Wind Directionality During Hail Events

Dave Banks[a], Graeme Wood[b]

[a]*CPP Wind Engineering Consultants, Windsor, Colorado, USA, dbanks@cppwind.com*
[b]*CPP Wind Engineering Consultants, St. Peters, NSW 2044, Australia, gwood@cppwind.com*

There is little published information on hail genesis, development, and outflow characteristics. Regardless, hail occurs during thunderstorm outflows, where the local wind direction is highly variable both spatially and temporally. Our hail analysis at weather stations in Australia and United States of America, has focused on the peak 3 s gust wind speed, and 1-minute mean wind speed and direction within ±30 minutes of predicted hail of greater than 20 mm diameter at cloud level. The hail events at weather stations were identified through radar observations, then the 1-minute climate data for the weather stations analysed. Simultaneous large hail and climate data were analysed for 48 and 137 events, in SE Queensland and Eastern Texas respectively. It is noted that in such a transient environment the 1-minute mean reported value is representative and the trend across the longer time period gives generic information on the nature of the event.

A selection of anemographs are presented in Figure 2, along with concurrent atmospheric conditions. The time stamp of predicted hail at cloud level is marked, hence it takes a while for the hail to impact the ground which is why the precipitation measurement is typically after the predicted hail timestamp. There is the potential for small hail to melt or evaporate before reaching ground level. Often, the hail events are accompanied by an increase in wind speed and rapid changes in wind direction, although some hail events occur during stable wind conditions. Rapid reductions in temperature and increased precipitation recordings are common. There are hail events where changes in the wind direction and temperature are sustained (potentially signifying large-scale storm fronts), as well as events where the wind direction rapidly recovers (consistent with thunderstorm downburst-type events). The different storm characteristics indicate there are fundamentally many different thunderstorm hail mechanisms from a meteorology perspective.

For the current analysis, the wind direction data within ±30 minutes of predicted hail have been characterised into 8 octants centred on Cardinal directions, Figure 1; the octant describes the direction from where the wind is coming. The percentage of events with multiple 1-minute wind directions represented in the measurements are presented in Table 1. It is evident that the average hail event has winds occurring in about 6 octants for a single event, and 4 octants for at least 5-minutes per octant. This is not surprising, as hail events typically occur near the storm front, where the inflow is generally between 90-180° to the general storm direction and varies significantly along the front, or in an outflow where the wind direction could change 180° in less than a couple of minutes. The findings are similar between geographical locations.
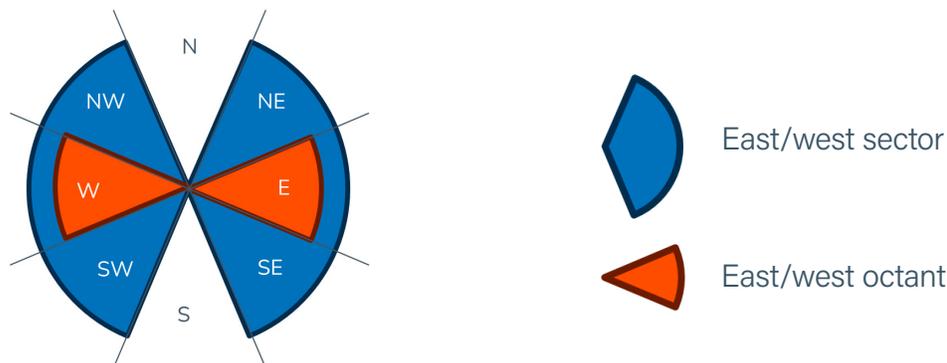

Figure 1: Octant directional nomenclature

Table 1: Percentage of hail events greater than 20 mm at cloud level, with 1-minute mean wind direction in multiple octants with a ±30 minute window

	Percentage of events with representation in multiple octants with duration of 1-minute, 5-minutes				
Location	≥3	≥4	≥5	≥6	≥7
SE Queensland, Australia	96, 85	90, 73	79, 40	69, 4	44, 0
East Texas, USA	98, 88	86, 53	72, 20	50, 4	31, 0

Linear structures, such as solar trackers that stow for strong wind and hail scenarios can be sensitive to winds from the east or west. Analysis has been conducted to determine the percentage of events where winds occur from both the east (NE, E, and SE) and west (SW, W, NW) sectors during the same hail event, as well as from just the east and west octants. The directional results independent of wind speed are presented in Table 2. It is evident that a large number of hail events will produce winds from both east/west sectors, with a significantly lower number for the octants. Similar results are found between the two locations, due to the majority of hail events at these latitudes occurring during thunderstorm outflows that produce a chaotic time- and spatial- variation of wind speed direction near ground level.

Table 2: Percentage of hail events greater than 20 mm at cloud level, with 1-minute mean wind direction from both the east and west sectors and octants lasting a set number of minutes within a ±30 minute window

	Percentage of hail events with representation from both east and west, for more than X minutes (sectors, octants)			
Location	1	5	8	10
SE Queensland, Australia	75, 48	65, 4	50, 0	42, 0
East Texas, USA	84, 45	68, 14	57, 5	47, 4

In summary, from the number of observations analysed, the wind conditions at ground level are chaotic during thunderstorm outflow events associated with production of large hail. The storm direction of travel or the wind direction at ground level prior to the onset of hail are not reliable predictors of the hail direction as conditions change rapidly.
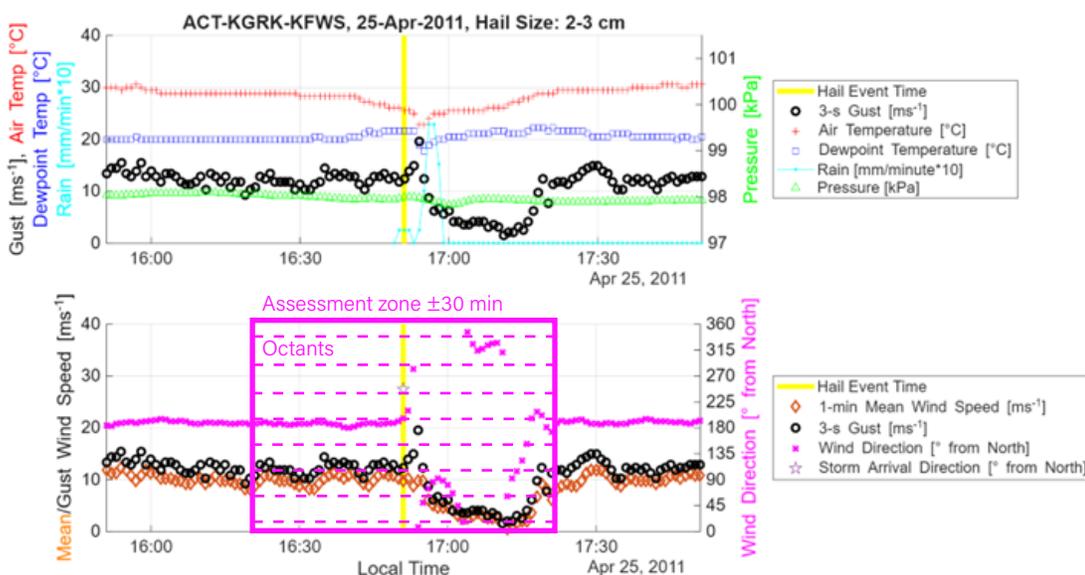
- Temporary drop in temperature around hail event.
- Heavy precipitation about 5 min after the predicted hail event.
- Temporary change in wind direction as hail event passes, but fluctuating during this period associated with the low wind speed.
- Slight increase in gust wind speed concurrent with hail event.
- Storm direction similar to ground level wind direction.

Figure 2: Various time series for an hour around the hail event time-stamp

AUS-KGRK, 04-May-2006, Hail Size: 6-7 cm
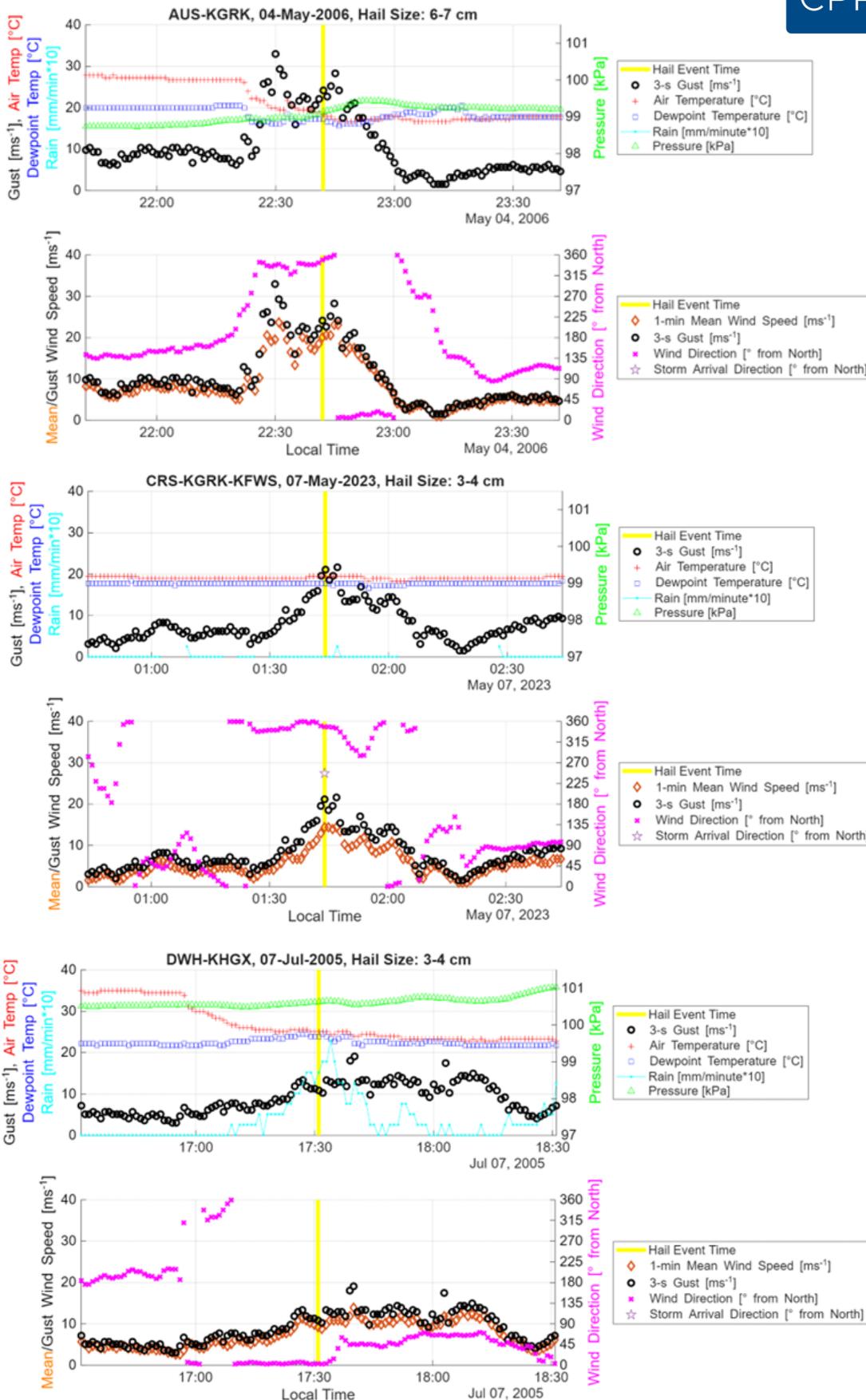
- Temporary drop associated with front ahead of predicted hail event.
- No precipitation recorded.
- Wind direction changes with frontal system.
- Rapid increase in gust wind speed at front.

CRS-KGRK-KFWS, 07-May-2023, Hail Size: 3-4 cm

- Constant temperature.
- Minimal precipitation about 2 min after the predicted hail event.
- Variable wind direction with relatively low wind speeds.
- Gradual increase in gust wind speed concurrent with hail event.
- Storm direction about 90° to ground level wind direction.

DWH-KHGX, 07-Jul-2005, Hail Size: 3-4 cm

- Drop in temperature with frontal system about 30 min before hail event.
- Heavy precipitation about 5 min after the predicted hail event.
- Sudden changes in wind direction with front and immediately after hail event.
- Slight localised increases in gust wind speed at tail end of hail event.

Figure 3-5: Various time series for an hour around the hail event time-stamp
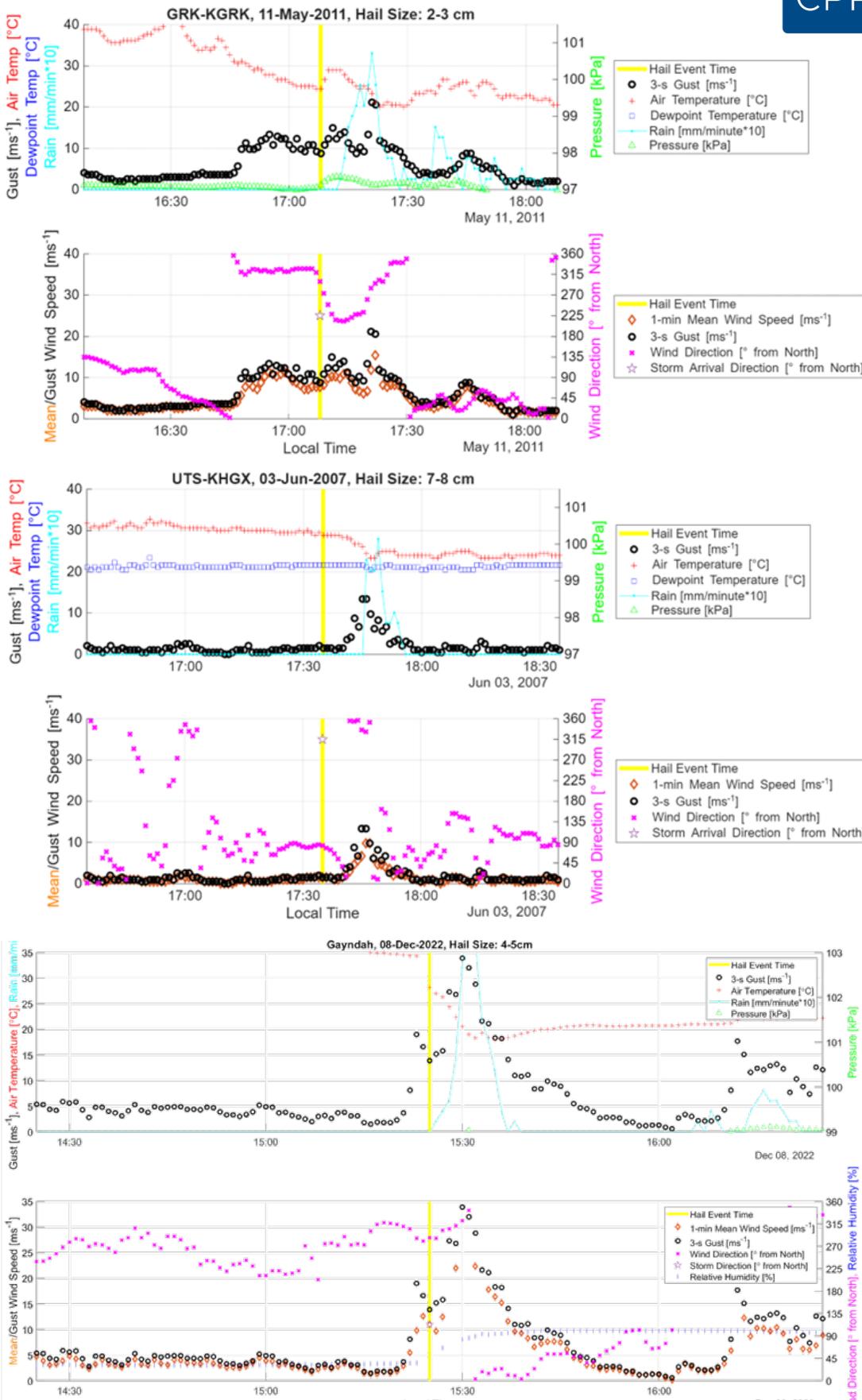
▪ Gradual drop in temperature over a long period with sudden increase just prior to the event.

▪ Peak precipitation about 10 min after predicted hail.

▪ Wind direction gradually changes ahead of the event, during a period of low wind speed, then changes as the speed increases, before temporarily changing about 90° during the event.

▪ Gust speed increases at tail end of peak precipitation.

▪ Gradual drop in temperature over a long period with sudden increase just prior to the event.

▪ Peak precipitation about 10 min after predicted hail.

▪ Wind direction gradually changes ahead of the event, during a period of low wind speed, then changes as the speed increases, before temporarily changing about 90° during the event.

▪ Gust speed increases at tail end of peak precipitation.

▪ Sudden drop in temperature.

▪ Heavy precipitation about 5 min after the predicted hail event.

▪ Steady change in wind direction as hail event passes.

▪ Sudden increase in gust wind speed over a 10 min period, and gust wind speed concurrent with high precipitation.

▪ Storm direction about 180° different to ground level wind direction.

Figure 6-8: Various time series for an hour around the hail event time-stamp

Figure 9: Various time series for an hour around the hail event time-stamp

Chart annotations (right side):
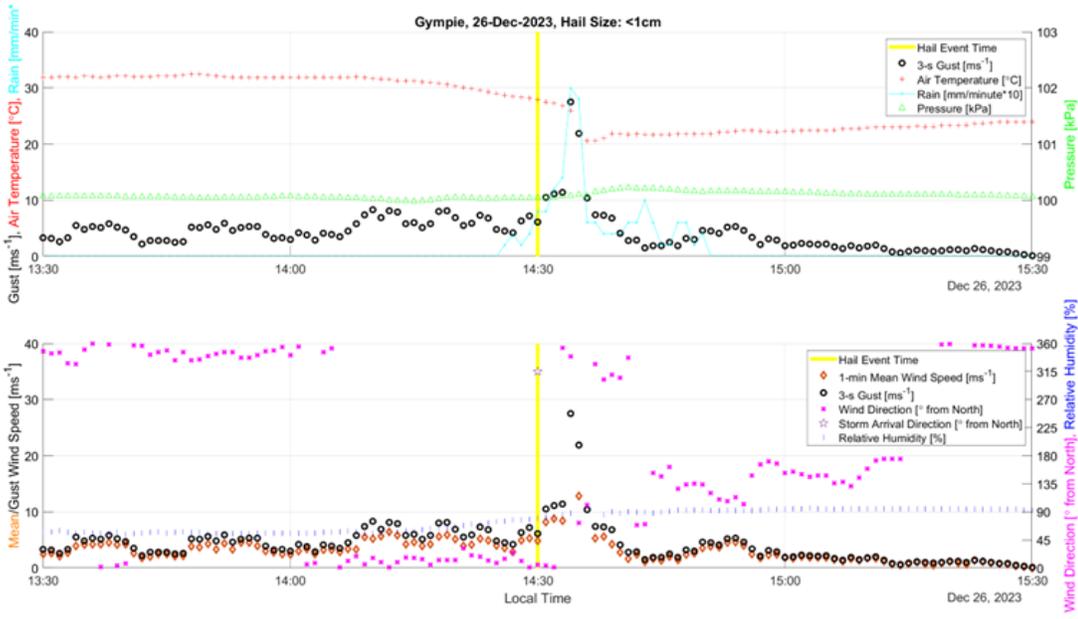
- Decreasing trend, then sudden drop in temperature at precipitation, then slowly increases.
- Heavy precipitation about 5 min after the predicted hail event.
- Steady change in wind direction as hail event passes, then sudden shift about 10 min after event.
- Sudden increase in gust wind speed during hail event.
- Storm direction about 45° different to ground level wind direction.

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