NASA's Carbon Cycle OSSE Initiative - Informing future space-based observing strategies

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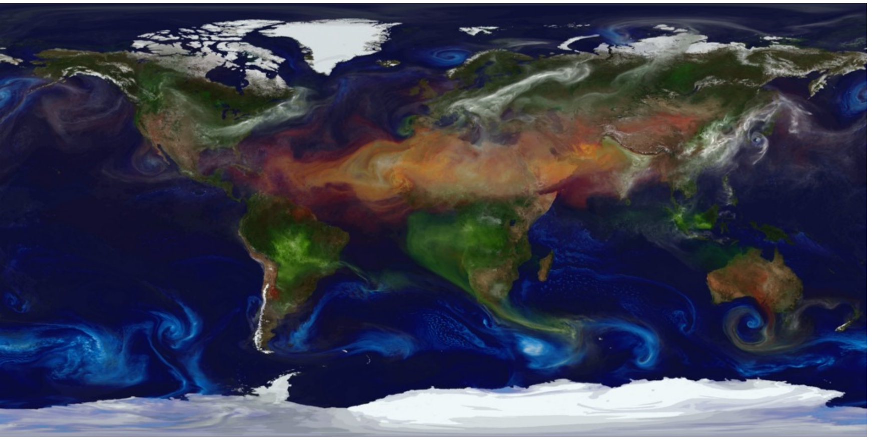
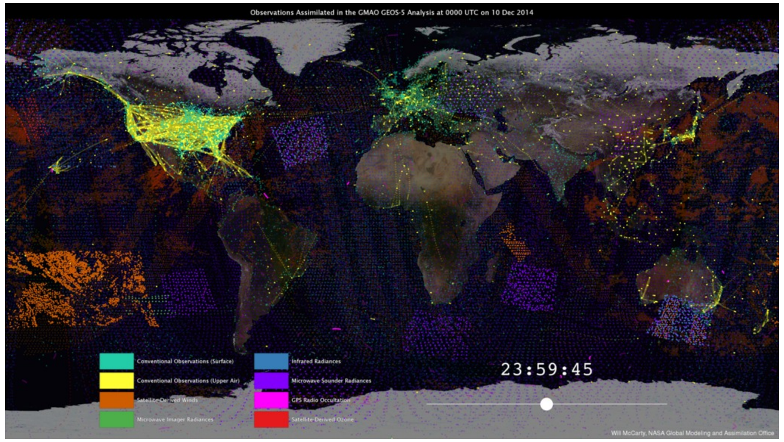
Observing System Simulation Experiments

Traditional Met OSSE – Create hi-res nature run (truth) -> simulate observations (radiance, conventional) for all current observing systems -> simulate proposed new observations -> assimilate all 'obs' into coarser resolution model -> evaluate impact of new observations on forecast skill

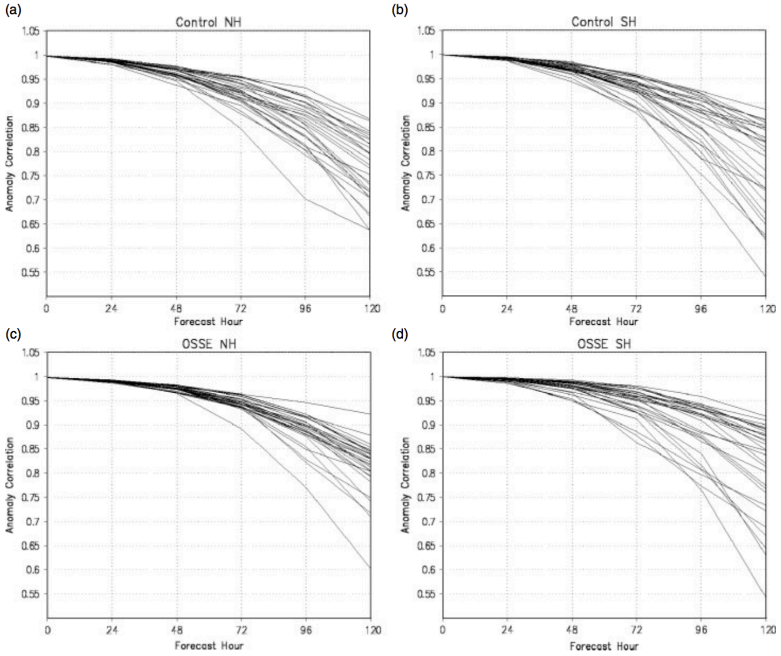
Nature Run ('truth')



Synthetic Datasets



Evaluation of assimilation experiments against 'truth'



Observing System Simulation Experiments

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Retrieval OSSE – Calculate radiance from nature run met, CO_2, aerosol fields -> use retrieval algorithm to estimate XCO_2 -> compare with 'true' XCO_2 from nature run

Sampling OSSE – Sample nature run using different orbit, remote sensing technique, scanning strategy, etc. -> evaluate yield of observations in key regions, ability to constrain key processes

Flux inversion OSSE – Create hi-res GHG nature run -> simulate GHG observations -> assimilate synthetic GHG observations into coarser res model (ideally driven with different meteorology) -> compare estimated fluxes with 'true' fluxes assumed in nature run

Previous GHG OSSE efforts (or, do we really have to keep doing these things???)

- OSSEs play an important role in assessing the value of new candidate observing systems

- Also needed to test and improve inverse modeling systems

- However, most OSSE efforts are focused on justifying a single mission and contain significant weakness

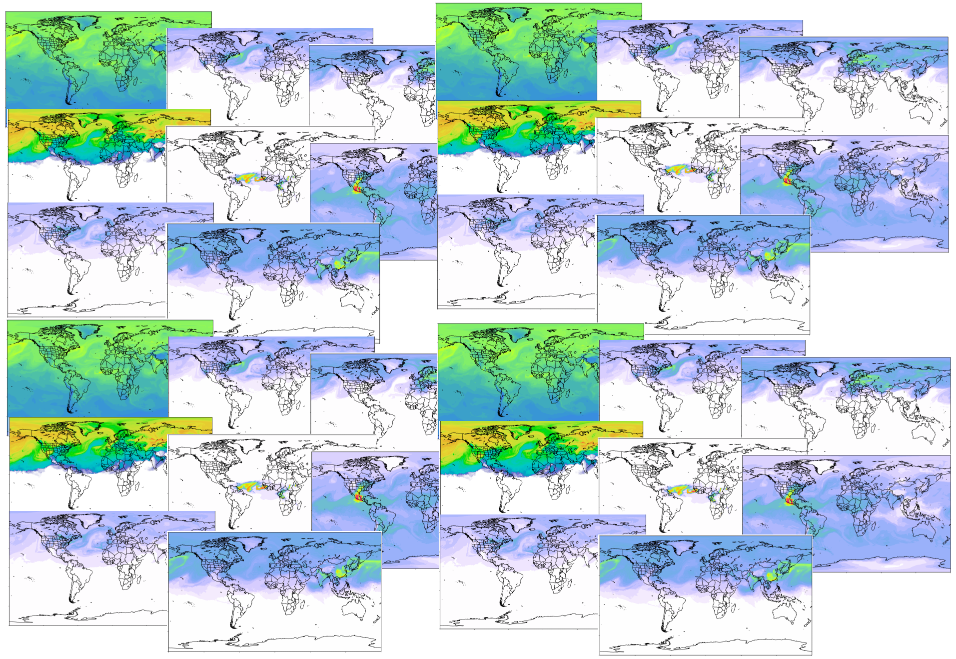
    - Inconsistent assumptions about the role of random, systematic errors
    - Lack of information about diurnal cloud variability
    - Lack of context about value added in context of existing, planned missions

NASA's Carbon Cycle OSSE Initiative

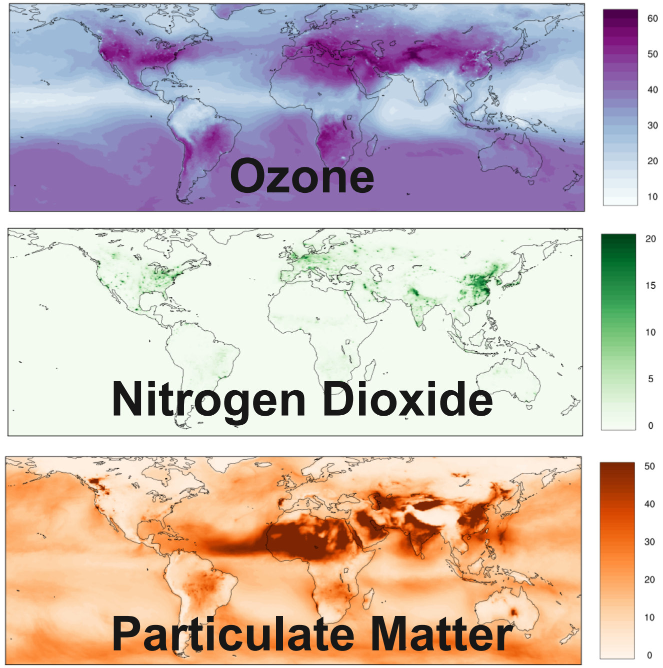
- Collaborative effort between (NASA GSFC, JPL, University of Oklahoma, Colorado State University
- Funding for 2 years of preliminary activities focused on generating data products to support consistency of Carbon Cycle OSSE efforts:
  - GEOS Carbon Nature Runs
    - 50-km, 7-year GEOS-5 Carbon Nature Run (including CO, CO_2, and CH_4) simulating ~50 tracers that represent realistic carbon cycle perturbations
    - 14-km 2-year simulation representing limited number of tracers (ongoing)
  - Multi-sensor cloud probability dataset
  - Pseudo-datasets for generic passive and active LEO and passive GEO missions created by sampling the Nature Run using instrument simulator models
  - Baseline single instrument inversions (ongoing)
  - All data free and publicly available

Scaling complexity of GEOS simulations, resolution

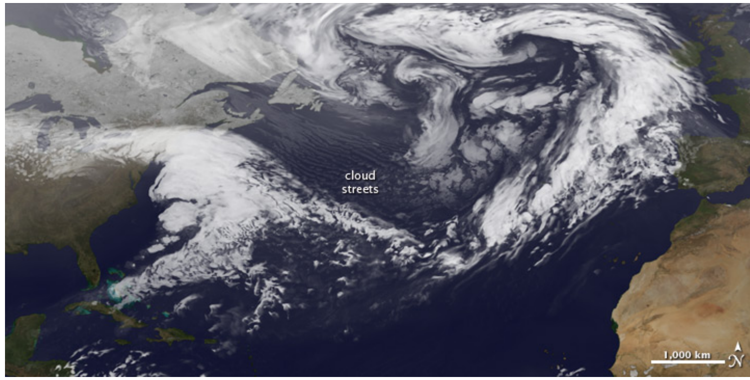
50 km – Supports large number of flux scenarios, use with existing reanalyses



14 km - Ability to model GHGs, aerosols, ozone photochemistry at urban relevant scales



3 km - Global cloud-resolving resolutions in support of retrievals OSSEs



Increasing resolution

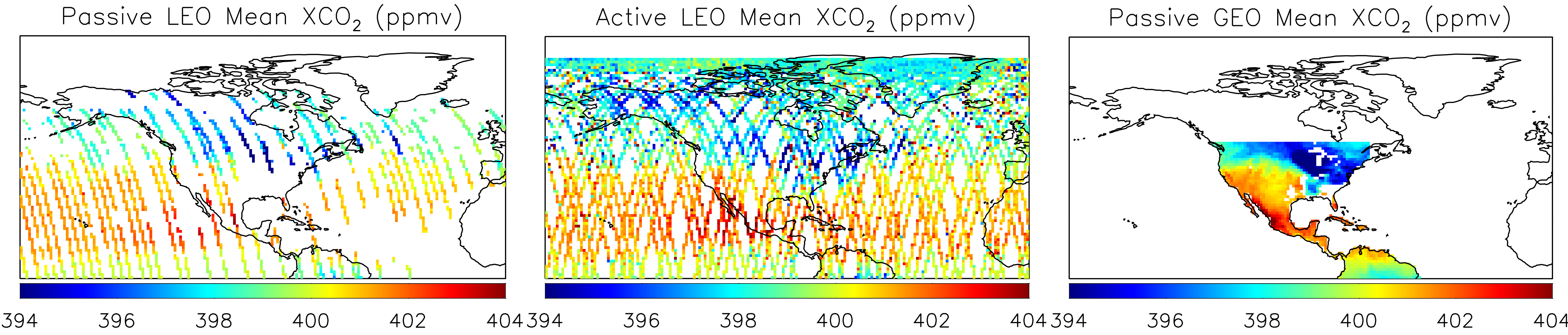
Decreasing GHG complexity

Carbon OSSE Flux Change Scenarios

- Growing uncertainty in fossil fuel emissions, megacities
  - 25 tracers designed to cover a range of latitudes, cities with both growing and static emissions, city pairs in close proximity, and cities in challenging observing environments (e.g. coastal, near agricultural region)
- Response of Arctic/Boreal Zone to warming
  - Moderate and high emission scenarios based on CLM simulations of CO_2, CH_4 (Koven et al., 2015)
- Mid-latitude carbon uptake / Tropical carbon uptake changes
  - Includes separate GPP and respiration tracers for 7 continental scale regions based on TRANSCOM region definitions (Gurney et al., 2003)
- Southern Ocean flux change
  - Uses two time-varying ocean flux estimates to assess ability to observe interannual sink variations
- Methane emission changes (anthropogenic and natural)
  - Tagged emissions from 7 wetland regions (Bloom et al., 2017), US fracking emissions (Maasakkers et al., 2016), and biomass burning

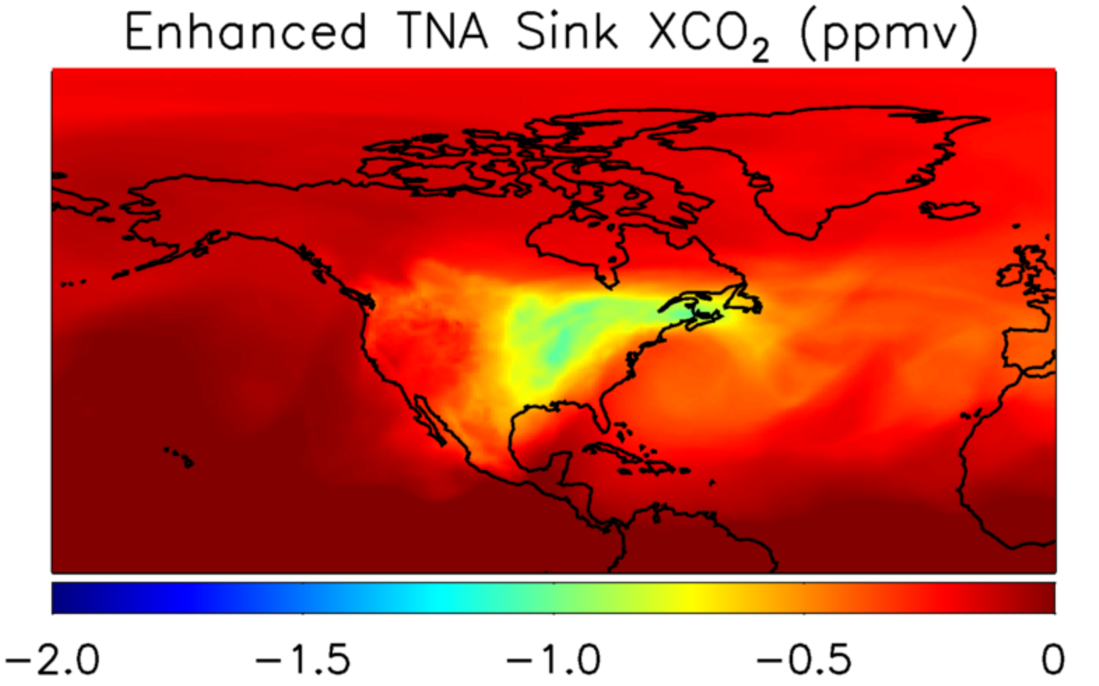
Nature Run Sampling

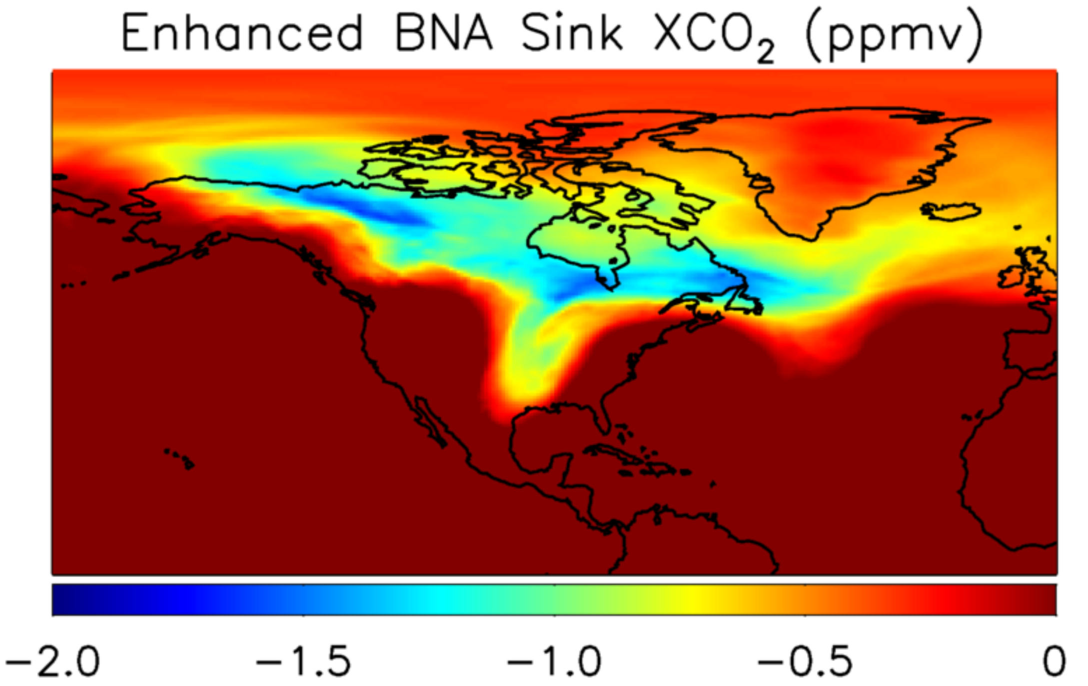
- Pseudo-datasets created by sampling Carbon Nature Run fields at measurement locations, applying estimated averaging kernel
- Assumes only random errors, work on implementing biases due to aerosols, airmass, and surface reflectance
- Uses MERRA-2 cloud and aerosol statistics



Average of 7 days of simulated psuedo-data

Comparison of 1 Pg C Sink for Temperate, Boreal North America





- Imposing a smaller, more realistic 1 Pg C sink results in a smaller concentration signature ranging form 1-2 ppm
- The BNA perturbation has a larger impact on concentrations because it is applied over a smaller spatial area than TNA
- One week averages show the that large flux differences can maintain coherence outside of the perturbation region

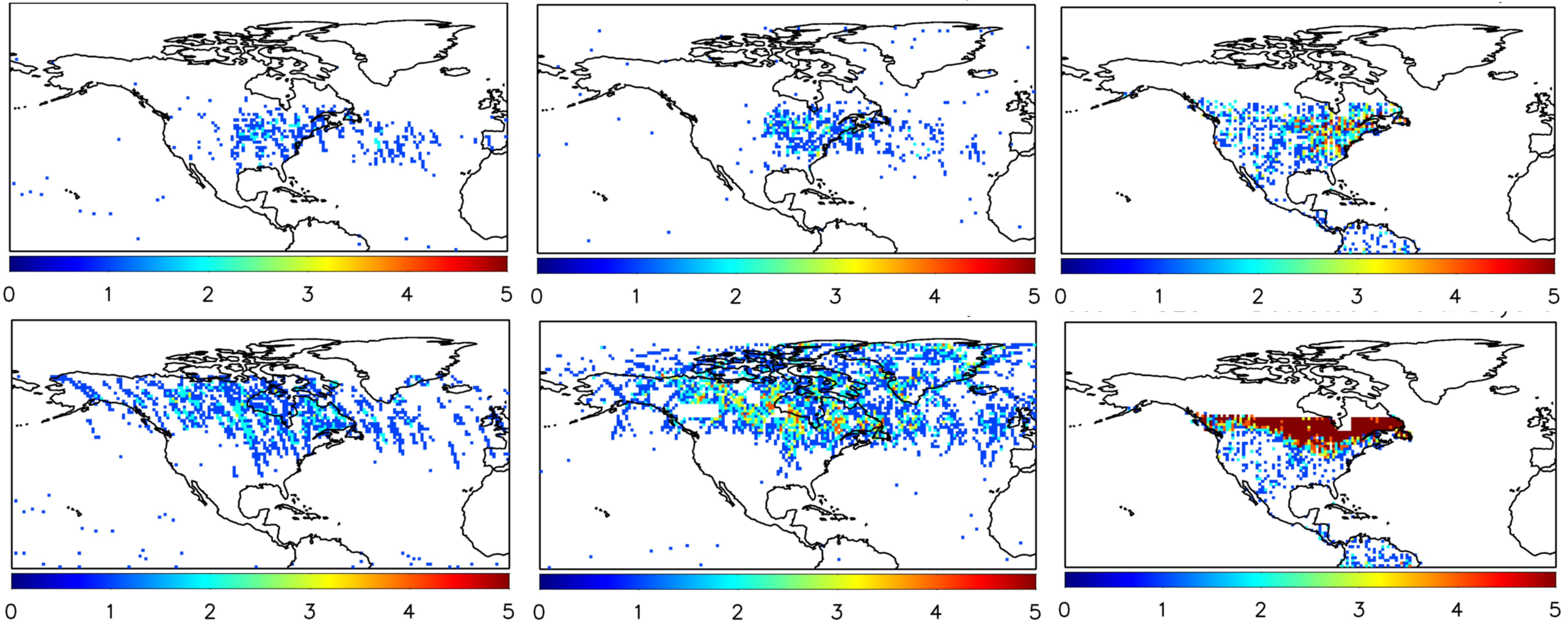
Comparison of 1 Pg C Sink for Temperate, Boreal North America

days during 201307 where flux perturbation is detectable

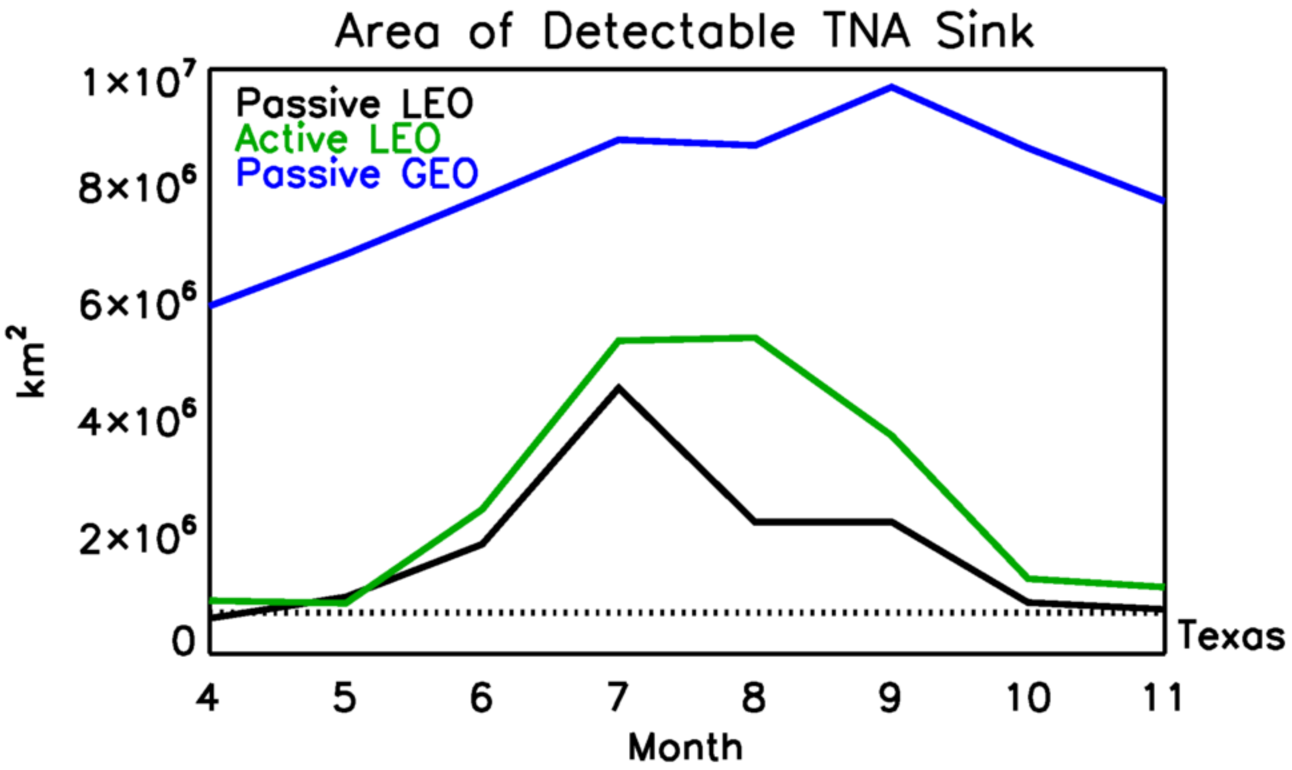
Passive LEO | Active LEO | Passive GEO

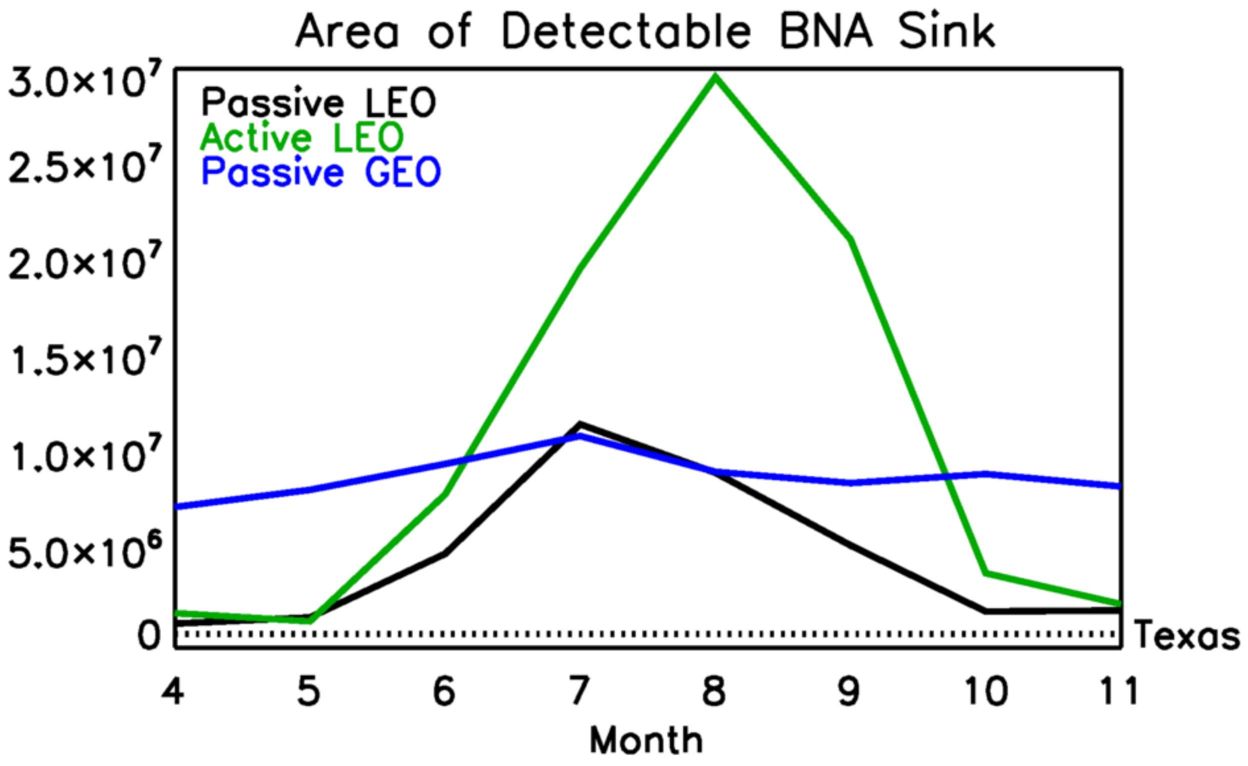
TNA Sink

BNA Sink



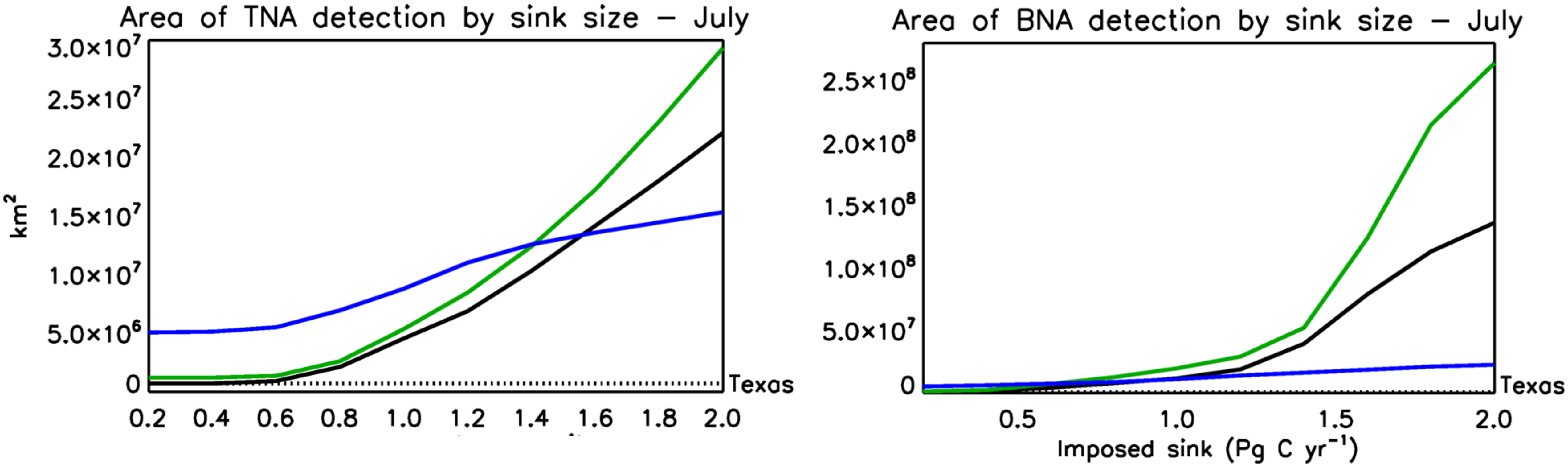
Seasonal variations in detectable area





- **Detectable area provides a simple metric for assessing the ability of different systems to observe flux changes**
- **This example shows how the area over which a flux perturbation is detected varies by season and observing system**

Variations in detectable area due to sink strength in July



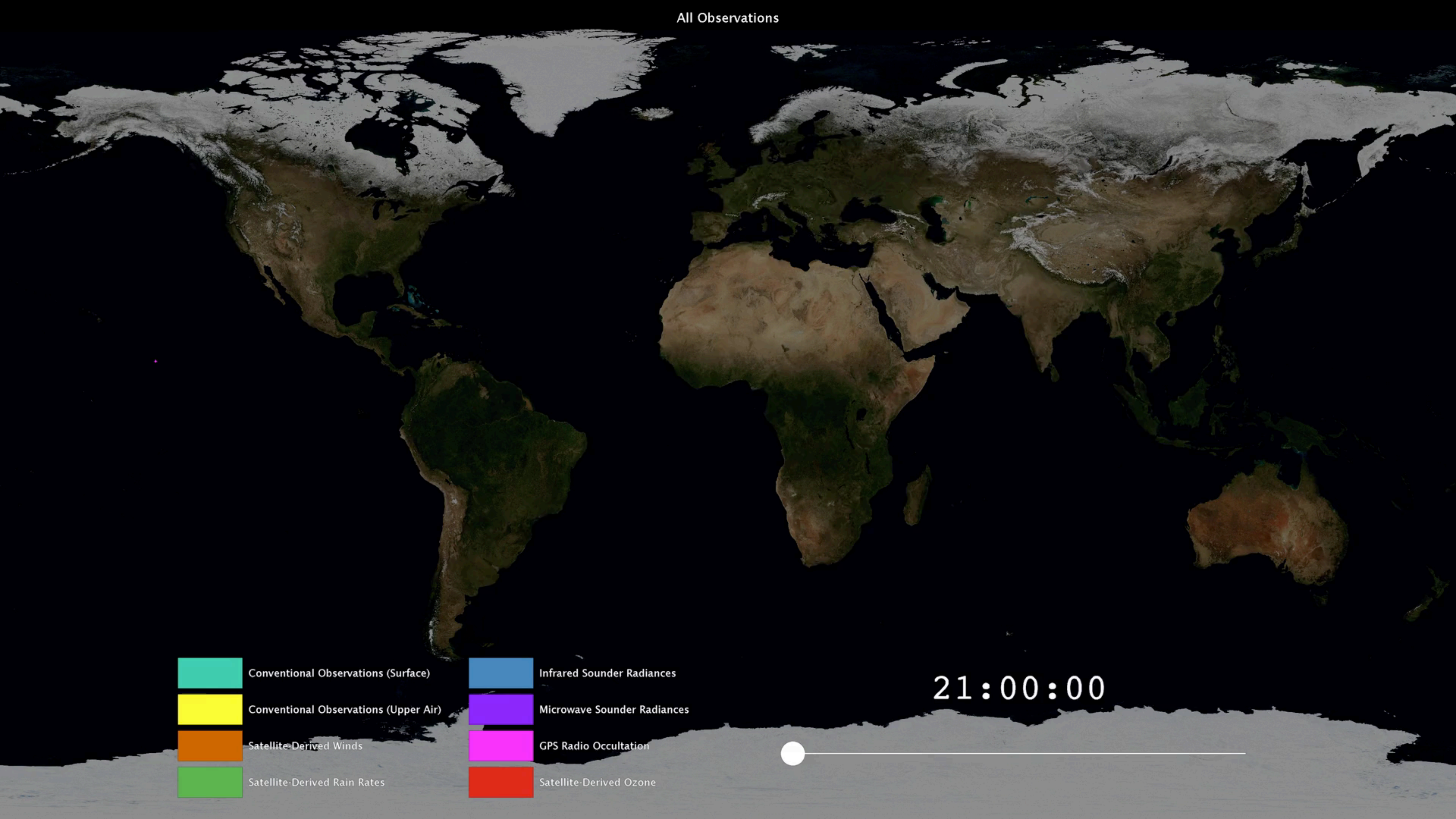
Detectable area can also be used to examine how well different systems observe flux perturbations of different magnitudes

Ongoing Work

- Working on documenting these datasets and releasing publicly
- Producing ensemble of single instrument inverse flux estimates for biosphere flux scenarios
- Moving from 50 to 14-km nature run to explore urban cases, aerosol influence

Future OSSE Needs

- Need framework for assessing the benefit of other trace gas measurements (CO, NO_2)
- Move toward retrieval OSSEs for GHGs to more realistically represent measurement errors
- Need a better way for representing transport error influence – could be addressed through coordinated nature run efforts
- Develop ability to assess how new satellites fit into the GHG constellation


All Observations
Conventional Observations (Surface)
Conventional Observations (Upper Air)
Satellite-Derived Winds
Satellite-Derived Rain Rates
Infrared Sounder Radiances
Microwave Sounder Radiances
GPS Radio Occultation
Satellite-Derived Ozone
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