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

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*

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

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

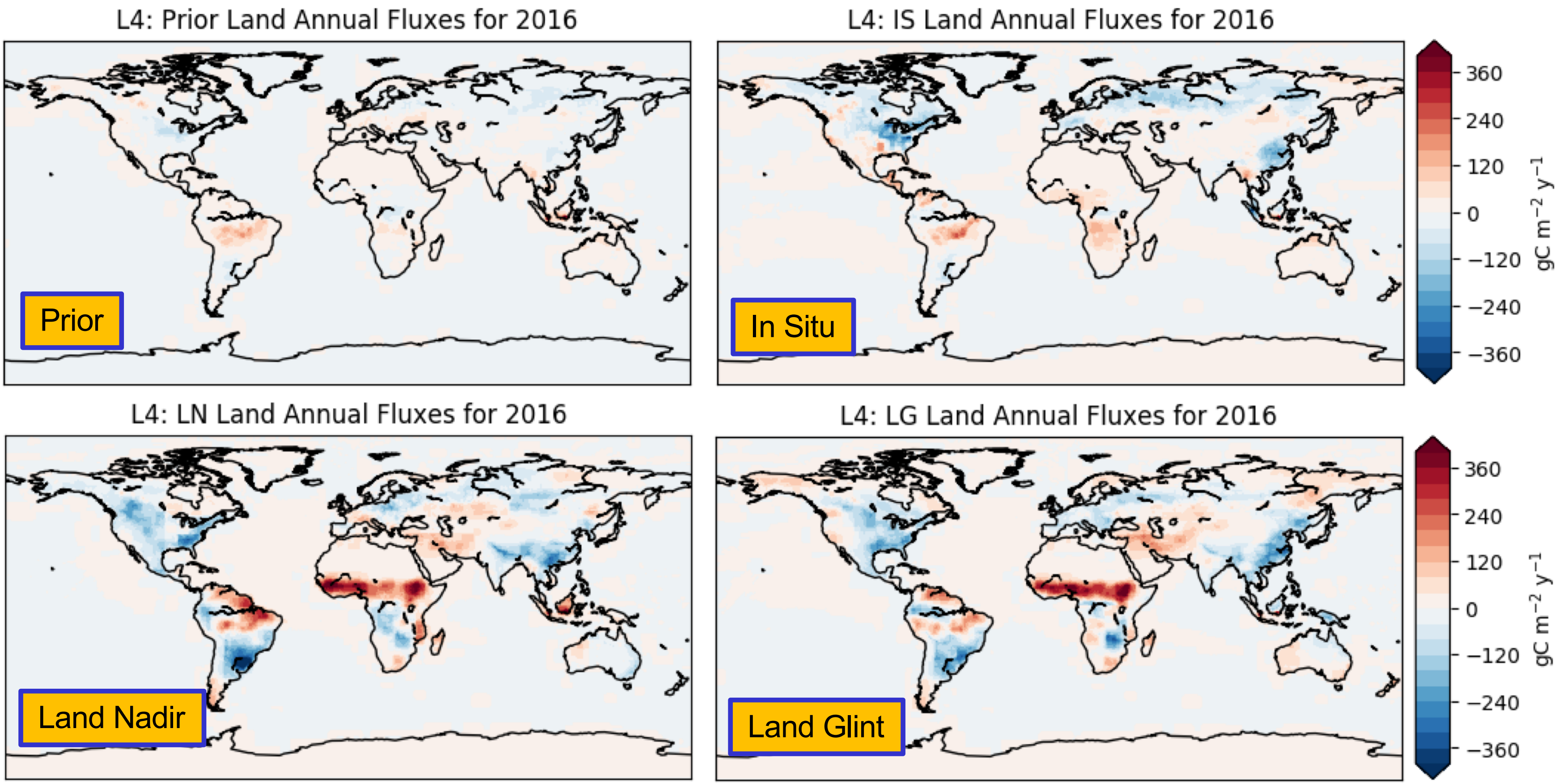
- CT2015/6 Clim
- Takahashi
- CESM-BEC
- Landschuetzer et al
- ECCO2-Darwin

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

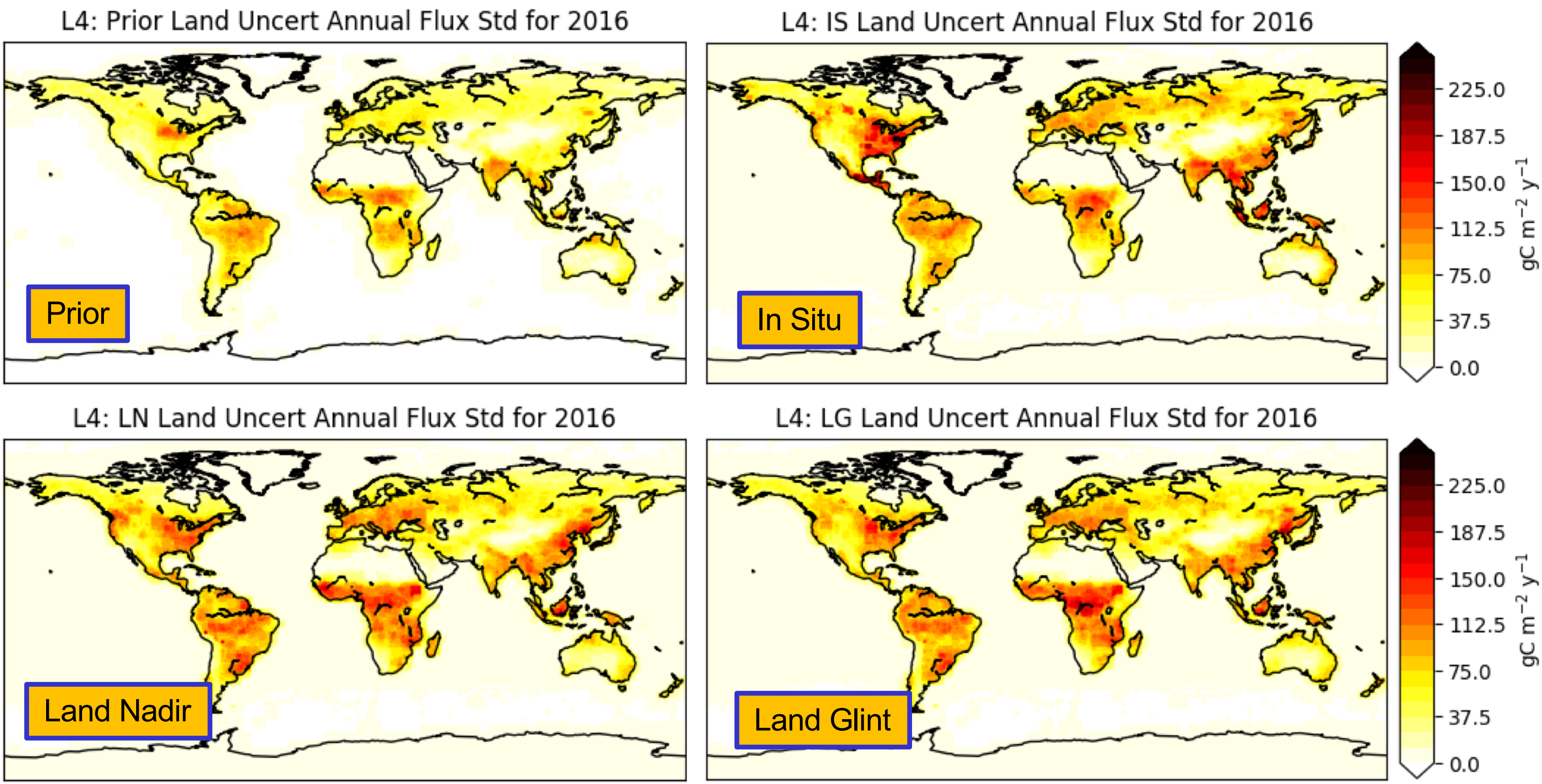
MIPs Require International Collaboration

- 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



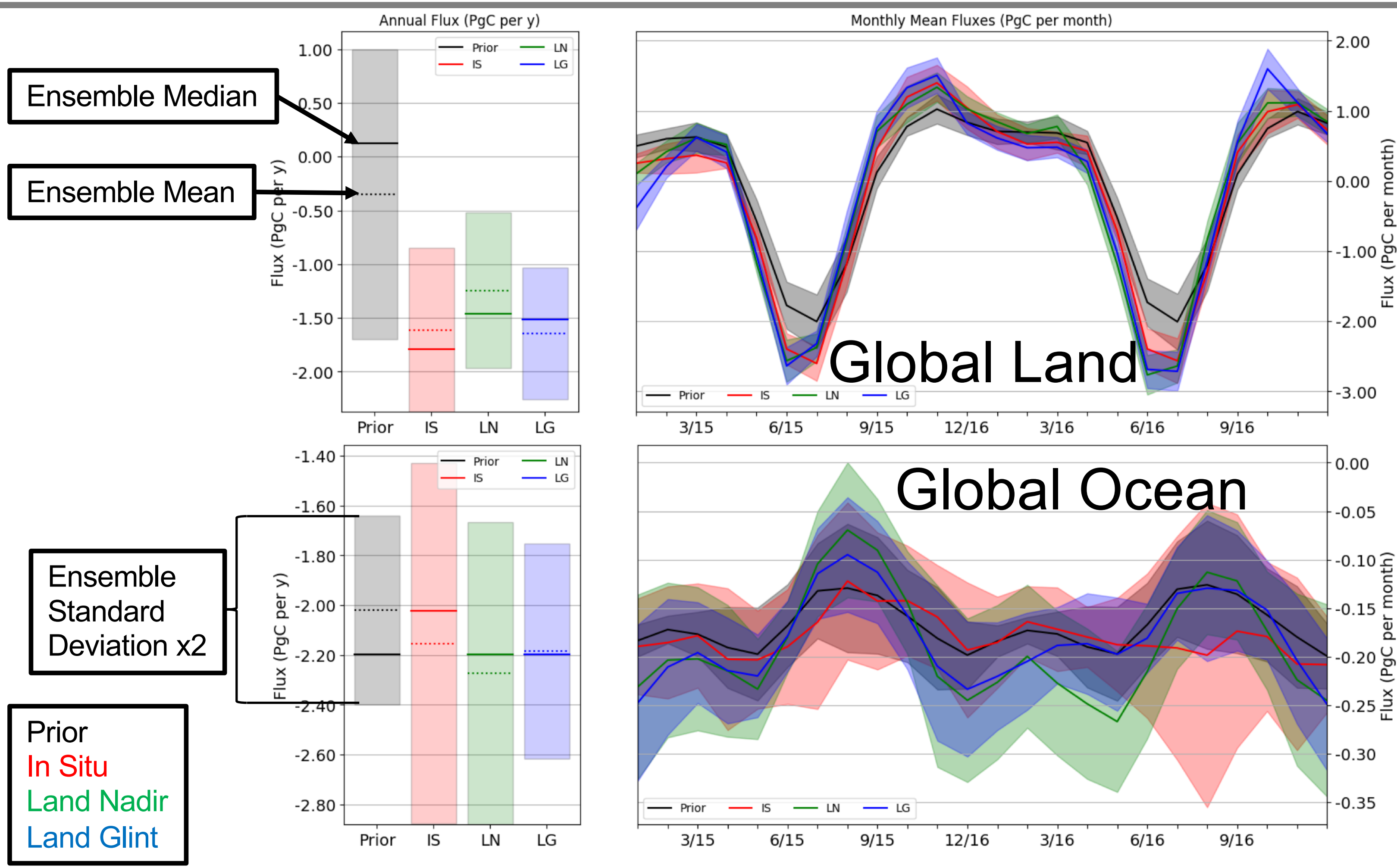
Level 4 Gridded Fluxes for 2016: Ensemble Standard Deviation



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.

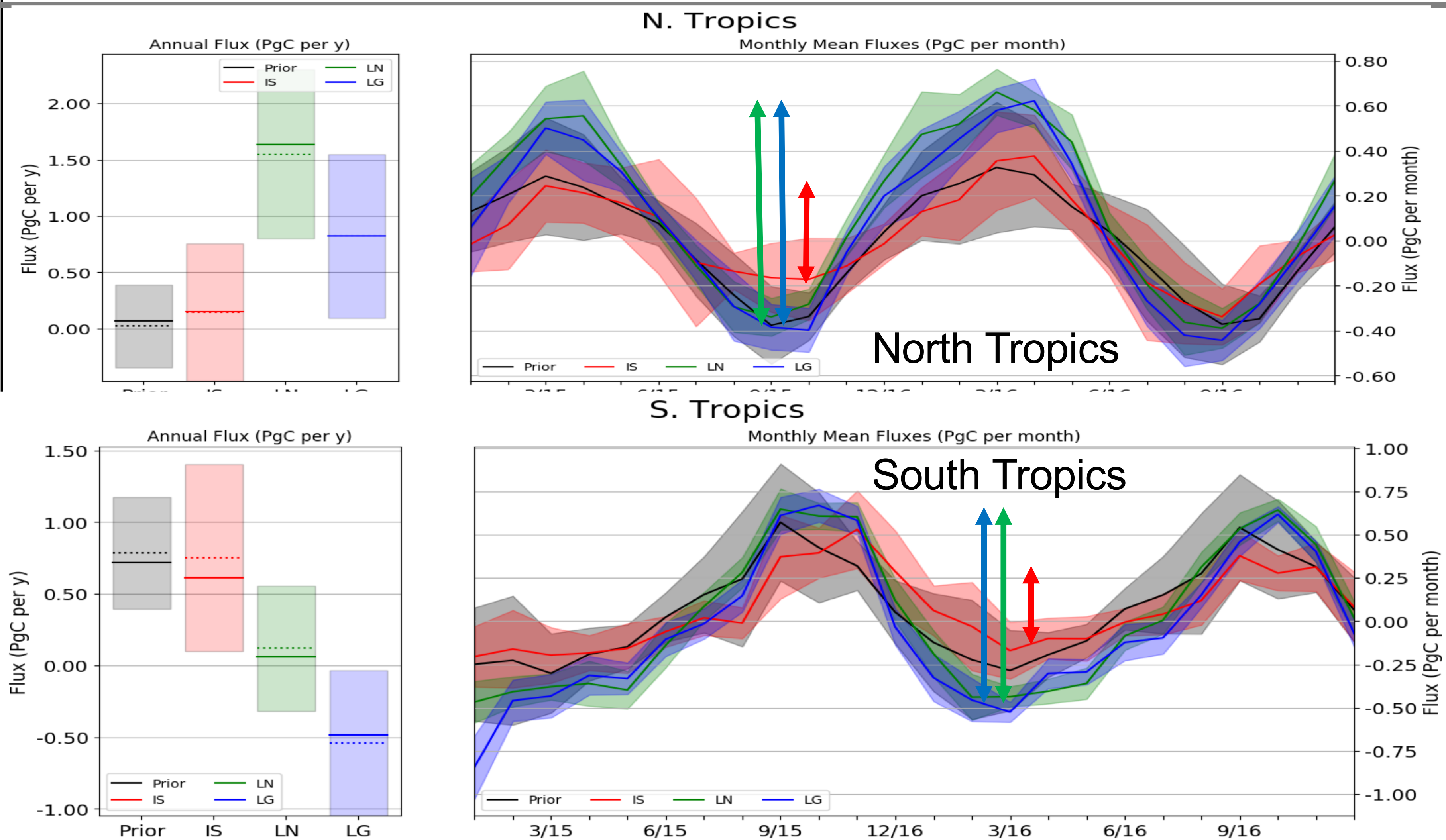
Global Land and Ocean Fluxes



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.

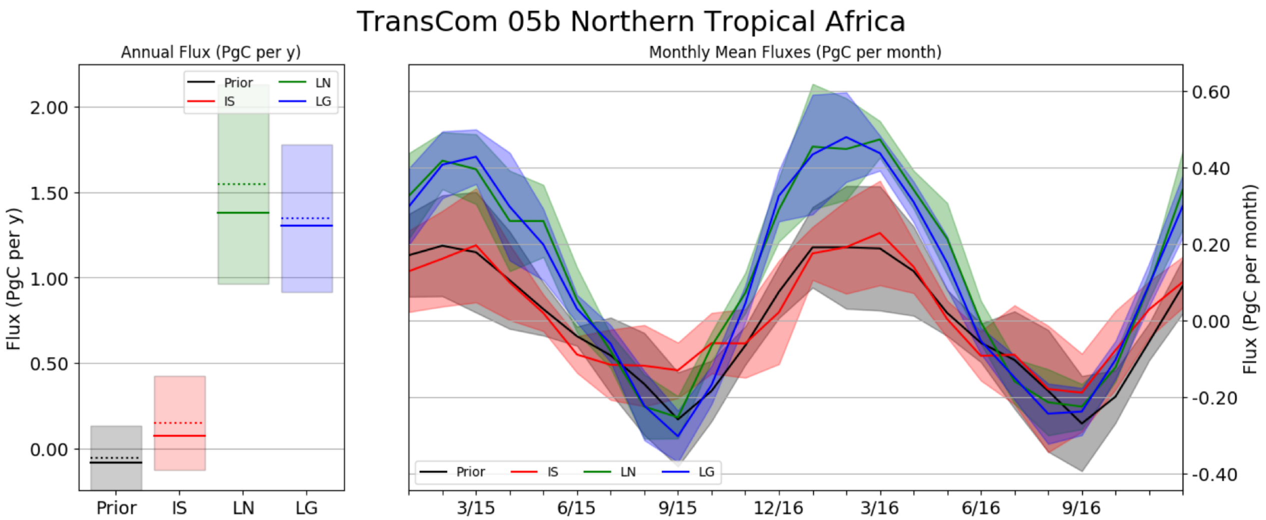
Tropics: OCO-2 sees a large source and double the seasonal cycle amplitude of IS

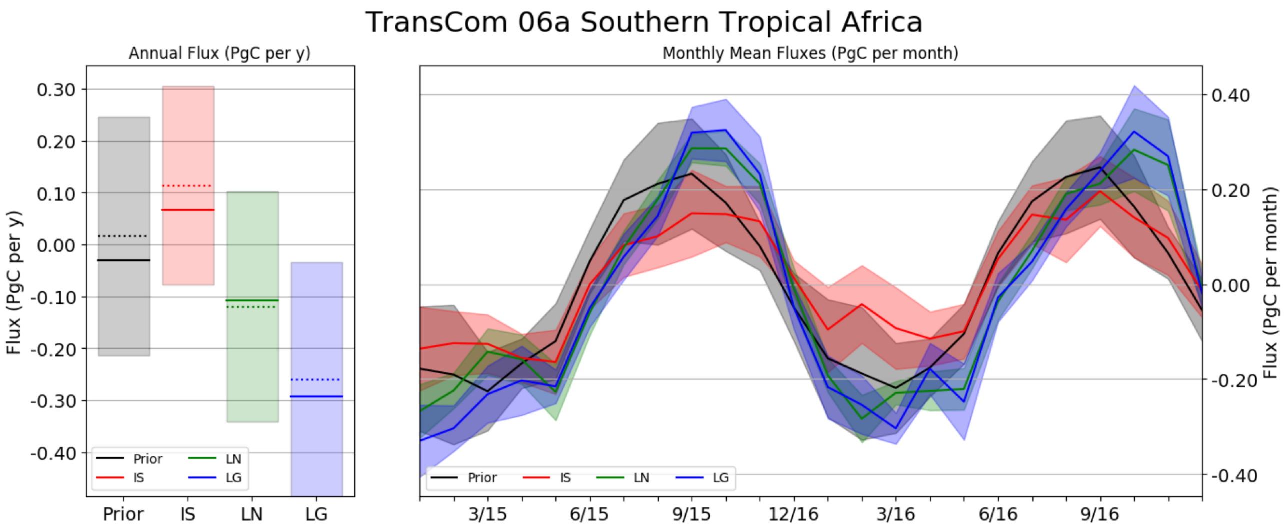


OCO-2 Level 4 Flux Findings

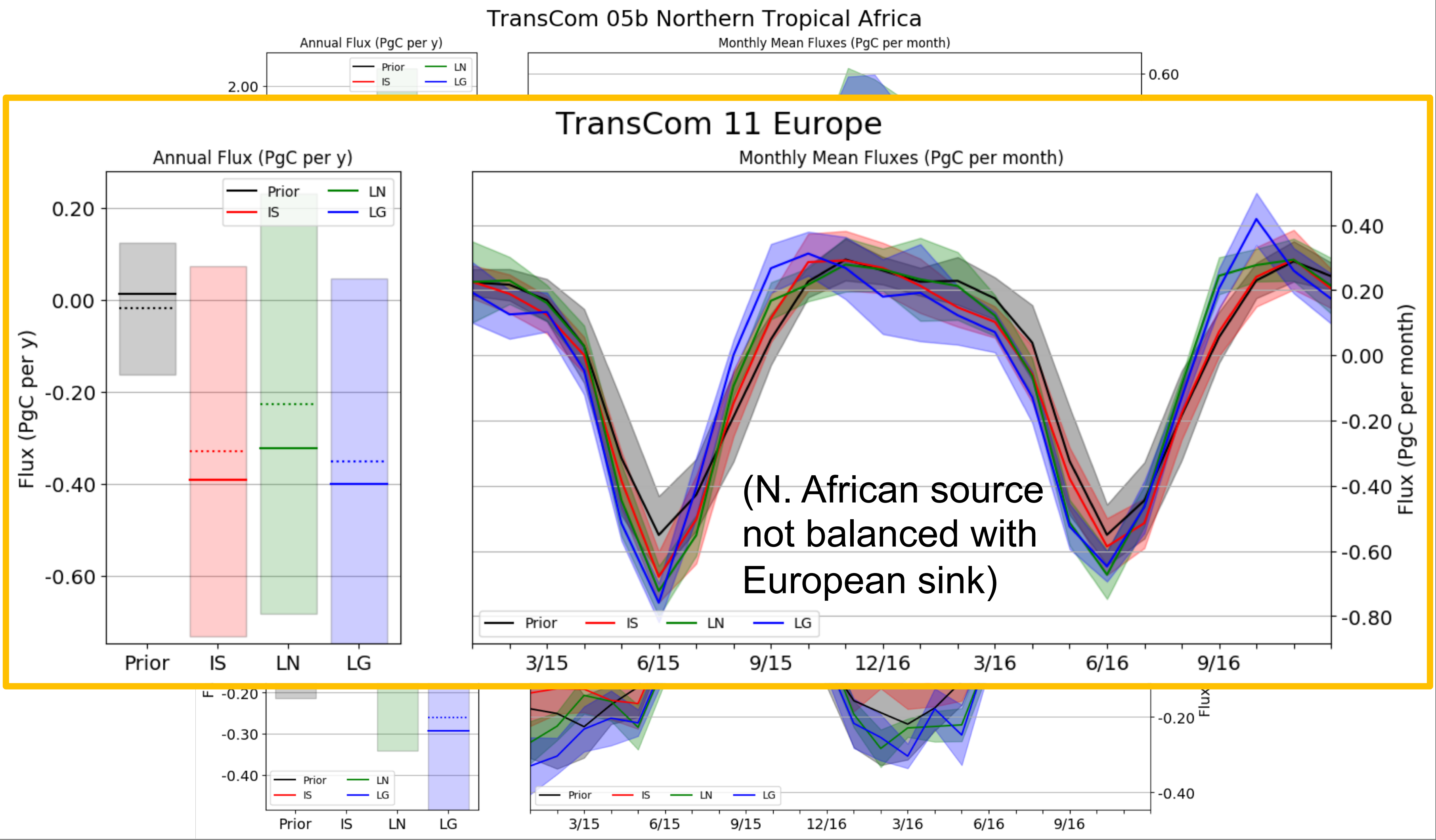
- Within the ensemble spread, IS, LN and LG agree on the annual global sink, as well as the partitioning into land and ocean.
- In the Tropics, OCO-2 sees a strong source for 2015-2016, as well as double the seasonal cycle amplitude as the fluxes inferred from IS.
  - This signal difference largely occurs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

Stronger Outgassing in Tropical Africa Inferred from OCO-2 Data





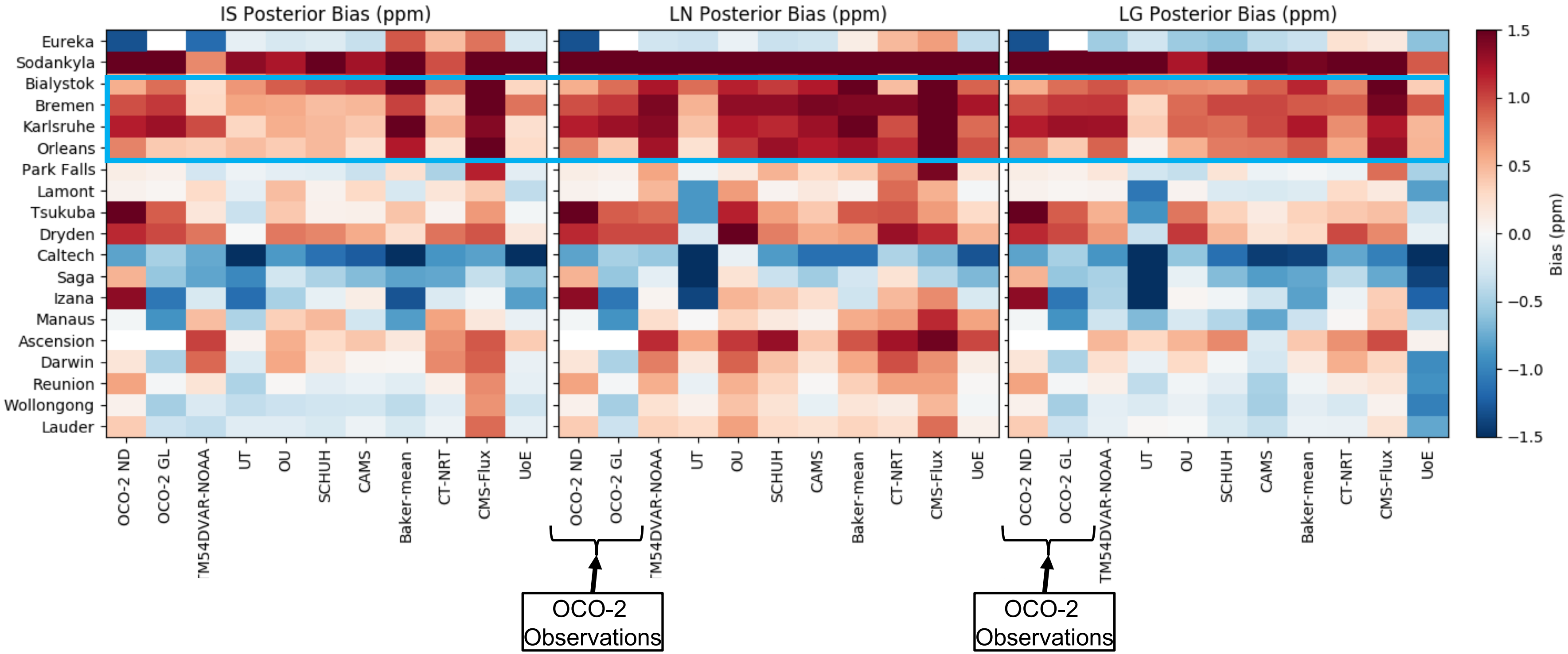
Stronger Outgassing in Tropical Africa Inferred from OCO-2 Data



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.

Comments

- 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

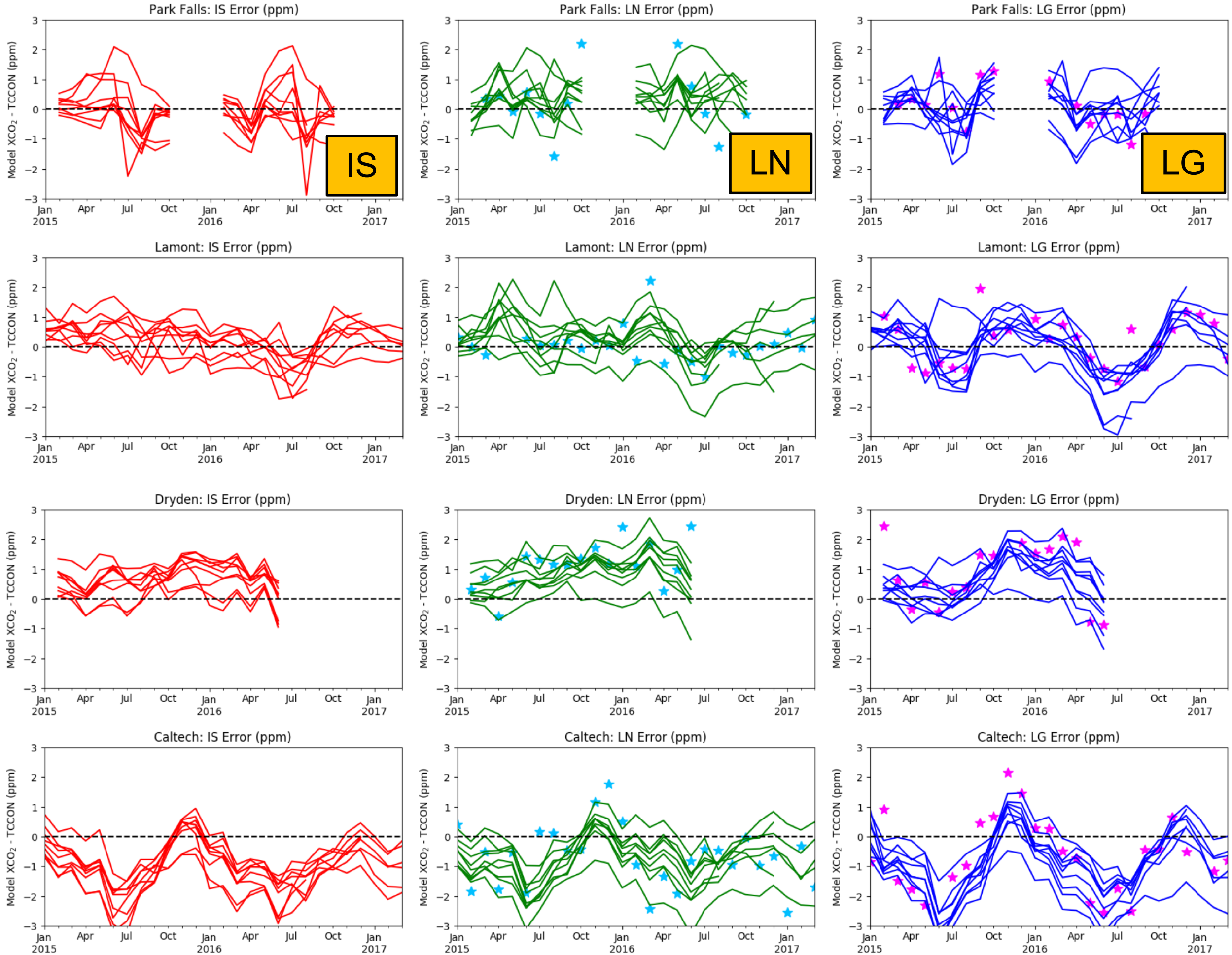
Monthly Bias relative to TCCON in Posterior Model Concentrations matches OCO-2 Bias

Park Falls

Lamont

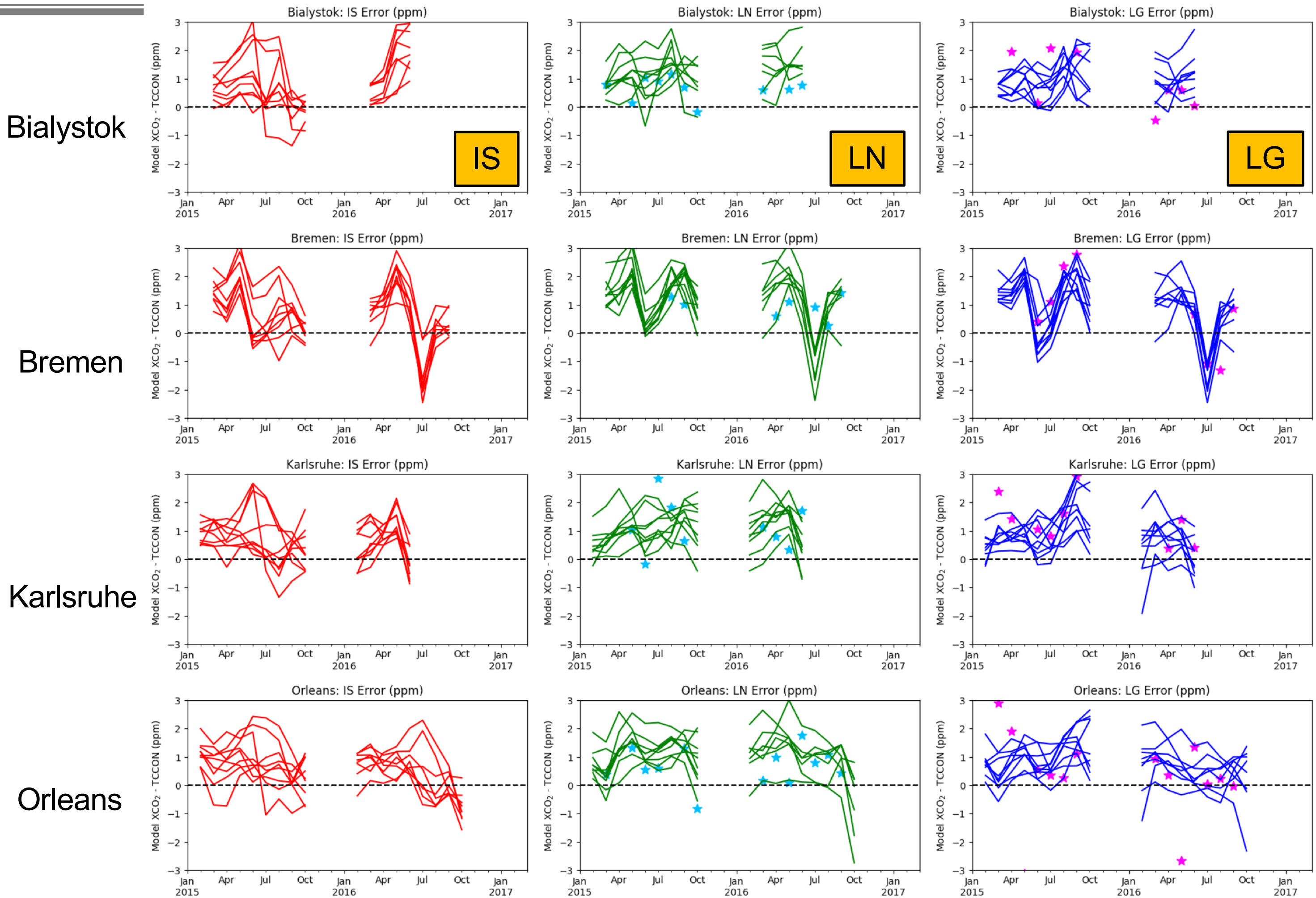
Dryden

Caltech



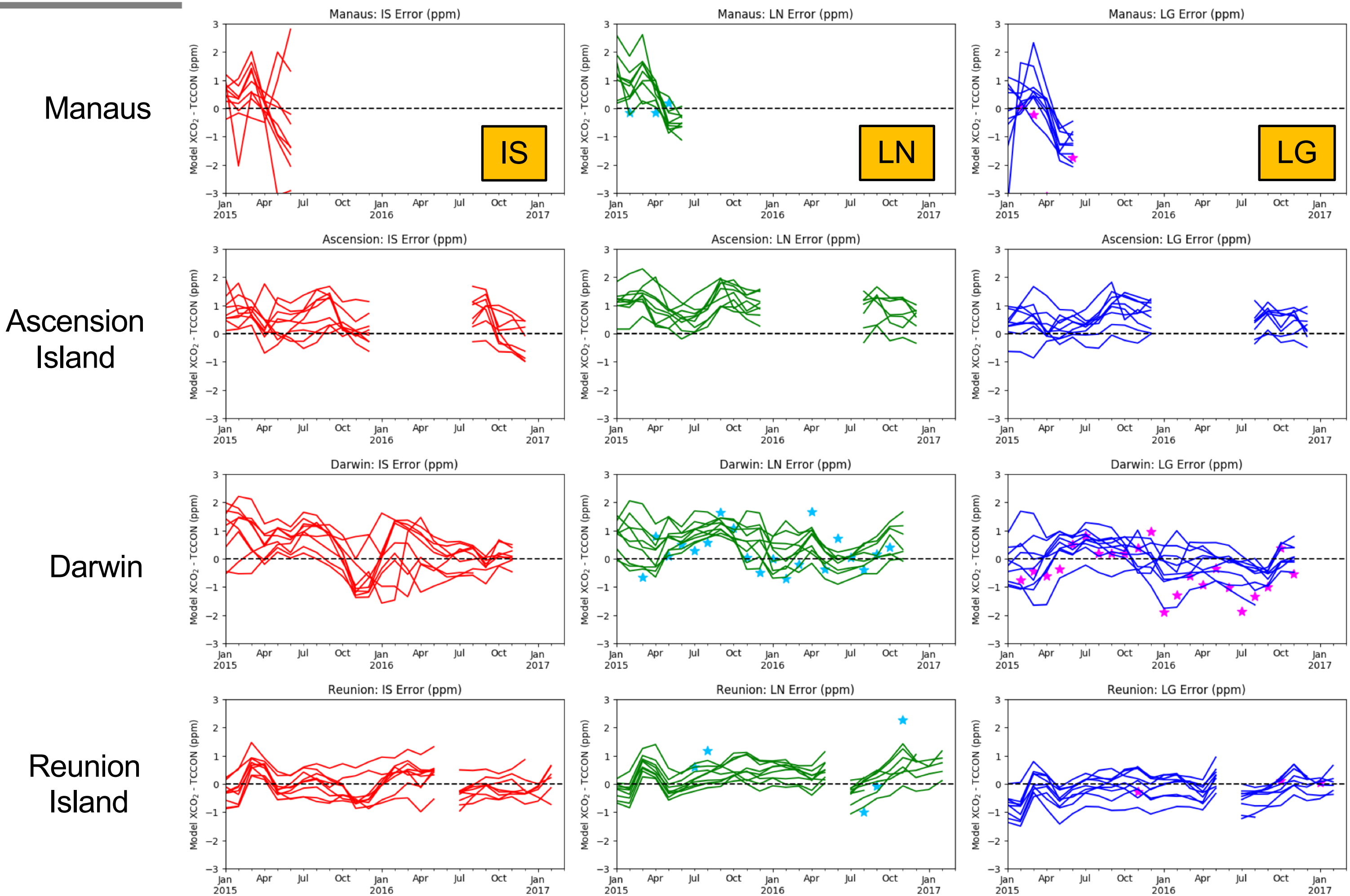
Likely elevated due to LA in model grid box

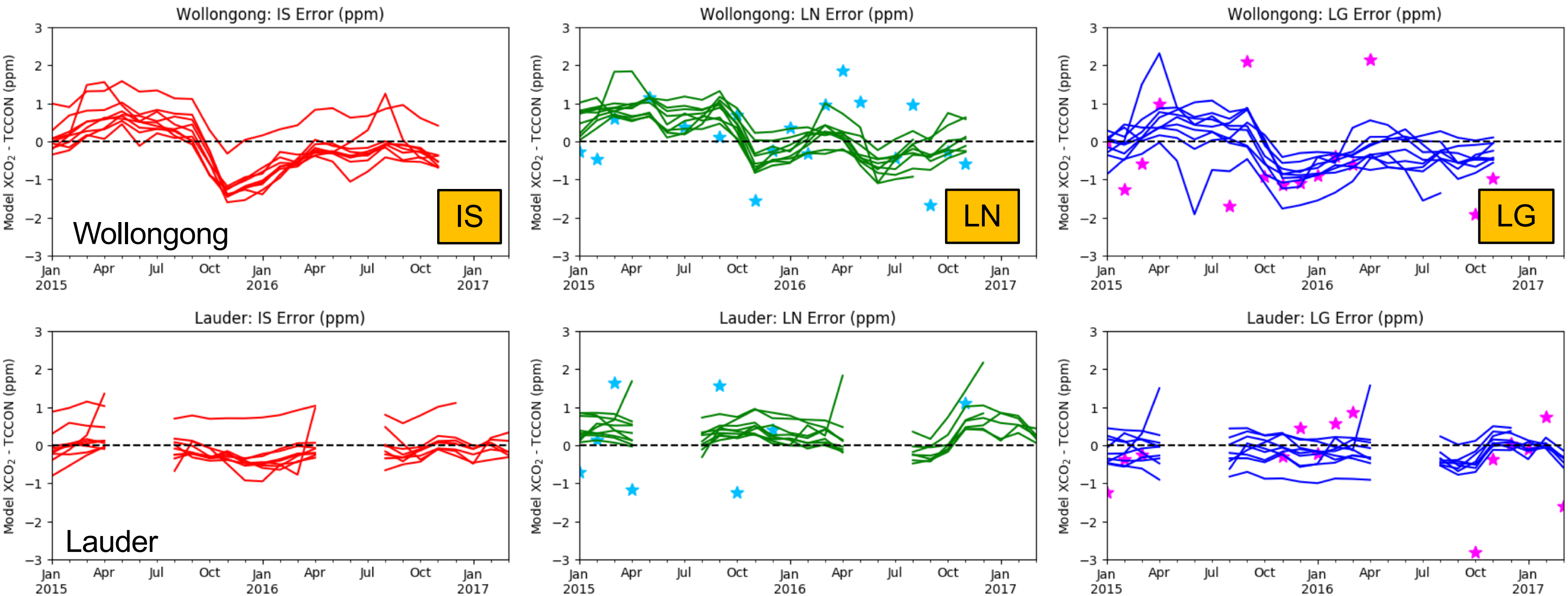
City influence diluted by area outside the LA basin



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

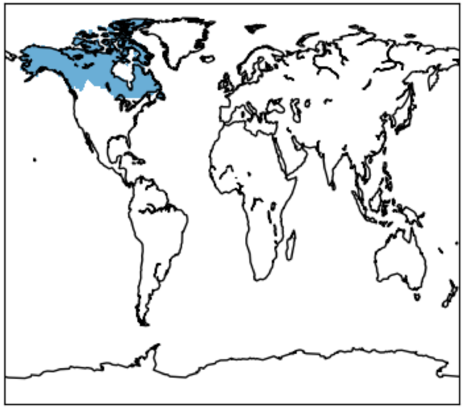

Manaus
Ascension Island
Darwin
Reunion Island
Manaus: IS Error (ppm)
Manaus: LN Error (ppm)
Manaus: LG Error (ppm)
Ascension: IS Error (ppm)
Ascension: LN Error (ppm)
Ascension: LG Error (ppm)
Darwin: IS Error (ppm)
Darwin: LN Error (ppm)
Darwin: LG Error (ppm)
Reunion: IS Error (ppm)
Reunion: LN Error (ppm)
Reunion: LG Error (ppm)
IS
LN
LG
Model XCO_2 - TCCON (ppm)
Jan 2015
Apr
Jul
Oct
Jan 2016
Apr
Jul
Oct
Jan 2017

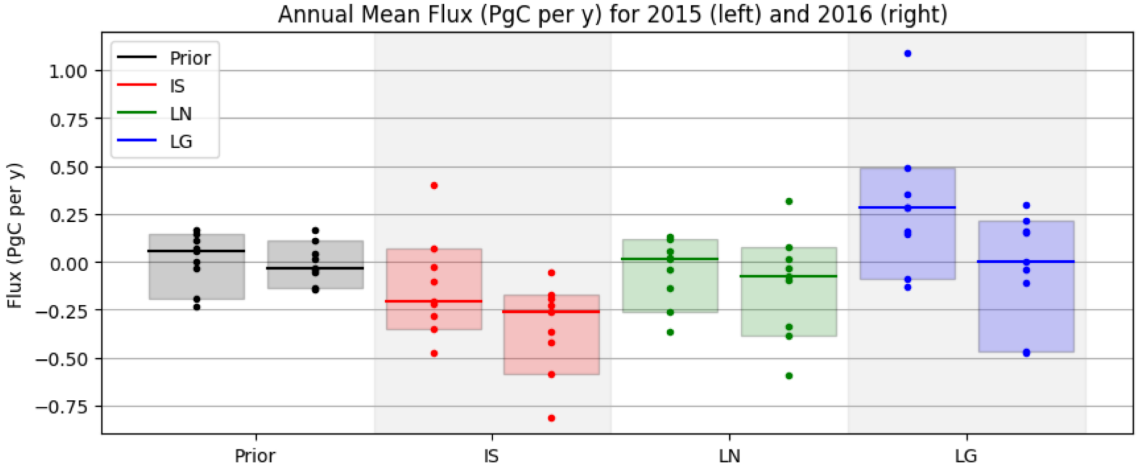

Wollongong: IS Error (ppm)
Wollongong: LN Error (ppm)
Wollongong: LG Error (ppm)
Lauder: IS Error (ppm)
Lauder: LN Error (ppm)
Lauder: LG Error (ppm)
Model XCO_2 - TCCON (ppm)
Wollongong
Lauder
IS
LN
LG
3
2
1
0
−1
−2
−3
Jan 2015
Apr
Jul
Oct
Jan 2016
Apr
Jul
Oct
Jan 2017

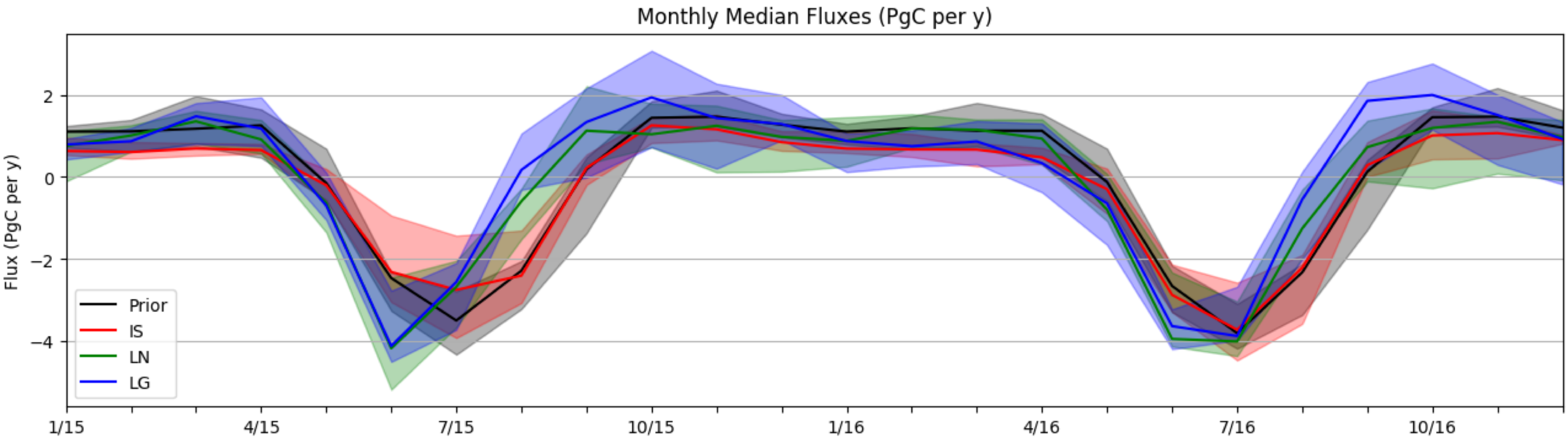
TCCON Eval Summary

- 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

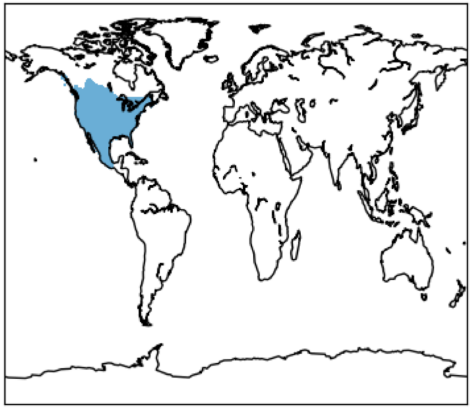
TransCom 01 North American Boreal

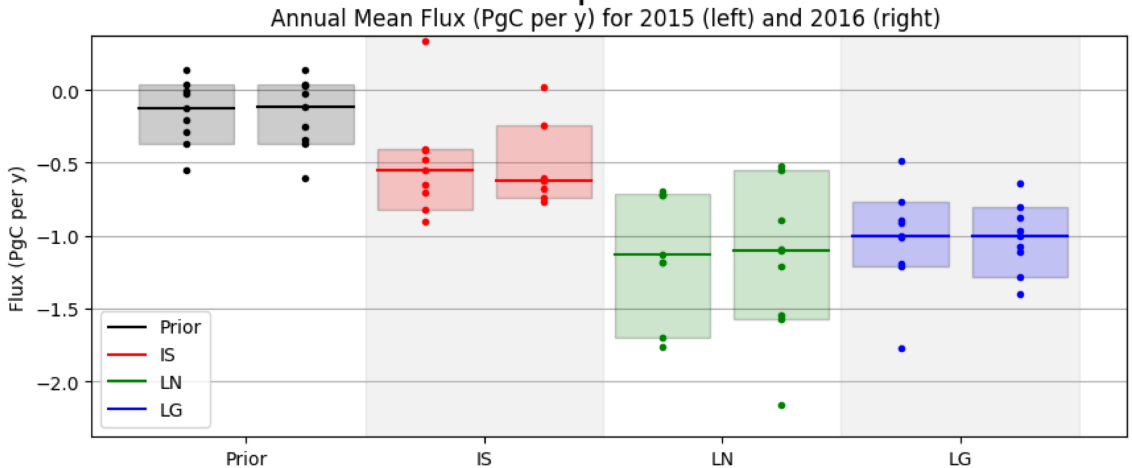


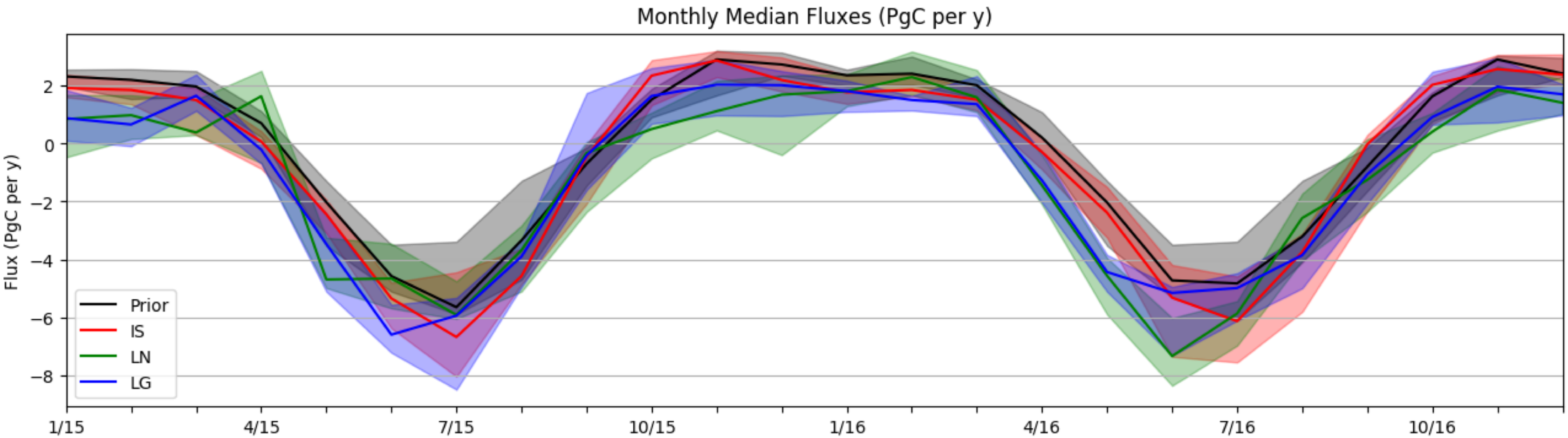


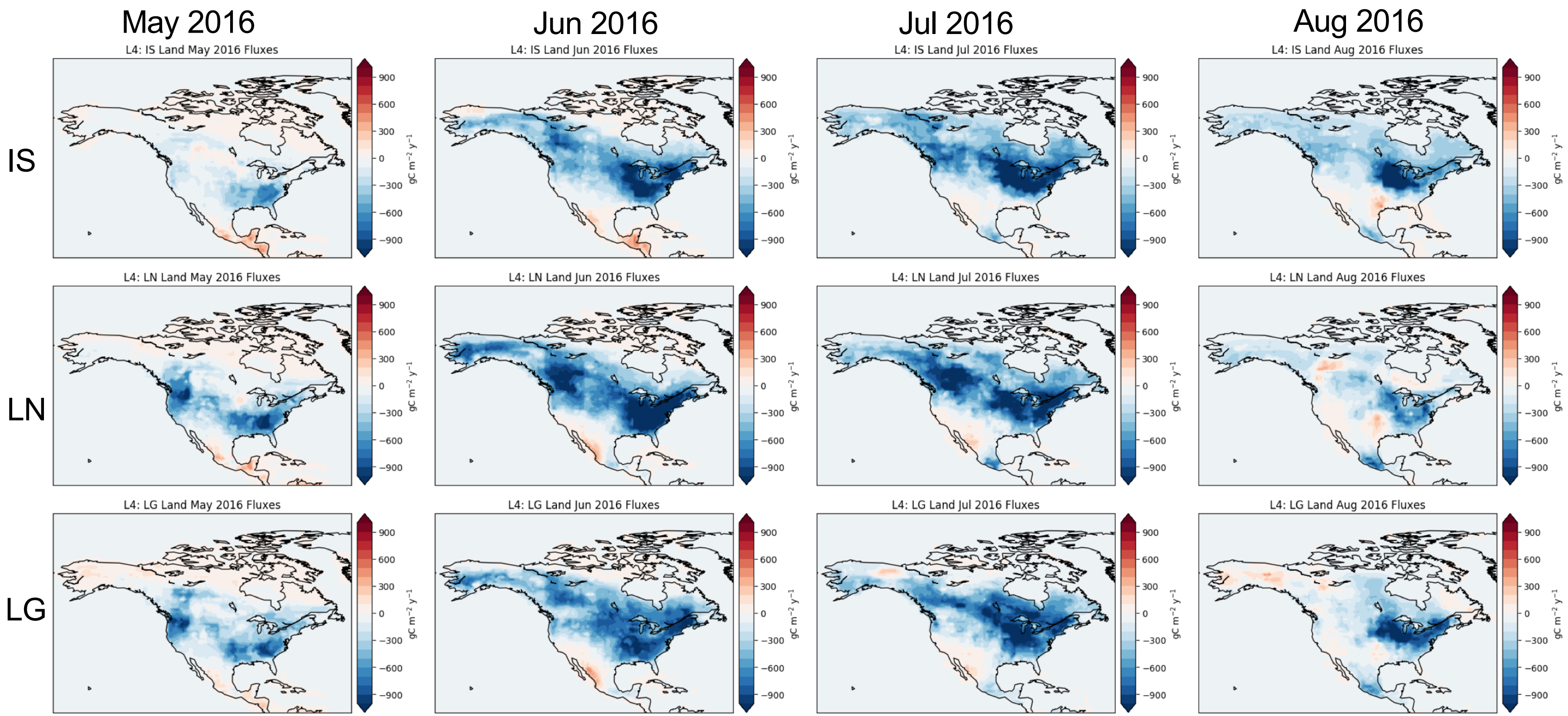


TransCom 02 North American Temperate

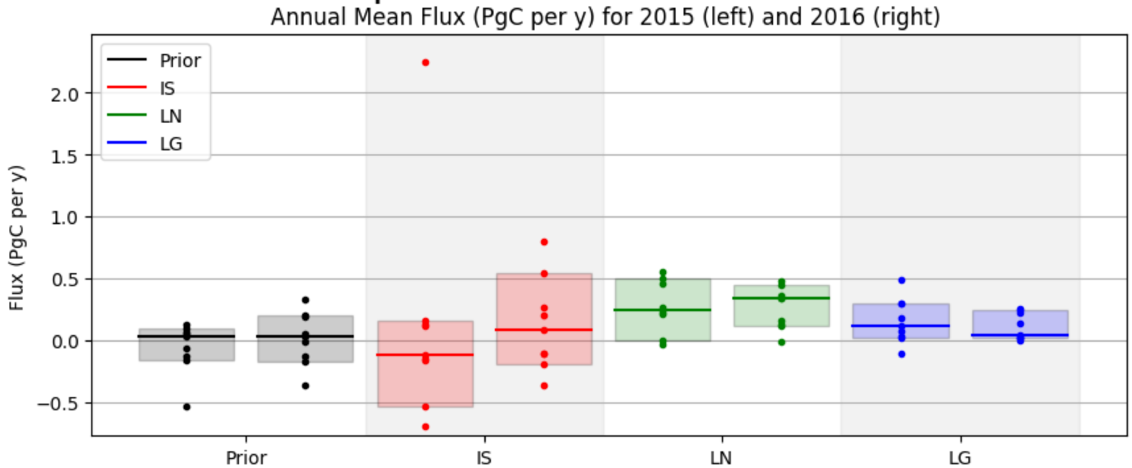


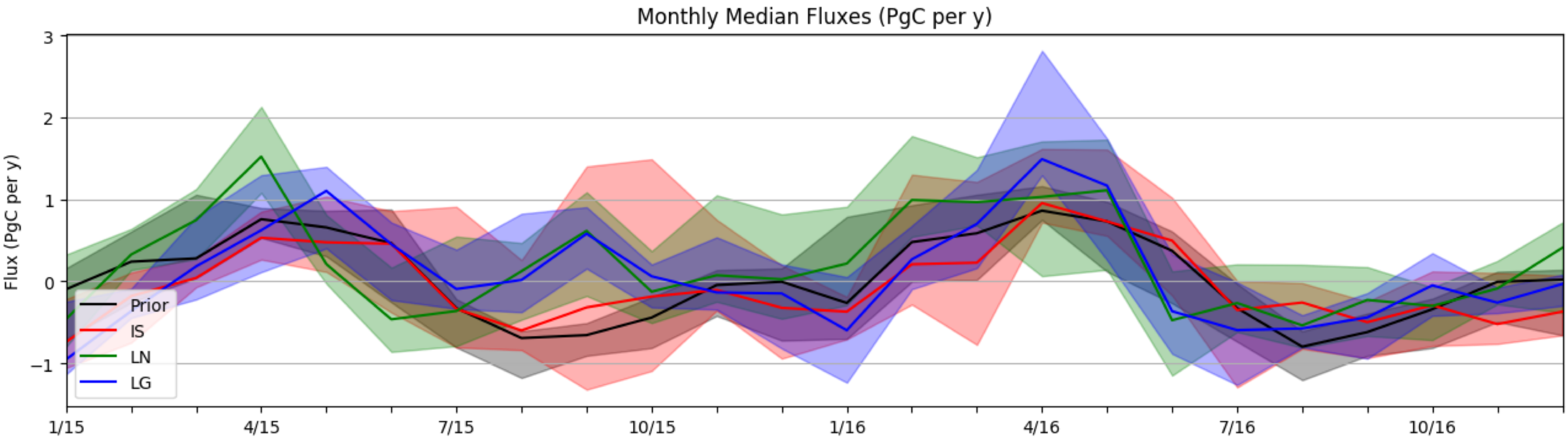




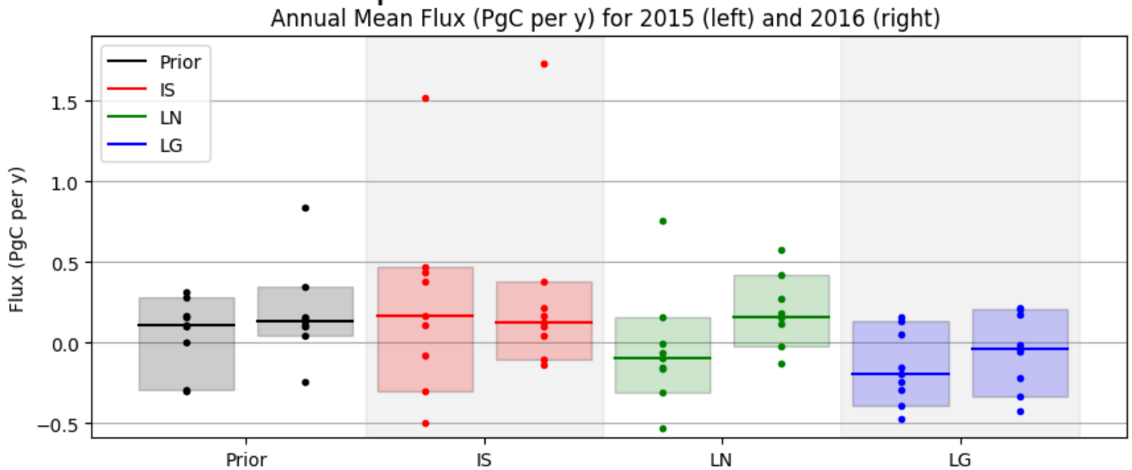

May 2016
Jun 2016
Jul 2016
Aug 2016
IS
LN
LG
L4: IS Land May 2016 Fluxes
L4: IS Land Jun 2016 Fluxes
L4: IS Land Jul 2016 Fluxes
L4: IS Land Aug 2016 Fluxes
L4: LN Land May 2016 Fluxes
L4: LN Land Jun 2016 Fluxes
L4: LN Land Jul 2016 Fluxes
L4: LN Land Aug 2016 Fluxes
L4: LG Land May 2016 Fluxes
L4: LG Land Jun 2016 Fluxes
L4: LG Land Jul 2016 Fluxes
L4: LG Land Aug 2016 Fluxes
900
600
300
0
−300
−600
−900
gC m⁻² y⁻¹

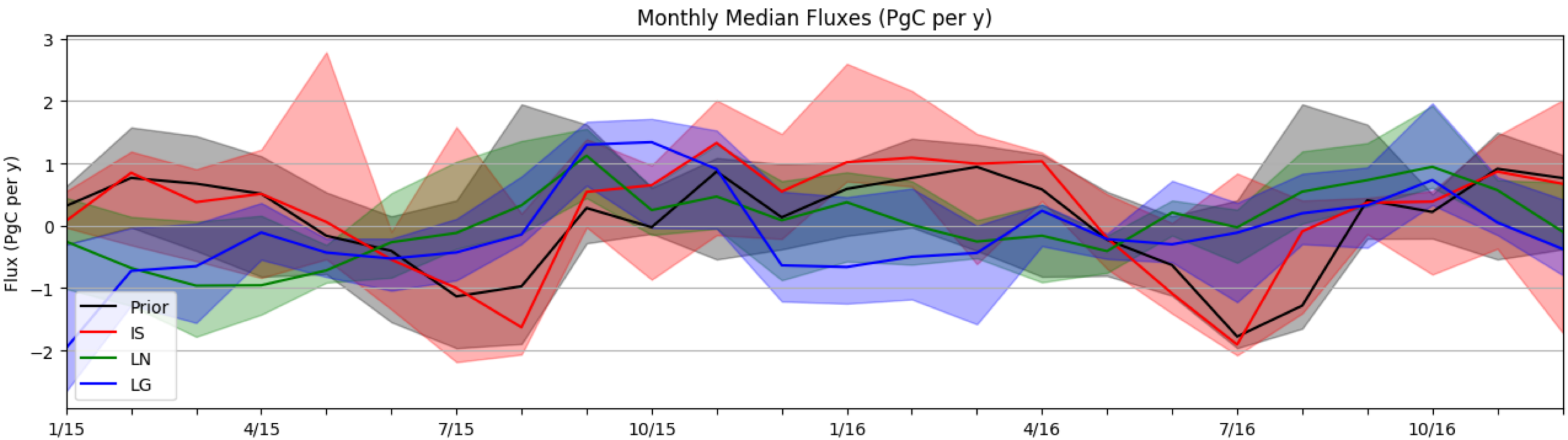
TransCom 03a Northern Tropical South America



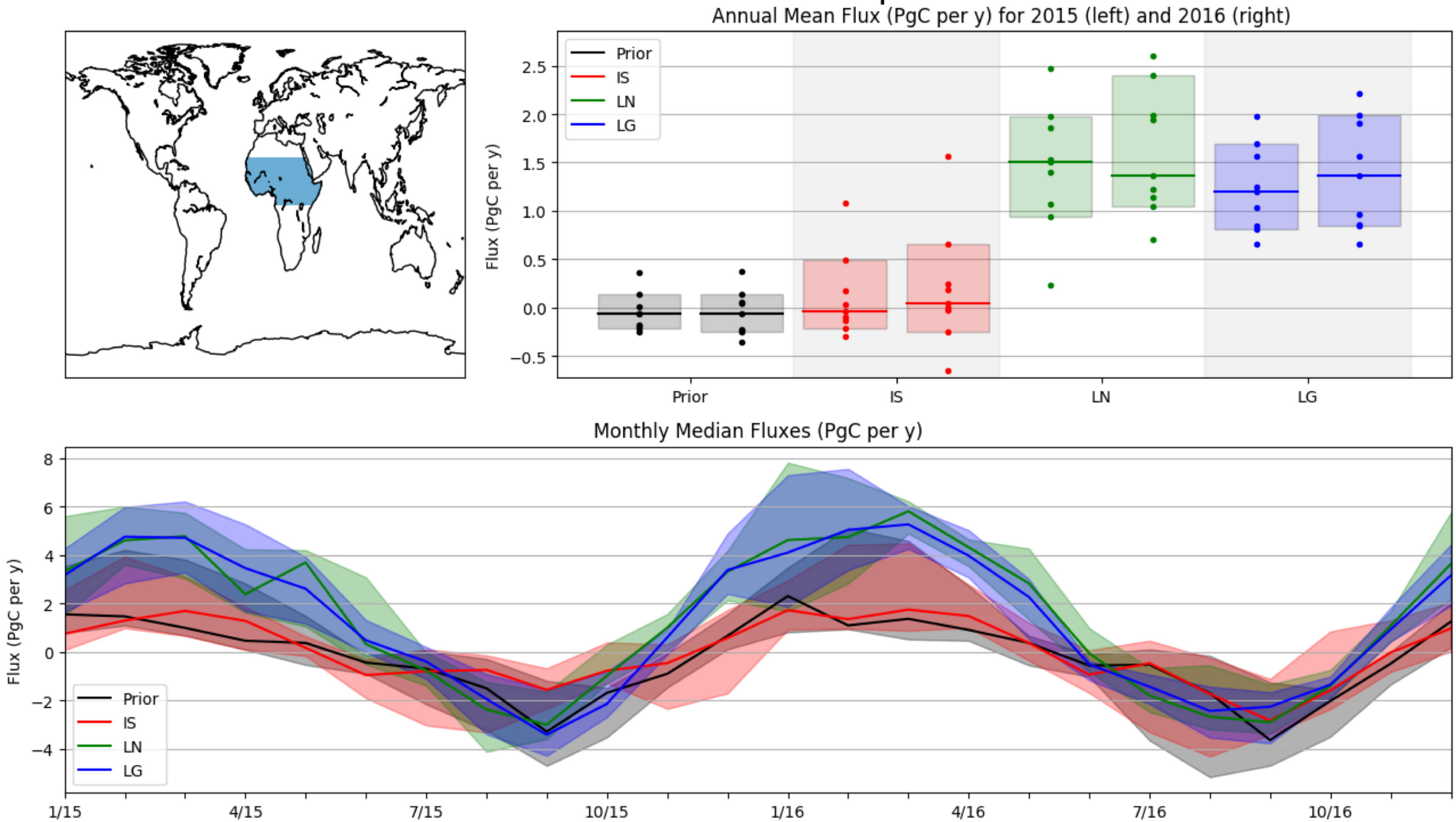


TransCom 03b Southern Tropical South America

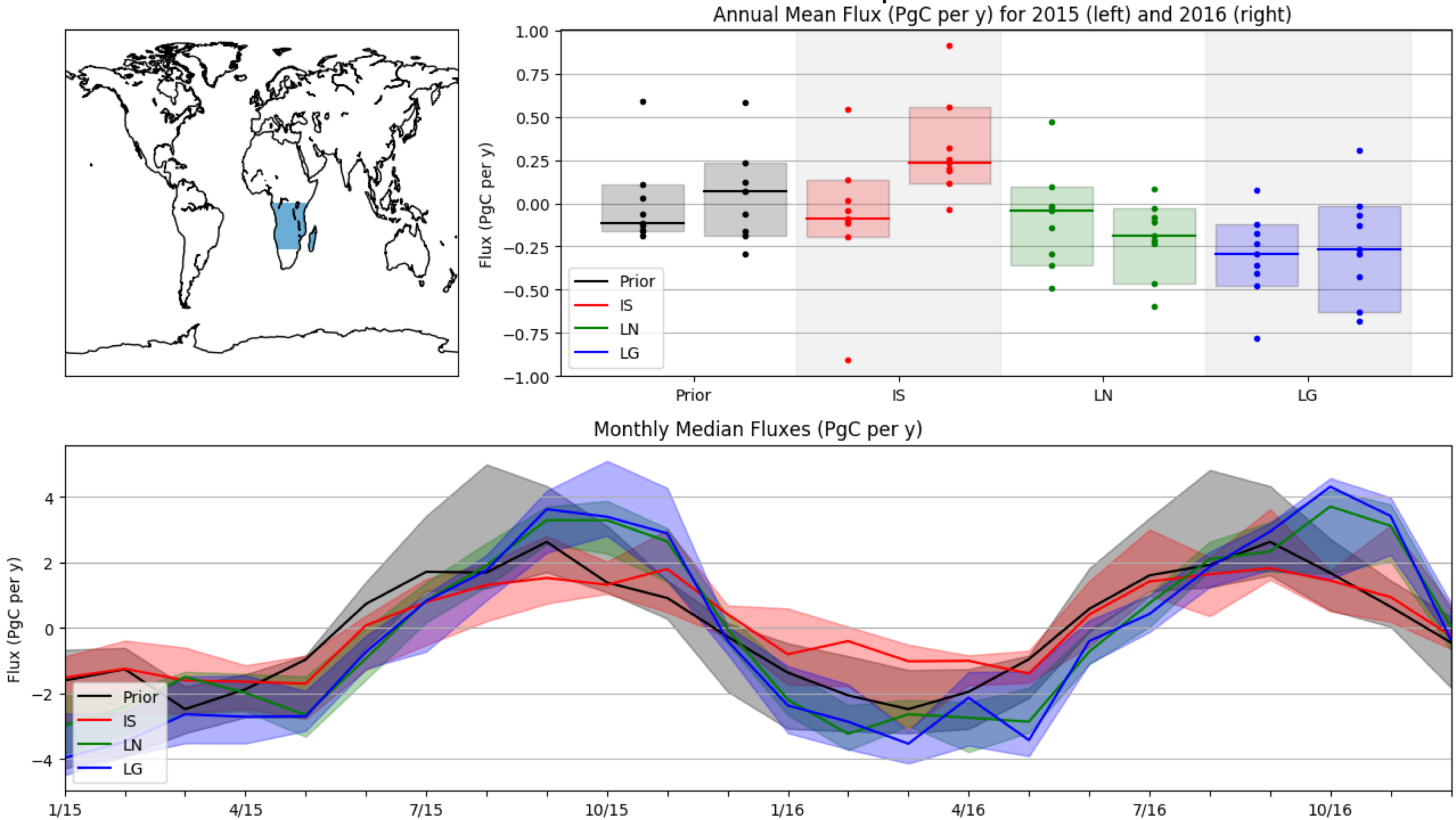




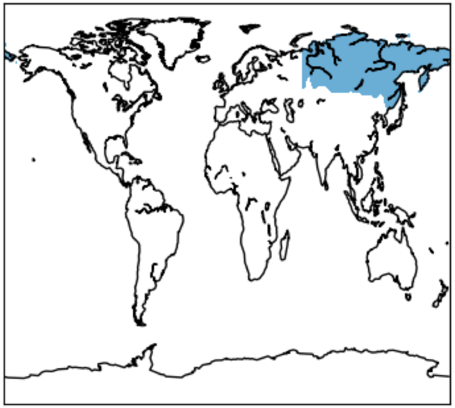
TransCom 05b Northern Tropical Africa



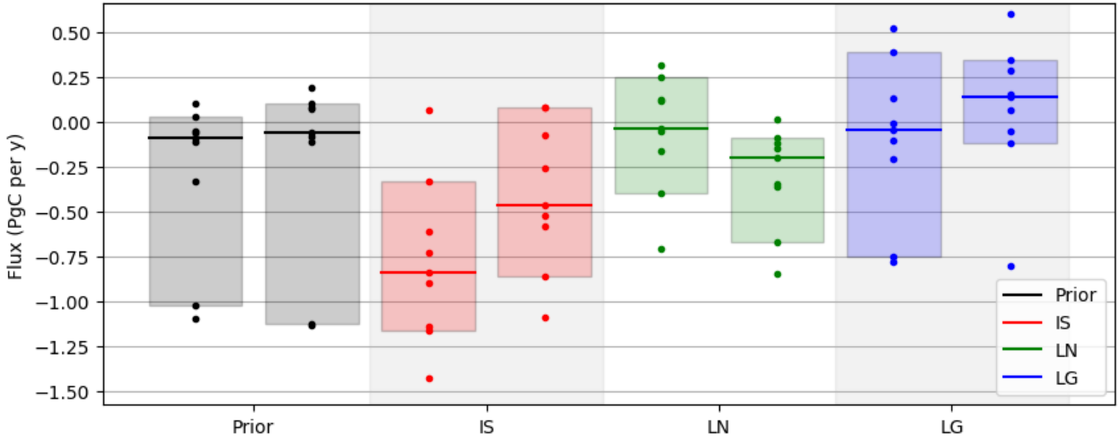
TransCom 06a Southern Tropical Africa



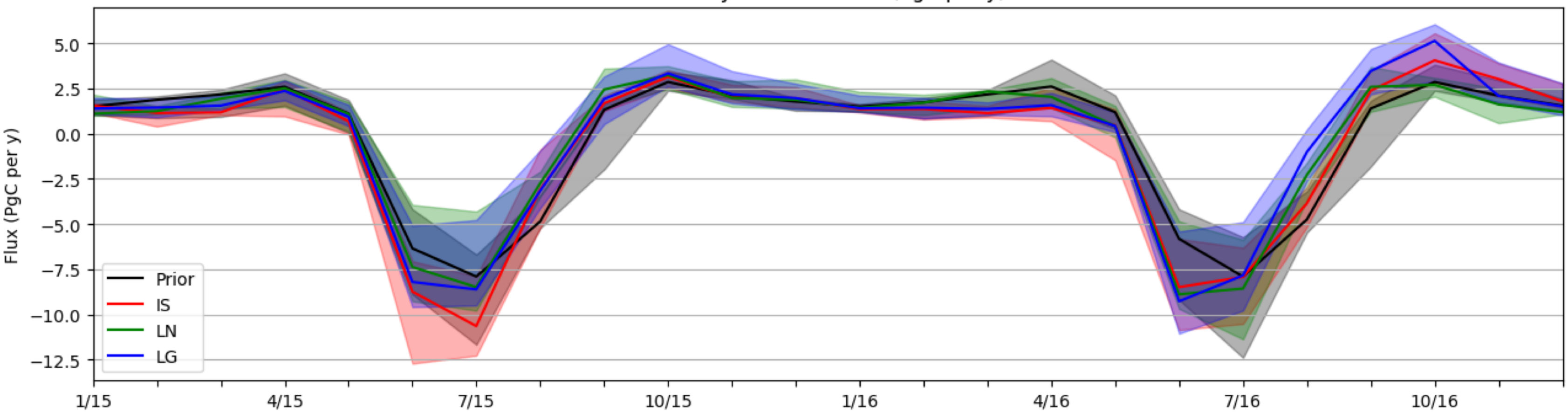
TransCom 07 Eurasia Boreal



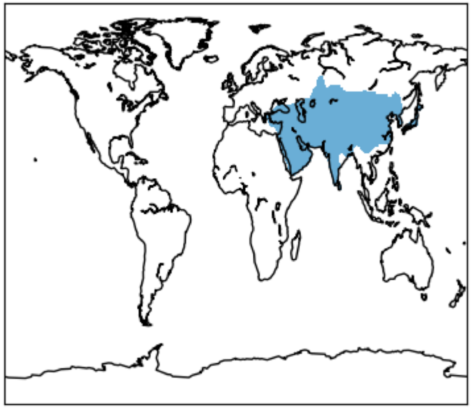
Annual Mean Flux (PgC per y) for 2015 (left) and 2016 (right)

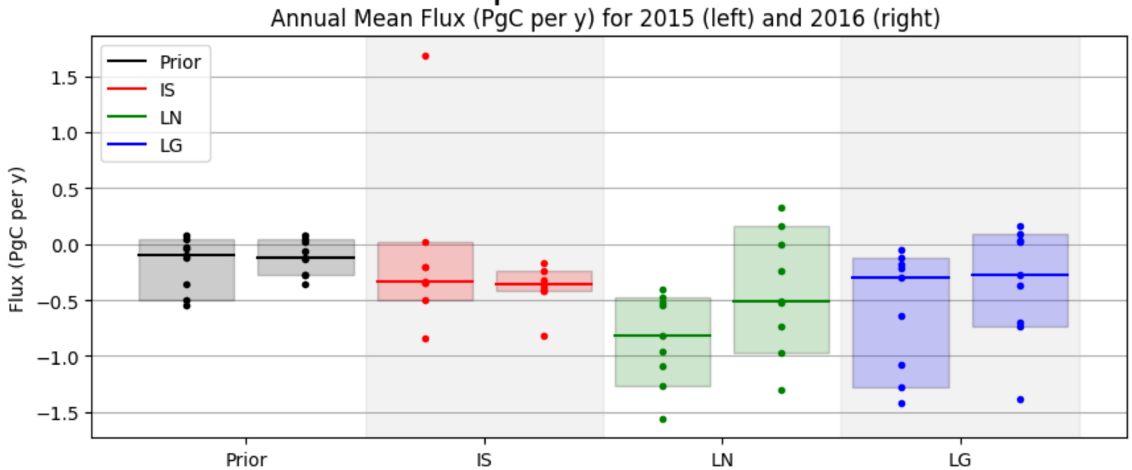


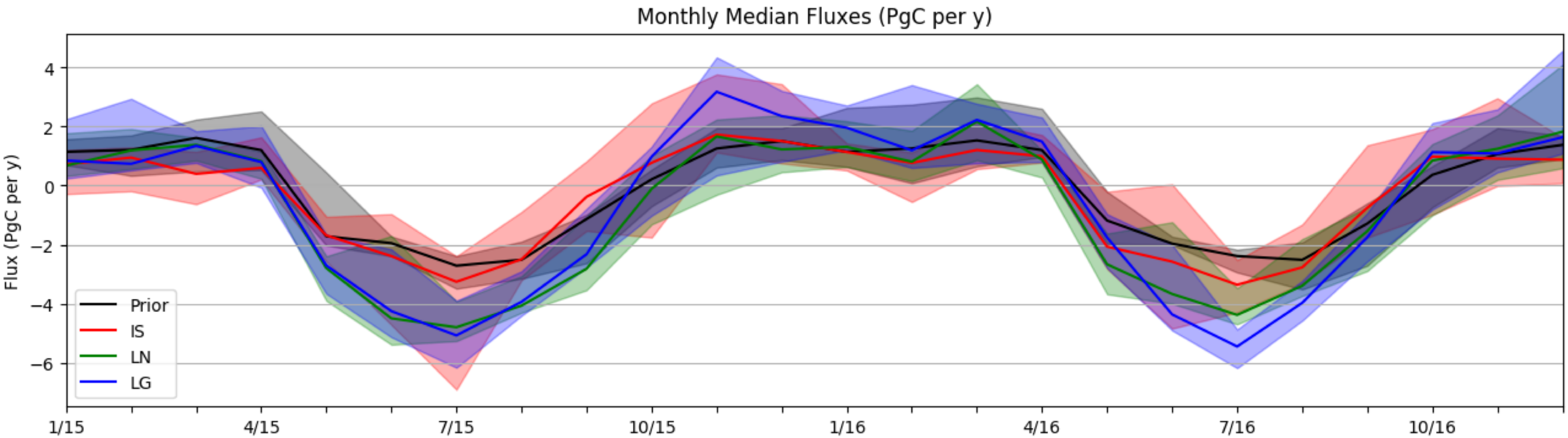
Monthly Median Fluxes (PgC per y)



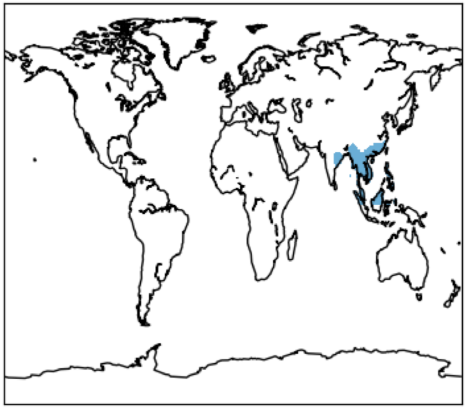
TransCom 08 Eurasia Temperate

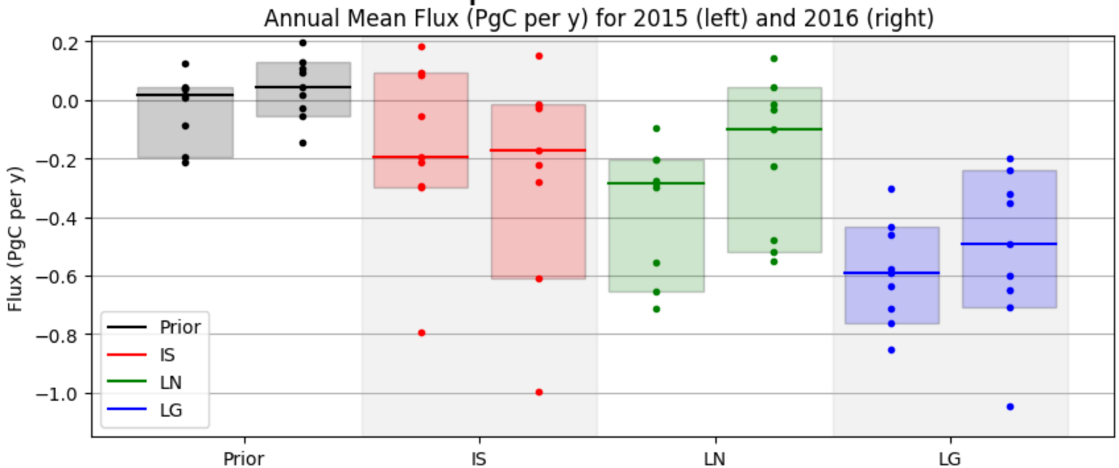


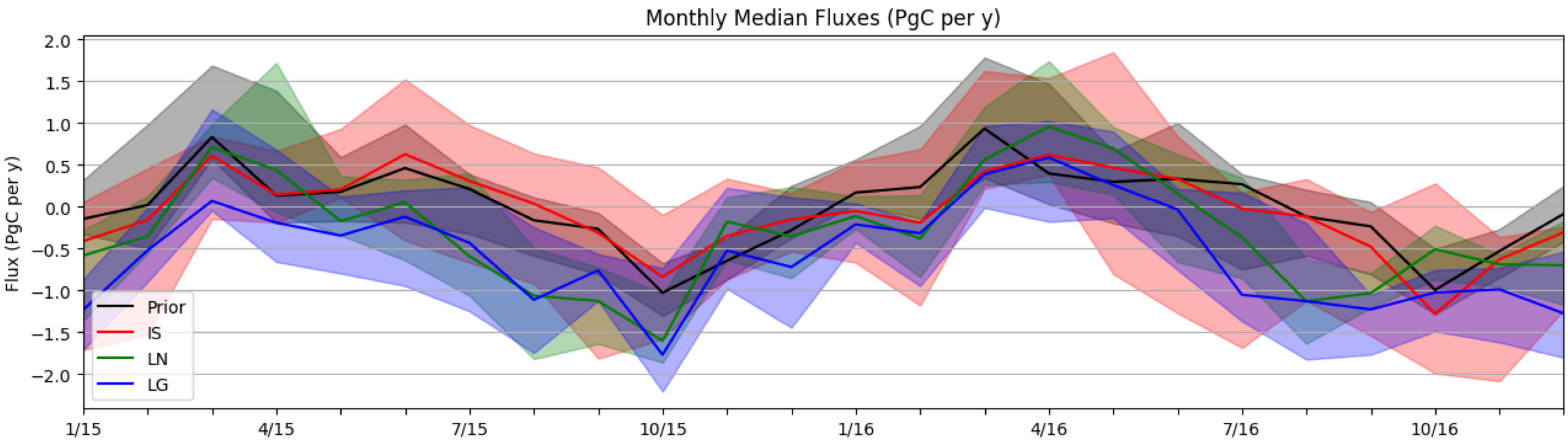




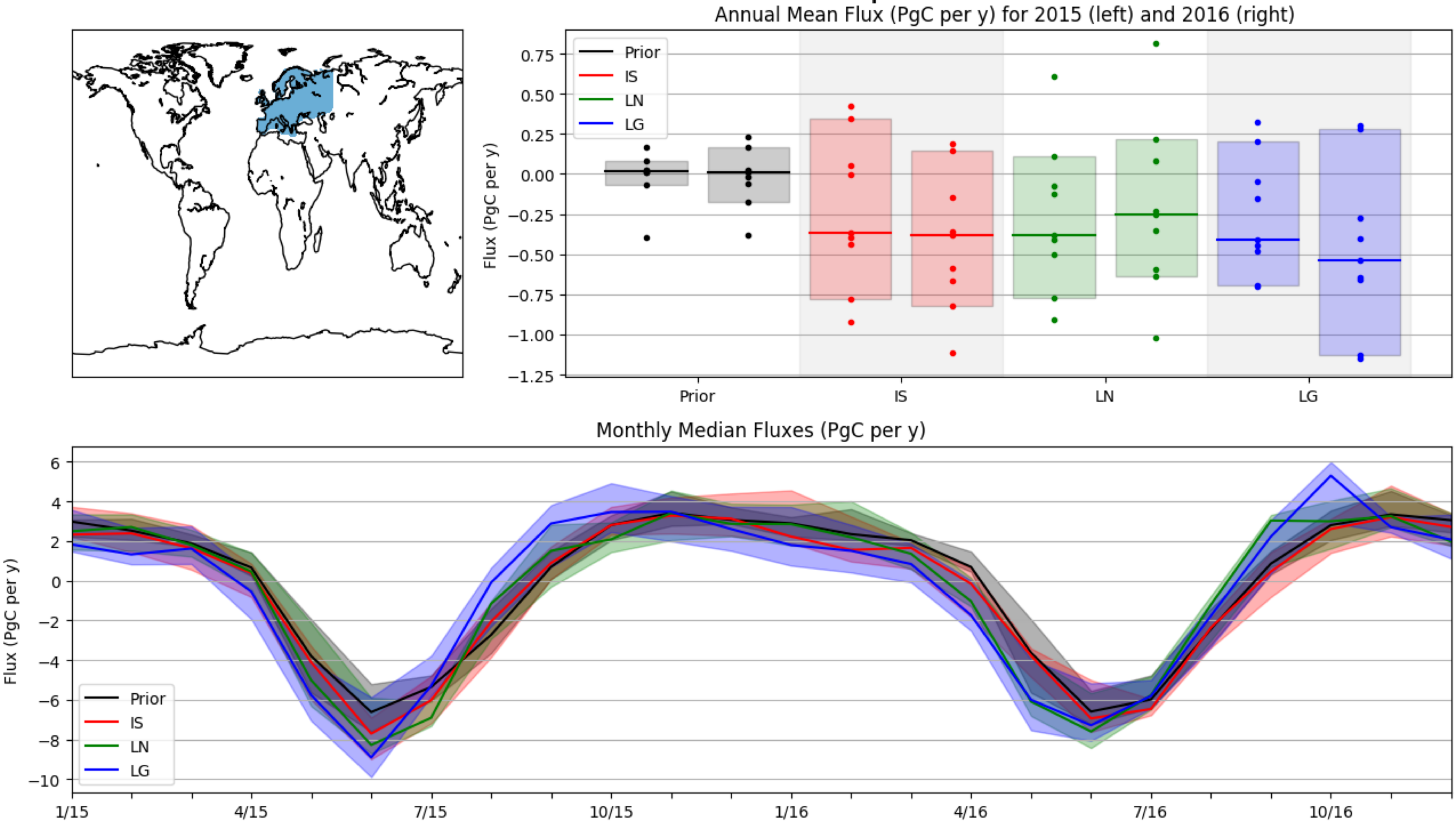
TransCom 09a Northern Tropical Asia







TransCom 11 Europe

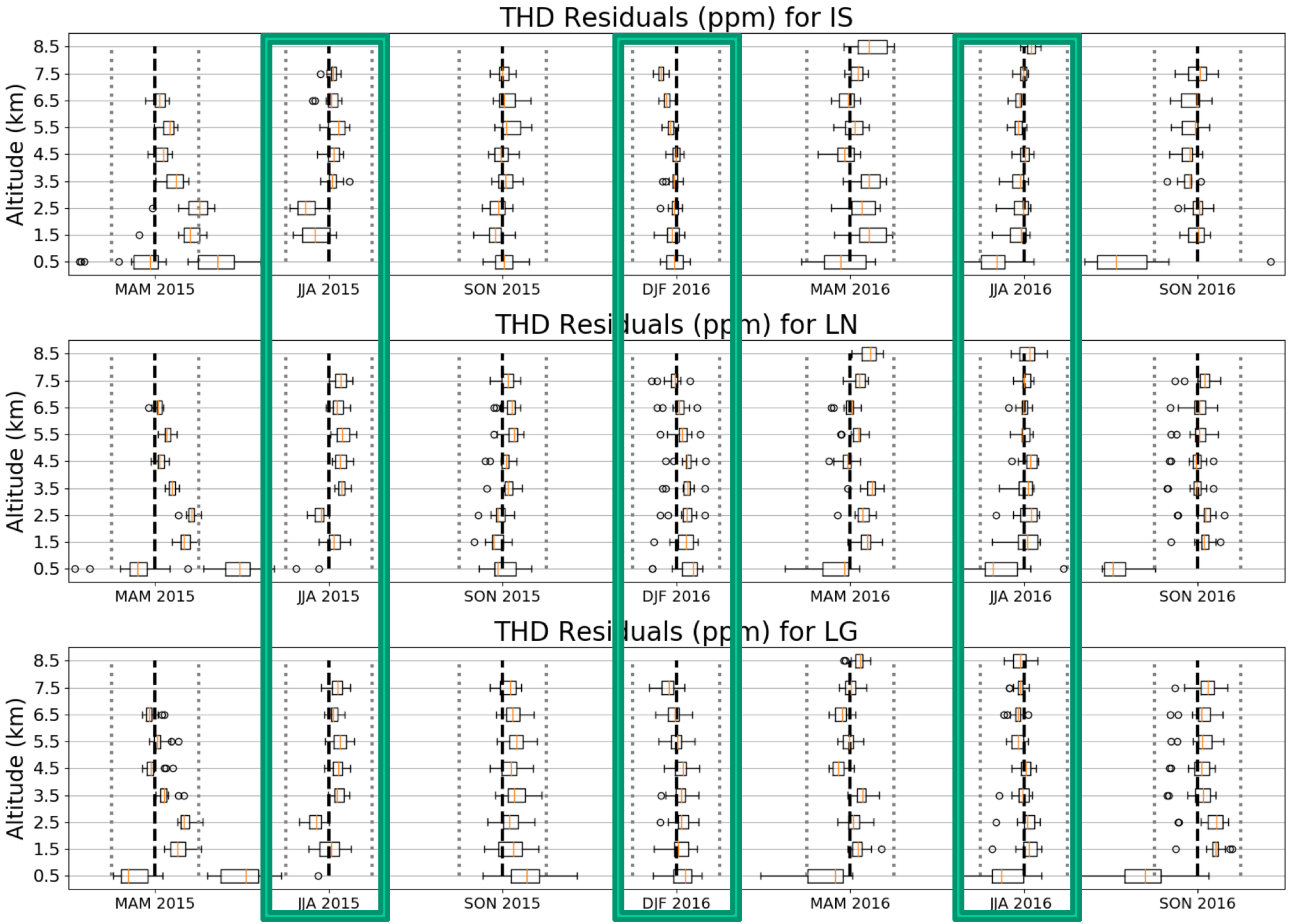


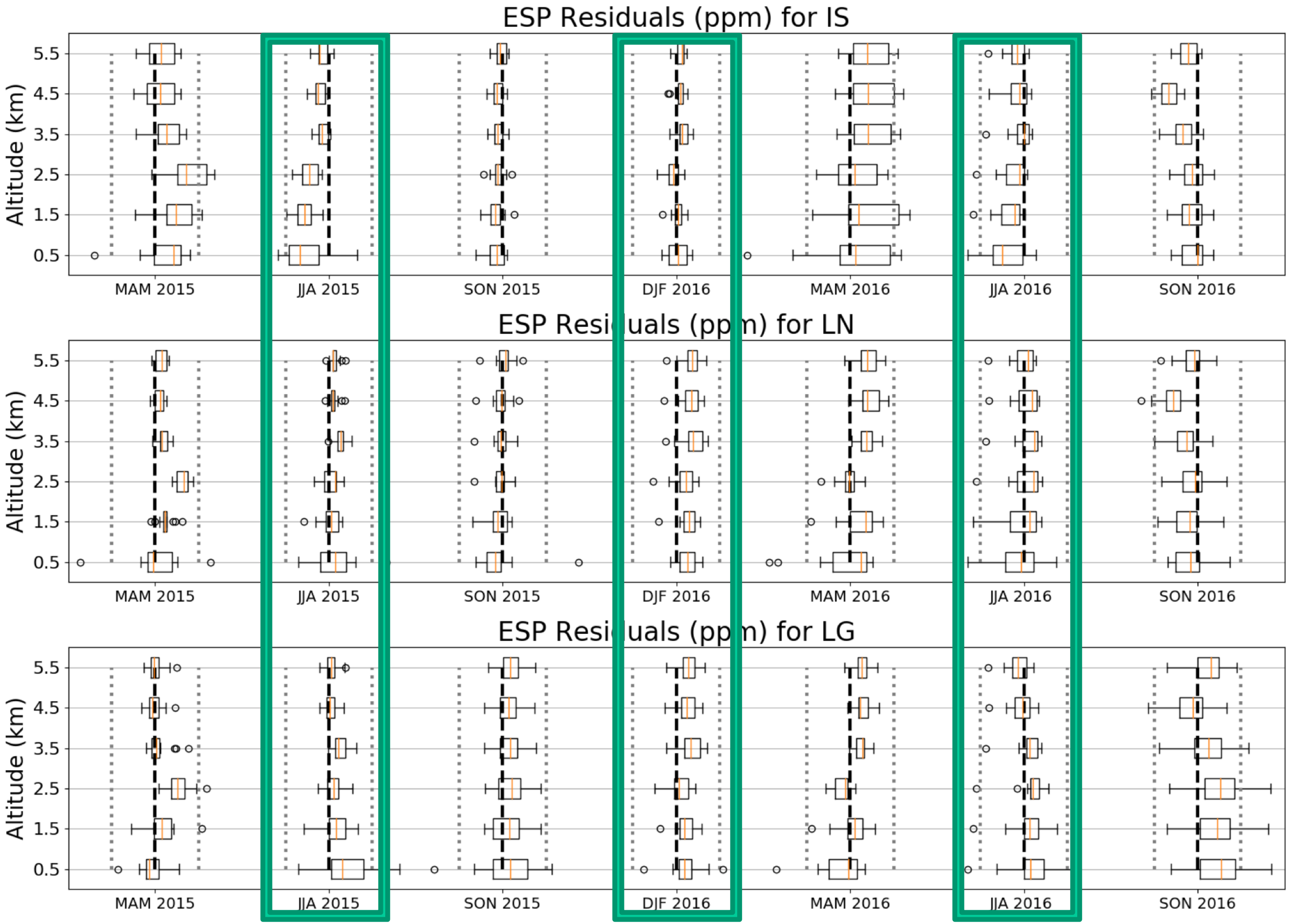
Aircraft Evaluation

Super preliminary (sorry!)

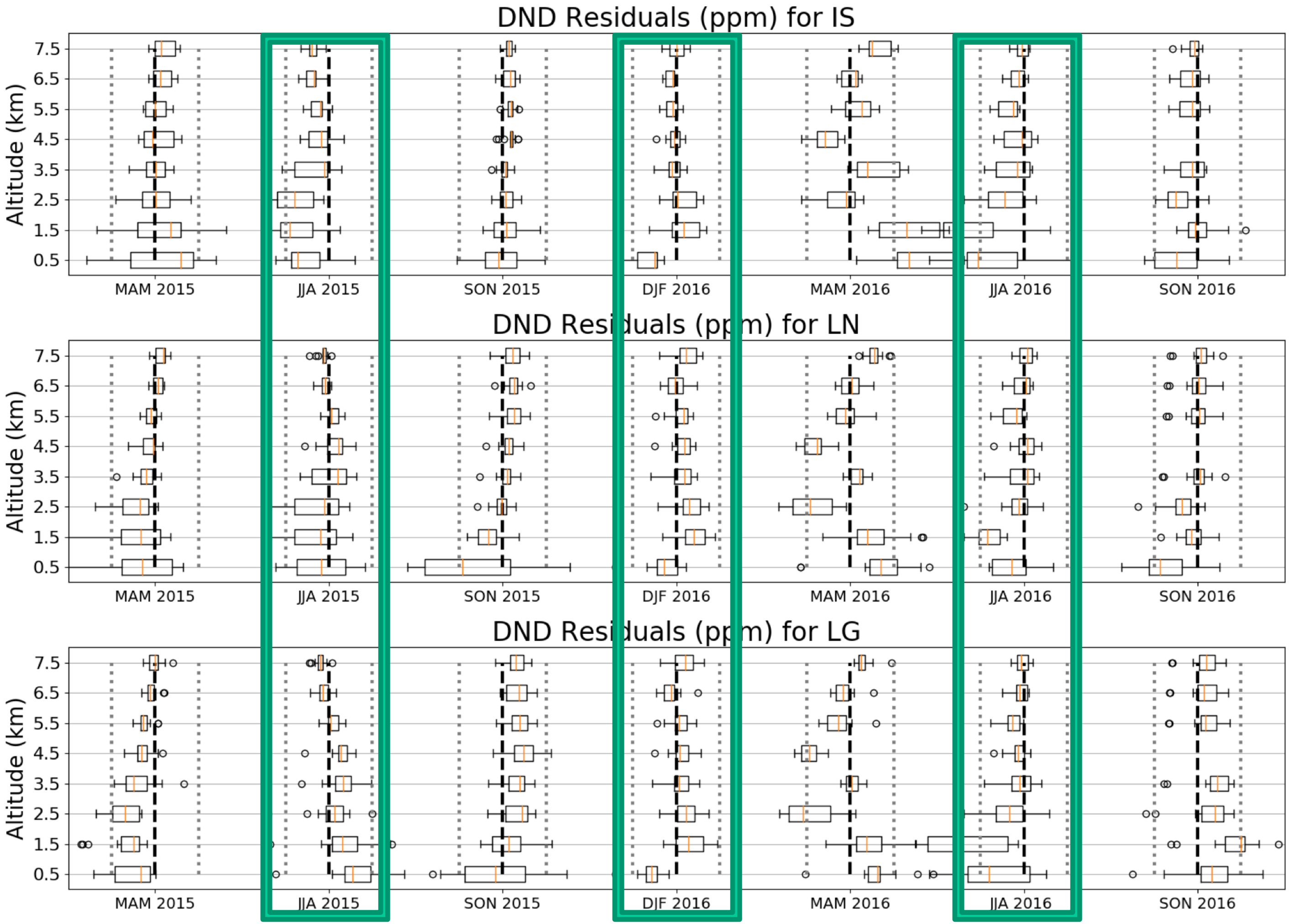
West Coast sites

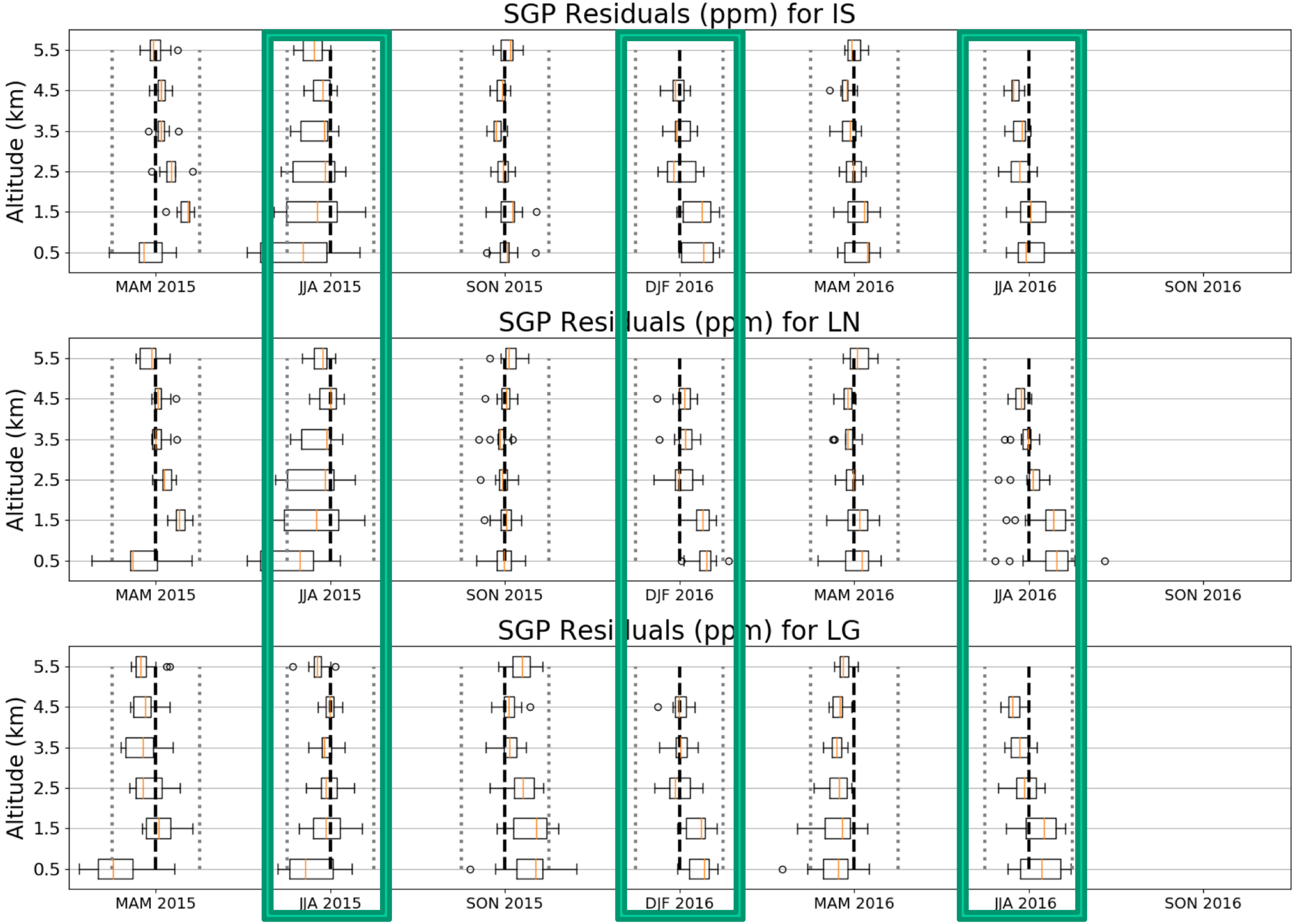
Small persistent high bias in OCO-2 data

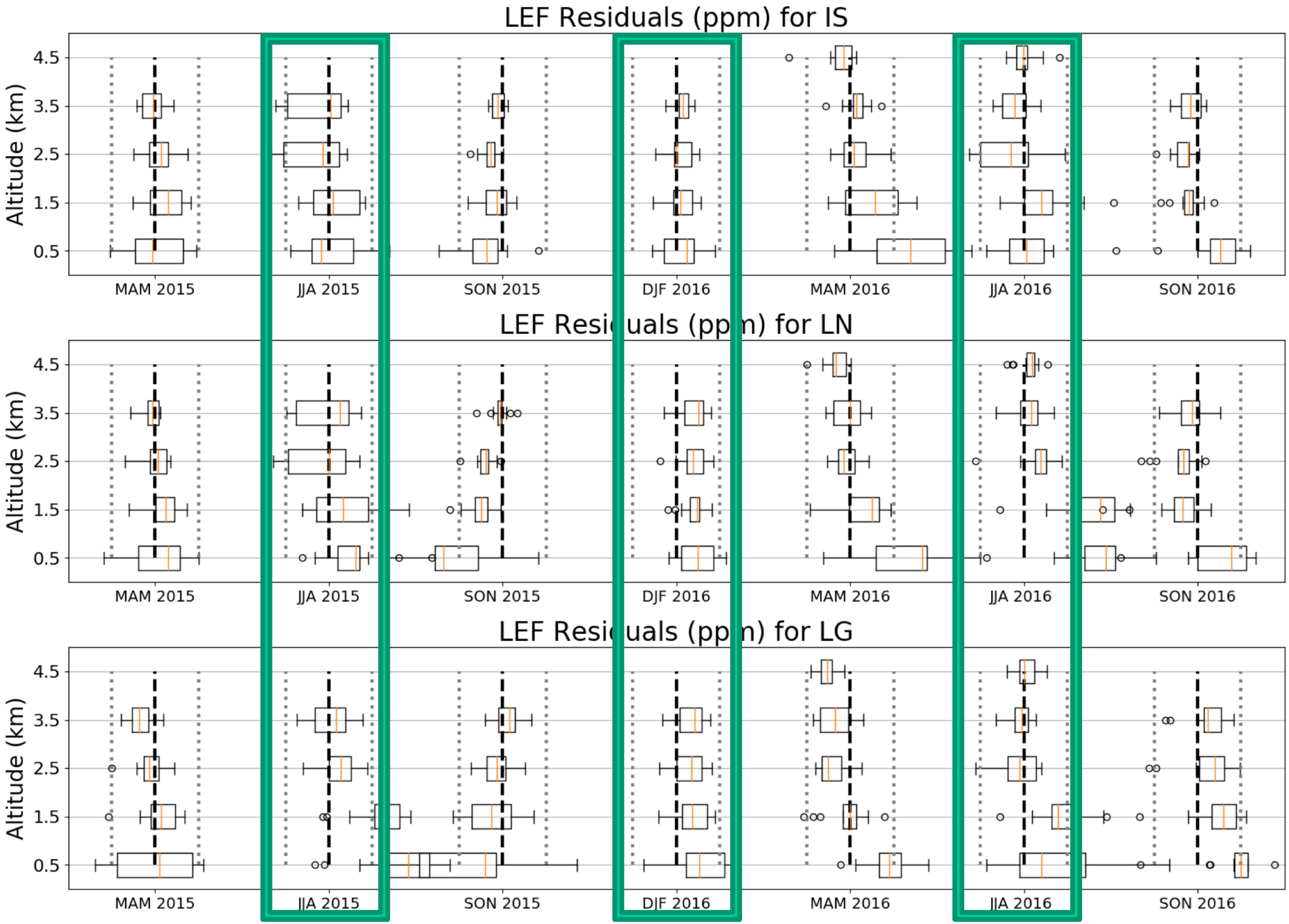

THD Residuals (ppm) for IS
THD Residuals (ppm) for LN
THD Residuals (ppm) for LG
Altitude (km)
8.5
7.5
6.5
5.5
4.5
3.5
2.5
1.5
0.5
MAM 2015
JJA 2015
SON 2015
DJF 2016
MAM 2016
JJA 2016
SON 2016

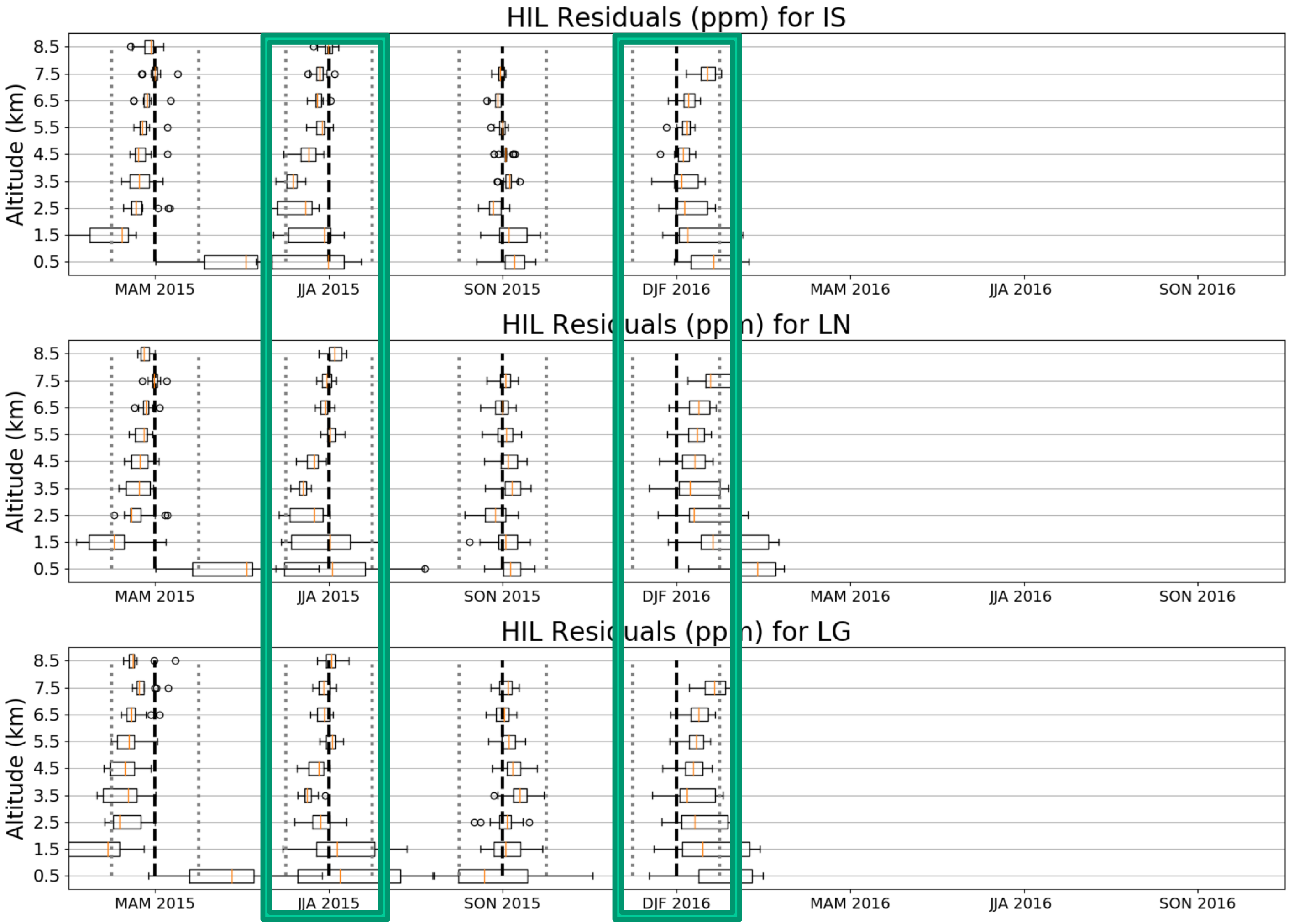

ESP Residuals (ppm) for IS
ESP Residuals (ppm) for LN
ESP Residuals (ppm) for LG
Altitude (km)
5.5
4.5
3.5
2.5
1.5
0.5
MAM 2015
JJA 2015
SON 2015
DJF 2016
MAM 2016
JJA 2016
SON 2016

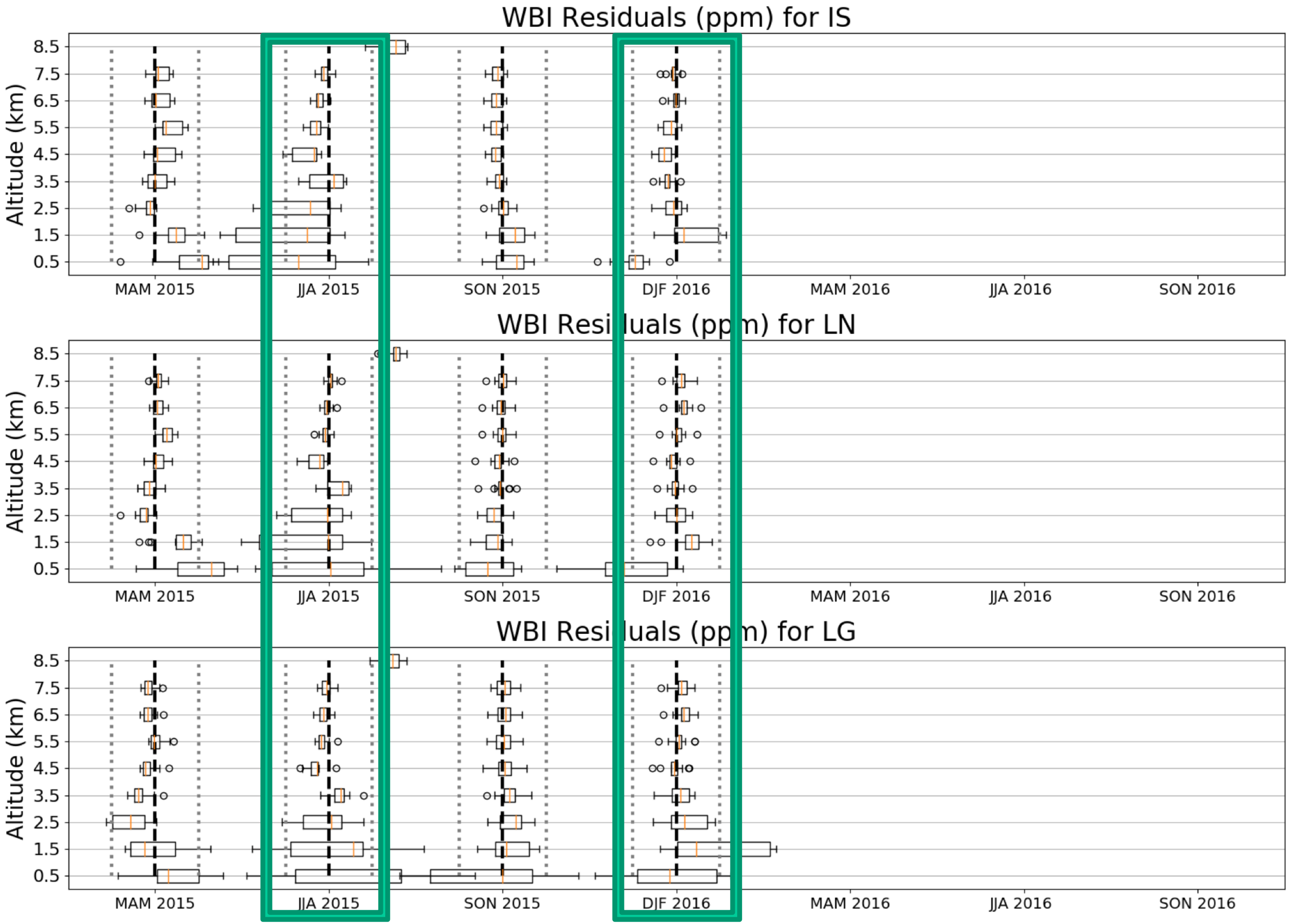
Mid-continent sites


DND Residuals (ppm) for IS
DND Residuals (ppm) for LN
DND Residuals (ppm) for LG
Altitude (km)
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

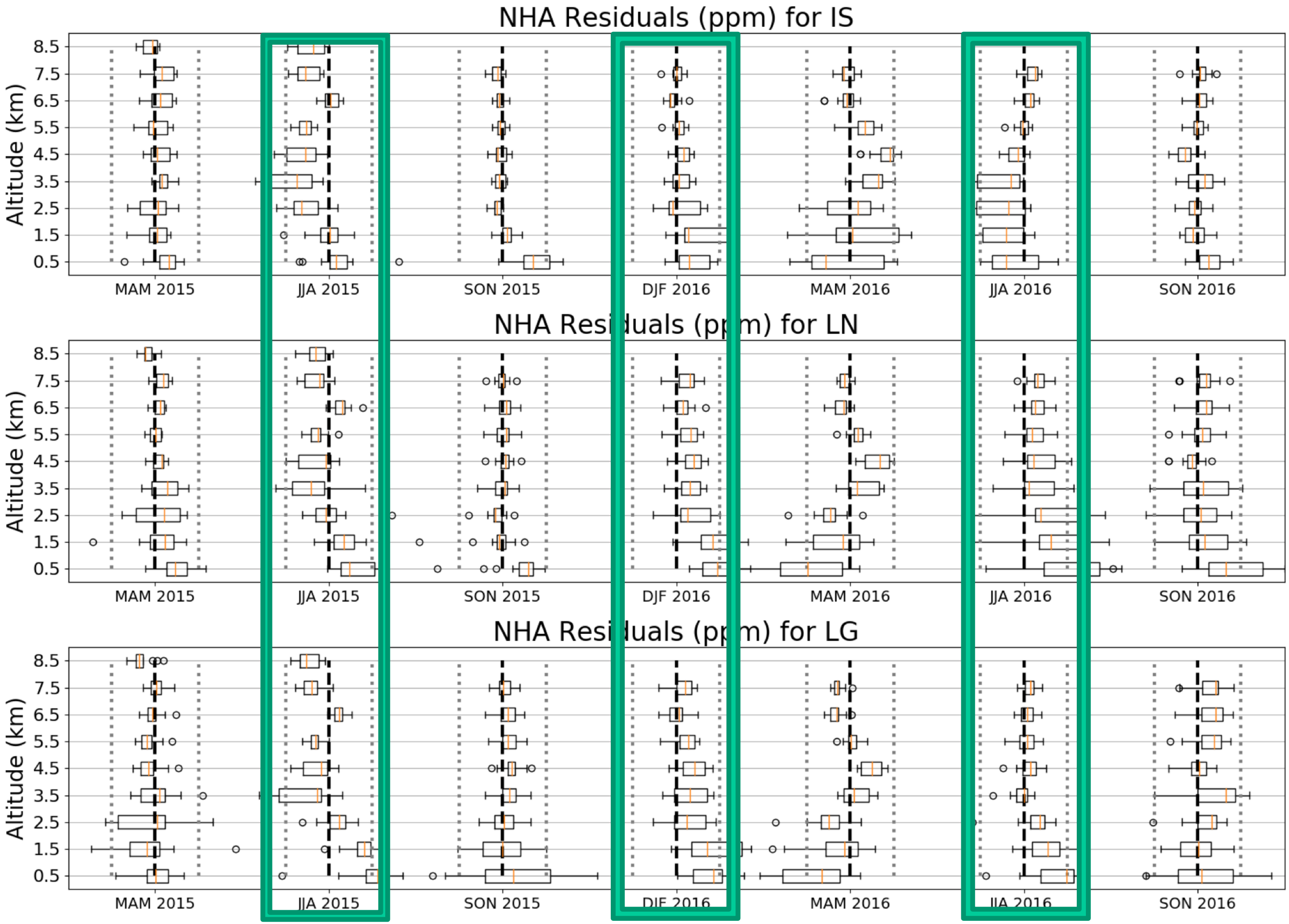

SGP Residuals (ppm) for IS
Altitude (km)
5.5
4.5
3.5
2.5
1.5
0.5
MAM 2015
JJA 2015
SON 2015
DJF 2016
MAM 2016
JJA 2016
SON 2016
SGP Residuals (ppm) for LN
SGP Residuals (ppm) for LG


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

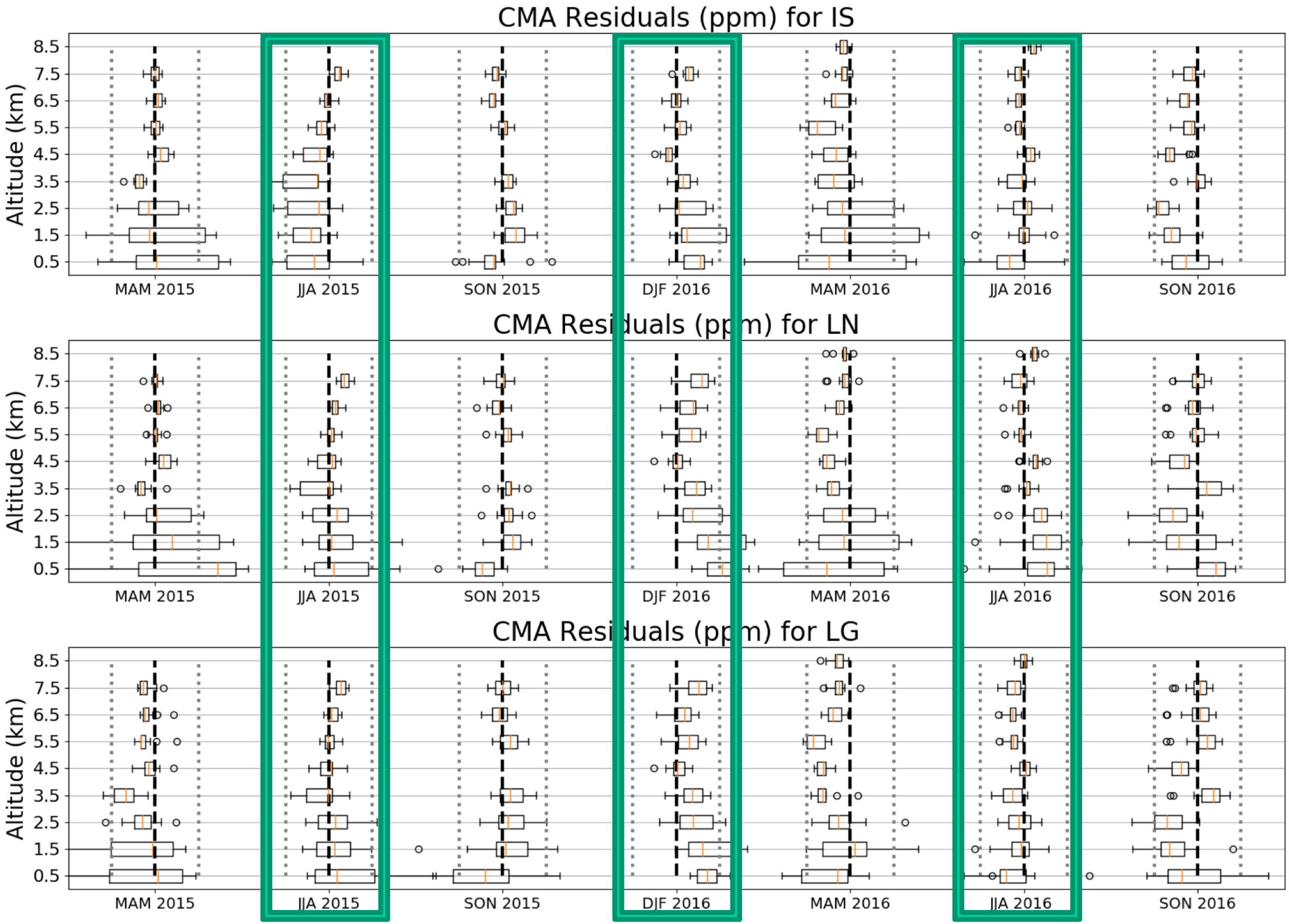

HIL Residuals (ppm) for IS
HIL Residuals (ppm) for LN
HIL Residuals (ppm) for LG
Altitude (km)
8.5
7.5
6.5
5.5
4.5
3.5
2.5
1.5
0.5
MAM 2015
JJA 2015
SON 2015
DJF 2016
MAM 2016
JJA 2016
SON 2016

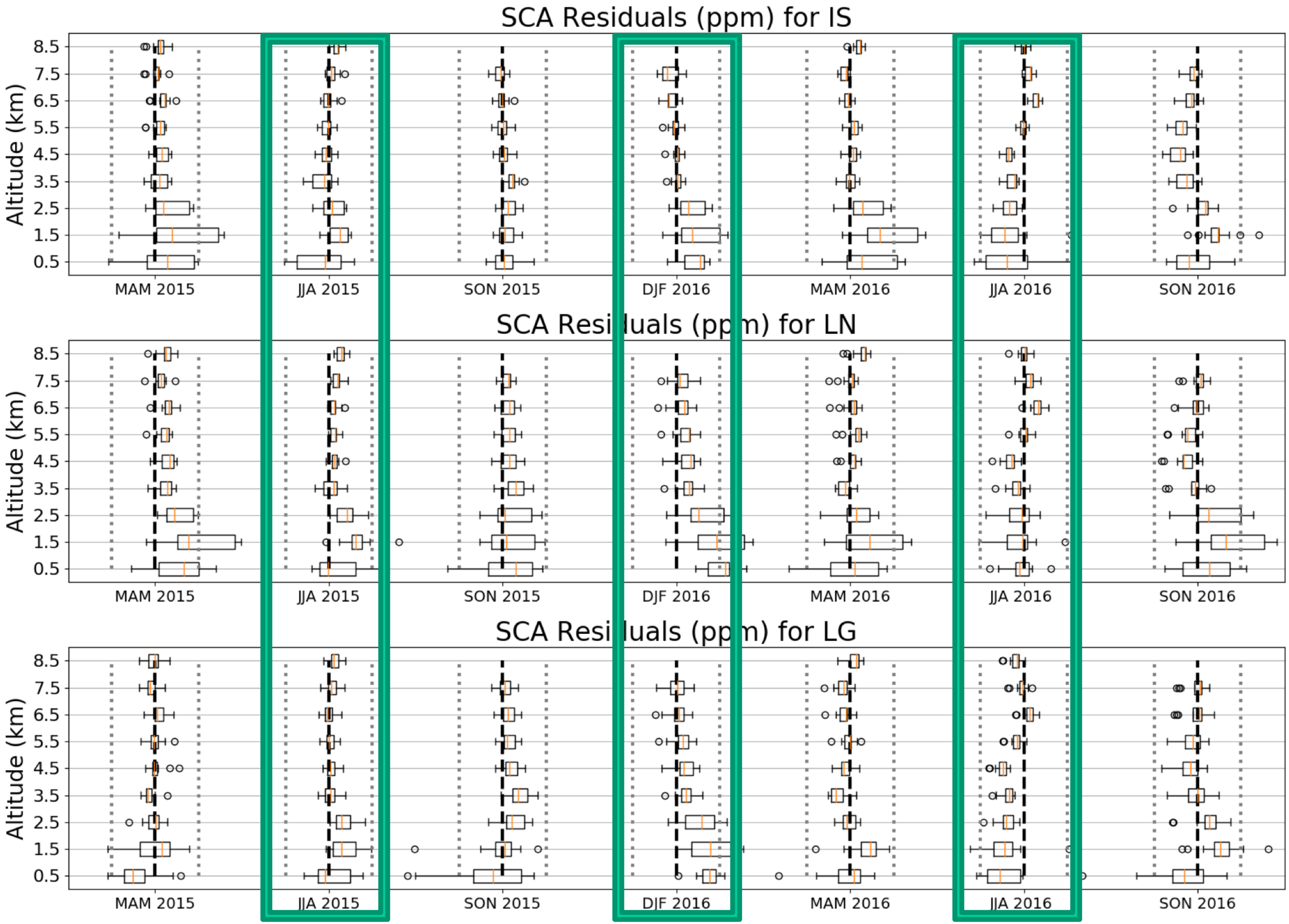

WBI Residuals (ppm) for IS
WBI Residuals (ppm) for LN
WBI Residuals (ppm) for LG
Altitude (km)
8.5
7.5
6.5
5.5
4.5
3.5
2.5
1.5
0.5
MAM 2015
JJA 2015
SON 2015
DJF 2016
MAM 2016
JJA 2016
SON 2016

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