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| **World Meteorological Organization**  **Commission for Instruments and Methods of Observation**  **CIMO Management Group**  **Fifteenth Session** Geneva, Switzerland, 26 – 29 March 2018 | **CIMO/MG-15/Doc. 2.3(4)** |
| Submitted by: Daniel Michelson  22.03.2018 |

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# Report on progress, recommendations and future activities of inter-programme Expert team on operational weather radarS (B4)

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| **Summary and purpose of document**  The document provides information on the status of the Inter-Programme Expert Team on Operational Weather Radars (IPET-OWR) work plan. |

**Action proposed**

The Meeting is invited to note the information contained in this document. There are no direct recommendations or requests for decisions, but instead points brought to the attention of the CIMO MG, welcoming feedback.

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**Appendices:** I [Work Plan](#Appendix1)

II [Terms of Reference for IPET-OWR](#Appendix2)

III [Draft guidance on wind turbine interference (Updated Annex 7.B to the CIMO Guide, Part II, Chapter 7)](#Appendix3)

**EXECUTIVE SUMMARY**

IPET-OWR is jointly managed by CIMO and CBS, and it addresses the emergence of weather radar as a global resource under WMO’s governance and coordination. The team’s kick-off meeting was held 13-17 March 2017 at the Japan Meteorological Agency in Tokyo. The work plan (appended) was finalized at that meeting. Several important deliverables were scheduled during 2017, most of which were due by the end of December. The team’s work addresses the following areas, in summary form:

**Data representation and exchange** – The objective is to propose a single global standard for representing weather radar data to be exchanged internationally. These deliverables are on track and comprise documentation at this point in time, with reference software to be produced during 2018.

**Metadata Management** – Synchronization of weather radar metadata used by IPET-OWR, WIGOS Metadata Standard, OSCAR/Surface, WMO Weather Radar Database, and EUMETNET OPERA has been undertaken, and outputs have been produced, but there is more work to be done to ensure harmonization.

**Advice and Guidance to WMO’s Members** – Several document deliverables have been produced or are under preparation, some of which are delayed. Such documentation addresses interference issues, network design, dual polarization, using radar in mountainous terrain, identifying best practices for quality control and quantitative precipitation estimation, among other topics. It has been difficult to build and sustain the momentum required to generate all these deliverables. It is hoped that efficiencies can be identified such that the work plan can be optimized with the priority to achieve these objectives. A focus on a Weather Radar Best Practices Guide may be the path to success.

**Collaboration with ISO** – Part 1 of a joint weather radar standard/norm has been drafted, addressing radar hardware and discussions are underway about cooperating on Part 2, addressing data quality/processing.

**International and regional collaboration** – The team contributed actively towards supporting the development of regional and inter-regional radar networking in Southeast Asia through a joint WMO/ASEA weather radar training event. Support in other regions is also envisaged.

IPET-OWR will hold its second meeting 14-17 May 2018 in Seoul, Republic of Korea. It is expected that the work plan will be streamlined and priorities defined in an effort to build and sustain the necessary momentum to succeed in producing its deliverables.

**REPORT ON ACHIEVEMENTS, RECOMMENDATIONS AND FUTURE ACTIVITIES OF CIMO INTER-PROGRAMME EXPERT TEAM ON OPERATIONAL WEATHER RADARS**

1. ***Major achievements with respect to Workplan***
   1. The first IPET-OWR meeting was successfully carried out 13-17 March 2017 at JMA, Tokyo, Japan.
   2. The work plan was reviewed and revised to its current form (Appendix I) at IPET-OWR-1.
   3. An online survey of WMO’s Members on Operational Weather Radars was conducted in January-February 2017. The survey yielded a total of 86 responses containing valuable information that is used as guidance to the team in carrying out its work.
   4. A high-level document on weather radar network design and application has been produced.
   5. Updated guidance on interference from wind turbines has been drafted (Appendix II). This is intended as an update to the existing Annex 7.B to the CIMO Guide, and will be submitted as such once approved by IPET-OWR.
   6. Work on weather radar data representation is on track, yielding an Information Model document, a Data Model document, a CfRadial 2.0 file format specification document, and a guidance document on how WMO’s Members are to use CfRadial 2.0 for the purposes of data exchange.
   7. A document proposing weather-radar data exchange methods has been produced.
   8. A radar calibration reporting software tool has been prototyped, potentially facilitating the validation and reporting of radar calibration results in a harmonized way.
   9. IPET-OWR participated in a Workshop on Radar Metadata for WIGOS, held 19-21 June 2017 in Locarno, Switzerland. A metadata mapping among IPET-OWR’s deliverables (1.6 above), the WIGOS Metadata Standard, and WMO Weather Radar Database was produced.
   10. IPET-OWR worked with the International Standards Organization in drafting Part 1 of a joint standard/norm for weather radar: ISO/DIS 19926-1:2017(E), currently under review and revision. Discussions on Part 2 addressing data quality/processing have commenced.
   11. Regarding coordination of / assistance with international training courses, syllabi for courses given in Turkey and the Republic of Korea were solicited and reviewed.
   12. IPET-OWR participated in the WMO/ASEAN Training Workshop on Weather Radar Data Quality and Standardization, held 5-13 February 2018 in Bangkok, Thailand.
2. ***Problems encountered*** 
   1. Several deliverables are delayed in relation to deadlines specified in the current version of the work plan. Most of these delays are with deliverables related to Regulatory Material and advice and guidance to WMO’s Members, i.e. documentation. Specifically:
      1. Guidance on dual-polarization radar.
      2. Guidance on operation of weather radars in mountainous terrain.
      3. Guidance on (radio) interference issues.
      4. Harmonized metadata management among WIGOS, WMO Weather Radar Database, and EUMETNET OPERA, along with links to OSCAR Surface.
      5. Entries to the Weather Radar Best Practices Guide.
3. ***Recommendations***

The following points do not require decisions from CIMO-MG at this time, but are included for information and feedback.

* 1. The work plan needs review and revision, with an eye on streamlining it, at IPET-OWR-2, to be held 14-17 May 2018 in Seoul, Republic of Korea.
  2. The documentation deliverables addressed above in 2.1 should probably be rationalized, with the potential priority being a focus on the Weather Radar Best Practices Guide.
  3. Liaison with CBS OPAG-ISS regarding data representation (1.6 above).
  4. Elaborated cooperation with ISO regarding Part 2 of the joint weather radar standard/norm, primarily focused on the content of the Weather Radar Best Practices Guide.

1. ***Major topics for future work with expected associated deliverables***

Pending IPET-OWR-2 in May 2018, and optimization of the work plan at that meeting, the deliverables in Appendix I may be modified in terms of content and timing.

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**APPENDIX I: Work plan of the Inter-Programme Expert Team on Operational Weather Radars (2016-2019)**CIMO-16, updated based on outcomes of IPET-OWR First Session

(ET-OWR deals with **all aspects** of operational weather radar under the ToR below.)

(Version: 1.5, 12 April 2017)

| **No.** | **Task description** | **Person responsible** | **Action** | **Deliverable** | **Deadline for delivery** | **Status**  **[%]** | **Comments** |
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| **1.** | IPET management  Addresses ToRs 8, 9 | Michelson  Secretariat | 1. Organize the activities of the IPET into a Work Plan 2. Review and revise the Work Plan as necessary. 3. Report on issues, activities and progress to CIMO and CBS 4. Meeting of IPET-OWR in Q1 2018 to consolidate deliverables ahead of CIMO session. | 1. Work Plan 2. Work Plan Review and Revision 3. Reports to CIMO-MG, CBS-MG and ICT-IOS 4. IPET-OWR-2; consolidated reporting and deliverables to CIMO; | 1. Jan 2017 2. Draft plan: Feb 2017; 3. Upon request; to CIMO annually; Chair to attend ICT-IOS-10 (Q1, 2018) 4. Q1 2018 |  | To be approved by the IPET members and CIMO MG.  Regular Teleconference sessions dedicated to Task collaboration. (e.g. Monthly)  Update status six-monthly. Annual update to CIMO-MG around October. Full report prior to CIMO Session. |
| **2.** | Survey of Members requirements  Addresses ToR 8 | Michelson  Secretariat | 1. Survey the Members aimed to obtain requirements for WMO assistance, guidance, etc. on OWR, and the status of the Members’ operational radars 2. Analyse survey replies 3. Review at IPET-OWR-1 and adjust work plan accordingly 4. Analyse survey results further and produce report. | 1. Survey 2. Survey report 3. Updated work plan 4. IOM report of survey | 1. Jan 2017 2. Mar 2017 3. Mar 2017 4. Mar 2018 | 50 | Survey was completed and results provided to IPET-OWR-1. |
| **3.** | Regulatory Material, advice and guidance to WMO’s Members  Addresses ToR 1a-b, 2, 3 | 1. Michelson, Tanaka, Kane (Editorial Board - EB), other contributors. 2. EB 3. Joe, P. Chong, Tanaka 4. Horvat, Buyukbas, P. Chong 5. Kong, Buyukbas, L. Bai, Boascacci, Jung 6. Horvat, Tsukamoto 7. Tsukamoto, Michelson, Mammen, Kane, P. Chong 8. Horvat, Saltikoff, Mammen | 1. Maintain, review and update existing RM for WIGOS and ensure consistency of the documents 2. Develop (WIGOS) Weather Radar Best Practice Guide (BPG) based on a review of existing materials, assessment of requirements (e.g. survey, Task 2) and materials from Actions below and other Tasks. 3. Draft, review and publish high-level document on weather radar network design and applications. Possibly first publish as WIGOS TR and then integrate into BPG. 4. Develop guidance on Dual Polarization Radar:    1. Review CIMO Guide wrt DP    2. Compile draft material for BPG. 5. Develop guidance on operation of weather radars in mountainous regions 6. Operation of Weather Radar Systems:    1. JMA is working on translation of their OWR manual as a contribution to the BPG. Chap. 5 (on applications) has been completed and published by JMA as a booklet.    2. Develop plan for drafting and integration of national contributions into general guidance. 7. Guidance on interference issues taking into account input from Task 9 | 1. Draft updates to WMO No. 8, 488, 544 and/or 1160 2. Guidance material:    1. Compiled user requirements    2. BPG template    3. BPG Content Outline 3. Draft guidance including integrated deliverables from all tasks. High-level document on weather radar, network design and applications 4. Guidance on DP radar operation 5. Guidance on WR operation in mountainous regions 6. Guidance on OWR as a contribution to BPG. 7. Improved policy and guidance on WR interference issues. | 1. Dec 2017 (No. 8: CIMO Guide)    1. May 2017    2. May 2017    3. May 2017    4. Jun 2017 2. Initial draft: Dec 2017 3. Dec 2017 4. Dec 2017 5. Dec 2018 6. Dec 2017 | 1. 0 2. 0 3. 90 4. 0 5. 70 6. 0 7. 5 | Carried over from ET-SBO (for WMO-No. 544 and 1160, approved by CBS-16), draft RM (Action 1) may be considered completed, but there may be follow-up requests.  Hence, the bulk of this task addresses guidance (Action 2).  Division of Action 2 work to be done at the kickoff, Mar 2017.  Deadlines indicate first versions. Deadlines for subsequent document versions will emerge from the work plan review.  Benefitting from the progress achieved by ET-ORST, and based on outputs from No. 6 below, develop and propose guidance material addressing the issues stated in ToR 1a, considering requirements of data users. Initially, proposed main areas of work, assuming the deployment of operational polarimetric radar technology, are:   1. Compiling and assessing user requirements, drawing on existing surveys as much as possible, including climate (GCOS) 2. While convenient to assume a well-calibrated radar, recommending methods for monitoring calibration status and stability should be addressed. 3. Recommendations on Quality Control (QC) practices, focussing on target/problem classification and correction 4. Recommendations on Quantitative Precipitation Estimation (QPE), focussing on polarimetric retrievals, VPR-based methods, and statistical adjustment methods based on surface observations. 5. Recommendations on weather-radar compositing that exploit the improvements from QC and QPE. 6. Quality Assurance (QA). For each step in QC, QPE, and compositing, recommend methods by which the performance of the algorithms applied, and accuracy of the results, may be monitored. |
| **4.** | Weather radar data exchange  Addresses ToR 1a-b, 2 | Michelson  Dixon  Curtis  Umehara  Rezende  Mammen  Chong | 1. Conclude work started in TT-WRDE on the creation of proposed standard weather-radar data representation 2. Propose weather-radar data exchange methods 3. Develop associated guidance material and provide for integration under Task No. 3. 4. Engage with Task 5 re exchanged metadata. 5. Engage with CBS OPAG-ISS for validation, approval and maintenance of format 6. Assess and initiate necessary actions on issue of data policy and licensing. 7. Investigate and report on processes for ensuring availability and compliance of software used for exchange. | 1. Data representation:    1. Information model    2. Data model    3. File format representation 2. Report on data exchange protocol(s) and mechanism(s) 3. Guidance material on use of exchange format. 4. Exchanged metadata integrated into WR metadata model 5. Format validation process activated. 6. Report on data policy issues to TCs. 7. Report on exchanged software processes. | * 1. Jan 2017   2. May 2017   3. Jun 2017  1. Dec 2017 2. Jun 2018 3. Sep 2017 4. Dec 2018 5. Jun 2018 6. Jun 2018 | 1. 75 2. 0 3. 0 4. 0 5. 0 6. 0 7. 0 | Current status as of CBS-16: data representation well organized by TT-WRDE, with work in advanced stage of preparation.  Data exchange remains TBD. |
| **5.** | Metadata management, WMO radar database (WRD) and Contribution to OSCAR  Addresses ToR 7 | Buyukbas  Curtis  Saltikoff | 1. Liaise with TSMS, and provide advice on structure/organization of WRDB, supporting the Members and WIGOS. Liaise with OPERA regarding metadata compatibility. 2. Facilitate Members contacts with the WRD to help the WRD stay up-to-date. 3. Develop the radar metadata model based on the WMDS and document within the WIGOS guide. 4. Guidance on use of OSCAR Surface and maintenance of metadata in WRD. | 1. Recommendations on potential WRD enhancements 2. Report and update WRD if required 3. WR metadata model and guidance 4. Guidance on OSCAR Surface and WRD | 1. May 2017 2. On request 3. Sep 2017 4. Dec 2017 | 1. 0 2. 0 3. 0 4. 0 | WRDB is updated by TSMS. IPET liaises with TSMS.  This is a placeholder, without specific foreseen recommendations or WRDB updates.  Task 2 requires liaison with OSCAR dev. team. |
| **6.** | Best practices for weather-radar quality control and quantitative precipitation estimation for user applications  Addresses ToR 1a | Kane (1.b, 2)  L. Bai (1.a, 1.d, 2)  Horvat (1.a)  Mammen (1.a)  Tsukamoto (1.a, 1.b, 1.c)  Dixon (1.b)  Kim J-H (1.b, 1.d, 2, 4)  Pei (1.b)  Michelson (1.c, 1.d, 2)  Becker E (1.c)  Curtis (1.c, 1.d, 2)  Jung (1.c, 4)  J. Kim (4)  Kong (1.c, 1.d, 2)  Saltikoff (1.c) | 1. Develop BP guidance on QC practices and processes for WR:    1. Calibration    2. Signal processing    3. Data processing    4. Applications requirements 2. Identify and document methods and metrics for intercomparisons of WR data processing and QC systems:    1. Identify the success metrics for intercomparisons    2. Identify the mechanisms by which an intercomparison might be conducted 3. Assess outcome of DWD workshop on radar DP calibration (Oct 2017) and coordinate a follow-up workshop on general WR calibration in 2018. 4. Conduct (participate in) an intercomparison in which weather-radar calibration, QC and QPE practices, with a priority on those identified under No. 3 above, are trialed and benchmarked according to agreed-upon performance metrics. 5. Prototype weather-radar data exchange using outputs from No. 4 above on data representation and data-exchange mechanisms and protocols. | 1. Guidance material for integration into the BP Guide. 2. Documented metrics and methodology for WR intercomparison. 3. Documentation of outcome from DWD workshop; WMO calibration workshop in 2018; Guidance on calibration integrated into Activity 1.a. 4. Real-time weather-radar data exchange using proposed WMO standards. 5. Intercomparison activity | 1. Dec 2017 2. Jun 2018 3. Dec 2018 4. Data: Feb-Mar 2018 5. Intercomparison: Dec 2018 | 1. 0 2. 0 3. 0 4. 0 5. 0 | This is the spirit of RQQI.  Assumes linkage with ICE-POP (PyeongChang 2018 winter Olympic Games) for site(s), instrumentation and data. |
| **7.** | International and regional collaboration - ISO  Addresses ToR 6 | Gabella  Joe  (Li Bai, Pavlyukov, Tsukamoto) | 1. Participate in the formulation of a joint ISO-WMO weather-radar standard 2. Liaise with/consult IPET members on the review of the committee draft (and other drafts, as appropriate) | 1. ISO-WMO weather-radar standard 2. Inform IPET on progress and seek IPET views on ISO standard committee draft (CD) | According to the ISO process |  | At least two phases of the joint work with ISO are envisaged. |
| **8.** | International and regional collaboration  Addresses ToR 6 | Michelson Tanaka | 1. Present relevant outcomes of IPET at international radar conferences, if appropriate. 2. Synthesize outcomes of international radar conferences for the benefit of the team members and WMO. 3. Organisation of WMO international conferences on meteorological radar systems in collaboration - initially investigate and discuss possible collaboration with ERAD (2020) 4. Maintain a watch on international and regional collaborations in relation to weather radar data exchange, including OPERA, RAII-V, BLACKRAD, SEERAD | 1. Presentations at international conferences 2. Report/Document summarizing outcomes of international conference 3. Offer made to collaborate with ERAD (2020) 4. Document activities and issues and report to CBS and CIMO as necessary | 1. Oct 2017 (AMS-38) 2. Dec 2017 (AMS-38) 3. Jul 2018 4. Jul 2018 |  | International conferences of interest:   * AMS 38th Conference on Radar Meteorology (2017, Chicago) * Report on ERAD 2018, Utrecht, NL * AMS 29th Conference on Radar Meteorology (2019) * (ERAD 2020) |
| **9.** | Policy  Addresses ToRs 4, 6, and 7 | Horvat  Saltikoff Mammen | 1. Contribute input to SG-RFC, strengthening the liaison with international organizations (ITU, EUMETFREQ, others), with the objective to protect frequency bands that are used for (operational) weather radar. 2. Monitor the use of frequency bands used for (operational) weather radar, gathering information on cases of interference. 3. Formulate, preferably together with other organizations, a sustainable policy for wind-turbine proximity to weather radars:    1. Review existing materials (CIMO Guide Chapter 7, OPERA document)    2. Identify differences, gaps and issues.    3. For BPG combine with interference generally (RF)    4. Update CIMO Guide Policy (chap 7, Annex)    5. Investigate ways to increase visibility of WMO policy on wind turbine issues for OWR. E.g. EC Resolution. | 1. Provide input to SG-RFC 2. Case log of RFI events 3. Weather-radar and wind turbine statement or policy | 1. Upon request 2. IPET-OWR-2 or conference 3. Dec 2017 |  |  |
| **10.** | Emerging technologies  Addresses ToR 5 | E. Becker  Horvat  Tsukamoto | Review and report on potential operational developing and emerging weather radar research and technologies, including collaborative and adaptive data collection methods.   1. First version to focus on “near future” emerging technology suitable for operations. 2. If necessary update CIMO guide. | 1. IOM Report(s) 2. Update of the CIMO Guide if required | 1. Mar 2018 2. Dec 2017 | 1. 0 2. 0 | E.g. solid state transmitters, phased array antennas, low cost X-band radars.  Benefit from ET-ORST results.  Stand-alone document to be produced – possibly IOM report.  Input can be derived from AMS, 2017 information.  Consult with CIMO/ET-NRST |
| **11.** | Capacity development and training  Addresses ToR 1c | Buyukbas  Joe  Michelson  Curtis  J-H Kim | 1. Coordination of/assistance with international training courses, e.g. TSMS (Turkey) and KMA (South Korea);    1. Develop and maintain list of expert speakers on particular topics.    2. Develop a curriculum outline and guidance for WR courses. 2. Conduct an inventory of (open) software for exchanging and processing weather-radar data 3. Development of competencies on weather radar (P. Joe) | 1. Expert speaker list; Curriculum outline and guidance. 2. Report on (open) software inventory 3. Examples of using weather-radar data processing software including interactive exercises 4. Advise on need for weather radar competencies | * 1. Nov 2017   2. Jun 2018 (Dec 2017)  1. ERAD 2018 2. TSMS KMA, Apr 2017 | 1. 0 2. 0 3. 0 | 1. Liaising with EUMETCAL, TSMS, and KMA 2. Software solutions based on the [Open Radar Virtual Machine](https://openradar.github.io/) |

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### Appendix II

### Terms of Reference for WMO Inter-Programme Expert Team on Operational Weather Radars

Within the WIGOS framework, under the governance of CIMO and the joint guidance of CIMO and CBS, act as the WMO primary working group on operational weather radars (S, C and X band) with responsibility to:

(1) Develop and propose regulatory and guidance material on:

(a) Standardization of, and regulations and guidance on, systems requirements and specifications, quality control, maintenance and operation, data processing algorithms, data products and data quality monitoring, weather radar composites, and scanning strategies;

(b) Response to requirements of data users; and

(c) Training and capacity development.

(2) Contribute to development of methods, models and formats for the international exchange of weather radar data and metadata.

(3) Provide advice on network design.

(4) Provide guidance on radio-frequency allocation and protection.

(5) Review and report on potential operational developing and emerging weather radar research and technologies.

(6) Collaborate with other international and regional organizations on relevant matters, particularly including international standards organizations and research bodies and associations.

(7) Collaborate with and respond to the requests of WMO constituent bodies, as appropriate.

(8) Develop and document proposals for the activities of the Inter-Programme Expert Team.

(9) Report on issues, activities and progress to CIMO and CBS.

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**APPENDIX III**

**ANNEX 7.B. WMO GUIDANCE STATEMENT ON WEATHER RADAR/WIND TURBINE SITING**

WMO expresses concern over increasing deployment of wind turbine farms proximate to weather radars, and stresses the need for adequate consultation, protection and mitigation efforts. WMO addresses its concern to policymakers, to national radio administration agencies, to national hydrological and meteorological societies, to wind turbine farm developers, to commercial vendors of wind turbine equipment and to the meteorological community.

Protection of weather radar data is critical to the continued function and improvement of weather sensing, monitoring, forecasting, and warning, and is therefore in the best interests of public safety and national security. Weather prediction models and localized operational forecasts increasingly depend on national networks of ground-based Doppler weather radars and wind profilers for severe weather warnings such as tornadoes, flash flooding, land-falling hurricanes, precipitation (rain, snow, hail) forecasts, aircraft icing and air traffic/weather avoidance. Worldwide, Doppler radar and wind profiler networks are contending with increasing pressures by wind farms.

Wind farms have already had an impact on operational weather radar networks, creating confounding ground echoes that create a significant loss of data or create false precipitation for hydrological applications. The motion of rotating blades can be misinterpreted as meteorological velocities, and could potentially be mistaken to be severe weather such as a tornado. In addition if sufficiently close to a radar, the wind turbines will block the radar beam in the direction of the turbine and possibly even scatter radio energy in directions outside the intended radar beam.

Development of new radar and wind profiler networks and wind farms will require strategic planning for mitigation by the meteorological and wind farm communities. WMO and the meteorological community rely on and support mandated international and national agencies and will proactively encourage and support these agencies’ efforts to promote and to protect the meteorological use of unobstructed space. WMO encourages national agencies to develop acceptable obstruction criteria and to provide tools to help the wind farm developer on site selection.

WMO also encourages wind farm developers to consult with local and national weather radar programs to minimize operational conflicts with weather warning and forecasting. Research tools and evaluation processes may be used to facilitate the site selection process. Analysis may be at low or no cost to the developer to determine the potential for impacts to nearby weather radars. If it appears that there could be significant impacts, wind farm developers should be willing to work with weather radar operators to reduce the impacts and potential loss to public safety. The timing of wind farm developer contact to a commercial or government radar operator is critical. The initial contact needs to take place prior to commitment to specific turbine locations. Early consultation can potentially result in alternate locations for turbines within a proposed area and avoid costly project changes after construction starts. A preliminary analysis can be performed based on wind farm area coordinates, preferably with exact locations of individual turbines. In some cases, weather radar operators can only provide predicted impacts and suggest mitigation options for developers to consider, such as eliminating certain turbines from the project, moving turbines a greater distance from the radar, or lowering turbine heights. Wind farm developers are encouraged to reach out to commercial and national radar operators for selection support to achieve cooperative siting decisions.

The range between wind turbines and the weather radar can be used to generally describe the impact on radar quality and also used to provide a mitigation strategy for cooperative siting of weather radars and wind turbines. Below are general guidelines for the impact on typical radars in flat terrain situations, but they may require modifications for specific situations and for particular radars. Higher powered radars such as S band (10 cm wavelength) radars with less attenuation may necessitate increasing the range limits in the table. Wind turbines in valleys will be less visible than turbines on ridges. Also, these ranges are general guidance for turbine heights around 180 meters or lower. Taller turbines will require a greater set-back distance for all of the following range categories in order to reduce impacts. Additionally, unlike air surveillance radars, there is not a reduction in impact for repower projects, in which the number of turbines in a project is reduced but the height of remaining turbines is increased. Weather radar is particularly concerned with the depth of contamination in multiple elevation angles.

WMO encourages funding and implementation of studies to develop methods and technologies to mitigate the impact. Weather radar signal processing techniques or use of other materials to construct wind turbines may be able to mitigate clutter at long ranges, in the future. Further, WMO recommends that the results of these studies be made available to commercial weather radar and wind turbine manufacturers.

It is in all nations’ best interests to protect unobstructed space for weather radars and wind profilers that are essential and critical to the accurate forecasting of adverse weather. Local, national and technological solutions are sought. WMO will support and provide guidance material to protect unobstructed space for weather radars and wind profilers.

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| *Range* | *Potential impact* | *Guideline* |
| 0–5 km | The wind turbine may completely or partially block the radar and can result in significant loss of data that cannot be recovered. Turbines constructed within this range can pose mechanical damage to the radar and a radiation hazard to wind turbine maintainers.  [Multiple reflections and effects seen at longer ranges also present.] | Definite impact zone: Wind turbines should not be installed in this zone. |
| 5–20 km | Multiple reflection and multipath scattering can create false echoes at multiple elevations. Doppler velocity measurements may be compromised by rotating blades. | Moderate to High impact zone: Terrain effects will be a factor. Analysis and consultation is recommended. Reorientation or resiting of individual turbines may reduce or mitigate the impact. |
| 20–45 km | Generally visible on the lowest elevation scan; groundlike echoes will be observed in reflectivity; Doppler velocities may be compromised by rotating blades. | Low impact zone: Notification is recommended. |
| > 45 km | Generally not observed in the data but can be visible due to propagation conditions. | Intermittent impact zone: Notification is recommended. |