Monitoring Global Integrals of Essential Climate Variables

J. Polcher, L. Cheng, R. Allan, P. Ciais, M. Cronin, H. Dolman, W. Dorigo, T. Haine, H. Kulaiappan Palanisamy, L.R. Leung, B. Meyssignac, S. Speich, D. Stammer, T. Tanhua, C. Tassone, A.M. Trofaier, K. Von Schuckmann, H. Wheater

A joint effort by WCRP and GCOS to establish the state of the art in closing geophysical cycles for the conservative quantities in the Earth system.

GCOS : Global Climate Observing System

WCRP :World Climate Research Program

Monitoring “global integrals”

- GCOS and WCRP produce a number of global estimates of key climatic variables which help us monitor the evolution of the Earth system.
- Each center producing these estimates make their best effort to verify the quality of the product.
- On of GEWEX’s activity is to compare and evaluate the various estimates.
- But we lack a method in order to asses the consistency of all these estimates (i.e. verify the link between variables) !
- Principles from physics, chemistry and biochemistry could enable us to perform this consistency check :
  - Closure of the dominant geophysical cycles.
  - The coupling of these cycles

How can these “global integrals” help us achieve this goal ?

Some fundamentals

For a conservative quantity ρ we can write :

$$\frac{\partial \rho}{\partial t} = \oiint_{S(v)} F_\rho dS + Q_\rho$$

Where F_ρ is the flux of ρ and Q_ρ the sink and source terms within volume *v*.

Each of the terms in this equation is a “global integral” !

To compute these “global integrals” two basic assumptions are needed :

- Over which domain will the integrals be estimated ?
- How to select fluxes and source/sink terms ?

The continuity equation is axiomatic : It defines the conservative quantity.

If we are confident in the variables estimated, their global integral should satisfy this equation.

Essential Climate Variables (ECV)

- For the 3 main cycles (enthalpy, water and carbon mass) most of the fluxes (F_ρ) are ECVs.
- In some cases $\partial\rho/\partial t$ can be observed (mass changes mostly) and are thus also ECVs.
- As the three cycles are closely coupled, the global integrals of the ECVs should also document these links.
- ***The continuity equation can also inform us on which variables should be observed and become an ECV.***
- ***In some cases, the ECVs are determined by the continuity equation itself. What is then the value of its global integral for the assessment ?***

How should the Earth system be separated into compartments ?

- The spatial decomposition of the Earth system is key as it determines how well the integrals can be computed.
- The proposal is to limit the global integrals to the **atmosphere, ocean and land**. It simplifies the problem as it can be assumed that their interfaces do not change over time.
- The cryosphere is a complication because of its time varying land/ocean transition.
- Furthermore its interactions between the enthalpy and water mass cycles is very different over both components.
- *A consequence of this choice* : the fluxes of mass and energy from land to ocean need to include the ice flow as well.

Difference between cycles and budgets

- The following definitions are proposed :
  - Continuity equation : the conservation of enthalpy or mass of water and carbon as given by the theory.
  - Budget equation : The closure as it can be estimated in the real world. Thus it always includes a residual !
- The residual has two components :
  - The **structural uncertainty** is the minimal residual resulting from all the fluxes which are not observed or have to be neglected.
  - The **methodological uncertainty** is the part of the residual resulting from the observations or retrieval of geophysical variables.

The continental water mass budget

The continental domain := The area in contact with the atmosphere, a vertical interface with the ocean along the shore line (net freshwater flux only) and a zero flux condition at the bottom.

$$\frac{\partial W}{\partial t} = \iint_{atm/cnt} P_{liq} + P_{ice} - \left(E_{ice} + E_{liq} + E_{tr} \right) dS - \iint_{oce/cnt} R_{surf} + R_{gw} + R_{ice} \, dS$$

There are only 3 ECVs in this continuity equation !

The most commonly used budget equation is:

$$\frac{\partial W}{\partial t} = \iint_{atm/cnt} P - E \, dS - \iint_{oce/cnt} R_{surf} \, dS + RES$$

Where :

$$RES = \iint_{oce/cnt} R_{gw} + R_{ice} \, dS + \epsilon$$

GEWEX

WMO IOC ICSU International Council for Science WCRP World Climate Research Programme

Illustration for the Mediterranean

The water mass balance of the Mediterranean :

- The riverine freshwater input is estimate to be about 400 km^3/y.
- The submarine discharge is between 40 and 60% of the surface flux. Which yield a total flux of about 570 km^3/y.
- It is a small quantity compared to the net flow through Gibraltar and its uncertainty : -2049 ±1040 km^3/y

The contribution of rivers to the enthalpy budget :

- The sensible heat flux contributed by rivers is about 0.6 W/m^2 (Neglecting the submarine discharge !).
- The average sensible heat flux between the atmosphere and the sea is -3±8 W/m^2.

Jorda et al. 2017,
Wang & Polcher 2019.

Implementation of the assessment method

- Establish the 9 continuity/budget equations (3 cycles over 3 domains) and quantify the associated systematic residuals.
- The land/ocean mask needs to be decided upon.
- Estimate the magnitude of the systematic errors done by neglecting some fluxes or processes.
- Then each group estimating one term of the continuity equation (flux or reservoir change) should compute the corresponding 3 “global integrals”.
- The time series of annual means will be archived and distributed.

The data can then be used to estimate how well we close the agreed budget equations and where our errors are much larger than the structural residual.

Conclusions

- It is a community effort to write the continuity equations as completely as possible and decide which approximations are needed ?
- Quantify the structural residuals.
- Will the collected data allow us to asses the following points :
  - Are our residuals close to the structural errors ? Does the errors estimation need to be refined ?
  - Can the variables determined from the continuity equation itself be detected ?
  - That the cycles are not stationary any more ?
  - Which ECVs are needed to better close the budgets ?

It is clear to GCOS and WCRP that more research on cycle quantification is needed. This effort should help identify the priorities.