FIELD TEST OF FORWARD SCATTER VISIBILITY SENSORS AT GERMAN AIRPORTS

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Abstract

The German Meteorological Service (DWD) plans to replace transmissometers used for visibility measurements at all international airports in Germany. ICAO admits the use of transmissometers as well as forward scatter sensors to measure runway visual range (RVR) [1]. A field test was conducted to gain operational experience with forward scatter sensors and to enable the decision which type of visibility sensor should be acquired.

The field test was accomplished at three international airports using 11 forward scatter sensors in parallel to the operational transmissometers. It covered a time period of 9 months beginning in fall 2006. Results of this comparison are presented.

1. Introduction

'Skopograph II' transmissometers presently being used by DWD at the international airports in Germany are out of production and spare parts are unavailable. A replacement of these visibility sensors was therefore initiated. ICAO admits the use of forward scatter sensors [1] which are less expensive, easier to install and require less maintenance compared to transmissometers.

The Meteorological Optical Range (MOR) in the German observational network is mainly measured by Degreane DF20+ forward scatter sensors. Since this sensor was already available, a 'RVR task force' had the mission to conduct a field test to gain operational experience with this type of visibility sensor as an example for the forward scatter measuring principle.

The DF20+ used in the observational network had to be modified by the use of a special main board and to be supplemented by an additional ambient light sensor (LU320). The type designation of the modified sensors is 'DF20+A'. A total of 11 DF20 were used at three airports (Hamburg, Munich and Düsseldorf) where backup transmissometers at the runway thresholds were replaced by DF20+A sensors.

The DF20 transmits modulated light (f=20Hz) of a white halogen lamp (λ=350-900nm). The receiver measures the part of the light which is scattered from a volume of ~10 liters within 20° to 50° toward s the receiver head (see [3] for details). The forward scatter coefficient is then used to calculate the MOR values which are averaged over 1 minute. Special converters were used to convert the DF20 telegrams which into the Skopograph format. In this way the present DWD data acquisition system ('ASDUV') could be used without change.

Fig. 1: DF20+A with ambient light sensor (LU320).

Fig. *2: Skopograph II* transmissometers and *DF20+A* forward scatter sensor at Hamburg airport.

2. Reference-Data

The operational '*Skopograph II*' transmissometers with double baseline of 15 m and 50 m were used as a reference for the MOR measurements (see Fig. 2 and [7]). They are in operation in Germany for about 20 years. The transmissometers use the light of a Xenon flash light to determine the transmission and to calculate the MOR. The measuring range of the instruments is from 7.5 m to 2 km; averaging time is 1 min. They are cleaned about once a week (or more if necessary) and calibrated about every six weeks during regular maintenance.

A big disadvantage of the *Skopograph II* transmissometers is that transmission readings are not corrected automatically for contaminations (as with modern transmissometers). For that reason the contamination accumulated during precipitation events, especially when aircraft turbine engines blew droplets and dust particles away from the runways towards the sensors. This reduced the transmission values continuously between the regular cleaning of the optical parts of the sensors. It resulted in particular in a problem with MOR values above 1000 m; below 200 m - 300 m almost no influence was noticeable.

3. Measurements

All data used for the comparison had to be validated by an operator. The operator sorted out all time sequences were one of the sensors could not be used due to contamination, problems with the data transmission or other technical reasons.

The data was used only when homogenous meteorological conditions (homogeneous MOR values) were determined: within a time period of 10 min. ahead of the measured value the fluctuation range had to be less than ±20% from the mean value for <u>both</u> of the sensors (see also [5]).

The sensors at positions 'Echo' and 'Hotel' at Munich airport were used for the evaluation. 'Echo' was used to compare two transmissometers. It could be demonstrated that even two reference systems of one kind can differ due to natural local variability and special properties of these sensors. The distance between the different sensors was about 30 m, the distance to the runways about 150 m.

4. Results

The following pages show some exemplary results of the comparison. Each of the figures consists of four diagrams and two tables:
On the left hand you find a) the comparison between a transmissometer and b) a DF20 and two transmissometers. In the left half of the diagrams time series of the two pairs of sensors (transmissometer/transmissometer, transmisssometer/DF20) are plotted in magenta and blue.

Homogenous periods (variation of MOR <± 20% from mean value) marked by green dots. In the upper diagram present weather is marked by blue dots (ww4677 code; 40s: fog, 50s: drizzle, 60s: rain, 70s: snow); in the lower diagram (also blue dots): visibility determined by an observer (limited to 10000 m).

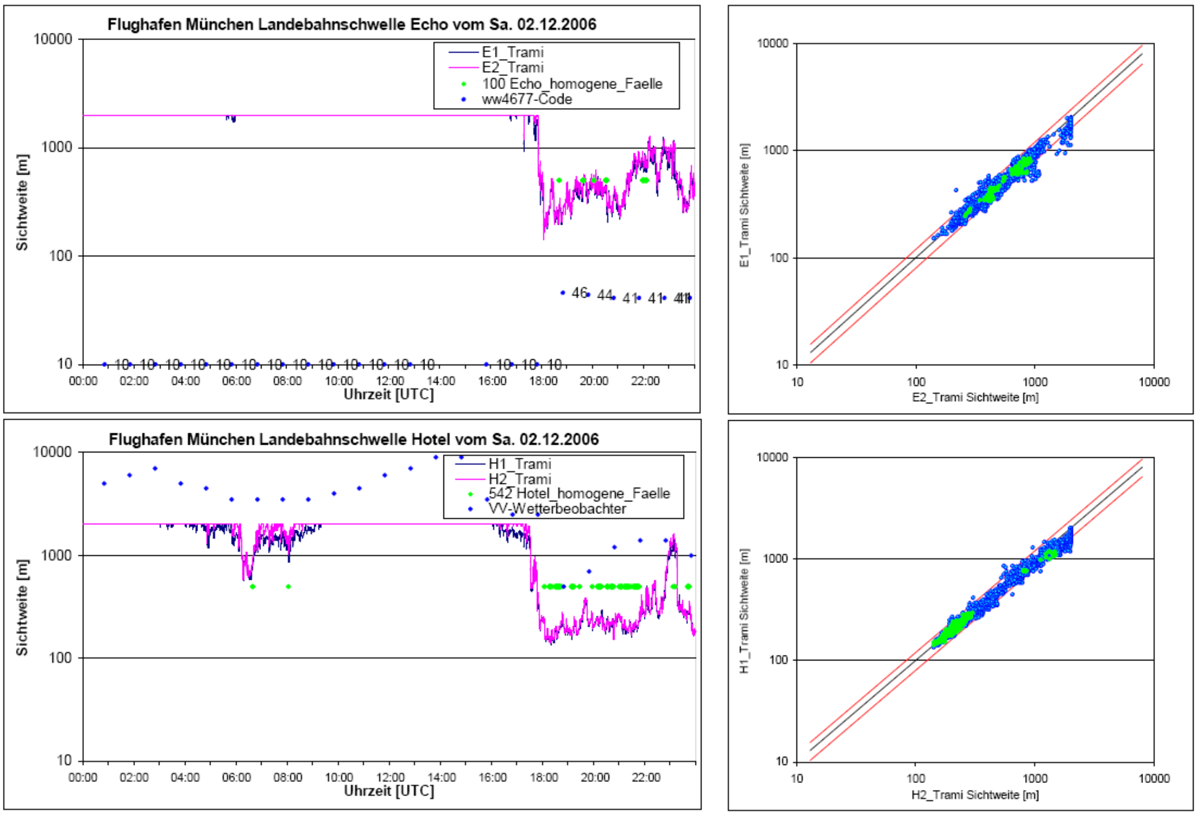
On the right hand two scatter plots are presented, where the measurements of both sensors are plotted against each other (identical values would be on the black diagonal, ±20% deviation shown as red lines). Homogenous conditions are plotted with green dots (analogue to the figure on the left side).

The tables on the bottom compare, which IFR category would have been proposed by the two sensors (only homogenous conditions were used). Shown is the number of cases of each class.

Indicated are the categories of instrument flight approaches CAT1, II, IIIa, IIIb, IIIc (according to the table below) and virtual CAT "0" (1550m < MOR < 2000, and MOR >= 2000m). 'Green' means agreement of the sensors, 'orange' disagreement of one step, and 'red' two or more steps difference.

Categories of precision approach and landing operations:					
	CAT I	**CAT II**	**CAT IIIA**	**CAT IIIB**	**CAT IIIC**
Decision Height	>60 m (200 ft)	<60 m (200 ft) >30 m (100 ft)	<30 m (100 ft)	<15 m (50 ft)	No limitations
RVR	> 550 m	> 350 m	> 200 m	< 200 m > 50 m	No limitations
RVR Range	550 - 1500	350 – 550	200 - 350	50 – 200	0 – 50
Visibility	> 800 m				

***Table 1*:** Categories of Instrument Approach Procedures according to ICAO [10].



Echo
E1 = Trami
E2 = Trami

E2 \ E1	>=2000m	CAT 0	CAT I	CAT II	CAT III A	CAT III B	CAT III C			
>=2000m										
CAT 0										
CAT I			49	2				96.078	3.922	0.000
CAT II				38	4			90.476	9.524	0.000
CAT III A					7			100.000	0.000	0.000
CAT III B										
CAT III C										

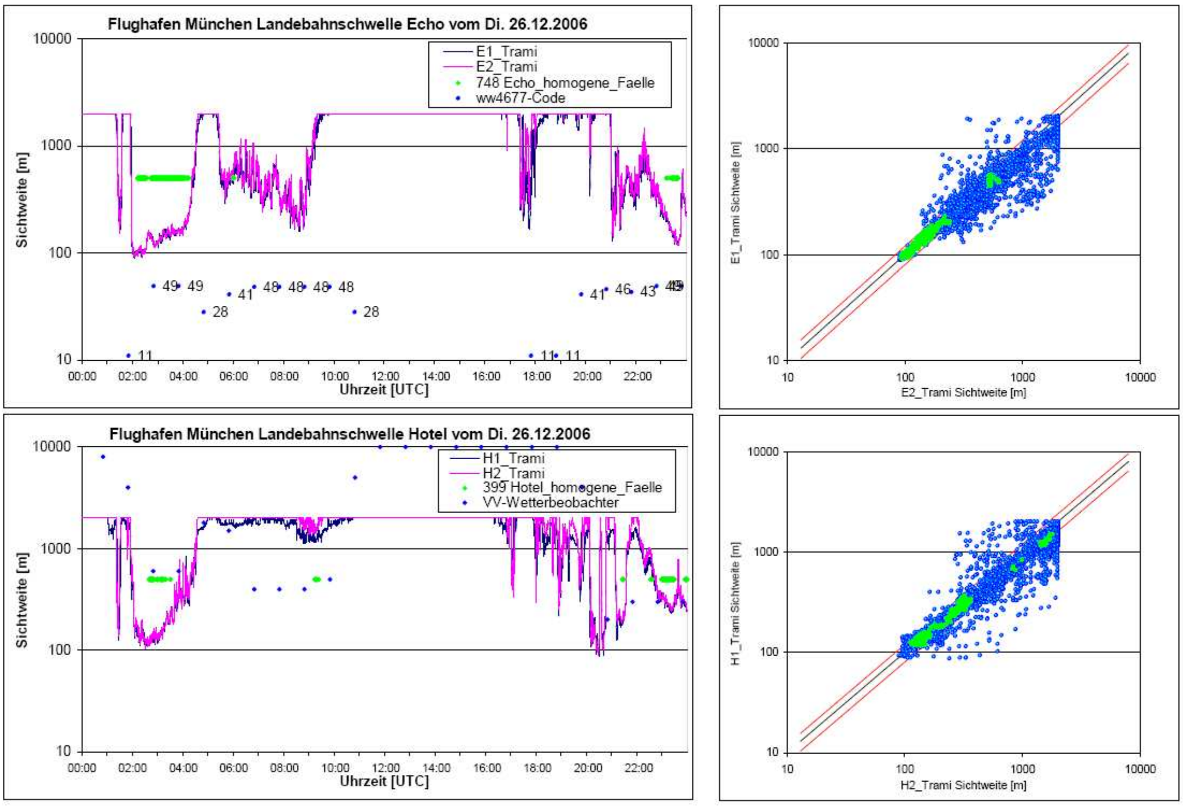
		100.000	95.000	63.636			94.000	94.000
		0.000	5.000	36.364			6.000	6.000
		0.000	0.000	0.000			0.000	0.000

Hotel
H1 = Trami
H2 = Trami

H2 \ H1	>=2000m	CAT 0	CAT I	CAT II	CAT III A	CAT III B	CAT III C			
>=2000m										
CAT 0			1					0.000	100.000	0.000
CAT I			18					100.000	0.000	0.000
CAT II										
CAT III A					273	47		85.313	14.688	0.000
CAT III B					6	197		97.044	2.956	0.000
CAT III C										

		94.737		97.849	80.738		90.037	90.037
		5.263		2.151	19.262		9.963	9.963
		0.000		0.000	0.000		0.000	0.000

Fig. 3: EDDM, Echo & Hotel, 2.12.2006
Example for good agreement of both transmissometer pairs in good maintenance condition. Homogenous events (green dots) are close to the diagonal, nearly all the rest lies within the ±20%-intervall. Observers (blue dots) estimate higher visibility values (6-9 UTC, 19-22 UTC)



	E2 \ E1	>=2000m	CAT 0	CAT I	CAT II	CAT III A	CAT III B	CAT III C			
Echo	>=2000m										
E1 = Trami	CAT 0										
E2 = Trami	CAT I				6				0.000	100.000	0.000
	CAT II			2	8				80.000	20.000	0.000
	CAT III A					13	7		65.000	35.000	0.000
	CAT III B					1	711		99.860	0.140	0.000
	CAT III C										

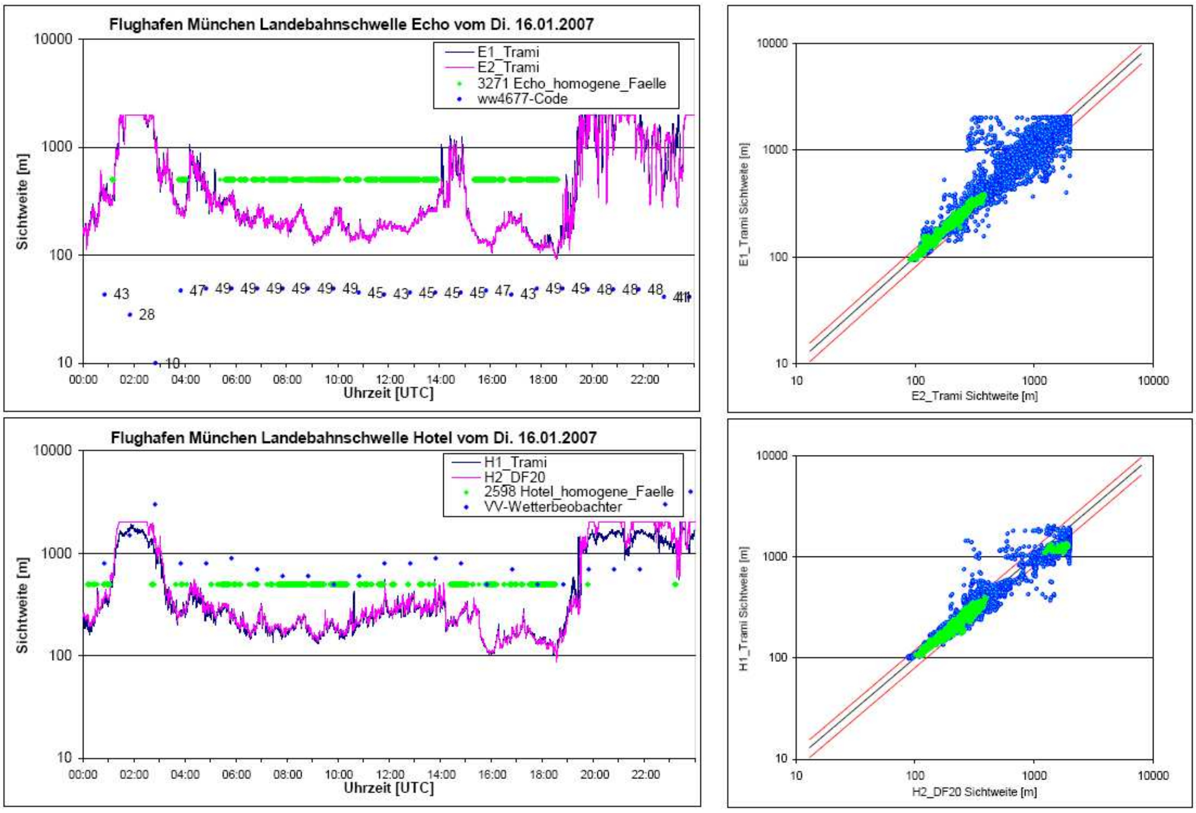
		0.000	57.143	92.857	99.025		97.861	97.861
		100.000	42.857	7.143	0.975		2.139	2.139
		0.000	0.000	0.000	0.000		0.000	0.000

	H2 \ H1	>=2000m	CAT 0	CAT I	CAT II	CAT III A	CAT III B	CAT III C			
Hotel	>=2000m										
H1 = Trami	CAT 0		2	17					10.526	89.474	0.000
H2 = Trami	CAT I			16					100.000	0.000	0.000
	CAT II					7			0.000	100.000	0.000
	CAT III A				7	201	9		92.627	7.373	0.000
	CAT III B						137		100.000	0.000	0.000
	CAT III C										

	100.000	48.485	0.000	96.635	93.836		89.899	89.899
	0.000	51.515	100.000	3.365	6.164		10.101	10.101
	0.000	0.000	0.000	0.000	0.000		0.000	0.000

Fig. 4: EDDM, Echo & Hotel, 26.12.2006

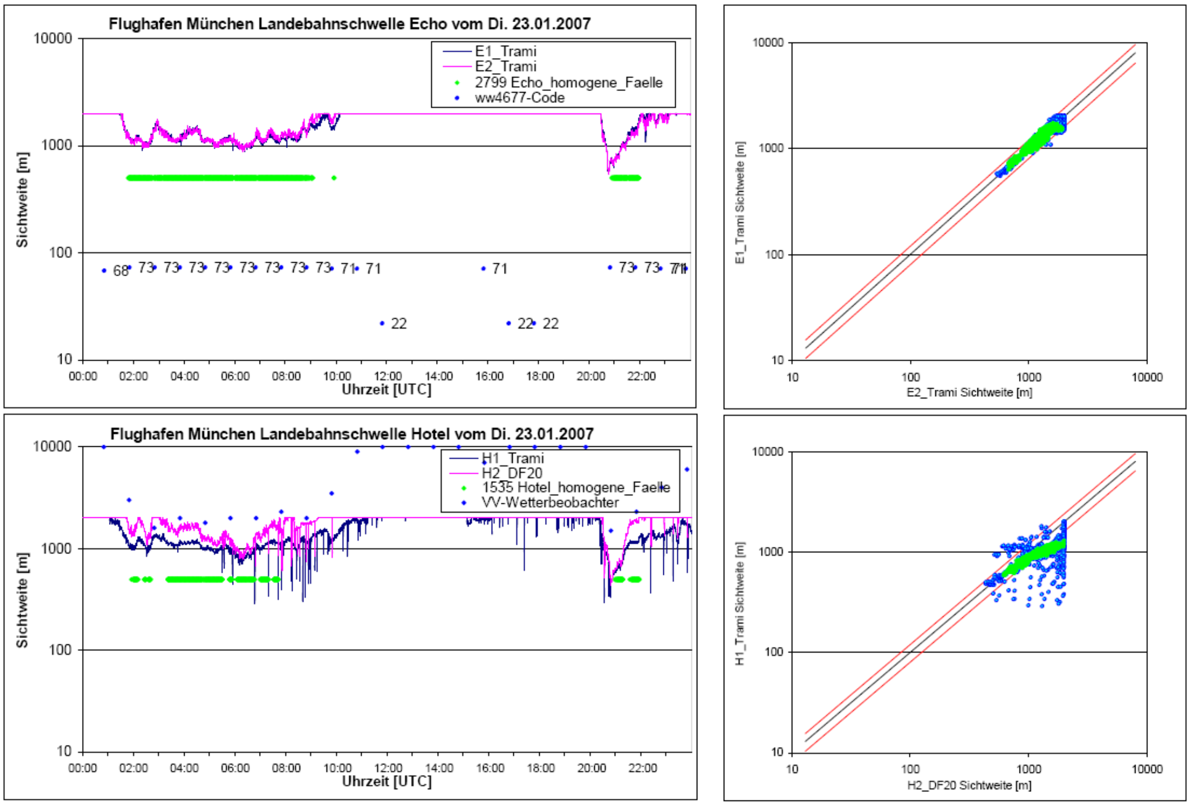
Example for large variation of both transmissometer pairs. Transmissometer H1 with some contamination results in lower MOR as H2 at values above 1000m. Homogenous events (green) are close to the diagonal. In this case, observers estimate lower visibility values as measured with transmissometers.



	E2 \ E1	>=2000m	CAT 0	CAT I	CAT II	CAT III A	CAT III B	CAT III C			
Echo	>=2000m										
E1 = Trami	CAT 0										
E2 = Trami	CAT I										
	CAT II				16	14			53.333	46.667	0.000
	CAT III A				6	1093	42		95.793	4.207	0.000
	CAT III B					100	2000		95.238	4.762	0.000
	CAT III C										
					72.727	90.555	97.943		95.047	95.047	
					27.273	9.445	2.057		4.953	4.953	
					0.000	0.000	0.000		0.000	0.000	

	H2 \ H1	>=2000m	CAT 0	CAT I	CAT II	CAT III A	CAT III B	CAT III C			
Hotel	>=2000m										
H1 = Trami	CAT 0			34					0.000	100.000	0.000
H2 = DF20	CAT I			20					100.000	0.000	0.000
	CAT II				16	30			34.783	65.217	0.000
	CAT III A				5	973	141		86.953	13.047	0.000
	CAT III B					20	1359		98.550	1.450	0.000
	CAT III C										
				37.037	76.190	95.112	90.600		91.147	91.147	
				62.963	23.810	4.888	9.400		8.853	8.853	
				0.000	0.000	0.000	0.000		0.000	0.000	

Fig. 5: EDDM, Echo & Hotel (now with DF20 in lower plot); 16.01.2006
Long duration of fog with good agreement of transmissometer H1 and DF20 H2, especially at homogenous events (green). Observers estimate considerably higher visibility values as the ones measured by the sensors.



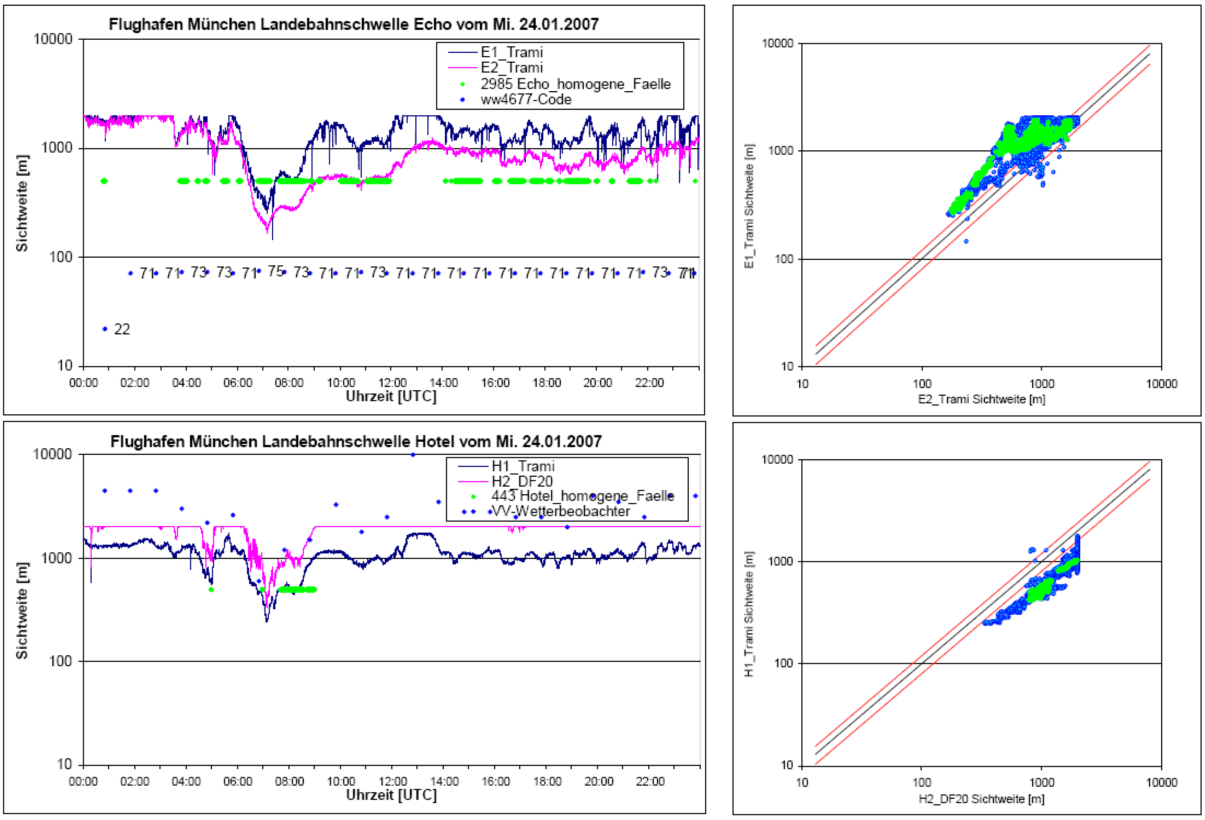
Echo
E1 = Trami
E2 = Trami

E2 \ E1	>=2000m	CAT 0	CAT I	CAT II	CAT III A	CAT III B	CAT III C				
>=2000m											
CAT 0		66	32						67.347	32.653	0.000
CAT I		30	2671						98.889	1.111	0.000
CAT II											
CAT III A											
CAT III B											
CAT III C											
		68.750	98.816						97.785	97.785	
		31.250	1.184						2.215	2.215	
		0.000	0.000						0.000	0.000	

Hotel
H1 = Trami
H2 = DF20

H2 \ H1	>=2000m	CAT 0	CAT I	CAT II	CAT III A	CAT III B	CAT III C				
>=2000m											
CAT 0			645						0.000	100.000	0.000
CAT I			890						100.000	0.000	0.000
CAT II											
CAT III A											
CAT III B											
CAT III C											
			57.980						57.980	57.980	
			42.020						42.020	42.020	
			0.000						0.000	0.000	

Fig. 6 EDDM, Echo & Hotel (DF20 in lower plot), 23.01.2006
Snow fall, starting at 2:00 UTC (ww: 71-73). Contamination of Transmissometer H1 clearly visible (typically identifiable by the bent green curve)



Echo
E1 = Trami
E2 = Trami

E2 \ E1	>=2000m	CAT 0	CAT I	CAT II	CAT III A	CAT III B	CAT III C			
>=2000m										
CAT 0		128	8					94.118	5.882	0.000
CAT I		456	1406					75.510	24.490	0.000
CAT II		43	458					0.000	91.417	8.583
CAT III A			207	193	48			10.714	43.080	46.205
CAT III B				1	37			0.000	97.368	2.632
CAT III C										

	20.415	67.629	0.000	56.471			52.998	52.998
	72.727	22.415	99.485	43.529			38.593	38.593
	6.858	9.957	0.515	0.000			8.409	8.409

Hotel
H1 = Trami
H2 = DF20

H2 \ H1	>=2000m	CAT 0	CAT I	CAT II	CAT III A	CAT III B	CAT III C			
>=2000m										
CAT 0			101					0.000	100.000	0.000
CAT I			84	258				24.561	75.439	0.000
CAT II										
CAT III A										
CAT III B										
CAT III C										

		45.405	0.000				18.962	18.962
		54.595	100.000				81.038	81.038
		0.000	0.000				0.000	0.000

Fig. 7: EDDM, Echo & Hotel; 24.01.2006

Heavy contamination of all transmissometers during snow fall resulting in strong disagreement even between the two transmissometers.

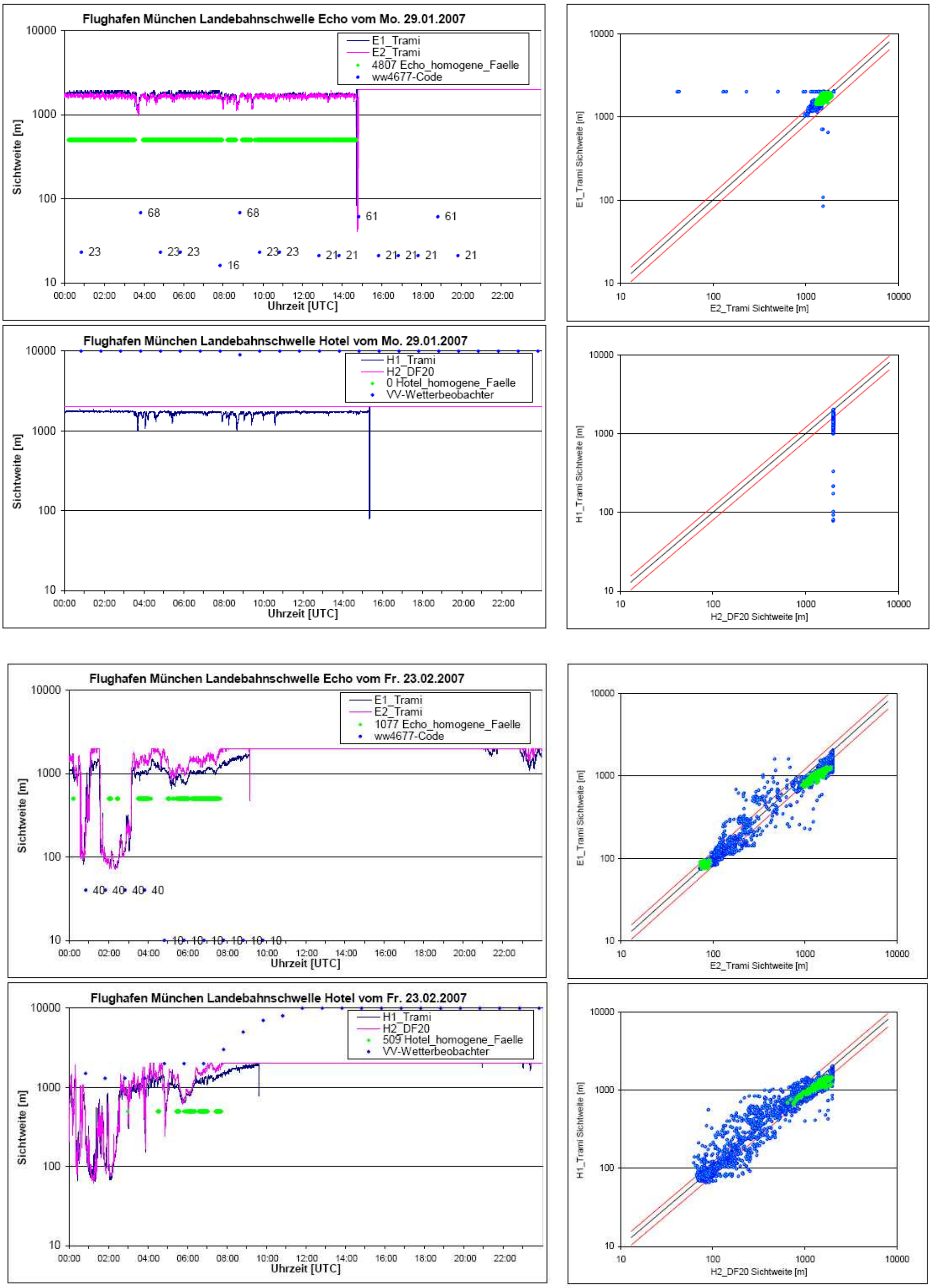
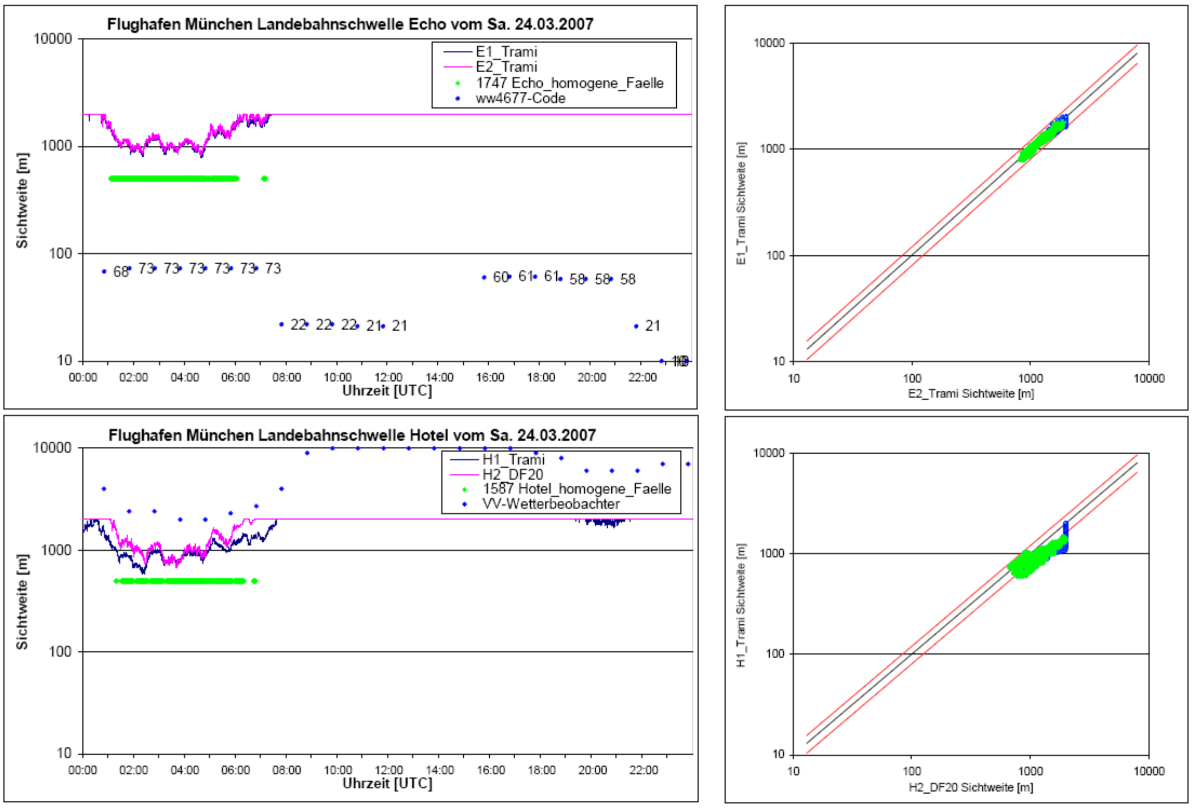


Fig. 8 EDDM, Echo & Hotel; 29.01. & 23.3.2007,
Influence of the cleaning of the transmissometers (peaks downwards).



Echo
E1 = Trami
E2 = Trami

E2 \ E1	>=2000m	CAT 0	CAT I	CAT II	CAT III A	CAT III B	CAT III C			
>=2000m										
CAT 0		81	64					55.862	44.138	0.000
CAT I		1	1601					99.938	0.062	0.000
CAT II										
CAT III A										
CAT III B										
CAT III C										

	98.780	96.156						96.279	96.279
	1.220	3.844						3.721	3.721
	0.000	0.000						0.000	0.000

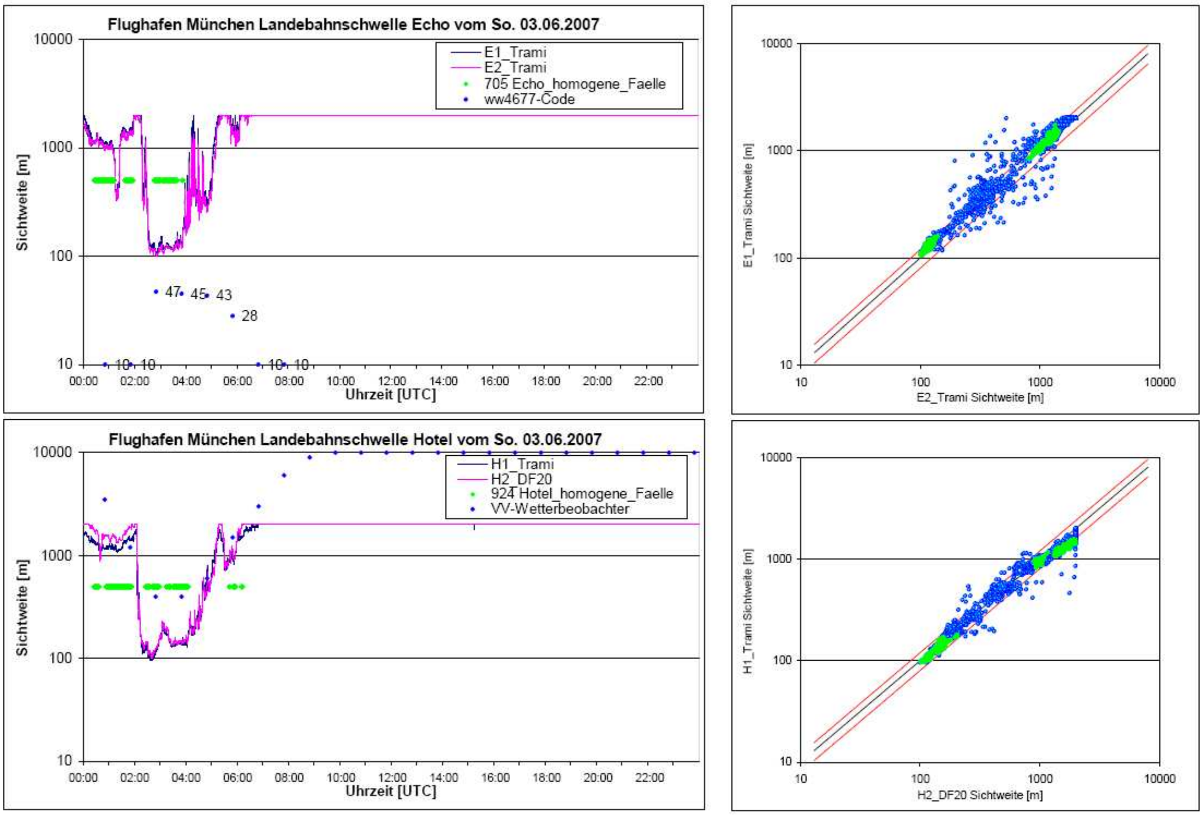
Hotel
H1 = Trami
H2 = DF20

H2 \ H1	>=2000m	CAT 0	CAT I	CAT II	CAT III A	CAT III B	CAT III C			
>=2000m										
CAT 0			213					0.000	100.000	0.000
CAT I			1374					100.000	0.000	0.000
CAT II										
CAT III A										
CAT III B										
CAT III C										

		86.578						86.578	86.578
		13.422						13.422	13.422
		0.000						0.000	0.000

Fig. 9: EDDM, Echo & Hotel, 24.3.2007

Heavy snowing from 3:00 to 7:00 UTC. Transmissometer H1 contaminated. Very good agreement of transmissometer E1 and E2. Visibilities of observers are higher then measured values (2000m and more).



Echo
E1 = Trami
E2 = Trami

E2 \ E1	>=2000m	CAT 0	CAT I	CAT II	CAT III A	CAT III B	CAT III C			
>=2000m										
CAT 0										
CAT I		26	368					93.401	6.599	0.000
CAT II										
CAT III A										
CAT III B						311		100.000	0.000	0.000
CAT III C										

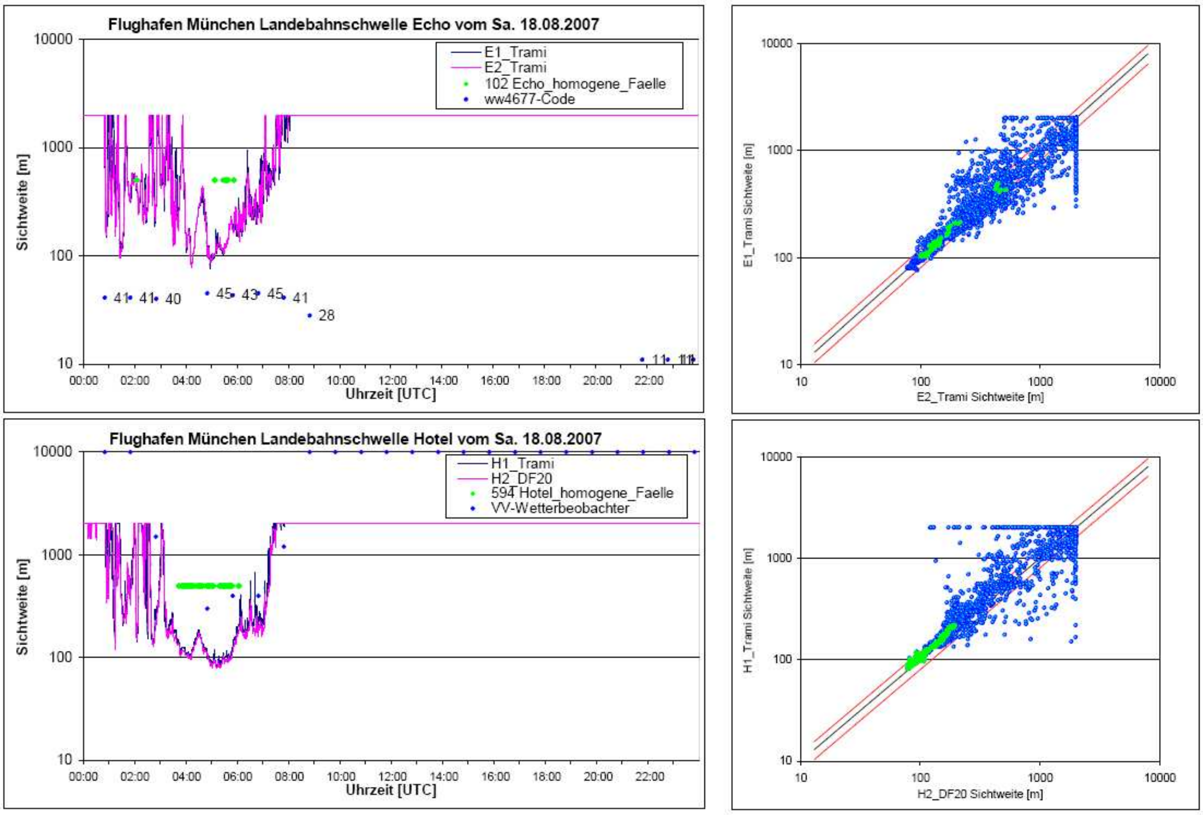
	0.000	100.000			100.000		96.312	96.312
	100.000	0.000			0.000		3.688	3.688
	0.000	0.000			0.000		0.000	0.000

Hotel
H1 = Trami
H2 = DF20

H2 \ H1	>=2000m	CAT 0	CAT I	CAT II	CAT III A	CAT III B	CAT III C			
>=2000m										
CAT 0		22	269					7.560	92.440	0.000
CAT I			199					100.000	0.000	0.000
CAT II										
CAT III A						6		0.000	100.000	0.000
CAT III B						428		100.000	0.000	0.000
CAT III C										

	100.000	42.521			98.618		70.238	70.238
	0.000	57.479			1.382		29.762	29.762
	0.000	0.000			0.000		0.000	0.000

Fig. 10: EDDM, Echo & Hotel; 3.6.2007
Very good agreement of transmissometer H1 and DF20 H2, especially in lower MOR range even with light contamination of transmissometer H1. Also very good agreement on CAT IIIB level.



Echo
E1 = Trami
E2 = Trami

E2 \ E1	>=2000m	CAT 0	CAT I	CAT II	CAT III A	CAT III B	CAT III C			
>=2000m										
CAT 0										
CAT I										
CAT II				8				100.000	0.000	0.000
CAT III A					2			100.000	0.000	0.000
CAT III B					1	91		98.913	1.087	0.000
CAT III C										

			100.000	66.667	100.000		99.020	99.020
			0.000	33.333	0.000		0.980	0.980
			0.000	0.000	0.000		0.000	0.000

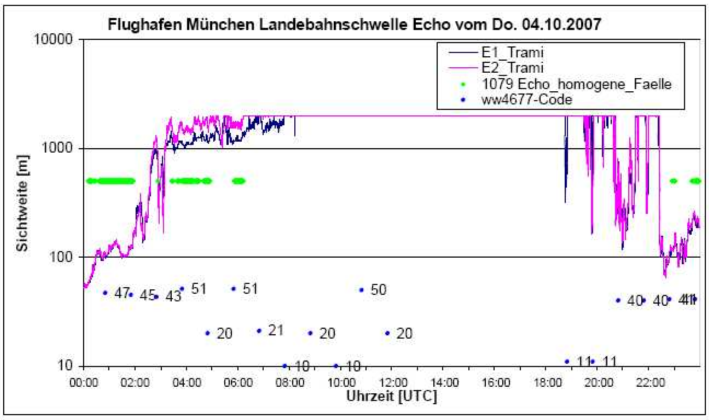
Hotel
H1 = Trami
H2 = DF20

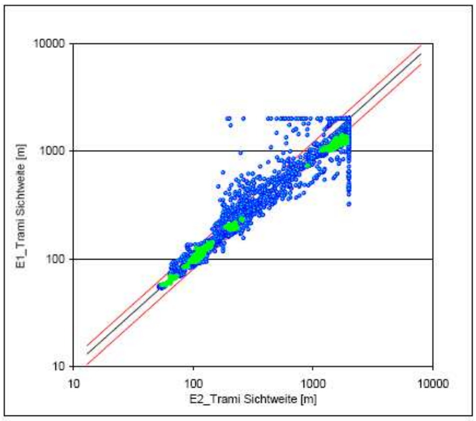
H2 \ H1	>=2000m	CAT 0	CAT I	CAT II	CAT III A	CAT III B	CAT III C			
>=2000m										
CAT 0										
CAT I										
CAT II										
CAT III A										
CAT III B					13	581		97.811	2.189	0.000
CAT III C										

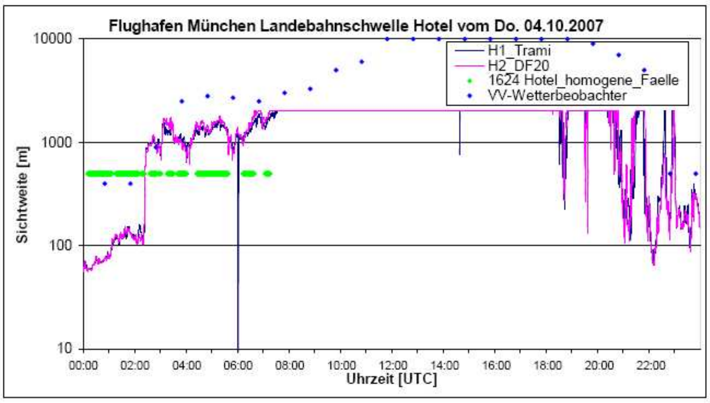
				0.000	100.000		97.811	97.811
				100.000	0.000		2.189	2.189
				0.000	0.000		0.000	0.000

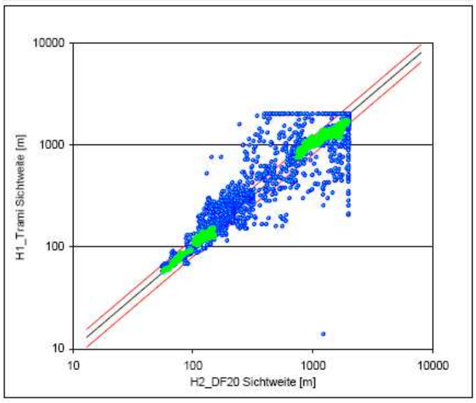
Fig. 11:* *EDDM, Echo & Hotel; 18.8.2007

Example for very inhomogeneous MOR-values with high variability. Homogenous events agree very well, especially CAT IIIB levels.









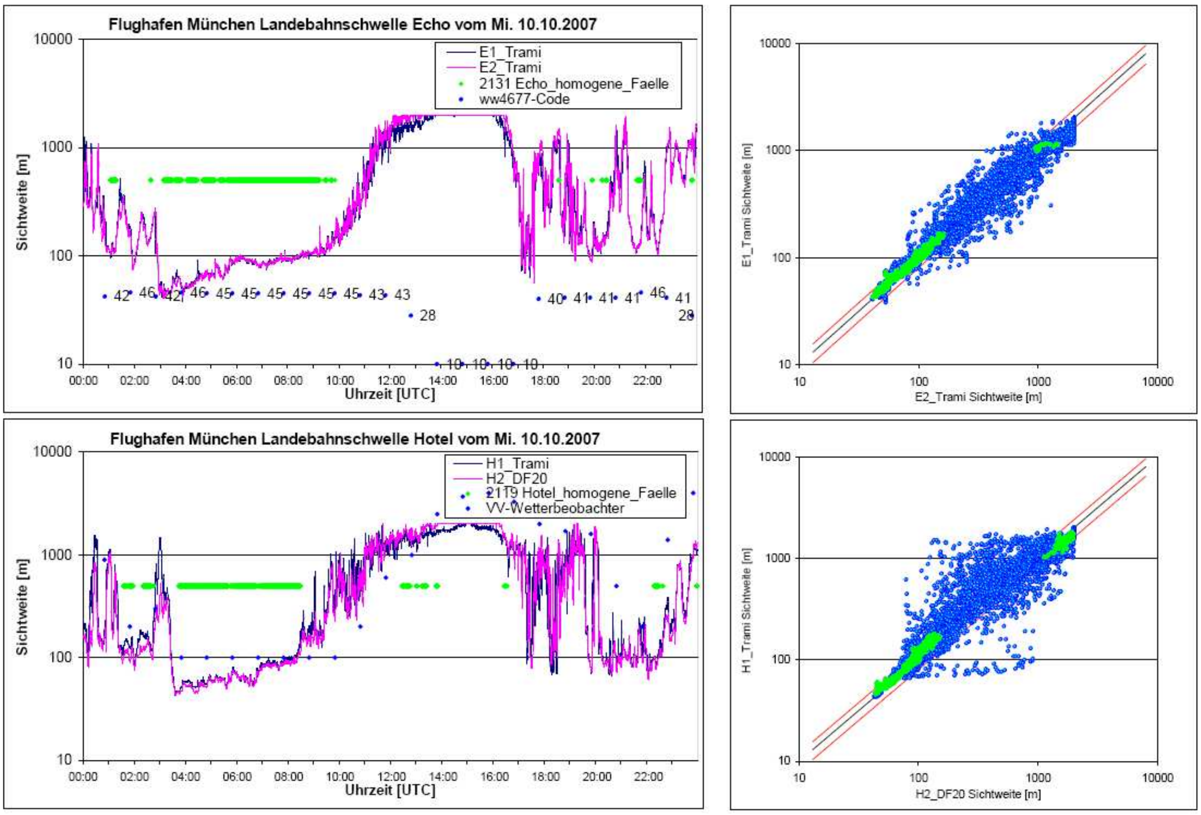
Echo
E1 = Trami
E2 = Trami

E2 \ E1	>=2000m	CAT 0	CAT I	CAT II	CAT III A	CAT III B	CAT III C			
>=2000m										
CAT 0			334					0.000	100.000	0.000
CAT I			126					100.000	0.000	0.000
CAT II										
CAT III A					27	32		45.763	54.237	0.000
CAT III B					4	553		99.282	0.718	0.000
CAT III C										
			27.391		87.097	94.530		65.613	65.613	
			72.609		12.903	5.470		34.387	34.387	
			0.000		0.000	0.000		0.000	0.000	

Hotel
H1 = Trami
H2 = DF20

H2 \ H1	>=2000m	CAT 0	CAT I	CAT II	CAT III A	CAT III B	CAT III C			
>=2000m										
CAT 0		93	243					27.679	72.321	0.000
CAT I			601					100.000	0.000	0.000
CAT II										
CAT III A										
CAT III B						687		100.000	0.000	0.000
CAT III C										
		100.000	71.209			100.000		85.037	85.037	
		0.000	28.791			0.000		14.963	14.963	
		0.000	0.000			0.000		0.000	0.000	

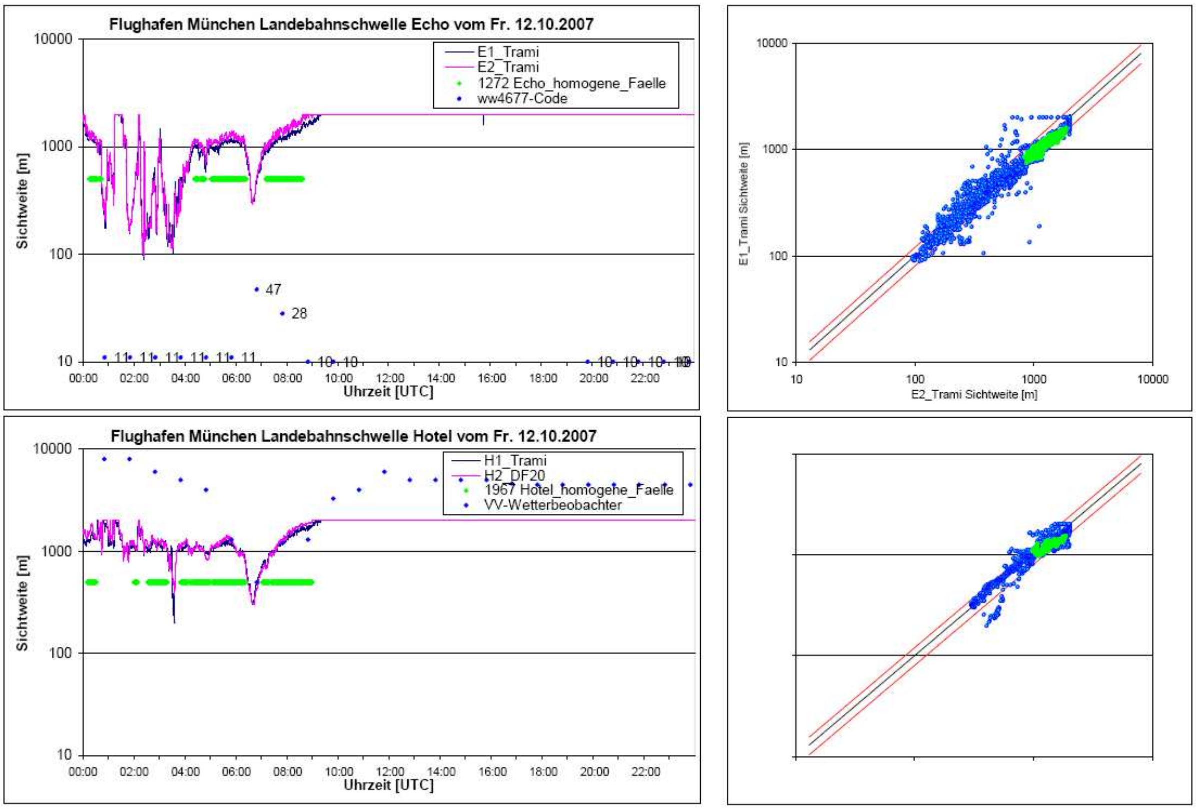
Fig. 12: EDDM, Echo & Hotel, 4.10.2007
Example for MOR values below 100m, very good agreement of Transmissometer H1 and DF20 H2, perfect agreement on CAT IIIb level.



	E2 \ E1	>=2000m	CAT 0	CAT I	CAT II	CAT III A	CAT III B	CAT III C			
Echo	>=2000m										
E1 = Trami	CAT 0										
E2 = Trami	CAT I			22					100.000	0.000	0.000
	CAT II										
	CAT III A										
	CAT III B						2004	1	99.950	0.050	0.000
	CAT III C						16	88	84.615	15.385	0.000
				100.000			99.208	98.876	99.202	99.202	
				0.000			0.792	1.124	0.798	0.798	
				0.000			0.000	0.000	0.000	0.000	

	H2 \ H1	>=2000m	CAT 0	CAT I	CAT II	CAT III A	CAT III B	CAT III C			
Hotel	>=2000m										
H1 = Trami	CAT 0		119	62					65.746	34.254	0.000
H2 = DF20	CAT I		3	27					90.000	10.000	0.000
	CAT II										
	CAT III A										
	CAT III B						1774		100.000	0.000	0.000
	CAT III C						114	20	14.925	85.075	0.000
			97.541	30.337			93.962	100.000	91.553	91.553	
			2.459	69.663			6.038	0.000	8.447	8.447	
			0.000	0.000			0.000	0.000	0.000	0.000	

Fig. 13: EDDM, Echo & Hotel, 10.10.2007
Additional example for MOR values below 100m; transmissometer H1 and DF20 H2 agree very well during homogenous conditions. Noticeable is the strong variation during non-homogenous events (blue dots).



	E2 \ E1	>=2000m	CAT 0	CAT I	CAT II	CAT III A	CAT III B	CAT III C				
Echo	>=2000m											
E1 = Trami	CAT 0		15	188						7.389	92.611	0.000
E2 = Trami	CAT I			1069						100.000	0.000	0.000
	CAT II											
	CAT III A											
	CAT III B											
	CAT III C											
			100.000	85.044						85.220	85.220	
			0.000	14.956						14.780	14.780	
			0.000	0.000						0.000	0.000	

	H2 \ H1	>=2000m	CAT 0	CAT I	CAT II	CAT III A	CAT III B	CAT III C				
Hotel	>=2000m											
H1 = Trami	CAT 0		276	130						67.980	32.020	0.000
H2 = DF20	CAT I		1	1560						99.936	0.064	0.000
	CAT II											
	CAT III A											
	CAT III B											
	CAT III C											
			99.639	92.308						93.340	93.340	
			0.361	7.692						6.660	6.660	
			0.000	0.000						0.000	0.000	

Fig. 14: EDDM, Echo & Hotel, 12.10.2007
Example for good agreement of indicated values in upper MOR range (*800m – 2000m).*

5. Conclusions

- ➔ In general, measurements of forward scatter sensors and transmissometers match very well in homogenous visibility conditions, especially at visibilities below 1000m which are most relevant for IFR approaches.
- ➔ During inhomogeneous visibility conditions even transmissometers can differ very strongly in direct comparison to each other.
- ➔ During rainfall events, both techniques agree quite well, although the measured values are lower than the visibility determined by an observer.
- ➔ In drizzle, forward scatter sensors tend to lower MOR values compared to transmissometers (which is the safe direction). (The reason might be the limited efficiency of the filter algorithm.)
- ➔ Snow: due to the few events during the winter season 2006/2007and long periods with contamination during the few snowing events a reliable statistical conclusion can not be drawn. Remark: transmissometers show considerable lower values compared to the ones determined by observers; DF20 values are higher and closer to the observed values.
- ➔ Differences at MOR above 1000m are normally caused by contamination of the transmissometers.
- ➔ CAT levels (for IFR approaches) determined by MOR values of the different sensors agree very well with both techniques.
- ➔ MOR values of the DF20s that were obviously too low during bright sunshine and high wind speeds were caused by moving weeds (blades of grass). (According to the manufacturer this has been improved by a firmware update.)
- ➔ Operational problems were mainly caused by difficulties with data transmission (partly due to lightning).
- ➔ For calibration of forward scatter sensors it is necessary to use a modern transmissometer with auto-correction of contamination. “Skopograph II” transmissometers are not appropriate for that purpose.
- ➔ The results of this test confirm the experience and findings of tests conducted by other meteorological services as well as the ICAO recommendation:

  Forward scatter sensors are technically capable to be used to measure MOR respectively RVR.

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