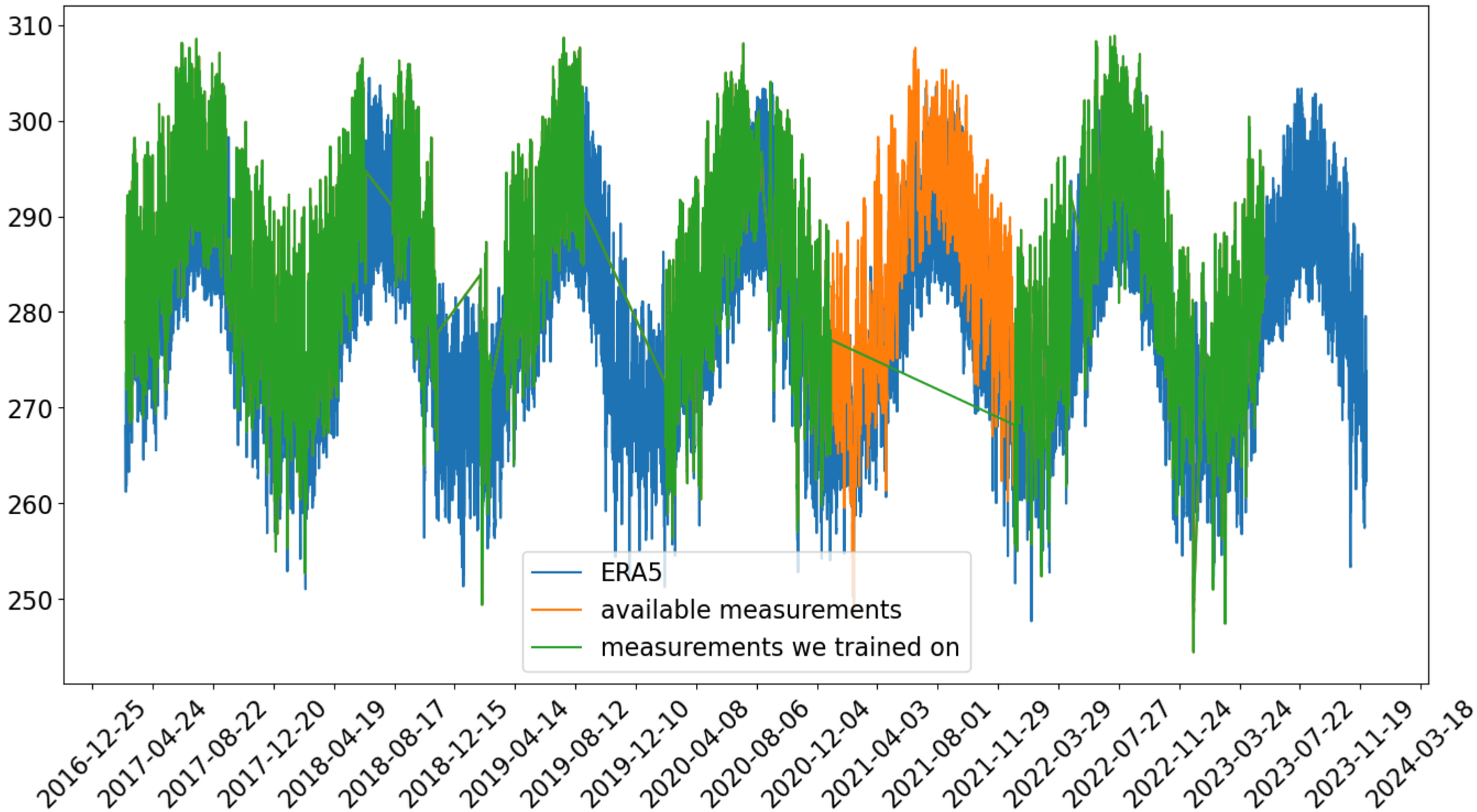
In [ ]:
```
import matplotlib.pyplot as plt
from climatereconstructionai import evaluate
import os
import regex as re
from dat_to_nc import DatToNcConverter
import pandas as pd
from tqdm import tqdm
```

In [ ]:
```
station_name = "Marshall"
model_name_note = "minutely"
test_year = 2021
at_iterations = "final"
has_no_time_context = False
```

In [ ]:
```
def evaluate_wrapper(use_time_context = True, iter = "final", station = station_name, reconstruct_gaps=False):

    snapshot_folder_name = f"snapshots_{station.lower()}"

    # copy "test_args_template.txt" to "test_args_temp.txt"
    # while replacing:

    replace_dir = {
        "STATIONNAME" : station.lower() if not reconstruct_gaps else f"the_gaps_{station.lower()}",
        "ITERATION" : str(iter),
        "SNAPSHOTDIR" : snapshot_folder_name,
        "_NOTE": f"_{model_name_note}" if model_name_note else ""
    }

    if reconstruct_gaps:
        replace_dir["_leading_trailing"] = ""
        replace_dir["cleaned_"] = "cleaned_era5_for_"


    template_file = "test_args_template_trailing.txt" if use_time_context else "test_args_template_no-time.txt"
    temp_file = "test_args_temp.txt"


    with open(template_file, "r") as f:
        lines = f.readlines()
        with open(temp_file, "w") as f2:
            for line in lines:
                for key in replace_dir:
                    line = re.sub(key, replace_dir[key], line)
                f2.write(line)

            # save and close
            f2.close()

    evaluate(temp_file)

    os.remove(temp_file)
```

In [ ]:
```
import xarray as xr
from utils import DataSet, DatasetPlotter
import numpy as np
import os
```

```
test_folder_path = "/work/bm1159/XCES/xces-work/k203179/data/test"
train_folder_path = "/work/bm1159/XCES/xces-work/k203179/data/train"
output_file_path = "outputs/output_output.nc"
era5_file = test_folder_path + f"/era5_for_{station_name.lower()}_leading_trailing.nc"
era5_full_file = f"/work/bm1159/XCES/xces-work/k203179/data_sets/era5_for_{station_name.lower()}.nc"
era5_gaps_file = f"/work/bm1159/XCES/xces-work/k203179/data_sets/era5_gaps_for_{station_name.lower()}.nc"

# get measurements values

measurements_data = xr.open_dataset(test_folder_path + f"/{station_name.lower()}.nc")
era5_data = xr.open_dataset(era5_file)
measurements_data_trained = xr.open_dataset(train_folder_path + f"/expected_{station_name.lower()}.nc")

era5_full_data = xr.open_dataset(era5_full_file)

plt.plot(era5_full_data["time"], era5_full_data["tas"].mean(axis=(1,2)), label = "ERA5")
plt.plot(measurements_data["time"], measurements_data["tas"].mean(axis=(1,2)), label = "available measurements")
plt.plot(measurements_data_trained["time"], measurements_data_trained["tas"].mean(axis=(1,2)), label = "measurements we trained on")
plt.legend()

# rotate x-axis labels, and show them every 6 months
plt.xticks(rotation=45)
plt.gca().xaxis.set_major_locator(plt.MultipleLocator(120))

# figure size A4 landscape
plt.gcf().set_size_inches(16, 8)
plt.show()
```



Evaluate with no timecontext

In [ ]:
```
output_no_time_data = None
evaluate_wrapper(use_time_context = False, iter = at_iterations, station = station_name)
output_no_time_ds = DataSet(output_file_path, name = "Reconstructed")
output_no_time_data = xr.open_dataset(output_file_path)
```

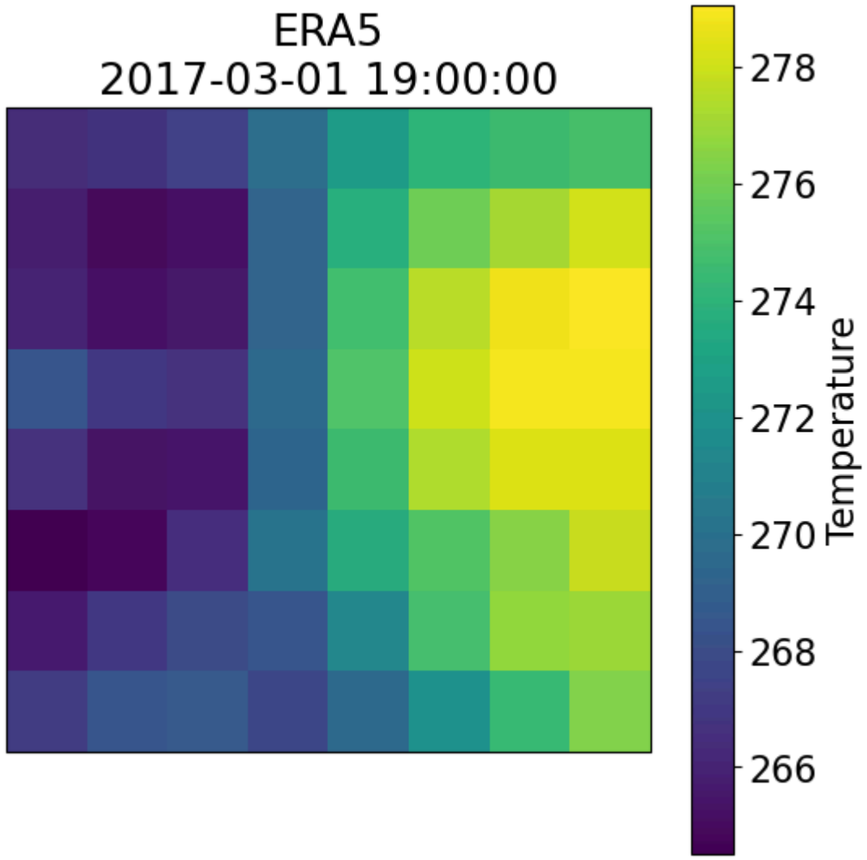
```
/home/k/k203179/.conda/envs/crai/lib/python3.10/site-packages/climatereconstructionai/utils/normalizer.py:10: RuntimeWarning: Mean of empty slice
  img_mean.append(np.nanmean(np.array(img_data[i])))
/home/k/k203179/.conda/envs/crai/lib/python3.10/site-packages/numpy/lib/nanfunctions.py:1879: RuntimeWarning: Degrees of freedom <= 0 for slice.
  var = nanvar(a, axis=axis, dtype=dtype, out=out, ddof=ddof,
```

```
---------------------------------------------------------------------------
RuntimeError                              Traceback (most recent call last)
/home/k/k203179/reconstructing-ai-for-weather-station-data/station_reconstruct/evaluate_station_model.ipynb Cell 6 line 2
      <a href='vscode-notebook-cell://ssh-remote%2Blevante/home/k/k203179/reconstructing-ai-for-weather-station-data/station_reconstruct/evaluate_station_model.ipynb#W5sdnNjb2RlLXJlbW90ZQ%3D%3D?line=0'>1</a> output_no_time_data = None
----> <a href='vscode-notebook-cell://ssh-remote%2Blevante/home/k/k203179/reconstructing-ai-for-weather-station-data/station_reconstruct/evaluate_station_model.ipynb#W5sdnNjb2RlLXJlbW90ZQ%3D%3D?line=1'>2</a> evaluate_wrapper(use_time_context = False, iter = at_iterations, station = station_name)
      <a href='vscode-notebook-cell://ssh-remote%2Blevante/home/k/k203179/reconstructing-ai-for-weather-station-data/station_reconstruct/evaluate_station_model.ipynb#W5sdnNjb2RlLXJlbW90ZQ%3D%3D?line=2'>3</a> output_no_time_ds = DataSet(output_file_path, name = "Reconstructed")
      <a href='vscode-notebook-cell://ssh-remote%2Blevante/home/k/k203179/reconstructing-ai-for-weather-station-data/station_reconstruct/evaluate_station_model.ipynb#W5sdnNjb2RlLXJlbW90ZQ%3D%3D?line=3'>4</a> output_no_time_data = xr.open_dataset(output_file_path)

/home/k/k203179/reconstructing-ai-for-weather-station-data/station_reconstruct/evaluate_station_model.ipynb Cell 6 line 3
     <a href='vscode-notebook-cell://ssh-remote%2Blevante/home/k/k203179/reconstructing-ai-for-weather-station-data/station_reconstruct/evaluate_station_model.ipynb#W5sdnNjb2RlLXJlbW90ZQ%3D%3D?line=31'>32</a>         # save and close
     <a href='vscode-notebook-cell://ssh-remote%2Blevante/home/k/k203179/reconstructing-ai-for-weather-station-data/station_reconstruct/evaluate_station_model.ipynb#W5sdnNjb2RlLXJlbW90ZQ%3D%3D?line=32'>33</a>         f2.close()
---> <a href='vscode-notebook-cell://ssh-remote%2Blevante/home/k/k203179/reconstructing-ai-for-weather-station-data/station_reconstruct/evaluate_station_model.ipynb#W5sdnNjb2RlLXJlbW90ZQ%3D%3D?line=34'>35</a> evaluate(temp_file)
     <a href='vscode-notebook-cell://ssh-remote%2Blevante/home/k/k203179/reconstructing-ai-for-weather-station-data/station_reconstruct/evaluate_station_model.ipynb#W5sdnNjb2RlLXJlbW90ZQ%3D%3D?line=36'>37</a> os.remove(temp_file)

File ~/.conda/envs/crai/lib/python3.10/site-packages/climatereconstructionai/evaluate.py:75, in evaluate(arg_file, prog_func)
     73 count += 1
     74 label = ckpt_dict["labels"][k]
---> 75 load_model(ckpt_dict, model, label=label)
     76 model.eval()
     77 batch_size = get_batch_size(model.parameters(), n_samples, image_sizes)

File ~/.conda/envs/crai/lib/python3.10/site-packages/climatereconstructionai/utils/io.py:42, in load_model(ckpt_dict, model, optimizer, label)
     38     label = ckpt_dict["labels"][-1]
     40 ckpt_dict[label]["model"] = \
     41     {key.replace("module.", ""): value for key, value in ckpt_dict[label]["model"].items()}
---> 42 model.load_state_dict(ckpt_dict[label]["model"])
     43 if optimizer is not None:
     44     optimizer.load_state_dict(ckpt_dict[label]["optimizer"])

File ~/.conda/envs/crai/lib/python3.10/site-packages/torch/nn/modules/module.py:2152, in Module.load_state_dict(self, state_dict, strict, assign)
   2147         error_msgs.insert(
   2148             0, 'Missing key(s) in state_dict: {}. '.format(
   2149                 ', '.join(f'"{k}"' for k in missing_keys)))
   2151 if len(error_msgs) > 0:
-> 2152     raise RuntimeError('Error(s) in loading state_dict for {}:\n\t{}'.format(
   2153                        self.__class__.__name__, "\n\t".join(error_msgs)))
   2154 return _IncompatibleKeys(missing_keys, unexpected_keys)

RuntimeError: Error(s) in loading state_dict for CRAINet:
        size mismatch for encoder.0.partial_conv.input_conv.weight: copying a param with shape torch.Size([18, 3, 7, 7]) from checkpoint, the shape in current model is torch.Size([18, 1, 7, 7]).
        size mismatch for encoder.0.partial_conv.mask_conv.weight: copying a param with shape torch.Size([18, 3, 7, 7]) from checkpoint, the shape in current model is torch.Size([18, 1, 7, 7]).
        size mismatch for decoder.2.partial_conv.input_conv.weight: copying a param with shape torch.Size([1, 21, 3, 3]) from checkpoint, the shape in current model is torch.Size([1, 19, 3, 3]).
        size mismatch for decoder.2.partial_conv.mask_conv.weight: copying a param with shape torch.Size([1, 21, 3, 3]) from checkpoint, the shape in current model is torch.Size([1, 19, 3, 3]).
```

In [ ]:

```
era5_ds = DataSet(era5_file, name = "ERA5")
plotter1 = DatasetPlotter(era5_ds)
plotter1.plot()
print(era5_ds.lat)
```

```
print(era5_ds.lon - 360)
plotter2 = DatasetPlotter(output_no_time_ds)
plotter2.time_index_list = plotter1.time_index_list
plotter2.plot()
```




```
[38.92270253 39.20373283 39.48476313 39.76579343 40.04682373 40.32785403
 40.60888433 40.88991463]
[-106.3125  -106.03125 -105.75    -105.46875 -105.1875  -104.90625
 -104.625   -104.34375]
```

```
---------------------------------------------------------------------------
NameError                                 Traceback (most recent call last)
/home/k/k203179/reconstructing-ai-for-weather-station-data/station_reconstruct/evaluate_station_model.ipynb Cell 7 line 6
      <a href='vscode-notebook-cell://ssh-remote%2Blevante/home/k/k203179/reconstructing-ai-for-weather-station-data/station_reconstruct/evaluate_station_model.ipynb#W6sdnNjb2RlLXJlbW90ZQ%3D%3D?line=3'>4</a> print(era5_ds.lat)
      <a href='vscode-notebook-cell://ssh-remote%2Blevante/home/k/k203179/reconstructing-ai-for-weather-station-data/station_reconstruct/evaluate_station_model.ipynb#W6sdnNjb2RlLXJlbW90ZQ%3D%3D?line=4'>5</a> print(era5_ds.lon - 360)
----> <a href='vscode-notebook-cell://ssh-remote%2Blevante/home/k/k203179/reconstructing-ai-for-weather-station-data/station_reconstruct/evaluate_station_model.ipynb#W6sdnNjb2RlLXJlbW90ZQ%3D%3D?line=5'>6</a> plotter2 = DatasetPlotter(output_no_time_ds)
      <a href='vscode-notebook-cell://ssh-remote%2Blevante/home/k/k203179/reconstructing-ai-for-weather-station-data/station_reconstruct/evaluate_station_model.ipynb#W6sdnNjb2RlLXJlbW90ZQ%3D%3D?line=6'>7</a> plotter2.time_index_list = plotter1.time_index_list
      <a href='vscode-notebook-cell://ssh-remote%2Blevante/home/k/k203179/reconstructing-ai-for-weather-station-data/station_reconstruct/evaluate_station_model.ipynb#W6sdnNjb2RlLXJlbW90ZQ%3D%3D?line=7'>8</a> plotter2.plot()

NameError: name 'output_no_time_ds' is not defined
```

Evaluate with time contex

In [ ]:
```python
if has_no_time_context:
    output_with_time_data = output_no_time_data
else:
    evaluate_wrapper(use_time_context = True, iter = at_iterations, station = station_name)
    output_with_time_ds = DataSet(output_file_path, name="Reconstructed with time context")
    output_with_time_data = xr.open_dataset(output_file_path)
```

```
/home/k/k203179/.conda/envs/crai/lib/python3.10/site-packages/climatereconstructionai/utils/normalizer.py:10: RuntimeWarning: Mean of empty slice
  img_mean.append(np.nanmean(np.array(img_data[i])))
/home/k/k203179/.conda/envs/crai/lib/python3.10/site-packages/numpy/lib/nanfunctions.py:1879: RuntimeWarning: Degrees of freedom <= 0 for slice.
  var = nanvar(a, axis=axis, dtype=dtype, out=out, ddof=ddof,
100%|██████████| 1/1 [00:27<00:00, 27.69s/it]
```

In [ ]:
```python
# get coordinates from measurements nc file
import numpy as np

converter_to_get_metadata = DatToNcConverter(station_name)
station_lon, station_lat = converter_to_get_metadata.meta_data.get("longitude"), converter_to_get_metadata.meta_data.get("latitude")
print(f"station is at {station_lon}, {station_lat}")

# get nearest coordinates in era5
def get_left_right_nearest_elem_in_sorted_array(array, value):
    length = len(array)
    left = len(list(filter(lambda x: x <= value, array))) - 1
    right = length - len(list(filter(lambda x: x >= value, array)))
    nearest = min(left, right, key=lambda x: abs(array[x] - value))
    return left, right, nearest

test_array = [1, 2, 3, 4, 5, 6, 7, 8]
test_search = 5.51

print(f"searching for {test_search} in {test_array}")
left_idx, right_idx, nearest_idx =  get_left_right_nearest_elem_in_sorted_array(test_array, test_search)
print(f"idx left to {test_search} is {left_idx}, idx right to {test_search} is {right_idx}, nearest idx is {nearest_idx}")
print(f"mid crop: {test_array[left_idx:right_idx+1]}")
```

```
station is at -105.196, 39.9496
searching for 5.51 in [1, 2, 3, 4, 5, 6, 7, 8]
idx left to 5.51 is 4, idx right to 5.51 is 5, nearest idx is 5
mid crop: [5, 6]
```

In [ ]:
```python
def era_vs_reconstructed_comparision_to_df(era5_data, reconstructed_with_time_data, reconstructed_no_time_data, measurements_data):

    lon_left_idx, lon_right_idx, lon_nearest_idx = get_left_right_nearest_elem_in_sorted_array(era5_data.lon.values, station_lon % 360)
    lat_left_idx, lat_right_idx, lat_nearest_idx = get_left_right_nearest_elem_in_sorted_array(era5_data.lat.values, station_lat)

    era5_nearest_values = era5_data.variables["tas"][:, lon_nearest_idx, lat_nearest_idx]

    reconstructed_with_time_data_values = reconstructed_with_time_data.variables["tas"].stack(grid=['lat', 'lon']).values
    if reconstructed_no_time_data is not None:
        reconstructed_no_time_data_values = reconstructed_no_time_data.variables["tas"].stack(grid=['lat', 'lon']).values

    measurements_data_values = measurements_data.variables["tas"][...].mean(axis=(1,2))


    # timeaxis
    time = era5_data.variables["time"][:]

    # create dataframe with all values
    df = pd.DataFrame()
```

```
    df["time"] = time

    # index should be time
    df.set_index("time", inplace=True)

    df["era5_nearest"] = era5_nearest_values
    if reconstructed_no_time_data is not None:
        df["reconstructed_median"] = [np.median(x) for x in reconstructed_no_time_data_values]
    df["reconstructed_with_time_context_median"] = [np.median(x) for x in reconstructed_with_time_data_values]
    df["measurements"] = measurements_data_values

    return df


def era_vs_reconstructed_comparision_to_minutely_df(era5_data, reconstructed_with_time_data, reconstructed_no_time_data, measurements_data):
    lon_left_idx, lon_right_idx, lon_nearest_idx = get_left_right_nearest_elem_in_sorted_array(era5_data.lon.values, station_lon % 360)
    lat_left_idx, lat_right_idx, lat_nearest_idx = get_left_right_nearest_elem_in_sorted_array(era5_data.lat.values, station_lat)

    era5_nearest_values = era5_data.variables["tas"][:, lon_nearest_idx, lat_nearest_idx]

    dfs_per_hour = []
    # for timestep in era5
    # add all the available minutely data from measurements and reconsturction using the map_minutes_to_grid funct.

    for hour_index, hour in tqdm(enumerate(era5_data.variables["time"][:].values), total=len(era5_data.variables["time"][:])):
        # interpolate from this hour to the next 60 minutes
        era5_minutely = np.linspace(era5_nearest_values[hour_index], (era5_nearest_values[hour_index+1] if hour_index + 1 < len(era5_nearest_values) else era5_nearest_values[h
        from map_minutes_to_grid import mapping_rule
        # array length 60 None s
        measr_minutely = [None] * 60
        reconstr_minutely = [None] * 60
        reconstr_with_time_minutely = [None] * 60
        for minute in range(60):
            _lat_idx, _lon_idx = mapping_rule[minute]
            measr_minutely[minute] = measurements_data.variables["tas"][hour_index, _lon_idx, _lat_idx].values
            measr_minutely[minute] = None if np.isnan(measr_minutely[minute]) else measr_minutely[minute]
            if reconstructed_no_time_data is not None:
                reconstr_minutely[minute] = reconstructed_no_time_data.variables["tas"][hour_index, _lon_idx, _lat_idx].values
                reconstr_minutely[minute] = None if np.isnan(reconstr_minutely[minute]) else reconstr_minutely[minute]
            if reconstructed_with_time_data is not None:
                reconstr_with_time_minutely[minute] = reconstructed_with_time_data.variables["tas"][hour_index, _lon_idx, _lat_idx].values
                reconstr_with_time_minutely[minute] = None if np.isnan(reconstr_with_time_minutely[minute]) else reconstr_with_time_minutely[minute]
        minutely_timestamps = [hour + pd.Timedelta(minutes=i) for i in range(60)]
        # append hour to df
        local_df = pd.DataFrame({
            "time": list(minutely_timestamps),
            "era5_nearest": list(era5_minutely),
            "measurements": list(measr_minutely),
            "reconstructed_median": list(reconstr_minutely),
            "reconstructed_with_time_context_median": list(reconstr_with_time_minutely)
        })
        dfs_per_hour.append(local_df)

df = pd.concat(dfs_per_hour)


# index should be time
df.set_index("time", inplace=True)
```

```
    return df
```

Generate Dataframe

- makes resampling easier

In [ ]:
```
minutely_df = era_vs_reconstructed_comparision_to_minutely_df(era5_data, output_with_time_data, output_no_time_data, measurements_data)
```

```
  0%|          | 0/32956 [00:00<?, ?it/s]
100%|██████████| 32956/32956 [11:34<00:00, 47.47it/s]
```

In [ ]:
```
# drop where measurements are nan
minutely_df["measurements"] = pd.to_numeric(minutely_df["measurements"], errors="coerce")
minutely_df = minutely_df.dropna(subset=["measurements"])
minutely_df
```

Out[ ]:

time	era5_nearest	measurements	reconstructed_median	reconstructed_with_time_context_median
2017-03-01 19:00:00	275.036621	278.04999999999995	None	277.59186
2017-03-01 19:01:00	275.061587	278.25	None	277.72116
2017-03-01 19:02:00	275.086552	278.45	None	277.60593
2017-03-01 19:03:00	275.111517	278.34999999999997	None	277.63104
2017-03-01 19:04:00	275.136483	278.25	None	277.54752
...	...	...	...	...
2023-05-18 08:55:00	282.003907	283.75	None	284.79736
2023-05-18 08:56:00	281.955643	284.04999999999995	None	284.75458
2023-05-18 08:57:00	281.907380	283.75	None	284.78787
2023-05-18 08:58:00	281.859116	283.75	None	284.7635
2023-05-18 08:59:00	281.810852	283.75	None	284.90186

1977300 rows × 4 columns

Implement plotting method of dataframe

In [ ]:
```
def plot_n_steps_of_df(df, as_delta, n=None, title=None, plot_trailing_time=False):

    plot_trailing_time = plot_trailing_time and not has_no_time_context

    time = df.index.values
    if n is None:
        n = len(df)
```

```python
# random slice of n consecutive datapoints
import random
slice_start = random.randint(0, len(time) - n)
time_slice = slice(slice_start, slice_start + n)

time = time[time_slice]

if not as_delta:
    era5_nearest_values = df["era5_nearest"].values - 273.15
    if "reconstructed_median" in df.columns and not df["reconstructed_median"].isnull().all():
        reconstructed_median_values = df["reconstructed_median"] - 273.15
    else:
        reconstructed_median_values = None
    reconstructed_median_with_time_context_values = df["reconstructed_with_time_context_median"] - 273.15

    measurements_values = df["measurements"].values - 273.15
else:
    era5_nearest_values = df["era5_nearest"].values
    if "reconstructed_median" in df.columns and not df["reconstructed_median"].isnull().all():
        reconstructed_median_values = df["reconstructed_median"]
    else:
        reconstructed_median_values = None
    reconstructed_median_with_time_context_values = np.array(df["reconstructed_with_time_context_median"])

    measurements_values = np.array(df["measurements"].values)

if reconstructed_median_values is not None:
    correlation_reconstructed = df["reconstructed_median"].corr(df["measurements"])
else:
    correlation_reconstructed = None
correlation_reconstructed_with_time_context = df["reconstructed_with_time_context_median"].corr(df["measurements"])
correlation_era5_nearest = df["era5_nearest"].corr(df["measurements"])

if reconstructed_median_values is not None:
    rmse_reconstructed = np.sqrt(np.nanmean((reconstructed_median_values[time_slice] - measurements_values[time_slice])**2))
else:
    rmse_reconstructed = None
rmse_reconstructed_with_time_context = np.sqrt(np.nanmean((reconstructed_median_with_time_context_values[time_slice] - measurements_values[time_slice])**2))
rmse_era5_nearest = np.sqrt(((era5_nearest_values[time_slice] - measurements_values[time_slice])**2).mean())



if as_delta:
 #   era5_mid_values = era5_mid_values - measurements_values
    era5_nearest_values = era5_nearest_values - measurements_values
    if reconstructed_median_values is not None:
        reconstructed_median_values = reconstructed_median_values - measurements_values
    reconstructed_median_with_time_context_values = reconstructed_median_with_time_context_values - measurements_values
    measurements_values = measurements_values - measurements_values

    # y-axis title, temperature difference
    plt.ylabel("Delta (data - measurement) [C°]")

else:
    plt.ylabel("Temperature at surface [C°]")

_, _, nearest_lon_idx = get_left_right_nearest_elem_in_sorted_array(era5_data.lon.values, station_lon % 360)
_, _, nearest_lat_idx = get_left_right_nearest_elem_in_sorted_array(era5_data.lat.values, station_lat)
plt.plot(time, era5_nearest_values[time_slice], label=f"ERA5 nearest point (lon: {(era5_data.lon.values[nearest_lon_idx] - 360):.3f}, lat: {era5_data.lat.values[nearest_la
         color="red")
```

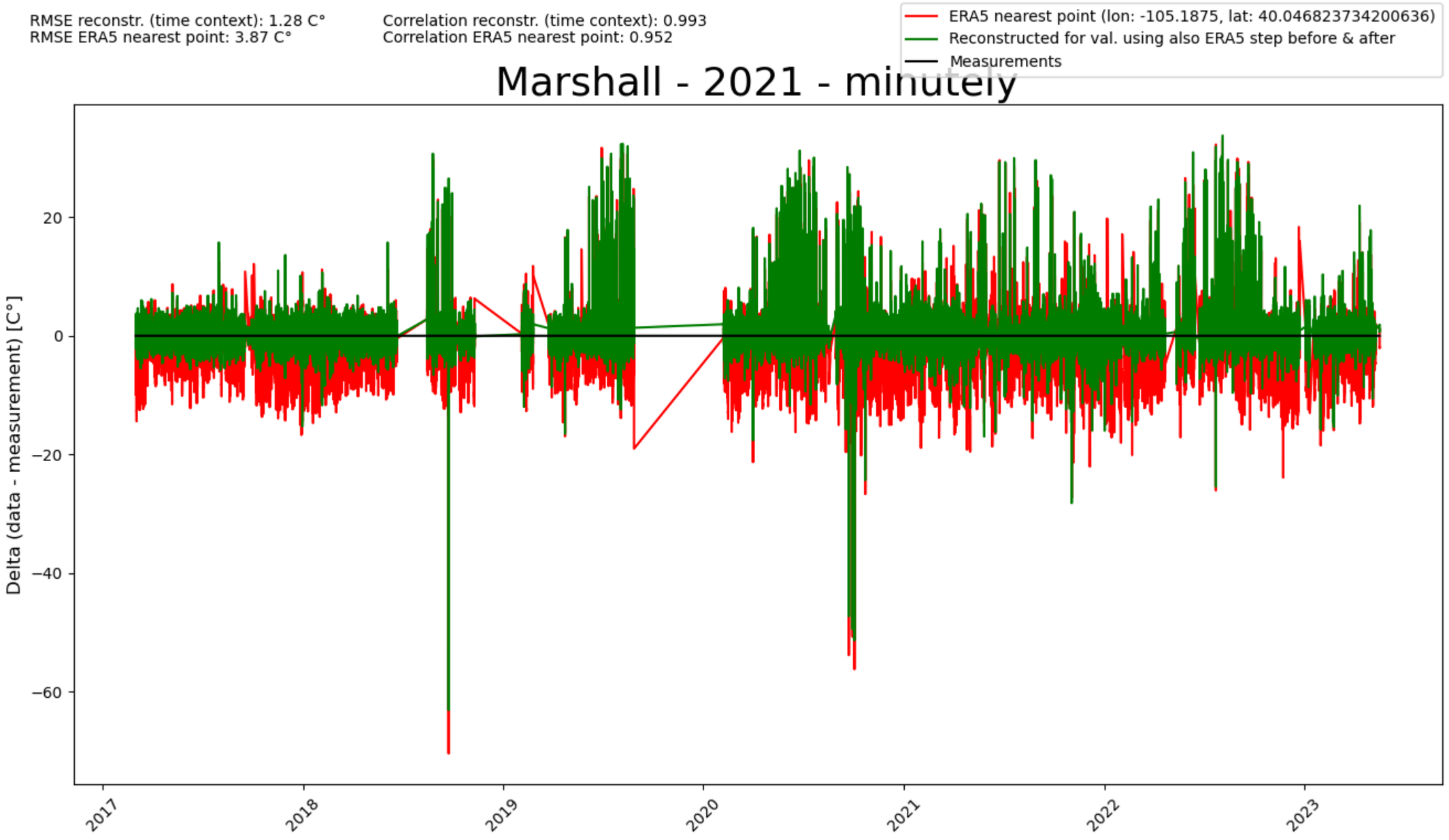
```
    # plt.plot(time, era5_mid_values[time_slice], label="ERA5 nearest 4 points")

    if reconstructed_median_values is not None:
        plt.plot(time, reconstructed_median_values[time_slice], label="Reconstructed for validation", color="blue")
    if plot_trailing_time:
        plt.plot(time, reconstructed_median_with_time_context_values[time_slice], label="Reconstructed for val. using also ERA5 step before & after", color="green")

    plt.plot(time, measurements_values[time_slice], label="Measurements", color="black")

    # x-axis labels 90 degrees
    plt.xticks(rotation=45)

    # title
    if title is not None:
        plt.title(title)


    # font size of legend
    plt.rcParams.update({'font.size': 10})

    # font size of axis labels
    plt.rcParams.update({'axes.labelsize': 12})

    # font size of title
    plt.rcParams.update({'axes.titlesize': 26})

    plt.legend()
    # position legend below chart to the right
    plt.legend(bbox_to_anchor=(1, 1.15), loc='upper right', borderaxespad=0.)

    # text below diagram with RMSE and Correlation in fontsize 10
    plt.text(0.1,0.95, (f"RMSE reconstructed: {rmse_reconstructed:.2f} C°\n" if rmse_reconstructed else "" ) +
             (f"RMSE reconstr. (time context): {rmse_reconstructed_with_time_context:.2f} C°\n" if plot_trailing_time  else "") +
             f"RMSE ERA5 nearest point: {rmse_era5_nearest:.2f} C°",

             fontsize=10, transform=plt.gcf().transFigure)

    plt.text(0.3, 0.95, (f"Correlation reconstructed: {correlation_reconstructed:.3f}\n" if correlation_reconstructed else "") +
             (f"Correlation reconstr. (time context): {correlation_reconstructed_with_time_context:.3f}\n" if plot_trailing_time else "") +
             f"Correlation ERA5 nearest point: {correlation_era5_nearest:.3f}",

             fontsize = 10, transform=plt.gcf().transFigure)

    # figure size A4 landscape
    plt.gcf().set_size_inches(16, 8)

    plt.show()
```

Minutely Analysis

In [ ]:
```
title = f"{station_name} - {test_year} - minutely"
plot_n_steps_of_df(minutely_df, as_delta=True, title=title, plot_trailing_time=True)
```

RMSE reconstr. (time context): 1.28 C°
RMSE ERA5 nearest point: 3.87 C°

Correlation reconstr. (time context): 0.993
Correlation ERA5 nearest point: 0.952

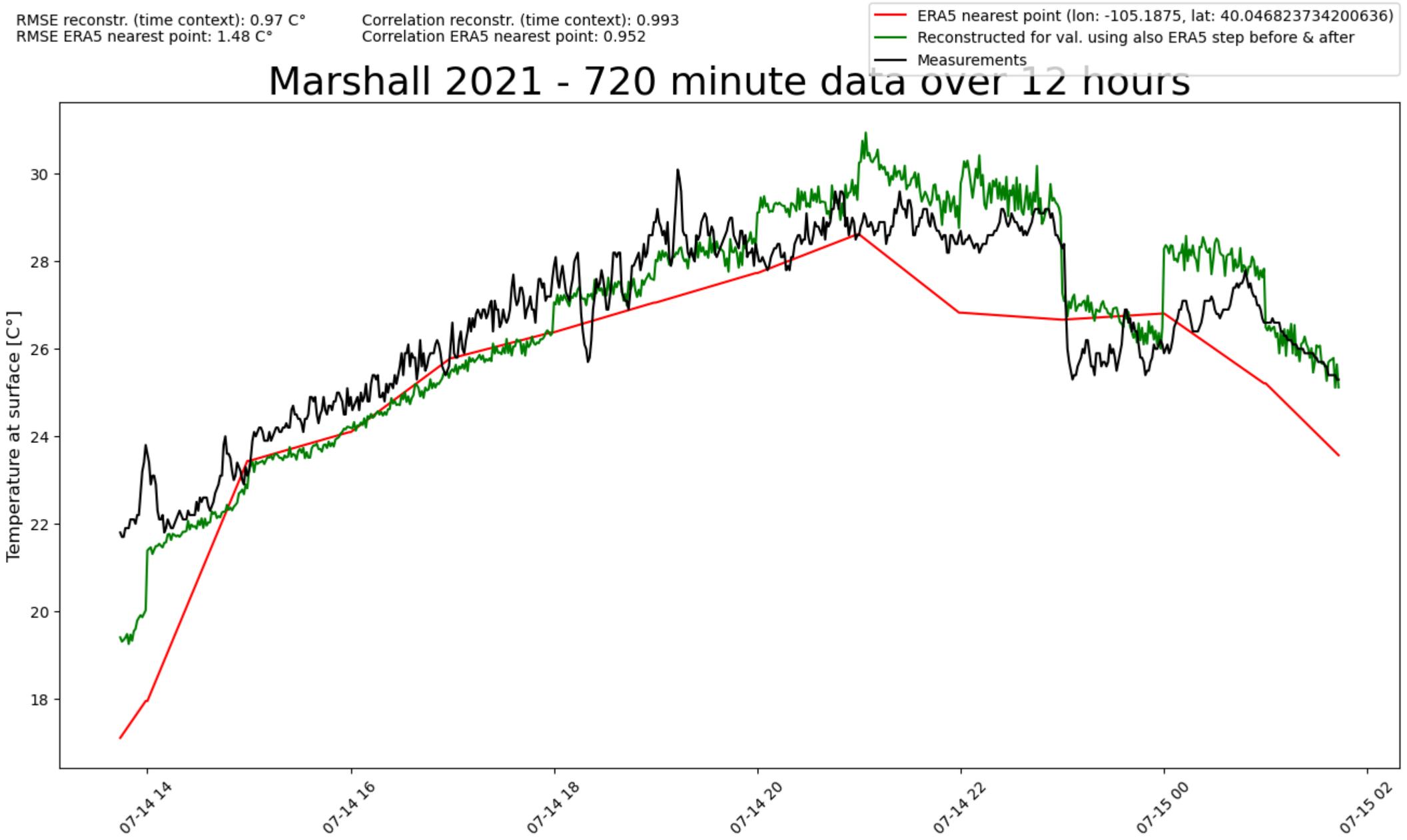


Plotting random Day minutely

In [ ]:
```
n = 720
title = f"{station_name} {test_year} - {n} minute data over 12 hours"
for _ in range(3):
    plot_n_steps_of_df(minutely_df, as_delta=False, n=n, title=title, plot_trailing_time=True)
```

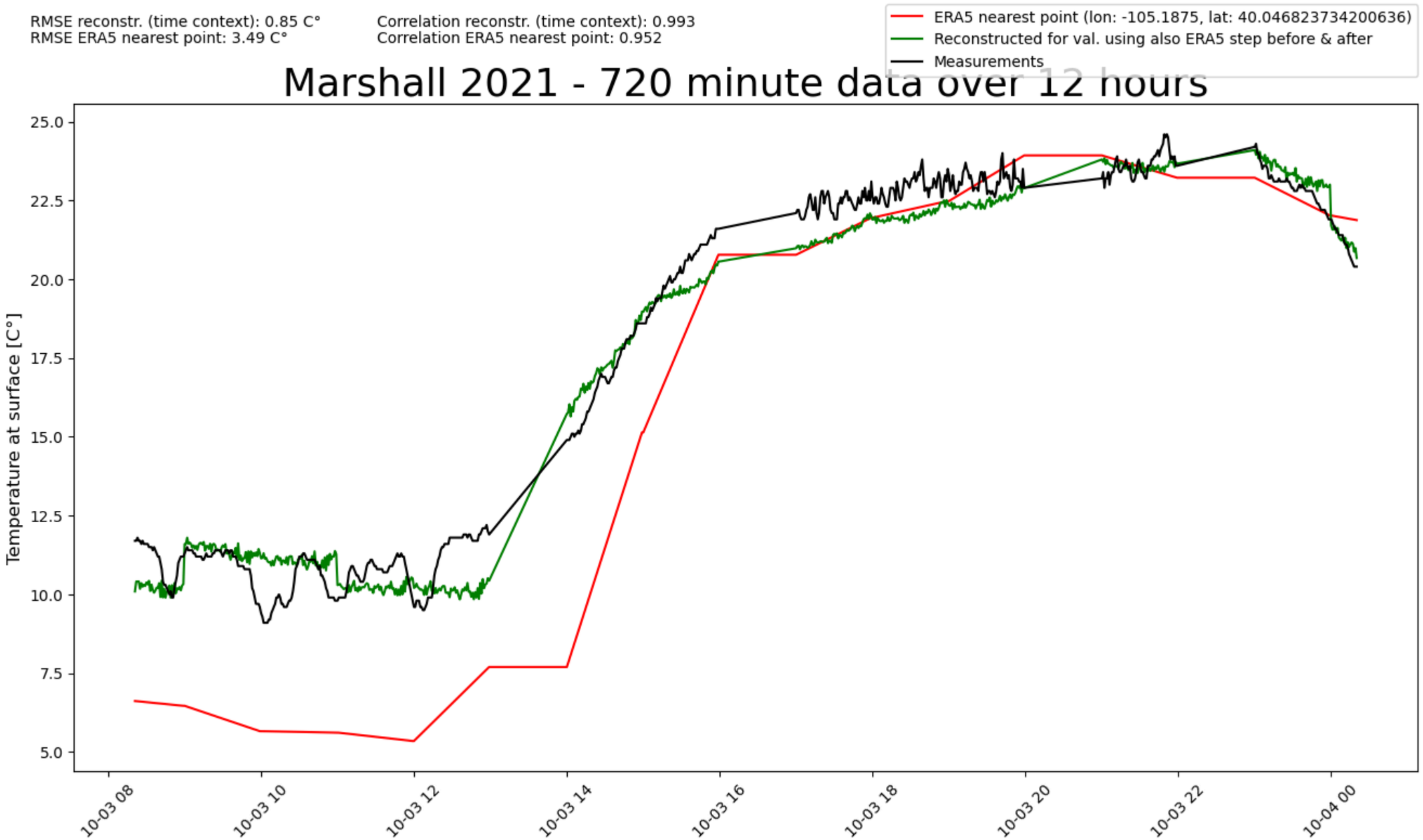
RMSE reconstr. (time context): 0.97 C°
RMSE ERA5 nearest point: 1.48 C°

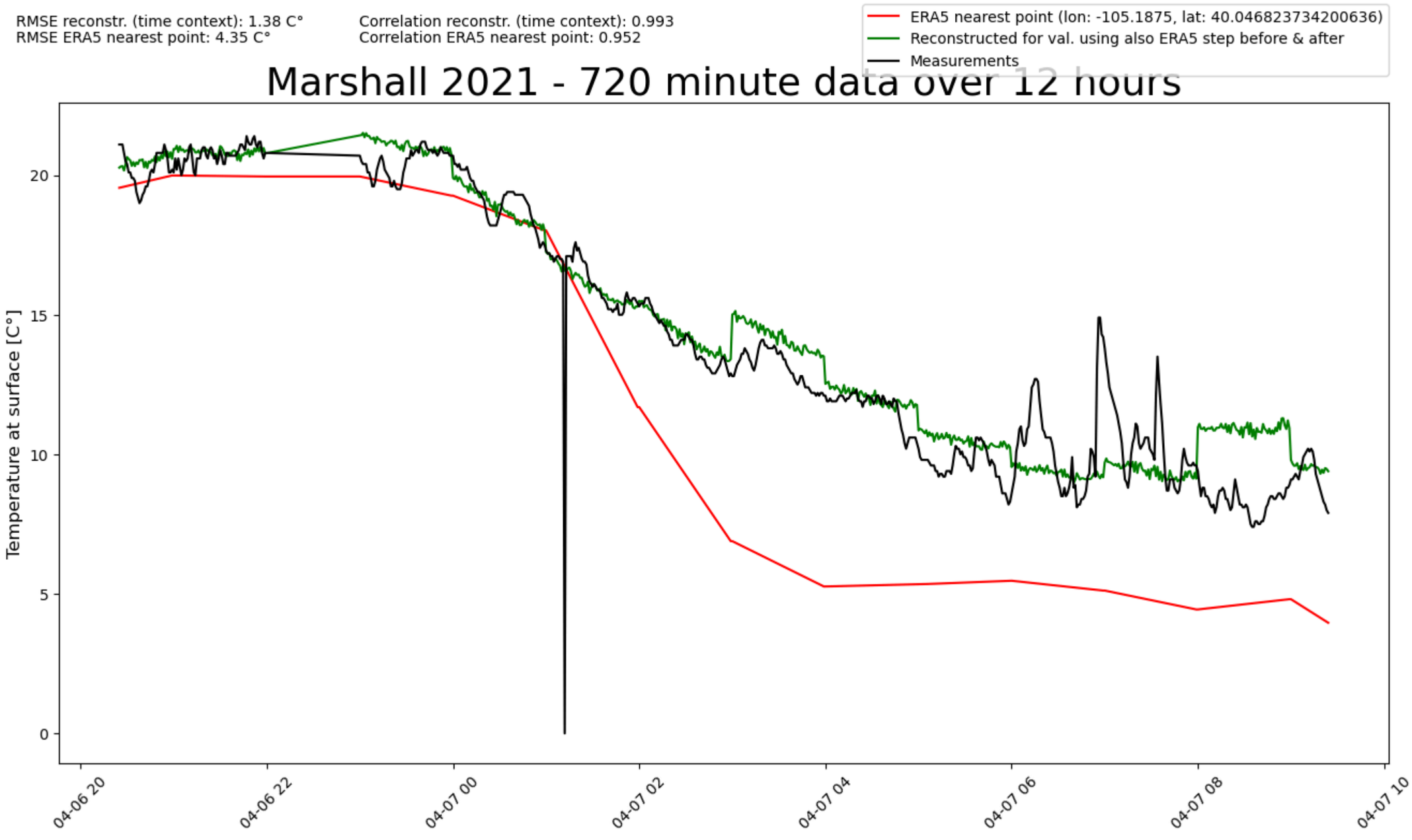
Correlation reconstr. (time context): 0.993
Correlation ERA5 nearest point: 0.952



RMSE reconstr. (time context): 0.85 C°
RMSE ERA5 nearest point: 3.49 C°

Correlation reconstr. (time context): 0.993
Correlation ERA5 nearest point: 0.952





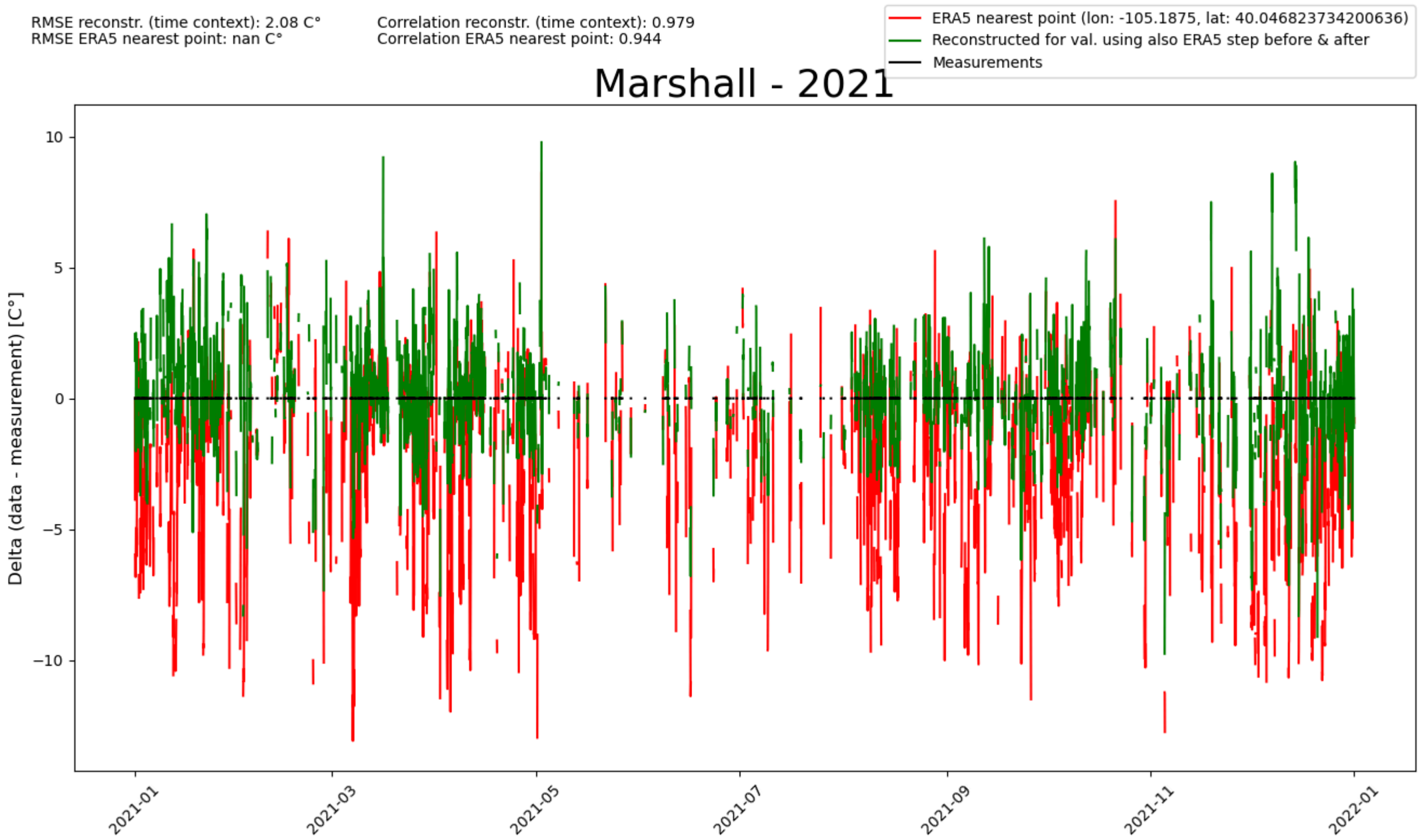
Hourly Analysis

In [ ]:
```
hourly_df = minutely_df.resample('H').mean()


# print a section of the df

start_date = test_year.__str__() + "-01-01"
end_date = test_year.__str__() + "-12-31"
```

```
hourly_df = hourly_df[start_date:end_date]
```

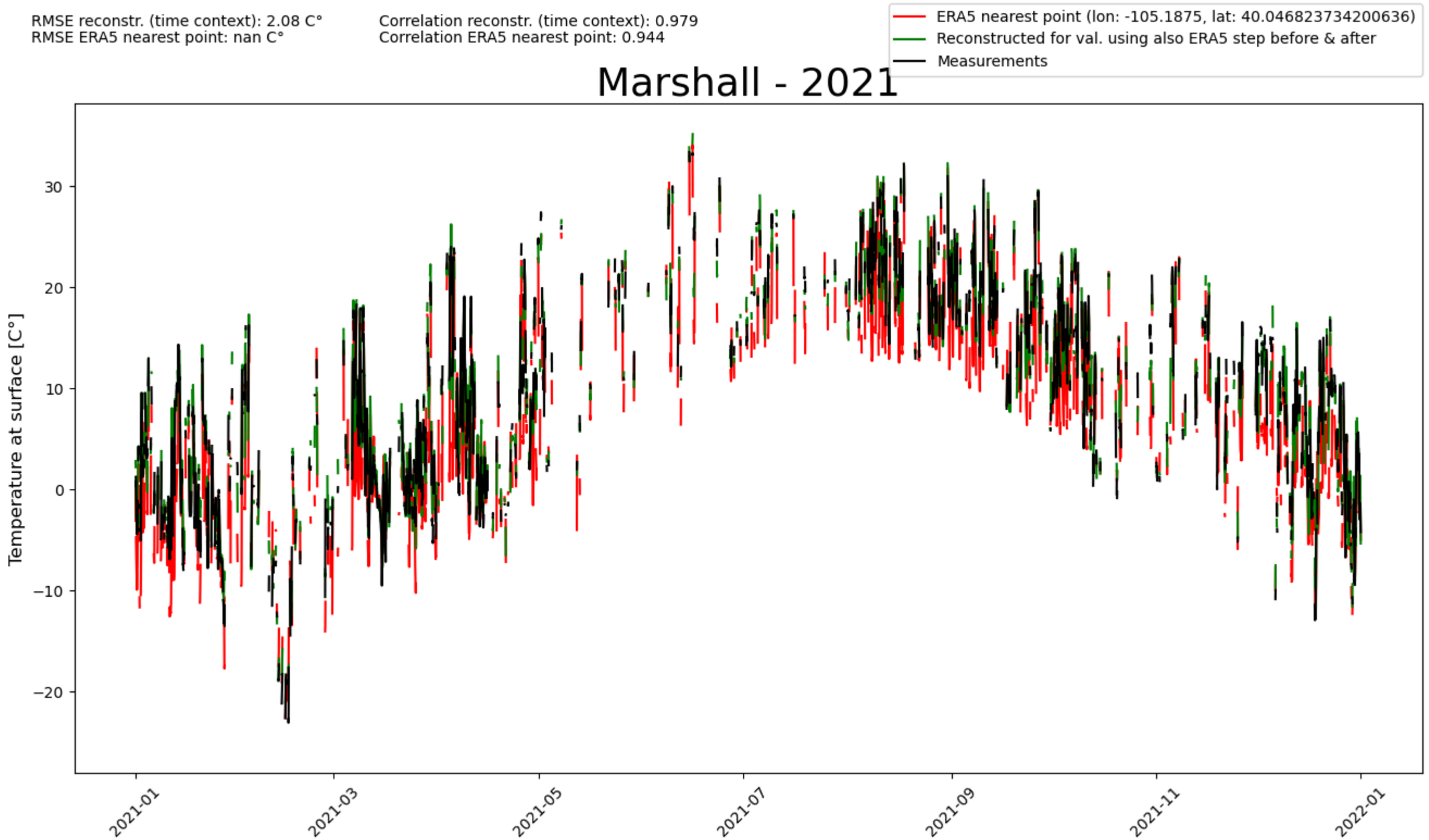
...over the full year

In [ ]:
```
title = f"{station_name} - {test_year}"
plot_n_steps_of_df(hourly_df, as_delta=True, title=title, plot_trailing_time=True)
plot_n_steps_of_df(hourly_df, as_delta=False, title=title, plot_trailing_time=True)
```



RMSE reconstr. (time context): 2.08 C°
RMSE ERA5 nearest point: nan C°

Correlation reconstr. (time context): 0.979
Correlation ERA5 nearest point: 0.944

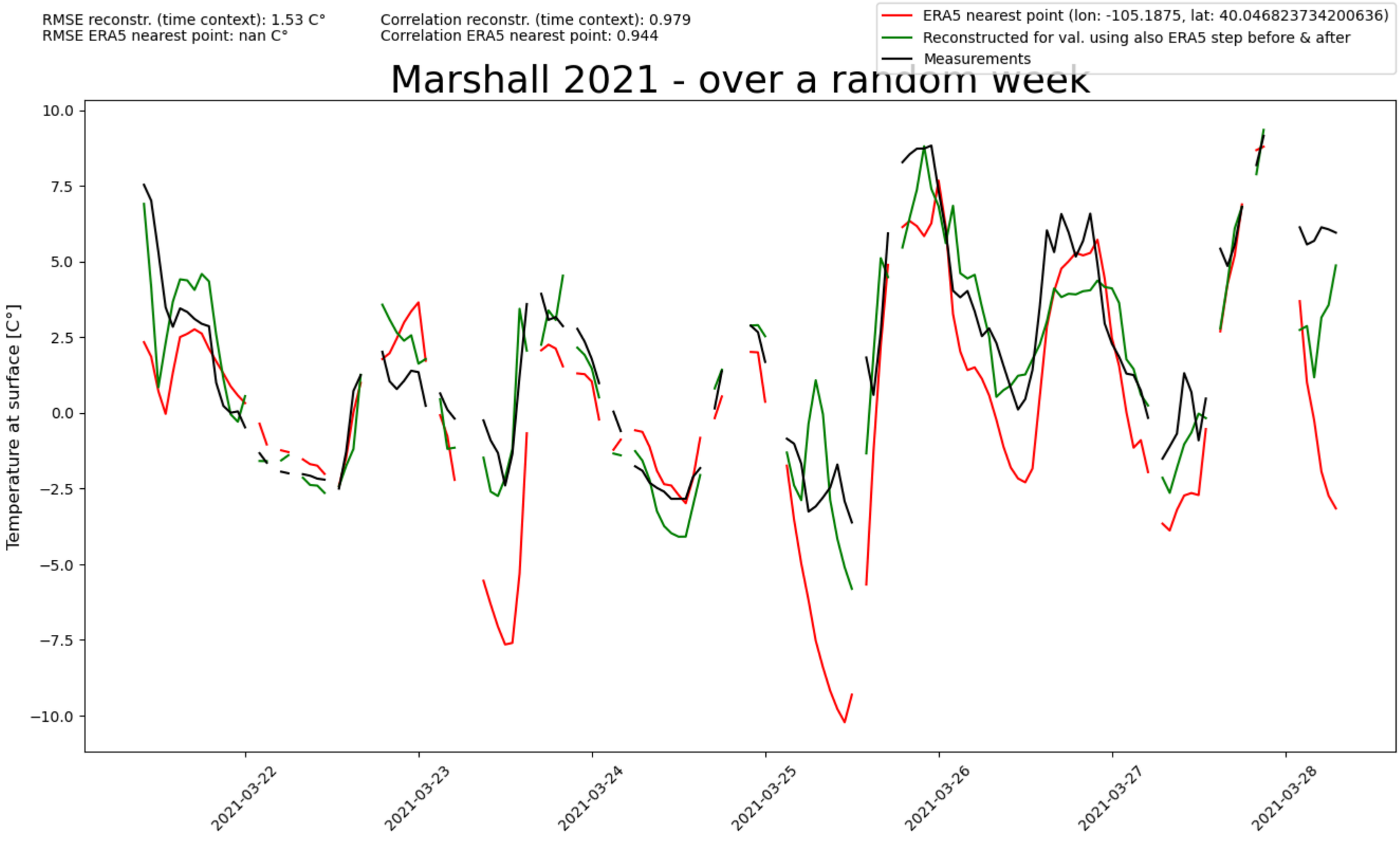


...over random weeks

In [ ]:
```
n = 168
if n == 168:
    title = f"{station_name} {test_year} - over a random week"
else:
    title = f"{station_name} {test_year} - {n} random consecutive hourly steps"
for _ in range(3):
    plot_n_steps_of_df(hourly_df, as_delta=False, n=n, title=title, plot_trailing_time=True)
```

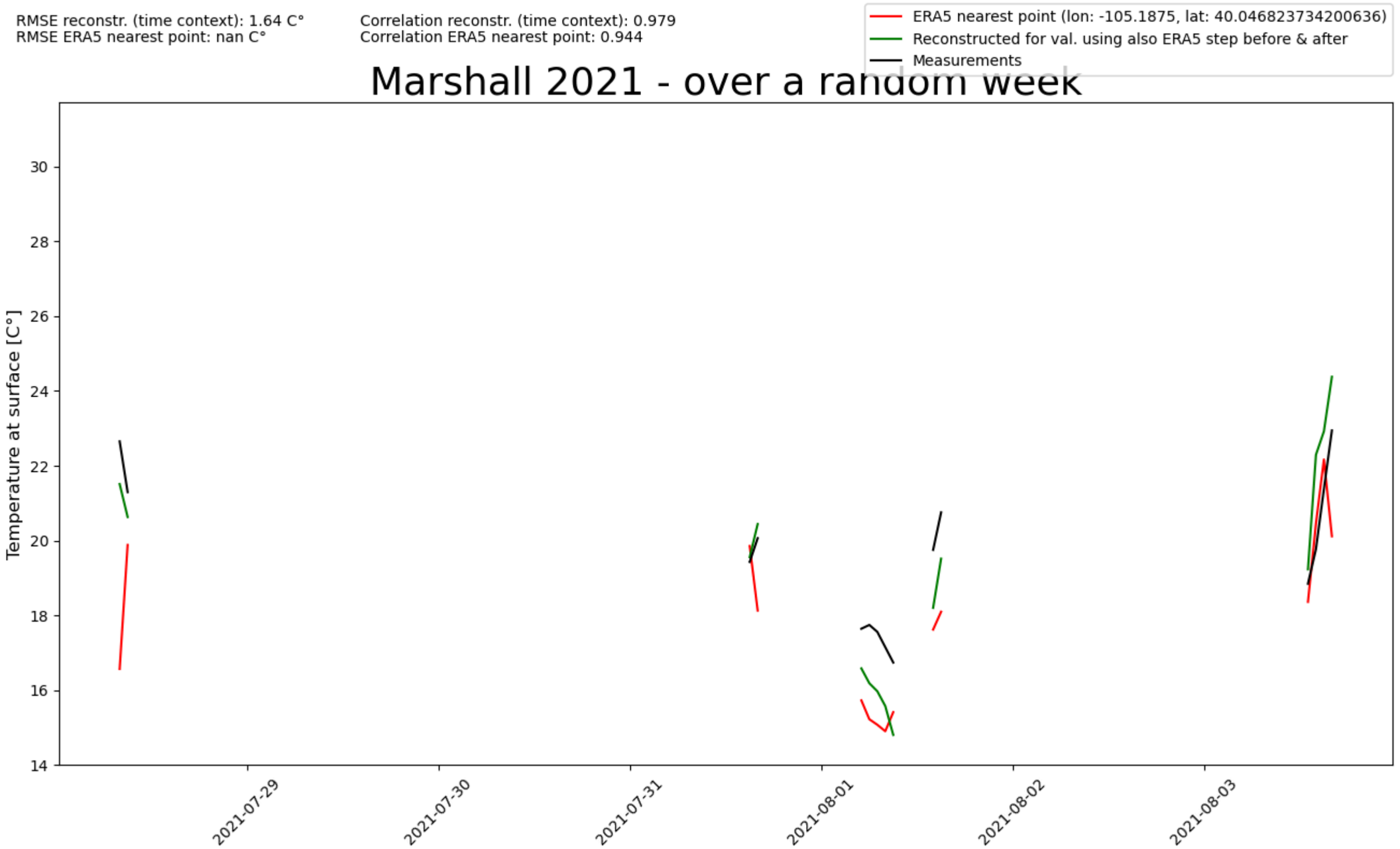
RMSE reconstr. (time context): 1.53 C°
RMSE ERA5 nearest point: nan C°

Correlation reconstr. (time context): 0.979
Correlation ERA5 nearest point: 0.944



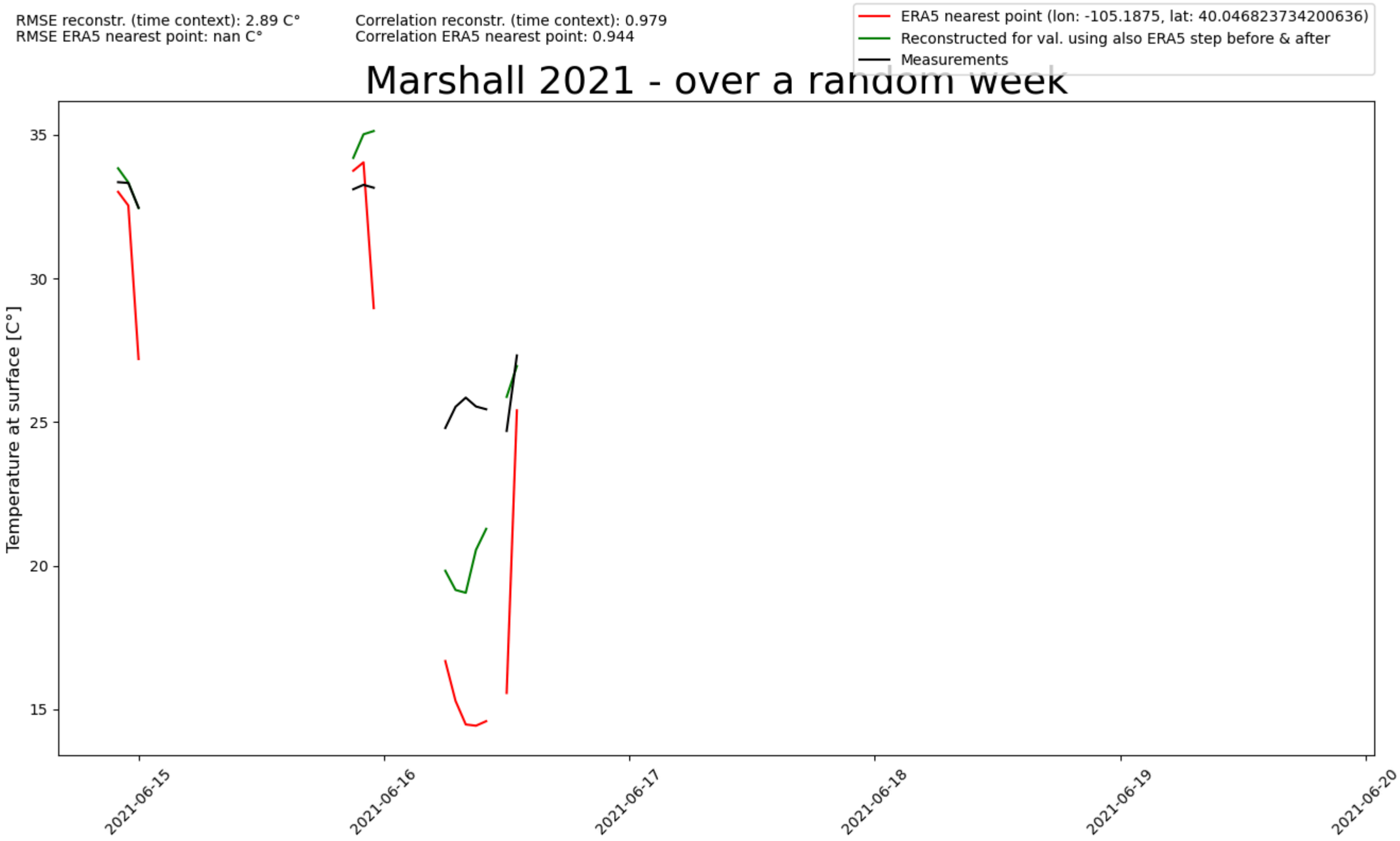
RMSE reconstr. (time context): 1.64 C°
RMSE ERA5 nearest point: nan C°

Correlation reconstr. (time context): 0.979
Correlation ERA5 nearest point: 0.944



RMSE reconstr. (time context): 2.89 C°
RMSE ERA5 nearest point: nan C°

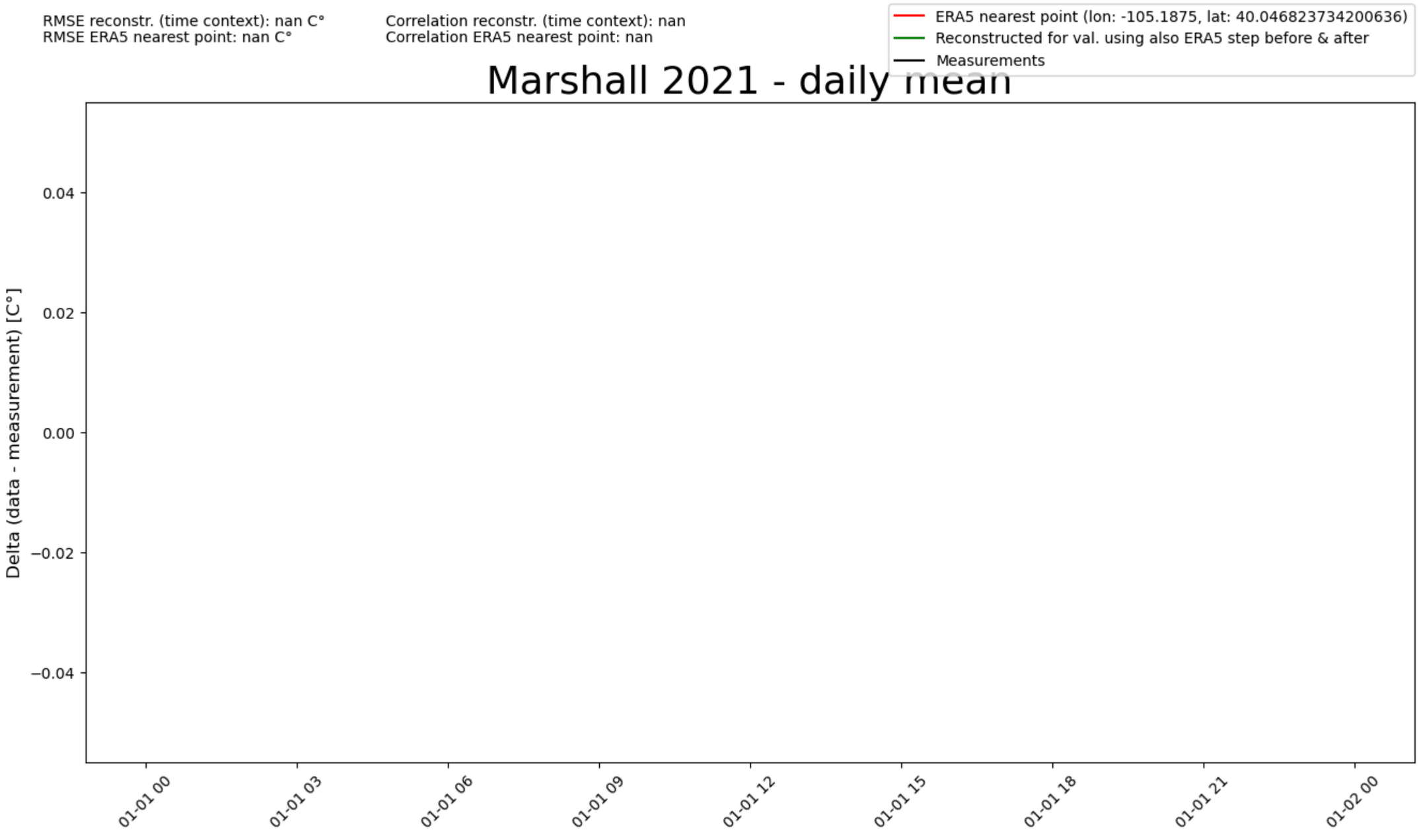
Correlation reconstr. (time context): 0.979
Correlation ERA5 nearest point: 0.944



Resample Data from hourly to daily or monthly

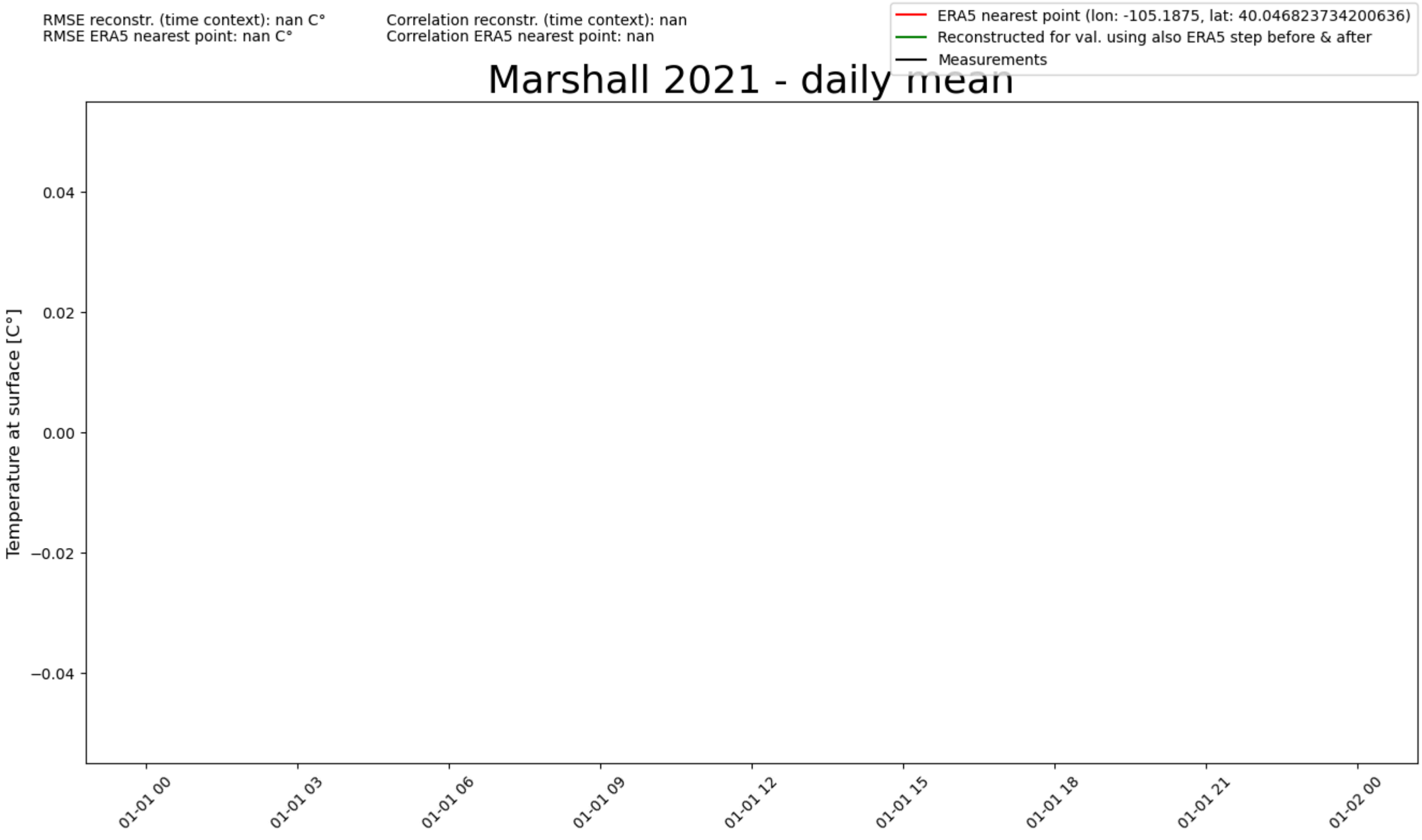
In [ ]:
```
# resample to daily mean
daily_df = hourly_df.resample("D").mean()
# drop nans
daily_df = daily_df.dropna()
title = f"{station_name} {test_year} - daily mean"
plot_n_steps_of_df(daily_df, as_delta=True, title=title, plot_trailing_time=True)
plot_n_steps_of_df(daily_df, as_delta=False, title=title, plot_trailing_time=True)
```

```
/tmp/ipykernel_1025179/953675197.py:46: RuntimeWarning: Mean of empty slice
  rmse_reconstructed_with_time_context = np.sqrt(np.nanmean((reconstructed_median_with_time_context_values[time_slice] - measurements_values[time_slice])**2))
/tmp/ipykernel_1025179/953675197.py:47: RuntimeWarning: Mean of empty slice.
  rmse_era5_nearest = np.sqrt(((era5_nearest_values[time_slice] - measurements_values[time_slice])**2).mean())
/home/k/k203179/.conda/envs/crai/lib/python3.10/site-packages/numpy/core/_methods.py:131: RuntimeWarning: invalid value encountered in scalar divide
  ret = ret / rcount
```

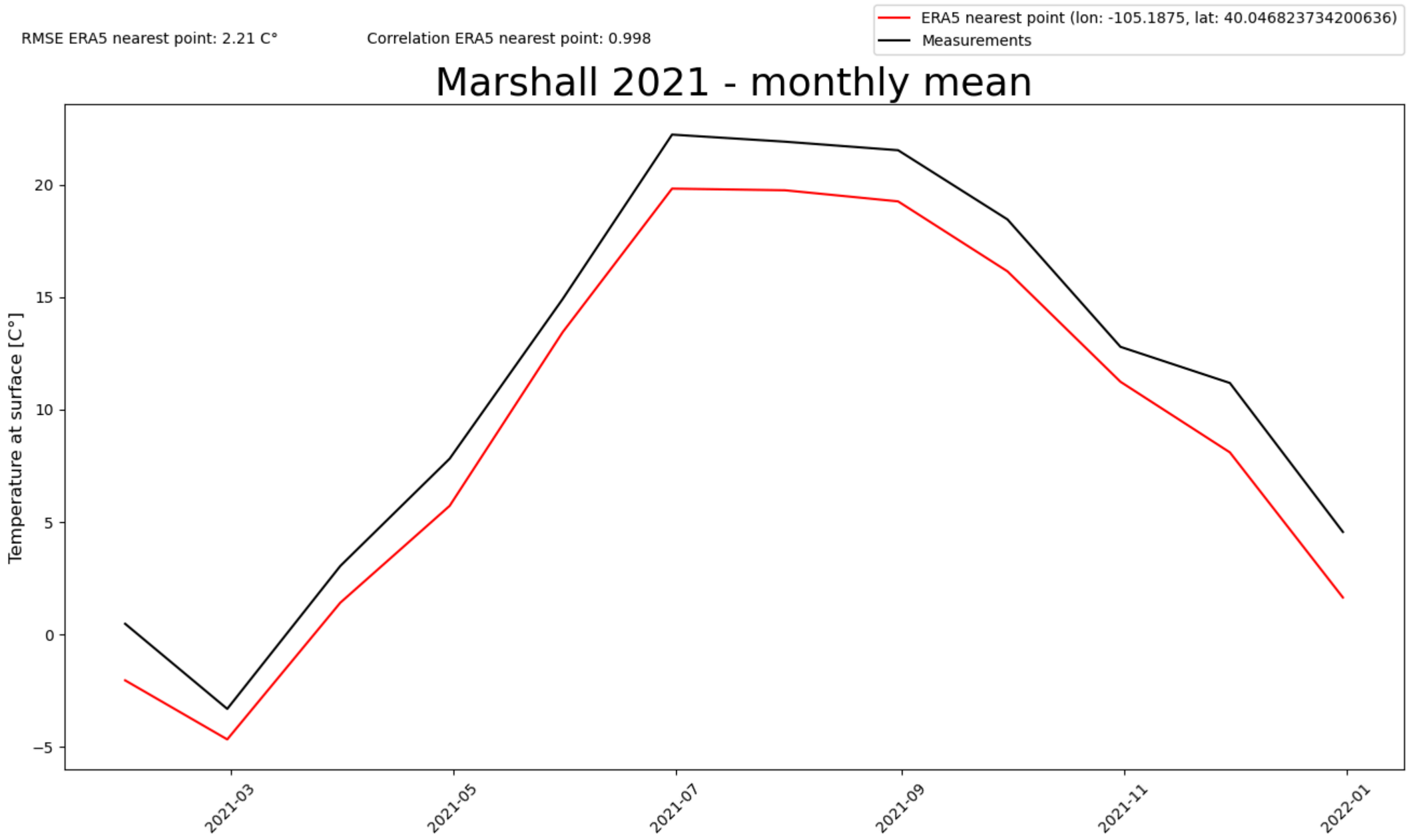


RMSE reconstr. (time context): nan C°
RMSE ERA5 nearest point: nan C°

Correlation reconstr. (time context): nan
Correlation ERA5 nearest point: nan

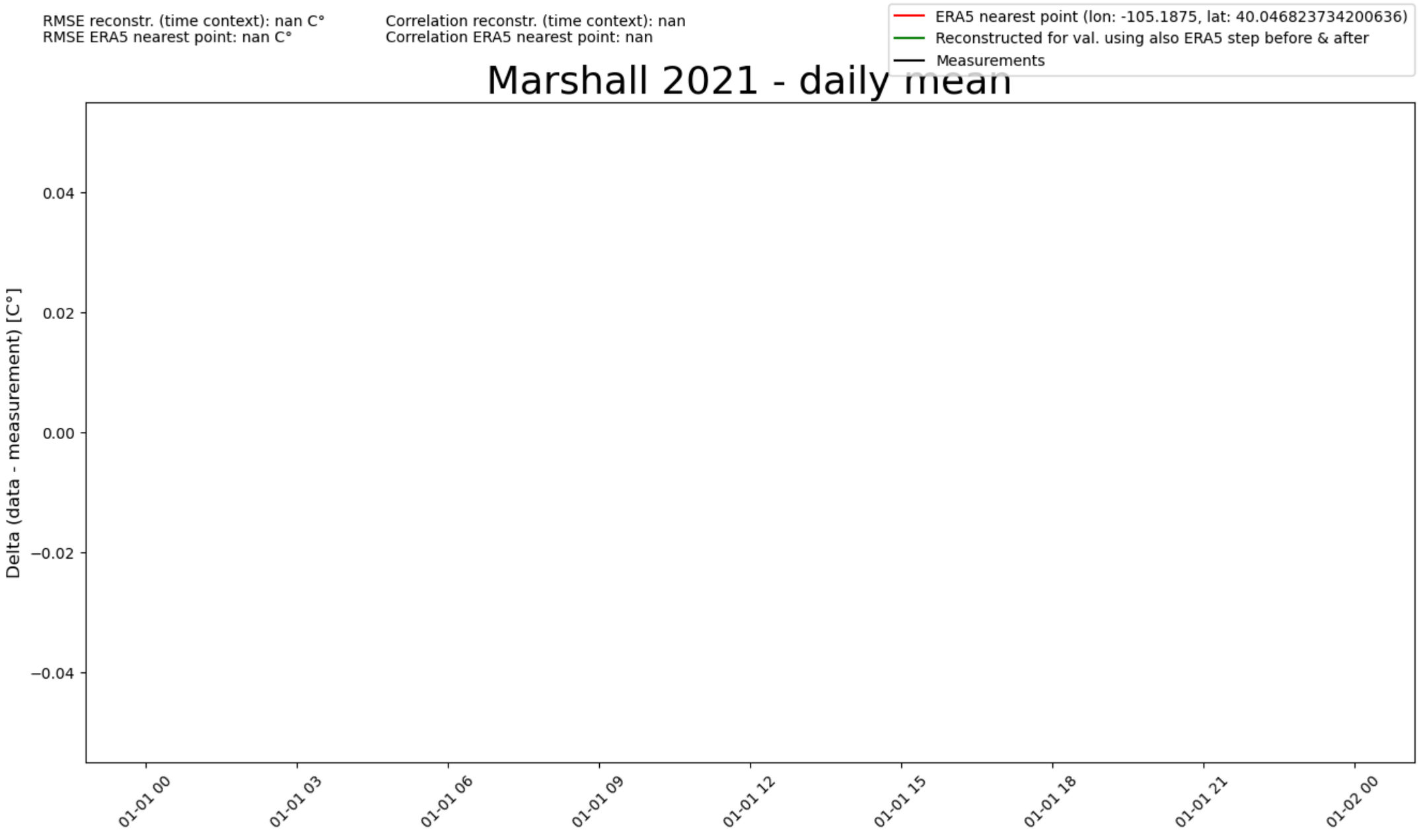


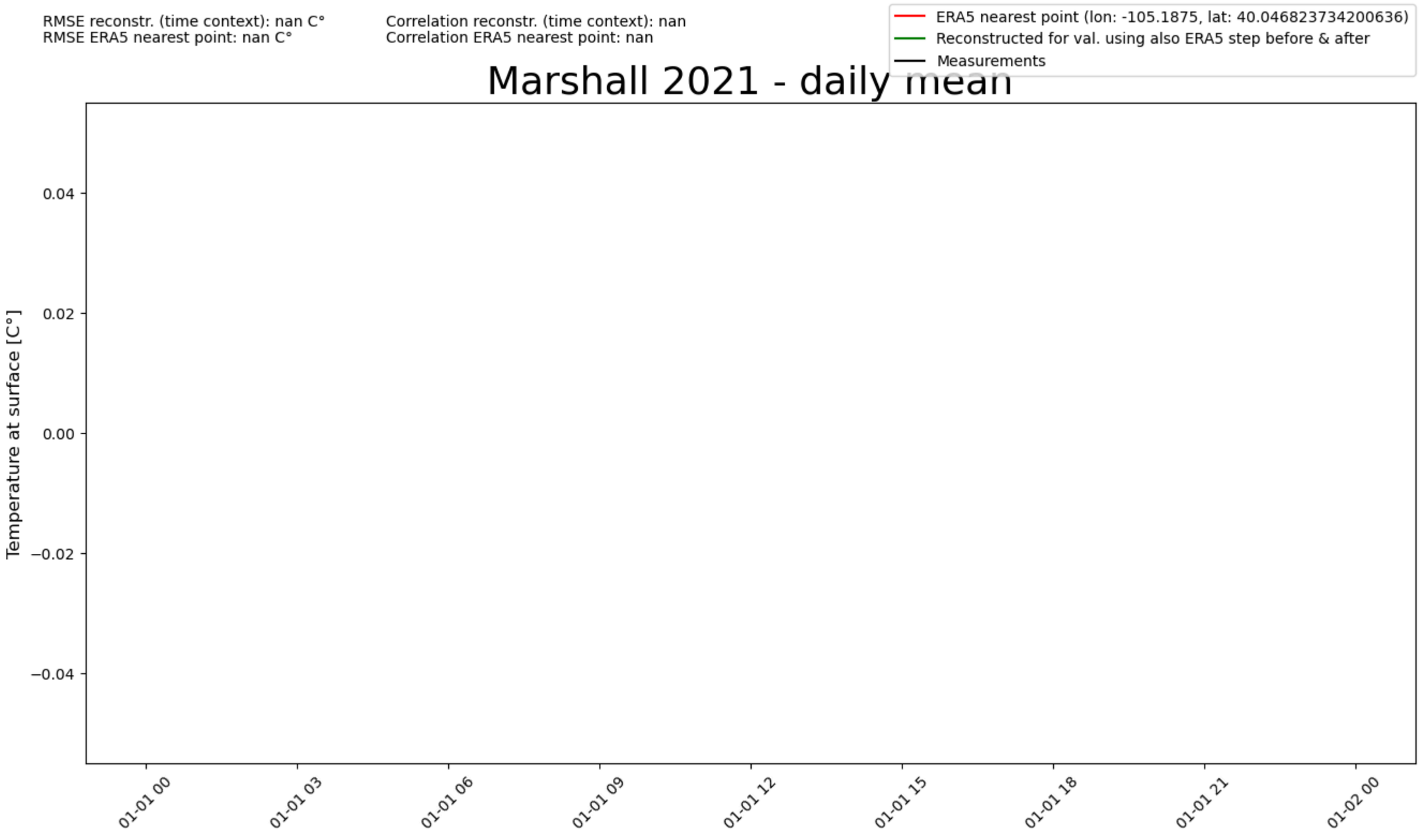
In [ ]:
```
# resample rows to monthly mean
df = hourly_df.resample("M").mean()
title = f"{station_name} {test_year} - monthly mean"
plot_n_steps_of_df(df, as_delta = False, title=title)
```



In [ ]:
```python
# resample to daily mean
daily_df = hourly_df.resample("D").mean()
# drop nans
daily_df = daily_df.dropna()
title = f"{station_name} {test_year} - daily mean"
plot_n_steps_of_df(daily_df, as_delta=True, title=title, plot_trailing_time=True)
plot_n_steps_of_df(daily_df, as_delta=False, title=title, plot_trailing_time=True)
```

```
/tmp/ipykernel_1025179/953675197.py:46: RuntimeWarning: Mean of empty slice
  rmse_reconstructed_with_time_context = np.sqrt(np.nanmean((reconstructed_median_with_time_context_values[time_slice] - measurements_values[time_slice])**2))
/tmp/ipykernel_1025179/953675197.py:47: RuntimeWarning: Mean of empty slice.
  rmse_era5_nearest = np.sqrt(((era5_nearest_values[time_slice] - measurements_values[time_slice])**2).mean())
/home/k/k203179/.conda/envs/crai/lib/python3.10/site-packages/numpy/core/_methods.py:131: RuntimeWarning: invalid value encountered in scalar divide
  ret = ret / rcount
```



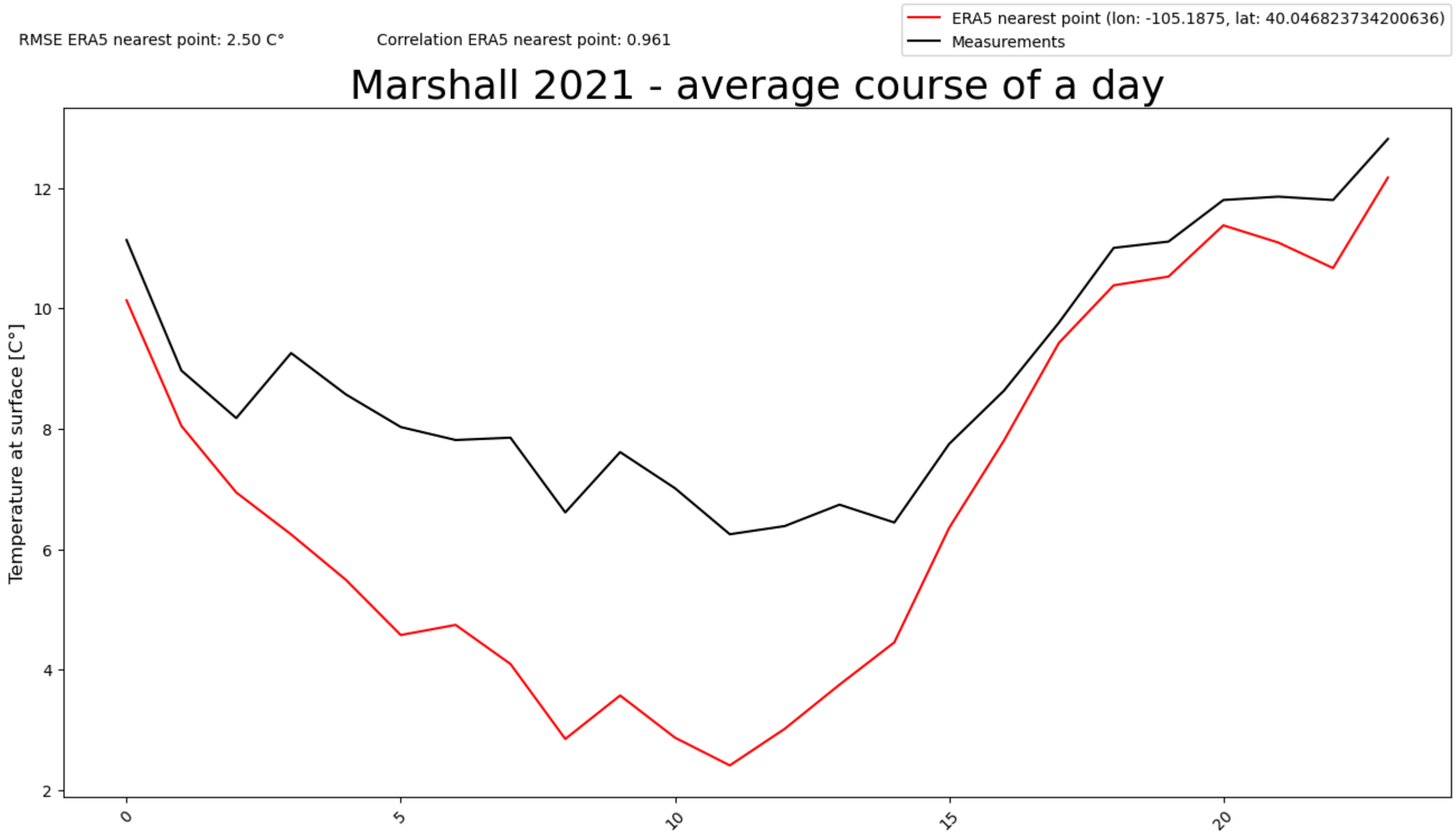


Average Course of a day

In [ ]:
```python
# calculate the mean of each 24 hours over the whole year

day_course_df = hourly_df.groupby(hourly_df.index.hour).mean()
title = f"{station_name} {test_year} - average course of a day"
plot_n_steps_of_df(day_course_df, as_delta = False, title=title)
```

RMSE ERA5 nearest point: 2.50 C°

Correlation ERA5 nearest point: 0.961

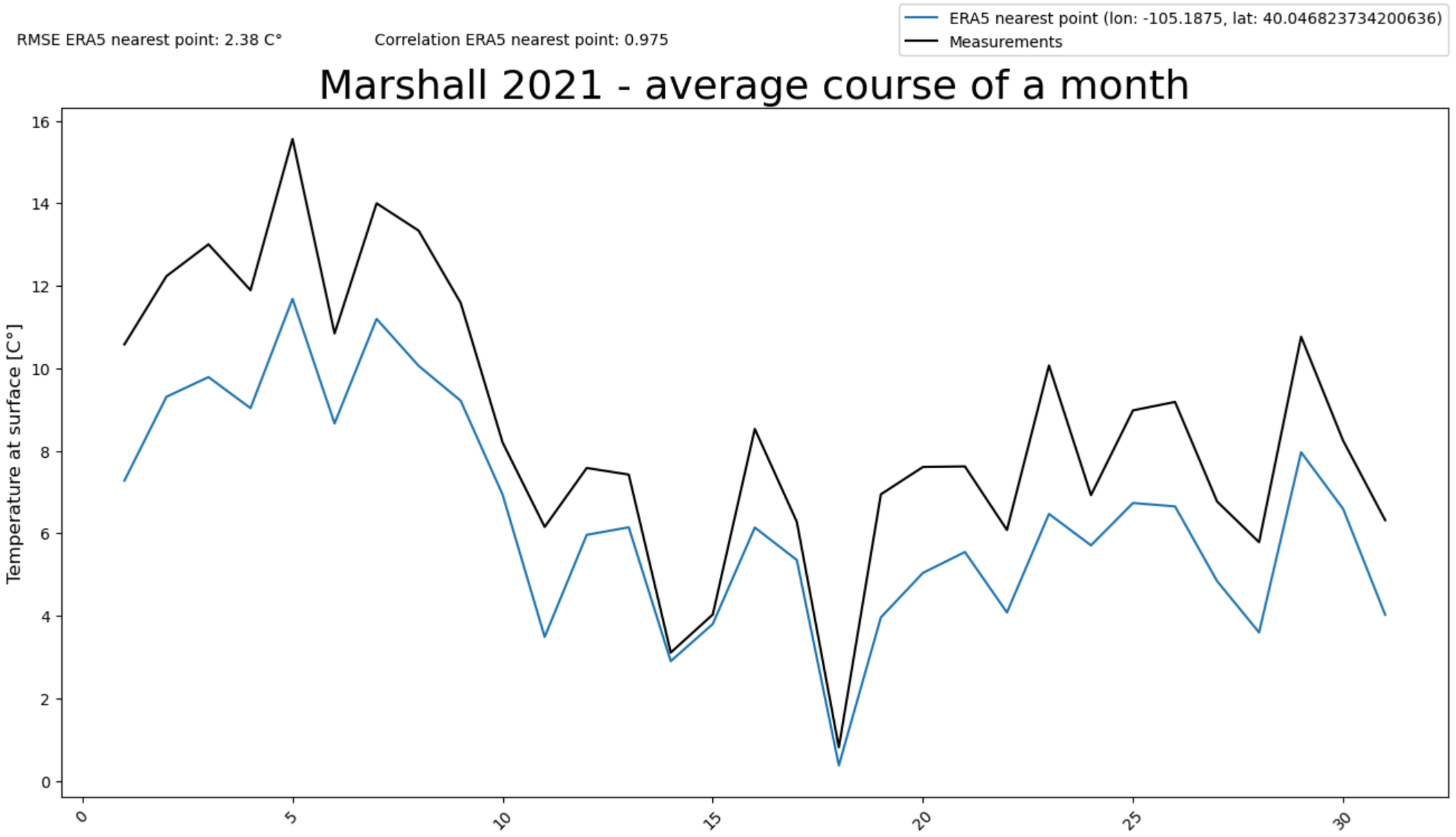


Average Course of a month

In [ ]:
```
# calculate the mean of each day of a month over the whole year

month_course_df = hourly_df.groupby(hourly_df.index.day).mean()
title = f"{station_name} {test_year} - average course of a month"
plot_n_steps_of_df(month_course_df, as_delta = False, title=title)
```

RMSE ERA5 nearest point: 2.38 C°

Correlation ERA5 nearest point: 0.975



Evaluate for the actually missing time steps

In [ ]:
```
evaluate_wrapper(use_time_context = False, iter = at_iterations, station = station_name, reconstruct_gaps=True)
output_filled_gaps_ds = DataSet(output_file_path, name="Reconstructed gaps")
output_actual_gaps_data = xr.open_dataset(output_file_path)
```

```
/home/k/k203179/.conda/envs/crai/lib/python3.10/site-packages/climatereconstructionai/utils/normalizer.py:10: RuntimeWarning: Mean of empty slice
  img_mean.append(np.nanmean(np.array(img_data[i])))
/home/k/k203179/.conda/envs/crai/lib/python3.10/site-packages/numpy/lib/nanfunctions.py:1879: RuntimeWarning: Degrees of freedom <= 0 for slice.
  var = nanvar(a, axis=axis, dtype=dtype, out=out, ddof=ddof,
100%|██████████| 1/1 [00:14<00:00, 14.17s/it]
```

In [ ]:
```python
def create_filled_in_gaps_df(full_era5_data, filled_gaps_data, measurements_data):

    import pandas as pd

    def single_df(time, tas, name):
        df = pd.DataFrame()
        df["time"] = time
        df.set_index("time", inplace=True)
        df[name] = tas
        return df

    lon_left_idx, lon_right_idx, lon_nearest_idx = get_left_right_nearest_elem_in_sorted_array(era5_data.lon.values, station_lon % 360)
    lat_left_idx, lat_right_idx, lat_nearest_idx = get_left_right_nearest_elem_in_sorted_array(era5_data.lat.values, station_lat)

    era5_nearest_values = full_era5_data.variables["tas"][:, lon_nearest_idx, lat_nearest_idx]
    reconstructed_values = filled_gaps_data.variables["tas"].stack(grid=['lat', 'lon']).values
    reconstructed_values = [np.median(x) for x in reconstructed_values]

    measurements_values = measurements_data.variables["tas"].stack(grid=['lat', 'lon']).values
    measurements_values = [np.median(x) for x in measurements_values]

    era_df = single_df(full_era5_data.variables["time"], era5_nearest_values, "era5_nearest")
    reconstructed_df = single_df(filled_gaps_data.variables["time"], reconstructed_values, "filled_in_gaps")
    measurements_df = single_df(measurements_data.variables["time"], measurements_values, "measurements")

    # merge on time
    merged = pd.concat([era_df, reconstructed_df, measurements_df], axis=1)
    # drop rows where reconstructed and measurements are both nan simultaneously
    return merged.dropna(subset=["filled_in_gaps", "measurements"], how="all")
```

In [ ]:
```python
hourly_filled_gaps_df = create_filled_in_gaps_df(era5_full_data, output_actual_gaps_data, measurements_data)
hourly_filled_gaps_df
```

Out[ ]:

time	era5_nearest	filled_in_gaps	measurements
2017-03-01 05:00:00	269.790222	269.832092	NaN
2017-03-01 06:00:00	270.518555	267.737396	NaN
2017-03-01 07:00:00	270.043579	267.802856	NaN
2017-03-01 08:00:00	263.223724	268.856720	NaN
2017-03-01 09:00:00	262.905365	266.871277	NaN
...	...	...	...
2023-11-29 14:00:00	262.271576	276.102234	NaN
2023-11-29 15:00:00	263.555298	277.880676	NaN
2023-11-29 16:00:00	268.792786	277.371429	NaN
2023-11-29 17:00:00	274.536865	278.312714	NaN
2023-11-29 18:00:00	278.119110	278.821899	NaN

59150 rows × 3 columns

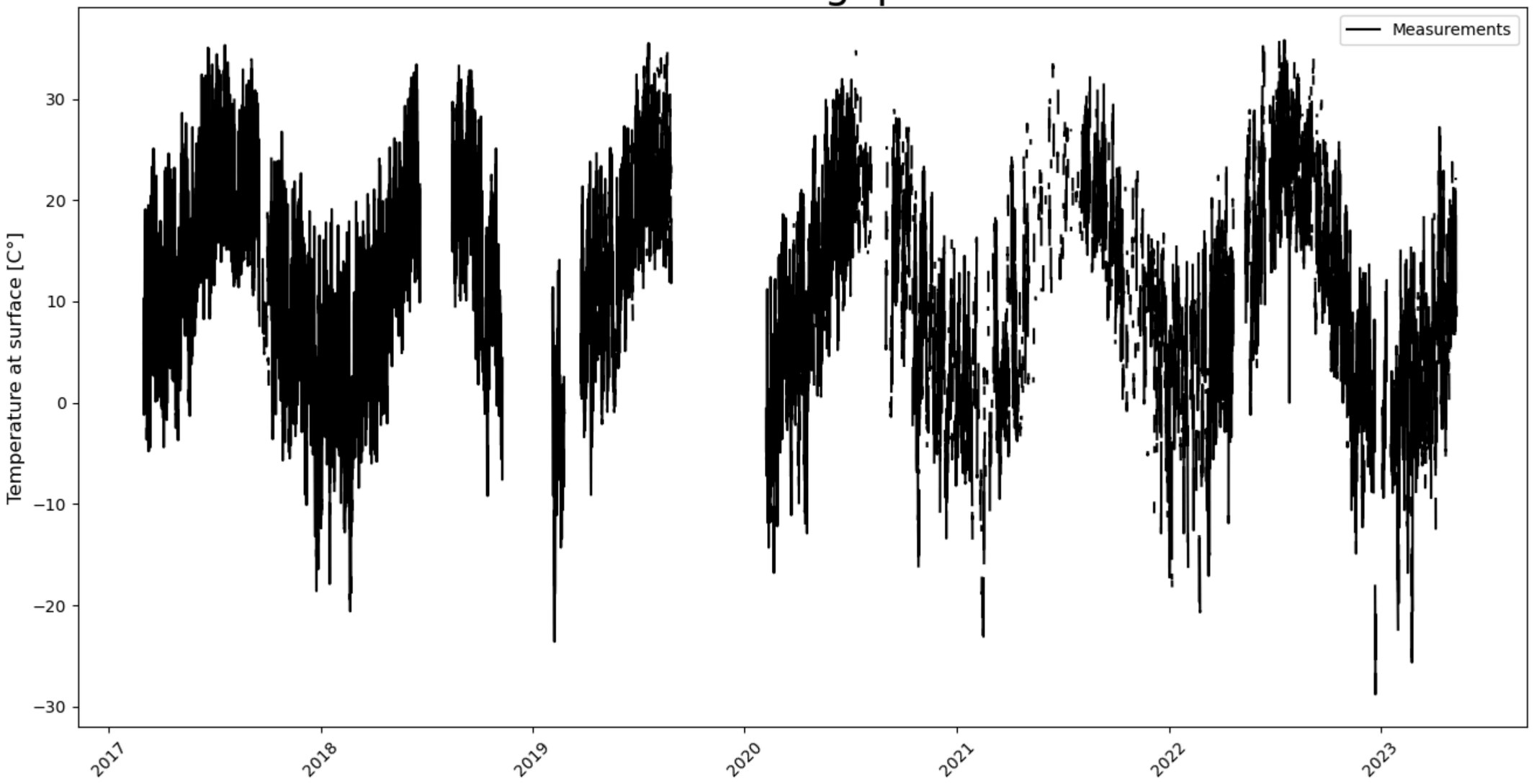
In [ ]:
```python
def plot_n_steps_of_filled_in_df(df, n=None, title=None, show_in_steps=False):

    time = df.index.values

    era5_nearest_values = df["era5_nearest"].values - 273.15
    reconstructed_median_values = df["filled_in_gaps"].values - 273.15

    measurements_values = df["measurements"].values - 273.15

    import random

    if n is None:
        n = len(df)

    break_loop = 0
    we_have_measurements_and_reconstructed_values_in_this_timeframe = False
    while not we_have_measurements_and_reconstructed_values_in_this_timeframe and break_loop < 1000:

        # random slice of n consecutive datapoints

        slice_start = random.randint(0, len(time) - n)
        time_slice = slice(slice_start, slice_start + n)

        if n == len(df):
            we_have_measurements_and_reconstructed_values_in_this_timeframe = True
        else:
            break_loop += 1
            # check in time slice if we have measurements and reconstructed values
            we_have_measurements_and_reconstructed_values_in_this_timeframe = not (np.all(np.isnan(measurements_values[time_slice])) or np.all(np.isnan(reconstructed_median_va

    time = time[time_slice]

    make_plots_with_era5 = [False, True, True] if show_in_steps else [True]
    make_plots_with_filled = [False, False, True] if show_in_steps else [True]
```

```
    for show_era, show_filled in zip(make_plots_with_era5, make_plots_with_filled):

        plt.ylabel("Temperature at surface [C°]")


        # x-axis labels 90 degrees
        plt.xticks(rotation=45)

        # title

        if title is not None:
            plt.title(title)


        # font size of legend
        plt.rcParams.update({'font.size': 10})

        # font size of axis labels
        plt.rcParams.update({'axes.labelsize': 12})

        # font size of title
        plt.rcParams.update({'axes.titlesize': 26})


        # figure size A4 landscape
        plt.gcf().set_size_inches(16, 8)

        if show_era:
            plt.plot(time, era5_nearest_values[time_slice], label="ERA5 nearest point", color="grey", linestyle="--" if n <= 168 else "-")

        plt.plot(time, measurements_values[time_slice], label="Measurements", color="black", linestyle="-", marker="o" if n <= 168 else "")

        if show_filled:
            plt.plot(time, reconstructed_median_values[time_slice], label="Reconstructed", color="#d13297", linestyle="-", marker="o" if n <= 168 else "")

        plt.legend()
        plt.show()
```

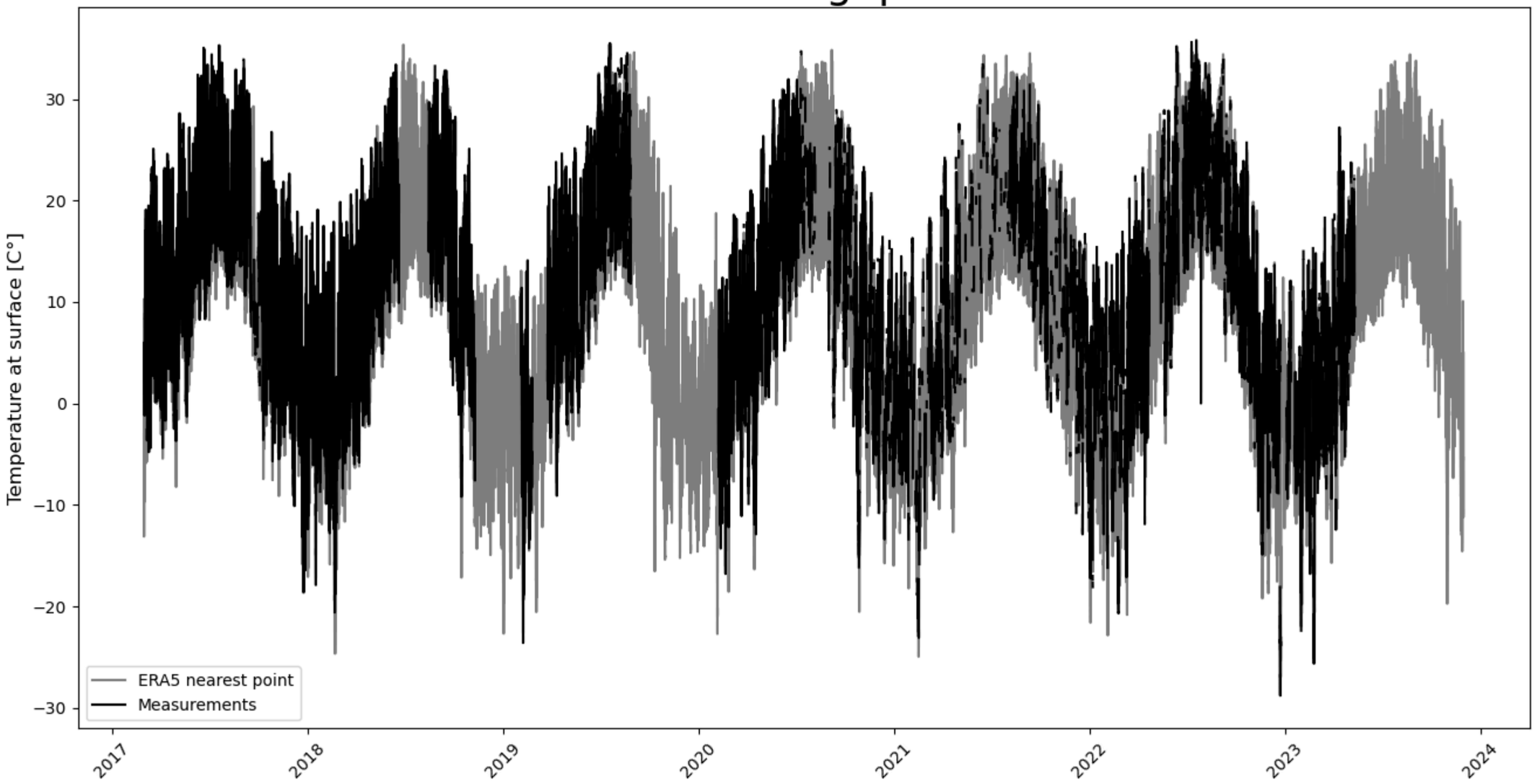
In [ ]:

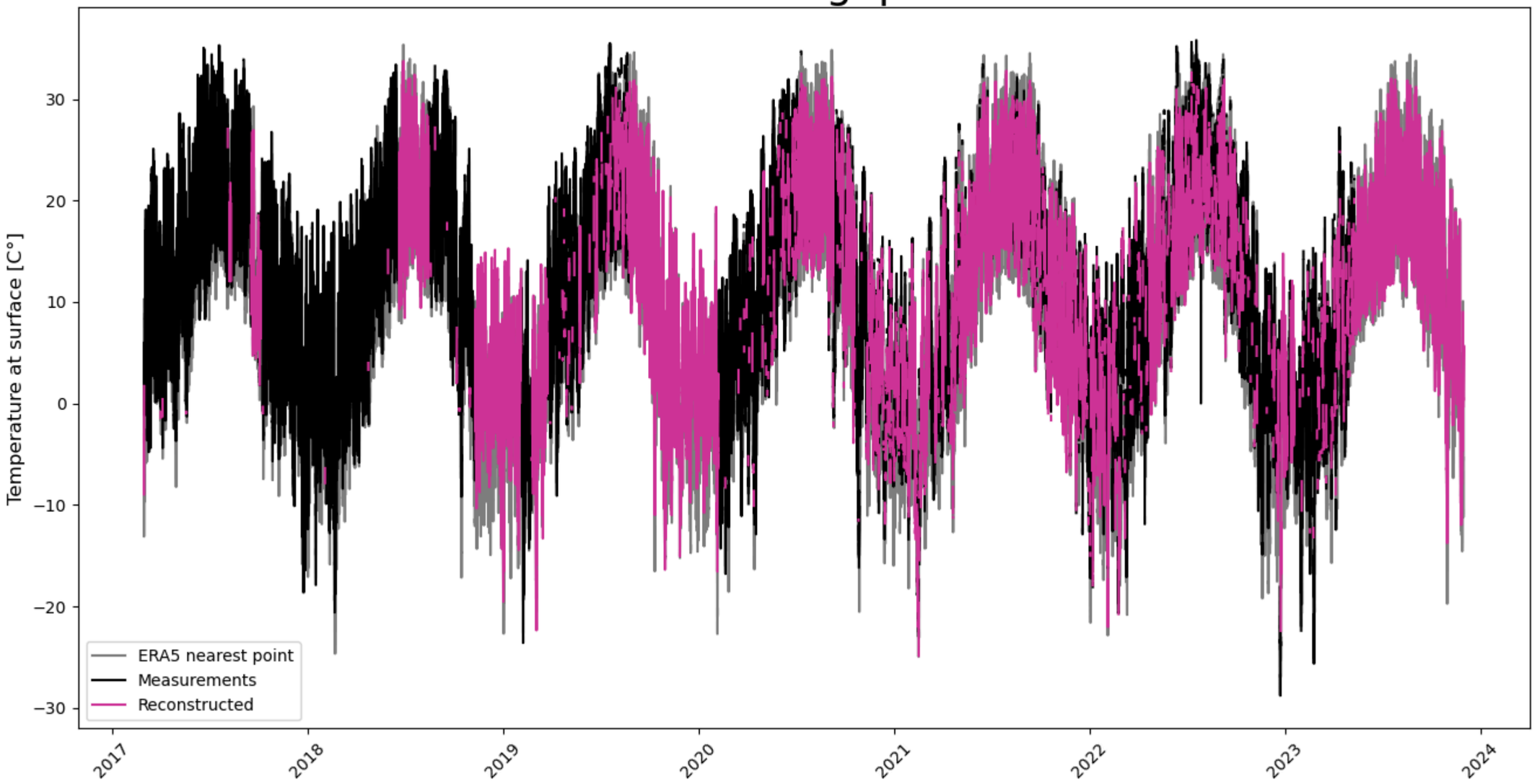
```
plot_n_steps_of_filled_in_df(hourly_filled_gaps_df, title=f"{station_name} - reconstructed gaps in measurements", show_in_steps=True)
```

Marshall - reconstructed gaps in measurements



Marshall - reconstructed gaps in measurements

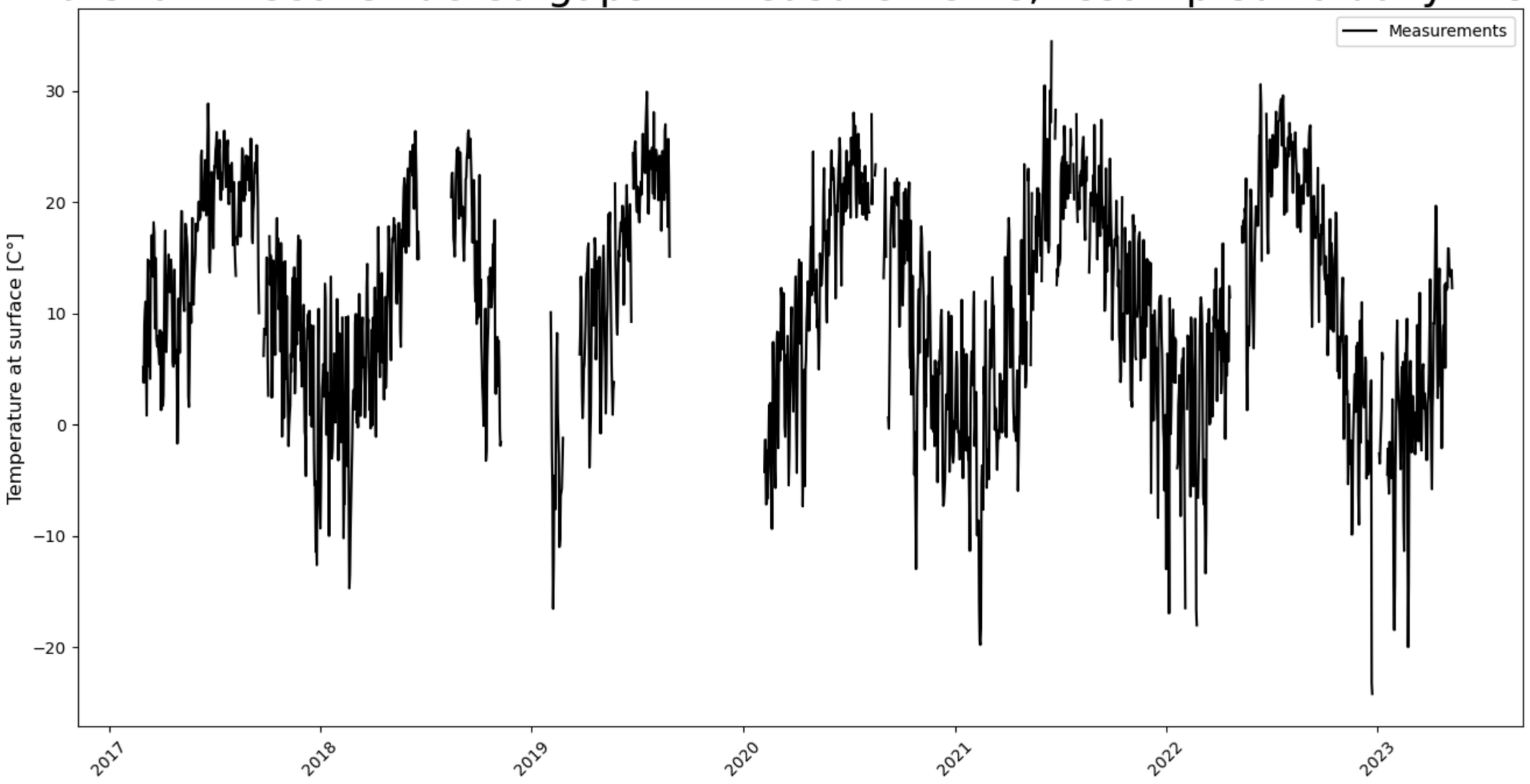




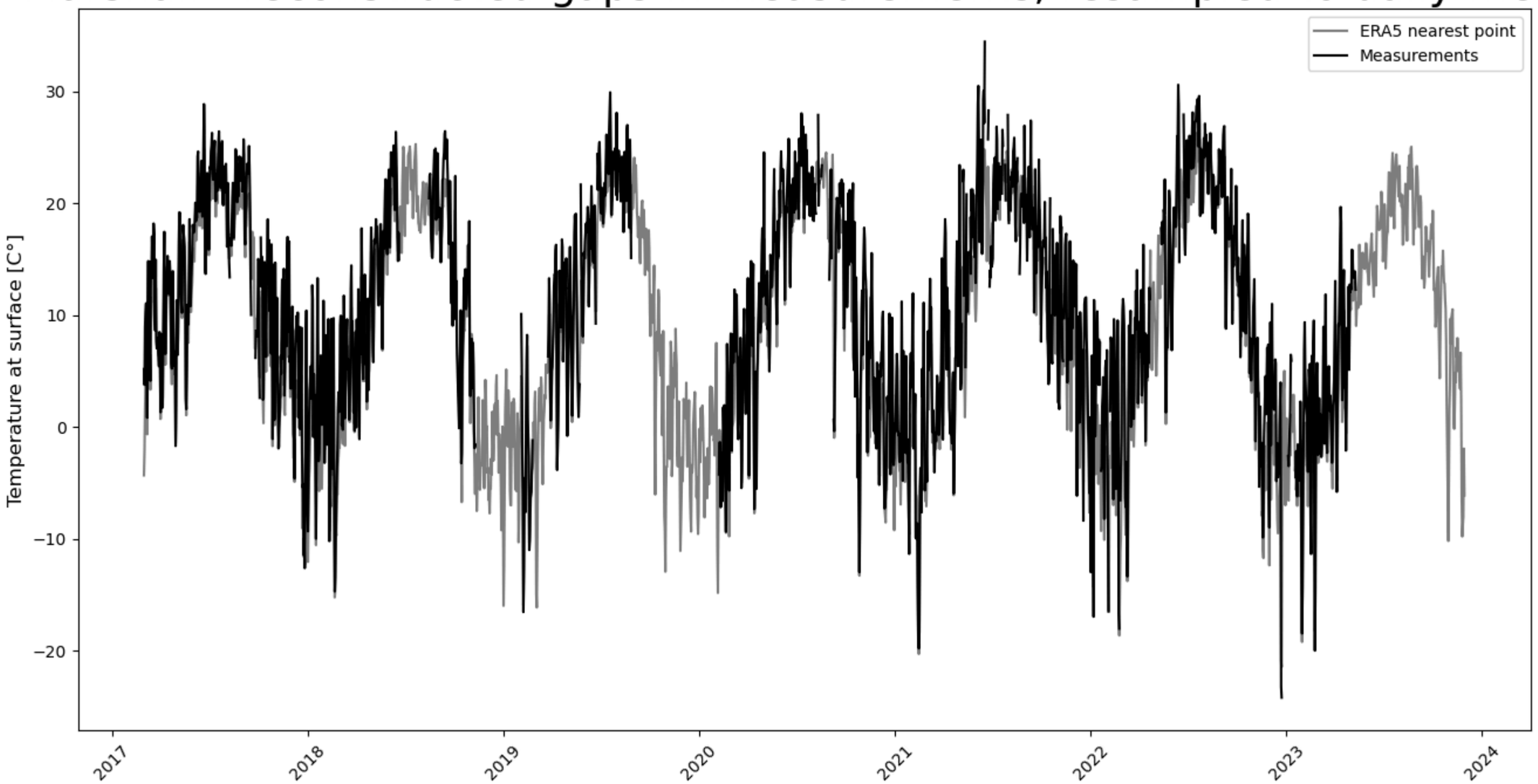
Resampled to Daily Mean

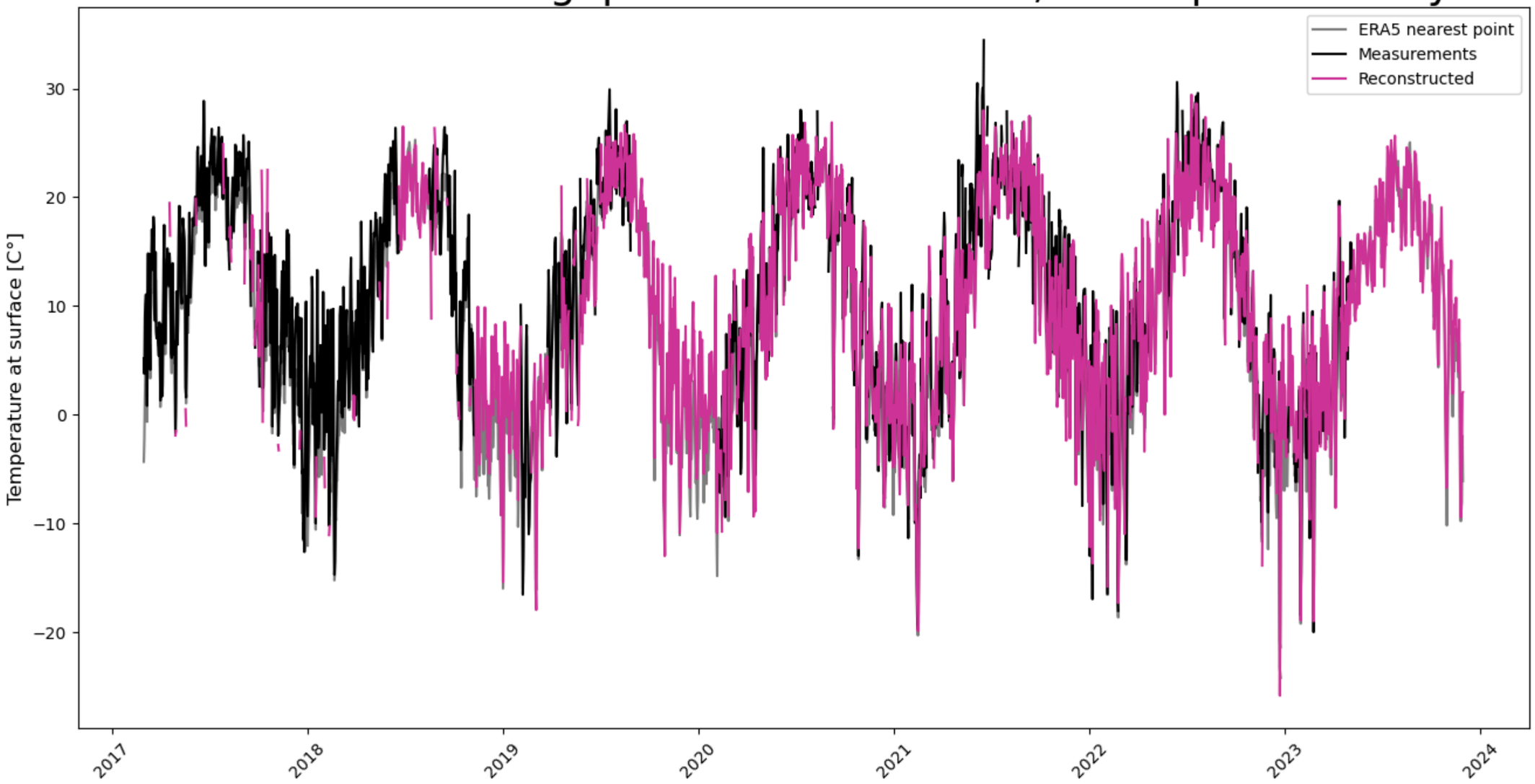
In [ ]:
```
daily_filled_gaps_df = hourly_filled_gaps_df.resample("D").mean()

plot_n_steps_of_filled_in_df(daily_filled_gaps_df, title=f"{station_name} - reconstructed gaps in measurements, resampled to daily mean", show_in_steps=True)
```

Marshall - reconstructed gaps in measurements, resampled to daily mean



Marshall - reconstructed gaps in measurements, resampled to daily mean

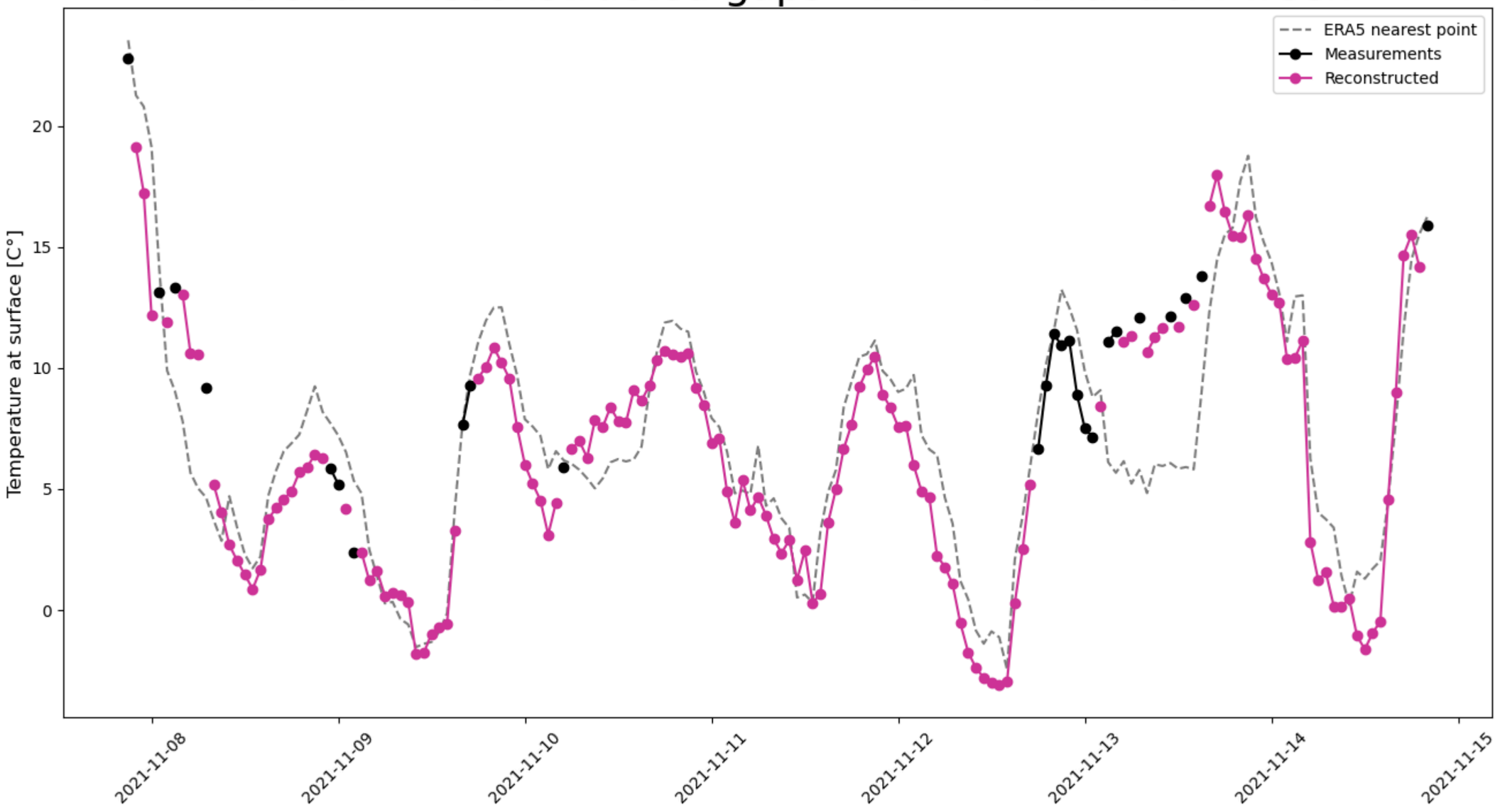




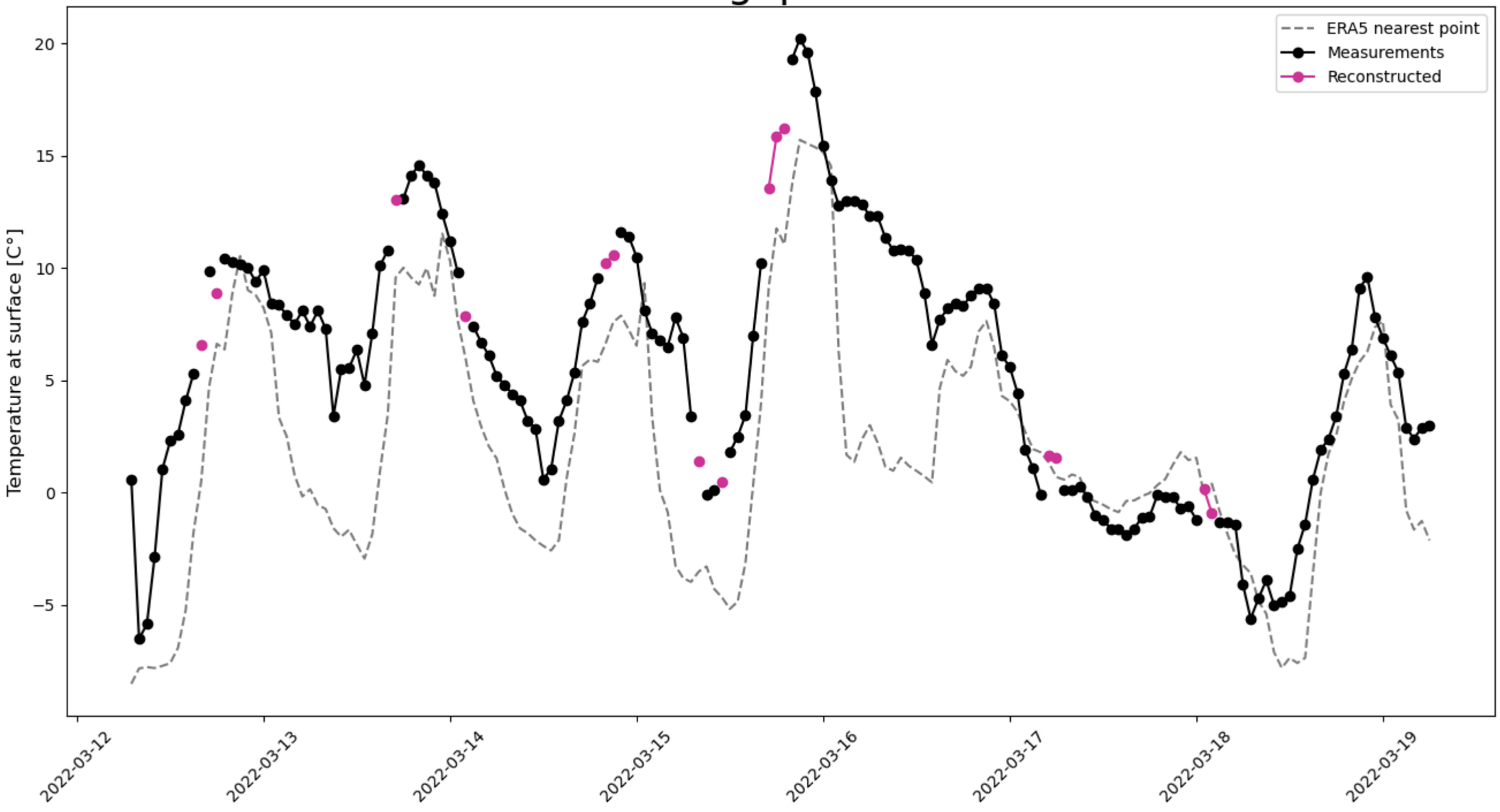
Plot random weeks

In [ ]:
```
for i in range(10):
    plot_n_steps_of_filled_in_df(hourly_filled_gaps_df, n=168, title=f"{station_name} - reconstructed gaps - view of a random week")
```

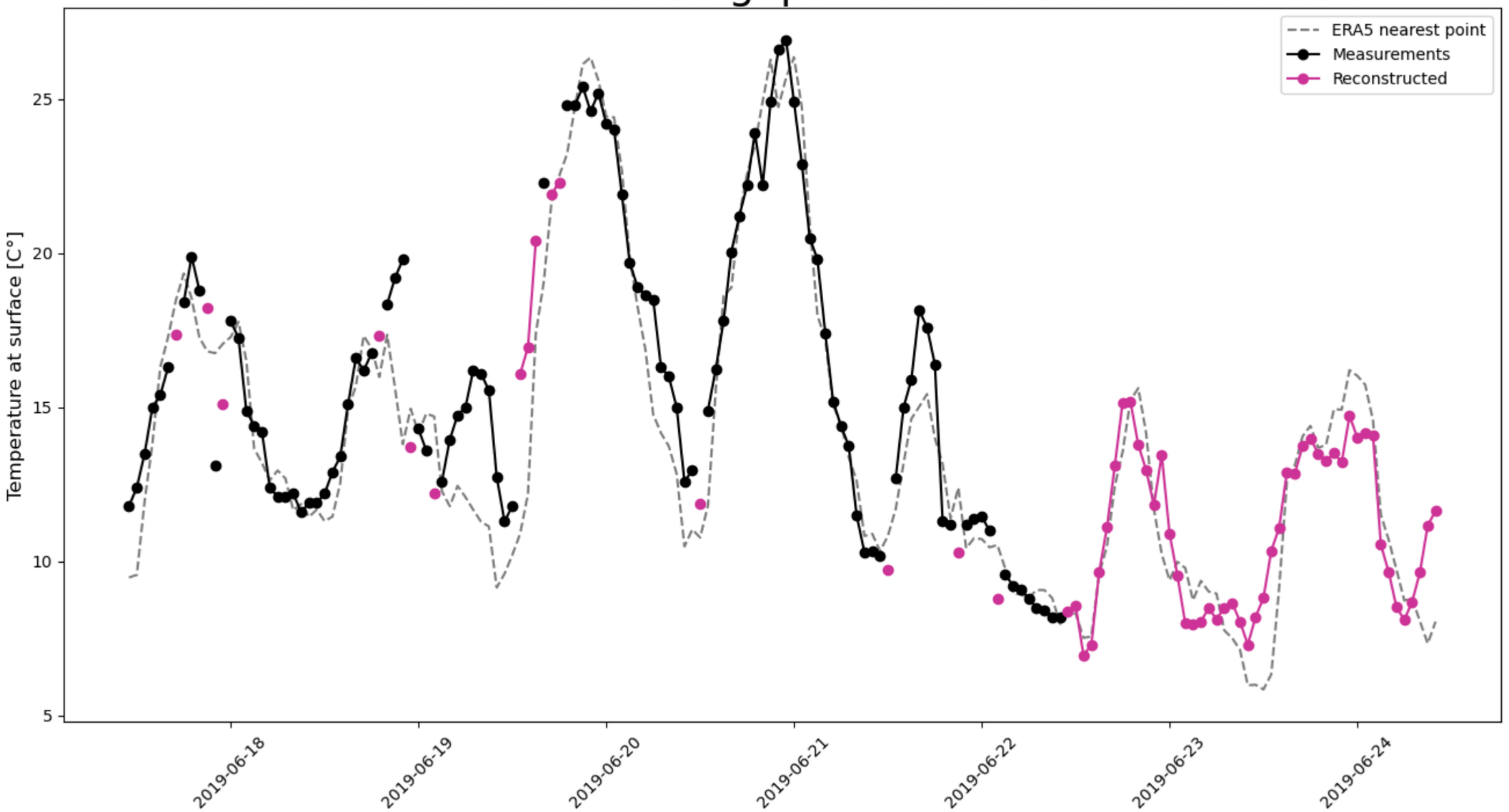
Marshall - reconstructed gaps - view of a random week



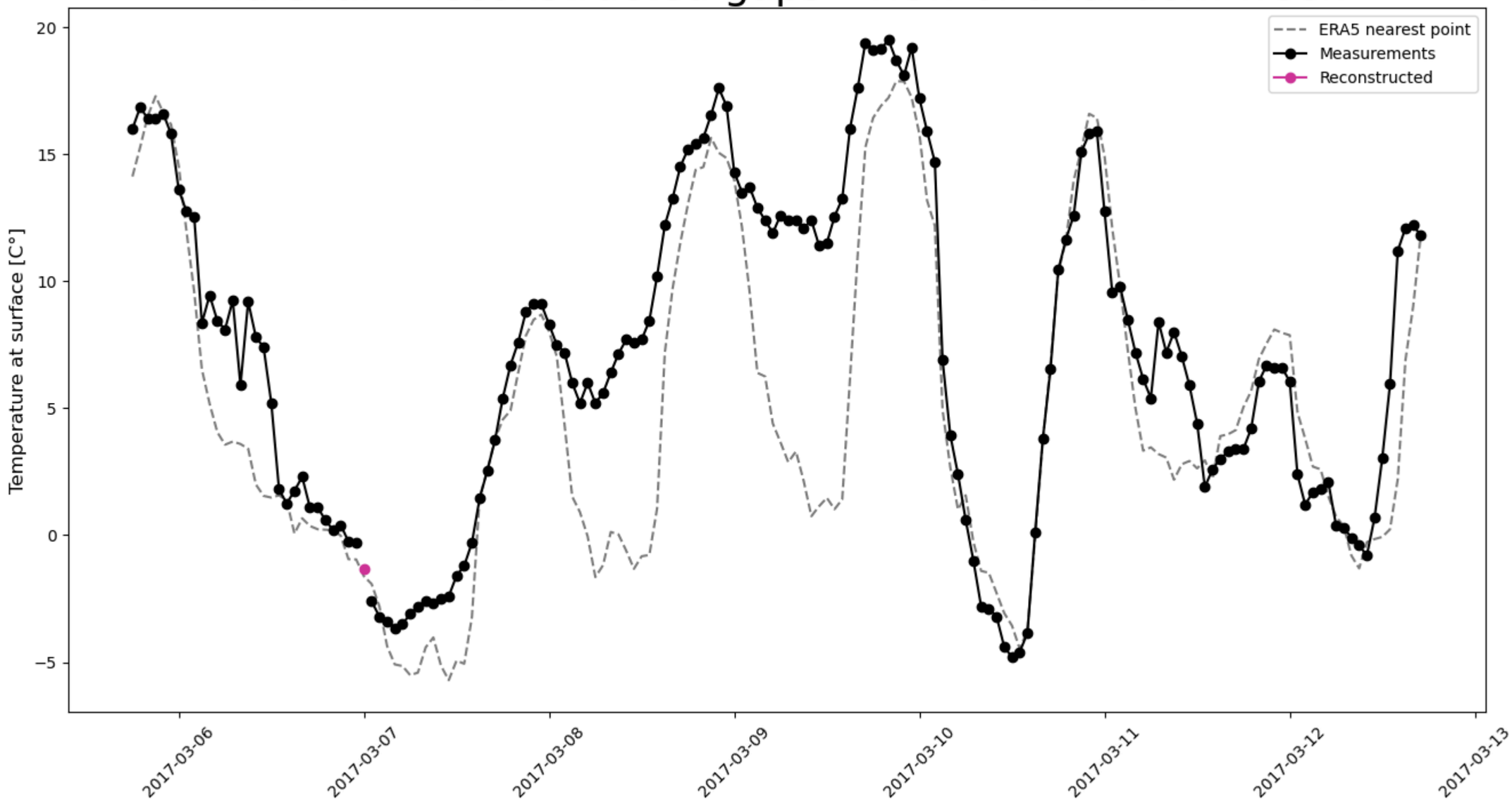
Marshall - reconstructed gaps - view of a random week



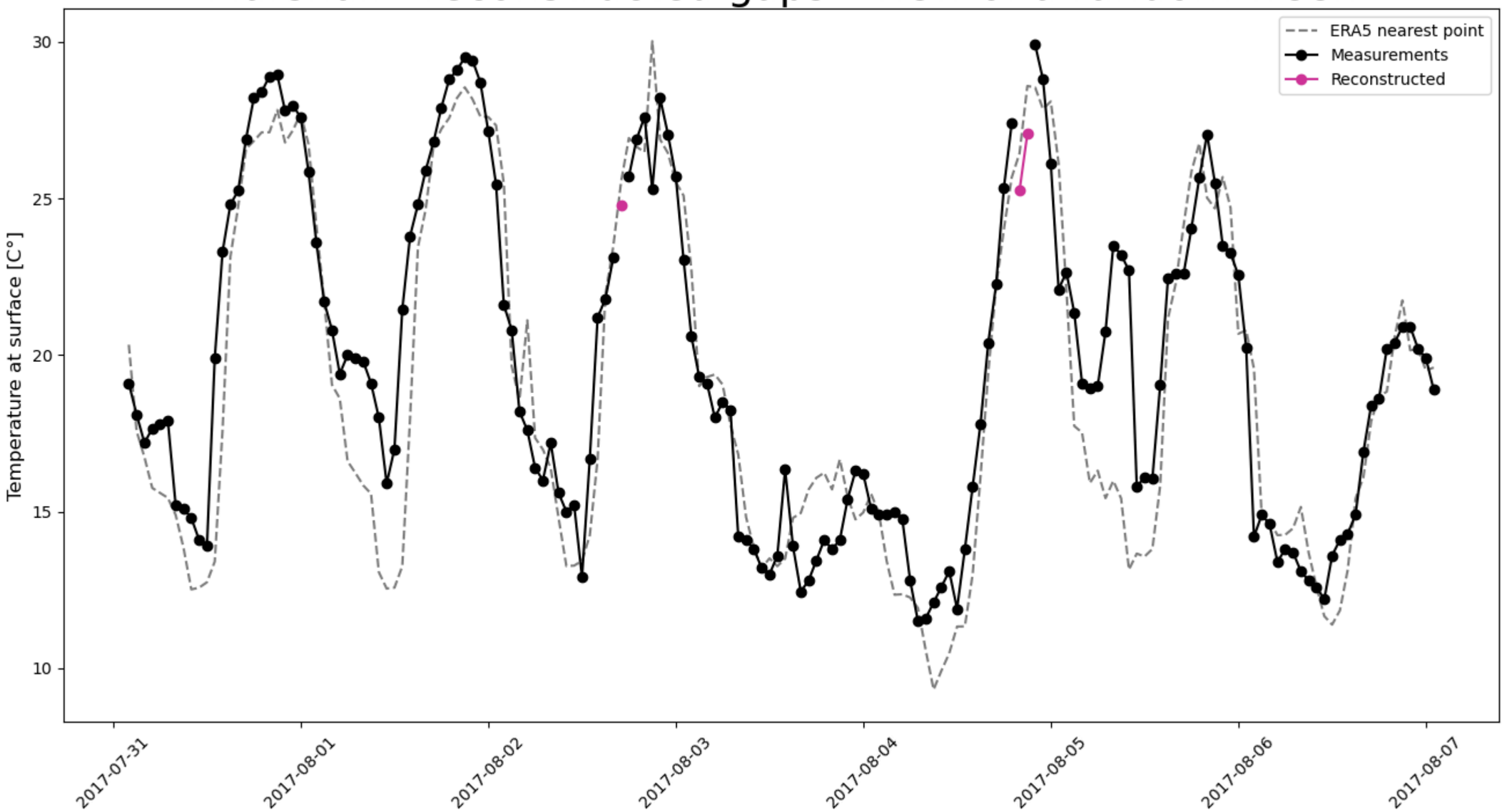
Marshall - reconstructed gaps - view of a random week



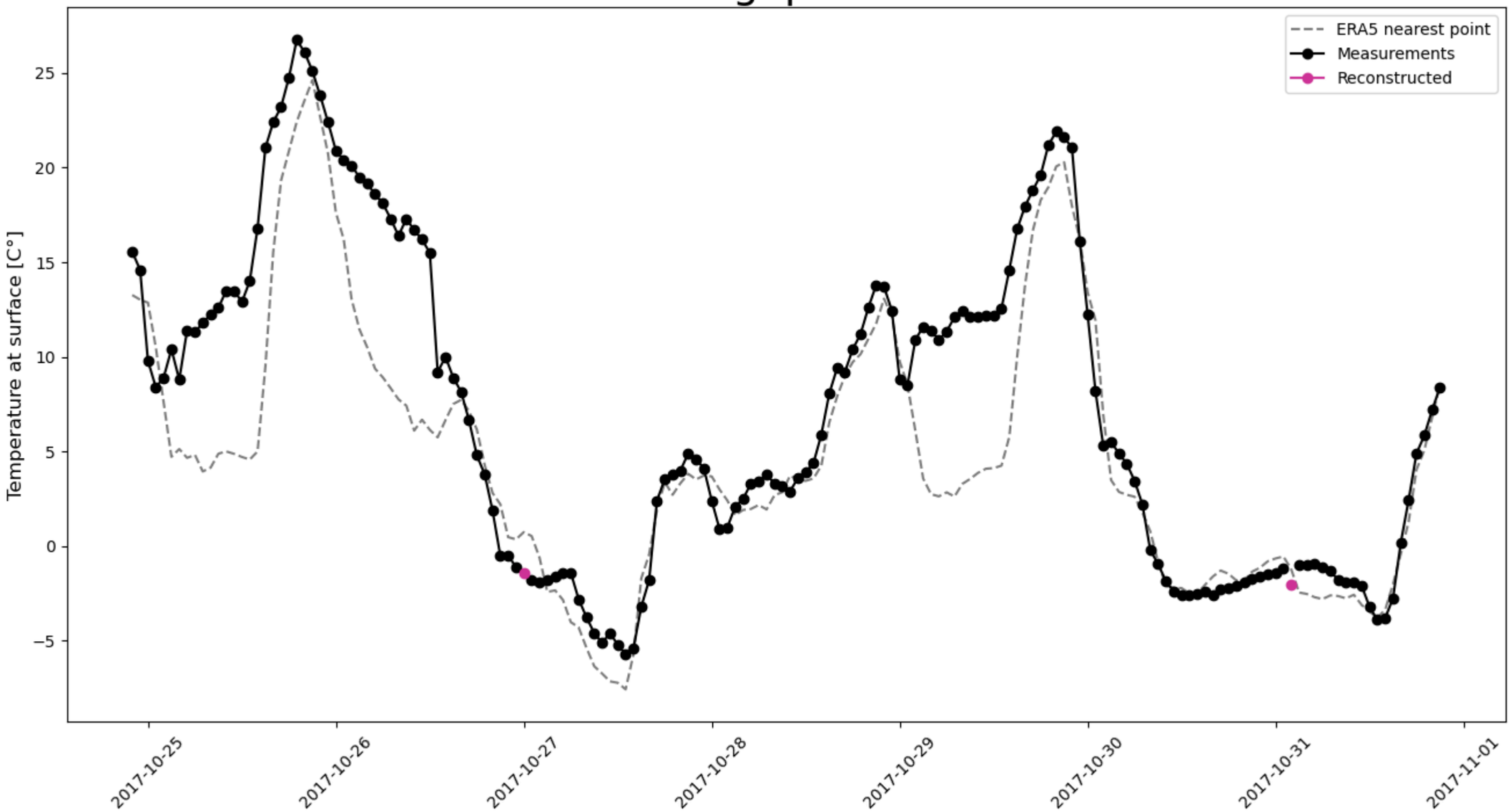
Marshall - reconstructed gaps - view of a random week

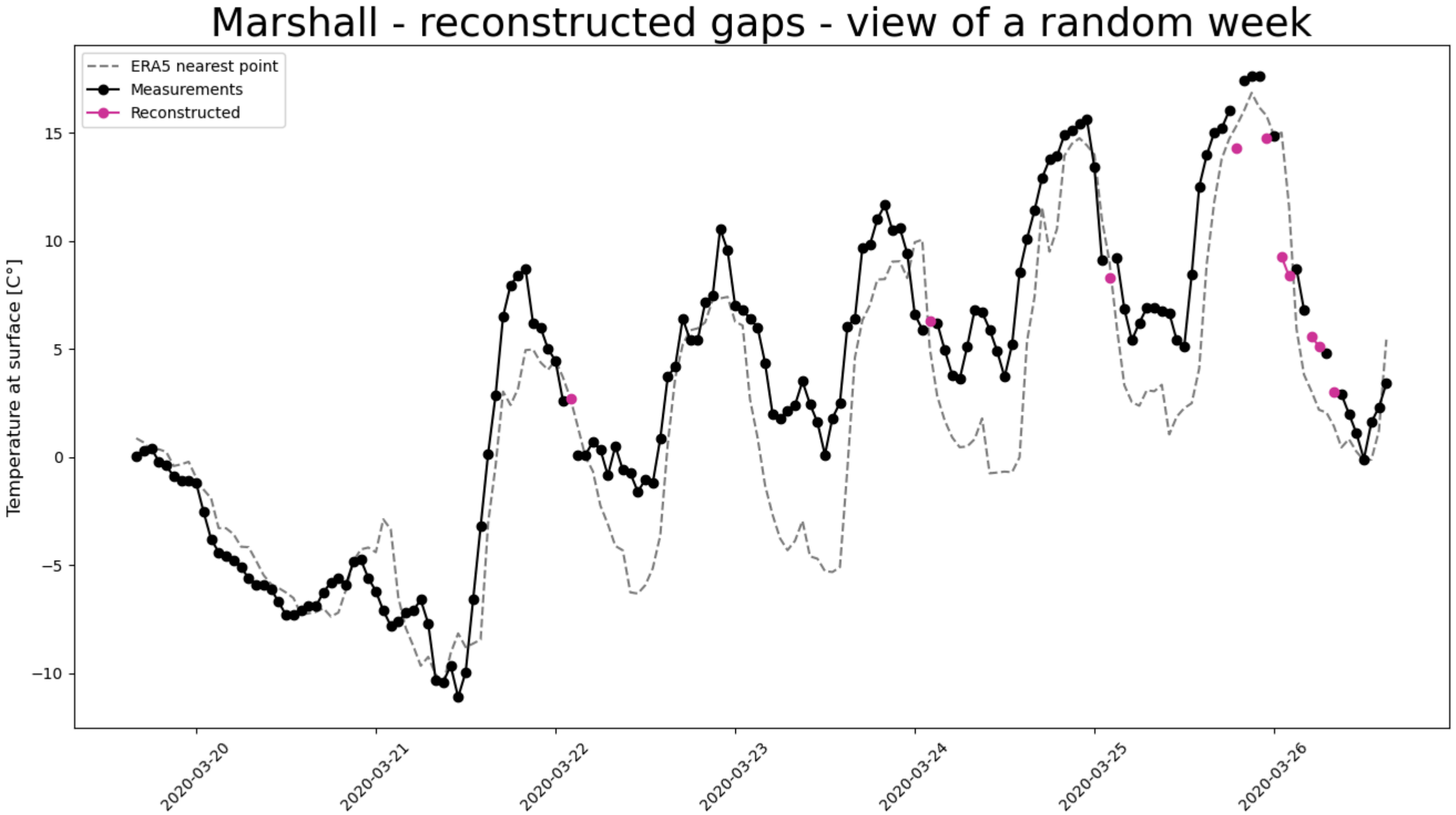


Marshall - reconstructed gaps - view of a random week

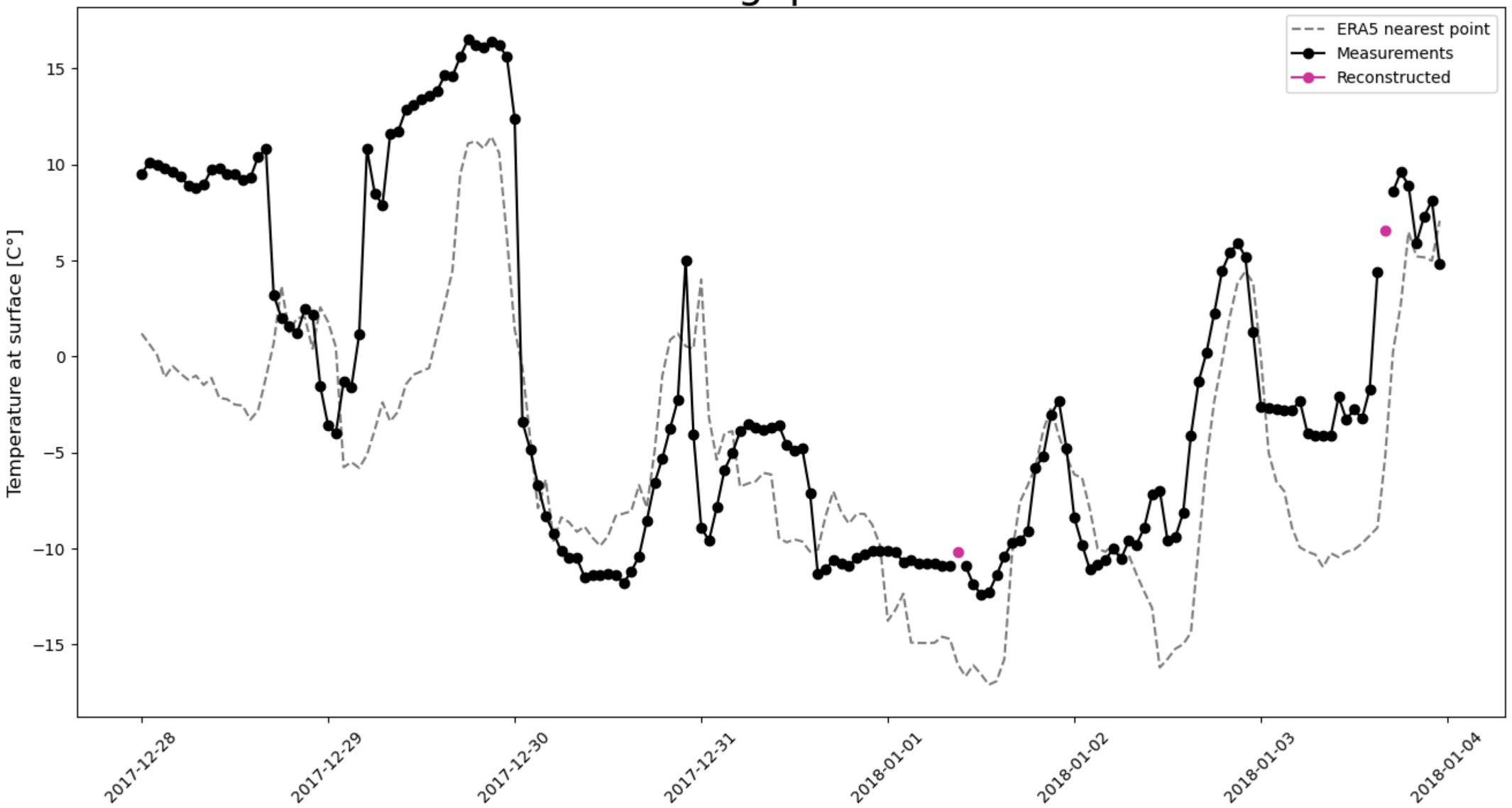


Marshall - reconstructed gaps - view of a random week

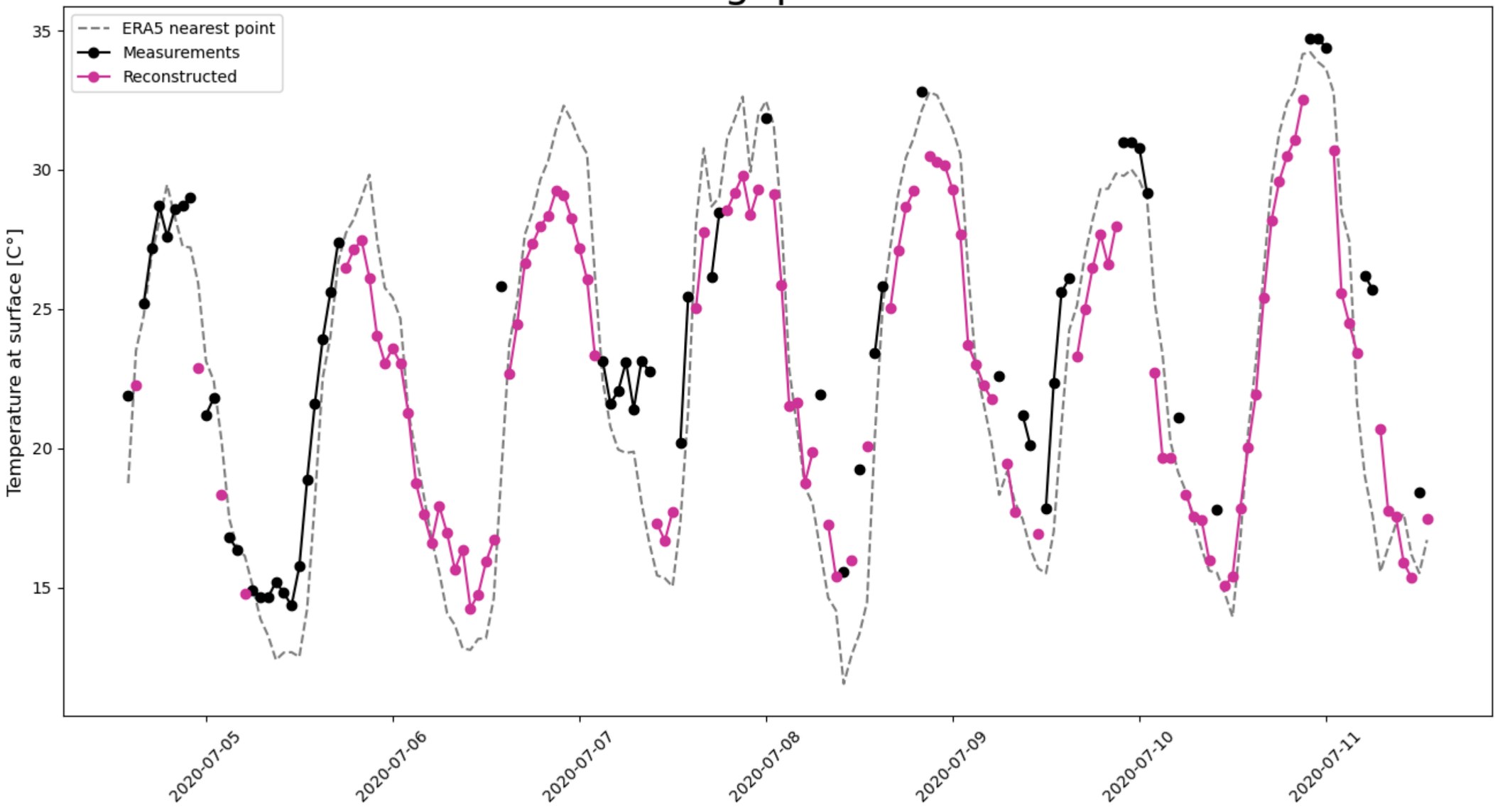


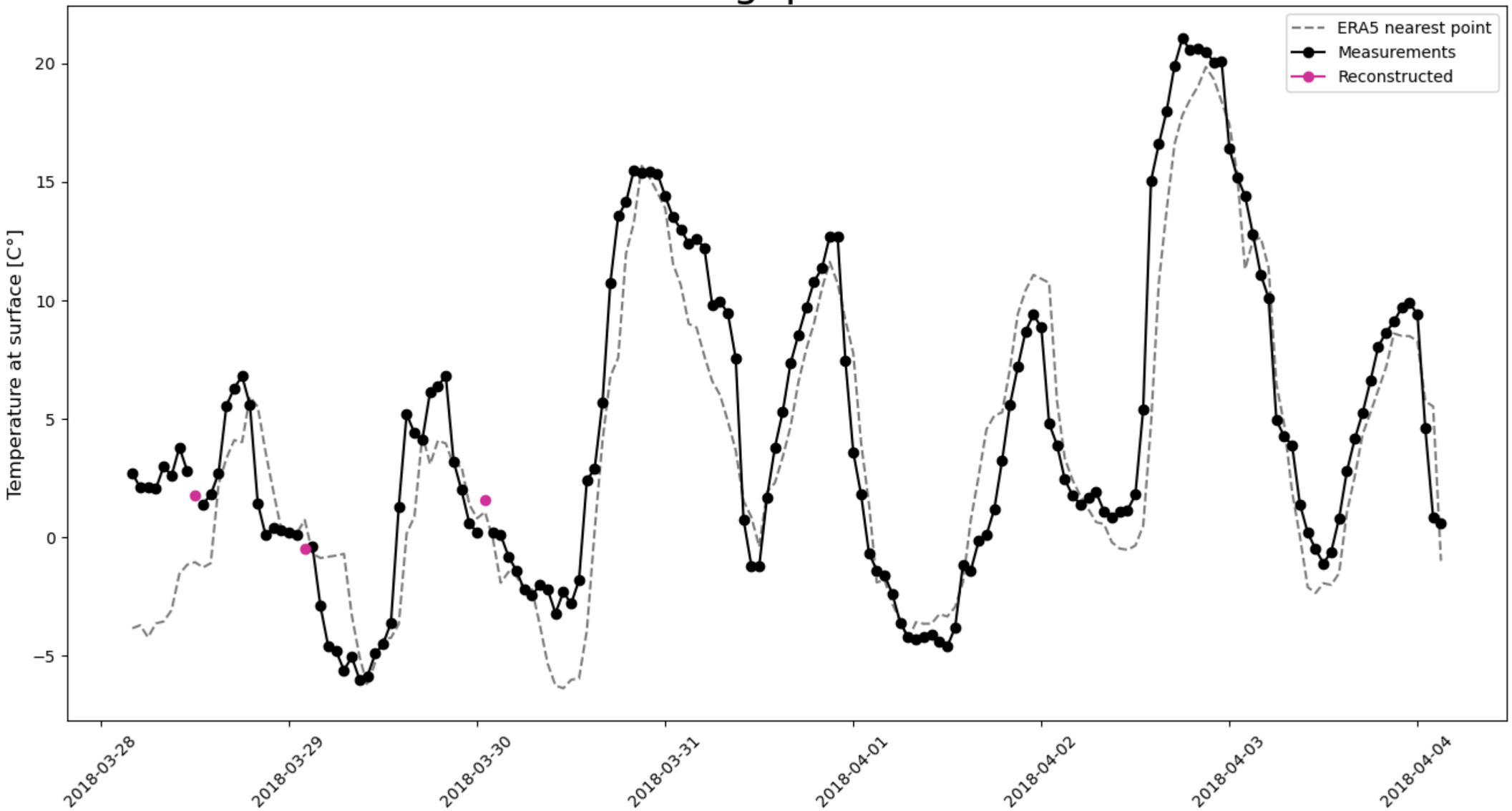

Marshall - reconstructed gaps - view of a random week
ERA5 nearest point
Measurements
Reconstructed
Temperature at surface [C°]
15
10
5
0
−5
−10
2020-03-20
2020-03-21
2020-03-22
2020-03-23
2020-03-24
2020-03-25
2020-03-26

Marshall - reconstructed gaps - view of a random week



Marshall - reconstructed gaps - view of a random week




Marshall - reconstructed gaps - view of a random week
ERA5 nearest point
Measurements
Reconstructed
Temperature at surface [C°]
20
15
10
5
0
−5
2018-03-28
2018-03-29
2018-03-30
2018-03-31
2018-04-01
2018-04-02
2018-04-03
2018-04-04