An ensemble approach to gas flux climatology

David Woolf
d.k.woolf@hw.ac.uk

International Centre for Island Technology
Heriot-Watt University
Overview

• Introduction
• Classifying Uncertainty
• Measurement Uncertainty
• Uncertainty in Systems
• An Ensemble “brute force” Approach
• Errors in Differences
• Examples from OceanFlux
• Whose Ensemble?
How do we arrive at realistic estimates of uncertainty?
Classifying Uncertainty I

Random Error and Systematic Bias

Level
- Statistical
- Scenario
- Qualitative
- Recognised Ignorance

Location
- Where in modelling/processing system

Nature
- Epistemic
- Natural Variability
- Ambiguity
Location. Where?
What and where?

e.g. parametrization of $k$

Parameter e.g. “$a_2$” in “$k = a_2 U^2$”

Structural e.g. “$a_2 U^2$” vs “$a_0 + a_3 U^3$”

Separate and distinct

Propagation characteristics differ
An example of a “simple” error budget:
Sea surface height, P-Y Le Traon, 2007

Sea Surface Height (SSH) (relative to an earth ellipsoid) = Orbit height – Range

SSH = Orbit – Range – Σ Corr

Precision of the SSH:
• Orbit error
• Errors on the range
  • Instrumental noise
  • Various instrument errors
• Various geophysical errors (e.g., atmospheric attenuation, tides, inverse barometer effects, …)
An example of a “simple” error budget: Sea surface height, P-Y Le Traon, 2007

Error Budget for altimetric missions

Geos 3
843 km
115°
various repeat cycles

SEASAT
800 km
108°
3 days

GEOSAT
800 km
108°
17 days (ERM)

ERS
780 km
98.5°
35 days (3/168)

T/P (before launch)
1336 km
66°
9.95 days

T/P (after launch)

Jason-1
ENVISAT

Centimeters

orbit error
Ra error
Ionosphere
Troposphere
EM Bias
Oceanic signal

GPS/DORIS

EMR
PRARE
TMR
a, *likely to be minor errors at global level, but much more important locally*

Identification of sources of error within the flux calculation and tentative estimates of the uncertainty that they contribute to the gross and net fluxes.

<table>
<thead>
<tr>
<th>Identifier</th>
<th>Location</th>
<th>Level</th>
<th>Nature</th>
<th>Randomness</th>
<th>Uncertainty Gross Flux</th>
<th>in</th>
<th>Uncertainty in Net Flux</th>
</tr>
</thead>
<tbody>
<tr>
<td>k kerfuffle</td>
<td>Model structure</td>
<td>Scenario</td>
<td>Ambiguity</td>
<td>Bias</td>
<td>50%</td>
<td>&gt;100%</td>
<td></td>
</tr>
<tr>
<td>k parameter</td>
<td>Parameter</td>
<td>Statistical</td>
<td>or Epistemic</td>
<td>Bias</td>
<td>20%</td>
<td>50%</td>
<td></td>
</tr>
<tr>
<td>Wind speed (products)</td>
<td>Input</td>
<td>Statistical</td>
<td>or Epistemic</td>
<td>Bias</td>
<td>10%</td>
<td>10%</td>
<td></td>
</tr>
<tr>
<td>Wind speed (sampling)</td>
<td>Input</td>
<td>Statistical</td>
<td>Natural Variability</td>
<td>Random</td>
<td>&lt;5%, a</td>
<td>&lt;5%</td>
<td></td>
</tr>
<tr>
<td>Cool skin and warm layers</td>
<td>Model structure</td>
<td>Statistical</td>
<td>or Epistemic</td>
<td>Bias</td>
<td>&lt;5%, a</td>
<td>25%</td>
<td></td>
</tr>
<tr>
<td>Temperature (products)</td>
<td>Input</td>
<td>Statistical</td>
<td>or Epistemic</td>
<td>Bias</td>
<td>&lt;5%, a</td>
<td>&lt;5%</td>
<td></td>
</tr>
<tr>
<td>Temperature (sampling)</td>
<td>Input</td>
<td>Statistical</td>
<td>Natural Variability</td>
<td>Random</td>
<td>&lt;5%, a</td>
<td>&lt;5%</td>
<td></td>
</tr>
<tr>
<td>Temperature – wind speed covariance (sampling)</td>
<td>Input</td>
<td>Statistical</td>
<td>Natural Variability</td>
<td>Random</td>
<td>&lt;5%, a</td>
<td>&lt;5%</td>
<td></td>
</tr>
<tr>
<td>Temperature – wind speed covariance</td>
<td>Model Structure</td>
<td>Statistical</td>
<td>or Natural Variability</td>
<td>Random</td>
<td>&lt;5%, a</td>
<td>&lt;5%</td>
<td></td>
</tr>
<tr>
<td>pCO2 (bias)</td>
<td>Input</td>
<td>Statistical</td>
<td>or Epistemic</td>
<td>Bias</td>
<td>&lt;5%, a</td>
<td>25%</td>
<td></td>
</tr>
<tr>
<td>pCO2 (random)</td>
<td>Input</td>
<td>Statistical</td>
<td>Epistemic</td>
<td>Random</td>
<td>&lt;5%, a</td>
<td>&lt;5%</td>
<td></td>
</tr>
<tr>
<td>Asymmetry</td>
<td>Model Structure</td>
<td>Statistical</td>
<td>or Epistemic</td>
<td>Bias</td>
<td>&lt;5%</td>
<td>25%</td>
<td></td>
</tr>
</tbody>
</table>
Uncertainty in a Modelling System
Ensemble Calculations

- + bias
- + random error
- Bootstrapping (by cruise)
- Parallel data
- Parallel Theories (ambiguity)
Ensemble Calculations II

- Core (project controlled)
- User
  - Moderated
  - Uncensored
- Expert Group
  - Censored
Errors in Differences

• Globally for CO$_2$, net flux is ~2% of gross exchange

• Propagation varies:
  – Acting on gross and net equally (e.g. $k$ parameter)
  – Acting on upward or downward separately
    • e.g. thermal and haline effects
    • 1% in gross corresponds to 50% in net
  – Complicated (e.g. $k$ structural)
Examples from OceanFlux net global CO$_2$

- Largest (>1 PgC/y)
- Large (>0.5 PgC/y)
- Substantial (0.1-0.5 PgC/y)
- $k$ ambiguity
- SOCAT vs Takahashi
- Tskin, Tsubskin
- Secular trend
- $k$ structural and parameter
- Data censoring (e.g. equilibrator temp)
- fugacity bias
- bootstrap
How would you define uncertainty on climatologies?

How can we agree what is and what is not credible?