Assessing and improving surface flux products across space-time scales

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Outline:

- Space-time scales is a key thing: need for the accurate description of surface flux distributions for all probabilities
- Comparison of modern era reanalyses and satellite products – means, parameters of PDFs, extreme fluxes
- VOS based fluxes: parameterizations and sampling uncertainty
- Is it a time for CAGE-2?
Which accuracy and resolution do we need: 
fetishism of XX W/m²

Requirements depend on space scales, time scales, and applications

- Convective precipitation
- Tropical cyclones
- Mesoscale and shelf processes, polynyas
- Boundary currents, ocean fronts and eddies
- Convection, surface water mass transformation
- ENSO, monsoon break
- Extratropical cyclones, diabatic heating
- Meridional ocean circulation
- Climate change, global ice mass balance

Idea of Sarah Gille
Global heat content: 0.4-0.8 W/m$^2$

Locally ~10 W/m$^2$

Sea level rise $\Rightarrow$ $Q_e = 1$ W/m$^2$ annually = 12 mm MSL
Data products: time coverage

Reanalyses:
- NCEP-DOE
- NCEP-CFSR
- MERRA
- ERA-INTERIM
- JRA-55

Blended:
- OA-FLUX
- CORE

Satellite products:
- HOAPS
- IFREMER
- JOFURO
- SEAFLUX

VOS:
- SOC-99
- SOClun-03
- NOC-09

back to 18th century

0.25 deg
daily

2000-2007
Turbulent fluxes in different products: inconsistency of methods and scales

\[ \begin{align*}
SH & \sim C_h \ (SST - T_a) \ V \\
LH & \sim C_e \ (q_0 (SST) - q_a) \ V
\end{align*} \]

Reanalyses: diagnostic variables derived from the prognostic state variables and integrated over the forecast time step (instantaneous values can be also obtained)

Recomputed reanalyses (blended): parameterizations are applied to the prognostic state variables (not as in the NWP)

Satellites: computed from the retrievals of state variables which have very different accuracies (and frequently different space-time scales of internal averaging, moderate sampling uncertainty)

VOS/buoys: parameterizations are applied [to a large extent] to the scales for which they have been derived, heavy sampling uncertainty

- Hard to validate and intercompare
- Hard to interpret intercomparisons
Flux climatologies for NCEP-CFSR

(A) $Q_h$, JAN - CFSR

(B) $Q_e$, JAN - CFSR

(A) CFSR p99.9($Q_h$), JAN

(B) CFSR p99.9($Q_e$), JAN

alpha, $Q_e$, Jan, CFS

beta, $Q_e$, Jan, CFS
Mean fluxes: differences with CFSR
Concept of intercomparison: probability distributions

Labrador Sea

Gulf Stream
Statistical distribution of turbulent fluxes

NAC Qh+Qe → January 1979 and January 1991

Mean (Jan 1979) = 347 W/m²
Mean (Jan 1991) = 351 W/m²

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?
Differences in means and differences in extremes

![Graph showing differences in flux with scale parameter beta and location parameter alpha.](image)

- **Change in extreme flux (99%)**
  - < -150
  - (-50) - (-150)
  - 0 - (-50)
  - 0 - 50
  - 50 - 100
  - 100 - 200
  - > 200

- **Legend**
  - Dark purple: < -150
  - Light purple: (-50) - (-150)
  - Light green: 0 - (-50)
  - Yellow: 0 - 50
  - Orange: 50 - 100
  - Red: 100 - 200
  - Maroon: > 200

- **Scale parameter, beta, W/m²**
  - Y-axis: 20 to 0

- **Location parameter, alpha**
  - X-axis: 8 to 1

- **World map**
  - Different regions colored according to change in extreme flux (99%)
Integration of fluxes at $\alpha,\beta$- diagrams
Relative extremeness

\[ \bar{x} = \int_{-\infty}^{x} P(x) \, dx = \frac{C + \ln \alpha}{\beta} \]

\[ \bar{x}_{95} = \int_{x_{95}}^{\infty} P(x) \, dx \]

\( X_{95} = 95\% \)
# Relative extremeness

<table>
<thead>
<tr>
<th></th>
<th>Winter (JFM)</th>
<th>Summer (JAS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DOE</td>
<td>28</td>
<td>42</td>
</tr>
<tr>
<td>MERRA</td>
<td>24</td>
<td>36</td>
</tr>
<tr>
<td>CFSR</td>
<td>38</td>
<td>59</td>
</tr>
<tr>
<td>ERA-Interim</td>
<td>29</td>
<td>40</td>
</tr>
<tr>
<td>JRA</td>
<td>24</td>
<td>36</td>
</tr>
<tr>
<td>OAFLUX</td>
<td>22</td>
<td>38</td>
</tr>
<tr>
<td>HOAPS</td>
<td>27</td>
<td>42</td>
</tr>
<tr>
<td>IFREMER</td>
<td>18</td>
<td>33</td>
</tr>
<tr>
<td>JOFURO</td>
<td>17</td>
<td>35</td>
</tr>
<tr>
<td>SEAFLUX</td>
<td>23 (36)</td>
<td>39 (49)</td>
</tr>
</tbody>
</table>
Regional comparisons

cfs – CFSR
mrr – MERRA
oaf – OAFLUX
doe – NCEP-DOE
int – INTERIM
hop – HOAPS
jof – JOFURO
sea – SEAFLUX
ifr – IFREMER
A lot of variance is behind the reanalyses resolution

→ WRF-ARM-3 NA, 9 km resolution, 41 level, forced by ERA-Interim (hindcast is available for 1979 – 2013)

AVG FLUX RATIO (WRF/ERAi) = 1.69
Turbulent flux parameterizations: what we do and do not account for

- COARE
- NCEP
- Large & Yeager
- ECMWF

Observational mean

Wind speed, m/s

$C_h, C_e \times 10^{-3}$

Bourassa et al. 2013

Severe weather conditions

COARE-3.0

Calm conditions
Extreme heat fluxes: sea spray

- Bianco et al. 2011
- Fairall et al. 2014
- Andreas et al. 2008, JPO

Spray flux
Importance of HR fluxes (Ma, Chang et al. 2015):
Coupled WRF+ROMS

Simulated anomalies of wind speed (color) and SST contours

Simulated anomalies of SST and total turbulent heat flux

Ma et al. 2015
Sub-mesoscale variability of radiative fluxes and impact of the cloud optical thickness

Broken clouds

8 octa NS $\rightarrow$ 380 W/m$^2$

Nearly clear sky conditions

8 octa St $\rightarrow$ 520 W/m$^2$
White caps and albedo

For 500 W/m²: 25-30 W/m² $\rightarrow$ 70+ W/m²
Revisiting “cage” concept

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.

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
Minimization of sampling uncertainty

\[ P(V \mid \delta T) \cdot P(\delta T) \]
Regionally integrated fluxes

\[ Q_\Sigma = \int dt \int Q dS = \int dV \int Q d(\delta T) \]

<table>
<thead>
<tr>
<th>Sampling uncertainty of the regionally integrated surface flux</th>
<th>1</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Real VOS sampling</td>
<td>$0.35 \times 10^{14}$ W</td>
<td>$0.57 \times 10^{14}$ W</td>
</tr>
<tr>
<td>1-D reconstruction (MFT)</td>
<td>$0.22 \times 10^{14}$ W</td>
<td>$0.43 \times 10^{14}$ W</td>
</tr>
<tr>
<td>2-D reconstruction (W+MFT)</td>
<td>$0.11 \times 10^{14}$ W</td>
<td>$0.37 \times 10^{14}$ W</td>
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Summary

Besides the means, reanalysis and satellite fluxes strongly differ in PDFs, differences in extreme fluxes amount to several hundreds Wm\(^{-2}\) and are not consistent with the differences in means.

CFSR and HOAPS show the highest extreme fluxes in reanalyses and satellite products. SEAFLUX shows the highest relative extremeness. Scaling from 3-hr to daily fluxes (SEAFLUX) results in 10-30% decrease of extremes.

Much of variance of surface fluxes on mesoscales is unexplained in reanalyses: going to mesoscales is important, also for understanding feedbacks.

Closure (both global and regional) remains a problem, parameterizations still do not account for critical effects.

CAGE: Sampling uncertainty can be partly minimized, but the problems of closure will remain.
Challenges

Implied fluxes from atmospheric convergences

HR fluxes

Using buoys and SAMOS for validation (co-location problem)

Satellite retrievals for state variables
Sampling errors amount to $80 \text{ W/m}^2$ in poorly sampled regions and where synoptic-scale variability is strong, being of about few $\text{W/m}^2$ in well sampled areas and in the regions of small magnitudes of synoptic variability.
Principal scientific question:

“How can we better constrain the surface energy fluxes and their spatio-temporal variations at regional scale?”

- The **present level of uncertainties** in global ocean estimates of heat and moisture fluxes is **not adequate for many applications**, including global and regional mass and energy budget closure and variability on different time scales.

- **Biases in surface fluxes lead to the systematic errors in climate models** and preclude their efficient use in climate simulation. Without accurate estimates of surface fluxes it is difficult to engage the predictive potential of the ocean in weather and climate prediction.

- **Improvements in all aspects** of producing surface flux estimates, including parameterizations, measurement techniques and post-processing are required for further progress.