Radar Wind Profilers
- Experience from the operational use in Europe
(CWINDE)

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Outline of talk

1. Radar Wind Profilers basics - recap
2. Advantages and challenges in the operational use
3. Status in Europe: The CWINDE Network
1. Radar Wind Profilers basics - recap
2. Advantages and challenges in the operational use
3. Status in Europe: The CWINDE Network
Wind profiler - a „clear air radar“

- ground-based
- pulsed
- coherent
- monostatic
- looks vertically
Wind profiler - a „clear air radar“
# Radar frequencies used in Meteorology

<table>
<thead>
<tr>
<th>Band Designation</th>
<th>VHF</th>
<th>UHF</th>
<th>L</th>
<th>S</th>
<th>C</th>
<th>X</th>
<th>K&lt;sub&gt;u&lt;/sub&gt;</th>
<th>K</th>
<th>K&lt;sub&gt;a&lt;/sub&gt;</th>
<th>V</th>
<th>W</th>
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</thead>
<tbody>
<tr>
<td>Frequency (GHz)</td>
<td>0.03</td>
<td>0.3</td>
<td>1.0</td>
<td>2.0</td>
<td>4.0</td>
<td>8.0</td>
<td>12.0</td>
<td>18.0</td>
<td>27.0</td>
<td>40.0</td>
<td>75.0</td>
</tr>
<tr>
<td>Wavelength (cm)</td>
<td>1000</td>
<td>100</td>
<td>30</td>
<td>15</td>
<td>7.5</td>
<td>3.7</td>
<td>2.5</td>
<td>1.7</td>
<td>1.1</td>
<td>0.75</td>
<td>0.4</td>
</tr>
</tbody>
</table>

- **VHF-Radar Wind Profiler** (50 MHz) (6 m)
- **UHF-Radar Wind Profiler** (482 MHz) (62 cm)
- **L-Band-Radar Wind Profiler** (1290 MHz) (23 cm)
- **Weather Radar** (5.6 GHz) (5.3 cm)
- **Micro Rain Radar** (24 GHz) (1.2 cm)
- **Ka-Band Cloud Radar** (35.5 GHz) (8 mm)
- **W-Band Cloud Radar** (95 GHz) (3 mm)
The seminal paper for radar wind profiling:

March 1974

R O N A L D F. W O O D M A N A N D A L B E R T O G U I L L E N

J. Atmos. Sci.

Radar Observations of Winds and Turbulence in the Stratosphere and Mesosphere

R O N A L D F. W O O D M A N A N D A L B E R T O G U I L L E N

Radio Observatorio de Jicamarca, Instituto Geofísico del Perú, Lima

(Manuscript received 16 August 1972, in revised form 19 September 1973)

ABSTRACT

A technique for the observation of radar echoes from stratospheric and mesospheric heights has been developed at the Jicamarca Radio Observatory. Signals are detected at the altitude ranges between 10–35 km and from 55–85 km with powers from many to several tens of decibels above noise level. The three most important frequency spectrum characteristics—power, Doppler shift and spectrum width—are observed in real time. The power levels as well as the spectral width are explained in terms of turbulent layers, with a thickness of the order of 100 m, in regions with a positive potential temperature or electron density vertical gradients. Continuous wind velocity records are obtained with a precision of the order of 0.02–0.2 m sec\(^{-1}\) for the vertical component and 0.20–2 m sec\(^{-1}\) for the horizontal, with a time resolution of the order of 1 min. The highest precisions are obtained at stratospheric heights. Fluctuations in velocity in the mesosphere are observed at the shortest gravity wave periods with amplitudes of the order of 1 m sec\(^{-1}\) for the vertical component and of 10 m sec\(^{-1}\) for the horizontal. Tidal components at these altitudes are not as large as predicted by theory. A technique to obtain the power, the Doppler shift, and the width of the frequency spectrum of the echo signals from only two points of the correlation function is described.
Jicamarca Radio Observatory (Peru): 49.92 MHz Radar

Antenna size 288 m x 288 m: 18,432 half-wave dipoles, 4 MW peak power
RWP Scattering Theory

Classical Electrodynamics (Maxwell)

\[ \nabla \cdot \epsilon \vec{E} = 0 \quad \nabla \times \vec{E} = -\mu_0 \frac{\partial \vec{H}}{\partial t} \]

\[ \nabla \cdot \vec{H} = 0 \quad \nabla \times \vec{H} = -\epsilon_0 \frac{\partial \epsilon \vec{E}}{\partial t} \]

+ 

Statistical Turbulence Theory (Kolmogorov)

\[ \Phi_n (\vec{r}, k) = 0.0330 \ c_n^2 (\vec{r}) k^{-\frac{11}{3}} \]

\[ \eta_b = 0.38 \ c_n^2 (\vec{r}) \lambda^{-\frac{1}{3}} \]
Relevant Echoing Mechanisms for RWP

Useful for wind determination:

- Clear air scattering at inhomogeneities of the refractive index
- Scattering at particulates (e.g. hydrometeors) - no info about vertical wind

Clutter:

- Scattering at free electrical charges (e.g. plasma in lightning channel)
- Scattering at airborne objects (e.g. aircraft, birds)
- Reflections from the ground (through antenna sidelobes)
Ideal clear-air scattering in a Convective Boundary Layer

Lindenberg, 482 MHz, Aug 9, 1998 - SNR

LES-Simulation of a CBL (Muschinski et.al 1999)
482 MHz Volume reflectivity (SNR) during a Thunderstorm

Lindenberg, 12. August 1998, vertical beam only

Height resolution: 250 m (pulse width 1.7 µs)
Temporal resolution: 20 s
Example: A UHF DBS Radar Wind Profiler
DWD 482 MHz RWP - Nordholz, Germany
Phased array antenna (passive CoCo)

- Radome
- COCO dipole elements, ~λ/2
- λ/4, typical spacing
- Balun
- Feed point
- Ground plane
- Ideal current distribution magnitude

Ideal current distribution magnitude

θ

P(θ,φ)

H

z

6.22 m

0.643·λ
(40 cm)

y

x

ϕ

Lindenberg Meteorological Observatory – Richard Aßmann Observatory (2010)
Doppler Beam Swinging: 5 beam system

For (horizontally) homogeneous wind field above the RWP:

\[
\begin{pmatrix}
\sin(\Phi_1)\sin(\Theta_1) & \cos(\Phi_1)\sin(\Theta_1) & \cos(\Theta_1) \\
\sin(\Phi_2)\sin(\Theta_2) & \cos(\Phi_2)\sin(\Theta_2) & \cos(\Theta_2) \\
\sin(\Phi_3)\sin(\Theta_3) & \cos(\Phi_3)\sin(\Theta_3) & \cos(\Theta_3) \\
\sin(\Phi_4)\sin(\Theta_4) & \cos(\Phi_4)\sin(\Theta_4) & \cos(\Theta_4) \\
\sin(\Phi_5)\sin(\Theta_5) & \cos(\Phi_5)\sin(\Theta_5) & \cos(\Theta_5)
\end{pmatrix}
\begin{pmatrix}
u \\
v \\
w
\end{pmatrix}
= 
\begin{pmatrix}
v_{r1} \\
v_{r2} \\
v_{r3} \\
v_{r4} \\
v_{r5}
\end{pmatrix}
\]

\[ A v = v_r \]

\[ v = (A^T A)^{-1} A^T v_r \]
1. Radar Wind Profilers basics - recap
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3. Status in Europe: The CWINDE Network
Advantages

High resolution of measurements:

\[ \Delta t = 10 - 60 \text{ min} \]  (depending on sampling)
\[ \Delta z = 100 - 500 \text{ m} \]  (depending on pulse width)

Important for mesoscale atmospheric structures
## Radiosonde Lindenberg

### Δt = 6 h

<table>
<thead>
<tr>
<th>Height (m-agl)</th>
<th>0</th>
<th>1000</th>
<th>2000</th>
<th>3000</th>
<th>4000</th>
<th>5000</th>
<th>6000</th>
<th>7000</th>
<th>8000</th>
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<td>8/17/2010</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Mode:** 250-m Winds  
**Elev. (m):** 112

- **Northerly Wind:***
  - Calm
  - < 1.25 m/s
  - 2.50 m/s
  - 5.00 m/s
  - 7.50 m/s
  - 10.00 m/s
  - 15.00 m/s
  - 17.50 m/s
  - 22.50 m/s
  - 25.00 m/s
  - 35.00 m/s
  - 37.50 m/s
  - 50.00 m/s

**WS (m/s):***
- Over
- Under

**Time (UTC):***
- 0000
- 0100
- 0200
- 0300
- 0400
- 0500
- 0600
- 0700
- 0800
- 0900

**Deutscher Wetterdienst**

*Wetter und Klima aus einer Hand*

Lindenberg Meteorological Observatory – Richard Aßmann Observatory (2010)
Northerly Wind

Calm

< 1.25 m/s

2.50 m/s

5.00 m/s

7.50 m/s

10.00 m/s

15.00 m/s

17.50 m/s

22.50 m/s

25.00 m/s

35.00 m/s

37.50 m/s

50.00 m/s

482 MHz RWP Lindenberg

$\Delta t = 30 \text{ min}$ factor 12 better

Lindenberg Meteorological Observatory – Richard Aßmann Observatory (2010)
Northerly Wind
Calm
< 1.25 m/s
2.50 m/s
5.00 m/s
7.50 m/s
10.00 m/s
15.00 m/s
17.50 m/s
22.50 m/s
25.00 m/s
35.00 m/s
37.50 m/s
50.00 m/s

COSMO-EU GP Lindenberg

Height (m-agl)

8/16/2010
Mode: CEU winds
Elev. (m): 67

8/17/2010

Time (UTC)
Advantages

High data quality

(if system is working properly)

At least as good as Radiosonde winds.
RWP data quality - NWP monitoring results I

LEGEND

W/Pro - U
R/Sonde - U
W/Pro - V
R/Sonde - V

Comparison of Wind Profiler/Radiosonde v UK Model Wind Measurements
RWP data quality - NWP monitoring results II

Comparison of Wind Profiler/Radiosonde v UK Model Wind Measurements

Comparison of Wind Profiler/Radiosonde v UK Model Wind Measurements

NUMBER OF OBSERVATIONS

<table>
<thead>
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<th>radiosonde</th>
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<tr>
<td>37.0000</td>
<td>444.00</td>
<td>1059.00</td>
</tr>
</tbody>
</table>
Impact in Global NWP: ECMWF - E-SAT OSE Study

NormDiff in RMS of 500 hPa z fc-Error: RMS(fc_ose – an) – RMS(fc_ref –an)
[Baseline + Windprofiler] – [Baseline], FC + 12 H
Date: 20041214 - 20050125
Advantages

Low costs per measurement

compared to alternative systems with similar capabilities
Economic aspects of radar wind profiler

From the COST-76 Final Report (November 2001)

(Based on data from UK Met Office, Meteo France, DWD, KNMI, MeteoSwiss, Austrocontrol and manufacturers)

Estimated costs for investment, operation, maintenance of a small network of 4 RWP,

2 wind profiles / hour

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Cost (EUR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 MHz</td>
<td>6.20 EUR</td>
</tr>
<tr>
<td>400 MHz</td>
<td>5.42 EUR</td>
</tr>
<tr>
<td>1 GHz</td>
<td>3.14 EUR</td>
</tr>
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</table>

Probably correct within 3 dB
NOAA Cost and Effectiveness Analysis (May 2004)

"The results of this COEA demonstrate that high-frequency winds benefit several important NWS missions: severe weather warnings (for tornadoes, flash floods and winter storms), watches and short-term forecasts."

"The NOAA Profiler Network provides the best overall wind profile performance since no alternative provides equal or higher performance at lower costs."

Systems considered:

- Radiosondes
- Aircraft data
- WSR-88D Doppler weather radar
- GOES satellite derived winds
Advantages

Furthermore:

True vertical and instantaneous profiles

Measurements in clear and cloudy atmosphere (all-weather)

Unattended, fully automatic measurements
Challenges

**Prerequisite**: Frequency allocation & bands without interfering RF signals

**Very sensitive radar**: Effective clutter filtering and quality control required

**DBS with few beams**: Problems in CBL and during patchy precip. (geometry)

**Fully automated system**: Problems not immediately obvious - monitoring important

**Qualified staff needed**: System monitoring, diagnostics, maintenance, repair
Challenges

Prerequisite: Frequency allocation & bands without interfering RF signals

Very sensitive radar: Effective clutter filtering and quality control required

DBS with few beams: Problems in CBL and during patchy precip. (geometry)

Fully automated system: Problems not immediately obvious - monitoring important

Qualified staff needed: System monitoring, diagnostics, maintenance, repair
RF interference due to external transmitter
Challenges

Prerequisite: Frequency allocation & bands without interfering RF signals

Very sensitive radar: Effective clutter filtering and quality control required

DBS with few beams: Problems in CBL and during patchy precip. (geometry)

Fully automated system: Problems not immediately obvious - monitoring important

Qualified staff needed: System monitoring, diagnostics, maintenance, repair
Signal processing

Converting electrical signals into meteorological parameters

Goals:

To obtain accurate, unbiased estimates of the characteristics of the desired atmospheric echoes.

To estimate the confidence/accuracy of the measurement.

To mitigate effects of clutter or interfering signals.
Raw data:

Demodulated receiver voltage
Classical method:
Doppler spectrum

Signal detection and identification
Raw signal during bird migration - intermittent clutter

Bayreuth 29.03.2008, Beam East, Height 1191 m @ 23:47:34

Re(s[t]), [arb. units]

Im(s[t]), [arb. units]
Time-frequency analysis of bird contaminated signal

Signal separation and filtering
Bayreuth (Standard processing)

Height (m agl)

WS (m/s)

Time (UTC)

29.03.2010

Mode: No Mode Name Found

Lindenberg Meteorological Observatory – Richard Aßmann Observatory (2010)
Challenges

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ECMWF: Forecast Sensitivity to Observations

Profiler North America

FSO tool showed FC Error due to NOAA profiler in Summer of 2006 (in contrast to PILOT obs)

Case associated with strong convective instability

Likely a problem with DBS

from Cardinali (2010) - ECMWF training course
Doppler Beam Swinging: Problems in a CBL

DBS assumptions violated if

\[ \frac{\partial w}{\partial x} \neq 0 \]

\[ \frac{\partial w}{\partial y} \neq 0 \]
Next Generation NOAA Profiler Network (NGNPN) RWP:
Flexible beam steering - improved DBS

Courtesy Scott McLaughlin
Challenges

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NWP Monitoring by ECMWF: OBS-MOD Statistics for RWP Bayreuth (10678)

Larger than normal differences at 200 hPa from Jan 2008 - August 2008

Station 10678(--) (50N, 012E) Elevation: 514 m
OBS-FG WINDSPEED: BIAS and STD (ALL TIMES)
Mean wind speed profiles: Profiler and NWP model

erroneous range calibration

Mean wind speed Bayreuth (Jan 15 - March 31, 2008)

correct range calibration

Mean wind speed Bayreuth (Sep 19 - Nov 30, 2008)
Challenges

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CWINDE Profiler Network (March 2010)

Co-operative network, Programme financed by 9 countries

26 Radar wind profiler - 20 operational

- 6 VHF radars (45 - 52 MHz)
- 6 UHF radars (482, 915 MHz)
- 14 L-band radars (1280, 1290 MHz)

Network hub: Exeter (UK MetO)

- Advisory committee (Management)
- Technical Advisory Group

South Uist (64 MHz)  

- Very diverse hardware from different manufacturers (contrast to NOAA and JMA)
- Different signal processing and quality control
- Different sampling set-up

Budapest (1290 MHz)
CWINDE Network - managed by E-WINPROF Programme

Technical objectives:

- Classification of systems: Operational or R/D
- Operation of network hub
- Monitoring of availability, timeliness and quality (through NWP)
- Integration of new systems (installed by member countries)
- Provide technical expertise to members through Technical Advisory Group
- Maintain archive of communicated data and metadata
- Maintain data exchange standards (BUFR code tables)
- Liaise with other Programmes in EUCOS

FUTURE: - Fault monitoring and data blocking

CWINDE also manages Weather Radar Wind data in EUCOS.
EUMETNET-WINPROF

TAG team visit to Bilbao
June 10-18, 2009

Data not assimilated in UK Model – Non-Operational
Plot generated at 12:00 UTC on 28/05/2009
Investigation of quality issues:

- check / optimize software settings
- check / repair hardware
- provide hands-on training
timeseries of daily mean wind profiler OBS-MOD differences as obtained in COSMO-EU model domain:

wind profiler: 08031
E-WINPROF: Technical workshop at Payerne, June 2010

- exchange of experience
- discussion with manufacturers
- hands-on training
  system checks
  RF-measurements...
Conclusions

- RWP can provide high-quality, high-resolution wind observations

- Ongoing development efforts are likely to improve the instrument further (signal processing, improved DBS)

- System complexity requires qualified and specialised staff

- Monitoring is important to detect technical issues at an early stage

- Importance of such data will gain significance with high-resolution models (see talk of Prof. Illingworth this afternoon)