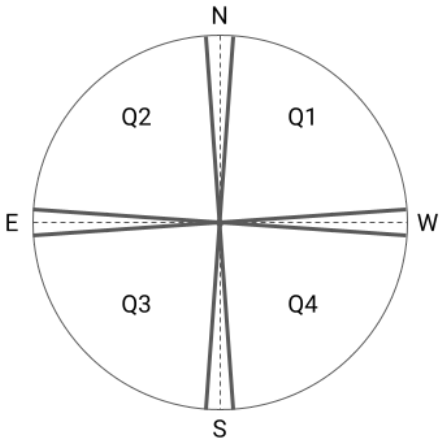
Flare to CME Association: Five-step Heuristic Approach

For integrating CME data to their solar sources, we perform a confidence-based scoring process that involves spatial and temporal data integration. For each GOES >C1.0 flare, we identify the likely CME candidate(s) with a temporal search using the start and peak times of flares and first detection time of CMEs. In this step, we check if the CMEs' first detection time is between 30 minutes before the flare's start time and 60 minutes after the flare's peak time. Then, for each potential CME candidate, if any, we generate a confidence score between 1 to 5 (from lowest to highest) based on checking four additional criteria where each criteria gives an extra confidence point for the association:

- Determine a potential one-to-one mapping between a given flare and a CME, in the case of only a single CME that satisfies the temporal search.
- Check if the flare's principal angle is in the same solar-disk quadrant as the CME's principal angle, which is assumed as a 8 degree margin for boundary conditions.
- Check if the difference between the flare's principal angle and the CME's principal angle (i.e., difference angle) is less than the CME's observed width.
- Check if the difference angle is less than 60 degrees threshold where such threshold is designated for wide CMEs (i.e., Halo and partial Halo) whose width almost always fulfill the width-based criterion in the previous criteria and aims to provide a more strict level of confidence.

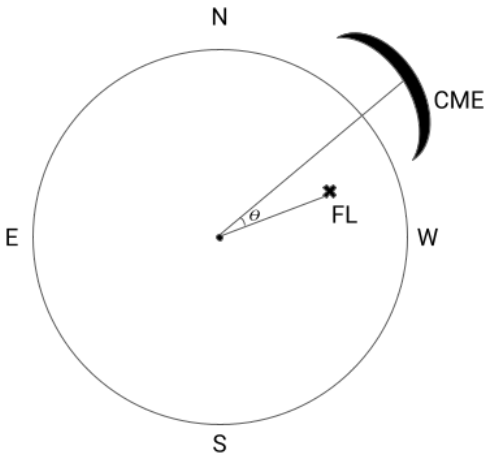
At the end of the integration procedure, CMEs are associated with flares using the maximum confidence score and therefore are connected to their most likely solar source. If there are multiple CMEs with the same high score, only those with the lowest difference angle between flare and the CME will be connected. Due to the fact that this process is not manually verified, we expect to generate certain 'noisy' data points. However, for overall model building, these data points should have a minimal statistical significance and hence a minimal impact.

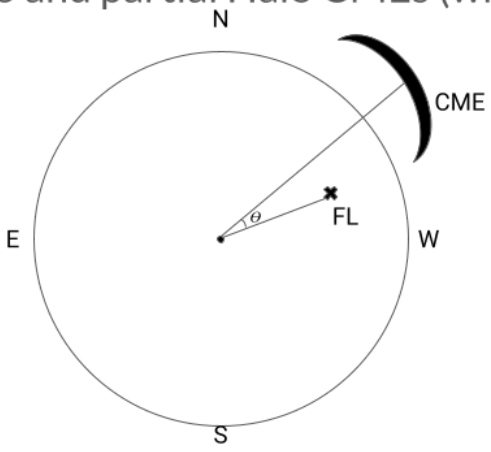
Spatial Criterion 1: Flares principal angle and CME's principal angle is in the same quadrant (with 8 deg room for boundaries)



-

Spatial Criterion 2: |Flare PA - CME PA| < CME Width



Spatial Criterion 3: |Flare PA - CME PA| < 60

Primarily for Halo and partial Halo CMEs (width>120)