# Development and Initial Application of WRF-Chem-GHGs: Integrated Modeling of Air Quality, Carbon, and Climate

**Yang Zhang[1], Kai Wang[1], Xiao-Yang Chen[1], Daniel Schuch[1], Eeshan Basu[1], Siqi Ma[2], Daniel Tong[2,3], and Ravan Ahmadov[4]**

[1]Department of Civil and Environmental Engineering, Northeastern University
[2]Department of Atmospheric, Oceanic and Earth Sciences, George Mason University
[3]IM Systems Group
[4]CIRES, University of Colorado, Earth Prediction Advancement Division, Global Systems Laboratory, National Oceanic and Atmospheric Administration

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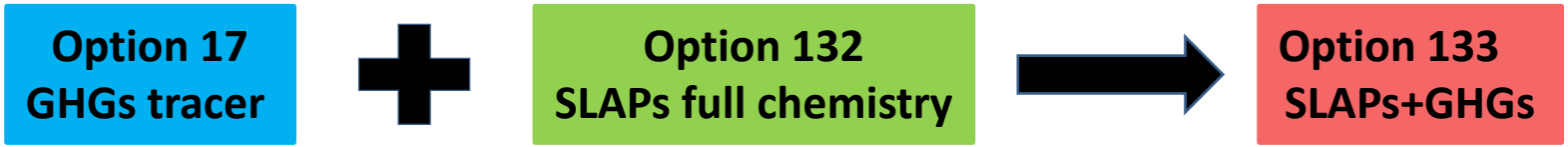
# Background and Objectives

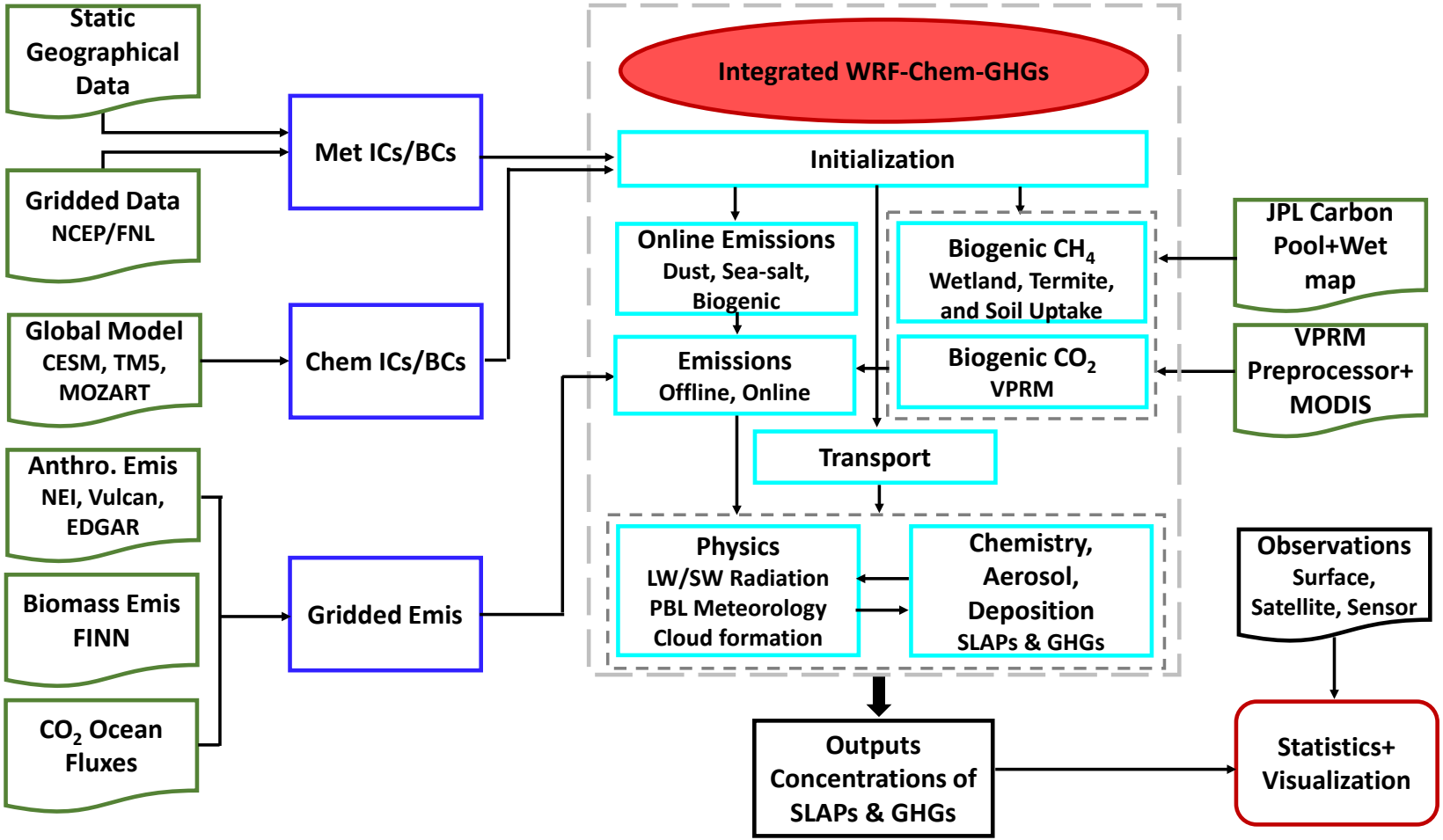
- **Background**
  - Current regional/urban air quality models (e.g., CMAQ and WRF-Chem) focus on atmospheric evolution of short-lived air pollutants (SLAPs)
  - Mitigation of air pollution, carbon, and climate changes requires an integrated modeling system to simulate both SLAPs and greenhouse gases (GHGs)
- **Objectives**
  - Develop a coupled model system based on WRF-Chem to simultaneously simulate the evolution of SLAPs and GHGs and their interactions for integrated assessment and policy analysis (referred to as **WRF-Chem-GHGs**)
  - Perform long-term simulations with this model under current and future scenarios in a warming climate to inform mitigation strategies that co-benefit air quality/carbon/climate change management at national/region/city scales

# New Representations in WRF-Chem-GHGs



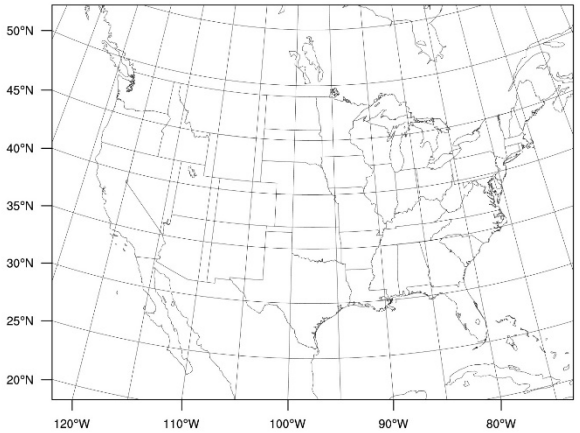

- An option to use anthropogenic and biogenic $CO_2$ and $CH_4$ emissions
- An online Vegetation Photosynthesis and Respiration Model (VPRM) that uses predicted temperature and radiation to estimate biogenic $CO_2$ fluxes
- The use of dynamic lateral boundary conditions (BCs) and initial conditions (ICs) for $CO_2$ and $CH_4$ based on Carbon tracker CT2019B and MOZART, respectively
- The use of time- and space-varying prognostic $CO_2$ and $CH_4$ concentrations in the RRTMG longwave and shortwave radiation schemes
- Chemical production of $CO_2$ from the oxidation of CO, $CH_4$, and volatile organic compounds (VOCs) (ongoing)

# Integrated WRF-Chem-GHGs Modeling System



# Simulation Setup and Evaluation Protocol for Initial Application

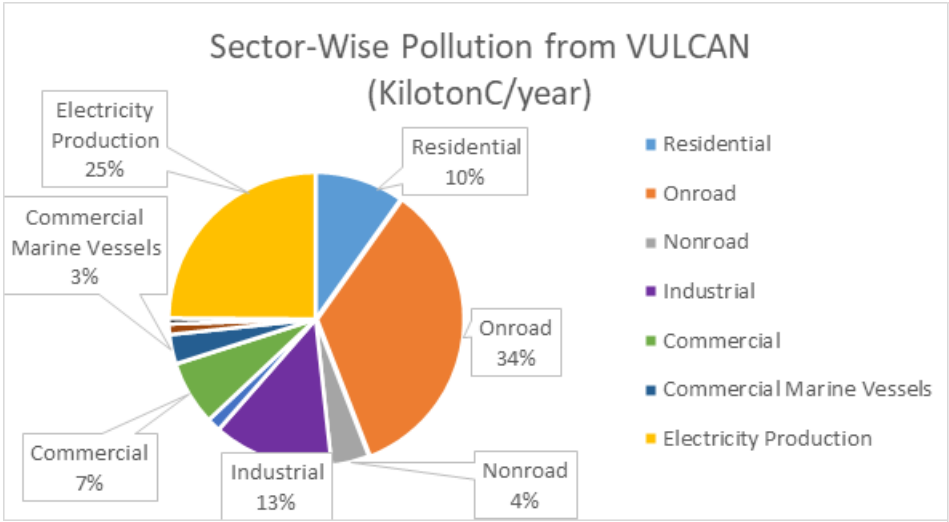
- **Period:** Jan. and Jul., 2012
- **Domain:** CONUS, 142 × 112 grid cells
- **Horizontal resolution:** 36 km
- **Vertical resolution:** 34 layers (up to 100 mb)
- **Emissions:**
  - Anthropogenic: NEI 2016(v1) for SLAPs; Vulcan, EDGAR, ODIAC, FFDAS for $CO_2$ & EDGAR for $CH_4$
  - Biogenic emissions: MEGAN2; Dust: AFWA scheme, Sea salt: Gong scheme for SLAPs, VPRM for $CO_2$
- **ICs and BCs:**
  - **Chemical:** Modified CESM/CAM5 for SLAPs; TM5 for $CO_2$; MOZART for $CH_4$/CO
  - **Meteorological:** NCEP/FNL
- **Chemical options**
  - **Gas-phase chemistry:** Modified CB05
  - **Aerosol module:** MADE/VBS
  - **Cloud chemistry module:** AQCHEM
- **Data for model evaluation:**
  - AQS/CASNET/IMPROVE/CSN: $O_3$, $PM_{2.5}$
  - CCGG: $CO_2$
  - NCDC/NADP: T2, RH2, WS10, WD10, Precip

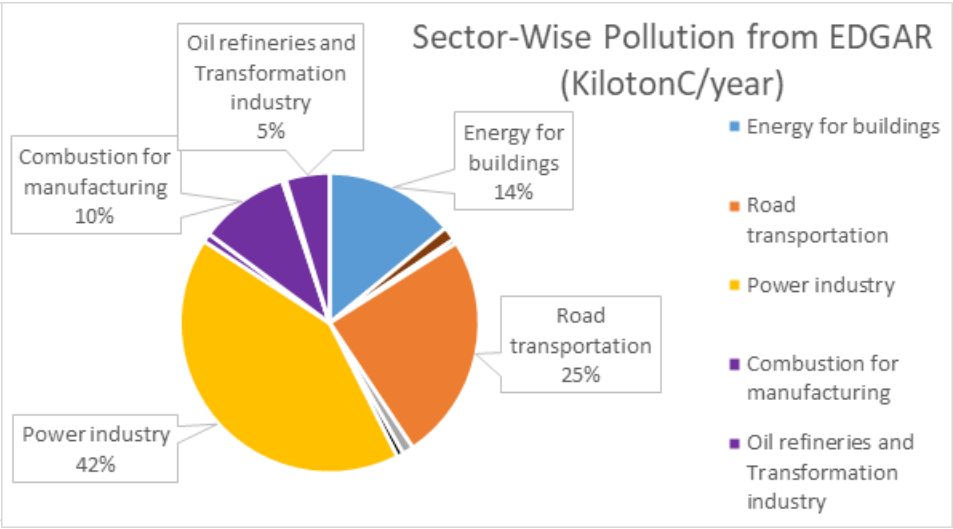



- **Evaluation Protocol**
  - **Statistics:** Mean Bias (MB), Normalized Mean Bias (NMB), Normalized Mean Error (NME), Root Mean Square Error (RMSE), Correlation coefficient (R)
  - Benchmark MBs for T2, WS10, and WD10: ≤ ± 0.5 °C, ± 0.5 m $s^{-1}$, and ± 10 °, respectively
  - Benchmark NMBs of ≤ ±15%, ± 30%, and ±5%; NMEs of < 25%, 50%, and 5%, for $O_3$, $PM_{2.5}$, $CO_2$, respectively
  - **Spatial distribution:** overlay, MB, NMB
  - **Temporal variation:** diurnal and time series plots

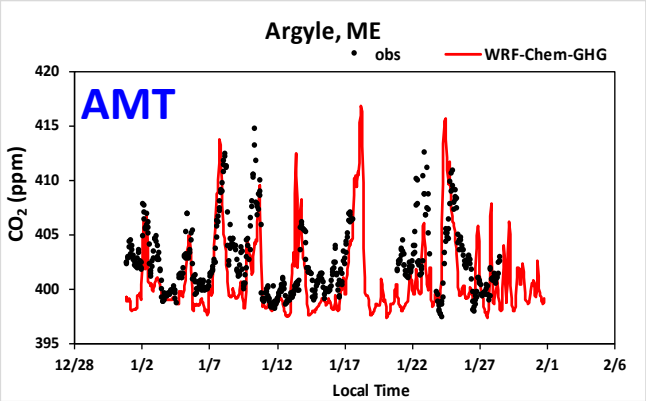
# Anthropogenic $CO_2$ Emission Datasets

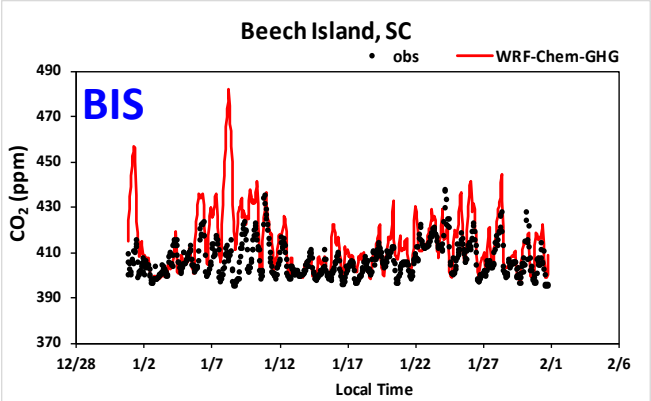
| Dataset | Temporal Resolution | Spatial Resolution | Year | kilotonC/year | Million metrictonCO$_2$/year | EIA (million metrictonCO$_2$/year) | Relative Difference with respect to EIA (%) |
|---|---|---|---|---|---|---|---|
| EDGAR | Annual | 0.1° | 2012 | 1376813.00 | 4579.76 | 5229 | 14.18 |
| VULCAN | Hourly | 1-km | 2012 | 1515675.00 | 5041.66 | | 3.72 |
| ODIAC | Monthly | 1° | 2012 | 1302459.00 | 4332.43 | | 20.69 |
| FFDAS | Annual | 0.1° | 2012 | 1359665.00 | 4522.71 | | 15.62 |

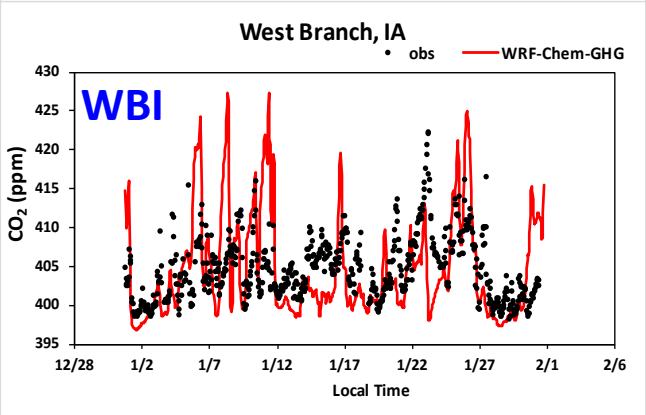


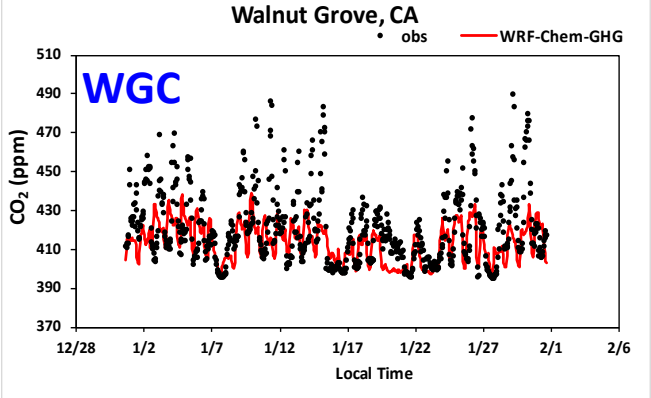



# WRF-Chem-GHGs: $CO_2$ Mixing Ratio, Jan 2012



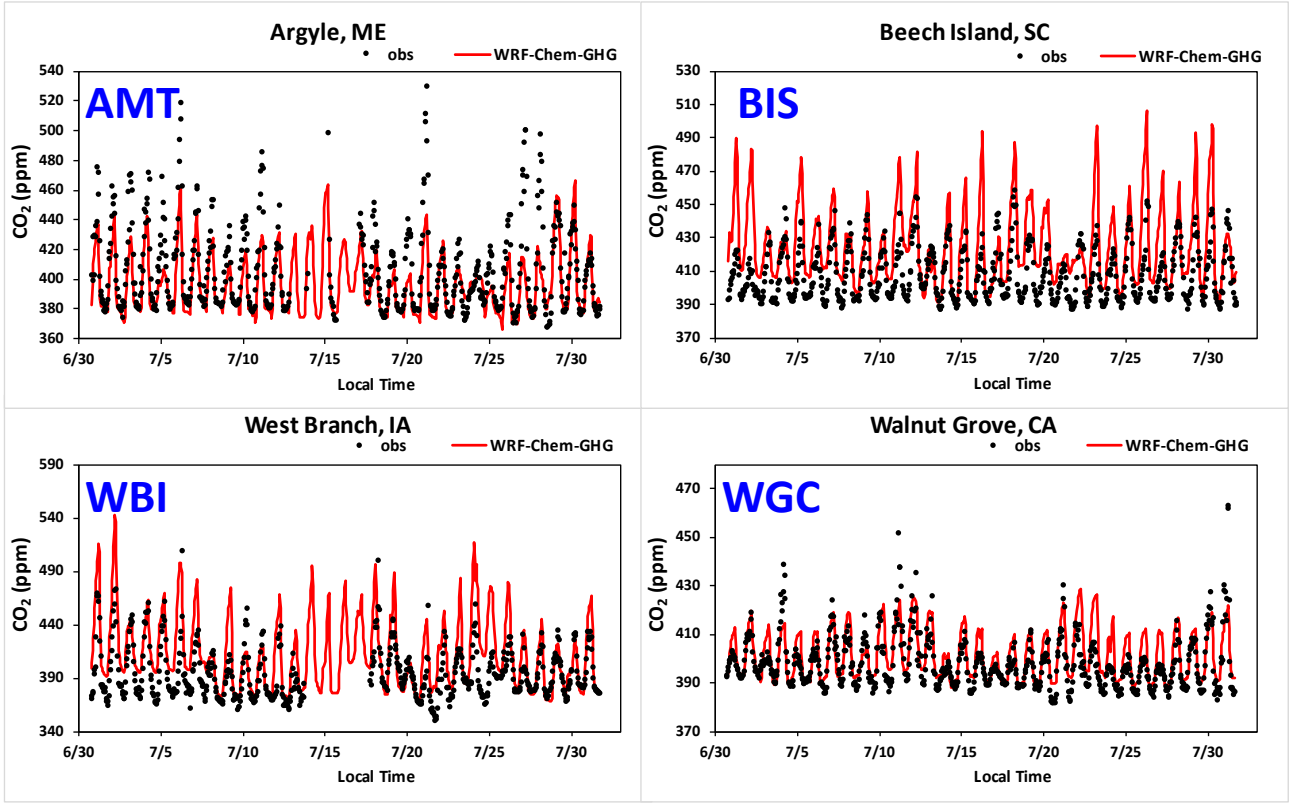




- Temporal variation of $CO_2$ is well captured for most days at all sites except WGC
- Underpredictions of may be associated with uncertainties in anthropogenic emissions at WGC

# WRF-Chem-GHGs: $CO_2$ Mixing Ratio, Jul 2012

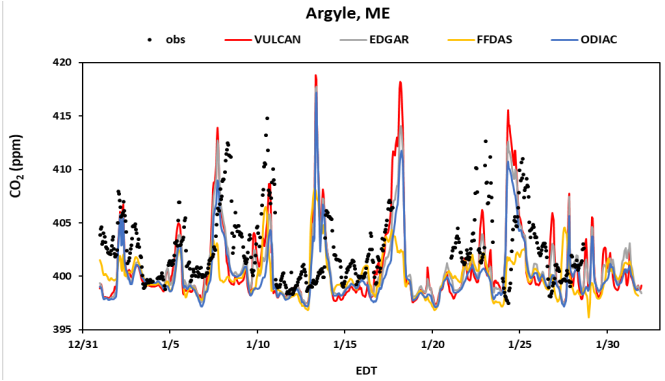


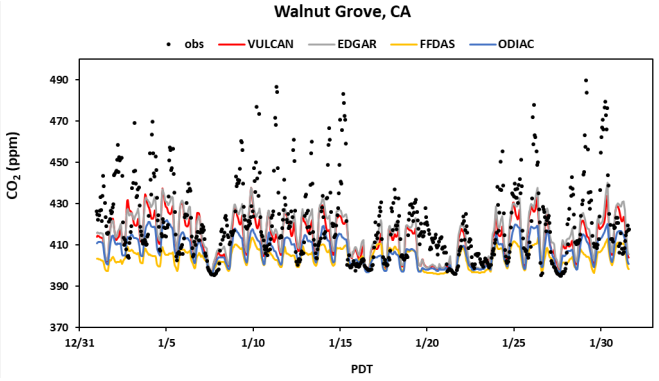

- Temporal variation of $CO_2$ is well captured for most days at all sites
- Underpredictions may be associated with uncertainties in biogenic emissions at AMT, and firework and wildfire emissions at WGC

# Sensitivity to $CO_2$ Emissions, Jan/Jul 2012

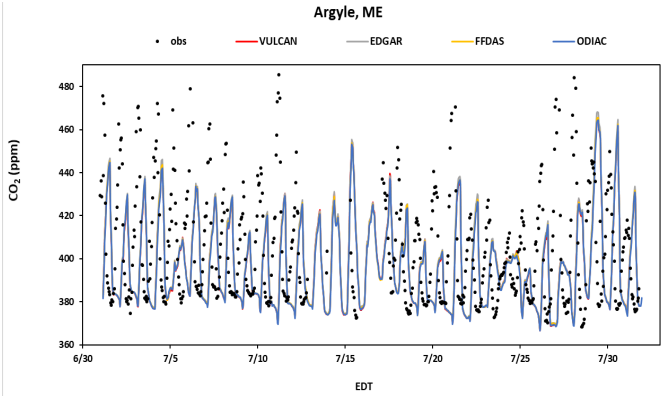
**AMT** | **WGC**

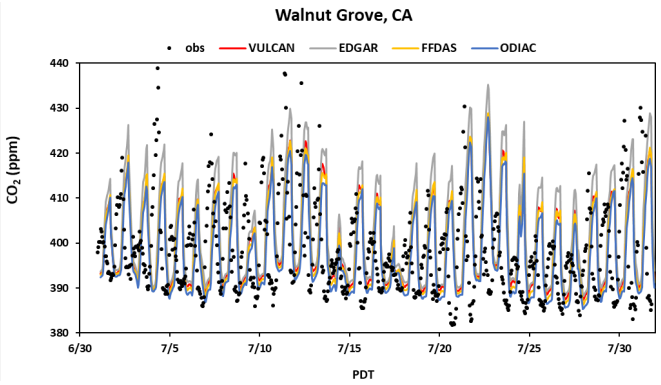
**Jan**



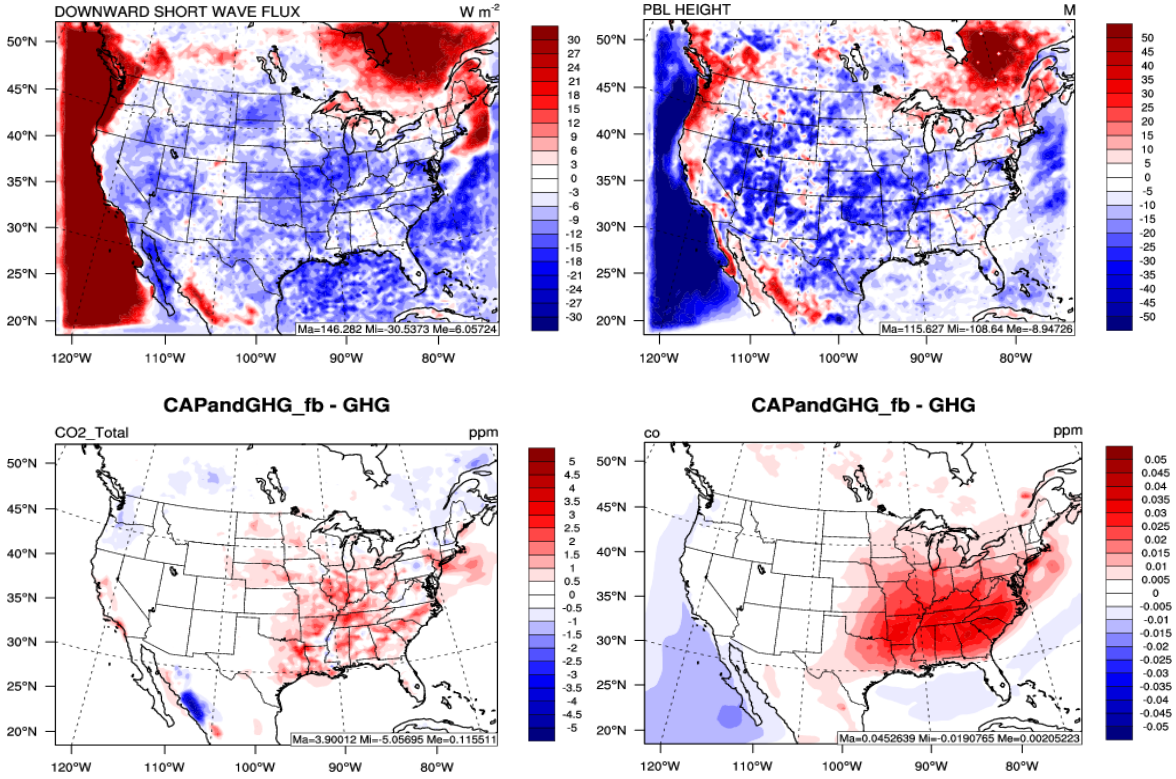

**Jul**




- $CO_2$ predictions are sensitive to different emission datasets in both months except at AMT in Jul
- VULCAN/EDGAR give the highest $CO_2$ in Jan/Jul, respectively

# Chemistry and $CO_2$ Feedbacks, Jul 2012




- Prognostic $CO_2$ in RRTMG predicts slightly stronger shortwave radiation, which is compensated by the reduction due to chemistry feedback, leading to a net decrease in shortwave radiation, temperature, and PBL height.
- Lower T2 can increase biogenic $CO_2$, thus total $CO_2$. Lower PBLH can increase CO.

# Summary of Preliminary Results and Future Work

- **WRF-Chem-GHGs is operational with overall good skill in reproducing observed $CO_2$. Underpredictions are mainly attributed to uncertainties in $CO_2$ emissions**
- **WRF-Chem-GHGs can simulate SLAPs and $CO_2$ feedbacks to boundary layer meteorology, radiation, and cloud formation, which in turn affect their concentrations and distributions**
- **Future work:**
  - Implement chemical production of $CO_2$
  - Account for $CH_4$ biogenic emissions from wetland, termite, and soil uptake
  - Evaluate for multi-year (2012-2017) at three grid resolutions (36-, 6- and 1-km) to establish baseline for future scenarios
  - Apply for 2047-2052 under future energy, climate, and land use change scenarios

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