The atmospheric composition geostationary satellite constellation for air quality and climate science: Evaluating performance with Observation System Simulation Experiments (OSSEs)

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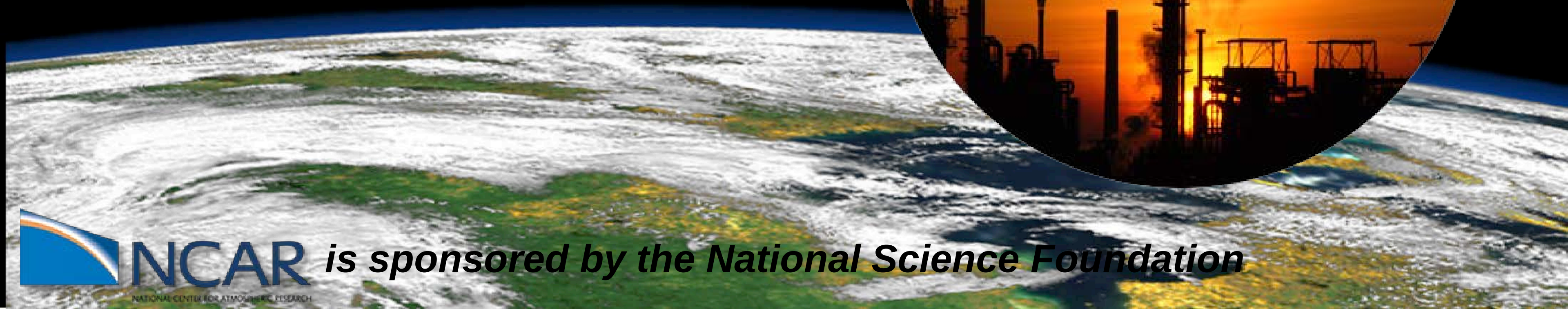

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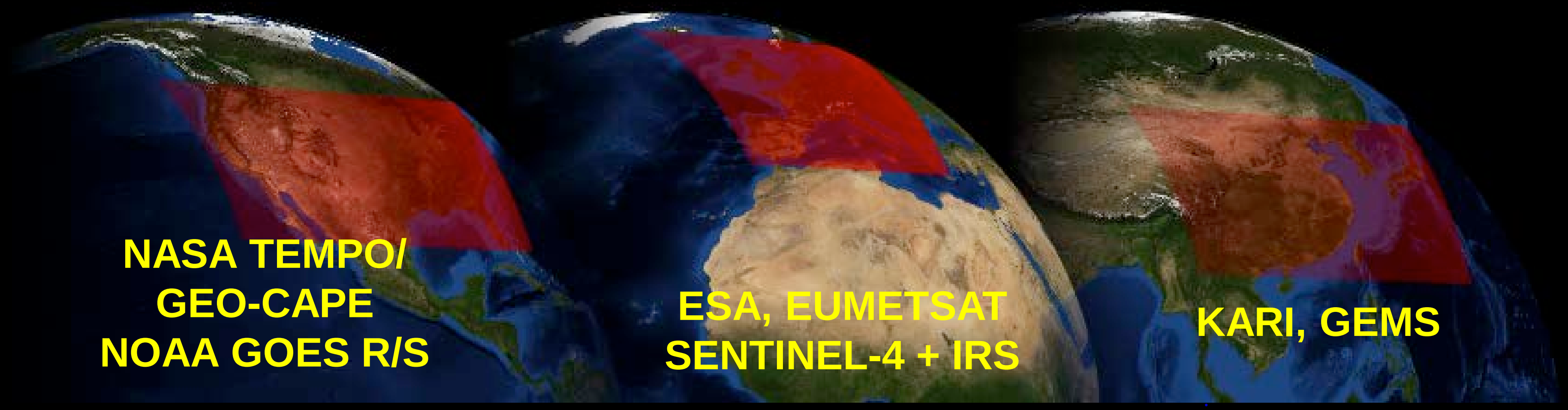
OSSEs & the GEO constellation

- The CEOS Atmospheric Composition Constellation activity identified joint OSSEs as a way to promote collaboration between the planned and proposed geostationary Earth orbit (GEO) missions from NASA GEO-CAPE/TEMPO, ESA Sentinel 4 & KARI GEMS
- OSSEs are extensively used by the NWP community to develop and optimize contemporary meteorological satellite instruments; now increasingly used in other fields of earth observation
- OSSEs assess the *impact of hypothetical observations on a model analysis/forecast/inversion* and provide a means to generalize on the conclusions of limited case-studies



Funded tropospheric chemistry missions

	Europe Sentinel 4	USA TEMPO	Korea GEMS	Europe Sentinel 5 Precursor TROPOMI
Orbit	Geostationary	Geostationary	Geostationary	Low-Earth
Launch	2019	~2018	2018	2015
Domain	Europe	North America	Asia-Pacific	Global
Resolution	8km x 8km at 40N	8km x 4.5km at 35N	7 km (56 km^2) at 38N	7km x 7km nadir
Revisit	1 hour	1 hour	1 hour	1 day
Payload	UV-Vis-NIR 305-500, 750-775 nm	UV-Vis 290-740 nm (tbc)	UV-Vis 300-500 nm (tbc)	UV-Vis-NIR-SWIR 270-500, 675-775, 2305-2385 nm
Species	O_3, NO_2, SO_2, HCHO, AAI, AOD, height-resolved aerosol	O_3 sensitivity to lowest 2km, NO_2, SO_2, HCHO, CHOCHO, AOD, AAOD, AAI	O_3, NO_2, SO_2, HCHO, AOD	O_3, NO_2, SO_2, HCHO, CO, CH_4, AAI, AOD, height-resolved aerosol

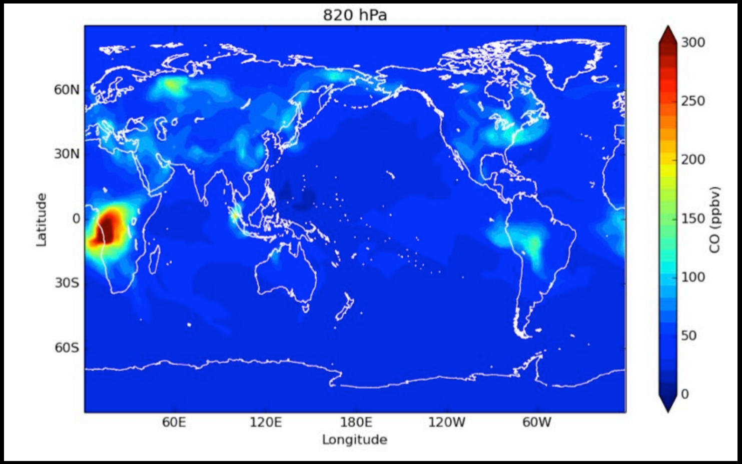
An OSSE to demonstrate value of a GEO constellation: *What is the impact of the constellation observations for improving analysis and forecast of pollutant distributions?*

OSSE goal

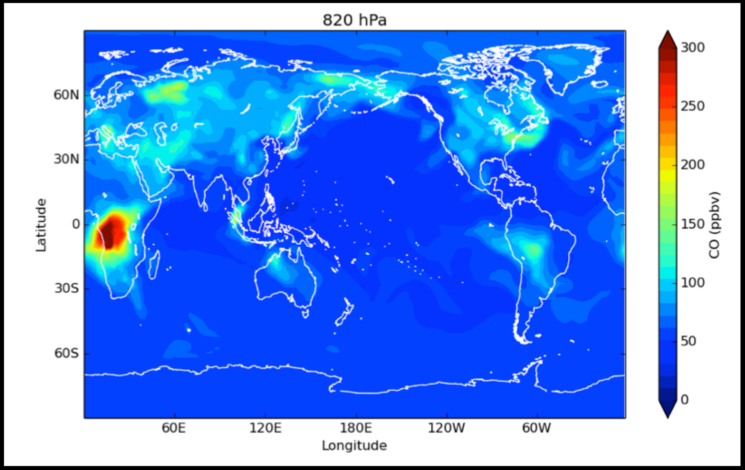
First experiments: **Build on experience assimilating Terra/MOPITT multispectral tropospheric CO observations that have sensitivity to the lower troposphere, and imagine similar capability for all the members of the GEO constellation**

Such capability proposed for GEO-CAPE over the USA with EV CHRONOS; Europe currently plans column CO measurements from IRS accompanying Sentinel 4; currently no CO plans for the Korean platform to accompany GEMS

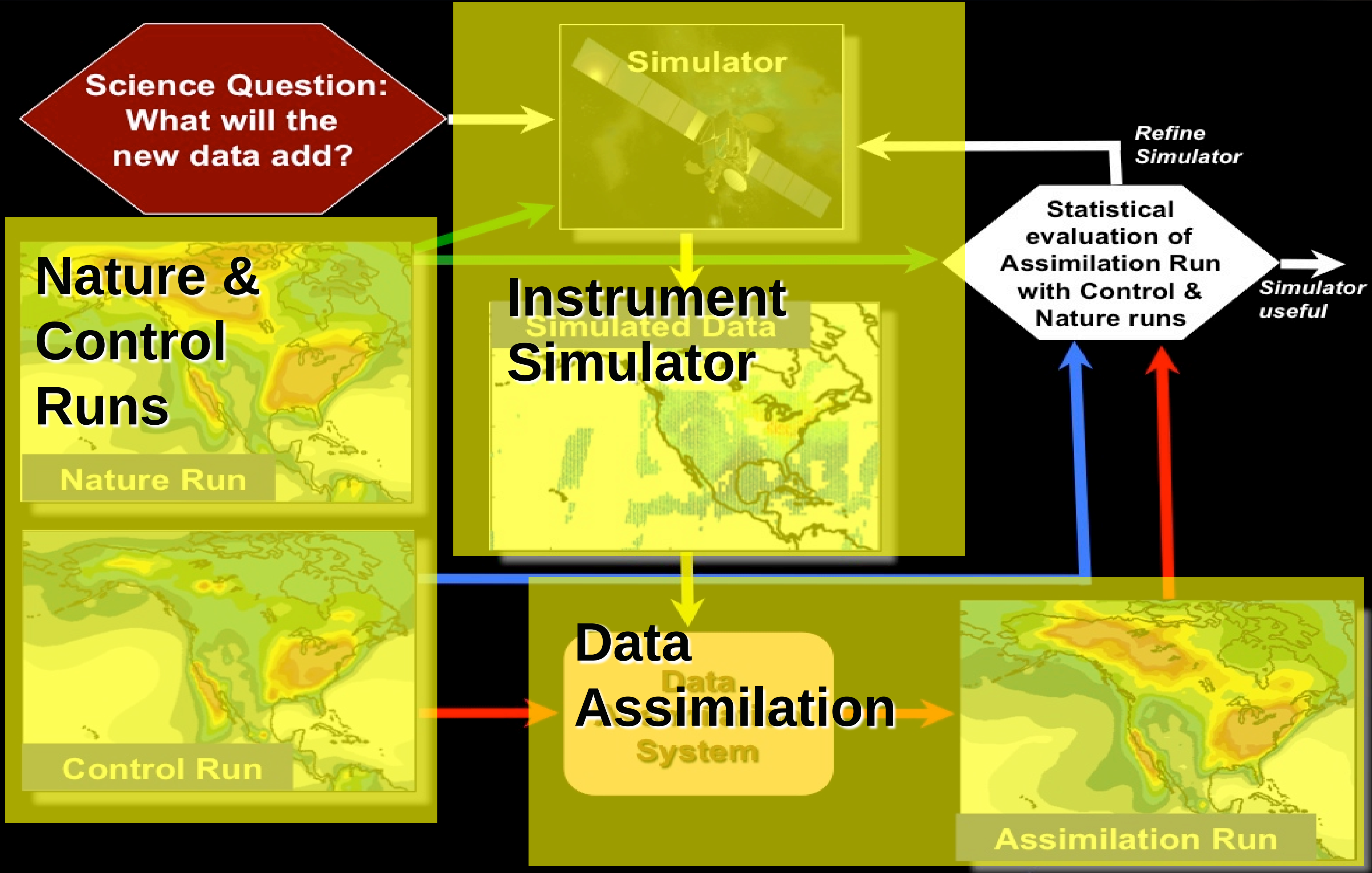
Control run: Met Only assimilated



Assimilation run: Met + MOPITT

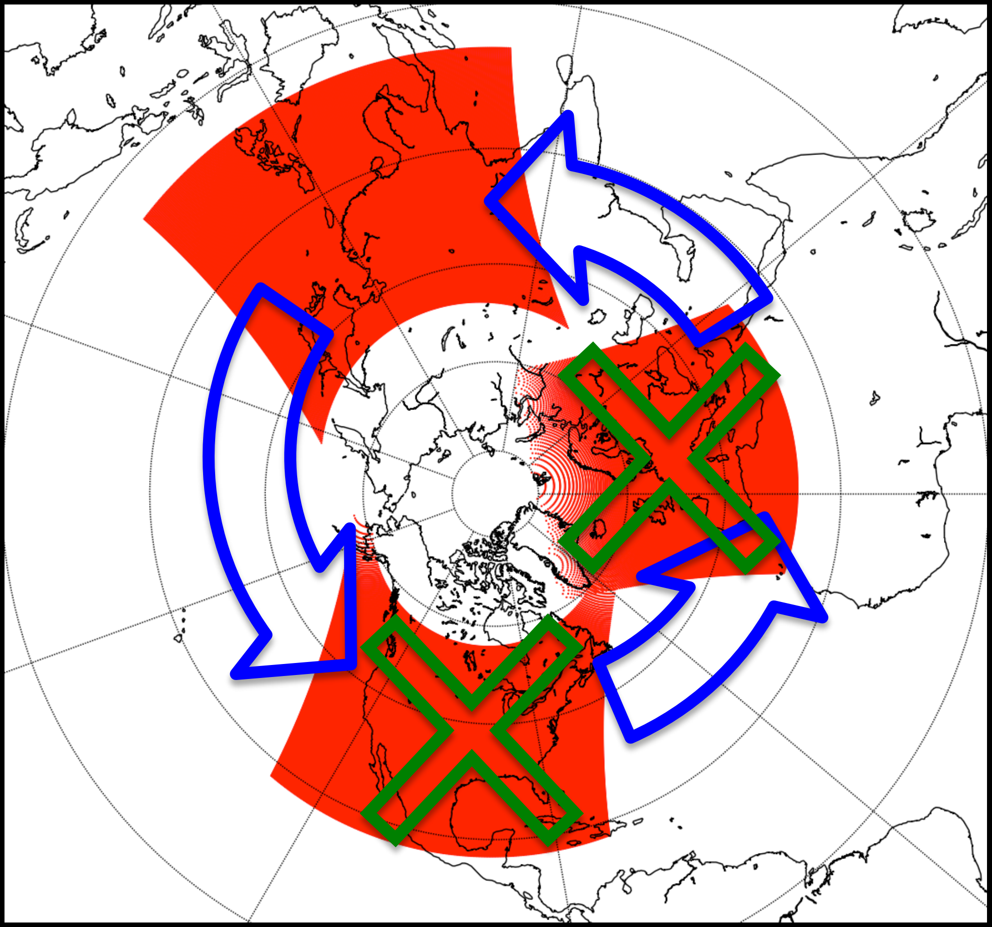


A chemical OSSE framework



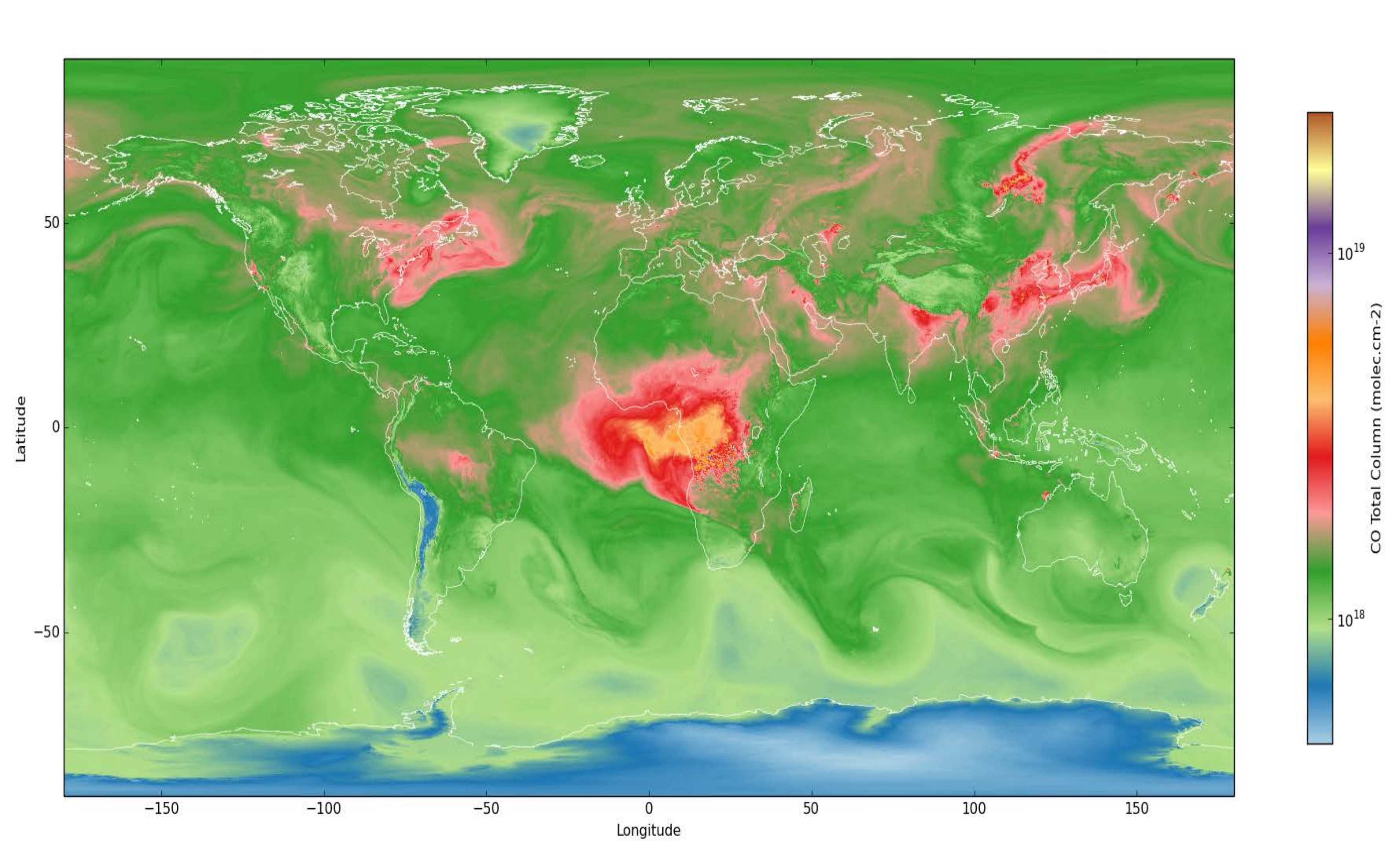
Experimental setup

- **Nature Run (NR):** GEOS-5 0.5º Global Mesoscale Simulation for summer 2006
- **Instrument Simulator:** Computationally efficient regression algorithm based on MOPITT multispectral observations (Worden et al., 2010)
- **Control Run (CR):** CESM CAM-Chem at 1º resolution
- **Assimilation Run (AS):** DART EAKF



- ➢ Assess the ability to observe impact of emissions over each region
- ➢ Look at importance of long range transport from one region to next
- ➢ Investigate the value of the measurements from each mission individually and together

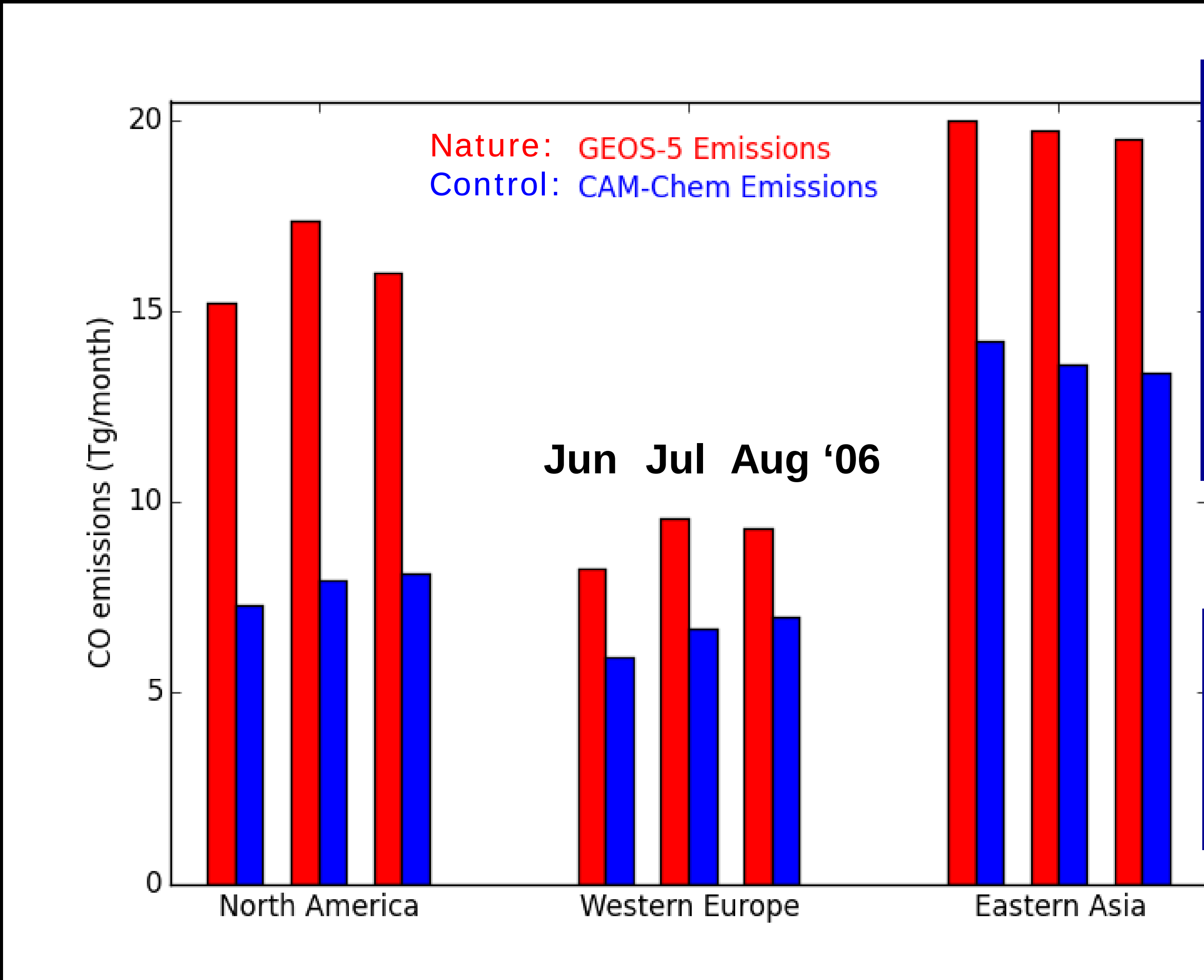
The Nature Run (NR)



Global Mesoscale Simulation: GMAO GEOS-5 7-km high resolution CO total column 15 July 2006

Courtesy Arlindo Da Silva, NASA GSFC

CO anthropogenic emissions budget



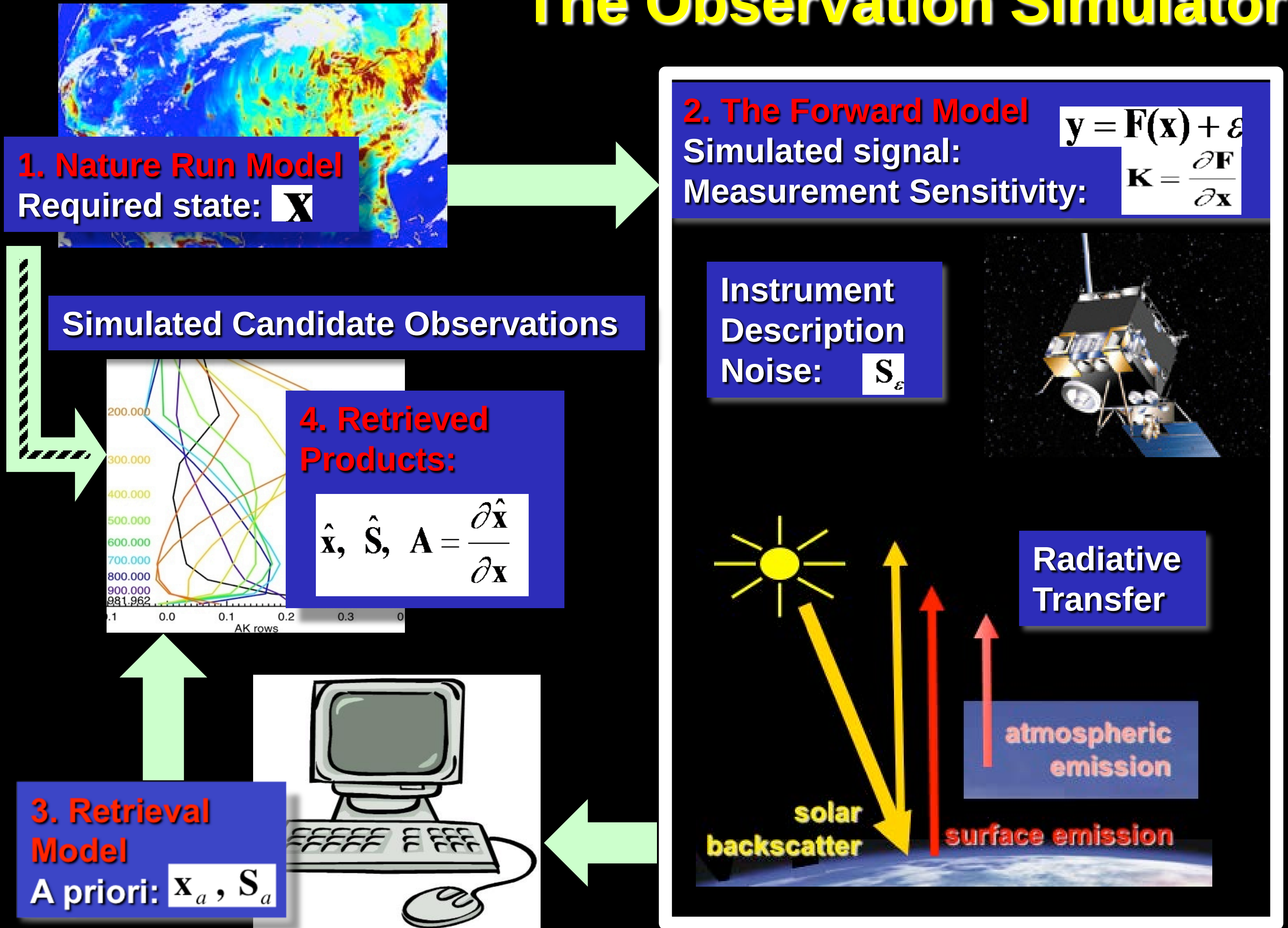
GMAO GEOS-5 NR

Anth: merge of several inventories with EDGAR (2000) as a base (EPA/NEI, CAC, BRAVO, EMEP); fires: QFED v2.2; biog: MEGAN

NCAR CAM-Chem CR

Anthro: MACCity; Fires: FINN biog: MEGAN

The Observation Simulator



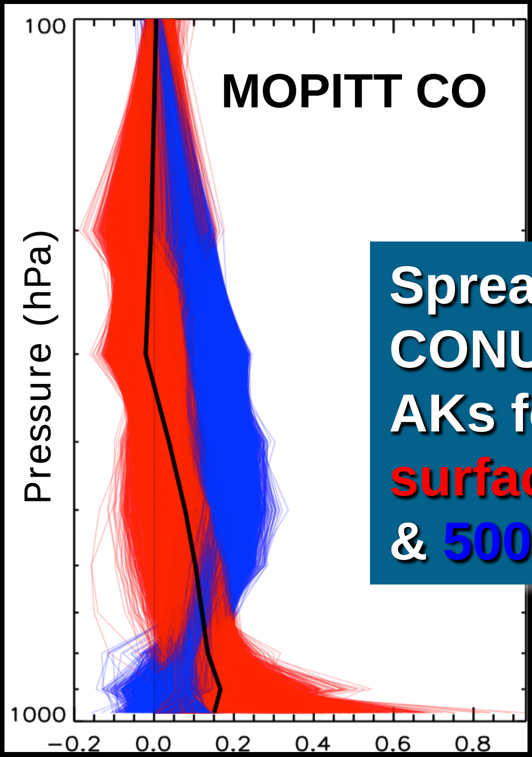
Retrieval Averaging Kernels

- **Observation Simulator measurement & retrieval characteristics are represented by the Averaging Kernel (AK) and retrieval error**
- **However, running the full Observation Simulator in the OSSE is expensive and very involved**
- **Previously, CO and O_3 OSSEs have been simplified by assuming all observations can be represented with a few AK cases and these are used to sample the Nature Run model everywhere/all day**

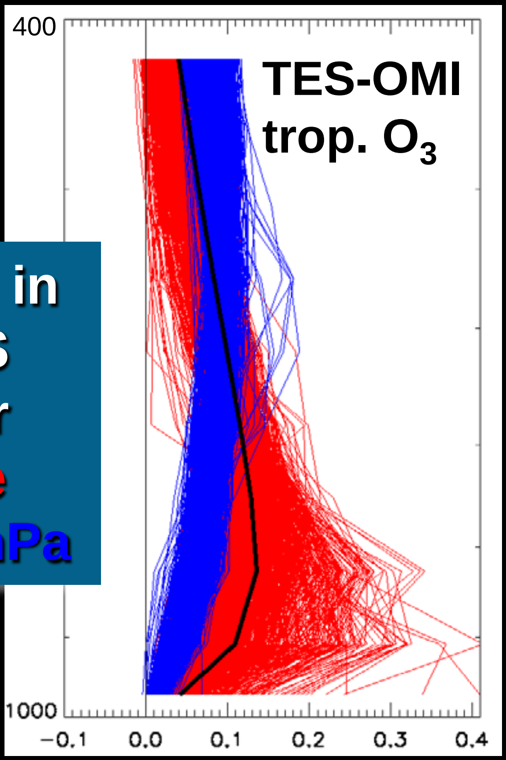
But AKs vary a lot….

- **Depend on surface characteristics, temperatures, clouds, aerosol loadings, trace gas loadings, viewing and solar angles**

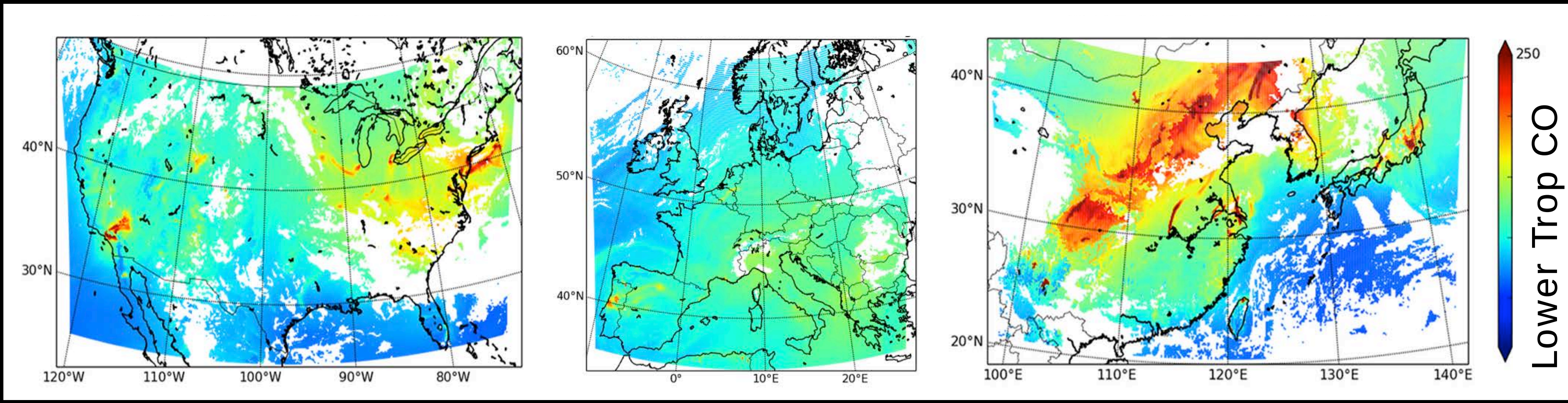
- realistic OSSEs need to account for this!



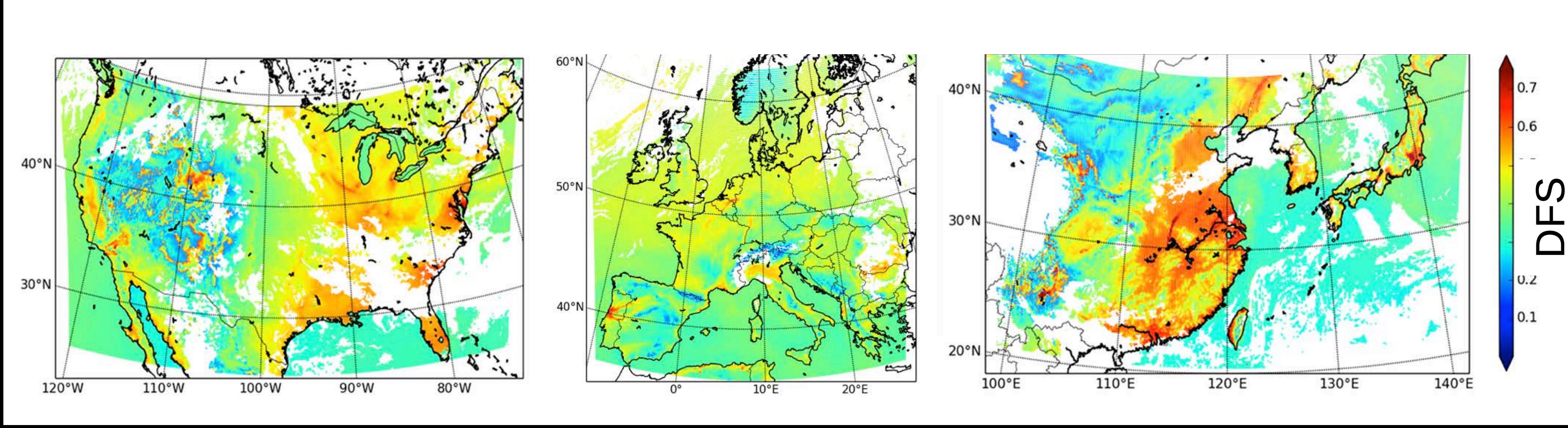
Spread in CONUS AKs for surface & 500 hPa



Observation simulator: Near-surface CO concentration accounting for scene-dependent measurement sensitivity

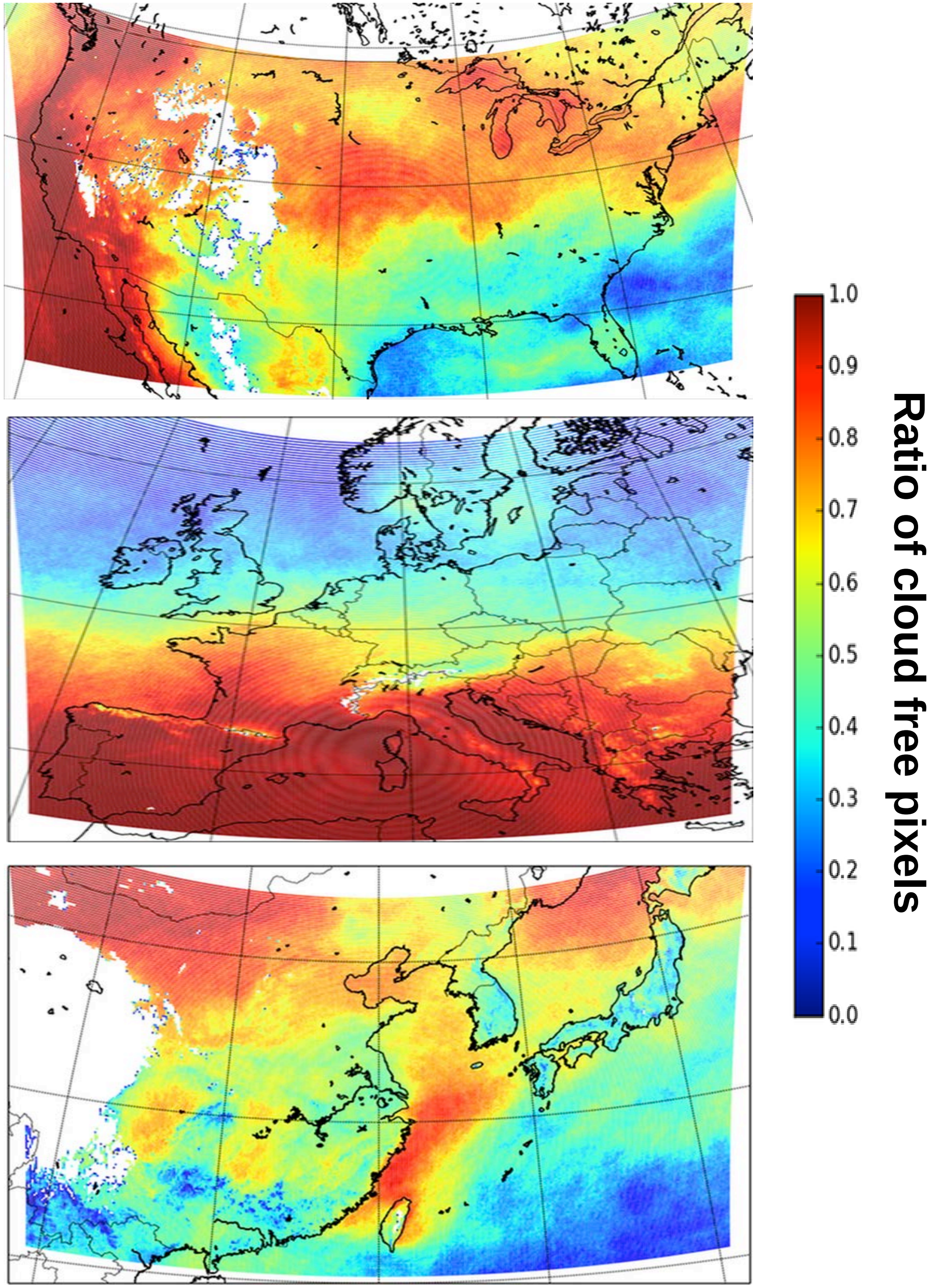


Scene-dependent retrieval near-surface information content – large differences between regions



15 July 2006, 3pm local time

Barré et al., Atm. Env., accepted, 2015



Simulated cloud coverage

Cloud coverage varies according to region with large differences affecting effective temporal coverage

July 2006 cloud coverage ratio

Barré et al., Atm. Env., in press, 2015

Assimilation

GMAO GEOS-5 Nature Run

Emissions:
Anth: merge of several inventories with EDGAR (2000) as a base (EPA/NEI, CAC, BRAVO, EMEP). Fires: QFED v2.2. Biog: MEGAN

Chemistry:
Only AeroChem: Global CO and CO2 tracers; GOCART aerosols

Resolution:
Vertical: 72 levels (Surface - 0.01hPa),
Horizontal: 0.5°(0.06°)

NCAR CAM-Chem Control Run

Emissions:
Anth/Fires: MACCity,
Biog: MEGAN

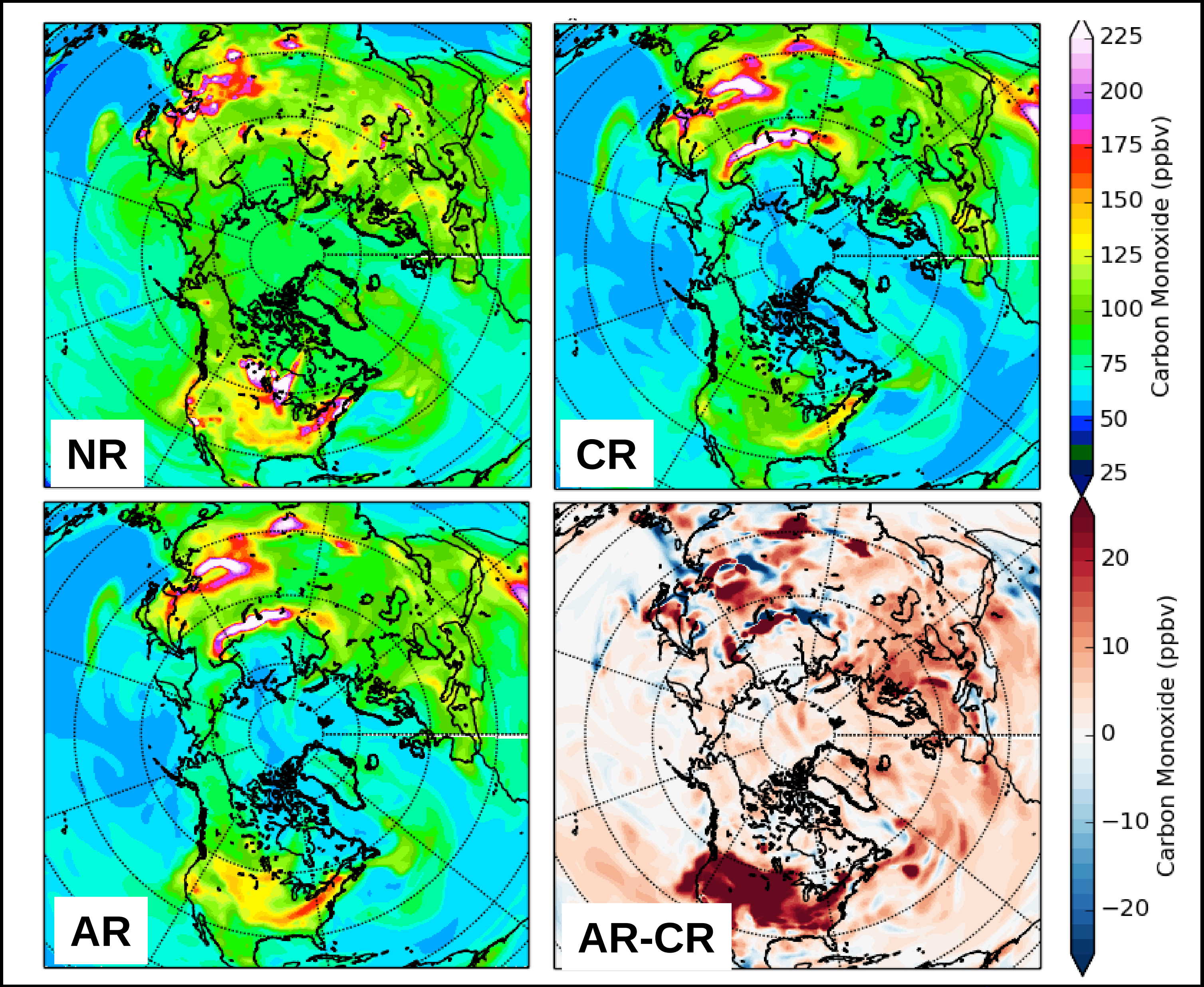
Chemistry:
MOZART “full” tropospheric chemistry
Aerosols and chemistry
(87 species + 16 bulk aerosols)

Resolution:
Vertical: 30 levels (Surface - 3hPa)
Horizontal: 1°

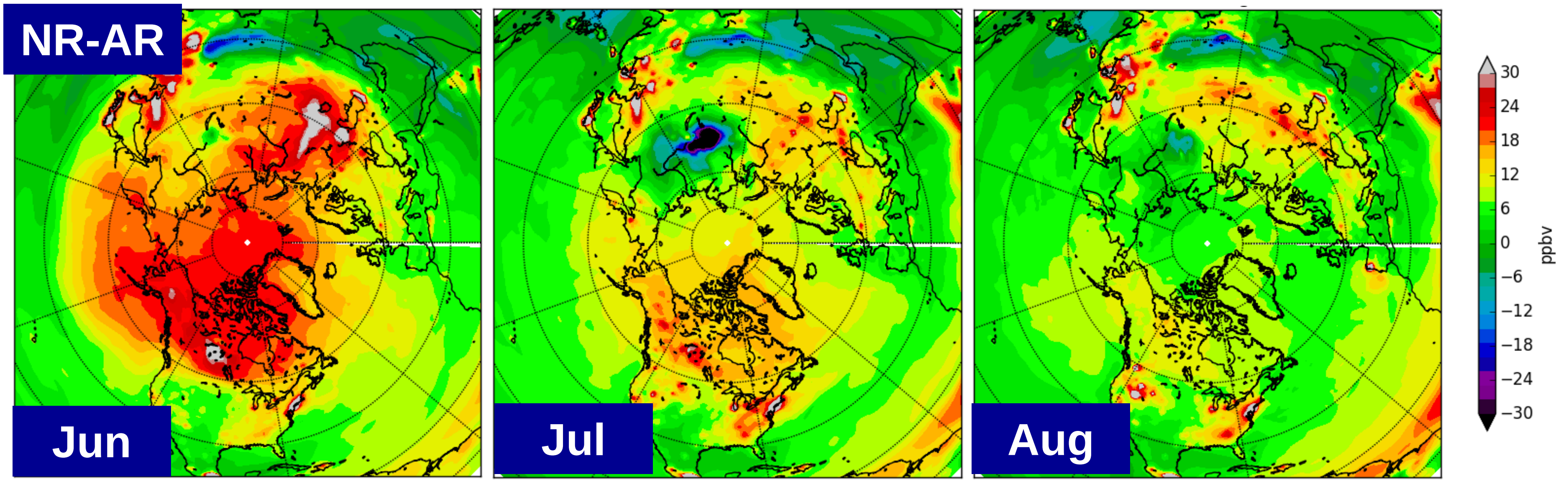
Assimilation run over Summer 2006.
Meteorological Spin-up over May. Reduced NR resolution (0.5°) used

Barré et al., Atm. Env., in prep.

The OSSE result for the difference between the Assimilation Run (AS) and Control Run (CR) for June 26, 2006, for CO concentration after the assimilation of Simulated Candidate Observations from GEO over Europe, Asia and USA



DA impact relative to nature run (NR): Assimilating all 3 GEOs
Monthly 200 – 1000 hPa average

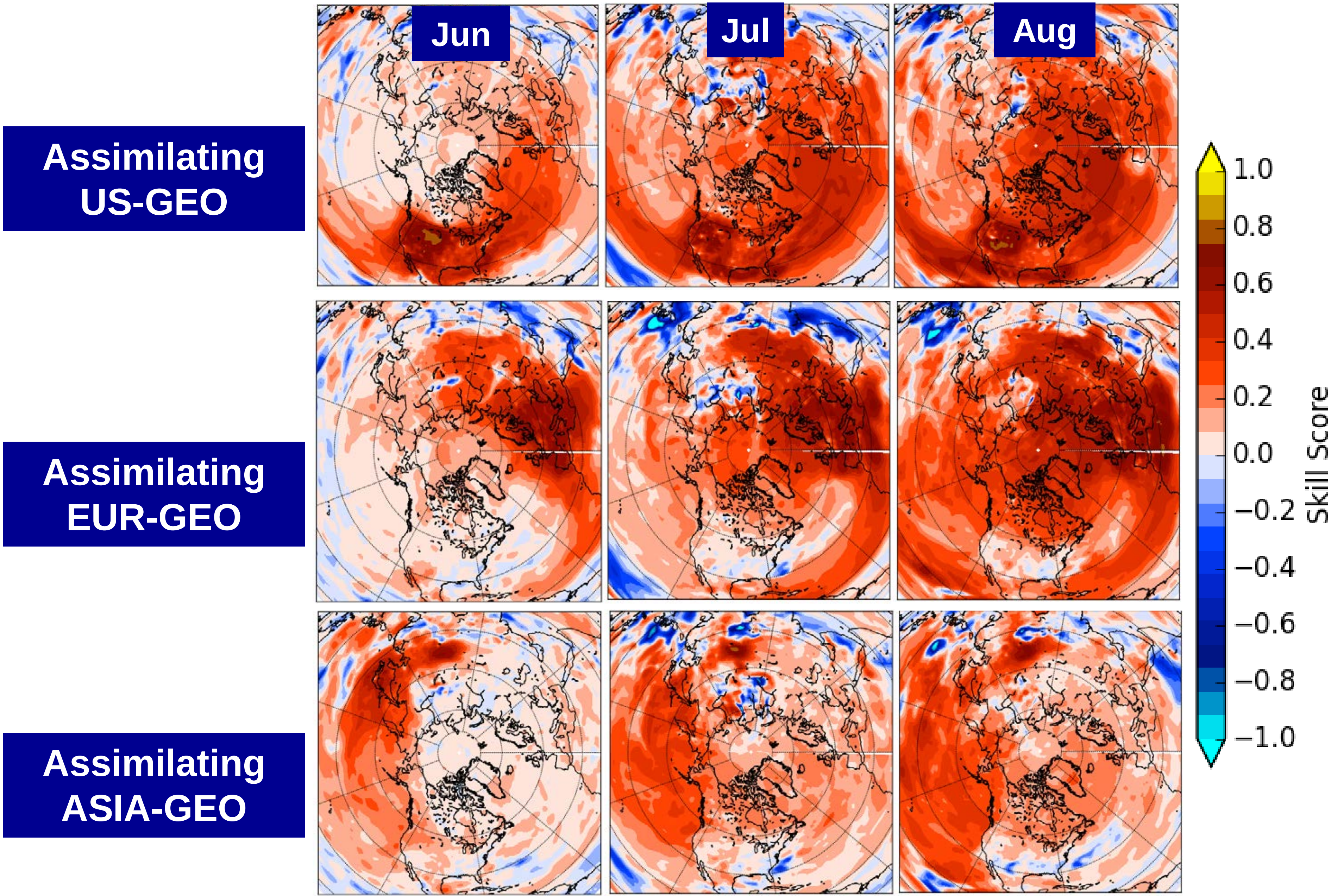


Next look at Skill Score

= 1 – MSE(AR-NR) / MSE(CR-NR)

SS < 0 degraded simulation
SS > 0 improved simulation
SS = 1 perfect simulation

DA impact relative to nature run: Assimilating individual GEOs
Monthly 200 – 1000 hPa average



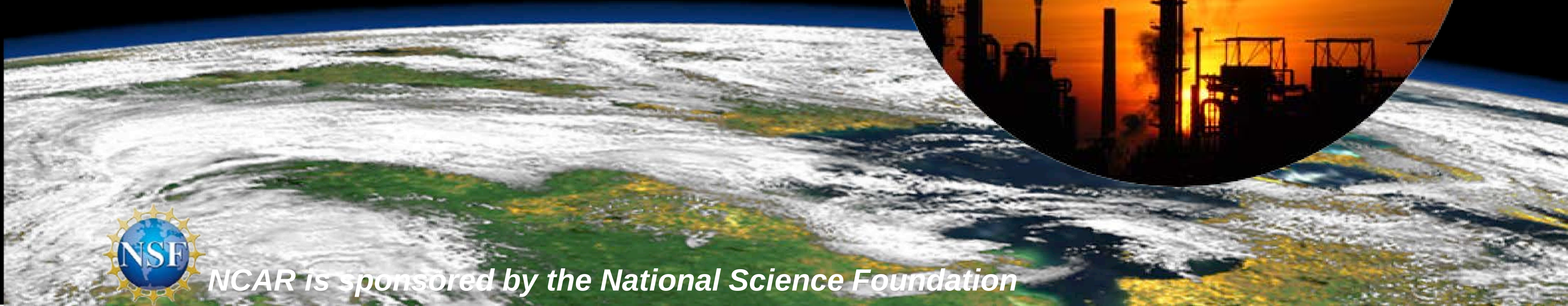
First OSSE results

- Assimilation of the GEO constellation provides a strong constraint over anthropogenic source locations
- Global constraint of CO is also strong in remote regions due to long range transport of assimilation increments
- Impacts are reduced over Asia due to increased cloud coverage limiting the number of clear observations
- Experiments are being extended with a winter case study when the CO lifetime is longer, and emissions and cloud coverage also change

Next steps

- Expand the experiments to consider LEO (TROPOMI) measurements, AOD, tropospheric ozone and chemical correlations

Thank You!



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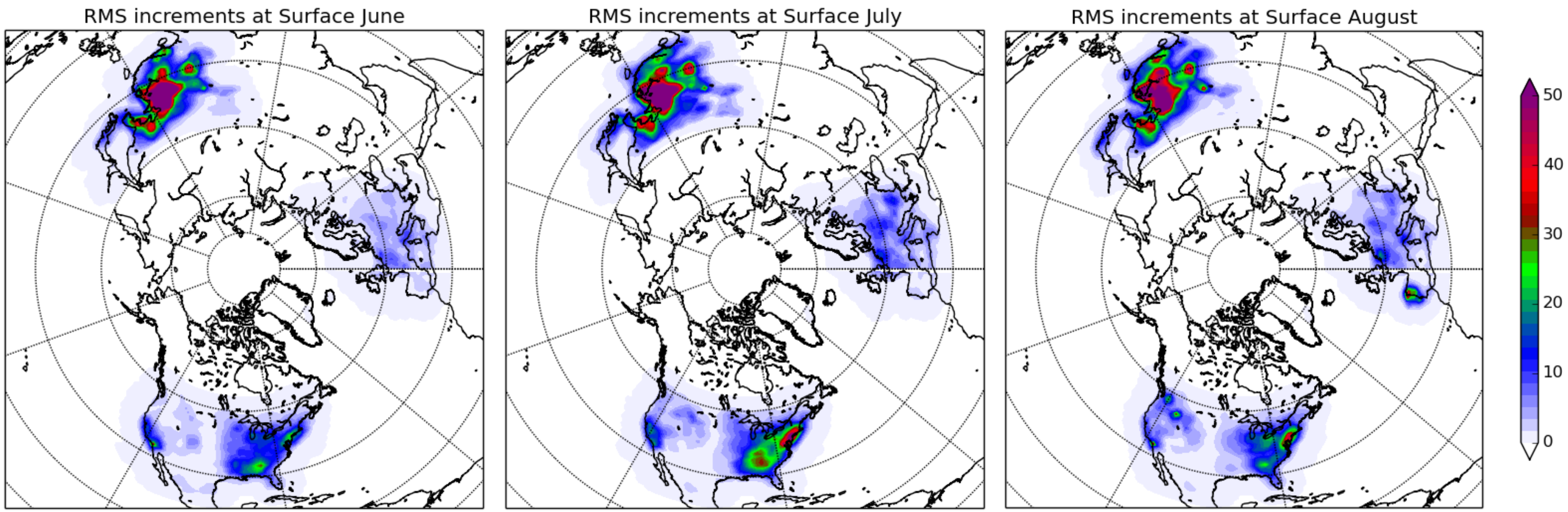
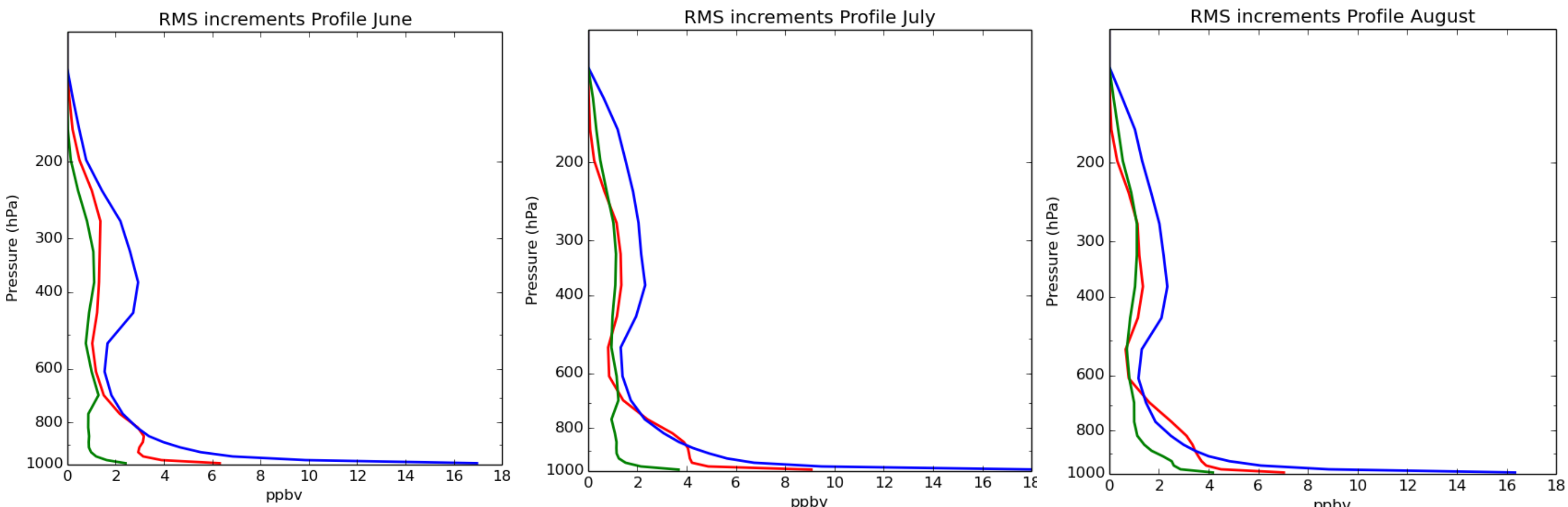
OSSE Infrastructure: Recommendations

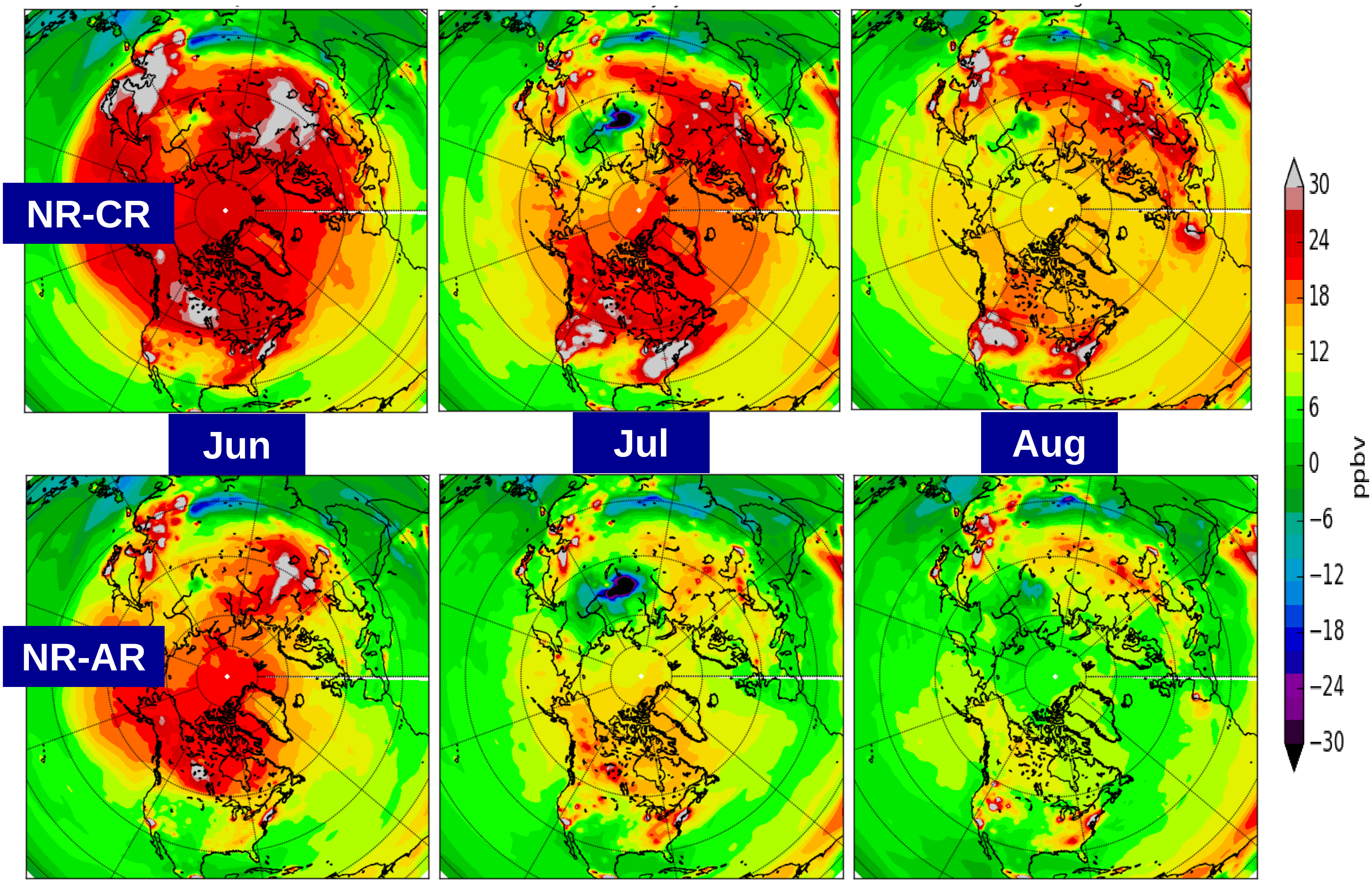
- **OSSEs need to account for realistic atmospheric variability:** Requires evaluation of NR with observations
- **OSSEs require realistic variability in measurement simulations generated from NR:** Requires incorporation of sensitivities due to cloud, aerosol, trace gases, surface UV-visible reflectivity, and IR emissivity
- **Simulated retrievals must include realistic range of sensitivities:** Requires generation of scene-dependent AKs and errors
- **OSSEs for relative performance between instruments/observation strategies may provide most reliable conclusions:** Difficult to predict absolute performance of future systems compared to the current capability; requires full system evaluation with the existing observing system
- **NWP experience:** OSSE-based decisions have international stakeholders and experiments should be developed as joint global projects; community ownership and oversight of OSSE capability is also important for maintaining credibility

GEO constellation DA increments



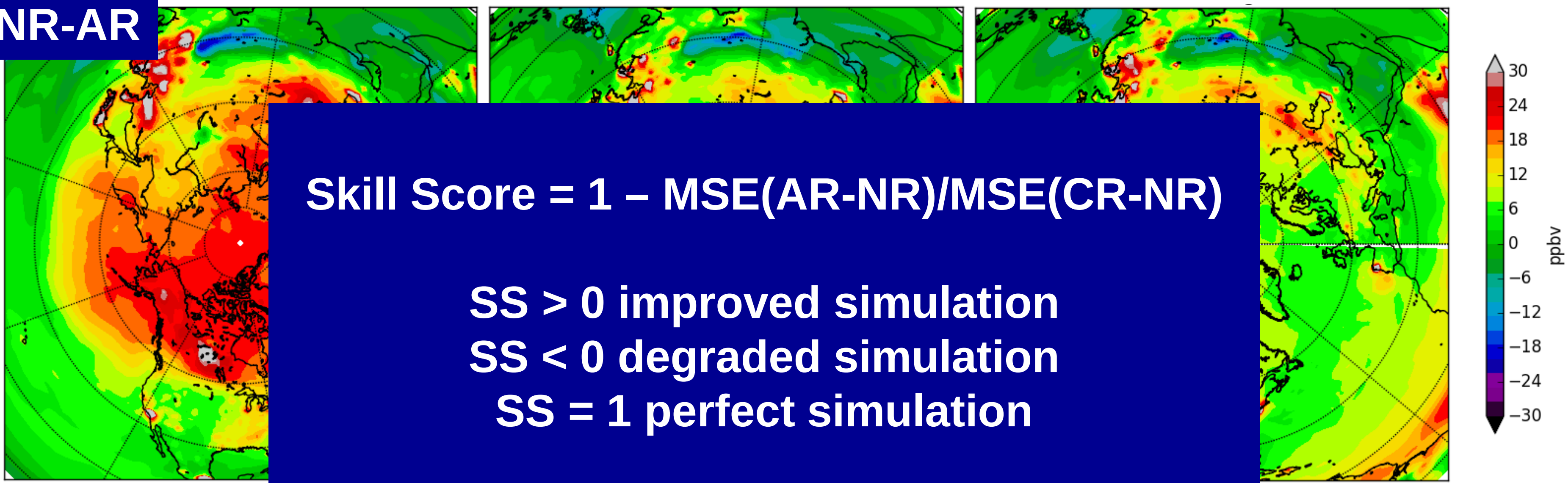


DA impact relative to nature run (NR): Assimilating all 3 GEOs
Monthly 200 – 1000 hPa average



DA impact relative to nature run (NR): Assimilating all 3 GEOs
Monthly 200 – 1000 hPa average

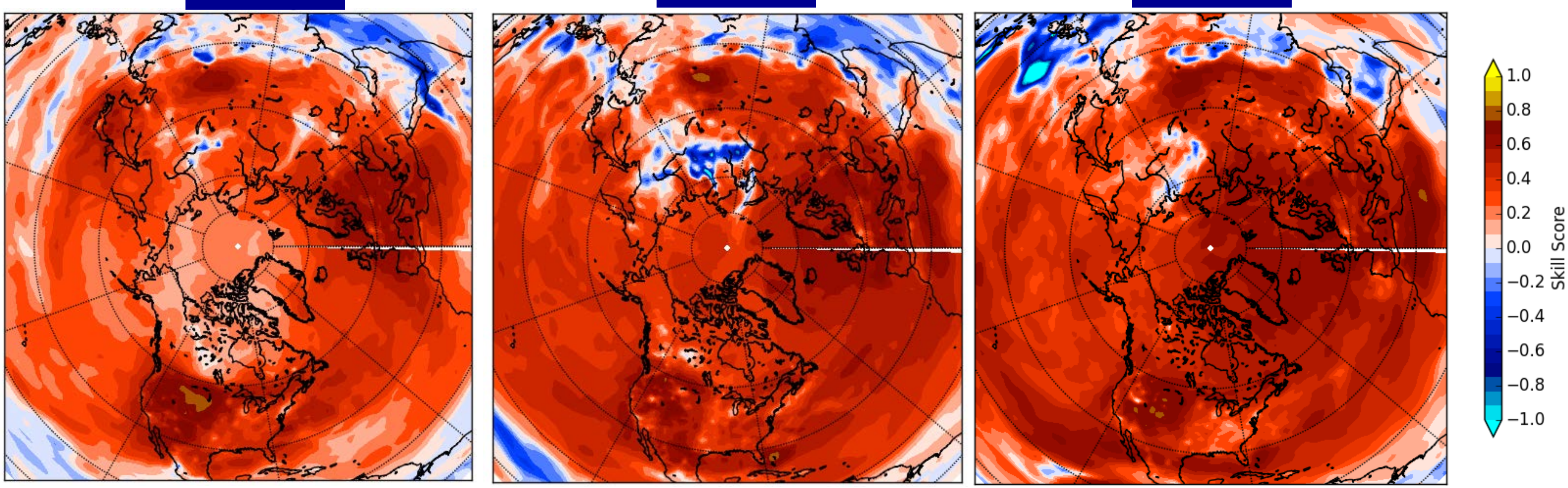
NR-AR



Skill Score = 1 – MSE(AR-NR)/MSE(CR-NR)

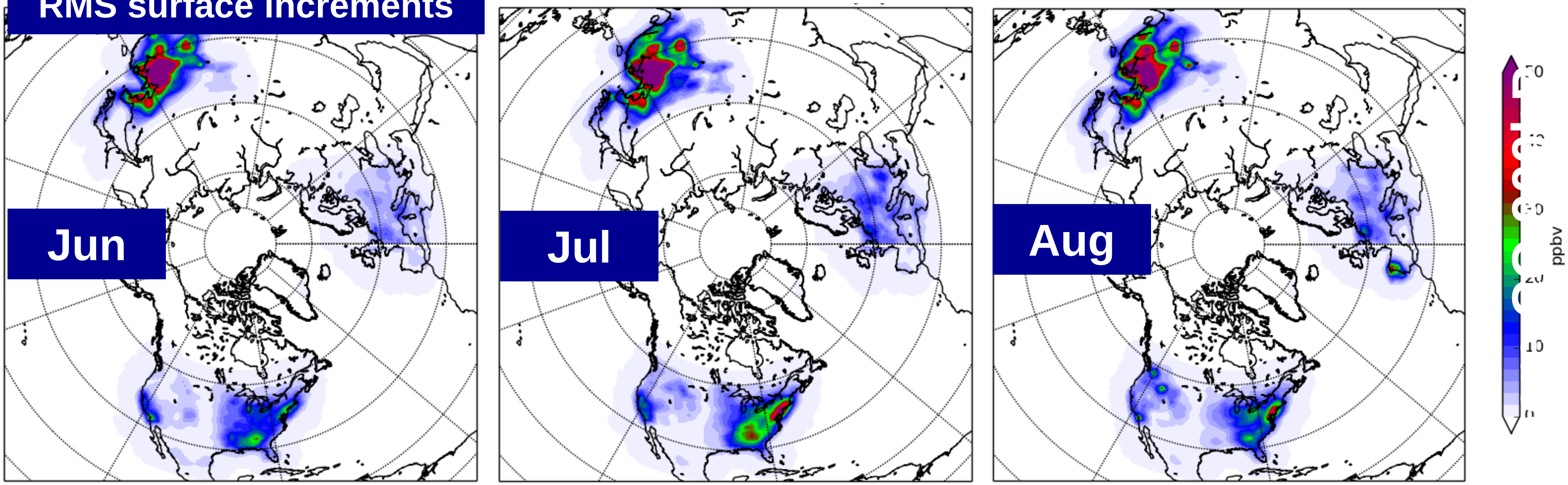
SS > 0 improved simulation
SS < 0 degraded simulation
SS = 1 perfect simulation

Jun **Jul** **Aug**

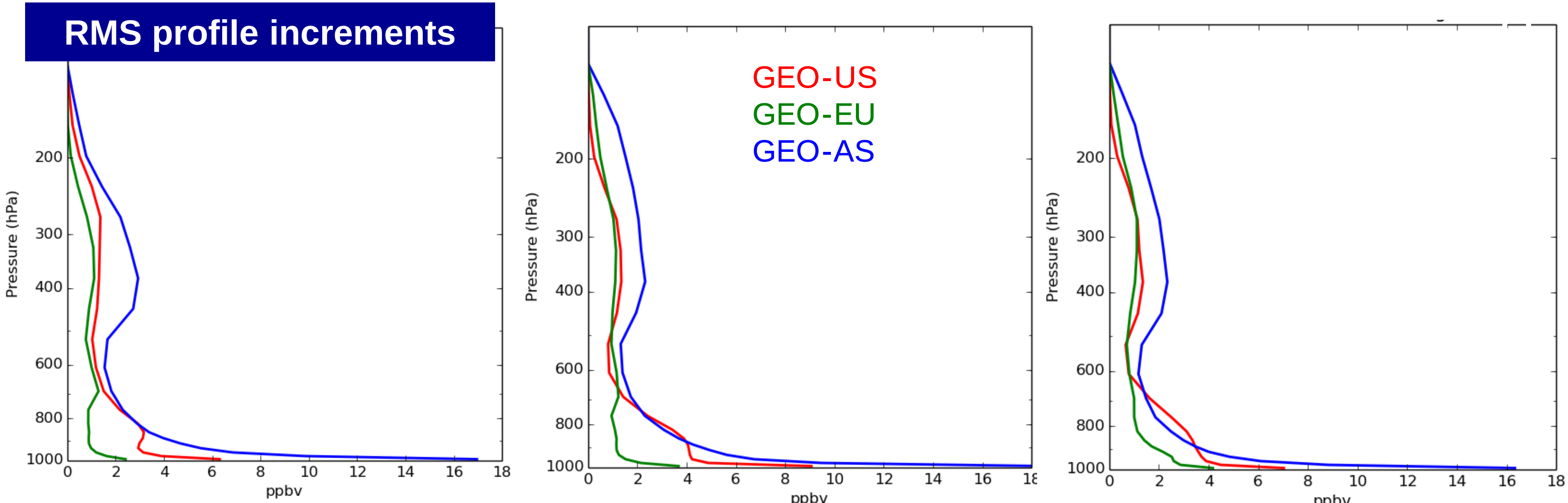


GEO constellation DA increments

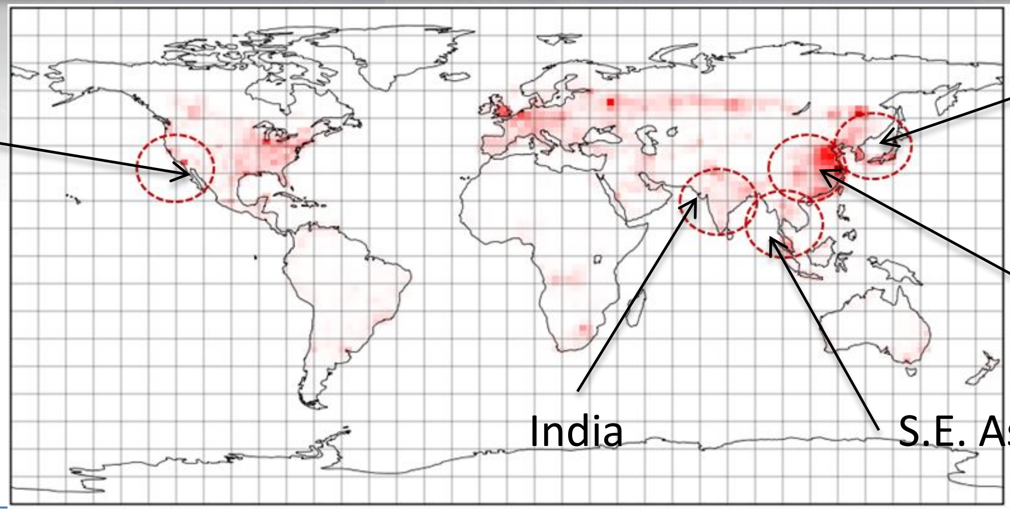
RMS surface increments



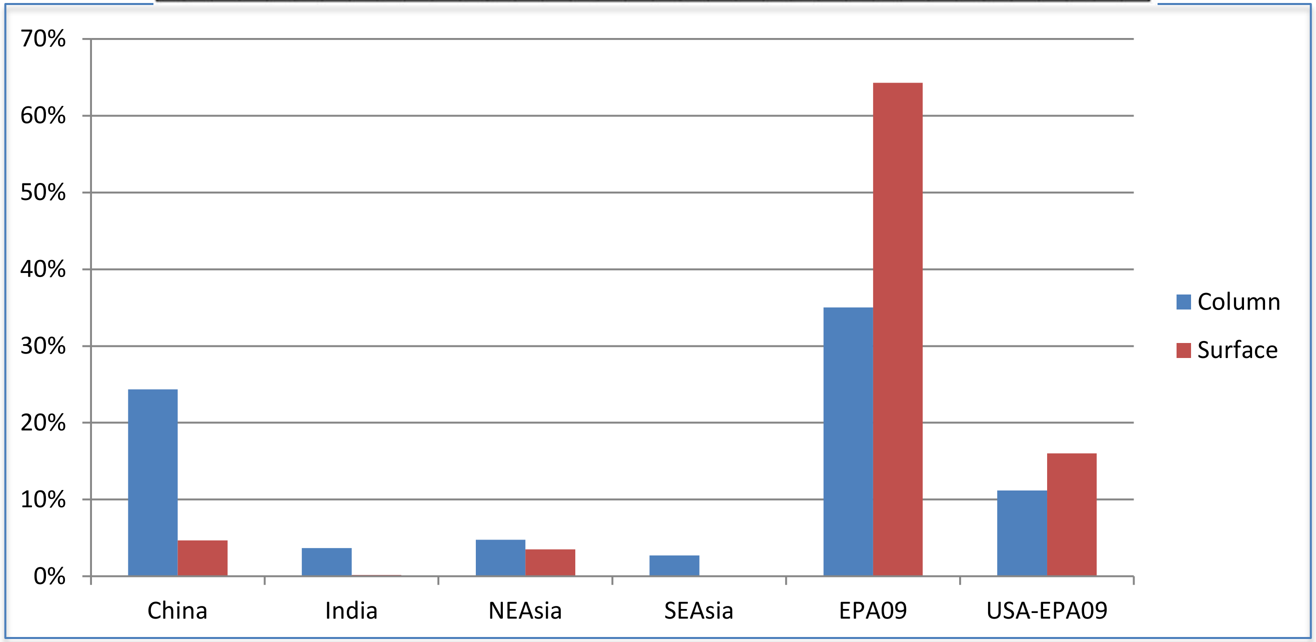
RMS profile increments



Regional Distribution of the EPA09 Ozone Sensitivity



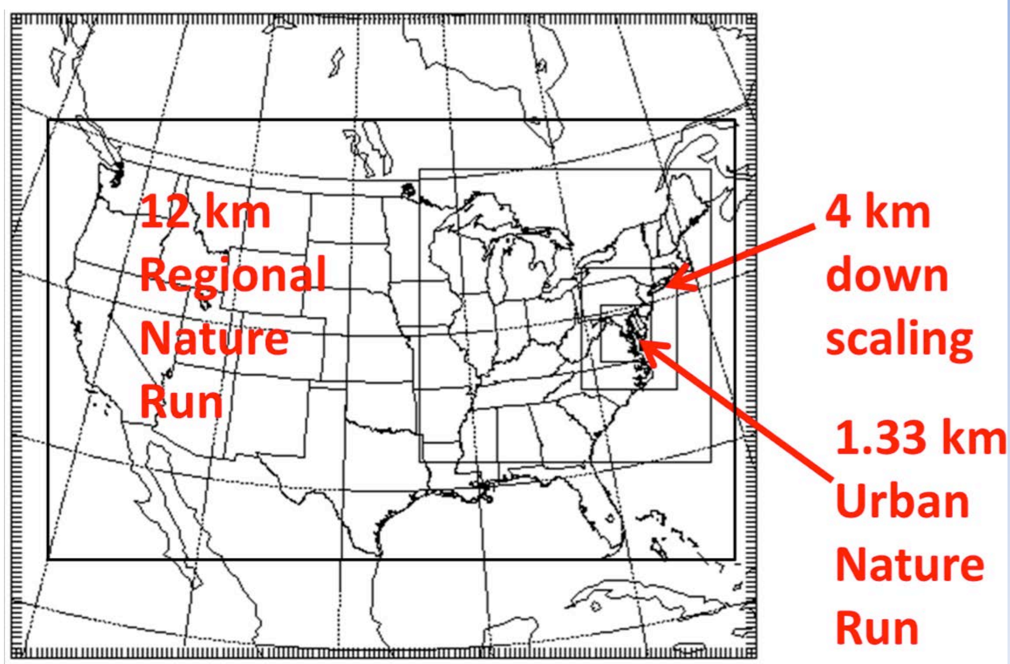
- **Over 35% of mean surface ozone in EPA09 comes from emissions outside EPA09**
- **Chinese emissions contribute to mean column ozone @ 70% of local emissions**



GEOCAPE Atmosphere Regional/Urban OSSE

Task	Participants	Institute
1. Urban Nature Run**	K. Pickering/C. Loughner	NASA/GSFC
2. Regional Nature Run*/DA*	B. Pierce/A. Lenzen/T. Schaack	NOAA/CIMSS
3. Forward RT Modeling*	K. Bowman/V. Natraj/T. Kurosu	JPL
4. AK Regression*	D. Edwards/H. Worden	NCAR
5. Multi-Spectral Retrieval*	L. Iraci/S. Kulawik	NASA/BAERI
6. Nature Run Verification*	M. Newchurch/L. Wang	UAH

* Completed in FY13 * Completed in FY14 * In preparation



Extends previous GEOCAPE OSSE studies by:

•Utilizing independent modeling systems for generation of the Nature atmosphere and conducting the assimilation impact experiments

•Accounting for realistic atmospheric variability, which requires evaluation of the nature runs with respect to observations.

•Inclusion of realistic variability in the synthetic radiances, which requires incorporation of realistic surface UV and visible reflectivities, and IR emissivities.

•Inclusion of realistic sensitivities, which requires generation of averaging kernels (AK) for each retrieval for use in assimilation studies

The OSSE Components

- OSSEs are extensively used by the NWP community to develop and optimize contemporary meteorological satellite instruments
- Now also increasingly used in other fields of earth observation
- OSSEs assess the impact of *hypothetical* observations on a model analysis/forecast/inversion and provide a means to generalize on the conclusions of limited case-studies

OSSE components:

- **Nature Run (NR):** Model representation of 'truth'
- **Simulated Candidate Observations:** The Observation Simulator samples the Nature Run
- **Control Run (CR):** An alternative model representation of the atmospheric state *(… this might represent current capability to provide 'ground-truth' or the 'a priori' best guess)*
- **Assimilation Run (AR):** Assimilation of the Simulated Candidate Observations in the Control Run
- **Compare:** Assess impact of the Candidate Observations - *Does the Assimilation Run tend to the Nature Run compared to the Control Run? If so, Candidate Observation may be useful*