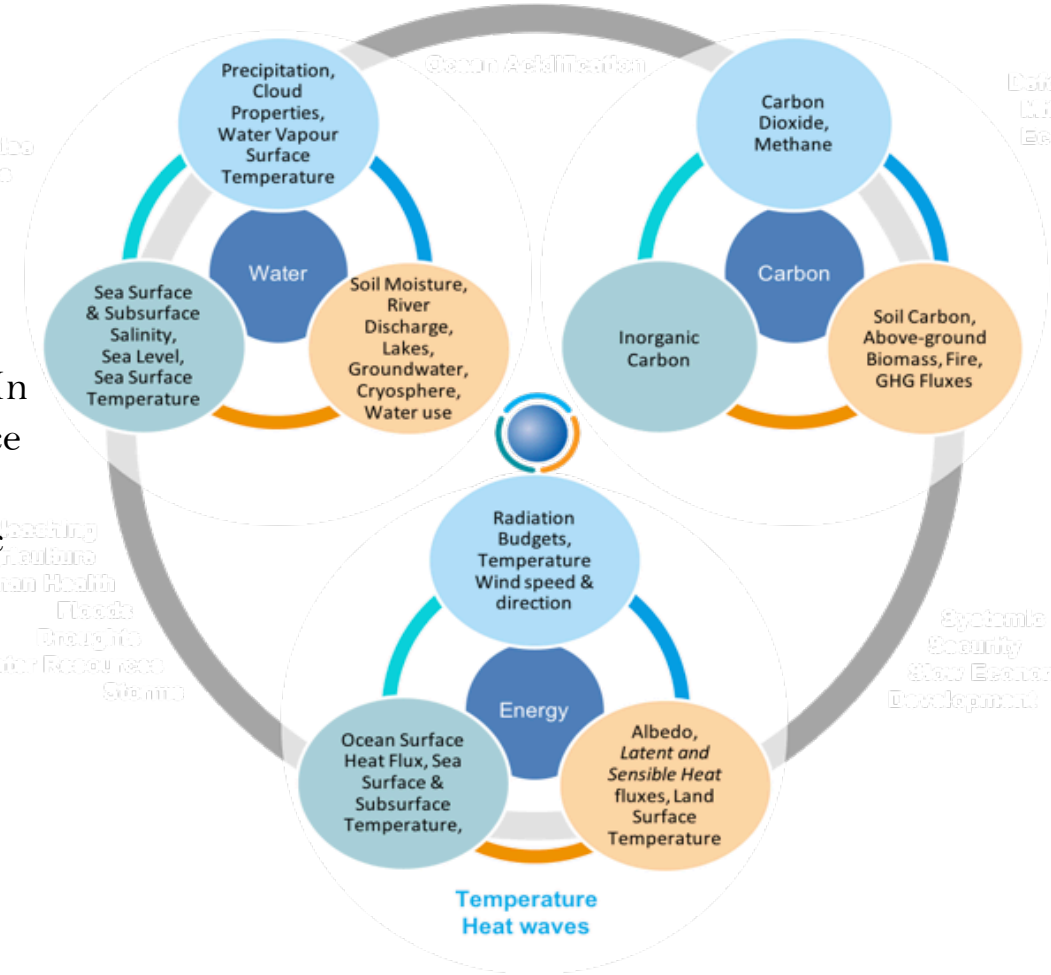
Observation strategies for Earth System Cycles

Han Dolman, Karina von Schuckmann, Nadine Gobron, Stephane Dietrich, Dave Crisp

The Earth cycles

- This new perspective on the importance of the Earth cycles in the selection of ECVs allows us to identify gaps and where ECVs contribute to fundamental understanding of the cycle.
- Closing the cycles will allow improved forecasts of the impacts of climate change. In particular, closing the Earth's energy balance and the carbon and water cycles through observations is still an outstanding scientific issue that requires high-quality climate records of key ECVs.
- If key pools or state variables are missing, these budgets cannot be closed.
- Importantly, closing the budget of a cycle requires attention to the exchange fluxes between the domains of atmosphere, land, ocean and ice.



The Earth Cycle budget closure in the IP

Box 4: Closing the carbon budget

Targets	Quantify fluxes of carbon-related greenhouse gases to +/- 10% on annual timescales Quantify changes in carbon stocks to +/- 10% on decadal timescales in the ocean and on land, and to +/- 2.5 % in the atmosphere on annual timescales
Who	Operators of GCOS-related systems, including data centres
Time frame	Ongoing
Performance indicator	Regular assessment of uncertainties in estimated fluxes and inventories

Box 5: Closing the global water cycle

Targets	Close water cycle globally within 5% on annual timescales
Who	Operators of GCOS-related systems, including data centres
Time frame	Ongoing
Performance indicator	Regular assessment of the uncertainties in estimated turbulent flux of latent heat

Box 6: Closing the global energy balance

Targets	Balance energy budget to within 0.1 Wm^{-2} on annual timescales
Who	Operators of GCOS-related systems, including data centres
Time frame	Ongoing
Performance indicator	Regular assessment of imbalance in estimated global energy budget

Box 7: Explain changing conditions of the biosphere

Targets	Measured ECVs that are accurate enough to explain changes of the biosphere (for example, species composition, biodiversity, etc.)
Who	Operators of GCOS-related systems, including data centres
Time frame	Ongoing
Performance indicator	Regular assessment of the uncertainty of estimates of changing conditions as listed above

Energy

Publication on
"Heat stored in the Earth system: Where does the energy go?"

Paper based on discussions during the topical breakout session at the GCOS general assembly, March 2019 (Marrakesh).

- **WMO/GCOS coordination:** Caterina Tassone
- **Ocean:** Karina von Schuckmann, Lijing Cheng, Tim Boyer, Matt Palmer
- **Atmosphere:** Andrea Steiner, Leopold Haimberger, Michael Mayer, Rainer Hollmann, Christian Lanconelli
- **Land:** Hugo Beltami, Sonia Seneviratne, Darren Ghent
- **Cryosphere:** Fiammetta Straneo, Andrew Shepherd

Proposed Journal: Earth System Science Data

Submission expected: Dec 2019 (i.e. for IPCC deadline)

Recommendations

- **RECOMMENDATION 1**: It is recommended that WCRP considers the regional and temporal resolutions needed to improve the understanding of the carbon cycle. WCRP should also look at how information about carbon isotopes can be used and what is needed to improve monitoring of the carbon cycle.

- **RECOMMENDATION *2***: Ask WCRP to work with modelling and observational communities to establish a scientific basis for improving observations, (i.e. how to capture the Earth's energy balance observationally and what is the required accuracy of these observations to close the Energy balance sufficiently to resolve the radiative forcing), including:
- Provide contribution of surface flux work as done under OceanObs / GCOS.
- Recommend and support that the community should submit a 'proposition of continuation' of CONCEPT-HEAT (Consistency between planetary heat balance and ocean heat storage).
- Encourage and support contributions to other scientific papers, for example on the EEI inventory (e.g. added expertise from observations on atmospheric, land and cryosphere storage)

Recommendations

- Building on a previous workshop, improve links between model and observational communities.
- Recommend and support the continuation of ORA-IP. Support related reanalysis inter-comparison projects.
- Determine the time-scales needed to understand the global energy balance.
- Identify the regional scale that needs to be considered (e.g. including heat re-distribution: transport in the atmosphere and ocean, and regional budgets)
- Continue to increase scientific understanding, knowledge and tools through the physical budget constraint approach, and address implications of changes in the energy budget

Publication on “Heat stored in the Earth system: Where does the energy go?”

Proposed paper structure

1. Introduction
2. Heat stored in the oceans
3. Heat available to warm the atmosphere
4. Heat available to warm land
5. Heat available to melt ice
6. Synthesis/Conclusion: Where does the energy go?

Publication on “Heat stored in the Earth system: Where does the energy go?”

Assess/review current state of knowledge

Proposed paper structure

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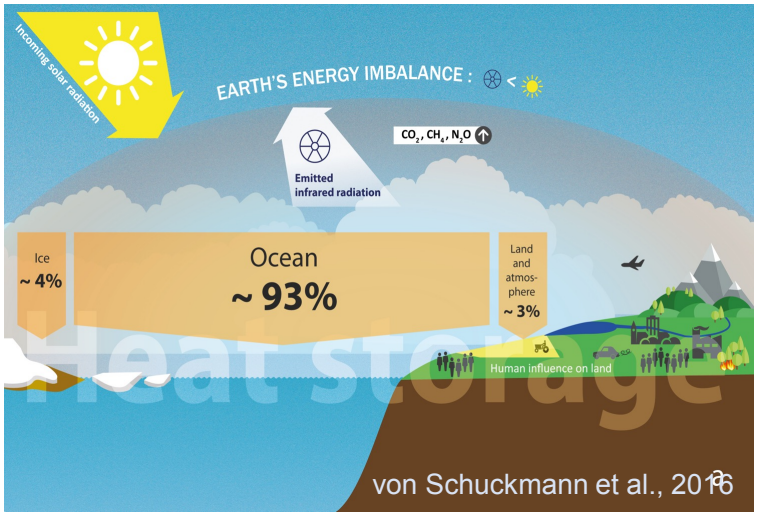

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- Assessment/update of available time series for heat content estimates & their rate of change
- discussion on current achieved accuracy, challenges, and recommendations for future improved estimates

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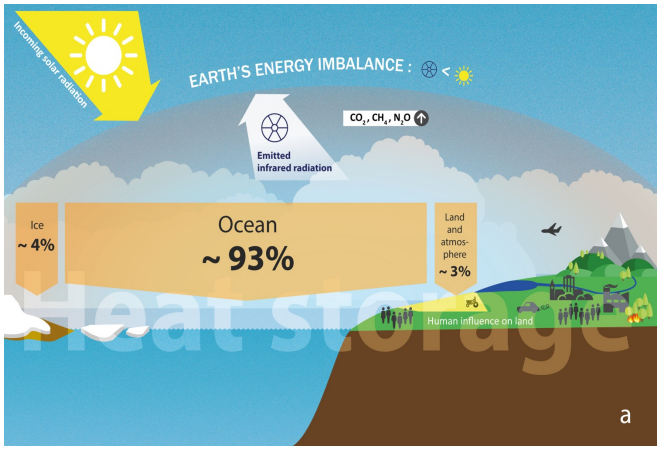
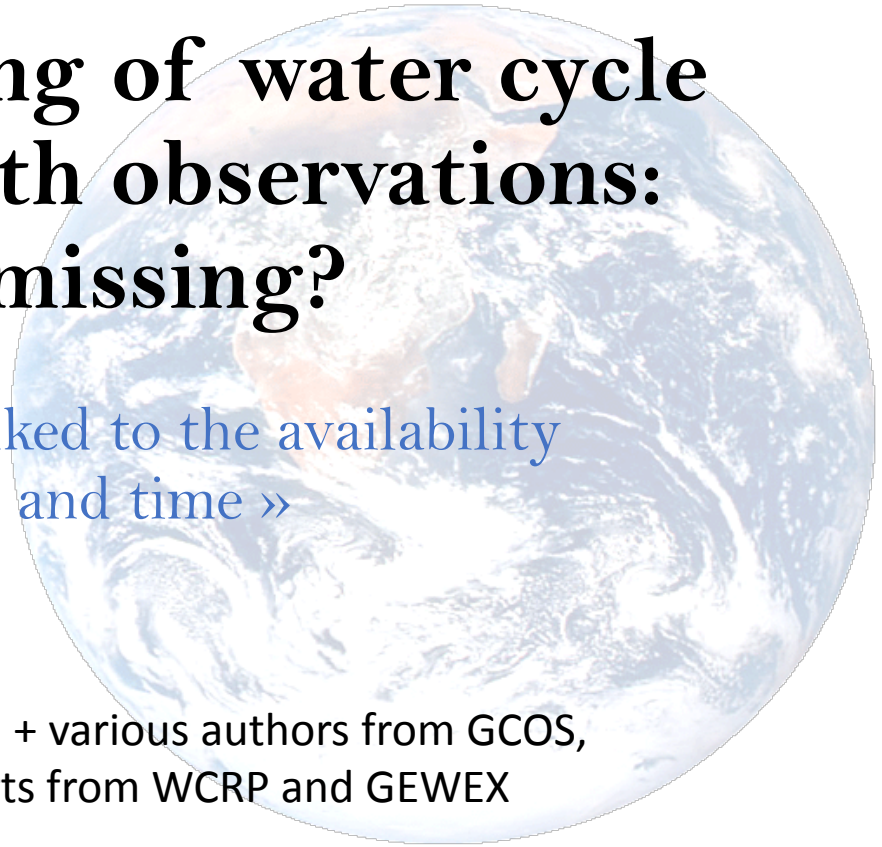


- Full inventory of energy stored in the Earth system as based on outcomes of 2)-5)
- comparison to net flux at the top of the atmosphere (CERES data for 2000 onwards, 1960 onwards from reconstructed time series, Allan et al.)
- discussion on current achieved accuracy, challenges, and recommendations for future improved and sustained estimates

Article Proposal to BAMS

Consistent monitoring of water cycle variability with Earth observations: What are we missing?

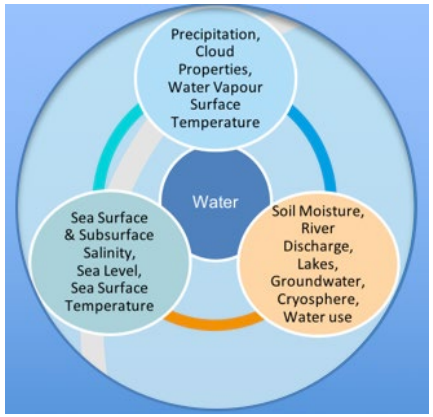


« Life on earth is closely linked to the availability of water in space and time »

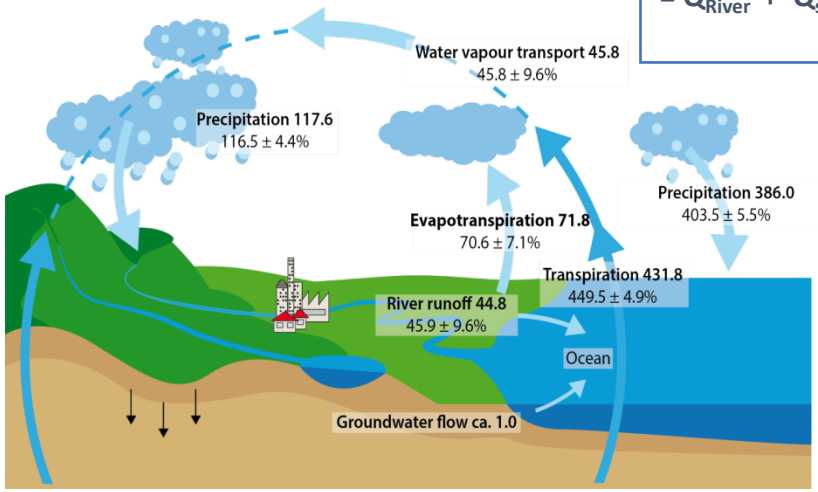
Authors: S. Dietrich & W. Dorigo (lead) + various authors from GCOS, including ECV stewards, and experts from WCRP and GEWEX

In this study, we

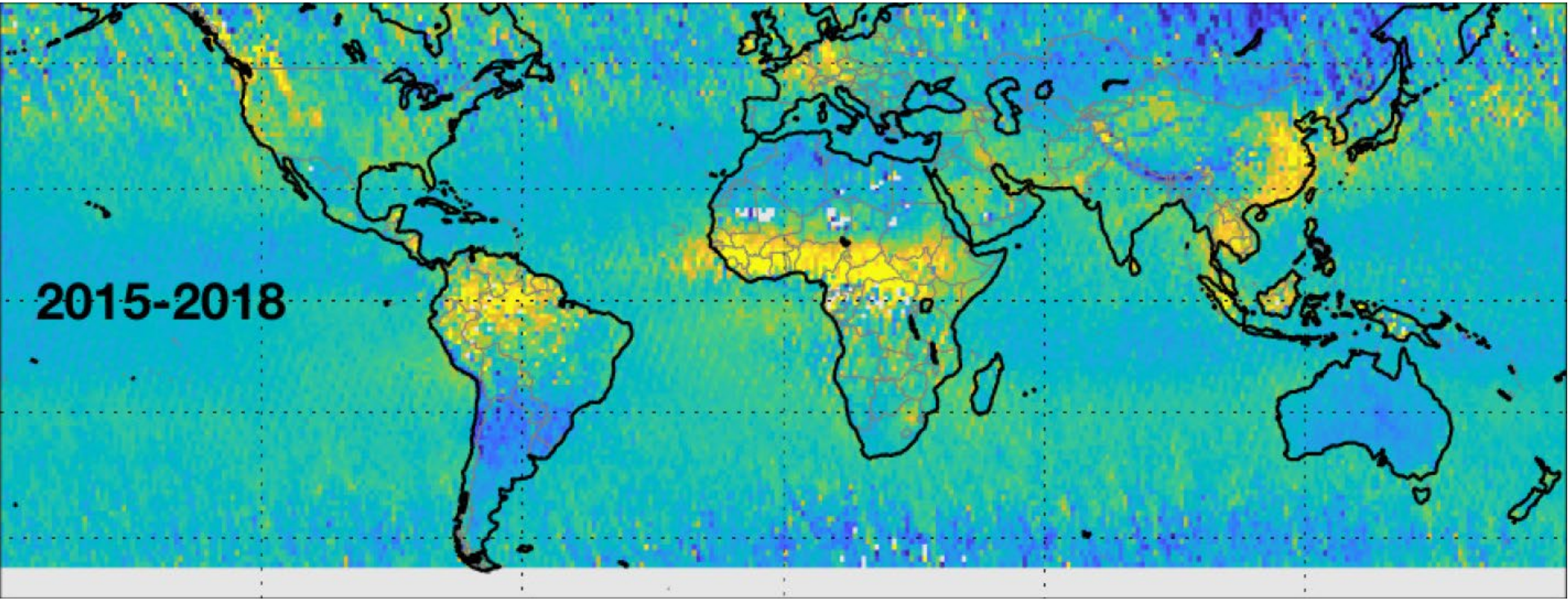
- assess the **status of consistently assessing the variability of the hydrological cycle** at various spatial and temporal scales,
- assess the relevant **land, atmosphere, and ocean water storages and the fluxes** between them, including anthropogenic water us,
- identify **gaps in existing observation systems and in consistency** and attribute their origin,
- conclude with formulating **guidelines for future water cycle observation** strategies.



Total continental runoff = 47.1
= 41.9 + 2.3 + 2.9
= Q_{River} + $Q_{submar.\ GW}$ + $Q_{ice\ sheet}$



Annual total water exchange: 520.1 ± 27.2 $10^3 km^3 yr^{-1}$



A Story Arc for the Carbon Cycle Paper

Dave Crisp
Jet Propulsion Laboratory, California Institute of Technology

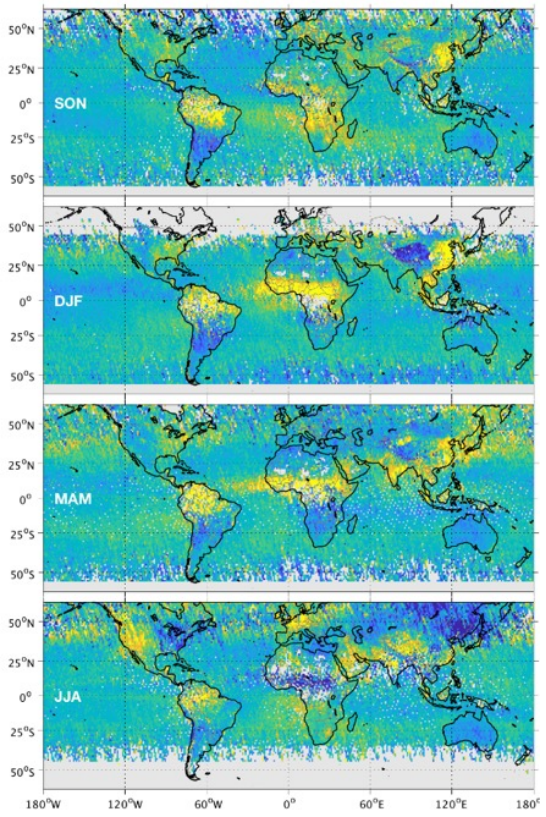
Jet Propulsion Laboratory
California Institute of Technology

A New Look at the Atmospheric Carbon Cycle from Space

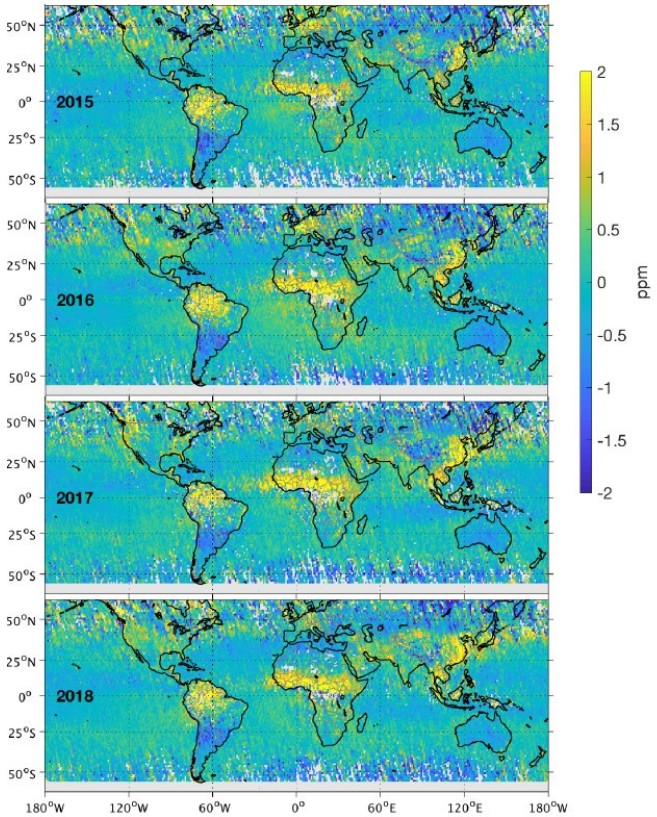
As GOSAT completed its 10th year in orbit and OCO-2 compiled its 5th, the data from these two missions began to reveal novel aspects of the carbon cycle:

- Tropical forests, once thought to be "the lungs of the planet" and a major natural sink of atmospheric CO_2, usually have positive CO_2 anomalies, indicating that they may be net sources of CO_2 rather than net sinks.
- The tropical oceans, which generally though to be a (weak) source of CO_2, appear to have persistent negative CO_2 anomalies, indicating that they might be CO_2 sinks rather than sources.
- Both forested and agricultural lands at mid- and high-latitudes appear to have both more vigorous CO_2 uptake and emissions than anticipated.

Persistent CO_2 Anomalies seen by OCO-2



Seasonal Anomalies



Annual Anomalies

Some regions have persistently high XCO_2 (positive anomalies) and low XCO_2 (negative anomalies) from season to season and from year to year

- Tropical forests exhibit persistent 1-2 ppm positive XCO_2 Anomalies.
- Tropical oceans have persistent 0.5-1.0 ppm negative anomalies.
- Mid- and high latitudes show large variations.

Hakkarainen et al. 2019

Possible Explanations for these Surprising Results

1. **Are the OCO-2 XCO_2 estimates are biased?**

   While OCO-2 measurements have be validated against TCCON and other standards, there are few validation sites in regions with the largest changes. There may still be persistent regional scale biases in OCO-2 XCO2.

2. **Are the earlier CO_2 measurements or carbon cycle models are wrong?**

   While ground-based and airborne data are more precise and accurate than the space based measurements, their spatial resolution and coverage is very sparse, especially in regions where the largest XCO_2 anomalies are seen by OCO-2. Flux inversion models cannot yield good results where there are no measurements.

3. **Has everything just changed?**

   There is increasing evidence from ground-based and space based measurements and from modeling studies suggesting that the carbon cycle is evolving in response to human activities and climate change. Measurements and models that based in earlier day may no longer describe this system.

WMO Experts in 1981

Table 2.3

Relationship between the scientific objectives and the requirements for background CO_2 measurements

Programme aim	Phenomena	Specific objective	Magnitude Time/Space Differences	Precision required		
				Type	Over time scales of	ppm
Long-term changes of atmospheric CO_2	1. Gross activities of carbon cycle, fossil fuel release, deforestation, ocean uptake	Trend determinations	~1 ppm yr^{-1}	Single or a few stations	Decades	1.0
	2. Temporal changes in gross features, El Nino, energy useage	Trend deviations	≷1 ppm yr^{-1}	Single or a few stations	Decades	~0.1
Source and sink distribution for development of more detailed models for future projection	3. Seasonal net ecosystem production, air-sea exchange seasonality	Annual cycle analysis	1-10 ppm/six months	Single station network	Year	≷0.1
	4. Regional surface fluxes, atmospheric dynamics	Vertical gradients	<1 ppm km^{-1}	Single/ Network	Month	≷0.1
	5. Regional surface fluxes	Latitudinal gradients	~0.1 ppm	Network	Month	≷0.1

REPORT OF THE WMO/UNEP/ICSU MEETING ON INSTRUMENTS, STANDARDIZATION AND MEASUREMENT TECHNIQUES FOR ATMOSPHERIC CO_2

Geneva, 8-11 September 1981

Observations sufficient to explain climate-induced changes in the global biosphere

to be submitted to Global Change Biology (editor agrees).

- This paper, co-leaded by Nic Bax and Nadine Gobrom, aims at covering both ocean and terrestrial domain.

- 1) to review available ECVs and their subvariables to identify where existing monitoring systems are sufficient to measure climate-induced 'biotic' changes
- 2) where changes have been measured but an ongoing monitoring system is lacking, and
- 3) where changes are anticipated and there is, or could be, accurate measurement sufficient to distinguish climate-induced changes from other anthropogenic or natural changes." (sic)

- contacting additional terrestrial co-authors (Martin Jung and Miguel Mahecha) knowing their work in BACI.
- proposed to review ECVs requirements that were mainly made for climate purposes (in term in radiative forcing ... from my side) to see if they can fit EEV, EOV (sic) and EBV purposes.
- concentrate on Biosphere Indicators based on actual ECVs as we cannot discuss everything.