Constraining carbon fluxes in northern regions by combining constraints from multiple atmospheric CO_2 observing systems

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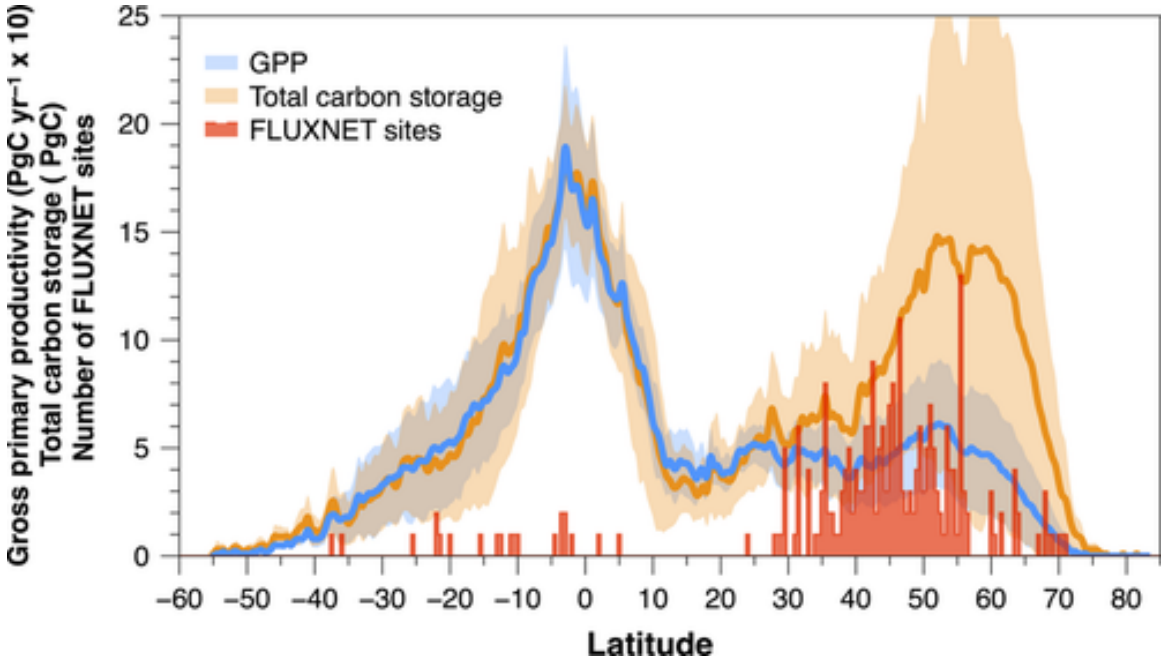
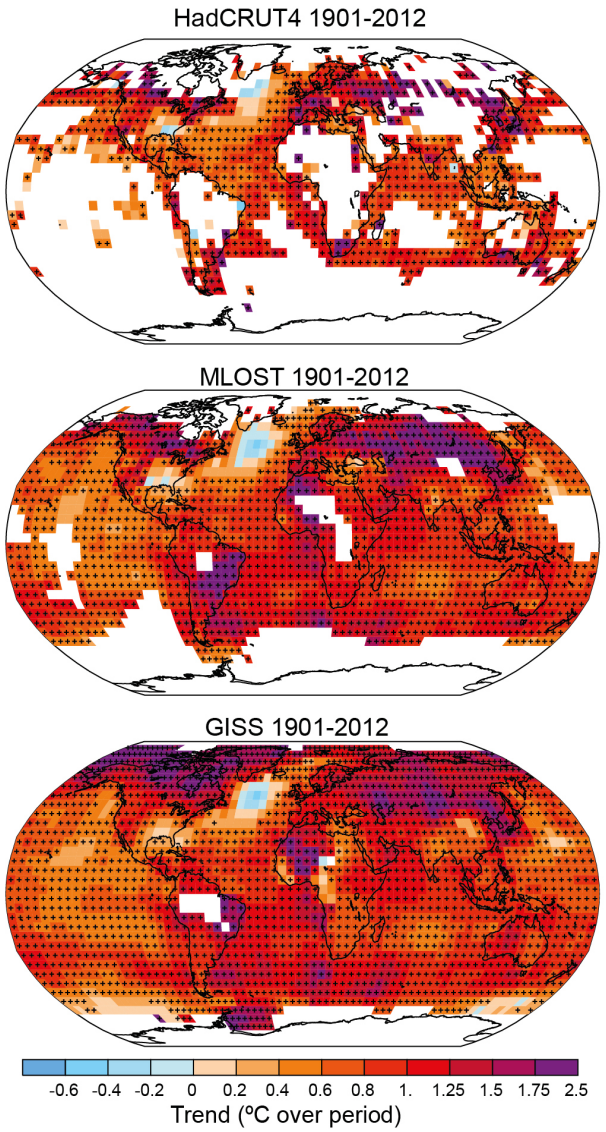
High latitudes are experiencing rapid climate change

- Northern latitude are experiencing the most rapid warming.
- These regions contain large stores of carbon, which may be sensitive to warming.
- Northern latitudes are poorly observed.



Schimel et al., GCP, 2015

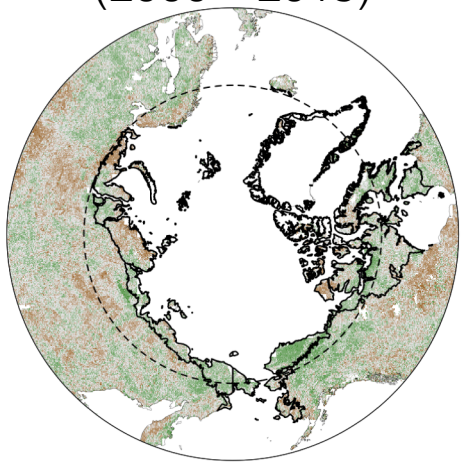


IPCC AR5 Fig 2.21

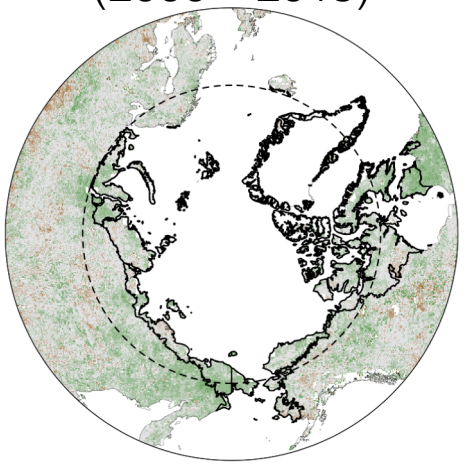
Changes in northern carbon cycle are already evident.

- Greening trends have been observed in NDVI, suggesting a more active terrestrial carbon cycle.
- The amplitude of the atmospheric CO_2 seasonal cycle has been increasing most rapidly at high latitudes.
- However, it is unclear how these changes will impact the carbon balance of northern ecosystems.

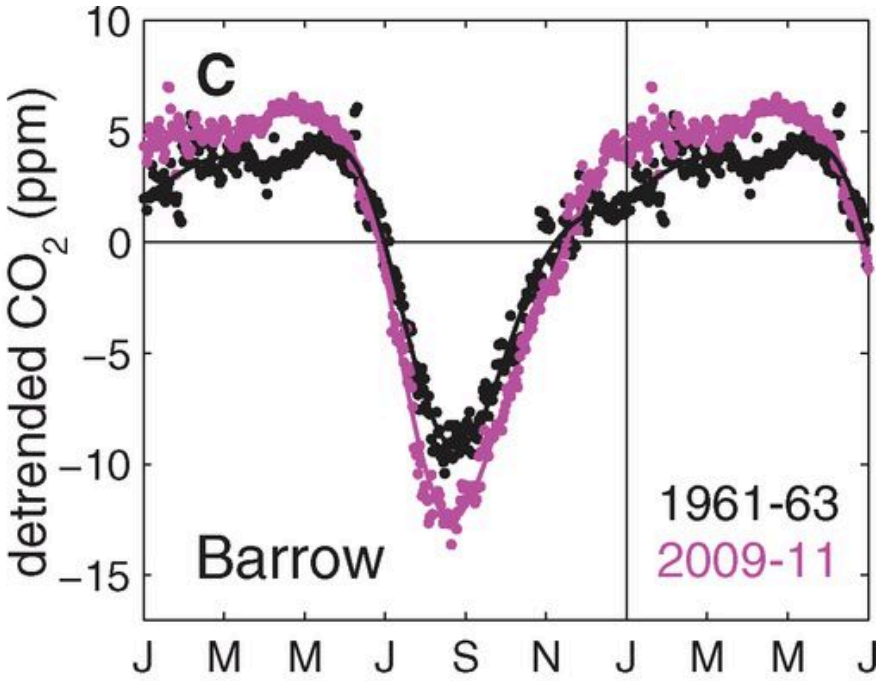
GIMMS trends
(2000 – 2015)



MODIS trends
(2000 – 2015)



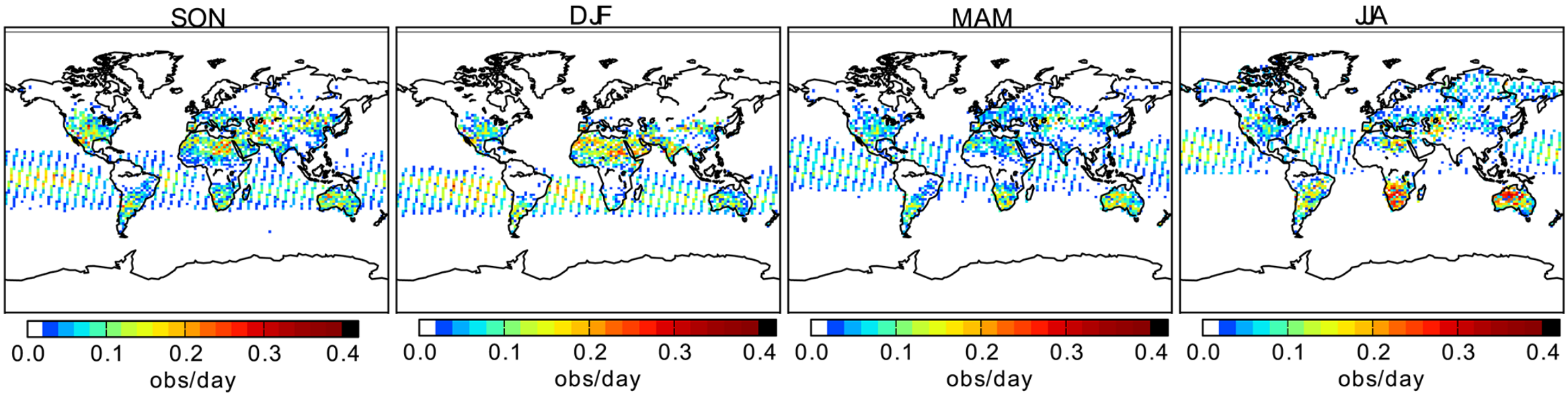
Myers-Smith, Kerby *et al.* EcoEvoRxiv 2019, https://ecoevorxiv.org/mzyjk/



Detrended seasonal cycle of boundary layer CO2 at Utqiagvik (Barrow), Alaska. *Graven et al., Science, 2013*

Seasonal coverage by space-based measurements

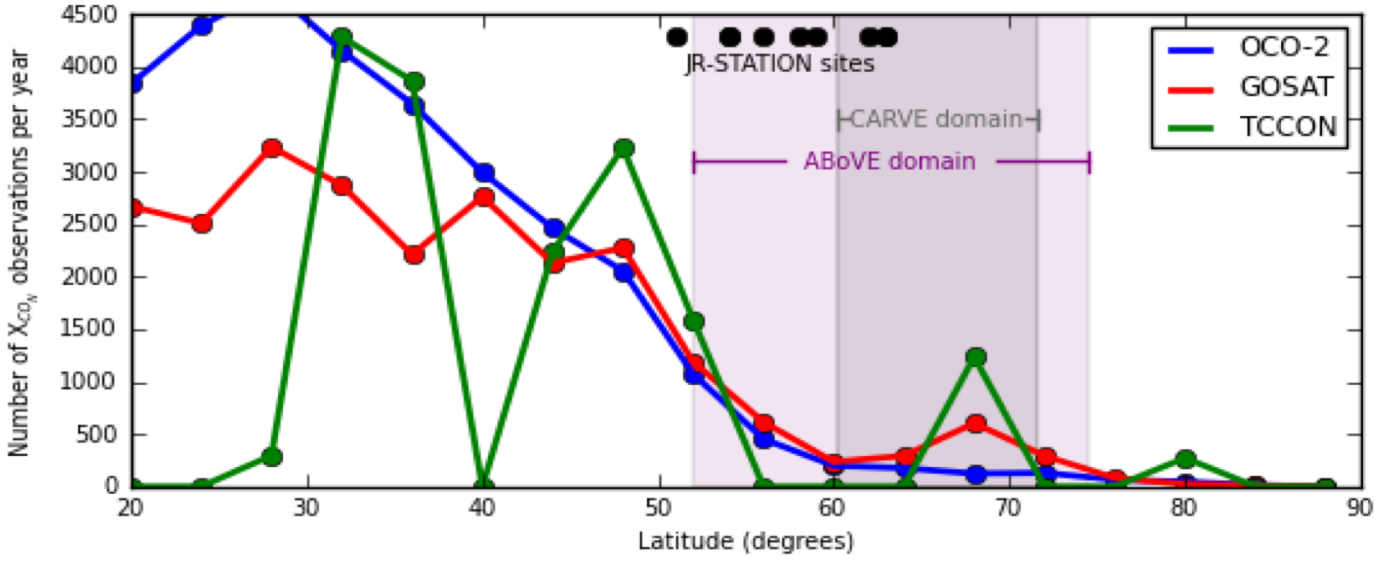
- Space-based measurements have greatly increased the number of atmospheric CO_2 measurements that can be used to estimate CO_2 fluxes.
- However, at high latitudes the observational coverage of the space-based XCO_2 measurements is highly seasonal, with good spatial coverage in the summer but sparse coverage in the winter.

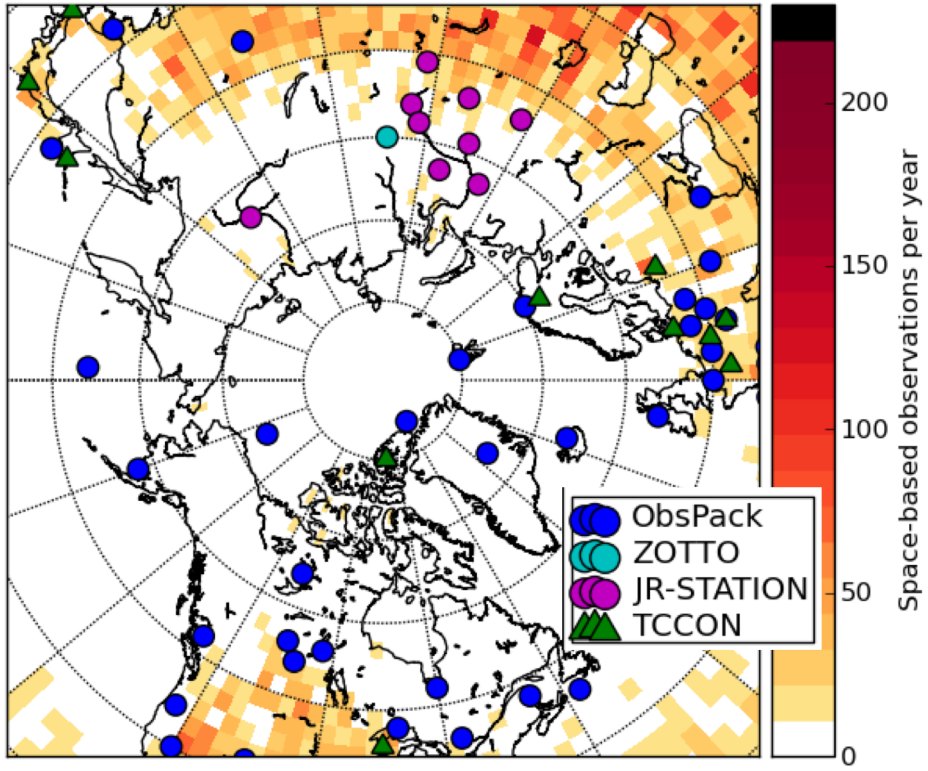


Number of measurements per day for GOSAT. Each subplot shows the number density of measurements for a given meteorological season. *Byrne et al., JGR-Atmos., 2017*

Ground-based measurements provide complimentary observational coverage

- Ground-based measurements have complimentary coverage.
- Ground-based measurements have good temporal coverage, but limited spatial coverage.
- There are a number of surface sites in the northern extra-tropics, such as:
  - NOAA ObsPack
  - JR-Station
  - TCCON





Research Question

Does assimilating both ground-based and space-based atmospheric CO_2 measurements within a flux inversion framework improve NEE estimates?

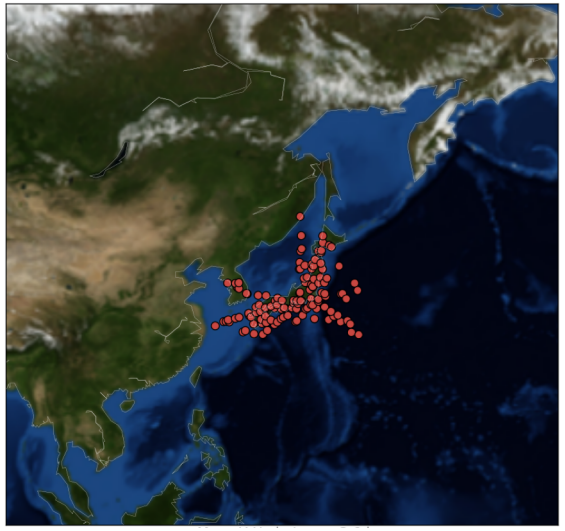
Methods

- Perform a series of six-year flux inversions (2010-2015) optimizing 14-day NEE and ocean fluxes (Using 4-DVar with CMS-Flux, 18-month windows).
- Prior fluxes and assimilated datasets are varied between flux inversion:

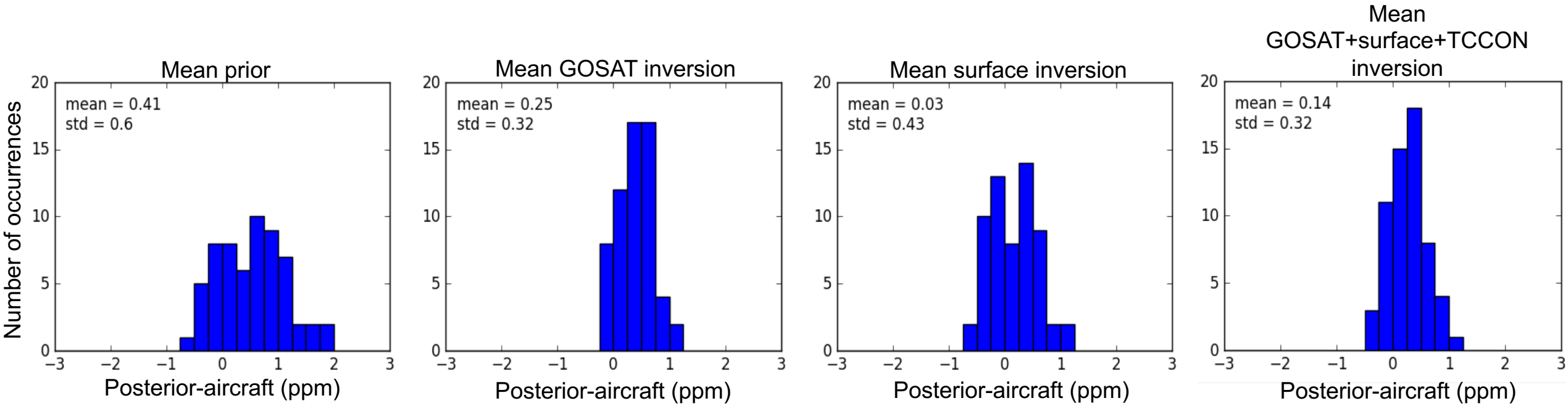
	Assimilated Observations		
Prior Fluxes	Surface Sites	GOSAT	GOSAT+Surface+TCCON
SiB3	✓	✓	✓
CASA	✓	✓	✓
FLUXCOM	✓	✓	✓

Evaluation of posterior CO_2 against aircraft data

- Examine monthly-mean mismatch between posterior CO_2 fields and aircraft data over Japan (between 3-8km altitude).
- All inversions improve agreement relative to prior.
- GOSAT+surface+TCCON inversion shows similar data-model mismatch to other inversions.

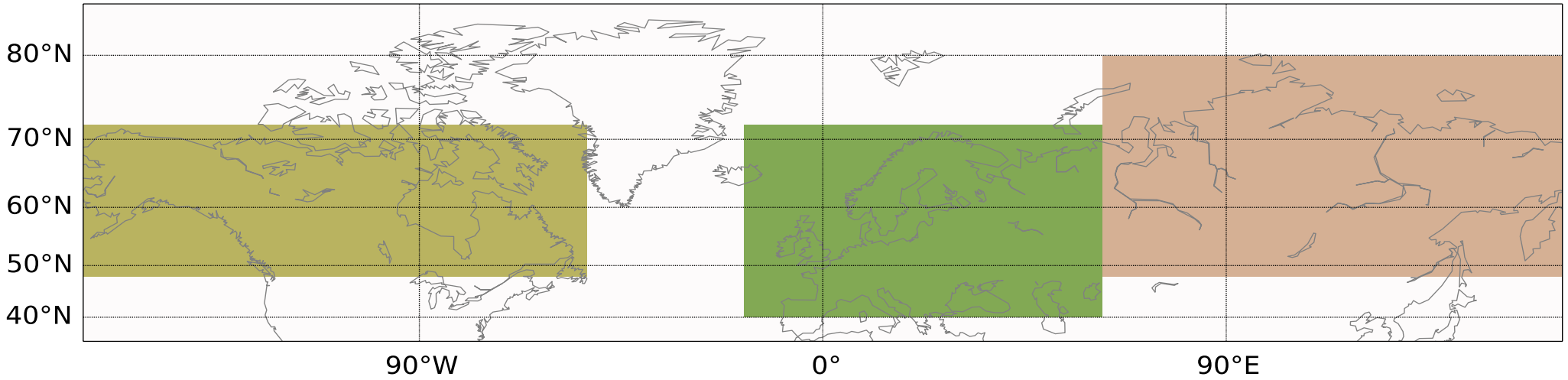


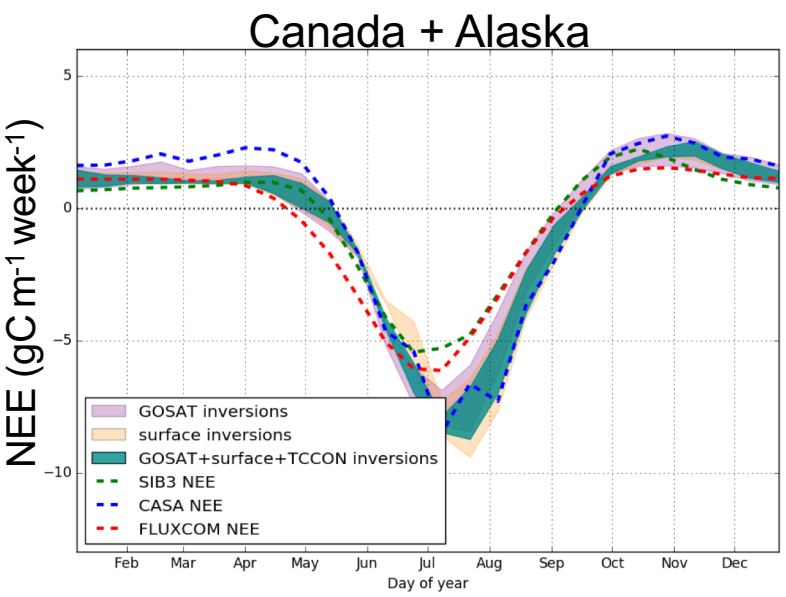
Location of CONTRAIL acircarft CO_2 measurements over Japan

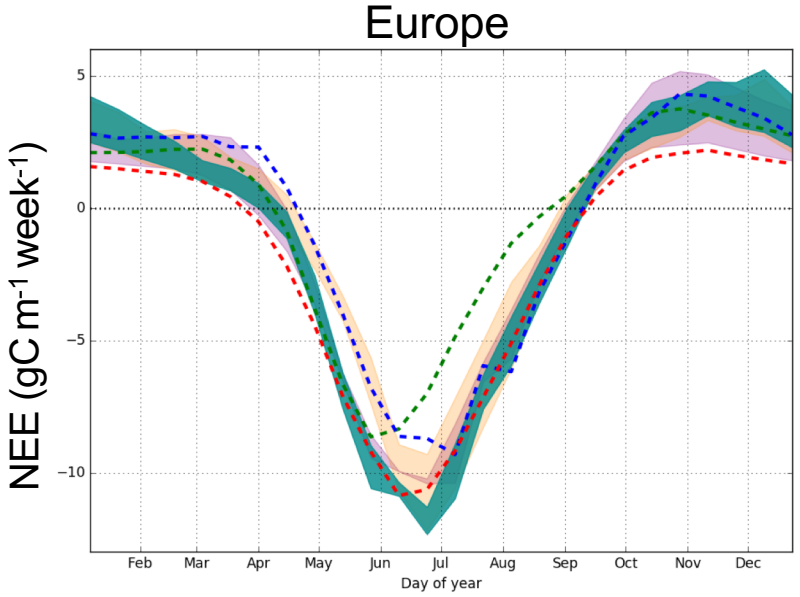


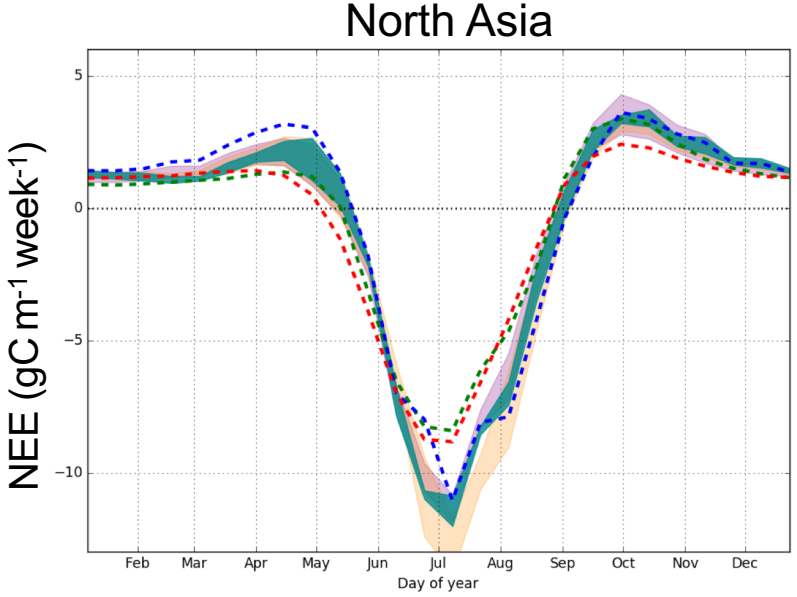
Mean posterior seasonal cycle over three northern regions

- Examine the range of NEE posterior fluxes obtained from using different prior fluxes.
- Spread in flux inversions gives measure of precision.







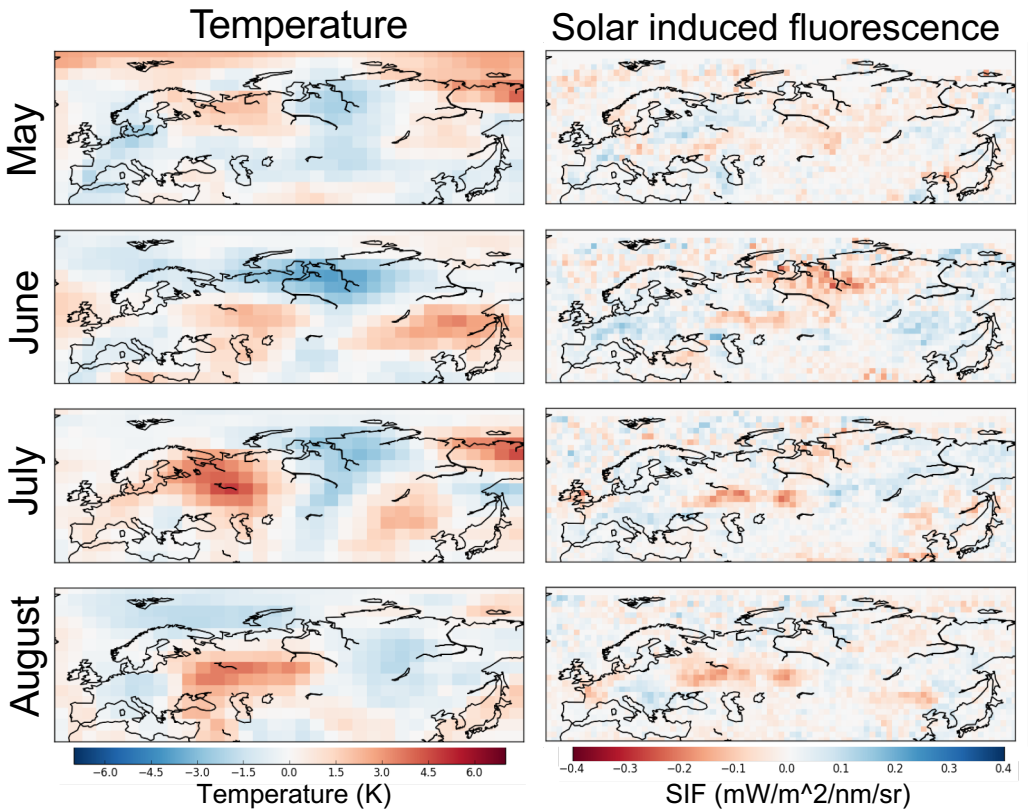


Interannual Variability – West Asia, 2010

- 2010 Heatwave/drought/forest fires in Eastern Europe/Western Asia.

Tourists in Moscow. *www.wunderground.com*

Monthly anomalies

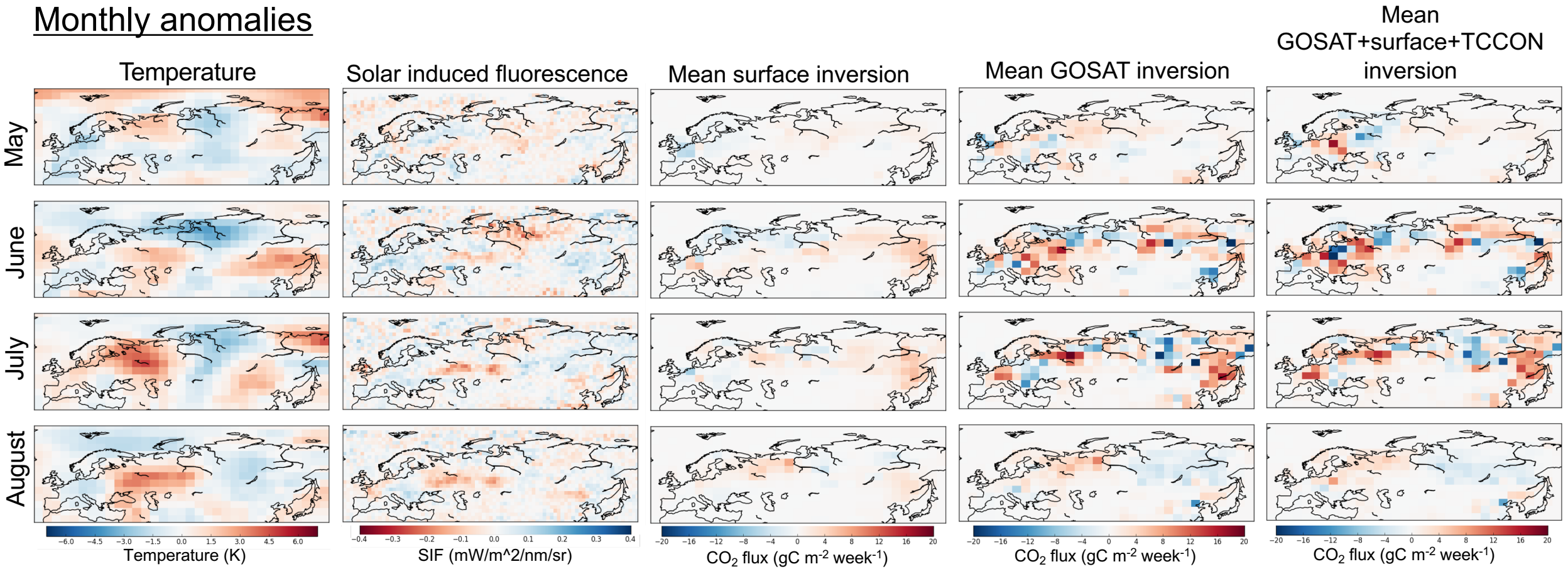


Interannual Variability – West Asia, 2010

- 2010 Heatwave/drought/forest fires in Eastern Europe/Western Asia.
- CO2 flux anomaly = NEE anomaly + Biomass Burning anomaly.
- GOSAT inversion and GOSAT+surface+TCCON inversions capture more spatial structure.

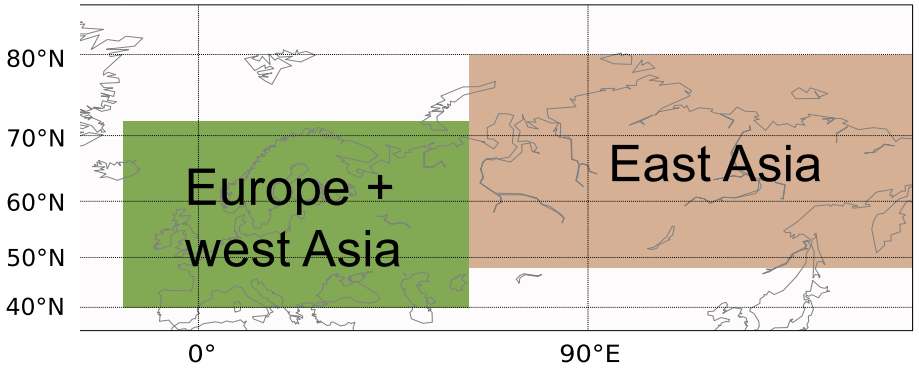
Tourists in Moscow. *www.wunderground.com*

Monthly anomalies

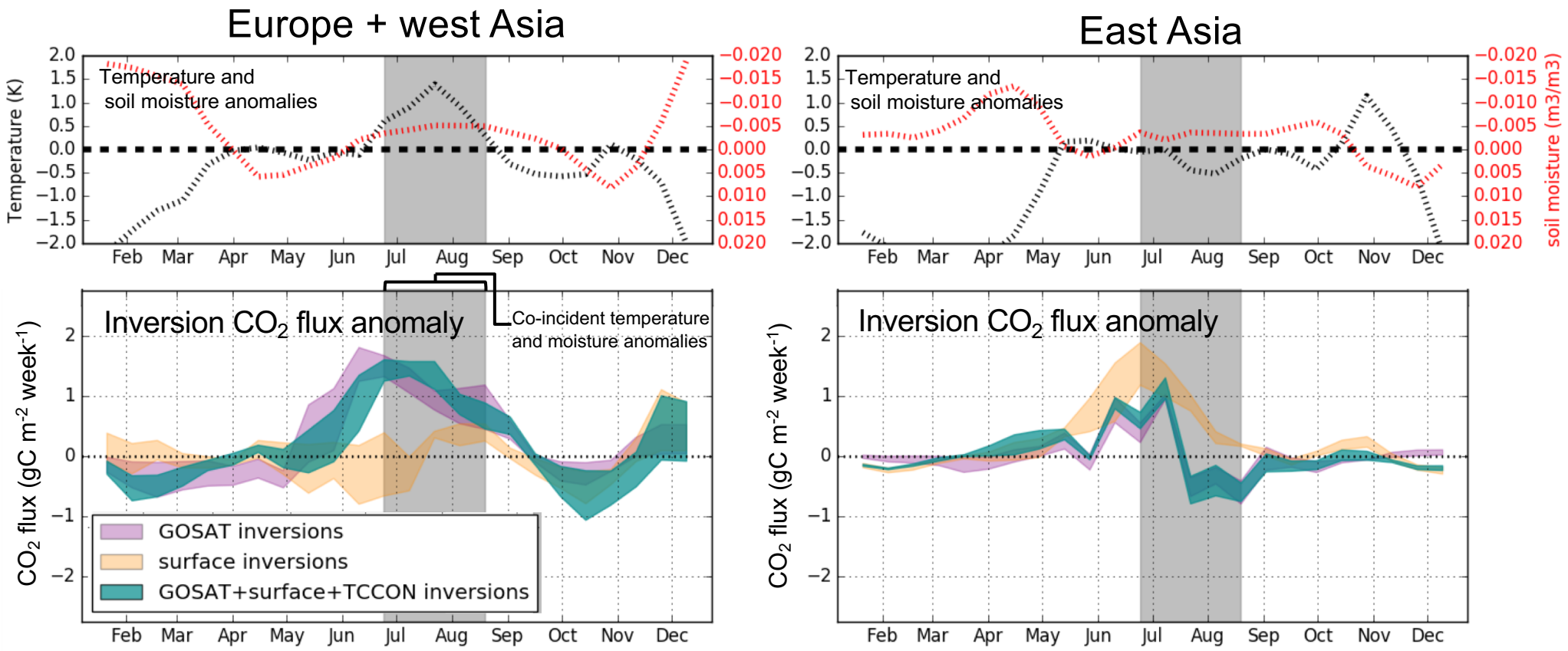


Interannual Variability – West Asia, 2010

- Surface inversion suggests attributes most of the summer anomaly to East Asia. Likely due to low data density.
- GOSAT+surface+TCCON inversion suggests the largest fluxes to the atmosphere for Europe + west Asia during July.



Timeseries of anomalies

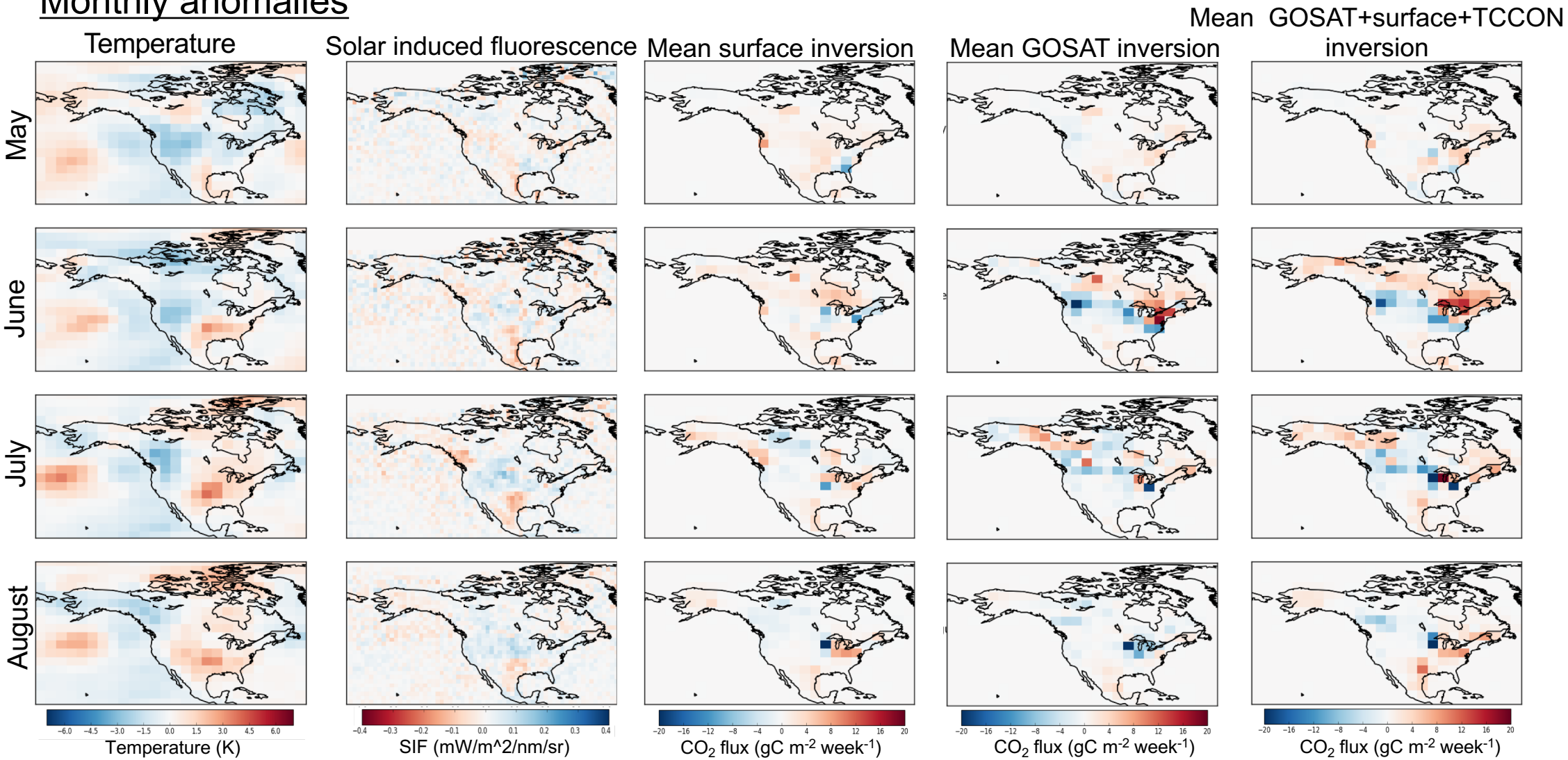


Interannual Variability – Texas, 2011

- 2011 Texas/Mexico drought. Driest year on record for Texas, USA.
- Productive year in northern USA.

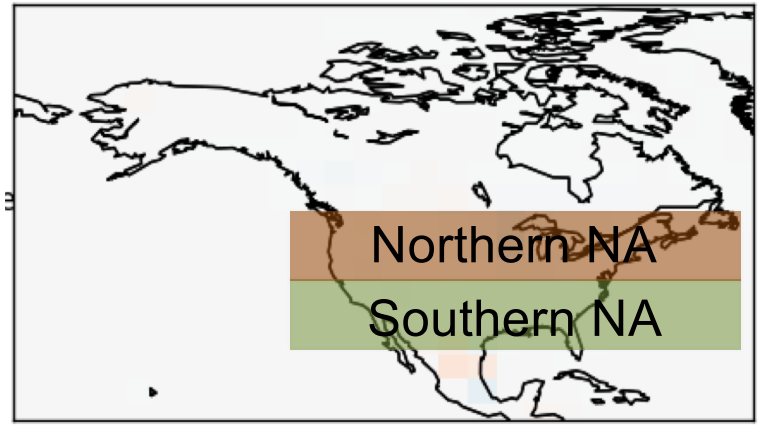
Cow in Texas. *http://archive.boston.com*

Monthly anomalies



Interannual Variability – Texas, 2011

- GOSAT+surface+TCCON inversion suggests large anomalous flux to the atmosphere in southern NA during July-August, co-incident with a positive temperature anomaly.



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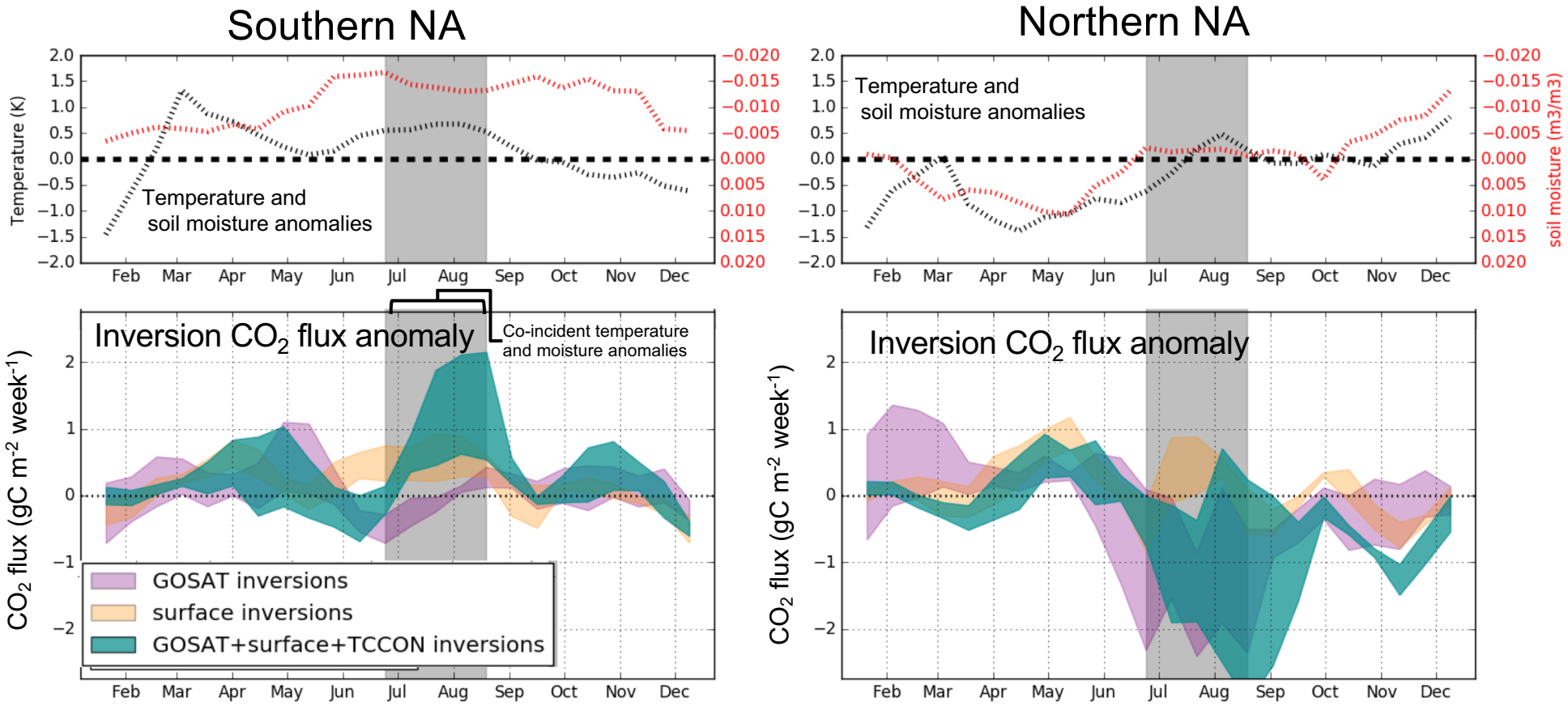

Conclusions

- Performed six-year (2010-2016) flux inversions using a range of prior flux estimates and assimilated measurements.
- GOSAT+surface+TCCON flux inversions have unprecedented observational coverage north of 50 deg N.
- Flux inversions assimilating GOSAT, surface, and TCCON measurements:
  - Compare well with aircraft measurements.
  - Provide precise constraints on the seasonal cycle of NEE over continental scales.
  - Capture IAV (at least as well as GOSAT/surface only inversions).