Collaborative Research to Advance Analysis, Forecast, and Decision Support Services for High-Impact Weather Events

Project Area Being Addressed:

Improving the lead time and accuracy of forecasts and warnings for high-impact weather, water, and climate events

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Final Project Report
Award Period: 1 July 2017 – 30 June 2021

1. Introduction

This is the final project report for NOAA Award NA17NWS4680001, covering the period from 1 July 2017 – 30 June 2021. Specific goals for this project were:

- To comprehensively verify operational numerical forecast systems and next-generation convection-allowing models and ensembles to improve forecasts and warnings of high-impact precipitation and wind events over the western U.S.
- To develop improved techniques for downscaling QPF and PQPF produced by coarser-resolution numerical forecast systems and ensembles for use in operational forecasts and hydrologic models over areas of complex terrain.
- To utilize high spatial and temporal resolution mesonet observations to evaluate and improve data fusion techniques for nowcasting damaging weather conditions arising from mesoscale convective systems, gravity waves, and terrain-flow interactions.

Significant progress was made in each of these areas, as summarized below. Publications, presentations, and theses/dissertations may appear more than once if the work spanned multiple research areas.

2. Verification of operational models and ensembles

a. Accomplishments and contributions

We made significant contributions to knowledge of the capabilities and limitations of convection allowing models, global precipitation downscaling, and NCEP operational model upgrades. These contributions focused, in particular, on precipitation and fire-weather parameters over complex terrain, including the western CONUS and Alaska, providing useful guidance for operational forecasters and model developers. Students who contributed to this research are now working in various positions in the weather enterprise including in the NOAA/National Weather Service: Brian Blaylock (Naval Research Laboratory), Marcel Caron (NCEP), Kevin Dougherty (NCEP), Tom Gowan (Spire Inc.), Wyndam Lewis (Meteorological Solutions, Inc.), Taylor Gowan (née McCorkle, DTN Weather), and Mike Wessler (NWS).

Specific contributions to improved forecasting and operational model development include the following:

- Documentation of widespread dry biases in GEFS cool-season precipitation forecasts at mountain locations in the western United States and the advantages of climatological downscaling for reducing such biases and improving forecast skill, including probabalistic quantitative precipitation forecasts (Lewis et al. 2017).
- Identification of the capabilities and limitations of mountain precipitation forecasts produced by a convective allowing ensemble, the NCAR Ensemble, and operational forecast systems (e.g., HRRR, NAM, GFS, SREF) over the western United States. Significant advantages for high-resolution models were identified, although the 10-member NCAR ensemble was not as proabilistically skillful as

the full 26-member SREF ensemble due to insufficient spread (Gowan et al. 2018).

- Analysis of how recent upgrades to the HRRR and GFS affected cool-season precipitation performance and biases over the western United States. Results were consistent with steady or improving NCEP model performance and useful to forecasters concerned with possible shifts in model bias and performance (Caron and Steenburgh 2020).
- Comparison of lightning forecasts from the HRRR with geostrationary lightning mapper observations, which illustrated a novel way for new observing tools to validate convective storm forecasts and the need for forecasters to use HRRR lightning forecasts for general tendencies rather than specific local prediction (Blaylock and Horel 2020).
- Examination of heavy California precipitation events from the HRRR and Navy COAMPS models that produced new ways to diagnose large volumes of model data and found that the HRRR model had superior accuracy compared to the COAMPS and NAM-3km models (Dougherty et al. 2021).
- Implemenation of approaches to overcome bottlenecks downloading large volumes of NCEP model output in GRIB2 format by reformatting GRIB2 model output to a cloud-compatible file type, Zarr, that is stored using the Amazon Web Service (AWS) Simple Storage Service (S3) and available publicly through the Amazon Sustainability Data Initiative and NOAA Open Data Program (Gowan et al. 2021).

b. Related peer-reviewed publications

Blaylock, B. K., and J. D. Horel, 2020: Comparison of lightning forecasts from the High-Resolution Rapid Refresh model to geostationary lightning mapper observations. *Wea. Forecasting*, **35**, 401–416. https://doi.org/10.1175/WAF-D-19-0141.1.

Caron, M., and W. J. Steenburgh, 2020: Evaluation of recent NCEP operational model upgrades for cool-season precipitation forecasting over the western conterminous United States. *Wea. Forecasting*, **35**, 857–877. https://doi.org/10.1175/WAF-D-19-0182.1.

Dougherty, K. J., J. D. Horel, and J. E. Nachamkin, 2021: Forecast skill for California Heavy Precipitation Events from the High-Resolution Rapid Refresh Model and the Coupled Ocean-Atmospheric Mesoscale Prediction System. *Wea. Forecasting*, in review.

Gowan, T. A., J. Horel, A. Jacques, 2021: Using cloud computing to analyze model output archived in ZARR format. *Journal of Atmospheric and Oceanic Technology*. In review.

Gowan, T. M., W. J. Steenburgh, and C. S. Schwartz, 2018a: Validation of mountain precipitation forecasts from the convection-permitting NCAR Ensemble and operational forecast systems over the western United States. *Wea. Forecasting*, **33**, 739–765. https://doi.org/10.1175/WAF-D-17-0144.1.

Lewis, W. R., W. J. Steenburgh, T. I. Alcott, and J. J. Rutz, 2017: GEFS precipitation forecasts and the implications of statistical downscaling over the western United States. *Wea. Forecasting*, **32**, 1007–1028. https://journals.ametsoc.org/view/journals/wefo/32/3/waf-d-16-0179_1.xml.

McCorkle, T., J. Horel, A. Jacques, T. Alcott, 2018: Evaluating the experimental High-Resolution Rapid Refresh–Alaska modeling system using USArray pressure observations. *Wea. Forecasting*, **33**, 933–953. https://doi.org/10.1175/WAF-D-17-0155.1.

c. Related conference presentations

Dougherty, K. J., J. Nachamkin, and J. Horel, 2020: Evaluation of the HRRR model and COAMPS during atmospheric river events in California. *30th Conference on Weather Analysis and Forecasting (WAF)/26th Conference on Numerical Weather Prediction*, Amer. Meteor. Soc., Boston, MA.

Gowan, T. M., and W. J. Steenburgh, 2017a: Overview of the NCAR High-resolution (3-km) Ensemble and validation of its quantitative precipitation forecasts over complex terrain in the western US. *28th Conference on Weather Analysis and Forecasting/24th Conference on Numerical Weather Prediction*, Amer. Meteor. Soc., Seattle, WA.

Gowan, T. M., and W. J. Steenburgh, 2017b: Validation and intercomparison of quantitative precipitation forecasts from the NCAR High-Resolution (3-km) Ensemble and NCEP and ESRL operational models over the western US. *28th Conference on Weather Analysis and Forecasting/24th Conference on Numerical Weather Prediction*, Amer. Meteor. Soc., Seattle, WA.

Gowan, T. M., W. J. Steenburgh, and C. S. Schwartz, 2018b: Validation of mountain precipitation forecasts from the convection-permitting NCAR Ensemble and operational forecast systems over the western United States. *29th Conference on Weather Analysis and Forecasting/25th Conference on Numerical Weather Prediction*, Amer. Meteor. Soc., Denver, CO.

Gowan, T. M., W. J. Steenburgh, and C. S. Schwartz, 2018c: Validation of mountain precipitation forecasts from the convection-permitting NCAR Ensemble and operational forecast systems over the western United States. *18th Conference on Mountain Meteorology*, Amer. Meteor. Soc., Santa Fe, NM.

McCorkle, T. A., J. D. Horel, and B. K. Blaylock, 2018: Communicating fire weather risks at short lead times using the High-Resolution Rapid Refresh forecast modeling system. *Special Symposium on Impact-Based Decision Support Services*, Amer. Meteor. Soc., Austin, TX.

Steenburgh, W. J., and M. Caron, 2020: Recent upgrades of the operational HRRR and GFS: Are cool-season precipitation forecasts improving over the mountain west? *30th Conference on Weather Analysis and Forecasting (WAF)/26th Conference on Numerical Weather Prediction*, Amer. Meteor. Soc., Boston, MA.

Wessler, M., J. Horel, and C. Galli, 2018: Analyzing extreme weather in complex terrain across the western United States. *18th Conference on Mountain Meteorology*, Amer. Meteor. Soc., Santa Fe, NM.

d. Related dissertations and theses

Blaylock, B., 2019: *High-Resolution Rapid Refresh Model Data Anlystics for Wildland Fire Weather Assessment*. Ph.D. Dissertation. University of Utah.

Caron, M., 2019: *Evaluation of cool-season precipitation forecasts produced over the western continental United States by experimental NCEP modeling systems*. M.S. Thesis. University of Utah.

Dougherty, K., 2020: *Evaluation of the High-Resolution Rapid Refresh Model and the Coupled Ocean-Atmosphere Mesoscale Prediction System during Atmospheric River Events in California.* M.S. Thesis. University of Utah.

Gowan, T. M., 2017: *Validation of mountain precipitation forecasts from the NCAR convection-permitting ensemble and operational forecast systems over the western United States*. M.S. Thesis. University of Utah.

Lewis, W. R., 2016: *GEFS precipitation forecasts and the implications of statistical downscaling over the western United States*. M.S. Thesis. University of Utah.

McCorkle, T. A., 2018: *An Evaluation of the Experimental High-Resolution Rapid Refresh – Alaska Modeling System during Winter 2017*. M. S. Thesis. University of Utah.

Wessler, M., 2018: *Analyzing Extreme Weather Situations across the western United States: Rapid Cooling and Elevated Wildfire Risk Episodes*. M. S. Thesis. University of Utah.

3. Improved techniques for downscaling

a. Accomplishments and contributions

Early in the project, we completed a major study illustrating the advantages of using climatological downscaling to improve lower resolution ensemble forecasts over the complex terrain the western CONUS (Lewis et al. 2017). Such an approach is simple and straightforward but does not account for variations in orographic precipitation gradient (OPG) from day to day. Motivated by this work, we completed a detailed study describing the spatio-temporal variations in orographic precipitation gradients (OPG) over the western CONUS (Bohne et al. 2020a). This work describes daily variations in OPG, including departures from climatological values, that are important for operational forecasting. We are now working to develop techniques to apply this knowledge to operational analyses and forecasts with support from our new CSTAR grant (NA20NWS4680046). Lucas Bohne who contributed to this research graduated and is now working as an Environmental Scientist in the Division of Air Quality at the Utah Department of Environmental Quality.

b. Related peer-reviewed publications

Bohne, L., C. Strong, and W. J. Steenburgh, 2020a: Climatology of orographic precipitation gradients in the contiguous western United States. *J. Hydrometeor.*, **21**, 1723–1740. doi: https://doi.org/10.1175/JHM-D-19-0229.1.

Lewis, W. R., W. J. Steenburgh, T. I. Alcott, and J. J. Rutz, 2017: GEFS precipitation forecasts and the implications of statistical downscaling over the western United States. *Wea. Forecasting*, **32**, 1007–1028. https://journals.ametsoc.org/view/journals/wefo/32/3/waf-d-16-0179_1.xml.

c. Related conference presentations

Bohne, L., C. Strong, and W.J. Steenburgh, 2020b. Potential for downscaling precipitation forecasts using orographic precipitation gradients in the western United States. *30th Conference on Weather Analysis and Forecasting/26th Conference on Numerical Weather Prediction, American Meteorological Society*, Boston, Massachusetts.

d. Related dissertations and theses

Bohne, L., 2020: Climatology of Orographic Precipitation Gradients and Application to Quantitative Precipitation Forecast Downscaling over the Western United States. M.S. Thesis. University of Utah.

4. Data fusion for nowcasting

a. Accomplishments and contributions

Throughout the project, we collaborated with NWS field offices and MADIS staff to improve access to mesonet observations around the nation from over 50,000 locations. This work was also supported by the NWS National Mesonet Program via a subcontract with Synoptic Data, PBC. We answered questions, identified new data resources, and improved software to minimize the latency between when observations are taken and when they are available to field offices. This involved typically dealing with more than a dozen issues per week, some of which were time consuming to resolve or to add data from newly deployed sensors.

We developed procedures to store model datasets in more efficient and acessible formats to benefit access by operational staff, model developers, and researchers. In particular, we developed techniques to improve access to archived and real-time HRRR model forecasts, most recently in highly compressed "zarr" format on AWS cloud resources as part of the NOAA Open Data Program (https://registry.opendata.aws/noaa-hrrr-pds/). This work is summarized in two peer reviewed papers (Blaylock et al. 2018; Gowan et al. 2021).

Students who contributed to this research are now working in various positions in the weather enterprise including Brian Blaylock (Naval Research Laboratory), Taylor Gowan (née McCorkle, DTN Weather), and Kevin Dougherty (NCEP).

b. Related peer-reviewed publications

Blaylock, B., J. Horel, C. Galli, 2018: High-Resolution Rapid Refresh Model Data Analytics Derived on the Open Science Grid to Assist Wildfire Weather Assessment. *J. Atmos. Ocean. Technol.*, **35**, 2213–2227. https://journals.ametsoc.org/doi/abs/10.1175/JTECH-D-18-0073.1.

Gowan, T., J. Horel, A. Jacques 2021: Using cloud computing to analyze model output archived in ZARR format. *J. Atmos. Ocean. Technol*. In review.

Gowan, T. A., and J. D. Horel, 2020: Evaluation of IMERG-E precipitaiton estimaes for fire weather applications in Alaska. *Wea. Forecasting*, **35**, 1831–1843.

c. Related conference presentations

Blaylock, B. K., and J. D. Horel, 2018: High-Resolution Rapid Refresh model analytics in a high-performance computing environment. *17th Conf on Artificial and Computational Intelligence and its Applications to the Environmental Sciences*, Amer. Meteor. Soc., Austin, TX.

Gowan, T. A., and J. D. Horel, 2020: Evaluation of near real-time IMERG precipitation estimates for fire weather applicatinos in Alaska. *19th Conference on Mountain Meteorology*, Amer. Meteor. Soc., Virtual.

McCorkle, T. A., A. A. Jacques, and J. D. Horel, 2017: Dynamic and statistical analyses of Alaskan surface pressure perturbations using the USArray Network. *Observation Symposium: Progress Problems,and Prospects*, Amer. Meteor. Soc., Seattle, WA.

McCorkle-Gowan, T. A., and J. Horel, 2020: Evaluation of near-real-time IMERG precipitation estimates for fire weather applicatinos in Alaska. *34th Conference on Hydrology*, Amer. Meteor. Soc., Boston, MA.

Welch, B., and J. Horel, 2020: Evaluating image-derived estimates of road weather conditions. *19th Conference on Mountain Meteorology*, Amer. Meteor. Soc., Virtual.

d. Related dissertations and theses

Blaylock, B., 2019: High-Resolution Rapid Refresh Model Data Analytics for Wildland Fire Weather Assessment. Ph.D. Dissertation. University of Utah.

McCorkle, T. A., 2018: *An Evaluation of the Experimental High-Resolution Rapid Refresh – Alaska Modeling System during Winter 2017*. M. S. Thesis. University of Utah.

Gowan, T. A., 2021: Data Analytics Applied to Satellite-Derived Precipitation Estimates and High-Resolution Model Output. Ph.D. Dissertation. University of Uah.