# Scoping for the GCOS Joint Panels Meeting

## The Global Energy Budget.

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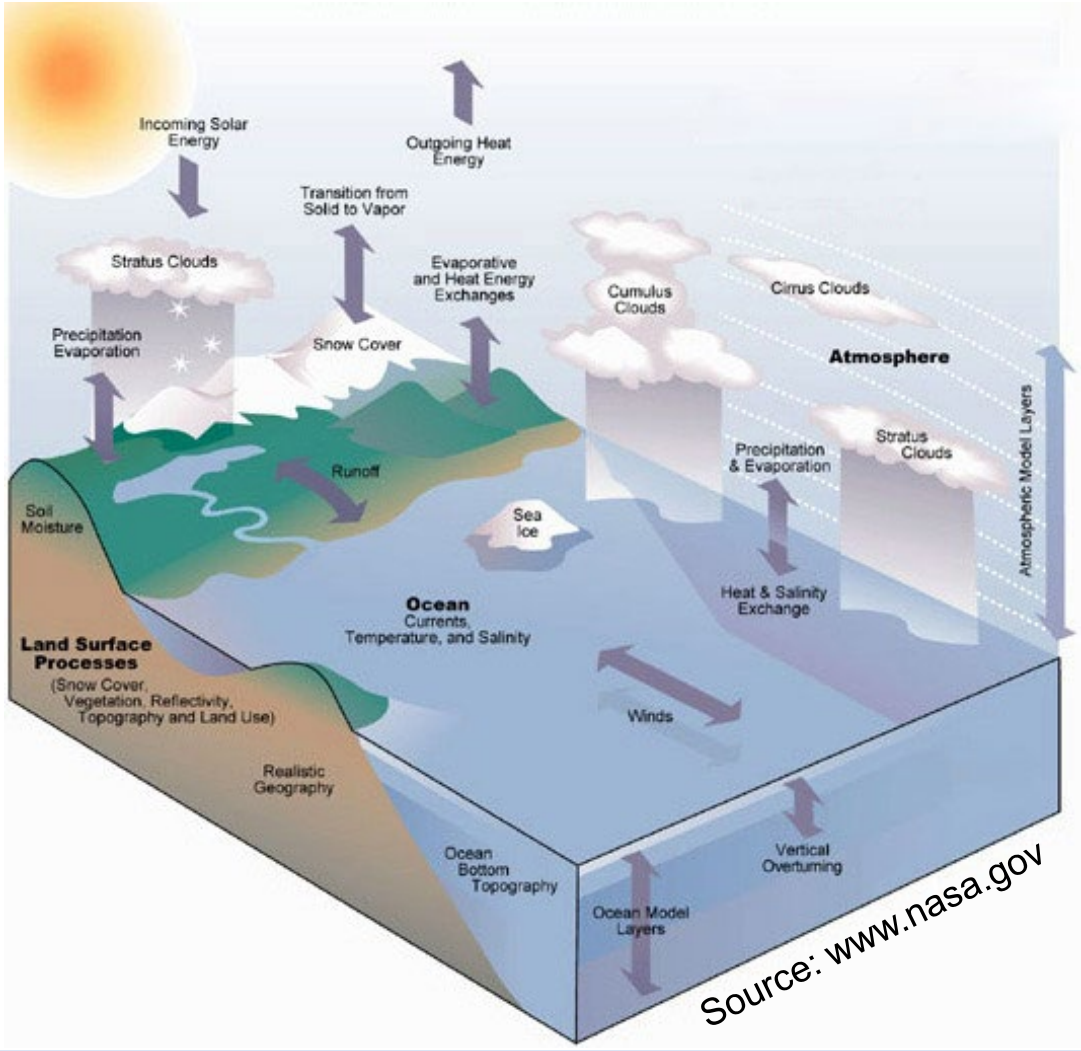
GCOS SC Representative: Sue Barrell

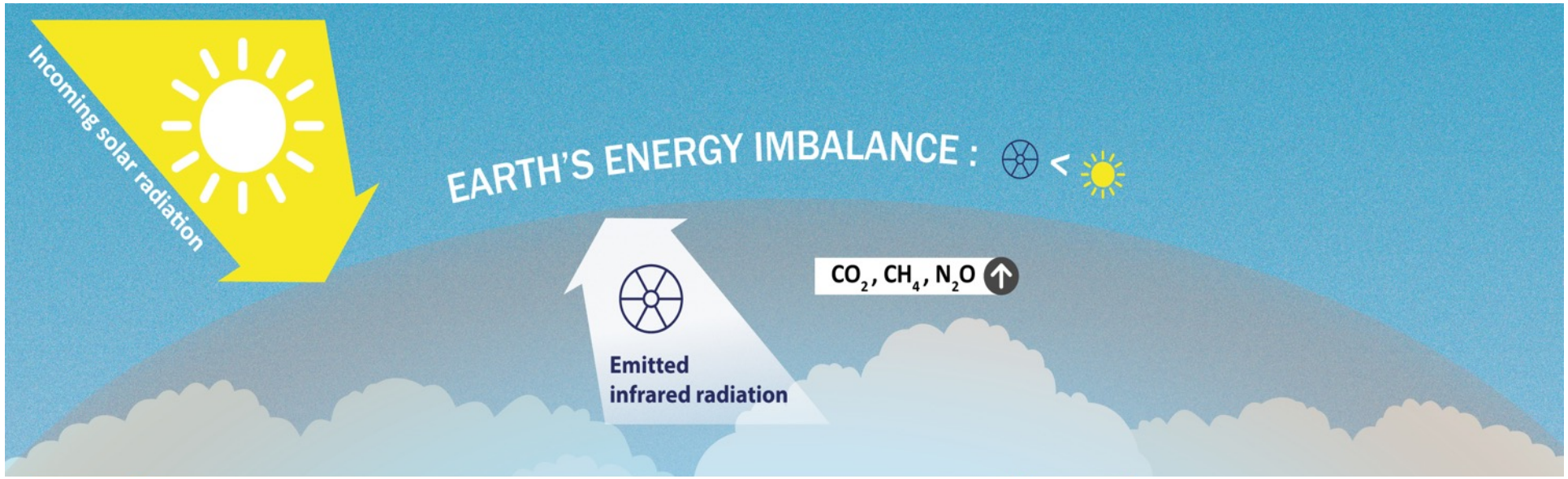
# Earth climate




- Spatial and temporal variations in the flows of energy between the different components of the Earth system play a central role in establishing the large-scale atmosphere and ocean circulation patterns that ultimately drive both weather and climate
- Energy flows alter clouds, and weather and internal climate modes can temporarily alter the energy balance for periods of days to several decades.
- **The most practical way to monitor climate state, variability and change is to continually assess the energy, mainly in the form of heat, in the Earth system.**

**The sensitivity of the climate system to external forcings is therefore governed by the energy imbalances they induce and the partitioning of these imbalances between the atmosphere, ocean, and cryosphere**

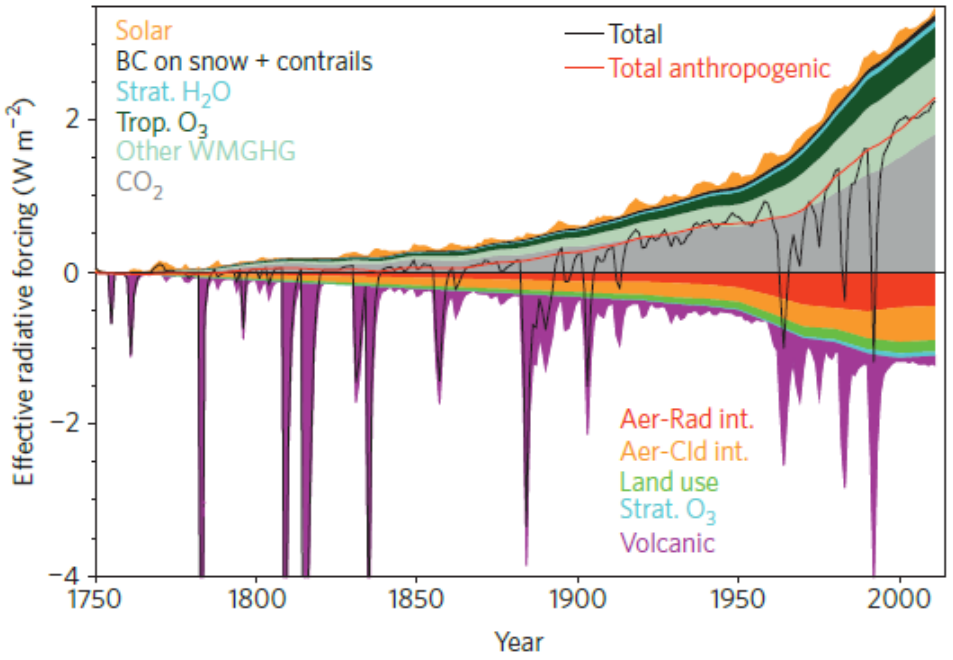
# Earth energy imbalance



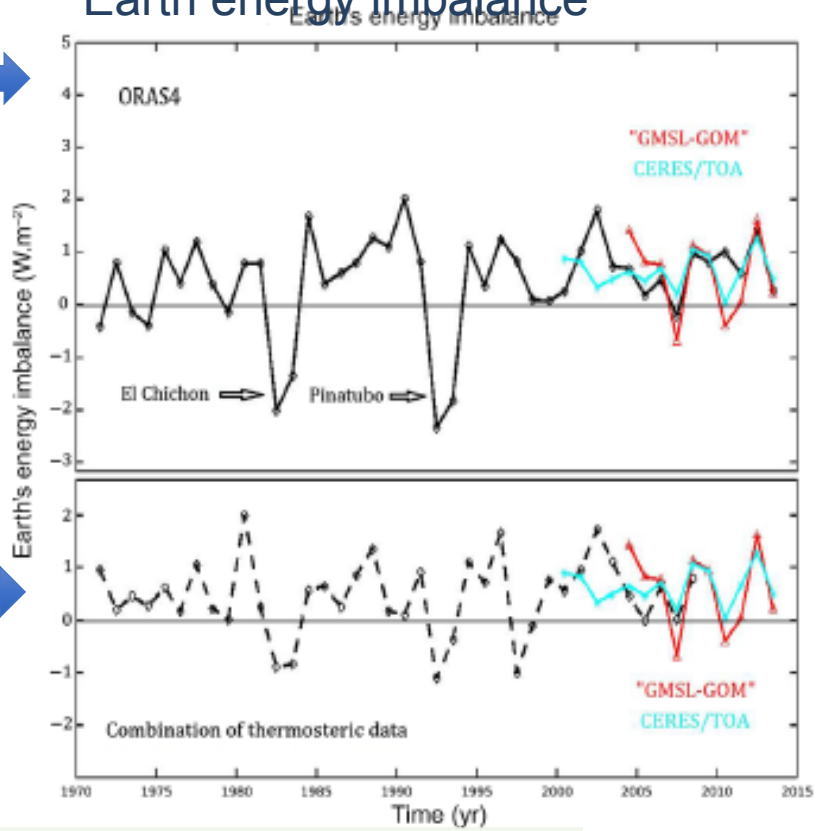

Perturbations of the equilibrium Earth energy budget arise from internal or external climate variations and can create a postive or negative Earth energy imbalance, manifested as a radiative flux imbalance at the top of the atmosphere

# Climate forcing

Effective radiative forcing




Earth energy imbalance




## EEI forcing due to:

Internal climate variability (e.g. ENSO, PDO) (+/-)

Large volcanic eruptions (-)

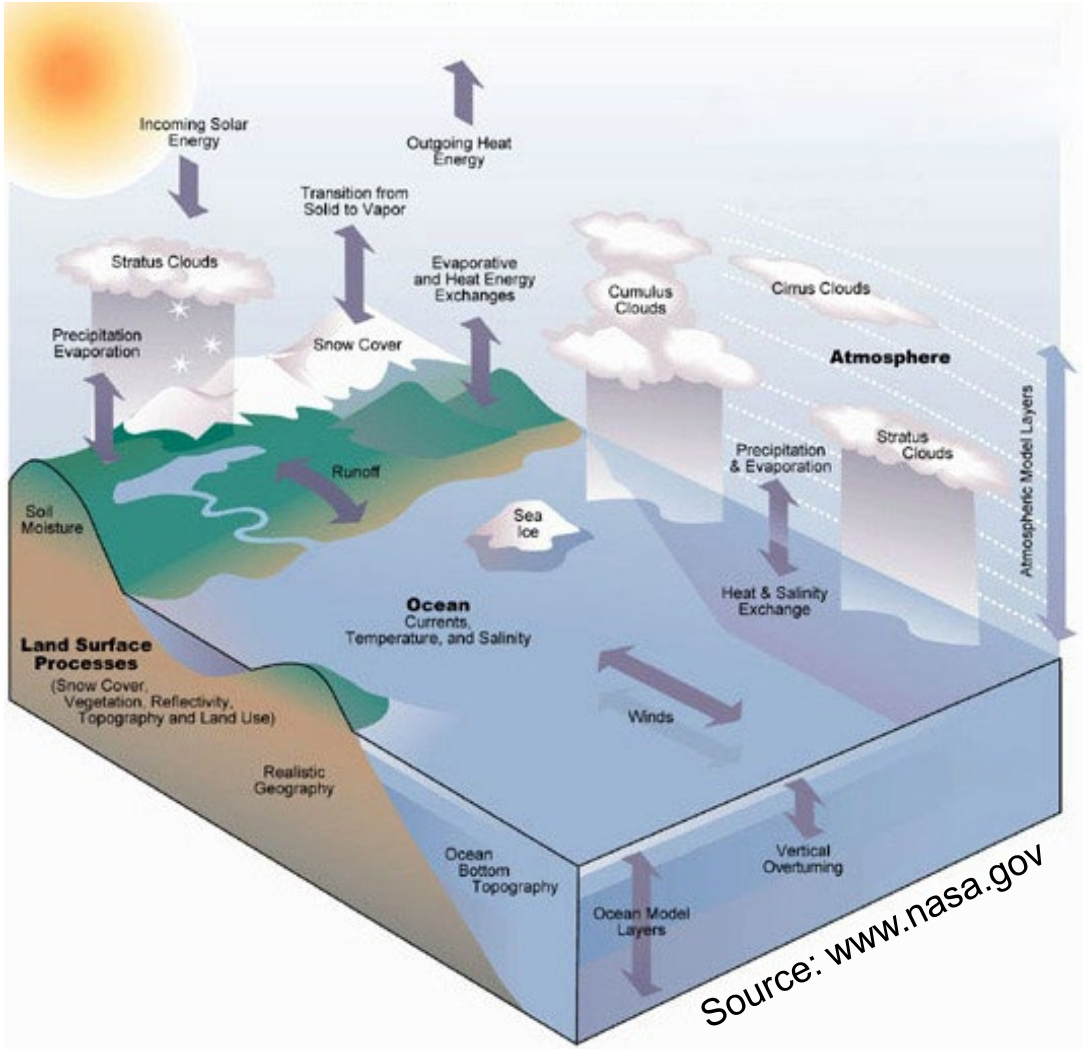
**Times-scales: subseasonal to decadal**

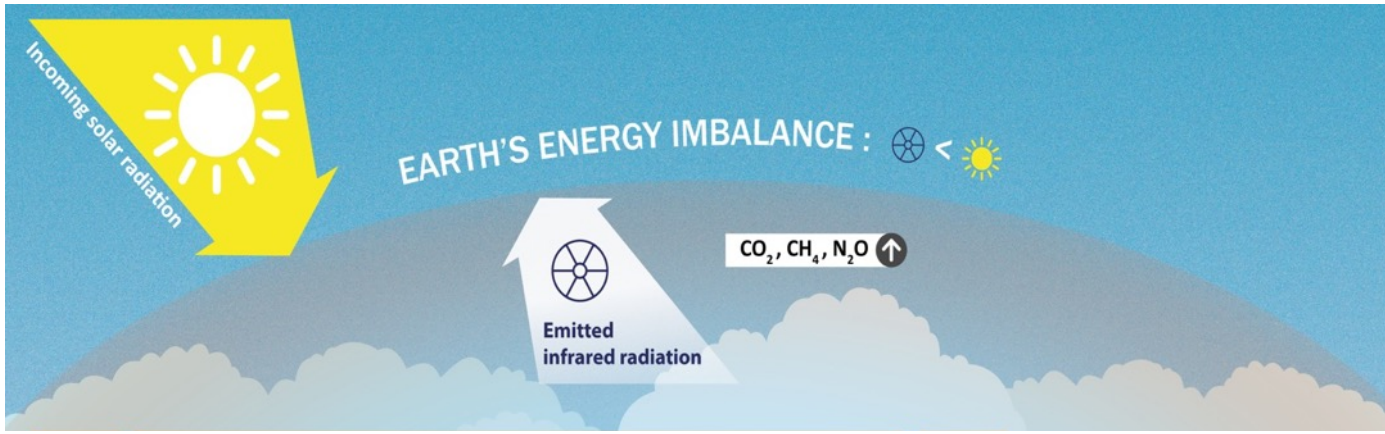
External climate forcing:

- Changes in solar output (+/-)
- Milankovitch cycle (+/-)
- Human induced changes (+)

**Times-scales: decadal and longer**

# **Earth Energy Budget closure:** an integrated way forward



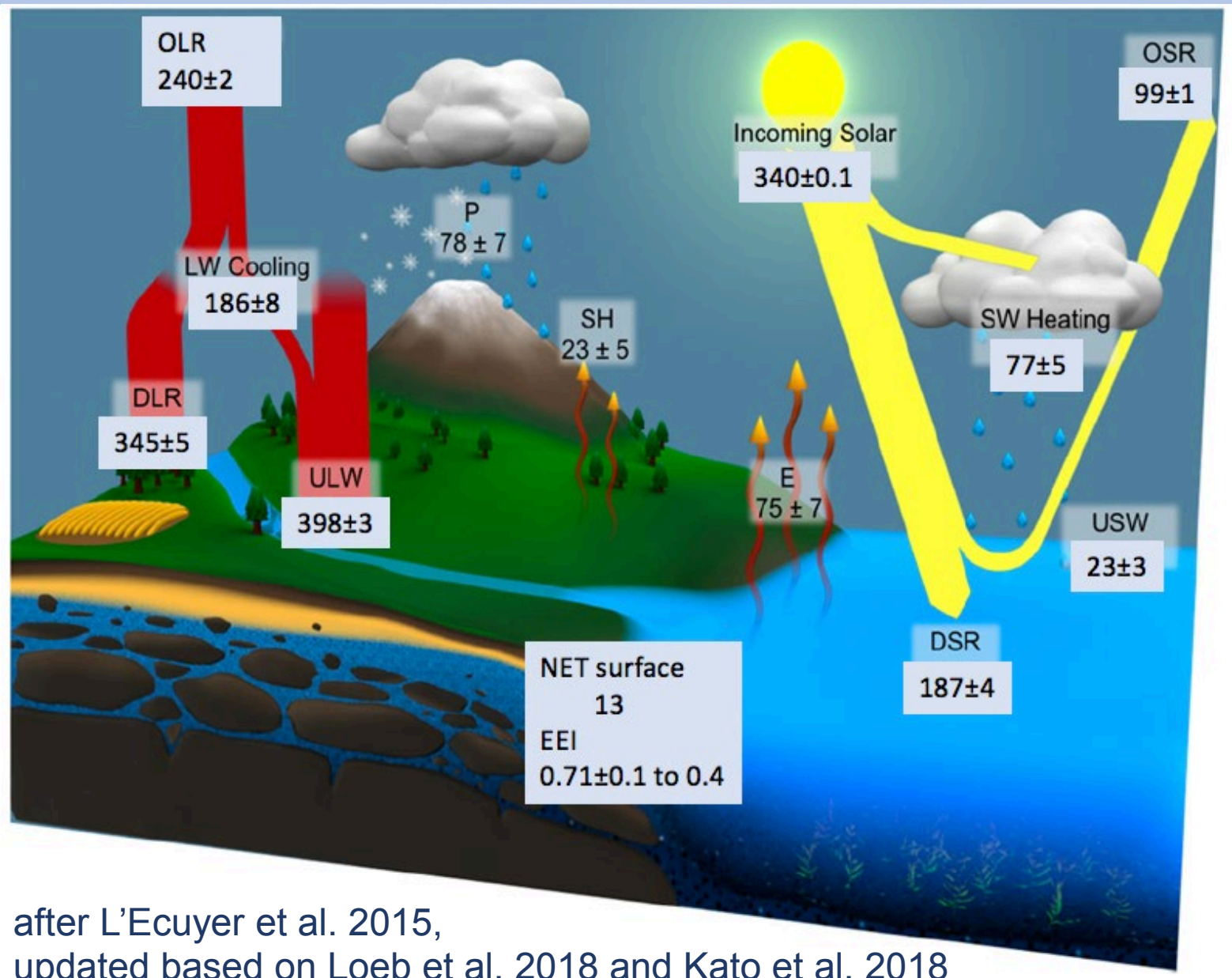

1. **Global observations for the Earth surface budget: state of the energy cycle**

2. **Global observations for Earth's Energy Imbalance: accumulated heat in the Earth system and its implications**

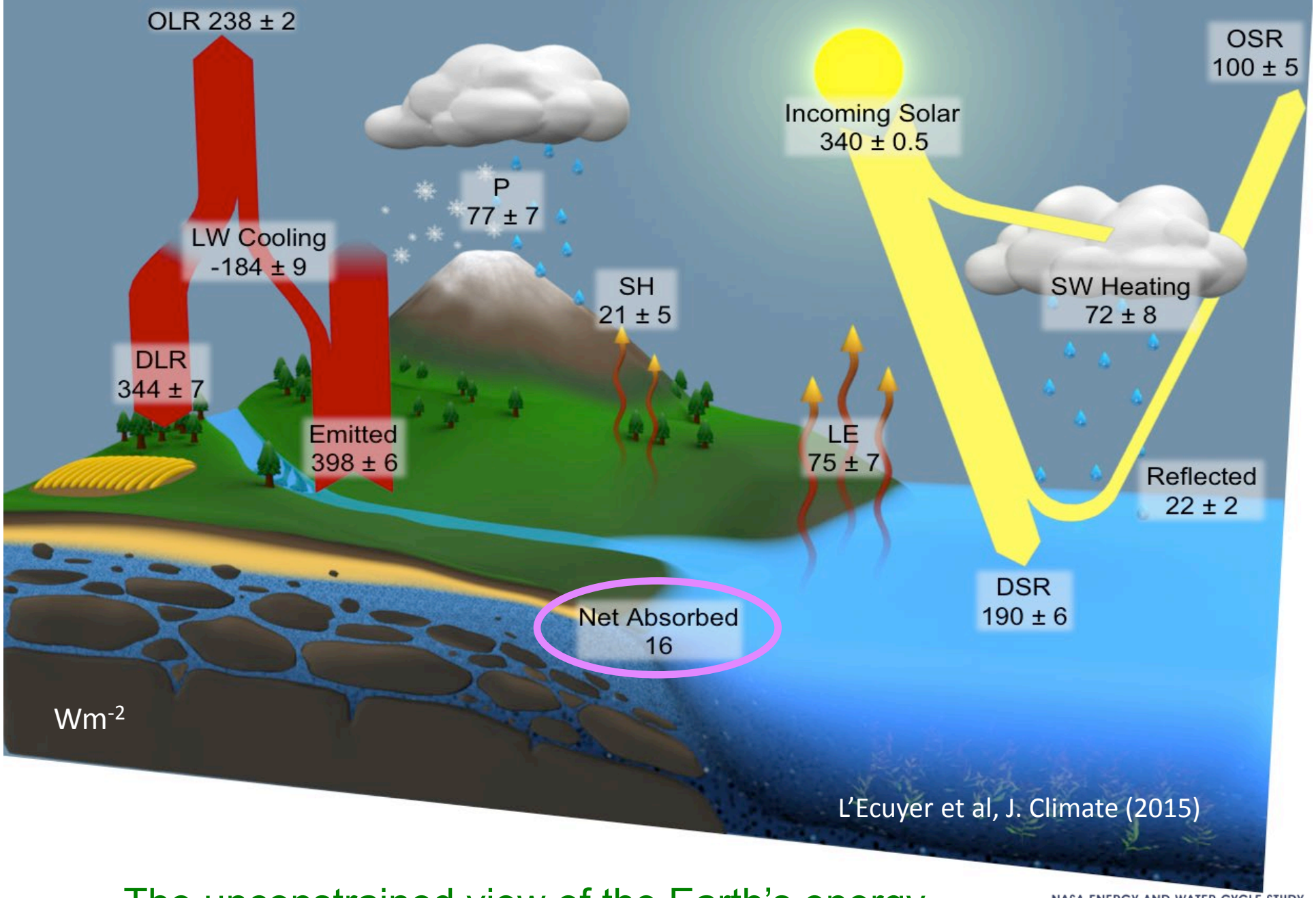
# The global mean energy balance at the Earth's surface

## Estimates of the current state of the energy cycle

OLR: outgoing longwave radiation
DLR: downward longwave radiation
ULR: upward longwave radiation
OSR: outgoing solar radiation
DSR: downward solar radiation
USR: upward solar radiation
P: precipitation rate
SH: sensible heat flux
E: latent heat flux

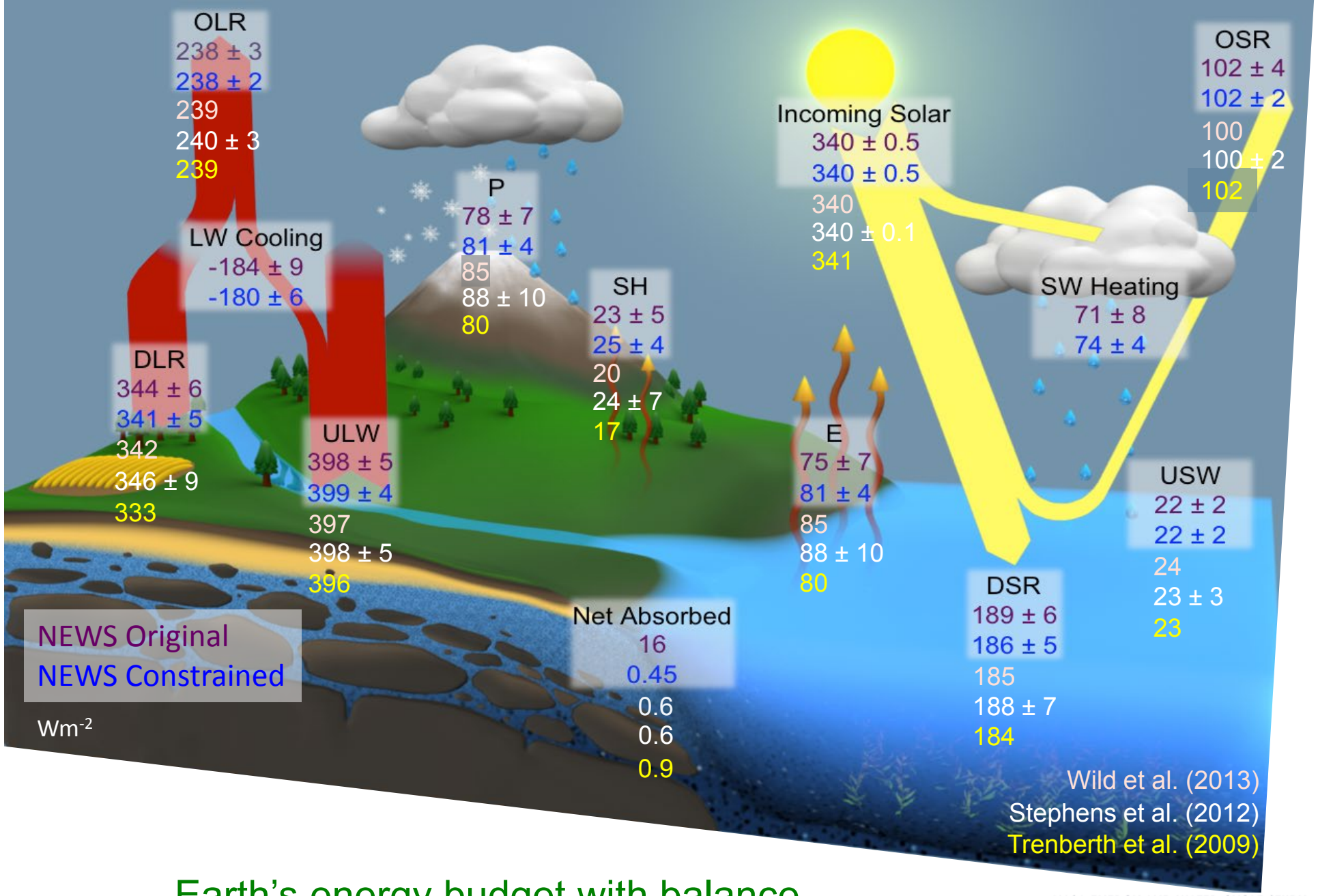



after L'Ecuyer et al. 2015,
updated based on Loeb et al. 2018 and Kato et al. 2018




The unconstrained view of the Earth's energy budget does not balance

NASA ENERGY AND WATER CYCLE STUDY
NEWS




Earth's energy budget with balance constraints imposed.

NASA ENERGY AND WATER CYCLE STUDY
NEWS

# **Earth Energy Budget closure:** an integrated way forward

## The global mean energy balance at the Earth's surface: **estimates of the current state of the energy cycle**

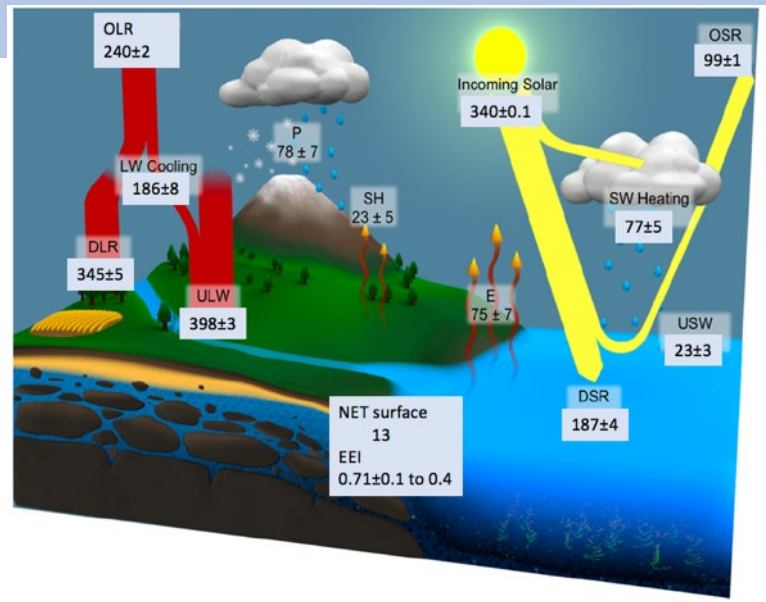
… subject of vigorous research for more than a century

… central for accurate observationally based benchmarks of energy flows to evaluate and refine model physics

… Satellite observations with improved calibration and increased spatial and temporal resolution have played a central role in refining reconstructions of Earth's energy balance

… growing network of surface-based measurements has provided substantially better constraints

… improvements in global atmospheric reanalyses through both increased resolution and the ability to assimilate extensive ground-based and satellite observations




after L'Ecuyer et al. 2015,
updated based on Loeb et al. 2018 and Kato et al. 2018

Together, these advances have enabled new reconstructions of energy balance on combinations of in situ observations, satellite datasets, and reanalyses

➔ **bring together complementary expertise and datasets to provide a comprehensive view of the Earth surface energy budget (e.g. NEWS type)**

# Earth Energy Surface Budget

| Box 1: The Earth energy surface budget | |
|---|---|
| **Target from GCOS IP** | **Balance energy budget to within 0.1 Wm-2 on annual timescales** |
| **Other proposed targets** | Upward longwave radiation:<br>Outgoing solar radiation:<br>Downward solar radiation:<br>Upward solar radiation:<br>Precipitation rate:<br>Sensible heat flux:<br>Latent heat flux: |
| **Who** | **Operators of GCOS-related systems, including data centres** |
| **Time frame** | **Ongoing** |
| **Performance indicator** | **Regular assessment of uncertainties in estimated changes and inventories** |

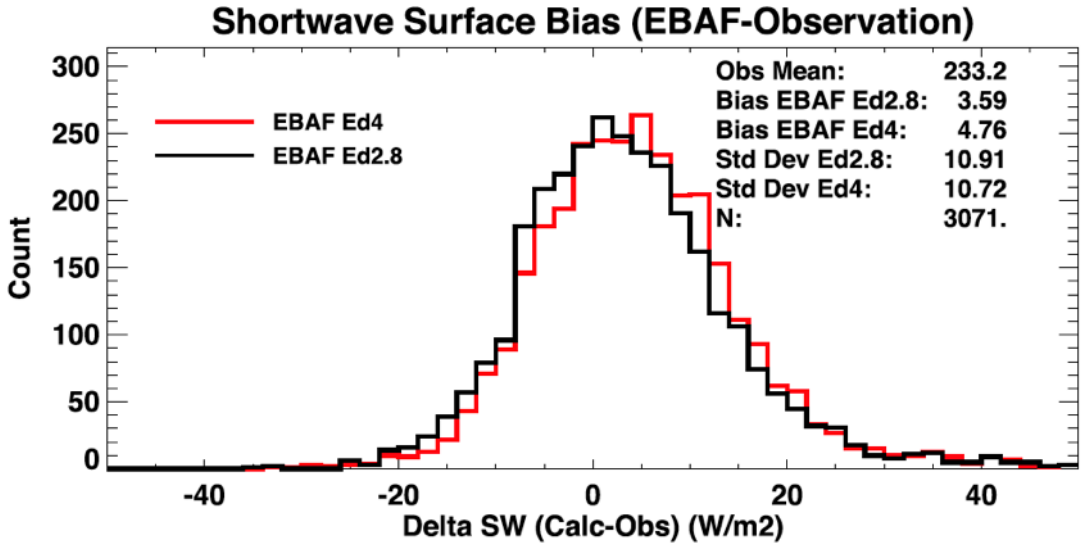
New proposition under the GCOS framework, needs to be developed

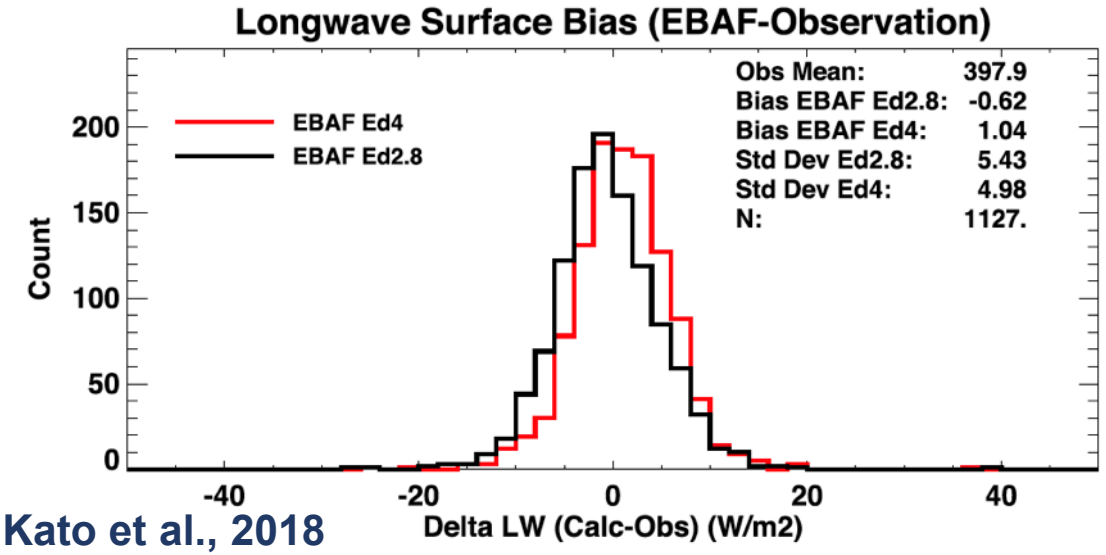
➔ Cross-cutting: to air/sea flux discussion

# **Earth Energy Surface Budget:** Validation of satellite-derived surface downward irradiances over ocean

**Courtesy: S. Kato**

Monthly mean differences (computed – observed) at 46 buoy sites




Kato et al., 2018

- Computed monthly mean shortwave and longwave downward surface radiative fluxes over ocean agree well with observed radiative fluxes at 46 buoy sites.
- Uncertainty in observed downward shortwave and longwave radiative fluxes are ~ 5 $Wm^{-2}$
- Computed radiative fluxes are used to compute global annual mean surface radiative fluxes
- **The surface energy budget balance residual is not explained by the uncertainty in the radiative flux alone**

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- To reduce the uncertainty in global mean radiative fluxes, it is necessary to reduce the uncertainty in near surface (boundary layer) temperature and humidity (especially in polar regions).
- **More buoys in midlatitude and polar regions are necessary to further quantify bias in radiative fluxes over ocean.**

# **The Earth surface budget:** key issues

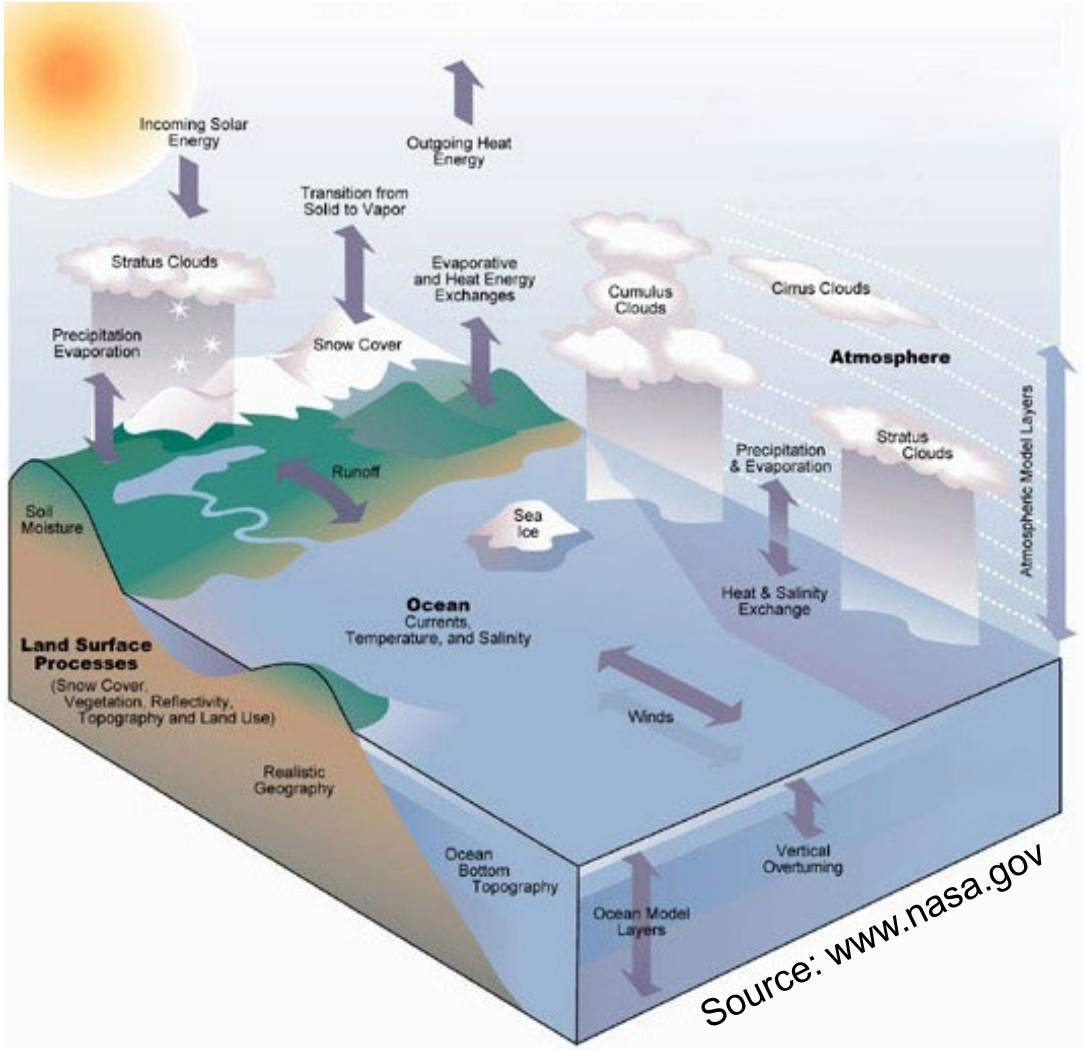
**Key issues:**

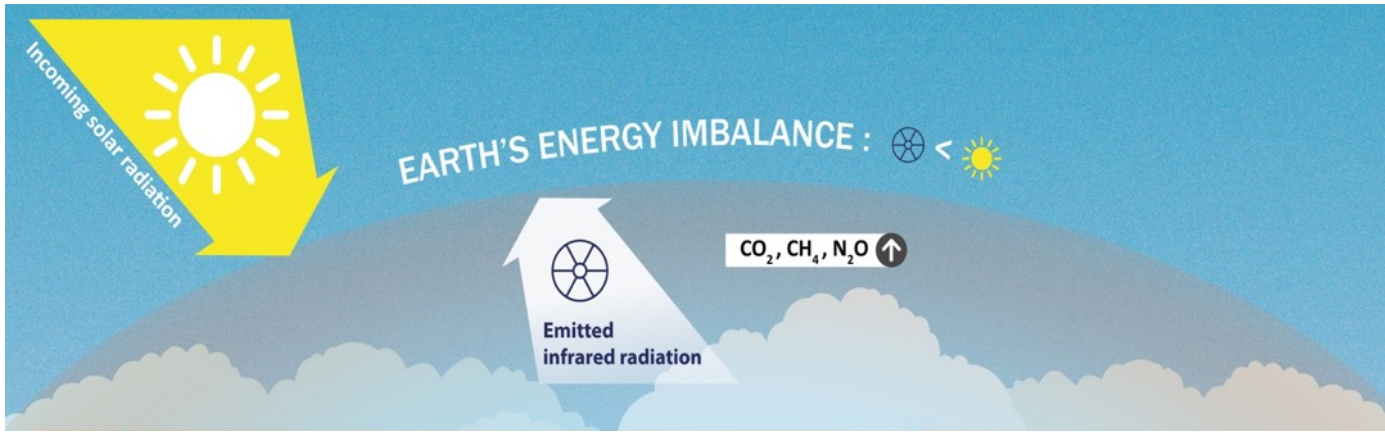
- Improve uncertainty understanding of the 10 Wm-2 to 15 Wm-2 global surface energy balance residual
- Investigation of surface energy budget at smaller temporal and spatial scales (e.g. monthly, regional)
- Adress issue on accuracy and stability requirements, which can widely vary depending on applications (climate change, regional, …)
- Accuracy and stability requirements need to be specified by flux type (radiative fluxes & turbulent fluxes).
- Horizontal energy transport to achieve regional energy budget closure regarding to regional energy budget.
- Target accuracy and stability needed to combine in situe surface observations and surface flux data products.

**Next steps:**

- Reduce the uncertainty in surface energy fluxes by reducing uncertainties in near surface properties (e.g. temperature, water vapor, wind speed).
- Assessments, intercomparisons activities are taking place under GEWEX/GDAP.

# **Earth Energy Budget closure:** an integrated way forward




1. **Global observations for the Earth surface budget: state of the energy cycle**

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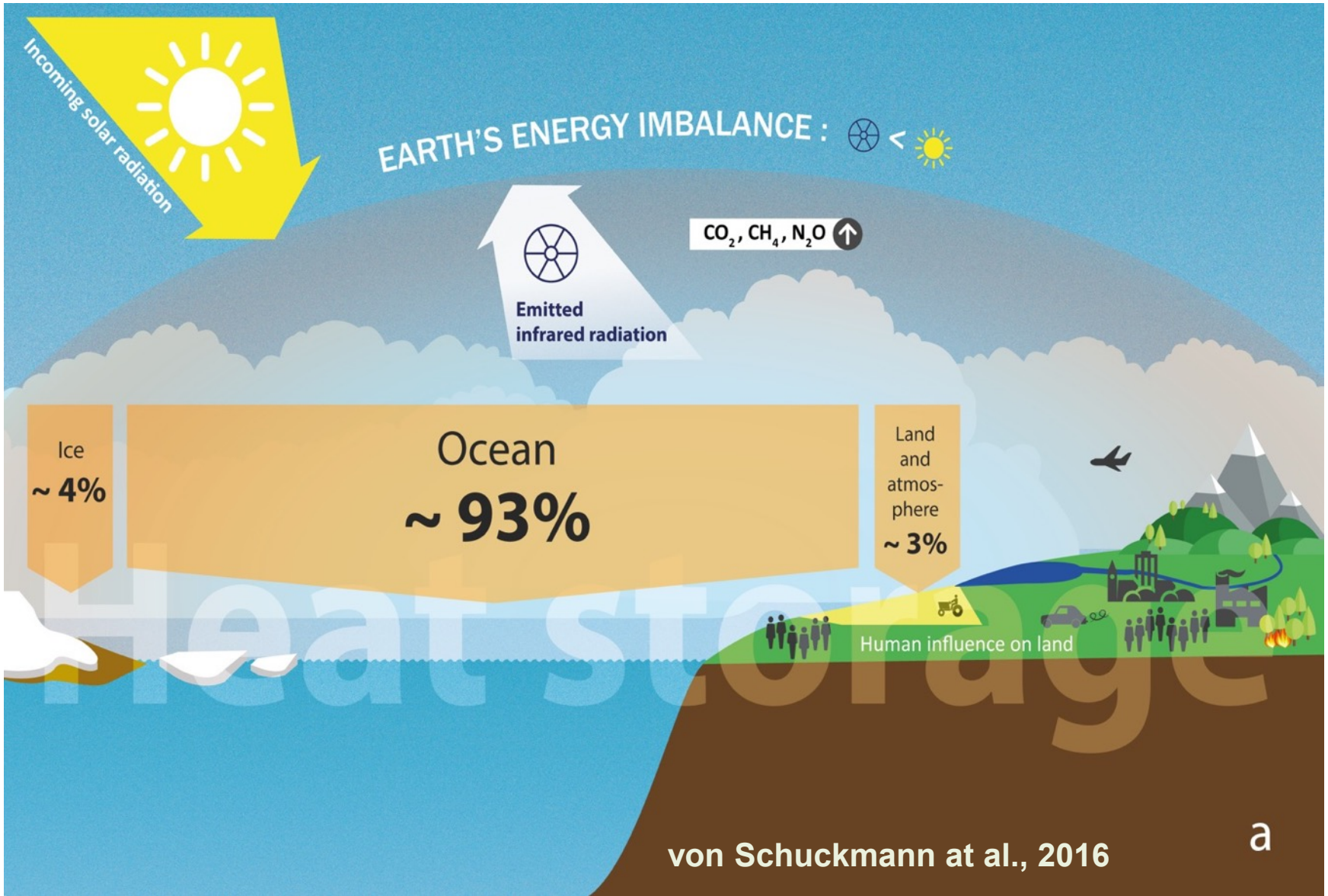
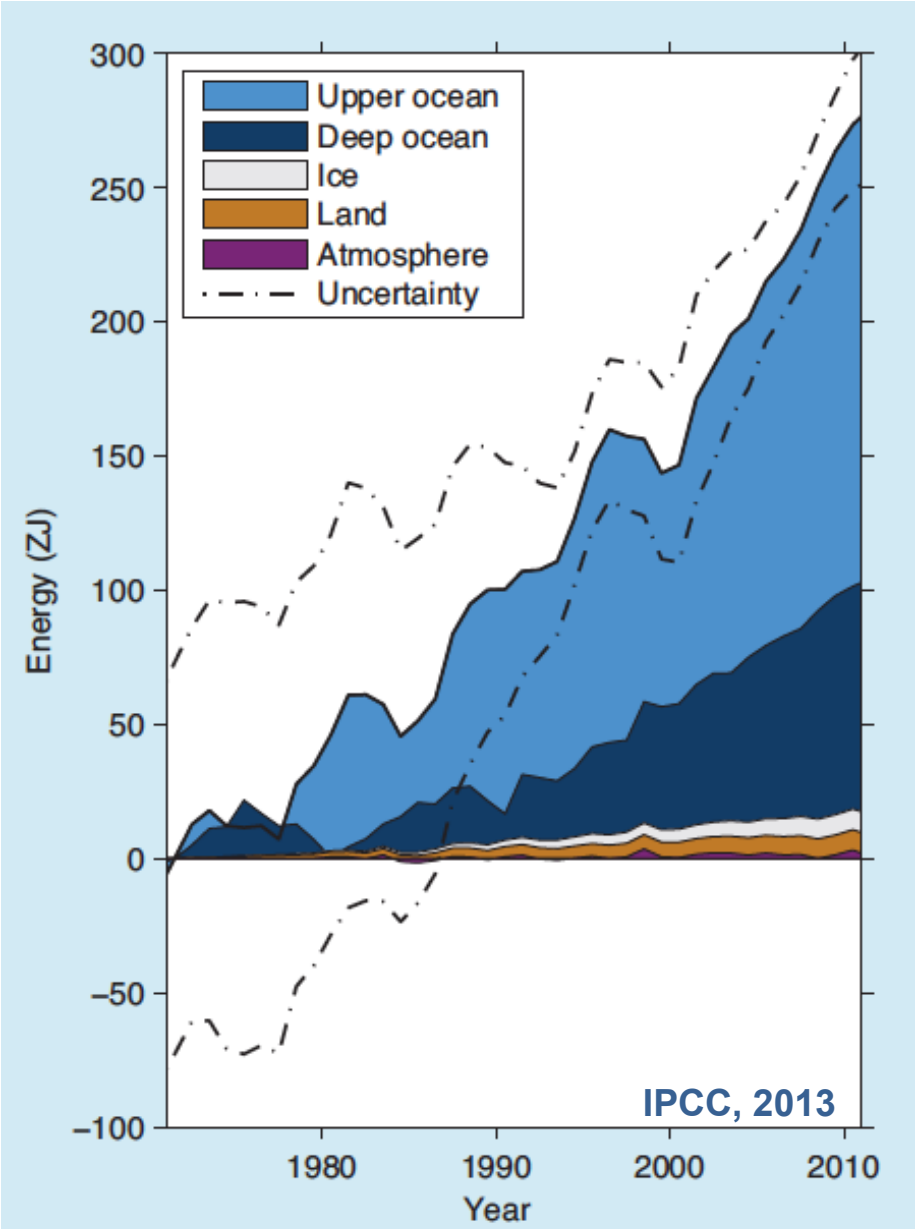
# Global observations for Earth's Energy Imbalance

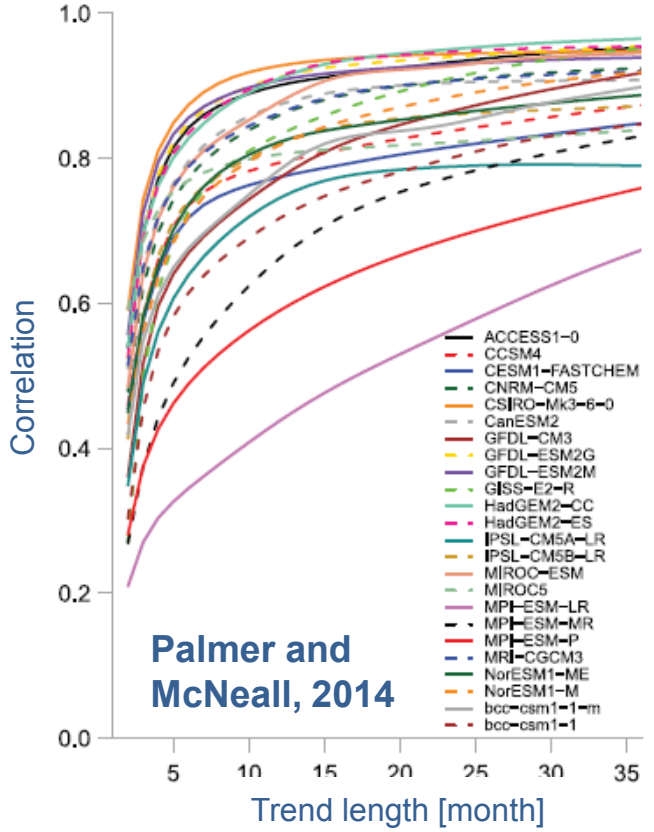
## Accumulated heat in the Earth system and its implications



# The Earth energy imbalance can currently best be estimated from changes in ocean heat content, complemented by radiation measurements from space (von Schuckmann et al., 2016, NCC)

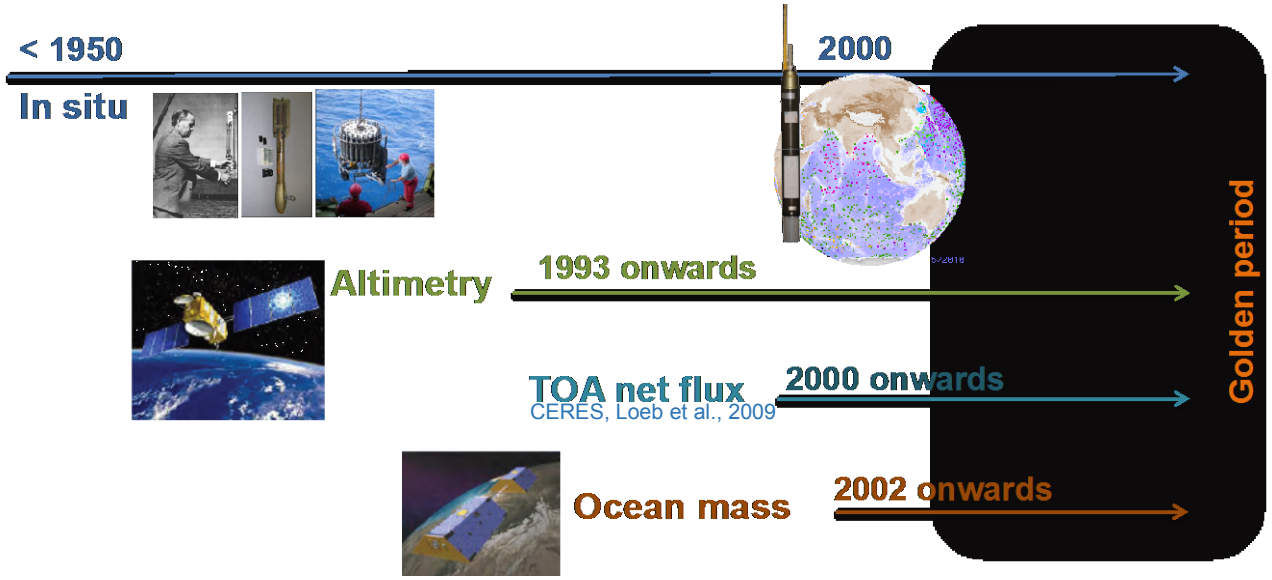


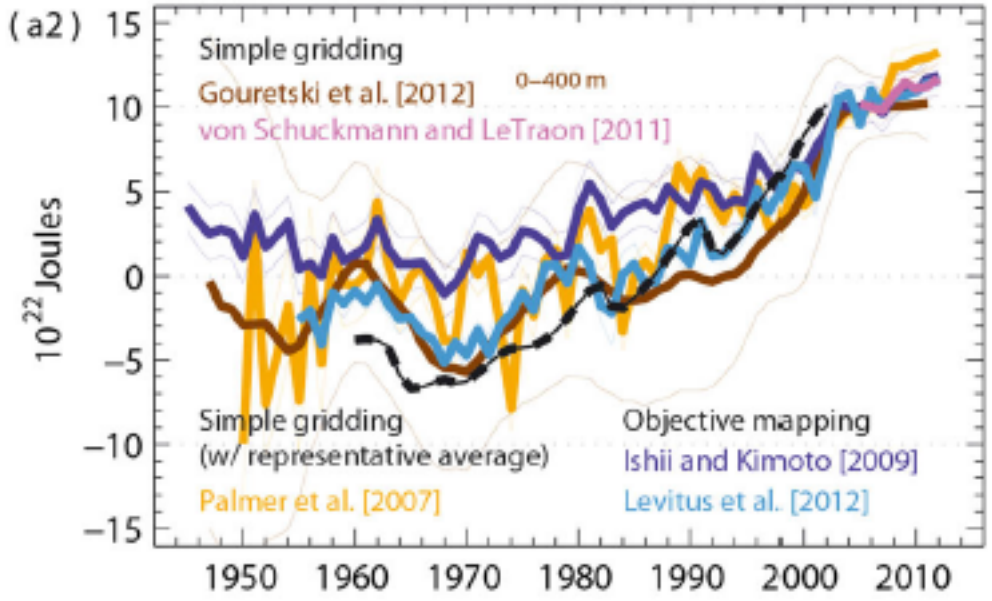

Correlation in total system energy & ocean heat content as a function of trend length



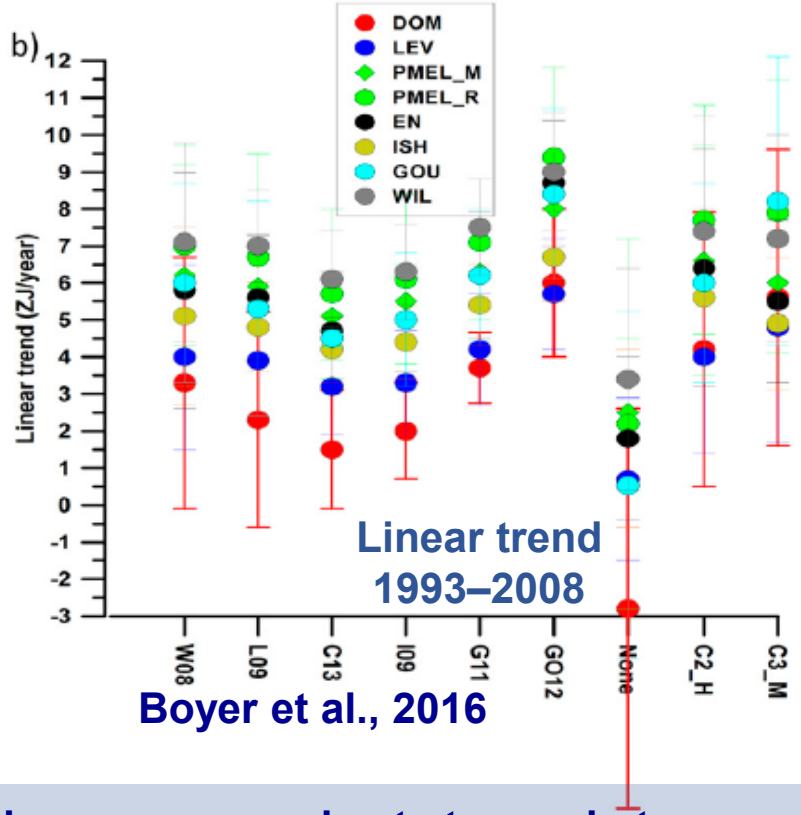

Climate models suggest that the global ocean becomes the dominant term in the Earth's energy budget on **timescales longer than about 1 year**

# Ocean heat content estimates: Current status and challenges



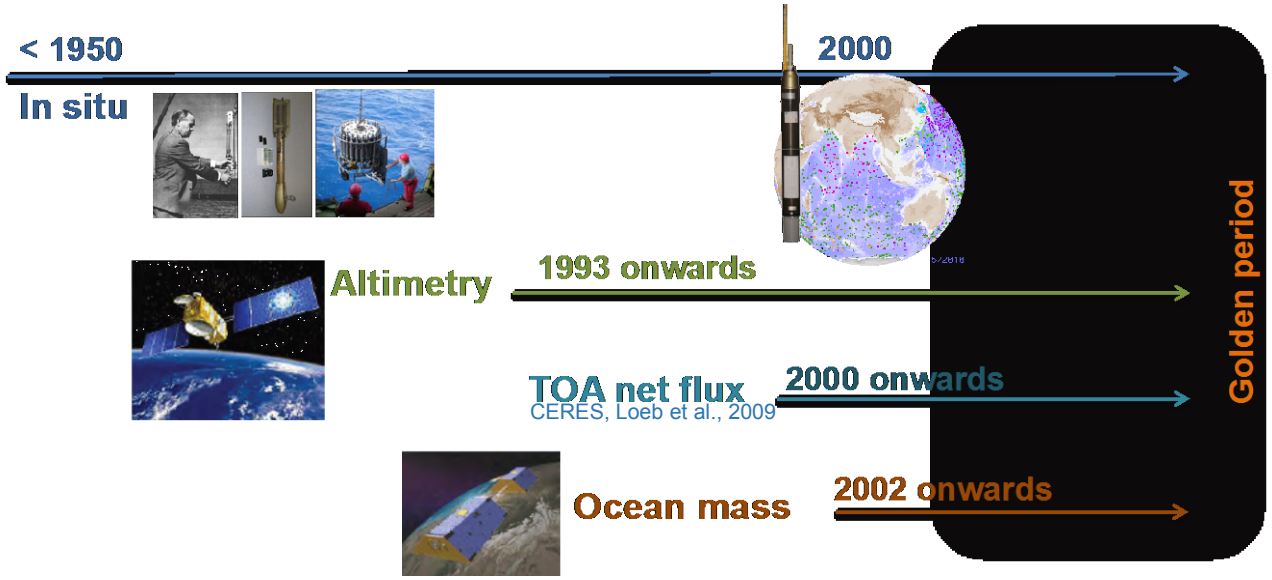

Abraham et al., 2013

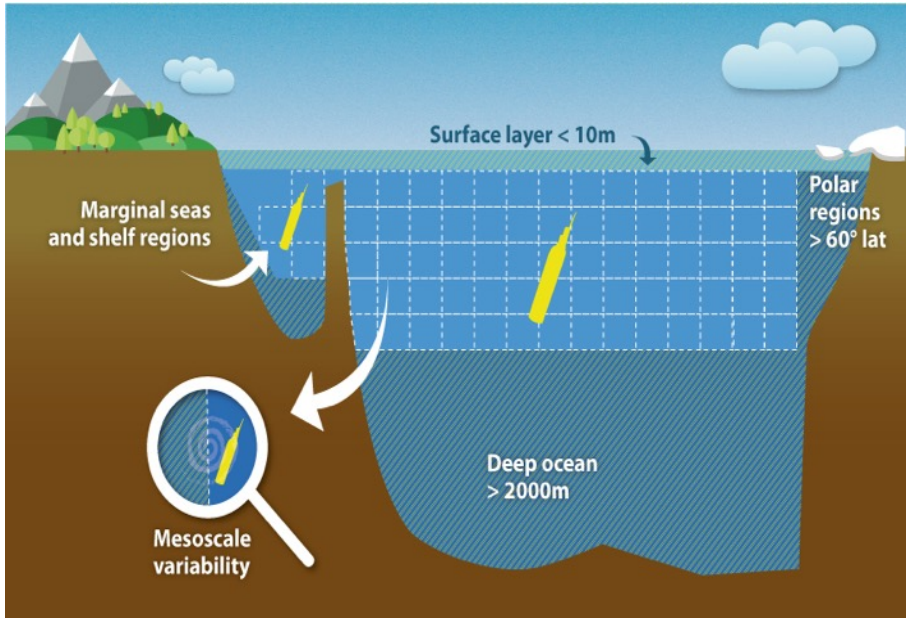



Boyer et al., 2016

- Differences in upper-ocean heat storage between analyses due to mapping, bias correction, baseline climatology & data quality (➔ www.iquod.org)
- Differences in "interannual to decadal variability" between analyses.
- All estimates show a multi-decadal increase in OHC in both, upper and deep ocean regions.

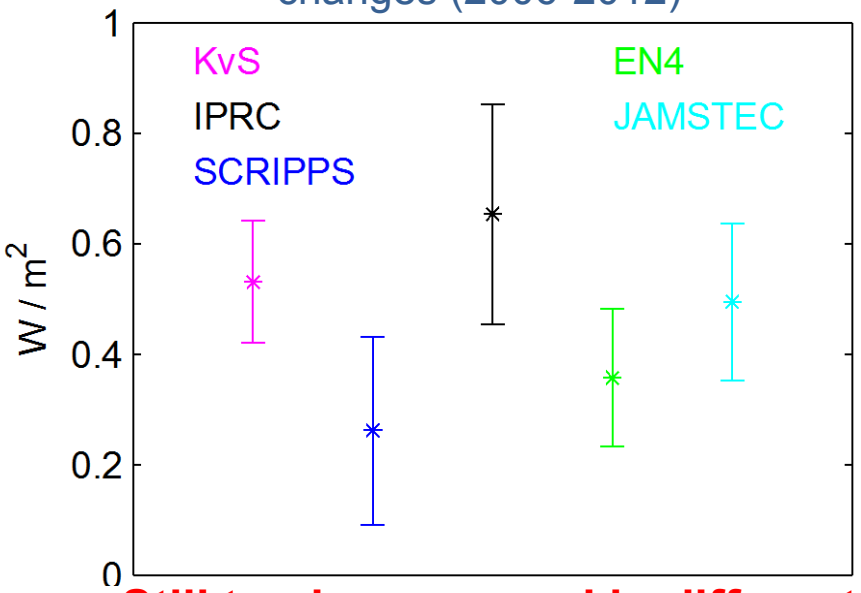
# Ocean heat content estimates: Current status and challenges




von Schuckmann et al. (2016)

Decadal OHC (upper 2000m) changes (2006-2012)

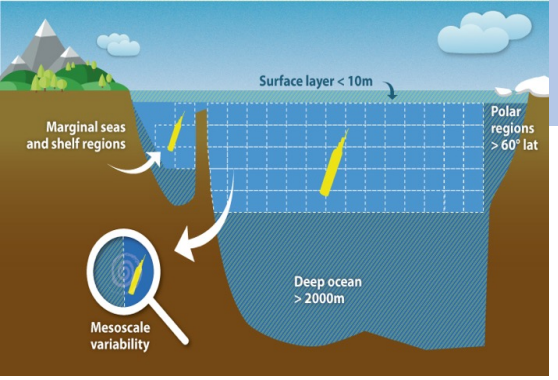



**Still too large spread in different estimates !!!**

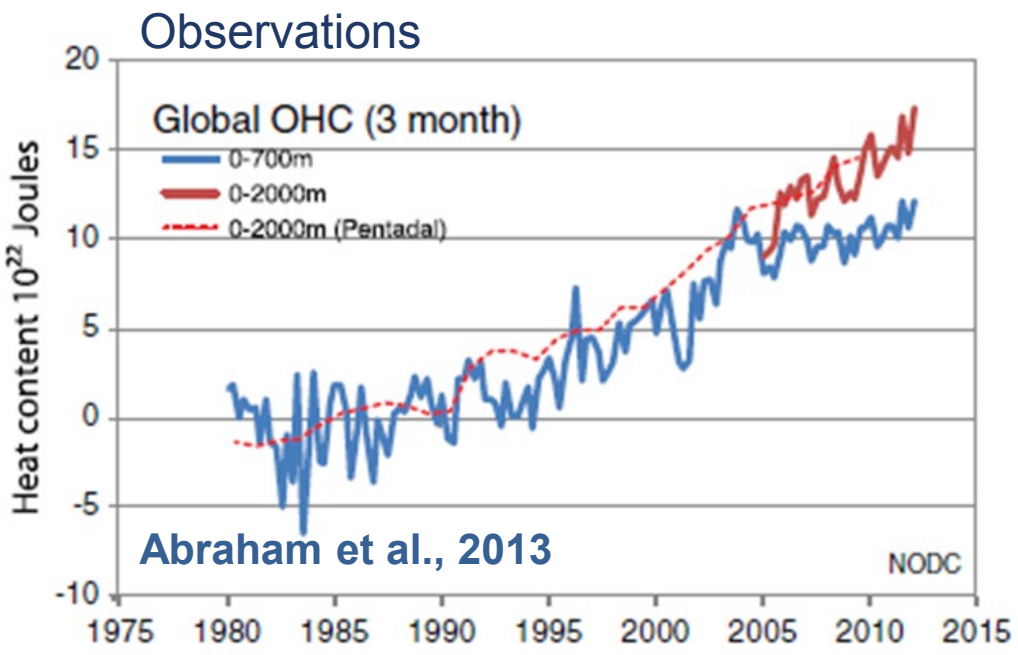
Coverage is not yet truly global, as Argo does not cover:

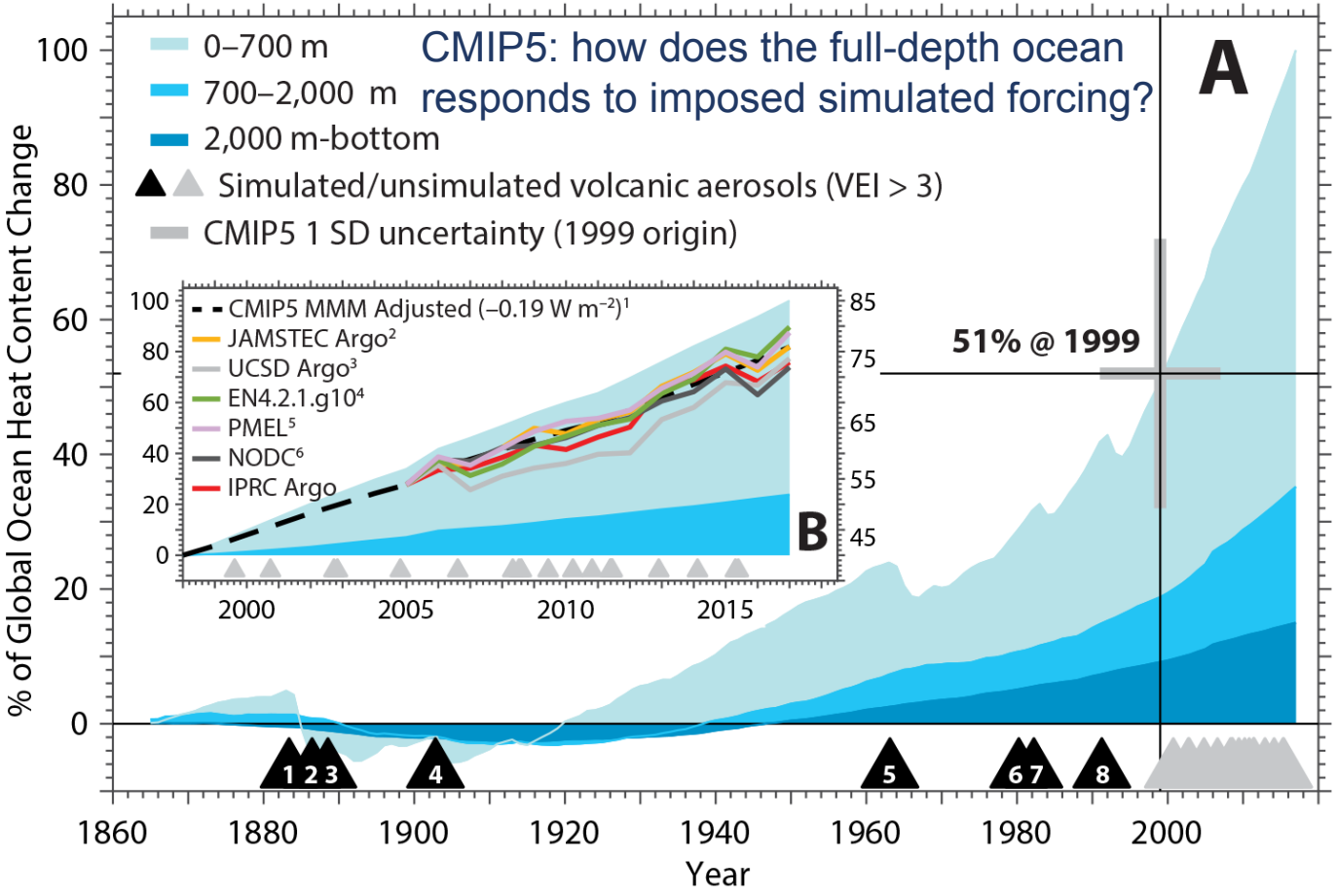
- the deep ocean below 2000m depth
- the shelf areas and marginal seas
- pole wards of 60° latitude
- the near surface layer

# Ocean heat content estimates: What can we expect from these undersampled regions?




Due to poor spatial coverage, particularly in the deeper ocean, the rate of deep ocean warming may have been underestimated.



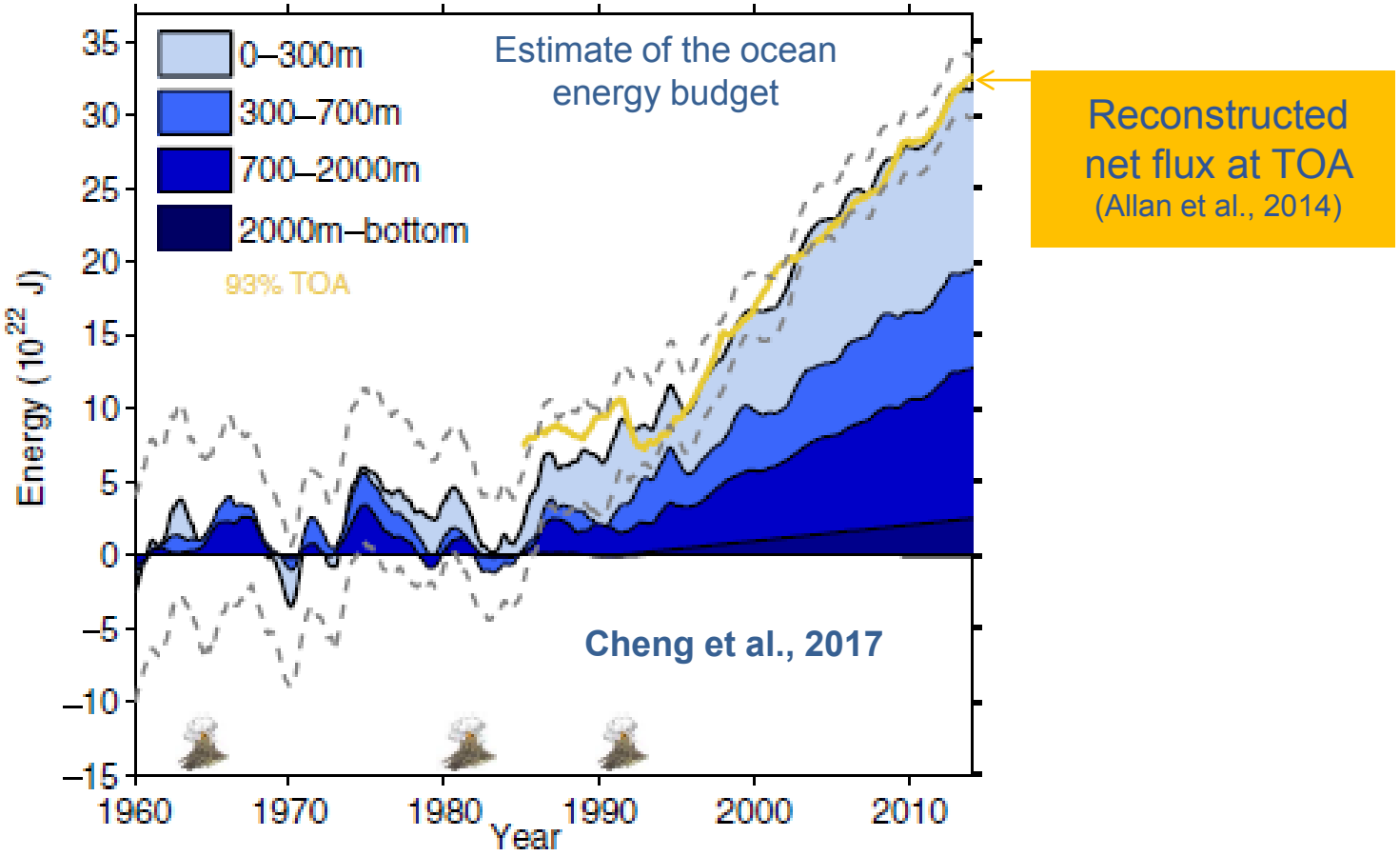

[1] Ridley et al., 2014; [2] Hosoda et al., 2008; [3] Roemmich & Gilson, 2009; [4] Good et al., 2013; [5] Johnson et al., 2018; [6] Levitus et al., 2012

**Palmer et al., 2019**

Several studies have highlighted the propagation of the climate change signal into the deeper ocean over time

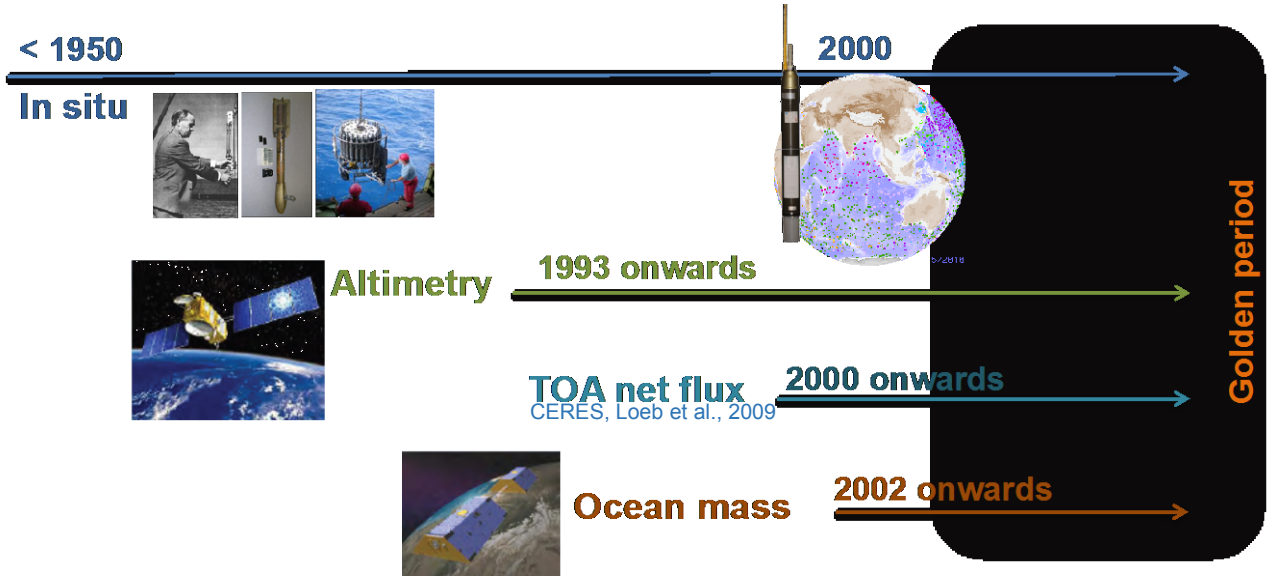
# Close correspondence:
# Rate of ocean heat content change and net flux at TOA

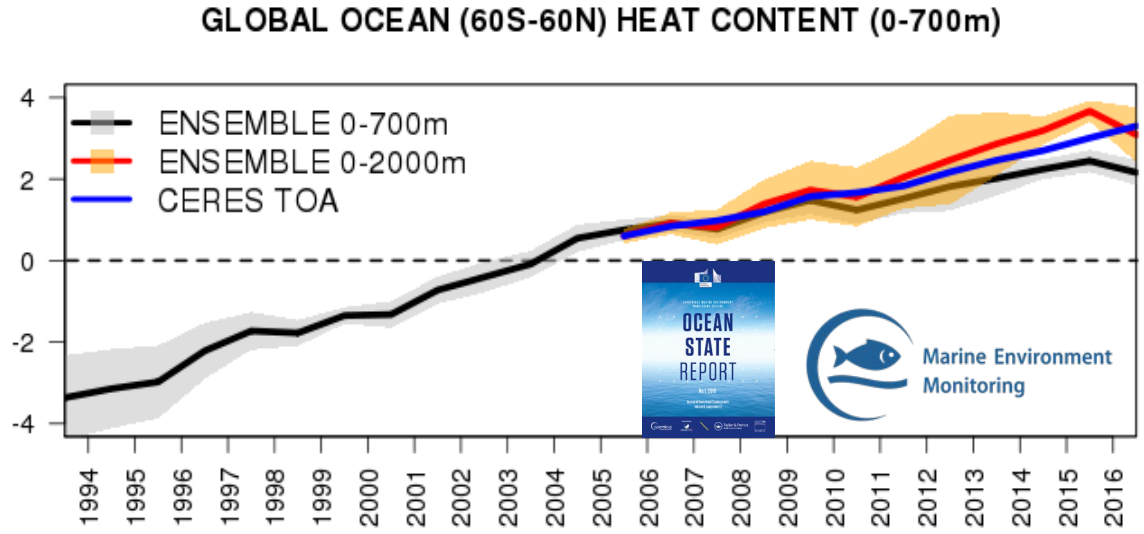
Change in **TOA net radiation** and **rate of global ocean heat storage** from independent global climate observing systems should be **in phase** and of the **same magnitude** on annual and longer time scales (e.g. Loeb et al., 2012)



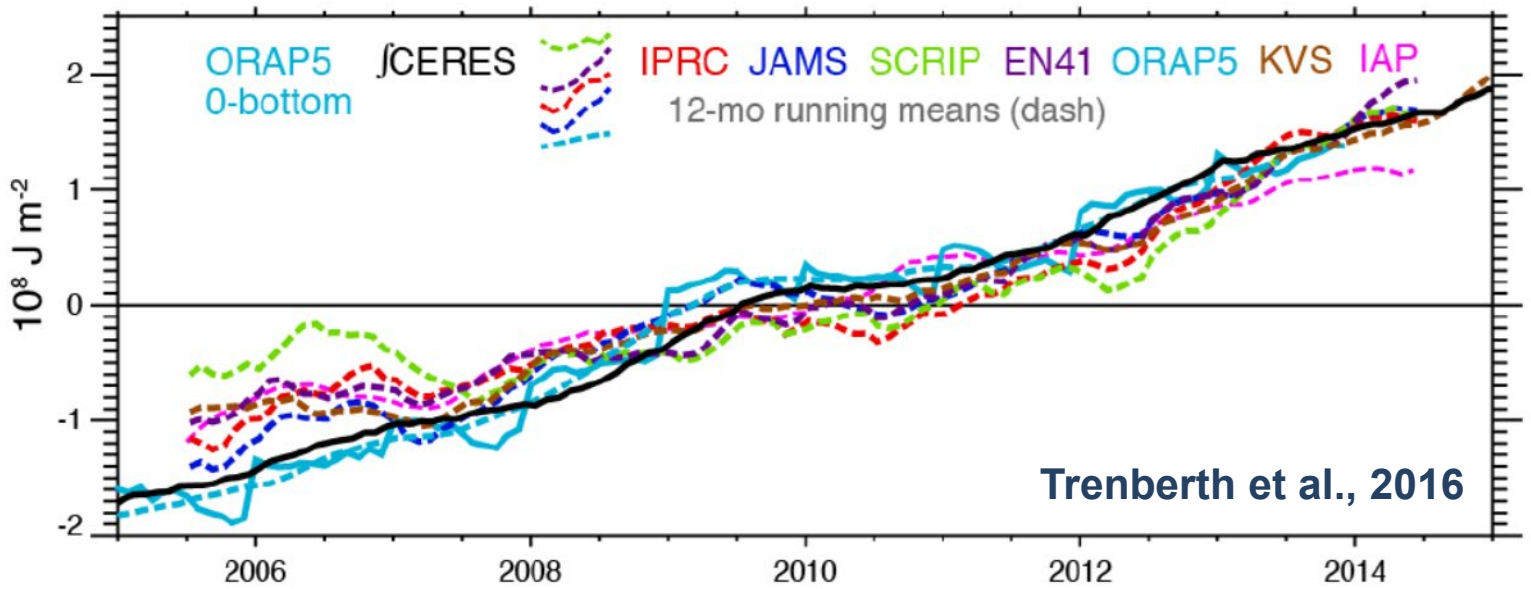

**All other forms** of heat storage are **factors of 10 smaller** at that time scale (Trenberth et al., 2009; Loeb et al., 2012, Palmer and Mc Neal 2014, von Schuckmann et al., 2016).

# Concept of physical budget constraint for the Earth energy imbalance




**von Schuckmann et al., 2018**




**Trenberth et al., 2016**

# Earth Energy Imbalance

**Box 2: The Earth Energy Imbalance**

| | |
|---|---|
| **Target from GCOS IP** | **Balance energy budget to within 0.1 $Wm^{-2}$ on annual timescales** |
| **Other proposed targets** | **Quantify changes in the Earth Energy Imbalance with an accuracy of < 0.1 $Wm^{-2}$ on multiannual-to-decadal time scales, and with an accuracy of < 0.5 $Wm^{-2}$ on subannual-to-interannual timescales**<br>**Quantify changes in heat stored in the Earth system on multiannual-to-decadal time scales with an accuracy of < 0.1 $Wm^{-2}$ for ocean, land, cryosphere and atmosphere (expressed relative to Earth's surface area)** |
| **Who** | **Operators of GCOS-related systems, including data centres** |
| **Time frame** | **Ongoing** |
| **Performance indicator** | **Regular assessment of uncertainties in estimated changes and inventories** |

# Earth Energy Imbalance

**Key issues:**

1. How can we improve the absolute value of the EEI estimate, and which are the major observing system recommendations?
2. What practical steps can be undertaken to perform/update the inventory of the EEI in the Earth system, and to obtain observing system recommendations from this approach?
3. How can we improve the understanding and estimate of the implications of a positive and changing EEI?
4. Are the existing ECV requirements adequate? Do they capture the scales needed?
5. Can we formulate recommendations for improved data availability, or novel observation techniques?
6. What practical steps can be undertaken/recommended in the short term? Could we establish application-related requirements in addition to the climate-related requirements?

# Earth Energy Imbalance:
# Progress can be achieved with a concerted international effort

**CLIVAR research focus CONCEPT-HEAT: Consistency between planetary energy balance and ocean heat storage:** An overall goal is to **bring together different climate research communities** all concerned with the energy flows in the Earth's System to advance on the **understanding of the uncertainties through budget constraints**:

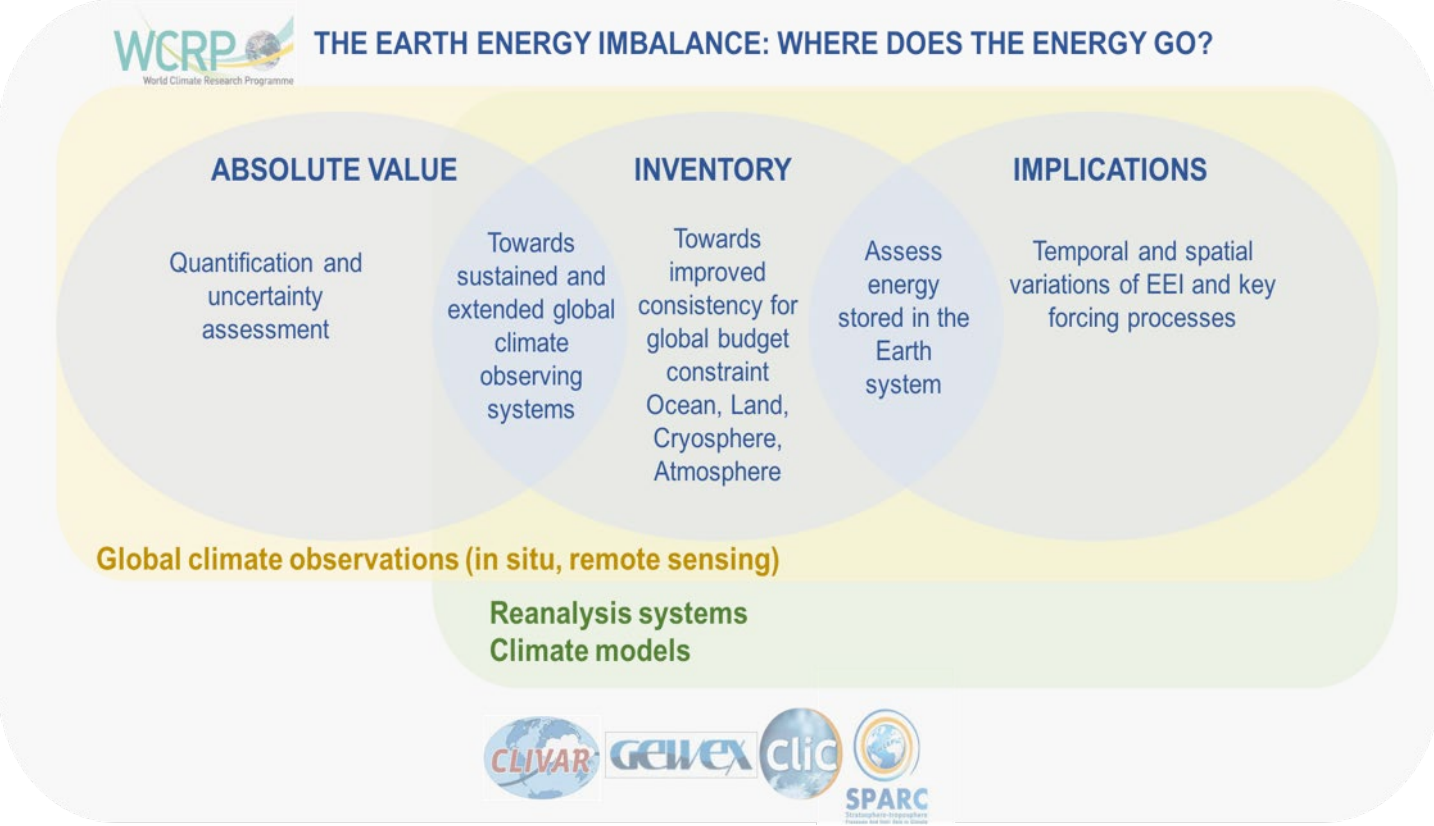

- **Atmospheric radiation**
- **Ocean Heat Content**
- **Earth's surface fluxes**
- **Climate variability and change**
- **Data assimilation & operational services (R&D)**
- **Climate projection**
- **Global sea level**

Co-chairs:
K. von Schuckmann,
T. L'Ecyuer

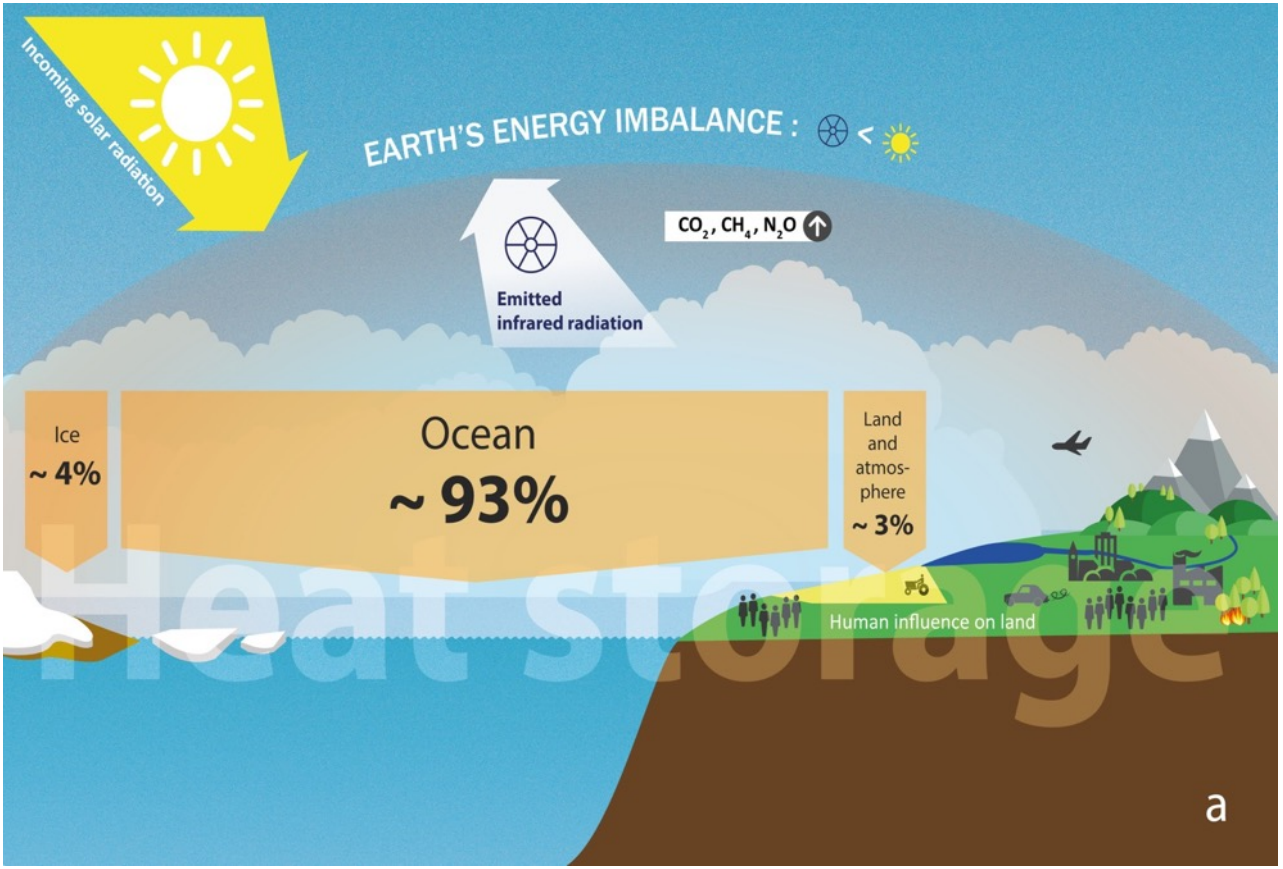
| Remote sensing | In situ | Reanalysis systems | Numerical model |
|---|---|---|---|

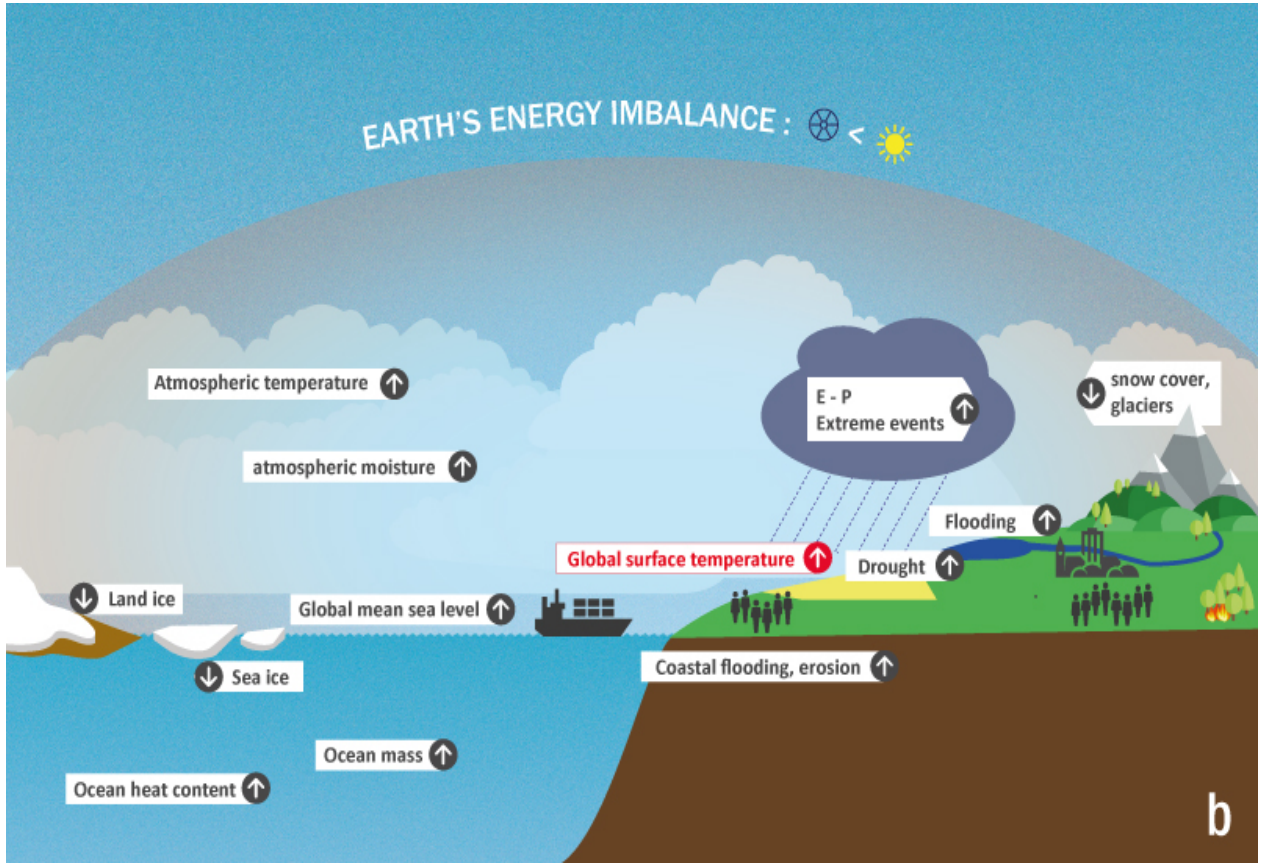
# WCRP workshop
# "The Earth's Energy Imbalance and its implications"
13 – 16 November 2018, Toulouse, France

Objective: to initiate a new WCRP-wide activity "The Earth's Energy Imbalance and its implications" and to thus strengthen and extend the community on the Earth's energy imbalance through a community wide discussion on links across all the WCRP core projects and relevant activities.



# The Earth Energy Imbalance and its implications: Where does the energy go ?



# Thank you !