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Are They Good Enough? Station-based and Reanalysis Measures of Climatic Conditions Compared

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4. Comparability, 2.5º Gridded Analysis
5. Comparability, 0.25º Nearest Gridpoint Analysis
6. Extreme Events
7. Conclusion

INTRODUCTION

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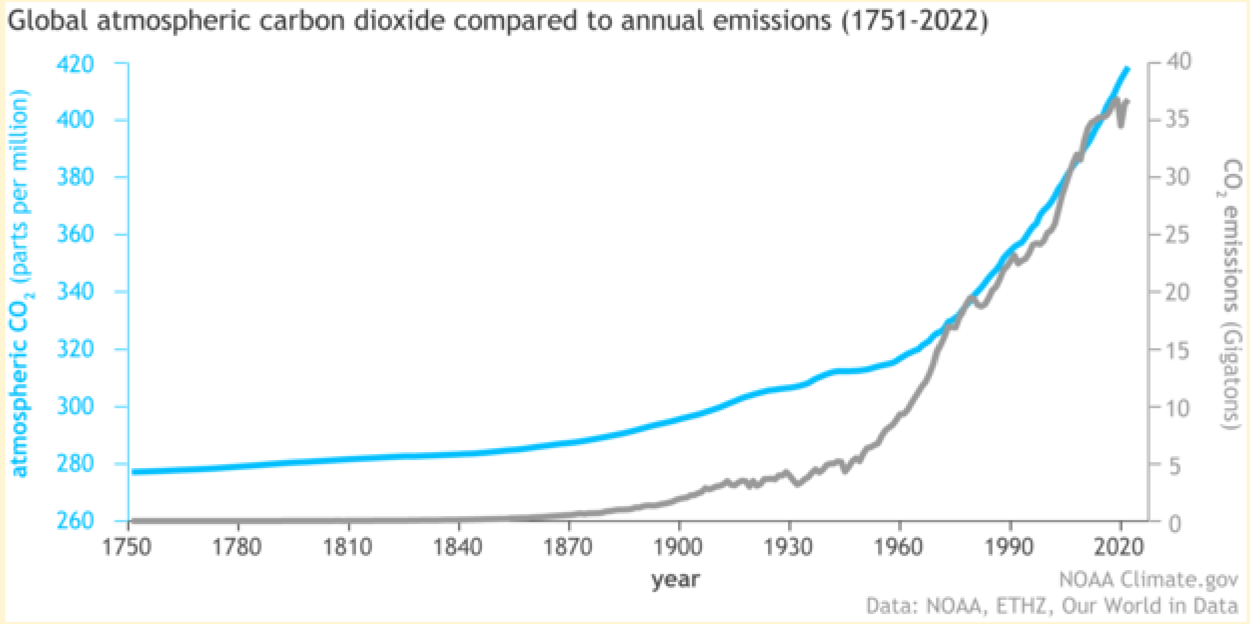
Introduction

- Sustainability depends on access to high quality data.
- Sustainability depends on much more than quality data but must include that data.
- While many kinds of data are and will be required, a foundational starting point is quality data on climatic conditions.

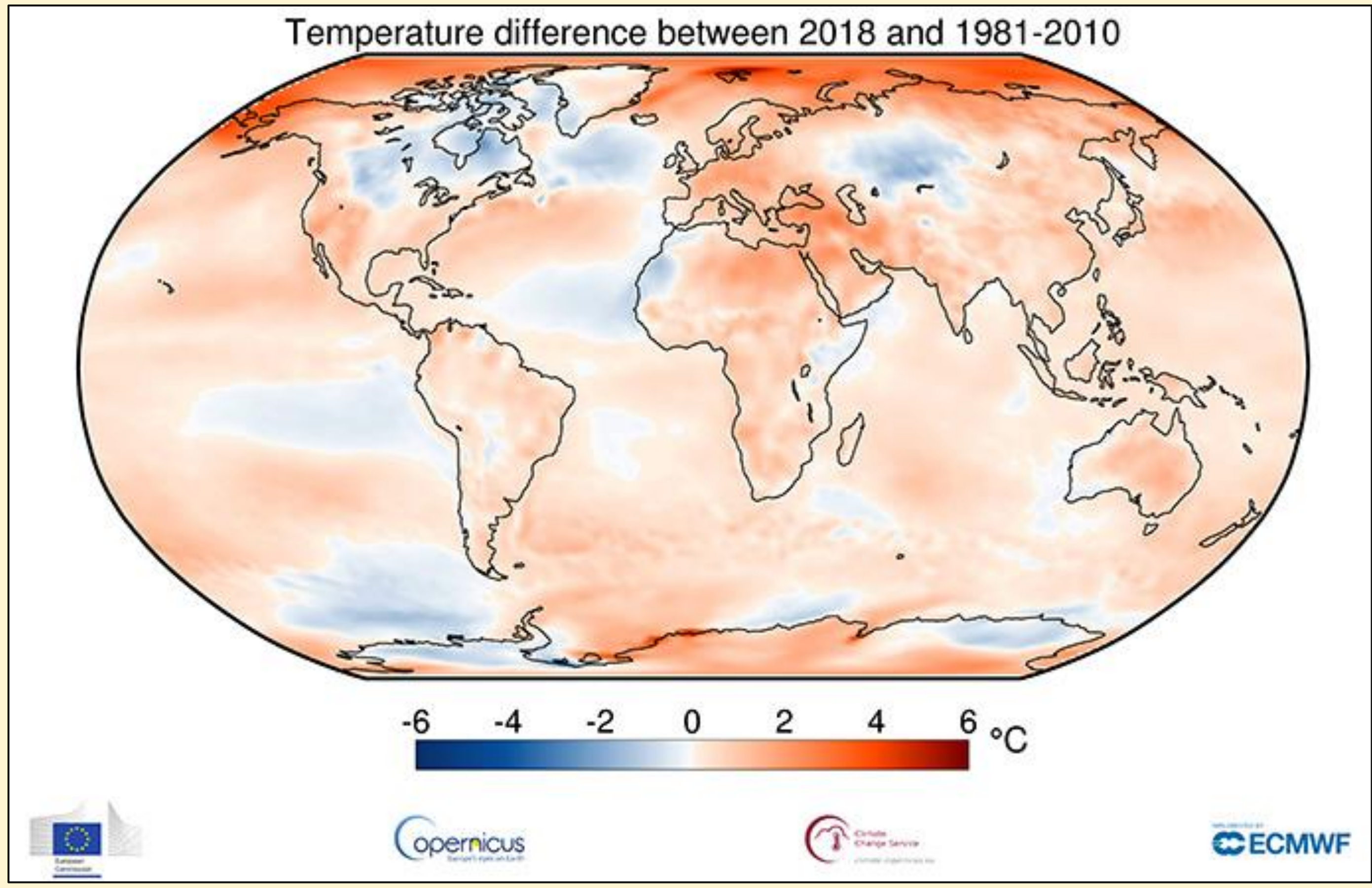


Sources of images: Environmental Sustainability image attributed to Universität Mannheim (UB/CO), CC0, via Wikimedia Commons. Global atmospheric carbon dioxide image attributed to NOAA Climate.gov (downloaded April 11, 2025)

Introduction, continued

Traditionally, such data originated from weather stations and, more recently, satellites, providing direct observations of key environmental features. See, for example the use of such data in the Actuaries Climate Index. More and more practitioners and researchers are turning to reanalysis, such as ERA5 from the European Centre for MidRange Weather Forecasts.

Given the characteristics of Global Historical Climate Network (GHCN) data (partially viewed as representative of station data from any source) and of the European Centre for Midrange Weather Forecast's (ECMWF) ERA5 data (partially viewed as representative of the best reanalysis datasets), this presentation assesses both in an effort to identify circumstances where researchers and/or practitioners might reasonably lean to the use of one dataset or the other.



Sources of images: National Weather Service Automated Surface Observing Systems location; ERA5 Analysis of Temperature Exceedances.

Literature and General Strategy

Literature

- Several scholarly articles have compared station and reanalysis data.
- Only one article (Keller and Wahl, 2020) has compared GHCN station data and ERA5 reanalysis. And that article was one of the few to look at more than one climatic element.
- Their article invites further inquiry with longer time periods and more granularity of analysis.

Question:

- *Is reanalysis data (such as ERA5) good enough to use in place of weather station data (such as the GHCN data)?*

Our general strategy:

- Examine the coverage and comparability of GHCN station data and ERA5 estimates for CAN and the USA (the two countries with the most weather stations in the GHCN global network).
- Further, examine extreme high temperatures and precipitation, the two most reported climatic elements from weather stations.

COVERAGE

GHCN Stations with Varying Consistency Criteria

Precipitation

0%	1941-2022	1961-2022	ERA5 Gridpoints
CAN	8,948	8,563	26,980
USA	68,454	65,533	17,565
50%	1941-2022	1961-2022	
CAN	70	165	26,980
USA	2,313	3,678	17,565
75%	1941-2022	1961-2022	
CAN	38	90	26,980
USA	1,538	2,600	17,565
90%	1941-2022	1961-2022	
CAN	6	15	26,980
USA	355	681	17,565

90% means that a station reported 90% of the days in each decade (treating 2011-2022 as a long decade)

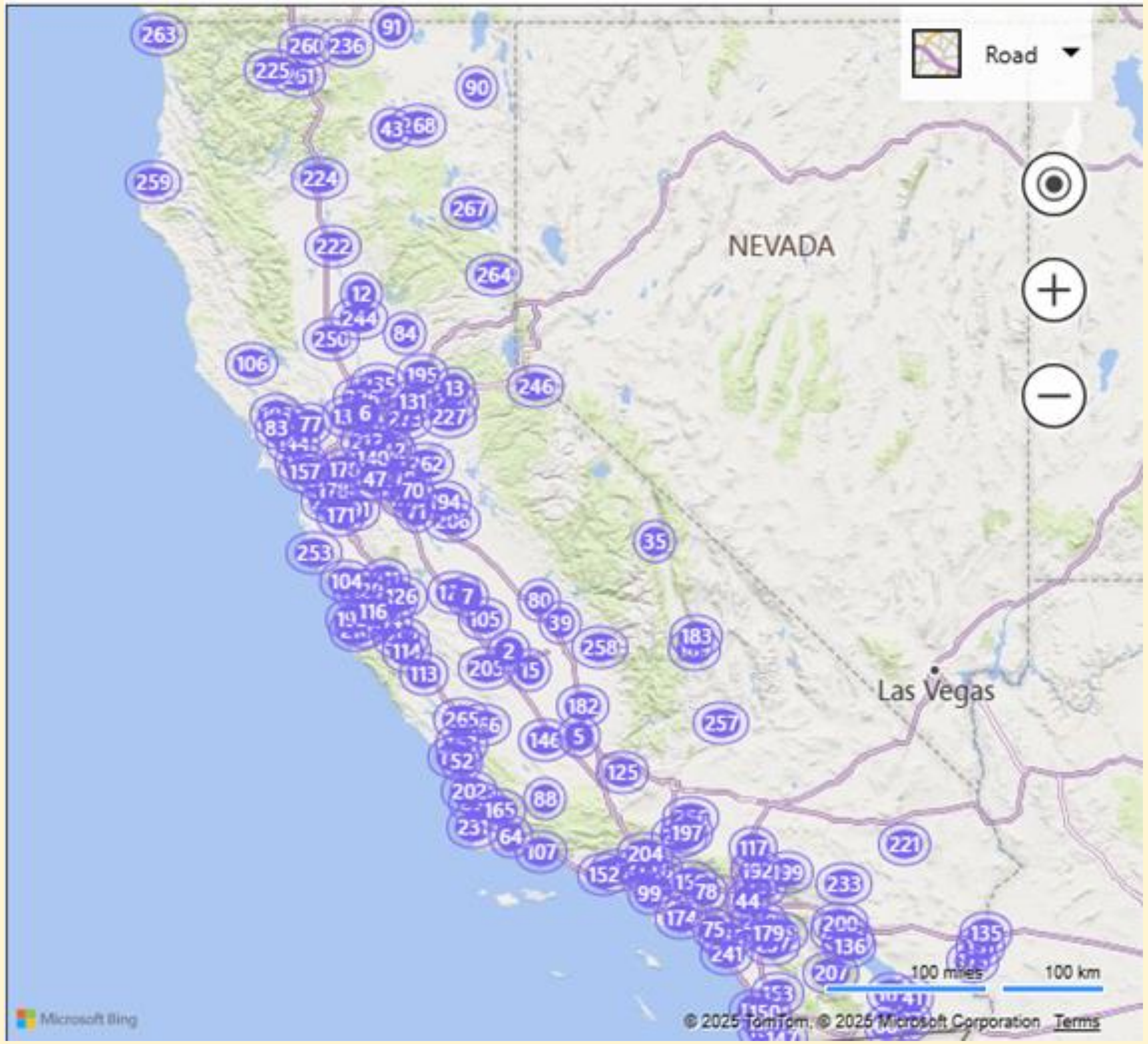
As the consistency criteria increases and the time period lengthens, the number of qualifying stations decreases

Temperature

0%	1941-2022	1961-2022	ERA5 Gridpoints
CAN	6,136	5,750	26,980
USA	17,107	15,054	17,565
50%	1941-2022	1961-2022	
CAN	65	155	26,980
USA	1,709	2,849	17,565
75%	1941-2022	1961-2022	
CAN	36	77	26,980
USA	1,349	2,311	17,565
90%	1941-2022	1961-2022	
CAN	14	29	26,980
USA	782	1,425	17,565

Source: Author's calculations based on GHCN data (downloaded February 4, 2025)

Weather Stations in the State of California: March 2025



California has more weather stations than any other state in the USA.

Yet, there are large areas of the state with few or no stations.

The usefulness of station data depends on the density and consistency of reporting stations in the area of interest.

Source: https://cimis.water.ca.gov/Stations.aspx

NOTES ON METHODOLOGY

Notes on Methodology

- Select stations meeting 90% consistency criteria, 1961-2022
  - for Temperature: 1,917; for Precipitation: 698
- Focus on extremes: 90th percentile of observations within a month
- Data analyzed monthly from 1941–2022.
- GHCN data was downloaded on February 5, 2025; ERA5 data was downloaded on May 23, 2024.
- While serial correlation (especially for temperature) requires GLS, currently reporting OLS results
  - Preliminary analysis suggests GLS results will be qualitatively the same

Vary lenses:

- Granularity
- Gridded vs Nearest Gridpoint Analysis
- Exceedances vs Natural Values
- Accumulation over time vs Single Day

COMPARABILITY
2.5º Gridded Analysis

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On Notation

T90 = 90th percentile of maximum daily temperature in a month

PRCP = 90th percentile of daily precipitation in a month

RX5Day = 90th percentile of 5-day total precipitation in a month

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Regression Results for CAN, USA, and CAN+USA (USC) High Temperatures (T90) and 5 Day Accumulations of Precipitation (RX5Day) 1961–2022

ERA5 = Intercept + Slope*GHCN

N(USC) = 744

1961-2022		CAN			USA			USC		
		Intercept	Slope	RSQ	Intercept	Slope	RSQ	Intercept	Slope	RSQ
	T90	0.01	0.93	0.60	-0.02	1.27	0.87	0.00	1.02	0.74
	RX5Day	-0.54	0.84	0.73	0.61	0.71	0.76	-0.05	0.78	0.82

In 2.5^0 grid analysis, both T90 and RX5Day are highly correlated.

For T90, the correlation in the USA is significantly higher than in CAN; for RX5Day, the correlations across countries are similar.

The distributions of T90 for GHCN and ERA5 are similar if not identical; the distributions for RX5Day differ significantly.

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Regression Results for CAN, USA, and CAN+USA (USC)
High Temperatures (T90) and 5 Day Accumulations of Precipitation (RX5Day)
1961-1990 (reference period)/1991–2022

ERA5 = Intercept + Slope*GHCN

N(USC) = 360 (1961-1990)/384 (1991-2022)

		CAN			USA			USC		
1961-1990		Intercept	Slope	RSQ	Intercept	Slope	RSQ	Intercept	Slope	RSQ
	T90	0.01	0.85	0.59	-0.01	1.14	0.85	0.01	0.89	0.71
	RX5Day	-0.56	0.87	0.76	0.63	0.72	0.76	-0.01	0.78	0.85

		CAN			USA			USC		
1991-2022		Intercept	Slope	RSQ	Intercept	Slope	RSQ	Intercept	Slope	RSQ
	T90	0.02	0.93	0.57	-0.02	1.28	0.87	0.01	1.00	0.71
	RX5Day	-0.62	0.85	0.71	0.52	0.72	0.77	-0.21	0.81	0.81

Results quite similar over time, as measured by two different time periods.

The only significant change is the increase in the slope of T90 in the USA (which then produces an increase in USC).

COMPARABILITY
0.25º Nearest Gridpoint Analysis

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Regression Results for CAN, USA, and CAN+USA (USC) High Temperatures (T90) and Daily Precipitation (PRCP) 1941–1922

ERA5 = Intercept + Slope*GHCN

N(USC) = (T90) 1,695,350/(PRCP) 635,080

1941 - 2022	CAN			USA			USC		
	Intercept	Slope	Adj RSQ	Intercept	Slope	Adj RSQ	Intercept	Slope	Adj RSQ
T90	0.32	0.94	0.95	-2.43	0.99	0.95	-2.26	0.99	0.95
PRCP	0.21	2.30	0.70	0.35	1.30	0.47	0.35	1.32	0.47

In 0.25^0 nearest gridpoint analysis, T90 is highly correlated and PRCP is reasonably highly correlated.

For T90, the correlation in the USA and in CAN is similar, but ERA5 measures are ~2.5 ^{0}F lower than equivalent GHCN values.

The distributions of T90 for GHCN and ERA5 are similar if not identical; the distributions for PRCP differ significantly.

Regression Results for CAN, USA, and CAN+USA (USC) High Temperatures (T90) and Daily Precipitation (PRCP) 1941–1970 (reference period)/1971–2022

ERA5 = Intercept + Slope*GHCN

T90(USC) N = 572,789 (1941–1970)/1,122,561(1971–2022)
PRCP(USC) N = 214,129 (1941–1970)/420,951 (1971–2022)

1941 - 1970	CAN			USA			USC		
	Intercept	Slope	Adj RSQ	Intercept	Slope	Adj RSQ	Intercept	Slope	Adj RSQ
T90	0.37	0.94	0.94	-3.82	1.00	0.95	-3.48	1.00	0.95
PRCP	0.20	2.30	0.68	0.41	0.97	0.34	0.41	0.99	0.35
1971 - 2022	CAN			USA			USC		
	Intercept	Slope	Adj RSQ	Intercept	Slope	Adj RSQ	Intercept	Slope	Adj RSQ
T90	0.31	0.95	0.95	-1.71	0.98	0.95	-1.63	0.98	0.96
PRCP	0.21	2.31	0.71	0.30	1.54	0.55	0.30	1.55	0.56

In the 0.25^0 nearest gridpoint analysis, results are quite stable over time, except for T90 (Intercept) and PRCP (Slope) in the USA.

Effects of Granularity: Temperature and Precipitation

Granularity	1961-1990	CAN			USA			USC		
		Intercept	Slope	Adj RSQ	Intercept	Slope	Adj RSQ	Intercept	Slope	Adj RSQ
2.5^0	T90	0.01	0.85	0.59	-0.01	1.14	0.85	0.01	0.89	0.71
0.25^0	T90	0.15	0.95	0.95	-2.36	0.99	0.96	-2.15	0.99	0.96
Granularity	1991-2022	CAN			USA			USC		
		Intercept	Slope	Adj RSQ	Intercept	Slope	Adj RSQ	Intercept	Slope	Adj RSQ
2.5^0	T90	0.02	0.93	0.57	-0.02	1.28	0.87	0.01	1.00	0.71
0.25^0	T90	0.63	0.94	0.95	-1.62	0.99	0.95	-1.57	0.99	0.95
Granularity	1961-1990	CAN			USA			USC		
		Intercept	Slope	Adj RSQ	Intercept	Slope	Adj RSQ	Intercept	Slope	Adj RSQ
2.5^0	RX5Day	-0.56	0.87	0.76	0.63	0.72	0.76	-0.01	0.78	0.85
0.25^0	PRCP	0.19	2.34	0.70	0.42	1.05	0.37	0.41	1.07	0.38
Granularity	1991 - 2022	CAN			USA			USC		
		Intercept	Slope	Adj RSQ	Intercept	Slope	Adj RSQ	Intercept	Slope	Adj RSQ
2.5^0	RX5Day	-0.62	0.85	0.71	0.52	0.72	0.77	-0.21	0.81	0.81
0.25^0	PRCP	0.20	2.38	0.71	0.29	1.54	0.56	0.29	1.55	0.56

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Takeaways from Analysis of Granularity

- 2.5^0 and 0.25^0 degree analyses produce similar but not identical results.
- T90 very similar, with higher granularity producing closer correlation.
  - This is likely due to the smooth gradient of temperature over large areas, a difference of 10-15 miles unlikely to make a difference.
- Precipitation more different, with two differences in analysis accounting for differences:
  - Precipitation is a more localized phenomenon; averaging over a larger area more likely to produce similar results.
  - For 2.5^0, RX5Day, which sums results over a number of days, leads to more likelihood of similarity.

EXTREME EVENTS

Weather Stations as a Gold Standard

- Weather stations, with readings based on direct observation, serve as a benchmark or “gold standard” for assessing reanalysis data.
- However, if the weather station is not operational, it is no longer a gold standard.
- Given the special importance of extreme events to the assessment of climate risk, it is especially important that weather stations are operational during those extreme events.
- On the following slides, we assess the operational resilience of weather stations during three extreme events.

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Chicago Heat Wave, July 12-15, 1995

Date	Number of Stations Reporting Maximum Temperature	
19950707	103	
19950708	102	
19950709	102	
19950710	103	
19950711	102	
19950712	**102**	
19950713	**103**	Heat
19950714	**103**	Wave
19950715	**103**	**0%**
19950716	102	
19950717	102	
19950718	102	
19950719	103	
19950720	103	

During an unprecedented heat wave In Chicago (USA) in 1995, none of the weather stations within 1^{0} of the center of Chicago appear to go offline during the heat wave.

Source: Author's calculations based on GHCN data (downloaded February 4, 2025)

Texas Winter Storm, February 13-17, 2021

DATE	Number of Stations Reporting Minimum Temperature	
20210208	415	
20210209	418	
20210210	419	
20210211	413	
20210212	409	
20210213	**404**	
20210214	**395**	Winter
20210215	**390**	Storm
20210216	**372**	**-11.22%**
20210217	**374**	
20210218	381	
20210219	389	
20210220	400	
20210221	396	
20210222	410	

During a winter storm in 2021, which affected many states in the country, Texas (USA) was particularly hard hit by one of its worst winter storms. Of the 419 weather stations in Texas that reported minimum temperatures in the days before the storm hit, 47 appeared to go offline during the storm, a loss of 11% of the stations.

Source: Author's calculations based on GHCN data (downloaded February 4, 2025)

Hurricane Katrina, New Orleans, LA
August 29-31, 2005

Date	Number of Stations Reporting Precipitation within 1 Degree of the Center of New Orleans	
20050824	46	
20050825	46	
20050826	46	
20050827	45	
20050828	41	
20050829	**30**	Hurricane
20050830	**28**	**-39.13%**
20050831	**34**	
20050901	39	
20050902	39	
20050903	39	
20050904	39	
20050905	39	

Hurricane Katrina, which hit the Gulf Coast of the USA in August 2005, is often described as the costliest hurricane in US history. Much of the damage and loss of life was centered on New Orleans, LA (USA). During the storm, 18 of the 46 weather stations within 1º of the center of New Orlean which were reporting precipitation levels in the days before the storm, appeared to go offline during the storm. This reduced the number of stations by 39%.

Source: Author's calculations based on GHCN data (downloaded February 4, 2025)

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ERA5 and GHCN: Precipitation Average Totals per Day During Hurricane Katrina, August 2005

CHARACTERISTIC	ERA5	GHCN	
New Orleans: Average Daily Precipitation August 2005	0.42	0.35	Inches
New Orleans: Average Precipitation August 29th	7.13	3.63	Inches
New Orleans: Average Precipitation August 30th	0.09	3.88	Inches
New Orleans: Average Precipitation August 29th + August 30th	7.23	7.52	Inches

During the month of August 2005, GHCN Stations and ERA5 gridpoints in New Orleans, LA (USA) recorded similar totals.

However, during the height of the storm, the average daily amounts differed dramatically.

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Discrepancies in the Record: Hammond 5 E

NAME	DATE	PRCP
HAMMOND 5 E, LA US	8/25/2005	0
HAMMOND 5 E, LA US	8/26/2005	0
HAMMOND 5 E, LA US	8/27/2005	0
HAMMOND 5 E, LA US	8/28/2005	0
HAMMOND 5 E, LA US	**8/29/2005**	**1.95**
HAMMOND 5 E, LA US	**8/30/2005**	**6.69**
HAMMOND 5 E, LA US	8/31/2005	0
HAMMOND 5 E, LA US	9/1/2005	0
HAMMOND 5 E, LA US	9/2/2005	0
HAMMOND 5 E, LA US	9/3/2005	0
HAMMOND 5 E, LA US	9/4/2005	0
HAMMOND 5 E, LA US	9/5/2005	0

On the left side, the Hammond 5 E weather station just north of New Orleans reported 1.95 inches of daily precipitation on August 29th.

On the right side, the hourly readings from the same station on August 29th total 6.1 inches before the station appears to go offline at 4pm (while Hurricane Katrina continues to produce large quantities of rain).

STATION_NAME	DATE	HPCP
HAMMOND 5 E LA US	20050829 02:00	0.2
HAMMOND 5 E LA US	20050829 03:00	0.2
HAMMOND 5 E LA US	20050829 04:00	0.5
HAMMOND 5 E LA US	20050829 05:00	0.3
HAMMOND 5 E LA US	20050829 06:00	0.4
HAMMOND 5 E LA US	20050829 07:00	0.4
HAMMOND 5 E LA US	20050829 08:00	0.5
HAMMOND 5 E LA US	20050829 09:00	0.8
HAMMOND 5 E LA US	20050829 10:00	0.8
HAMMOND 5 E LA US	20050829 11:00	0.5
HAMMOND 5 E LA US	20050829 12:00	0.3
HAMMOND 5 E LA US	20050829 13:00	0.4
HAMMOND 5 E LA US	20050829 14:00	0.1
HAMMOND 5 E LA US	20050829 15:00	0.5
HAMMOND 5 E LA US	20050829 16:00	0.2
HAMMOND 5 E LA US	20050901 01:00	0
HAMMOND 5 E LA US	20050901 09:00	999.99
HAMMOND 5 E LA US	20050901 12:00	999.99
HAMMOND 5 E LA US	20050905 04:00	1.1

Takeaways on the Resilience of Weather Stations during Extreme Events

Observing three extreme events of different types, we find:

- One manifested no loss of stations;
- One manifested a modest loss of stations; and
- One manifested a large loss of station.

These results suggest:

- The need for further research on additional extreme events; and
- Caution in assuming that stations are resilient in most extreme events.

CONCLUSION

Pulling the Threads Together

1. In CAN and the USA, there are large numbers of weather stations providing observations of temperature and precipitation.
2. The more focused an inquiry (in time and space), the more useful the stations are likely to be. The broader the inquiry, the less likely it will be that stations are useful.
3. Weather stations are akin to a gold standard for the precise location of the station, assuming the station is operational.
4. There is some reason to be concerned about the operational status of stations during extreme weather events.
5. Reanalysis data, such as ERA5, appears to generate estimates of temperature and precipitation which are generally comparable to the station data.
6. Reanalysis data provides superior coverage without regard to the breadth (in time and space) of the inquiry.
7. When reanalysis is applied to highly localized phenomena (such as precipitation), one may need to sacrifice some granularity to obtain reliable estimates.

Finally, answering the original question

- Weather station data remains a gold standard of observation for temperature and precipitation.
- However, it is only golden in the locations of the stations and when the stations are operational.
- Given limits on the coverage provided by networks of stations, and some doubt about operational status during extreme events, there will be use cases where reanalysis, similar but not identical to station data, is more than good enough.

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Thank you! Obrigado!

Questions?

For more information and/or questions: Steve Jackson, sjackson@actuary.org

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