Optimizing C-Band radar settings for mesocyclone and tornado cyclone detection

European Severe Storms Laboratory

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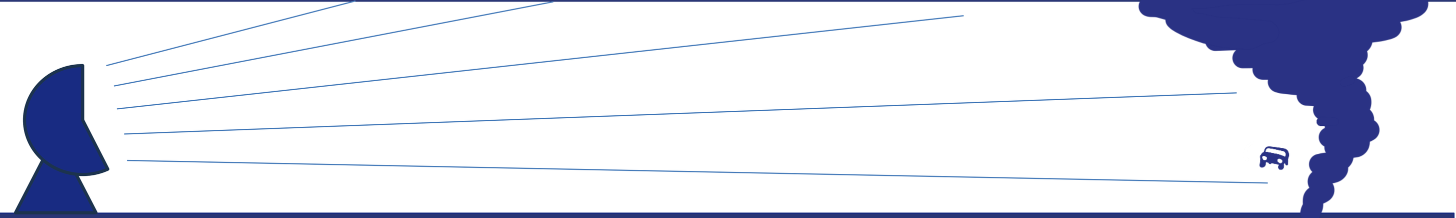


Ranking the Radars

C-Band Doppler radars with a wavelength of about 5 cm are the most common weather radars in Europe. Like S-band radars, they can detect tight circulations that may indicate a tornado, but only if they are configured to be able to.

We subjectively ranked the quality of velocity data from European radar operators with respect to how easy one can detect tornadic circulations based on five aspects.

Country	Band	Time resolution*		Gate length		Elevations		Excessive Filtering	Number and severity of aliasing errors						Final overall grade	Main issues
		min.	grade	m	grade	issues?	grade	grade	V_low	V_high	V_3	VN_ext	ratio	grade	grade	
Italy (FVG)	C	5	9	125	10	no scan below 1.0°	8	8	10.0	15.0		30.0	2/3	9	7.4	no scan below 1.0°, some filtering remains
Romania	S	5	9	250	10	no 1.0° elevation scan	8	8	11.5	15.3		46.0	3/4	8	7.3	missing 1.0° elevation, filtering
Poland	C	5	9	500	8	gap between 0.5° and 1.5°	8	9	11.9	15.9		47.8	3/4	8	7.1	gate length a bit big, missing 1.0° elevation, some aliasing errors
Estonia	C	5	9	250	10	gap between 0.5° and 2.0°	7	9	12.0	16.0		48.0	3/4	8	6.8	gap between 0.5° and 2.0°
United Kingdom	C	10	7	600	8	no elevation below 1.0°	8	10	11.9	15.9		48.0	3/4	9	6.5	time resolution too high
Italy (Veneto)	C	10	7	500	8		10	10		15.8				7	6.5	time resolution too high, gate length too low
Sweden	C	5	9	500	8		10	10	6.0	8.0		24.1	3/4	6	6.2	large number of alaiasing errors (because of poor dual PRF settings)
Finland	C	5	9	125 / 250	10	gap between 0.5° and 2.0°	7	7	12.0	16.0		47.9	3/4	7	6.0	gap between 0.5° and 2.0°, fair number of aliasing errors remain
Denmark	C	10	7	500	8		10	8	11.9	15.7		47.2	3/4	7	6.1	overactive clutter filter, minor filtering artifacts along radials (Z&V), gate length and time resolution bit large
Belgium (Jabbeke)	C	5	9	500	8		10	6	10.7	13.3		53.3	4/5	8	5.7	excessive filtering of V data
Netherlands	C	5	9	250	10	staggered scanning	8	7	7.9	10.6		32.0	3/4	6	5.5	strong filtering every second beam, fair number of aliasing errors
Germany	C	5	9	250	10	gap between 0.5° and 1.5°	8	7	7.9	10.6		32.0	3/4	6	5.5	fair number of aliasing errors, filtering near mesocyclone centres
Slovakia	C	5	9	250	10		10	6	8.0	10.0		39.9	4/5	7	5.5	quite strong filtering near centre of mesocyclone, quite a few aliasing errors
France (C-band)	C	5	9	1000	5		10	10	5.9	6.5	7.3	58.5		6	4.9	gate length too large, noisy V, post-processing to improve
Austria (AustroControl)	C	5	9	250	10		10	8	8.0	10.6		32.0	3/4	4	4.4	very noisy velocities (unclear why), overactive clutter filtering,
Belgium (Zaventem)	C	5	9	125	10		10	4	10.6	15.9		32.0	2/3	8	4.4	excessive filtering of V data
Austria (Geosphere)	C	5	9	250	10		10	9	4.0	4.7		28.0	5/6	3	3.7	very noisy velocities (because of poor dual-PRF settings)
Croatia	C	5	9	300	9	gap between 0.5° and 1.5°	8	3	12.0	16.0		48.0	3/4	7	3.2	excessive filtering of Z and V data
Belgium (Helchteren)	C	5	9	250	10		10	8		7.4		7.4		1	1.9	unusuable V because of single PRF
Slovenia (Pasja Ravan)	C	5	9	500	8		10	8		8.0		8.0		1	1.8	unusuable V because of single PRF
Czechia	C	5	9	400	9		10	2		7.3		7.3		1	1.6	excessive filtering of Z and V data, unusable V because of single PRF
Slovenia (Lisca)	C	5	9	1000	5		10	1		8.1		8.1		1	1.5	excessive filtering of Z and V data, unusable V because of single PRF

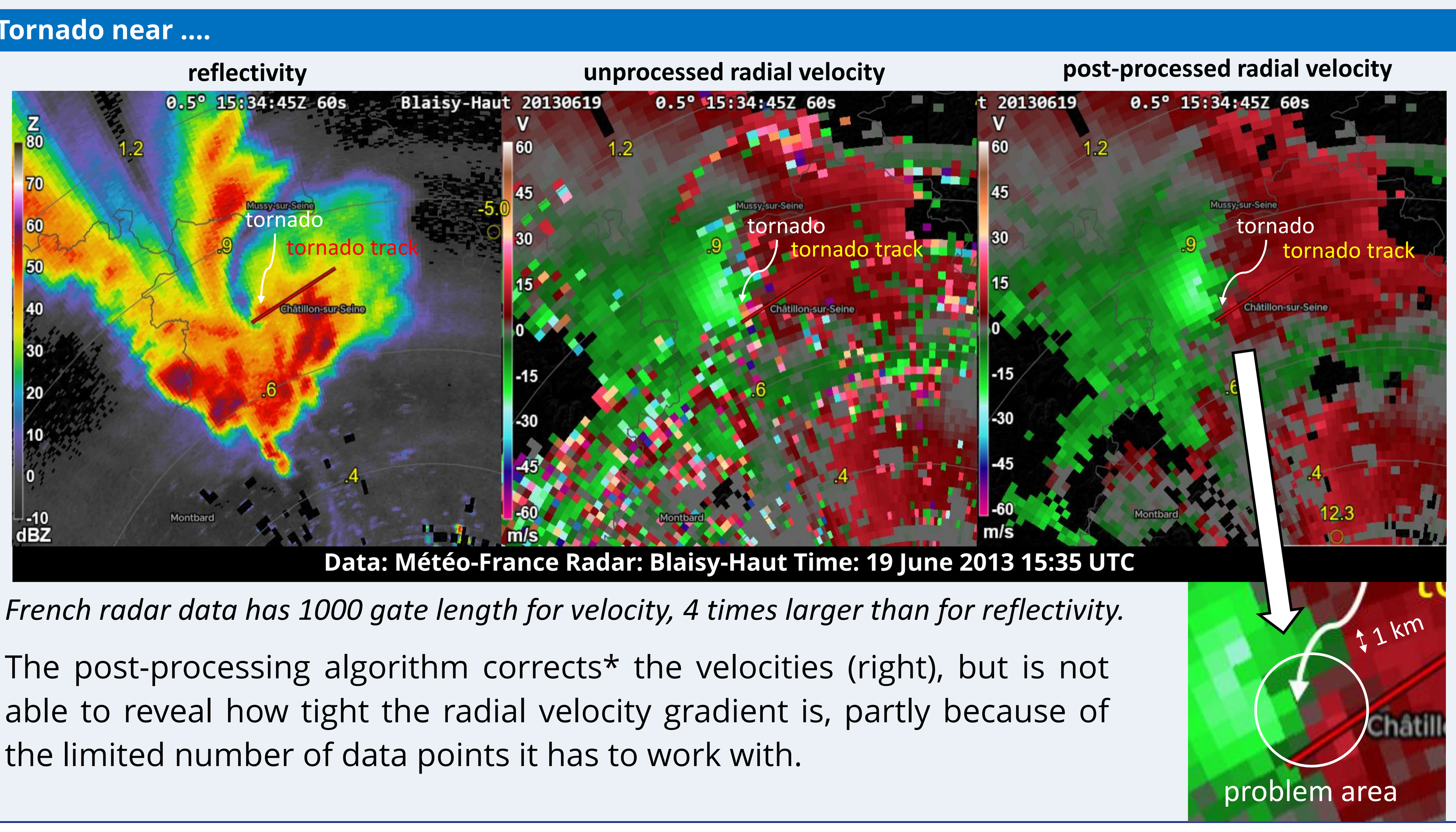
1. Time resolution

Most radars in Europe scan the lowest angles (1.0° or lower) above the horizon (elevations in radar jargon) every 5 minutes, which is great. Some use a 10-minute scanning pattern which reduces valuable lead time.

2. Gate length (radial resolution)

The size of the bins for which data is collected in the tangential direction is approximately 1° for all radars, but in the radial direction varies from 125 to 1000 m. To detect small circulations, 1000 m is not sufficient, certainly if the data is noisy which it almost always is near tornadoes.

Tornado near ….



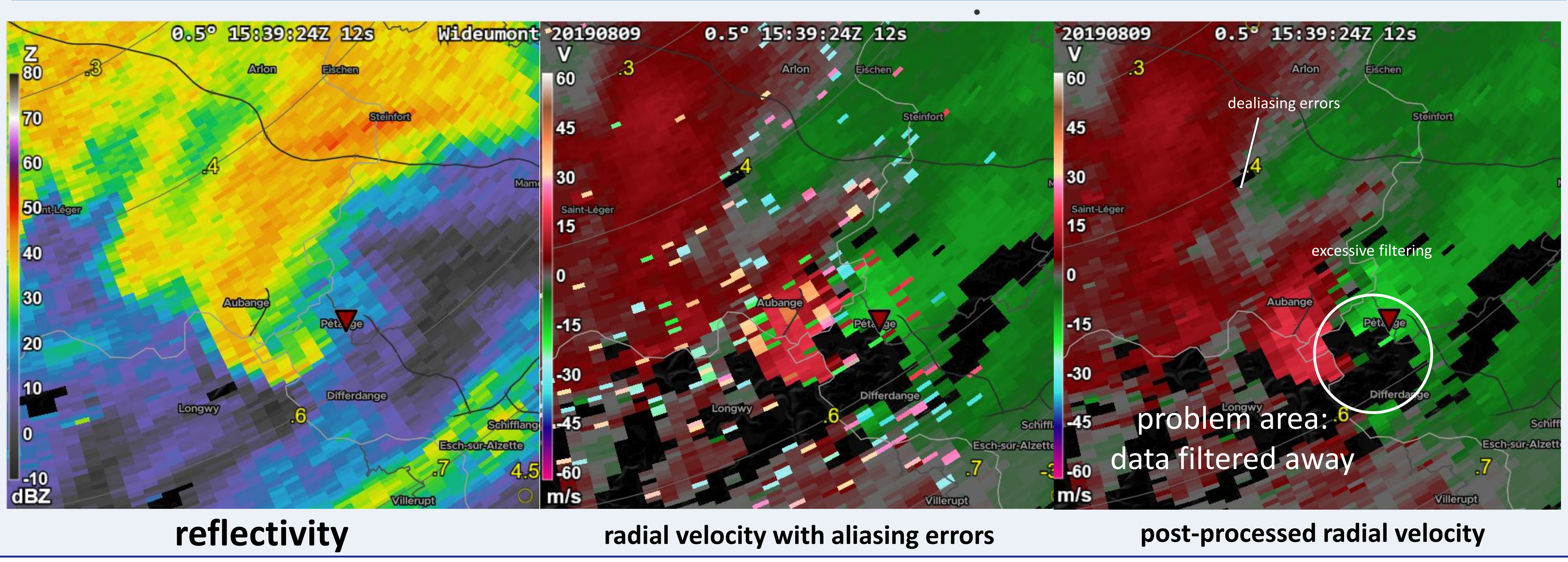
French radar data has 1000 gate length for velocity, 4 times larger than for reflectivity.

The post-processing algorithm corrects* the velocities (right), but is not able to reveal how tight the radial velocity gradient is, partly because of the limited number of data points it has to work with.

3. Filtering

Ground clutter, i.e. reflections from things on the ground rather than weather, is a big problem. Likewise, velocity data can be noisy because of a host of reasons which is a problem for some purposes such as data assimiliation in weather models. The filters (e.g. a signal-quality index filter) used to remove such unwanted data are often overzealous and important data for the detection of tornado cyclones are removed.

Tornado near ….



4. Elevations

As per the definition of a tornado, these vortices cause damaging winds at the ground. That is why one must scan at small angles (elevations) above the horizon, and optimally at slightly different angles, for example at 0.5°, 1.0° every scan pattern.

5. Dealiasing errors

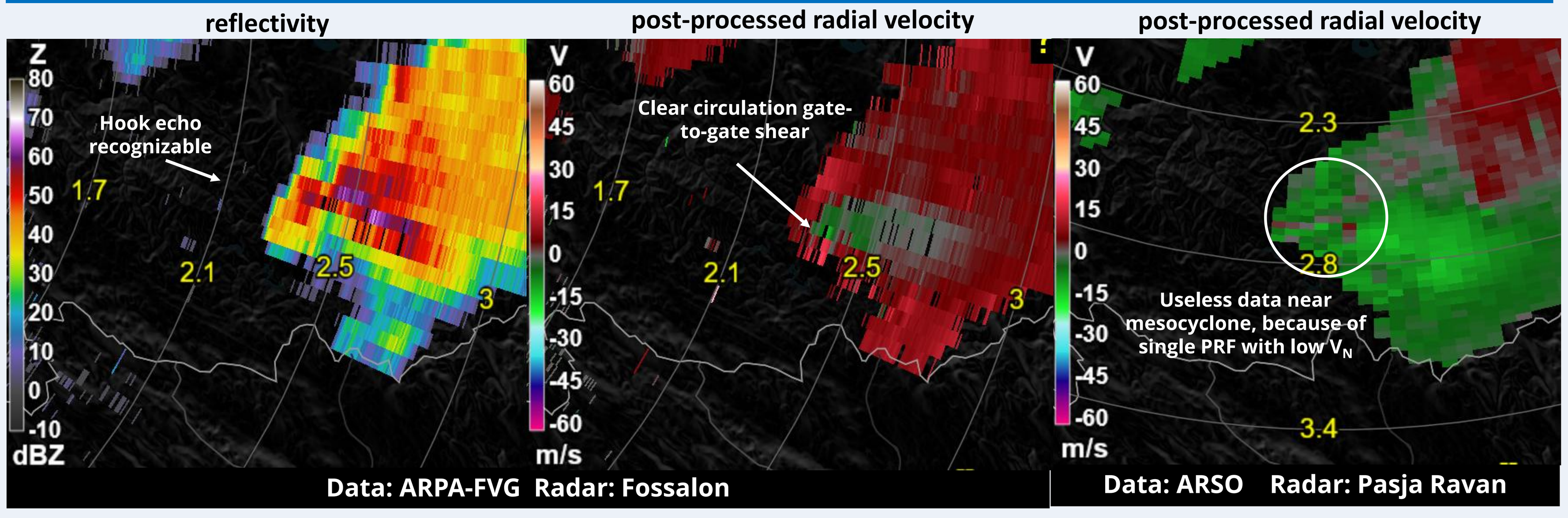
When scanning velocities with radar, velocities above a certain value (the Nyquist velocity) cannot be distinguished from those any multiple of two Nyquist velocities higher or lower. In other words, if the Nyquist velocity is 10 m/s, a radar could give the velocity as:

$$V = 2.7 + 2N * 10 \text{ m/s, where } N = \{\ldots, -2, -1, 0, 1, 2, \ldots\}.$$

So V might be 2.7 m/s, 22.7 m/s, 42.7 m/s, -17.3 m/s, -37.3 m/s, etc., which is pretty useless.

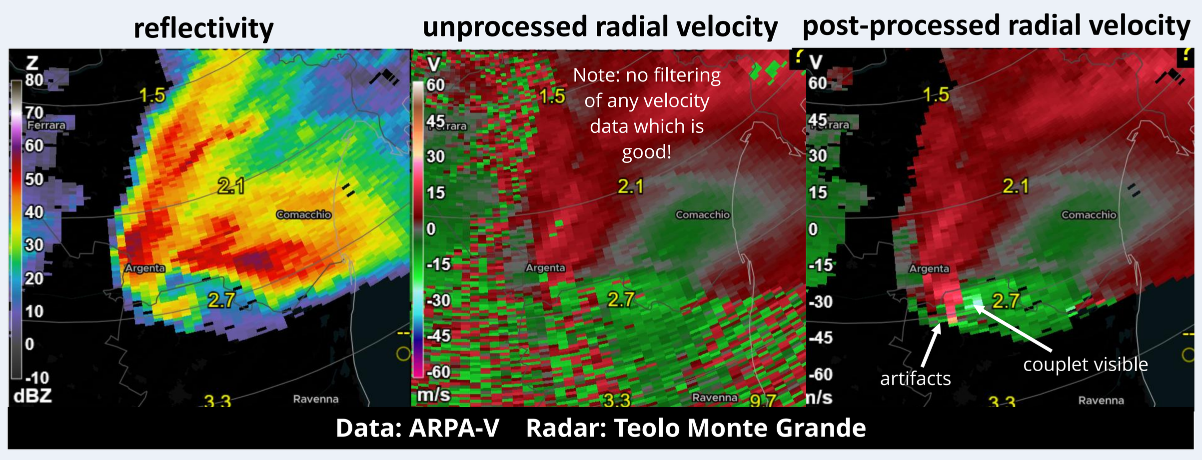
However, by combining data from two adjacent radials and scanning using different pulse frequencies (**Dual-PRF**) that give different Nyquist velocities, a much higher "effective Nyquist velocity" can be obtained. There will be some errors when the wind field changes much, like in tornadoes, but post-processing can mostly fix these errors. But if the errors are **too prevalent**, or the two Nyquist intervals **too close together**, this is not possible.

Tornadic storm seen by two radars (Koseze, Slovenia, IF2)



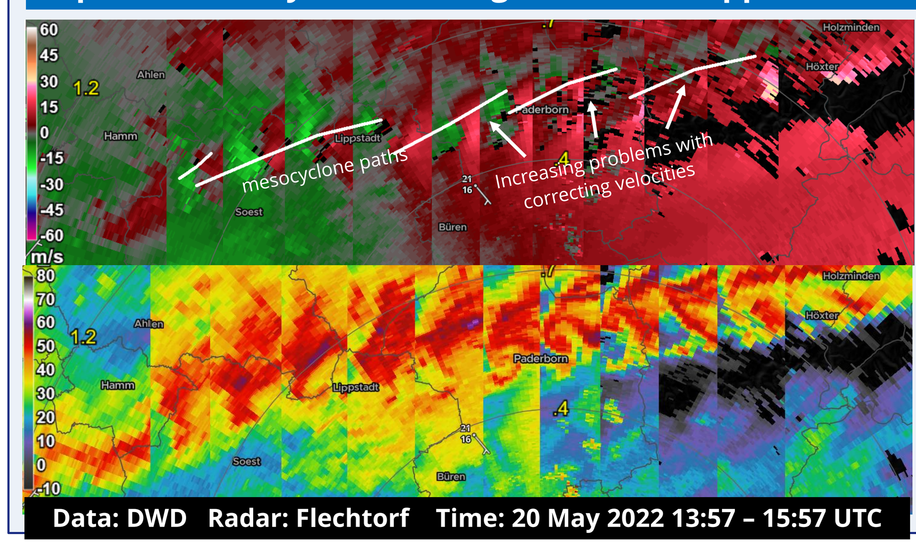
Both radars scan the storm at about 2.5 km AGL and are at a distance of about 80 km at the same time: 22 June 2023 at 18:05 UTC while the tornado is ongoing. The Fossalon radar operated by ARPA-FVG uses 2/3 low to high PRF/VN with VN , high = 15 m/s which leaves essentially no velocity errors after post-processing, albeit with a little filtering. The Pasja Ravan radar uses single-PRF and cannot be used.

Tornadic storm in Veneto region (Alfonsine, Italy IF3, 22 July 2023)



This tornadic supercell was well-sampled by the Teolo Monte Grande radar. The radar uses single-PRF, however with a relatively high V_N of 15.8. The post-processing can still correct the velocities on some scans but not fully. Dual-PRF would have probably helped.

Supercell with cyclic tornadogenesis over Lippstadt and Paderborn, Germany on 20 May 2022



This supercell produced a series of tornadoes, approximately aligned with the mesocyclone paths with up to IF2.5 intensity.

Operational C-Band Doppler data can reveal the circulations quite well after post-processing the velocity data. With a high Nyquist velocity of 10.8, quite a few errors are not resolved especially during the second half of the shown period. We recommend a higher V_N and stop filtering altogether.

"How to make my C-band radar see tornadoes" - CHECKLIST

1. Time between scans: 5 minutes or less
2. At least one scan in the pattern at 1.0° or lower
3. Gate length 250 m or less
4. Don't filter V based on signal quality
5. Prevent too agressive clutter filtering
6. Use dual PRF, optimally with a 3:2 PRF ratio
7. Ensure the high Nyquist velocity = 15 m/s or higher

This will cost you some range, but looking further and not seeing anything clearly seems a worse choice. An extended Nyquist velocity > 30 m/s is not necessary: any resulting folding can easily and reliably be resolved by post-processing.

8. Use a good algorithm to correct aliasing errors

What about inserting one "tornado scan" meeting these requirements into the 5-minute scanning pattern ?

Acknowledgements

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