This code is a part of a published article doi:

Please review the article for further understanding before executing the code below.

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Variable Parameters

In [1]:
```
# Input Parameters
Direction = "Y"  # Set direction for analysis (X or Y)
SetLag = 4  # Set desired lag distance (up to 3 for X direction and 4 for Y directi
SimulationTime = 10  # Simulation time in minutes (up to 10 minutes)
```

Sample Data

In [2]:
```
# Neccesary libraries
import pandas as pd
import numpy as np
import matplotlib.pyplot as plt
from matplotlib.colors import ListedColormap, BoundaryNorm
from matplotlib.cm import ScalarMappable
from matplotlib.ticker import NullLocator


# Sample total rainfall per 1 minute for 10 minute rainfall (mm)
Rainfall = {
    "DATETIME": [
        "2023-03-15 12:23:00",
        "2023-03-15 12:24:00",
        "2023-03-15 12:25:00",
        "2023-03-15 12:26:00",
        "2023-03-15 12:27:00",
        "2023-03-15 12:28:00",
        "2023-03-15 12:29:00",
        "2023-03-15 12:30:00",
        "2023-03-15 12:31:00",
        "2023-03-15 12:32:00",
```

```
    ],
    "R1": [1.4, 1.2, 1.2, 1.6, 1.2, 1.4, 1.0, 1.4, 1.4, 1.0],
    "R2": [1.8, 1.6, 1.8, 2.2, 2.2, 2.2, 2.2, 2.4, 1.8, 1.6],
    "R3": [1.6, 1.8, 1.8, 2.2, 2.0, 2.2, 2.2, 2.2, 1.8, 1.6],
    "R4": [1.4, 1.6, 1.6, 2.2, 1.8, 2.6, 2.4, 2.4, 1.8, 1.4],
    "R5": [1.2, 1.4, 1.2, 1.4, 1.4, 2.0, 1.8, 1.4, 1.2, 1.4],
    "R6": [1.4, 1.2, 1.2, 1.2, 1.2, 1.0, 1.2, 1.2, 1.2, 1.4],
    "R7": [1.2, 1.2, 1.0, 1.0, 1.2, 1.4, 1.0, 1.2, 1.2, 1.2],
    "R8": [1.6, 1.6, 1.2, 1.2, 1.2, 1.6, 1.2, 1.4, 1.4, 1.8],
    "R9": [0.8, 1.0, 0.8, 0.8, 1.0, 1.2, 0.8, 1.0, 0.8, 1.0],
    "R10": [0.8, 0.8, 0.8, 1.0, 0.8, 1.0, 0.8, 0.8, 1.0, 0.8],
    "R11": [2.4, 2.0, 1.8, 2.2, 2.0, 1.6, 1.6, 2.2, 2.0, 2.2],
    "R12": [2.6, 2.8, 2.4, 2.2, 2.6, 1.6, 1.8, 2.2, 2.2, 2.8],
    "R13": [2.8, 2.6, 2.6, 2.4, 2.4, 2.0, 2.0, 2.4, 2.4, 2.6],
    "R14": [2.2, 2.8, 2.0, 1.8, 2.0, 1.4, 1.8, 1.8, 2.0, 2.4],
    "R15": [1.0, 1.4, 1.0, 1.0, 1.2, 0.8, 1.0, 1.0, 1.2, 1.2],
    "R16": [2.4, 1.8, 2.2, 2.8, 2.4, 2.6, 2.2, 2.6, 2.4, 2.0],
    "R17": [2.8, 2.8, 2.6, 2.4, 2.8, 2.2, 2.6, 2.6, 2.4, 2.6],
    "R18": [2.4, 2.2, 2.4, 2.2, 2.4, 2.2, 2.4, 2.2, 2.2, 2.4],
    "R19": [2.6, 2.8, 2.6, 2.6, 2.8, 2.2, 2.8, 2.6, 2.4, 2.6],
    "R20": [1.4, 2.2, 1.6, 1.4, 1.6, 1.2, 1.6, 1.6, 1.4, 1.6],
}

# Spatial distribution of tipping rain gauges over rainfall area
SpatialDistribution = {
    "Gauge": ["R1", "R2", "R3", "R4", "R5", "R6", "R7", "R8", "R9", "R10", "R11", "
              "R15", "R16", "R17", "R18", "R19", "R20"],
    "X": [60, 60, 60, 60, 60, 100, 100, 100, 100, 100, 140, 140, 140, 140, 140, 180
    "Y": [20, 60, 100, 140, 180, 20, 60, 100, 140, 180, 20, 60, 100, 140, 180, 20,
}

# Converting dictionaries to pandas Dataframe
dfSpatialDistribution = pd.DataFrame(SpatialDistribution)
dfRainfall = pd.DataFrame(Rainfall)
```

Spatil Distribution of Rain Gauges

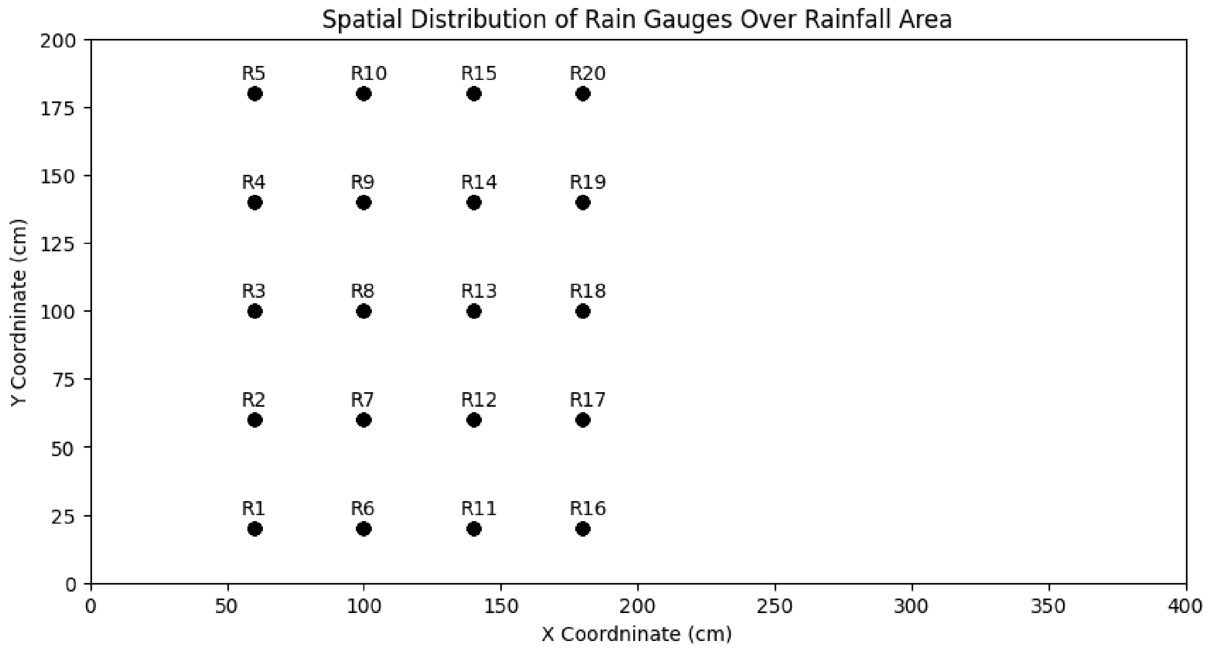
In [7]:

```
# Recognizing the spatial distribution of rain gauges
fig, ax = plt.subplots(figsize=(10,5))
for RainGauge in SpatialDistribution["Gauge"]:
    x = SpatialDistribution["X"]
    y = SpatialDistribution["Y"]
    ax.scatter(x, y, c="black", label=RainGauge)

n=0
for (i, j) in zip(x, y):
    plt.text(i-5, j+8, f"{SpatialDistribution['Gauge'][n]}",verticalalignment="cent
    n+=1

ax.set_xlim(0,400)
ax.set_ylim(0,200)
ax.set_xlabel("X Coordninate (cm)")
ax.set_ylabel("Y Coordninate (cm)")
```

```
ax.set_title("Spatial Distribution of Rain Gauges Over Rainfall Area")
plt.show()
```



Main Functions

In [4]:
```
# Create Pairs in Set Direction
def CustomPairs(spatial_df, time_series_df, row_index, lag, direction):
    """Create pairs in a given direction with respect to spatial distribution and s
    pairs_data = []
    warnings = []

    # Function to add pairs based on direction and lag
    def add_pairs(gauges_in_line):
        """Check available pairs for a given lag and return DataFrame with vectors.
        nonlocal pairs_data, warnings
        if len(gauges_in_line) <= lag:
            warnings.append(f"Lag {lag} is too large for the current line of gauges
            raise KeyError(f"Lag {lag} is too large for the current line of gauges.
            return False  # Indicating that the function should break
        else:
            for i in range(len(gauges_in_line) - lag):
                head = time_series_df.iloc[row_index][gauges_in_line.iloc[i]]
                tail = time_series_df.iloc[row_index][gauges_in_line.iloc[i + lag]]
                pairs_data.append([head, tail])
            return True  # Indicating that pairs were successfully added

    if direction == "X":
        for y in sorted(spatial_df["Y"].unique()):
            gauges_in_line = spatial_df[spatial_df["Y"] == y].sort_values(by=["X"])
            if not add_pairs(gauges_in_line):  # Check if it should break
                break
    elif direction == "Y":
        for x in sorted(spatial_df["X"].unique()):
            gauges_in_line = spatial_df[spatial_df["X"] == x].sort_values(by=["Y"])
            if not add_pairs(gauges_in_line):  # Check if it should break
```

```python
                break
    else:
        raise ValueError("Invalid direction. Choose either 'X' or 'Y'")

    # Check for warnings and act accordingly
    if warnings:
        for warning in warnings:
            print(warning)
        return pd.DataFrame()  # You might return an empty DataFrame or some indica

    # Return a DataFrame with a default value if no pairs were formed
    if not pairs_data:
        print("No pairs could be formed with the given parameters. Returning defaul
        pairs_df = pd.DataFrame([[1, 1]], columns=["Tail", "Head"])  # Default Data
    else:
        pairs_df = pd.DataFrame(pairs_data, columns=["Tail", "Head"])

    return pairs_df

# SemiVariogram is divided into two functions
def SumSqrDiff(df, col1:str, col2:str):
    """Calculate the sum of the squared differences between two columns."""
    SqrDiff = ((df[col1] - df[col2]) ** 2).sum()
    return SqrDiff

def SemiVariogram(df, col1:str, col2:str, interval):
    """Calculate values of semi-variance for a given DataFrame."""
    Sum = SumSqrDiff(df, col1, col2)
    N = len(df)
    Gama = (1/(2*N) * Sum)
    Lag = interval
    SV = pd.DataFrame({"Gama":[Gama],"Lag":[Lag]})
    return SV
```

Main Loop

In [5]:

```python
MaxLag = SetLag
dfs = dfSpatialDistribution
dfR = dfRainfall
Time = SimulationTime

SV = pd.DataFrame()  # Initialize an empty DataFrame for the final semivariogram da

# Main loop to generate semivariogram data for each TimeIndex
for TimeIndex in range(Time):
    # Initialize an empty DataFrame for accumulating semivariogram data for this Ti
    SV_df_for_time_index = pd.DataFrame()

    # Iterate over each lag up to MaxLag
    for lag in range(1, MaxLag + 1):
        # Generate pairs and semivariogram data for the current lag
        Pairs = CustomPairs(dfs, dfR, TimeIndex, lag, Direction)
        current_sv_data = SemiVariogram(Pairs, "Tail", "Head", lag)

        if lag == 1:  # For the first lag, initialize the DataFrame directly
```

```
            SV_df_for_time_index = current_sv_data
        else:  # For subsequent lags, concatenate the new data
            SV_df_for_time_index = pd.concat([SV_df_for_time_index, current_sv_data

    # Add a column for TimeIndex to distinguish rows after final concatenation
    SV_df_for_time_index["TimeIndex"] = TimeIndex

    # Concatenate the DataFrame for this TimeIndex with the final DataFrame
    SV = pd.concat([SV, SV_df_for_time_index], ignore_index=True)

SVT0 = SV[SV["TimeIndex"] == 0]
SVT1 = SV[SV["TimeIndex"] == 1]
SVT2 = SV[SV["TimeIndex"] == 2]
SVT3 = SV[SV["TimeIndex"] == 3]
SVT4 = SV[SV["TimeIndex"] == 4]
SVT5 = SV[SV["TimeIndex"] == 5]
SVT6 = SV[SV["TimeIndex"] == 6]
SVT7 = SV[SV["TimeIndex"] == 7]
SVT8 = SV[SV["TimeIndex"] == 8]
SVT9 = SV[SV["TimeIndex"] == 9]
```

Plotting of the Calculated Variogram

In [6]:

```
# Constants for font and line sizes
fSIZE = 12
tSIZE = 10
LINEo = 1
POINTo = 2
LINEw = 0.4
SIZE = 25


# Define colorblind-friendly colors
colorblind_friendly_colors = [
    "#444444",  # dark grey
    "#E69F00",  # orange
    "#56B4E9",  # sky blue
    "#009E73",  # bluish-green
    "#F0E442",  # yellow
    "#0072B2",  # blue
    "#D55E00",  # vermillion
    "#CC79A7",  # reddish-purple
    "#999933",  # olive green
    "#882255",  # wine
]
CustomColor = colorblind_friendly_colors

# SemiVariogram Plotting
fig, ax1 = plt.subplots(figsize=(4, 3))
ax1.set_ylabel("Semivariance (mm$^{2}$)", fontsize=fSIZE, labelpad=6)
ax1.set_xlabel("Lag Distance", fontsize=fSIZE, labelpad=6)
ax1.set_xlim(0, 6)
ax1.set_xticks(np.arange(0, 6, 1))
ax1.set_ylim(0, 1.1)
ax1.tick_params(axis="both", length=5, width=0.7, which="major", labelsize=tSIZE)
```

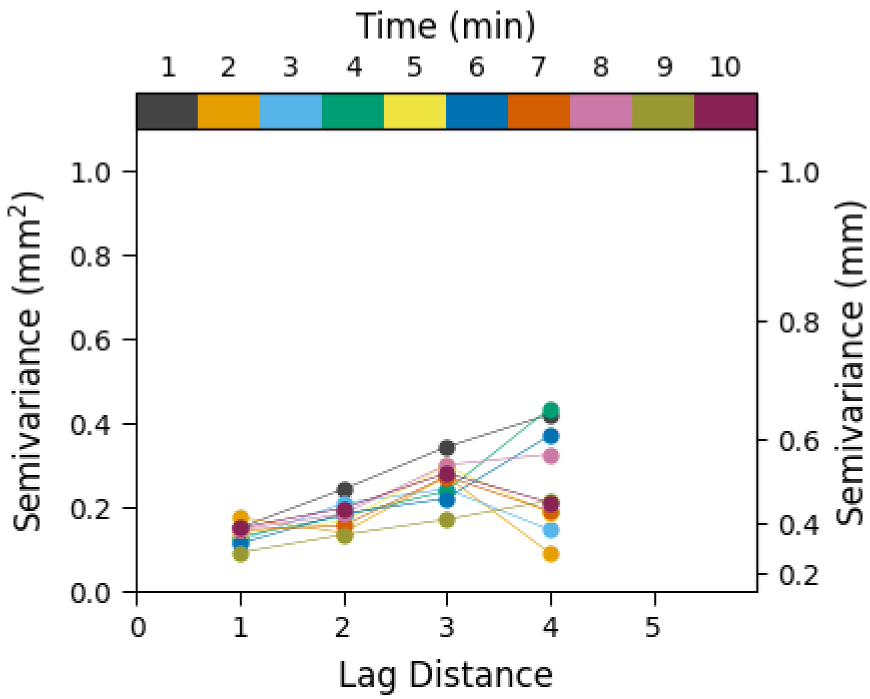
```python
ax1.spines["top"].set_linewidth(0.7)
ax1.spines["bottom"].set_linewidth(0.7)
ax1.spines["left"].set_linewidth(0.7)
ax1.spines["right"].set_linewidth(0.7)

# Secondary y-axis for semivariance in mm
ax2 = ax1.secondary_yaxis("right", functions=(lambda x: np.sqrt(x), lambda x: x**2)
ax2.set_ylabel("Semivariance (mm)", fontsize=fSIZE, labelpad=6)
ax2.tick_params(axis="y", labelsize=tSIZE)
secondary_yticks = ax2.get_yticks()
secondary_yticks = secondary_yticks[secondary_yticks != 0.0]
ax2.set_yticks(secondary_yticks)
ax2.set_yticklabels(["{:.1f}".format(ytick) if ytick != 0.0 else "" for ytick in se

# Plotting semi-variogram data for each time index
for i, SVT in enumerate([SVT0, SVT1, SVT2, SVT3, SVT4, SVT5, SVT6, SVT7, SVT8, SVT9
    ax1.scatter(SVT["Lag"], SVT["Gama"], c=CustomColor[i], s=SIZE, zorder=POINTo)
    ax1.plot(SVT["Lag"], SVT["Gama"], c=CustomColor[i], zorder=LINEo, lw=LINEw)

# Colorbar setup
CustomCmap = ListedColormap(CustomColor)
Boundaries = np.arange(0, 11, 1)
norm = BoundaryNorm(Boundaries, CustomCmap.N)
sm = ScalarMappable(norm=norm, cmap=CustomCmap)
pos = ax1.get_position()
colorbar_ax = fig.add_axes([pos.x0, pos.y0 + pos.height + 0.00, pos.width, 0.06])
cbar = fig.colorbar(sm, cax=colorbar_ax, orientation='horizontal', ticks=np.arange(
cbar.set_ticklabels(np.arange(1, 11))
cbar.ax.tick_params(direction="in")
cbar.ax.xaxis.set_minor_locator(NullLocator())
cbar.ax.tick_params(size=0)
cbar.set_label("Time (min)", rotation=0, labelpad=6, fontsize=fSIZE)
cbar.ax.xaxis.set_label_position("top")
cbar.ax.xaxis.set_ticks_position("top")

plt.show()
```



Time (min)
1
2
3
4
5
6
7
8
9
10
Semivariance (mm²)
1.0
0.8
0.6
0.4
0.2
0.0
Semivariance (mm)
1.0
0.8
0.6
0.4
0.2
0
1
2
3
4
5
Lag Distance