Multiscale Convection-Permitting Wildfire Simulation over California: 2020 Creek Fire

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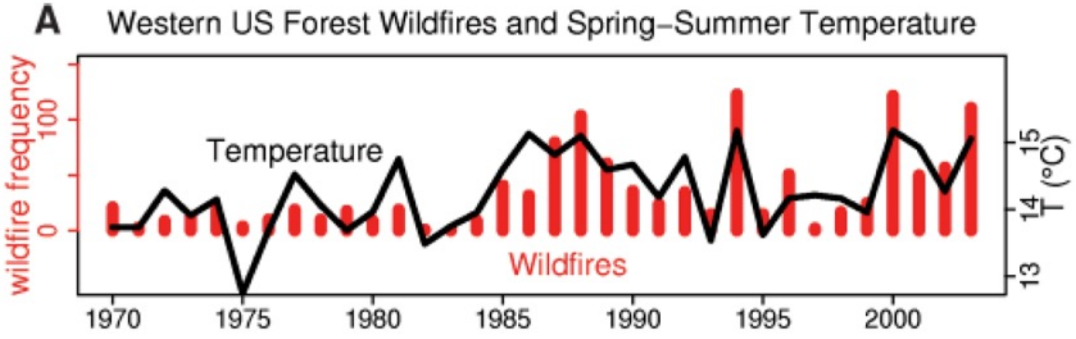
Large Wildfires are increasing in the western US over recent decades

Warming and Earlier Spring Increase Western U.S. Forest Wildfire Activity

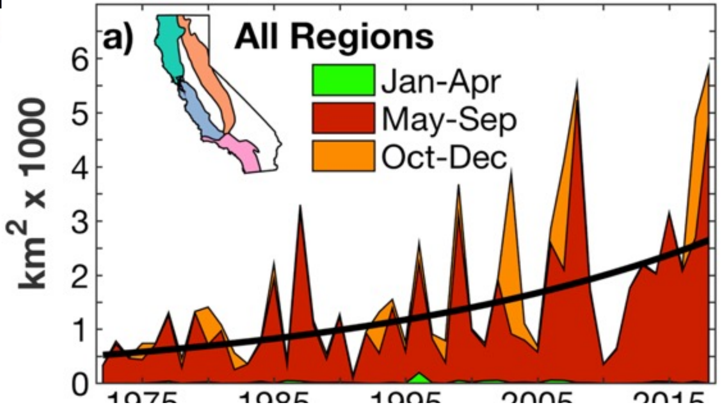
A. L. Westerling,[1,2*] H. G. Hidalgo,[1] D. R. Cayan,[1,3] T. W. Swetnam[4]



Greater frequency

Observed Impacts of Anthropogenic Climate Change on Wildfire in California

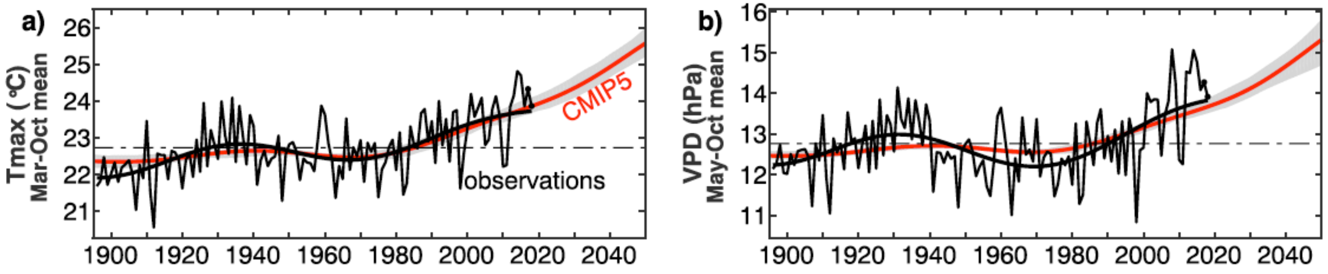
A. Park Williams[1], John T. Abatzoglou[2], Alexander Gershunov[3],
Janin Guzman
and Dennis P.



Greater area (intensity)

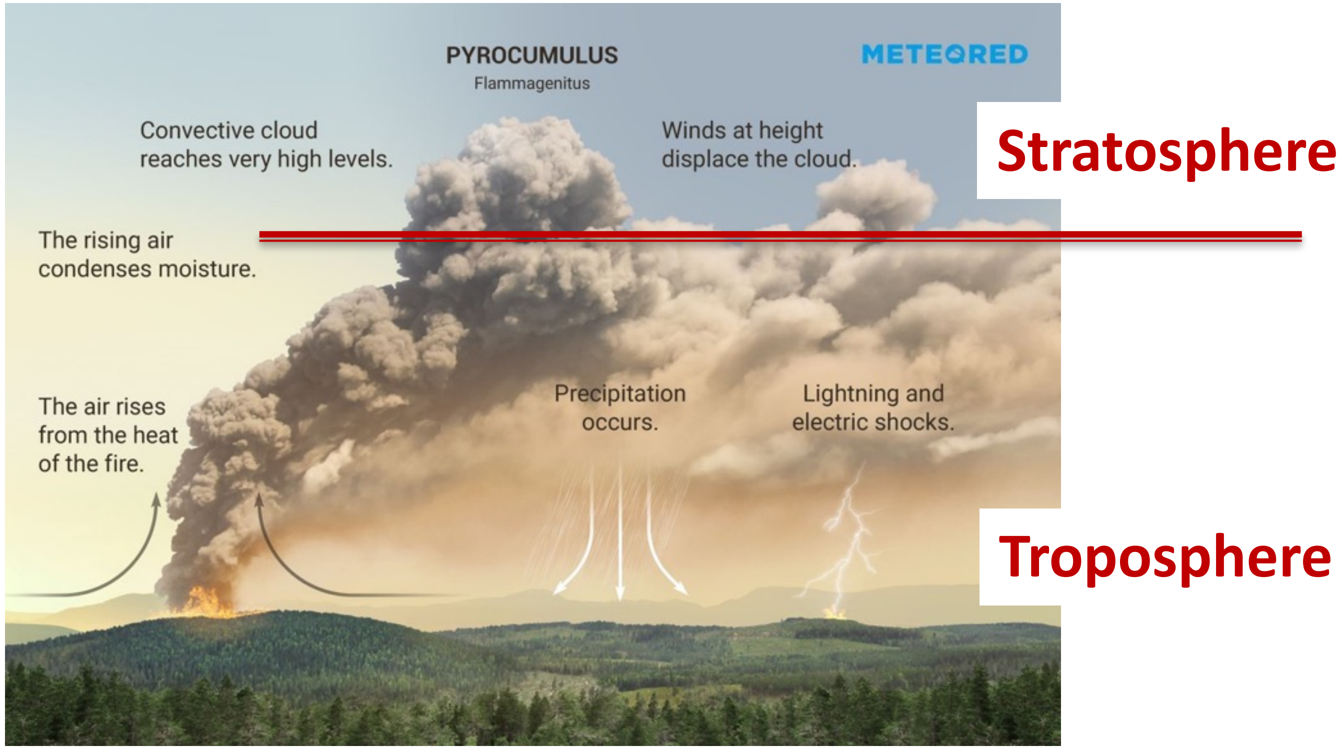
2020 California wildfire season was worst-ever of the modern era ($12B damages).

Projected: more & more

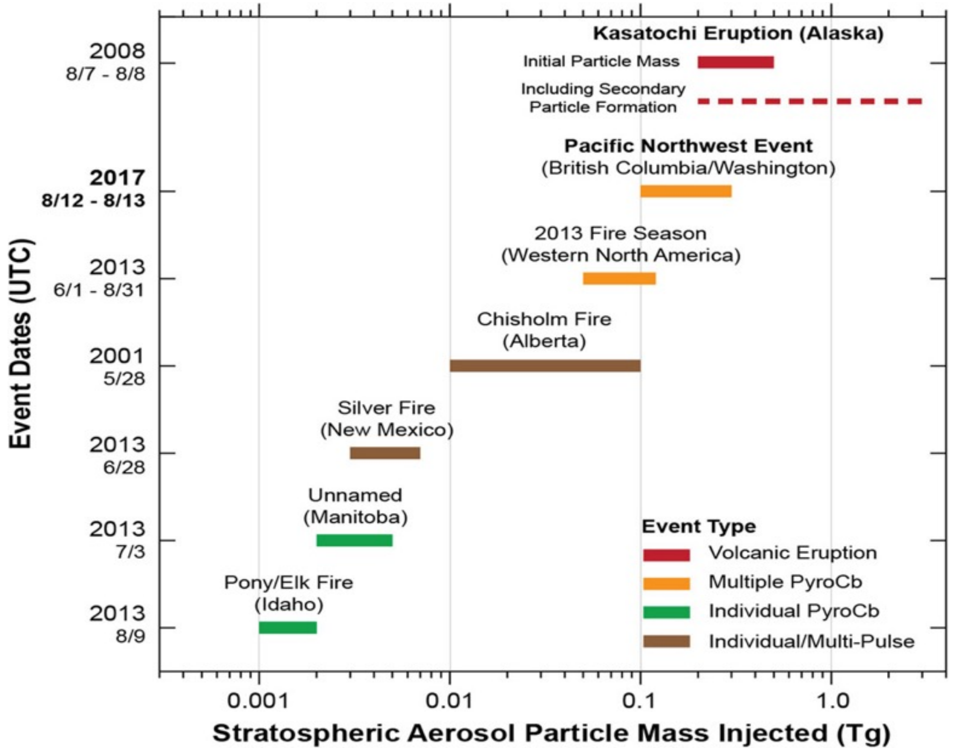


Wildfire-driven thunderstorms pump smoke into the stratosphere

Pyrocumulonimbus (PyroCb)



Aerosol Mass (Tg) injected into the stratosphere from Wildfires and Volcanoes



- Fire smoke enters the stratosphere by **PyroCb convection** or **self-lofting**
- Smoke absorbs & reflects sunlight = long-time **negative radiative forcing (RF)**
- Aerosols = heterogeneous chemistry = stratospheric **O_3 depletion & UV-B increase**

Multiscale framework for large wildfires

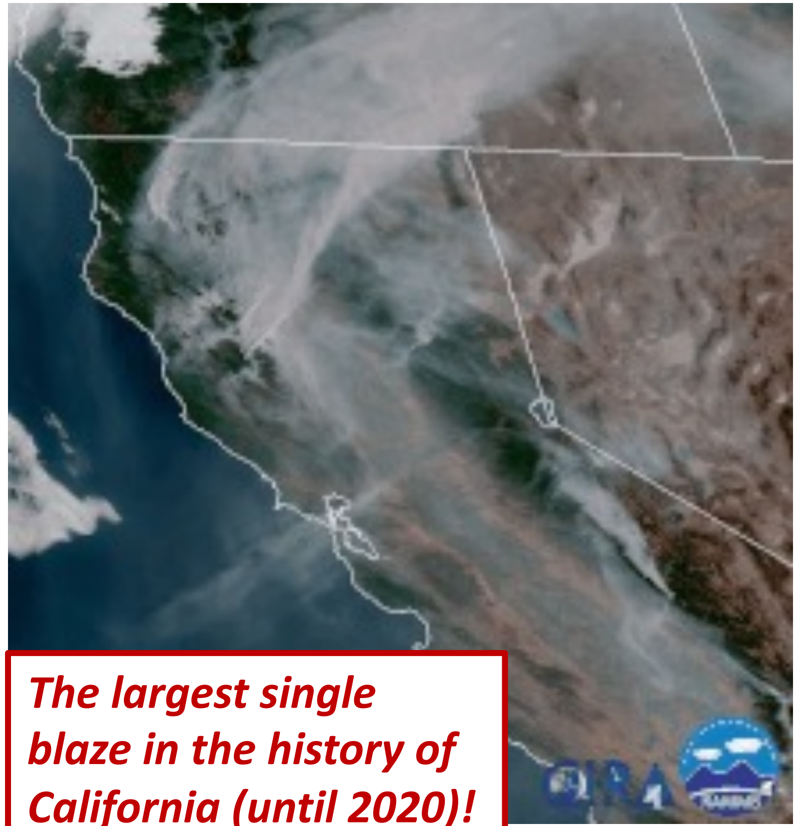
- pyrocumulonimbus cloud
- weakness in global climate models (GCMs):
  - O(100) km is too coarse for local processes in the source region after wildfire emissions
  - missing physics (e.g., chemical-aerosol interactions) in global convection-permitting models (i.e, O(0-5) km)

3km Regional Refinement Model (RRM)

Interactive chemistry (chemUCI+Linoz v3)

WRF-SFIRE HRRR

** GCM with the fineset resolution achieved 3 km & feasible for climate-length simulations*



The largest single blaze in the history of California (until 2020)!

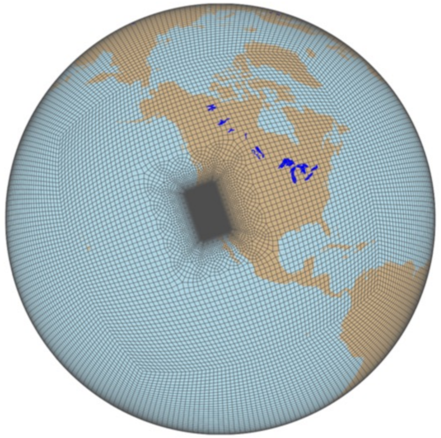
In *Wikipedia*.

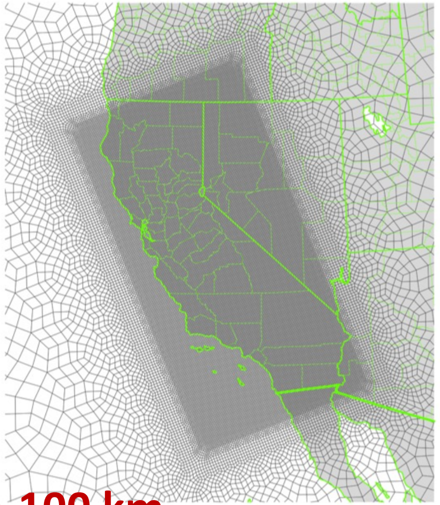
Creek Fire 2020 CA

- 14 km pyrocumulonimbus
- duration: 1 month (active > 50%)
- Area: 290,000 acres (1,200 km^2)

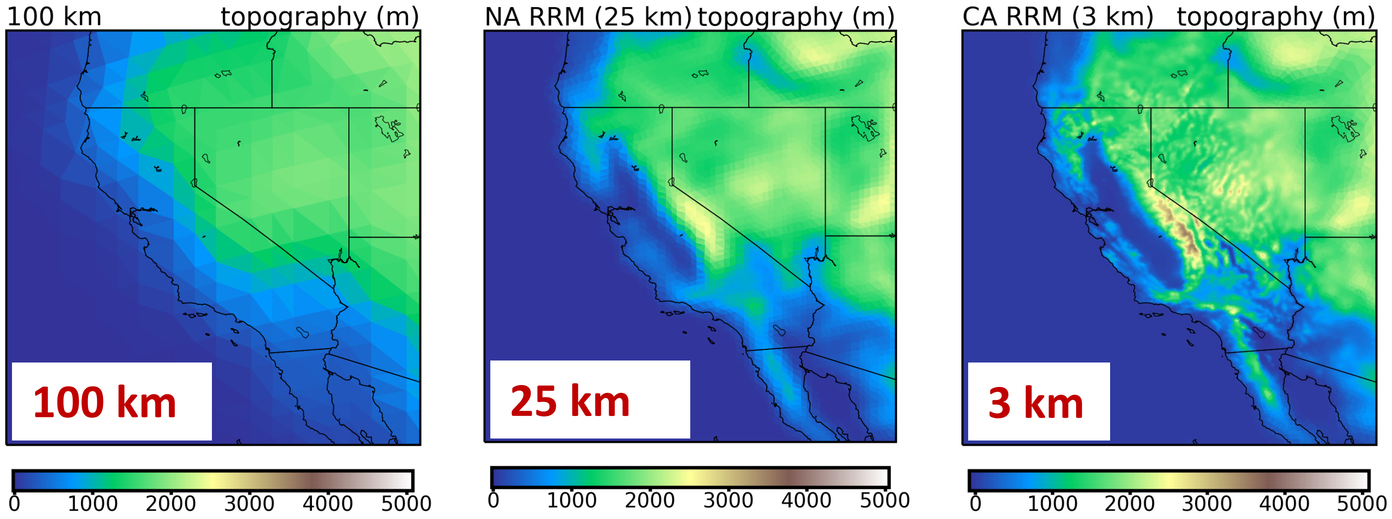
EAMv2 3km CARRM

- EAMv2 = Energy Exascale Earth System Model, atmosphere model version 2 (100 km) (Golaz et al, 2022)
- RRM = Regionally Refined Model (Tang et al. 2019, 2023)
- CP = Convection-Permitting (1-5 km) SCREAM (Caldwell et al, 2021)
  - v1: dx = 3 km over Califormia and 1° resolution covering the remainder of the globe





CARRM: 3 -> 100 km

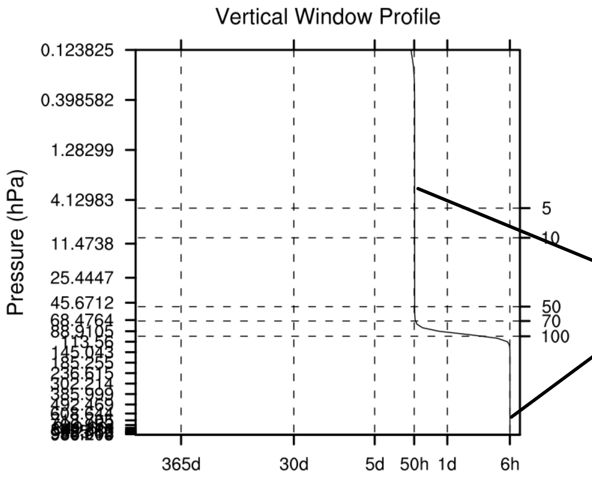


CARRM: efficient configuration

- Global CP models are too expensive
  - the global 3 km SCREAM simulation using NERSC Cori KNL 68-core 1536 nodes has a total throughput of about 4-5 simulation days per day (SDPD)
- Small enough high-res domain so that climate length simulations can be performed
  - 0.68 simulation years per day (240 SDPD) using LC quartz Intel(R) Xeon(R) 36-core 120 nodes

Model	Element	Physics Column	Dynamics Timesteps
SCREAM (global 3km)	6,291,456	25,165,824	9.375
CARRM (CA 3km)	16,968	67,872	9.375
NARRM (CONUS+ 25km)	14,454	57,816	75

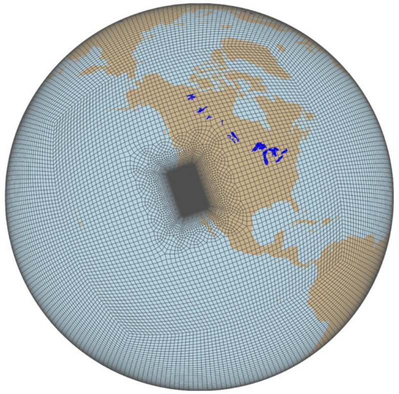
CARRM nudging strategy focusing on strat aerosol

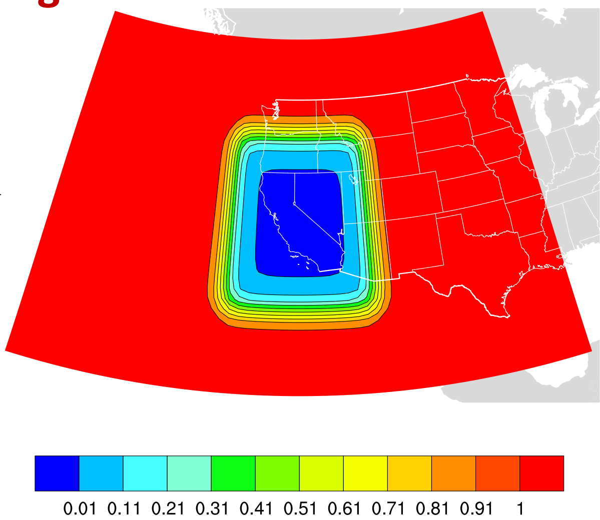


UV50h6hL: nudging towards ERA5 winds with 50h-strato and 6h-tropo timescale

- “U” – stratosphere (< 100 hP)
- “L” – troposphere (> 100 hPa)

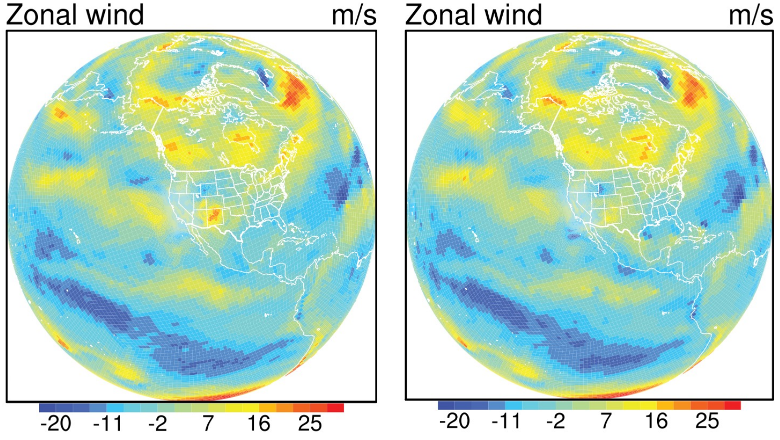
nudging window



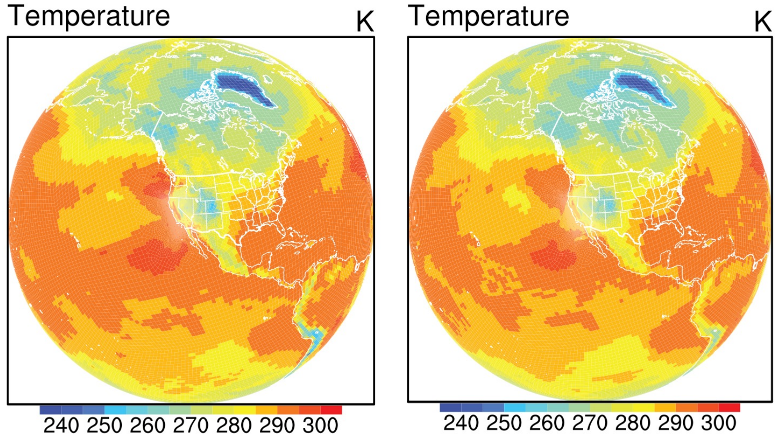


* deep_conv is turned off globally

zonal wind **ERA5** **UVT50hU6hL (WiOC)**



temperatrue **ERA5** **UVT50hU6hL (WiOC)**



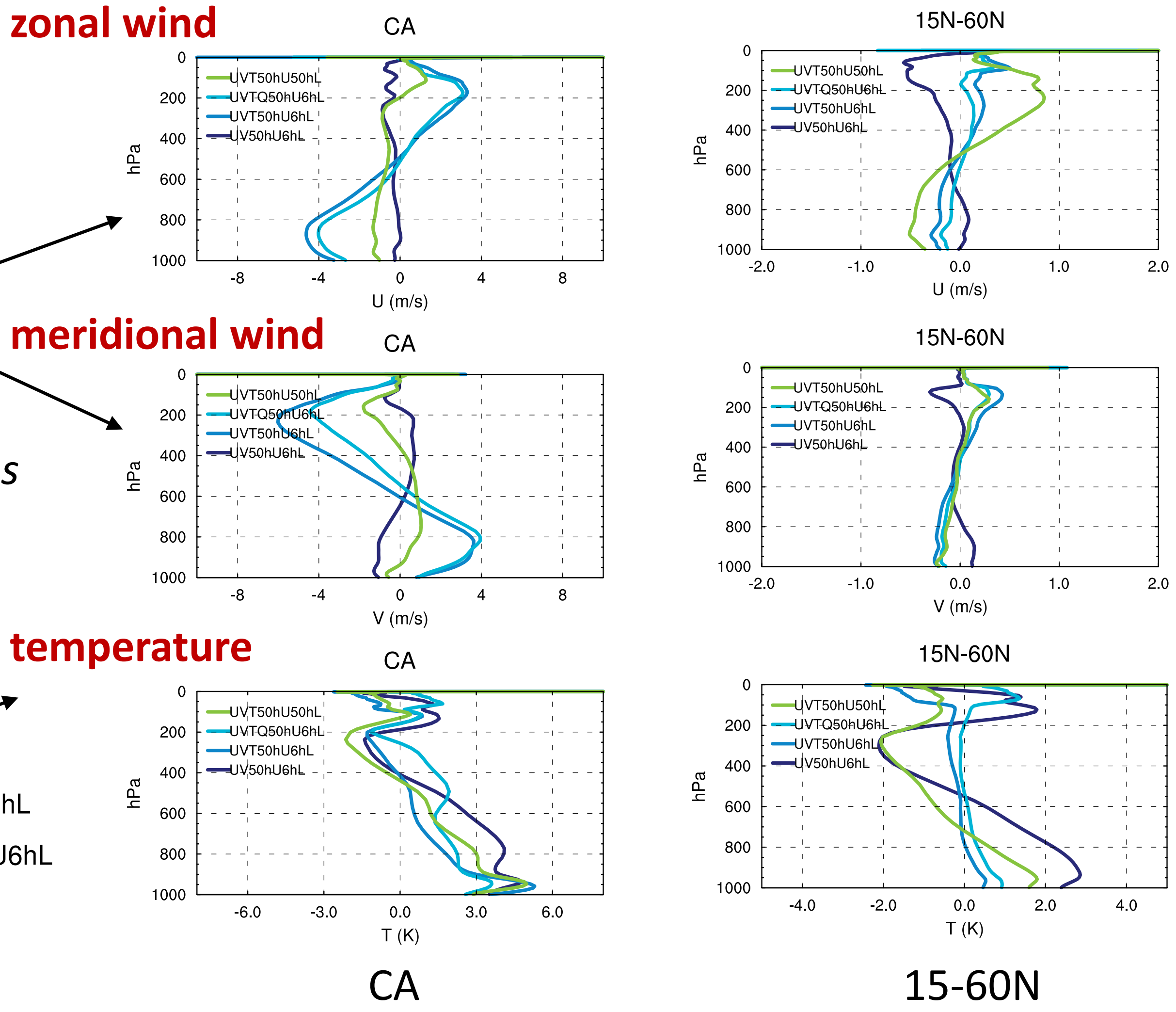
CARRM nudging sensitivities

- nudging timescales, components

wind-only nudging UV50hU6hL
gives better wind profile over CA

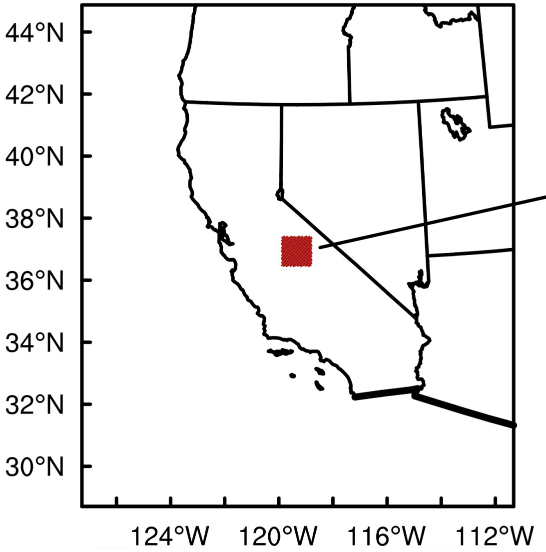
** important for certain research objectives (e.g., BC-heating studies)*

temperature-nudging UVT50hU6hL UVTQ50hU6hL
gives more realistic thermodynamic conditions



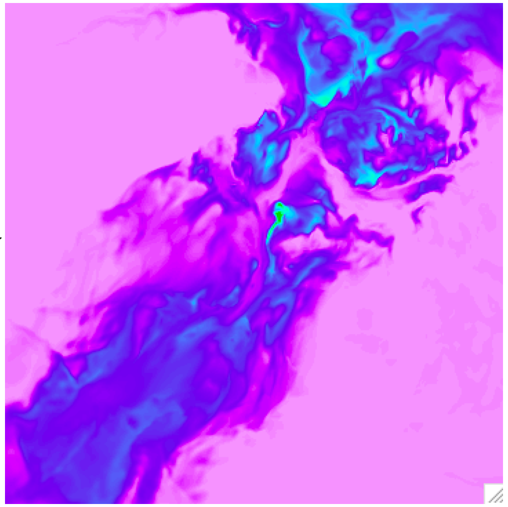
WRF-SFIRE smoke as initial condiations

- WRF-CHEM-SFIRE (William Lassman) ⟶ BC after 5 days



total smoke mass:

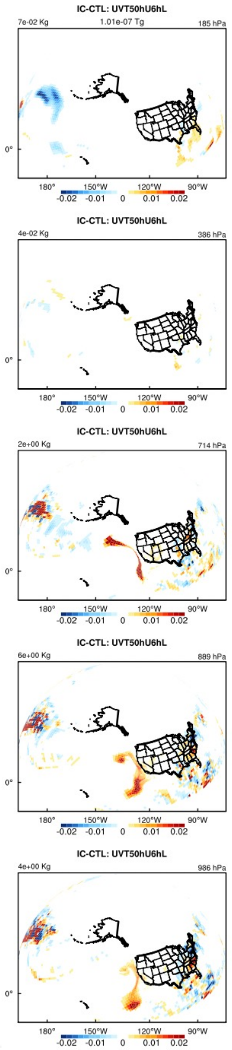
0.013 Tg



WRF box ~ 1x1 deg horizontal resolution: 300m x 300m

Creek fire: 0.06 Tg *(*Yang Chen, GFED5)*

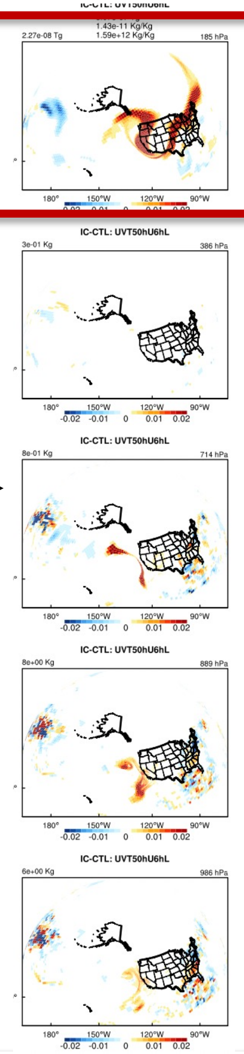
WRF (0.013 Tg)



too weak BC pump to the stratosphere ⟶

+ prescribed smoke Injection at high level

WRF+0.3Tg at 185 hPa



185 hPa

386 hPa

714 hPa

889 hPa

986 hPa

cb:
-0.2 – 0.2 ppbm

Height-time evolution of BC, OC

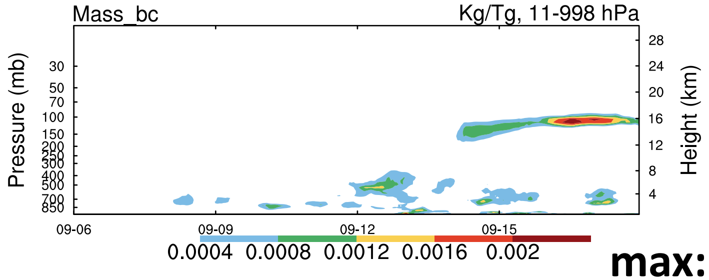
- WRF-CHEM-SFIRE

Black Carbon

Organic Carbon

BC

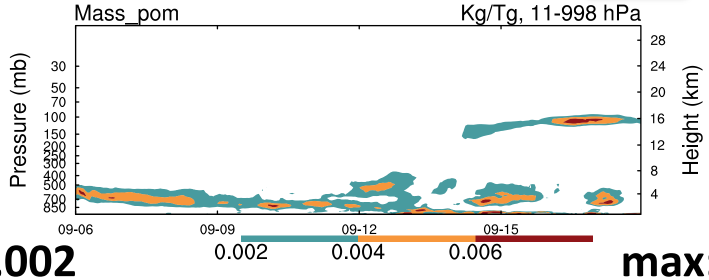
UVT50hU6hL: WRF vs. CTL



max: 0.002

OC

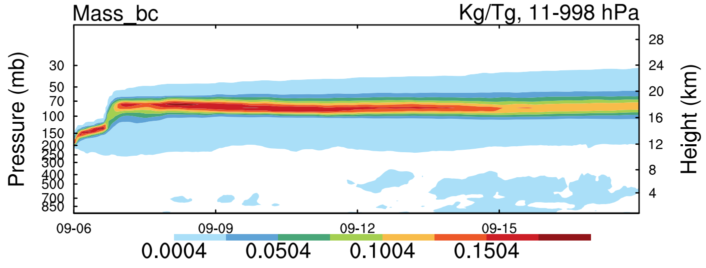
UVT50hU6hL: WRF vs. CTL



max: 0.06

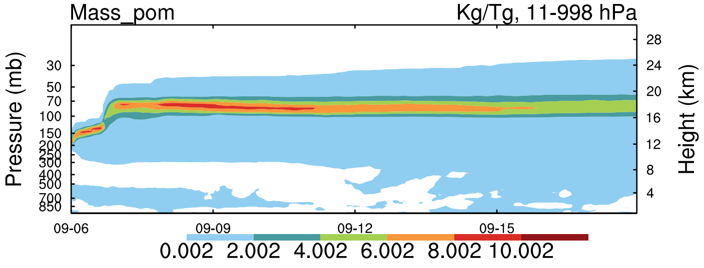
CARRM + WRF-CHEM-SFIRE

UVT50hU6hL: WRF+0.3Tg vs. CTL



max: 0.1504

UVT50hU6hL: WRF+0.3Tg vs. CTL



max: 10.002

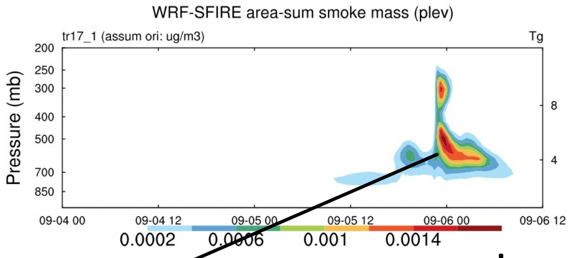
CARRM + WRF-CHEM-SFIRE+0.3Tg at 185 hPa

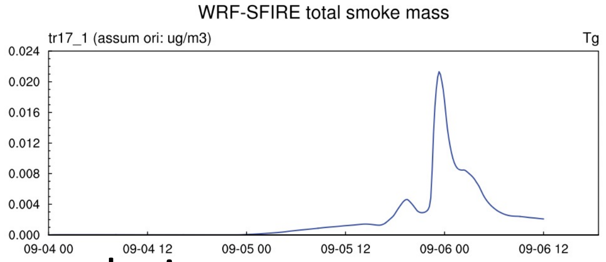
** all for IC–CTL (box: 15N-60N)*

Height-time evolution of BC, OC

- Why smoke pumping is so weak? Inadequate fuel loading? =>WRF-SFIRE (Jungmin Lee)

  ** area averaged fuel mass loading X2 larger than the WRF-CHEM-SFIRE run*





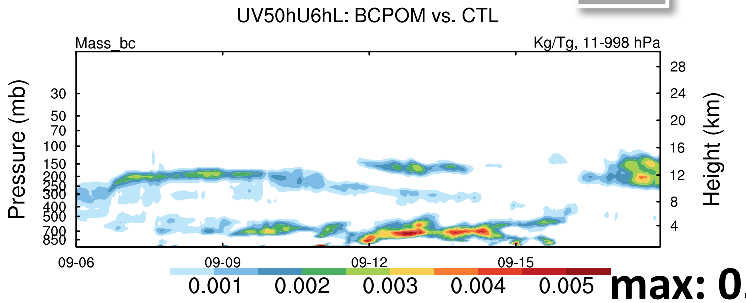
smoke mass evolution

BC

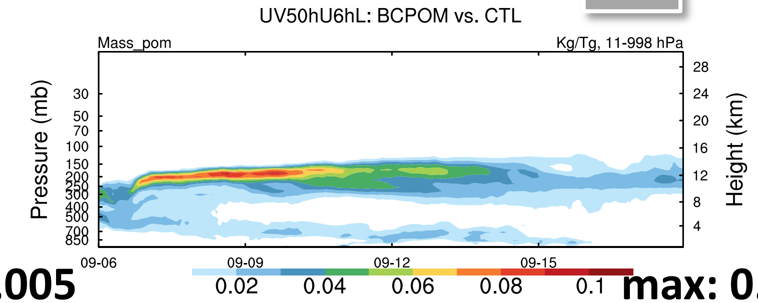
OC

total smoke mass:

0.021 Tg

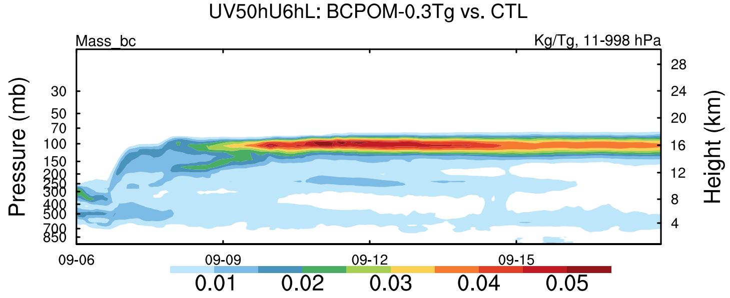


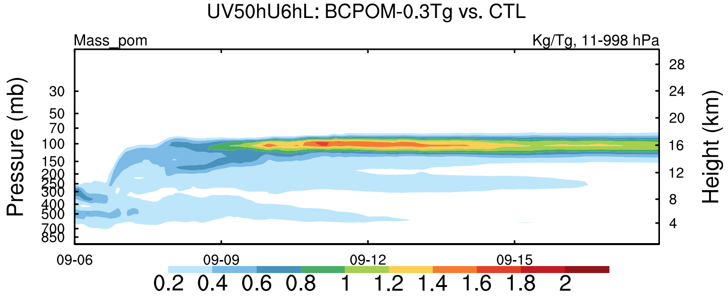
max: 0.005



max: 0.1

CARRM + WRF-SFIRE





CARRM + WRF-SFIRE+0.3Tg

** all for IC–CTL (box: 15N-60N)*

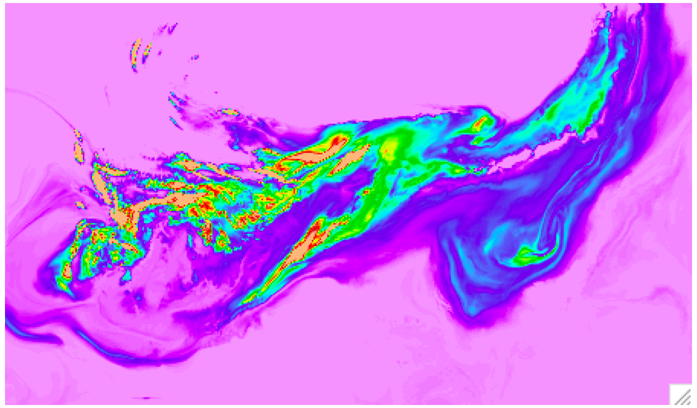
HRRR-smoke as initial condiations

- Why smoke pumping is still too weak? Will fire radiative power helps?

HRRR vs. WRF-SFIRE simulations:

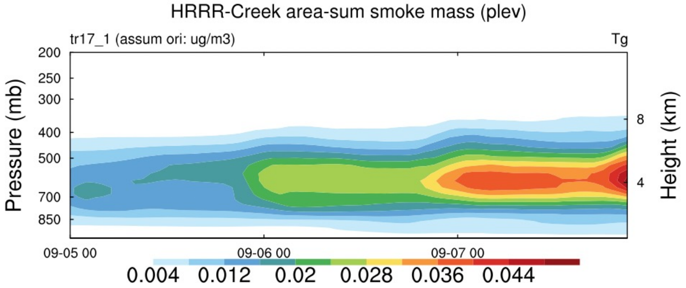
- domain: **CONUS** vs. tiny box in CA
- resoluation: 3km vs. 300m
- HRRR: plume injection height using fire size and heat flux determined by **fire radiative power** (FRP) data

The High-Resolution Rapid Refresh (HRRR) - Smoke

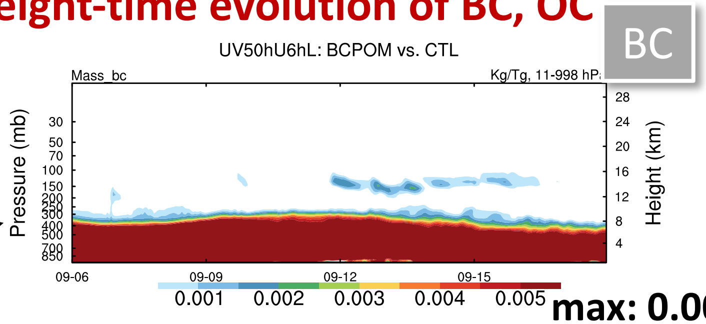


** Provided by Eric James from NOAA*

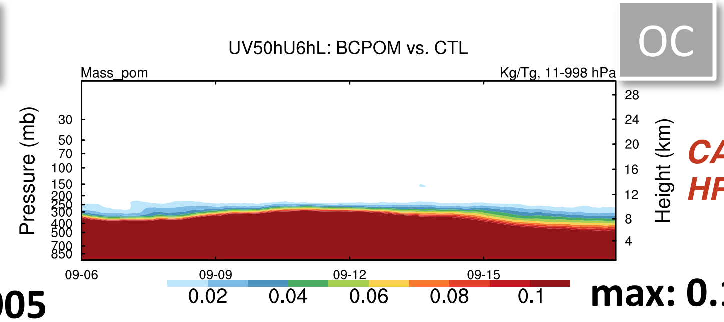
Smoke mass evolution



Height-time evolution of BC, OC



max: 0.005



CARRM + HRRR

max: 0.1

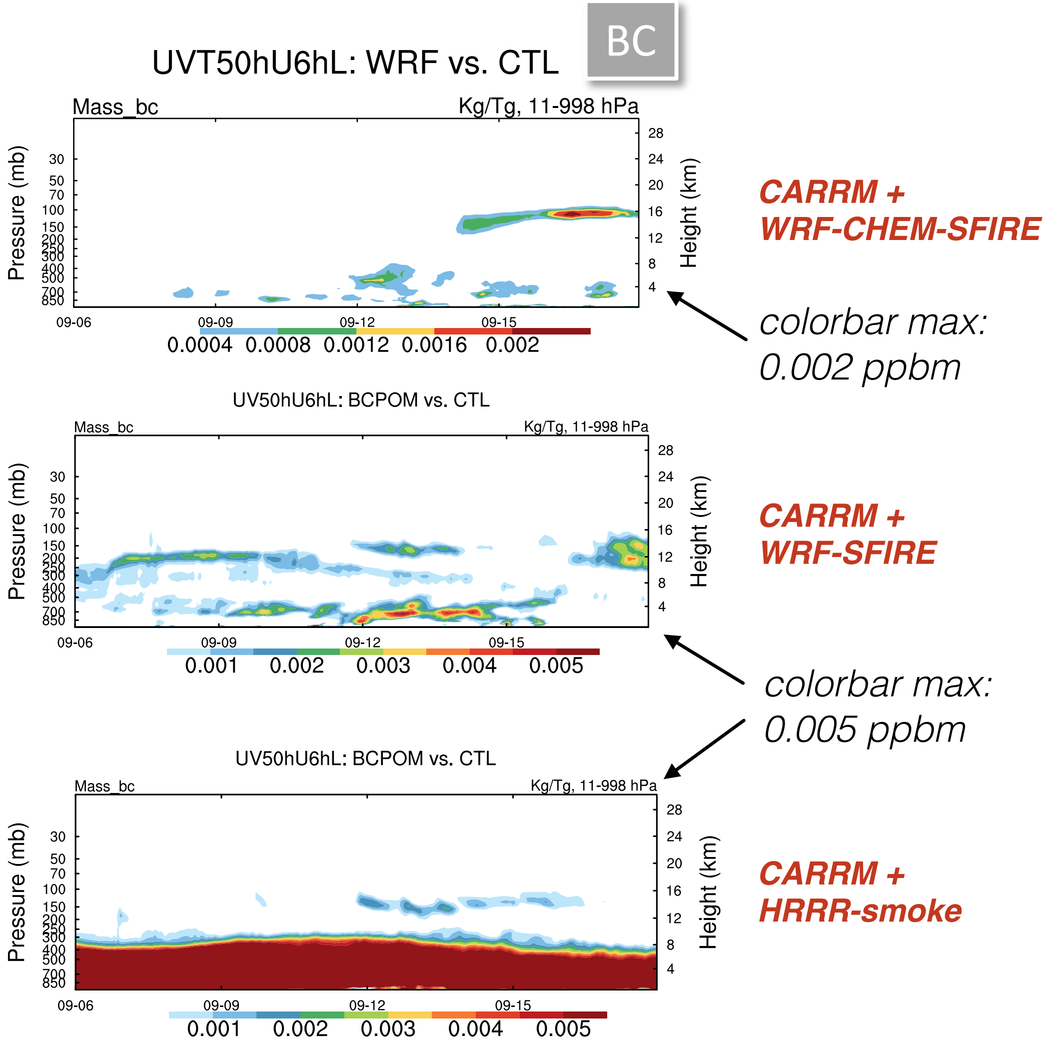
- The plume injection height are lower than that of WRF-SFIRE

Comparison of smoke burden

- WRF-CHEM-SFIRE
- WRF-SFIRE
- HRRR-smoke

initial input	total smoke mass over the same WRF domain (Tg)
WRF-CHEM-SFIRE (Wi)	0.013
WRF-SFIRE (JM)	0.021 *
HRRR-smoke	0.017

- HRRR simulation suggests that the key is not the **smoke amount** but the **smoke injection height** (been quantified in Lee et al., 2023).

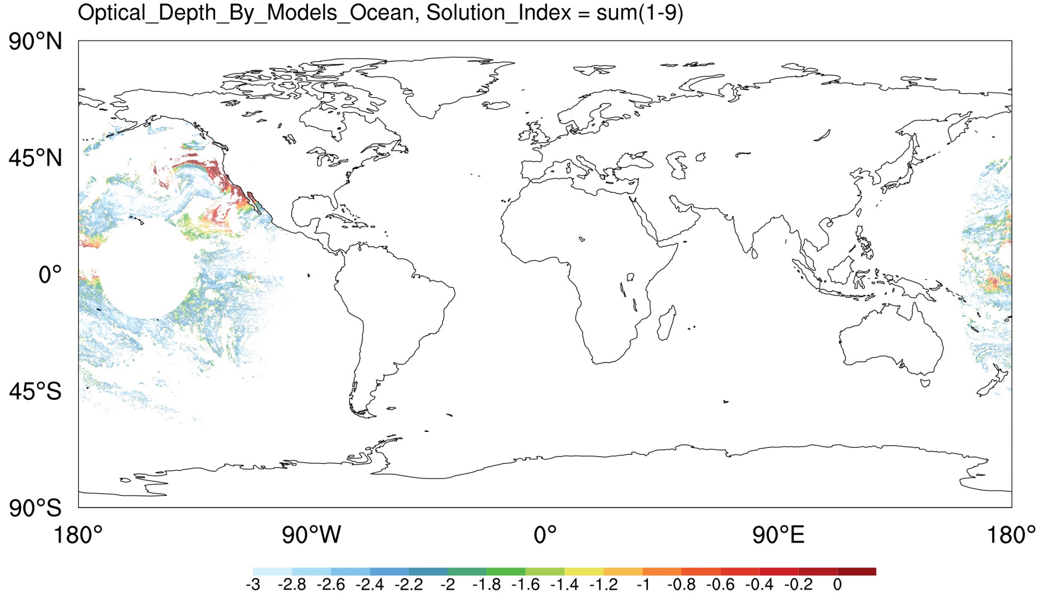


** note HRRR has a much bigger domain*

Comparison with NASA GOES-R ABI AOD

- high frequency: 10 min

2020-09-11 1730-2330

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Retrieved AOT (at 0.55 micron) partioned by mode
index (for Best solution)
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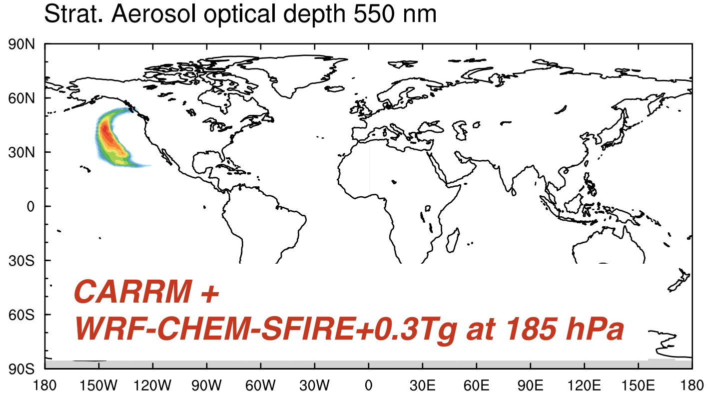
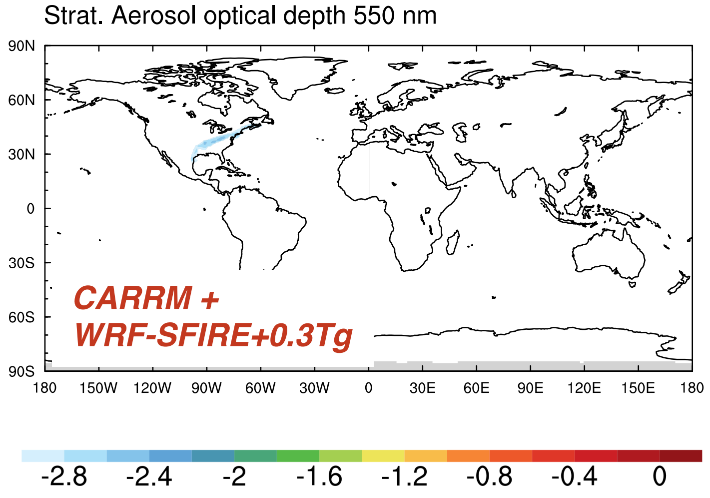
** Provided by YingXi Shi in NASA*

UVT50hU6hL (WiOC-0.3Tg)



0.3Tg added at 185 hPa

UV50hU6hL (JMOC-0.3Tg)



- The smoke injection height is crucial

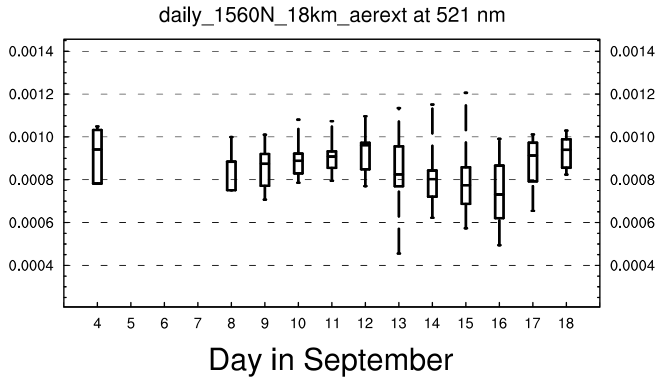
0.3Tg added by scaled with the vertical distribution of WRF-smoke

** 2020-09-11*

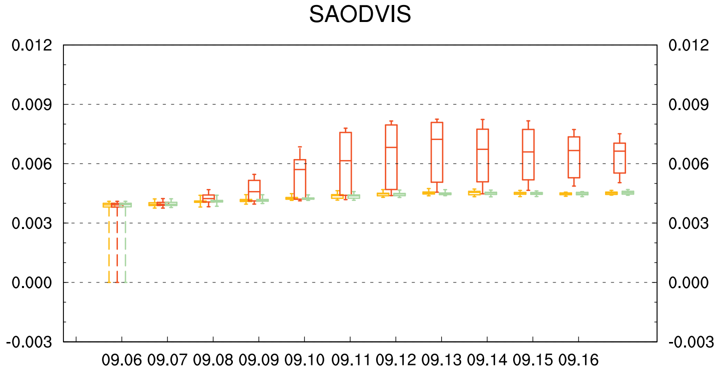
Comparison with SAGE III-ISS

- Stratospheric aerosol extinction coefficient
- Stratospheric AOD

SAGE-III 18 km aerext



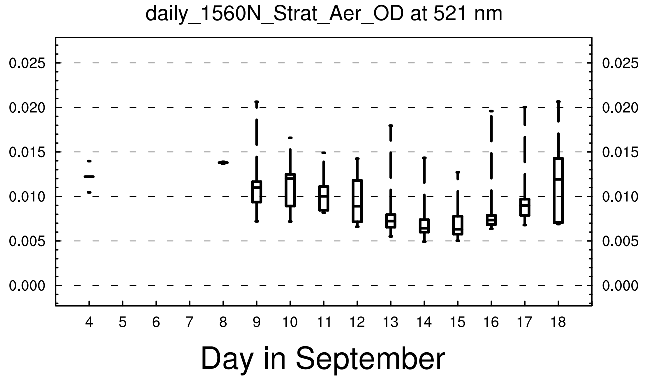
CARRM simulated SAODVIS



** note the sampling process are different:*

hourly 15-60N mean vs. *hourly data points within 15-60N*

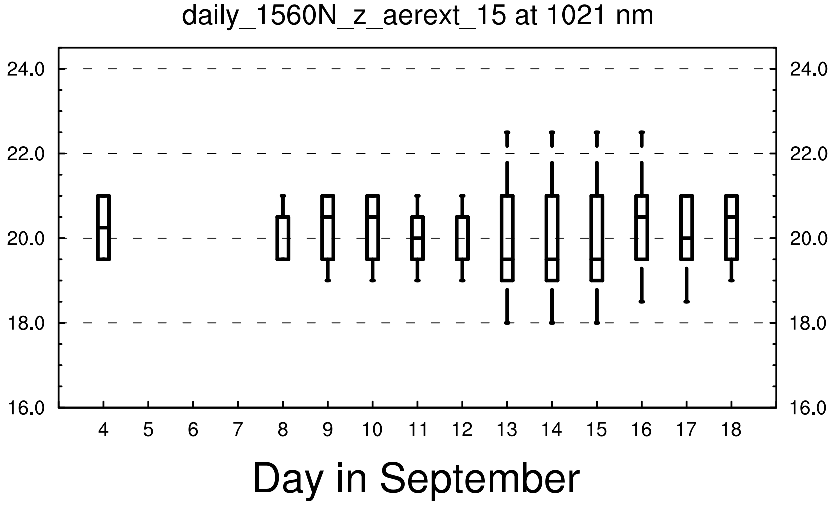
SAGE-III SAOD 521 nm

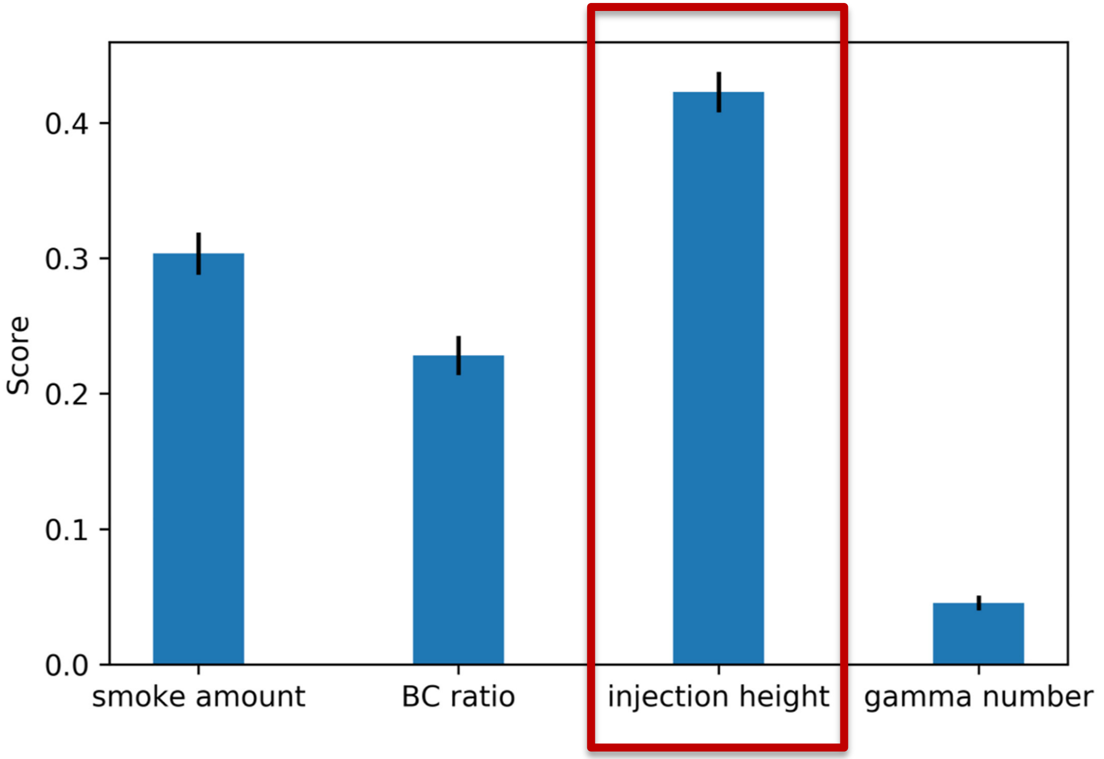


- the simulated SAODVIS using the default smoke amount in WRF-SFIRE/HRRR are 2-3X smaller than SAGE-III SAOD at 521 nm
- WRF-SFIRE-0.3Tg is comparable to SAGE-III

Maximum plume rise height

- SAGE III-ISS solar L2 v5.2: height with aerosol extinction coefficient > 1.5 x 10-4 km-1
- CALIOP L2 v4.21: pressure with aerosol backscatter coefficient at 532 nm > 3 x 10-4 km-1 sr-1





The random forest ML technique quantify the relative importance of each parameter (Lee et al. 2023).

Summary and future work

- This framework enables us to capture large wildfires and explore its climate impacts from the high-resolution source region.
- Implementing smoke initial conditions from WRF/HRRR still cannot pump enough smoke into stratosphere, suggesting for better representation of plume rise process.
- Future work:
  - Improve aerosol scheme to include brown carbon (Ziming Ke, implementation finished)
  - Implement a plume rise parameterization to include the satellite fire radiative power (Ziming Ke and collaborators in UC Irvine)

Lawrence Livermore National Laboratory