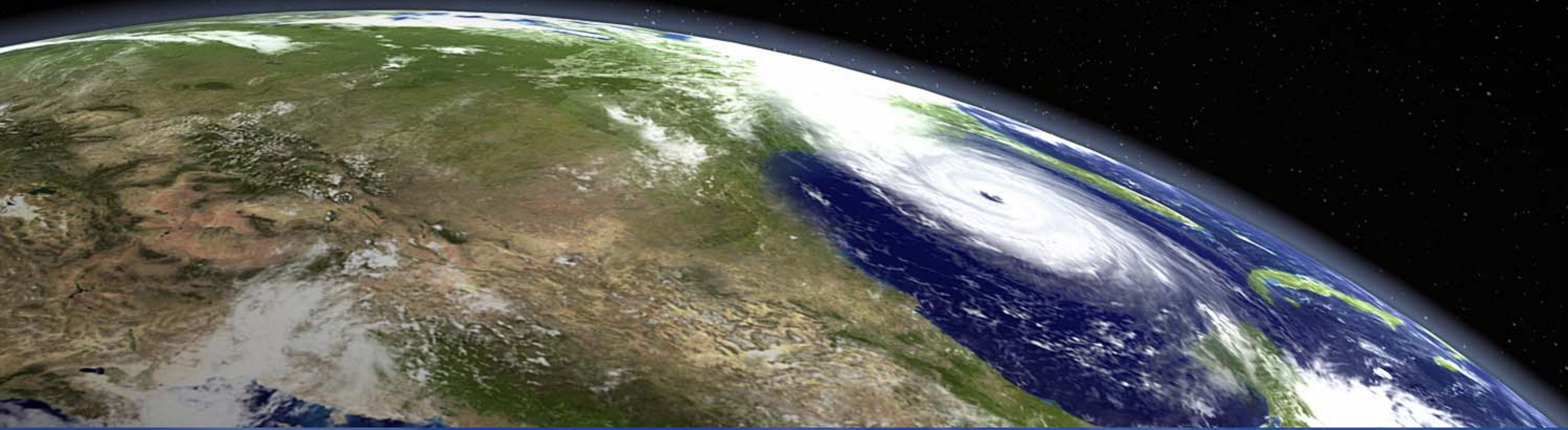
Earth Networks

Taking the Pulse of the Planet™

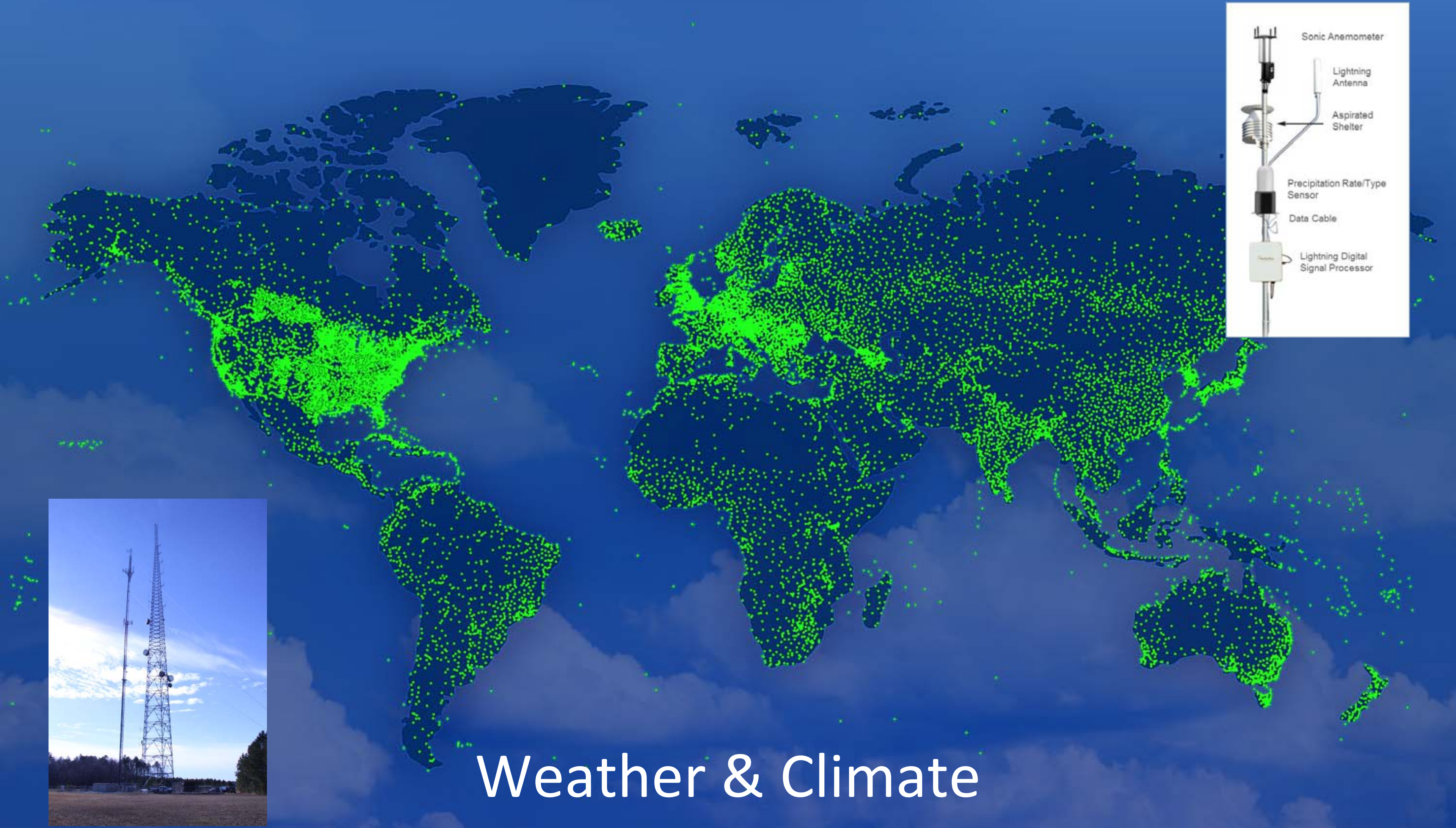
NOAA GMD Annual Conference
Update on Global Greenhouse Gas Network

Bob Marshall, Founder & CEO

May 2, 2012



Network of Networks



Weather & Climate

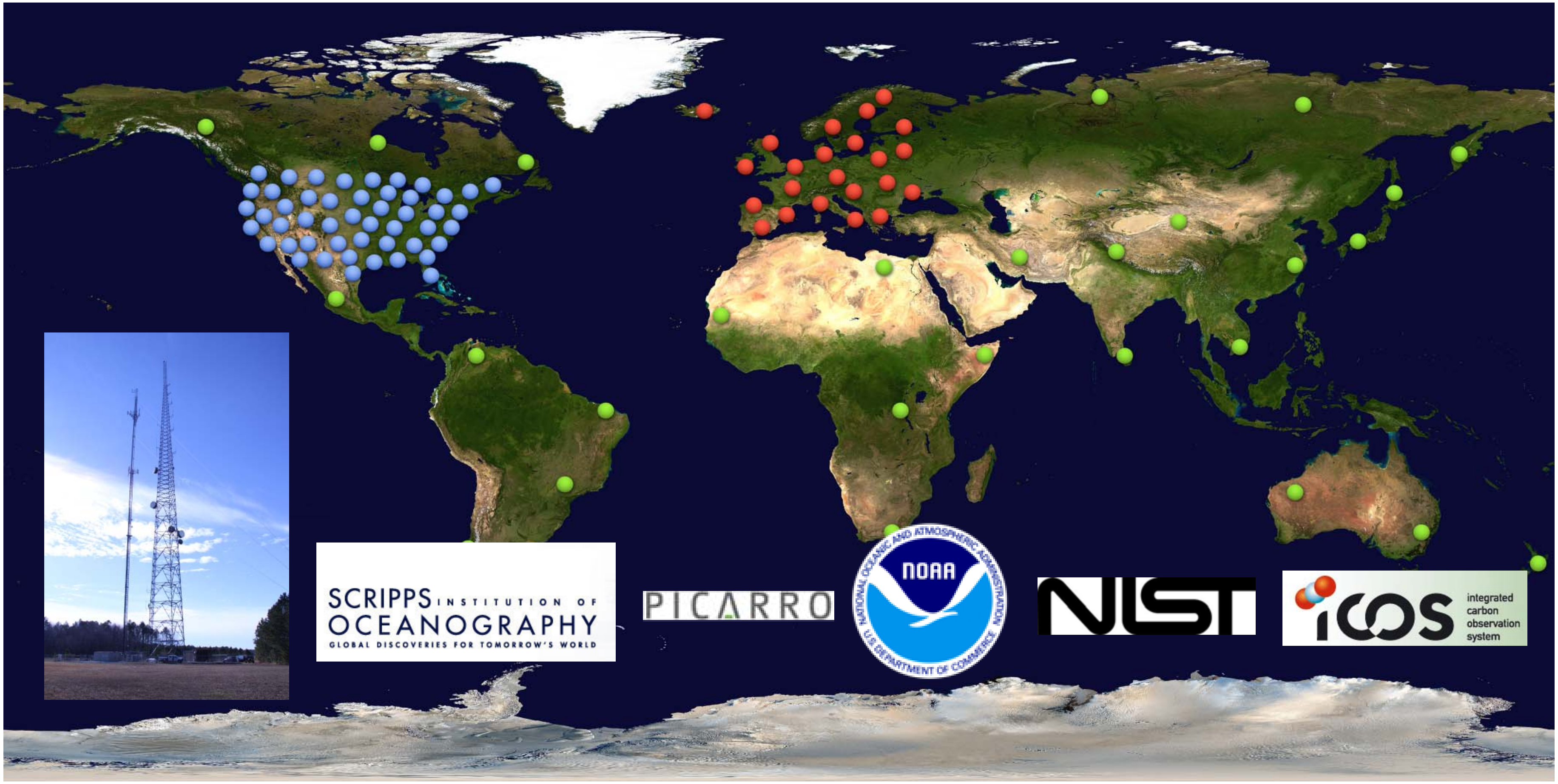
Operate ~10,000 Stations Globally

Innovation & Public/Private Partnerships
Across Entire Value Chain

Accelerate Solutions…

What we said last year…

Global Greenhouse Gas Network



- Spatial and temporal resolution like never before – continuous network growth
- $25M, 5 year investment to install & operate 100 advanced GHG systems
- ~50 in U.S., ~25 in Europe, ~25 around remaining continents
- Picarro Analyzers: Measure CO_2 (carbon dioxide) & CH_4 (methane)

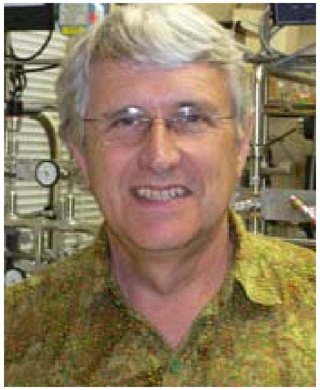
Where are we today?

Earth Networks

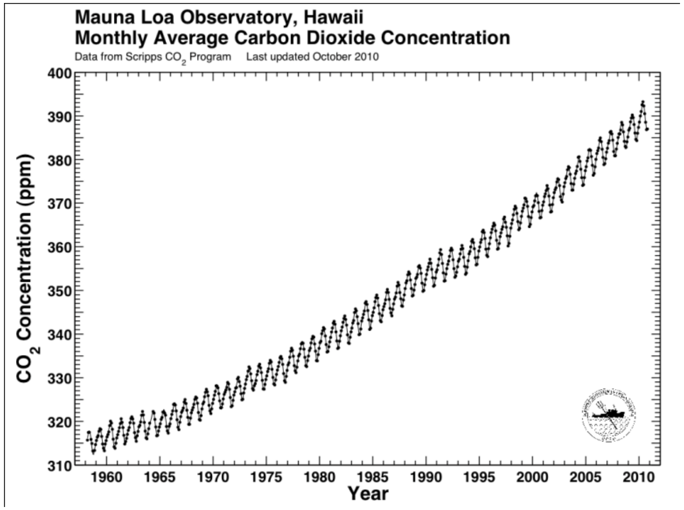
SCRIPPS INSTITUTION OF OCEANOGRAPHY

Center For Environmental Research

Dr. Ralph Keeling



Dr. Ray Weiss



Scripps Focus:

- System Design
- Network Design
- Calibration and Quality Control Design
- Modeling Support
- Cutting Edge Research

Measurement System

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GLOBAL DISCOVERIES FOR TOMORROW'S WORLD

Front View

Side View

Top View

NOAA Flask Package

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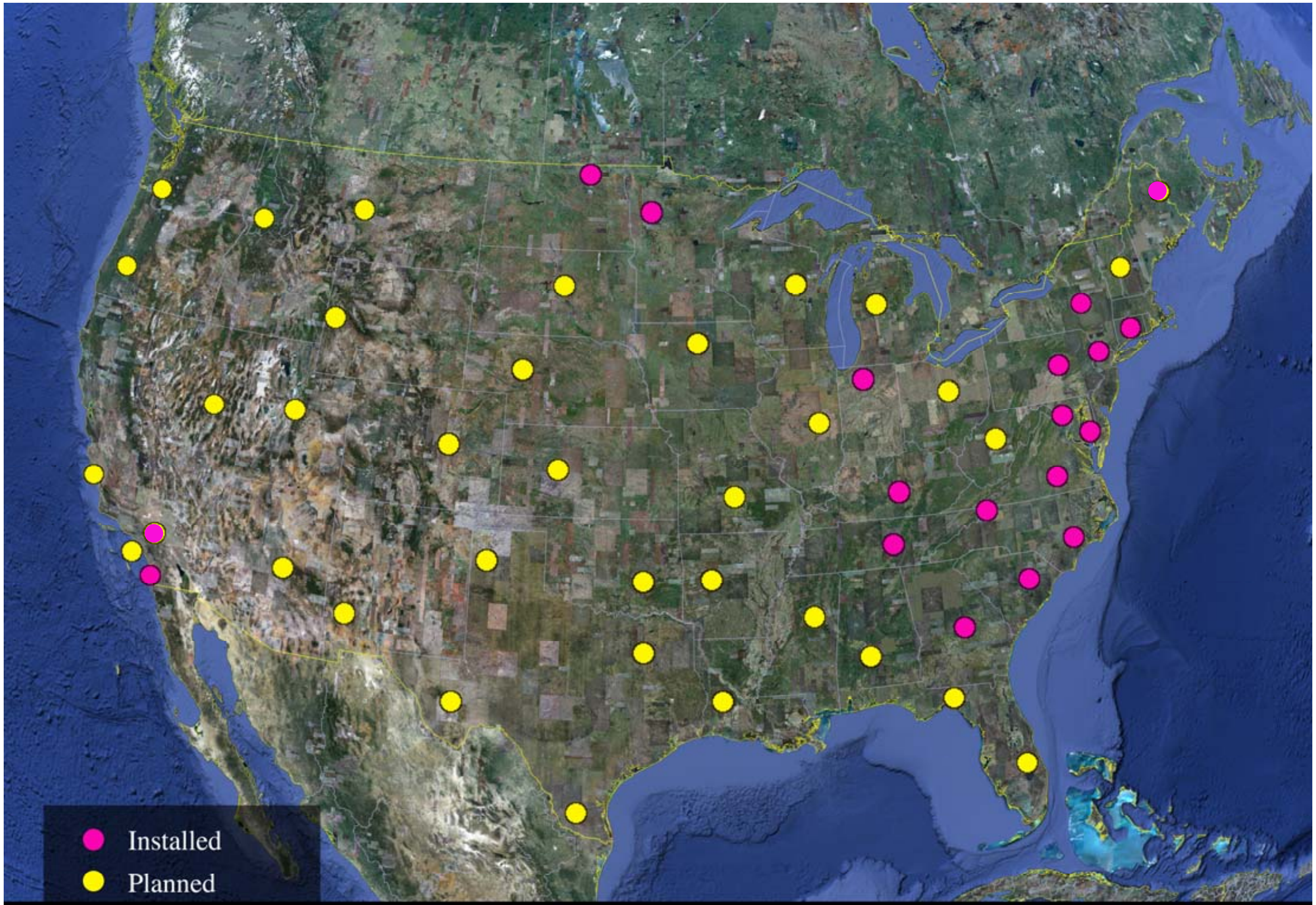
Network Status



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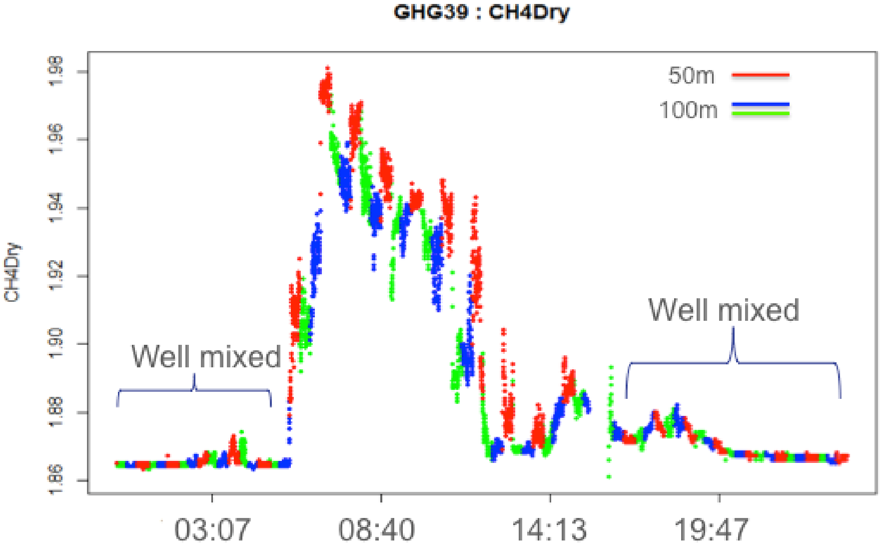
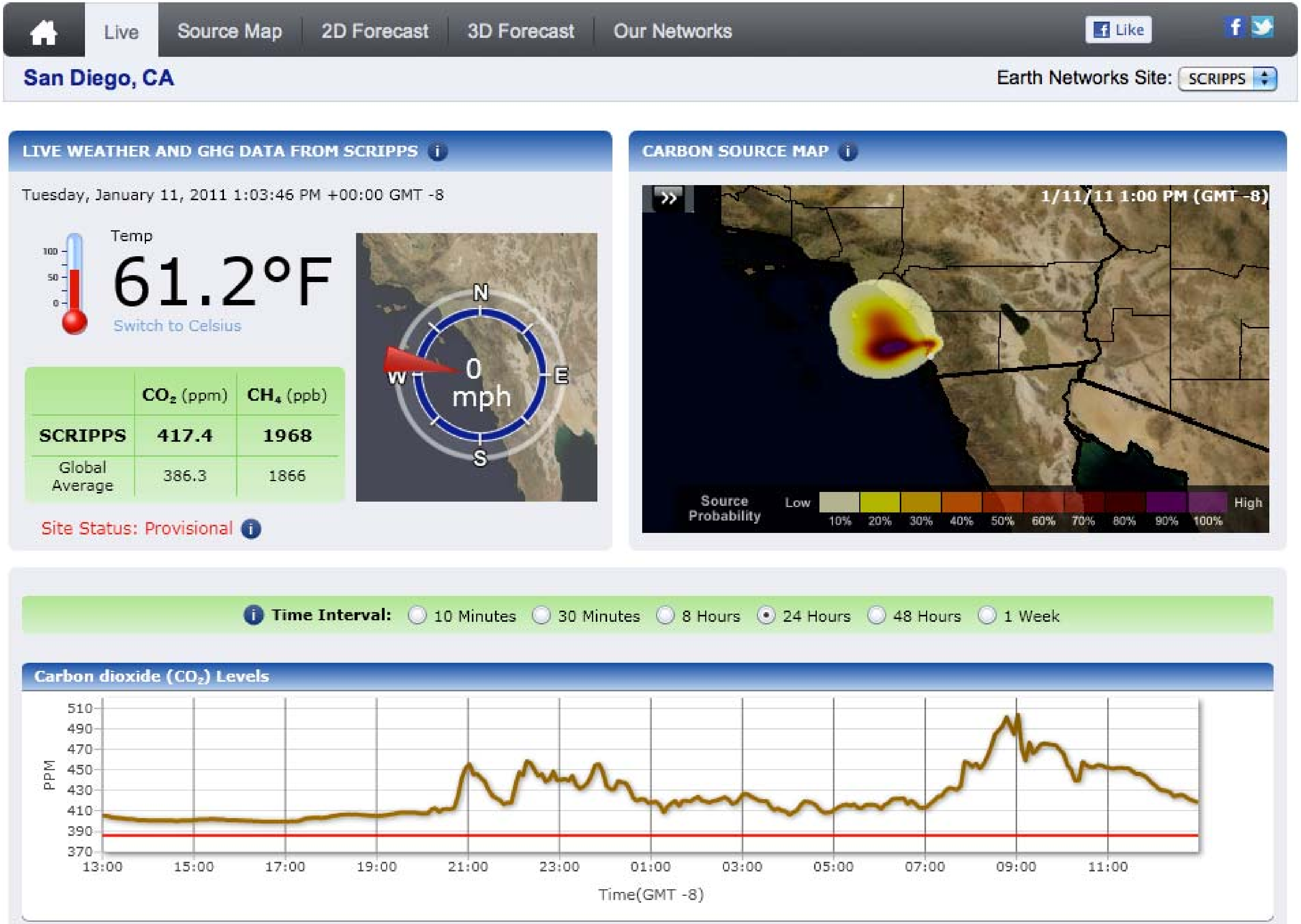
Typical Tower: Lewisburg, Pennsylvania



Site Data…



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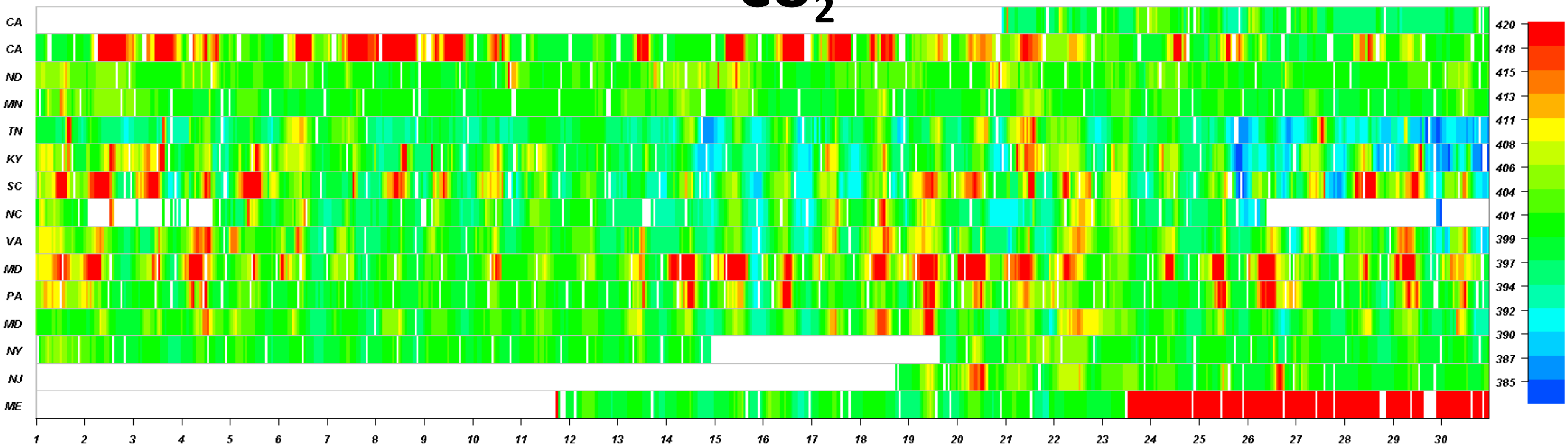
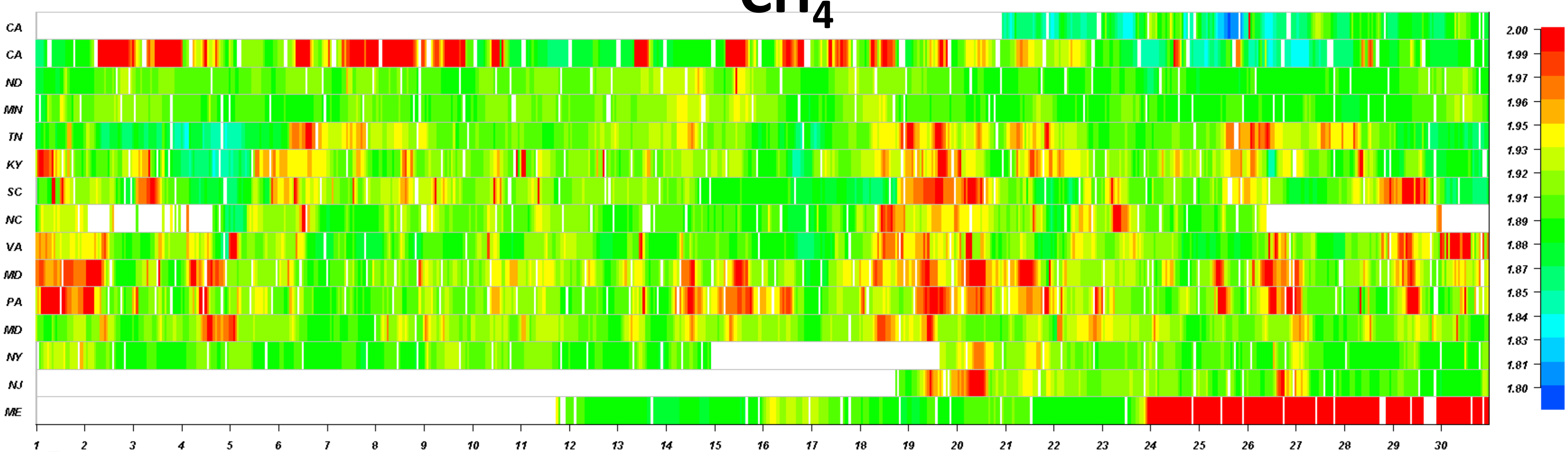
Network Data Accumulating!

CO_2



CH_4



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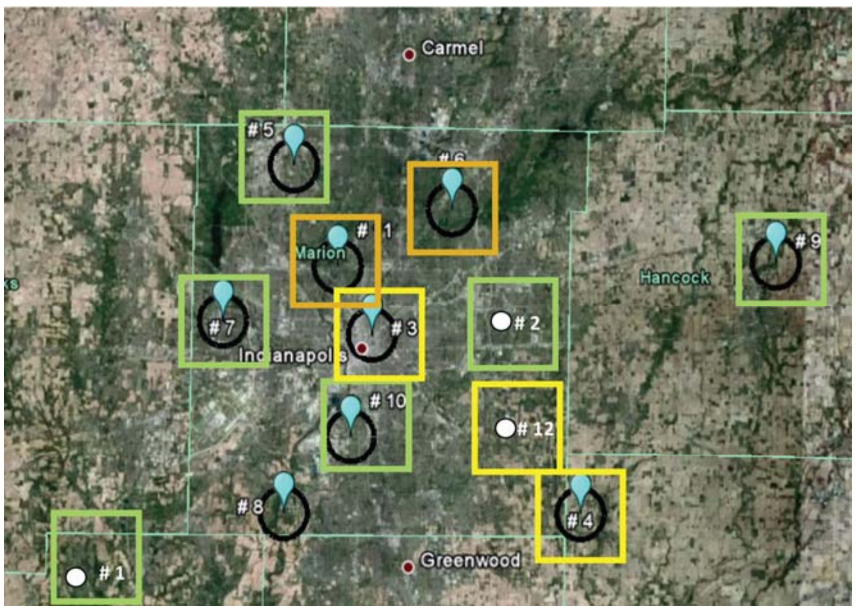
MegaCity Emissions

Urban Scale Carbon Networks (MegaCities)

Indianapolis Network (INFLUX)



Proposing LA Network

Pre-existing or already planned sites: Installed, Planned

Proposed new sites: Tower, Building

Europe?

Atmospheric Network Design in Europe

C. Gerbig[1], T. Koch[1], G. Broquet[2], F. Chevallier[2], P. Ciais[2], E. Novakovskaia[3]

1 Max-Planck-Institut für Biogeochemie, Jena, Germany
2 Laboratoire des Sciences du Climat et l'Environnement, Gif sur Yvette, France
3 Earth Networks, Germantown, USA
Contact: cgerbig@bgc-jena.mpg.de

1. Introduction and Motivation

To improve our understanding of GHG sources and sinks, as well as their rebalancing due to changes in climate and human impacts, long-term observations of atmospheric GHG made at representative locations over the continent will be an essential source of information. Atmospheric inverse systems provide the link between observed spatiotemporal patterns of atmospheric concentrations to surface fluxes based on the use of atmospheric transport models. As surface-atmosphere exchange fluxes of CO_2 and CH_4 exhibit significant variability in time and space, and as atmospheric mixing is not a reversible process, a priori information is required to regularize the inversion. This information is provided in the form of gridded inventories for anthropogenic emissions, and in the form of diagnostic or prognostic models for biospheric fluxes. Within the upcoming years ICOS and Earth Networks (EN) will largely increase the density of the atmospheric network in Europe. Coordinated efforts on planning, model aided network design, as well as data and instruments quality control have already been started. To assist decision-making with respect to the location and density of observing stations to be deployed, a quantitative network design is focused on optimizing the atmospheric constraint on specific targeted quantities. The target quantities for CO_2 are biospheric fluxes and anthropogenic emissions (fossil fuel combustion for CO_2) at a spatial resolution of 50 km, primarily focusing on mean annual fluxes, decadal trends, but also on seasonal and interannual time scales. For CH_4, anthropogenic emissions from agriculture, waste disposal, and fugitive emissions from fuel as well as natural emissions from wetlands are targeted. This network design assessment will also help refining those targets with respect to what can be achieved given a fixed number of atmospheric observing sites. The assessment uses multiple inversion modelling systems with different transport models, different definitions of the flux space (e.g. in term of space and time resolution) to be optimized by the inversion, and different implementations of error covariances to account for the uncertainties in transport modeling and prior fluxes. A step by step methodology is applied to select sensible locations for the new stations to be set-up, to characterize the sensitivity of concentrations at these locations to anthropogenic or biogenic fluxes and to assess their potential for constraining the inversion of fluxes.

Category	Quantity	Expected flux signal at 50 km resolution
NEP (biosphere)	seasonal variability	400 g C/m^2/y over a month
	interannual variability	150 g C/m^2/y from year to year
	fluxes mean value	20 g C/m^2/y over a decade
	decadal trends	5 g C/m^2/y^2 over a decade
Fossil fuel CO_2 Emissions	Variability	10 to 10^3 g C/m^2/y over a week
	Mean	100 to 10^4 g C/m^2/y over a decade
	Trends	25 g C/m^2/y over a decade

Table 1. Notional target accuracy requirements under discussion for network design assessment, together with typical expected signals for different temporal scales. The targeted uncertainty is 10% of the expected signal at a resolution of 50 km. (Source: ICOS network design workshop, Sep. 2010)

2. Background

In a Bayesian inversion with Gaussian error statistics (assuming all errors to be of random nature with no bias), statistically optimal fluxes derived from atmospheric mole fraction measurements and their spatial and temporal patterns and from prior information (e.g. fluxes from diagnostic biosphere models) minimize the following cost function:

$$J = (\mathbf{H}x - y)^T \mathbf{C}_y^{-1} (\mathbf{H}x - y) \quad + \quad (x - x_{prior})^T \mathbf{C}_{prior}^{-1} (x - x_{prior})$$

When assessing a network for its potential to constrain surface-atmosphere fluxes, the main quantity of interest is the posterior uncertainty, which combines measurement uncertainty C_y, transport operator H, and prior uncertainty C_{prior}:

$$\mathbf{C}_{post} = \left(\mathbf{H}^T \mathbf{C}_y^{-1} \mathbf{H} + \mathbf{C}_{prior}^{-1}\right)^{-1}$$

Rows of the transport operator (H matrix) contain the sensitivities of atmospheric mixing ratio at a specific time and location to upstream surface fluxes ("footprints"). The denser a network is, and the larger the H matrix terms are for a given network locations, the better will be the constraint on fluxes.

For network optimization, measurement locations can be varied individually until the posterior uncertainties of the target quantities are minimized; alternatively, the posterior uncertainty of different candidate networks can used to assess their potential. It is obvious that the resulting uncertainty of a target quantity strongly depends on the off-diagonal elements, i.e. on the correlation of uncertainties in fluxes at different locations or different times.

3. General Approach

3.1. Step one: Initial selection considering emission patterns

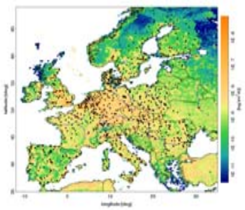


Fig. 1: Locations of 989 feasible towers and masts with a height taller than 100m, using databases from ICOS (existing stations and stations, where location has been decided on), from Wikipedia, and from the European AIS (aeronautical information service) database (EAD). The background map shows CO_2 emissions based on the EDGAR V4.1 inventory at 0.1 deg resolution.

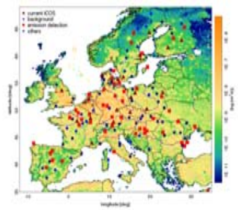


Fig. 2: Locations of 140 potential tall tower stations retained using criteria related to fossil fuel emission distribution. This includes 19 current ICOS sites (dark red triangles), 22 background sites (blue filled circles), 51 emission detection sites (red filled squares), and 48 other sites (dark blue filled circles).

Site category	Near-field criterion	Intermediate distance criterion	
Emission detection	Within 20 km: emissions < 70%ile of all emissions within 500 km	Within 20 – 150 km: some emissions > 98 %ile of all emissions within 500 km	Minimum distance of 50 km to current ICOS stations
Background	Within 35 km: emissions < 85%ile of all emissions within 500 km	-	Minimum distance of 50 km to current ICOS stations and to "Emission detection" sites
Other	Within 35 km: emissions < 95%ile of all emissions within 500 km	-	Minimum distance of 50 km to current ICOS stations and to "Emission detection" sites

Table 2: Selection criteria for the different stations

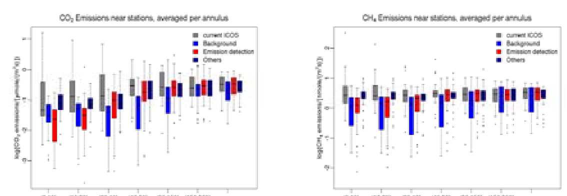


Fig. 3: Distribution of CO_2 (left) and CH_4 (right) emissions averaged over specific distance ranges from the potential observing sites belonging to the different site categories "current ICOS" (grey), "Background" (blue), "Emission detection" (red), and "Others" (dark blue).

3.2. Step two: Footprint analysis

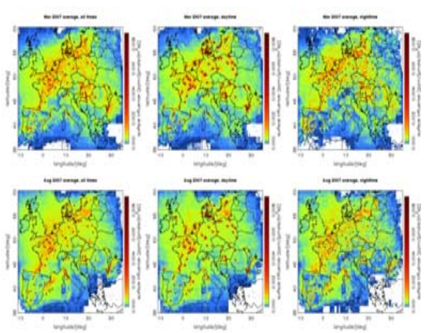


Fig. 4: Combined footprints for monthly mean mixing ratios measured at 79 potential stations (indicated by black dots) during afternoon (15:00 GMT). Shown are STILT-ECMWF derived sensitivities to surface-atmosphere fluxes independent of when fluxes occur (left), to daytime fluxes between 12:00 and 18:00 (middle), and to night-time fluxes between 0:00 and 6:00 (right). Results are for March 2007 (upper row) and August 2007 (bottom row). Footprint numerical values decrease very quickly with increasing spatial distance from each station (notice the non-linear color scale).

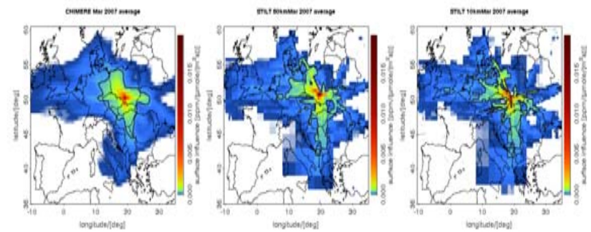


Fig. 5: Comparison of footprints for a potential tall tower in southern Poland (FM and TV mast Kosztowy) calculated with ECMWF-CHIMERE (left), ECMWF-STILT with 0.5x0.5 deg lat-lon resolution (middle) and STILT with 1/12 x 1/8 deg lat-lon resolution (right). Shown are sensitivities of monthly mean observations made at 15:00 to surface fluxes (day and night) for the month of March 2007. Note that the values for the high resolution STILT footprints were scaled up by the grid area ratio to achieve comparable color scales. The black contour line indicates the 50% largest sensitivities.

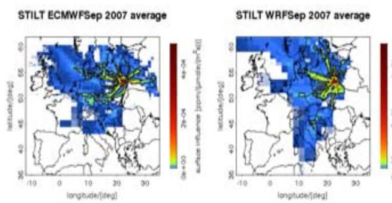


Fig. 6: Comparison of footprints for a potential tall tower in southern Poland (FM and TV mast Kosztowy) for the month of September 2007 calculated with ECMWF-STILT (left) and WRF-STILT(right). Notation as in Fig 5.

"Figure of merit in space" (FMS) to analyze the agreement of the contour lines (or the area within) corresponding to the percent largest footprint (e.g. the 50% contour in the monthly mean footprint plot). The FMS is the number of pixels within the contour of both models divided by the number of pixels in the combined area (ratio of intersecting set to union set).

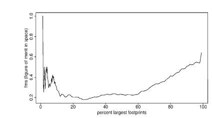


Fig. 7: FMS for different contour levels. For x<1% there is a perfect agreement, as both models identify the local pixel as the one with strongest influence.

3.3. Step three: uncertainty reduction (Outlook)

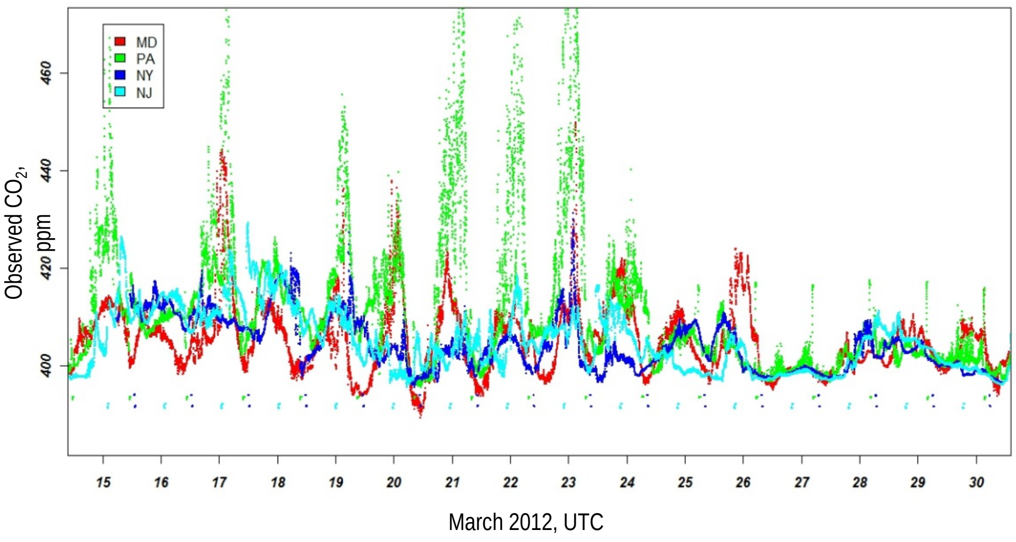
To assess uncertainty reduction that can be expected from the use of potential networks, two different inversion systems will be used, one solving for fluxes at pixel based resolution, and one solving for linearized (scaling) parameters in a flux model. This requires:
-Coherent a priori estimates of the state (flux or parameter values) is required with associated a priori uncertainty matrix, which impose the same constraint on the fluxes at specific temporal and spatial scales of aggregation (e.g. EU wide annual fluxes and national monthly fluxes).
-Coherent treatments of uncertainty related to the lateral boundary conditions of the regional inversions.
-Coherent accounts for uncertainties in fluxes from fossil fuel emissions, potentially solving for associated fluxes
-Candidate networks of 70 potential tall tower sites (the size of the combined ICOS-EN network) will be chosen that represent different strategies (network with spatial gaps vs. homogeneous network vs. network focusing on emissions)
-Each candidate network will be evaluated for its potential to reduce uncertainties in the target quantities listed in Table 1.

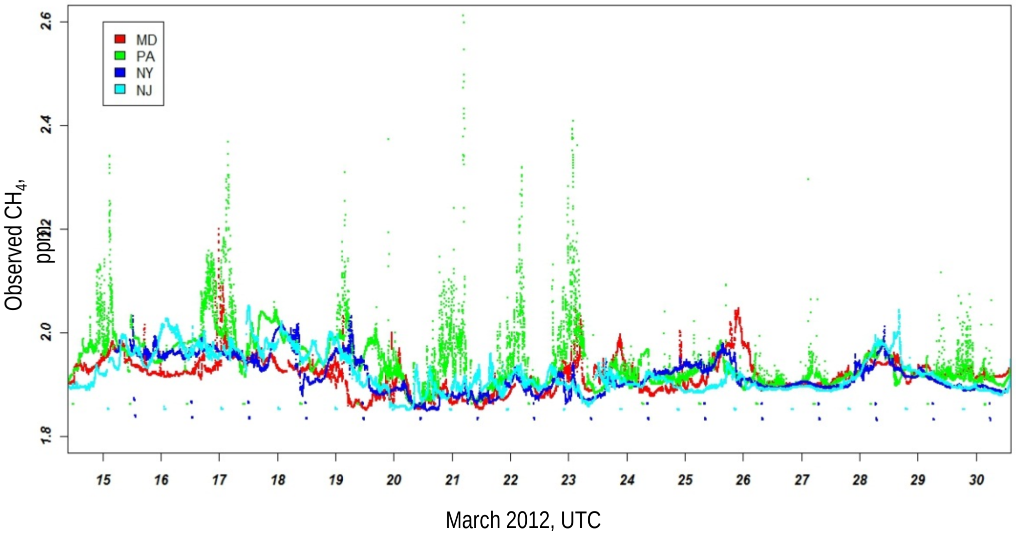
4. Conclusions

A network design assessment has been initiated for atmospheric network to quantify regional scale budgets of CO_2 and CH_4 using various high-resolution inversion systems:
-An initial selection of 140 existing tall towers and footprint analysis implies the need for more spatial homogeneity of the network.
-Comparison of the Lagrangian model STILT and the Eulerian model CHIMERE, and various meteorology suggests the use of a larger "ensemble" of transport models with more spread.
-Future assessment of uncertainty reduction will take into account the full posterior error covariances resulting from different regional scale inversion systems.

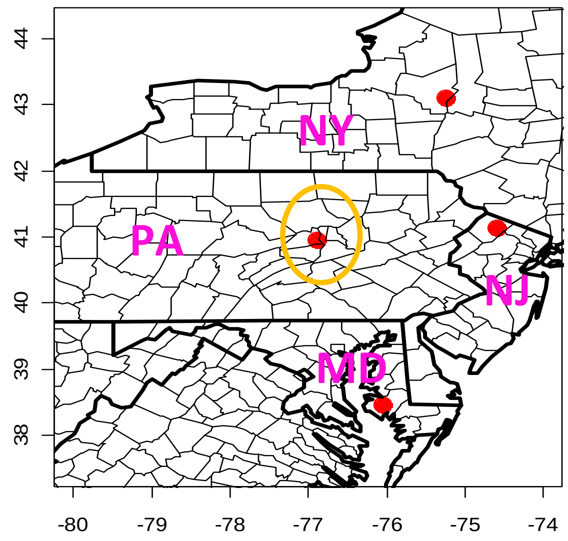
Inversion Example…

Recent Northeast Data

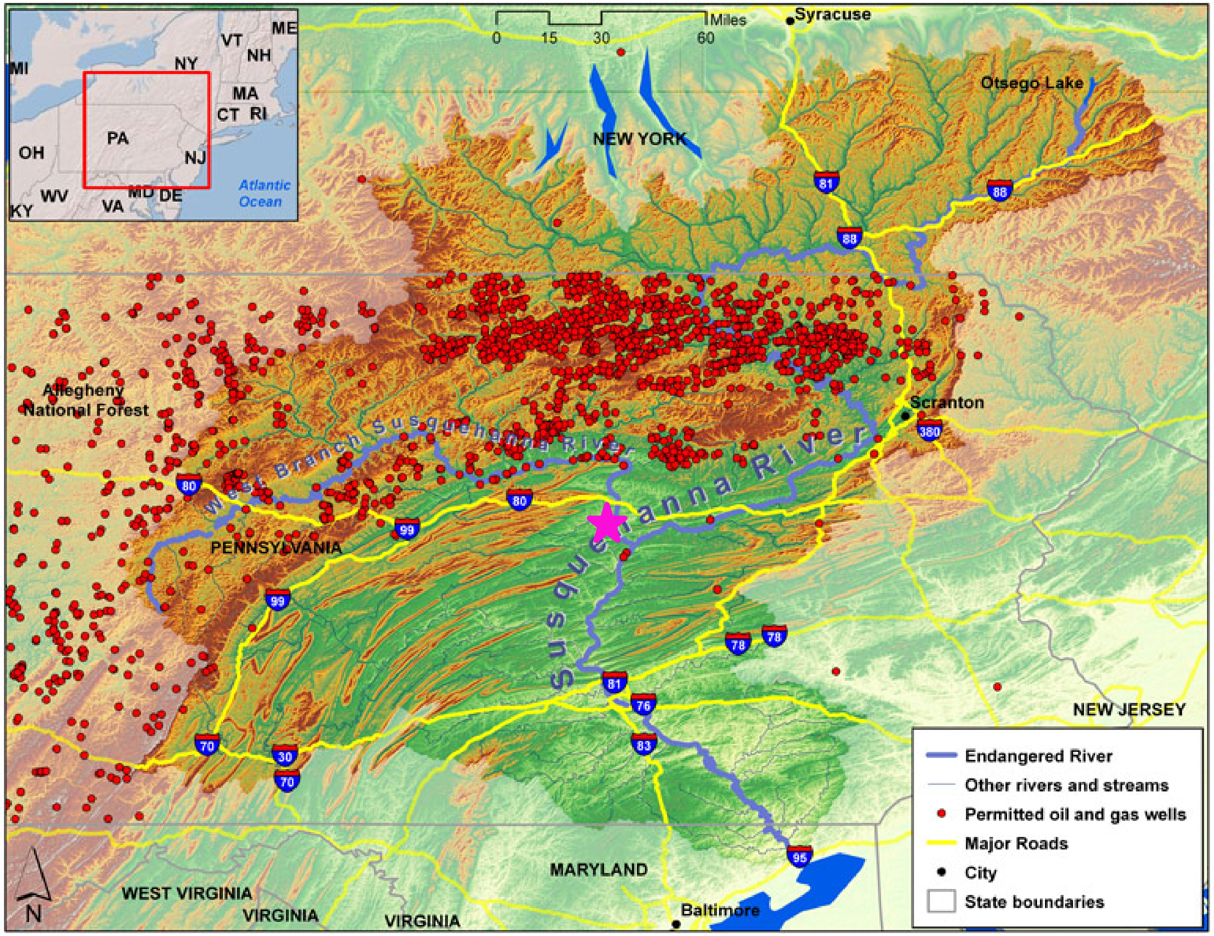




- Timeseries of CO_2 (top) and CH_4 (bottom) at the sites in MD, PA, NY and NJ on March 15-30, 2012 (top of the tower measurements)
- Line of lower points shows calibration data (once per day)



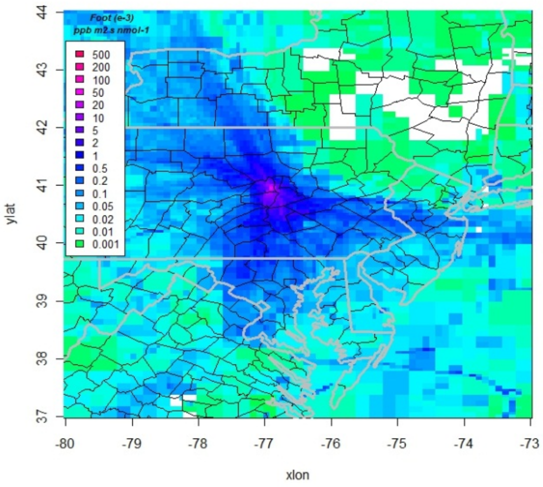
Relevance to Gas and Oil Wells in PA



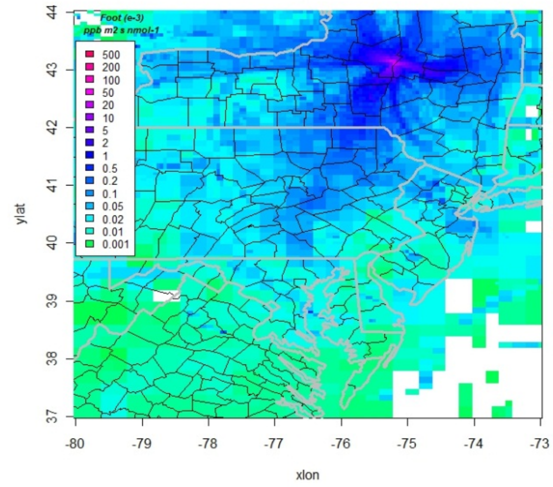
[Source: http://www.americanrivers.org/our-work/protecting-rivers/endangered-rivers/endangered-susquehanna.html?gclid=CLC1oq-fj68CFUXc4AodTSv0zA](http://www.americanrivers.org/our-work/protecting-rivers/endangered-rivers/endangered-susquehanna.html?gclid=CLC1oq-fj68CFUXc4AodTSv0zA)

72hr Footprints and Multi-site Analysis

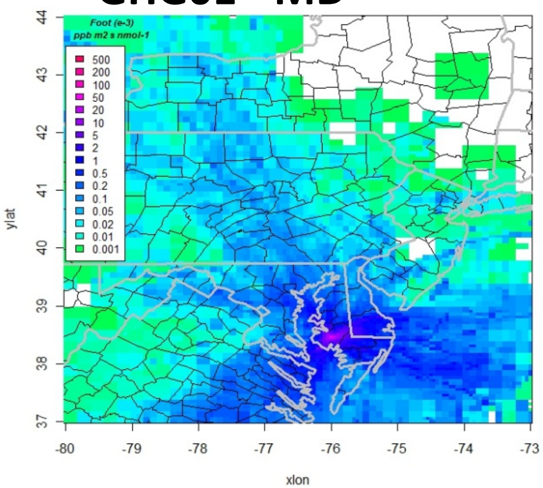
GHG25 - PA



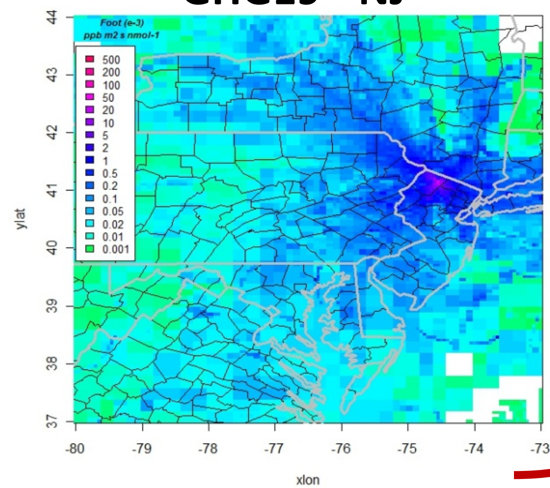
GHG38 - NY



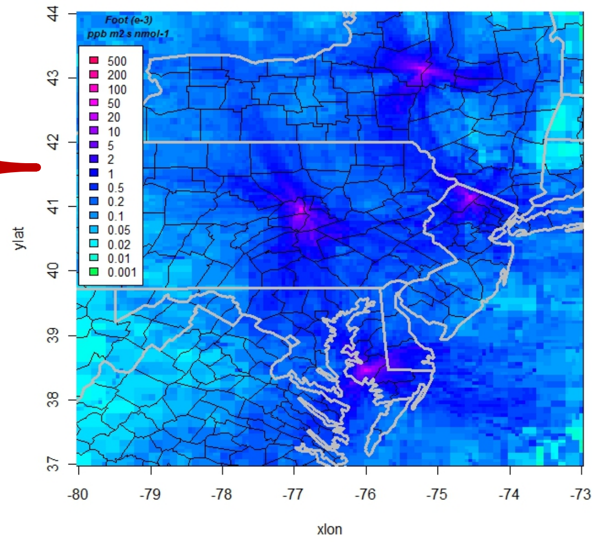
GHG01 - MD



GHG19 - NJ

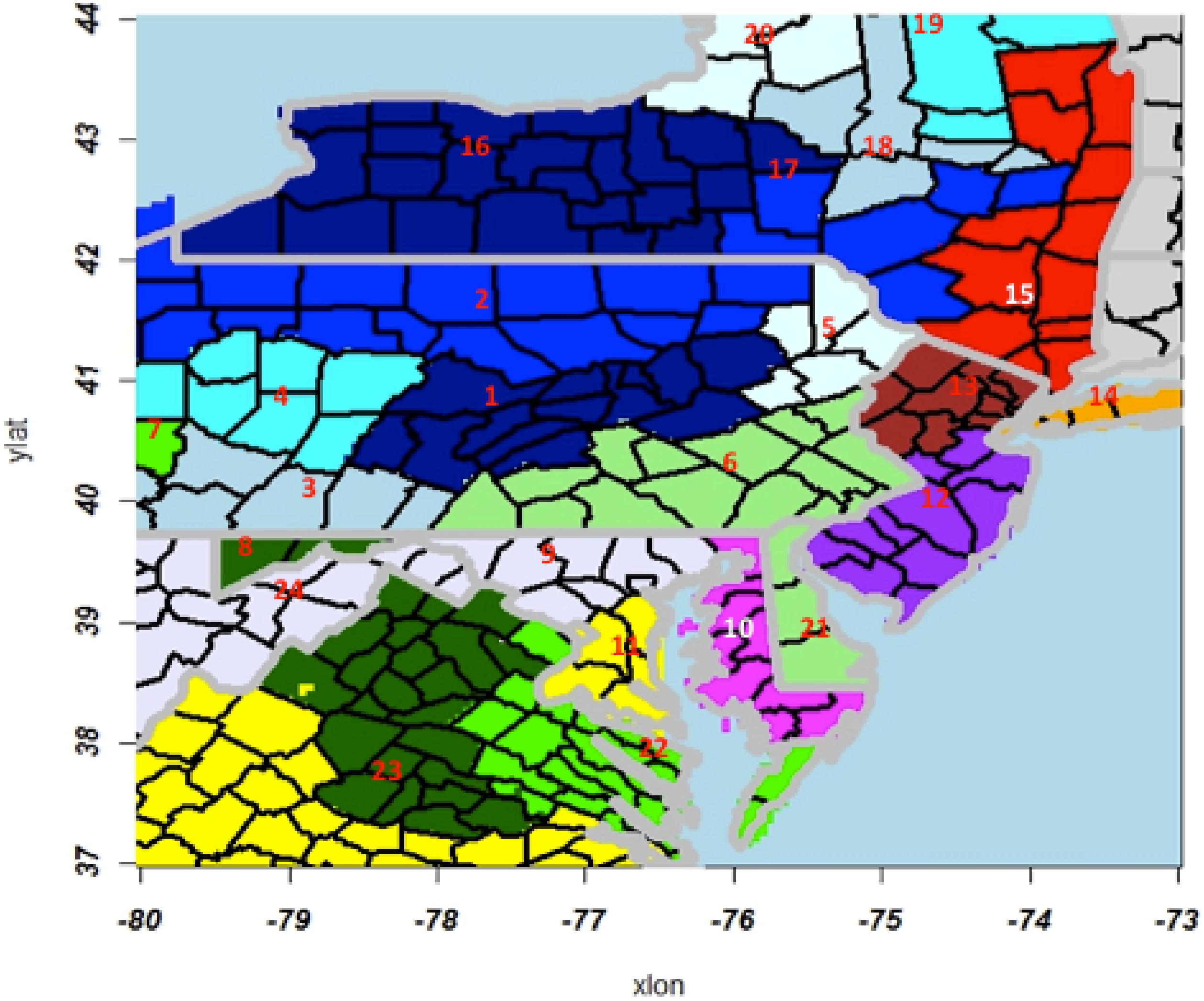


COMBINED



March 2012 monthly averaged 3-day backward footprints for mixing ratio measured at each tower

Spatial Regions in the Domain



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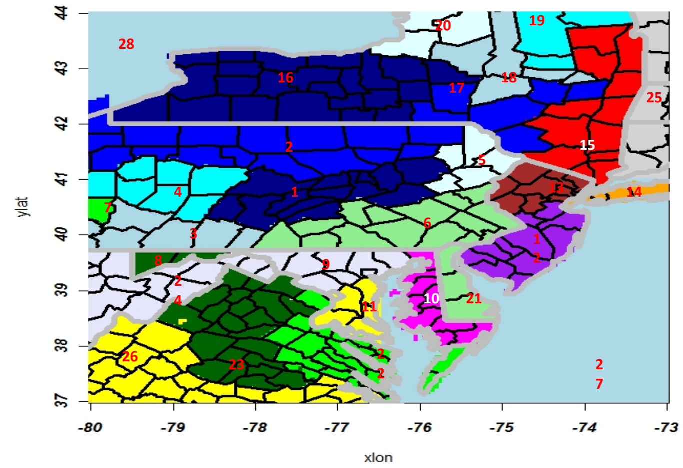
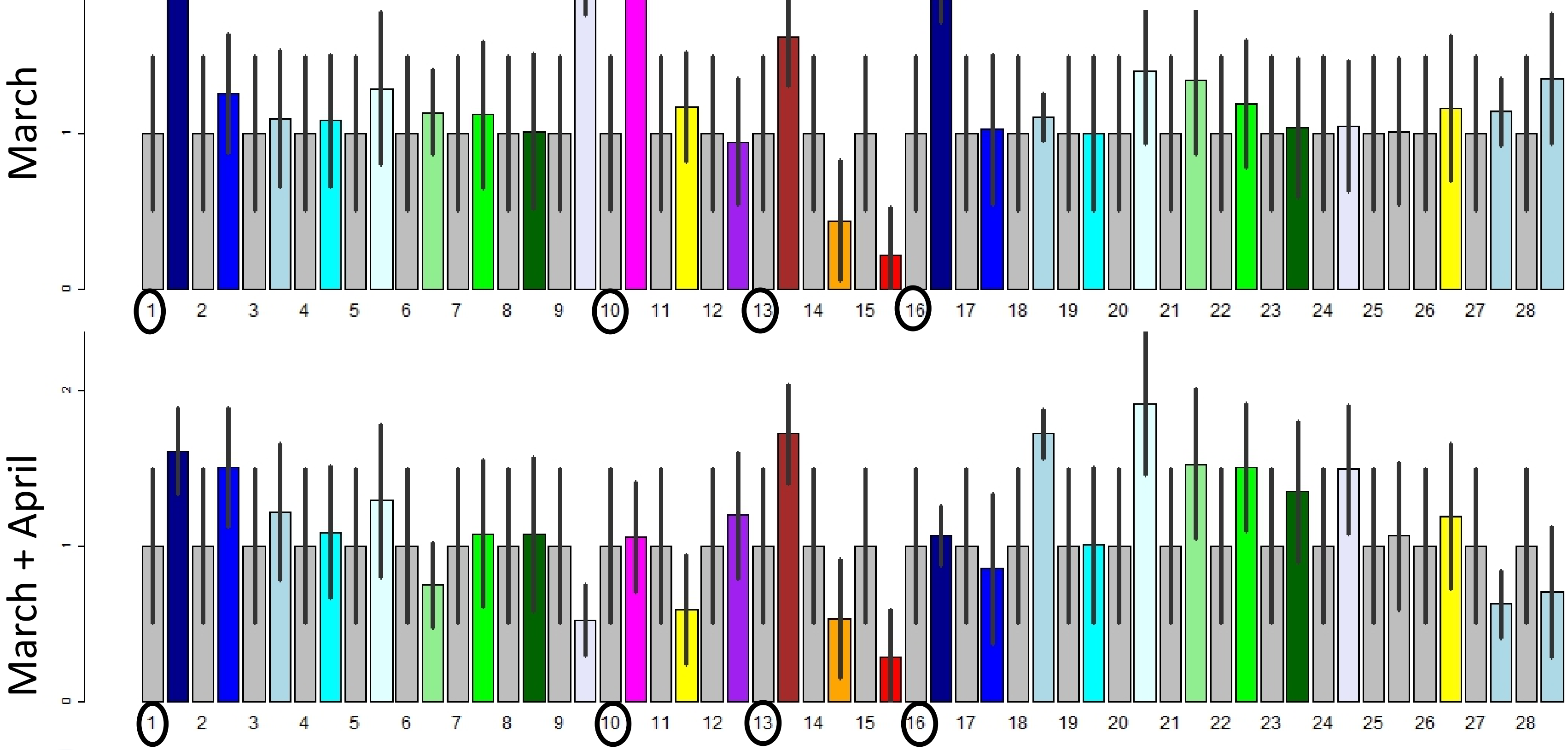
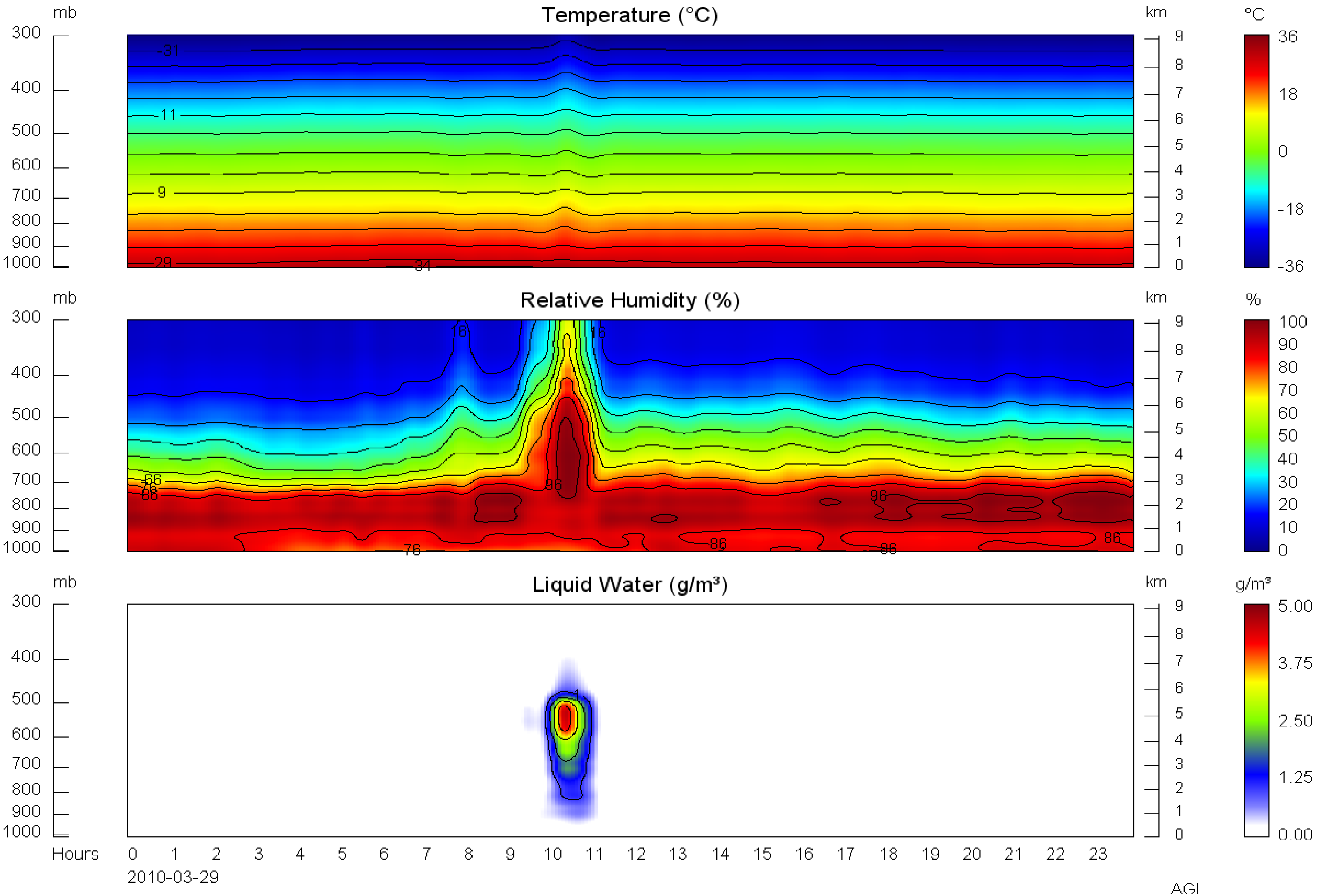
Initial Inversion Results (Preliminary)





Boundary Layer Network


radiometrics
CORPORATION
DO NOT TOUCH



Landward (off-zenith) retrievals 29 Mar 2010

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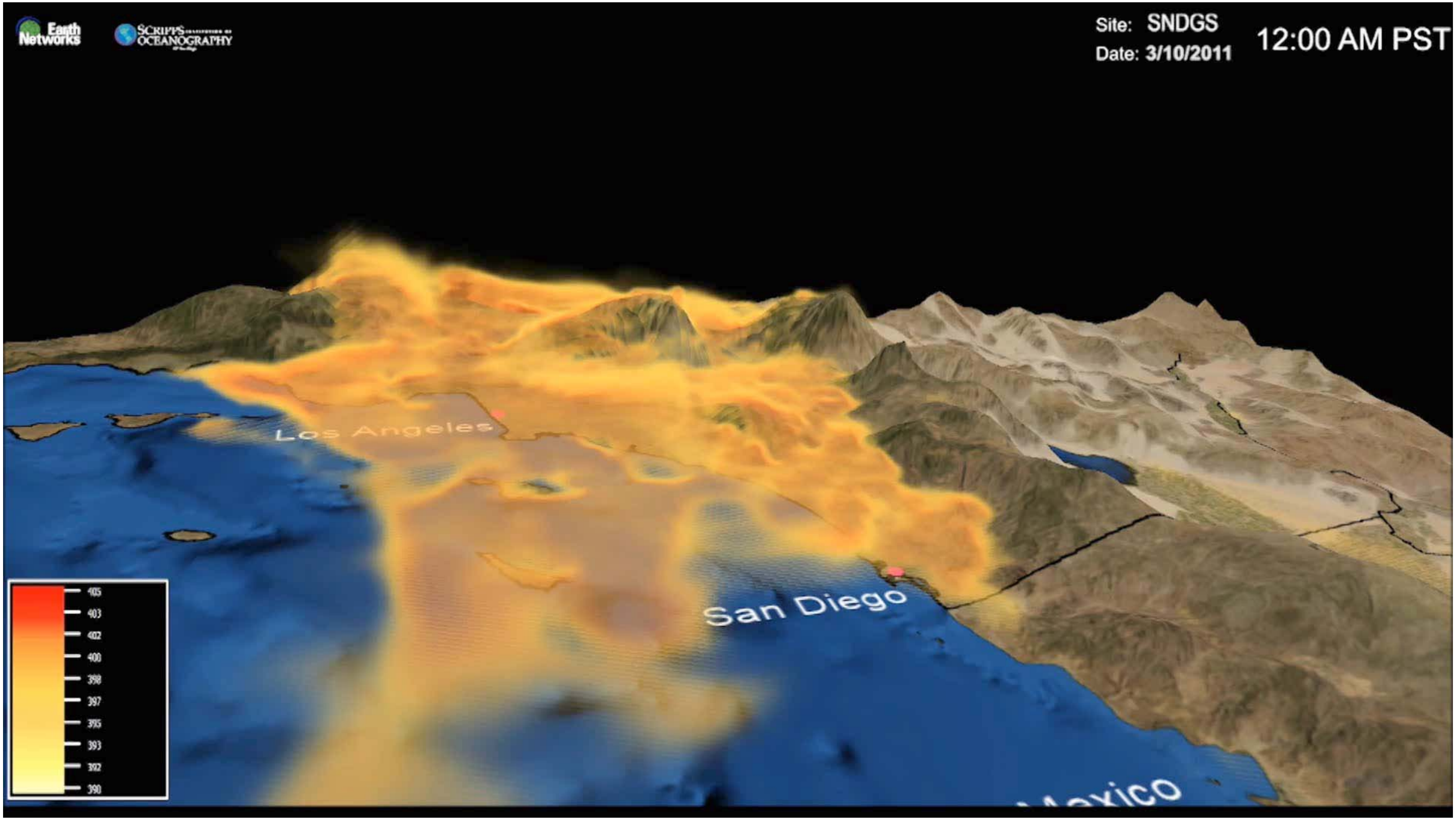
Carbon Weather : Educating the Public

CO2 Above Global Mean



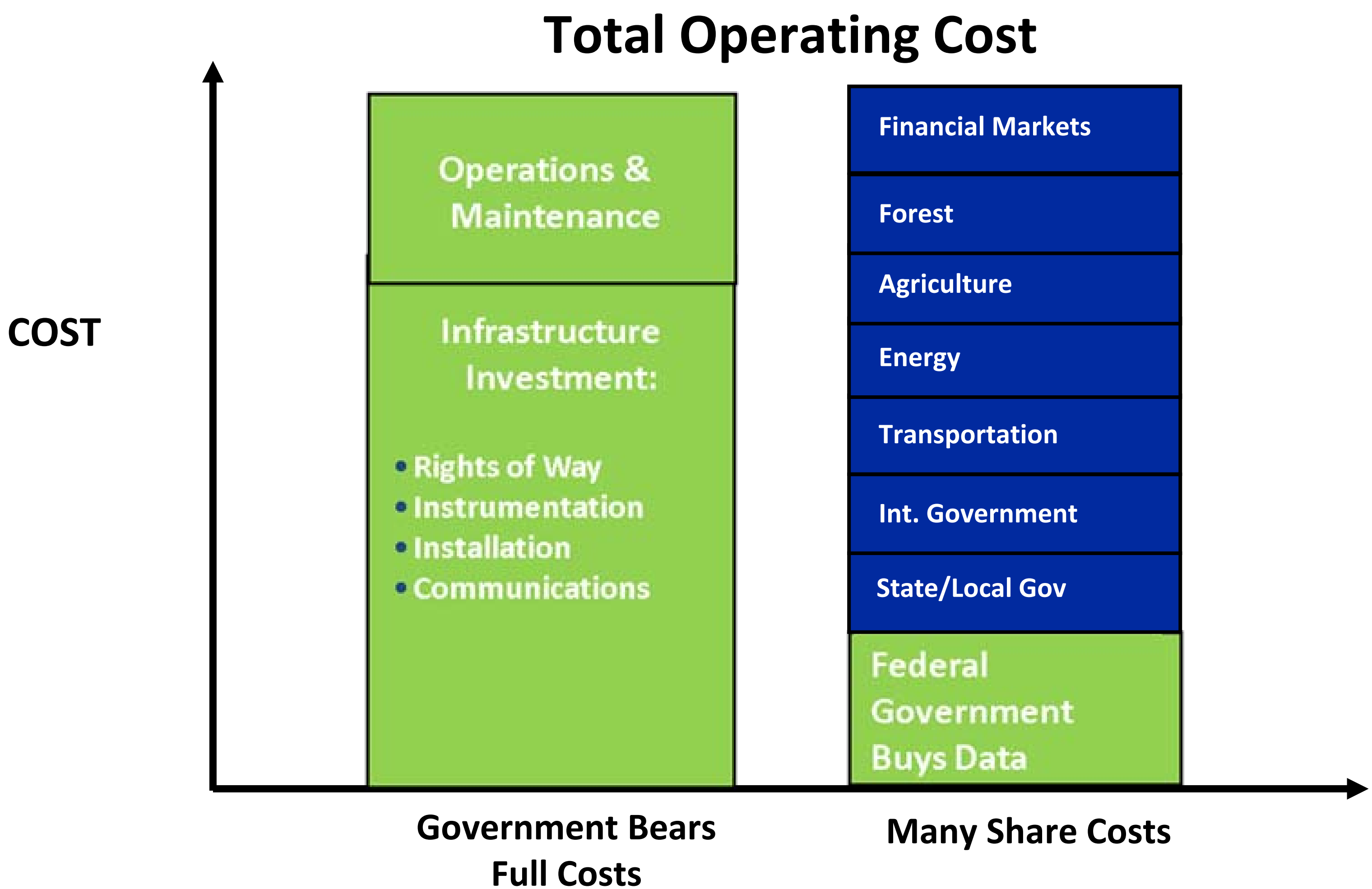
How can we partner?

What discoveries are hiding in the data?
Where else would you like to measure?
What else would you like to measure?
How can we do this faster?

We invite you to engage us in collaborative discourse!

Thank You!

Public-Private Partnership Model Shares Obs Cost Across Many Users



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