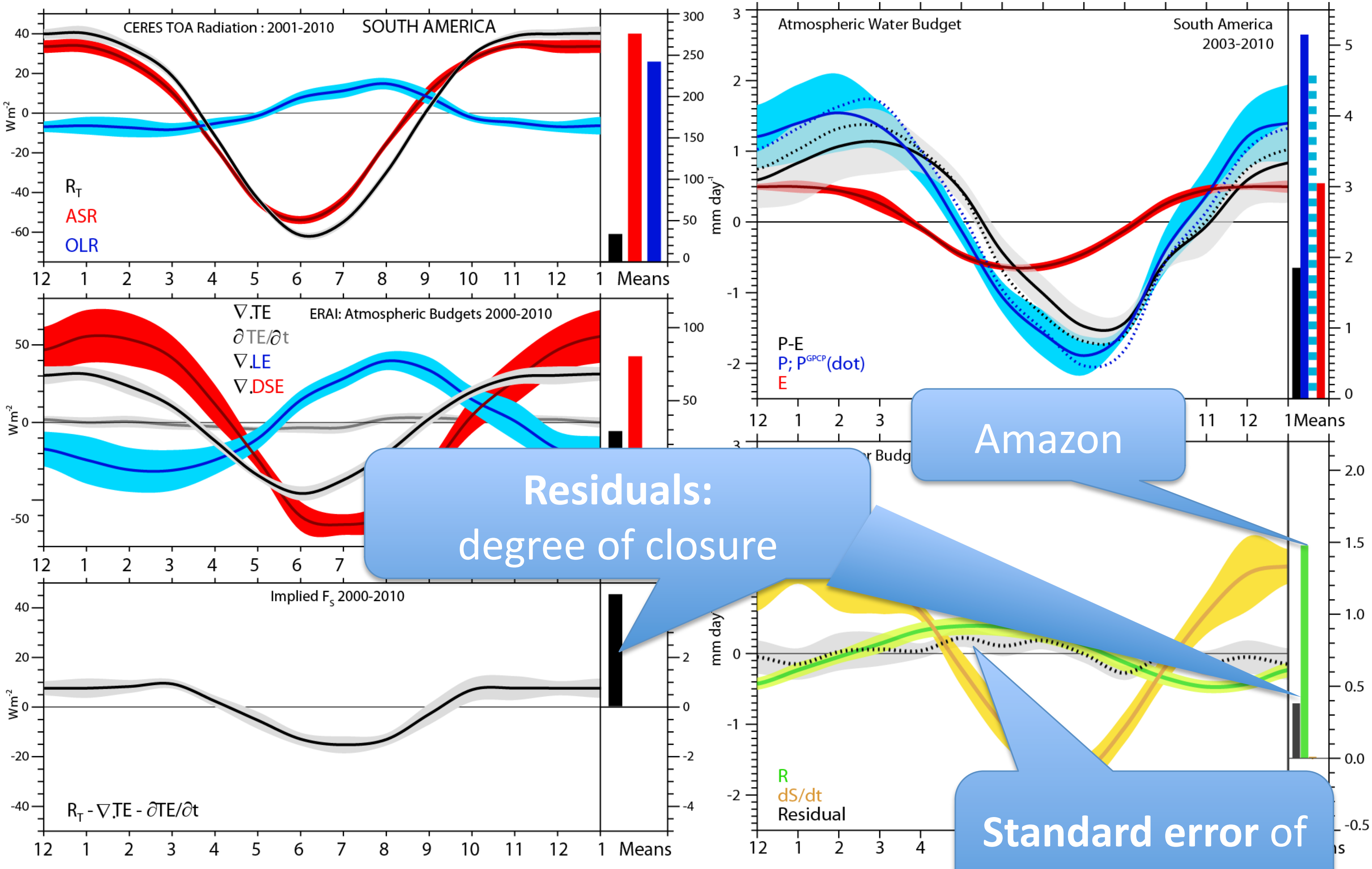
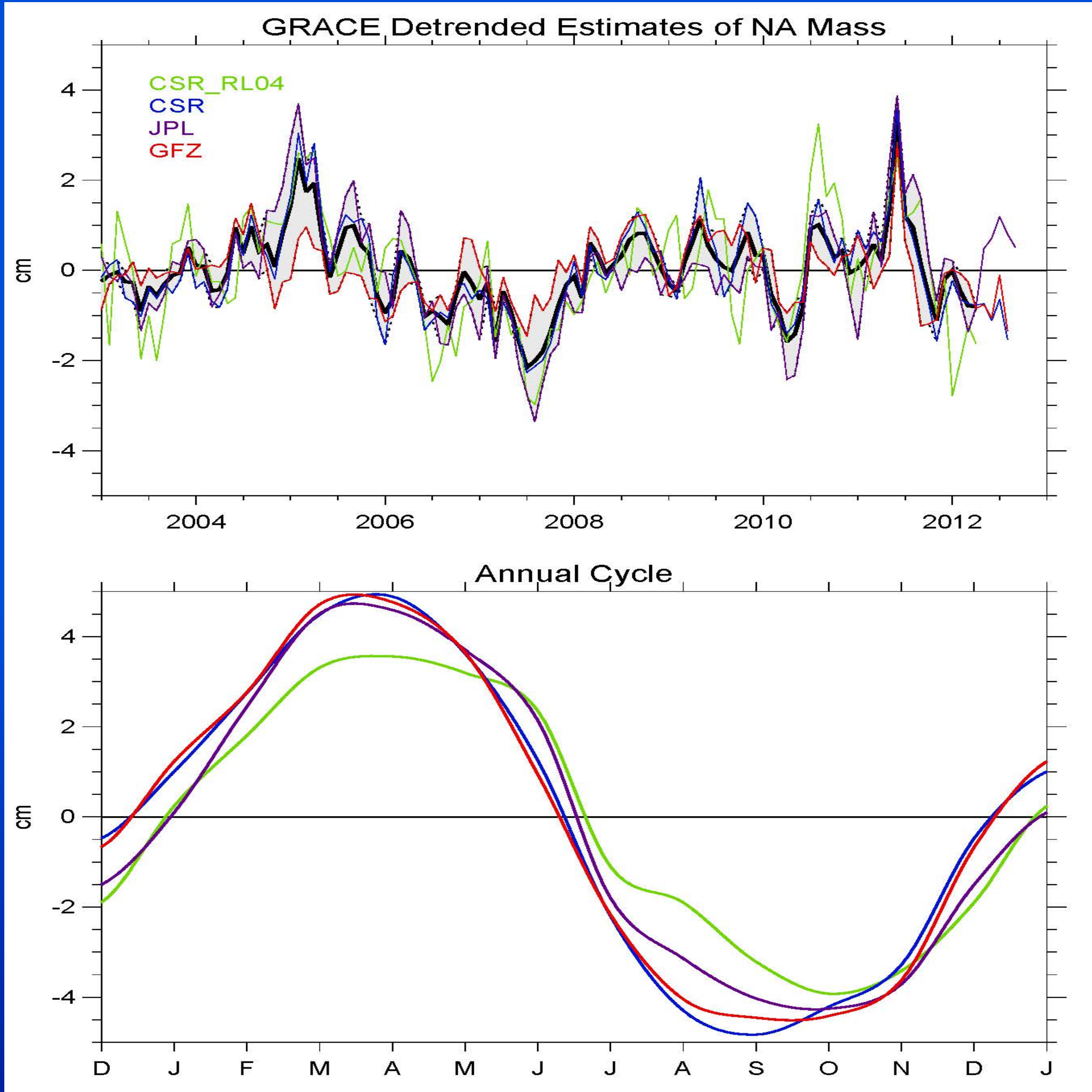
Regional energy and water budgets

1 sigma error bars included based on interannual variability

Energy South America Water



Huge annual cycle of moisture convergenc



GRACE surface mass anomalies for North America;

top: detrended with a 5 year running mean and annual cycle removed, and smoothed (1-3-4-3-1) to show interannual variability for 4 datasets,

bottom: the mean annual cycle for 2003-11.

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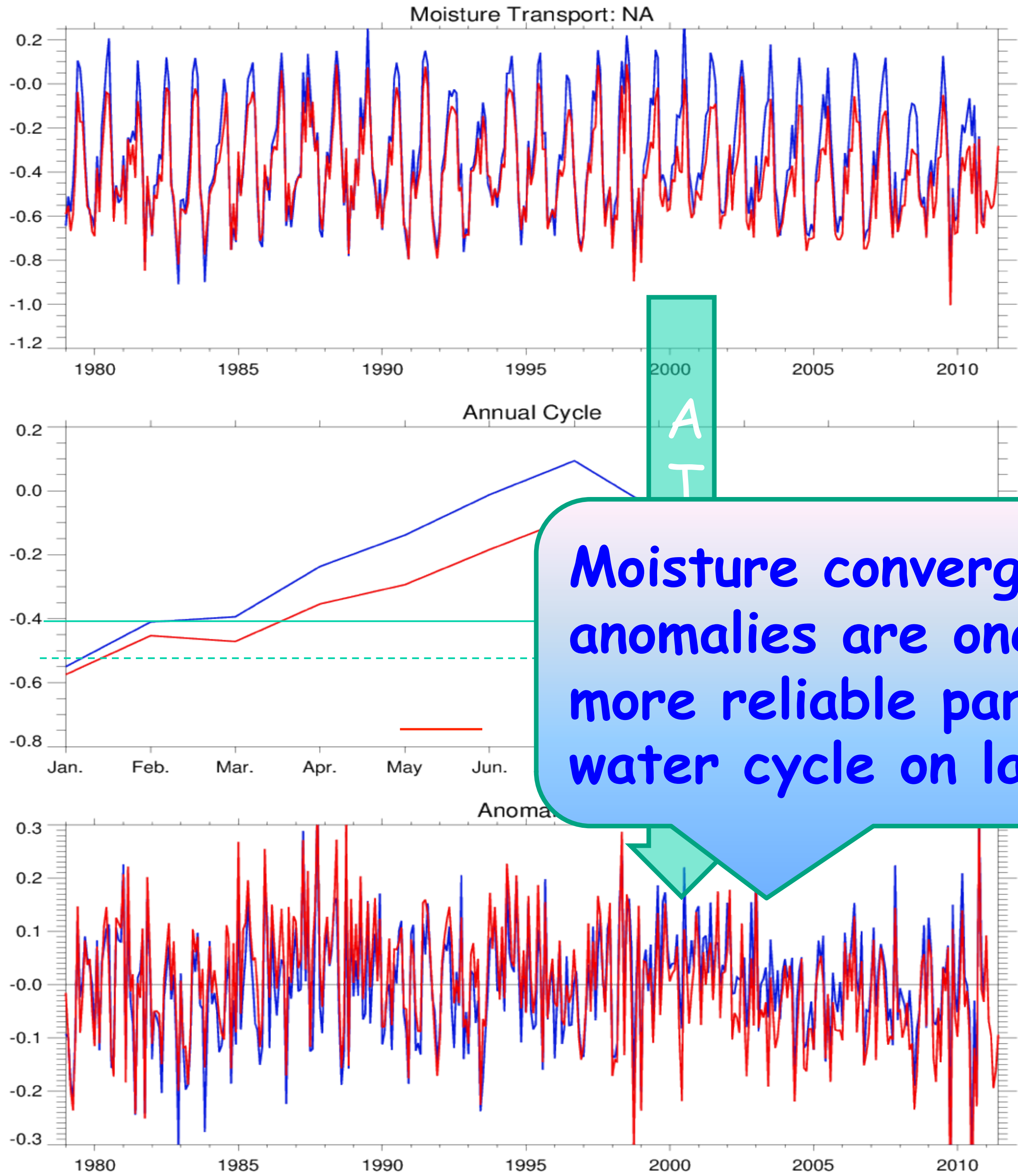
1979-2010
means

0.1 Eg/mo=
0.163 mm/
day
N Am



MERRA
ERA-I

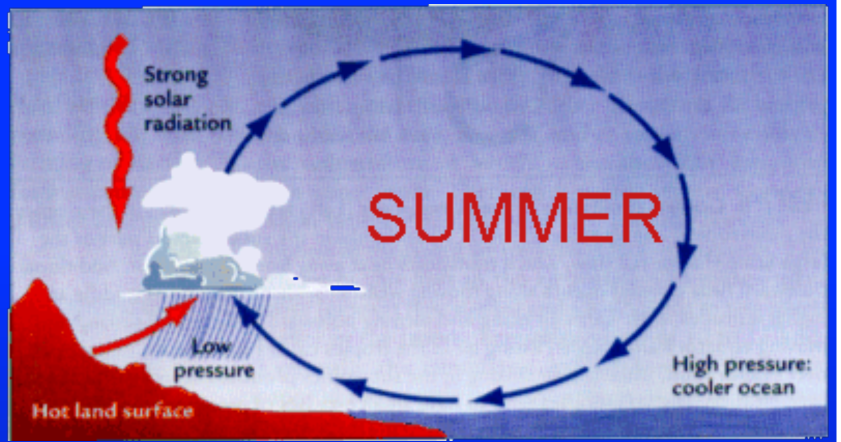
Annual mean
02-08 1990s

Moisture convergence anomalies are one of the more reliable parts of the water cycle on land.

Transport of energy from ocean to land

1) NH winter: strong westerlies transport heat and moisture from ocean to land: maritime vs continental climates

2) Summer Monsoons: transport moisture (LE) from ocean to land but transport heat (DSE) from land to ocean as part of monsoon overturning => large compensation



3) Overall there is a transport of moisture from ocean to land as part of the hydrological cycle

4) Land is warmer in summer but cooler in winter: large annual cycle in DSE transports

Observing the terrestrial water cycle from space:

cycle

od:

HYDROLOGICAL PROCESSES
Hydrol. Process. **25**, 3993–4010 (2011)
Published online 14 December 2011 in Wiley Online Library
(wileyonlinelibrary.com) DOI: 10.1002/hyp.8393

Mu
evapotran

Raghuveer
[1] *Depart*

Estimating evapotrans
at the earth's surface a
evaluations of global
indicate large uncertai

Remote Sensing of Environment 115 (2011) 1850–1865

Contents lists available at ScienceDirect

Remote Sensing of Environment

journal homepage: www.elsevier.com/locate/rse

ELSEVIER

Reconciling the global terrestrial water budget using satellite remote sensing

Alok K. Sahoo *, Ming Pan, Tara J. Troy, Raghuveer K. Vinukollu, Justin Sheffield, Eric F. Wood

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1 MAY 2012 PAN ET AL. 3191

Multisource Estimation of Long-Term Terrestrial Water Budget for Major Global River Basins

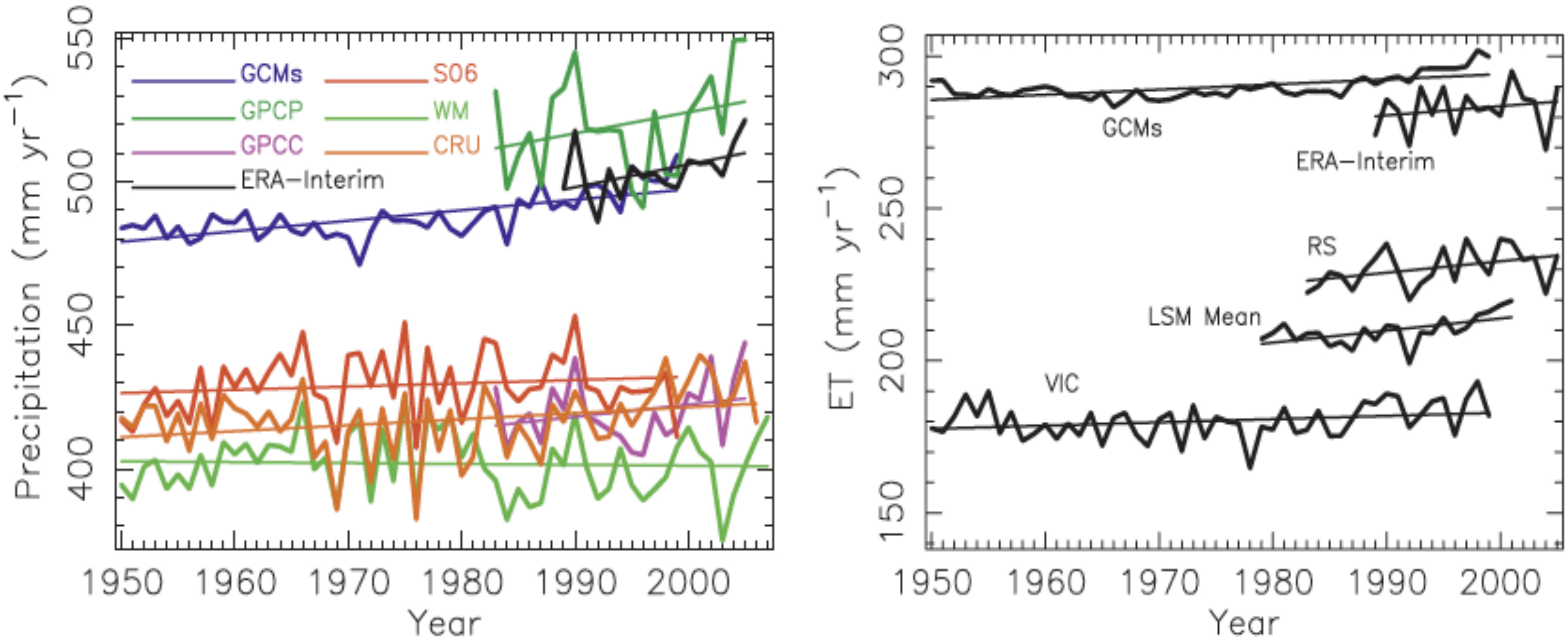
MING PAN, ALOK K. SAHOO, TARA J. TROY, RAGHUVEER K. VINUKOLLU,
JUSTIN SHEFFIELD, AND ERIC F. WOOD

Department of Civil and Environmental Engineering, Princeton University, Princeton, New Jersey

Courtesy Eric Wood

Determining the water cycle in the pan-Arctic

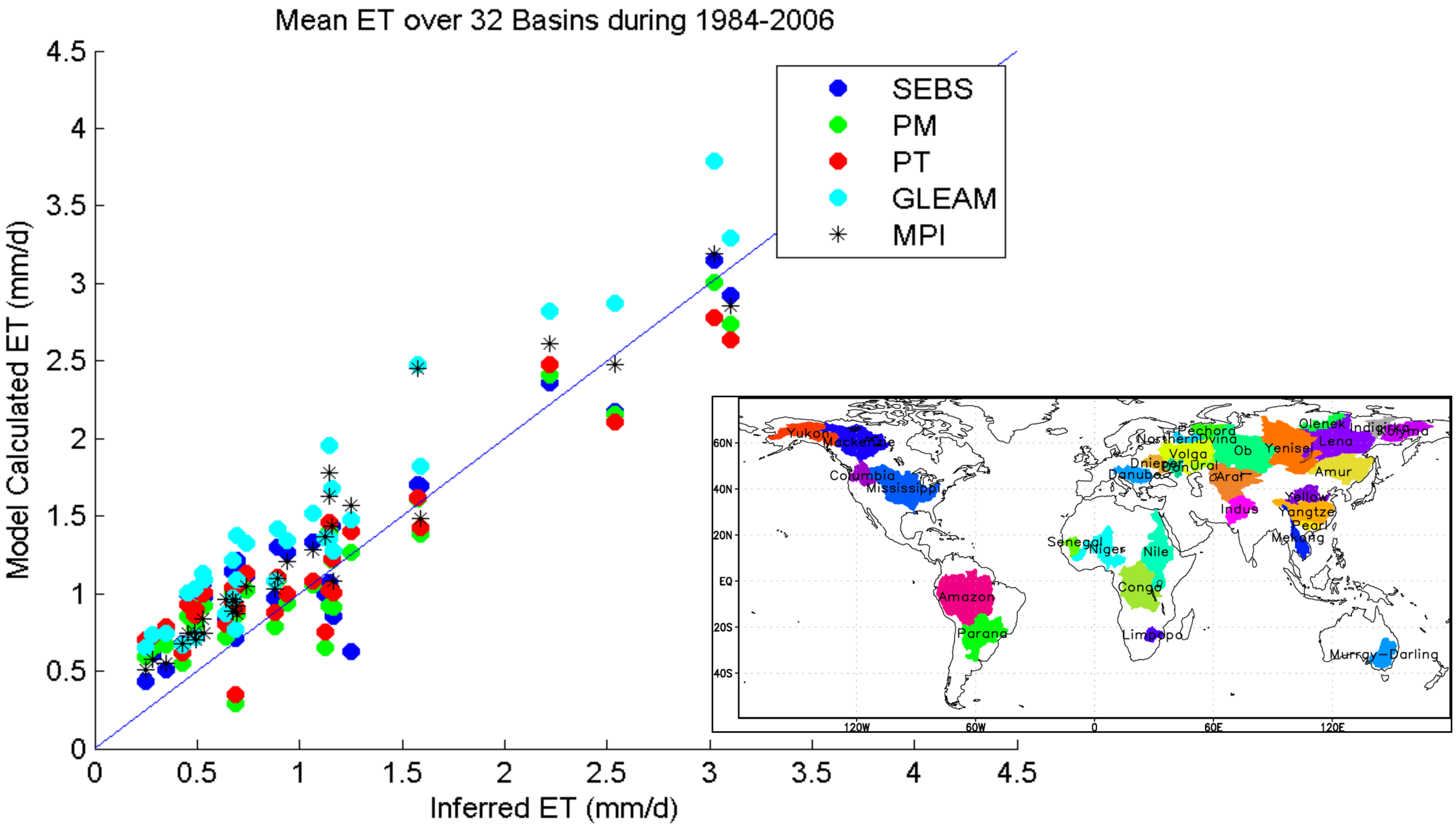
Estimates of water cycle variables over the pan-Arctic from observations, coupled GCMs, uncoupled LSMs, and remote sensing vary widely.



(from Rawlins, et al. 2010 , *J Climate* 23(21): 5715–5737)

Courtesy Eric Wood

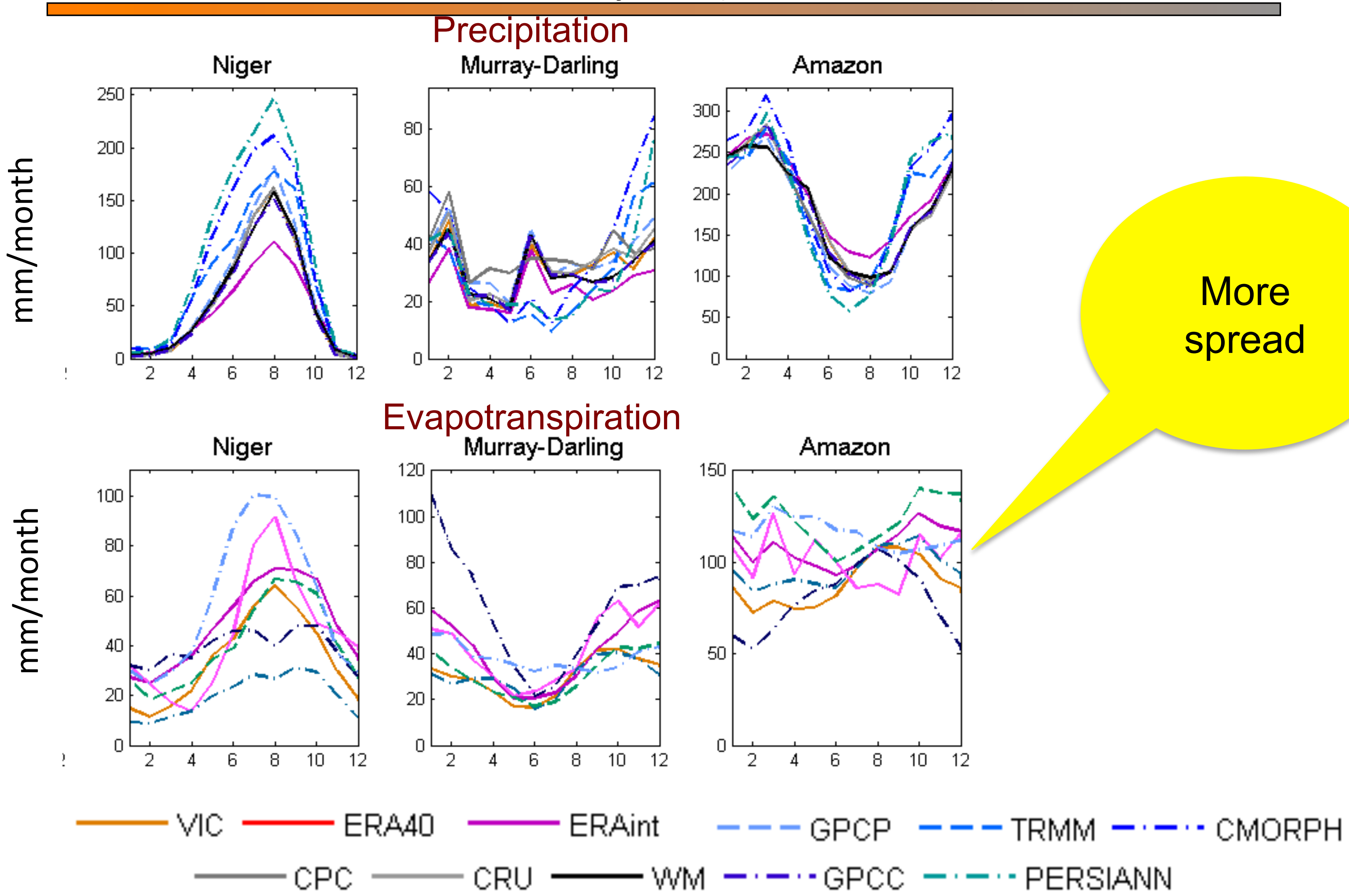
Product validation using basin budgets
Long-term estimates of evapotranspiration (LandFlux)



Inferred ET (mm/d) from basin budget analysis ($ET = P_{obs} - Q_{obs}$)

Courtesy Eric Wood

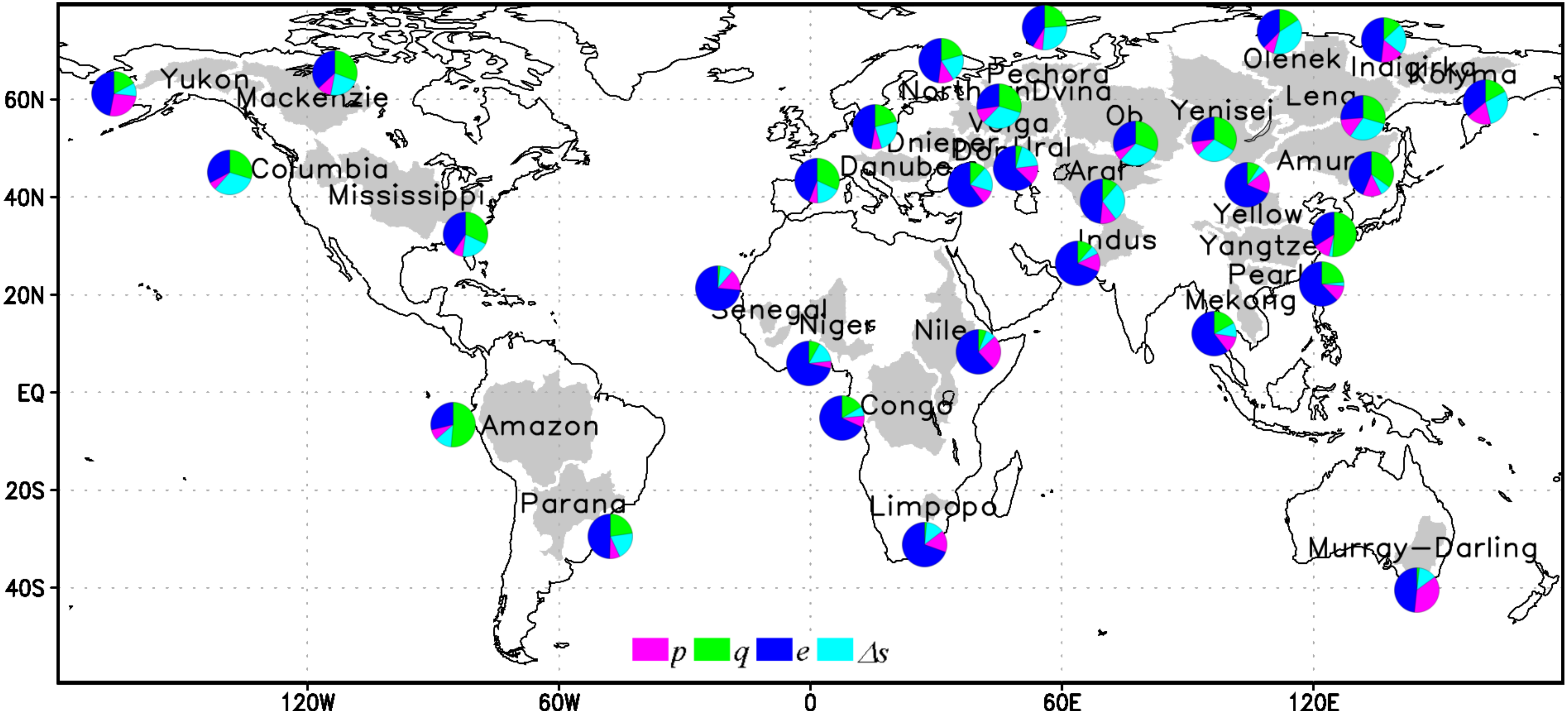
Challenge #1: Product consistency
Seasonal Cycle (w/ Satellite)



More spread

Courtesy Eric Wood

Mean Imbalance attribution

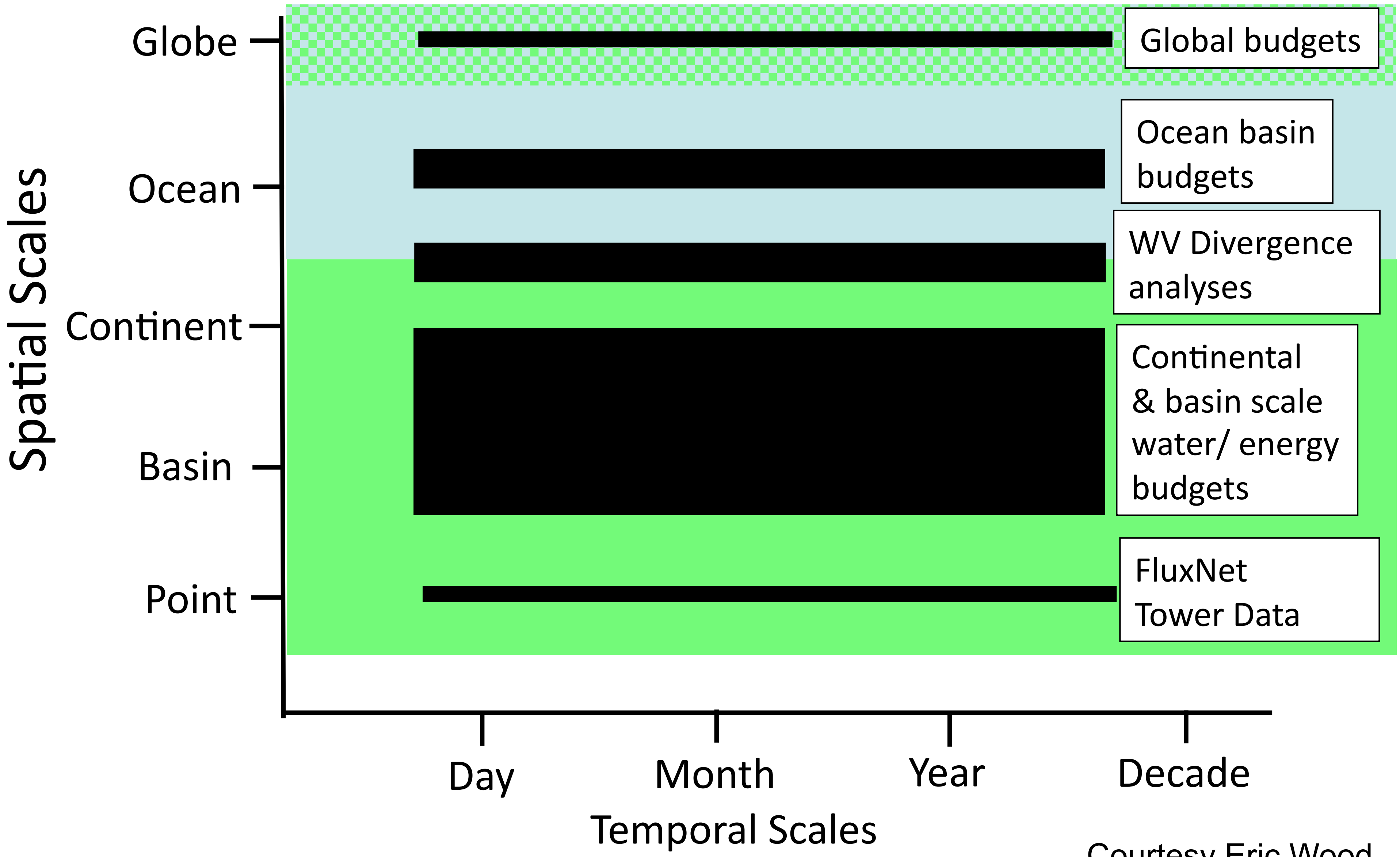


ET biggest uncertainty

Courtesy Eric Wood

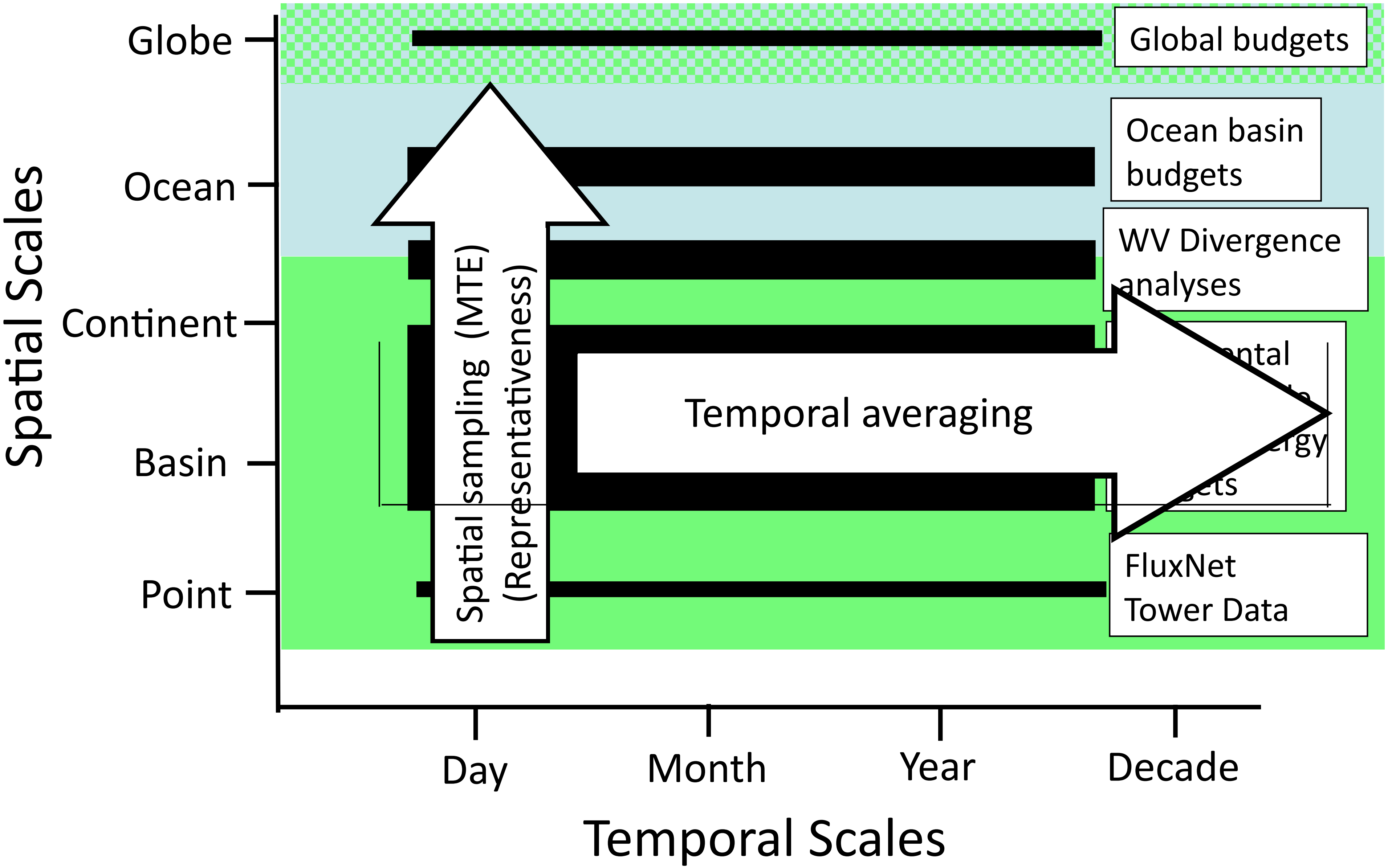
Challenge #2: Water and Energy Cycle Product Validation

What are the statistical issues and approaches available for assessing various water and energy cycle products, and their uncertainty?



Courtesy Eric Wood

Product validation: Some statistical issues



Courtesy Eric Wood

2013 European Geophysical Union • Vienna, Austria • EGU2013-6439




Global products of evapotranspiration: the GEWEX LandFLUX Initiative

KING ABDULLAH UNIVERSITY OF SCIENCE AND TECHNOLOGY, SAUDI ARABIA

Matthew McCabe[1], Ali Ershadi[2], Eric Wood[3], Nathaniel Chaney[3], Carlos Jimenez[4], Diego Miralles[5], Brigitte Mueller[6] and Sonia Seneviratne[6]

[1] King Abdullah University of Science and Technology, Saudi Arabia
[2] University of New South Wales, Australia
[3] Princeton University, United States of America
[4] Observatoire de Paris, France,
[5] University of Bristol, United Kingdom
[6] ETH Zurich, Switzerland

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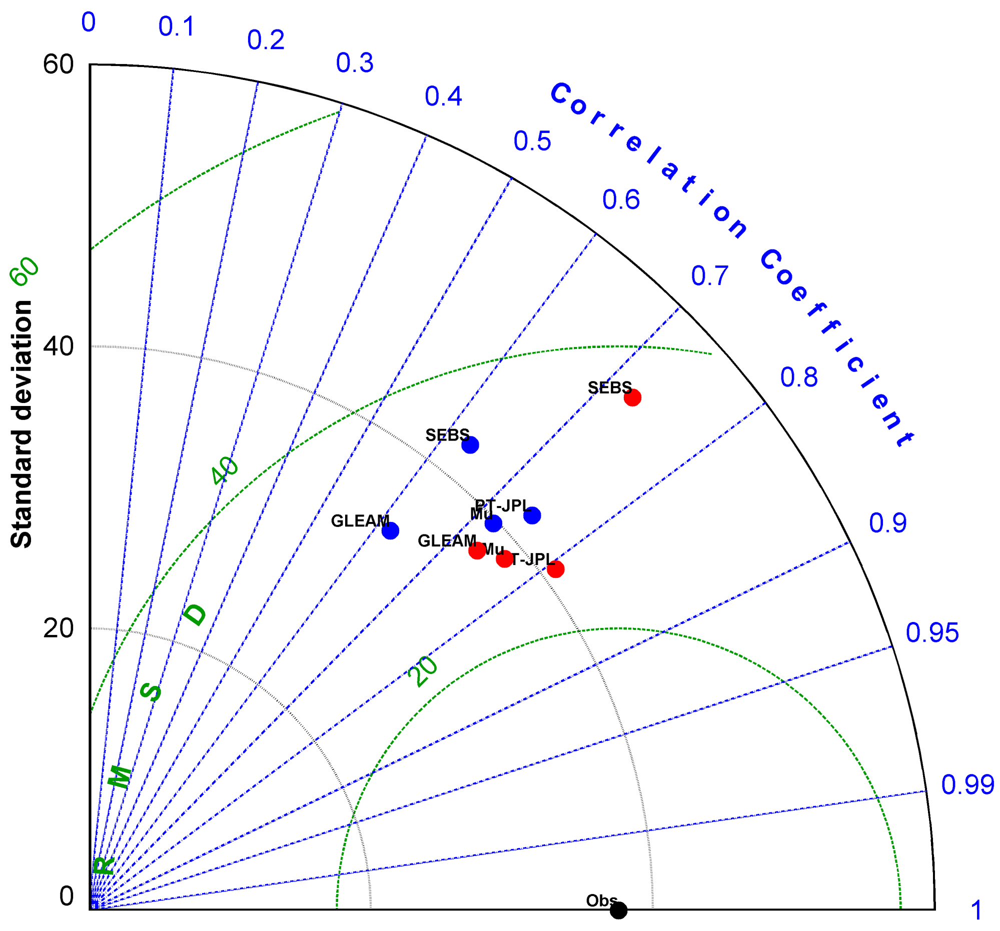
للعلوم والتقنية
King Abdullah University of Science and Technology

To what extent are FluxNet towers sufficient for global validation?

Daily



red = tower-based results, blue = grid-based results

Daily and monthly flux tower data have been developed for evaluation purposes. Landflux project under GDAP

Challenge #3 Using the products for assessing climate change

Relevant research questions raised by GEWEX and relevant to Climate Data Record programs

1. What are the magnitudes and consistency of trends in specific water cycle variables?
2. Given current trends in each water cycle variables, can we assess (statistically) if change has occurred, or if not, how long until detection (assuming the trend remains constant)?
3. Can these results be used to say how the terrestrial hydrological cycle is changing?

Courtesy Eric Wood

New observations:

Global Precipitation Mission: 3 hr sampling (2014)
Cloudsat, Earthcare: clouds, aerosols (2015)
GRACE: mass
SMOS: soil moisture, salinity
SMAP: soil moisture, freeze/thaw cycle (Nov 2014)
Aquarius: salinity (sfc)
Argo floats: salinity (3D)
Radar; in situ
Flux towers

New products and datasets:

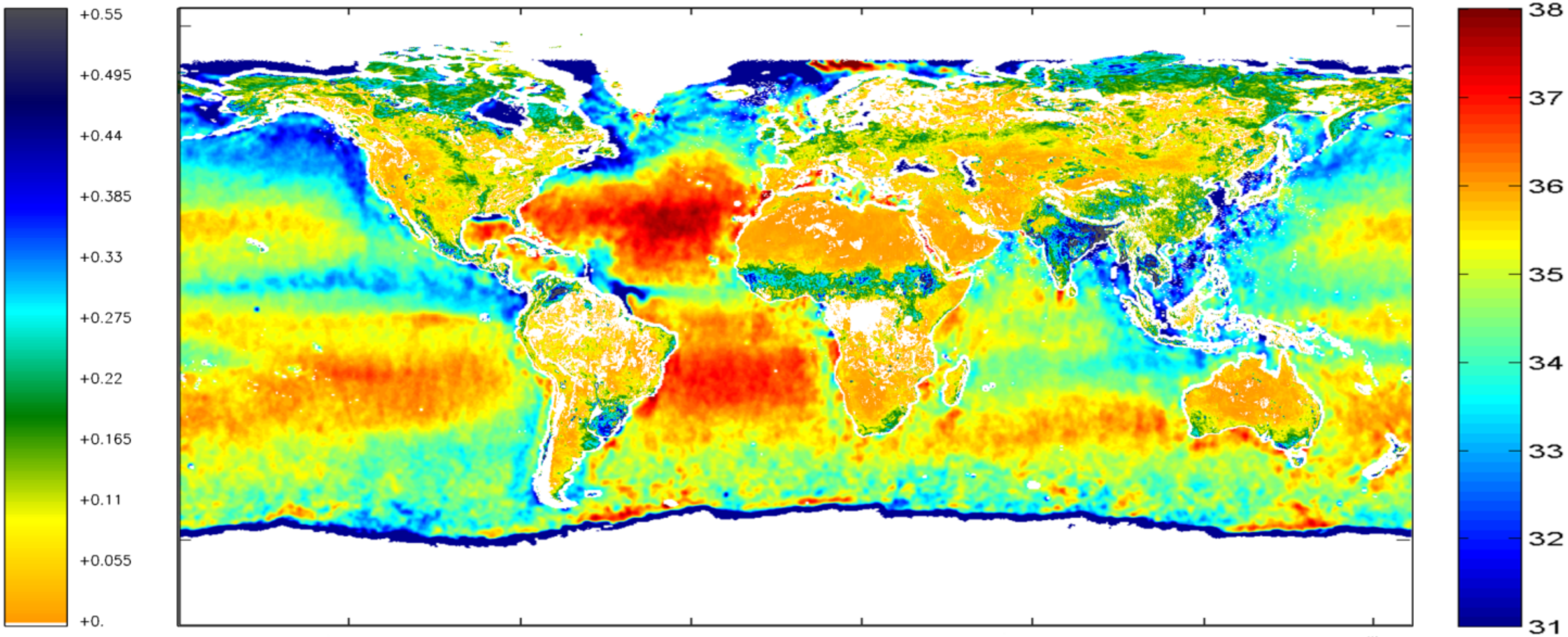
Advanced diagnostics
Downscaling, realistic land sfc hydrology,
land use, land management, cryosphere
Data assimilation
Modeling
Synthesis (water balance)
Drought Information System

SMOS
Principle and key points

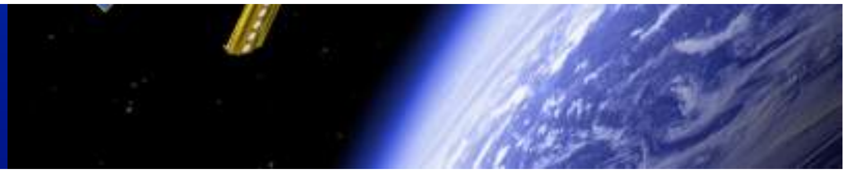
Soil Moisture
August 2011

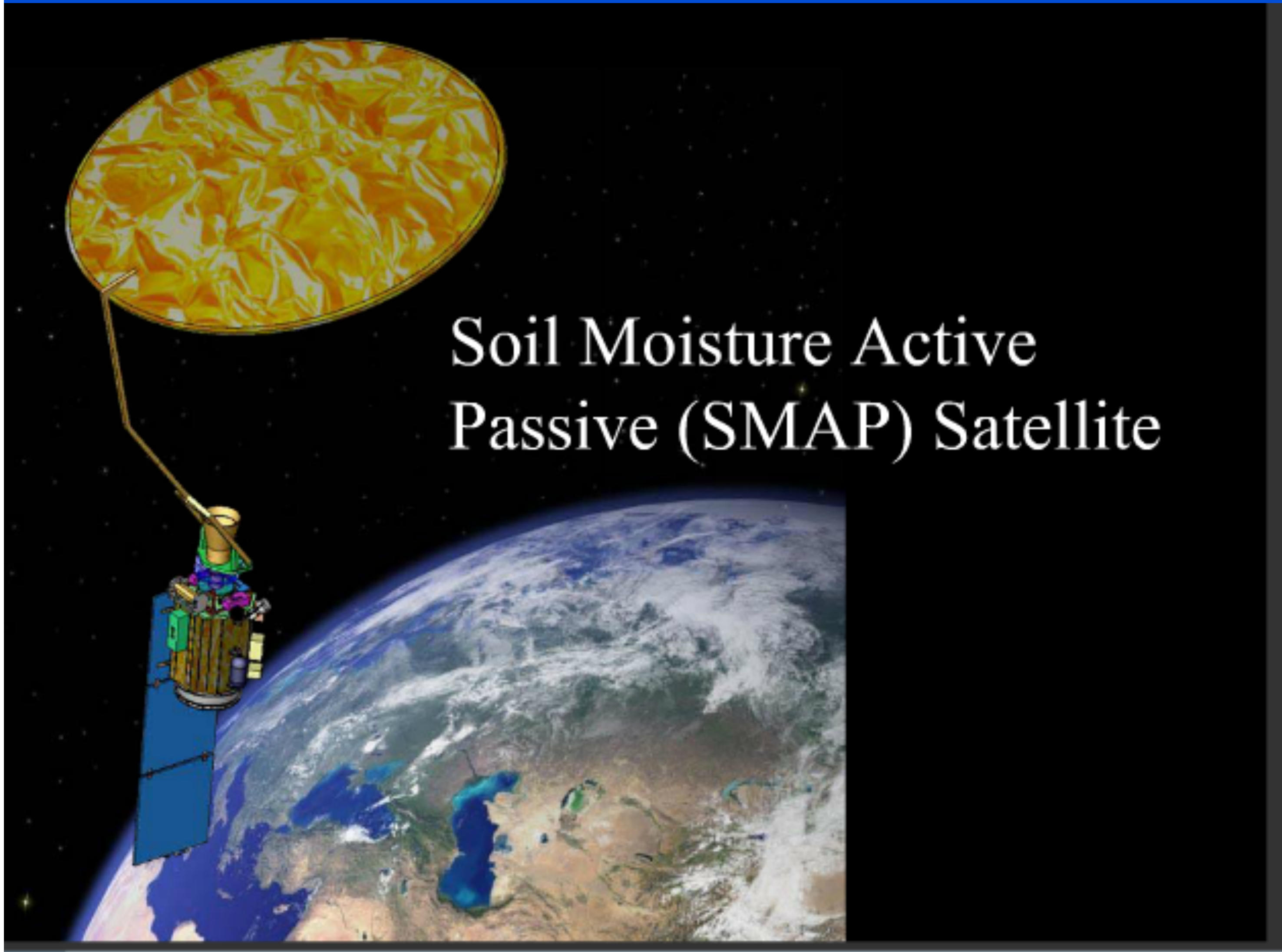
Ocean Salinity
August 2010

Morning orbits



- Launched November 2 2009





Launch 2014
L-band microwave radar
6 m reflector
3 day coverage
40 km res for radiometer
3 km res for radar

NCAR

Workshop on GSQ 2:
Saskatoon, Canada (host Wheater)
June 5-7, 2013

- Format: 4 half day sessions
- 2 presentations, each
- discussion w moderator and rapporteur
- Feature topic at GEWEX Science Conference:
  - Sessions to be convened
- Role of panels? WGs?
- Is there an exec. group in charge? Who?
- Progress, schedules, expected outcomes, metrics, etc.
- Written report on recommendations

NCAR

Workshop on GSQ 2:

- SQ-1) *How do changes in land surface and hydrology influence past and future changes in water availability and security?* Wheater, Dairaku, (Buytaert)
- (SQ-2) *How do changes in climate affect terrestrial ecosystems , hydrological processes, water resources and water quality, especially water temperature?* Harding, Li, (Pomeroy, Jayasuriya)
- (SQ-3) *How can new observations lead to improvements in water management?* Houser, (van Oevelen, Benedict)
- (SQ-4) *How do models become better and how much confidence do we have in global and regional climate predictions and projections of precipitation?* Evans, (Clark)
- (SQ-5) *How can better climate models lead to improvements in water management ?* Harding, (Buytaert)

Considerations (by speakers): Progress to date, knowledge gaps, pathways forward, metrics, how to track progress, review paper(?), planned activities, implementation, schedule

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There are multiple benefits and the results are important for society

- Improved models => improved predictions
- All time scales, monthly, seasonal, decadal, centennial
- All space scales: regional to global
- Extremes
- Quantified uncertainties
- Information for water managers, decision makers, users
- Drought Information System
- Effects of management decisions
- Better interactions between research and users

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