ACT-America: WRF-Chem Baseline Simulations for North America, 2016-2019

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Documentation Revision Date: 2021-11-22

Dataset Version: 1

Summary

This dataset includes hourly output from the WRF-Chem simulation model for North America at a resolution of 27 km for 2016-06-29 through 2019-07-31. WRF-Chem is the Weather Research and Forecasting (WRF) model coupled with Chemistry. The output provides baseline conditions for comparison to data from ACT-America airborne campaigns conducted to study atmospheric CO2 and CH4 from 2016 to 2019. The WRF-Chem (v. 3.6.1) model was driven by meteorological conditions and sea-surface temperatures. The output includes 50 vertical layers up to atmospheric pressure of 50 hPa with 20 levels in the lowest 1 km. It provides information for understanding the fluxes and atmospheric transport of carbon dioxide (CO2), methane (CH4), and ethane (C2H6).

The NASA Atmospheric Carbon and Transport (ACT) - America project conducted five airborne campaigns across three regions in the eastern United States to study the transport and fluxes of atmospheric carbon dioxide (CO_2) and methane (CH_4). Each six-week campaign measured how weather systems transport these greenhouse gases. The objective of the study is to enable more accurate and precise estimates of the sources and sinks of these gases.

There are 27,037 data files in netCDF (*.nc) format included in this dataset.

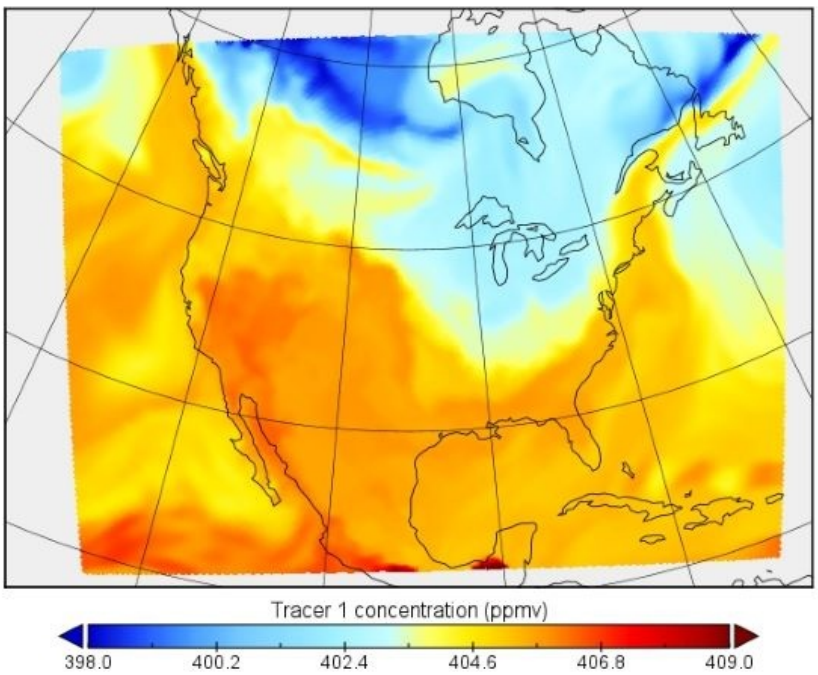

Figure 1. Simulated tracer 1 concentrations (ppmv) in vertical level 5 on 2016-06-29 at 12:00 pm. Output from WRF-Chem (v. 3.6.1) model. Source: wrfout_d01_2016-06-29_12:00:00.nc

Citation

Feng, S., T. Lauvaux, Z.R. Barkley, K.J. Davis, M.P. Butler, A. Deng, B. Gaudet, and D. Stauffer. 2021. ACT-America: WRF-Chem Baseline Simulations for North America, 2016-2019. ORNL DAAC, Oak Ridge, Tennessee, USA. https://doi.org/10.3334/ORNLDAAC/1884

Table of Contents

1. Dataset Overview

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The NASA Atmospheric Carbon and Transport (ACT) - America project conducted five airborne campaigns across three regions in the eastern United States to study the transport and fluxes of atmospheric carbon dioxide (CO_2) and methane (CH_4). Each six-week campaign measured how weather systems transport these greenhouse gases. The objective of the study is to enable more accurate and precise estimates of the sources and sinks of these gases.

Project: Atmospheric Carbon and Transport - America

The ACT-America, or Atmospheric Carbon and Transport - America, project is a NASA Earth Venture Suborbital-2 mission to study the transport and fluxes of atmospheric carbon dioxide and methane across three regions in the eastern United States. Flight campaigns measured transport of greenhouse gases by continental-scale weather systems. Ground-based measurements of greenhouse gases were also collected. Project goals include better estimates of greenhouse gas sources and sinks which are required for climate management and for prediction of future climate.

Related Publications

Feng, S., T., Lauvaux, C. A., Williams, K. J., Davis, Y., Zhou, I., Baker, et al. 2021. Joint CO2 mole fraction and flux analysis confirms missing processes in CASA terrestrial carbon uptake over North America. Global Biogeochemical Cycles, 35, e2020GB006914. https://doi.org/10.1029/2020GB006914

Feng, S., T. Lauvaux, K. Keller, K.J. Davis, P. Rayner, T. Oda, and K.R. Gurney. 2019. A Road Map for Improving the Treatment of Uncertainties in High-resolution Regional Carbon Flux Inverse Estimates. Geophysical Research Letters 46:13461–13469. https://doi.org/10.1029/2019GL082987

Acknowledgment

This work received financial support from NASA's ACT-America program (grant NNX15AG76G).

2. Data Characteristics

Spatial Coverage: North America

Spatial Resolution: 27 km

Temporal Coverage: 2016-06-29 to 2019-07-31

Temporal Resolution: hourly

Study Area: Latitude and longitude are given in decimal degrees.

Site	Northernmost Latitude	Southernmost Latitude	Easternmost Longitude	Westernmost Longitude
North America	62.841	12.993	-41.608	150.392

Data File Information

There are 27,037 data files in netCDF (*.nc) format included in this dataset. The files are named wrfout_d01_**YYYY**-**MM**-**DD**_**hh**:**mm**:**ss**.nc (e.g., wrfout_d01_2016-06-29_12:00:00.nc), where **YYYY** = year, **MM** = month, **DD** = day, **hh** = hour, **mm** = minute, and **ss** = second of data collection.

Data File Details

Missing values are variable and encoded in the metadata of each netCDF. Each file contains 184 rows and 249 columns. The Coordinate Reference System is "WGS84" (EPSG:4326).

Table 1. Variable names and descriptions. See documents provided at https://ruc.noaa.gov/wrf/wrf-chem/ for explanations of these 218 variables.

Variable	Units	Description
ACGRDFLX	J m-2	accumulated ground heat flux
ACSNOM	kg m-2	accumulated melted snow
ALBBCK	1	background albedo
ALBEDO	1	albedo
ALPHA_VPRM		
ALT	m3 kg-1	inverse density
AVGFLX_RUM	Pa m s-1	hist-time-averaged mu-coupled u
AVGFLX_RVM	Pa m s-1	hist-time-averaged mu-coupled v
AVGFLX_WWM	Pa s-1	hist-time-averaged mu-coupled eta-dot
BIOMT_PAR	g m-2	biomass termite per vegetation type
CANWAT	kg m-2	canopy water

CF1	1	2nd order extrapolation constant
CF2	1	2nd order extrapolation constant
CF3	1	2nd order extrapolation constant
CFD1	kg m-2 s-1	average downdraft mass flux from gd-scheme
CFN	1	extrapolation constant
CFN1	1	extrapolation constant
CFU1	kg m-2 s-1	average updraft mass flux from gd-scheme
CLAT	degree_north	computational grid latitude
COSALPHA	1	local cosine of map rotation
COSZEN	1	cos of solar zenith angle
DFD1	kg m-2 s-1	average detrainment from downdraft from gd-scheme
DFU1	kg m-2 s-1	average detrainment from updraft from gd-scheme
DMS_0	nM l-1	dms oceanic concentrations
DN	1	d(eta) values between half (mass) levels
DNW	1	d(eta) values between full (w) levels
DZS	m	thicknesses of soil layers
E	s-1	coriolis cosine latitude term
E_TRA1	mol km-2 h-1	Boundary tracer (zero)
E_TRA2	mol km-2 h-1	CT Miller fossil fuel emissions
E_TRA3	mol km-2 h-1	CT ODIAC fossil fuel emissions
E_TRA4	mol km-2 h-1	CT ocean fluxes
E_TRA5	mol km-2 h-1	CT fire emissions
E_TRA6	mol km-2 h-1	CT posterior biogenic fluxes
E_TRA7	mol km-2 h-1	CASA mean GPP
E_TRA8	mol km-2 h-1	CASA Para05 GPP
E_TRA9	mol km-2 h-1	CASA mean respiration
E_TRA10	mol km-2 h-1	CASA Para05 respiration
E_TRA11	mol km-2 h-1	SIB4 GPP
E_TRA12	mol km-2 h-1	SIB4 respiration
E_TRA13	mol km-2 h-1	EPA 2012 oil and gas
E_TRA14	mol km-2 h-1	EPA 2012 coal
E_TRA15	mol km-2 h-1	EPA 2012 enteric Fermentation and Manure management
E_TRA16	mol km-2 h-1	EPA 2012 landfills
E_TRA17	mol km-2 h-1	EPA 2012 other
E_TRA18	mol km-2 h-1	Anthropogenics outside US (Daniel Jacob Canada+Mexico for oil and gas, and EDGAR v. 4.3.2 for other)
E_TRA19	mol km-2 h-1	WetCHARTs V1.2 Extended ensemble (member 1913)
E_TRA20	mol km-2 h-1	WetCHARTs V1.2 Extended ensemble (member 1914)
E_TRA21	mol km-2 h-1	WetCHARTs V1.2 Extended ensemble (member 1923)

E_TRA22	mol km-2 h-1	CT-CH4 2010
E_TRA23	mol km-2 h-1	CMS-CH4-NAD (averaged monthly)
E_TRA24	mol km-2 h-1	EDGAR v4.3.2
E_TRA25	mol km-2 h-1	2010 C2H6 Global Emissions Inventory (Tzompa Sosa)
EFD1	kg m-2 s-1	average entrainment into downdraft from gd-scheme
EFU1	kg m-2 s-1	average entrainment into updraft from gd-scheme
EMISS	1	surface emissivity
EMIT_PAR	1	
EROD	none	fraction of erodible surface in each grid cell (0-1)
F	s-1	coriolis sine latitude term
FNM	1	upper weight for vertical stretching
FNP	1	lower weight for vertical stretching
GLW	W m-2	downward long wave flux at ground surface
GRAUPELNC	mm	accumulated total grid scale graupel
GRDFLX	W m-2	ground heat flux
GUST	m s-1	gust at 10 m
HAILNC	mm	accumulated total grid scale hail
HFX	W m-2	upward heat flux at the surface
HFX_FORCE	W m-2	scm ideal surface sensible heat flux
HFX_FORCE_TEND	W m-2 s-1	scm ideal surface sensible heat flux tendency
HGT	m	terrain height
ISLTYP		dominant soil category
ITIMESTEP	1	I timestep
IVGTYP		dominant vegetation category
LAI	1	leaf area index (m2 m-2)
LAI_VEGMASK	1	MODIS LAI vegetation mask for this date; 0=no dust produced (vegetation)
LAMBDA_VPRM		
LANDMASK	1	land mask, 1=land
LH	W m-2	latent heat flux at the surface
LH_FORCE	W m-2	scm ideal surface latent heat flux
LH_FORCE_TEND	W m-2 s-1	scm ideal surface latent heat flux tendency
LU_INDEX		land use category
MAPFAC_M	1	map scale factor on mass grid
MAPFAC_MX	1	map scale factor on mass grid
MAPFAC_MY	1	map scale factor on mass grid
MAPFAC_U	1	map scale factor on u-grid
MAPFAC_UX	1	map scale factor on u-grid
MAPFAC_UY	1	map scale factor on u-grid
MAPFAC_V	1	map scale factor on v-grid
MAPFAC_VX	1	map scale factor on v-grid
MAPFAC_VY	1	map scale factor on v-grid
MAX_MSTFX	1	max map factor in domain
MAX_MSTFY	1	max map factor in domain
MF_VX_INV	1	inverse map scale factor on v-grid
MU	Pa	perturbation dry air mass in column
MUB	Pa	base state dry air mass in column
MUT		

MUU		
MUV		
NEST_POS		
NOAHRES	W m-2	residual of the NOAH surface energy budget
OLR	W m-2	TOA outgoing long wave
P	Pa	perturbation pressure
P_STRAT	Pa	base state pressure at bottom of stratosphere
P_TOP	Pa	pressure top of the model
P00	Pa	base state pressure
PB	Pa	base state pressure
PBLH	m	pbl height
PH	m2 s-2	perturbation geopotential
PHB	m2 s-2	base-state geopotential
PREC_ACC_C	mm	accumulated cumulus precipitation over PREC_ACC_DT periods of time
PREC_ACC_NC	mm	accumulated grid scale precipitation over PREC_ACC_DT periods of time
PSFC	Pa	sfc pressure
Q2	kg kg-1	qv at 2 m
QCLOUD	1	cloud water mixing ratio (kg kg-1)
QFX	kg m-2 s-1	upward moisture flux at the surface
QGRAUP	1	graupel mixing ratio (kg kg-1)
QICE	1	ice mixing ratio (kg kg-1)
QKE	m2 s-2	twice TKE from mynn
QNICE	kg-1	ice number concentration
QNRAIN	kg-1	rain number concentration
QRAIN	1	rain water mixing ratio (kg kg-1)
QSNOW	1	snow mixing ratio (kg kg-1)
QVAPOR	1	water vapor mixing ratio (kg kg-1)
RAD_VPRM		
RAINC	mm	accumulated total cumulus precipitation
RAINNC	mm	accumulated total grid scale precipitation
RAINSH	mm	accumulated shallow cumulus precipitation
RDN	1	inverse d(eta) values between half (mass) levels
RDNW	1	inverse d(eta) values between full (w) levels
RDX	1	inverse x grid length
RDY	1	inverse y grid length
RESM	1	time weight constant for small steps
RESP_VPRM		
SAVE_TOPO_FROM_REAL	flag	flag, 1=original topo from real, 0=topo modified by WRF
SEAICE	flag	sea ice flag
SEED1	1	random seed number 1
SEED2	1	random seed number 2
SH2O	1	soil liquid water (m3 m-3)
SHDMAX	1	annual max veg fraction
SHDMIN	1	annual min veg fraction
SINALPHA	1	local sine of map rotation
SMCREL	1	relative soil moisture
SMOIS	1	soil moisture (m3 m-3)
SNOALB	1	annual max snow albedo in fraction
SNOW	kg m-2	snow water equivalent

SNOW_ACC_NC	mm	accumulated snow water equivalent over prec_acc_dt periods of time
SNOWC	flag	flag indicating snow coverage, 1 = snow cover
SNOWH	m	physical snow depth
SNOWNC	mm	accumulated total grid scale snow and ice
SR	1	fraction of frozen precipitation
SST	K	sea surface temperature
SSTSK	K	skin sea surface temperature
SWDDIF	W m-2	shortwave surface downward diffuse irradiance
SWDDIR	W m-2	shortwave surface downward direct irradiance
SWDDNI	W m-2	shortwave surface downward direct normal irradiance
SWDOWN	W m-2	downward short wave flux at ground surface
SWNORM	W m-2	normal short wave flux at ground surface (slope-dependent)
T	K	perturbation potential temperature (theta-t0)
T00	K	base state temperature
T2	K	temperature at 2 m
TH2	K	pot temperature at 2 m
TISO	K	temp at which the base T turns const
TKE	m2 s-2	turbulence kinetic energy
TKE_PBL	m2 s-2	tke from pbl
TLP	1	base state lapse rate
TLP_STRAT	K	base state lapse rate (dt/d(ln(p)) in stratosphere
TMN	K	soil temperature at lower boundary
tracer_1	ppmv	CO2 continental boundary inflow
tracer_2	ppmv	CO2 signals due to CT Miller fossil fuel +300
tracer_3	ppmv	CO2 signals due to CT ODIAC fossil fuel +300
tracer_4	ppmv	CO2 signals due to CT ocean +300
tracer_5	ppmv	CO2 signals due to CT fire +300
tracer_6	ppmv	CO2 signals due to CT posterior biogenic +300
tracer_7	ppmv	CO2 signals due to CASA mean GPP +300
tracer_8	ppmv	CO2 signals due to CASA Para05 GPP +300
tracer_9	ppmv	CO2 signals due to CASA mean respiration +300
tracer_10	ppmv	CO2 signals due to CASA Para05 respiration +300
tracer_11	ppmv	CO2 signals due to SIB4 GPP +300
tracer_12	ppmv	CO2 signals due to SIB4 respiration +300
tracer_13	ppmv	(CH4 enhancement due to EPA 2012 oil and gas) x 10^9 + 300
tracer_14	ppmv	(CH4 enhancement due to EPA 2012 coal) x 10^9 + 300
tracer_15	ppmv	(CH4 enhancement due to EPA 2012 enteric Fermentation and Manure management) x 10^9 + 300
tracer_16	ppmv	(CH4 enhancement due to EPA 2012 landfills) x 10^9 + 300
tracer_17	ppmv	(CH4 enhancement due to EPA 2012 other) x 10^9 + 300
tracer_18	ppmv	(CH4 enhancement due to Anthropogenics outside US (Daniel Jacob Canada+Mexico for oil and gas, and EDGAR v4.3.2 for other)) x 10^9 + 300
tracer_19	ppmv	(CH4 enhancement due to WetCHARTs V1.2 Extended ensemble (member 1913)) x 10^9 + 300
tracer_20	ppmv	(CH4 enhancement due to WetCHARTs V1.2 Extended ensemble (member 1914)) x 10^9 + 300
tracer_21	ppmv	(CH4 enhancement due to WetCHARTs V1.2 Extended ensemble (member 1923)) x 10^9 + 300
tracer_22	ppmv	(CH4 enhancement due to CT-CH4 2010) x 10^9 + 300
tracer_23	ppmv	(CH4 enhancement due to CMS-CH4-NAD (averaged monthly)) x 10^9 + 300

tracer_24	ppmv	(CH4 enhancement due to EDGAR v4.3.2) x 10^9 + 300
tracer_25	ppmv	(C2H6 enhancement due to 2010 C2H6 Global Emissions Inventory (Tzompa Sosa)) x 10^9 + 300
TSK	K	surface skin temperature
TSK_FORCE	W m-2	scm ideal surface skin temperature
TSK_FORCE_TEND	W m-2 s-1	scm ideal surface skin temperature tendency
TSLB	K	soil temperature
U	m s-1	x-wind component
U10	m s-1	u at 10 m
UST	m s-1	u* in similarity theory
UST_T	m s-1	threshold friction velocity
V	m s-1	y-wind component
V10	m s-1	v at 10 m
VAR	1	orographic variance
VAR_SSO	m2	variance of subgrid-scale orography
VEGFRA	1	vegetation fraction
W	m s-1	z-wind component
XLAND	flag	land mask, 1= land
XLAT	degree_north	latitude
XLAT_U	degree_north	latitude
XLAT_V	degree_north	latitude
XLONG	degree_east	longitude
XLONG_U	degree_east	longitude
XLONG_V	degree_east	longitude
XTIME	min	minutes since simulation start
ZETATOP	1	zeta at model top
ZNU	1	eta values on half (mass) levels
ZNW	1	eta values on full (w) levels
ZS	m	depths of centers of soil layers

1. To calculate total CT CO2 mole fractions, CO2_total (ppm) = tracer_1 + (tracer_2 + tracer_3)/2 – 300 + tracer_4 -300. + tracer_5-300. + tracer_6-300.
2. CH4 and C2H6 tracers only provide the enhancement, not the mole fraction, and there are no boundary conditions in the model run.
3. To calculate total anthropogenic CH4, add together tracers 13-18 (subtracting off 300 from each) and then divide by 1e9 to get an enhancement in ppm.

3. Application and Derivation

ACT-America, or Atmospheric Carbon and Transport - America, conducted five airborne campaigns across three regions in the eastern United States to study the transport and fluxes of atmospheric carbon. The eastern half of the United States is a region that includes a highly productive biosphere, vigorous agricultural activity, extensive gas and oil extraction and consumption, dynamic, seasonally varying weather patterns and the most extensive carbon cycle and meteorological observing networks on Earth, serves as an ideal setting for the mission.

Each 6-week campaign accurately and precisely quantified anomalies in atmospheric carbon, also known as carbon flux. Accurate carbon flux data is necessary to address all terrestrial carbon cycle science questions. ACT-America addressed the three primary sources of uncertainty in atmospheric inversions—transport error, prior flux uncertainty, and limited data density.

ACT-America advances society's ability to predict and manage future climate change by enabling policy-relevant quantification of the carbon cycle. Sources and sinks of atmospheric carbon dioxide (CO_2) and methane (CH_4) are poorly known at regional to continental scales. ACT-America enables and demonstrates a new generation of atmospheric inversion systems for quantifying CO_2 and CH4 sources and sinks.

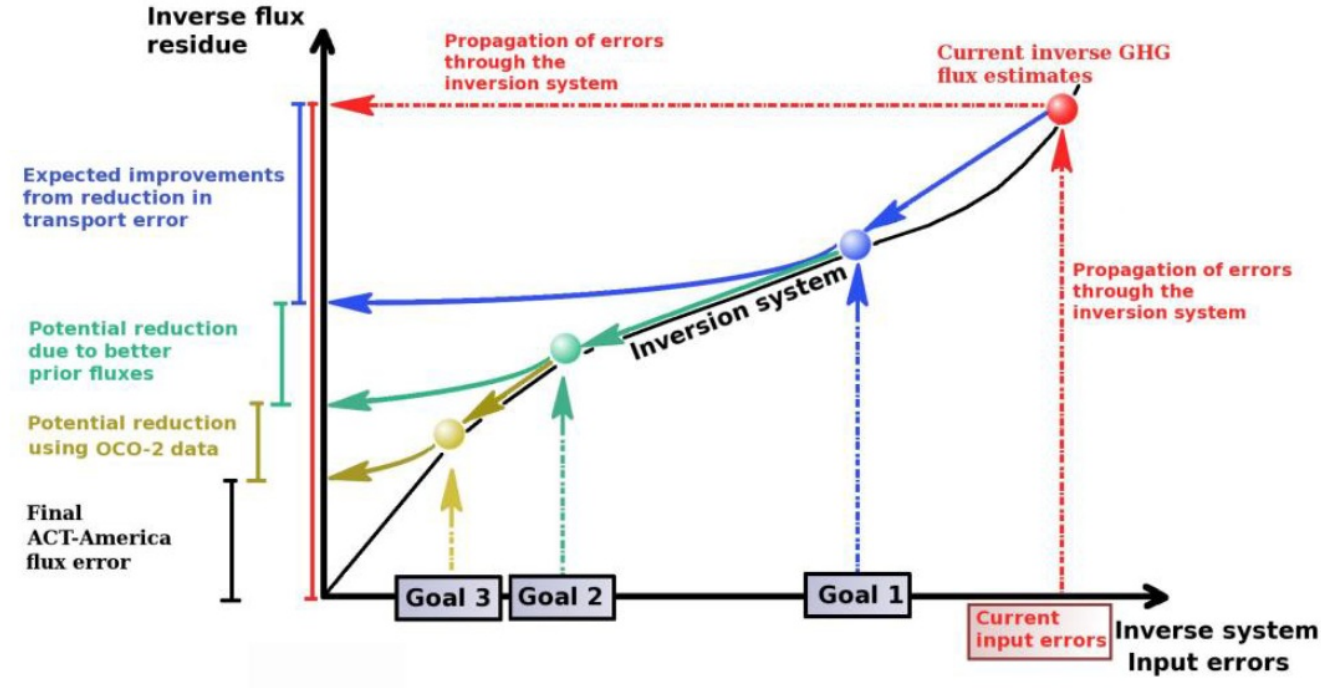

Figure 2. A schematic showing ACT-America mission goals.

ACT-America Goals:

1. To quantify and reduce atmospheric transport uncertainties.
2. To improve regional-scale, seasonal prior estimates of CO_2 and CH_4 fluxes.
3. To evaluate the sensitivity of Orbiting Carbon Observatory (OCO-2) column measurements to regional variability in tropospheric CO_2.

ACT-America achieved these goals by deploying airborne and ground-based platforms to obtain data that were combined with data from existing measurement networks and integrated with an ensemble of atmospheric inversion systems. Aircraft instrumented with remote and in-situ sensors observed how mid-latitude weather systems interact with CO_2 and CH_4 sources and sinks to create atmospheric CO_2/CH_4 distributions. A model ensemble consisting of a mesoscale atmospheric transport model with multiple physics and resolutions options nested within global inversion models and surface CO_2/CH_4 flux ensembles was used to predict atmospheric CO_2 and CH_4 distributions.

Beyond the conclusion of the mission, the application of knowledge gained from this mission will improve diagnoses of the carbon cycle across the globe for decades.

4. Quality Assessment

This dataset includes replication in space, time, and within model runs to allow users to compute relevant measures of variability and uncertainty. See Feng et al. (2019a; 2019b; 2021) for studies of uncertainty based on these WRF-Chem simulations.

5. Data Acquisition, Materials, and Methods

The objective of the study was to enable more accurate and precise estimates of the sources and sinks of greenhouse gases in order to support development of climate-focused management strategies and for prediction of future climate conditions. ACT-America addresses three primary sources of uncertainty in carbon dioxide and methane sources and sinks by accounting for transport error, prior flux uncertainty and limited data density. This WRF-Chem simulation is the baseline simulation in support of related research by the ACT-America team and broader scientific community. It serves as complementary information to the ACT-America field measurements and helps scientists interpret the data with a broader context in space and time.

These simulations were run with WRF-Chem version 3.6.1 (Grell et al., 2005; Skamarock et al., 2005) with the tracer modification described in Lauvaux et al. (2012). Specifically, fluxes from the CarbonTracker (Peters et al., 2007) CO_2 components, CASA biogenic fluxes (Zhou et al., 2019), SiB4 biogenic fluxes (Haynes et al., 2019a, 2019b), CH_4 EPA emissions (Maasakkers et al., 2016), CH_4 wetland emissions (from WETCharts), CarbonTracker CH_4, EDGAR (Janssens-Maenhout et al., 2019), and updated ethane (C_2H_6) emissions inventory (Tzompa-Sosa et al., 2017) were included.

The simulation domain contains most of North America at 27 km horizontal resolution. The model has 50 vertical levels up to 50 hPa, with 20 levels in the lowest 1 km. The model meteorology was initialized every five days and driven with ERA5 reanalysis every six hours at 25 km horizontal resolution. The WRF-Chem dynamic was relaxed to ERA5 meteorology every six hours using grid nudging. Sea surface temperature was updated every six hours at 12 km resolution. Choices of the model physics parameterizations used in this experiment are documented as the baseline setup in Feng et al. (2019a; 2019b; 2021).

6. Data Access

These data are available through the Oak Ridge National Laboratory (ORNL) Distributed Active Archive Center (DAAC).

ACT-America: WRF-Chem Baseline Simulations for North America, 2016-2019

Contact for Data Center Access Information:

- E-mail: uso@daac.ornl.gov
- Telephone: +1 (865) 241-3952

7. References

Feng, S., T. Lauvaux, K. Keller, K.J. Davis, P. Rayner, T. Oda, and K.R. Gurney. 2019. A Road Map for Improving the Treatment of Uncertainties in High-resolution Regional Carbon Flux Inverse Estimates. Geophysical Research Letters 46:13461–13469. https://doi.org/10.1029/2019GL082987

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