```
# Run this cell to import pyspark and to define start_spark() and stop_spark()

import findspark

findspark.init()

import getpass
import random
import re

import pandas
import pyspark
from IPython.display import HTML, display
from pyspark import SparkContext
from pyspark.sql import SparkSession

# Constants used to interact with Azure Blob Storage using the hdfs command or Spark

global username

username = re.sub("@.*", "", getpass.getuser())

global azure_account_name
global azure_data_container_name
global azure_user_container_name
global azure_user_token

azure_account_name = "madsstorage002"
azure_data_container_name = "campus-data"
azure_user_container_name = "campus-user"
azure_user_token = r"sp=racwdl&st=2025-08-01T09:41:33Z&se=2026-12-30T16:56:33Z&spr=https&sv=2024-11-04&sr=c&sig=Gz


# Functions used below


def dict_to_html(d):
    """Convert a Python dictionary into a two column table for display."""

    html = []

    html.append(f'<table width="100%" style="width:100%; font-family: monospace;">')
    for k, v in d.items():
        html.append(f'<tr><td style="text-align:left;">{k}</td><td>{v}</td></tr>')
    html.append(f"</table>")

    return "".join(html)


def show_as_html(df, n=20):
    """Leverage existing pandas jupyter integration to show a spark dataframe as html.

    Args:
        n (int): number of rows to show (default: 20)
    """

    display(df.limit(n).toPandas())


def display_spark():
    """Display the status of the active Spark session if one is currently running."""

    if "spark" in globals() and "sc" in globals():

        name = sc.getConf().get("spark.app.name")

        html = [
            f"<p><b>Spark</b></p>",
            f'<p>The spark session is <b><span style="color:green">active</span></b>, look for <code>{name}</code>
            f"<ul>",
            f'<li><a href="http://localhost:{sc.uiWebUrl.split(":")[-1]}" target="_blank">Spark Application UI</a>
            f"</ul>",
            f"<p><b>Config</b></p>",
            dict_to_html(dict(sc.getConf().getAll())),
            f"<p><b>Notes</b></p>",
            f"<ul>",
            f"<li>The spark session <code>spark</code> and spark context <code>sc</code> global variables have bee
            f"<li>Please run <code>stop_spark()</code> before closing the notebook or restarting the kernel or kil
            f"</ul>",
        ]
        display(HTML("".join(html)))
```

```
    else:

        html = [
            f"<p><b>Spark</b></p>",
            f'<p>The spark session is <b><span style="color:red">stopped</span></b>, confirm that <code>{username}
            f"<ul>",
            f'<li><a href="http://mathmadslinux2p.canterbury.ac.nz:8080/" target="_blank">Spark UI</a></li>',
            f"</ul>",
        ]
        display(HTML("".join(html)))


# Functions to start and stop spark


def start_spark(
    executor_instances=2, executor_cores=1, worker_memory=1, master_memory=1
):
    """Start a new Spark session and define globals for SparkSession (spark) and SparkContext (sc).

    Args:
        executor_instances (int): number of executors (default: 2)
        executor_cores (int): number of cores per executor (default: 1)
        worker_memory (float): worker memory (default: 1)
        master_memory (float): master memory (default: 1)
    """

    global spark
    global sc

    cores = executor_instances * executor_cores
    partitions = cores * 4
    port = 4000 + random.randint(1, 999)

    spark = (
        SparkSession.builder.config(
            "spark.driver.extraJavaOptions",
            f"-Dderby.system.home=/tmp/{username}/spark/",
        )
        .config("spark.dynamicAllocation.enabled", "false")
        .config("spark.executor.instances", str(executor_instances))
        .config("spark.executor.cores", str(executor_cores))
        .config("spark.cores.max", str(cores))
        .config("spark.driver.memory", f"{master_memory}g")
        .config("spark.executor.memory", f"{worker_memory}g")
        .config("spark.driver.maxResultSize", "0")
        .config("spark.sql.shuffle.partitions", str(partitions))
        .config(
            "spark.kubernetes.container.image",
            "madsregistry001.azurecr.io/hadoop-spark:v3.3.5-openjdk-8",
        )
        .config("spark.kubernetes.container.image.pullPolicy", "IfNotPresent")
        .config("spark.kubernetes.memoryOverheadFactor", "0.3")
        .config("spark.memory.fraction", "0.1")
        .config(
            f"fs.azure.sas.{azure_user_container_name}.{azure_account_name}.blob.core.windows.net",
            azure_user_token,
        )
        .config("spark.app.name", f"{username} (notebook)")
        .getOrCreate()
    )
    sc = SparkContext.getOrCreate()

    display_spark()


def stop_spark():
    """Stop the active Spark session and delete globals for SparkSession (spark) and SparkContext (sc)."""

    global spark
    global sc

    if "spark" in globals() and "sc" in globals():

        spark.stop()

        del spark
        del sc

    display_spark()
```

```
# Make css changes to improve spark output readability

html = [
    "<style>",
    "pre { white-space: pre !important; }",
    "table.dataframe td { white-space: nowrap !important; }",
    "table.dataframe thead th:first-child, table.dataframe tbody th { display: none; }",
    "</style>",
]
display(HTML("".join(html)))
```

```
# Run this cell to start a spark session in this notebook

start_spark(executor_instances=8, executor_cores=2, worker_memory=4, master_memory=6)
```

```
Warning: Ignoring non-Spark config property: fs.azure.sas.campus-user.madsstorage002.blob.core.windows.net
Warning: Ignoring non-Spark config property: SPARK_DRIVER_BIND_ADDRESS
25/09/14 12:00:39 WARN NativeCodeLoader: Unable to load native-hadoop library for your platform... using builtin-java
Setting default log level to "WARN".
To adjust logging level use sc.setLogLevel(newLevel). For SparkR, use setLogLevel(newLevel).
```

Spark

The spark session is **active**, look for `yxi75 (notebook)` under the running applications section in the Spark UI.

- Spark Application UI

Config

spark.dynamicAllocation.enabled	false
spark.app.id	spark-77fd2001216d4e54bbde6baa86933163
spark.fs.azure.sas.uco-user.madsstorage002.blob.core.windows.net	"sp=racwdl&st=2024-09-19T08:00:18Z&se=2025-09-19T16:00:18Z&spr=https&sv=2022-11-02&sr=c&sig=qtg6fCdoFz6k3EJLw7dA8D3D8wN0neAYw8yG4z4Lw2o%3D"
spark.kubernetes.driver.pod.name	spark-master-driver
spark.cores.max	16
spark.app.name	yxi75 (notebook)
spark.fs.azure.sas.campus-user.madsstorage002.blob.core.windows.net	"sp=racwdl&st=2024-09-19T08:03:31Z&se=2025-09-19T16:03:31Z&spr=https&sv=2022-11-02&sr=c&sig=kMP%2BsBsRzdVVR8rrg%2BNbDhkRBNs6Q98kYY695XMRFDU%3D"
spark.kubernetes.container.image.pullPolicy	IfNotPresent
spark.app.submitTime	1757808039790
spark.driver.memory	6g
spark.kubernetes.namespace	yxi75
spark.serializer.objectStreamReset	100
spark.driver.maxResultSize	0
spark.submit.deployMode	client
spark.master	k8s://https://kubernetes.default.svc.cluster.local:443
spark.driver.extraJavaOptions	-Djava.net.preferIPv6Addresses=false -XX:+IgnoreUnrecognizedVMOptions --add-opens=java.base/java.lang=ALL-UNNAMED --add-opens=java.base/java.lang.invoke=ALL-UNNAMED --add-opens=java.base/java.lang.reflect=ALL-UNNAMED --add-opens=java.base/java.io=ALL-UNNAMED --add-opens=java.base/java.net=ALL-UNNAMED --add-opens=java.base/java.nio=ALL-UNNAMED --add-opens=java.base/java.util=ALL-UNNAMED --add-opens=java.base/java.util.concurrent=ALL-UNNAMED --add-opens=java.base/java.util.concurrent.atomic=ALL-UNNAMED --add-opens=java.base/jdk.internal.ref=ALL-UNNAMED --add-opens=java.base/sun.nio.ch=ALL-UNNAMED --add-opens=java.base/sun.nio.cs=ALL-UNNAMED --add-opens=java.base/sun.security.action=ALL-UNNAMED --add-opens=java.base/sun.util.calendar=ALL-UNNAMED --add-

	opens=java.security.jgss/sun.security.krb5=ALL-UNNAMED -Djdk.reflect.useDirectMethodHandle=false -Dderby.system.home=/tmp/yxi75/spark/
spark.fs.azure	org.apache.hadoop.fs.azure.NativeAzureFileSystem
spark.sql.shuffle.partitions	64
spark.memory.fraction	0.1
spark.executor.memory	4g
spark.executor.id	driver
spark.kubernetes.executor.container.image	madsregistry001.azurecr.io/hadoop-spark:v3.3.5-openjdk-8-1.0.16
spark.executor.instances	8
spark.executor.cores	2
spark.kubernetes.memoryOverheadFactor	0.3
spark.driver.host	spark-master-svc
spark.ui.port	${env:SPARK_UI_PORT}
spark.kubernetes.container.image	madsregistry001.azurecr.io/hadoop-spark:v3.3.5-openjdk-8
spark.kubernetes.executor.podTemplateFile	/opt/spark/conf/executor-pod-template.yaml
fs.azure.sas.campus-user.madsstorage002.blob.core.windows.net	sp=racwdl&st=2025-08-01T09:41:33Z&se=2026-12-30T16:56:33Z&spr=https&sv=2024-11-04&sr=c&sig=GzRlhq7EJ0lRHj92oDO1MBNjkc602nrpfB5H8Cl7FFY%3D
spark.rdd.compress	True
spark.kubernetes.executor.podNamePrefix	yxi75-notebook-4f45329945861b0e
spark.executor.extraJavaOptions	-Djava.net.preferIPv6Addresses=false -XX:+IgnoreUnrecognizedVMOptions --add-opens=java.base/java.lang=ALL-UNNAMED --add-opens=java.base/java.lang.invoke=ALL-UNNAMED --add-opens=java.base/java.lang.reflect=ALL-UNNAMED --add-opens=java.base/java.io=ALL-UNNAMED --add-opens=java.base/java.net=ALL-UNNAMED --add-opens=java.base/java.nio=ALL-UNNAMED --add-opens=java.base/java.util=ALL-UNNAMED --add-opens=java.base/java.util.concurrent=ALL-UNNAMED --add-opens=java.base/java.util.concurrent.atomic=ALL-UNNAMED --add-opens=java.base/jdk.internal.ref=ALL-UNNAMED --add-opens=java.base/sun.nio.ch=ALL-UNNAMED --add-opens=java.base/sun.nio.cs=ALL-UNNAMED --add-opens=java.base/sun.security.action=ALL-UNNAMED --add-opens=java.base/sun.util.calendar=ALL-UNNAMED --add-opens=java.security.jgss/sun.security.krb5=ALL-UNNAMED -Djdk.reflect.useDirectMethodHandle=false
spark.driver.port	7077
spark.submit.pyFiles	
spark.app.startTime	1757808039932
spark.ui.showConsoleProgress	true

Notes

- The spark session `spark` and spark context `sc` global variables have been defined by `start_spark()`.
- Please run `stop_spark()` before closing the notebook or restarting the kernel or kill `yxi75 (notebook)` by hand using the link in the Spark UI.

```
# Write your imports here or insert cells below

import os
import re
import subprocess
import sys
from math import asin, cos, radians, sin, sqrt
from pprint import pprint

import cartopy
import cartopy.crs as ccrs
```

```
import geopandas as gpd
import matplotlib.pyplot as plt
import numpy as np
import pandas as pd
from cartopy.mpl.gridliner import LATITUDE_FORMATTER, LONGITUDE_FORMATTER
from pyspark.sql import functions as F
from pyspark.sql.functions import udf
from pyspark.sql.types import *
```

```
# Paths global variables
DATA_ROOT = "wasbs://campus-data@madsstorage002.blob.core.windows.net/ghcnd/"
USER_ROOT = "wasbs://campus-user@madsstorage002.blob.core.windows.net/yxi75/"

paths = {
    "daily": DATA_ROOT + "daily/",
    "stations": DATA_ROOT + "ghcnd-stations.txt",
    "countries": DATA_ROOT + "ghcnd-countries.txt",
    "states": DATA_ROOT + "ghcnd-states.txt",
    "inventory": DATA_ROOT + "ghcnd-inventory.txt",
}

stations_enriched_savepath = USER_ROOT + "stations_enriched_parquet"
station_count_by_country_path = USER_ROOT + "station_count_by_country_parquet"
station_count_us_terri_path = USER_ROOT + "station_count_us_terri_parquet"
country_meta_with_station_num_path = USER_ROOT + "country_meta_with_station_num"
states_meta_with_station_num_path = USER_ROOT + "states_meta_with_station_num"
daily_nz_tmin_tmax_path = USER_ROOT + "daily_nz_tmin_tmax_parquet"
prcp_pdf_path = USER_ROOT + "prcp_pdf_parquet"
```

plot observation of TMIN and TMAX for stations in NZ

```
!hdfs dfs -ls {USER_ROOT}
```

```
Found 7 items
drwxr-xr-x   - yxi75 supergroup          0 2025-09-11 22:55 wasbs://campus-user@madsstorage002.blob.core.windows.net/
drwxr-xr-x   - yxi75 supergroup          0 2025-09-13 13:02 wasbs://campus-user@madsstorage002.blob.core.windows.net/
drwxr-xr-x   - yxi75 supergroup          0 2025-09-14 07:29 wasbs://campus-user@madsstorage002.blob.core.windows.net/
drwxr-xr-x   - yxi75 supergroup          0 2025-09-11 23:18 wasbs://campus-user@madsstorage002.blob.core.windows.net/
drwxr-xr-x   - yxi75 supergroup          0 2025-09-11 22:33 wasbs://campus-user@madsstorage002.blob.core.windows.net/
drwxr-xr-x   - yxi75 supergroup          0 2025-09-11 22:33 wasbs://campus-user@madsstorage002.blob.core.windows.net/
drwxr-xr-x   - yxi75 supergroup          0 2025-09-11 18:30 wasbs://campus-user@madsstorage002.blob.core.windows.net/
```

```
station_count_by_country = spark.read.parquet(station_count_by_country_path)
```

```
# How many stations we have in NZ
station_count_by_country.filter(F.col("COUNTRY_CODE").contains("NZ")).show()
# so we only have 15 stations in NZ, not a big number.
```

```
+------------+------------+-----+
|COUNTRY_CODE|COUNTRY_NAME|count|
+------------+------------+-----+
|          NZ|New Zealand |   15|
+------------+------------+-----+
```

```
#  now we get NZ stations' ID from stations_enriched first
# then inner join with daily dataset to filter out NZ station observations
stations_enriched = spark.read.parquet(stations_enriched_savepath)

nz_station_ids = stations_enriched.filter(F.col("COUNTRY_CODE").contains("NZ")).select(
    "ID"
)
```

```
# in order to inner join daily, we should load daily first.

# Define schma for Daily
daily_schema = StructType(
    [
        StructField("ID", StringType(), nullable=False),
```

```
        StructField("DATE", StringType(), nullable=False),
        StructField("ELEMENT", StringType(), nullable=False),
        StructField("VALUE", FloatType(), nullable=False),
        StructField("MEASUREMENT_FLAG", StringType(), nullable=True),
        StructField("QUALITY_FLAG", StringType(), nullable=True),
        StructField("SOURCE_FLAG", StringType(), nullable=True),
        StructField("OBSERVATION_TIME", StringType(), nullable=True),
    ]
)

# load daily and check daily schema for later join parameter on = ""
daily = spark.read.csv(paths["daily"], schema=daily_schema)
```

```
# Here's a decision making point
# A small table nz_station_ids and a large table daily, when join, choose broadcast join rather than shuffle join.
# broadcast nz_station_ids to all partitions for locally join, and pass the join result back to the master node only.

daily_nz = daily.join(F.broadcast(nz_station_ids), on="ID", how="inner")

show_as_html(daily_nz)
```

```
.dataframe tbody tr th {
    vertical-align: top;
}

.dataframe thead th {
    text-align: right;
}
```

ID	DATE	ELEMENT	VALUE	MEASUREMENT_FLAG	QUALITY_FLAG	SOURCE_FLAG	OBSERVATION_TIME
NZ000093012	20100101	TAVG	178.0	H	None	S	None
NZ000093292	20100101	TMAX	297.0	None	None	S	None
NZ000093292	20100101	TMIN	74.0	None	None	S	None
NZ000093292	20100101	PRCP	0.0	None	None	S	None
NZ000093292	20100101	TAVG	235.0	H	None	S	None
NZ000093417	20100101	TMAX	180.0	None	None	S	None
NZ000093417	20100101	TMIN	125.0	None	None	S	None
NZ000093417	20100101	PRCP	0.0	None	None	S	None
NZ000093417	20100101	TAVG	163.0	H	None	S	None
NZ000093844	20100101	TMAX	232.0	None	None	S	None
NZ000093844	20100101	TMIN	96.0	None	None	S	None
NZ000093844	20100101	PRCP	8.0	None	None	S	None
NZ000093844	20100101	TAVG	167.0	H	None	S	None
NZ000093994	20100101	PRCP	0.0	None	None	S	None
NZ000093994	20100101	TAVG	204.0	H	None	S	None
NZ000933090	20100101	TMAX	197.0	None	None	S	None
NZ000933090	20100101	TMIN	82.0	None	None	S	None
NZ000933090	20100101	PRCP	0.0	None	None	S	None
NZ000933090	20100101	TAVG	168.0	H	None	S	None
NZ000936150	20100101	TMAX	324.0	None	None	S	None

```
# filter out TMIN and TMAX from daily_nz, and save it to output path for later plot use
daily_nz_tmin_tmax = daily_nz.filter(F.col("ELEMENT").isin(["TMIN", "TMAX"]))

show_as_html(daily_nz_tmin_tmax)

daily_nz_tmin_tmax_count = daily_nz_tmin_tmax.count()
print(f"daily_nz_tmin_tmax observation count: {daily_nz_tmin_tmax_count}")
```

```
.dataframe tbody tr th {
    vertical-align: top;
}

.dataframe thead th {
    text-align: right;
}
```

ID	DATE	ELEMENT	VALUE	MEASUREMENT_FLAG	QUALITY_FLAG	SOURCE_FLAG	OBSERVATION_TIME
NZ000093292	20100101	TMAX	297.0	None	None	S	None
NZ000093292	20100101	TMIN	74.0	None	None	S	None
NZ000093417	20100101	TMAX	180.0	None	None	S	None
NZ000093417	20100101	TMIN	125.0	None	None	S	None
NZ000093844	20100101	TMAX	232.0	None	None	S	None
NZ000093844	20100101	TMIN	96.0	None	None	S	None
NZ000933090	20100101	TMAX	197.0	None	None	S	None
NZ000933090	20100101	TMIN	82.0	None	None	S	None
NZ000936150	20100101	TMAX	324.0	None	None	S	None
NZM00093110	20100101	TMAX	215.0	None	None	S	None
NZM00093110	20100101	TMIN	153.0	None	None	S	None
NZM00093439	20100101	TMAX	204.0	None	None	S	None
NZM00093439	20100101	TMIN	134.0	None	None	S	None
NZM00093678	20100101	TMAX	242.0	None	None	S	None
NZM00093678	20100101	TMIN	94.0	None	None	S	None
NZM00093781	20100101	TMAX	324.0	None	None	S	None
NZ000093292	20100102	TMAX	302.0	None	None	S	None
NZ000093292	20100102	TMIN	180.0	None	None	S	None
NZ000093417	20100102	TMAX	181.0	None	None	S	None
NZ000093417	20100102	TMIN	153.0	None	None	S	None

```
[Stage 10:=====================================================>(106 + 1) / 107]

daily_nz_tmin_tmax observation count: 494311
```

```
# save to daily_nz_tmin_tmax_path
# daily_nz_tmin_tmax.write.parquet(daily_nz_tmin_tmax_path)

# check save result
!hdfs dfs -ls -h {daily_nz_tmin_tmax_path}
```

```
Found 86 items
-rw-r--r--   1 yxi75 supergroup          0 2025-09-13 13:02 wasbs://campus-user@madsstorage002.blob.core.windows.net/yxi75/daily_nz_tmin_tmax
-rw-r--r--   1 yxi75 supergroup     13.7 K 2025-09-13 13:02 wasbs://campus-user@madsstorage002.blob.core.windows.net/yxi75/daily_nz_tmin_tmax
-rw-r--r--   1 yxi75 supergroup     13.7 K 2025-09-13 13:02 wasbs://campus-user@madsstorage002.blob.core.windows.net/yxi75/daily_nz_tmin_tmax
-rw-r--r--   1 yxi75 supergroup     13.7 K 2025-09-13 13:02 wasbs://campus-user@madsstorage002.blob.core.windows.net/yxi75/daily_nz_tmin_tmax
-rw-r--r--   1 yxi75 supergroup     13.8 K 2025-09-13 13:02 wasbs://campus-user@madsstorage002.blob.core.windows.net/yxi75/daily_nz_tmin_tmax
-rw-r--r--   1 yxi75 supergroup     13.9 K 2025-09-13 13:02 wasbs://campus-user@madsstorage002.blob.core.windows.net/yxi75/daily_nz_tmin_tmax
-rw-r--r--   1 yxi75 supergroup     16.1 K 2025-09-13 13:02 wasbs://campus-user@madsstorage002.blob.core.windows.net/yxi75/daily_nz_tmin_tmax
-rw-r--r--   1 yxi75 supergroup     16.0 K 2025-09-13 13:02 wasbs://campus-user@madsstorage002.blob.core.windows.net/yxi75/daily_nz_tmin_tmax
-rw-r--r--   1 yxi75 supergroup     15.7 K 2025-09-13 13:02 wasbs://campus-user@madsstorage002.blob.core.windows.net/yxi75/daily_nz_tmin_tmax
-rw-r--r--   1 yxi75 supergroup     13.6 K 2025-09-13 13:02 wasbs://campus-user@madsstorage002.blob.core.windows.net/yxi75/daily_nz_tmin_tmax
-rw-r--r--   1 yxi75 supergroup     16.5 K 2025-09-13 13:02 wasbs://campus-user@madsstorage002.blob.core.windows.net/yxi75/daily_nz_tmin_tmax
-rw-r--r--   1 yxi75 supergroup     14.5 K 2025-09-13 13:02 wasbs://campus-user@madsstorage002.blob.core.windows.net/yxi75/daily_nz_tmin_tmax
-rw-r--r--   1 yxi75 supergroup     15.5 K 2025-09-13 13:02 wasbs://campus-user@madsstorage002.blob.core.windows.net/yxi75/daily_nz_tmin_tmax
-rw-r--r--   1 yxi75 supergroup     16.2 K 2025-09-13 13:02 wasbs://campus-user@madsstorage002.blob.core.windows.net/yxi75/daily_nz_tmin_tmax
-rw-r--r--   1 yxi75 supergroup     13.4 K 2025-09-13 13:02 wasbs://campus-user@madsstorage002.blob.core.windows.net/yxi75/daily_nz_tmin_tmax
-rw-r--r--   1 yxi75 supergroup     14.6 K 2025-09-13 13:02 wasbs://campus-user@madsstorage002.blob.core.windows.net/yxi75/daily_nz_tmin_tmax
-rw-r--r--   1 yxi75 supergroup     15.2 K 2025-09-13 13:02 wasbs://campus-user@madsstorage002.blob.core.windows.net/yxi75/daily_nz_tmin_tmax
-rw-r--r--   1 yxi75 supergroup     16.0 K 2025-09-13 13:02 wasbs://campus-user@madsstorage002.blob.core.windows.net/yxi75/daily_nz_tmin_tmax
```

```
-rw-r--r--   1 yxi75 supergroup     14.5 K 2025-09-13 13:02 wasbs://campus-user@madsstorage002.blob.core.windows.net/yxi75/daily_nz_tmin_tmax
-rw-r--r--   1 yxi75 supergroup     14.5 K 2025-09-13 13:02 wasbs://campus-user@madsstorage002.blob.core.windows.net/yxi75/daily_nz_tmin_tmax
-rw-r--r--   1 yxi75 supergroup     19.4 K 2025-09-13 13:02 wasbs://campus-user@madsstorage002.blob.core.windows.net/yxi75/daily_nz_tmin_tmax
-rw-r--r--   1 yxi75 supergroup     19.3 K 2025-09-13 13:02 wasbs://campus-user@madsstorage002.blob.core.windows.net/yxi75/daily_nz_tmin_tmax
-rw-r--r--   1 yxi75 supergroup     19.3 K 2025-09-13 13:02 wasbs://campus-user@madsstorage002.blob.core.windows.net/yxi75/daily_nz_tmin_tmax
-rw-r--r--   1 yxi75 supergroup     16.1 K 2025-09-13 13:02 wasbs://campus-user@madsstorage002.blob.core.windows.net/yxi75/daily_nz_tmin_tmax
-rw-r--r--   1 yxi75 supergroup     14.6 K 2025-09-13 13:02 wasbs://campus-user@madsstorage002.blob.core.windows.net/yxi75/daily_nz_tmin_tmax
-rw-r--r--   1 yxi75 supergroup     14.7 K 2025-09-13 13:02 wasbs://campus-user@madsstorage002.blob.core.windows.net/yxi75/daily_nz_tmin_tmax
-rw-r--r--   1 yxi75 supergroup     14.8 K 2025-09-13 13:02 wasbs://campus-user@madsstorage002.blob.core.windows.net/yxi75/daily_nz_tmin_tmax
-rw-r--r--   1 yxi75 supergroup     16.5 K 2025-09-13 13:02 wasbs://campus-user@madsstorage002.blob.core.windows.net/yxi75/daily_nz_tmin_tmax
-rw-r--r--   1 yxi75 supergroup     16.7 K 2025-09-13 13:02 wasbs://campus-user@madsstorage002.blob.core.windows.net/yxi75/daily_nz_tmin_tmax
-rw-r--r--   1 yxi75 supergroup     16.7 K 2025-09-13 13:02 wasbs://campus-user@madsstorage002.blob.core.windows.net/yxi75/daily_nz_tmin_tmax
-rw-r--r--   1 yxi75 supergroup     16.5 K 2025-09-13 13:02 wasbs://campus-user@madsstorage002.blob.core.windows.net/yxi75/daily_nz_tmin_tmax
-rw-r--r--   1 yxi75 supergroup     16.4 K 2025-09-13 13:02 wasbs://campus-user@madsstorage002.blob.core.windows.net/yxi75/daily_nz_tmin_tmax
-rw-r--r--   1 yxi75 supergroup     14.6 K 2025-09-13 13:02 wasbs://campus-user@madsstorage002.blob.core.windows.net/yxi75/daily_nz_tmin_tmax
-rw-r--r--   1 yxi75 supergroup     16.4 K 2025-09-13 13:02 wasbs://campus-user@madsstorage002.blob.core.windows.net/yxi75/daily_nz_tmin_tmax
-rw-r--r--   1 yxi75 supergroup     16.5 K 2025-09-13 13:02 wasbs://campus-user@madsstorage002.blob.core.windows.net/yxi75/daily_nz_tmin_tmax
-rw-r--r--   1 yxi75 supergroup     16.4 K 2025-09-13 13:02 wasbs://campus-user@madsstorage002.blob.core.windows.net/yxi75/daily_nz_tmin_tmax
-rw-r--r--   1 yxi75 supergroup     16.2 K 2025-09-13 13:02 wasbs://campus-user@madsstorage002.blob.core.windows.net/yxi75/daily_nz_tmin_tmax
-rw-r--r--   1 yxi75 supergroup     16.3 K 2025-09-13 13:02 wasbs://campus-user@madsstorage002.blob.core.windows.net/yxi75/daily_nz_tmin_tmax
-rw-r--r--   1 yxi75 supergroup     16.6 K 2025-09-13 13:02 wasbs://campus-user@madsstorage002.blob.core.windows.net/yxi75/daily_nz_tmin_tmax
-rw-r--r--   1 yxi75 supergroup     16.3 K 2025-09-13 13:02 wasbs://campus-user@madsstorage002.blob.core.windows.net/yxi75/daily_nz_tmin_tmax
-rw-r--r--   1 yxi75 supergroup     16.5 K 2025-09-13 13:02 wasbs://campus-user@madsstorage002.blob.core.windows.net/yxi75/daily_nz_tmin_tmax
-rw-r--r--   1 yxi75 supergroup     15.6 K 2025-09-13 13:02 wasbs://campus-user@madsstorage002.blob.core.windows.net/yxi75/daily_nz_tmin_tmax
-rw-r--r--   1 yxi75 supergroup     14.8 K 2025-09-13 13:02 wasbs://campus-user@madsstorage002.blob.core.windows.net/yxi75/daily_nz_tmin_tmax
-rw-r--r--   1 yxi75 supergroup     14.9 K 2025-09-13 13:02 wasbs://campus-user@madsstorage002.blob.core.windows.net/yxi75/daily_nz_tmin_tmax
-rw-r--r--   1 yxi75 supergroup     14.7 K 2025-09-13 13:02 wasbs://campus-user@madsstorage002.blob.core.windows.net/yxi75/daily_nz_tmin_tmax
-rw-r--r--   1 yxi75 supergroup     16.5 K 2025-09-13 13:02 wasbs://campus-user@madsstorage002.blob.core.windows.net/yxi75/daily_nz_tmin_tmax
-rw-r--r--   1 yxi75 supergroup     13.9 K 2025-09-13 13:02 wasbs://campus-user@madsstorage002.blob.core.windows.net/yxi75/daily_nz_tmin_tmax
-rw-r--r--   1 yxi75 supergroup     15.8 K 2025-09-13 13:02 wasbs://campus-user@madsstorage002.blob.core.windows.net/yxi75/daily_nz_tmin_tmax
-rw-r--r--   1 yxi75 supergroup     13.8 K 2025-09-13 13:02 wasbs://campus-user@madsstorage002.blob.core.windows.net/yxi75/daily_nz_tmin_tmax
-rw-r--r--   1 yxi75 supergroup     13.9 K 2025-09-13 13:02 wasbs://campus-user@madsstorage002.blob.core.windows.net/yxi75/daily_nz_tmin_tmax
-rw-r--r--   1 yxi75 supergroup     13.8 K 2025-09-13 13:02 wasbs://campus-user@madsstorage002.blob.core.windows.net/yxi75/daily_nz_tmin_tmax
-rw-r--r--   1 yxi75 supergroup     13.8 K 2025-09-13 13:02 wasbs://campus-user@madsstorage002.blob.core.windows.net/yxi75/daily_nz_tmin_tmax
-rw-r--r--   1 yxi75 supergroup     13.8 K 2025-09-13 13:02 wasbs://campus-user@madsstorage002.blob.core.windows.net/yxi75/daily_nz_tmin_tmax
-rw-r--r--   1 yxi75 supergroup     12.7 K 2025-09-13 13:02 wasbs://campus-user@madsstorage002.blob.core.windows.net/yxi75/daily_nz_tmin_tmax
-rw-r--r--   1 yxi75 supergroup     15.4 K 2025-09-13 13:02 wasbs://campus-user@madsstorage002.blob.core.windows.net/yxi75/daily_nz_tmin_tmax
-rw-r--r--   1 yxi75 supergroup     15.4 K 2025-09-13 13:02 wasbs://campus-user@madsstorage002.blob.core.windows.net/yxi75/daily_nz_tmin_tmax
-rw-r--r--   1 yxi75 supergroup     14.5 K 2025-09-13 13:02 wasbs://campus-user@madsstorage002.blob.core.windows.net/yxi75/daily_nz_tmin_tmax
-rw-r--r--   1 yxi75 supergroup     15.4 K 2025-09-13 13:02 wasbs://campus-user@madsstorage002.blob.core.windows.net/yxi75/daily_nz_tmin_tmax
-rw-r--r--   1 yxi75 supergroup     11.2 K 2025-09-13 13:02 wasbs://campus-user@madsstorage002.blob.core.windows.net/yxi75/daily_nz_tmin_tmax
-rw-r--r--   1 yxi75 supergroup     14.1 K 2025-09-13 13:02 wasbs://campus-user@madsstorage002.blob.core.windows.net/yxi75/daily_nz_tmin_tmax
-rw-r--r--   1 yxi75 supergroup     13.9 K 2025-09-13 13:02 wasbs://campus-user@madsstorage002.blob.core.windows.net/yxi75/daily_nz_tmin_tmax
-rw-r--r--   1 yxi75 supergroup     14.3 K 2025-09-13 13:02 wasbs://campus-user@madsstorage002.blob.core.windows.net/yxi75/daily_nz_tmin_tmax
-rw-r--r--   1 yxi75 supergroup     13.4 K 2025-09-13 13:02 wasbs://campus-user@madsstorage002.blob.core.windows.net/yxi75/daily_nz_tmin_tmax
-rw-r--r--   1 yxi75 supergroup     13.2 K 2025-09-13 13:02 wasbs://campus-user@madsstorage002.blob.core.windows.net/yxi75/daily_nz_tmin_tmax
-rw-r--r--   1 yxi75 supergroup     12.4 K 2025-09-13 13:02 wasbs://campus-user@madsstorage002.blob.core.windows.net/yxi75/daily_nz_tmin_tmax
-rw-r--r--   1 yxi75 supergroup     12.5 K 2025-09-13 13:02 wasbs://campus-user@madsstorage002.blob.core.windows.net/yxi75/daily_nz_tmin_tmax
-rw-r--r--   1 yxi75 supergroup     11.2 K 2025-09-13 13:02 wasbs://campus-user@madsstorage002.blob.core.windows.net/yxi75/daily_nz_tmin_tmax
-rw-r--r--   1 yxi75 supergroup     11.2 K 2025-09-13 13:02 wasbs://campus-user@madsstorage002.blob.core.windows.net/yxi75/daily_nz_tmin_tmax
-rw-r--r--   1 yxi75 supergroup     11.2 K 2025-09-13 13:02 wasbs://campus-user@madsstorage002.blob.core.windows.net/yxi75/daily_nz_tmin_tmax
-rw-r--r--   1 yxi75 supergroup     10.7 K 2025-09-13 13:02 wasbs://campus-user@madsstorage002.blob.core.windows.net/yxi75/daily_nz_tmin_tmax
-rw-r--r--   1 yxi75 supergroup     10.4 K 2025-09-13 13:02 wasbs://campus-user@madsstorage002.blob.core.windows.net/yxi75/daily_nz_tmin_tmax
-rw-r--r--   1 yxi75 supergroup     10.4 K 2025-09-13 13:02 wasbs://campus-user@madsstorage002.blob.core.windows.net/yxi75/daily_nz_tmin_tmax
-rw-r--r--   1 yxi75 supergroup     10.4 K 2025-09-13 13:02 wasbs://campus-user@madsstorage002.blob.core.windows.net/yxi75/daily_nz_tmin_tmax
-rw-r--r--   1 yxi75 supergroup     10.5 K 2025-09-13 13:02 wasbs://campus-user@madsstorage002.blob.core.windows.net/yxi75/daily_nz_tmin_tmax
-rw-r--r--   1 yxi75 supergroup     10.5 K 2025-09-13 13:02 wasbs://campus-user@madsstorage002.blob.core.windows.net/yxi75/daily_nz_tmin_tmax
-rw-r--r--   1 yxi75 supergroup     10.4 K 2025-09-13 13:02 wasbs://campus-user@madsstorage002.blob.core.windows.net/yxi75/daily_nz_tmin_tmax
-rw-r--r--   1 yxi75 supergroup     10.6 K 2025-09-13 13:02 wasbs://campus-user@madsstorage002.blob.core.windows.net/yxi75/daily_nz_tmin_tmax
-rw-r--r--   1 yxi75 supergroup      9.9 K 2025-09-13 13:02 wasbs://campus-user@madsstorage002.blob.core.windows.net/yxi75/daily_nz_tmin_tmax
-rw-r--r--   1 yxi75 supergroup     10.6 K 2025-09-13 13:02 wasbs://campus-user@madsstorage002.blob.core.windows.net/yxi75/daily_nz_tmin_tmax
-rw-r--r--   1 yxi75 supergroup      9.0 K 2025-09-13 13:02 wasbs://campus-user@madsstorage002.blob.core.windows.net/yxi75/daily_nz_tmin_tmax
-rw-r--r--   1 yxi75 supergroup      9.0 K 2025-09-13 13:02 wasbs://campus-user@madsstorage002.blob.core.windows.net/yxi75/daily_nz_tmin_tmax
-rw-r--r--   1 yxi75 supergroup      9.1 K 2025-09-13 13:02 wasbs://campus-user@madsstorage002.blob.core.windows.net/yxi75/daily_nz_tmin_tmax
-rw-r--r--   1 yxi75 supergroup      9.1 K 2025-09-13 13:02 wasbs://campus-user@madsstorage002.blob.core.windows.net/yxi75/daily_nz_tmin_tmax
-rw-r--r--   1 yxi75 supergroup      8.0 K 2025-09-13 13:02 wasbs://campus-user@madsstorage002.blob.core.windows.net/yxi75/daily_nz_tmin_tmax
-rw-r--r--   1 yxi75 supergroup      7.5 K 2025-09-13 13:02 wasbs://campus-user@madsstorage002.blob.core.windows.net/yxi75/daily_nz_tmin_tmax
-rw-r--r--   1 yxi75 supergroup      9.9 K 2025-09-13 13:02 wasbs://campus-user@madsstorage002.blob.core.windows.net/yxi75/daily_nz_tmin_tmax
```

```
# cache daily_nz_tmin_tmax for frequetly use
daily_nz_tmin_tmax = spark.read.parquet(daily_nz_tmin_tmax_path)
daily_nz_tmin_tmax.cache()
```

```
DataFrame[ID: string, DATE: string, ELEMENT: string, VALUE: float, MEASUREMENT_FLAG: string, QUALITY_FLAG: string, SOURCE_FLAG: string, OBSERV
```

```
# how many years are covered by the daily_nz_tmin_tmax
# parse DATE col
daily_nz_tmin_tmax = daily_nz_tmin_tmax.withColumn(
    "DATE", F.to_date(F.col("DATE"), "yyyyMMdd")
)

# extract years col
years = (
    daily_nz_tmin_tmax.select(F.year("DATE").alias("year")).distinct().orderBy("year")
)

# calculate year range
years_agg = years.agg(
    F.min("year").alias("min_year"),
    F.max("year").alias("max_year"),
    F.countDistinct("year").alias("n_year"),
)
show_as_html(years_agg)
```

```
.dataframe tbody tr th {
    vertical-align: top;
}

.dataframe thead th {
    text-align: right;
}
```

min_year	max_year	n_year
1940	2025	86

Check data gap in year level

From 1940 to 2025, there should have 2025-1940+1=86 years, where our distinct method found 86 in years_agg, so no year-level gap.

Check data gap in month level

```
# ===== 0) Set year range  =====
min_y, max_y = 1940, 2025

# ===== 1) Dimension tables: station / year / month =====
# Station table: you already have nz_station_ids (small table).
# If IDs are not guaranteed unique, apply distinct upstream.
ids_df = nz_station_ids.select("ID")
years_df = spark.range(min_y, max_y + 1).withColumnRenamed("id", "year")
months_df = spark.range(1, 13).withColumnRenamed("id", "month")

# Cartesian product to generate the full (ID, year, month) frame
# Expected size = num_stations × num_years × 12 = 15480 row
full_frame = ids_df.crossJoin(years_df).crossJoin(months_df)
```

```
show_as_html(full_frame)
```

```
.dataframe tbody tr th {
    vertical-align: top;
}

.dataframe thead th {
    text-align: right;
}
```

ID	year	month
NZ000936150	1940	1
NZ000936150	1940	2
NZ000936150	1940	3
NZ000936150	1940	4
NZ000936150	1940	5
NZ000936150	1940	6

NZ000936150	1940	7
NZ000936150	1940	8
NZ000936150	1940	9
NZ000936150	1940	10
NZ000936150	1940	11
NZ000936150	1940	12
NZ000936150	1941	1
NZ000936150	1941	2
NZ000936150	1941	3
NZ000936150	1941	4
NZ000936150	1941	5
NZ000936150	1941	6
NZ000936150	1941	7
NZ000936150	1941	8

```
# ===== 2) Observed (ID, year, month) combinations =====
# Instead of distinct, aggregate with groupBy once
obs_by_month = (
    daily_nz_tmin_tmax.select(
        F.col("ID"), F.year("DATE").alias("year"), F.month("DATE").alias("month")
    )
    .groupBy("ID", "year", "month")
    .agg(F.count(F.lit(1)).alias("cnt"))  # just to prove existence
    .select("ID", "year", "month")  # reduce back to presence set
)
```

```
print(f"obs_by_month has {obs_by_month.count()} rows")
# obs_by_month is a small table too! only 8954 rows

obs_by_month.show()
```

```
obs_by_month has 8954 rows
+-----------+----+-----+
|         ID|year|month|
+-----------+----+-----+
|NZ000093417|2011|    8|
|NZM00093439|2011|   10|
|NZ000093292|2011|    3|
|NZ000093292|2011|    8|
|NZ000093417|2011|   11|
|NZ000093417|2011|    4|
|NZM00093678|2011|    4|
|NZM00093678|2011|    6|
|NZ000093292|2011|    7|
|NZM00093678|2011|    7|
|NZ000936150|2011|   10|
|NZ000936150|2011|   11|
|NZ000093417|2011|    2|
|NZ000093844|2011|    7|
|NZ000093844|2011|    4|
|NZ000093292|2011|    4|
|NZ000093417|2011|    5|
|NZ000093417|2011|    7|
|NZ000093417|2011|    9|
|NZM00093678|2011|   10|
+-----------+----+-----+
only showing top 20 rows
```

```python
# ===== 3) Find missing (expected minus observed) =====
# full_frame is small (15480 rows),  use it as left table with left_anti join
missing = full_frame.join(obs_by_month, on=["ID", "year", "month"], how="left_anti")

# ===== 4) Aggregate missing months for each (ID, year) =====
gaps_by_id_year = (
    missing.groupBy("ID", "year").agg(F.collect_list("month").alias("missing_months"))
).orderBy("ID", "year", "missing_months")

gaps_by_id_year.show(100, truncate=False)
```

```
+-----------+----+---------------------------------------+
|ID         |year|missing_months                         |
+-----------+----+---------------------------------------+
|NZ000093012|1940|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093012|1941|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093012|1942|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093012|1943|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093012|1944|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093012|1945|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093012|1946|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093012|1947|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093012|1948|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093012|1949|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093012|1950|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093012|1951|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093012|1952|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093012|1953|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093012|1954|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093012|1955|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093012|1956|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093012|1957|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093012|1958|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093012|1959|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093012|1960|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093012|1961|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093012|1962|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093012|1963|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093012|1964|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093012|1965|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093012|1970|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093012|1971|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093012|1972|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093012|1973|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093012|1974|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093012|1975|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093012|1976|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093012|1977|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093012|1978|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093012|1979|[1, 2, 3]                              |
|NZ000093012|2006|[1, 2, 3, 4, 5, 6, 8, 9, 10, 11, 12]   |
|NZ000093012|2007|[1, 2, 3, 4, 5, 8, 10, 11, 12]         |
|NZ000093012|2008|[1, 2, 3, 4, 5, 6, 7, 9, 10, 11, 12]   |
|NZ000093012|2009|[1, 2, 3, 4, 5, 9, 10, 11, 12]         |
|NZ000093012|2010|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093012|2011|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093012|2012|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093012|2013|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093012|2014|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093012|2015|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093012|2016|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093012|2017|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093012|2018|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093012|2019|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093012|2020|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093012|2021|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093012|2022|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093012|2023|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093012|2024|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093012|2025|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093292|1940|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093292|1941|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093292|1942|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093292|1943|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093292|1944|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093292|1945|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093292|1946|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093292|1947|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093292|1948|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093292|1949|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093292|1950|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093292|1951|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
```

```
|NZ000093292|1952|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093292|1953|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093292|1954|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093292|1955|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093292|1956|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093292|1957|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093292|1958|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093292|1959|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093292|1960|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093292|1961|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093292|1962|[1]                                    |
|NZ000093292|2025|[8, 9, 10, 11, 12]                     |
|NZ000093417|1940|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093417|1941|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093417|1942|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093417|1943|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093417|1944|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093417|1945|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093417|1946|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093417|1947|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093417|1948|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093417|1949|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093417|1950|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093417|1951|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093417|1952|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093417|1953|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093417|1954|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093417|1955|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093417|1956|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093417|1957|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093417|1958|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093417|1959|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
+-----------+----+----------------------------------------+
only showing top 100 rows
```

gap months stats

```python
# define the latest observation month in our daily dataset, so 2025 Aug or later should not be missing.
obs_by_month.filter(F.col("year") == 2025).agg(F.max(F.col("month"))).show()
```

```
+----------+
|max(month)|
+----------+
|         7|
+----------+
```

```python
daily_nz_tmin_tmax_missing_stats = (
    gaps_by_id_year.withColumn(
        "missing_month_count", F.size("missing_months")
    )  # missing in current year
    .withColumn(
        "missing_year_flag", F.when(F.size("missing_months") > 0, 1).otherwise(0)
    )  # if current year has missing month, flag=1
    .groupBy("ID")
    .agg(
        F.lit(F.sum("missing_year_flag")).alias(
            "missing_year_total"
        ),  # -5 is because 2025 the latest record is July, so Aug or later is not missing.
        F.lit(F.sum("missing_month_count") - 5).alias("missing_month_total"),
    )
).orderBy("missing_month_total")

show_as_html(daily_nz_tmin_tmax_missing_stats)
```

```css
.dataframe tbody tr th {
    vertical-align: top;
}

.dataframe thead th {
    text-align: right;
}
```

ID	missing_year_total	missing_month_total
NZ000933090	5	48

NZ000093994	10	87
NZ000093844	10	100
NZ000939450	17	176
NZ000093292	24	265
NZ000936150	25	288
NZ000937470	31	364
NZ000093417	33	384
NZM00093781	40	448
NZ000939870	39	450
NZ000093012	56	650
NZM00093678	64	750
NZM00093110	64	752
NZM00093439	64	752
NZM00093929	81	937

```
# verify result by sampling check one station ID
gaps_by_id_year.filter(F.col("ID") == "NZ000093844").show(
    100, truncate=False
)  # should missing 100 months

# check: misisng 1940-1947, 1948 obs has 8 months, matching gaps_by_id_year misisng 4 months in 1948
obs_by_month.filter(F.col("ID") == "NZ000093844").groupBy("year").agg(
    F.count("month")
).orderBy("year").show(100)
```

```
+-----------+----+---------------------------------------+
|ID         |year|missing_months                         |
+-----------+----+---------------------------------------+
|NZ000093844|1940|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093844|1941|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093844|1942|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093844|1943|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093844|1944|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093844|1945|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093844|1946|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093844|1947|[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]|
|NZ000093844|1948|[1, 2, 3, 4]                           |
|NZ000093844|2025|[8, 9, 10, 11, 12]                     |
+-----------+----+---------------------------------------+

+----+------------+
|year|count(month)|
+----+------------+
|1948|           8|
|1949|          12|
|1950|          12|
|1951|          12|
|1952|          12|
|1953|          12|
|1954|          12|
|1955|          12|
|1956|          12|
|1957|          12|
|1958|          12|
|1959|          12|
|1960|          12|
|1961|          12|
|1962|          12|
|1963|          12|
|1964|          12|
|1965|          12|
|1966|          12|
|1967|          12|
|1968|          12|
|1969|          12|
|1970|          12|
|1971|          12|
|1972|          12|
|1973|          12|
```

```
|1974|          12|
|1975|          12|
|1976|          12|
|1977|          12|
|1978|          12|
|1979|          12|
|1980|          12|
|1981|          12|
|1982|          12|
|1983|          12|
|1984|          12|
|1985|          12|
|1986|          12|
|1987|          12|
|1988|          12|
|1989|          12|
|1990|          12|
|1991|          12|
|1992|          12|
|1993|          12|
|1994|          12|
|1995|          12|
|1996|          12|
|1997|          12|
|1998|          12|
|1999|          12|
|2000|          12|
|2001|          12|
|2002|          12|
|2003|          12|
|2004|          12|
|2005|          12|
|2006|          12|
|2007|          12|
|2008|          12|
|2009|          12|
|2010|          12|
|2011|          12|
|2012|          12|
|2013|          12|
|2014|          12|
|2015|          12|
|2016|          12|
|2017|          12|
|2018|          12|
|2019|          12|
|2020|          12|
|2021|          12|
|2022|          12|
|2023|          12|
|2024|          12|
|2025|           7|
+----+------------+
```

```python
# verify daily_nz_tmin_tmax_missing_stats with daily record sampling
daily_nz_tmin_tmax.filter(
    (F.col("ID") == "NZ000093844") & (F.col("DATE").contains("1948"))
).show(400, truncate=False)
```

```
+-----------+----------+-------+-----+----------------+------------+-----------+----------------+
|ID         |DATE      |ELEMENT|VALUE|MEASUREMENT_FLAG|QUALITY_FLAG|SOURCE_FLAG|OBSERVATION_TIME|
+-----------+----------+-------+-----+----------------+------------+-----------+----------------+
|NZ000093844|1948-05-31|TMIN   |-28.0|NULL            |NULL        |G          |NULL            |
|NZ000093844|1948-06-01|TMAX   |90.0 |NULL            |NULL        |G          |NULL            |
|NZ000093844|1948-06-01|TMIN   |14.0 |NULL            |NULL        |G          |NULL            |
|NZ000093844|1948-06-02|TMAX   |93.0 |NULL            |NULL        |G          |NULL            |
|NZ000093844|1948-06-02|TMIN   |10.0 |NULL            |NULL        |G          |NULL            |
|NZ000093844|1948-06-03|TMAX   |88.0 |NULL            |NULL        |G          |NULL            |
|NZ000093844|1948-06-03|TMIN   |-32.0|NULL            |NULL        |G          |NULL            |
|NZ000093844|1948-06-04|TMAX   |94.0 |NULL            |NULL        |G          |NULL            |
|NZ000093844|1948-06-04|TMIN   |12.0 |NULL            |NULL        |G          |NULL            |
|NZ000093844|1948-06-05|TMAX   |84.0 |NULL            |NULL        |G          |NULL            |
|NZ000093844|1948-06-05|TMIN   |17.0 |NULL            |NULL        |G          |NULL            |
|NZ000093844|1948-06-06|TMAX   |100.0|NULL            |NULL        |G          |NULL            |
|NZ000093844|1948-06-06|TMIN   |-4.0 |NULL            |NULL        |G          |NULL            |
|NZ000093844|1948-06-07|TMAX   |93.0 |NULL            |NULL        |G          |NULL            |
|NZ000093844|1948-06-07|TMIN   |-61.0|NULL            |NULL        |G          |NULL            |
|NZ000093844|1948-06-08|TMAX   |72.0 |NULL            |NULL        |G          |NULL            |
|NZ000093844|1948-06-08|TMIN   |-22.0|NULL            |NULL        |G          |NULL            |
```

```
|NZ000093844|1948-06-09|TMAX |92.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-06-09|TMIN |45.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-06-10|TMAX |106.0|NULL |NULL |G |NULL |
|NZ000093844|1948-06-10|TMIN |-2.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-06-11|TMAX |114.0|NULL |NULL |G |NULL |
|NZ000093844|1948-06-11|TMIN |8.0  |NULL |NULL |G |NULL |
|NZ000093844|1948-06-12|TMAX |117.0|NULL |NULL |G |NULL |
|NZ000093844|1948-06-12|TMIN |38.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-06-13|TMAX |89.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-06-13|TMIN |-39.0|NULL |NULL |G |NULL |
|NZ000093844|1948-06-14|TMAX |88.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-06-14|TMIN |-44.0|NULL |NULL |G |NULL |
|NZ000093844|1948-06-15|TMAX |106.0|NULL |NULL |G |NULL |
|NZ000093844|1948-06-15|TMIN |22.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-06-16|TMAX |97.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-06-16|TMIN |2.0  |NULL |NULL |G |NULL |
|NZ000093844|1948-06-17|TMAX |100.0|NULL |NULL |G |NULL |
|NZ000093844|1948-06-17|TMIN |-9.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-06-18|TMAX |94.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-06-18|TMIN |6.0  |NULL |NULL |G |NULL |
|NZ000093844|1948-06-19|TMAX |61.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-06-19|TMIN |17.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-06-20|TMAX |87.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-06-20|TMIN |7.0  |NULL |NULL |G |NULL |
|NZ000093844|1948-06-21|TMAX |89.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-06-21|TMIN |47.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-06-22|TMAX |107.0|NULL |NULL |G |NULL |
|NZ000093844|1948-06-22|TMIN |5.0  |NULL |NULL |G |NULL |
|NZ000093844|1948-06-23|TMAX |128.0|NULL |NULL |G |NULL |
|NZ000093844|1948-06-23|TMIN |16.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-06-24|TMAX |83.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-06-24|TMIN |32.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-06-25|TMAX |79.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-06-25|TMIN |36.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-06-26|TMAX |81.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-06-26|TMIN |-27.0|NULL |NULL |G |NULL |
|NZ000093844|1948-06-27|TMAX |86.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-06-27|TMIN |4.0  |NULL |NULL |G |NULL |
|NZ000093844|1948-06-28|TMAX |122.0|NULL |NULL |G |NULL |
|NZ000093844|1948-06-28|TMIN |-8.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-06-29|TMAX |89.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-06-29|TMIN |19.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-06-30|TMAX |72.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-06-30|TMIN |22.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-07-01|TMAX |73.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-07-01|TMIN |43.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-07-02|TMAX |88.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-07-02|TMIN |-6.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-07-03|TMAX |82.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-07-03|TMIN |7.0  |NULL |NULL |G |NULL |
|NZ000093844|1948-07-04|TMAX |106.0|NULL |NULL |G |NULL |
|NZ000093844|1948-07-04|TMIN |17.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-07-05|TMAX |121.0|NULL |NULL |G |NULL |
|NZ000093844|1948-07-05|TMIN |-11.0|NULL |NULL |G |NULL |
|NZ000093844|1948-07-06|TMAX |133.0|NULL |NULL |G |NULL |
|NZ000093844|1948-07-06|TMIN |23.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-07-07|TMAX |106.0|NULL |NULL |G |NULL |
|NZ000093844|1948-07-07|TMIN |42.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-07-08|TMAX |106.0|NULL |NULL |G |NULL |
|NZ000093844|1948-07-08|TMIN |-22.0|NULL |NULL |G |NULL |
|NZ000093844|1948-07-09|TMAX |112.0|NULL |NULL |G |NULL |
|NZ000093844|1948-07-09|TMIN |-13.0|NULL |NULL |G |NULL |
|NZ000093844|1948-07-10|TMAX |77.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-07-10|TMIN |21.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-07-11|TMAX |97.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-07-11|TMIN |36.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-07-12|TMAX |129.0|NULL |NULL |G |NULL |
|NZ000093844|1948-07-12|TMIN |11.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-07-13|TMAX |106.0|NULL |NULL |G |NULL |
|NZ000093844|1948-07-13|TMIN |37.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-07-14|TMAX |84.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-07-14|TMIN |36.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-07-15|TMAX |96.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-07-15|TMIN |4.0  |NULL |NULL |G |NULL |
|NZ000093844|1948-07-16|TMAX |107.0|NULL |NULL |G |NULL |
|NZ000093844|1948-07-16|TMIN |8.0  |NULL |NULL |G |NULL |
|NZ000093844|1948-07-17|TMAX |91.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-07-17|TMIN |-43.0|NULL |NULL |G |NULL |
|NZ000093844|1948-07-18|TMAX |77.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-07-18|TMIN |-59.0|NULL |NULL |G |NULL |
|NZ000093844|1948-07-19|TMAX |82.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-07-19|TMIN |-31.0|NULL |NULL |G |NULL |
|NZ000093844|1948-07-20|TMAX |99.0 |NULL |NULL |G |NULL |
```

```
|NZ000093844|1948-07-20|TMIN|-19.0|NULL|NULL|G|NULL|
|NZ000093844|1948-07-21|TMAX|78.0|NULL|NULL|G|NULL|
|NZ000093844|1948-07-21|TMIN|18.0|NULL|NULL|G|NULL|
|NZ000093844|1948-07-22|TMAX|97.0|NULL|NULL|G|NULL|
|NZ000093844|1948-07-22|TMIN|31.0|NULL|NULL|G|NULL|
|NZ000093844|1948-07-23|TMAX|89.0|NULL|NULL|G|NULL|
|NZ000093844|1948-07-23|TMIN|64.0|NULL|NULL|G|NULL|
|NZ000093844|1948-07-24|TMAX|101.0|NULL|NULL|G|NULL|
|NZ000093844|1948-07-24|TMIN|52.0|NULL|NULL|G|NULL|
|NZ000093844|1948-07-25|TMAX|111.0|NULL|NULL|G|NULL|
|NZ000093844|1948-07-25|TMIN|9.0|NULL|NULL|G|NULL|
|NZ000093844|1948-07-26|TMAX|122.0|NULL|NULL|G|NULL|
|NZ000093844|1948-07-26|TMIN|-29.0|NULL|NULL|G|NULL|
|NZ000093844|1948-07-27|TMAX|132.0|NULL|NULL|G|NULL|
|NZ000093844|1948-07-27|TMIN|-34.0|NULL|NULL|G|NULL|
|NZ000093844|1948-07-28|TMAX|106.0|NULL|NULL|G|NULL|
|NZ000093844|1948-07-28|TMIN|-18.0|NULL|NULL|G|NULL|
|NZ000093844|1948-07-29|TMAX|127.0|NULL|NULL|G|NULL|
|NZ000093844|1948-07-29|TMIN|14.0|NULL|NULL|G|NULL|
|NZ000093844|1948-07-30|TMAX|103.0|NULL|NULL|G|NULL|
|NZ000093844|1948-07-30|TMIN|10.0|NULL|NULL|G|NULL|
|NZ000093844|1948-07-31|TMAX|82.0|NULL|NULL|G|NULL|
|NZ000093844|1948-07-31|TMIN|-1.0|NULL|NULL|G|NULL|
|NZ000093844|1948-08-01|TMAX|77.0|NULL|NULL|G|NULL|
|NZ000093844|1948-08-01|TMIN|-54.0|NULL|NULL|G|NULL|
|NZ000093844|1948-08-02|TMAX|88.0|NULL|NULL|G|NULL|
|NZ000093844|1948-08-02|TMIN|-36.0|NULL|NULL|G|NULL|
|NZ000093844|1948-08-03|TMAX|131.0|NULL|NULL|G|NULL|
|NZ000093844|1948-08-03|TMIN|34.0|NULL|NULL|G|NULL|
|NZ000093844|1948-08-04|TMAX|120.0|NULL|NULL|G|NULL|
|NZ000093844|1948-08-04|TMIN|17.0|NULL|NULL|G|NULL|
|NZ000093844|1948-08-05|TMAX|134.0|NULL|NULL|G|NULL|
|NZ000093844|1948-08-05|TMIN|36.0|NULL|NULL|G|NULL|
|NZ000093844|1948-08-06|TMAX|116.0|NULL|NULL|G|NULL|
|NZ000093844|1948-08-06|TMIN|23.0|NULL|NULL|G|NULL|
|NZ000093844|1948-08-07|TMAX|116.0|NULL|NULL|G|NULL|
|NZ000093844|1948-08-07|TMIN|31.0|NULL|NULL|G|NULL|
|NZ000093844|1948-08-08|TMAX|127.0|NULL|NULL|G|NULL|
|NZ000093844|1948-08-08|TMIN|39.0|NULL|NULL|G|NULL|
|NZ000093844|1948-08-09|TMAX|146.0|NULL|NULL|G|NULL|
|NZ000093844|1948-08-09|TMIN|23.0|NULL|NULL|G|NULL|
|NZ000093844|1948-08-10|TMAX|145.0|NULL|NULL|G|NULL|
|NZ000093844|1948-08-10|TMIN|23.0|NULL|NULL|G|NULL|
|NZ000093844|1948-08-11|TMAX|116.0|NULL|NULL|G|NULL|
|NZ000093844|1948-08-11|TMIN|-6.0|NULL|NULL|G|NULL|
|NZ000093844|1948-08-12|TMAX|126.0|NULL|NULL|G|NULL|
|NZ000093844|1948-08-12|TMIN|31.0|NULL|NULL|G|NULL|
|NZ000093844|1948-08-13|TMAX|122.0|NULL|NULL|G|NULL|
|NZ000093844|1948-08-13|TMIN|14.0|NULL|NULL|G|NULL|
|NZ000093844|1948-08-14|TMAX|161.0|NULL|NULL|G|NULL|
|NZ000093844|1948-08-14|TMIN|9.0|NULL|NULL|G|NULL|
|NZ000093844|1948-08-15|TMAX|131.0|NULL|NULL|G|NULL|
|NZ000093844|1948-08-15|TMIN|53.0|NULL|NULL|G|NULL|
|NZ000093844|1948-08-16|TMAX|165.0|NULL|NULL|G|NULL|
|NZ000093844|1948-08-16|TMIN|43.0|NULL|NULL|G|NULL|
|NZ000093844|1948-08-17|TMAX|110.0|NULL|NULL|G|NULL|
|NZ000093844|1948-08-17|TMIN|23.0|NULL|NULL|G|NULL|
|NZ000093844|1948-08-18|TMAX|102.0|NULL|NULL|G|NULL|
|NZ000093844|1948-08-18|TMIN|19.0|NULL|NULL|G|NULL|
|NZ000093844|1948-08-19|TMAX|72.0|NULL|NULL|G|NULL|
|NZ000093844|1948-08-19|TMIN|-37.0|NULL|NULL|G|NULL|
|NZ000093844|1948-08-20|TMAX|84.0|NULL|NULL|G|NULL|
|NZ000093844|1948-08-20|TMIN|-46.0|NULL|NULL|G|NULL|
|NZ000093844|1948-08-21|TMAX|105.0|NULL|NULL|G|NULL|
|NZ000093844|1948-08-21|TMIN|-57.0|NULL|NULL|G|NULL|
|NZ000093844|1948-08-22|TMAX|119.0|NULL|NULL|G|NULL|
|NZ000093844|1948-08-22|TMIN|-2.0|NULL|NULL|G|NULL|
|NZ000093844|1948-08-23|TMAX|160.0|NULL|NULL|G|NULL|
|NZ000093844|1948-08-23|TMIN|29.0|NULL|NULL|G|NULL|
|NZ000093844|1948-08-24|TMAX|178.0|NULL|NULL|G|NULL|
|NZ000093844|1948-08-24|TMIN|57.0|NULL|NULL|G|NULL|
|NZ000093844|1948-08-25|TMAX|143.0|NULL|NULL|G|NULL|
|NZ000093844|1948-08-25|TMIN|66.0|NULL|NULL|G|NULL|
|NZ000093844|1948-08-26|TMAX|116.0|NULL|NULL|G|NULL|
|NZ000093844|1948-08-26|TMIN|51.0|NULL|NULL|G|NULL|
|NZ000093844|1948-08-27|TMAX|104.0|NULL|NULL|G|NULL|
|NZ000093844|1948-08-27|TMIN|19.0|NULL|NULL|G|NULL|
|NZ000093844|1948-08-28|TMAX|141.0|NULL|NULL|G|NULL|
|NZ000093844|1948-08-28|TMIN|33.0|NULL|NULL|G|NULL|
|NZ000093844|1948-08-29|TMAX|139.0|NULL|NULL|G|NULL|
|NZ000093844|1948-08-29|TMIN|-19.0|NULL|NULL|G|NULL|
|NZ000093844|1948-08-30|TMAX|129.0|NULL|NULL|G|NULL|
|NZ000093844|1948-08-30|TMIN|8.0|NULL|NULL|G|NULL|
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|NZ000093844|1948-08-31|TMAX |128.0|NULL |NULL |G |NULL |
|NZ000093844|1948-08-31|TMIN |-5.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-09-01|TMAX |111.0|NULL |NULL |G |NULL |
|NZ000093844|1948-09-01|TMIN |-31.0|NULL |NULL |G |NULL |
|NZ000093844|1948-09-02|TMAX |131.0|NULL |NULL |G |NULL |
|NZ000093844|1948-09-02|TMIN |-3.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-09-03|TMAX |89.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-09-03|TMIN |60.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-09-04|TMAX |96.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-09-04|TMIN |17.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-09-05|TMAX |130.0|NULL |NULL |G |NULL |
|NZ000093844|1948-09-05|TMIN |24.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-09-06|TMAX |162.0|NULL |NULL |G |NULL |
|NZ000093844|1948-09-06|TMIN |68.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-09-07|TMAX |139.0|NULL |NULL |G |NULL |
|NZ000093844|1948-09-07|TMIN |1.0  |NULL |NULL |G |NULL |
|NZ000093844|1948-09-08|TMAX |127.0|NULL |NULL |G |NULL |
|NZ000093844|1948-09-08|TMIN |42.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-09-09|TMAX |177.0|NULL |NULL |G |NULL |
|NZ000093844|1948-09-09|TMIN |47.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-09-10|TMAX |115.0|NULL |NULL |G |NULL |
|NZ000093844|1948-09-10|TMIN |56.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-09-11|TMAX |128.0|NULL |NULL |G |NULL |
|NZ000093844|1948-09-11|TMIN |5.0  |NULL |NULL |G |NULL |
|NZ000093844|1948-09-12|TMAX |144.0|NULL |NULL |G |NULL |
|NZ000093844|1948-09-12|TMIN |17.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-09-13|TMAX |144.0|NULL |NULL |G |NULL |
|NZ000093844|1948-09-13|TMIN |55.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-09-14|TMAX |127.0|NULL |NULL |G |NULL |
|NZ000093844|1948-09-14|TMIN |19.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-09-15|TMAX |161.0|NULL |NULL |G |NULL |
|NZ000093844|1948-09-15|TMIN |-1.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-09-16|TMAX |149.0|NULL |NULL |G |NULL |
|NZ000093844|1948-09-16|TMIN |41.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-09-17|TMAX |152.0|NULL |NULL |G |NULL |
|NZ000093844|1948-09-17|TMIN |58.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-09-18|TMAX |149.0|NULL |NULL |G |NULL |
|NZ000093844|1948-09-18|TMIN |39.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-09-19|TMAX |136.0|NULL |NULL |G |NULL |
|NZ000093844|1948-09-19|TMIN |39.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-09-20|TMAX |98.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-09-20|TMIN |-16.0|NULL |NULL |G |NULL |
|NZ000093844|1948-09-21|TMAX |121.0|NULL |NULL |G |NULL |
|NZ000093844|1948-09-21|TMIN |-12.0|NULL |NULL |G |NULL |
|NZ000093844|1948-09-22|TMAX |186.0|NULL |NULL |G |NULL |
|NZ000093844|1948-09-22|TMIN |95.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-09-23|TMAX |156.0|NULL |NULL |G |NULL |
|NZ000093844|1948-09-23|TMIN |48.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-09-24|TMAX |124.0|NULL |NULL |G |NULL |
|NZ000093844|1948-09-24|TMIN |9.0  |NULL |NULL |G |NULL |
|NZ000093844|1948-09-25|TMAX |161.0|NULL |NULL |G |NULL |
|NZ000093844|1948-09-25|TMIN |44.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-09-26|TMAX |130.0|NULL |NULL |G |NULL |
|NZ000093844|1948-09-26|TMIN |57.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-09-27|TMAX |144.0|NULL |NULL |G |NULL |
|NZ000093844|1948-09-27|TMIN |61.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-09-28|TMAX |119.0|NULL |NULL |G |NULL |
|NZ000093844|1948-09-28|TMIN |21.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-09-29|TMAX |94.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-09-29|TMIN |17.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-09-30|TMAX |82.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-09-30|TMIN |27.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-10-01|TMAX |83.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-10-01|TMIN |31.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-10-02|TMAX |104.0|NULL |NULL |G |NULL |
|NZ000093844|1948-10-02|TMIN |34.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-10-03|TMAX |99.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-10-03|TMIN |-6.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-10-04|TMAX |167.0|NULL |NULL |G |NULL |
|NZ000093844|1948-10-04|TMIN |8.0  |NULL |NULL |G |NULL |
|NZ000093844|1948-10-05|TMAX |144.0|NULL |NULL |G |NULL |
|NZ000093844|1948-10-05|TMIN |-27.0|NULL |NULL |G |NULL |
|NZ000093844|1948-10-06|TMAX |114.0|NULL |NULL |G |NULL |
|NZ000093844|1948-10-06|TMIN |47.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-10-07|TMAX |128.0|NULL |NULL |G |NULL |
|NZ000093844|1948-10-07|TMIN |57.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-10-08|TMAX |115.0|NULL |NULL |G |NULL |
|NZ000093844|1948-10-08|TMIN |36.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-10-09|TMAX |124.0|NULL |NULL |G |NULL |
|NZ000093844|1948-10-09|TMIN |61.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-10-10|TMAX |111.0|NULL |NULL |G |NULL |
|NZ000093844|1948-10-10|TMIN |-22.0|NULL |NULL |G |NULL |
|NZ000093844|1948-10-11|TMAX |139.0|NULL |NULL |G |NULL |
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|NZ000093844|1948-10-11|TMIN |12.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-10-12|TMAX |192.0|NULL |NULL |G |NULL |
|NZ000093844|1948-10-12|TMIN |123.0|NULL |NULL |G |NULL |
|NZ000093844|1948-10-13|TMAX |179.0|NULL |NULL |G |NULL |
|NZ000093844|1948-10-13|TMIN |32.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-10-14|TMAX |157.0|NULL |NULL |G |NULL |
|NZ000093844|1948-10-14|TMIN |56.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-10-15|TMAX |153.0|NULL |NULL |G |NULL |
|NZ000093844|1948-10-15|TMIN |69.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-10-16|TMAX |114.0|NULL |NULL |G |NULL |
|NZ000093844|1948-10-16|TMIN |44.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-10-17|TMAX |160.0|NULL |NULL |G |NULL |
|NZ000093844|1948-10-17|TMIN |46.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-10-18|TMAX |136.0|NULL |NULL |G |NULL |
|NZ000093844|1948-10-18|TMIN |57.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-10-19|TMAX |175.0|NULL |NULL |G |NULL |
|NZ000093844|1948-10-19|TMIN |81.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-10-20|TMAX |133.0|NULL |NULL |G |NULL |
|NZ000093844|1948-10-20|TMIN |41.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-10-21|TMAX |113.0|NULL |NULL |G |NULL |
|NZ000093844|1948-10-21|TMIN |30.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-10-22|TMAX |144.0|NULL |NULL |G |NULL |
|NZ000093844|1948-10-22|TMIN |54.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-10-23|TMAX |130.0|NULL |NULL |G |NULL |
|NZ000093844|1948-10-23|TMIN |27.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-10-24|TMAX |130.0|NULL |NULL |G |NULL |
|NZ000093844|1948-10-24|TMIN |33.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-10-25|TMAX |97.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-10-25|TMIN |32.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-10-26|TMAX |107.0|NULL |NULL |G |NULL |
|NZ000093844|1948-10-26|TMIN |74.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-10-27|TMAX |154.0|NULL |NULL |G |NULL |
|NZ000093844|1948-10-27|TMIN |82.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-10-28|TMAX |223.0|NULL |NULL |G |NULL |
|NZ000093844|1948-10-28|TMIN |98.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-10-29|TMAX |234.0|NULL |NULL |G |NULL |
|NZ000093844|1948-10-29|TMIN |95.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-10-30|TMAX |158.0|NULL |NULL |G |NULL |
|NZ000093844|1948-10-30|TMIN |87.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-10-31|TMAX |177.0|NULL |NULL |G |NULL |
|NZ000093844|1948-10-31|TMIN |104.0|NULL |NULL |G |NULL |
|NZ000093844|1948-11-01|TMAX |179.0|NULL |NULL |G |NULL |
|NZ000093844|1948-11-01|TMIN |88.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-11-02|TMAX |117.0|NULL |NULL |G |NULL |
|NZ000093844|1948-11-02|TMIN |-6.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-11-03|TMAX |143.0|NULL |NULL |G |NULL |
|NZ000093844|1948-11-03|TMIN |38.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-11-04|TMAX |175.0|NULL |NULL |G |NULL |
|NZ000093844|1948-11-04|TMIN |86.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-11-05|TMAX |135.0|NULL |NULL |G |NULL |
|NZ000093844|1948-11-05|TMIN |42.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-11-06|TMAX |139.0|NULL |NULL |G |NULL |
|NZ000093844|1948-11-06|TMIN |63.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-11-07|TMAX |199.0|NULL |NULL |G |NULL |
|NZ000093844|1948-11-07|TMIN |111.0|NULL |NULL |G |NULL |
|NZ000093844|1948-11-08|TMAX |238.0|NULL |NULL |G |NULL |
|NZ000093844|1948-11-08|TMIN |124.0|NULL |NULL |G |NULL |
|NZ000093844|1948-11-09|TMAX |161.0|NULL |NULL |G |NULL |
|NZ000093844|1948-11-09|TMIN |94.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-11-10|TMAX |144.0|NULL |NULL |G |NULL |
|NZ000093844|1948-11-10|TMIN |71.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-11-11|TMAX |121.0|NULL |NULL |G |NULL |
|NZ000093844|1948-11-11|TMIN |20.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-11-12|TMAX |131.0|NULL |NULL |G |NULL |
|NZ000093844|1948-11-12|TMIN |32.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-11-13|TMAX |128.0|NULL |NULL |G |NULL |
|NZ000093844|1948-11-13|TMIN |46.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-11-14|TMAX |122.0|NULL |NULL |G |NULL |
|NZ000093844|1948-11-14|TMIN |19.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-11-15|TMAX |138.0|NULL |NULL |G |NULL |
|NZ000093844|1948-11-15|TMIN |39.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-11-16|TMAX |111.0|NULL |NULL |G |NULL |
|NZ000093844|1948-11-16|TMIN |46.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-11-17|TMAX |133.0|NULL |NULL |G |NULL |
|NZ000093844|1948-11-17|TMIN |25.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-11-18|TMAX |209.0|NULL |NULL |G |NULL |
|NZ000093844|1948-11-18|TMIN |20.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-11-19|TMAX |191.0|NULL |NULL |G |NULL |
|NZ000093844|1948-11-19|TMIN |62.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-11-20|TMAX |169.0|NULL |NULL |G |NULL |
|NZ000093844|1948-11-20|TMIN |92.0 |NULL |NULL |G |NULL |
|NZ000093844|1948-11-21|TMAX |134.0|NULL |NULL |G |NULL |
|NZ000093844|1948-11-21|TMIN |74.0 |NULL |NULL |G |NULL |
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|NZ000093844|1948-11-22|TMAX  |142.0|NULL           |NULL       |G          |NULL           |
|NZ000093844|1948-11-22|TMIN  |29.0 |NULL           |NULL       |G          |NULL           |
|NZ000093844|1948-11-23|TMAX  |154.0|NULL           |NULL       |G          |NULL           |
|NZ000093844|1948-11-23|TMIN  |22.0 |NULL           |NULL       |G          |NULL           |
|NZ000093844|1948-11-24|TMAX  |134.0|NULL           |NULL       |G          |NULL           |
|NZ000093844|1948-11-24|TMIN  |-6.0 |NULL           |NULL       |G          |NULL           |
|NZ000093844|1948-11-25|TMAX  |180.0|NULL           |NULL       |G          |NULL           |
|NZ000093844|1948-11-25|TMIN  |6.0  |NULL           |NULL       |G          |NULL           |
|NZ000093844|1948-11-26|TMAX  |228.0|NULL           |NULL       |G          |NULL           |
|NZ000093844|1948-11-26|TMIN  |79.0 |NULL           |NULL       |G          |NULL           |
|NZ000093844|1948-11-27|TMAX  |150.0|NULL           |NULL       |G          |NULL           |
|NZ000093844|1948-11-27|TMIN  |0.0  |NULL           |NULL       |G          |NULL           |
|NZ000093844|1948-11-28|TMAX  |203.0|NULL           |NULL       |G          |NULL           |
|NZ000093844|1948-11-28|TMIN  |1.0  |NULL           |NULL       |G          |NULL           |
|NZ000093844|1948-11-29|TMAX  |201.0|NULL           |NULL       |G          |NULL           |
|NZ000093844|1948-11-29|TMIN  |64.0 |NULL           |NULL       |G          |NULL           |
|NZ000093844|1948-11-30|TMAX  |134.0|NULL           |NULL       |G          |NULL           |
|NZ000093844|1948-11-30|TMIN  |39.0 |NULL           |NULL       |G          |NULL           |
|NZ000093844|1948-12-01|TMAX  |117.0|NULL           |NULL       |G          |NULL           |
|NZ000093844|1948-12-01|TMIN  |44.0 |NULL           |NULL       |G          |NULL           |
|NZ000093844|1948-12-02|TMAX  |128.0|NULL           |NULL       |G          |NULL           |
|NZ000093844|1948-12-02|TMIN  |52.0 |NULL           |NULL       |G          |NULL           |
|NZ000093844|1948-12-03|TMAX  |147.0|NULL           |NULL       |G          |NULL           |
|NZ000093844|1948-12-03|TMIN  |92.0 |NULL           |NULL       |G          |NULL           |
|NZ000093844|1948-12-04|TMAX  |142.0|NULL           |NULL       |G          |NULL           |
|NZ000093844|1948-12-04|TMIN  |49.0 |NULL           |NULL       |G          |NULL           |
|NZ000093844|1948-12-05|TMAX  |172.0|NULL           |NULL       |G          |NULL           |
|NZ000093844|1948-12-05|TMIN  |82.0 |NULL           |NULL       |G          |NULL           |
|NZ000093844|1948-12-06|TMAX  |223.0|NULL           |NULL       |G          |NULL           |
|NZ000093844|1948-12-06|TMIN  |95.0 |NULL           |NULL       |G          |NULL           |
|NZ000093844|1948-12-07|TMAX  |177.0|NULL           |NULL       |G          |NULL           |
|NZ000093844|1948-12-07|TMIN  |82.0 |NULL           |NULL       |G          |NULL           |
|NZ000093844|1948-12-08|TMAX  |184.0|NULL           |NULL       |G          |NULL           |
|NZ000093844|1948-12-08|TMIN  |63.0 |NULL           |NULL       |G          |NULL           |
|NZ000093844|1948-12-09|TMAX  |150.0|NULL           |NULL       |G          |NULL           |
|NZ000093844|1948-12-09|TMIN  |7.0  |NULL           |NULL       |G          |NULL           |
|NZ000093844|1948-12-10|TMAX  |198.0|NULL           |NULL       |G          |NULL           |
|NZ000093844|1948-12-10|TMIN  |53.0 |NULL           |NULL       |G          |NULL           |
|NZ000093844|1948-12-11|TMAX  |243.0|NULL           |NULL       |G          |NULL           |
|NZ000093844|1948-12-11|TMIN  |115.0|NULL           |NULL       |G          |NULL           |
|NZ000093844|1948-12-12|TMAX  |198.0|NULL           |NULL       |G          |NULL           |
|NZ000093844|1948-12-12|TMIN  |144.0|NULL           |NULL       |G          |NULL           |
|NZ000093844|1948-12-13|TMAX  |189.0|NULL           |NULL       |G          |NULL           |
|NZ000093844|1948-12-13|TMIN  |77.0 |NULL           |NULL       |G          |NULL           |
|NZ000093844|1948-12-14|TMAX  |162.0|NULL           |NULL       |G          |NULL           |
|NZ000093844|1948-12-14|TMIN  |49.0 |NULL           |NULL       |G          |NULL           |
|NZ000093844|1948-12-15|TMAX  |128.0|NULL           |NULL       |G          |NULL           |
|NZ000093844|1948-12-15|TMIN  |56.0 |NULL           |NULL       |G          |NULL           |
|NZ000093844|1948-12-16|TMAX  |138.0|NULL           |NULL       |G          |NULL           |
|NZ000093844|1948-12-16|TMIN  |78.0 |NULL           |NULL       |G          |NULL           |
|NZ000093844|1948-12-17|TMAX  |172.0|NULL           |NULL       |G          |NULL           |
+-----------+----------+------+-----+---------------+-----------+-----------+---------------+
only showing top 400 rows
```

Data preparation for plot

```
pmonth_avg = (
    daily_nz_tmin_tmax.select("ID", "DATE", "ELEMENT", "VALUE")
    .withColumn("year", F.year("DATE"))
    .withColumn("month", F.month("DATE"))
    .groupBy("ID", "year", "month")
    .pivot("ELEMENT", ["TMIN", "TMAX"])
    .agg(F.avg("VALUE"))
    .withColumnRenamed("TMIN", "TMIN_avg")
    .withColumnRenamed("TMAX", "TMAX_avg")
)

show_as_html(pmonth_avg)
```

```
/opt/spark/python/pyspark/sql/pandas/conversion.py:111: UserWarning: toPandas attempted Arrow optimization because 'spark.sql.execution.arrow.
  PyArrow >= 4.0.0 must be installed; however, it was not found.
Attempting non-optimization as 'spark.sql.execution.arrow.pyspark.fallback.enabled' is set to true.
  warn(msg)
```

```
.dataframe tbody tr th {
    vertical-align: top;
}

.dataframe thead th {
    text-align: right;
}
```

ID	year	month	TMIN_avg	TMAX_avg
NZM00093439	2006	10	91.933333	151.346154
NZ000093417	2006	11	106.500000	168.400000
NZ000093417	2006	9	94.210526	148.892857
NZM00093439	2014	10	79.941176	164.827586
NZM00093110	2014	2	152.500000	246.464286
NZ000093012	2003	7	66.838710	151.935484
NZ000093994	2003	2	206.214286	261.285714
NZM00093439	2003	3	129.736842	210.344828
NZ000933090	1985	10	83.774194	162.193548
NZ000937470	1985	8	-15.225806	94.645161
NZM00093781	1985	6	-2.333333	125.333333
NZM00093781	1985	2	108.680000	238.333333
NZM00093781	1985	4	57.947368	194.500000
NZ000093292	1993	7	42.900000	133.366667
NZ000937470	1993	10	55.923077	185.538462
NZ000093994	1971	3	199.322581	238.709677
NZM00093781	1965	8	20.076923	72.000000
NZ000939450	1950	11	44.233333	95.333333
NZ000933090	1950	3	99.677419	202.419355
NZ000093844	1950	2	77.607143	179.178571

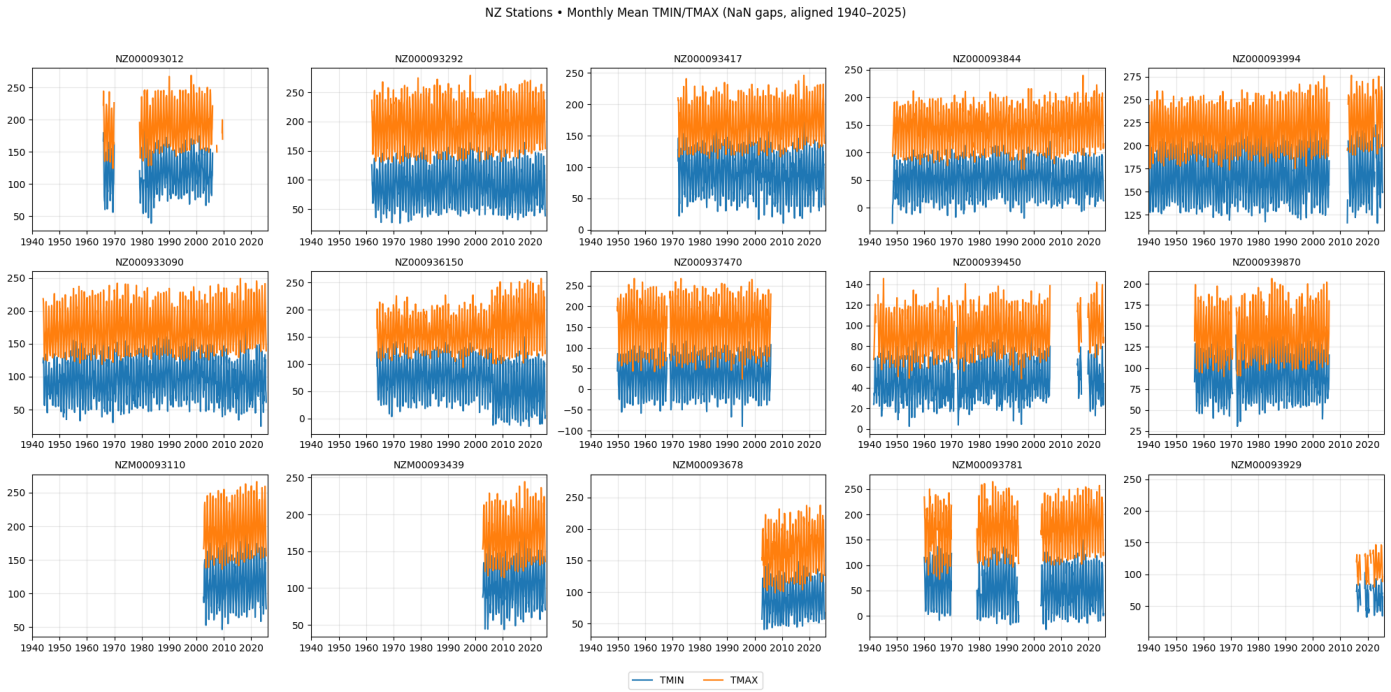
Plot monthly average TMIN, TMAX

```
# ===== 0) Spark→Pandas： =====
# first time run shoudl install PyArow to speed up .toPandas processing
# !pip install PyArrow
# spark.conf.set("spark.sql.execution.arrow.pyspark.enabled", "true")
pdf = pmonth_avg.toPandas()  # 列: ID, year, month, TMIN.avg, TMAX.avg
```

```
/opt/spark/python/pyspark/sql/pandas/conversion.py:111: UserWarning: toPandas attempted Arrow optimization because 'spark.sql.execution.arrow.
  PyArrow >= 4.0.0 must be installed; however, it was not found.
Attempting non-optimization as 'spark.sql.execution.arrow.pyspark.fallback.enabled' is set to true.
  warn(msg)
```

```
# get the first day in each month
pdf["month_start"] = pd.to_datetime(
    pdf["year"].astype(str) + "-" + pdf["month"].astype(str) + "-01",
    errors="coerce",  # if convertion fails, the time will be set to Nat(Not a time).
)

# Keep only the columns needed for plotting & optimize types
pdf = pdf[["ID", "month_start", "TMIN_avg", "TMAX_avg"]]
pdf["ID"] = pdf["ID"].astype("category")

# ===== 1) Alignment: reindex each station to a full monthly sequence (1940-01 ~ 2025-12) =====
# Missing months are kept as NaN so that gaps remain visible in the plots
full_index = pd.date_range("1940-01-01", "2025-12-01", freq="MS")  # Month Start


def reindex_station(g):
    g = g.set_index("month_start")[["TMIN_avg", "TMAX_avg"]].reindex(
        full_index
```

```
    )  # Fill missing months with NaN
    g.index.name = "month_start"
    return g


blocks = []
for sid, g in pdf.groupby("ID", observed=True):
    gg = reindex_station(g)
    gg["ID"] = sid
    blocks.append(gg.reset_index())

aligned = pd.concat(
    blocks, ignore_index=True
)  # Final columns: month_start, TMIN_avg, TMAX_avg, ID
aligned = aligned[["ID", "month_start", "TMIN_avg", "TMAX_avg"]]

# ===== 2) Select 15 stations to plot (default: first 15, or replace with custom IDs) =====
ids_all = aligned["ID"].astype("category").cat.categories.tolist()
ids_15 = ids_all[:15]  # Example customization: ids_15 = ["NZ000093012", "...", ...]

# ===== 3) Create 15 subplots (each station in its own axis, plot TMIN/TMAX with same x-range) =====
import matplotlib.pyplot as plt

nrows, ncols = 3, 5
fig, axes = plt.subplots(nrows=nrows, ncols=ncols, figsize=(20, 10), sharex=False)
axes = axes.ravel()

x_min = pd.Timestamp("1940-01-01")
x_max = pd.Timestamp("2025-12-31")

for ax, sid in zip(axes, ids_15):
    g = aligned[aligned["ID"] == sid]
    ax.plot(g["month_start"], g["TMIN_avg"], label="TMIN")
    ax.plot(g["month_start"], g["TMAX_avg"], label="TMAX")
    ax.set_title(str(sid), fontsize=10)
    ax.set_xlim(x_min, x_max)
    ax.grid(True, alpha=0.3)

# Hide unused subplots (in case there are fewer than 15 stations)
for k in range(len(ids_15), len(axes)):
    axes[k].axis("off")

# Add a shared legend and overall layout adjustments
handles, labels = axes[0].get_legend_handles_labels()
fig.legend(handles, labels, loc="lower center", ncol=2)

fig.suptitle(
    "NZ Stations • Monthly Mean TMIN/TMAX (NaN gaps, aligned 1940–2025)",
    y=0.98,
    fontsize=12,
)
fig.tight_layout(rect=[0, 0.04, 1, 0.96])
plt.show()

# Save figure
fig.savefig("./supplementary/nz_15stations_tmin_tmax_monthly_avg.png", dpi=300)
```



Plot yearly average

```
pyear_avg = (
    daily_nz_tmin_tmax.select("ID", "DATE", "ELEMENT", "VALUE")
    .withColumn("year", F.year("DATE"))
    .groupBy("ID", "year")
    .pivot("ELEMENT", ["TMIN", "TMAX"])
    .agg(F.avg("VALUE"))
    .withColumnRenamed("TMIN", "TMIN_avg")
    .withColumnRenamed("TMAX", "TMAX_avg")
)

show_as_html(pyear_avg)
```

```
/opt/spark/python/pyspark/sql/pandas/conversion.py:111: UserWarning: toPandas attempted Arrow optimization because 'spark.sql.execution.arrow.
  PyArrow >= 4.0.0 must be installed; however, it was not found.
Attempting non-optimization as 'spark.sql.execution.arrow.pyspark.fallback.enabled' is set to true.
  warn(msg)
```

```
.dataframe tbody tr th {
    vertical-align: top;
}

.dataframe thead th {
    text-align: right;
}
```

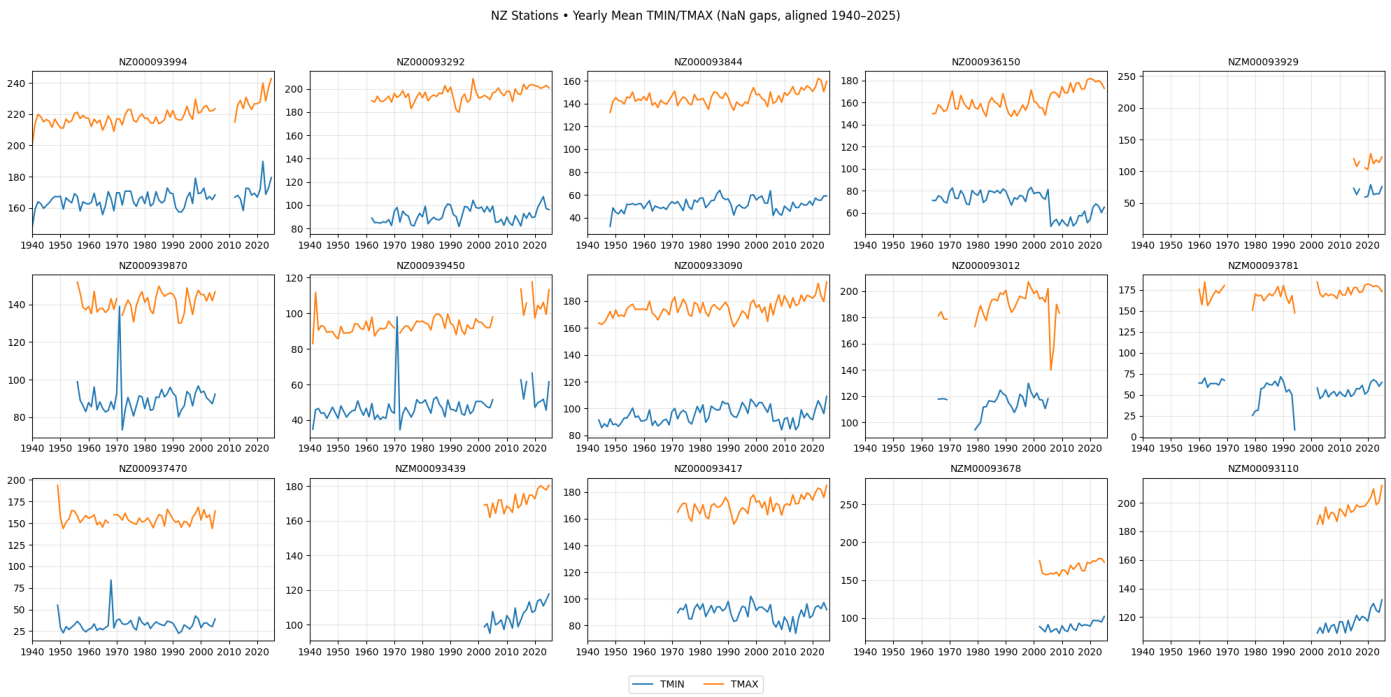
ID	year	TMIN_avg	TMAX_avg
NZ000093994	2019	169.269058	226.533742
NZ000093292	1999	98.085165	197.857534
NZ000093844	1991	51.408219	138.531507
NZM00093929	1994	13.000000	NaN
NZ000939450	2023	51.741697	106.269710
NZ000933090	2024	96.240741	179.644068
NZM00093929	2020	60.590909	102.609929
NZ000093012	1993	107.586301	186.632877
NZ000939870	1970	92.683824	143.194139
NZ000936150	1972	72.989071	154.704918

NZ000939450	1960	46.617486	95.576503
NZM00093929	2021	78.785714	127.712500
NZ000093012	1980	97.402597	181.987768
NZ000093012	1969	117.449367	178.551020
NZM00093439	2024	114.193309	177.675958
NZ000933090	1971	100.079452	183.115068
NZ000937470	1989	35.748603	160.530556
NZ000093844	1973	50.293151	142.676712
NZ000933090	1981	102.865385	178.986301
NZ000936150	1964	71.142077	149.901639

```
pdfy = pyear_avg.toPandas()
pdfy["ID"] = pdfy["ID"].astype("category")

# Create a datetime column representing the first day of each year
pdfy["year_start"] = pd.to_datetime(
    pdfy["year"].astype(str) + "-01-01", errors="coerce"
)

# Keep only the columns needed for plotting
pdfy = pdfy[["ID", "year_start", "TMIN_avg", "TMAX_avg"]]

# Full yearly index from 1940 to 2025 (one timestamp per year start)
full_years = pd.date_range("1940-01-01", "2025-01-01", freq="YS")


def reindex_station_year(g):
    # Reindex to the full yearly range; missing years become NaN
    g2 = g.set_index("year_start")[["TMIN_avg", "TMAX_avg"]].reindex(full_years)
    g2.index.name = "year_start"
    return g2


blocks = []
for sid, g in pdfy.groupby("ID", observed=True):
    gg = reindex_station_year(g)
    gg["ID"] = sid
    blocks.append(gg.reset_index())

aligned_year = pd.concat(blocks, ignore_index=True)
aligned_year = aligned_year[["ID", "year_start", "TMIN_avg", "TMAX_avg"]]


import matplotlib.pyplot as plt

# Select 15 stations (customize this list if needed)
ids_all = aligned_year["ID"].drop_duplicates().tolist()
ids_15 = ids_all[:15]

nrows, ncols = 3, 5
fig, axes = plt.subplots(nrows=nrows, ncols=ncols, figsize=(20, 10), sharex=False)
axes = axes.ravel()

x_min, x_max = pd.Timestamp("1940-01-01"), pd.Timestamp("2025-12-31")
# Optional: set a fixed y-axis for easier comparison across stations
# y_min, y_max = -5, 40

for ax, sid in zip(axes, ids_15):
    g = aligned_year[aligned_year["ID"] == sid]
    ax.plot(g["year_start"], g["TMIN_avg"], label="TMIN")
    ax.plot(g["year_start"], g["TMAX_avg"], label="TMAX")
    ax.set_title(str(sid), fontsize=10)
    ax.set_xlim(x_min, x_max)
    # ax.set_ylim(y_min, y_max)
    ax.grid(True, alpha=0.3)

# Hide unused subplots if fewer than 15 stations
for k in range(len(ids_15), len(axes)):
    axes[k].axis("off")

# Add a shared legend and adjust layout
handles, labels = axes[0].get_legend_handles_labels()
```

```
fig.legend(handles, labels, loc="lower center", ncol=2)
fig.suptitle(
    "NZ Stations • Yearly Mean TMIN/TMAX (NaN gaps, aligned 1940–2025)",
    y=0.98,
    fontsize=12,
)
fig.tight_layout(rect=[0, 0.04, 1, 0.96])
plt.show()

# Save figure
fig.savefig("./supplementary/nz_15stations_tmin_tmax_yearly_avg.png", dpi=300)
```

```
/opt/spark/python/pyspark/sql/pandas/conversion.py:111: UserWarning: toPandas attempted Arrow optimization because 'spark.sql.execution.arrow.
  PyArrow >= 4.0.0 must be installed; however, it was not found.
Attempting non-optimization as 'spark.sql.execution.arrow.pyspark.fallback.enabled' is set to true.
  warn(msg)
```



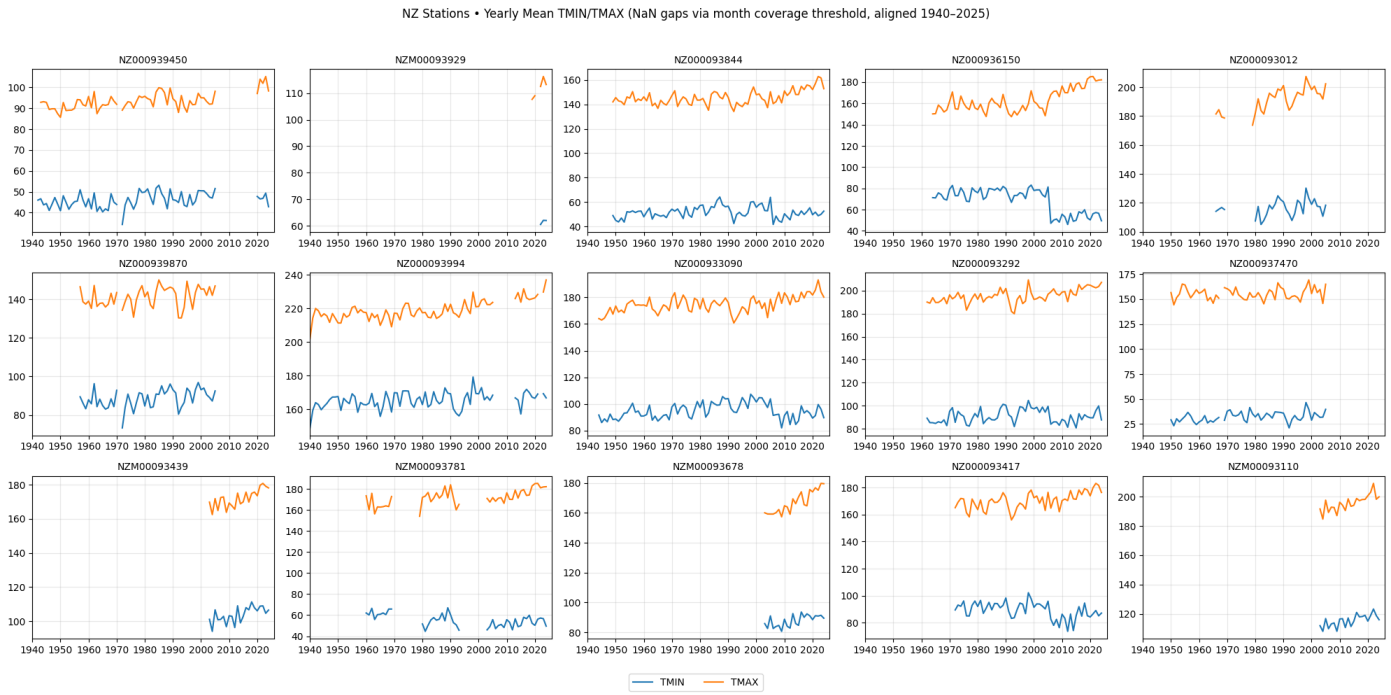
Plot yearly average, fillter out years that have less than 9 months data

```
# 0) Parameters
MIN_MONTHS = 9  # set to 10 if you want a stricter threshold
VALUE_IN_TENTHS = False  # set True if raw VALUE is in tenths of °C


# 1) Spark — null invalid yearly means (variant B)

# 1) Monthly means per (ID, ELEMENT, year, month)
monthly_means = (
    daily_nz_tmin_tmax.select("ID", "DATE", "ELEMENT", "VALUE")
    .withColumn("DATE", F.to_date("DATE"))
    .withColumn("year", F.year("DATE"))
    .withColumn("month", F.month("DATE"))
    .groupBy("ID", "ELEMENT", "year", "month")
    .agg(F.avg("VALUE").alias("monthly_mean"))
)

# 2) Yearly stats per (ID, ELEMENT, year): count months and average of monthly means
year_stats = (
    monthly_means.groupBy("ID", "ELEMENT", "year")
    .agg(
        F.count("*").alias("months_present"),
        F.avg("monthly_mean").alias("year_mean_raw"),
    )
    .withColumn(
        "year_mean",
        F.when(
            F.col("months_present") >= F.lit(MIN_MONTHS), F.col("year_mean_raw")
        ).otherwise(F.lit(None)),
    )
```

```
)

# 3) Pivot to wide format with NULLs where months_present < MIN_MONTHS
pyear_all = (
    year_stats.groupBy("ID", "year")
    .pivot("ELEMENT", ["TMIN", "TMAX"])
    .agg(F.first("year_mean"))
    .withColumnRenamed("TMIN", "TMIN_avg")
    .withColumnRenamed("TMAX", "TMAX_avg")
)

# (Optional) diagnostics: months_present by element, for QC or annotation
months_diag = (
    year_stats.groupBy("ID", "year")
    .pivot("ELEMENT", ["TMIN", "TMAX"])
    .agg(F.first("months_present"))
    .withColumnRenamed("TMIN", "TMIN_months")
    .withColumnRenamed("TMAX", "TMAX_months")
)

# Join diagnostics if you want them available downstream (safe to skip if not needed)
pyear_all = pyear_all.join(months_diag, on=["ID", "year"], how="left")


# 2) Pandas — align to full yearly index (1940–2025), keep NaN for gaps
import pandas as pd

spark.conf.set("spark.sql.execution.arrow.pyspark.enabled", "true")

pdfy = pyear_all.toPandas()

# Convert units if raw values are tenths of °C
if VALUE_IN_TENTHS:
    for col in ["TMIN_avg", "TMAX_avg"]:
        if col in pdfy.columns:
            pdfy[col] = pdfy[col] / 10.0

pdfy["ID"] = pdfy["ID"].astype("category")
pdfy["year_start"] = pd.to_datetime(
    pdfy["year"].astype(str) + "-01-01", errors="coerce"
)

# Keep only plotting columns (keep diagnostics if you want to annotate)
keep_cols = ["ID", "year_start", "TMIN_avg", "TMAX_avg"]
diag_cols = [c for c in ["TMIN_months", "TMAX_months"] if c in pdfy.columns]
pdfy = pdfy[keep_cols + diag_cols]

# Build full yearly index 1940–2025
full_years = pd.date_range("1940-01-01", "2025-01-01", freq="YS")


def reindex_station_year(g):
    g2 = g.set_index("year_start").reindex(full_years)
    g2.index.name = "year_start"
    return g2


blocks = []
for sid, g in pdfy.groupby("ID", observed=True):
    gg = reindex_station_year(g)
    gg["ID"] = sid
    blocks.append(gg.reset_index())

aligned_year = pd.concat(blocks, ignore_index=True)
aligned_year = aligned_year[["ID", "year_start", "TMIN_avg", "TMAX_avg"] + diag_cols]

# 3) Matplotlib — 15 subplots, TMIN/TMAX per station, aligned 1940–2025
import matplotlib.pyplot as plt

ids_all = aligned_year["ID"].drop_duplicates().tolist()
ids_15 = ids_all[:15]  # customize this selection if needed

nrows, ncols = 3, 5
fig, axes = plt.subplots(nrows=nrows, ncols=ncols, figsize=(20, 10), sharex=False)
axes = axes.ravel()

x_min, x_max = pd.Timestamp("1940-01-01"), pd.Timestamp("2025-12-31")
# Optional fixed y-limits for comparability across stations (adjust ranges as needed)
# y_min, y_max = -5, 40

for ax, sid in zip(axes, ids_15):
    g = aligned_year[aligned_year["ID"] == sid]
    ax.plot(g["year_start"], g["TMIN_avg"], label="TMIN")
```

```
    ax.plot(g["year_start"], g["TMAX_avg"], label="TMAX")
    ax.set_title(str(sid), fontsize=10)
    ax.set_xlim(x_min, x_max)
    # ax.set_ylim(y_min, y_max)
    ax.grid(True, alpha=0.3)

# Hide unused subplots if fewer than 15 stations
for k in range(len(ids_15), len(axes)):
    axes[k].axis("off")

# Shared legend and layout
handles, labels = axes[0].get_legend_handles_labels()
fig.legend(handles, labels, loc="lower center", ncol=2)
fig.suptitle(
    "NZ Stations • Yearly Mean TMIN/TMAX (NaN gaps via month coverage threshold, aligned 1940–2025)",
    y=0.98,
    fontsize=12,
)
fig.tight_layout(rect=[0, 0.04, 1, 0.96])

# Show and/or save
# plt.show()
fig.savefig(
    "./supplementary/nz_15stations_tmin_tmax_yearly_avg_filtered_null.png", dpi=300
)
```

```
/opt/spark/python/pyspark/sql/pandas/conversion.py:111: UserWarning: toPandas attempted Arrow optimization because 'spark.sql.execution.arrow.
  PyArrow >= 4.0.0 must be installed; however, it was not found.
Attempting non-optimization as 'spark.sql.execution.arrow.pyspark.fallback.enabled' is set to true.
  warn(msg)
```




```
nz_station_loc = stations_enriched.join(nz_station_ids, on="ID", how="inner")
show_as_html(nz_station_loc)
```

```
.dataframe tbody tr th {
    vertical-align: top;
}

.dataframe thead th {
    text-align: right;
}
```

ID	STATE	COUNTRY_CODE	LATITUDE	LONGITUDE	ELEVATION	NAME	GSN_FLAG	HCN_CRN	WMO_ID
NZ000936150		NZ	-42.717	170.983	40.0	HOKITIKA AERODROME			93781

NZ000937470		NZ	-44.517	169.900	488.0	TARA HILLS	GSN		93747
NZ000939870		NZ	-43.950	-176.567	49.0	CHATHAM ISLANDS AWS			93987
NZM00093781		NZ	-43.489	172.532	37.5	CHRISTCHURCH INTL			93781
NZ000093012		NZ	-35.100	173.267	54.0	KAITAIA			93119
NZ000093292		NZ	-38.650	177.983	5.0	GISBORNE AERODROME	GSN		93292
NZM00093110		NZ	-37.000	174.800	7.0	AUCKLAND AERO AWS			93110
NZ000093417		NZ	-40.900	174.983	7.0	PARAPARAUMU AWS	GSN		93420
NZ000933090		NZ	-39.017	174.183	32.0	NEW PLYMOUTH AWS	GSN		93309
NZ000093994		NZ	-29.250	-177.917	49.0	RAOUL ISL/KERMADEC			93997
NZ000939450		NZ	-52.550	169.167	19.0	CAMPBELL ISLAND AWS	GSN		93947
NZM00093439		NZ	-41.333	174.800	12.0	WELLINGTON AERO AWS			93439
NZM00093929		NZ	-50.483	166.300	40.0	ENDERBY ISLAND AWS			93929
NZ000093844		NZ	-46.417	168.333	2.0	INVERCARGILL AIRPOR	GSN		93845
NZM00093678		NZ	-42.417	173.700	101.0	KAIKOURA			93678

15 rows × 21 columns

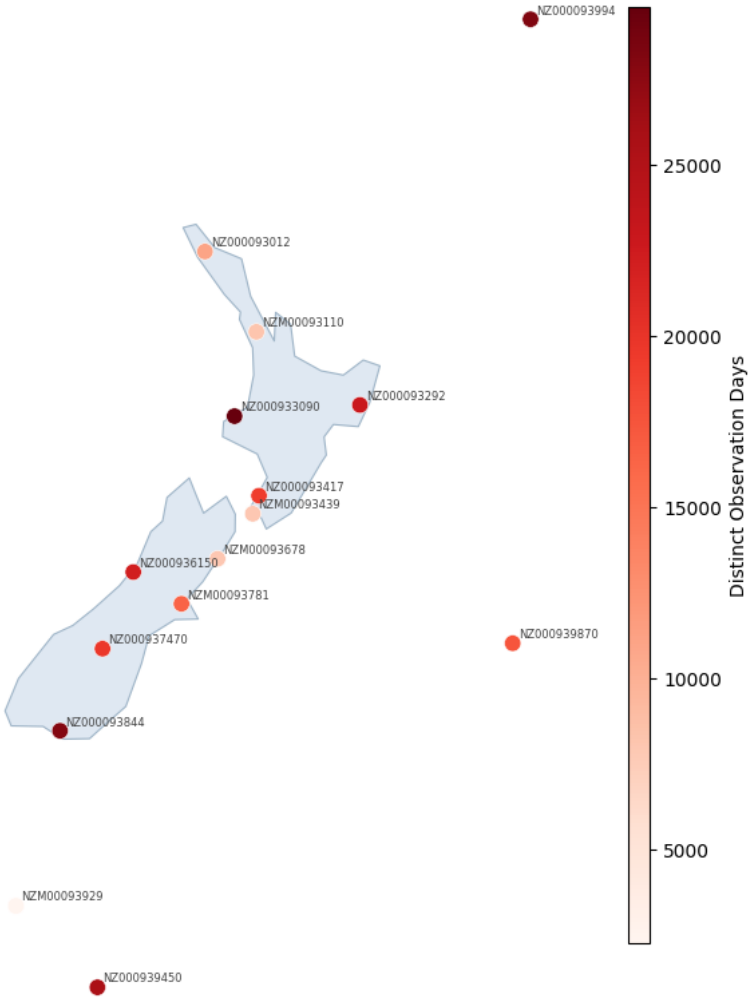
NZ Station location plot

```python
# === Imports ===
import geopandas as gpd
import matplotlib.pyplot as plt

# ------------------------------------------------------------
# 1) Station table (Spark → pandas)
# ------------------------------------------------------------
nz_pdf = nz_station_loc.select("ID", "LATITUDE", "LONGITUDE").toPandas()

# ------------------------------------------------------------
# 2) Count distinct observation days per station
#    (remove duplicated TMIN/TMAX records on the same day)
# ------------------------------------------------------------
obs_count_df = (
    daily_nz_tmin_tmax.filter(F.col("ELEMENT").isin("TMIN", "TMAX"))
    .select("ID", "DATE")  # keep only station and date
    .distinct()  # remove duplicate TMIN/TMAX for the same day
    .groupBy("ID")
    .agg(F.count("*").alias("obs_count"))
)

obs_count_pdf = obs_count_df.toPandas()

# ------------------------------------------------------------
# 3) Merge with station table & fill missing values
#    Ensure all 15 stations are included (fill NaN with 0)
# ------------------------------------------------------------
merged = pd.merge(nz_pdf, obs_count_pdf, on="ID", how="left")
merged["obs_count"] = merged["obs_count"].fillna(0).astype(int)

# print(f"Stations listed: {len(nz_pdf)}")
# print(f"Stations after merge: {len(merged)}")
# if merged["obs_count"].isna().any():
#     print("Warning: some stations still have NaN in obs_count.")
# missing_ids = set(nz_pdf["ID"]) - set(merged["ID"])
# if missing_ids:
#     print("Missing station IDs in merged:", missing_ids)

# ------------------------------------------------------------
# 4) Build GeoDataFrame (WGS84 → NZTM2000)
# ------------------------------------------------------------
gdf_pts = gpd.GeoDataFrame(
    merged,
    geometry=gpd.points_from_xy(merged["LONGITUDE"], merged["LATITUDE"]),
    crs="EPSG:4326",
)
gdf_pts_nztm = gdf_pts.to_crs(2193)

# Ensure all 15 stations are present
assert len(gdf_pts_nztm) == 15, f"Expected 15 stations, got {len(gdf_pts_nztm)}"

# ------------------------------------------------------------
```

```python
# 5) Load New Zealand polygon (Natural Earth) → NZTM2000
# ------------------------------------------------------------
world = gpd.read_file(gpd.datasets.get_path("naturalearth_lowres"))
nz_poly = world[world["name"] == "New Zealand"].to_crs(2193)

# ------------------------------------------------------------
# 6) Plotting (darker = more data → use 'Reds' colormap)
# ------------------------------------------------------------
fig, ax = plt.subplots(figsize=(8, 10))

# 6a) Base map
nz_poly.plot(ax=ax, facecolor="#dfe8f2", edgecolor="#9fb5c8", linewidth=0.8, zorder=0)

# 6b) Station points (color by obs_count)
vals = gdf_pts_nztm["obs_count"].to_numpy(dtype=float)
vmin = float(np.nanmin(vals))
vmax = float(np.nanmax(vals)) if np.nanmax(vals) > 0 else 1.0

gdf_pts_nztm.plot(
    ax=ax,
    column="obs_count",
    cmap="Reds",  # darker = more data
    markersize=80,
    linewidth=0.4,
    edgecolor="white",
    legend=False,
    vmin=vmin,
    vmax=vmax,
    zorder=1,
)

# 6c) Station labels
for _, r in gdf_pts_nztm.iterrows():
    if r.geometry is not None:
        ax.annotate(
            r["ID"],
            xy=(r.geometry.x, r.geometry.y),
            xytext=(3, 3),
            textcoords="offset points",
            fontsize=6,
            color="#404040",
        )

# 6d) Map extent & title
minx, miny, maxx, maxy = nz_poly.total_bounds
pad_x = (maxx - minx) * 0.5
pad_y = (maxy - miny) * 0.5
ax.set_xlim(minx - pad_x, maxx + pad_x)
ax.set_ylim(miny - pad_y, maxy + pad_y)
ax.set_axis_off()

ax.set_title(
    "Uneven Sample Sizes Across Stations (darker = more data): Implications for Nationwide Aggregation",
    fontsize=12,
)

# 6e) Standalone colorbar (right side)
cax = fig.add_axes([0.92, 0.15, 0.02, 0.7])
sm = plt.cm.ScalarMappable(cmap="Reds", norm=plt.Normalize(vmin=vmin, vmax=vmax))
sm._A = []
cbar = fig.colorbar(sm, cax=cax)
cbar.set_label("Distinct Observation Days", fontsize=10)
plt.savefig(
    "./supplementary/Uneven Sample Sizes Across Stations.png",
    dpi=300,
    bbox_inches="tight",
)
plt.show()
```

```
/tmp/ipykernel_53/3388839370.py:55: FutureWarning: The geopandas.dataset module is deprecated and will be removed in GeoPandas 1.0. You can ge
  world = gpd.read_file(gpd.datasets.get_path("naturalearth_lowres"))
```

Uneven Sample Sizes Across Stations (darker = more data): Implications for Nationwide Aggregation



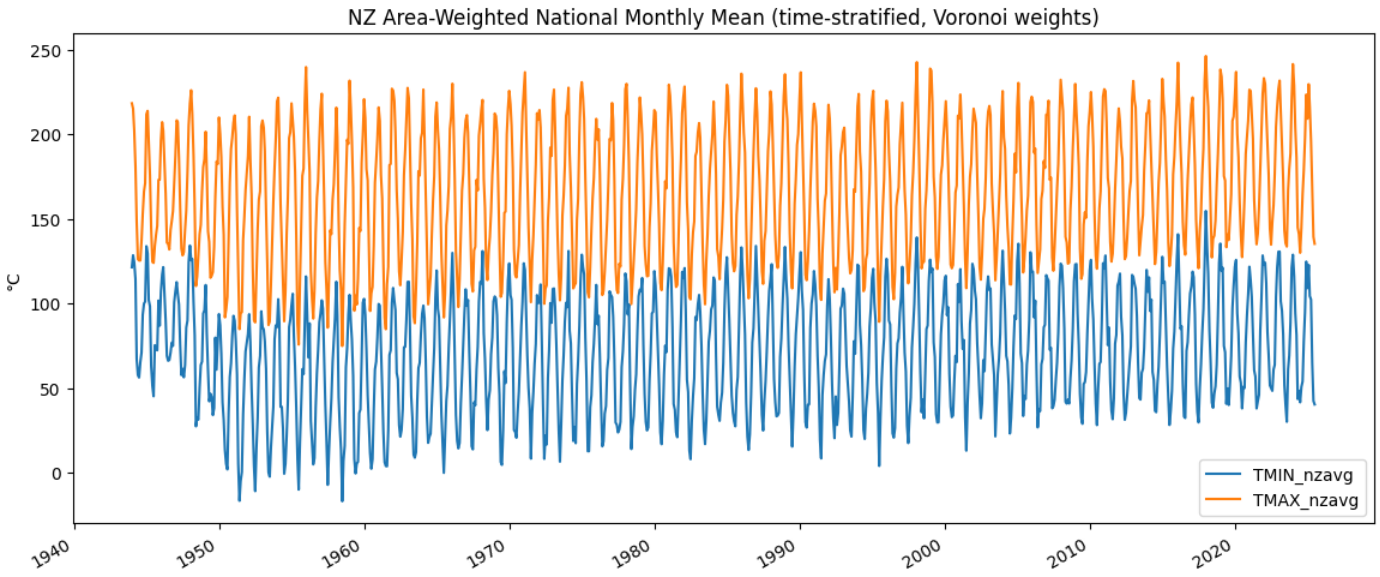
plot national region average TMIN TMAX

```
# ------------------------------------------------
# NZ monthly area-weighted national means for TMIN / TMAX
# Time stratification (by month) + Voronoi area weights + availability re-normalization
# ------------------------------------------------
#
# Algorithm overview & design considerations
# ------------------------------------------------
# Goal:
#   Estimate New Zealand's national monthly means for TMIN and TMAX using
#   (1) time stratification (aggregate by month),
#   (2) spatial weights from a Voronoi tessellation over station locations, and
#   (3) per-month availability re-normalization so that months with missing stations
#       are not biased toward the subset that happened to report.
#
# Inputs:
#   - daily_nz_tmin_tmax (Spark DataFrame): columns ID, DATE (yyyy-mm-dd), ELEMENT in {TMIN,TMAX}, VALUE
#   - nz_station_loc     (Spark DataFrame): columns ID, LATITUDE, LONGITUDE (WGS84)
#
# Steps:
#   1) Pivot daily data to wide (TMIN/TMAX columns), then convert to pandas and add a month_start key.
#   2) For each station-month, compute daily-count QC and the monthly averages of TMIN/TMAX.
#      A station-month is considered valid if days_present >= MIN_DAYS_PER_MONTH.
#   3) Build spatial weights once, independent of time:
#        - Project station points to NZTM (EPSG:2193).
#        - Extract the New Zealand polygon from Natural Earth and project to EPSG:2193.
#        - Build a Voronoi tessellation with the NZ polygon as the envelope.
#        - Clip Voronoi cells to the NZ polygon.
#        - Map each cell to its nearest station; sum cell areas per station to get area weights.
#        - Normalize areas to sum to 1 to get w_i.
#   4) Merge the weights into the station-month table.
#   5) For each month, compute an availability re-normalized weighted mean:
#        - Filter to valid station-months having both a value and weight.
```

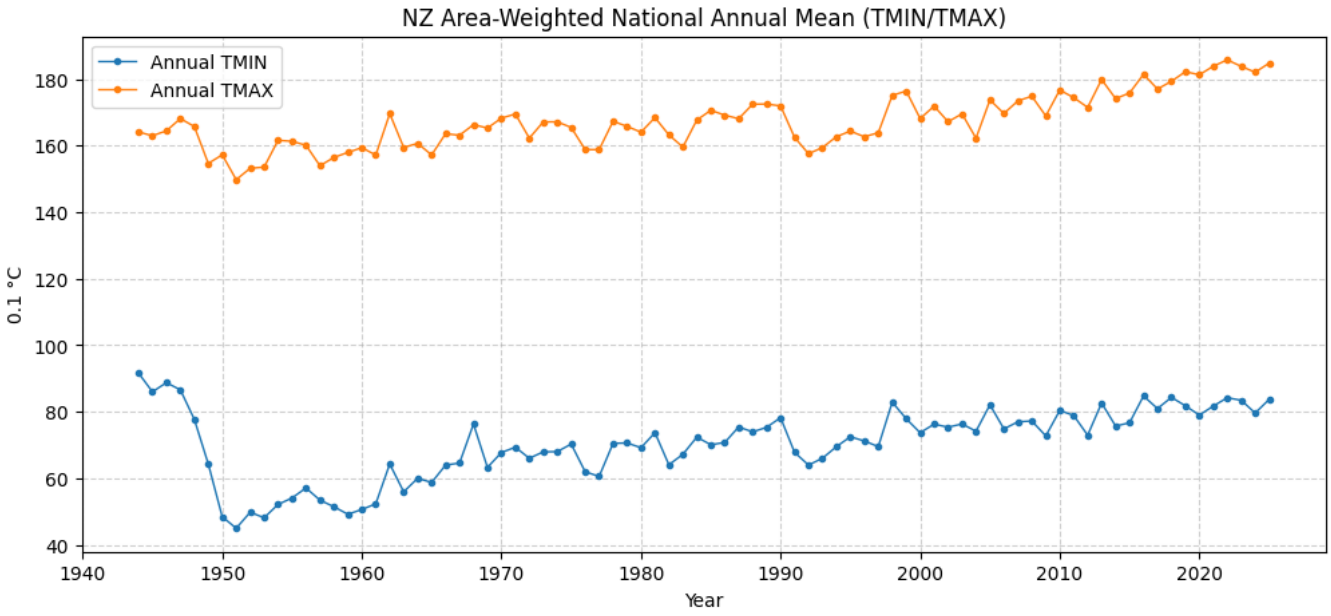
```
#        - Re-normalize the weights within that month so the subset of available stations sums to 1.
#        - Compute the weighted average for TMIN and TMAX separately.
#        - Record how many stations contributed in that month (n_used_*).
#
# Why Voronoi weights?
#   Voronoi area approximates each station's "zone of influence" given only point locations,
#   offering a simple, reproducible spatial weighting when gridded climatologies are unavailable.
#
# CRS & geometry notes:
#   - Areas are computed in EPSG:2193 (metres), so weights are physically meaningful.
#   - We use Natural Earth's New Zealand polygon as the clipping boundary. For production,
#     replace with a higher-resolution NZ boundary if desired.
#
# QC & robustness:
#   - MIN_DAYS_PER_MONTH guards against months with too few reports at a station.
#   - The availability re-normalization removes bias when some stations are missing in a month.
#   - If no valid stations exist in a month, the result is NaN.
#
# Caveats:
#   - Voronoi-based areal weighting assumes spatial representativeness of stations; complex terrain,
#     microclimates, and coastal effects are not explicitly modeled.
#   - Using Natural Earth boundaries may slightly mis-estimate coastal areas; swap in a better coastline if needed.
#   - If stations move or IDs represent changing locations, re-compute weights per epoch or resolve metadata first.
#
# Output:
#   - nz_monthly_avg (pandas DataFrame):
#       [month_start, TMIN_nzavg, TMAX_nzavg, n_used_TMIN, n_used_TMAX]
#   - A PNG figure saved to ./supplementary/National_monthly_TM_avg.png
# ------------------------------------------------

from shapely.ops import voronoi_diagram

# ========= 0) PARAMETERS =========
# Monthly validity threshold: a station-month is valid if it has at least this many daily observations
MIN_DAYS_PER_MONTH = 20

# ========= 1) LOAD / PREPARE TABULAR DATA =========
# daily_nz_tmin_tmax: Spark DataFrame with columns: ID, DATE (yyyy-mm-dd), ELEMENT in {TMIN,TMAX}, VALUE
# nz_station_loc:     Spark DataFrame with columns: ID, LATITUDE, LONGITUDE

daily_nz_tmin_tmax = spark.read.parquet(daily_nz_tmin_tmax_path)

daily_nz_tm_wide = (
    daily_nz_tmin_tmax.groupBy("ID", "DATE")
    .pivot("ELEMENT", ["TMIN", "TMAX"])
    .agg(F.first("VALUE"))
)

# Convert to pandas
daily_pdf = daily_nz_tm_wide.select("ID", "DATE", "TMIN", "TMAX").toPandas().copy()
stations_pdf = nz_station_loc.select("ID", "LATITUDE", "LONGITUDE").toPandas().copy()

# Parse dates & make month_start (month floor)
daily_pdf["DATE"] = pd.to_datetime(daily_pdf["DATE"])
daily_pdf["month_start"] = daily_pdf["DATE"].values.astype("datetime64[M]")

# ========= 2) STATION-MONTH AGGREGATION + QC =========
# Per-station per-month: mean TMIN/TMAX + number of distinct days present
monthly_station = daily_pdf.groupby(["ID", "month_start"], as_index=False).agg(
    TMIN_avg=("TMIN", "mean"),
    TMAX_avg=("TMAX", "mean"),
    days_present=("DATE", "nunique"),
)
monthly_station["is_valid"] = monthly_station["days_present"] >= MIN_DAYS_PER_MONTH

# ========= 3) VORONOI AREA WEIGHTS (SPATIAL) =========
# 3.1 Stations → GeoDataFrame (WGS84) and reproject to NZTM (EPSG:2193)
gdf_pts_wgs84 = gpd.GeoDataFrame(
    stations_pdf,
    geometry=gpd.points_from_xy(stations_pdf["LONGITUDE"], stations_pdf["LATITUDE"]),
    crs="EPSG:4326",
)
gdf_pts_2193 = gdf_pts_wgs84.to_crs(2193)

# 3.2 New Zealand polygon (Natural Earth) → EPSG:2193
world = gpd.read_file(gpd.datasets.get_path("naturalearth_lowres"))
nz_poly_2193 = world[world["name"] == "New Zealand"].to_crs(2193)
nz_envelope = nz_poly_2193.unary_union  # used as Voronoi envelope and for clipping

# 3.3 Voronoi tessellation on the NZ envelope
#     Note: shapely>=2.0 voronoi_diagram expects a MultiPoint / GeometryCollection
vor = voronoi_diagram(gdf_pts_2193.unary_union, envelope=nz_envelope)

```

```python
# Convert to GeoDataFrame and associate each cell with its nearest station
vor_gdf = gpd.GeoDataFrame(geometry=list(vor.geoms), crs=2193)

# Clip Voronoi cells to NZ boundary
vor_clip = gpd.overlay(vor_gdf, nz_poly_2193, how="intersection")

# Join each cell to the nearest station (each cell corresponds to one nearest station)
# Requires a spatial index (pygeos or rtree) to be installed for performance.
cell_to_station = vor_clip.sjoin_nearest(gdf_pts_2193[["ID", "geometry"]], how="left")
cell_to_station = cell_to_station.rename(columns={"ID": "ID"})

# 3.4 Compute area weights (aggregate: a station can own multiple clipped fragments)
cell_to_station["area"] = cell_to_station.geometry.area
weights_df = (
    cell_to_station.groupby("ID", as_index=False)["area"]
    .sum()
    .rename(columns={"area": "area_total"})
)

# Normalize to get per-station weights w_i (sum to 1 over all stations)
weights_df["w"] = weights_df["area_total"] / weights_df["area_total"].sum()

# ========= 4) MERGE WEIGHTS WITH STATION-MONTH TABLE =========
aligned = monthly_station.merge(weights_df[["ID", "w"]], on="ID", how="left")


# ========= 5) TIME-STRATIFIED, AVAILABILITY RE-NORMALIZED MEAN =========
def weighted_mean_in_month(g, col):
    """
    Compute the re-normalized Voronoi-weighted mean for a single month.
    g: rows for one month
    col: 'TMIN_avg' or 'TMAX_avg'
    Returns (value, n_used) where n_used is the number of contributing stations.
    """
    g_valid = g[g["is_valid"] & g[col].notna() & g["w"].notna()]
    if g_valid.empty:
        return np.nan, 0
    w_norm = g_valid["w"] / g_valid["w"].sum()
    val = np.sum(w_norm * g_valid[col].to_numpy())
    return val, len(g_valid)


rows = []
for month, g in aligned.groupby("month_start"):
    tmin_val, n_tmin = weighted_mean_in_month(g, "TMIN_avg")
    tmax_val, n_tmax = weighted_mean_in_month(g, "TMAX_avg")
    rows.append(
        {
            "month_start": month,
            "TMIN_nzavg": tmin_val,
            "TMAX_nzavg": tmax_val,
            "n_used_TMIN": n_tmin,
            "n_used_TMAX": n_tmax,
        }
    )

nz_monthly_avg = pd.DataFrame(rows).sort_values("month_start").reset_index(drop=True)

# ========= 6) OPTIONAL: PLOT =========
import matplotlib.pyplot as plt

fig, ax = plt.subplots(figsize=(14, 6))
ax.plot(nz_monthly_avg["month_start"], nz_monthly_avg["TMIN_nzavg"], label="TMIN_nzavg")
ax.plot(nz_monthly_avg["month_start"], nz_monthly_avg["TMAX_nzavg"], label="TMAX_nzavg")
ax.set_title(
    "NZ Area-Weighted National Monthly Mean (time-stratified, Voronoi weights)"
)
ax.set_ylabel("°C")
ax.legend()
fig.autofmt_xdate()

# Save a copy (adjust path as needed)
plt.savefig("./supplementary/National_monthly_TM_avg.png", dpi=300, bbox_inches="tight")
plt.show()

# Final table:
#   nz_monthly_avg → columns:
#     [month_start, TMIN_nzavg, TMAX_nzavg, n_used_TMIN, n_used_TMAX]
```

```
/tmp/ipykernel_53/224542698.py:108: FutureWarning: The geopandas.dataset module is deprecated and will be removed in GeoPandas 1.0. You can ge
  world = gpd.read_file(gpd.datasets.get_path("naturalearth_lowres"))
```




```python
# ========= 7) AGGREGATE TO ANNUAL MEANS =========
# Add year column
nz_monthly_avg["year"] = nz_monthly_avg["month_start"].dt.year

# For each year, compute mean TMIN/TMAX across valid months
nz_annual_avg = nz_monthly_avg.groupby("year", as_index=False).agg(
    TMIN_nzavg=("TMIN_nzavg", "mean"),
    TMAX_nzavg=("TMAX_nzavg", "mean"),
    n_used_TMIN=("n_used_TMIN", "sum"),
    n_used_TMAX=("n_used_TMAX", "sum"),
)

# ========= 8) PLOT ANNUAL MEANS =========
fig, ax = plt.subplots(figsize=(12, 5))
ax.plot(
    nz_annual_avg["year"],
    nz_annual_avg["TMIN_nzavg"],
    marker="o",
    markersize=3,
    linewidth=1,
    label="Annual TMIN",
)
ax.plot(
    nz_annual_avg["year"],
    nz_annual_avg["TMAX_nzavg"],
    marker="o",
    markersize=3,
    linewidth=1,
    label="Annual TMAX",
)
ax.set_title("NZ Area-Weighted National Annual Mean (TMIN/TMAX)")
ax.set_ylabel("0.1 °C")
ax.set_xlabel("Year")
ax.legend()
plt.grid(True, linestyle="--", alpha=0.6)

plt.savefig("./supplementary/National_annual_TM_avg.png", dpi=300, bbox_inches="tight")
plt.show()

# Final table: nz_annual_avg → [year, TMIN_nzavg, TMAX_nzavg, n_used_TMIN, n_used_TMAX]
```



Precipitation Plot

PRCP station stats

```
# when processed, directly load from cloud.
daily_prcp = (
    daily.filter(F.col("ELEMENT") == "PRCP")
    .select(["ID", "DATE", "VALUE"])
    .withColumn("DATE", F.to_date(F.col("DATE"), "yyyyMMdd"))
    .withColumnRenamed("VALUE", "PRCP_VALUE")
    .withColumn("year", F.year("DATE"))
)

prcp_stations = daily_prcp.join(
    F.broadcast(stations_enriched.filter(F.col("PRCP") == "1")),
    on="ID",
    how="left",
).withColumnRenamed("NAME", "STATION_NAME")

show_as_html(prcp_stations)
```

```
.dataframe tbody tr th {
    vertical-align: top;
}

.dataframe thead th {
    text-align: right;
}
```

ID	DATE	PRCP_VALUE	year	STATE	COUNTRY_CODE	LATITUDE	LONGITUDE	ELEVATION	STATION_NAME
ASN00030018	2008-01-01	0.0	2008		AS	-18.2922	143.5483	291.7	GEORGETOWN POST OFFICE
ASN00030019	2008-01-01	0.0	2008		AS	-19.2647	143.6741	536.0	GILBERTON
ASN00030021	2008-01-01	0.0	2008		AS	-20.7389	144.4853	430.0	GLENDOWER STATION
ASN00030022	2008-01-01	0.0	2008		AS	-20.8192	144.2333	316.4	HUGHENDEN AIRPORT
ASN00030025	2008-01-01	0.0	2008		AS	-20.8528	144.2258	320.0	HUGHENDEN STATION
ASN00030009	2008-01-01	0.0	2008		AS	-20.0078	144.8992	722.4	CARGOON STATION
ASN00029121	2008-01-01	0.0	2008		AS	-20.5958	139.6939	280.0	WEST LEICHHARDT STATION
ASN00029123	2008-01-01	0.0	2008		AS	-20.5833	139.5767	330.0	LAKE MOONDARRA
ASN00029126	2008-01-01	0.0	2008		AS	-20.7361	139.4817	381.0	MOUNT ISA MINE
ASN00029127	2008-01-01	0.0	2008		AS	-20.6778	139.4875	340.3	MOUNT ISA AERO

ASN00029129	2008-01-01	0.0	2008		AS	-21.2150	140.2333	282.0	DEVONCOURT STATION
ASN00029130	2008-01-01	0.0	2008		AS	-20.9542	139.5861	339.0	MIM RIFLE CREEK
ASN00029131	2008-01-01	0.0	2008		AS	-20.0200	139.8433	190.0	GERETA STATION
ASN00029132	2008-01-01	0.0	2008		AS	-20.6556	142.1006	120.0	MANFRED DOWNS STATION
ASN00029136	2008-01-01	0.0	2008		AS	-21.3661	140.4986	300.0	FARLEY STATION
ASN00029137	2008-01-01	0.0	2008		AS	-19.6661	141.3961	100.0	NUMIL DOWNS STATION
ASN00029139	2008-01-01	180.0	2008		AS	-17.1142	139.5981	4.0	SWEERS ISLAND
ASN00029141	2008-01-01	0.0	2008		AS	-20.6664	140.5050	186.0	CLONCURRY AIRPORT
ASN00029144	2008-01-01	0.0	2008		AS	-20.4350	141.5481	120.0	KESWICK STATION
ASN00029150	2008-01-01	0.0	2008		AS	-20.8422	141.4292	150.0	MALVIE DOWNS STATION

20 rows × 24 columns

```
prcp_pdf = (
    prcp_stations.groupBy("year", "COUNTRY_CODE","COUNTRY_NAME")
    .agg(F.avg("PRCP_VALUE").alias("PRCP_yavg"))
    .orderBy("PRCP_yavg")
)


show_as_html(prcp_pdf)

# when needed, make next line run.
# prcp_pdf.write.mode("overwrite").parquet(prcp_pdf_path)
```

```
# when needed, make next line run.
# prcp_pdf.write.mode("overwrite").parquet(prcp_pdf_path)
!hdfs dfs -ls -h {prcp_pdf_path}
```

```
Found 2 items
-rw-r--r--   1 yxi75 supergroup          0 2025-09-14 07:29 wasbs://campus-user@madsstorage002.blob.core.windows.net/yxi75/prcp_pdf_parquet/_S
-rw-r--r--   1 yxi75 supergroup    194.3 K 2025-09-14 07:29 wasbs://campus-user@madsstorage002.blob.core.windows.net/yxi75/prcp_pdf_parquet/pa
```

```
prcp_pdf = spark.read.parquet(prcp_pdf_path)
prcp_pdf.cache()
show_as_html(prcp_pdf)
```

```
.dataframe tbody tr th {
    vertical-align: top;
}

.dataframe thead th {
    text-align: right;
}
```

year	COUNTRY_CODE	COUNTRY_NAME	PRCP_yavg
1874	UK	United Kingdom	-1.076712
2021	WQ	Wake Island [United States]	0.000000
2021	VE	Venezuela	0.000000
2021	AE	United Arab Emirates	0.000000
2021	BG	Bangladesh	0.000000
2002	MV	Maldives	0.000000
2002	CK	Cocos (Keeling) Islands [Australia]	0.000000
2020	WQ	Wake Island [United States]	0.000000
2004	BM	Burma	0.000000
2004	MV	Maldives	0.000000

2004	KT	Christmas Island [Australia]	0.000000
2004	LI	Liberia	0.000000
2001	SB	Saint Pierre and Miquelon [France]	0.000000
1990	MC	Macau S.A.R	0.000000
1990	BM	Burma	0.000000
1988	KU	Kuwait	0.000000
1988	QA	Qatar	0.000000
1988	MC	Macau S.A.R	0.000000
1978	CK	Cocos (Keeling) Islands [Australia]	0.000000
1978	AE	United Arab Emirates	0.000000

```
# Calculate summary statistics from the global precipitation average dataframe
prcp_stats = prcp_pdf.agg(
    F.countDistinct("COUNTRY_CODE").alias("unique_country_codes"),
    F.count("*").alias("total_rows"),
    F.countDistinct("YEAR").alias("unique_years"),
).collect()[0]

# Print the summary statistics with improved, more informative output strings
print(f"Number of unique countries: {prcp_stats['unique_country_codes']}")
print(f"Total number of records: {prcp_stats['total_rows']}")
print(f"Number of years in the dataset: {prcp_stats['unique_years']}")
```

```
[Stage 732:=====================================================>(106 + 1) / 107]

There are 17731 PRCP records.
```

```
prcp_pdf = prcp_pdf.orderBy(F.asc("PRCP_yavg")).toPandas()
```

```
# Calculate descriptive statistics grouped by year and country
stats_by_year_country = prcp_pdf.groupby(["year", "COUNTRY_NAME"])[
    "PRCP_yavg"
].describe()

# Display grouped statistics
print("Descriptive statistics for average rainfall by year and country:")
print(stats_by_year_country)

# Calculate and display overall descriptive statistics
overall_stats = prcp_pdf["PRCP_yavg"].describe()
print("\nOverall average rainfall descriptive statistics:")
print(overall_stats)
```

```
Descriptive statistics for average rainfall by year and country:
                                    count        mean  std         min  \
year COUNTRY_NAME
1750 Australia                        1.0   23.187021  NaN   23.187021
1781 Germany                          1.0   24.558904  NaN   24.558904
1782 Germany                          1.0   13.712329  NaN   13.712329
1783 Germany                          1.0   17.832877  NaN   17.832877
1784 Germany                          1.0   16.576503  NaN   16.576503
...                                   ...         ...  ...         ...
2025 Virgin Islands [United States]   1.0   27.814272  NaN   27.814272
     Wake Island [United States]      1.0   21.909091  NaN   21.909091
     Wallis and Futuna [France]       1.0  151.692308  NaN  151.692308
     Zambia                           1.0   59.500000  NaN   59.500000
     Zimbabwe                         1.0   54.647668  NaN   54.647668

                                         25%         50%         75%  \
year COUNTRY_NAME
1750 Australia                     23.187021   23.187021   23.187021
1781 Germany                       24.558904   24.558904   24.558904
1782 Germany                       13.712329   13.712329   13.712329
1783 Germany                       17.832877   17.832877   17.832877
1784 Germany                       16.576503   16.576503   16.576503
...                                      ...         ...         ...
2025 Virgin Islands [United States] 27.814272   27.814272   27.814272
     Wake Island [United States]    21.909091   21.909091   21.909091
```

```
      Wallis and Futuna [France]       151.692308  151.692308  151.692308
      Zambia                            59.500000   59.500000   59.500000
      Zimbabwe                          54.647668   54.647668   54.647668

                                             max
year COUNTRY_NAME
1750 Australia                          23.187021
1781 Germany                            24.558904
1782 Germany                            13.712329
1783 Germany                            17.832877
1784 Germany                            16.576503
...                                           ...
2025 Virgin Islands [United States]     27.814272
     Wake Island [United States]        21.909091
     Wallis and Futuna [France]        151.692308
     Zambia                             59.500000
     Zimbabwe                           54.647668

[17726 rows x 8 columns]

Overall average rainfall descriptive statistics:
count    17731.000000
mean        44.393026
std        198.491195
min         -1.076712
25%         15.557789
50%         25.204204
75%         48.160650
max      15875.000000
Name: PRCP_yavg, dtype: float64
```

```
# the highest average rainfll in a single year country
max_prcp = prcp_pdf.loc[prcp_pdf.PRCP_yavg == prcp_pdf.PRCP_yavg.max()]
print(max_prcp)
```

```
       year COUNTRY_CODE COUNTRY_NAME  PRCP_yavg
17730  1952         None         None    15875.0
```

```
# how many prcp recorded stations are there?
# stations:127610 /129657 (prcp num/total num)
prcp_station_ids = daily_prcp.select("ID").distinct()
prcp_station_ids_count = prcp_station_ids.count()
print(f"There are {prcp_station_ids_count} stations which recored PRCP value.")
```

```
[Stage 13:=============================================================>(106 + 1) / 107]

There are 127610 stations which recored PRCP value.
```

```
# how many countries are these prcp stations distributed?
# countries: 218/219 ((prcp num/total num))
prcp_station_country_count = prcp_stations.select("COUNTRY_NAME").distinct().count()
print(f"These 127610 PRCP stations distribute in {prcp_station_country_count} countries.")
```

outliers study

```
show_as_html(prcp_pdf)
```

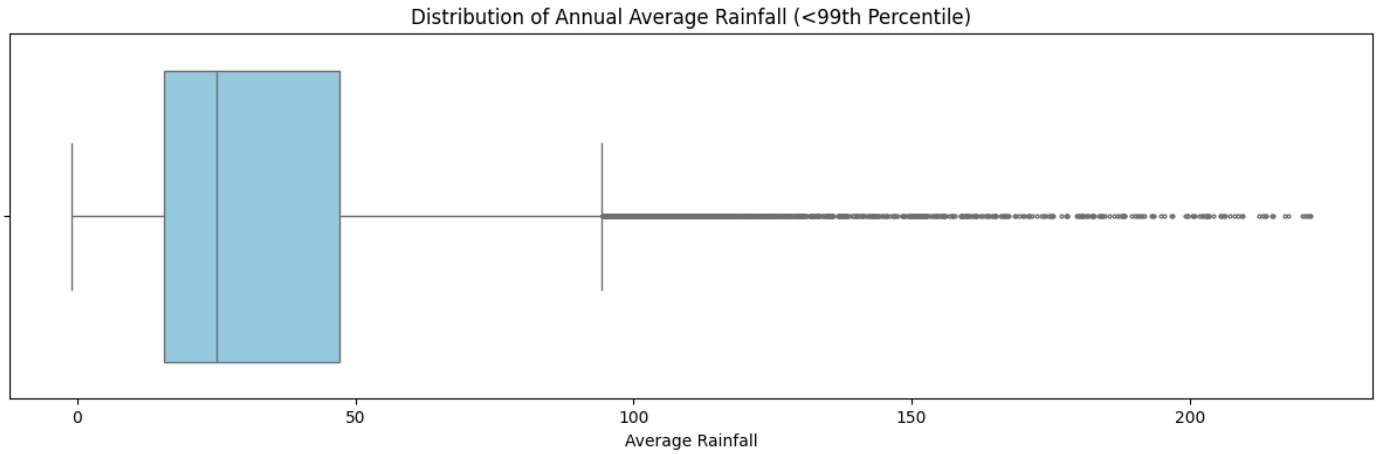
```
.dataframe tbody tr th {
    vertical-align: top;
}

.dataframe thead th {
    text-align: right;
}
```

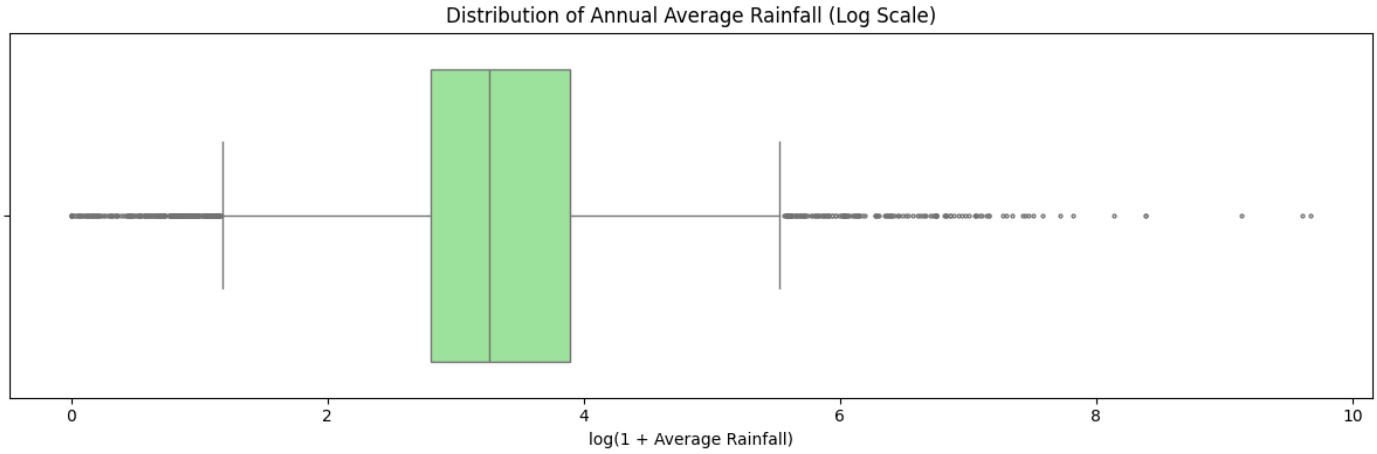
year	COUNTRY_CODE	COUNTRY_NAME	PRCP_yavg
1874	UK	United Kingdom	-1.076712
2021	WQ	Wake Island [United States]	0.000000

2021	VE	Venezuela	0.000000
2021	AE	United Arab Emirates	0.000000
2021	BG	Bangladesh	0.000000
2002	MV	Maldives	0.000000
2002	CK	Cocos (Keeling) Islands [Australia]	0.000000
2020	WQ	Wake Island [United States]	0.000000
2004	BM	Burma	0.000000
2004	MV	Maldives	0.000000
2004	KT	Christmas Island [Australia]	0.000000
2004	LI	Liberia	0.000000
2001	SB	Saint Pierre and Miquelon [France]	0.000000
1990	MC	Macau S.A.R	0.000000
1990	BM	Burma	0.000000
1988	KU	Kuwait	0.000000
1988	QA	Qatar	0.000000
1988	MC	Macau S.A.R	0.000000
1978	CK	Cocos (Keeling) Islands [Australia]	0.000000
1978	AE	United Arab Emirates	0.000000

```
import matplotlib.pyplot as plt
import seaborn as sns
import numpy as np

# Use the PRCP_yavg column from prcp_pdf
data = (
    prcp_pdf
    .select("PRCP_yavg")
    .where(F.col("PRCP_yavg").isNotNull())
    .toPandas()["PRCP_yavg"]
)

# Threshold for clipping (99th percentile)
clip_threshold = np.percentile(data, 99)

# Create figure with 2 subplots (stacked vertically)
fig, axes = plt.subplots(2, 1, figsize=(12, 8))

# --- (A) Boxplot with clipping (focus on bulk distribution) ---
sns.boxplot(
    x=data[data < clip_threshold],
    ax=axes[0],
    color="skyblue",
    fliersize=2
)
axes[0].set_title("Distribution of Annual Average Rainfall (<99th Percentile)")
axes[0].set_xlabel("Average Rainfall")

# --- (B) Boxplot with log scale (full data, outliers compressed) ---
sns.boxplot(
    x=np.log1p(data),  # log(1+x) transform
    ax=axes[1],
    color="lightgreen",
    fliersize=2
)
axes[1].set_title("Distribution of Annual Average Rainfall (Log Scale)")
axes[1].set_xlabel("log(1 + Average Rainfall)")

plt.tight_layout()

plt.savefig("./supplementary/annual_PRCP_outlier_bboxplot.png",dpi=220)
plt.show()
```

```
/usr/local/lib/python3.8/dist-packages/pandas/core/arraylike.py:402: RuntimeWarning: invalid value encountered in log1p
  result = getattr(ufunc, method)(*inputs, **kwargs)
```






```
prcp_pdf[prcp_pdf.PRCP_yavg < 0]
```

```
.dataframe tbody tr th {
    vertical-align: top;
}

.dataframe thead th {
    text-align: right;
}
```

year	COUNTRY_CODE	COUNTRY_NAME	PRCP_yavg
1874	UK	United Kingdom	-1.076712

Global Station Location View

```
prcp_pdf
```

```
.dataframe tbody tr th {
    vertical-align: top;
}

.dataframe thead th {
    text-align: right;
}
```

year	COUNTRY_CODE	COUNTRY_NAME	PRCP_yavg
1874	UK	United Kingdom	-1.076712

2021	WQ	Wake Island [United States]	0.000000
2021	VE	Venezuela	0.000000
2021	AE	United Arab Emirates	0.000000
2021	BG	Bangladesh	0.000000
...	...	...	...
1951	None	None	4359.000000
2000	EK	Equatorial Guinea	4361.000000
1949	None	None	9271.000000
1950	None	None	14827.250000
1952	None	None	15875.000000

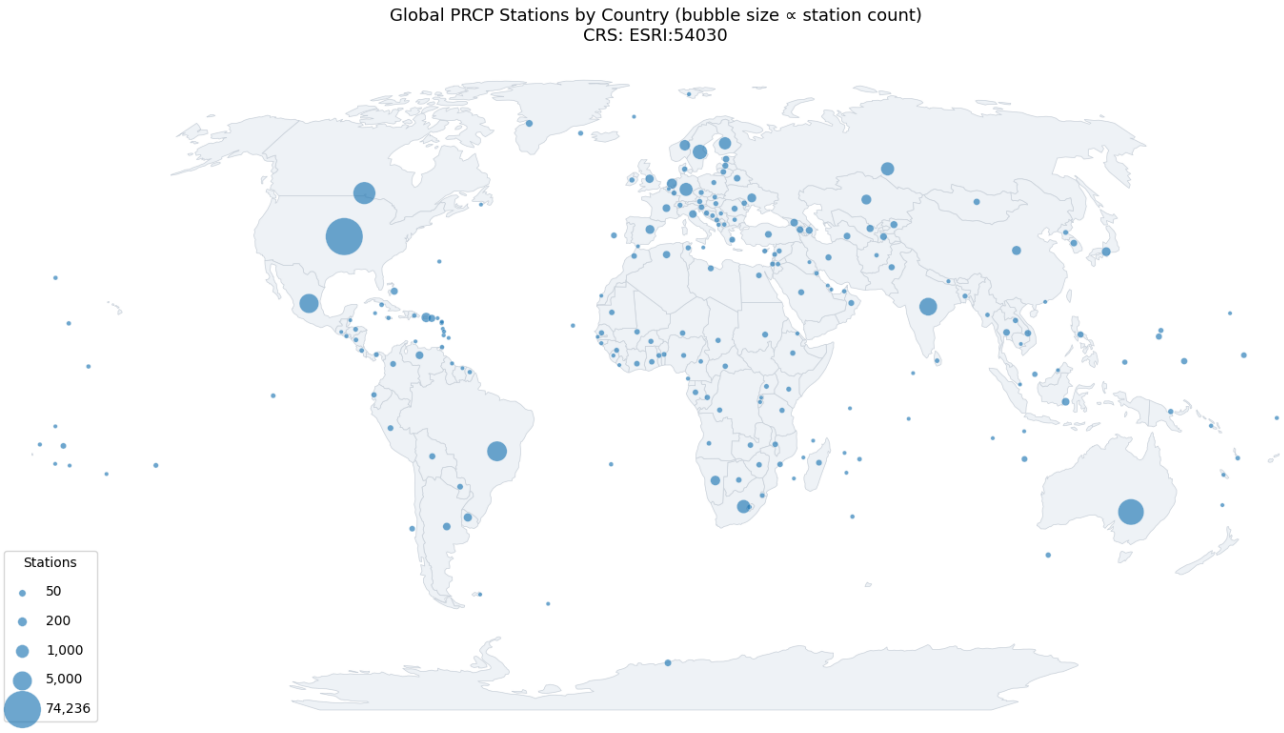
17731 rows × 4 columns

```python
# ============================================
# Bubble map: PRCP stations per country
# (Spark aggregates → 218 rows → Pandas → plot)
# ============================================

import math
import pandas as pd
import geopandas as gpd
import matplotlib.pyplot as plt
from pyspark.sql import functions as F

# 1) Spark: 国家级聚合（每站只计一次，计算数量与国家“代表点”）
country_agg = (
    prcp_stations
    .select("ID", "COUNTRY_CODE", "LATITUDE", "LONGITUDE")
    .dropna()
    .filter((F.col("LATITUDE").between(-90, 90)) & (F.col("LONGITUDE").between(-180, 180)))
    .dropDuplicates(["ID"])  # 避免同一站多次计入
    .groupBy("COUNTRY_CODE")
    .agg(
        F.count("*").alias("station_count"),
        F.avg("LATITUDE").alias("avg_lat"),
        F.avg("LONGITUDE").alias("avg_lon"),
    )
)

# 2) 收集到 Pandas（只有 ~218 行）
bubble_df = country_agg.toPandas()
```

```python
# 3) 世界底图（WGS84）
world = gpd.read_file(gpd.datasets.get_path("naturalearth_lowres")).to_crs(4326)

# 4) 把国家代表点做成 GeoDataFrame（WGS84）
bubbles = gpd.GeoDataFrame(
    bubble_df,
    geometry=gpd.points_from_xy(bubble_df["avg_lon"], bubble_df["avg_lat"]),
    crs="EPSG:4326"
)

# 5) 可选：投影到 Robinson（观感更好）；失败则保持 4326
target_crs = "ESRI:54030"
try:
    world_proj = world.to_crs(target_crs)
    bubbles_proj = bubbles.to_crs(target_crs)
except Exception:
    target_crs = "EPSG:4326"
    world_proj = world
    bubbles_proj = bubbles

# 6) 气泡大小（按平方根缩放，保证视觉面积接近线性）
c = bubbles_proj["station_count"].astype(float)
c_min, c_max = float(c.min()), float(c.max())
# 你可以调 min/max_size 来控制视觉效果
min_size, max_size = 10, 800  # matplotlib scatter 的 s 是面积像素
if c_max > 0:
    s = min_size + (max_size - min_size) * (c.pow(0.5) - math.sqrt(max(1.0, c_min))) / (math.sqrt(c_max) - math.sqrt(max(1.0, c_min)))
    s = s.clip(lower=min_size)
else:
    s = pd.Series([min_size] * len(c))
```

```python

# 7) 绘图
fig, ax = plt.subplots(figsize=(16, 8))
world_proj.plot(ax=ax, color="#eef2f6", edgecolor="#c9d1da", linewidth=0.5, zorder=0)

# 国家代表点（按站点数大小）
bubbles_proj.plot(
    ax=ax,
    markersize=s,     # 比例符号
    alpha=0.65,
    color="#1f77b4",
    edgecolor="white",
    linewidth=0.3,
    zorder=2,
)

ax.set_axis_off()
ax.set_title(
    f"Global PRCP Stations by Country (bubble size ∝ station count)\nCRS: {target_crs}",
    fontsize=13
)

# 8) 自定义气泡图例（计算 5 个分级刻度（对数刻度更均匀））
legend_vals = [50, 200, 1_000, 5_000, int(c_max)]

for legend_val in legend_vals:
    if legend_val <= 0 or legend_val > c_max:
        continue
    # 用同样的缩放公式计算面积
    area = min_size + (max_size - min_size) * (
        (math.sqrt(legend_val) - math.sqrt(max(1.0, c_min)))
        / (math.sqrt(c_max) - math.sqrt(max(1.0, c_min)))
    )
    plt.scatter([], [], s=area, color="#1f77b4", alpha=0.65,
                edgecolors="white", linewidths=0.3, label=f"{legend_val:,}")

leg = ax.legend(
    scatterpoints=1,
    frameon=True,
    labelspacing=1.2,
    title="Stations",
    loc="lower left",
    bbox_to_anchor=(0.02, 0.02),
)
leg.get_title().set_fontsize(10)

plt.tight_layout()
plt.savefig("./supplementary/global_prcp_stations_bubble.png", dpi=300, bbox_inches="tight")
plt.show()

# 9) 导出聚合表
out_csv = "./supplementary/prcp_station_country_bubbles.csv"
bubbles[["COUNTRY_CODE", "station_count", "avg_lat", "avg_lon"]].to_csv(out_csv, index=False)
print("Saved:", out_csv)
```

```
/tmp/ipykernel_56/3098757670.py:2: FutureWarning: The geopandas.dataset module is deprecated and will be removed in GeoPandas 1.0. You can get
  world = gpd.read_file(gpd.datasets.get_path("naturalearth_lowres")).to_crs(4326)
```




```
Saved: ./supplementary/prcp_station_country_bubbles.csv
```

PRCP Global Map

```python
# ============================================================
# 2024各国平均降水：FIPS10-6→ISO3映射（自动补齐）+ Choropleth
# 输出：
#   1) ./supplementary/fips_to_iso3_completed.csv    （完整映射）
#   2) ./supplementary/precip_2024_by_country.csv    （各国均值）
#   3) ./supplementary/precip_2024_choropleth.png    （地图）
# ============================================================

import os, math, json
import pandas as pd
import geopandas as gpd
import matplotlib.pyplot as plt
from pyspark.sql import functions as F

# ---------- Spark 设置（Arrow提速） ----------
spark.conf.set("spark.sql.execution.arrow.pyspark.enabled", "true")

# ---------- 0) 基础FIPS→ISO3字典（常见+高频；其余自动补全） ----------
FIPS_TO_ISO3_BASE = {
    # 常见主权国家（示例，非穷举；其余会自动补齐）
    "AF": "AFG","AL": "ALB","AG": "DZA","AN": "AND","AO": "AGO","AC": "ATG","AR": "ARG","AM": "ARM",
    "AS": "AUS","AU": "AUT","AJ": "AZE",
    "BA": "BHS","BG": "BGD","BB": "BRB","BO": "BEL","BF": "BFA","BU": "BGR","BN": "BEN","BD": "BMU",
    "BT": "BTN","BL": "BOL","BK": "BIH","BC": "BWA","BR": "BRA","BX": "BRN","BUK":"MMR",  # BU=保加利亚，BUK=缅甸（旧称Burma）
    "BY": "BLR","BZ": "BLZ",
    "CB": "KHM","CM": "CMR","CA": "CAN","CV": "CPV","CJ": "CYM","CT": "CAF","CD": "TCD","CI": "CHL",
    "CH": "CHN","CO": "COL","CN": "COM","CF": "COG","CW": "COG","CS": "CRI","IV": "CIV","HR": "HRV",
    "CU": "CUB","CY": "CYP","EZ": "CZE",
    "DA": "DNK","DJ": "DJI","DO": "DMA","DR": "DOM",
    "EC": "ECU","EG": "EGY","ES": "SLV","EK": "GNQ","ER": "ERI","EN": "EST","ET": "ETH",
    "FK": "FLK","FJ": "FJI","FI": "FIN","FR": "FRA",
    "GB": "GAB","GA": "GMB","GG": "GEO","GM": "DEU","GH": "GHA","GI": "GIB","GR": "GRC","GL": "GRL",
    "GJ": "GRD","GT": "GTM","GV": "GIN","PU": "GNB","GY": "GUY",
    "HA": "HTI","HO": "HND","HU": "HUN",
    "IC": "ISL","IN": "IND","ID": "IDN","IR": "IRN","IZ": "IRQ","EI": "IRL","IS": "ISR","IT": "ITA",
    "JM": "JAM","JA": "JPN","JO": "JOR",
    "KZ": "KAZ","KE": "KEN","KR": "KIR","KN": "KWT",
    "LA": "LAO","LG": "LVA","LE": "LBN","LT": "LSO","LI": "LBR","LY": "LBY","LS": "LIE","LH": "LTU",
    "LU": "LUX",
    "MK": "MDG","MI": "MWI","MY": "MYS","MV": "MDV","ML": "MLI","MT": "MLT","RM": "FSM","MR": "MRT",
    "MU": "MUS","MX": "MEX","MD": "MDA","MN": "MCO","MG": "MNG","MJ": "MNE","MO": "MAR","MZ": "MOZ",
    "WA": "NAM","NR": "NRU","NP": "NPL","NL": "NLD","NC": "NZL","NU": "NIU","NI": "NER","NG": "NGA",
    "NO": "NOR",
    "MUQ":"OMN","PK": "PAK","PS": "PLW","PM": "PAN","PP": "PNG","PA": "PRY","PE": "PER","RP": "PHL",
```

```
    "PL": "POL","PO": "PRT",
    "QA": "QAT",
    "RO": "ROU","RS": "RUS","RW": "RWA",
    "SC": "KNA","ST": "LCA","VC": "VCT","WS": "WSM","SM": "SMR","TP": "STP","SA": "SAU","SG": "SEN",
    "RI": "SRB","SE": "SYC","SL": "SLE","SN": "SGP","LO": "SVK","SI": "SVN","BP": "SOM","SF": "ZAF",
    "OD": "SSD","SP": "ESP","CE": "LKA","SU": "SDN","NS": "SUR","SV": "SWE","SZ": "CHE","SY": "SYR",
    "TW": "TWN","TI": "TJK","TZ": "TZA","TH": "THA","TT": "TLS","TO": "TGO","TN": "TUN","TU": "TUR",
    "TX": "TKM","TV": "TUV",
    "UG": "UGA","UP": "UKR","AE": "ARE","UK": "GBR","US": "USA","UY": "URY","UZ": "UZB",
    "NH": "VUT","VE": "VEN","VM": "VNM",
    "YM": "YEM",
    "ZA": "ZMB","ZI": "ZWE",

    # 常见属地/地区（部分库会并到主权国；此处给出常用ISO3便于merge）
    "AQ": "ATA",  # Antarctica
    "BXM": "MAC", # Macau（若你的数据用MO/MAC，按需调整）
    "HK": "HKG",
    "FO": "FRO","GLP":"GLP","GP":"GLP","GF":"GUF","PF":"PYF","NCY":"NCL",
    "RE": "REU","PFY":"PYF","GI": "GIB",
}
```

```
# ---------- 1) 用Spark聚合 2024 年国家平均降水 ----------
# 假设你已有 daily_prcp：列 [ID, DATE(yyyy-mm-dd), PRCP_VALUE, year]
# 以及 prcp_stations：列 [ID, COUNTRY_CODE, LATITUDE, LONGITUDE, ...]
# Define schma for Daily
stations_enriched = spark.read.parquet(stations_enriched_savepath)
daily_schema = StructType(
    [
        StructField("ID", StringType(), nullable=False),
        StructField("DATE", StringType(), nullable=False),
        StructField("ELEMENT", StringType(), nullable=False),
        StructField("VALUE", FloatType(), nullable=False),
        StructField("MEASUREMENT_FLAG", StringType(), nullable=True),
        StructField("QUALITY_FLAG", StringType(), nullable=True),
        StructField("SOURCE_FLAG", StringType(), nullable=True),
        StructField("OBSERVATION_TIME", StringType(), nullable=True),
    ]
)

# load daily and check daily schema for later join parameter on = ""
daily = spark.read.csv(paths["daily"], schema=daily_schema)

daily_prcp = (
    daily.filter(F.col("ELEMENT") == "PRCP")
    .select(["ID", "DATE", "VALUE"])
    .withColumn("DATE", F.to_date(F.col("DATE"), "yyyyMMdd"))
    .withColumnRenamed("VALUE", "PRCP_VALUE")
    .withColumn("year", F.year("DATE"))
)

prcp_stations = daily_prcp.join(
    F.broadcast(stations_enriched.filter(F.col("PRCP") == "1")),
    on="ID",
    how="left",
).withColumnRenamed("NAME", "STATION_NAME")

prcp_2024 = (
    daily_prcp
    .filter(F.col("year") == 2024)
    .select("ID", "PRCP_VALUE")
    .groupBy("ID")
    .agg(F.avg("PRCP_VALUE").alias("PRCP_2024_station_avg"))
)

# 连接国家代码（只需要ID→COUNTRY_CODE）
station_country = prcp_stations.select("ID", "COUNTRY_CODE").dropna().dropDuplicates(["ID"])

country_avg_2024 = (
    prcp_2024.join(station_country, on="ID", how="inner")
    .groupBy("COUNTRY_CODE")
    .agg(F.avg("PRCP_2024_station_avg").alias("PRCP_2024_country_avg"),
         F.countDistinct("ID").alias("n_stations_2024"),
         F.avg("PRCP_2024_station_avg").alias("check_same"))  # 冗余校验
)

# 拉到 pandas（只有 ~218 行）
avg_pdf = country_avg_2024.toPandas()
```

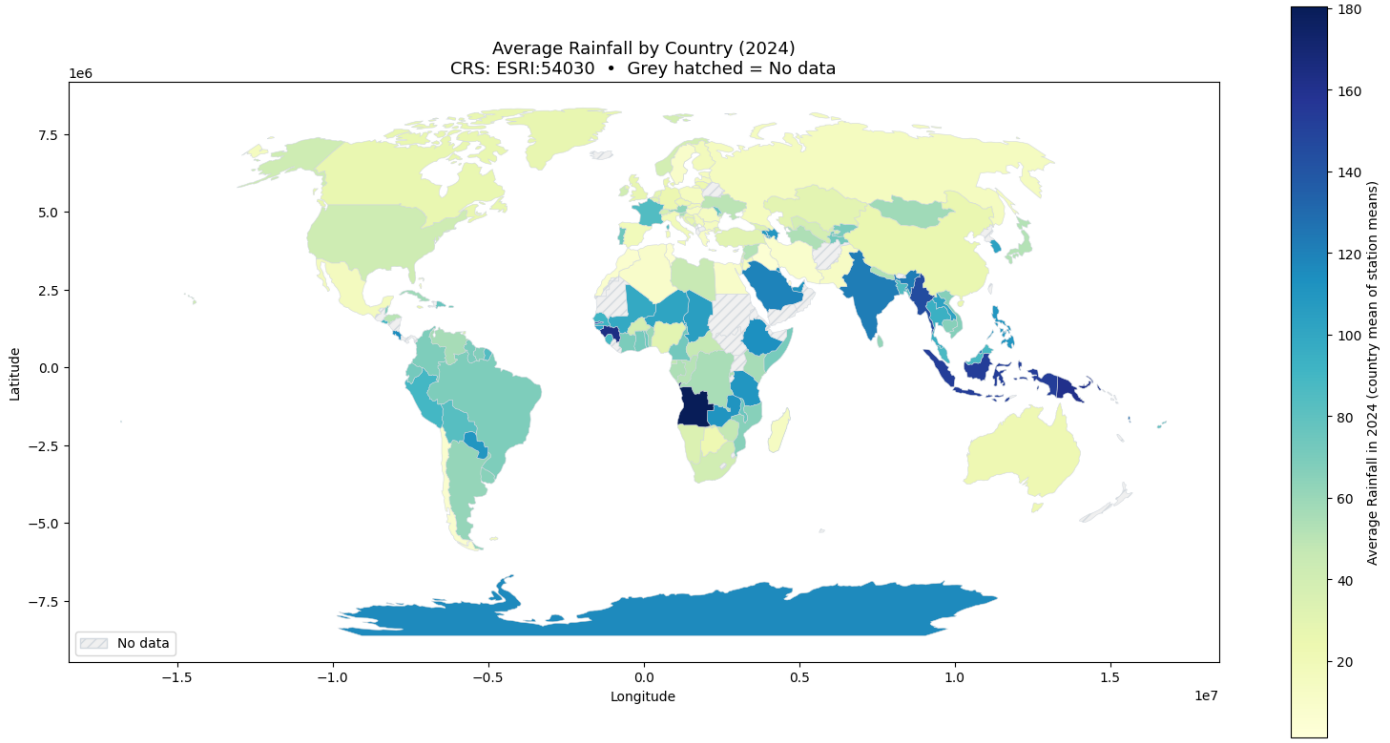
```
# ---------- 2) 先用基础字典做FIPS→ISO3映射 ----------
```

```
avg_pdf["iso_a3"] = avg_pdf["COUNTRY_CODE"].map(FIPS_TO_ISO3_BASE)

# ---------- 3) 对未映射成功的FIPS，做“轻量空间补齐”（每FIPS取站点平均坐标→落国界） ----------
need_fill = avg_pdf[avg_pdf["iso_a3"].isna()]["COUNTRY_CODE"].unique().tolist()

if len(need_fill) > 0:
    # 为这些FIPS计算代表点（该FIPS内所有站点的经纬度均值）
    fips_reps = (
        prcp_stations
        .select("COUNTRY_CODE", "LATITUDE", "LONGITUDE")
        .where(F.col("COUNTRY_CODE").isin(need_fill))
        .groupBy("COUNTRY_CODE")
        .agg(F.avg("LATITUDE").alias("avg_lat"), F.avg("LONGITUDE").alias("avg_lon"))
        .toPandas()
    )

    # 点→GeoDataFrame（WGS84）
    reps_gdf = gpd.GeoDataFrame(
        fips_reps,
        geometry=gpd.points_from_xy(fips_reps["avg_lon"], fips_reps["avg_lat"]),
        crs="EPSG:4326"
    )
    # 世界底图（WGS84）
    world = gpd.read_file(gpd.datasets.get_path("naturalearth_lowres")).to_crs(4326)
    world = world[~world["iso_a3"].isin(["-99"])][["iso_a3", "name", "geometry"]]

    # 空间匹配（点落国家多边形）
    reps_joined = gpd.sjoin(reps_gdf, world, how="left", predicate="within")
    # 生成补齐映射
    filled_map = dict(zip(reps_joined["COUNTRY_CODE"], reps_joined["iso_a3"]))

    # 合并到基础字典
    FIPS_TO_ISO3_COMPLETED = {**FIPS_TO_ISO3_BASE, **filled_map}
else:
    FIPS_TO_ISO3_COMPLETED = FIPS_TO_ISO3_BASE.copy()

# 应用完整映射
avg_pdf["iso_a3"] = avg_pdf["iso_a3"].fillna(avg_pdf["COUNTRY_CODE"].map(FIPS_TO_ISO3_COMPLETED))

# 落盘保存完整映射（便于复现）
os.makedirs("./supplementary", exist_ok=True)
pd.Series(FIPS_TO_ISO3_COMPLETED).rename("ISO3").to_csv(
    "./supplementary/fips_to_iso3_completed.csv", header=True
)

# ---------- 4) 与世界底图合并并绘图（No data 灰色） ----------
world = gpd.read_file(gpd.datasets.get_path("naturalearth_lowres")).to_crs(4326)
world = world[~world["iso_a3"].isin(["-99"])]

# 合并（左表为世界底图，确保无观测国家也在图上）
world_join = world.merge(
    avg_pdf[["iso_a3", "PRCP_2024_country_avg", "n_stations_2024"]],
    on="iso_a3", how="left"
)

# 导出表
world_join[["iso_a3", "name", "PRCP_2024_country_avg", "n_stations_2024"]]\
    .to_csv("./supplementary/precip_2024_by_country.csv", index=False)

# 选择投影（Robinson观感好；失败则保持WGS84）
target_crs = "ESRI:54030"
try:
    world_plot = world_join.to_crs(target_crs)
except Exception:
    target_crs = "EPSG:4326"
    world_plot = world_join
```

```
# 绘图（无观测国家灰色）
fig, ax = plt.subplots(figsize=(16, 8))
world_plot.plot(
    ax=ax,
    column="PRCP_2024_country_avg",
    cmap="YlGnBu",
    legend=True,
    legend_kwds={"label": "Average Rainfall in 2024 (country mean of station means)"},
    edgecolor="#d3d9df",
    linewidth=0.4,
    missing_kwds={"color": "#f0f0f0", "edgecolor": "#d3d9df", "hatch": "///", "label": "No data"},
)
# ax.set_axis_off()
ax.set_title(
    "Average Rainfall by Country (2024)\n"
```

```
    f"CRS: {target_crs}  •  Grey hatched = No data",
    fontsize=13
)

# display longitude and latitude axis
ax.set_xlabel("Longitude")
ax.set_ylabel("Latitude")

# 给“无数据”加图例项（有的版本会自动，有的需要手动补）
handles, labels = ax.get_legend_handles_labels()
if "No data" not in labels:
    from matplotlib.patches import Patch
    handles.append(Patch(facecolor="#f0f0f0", edgecolor="#d3d9df", hatch="///", label="No data"))
    ax.legend(handles=handles, loc="lower left")

plt.tight_layout()
plt.savefig("./supplementary/precip_2024_choropleth.png", dpi=220, bbox_inches="tight")
plt.show()

print("✓ Saved mapping to ./supplementary/fips_to_iso3_completed.csv")
print("✓ Saved country table to ./supplementary/precip_2024_by_country.csv")
print("✓ Saved map to ./supplementary/precip_2024_choropleth.png")
```

```
/tmp/ipykernel_44/1411382327.py:25: UserWarning: Legend does not support handles for PatchCollection instances.
See: https://matplotlib.org/stable/tutorials/intermediate/legend_guide.html#implementing-a-custom-legend-handler
  handles, labels = ax.get_legend_handles_labels()
```

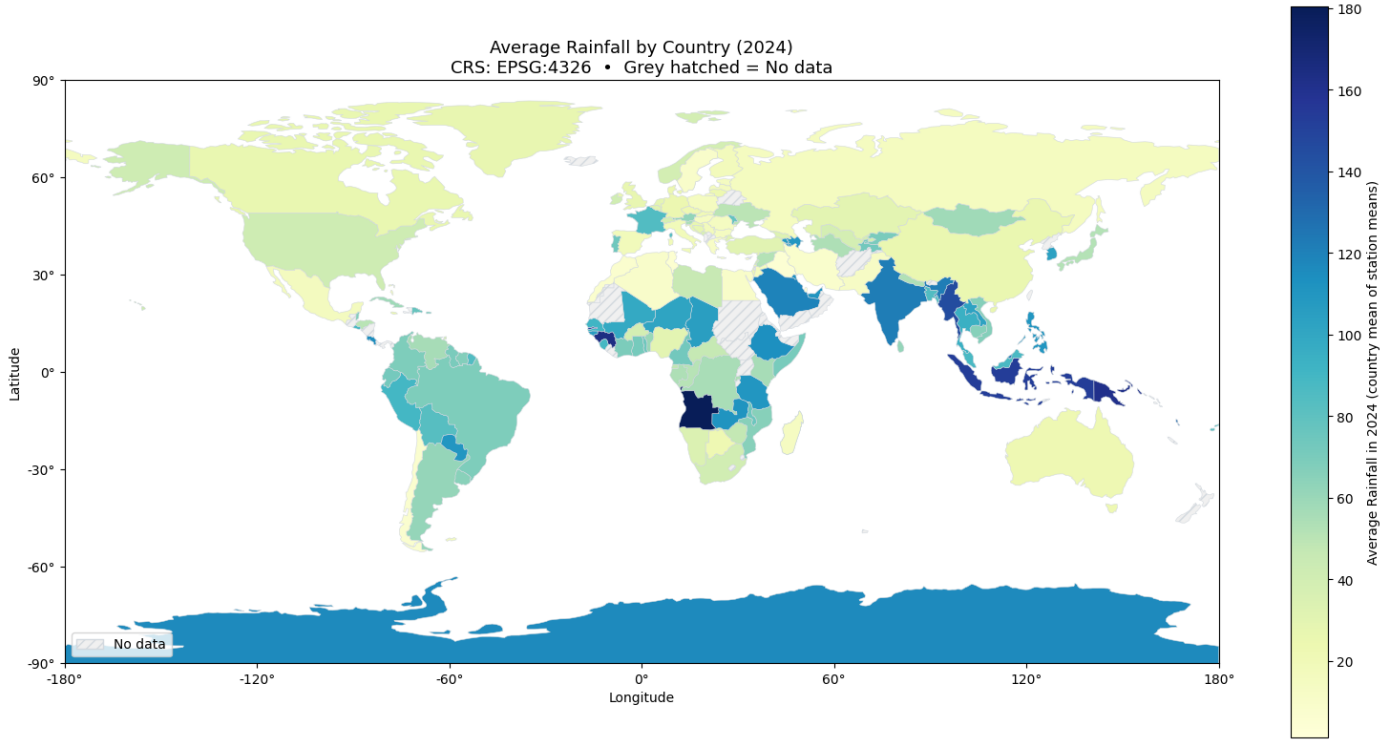



```
✓ Saved mapping to ./supplementary/fips_to_iso3_completed.csv
✓ Saved country table to ./supplementary/precip_2024_by_country.csv
✓ Saved map to ./supplementary/precip_2024_choropleth.png
```

```
import pandas as pd
import geopandas as gpd
import matplotlib.pyplot as plt
from matplotlib.ticker import MultipleLocator, FuncFormatter

# 1) 读入几何和csv（无需再计算）
world_base = gpd.read_file(gpd.datasets.get_path("naturalearth_lowres"))[
    ["iso_a3", "name", "geometry"]
]
prec = pd.read_csv("./supplementary/precip_2024_by_country.csv")

# 如果你的csv列名不同，请在这里对齐列名
# 例如：prec.rename(columns={"iso3":"iso_a3"}, inplace=True)
```

```python

# 2) 合并到GeoDataFrame
world_plot = world_base.merge(
    prec[["iso_a3", "PRCP_2024_country_avg"]],
    on="iso_a3", how="left"
).to_crs("EPSG:4326")

# 3) 画图：坐标轴显示度数
fig, ax = plt.subplots(figsize=(16, 8))
world_plot.plot(
    ax=ax,
    column="PRCP_2024_country_avg",
    cmap="YlGnBu",
    legend=True,
    legend_kwds={"label": "Average Rainfall in 2024 (country mean of station means)"},
    edgecolor="#d3d9df", linewidth=0.4,
    missing_kwds={"color":"#f0f0f0", "edgecolor":"#d3d9df", "hatch":"///", "label":"No data"}
)

ax.set_xlabel("Longitude")
ax.set_ylabel("Latitude")

def deg(x, pos):  # 度数格式
    return f"{int(x)}°"

ax.xaxis.set_major_locator(MultipleLocator(60))
ax.yaxis.set_major_locator(MultipleLocator(30))
ax.xaxis.set_major_formatter(FuncFormatter(deg))
ax.yaxis.set_major_formatter(FuncFormatter(deg))
ax.set_xlim(-180, 180)
ax.set_ylim(-90, 90)

ax.set_title(
    "Average Rainfall by Country (2024)\n"
    "CRS: EPSG:4326  •  Grey hatched = No data",
    fontsize=13
)

# 补上“No data”图例（如果自动没加上）
handles, labels = ax.get_legend_handles_labels()
if "No data" not in labels:
    from matplotlib.patches import Patch
    handles.append(Patch(facecolor="#f0f0f0", edgecolor="#d3d9df", hatch="///", label="No data"))
    ax.legend(handles=handles, loc="lower left")

plt.tight_layout()
plt.savefig("./supplementary/precip_2024_choropleth_from_csv_wgs84.png", dpi=220, bbox_inches="tight")
plt.show()
```

```
/tmp/ipykernel_44/2271823713.py:7: FutureWarning: The geopandas.dataset module is deprecated and will be removed in GeoPandas 1.0. You can get
  world_base = gpd.read_file(gpd.datasets.get_path("naturalearth_lowres"))[
/tmp/ipykernel_44/2271823713.py:53: UserWarning: Legend does not support handles for PatchCollection instances.
See: https://matplotlib.org/stable/tutorials/intermediate/legend_guide.html#implementing-a-custom-legend-handler
  handles, labels = ax.get_legend_handles_labels()
```




```
stop_spark()
```

```
25/09/14 13:03:42 WARN ExecutorPodsWatchSnapshotSource: Kubernetes client has been closed.
```

Spark

The spark session is **stopped**, confirm that `yxi75 (notebook)` is under the completed applications section in the Spark UI.

- Spark UI

```

```