Comparison of Metrics for Clutter Data Comparison

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***Abstract*—Some radar applications require to measure a distance between different sets of clutter data. For instance, refractivity from clutter (RFC) is a technique to retrieve the atmospheric conditions from the measured clutter in the absence of target. The clutter measurements are compared to simulations to infer the refractive index along the pathway. When a distance between two clutter data is required, the L2 norm between data in dB is usually chosen. This paper investigates other metrics and claims that the L2 norm is not the most appropriate.**

***Index Terms*—refractivity from clutter, propagation, metrics, clutter.**

I. Introduction

Refractivity from clutter (RFC) [1], [2] is a technique to retrieve the low troposphere atmospheric conditions. The basic idea is to infer the propagation channel from the large-scale variations in the clutter measurements. These measurements are performed in a monostatic configuration, the radar illuminating the sea surface. Atmospheric ducts significantly modify the radar coverage. The aim of RFC is to infer the atmospheric ducts to predict the coverage of electromagnetic systems in the presence of the ducts.

To do so, inverse methods are required. In any inverse method, an objective function has to be defined. In the RFC literature, authors use the L2 norm as the objective function [3]. So, the inverse problem is to retrieve the duct described by the vector parameter $\mathbf{m}$ that minimises

$$\left\|\mathbf{P}_{\mathrm{o}}^{\mathrm{dB}} - \mathbf{P}_{\mathrm{s}}^{\mathrm{dB}}(\mathbf{m})\right\|_2^2, \tag{1}$$

where $\mathbf{P}_{\mathrm{o}}^{\mathrm{dB}}$ is the observed clutter power with respect to the range expressed in dB, and $\mathbf{P}_{\mathrm{s}}^{\mathrm{dB}}$ is the power clutter with respect to the range expressed in dB and simulated in the presence of an atmosphere described by the parameters $\mathbf{m}$. $\|\cdot\|_2$ is the L2 norm, defined for a vector $\mathbf{X}$ of length N by

$$\|\mathbf{X}\|_2 = \sqrt{\sum_{n=1}^{N} X_n^2}. \tag{2}$$

II. Proposed metrics

Recently, Douvenot et al. [4] have shown that taking values in dB in the objective functions overestimates the difference between two low power clutter data. Moreover, clutter data are functional data, and the L2 norm does not take this information into account. From this fact, two metrics are proposed in this paper, namely ϕ_{L1} and ϕ_{L2}.

The metrics ϕ_{L1} and ϕ_{L2} are derived from the L1 and L2 norm, respectively. Considering that clutter data are continuous, the covariance is introduced to define the metrics. ϕ_{L1} and ϕ_{L2} are defined as

$$\phi_{\mathrm{L1}} = \begin{cases} \dfrac{1}{n^2}\dfrac{\|\mathbf{P}_{\mathrm{o}} - \mathbf{P}_{\mathrm{s}}(\mathbf{m})\|_1^2}{\mathrm{cov}(\mathbf{P}_{\mathrm{o}}, \mathbf{P}_{\mathrm{s}})} & \text{if } \mathrm{cov}(\mathbf{P}_{\mathrm{o}}, \mathbf{P}_{\mathrm{s}}) > 0, \\ +\infty & \text{if } \mathrm{cov}(\mathbf{P}_{\mathrm{o}}, \mathbf{P}_{\mathrm{s}}) \leq 0, \end{cases} \tag{3}$$

and

$$\phi_{\mathrm{L2}} = \begin{cases} \dfrac{1}{n^2}\dfrac{\|\mathbf{P}_{\mathrm{o}} - \mathbf{P}_{\mathrm{s}}(\mathbf{m})\|_2^2}{\mathrm{cov}(\mathbf{P}_{\mathrm{o}}, \mathbf{P}_{\mathrm{s}})} & \text{if } \mathrm{cov}(\mathbf{P}_{\mathrm{o}}, \mathbf{P}_{\mathrm{s}}) > 0, \\ +\infty & \text{if } \mathrm{cov}(\mathbf{P}_{\mathrm{o}}, \mathbf{P}_{\mathrm{s}}) \leq 0. \end{cases} \tag{4}$$

where cov is the covariance function, n is the length of the vectors $\mathbf{P}_{\mathrm{o/s}}$, and $\|\cdot\|_1$ is the L1 norm, defined for a vector $\mathbf{X}$ of length N by

$$\|\mathbf{X}\|_1 = \sum_{n=1}^{N} |X_n|. \tag{5}$$

Note that ϕ_{L1} and ϕ_{L2} are dimensionless.

Compared to the usual L2 norm, the major change is the weighting by the covariance. Whereas L2 and L1 norms are point-to-point norms, the covariance gives an indication on the overall behaviour of the data [5]. This is relevant since propagation factors are handled as nonparametric functional data. This improvement dismisses some major drawbacks and improves the metrics quality in general, as shown in section III.

For the metric ϕ_{L1}, the L1 norm is chosen. Indeed, L1 norm favours the "sparsity" of $\mathbf{P}_{\mathrm{o}} - \mathbf{P}_{\mathrm{s}}(\mathbf{m})$ when the L2 norm favours a minimised mean error. Indeed, the simulated clutter data usually have minima more pronounced than the measured ones. This large local discrepancies affect less the L1 norm than the L2 norm.

Note that ϕ_{L1} and ϕ_{L2} are semimetrics because they do not satisfy the triangle inequality. However, for the sake of conciseness, we use the term metric to mention them. In inverse and optimisation methods, the triangle inequality is not necessary. Thus semimetrics are compatible with RFC requirements.

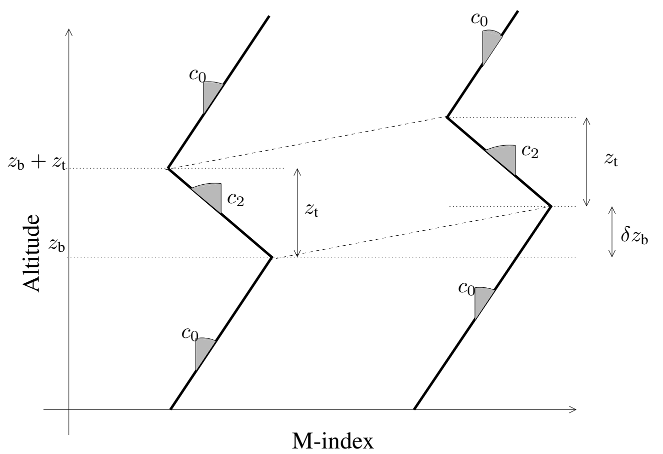


Fig. 1. The trilinear duct, (left) at the antenna, (right) at the maximum range. δz_b is the height variation of the duct.

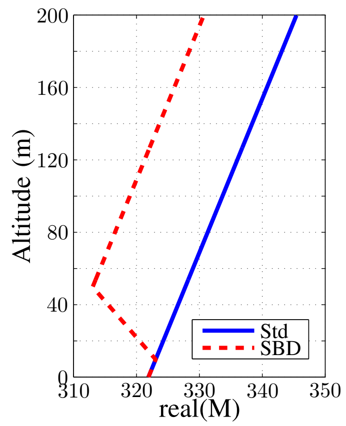


Fig. 2. The modified refractivity of the two samples corresponding to the standard atmosphere (Std) and to a surface-based duct (SBD).

III. Comparison of the metrics

Two examples are displayed to highlight the benefits of the metrics proposed in (3) and (4). This study is based on 1998 Wallops Island data [6] measured with the SPANDAR radar in the presence of surface-based ducts.

A. *Principle of the comparison*

A library of N propagation factors corresponding to N ducting conditions is generated by simulations. These simulations are performed by a parabolic equation method [7]. The ducts are considered as trilinear with a simple distance variation. They are described by the parameters z_b the duct height, c_2 the M-index slope in the inversion layer, and z_t the inversion layer thickness. Finally, δz_b is the inversion layer height variation with the distance, see figure 1. The parameters are chosen within the following limits: $0 \leq z_b \leq 150$ m, $0 \leq -c_2 \leq 1.5$ M-units.m^{-1}, $0 \leq z_t \leq 70$ m, and $-20 \leq \delta z_b \leq 20$ m. $N = 10000$ ducts are generated with a Latin hypercube sampling for the library to statistically cover all the possible ducts [8]. From these latter, N propagation factors are generated with the parabolic equation software simulating the conditions of the 1998 Wallops Island measurement campaign.

To highlight how the parameters and the clutter data are related, two samples are presented. The two ducts considered are the standard atmosphere ($z_b = 0$ m, $c_2 = 0$ M-unit.m^{-1}, $z_t = 0$ m, and $\delta z_b = 0$ m) and a surface-based duct (SBD) of parameters $z_b = 10$ m, $c_2 = 0.25$ M-unit.m^{-1}, $z_t = 40$ m, and $\delta z_b = 0$ m. They are represented with respect to altitude in figure 2. (They are invariant with the distance.)

From these two ducts, two propagation factors are obtained with respect to altitude and distance, as plotted in figure 3. The propagation factor just above the sea level (figure 4) is extracted because in it proportional to the sea clutter received power, as detailed in section III-B. RFC consists in inferring the duct conditions from the clutter return with respect to distance.

RFC is then performed on two examples from Wallops measurement data. On these examples, the measured propagation factor and the simulated propagation factors that minimise the metrics are shown. The following norms are compared: L2 squared (2), ϕ_{L2} (4), L1 squared (5), and ϕ_{L1} (3).

Note that in this study, the aim is to compare the metrics by comparing the nearest neighbour with respect to each metric: the ducts responsible for the propagation factors are not considered.

B. *The measured data*

The data were measured on the Wallops Island, Virginia, on April 1998. They were collected by Space Range Radar (SPANDAR) in coastal environment. The radar operates at 2.84 GHz in vertical polarisation. The antenna is 30.78 m high, with an horizontal beamwidth of $0.4°$. Clutter to noise ratios (CNR) were measured with respect to range and azimuth [6].

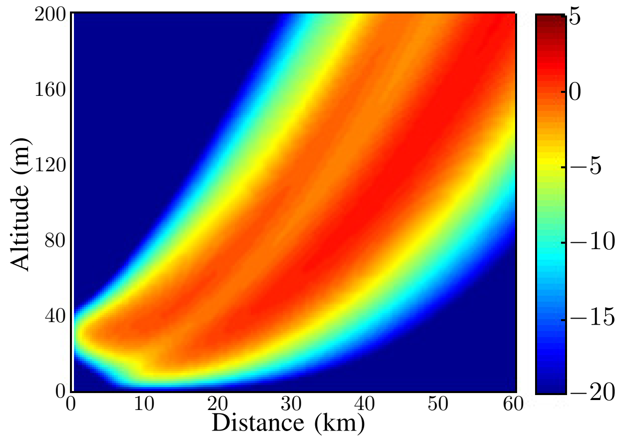
From the radar equation, the CNR measured with respect to the distance R on one azimuth is expressed as [9]

$$\mathrm{CNR} = P_e \frac{G^2 \lambda^2}{(4\pi R)^3} C_0 \sigma_r^0 F^4, \tag{6}$$

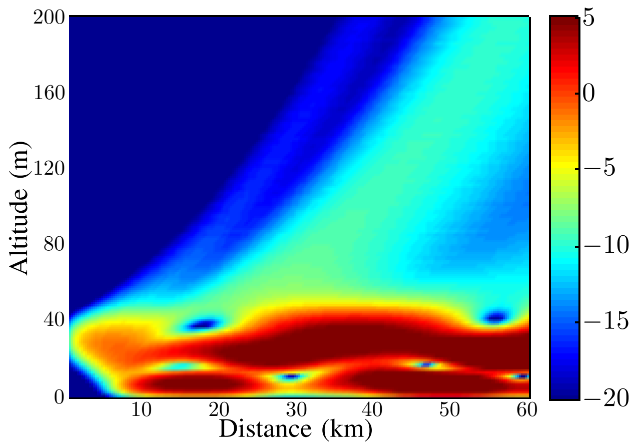
where P_e is the emitted power, G is the antenna gain, λ is the wavelength, F is the propagation factor, C_0 is a constant, and σ_r^0 is the reduced normalised radar cross section considered as constant. It is defined such that $\sigma_r^0 \theta_g^4 = \sigma^0$, σ^0 being the normalised radar cross section, and θ_g being the grazing angle. σ_r^0 is considered as constant. Note that other interpretations lead to the same distance variation of the CNR [3].

The propagation factor F^2 is deduced from the clutter return up to a constant multiplier. This constant is suppressed by normalising the signal at 10 km, obtaining a normalised propagation factor $F_n^2(R)$. What is called the measured propagation factor in the following of the text is this normalised propagation factor.

Finally, the data are smoothed on 1 km in distance and $5°$ in azimuth.



(a) Standard atmosphere



(b) Surface-based duct

Fig. 3. Propagation factors (in dB) obtained with respect to altitude and distance from the antenna for the two considered atmospheric conditions.

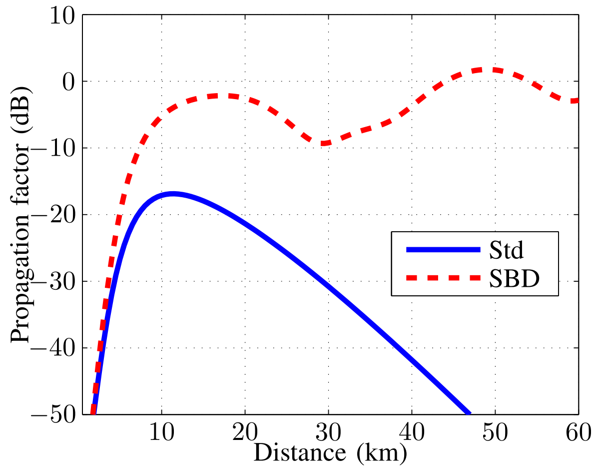


Fig. 4. Propagation factors with respect to distance just above the sea level corresponding to the standard atmosphere (Std) and to a surface-based duct (SBD).

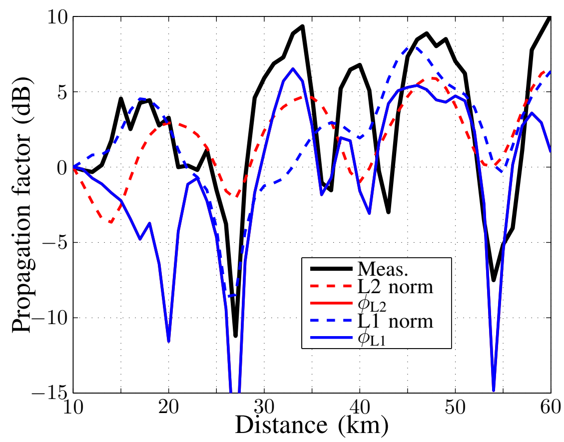


Fig. 5. First example. The simulated propagation factors from the database the nearest to the measurement (black) with respect to the L2 norm (dotted red), ϕ_{L2} (continuous red), L1 norm (dotted blue), and ϕ_{L1} (continuous blue). The continuous blue and red curves coincide.

C. Results

The results presented in this section are not typical of all the data from 1998 Wallops Island campaign. Sometimes, the different metrics all lead to the same simulated propagation factor (when the library contains a simulation very similar to the measurement). The presented examples are chosen to highlight the behaviours specific to the different metrics.

A first result is presented in figure 5. It corresponds to a measurement carried out on April 2, 1998, at 17h20'47", on the azimuth 170°. The propagation factors are plotted with respect to the distance R. The measured one is in black. In dotted red, continuous red, dotted blue, and continuous blue are the propagation factors from the library the closest to the measured one with respect to the L2 norm, ϕ_{L2}, the L1 norm, and ϕ_{L1}, respectively.

The L2 norm propagation factor tends to follow all the maxima and minima of the measured propagation factor. However, none of the data in the library being close to the measurement, the proposed best one is an unsatisfying compromise that misses a maximum at 40 km, and underestimates all the extreme values.

The L1 norm propagation factor follows the measurements on the first 30 km to the detriment of the rest of the fitting. Indeed, it favours sparseness (the objective function is almost equal to zero on these first 30 km).

When the covariance weighting is added to the L1 and L2 norms, the result is close to the measurement (the continuous blue and red curves coincide). The overall shape of the measured propagation factor is correctly described by the chosen simulation. The correlation emphasises the propagation factors that present the same minima/maxima than the measurement. Note that in this case, the metrics ϕ_{L1} and ϕ_{L2} give the same result.

A second result is presented in figure 6. It corresponds to a measurement carried out on April 2, 1998, at 17h10'25", on the azimuth 100°. The L1 and L2 norms give poor results since their best solutions miss all the extrema of the measurement. This case emphasises on the need for a metric that takes into account the global behaviour of the data.

The metrics ϕ_{L1} and ϕ_{L2} give results of similar shapes. The peak at 45 km has less influence with the L1 norm, that is why ϕ_{L1} result seems a bit better.

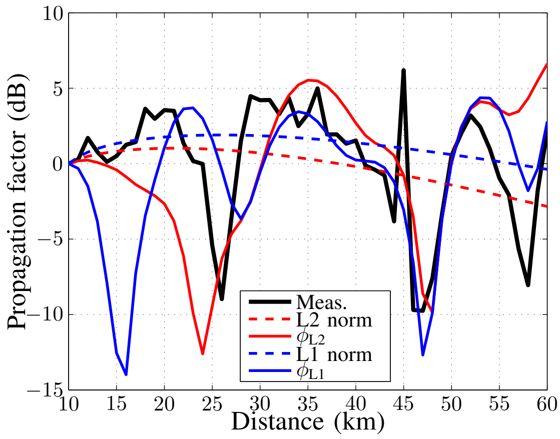


Fig. 6. Second example. The simulated propagation factors from the database the closest to the one from measurement (black) with respect to the L2 norm (dotted red), ϕ_{L2} (continuous red), L1 norm (dotted blue), and ϕ_{L1} (continuous blue).

From the presented results and the global observed behaviours, ϕ_{L1} and ϕ_{L2} metrics are much more appropriate than L1 and L2 norms for quantifying the similarity between two propagation factors obtained from clutter data. However, the debate between the choice of ϕ_{L1} or ϕ_{L2} should stay open without further studies.

IV. Conclusion

In this paper, new metrics including the covariance have been introduced. They are used to measure the distance between two propagation factors. On the presented results, the proposed metrics are more efficient than the usual L2 norm. However, further studies should be necessary to take a decision. Moreover, the signal after the radioelectric horizon (here around 26.4 km) is more important for this application since the effect of atmospheric ducts is prominent. It could be taken into account by modifying the proposed metrics as in [10].

This point is important for the RFC application because this latter requires inverse or optimisation algorithms that necessitate an objective function. The accuracy and the convergence speed of these algorithms depend on the objective function. Thus this latter should be carefully chosen. Note that the proposed functions are semimetrics that are compatible with the needs of inverse or optimisation algorithms.

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