Dr. William F. Holmgren

CONTACT
INFORMATION

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RESEARCH
INTERESTS

Energy, Weather, and Climate
- Tools, data analysis, and algorithms that enable high penetrations of clean energy
- High resolution weather and climate modeling to support regional energy and water stakeholders

Open source science
- Developing open source software for scientific applications
- Systems for data and software sharing that facilitate transparent, robust, and reproducible scientific results

EDUCATION

Ph.D. in Physics, University of Arizona, Tucson, May 2013
M.S. in Physics, University of Arizona, Tucson, May 2010
B.A. in Physics, University of Colorado, Boulder, May 2006

PROFESSIONAL
EXPERIENCE

University of Arizona, Department of Hydrology and Atmospheric Sciences

Assistant Research Professor   December 2016 to present

- Principal investigator of the Solar Forecast Arbiter, funded by the Department of Energy Solar Energy Technologies Office ($1.2M over 3.5 years). The Arbiter enables transparent reporting of solar and net-load forecast performance through an open source software platform, leading to better decision making, incentivizing forecast improvements, and furthering renewables integration. Led proposal development, project reporting, supervised technical implementation, implemented Python code, and wrote extensive documentation and tutorials. Managed 3 professionals at UArizona, 3 subcontractors, and stakeholder communications with dozens of industry professionals.
- Led group of professionals, graduate students, and undergraduates to deliver and enhance solar and wind power forecasts for 2 GW of solar and wind at utilities in the Southwest ($2M over 8 years).
- Led the technical implementation team of the Solar Performance Insight project, a DOE SETO funded effort to standardize assessment of solar plant performance ($80k over 1 year). Interfaced between PI, team members, and the technical team. Primary reviewer of Python analysis code and supporting improvements to pvlib python library.
- Principal investigator of the Expected Solar Power Plant Ramp Tool (ESPRR), a project funded by Salt River Project that calculates solar

power ramp statistics using the NSRDB and regional weather model data ($90k over 1 year).

- Co-advisor for Ph.D. students in Optical Sciences, Applied Math, and Hydrology and Atmospheric Sciences.
- Co-maintainer of the open source pvlib python solar energy modeling tool (over 550 GitHub stars, 480 mailing list subscribers, and 130 literature citations).
- Collaborated with Tucson Electric Power and UArizona social scientists to develop a quantitative model of TEP carbon emissions consistent with 1.5° C and 2.0° global warming targets for TEP's 2020 integrated resource plan.

University of Arizona, Institute for Energy Solutions

Co-Director   March 2021 to present

- Developed strategic initiatives planning documents through synthesizing discussions with stakeholders throughout university community.
- Supervised redevelopment of Institute website.

ACADEMIC
EXPERIENCE

University of Arizona, Department of Atmospheric Sciences

Postdoctoral Research Associate   May 2013 to December 2014

DOE EERE Postdoctoral Fellow   December 2014 to December 2016

- Developed a hybrid forecasting system for photovoltaic power production that combines data from a network of irradiance sensors and PV plants, satellite imagery, and numerical weather models by coordinating research teams in the Department of Atmospheric Sciences, the Department of Physics, and the Renewable Energy Network.
- Created websites to deliver power production forecasts to Tucson Electric Power, Arizona Public Service, and Public Service Company of New Mexico, and a public website with selected point forecasts from the UA high resolution weather model.
- Led the development of a website (sveri.energy.arizona.edu, retired) that shows the real-time mix of renewable and conventional generation in the Southwest U.S. Led and coordinated the seven utilities of SVERI and four web designers and developers.
- Analyzed and quantified solar and wind power variability of the SVERI utilities across a range of temporal and spatial scales.
- Lead developer and maintainer of the open source pvlib python solar energy modeling tooI.

University of Arizona, Department of Physics

Graduate Research Associate   May 2008 to May 2013

- Designed and published a novel experiment to measure the dynamic polarizability and tune-out wavelengths of potassium.

- Designed and published an atom interferometer experiment to measure atomic polarizabilities with 0.3% precision.
- Designed and published a novel method to measure atom beam velocity in an interferometer with improved precision.
- Mentored three graduate students, two of which won NSF GRFP fellowships.
- Mentored four undergraduate students that went on to top graduate schools in physics.
- Assisted the design, data collection, and analysis of experiments to precisely measure the van der Waals potentials of alkali atoms using atom diffraction and the rotation rate of the Earth using atom interferometry.

Graduate Research Assistant   May 2008 to May 2010

- Designed, built, operated and published an atom interferometer experiment to measure atomic polarizabilities with 0.3% precision
- Developed potassium and rubidium atom beam sources
- Mentored two undergraduate students, one of which graduated with honors in Physics in May 2009

Teaching Assistant   August 2007 to May 2008

- Assisted instruction of Physics Methods in Experimental Physics. Motivated and guided weekly and semester-long student projects.
- Mentored students in graduate school application process.

University of Colorado, Department of Physics and JILA

Undergraduate Research and Teaching Assistant Apr 2004 to May 2007

- Worked with a team of 20 people at CU and two large companies to develop a portable atom chip vacuum cell for rapid Bose-Einstein condensate production.
- Co-taught introductory physics classes with graduate students as part of a pilot program to improve physics education.
- Modeled magnetic fields for an atom trap in a unique geometry
- Mentored undergraduate students

Undergraduate Research Assistant   April 2004 to May 2006

- Developed atom chip technology for miniaturized Bose-Einstein condensate experiments
- Developed a cleaner source of atoms and a more effective vacuum pump for rubidium atoms in Bose-Einstein condensate experiments
- Built and maintained electronics systems for use in optical physics experiments including diode laser servo systems, low noise current sources, and photodetectors.
- Built and maintained ultra-high vacuum systems for portable Bose-Einstein condensate systems

University of Colorado, Department of Physics

Learning Assistant   August 2003 to May 2004

- Team-taught introductory physics recitations with a graduate teaching assistant
- Emphasized learning through discovery and logic
- Part of a physics education research project and the STEM-TP program

AWARDS
2014-2016 DOE EERE Postdoctoral Fellowship
2011, 2012 Galileo Circle Fellowships
2011-2012 TRIF Imaging Fellowship
2008-2009 TRIF Photonics Fellowship

PUBLICATIONS   **Selected peer-reviewed journal articles**

T.M. Harty, W.F. Holmgren, and A.T. Lorenzo, *"Probabilistic intra-hour cloud index forecasting with ensemble data assimilation"* to be submitted.

M.A. Crimmins, B. McMahan, W.F. Holmgren, and G. Woodard, *"Tracking precipitation patterns across a western U.S. metropolitan area using volunteer observers: RainLog.Org"* International Journal of Climatology **41**, 4201 (2021).

P.T.W. Bunn, W.F. Holmgren, M. Leuthold, and C.L. Castro, *"Using GEOS-5 forecast products to represent aerosol optical depth in operational day-ahead solar irradiance forecasts for the southwest United States"* Journal of Renewable and Sustainable Energy **12**, 053702 (2020).

T.M. Harty, W.F. Holmgren, A.T. Lorenzo, and M. Morzfeld, *"Intra-hour cloud index forecasting with data assimilation"* Solar Energy **185**, 270 (2019).

W.F. Holmgren, C.W. Hansen, and M.A. Mikofski, *"pvlib python: a python package for modeling solarenergy systems"* Journal of Open Source Software **3**, 884 (2018).

A.T. Lorenzo, M. Morzfeld, W.F. Holmgren, and A.D. Cronin, *"Optimal Interpolation of Satellite and Ground Data for Irradiance Nowcasting at City Scales"* Solar Energy **144**, 466 (2016).

R. Trubko, M.D. Gregoire, W.F. Holmgren, and A.D. Cronin, *"Tune-Out Wavelength Measurement with Atom Interferometry and a Multi-Pass Optical Cavity"* Physical Review A **95**, 052507 (2016).

C.K. Kim, W.F. Holmgren, M. Stovern, and E.A. Betterton, *"Toward Improved Solar Irradiance Forecasts: Derivation of Downwelling Surface Shortwave Radiation in Arizona from Satellite"* Pure and Applied Geophysics **173**, 2535 (2016).

C.K. Kim, W.F. Holmgren, M. Stovern, and E.A. Betterton, *"Toward Improved Solar Irradiance Forecasts: Comparison of Downwelling Surface Shortwave Radiation in Arizona Derived from Satellite with the Gridded Datasets"* Pure and Applied Geophysics **173**, 2929 (2016).

C.K. Kim, M. Leuthold, W.F. Holmgren, A.D. Cronin, E.A. Betterton, *"Toward Improved Solar Irradiance Forecasts: a Simulation of Deep Planetary Boundary Layer with Scattered Clouds Using the Weather Research and Forecasting Model"* Pure and Applied Geophysics, 1 (2015).

A.T. Lorenzo, W.F. Holmgren, and A.D. Cronin, *"Irradiance forecasts based on an irradiance network, cloud motion, and spatial averaging"* Solar Energy **122**, 1158 (2015).

M.D. Gregoire, I. Hromada, W.F. Holmgren, R. Trubko, and A.D. Cronin, *"Measurements of the ground-state polarizabilities of Cs, Rb, and K using atom interferometry"* Physical Review A **92**, 052513 (2015).

R. Trubko, J. Greenberg, M.T. St. Germaine, M.D. Gregoire, W.F. Holmgren, I. Hromada, and A.D. Cronin, *"Atom Interferometer Gyroscope with Spin-Dependent Phase Shifts Induced by Light near a Tune-Out Wavelength"* Physical Review Letters **114**, 140404 (2015).

I. Hromada, R. Trubko, W.F. Holmgren, M.D. Gregiore, and A.D. Cronin, *"de Broglie wave-front curvature induced by electric-field gradients and its effect on precision measurements with an atom interferometer"* Physical Review A **89**, 033612 (2014).

W.F. Holmgren, R. Trubko, I. Hromada, and A.D. Cronin, *"Measurement of a Wavelength of Light for Which the Energy Shift for an Atom Vanishes"* Physical Review Letters **109**, 243004, (2012).

W.F. Holmgren, I. Hromada, C.E. Klauss, and A.D. Cronin, *"Atom beam velocity measurements using phase choppers"* New Journal of Physics **13**, 115007 (2011).

V.P.A. Lonij, C.E. Klauss, W.F. Holmgren, and A.D. Cronin, *"Can atom-surface potential measurements test atomic structure models?"*, Journal of Physical Chemistry **115**, 7134 (2011).

V.P.A. Lonij, C.E. Klauss, W.F. Holmgren, and A.D. Cronin, *"Atom diffraction reveals the impact of atomic core electrons on atom-surface potentials"*, Physical Review Letters **105**, 233202 (2010).

W.F. Holmgren, M.C. Revelle, V.P.A. Lonij, and A.D. Cronin *"Absolute and ratio measurements of the polarizability of Na, K, and Rb with an atom interferometer"*, Physical Review A **81**, 053607 (2010).

V.P.A. Lonij, W.F. Holmgren, and A.D. Cronin, *"Magic ratio of window width to grating period for van der Waals potential measurements using material gratings"*, Physical Review A **80**, 062904 (2009).

Selected conference proceedings

C.W. Hansen, W.F. Holmgren, A. Tuohy, J. Sharp, A.T. Lorenzo, L.J. Boeman, A. Golnas, *"The Solar Forecast Arbiter: An Open Source Evaluation Framework for Solar Forecasting"* 46th IEEE Photovoltaic Specialist Conference (2019).

M. Dzurick, B.G. Potter, Jr., W.F. Holmgren, K. Simmons-Potter, *"Enhanced Photovoltaic Power Model Fidelity Using On-Site Irradiance and Degradation-Informed Performance Input"* 46th IEEE Photovoltaic Specialist Conference (2019).

B.G. Potter, Jr., K. Simmons-Potter, W.F. Holmgren *"Broad-Time-Horizon Solar Power Prediction and PV Performance Degradation Research at the University of Arizona"* 45th IEEE Photovoltaic Specialist Conference (2018).

W.F. Holmgren, C.W. Hansen, J.S. Stein, M. Mikofski *"Review of open source tools for PV modeling"* 45th IEEE Photovoltaic Specialist Conference (2018).

W.F. Holmgren, A.T. Lorenzo, C.W. Hansen, *"Comparison of PV Power Forecasts Using PVLib-Python"* 44th IEEE Photovoltaic Specialist Conference (2017).

M. Mikofski, C.W. Hansen, W.F. Holmgren, G. Kimball, *"Variability in Clear Sky Irradiance Due to Aerosol Optical Depth and Precipitable Water"* 44th IEEE Photovoltaic Specialist Conference (2017).

W.F. Holmgren and D.G. Groenendyk, *"An Open Source Solar Power Forecasting Tool Using PVLIB Python"* 43rd IEEE Photovoltaic Specialist Conference (2016).

A.T. Lorenzo, M. Morzfeld, W.F. Holmgren and A.D. Cronin, *"Optimal Interpolation of Satellite Derived Irradiance and Ground Data"* 43rd IEEE Photovoltaic Specialist Conference (2016).

J.S. Stein, W.F. Holmgren, J. Forbess, and C.W. Hansen *"PVLIB: Open Source Photovoltaic Performance Modeling Functions for Matlab and Python"* 43rd IEEE Photovoltaic Specialist Conference (2016).

W.F. Holmgren, R.W. Andrews, A.T. Lorenzo, and J.S. Stein, *"PVLIB Python 2015"* 42nd IEEE Photovoltaic Specialist Conference (2015).

W.F. Holmgren, A.T. Lorenzo, M. Leuthold, C.K. Kim, A.D. Cronin, and E.A. Betterton, *"An Operational, Real-Time Forecasting System for 250 MW of PV Power Using NWP, Satellite, and DG Production data"* 40th IEEE Photovoltaic Specialist Conference (2014).

D. Cormode, W. Richardson, A. Lorenzo, W.F. Holmgren, A. Cronin, *"Observed Fluctuations in Output from a Regional Fleet of PV Power Plants used to Compute Hourly Schedules of Spinning Reserve Requirements"* 29th European Photovoltaic Solar Energy Conference (2014).

A.T. Lorenzo, W.F Holmgren, and A.D. Cronin, *"Short-term PV Power Forecasts Based on a Real-Time Irradiance Monitoring Network"* 40th IEEE Photovoltaic Specialist Conference (2014).

Non-refereed articles
A.D. Cronin and W.F. Holmgren, *"Matter waves in a new light"* Nature Physics **9**, 137 (2013).

SVERI Variability Analysis

PATENTS	*Solar irradiance measurement system and weather model incorporating results of such measurement*, V. Lonij, W.F. Holmgren, A. Cronin, E. Betterton, M. Leuthold, No. 14/090602.
	Alkali metal dispenser and uses for same, S.E. McBride, S.A. Lipp, J.J. Michalchuk, D.Z. Anderson, W.F. Holmgren, M.B. Squires, No. 7955551.
SELECTED PRESENTATIONS AND POSTERS	AMS 2021, Virtual Poster: *The Solar Forecast Arbiter enables reproducible irradiance, power, and net load forecast analysis.* WFH, A.T. Lorenzo, L. Boeman, C.W. Hansen, A. Tuohy, J. Sharp, A. Wigington, D. Larson, Q. Wang, A. Golnas
	IEA Task 36 Wind Forecasting 2020, Virtual Talk: *The Solar Forecast Arbiter.* WFH, J. Sharp
	Department of Hydrology and Atmospheric Sciences Colloquium, University of Arizona, 2020, Virtual Talk: *The Solar Forecast Arbiter.*
	DOE Solar Energy Technologies Office Solar Forecasting 2 Project Review, 2019, Talk: *The Solar Forecast Arbiter.*
	AMS 2019, Talk: *The Solar Forecast Arbiter.* WFH, A.T. Lorenzo, C.W. Hansen, J. Sharp, A. Tuohy, A. Golnas
	AMS 2019, Poster: *Benchmark Solar Power Forecasts.* WFH, A.T. Lorenzo, C.W. Hansen, J. Sharp, A. Tuohy

EPRI Load Forecasting Workshop, 2018, Talk: *The Solar Forecast Arbiter.*

Energy Systems Integration Group Meteorology and Market Design Workshop, 2018 Talk: *An Open Source Framework for Solar Forecast Evaluation.*

PVPMC 2018 Talk: *Review of open source tools for PV modeling.* WFH, C. Hansen, J. Stein, M. Mikofski

AMS 2017 Poster: *Utility Scale Solar and Wind Power Variability in the Southwest United States.* WFH, A.T. Lorenzo

AMS 2017 Poster: *An Open Source Solar Power Forecasting Tool Using PVLIB Python.* WFH, A.T. Lorenzo, D.G. Groenendyk

PVPMC 2016 PVLIB for Matlab and Python Users Meeting Talk: *PVLIB Python Design and Development.*

Department of Applied Mathematics Colloquium, University of Arizona, 2016, Talk: *UArizona Renewable Power Forecasting*

Department of Atmospheric Sciences Colloquium, University of Arizona, 2015, Talk: *UArizona Renewable Power Forecasting*

W.F. Holmgren, M. Leuthold, C.K. Kim, A.T. Lorenzo, E.A. Betterton, and A.D. Cronin, *"An Operational Forecasting System for Renewable Power in the Southwest US Using NWP, Satellite Imagery, and DG PV Production Data"* 95th American Meteorological Society Meeting (2015).

Arizona Corporation Commission Workshop on Emerging Technologies, 2014, Talk: *Real-Time Renewable Power Forecasting*

Utility Variable-Generation Integration Group, Workshop on VG Forecasting Applications to Power System Planning and Operations, 2014, Talk: *Real-Time Renewable Power Forecasting*

Tucson Electric Power Integrated Resource Plan, 2013, Talk: *Real-Time PV Power Forecasting* WFH, T. Burhans.

Pima County Department of Environmental Quality Advisory Council, 2013, Talk: *Real-Time Renewable Power Forecasting* WFH, M. Leuthold

SERVICE   Co-maintainer of open source pvlib python solar energy modeling library
Reviewer for Journal Renewable and Sustainable Energy, IEEE Transactions and Sustainable Energy, Solar Energy, Journal of Open Source Software
Guest lecturer for atmospheric sciences, math, and engineering classes

TECHNICAL SKILLS   Software packages

- Scientific Python stack (python, numpy, scipy, pandas): data processing and analysis, software packaging
- git and GitHub: version control and collaborative software development
- HTML, CSS, PHP, Javascript, D3, jquery, MySQL: static and interactive website design integrated with database queries and management
- Microsoft Office, LaTeX: proposals, reports, publications, presentations, budget management

Electronics systems including data acquisition systems, servo systems, low noise current sources, and photodetectors.