Spectral Polarimetric Filter Design for Weather Radar Clutter Suppression

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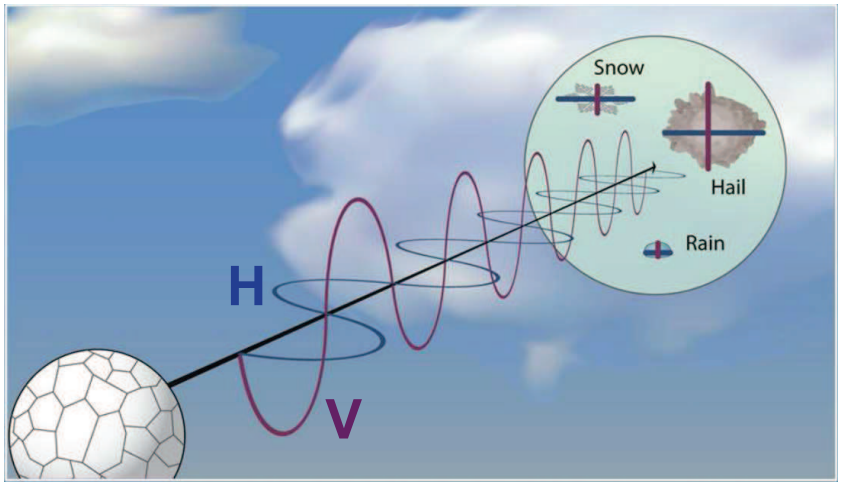
What is polarimetric weather radar?

- Many radars transmit and receive radio waves with a single horizontal polarization
- Polarimetric radars transmit and receive both horizontal and vertical polarizations
- Can determine:
  - ➢ Shape
  - ➢ Size
  - ➢ Variety



Picture from https://www.weather.gov/news/130425-dualpol/

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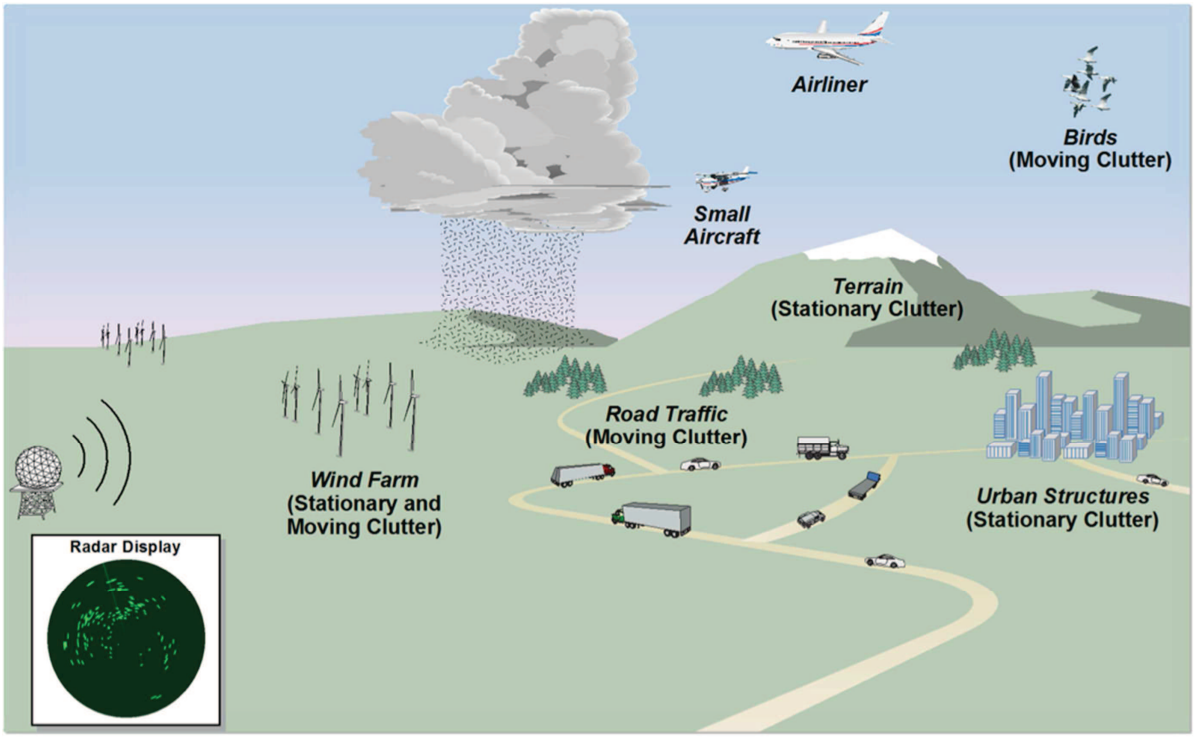
Why polarimetric weather radar?

- METEOROLOGISTS:
  - estimate the amounts of precipitation
  - improve flash flood watches and warnings
  - may contribute to increased lead time in flash flood and winter weather hazard warnings
- HYDROLOGISTS:
  - provides critical rainfall estimation information for stream flow forecasts and river flooding.
  - may be useful in water management.

Why polarimetric weather radar?

- AVIATION USERS:
  - detects aviation hazards such as birds
  - can detect aircraft icing conditions
  - can identify regions of large and giant hail
- SOCIETY:
  - can improve forecasts and warnings and reduce the impact of hazardous weather on our national transportation.
  - better equips forecasters to issue accurate warnings, and in turn helps the public make wiser decisions about our safety.

Weather radar clutter



Picture from http://www.windpowerengineering.com/policy/teaching-wind-turbines-radar-play-nice/

Clutter suppression in weather radar

- Polarimetric Doppler weather radar in atmospheric observation:
  - Doppler --- Dynamic indication
  - Polarimetry --- Microphysical retrieval
- Clutter suppression method should keep precipitation regardless of its intensity.
  - Storms --- natural hazard monitor
  - Drizzle --- climate change study

IDRA --- TU Delft IRCTR Drizzle Radar

IDRA is mounted on top of the 213 m high meteorological tower.

Specifications

- 9.475 GHz central frequency
- FMCW with sawtooth modulation
- transmitting alternately horizontal and vertical polarisation, receiving simultaneously the co- and the cross-polarised component
- 20 W transmission power
- 102.4 μs – 3276.8 μs sweep time
- 2.5 MHz – 50 MHz Tx bandwidth
- 60 m – 3 m range resolution
- 1.8° antenna half-power beamwidth

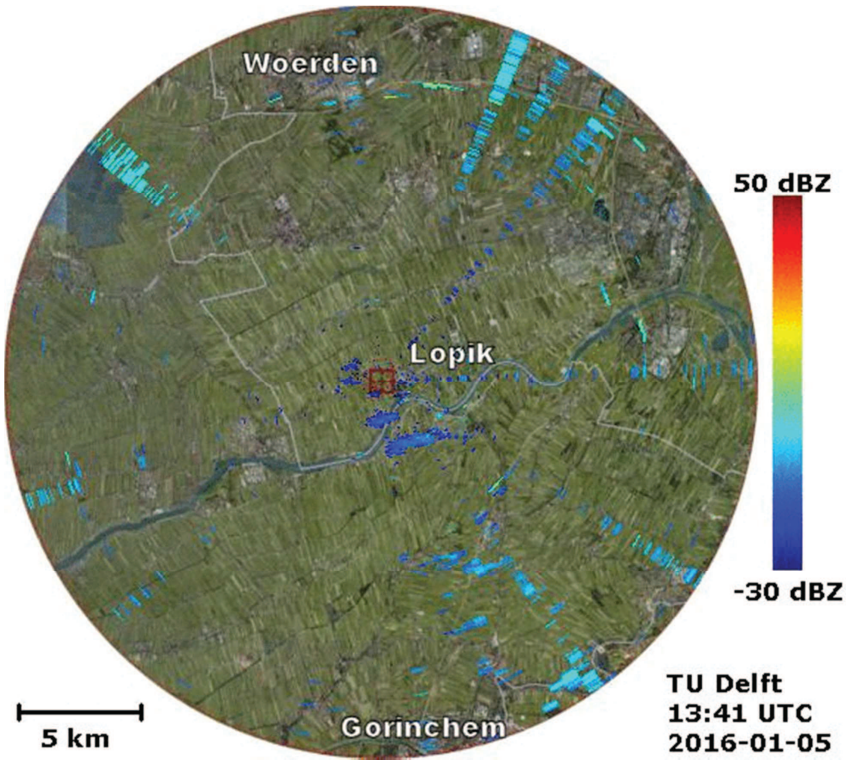
Reference

J. Figueras i Ventura: "Design of a High Resolution X-band Doppler Polarimetric Weather Radar", *PhD Thesis*, TU Delft, 2009. (online available at http://repository.tudelft.nl)

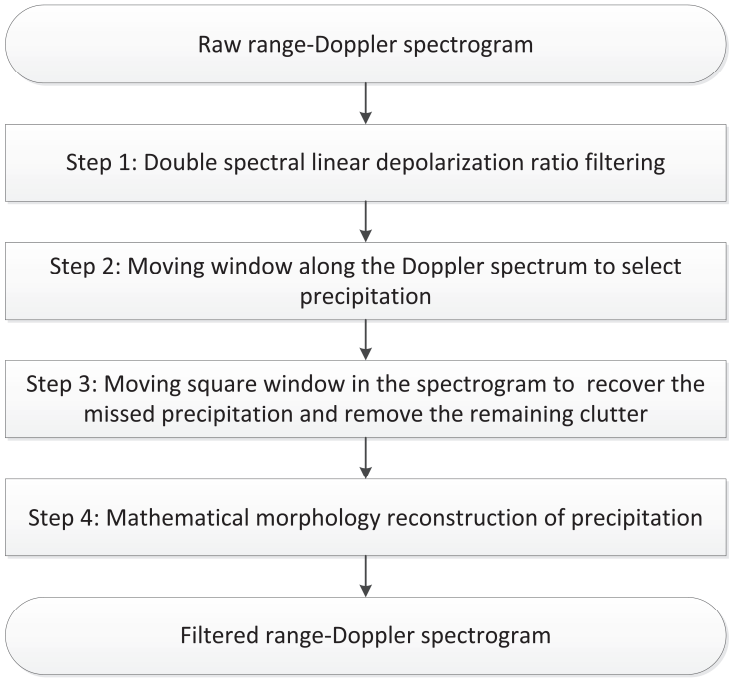
Near real-time display:
http://ftp.tudelft.nl/TUDelft/irctr-rse/idra

Processed and raw data available at:
http://data.3tu.nl/repository/collection:cabauw

IDRA narrow-band moving clutter



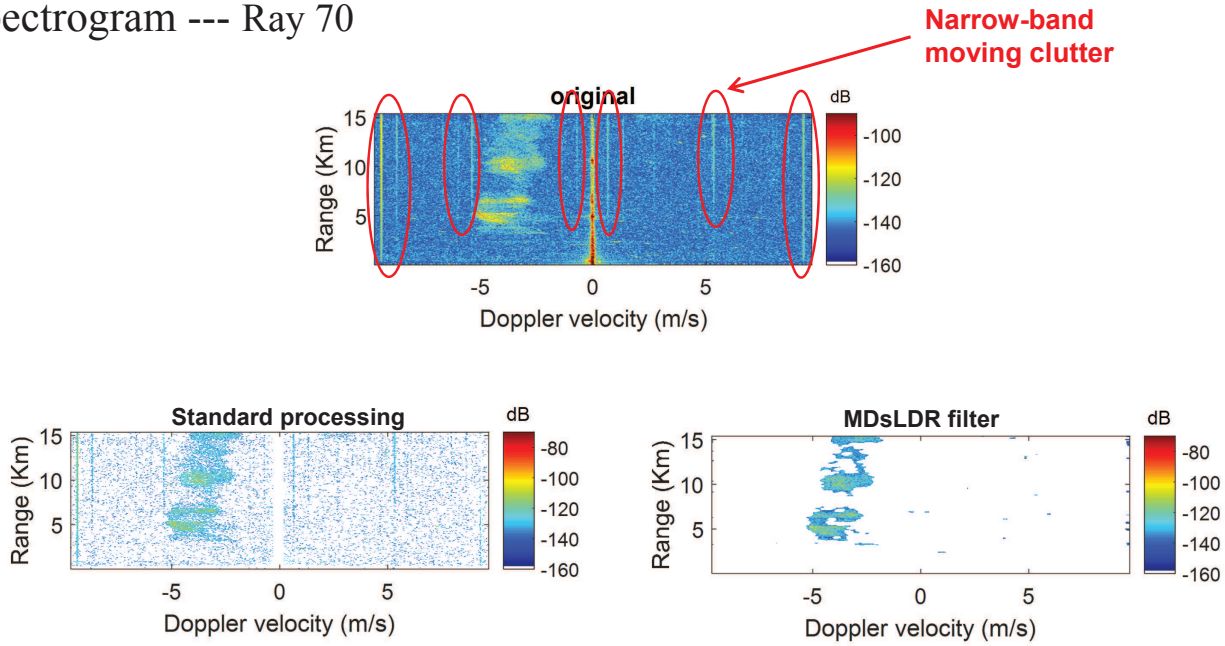
Moving double sLDR (MDsLDR) filter



J. Yin, C. M. Unal, and H. W. Russchenberg, "Narrow-band clutter mitigation in spectral polarimetric weather radar," IEEE Trans. Geosci. Remote Sens., vol. 55, no. 8, pp. 4655 – 4667, Aug. 2017.

MDsLDR filter

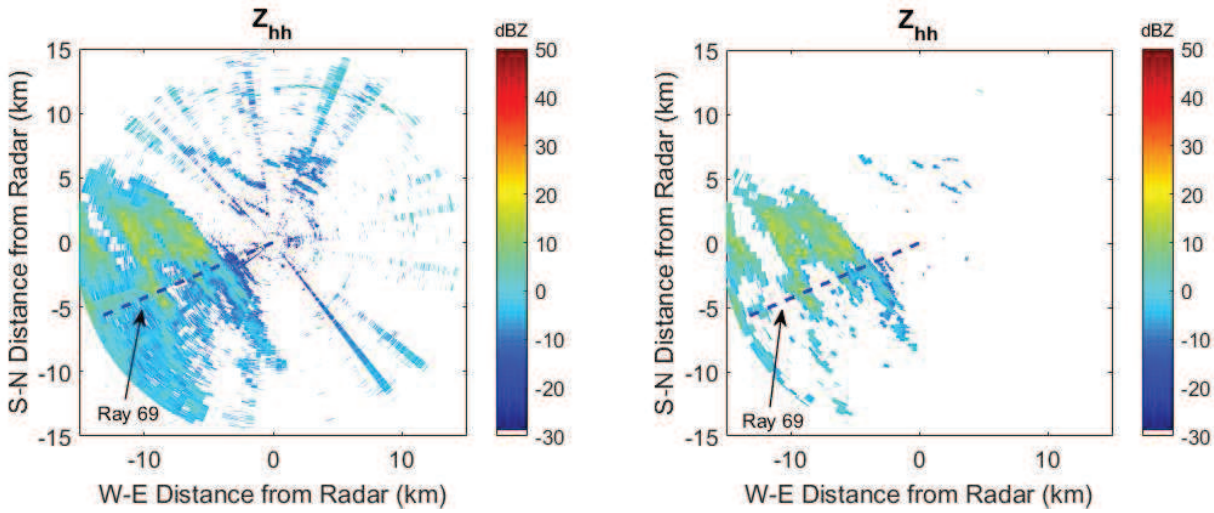
- Spectrogram --- Ray 70



J. Yin, C. M. Unal, and H. W. Russchenberg, "Narrow-band clutter mitigation in spectral polarimetric weather radar," IEEE Trans. Geosci. Remote Sens., vol. 55, no. 8, pp. 4655 – 4667, Aug. 2017.

MDsLDR filter

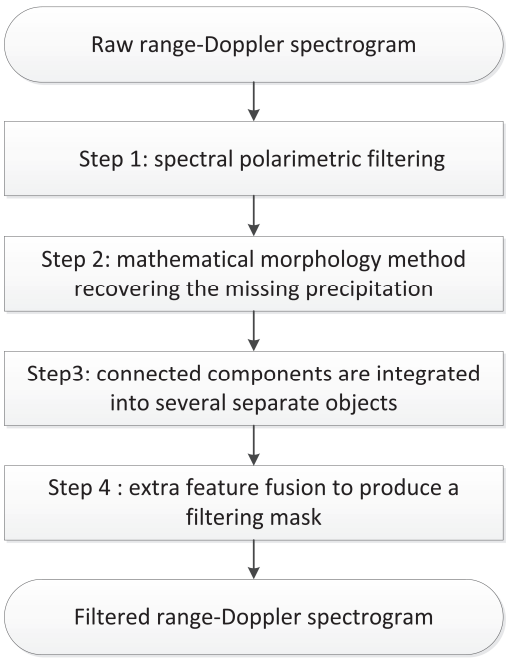
- PPI



(a) Standard processing **(b) MDsLDR filter**

The limitation of this filter is the cross-pol measurements, which is not always available for most polarimetric weather radars.

Any filter designed for dual-pol operational radars?



Objected-based spectral polarimetric filter.

J. Yin, C. M. Unal, and H. W. Russchenberg, "Object-Orientated Filter Design in Spectral Domain for Polarimetric Weather Radar," IEEE Trans. Geosci. Remote Sens., Nov. 2018, in press.

Spectral polarimetric observables

$$\begin{bmatrix} S_{HH} & S_{HV} \\ S_{VH} & S_{VV} \end{bmatrix}$$

- Spectral power

$$sZ_{XY}(r,v) = \left\langle |S_{XY}(r,v)|^2 \right\rangle$$

power of radar echoes

- Spectral differential reflectivity

$$sZ_{dr}(r,v) = 10log_{10}\left(\frac{sZ_{HH}(r,v)}{sZ_{VV}(r,v)}\right)$$

shape indicator

- Spectral linear depolarization ratio

$$sLDR^{HH}(r,v) = 10log_{10}\left(\frac{sZ_{VH}(r,v)}{sZ_{HH}(r,v)}\right)$$

$$sLDR^{VV}(r,v) = 10log_{10}\left(\frac{sZ_{HV}(r,v)}{sZ_{VV}(r,v)}\right)$$

shape & clutter-contaminated indicator

- Spectral co-pol correlation coefficient

$$s\rho_{co}(r,v) = \frac{\langle S_{VV}(r,v)\, S^*_{HH}(r,v)\rangle}{\sqrt{\left\langle |S_{HH}(r,v)|^2 \right\rangle \left\langle |S_{VV}(r,v)|^2 \right\rangle}}$$

clutter-contaminated indicator

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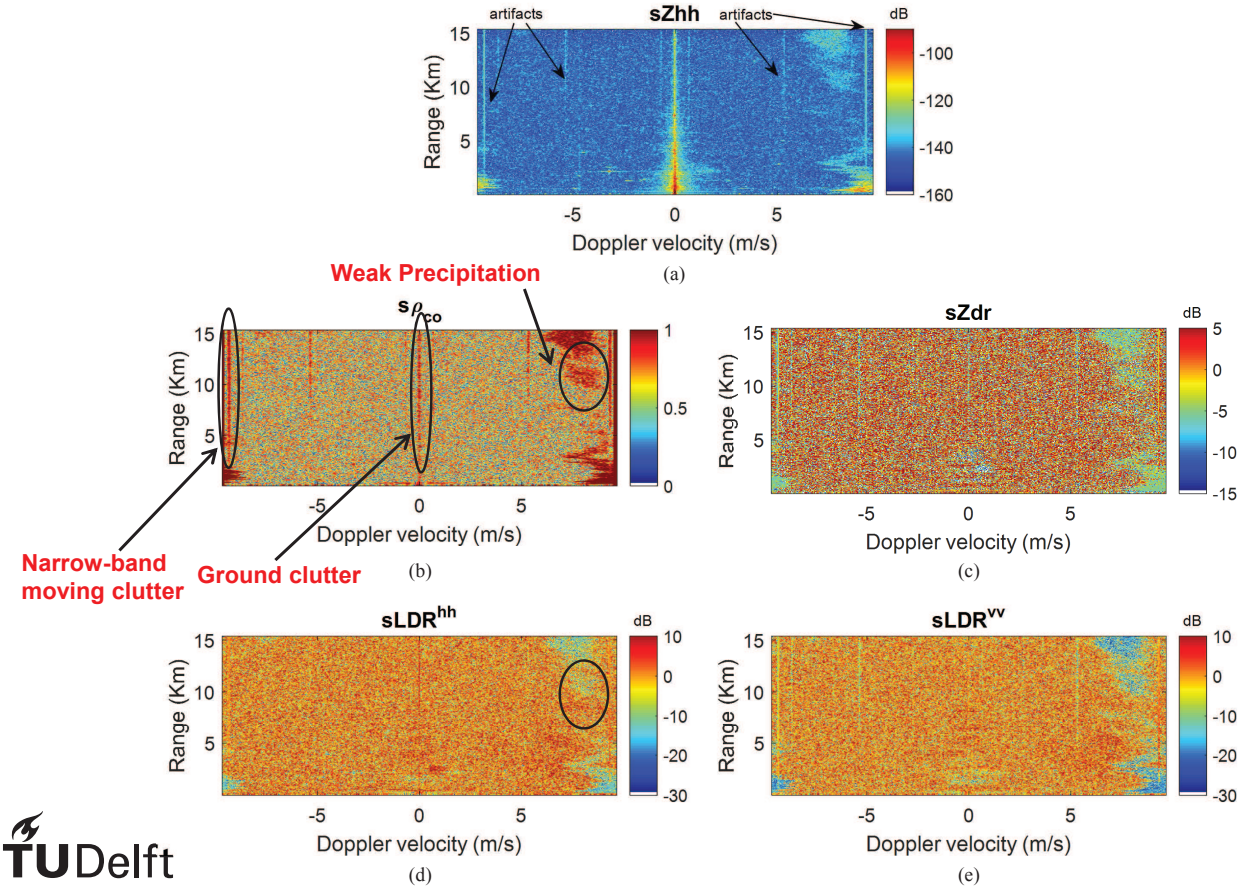
Spectral polarimetric observables



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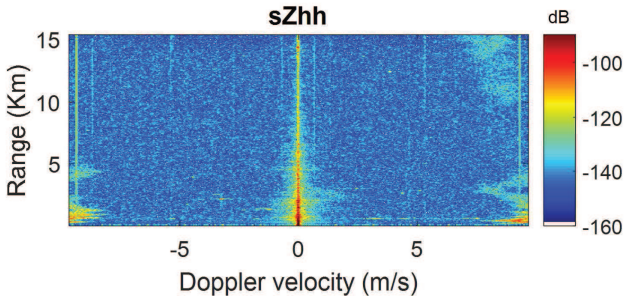
Objected-based spectral polarimetric filter.

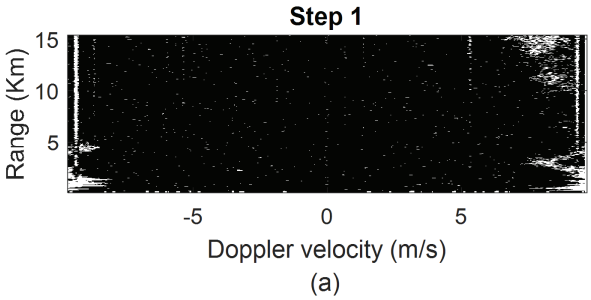


Step 1: spectral polarimetric filtering

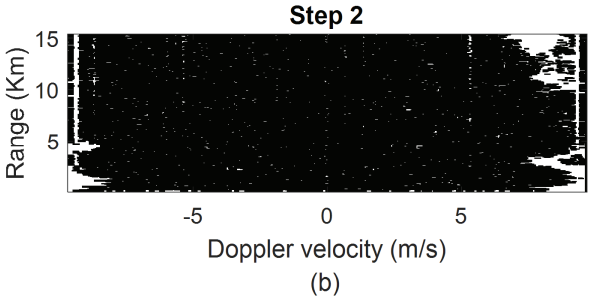
$$M^{s\rho_{co}} = \begin{cases} 1, & if\ |s\rho_{co}| > 0.95 \\ 0, & otherwise \end{cases}$$

Step 2: mathematical morphology method recovering the missing precipitation

A dilation followed by an erosion



(a)



(b)

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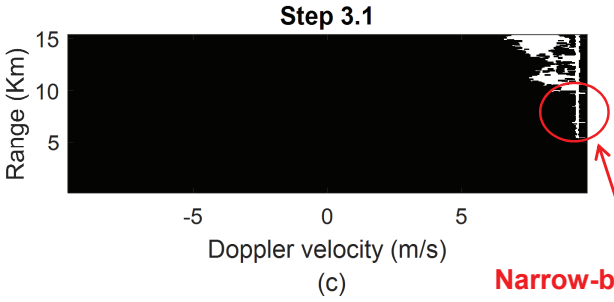
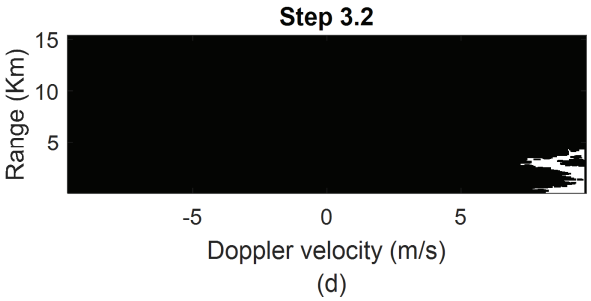
Objected-based spectral polarimetric filter.

Step3: connected components are integrated into several separate objects

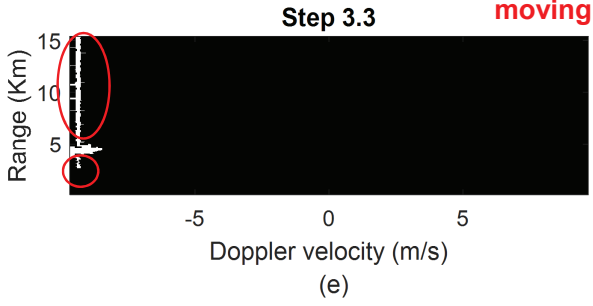


(c)

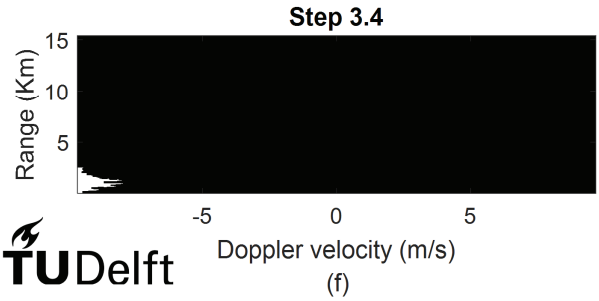
Narrow-band moving clutter



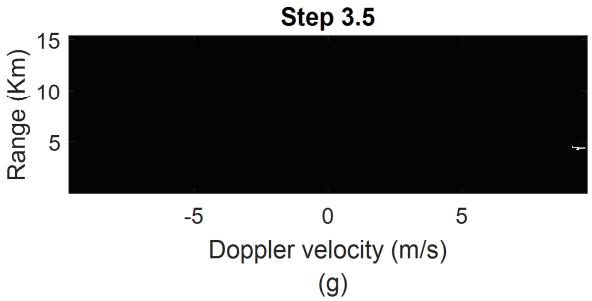
(d)



(e)



(f)



(g)

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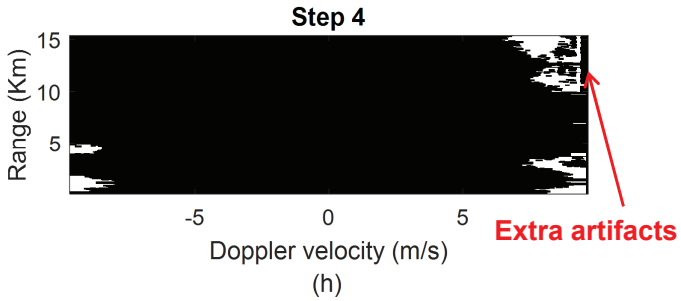
Objected-based spectral polarimetric filter.

Step 4 : extra feature fusion to produce a filtering mask

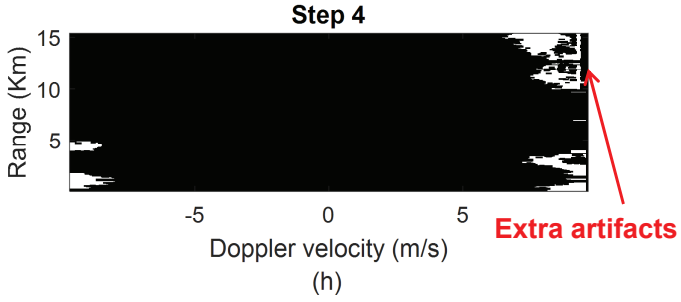
Spectral width filtering

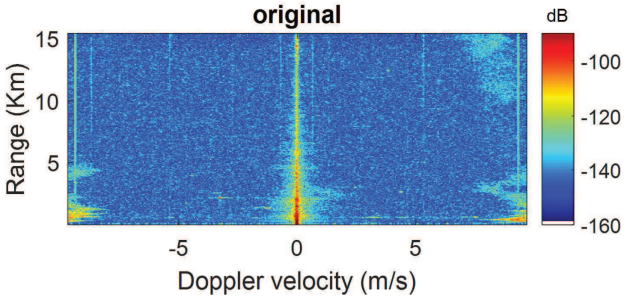


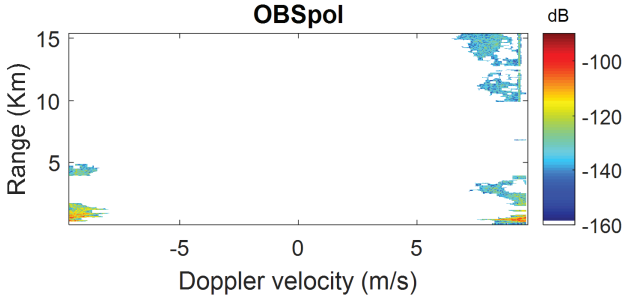
Objected-based spectral polarimetric filter.

Step 4 : extra feature fusion to produce a filtering mask

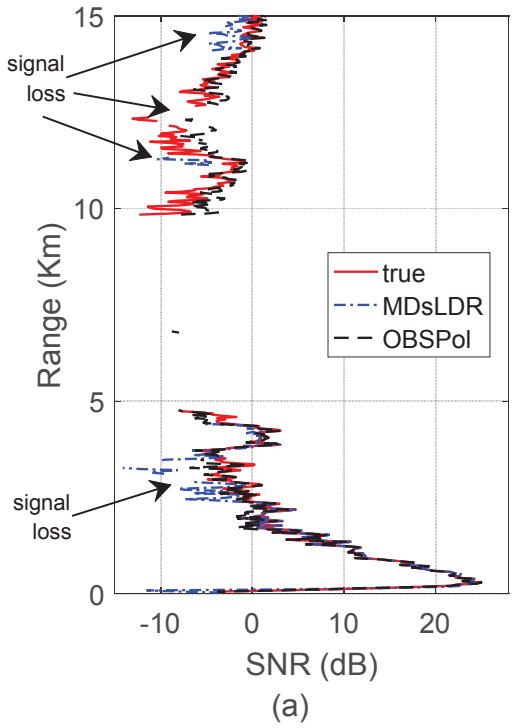
Spectral width filtering

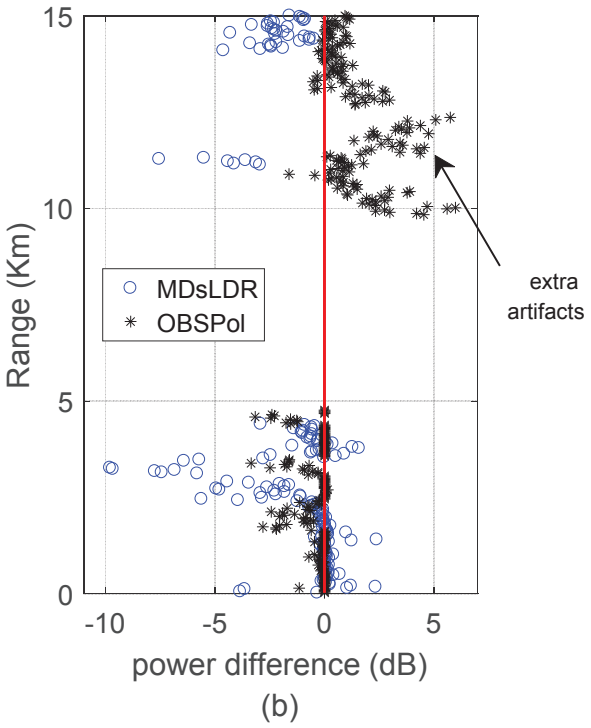






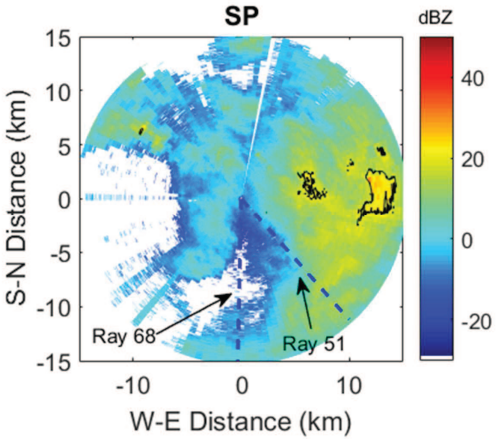
Spectrogram performance comparison

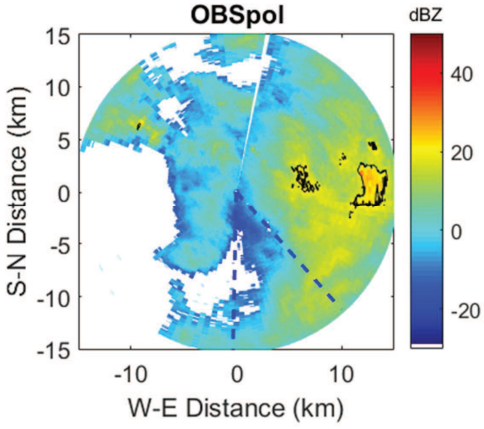




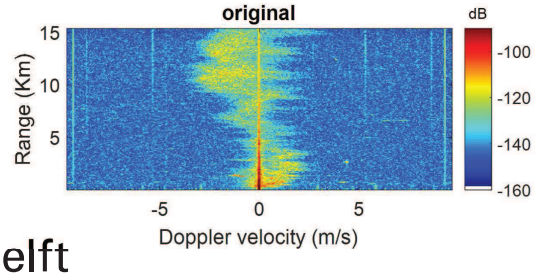
Performance comparison

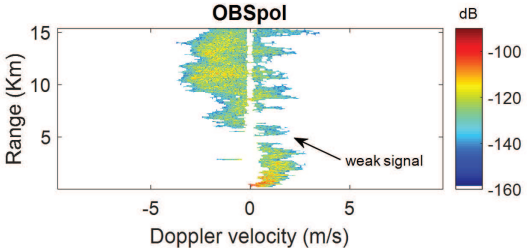
- PPI





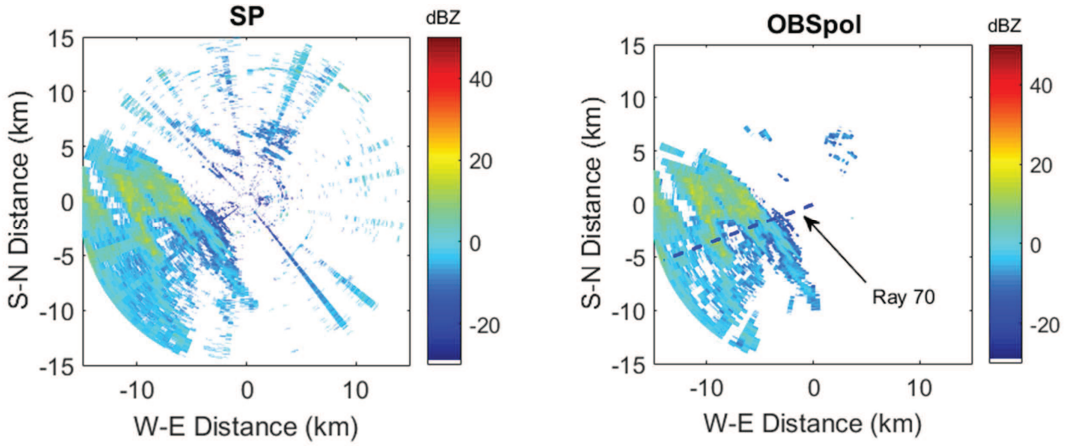
- Spectrogram --- Ray 51



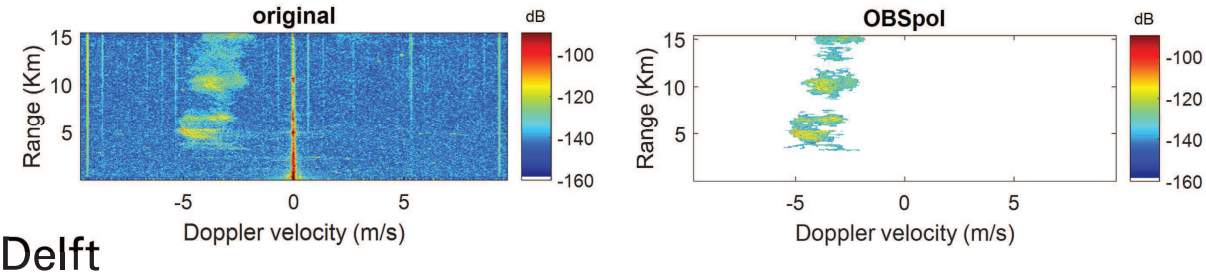


Case 2 Performance verification

- PPI

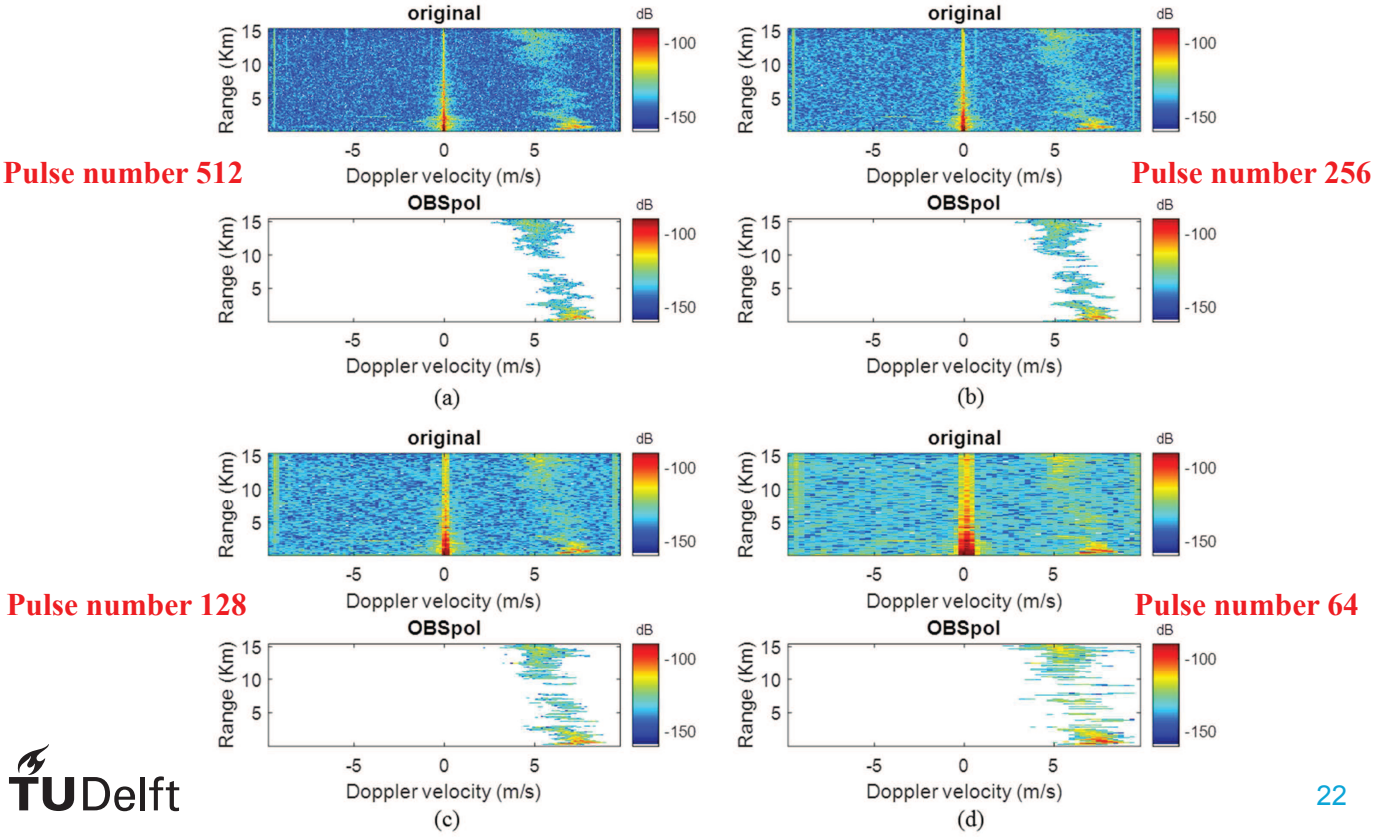


- Spectrogram --- Ray 70



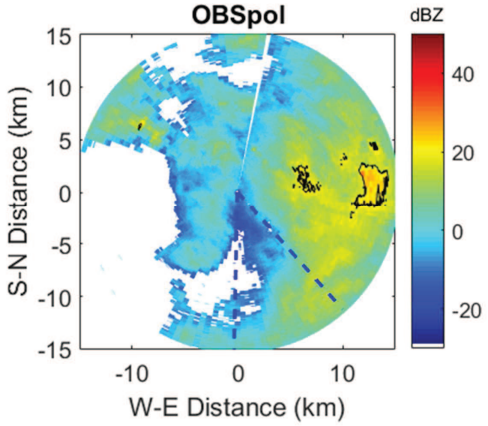
Different Doppler velocity resolutions

- Spectrogram --- Ray 62



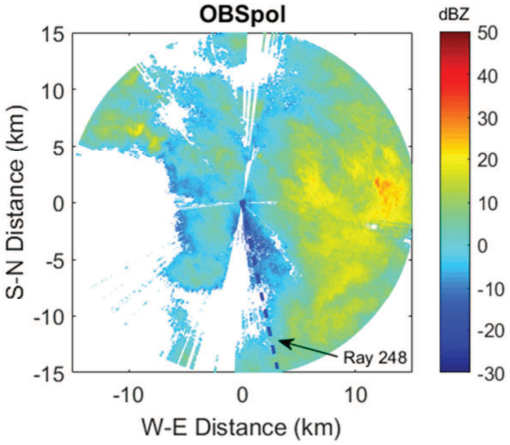
Different Doppler velocity resolutions

- PPI

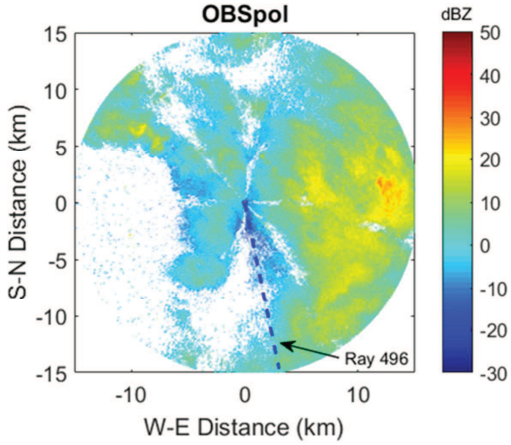


Pulse number 512

Pulse number 128

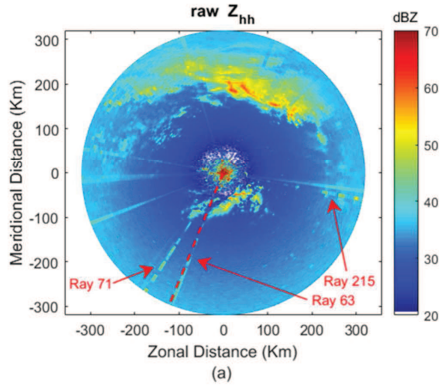


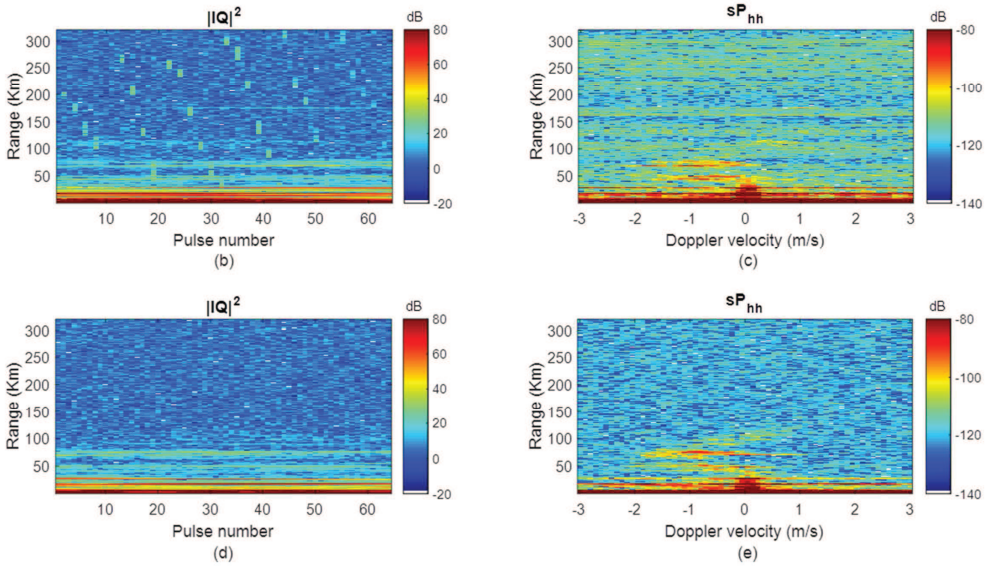
Pulse number 64



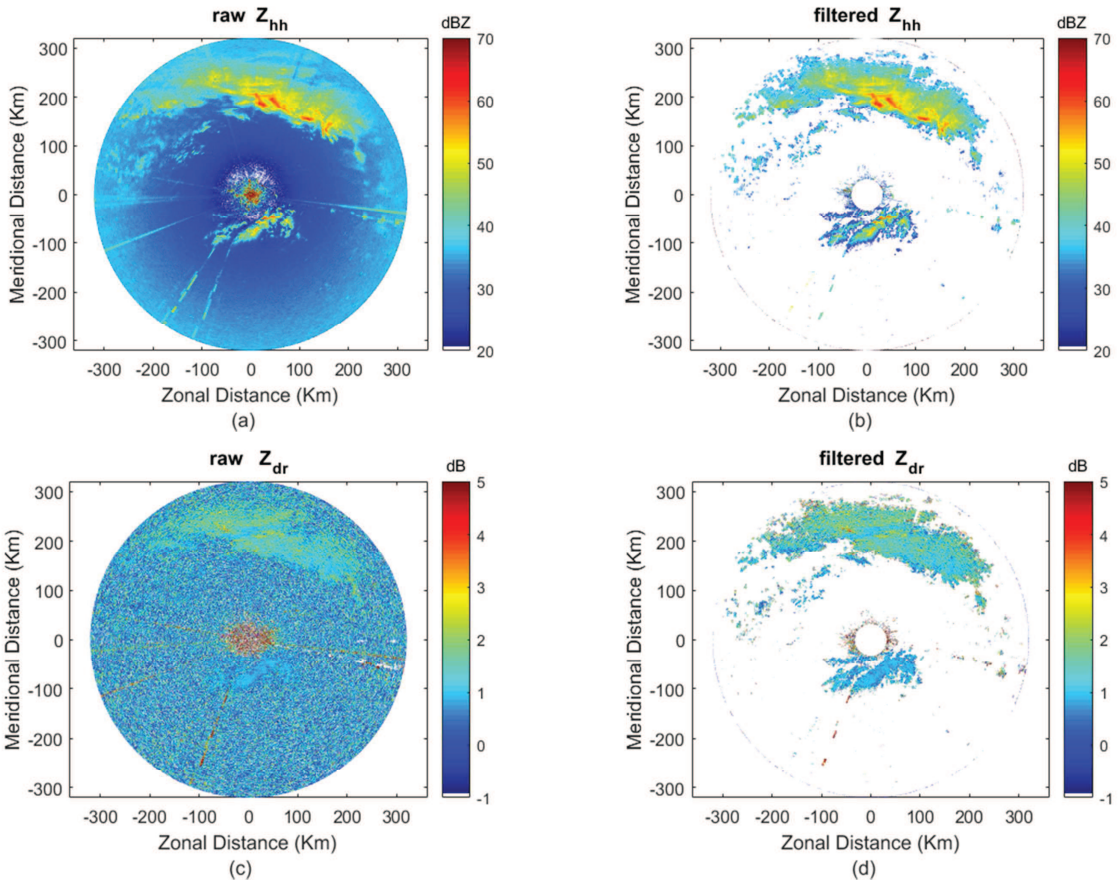
Case 3 Application to RF interference mitigation

C-band KNMI radar



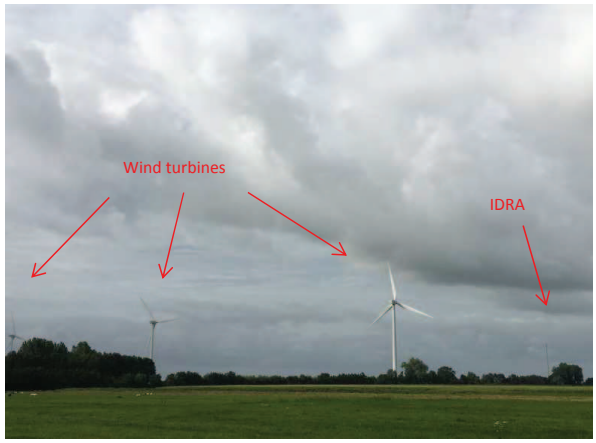


Case 3 Application to RF interference mitigation

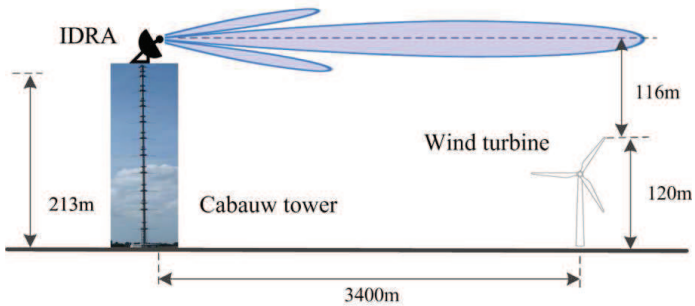


Case 4 Application to wind turbine clutter mitigation

(a)



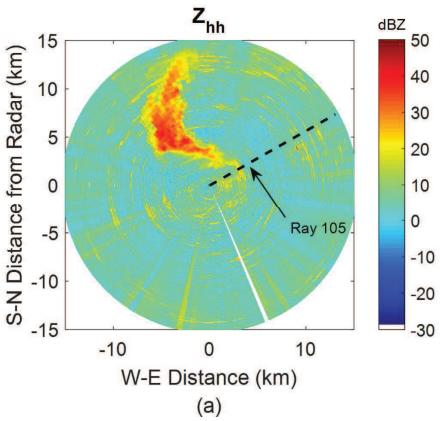
(b)

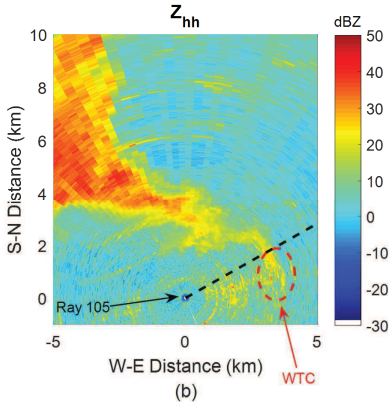


(c)

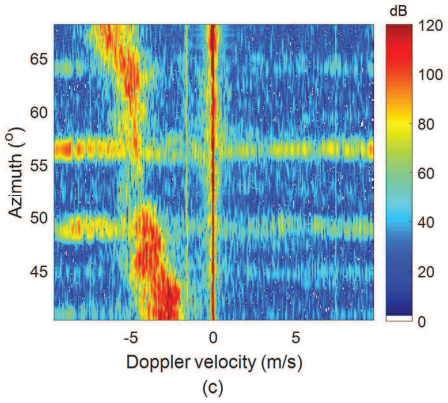
Wind turbine clutter

- PPI



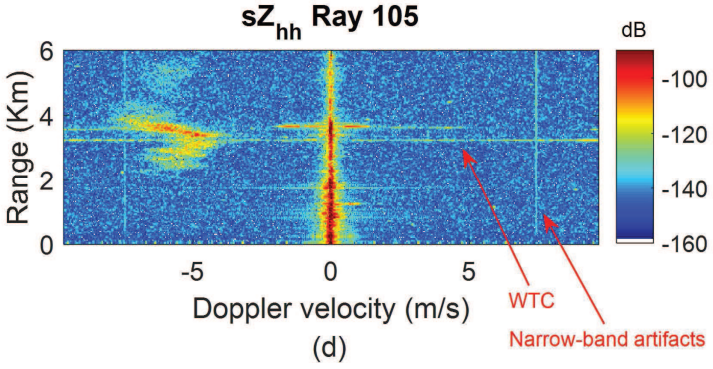


- Time-frequency image

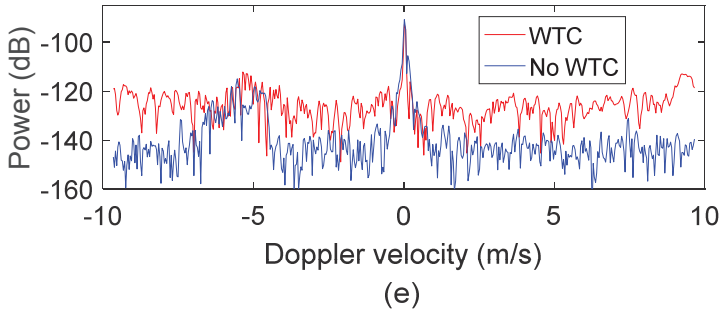


Wind turbine clutter

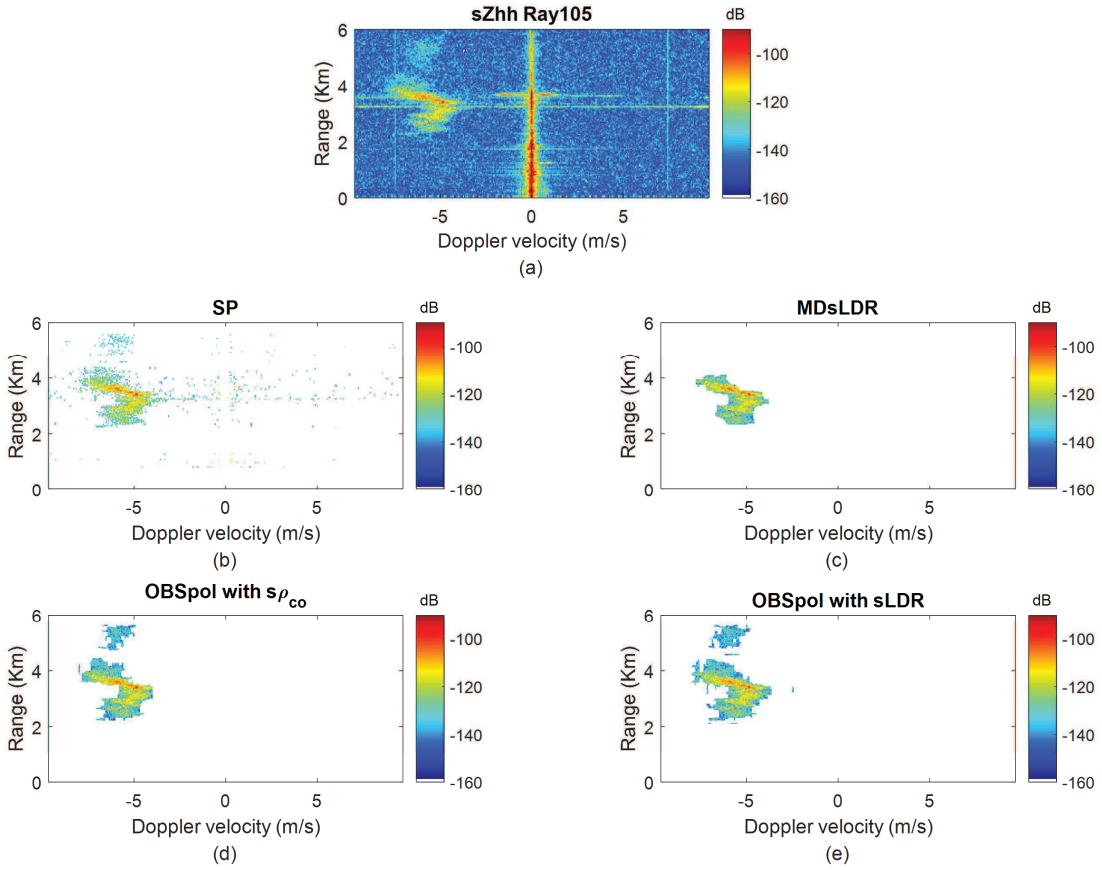
- Range-Doppler spectrogram



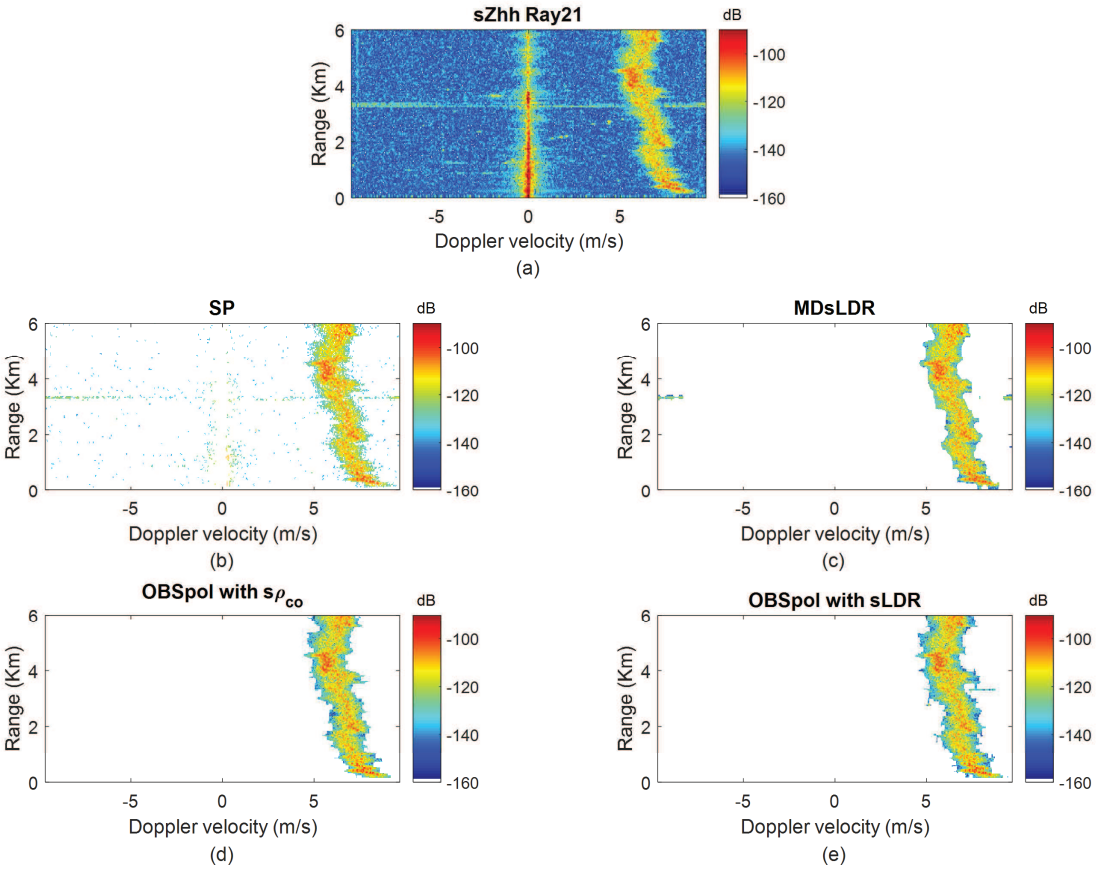
- Doppler spectra



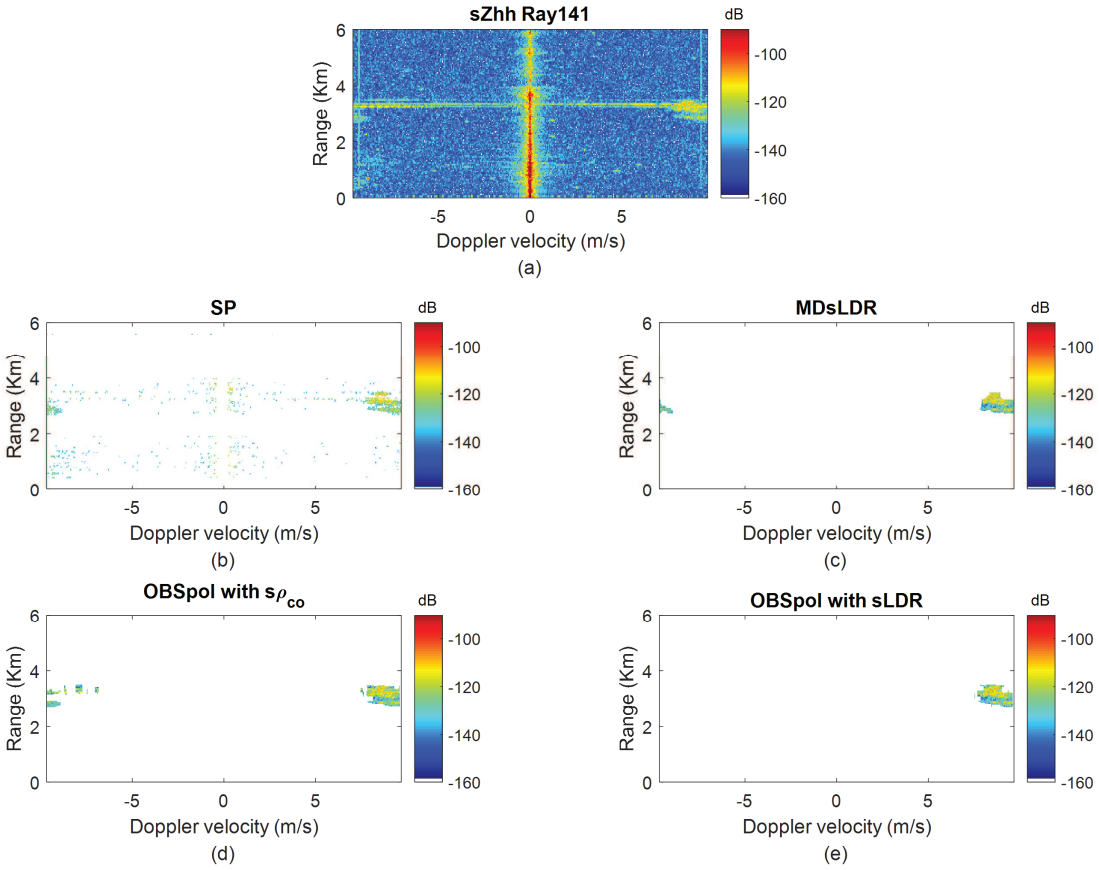
- Data measured at 00:00 UTC on 26th April 2017



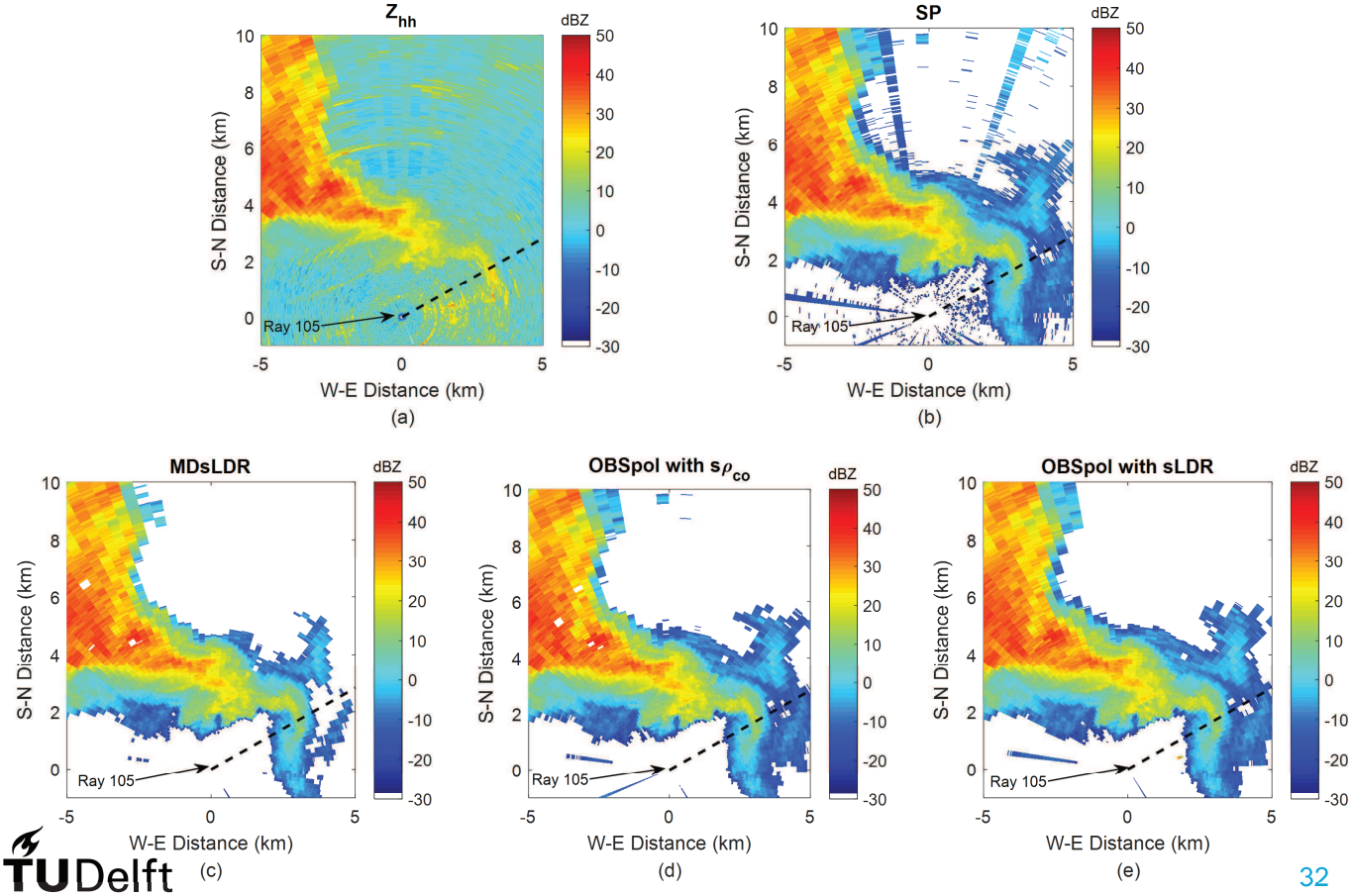
- Data measured at 13:00 UTC on 22nd August 2014



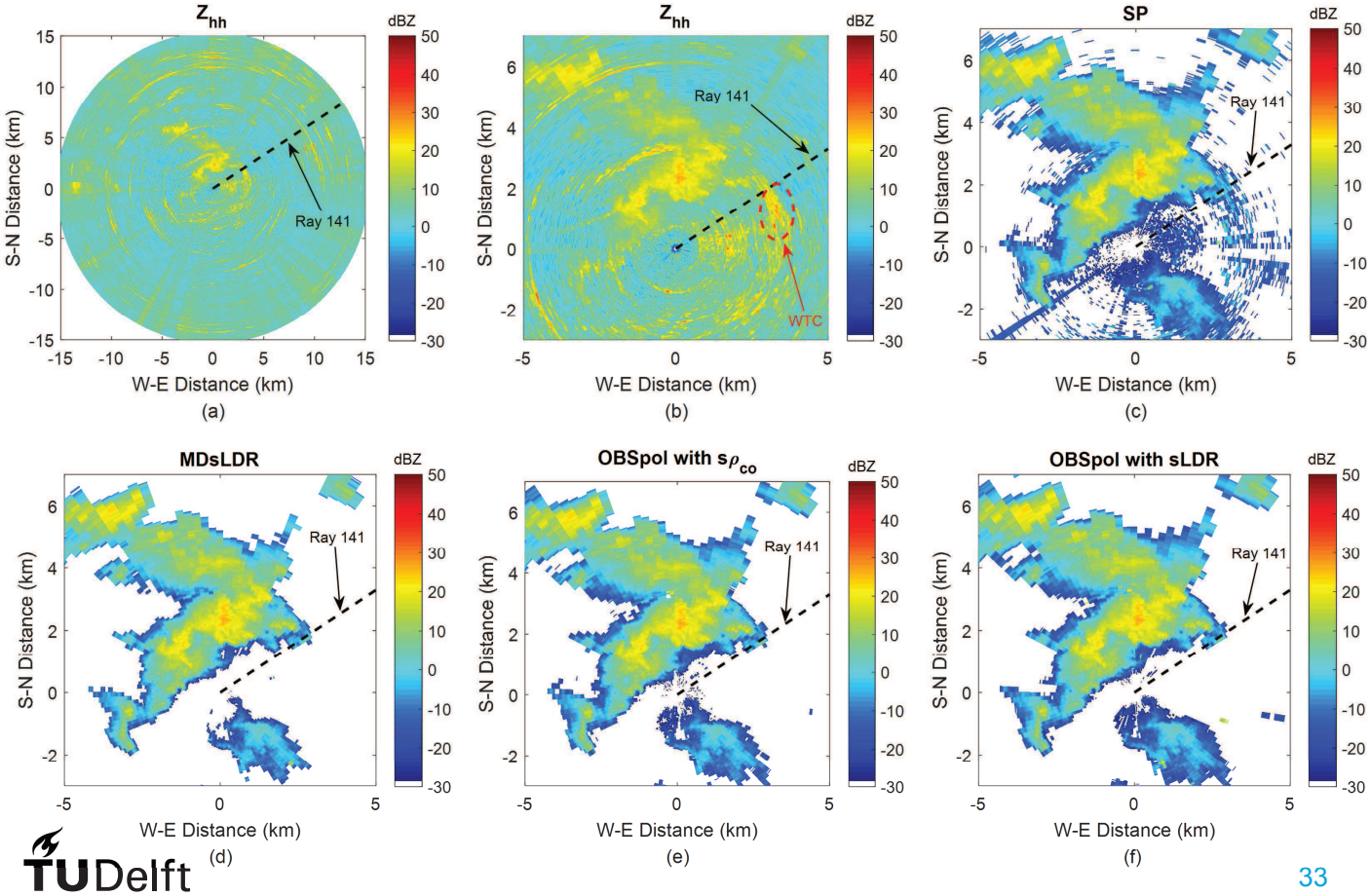
- Data measured at 12:00 UTC on 24th April 2017



- Data measured at 00:00 UTC on 26th April 2017



- Data measured at 12:00 UTC on 24th April 2017



Conclusion

--- Effective filters for polarimetric weather radars

The moving double sLDR (MDsLDR) filter and object-based spectral polarimetric (OBSpol) filter is proposed to remove both stationary and moving clutter and retaining precipitation:

- ❑ Spectral polarimetric feature and spatial continuity of precipitation.
- ❑ The filters are implemented in the range-Doppler spectrogram.
- ❑ Specifically designed for narrow-band clutter mitigation in X-band IDRA, but extended to RFI mitigation in C-band KNMI radar and side-lobe wind turbine clutter.
- ❑ Good performance, easy to implement and low computation complexity.
- ❑ Applicable to different Doppler velocity resolutions.

Thanks for attention!