Surface heat fluxes and ocean heat content budget

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2015 US CLIVAR Summit
Tucson, AZ
5 August 2015
One estimate of the global heat budget

Stephens et al. 2012.
Another estimate

L’Ecuyer et al. 2015.
Another estimate

L’Ecuyer et al. 2015.
Global mean water fluxes (1,000 km³/yr) at the start of the 21st century

With simultaneous adjustment, we move away from Trenberth

Trenberth et al. (2011) for comparison

Rodell et al. 2015
Trends in Evaporation

Robertson et al. (2015)
Trends in E-P

HOAPS (Romanova et al. 2010)

GECCO (Romanova et al. 2010)
Current Satellite/Blended Datasets

- **Goddard product: GSSTF3**
  - Daily, 0.25°, input variables and turbulent fluxes;
    - Satellite plus Ta from reanalysis
  - 1988- 2008; global oceans

- **IFREMER version 3**
  - Daily, 0.25°, input variables, turbulent fluxes; satellites plus Ta from reanalysis
  - Currently available: 1992 (1999 with QuikSCAT) – November 2009; global oceans

- **Japanese Ocean Flux datasets: J-OFURO2v2**
  - Input variables, fluxes, radiation, satellites plus Ta from reanalysis
    - Daily, 1°, 1988 – 2005; global oceans
    - Satellites, JMA model analyses

- **HOAPS3.2**
  - 6-hourly, 0.5°, global oceans; input variables, precipitation; satellites
  - July 1987 - December 2008

- **OAFlux**
  - Daily, 1°, global oceans; blended using reanalysis, in situ, satellites
  - July 1985 – current (monthly available back to 1958)
Sensible Heat Flux: 1999 - 2005
In-situ measured fluxes used in comparisons: true eddy-correlation fluxes in blue

Locations of Validation Data; Buoys (Red) and R/V (Blue)

NOTE: ONLY SHOWING MEASUREMENTS DURING TYPICAL SATELLITE COMPARISON TIMES (1990 – 2005)
In situ measurements

- Directly measured fluxes (covariance fluxes): the GOLD STANDARD
  - Buoys
  - Ships
  - Floating (Xspar, etc.?)

- Calculated from measured bulk parameters (SST, Ta, Qa, U)
  - Wave information very important – rarely captured
  - Need to know depth of SST
  - Ocean surface current information important

- Need to know characteristics of platform for distortion
Measurements of fluxes over the oceans

Locations of Validation Data; Buoys (Red) and R/V (Blue)

New OOI moorings
Some comparisons

Here we do comparison with eddy covariance fluxes from research vessels -- they are our “ground truth”

Bias: 2.1 W m\(^{-2}\)
Std Error: 38 W m\(^{-2}\)

Bias: -3.1 W m\(^{-2}\)
Std Error: 13.2 W m\(^{-2}\)
Some sample comparisons

Paired T-Test Difference in Means (95% C.I.)

Seaflux
Ncep2
Era40
Hoaps3
Oaflux3
Jofuro2v2
Gsstf2
Ifremer3

PRODUCT–INSITU (W/m²)

Paired T-Test Difference in Means (95% C.I.): LHF

MERRA
ERA-INT
NOCS
NCEP2
ERA-40
HOAPS3
OAFlux3
J-OFURO2v2
GSSTF2b
IFREMER3

PRODUCT–INSITU (W/m²)
Some estimated errors from satellite

<table>
<thead>
<tr>
<th>Variable</th>
<th>Global uncertainty</th>
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<tbody>
<tr>
<td>LHF (W m⁻²)</td>
<td>8.2 (9%)</td>
</tr>
<tr>
<td>SHF (W m⁻²)</td>
<td>4.2 (24%)</td>
</tr>
<tr>
<td>Windspeed (m s⁻¹)</td>
<td>0.39 (5.2%)</td>
</tr>
<tr>
<td>Qa (g kg⁻¹)</td>
<td>0.45 (4.0%)</td>
</tr>
<tr>
<td>SST (°C)</td>
<td>0.12 (&lt; 1%)</td>
</tr>
<tr>
<td>Ta (°C)</td>
<td>0.35 (2%)</td>
</tr>
<tr>
<td>Ts - Ta (°C)</td>
<td>0.44 (33%)</td>
</tr>
<tr>
<td>Qs - Qa (g kg⁻¹)</td>
<td>0.27 (8.2%)</td>
</tr>
</tbody>
</table>
Errors correlated with weather states (?)

Relative Frequency of Cloud

Convective with Cirrus

Stratocumulus and Boundary Layer Clouds

Trade Cumulus and Thin Cirrus

Errors in Surface Humidity

Specific Humidity Bias (SeaFlux-IVAD), gkg⁻¹

Specific Humidity Bias (GSSTF3-IVAD), gkg⁻¹

Specific Humidity Bias (OAFLUX3-IVAD), gkg⁻¹
Surface fluxes and predictability – synoptic scales (space-time resolution matters)

Ping Chang: surface flux – SST relationship is scale dependent on mesoscales and synoptic scales

\[ \text{OAFLUX (1987- onwards)} - \text{Lisan Yu} \]
Joint challenges of CLIVAR and GEWEX in fluxes

Inventory, classification and discrimination of the existing products by their accuracy and relevance for different purposes

Satellite products, NWP (atmospheric reanalyses and operational analyses), VOS and in-situ, ocean reanalyses, blended products

Accuracy of state variables – from in-situ, satellites (retrievals), NWP

Space-time scaling of fluxes → understanding the applicability of parameterizations → Uncertainties associated with scaling

Ocean precipitation (validating GPCP, TRMM, potentially GPM, NWP and reanalyses; VOS-approach – does it have the future?) → in-situ campaigns

More observed fluxes (OCEANSites, more in mid and high latitudes)

Test beds → forcing functions for OGCMs, synoptic air-sea interactions in mid latitudes (diabatic sources of heat and moisture), decadal and longer variability
Under WCRP Data Advisory Council (WDAC)

- Discussion of need for coordination and highlighting surface flux issues
  - Land, ocean, ice
  - Biogeochemical, heat, moisture, momentum
  - Turbulent, radiative
  - In situ, remote

- Formation of a Surface Flux Task Team (C. A. Clayson, chair)
  - Cuts across GEWEX, CLIVAR, other WCRP groups
PROBLEM: Significant quantitative differences between the different products at regional scales → inconsistencies in methodology and data input and use of different time constants

First order flux accuracy desired for various applications

Differences between IFREMER and WHOI OAFlux adopted from Pinker et al, 2014

Bourassa et al. 2013

Latent Heat Flux

Sensible Heat Flux

2003-2005
Net flux at Gibraltar

Net atmospheric fluxes

Budget:

Radiative and turbulent fluxes
Precipitation, Evaporation

Net flux at Gibraltar

OHC, OFC

Budget = Lateral net flux – Ocean integrated heat and/or freshwater

First steps done … Natural cage: Mediterranean Sea

\[ OHC = \int_{z} \rho c_p T_0(z) \, dz \]

\[ OFC = -a \int_{z} \frac{\rho(T,S,p)}{\rho(T,0,p)} \frac{S_0}{S_r+S_0} \, dz \]
Next steps?

**Implementation plan (suggestion):**

1.) Develop 2 “test-cages” for method development: Mediterranean Sea, North Atlantic: (note that for high latitudes uncertainties for turbulent fluxes increase, and hence, knowledge of uncertainty scales are needed (➡️ DWD (CM SAF) will deliver uncertainty scales in March 2015)

2.) Clarify which datasets aught to be used for the test-cages: organize teleconf in beginning of January?
   i) OHC: for MedSea developed (2004-2012); next step: develop OHC for North Atlantic box

3.) Develop team and strategy plan for implementation (teleconf.) and start to draft scientific paper for cage method

**Suggestion for cage-team:**

**General concept:** Sergey Gulev, Simon Josey, Carol-Anne Clayson, Bertrand Chapron, Keith Haines, Semyon A. Grodsky, Rachel T. Pinker

**OHC:** Karina von Schuckmann, Clement de Boyer Montégut

**Net atmospheric flux:** Axel Andersson, Chris Merchant, Rainer Hollmann, Abderahim Bentamy, Richard Danielson, Igor Esau

**Lateral flux:** Keith Haines, Maria Valdivieso, Semyon A. Grodsky
Ocean Heat Flux Thematic Exploitation Platform

**INPUT PARAMETERS**
- Surface Wind
- Sea Temp
- Specific Humidity
- Air Temperature
- Sea State
- Ancillary
- Model data

**OTHER FLUX DATA SETS**
- Quality Inter-comparison (global)
- Validation (point-based)
- Consistency Checks (regional assessment)

**PDF Turbulent Heat Flux**
- State-of-the-art Bulk Formula
- + Ensemble Approach
- 20yrs, 0.25deg Sensible Flux, Latent Flux, Uncertainty

**REGIONAL HEAT BUDGET**
- Net Heat derived from OHC and lateral fluxes
- Mixed Layer Depth derived from GOTM

**INPUT PARAMETERS**
- ERS, Envisat, SSM/I
- QSCAT, ASCAT, AMSR-E, HY-2
- CCI SST (AATSR, AVHRR)
- Specific Humidity
- SSM/I, AMSR-E, ADEOS
- Air Temperature
- ERA-Interim
- Sea State
- Globwave (ERS, Envisat altimeter)
- Ancillary
- ERA_Int CFSR

**OTHER FLUX DATA SETS**
- J-OFURO
- HOAPS
- SeaFlux
- IFREMER
- AOFlux
- Buoys, PIRATA, TAO Experiments, NOCS

**Uncertainty Characteristics**

Source: PPM v01
Upcoming CLIVAR-sponsored workshops

  - Sponsored by US CLIVAR, NOAA, ESA, WCRP, SOOS

- Workshop on energy flow through the climate system, 29 September - 01 October 2015, MetOffice - Exeter – UK.
Strategies for Improving Ocean Turbulent Fluxes

- **More routine observations:**
  - Extremes: cold air outbreaks, hurricanes
  - High-latitudes
  - Both limited duration focused on physical processes and long time series at given locations
  - Should be noted: we also need the actual turbulent flux measurements as well for continued understanding of bulk flux parameterizations

- **Clearly defined, common measures of accuracy:**
  - Tropical array of surface flux moorings (some sub-tropical) – use to benchmark
  - Process studies – why are some biased?
  - More flux intercomparisons with standardized methods

- **More process studies:** put together evap, precip, latent heating profiles into some case studies

- **Better calibration:** we need to resolve what are appropriate calibrations for multiple uses

- **More global coverage:** “missing” events significant problem

- **More funding:** compare surface turbulent flux with precipitation groups

- **Increase accessibility** of available datasets
Questions to be discussed

- How do we work across the three very different communities: atmospheric radiation, air-sea flux communities, ocean heat content communities?
- What are the reasons for the disconnects?
  - Communities do not understand the uncertainties of the others
- What should we be promoting for measurements/platforms?
- Satellies? Microwave, for instance?