EARTH SCIENCE
APPLIED SCIENCES

HEALTH & AIR QUALITY

Improving Air Quality State Implementation Plans (SIPs) using Land Surface Remote Sensing

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PennState
pennsylvania DEPARTMENT OF ENVIRONMENTAL PROTECTION
CALIFORNIA AIR RESOURCES BOARD
PRINCETON UNIVERSITY

Introduction

SIPs and ABL properties

- Simulation of the **atmospheric boundary layer (ABL)** is central to meteorological and air quality modeling and therefore is critically important for the development of a high-quality **state implementation plan (SIP)**.
- The properties of the ABL are tightly coupled with the land surface, and fluxes of energy, radiation and momentum at the land surface (Figure 1 - red subset).

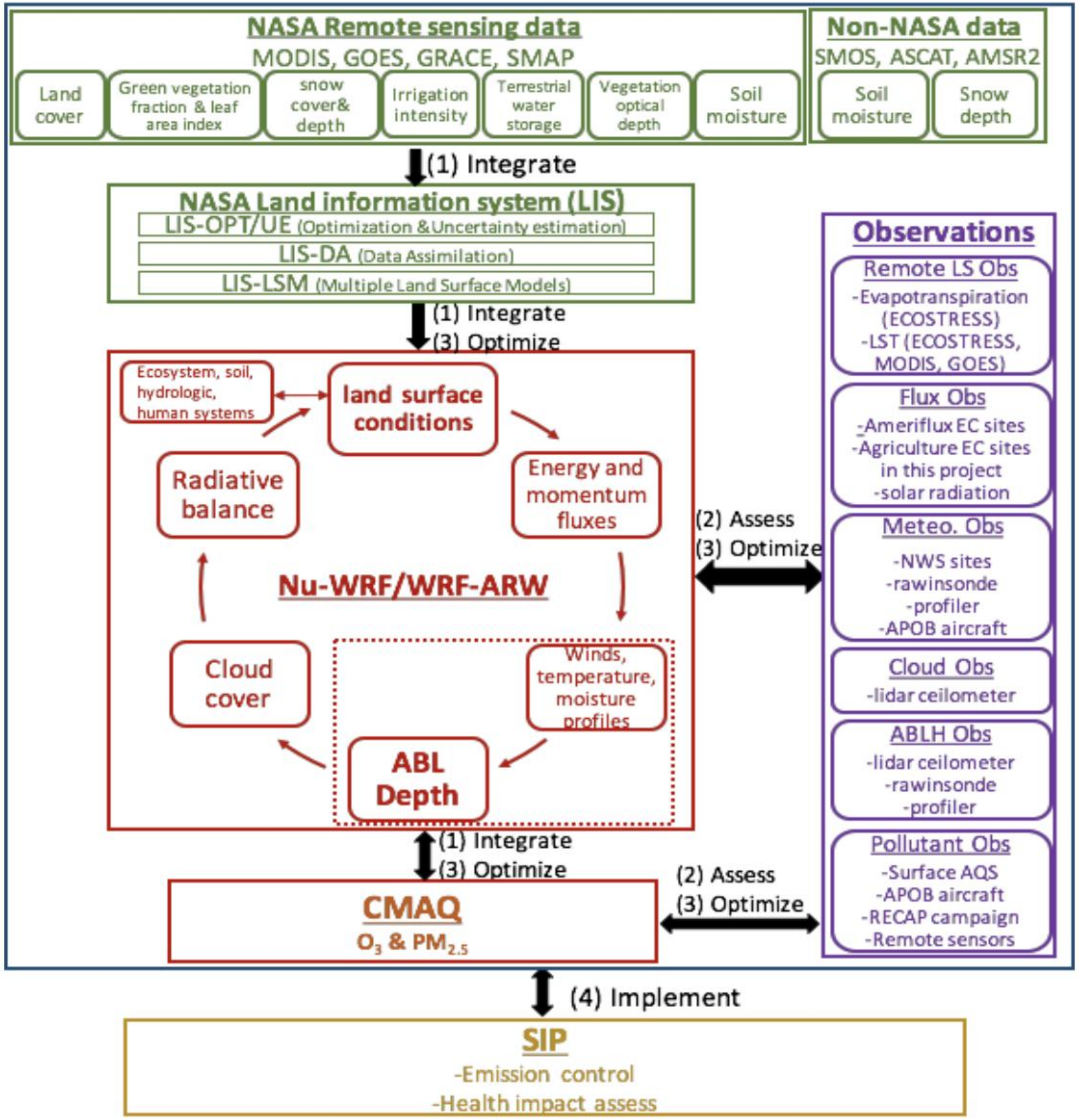
What's a State Implementation Plan (SIP)?

1. Plan to reduce pollution to "get under" EPA pollution limits.
2. State simulates meteorology for a region.
3. State then adds in estimated pollutant emissions and air chemistry to simulate pollution levels.
4. State then experiments with "emissions reductions" in the model…develops an emissions reduction plan that will put the region back into compliance.
5. This plan is the SIP - and is submitted to EPA for approval. Then implemented.

Figure 1. Conceptual map of the proposed research

Red subset: ABL properties

- "wheel of interaction": the coupled land surface - boundary layer system



Introduction

CA and PA

California and Pennsylvania are two states whose SIP modeling systems could benefit substantially from the use of the NASA LIS / NU-WRF system.

- San Joaquin Valley (SJV),
- Allegheny County (Pittsburgh),
- Lancaster/Philadelphia,

all likely or existing air quality violation areas that will require SIPs

SJV ABL modeling challenge

Simulated atmospheric mixing depth is highly dependent on the choice of land surface model in the San Joaquin Valley.

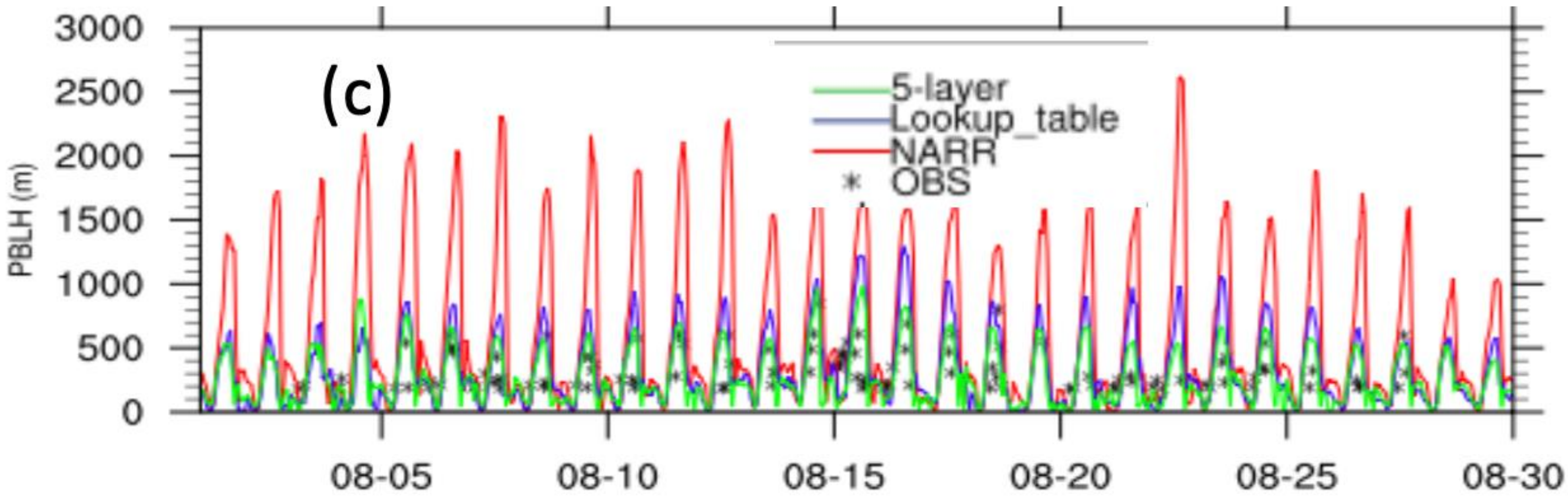


Figure 2: Simulated and observed August (x-axis shows month and day of the month) (a) 2-m temperature; (b) 2-m relative humidity in Fresno (southern SJV); and (c) planetary boundary layer height (PBLH) at a site in Visalia (also southern SJV), from three WRF simulations. "5_layer" denotes the 5-layer TD LSM driven by lookup table soil moisture; "NARR" denotes the PX LSM driven by soil moisture from NLDAS-2; "lookup_table" denotes the PX LSM initialized by the default soil moisture lookup table. The PBLH at Visalia is derived from a radar wind profiler.

Introduction

ABL properties and NASA Unified WRF (NuWRF) and LIS

- Increasingly sophisticated and detailed observations of the earth's land surface are being used to inform these land surface models (LSMs).
- Many of these observations are obtained from space-based platforms .
- Many of these space-based land surface observations have been integrated into **NASA's Land Information System (LIS**, Kumar et al, 2006; Peters-Lidard et al, 2007; Arsenault et al, 2018). (Figure 1 - green subset).
- This land information system can improve surface fluxes, thus atmospheric boundary layer (ABL) simulations when integrated into a **numerical weather model (NuWRF/LIS)**.

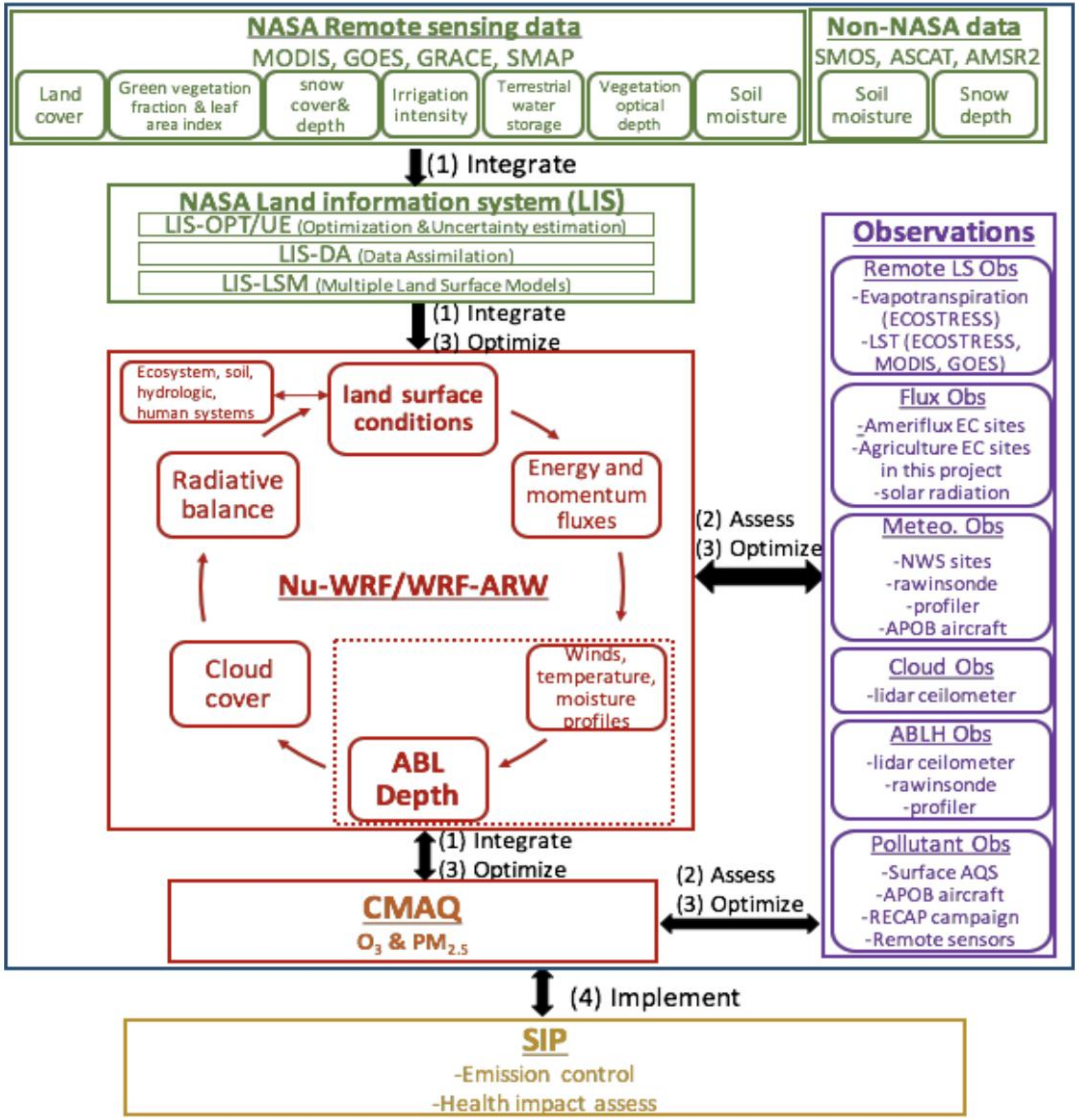
Figure 1. Conceptual map of the proposed research

Green subset: NASA LIS

- Remote sensing observations integrated into NASA LIS

Red subset: includes NuWRF/LIS

Purple subset: observations used to evaluate the modeling systems



Objectives

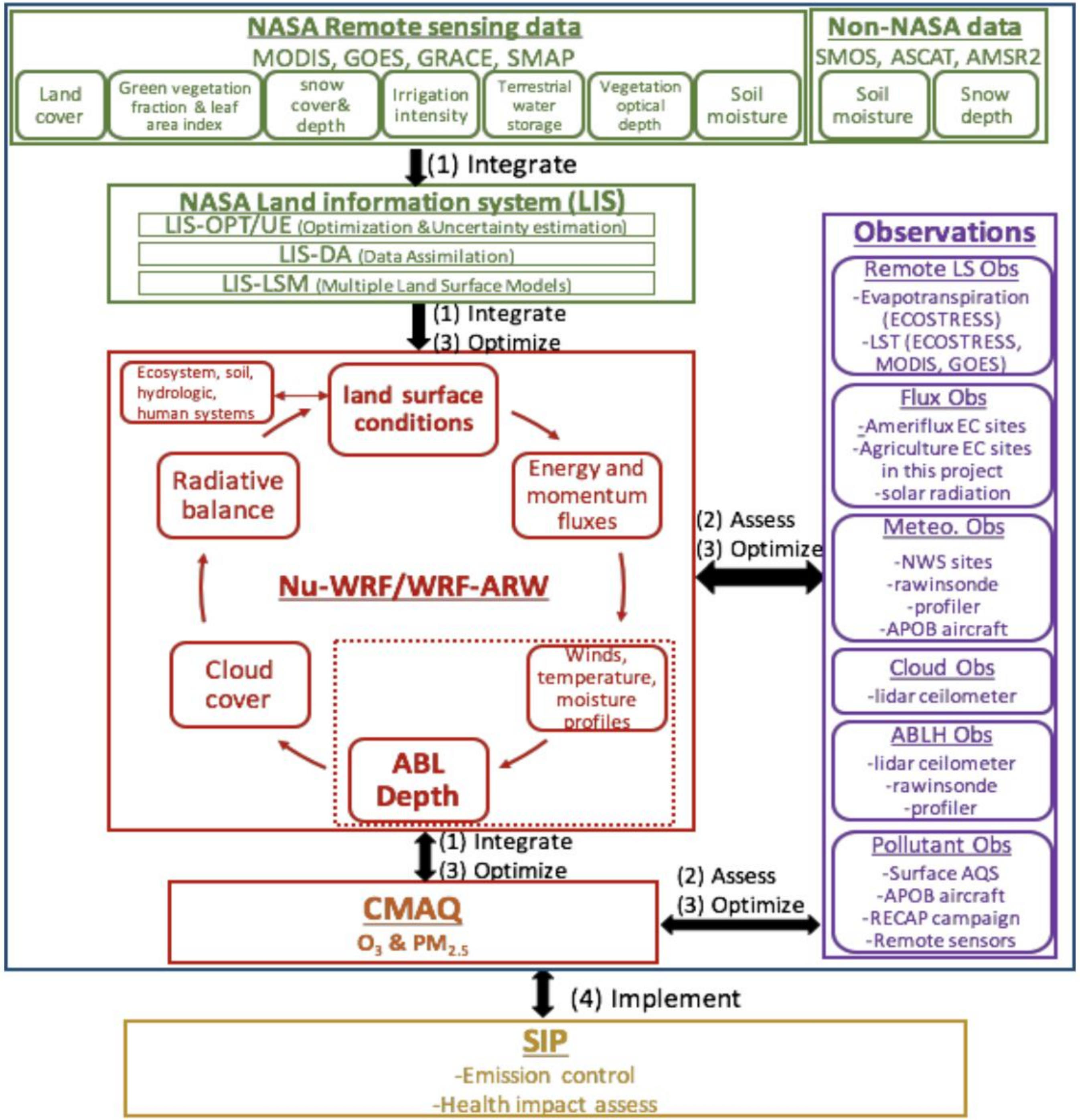
Work closely with the **California Air Resources Board (CARB)** and the **Pennsylvania Department of Environmental Protection (PA DEP)** to:

- incorporate state-of-the-science land surface remote sensing into the numerical weather models used for California and Pennsylvania SIPs,
- assess the impact of these changes on land surface fluxes and ABL properties in each state,
- adjust model physics and chemistry to achieve optimal regional performance,
- work with CARB and PA DEP to integrate these changes into their air quality modeling systems.

These improved AQ modeling systems will improve their SIPs and any future air quality planning or forecasting performed with these modeling systems.

Hypotheses

1. The numerical weather prediction (NWP) modeling used by each state for their SIPs, especially their simulation of ABL properties, will be more accurate as a result of the implementation of land surface remote sensing that improves the modeled surface energy balance and momentum fluxes.
2. The improvement of ABL properties in the state-level atmospheric modeling systems will improve the ability of each state to develop efficient and effective SIPs, thus improving air quality and human health with cost-effective measures.

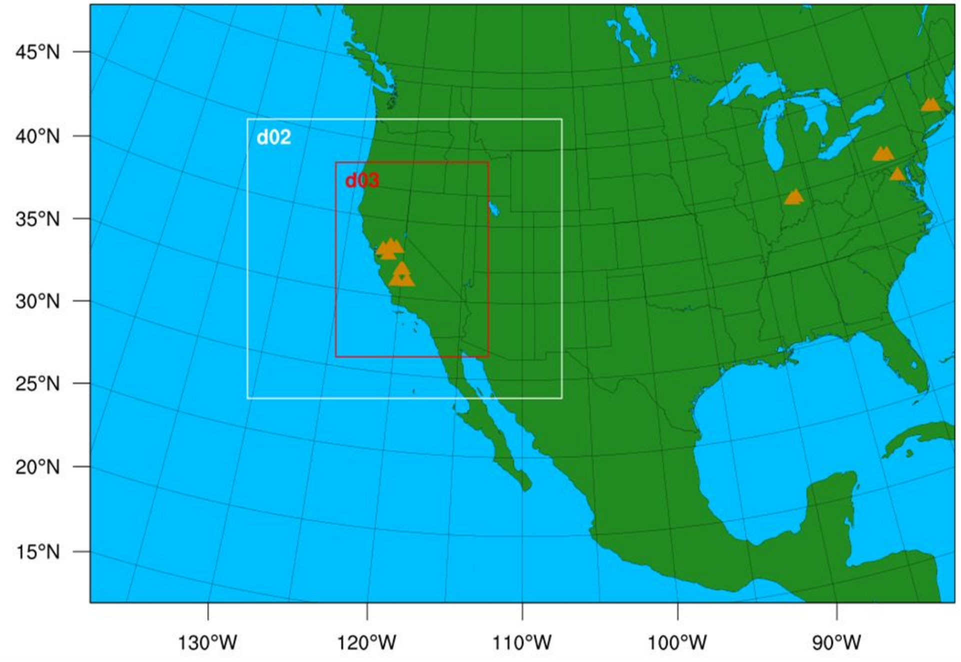


Research plan:

1. Integrate remote sensing of the land surface into NuWRF/LIS.
2. Assess the performance of existing state models (WRF) vs. NuWRF/LIS.
    a. Meteorological variables
    b. Air quality variables
3. Optimize performance.
4. Implement into the state air quality modeling efforts.

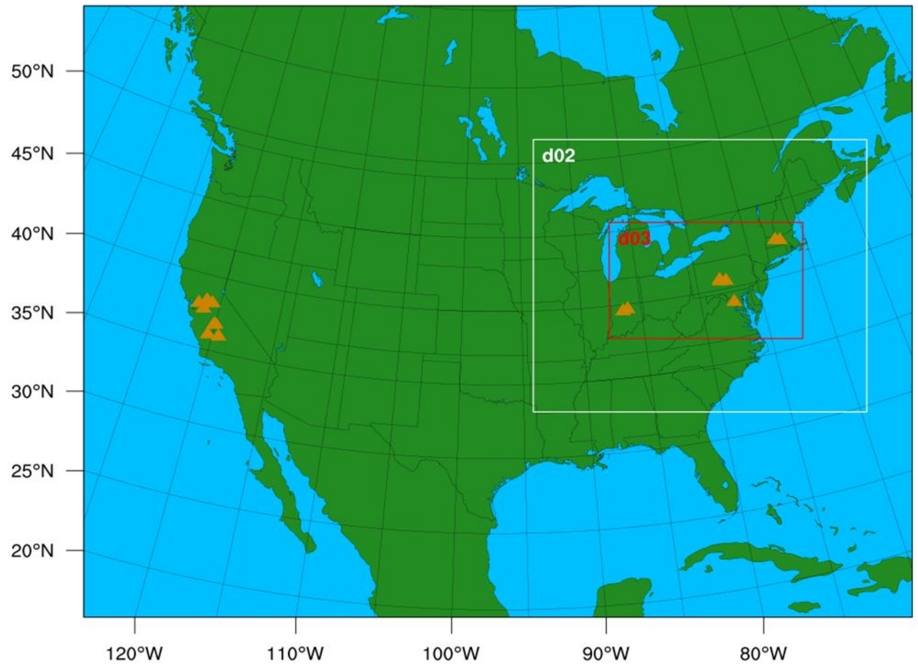
Results to date

Weather Research and Forecast (WRF) model configurations used by our state partners.



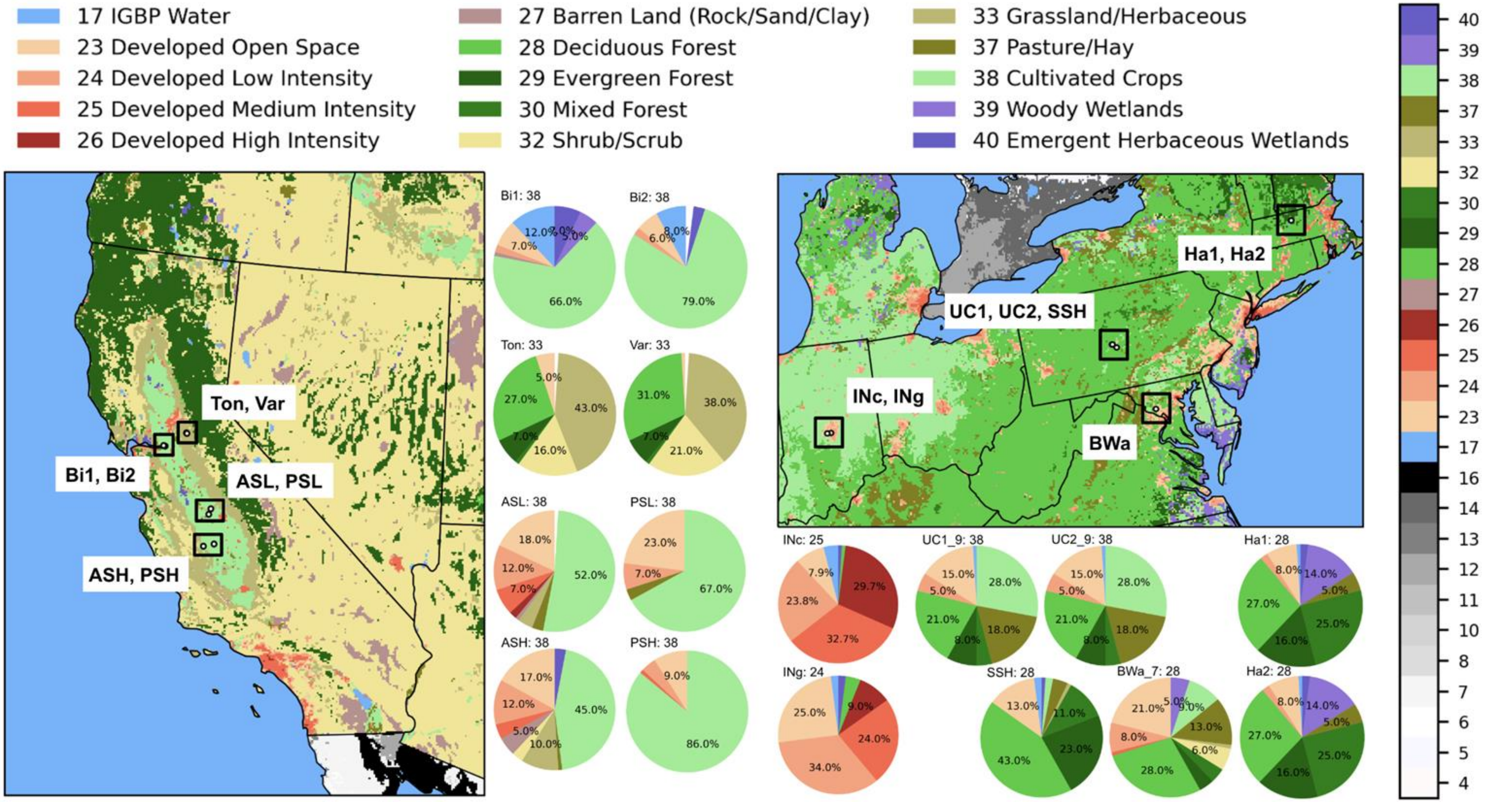
Major Modules	Option	Reference
Microphysics scheme	WSM6	*Hong and Lim [2006]*
Cumulus scheme	Kain-Fritsch	*Kain et al. [2004]*
Longwave radiation	RRTM	*Mlawer et al*. [1997]
Shortwave radiation	Dudhia	Dudhia [1989]
Land-surface physics	Pleim-Xiu	*Xiu and Pleim [2001]*
Urban surface scheme	single-layer UCM	*Kusaka et al*. [2001]
PBL scheme	YSU	*Hong et al*. [2006]

Domains modified to include flux towers in the MidAtlantic.



Major Modules	Option	Reference
Microphysics scheme	Morrison 2-mom	*Marrison et al. [2009]*
Cumulus scheme	Kain-Fritsch	*Kain et al. [2004]*
Longwave radiation	RRTMG	*Iacono et al. [2008]*
Shortwave radiation	RRTMG	*Iacono et al. [2008]*
Land-surface physics	Pleim-Xiu	*Xiu and Pleim [2001]*
Urban surface scheme	Off	/
PBL scheme	ACM2	*Pleim [2007]*

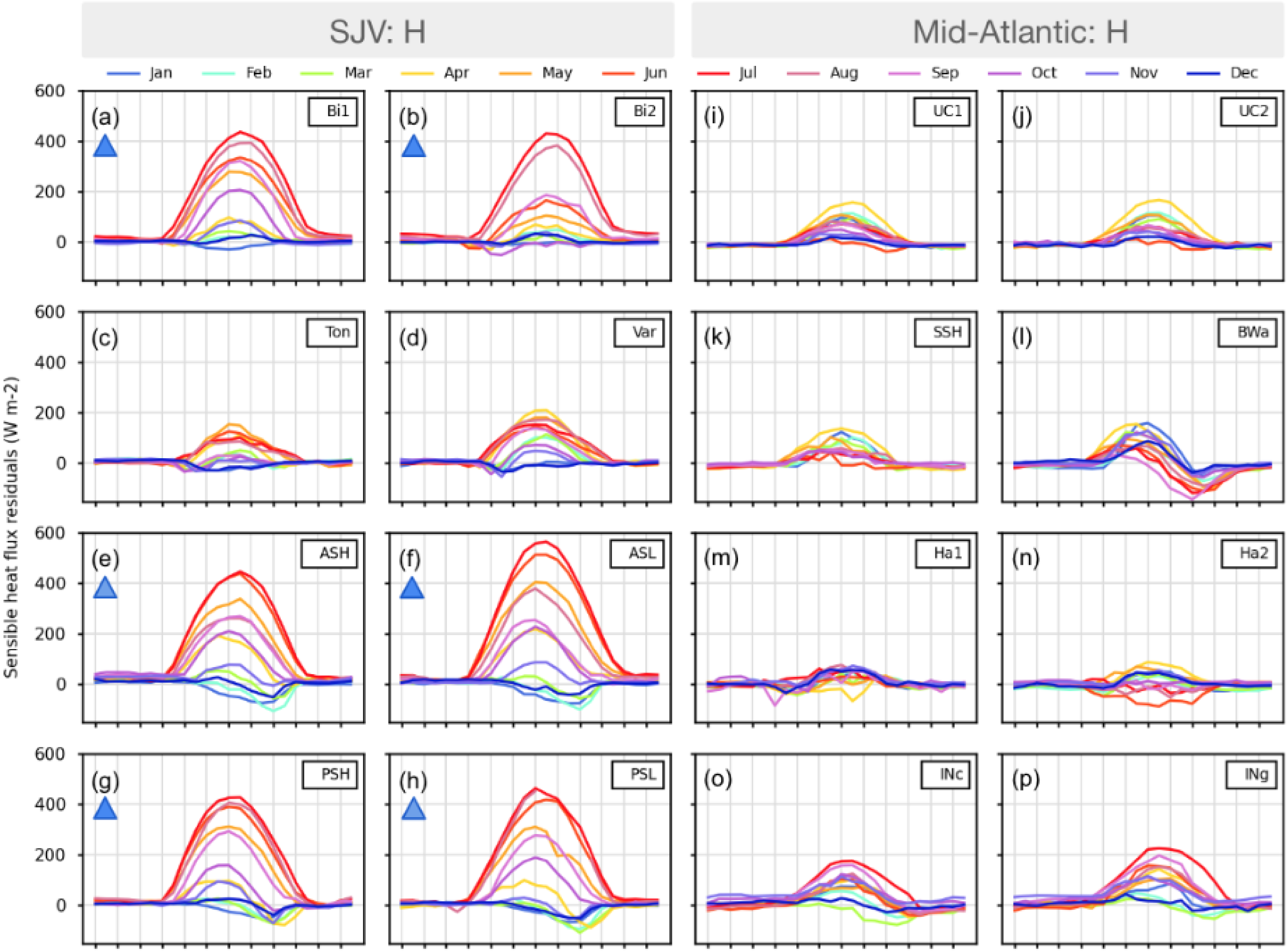
Most of the crop cover in the SJV is irrigated.



WRF vs. observations

Sensible heat flux residuals (model - observation) are very large:

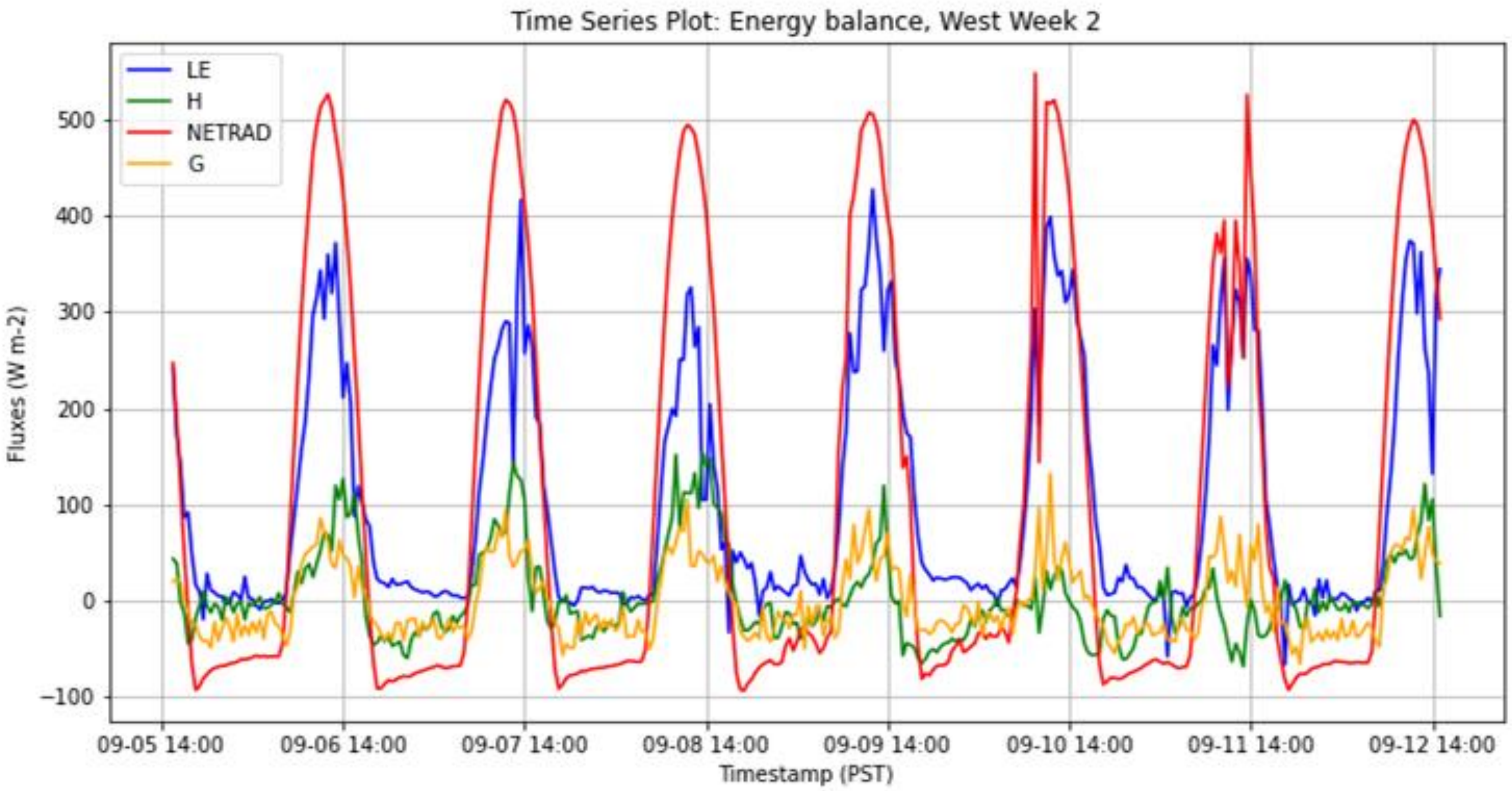
- in the SJV
- during summer months
- at irrigated sites.



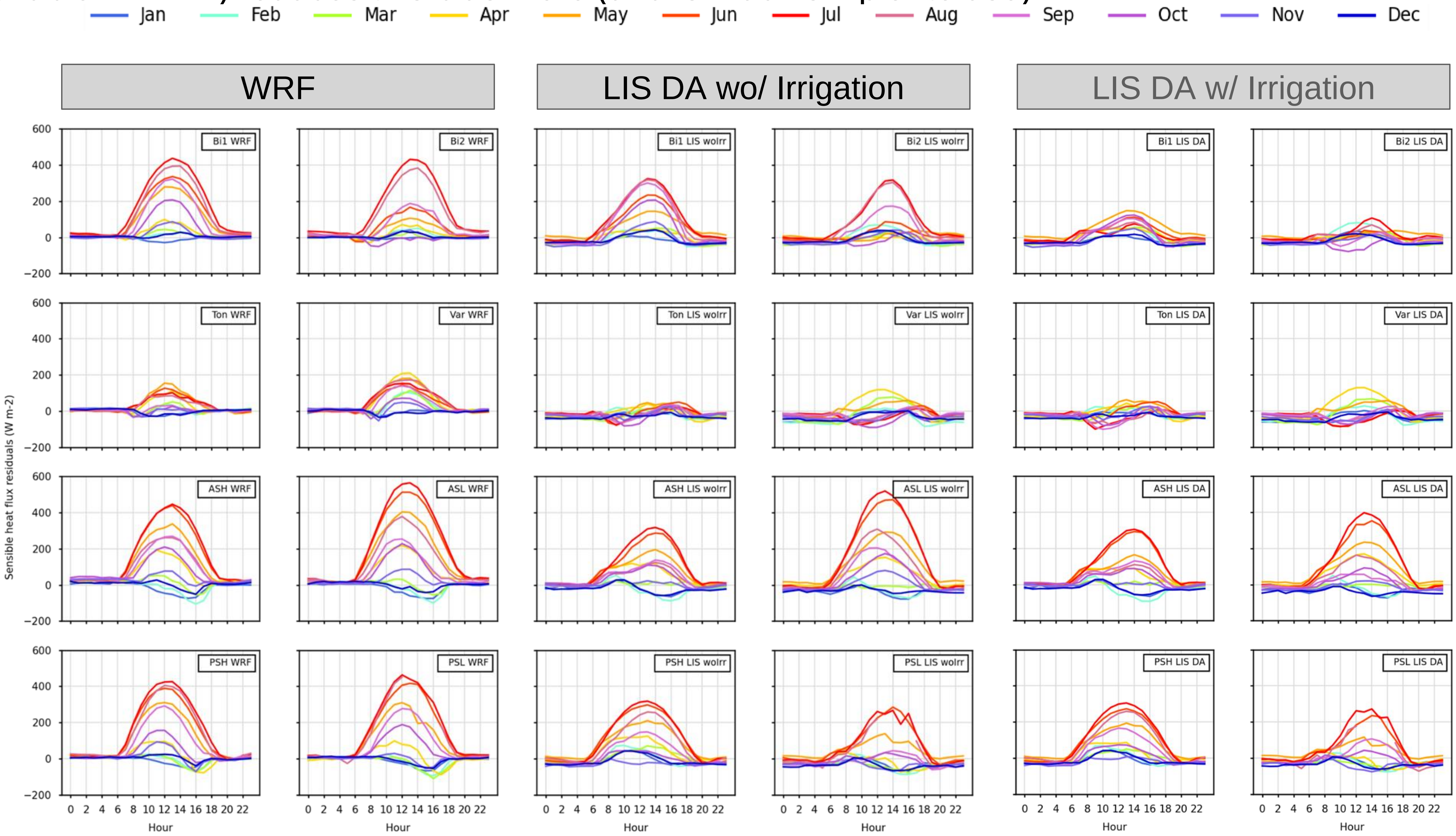
Sensible heat flux residuals (model - observation) are very large:

- in the SJV
- during summer months
- at irrigated sites.

- We have added two more flux towers in irrigated crops in the southern SJV to confirm this finding.



DOES LIS help? NASA LIS reduces the sensible heat flux bias. An irrigation module (also available in WRF) reduces this bias more (and is much simpler to use).



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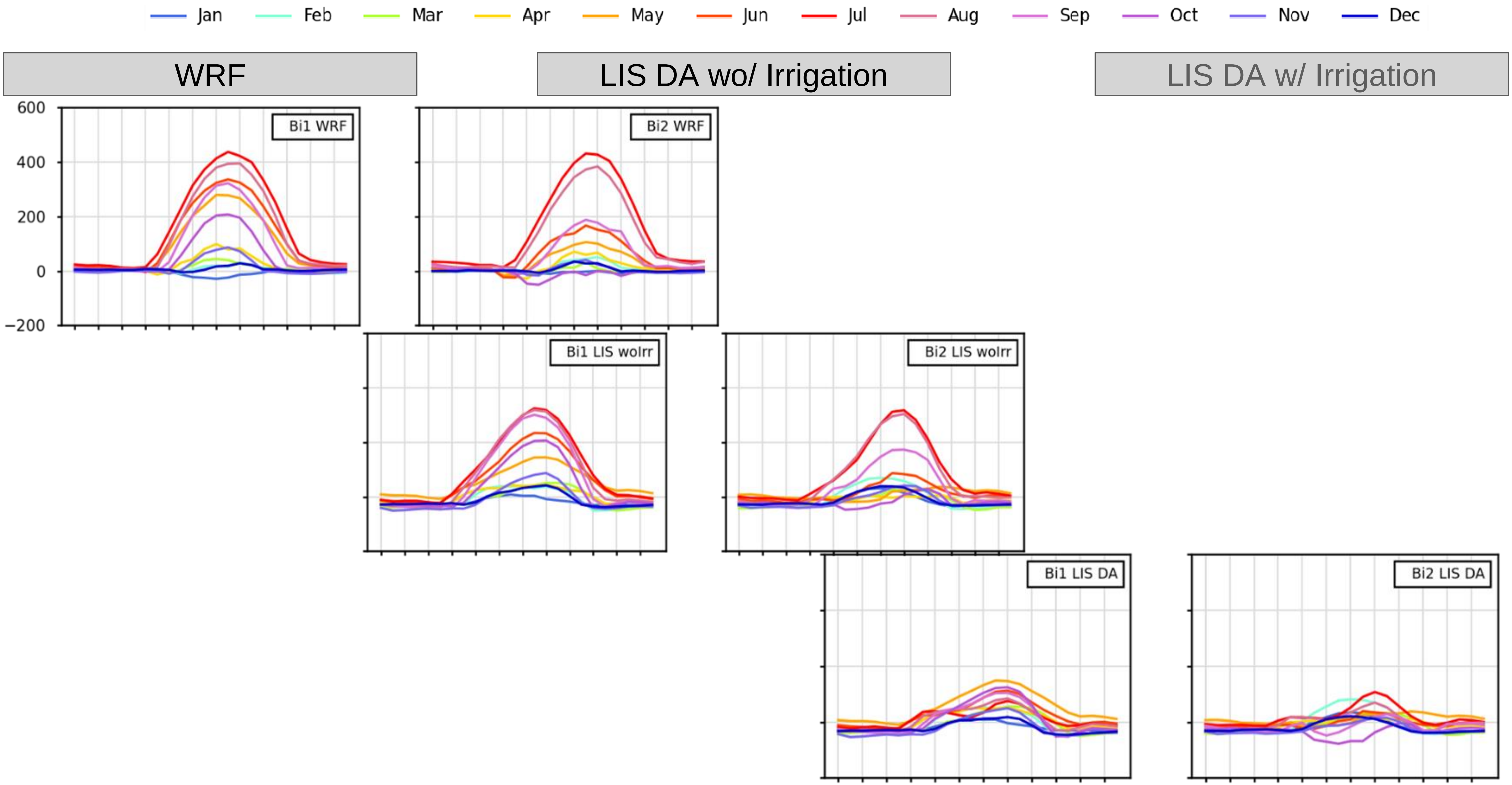


LIS Data Assimilation (DA)

- **Met forcings:**

switch from GDAS to MERRA2 (higher resolution), add IMEG precipitation data (NASA Integrated Multi-satellitE Retrievals for Global Precipitation Measurement, V06B, 0.1x0.1 deg, half-hourly)

- **SMAP Soil moisture:**

switch from "SPL3SMP" (36x36km) to "SPL3SMP_E", (L3, daily, 9x9km) enhanced/oversampled product (*"SMAP project used a Backus-Gilbert optimal interpolation scheme which takes advantage of the SMAP radiometer oversampling on orbit to generate an enhanced radiometer-based soil moisture product posted on a 9 km grid"*)

- **MODIS LAI:**

MCD15A2H, 8-day, 500m

- **MODIS Land cover**:

MCD12Q1, yearly, 500m, (default is climatology in LIS and WRF)

- **MODIS Greenness:**

Time-varying, 5km, based on MODIS 500m (default is climatology in LIS and WRF)

- **Irrigation:**

turned on; crop classification: CROMMAP, crop type data source: Mondreda08; irrigation map: GRIPC, based on Salmon (2013); resolution: 500mx500m

How does NASA LIS impact the ABL?

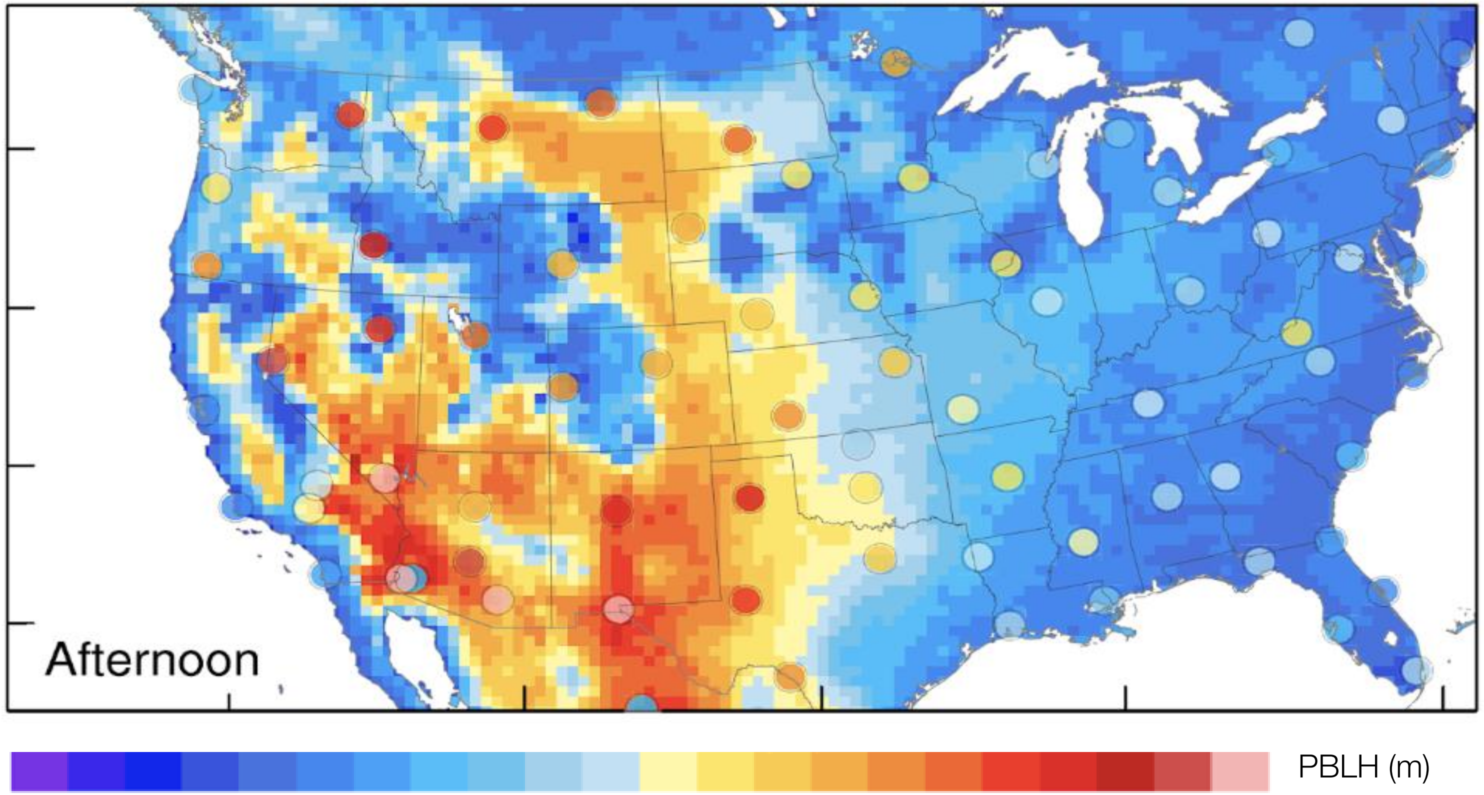
ABL properties to be evaluated

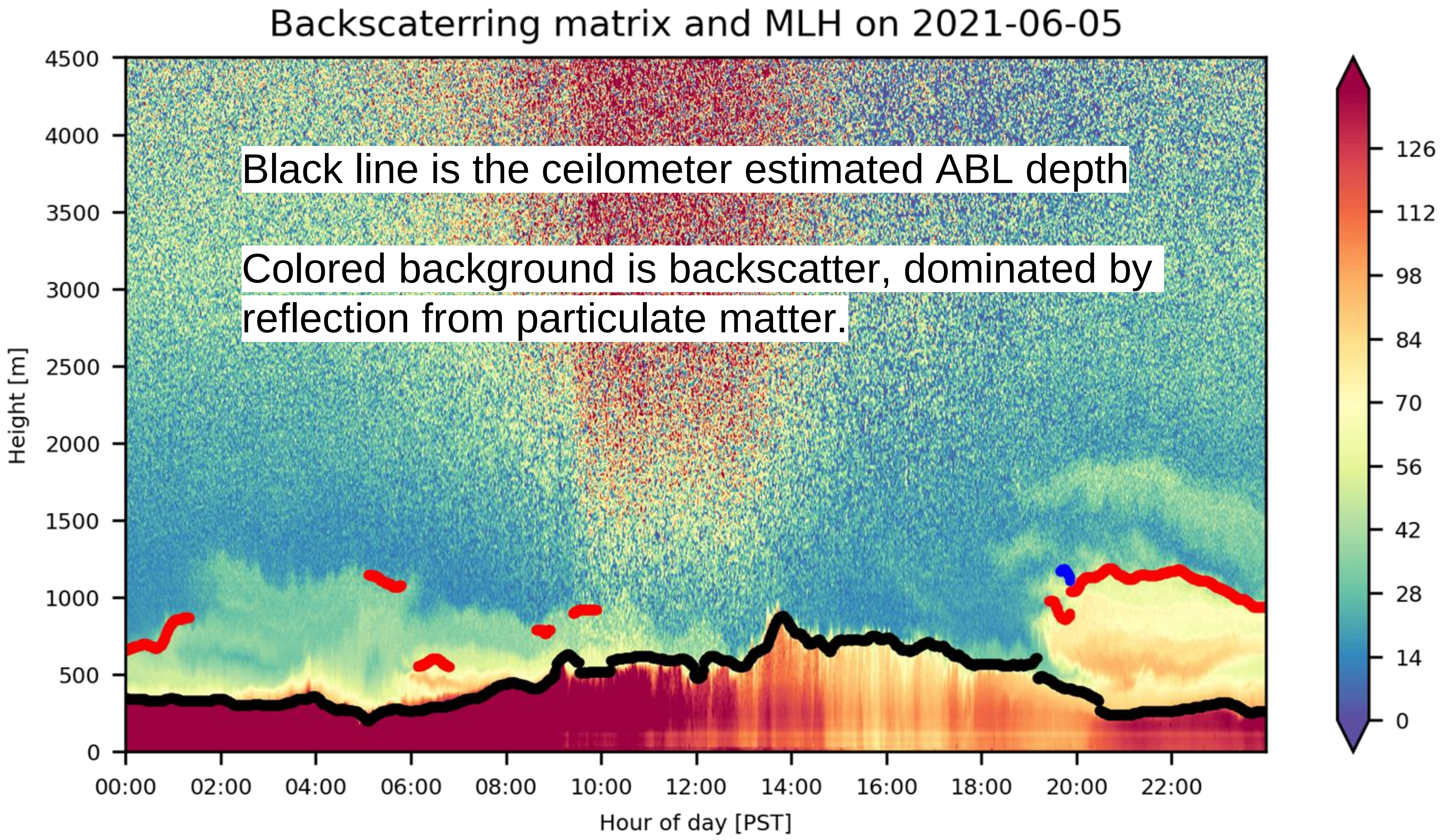
ABL depth, winds, cloud cover, relative humidity.
All have significant impacts on pollutant concentrations.

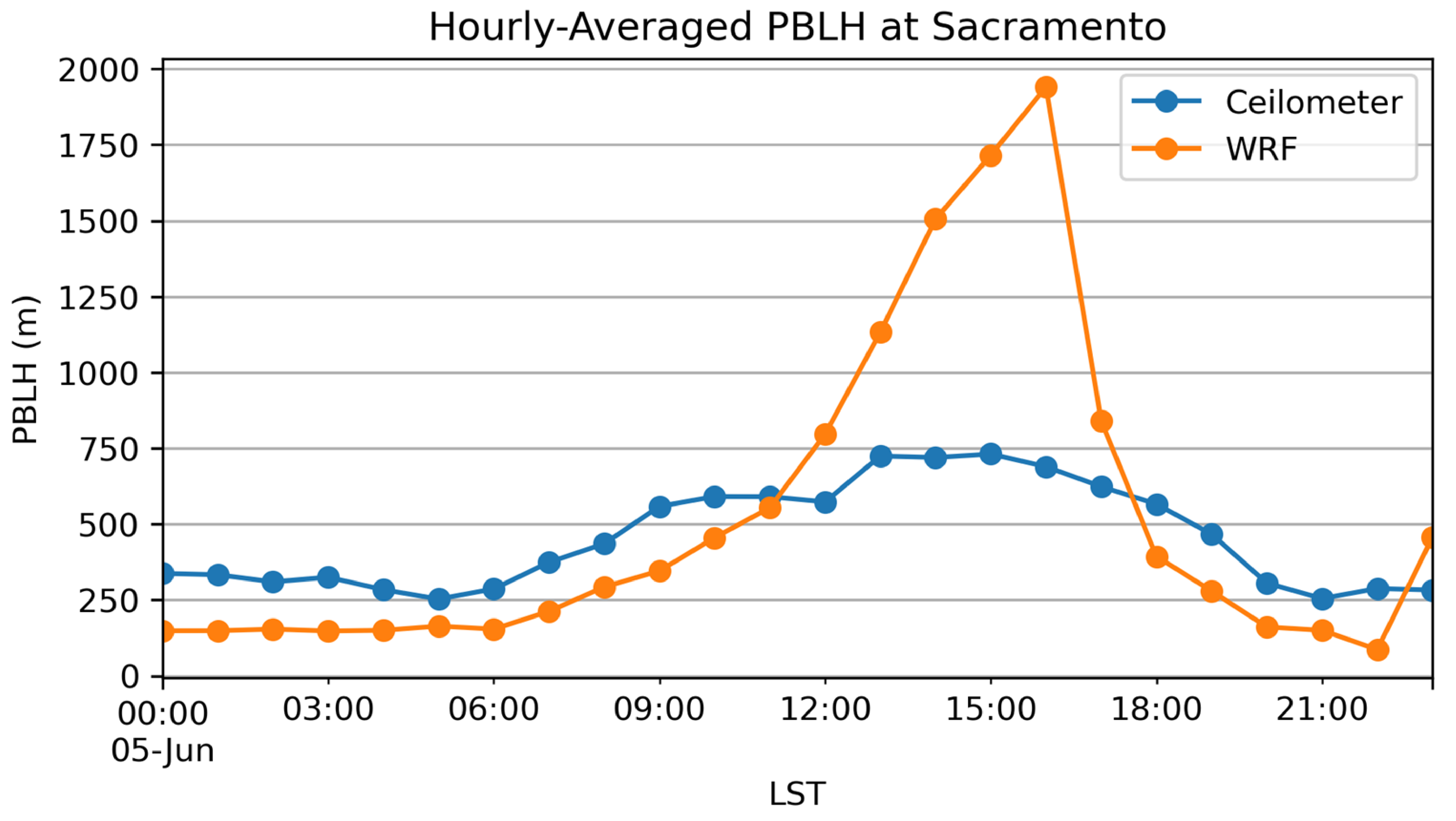
Note: No rawinsondes in the SJV.

We rely, therefore, on CARB ceilometers.

Modeled vs observed annual mean ABLH in 2021

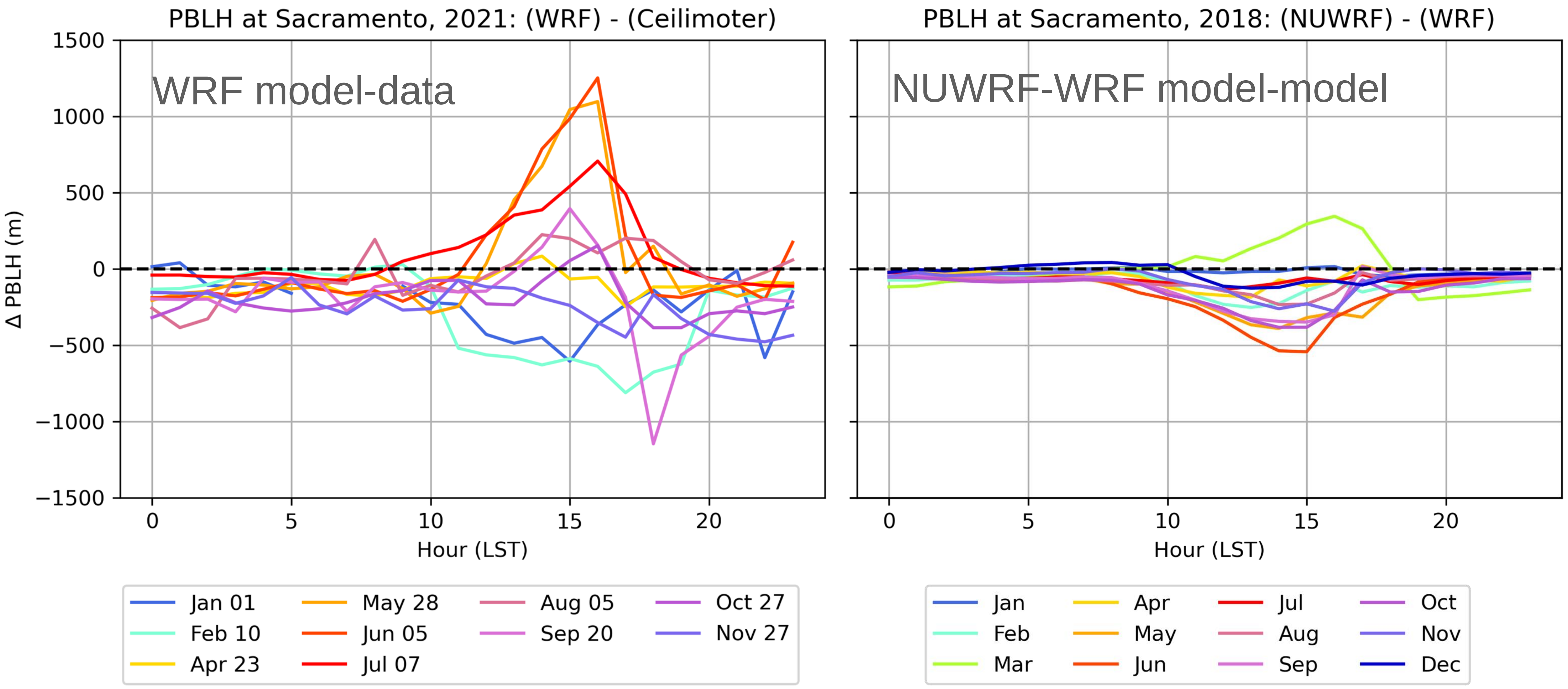



Backscaterring matrix and MLH on 2021-06-05
Black line is the ceilometer estimated ABL depth
Colored background is backscatter, dominated by reflection from particulate matter.
Height [m]
4500
4000
3500
3000
2500
2000
1500
1000
500
0
00:00
02:00
04:00
06:00
08:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
Hour of day [PST]
126
112
98
84
70
56
42
28
14
0


Hourly-Averaged PBLH at Sacramento
PBLH (m)
2000
1750
1500
1250
1000
750
500
250
0
00:00
05-Jun
03:00
06:00
09:00
12:00
15:00
18:00
21:00
LST
Ceilometer
WRF

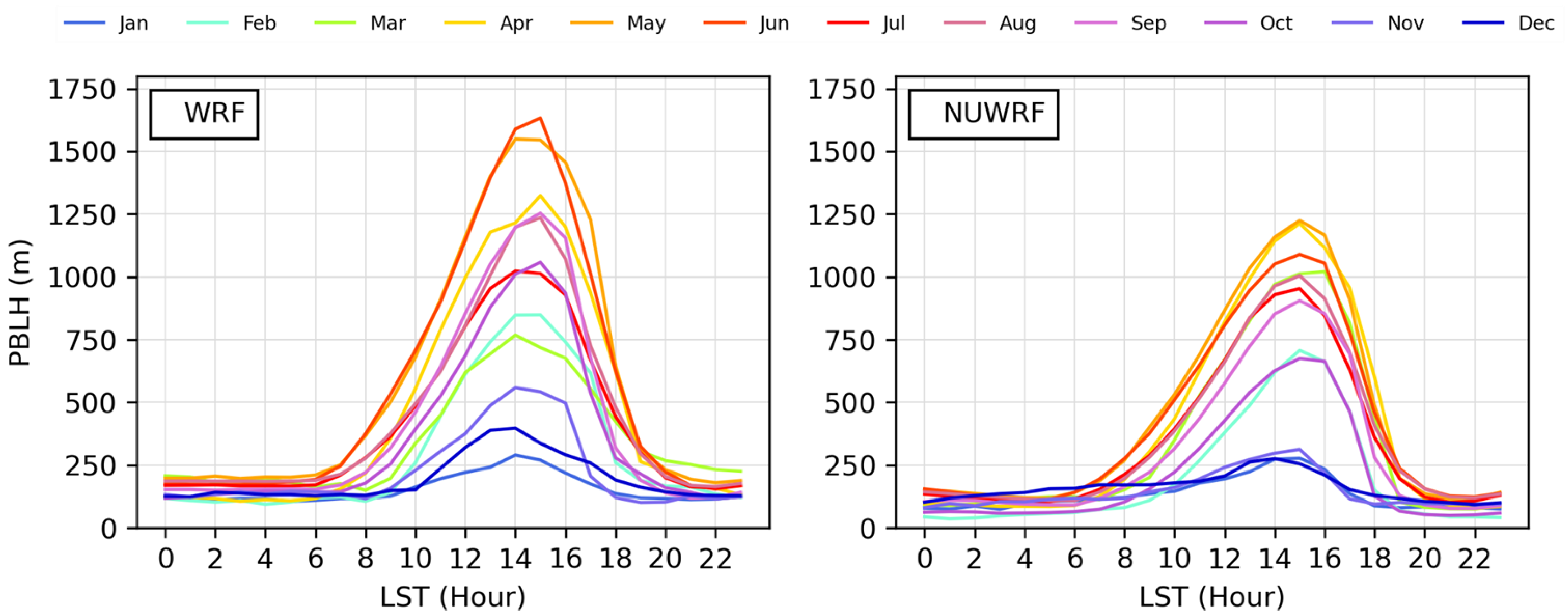
How does NASA LIS impact the ABL?

NUWRF (with irrigation) does reduce the ABL depth bias in summer.



**March, December Ceilometer data not available

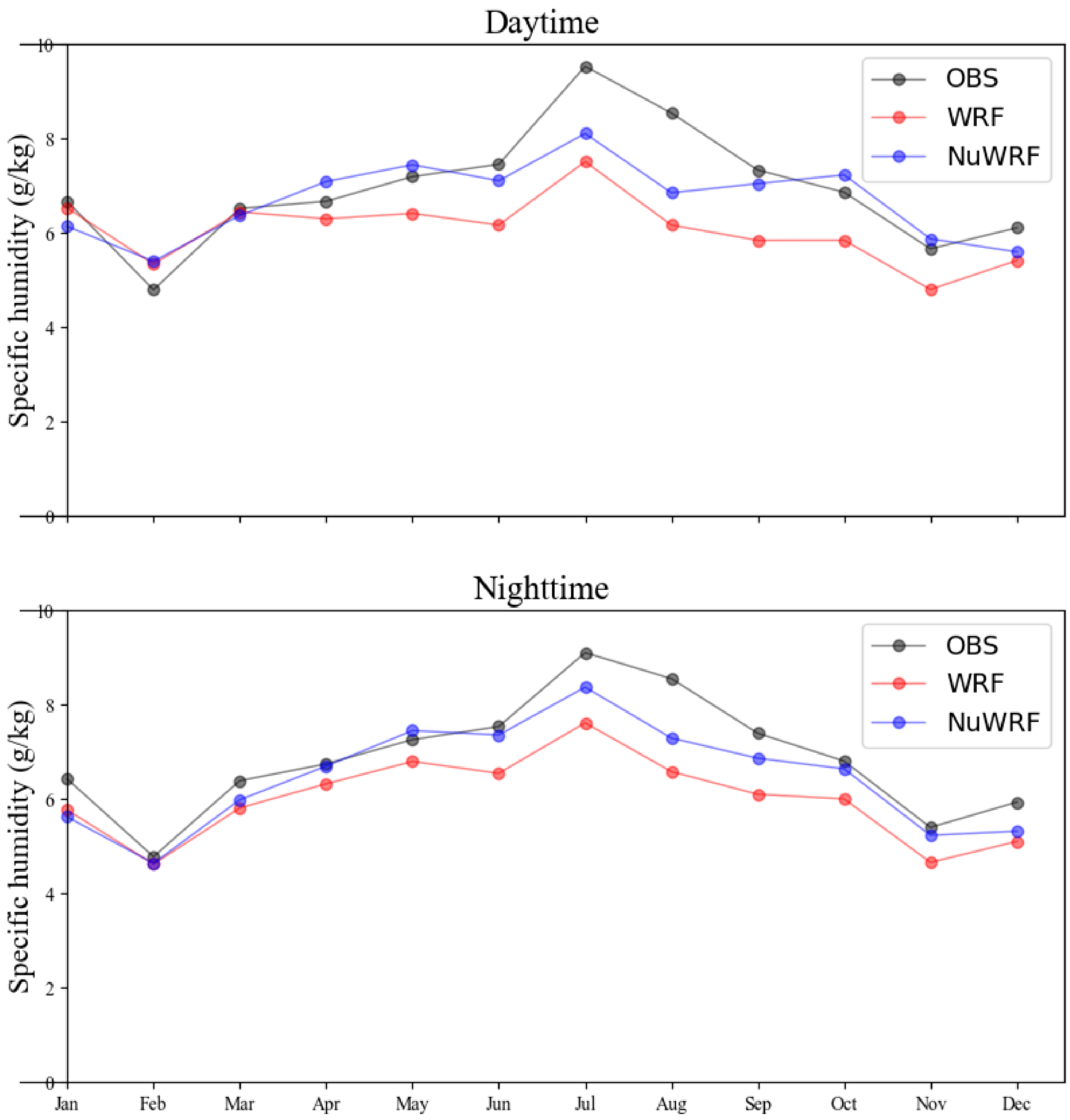
WRF vs NUWRF: averaged PBLH for each hour of the day across the entire month, Sacramento 2018



NUWRF (with irrigation) also reduces our underestimate of specific humidity in the ABL.

2018 annual mean.

ASOS stations located in the SJV.

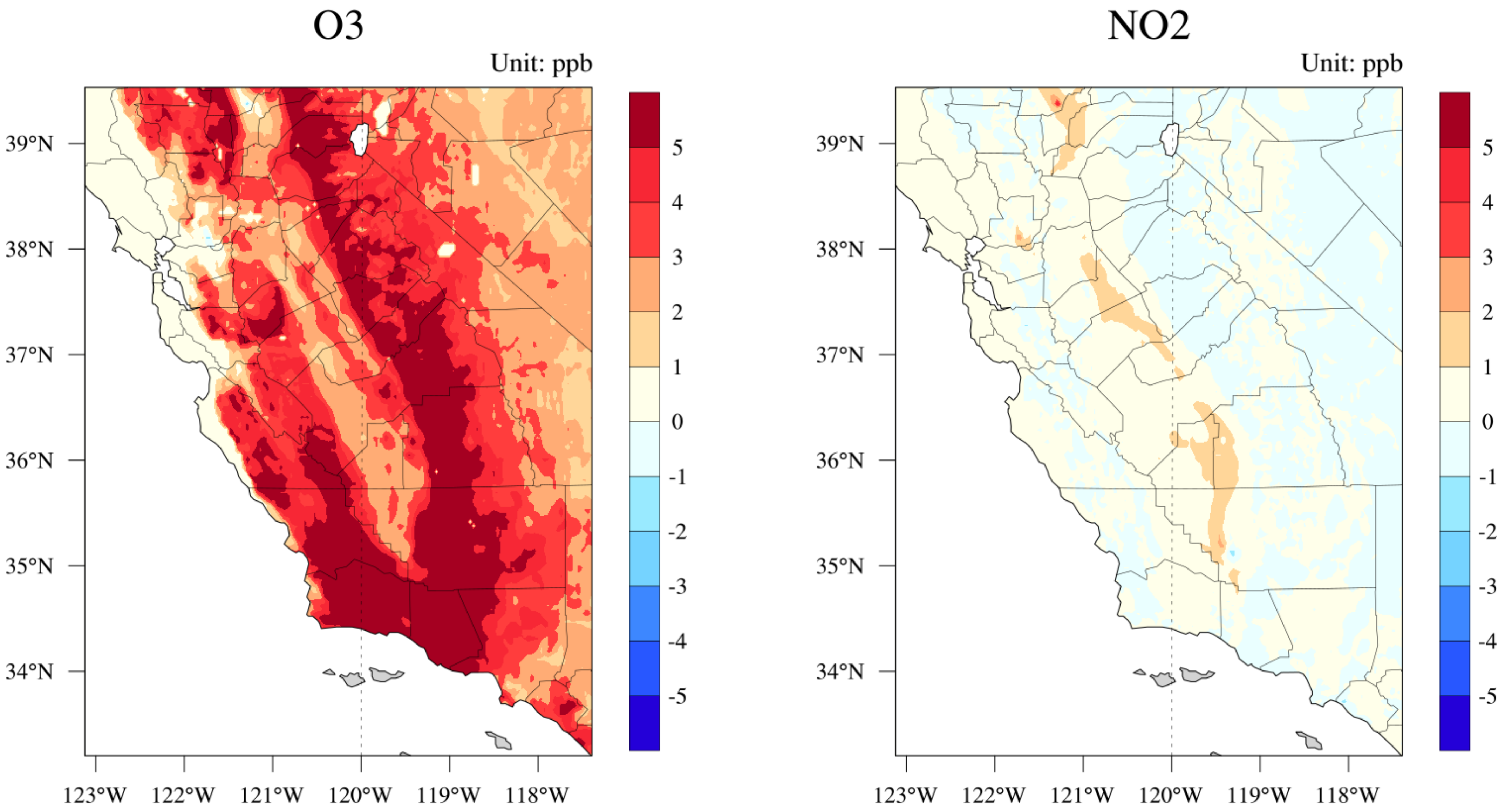


How does NUWRF meteorology impact SJV air quality?

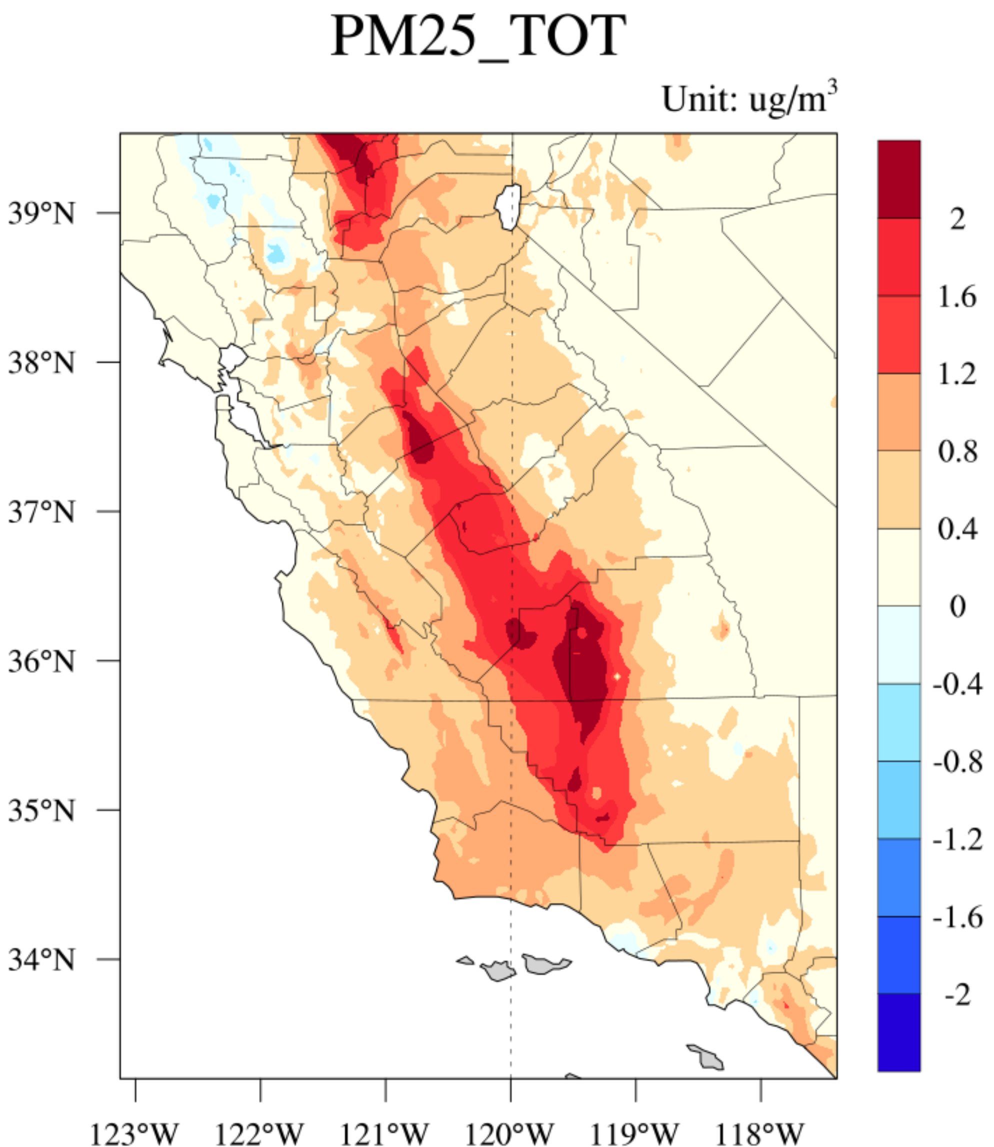
CMAQ model configuration

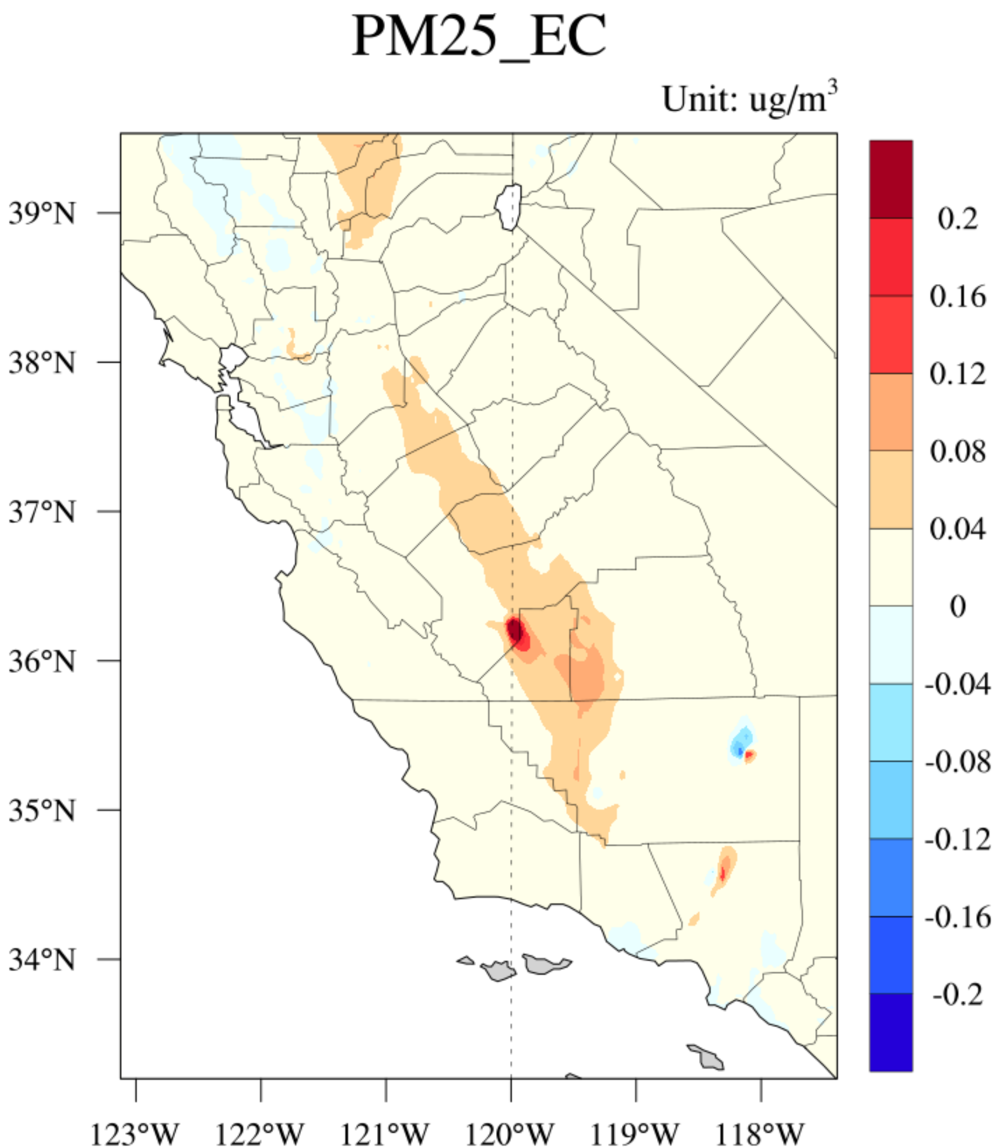
- Period: 2018.07
- Domain: 4 km resolution
  262 rows * 298 cols
- Mechanism: Saprc07tic_ae7
- Emissions: anthropogenic - CARB
  biogenic - MEGANv3.0
- Scenarios: 1. Meteorology conditions from regular WRF
  2. Meteorology conditions from NuWRF

NuWRF case minus WRF case

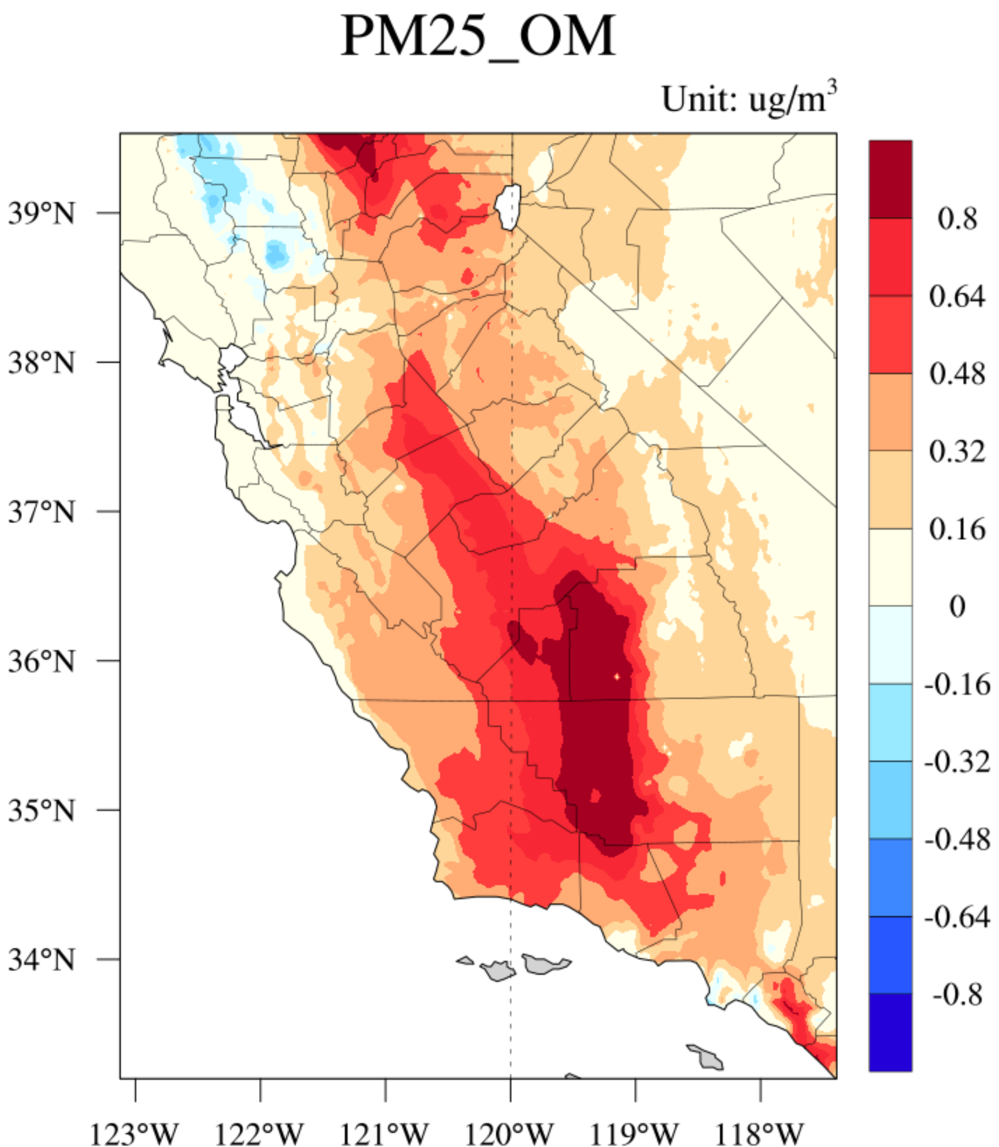


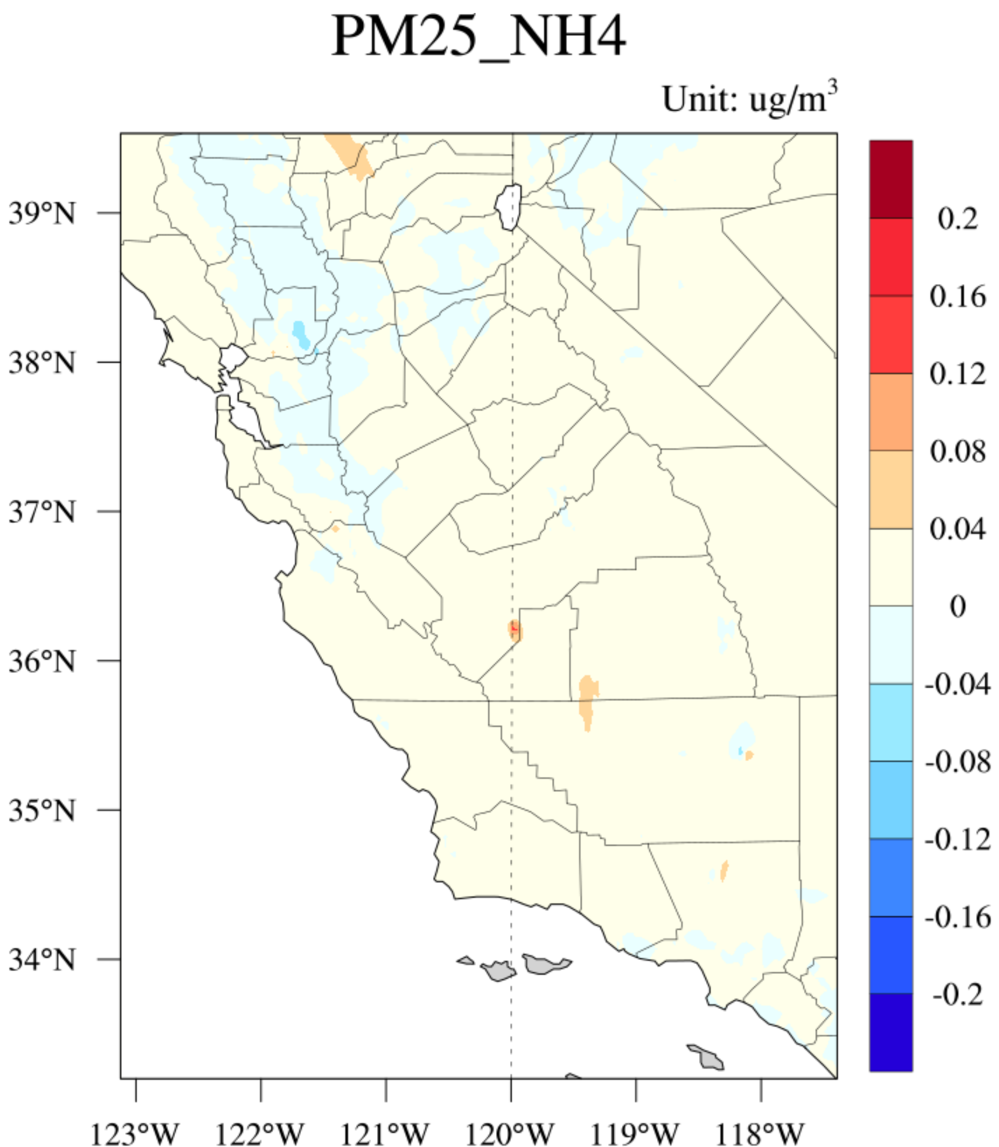
NuWRF case minus WRF case



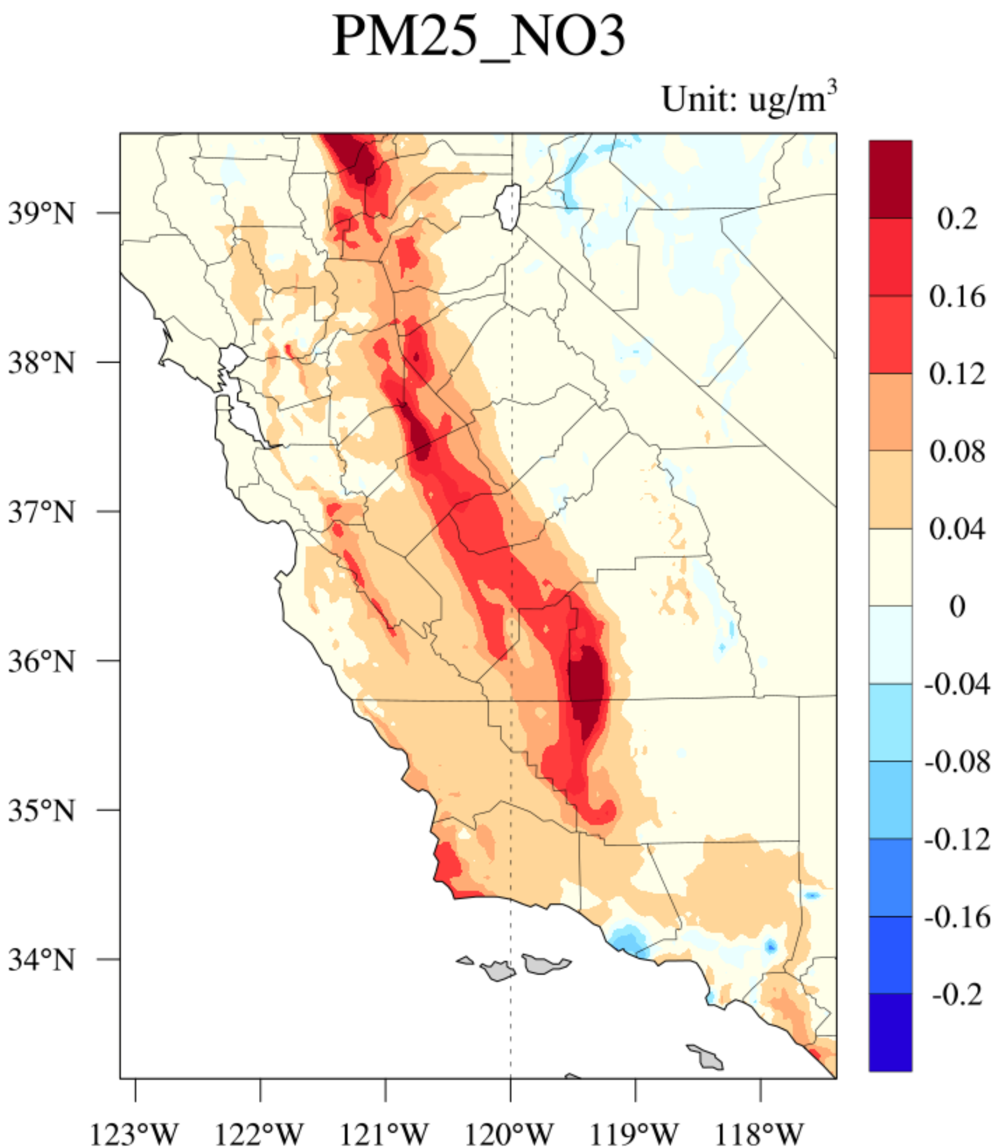


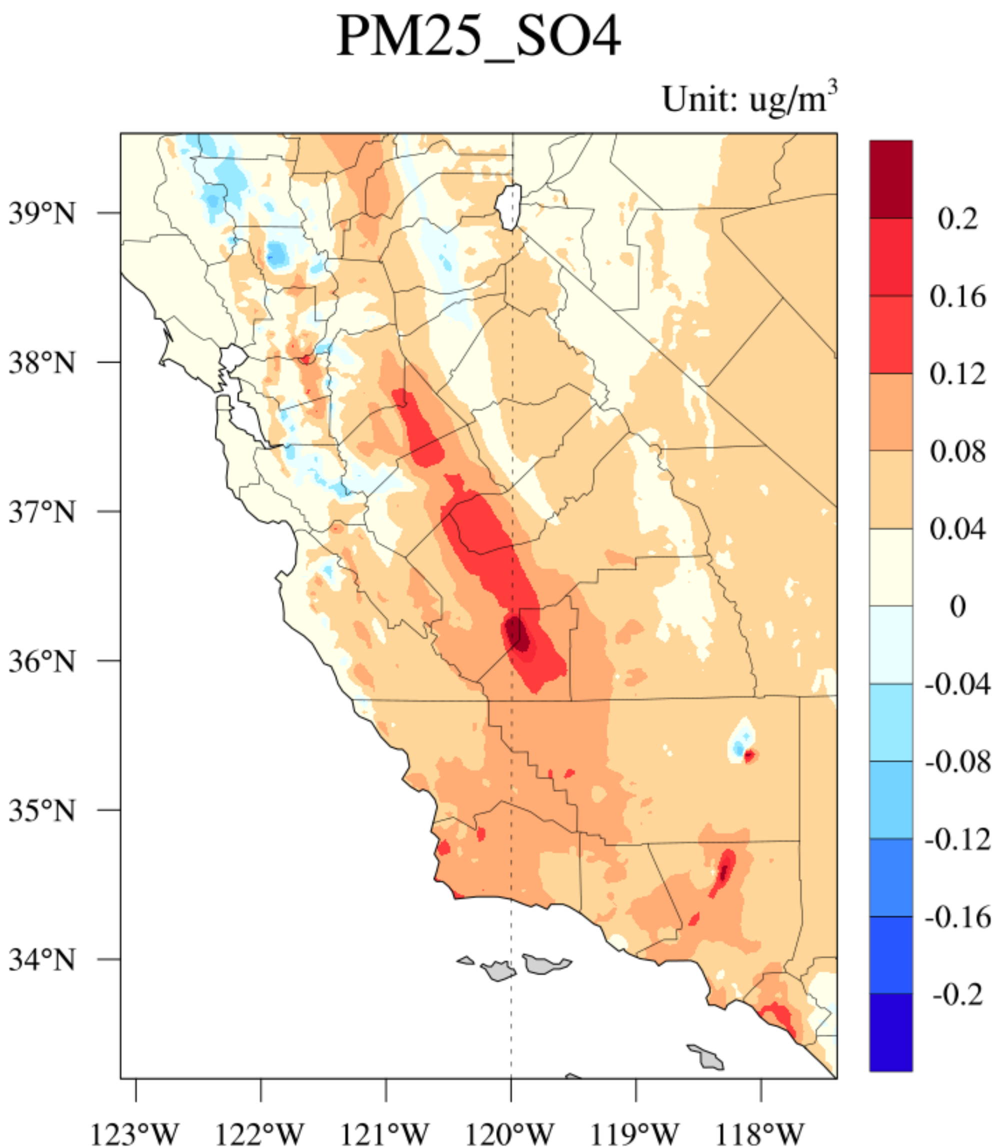
NuWRF case minus WRF case





NuWRF case minus WRF case





How does NUWRF meteorology impact SJV air quality?

What is closer to observations? TBD.

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Thanks

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