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Evaluation of RSD-DRFs technique using deterioration experimental data

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Introduction

A synchronous tool for estimating the effects of air pollution and climate change on the materials are the Dose Response Functions (DRFs). These functions express the relationship between the corrosion or deterioration rate of a material and the levels or loads of pollutants in combination with climatic parameters. DRFs use as input ground based data.

Example

Carbon Steel

$$ML = 51 + 1.39*[SO_2]^{0.6}*Rh_{60}e^{f(T)} + 0.593*PM_{10} + 1.29*Rain*[H^+]$$

$$f(T)=\begin{cases} 0.15(T-10), & T<10°C \\ -0.054(T-10), & T \geq 10°C \end{cases}$$

Air pollutants

Climatic parameters

In this study, the following DRFs have been used (Kucera et al., 2005)

Carbon Steel

$ML = 51 + 1.39*[SO_2]^{0.6}*Rh_{60}e^{f(T)} + 0.593*PM_{10}$ (Eq. 1)

$$f(T)=\begin{cases} 0.15(T-10), & T<10°C \\ -0.054(T-10), & T \geq 10°C \end{cases}$$

Zinc

$ML = 3.5 + 0.471*[SO_2]^{0.22}*e^{0.018Rh+f(T)} + 1.37*[HNO_3]$ (Eq. 2)

$$f(T)=\begin{cases} 0.062(T-10), & T<10°C \\ -0.021(T-10), & T \geq 10°C \end{cases}$$

Limestone

$R = 4 + 0.0059*[SO_2]*Rh_{60} + 0.078*[HNO_3]*Rh_{60} + 0.0258*PM_{10}$ (Eq. 3)

Modern glass

$H = (0.2215*[SO_2] + 0.1367*[NO_2] + 0.1092*PM_{10}) / (1 + (382/t)^{1.86})$ (Eq. 4)

$[HNO_3] = 516*e^{-3400/(T+273)} *([NO_2]*[O_3]*Rh)^{0.5}$ (Eq. 5)

$[O_3]$ = annual average concentration, in μg m^{-3}

ML = mass loss after one year exposure, in g/m^2

R = surface recession after one year exposure, in μm

Rh = Relative humidity, in %

Rh_{60} = Rh – 60 when Rh > 60%, 0 otherwise- annual average

T = annual average temperature, in °C

H = Haze (%)

t = Time, in days

$[SO_2]$ = annual average concentration, in μg m^{-3}

$[NO_2]$ = annual average concentration, in μg m^{-3}

$[HNO_3]$ = annual average concentration, in μg m^{-3}

PM_{10} = annual average concentration, in μg m^{-3}

Remarks

- From Eq. 1, 2 and 3 the terms containing total rain amount and rain pH have been ignored because they are responsible for only the 0.04% of the Carbon Steel and the 0.01% of the Zinc ML as well as the 0.02% of the Limestone R.

- The available HNO_3 satellite data are not suitable for our study because:

i) They do not include observations near surface

ii) They exhibit large systematic uncertainties at low altitudes.

For these reasons, the annual mean HNO_3 concentration was estimated by the Eq. 5 (Kucera et al., 2005).

In DRAGON 3 2016 Symposium Christodoulakis et al. (2016) presented a methodology for processing satellite observations in order they can be used in the already developed DRFs instead of ground based data. In the following, it is summarized the processing procedure for each parameter.

Temperature : Air temperature at surface (Daytime / Ascending) obtained directly by satellite data of AIRS (AIRX3STD v006). No further processing.

Relative humidity : Relative Humidity at Surface (Daytime / Ascending) obtained directly by satellite data of AIRS (AIRX3STD v006). No further processing.

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SO_2 concentration:

i) OMI SO2 Column Amount (Planetary Boundary Layer) OMSO2e v003 data were collected (daily values expressed in DU).

ii) Annual mean value was calculated and converted to µg m^{-2}.

iii) Previous value was divided by the annual mean height of Planetary Boundary Layer, as calculated by Mera model, MATMFXCHM v5.2.0, over each specific location in order to obtain the annual mean concentration in µg m^{-3}.

NO_2 concentration:

i) OMI NO2 Tropospheric Column OMNO2d v003 data were collected (daily values expressed in molec/cm^2).

ii) Annual mean value was calculated and converted to μg m^{-2}.

iii) For estimating the part of the NO_2 quantity which resides in Planetary Boundary Layer it was used the percentage value (69%) proposed in literature (Schaub et al. 2006).

iv) The last was divided by the annual mean height of Planetary Boundary Layer as calculated by Mera model, MATMFXCHM v5.2.0, over each specific location in order to obtain the annual mean concentration in μg m^{-3}.

O_3 concentration:

i) OMI O3 Total Column OMTO3e v003 data were collected (daily values expressed in DU).

ii) Monthly means were calculated.

iii) As tropospheric O_3 was estimated the 10% of the previous values.

iv) In order tropospheric O_3 monthly means (DU) to be converted in concentration ($\mu g\ m^{-3}$) they were divided by the monthly mean height of tropopause obtained by AIRS satellite data (AIRSX3STD v006).

v) Annual mean concentration was calculated.

PM$_{10}$ concentration:

No satellite instrument makes observations of this parameter.

In literature, are proposed some techniques for estimating PM$_{10}$ concentration using satellite Aerosol Optical Depth (AOD) observations.

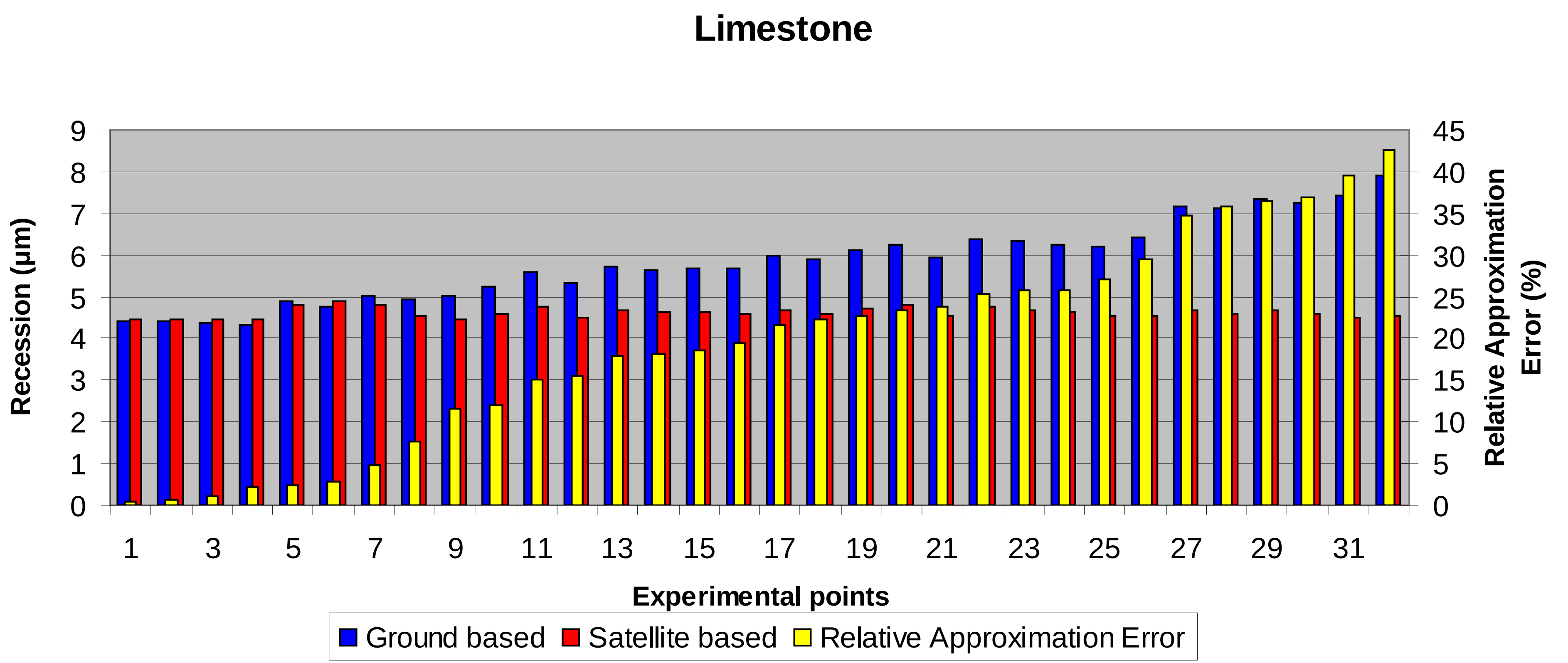
Here, PM$_{10}$ concentration was calculated using MODIS Aqua AOD 550 nm (Deep Blue , land only) observations (MYD08 D3 v6) and the mathematical function, proposed by Pere et al. (2009).

$$PM_{10} = 54 \cdot AOD + 13$$

For this technique, which is based on remotely sensed data, we propose the term Remotely Sensed Data – Dose Response Functions or RSD-DRFs technique.

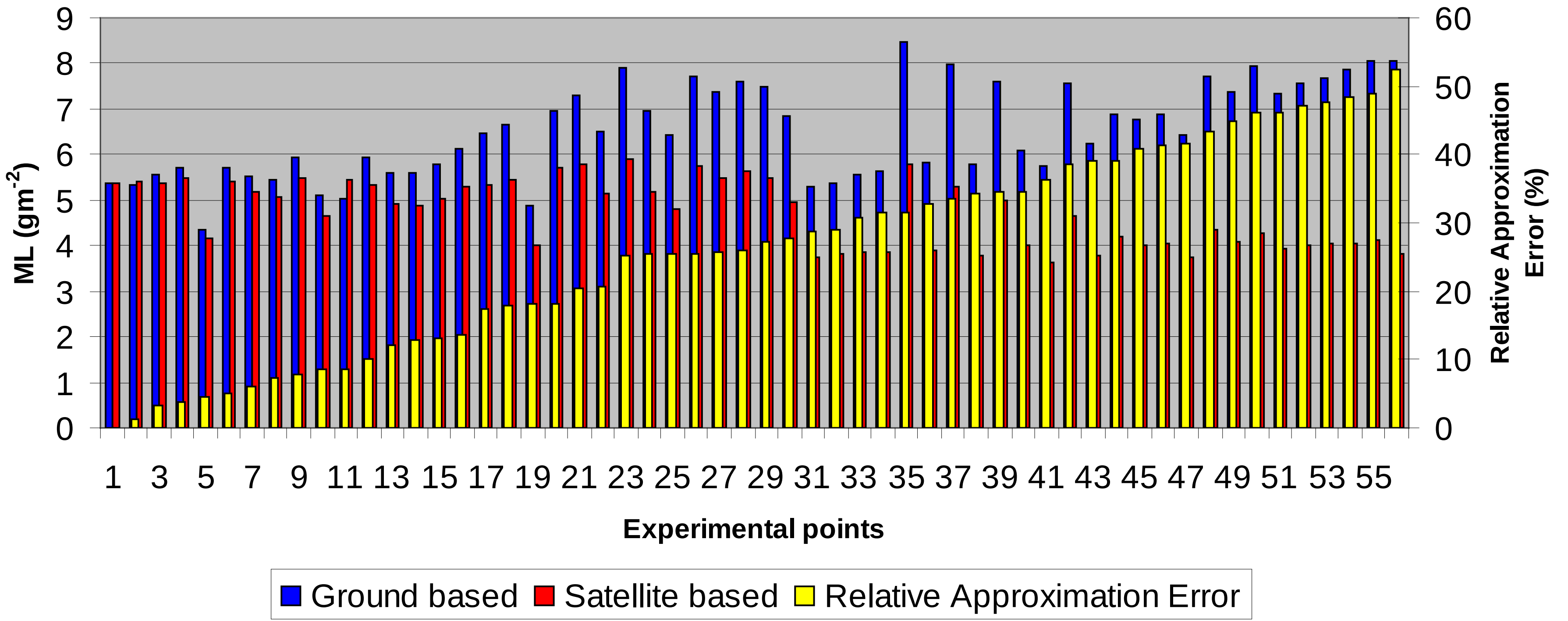
The main advantage of RSD-DRFs is that it expands the applicability of DRFs in cases/areas where there is no availability of ground based measurements while it also introduces a totally new application of Earth observation data.

In order to evaluate the performance of the RSD-DRFs, the corrosion estimations for limestone, zinc and carbon steel obtained by implementing this technique are compared with the estimations of “classic” DRFs using (open access) experimental ground based data obtained during different exposure periods of ICP Materials project from more than 10 European sites.



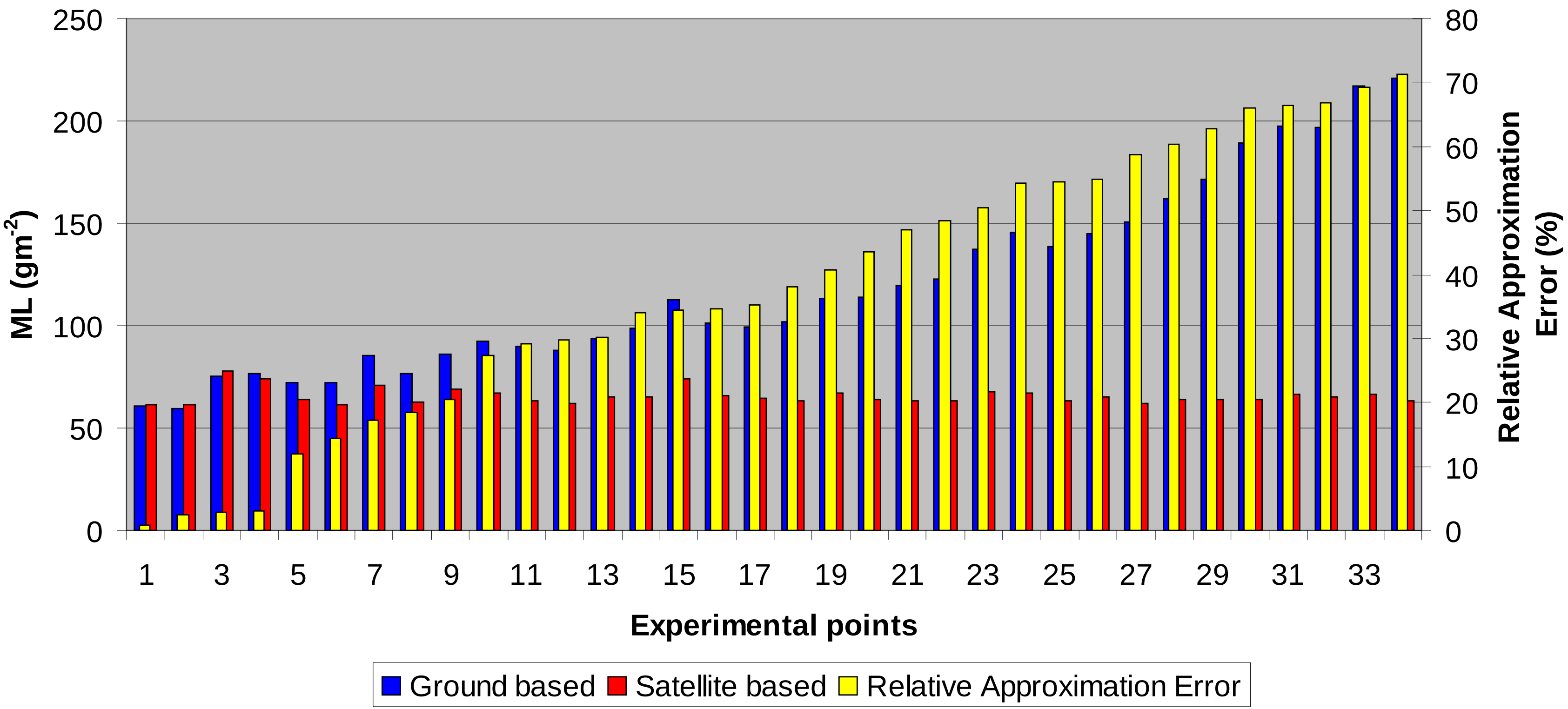
Limestone
Recession (µm)
9
8
7
6
5
4
3
2
1
0
45
40
35
30
25
20
15
10
5
0
Relative Approximation Error (%)
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
Experimental points
Ground based
Satellite based
Relative Approximation Error

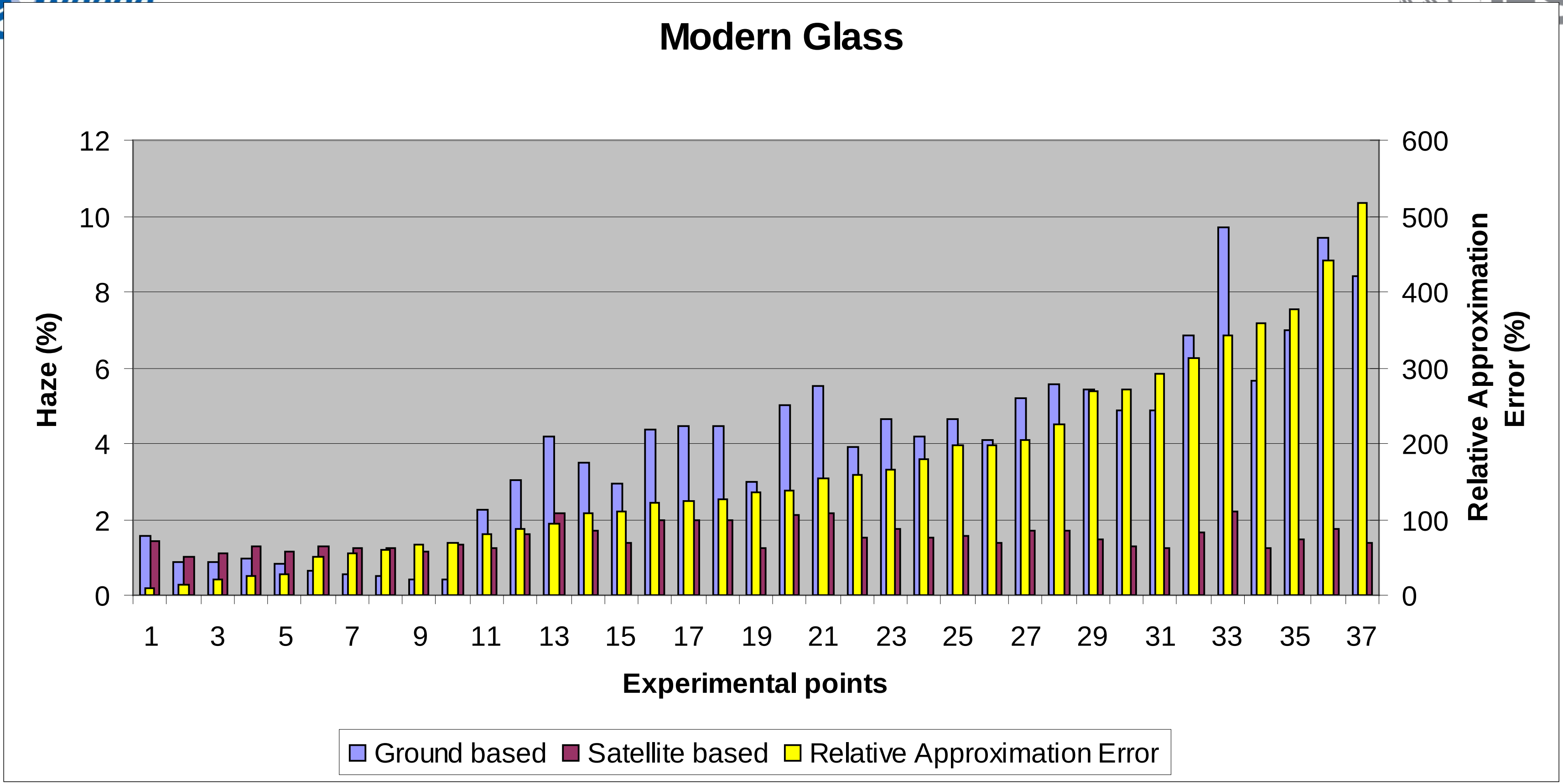
Zinc



ML (gm^{-2})
Relative Approximation Error (%)
Experimental points
9
8
7
6
5
4
3
2
1
0
60
50
40
30
20
10
0
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51 53 55
Ground based
Satellite based
Relative Approximation Error

Carbon Steel





Modern Glass
12
10
8
6
4
2
0
600
500
400
300
200
100
0
Haze (%)
Relative Approximation Error (%)
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
33
35
37
Experimental points
Ground based
Satellite based
Relative Approximation Error

Conclusions

Limestone: The Relative Approximation Error (%) among the corrosion estimations obtained using ground based and remotely sensed data for about the 80% of the studied cases is less than 30%, denoting a good applicability of the RSD-DRFs technique for this material. Further improvement in PM_{10} estimation procedure is expected to increase the applicability as this is the mandatory parameter for the particular material (Christodoulakis et al., 2017).

Zinc: The Relative Approximation Error (%) among the corrosion estimations obtained using ground based and remotely sensed data for about the 60% of the studied cases is less than 30%, denoting a relatively good applicability of the RSD-DRFs technique for this material. Further improvement in SO_2 estimation procedure is expected to increase the applicability as this is the mandatory parameter for the particular material (Christodoulakis et al., 2017).

Carbon Steel: The Relative Approximation Error (%) among the corrosion estimations obtained using ground based and remotely sensed data for about the 40% of the studied cases is less than 30%, denoting a limited applicability of the RSD-DRFs technique for this material. Further improvements in SO_2 and PM_{10} estimation procedures is expected to increase the applicability as these are the mandatory parameters for the particular material (Christodoulakis et al., 2017).

Modern glass: The most problematic material. Estimations obtained using RSD-DRFs technique differ by estimations obtained using ground based data, by more than 30% in the 85% of the examined cases. Further investigation of these big differences revealed that NO_2 estimation procedure mainly affect the obtained results and should be improved.

Future work

The development of totally new DRFs which will be based on remotely sensed data will be attempted. In addition, the impact of $PM_{2.5}$ on the deterioration of the materials will be studied.

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