The OCO-2 Level 4 Gridded Flux Product

Sean Crowell, Andrew Schuh, David Baker, Andy Jacobson, Sourish Basu, Junjie Liu, Frederic Chevallier, Feng Deng, Liang Feng, Annmarie Eldering, Chris O’Dell, Mike Gunson, David Crisp, Dylan Jones, Paul Palmer
The OCO-2 Flux MIP: Round 1

OCO-2 v7 Standard
✓ 10s “Good” Data
✓ Standardized errors
✓ Separate by mode/surface type

Inversion Models
✓ Different transport
✓ Different initial conditions
✓ Different bio and ocean priors
✓ Different prior uncertainties
✓ Different DA methods
✓ Standardized fossil fuel

Meaningful Spread
✓ Transport + Prior + Prior Uncert
✓ (Not from obs handling)

Also, standardized ObsPack NRT in situ data from Andy Jacobson and Ken Schuldt at NOAA

Baseline In Situ Results
✓ Ties to previous literature (Transcom, etc)
✓ Gives useful comparisons in well observed regions

Round 2 Starts Soon!
Email david.f.baker@noaa.gov!
Ensemble Spread Ingredients

Inversion Models
- Different transport
- Different initial conditions
- Different bio and ocean priors
- Different prior uncertainties
- Different DA Methods
- Standardized fossil fuel (ODIAC with Nassar temporal scaling)

- GEOS-Chem
- PCTM
- LMDZ
- TM5

- CASA-GFED
- BEAS
- CT2016 Clim
- SiB-CASA
- SiB4
- ORCHIDEE

- CT2015/6 Clim
- Takahashi
- CESM-BEC
- Landschuetzer et al
- ECCO2-Darwin

- 4DVar
- Ensemble Kalman Filter
- Ensemble
- Kalman Smoother
- Batch Synthesis
MIPs Require International Collaboration

- Surface data: NOAA ObsPack consists of the global cooperative network
- TCCON data: international network
- Aircraft data for evaluation from NOAA, CONTRAIL, ATom, ACT-America, ...
- Transport Ensemble
  - GEOS-Chem/PCTM
    - JPL
    - University of Toronto
    - University of Edinborough
    - NOAA GMD
  - TM5/LMDz
    - NOAA GMD
    - University of Oklahoma
    - LSCE
Level 4 Gridded Fluxes for 2016: Ensemble Mean

L4: Prior Land Annual Fluxes for 2016
L4: IS Land Annual Fluxes for 2016
L4: LN Land Annual Fluxes for 2016
L4: LG Land Annual Fluxes for 2016

Prior
In Situ
Land Nadir
Land Glint
Level 4 Gridded Fluxes for 2016:
Ensemble Standard Deviation

L4: Prior Land Uncert Annual Flux Std for 2016

L4: IS Land Uncert Annual Flux Std for 2016

L4: LN Land Uncert Annual Flux Std for 2016

L4: LG Land Uncert Annual Flux Std for 2016

Prior

In Situ

Land Nadir

Land Glint
Within the ensemble spread, IS, LN and LG agree on the annual global sink, as well as the partitioning into land and ocean.
Global Land and Ocean Fluxes

**Ensemble Median**

**Ensemble Mean**

**Ensemble Standard Deviation x2**

**Prior**
- In Situ
- Land Nadir
- Land Glint

**Global Land**

**Global Ocean**

**Annual Flux (PgC per y)**

**Monthly Mean Fluxes (PgC per month)**
OCO-2 Level 4 Flux Findings

• Within the ensemble spread, IS, LN and LG agree on the annual global sink, as well as the partitioning into land and ocean.

• In the Tropics, OCO-2 sees a strong source for 2015-2016, as well as double the seasonal cycle amplitude as the fluxes inferred from IS.
Tropics: OCO-2 sees a large source and double the seasonal cycle amplitude of IS.
OCO-2 Level 4 Flux Findings

- Within the ensemble spread, IS, LN and LG agree on the annual global sink, as well as the partitioning into land and ocean.
- In the Tropics, OCO-2 sees a strong source for 2015-2016, as well as double the seasonal cycle amplitude as the fluxes inferred from IS.
  - This signal difference largely occurs in Tropical Africa.
Stronger Outgassing in Tropical Africa Inferred from OCO-2 Data

TransCom 05b Northern Tropical Africa

Annual Flux (PgC per y)

Flux (PgC per y)

Prior IS LN LG

Monthly Mean Fluxes (PgC per month)

TransCom 06a Southern Tropical Africa

Annual Flux (PgC per y)

Flux (PgC per y)

Prior IS LN LG

Monthly Mean Fluxes (PgC per month)
Stronger Outgassing in Tropical Africa Inferred from OCO-2 Data

(N. African source not balanced with European sink)
• The spatial scale of fluxes to which a TCCON site is sensitive is largely zonal (Keppel-Aleks et al, 2011), but there are definitely local influences that aren’t well reproduced by large scale models (e.g. Caltech).

• Models mostly match TCCON to within OCO-2 overpass error statistics, and in many cases the model residuals are correlated with corresponding OCO-2 overpass residuals.

• Models are biased high relative to all European sites.

• There is seasonality in both the OCO-2 and posterior concentration residuals with TCCON at some sites, but not at others.
Annual Bias relative to TCCON in Posterior Model Concentrations matches OCO-2 Bias

Overall bias relative to TCCON is slightly larger for OCO-2 driven inversions than for IS inversions, as is RMSE.
To support the 2021 global stock take requires both a flux and a flux uncertainty.

A full flux uncertainty budget requires an ensemble of transport models with different prior fluxes and uncertainties
  – This requires an international effort!

OCO-2 is seeing new and exciting things in the carbon cycle, and the newest version of the data evaluates even better against independent data – the next round of the MIP will be even more exciting.
Backup
Monthly Bias relative to TCCON in Posterior Model Concentrations matches OCO-2 Bias

Likely elevated due to LA in model grid box

City influence diluted by area outside the LA basin
assimilated data includes the S31 bias correction term, but still shows a high bias relative to TCCON at every site in almost every month with valid data.

* = individual OCO-2 overpasses
TCCON Eval Summary

- European flux results do not agree with TCCON, and suggest too much CO2 across the board – 0.25 PgC annual high bias in Europe in Sourish’s paper.
- Land Nadir observations in tropics convolved with transport errors are leading to more CO2 than TCCON suggests – high tropical land flux bias is implied by transport alone in Sourish’s current discussion paper, but it is compensated by a low ocean bias.
- Results from Lamont and Park Falls are comparable between experiments, suggesting that fluxes that affect these sites are fairly well constrained – errors from transport should be minimal here.
TransCom 02 North American Temperate

Annual Mean Flux (PgC per y) for 2015 (left) and 2016 (right)

Monthly Median Fluxes (PgC per y)
TransCom 03a Northern Tropical South America

Annual Mean Flux (PgC per y) for 2015 (left) and 2016 (right)

Monthly Median Fluxes (PgC per y)
TransCom 08 Eurasia Temperate

Annual Mean Flux (PgC per y) for 2015 (left) and 2016 (right)

Monthly Median Fluxes (PgC per y)

Prior
IS
LN
LG

1/15 4/15 7/15 10/15 1/16 4/16 7/16 10/16
TransCom 09a Northern Tropical Asia

Annual Mean Flux (PgC per y) for 2015 (left) and 2016 (right)

Monthly Median Fluxes (PgC per y)

1/15 4/15 7/15 10/15 1/16 4/16 7/16 10/16
Aircraft Evaluation

Super preliminary (sorry!)
West Coast sites

Small persistent high bias in OCO-2 data
Mid-continent sites
HIL Residuals (ppm) for IS

HIL Residuals (ppm) for LN

HIL Residuals (ppm) for LG
East coast sites