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VERIFICATION OF TRAFFIC INFORMATION USING ADVANCED RADAR SATELLITES

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ABSTRACT

Modern traffic information systems base on several sources of raw data like from induction loops, cameras, floating cars, cell phones, call-ins from drivers and traffic models. Typically, they provide maps with annotated road segments, indicating the average speed and travel time or they feed the information directly into the navigation system of the cars.

The verification of such large traffic maps is very difficult; because “ground truth” activities which make use of cameras or floating data are man-power intensive and they can only deliver point-like measurements. In this paper we introduce a satellite based system which can overcome these problems. We report from a joint IFSTTAR / DLR test campaign which has been conducted in May 2010. Test sites near Paris, Lyon and Marseille have been observed by the German radar satellite TerraSAR-X several times and the traffic maps generated from these snapshots from space can be compared with results from the in-situ measurements. We report from a first comparison which has been performed on the motorway A50 east of Marseille.

Furthermore, the paper provides a brief summary of the satellite based traffic acquisition and processing chain which has been developed at the German Aerospace Center DLR.

THE RADAR SATELLITES

The TerraSAR-X and TanDEM-X radar satellites (launched in 2007 and 2010 respectively) are a public private partnership between the German Aerospace Center DLR and EADS Astrium (http://www.dlr.de/eo/en/desktopdefault.aspx/tabid-5725/9296_read-15979). The main data products are high resolution (up to 1m) Synthetic Aperture Radar (SAR) images of all parts of the Earth. The aim of the second satellite TanDEM-X is to generate a global digital elevation model. For this purpose the two satellites fly in a close formation. They orbit around the Earth in 515 km altitude. One site in Central Europe can be imaged nearly on a daily basis in the morning or in the evening if the so called “Left Looking Mode” is used.

The radar system works independently of sunlight, even at night and is not affected by fog and rain. Due to the high speed of the satellite of app. 7 km/s it can produce snapshot-like traffic maps of large areas of up to 30km x 100km in a few seconds. The velocity of individual cars and trucks is measured by the space based radar with an accuracy of 3 km/h. Current limitations are still the relatively low detection rate of passenger cars and dependency on the orientation of the road segments. Nevertheless, the system can operationally been used and can produce independent traffic reference data sets for the validation of other traffic acquisition systems worldwide (1).

The development of the traffic data extraction processor has been performed as one out of more than 100 TerraSAR-X scientific exploitation projects. Traffic measurement hasn't been a design criterion for the development of the satellites and therefore they aren't optimized for this application. However, they can be used to demonstrate and develop this new application for remote sensing and to gain experience for an improved satellite design in the future.

The two German satellites as well as the Canadian Radarsat-2 have, however one feature which is very important for the detection of moving objects: They can split their receive antennas into a forward and aft half, each connected with one receiver chain. This dual-channel mode enables the system to take two snapshot images with less than a micro-second time lag. During this short time interval the cars on the ground move only in the mm-range, but enough to be measured with advanced radar interferometer methods. The use of both German satellites in the formation will lead to even more sensitive traffic measurements in the future.

TRAFFIC INFORMATION EXTRACTION FROM SPACE BORNE RADAR DATA

A dedicated software system, the so called “TerraSAR-X Traffic Processor” (TTP) has been developed for the automatic extraction of traffic information from TerraSAR-X dual channel data. It is based on the detection and measurement of single vehicles

Figure 1 shows the TTP block diagram. The TerraSAR-X Multi-Mode SAR Processor (TMSP) is used to obtain focused images from the recorded raw data of each channel. After geometric co-registration of the two images and a compensation for channel imbalances, the actual traffic data extraction part starts.

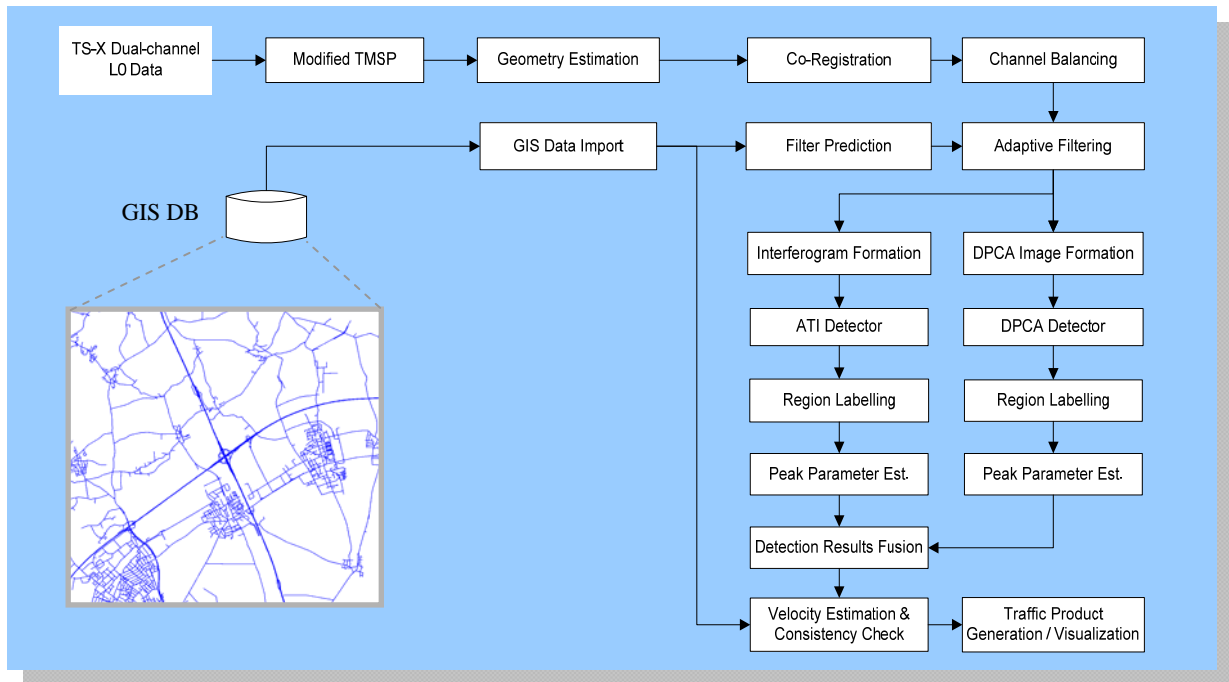


Figure 1: Functional diagram of the TerraSAR-X traffic data extraction processor TTP

The vehicle detection is based on the statistical evaluation of the differential information in between the images. These are the signal delay (phase) difference of the so called interferogram and the magnitude of the image difference, the so called Displaced Phase Center Array (DPCA) image. Both quantities depend on the vehicles motion component in the radar look direction. Since this is perpendicular to the nearly in North-South direction oriented flight track, only cars with a certain motion in East-West direction can be detected by the implemented detectors. The pixel based detections are grouped to objects, for which quality parameters of the detections and the velocity determination are estimated.

The vehicle velocity is estimated with two different methods. One estimate is obtained from the interferogram phase, the other one from an apparent image displacement of a vehicle from its original (road) position in azimuth. Both are proportional to the velocity component in the radar look direction. The displacement of a car in a SAR image is an effect of the SAR data focusing and is owed to its motion-induced Doppler frequency offset when compared to the stationary background. Though, this complicates vehicle detection when compared to optical images, it also provides a very accurate velocity estimate, if the displacement is measured against a reference. This is done in the TTP by extracting a priori knowledge about the road network from an integrated GIS data base. The processor uses the road network data also for predicting image areas that can contain vehicles at all in order to make the processing more efficient. The obtained images usually have a size of several 10.000 pixels in each dimension. The GIS data are further used to assign detected vehicles to the correct road and to estimate the absolute vehicle velocities through projection of the radar line-of-sight estimate onto the road direction. Beside the detection and velocity measurement, the TTP also performs a coarse vehicle classification into passenger cars and trucks.

After traffic data extraction, the information about the detected vehicles, i.e. geographical position, speed, type and time of measurement are integrated into a Google Earth (KML) product, which can easily be distributed and viewed by users. A data set in text format is generated too. An example of Google Earth visualization can be seen in Figure 2. Each

detected vehicle is designated with a little triangle and by clicking on it, its speed, coordinates; time stamp and type (truck or passenger car) are displayed.

The vehicle detection rate and correctness depend mainly the used instrument acquisition parameters, the vehicle radar reflectivity and on the type of the scene contents, in which traffic is detected. From the SAR instrument side e.g. the image resolution, the azimuth sampling rate, the sensor look angle and the interferometric baseline have a great influence. The vehicle reflectivity, i.e. the so called Radar Cross Section (RCS) strongly influences the probability of detection. It is determined by its shape and material. It also varies with its orientation, i.e. the heading angle under which the radar illuminates the vehicle. This is one reason why traffic detection may have gaps for roads, which are oriented in a unfavorable direction (2).

Since vehicles appear off from their original position in the SAR images, their signal has to compete with the one of the stationary background (the “clutter”) at those positions. The stronger the reflectivity of the clutter, the more difficult it is to detect the vehicles. Strong clutter reflectivity is observed for instance in urban areas with many densely spaced manmade objects. Due to this problem the detection rate and correctness depends on the scene contents. We have empirically determined the performance of the TTP by comparing TerraSAR-X vehicle detections to reference data from an airborne camera system that simultaneously imaged the a traffic situation. The test area was the motorway A4 near Dresden, Germany. A total of 81 reference vehicles were extracted from the optical data with information on speed, position and type. The results of the comparison are summarized in Table 1. The mid column lists the number of vehicles that were correctly detected out of the set of reference vehicles. With two occurring false alarms (wrong detections), the overall detection correctness is about 94 %. The error of the estimated vehicle velocity against the reference is only 3 km/h. The right column gives the classification results. Detected vehicles were classified correctly into trucks and passenger cars with an overall rate of about 80 % (3).

	TTP Detections	TTP Classification
Trucks	17 / 23 (73.9 %)	15 / 17 (88.2 %)
Passenger cars	14 / 58 (24.1 %)	10 / 14 (71.4 %)
Total	31 / 81 (38.2 %)	25 / 31 (80.6 %)
False alarms	2	
Correctness	93.9 %	
Velocity error	3 km/h	

Table 1: Performance of the TerraSAR-X traffic measurements in comparison with an airborne optical reference system

Please note that these results are valid for the TerraSAR-X acquisition parameters used in the setup of that specific experiment (imaging mode: Stripmap aperture switching, incidence angle: 28 deg, azimuth sampling rate: 3334 Hz, range bandwidth: 300 MHz, effective interferometric baseline: 1 m) and for a rural environment.

We are currently working on a couple of TTP improvements. The limitation that only vehicles with a motion component in the radar look direction are detected can be overcome with the integration of an additional “along-track” detector. It is sensitive to motions in the radar flight direction and exploits the amount of blurring of the vehicle image signature caused by the along-track motion.

For a complete representation of some traffic situations it is also important to detect non-moving traffic, i.e. total congestions. We have developed a change detection based technique for this purpose. It compares the state of the roads in an actual satellite acquisition against the ones found in earlier acquisitions of the same area. Prototypes of both the along-track and the congestion detection already exist and will soon be integrated in the TTP. There are also plans to improve the existing detectors to increase the vehicle detection rates.

COMPARISON WITH GROUND BASED DATA

The aim of the paper is to perform a comparative analysis of satellite and stationary detectors (ILDs – Inductive Loop Detectors) for road traffic speed measurement. The ultimate goal is then to derive a reliability indicator of traffic information based on the conventional ILDs.

The proposed methodology is based on the comparison of both the time-mean speed (ILDs data) and space-mean speed (radar satellite TerraSAR-X) as a proxy of the ILDs’ information reliability. This first step can be seen as a prerequisite of the accuracy of traffic information improvement.

TEST SITE AND DATA DESCRIPTION

As already mentioned two different data sources are considered in this section:

- ILDs data (either individual data or aggregated ones)
- Radar satellite TerraSAR-X data.

Both sources are characterized by several attributes listed in Table 2 below:

ILDS data attributes	Radar data attributes
<ul style="list-style-type: none"> • Motorway segment ID • Detector ID • Detector location (linear abscissa in meters) • Direction of the flow • Time stamp (seconds) • Speed value • Vehicle's length 	<ul style="list-style-type: none"> • Motorway segment ID • Direction of the flow • Time stamp (seconds) • Speed value • Vehicle's location (linear abscissa in meters) • Vehicle's category: {Car, Light Van and HGV }

Table 2: Attributes of the two data sources

An important issue is that these two sources are not aligned in both space and time. More precisely, both sources don’t provide the same type of data: Traffic data collected by ILDs

exhibit temporal evolutions of traffic flow, i.e. traffic evolution during a time period at a specific location, while radar satellite snapshots provide spatial characteristics of traffic flow, i.e. traffic distribution at a specific time within a road section.

For this preliminary study, we focused on a single satellite snapshot East of Marseille on **Monday 10th May 2010 at 07:54:39 AM**. This time period is selected mainly because this road section under study experiences heavy traffic condition in westbound direction (towards Marseille) and normal traffic conditions in eastbound direction.

The granularity of the ILDs traffic data is of individual nature extracted from the MARIUS ILDs network is depicted in Figure 2. The set of data which we used only involve vehicles on the A50 motorway between 07:50 AM and 07:56 AM.

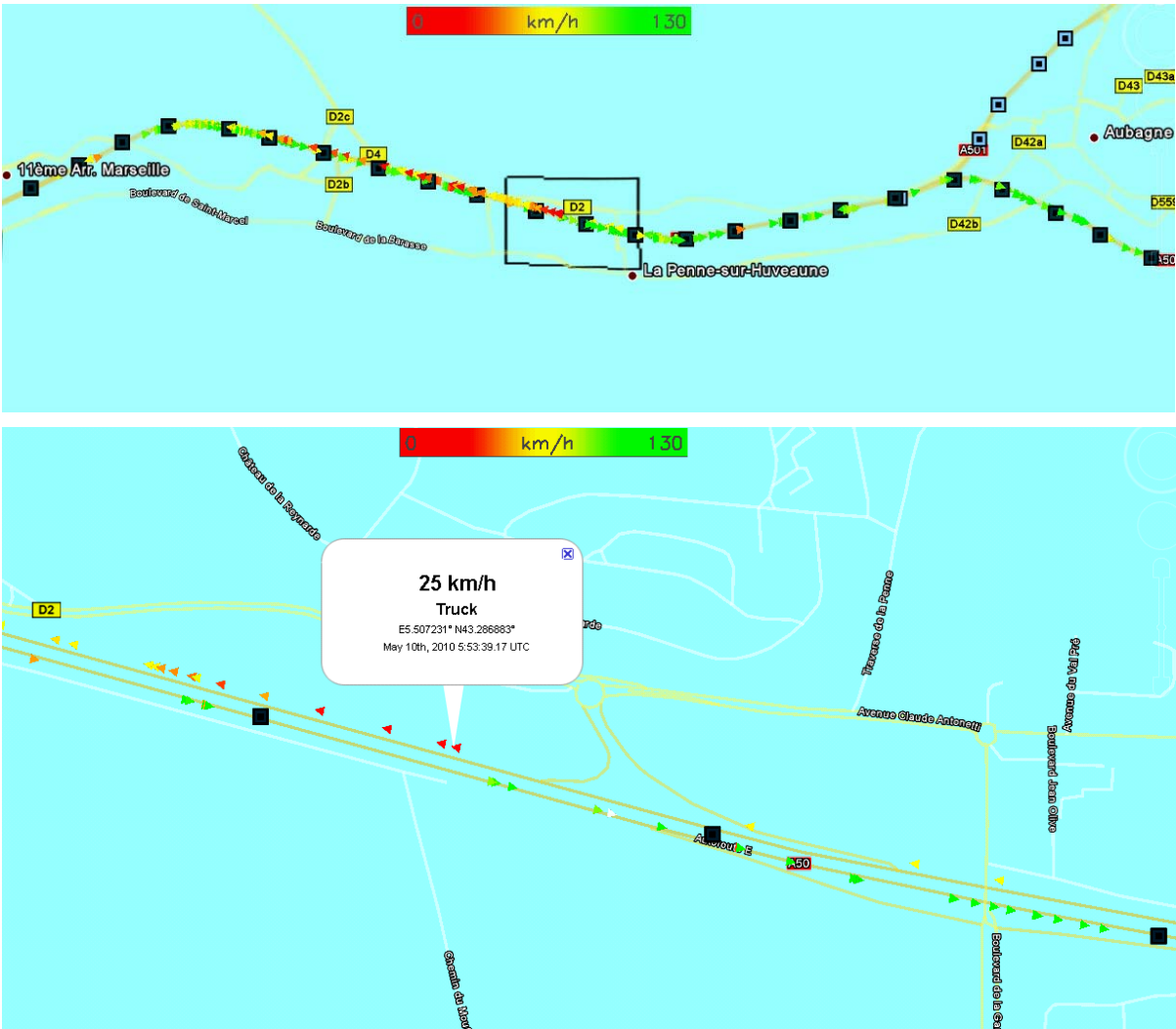


Figure 2: Inductive Loop Detectors (ILD) positions (black squares) and instantaneous satellite measurements of vehicles on motorway A50 east of Marseille (top: complete extension, bottom: enlargement with end of congestion in westbound direction)

DATA SOURCES ALIGNMENT PROCESS

In order to process and compare the two types of data, it is necessary to achieve a time and space alignment of both data sources. More specifically, it is important to create an accurate mapping of the vehicles location detected by the satellite and recorded by ILDs as well.

To do so, we first locate each vehicle along with ILD and derive a relative distance between a vehicle and a nearest ILD. Then, a mapping of both data sources is performed based on the mean speed derived from satellite data and ILDs. The used alignment process is shown in Table 3. Let t_0 and x_i be the time the satellite snapshot is taken and the location of ILD # i .

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1. *First we choose a short period of time Δt .*
 2. *For each loop,*
 - *Calculate the mean speed of the vehicles which passed on the loop during a period centered on the time of the satellite snapshot: $\left[t_0 - \frac{\Delta t}{2}, t_0 + \frac{\Delta t}{2} \right]$*
 - *Derive a time mean speed value noted: V_{mT} (Harmonic mean of spot speeds of all vehicles crossing the ILD location during the time period)*
 - *Calculate a space neighborhood Δx which correspond to the distance a vehicle go through with constant speed equal to V_{mT} .*
 3. *Based on these parameters, for each loop*
 - *Calculate the mean speed of the vehicles of the satellite snapshot in the vicinity of the loop, which means on the section $[x_i - \Delta x, x_i + \Delta x]$*
 - *Derive a second value of “spatial” mean speed noted: V_{mS} (average of all vehicles’ speeds located on the segment of road of length Δx at time t_0)*
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Table 3: Temporal and spatial alignment process

Based on this process and for a given Δt , we thus obtain two speeds values to be compared. Their comparison would give us an idea on the discrepancy between the speed information measured by the satellite and the one derived from conventional ILDs. It is clear that the more the two mean speeds are similar, the more the two systems, namely radar satellite and the conventional ILDs, similarly detect the traffic flow characteristics, e.g. onset and offset of congestion.

To compare these two mean speeds, the scatterplot of (V_{mT}, V_{mS}) was depicted along with the line of unity slope. Figure 3 exhibits a good match between both speeds and the line of unity slope indicates a *perfect* correspondence between radar satellite’s speed and ILD’s speed!

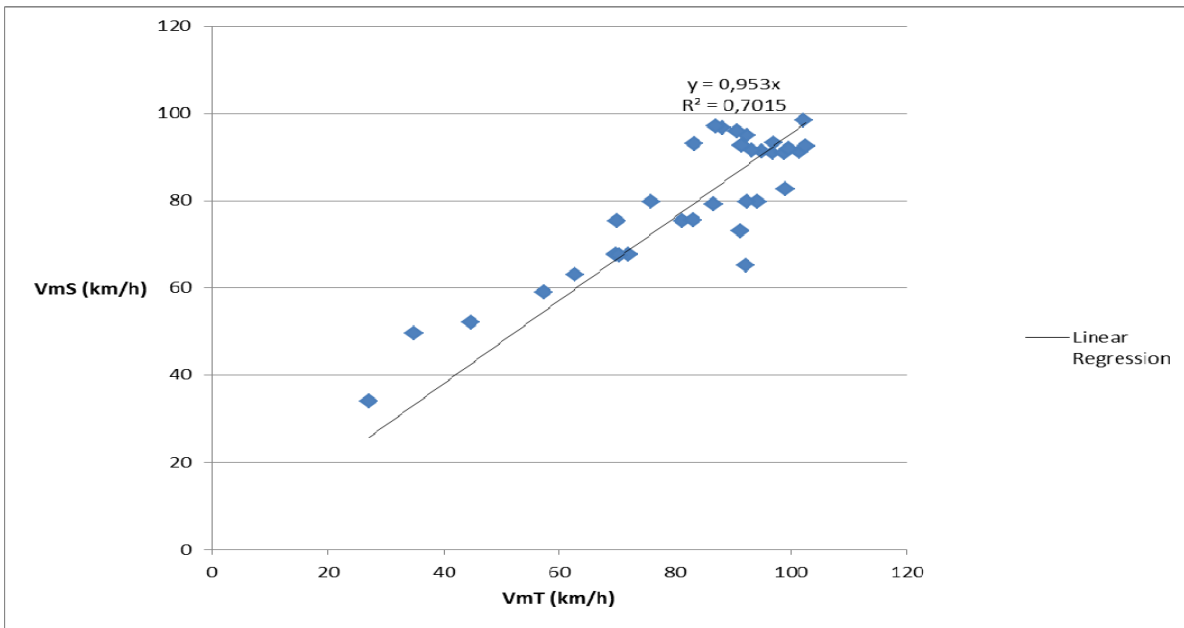


Figure 3: Comparison of VmS and VmT for $\Delta t = 40$ s

The discrepancy measure used here is based on the Pearson's linear correlation coefficient R . To assess the impact of different aggregation periods Δt on the matching accuracy, different values of Δt , laying between 10 and 100 seconds with a time increment of 10 seconds have been tested. One can note that in one hand if Δt is too short, there are too few vehicles on the section associated to an ILD station and the spatial mean speed is based on a very limited number of vehicles which makes it less representative of traffic flow conditions. In the other hand, if Δt is too long, the spatial mean speed is based on speed vehicles which are far away from the ILD station. Those vehicles don't represent the local traffic conditions anymore. The optimal value of Δt is then a trade-off between these two considerations: it corresponds to the period of time for which the vehicles on the section associated to the ILD station are more or less the same whose speed has been used to calculate the temporal mean speed of the loop.

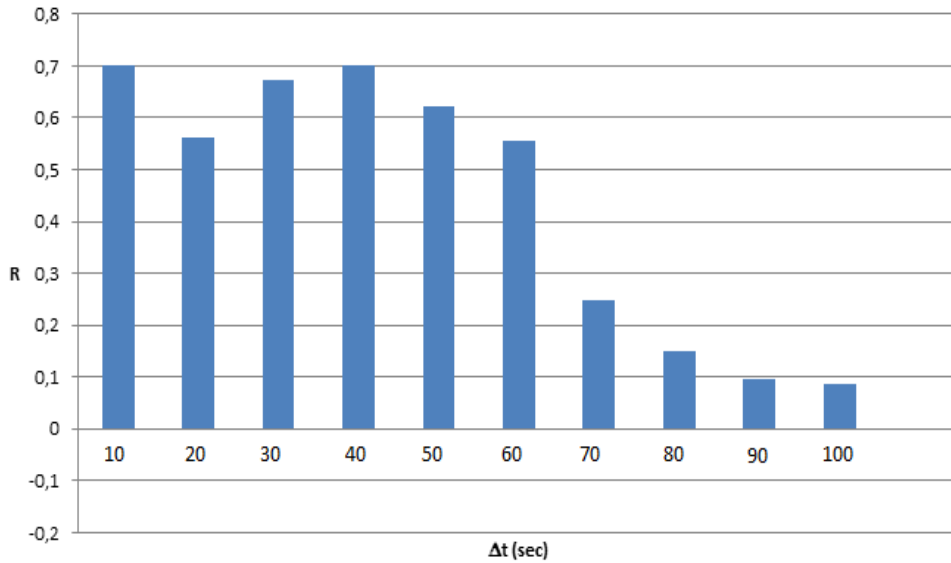
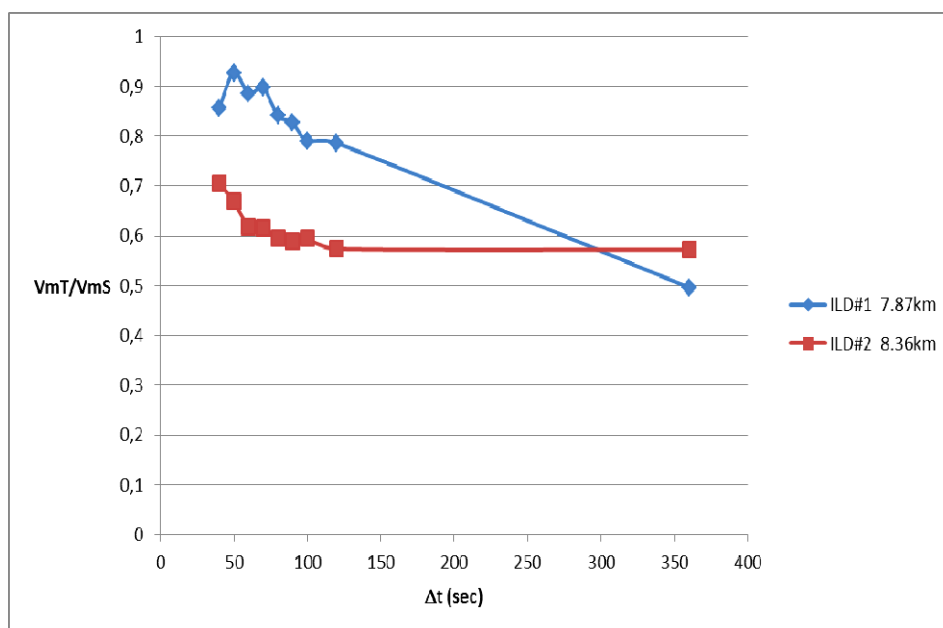


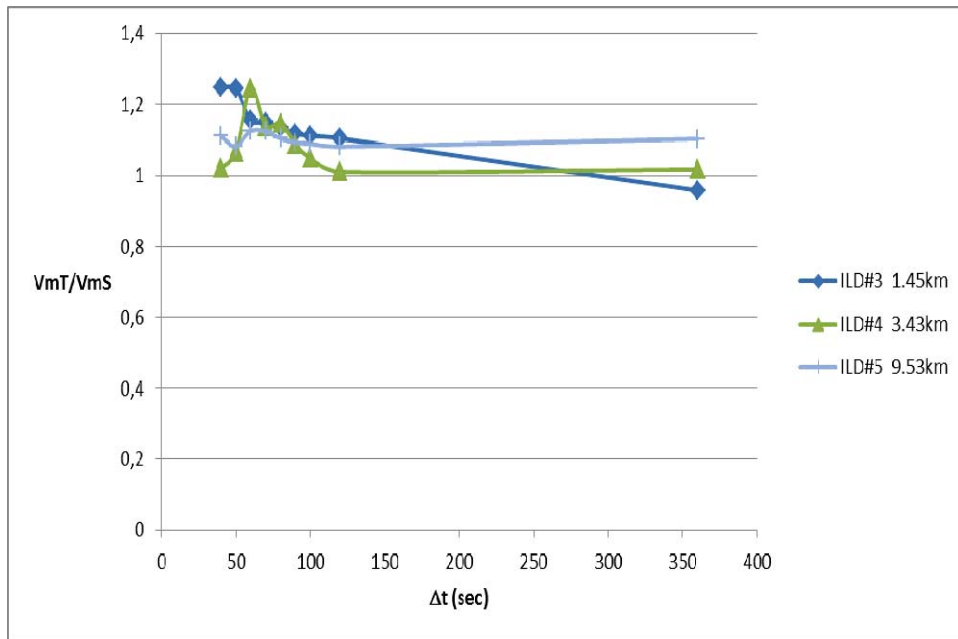
Figure 4: Radar/loop speed correlation as a function of the aggregation period

Based on these aforementioned considerations and the correlation coefficient, it turns out that the optimal value of Δt , in terms of the correlation as a measure of similarity, is to be into the interval [30s , 50s] (see Figure 4). This optimal range provides the maximum matching between satellite and ILD speed measurements and corresponds to a time period for which the ILDs and the satellite approximately detect the same traffic conditions. Hence, based on this empirical analysis, Δt is chosen to be the center on this interval, namely, $\Delta t = 40$ sec.

Given that the traffic information disseminated to drivers is usually based on aggregated traffic data and that the common aggregation period is 6 minutes (i.e. 360 sec.), we find it meaningful to compare the associated speed, noted V_{mT360} to the spatial mean (radar) speed calculated over $\Delta t = 40$ sec., noted V_{mS40} , which we consider as the “ground truth” speed reference.



(a) – Heavy traffic conditions



(b) – Light traffic conditions

Figure 5: VmS / VmT ratio evolution as a function of Δt

Figure 5 shows that the ILDs stations often underestimate the speed (i.e. satellite snapshots) during heavy traffic conditions (a) whereas they overestimate it in case of light traffic conditions (b). This is consistently observed on other road sections and ILDs. Therefore, this finding could provide an efficient and a practical tool to elaborate a correcting factor to the time mean speed measured from ILDs data aggregated on a 6 min period.

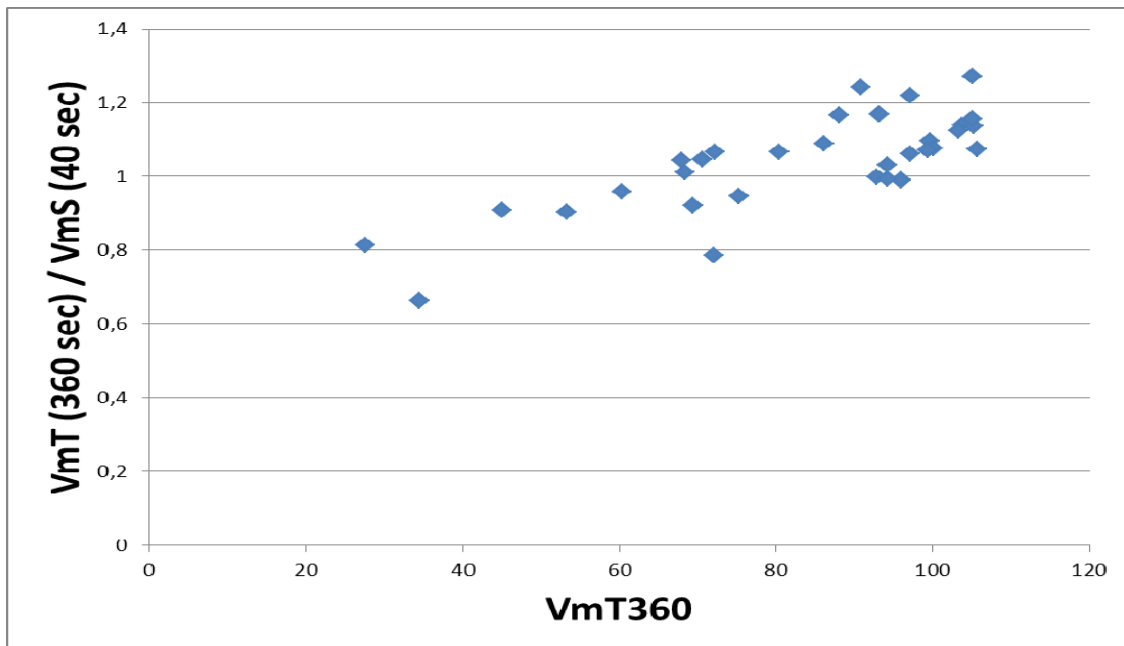


Figure 6: VmS / VmT ratio evolution as a function of VmT

Figure 6 exhibits a similar relation between V_{mT360} and V_{mS40} . In fact, the observations based on different loop time intervals (40 and 360 seconds) show the same trend: ILDs stations underestimate the speed (satellite snapshots) up to approximately 65 km/h while it overestimates it for speed flow over 65 km/h.

As an example, we present a spatial-temporal comparison (contour plots) of the two speed sources (loops VS satellite) along the East-West motorway link leading to Marseille downtown (Figure 7). This diagram has been elaborated by calculating a mean speed on 100 meters by 30 seconds cell unit, based on loop measures. The color scale represents the range of speeds.

Both ILDs and satellite snapshots capture important features of the congestion pattern including the size of the queue resulting from congestion, which propagates upstream. The figure also illustrates that radar detection could possibly anticipate congestions over loops.

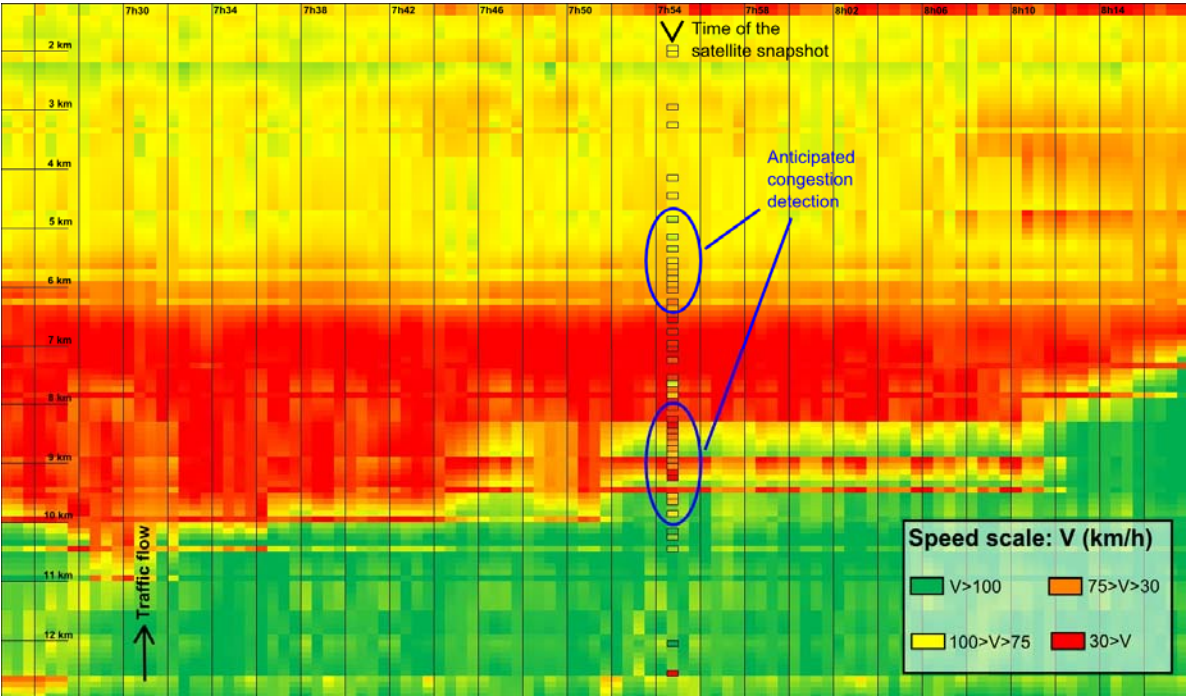


Figure 7: Loop speed diagram: loops measures versus satellite snapshot
 (Color denotes speed in km/h. x-axis: time of day. y-axis: post kilometer.
 Rectangles represent satellite snapshots at t = 7h54.)

CONCLUSION

These results obtained on a limited scale show that the reference radar satellite traffic speed measurements offer new solutions to validate traffic data provided by dedicated devices implemented along road infrastructures.

In order to better understand the potential of this new tool, we must pursue the study on a much larger data set. Statistical analysis would thus help us to determine the parameters of the comprehensive model of comparison:

- Calibration of the speed threshold between the two observed trends.
- Interrelation between the outputs of the two technologies.

Further studies would lead us to try to create a mathematical model for these variables according to different sensitivity parameters of speed.

The results of the study conducted here should open new opportunities for cooperation in the field of road traffic data collection and analysis.

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