



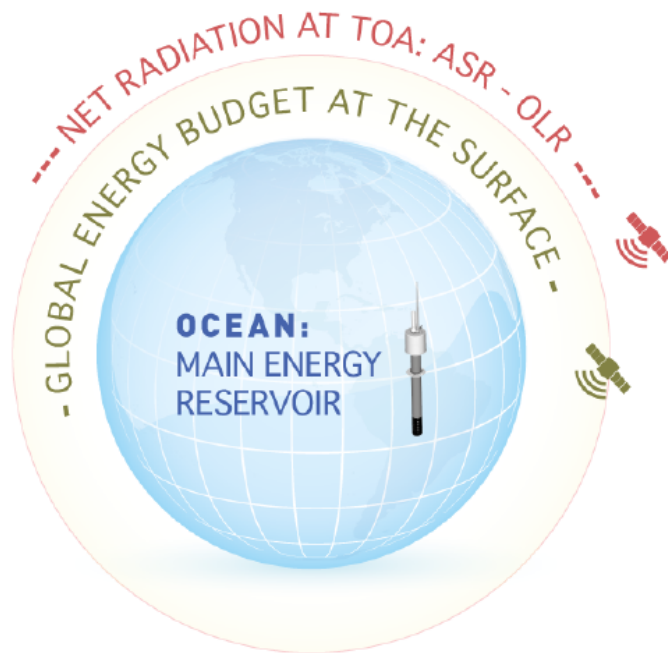
## « An Integrated Approach to Earth Energy Imbalance »

**Objective:** Quantify Earth's energy imbalance, its temporal and regional variability, and the associated energy flows in the Earth system

**Practical Goal:**

Strengthen and extend the synergy community on the Earth's energy imbalance aiming to discuss cross-links between the different WCRP core programs, in particular between CLIVAR and GEWEX, but also including CliC.

**Overall Goal:** bring together the climate research communities concerned with the energy flows in the Earth system to advance understanding of the uncertainties through physical budget constraints:



- Atmospheric radiation
- Ocean Heat Content
- Earth's surface fluxes
- Climate variability and change
- Data assimilation & operational services (R&D)
- Climate projection
- Global sea level

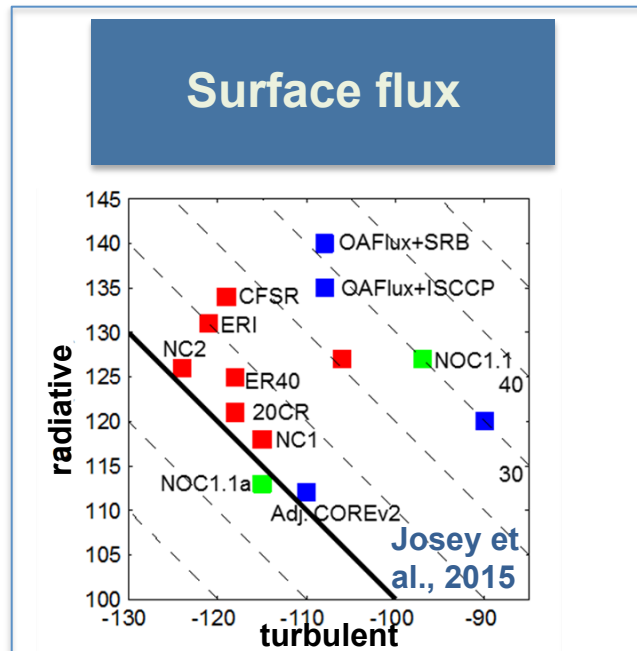
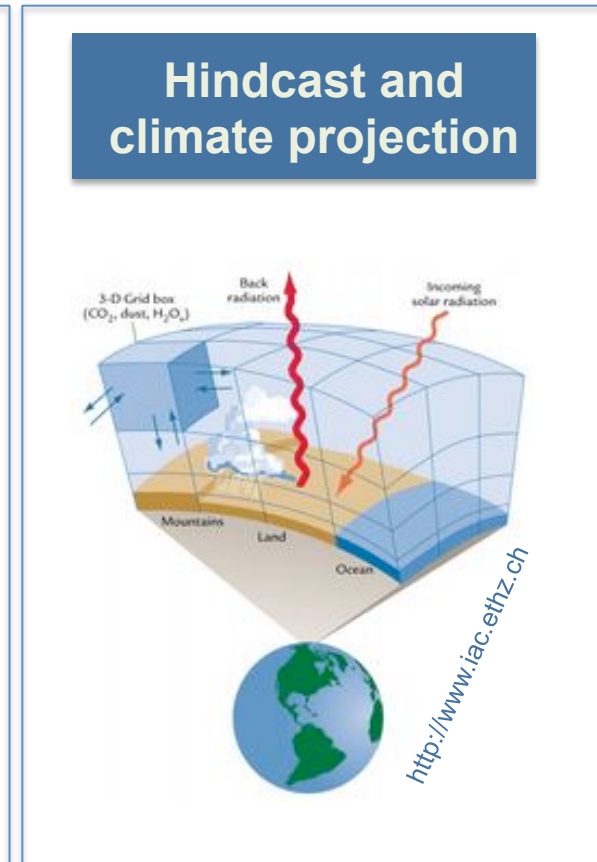
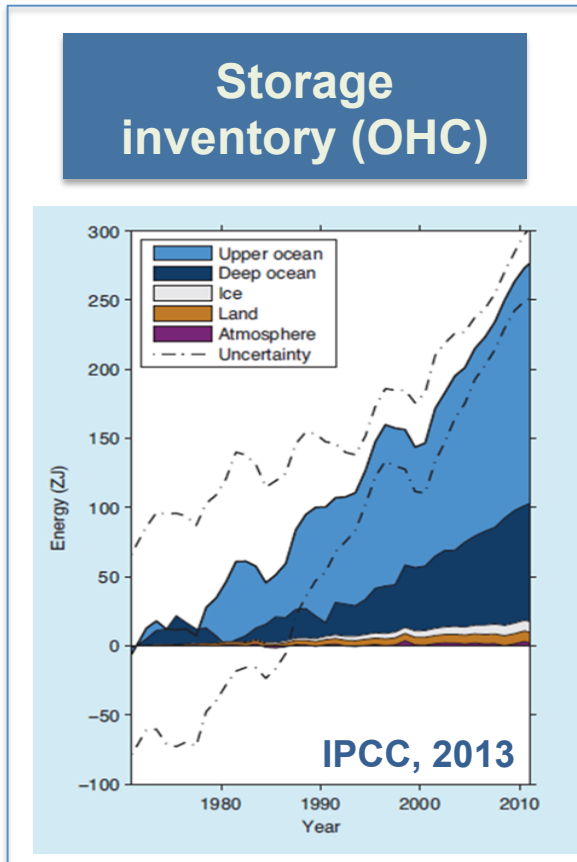
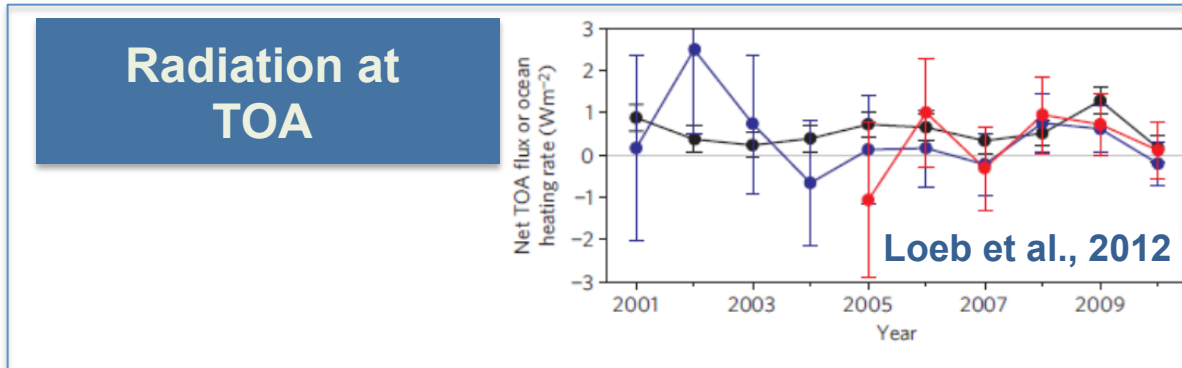
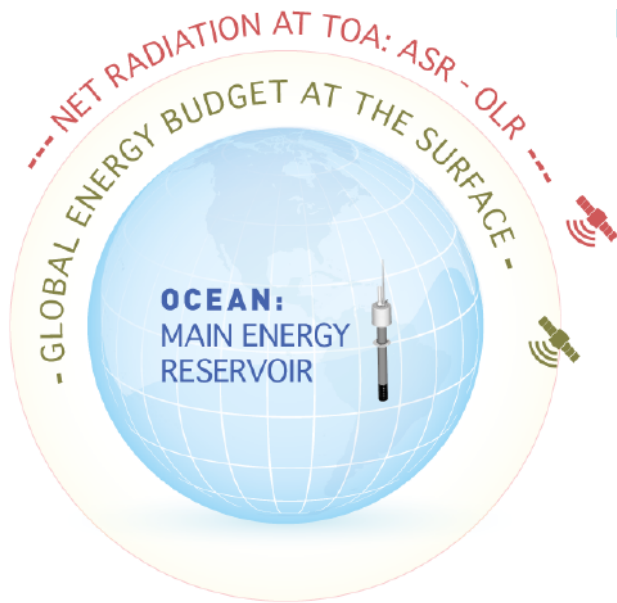
Remote  
sensing

In situ

Reanalysis  
systems

Numerical  
model

# CLIVAR RESEARCH FOCUS CONCEPT-HEAT



# CLIVAR RESEARCH FOCUS CONCEPT-HEAT

The **CLIVAR** research focus **CONCEPT-HEAT** has the main objective to build up a pluri-disciplinary synergy community for climate research aiming to work on two different issues:

1. Quantify Earth's energy imbalance, the ocean heat budget, and atmosphere-ocean turbulent and radiative heat fluxes, their observational uncertainty, and their variability for a range of time and space scales using different observing strategies (e.g., in-situ ocean, satellite), reanalysis systems, and climate models.
2. Analyze the consistency between the satellite-based planetary heat balance and ocean heat storage estimates, using data sets and information products from global observing systems (remote sensing and in situ) and ocean reanalysis, and compare these results to outputs from climate models to obtain validation requirements (for model and observations).



# CONCEPT-HEAT: Consistency between planetary energy balance and ocean heat storage

<b>Name</b>	<b>Institute</b>	<b>Role</b>	<b>Country</b>
Karina von Schuckmann	Mercator Ocean	Co-chair	France
Tristan L'Ecuyer	University of Wisconsin-Madison	Co-chair	USA
Kevin Trenberth	NCAR	Member	USA
Carol Anne Clayson	WHOI	Member	USA
Catia Domingues	IMAS/ACE-CRC	Member	Australia
Sergey Gulev	IORAS	Member	Russia
Keith Haines	UR	Member	UK
Norman Loeb	NASA	Member	USA
Matt Palmer	Met Office	Member	UK
Martin Wild	ETH	Member	Switzerland
Pierre-Philippe Mathieu	ESA	Member	Italy
Robert Weller	WHOI	Member	USA

# ACTIVITIES

## Workshops

2013: CLIVAR-ESA  
2014: 1st ISSI meeting  
2014: Pan-CLIVAR session  
2015: 2<sup>nd</sup> ISSI meeting  
2015: CLIVAR C-H  
2017: C-H/GDAP workshop  
2018: CLIVAR/GEWEX workshop

## Collaborations

2014-2015: ISSI working group  
2014-2016 ESA project OHF  
2016-current: global sea level budget  
2016-current: Transport constraints  
2016-current: synthetic profile experiments  
Future: C-H/GDAP collaboration



## Funding



## Sessions

- Pre-COP21: Our common future under climate change
- AGU 2016 & 2017
- Ocean Science 2017
- GEWEX international science conference

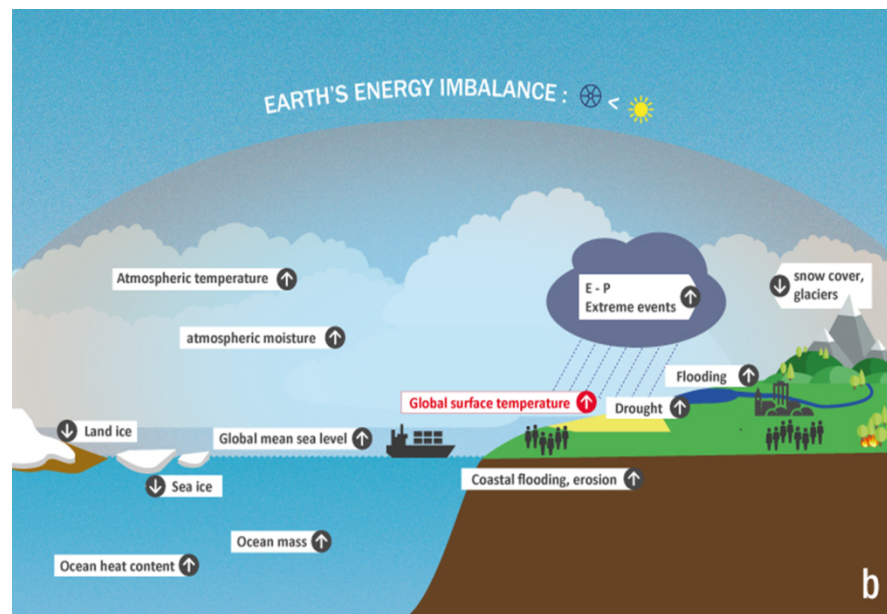
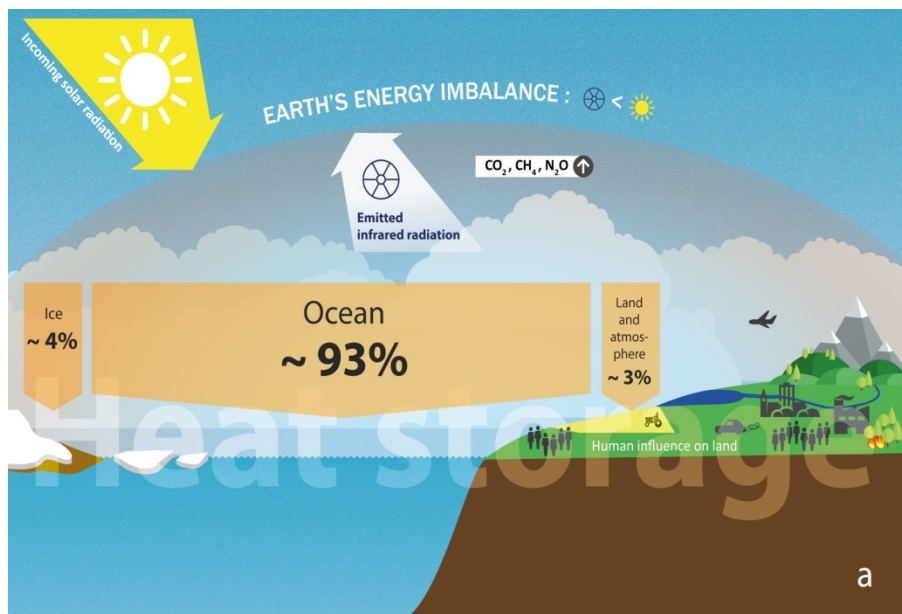
## PERSPECTIVE

PUBLISHED ONLINE: 27 JANUARY 2016 | DOI: 10.1038/NCLIMATE2876

nature  
climate change

# An imperative to monitor Earth's energy imbalance

K. von Schuckmann<sup>1,2\*</sup>, M.D. Palmer<sup>3</sup>, K.E. Trenberth<sup>4</sup>, A. Cazenave<sup>5,6</sup>, D. Chambers<sup>7</sup>, N. Champollion<sup>6</sup>, J. Hansen<sup>8</sup>, S.A. Josey<sup>9</sup>, N. Loeb<sup>10</sup>, P.-P. Mathieu<sup>11</sup>, B. Meyssignac<sup>5</sup> and M. Wild<sup>12</sup>



## Toward an improved estimation of turbulent fluxes. JUL 2014 – JUL 2016

<https://wwz.ifremer.fr/oceanheatflux/>

- .. obtaining and analyzing all heat flux components (turbulent and radiative) using multiple satellite sensors, in situ measurements and models (20 products, 20 years (1992-2011), 80°N and 80°S

Remote Sensing of Environment 201 (2017) 196–218



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Remote Sensing of Environment

journal homepage: [www.elsevier.com/locate/rse](http://www.elsevier.com/locate/rse)



Review and assessment of latent and sensible heat flux accuracy over the global oceans



A. Bentamy<sup>a,\*</sup>, J.F. Piollé<sup>a</sup>, A. Grouazel<sup>a</sup>, R. Danielson<sup>e</sup>, S. Gulev<sup>f</sup>, F. Paul<sup>a</sup>, H. Azelmat<sup>a</sup>, P.P. Mathieu<sup>b</sup>, K. von Schuckmann<sup>c</sup>, S. Sathyendranath<sup>d</sup>, H. Evers-King<sup>d</sup>, I. Esau<sup>e</sup>, J.A. Johannessen<sup>e</sup>, C.A. Clayson<sup>g</sup>, R.T. Pinker<sup>h</sup>, S.A. Grodsky<sup>h</sup>, M. Bourassa<sup>i</sup>, S.R. Smith<sup>i</sup>, K. Haines<sup>j</sup>, M. Valdivieso<sup>j</sup>, C.J. Merchant<sup>j</sup>, B. Chapron<sup>a</sup>, A. Anderson<sup>k</sup>, R. Hollmann<sup>k</sup>, S.A. Josey<sup>l</sup>

<sup>a</sup> Institut Français de Recherche pour l'Exploitation de la Mer (IFREMER), Plouzané, France



## Assess surface flux closure using multiple methods

- Estimating the net surface flux as a residual of the top-of-atmosphere (TOA) radiative fluxes (from CERES) combined with comprehensive estimates of the vertically integrated atmospheric divergence of energy (from reanalyses).
  - Surface fluxes from reanalyses: atmospheric, ocean
  - Surface fluxes from satellite, in situ
- 1) focus first on the Atlantic (e.g. North Atlantic) in the form of a Cage experiment, i.e. an analysis of regional heat and mass budget closure.
  - 2) By combining with analysis of OHC, derive ocean meridional heat transports (MHT) and their variability.
  - 3) Validate with ocean time series, such as RAPID/MOCHA, ocean reanalyses

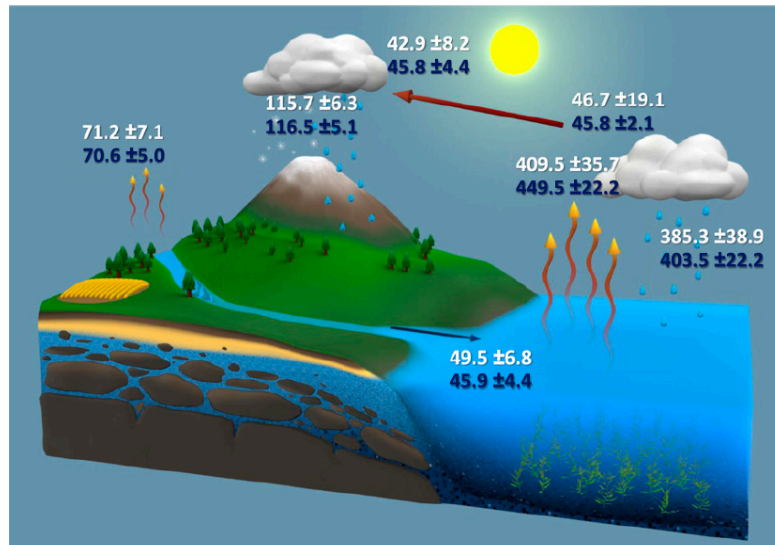
The key point for C-H is that this approach can be used for all the **surface flux** datasets combined with any or all **OHC** datasets, and it provides a metric of comparison and evaluation. Surface fluxes are prominent issues for C-H, GSOP, and GDAP, and the framework proposed here is the basis for an intercomparison project. This could lead to a workshop on results.

- Flux perspective

- fluxes of energy and water; many GEWEX: SeaFlux, GPCP, SRB, ISCCP
- balance constraints imposed objectively
- energy and water budgets considered simultaneously

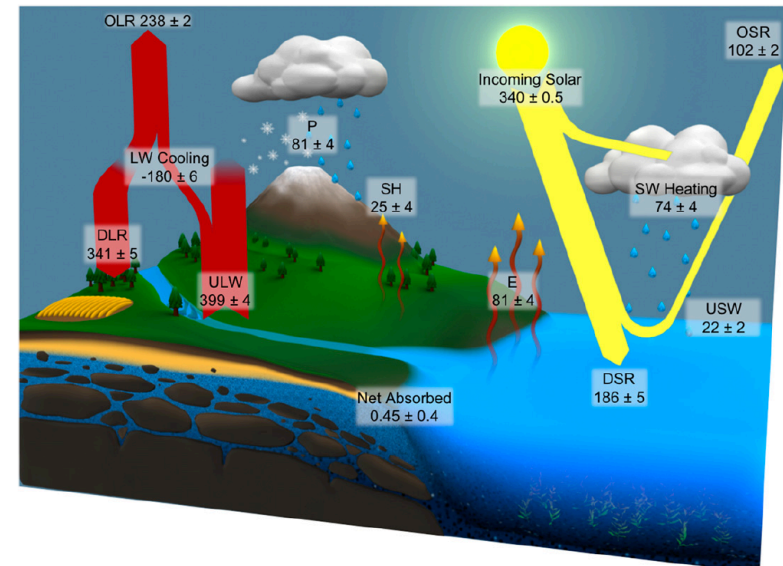
### The Observed State of the Water Cycle in the Early Twenty-First Century

M. RODELL,<sup>a</sup> H. K. BEAUDOING,<sup>ab</sup> T. S. L'ECUYER,<sup>c</sup> W. S. OLSON,<sup>ad</sup> J. S. FAMIGLIETTI,<sup>e</sup> P. R. HOUSER,<sup>f</sup> R. ADLER,<sup>b</sup> M. G. BOSILOVICH,<sup>a</sup> C. A. CLAYSON,<sup>g</sup> D. CHAMBERS,<sup>h</sup> E. CLARK,<sup>i</sup> E. J. FETZER,<sup>c</sup> X. GAO,<sup>j</sup> G. GU,<sup>ab</sup> K. HILBURN,<sup>k</sup> G. J. HUFFMAN,<sup>a</sup> D. P. LETTENMAIER,<sup>l</sup> W. T. LIU,<sup>e</sup> F. R. ROBERTSON,<sup>l</sup> C. A. SCHLOSSER,<sup>j</sup> J. SHEFFIELD,<sup>m</sup> AND E. F. WOOD<sup>m</sup>



### The Observed State of the Energy Budget in the Early Twenty-First Century

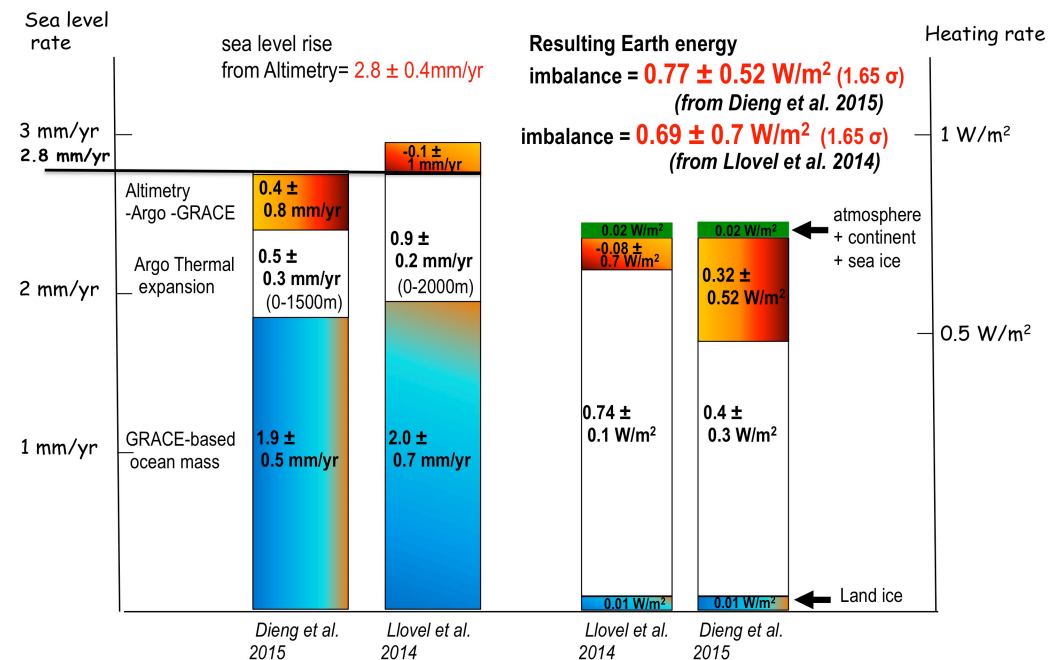
TRISTAN S. L'ECUYER,<sup>a</sup> H. K. BEAUDOING,<sup>bc</sup> M. RODELL,<sup>b</sup> W. OLSON,<sup>d</sup> B. LIN,<sup>e</sup> S. KATO,<sup>c</sup> C. A. CLAYSON,<sup>f</sup> E. WOOD,<sup>g</sup> J. SHEFFIELD,<sup>h</sup> R. ADLER,<sup>c</sup> G. HUFFMAN,<sup>b</sup> M. BOSILOVICH,<sup>b</sup> G. GU,<sup>b</sup> F. ROBERTSON,<sup>b</sup> P. R. HOUSER,<sup>i</sup> D. CHAMBERS,<sup>j</sup> J. S. FAMIGLIETTI,<sup>k</sup> E. FETZER,<sup>k</sup> W. T. LIU,<sup>k</sup> X. GAO,<sup>l</sup> C. A. SCHLOSSER,<sup>l</sup> E. CLARK,<sup>m</sup> D. P. LETTENMAIER,<sup>m</sup> AND K. HILBURN<sup>n</sup>



# THIRD PERSPECTIVE: MASS and SEA-LEVEL

- Sea level (from satellite altimetry) minus ocean mass (from space gravimetry) provides a satellite-based alternative to Argo for estimating OHC
- The current best estimate of the OHC change from satellite is  $0.7 \pm 0.5 \text{ Wm}^{-2}$  over 2005-2015
- GDAP endorses expansion of this activity to regional and shorter timescales as part of a new EEI-themed energy budget assessment.

Sea level budget and Earth Energy imbalance : 2005-2013



Courtesy: Benoit Meyssignac

# A New GDAP Vision

Consistency as a way of life...

An integrated approach to energy-water-mass consistency based on refined uncertainty characterization

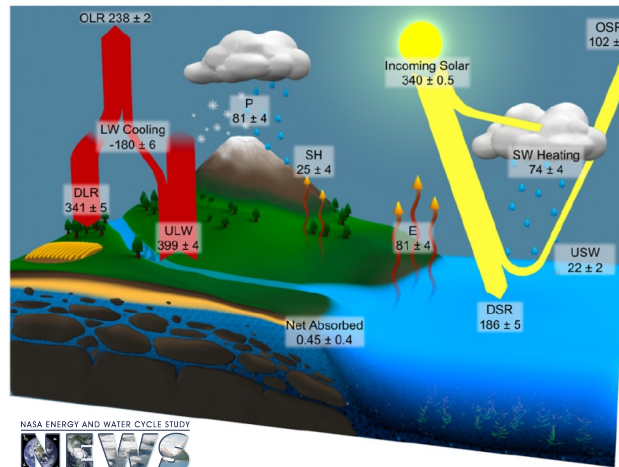
## Precipitation



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## Radiation



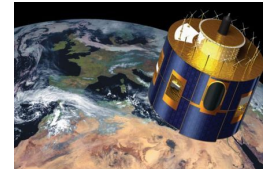
## Sea level



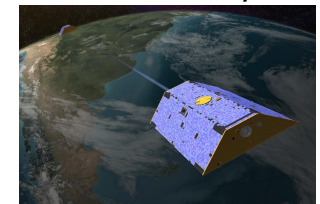
## Surface Flux



## Cloud



## Gravimetry



# MERGING THE PERSPECTIVES

**GDAP meeting, NCAR, Boulder CO, USA**

9 October 2017

**Topic:**

EEI-related Interactions within WCRP



## Toward an Integrated View

- There are clear advantages to pursuing a synthesis that seeks consistency
- GEWEX and NEWS have looked into consistency between atmosphere and surface fluxes. CLIVAR has looked at consistency between independent measures of ocean heat content changes. Can these activities be combined into a single integrated framework?
- Expanding approaches for imposing closure constraints to include spatially and temporally-resolved measures of OHC (e.g. Argo or altimetry), terrestrial heat and water storage (e.g. GRACE), and moisture convergence from reanalyses may offer potential to improve representation of heat transports and track time evolution of flux components.
  - Explicitly coupling energy budget and water cycles provides stronger constraints
  - The magnitude of flux adjustments as well as correlations between errors have value for flux assessment and improvement.



## « An Integrated Approach to Earth Energy Imbalance » Fall 2018, Toulouse, France

- Open workshop or limited participation (e.g. 60? 120?)
- Invited key-note talks
- Reserved long time slots for coordinated common discussions
- Set up working groups to report back on last day
- Expected length: 3.5 days
- Scientific steering team: CLIVAR & GEWEX members + CliC
- Location: to be discussed (see next slides)
- 4 principal sessions (see next slides)



## « An Integrated Approach to Earth Energy Imbalance » Fall 2018, Toulouse, France

### DAY 1: Global EEI

#### Morning

- Welcome
- Introduction
- Scientific talks: invited
- Scientific talks

#### Afternoon

- Introduce EEI Assessment Activity
  - ✓ Outcomes
  - ✓ Discussion: future
- Set up WGs
- Common Discussion
- Posters

#### Evening

- Ice breaker

### DAY 2: Regional EEI

#### Morning

- Introduction
- Scientific talks: invited
- Scientific talks
- Posters

#### Afternoon

- Scientific talks continued
- Working group meetings
- Common discussion

#### Evening

- Workshop Dinner

### DAY 3 – Modeling and Predictability

#### Morning

- Introduction
- Scientific talks: invited
- Scientific talks
- Posters

#### Afternoon

### DAY 3 – Cross-WCRP EEI Activity

- WCRP
- Working group meetings
- Common discussion

### DAY 4 – Synthesis

#### Morning

- Common Discussion
  - ✓ Invited commentary
  - ✓ WG reports
  - ✓ Discussion
  - ✓ Summary of Outcomes/Action Items
  - ✓ Closing remarks

- **Session 1: Estimate EEI globally:** Topics include OHC, ocean surface energy balance, land heat storage and energy balance, atmospheric heat storage, TOA net flux, EEI physical budget constraint.
  - All topics should utilize results from observations, reanalyses and models. The stocktake and EEI assessment activity are included as well in this session, where future steps of these activities will be discussed.
  - [1 day]
  
- **Session 2: Estimate EEI locally:** Cage experiments: comprehensive energy and water balances over specific regions: land, ocean, Arctic.
  - Annual cycle, interannual variability, longer-term changes.
  - ENSO: Recharge-discharge model; impact on OHC, SLR, GMST
  - Cryosphere energy storage and balance, How much energy has gone into melting ice: Arctic, Antarctic, and what is the annual cycle in each hemisphere? (CliC)
  - [1 day]



- **Session 3: Modeling and Predictability:** Implications of anomalous heat storage for predictions, especially decadal and regional. [1/2 day]
- **Session 4: Cross WCRP interactions on the Earth's energy imbalance:** Objective is to strengthen and extend the community on the Earth energy imbalance, and is the key part of the workshop to achieve expected outcomes based on the gained knowledge from the previous sessions. It includes the need for different groups (e.g. within GDAP) to confront each other and enforce consistency (wrt energy and water). [1/2 day]
- **Session 5: Working Group outcomes and Wrap up.** [1/2 day]

- Finalizing scientific steering committee
- Session descriptions, webpage, etc.
- Advertising

## **Near-term Decisions:**

- Dates? (November 13-16, 2018 proposed)
- Size of participation?
- Venue in Toulouse? (Karina, Remy, and Benoit)

## **Funding Support?**

- Limited funding from local host
- WCRP - CLIVAR/GEWEX
- GRACE?
- Other options? ESA?