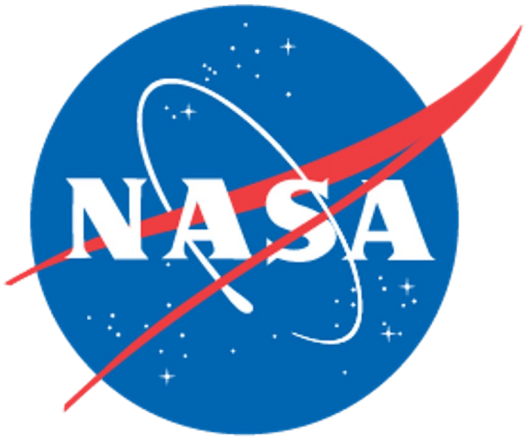

HEALTH & AIR QUALITY

EARTH SCIENCE
APPLIED SCIENCES

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

Grant Number 80NSSC22K1049

Kenneth J. Davis

April 01, 2023

Project Summary

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- Improving Air Quality State Implementation Plans (SIPs) using Land Surface Remote Sensing
- Short title: Improving SIPs using remote sensing
- Project PI: Kenneth J. Davis
- Solicitation: 21-HAQ21
- Project Summary: Working closely with the California Air Resource Board (CARB) and the Pennsylvania Department of Environmental Protection (PA DEP), we aim to incorporate state-of-the-science land surface remote sensing into the numerical weather models used for California and Pennsylvania SIPs, to assess the impact of these changes on land surface fluxes and ABL properties in each state, to adjust model physics and chemistry to achieve optimal regional performance, and 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.
- Geographic Scope: California and Pennsylvania

Earth Observations, Models, and/or Technologies

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Satellite Sensor/Model/Tech.	Product Used	Temporal Coverage and Latency required	Comments
Terra/Aqua MODIS	landcover, albedo, LAI, snow coverage & depth, land-surface temperature, clouds	2018, 2021	/
SMAP	soil moisture, vegetation optical depth	2018, 2021	Soil Moisture Active Passive mission
GEOS series	landcover, land-surface temperature, snow coverage	2018, 2021	Geostationary Operational Environmental Satellite
GRACE	terrestrial water storage	2018, 2021	Gravity Recovery and Climate experiment
ECOSTRESS	land-surface temperature, evapotranspoiration	2018, 2021	ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station
NASA Nu-WRF	Unified Weather Research Forecast model	2018, 2021	/
NASA LIS	Land Information System	2018, 2021	/

Project Partners/Collaborators

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List project Co-Investigators, collaborators, and other partners

Role	Name	Affiliation	Organization Type
Co-Investigators	Wei Peng	Penn State University	University
Co-Investigators	Scott Richardson	Penn State University	University
Co-Investigators	Alex Zhang	Penn State University	University
Collaborator	Sujay Kumar	NASA Goddard Space Flight Center	Federal agency
Collaborator	Jeremy Avise, Chenxia Cai, Yuyan Cui, Yin-Kuang Hsu, Zhan Zhao	California Air Resource Board	State agency
Collaborator	Andrew Fleck, Sean Nolan, Min Zhong	Pennsylvania Department of Environmental Protection	State agency

Project End-users & Stakeholders

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List organization names and organization types

Organization Name	Organization Type	Decision Making Activity
California Air Resource Board	State agency	Improve air quality SIPs based on our optimized modeling systems
Pennsylvania Department of Environmental Protection	State agency	Improve air quality SIPs based on our optimized modeling systems

Engagement plan and recent updates

We have been meeting with our end-users (CARB and PA DEP) every four weeks. We discuss with our partners on regional weather and air quality model simulations, meteorology and surface flux measurements, and model-measurement comparisons regularly during the meetings.

Schedule & Milestones

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Year 1 (1 July, 2022 - 30 June, 2023).

Updated system (NASA LIS / NU-WRF and enhanced meteorological assessment) for SIP air quality modeling starts at ARL 5.

F1) Deploy agricultural flux measurements at 2 sites in the SJV.
Run NASA LIS 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) Run meteorological models for 2021 for California and Pennsylvania study domains.

1.3) Assemble expanded meteorological evaluation data.

1.4) Assess state baseline and enhanced meteorological modeling systems vs. expanded observations.

1.5) Evaluate surface conditions with remote LST observations.

Schedule & Milestones

EARTH SCIENCE
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Year 2 (1 July, 2023 - 30 June, 2024).

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

2.1) Optimize NU-WRF 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

Schedule & Milestones

EARTH SCIENCE
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Year 3 (1 July, 2024 - 30 June, 2025).

F3) Deploy agricultural flux measurements at 2 sites in PA.
Run NASA LIS 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.

Schedule & Milestones

EARTH SCIENCE
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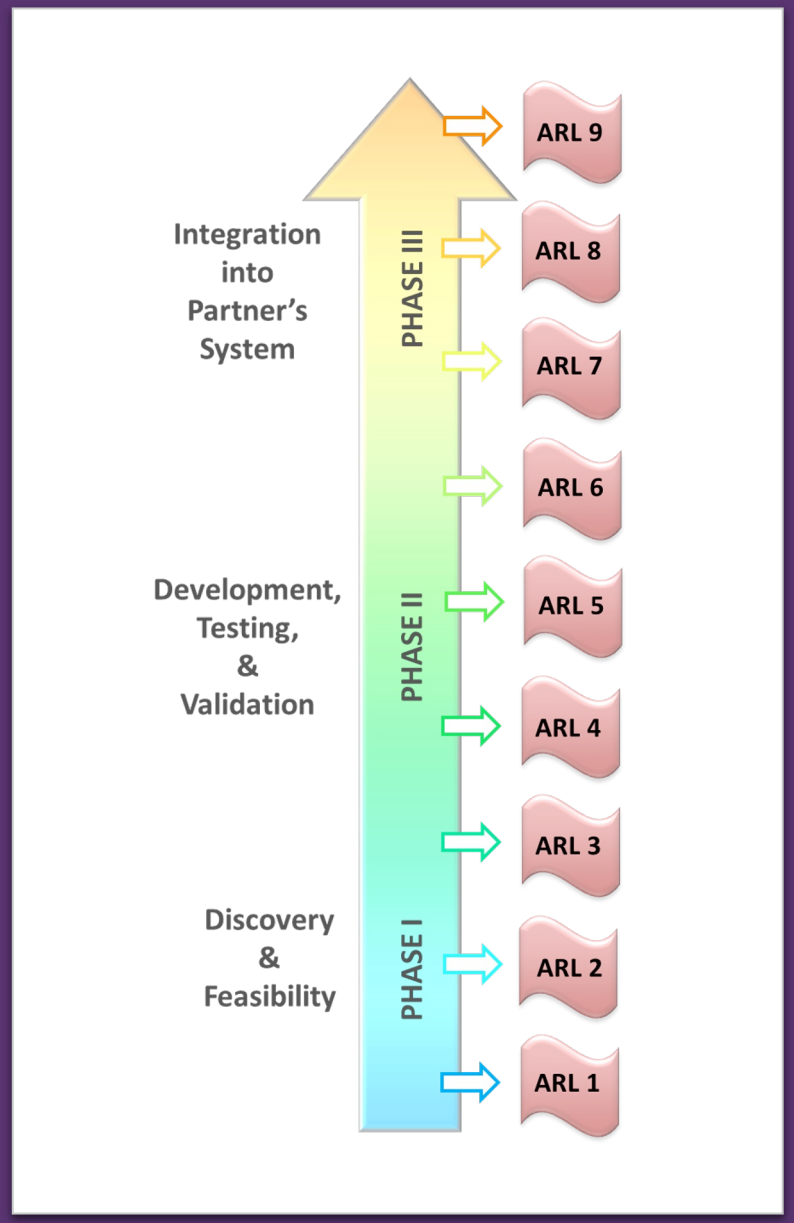
We have done a detailed investigation of land cover and existing Ameriflux sites in both the San Joaquin Valley (SJV), CA and the mid-Atlantic region; We have done a comprehensive evaluation of surface energy flux in the WRF baseline model simulations comparing against measurements at multiple flux sites. These flux sites cover various land-covers, including irrigated cropland, non-irrigated cropland, savanna, and forest, over the SJV in the western U.S. and the mid-Atlantic region in the eastern U.S; We have finished data collections of surface and upper air weather station measurement, wind profiler measurements, radiation measurements, and ceilometer lidar measurement in both CA and PA and started processing the datasets; We have made purchase of two sets of flux tower equipment and made contract for tower site rentals with University of California ARN; We are working on getting computing accounts on the Discover cluster at Goddard center to conduct simulations with the Nu-WRF/LIS system for both CA and PA.



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ARL Performance

- Start-of-Project ARL = 5 *(Jul 2022)*
  - The NASA Land Information System (LIS) has been developed and incorporated into the NASA's Unified WRF system (NU-WRF). The system has been well tested on Discover supercluster in Goddard and has been demonstrated to improve surface fluxes within NU-WRF over CONUS. We thus judge this system to be at an Application Readiness Level (ARL) of 5
- Goal ARL = 8
- Current ARL = 5 *(Mar 2023)*
  - We're setting up and testing the system on Pleiades and Discover superclusters and running it for California and Pennsylvania.

Current ARL-Supporting Evidence

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- The NASA Land Information System (LIS), which assimilates remote sensing of soil moisture, vegetation optical depth, terrestrial water storage, and irrigation intensity, has been shown to improve land surface flux simulations (Kumar et al, 2015; 2016; 2019; 2020), particularly in regions of intensive agriculture and irrigation (Kumar et al, 2015). NASA LIS has been incorporated into the NASA's Unified WRF system (NU-WRF) and run as the land surface model component of NU-WRF. The system has been well tested on Discover supercluster in Goddard and has been demonstrated to improve surface fluxes within NU-WRF over CONUS. We're currently setting up and testing the system on Pleiades supercluster and testing it over California and Pennsylvania. We aim to demonstrate the system in the environments needed by our stakeholders in both California and Pennsylvania.

References:

1.Kumar, S. V., Peters-Lidard, C. D., Tian, et al. (2006), Land information system: An interoperable framework for high resolution land surface modeling, Environmental Modelling & Software, 21(10), 1402-1415. https://doi.org/10.1016/j.envsoft.2005.07.004
2.Kumar, S. V., Peters-Lidard, C. D., Santanello, et al. (2015), Evaluating the utility of satellite soil moisture retrievals over irrigated areas and the ability of land data assimilation methods to correct for unmodeled processes, Hydrol. Earth Syst. Sci., 19(11), 4463-4478 https://doi.org/10.5194/hess-19-4463-2015
3.Kumar, S. V., Zaitchik, B. F., Peters-Lidard, C. D., et al. (2016), Assimilation of Gridded GRACE Terrestrial Water Storage Estimates in the North American Land Data Assimilation System, Journal of Hydrometeorology, 17(7), 1951-1972. https://doi.org/10.1175/jhm-d-15-0157.1
4.Kumar, S. V., Jasinski, M., Mocko, D. M., et al. (2019), NCA-LDAS Land Analysis: Development and Performance of a Multisensor, Multivariate Land Data Assimilation System for the National Climate Assessment, Journal of Hydrometeorology, 20(8), 1571-1593. https://doi.org/10.1175/jhm-d-17-0125.1
5.Kumar, S. V., Holmes, T. R., Bindlish, R., et al. (2020), Assimilation of vegetation optical depth retrievals from passive microwave radiometry, Hydrol. Earth Syst. Sci., 24(7), 3431-3450. https://doi.org/10.5194/hess-24-3431-2020

Challenges and Risks

Rank	Type*	Risk	Mitigation Action	Date first noted/Date resolved (if applicable)
1	PM	Flux equipment delays	Choose Alternative manufacturers	Jul 2022/Nov 2022
2	PM	Flux site identification and access	More survey and discussion with potential collaborators in CA and PA	Jul 2022/Nov 2022
3	PM	Meteorology data access limited or slow	Work with partners to ensure access to relevant meteorological data	Jul 2022/Oct 2022
4	T	NU-WRF / LIS support or run-time problems	NASA Pleiades support staff, NASA GSFC guidance, switch to Discover at GSFC	Sep 2022/Mar 2023
5	T	Meteorology data gathering and model evaluation take longer than planned	Extend meteorology evaluation into year 2, air chemistry into year 3.	Sep 2022
6	T	NU-WRF / LIS / CMAQ degrades air quality simulations wrt state implementations of WRF / CMAQ	Diagnose cause, vary physics and chemistry choices in WRF and CMAQ	Jul 2022
7	ES	NU-WRF / LIS / CMAQ too difficult for states to implement	Work with state and NASA staff to support system implementation	Sep 2022

* Please designate risk type as: Technical (T), Budget (B), End-User/Stakeholder (ES), or Project Management (PM)

Accomplishments during July 2022-March 2023

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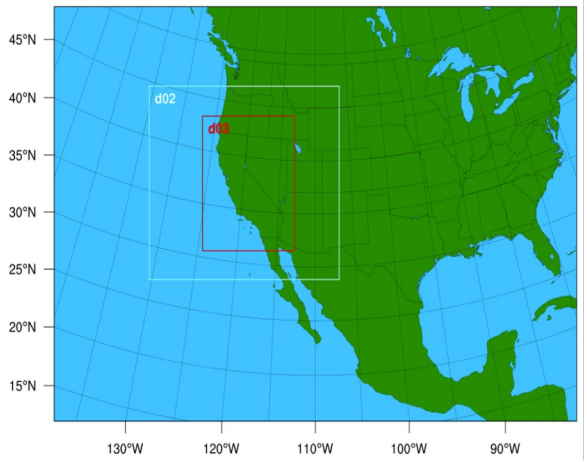
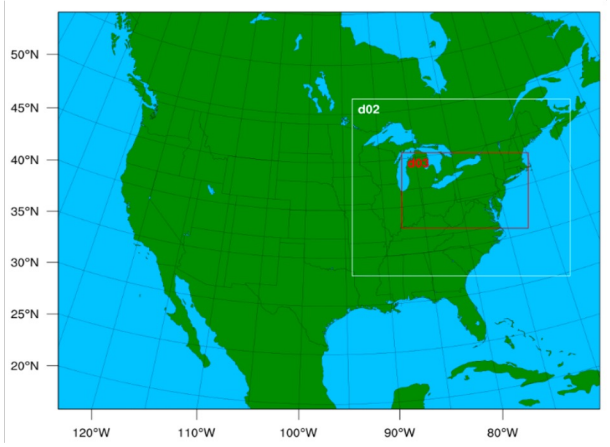
1. We have finished 3-nested-domain high-resolution baseline meteorology simulations with WRF for the San Joaquin Valley in the western U.S. in 2018 and 2021 and high-resolution simulation for the mid-Atlantic region in the eastern U.S. in 2021. These model simulations are being evaluated against in-situ and remote sensing measurements.

Model domains and physics configuration in CA



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]

Model domains and physics configuration in PA



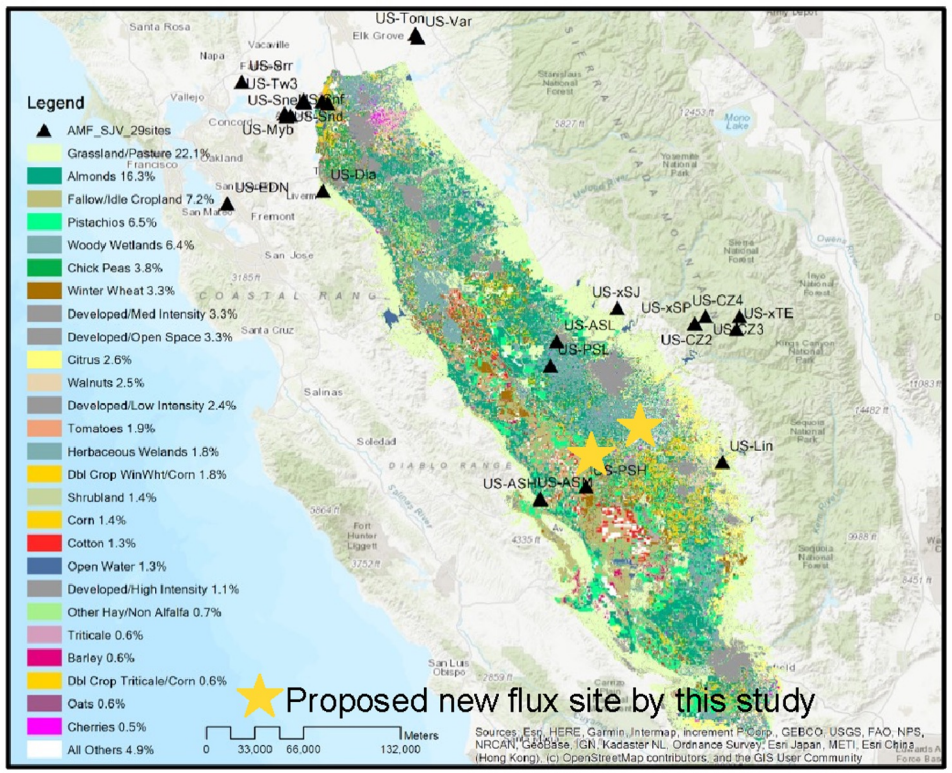
Major Modules	Option	Reference
Microphysics scheme	Morrison 2-mom	*Marrison et al. [2009]*
Cumulus scheme	Kain-Fritsch	*Kain et al. [2004]*
Longwave radiation	RRTMG	*Iacono et al. [2008]*
Shortwave radiation	RRTMG	*Iacono et al. [2008]*
Land-surface physics	Pleim-Xiu	*Xiu and Pleim [2001]*
Urban surface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

Accomplishments during July 2022-March 2023

EARTH SCIENCE APPLIED SCIENCES

2. We have finished data collection of existing eddy-covariance measurement sites, ceilometer sites, wind-profiler, and other meteorological measurements in the San Joaquin Valley, CA and Pennsylvania. Model evaluation against these comprehensive measurements is underway.

Land cover and flux sites in SJV



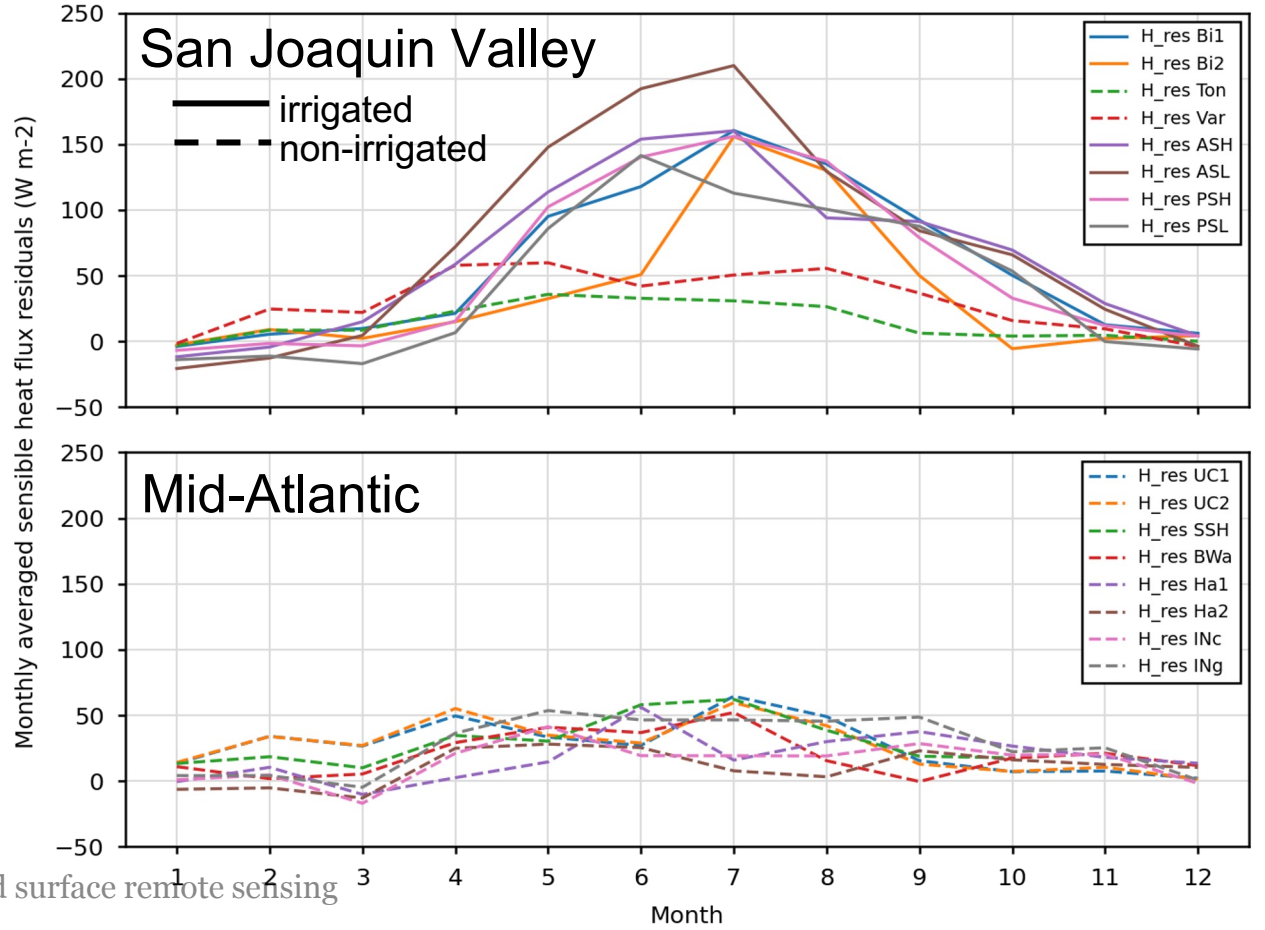
Measurements in California that we compiled
16 eddy covariance flux tower sites
720 surface meteo sites
358 surface radiation sites
6 wind profilers (with available data)
8 rawinsonde sites
5 APOB aircraft measurement sites
7 Ceilometer sites
RECAP aircraft measurement campaign (in July 2021)

Accomplishments during July 2022-March 2023

EARTH SCIENCE APPLIED SCIENCES

3. We have done a comprehensive evaluation of surface energy flux in the WRF baseline model simulations comparing against measurements at sites in irrigated croplands, non-irrigated croplands, savanna, and forests over the San Joaquin Valley and the mid-Atlantic region. A manuscript on these analysis in under preparation.

- Here we show the model-data discrepancies in sensible heat fluxes at sites in the **San Joaquin Valley** in the western U.S. and the **mid-Atlantic region** in the eastern U.S. Irrigation in the San Joaquin Valley (SJV) causes severe overestimation in sensible heat fluxes (solid lines) while the model-data discrepancies are much smaller at non-irrigated sites (dash lines) in the SJV and the mid-Atlantic region. The large overestimate in sensible heat flux in the irrigated SJV region is likely to cause a significant overestimate in boundary layer depth mixing, especially in the summer. NU-WRF with remote sensing of the land surface has the potential to correct the errors in sensible heat flux in the two regions.



Accomplishments during July 2022-March 2023

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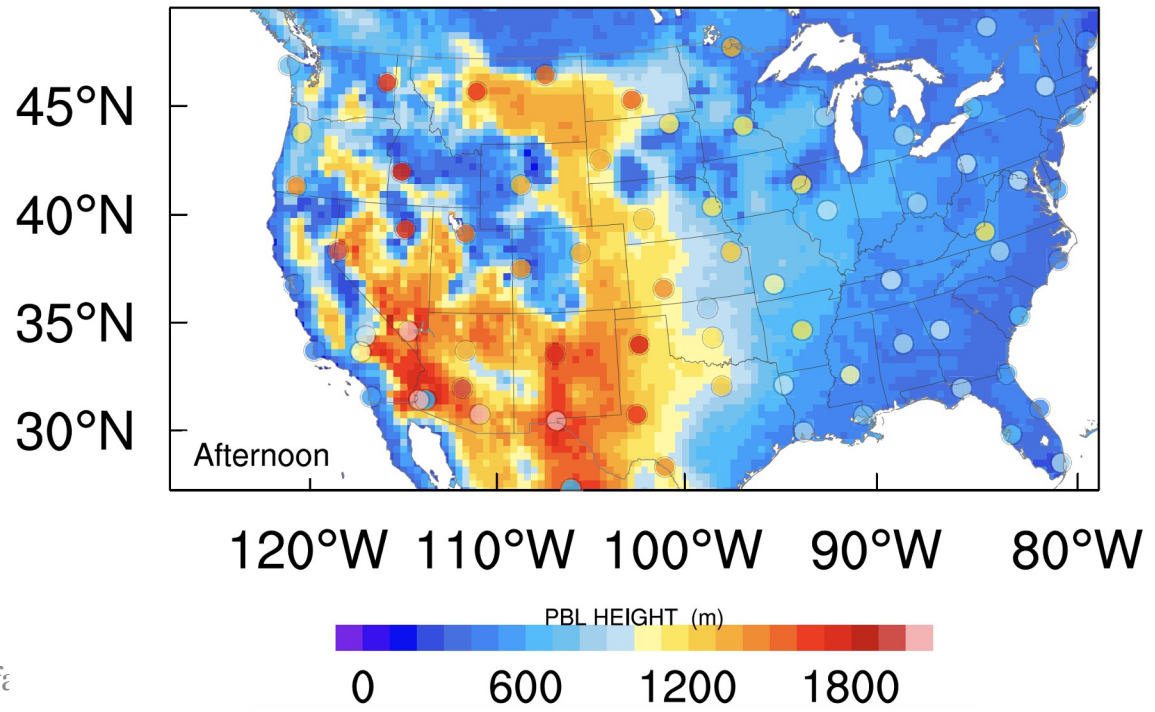
4. We have done a preliminary evaluation of boundary layer height in the WRF baseline model simulations comparing against measurements at rawinsonde sites in the U.S. More model evaluation of boundary layer height derived with ceilometer measurements is underway.

- Here we show the PBLH as simulated with baseline WRF and observed by rawinsonde measurements (derived) in afternoon over the entire U.S. in 2021. The WRF model slightly underestimates "observed" PBLH by ~100-200 m in the mid-Atlantic region whereas overestimates PBLH in costal California by ~100 m. The model also shows elevated PBLH over the irrigated SJV, which might not be the case.

- No rawinsonde site is available in the SJV and very limited sites are in the mid-Atlantic. The ceilometer measurement at multiple sites that we collected will fill the gap in PBLH measurement in both SJV and mid-Atlantic region

WRF simulated PBLH (shadings) vs. Rawinsonde measurement-derived PBLH (dots) in 2021



Accomplishments during July 2022-March 2023

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5. We have identified candidate sites for flux tower deployments in the San Joaquin Valley and purchased two sets of flux tower equipment to be shipped on May 1. The proposed sites are located in the heart of the irrigated area in SJV valley (see the figure in the page 16). We are negotiating a contract for tower site rentals with University of California ARN.

6. Project scientists are mentoring four undergraduate / high school student investigators as part of the Environmentors program. The undergraduates co-mentor the high school students. The students are largely from groups underrepresented in STEM fields. The programs seeks to introduce these students to careers in environmental science.

Presentations and on-going manuscripts

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1. Davis, K.J. Improving air quality state implementation plans using land surface remote sensing, Sep 2022, NASA HAQ meeting.
2. Davis, K.J., Land data assimilation in support of improved regulatory air quality modelling, In AGU Fall Meeting, Dec 2022, Chicago, IL,
3. Wu, F., Improving air quality state implementation plans using land surface remote sensing, Mar 2024, NASA HAQ meeting, Asheville, NC.
4. Zhang, L., Davis, K.J., et al., 2023, Investigation of long-term atmospheric boundary layer heights over CONUS using radiosondes and their comparisons with multiple reanalyses, in preparation
5. Wu, F., Davis, K.J., Zhang, L., et al., 2023, Evaluation of surface energy balance in the WRF model over the western and eastern U.S., in preparation

Collaborations with scientists beyond current Co-Is

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1. Collaboration with UC Berkeley

- We collaborated with Dr. Dennis Baldocchi and his group regarding their eddy-covariance flux measurements at both irrigated and non-irrigated sites in the northern San Joaquin Valley.

2. Collaboration with USDA

- We collaborated with Dr. Raymond Anderson at USDA-ARS at Riverside (CA) on surface flux measurements in California
- We collaborated with Dr. Sarah Goslee and Jeffery Gonet at USDA-ARS at University Park (PA) on surface flux measurements in Pennsylvania
- We have talked with Dr. Matthew Roby at USDA-ARS at Davis (CA) on potential collaborations on surface flux measurements in central valley, CA.

3. Collaboration with UC Davis

- We have talked with Dr. Kosana Suvocarev and Dr. Holly Oldroyd at UC Davis on flux measurements in central valley, CA. The scientists have frequently join our monthly project meetings.

Connection with other projects

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Collaboration with other projects

- We collaborated with the INFLUX (Indianapolis Flux Experiment) project and obtained surface flux at urban sites in the mid-Atlantic region for the use of this study.

Educational efforts

Fan Wu, a Ph.D. student in Meteorology and Atmospheric Science at Penn State, is continuing to make progress toward her Ph.D. qualifying exam.

As noted previously, the project supports four Environmentors student investigations. These high school students, largely from URM groups, are being mentored in a research investigation related to our project to encourage them to pursue further education and careers in environmental science. University undergraduate students (also frequently URMs) serve as co-mentors with one faculty member leading the investigation.