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RESEARCH AND OBSERVATORY CATCHMENTS: THE LEGACY AND THE FUTURE

WILEY

Long-term stream hydrology and meteorology of a Polar Desert, the McMurdo Dry Valleys, Antarctica

Michael N. Gooseff[1] | Diane M. McKnight[1] | Peter T. Doran[2] | Andrew Fountain[3]

[1]Institute of Arctic and Alpine Research, University of Colorado Boulder, Boulder, Colorado, USA

[2]Department of Geology & Geophysics, Louisiana State University, Baton Rouge, Louisiana, USA

[3]Department of Geology, Portland State University, Portland, Oregon, USA

Correspondence
Michael N. Gooseff, Institute of Arctic and Alpine Research, University of Colorado Boulder, Boulder, CO 80303, USA.
Email: michael.gooseff@colorado.edu

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Abstract

The McMurdo Dry Valleys (MDVs; 77.50°S, 162.25°E) make up the largest ice-free region of Antarctica at ~3500 km^2. Their position near the coast of the Ross Sea provides for a milder climate than much of the rest of the continent. Alpine and piedmont glaciers in the MDVs melt during the austral summer providing water to down gradient streams and terminal lakes on valley floors. There are currently 14 meteorological stations and 17 stream gauges operating across the MDVs, some with continuous records that go back to 1969. This relatively high density of monitoring stations reflects the fact that glaciers of different sizes and elevation ranges are the main source of water to streams. Thus, each glacier represents a different watershed. The bulk of these records start in the late 1980s/early 1990s. These data collection activities directly support research endeavours of the McMurdo Dry Valleys Long Term Ecological Research project, as well as a host of other science groups working in the MDVs. As such, both real time data and archived data from these sites is available through the online database interface of the project (http://mcmlter.org).

KEYWORDS
Antarctica, LTER, McMurdo Dry Valleys, meltwater streams, polar desert, research catchment

1 | SITE AND PROCESS DESCRIPTION

The McMurdo Dry Valleys (MDVs) make up the largest ice-free region of Antarctica (Figure 1). The landscape is a mosaic of alpine, piedmont and terminal glaciers, exposed soils and rocky outcrops, streams, and ice-covered ponds and lakes (Figure 2). The climate of the MDVs region is cold (mean annual air temperature of −19.6°C; Obryk et al., 2020) and dry (<10 mm snow water equivalent on the valley floors; Fountain et al., 2010). In the austral summer, surface energy balance is great enough to generate melt from the glaciers, which feeds streams, many of which eventually convey water to closed-basin lakes on the valley floors. Streams derive more than 95% of their flow from glacial melt (remainder is snow patch melt) and flow for 6–10 weeks on average (late November to mid February; Wlostowski et al., 2016), activating the extensive microbial mats along streambeds. This polar desert landscape has been studied intensively within the McMurdo Dry Valleys Long Term Ecological Research (MCM LTER) project since 1993. Like other LTER projects, MCM LTER participants collect core monitoring data and conduct short- and long-term experiments.

The seasonal meteorology of the MDVs revolves from the dark, cold austral winter (JJA) with air temperatures regularly around −40°C, to the spring (SO) with the onset of sunlight (generally reaching the valley floors for extended periods of the day in mid-November) and warming air temperatures, to the austral summer (NDJF) with peak solar radiation for the year and air temperatures around 0°C, to the fall (MAM) with fading light and cooling air temperatures (Doran et al., 2002; Obryk et al., 2020). The MDVs, especially Taylor Valley, experience strong foehn wind events blowing down-valley (>20 m/s; Nylen et al., 2004; Speirs et al., 2010). These wind

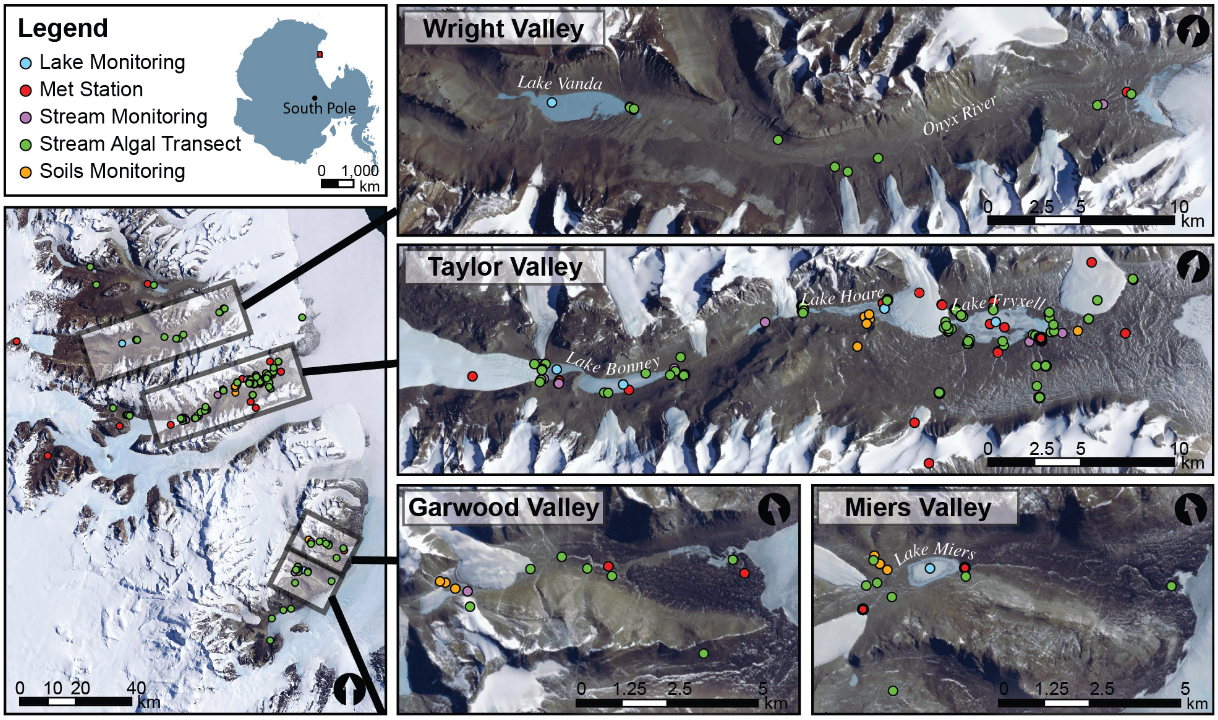

FIGURE 1 Map of the McMurdo Dry Valleys region and the locations of ecosystem studies conducted by the McMurdo Dry Valleys long-term ecological research project (map generated by Eric Parrish)

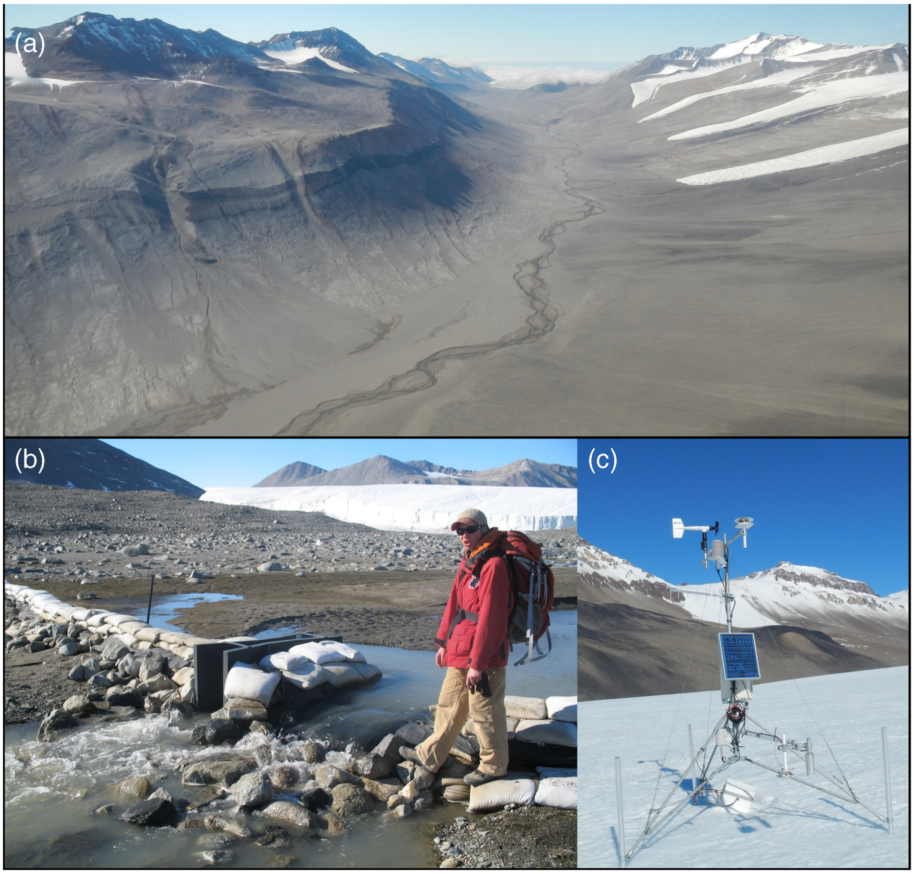

FIGURE 2 Images of (a) Wright Valley and the Onyx River looking upstream towards the coast, (b) the lost seal stream gage with a flume and overflow notch in its control structure, and (c) Taylor glacier meteorological station

events are most common in the winter months and induce increases in air temperature and reductions of relative humidity. These high wind events promote aeolean transport of sediment, microbes, and algal mat material as a key vector of landscape connectivity moving these materials among landscape units (Šabacká et al., 2012). Snow falls in all seasons in the MDVs, though winter snow is typically consolidated into patches in topographic lees across the landscape due to wind redistribution (Eveland et al., 2013). These patches sublimate and melt through the austral summer.

Active layers (seasonally thawed ground) are shallow across the MDVs, expanding under and adjacent to streams and lakes (Conovitz et al., 2006; Northcott et al., 2009). Permafrost is generally found to be >100 m deep across most of the MDVs, though recent airborne geophysics studies suggest that a deep briny groundwater system may exist under some of the MDVs (Mikucki et al., 2015). Thawed hyporheic zones adjacent to streams actively exchange stream water providing an important location of biogeochemical transformations prior to water and solutes entering lakes, including nutrient cycling (Gooseff et al., 2004; Koch et al., 2010; Kohler et al., 2018; McKnight et al., 2004), and weathering of the streambed sediments (Gooseff et al., 2002; Nezat et al., 2001). Across the MDV streams there are 16 established transects at which algal mats are sampled regularly to track biomass changes and diatom community dynamics (Kohler et al., 2016).

Research personnel can only access the MDVs from October to February of a given field season. In a few cases, science groups have deployed during Winter Fly In, accessing the MDVs in August, and in 1 year a group stayed as late as April. Field teams access remote locations via helicopter typically on day trips from McMurdo Station or one of the several field camps established by the US Antarctic Program in Taylor Valley.

Two primary data collection networks described here are the stream gaging network (17 current gages) and meteorological stations (14 current stations). Because streamflow is primarily generated by glacial melt, each gage provides an estimate of streamflow from a portion of a glacier (see Bergstrom et al., n.d.). Many of the closed-basin lakes are fed by multiple streams. Thus, gaging these streams provides a means towards estimating a component of the water mass balance of the lakes. Meteorological stations are distributed across elevations and land surface types to estimate surface energy balances (i.e., dry ground vs. glacier surface) and provide basic weather and climate data. Some are also set up adjacent to lakes to estimate surface energy balance of lake ice-covers.

2 | HYDROLOGIC INSTRUMENTATION AND MEASUREMENTS

Early science in the MDVs included the installation and operation of a stream gage on the Onyx River just above its mouth at Lake Vanda by a group of New Zealand scientists in 1968. The Onyx River is the largest stream in the MDVs and in Antarctica (Figure 2a). Soon after establishing the Onyx River at Vanda gage, another gage was installed near its headwater lake (Onyx at Lower Wright), approximately 25 km upstream. The Onyx River at Vanda gage has been operated continuously since 1969 (field personnel depart in early February and data loggers run well-beyond this; Chinn & Mason, 2015). In the early 1990s other gages were established on glacial meltwater streams across the MDVs by MCM LTER researchers, though several have been removed or relocated due to lake level rise or damage from glacier movement. The entire Onyx River flow records and those of the LTER stream gages are available from the MCM LTER database.

All 17 stream gages presently measure and report water stage, water temperature, and electrical conductivity on a 15-min frequency. Each stream gage contains a control cross-section: a flume, a low rock weir with a notch, a v-notch weir, or a gabion and a small gage house located adjacent to the stream where dataloggers, conoflow, N_2 tank, and power supplies are contained and protected from the elements. Stage at the control section is measured by bubbling N_2 gas through a conoflow gas pressure purge/regulation system connected to a pressure transducer (either a PSS-1 or PSS-2 model from Paroscientific Corporation [Redmond, WA USA] or an Accubar model from Sutron Corporation [Sterling, VA USA], accuracy of 0.2 hPa), making up a bubbling gage (Sauer & Turnipseed, 2010). This approach reduces the need for electronic sensors in the stream. Outlet orifices of the tubes from the conoflows are fixed to flumes or to rebar established near the control cross sections. Elevations of points of zero flow (i.e., lowest point of control cross section), orifices, and other points of interest are measured in relationship to established benchmarks at each control cross-section at the start and end of each flow season. In the past, water temperature was measured with Campbell Scientific CS 107 probes (accuracy of 0.01°C). Recently these were removed so that stream water temperature and electrical conductivity are both being measured with Campbell Scientific CS-547A sensors (as of 2019; accuracy of EC measurement is 5% and 0.2°C for temperature). Sensors are controlled by either Campbell Scientific CR-10X or CR-1000 data loggers (depending on the gage). Power is supplied by solar chargers and 12 V batteries. Stream gages are 'opened' in mid-November and 'closed' in late January. In addition to running levels at gages, these activities include swapping of data storage modules and deployment of new N_2 tanks in November. Stream gages run year-round, but flow seasons cease in February or March each year. Dataloggers run through the winter but N_2 is exhausted before the beginning of the next flow season. Data gaps are present due to field sensor failures, freeze up of sensors, and so on. In the records these gaps are noted with indicators (i.e., 'Nan') or no entry within the csv file containing the data set. Data collected after one flow season ends (February or March) and the next begins (November/December) are not included in the data archives.

During the austral summer, the MCM LTER stream team maintains the gaging network, makes manual discharge measurements, and collects stream water samples for chemical analysis. The manual measurements of discharge are used to generate a rating curve for each gage. At high enough flows, discharge measurements are made by wading methods, and at low flows, they are made using small portable Baski flumes (Englewood, CO, USA; accuracy depends on stage measurements made within the flume). Water temperature and electrical conductivity are measured during stream gage visits during the flow season using YSI (Yellow Springs Inc.; Yellow Springs, OH USA) portable field metres (as provided by the US Antarctic programme, so not necessarily the same model each season) for comparison to time series data collected by the data logger. All-time series gage data are currently processed (i.e., stages/temperatures/electrical conductivities are corrected and flows calculated) using Aquarius software (Aquatic Informatics; Vancouver, BC Canada). Historic flow data work-ups using USGS protocols (Sauer, 2002) and Automated DAta Processing System (ADAPS) software have been integrated into Aquarius as well. Stream hydrograph data (i.e., after processing) are rated as excellent, good, fair, or poor in adherence with US Geological Survey guidelines (Sauer, 2002). Uncertainties for these ratings are 2, 5, 8, and 10%, respectively, depending on conditions of the gage at the time of or between visits, and/or the quality of the discharge measurement made during a visit.

3 | METEOROLOGIC INSTRUMENTATION AND MEASUREMENTS

The longest meteorological record in the MDVs comes from the Lake Hoare site, established in 1987 (prior to the initiation of the MCM LTER). Expansion of the meteorological station network was substantial in 1994 when protocols and common measurements were developed (Doran et al., 1995). Meteorological stations are deployed on top of several glaciers (Commonwealth, Canada, Howard, and Taylor Glaciers) in Taylor Valley to measure the surface energy balance of the glacier ice. Some of the meteorological stations established adjacent to major lakes of the MDVs with the goal of quantifying much of the surface energy balance of the lake ice covers.

Meteorological stations measure several common parameters: air temperature (with Campbell Scientific CS 107 sensor), relative humidity (with Campbell Scientific 207 Phys-Chem transducers, with an accuracy of 5% at 25°C for the operating range of 12%–100%), wind speed and direction (currently measured with RM Young 05103 sensor, which has a wind speed accuracy of 1.5% and direction accuracy of 4%), and incoming solar radiation flux (with a Licor LI-200 pyranometer [Lincoln, NE USA], with a cosine-corrected silicon photodiode and maximum uncertainty of 5%). All parameters are recorded on a 15-min interval, however, wind speed and direction are measured at higher frequencies and statistics (e.g., mean wind speed, gust speed) are reported on 15-min intervals. At some of the glacier sites both incoming and outgoing long-wave (Eppley PIR pyrgeometer, uncertainty of 5 Wm^{-2}) and shortwave (Eppley SPP pyranometer, uncertainty of 10 Wm^{-2}) radiation have been and/or are currently being measured. Some stations deployed on soils also include soil moisture and temperature sensors deployed at 0, 5, and 10 cm depths (Campbell Scientific CS655 with a 3% accuracy for water content and 0.5°C accuracy for soil temperature; and Decagon 5TM with a 3% accuracy for water content and 1°C accuracy for soil temperature). Several met stations also have sonic ranging sensors (Campbell Scientific SR50 with an accuracy of 1 cm) pointed at the ground from a high cross arm to measure the accumulation and ablation of snow. Precipitation gages (OTT Pluvio precipitation gage with an accuracy of 0.05 mm) are deployed at two locations in Taylor Valley. All sensors are calibrated on a regular schedule.

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DATA AVAILABILITY STATEMENT

All data described here (along with additional data from the McMurdo Dry Valleys) are freely available through the McMurdo LTER web page: http://mcmlter.org (select the Data dropdown menu) as well as the Environmental Data Initiative repository: https://environmentaldatainitiative.org/. From the 17 current stream gages discharge, electrical conductivity and water temperature data are provided on a 15 minute interval during each flow season (~late November to ~late February). From the 14 current meteorological stations, the following data are provided on a 15 minute interval: air temperature, relative humidity, incoming shortwave radiation, wind speed (gust and average), and wind direction (average). These data are provided from year-round measurements and quality assured data are provided to the data archive annually. Eight of the MDV stream gages and all of the meteorological stations are currently telemetering data on a sub-daily basis. Real time (raw) stream data are available at http://mcm.lternet.edu/stream-gages-real-time-data, and archived streamflow records (and other stream-related data) are available at http://mcm.lternet.edu/streams-data-sets. Real time (raw) meteorological data are available at http://mcm.lternet.edu/meteorology-real-time-data, and archived meteorological records are available at http://mcm.lternet.edu/meteorology-data-sets. The McMurdo LTER project is responsible for collecting, assuring the quality of, and providing freely the stream and meteorological data described here. The data are released under Creative Commons Attribution 4.0 International License (CC BY 4.0).

ORCID

Michael N. Gooseff https://orcid.org/0000-0003-4322-8315
Diane M. McKnight https://orcid.org/0000-0002-4171-1533
Peter T. Doran https://orcid.org/0000-0002-3774-2847

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