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The COVID-19 bottom-up emissions inventory development with human activities during the pandemic outbreak

NOAA Atmospheric Chemistry, Carbon Cycle, Climate (AC4) Project

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Motivations

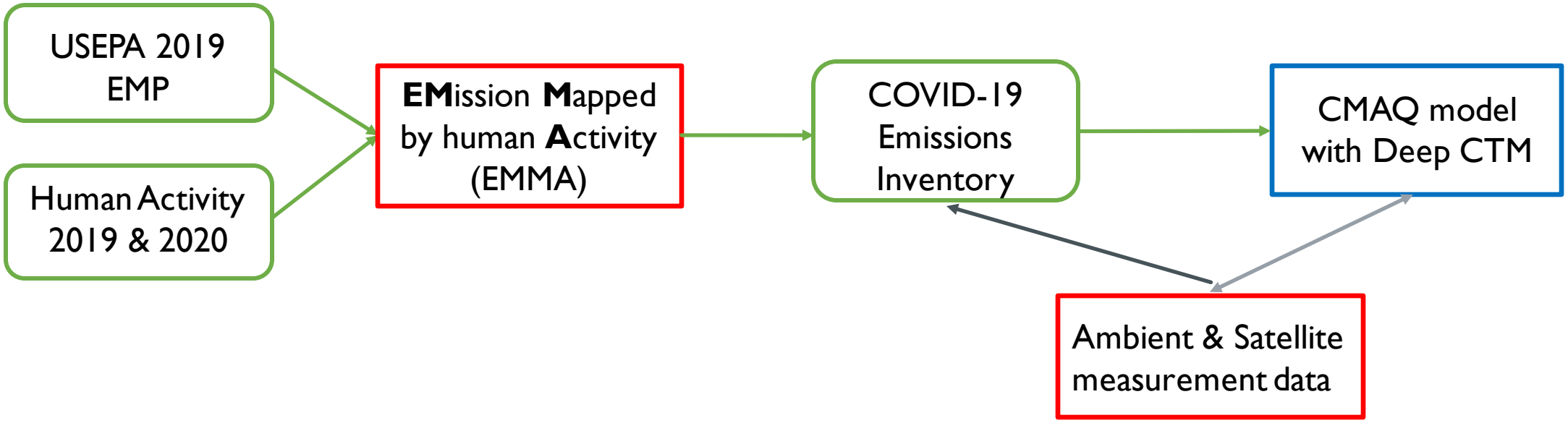
- The ambient measurement and satellite observational data indicated that some air pollutants (NOx and PM) largely decreased during the COVID pandemic. (Venter et. al., 2020; Tanzer-Gruener et. Al., 2020; Liu et. al., 2020; Kroll et. al. 2020)
- Some studies did the CTM model sensitivity study or used simple scale method based on ambient observational data to represent the decline of emissions and reflected the air quality changes in CTM model simulation. (Liu et. al., 2021, Kang et.al., 2020)
- The sensitivity study or emission adjustment by observational data can be processed fast, but those methods did not consider the details of human activity changes by emission sources.
- Development of **Neal-Real-Time (NRT) Emissions Inventory Tool** to incorporate these human activities into the base emissions inventory for CTM forecast and regulatory modeling applications.

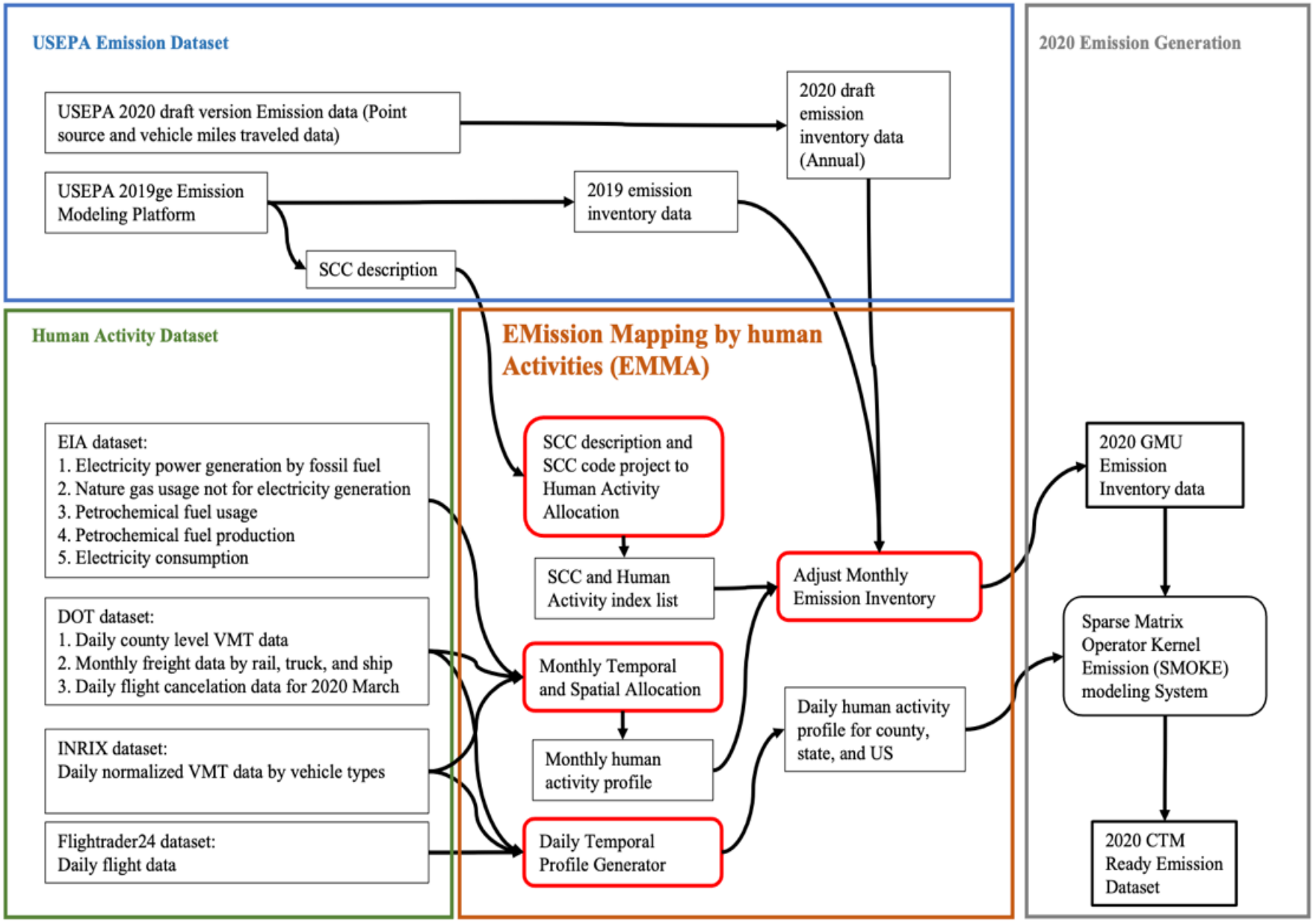
COVID-19 2020 Emissions Development

- Base Emissions: U.S. EPA's 2019ge Emissions Modeling Platform (EMP) (as of September 2022)
- COVID-19 EMP Development based on the human activity datasets
  - Collect the **human activity datasets** for 2019 and 2020, and then compute the ratio of 2020 to 2019
  - Apply the 2020/2019 ratio to activity-related emission inventory sources (annual or monthly)
  - Calculate the 2020 COVID-19 annual totals, and then
  - Compute monthly totals based on the 2020 monthly temporal profiles, and then export them in FF10 SMOKE inventory formats
  - Updated the SMOKE run scripts to correctly process monthly total inventories
  - **Month2Day T**emporal **PRO**files (**TPRO**): onroad (RPD), airports, and oilgas (with oil production)
- Updated Sectors: nonpt, ptegu, ptnonipm, np_oil_gas, pt_oilgas, np_solvent, airports, noroad, rail, RPD
- Exempted Sectors: RPV, RPS, RPH, Hourly CEMS, rwc, Ag NH_3, ptfires, afdust, and ptagfires

Research Outline

- **Phase I**: Developed a rapid refresh Neal-Real-Time (NRT) method to develop the future emissions using human activity data.
- **Phase II**: Develop the Machine-learning-based CTM (DeepCTM) based on the CMAQ simulations for 2019 and projected 2020 emissions
- **Phase III**: Develop the physically-informed top-down emissions inventory based on the observations(surface AQS and satellite data) using the DeepCTM and Calibrate the estimated emissions





EMission Mapped by human Activity (EMMA)

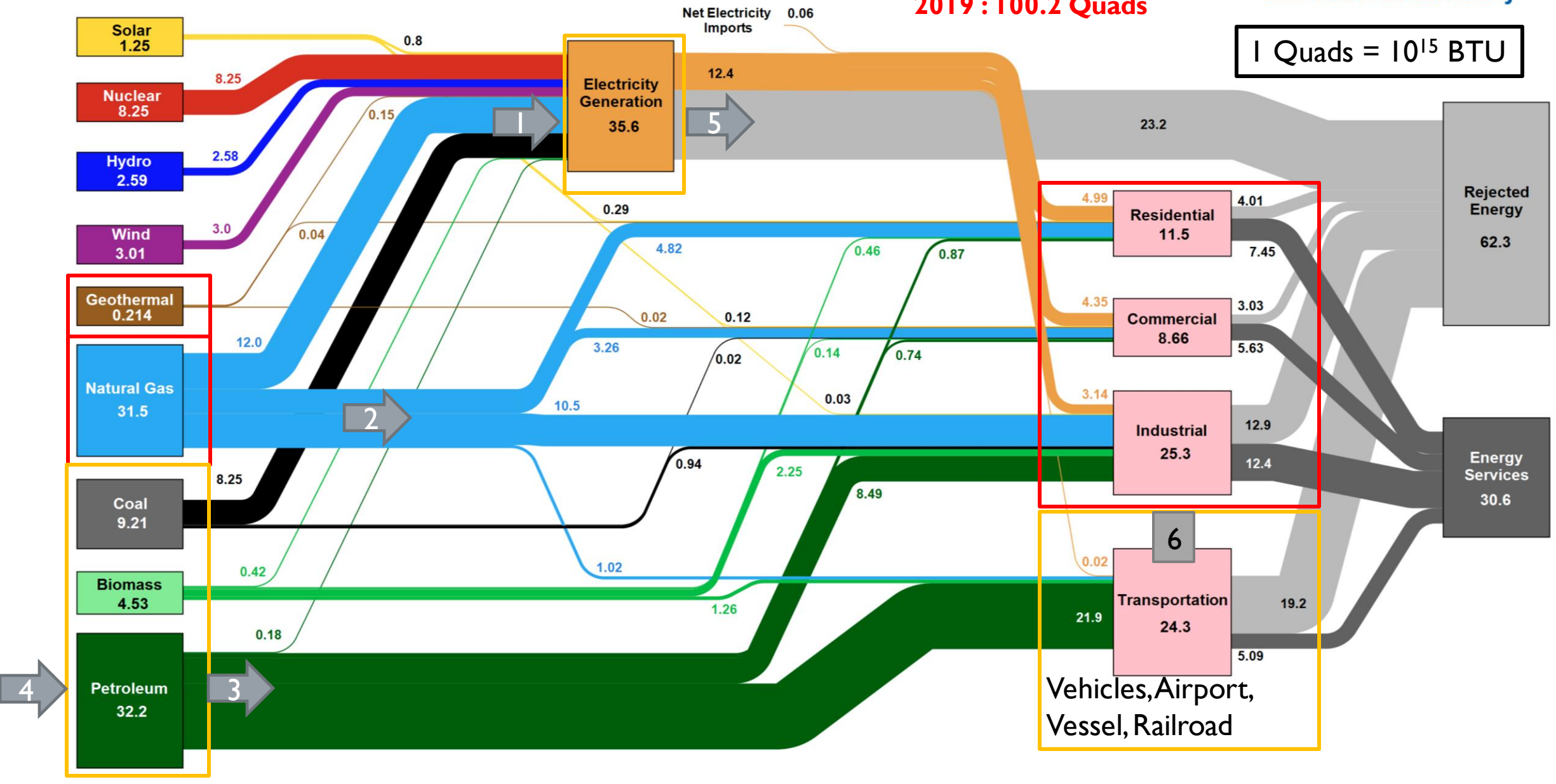
Data Flow Diagrams

Estimated U.S. Energy Consumption in 2020: 92.9 Quads

2019 : 100.2 Quads

Lawrence Livermore National Laboratory

1 Quads = 10^{15} BTU



Human Activity Data Collections

U.S. EIA Data :

- Electricity Generation data (Fuel type, State, Monthly)
- Natural Gas Consumption (not for EGU) (State, Monthly)
- Petroleum Sale End users (Fuel type, State, Yearly)
- Petroleum Consumption (End user, Fuel type ,US, Monthly)
- Net petroleum product (5 PADD regions, Monthly)
- Petroleum Production supply (6 products, 5 regions, Monthly)
- Electricity Usage (End users, State, Monthly)

Petroleum Administration for Defense Districts (PADD)

U.S. DOT Data :

- Daily travel distance data (County, Daily)
- March 2020 US flight data (US, Daily)
- Freight Weight data (Mode , State ,Monthly)

INRIX Data:

- Normalized Daily VMT data (Vehicle type, State, Monthly)

Flighttrader24 Data:

- Flight tracked by Flightradar24 (Global, Daily)

❖ *Total number of temporal profiles developed (county/state, daily/month/annual, source):* ***5995 + no of county-vehicle VMT TPRO***

Energy-related sectors : ptegu, ptnonipm, pt_oilgas, np_oilgas, nonpt, solvent

EIA Data

(S=State level, M=Monthly, US=US total, R=Regions)

1) Electricity Generation by fuel (S, M)

2) Natural Gas Usage by end-user (S,M)

3) Petroleum sale by end-user and fuel types (S,A)
Petroleum consumption by end-user and fuel types (US, M)

4) Petroleum Process data related to Crude Oil (R, M)

Petroleum Supply by fuel types (R, M)

5) Electricity Usage by end-user (S, M)

Combustion or Consumption

Electric Generation

Natural Gas Consumption

Petroleum Consumption: Distillate fuel, Kerosene, Residual fuel, Coal, Propane, Biomass.
Gasoline, Petroleum Coke, propane, propylene, total petroleum

Oil and Gas Production and supply

Other data that can not be identified by energy consumption or Production.

SCC Mapping

PTEGU or Electric Generation

Nature Gas usage : Boilers, Combustion, Industrial Process, Chemical Evaporation, Stationary Source fuel combustion (Residential, commercial, industrial), space Heater, Dryer, Roasting, Turbine, Heater

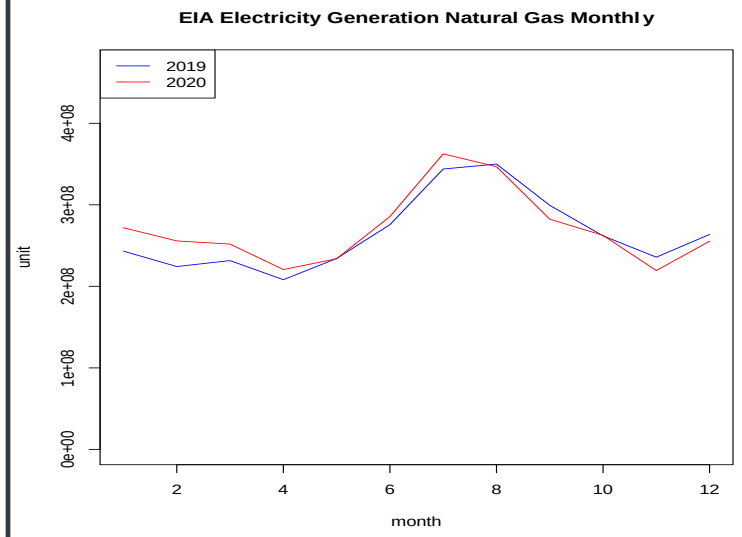
Petroleum product usage : Boilers, Combustion, Industrial Process, Chemical Evaporation, Stationary Source fuel combustion (Residential, commercial, industrial), space Heater, Dryer, Roasting, Turbine, Asphalt concrete,

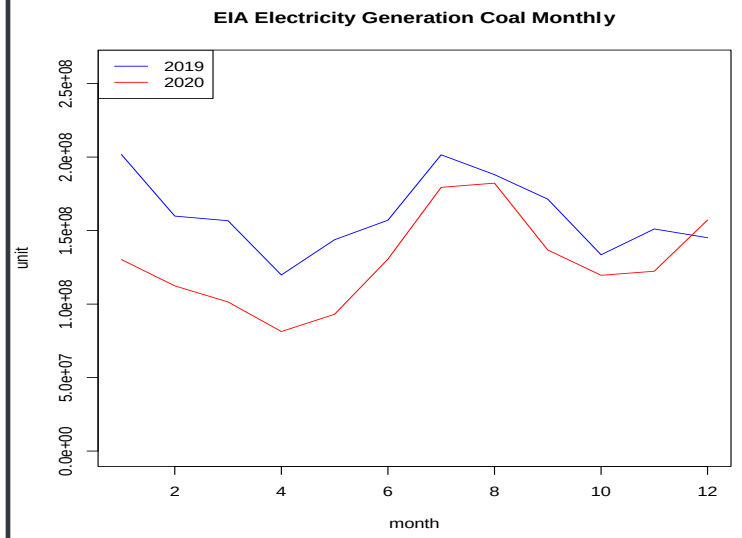
Pt_oilgas, np_oilgas: Oil and gas Production, Exploration, product storage, transportation and Marketing petroleum products, Refinery, Fugitive Emissions

Other : Chemical Manufacturing All process, Food and Kindred Products, Agriculture Production, and others

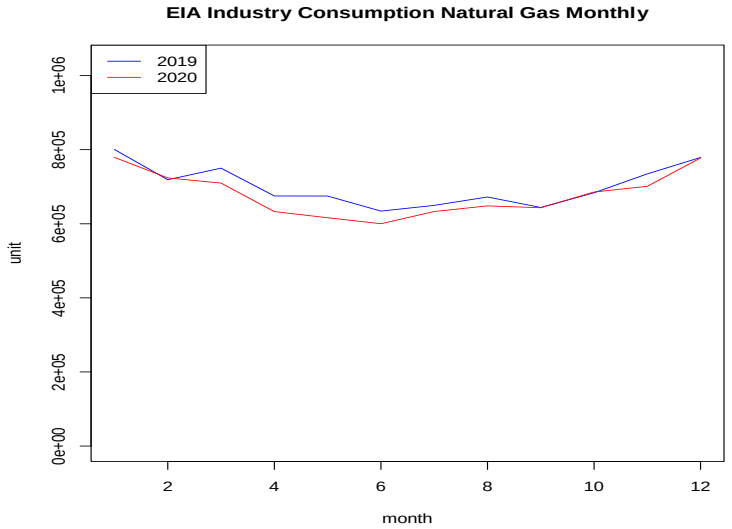
Energy-related Emission Source Monthly Trends

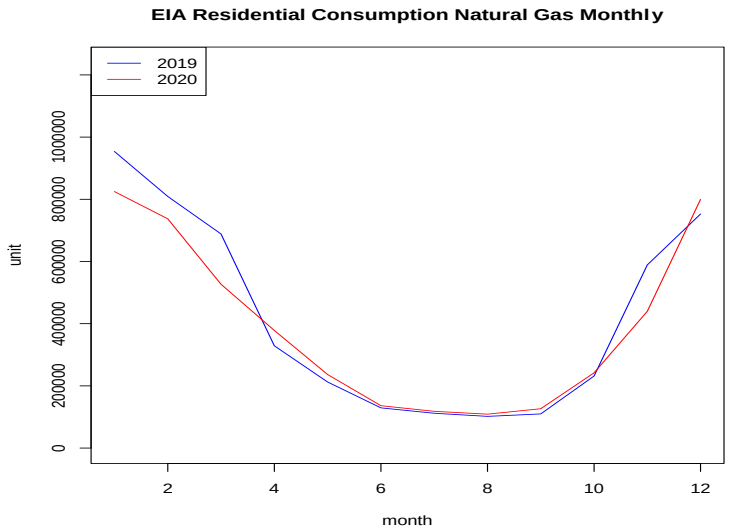
Electricity Generation



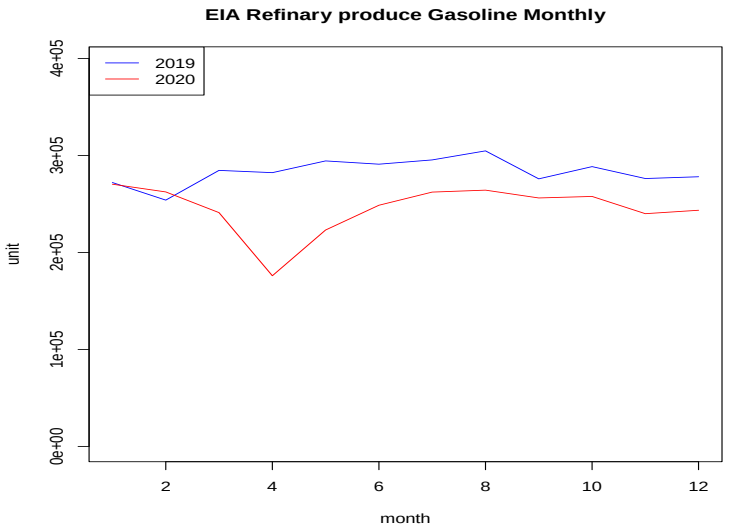


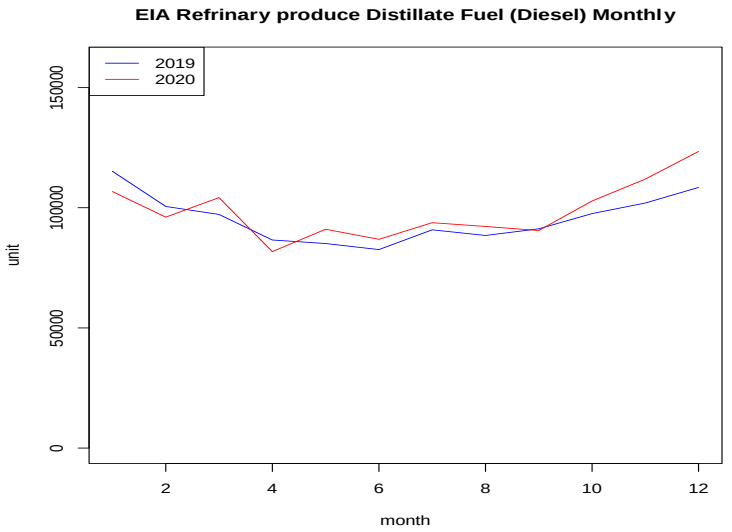
Natural Gas Consumption in Industry and residential



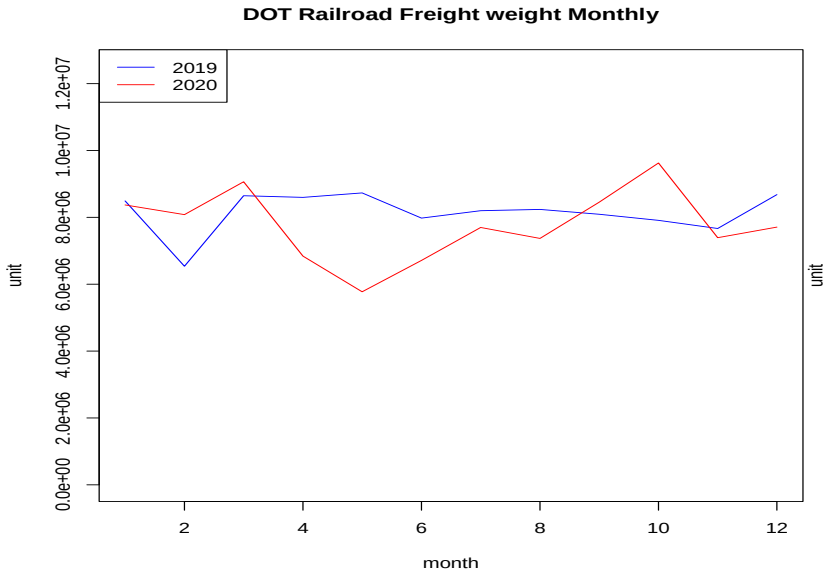


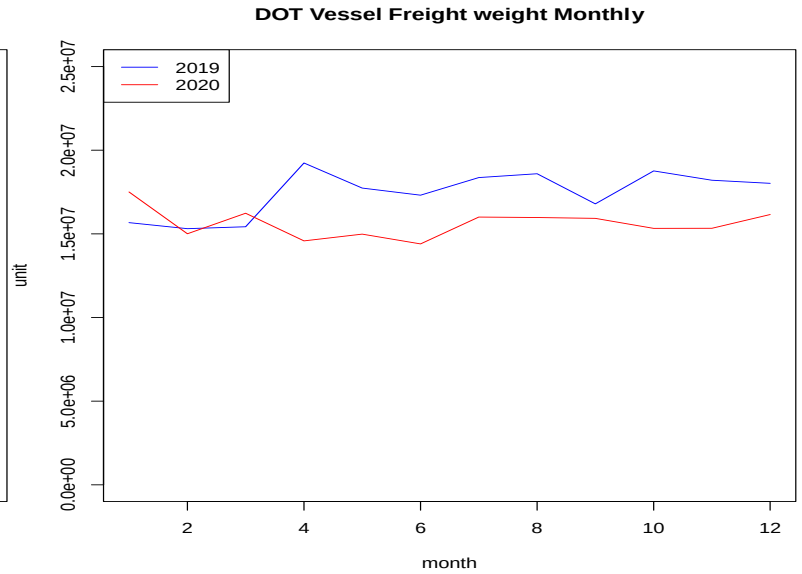
Petroleum supply



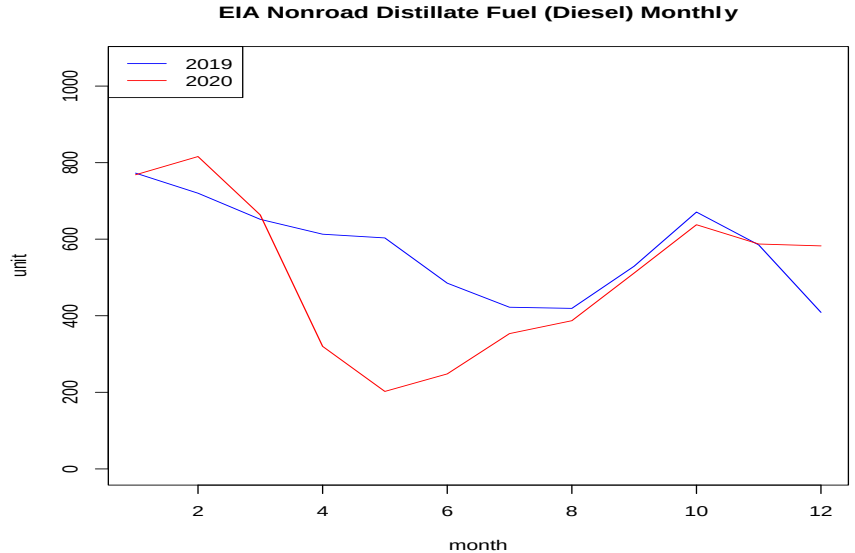


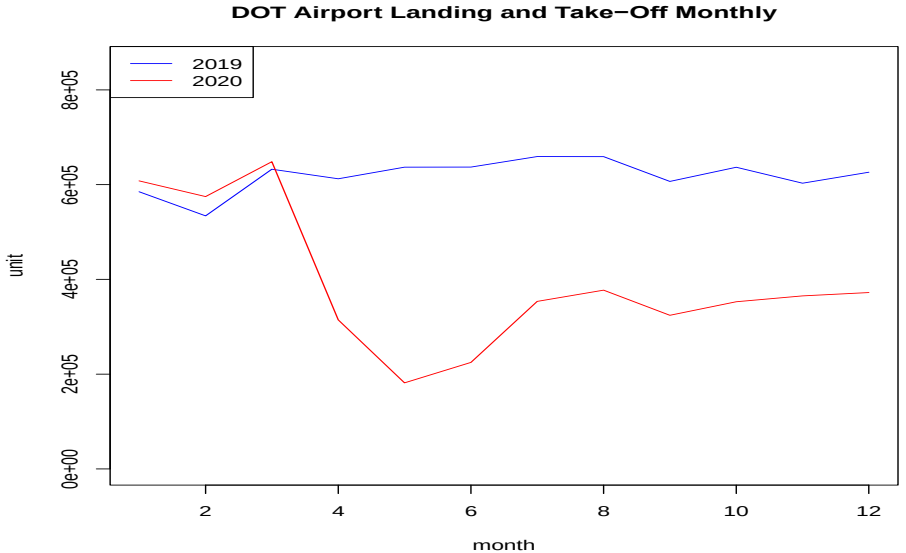
Transportation: Railroad, Vessel, Nonroad, Airport



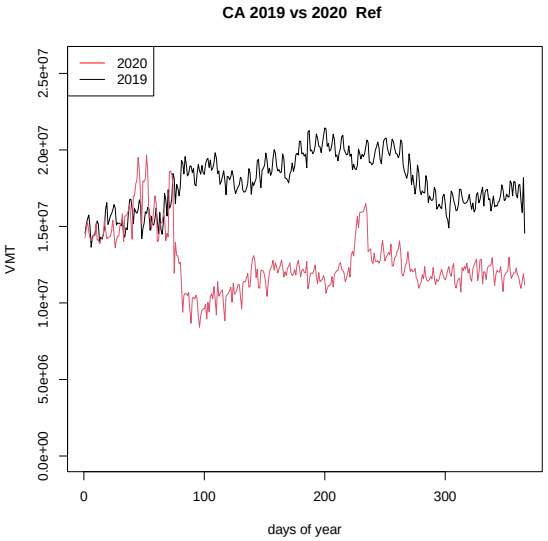


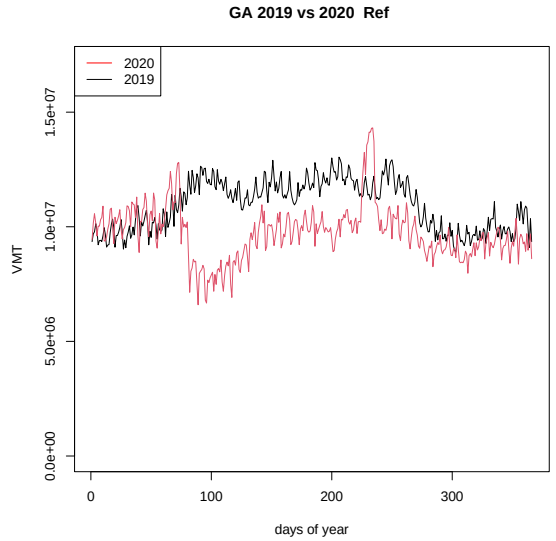
- Activity data from U.S. DOT and EIA
- Most of transportation sectors are impacted by the lockdown except for Vessel Freight

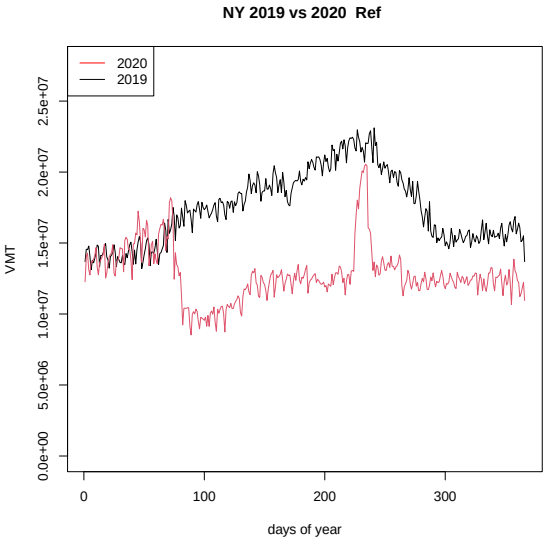


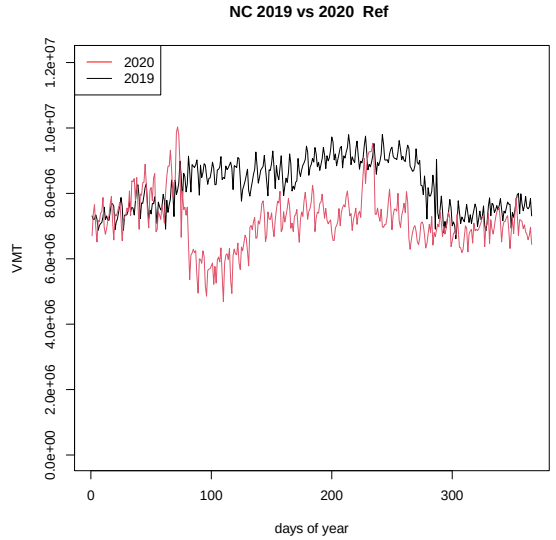


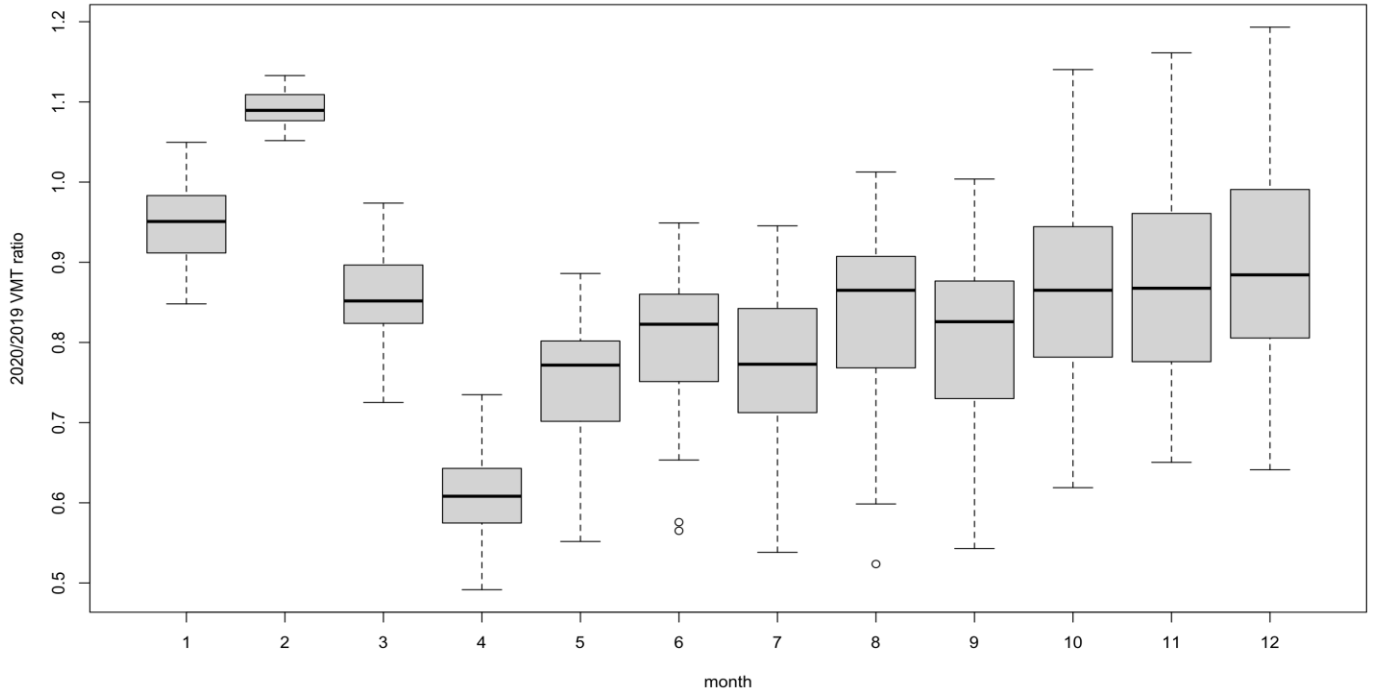
U.S. DOT VMT Changes: County/State-level





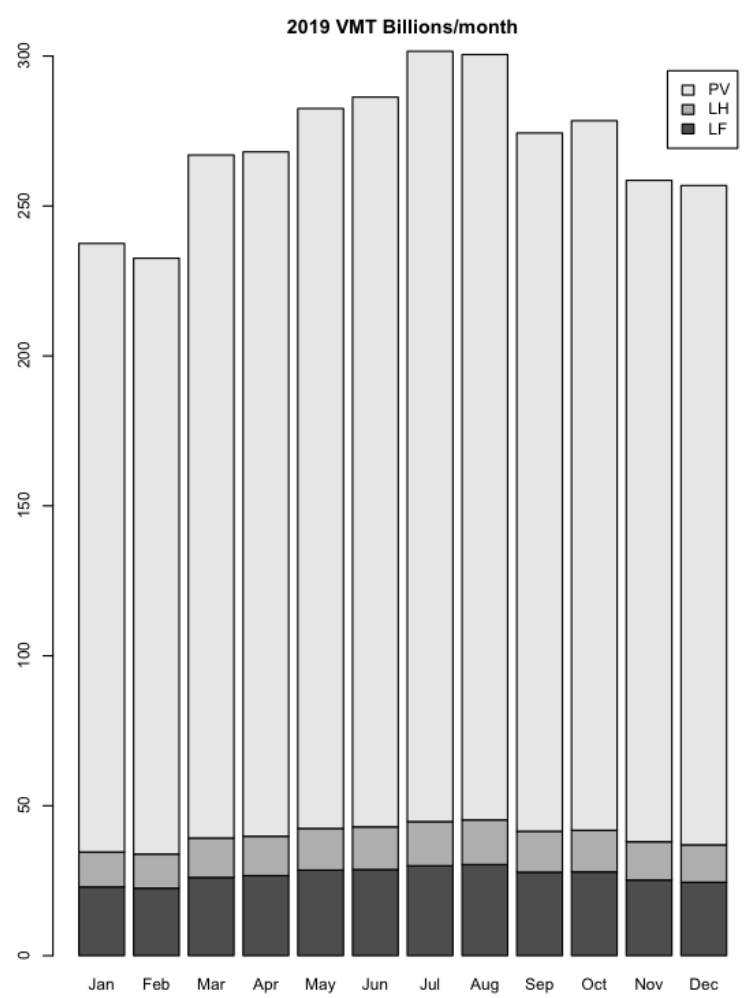


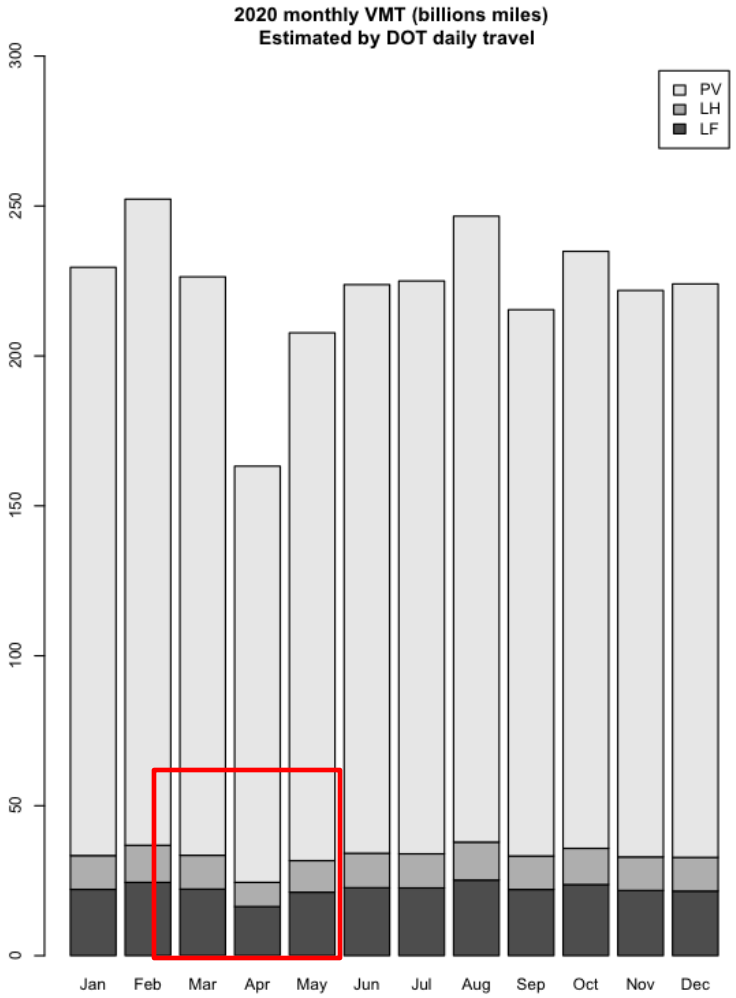


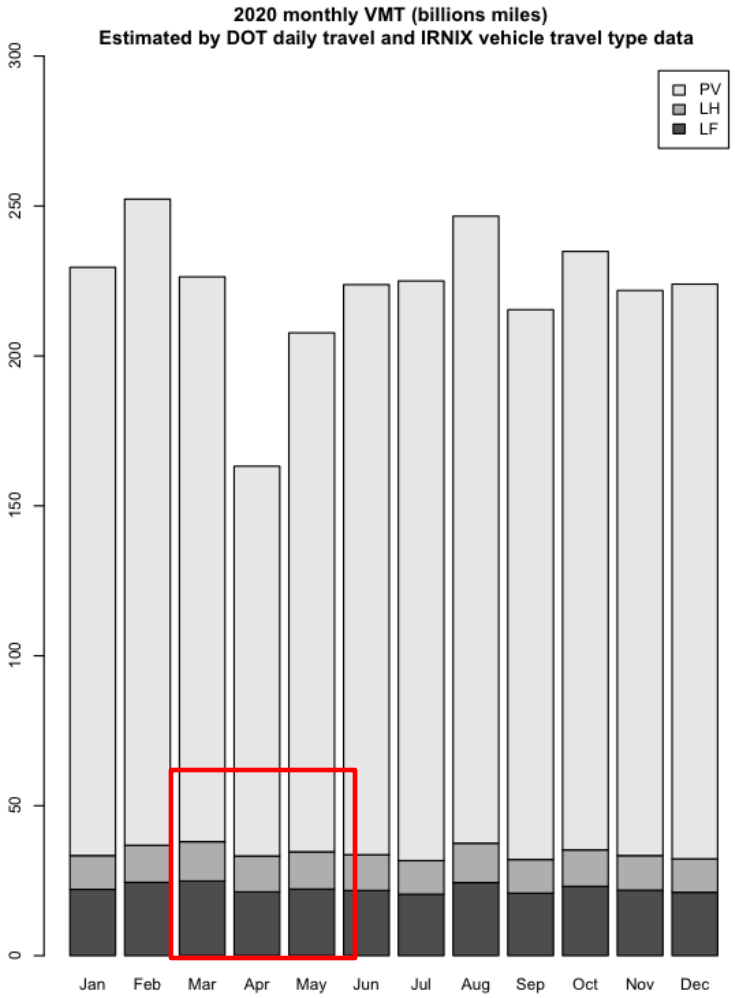


- Different VMT daily patterns in Megacities (NY and CA)
- Urban vs Rural shows different patterns
- Higher VMT during the holidays due to long-distance trips

U.S. DOT VMT Changes



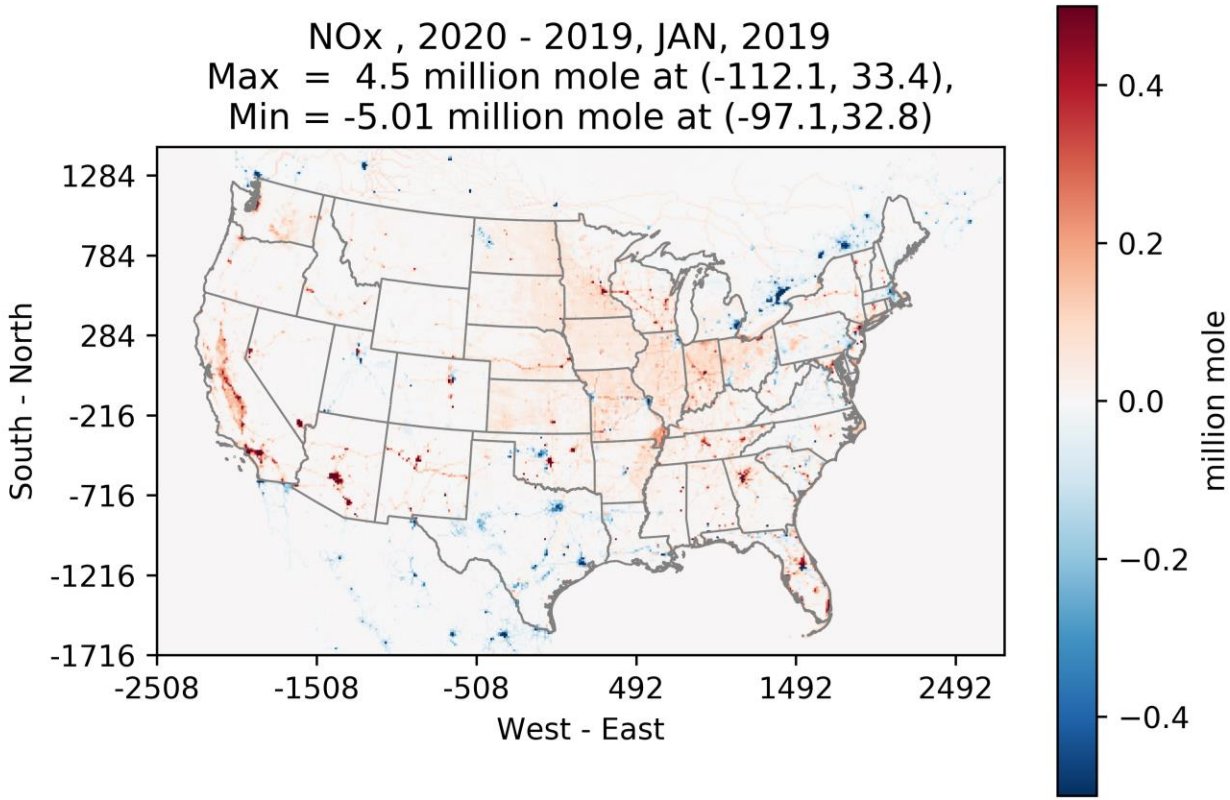




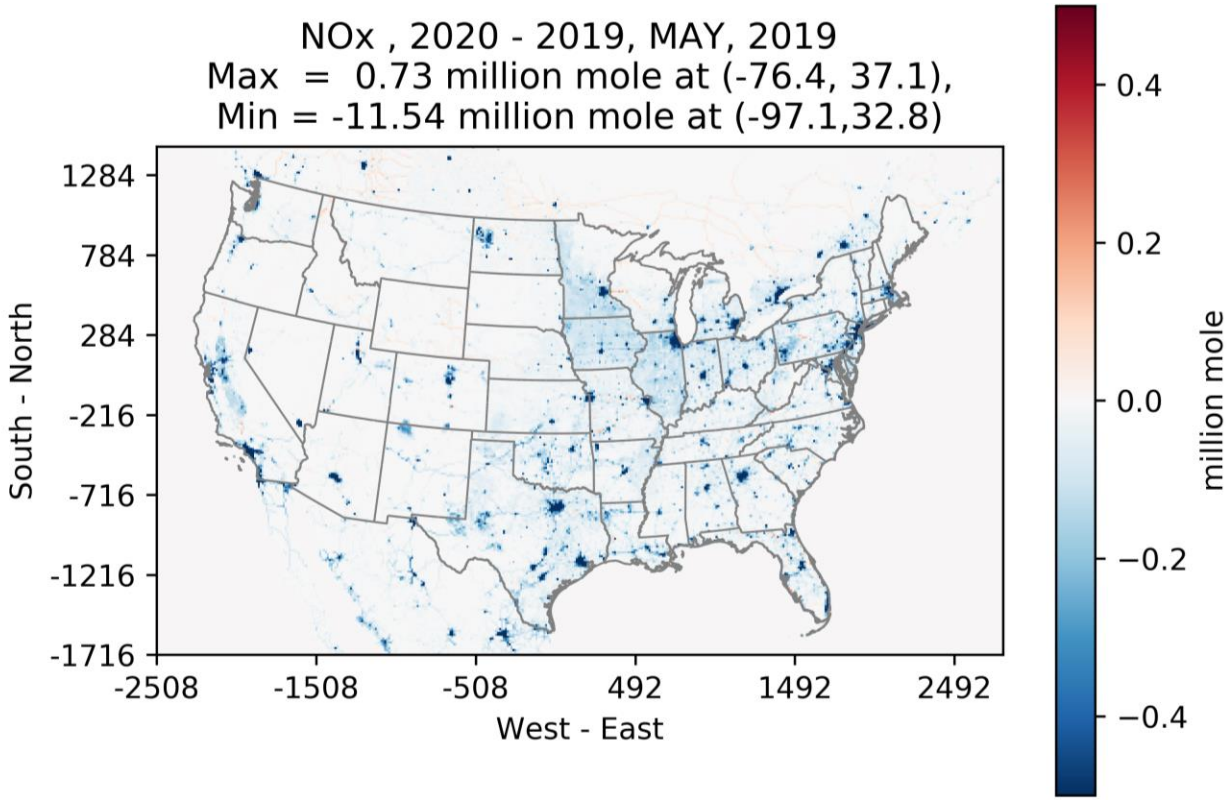
PV: Passenger Vehicle, LH: Long Haul, LF: Local Fleet

2020 Monthly total NOx Emission Differences

January



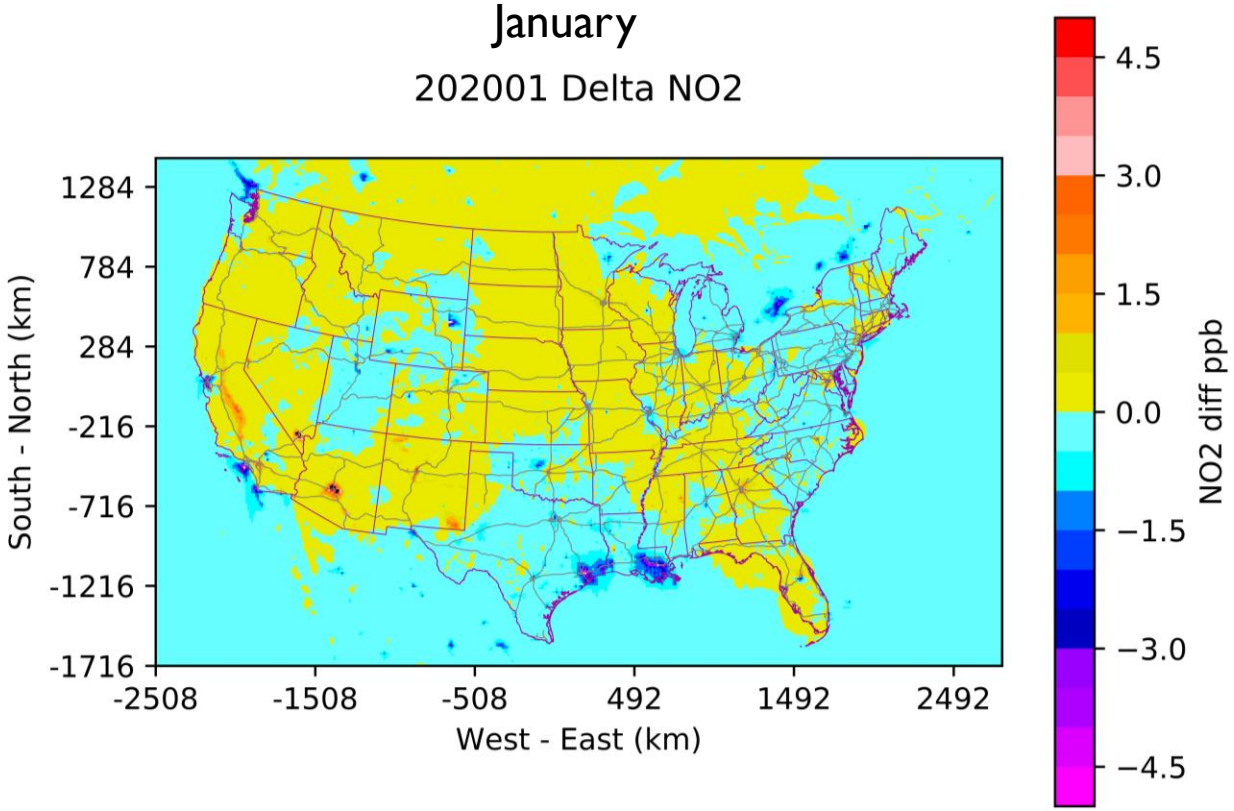
May

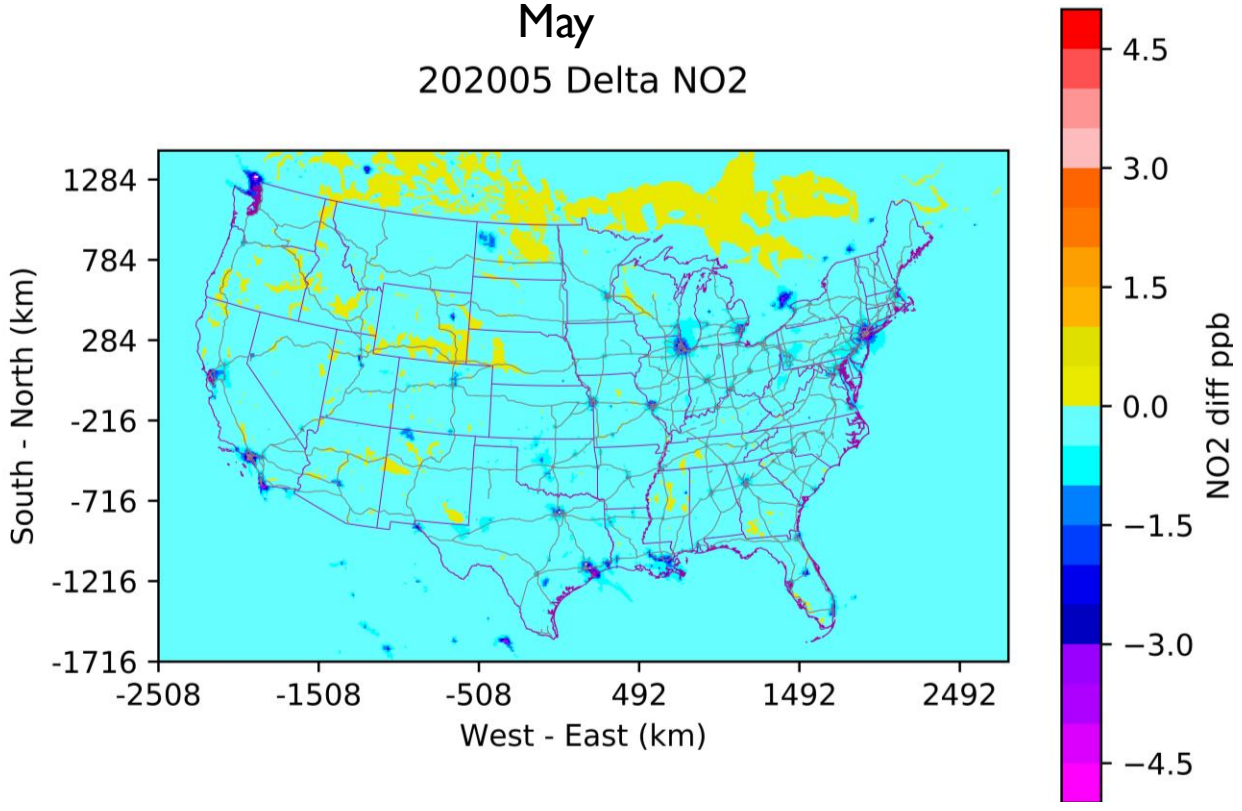


We processed two model scenarios:

1. 2020 Met data with 2020 Emission
2. 2020 Met data with 2019 Emission

CMAQ Monthly Average Delta NO_2 (2020-2019) Difference (%)

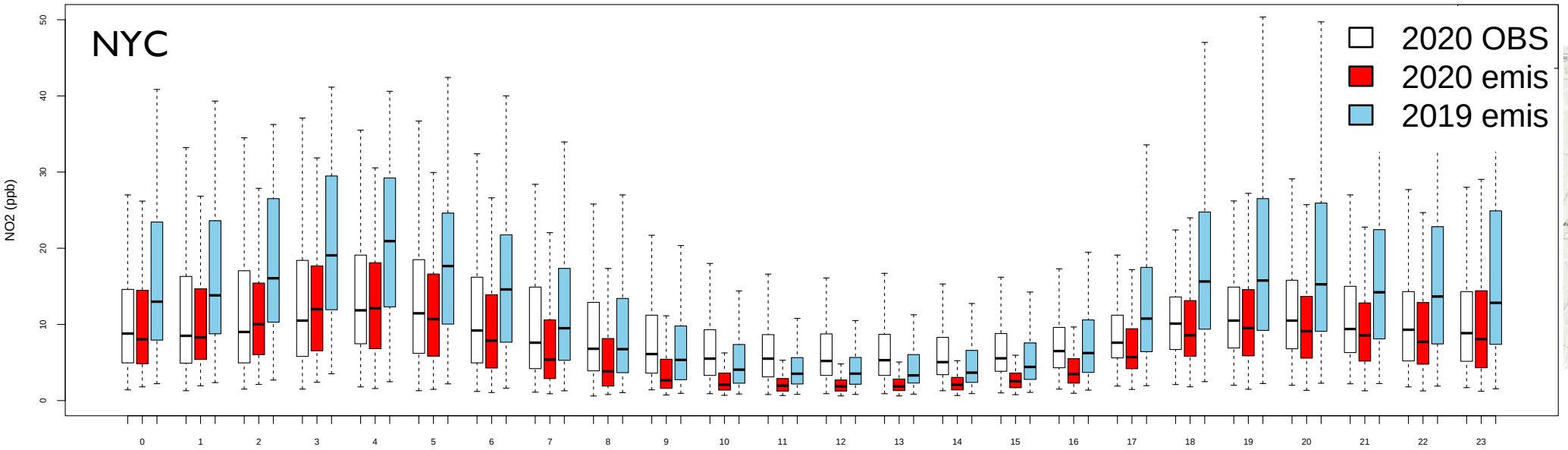


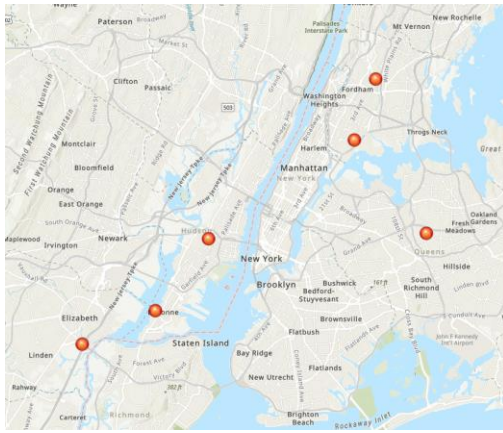


- Due to emission change in 2020, the CMAQ model result showed NO_2 concentrations in some urban areas are increased in January 2023, but all urban areas are decrease in May, 2023.

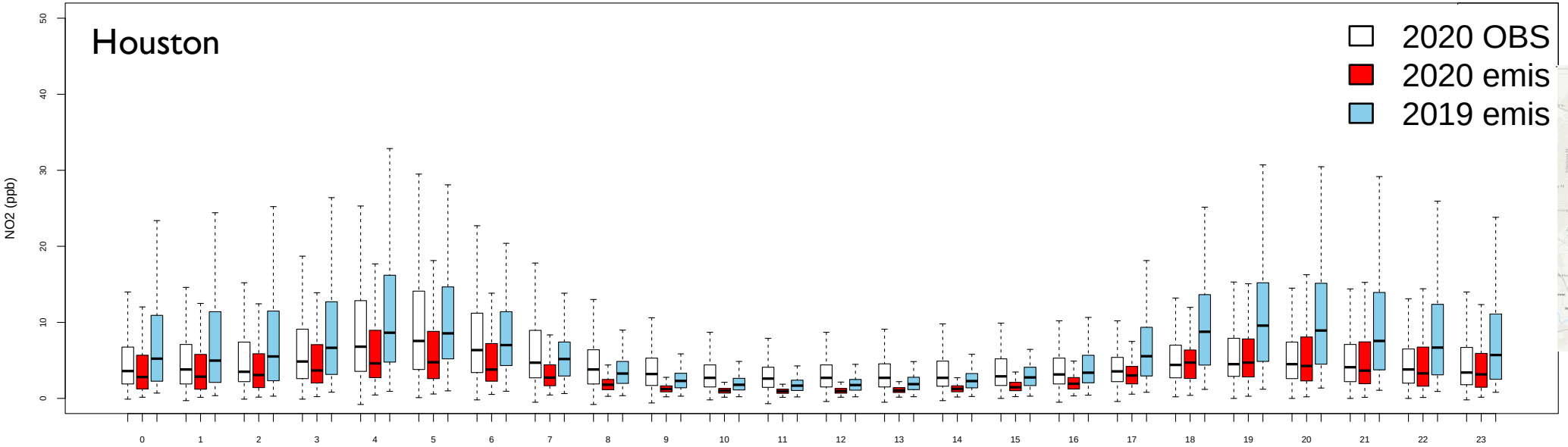
Monthly Hourly NO_2 for 2020 May in New York City, and Houston (No Near Road Site)

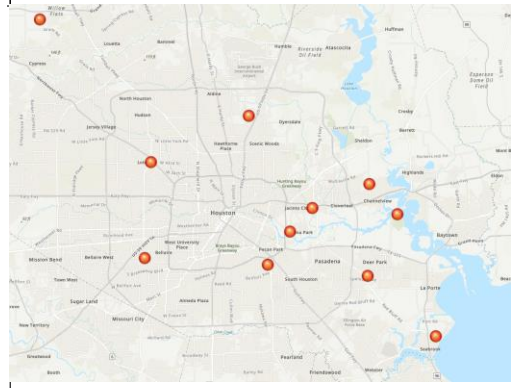
New York 2020 May CMAQ model monthly hourly boxplot



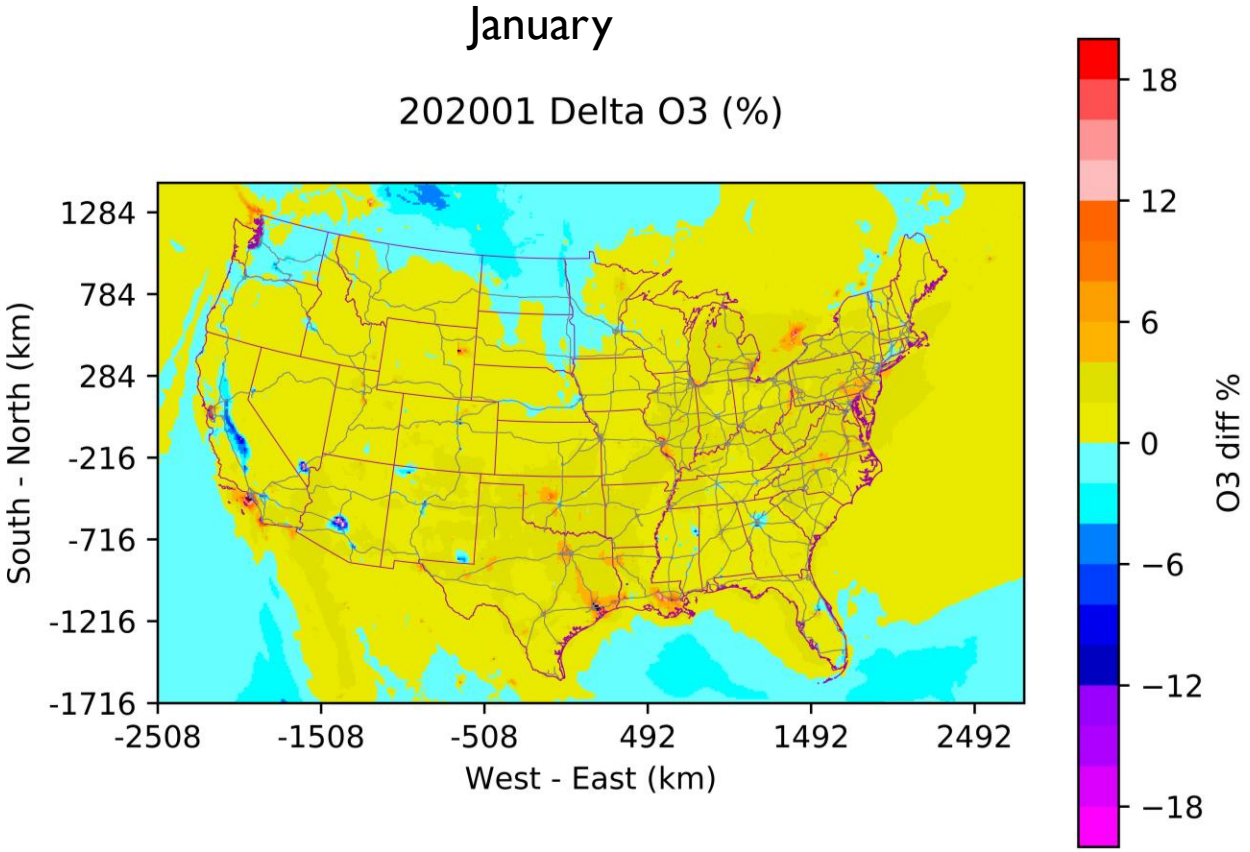


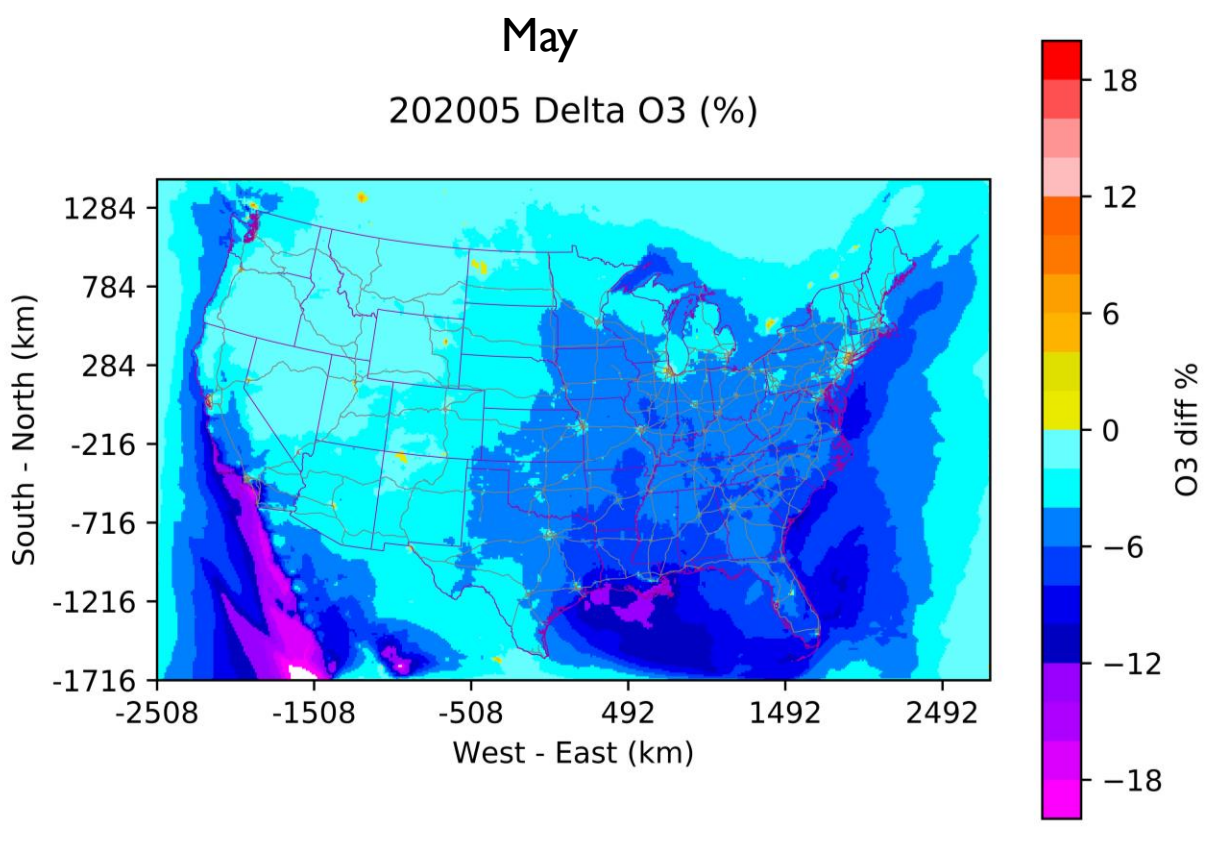
Houston 2020 May CMAQ model monthly hourly boxplot





CMAQ Monthly Average Delta O_3 (2020-2019) Difference (%)





- O_3 concentration slightly increase in 2020 emission case in January, but **no significant reduction** happened in many urban areas in May. Other rural area Delta ozone concentration is 1.5 ppb to 5 ppb

Comparison COVID-19 2020 Emissions against the 2020 NEI

Sectors	airports	ptegu	ptnonipm	pt_oilgas	AC4 Point draft	EPA 2020 point draft Aug 2022	AC4_2020 vs EPA2020
2019 NOX (tons)	140,837	1,028,545	866,977	442,842	2,479,201		
2020 NOX (tons)	90,603	887,205	798,319	439,382	**2,215,484**	**2,185,147**	**1.39%**
NOX change (%)	**64.30%**	86.30%	92.10%	99.20%	89.36%	88.1%	
2019 VOC (tons)	58,511	29,912	763,440	184,092	1,035,955		
2020 VOC (tons)	38,171	27,073	723,870	168,885	**957,982**	**1,031,292**	**-7.11%**
VOC change (%)	**65.20%**	90.50%	94.80%	91.70%	92.47%	99.55%	
2019 PM25 (tons)	9,087	100,082	242,308	14,236	365,713		
2020PM25 (tons)	5,985	87,940	227,804	13,906	**335,631**	**335,671**	**-0.01%**
PM25 change (%)	**65.90%**	87.90%	94%	97.70%	91.77%	91.79%	
2019 SO2 (tons)	17,685	1,048,032	504,057	38,959	1,608,733		
2020 SO2 (tons)	11,341	854,721	431,459	38,194	**1,335,711**	**1,343,979**	**-0.62%**
SO2 change (%)	**64.10%**	81.60%	85.60%	98%	83.03%	83.54%	
2019 CO (tons)	516,605	484,817	1,363,324	234,232	2,598,978		
2020 CO (tons)	335,270	428,567	1,272,253	228,987	**2,264,875**	**2,154,426**	**5.13%**
CO change (%)	**64.90%**	88.40%	93.30%	97.80%	87.14%	82.90%	
2019 NH3 (tons)	0	20,965	68,813	3,767	93,545		
2020 NH3 (tons)	0	20,701	66,205	3,980	**90,886**	**93,664**	**-2.97%**
NH3 change (%)	0%	98.70%	96.20%	105.70%	97.16%	100.13%	

Findings

- Various human activity temporal (daily~annual) and spatial (county, state, country)
- The activity data availability also varies by the data sources (Daily to Monthly)
- EMMA is customizable and capable of adopting various types of human activity to update the base NEIs
- EMMA shows its capability to rapidly refresh the base NEI with the NRT human activity datasets for CTM modeling applications such as daily forecasting simulation.
- The estimated COVID-19 Emissions Inventory is comparable to the official 2020 NEIs
- The COVID-19 emissions (NO_2 and NH_3) have been calibrated with the observations (AQS + Satellites) using the DeepCTM and Variational AutoEncorder (VAE) presented in the "COVID-19" session

Acknowledgement

- NOAA Atmospheric Chemistry Carbon Cycle &Climate (AC4) project.
  - Monica Kopaz (NOAA AC4 Project Manager)
- USEPA OAQPS Invetory Groups
  - Latest NEI Emission Modeling Platform Packages
- U.S. Energy Information Administration (EIA)
- U.S. DOT Daily VMT travel data
- INRIX State-level normalized daily VMT data by vehicle types
- Flight activity dataset from Flighttrader