Some highlights on CLIVAR Energy Activities

Reporting by Pierre-Philippe Mathieu, ESA/ESRIN, Frascati, Italy.
pierre.philippe.mathieu@esa.int
WCRP WDAC-05, Asheville, USA, 7 Apr 2016 Draft V01

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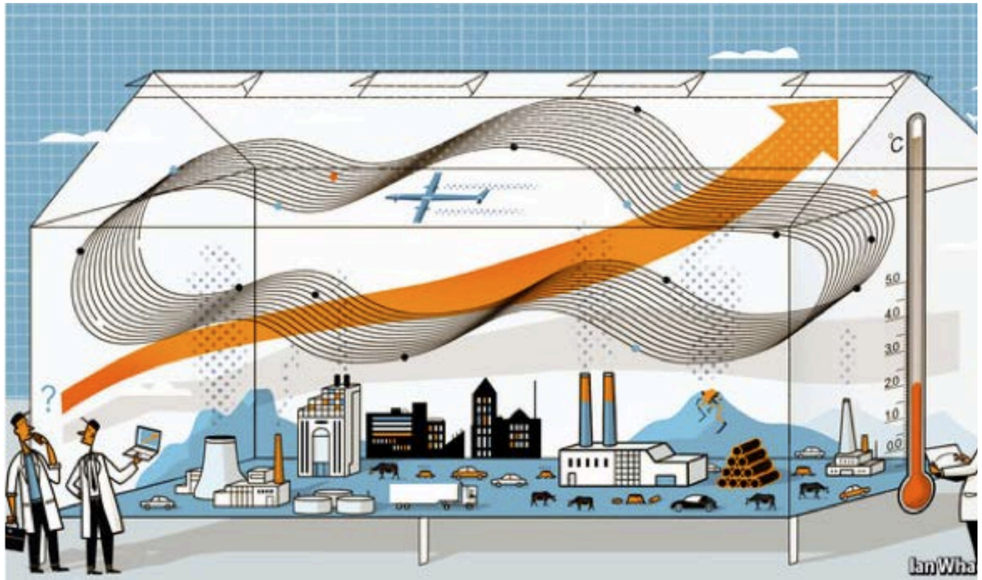
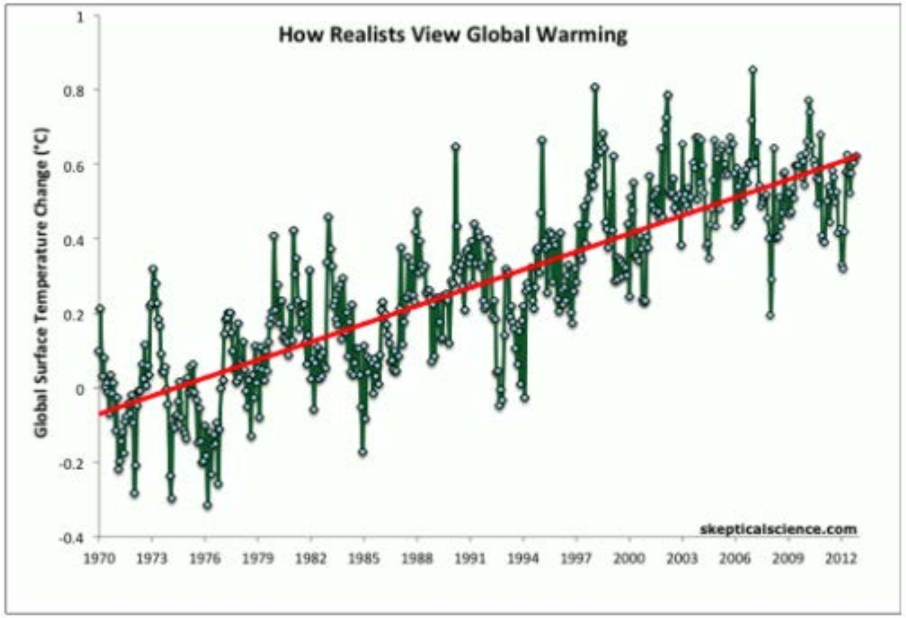
Why?

The Temperature Plateau - A Sensitive Matter

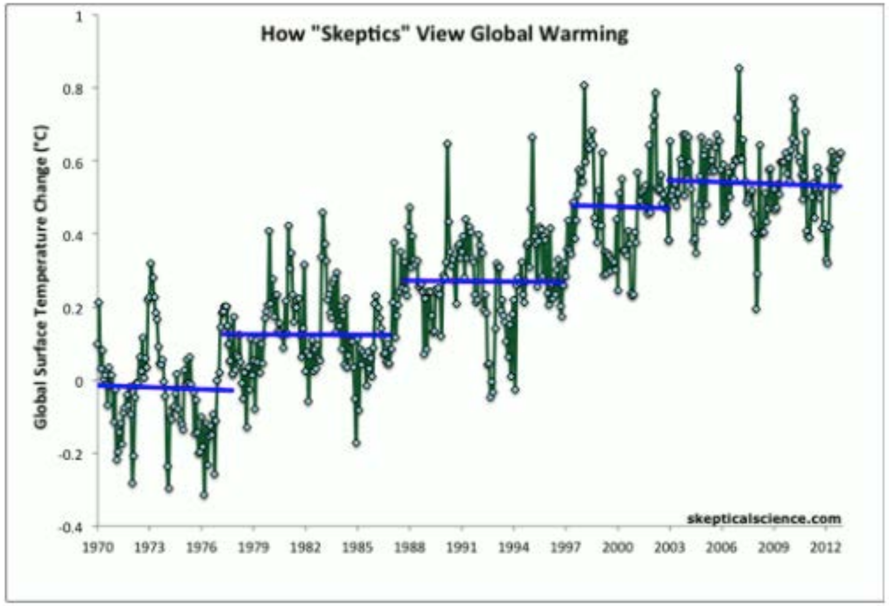




Climate science

A sensitive matter

The climate may be heating up less in response to greenhouse-gas emissions than was once thought. But that does not mean the problem is going away



Source: The Economist, March 2013

Hiatus period as seen from space (SST)

space for our climate

ESA | SPACE FOR OUR CLIMATE | OBSERVING THE EARTH

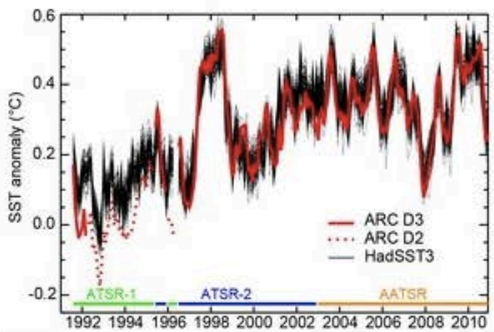
- About climate change
- Space and Earth Monitoring
  - + Land
  - + Oceans
  - + Ice
  - + Atmosphere
  - + Biosphere
- + International treaties implementation
- + About Observing the Earth

EO programmes

- The Living Planet
- Copernicus

ESA > Our Activities > Observing the Earth > Space for our climate

IS GLOBAL WARMING HIDING UNDERWATER?



Sea-surface temperature

7 February 2014 Satellite observations of global sea-surface temperature show that a 30-year upward trend has slowed down within the last 15 years. Climate scientists say this is not the end of global warming, but the result of a rearrangement in the energy flow of the climate system and, in particular, how the ocean stores heat.

Like flying thermometers, some satellites carry instruments that provide a global view of the surface temperature of oceans and seas. Measuring the sea-surface temperature is important for improving weather and ocean forecasting and climate change research.

Search here

Related links

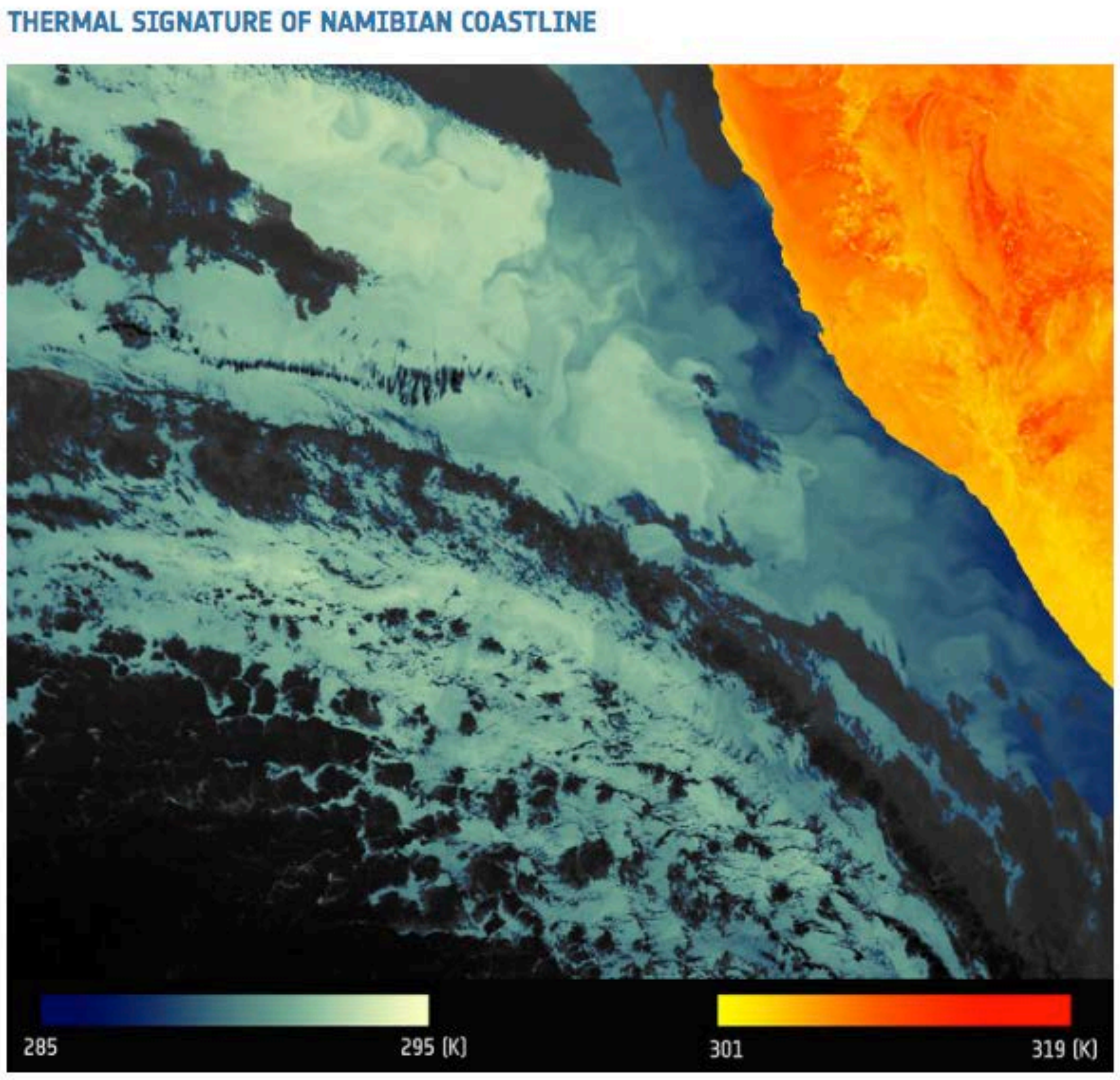
- ESA's Climate Change Initiative (CCI)
- Intergovernmental Panel on Climate Change (IPCC)
- UK Met Office
- University of Reading
- Copernicus

Related missions

- ERS
- Envisat
- Sentinel-3

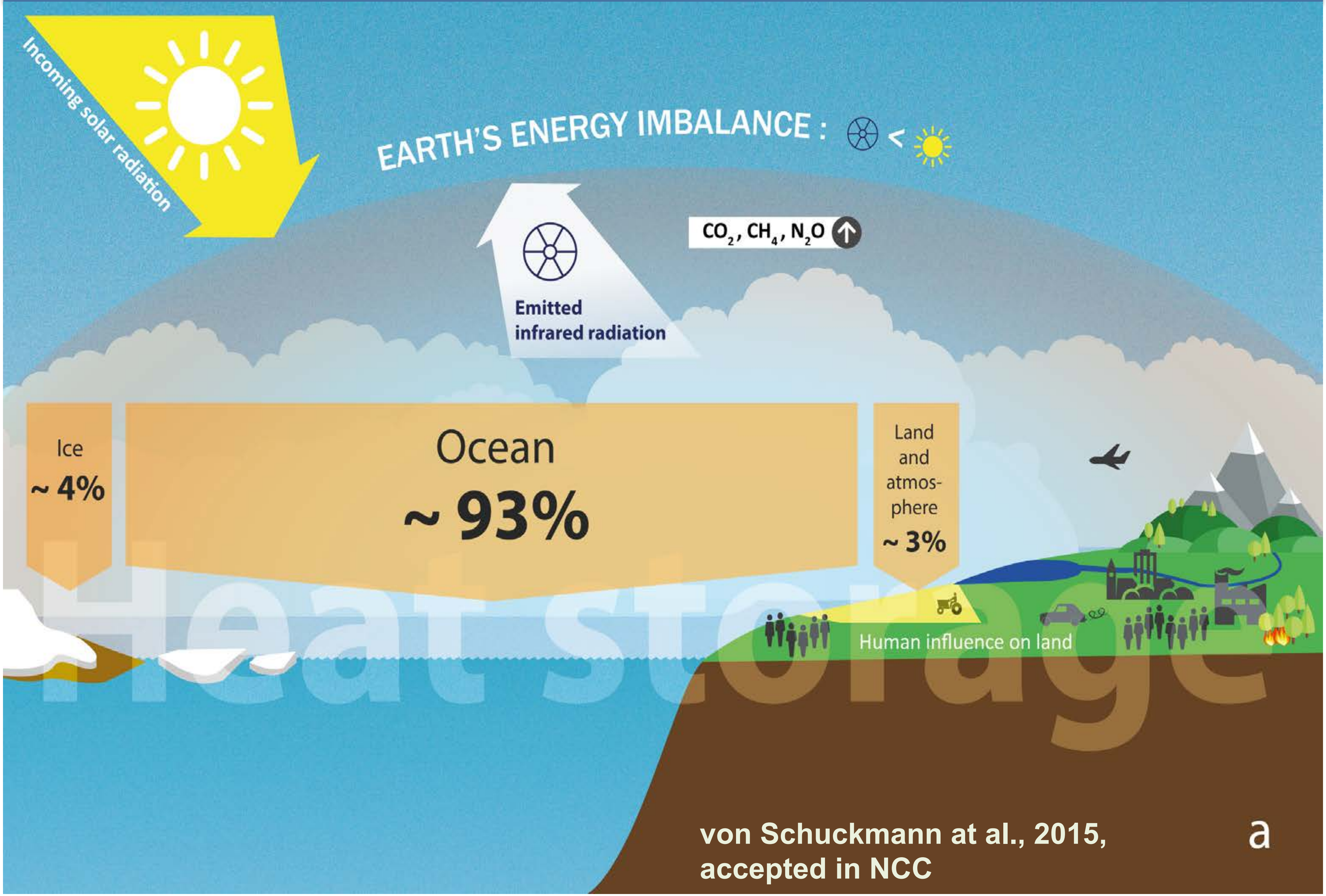
Possible causes? .. Natural Climate Variability, Reduced Solar Variability, ENSO (La Nina), Increased Stratospheric Aerosols from Volcanoes, Asian Pollution, Deep ocean heat uptake, Sampling Bias in polar regions, Obs quality, ….

Heat as seen from Space through S-3



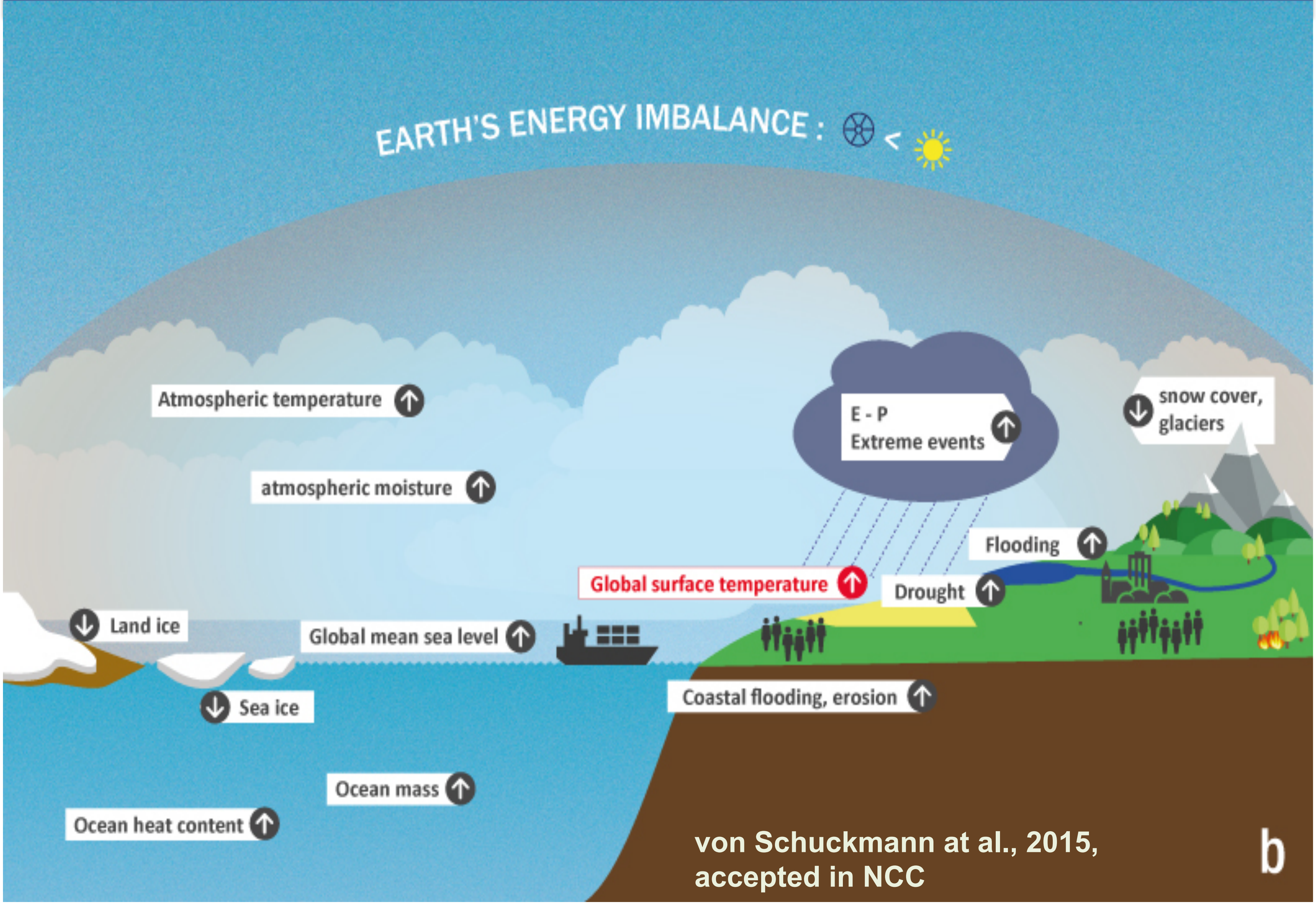
S3A SLSTR
05.04.2016
Namibian coast

Positive Earth's Energy Imbalance: accumulation and storage of heat



von Schuckmann at al., 2015, accepted in NCC

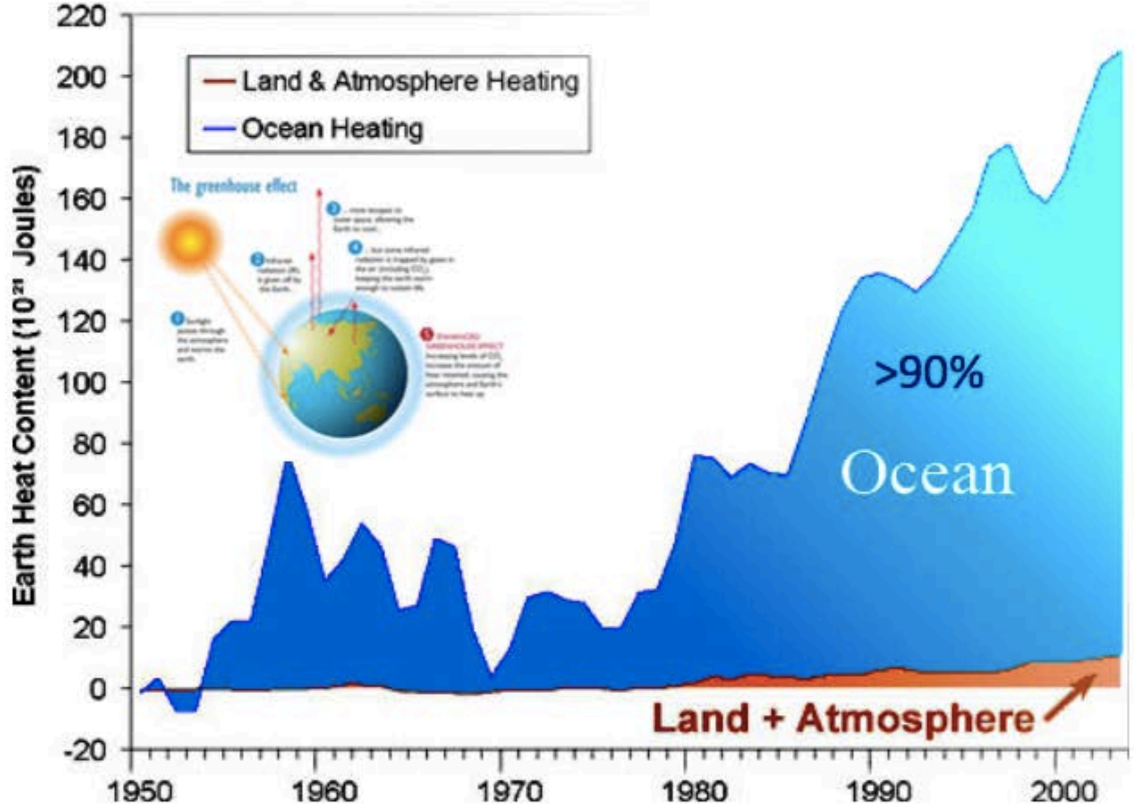
“Symptoms” of positive EEI



von Schuckmann at al., 2015, accepted in NCC

Integrated Earth System Approach

Earth's total heat content



Rhein et al. (2013) IPCC AR5

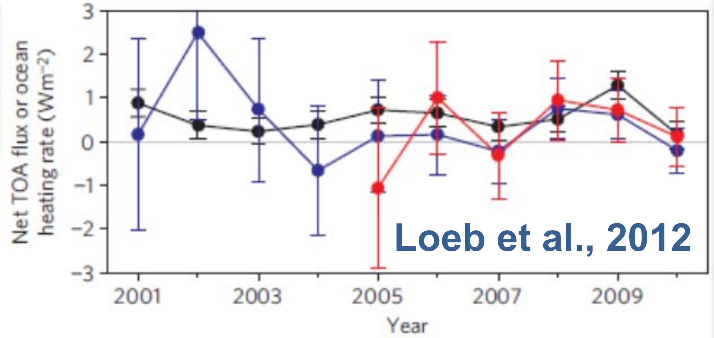
Ocean is a big player in our understanding of climate variability as well as changing climate.

- Earth Energy Imbalance
- Water cycle
- Sea level

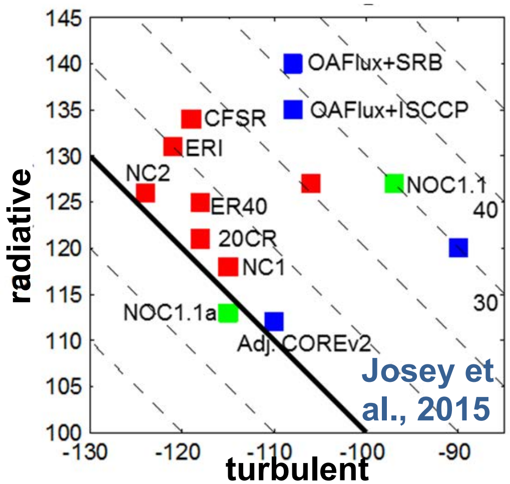
Demands high-quality, complete and consistent long-term ocean data

Different approaches determining Earth's energy imbalance

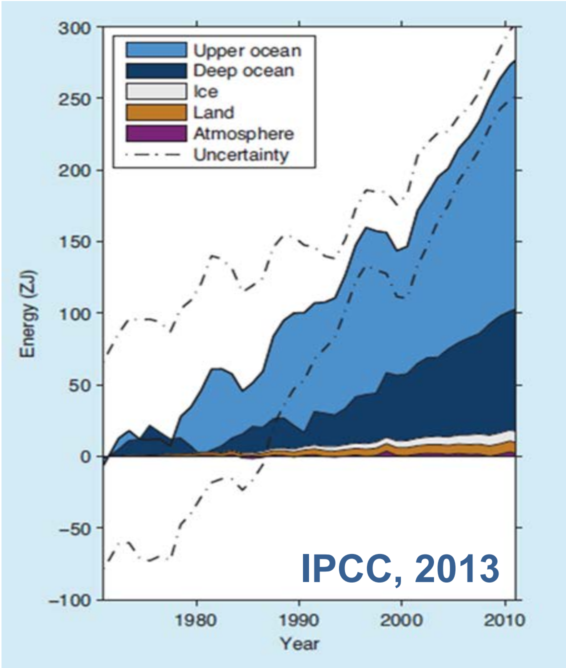
Radiation at TOA



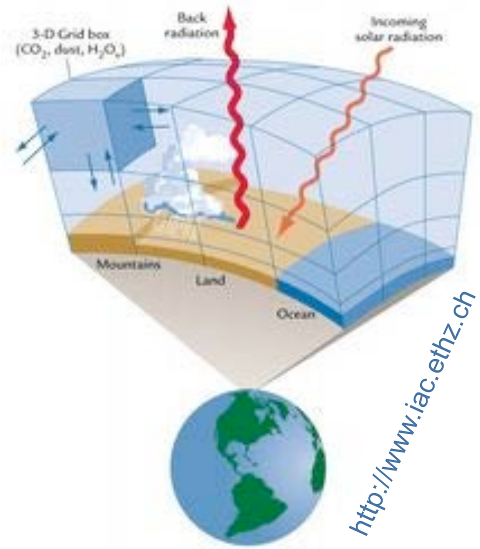
Surface flux



Storage inventory (OHC)



Hindcast and climate projection



Different approaches determining Earth's energy imbalance: TOA & OHC

Estimates of EEI

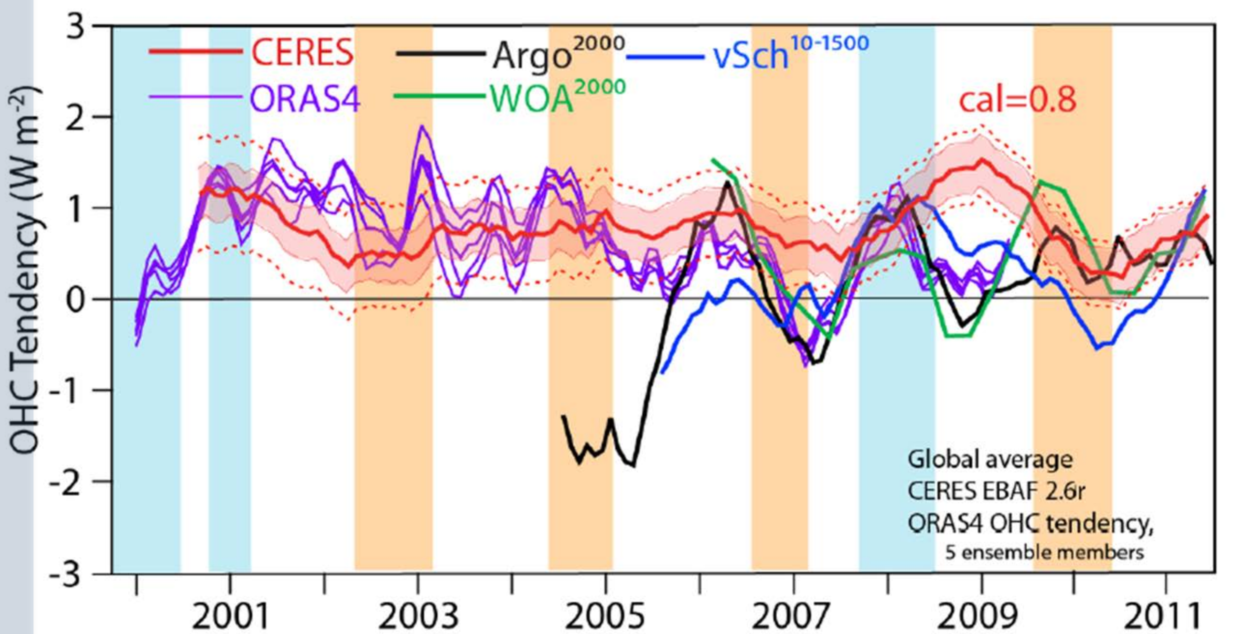
1993-2008: 0.8 to 0.9 Wm²
(Trenberth et al., 2011; Trenberth and Fasullo, 2011; Hansen et al., 2011; Balmaseda et al., 2013b)

1993-2008: 0.57 Wm²
(Hansen et al., 2001 with Levitus et al., 2009 OHC, or similar with Johnson et al., 2012 OHC)

2001-2010: 0.50 ± 0.43Wm²
(Loeb et al., 2012 with Lyman et al., 2010 OHC (up-dated)).

2005-2010: 0.58 ± 0.15Wm²
(Hansen et al., 2011 with Argo OHC, von Schuckmann and Le Traon, 2011)

2001-2011: 0.5-1 Wm² (Trenberth et al., 2014, range from different OHC estimates)



Trenberth et al., 2014

"Missing energy" remains at interannual time-scales:
All OHC estimates show CERES 2007 cooling, all miss CERES warming in 2008/2009
➔ unable to achieve closure at interannual scales
➔ remaining errors either in CERES or **OHC**

How?

CONCEPT-HEAT

Clivar research focus

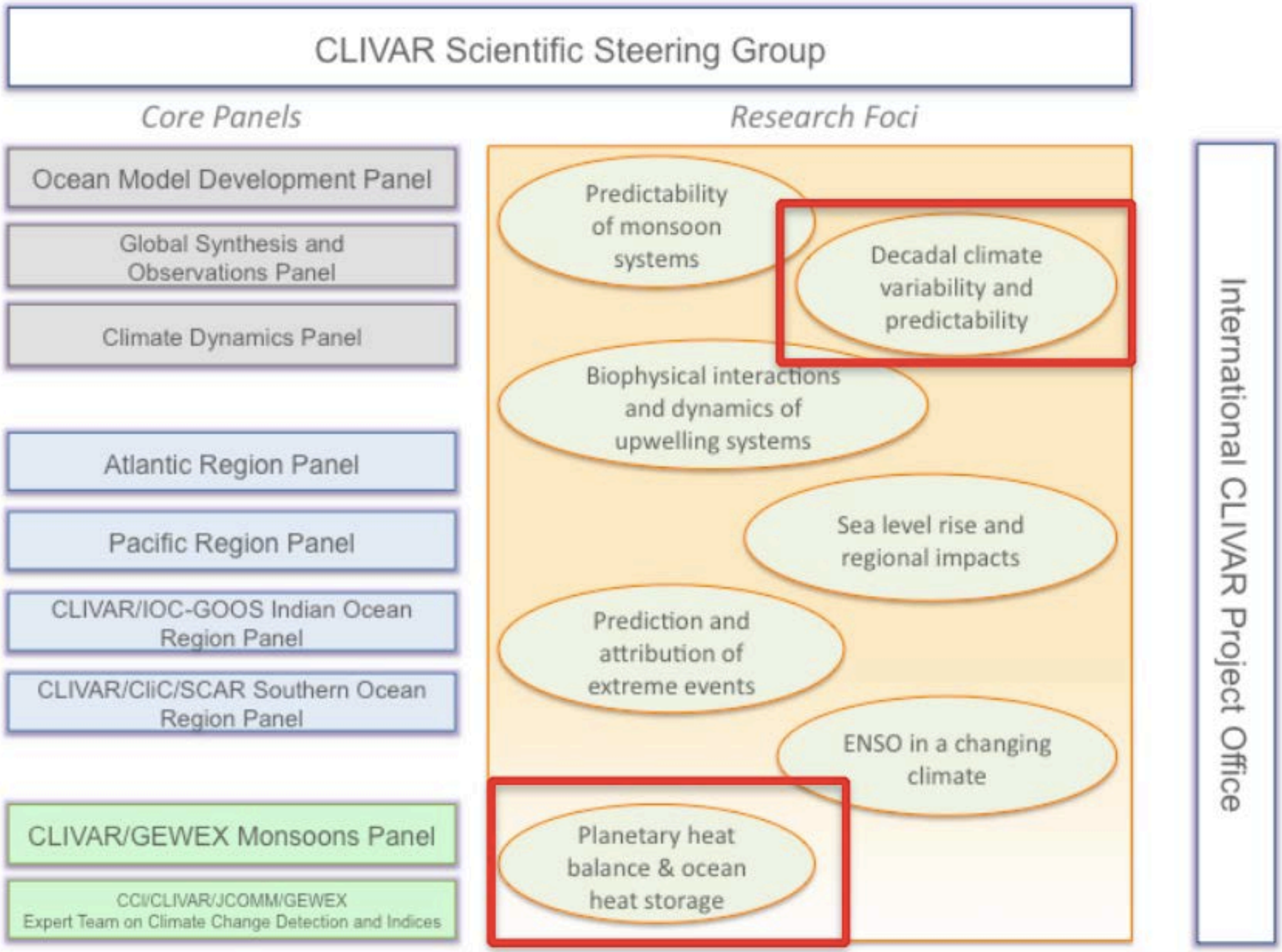
Consistency between planetary energy balance and ocean heat storage (CONCEPT-HEAT)

Co-chairs:

K. von Schuckmann, K. Trenberth

Scientific steering team members:

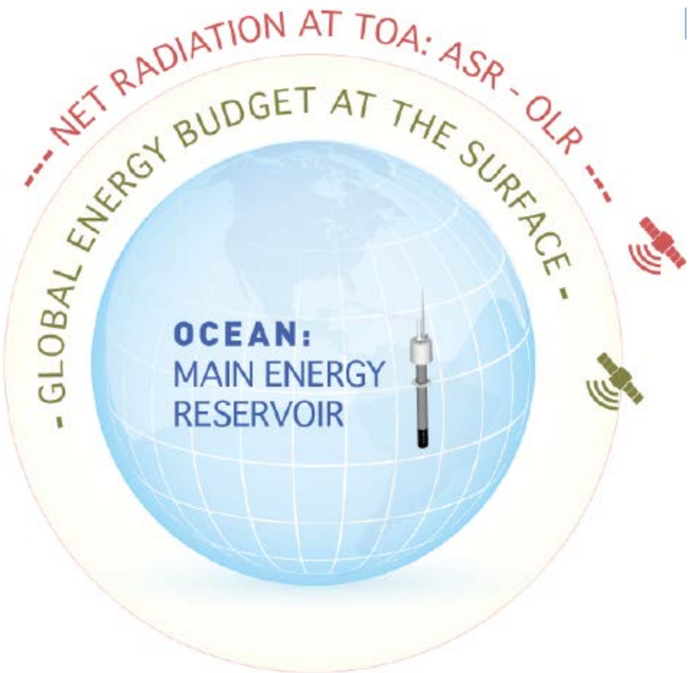
C.-A. Clayson; C. Domingues; S. Gulev; K. Haines; N. Loeb; M. Palmer; P.-P. Mathieu; R. Weller; M. Wild; Y. Xue



The Research Foci are proposed as crosscutting activities

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**:



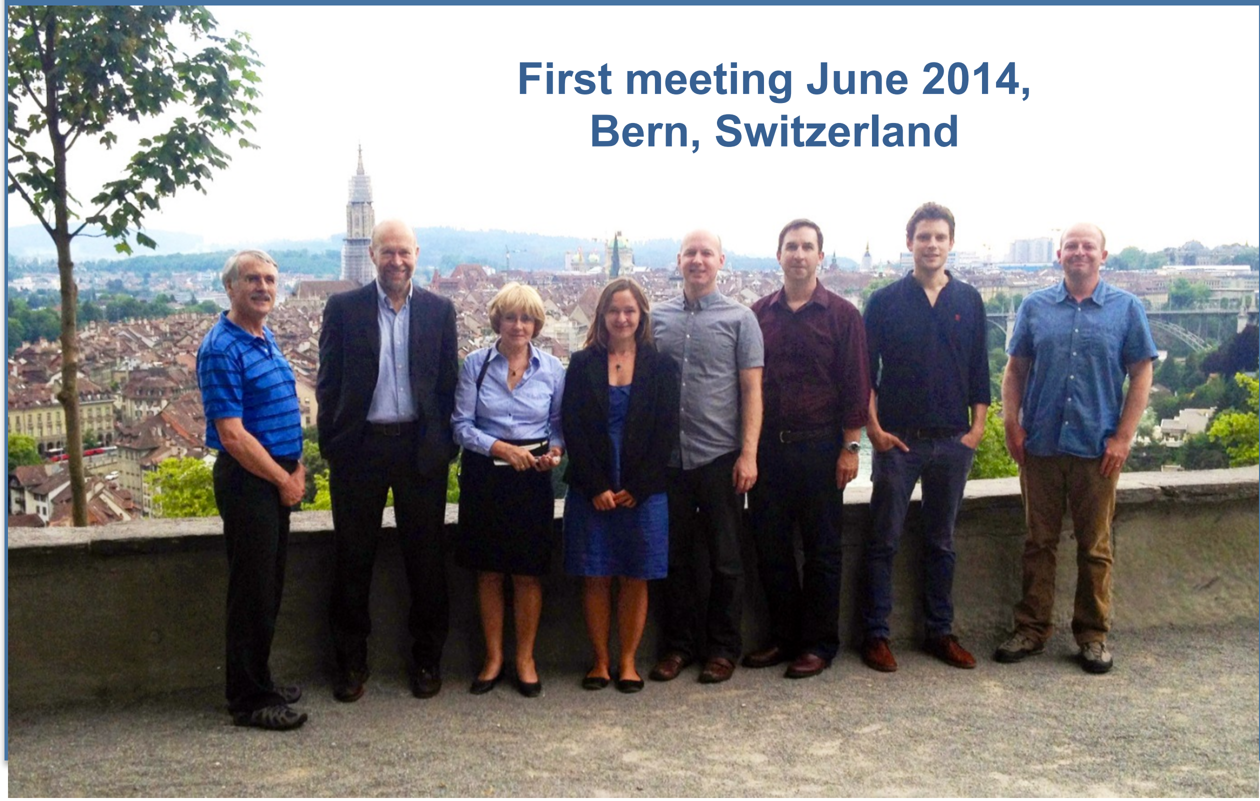
- Atmospheric radiation
- Ocean Heat Content
- Earth's surface fluxes
- Climate variability and change
- Data assimilation & operational services (R&D)
- Climate projection
- Global sea level

Remote sensing	In situ	Reanalysis systems	Numerical model

CLIVAR CONCEPT-HEAT: Development

The absolute measure of the Earth Energy Imbalance and its changes over time are vital pieces of information related to climate change as this is the single quantity defining the status of global climate change and expectations for continued global warming.

ISSI working group: "Consistency of Integrated Observing Systems monitoring the energy flows in the Earth System"



K. von Schuckmann
A. Cazenave, D. Chambers, J. Hansen, S. Josey, Y. Kosaka, N. Loeb, P.P. Mathieu, B. Meyssignac, M. Palmer, K. Trenberth, M. Wild

Perspective paper NCC accepted
(von Schuckmann et al., 2015)

CLIVAR research focus CONCEPT-HEAT:

Consistency between planetary energy balance and ocean heat storage

First CONCEPT-HEAT workshop, Met Office, Exeter (29.09.-01.10.2015)

Integrated Earth System Approach

nature climate change

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NATURE CLIMATE CHANGE | PERSPECTIVE

An imperative to monitor Earth's energy imbalance

K. von Schuckmann, M. D. Palmer, K. E. Trenberth, A. Cazenave, D. Chambers, N. Champollion, J. Hansen, S. A. Josey, N. Loeb, P.-P. Mathieu, B. Meyssignac & M. Wild

Affiliations | Contributions | Corresponding author

Nature Climate Change **6**, 138–144 (2016) | doi:10.1038/nclimate2876
Received 24 June 2015 | Accepted 22 October 2015 | Published online 27 January 2016

CLIVAR research focus CONCEPT-HEAT:

Consistency between planetary energy balance and ocean heat storage

More precisely, this **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).

CLIVAR research focus CONCEPT-HEAT:
Consistency between planetary energy balance and ocean heat storage

Key scientific questions

Question A: **What is the magnitude and the uncertainties of our estimates of Earth's energy imbalance (EEI), and how does it vary over time?**

Question B: **Can consistency between planetary heat balance and ocean heat storage achieved and what are the major limitations?**

Question C: **How are TOA net radiation and ocean heating rate distributed in space and time?**

Question D: **How can we improve validation requirements for and from coupled climate models to improve estimates of EEI?**

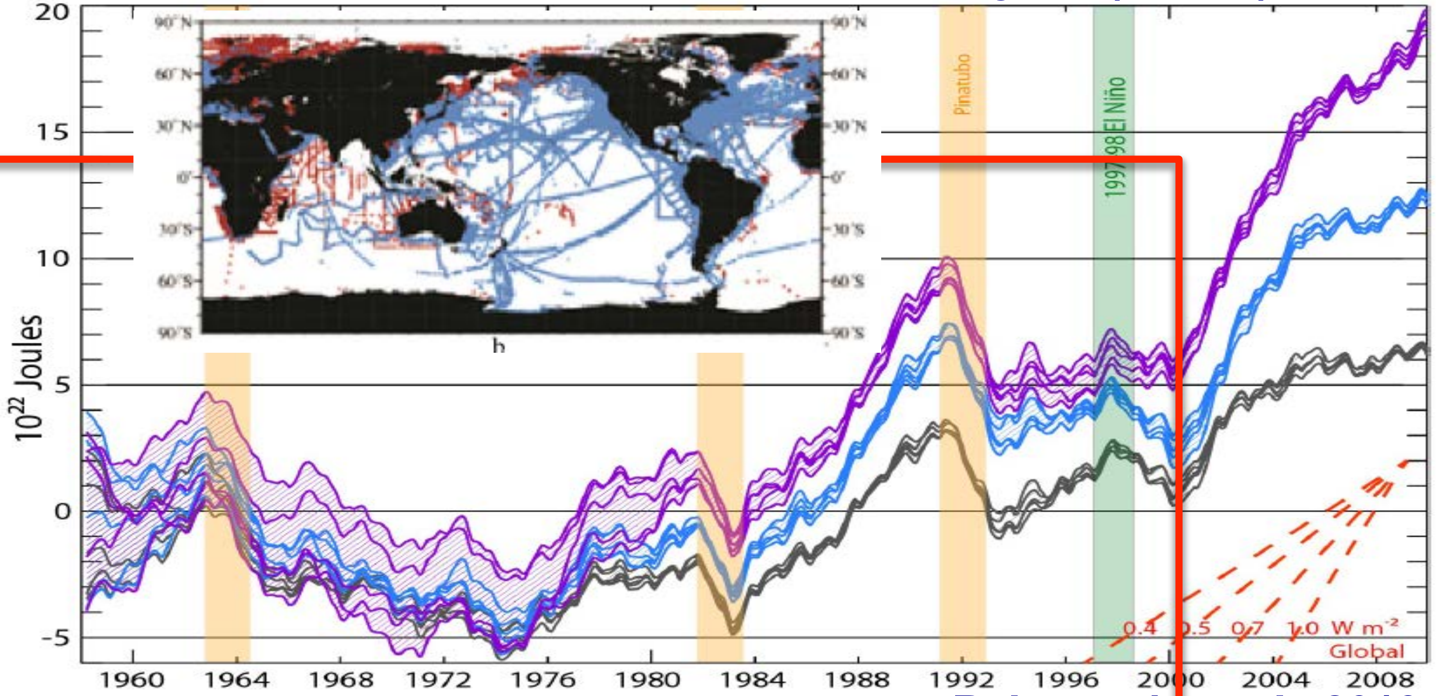
Question E: **How can we better constrain the surface energy fluxes and their spatio-temporal variations at regional scale?**

(a) Ocean Reanalysis

Different approaches determining Earth's energy imbalance: OHC

Global OHC from an ocean reanalysis (ORS4)

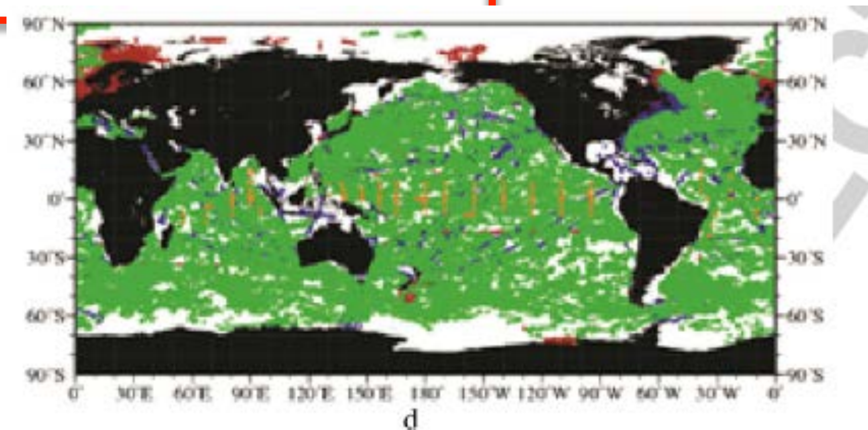
Abraham et al., 2013



Balmaseda et al., 2013

Historical measurements

Argo era



Abraham et al., 2013

ORA-IP Objectives

- To Quantify Signal/Noise from Ensemble
- To gain insight into the ocean variability and trends
- To identify current deficiencies
- To measure progress
- To exploit existing multi-ORA ensemble
  - For climate indicators
  - For model validation
  - For real-time monitoring
  - For initialization of coupled models

CLIVAR GSOP/GODAE Ocean View
Ocean Reanalysis Inter-comparison (ORA-IP)

- 6 Observation only products
- 13 Low resolution models
- 8 High resolution models (1/3 or ¼ degree)
- 4 Coupled DA products
- 6 Long reanalyses, starting 1950's

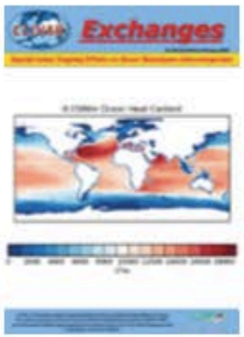
Summary Paper

Balmaseda, M.A. et al., The Ocean Reanalysis Intercomparison project (ORA-IP) J.Op.Oceanogr. Volume 8, supplement 1, 9 June 2015

Special Issue Climate Dynamics:

7 papers accepted so far, 2 under revision

+ other papers with sensitivities



http://www.clivar.org/sites/default/files/documents/Exchanges64.pdf

Variable	
Ocean Heat Content	MetOffice
Steric Height	CMCC
Sea Level	Mercator Ocean
Surface Heat Fluxes	University Reading
Mixed Layer Depth	MRI/JMA
Salinity	CAWCR
Depth of 20 degree Isotherm	Mercator Ocean
Sea Ice	Env Canada
AMOC	**NCAR**
MyOcean ¼ degree	**CMCC**

The Ocean Reanalyses Intercomparison Project (ORA-IP)

Product	Forcing	Configuration	Data Assim. Method
ARMOR3D[aa] CLS	N/A	1/3° Obs-Only (T/S/SSH/U/V)	OI (SLA/MDT/T/S/SST)
CFSR[b,c] NOAA NCEP	Coupled DA	1/2° MOM4 coupled	3DVAR (T/SST/SIC)
C-GLORS05V3[e] CMCC	ERAi corr+ Bulk	1/2° NEMO3.2	3DVAR (SLA/T/S/SST/SIC)
ECCO-NRT[f] JPL/NASA	NCEP-R1 + CORE Bulk	1° MITgcm	KF-FS (SLA/T)
ECCO-v4[g,h] MIT/AER/JPL	ERA+CORE Bulk	1° MITgcm	4DVAR (SLA/SSH/T/S/SST)
EN3 v2a[i] Hadley Center	N/A	1° Obs-Only (T/S)	OI (T/S)
GECCO2[j] U of Hamburg	NCEP-R1+Bulk	1°x1/3° MITgcm	4DVAR (SLA/T/S/MDT/SST)
ECDA[k,l] GFDL/NOAA	Coupled DA	1/3° MOM4 coupled	EnKF (T/S/SST)
GloSea5[m,n] **UK MetOffice**	ERA+CORE Bulk	1/4° NEMO3.2	3DVAR (SLA/T/S/SST/SIC)
MERRA Ocean GSFC/NASA/GMAO	Merra + Bulk	1/2° MOM4	EnOI (SLA/T/S/SST/SIC)
GODAS[p] NOAA NCEP	NCEP-R2 Flux.	1°x1/3° MOM3	3DVAR (SST/T)
GLORYS2V1(G2V1) Mercator Océan	ERAi corr+CORE Bulk	1/4° NEMO3.1	KF+3DVAR (SLA/T/S/SST/SIC)
GLORYS2V3(G2V3) Mercator Océan	ERAi corr+ CORE Bulk	1/4° NEMO3.1	KF+3DVAR (SLA/T/S/SST/SIC)
K7-ODA(ESTOC)[r] JAMSTEC/RCGC	NCEP-R1 corr. Flux	1° MOM3	4DVAR (SLA/T/S/SST)
K7-CDA[s] JAMSTEC/CBST	Coupled DA	1° MOM3 coupled	4DVAR (SLA/SST)
LEGOS[t] LEGOS	N/A	1/4° Obs-Only (SL)	OI+EOF (SLA/SSH)
NODC[u] **NODC/NOAA**	N/A	1° Obs-only (T/S)	OI (T/S)
PEODAS[v] CAWCR(BoM)	ERA40 to 2002; NCEP-R2 thereafter Flux	1°x2° MOM2	EnKF (T/S/SST)
ORAS4[w,x] ECMWF	ERA40 to 1988; ERAi thereafter Flux	1° NEMO3	3DVAR (SLA/T/S/SST)
MOVE-C[y] MRI/JMA	Coupled DA	1° MRI.COM2 coupled	3DVAR (SLA/T/S/SST)
MOVE-G2[z] MRI/JMA	JRA-55 corr+ Bulk	0.5°x1° MRI.COM3	3DVAR (SLA/T/S/SST)
MOVE-CORE[z] **MRI/JMA**	CORE2 Bulk	0.5°x1° MRI.COM3	3DVAR (T/S)
SODA[aa] U of Maryland and TAMU	ERA40 to 2002; ERAi thereafter Bulk	1/4° POP2.1	OI (T/S/SST)
UR025.4[bb] U of Reading	ERAi + CORE Bulk	1/4° NEMO3.2	OI (SLA/T/S/SST/SIC)
AVISO[cc] CLS	N/A	1/4° Obs-Only (SSH/SLA)	OI (SLA)
SLCCI[dd] ESA	N/A	1/4° Obs-Only (SSH)	OI (SSH)

ORA-IP

[§]**Table 1** List of ocean reanalysis products entering the inter-comparison.

Product	Forcing	Configuration	Data Assim. Method	Analysis Period
GFDL/NOAA (ECDA)	Coupled DA	1ºx1/3° MOM4 coupled	*EnKF (T/S/SST)*	1979-present
GMAO/**NASA** (MERRA Ocean)	Merra + Bulk	0.5° MOM4	*EnOI (SLA/T/S/SST/SIC)*	*1979-present*
NCEP/NOAA (**GODAS**)	NCEP-R2 Flux.	1°x1/3° MOM3	*3DVAR (SST/T)*	*1979-present*
NCEP/NOAA (**CFSR**)	Coupled DA	0.5°x1/4°	*3DVAR (SST/T)*	*1979-present*
CAWCR/**BOM** (PEODAS)	ERA40 to 2002; NCEP-R2 thereafter. Flux	1°x2° MOM2	*EnKF (T/S/SST)*	*1979-present*
ECMWF (ORAS4)	ERA40 to 1988; ERAi thereafter. Flux.	1°x 1/3° NEMO3	*3DVAR (SLA/T/S/SST)*	*1979-present*
MRI/**JMA** (MOVE-G2)	JRA-55 corr+ CORE Bulk	1ºx0.5° MRI.COM3	*3DVAR (SLA/T/S/SST)*	*1979-present*
UK **MET** (GloSea5)	ERAi+CORE Bulk	1/4° NEMO3.2	*3DVAR (SLA/T/S/SST/SIC)*	*1993-present*
MERCATOR (GLORYS2V3)	ERAi corr+ CORE Bulk	1/4° NEMO3.1	*EnKF+3DVAR (SLA/T/S/SST/SIC)*	*1993-present*

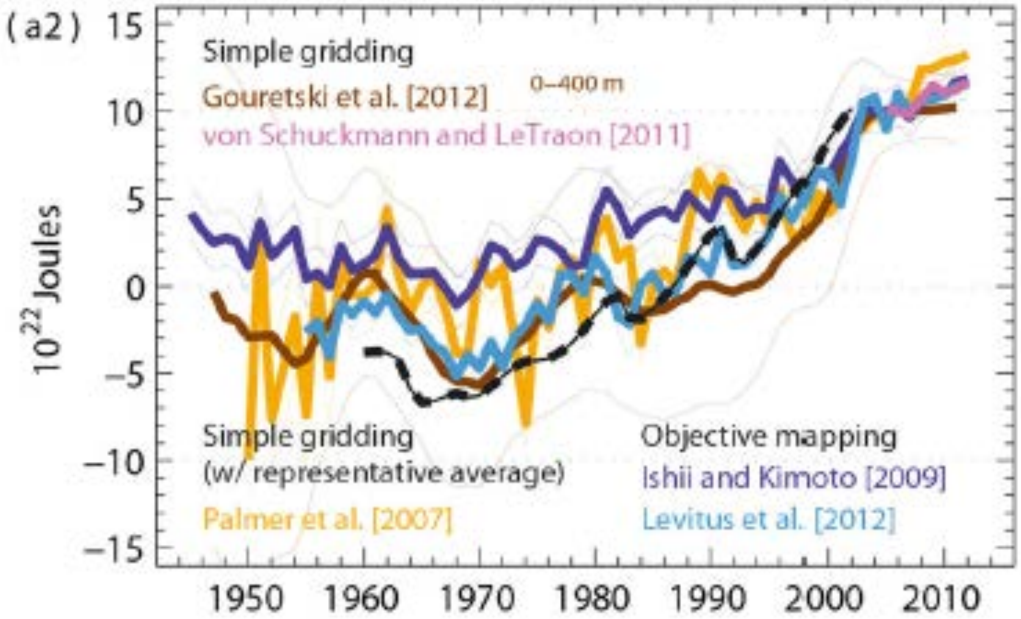
Rev., 130, 1370

Table 1: List of Ocean Variables Inter-compared

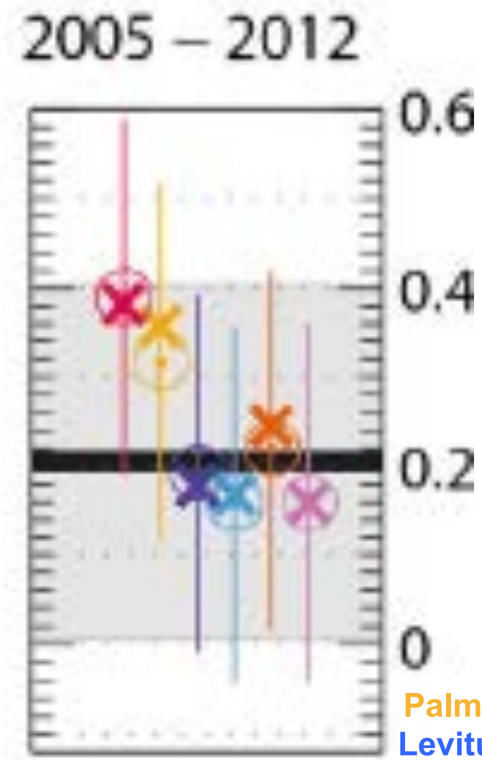
Variable	Responsible	Institution
Steric Height	Andrea Storto	CMCC
Sea Level	Fabrice Hernandez	Mercator Océan
Ocean Heat Content	Matthew Palmer	UK MetOffice
Depth of 20 degree Isotherm	Fabrice Hernandez	Mercator Océan
Mixed Layer Depth	Takahiro Toyoda	MRI-JMA
Salinity	Li Shi	BMRC
Surface fluxes and transports	Maria Valdivieso	UoR
AMOC at 26N	Vladimir Stepanov	UoR
Sea Ice	Gregory Smith	En-Canada

Different approaches determining Earth's energy imbalance: OHC

Global Ocean Heat Content: Historical data & Argo era



Abraham et al., 2013



Palmer et al., 2007
Levitus et al., 2012
von Schuckmann & Le Traon, 2011
Johnson et al., 2013
Ishii and Kimoto, 2009
Domingues et al., 2008

- Differences in upper-ocean heat storage between analyses/periods.
- Differences in "interannual to decadal variability" between analyses.
- All estimates show a multi-decadal increase in OHC in both, upper and deep ocean regions.

EVALUATION OF OCEAN SYNTHESES
COST Action 1402

An overview of EOS

http://www.eos-cost.eu

Chair : Aida Alvera-Azcarate

Vice-chair: Keith Haines

COST
EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

EUROPEAN SCIENCE FOUNDATION

COST Action "Evaluation of Ocean Syntheses"

November 2014 to November 2018

Main objective:

Establish and consolidate a network of European scientists working on the generation and evaluation of ocean synthesis products, data providers, experts in data assimilation and ocean modelling...

Support individual mobility, strengthen existing networks and foster collaboration between researchers.

↓

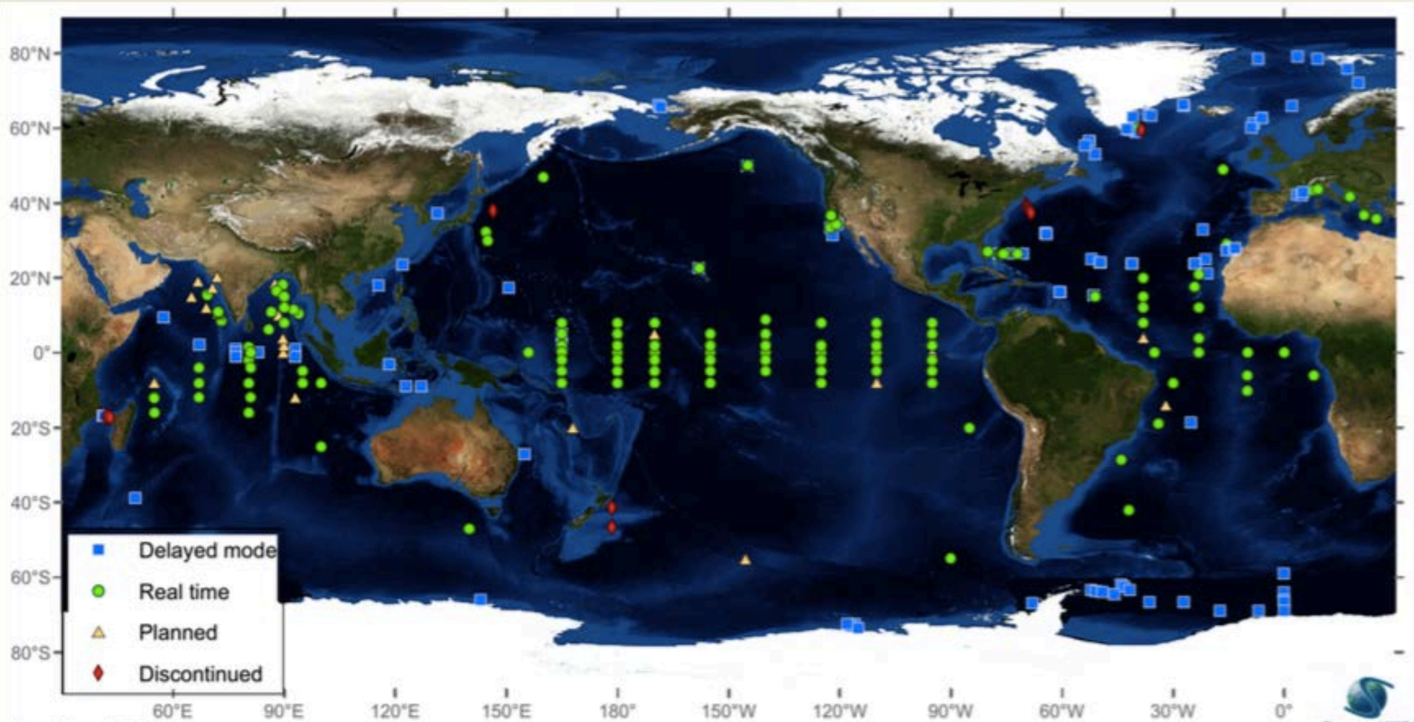
- compile an inventory of end-user requirements (quality and availability of ocean syntheses)
- improve the understanding of the value and use of ocean syntheses
- issue recommendations on which data products are the most suitable for which task.
- increase awareness of ocean synthesis products among end users

(b) In-situ

Integrated Earth System Approach

The **mission of OceanSITES** is to **collect, deliver and promote** the use of high-quality data from long-term, high-frequency observations at **fixed locations** in the open ocean.

http://www.oceansites.org/index.html



As of April 2015

Integrated Earth System Approach

I Q u O D

www.iquod.org

International Quality-Controlled Ocean Database

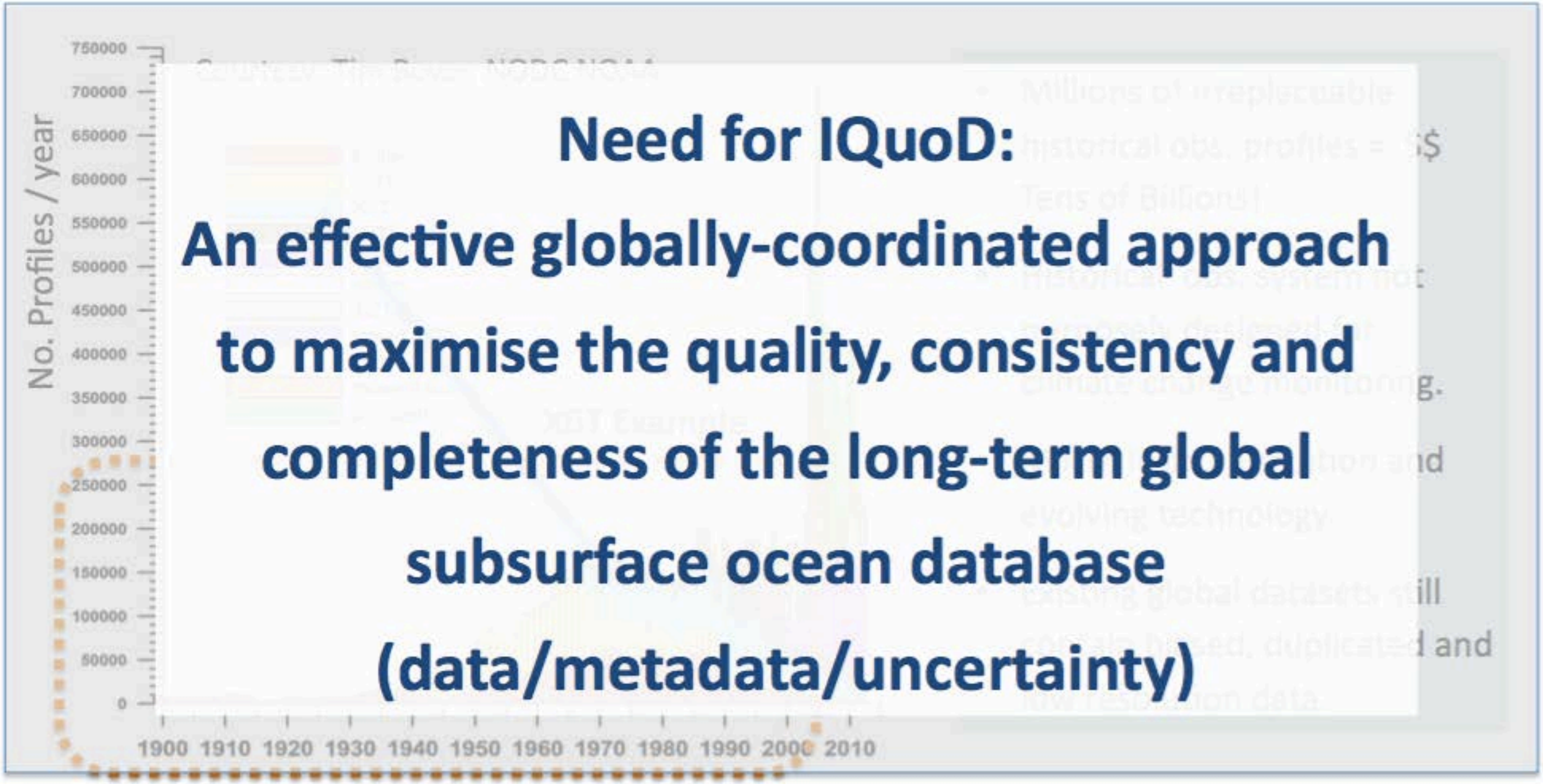
To **maximize the quality, consistency and completeness** of the long-term global subsurface ocean database.
(data | (intelligent) metadata | uncertainty)

To **freely distribute** for use in ocean, climate and Earth system research and services of societal benefit.

CLIVAR

One of CLIVAR GSOP's future plans/priorities (CONCEPT-HEAT)

Today's big challenge: "Climate quality" ocean database



Need for IQuoD:

An effective globally-coordinated approach to maximise the quality, consistency and completeness of the long-term global subsurface ocean database (data/metadata/uncertainty)

Long-term subsurface ocean temperature data

Experts and users from various institutions across 17 nations

IQuOD

Latest News

The IOC Committee on International Oceanographic Data and Information Exchange has established **IQuOD as an IODE project** and **encourages all IOC member States, Programmes, relevant organizations and projects to collaborate with IQUOD.**

www.iquod.org

www.iquod.org

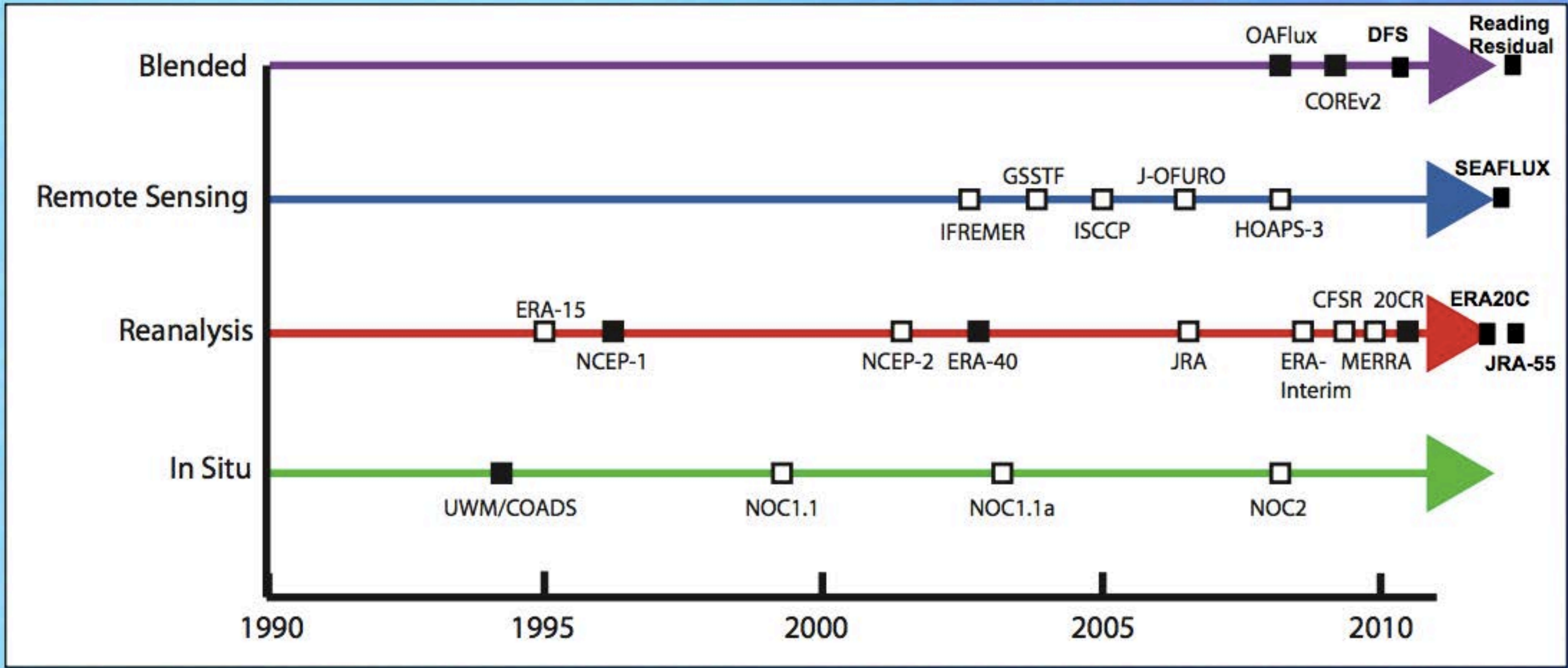
mozilla
Science Lab

Join our software collaboration

Visit collaborate.mozillascience.org/projects/autoqc to find out more about our open source software development project with Mozilla Science Lab and to take part.

IQuOD

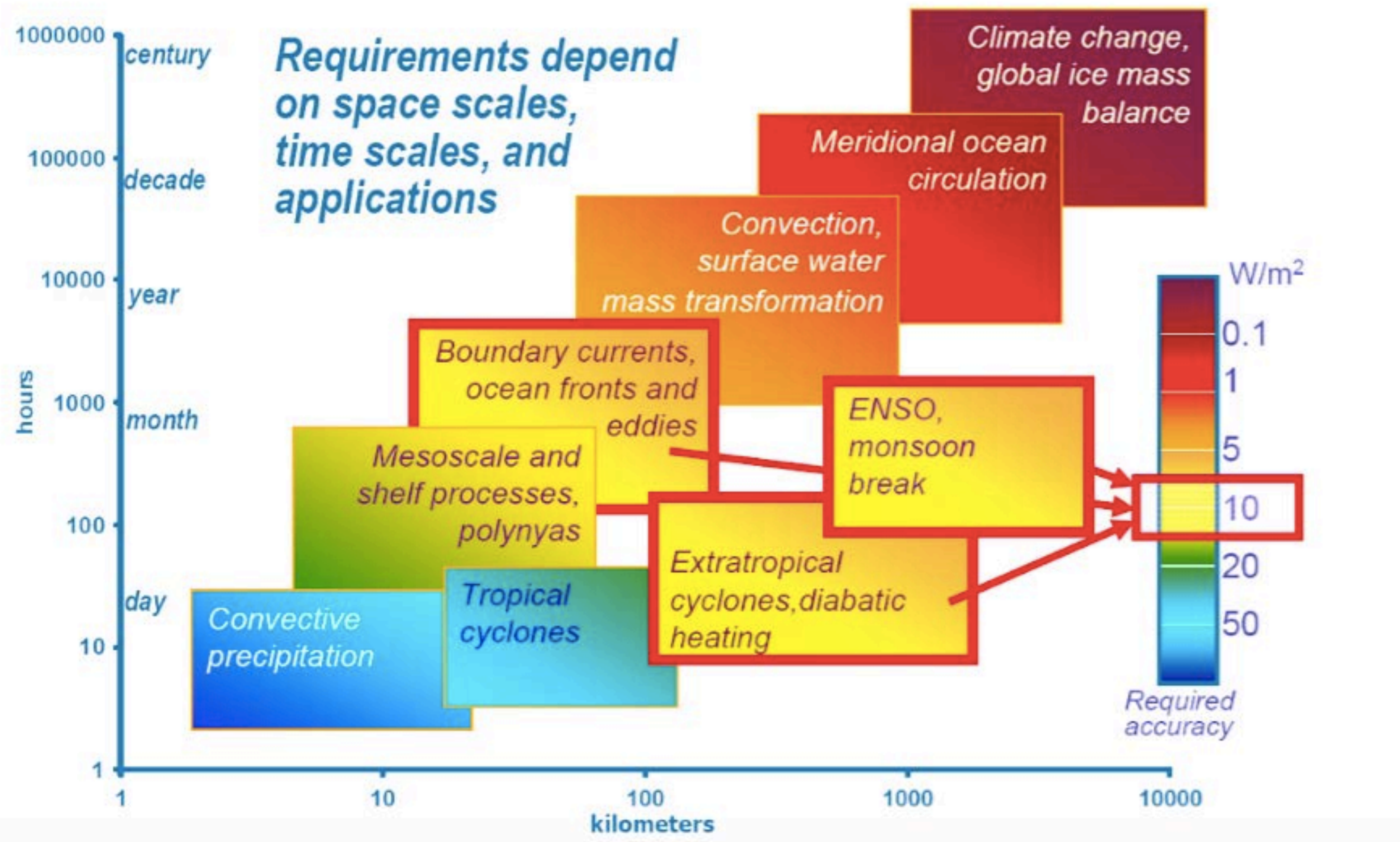
(c) Fluxes



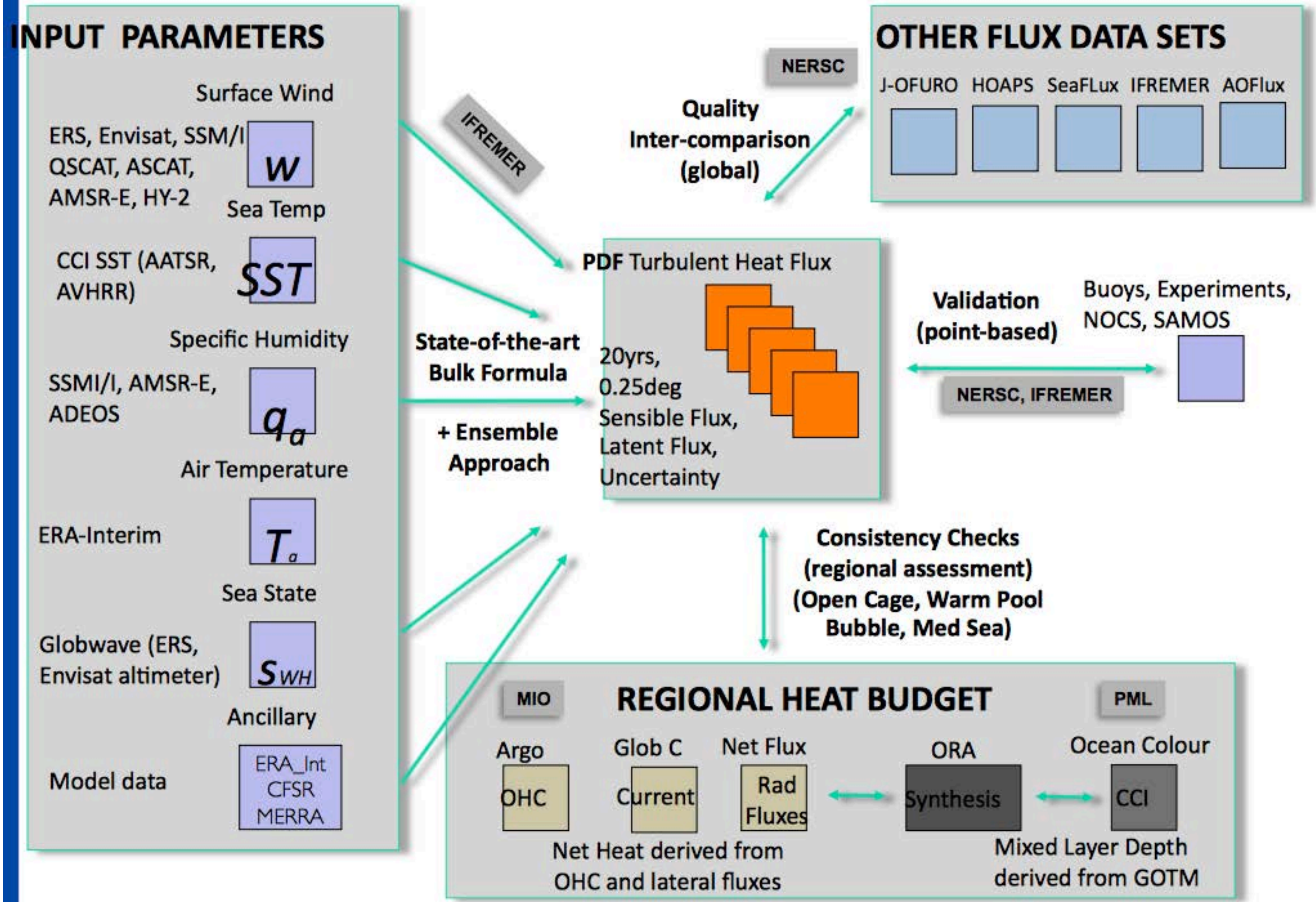
ated from: Josey, S. A., S. Gulev and L. Yu, 2013: Exchanges through the ocean surface, in G. Siedler, J. Church, W. J. Gould S. Griffies (eds): Ocean Circulation and Climate, Academic Press, International Geophysics Series, Volume 103, p. 115-140.

Ocean Heat Flux

	IFREMER	HOAPS	OAFlux	SeaFlux	J-OFURO	ERA Int	CFSR	MERRA	NOCS
Period	1999 – 2009	1992 – 2008	1992 – 2012	1992 – 2007	1992 – 2008	1992 - 2012	1992 - 2012	1992 - 2012	1992 - 2010
Spatial sampling	0.25°× 0.25°	0.50°× 0.50°	1°×1°	0.25°× 0.25°	0.50°× 0.50°	0.70°× 0.70°	0.38°× 0.38°	0.50°× 0.66°	1°×1°
Wind	QSCAT	SSM/I	SSM/I+ QSCAT+ NWP	CCMP	ERS2+ QSCAT+ AMSRE				
SST	OISST	NOAA/ RSMAS	OISST+ NWP	OISST	NCEP+ METOP				ICOADS2
qa	SSM/I	SSM/I	SSM/I+ NWP	SSM/I+ AMSRE	SSM/I				
Ta	ERA Int	SSM/I+ NWP	NWP	SSM/I+ AMSRE	NCEP				
Algoritms	COARE3	COARE3	COARE3	COARE3	COARE3				COARE3

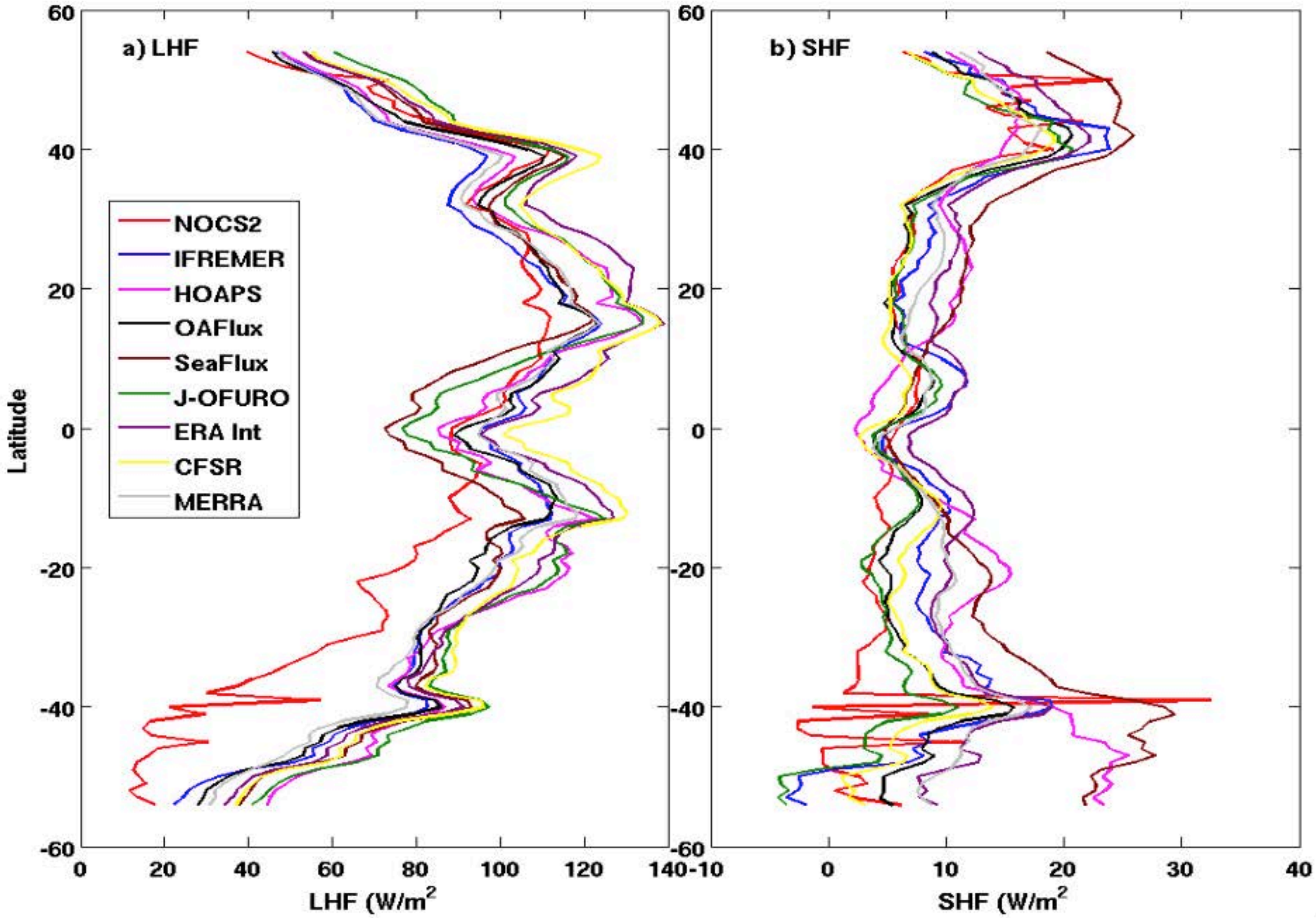


Requirements depend on space scales, time scales, and applications
1000000
century
100000
decade
10000
year
1000
month
100
day
10
1
hours
1
10
100
1000
10000
kilometers
Climate change, global ice mass balance
Meridional ocean circulation
Convection, surface water mass transformation
Boundary currents, ocean fronts and eddies
ENSO, monsoon break
Mesoscale and shelf processes, polynyas
Extratropical cyclones,diabatic heating
Tropical cyclones
Convective precipitation
W/m2
0.1
1
5
10
20
50
Required accuracy

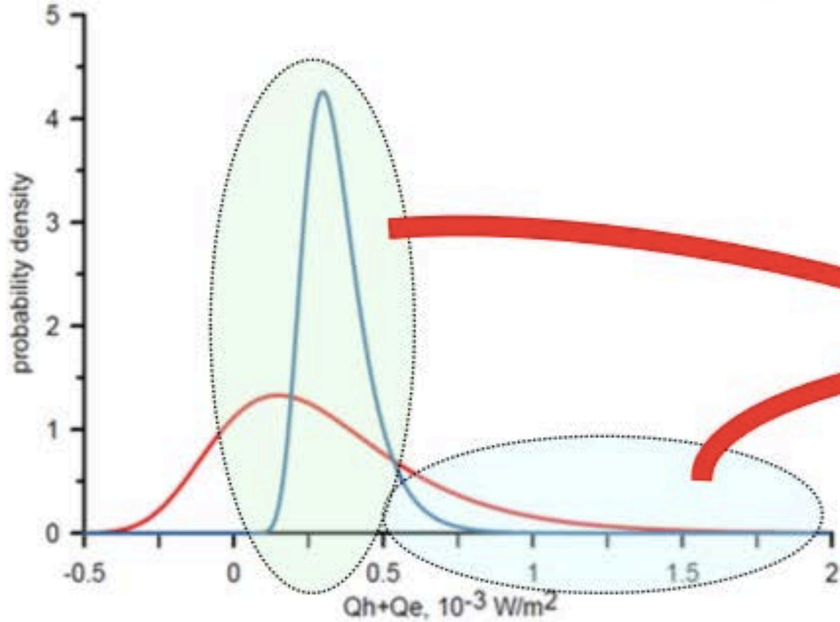

INPUT PARAMETERS
Surface Wind
ERS, Envisat, SSM/I
QSCAT, ASCAT,
AMSR-E, HY-2
w
Sea Temp
CCI SST (AATSR,
AVHRR)
SST
Specific Humidity
SSMI/I, AMSR-E,
ADEOS
q_a
Air Temperature
ERA-Interim
T_a
Sea State
Globwave (ERS,
Envisat altimeter)
S_WH
Ancillary
Model data
ERA_Int
CFSR
MERRA
IFREMER
State-of-the-art
Bulk Formula
+ Ensemble
Approach
NERSC
Quality
Inter-comparison
(global)
OTHER FLUX DATA SETS
J-OFURO
HOAPS
SeaFLux
IFREMER
AOFlux
PDF Turbulent Heat Flux
20yrs,
0.25deg
Sensible Flux,
Latent Flux,
Uncertainty
Validation
(point-based)
Buoys, Experiments,
NOCS, SAMOS
NERSC, IFREMER
Consistency Checks
(regional assessment)
(Open Cage, Warm Pool
Bubble, Med Sea)
MIO
REGIONAL HEAT BUDGET
PML
Argo
OHC
Glob C
Current
Net Flux
Rad
Fluxes
ORA
Synthesis
Ocean Colour
CCI
Net Heat derived from
OHC and lateral fluxes
Mixed Layer Depth
derived from GOTM

Inter-comparison OHF

➢**Example of inter-comparison results from OHF reference data**



6-hr time moments



2-parameter MFT PDF (*Gulev and Belyaev 2012*)

$$P(x) = (\alpha \cdot \beta) \cdot e^{\beta x} \cdot e^{-\alpha \cdot e^{\beta x}}$$

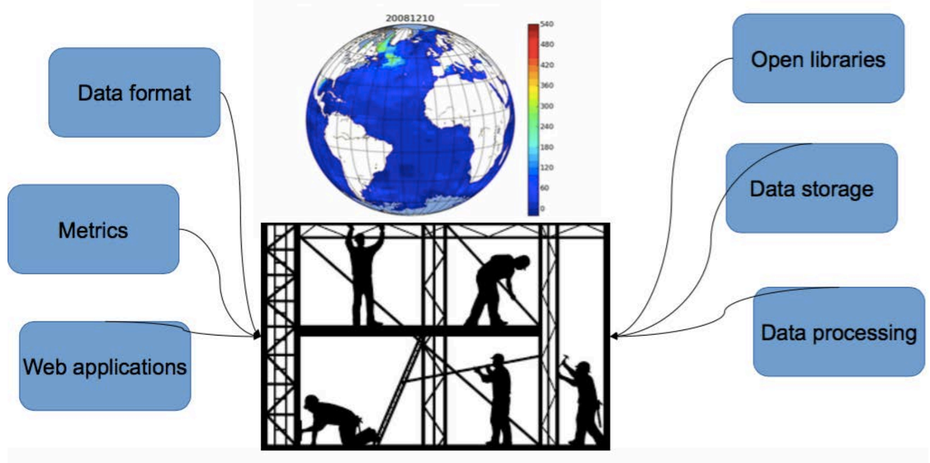
How accurately captured by parameterizations and different data?

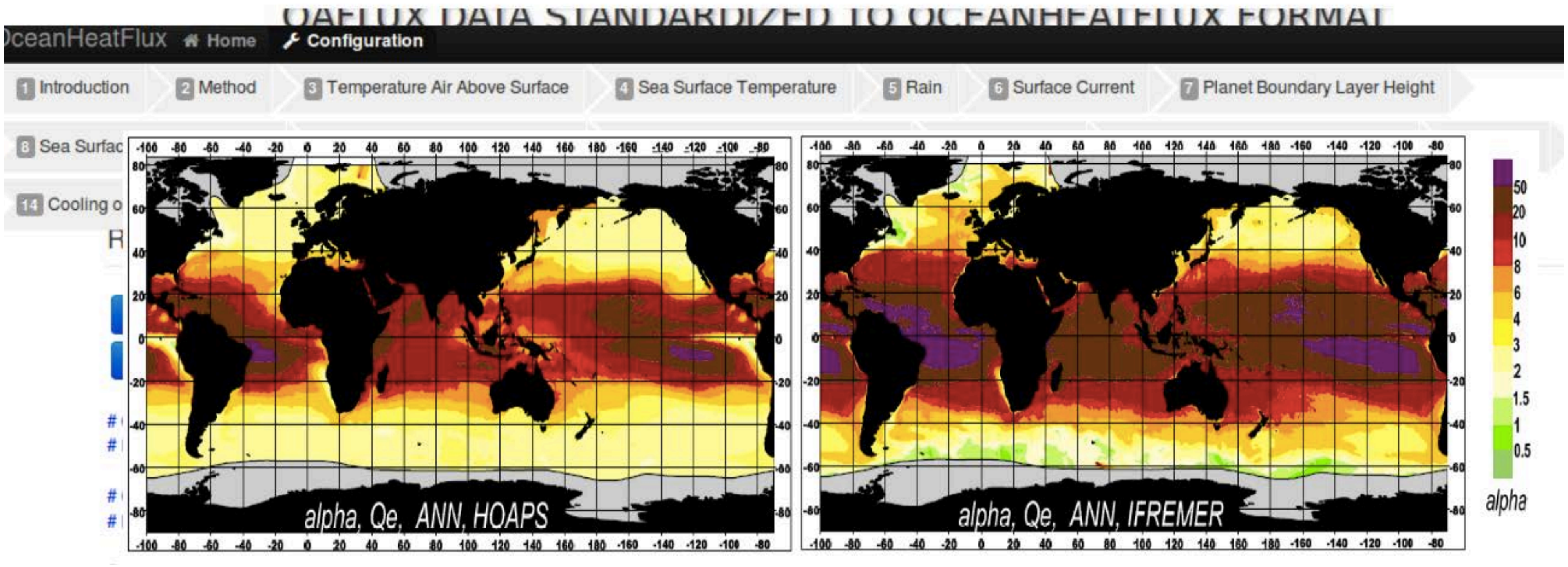
How can be accounted in large-scale integrations?

Collaborative Platform

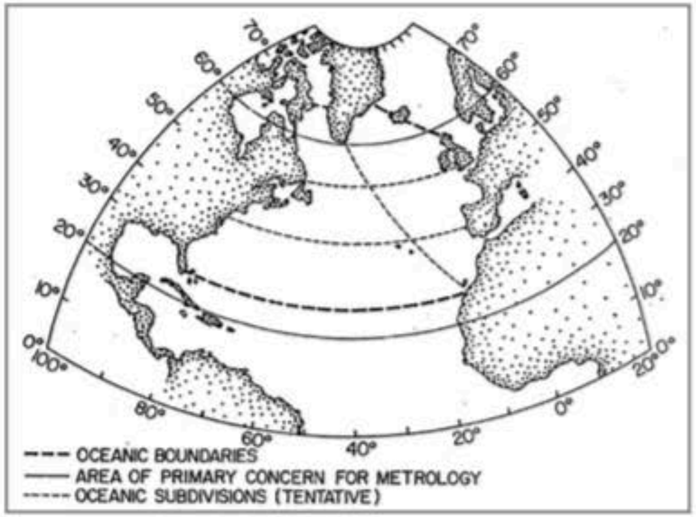
Oceanheatflux.org

Open collaborative research frameworks





Revisiting "cage" concept



THE 'CAGE' EXPERIMENT: A FEASIBILITY STUDY

Final Report, January 1982

Commissioned by the JSC/CCCO Liaison Panel

F.P. Bretherton, NCAR

D.M. Burridge, ECMWF

J. Crease, IOS Wormley

F.W. Dobson, BIO (Chairman)

E.B. Kraus, CIRES/NCAR

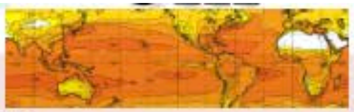
T.H. Vonder Haar, CSU

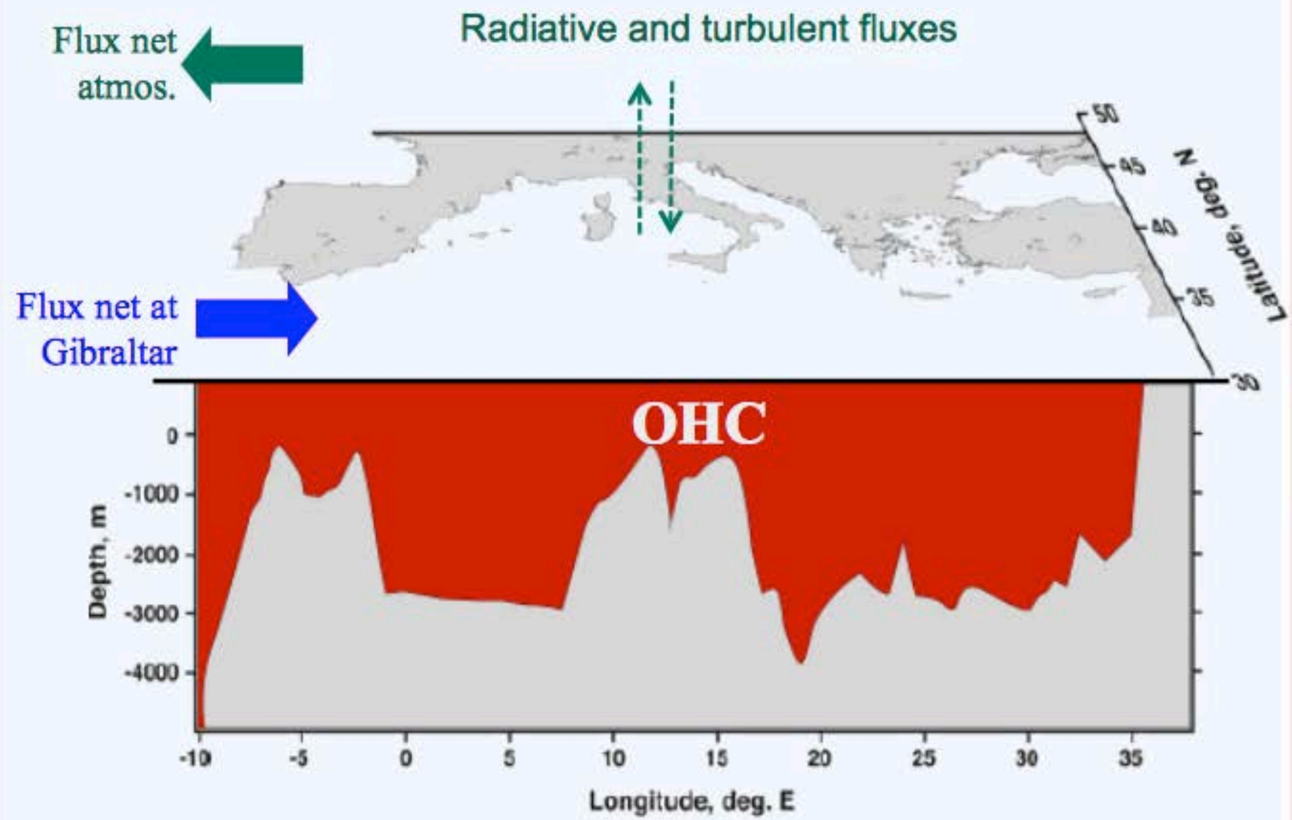
The CAGE accuracy requirements cannot be met, even over the North Atlantic, if the local fluxes are to be computed with data from the existing radiosonde network alone and then analysed and differentiated to give the flux divergences (Oort, 1978). The principal difficulty in using this technique lies in the lack of samples (stations) over the ocean. It is

The sea surface fluxes are very difficult to measure well. The best way at present is to "parameterize" the fluxes in terms of their bulk properties. Errors of up to 50% arise from poor sampling in time and space such as avoidance of heavy weather by most ships, inadequate parameterization and biases in the data themselves.

Over most of the ocean, the heat stored and released over the course of the year (at latitudes other than those where it is stored) is found in the top few hundred meters (Oort and Vonder Haar, 1976). To allow estimation of the heat storage trend over the five-year time scale of the experiment, however, the heat content of the water column to far greater depths must be measured at least twice, preferably at the beginning and the end of the experiment.

Evaluation of Ocean Heat Budget (OHB)





Lateral flux

– d(OHC)/dt

Budget

$$OHC = \int_z \rho c_p T_0(z) dz$$

$$\frac{d(HB)}{dt} = \frac{d(OHC)}{dt} - HF_{lateral}$$

$T_0 = T - T_{clim}$

$$HB = (SW\downarrow - SW\uparrow + LW\downarrow - LW\uparrow) + Lhf + Shf$$

Lhf = latent heat flux; Shf=Sensible heat flux

Concluding Remarks

COP-21 impact

opinion & comment

COMMENTARY:

1.5 °C and climate research after the Paris Agreement

Mike Hulme

The Paris Agreement contains an ambition to limit global warming to no more than 1.5 °C above pre-industrial levels, changing the context for policy-relevant research and extending a challenge to the IPCC and researchers.

Integrated Earth System Approach

Charting the course for climate & ocean research

CLIVAR
Open Science Conference
Qingdao, 2016

CHARTING THE COURSE FOR CLIMATE AND OCEAN RESEARCH

18-25 SEPTEMBER 2016 QINGDAO, CHINA

18, 24-25 September: **Early Career Scientists Symposium**

19-23 September: **Open Science Conference**