Advanced signal processing for weather radars

Towards clean radar data for daily operations and science

MOTIVATION

Weather radar data should ideally only contain weather, but it is **affected by many unwanted influences**, among others:

- Noise
- Stationary clutter
- Multi-trip echoes
- Radio frequency interference (RF)
- Wind turbine clutter (WTC)

Some can be mitigated with simple algorithms (e.g. fixed clutter), others need **more sophisticated approaches** (multi-trip echoes, RF, WTC).

GAMIC signal processor ENIGMA has built-in all signal processing features, moments, and data types presented here.

BASIC SIGNAL PROCESSING

Noise thresholding:
Cutting off data below the noise threshold.

Speckle filter:
Removal of stand-alone data bins without neighbours and filling up small data gaps by interpolation of surrounding bins.

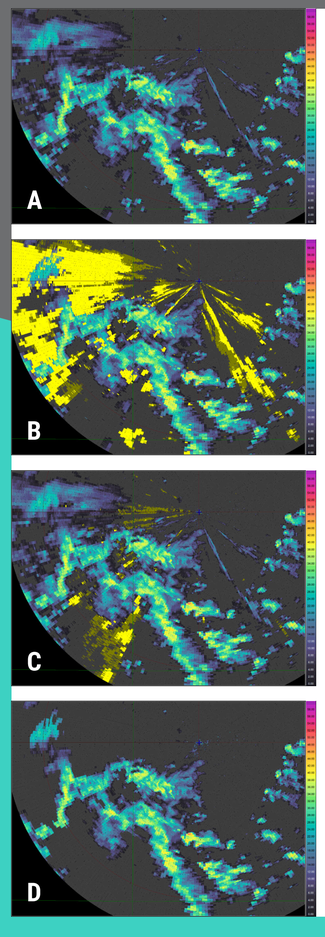
(Stationary) Clutter filter:
Pulse spectra are filtered for zero-velocity peaks (indicator for stationary clutter).

ADVANCED SIGNAL PROCESSSING →

DATA TYPES

Scientific measurements **can require a high dynamic data range**. Digitized radar data can be stored as different data types:

- **8bit integer** (typical for basic data with no need for high value resolution)
- **16bit integer** (useful for moments with need for very high value resolution, e.g. PHIDP)
- **32bit float** (highest dynamic range, needed for the investigation of raw data, e.g. DFT)



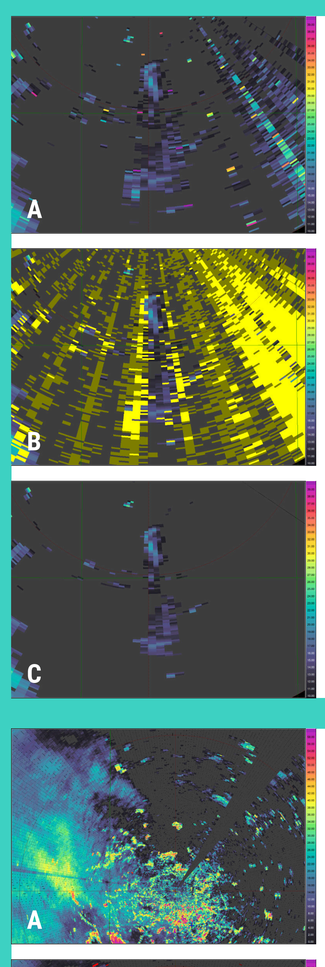
MULTI-TRIP ECHOES

Echoes coming from **behind the maximum unambiguous range** are ambiguous and called multi-trip echoes.

Multi-trip echoes can be detected by a **coherent radar** (coherent on recieve or fully coherent).

- Requirement: the **transmitted phase is coded and varies** from pulse to pulse (magnetron: inherent random phase of transmitted pulse; solid state: random phase or SZ64 coding).
- Due to knowledge about the phase for each transmitted pulse, any received pulse can be **associated** with previous transmissions (multi-trips).
- Detected multi-trip echoes can be **flagged** and **classified**.
- Multi-trip echoes can be **filtered** by removing the respective coherent values from the time series data.

Fig. 1: Reflectivity data with multi-trip echoes (a), second-trip flagged (b), third-trip flagged (c), and corrected (d).

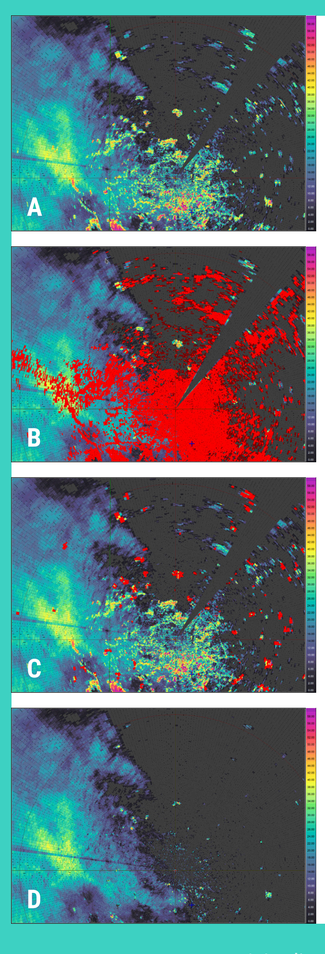


RADIO FREQUENCY INTERFERENCE

Radio frequency (RF) interference signals (wifi, other radars, etc.) occur especially in **densly populated areas**. These signals contaminate weather radar data but can be detected in real time.

- Pulsed interference is uncorrelated with the pulse repetition frequency of the radar system
- A distinct RF interference signature is detected in the **time series data** in **real time**
- Bins contaminated by RF interference are **flagged** (can be used for filtering).

Fig. 2: Reflectivity data with RF interference (a), RF interference flagged (b), and corrected (c).



WIND TURBINE CLUTTER (WTC)

Active wind turbines cause **more complex clutter** than stationary targets. The rotating blades cause an **elevated noise floor** in the Doppler spectrum due to their tangential velocity.

- Wind turbines visible as point targets in the estimated noise **NCP** (non-coherent power).
- Strong fixed targets (e.g. power lines, towers) also cause peaks in NCP (due to phase noise)
- Differentiation with **CR** (clutter ratio) moment (small for WTC, large for strong fixed targets)
- Identifying and flagging bins as wind turbine clutter at **local peaks and their flanks**
- Optional: Stabilising detections with a **confidence map**, **thresholding** of detections

Fig. 3: Reflectivity data with clutter and WTC (a), clutter flagged (b), WTC flagged (c), and corrected (d).

LIST OF ALL AVAILABLE MOMENTS* →

Z
Radar reflectivity

UZ
Radar reflectivity (unfiltered)

AZh
Attenuation corrected horizontal reflectivity

ZDR
Differential reflectivity

UZDR
Differential reflectivity (unfiltered)

AZDR
Attenuation corrected differential reflectivity

ZDR1
Differential reflectivity calculated from LAG1

UZDR1
Differential reflectivity calculated from LAG1 (unfiltered)

AZDR1
Attenuation corrected differential reflectivity from LAG1

V
Radial velocity

UnV
Radial velocity (unfiltered)

VF
Folded radial velocity

UVF
Folded radial velocity (unfiltered)

W
Spectral width

UW
Spectral width (unfiltered)

CW
Spectral width (corrected for antenna motion)

PHIDP
Differential phase

PHIH
Differential phase for H-transmit only (LDR mode)

UPHIDP
Differential phase (unfiltered)

UPHIH
Differential phase for H-transmit only (LDR mode) (unfiltered)

KDP
Specific differential phase

RHOHV
Cross correlation coefficient

RHOH
Cross correlation coefficient for H-transmit only (LDR mode)

URHOHV
Cross correlation coefficient (unfiltered)

URHOH
Cross correlation coefficient for H-transmit only (LDR mode) (unfiltered)

LDR
Linear depolarization ratio

ULDR
Linear depolarization ratio (unfiltered)

SQI
Signal quality index

SQI2
Signal quality index of second trip

SQI3
Signal quality index of third trip

CPA
Clutter phase alignment

STD
Normalized standard deviation

CCOR
Clutter correction ratio

I
Inphase signal

Q
Quadrature signal

LOG
Log power

SIGPOW
Signal power

SNR
Signal to noise ratio

NCP
Non-coherent power (realtime estimation of noise power)

CR
Clutter ratio (ratio clutter-to-signal)

DR
Depolarization ratio (only for radars with phase shifter)

UDR
Depolarization ratio (only for radars with phase shifter) (unfiltered)

DFT
Doppler spectrum

CSRE
Cross spectrum (real part)

CSIM
Cross spectrum (imaginary part)

CSMAG
Cross spectrum (magnitude)

CMAP
Censor map (flags for thresholding)

CLASS
Classification flags (CLUTTER, INTERFERENCE, WTC, SECOND_TRIP, THIRD_TRIP)

* Applies for GAMIC signal processor ENIGMA. For dual polarization radars, many moments (e.g. Z, V, W) are available for the horizontal (h) and vertical (v) channel.

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