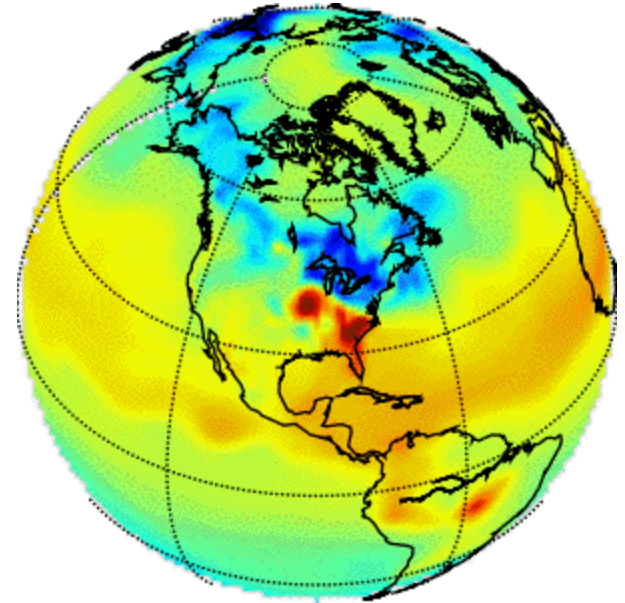


A Lagrangian Particle Dispersion Model Approach for Evaluating CarbonTracker



A. Andrews¹, A. Hirsch², A. Michalak³, C. Sweeney², S. Wofsy⁴,
J. Eluszkiewicz⁵, T. Nehrkorn⁵, A. Jacobson², K. Masarie¹,
W. Peters^{2,6}, K. Croasdale⁷, P. Tans¹

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²Cooperative Institute for Research in Environmental Sciences, University of Colorado,
Boulder, CO 80309

³Department of Civil and Environmental Engineering, and Department of Atmospheric,
Oceanic and Space Sciences, University of Michigan, Ann Arbor, MI 48109

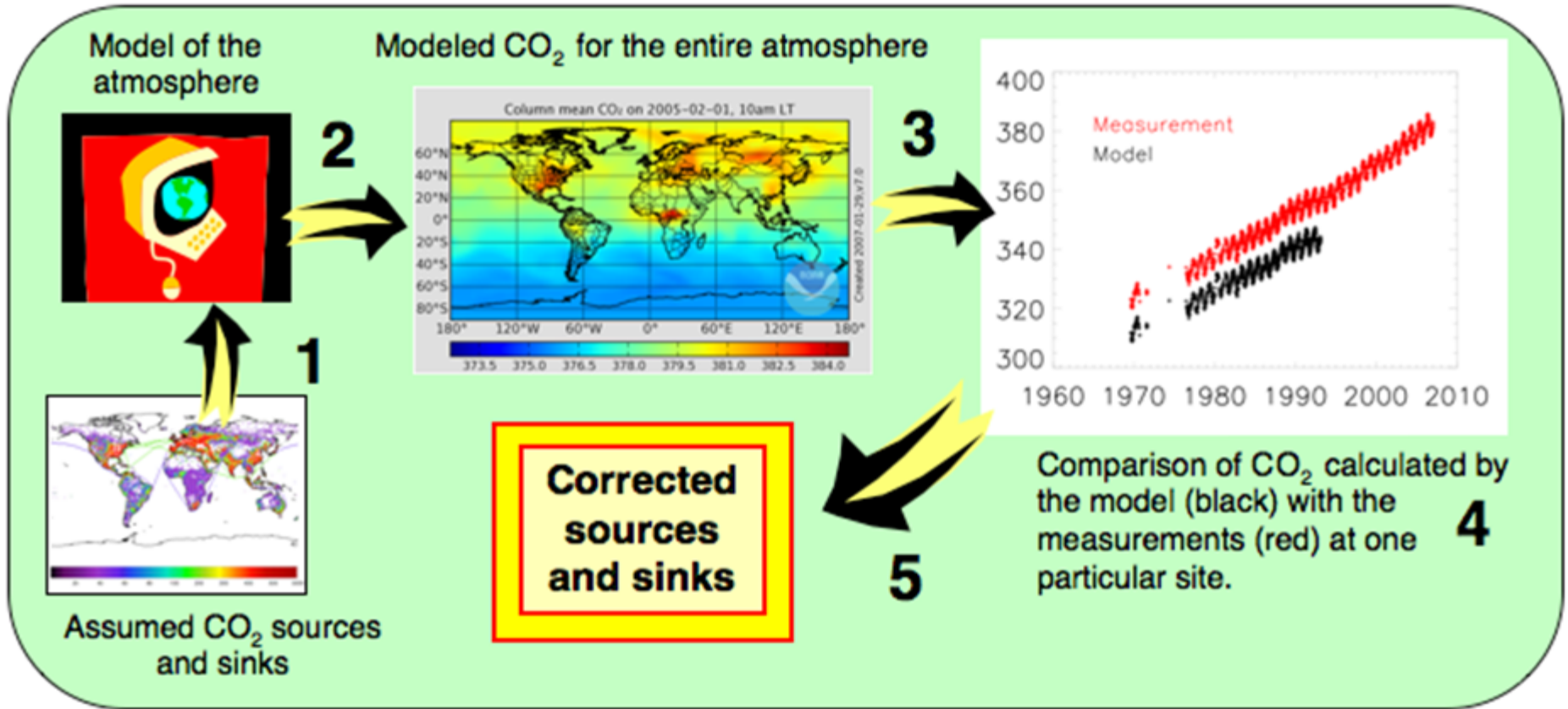
⁴Department of Earth and Planetary Sciences, Harvard University, Cambridge, MA 02138

⁵Atmospheric and Environmental Research, Inc., Lexington, MA 02421

⁶Wageningen University and Research Center, Wageningen, 6708 PB, the Netherlands

⁷Department of Environmental Sciences, University of Illinois, Springfield, IL 62703

CarbonTracker Overview

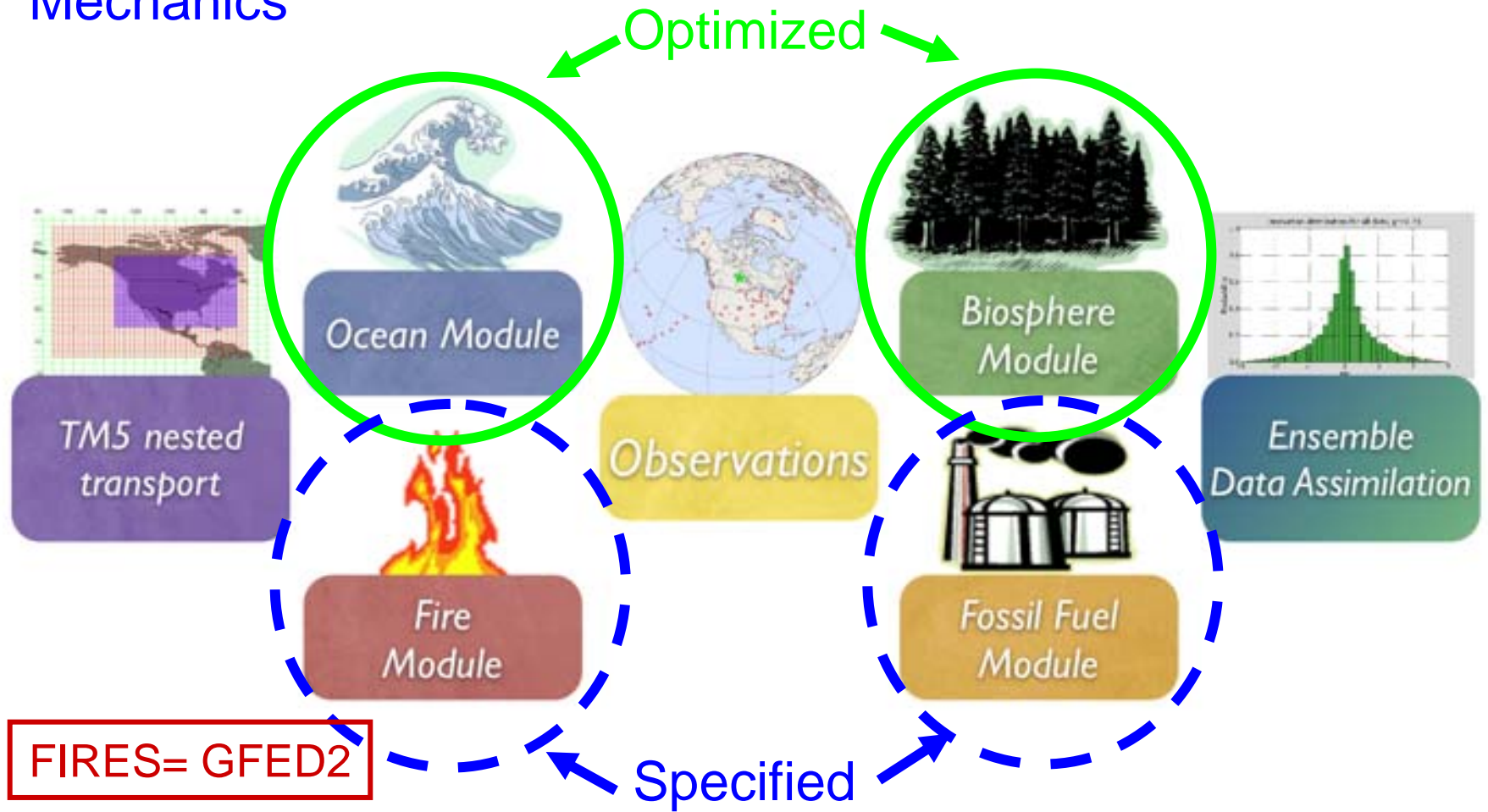


Optimization step is **Ensemble Kalman Filter**

<http://carbontracker.noaa.gov>



Mechanics

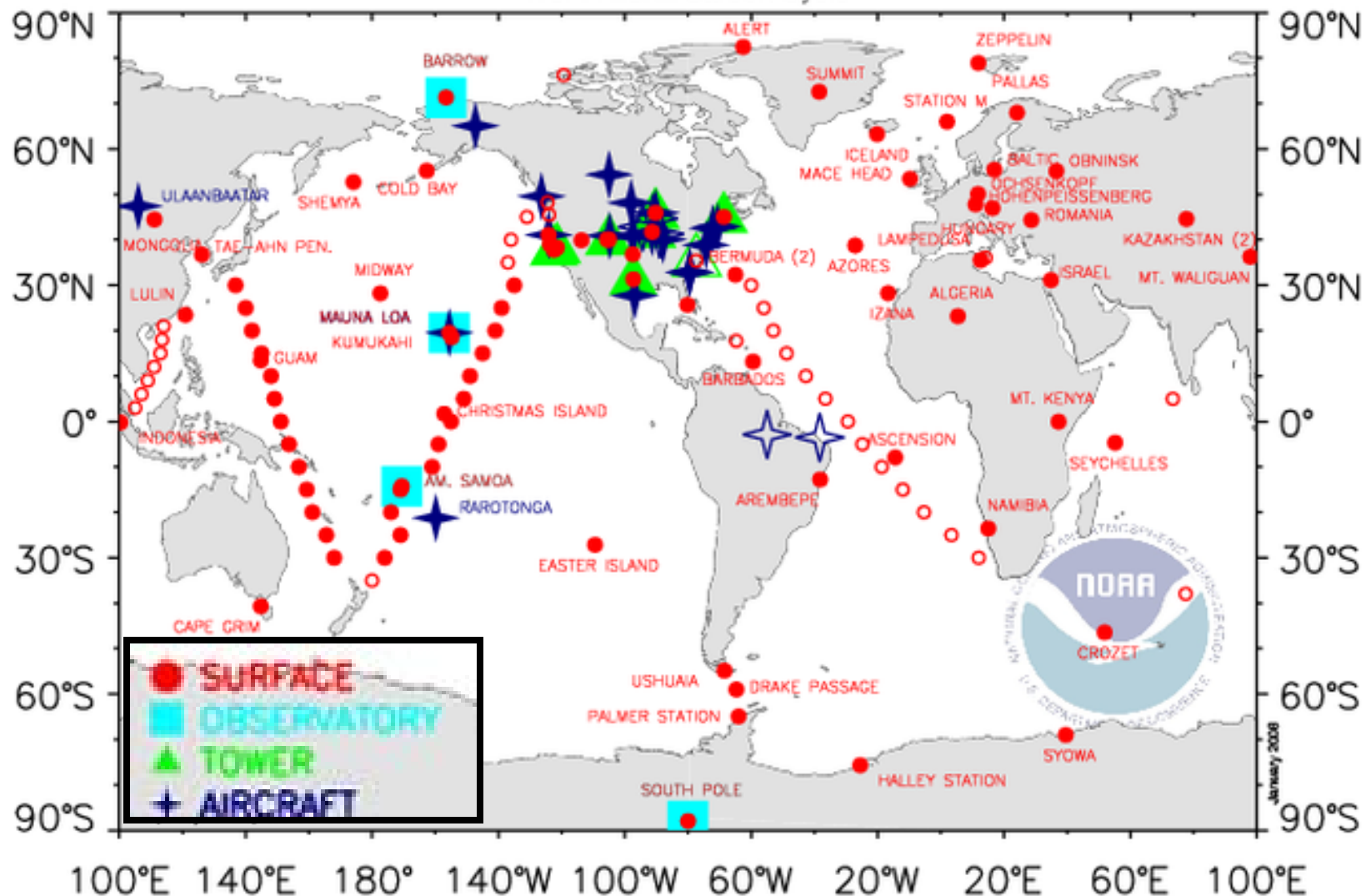


<http://carbontracker.noaa.gov>



Measurement Programs

NOAA ESRL Carbon Cycle



NOAA ESRL Carbon Cycle operates 4 measurement programs. Semi-continuous measurements are made at 4 baseline observatories and from tall towers. Discrete surface and aircraft samples are measured in Boulder, CO. Presently, atmospheric carbon dioxide, methane, carbon monoxide, hydrogen, nitrous oxide, sulfur hexafluoride, the stable isotopes of carbon dioxide and methane, and halocarbon and volatile organic compounds are measured. Contact: Dr. Pieter Tans, NOAA ESRL Carbon Cycle, Boulder, Colorado, (303) 497-6678, pieter.tans@noaa.gov, <http://www.esrl.noaa.gov/gmd/ccgg/>.

Optimized



An atmospheric perspective on North American carbon dioxide exchange: CarbonTracker

Wouter Peters^{*†‡}, Andrew R. Jacobson^{*†}, Colm Sweeney^{*†}, Arlyn E. Andrews^{*}, Thomas J. Conway^{*}, Kenneth Masarie^{*}, John B. Miller^{*†}, Lori M. P. Bruhwiler^{*}, Gabrielle Pétron^{*†}, Adam I. Hirsch^{*†}, Douglas E. J. Worthy[§], Guido R. van der Werf[¶], James T. Randerson^{||}, Paul O. Wennberg^{**}, Maarten C. Krol^{††}, and Pieter P. Tans^{*}

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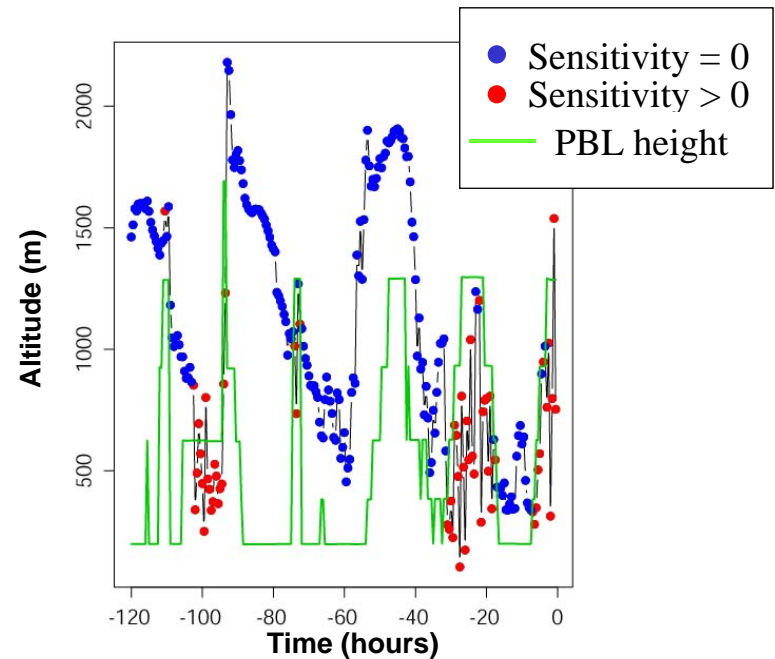
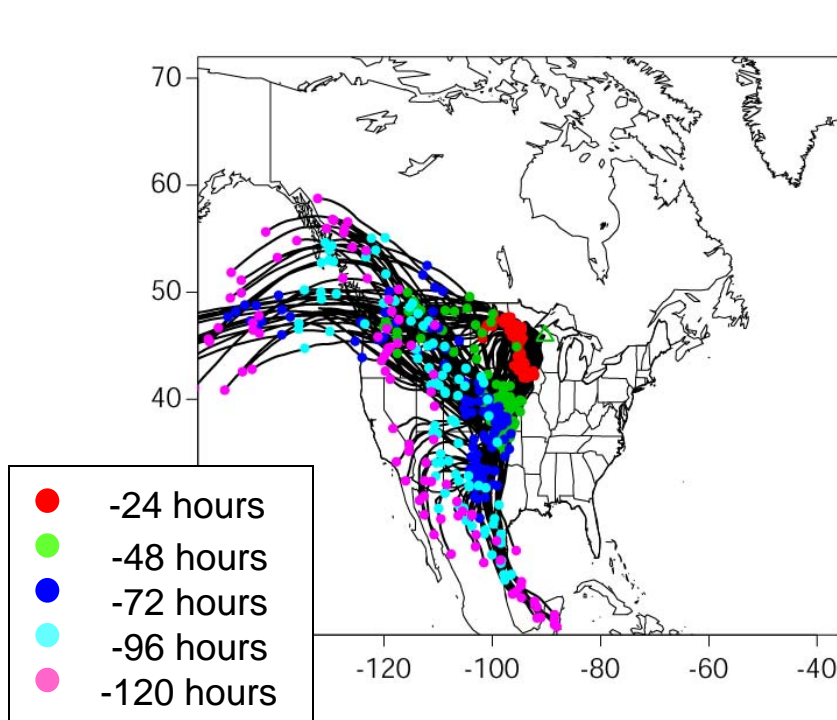
Communicated by A. R. Ravishankara, National Oceanic and Atmospheric Administration, Boulder, CO, September 27, 2007 (received for review May 23, 2007)

PNAS | November 27, 2007 | vol. 104 | no. 48 | 18925–18930

Sampling Footprints

Lagrangian Particle Dispersion Modeling

Stochastic Time Inverted Lagrangian Transport Model



$$CO_2^{meas} = CO_2^{BC} + \frac{1}{N} \sum_{p=0}^N \sum_{t=0}^{t_f} SENS * FLUX$$

Initial Condition (CarbonTracker)

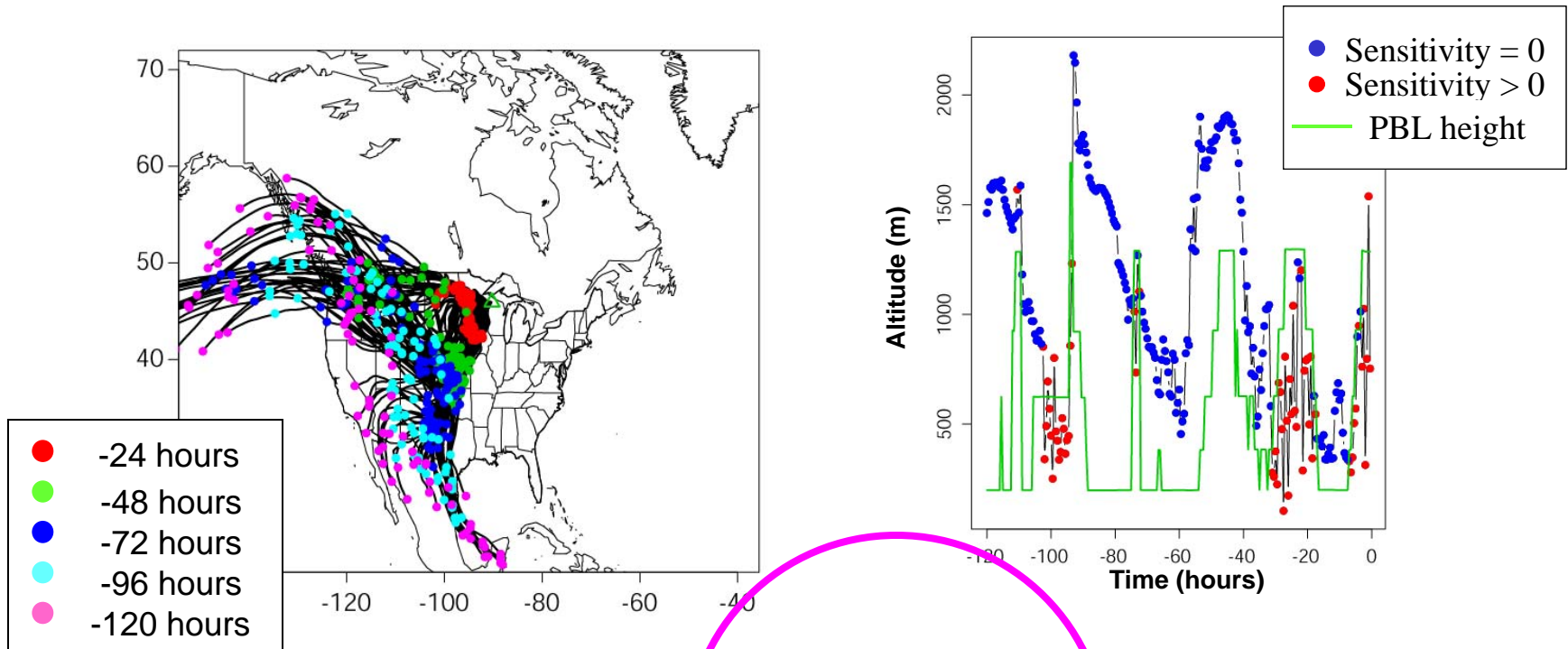
Footprint [ppm per unit flux]

CarbonTracker

Sampling Footprints

Lagrangian Particle Dispersion Modeling

Stochastic Time Inverted Lagrangian Transport Model

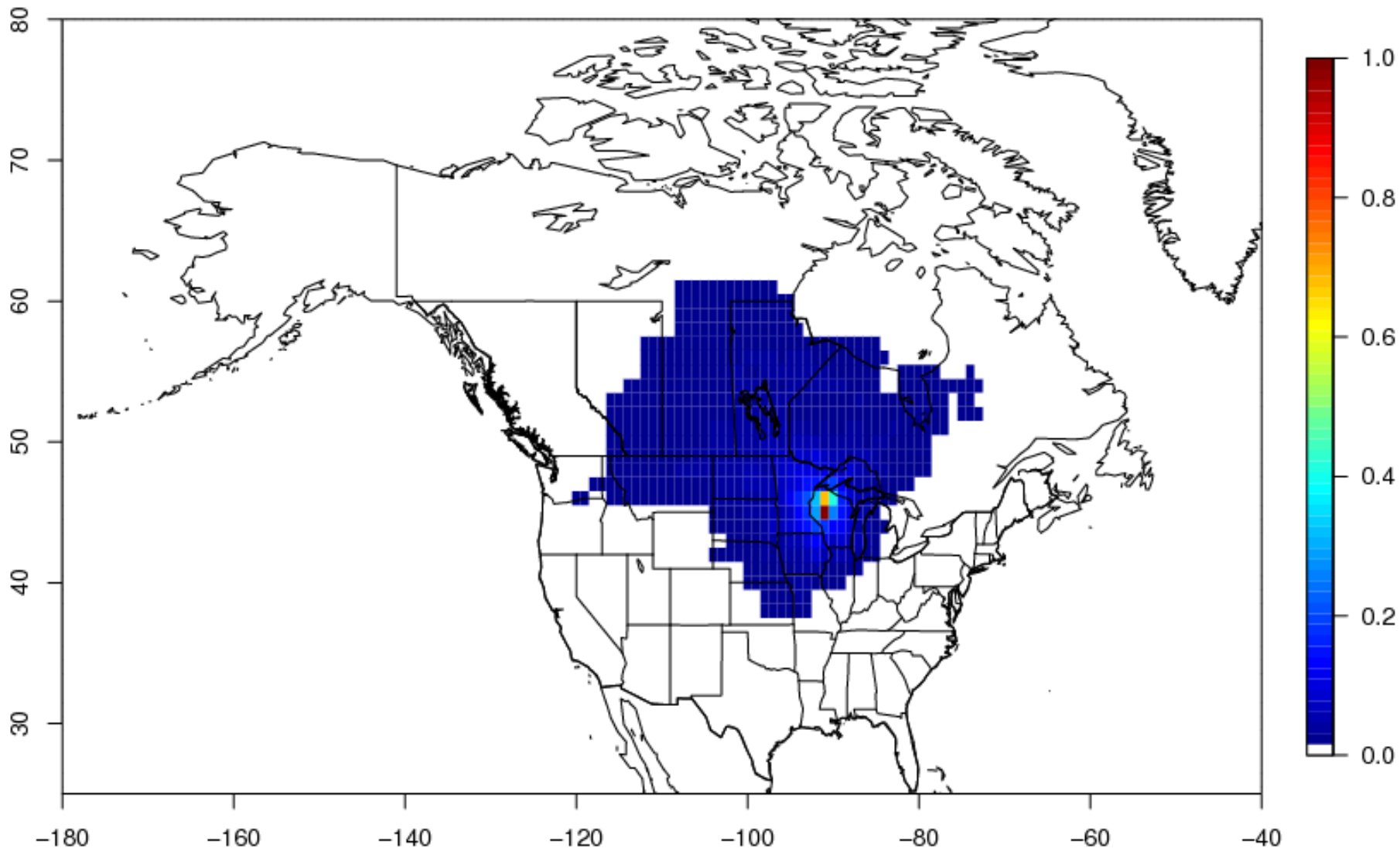


$$CO_2^{meas} = CO_2^{BC} + \frac{1}{N} \sum_{p=0}^N \sum_{t=0}^{t_f} SENS * FLUX$$

Initial Condition (CarbonTracker)

Footprint [ppm per unit flux]

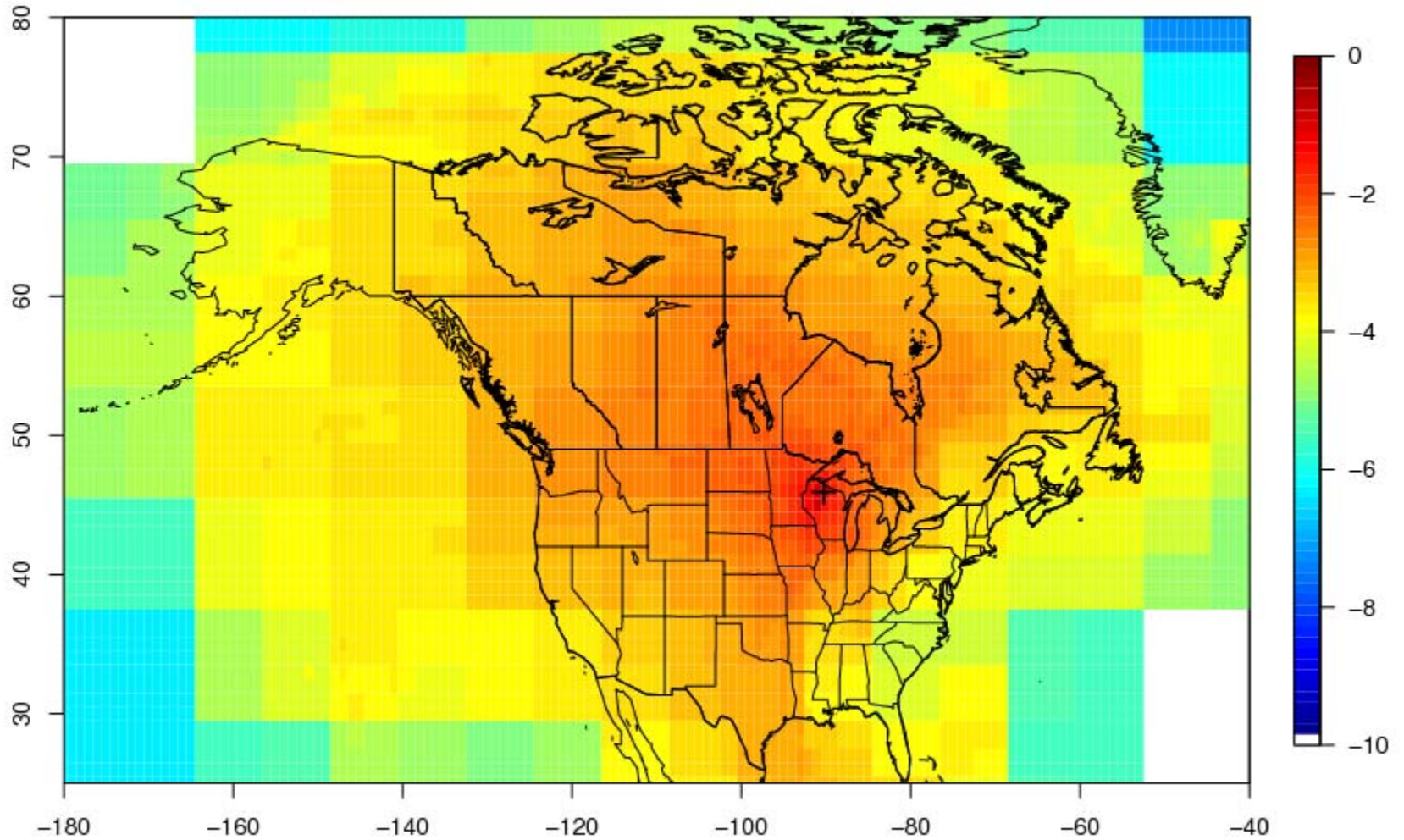
CarbonTracker



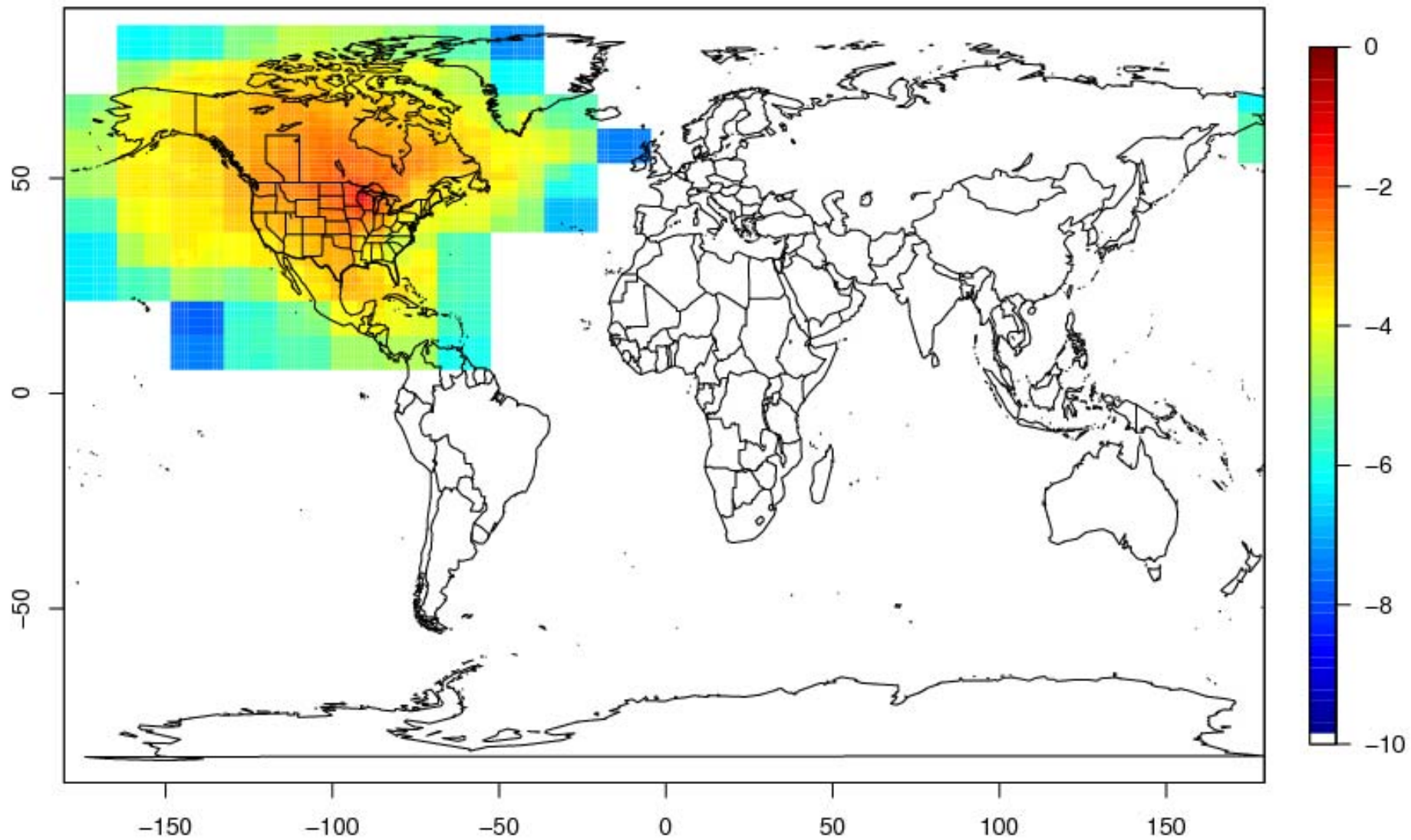
Normalized Footprint: Linear Color Scale
Composite: MAY-JULY 2004 LEF, 19GMT

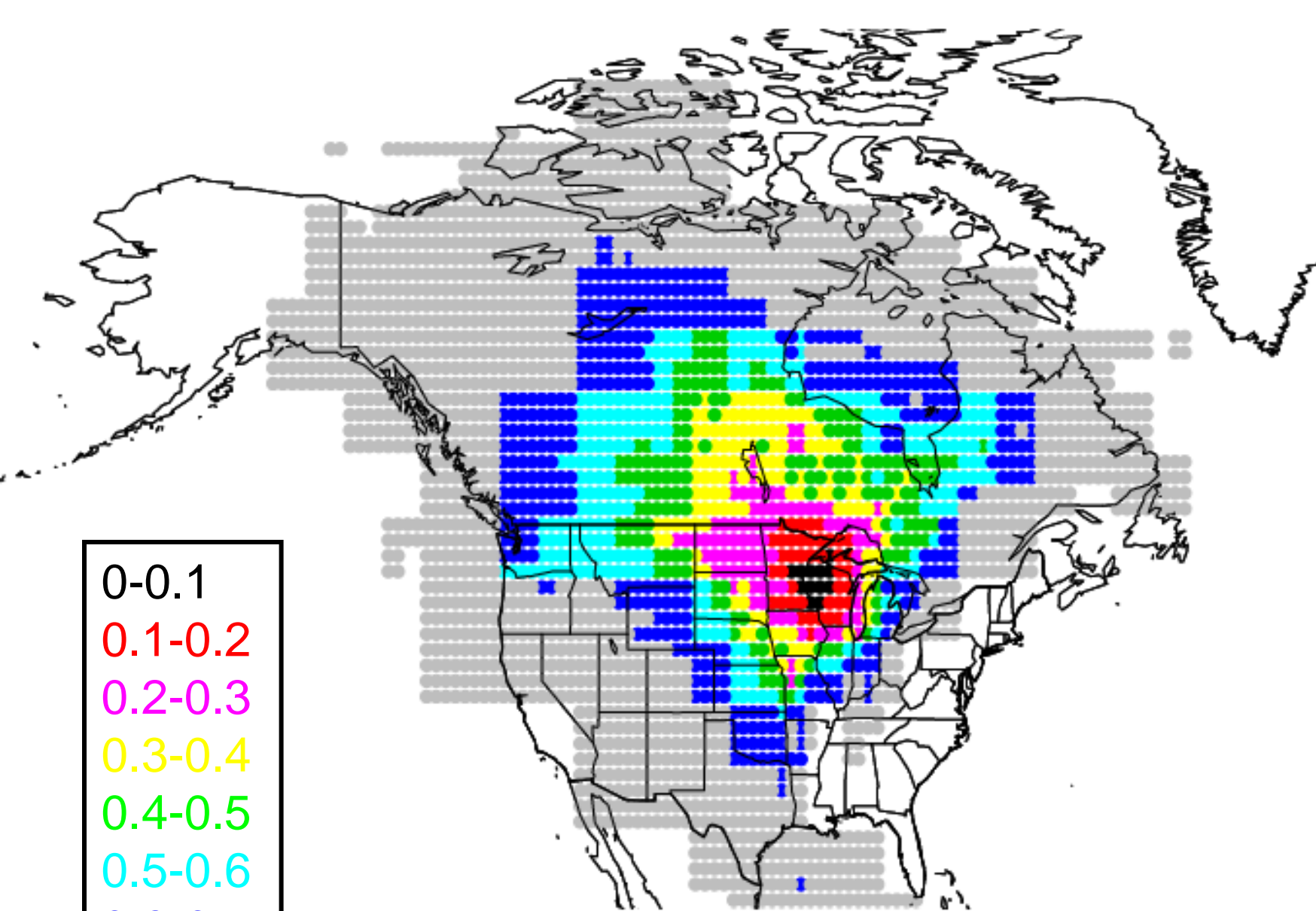
Note: Footprints are time-resolved, but shown as 10-day composite

Cumulative Footprint 19:00 GMT: LEF 396m May–July 2004



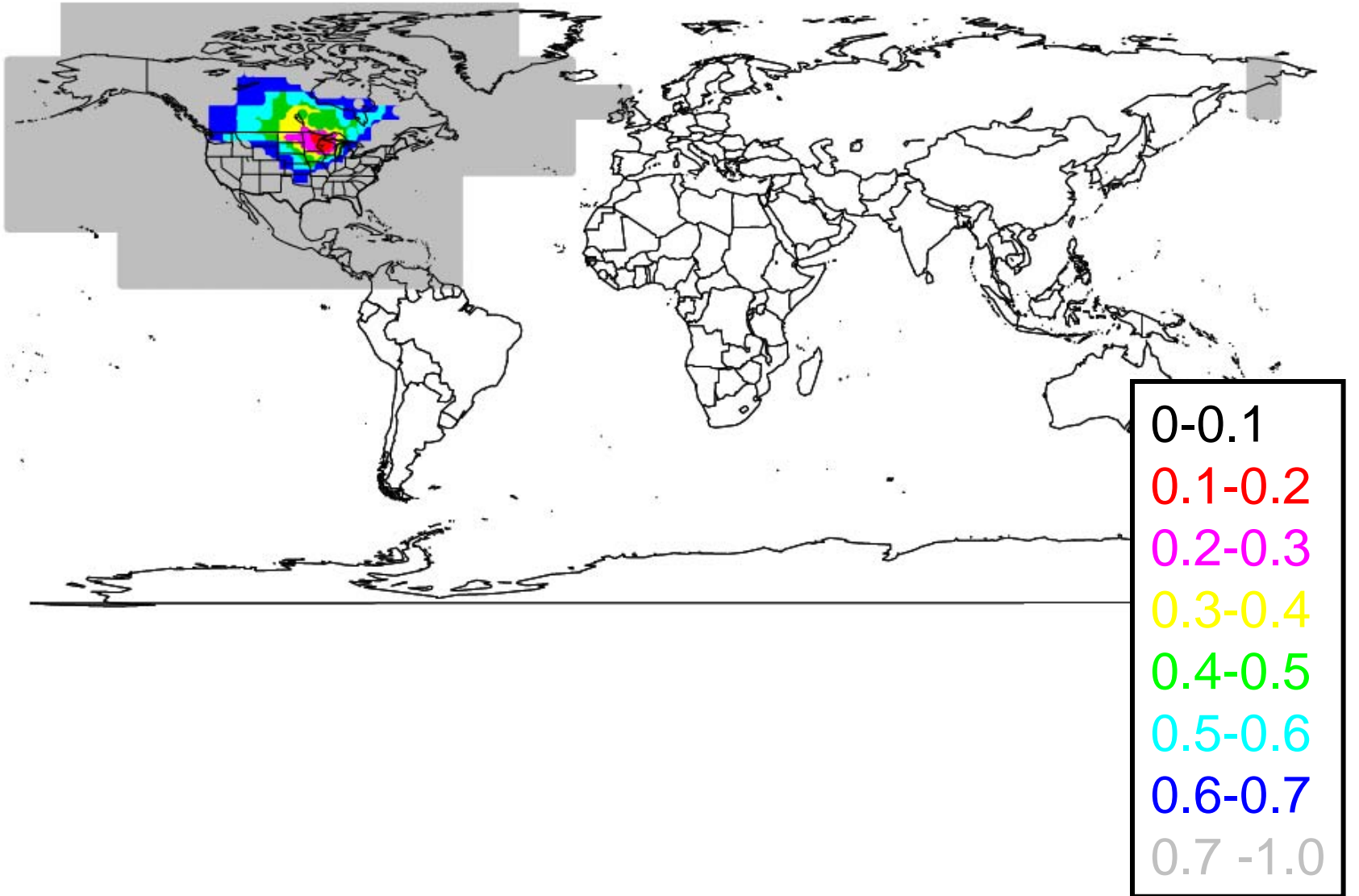
Normalized Footprint: Log10 Color Scale
Composite: MAY-JULY 2004 LEF, 19GMT



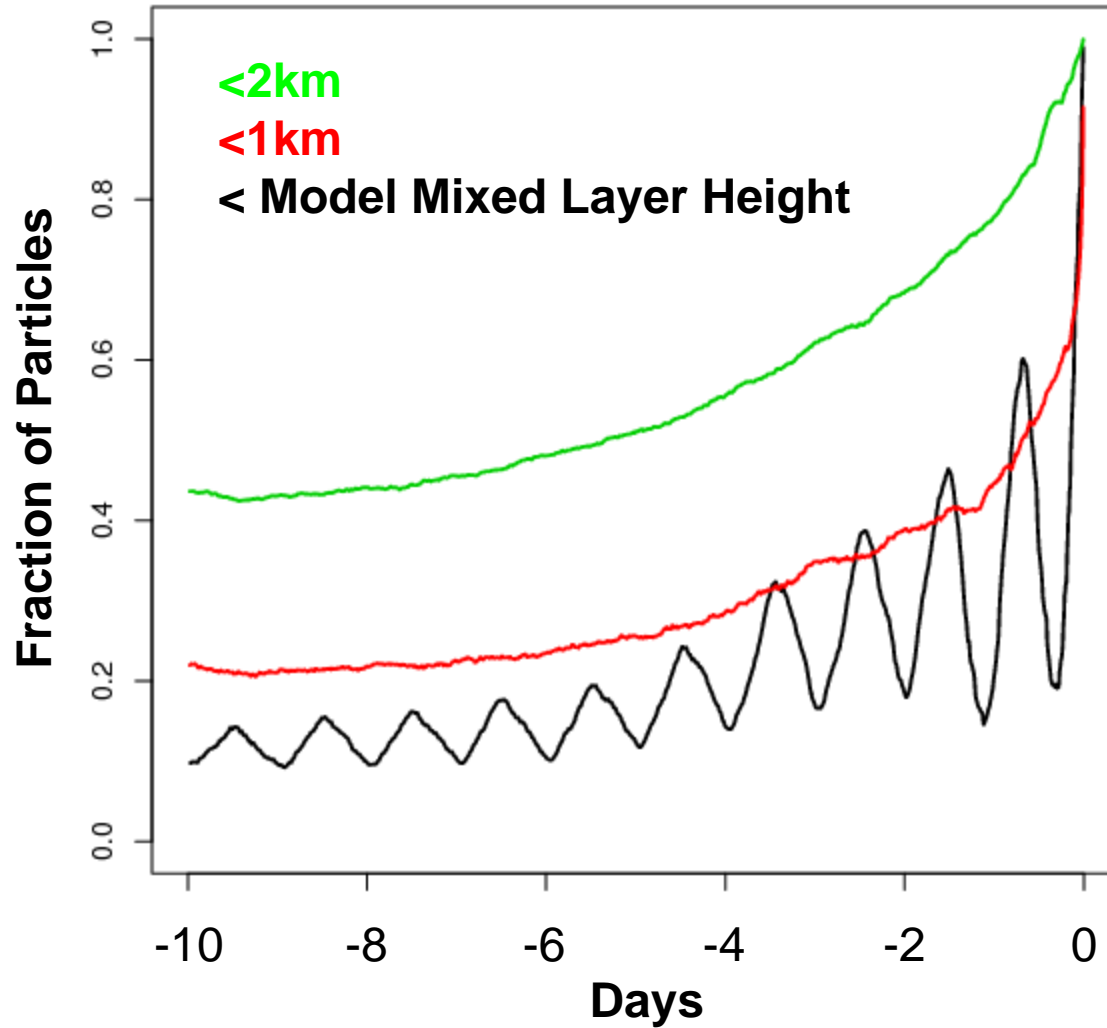


- 0-0.1
- 0.1-0.2
- 0.2-0.3
- 0.3-0.4
- 0.4-0.5
- 0.5-0.6
- 0.6-0.7
- 0.7-0.9

Cumulative Surface Sensitivity

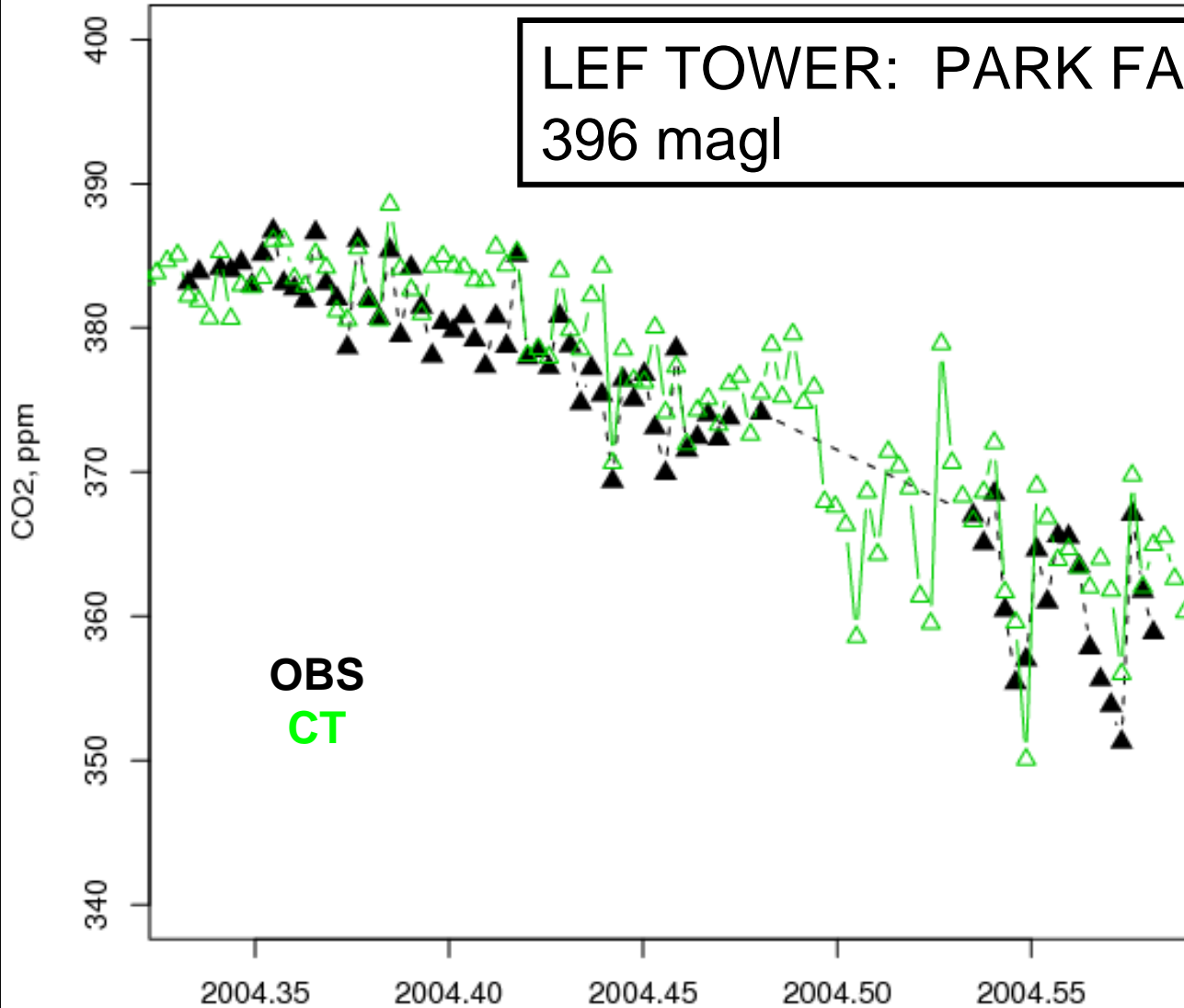


STILT BOUNDARY LAYER RESIDENCE TIME



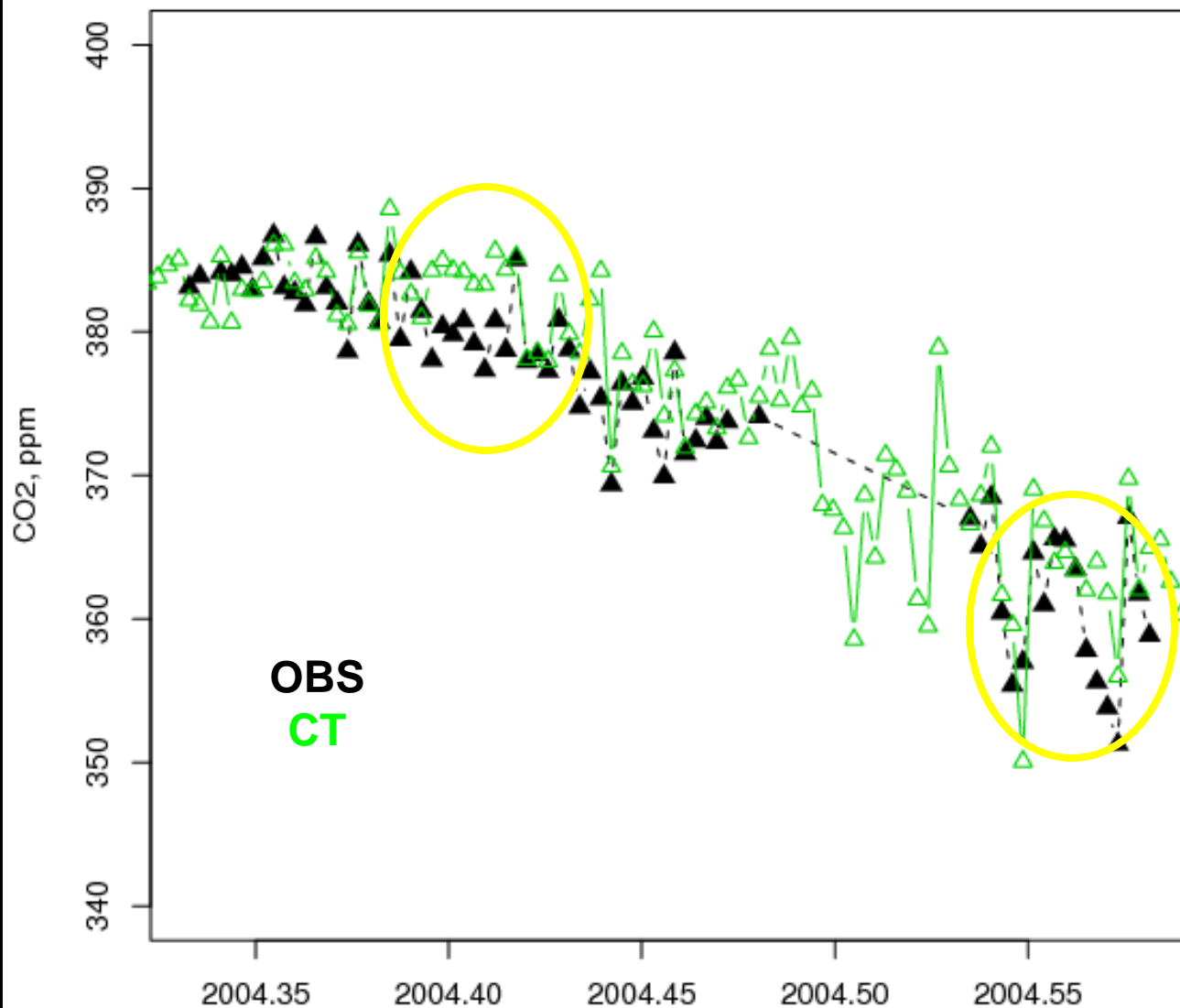
LEF: MAY-JULY 2004 19:00 GMT (TOWER)

LEF TOWER: PARK FALLS, WI
396 magl

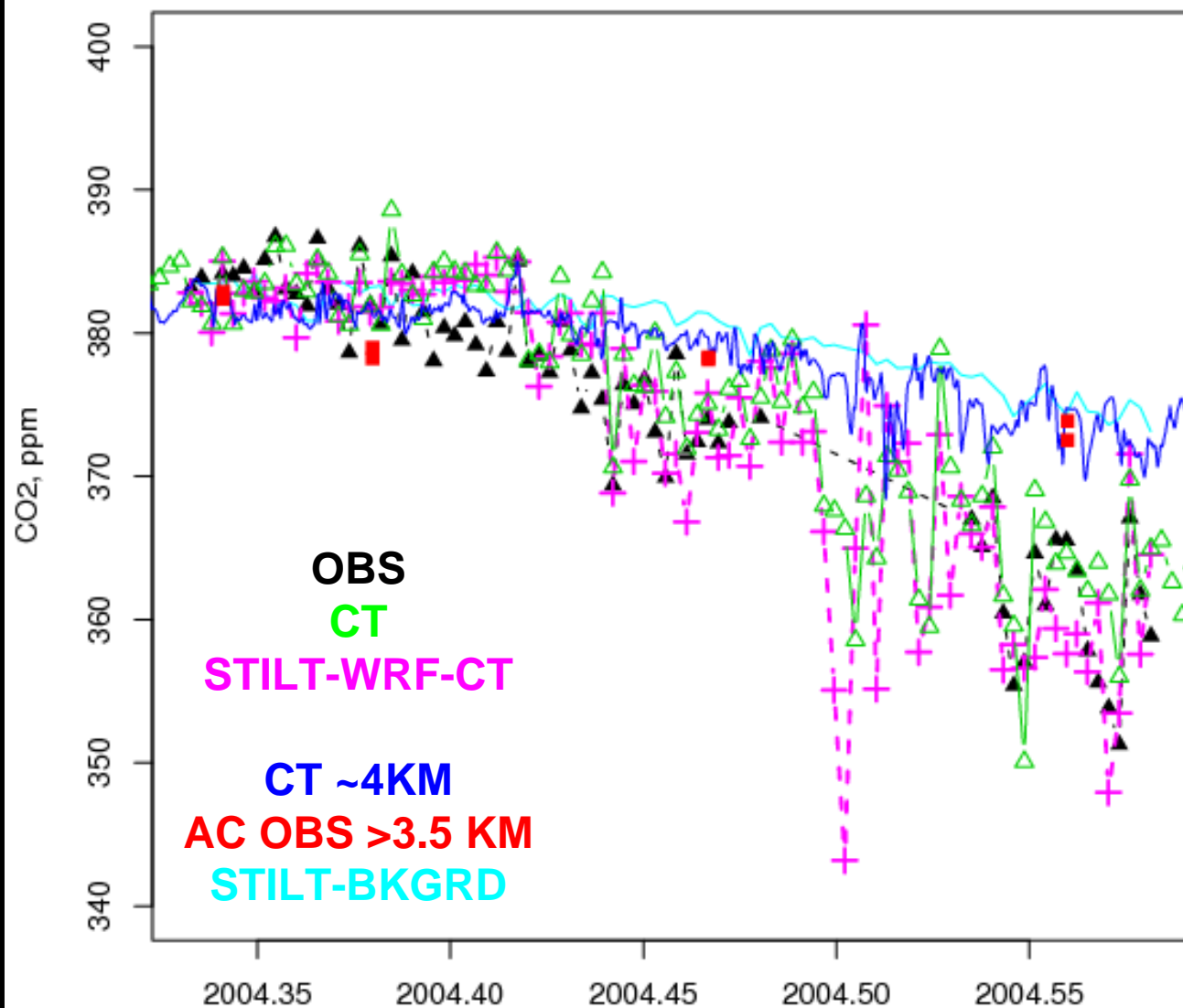


OBS
CT

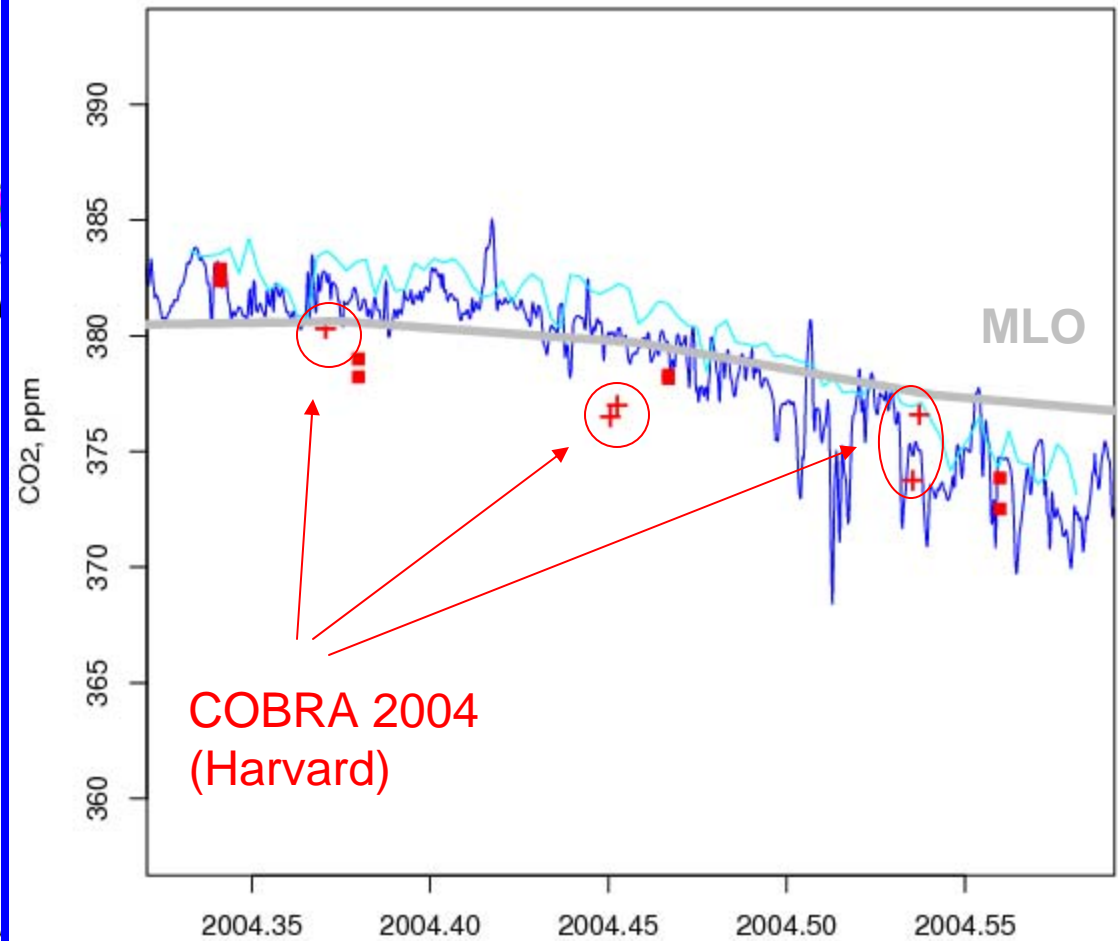
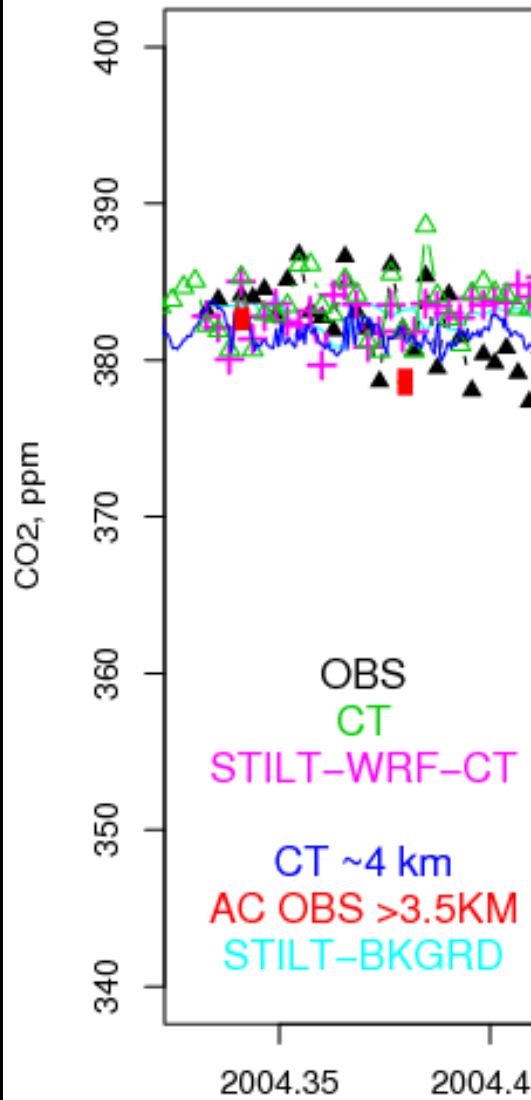
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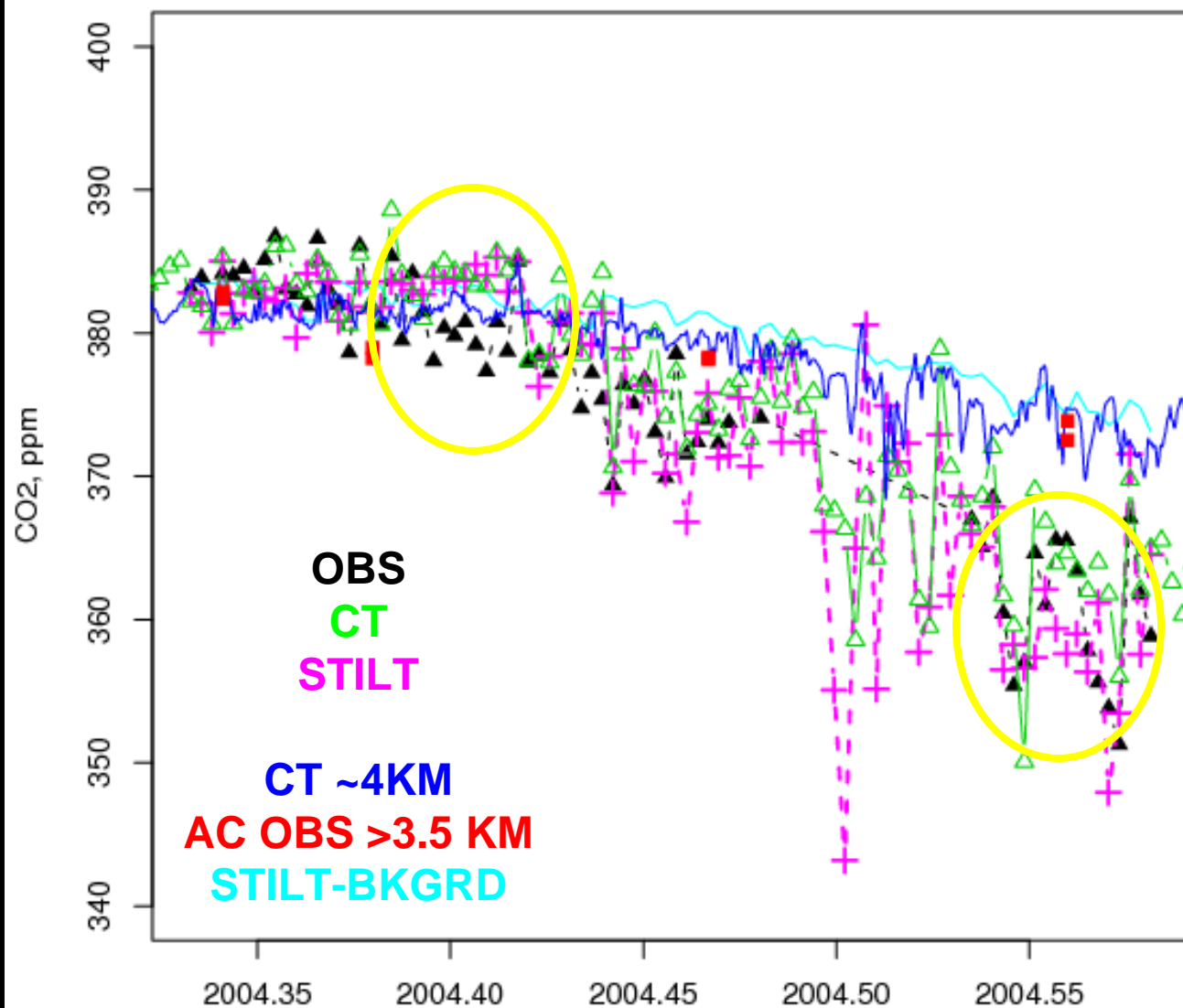
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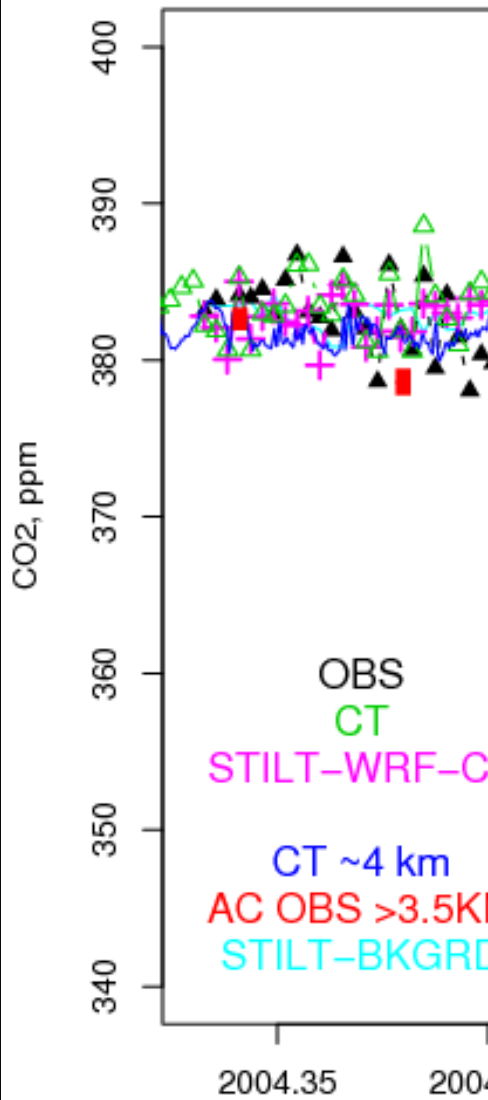
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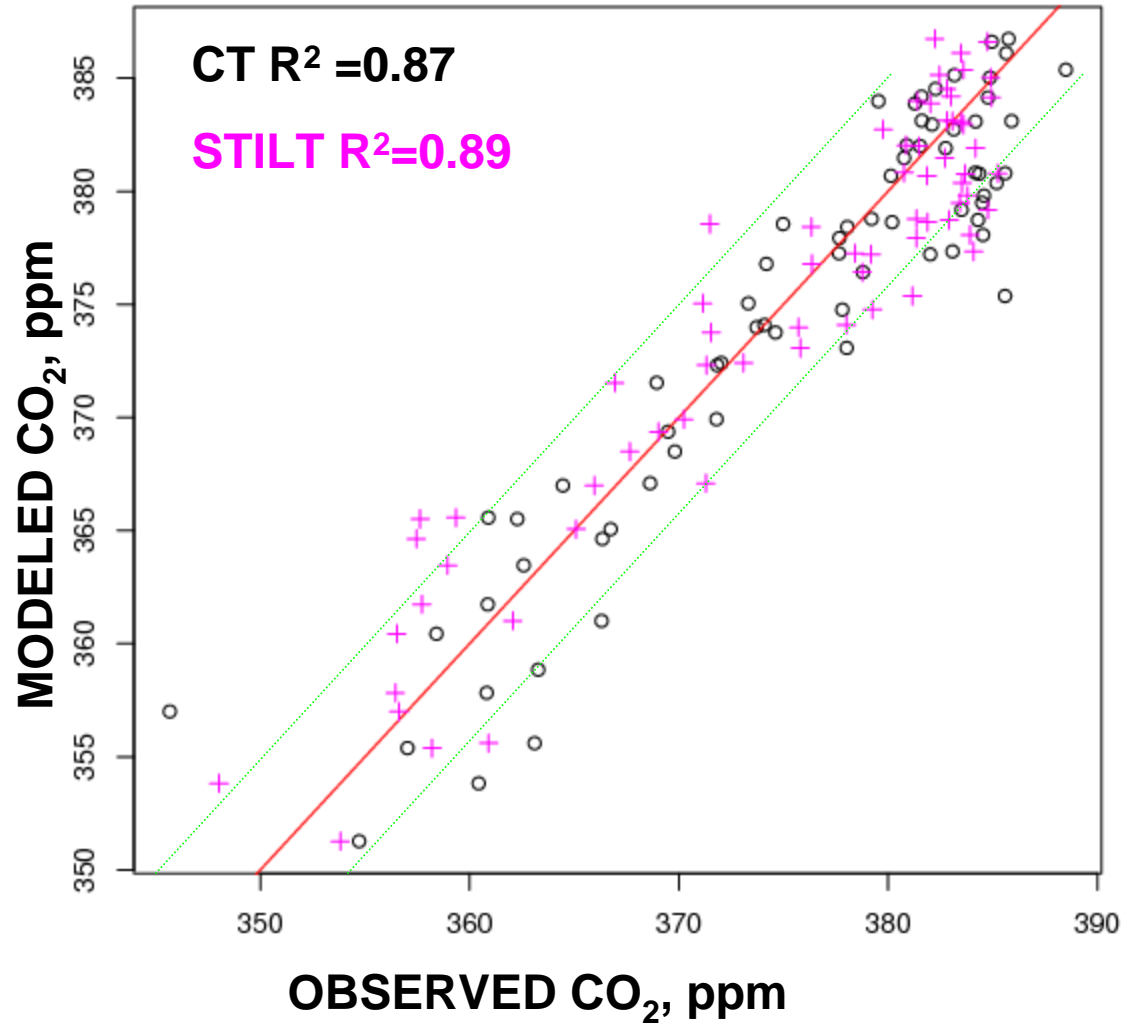
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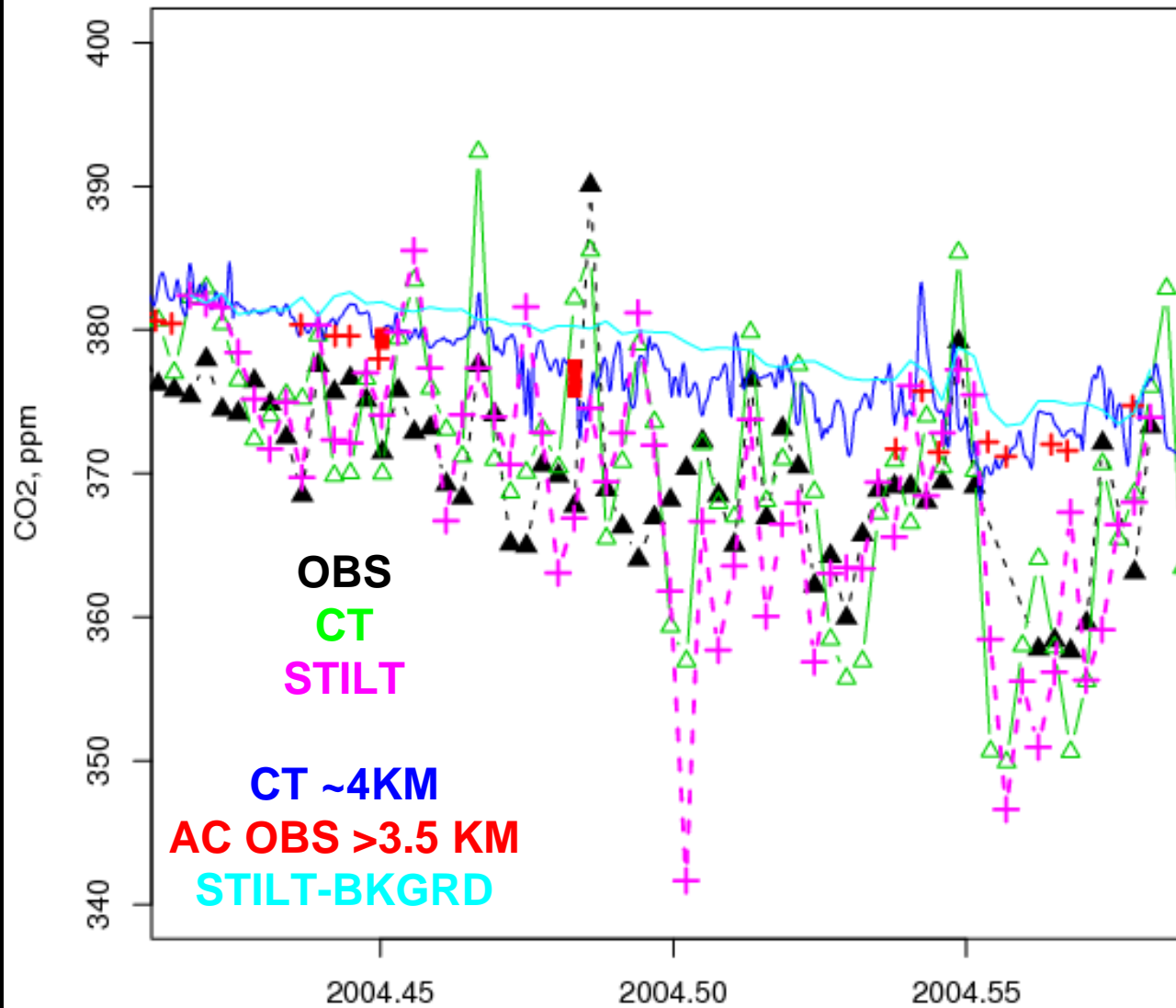
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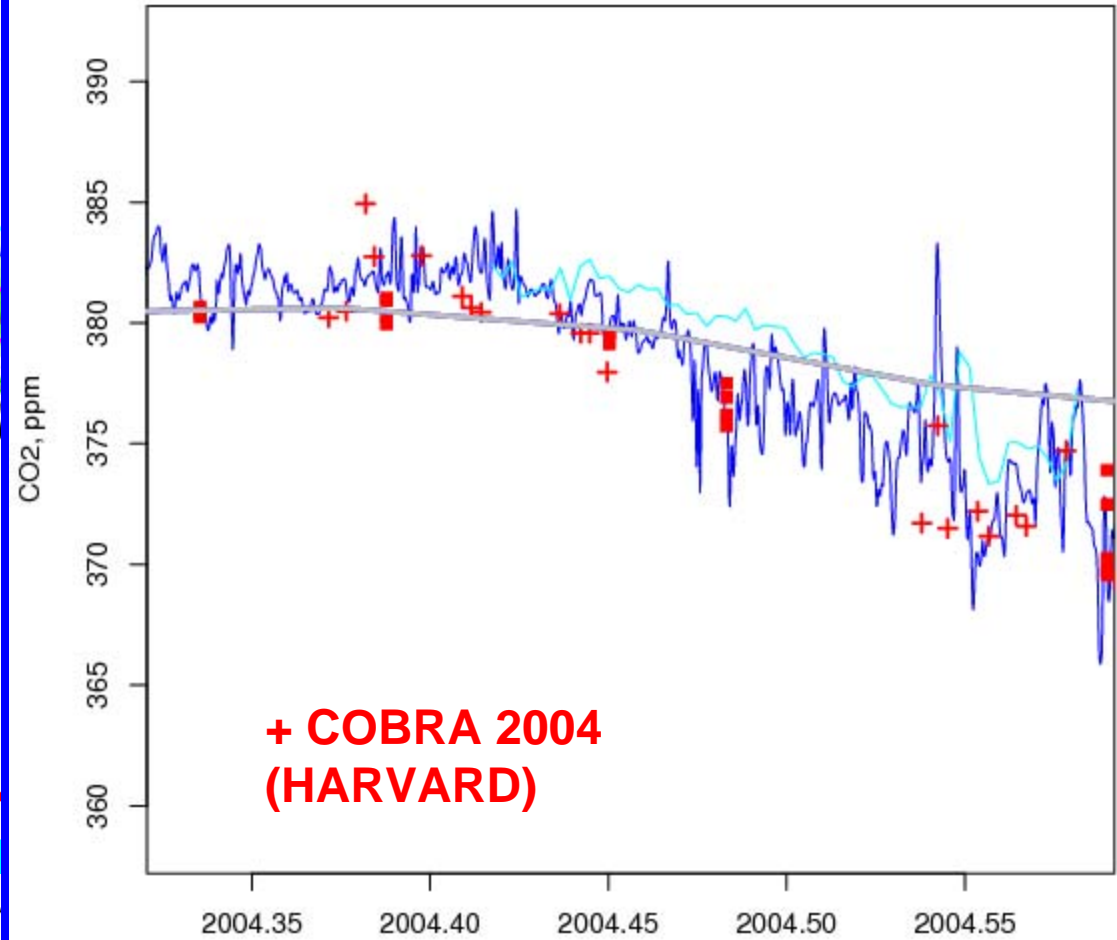
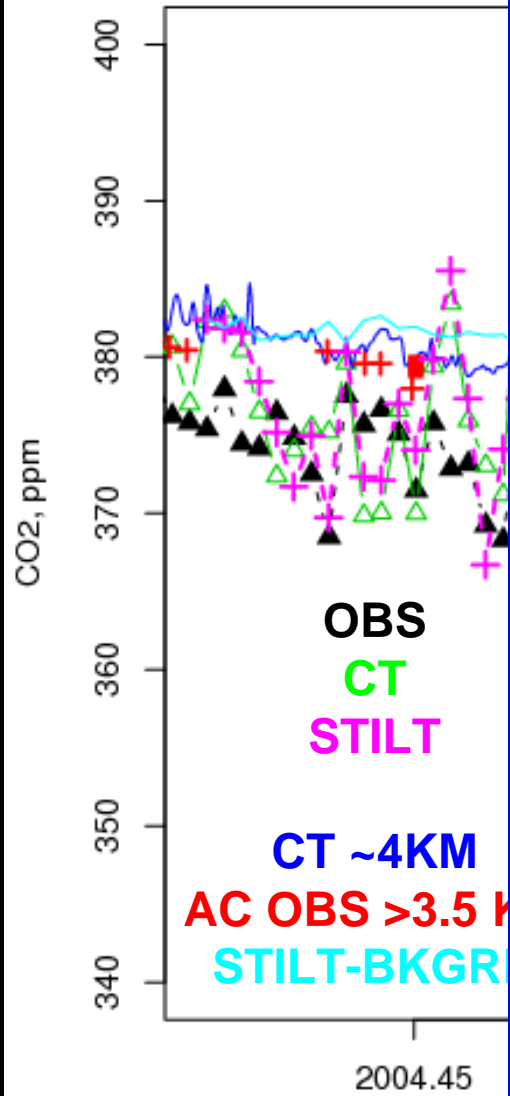
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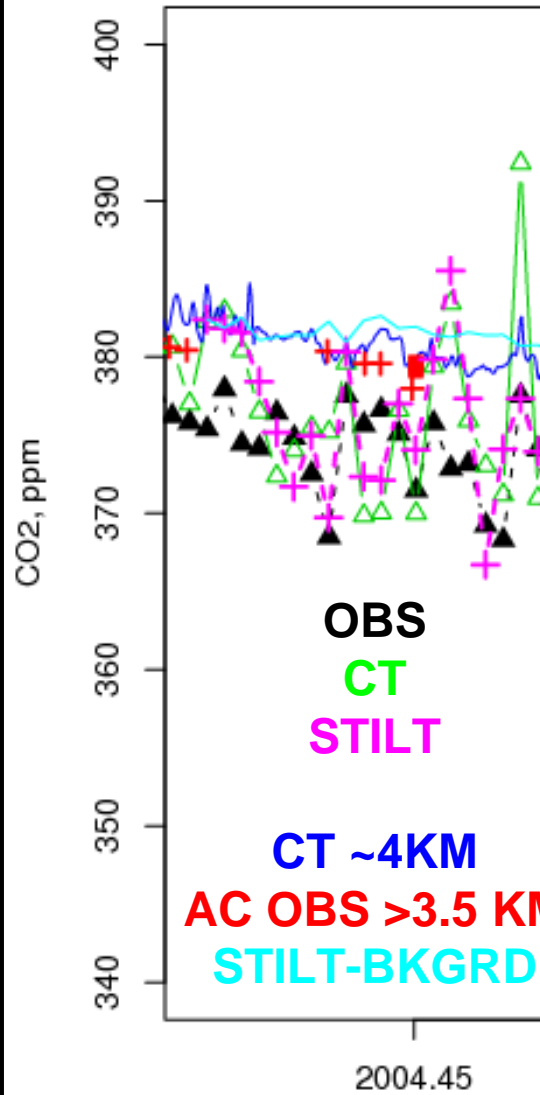
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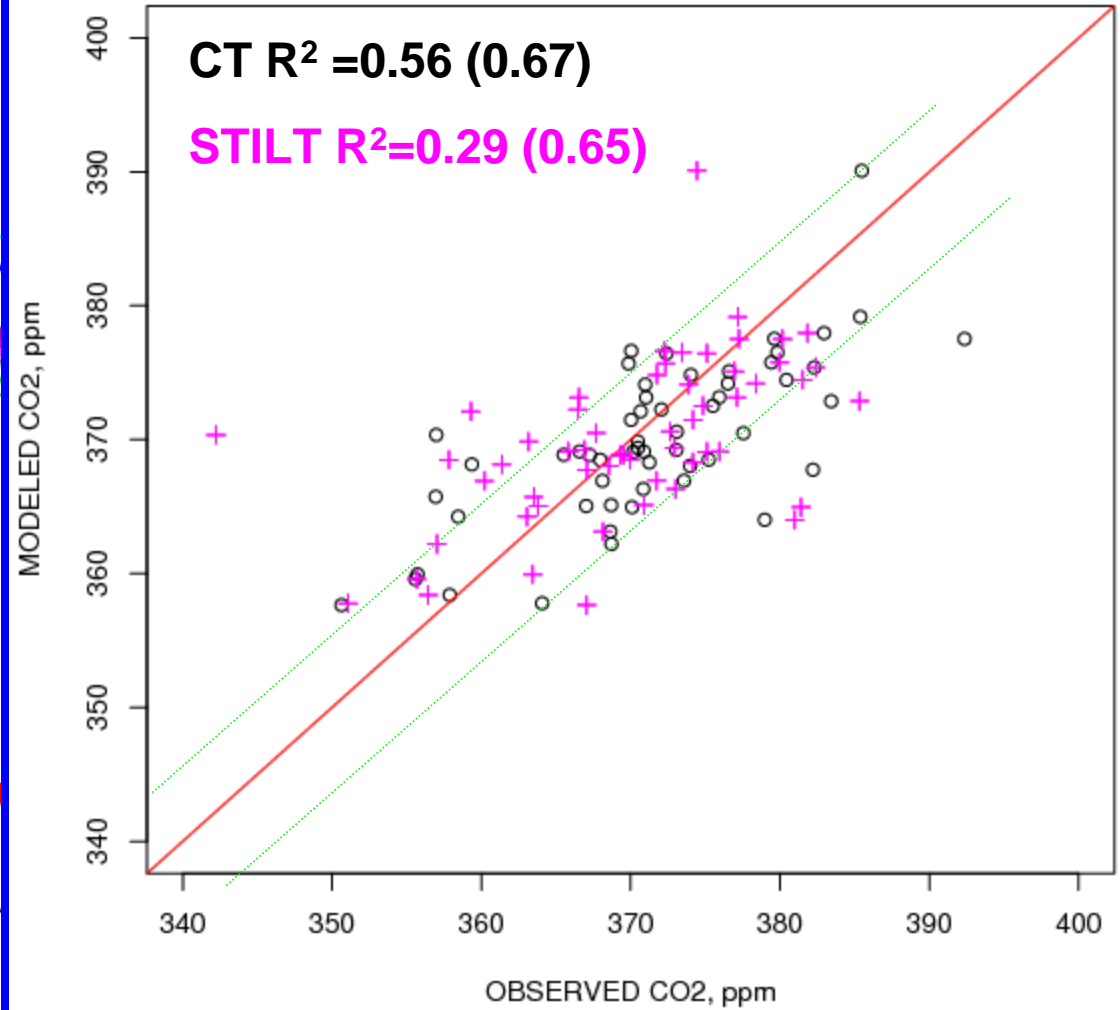
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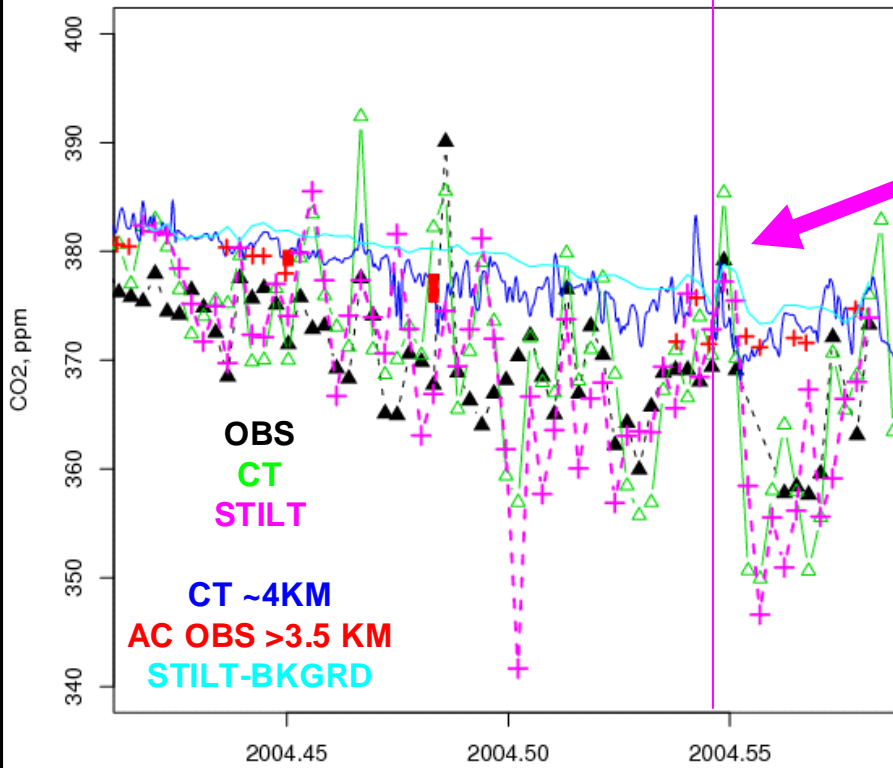
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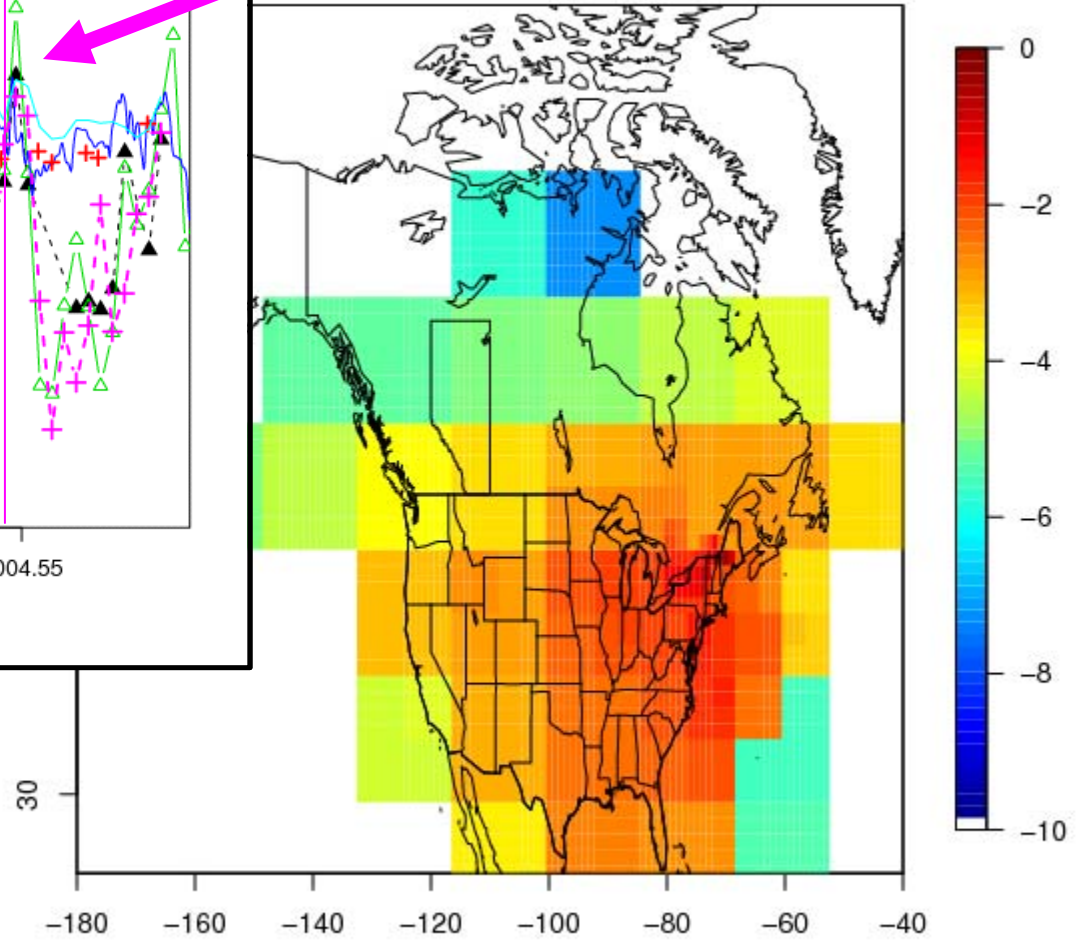
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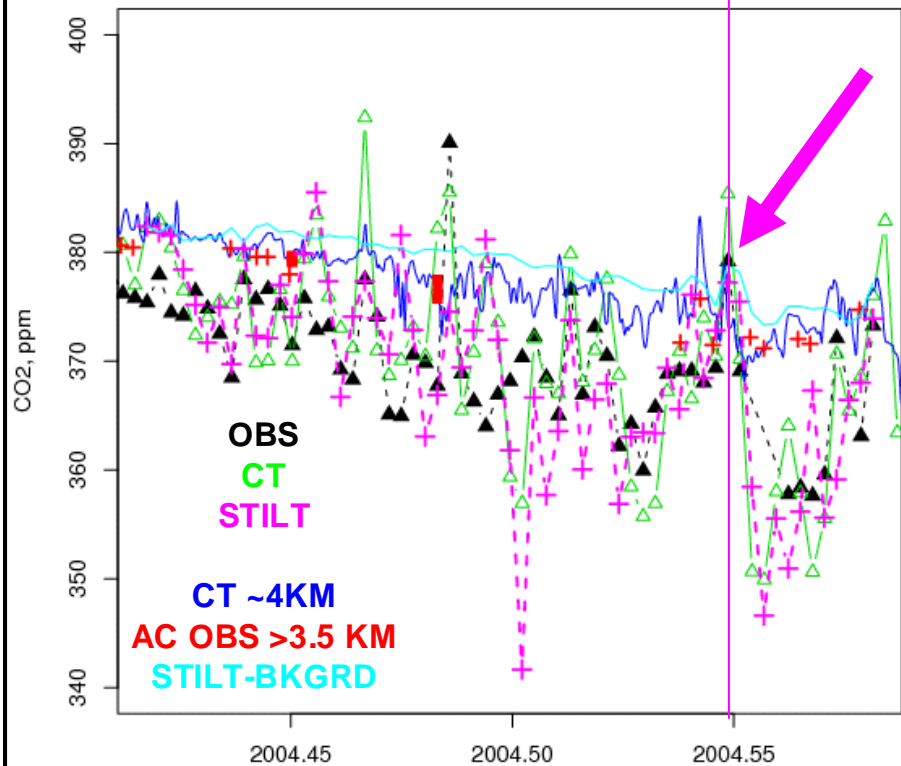
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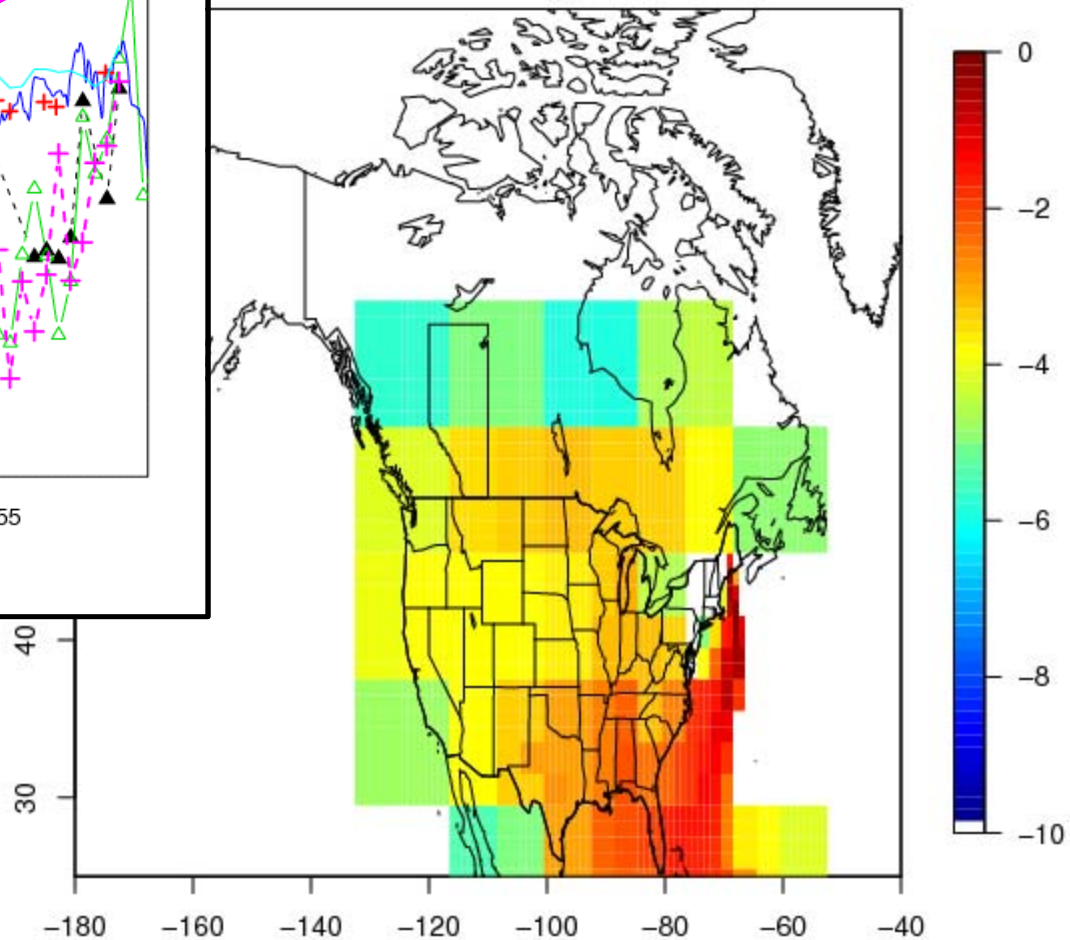
JULY 18, 19:00 GMT



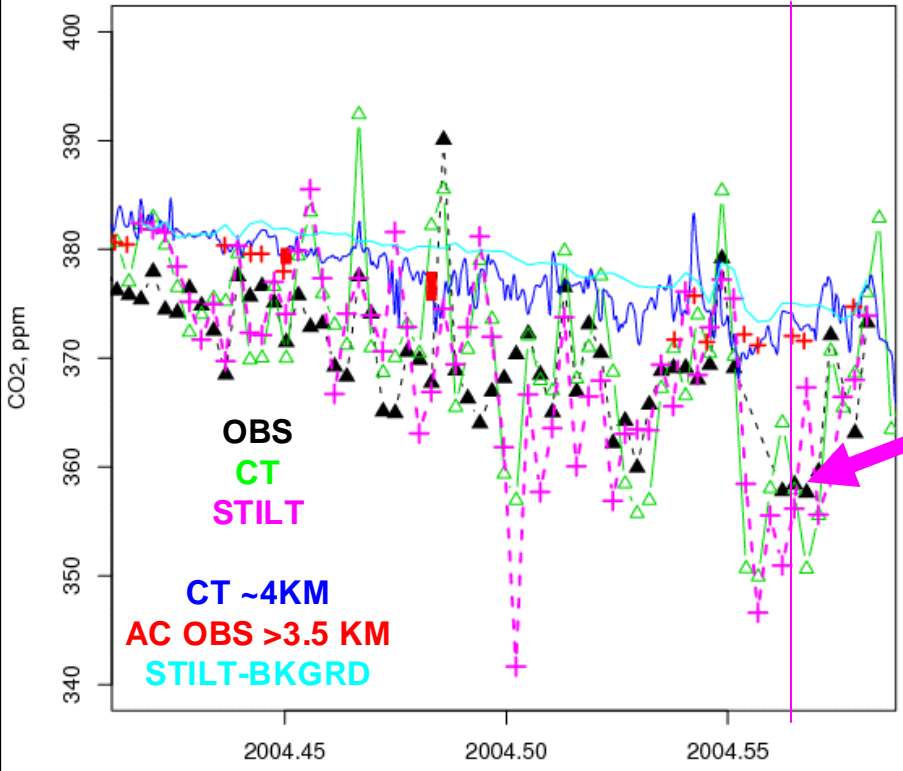
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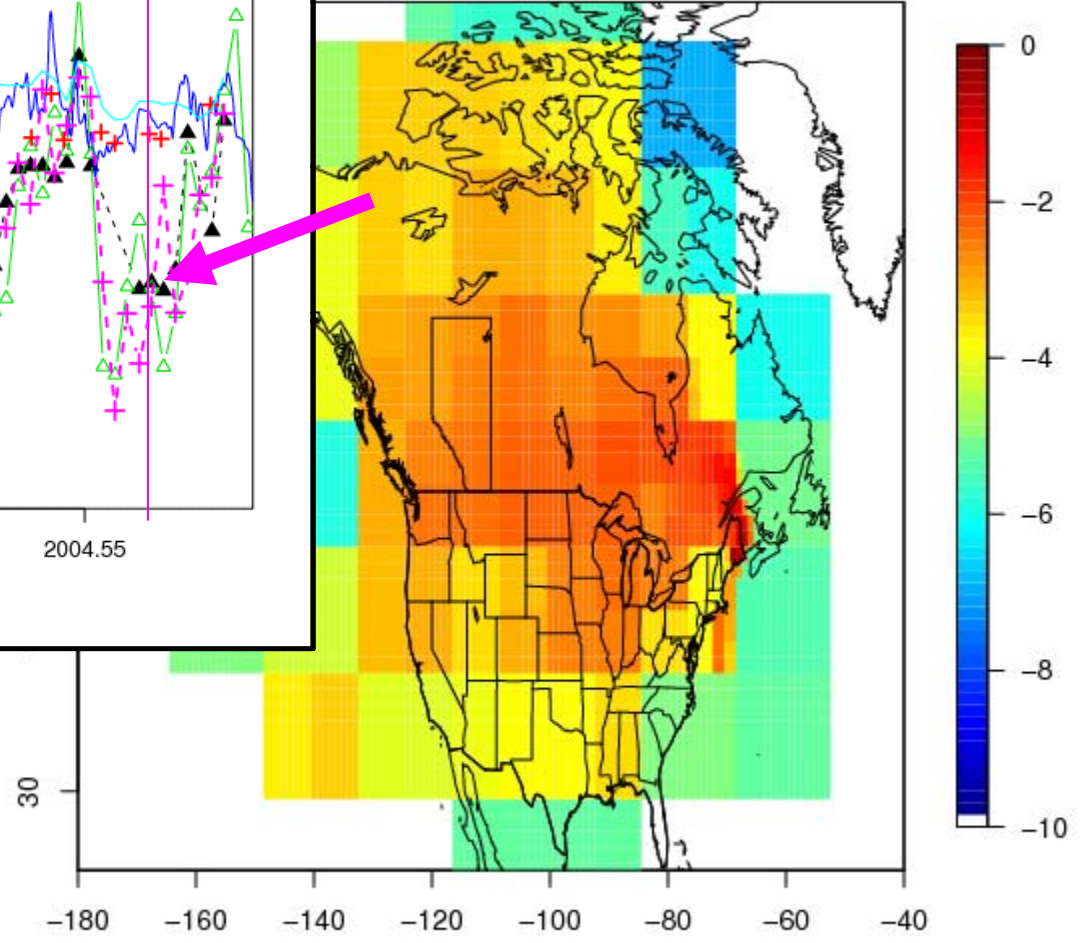
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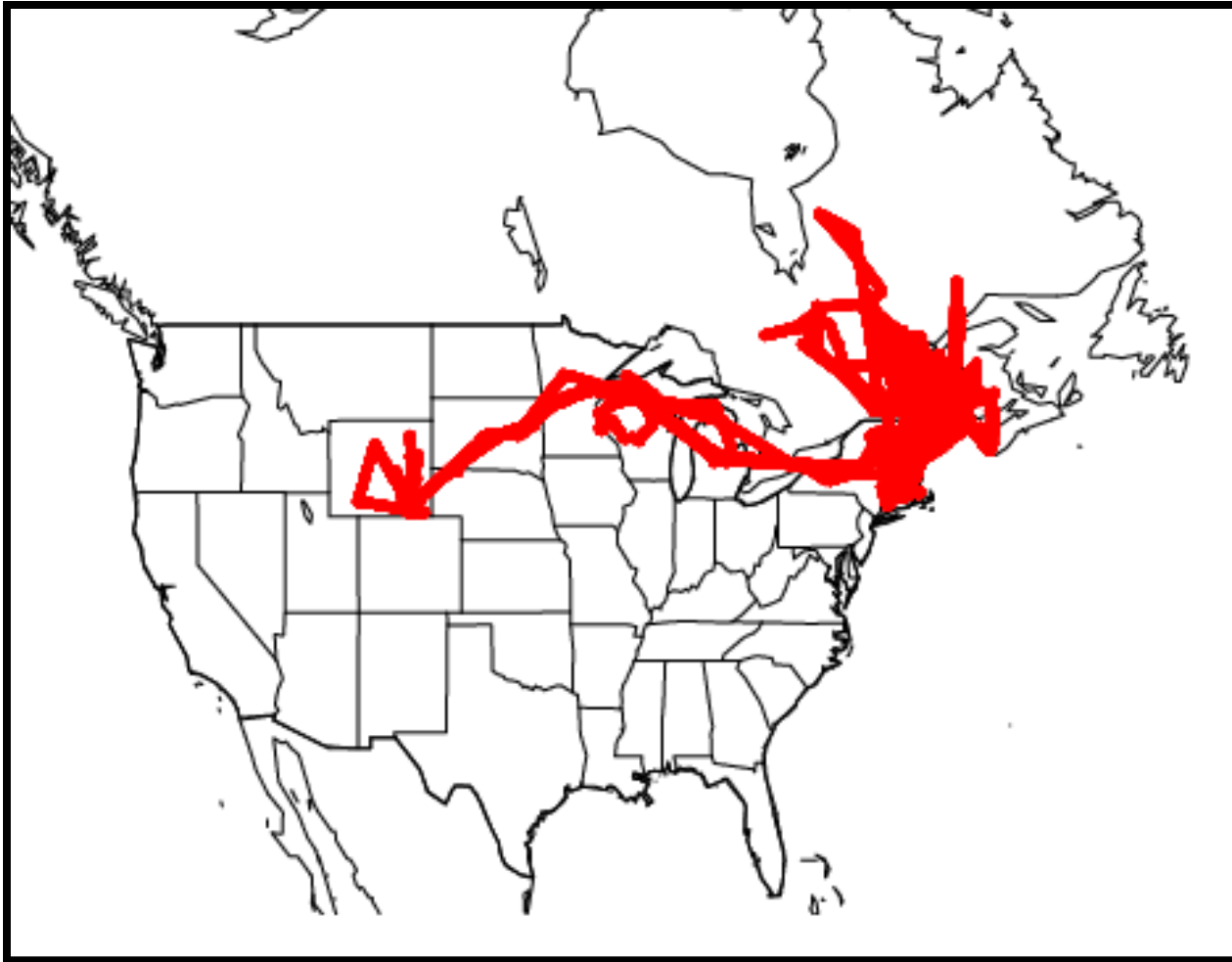


AMT: JUNE-JULY 2004 19:00 GMT (TOWER)



JULY 25, 19:00 GMT





COBRA-MAINE: HARVARD UNIVERSITY/NSF & NOAA

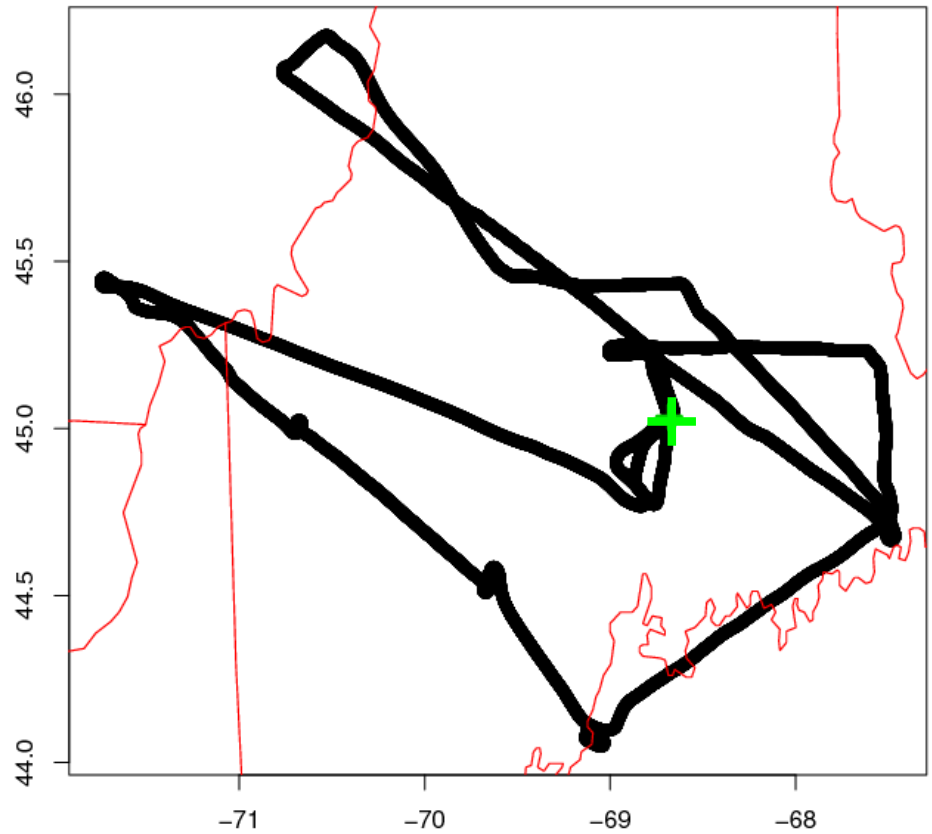
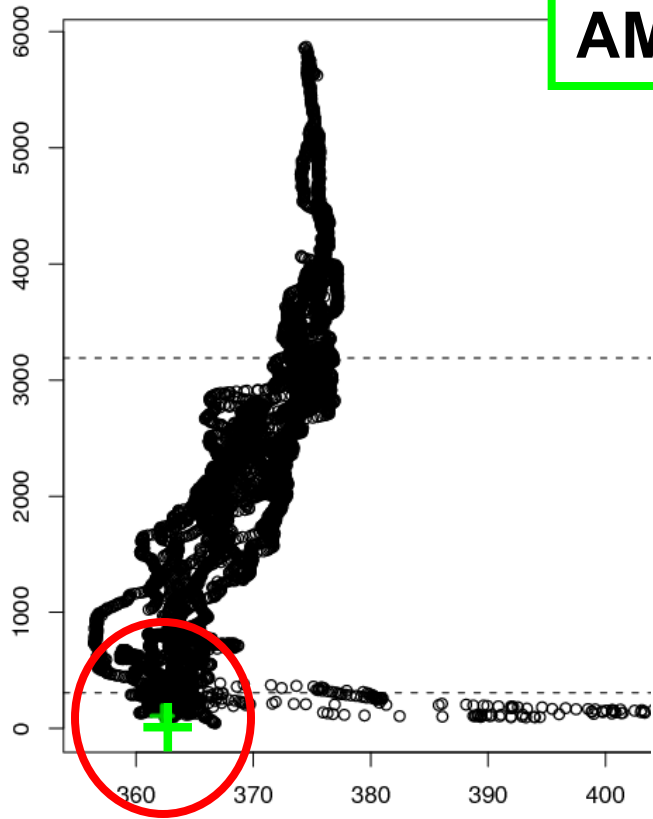
7 MAY – 16 AUGUST 2004

33 FLIGHTS

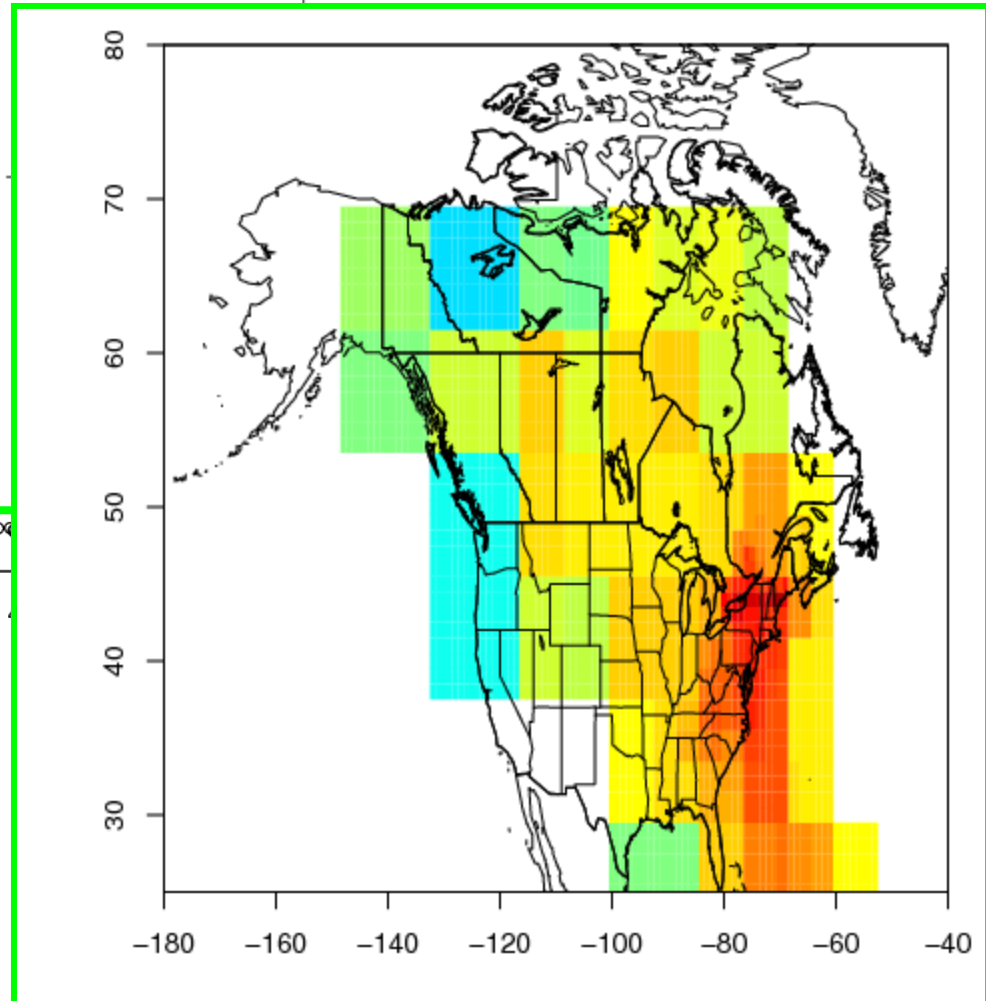
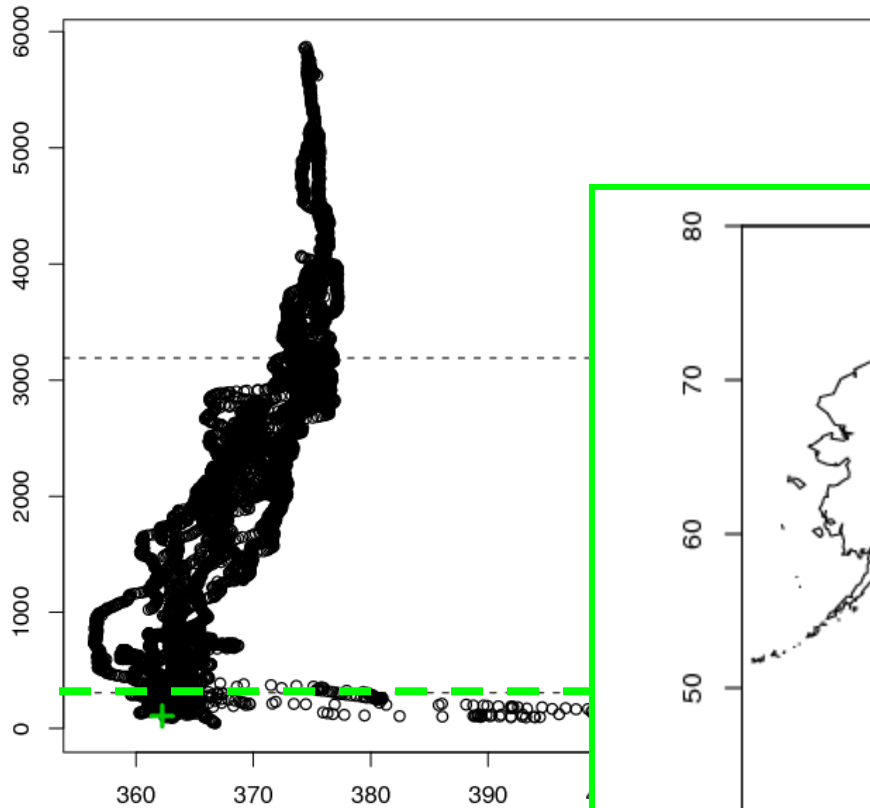
Wyoming King Air

NSF paid for equipment & establishing AMT tower site under this project

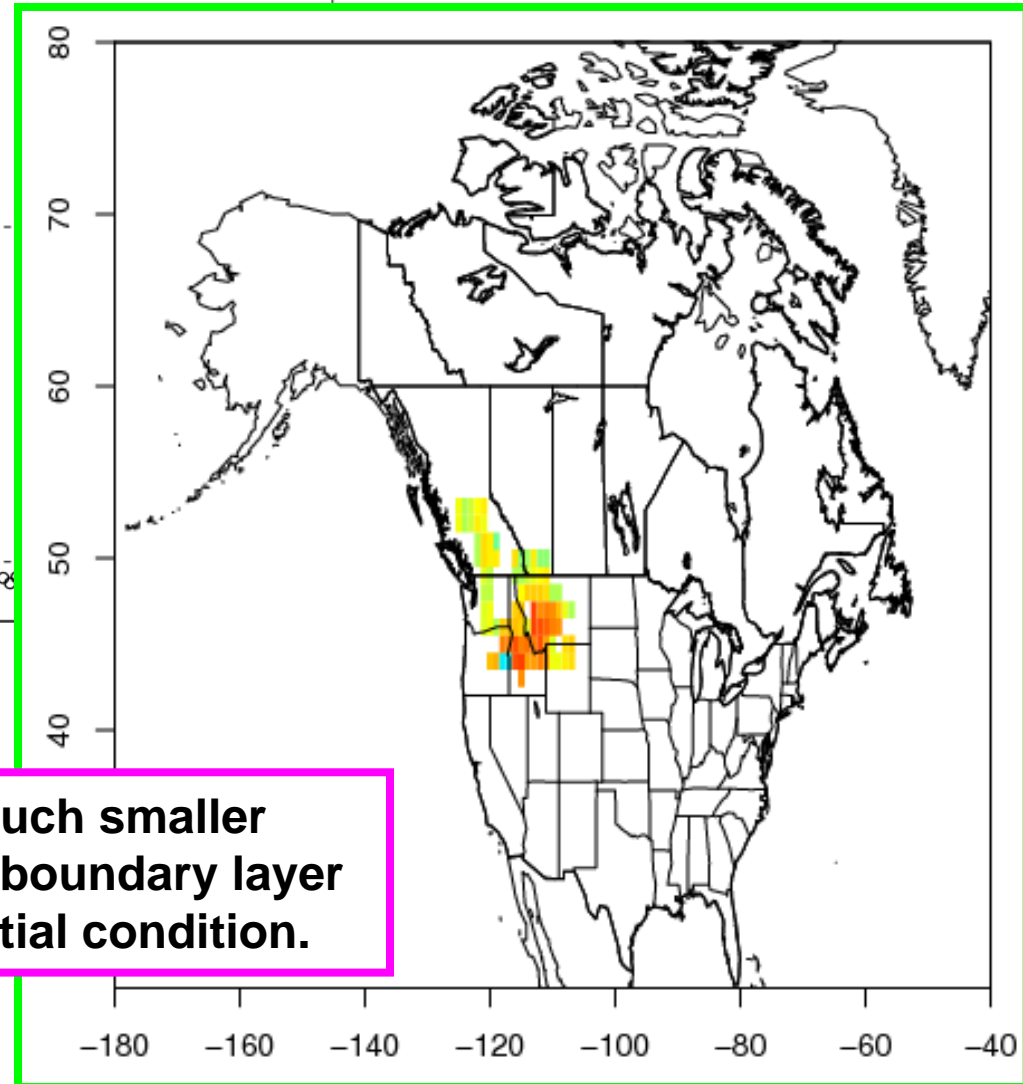
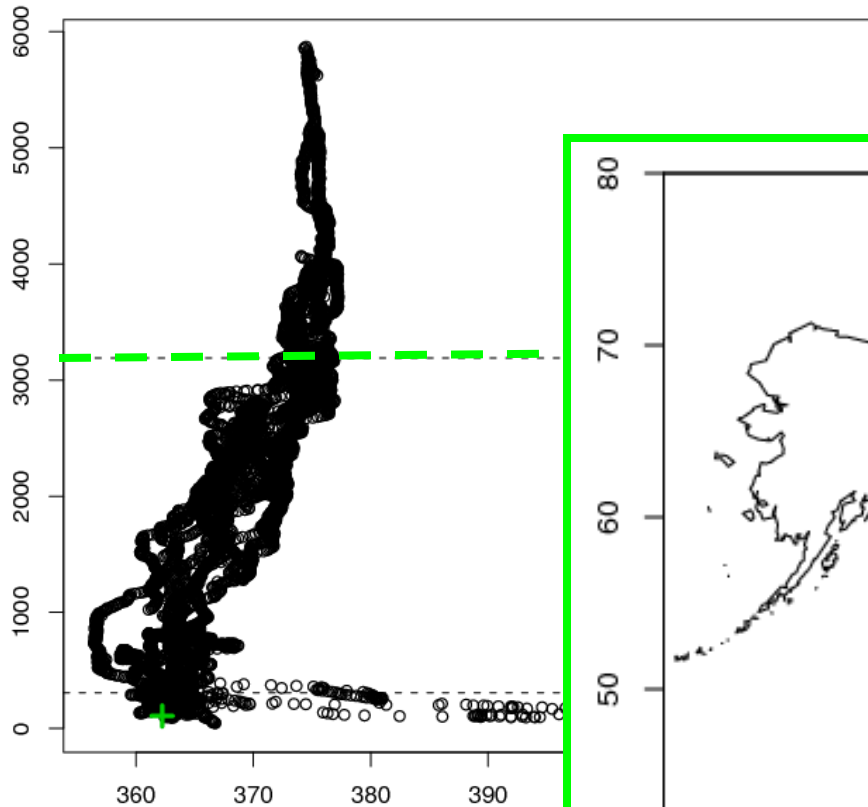
COBRA: 2004-07-30 AMT OVERFLIGHT



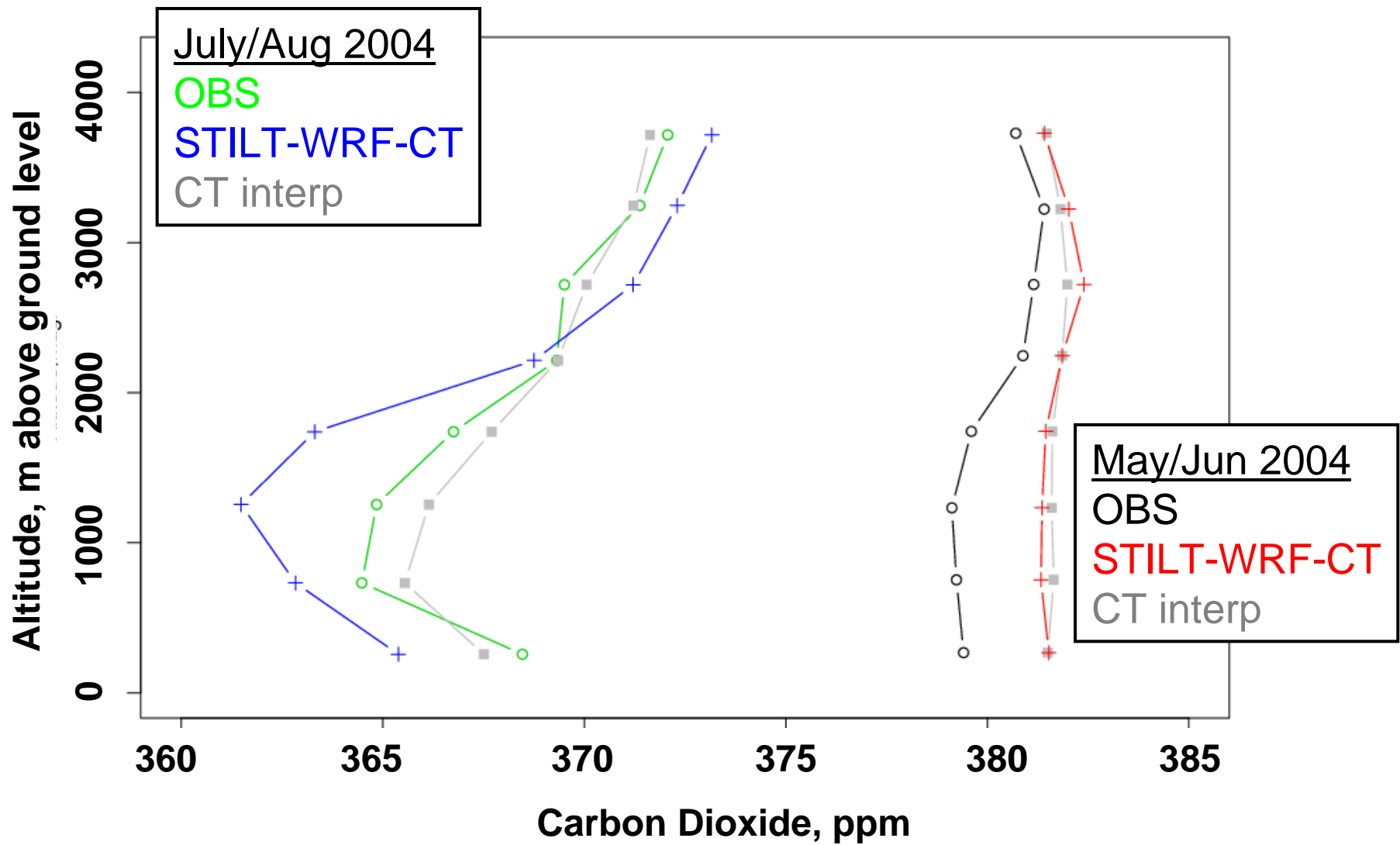
COBRA: 2004-07-30
300m agl

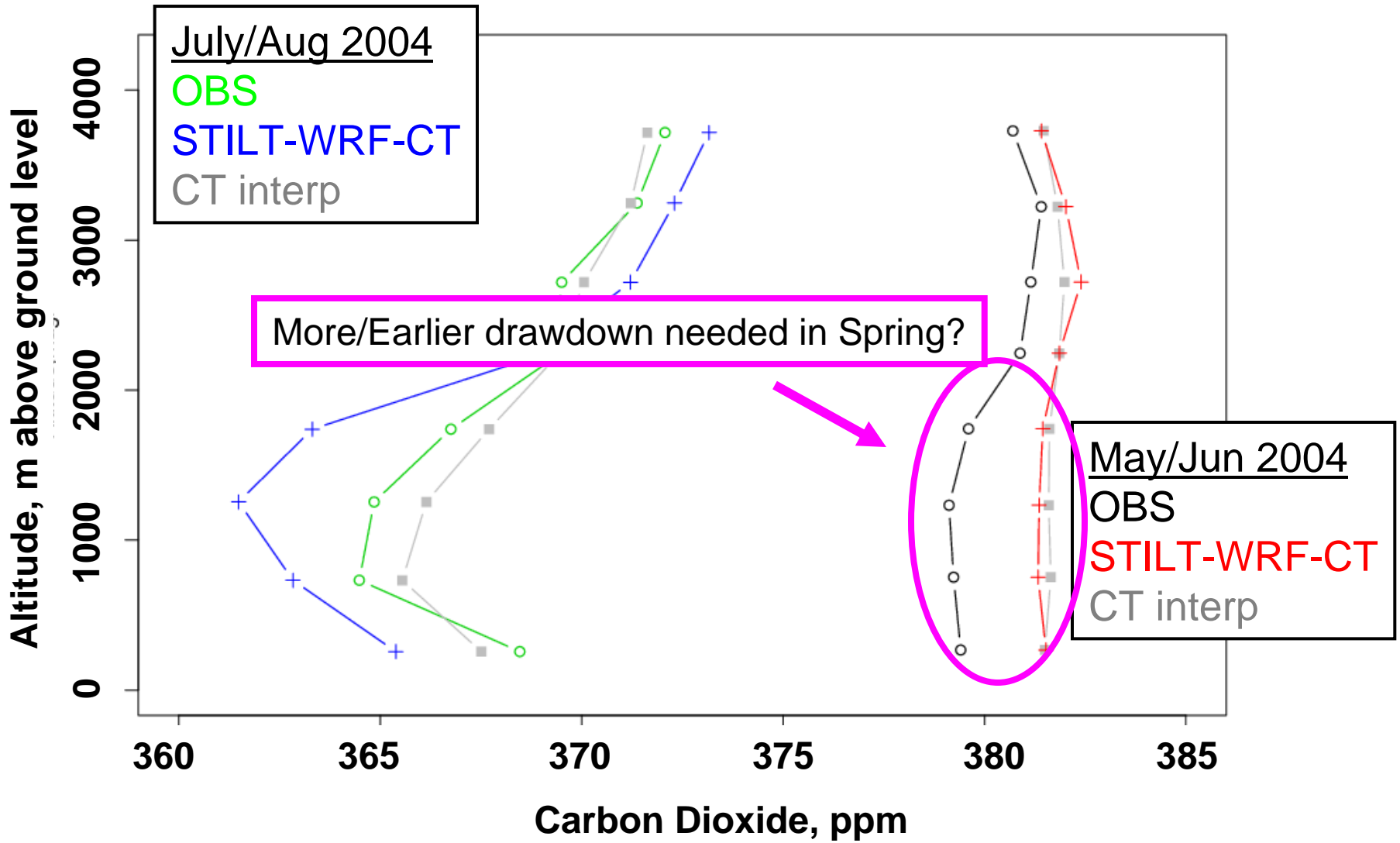


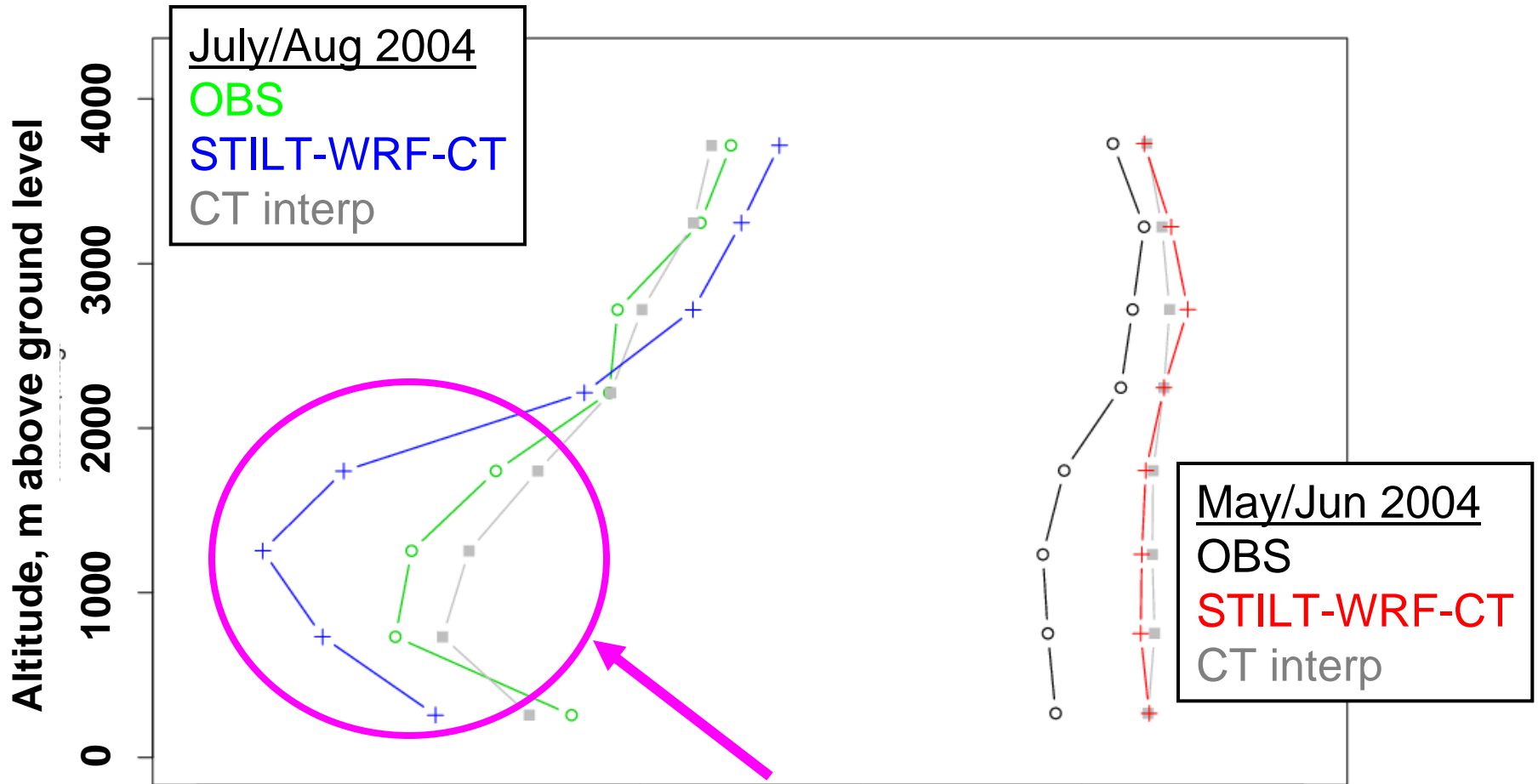
COBRA: 2004-07-30
3200m agl



**Free troposphere has much smaller
surface sensitivity than boundary layer
→ strongly driven by initial condition.**





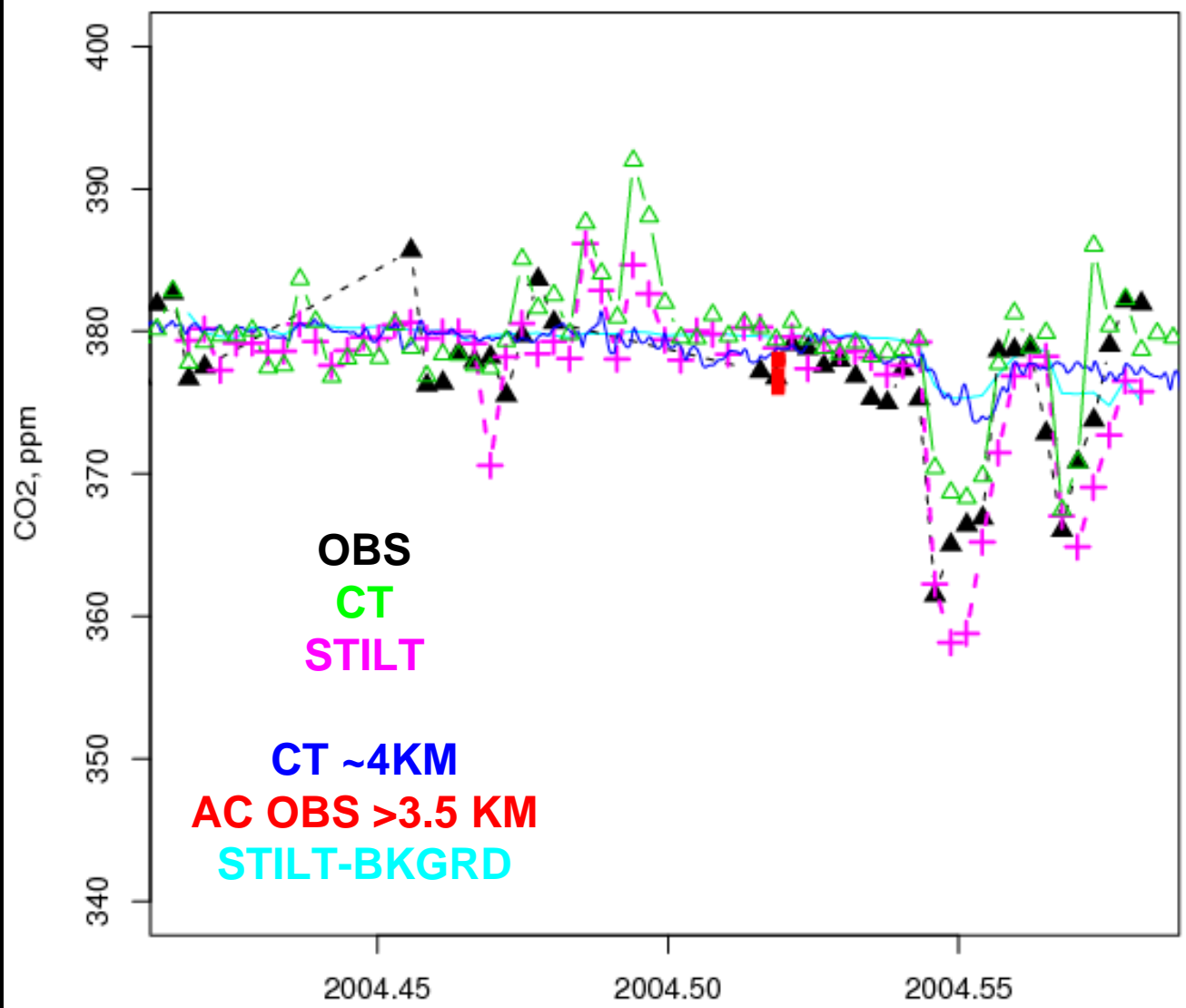


- Differences are due to model transport.
- Keep in mind that fluxes have been optimized using CT.
- Aircraft data were not optimized.

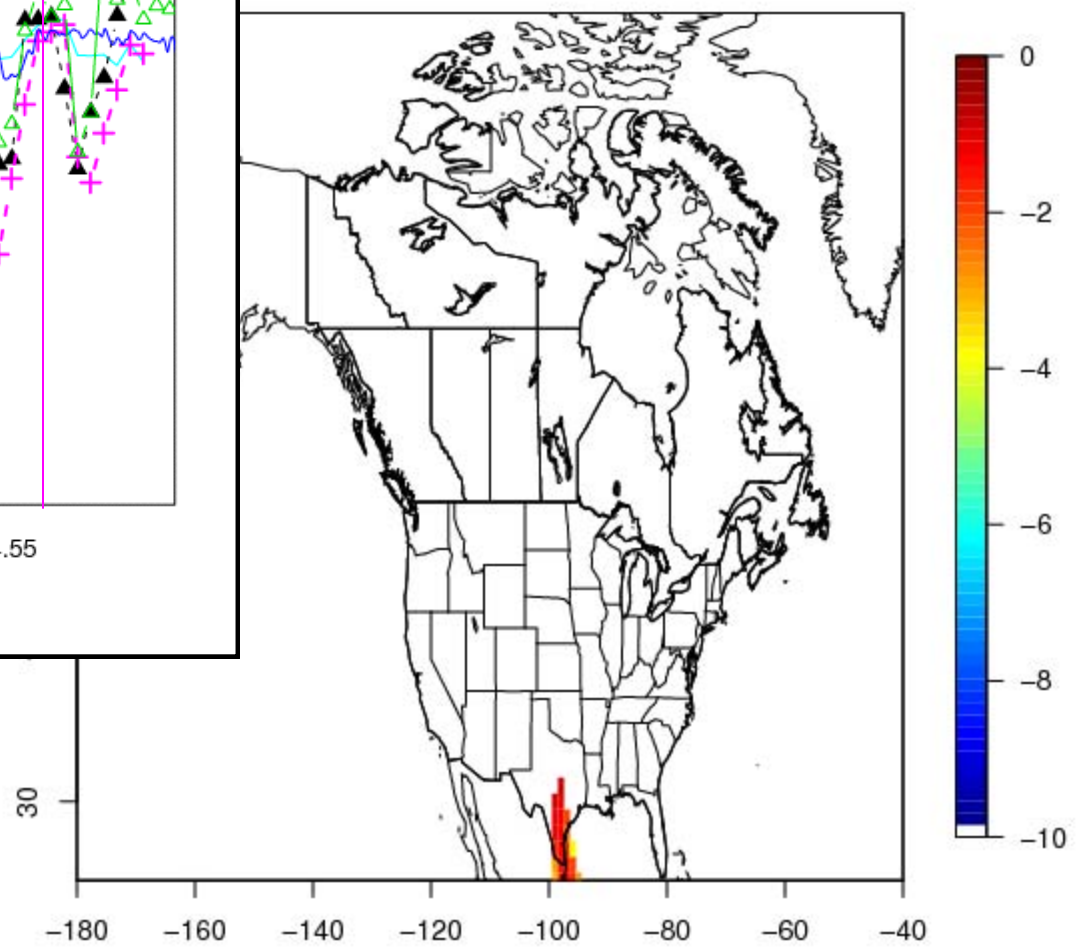
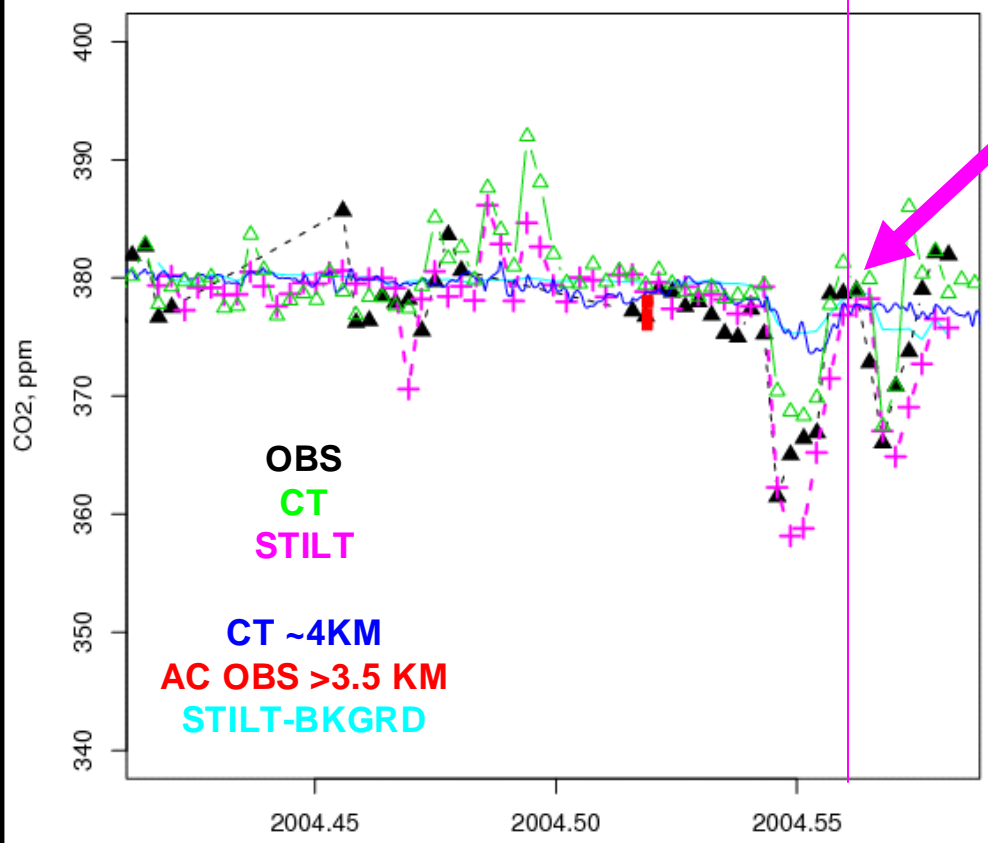
Summary Points

- Lagrangian models can provide insight into the mechanics of CarbonTracker
 - Diagnose patterns and residuals
 - Footprint information can inform decisions about how to weight different types of data
- Generally good agreement between STILT-WRF-CT and CarbonTracker is encouraging—STILT tends to predict lower CO₂ near the surface
- “Campaign” data are valuable independent datasets for CarbonTracker evaluation: e.g, COBRA-2003, COBRA-2004, TEXAS AQS 2006, ARCPAC-2008, START-08, HIPPO
- Footprints are generic and can be used to interpret mixing ratio measurements of other species (halocarbons, COS, isotopes, etc.)
- Other LPDMS are in use around ESRL: FLEXPART, CSU LPDM, HYSPLIT
- We are working toward building an archive of footprints that can be linked to the GMD database

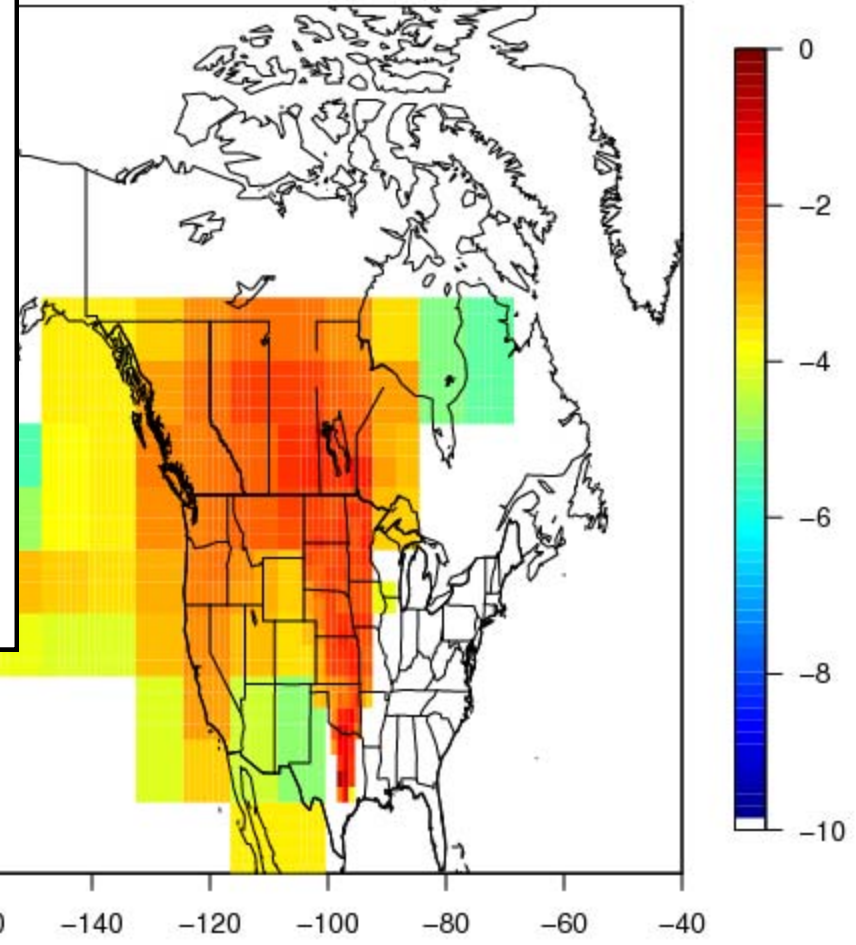
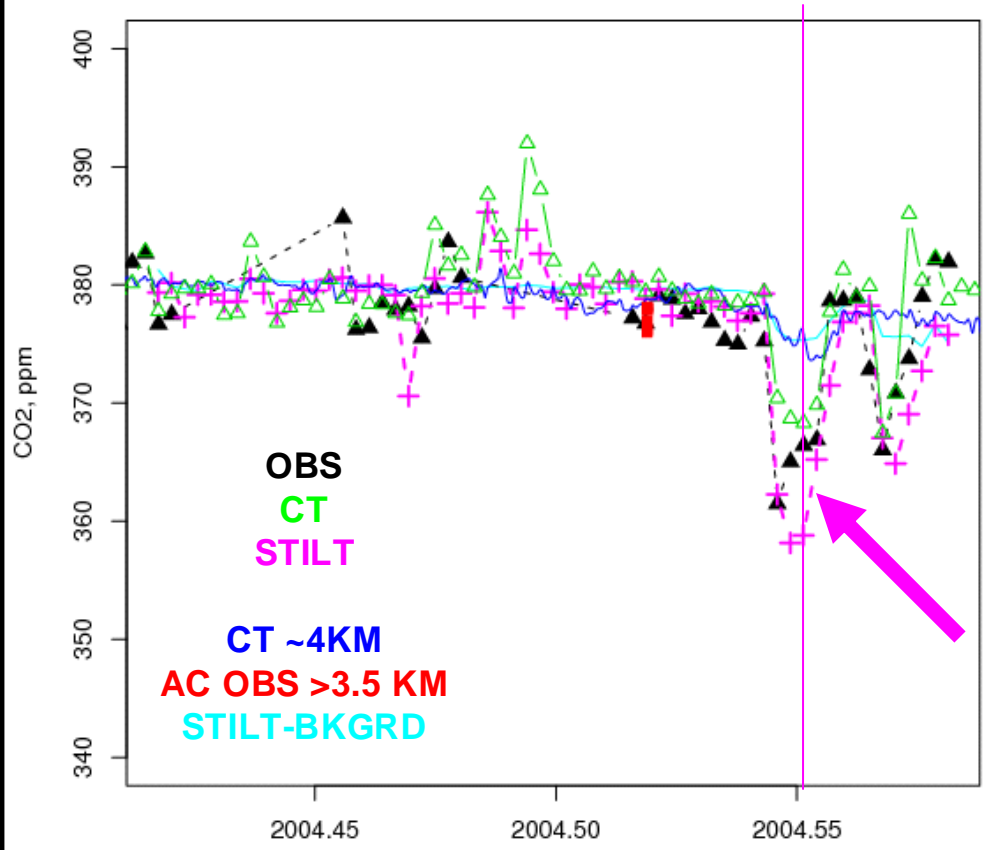
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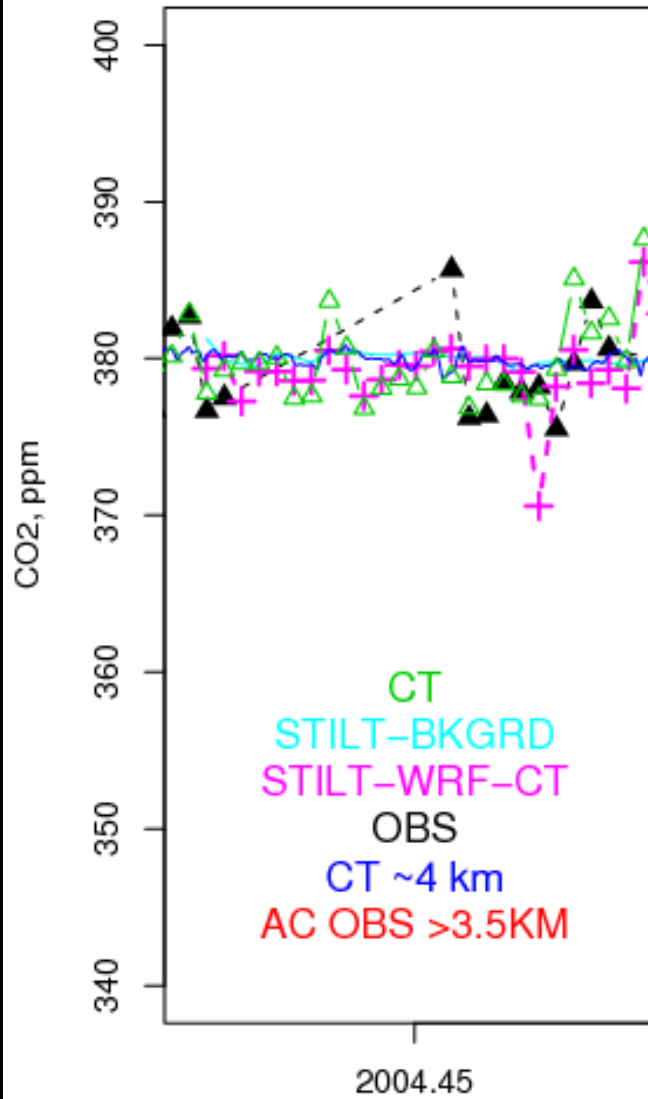
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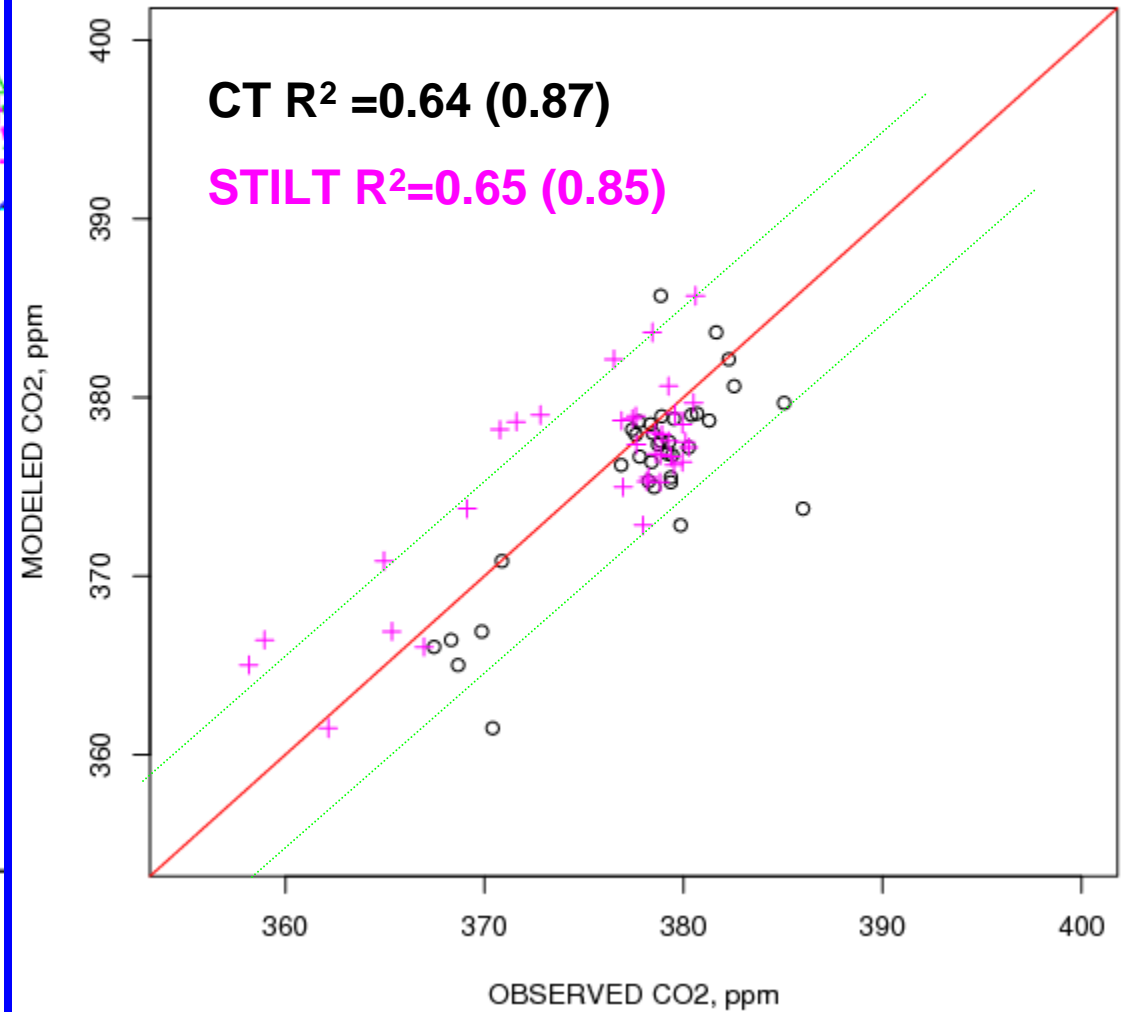
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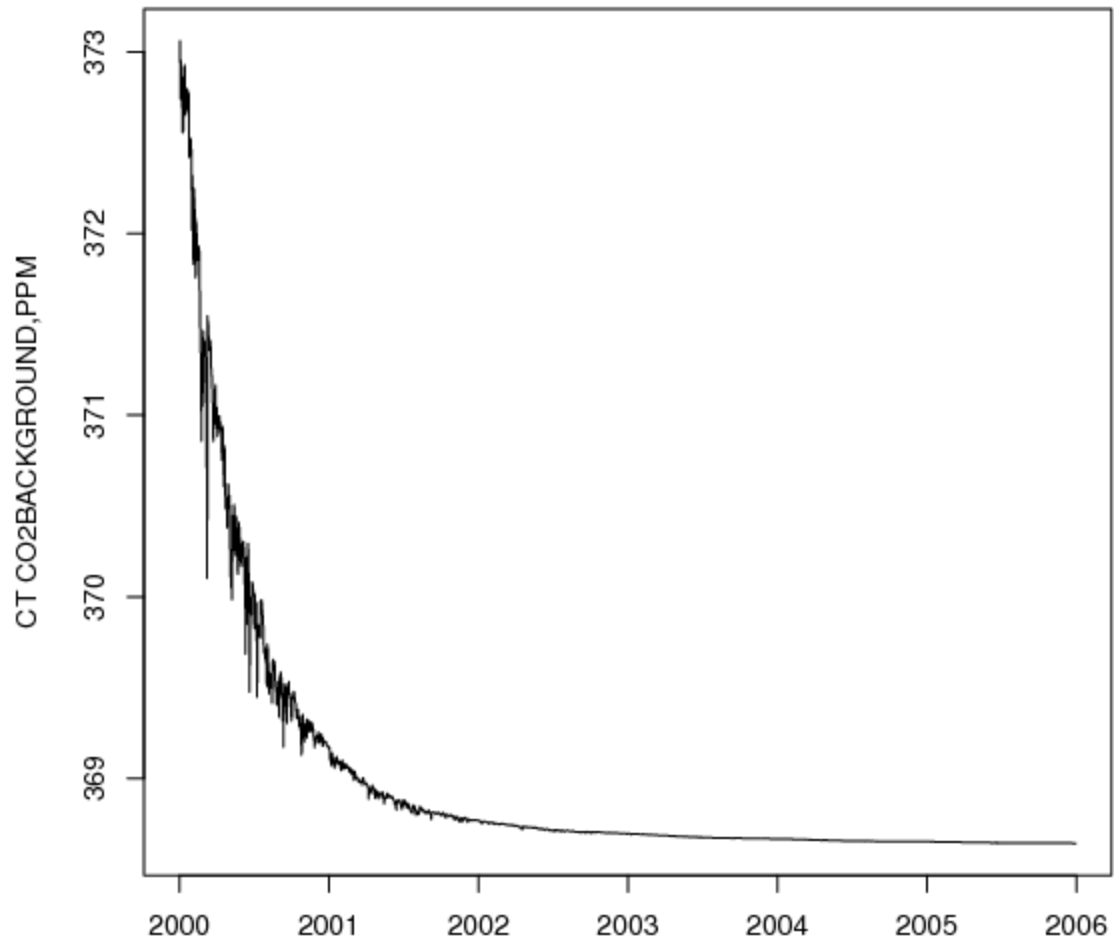


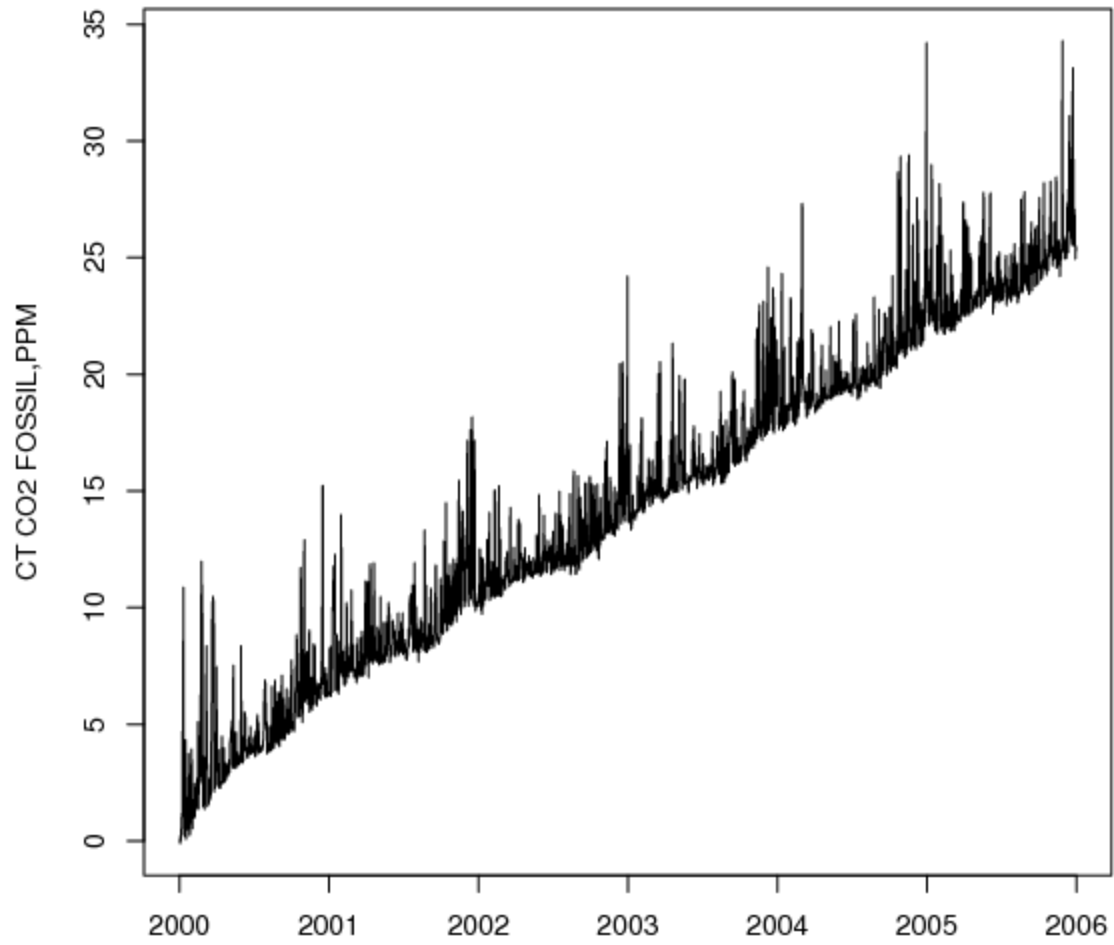
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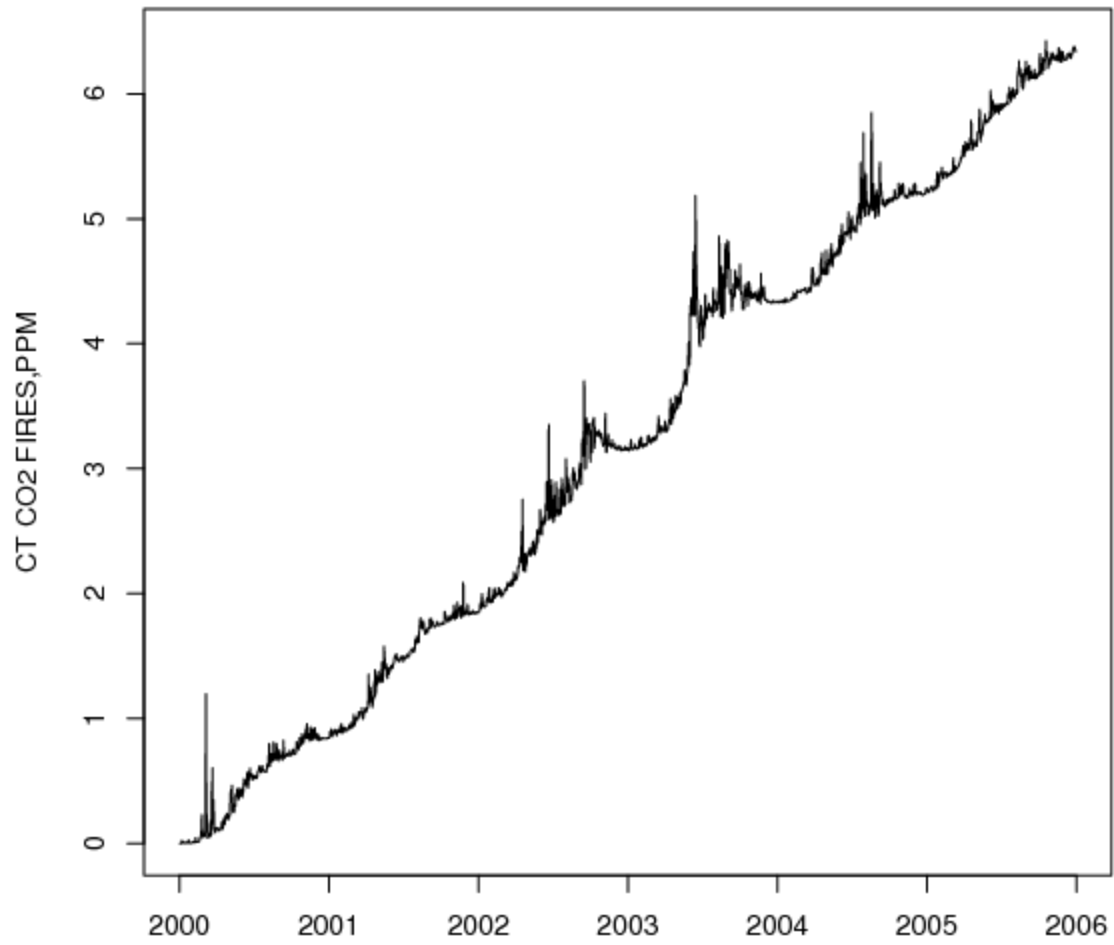


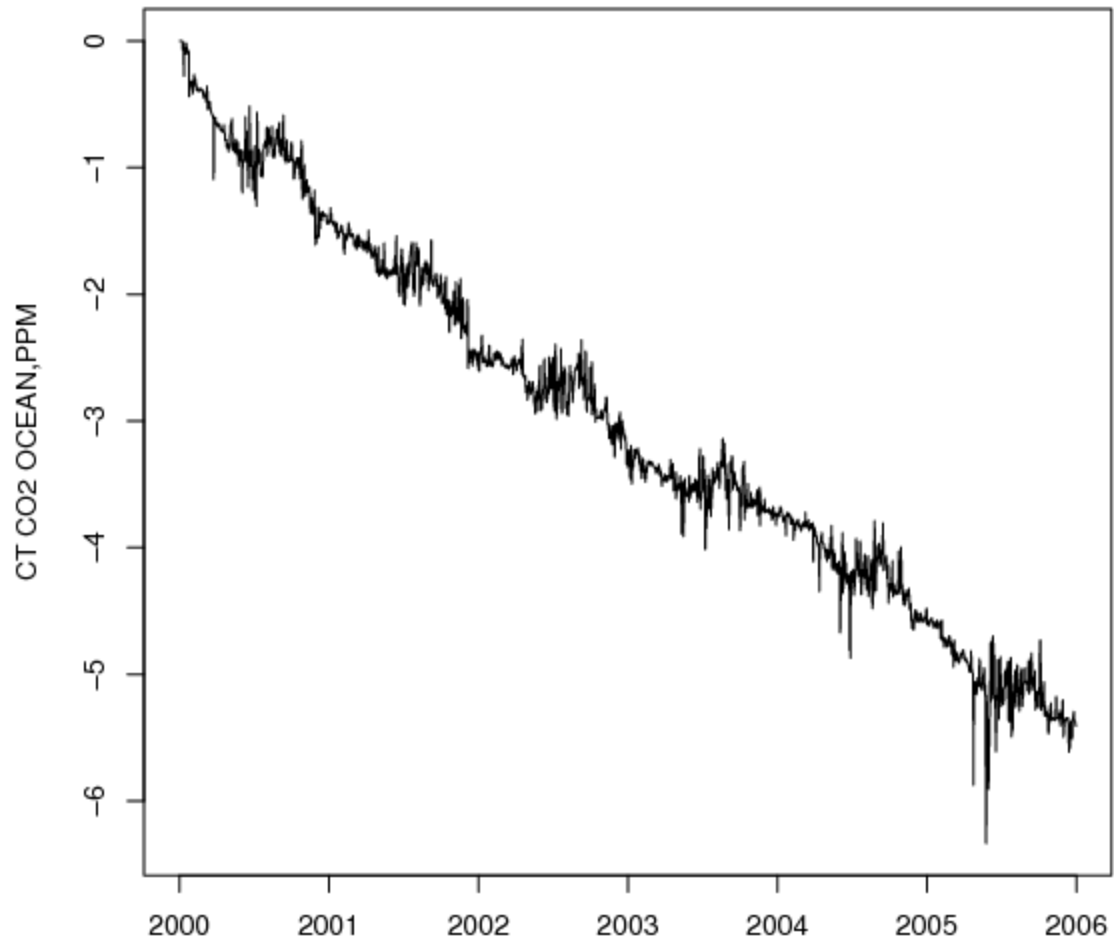
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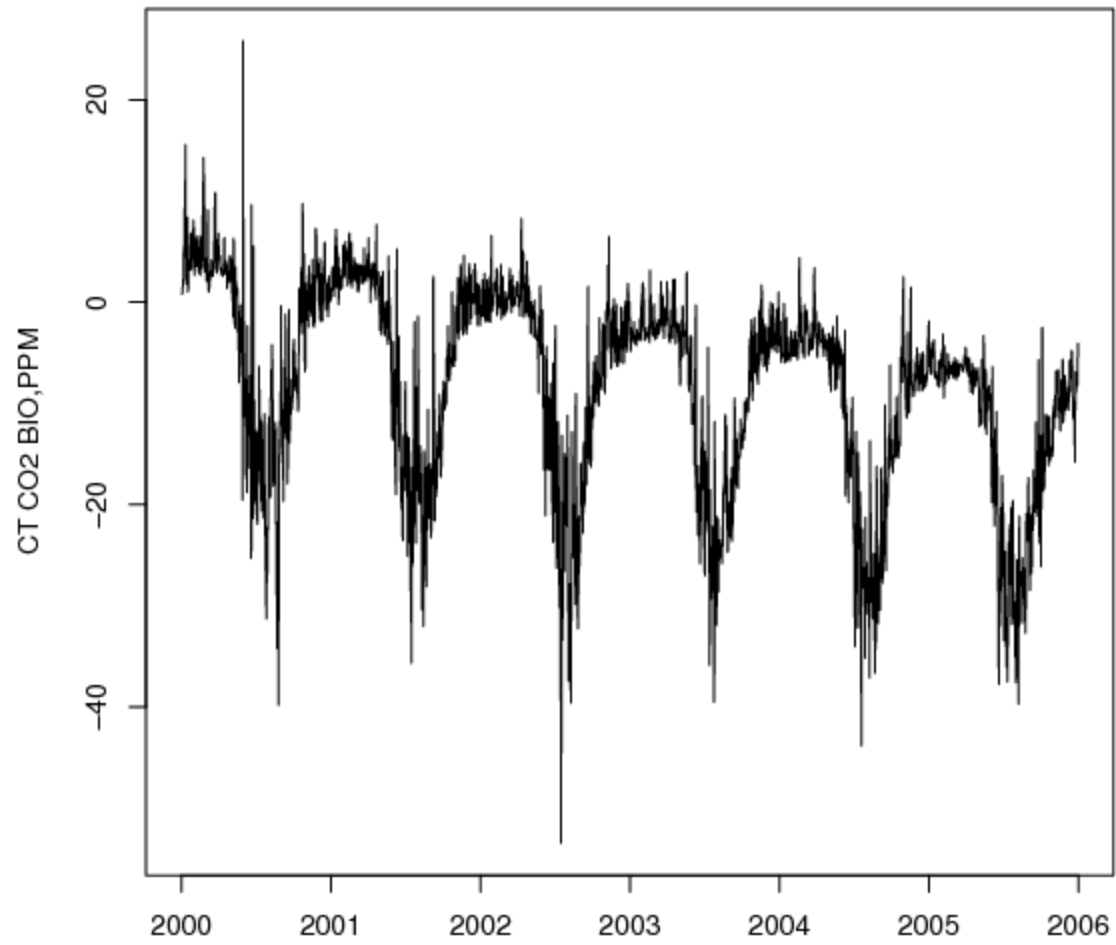


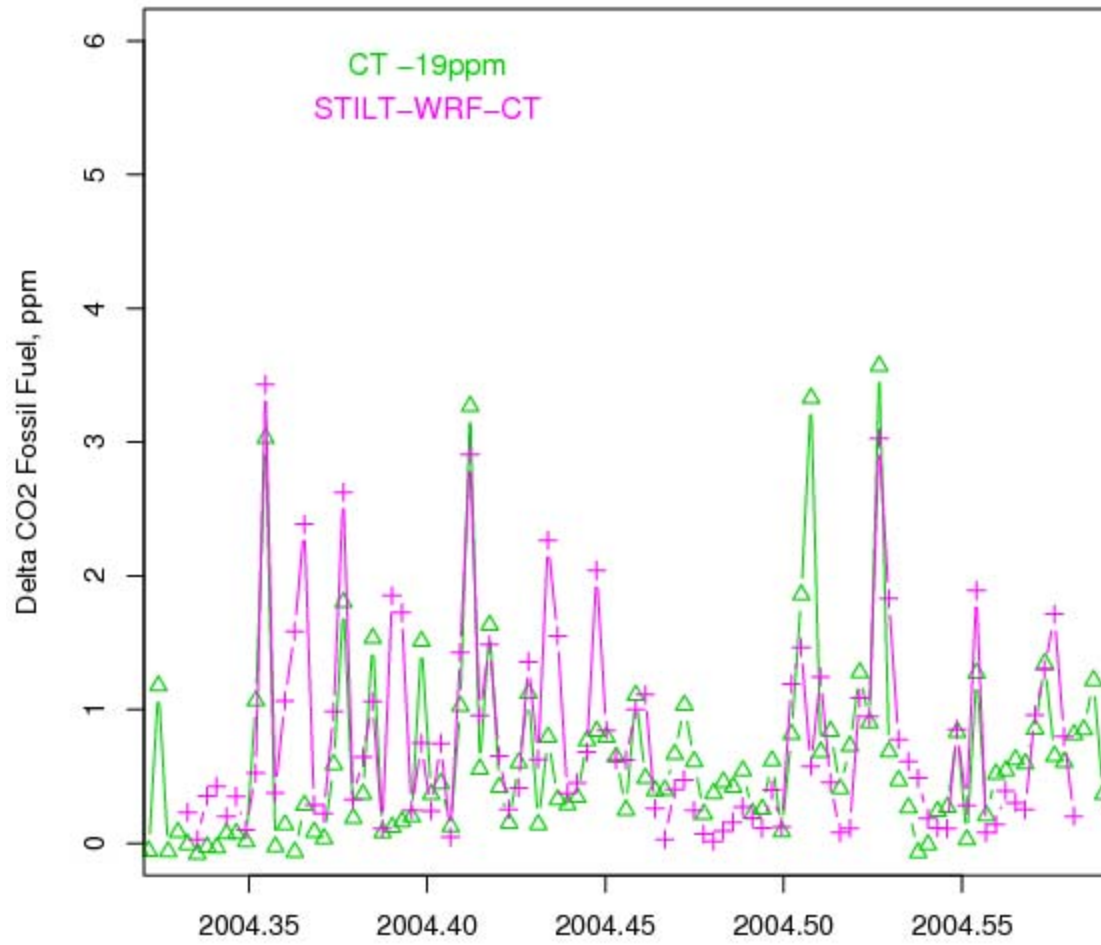


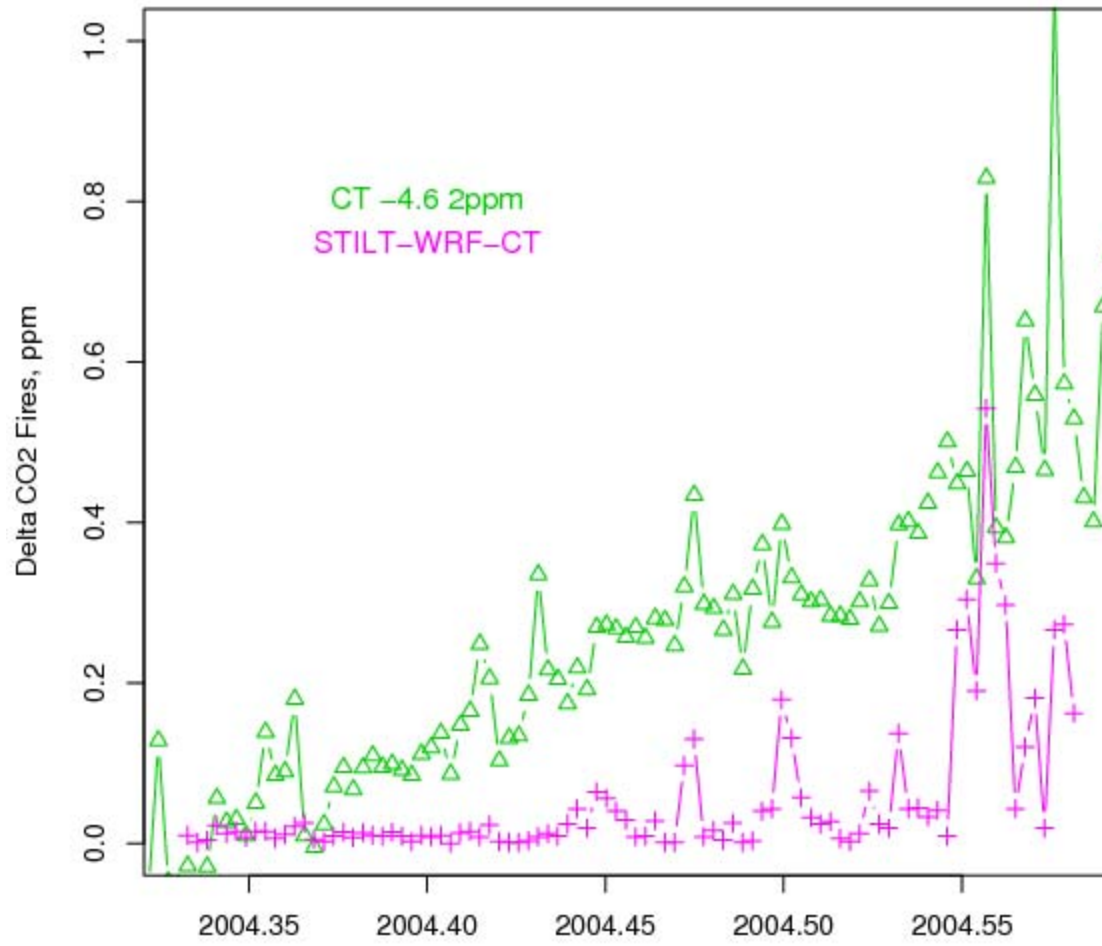


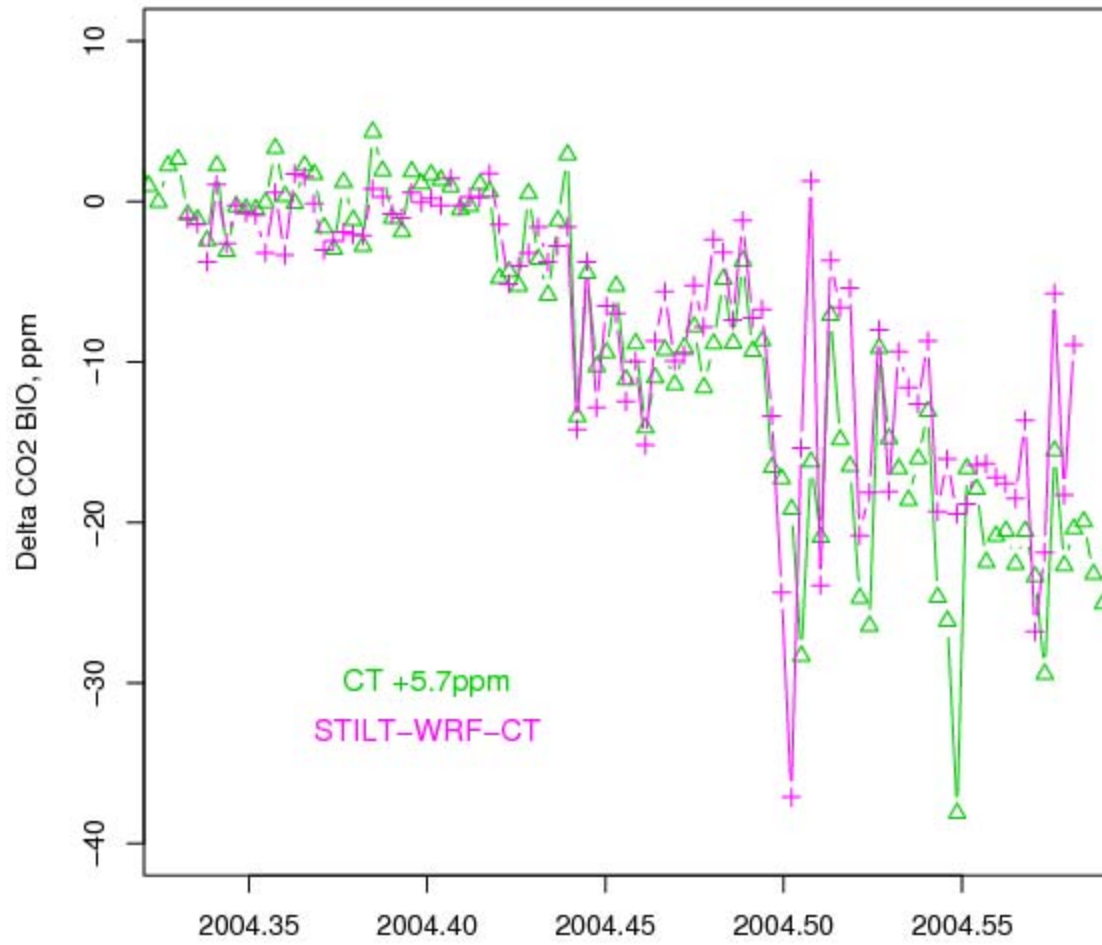


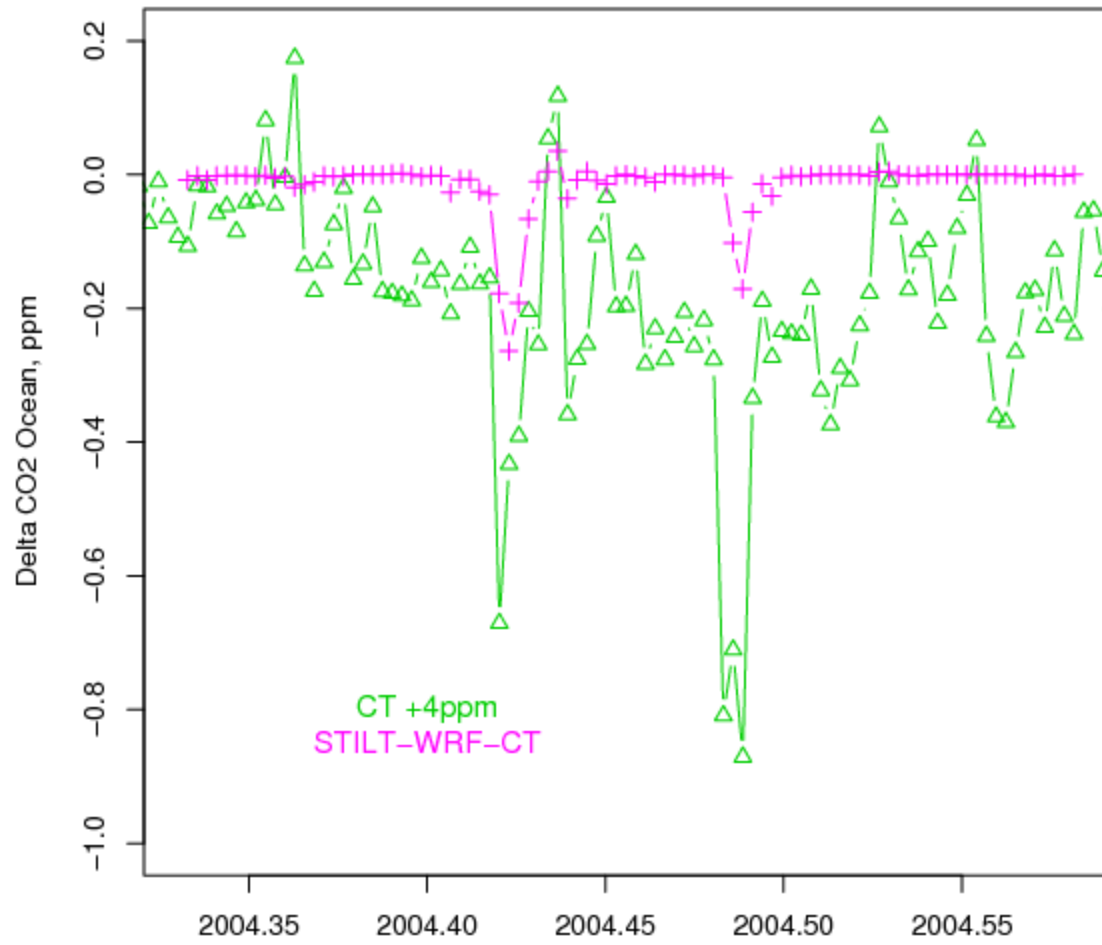




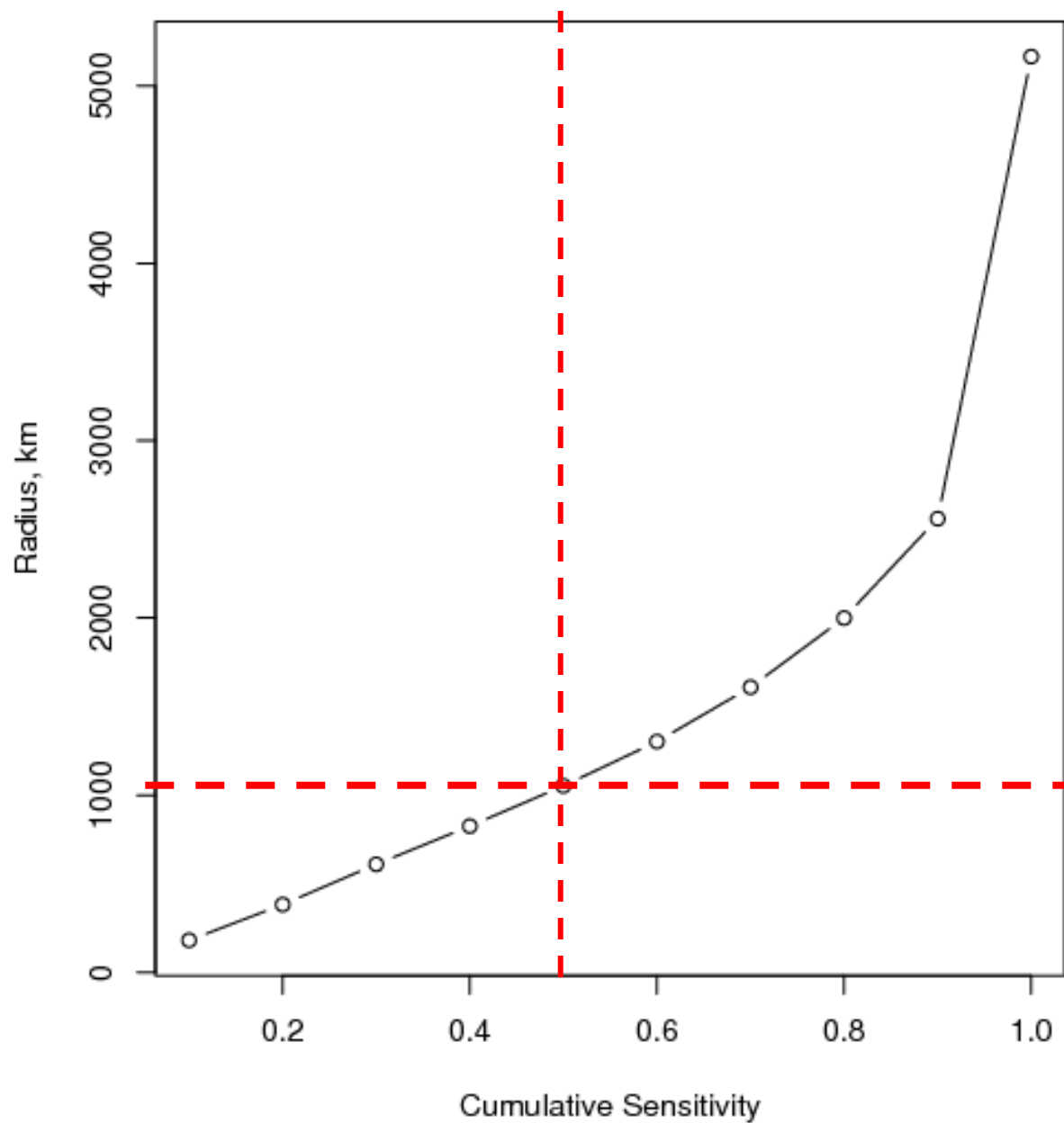




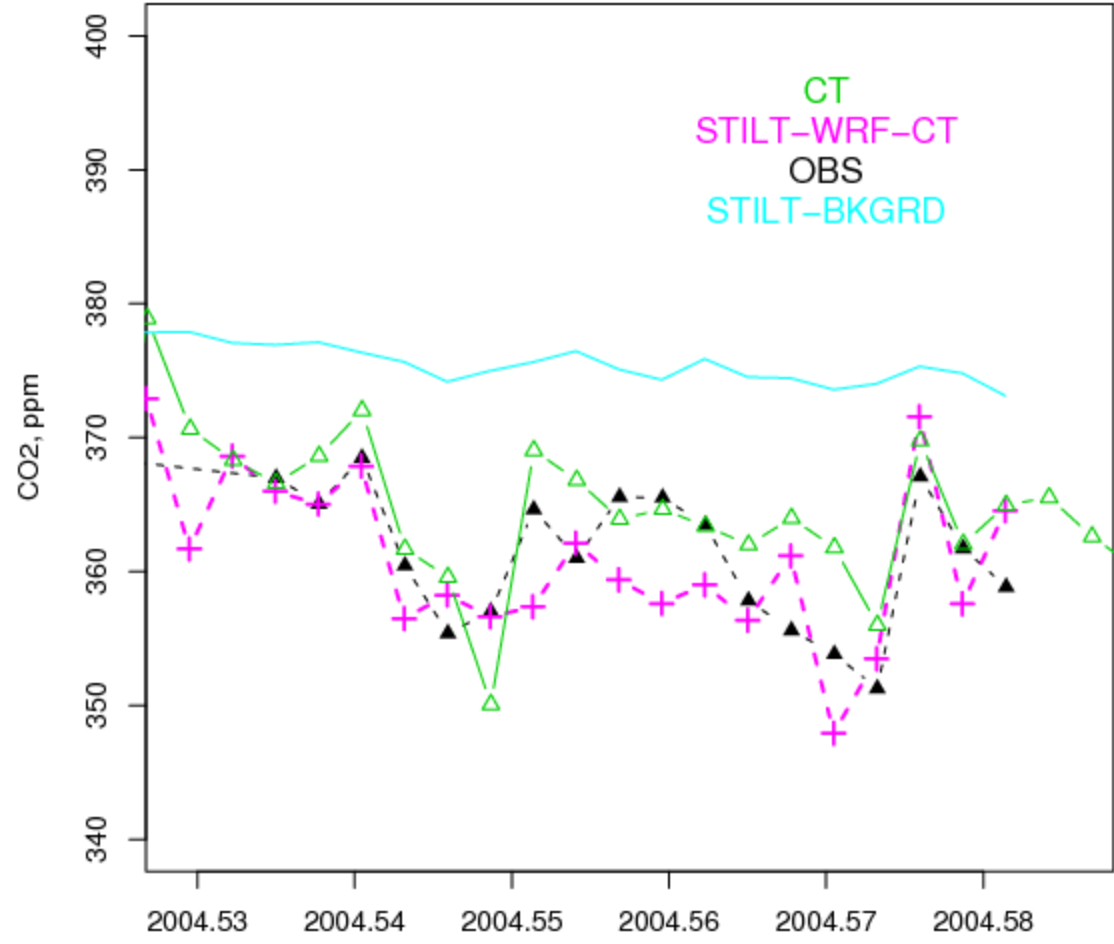




Nominal Radius of Footprint, 19:00 GMT: LEF 396m May–July 2004



LEF: MAY-JULY 2004 19:00 GMT (TOWER)



LEF: MAY-JULY 2004 19:00 GMT (TOWER)

