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VIRGINIA TECH

Implementation and Evaluation of Total Vegetation Data in the CMAQ Windblown Dust Module

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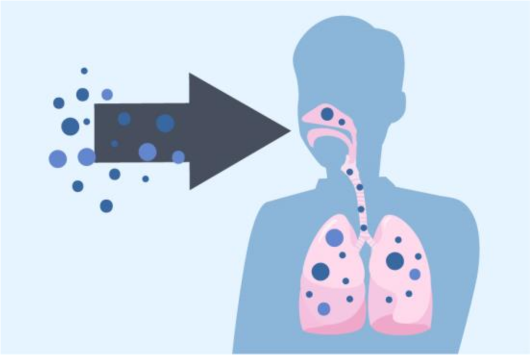
United States Environmental Protection Agency

NASA

Importance of windblown dust (WBD) emissions

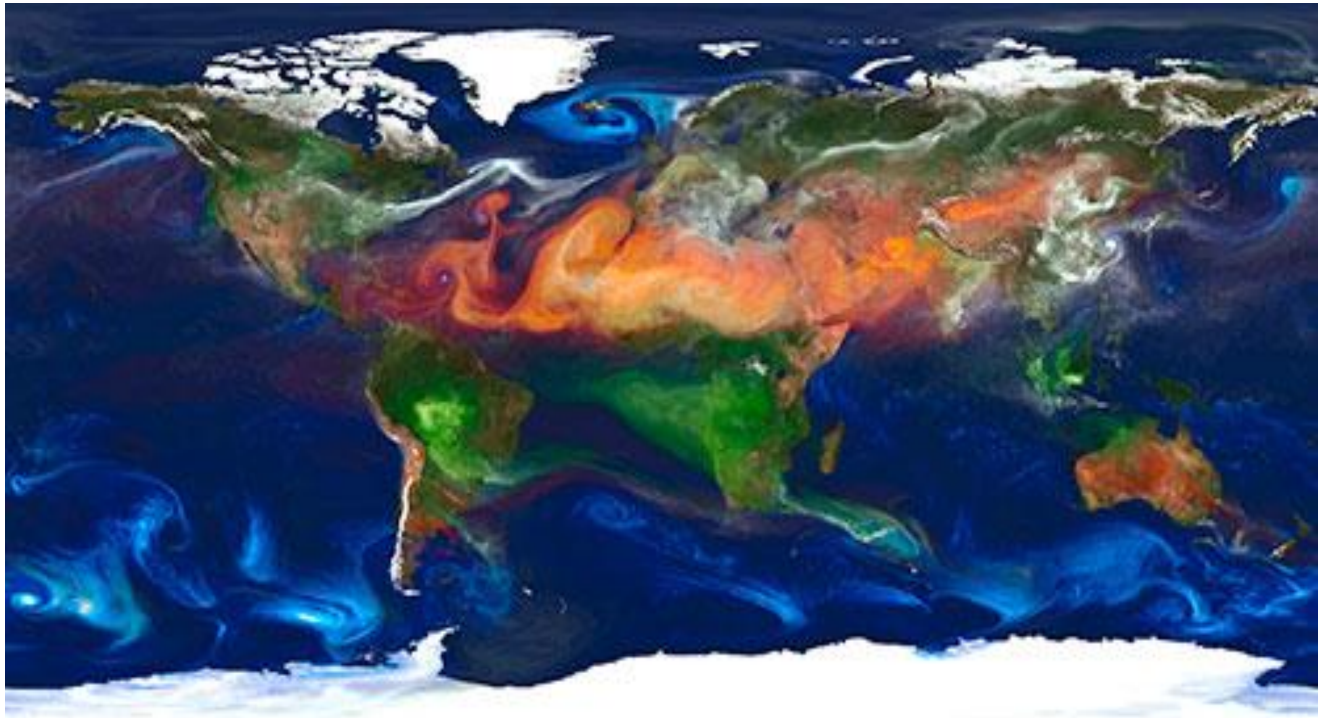
Human activities

Health issues



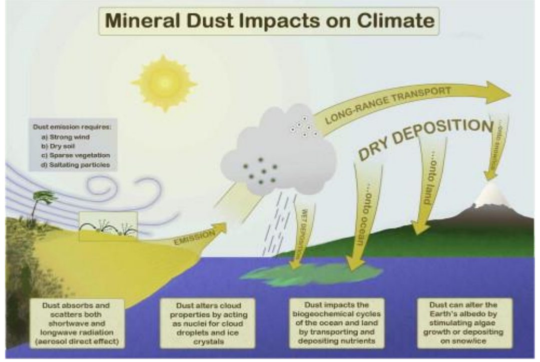
(CDC)

Mineral dust is among top contributors of global aerosols



(Global aerosol, NASA/Goddard)

Complex climate effects



(Mahowald et al., 2014)

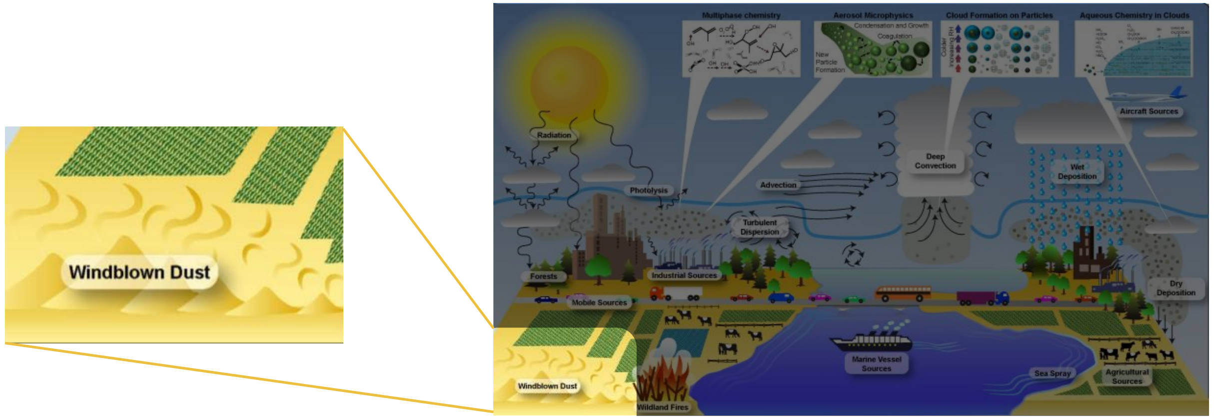
Transport of nutrients

Credit to Steve Greco

Overview of the WBD module in the Community Multiscale Air Quality (CMAQ) model

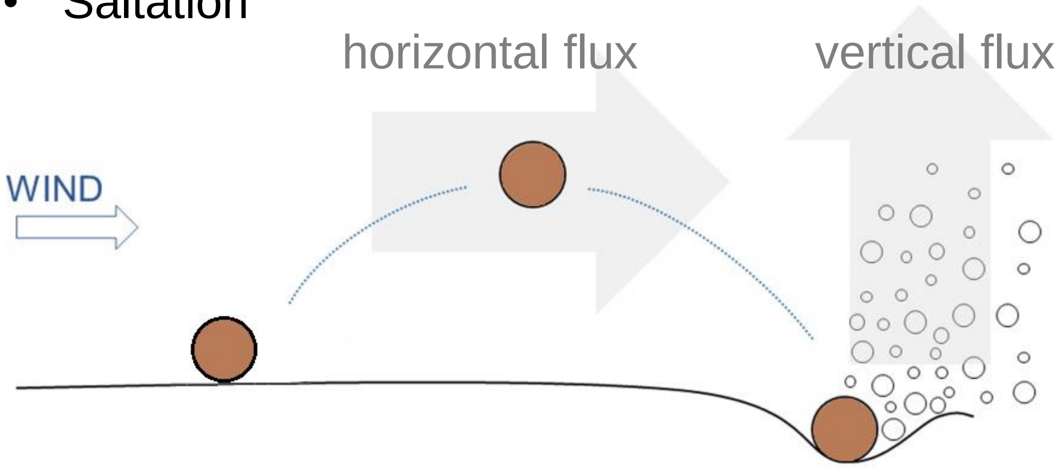
- First released in CMAQv5.0 in 2012
- Major updates in CMAQv5.2 in 2017

(Appel et al., 2013, GMD; Foroutan et al., 2017, JAMES.)



(EPA)

- Saltation



Remade from Fig. 1 in Foroutan et al., 2017.

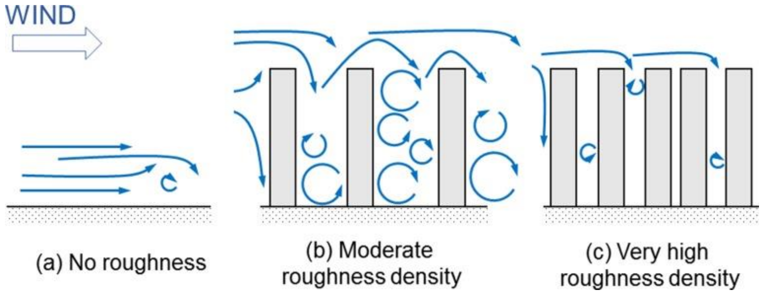
- Saltation flux is a function of friction velocity (u_*) and threshold velocity ($u_{*,t}$)

When $u_* > u_{*,t}$

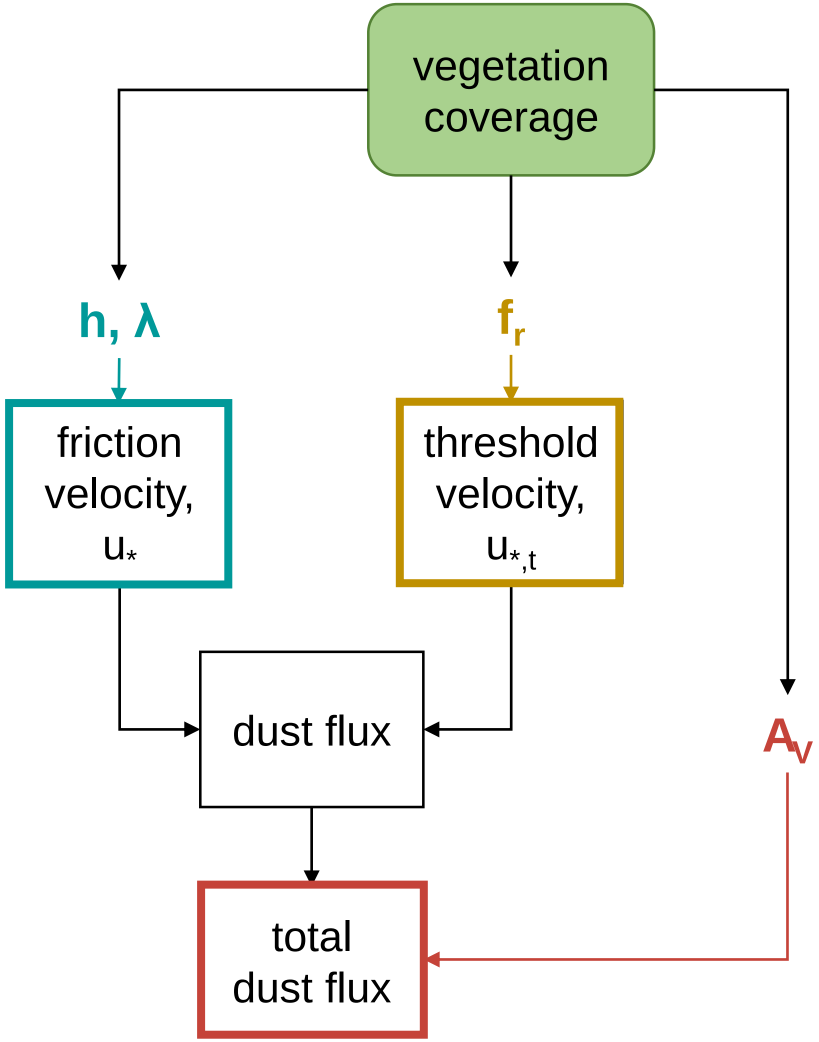
$$F_H = C\frac{\rho_a}{g}{u_*}^3\left(1-\frac{u_{*,t}}{u_*}\right)\left(1+\frac{u_{*,t}}{u_*}\right)^2$$

Vegetation modulates WBD simulations

- Increase or decrease u_* by changing flow pattern



(Foroutan et al., 2017, JAMES.)



$$u_{*,t} = u_{*,t0} f_m f_r$$

- f_r – roughness correction factor
- Always raise $u_{*,t}$ by partitioning the wind drag on surface

- Prevent the surface from erosion

Motivation and Objectives

Current model uses maps for **PV** (photosynthetic vegetation) or look-up table for unspecified vegetation, omitting effects of **NPV** (non-photosynthetic vegetation)

NPV
- dead trees, yellowed grasses, litter, etc.
- abundant in dust sources regions

Credits to Lorraine Bryant, Wesley Tingey

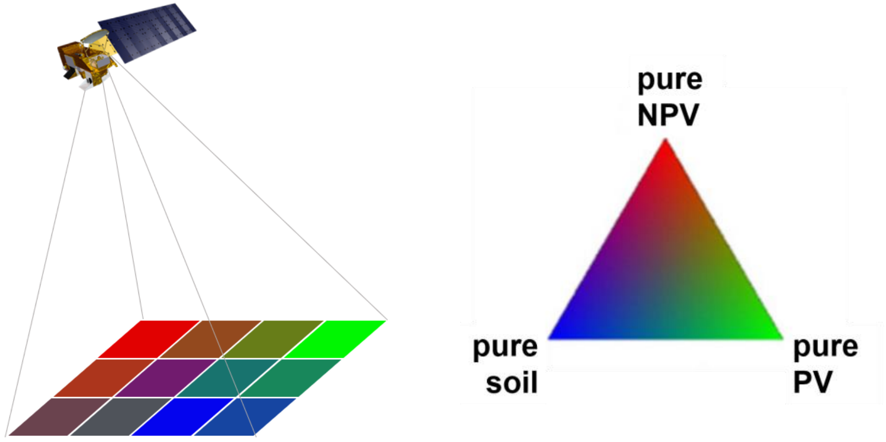
Objectives:

1) To implement a total vegetation dataset in the WBD module
2) To test the effects of NPV on simulated dust emissions

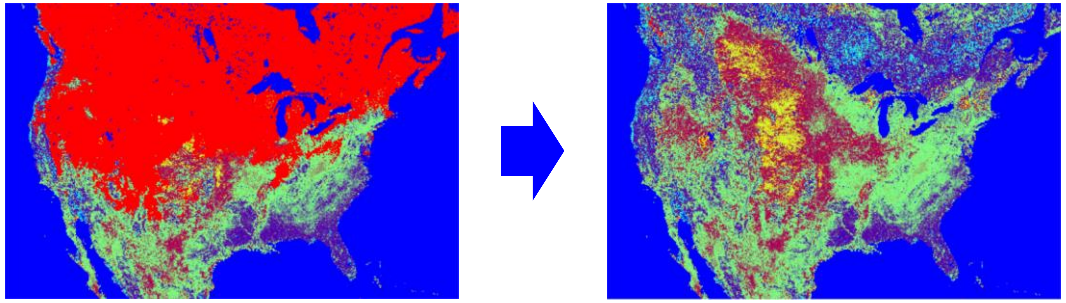
Total vegetation dataset derived using spectral mixture analysis (SMA) method

- Based on satellite observation of surface reflectance
- SMA: resolve fractions of three surface components
- Total vegetation = PV + NPV
- Resolution: monthly, 5 km

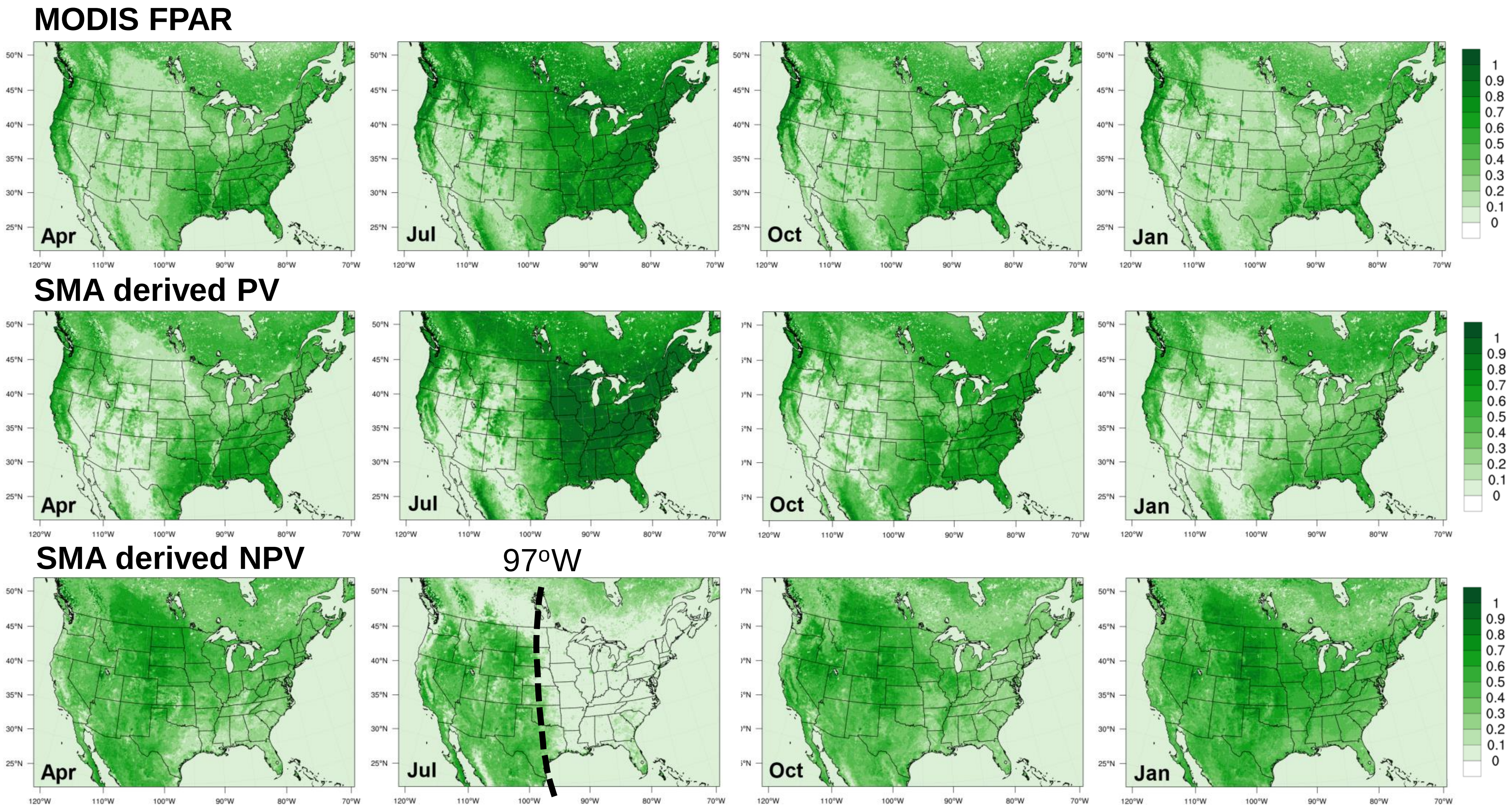
(Guerschman et al., 2015)



- Linearly interpolated to daily
- Gap-filled
- Re-gridded to 12 km resolution

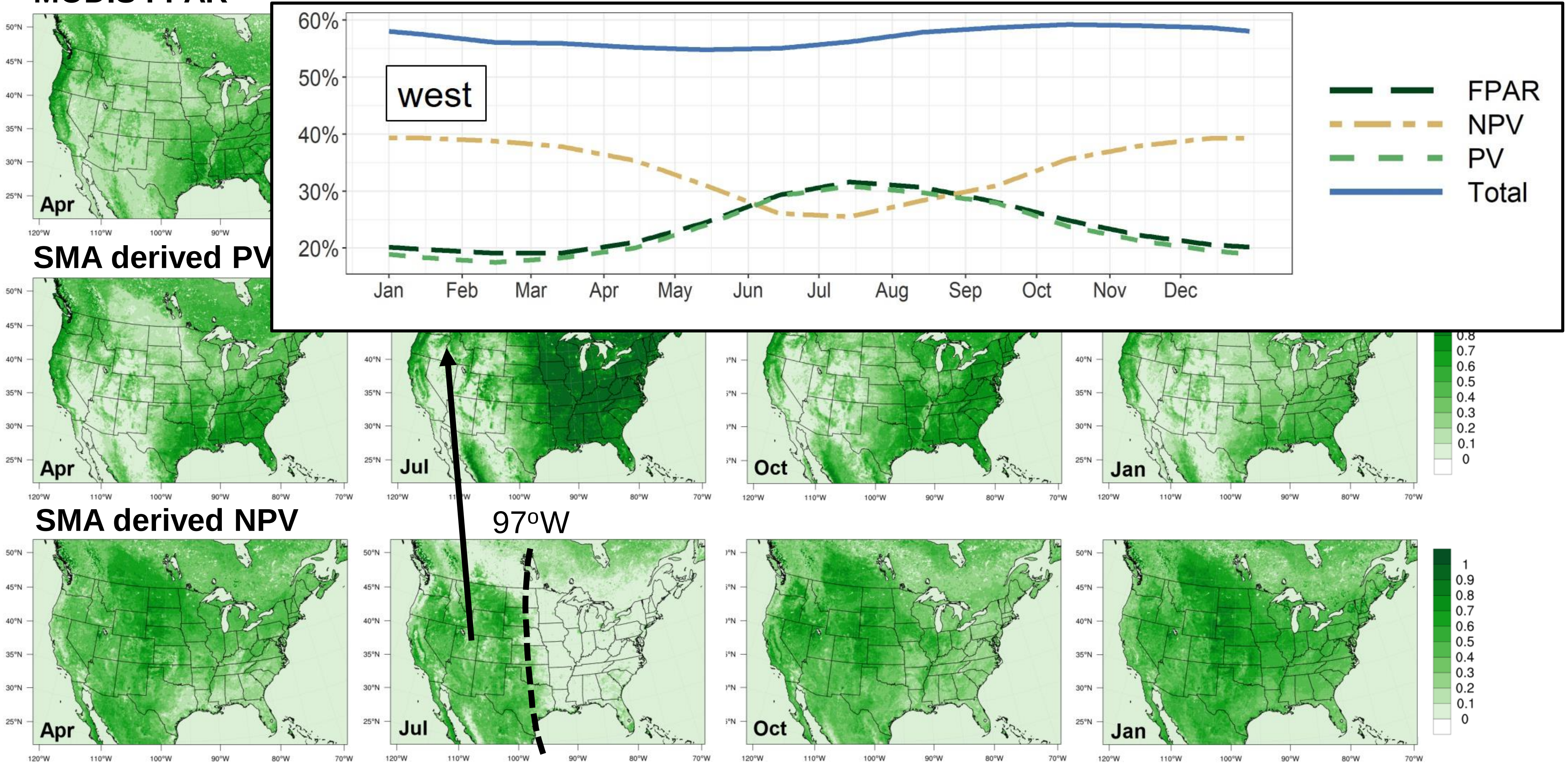


Comparison of MODIS FPAR (fraction of absorbed photosynthetically active radiation) and total vegetation dataset

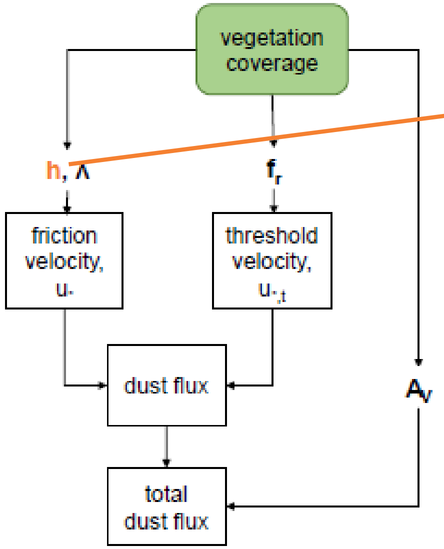


Comparison of MODIS FPAR (fraction of absorbed photosynthetically active radiation) and total vegetation dataset

MODIS FPAR



Updates in parameterization



roughness height

$$h = \frac{h_{PV}\lambda_{PV} + \boxed{h_{NPV}}\lambda_{NPV} + h_s\lambda_s}{\lambda_{PV} + \lambda_{NPV} + \lambda_s}$$

Predefined NPV heights based on magnitude and seasonal trends of biomass

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Shrubland	PV	5	5	15	15	12	12	10	10	10	5	5	5
	NPV	6	6	5	5	5	5	5	5	6	8	8	6
Grass	PV	5	5	5	10	20	15	12	12	10	5	5	5
	NPV	8	5	5	5	5	5	5	5	10	10	8	8
Barren	PV	5	5	10	10	10	10	10	10	10	10	5	5
	NPV	4	4	4	3	3	3	3	3	5	5	5	5

Uncertainties?
Sensitivity tests show that +/- 50% of change in h_{NPV} leads to within +/- 6% of change in soil concentration over most areas

(Pierre et al., 2015; Nandintsetseg & Shinoda, 2015; Shinoda et al., 2011.)

Experimental design

Simulations: **“PV” run** and **“PV+NPV” run**

Model: CMAQv5.3

Domain: Conterminous United States

Time: Entire 2016

Grid: 12 km x 12 km, 35 layers

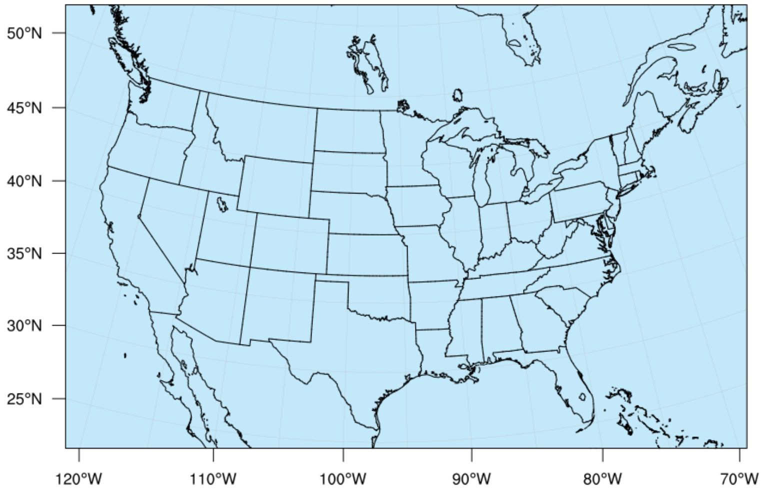
Meteorology: WRFv3.8 and MCIPv5.0

Landuse: Biogenic Emission Landcover Database version 3 (BELD3)

Chemistry: CB06r3

Aerosol: AERO7

Soil type: US State Soil Geographic (STATSGO) soil database



(Appel et al., 2021, GMD.)

Evaluation method

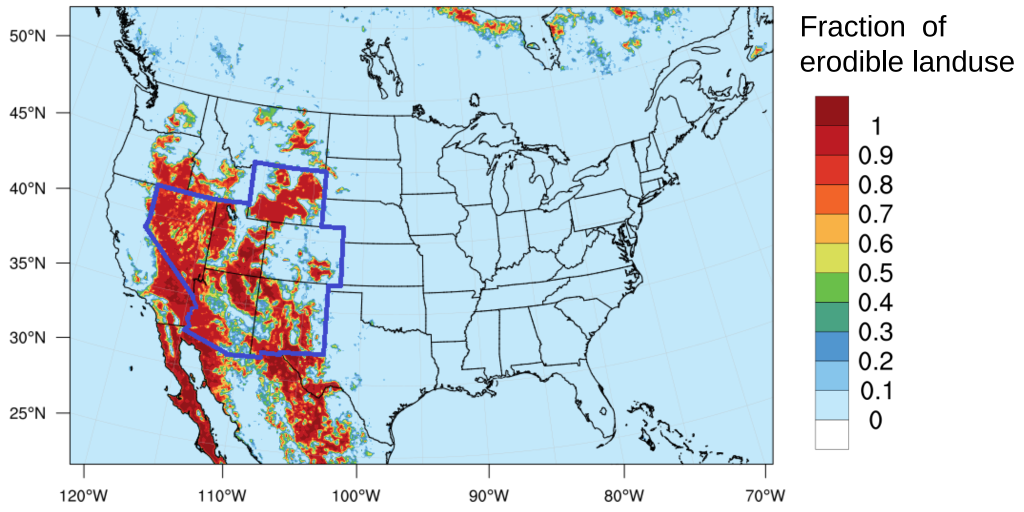
- Soil concentration

$$[Soil] = 2.2[Al] + 2.49[Si] + 1.63[Ca] + 2.42[Fe] + 1.94[Ti]$$

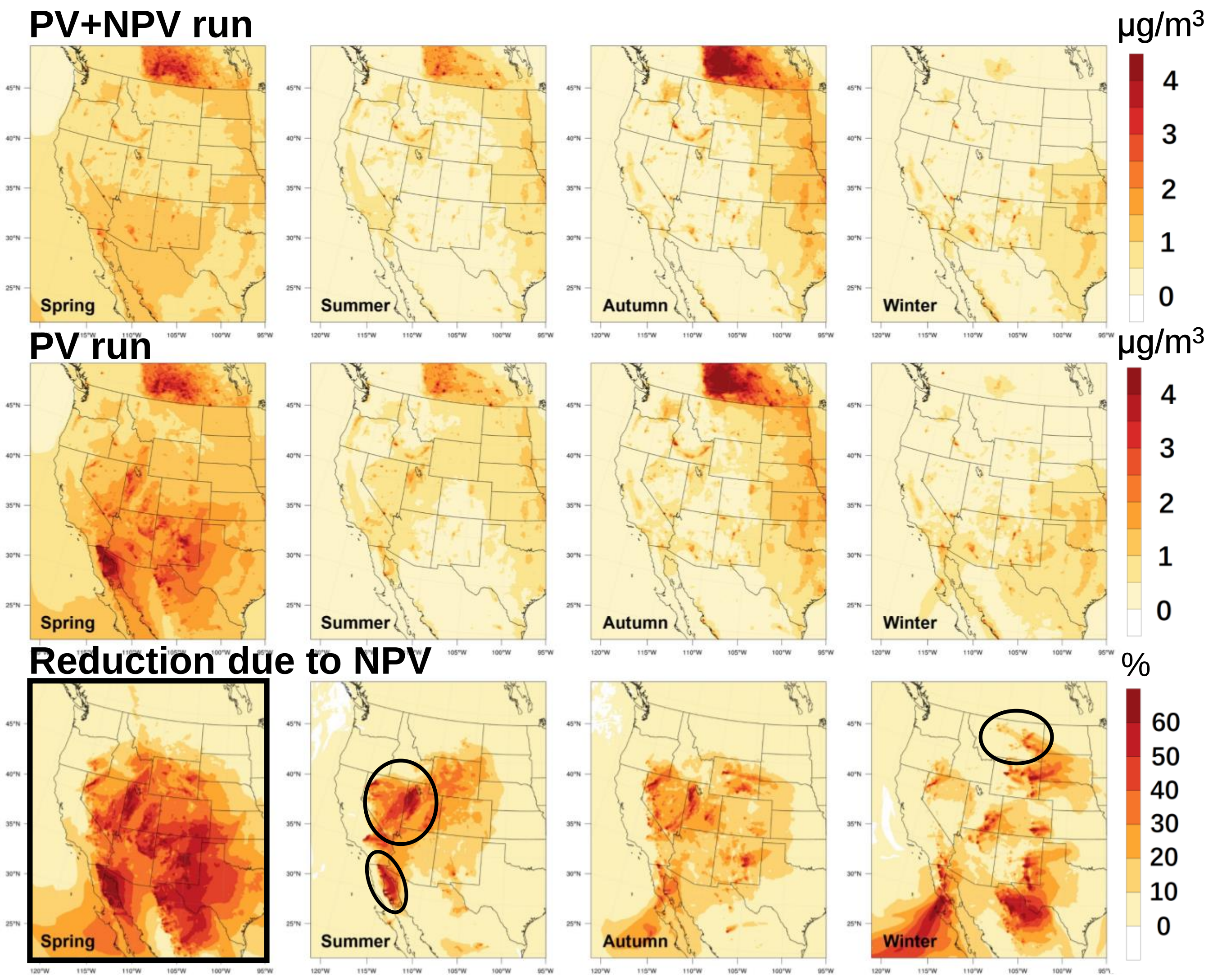
(Malm, 1994)

- IMPROVE (Interagency Monitoring of Protected Visual Environments) sites

- Normalized mean bias calculated for six western states (Nevada, Utah, Arizona, Wyoming, Colorado, New Mexico)



Seasonal average soil concentration reduces over most of southwestern US due to NPV



- Biggest changes in spring:
  over 50% of reduction in source regions
- During summer, most reductions seen in Salt Lake Desert and Sonoran Desert
- Suppression in the northern state of Montana
- More than 10% of changes over most southwestern US from spring to autumn

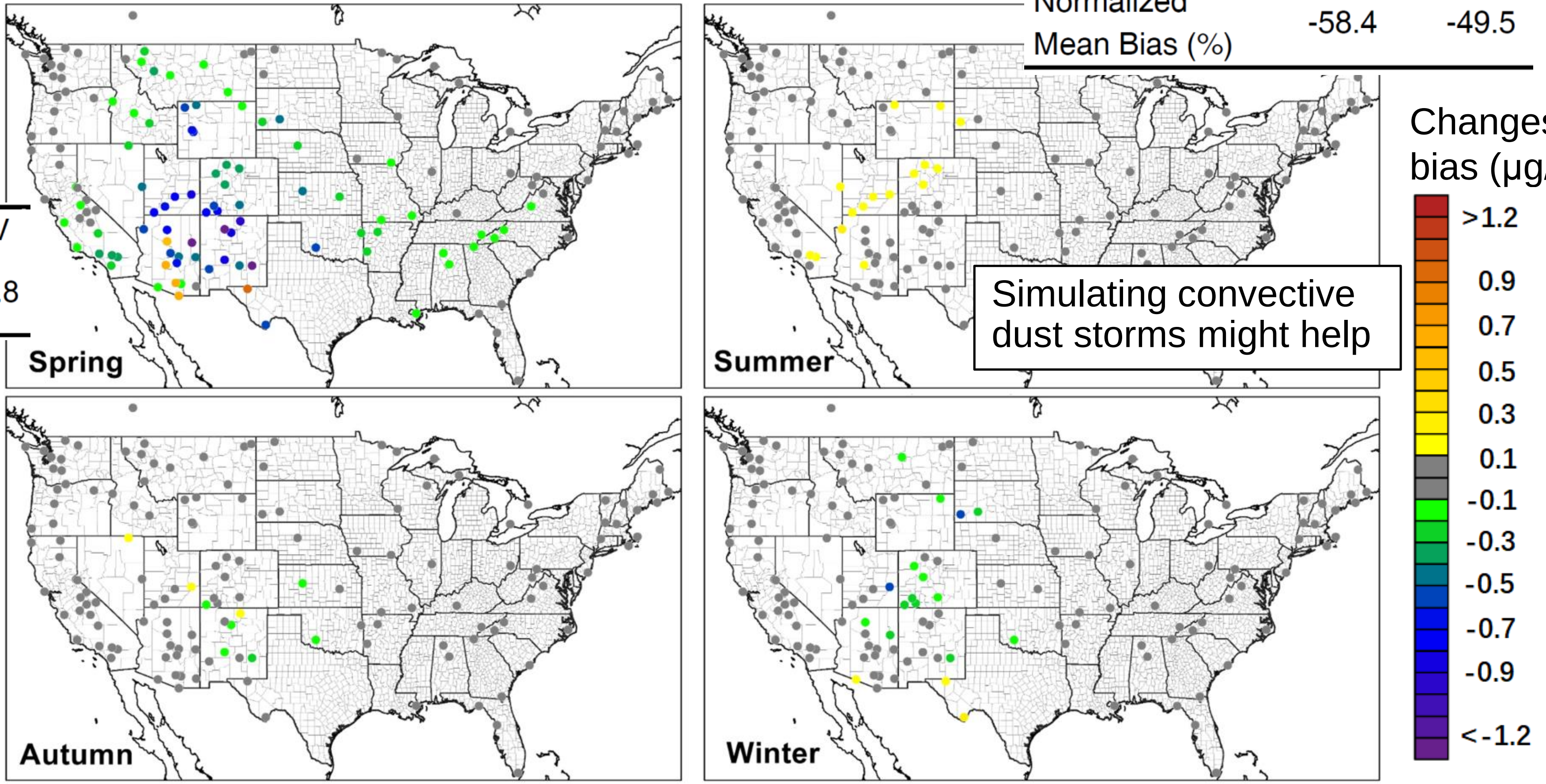
Overpredictions are reduced over most sites during spring, but underprediction are slightly worsen during summer

Improvements over most sites, except in southern AZ and NM

	PV+NPV	PV
Normalized Mean Bias (%)	3.6	72.8

	PV+NPV	PV
Normalized Mean Bias (%)	-58.4	-49.5

Simulating convective dust storms might help



Changes in bias ($\mu g/m^3$)

worse with NPV

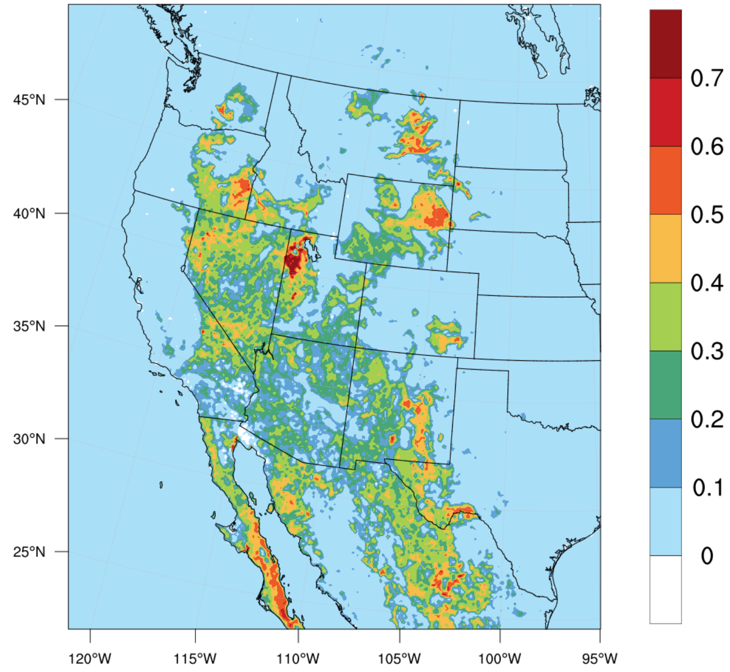
better with NPV

(Anisimov et al., 2018; Heinold et al., 2013; Pantillon et al., 2016; Foroutan and Pleim, 2017).

NPV suppresses dust emissions mainly by sheltering the surface and increasing the threshold velocity

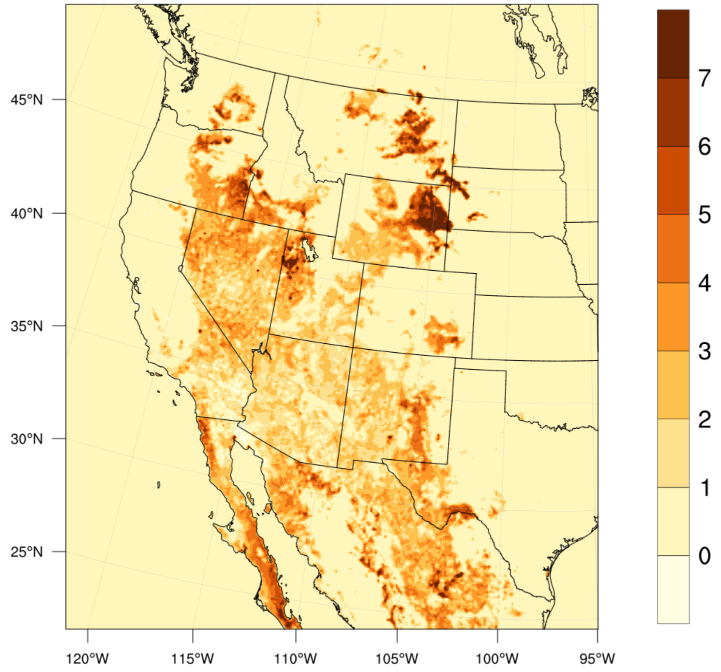
Changes in three intermediate parameters during spring

Reduction in dust sources



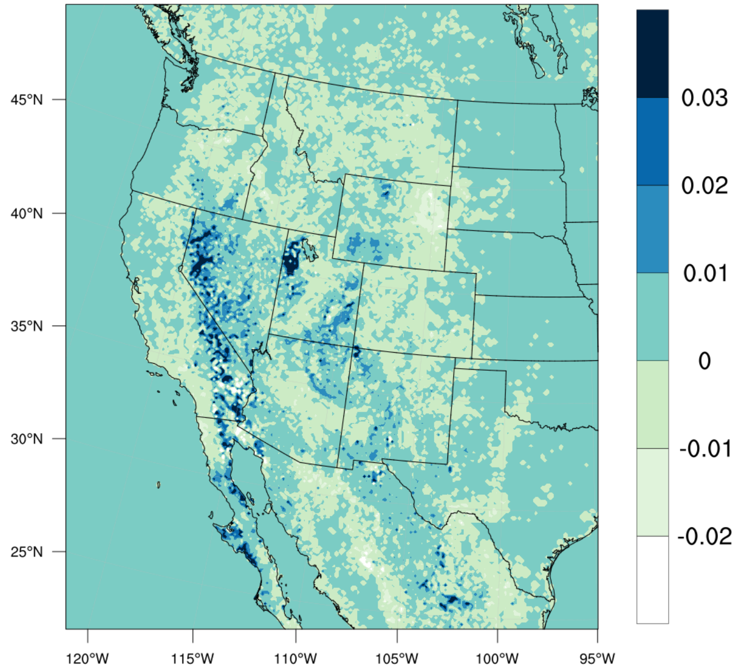
Vegetation-free erodible land fraction

Increase in threshold velocity



Roughness correction factor, f_r

Increase/decrease in friction velocity



Friction velocity, u_* (m/s)

Conclusion

- We implemented a total vegetation dataset into the CMAQ windblown dust module, with uncertainty addressed.
- Soil concentration reductions are most prominent in spring; more than 10% over most areas of southwestern US from spring to autumn.
- Overpredictions in spring are improved at most sites, but underpredictions in summer are intensified.
- Main mechanisms for dust suppression are through surface protection and raising threshold velocity.
- There are other potential applications of the total vegetation dataset (e.g. in dry deposition models).

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