Nowcasting of thunderstorm downdraft winds using weather radar data

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Nowcasting of thunderstorm downdraft winds using weather radar data

- convective downdrafts one of the major thunderstorm hazards
- prediction a challenge for forecasters
- How can radar data help nowcasting thunderstorm downdrafts/downbursts?

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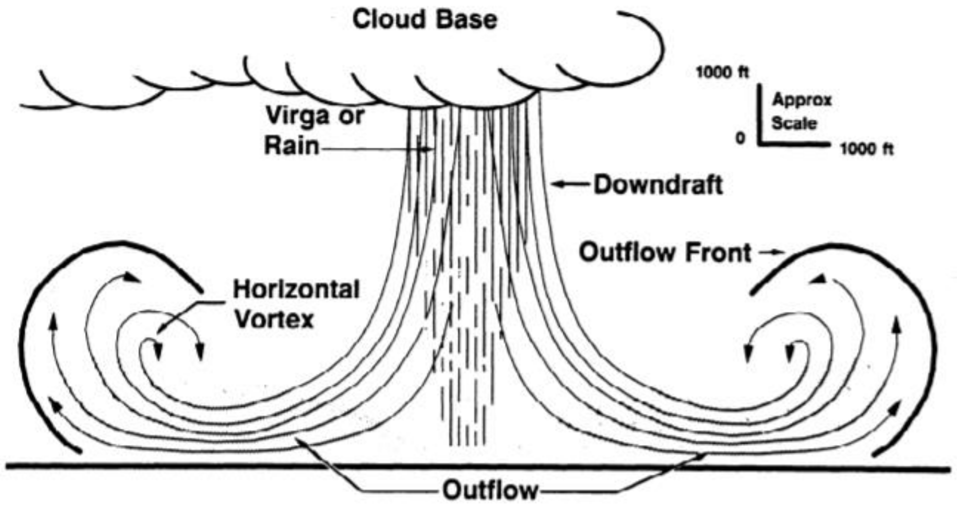
downburst

“**a strong downdraft which induces an outburst of damaging winds on or near the ground**“ (Fujita 1978)

downdraft**:** small-scale column of air that rapidly sinks toward the ground

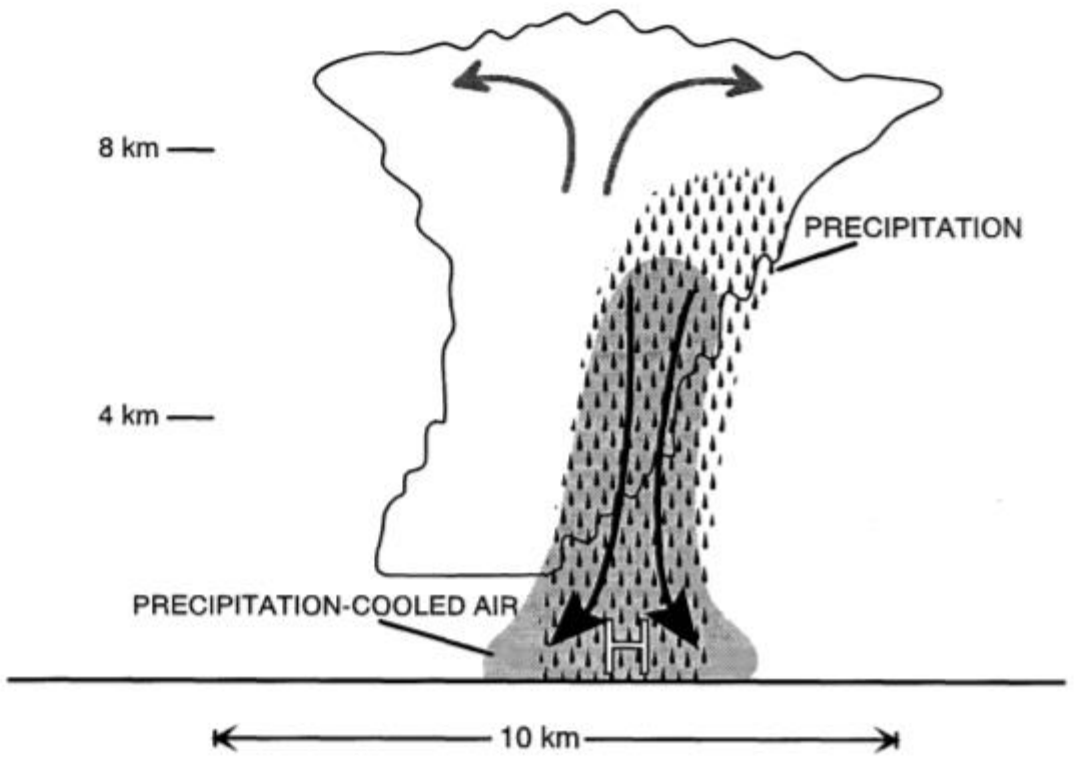
- Macroburst
  - > 4 km horizontal diameter
  - 5-20 minutes
- Microburst
  - < 4 km horizontal diameter
  - 2-5 minutes
- wet/dry downbursts



US Federal Aviation Administration (1988): Pilot Windshear Guide

Fujita, T. T. (1978). Manual of downburst identification for project NIMROD (No. NASA-CR-156953).
National Severe Storms Laboratory, 2016: Severe weather 101: Types of damaging winds,https://www.nssl.noaa.gov/education/svrwx101/wind/types/.

downburst



Schematic picture of the mature stage of a convective cell, from: Doswell (1994)

Following processes contribute to the velocity of a downdraft:

1. (negative) buoyancy due to evaporation and/or melting of precipitation
2. precipitation loading
3. incorporation of horizontal momentum

Doswell, C. A. (1994). Extreme convective windstorms: current understanding and research.
In *Report of the Proceedings of the US-Spain Workshop on Natural Hazards (Barcelona, Spain, 8–11 June 1993)* (pp. 44-55).
Holleman, I. (2001). Estimation of the maximum velocity of convective wind gusts. *Internal KNMI report*.

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Methods: ET/VIL (Stewart)

Maximum wind gust in m/s according to Holleman (2001) and Stewart (1991, 1996):

$$w_{max}^2 = -3.1 \times 10^{-6} \cdot \mathrm{ET}^2 + 20.6\mathrm{VIL}$$

VIL…Vertically Integrated Liquid water [kg/m²], ET…EchoTop [m]

final maximum wind gust obtained by adding one-third of the mean horizontal wind speed in the lowest 5000 feet of the atmosphere (Stewart, 1991)

Holleman, I. (2001). Estimation of the maximum velocity of convective wind gusts. *Internal KNMI report*.
Stewart, S. R. (1991). The prediction of pulse-type thunderstorm gusts using vertically integrated liquid water content (vil) and the cloud top penetrative downdraft mechanism. Technical Memorandum NWS SR-136, NOAA.
Stewart, S. R. (1992). An empirical forecasting technique for predicting pulse-type thunderstorm gusts using radar derived Verically Integrated Liquid water (VIL) and the penetrative downdraft mechanism. Master's thesis, University of Oklahoma.
Stewart, S.R. (1996) Wet microbursts — predicting peak wind gusts associated with summertime pulse-type thunderstorms. 15th conference on weather analysis and forecasting, AMS, 324–327.

Methods: ET/VIL (Stewart)

Loconto (2006) evaluated the method with data from 1995-2005, May-Sept, convective winds in Florida (USA) were analysed: ≥35 knots (65 km/h) 30 cases, 14 below-critera cases

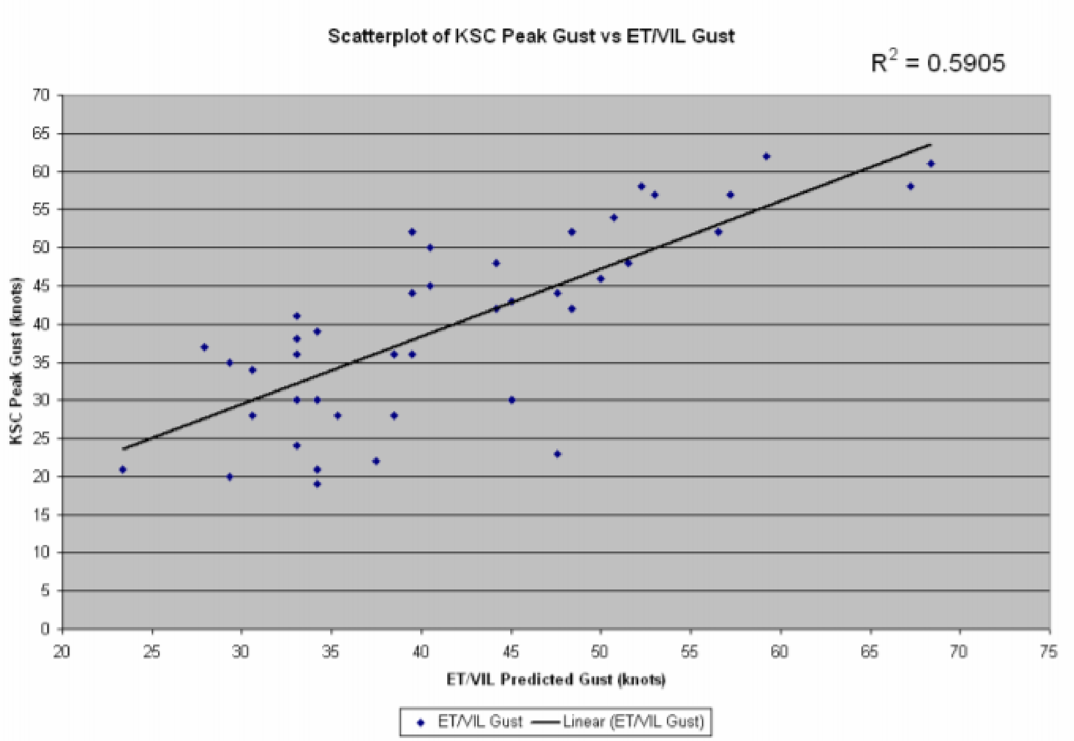

Figure 20. Scatterplot of ET/VIL predicted gust speed vs peak observed gust speed, with correlation coefficient in upper right corner.

Table 9. Error Statistics Table for ET/VIL.

Category	RMSE	MAE	Hits	% Hits
All Winds	8.1	6.58	26	60.4
Below Criteria	11.5	9.65	5	35.4
Above Criteria	5.93	5.23	21	70.0
35-49 Knots	5.45	4.95	14	68.4
≥ 50 Knots	6.67	5.72	7	54.5

Loconto, A. N. (2006). *Improvements of warm-season convective wind forecasts at the Kennedy Space Center and Cape Canaveral Air Force Station* (Doctoral dissertation, Plymouth State University).

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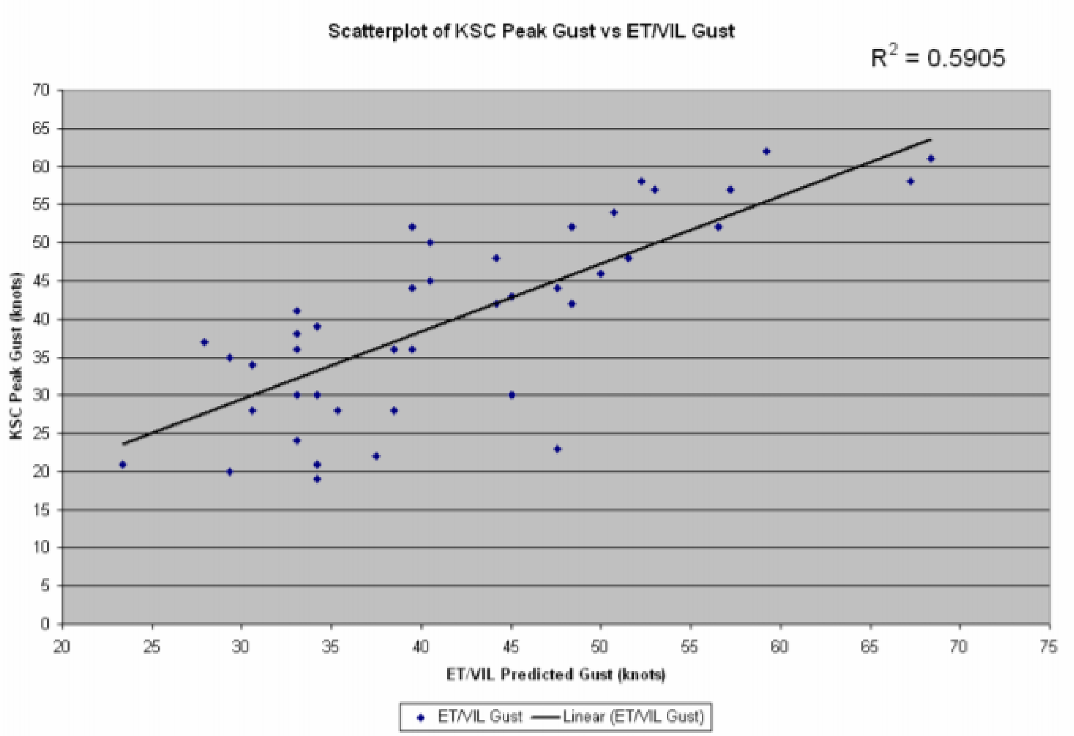

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Methods: VIL/MaxZ/height (Loconto)

$$GU = (.4138 \times VIL) + (.9194 \times MaxZ) + (.6253 \times height) - 28.7719$$

VIL… [kg/m²], MaxZ…maximum reflectivity [dBZ], height…height of maximum reflectivity [kft], GU…predicted peak wind gust [kn]

Table 11. Error Statistics Table for Eq. (12).

Category	RMSE	MAE	Hits	%Hits
All Winds	6.39	5.25	13	59.02
Below Criteria	5.22	3.96	7	77.78
Above Criteria	7.09	6.14	6	46.1
35-49 Knot	5.44	4.9	5	55.56
≥ 50 Knot	9.85	8.92	1	25

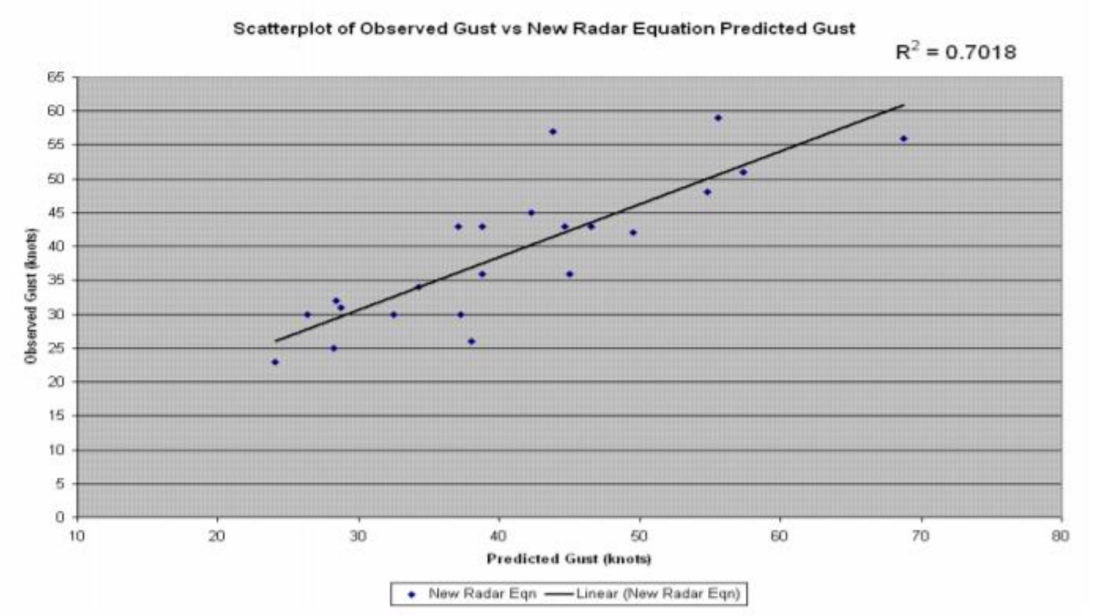


Figure 23. Scatterplot of observed versus predicted peak wind gusts using Eq. (12).

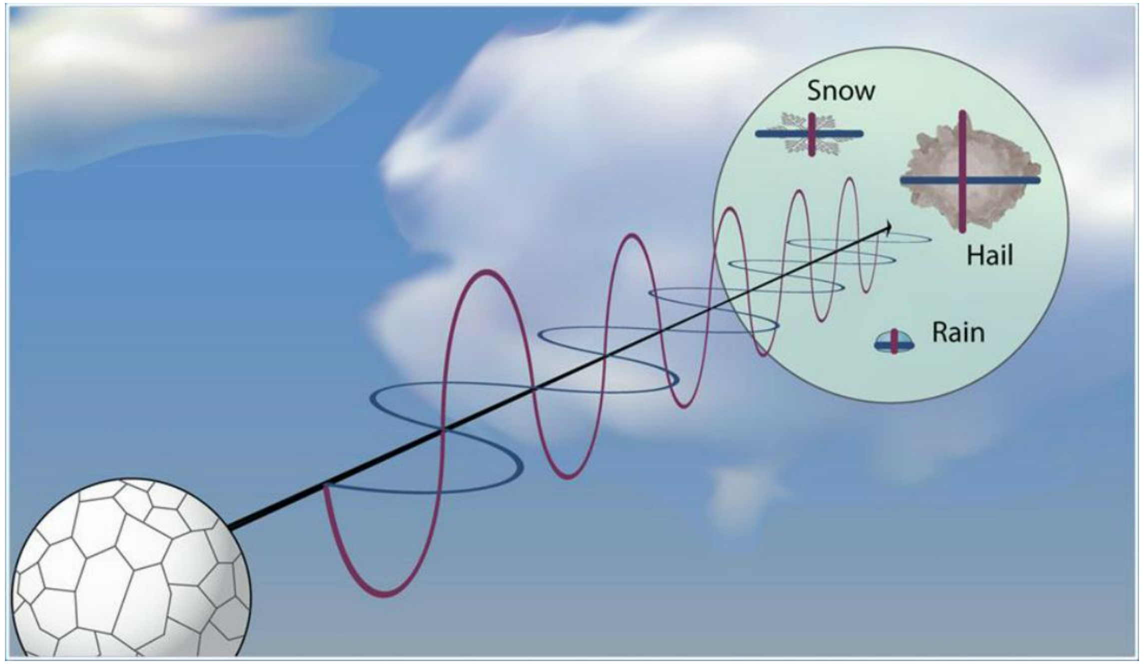
Loconto, A. N. (2006). *Improvements of warm-season convective wind forecasts at the Kennedy Space Center and Cape Canaveral Air Force Station* (Doctoral dissertation, Plymouth State University).

Dual-pol weather radar

- horizontal AND vertical oriented pulses (transmission and receiving)

- additional information about the targets

- ZDR: differential reflectivity
- PhiDP/KDP: differential phase
- RhoHV: correlation coefficient



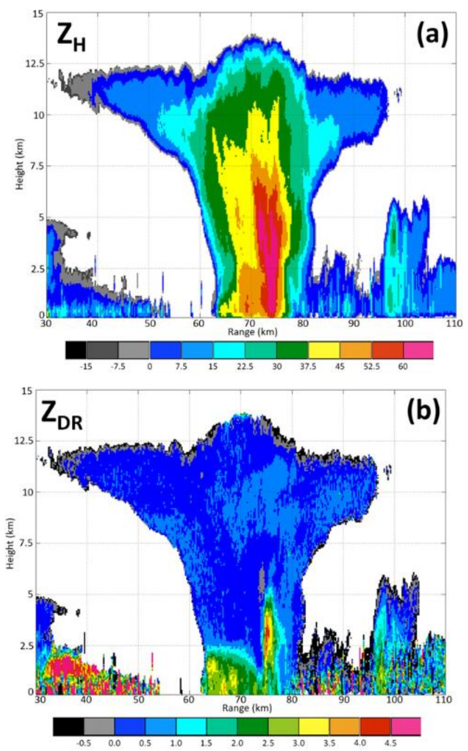
US National Weather Service: https://www.weather.gov/images/news/130425_dual_pol_illustration.jpg

Methods: dual-polarization

Amiot et al. (2019) analysed C-band dual-polarization radar signatures of wet downbursts around Cape Canaveral, Florida:

- Height of ZDR-column above 0°C
- Height of precipitation ice signature above 0°C (>=30dBZ Z, ~0dB ZDR)
- Peak Zh in storm cell
- Height of ZDR 3dB below 0°C
  (indication of negative buoyancy through more concentrated melting of hydrometeors)
- Vertical ZDR gradient (high gradient, rapid melting)

Leadtimes 1-3: 20-28min, 4-5: 13-15min



from:
Kumjian, M. R., Khain, A. P., Benmoshe, N., Ilotoviz, E., Ryzhkov, A. V., & Phillips, V. T. (2014). The anatomy and physics of Z DR columns: Investigating a polarimetric radar signature with a spectral bin microphysical model. *Journal of Applied Meteorology and Climatology*, *53*(7), 1820-1843.

Amiot, C. G., Carey, L. D., Roeder, W. P., McNamara, T. M., & Blakeslee, R. J. (2019). C-band dual-polarization radar signatures of wet downbursts around Cape Canaveral, Florida. *Weather and Forecasting*, *34*(1), 103-131.

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Methods: dual-polarization random forest

Medina et al. (2019) used a random forest method to forecast downbursts

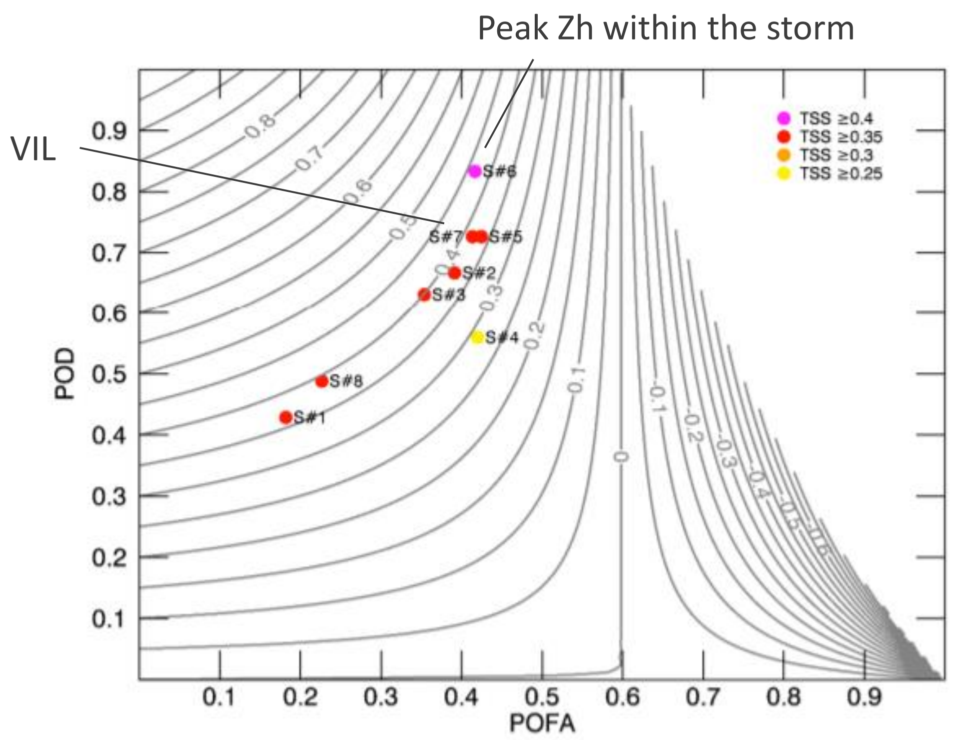


Figure 6. TSS for the radar signatures' threshold with maximum TSS (contours), presented in terms of POD and POFA. Radar signatures are S#1: Z_{dr} column maximum height; S#2: Precipitation ice signature maximum height; S#3: VII; S#4: Height of peak Z_h above the 0°C isotherm level; S#5: Peak Z_h above the 0°C isotherm level; S#6: Peak Z_h within the storm; S#7: VIL; S#8: DVIL.

True Skill Statistic (TSS)

Random Forest method TSS=0.4

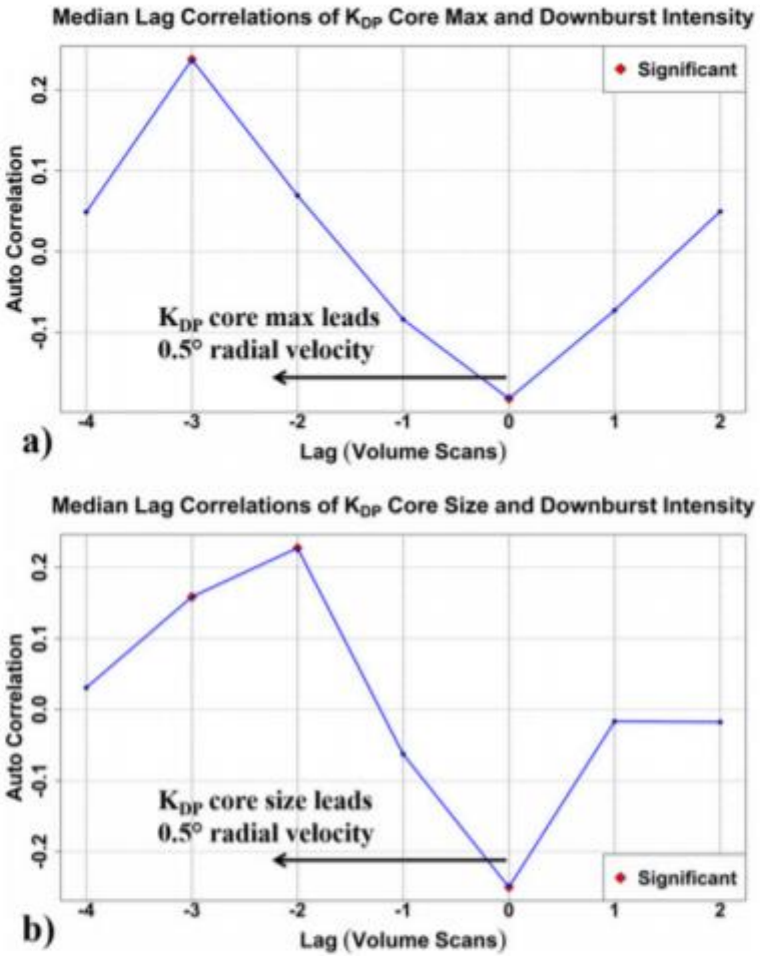
Maximum Zh over the entire storm (52dBZ-threshold) TSS=0.43

Medina, B. L., Carey, L. D., Amiot, C. G., Mecikalski, R. M., Roeder, W. P., McNamara, T. M., & Blakeslee, R. J. (2019). A random forest method to forecast downbursts based on dual-polarization radar signatures. *Remote Sensing*, *11*(7), 826.

Methods: dual-polarization

Other methods using KDP core as it indicates areas of melting graupel and hail (KDP … specific differential phase)

- Kuster, C. M., Bowers, B. R., Carlin, J. T., Schuur, T. J., Brogden, J. W., Toomey, R., & Dean, A. (2021). Using K DP Cores as a Downburst Precursor Signature. *Weather and Forecasting, 36*(4), 1183-1198.
- Weber, M., Hondl, K., Yussouf, N., Jung, Y., Stratman, D., Putnam, B., ... & Vincent, M. (2021). Towards the next generation operational meteorological radar. *Bulletin of the American Meteorological Society, 102*(7), E1357-E1383.



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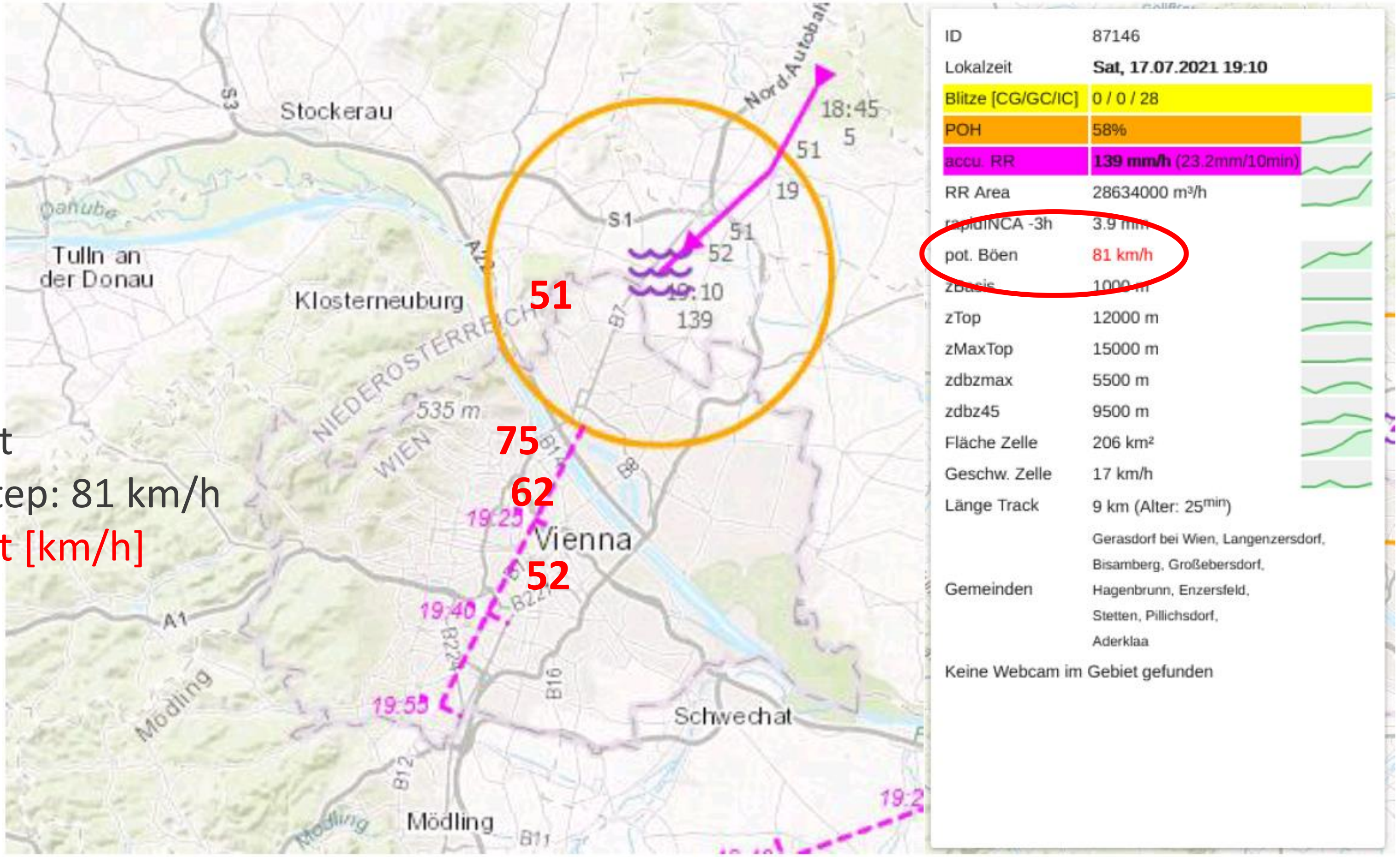
Example

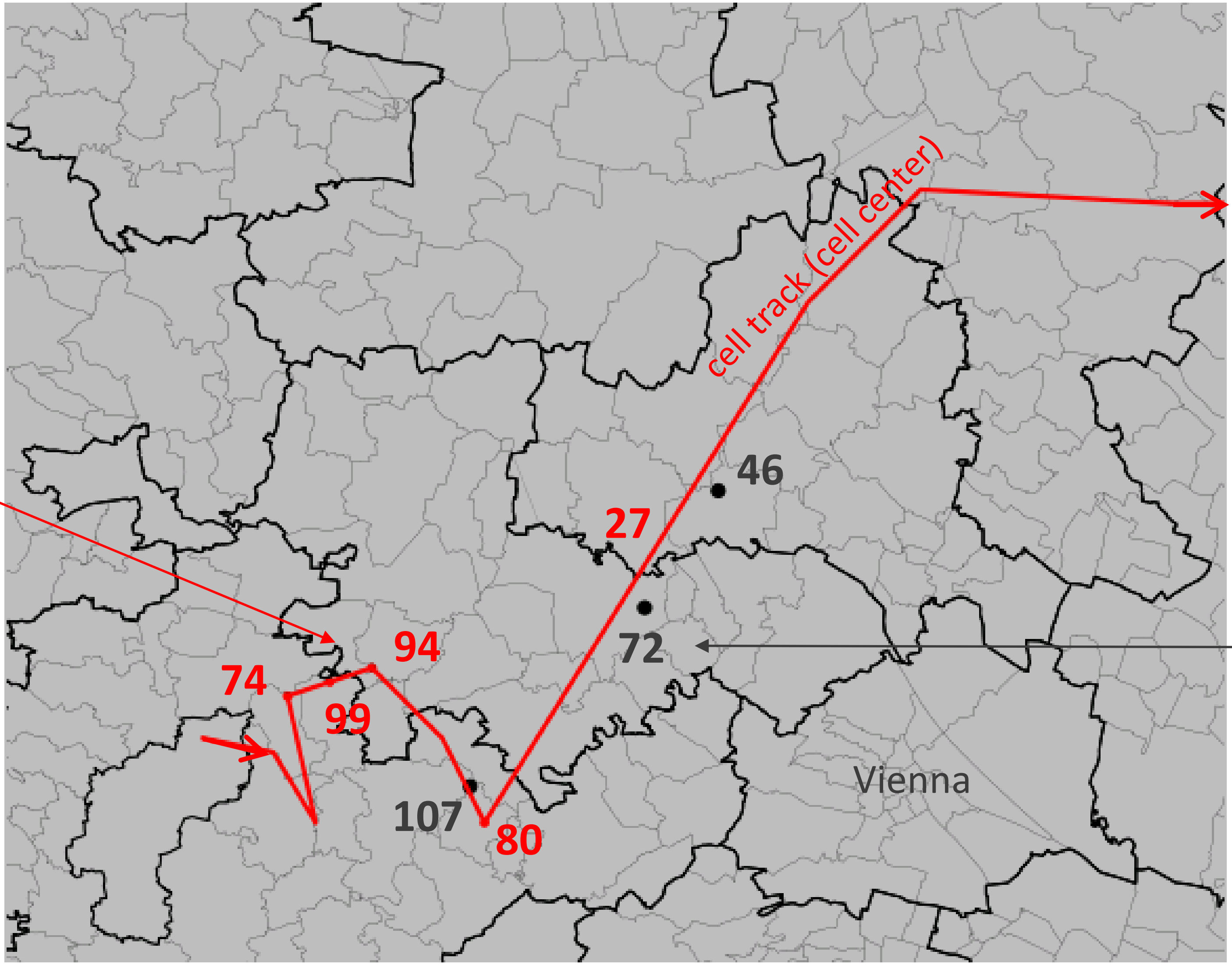


estimated wind gust
speed of this timestep: 81 km/h
measured wind gust [km/h]

Example

20190701
radell 3213

estimated wind gust speed [km/h]



AWS wind gust measurement [km/h]

leadtime ~ 15min

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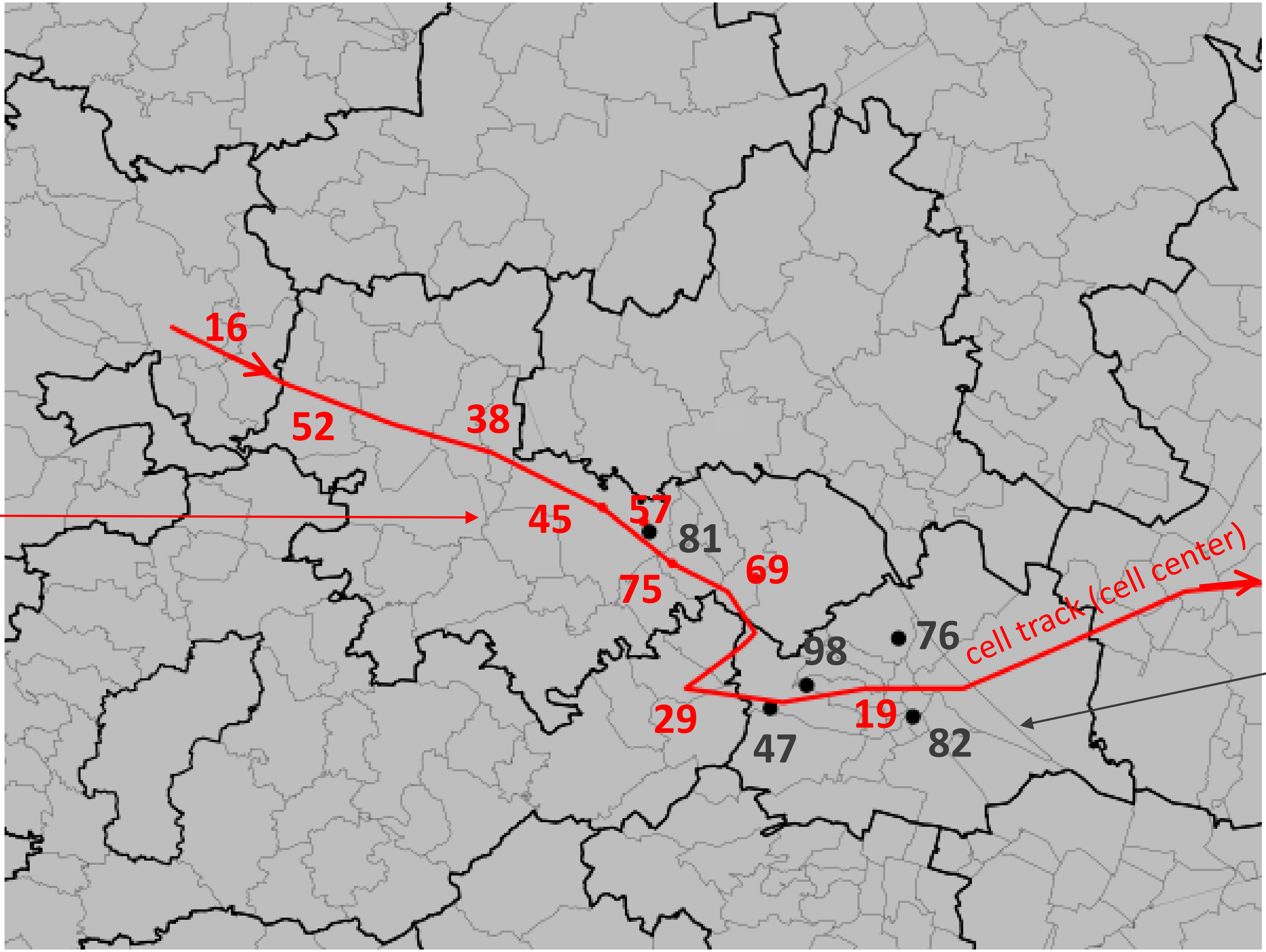
Example

20200728
radell 1248

estimated
wind gust
speed [km/h]



AWS wind gust
measurement
[km/h]

Summary

- Downdrafts are one of the major hazards of convective cells and a challenge in forecasting.

- Radar data can under certain circumstances help in nowcasting downdrafts:

  – we have seen different methods using reflectivity (ETOP, VIL)
  – newer ones using dual-pol data and machine learning, partly using also NWP data (e.g. Lagerquist et al., 2017)

- Tests at ZAMG: Some inconsistent results in first tests, improvements may be needed

Lagerquist, R., McGovern, A., & Smith, T. (2017). Machine learning for real-time prediction of damaging straight-line convective wind. Weather and Forecasting, 32(6), 2175-2193.