Analysis of Record for Calibration:

Version 1.1

Sources, Methods, and Verification

National Weather Service

Office of Water Prediction

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1. Abstract

The Analysis of Record for Calibration (AORC) is a gridded record of near-surface weather conditions covering the continental United States and Alaska and their hydrologically contributing areas. It is defined on a latitude/longitude spatial grid with a mesh length of ~800 m (30 arc seconds), and a temporal resolution of one hour. Elements include hourly total precipitation, temperature, specific humidity, terrain-level pressure, downward longwave and shortwave radiation, and west-east and south-north wind components. It spans the period from 1979 at Continental U.S. (CONUS) locations / 1981 in Alaska, to the near-present (at all locations). This suite of eight variables is sufficient to drive most land-surface and hydrologic models and is used to force the calibration run of the National Water Model (NWM).

2. Preface to AORC

The Analysis of Record for Calibration (AORC) gridded record is provided in hourly NetCDF file format that follow the [Climate and Forecast (CF) metadata conventions](https://cfconventions.org) (https://cfconventions.org)/. Each hourly NetCDF file contains eight essential elements representing the meteorological conditions for a specific hour. The naming and unit conventions for these eight elements are listed in Table 2.1.

Table 2.1. AORC element naming and unit conventions

CF Name	Abbreviation	Units	Where Measured
Precipitation - 1-hour Accumulation	apcp	kg/m^2 or mm	Surface
Air Temperature	tmp	°K	2-m AGL*
Specific Humidity	spfh	g/g	2-m AGL
Air Pressure	pres	Pa	Surface
Downward Shortwave (solar) Radiation flux	dswrf	W/m^2	Surface
Downward Longwave (infrared) Radiation flux	dlwrf	W/m^2	Surface
Eastward (U) Wind	uwnd	m/s	10-m AGL
Northward (V) Wind	vwnd	m/s	10-m AGL

*AGL - Above Ground Level

The AORC datasets corresponding to the two geographic regions addressed in this document, and their file-naming conventions, use the following filename format:

Table 2.2. AORC file-naming conventions

Area	File name
CONUS	AORC-OWP_yyyymmddhh.nc4
Alaska	AK_AORC-OWP_yyyymmddhh.nc4

The AORC-Version 1.1 has been developed by the Office of Water Prediction (OWP) of the National Oceanic and Atmospheric Administration (NOAA)'s National Weather Service (NWS). Any use of trade names in this publication is for descriptive purposes only and does not imply endorsement by the U.S. Government.

Citation and Version History

This documentation and associated grids are part of a whole product with a single version number and can be referenced as:

> *Analysis of Record for Calibration Version 1.1 - Sources, Methods, and Verification, National Oceanic and Atmospheric Administration (NOAA), National Weather Service (NWS), Office of Water Prediction (OWP), Silver Spring, MD.*

The AORC dataset was created after reviewing, identifying, and processing multiple, large-scale, input observational and analysis datasets. This initial AORC dataset was completed in November 2019 and consisted of an approximately 1-km resolution, eight-element gridded version. The 1-km CONUS portion of this product was further broken down into 12 River Forecast Center-based hydrologic areas of 4-km resolution (temperature and precipitation elements, only) and was disseminated through a secure FTP site.

The 1-km AORC Version 1.1 dataset is described herein this document. The AORC continues to be developed. A new version number will be applied when any changes to the data or documentation are made. The document that accompanies each dataset reflects the latest version of AORC development.

The version number has the format P.S, where **P** is the *primary version number*, representing the sequence number among the successive releases of primary information. Primary information is essentially the development methodology. **S** is the *secondary version number*, representing data and data format information. When change to the data or data format is completed and added without the methodology changing significantly, the primary version number is not incremented, just the secondary version number. Table 2.3. lists the version histories associated with the AORC products to date, and indicates the nature of changes made.

Table 2.3. History of AORC Version Releases

Version Number	CONUS	Alaska	Notes
AORC 1-km Version 1.1	Not publicly available	Not publicly available	
AORC 4-km Version 1.1 (precipitation and temperature elements only)	4-km version (https://hydrology.nws.noaa.gov/aorc-historic/)	---	RFC subsets

3. Introduction

The Analysis of Record for Calibration (AORC) is a high-resolution, gridded record of eight meteorological fields at the near-surface level, presently encompassing the conterminous United States (i.e. "lower 48"), Alaska (including most of the Aleutian Island chain), and adjacent areas of northern Mexico and southern and northwestern Canada that hydrologically contribute to U.S. watersheds. It also includes nearby, offshore waters; it spans up to the past four decades. The Continental United States geographic coverage in this document is referred to as a "superCONUS" region, given that it includes adjacent areas of northern Mexico and southern Canada.

The NWS Office of Water Prediction (OWP)'s goal in constructing this dataset was to assemble a single, coherent source of all meteorological inputs necessary for calibrating and driving land-surface, snow and hydrologic models, and which would be extensible to update with recent data.

Those AORC datasets are formulated on a 1/120-degree or 30 arc-second (0.008333°), World Geodetic System (WGS-1984), geographic coordinate system. Note that at that resolution, the size of an individual grid cell is approximately 926 m in the latitudinal direction at all locations, while in the longitudinal direction it ranges from about 834 m at the latitude of Brownsville, TX to 635 m at the latitude of Bismarck, ND to 394 m at the latitude of Fairbanks, AK.

The timespan covered by the AORC dataset varies among the above-described grids, ranging from as early as 1979 (over the conterminous U.S.) to near-present. The temporal resolution is one hour. The (8) constituent elements, as enumerated in Table 2.1 above, are:

- Hourly total precipitation (kg/m^2 or mm)
- Temperature (at 2 m above-ground-level (AGL)) (^oK)
- Specific humidity (at 2 m AGL) (g/g)
- Air pressure (at the surface) (Pa)
- Downward shortwave (solar) and longwave (infrared) radiation flux (at the surface) (W/m^2)
- U (west-east) and V (south-north) components of the wind (at 10 m AGL) (m/s)

The AORC was constructed from over a dozen individual datasets, not all of which were available through the entire period-of-record of each of the AORC grids. The best available input dataset for each of the constituent elements was used at any given time and place. These input datasets can be characterized as two basic types: time-series and climatological.

The time-series inputs are of various, daily or multi-hourly durations and provide the basis for the high temporal resolution of the AORC dataset. Some of these datasets provide the main input focings in building the AORC, such as the following data sets:

- North American Regional Reanalysis (NARR)
- North American Land Data Assimilation System-Version2 (NLDAS2)
- National Centers for Environmental Prediction (NCEP) Unrestricted Mesoscale Analysis (URMA)
- NCEP Stage IV
- Canadian Meteorological Centre (CMC) - Canadian Precipitation Analysis (CaPA)
- NCEP - Global Data Assimilation System (GDAS)

Alternative time series data were used to replace the input forcings at particular areas or to temporally disaggregate higher-temporal resolution data. The following datasets were used for this purpose:

- pre-NEXRAD Manually Digitized Radar (MDR) reflectivity-based precipitation estimates
- NEXRAD-era automated and quality-controlled, gauge-radar estimated precipitation (WSI NOWrad and Stage II and Stage IV)
- Canadian Meteorological Center (CaPA) gridded 6-hour and 24-hour precipitation accumulations
- NCEP Climate Forecast System Reanalysis (CFSR)

- NOAA Climate Data Record Morphing Technique (CMORPH) microwave-infrared, satellite-estimated precipitation.

The climatological datasets are of mean, monthly, or annual amounts and are used to bias-correct the time series data. These datasets, such as PRISM 1981–2010; Vose et al. (2014) 1981–2010; Servicio Meteorológico Nacional (SMN) 1981–2010; Livneh et al. (2015) (1981-2015); and Hill at el. (2015) (1981-2009), were all developed based on ground-based gauge observations.

The numerous inputs used in construction of the AORC are summarized in Table 3.1.; greater details on how these datasets were used are provided in Section 4 and 5.

Table 3.1. AORC Dataset Source Content Descriptions

Datasets Sources	**Dataset temporal and spatial resolution**	**Elements**	**AORC domain**
Canadian Meteorological Centre (CMC) - Canadian Precipitation Analysis (CaPA)	6-hour, 2.5-km	acpc	superCONUS (portion over Canada around Great Lakes))
Daly et al's Pacific Climate Impacts Consortium dataset	1-mo, 1-km	acpc, tmp	Alaska
Environment Canada (EC) - Gauge Network	1-day	acpc, tmp	superCONUS (portion over Canada around Great Lakes)
Hill monthly gridded dataset (Hill et al's dataset, 2015)	1-mo, 2-km	acpc, tmp	Alaska
NASA - The North American Land Data Assimilation System-version 2 (NLDAS2)	1-hour, 12-km 1-day, 12-km	acpc, tmp, spfh, pres, dswrf, dlwrf, uwnd, vwnd	superCONUS
Livneh daily gridded dataset (Livneh et al.,2015)	1-mo, 7-km 1-day, 7-km	acpc, tmp	superCONUS
NCEI Gauge Network (Vose et al. (2014))	15-min	acpc, tmp	superCONUS, Alaska
NCEP - Climate Forecast System Reanalysis (CFSR)	1-hour, 6-hour, 35-km	acpc	superCONUS

Datasets Sources	Dataset temporal and spatial resolution	Elements	AORC domain
NCEP - Global Data Assimilation System (GDAS)	1-hour, 27-km	acpc	superCONUS
NCEP- NEXRAD Stage IV	1-hour, 6-hour and 24-hour, 4-km	acpc	superCONUS, Alaska
NCEP North American Regional Reanalysis (NARR)	3-hour, 32-km	acpc, tmp, spfh, pres, dswrf, dlwrf, uwnd, vwnd	Alaska
NCEP- Unrestricted Real-time Mesoscale Analysis (URMA)	1-hour, 2.5-km	tmp, pres, uwnd, vwnd	superCONUS, Alaska
NOAA Climate Data Record Morphing Technique (CMORPH) Microwave-infrared satellite-estimated precipitation (only)	30-min, 8-km	acpc	superCONUS
NWS - (pre-NEXRAD) Manually Digitized Radar (MDR)	1-hour, 47-km	acpc (6-level radar imagery)	superCONUS
NWS(NCEI) - NEXRAD Stage II	1-hour, and 6-hour, 4-km	acpc	superCONUS
PRISM (several versions)	1-mo, 4-km 1-mo, 1-km	acpc, tmp	superCONUS, Alaska
SMN (Servicio Meteorológico Nacional Gauge Network)	15-min	acpc, tmp	superCONUS (over Mexico)
UCAR - WSI NOWrad	15-min, 4-km	acpc	superCONUS

More than a dozen datasets and techniques were utilized in the AORC's construction. Often, several of the datasets listed in the Table 3.1. were used for the construction of one gridded AORC hour. Often these datasets were stitched together to provide full coverage over the AORC domain for bias correction datasets, or as daily or hourly input forcings. Several processes and numerous techniques were used to develop bias correction grids; interpolate observation sites to AORC grid locations (at cell center); disaggregate daily and sub-daily time-series data to the hourly, temporal resolution of the AORC; blend disparate datasets across national boundaries (e.g. U.S - Canada); and apply bias adjustments to the time-series data by climatological data. Most of these techniques are described in more detail in Sections 4 and 5 of this document.

However, as a result of several input datasets having been stitched together to provide the full spatial coverage within the CONUS domain, spatial boundary inconsistencies within the individual hourly grids are sometimes observed. Aside from the spatial inconsistencies, temporal inconsistencies are also observed for some or all eight elements. Temporal shifts in minimum, maximum, or mean values are visible as a result of switching between input datasets from one time period to the next, or due to changes in the bias correction procedures

Finally, known artifacts within the various input forcings are often carried over to the final AORC elements. For example, Stage IV (Lin and Mitchell 2005; AHPS 2019) radar blockage issues in areas with high topographic variability (e.g. Appalachians & Shenandoah) are carried into the final AORC output. The artifacts of the input forcing datasets are more pronounced for the precipitation element for the period before 2000 or pre-NEXRAD period. Section 4 of this document discusses some of the limitations of the precipitation elements for this period in more detail.

The remainder of this document, under Section 4 and 5, provides a detailed description of the input elements, methodology and verification used in constructing the AORC datasets for the CONUS and Alaska, broken down by their individual weather elements. The CONUS dataset is described in detail in Section 4, and the one for Alaska and nearby environs is described in Section 5. All the datasets include eight elements: hourly total precipitation, temperature, specific humidity, terrain-level pressure, downward longwave and shortwave radiation, and west-east and south-north wind components.

4. Continental United States Analysis of Record for Calibration

The CONUS AORC dataset spans the period from the beginning of 1979 to the near-present. Its Geographic coverage is referred to as a “superCONUS” region, extending S-N from the Rio Conchos in northern Mexico to the Columbia River basin in the northwest U.S. and southwest Canada (approximately 23 to 53° N), and W-E from the northwest Pacific Coast to the northeast Atlantic Coast (approximately 125 to 65° W). It covers all the “lower 48” United States of America, as well as any point on the North American continent that drains into them. The hydrological contributing drainage area is represented by the boundaries of the 12 River Forecast Centers covering the Contiguous United States, as shown in Figure 4.1.

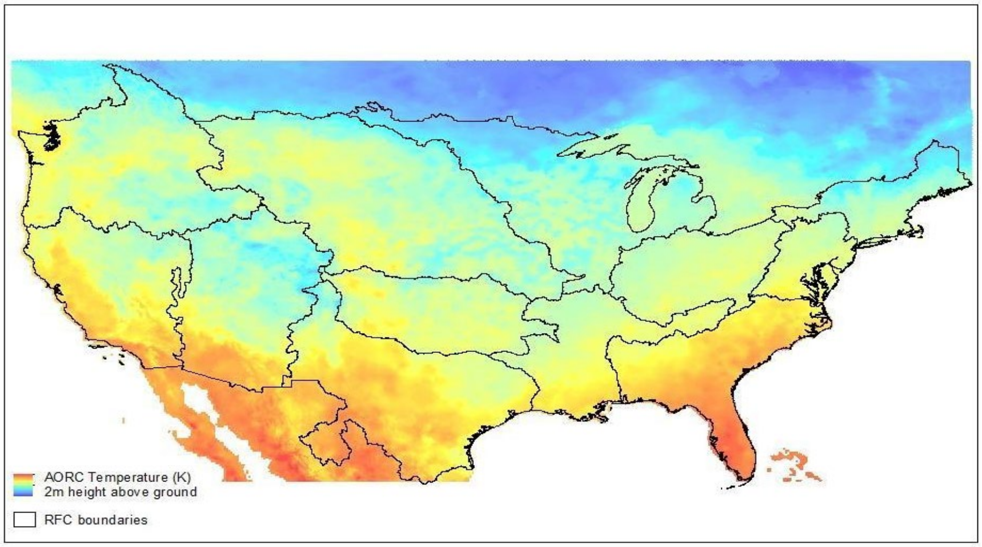

Figure 4.1. The spatial domain of the CONUS AORC dataset.

4.1. Precipitation and Temperature

The gridded AORC precipitation dataset contains one-hour accumulated surface-precipitation (APCP) ending at the "top" of each hour, in liquid water-equivalent units (kg/m^2 to the nearest .01 kg/m^2), while the gridded AORC temperature dataset is comprised of instantaneous, 2 m above-ground-level (AGL) temperatures at the top of each hour (in degrees Kelvin, to the nearest .01 degree).

4.1.1. Dataset Sources

The 1-hour, 12-km North American Land Data Assimilation System–version 2 (NLDAS2: Xia et al. 2013; Cosgrove et al. 2003) hourly dataset informs much of the AORC content over the superCONUS region for all the earlier-mentioned, eight AORC elements. Additional datasets, comprised of observations and estimates, are utilized in developing the precipitation and temperature elements, with temporal frequency ranging from 30-year climatological to monthly to daily to sub-daily to hourly. These come from documented and operational sources.

They include temperature and precipitation monthly normal products from PRISM 1981-2010; Vose et al. 2014 (hereafter referred to as NCEI) 1981-2010; and Servicio Meteorológico Nacional (SMN) 1981-2010. They also include daily and monthly precipitation and maximum/minimum temperature from the dataset of Livneh et al. (2015); pre-NEXRAD Manually Digitized Radar (MDR) reflectivity; NEXRAD-era automated and quality-controlled, gauge-adjusted radar estimated precipitation (WSI NOWrad and Stage II, IV); Canadian Meteorological Center (CaPA) gridded 6-hour and

24-hour precipitation accumulations; the NCEP Climate Forecast System Reanalysis (CFSR: Saha et al. 2010); and Global Data Assimilation System (GDAS) and NOAA Climate Data Record Morphing Technique (CMORPH) microwave-infrared satellite-estimated precipitation. For the 2016-present period, the Unrestricted Real-time Mesoscale Analysis (extended) (URMA), NEXRAD Stage IV and NLADS2 datasets inform much of the AORC components.

Table 4.1. List of input datasets and their resolutions, component-elements, and periods over which applied, used to develop CONUS AORC precipitation and temperature datasets.

Dataset	Dataset component	Dataset grid resolution	Dataset applied to the AORC	Spatial domain
TIME-SERIES DATASETS				
The North American Land Data Assimilation System - version 2 (NLDAS2)	1-hour precipitation 1-hour temperature	12-km 12-km	1979–present 1979–2015	superCONUS
NCEP Unrestricted Mesoscale Analysis (URMA)	1-hr temperature	2.5-km	2016–present	superCONUS
Canadian Meteorological Center (CaPA)	24-hour precipitation	2.5-km	2012–present	superCONUS (over SW Ontario)
Climate Forecast System Reanalysis (CFSR)	1-hour precipitation	35-km	1979–2015	superCONUS
MDR (Manually Digitized Radar)	6-level radar imagery converted to 1-hour precipitation	47-km	1979–1994	superCONUS
WSI NOWrad	1-hour precipitation	4-km	1996–2001	superCONUS
NEXRAD Stage II	aggregated to1-hour precipitation	4-km	1996–2002	superCONUS
NEXRAD Stage IV	1-hour precipitation 24-hour precipitation	4-km “	2002–present	superCONUS
NCEP Global Data Assimilation System (GDAS)	1-hour precipitation	27-km	1979–present	superCONUS
CMORPH (microwave-IR satellite)	30 minutes aggregated to 1-hour precipitation	8-km	1998–present	superCONUS
CLIMATIC DATASETS				
Vose et al. 2014 (hereafter referred to as NCEI) 1981-2010	temperature and precipitation daily gauge data	/	1981–2010	superCONUS (over Canada)

Dataset	Dataset component	Dataset grid resolution	Dataset applied to the AORC	Spatial domain
Servicio Meteorológico Nacional (SMN) 1981-2010	temperature and precipitation daily gauge data	/	1981–2010	superCONUS (over Mexico)
PRISM 1981-2010 (Daly et al. 2018)	Mean annual precipitation and temperature	~800-m	1981–2010	superCONUS
Monthly Precipitation and Temperature (Livneh, 2015) ("LIV15")	Daily and monthly precipitation and max/min temperature	7-km	1979–2015	superCONUS

Time-series datasets

Daily precipitation

For the duration of the period of record, NLDAS2 daily precipitation was used as the reference for all areas except as noted. From 1979 to 2001, NLDAS2 24-hour totals ending at 1200 UTC were the daily reference over the CONUS. Stage IV daily precipitation, with interactive, manual quality control and the introduction of radar data, has been used since 2002.

Examination of Stage IV daily precipitation showed that, in some areas, it was consistently biased low during the winter months from 2002 to approximately 2009 as a result of limitations in radar capability for precipitation-type discrimination prior to the implementation of dual-polarimetric technology. The implementation of that technology, and the increasing use of software tools such as the Multisensor Precipitation Estimator (MPE) for incorporating daily rain gauge reports, improved the accuracy of precipitation estimates substantially, from 2010 to the near-present.

Outside the Stage IV coverage area, NLDAS2 daily precipitation was used (i.e. in Mexico and Canada) except in a region of southwestern Ontario, after May 2012, when the NLDAS2 precipitation exhibited anomalous behavior, with some unrealistically large totals (NASA 2020). Over that area, during this time, the NLDAS2 was replaced with Canadian Precipitation Analysis (CaPA) v2.4 data (Fortin et al. 2015). Furthemore, the NLDAS2 daily product was used as an alternative to Stage IV in the Northeastern United States (Connecticut, Maine, Massachusetts, New Hampshire, New York, Pennsylvania, Rhode Island and Vermont) from the beginning of 2016 through the fall of 2017.

In order to incorporate heavy precipitation events as detected in daily input forcings (NLDAS2 and Stage IV) into the AORC while retaining long-term consistency with the gauge-based "Livneh" data, the AORC daily precipitation between 1979 and 2015 was bias corrected with monthly accumulated Livneh data, where available. The daily input forcings were also constrained with the long-term annual climatic datasets, described below. After 2015, the Stage IV daily product was directly used without a bias correction procedure.

After daily AORC input forcing data was bias-corrected for the long-term climatology, the daily time series were then disaggregated using available hourly data, as detailed further in this section.

Hourly precipitation

The hourly time-series datasets used to disaggregate the daily precipitation time series to hourly precipitation are referenced in Table 4.1.

Two of the sources, Manually Digitized Radar (MDR) and hourly precipitation from WSI-NOWrad reflectivity grids, warrant explanation. The MDR data were once-per-hour reflectivity summaries produced by manual reduction of WSR-57 and WSR-74 scope displays at NWS field offices (Reap and Foster, 1983; Miller and Kitzmiller, 2017). This limited-precision reflectivity information was converted to approximate rainfall rates for use in the AORC. The WSI data were used to derive precipitation products for various NWS/Office of Water Prediction (OWP) applications (Zhang et al. 2017) and - during the period in which they were used - often served to fill spatial coverage gaps in the operational Stage II precipitation fields.

For the more recent years, Stage IV hourly data has been used to disaggregate the daily precipitation grids blended from several datasets. This disaggregation procedure performs better at maintaining spatial precipitation characteristics compared to the procedure of just using the Stage IV hourly data directly. GDAS hourly precipitation is used to disaggregate the 24-hour AORC values to 1-hour values in the case that remote-sensing information from radar or satellite is unavailable.

Temperature

1-hour, 12-km NLDAS2 temperature data informs the AORC temperature field for the period 1979-2015. Since 2016, the update portion of the AORC temperature record has been based on the Unrestricted Real-time Mesoscale Analysis (extended) (URMA). This operational analysis has sufficient spatial coverage and, with its 2.5 km resolution, provides more accurate temperatures, particularly at high terrain. However, its archive was too short for incorporation with the earlier AORC. The original, 2.5-km URMA data has been downscaled to the AORC 1-km resolution for the 2016-2017 period using a difference factor constructed by calendar month, by differencing the 2010-2015 URMA means and the corresponding 2010-2015 AORC means, in an attempt to maintain temporal continuity. After 2017, neighbor interpolation was used to downscale URMA to the AORC 1-km resolution.

Climatic datasets
An important consideration was the constraint of long-term climatology, particularly for temperature and precipitation - the dominant influences on runoff processes. The 1981-2010 CONUS PRISM high-resolution, gridded climatology (Daly et al. 2008) for monthly mean-total precipitation and monthly mean-maximum and mean-minimum temperature (Tmax and Tmin) was used to correct the AORC input forcings for the long-term climatology. Over the Canadian portion of the Columbia River basin, the CONUS PRISM dataset was merged with a regional PRISM dataset (Daly et al. 2008). A climatic dataset (Vose et al. 2014; NCEI) similar to the PRISM datasets was applied to cover the remainder of southern Canada. A new climatology for Mexico was developed using 1981-2010 SMN station climatic values, interpolated with the ANUSPLIN 4.4 thin-plate spline package (Hutchinson and Xu, 2013). The resulting precipitation climatology grids over Mexico showed appreciable improvement, in terms of absolute accuracy, when compared to alternative available datasets such as Vose et al., WorldClim v1.4 (Hijmans et al. 2005) or Uniatmos (Fernandez et al., 2012).

Examples of the AORC merged temperature and precipitation climatology grids appear in Figure 4.2. for July precipitation (a), Tmax (b), and Tmin (c). The final products preserve the PRISM sources at all grid points where they are defined. To reduce discontinuities at the boundaries between sources and to preserve information from the PRISM datasets over adjacent non-PRISM areas, an adjustment was made to the NCEI and SMN-based grids using a local regression relationship between coincident PRISM and alternative values. The adjustment was maximized at the boundary itself, but reduced to zero at the far edge of the blending radius of 40 km.

None of the original input climatology datasets had defined values over large inland water bodies, such as the Great Lakes, Lake Winnipeg, and the Great Salt Lake. Values for these water areas were estimated from the 30-year monthly means of NLDAS2, which were modified to agree with the PRISM values at the shore boundaries via a statistical relaxation approach. As shown in Figure 4.2. (d), for temperature, this method yielded the expected results at times when water/land contrasts might be maximized, such as October mornings.

During 2010-2015, the annual bias correction grids were developed from the Livneh data directly. These bias correction ratios were set using the 6-year accumulations from the Livneh data against the Stage IV data. This long-term bias correction was then applied to the daily accumulation data.

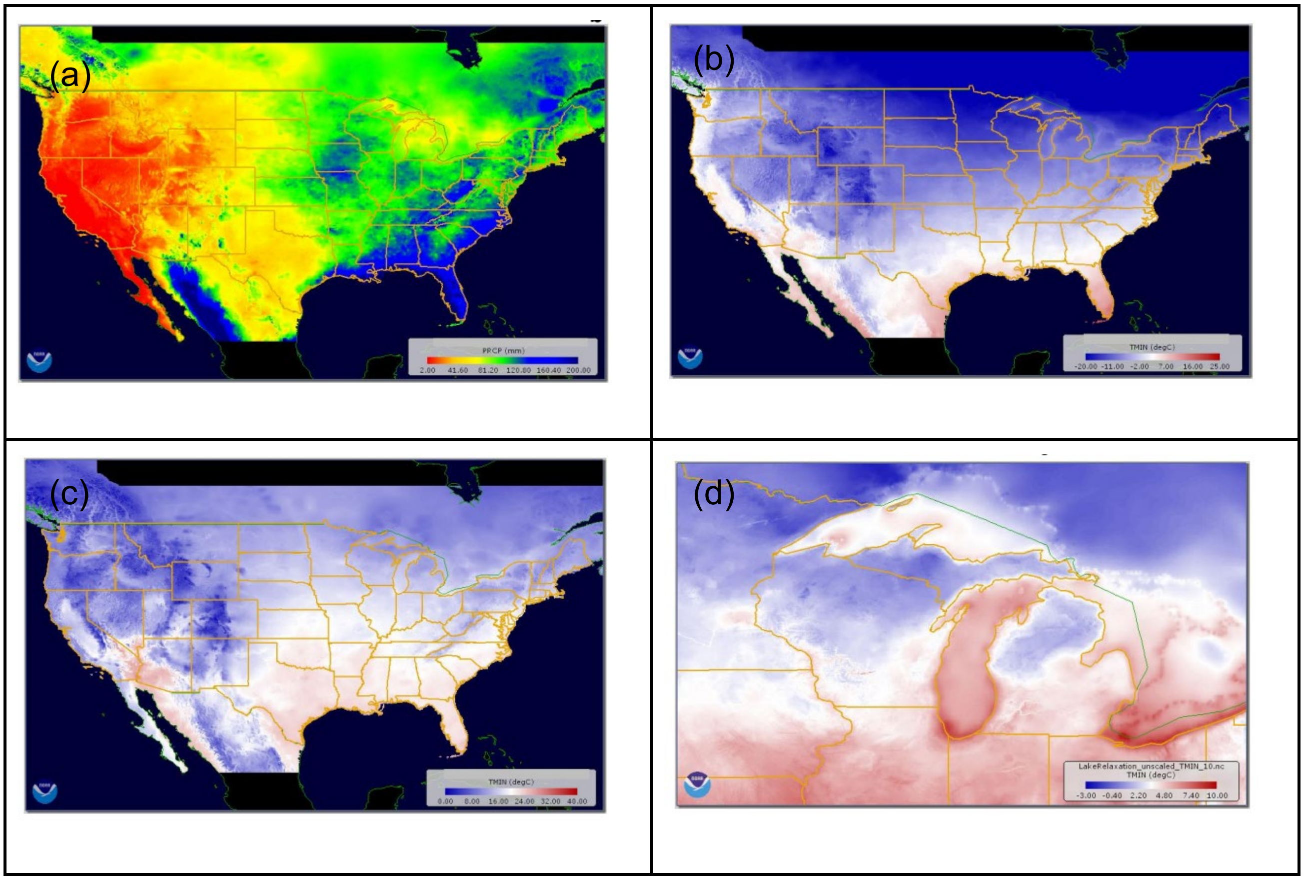

Figure 4.2. AORC climatic values for (a-upper left) mean monthly June precipitation, (b -upper right) mean June Tmin, (c - lower left) mean June Tmax, and (d - lower right) detail of Tmin October mean temperature over the Great Lakes. Data fields are from a combination of PRISM, NCEI, and SMN sources over land, and NLDAS2 over ocean.

4.1.2. Methodology

Spatial and Temporal Downscaling

Precipitation

A spatial downscaling technique was applied to downscale coarser resolution datasets (ex. NLDAS2) to the finer resolution using the finer-resolution gridded dataset (ex. PRISM) with more realistic spatial variability. This technique's approach (referred to as anomaly method, perturbation, or delta-change approaches) maintains the lower resolution characteristics of the NLDAS2 dataset while introducing the PRISM and LIV15 datasets' spatial variability and long-term characteristics (due to bias correction). The LIV15 monthly precipitation, with adjustments to ensure agreement with the 30-year climatology, was applied as an intermediate step between climatology and daily frequencies from 1979 to 2009. AORC daily precipitation during and after 2010 is based on Stage IV, where available, with a bias correction factor, varying by month, applied.

The bias correction is set by the ratio of the 6-year accumulations for the Livneh data to the Stage IV data, during 2010-2015. Outside Stage IV coverage areas, the NLDAS2 daily precipitation is used.

Temporal downscaling from daily to hourly precipitation amounts is based on a multiplicative-correction approach. The multiplicative correction approach disaggregates, temporally, daily rainfall amounts to hourly amounts using factors. These factors are calculated by aggregating hourly grids to 0:00, 1:00, 2:00 ...23:00 time steps and dividing these amounts with the coincident daily grids. The hourly grids were calculated from the mosaic of datasets that were applied: Stage IV, GDAS, Stage II, CFSR (Climate Forecast System Reanalysis), CMORPH (microwave-IR satellite, Xie et al. 2017), WSI NOWrad (Zhang Y. et al. 2017), and MDR (Manually Digitized Radar).

The influence of the progression in radar data sources from the rather coarse-mesh MDR to higher-resolution NEXRAD is illustrated in Figure 4.3, which shows examples of 1-hour precipitation from (a) pre-NEXRAD (1983) and (b) NEXRAD-era (2011). The application of 40-km grid mesh MDR data as a temporal disaggregator did yield improvements in correlation between hourly rain gauge reports and gridded QPE relative to the NLDAS2 (Miller and Kitzmiller 2017). Furthermore, the availability of 4-km mesh, continuously-updated precipitation from the NEXRAD network clearly improved the scale representation of precipitation, particularly for higher-intensity events.

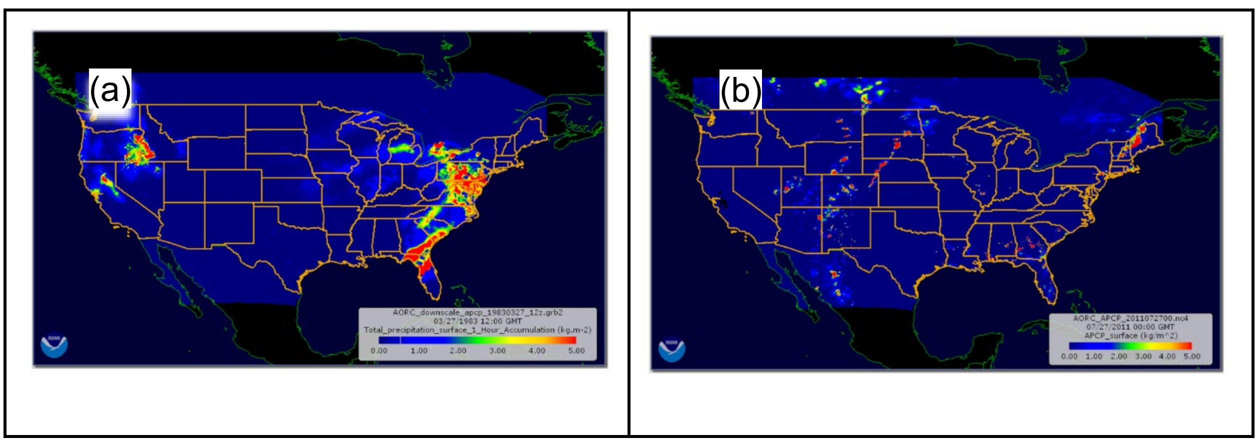

Figure 4.3. 1-h AORC precipitation from (a) 1200 UTC, 27 March 1983, during the pre-NEXRAD period, and (b) 0000 UTC 27 July 2011, with NEXRAD and CMORPH input.

Temperature

A procedure was developed that applied the PRISM/NCEI climatology and the LIV15 daily temperature maxima/minima to adjust the NLDAS2 1-hour temperature data that was previously interpolated to 1-hourly values. The LIV15 daily temperature dataset consists of maximum and minimum values for calendar days. Monthly time-series of mean values for Tmax and Tmin are also published. To ensure that long-term climatology was preserved, the 30-year mean LIV15 Tmax and Tmin grids were interpolated for each of the twelve months to the AORC grid, and additive biases relative to the corresponding PRISM values were computed on a grid point-by-grid point basis. The monthly additive bias correction factors were then applied to all LIV15 daily values within the corresponding months, for the entire period 1979-2015. This effectively downscaled the temperatures to account for climatic/elevation effects.

The daily LIV15 max/min values at all grid points are distributed temporally via the NLDAS2 1-h temperature time series. Two potential adjustments are calculated for the original NLDAS2 temperature. A range adjustment constrains the original temperature toward the Livneh maximum/minimum range. A mean adjustment constrains a running mean temperature toward that of the mean of the "Livneh" (2015) dataset. A final adjustment is based on one of these two adjustments, or a weighted average of the two. The range adjustment is applied if the 3-day daily max/min correlation between the NLDAS2 and Livneh values is at least 0.8; the mean adjustment is applied if the correlation is less than 0.5. A linearly-varying weight is applied if the correlation is within the range 0.5 to 0.8.

Temperatures intermediate to the 1-hour intervals were derived from linear interpolation. Subsequent tests showed that this approach improved the agreement with observed 2-m temperature values, relative to the original NLDAS2 estimates. The LIV15 data release incorporated into the AORC excluded coverage for Mexico during 2013-2015 (Ben Livneh, personal communication, 2016). NLDAS2 temperature data with long-term bias adjustments were used in their place.

4.1.3. Verification

The accuracy of the primary hydrologic drivers within the AORC dataset, precipitation and temperature, was assessed by comparison with monthly total precipitation and mean monthly temperature from stations in the Global Historical Climatology Network (GHCN; Lawrimore et al. 2011) over the CONUS, southern Canada, and northern Mexico. Only a small number of those quality controlled GHCN station monthly time series were available for the full period, namely 118 sites within the CONUS, 5 over Canada, and 5 over Mexico. Given the small number of GHCN sites covering the entire period of record for Canada and Mexico, additional monthly-scale data were collected from Environment Canada (EC, 2019) and Servicio Meteorológico Nacional (SMN, 2019). Due to the different quality control procedures applied to these latter data, and because some inputs to the AORC over Canada and Mexico were substantially different from inputs to the AORC over the CONUS, the Canadian and Mexican areas were verified separately.

Monthly time series data at all stations were verified for the period of record 1980-2015, corresponding to the end of the LIV15 datasets. The performance metrics were long-term mean value (as compared to the observed reference), time series root-mean squared error (RMSE), and linear correlation.

Mean monthly precipitation

Monthly precipitation was verified separately for each of the individual twelve months; results for January (Figure 4.4.a) and July (Figure 4.4.b) are shown below. The mean values for January precipitation over the CONUS (Figure 4.4.a) generally fell within 15 mm of the observed, though the error was larger for data values over 350 mm for a site in northwestern Washington State. Error in the mean precipitation was larger during July, when most precipitation over North America had a convective component (Figure 4.4.b).

Approximately 225 observing GHCN sites (varying by month) were available for southern Canada within the AORC domain. The overall accuracy of the AORC precipitation was poor relative to that over the CONUS. This might be attributable to the relatively sparse gauge network over the northern half of the Canadian portion of the AORC domain (LIV15).

Between 200 and 205 stations were available for northern Mexico. For these sites, daily reports were summed to monthly accumulations. As with the Canadian data, agreement between AORC and station values was lower, relative to that for the CONUS.

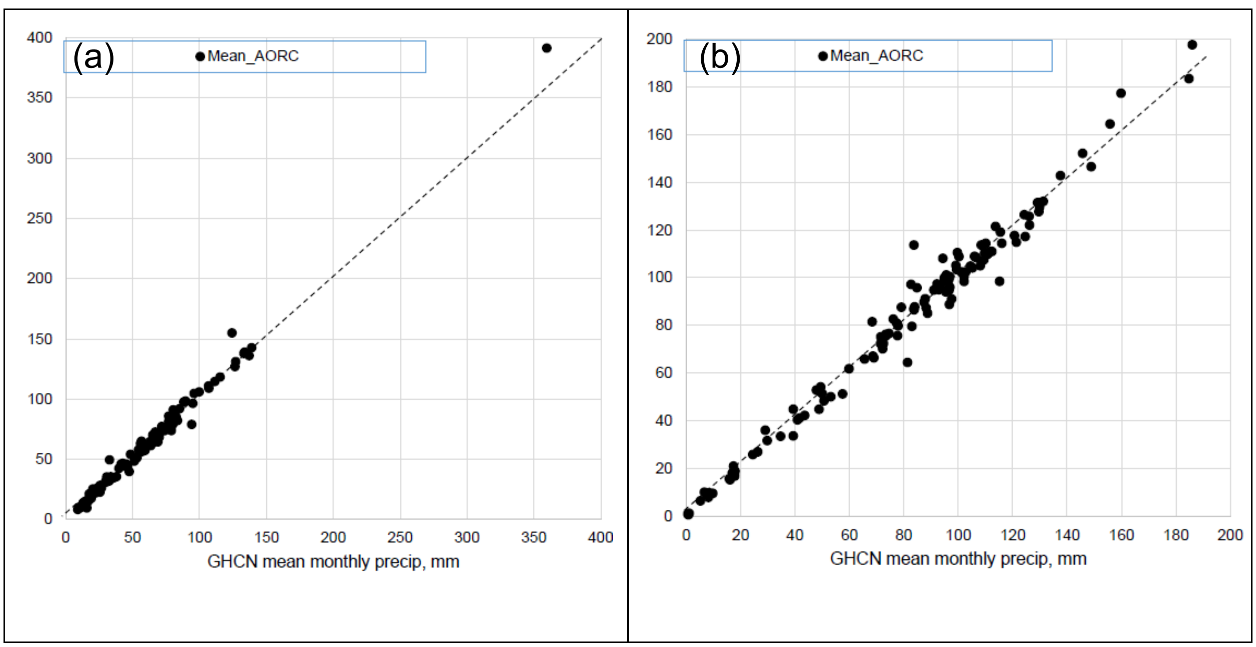

Figure 4.4. AORC versus GHCN mean monthly precipitation, in mm, for the period between 1980-2015 over the CONUS for (a) January, and (b) July.

Mean monthly temperature
A comparison between the mean-monthly AORC and GHCN gauge temperatures was performed for the CONUS and some Canadian sites. The temperature analysis against the GHCN was broken down by month. For January estimates (Figure 4.5.a), most mean AORC temperatures were found to be within 1.5°C of the observed, over both the CONUS and Canada. For July temperatures (Figure 4.5.b), AORC accuracy was similar, but there were larger errors at Canadian sites. Overall, the AORC featured a slight low bias.

Very few Mexican GHCN sites reported temperature throughout the period of record, so the AORC was verified against time-averaged temperatures from hourly reporting sites. Station data were obtained from archives collected by the NWS Meteorological Development Laboratory (MDL) and provided via UCAR. Though these hourly reports generally did not include early-morning observations (when airports were closed), the mean AORC and station values were mostly within 2°C of one another.

Monthly temperature time-series correlations for January and July, for Canada and the CONUS, were often 0.95 or higher, though values tended to be lower over Canada and the southwestern CONUS.

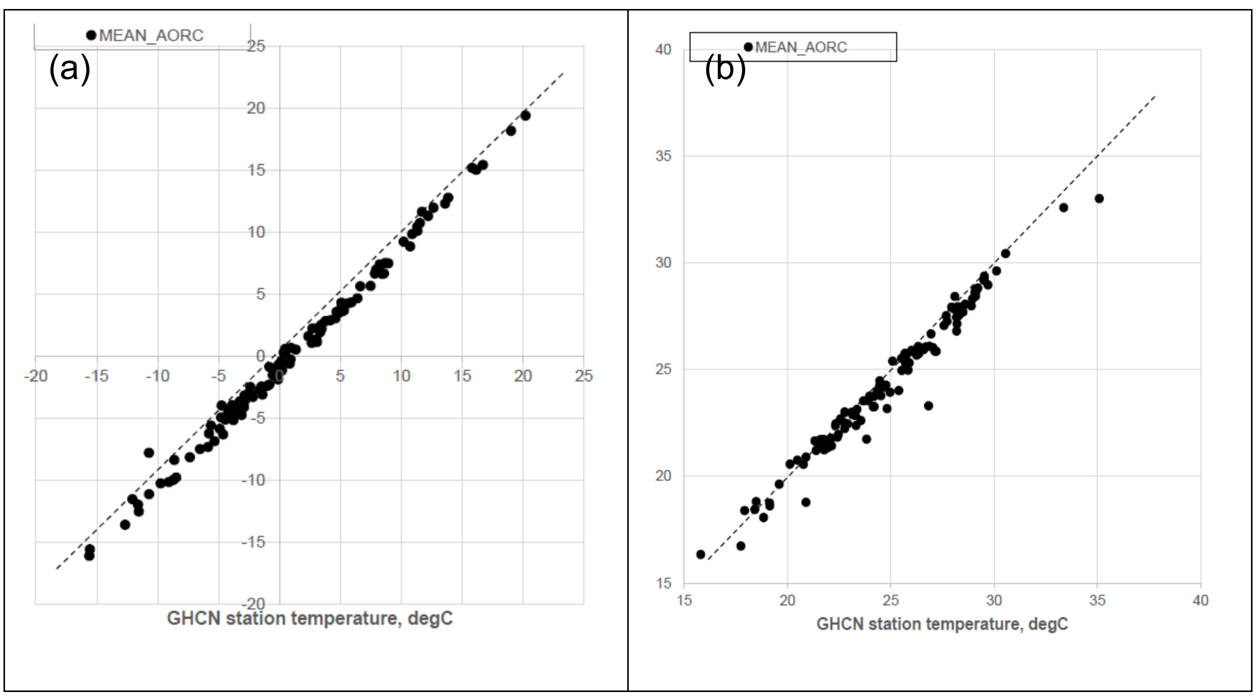

Figure 4.5. AORC versus GHCN mean monthly temperature, in degrees Celsius, for the period between 1980-2015 over CONUS for (a) January, and (b) July.

4.2. Specific Humidity, Pressure, Downward Radiation, Wind

The development process for the six additional dataset components of the superCONUS AORC [i.e., specific humidity at 2m above ground (kg/kg); downward longwave and shortwave radiation fluxes at the surface (W/m2); terrain-level pressure (Pa); and west-east and south-north wind components at 10m above ground (m/s)] has two distinct periods, based on datasets and methodology applied: 1979–2015 and 2016–present.

4.2.1. Dataset Sources

The North American Land Data Assimilation System - version 2 (NLDAS2) 1-hour fields on their native, 12-km resolution grid, provided the basis for the high temporal resolution of the AORC CONUS dataset for the period 1979 - 2015 for specific humidity, pressure, downward shortwave and longwave radiation, and winds (Table 4.2.). The NLDAS2 was replaced in 2016 with newer datasets that provided the input forcings for, among other fields, temperature at a higher spatial and temporal resolution. Because specific humidity, pressure and downward longwave radiation are all dependent on temperature, these fields were also replaced at the beginning of 2016 by the NWS's UnRestricted Mesoscale Analysis (URMA). The original NLDAS2 datasets for the downward shortwave radiation and the west-east and south-north wind components were retained, through bilinear interpolation from the NLDAS2 grid to the AORC grid.

Table 4.2. List of input datasets and their resolutions, component-elements, and periods over which applied, used to develop CONUS AORC specific humidity, pressure, downward short and long wave radiation, and wind fields.

Dataset	Dataset component	Dataset grid resolution	Dataset applied to the AORC	Spatial domain
The North American Land Data Assimilation System - version 2 (NLDAS2)	1-hr specific humidity, pressure, and downward longwave radiation. 1-hr shortwave radiation, wind (u,v)	12-km	1979–2015 1979–present	superCONUS
NCEP Unrestricted Mesoscale Analysis (URMA)	1-hr specific humidity, pressure, and downward longwave radiation.	2.5-km	2016–present	Super CONUS

The 12-km, 1-hr fields from the NLDAS2 were initially interpolated to the 1-km AORC grid using bilinear interpolation. The surface pressure, longwave radiation and specific humidity fields were then adjusted vertically to account for terrain differences between the NLDAS2 and AORC, caused by the difference in spatial resolution between these two datasets (i.e., average terrain heights over areas estimated). The vertical adjustment applies a standard atmospheric lapse rate of 0.65°C/100m for air temperature. The shortwave radiation and west-east and south-north winds 10m above ground level were not adjusted for terrain differences. Downward longwave radiation was then calculated from temperature, humidity and pressure, applying the cloud adjustment factor derived from the same quantities in the NLDAS2 record (method shown in Cosgrove et al. 2003) and described in the section below.

4.2.2. Methodology

Specific humidity and terrain-level pressure

For the period when the NLDAS2 was used as an input forcing to the AORC, the specific humidity (SPFH) and pressure (P) variables were developed following the procedure used for downscaling those fields in the NARR to the higher-density grid mesh of the North American Land Data Assimilation System version-2 (Cosgrove et al. 2003). However, an additional step was required to account for differences between the NLDAS2 and AORC temperatures, since both height and temperature differ (due to terrain resolution) between the two datasets.

To blend the mass, elevation, and temperature information from the NLDAS2 with the temperature and elevation information from the AORC, the temperature was calculated as the mean of the NLDAS2 and AORC in the layer between their grid elevations. The hydrostatic formula (neglecting water vapor effects) was then applied to the NLDAS2 pressure to determine the AORC pressure:

$$P_{AORC} = P_{NLDAS2}{}^{\frac{g*\Delta Z}{R*T_{mean}}} \quad \text{[Eq.4.1.]}$$

where g is the gravitational acceleration (m s-1), R is the gas constant for dry air, ΔZ is the height difference between the AORC and NLDAS2 elevation grids, and Tmean is the average of the AORC and NLDAS2 temperatures (K). The effect of water vapor on the pressure/height lapse rate was neglected, since, in much of the domain, steeply-sloping terrain is generally at high elevations, where the absolute humidity is low. For the period 2018 - near present, the same process was followed except both temperature and pressure were based on URMA.

The AORC specific humidity at 2m above-ground-level (kg/kg) is based on the NLDAS2 specific humidity at 2m AGL. In order to maintain the identical atmospheric demand for water vapor at the AORC and NLDAS2 heights, the NLDAS2 specific humidity is adjusted vertically to account for terrain differences between the two. Relative humidity

(%) is assumed constant throughout the ΔZ, enabling the calculation of both AORC temperature and pressure, as shown below.

The saturation humidity for NLDAS2 and AORC (kg/kg) are calculated by combining the equations of state for water vapor and dry air:

$$q_{sat_{AORC}} = 0.622 * \frac{e_{sat\ AORC}}{P_{\ AORC} - 0.378\, e_{sat\ AORC}}$$, and [Eq.4.2.]

$$q_{sat_{NLDAS2}} = 0.622 * \frac{e_{sat\ NLDAS2}}{P_{\ NLDAS2} - 0.378\, e_{sat\ NLDAS2}}$$ [Eq.4.3.]

where q_{sat} is the saturated specific humidity (g g^{-1}), e_{sat} is the saturated vapor pressure (hPa), and P is the pressure (hPa).

Based on Wexler's equation, e_{sat} is the saturated vapor pressure (hPa), which is calculated by:

$$e_{sat_{AORC}} = 6.112^{\frac{17.67(T_{AORC} - 273.15)}{(T_{AORC} - 273.15) + 243.5}}$$, and [Eq.4.4.]

$$e_{sat_{NLDAS2}} = 6.112^{\frac{17.67(T_{NLDAS2} - 273.15)}{(T_{NLDAS2} - 273.15) + 243.5}}$$ [Eq.4.5.]

Given that:

$$RH_{NLDAS2} = \frac{q_{NLDAS2}}{q_{sat_{NLDAS2}}} * 100$$ [Eq.4.6.]

Then, under the assumption that relative humidity is being held constant over the course of the adjustment, this yields the AORC specific humidity in the form:

$$q_{AORC} = \frac{1}{100}\left(RH_{NLDAS2} * q_{sat_{AORC}}\right)$$ [Eq.4.7.]

During winter, the NLDAS2 specific humidity field routinely contains small regions of supersaturation (specific humidity exceeding the nominal saturation value). Also, the formulation in (4.6) and (4.7) sometimes leads to zero or undefined values of q_{AORC} in extremely cold and dry conditions. In the current system, these circumstances are avoided by limiting the RH_{NLDAS2} values to the range of 0.05 to 1.0.

For the period since 2018, when the URMA dataset replaced the NLDAS2 in the AORC, the same process (Eq.4.2–Eq.4.7) was followed.

Downward longwave and shortwave radiation

Downward longwave radiation flux (DLWRF) at the surface is a function of the near-surface air temperature and specific humidity, with a possible contribution of blackbody radiation from any cloudiness present. Following the NLDAS2 convention (Cosgrove et al. 2003), DLWRF is calculated from the AORC temperature and specific humidity, while preserving cloud contributions from the NLDAS2. The near-surface contribution is given by:

$$DLWRF_{AORC} = \frac{(\varepsilon\sigma T^4)_{AORC}}{(\varepsilon\sigma T^4)_{NARR}} DLWRF_{NLDAS2} \quad \text{[Eq.4.8.]}$$

where DLWRF is radiative flux (W m^{-2}), σ is the Stefan-Boltzmann constant (W m^{-2} T^{-4}) and ε is the emissivity, which is, itself, a function of temperature T and vapor pressure:

$$\varepsilon_{AORC} = 1.08 * \{1 - exp * [\frac{q_{AORC}P_{AORC}}{0.622}^{\left(\frac{T_{AORC}}{2016}\right)}]\}, \quad \text{,and [Eq.4.9.]}$$

$$\varepsilon_{NARR} = 1.08 * \{1 - exp * [-\frac{q_{NARR}P_{NLDAS2}}{0.622}^{\left(\frac{T_{NLDAS2}}{2016}\right)}]\} \quad \text{[Eq.4.10.]}$$

where q and P refer to specific humidity in g g-1 and pressure in pascals, calculated using Equations 4.7 and 4.1, respectively.

Incoming solar (shortwave) radiation flux (DSWRF) (W/m2) in the AORC was incorporated from NLDAS2 (1981-2017) without downscaling. The DSWRF fields were bilinearly interpolated directly to the superCONUS AORC grid. The DSWRF was neither downscaled nor modified, because attempts to improve the shortwave radiation in the CONUS from NLDAS2 didn't produce measurable improvements.

Wind components

A number of statistically-based algorithms for downscaling wind vectors exist, though many are designed to capture speed variations due to terrain and not necessarily directional turning (e.g. Winstral et al. 2009, 2017; Huang et al. 2015). We attempted to downscale the NLDAS2 wind vectors by applying both terrain-based climatology, through an ANUSPLIN approach (Hutchinson, 2007), and simple statistical adjustment, using coincident vectors from NLDAS2 and higher-resolution URMA data from 2013-2015. However we were unable to demonstrate consistent improvement over the original NLDAS2 wind fields when comparing original and downscaled grids to observational data, including some from the Mesowest network. Therefore, we have retained the original NLDAS2 wind components, through bilinear interpolation from the NLDAS2 grid to the AORC grid, through the end of 2015. From the beginning of 2016, the URMA wind elements replaced NLDAS2 and were bilinearly interpolated from 2.5-km to 1-km resolution.

5. Alaska Analysis of Record for Calibration

The Alaska AORC dataset spans the period from the beginning of 1981 to the near-present. Its domain covers all of Alaska (including most of the Aleutian Island chain) as well as nearby regions of Canada's British Columbia (BC) and Yukon and Northwest Territories that contribute to Alaskan watersheds (Figure 5).

The AORC dataset is formulated on a 1/120-degree or 30 arc-second (0.008333°) (Note that at the latitude/longitude coordinates of Anchorage, AK (i.e. 61.2181 N; 149.9003 W), a 30 arc-second grid cell measures approximately .9277 km in the N-S direction and .4467 km in the E-W direction).

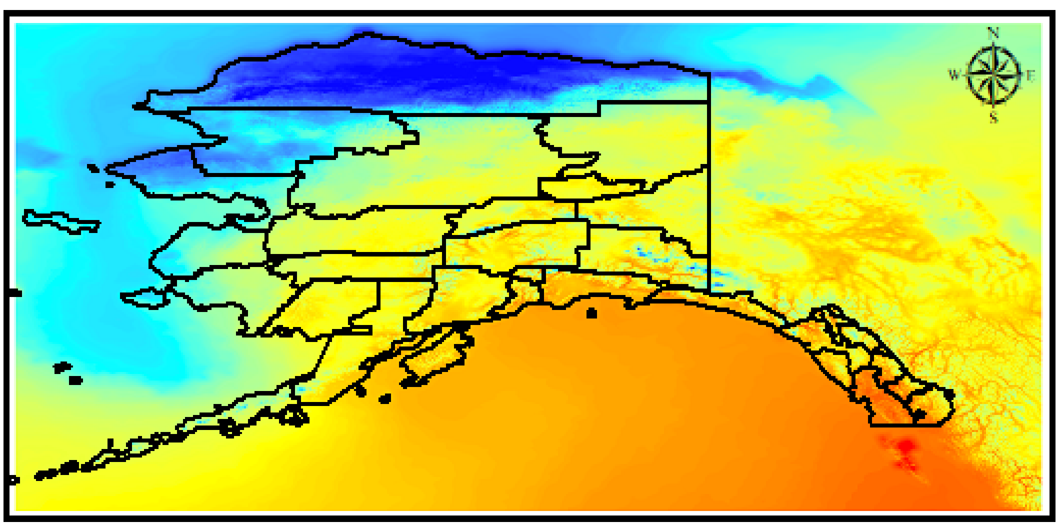

Figure 5.1. The spatial domain of the Alaska AORC dataset.

5.1. Precipitation and Temperature

The gridded AORC precipitation dataset contains one-hour accumulated surface-precipitation (APCP) ending at the top of each hour, in liquid water-equivalent units (kg/m^2 to the nearest .01 kg/m^2), while the AORC temperature dataset is comprised of instantaneous, 2 m above ground-level (AGL) temperatures at the top of each hour (in degrees Kelvin, to the nearest .01 degree).

5.1.1. Dataset Sources

Over a half-dozen individual datasets went into construction of the Alaska AORC precipitation and temperature datasets (Table 5.1.). These inputs can be characterized as two basic types: time-series and climatic. The time-series inputs are of various multi-hourly durations, and provide the basis for the high temporal resolution of the AORC dataset. The climatic datasets are of mean, monthly or annual amounts and are, themselves, of two types: gridded and gauge or point. The gridded, climatic datasets are used to bias-correct the time-series data, while the gauge data are used for point correction of the climatic datasets.

The time-series datasets utilized in building the AORC include North American Regional Reanalysis (NARR) 3-hour accumulations and every-third-hour temperatures on a 32-km resolution grid, which were used from the beginning of the Alaska dataset in January 1981 through the end of 2009 for precipitation, and through the end of 2017 for temperature. At the beginning of 2010, Stage IV, 6-hour precipitation accumulations on a 4-km grid became available for Alaska and, from then to near-present, replaced the NARR precipitation as input to the AORC. Regarding temperature, a higher spatial and temporal resolution dataset, i.e. NCEP Unrestricted Mesoscale Analysis (URMA) containing hourly values on a 2.5 km grid, replaced the NARR temperatures at the beginning of 2018, and then through to near-present.

The gridded, climatic datasets employed in building the AORC mean annual precipitation (MAP) and mean annual temperature (MAT) fields include three varieties of PRISM data of high spatial resolution (~800m and 4km), which cover various portions of the Alaska AORC domain and were spatially blended along dataset boundaries (as described below). Rain gauge observations from the Environment Canada network were used to develop and correct the MAP climatic datasets for the Yukon and Northwest Territories before they were blended. The gridded, climatic datasets also include a record of monthly accumulations and monthly average temperatures assembled by Hill et al., which were used for bias correction until 2009, and PRISM mean monthly precipitation and temperature datasets (~800m), used for bias correction from the beginning of 2010 to the end of 2017.

Table 5.1. List of input datasets and their resolutions, component-elements, and periods over which applied, used to develop Alaska AORC precipitation and temperature datasets.

Dataset	Dataset component	Dataset grid resolution	Dataset applied to the AORC	Spatial domain
TIME-SERIES DATASETS				
NCEP North American Regional Reanalysis (NARR)	3-hr precipitation 3-hr temperature	32-km	1981–2009 1981–2017	Alaska
NCEP and APRFC* Stage IV	6-hr precipitation	4-km	2010–present	Alaska
NCEP Unrestricted Mesoscale Analysis (URMA)	1-hr temperature	2.5-km	2018-–present	Alaska
CLIMATIC DATASETS				
Environment Canada gauge network	Precipitation and temperature	---	1971–2009	Yukon and Northwest Territories (point correction of a climatic dataset)
PRISM 1971-2000 (Climatology corrected to 1981-2010 using Environmental Canada)	Mean annual precipitation and temperature	4-km	1981–2009	Yukon and NW Territories
PRISM 1981-2010 (Daly et al. 2018)	Mean annual precipitation and temperature	~800-m	1981–2009	Alaska
Pacific Climate Impacts Consortium (Daly et al. 2008)	Mean annual precipitation temperature	~800-m	1981–2009	British Columbia and southeastern Alaska
MONTHLY BIAS CORRECTION DATASETS				
Monthly Precipitation and Temperature (Hill et al. (2012)	Mean monthly temperature and total monthly precipitation	2-km	1981–2009	Alaska
PRISM 1981-2010**	Mean monthly precipitation and temperature	~800-m	2010–2017	Alaska

*The APRFC QPE has been available since 01/2010, and provided to the AORC team by NWS APRFC.
**PRISM 1981-2010 mean monthly precipitation to bias correct NARR precipitation only for dates where Stage IV data was missing.

Time-series datasets

The formulation of the AORC precipitation and temperature datasets for Alaska has been guided by the availability of high resolution spatial and temporal gridded datasets, a scarcity of gauge observations, and limitations on the ability to accurately measure frozen precipitation and other elements.

The North American Land Data Assimilation System - version 2 (NLDAS2) dataset, used in developing the precipitation and temperature components over the CONUS, was not available for Alaska, while NCEP Stage IV had limited spatial coverage in and around Alaska until 2010. The North American Regional Reanalysis (NARR; Messinger et al. 1996) 3-hour precipitation record, which was used to develop the higher-density grid mesh of the NLDAS2 dataset over the CONUS, has been available for Alaska since 1979. The NARR model is based on a high resolution NCEP Eta Model (32km/45 layer) together with the Regional Data Assimilation System (RDAS). This product has also been evaluated and used in operations by the NWS Alaska-Pacific River Forecast Center (APRFC) to estimate the total precipitation for remote areas of AK and Canada, due to a lack of ground observations there. The NARR was selected and used for developing precipitation, temperature, and all the other AORC elements for the period 1981 through the end of 2009.

In April 2017, the NCEP Stage IV 6-hour product, covering the whole Alaskan domain, became available on the NCEP website. However, a version of the Stage IV 6-hour product for the whole Alaskan domain that was produced and used in operations by the NWS APRFC has been available for the period between January 2010 and April 2017. This dataset was provided by the NWS APRFC and has been used for precipitation in the AORC since January 2010, in lieu of the NARR. The quality of Alaska's Stage IV data, especially during winter months, may be impacted by the scarcity of gauge observations and the limited ability of the gauge stations to accurately measure frozen precipitation.

The UnRestricted Mesoscale Analysis (URMA) 2.5-km, 1-hour dataset was developed by the National Weather Service and is used in several NWS operations. This dataset is essentially a version of NWS's Real-Time Mesoscale Analysis (RTMA) with a six-hour delay to account for late, incoming reports (including temperature). The URMA dataset for Alaska contains fourteen weather elements, including temperature, wind components, pressure, and specific humidity. This higher-quality, higher-resolution dataset replaced NARR temperature in the AORC at the beginning of 2018 and continues to the near present.

Climatic datasets

The three PRISM-based, climatic, gridded datasets (see Table 5.1.) were merged to define the AORC domain and correct the time-series data for yearly biases, from 1981 through 2010. The PRISM mean, annual precipitation and temperature (Daly et al., 2018) dataset that covers the political boundaries of AK was blended with the PRISM Pacific Climate Impacts Consortium (PCIP) record (Daly et al., 2008) that covers BC and southeastern AK, to cover the majority of the spatial domain. These datasets were blended by extending the amount difference of the one that covers the political boundaries of AK over the domain of the PCIP dataset, employing a weight inversely proportional to the distance from the BC/AK border. For the coverage over Yukon and the NW Territories, a previously-published 1971-2000 PRISM climatology, provided by APRFC, was blended, as described above, into the aforementioned, merged PRISM product. Before the blending process, this 1971-2000 PRISM dataset was point-corrected to the climatological 1981-2010 period, using Environmental Canada gauge observations (Environment Canada, 2019a, Environment Canada, 2019b).

5.1.2. Methodology

Spatial and Temporal Downscaling

The spatial disaggregation method used to downscale the NARR datasets from 32km to 1km resolution, using PRISM MAP and monthly mean grids, follows approximately the "anomaly technique" spatial disaggregation technique (Riverside Technology, 2012). This spatial disaggregation method maintains the 3-hourly characteristics of the NARR dataset while introducing the PRISM dataset's spatial variability and long-term characteristics (due to bias correction). The spatial variability of the PRISM climatology grids (800 m) reflects the terrain's ability to affect precipitation patterns, since both topography and coastal effects were accounted for in the development of the PRISM product (Daly et al., 2018). In the case of the AORC, the NARR dataset was both bias-corrected and spatially disaggregated in the same process.

Between 1981 and 2010, two multiplicative bias corrections were performed on the NARR precipitation. The first of these procedures is based on the 2-km total monthly precipitation developed by Hill et al. (2012). The second multiplicative bias correction procedure is based on the 1-km, 1981–2010 PRISM 30-year mean monthly precipitation. In the AORC 2010-2017 period, when the Stage IV dataset provided by the APRFC was used and when the Hill dataset was not available, Stage IV data was only bias corrected using the 1-km, 1981–2010 PRISM 30-year mean monthly precipitation. However, the Stage IV was missing the majority of its data during the following five months: January, 2010; April, 2013; May, 2013; January, 2014; and April, 2015. For those five months, the 3-hour NARR precipitation field was used instead, and corrected following the same procedure described for the period before 2010. Between 2017-present, Stage IV data was not biased-corrected using climatologic datasets. The Stage IV data was initially projected and regridded, using bilinear interpolation, to the AORC grid domain.

The difference factor corrections were used to correct and downscale the 3-hour, 27-km NARR temperature to the 1-km AORC resolution. Similarly to the precipitation, two difference factor procedures were used to correct NARR temperature between 1981-2009. The first correction is based on the 2-km mean monthly temperature developed by Hill et al. (2012), and the second correction procedure is based on the 1-km, 1981–2010 PRISM 30-year mean monthly temperature. Between 2010 and 2017, when the Hill dataset was not available, NARR temperature downscaling was based on the 1-km, 1981–2010 PRISM 30-year mean monthly temperature only (Daly et al., 2018). After 2017, when URMA temperature provided the input forcing to the AORC, the URMA data was projected and regridded, using bilinear interpolation, to the AORC grid domain and not bias corrected using climatology datasets.

Both NARR and Alaska Stage IV data were temporally disaggregated, uniformly, over the dataset period. Several experiments were performed to temporally disaggregate these datasets using various sources of sub-daily precipitation. For example, the Global Data Assimilation System (GDAS) APCP field was tested to subdivide Stage IV datasets from 6- to 1-hour increments. The GDAS analysis revealed a rather weak temporal correlation with the Stage IV data. It might be possible in the future, when more remote-sensing, hourly, high-latitude precipitation datasets become available, to more accurately subdivide and distribute the NARR and Stage IV data to 1-hour resolution.

5.1.3. Verification

Similarly to CONUS verification analysis, the precipitation and temperature elements within the Alaska domain were assessed by comparison with mean monthly precipitation and mean monthly temperature from stations in the Global Historical Climatology Network (GHCN; Lawrimore et al. 2011). For precipitation verification in Alaska, an additional 68 stations from the National Resources Conservation Service (NRCS), Snow Telemetry (SNOTEL: USDA NRCS 2021) network were utilized. The SNOTEL stations tend to be located in challenging areas (high terrain, etc.) and thus provide better verification analysis, given that Alaska's wettest area is in the southern coastal region, especially at higher elevations.

Monthly time series data at all stations were verified for the period of record 1981-2019. Similarly to the CONUS verification analysis, the performance metrics were long-term mean value (as compared to the observed reference), time series root-mean squared error (RMSE), and linear correlation.

Mean monthly precipitation

A total of 97 (29 GHCN and 68 SNOTEL) gauge sites were used for the mean monthly precipitation comparison between AORC and gauge observations. The mean monthly analysis was broken down by month. Figure 5.2.a. shows comparison for January (winter month) and Figure 5.2.b. shows comparison for July (summer month). For both the January and July estimates, the mean absolute error shows that estimates were within 10 mm of the observed. However, larger errors for data values over 400 mm were observed for January at Little Port Walter on Baranof Island in southeast Alaska.

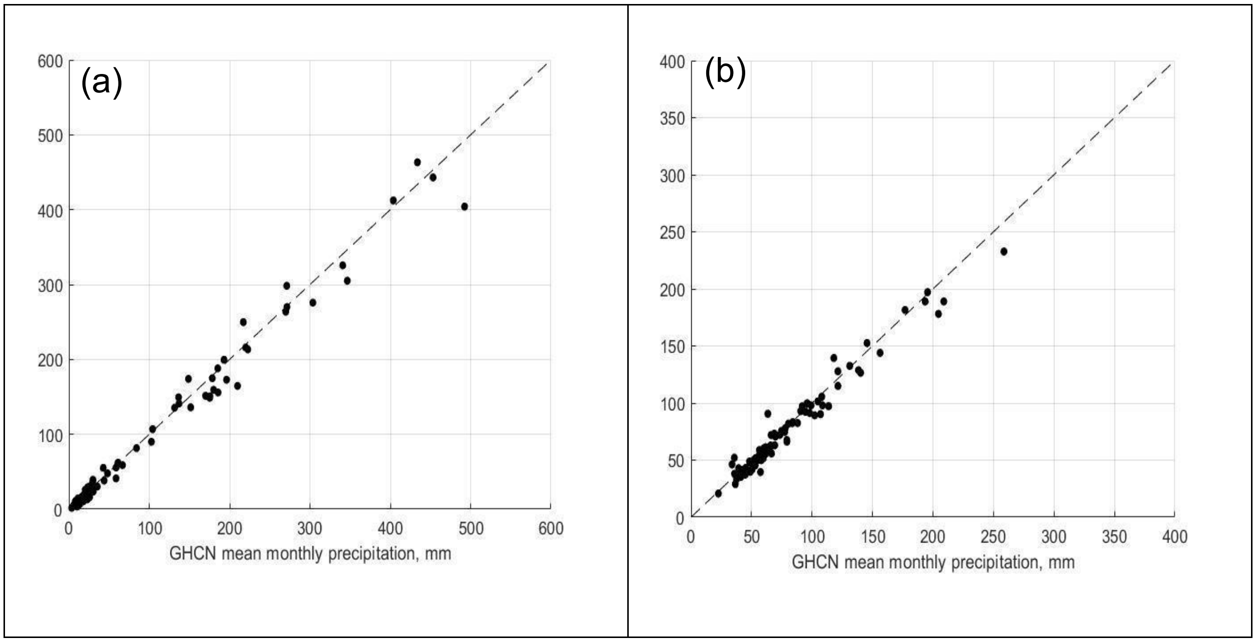

Figure 5.2. AORC versus GHCN and SNOTEL mean monthly precipitation, in mm, for the period between 1981-2019 over Alaska for (a) January, and (b) July.

Mean monthly temperature

The mean-monthly AORC and gauge temperature comparisons were performed for Alaskan and Canadian sites from GHCN sources. A total of 29 gauge sites were used for the analysis and the spatial distribution of the sites across Alaska was relatively good. The analysis was broken down by month, and those for January and July are shown in Figures 5.3.a and 5.3.b. For those estimates, most mean AORC temperatures were found to be within 1.0°C of the observed, though the July statistics show a bit better performance.

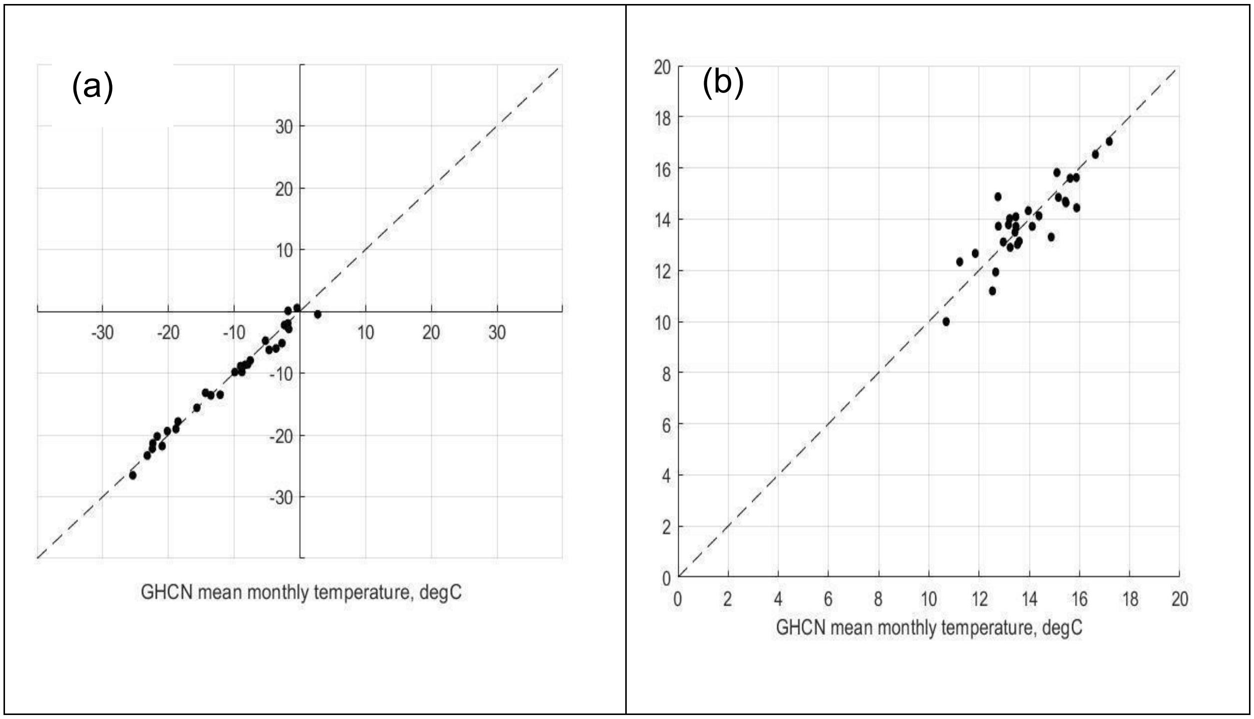

Figure 5.3. AORC versus GHCN mean monthly temperature over Alaska for the period between 1981-2019 in degrees Celsius for (a) January, and (b) July.

5.2. Specific Humidity, Pressure, Downward Radiation, Wind

The development process for the six additional dataset components of the Alaska AORC [i.e., specific humidity at 2m above ground (kg/kg); downward longwave and shortwave radiation fluxes at the surface (W/m2); terrain-level pressure (Pa); and west-east and south-north wind at 10m above ground (m/s)] has two distinct periods, based on datasets and methodology applied: 1981–2017 and 2018–present.

5.2.1. Dataset Sources

The North American Regional Reanalysis (NARR) 3-hour fields on their native, 32-km resolution grid provided the basis for the high temporal resolution of the AORC dataset for the period between 1981 and 2017, for specific humidity, pressure, downward short and long wave radiation, and winds (Table 5.2.). Given the NARR input dataset's coarse spatial and temporal resolution, it was replaced in 2018 with newer datasets that provide the input forcings at a higher spatial and temporal resolution. The NWS's UnRestricted Mesoscale Analysis (URMA) and NCEP's Global Data Assimilation System (GDAS) datasets were used to develop the six components (above) since 2018. The URMA dataset provides the time-series data for humidity, pressure, and the wind vectors, while GDAS provides the time-series data for the shortwave and longwave radiation fluxes. (Note that no climatological datasets were used in the development of these six Alaska AORC fields.)

Table 5.2. List of input datasets and their resolutions, component-elements, and periods over which applied, used to develop Alaska AORC specific humidity, pressure, downward short and long wave radiation, and wind fields.

Dataset	Dataset component	Dataset grid resolution	Dataset applied to the AORC	Spatial domain
NCEP North American Regional Reanalysis (NARR)	3-hr specific humidity, pressure, wind (u,v) 3-hr downward longwave and shortwave radiation	32-km	1981–2017 1981–present	Alaska
NCEP Unrestricted Mesoscale Analysis (URMA)	1-hr specific humidity, pressure, and wind (u,v)	2.5-km	2018–present	Alaska

The 32-km, 3-hr fields from the NARR are initially interpolated to the 1-km AORC grid using bilinear interpolation, and are temporally disaggregated to the AORC's 1-hr interval. The surface pressure, longwave radiation and specific humidity fields are then adjusted vertically to account for terrain differences between the NARR and AORC, caused by the difference in spatial resolution between these two datasets. The vertical adjustment applies a standard atmospheric lapse rate of 0.65°C/100m for air temperature. The shortwave radiation and west-east and south-north winds 10m above ground are not adjusted for terrain differences.

The UnRestricted Mesoscale Analysis (URMA) 2.5-km, 1-hour surface pressure, specific humidity and wind components replaced the NARR starting January 2018. As with NARR, the URMA elements were interpolated to the 1-km AORC domain using bilinear interpolation and temporally disaggregated to the AORC's 1-hr interval. The surface pressure and specific humidity were then adjusted to account for terrain differences between the URMA and AORC, with the lapse rate noted above.

5.2.2. Methodology

Specific humidity and terrain-level pressure

For the period when the NARR was used as an input forcing to the AORC, the specific humidity (SPFH) and pressure (P) variables were developed following the procedure used for downscaling those fields in the NARR, to the higher-density grid mesh of the North American Land Data Assimilation System version-2 (Cosgrove et al. 2003). However, an additional step was required to account for differences between the NARR and AORC temperatures, since both height and temperature (due to terrain resolution) differ between the NARR and AORC.

To blend the mass, elevation, and temperature information from the NARR with the temperature and elevation information from the AORC, the temperature was calculated as the mean of the NARR and AORC temperatures in the layer between their grid elevations. The hydrostatic formula (neglecting water vapor effects) was then applied to the NARR pressure to determine the AORC pressure:

$$P_{AORC} = P_{NARR}{}^{\frac{g*\Delta Z}{R*T_{mean}}} \qquad \text{[Eq.5.1]}$$

where g is the gravitational acceleration (m s-1), R is the gas constant for dry air, ΔZ is the height difference between the AORC and NARR elevation grids, and Tmean is the average of the AORC and NARR temperatures (K). The effect of water vapor on the pressure/height lapse rate was neglected, since, in much of the domain, steeply-sloping terrain is generally at high elevations, where the absolute humidity is low. For the period between 2018 - near present, the same process was followed except that both temperature and pressure were based on URMA.

The specific humidity 2m above-ground-level (kg/kg) is based on the NARR specific humidity at 2m AGL. In order to maintain the identical atmospheric demand for water vapor at the AORC and NARR heights, the NARR specific humidity is adjusted vertically to account for terrain differences between the two. Relative humidity (%) is assumed constant throughout the ΔZ, enabling the calculation for both AORC temperature and pressure, shown below. The development of the humidity elements for Alaska closely follows the development described, in detail, in Section 4.1.2, above, for the CONUS. The only difference is that, instead of NLDAS2 being used as the input forcing dataset, the NARR dataset was used for Alaska.

Downward longwave and shortwave radiation

The development of the downward longwave element closely follows the development for the CONUS [described, in detail, in Section 4.1.2.] The methodology for developing this element is exactly the same except that, instead of NLDAS2 as the input forcing dataset, for Alaska, the NARR dataset was used.

Incoming solar (shortwave) radiation flux (DSWRF) (W/m2) in the AROC was incorporated from the NARR (1981-present) without downscaling. The DSWRF fields were bilinearly interpolated directly to the Alaska-region AORC. The DSWRF was not downscaled or modified, since attempts to improve the shortwave radiation in the CONUS from NLDAS2 (based on NARR) didn’t produce measurable improvements.

Wind vectors

In Alaska, we also investigated calculating the magnitude and direction from the NARR/URMA wind vectors, interpolating them to the AORC 1-km resolution, and disaggregating them to the AORC wind vector components. This tested procedure, even though it conserves magnitude, does not show significant improvement with respect to spatial patterns. The complexity and the processing time for making the wind calculation improvements have not shown overall benefits in spatial or temporal wind component characteristics.

Based on experience with the downscaled NLDAS2 wind fields (which are derived from the NARR) over the conterminous United States, it was decided that the NARR wind vectors should be applied directly in Alaska, through bilinear interpolation to the AORC grid, and that those wind vectors be temporally disaggregated, uniformly, over 3-hour periods. The same process was applied for the later period, when URMA was used as the input forcing.

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Appendix A: Data Source References

Canadian monthly time series data were obtained from Environment Canada through

http://climate.weather.gc.ca/prods_servs/cdn_climate_summary_e.html.

Canadian Meteorological Center Regional Deterministic Precipitation Analysis (RDPA - CaPA), for daily precipitation over southwest Ontario:

https://dd.weather.gc.ca/analysis/precip/rdpa/grib2/polar_stereographic/24/

CMORPH microwave hourly precipitation (from 2 30-min precipitation rate grids):

ftp://ftp.cpc.ncep.noaa.gov/precip/CDR_CMORPH

Livneh (LIV15) monthly and daily precipitation and temperature data were obtained from the University of Colorado through

ftp://livnehpublicstorage.colorado.edu/public/Livneh.2016.Dataset/.

Manually-Digitized Radar (MDR) data were obtained from UCAR through

https://rda.ucar.edu/datasets/ds840.1/.

Mexican climatic and time-series station data from Servicio Nacional Meteorologico are presently sourced through http://clicom-mex.cicese.mx/.

NLDAS2 records were obtained from NASA Goddard Earth Science Data Information and Services Center (through https://hydro1.gesdisc.eosdis.nasa.gov/data/NLDAS/.

StageIV and StageII hourly and daily precipitation were obtained from UCAR/NCAR Earth Observing Laboratory, https://data.eol.ucar.edu/dataset/21.006, https://data.eol.ucar.edu/dataset/21.050, https://data.eol.ucar.edu/dataset/21.090, https://data.eol.ucar.edu/dataset/21.093.

NEXRAD reflectivity national composites for 1995 were obtained from Iowa Environmental Mesonet, https://mesonet.agron.iastate.edu/docs/nexrad_composites/.

NOWrad (™) gridded reflectivity data were obtained from NCAR through

http://www2.mmm.ucar.edu/imagearchive/WSI/.

NCEP Global Data Assimilation System (GDAS) precipitation and radiative fluxes:

https://nomads.ncep.noaa.gov/pub/data/nccf/com/gfs/prod/

NCEP North American Land Data Assimilation System (NLDAS) radiative fluxes and winds:

https://nomads.ncep.noaa.gov/pub/data/nccf/com/nldas/prod/

NCEP North American Regional Reanalysis (NARR):ftp.cdc.noaa.gov/Datasets/NARR/

NCEP StageIV hourly and daily precipitation:

https://www.emc.ncep.noaa.gov/mmb/SREF/pcpanl/stage4/

NCEP StageII hourly and daily precipitation;

https://www.emc.ncep.noaa.gov/mmb/SREF/pcpanl/stage2/

NCEP Unrestricted Mesoscale Analysis (URMA) temperature and other non-precipitation variables:

http://nomads.ncep.noaa.gov/pub/data/nccf/com/urma/prod/

PRISM climatology information was provided by PRISM Climate Group, Oregon State University, http://prism.oregonstate.edu, and by Pacific Climate Impacts Consortium, University of Victoria, https://data.pacificclimate.org/portal/bc_prism/map/.

WorldClim v1.4 and Uniatmos gridded global and Mexico climatology were obtained through http://worldclim.org/version1 and http://uniatmos.atmosfera.unam.mx/ACDM/, respectively.