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HYDRIX® Radar in FRAMEA

− Evaluation of an X band polarimetric radar Using a quasi-co located S band radar and a raingauge network −

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1. Introduction

FRAMEA (Flood forecast by RAdar in the MEditerranean Alps) is an experiment that aims evaluating the capability of an X-band polarimetric radar exploited with ZPHI® algorithm, to anticipate the floods in the Mediterranean areas exposed to this type of hazard. The experiment is conducted in two steps: the first step is a one-year validation experiment with the X band radar sited very close to an S band operational Météo-France radar, and to an area where a dense rain gauge network is available. The second step is a one-year experiment with the radar installed 20 km North of Nice, in order to achieve a pre-operational test for forecasting the floods of the river Var that threaten the Nice Airport and the industries in the lower valley of Var.

This paper aims reporting the results of the validation experiment, first step of FRAMEA.

2. The HYDRIX® & ZPHI® technology

HYDRIX® is the X band polarimetric&Doppler radar deployed in FRAMEA by CETP-CNRS and provided by NOVIMET. Its main characteristics are the following:

Frequency	9.3 GHz
Antenna type	Offset
Antenna diameter	1.5 m
Beam aperture	1.5° (3dB one-way)
Side lobes	<30 dB
Radome	no
Hybrid technology	H&V simultaneously transmitted
Detection threshold	0 dBZ at 70 km (at 0dB SNR)
Measured parameters	Z, Z_{DR}, Φ_{DP}, ρ_{HV}, V, σ_V

Table 1: HYDRIX characteristics

ZPHI® is the real time software provided by NOVIMET to exploit the primary data generated by HYDRIX. Its functionality is:

(i)- radar echo classification (ground clutter, sea clutter, clear air, stratiform rain, convective rain, melting hydrometeors, snow, hail).

(ii)- correction for attenuation of Z and Z_{DR}.

(iii)- retrieval of parameter N_0* characteristic of the rain drop size distribution.

(iv)- radar calibration

(v)- retrieval of the rainfall rate.

Algorithm ZPHI is described in Testud et al, (1999) and is protected by a CNRS patent.

Figure 1: The HYDRIX radar in the validation experiment.

3. The Validation experiment

For the validation experiment, the radar was installed in the Massif des Maures at Laquina, a place 4 km close to the S band radar of Météo-France in Collobrières. Massif des Maures represent a complex terrain close to the Mediterranean sea, with steep hills whose altitude nevertheless does not exceed 750m.

The choice of Laquina was also guided by the fact that Cemagref maintains in the vicinity of this site an experimental catchment ("Real Collobrier") of 80 km^2 with 17 rain gauges and 5 limnigraphs.

The validation experiment lasted from February 2006 to March 2007.

3.1 The S band radar of Météo-France in Collobrières

The S band Collobrières radar has the following characteristics:

Frequency	3 GHz
Antenna type	Central feed
Antenna diameter	5.5 m,
Beam aperture	1.2° (3dB one-way)
Side lobes	<25 dB
Radome	Yes, with classical architecture
Detection threshold	0 dBZ at 70 km (at 0dB SNR)
Measured parameters	Z, V, σ_v

Table 2: S band radar characteristics.

3.2 The rain gauge network

The rain gauge network combines the regular Météo-France network, and the 17 gauges of the Cemagref "Real Collobrier" catchment. Globally, the number of available rain gauges as a function of range is the following:

Range from HYDRIX	Number of gauges
0 to 30 km	29
30 to 60 km	22
60 to 80 km	25

Table 3: Available rain gauge network

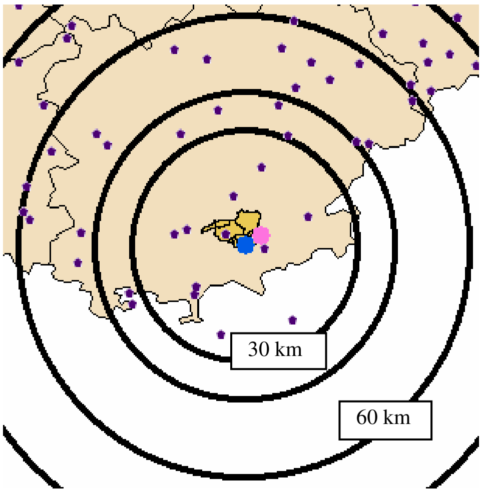

Figure 2: The available equipment in the validation experiment: HYDRIX (blue spot at the center); S-band Météo-France radar (pink spot); Cemagref experimental catchment (yellow area); regular Météo-France rain gauge network (purple dots).

3.3 Disdrometers

Two optical disdrometers were deployed at Portanière, 8km West from HYDRIX: a system built by CETP, and a THIES system of Météo-France.

4. Data set considered in this study

The longer and most intense rainy events in this coastal Mediterranean area occur during autumn, under South-Easterly regime. Four intense events have been selected in this study:

(1): September 14-15, 2006

(2): September 24-25, 2006

(3): October 18-21, 2006

(4): December 1-3, 2006

Event (2) brought an accumulated rainfall of 100 mm in one hour in the city of Toulon, producing big disorder.

Event (4) produced an accumulated rainfall up to 300 mm in 12 hours at some spot of the Argens river water shed. The lower districts of the town of Fréjus were subsequently flooded.

5. The S band radar as a tool to evaluate HYDRIX® and ZPHI®

The S-band radar may be used to evaluate HYDRIX® and ZPHI® for two purposes:

1- to check the correction for attenuation.

2- to appreciate the impact of total extinction at X band in the evaluation of accumulated rain.

5.1 Checking the correction for attenuation

At S band, the attenuation is negligible. Thus, where the Rayleigh approximation is valid, the difference Z_{attX}-Z_S measures the path integrated attenuation (PIA) at X band (Here Z_S and Z_{attX} denote the observed reflectivities at S band and X band, respectively. Subscript "att" at X band reminds that the observed Z is attenuated). If the correction for attenuation by ZPHI® were perfect, then Z_{corrX} -Z_S (Z_{corrX} is the corrected reflectivity at X band) should be zero. Fig. 3 shows the effectiveness of the correction process by ZPHI®. The results are stratified by Φ_{DP} (known to be a good indicator of the PIA), and by range of Z_S (25 to 40 dBZ, 40 to 55 dBZ). It can be seen than while Z_{attX}-Z_S decreases from zero to -15 dB when Φ_{DP} goes from zero to 50 degrees, Z_{corrX} -Z_S remains flat and close to zero. The comparison has been restricted to range < 30 km in order to make sure that the data refer to rain where the assumption Z_S = Z_X is reasonably good.

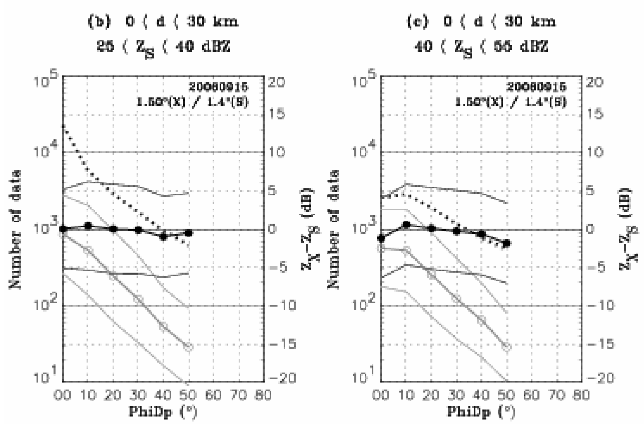

Figure 3: Mean value and standard deviation of Z_{corrX} -Z_S (dark circles) and Z_{attX}-Z_S (open circles) as a function of Φ_{DP}, for three ranges of Z_S and a distance range < 30 km.

5.2 Appreciating the importance of X band extinction

In order to appreciate the importance of X band extinction in the estimate of the accumulated rainfall, the following methodology was considered:

1- The 24 accumulated rainfall estimated from the S band radar, using a standard Z-R relationship, is used as a reference.

2- Everywhere and every time the X band radar signal is extinct, the estimate of the rain rate by the S band radar is accumulated, and the corresponding 24 hr accumulation provides an estimate of the rainfall amount missed by HYDRIX® due to extinction.

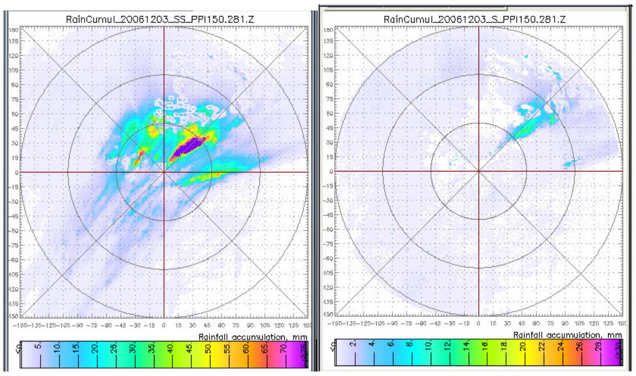

Figure 4: *Left diagram:* 24 hr accumulated rainfall estimated by the S band radar on December 3, 2006 (maximum range 150 km). *Right diagram:* Conditional 24hr accumulated rainfall estimated by the S band radar, everywhere the X band radar signal was extinct.

This analysis practiced in Fig. 4 for the most intense case of this study, shows that the bias due to X band extinction is negligible to up to 50 km range and moderate beyond.

6. Compared visibilities of HYDRIX and of the S band radar

With the complex topography of Massif des Maures, ground clutter is a serious problem. A definite advantage of HYDRIX® on the S band radar lays in its improved visibility, illustrated in Fig. 5. This improvement is due both to the performance of the offset antenna, and to the fact that at X band, the contrast between meteorological targets and the ground clutter is improved as $1/\lambda^4$ (λ: radar wavelength).

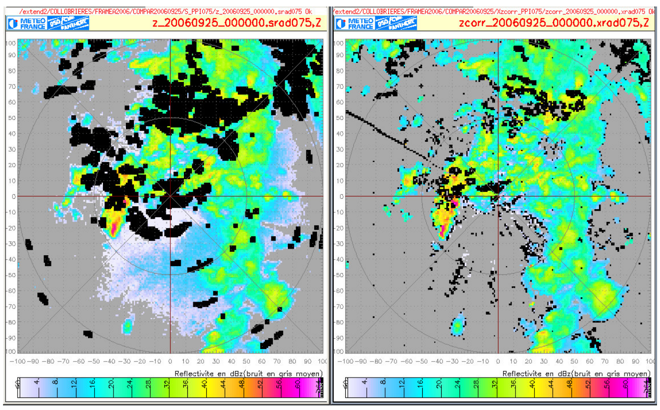

Figure 5: Two simultaneous PPI obtained at 0.75° elevation by the S band radar (left) and by HYDRIX (right) on September 25, 2006. No observation is possible in the black areas because of the ground clutter.

7. Validation of the rainfall rate estimate of the rainfall rate

7.1 Radar calibration

With HYDRIX, the calibration is obtained by comparing the histogram of N_0* derived from ZPHI® with that actually observed from the disdrometer. The right calibration is that which realizes the coincidence of the two histograms (Le Bouar et al., 2001).

The S band radar is calibrated using the standard techniques in use in the Met Offices.

7.2 Rainfall rate retrieval

With HYDRIX®, the rainfall rate estimate is obtained using a universal *Z-R* relationship (*Z:* reflectivity, *R*: rainfall rate) (Testud et al., 2000) as:

$$R = aN_0^* Z^b$$

where *Z* is the reflectivity corrected by ZPHI® and N_0* is adjusted "ray by ray" by ZPHI®.

With the Météo-France radar, *R* is calculated using a *Z-R* relationship $R = a\ Z^b$ where *a* is adjusted globally from a real time comparison with all the rain gauges in the field of the radar. The time constant for this adjustment is several hours.

7.3 Protocol for comparison with rain gauges

From both radars, a geo referenced rainfall rate estimate is produced at a common Cartesian grid with $1km^2$ resolution. In order to obtain an estimate at the rain gauge site, a 4 point interpolation is practiced.

The comparison between radar and rain gauges is made on the basis of *hourly rainfall.*

7.4 Results

Fig. 6 shows the scatter plot comparing the HYDRIX hourly rainfall against the rain gauge one (for hourly rainfalls >1mm) for all rain gauges within 30km (the orthogonal fit regression line is also shown). Fig. 7 shows the same plot for the S band radar.

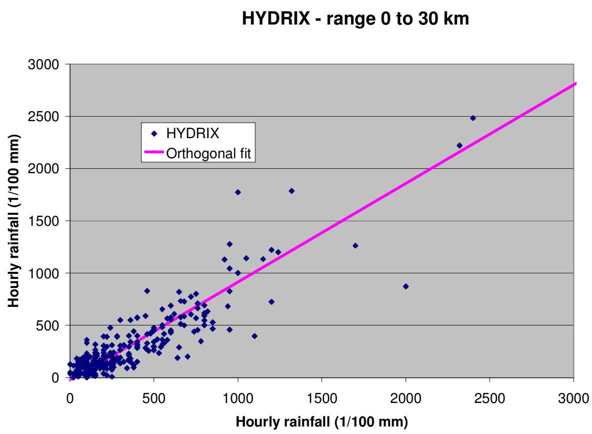

Figure 6: Scatter plot of the hourly rainfalls derived from HYDRIX® against those observed at the rain gauges within 30 km from the radar (275 data points - statistics restricted to hourly rainfalls >1mm).

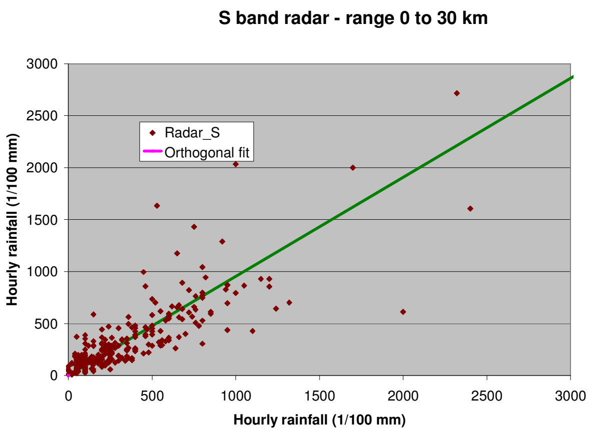

Figure 7: Scatter plot of the hourly rainfalls derived from the S band radar against those observed at the rain gauges within 30 km from the radar (275 data points - statistics restricted to hourly rainfalls >1mm).

Table 4 summarizes the statistics of the comparison by consideration of the Pearson correlation and of the Nash coefficient. It shows that for the two ranges 0 to 30 km and 30 to 60 km, the HYDRIX estimate performs significantly better than the S band radar, though this last instrument is "calibrated" by the rain gauge network.

DISTANCE RANGE	S-band radar		HYDRIX® + ZPHI®	
	Pearson	Nash	Pearson	Nash
0 to 30 km	0.82	0.65	0.89	0.77
30 to 60 km	0.85	0.71	0.87	0.75

Table 4: Pearson and Nash coefficient in the comparison of hourly rainfall derived from HYDRIX® and the S band radar using rain gauges as the reference (hourly rainfalls >1mm).

7.5 Error estimate

Assuming that the hourly rainfall is statistically distributed according to a log normal, and that the error of the gauge estimate *G*, HYDRIX® estimate *H* and S band radar estimate *S* are themselves described by a log normal, it is possible to derive the statistical error attached to each sensor. The input of this analysis is the Pearson correlation coefficient, the slope of the orthogonal fit, and the mean and variance of each data set. The results are displayed in Table 5 (for 0 to 30 km range) and 6 (for 30 to 60 km range).

At short range (<30 km), the multiplicative bias of the two radars is weak (<5%). It may not be due to a calibration error, but rather to the space averaging (over 1 km^2) inherent to the radar analysis. Meanwhile the HYDRIX® statistical error (±15%) is about twice less that that of the rain gauges and of the S band radar.

At medium range (30 to 60 km), the bias of the two radars increases. Surprisingly, the bias of the S band radar (-22%) is more important than that of HYDRIX® (-11%). The statistical error of HYDRIX® estimate increases to be similar to that of rain gauges while that of the S band is once and larger half.

Data Set	R. Gauges	HYDRIX®	S- Radar
Pearson	NA	0,89	0,82
Slope	NA	0,94	0,95
Shift (mm)	NA	-0,29	-0,01
Mean (mm)	3,48	3,00	3,31
Var. (mm^2)	12,65	11,42	11,70
Bias (%)	NA	-5,59%	-4,67%
Stat. Err. (%)	±32,73%	±14,87%	±33,94%

Table 5: Performance of HYDRIX and of the S band radar at range 0 to 30 km (275 data points - statistics restricted to hourly rainfalls >1mm).

Data Set	R. Gauges	HYDRIX®	S- Radar
Pearson	NA	0,87	0,85
Slope	NA	0,89	0,78
Shift (mm)	NA	0,00	0,29
Mean (mm)	4,35	3,86	3,70
Var. (mm^2)	29,48	24,07	19,48
Bias (%)	NA	-10,99%	-21,54%
Stat. Err. (%)	±24,91%	±28,47%	±42,95%

Table 6: Performance of HYDRIX and of the S band radar at range 30 to 60 km (702 data points - statistics restricted to hourly rainfalls >1mm).

8. Conclusion

On test during the validation experiment in FRAMEA, radar HYDRIX® exploited with software ZPHI produced high quality rainfall data. Compared to the S band radar installed on the same site and calibrated in real time by the rain gauge network, HYDRIX® reduces both the bias and the statistical error of the rainfall estimate (even achieving a statistical error twice less that the rain gauges at short range). This attests that the calibration procedure by N0* statistics, the dynamic adjustment of N0* ray by ray, and the correction for attenuation operate properly.

References

Le Bouar E., J. Testud and TD Keenan, 2001: Validation of the rain profiling algorithm "ZPHI" from the C-band polarimetric weather radar in Darwin, *Jour. Atmosph. And Ocean. Technol*., **18**, 1819–1837.

Testud J., E. Le Bouar, Obligis E., and Ali-Mehenni M. The rain profiling algorithm applied to polarimetric weather radar, *Jour. Atmosph. and Ocean. Technol.*,**17**, *332-356* (1999)

Testud J., Oury S., Black R.A., Amayenc P., Dou X. The concept of "normalized distribution to describe raindrop spectra: a tool for cloud physics and cloud remote sensing, *Jour. Atmosph. and Ocean. Technol.*,**40**, *1118-1139* (2000).