Royal Netherlands
Meteorological Institute
Ministry of Infrastructure and the Environment

Availability and quality of Mode-S MRAR (BDS4.4) in the MUAC area : a first study

Siebren de Haan

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Chapter 1

Introduction

This report presents the results of a first study on the availability and quality of Mode-S Meteorological Routine Air Report (MRAR) data received through Maastricht Upper Area Control Centre (MUAC). MUAC is operated by EUROCONTROL on behalf of Belgium, the Netherlands, Luxembourg and Germany. The information content of Mode-S MRAR is direct observations of wind and temperature. This data is compared to the wind and temperature estimates from Mode-S Enhanced Surveillance (EHS) data, which is based upon Broadcast Dependent Surveillance (BDS) registers 5,0 and 6,0. The BDS 4,0 is not essential for the derivation of wind and temperature since it contains so-called "selected vertical intention" information (the actual altitude is obtain from other sources). Mode-S MRAR is collected by interrogation of BDS register 4,4 by the Mode-S EHS air traffic control radar. At present, only one Mode-S EHS radar (Kastrup, Copenhagen) in the MUAC data set is interrogating aircraft for this information.

The Mode-S EHS and MRAR wind and temperature observations are compared to each other and to the wind and temperature obtained from the operational numerical weather prediction (NWP) model HIRLAM run at KNMI.

Scope of this report

The intention of this report is to present a comparison of Mode-S EHS and MRAR; a certain background information is required but not described in this report. The reader is referred to the following for this information

- Mode-S EHS wind and temperature observations: de Haan (2011) and de Haan (2013)
- Mode-S MRAR Strajnar (2012) and Hrastovec and Solina (2013)

Outline

The outline of this report is as follows: first we start with the description of the observations (coverage, types of aircraft and amounts). Next collocated Mode-S MRAR and Mode-S EHS observations are compared to each other and to a numerical weather prediction model. Finally, the conclusions are presented.

Chapter 2

Mode-S Aircraft observations

The Mode-S data is collected in real-time by Maastricht Upper Area Control Centre (MUAC). MUAC makes this data available to KNMI in `ASTERIX CAT048` format. This report considers five days of data gathered routinely covering the period from 2014/03/20 to 2013/03/24.

2.1 Mode-S EHS and Mode-S MRAR

To obtain a good quality wind and temperature observation, the Mode-S information needs to be pre-processed with heading, airspeed and temperature corrections. The corrections are based on comparison of historic raw data with numerical weather prediction data. See de Haan (2013). The benefit of Mode-S MRAR is that the meteorological information itself is transmitted down and thus no processing is required. The drawback is that not all aircraft respond to the request for register BDS4,4/MRAR and that no additional information on for example roll angle is transmitted within BDS4,4. In the following, roll angle information (available in the BDS 5,0 messages) will be used to quality control the Mode-S MRAR observation. Only observations with a roll angle of maximal 2.5 degrees are used.

At present, the radar data from Kastrup is not received continuously, the cause of this is under investigation. It might be that this radar is not operational at the moment.

2.2 Observations statistics

The number of aircraft in view of the Kastrup radar responding with Mode-S MRAR and Mode-S EHS is presented in Table 2.1. All Mode-S MRAR aircraft also respond to the BDS4,0/5,0/6,0 interrogation. About 16% of the aircraft respond with Mode-S MRAR information, resulting

Table 2.1: Number of unique aircraft and wind/temperature observations derived from Mode-S EHS and recieved from Mode-S MRAR by the Mode-S ATC radar at Kastrup on a single day (2014/03/20).

	aircraft	wind observations	temperature observations
Mode-S MRAR	193	563354	641894
Mode-S EHS	1214	2155738	2004334

in slightly more than 26% of wind and 32% temperature observations compared to available Mode-S derived wind and temperature observations. Note that the number of Mode-S EHS derived temperature is smaller than the number of Mode-S EHS derived wind observations due to the fact that the wind and temperature corrections are determined independently, see de Haan (2013) for more details. The reason that 16% aircraft result 26% of wind and 32% of temperature observations can be found in the fact that Mode-S MRAR is direct information, while Mode-S EHS needs processing (and thus the latter observations are filtered). The reason for the larger amount of Mode-S MRAR temperature observations is discussed later.

An example of the coverage of Mode-S EHS and Mode-S MRAR is shown in Figure 2.1. All Mode-S MRAR aircraft are also present as Mode-S EHS observations. Clearly visible is the better coverage of Mode-S EHS compared to Mode-S MRAR since all aircraft are obliged to

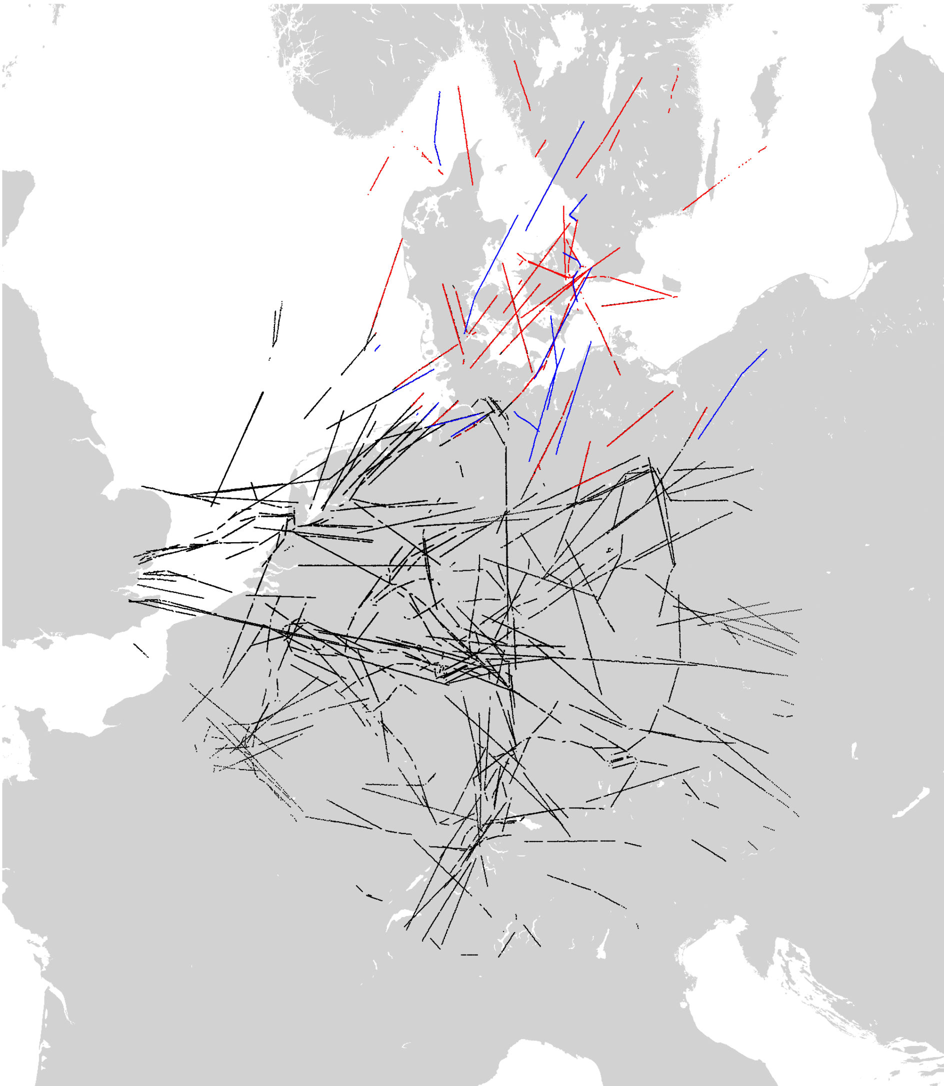

Figure 2.1: Coverage of all MUAC Mode-S EHS derived wind and temperature observations (black for all radars and red the Kastrup received Mode-S EHS data) and all Mode-S MRAR observations (blue, received by the Kastrup) between 2014/03/26 18:00 UTC and 18:15 UTC

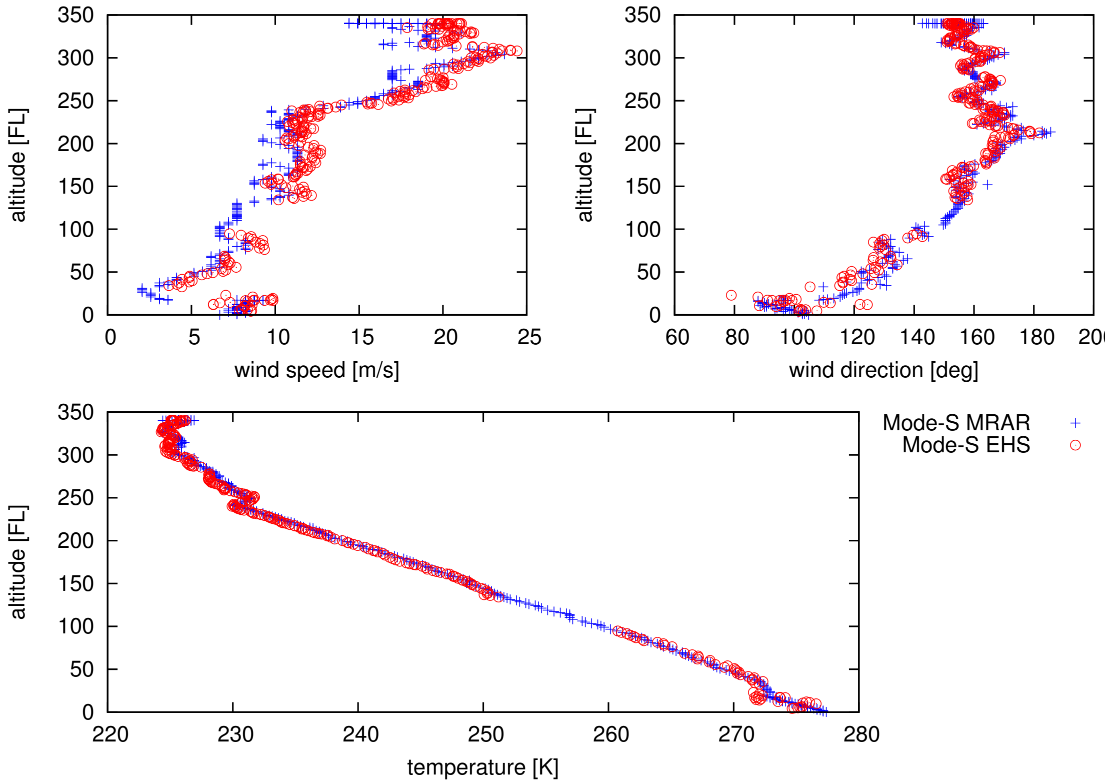

Figure 2.2: Wind speed and direction and temperature profile of an aircraft landing at Kastrup.

respond the the Mode-S EHS interrogation. An example of an aircraft landing at Kastrup is shown in Figure 2.2. The "gap" in the Mode-S EHS data is due to the preprocessing process applied, which uses batches of 15 minutes; a minimum of observation time of one minute is necessary for the processing algorithm. A more sophisticated processing of Mode-S, incorporating the previous batch, will be beneficial for the output, but requires some adjustment of the current processing set up.

The temperatures of Mode-S EHS and MRAR compare very well, apart from the boundary, where the value of the reported Mach number and airspeed influence the quality of the derived temperature from Mode-S EHS data. Clearly, there are differences between wind speed and wind direction.

2.3 Aircraft types

For the five day period, in total 193 different aircraft responded to the Mode-S BDS4,4 interrogation by the radar. Table 2.2 shows a (subset) of the aircraft types recorded. Unfortunately, the public database used to identify the aircraft type is not complete and thus for 38 aircraft no type definition could be found.

Most remarkable is that no Boeing and no Airbus aircraft respond to the BDS4,4 request with valid information in the period under consideration[1]. Canadair aircraft form the majority of Mode-S MRAR aircraft; SAS has at present a considerable fleet of these aircraft. This fact will influence the statistics of availability of Mode-S MRAR. Most MRAR aircraft report both wind and temperature, while only a few report only wind and all aircraft build by "Aerospatiale" only report temperature. This is the reason for the larger amount of temperature observations as was presented in Table 2.1. Some aircraft report sometimes only wind and/or temperature but not always both, but the majority reports both wind and temperature. Note that some aircraft have a general manufacturer name (e.g. "Bombardier inc").

[1] We have seen a few Airbus aircraft on other days

Table 2.2: Different aircraft types observed and their number of occurrences for wind and temperature parameters.

aircraft type	temperature and wind	temperature only total/unique	wind only total/unique
aerospatiale atr42-512	-	2/2	-/-
aerospatiale atr72-202	-	1/1	-/-
aerospatiale atr72-212a	-	8/8	-/-
aerospatiale atr72-212	-	1/1	-/-
beech 300 super king air 350	3	1/-	-/-
beech 400a beechjet	1	-/-	-/-
beech 400 beechjet	1	-/-	-/-
beech b200 super king air	2	-/-	-/-
beech c90gt king air	1	-/-	-/-
bombardier bd100 challenger 300	5	1/-	-/-
bombardier challenger 850	1	-/-	-/-
bombardier inc	7	1/-	1/-
bombardier regional jet 200er	1	-/-	-/-
canadair cl604 challenger	7	2/-	-/-
canadair cl605 challenger	6	-/-	-/-
canadair crj100er regional jet	1	-/-	-/-
canadair crj200er regional jet	2	-/-	-/-
canadair crj200lr regional jet	4	-/-	-/-
canadair crj200 regional jet	1	-/-	-/-
canadair crj701er regional jet	10	-/-	-/-
canadair crj900er regional jet	2	-/-	-/-
canadair crj900ng regional jet	16	-/-	-/-
canadair crj900 regional jet	21	-/-	-/-
cessna 525a citationjet cj2+	3	-/-	-/-
cessna 525b citationjet cj3	3	-/-	-/-
cessna 525 citationjet cj1+	3	-/-	-/-
cessna 560xls citation excel	7	-/-	2/-
cessna aircraft company	1	-/-	1/-
dassault falcon 2000	3	-/-	-/-
dassault falcon 900ex	2	-/-	-/-
gulfstream iv	1	-/-	-/-
hawker 750	3	1/-	-/-
hawker 800xp	5	-/-	-/-
hawker 800xpi	2	-/-	-/-
hawker 900xp	2	-/-	-/-
iai 1125 astra spx	1	-/-	-/-
learjet 60	6	-/-	-/-
raytheon aircraft company	1	-/-	-/-
saab 2000	8	-/-	-/-
Aircraft with type information	143	18/12	4/0
Aircraft without type information	37	1/1	0/0
Total unique aircraft	180	13	0

Chapter 3

Comparison results

Figure 3.1 shows the scatter plot of Mode-S MRAR versus Mode-S EHS for wind speed, wind direction and temperature for all data points exactly collocated in position and time. Also shown are the bias and standard deviations of the differences between Mode-S MRAR and Mode-S EHS. All biases and standard deviations are small with respect to the measurement uncertainty.

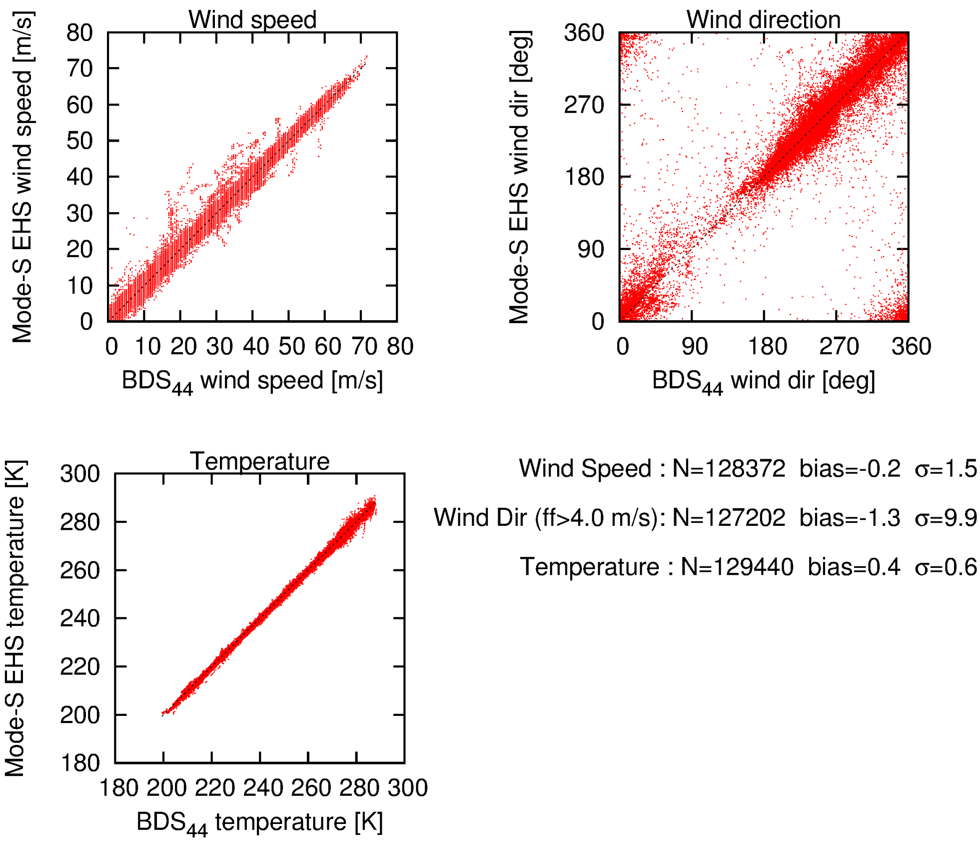

Figure 3.1: Scatter plot of wind speed, wind direction and temperature from BDS4,4 versus derived from Mode-S EHS.

Table 3.1: Statistics of comparison with HIRLAM D11.

		BDS4,4 versus D11		Mode-S EHS versus D11	
	number	bias	std.dev.	bias	std.dev.
wind speed	128356	0.11 m/s	2.50 m/s	0.29 m/s	2.63 m/s
wind direction	127186	0.15 deg	12.69 deg	1.35 deg	14.32 deg
temperature	129424	0.34 K	0.82 K	-0.03 K	0.99 K

Table 3.1 shows the results of the Mode-S MRAR and Mode-S EHS collocation with the operational numerical weather prediction model HIRLAM. Note, none of the observations is used in the assimilation of HIRLAM. For all bias and standard deviations, except temperature bias, Mode-S MRAR is closer to the model indicating the good quality of Mode-S MRAR. The very small bias in temperature for Mode-S EHS is the result of the applied temperature correction.

The bias and standard deviation between D11 and Mode-S EHS and Mode-S MRAR wind and temperature with respect to height are shown in Figure 3.2.

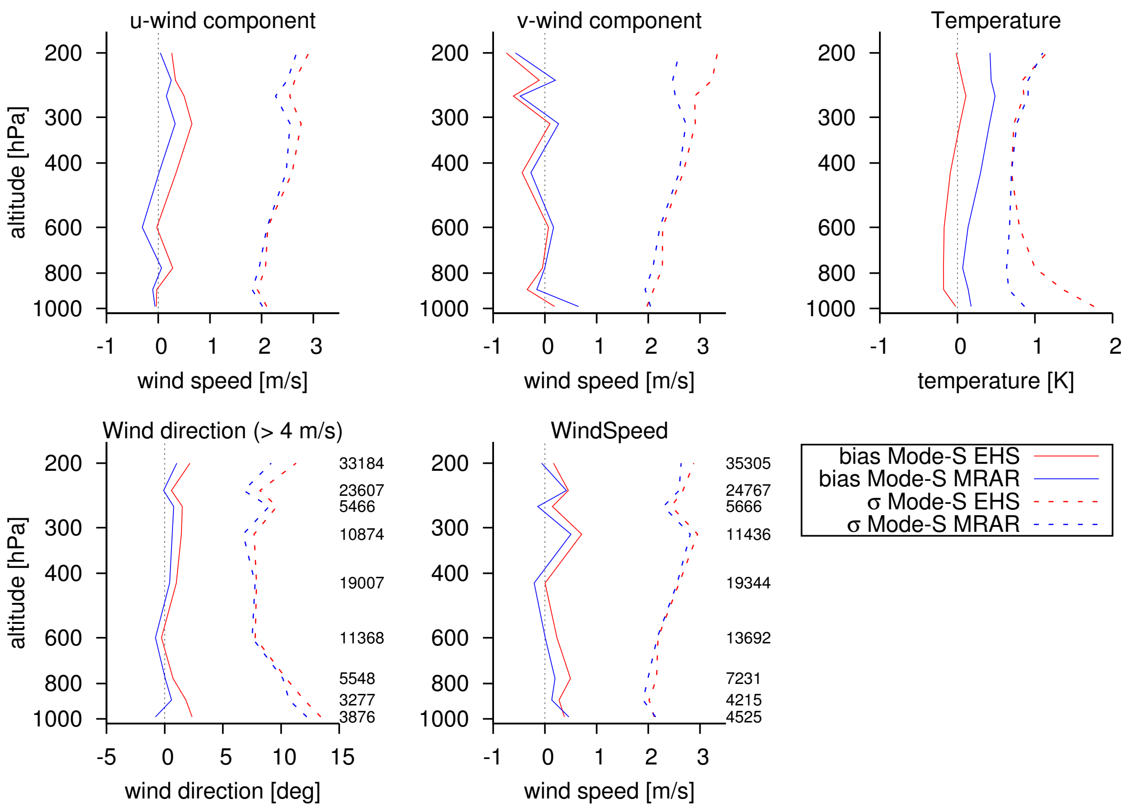

Figure 3.2: Bias (solid) and standard deviation (dashed) of the comparison of NWP and derived Mode-S EHS (red) and Mode-S MRAR (blue) for wind (u-component, v-component and speed), wind direction and temperature versus height; the numbers indicate the bin amounts.

Clearly visible is the increasing temperature standard deviation towards the surface of Mode-S EHS. This is due to the resolution of the Mach report and the fact that aircraft fly with less speed when landing. It might be interesting to distinguish between ascending and descending aircraft for Mode-S EHS. The Mode-S MRAR temperature standard deviation is below 1 K; at height above approximately 500 hPa, both standard deviations area more or less equal. The temperature bias of Mode-S EHS is close to zero, while Mode-S MRAR shows a positive bias.

The biases in wind speed for Mode-S MRAR are clearly smaller than Mode-S EHS, while the standard deviation is comparable. The same is true for wind direction, although the bias and standard deviation near the surface for Mode-S EHS is slightly larger than Mode-S MRAR.

The statistics of the u-component of the wind show a small positive bias (at most 0.5 m/s) for Mode-S EHS higher than 600 hPa while Mode-S MRAR shows a bias close to zero. Remarkable is the resemblance of both biases. The standard deviation for Mode-S EHS is slightly larger than Mode-S MRAR. For the v-component of the wind the biases are very close. The standard deviations are comparable up to 250 hPa; at higher altitudes Mode-S EHS has a larger standard deviation than Mode-S MRAR with respect to the v-component of the wind from D11.

Chapter 4

Conclusions

In this short report wind and temperature observations derived from Mode-S EHS and collected using Mode-S MRAR are compared to each other and to an operational numerical weather prediction model. The focus is on all aircraft interrogated by the Kastrup, Copenhagen air traffic control radar, for a period of five days.

From this research we conclude that:

- (Aircraft are not obliged to respond to the BDS4,4 interrogation);
- No Boeing and no Airbus aircraft respond with valuable information to the BDS4,4 request in this specific airspace and time slots;
- For this specific airspace and time slots, about 16% of the aircraft transmit valuable BDS4,4 information;
- For this specific airspace and time slots, the number of Mode-S MRAR observations is 26% (wind) and 32% (temperature) of the total and quality controlled derived Mode-S EHS volume;
- Additional information is needed (available in for example BDS5,0) for quality control of BDS4,4 information content;
- The observations of wind and temperature received from Mode-S MRAR and derived from Mode-S EHS are very close, with small biases and similar standard deviations (apart from temperature between the surface and 500 hPa);
- Compared to an operational numerical weather prediction model, the Mode-S MRAR observations are slightly better than Mode-S EHS derived observations; and,
- A temperature bias for Mode-S MRAR needs to be applied.

Acknowledgements

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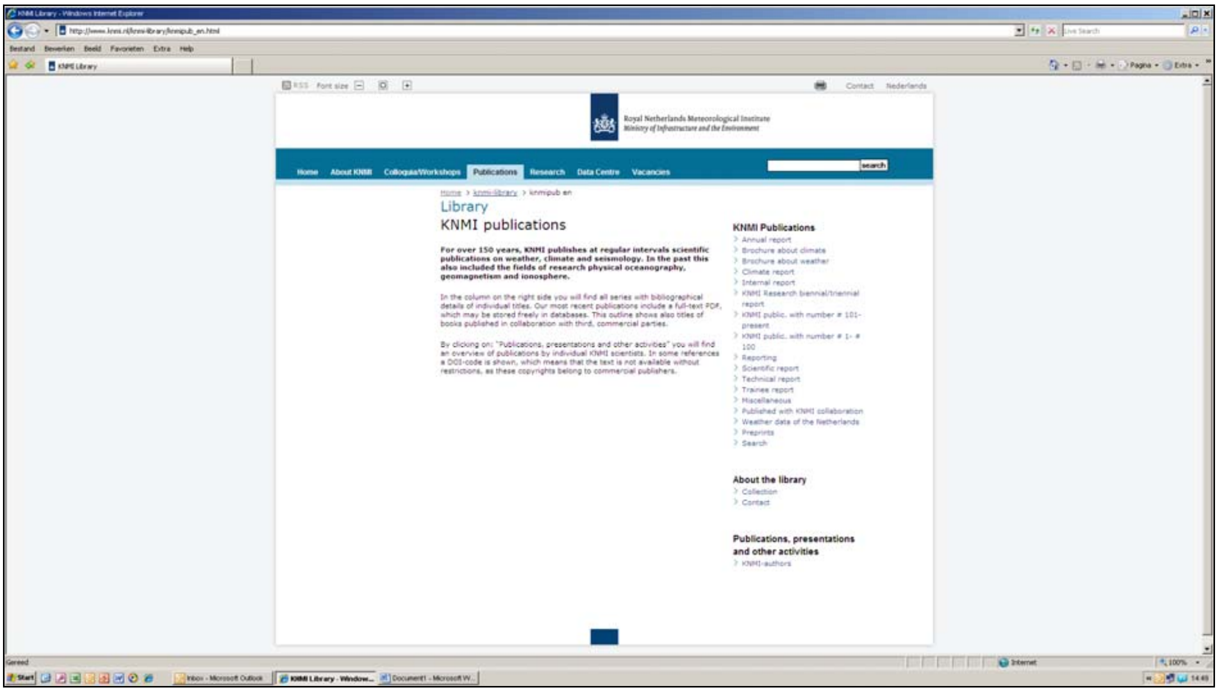

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