WMO Activities on Operational Weather Radar

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World trends on weather radar observations

- The usefulness and importance of weather radar is increasing around the world.
  - Spatial distribution of precipitation can be captured in real time.
  - Quantitative accuracy has been greatly improved by dual polarization capability.
  - The scope of use is expanding beyond early warning services to include numerical weather prediction and climate monitoring.
- On the other hand, the following issues have emerged.
  - Higher quality and accuracy are required for radar, and improvements in its operation and data usage are necessary. Operating and utilizing dual polarization radar is not an easy task.
  - Increasing interference from wind turbines and other radio sources.
  - Observation conditions and data formats vary depending on the radar.

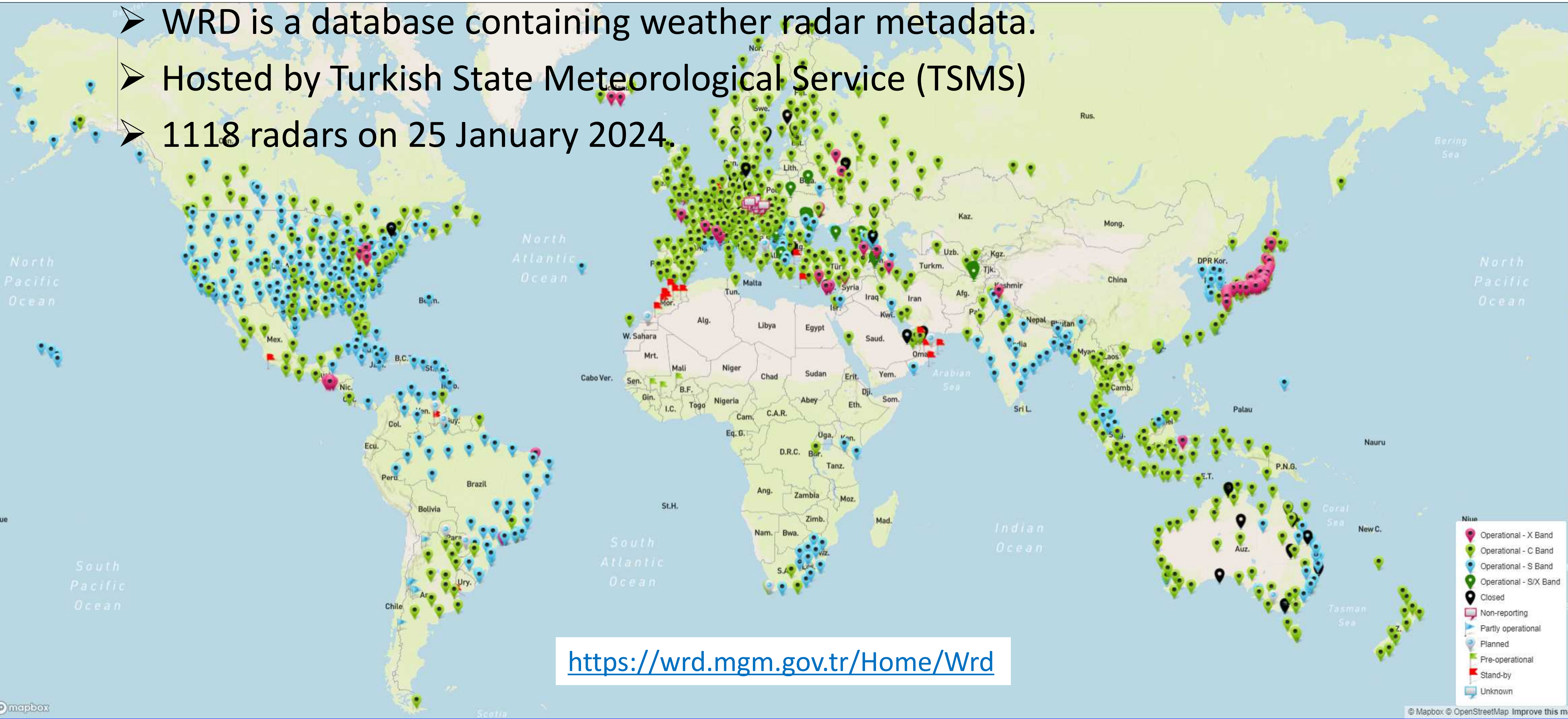
Joint Expert Team on Operational Weather Radar

- The Joint Expert Team on Operational Weather Radars (JET-OWR) is the lead body responsible for coordinating WMO international activities relating to operational weather radars.
  - Under SC-MINT and SC-ON
  - Chaired by Dr. Daniel Michelson, Canada.

- To address the above mentioned issues, JET-OWR is conducting mainly the following activities.
  - Operation of radar metadata database (WRD)
  - Development of radar data formats for data exchange (FM301)
  - Development of guidance materials

WMO Radar Database (WRD)

- WRD is a database containing weather radar metadata.
- Hosted by Turkish State Meteorological Service (TSMS)
- 1118 radars on 25 January 2024.



https://wrd.mgm.gov.tr/Home/Wrd

WMO Radar Database (WRD)

➢ WRD contains metadata that includes not only location information, but also other parameters such as transmitting frequency.

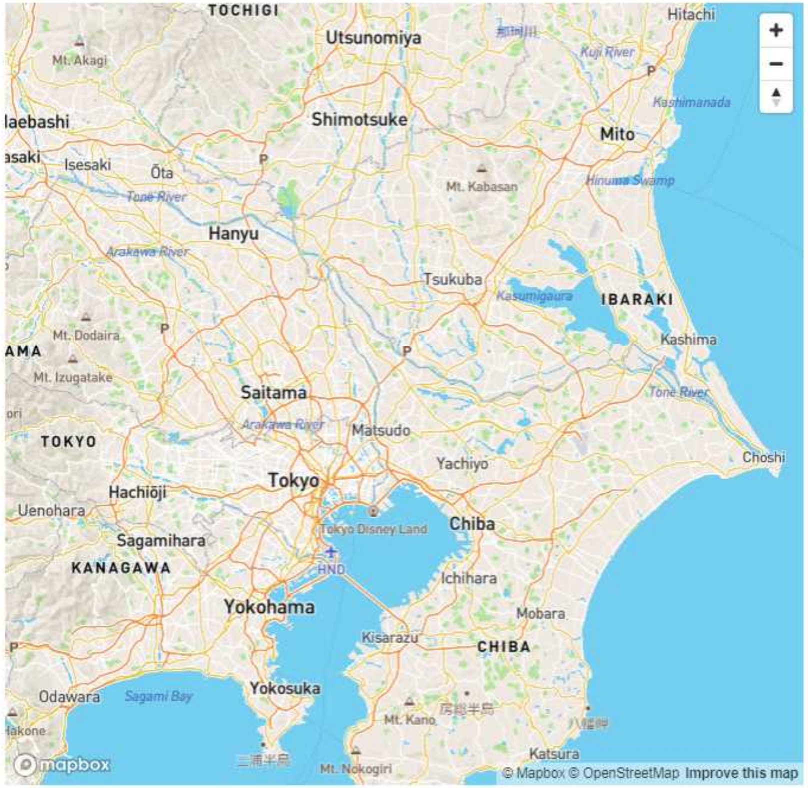
Tokyo

Radar Information

Radar name	**Tokyo**	Country	**392 - Japan**
WSI code	**0-20010-0-47695**	Station operating status	**Operational**
Supervising organization	**Japan Meteorological Agency**	Station Type	**Land (fixed)**
Installation date	**2020-03-05**	Region of origin of data	**Asia**
Latitude	**35.8597**	Longitude	**139.9597**
Elevation	**19m**	Tower height	**50**
Owner name	**Japan Meteorological Agency**	Manufacturer	**Mitsubishi**
Time zone	**Asia/Tokyo**	Spatial extent	**Volume**
Communication method		Frequency Band	**C**
Frequency	**5358**	Beam width	**1.10**
Peak power	**6.0**	Pulse width 1-2-3-4	**1.00 32.00 64.00 128.00**
Pulse repetation frequency min	**330**	Pulse repetation frequency max	**1830**
Signal processor	**Original**	TX/RX type	**Solid State D**
Polarization	**D**	Lowest & Highest angle	**0.0 90.00**
Task cycle time min	**10.0**	Task cycle time max	**0.0**
Minimum detectable signal of the receiver (DBM)	**-110**	Minimum detectable signal of the receiver (DBZ)	**0**
Summer reflectivity [Z-R]	**200 1.60**	Status of Observation	
Winter reflectivity [Z-R]	**200 1.60**	Sampling strategy	**continuous**
Other reflectivity [Z-R]	**200 1.60**	Instrument Status	
Level Of Data		Reference time	
Schedule of international exchange	**0**		
Local Web Url	**https://www.jma.go.jp/bosai/en_nowc/**		

Radar Data Exchange (Organizations)

Location & Media



Weather Radar Data Exchange Formats (FM301)

- FM301 was endorsed by the WMO Executive Council (EC-76) in February 2023.
- Polar coordinate radar/lidar data format.
- The self-describing data format netCDF is convenient and widely used in meteorology.
- Raw netCDF format is too flexible to maintain compatibility between users.
- FM301 is a netCDF that defines rules for maintaining compatibility. The rules can be applied to various radar data.

WMO CF-Extensions

10 March 2021, version 0.1

FM 301-XX WMO-CF RADIAL

1. **Scope**
   a. This profile is for the representation of weather radar and lidar data in the native instrument-centric polar coordinates. Such data is the primary output of the radar/lidar signal processor known as "Level 2" data. This is the lowest level output commonly available from operational instruments and is well suited to data exchange.
   b. The structure of this profile conforms to the WMO Information and Data Models for Radial Radar and Lidar Data. Effort has also been made to maximize compatibility with the CfRadial 2 format from which this profile has been derived
2. **Overview**
   a. Level 2 radar/lidar data may be conceptualized as a simple hierarchy of data objects where each object contains a collection of objects from the level below. These objects are:
      i. Volume – The top-level object for the profile. A Volume is a collection of logically associated sweeps. Typically, these sweeps will represent a continuous or near-continuous series of observations acquired by the instrument during a single cycle of the scan schedule.
      ii. Sweep – Represents a subset of the data in the volume over which certain fundamental conditions remain constant. A common example is for a sweep to contain the data observed during a single 360-degree scan at a fixed elevation angle.

https://community.wmo.int/activity-areas/wis/wmo-cf-extensions

Guide to Operational Weather Radar Best Practices

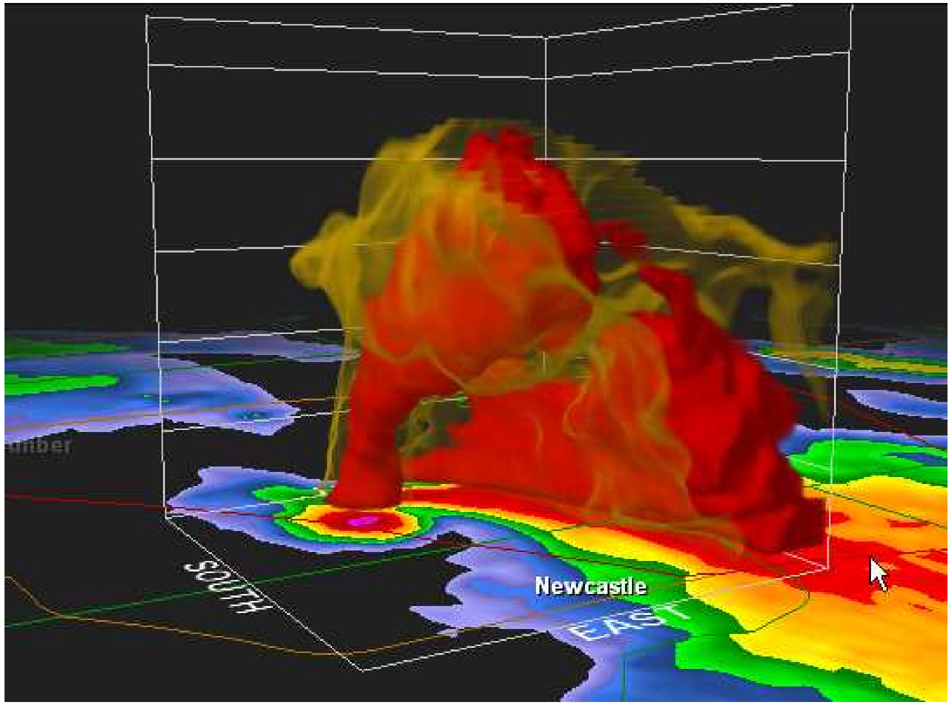
Volume	Content	Draft Available
I	Weather Radar Network Program Design	Provisional Edition
II	Weather Radar Technology	Provisional Edition
III	Weather Radar Procurement	Provisional Edition
IV	Weather Radar Siting, Configuration and Scan Strategies	Coming soon
V	Weather Radar Calibration, Monitoring and Maintenance	Coming soon
VI	Weather Radar Data Processing	Coming soon
VII	Weather Radar Data Representation and International Exchange	Provisional Edition
VIII	Weather Radar Glossary of Terminology	Planned

https://community.wmo.int/en/activity-areas/weather-radar-observations/best-practices-guidance

Vol. I: Guide to Weather Radar Network Program Design

Target audience: Upper management, decision makers, funding agencies

- What is weather radar useful for?
- What kind of network is required depending on the purpose?
- How to estimate life cycle costs



Radar can see into a thunderstorm in three dimensions every few minutes.

Vol. II: Guide to Weather Radar Technology

Target audience: Decision makers, managers, engineering and technical practitioners, scientists

- Technical options for the weather radar to be introduced
- Select frequencies, transmitters, and infrastructure according to each purpose

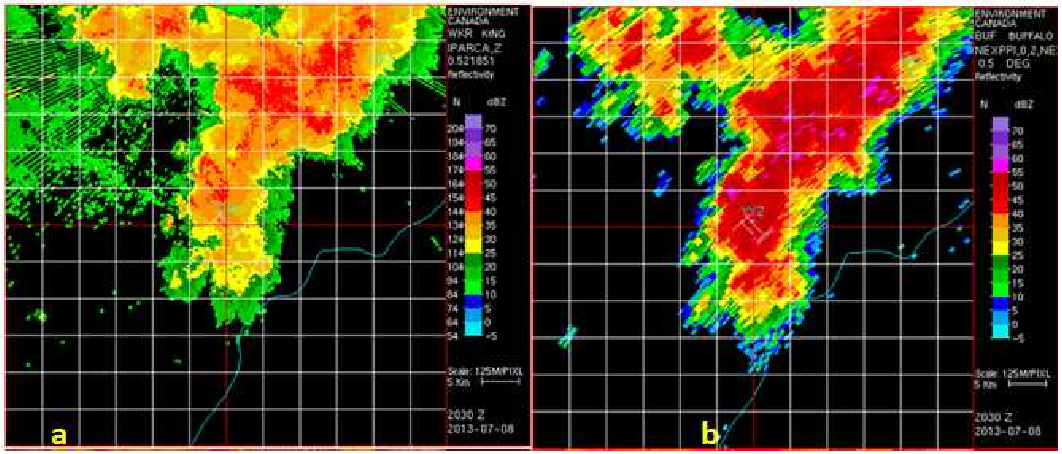


Figure 7. An example of a severe thunderstorm from well calibrated C and S-band radars. (a) C-band radar with wet radome about 32 km from the image center and (b) S-band located about 100 km from image center.

Vol. III: Guide to Weather Radar Procurement

Target audience: Decision makers, managers, procurement specialists, engineering, technical, and scientific support to the procurement process

- How to make a weather radar procurement plan
- Necessary human resources and their development
- Provide examples of different approaches to weather radar procurement.

Phase (i) requirements, technical specification, tendering and evaluation

↓

Phase (ii) installation, implementation and configuration

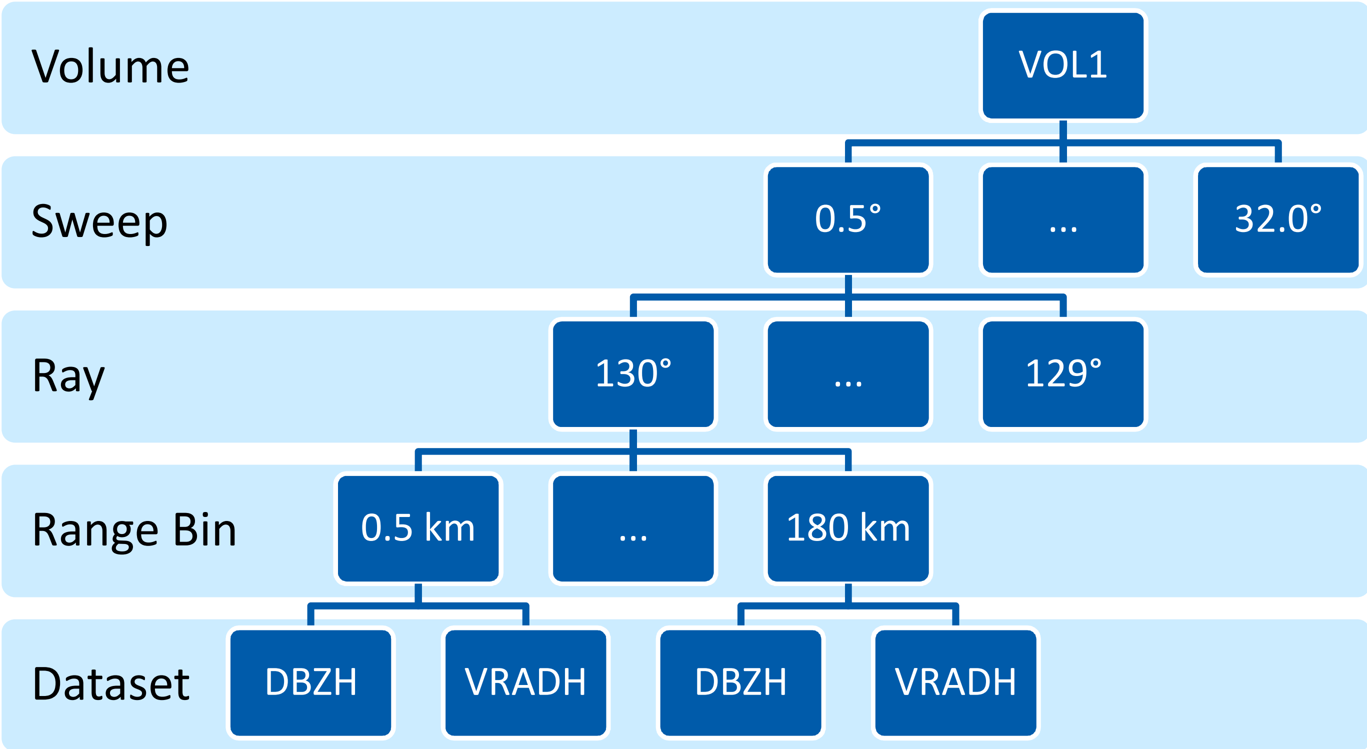
↓

Phase (iii) operational support and maintenance.

Vol. VII: Guide to Weather Radar Data Representation and International Exchange

Target audience: Decision makers, IT experts, radar application developers, radar data users

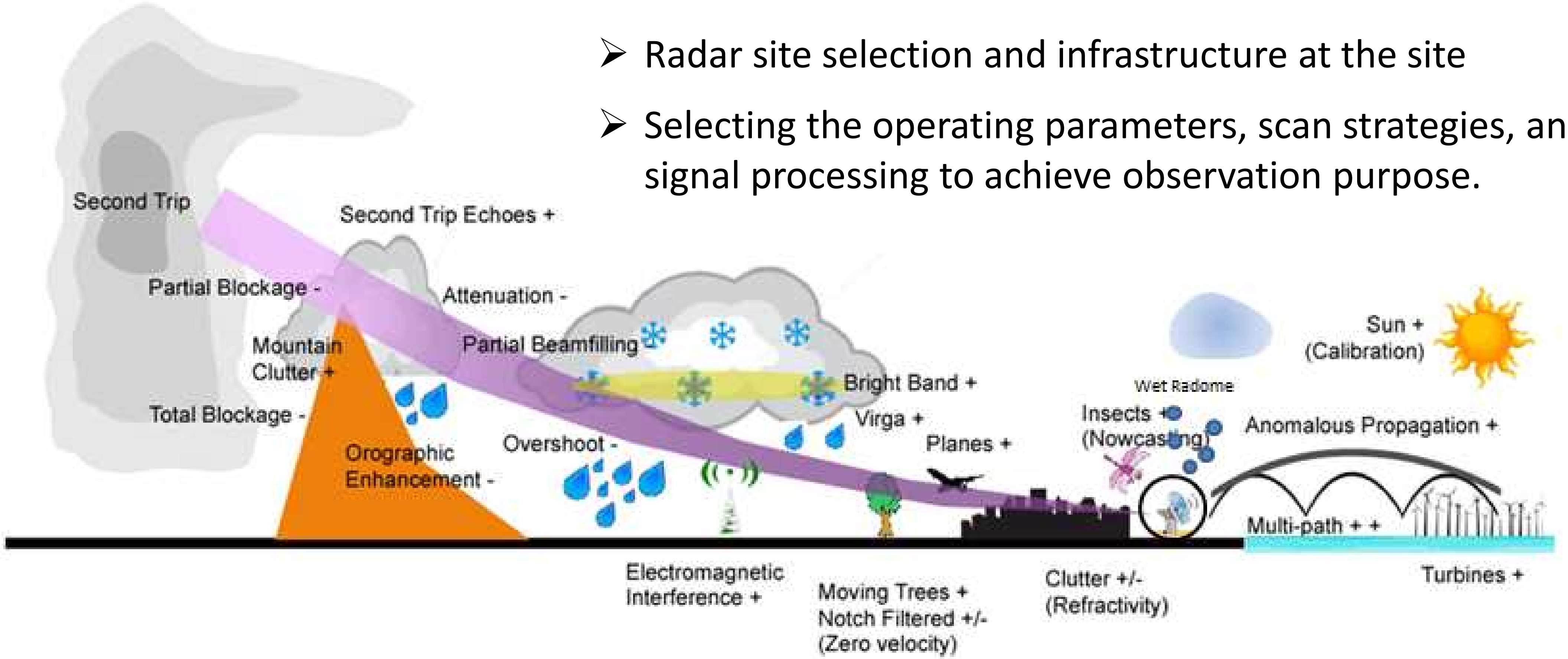
- Radar site metadata
- Representation of weather radar data standardized as FM301.
- Methods of data exchange



Vol. IV: Guide to Weather Radar Siting, Configuration, and Scan Strategies

Target audience: People who are in the process of getting their first weather radar

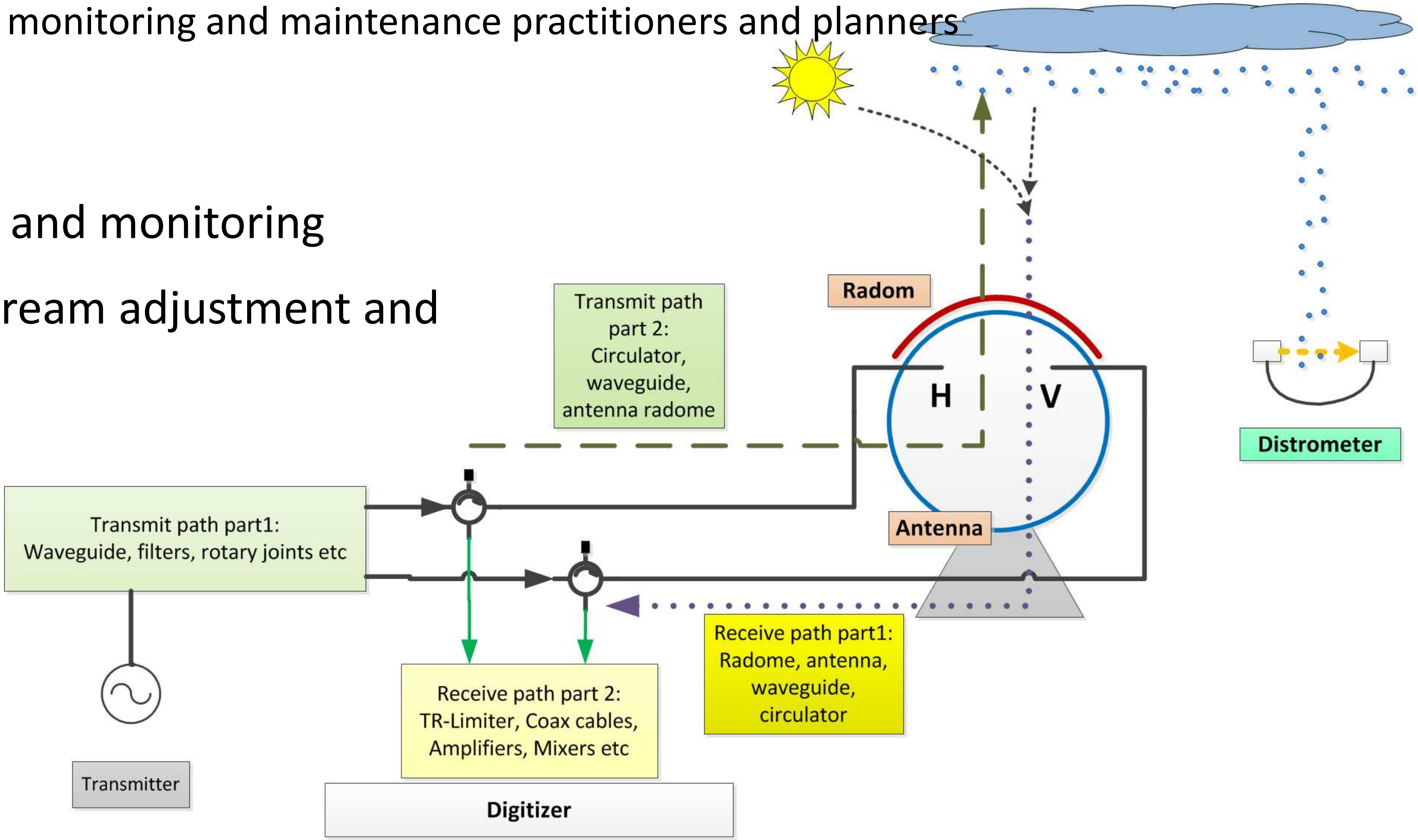
- Radar site selection and infrastructure at the site
- Selecting the operating parameters, scan strategies, and signal processing to achieve observation purpose.



Vol. V: Guide to Weather Radar Calibration, Monitoring, and Maintenance

Target audience: Operations, monitoring and maintenance practitioners and planners

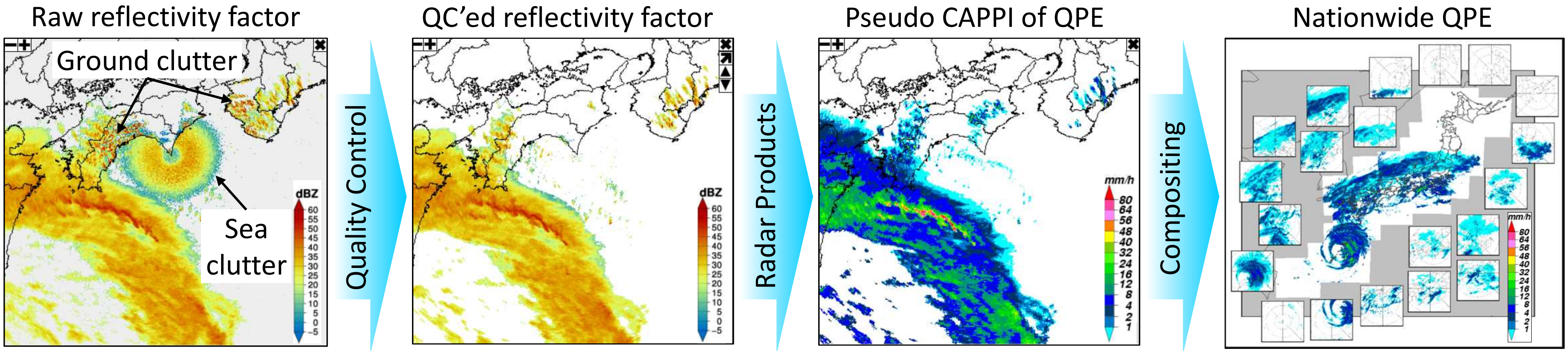
- Hardware calibration
- Real-time adjustment and monitoring
- Opportunistic downstream adjustment and monitoring
- Maintenance



Vol. VI: Guide to Weather Radar Data Processing

Target audience: radar operators, radar engineers, radar application developers, radar data product users

- Chapter 1: Data quality control and data correction methods
- Chapter 2: Radar products and their processing methods (Such as CAPPI, hydrometeor classification, wind shear detection, Quantitative Precipitation Estimation)
- Chapter 3: Radar compositing



Example of radar data processing chain

Vol. VI > Chapter 2 : Quality control

2.1 Removal of incoherent spurious echoes

RFI, second trip echo, sun noise

2.2 Removal of non-meteorological echoes

Ground clutter, Sea clutter, Anomalous propagation

Wind turbines, Moving clutter, Biological scatterers

Chaff, Volcanic ash, Wildfires

Side-lobe and range side-lobe, Specular reflection

2.3 Further processing of meteorological echoes

Dealiasing of Doppler velocities, Derivation of K_{DP}, Correction of attenuation, beam blockage, and ρ_{hv}

2.4 Monitoring of data quality

Vol. VI > 2.1 Removal of incoherent spurious echoes

- List of multiple effective methods for spurious echo removal.
- List of spurious echoes to which each method is effective.
- List notes when each method is used.

Filtering Technique	Comments	Spurious that can be removed
SQI Thresholding	Removal of echoes with low signal quality index (SQI): either broad Doppler spectrum or relatively low signal strength. SQI is also called normalized coherent power (NCP). This method is effective in removing all type of incoherent spurious echoes. Note: this method also removes meteorological echoes in strong shear region where Doppler spectrum is broad. To mitigate this problem, the SQI threshold may be disabled for echoes with a high SNR.	RFI, 2ND TRIP, SUN
SNR Thresholding	Removal of echoes with low signal to noise ratio (SNR). Good for SUN and EMISSION which SNR is relatively low (several to ten dB). Note: this method also removes meteorological echoes with weak reflectivity.	RFI, 2ND TRIP, SUN
STD Thresholding	Removal of echoes with large normalized standard deviation (STD) of the received power (pulse by pulse).	RFI
Z_{DR} Thresholding	Removal of echoes with unusual high or low differential reflectivity (Z_{DR}). Artificial radio station tends to use horizontal or vertical wave only. So Z_{DR} of RFI shows unusual high or low value.	RFI

Vol. VI > 2.1 Removal of incoherent spurious echoes

- Descriptions of the characteristics of each spurious echo and how to distinguish them.
- Example of RFI

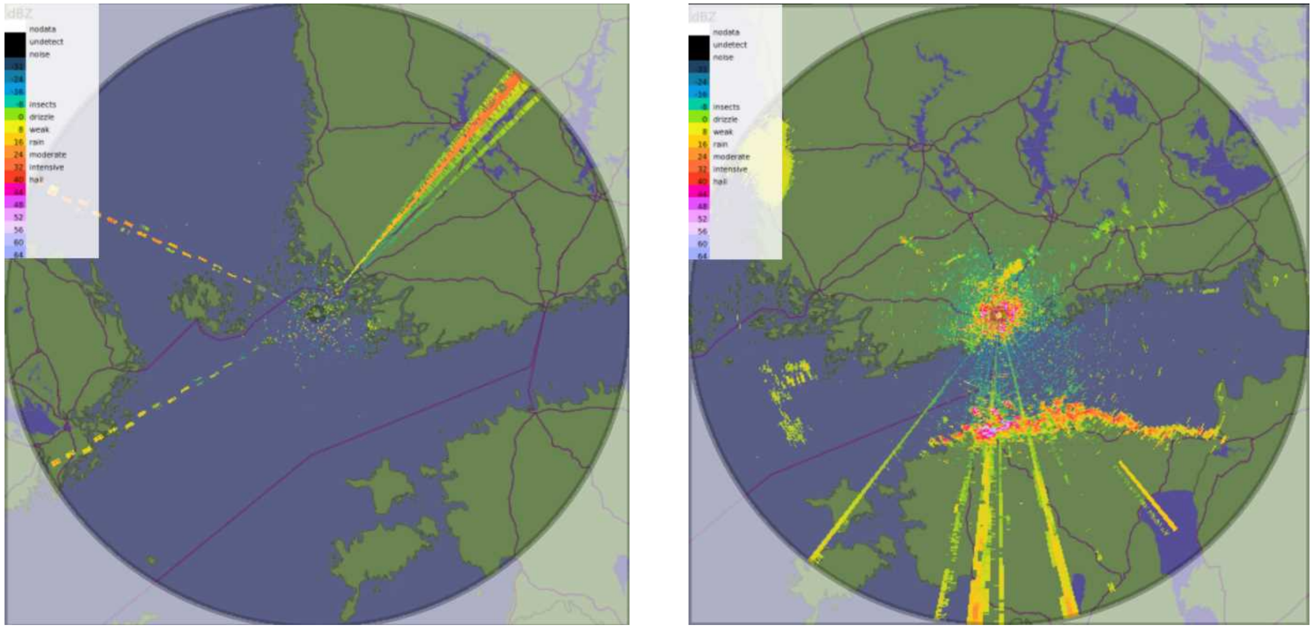


Figure 2.1.1.1 Example images of RFI. Left: In the reflectivity factor data, static pulsed sources (here in SW and NW) can be seen, however at specific times, the interference is stronger and has more continuous nature as here shown in the NE direction. Right: Due to anomalous propagation conditions, RFI is observed beyond the far coastline as seen in this unfiltered reflectivity factor image. (Source: Finnish Meteorological Institute)

Vol. VI > 2.2 Removal of non-meteorological echoes

- List of multiple effective methods for non-meteorological echo removal.
- List of non-meteorological echoes to which each method is effective.
- List notes when each method is used.

Filtering Technique	Comments	Clutter that can be removed
Masking	Collect data in non-precipitating situations, use a sum or average as a mask to remove clutter targets. Note: this is a simple method but when there is rain over hills, this method removes both rain and hills.	GC
Clutter Maps (Hit accumulation or other statistical methods.)	During non-precipitating conditions, echoes on the radar indicate ground clutter and this is used to create a clutter map for each elevation angle. This clutter map may be manually edited/created. This can be subtracted from the data. As there are significant fluctuations in the clutter, over or under correction may occur and results in "clumpy speckles" in the final product. Anomalous propagation significantly increases reflectivity of the clutter, making the clutter maps meaningless. Same as masking, but the entire range bin is not removed, just the dBZ value of dry situation. When there is rain over hills, this method tries to keep the rain and remove the hills.	GC
Speckle Removal	Removal of isolated echoes. In some cases, strong clutter can be within a small range interval and isolated as in the case of mountain top sited	GC WINDMILLS SHIP

Vol. VI > 2.2 Removal of non-meteorological echoes

- Descriptions of the characteristics of each non-meteorological echo and how to distinguish them.
- Example of wildfire echoes

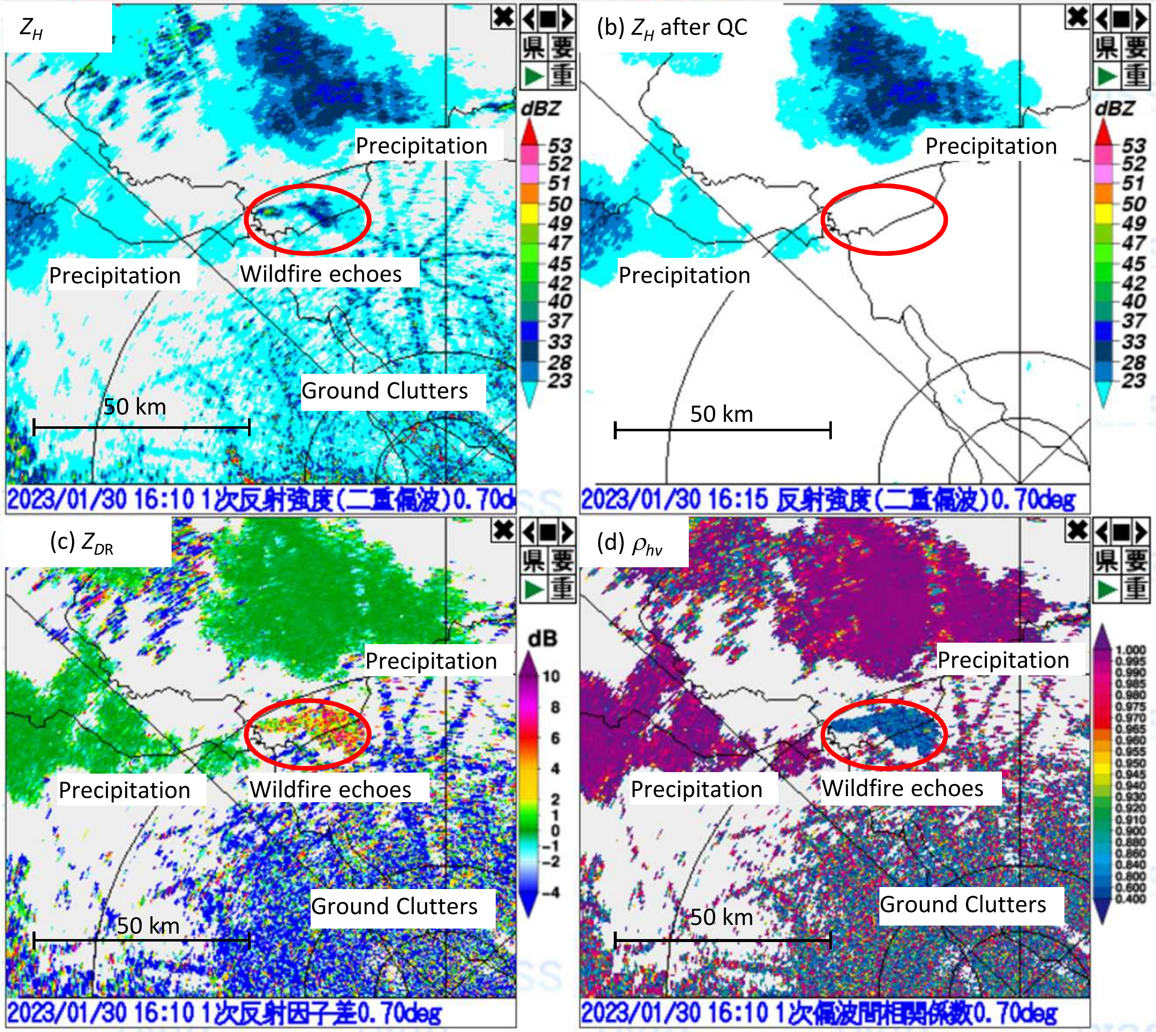


Figure. 2.2.9.1 (a) Reflectivity factor, (b) reflectivity factor quality controlled by clutter discrimination algorithm (Tsukamoto et al. 2016), (c) differential reflectivity, (d) copolar correlation coefficient of wildfire echoes observed with a dual-pol radar. The clutter discrimination algorithm efficiently discriminate and remove wildfire echoes. (Source: Japan Meteorological Agency)

Vol. VI > 2.2 Removal of non-meteorological echoes

- Example of wind farm

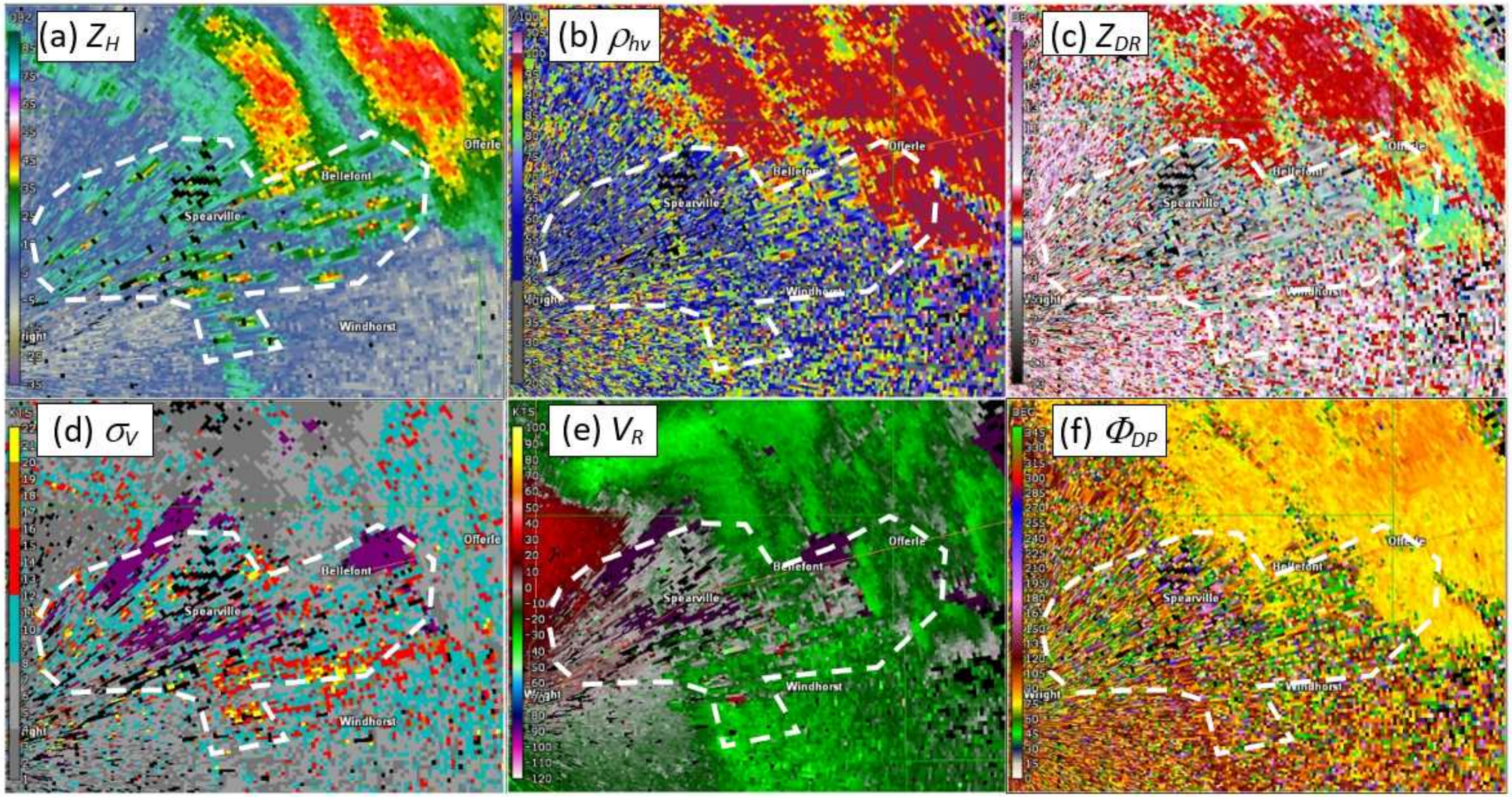


Figure 2.2.4.3 Example of dual-pol variables contaminated by wind farm (in dashed white line region). (a) Reflectivity factor, (b) correlation coefficient, (c) differential reflectivity, (d) spectrum width , (e) Doppler velocity, (f) differential phase. (Source: National Weather Service)

Vol. VI > 2.2 Removal of non-meteorological echoes

- Identification of specular reflection

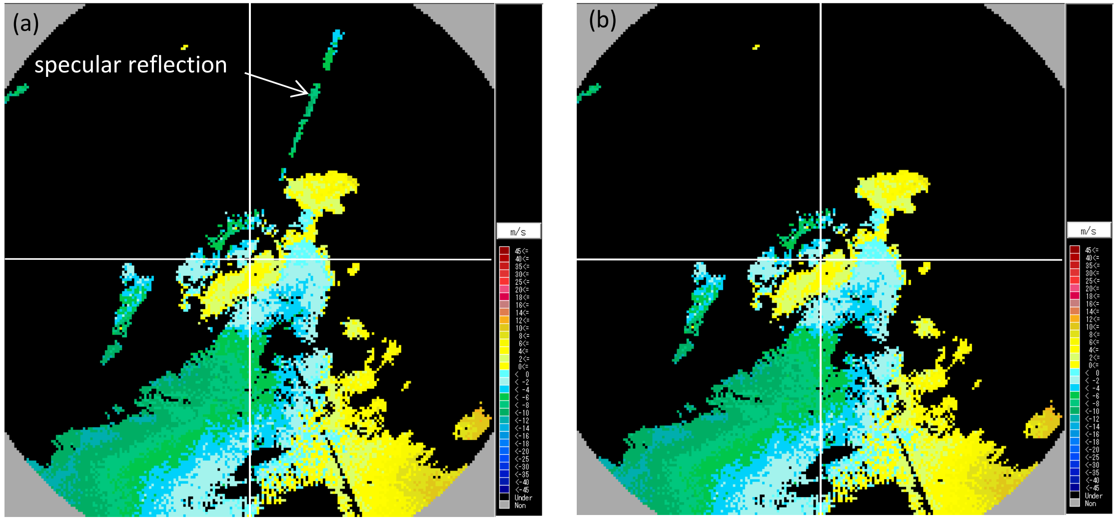


Figure 2.2.11.2 (a) PPI of Doppler velocity with specular reflection. (b) Same as (a) but after correction of specular reflection. (Source: Japan Meteorological Agency)

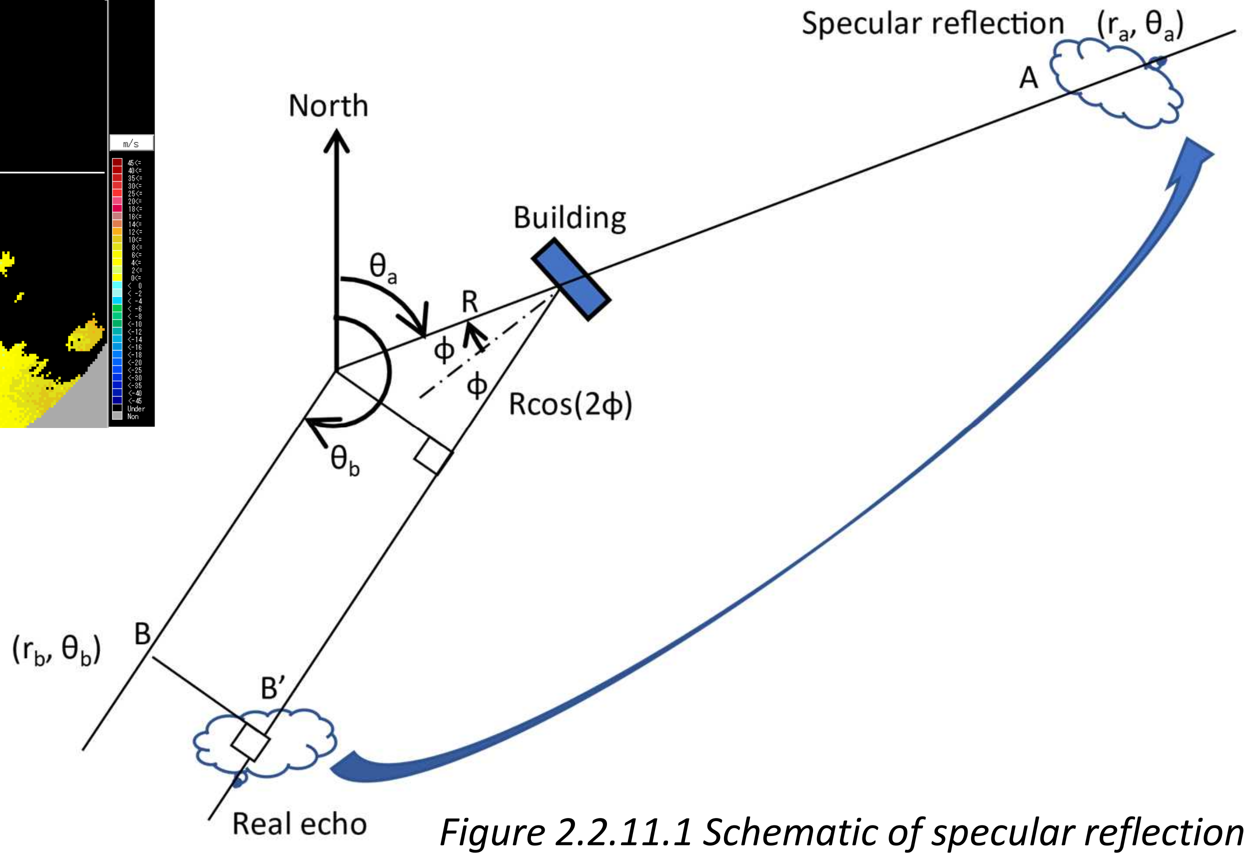


Figure 2.2.11.1 Schematic of specular reflection

Vol. VI > 2.3 Further processing of meteorological echoes

- Dealiasing of Doppler velocities

  Methods using two or more Nyquist velocities, methods assuming spatial continuity

Reflectivity (b) Raw Doppler velocity (c) Dealiased Doppler velocity-

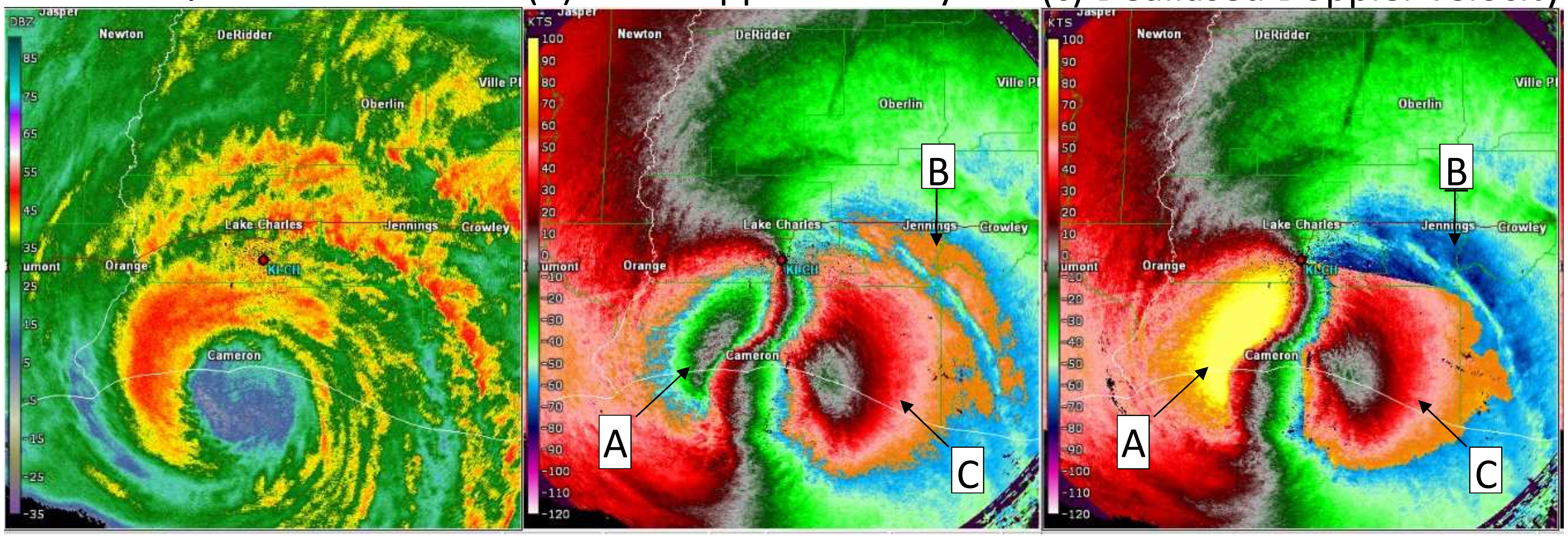


Figure 2.3.1.2 Example of failed dealiasing in a hurricane wind distribution: (a) reflectivity factor, (b) raw Doppler velocity, (c) dealiased Doppler velocity. In (b), there are three areas A, B, and C where Doppler velocities are spatially discontinuous (blue/orange transition). In (c), Doppler velocities in A and B areas are successfully dealiased, but Doppler velocities in C area are failed to be dealiased. (Source: National Weather Service)

Vol. VI > 2.3 Further processing of meteorological echoes

- Correction of precipitation attenuation
  - A method using the reflectivity factor itself (H&B method),
  - A method using dual polarization
  - A method using radio emission

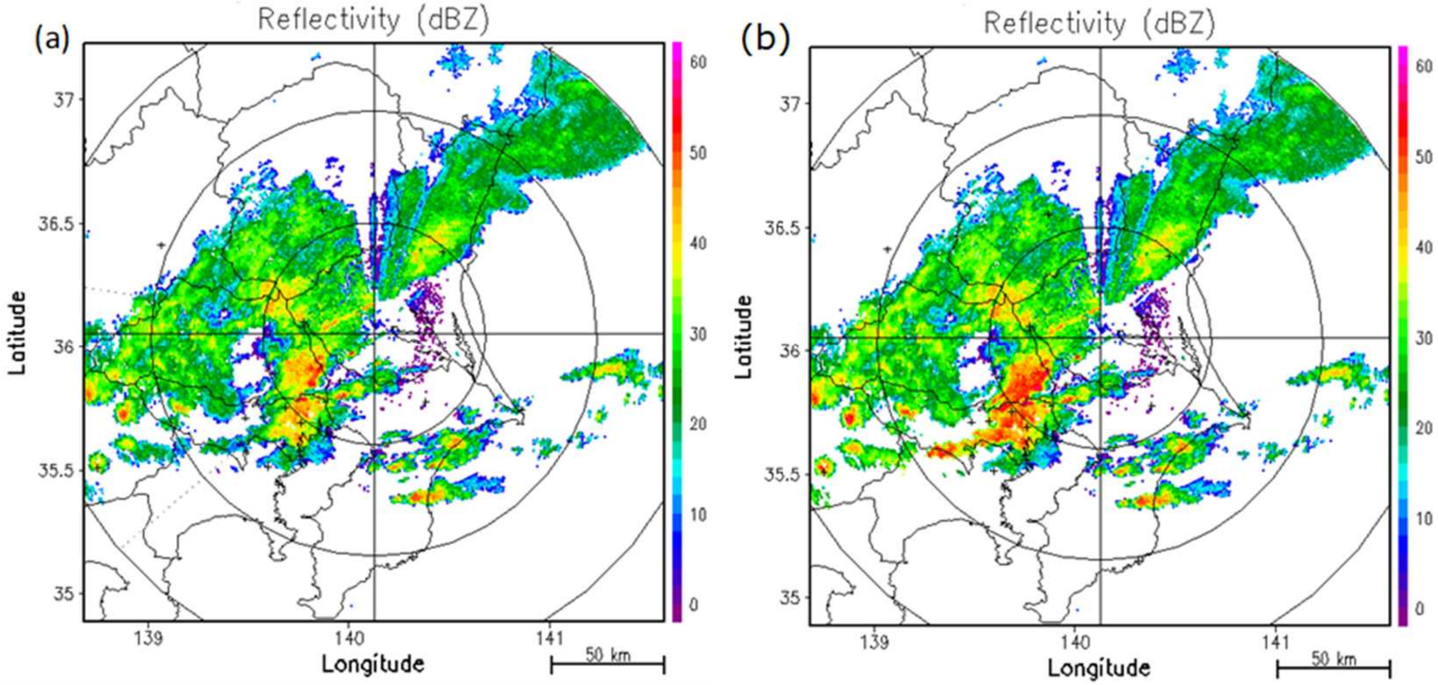


Figure 2.3.3.2 Example of rain attenuation correction at C band using dual-pol method. (a) Before correction, (b) after correction. (Source: Japan Meteorological Agency)

Vol. VI > 2.3 Further processing of meteorological echoes

- Correction of ρ_{hv}

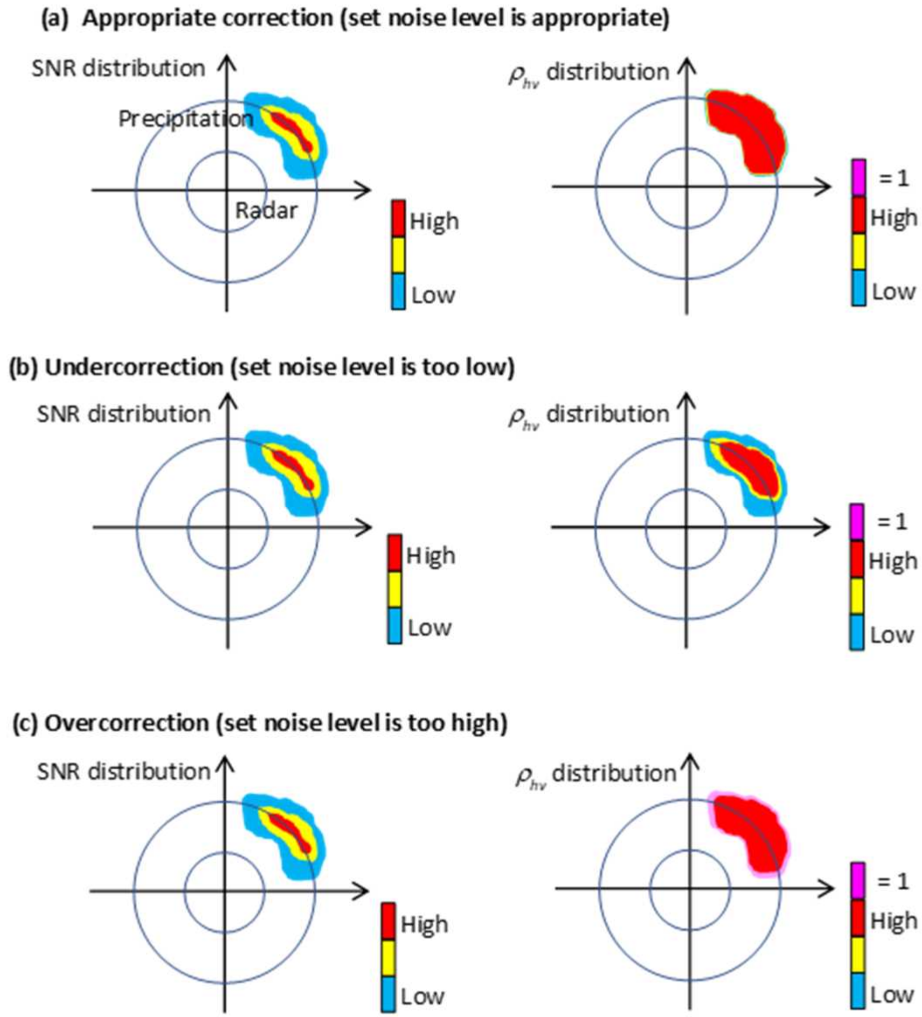


Figure 2.3.5.1 Distribution images of SNR (left) and ρ_{hv} (right) for precipitation echo with appropriate correction (a), with undercorrection (b), and with overcorrection (c). (Source: Japan Meteorological Agency)

Vol. VI > 2.4 Monitoring of data quality

- Example of identifying beam blockage and remaining ground clutter by monthly accumulated precipitation fall

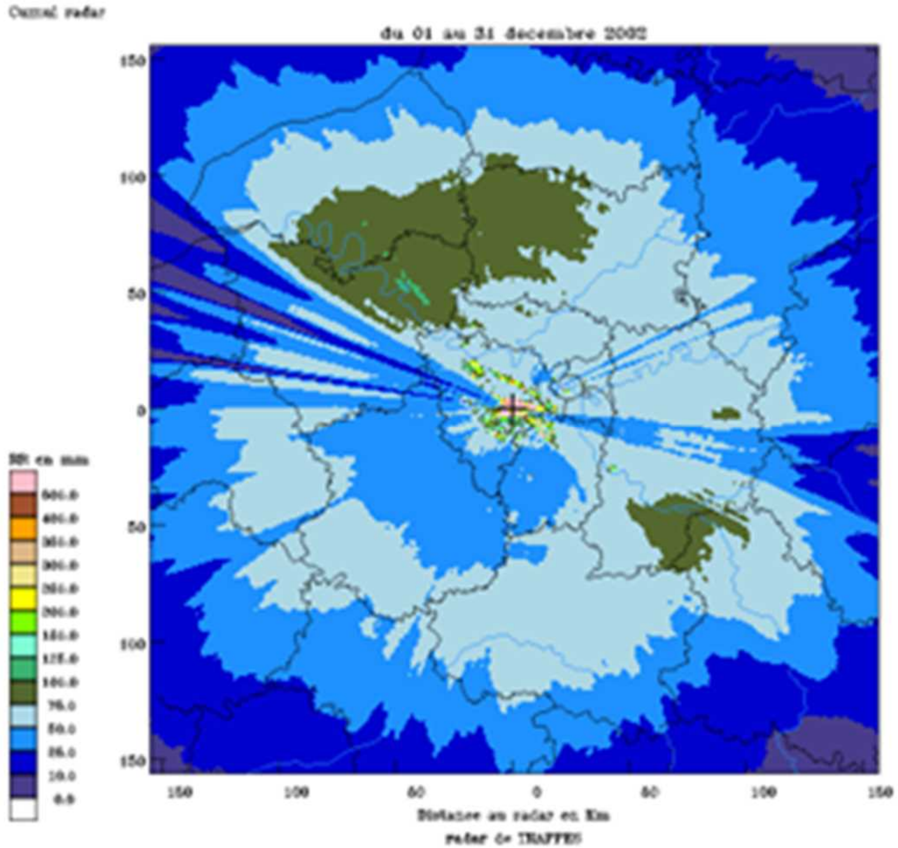


Figure 3.3.4.1 A month-long accumulation of the retrieved precipitation rate. (Source: Météo-France)

Vol. VI > Chapter 3 : Radar products

3.1 Basic products

PPI, RHI, CAPPI, Cross Section,

MAX, Echo Tops, VIL and VIL density,

VAD, VVP

3.2 Feature analysis

Target classification, Hail detection, Tornadic debris detection, Mesocyclone and tornado analysis, Microburst and shear line detection

3.3 Quantitative Precipitation Estimation

Z-R relations, Estimation using dual polarization, Vertical Profile of Reflectivity correction, Advection correction, Gauge adjustment

Vol. VI > 3.1 Basic products

- CAPPI : Methods to create constant altitude data

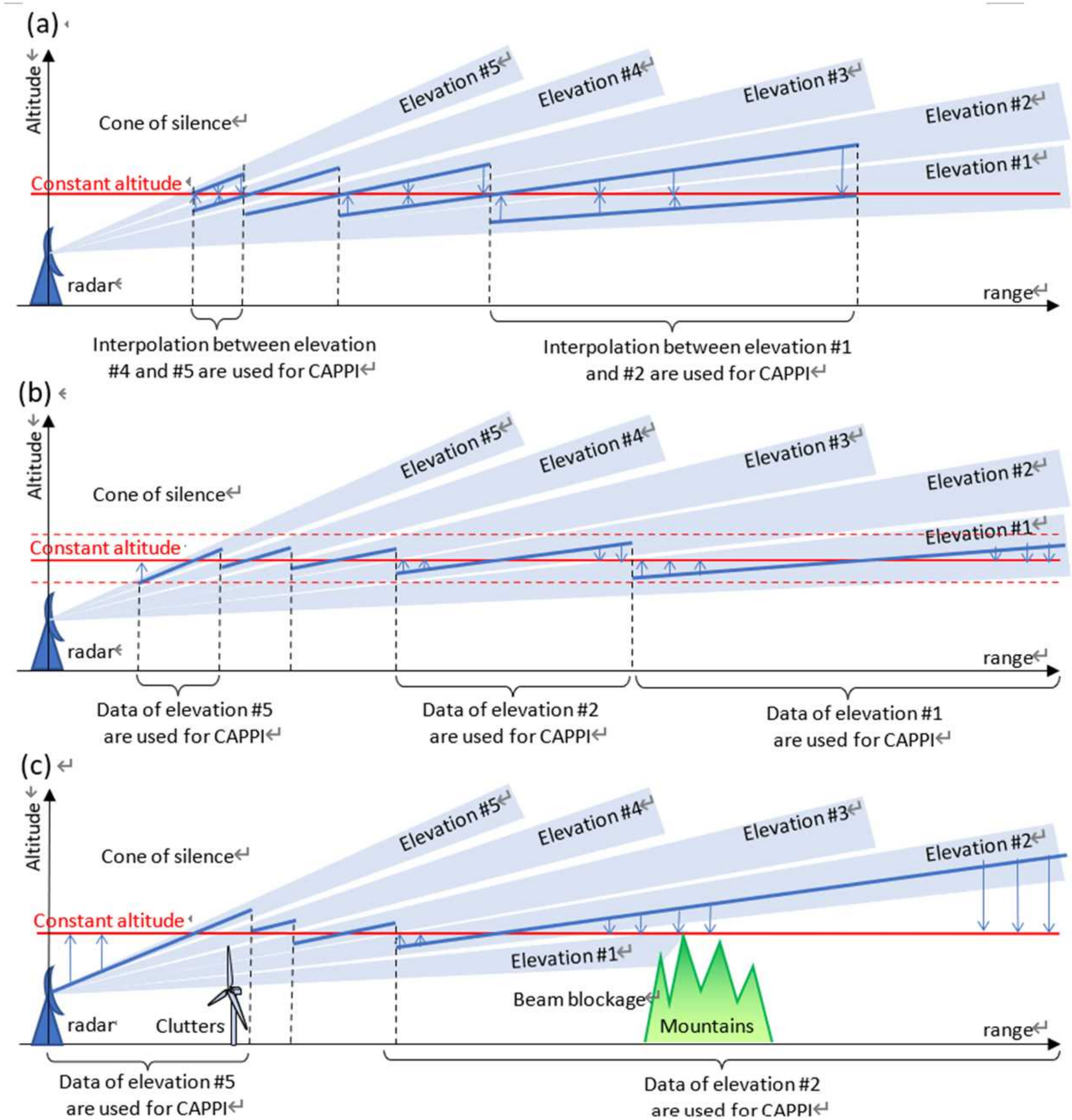


Figure 3.1.2.1 Methods to synthesize CAPPI from multiple elevation data (Source: Japan Meteorological Agency)

Vol. VI > 3.1 Basic products

- VAD ： Method to create a vertical wind profile

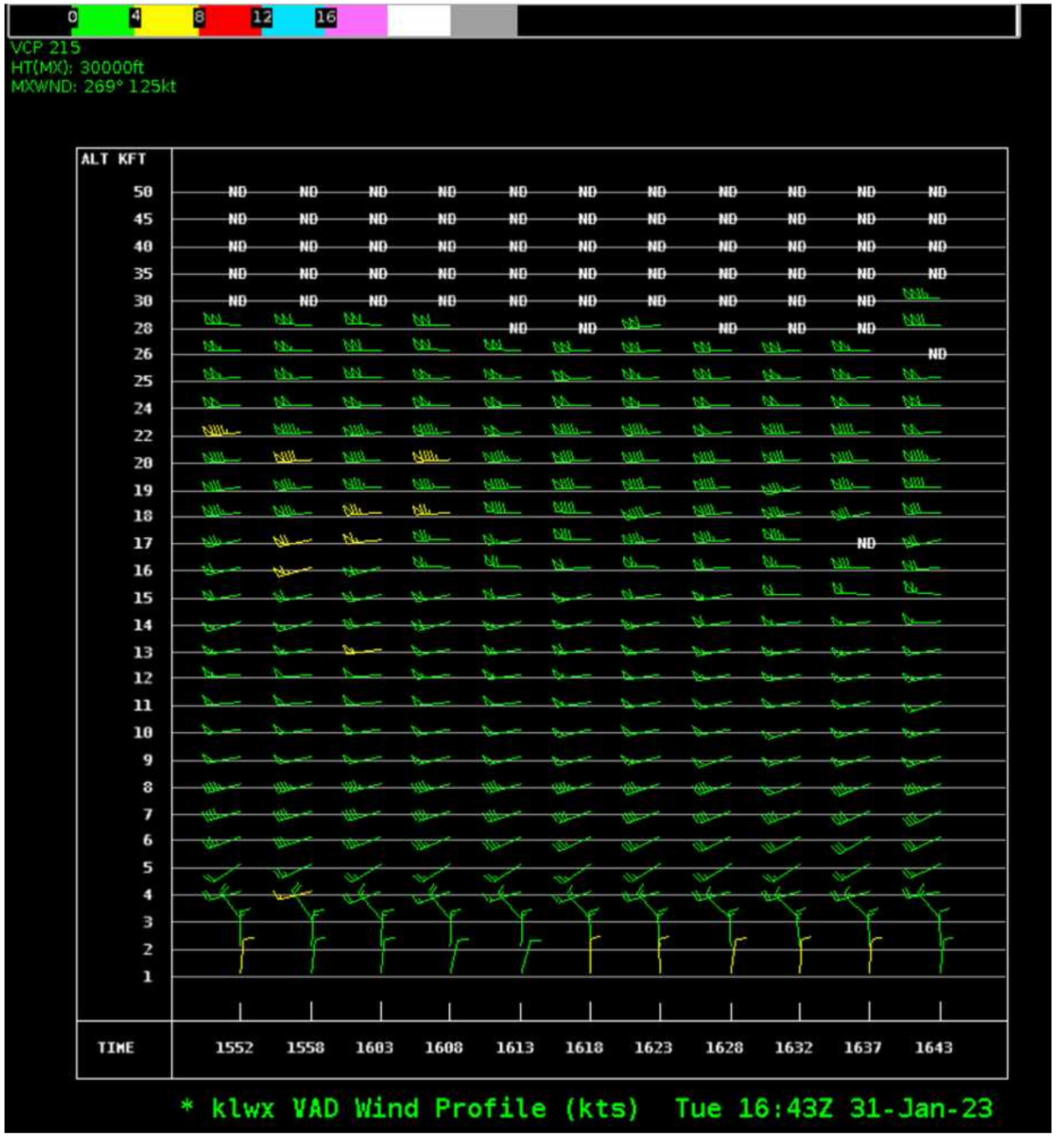


Figure 3.1.6.3 VAD wind profile time-height display of wind speed and direction. Wind barb color indicates RMS velocity and ND indicates the wind estimate failed quality checks. (Source: National Weather Service)

Vol. VI > 3.2 Feature analysis

➢ Target classification

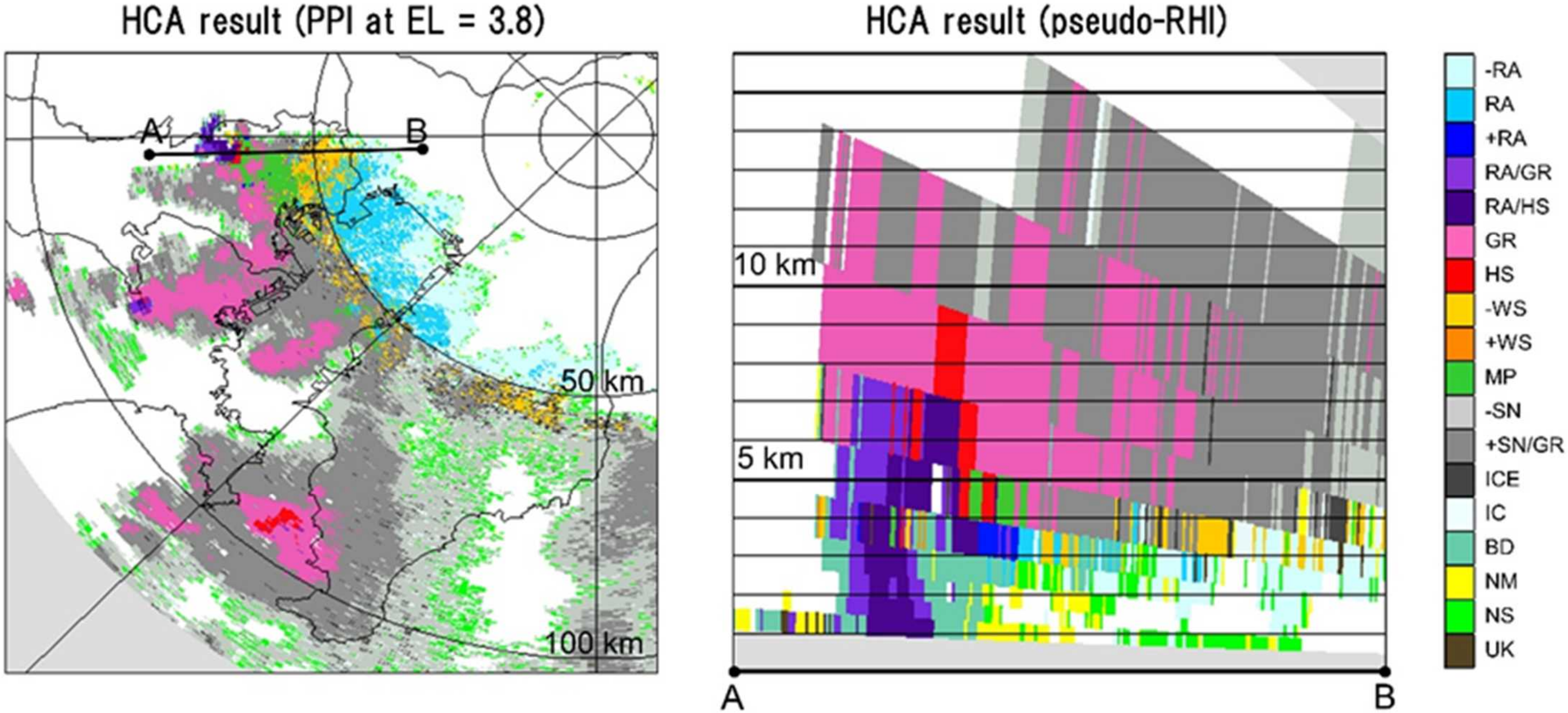
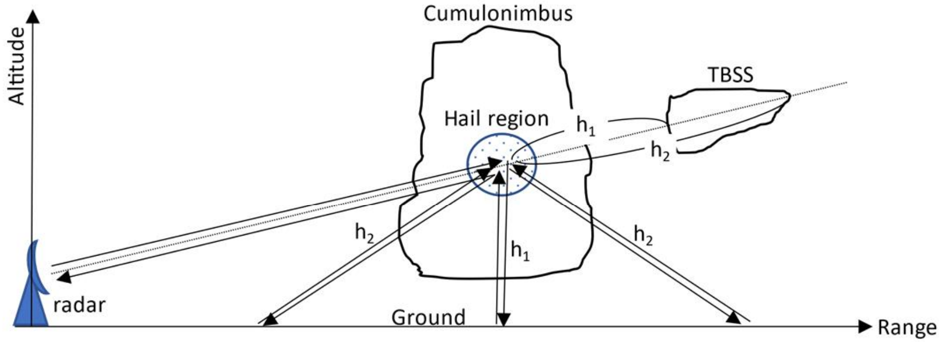


Figure 3.2.1.1. Bayesian HCA example for a C-band radar in Japan. (Source: Japan Meteorological Agency)

Vol. VI > 3.2 Feature analysis

- Hail detection



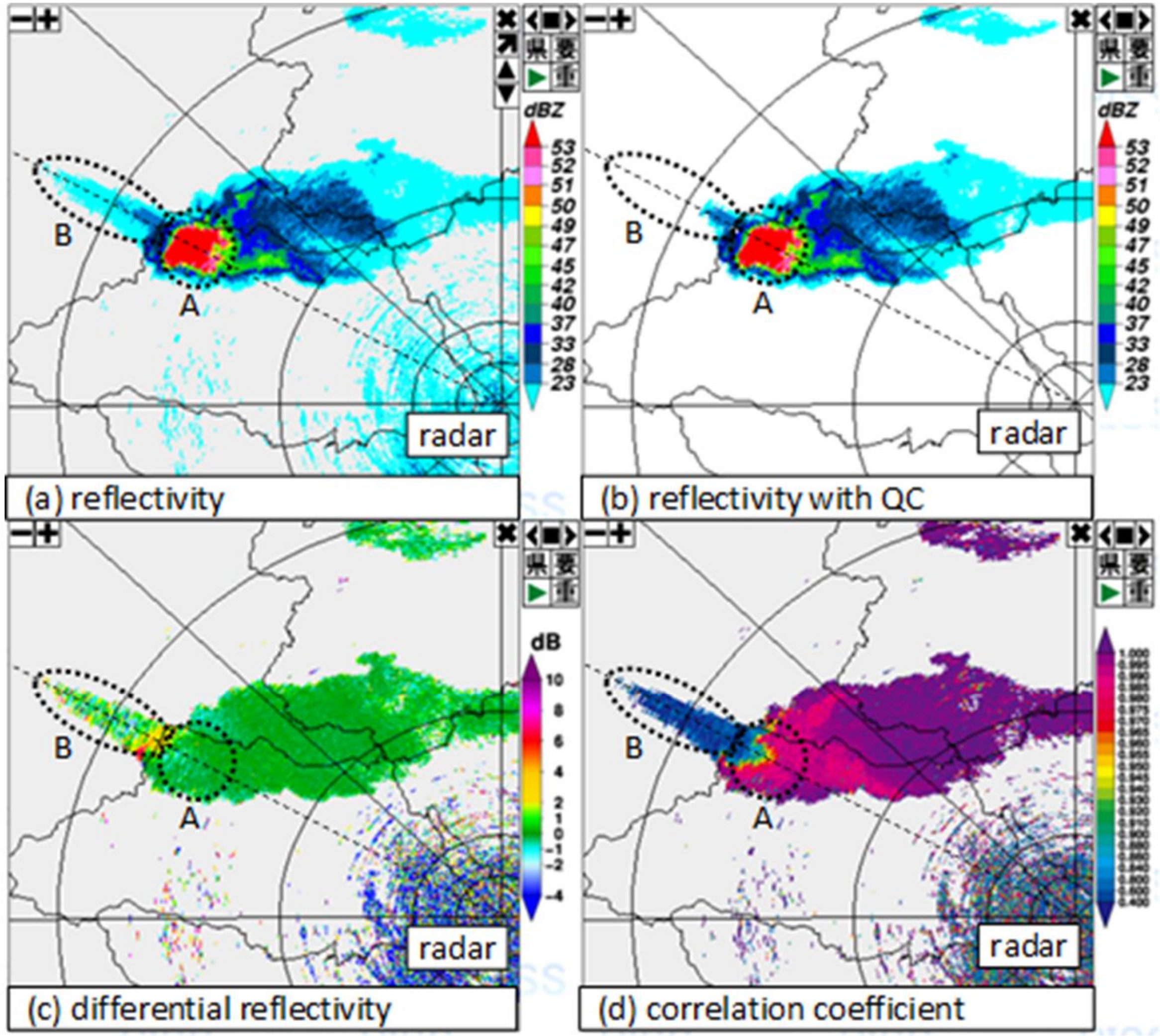


Figure 3.2.2.2 PPI examples of a hailstorm observation with a dual-pol radar (Elevation angle of 4.5 degree). (a) reflectivity factor (Z_H), (b) reflectivity factor with quality control, (c) differential reflectivity (Z_{DR}), (d) correlation coefficient (ρ_{hv}). The maximum reflectivity factor in the region A is 67 dBZ. Region B is a TBSS that occurred just behind the hail area of region A as seen from the radar. TBSS can be removed by radar data quality control as shown in the figure (b). (Source: Japan Meteorological Agency)

Vol. VI > 3.2 Feature analysis

- Tornado debris detection

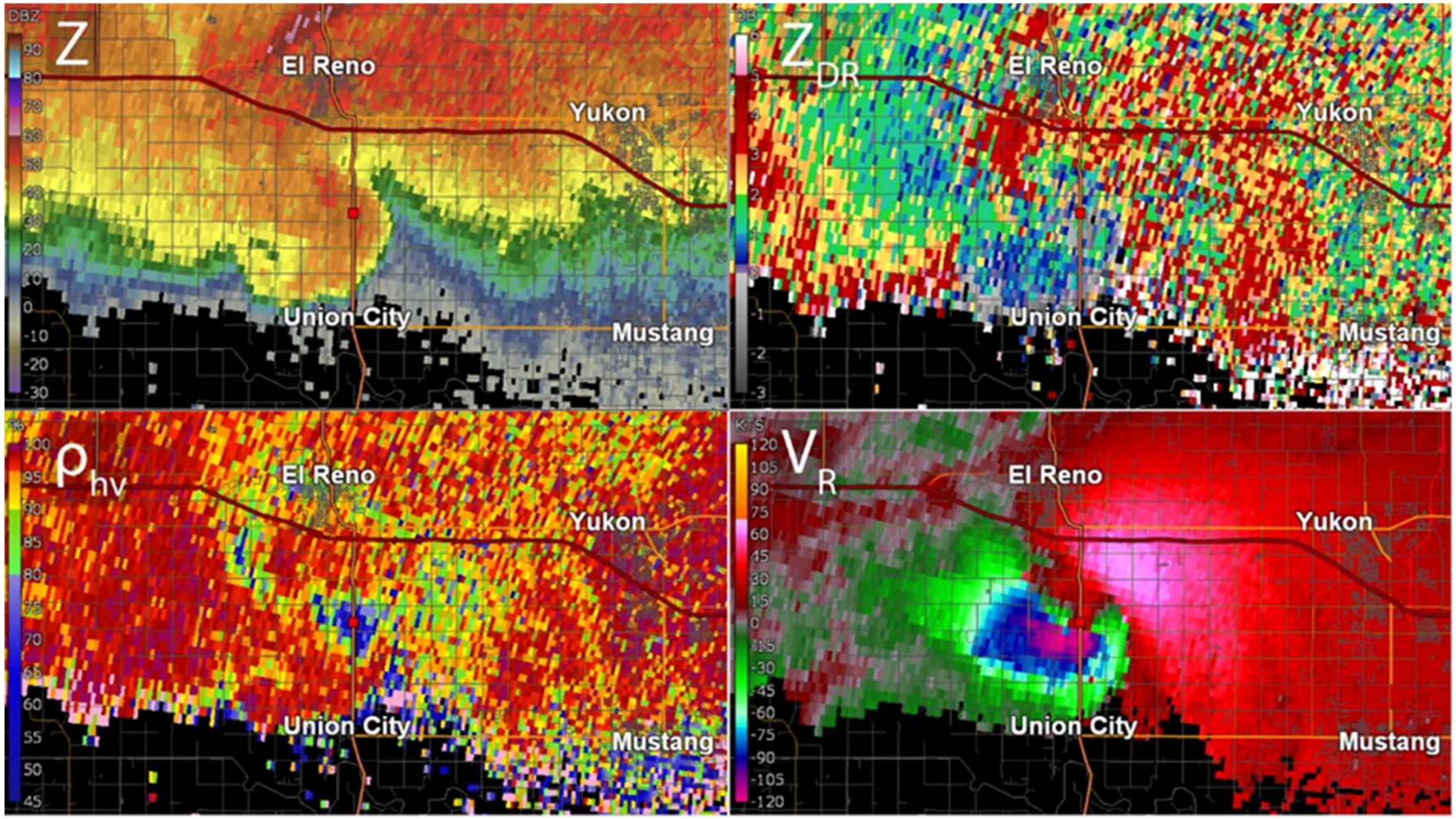


Figure 3.2.3.1 ZH, ZDR, phv, and VR from a WSR-88D radar in central Oklahoma, USA, on the evening of 31 May 2013. An intense tornado is producing a prominent TDS, the approximate center of which is marked by the red square near the center of each panel. (Source: National Weather Service)

Vol. VI > 3.3 Quantitative Precipitation Estimation

- Z-R relations

Table 3.3.1.1. Examples of different Z-R relationships

Reflectivity factor Z_H ($Z_H = 10 \log z_h$)	Marshall & Gunn ($z_h = 200 R^{1.6}$)	East-Cool Stratiform ($z_h = 130 R^{2.0}$)	West-Cool Stratiform ($z_h = 75 R^{2.0}$)	WSR-88D Convective ($z_h = 300 R^{1.4}$)	Rosenfeld Tropical ($z_h = 250 R^{1.2}$)
15 dBZ	0.32 mm h^{-1}	0.49 mm h^{-1}	0.65 mm h^{-1}	0.20 mm h^{-1}	0.18 mm h^{-1}
25 dBZ	1.33 mm h^{-1}	1.56 mm h^{-1}	2.05 mm h^{-1}	1.04 mm h^{-1}	1.22 mm h^{-1}
35 dBZ	5.62 mm h^{-1}	4.93 mm h^{-1}	6.49 mm h^{-1}	5.38 mm h^{-1}	8.29 mm h^{-1}
45 dBZ	23.68 mm h^{-1}	15.60 mm h^{-1}	20.53 mm h^{-1}	27.86 mm h^{-1}	56.46 mm h^{-1}
55 dBZ	99.85 mm h^{-1}	49.32 mm h^{-1}	64.93 mm h^{-1}	144.28 mm h^{-1}	384.64 mm h^{-1}

Vol. VI > 3.3 Quantitative Precipitation Estimation

- Estimation using dual polarization

(1) $R(K_{DP})$ relationships

$$R(K_{DP}) = a(K_{DP}/f)^b$$

(2) $R(Z, Z_{DR})$ relationships

$$R(Z_H, Z_{DR}) = a(z_h)^b(z_{dr})^c$$

(3) R(A) relationships

$$R(A_H) = aA_H{}^b$$

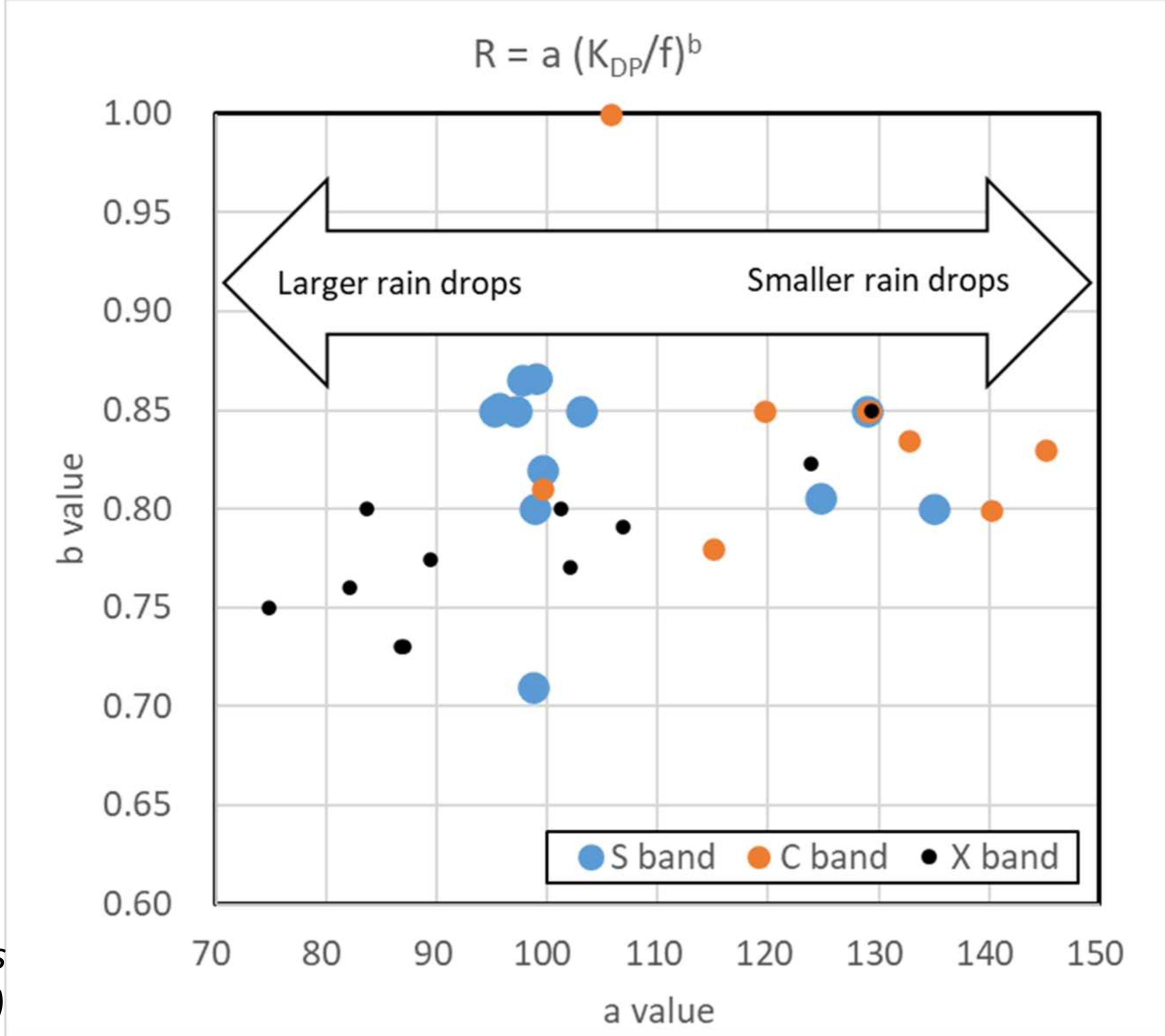


Figure 3.3.2.1 Plotted a and b values of K_{DP}-R relationships for various regions (Source: Japan Meteorological Agency)

Vol. VI > 3.3 Quantitative Prexipiatation Estimation

- Advection correction

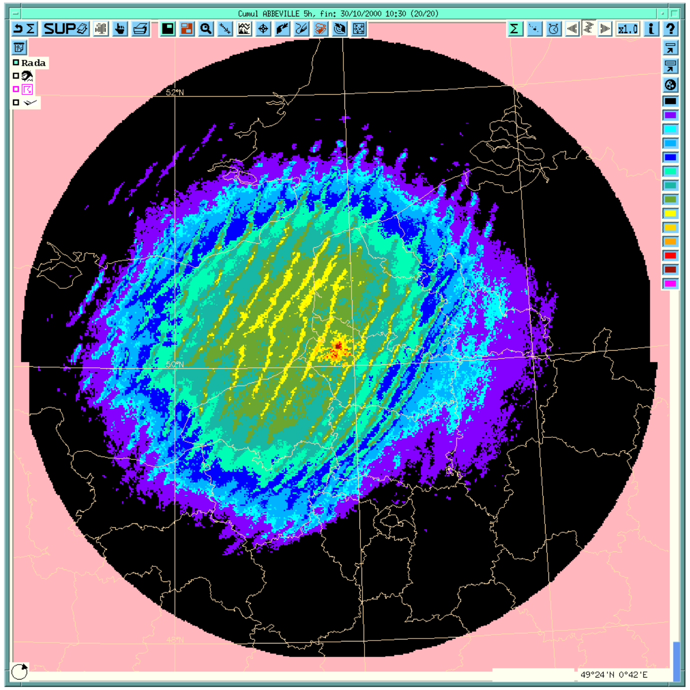


Figure 3.3.3.1 Example of accumulative precipitation fall product affected by the "stroboscopic effect." In this case a squall line moves fast from west to east. The duration of integration is 5 hours, with observation time interval of 15 minutes. (Source: Météo-France)

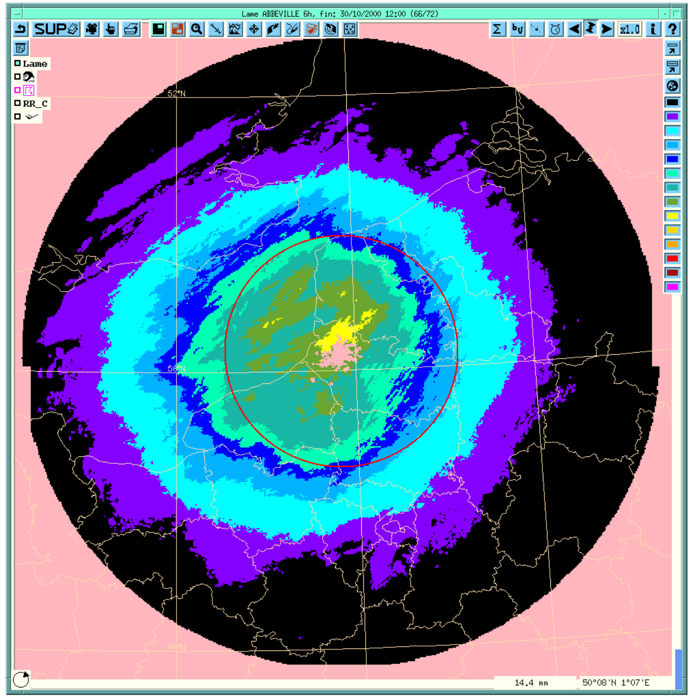


Figure 3.3.3.2 Example of accumulative precipitation product using advection correction (Source : Météo-France)

Vol. VI > 3.3 Quantitative Precipitation Estimation

- Vertical Profile of Reflectivity (VPR) correction

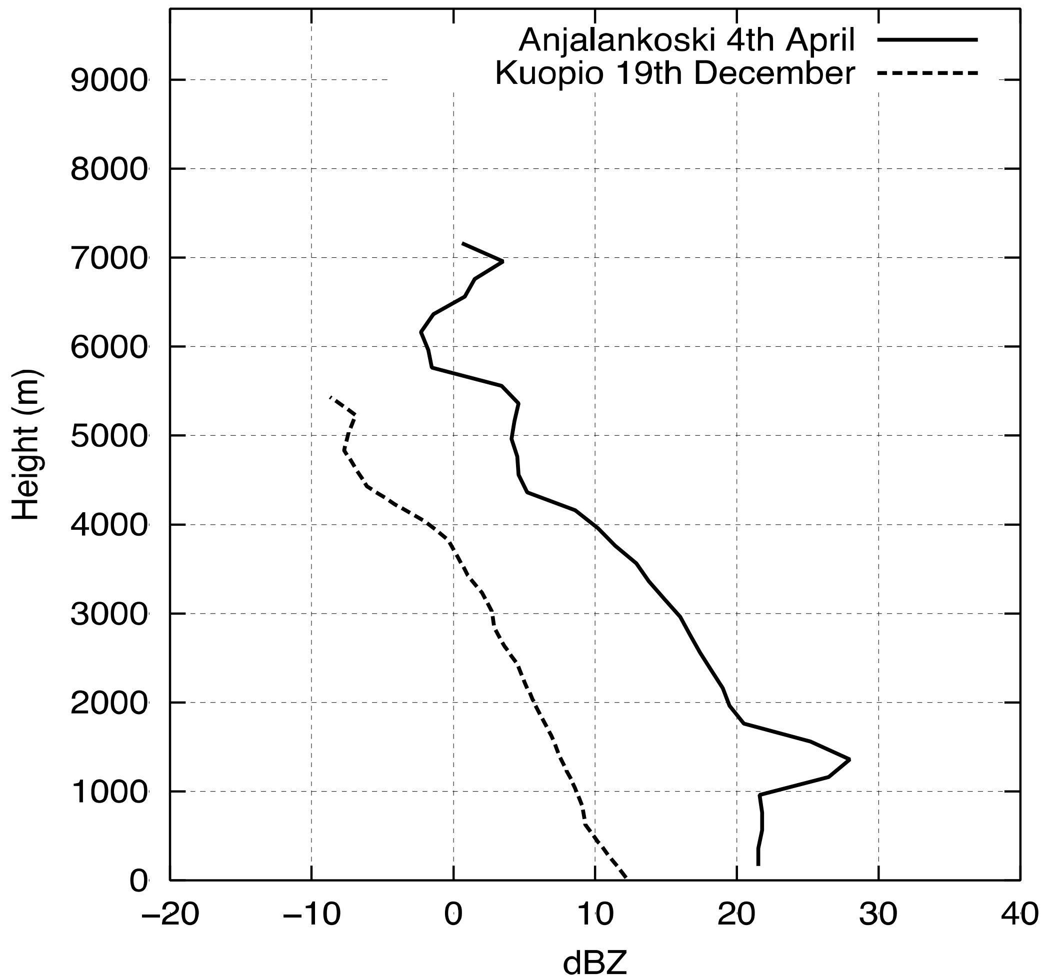


Figure 3.3.4.1 Two typical VPRs from two Finnish radars. The VPR from the radar in Anjalankoski is from a spring rain event containing a characteristic "bright band" of reflectivity identifying the melting layer. The VPR from the radar in Kuopio is from snow. From Koistinen and Michelson (2002).

Vol. VI > 3.3 Quantitative Precipitation Estimation

- Gauge adjustment

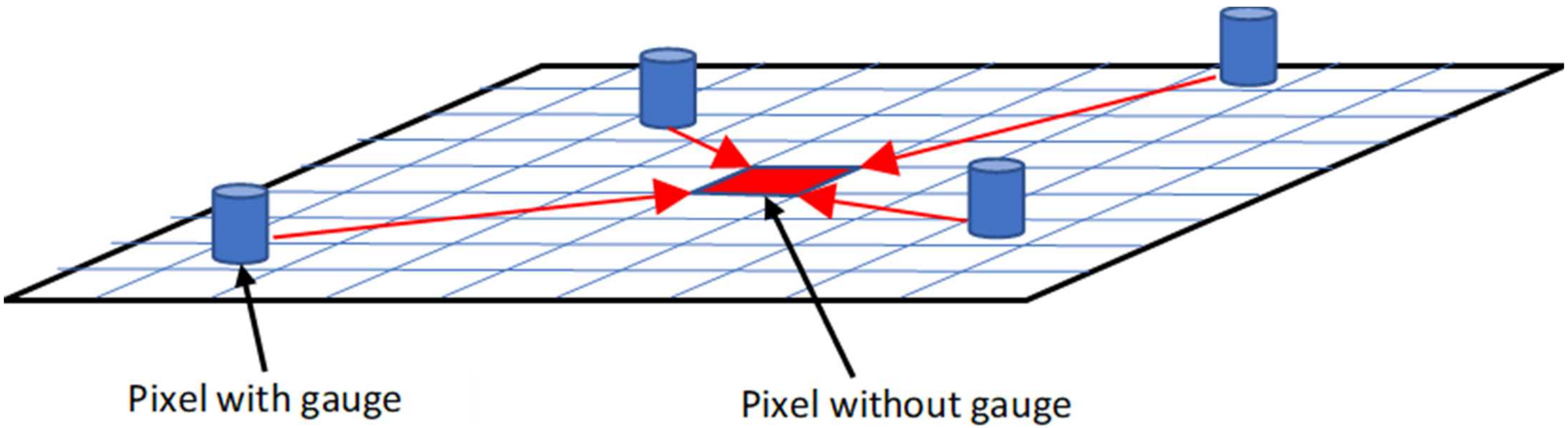
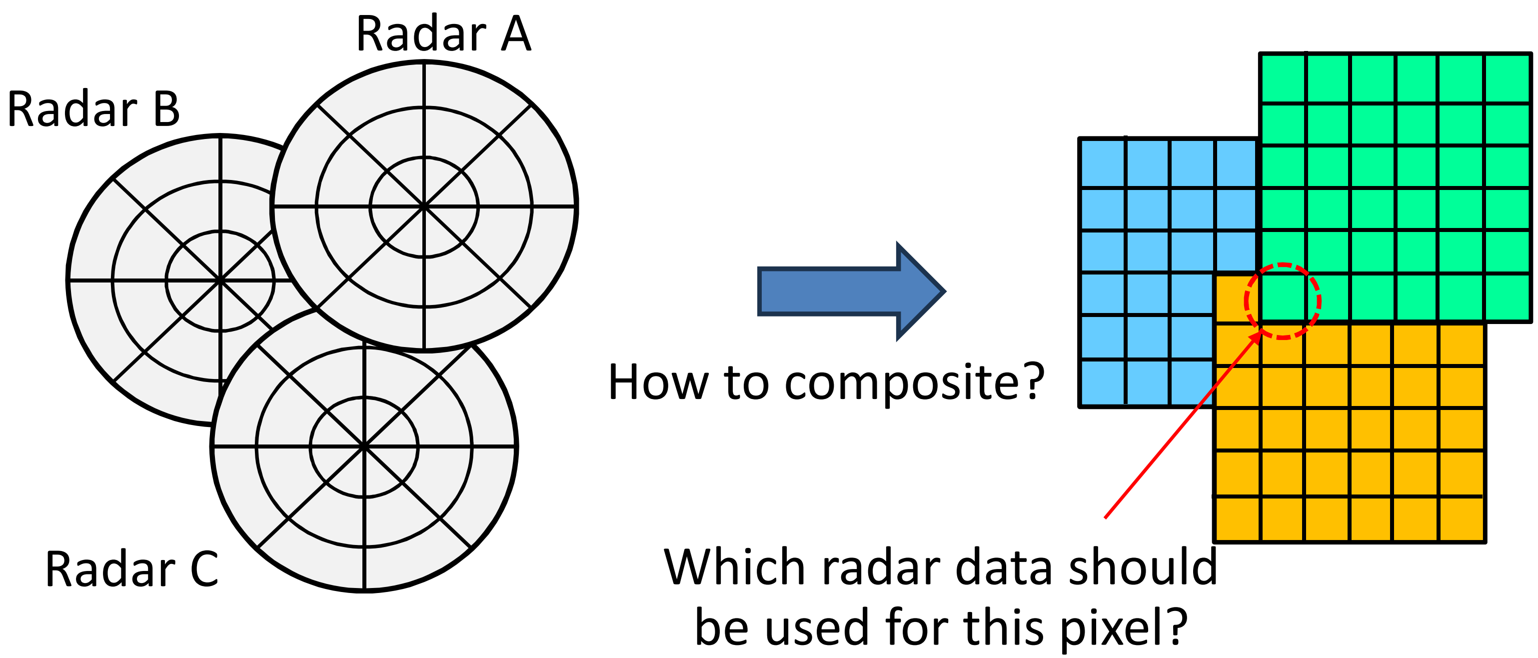


Figure 3.3.5.2 Schematic of spatial adjustment. The gauge-to-radar ratio for a pixel with gauge is simply derived as the ratio between precipitation amount estimated using radar and that observed using gauge. The gauge-to-radar ratio for a pixel without gauge is derived as the weighted interpolation of gauge-to-radar ratio values for surrounding pixels with gauge.

Vol. VI: Chapter 4 : Weather radar compositing

- Methods to composite products of multiple radars
- Different methods are suitable depending on the purpose
- Which data quality should be used as an indicator for radar selection and weighting?



Vol. VI: Chapter 4 : Weather radar compositing

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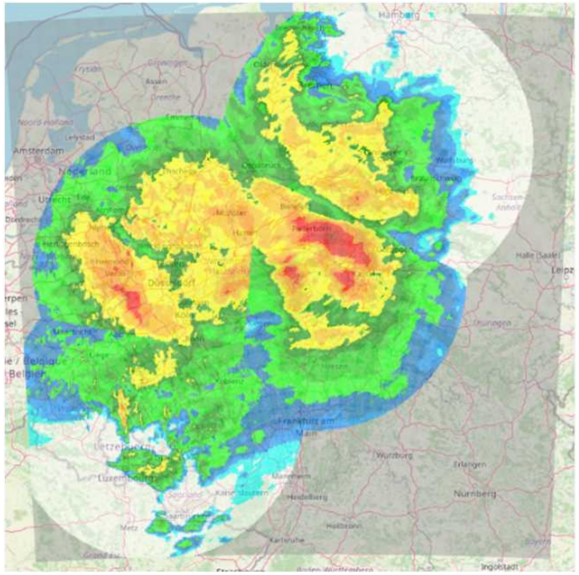
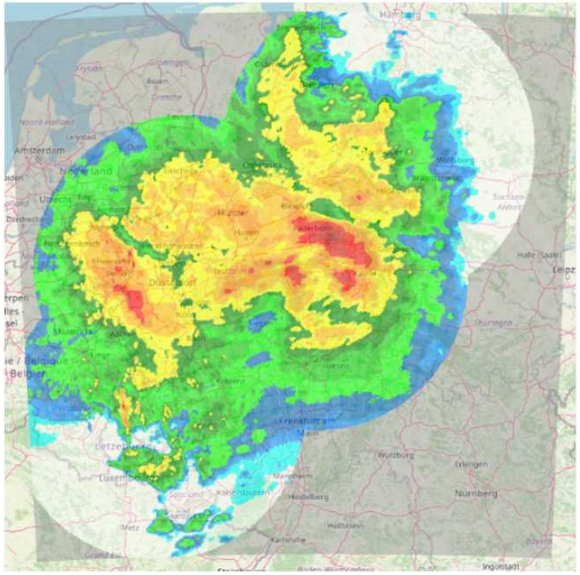
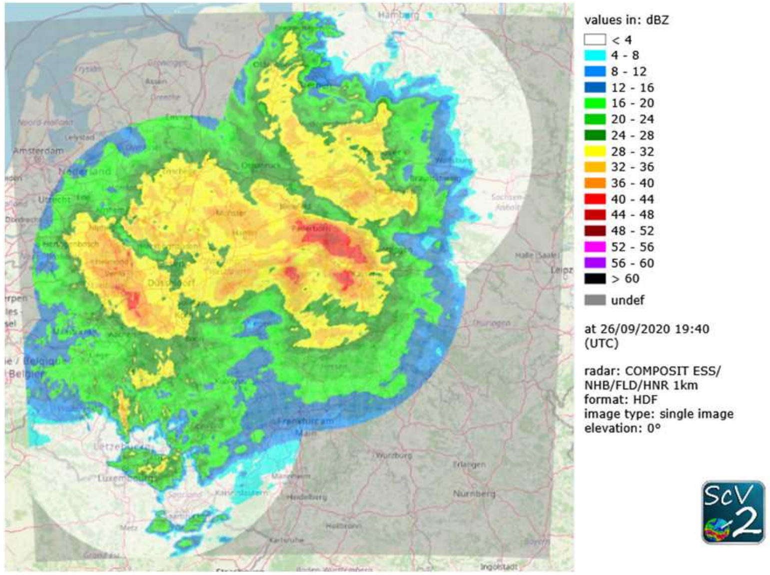


The nearest neighbor compositing strategy



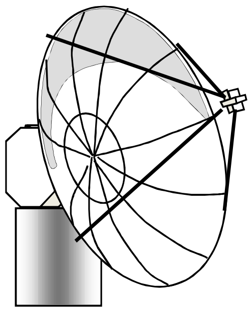
The maximum value compositing strategy



The weighted compositing strategy

(Source: hydro & meteo GmbH)

Expectations to encourage use and development of open source radar tools.



Radar data in manufacturer-specific format

convert →

Radar data in data exchange format (FM301)

input →

Open source radar tools

↑

Radar data product

Metadata in WMO radar database may assist in this conversion.

“Guide to Operational Weather Radar Best Practices” can serve as a tool manual or serve as a starting point for tool development.

Summary

- As the usefulness and importance of weather radar observation increases, it is necessary to promote data exchange and share knowledge for the introduction, operation, and utilization of weather radar.
- To address above issues, WMO JET-OWR has developed data exchange format (FM301), operates metadata database (WRD), and is developing the Guide to Operational Weather Radar Best Practices.
- Volume VI provides easy-to-understand reviews of the roles and options of each process in the radar data processing chain from quality control to compositing.
- The guide and the data format are expected to promote radar data usage and data exchange in NHMSs, and also promote use and development of open source radar tools.

Stay tuned for the upcoming open of the Guide to Operational Weather Radar Best Practices Vol. IV, V, and VI!

Thank you
Khob khun Krab