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

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Introduction

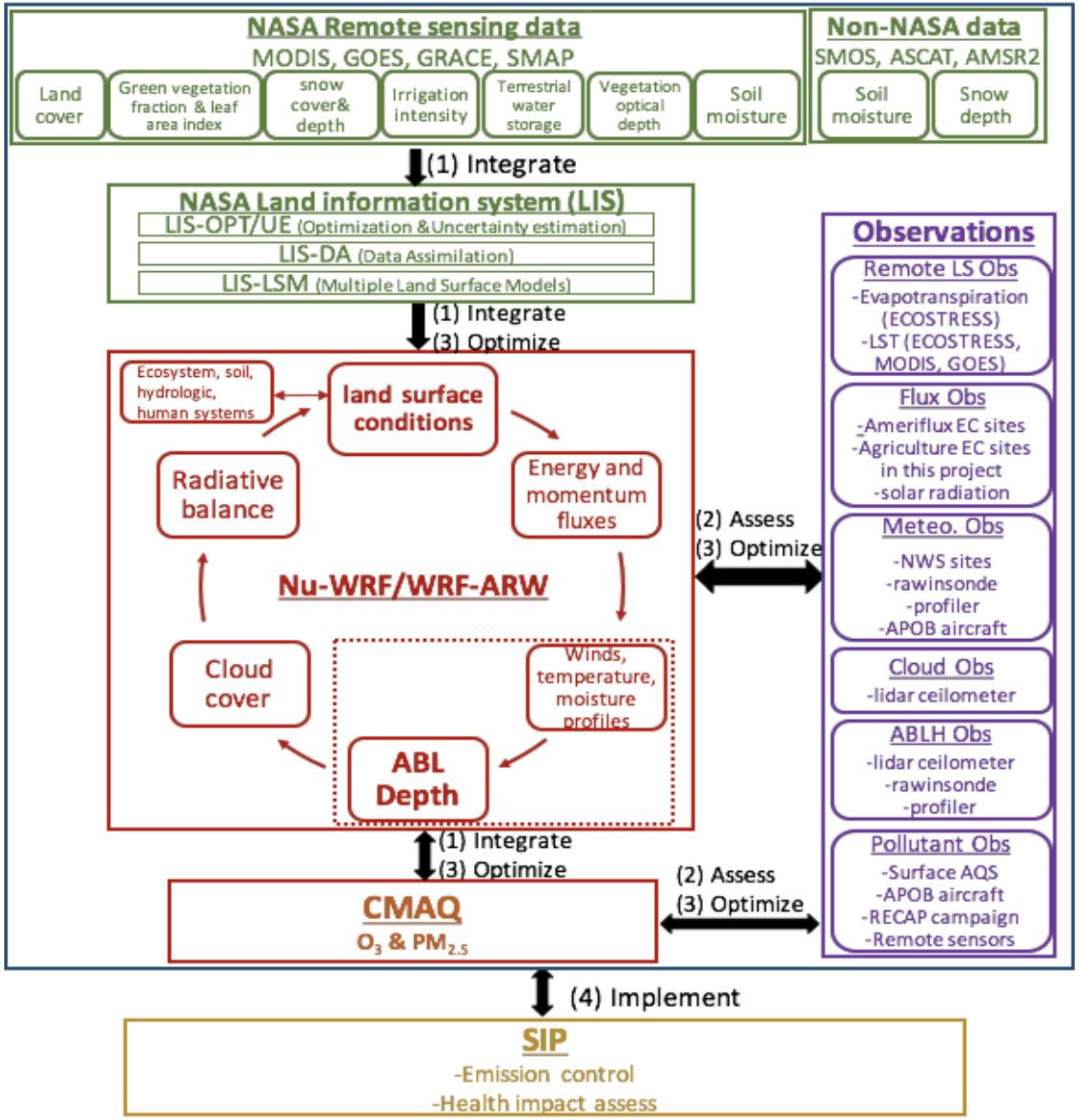
SIPs and ABL properties

- The 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).

Figure 1. Conceptual map of the proposed research

Red subset: ABL properties

- “wheel of interaction”: the coupled land surface - boundary layer system, simulated within NASA LIS /NU-WRF



Introduction

ABL properties and NASA LIS

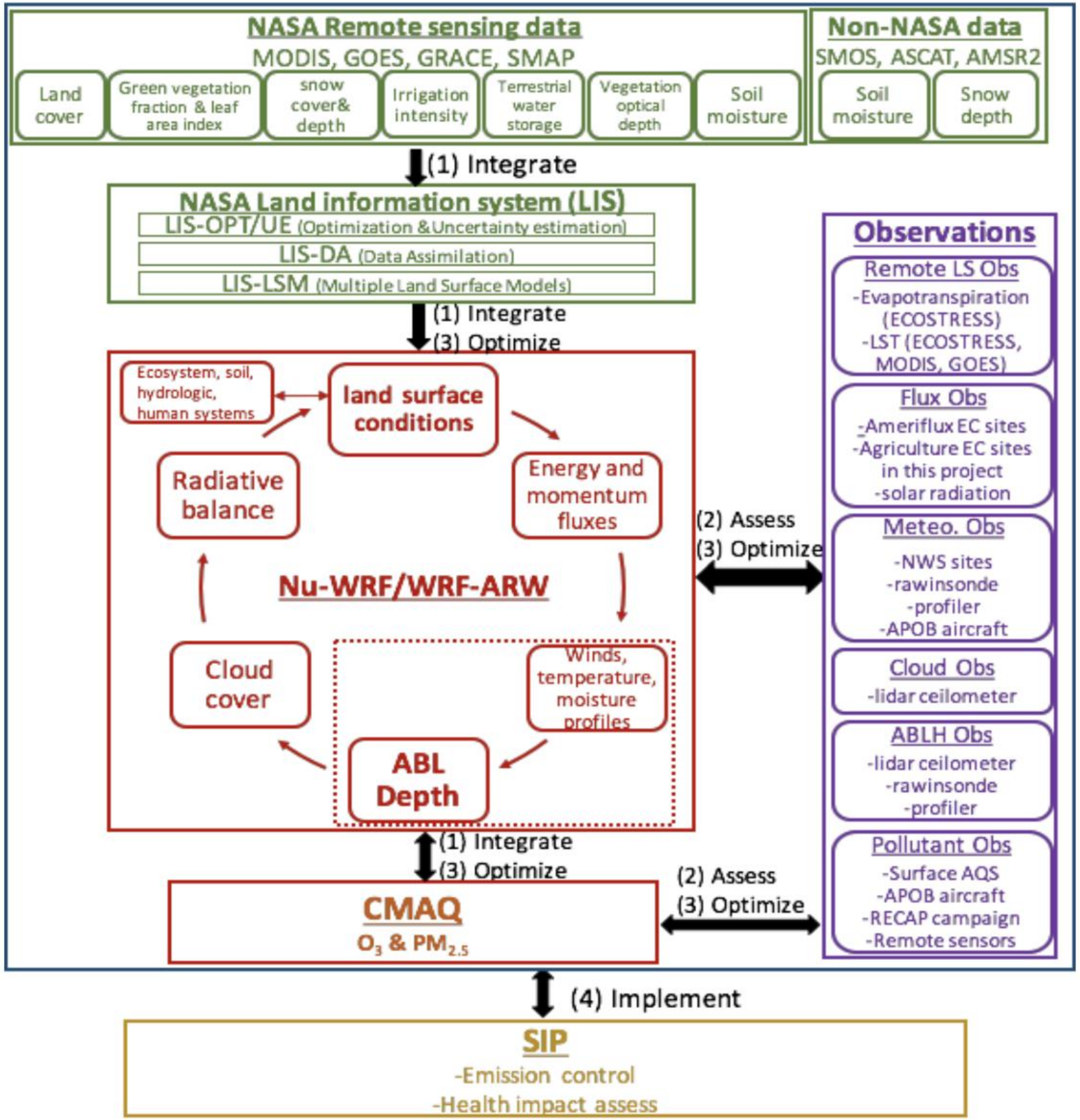
- Increasingly sophisticated and detailed observations of the earth's land surface are being used to inform these land surface models (LSMs).
- Many of these observations are obtained from spacebased platforms which are capable of mapping the entire land surface of the earth with varying degrees of spatial and temporal resolution.
- 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).

Figure 1. Conceptual map of the proposed research

Green subset: NASA LIS

- Remote sensing observations integrated into NASA LIS

Purple subset: observations used to evaluate the modeling 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.

- SJV, Allegheny County, Lancaster/Philly discussion - all likely or existing air quality violation areas that will require SIPs
- (SJV modeling challenge figure)

SJV modeling challenge

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

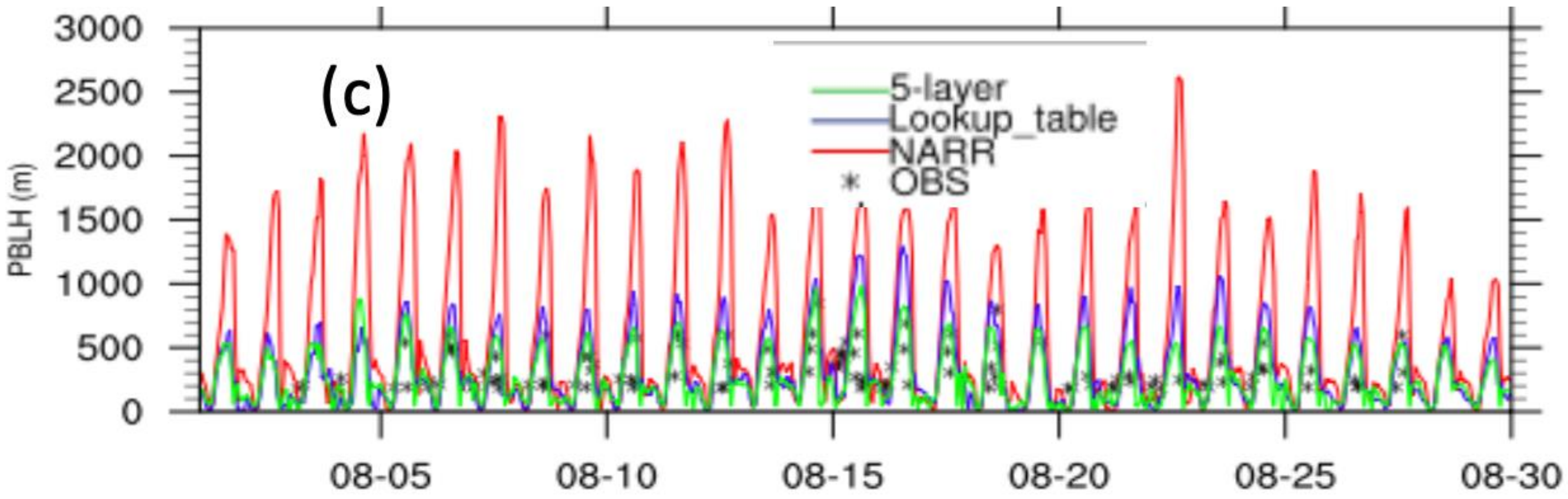


Figure 2: Simulated and observed August (x-axis shows month and day of the month) (a) 2-m temperature; (b) 2-m relative humidity in Fresno (southern SJV); and (c) planetary boundary layer height (PBLH) at a site in Visalia (also southern SJV), from three WRF simulations. "5_layer" denotes the 5-layer 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.

What's a SIP?

Explain briefly.

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 (check to see if current conditions are simulated well…if not…adjust modeling system).
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.

Objective Statement

Working closely with the CARB and with the Pennsylvania Department of Environmental Protection (PA DEP), we propose to

- incorporate state-of-the-science land surface remote sensing into the numerical weather models used for California and Pennsylvania SIPs.
- We will 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. An expanded system for assessing the NWP models will increase the likelihood that the atmospheric simulations are achieving accurate results because of sound mechanistic behavior.
3. 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.

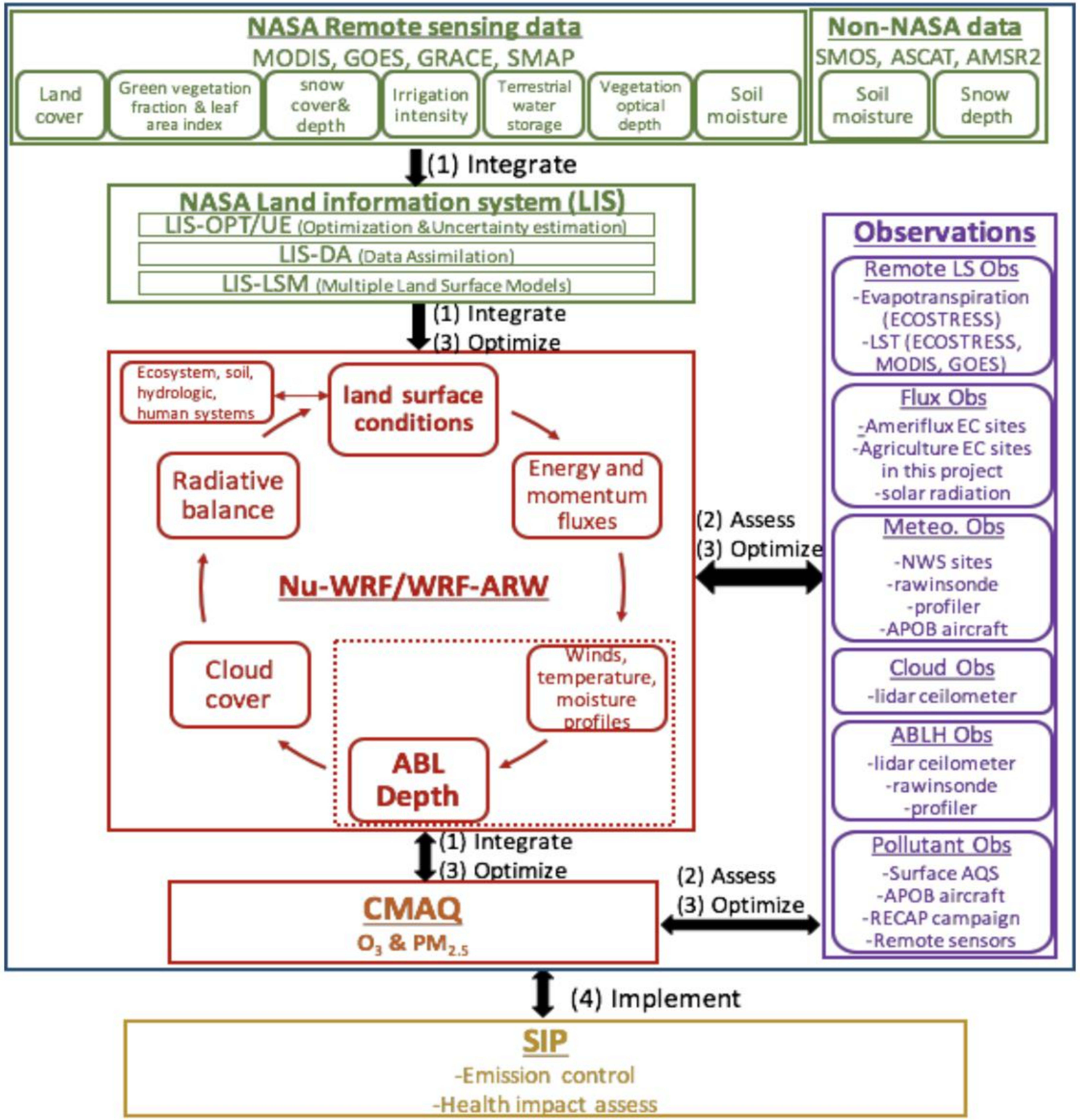


Figure 1. Conceptual map of the proposed research. Each research action is numbered. Remote sensing observations integrated into NASA LIS are in green. Observations used to evaluate the modeling system are in purple. The coupled land surface - boundary layer system, simulated within NASA LIS / NU-WRF, is represented by the "wheel of interaction" in the center of the figure. Remote sensing and in situ observations are both integrated into and used to assess those interactions to ensure that the SIP modeling systems "get the right answers for the right reasons."

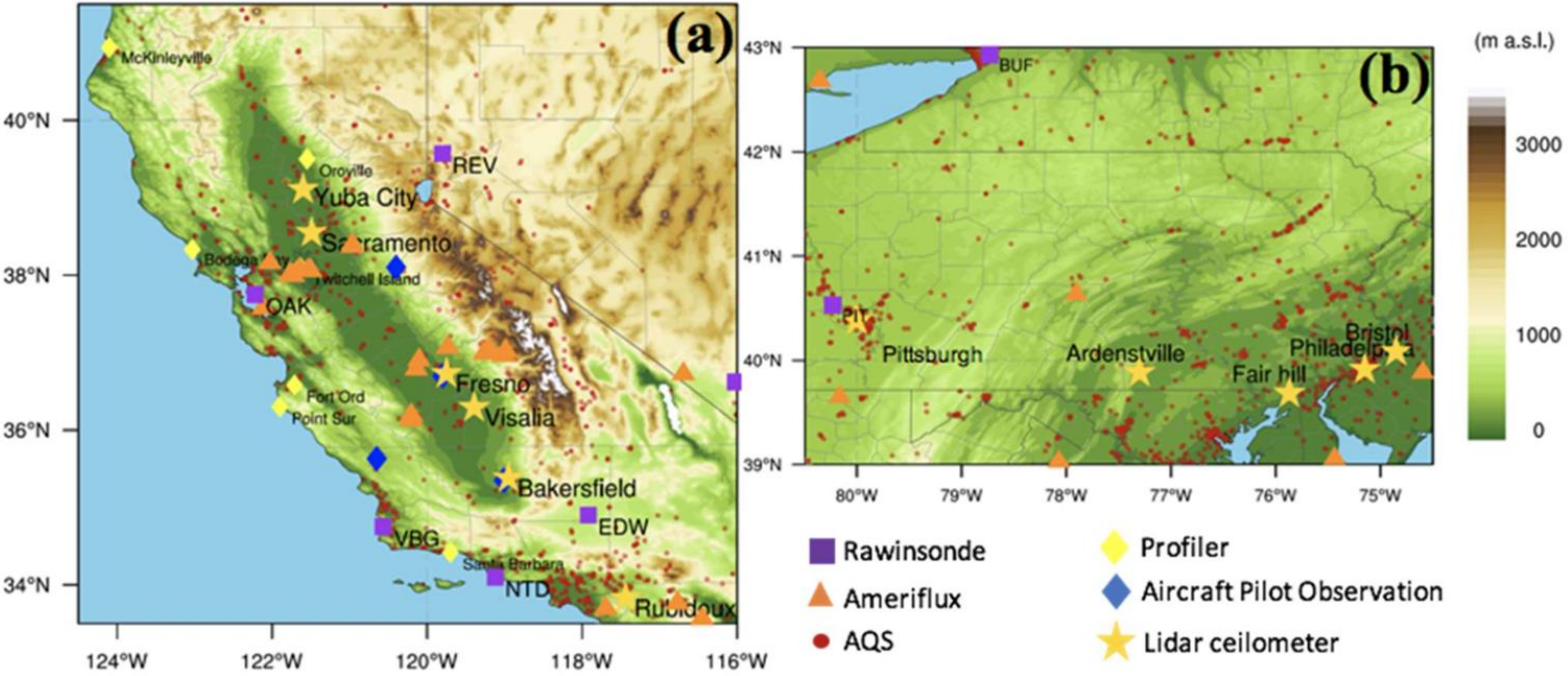


Figure 4. Topographic maps of (a) California and (b) Pennsylvania showing the surface and upper air observation networks, including the National Weather Service (NWS) rawinsonde network, active AmeriFlux sites, the EPA's Air Quality System (AQS) network, the profiler network, the Aircraft Pilot Observation (APOB) network, and the lidar ceilometer network.

Plans

We propose (Figure 1) to:

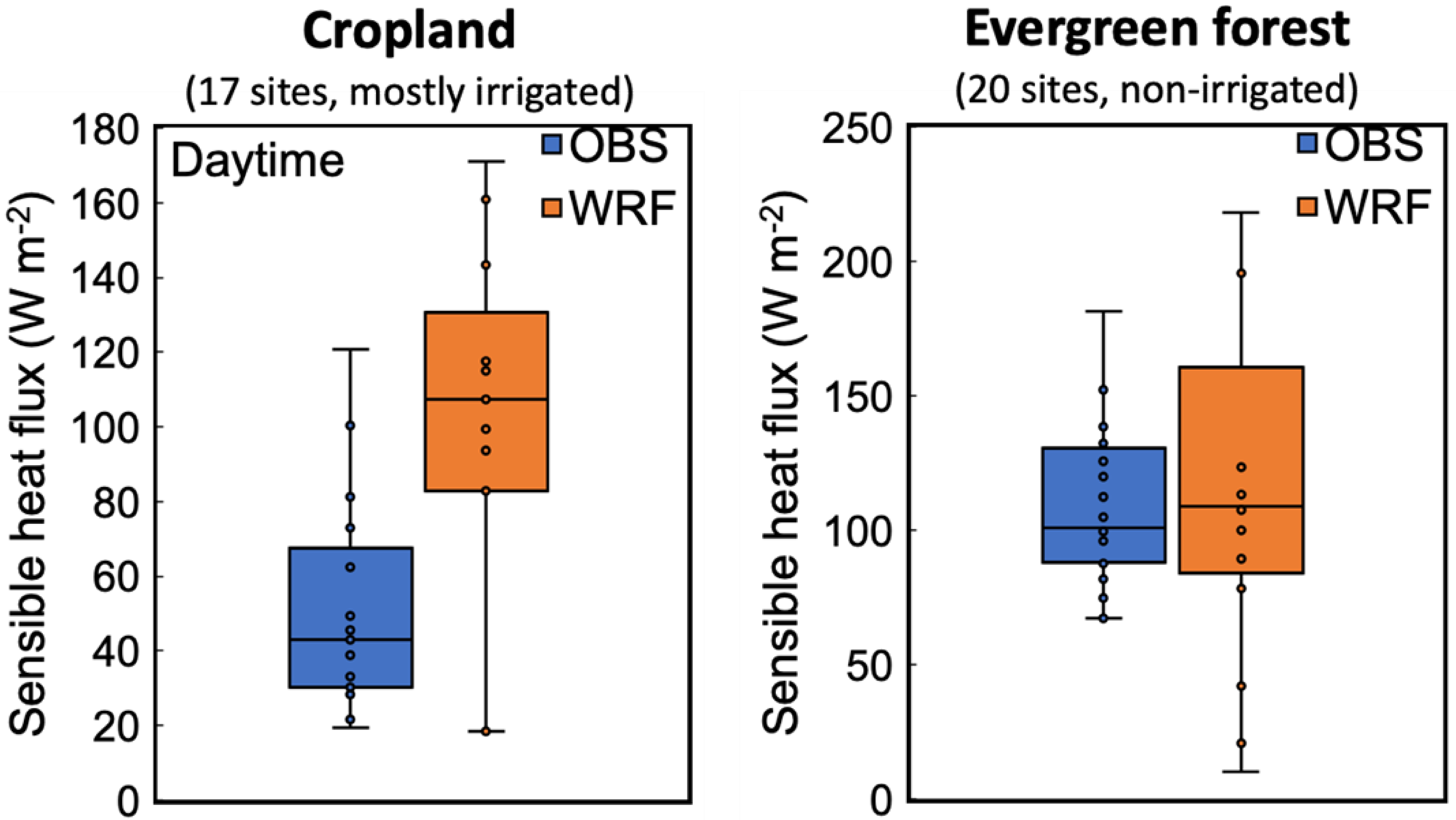
- integrate state-of-the science land surface remote sensing into the numerical weather modeling used in California and Pennsylvania air quality modeling systems. These modeling systems are used to design the SIPs used to attain the NAAQS. States may use these modeling systems to support decision making activities beyond the SIPs

We will then:

- assess the performance of this modeling system by comparing with state-of-the-science observations, including both land surface fluxes and atmospheric boundary layer properties, as well as pollution concentration observations
- explore options within our numerical modeling system that optimize system performance across the spectrum of evaluation metrics, with the aim of improving air quality simulations as a robust tool for guiding decisions concerning emission mitigation
- implement the improved simulation systems in the state air quality modeling systems

Progress

WRF vs. Flux towers



*Comparisons cover the entire 2021 in U.S.

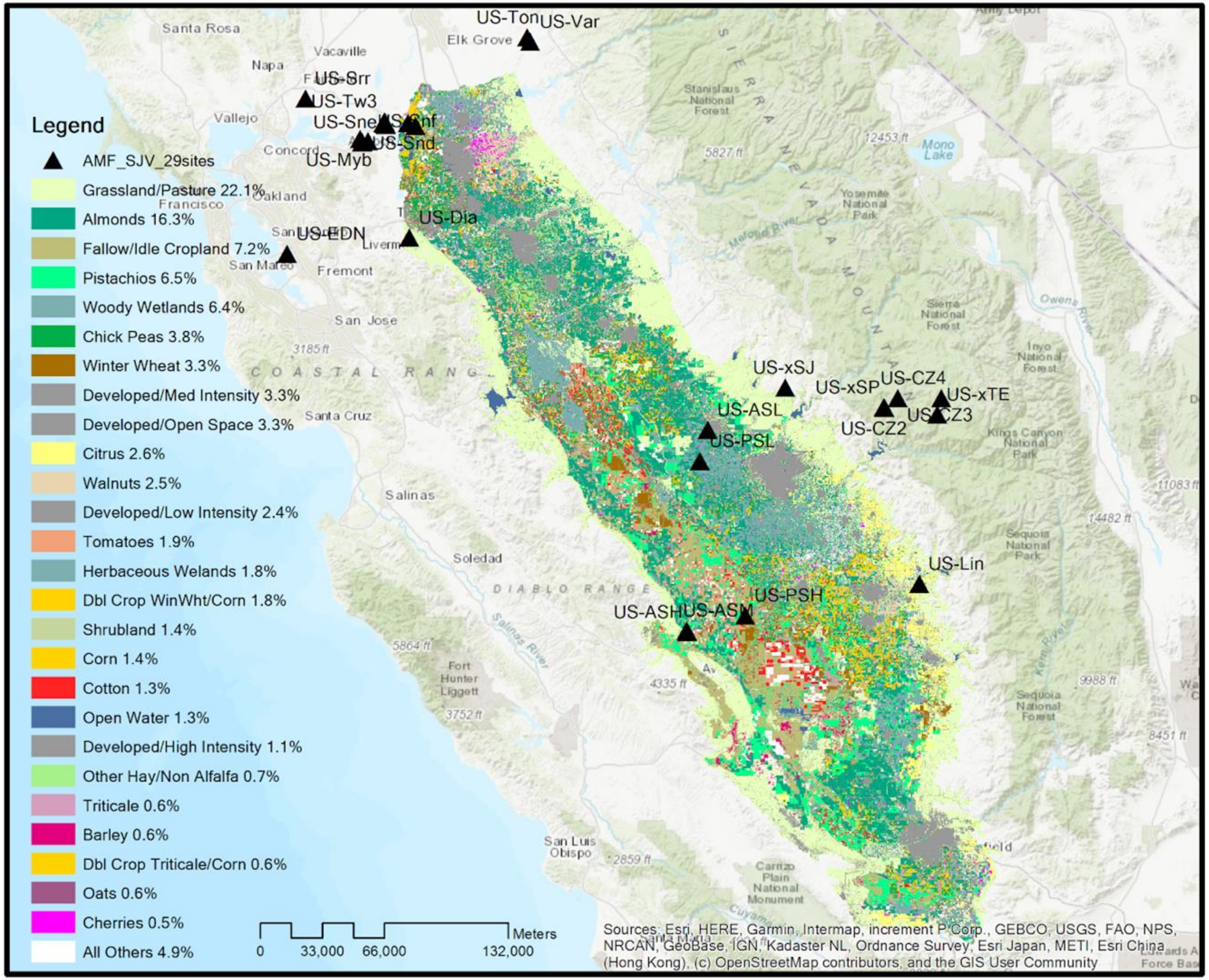
- ❖WRF matches well with measurements at non-irrigated evergreen forest sites.
- ❖WRF significantly overestimates observed sensible heat fluxes at irrigated cropland sites by ~100%

Progress

Flux tower deployments

SJV land cover and existing AmeriFlux sites (triangles)

Two towers will be deployed this Autumn



Supplementary

Earth Observations: Models and observations in blue will be integrated into state modeling systems. Observations in red will be used for modeling system assessment.

NASA land surface remoting sensing	Moderate Resolution Imaging Spectroradiometer (MODIS) on Terra and Aqua satellites and Geostationary Operational Environmental Satellite (GOES): land cover, land surface temperature, snow cover, green vegetation fraction, leaf area index, irrigation intensity; Soil Moisture Active Passive (SMAP) mission: soil moisture, vegetation optical depth; Gravity Recovery and Climate (GRACE) experiment: terrestrial water storage; ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS): land surface temperature, evapotranspiration
Non-NASA land surface remote sensing	Soil Moisture Ocean Salinity (SMOS) and Advanced SCATterometer (ASCAT): soil moisture; Advanced Microwave Scanning Radiometer2 (AMSR2): snow depth
Land surface flux observations	Ameriflux network and eddy-covariance flux sites proposed in this project: H_2O, temperature and radiative energy fluxes
	EPA Air Quality System (AQS) network; California Irrigation Management Information System (CIMIS); Remote Automated Weather Stations (RAWS): incoming solar radiation
Meteorological observations	National Weather Service (NWS), EPA AQS, CIMIS, and RAWS observation networks: surface wind speed, temperature, relative humidity
	CARB Aircraft Pilot Observation program (APOB); NWS rawinsonde network; NOAA radar wind profiler network: temperature, relative humidity and wind profiles, ABL depth
	CARB and PA DEP ceilometer networks: ABL depth, cloud fraction and cloud base height
Air pollutant observations	**Remoting sensing:** MODIS: $PM_{2.5}$; TROPOspheric Monitoring Instrument (TROPOMI): Column NO_2
	Surface: EPA AQS network; CO, NO_x, VOC, $PM_{2.5}$, O_3
	Aircraft: CARB APOB program: O_3; UCB/CARB airborne flux measurement in SJV in summer 2021: NO_x, VOC
Models	NASA Land Information System (LIS); NASA-unified WRF/WRF-ARW; Community Multiscale Air Quality model (CMAQ)

Model spatial domain and resolution

5.1 Model spatial domains and resolutions. We anticipate using similar domains and resolutions to those used at present by CARB and PA DEP. Both states have employed a nested domainapproach that includes: a) a large, 36 km horizontal resolution domain that extends far beyond state boundaries, and b) three to four nested domains with a high-resolution domain over areas of interest (4 km over the SJV, 400 m horizontal resolution over the Monongahela Valley, PA). We will use tiling of the land surface within the atmospheric model grids as needed to capture higher resolution land surface fluxes enabled by remote sensing data inputs. Our three study areas will be the SJV, SWPA and SEPA. We anticipate encompassing all of PA in one domain, with higher resolution subdomains over the SWPA and SEPA. We will consider higher resolution subdomains as options when experimenting with simulation configuration

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Model temporal domain

5.2 Model temporal domains. We have tentatively selected 2021 because this time period will encompass the important air quality problems in both states, enable a robust comparison across modeling systems, and include the new remote sensing data and model assessment that we propose to use in both systems. An entire year is required since NAAQS for $PM_{2.5}$ include a standard for the annual mean concentrations, and $PM_{2.5}$ is a challenge in both states. This will encompass high O_3 periods typically encountered during summer. CARB has confirmed their ability to run preliminary simulations for 2021 for comparison to our work. We will work in advance of PA DEP in this respect.

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Flux tower deployments

5.3 Flux measurements. One exception regarding the time and spatial domain constraints regards flux tower measurements. The number of agricultural flux towers in the southern SJV is limited, as is the number of flux tower measurements within Pennsylvania. The NASA LIS can be run offline (independent of NU-WRF) to compute land surface fluxes. We will deploy two eddy-covariance flux towers in the SJV in 2022 and 2023, sampling a different agricultural cover each year, thus encompassing four additional agricultural sites chosen in collaboration with CARB, and two agricultural sites in Pennsylvania, likely in Lancaster County, in 2024. NASA LIS will be run for these locations and times for evaluation of the LSM flux estimates. While awkward in the project timeline, we believe the data will prove valuable for assessment of the modeling systems. In addition, the MidAtlantic region and the city of Indianapolis (Davis et al, 2017) host flux tower sites that may be outside our model domain, but that can be used to evaluate NASA LIS over surfaces similar to those found in Pennsylvania. Thus as needed we will run NASA LIS for these flux tower locations to extend assessment efforts for Pennsylvania.

Who does what?

Management plan. PI Davis will direct the project.

Co-I Zhang, working with the graduate student and Collaborator Cui, will lead the air quality modeling development, assessment, and implementation at CARB and PA DEP.

Co-I Richardson will supervise flux measurement deployment, and Zhang and the graduate student will maintain operations.

Collaborator Hsu will assist with flux site location and maintenance in California.

Co-I Peng will work with the project postdoc and Zhang on assessment of simulated air quality and impacts on SIP development.

Collaborators Zhong, Fleck, Avise, Cai and Zhan will assist with state modeling system setup at Penn State, evaluation and approval of model performance, and transition of the approved system to state modeling systems.

Collaborators Hsu and Nolan will assist with assembly of ground-based meteorological and air quality observations.

Co-I Blaszczak-Boxe will lead the Environmentors student research effort.

Collaborator Kumar will assist in the set up and evaluation of the NASA LIS system at Penn State.

PI Davis will coordinate weekly Penn State project meetings, inviting collaborators as appropriate, in addition to monthly meetings with state agency partners. Project documents will be shared via OneDrive.

Work, year by year

(more details in the proposal)

Year 1 (1 June, 2022 - 31 May, 2023).

F1) Agricultural flux measurements at 2 sites in the SJV. NASA LIS run offline for these two sites for assessment of land surface fluxes.

1.1) Set up state air quality modeling systems and NASA LIS / Nu-WRF at Penn State, perform baseline comparison with states.

1.2) Meteorological models run for 2021 for California and Pennsylvania study domains.

1.3) Assemble expanded meteorological evaluation data.

1.4) Assessment of state baseline and enhanced meteorological modeling systems vs. expanded observations. Meteorological modeling system reaches ARL 6. Publish [6] the impact of NASA LIS on the meteorological simulations.

1.5) Evaluate surface conditions with remote LST observations

Year 2 (1 June, 2023 - 31 May, 2024)

(more details in the proposal)

F2) Agricultural flux measurements at 2 sites in the SJV. NASA LIS run offline for these two sites for assessment of land surface fluxes.

2.1) Optimize NUWRF configuration to minimize meteorological system biases. States approve meteorological model configurations. Meteorological modeling system achieves ARL 7.

2.2) Set up CMAQ as used by states to interface with the meteorological simulations and perform baseline simulation comparison.

2.3) Run CMAQ for 2021 for each study region using state default and optimized meteorological models. Assess air quality simulations with respect to in situ air quality observations. Air quality simulations achieve ARL 6.

2.4) If needed, consider updates to the atmospheric chemistry modeling system (background, chemistry mechanism, emissions). States approve air quality simulation system. Air quality simulation system achieves ARL 7. Publish the impact of NASA LIS on state air quality simulations, and sensitivity of air quality to model components. Ensemble model uncertainty assessment achieves ARL 6.

Year 3 (1 June, 2024 - 31 May, 2025)

(more details in the proposal)

F3) Agricultural flux measurements at 2 sites in PA. NASA LIS run offline for these two sites for assessment of land surface fluxes.

3.1) Implement upgraded air quality simulation system at CARB and PA DEP.

3.2) Complete documentation of modeling system; train state personnel in system operations.

3.3) Publish an assessment of project model advances on the SIP development process. Integrated air quality modeling and evaluation system achieves ARL 8