Impacts of soil NO_x emission on O_3 air quality in rural California

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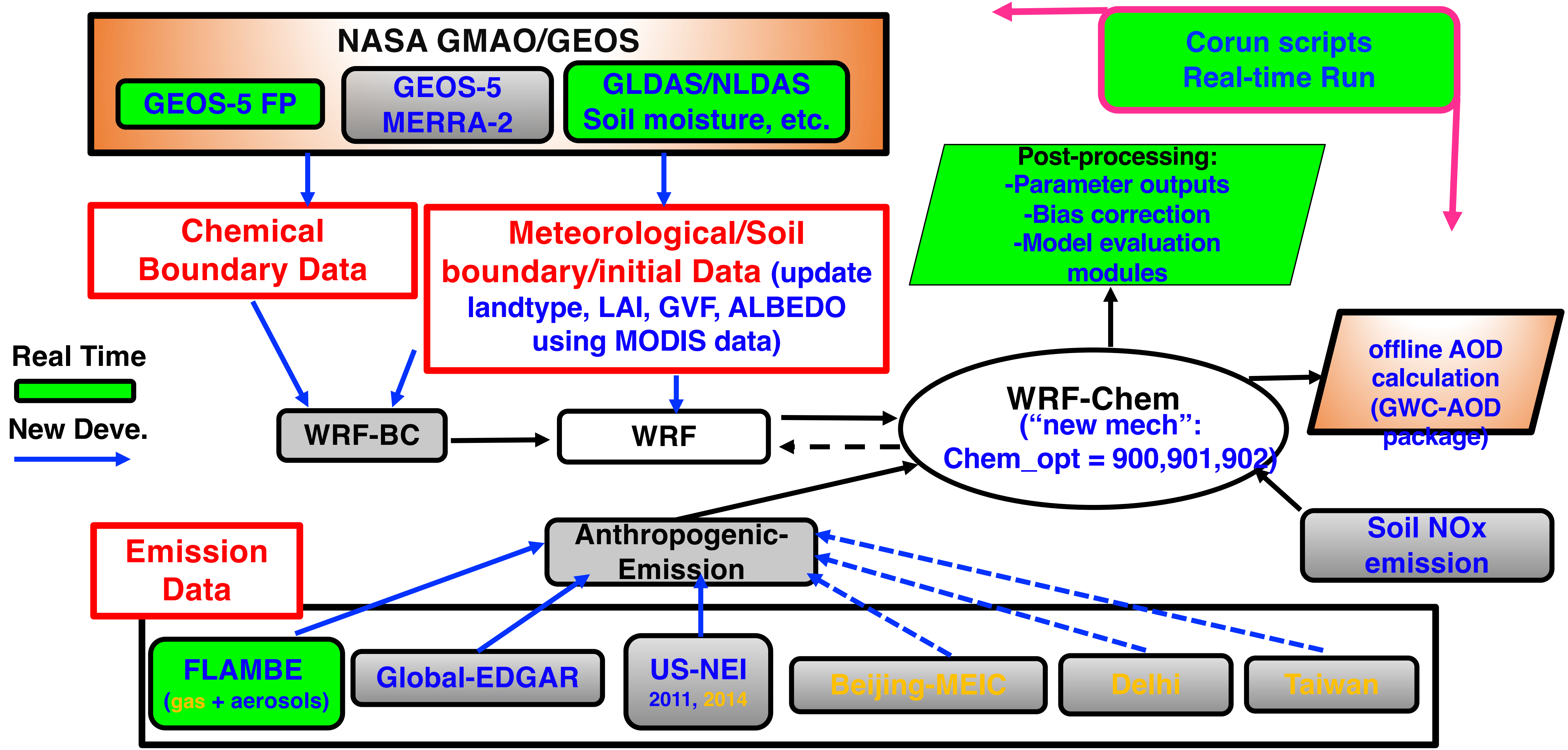
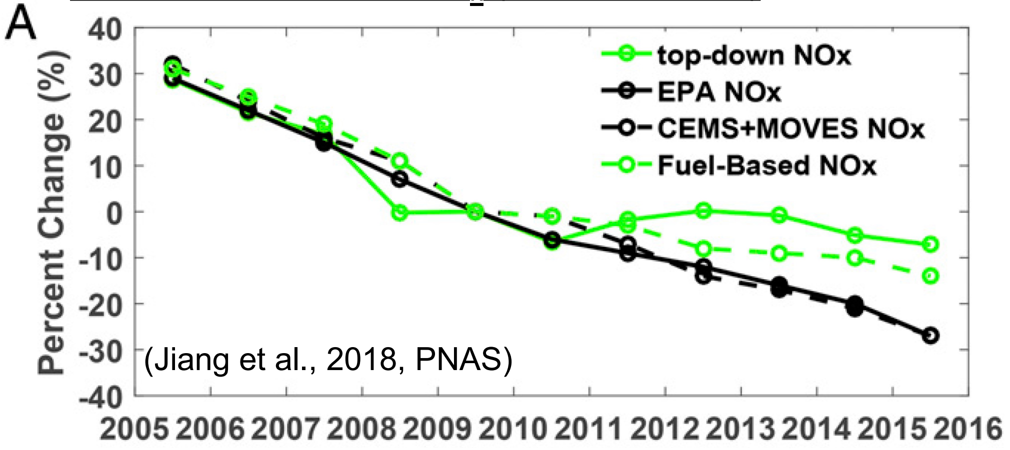
Unified Inputs (initial/boundary conditions) for WRF-Chem: UI-WRF-Chem

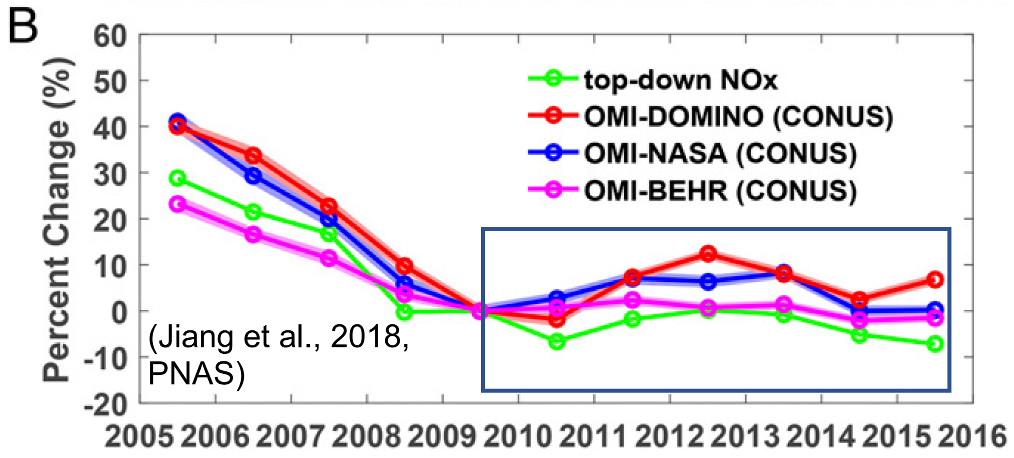


Background

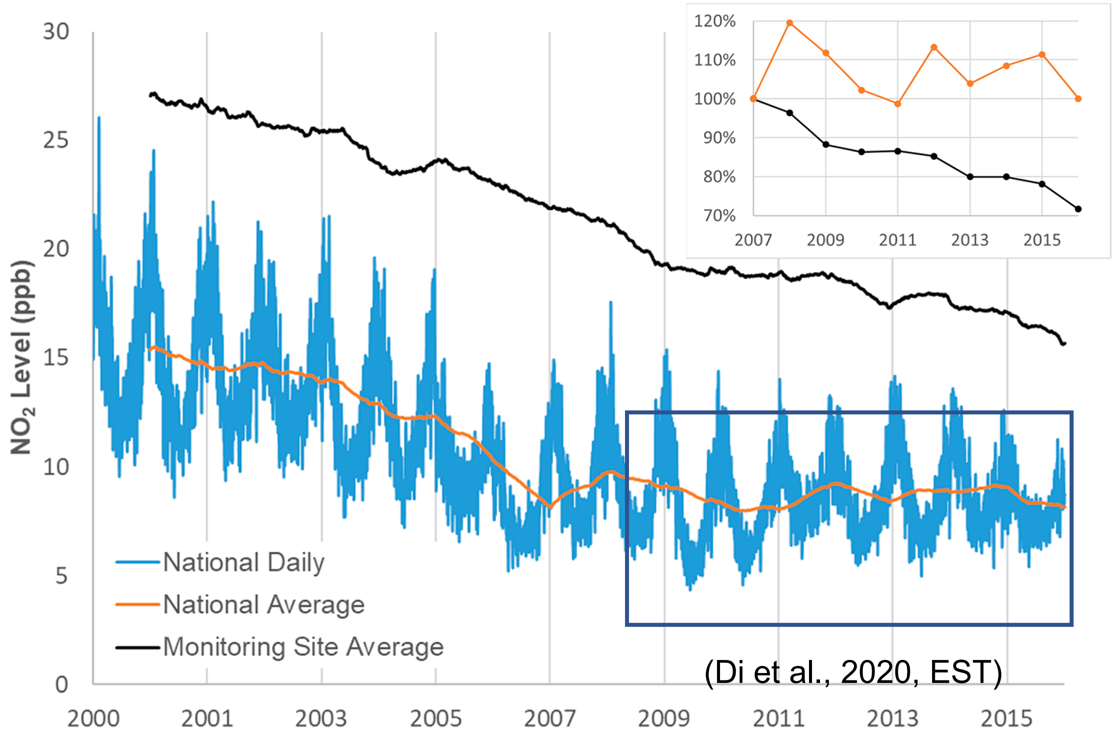
Percent changes (normalized at 2009) of EPA's emissions trends report data of NO_x (black solid line)



The trend of tropospheric NO_2 column densities observed by satellites



Nationwide NO_2 concentrations predicted by an ensemble of models

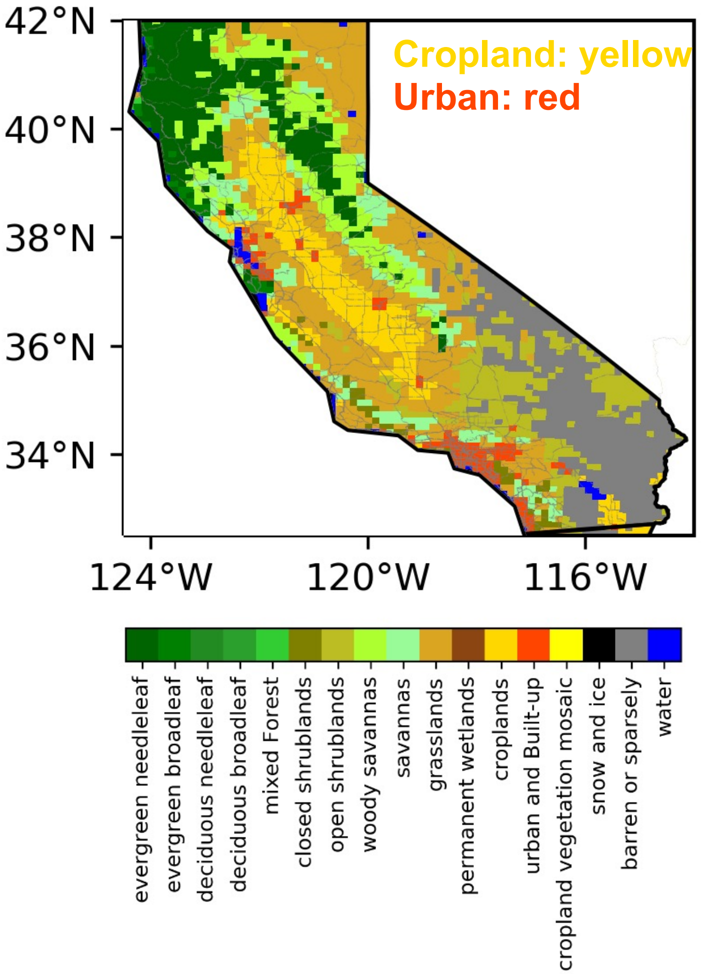


- The U.S. EPA reported a steady decrease in NO_x emissions from anthropogenic sources over the U.S.
- Soil NOx emissions may play a role but overlooked.

Motivation

California

- The highest agricultural output in the U.S.
- Extensive agricultural and natural drylands
- Experiencing warmer temperatures and increasing droughts
- Suffering from the O_3 pollution, especially over the rural region



- To improve the air quality and human health of California, understanding how soil NO_x emissions contribute to O_3 formation is necessary.

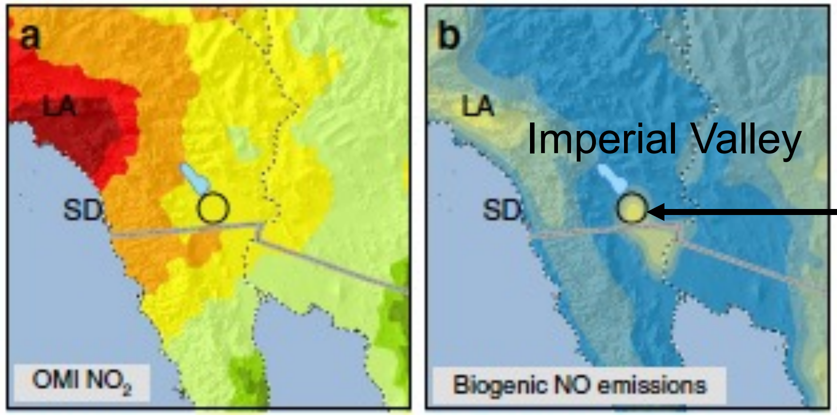
- **Quantify the impacts of soil NO_x emissions on NO_x budget and O_3 pollution in California by using the WRF-Chem model.**

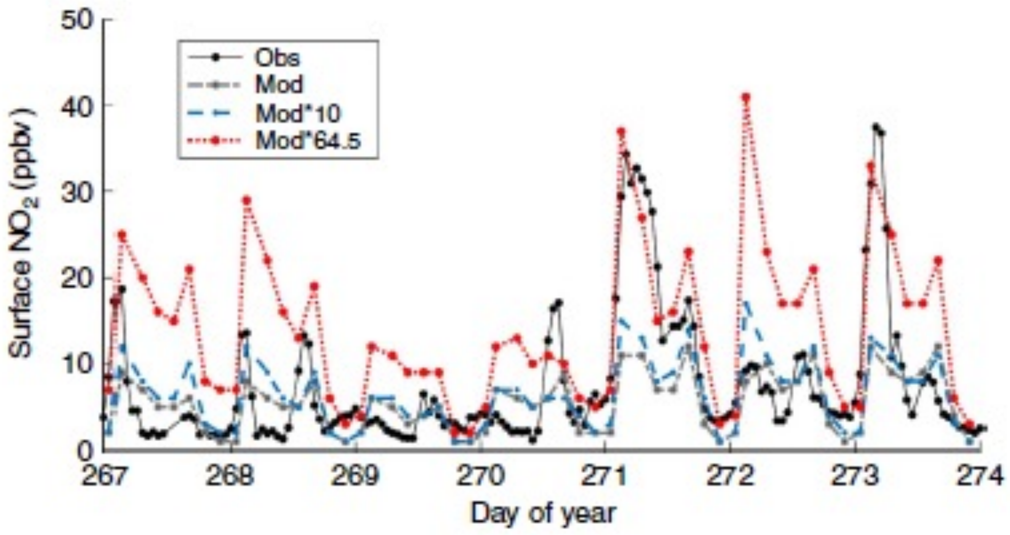
Default soil NO_x emission scheme in the WRF-Chem

MEGAN MEGAN biogenic emissions calculate online based on the weather, land use data.

$$soil\ NOx\ flux = A_{veget} \times f(T)$$

- A_{veget} is a emission factor based on vegetation type (only four types: Broad leaf, Needle leaf, Shrubs, Herbaceous biota)
- f(T) is a temperature response factor





(Oikawa et al., 2015, Nature Communications)

- Model underestimates soil NOx emissions

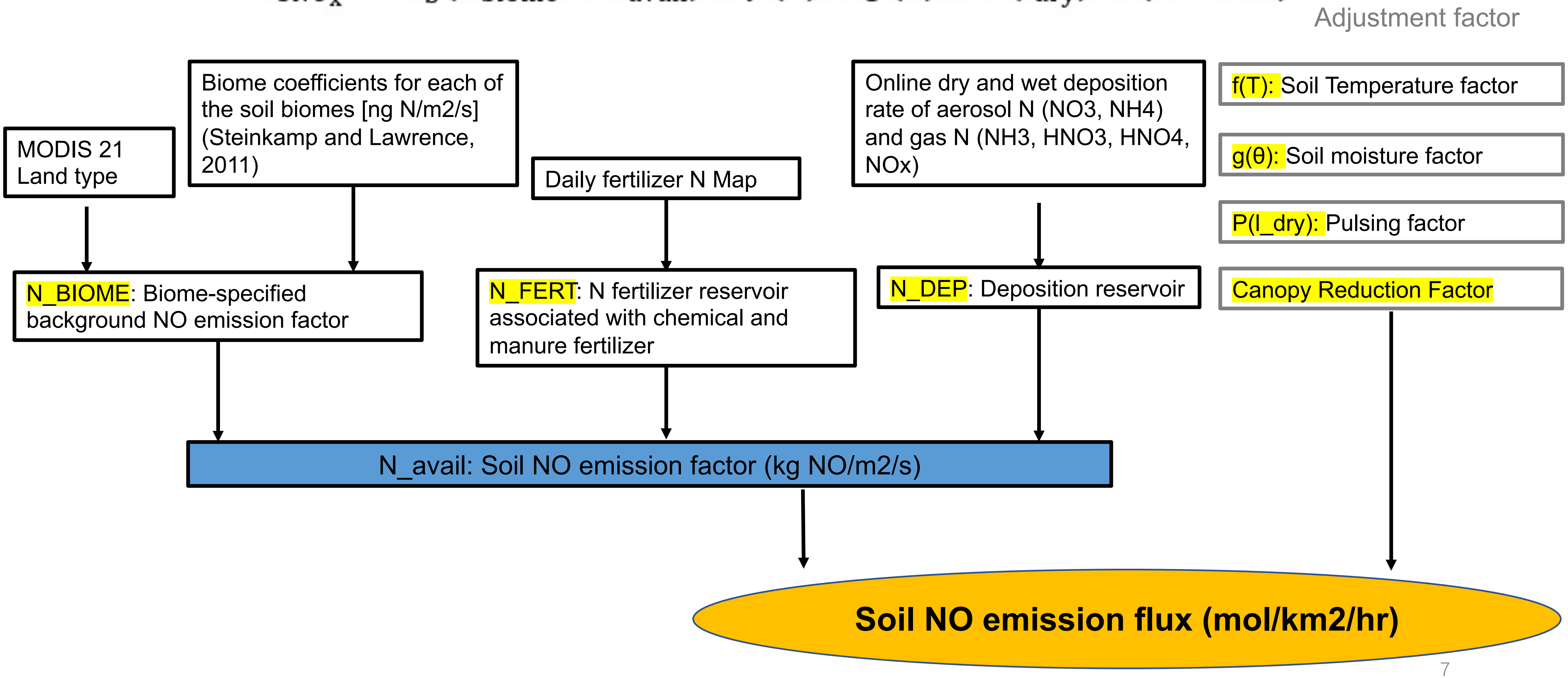
Updated soil NO_x emission scheme in the WRF-Chem

Implementation of the BDSNP (Hudman et al., 2012) with modifications:
Berkley Dalhousie Iowa Soil NO Parameterization (BDISNP)

- Land cover types: Updating the land cover types in WRF model by using the MODIS Land Cover Type (MCD12Q1) v6 in 2018 to reflect more diverse land covers
- Surface temperature representation: Using the GLDAS data to predict the initial and boundary condition of soil moisture and temperature, and directly adopting soil temperature at the top layer to simulate soil NO_x emissions
- Climate zones distribution: Using the modelled green vegetation fraction (VGF) to determine the arid and non-arid region (due to the response of soil moisture factor depending on climate zones)

Flow Chart of BDISNP

$$F_{SNO_x} = A'_b(N_{\mathrm{biome}} + N_{\mathrm{avail}}) \times f(T) \times g(\theta) \times P(l_{\mathrm{dry}}) \times (1 - \mathrm{CRF})$$



Model experiments design and data description

Experiment	Description
Default	The simulation uses MEGAN to calculate soil NO_x emissions during July 2018 in California.
BDISNP	The simulation uses BDISNP to calculate soil NO_x emissions, and also updates land type to the year of 2018 by using MODIS Land Cover Type (MCD12Q1) Version 6 data during July 2018 in California.
NoSNOx	The simulation is the same as BDISNP except that the NO_x emissions from soils are turned off.

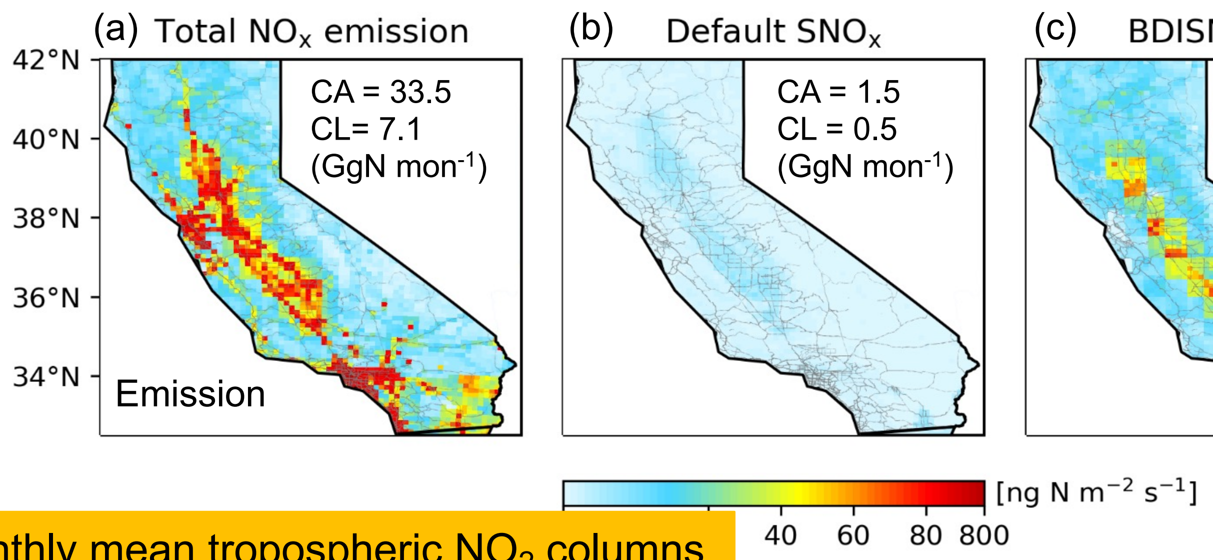
The improvement of model performance after updating the soil NO_x emissions scheme in the WRF-Chem (Default vs. BDISNP)

The impacts of soil NO_x emissions on the air quality (BDISNP vs. NoSNOx)

Variables	Observation Data
NO_2 columns density	TROPOMI (3.5 × 7 km^2)
Soil moisture and temperature	Soil Moisture Active Passive Level 4 Soil Moisture (SMAP L4_SM) product (9 × 9 km^2)
Precipitation	Global Precipitation Measurement (GPM) (0.25° × 0.25°)
Surface NO_2 and O_3 concentrations	U.S. EPA Air Quality System (AQS)

Soil NO_x emissions and Tropospheric NO_2 columns density

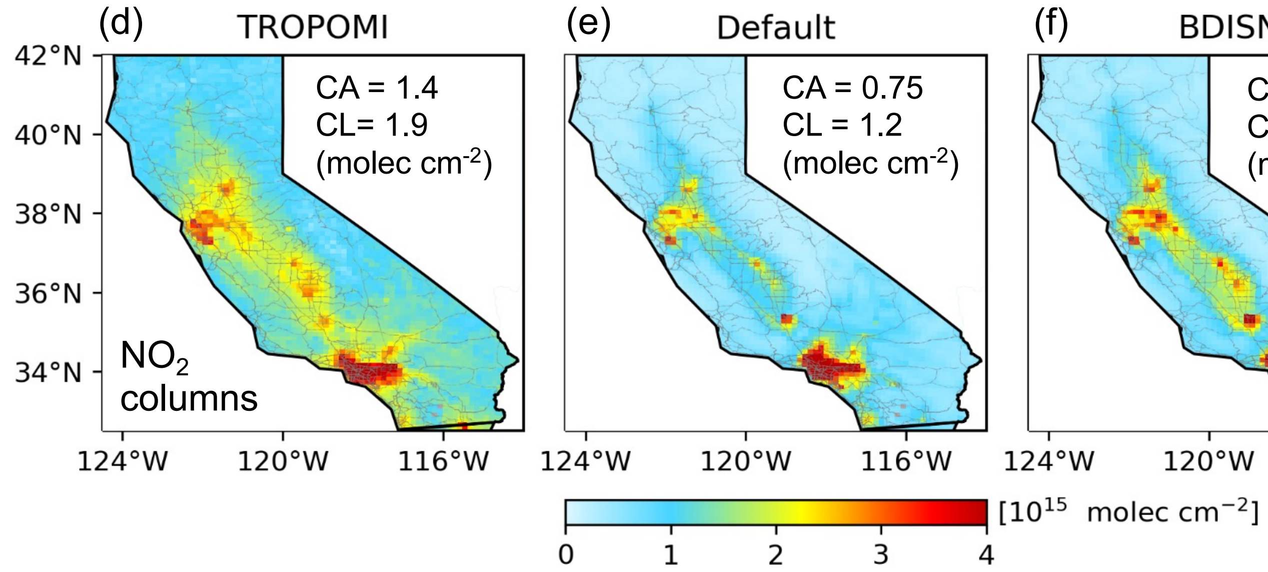
Simulated monthly mean soil NO_x emission flux



CA: California
CL: Cropland

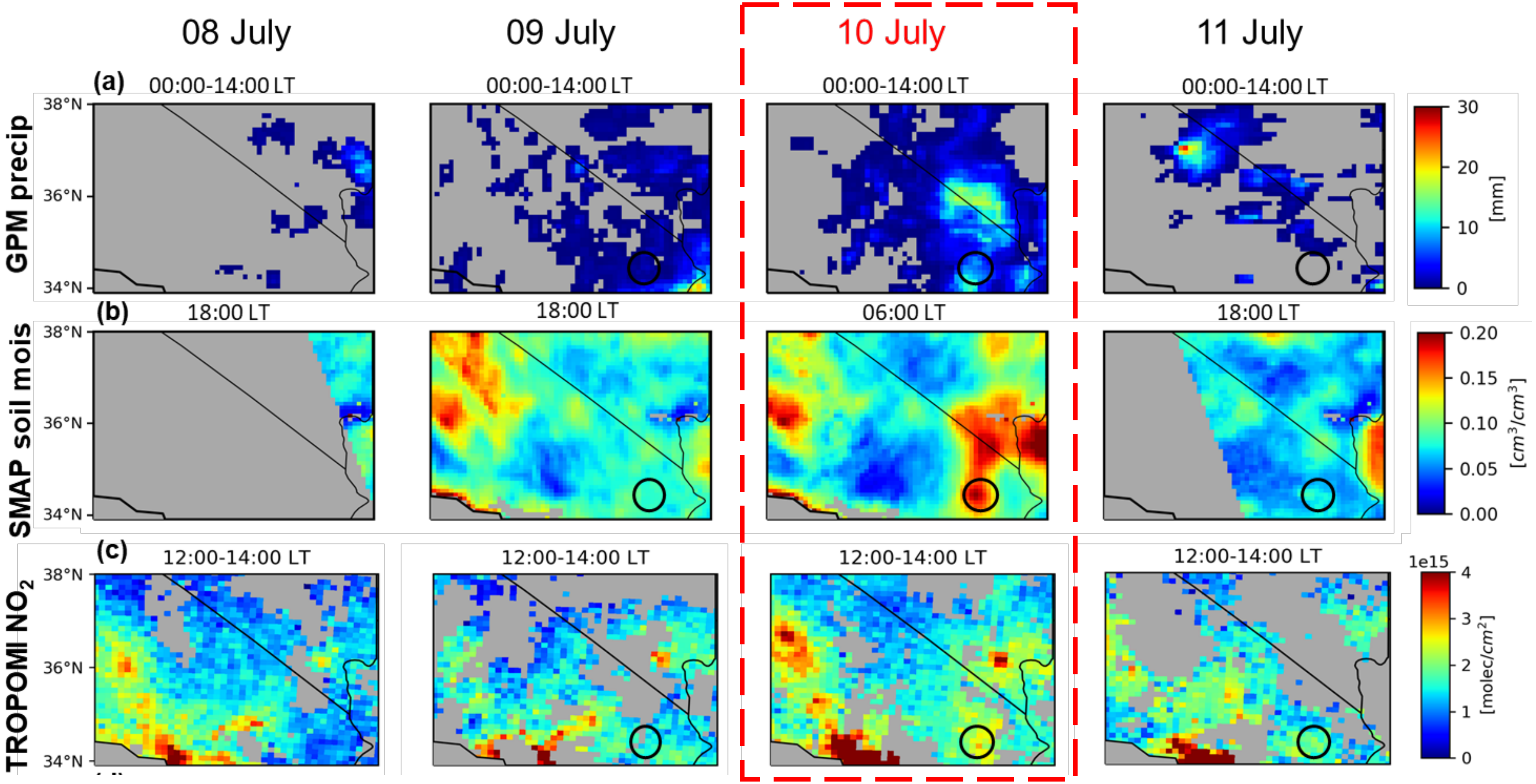
- BDISNP increases soil NO_x emissions fluxes by a factor of 7-9.

Monthly mean tropospheric NO_2 columns



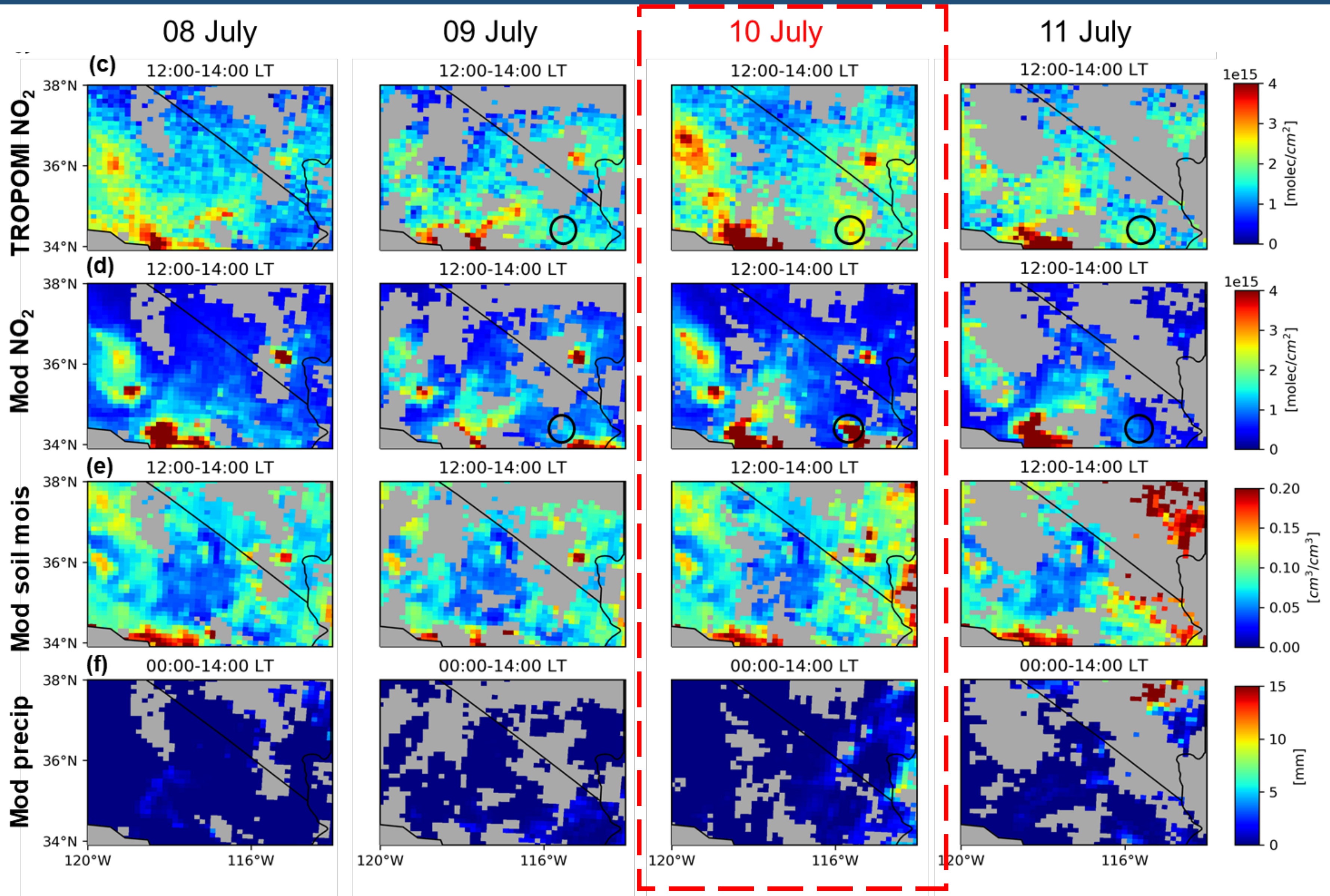
- BDISNP improves the performance of simulated tropospheric NO_2 columns.

Rain-induced emission pulse — observations



- The precipitation appeared in the Sheephole Valley (located in the Mojave Desert) on 10 July, accompanied with the enhancement of soil moisture and NOx column concentration.

Rain-induced emission pulse — model results

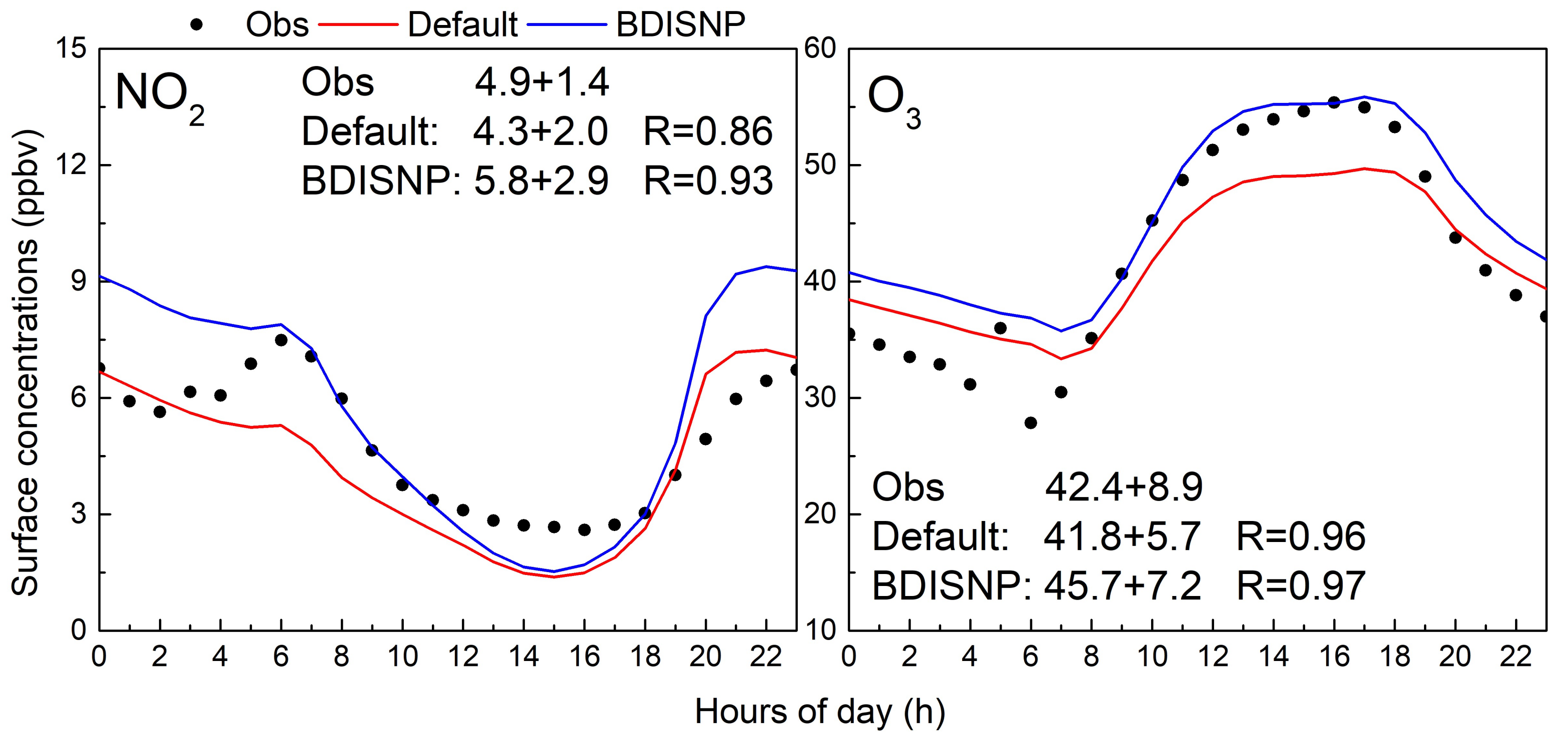


The model with BDISNP scheme:

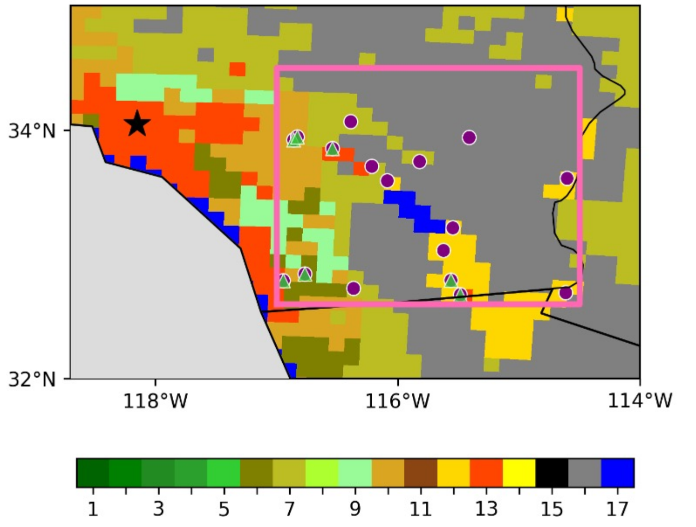
- Shows a better agreement with the TROPOMI NO_2 columns;
- reproduces the observed rain-induced pulse emission in drylands;
- giving us confidence in soil NO_x emissions estimates.

Impact of soil NO_x emissions on air quality

Diurnal variation of simulated and observed surface NO_2 and O_3 concentrations in the rural area downwind from LA, California during July 2018



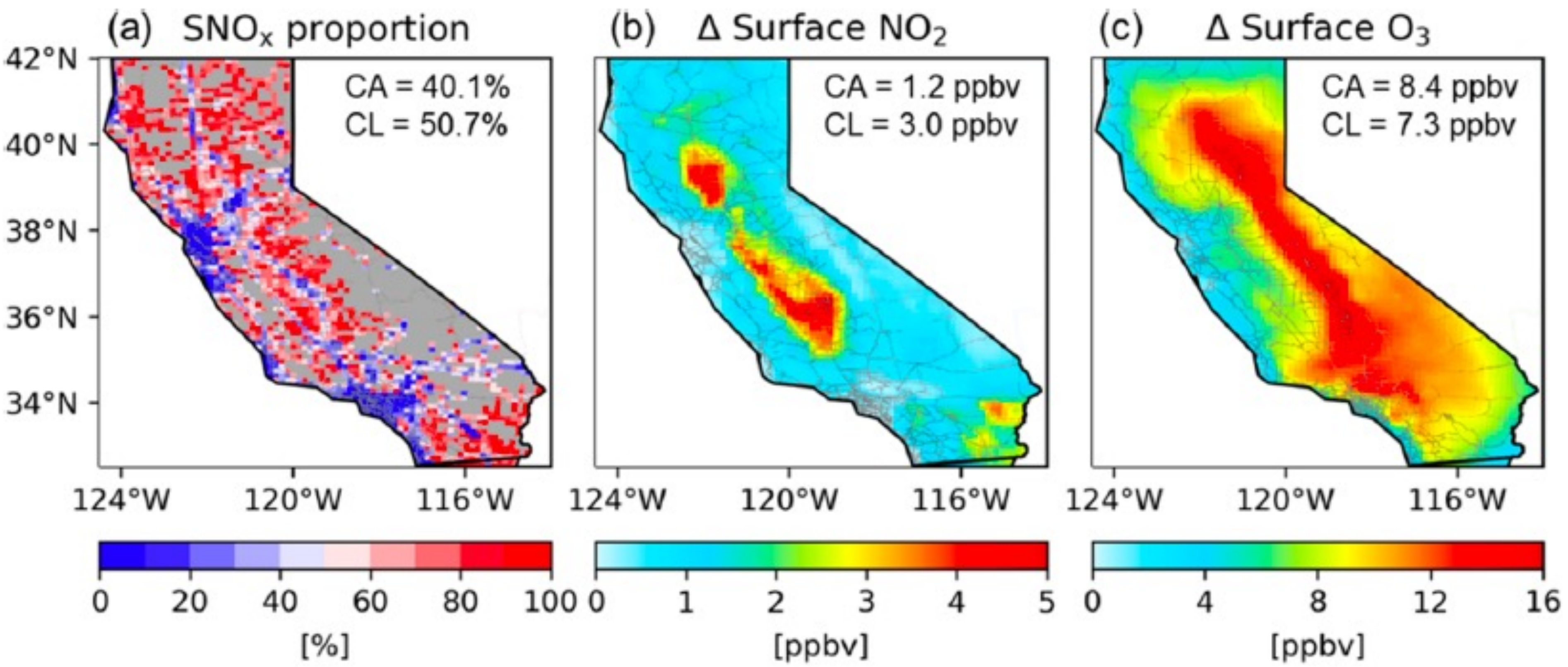
EPA NO_2 (Green triangles) and O_3 (purple dots) measurement sites



- BDISNP show a better agreement with the observed diurnal variation of NO_2 and O_3

Impact of soil NO_x emissions on air quality

Contribution of soil NOx to surface NO_2 and O_3



- This rural region is NO_x-limited and the air quality is sensitive to soil NO_x emissions
- Therefore, the intensive agriculture and dry desert soils associated with high SNO_x in rural California could lead to poor air quality

Summary

- The model with BDISNP shows a better agreement with TROPOMI NO_2 columns and can reproduce the observed rain-induced pulse event of SNO_x, giving us confidence in SNO_x estimates.

- 40.1% of the state's total NO_x emissions are from soils in July 2018, and SNO_x could exceed anthropogenic sources over croplands, accounting for 50.7% of NO_x emissions.

- Such considerable SNO_x enhance the monthly mean NO_2 columns by 34.7% (53.3%) and surface NO_2 concentrations by 176.5% (114.0%), leading to an additional 23.0% (23.2%) of surface O_3 concentration in California (cropland).

- **SNO_x serves as an important source of atmospheric NO_x in California, particularly in rural regions with high fertilizer application but also in minimally managed native drylands, and should be included in regulations to reduce adverse effects to air quality and human health.**
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Sha, T.*, X. Ma, H. Zhang*, N. Janechek*, Y. Wang*, Y. Wang*, L. Castro*, G. Jenerette, **J. Wang**, Impacts of soil NOx emission on O3 air quality in rural California, *Environmental Science & Technology*, 55, 7113−7122, DOI: https://doi.org/10.1021/acs.est.0c06834, 2021.