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Impact of Wildfires on Solar Resource Availability in California in a Changing Climate

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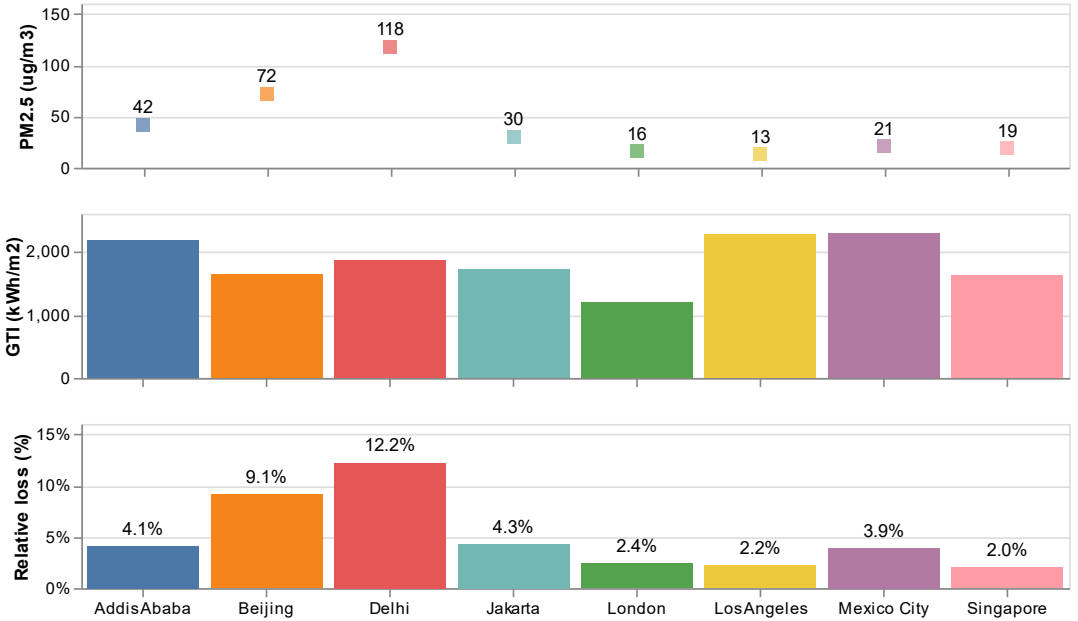
Introduction

Impact of air pollution on solar generation

- Air pollution, especially atmospheric particulate matter (PM), can scatter solar irradiance
- Previous studies reported yearly solar generation can be reduced by 4 - 12 % in highly polluted urban environments (Peters et al., 2018)



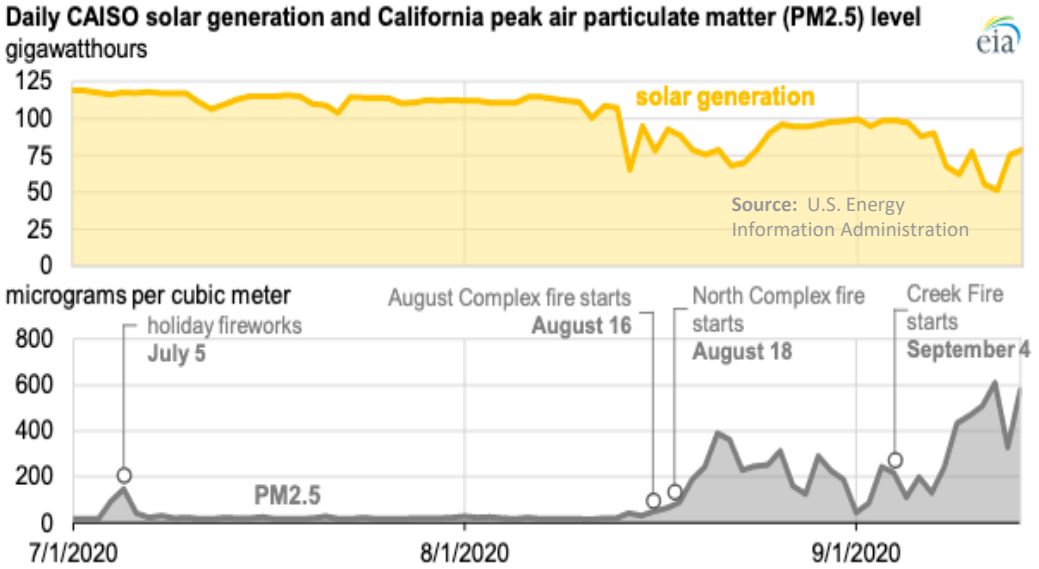
GTI = Global Tilted Irradiance

$PM_{2.5}$ concentration in ug/m^3

Source: Based on Peters et al. (2018), https://doi.org/10.1039/C8EE01100A and air quality data from US Embassies and other sources

Wildfire impact on solar resource

- Compared to anthropogenic pollution, wildfire-released smoke aerosols can have an outsized impact on $PM_{2.5}$ concentration and subsequently on solar photovoltaic (PV) generation.
- Increasing trend of wildfire activities has been observed over western North America. Average annual area burned in California increased by >400% between 1972 and 2018 (Westerling et al.,2016; Williams et al., 2019)



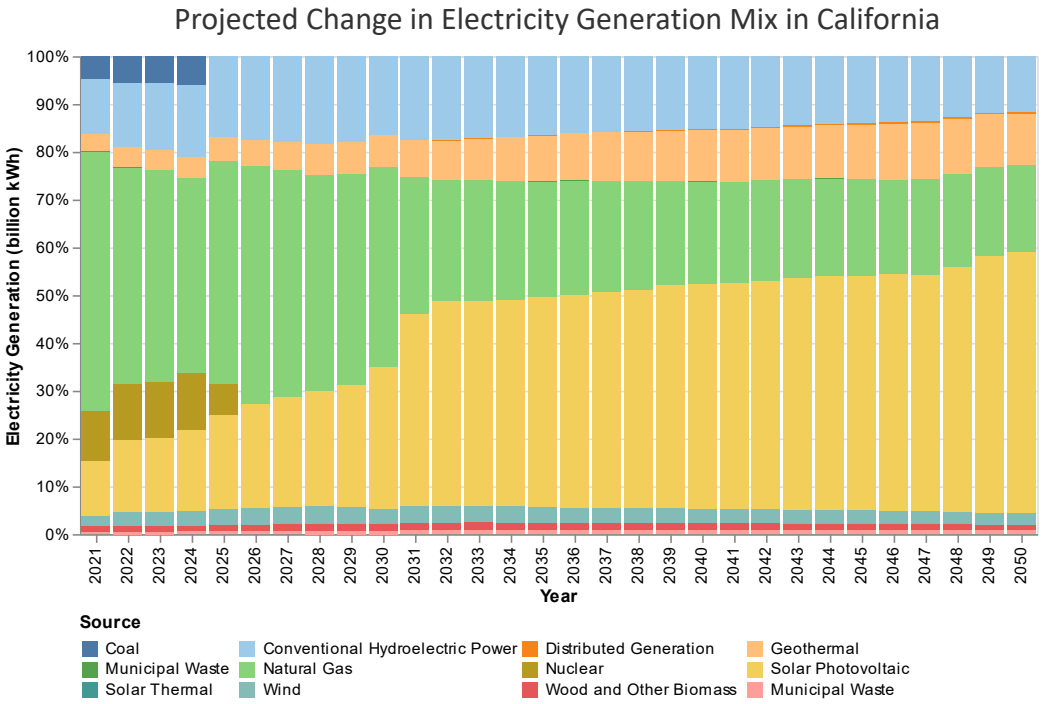
CAISO=California Independent System Operator
Data Source: U.S. Energy Information Administration

Project objectives and focus region

To quantify the impact of wildfire-caused changes in atmospheric aerosol loading on solar PV generation and thus on the availability of solar energy under a changing climate

We focus on California which:

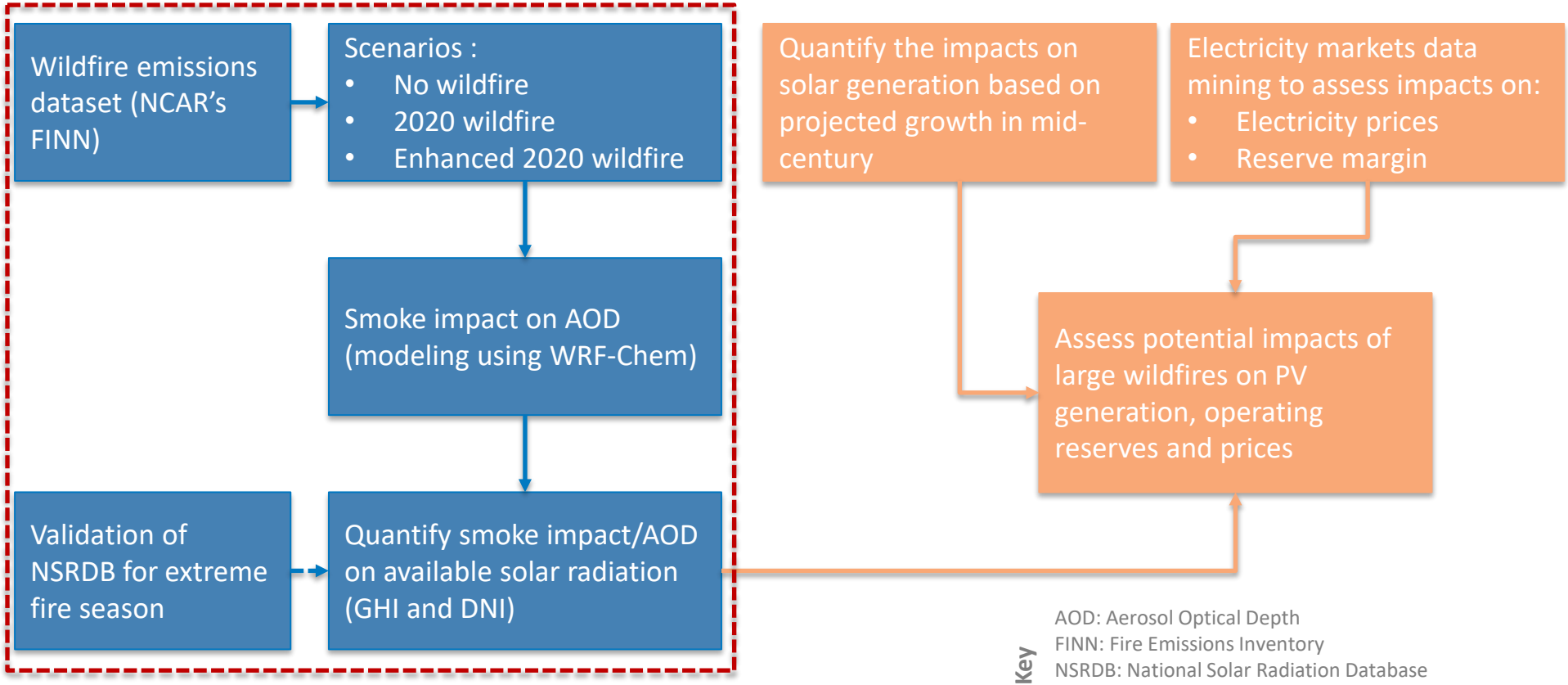
- leads solar power integration in the U.S.
- expects significant projected growth of solar photovoltaic (PV) generation
- has experienced large wildfires in recent years



Data Source: U.S. Energy Information Administration, Annual Energy Outlook (AEO) 2022 (based on electric power sector generation for WECC California North and South regions for Reference Case)

Methodology

Methodology



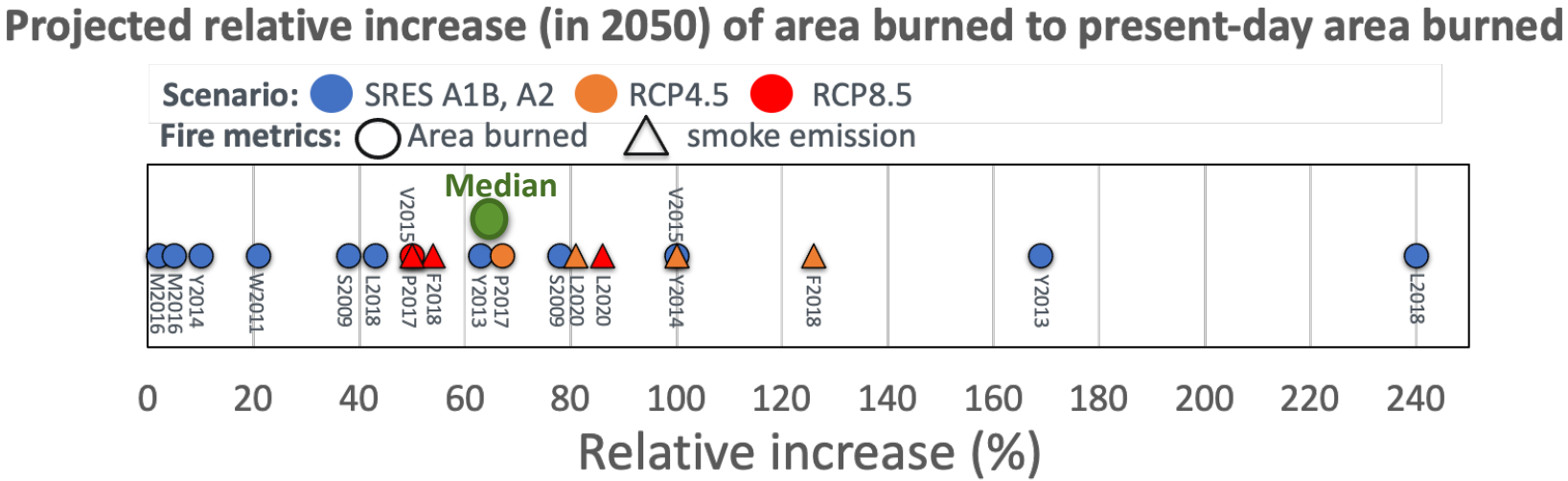
Focus of this presentation

Key

AOD: Aerosol Optical Depth
FINN: Fire Emissions Inventory
NSRDB: National Solar Radiation Database
GHI: Global Horizontal Irradiance
DNI: Direct Normal Irradiance

Projected changes in wildfire activity

- Projected relative increase (in around 2050) of fire metrics ranges from 2 % - 240 % with the majority of previous studies ranging from 40 % - 100%.
- Large variation is possibly due to selection of scenario, climate models, land model, and focus area and period.
- The median value (165%) of projected increase in area burned is selected for this analysis.



Model configuration and products

WRF-Chem

- WRF-Chem: a fully coupled meteorology-chemistry model
- **Fire emission**: Fire Inventory from NCAR (**FINN**v2.5). Fire counts derived from the MODIS satellite.
- Only area burned is intensified. Locations and periods of wildfires remain the same as the wildfires in 2020.

WRF-Chem(v4.0) [Jun-Oct, 12-km]	
MET IC/BC	NAM
Chem IC/BC	CAM-Chem
Chemistry	MOZART-GOCART
Anth Em	12-km 2018 NEI
Fire Em	FINN v2.5
Biogenic Em	MEGAN

*Em: emission

NSRDB

- NREL's NSRDB provides solar radiation data at high spatial (2-km) and temporal (5-min) resolution.
- The correlation coefficient of AOD and DNI is about 0.7 and 0.86 during high fire period, indicating NSRDB can well capture the variation of AOD and solar radiation.

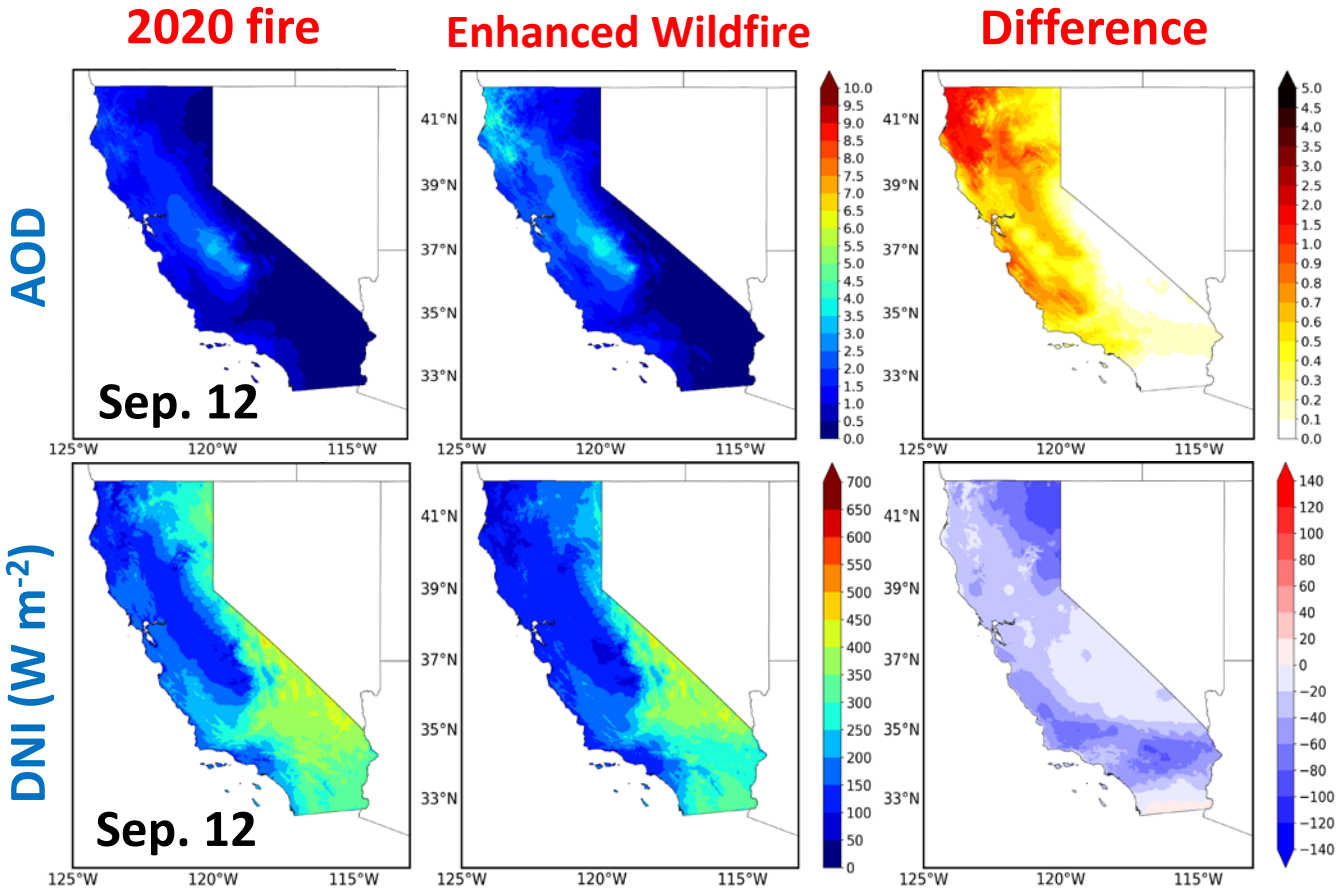
NSRDB: https://nsrdb.nrel.gov

Results and Discussion

Wildfire-caused changes in AOD and solar radiation

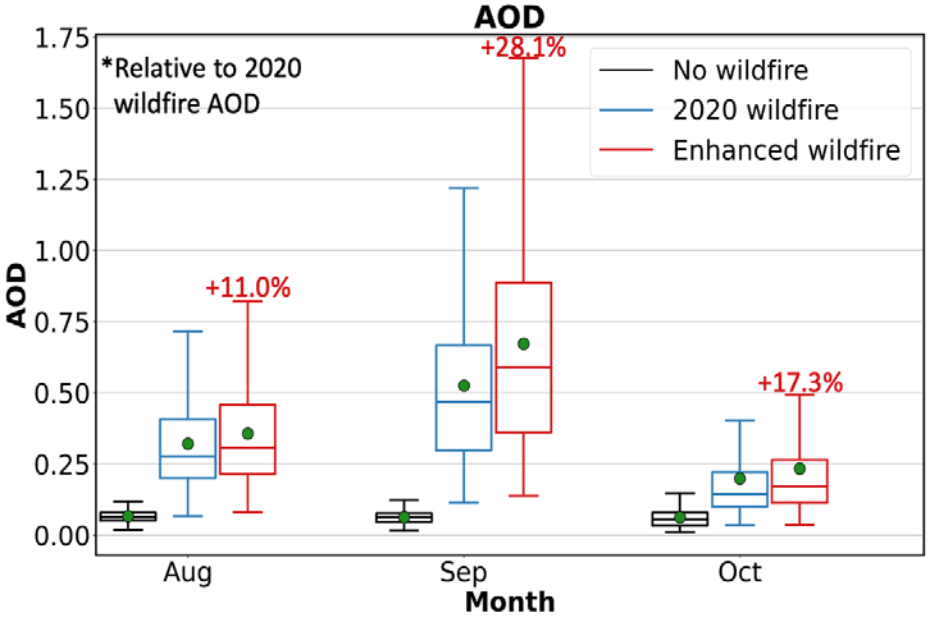
Simulated results for Sep. 12 show that:

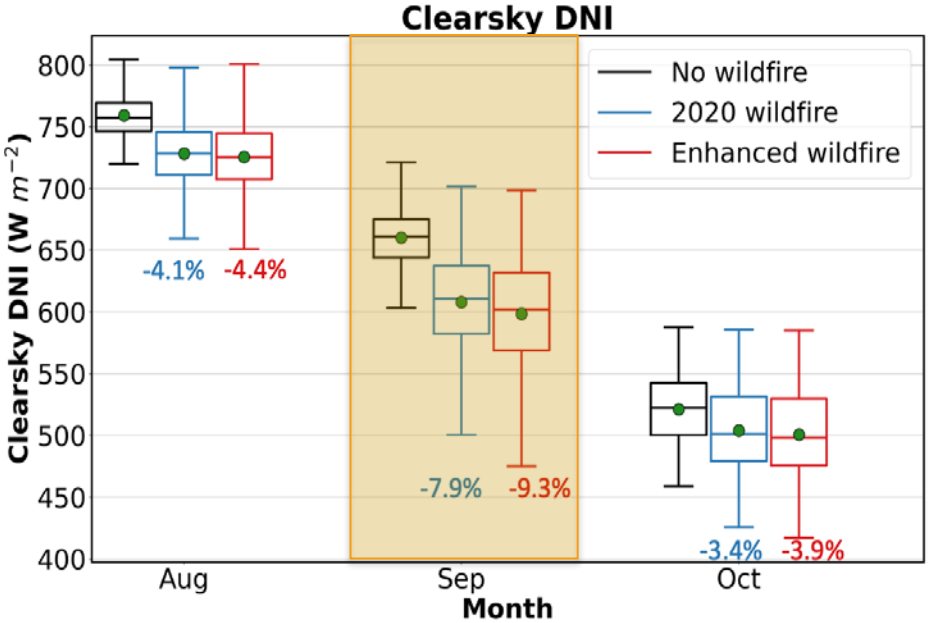
- Enhanced wildfire increases AOD by up to 2.25 (about 200%) over both source and downwind areas.
- Enhanced AOD leads to reduction of DNI by about 100 W m^{-2}.
- Exponential attenuation effect of AOD on DNI ($DNI = DNI_{initial}\, e^{-AOD}$): pronounced DNI impact occurred in areas with relatively low AOD.



Quantification of enhanced wildfire impact

- Compared to 2020 condition, enhanced fire emission leads to increase of monthly AOD by 0.001—0.15 (0.7-28.1%) in California.
- Compared to no wildfire condition, wildfire impact leads to reduction of clearsky DNI by 3.4 — 7.9% in 2020 scenario and 3.9 — 0.3% in enhanced wildfire scenario.





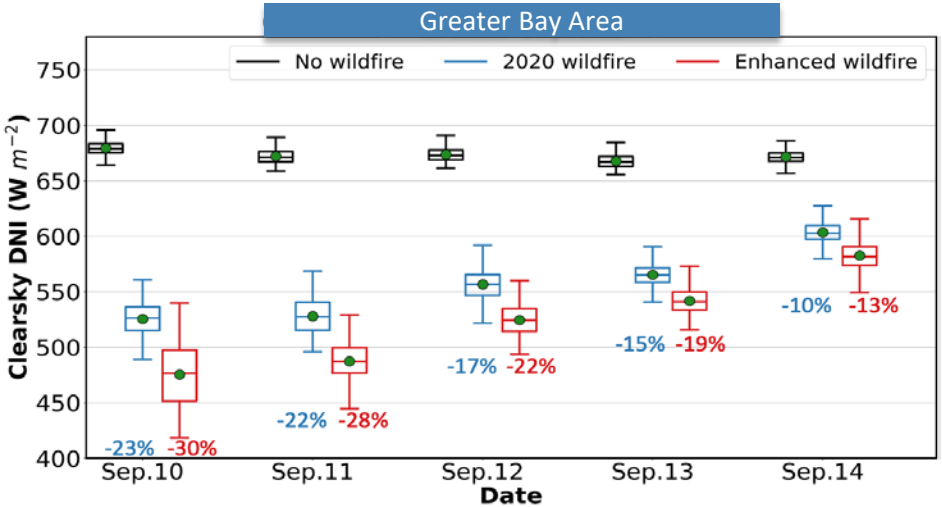
*Clearsky DNI is selected within 10 am – 6 pm local time

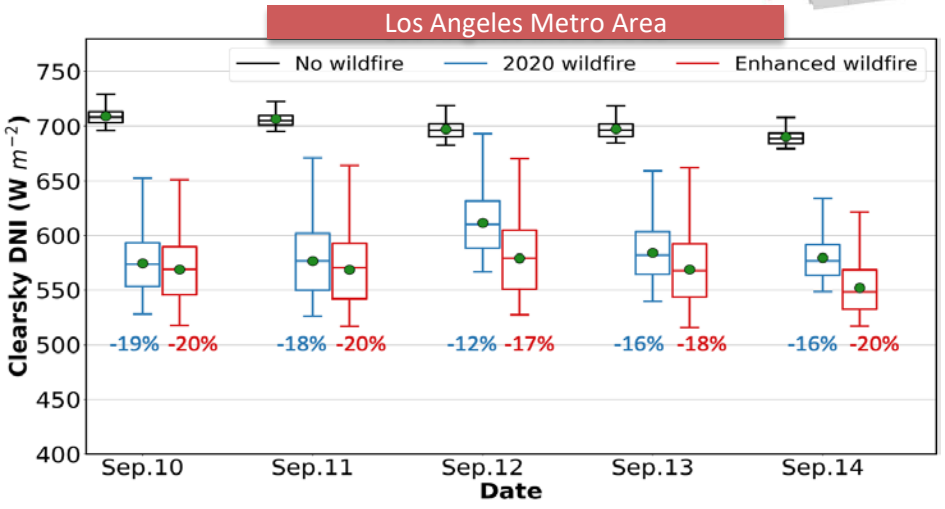
*Month with largest impact

Quantification of enhanced wildfire impact

Focusing on smaller domain and shorted period (daily):

- Compared to no wildfire condition, impact of 2020 wildfire leads to decrease of clearsky DNI by up to 23% (near source) and 19% (downwind)
- Impact of enhanced wildfire activity further intensifies the reduction of clearsky DNI by up to 30% (near source) and 20% (downwind).





*Clearsky DNI is selected within 10 am – 6 pm local time

Conclusions

Summary and future work

- The evaluation results show NSRDB can well capture both AOD and solar radiation during high-fire activity period in 2020.
- Accounting for projected increases in areas burned in California, simulations suggest increases in monthly AOD over California, and more moderate increases in monthly clearsky DNI.
  - Given limited scope, our analysis does not capture full variability (wildfires location, size, time of year, aerosol indirect effects) which can be equally important
- The impact of enhanced fire activity on clearsky DNI could be greater on shorter (daily) timescales and the impacts can significantly vary by region.

Next steps:

- PV generation for different fire scenarios
- Controlled experiments under different scenario (PLEXOS modelling for CAISO/WECC) to assess impacts on generation, operating reserves, and prices.

Thank You

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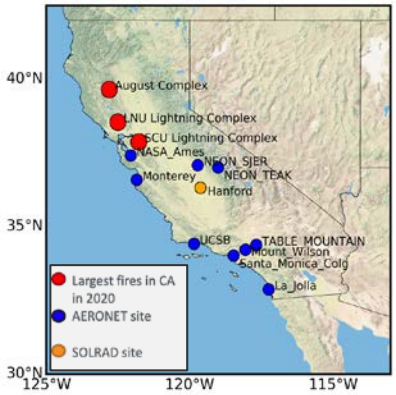
Methodology

Evaluation of NREL NSRDB

- AERONET aerosol optical depth(AOD)
- SOLRAD solar radiation



Creation of AOD datasets

- Three scenarios: **no** / **2020** / **enhanced** wildfire
- Projection of wildfire activity
- WRF-Chem modeling for enhanced wildfire AOD

NSRDB/PSM modeling

- Simulation of solar radiation (global horizontal irradiance (GHI) and direct normal irradiance (DNI)) for three scenarios

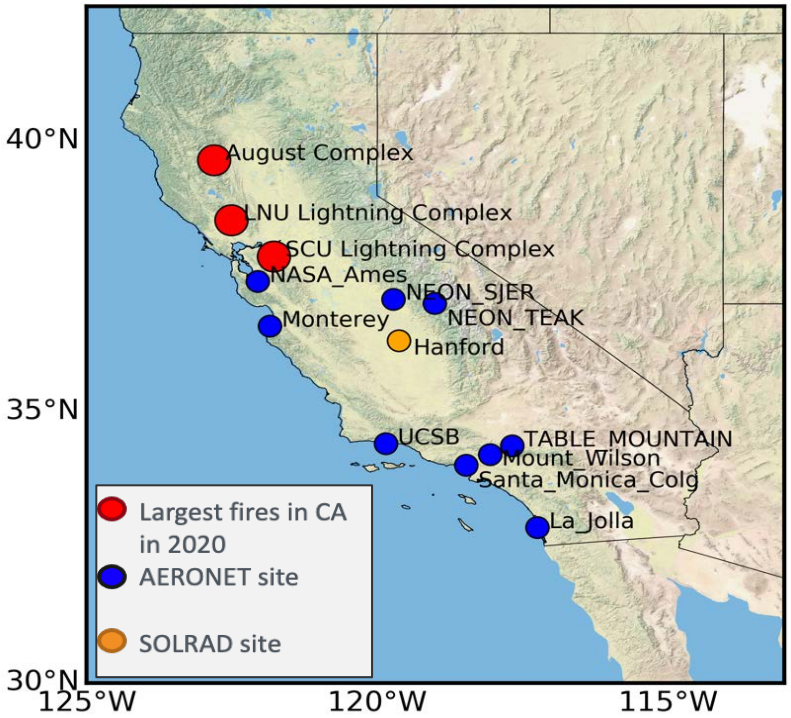
Assessment of wildfire impacts

- Analysis of three controlled numerical experiments

*NSRDB: National Solar Radiation Database
*PSM: Physical solar model

Observational data

- The **AERONET** project is a ground-based remote sensing network for observation of aerosol (Holben et al., 1998).
- NOAA **SOLRAD** Network monitors solar radiation over the U.S. and provides radiance data at 1-minute frequency.
- AOD and solar radiation data during Jul-Oct 2019 and 2020 (low/high-fire-activity period) were used to evaluate NSRDB.



National Solar Radiation Database (NSRDB)

- NREL's NSRDB provides solar radiation data at high spatial (2-km) and temporal (5-min) resolution.
- AOD used to simulate NSRDB is from MERRA-2 aerosol reanalysis product (Molod et al. 2015, Randles et al. 2016) and then the spatial and temporal resolution are downscaled from 0.5° to 2-km and from 1-hour to 5-minute (Sengupta et al., 2018).

NSRDB: https://nsrdb.nrel.gov

- The correlation coefficient (R) of AOD and DNI is about 0.7 and 0.86 during high fire period, indicating NSRDB can well capture the variation of AOD and solar radiation.

Creation of AOD dataset for future scenario

- **Fire emission**: Fire Inventory from NCAR (**FINN**v2.5). Fire counts derived from the MODIS satellite.
- **WRF-Chem** (A fully coupled meteorology-chemistry model):

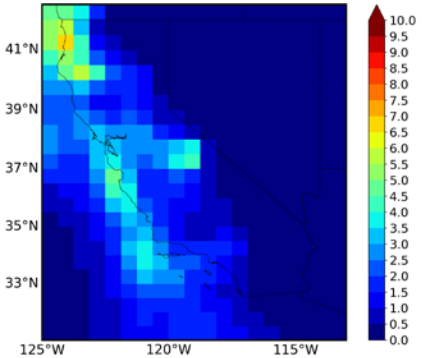
  AOD increment= AOD(enhanced FINN) - AOD(original FINN)
- 2020 AOD + AOD increment = Enhanced wildfire AOD
- Three scenarios (**No wildfire**, **2020 wildfire**, **enhanced wildfire**) were modeled using the Physical Solar Model.

WRF-Chem(v4.0) [Jun-Oct]	
Domain	California (12km)
MET IC/BC	NAM
Chem IC/BC	CAM-Chem
Chemistry	MOZART-GOCART
Anth Em	12-km 2018 NEI
Fire Em	FINN v2.5
Biogenic Em	MEGAN

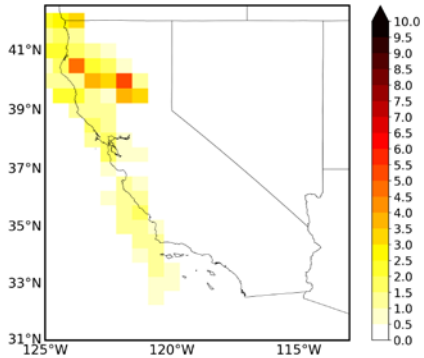
*Em: emission

**Only area burned is intensified, locations and periods of wildfire activity remain the same as the wildfire activity in 2020.

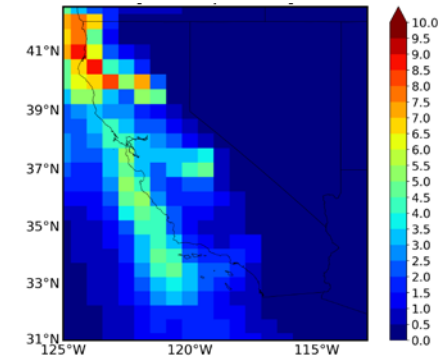
2020 AOD



AOD increment



Enhanced wildfire AOD



Creation of AOD dataset for future scenario

- **Fire emission**: Fire Inventory from NCAR (FINNv2.5). Fire counts derived from the MODIS satellite.
- **WRF-Chem**: A fully coupled meteorology-chemistry model
- AOD increment=
  AOD(enhanced (165%) FINN)-AOD(original FINN)
- 2020 AOD + AOD increment = Enhanced 2020 AOD

WRF-Chem(v4.0) [Jun-Oct]	
Domain	California (12km)
MET IC/BC	NAM
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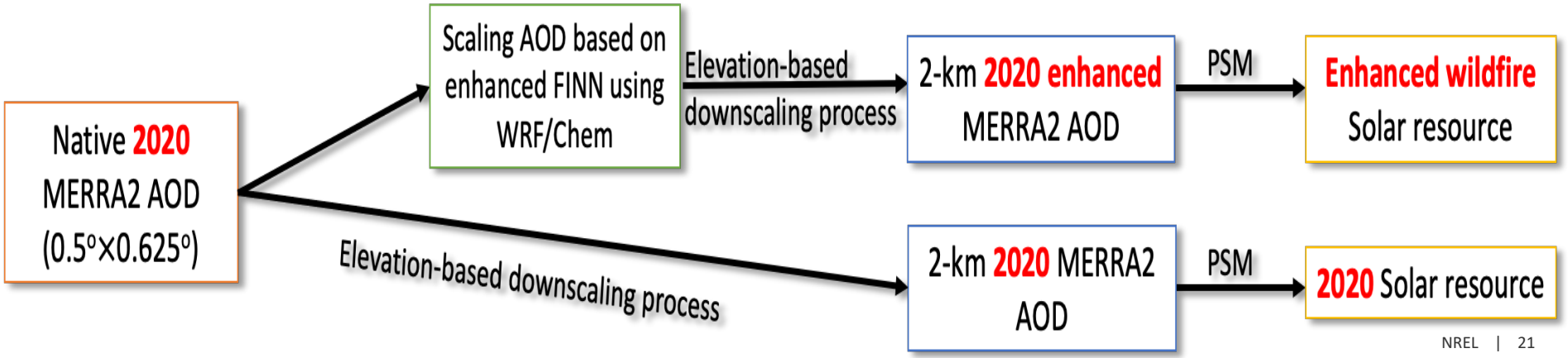

Evaluation of NSRDB

- The correlation coefficient (R) is about 0.7 and 0.86-0.95 during high fire period, indicating NSRDB can well capture the variation of AOD and solar radiation.

	July-October 2019 (low fire activity period)			July-October 2020 (high fire activity period)		
Site	MBE	RMSE	R	MBE	RMSE	R
NASA Ames	-0.01	0.03	0.53	-0.05	0.34	0.78
Monterey	≈0	0.03	0.48	-0.09	0.42	0.78
NEON SJER	0.01	0.06	0.43	-0.06	0.54	0.72
NEON TEAK	0.01	0.03	0.5	-0.01	0.38	0.7
UCSB	0.03	0.04	0.68	-0.06	0.37	0.72
Mount Wilson	0.03	0.04	0.32	≈0	0.51	0.57
Table Mountain	≈0	0.02	0.49	-0.01	0.25	0.64
La Jolla	-0.01	0.04	0.25	-0.07	0.3	0.76
Santa Monica College	-0.01	0.05	0.44	0.04	0.37	0.72
Average	0.01	0.04	0.46	-0.03	0.39	0.71

July-October 2019 (low fire activity period)					
Variable	MBE ($W\ m^{-2}$)	RMSE ($W\ m^{-2}$)	R	Average (SOLRAD)	Averaged (NSRDB)
GHI ($W\ m^{-2}$)	11.2	50.7	0.99	524	535
DNI ($W\ m^{-2}$)	14.0	107.4	0.95	558	572
July-October 2020 (high fire activity period)					
Variable	MBE ($W\ m^{-2}$)	RMSE ($W\ m^{-2}$)	R	Average (SOLRAD)	Averaged (NSRDB)
GHI ($W\ m^{-2}$)	3.1	91.9	0.95	494	497
DNI ($W\ m^{-2}$)	-6.5	172.2	0.86	481	475