Regeneration of CO_2 Satellite Column Data tailored to an Atmospheric inversion Scheme

A. Webb[1,2], H. Boesch[1,2], F. Chevallier[3], C. O'Dell[4]

Contact: alex.webb@leicester.ac.uk

[1]National Centre for Earth Observation, University of Leicester, Leicester, UK.
[2]Earth Observation Science, Department of Physics and Astronomy, University of Leicester, Leicester, UK.
[3]Laboratoire des Sciences du Climat et de l'Environnement, CEA-CNRS-UVSQ, L'Orme des Merisiers, Bat 701, 91191 Gif-sur-Yvette, France.
[4]Colorado State University, Fort Collins, CO, USA.

Introduction

- Current atmospheric inversion schemes assume rather realistic prior information when projected in concentration space, while satellite retrieval schemes try to maximize the measurement contribution in the retrievals by giving a very weak weight to prior information.

- Such inconsistent statistical hypotheses between XCO_2 retrieval and atmospheric inversion schemes may be a significant cause of error in atmospheric inversions assimilating satellite data.

- By using sounding-specific covariances from model covariances representing the prior flux uncertainties of the MACC model projected in space and time, we can derive satellite CO_2 columns tailored towards and consistent with the specific assumptions of the MACC atmospheric inversion scheme.

- Using global level-2 CO_2 data from NASA's OCO-2 satellite we reconstruct CO_2 columns with prior information from the MACC model using linear approximations thus avoiding the need for time-consuming re-retrieval of the satellite observations.

OCO-2 CO_2

- NASA's OCO-2 satellite (Orbiting Carbon Observatory 2) was launched on July 2nd 2014 into a near-polar orbit, joining the A-Train formation of satellites.

- The instrument incorporates three high-resolution spectrometers that make coincident measurements of reflected sunlight in the near-infrared CO_2 near 1.61 and 2.06 µm, and in the O_2 A-Band at 0.76 µm.

- CO_2 vertical profiles are retrieved using an optimal estimation scheme which combines OCO-2 radiance measurements with a priori information, a radiative transfer model and error covariance matrices associated with the measurements and a priori values.

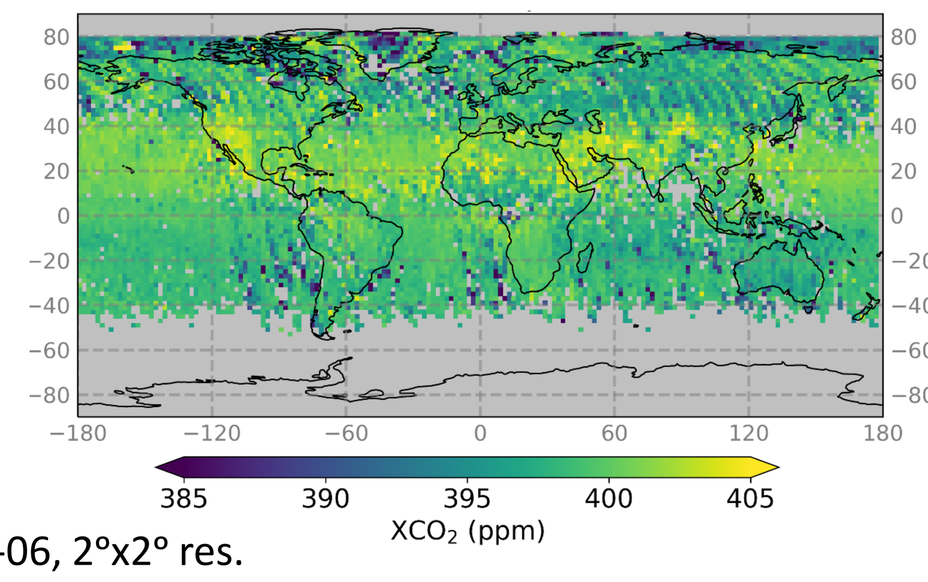
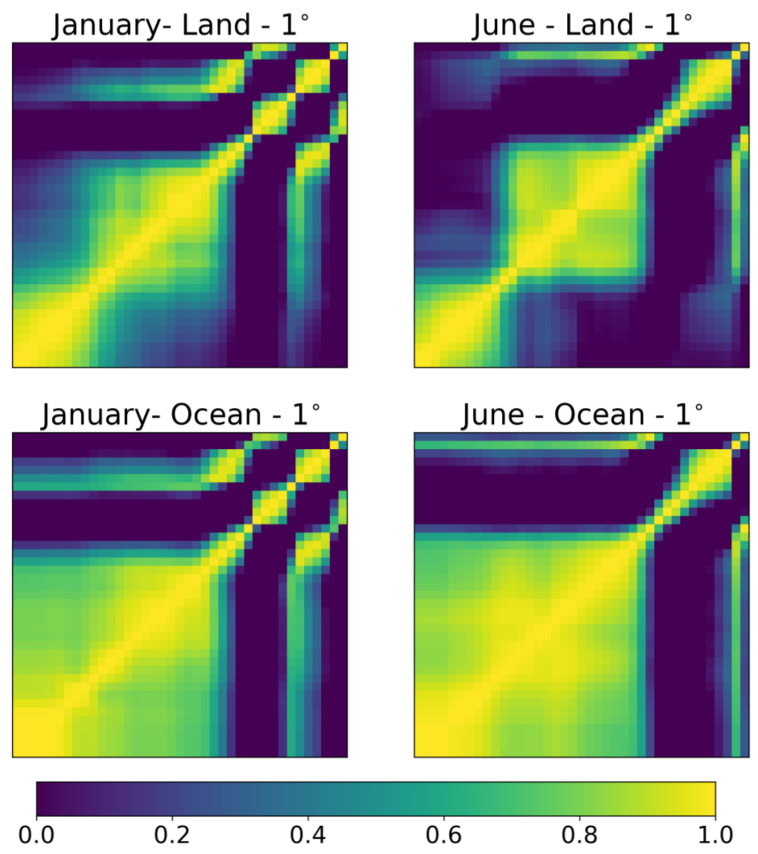


Figure 1: OCO-2 L2 Diagnostic 8r XCO_2, 2016-06, 2°x2° res.

MACC CO_2 Correlation Matrices



- We use correlation matrices from the MACC CO_2 inversion model v14.2 which covers 1970-2014 at 3.75°x1.9° and 3-hourly resolution.

- The MACC inversion also relies on optimal estimation, using a priori, a transport model and error covariance matrices.

- The a priori error covariance matrices utilised by the model are constructed using a climatology as a function of month, latitude and surface type.

Figure 2 (left): Example MACC a priori error correlation matrices for CO_2 for January (left), June (right), land (top), ocean (bottom) at 1° latitude. The top right represents the top of atmosphere, the bottom left represents the surface.

Method

Retrieval schemes like ACOS usually try to follow Bayes' theorem in a Gaussian framework in order to find the most likely values of a series of variables gathered in a state vector $\boldsymbol{x}$ given:

- A prior value of $\boldsymbol{x}$: $\boldsymbol{x^b}$ and its error covariance matrix: $\boldsymbol{B}$
- Satellite measurements $\boldsymbol{y}$ and their error covariance matrix $\boldsymbol{R}$
- An operator H which links the two types of variables

If H is linear, the solution $\boldsymbol{x^a}$ to the inverse problem and its error covariance matrix $\boldsymbol{A}$ are given by:

$$\boldsymbol{x^a} = \boldsymbol{x^b} + \boldsymbol{K}\left(\boldsymbol{y} - \boldsymbol{H}\boldsymbol{x^b}\right), \qquad (1)$$

$$\boldsymbol{A} = \left(\boldsymbol{H}^T\boldsymbol{R}^{-1}\boldsymbol{H} + \boldsymbol{B}^{-1}\right)^{-1}, \qquad (2)$$

$$\boldsymbol{A} = (\boldsymbol{I} - \boldsymbol{K}\boldsymbol{H})\boldsymbol{B}, \qquad (3)$$

where $\boldsymbol{H}$ is the Jacobian matrix of H, $\boldsymbol{I}$ is the appropriate identity matrix and $\boldsymbol{K}$ is defined as:

$$\boldsymbol{K} = \left(\boldsymbol{H}^T\boldsymbol{R}^{-1}\boldsymbol{H} + \boldsymbol{B}^{-1}\right)^{-1}\boldsymbol{H}^T\boldsymbol{R}^{-1}. \qquad (4)$$

We can rewrite (1) and use (2), (3) and (4) to show that,

$$\boldsymbol{A}^{-1}\boldsymbol{x}^a - \boldsymbol{B}^{-1}\boldsymbol{x}^b = \boldsymbol{H}^T\boldsymbol{R}^{-1}\boldsymbol{y}, \qquad (5)$$

Equation 5 implies that for given measurements $\{\boldsymbol{y}, \boldsymbol{R}\}$ and for a given observation operator $\boldsymbol{H}$, two retrieval schemes (noted 1 and 2) that differ by their a priori information $\{\boldsymbol{x_1^b}, \boldsymbol{B_1}\}$ and $\{\boldsymbol{x_2^b}, \boldsymbol{B_2}\}$ respect the equality:

$$\boldsymbol{A}_1^{-1}\boldsymbol{x}_1^a - \boldsymbol{B}_1^{-1}\boldsymbol{x}_1^b = \boldsymbol{A}_2^{-1}\boldsymbol{x}_2^a - \boldsymbol{B}_2^{-1}\boldsymbol{x}_2^b, \qquad (6)$$

So that:

$$\boxed{\boldsymbol{x}_2^a = \boldsymbol{A}_2\left(\boldsymbol{A}_1^{-1}\boldsymbol{x}_1^a - \boldsymbol{B}_1^{-1}\boldsymbol{x}_1^b + \boldsymbol{B}_2^{-1}\boldsymbol{x}_2^b\right), \qquad (7)}$$

and:

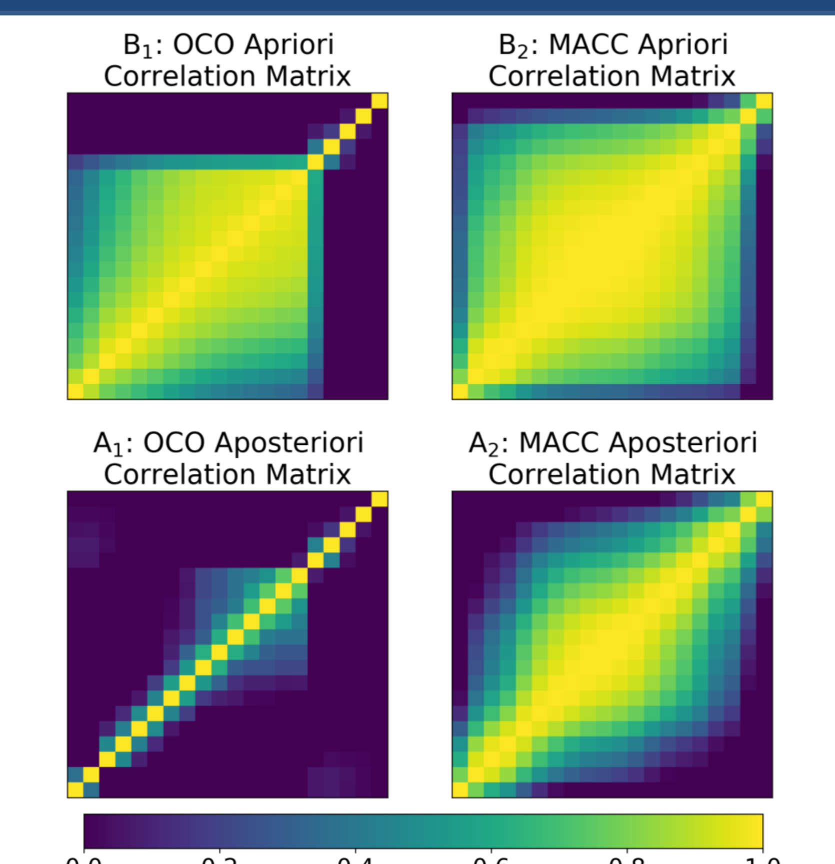
$$\boxed{\boldsymbol{A}_2 = \left(\boldsymbol{A}_1^{-1} - \boldsymbol{B}_1^{-1} + \boldsymbol{B}_2^{-1}\right)^{-1}. \qquad (8)}$$

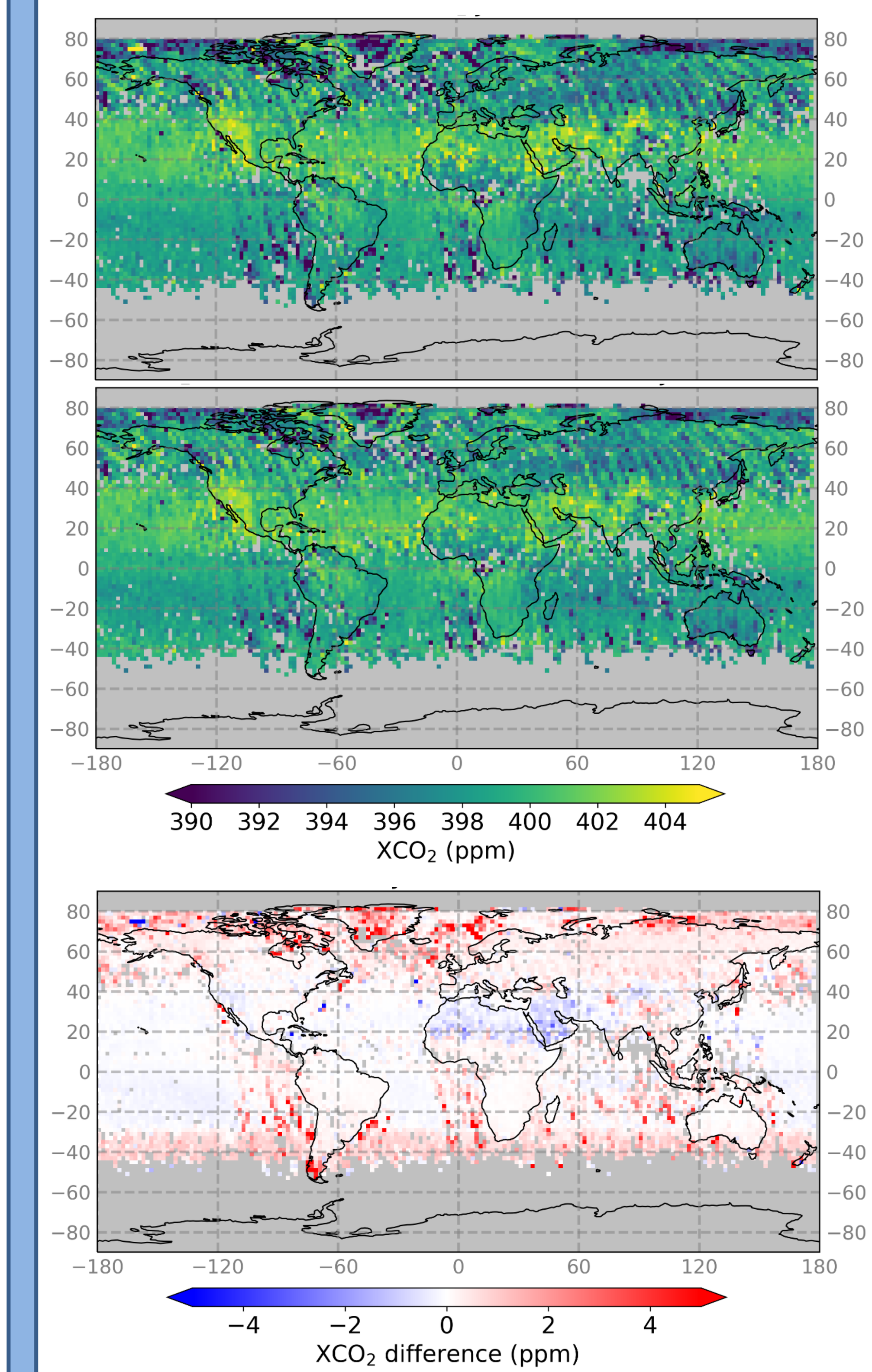
Equations 7 and 8 are entirely in the space of the state vector, allowing us to change the a priori error covariance matrix and obtain a new solution to the inverse problem without requiring the observations, their error covariance matrix or the observation operator.

These two equations have the clear advantage (over equations 1 and 2) of limiting the size of matrices in solving the retrieval.

Results and Future Work

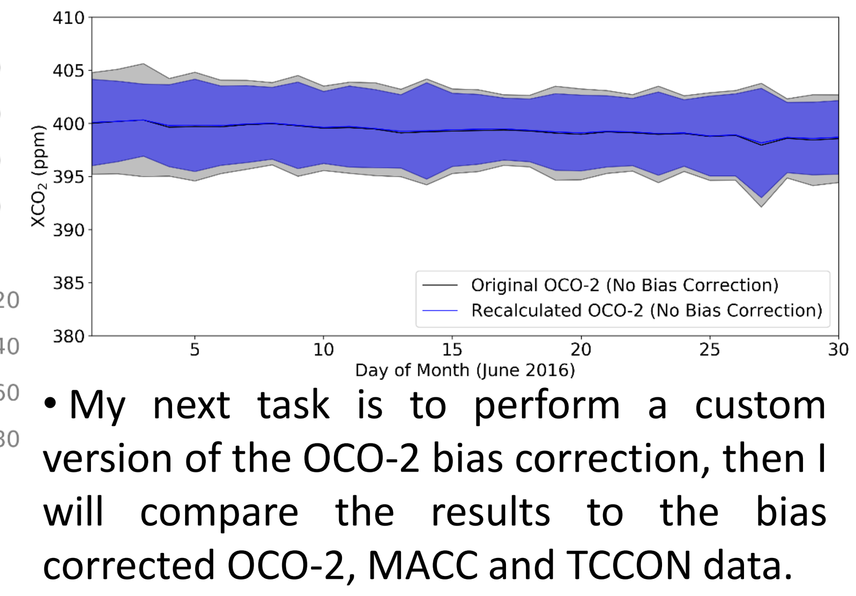
Figure 4 (right) shows the original a priori correlation matrix from OCO-2 and the corresponding a posteriori correlation matrix for an example case alongside the MACC a priori error correlation matrix (interpolated onto the OCO-2 pressure profile) and the newly calculated a posteriori error correlation.





Figures 5, 6, 7 (left top to bottom) show: The original L2 OCO-2 data (June 2016), the recalculated OCO-2 and the difference (recalculated minus original).

Figure 8 (below) shows time-series of the daily averaged XCO_2: shaded area showing the standard deviation (std) of the data. The recalculated dataset is in blue and the original OCO-2 data in grey.



- My next task is to perform a custom version of the OCO-2 bias correction, then I will compare the results to the bias corrected OCO-2, MACC and TCCON data.

Acknowledgements

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