A time-series method to identify and correct range sidelobes

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1. Summary of key findings:

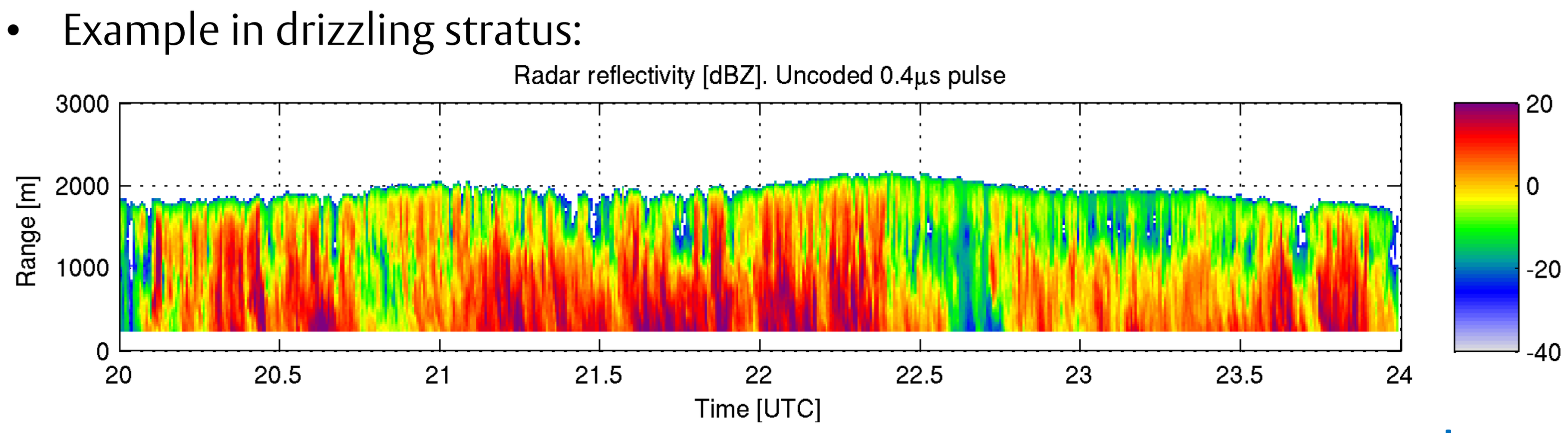
- Want to identify and correct range sidelobe artefacts from pulse compression
- We use the fluctuating echo of meteorological targets as a "fingerprint"
- We identify sidelobes by searching for traces of this fingerprint in other range gates
- Cross-correlation tells you how much power has leaked from one gate to another
- Works best when number of independent pulses is large

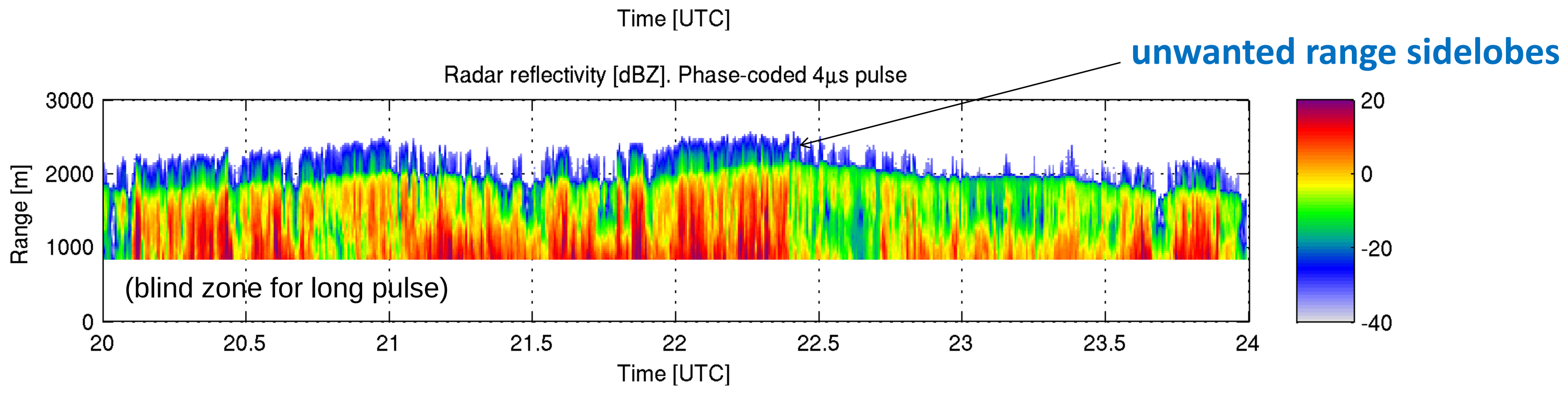
2. Background

- Use of pulse compression is increasingly common in meteorological radars (ARM cloud radars, wind profilers, solid state weather radars...)
- In theory, you get extra sensitivity while maintaining high range resolution
- Traditional radar: trade-off between longer pulse (> sensitivity) and range resolution
- Pulse compression: transmit long pulse, but encode extra information in form of phase or frequency modulation so you can decode the echo into desired high range resolution.
- Problem: there is not enough information to perfectly decode the echo, and you get some fraction of the true echo from one range gate leaking in to other gates nearby – these are "range sidelobes". If there are both strong and weak echoes present (eg. near edge of a cloud, or near the bright band) this can significantly corrupt the measurements.

3. Example

- 35 GHz "Copernicus" radar at Chilbolton Observatory in UK
- Transmits both "traditional" pulses with 60m range resolution, and complementary 10bit phase-coded pulses which have same resolution but 13dB more sensitivity.
- Example in drizzling stratus:

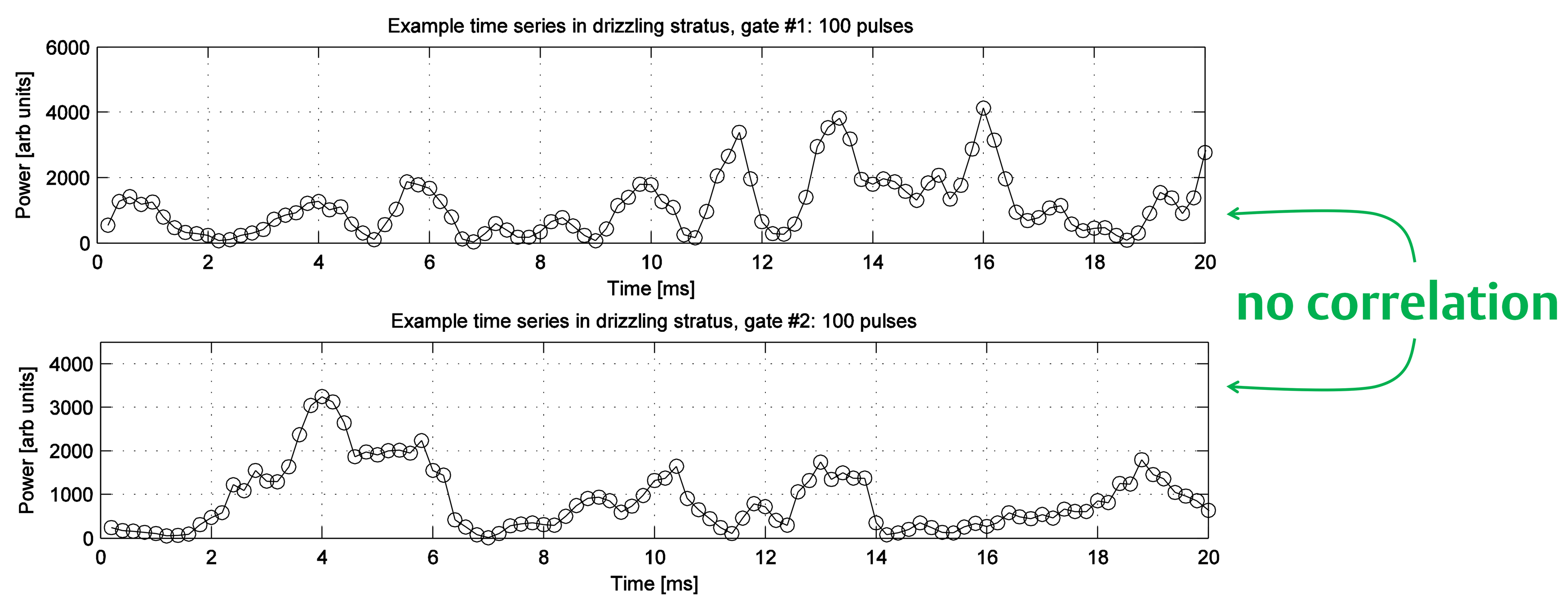




- We want to get rid of these sidelobes! But how?

4. The idea

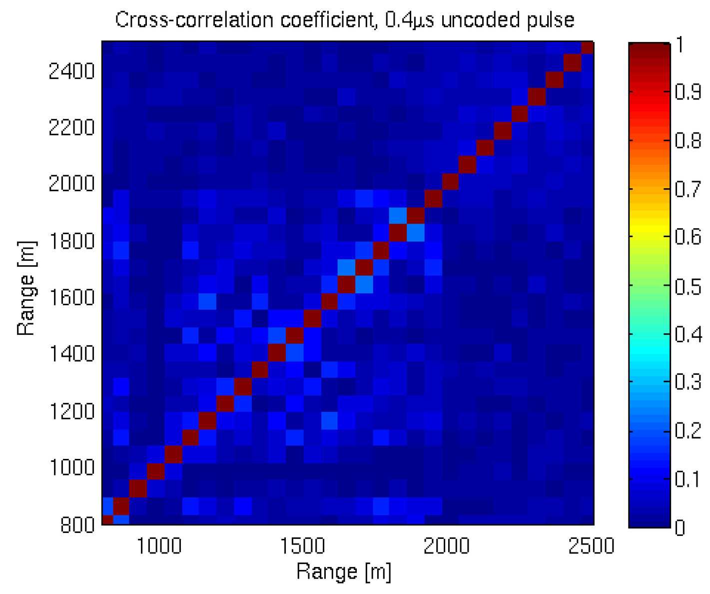
- Echo from meteorological targets fluctuates randomly as the scatterers (cloud particles or refractive index inhomogeneities) reshuffle relative to each other on scales of quarter of wavelength, leading to constructive / destructive interference at the radar antenna:



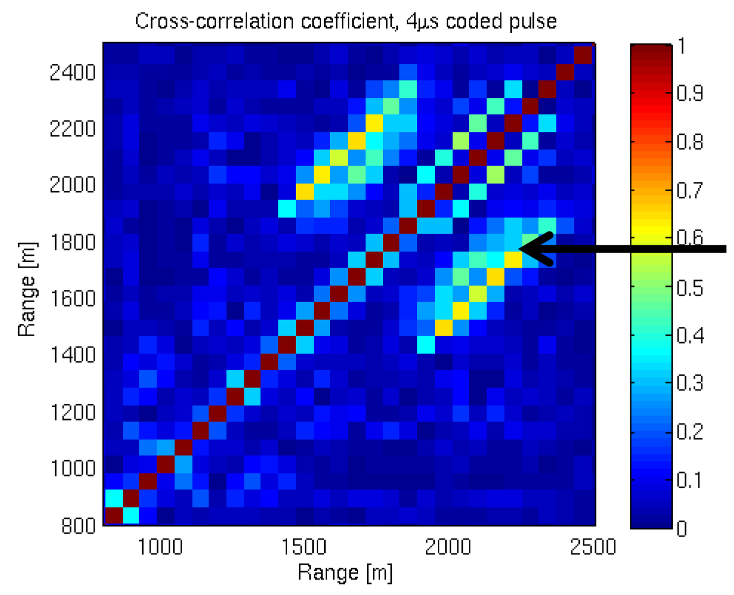
- This reshuffling happens on scales much smaller than the range resolution (60m here), so different gates are uncorrelated: **each fluctuating echo is unique (like a fingerprint)**
- So to see if the power from one range gate has leaked into another, all we need to do is look for traces of that fingerprint – ie we want to cross-correlate the echo time series
- **If no sidelobes then correlation coefficient |ρ|=0**
- **If there are sidelobes then |ρ|>0**

5. A practical example

- Examine a vertical profile from the drizzling stratus example in box 3
- 0.5 second dwell at 22 UTC. Time series of pulse-to-pulse power and phase is recorded at each range gate.
- We calculated |ρ| for each possible pair of range gates:



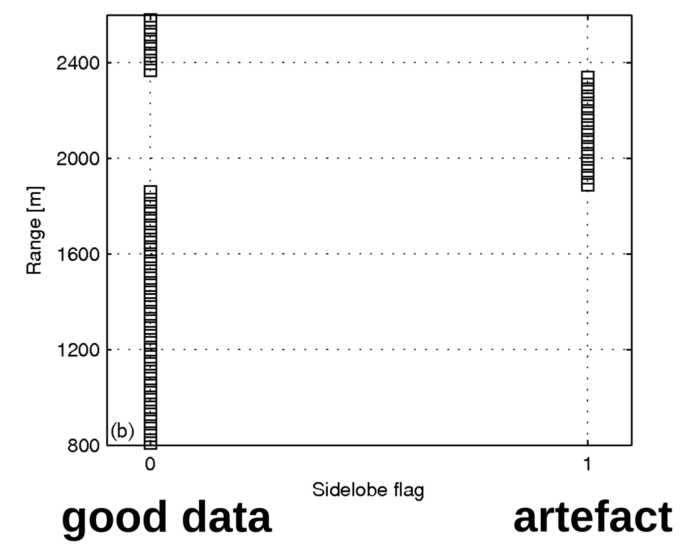
- **Uncoded data**: we expect no correlations, except when correlating a gate with itself. Should have |ρ|=1 on diagonal and zero everywhere else
- ✓ This is what we see !
- Note |ρ| is not precisely zero on off-diagonal elements, and this is because the time series is not infinitely long



- **Coded data**: we observe correlations as high as 0.6 between different range gates
- ***These are the range sidelobes***
- If we identify correlations > some critical value (say |ρ|>0.25) then we can flag the location of these sidelobes objectively.

Simple Flagging algorithm: identify |ρ|>0.25

- We would also like to know "which way" the information is flowing
- Realise that echo leaks from strong echo to weaker one, rather than vice versa
- Flag weaker of two echoes as corrupted
- This very simple algorithm correctly flags data above 1900m as likely sidelobe artefacts



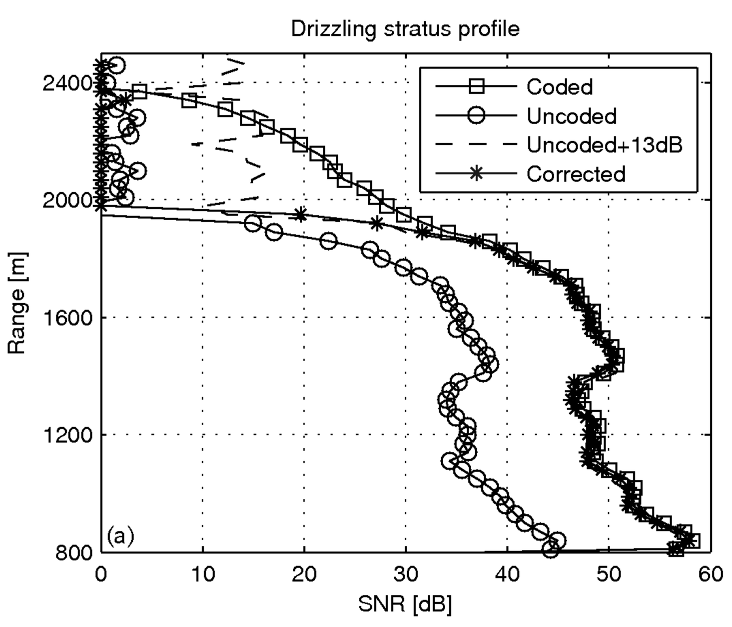
6. A tentative idea for correcting the *Z* profile

- Have shown how we can identify sidelobes using these correlations – what about actually correcting for their effects in the reflectivity profile?
- Consider correlation between two gates *k* and *i*, where the echo at *k* is much stronger than at gate *i*. We measure two complex time series V_k, V_i . After some manipulation we find

$$|\rho|^2 \approx |\langle f \rangle|^2 \times \left(\frac{\sum_{time} |V_k|^2}{\sum_{time} |V_i|^2} \right)$$

where $\langle f \rangle$ is an average "leakage factor" of signal from gate *k* to gate *i*

- In other words, $|\rho|^2$ tells you the fraction of the power at gate *i* which is due to leakage from gate *k*
- We can use this information to correct the reflectivity profile by subtracting this from the measured signals



Applying the correction to the stratus profile:

- plot shows SNR profile for coded and uncoded pulses for the time series in box 5
- note the sidelobe artefacts above 1900m
- stars show coded profile with correction applied – matches uncoded profile perfectly and correctly removes all echoes above 2000m.
- Promising indication that can correct profiles corrupted by pulse compression

- Challenges:
  - Correlation coefficients are noisy if not enough independent samples (dwells here have $N \approx 120$) – tricky for scanning weather radars?
  - Ignoring "3-way" correlations – could be issue for very long coded pulses?

7. For more details...

preprint at tinyurl.com/sidelobe

CD Westbrook and JC Nicol 'A time-series method to identify and correct range sidelobes in meteorological radar data' *J. Atmos. & Ocean. Tech.* in press