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 Model Intercomparison Project

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

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

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

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

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

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

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)*

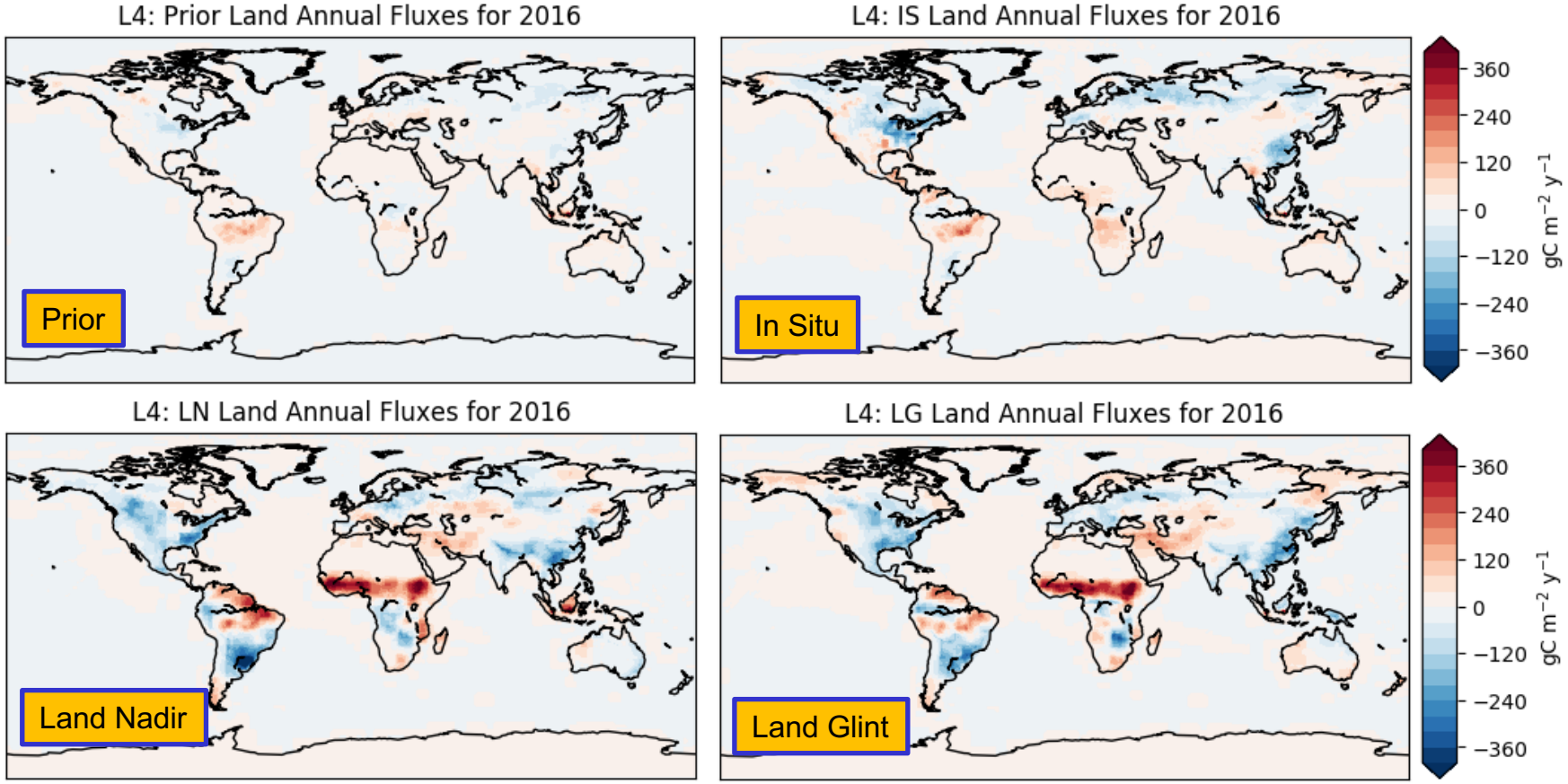
- GEOS-Chem
- PCTM
- LMDZ
- TM5

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

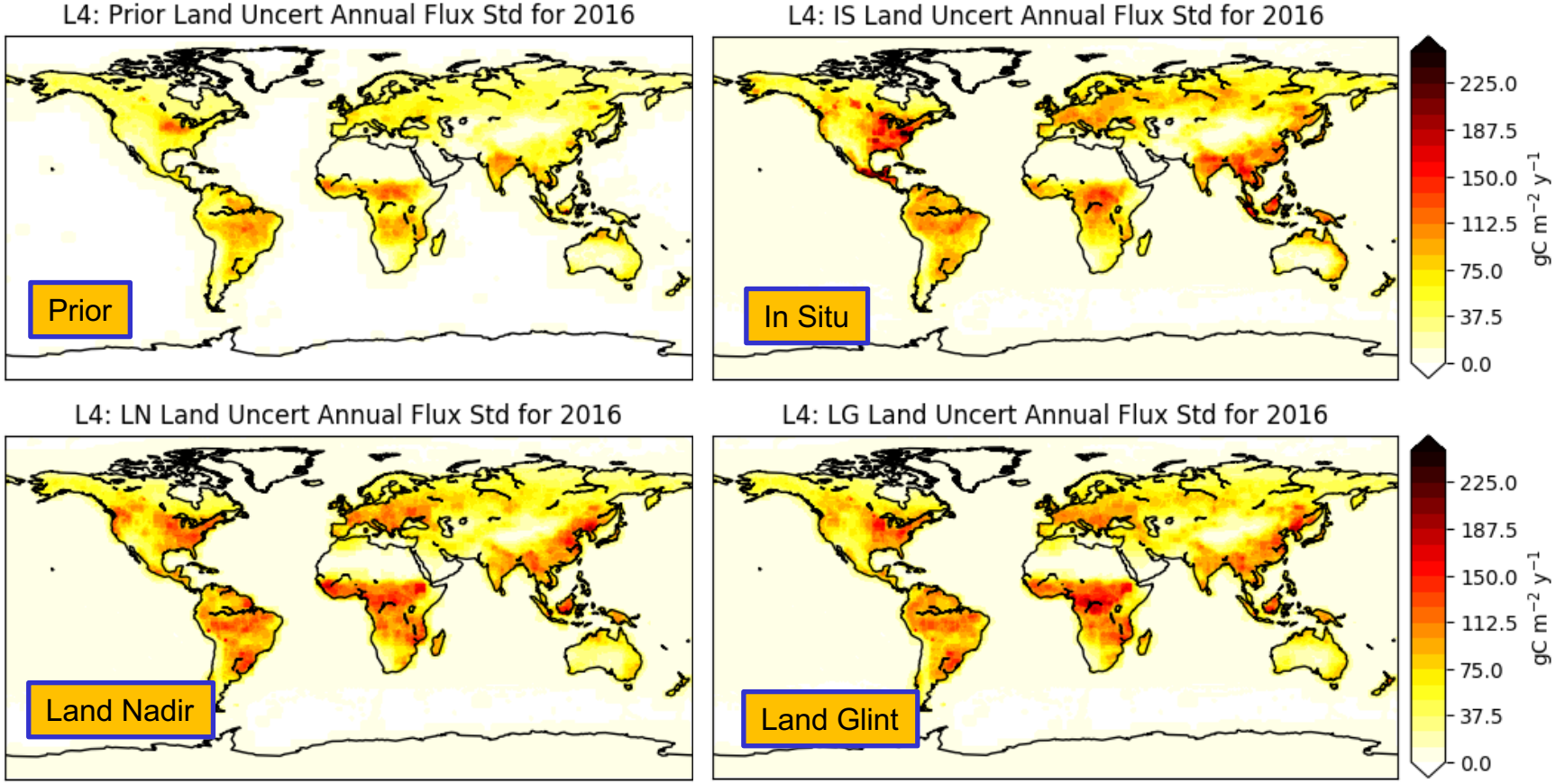
- CT2015/6 Clim
- Takahashi
- CESM-BEC
- Landschuetzer et al
- ECCO2-Darwin

- 4DVar
- Ensemble Kalman Filter
- Ensemble Kalman Smoother
- Batch Synthesis

Level 4 Gridded Fluxes for 2016: Ensemble Mean



Level 4 Gridded Fluxes for 2016: Ensemble Standard Deviation



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.

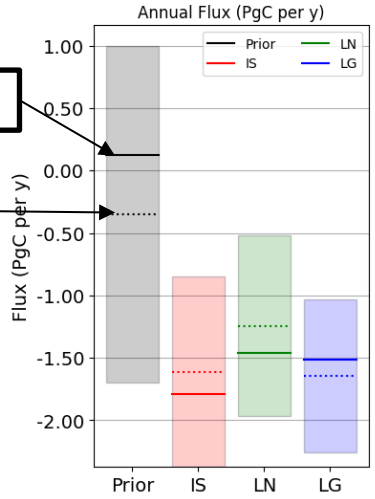
Global Land and Ocean Fluxes

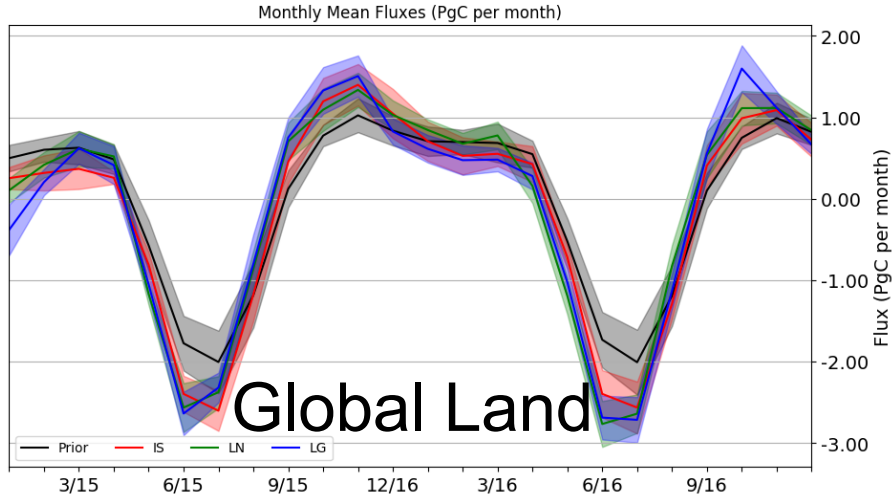
Ensemble Median

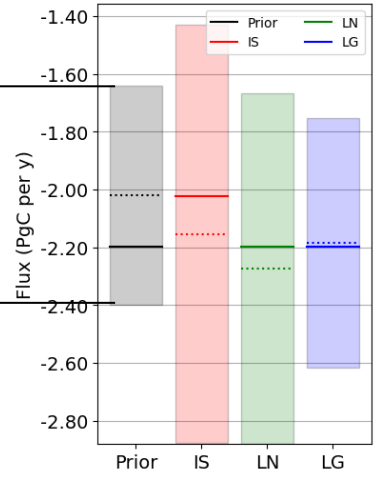
Ensemble Mean

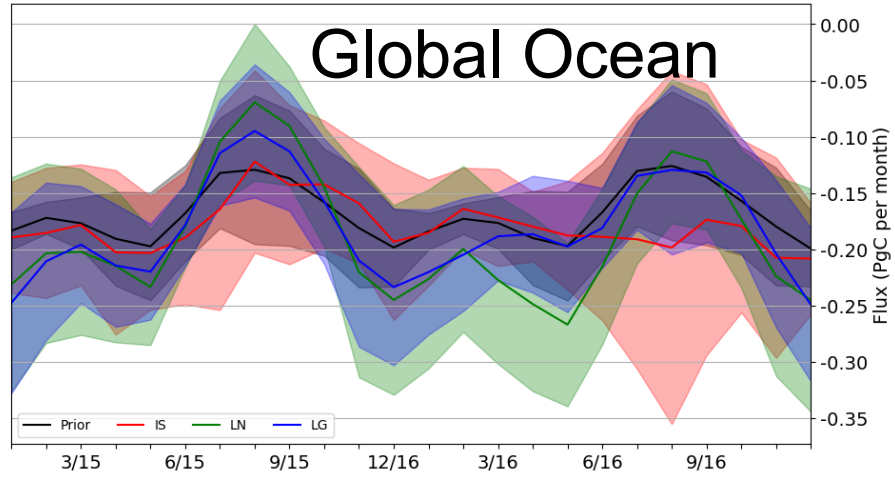
Ensemble Standard Deviation x2

Prior
In Situ
Land Nadir
Land Glint









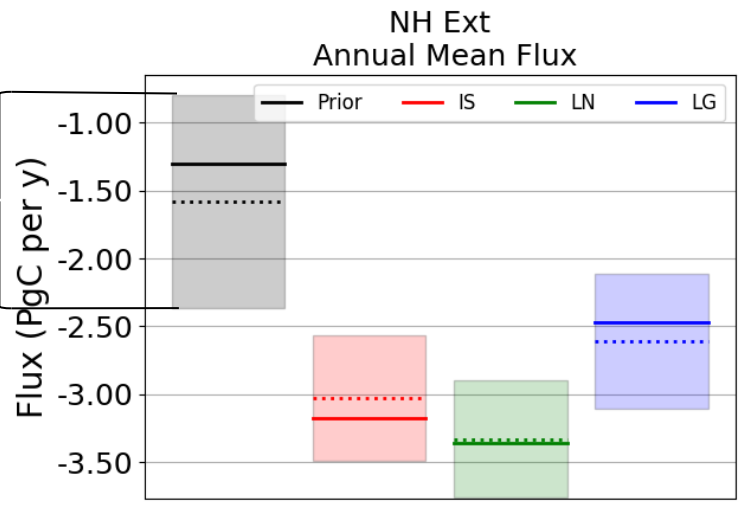
OCO-2 Level 4 Flux Findings

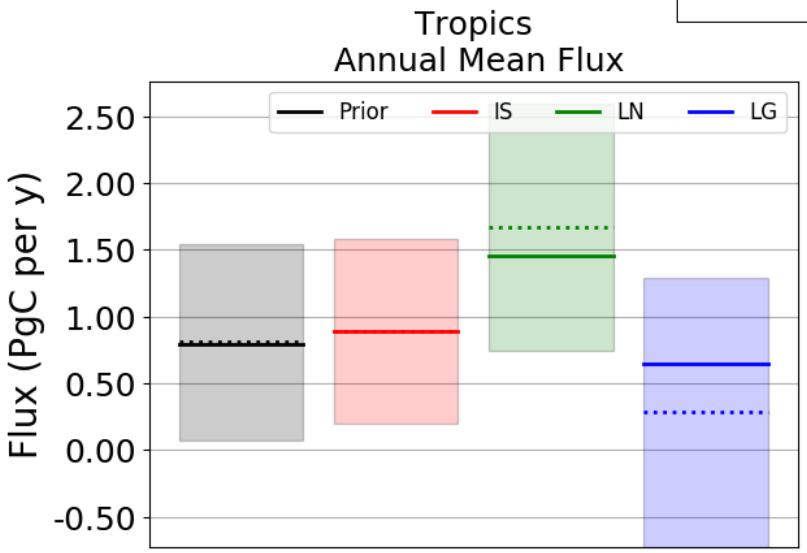
- Within the ensemble spread, IS, LN and LG agree on the annual global sink, as well as the partitioning into land and ocean.
- Each data set sees a different N/S gradient

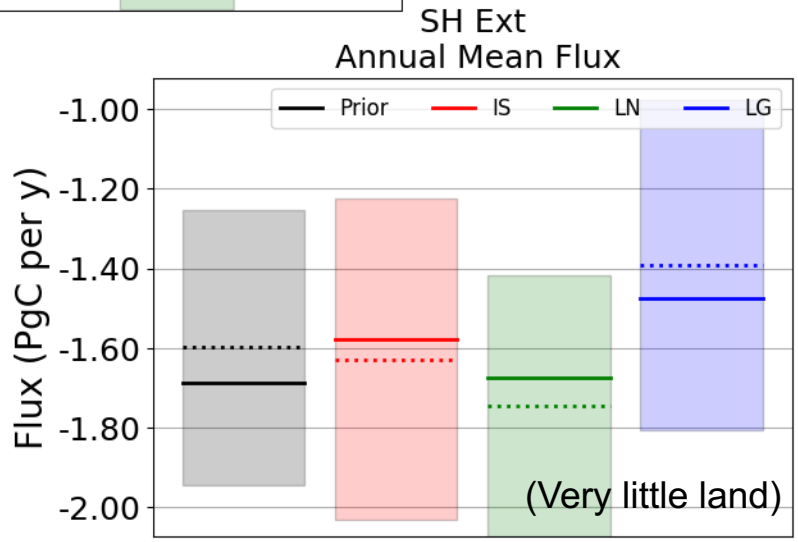
Double the Seasonal Cycle Amplitude in the Tropics As Inferred from OCO-2 Data

Prior
In Situ
Land Nadir
Land Glint

Ensemble Standard Deviation x2



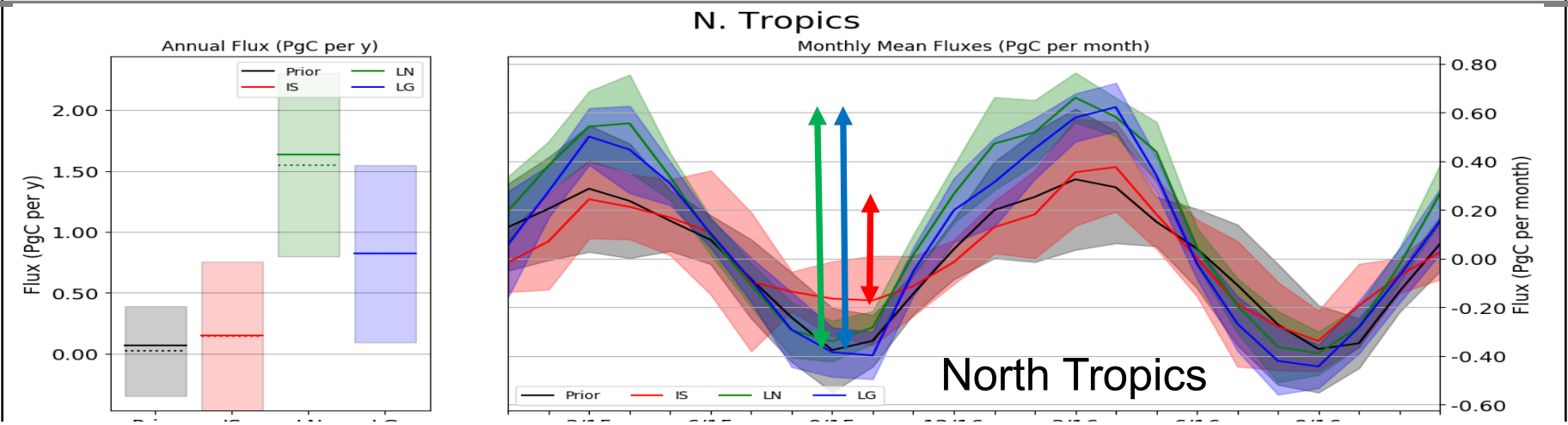


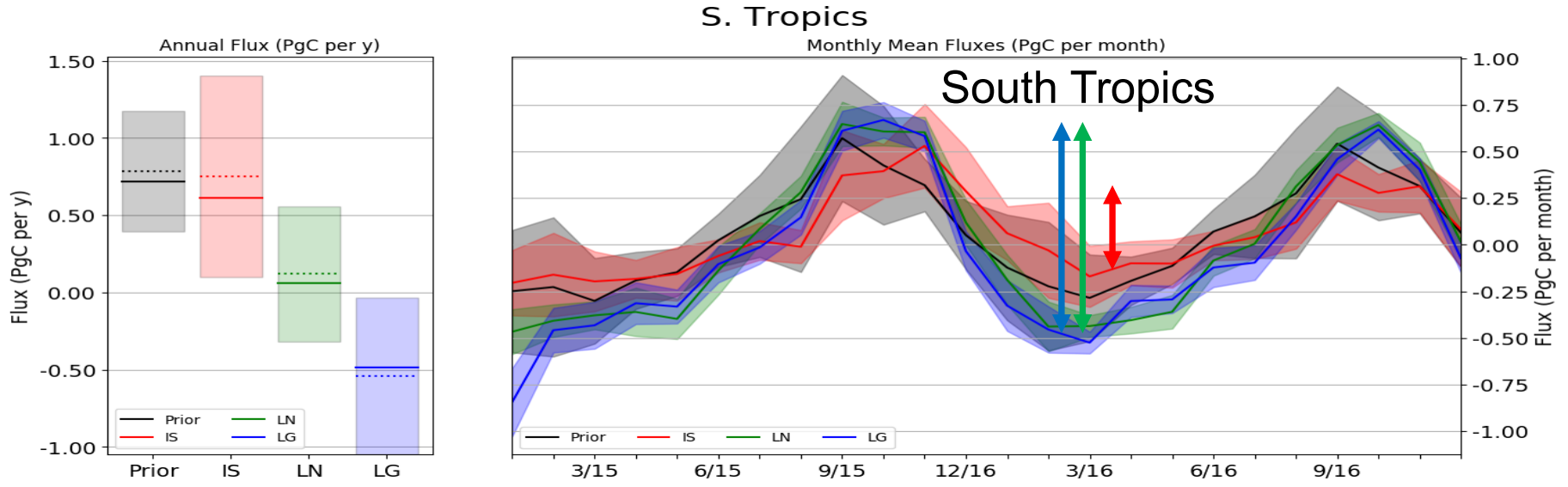


OCO-2 Level 4 Flux Findings

- Within the ensemble spread, IS, LN and LG agree on the annual global sink, as well as the partitioning into land and ocean.
- Each data set sees a different N/S gradient
- 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

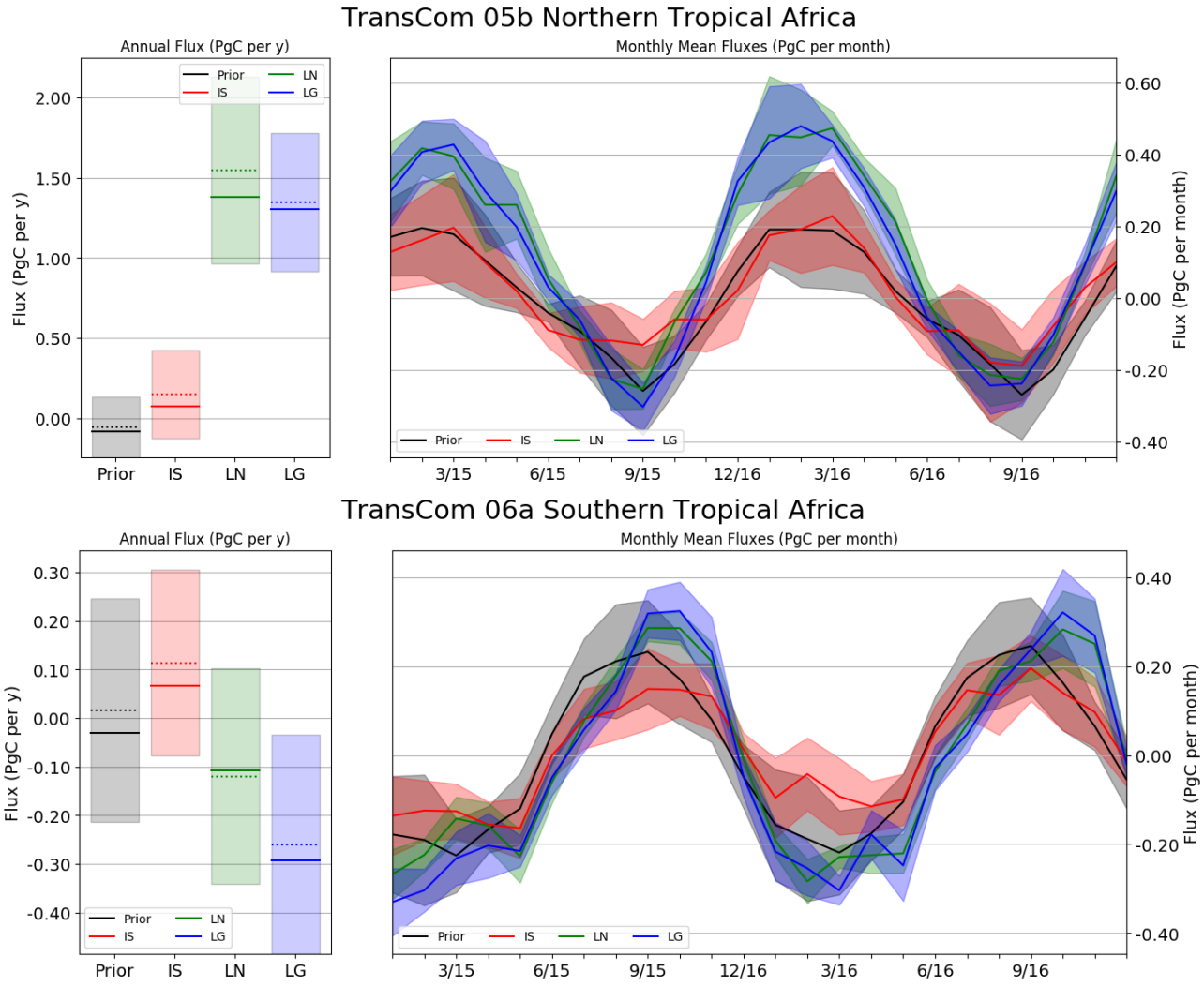




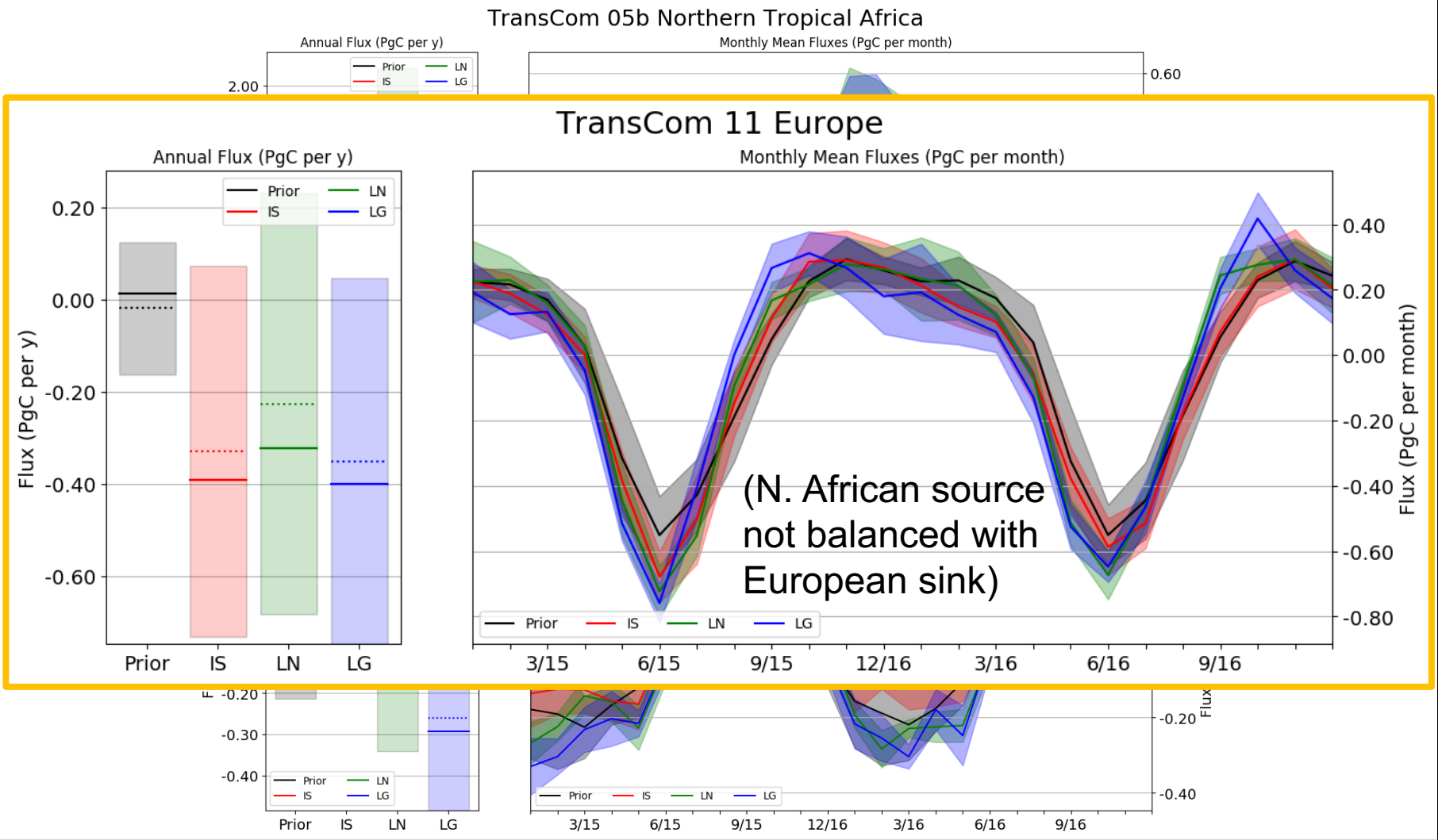
OCO-2 Level 4 Flux Findings

- Within the ensemble spread, IS, LN and LG agree on the annual global sink, as well as the partitioning into land and ocean.
- Each data set sees a different N/S gradient
- 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



Stronger Outgassing in Tropical Africa Inferred from OCO-2 Data

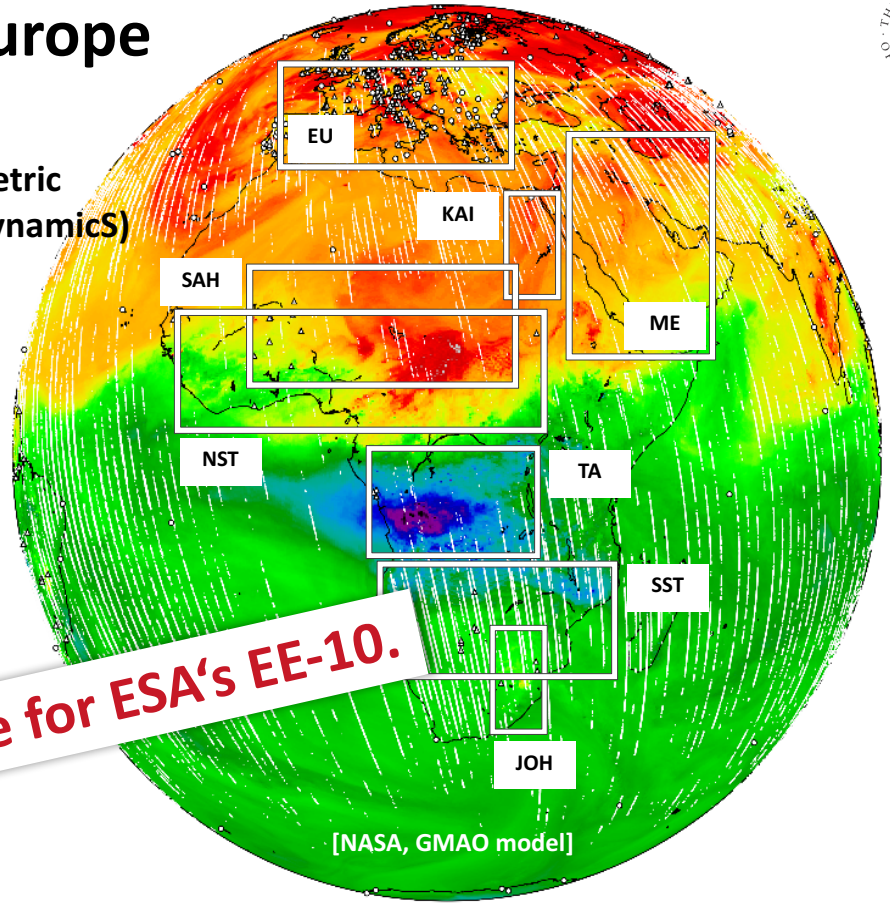


Speaking of Africa...

ARRHENIUS: a Geostationary Carbon Process Explorer for Africa, Europe and the Middle-East

(ARRHENIUS = AbsoRption spectRometric patHfindEr for carboN regIonal flUx dynamicS)

André Butz (PI, U Heidelberg, D)
Paul Palmer (co-PI, U Edinburgh, UK)
Hartmut Bösch (U Leicester, UK)
Philippe Bousquet (LSCE, F)
Heinrich Bovensmann (U Bremen, D)
Dominik Brunner (EMPA, CH)
Luca Bugliaro (DLR, D)
David Crisp (JPL, USA)
Sean Crowell (U Oklahoma, USA)
Juan Cuesta (LISA, F)
Bart Dils (BIRA-IASB, B)
Emanuel Gloor (U Leeds, UK)
Sander Houweling (U Amsterdam, SRON, NL)
Jochen Landgraf (SRON, NL)
Julia Marshall (MPI BGC, D)
Charles Miller (JPL, USA)
Ray Nassar (ECCC, CA)
Johannes Orphal (KIT, D)
Guido van der Werf (U Amsterdam, NL).



Candidate for ESA's EE-10.

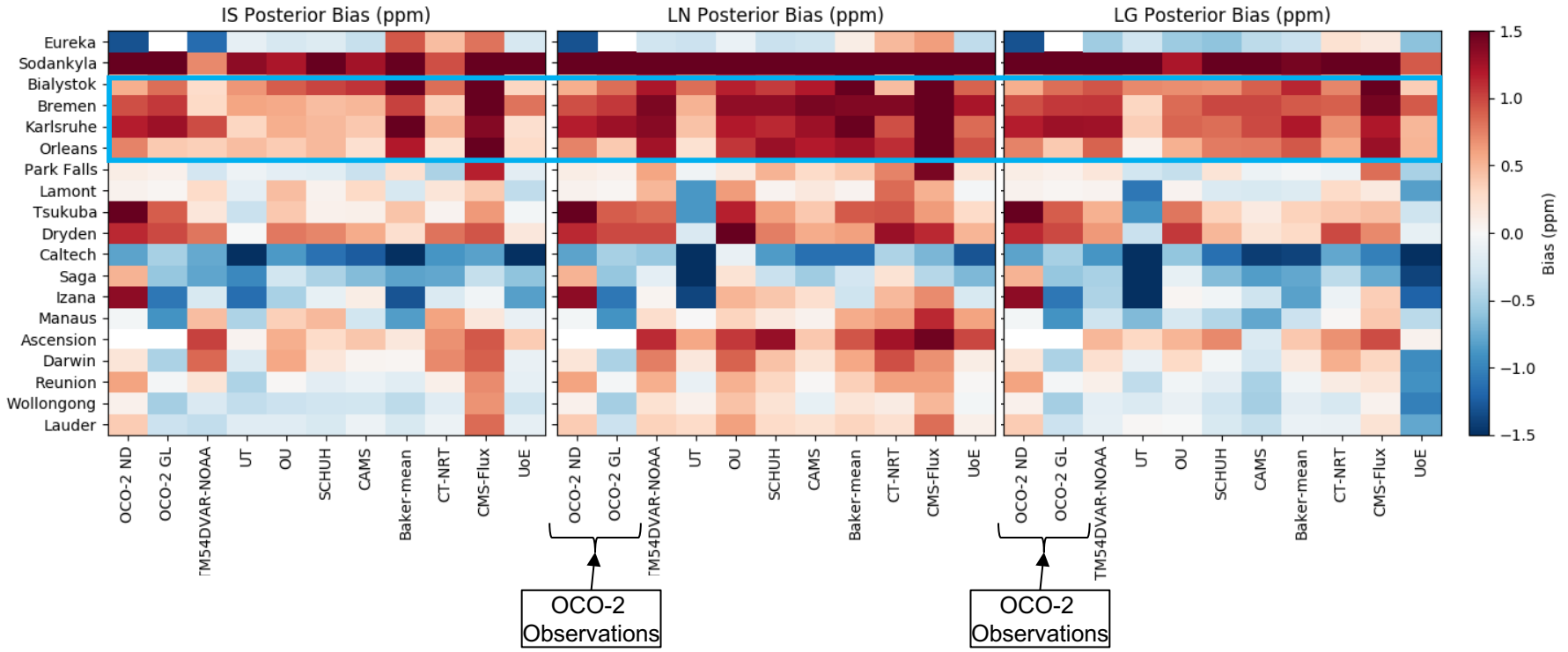
1

TCCON Evaluation

TCCON Evaluation Summary

- 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.

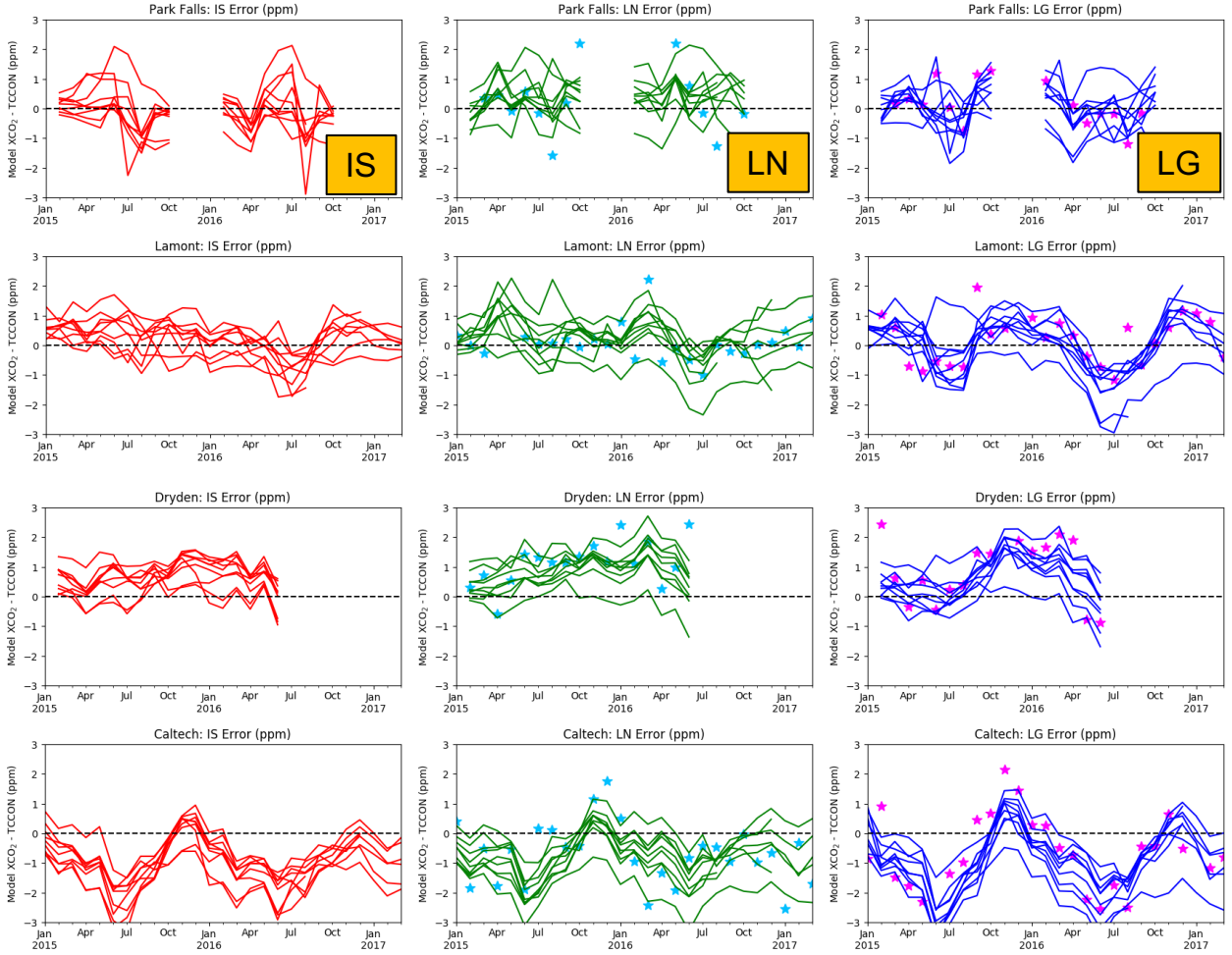
Monthly Bias relative to TCCON in Posterior Model Concentrations matches OCO-2 Bias

Park Falls

Lamont

Dryden

Caltech



Likely elevated due to LA in model grid box

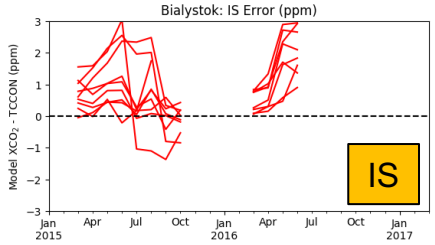
City influence diluted by area outside the LA basin

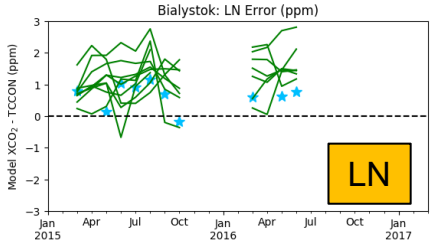
Comments

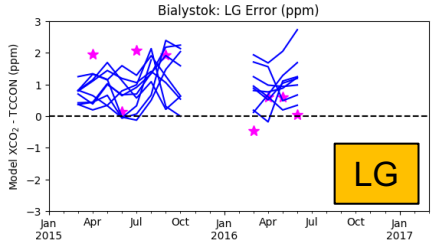
- OCO-2 data is in agreement with the in situ network at the largest scales, but implies a much more dynamic carbon cycle at regional and seasonal scales than the in situ network, especially in the tropics
- Validation vs. TCCON (and aircraft) does not pick a clear winner.
- Next iteration of the MIP with v9 OCO-2 data and ACOS B8 GOSAT data begins this summer! Email david.f.baker@noaa.gov to get involved.
- Gridded L4 Fluxes and Uncertainties will be available online soon for community download.

Backup

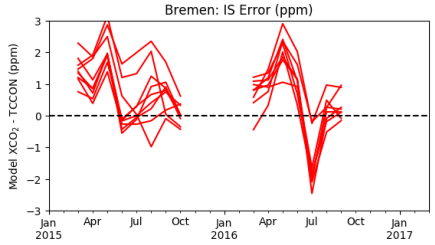
Bialystok

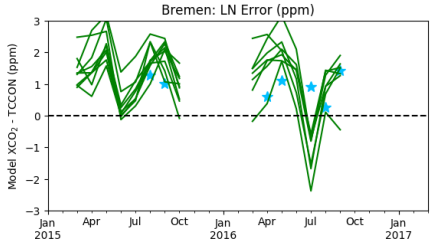


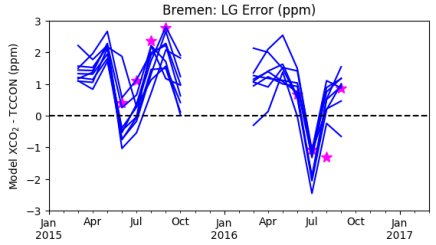




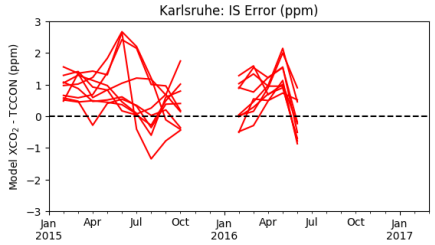
Bremen

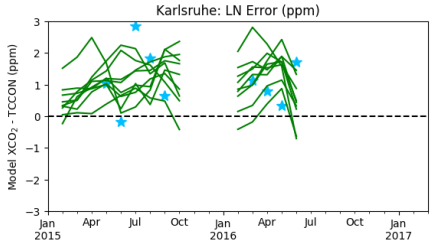


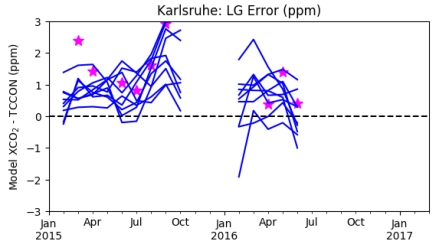




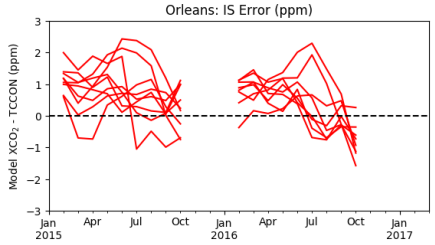
Karlsruhe

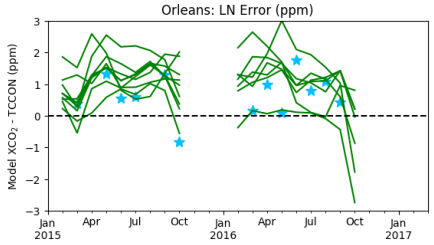


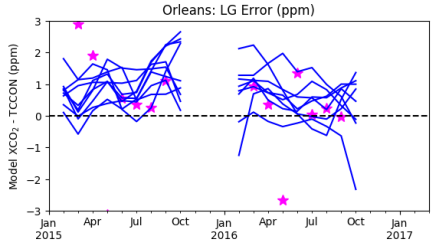




Orleans

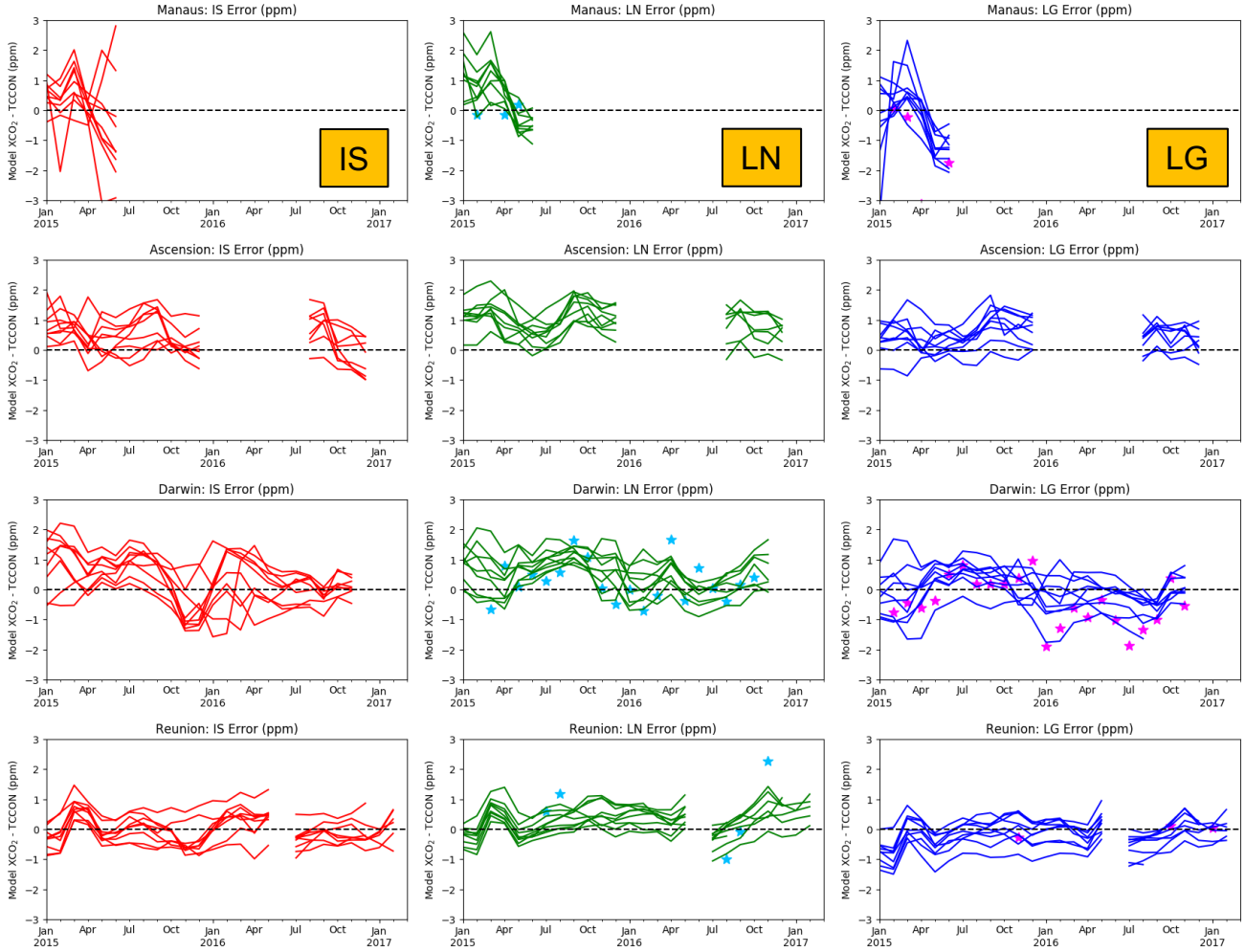






OCO-2 assimilated data includes the S31 bias correction term, but still shows a high bias relative to TCCON at every site in almost every month with valid data

* = individual OCO-2 overpasses


Manaus
Ascension Island
Darwin
Reunion Island
Manaus: IS Error (ppm)
Manaus: LN Error (ppm)
Manaus: LG Error (ppm)
Ascension: IS Error (ppm)
Ascension: LN Error (ppm)
Ascension: LG Error (ppm)
Darwin: IS Error (ppm)
Darwin: LN Error (ppm)
Darwin: LG Error (ppm)
Reunion: IS Error (ppm)
Reunion: LN Error (ppm)
Reunion: LG Error (ppm)
Model XCO2 - TCCON (ppm)
IS
LN
LG
Jan 2015
Apr
Jul
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Apr
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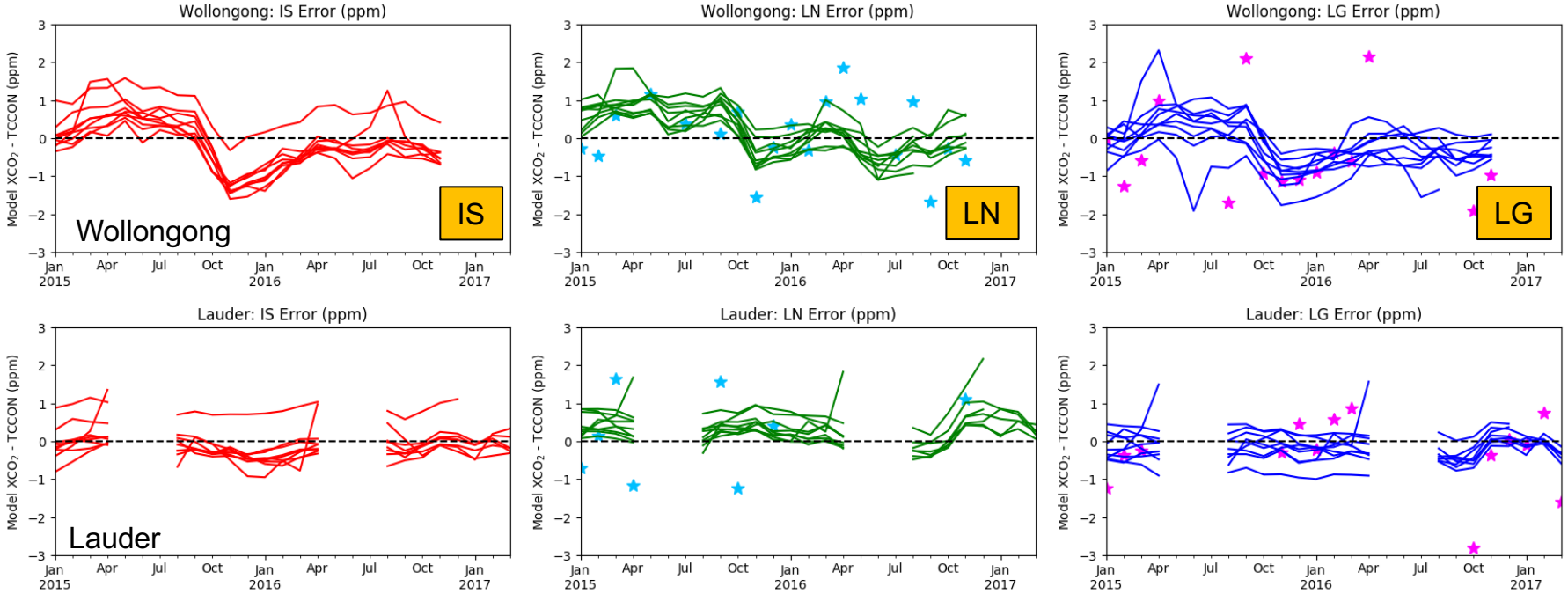
Oct
Jan 2017


Wollongong: IS Error (ppm)
Wollongong: LN Error (ppm)
Wollongong: LG Error (ppm)
Lauder: IS Error (ppm)
Lauder: LN Error (ppm)
Lauder: LG Error (ppm)
Model XCO2 - TCCON (ppm)
Wollongong
Lauder
IS
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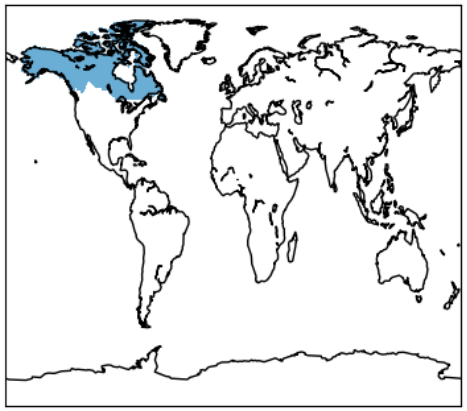
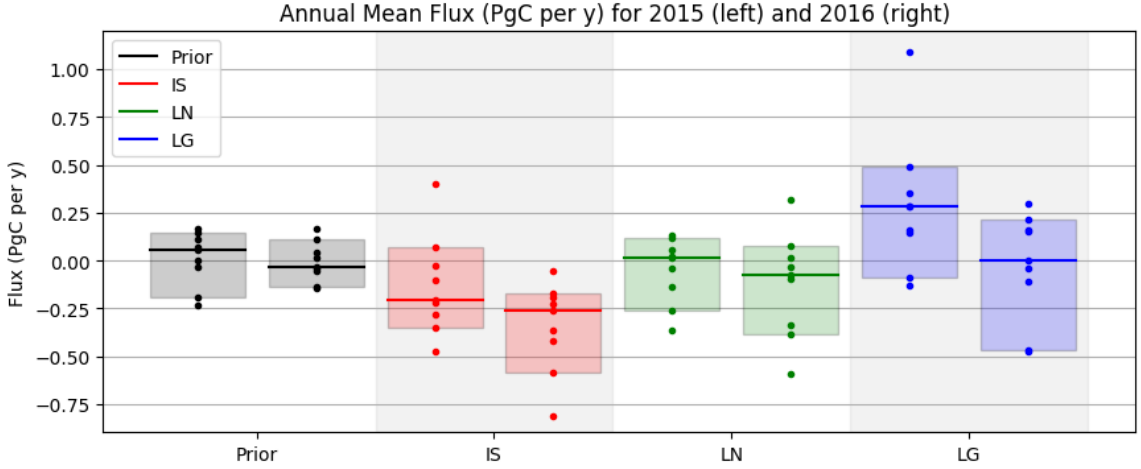
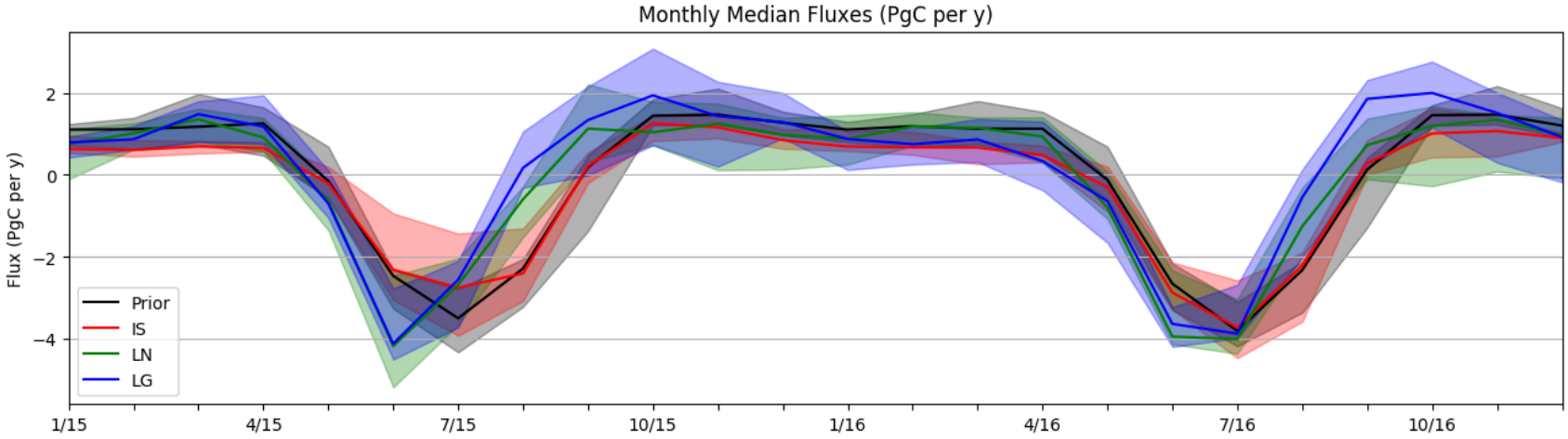
Jan 2017

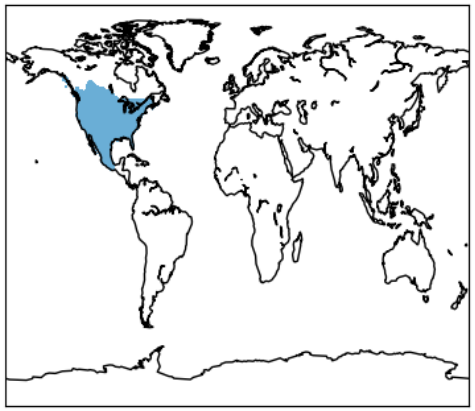
TransCom 01 North American Boreal

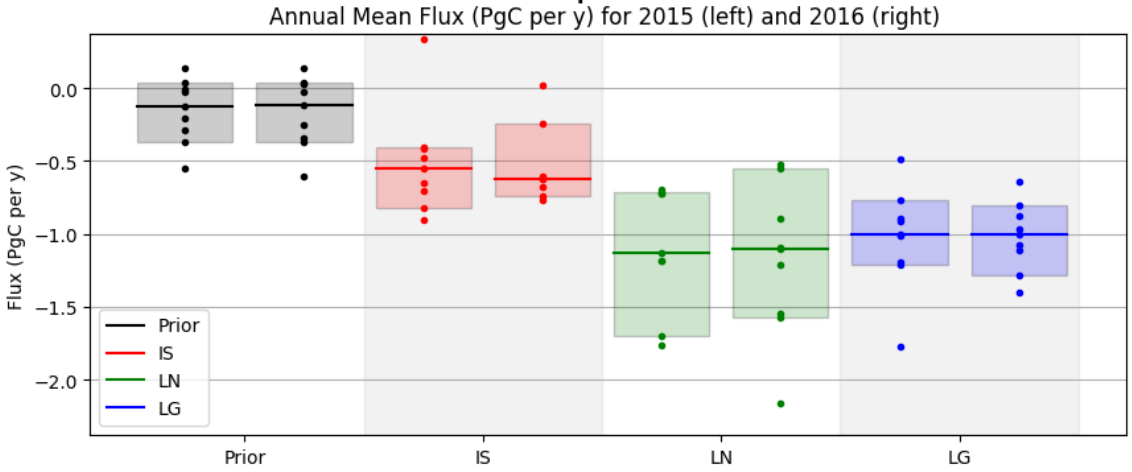


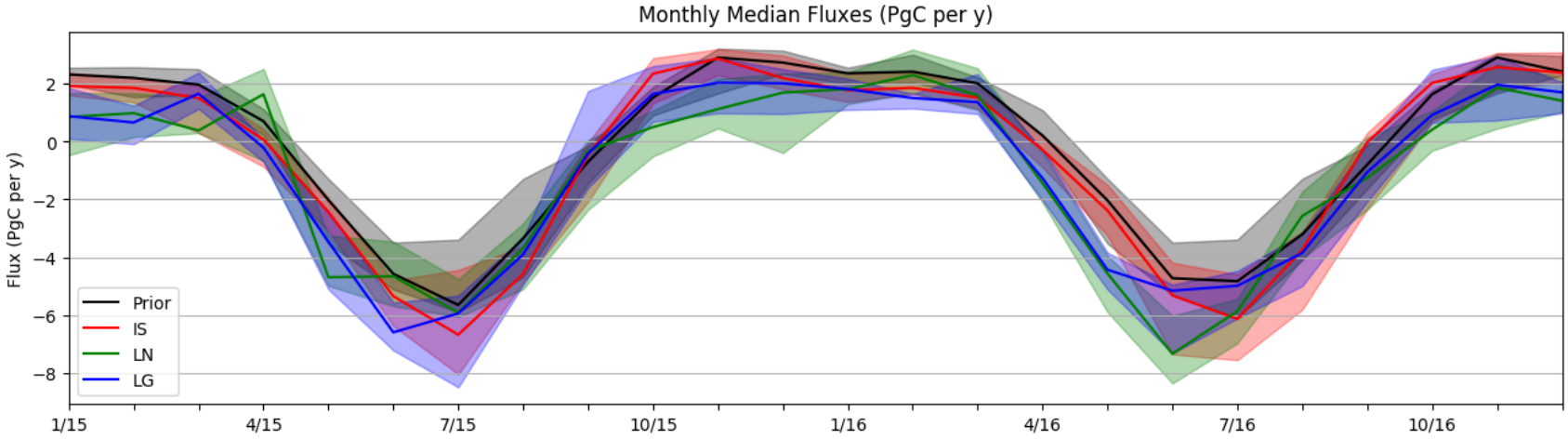


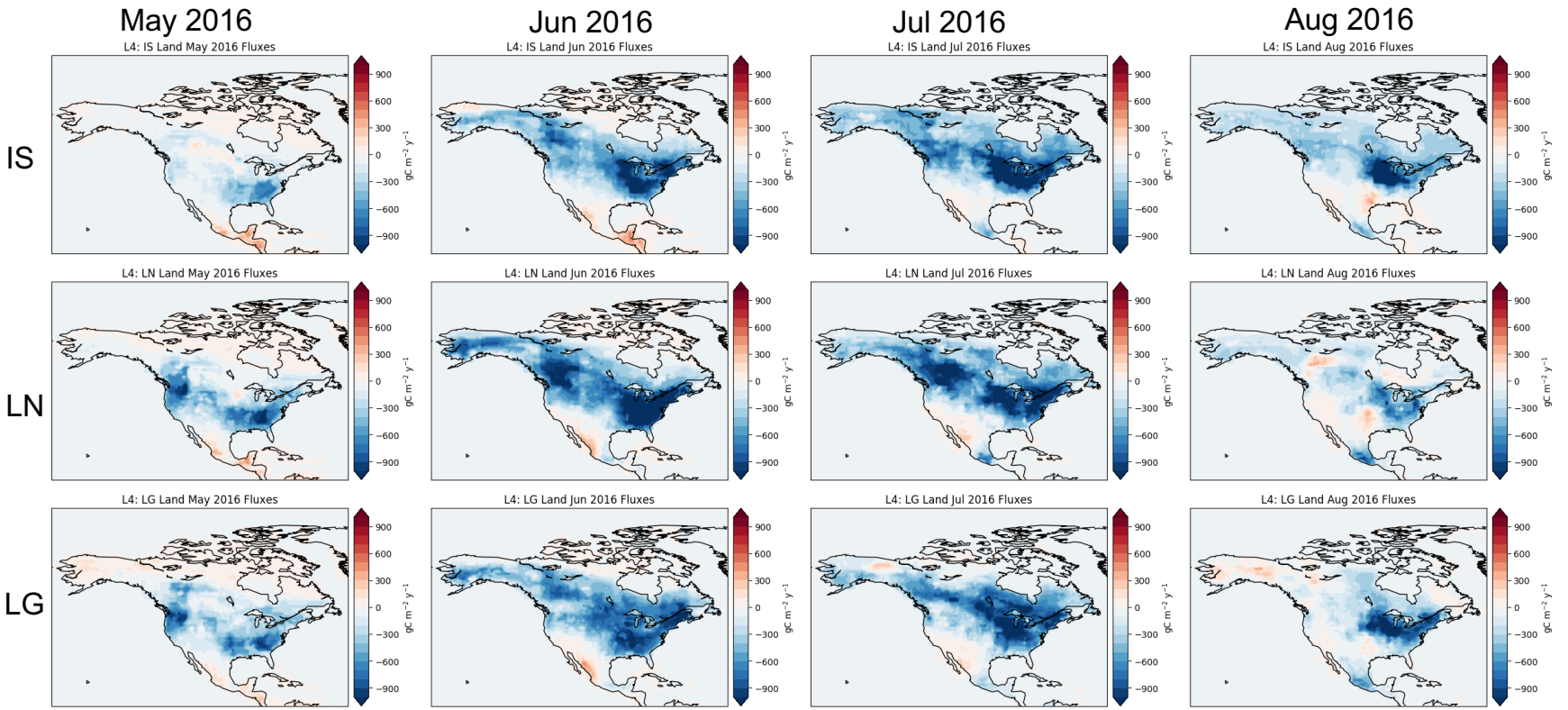


TransCom 02 North American Temperate

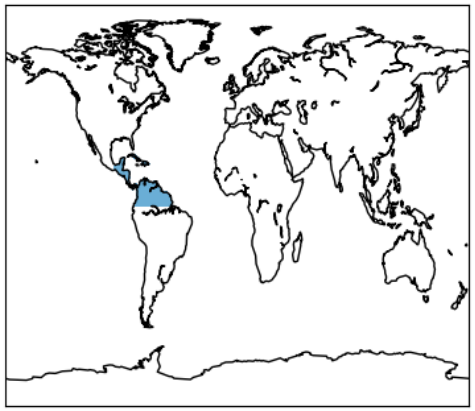


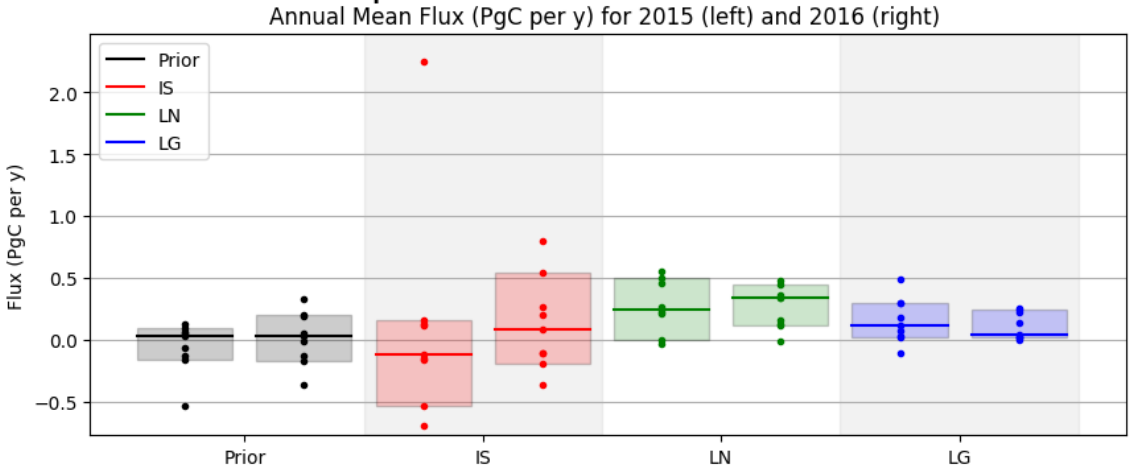


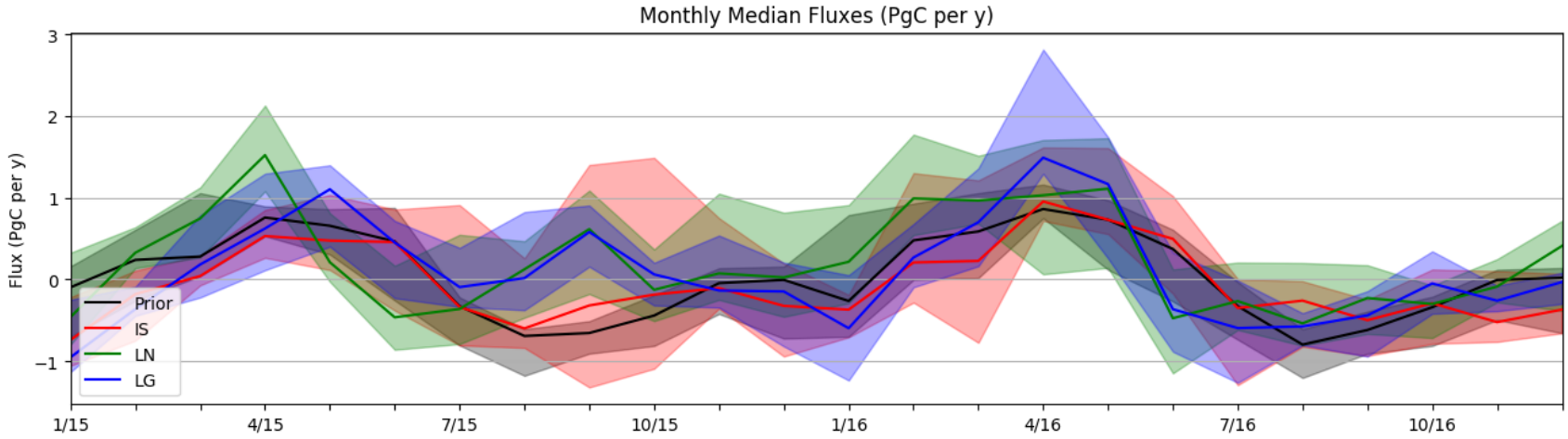




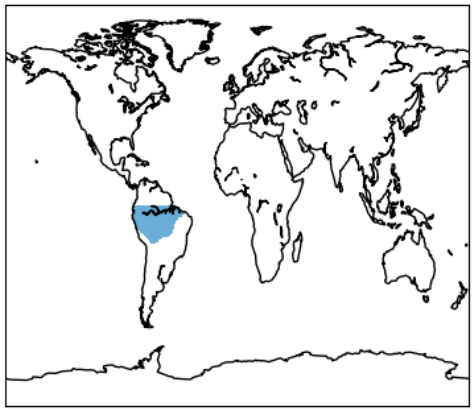
TransCom 03a Northern Tropical South America

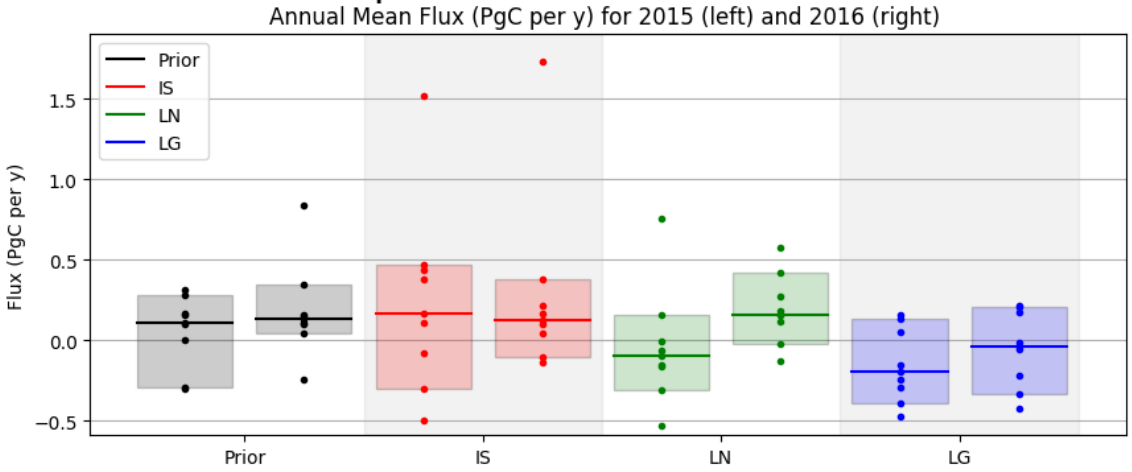


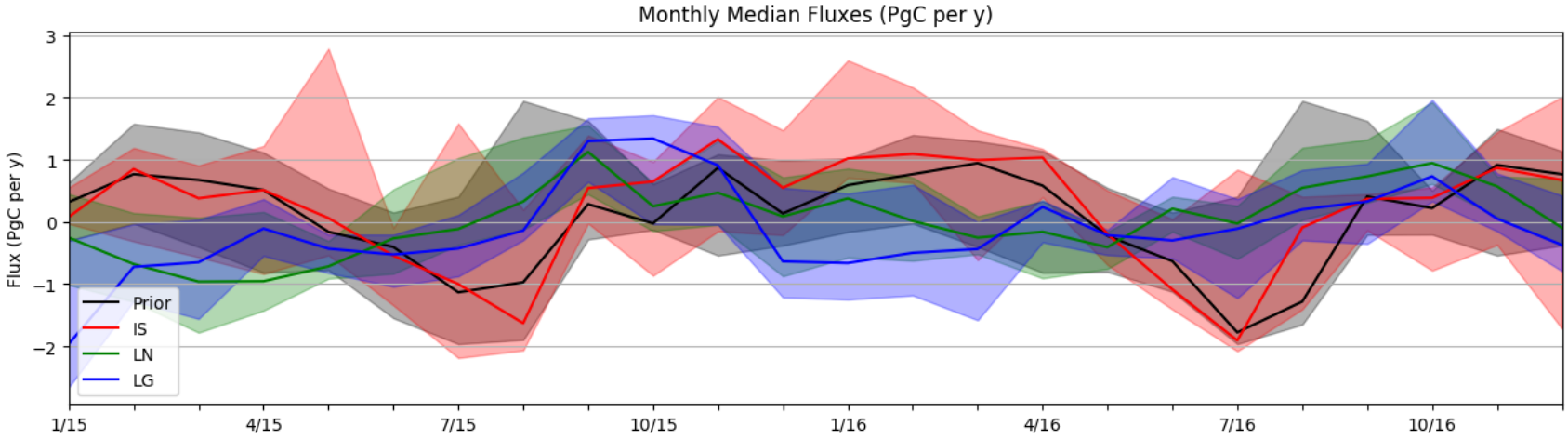




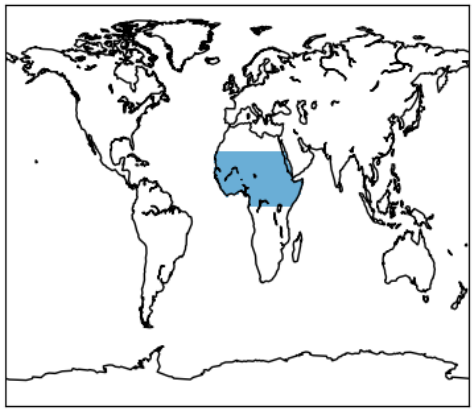
TransCom 03b Southern Tropical South America

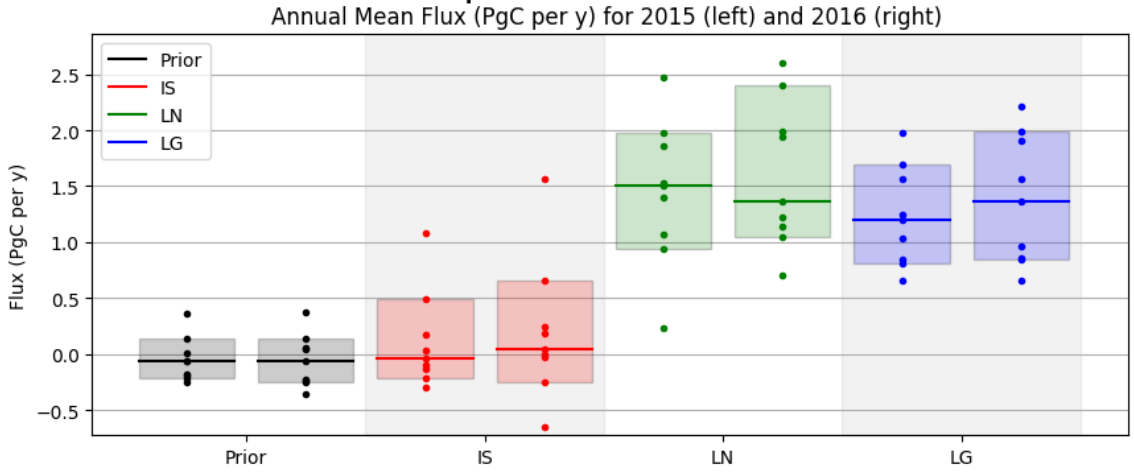


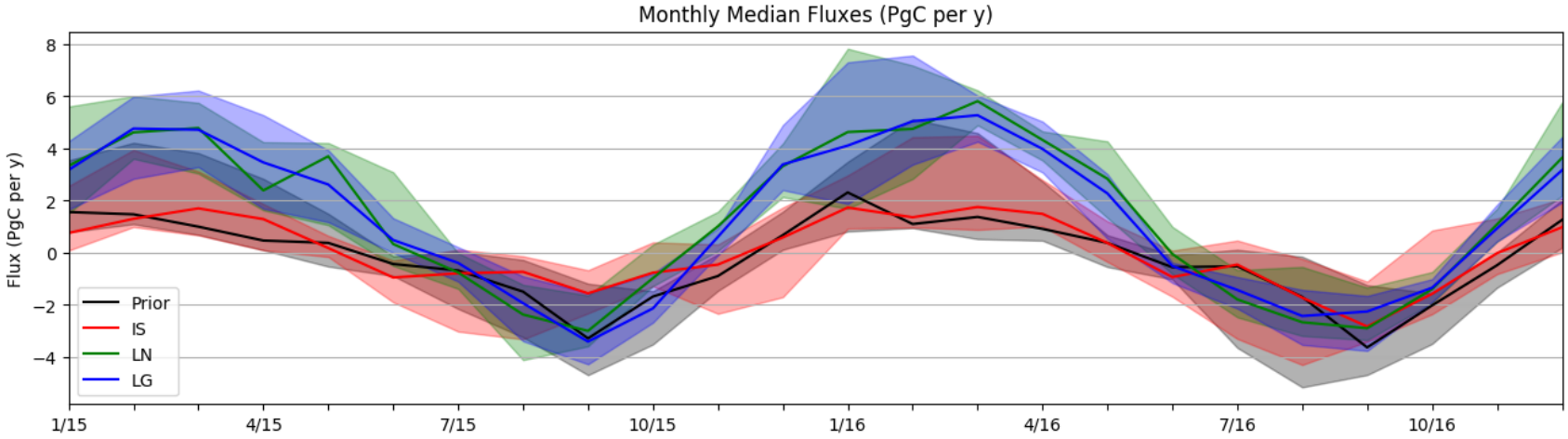




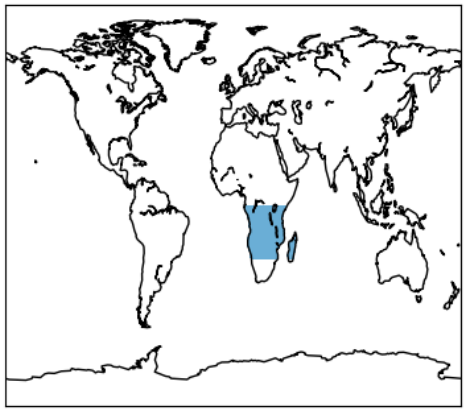
TransCom 05b Northern Tropical Africa

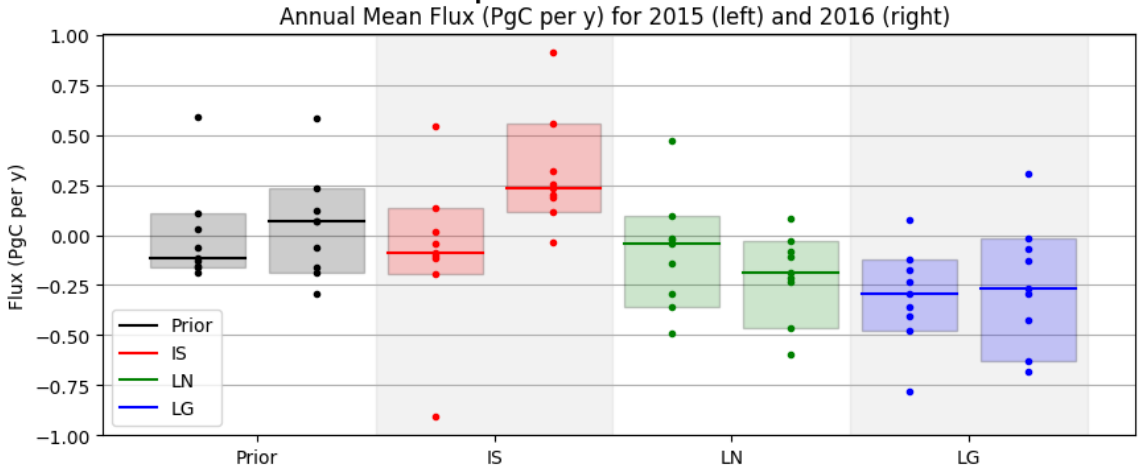


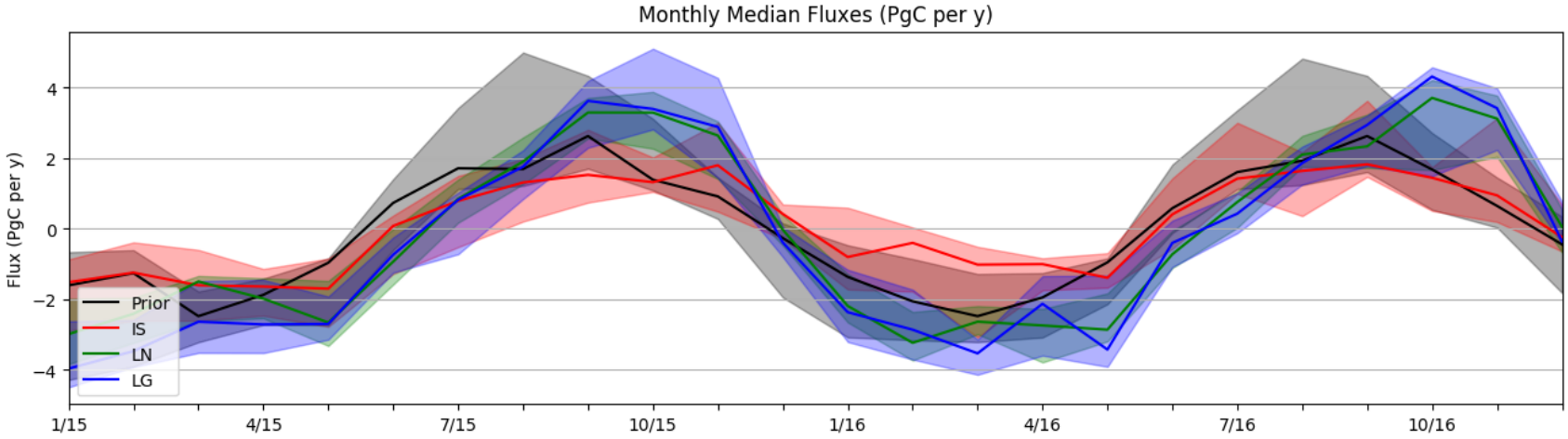




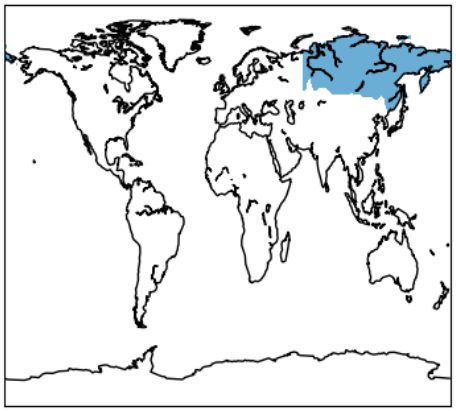
TransCom 06a Southern Tropical Africa

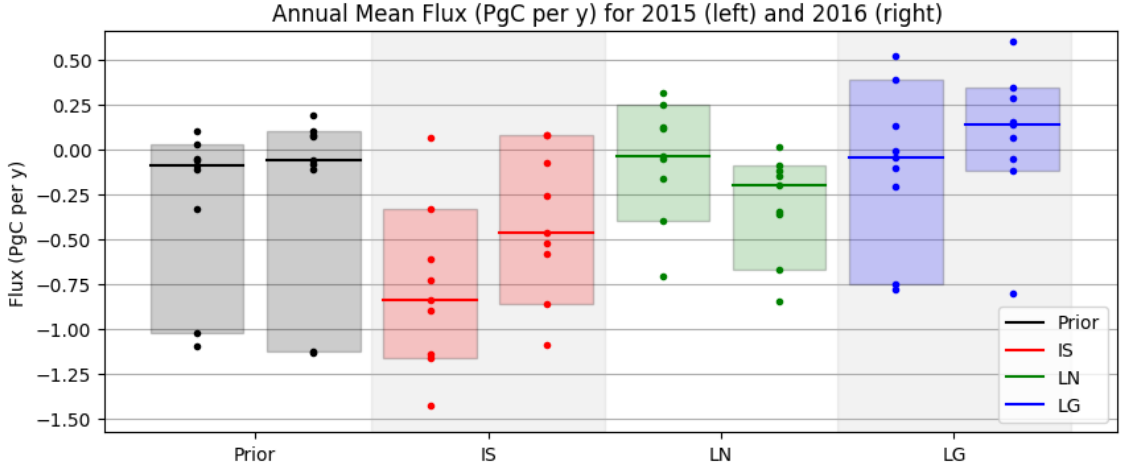


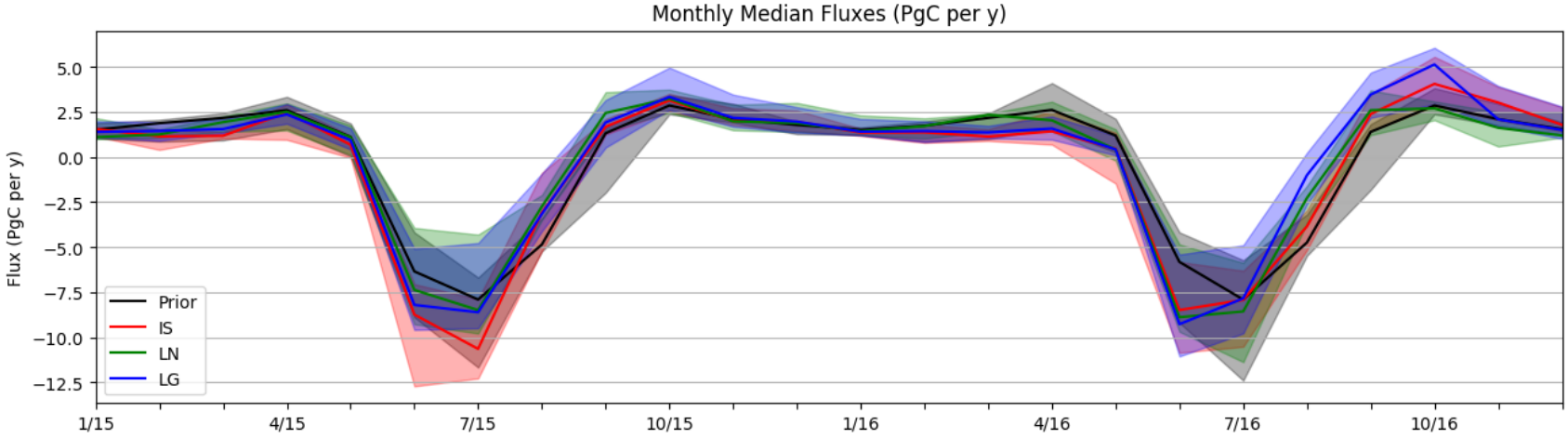




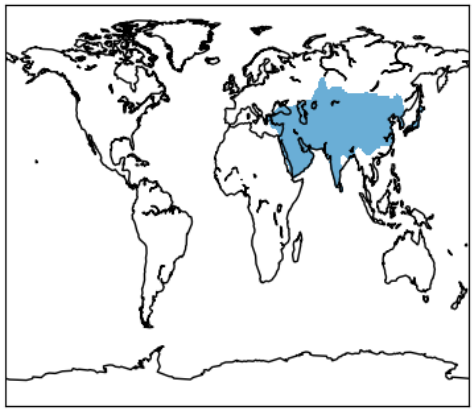
TransCom 07 Eurasia Boreal

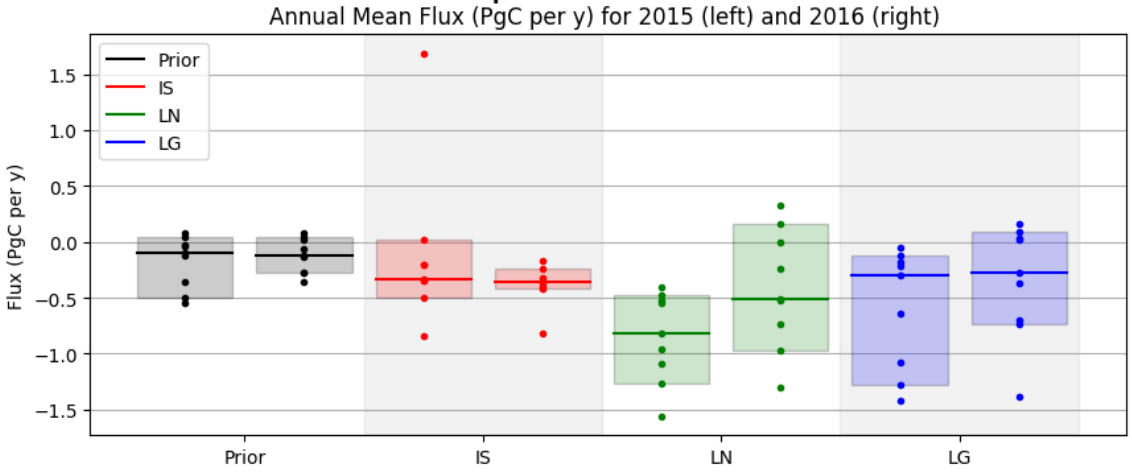


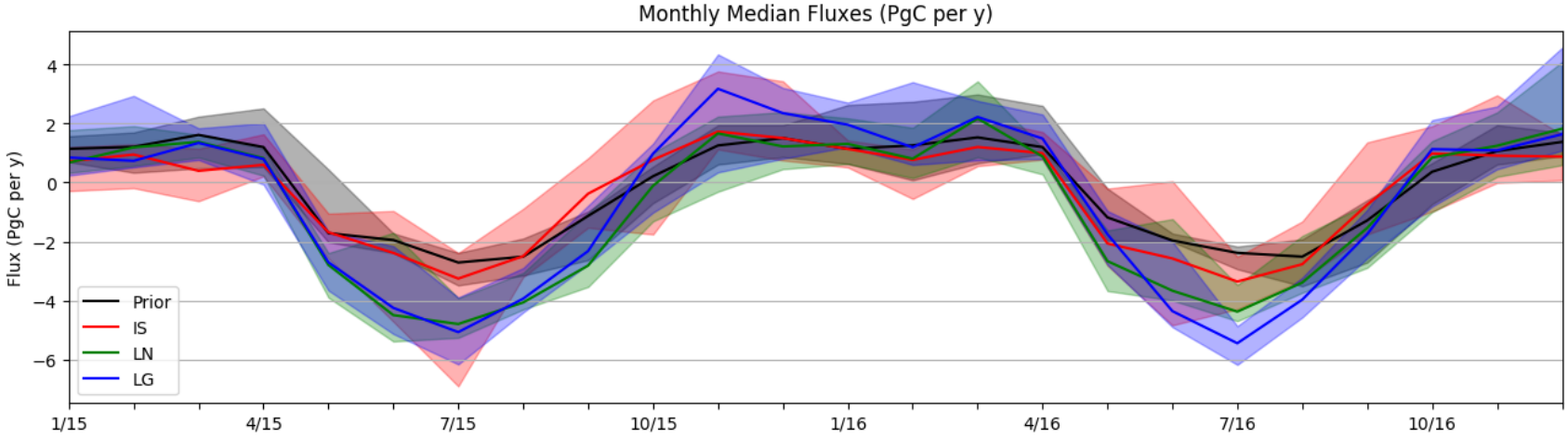




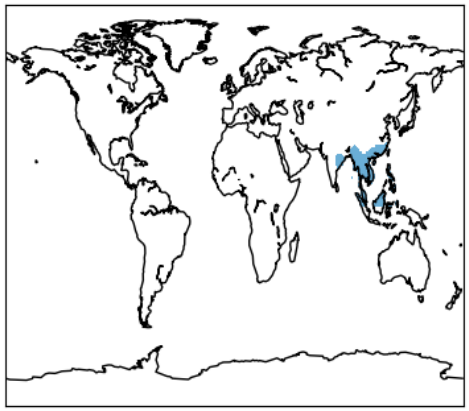
TransCom 08 Eurasia Temperate

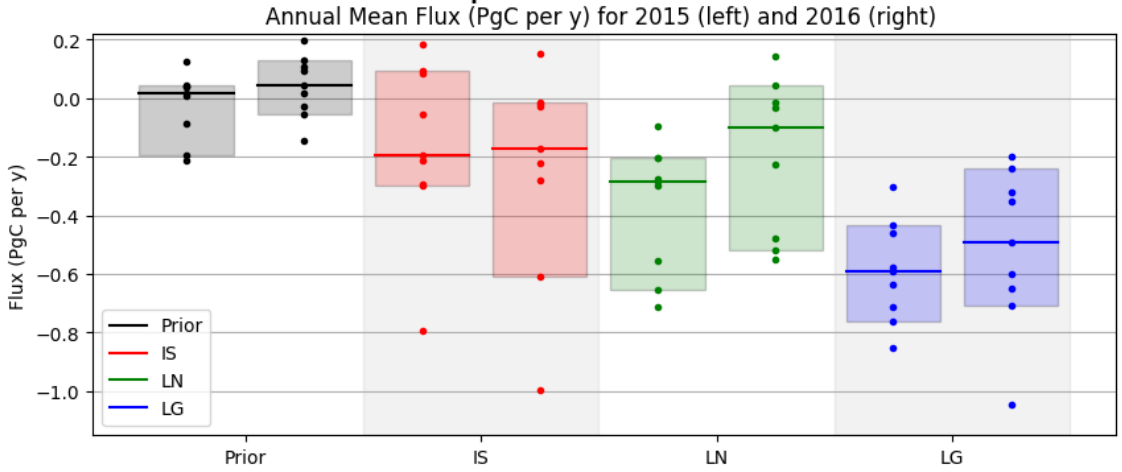


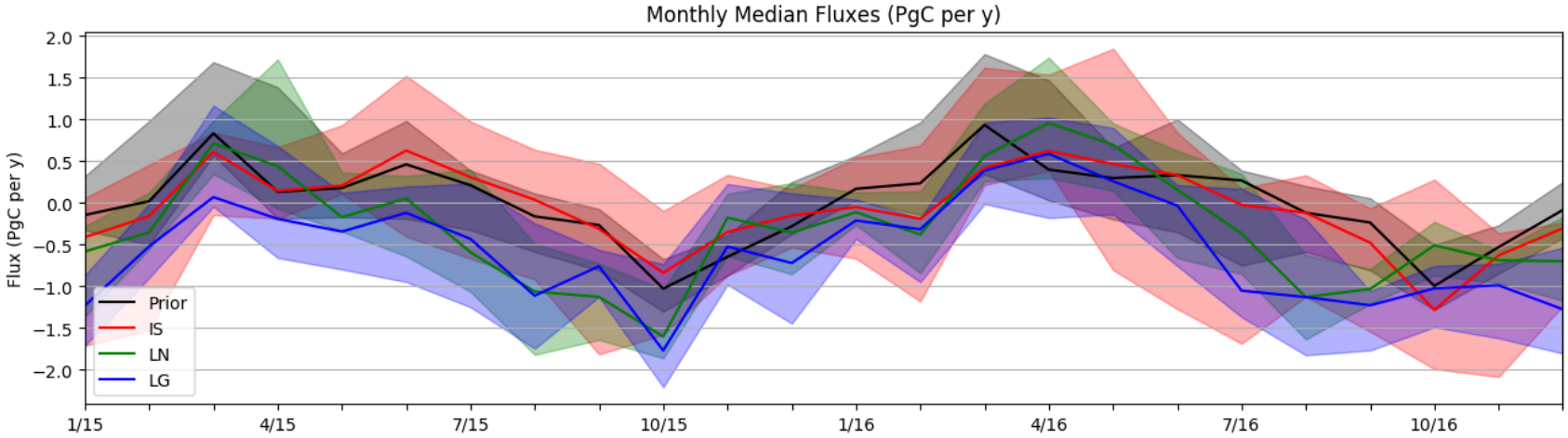




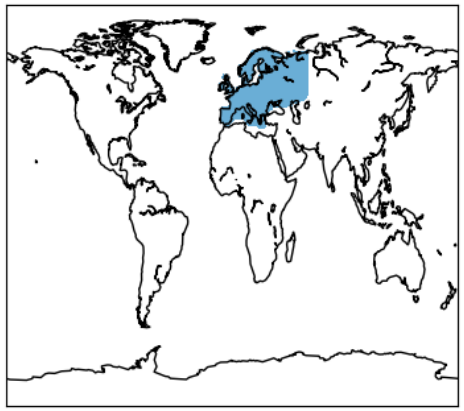
TransCom 09a Northern Tropical Asia

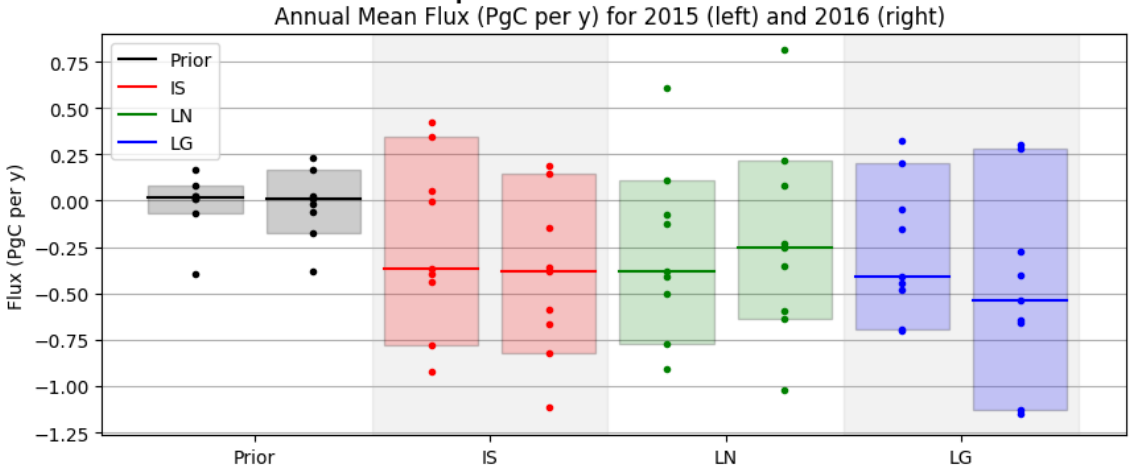


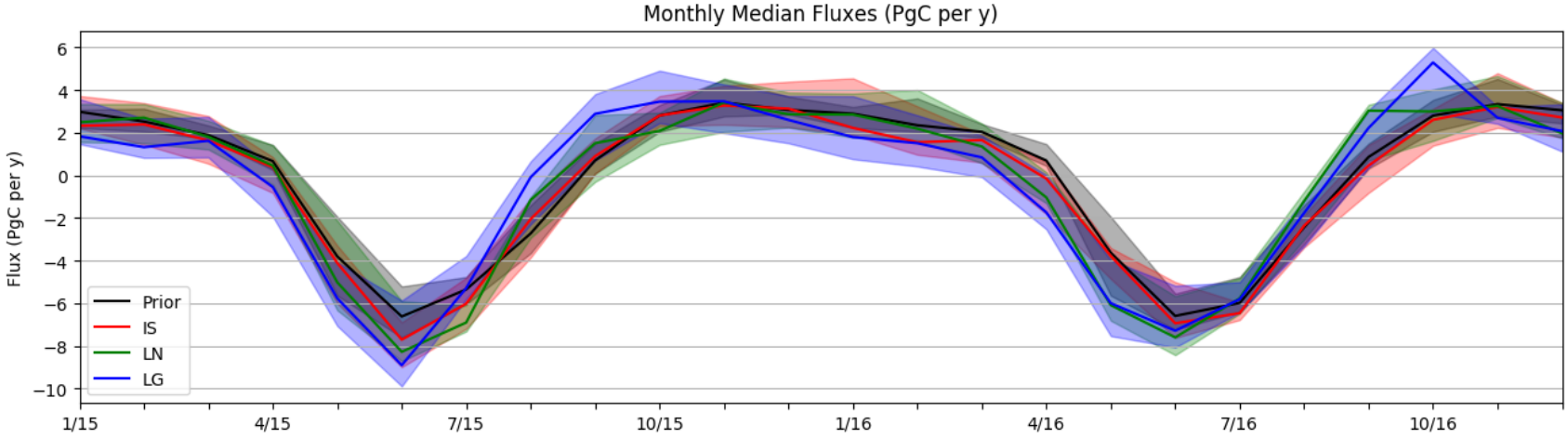




TransCom 11 Europe







TCCON Eval Summary

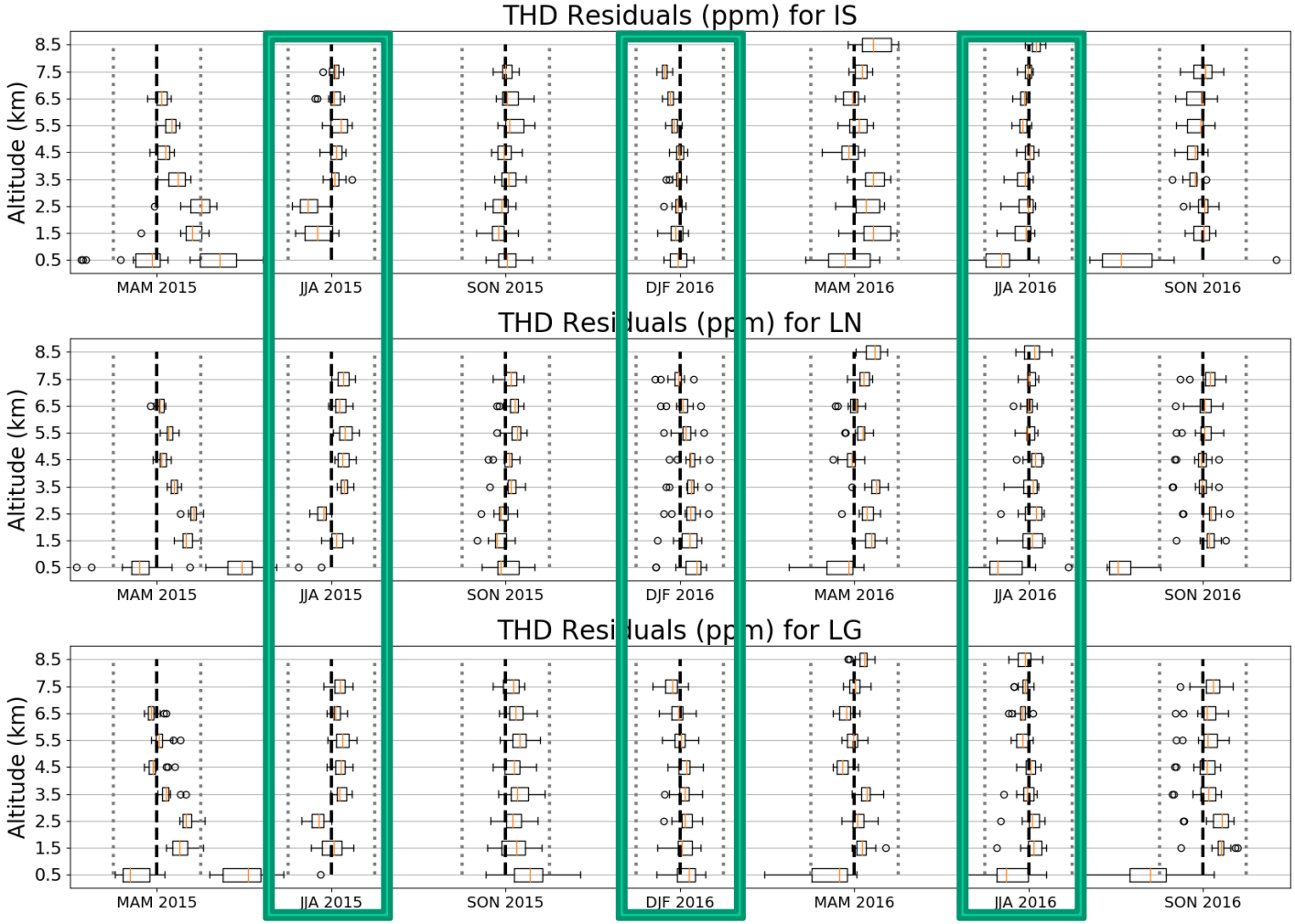
- European flux results do not agree with TCCON, and suggest too much CO2 across the board – 0.25 PgC annual high bias in Europe in Sourish's paper
- Land Nadir observations in tropics convolved with transport errors are leading to more CO2 than TCCON suggests – high tropical land flux bias is implied 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

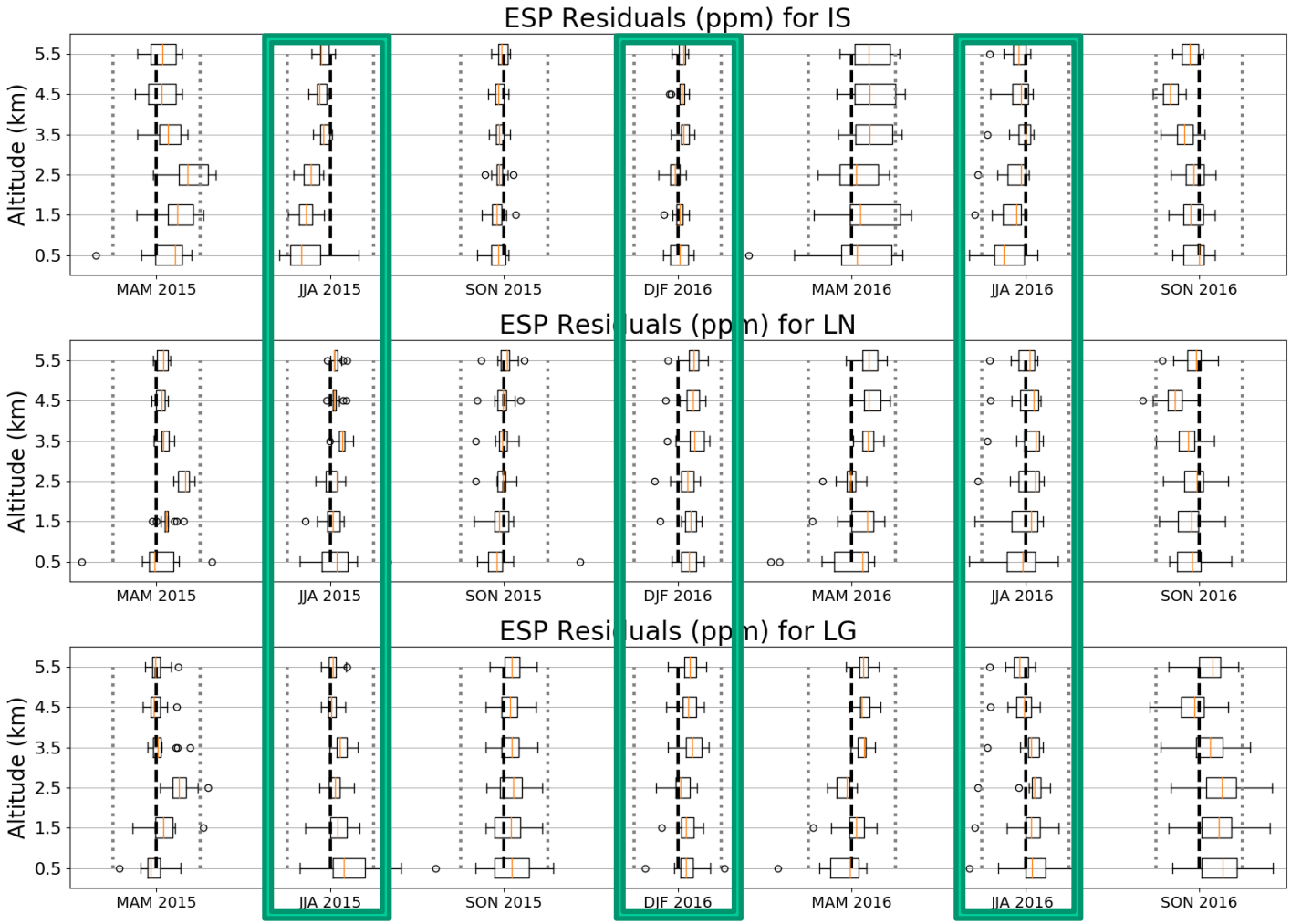
Aircraft Evaluation

Super preliminary (sorry!)

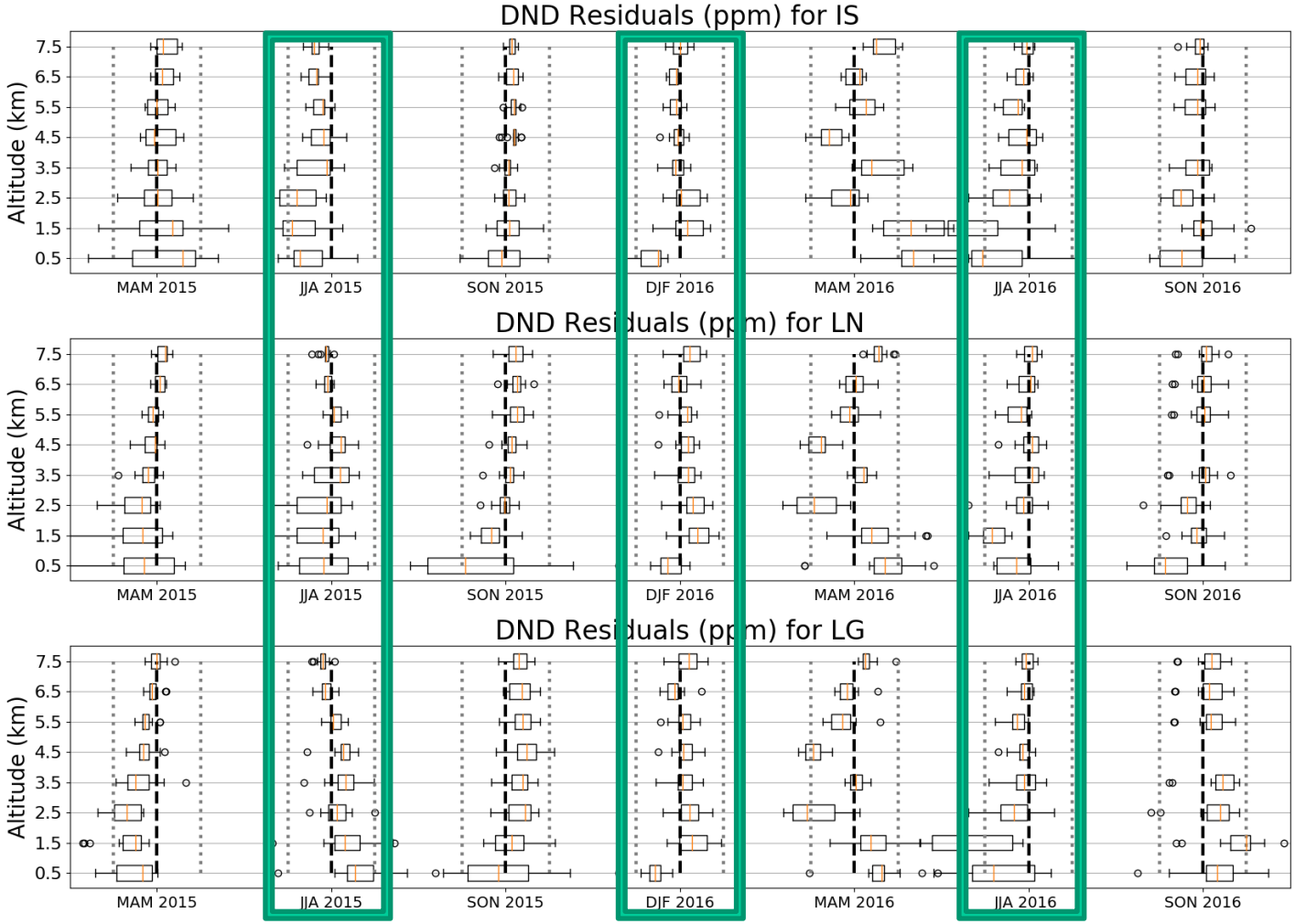
West Coast sites

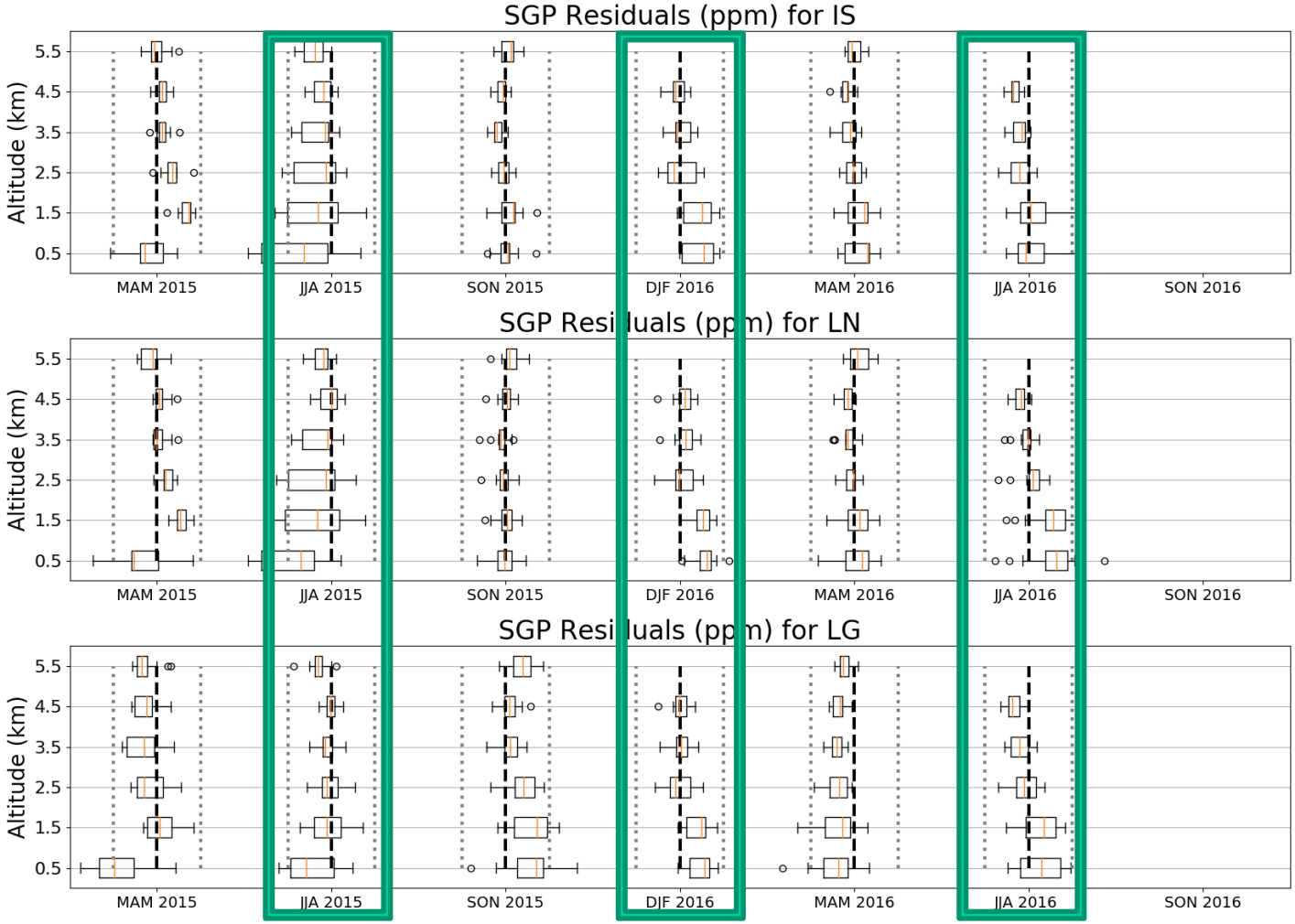
Small persistent high bias in OCO-2 data

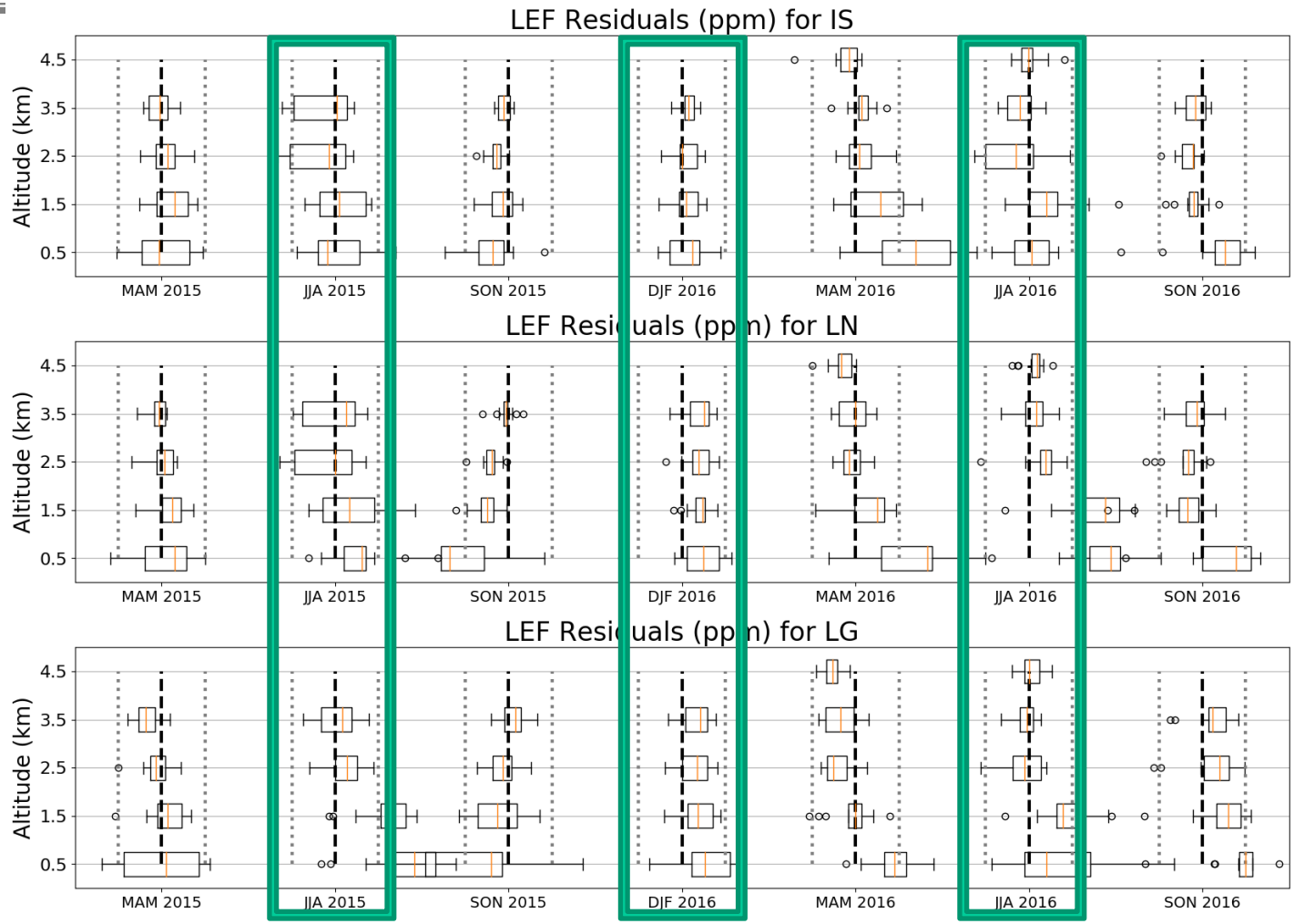

THD Residuals (ppm) for IS
THD Residuals (ppm) for LN
THD Residuals (ppm) for LG
Altitude (km)
8.5
7.5
6.5
5.5
4.5
3.5
2.5
1.5
0.5
MAM 2015
JJA 2015
SON 2015
DJF 2016
MAM 2016
JJA 2016
SON 2016

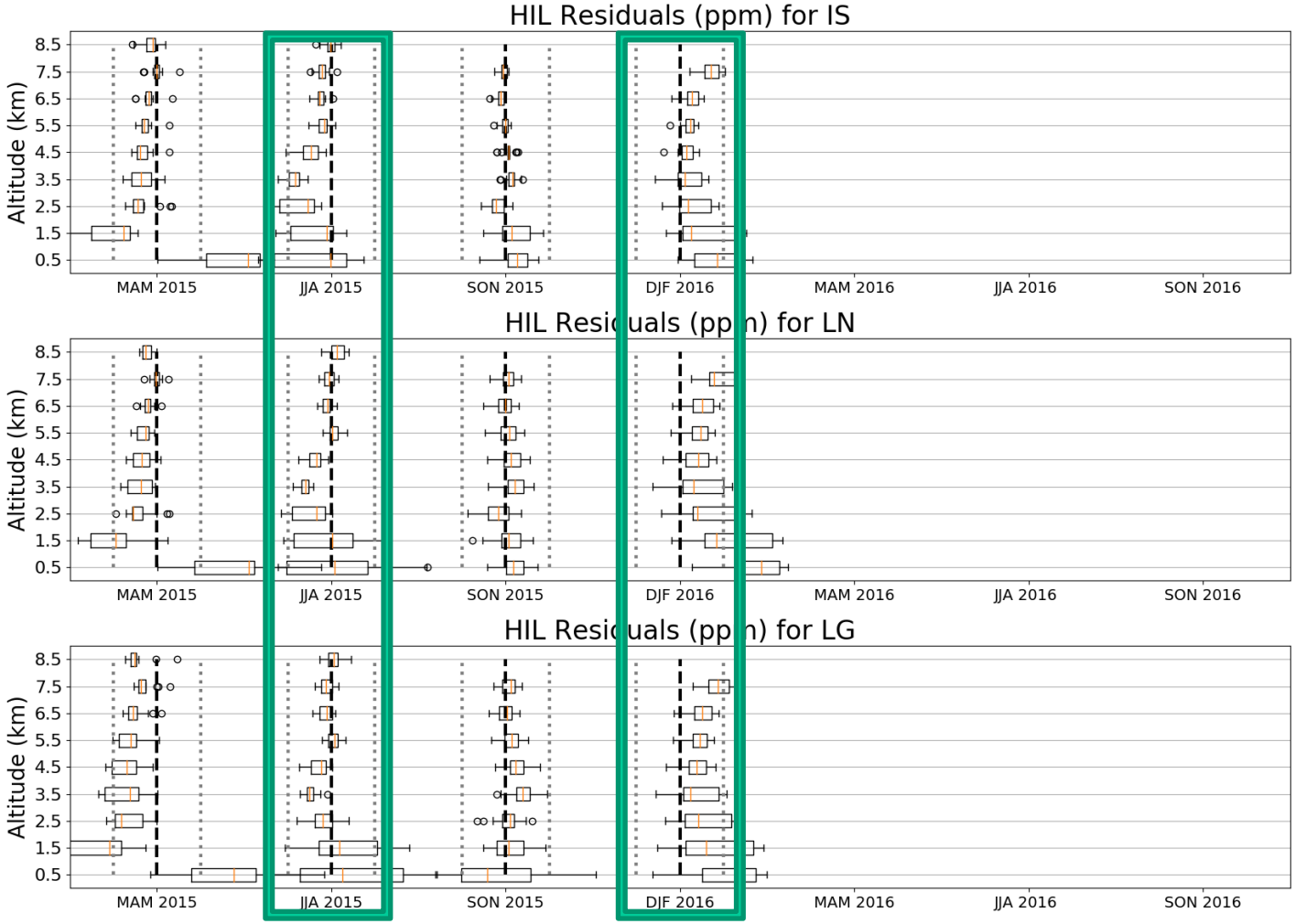

ESP Residuals (ppm) for IS
ESP Residuals (ppm) for LN
ESP Residuals (ppm) for LG
Altitude (km)
5.5
4.5
3.5
2.5
1.5
0.5
MAM 2015
JJA 2015
SON 2015
DJF 2016
MAM 2016
JJA 2016
SON 2016

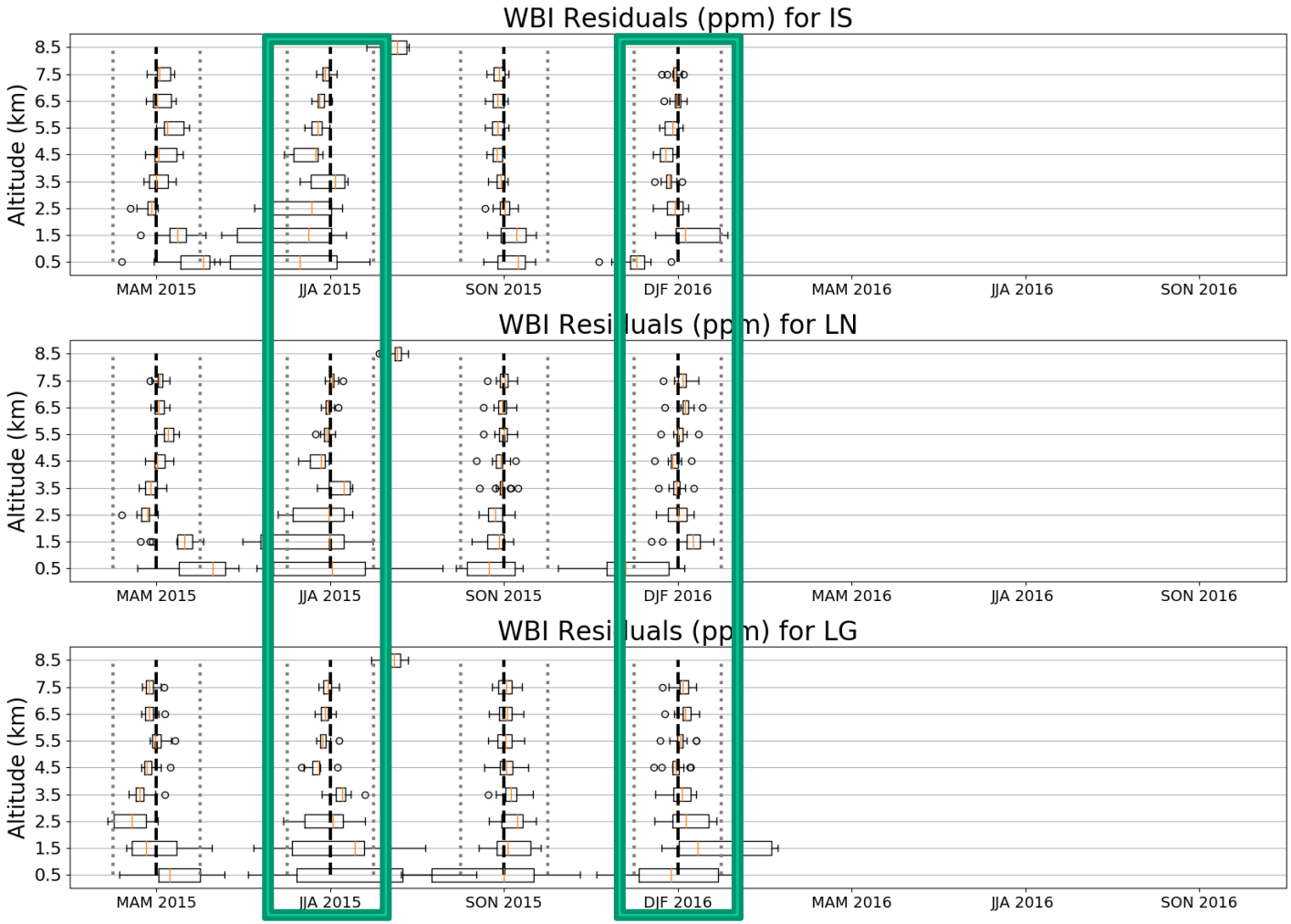
Mid-continent sites



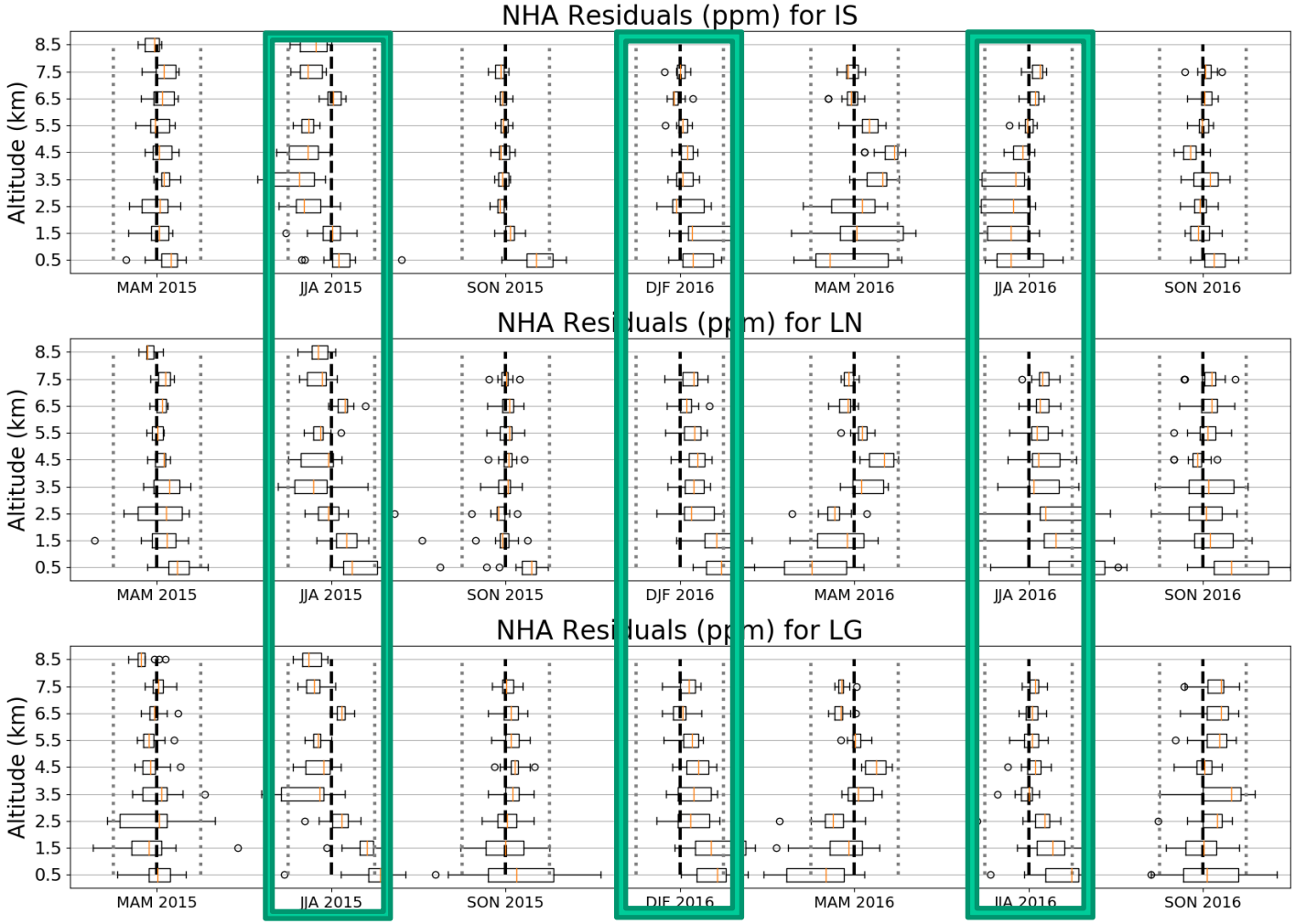

SGP Residuals (ppm) for IS
SGP Residuals (ppm) for LN
SGP Residuals (ppm) for LG
Altitude (km)
5.5
4.5
3.5
2.5
1.5
0.5
MAM 2015
JJA 2015
SON 2015
DJF 2016
MAM 2016
JJA 2016
SON 2016

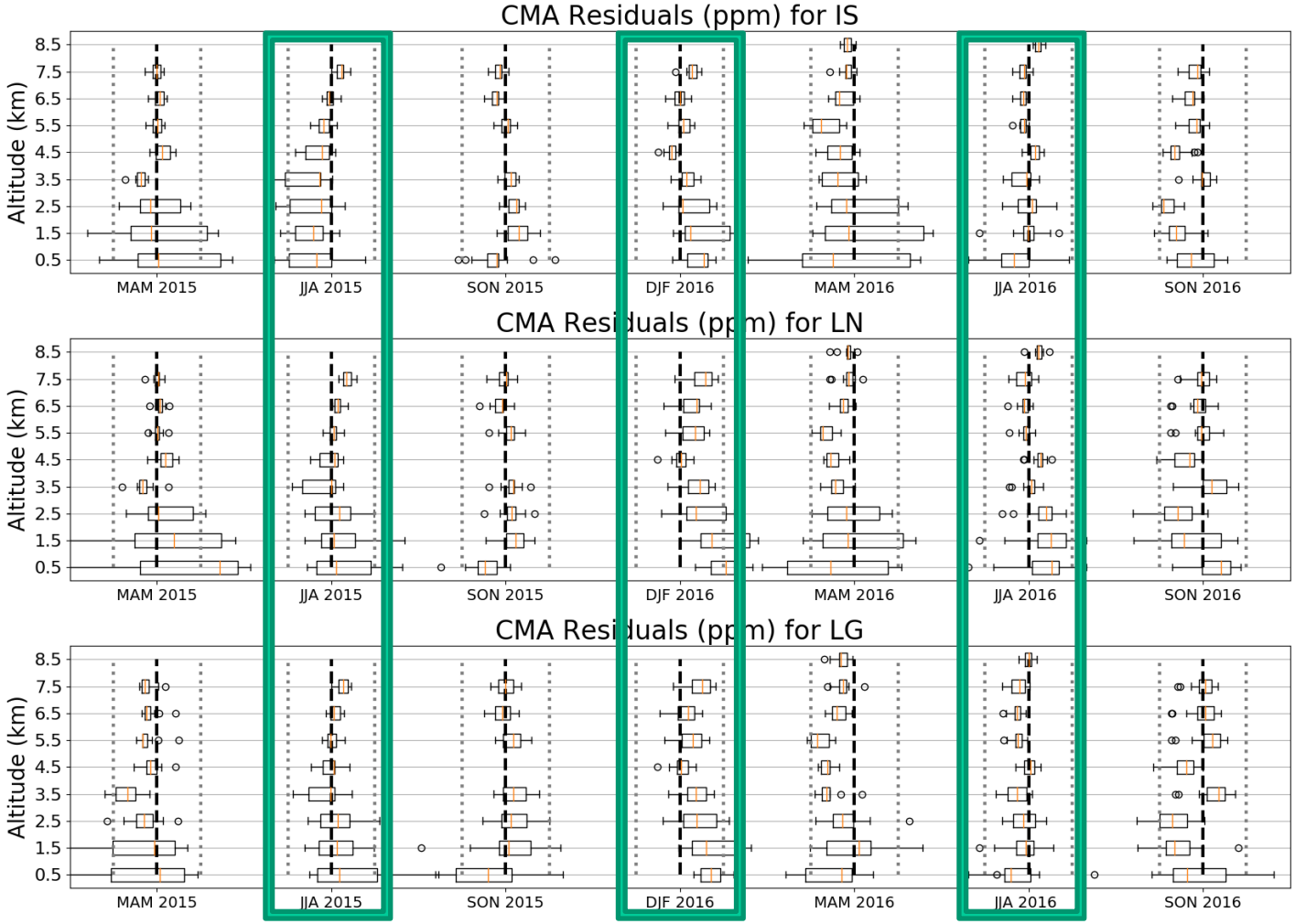

LEF Residuals (ppm) for IS
LEF Residuals (ppm) for LN
LEF Residuals (ppm) for LG
Altitude (km)
4.5
3.5
2.5
1.5
0.5
MAM 2015
JJA 2015
SON 2015
DJF 2016
MAM 2016
JJA 2016
SON 2016

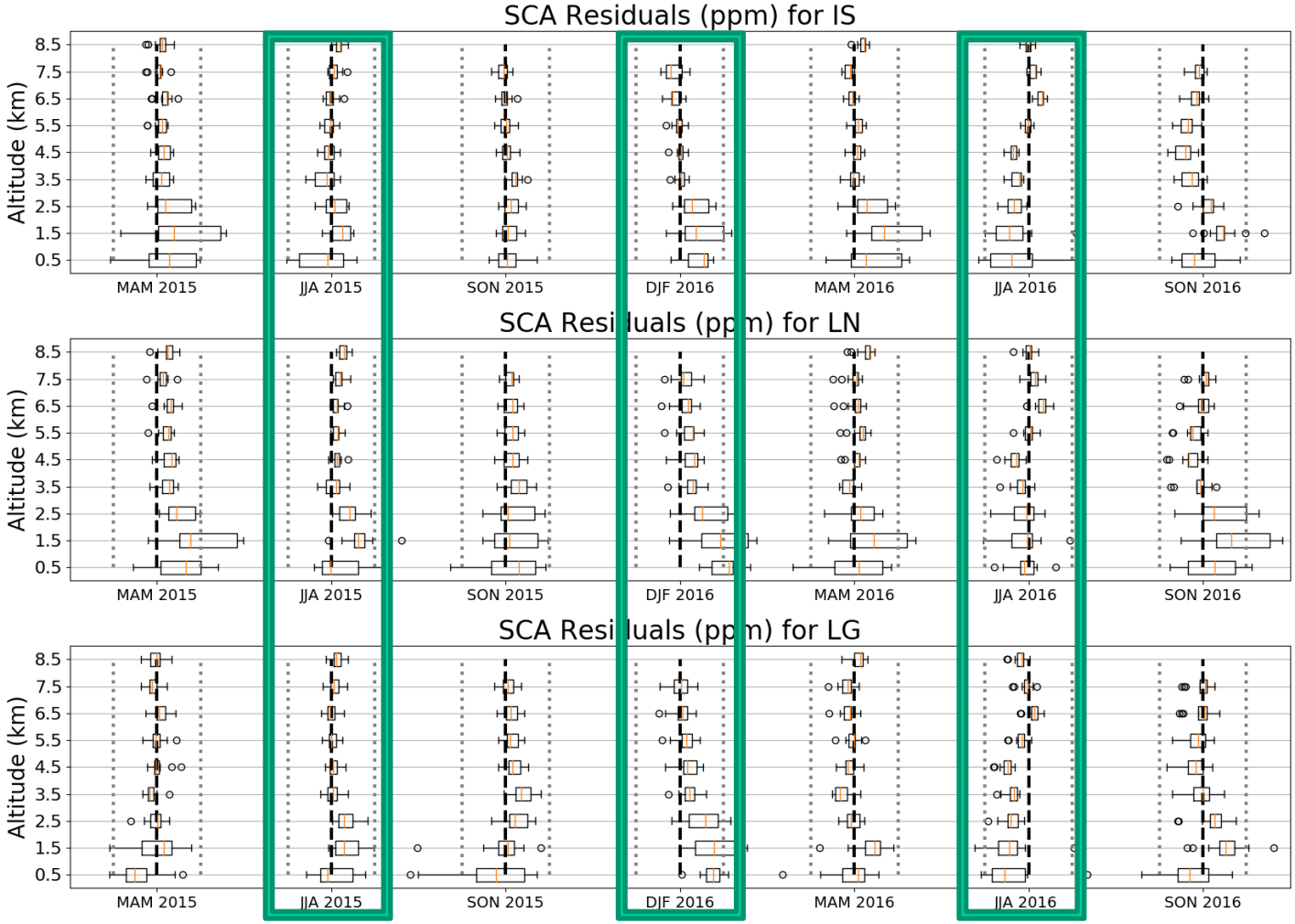




East coast sites


NHA Residuals (ppm) for IS
NHA Residuals (ppm) for LN
NHA Residuals (ppm) for LG
Altitude (km)
8.5
7.5
6.5
5.5
4.5
3.5
2.5
1.5
0.5
MAM 2015
JJA 2015
SON 2015
DJF 2016
MAM 2016
JJA 2016
SON 2016


CMA Residuals (ppm) for IS
CMA Residuals (ppm) for LN
CMA Residuals (ppm) for LG
Altitude (km)
8.5
7.5
6.5
5.5
4.5
3.5
2.5
1.5
0.5
MAM 2015
JJA 2015
SON 2015
DJF 2016
MAM 2016
JJA 2016
SON 2016


SCA Residuals (ppm) for IS
SCA Residuals (ppm) for LN
SCA Residuals (ppm) for LG
Altitude (km)
8.5
7.5
6.5
5.5
4.5
3.5
2.5
1.5
0.5
MAM 2015
JJA 2015
SON 2015
DJF 2016
MAM 2016
JJA 2016
SON 2016