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On the validation of rainfall retrieval algorithms for satellite microwave data

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Summary. — The Algorithm Intercomparison Project utilises rainfall estimates derived from radar data to validate the algorithms developed for rainfall retrievals from satellite microwave data. Since seven minutes are needed in order to have a complete radar scan, while the acquisition of the corresponding satellite microwave image needs only a few seconds, the same pixel can be sensed by radar as much as seven minutes later. Within this time delay the raining cells can be displaced and the consequent mismatch can cause a decrease in the correlation coefficient of the comparison. A method to reveal this time-lag effect is presented and a possible approach to take it into account in the validation process for future missions is suggested.

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1. – Introduction

The Algorithm Intercomparison Project (AIP) is used to validate the algorithms for the retrieval of precipitation from radiometric microwave data, by comparison with the precipitation estimates obtained from the corresponding radar data.

The algorithms tested in the AIP-1 (Lee *et al.*, 1991) gave acceptable results because the comparison was performed on area-time averaged values of the precipitation. It is, however, desirable to have an algorithm capable of estimating the instantaneous precipitation on the highest resolution possible, for example 15 km of the 85 GHz channel of the Special Sensor Microwave Imager (SSM/I).

Most of the algorithms tested in the AIP-3 (Ebert, 1995) used two or more frequencies in the attempt to make the best use of the information contained in the data, but if the comparison is performed on a pixel by pixel basis, the quality of the results is disappointing.

The introduction of some additional information based on radiative transfer simulations and on the known cloud physics did not substantially improve the results

(Prabhakara *et al.*, 1996). In fact, the correlation coefficients of the comparisons were so low that made us wonder if we were comparing two completely different sets of data.

The radar scan starts from low elevation, and changes zenith angle after every 360° horizontal scan, which takes about 20 seconds. Precipitation is estimated from the radar data obtained at a constant altitude of about 2 km (Battan, 1973).

Twenty zenith angles are necessary to obtain an image of the 2 km altitude radar data and a complete image is obtained in seven minutes. The next image starts after ten minutes. The corresponding satellite image is obtained in about 15 seconds. As a result, only a few percent of the pixels are simultaneous, and some of them can be as much as seven minutes apart.

The raining cells, and clouds in general, are rapidly evolving phenomena and can change dramatically in a few minutes. But the highest changes, from heavy rain to no rain, is simply due to the fact that the raining cell can be advected by the wind to an adjoining pixel, *i.e.* the raining cell is not exactly on the same location anymore. This explains why sometimes heavy rain sensed by radar has no rain in the corresponding SSM/I field of view, and viceversa. This type of results reduces the correlation coefficients in the comparisons for the validation.

2. – The time-lag effect

Since corresponding pixels can be sensed by the radar and by the satellite microwave radiometer with a time-lag as long as seven minutes, it is important to know if some real change in precipitation has not taken place.

To quantify the effect of this time-lag, and of the consequent mismatching, we have compared the radar images among themselves. In this way, there is no difference in the retrieval method, instrumentation, or measuring techniques. In fact, if we superimpose two successive radar images taken in a windy day, the displacement of the raining cells is evident.

Comparisons were done as follows. All the images were pre-processed to degrade the spatial resolution to the field of view of the 85 GHz channel, 15 km, which was taken as reference pixel. Then all the pixels with rain rate less than 0.04 mm/h in the first image were neglected. This was done because a large population of pixels without rain can artificially increase the correlation coefficient and change the slope of the comparison. The chosen pixels of the first image were compared with the corresponding pixels of the image taken ten minutes later, then with the corresponding pixels of the image taken twenty minutes later, and so on.

In fig. 1 we present the correlation coefficients in three cases with increasing wind velocity. Starting from the maximum correlation coefficient of 1, obtained by comparing the first radar image with itself, and taken as a reference image, we have a decrease as large as 0.5 in the following image, with corresponding pixels observed only ten minutes later.

The upper curve is obtained from the radar data of December 24, 1992, with moderate wind velocity. The lowest curve is for January 31, 1993, with relative strong wind. In this case the correlation coefficient drops to less than 0.2 in twenty minutes.

It is evident that the corresponding satellite and radar data for the validation of a retrieval algorithm have to be simultaneous.

The Tropical Rainfall Measuring Mission (TRMM) (Simpson *et al.*, 1996) satellite has a multichannel microwave radiometer (TRMM Microwave Imager, TMI) and a

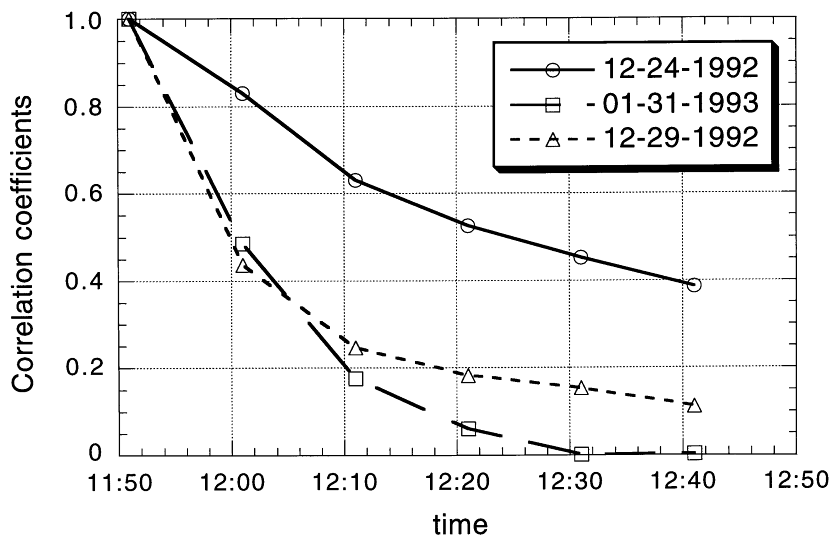

Fig. 1. – Correlation coefficients as a function of time for three different days with increasing wind velocity, going from the upper graph to the lower graph.

Precipitation Radar (PR). However, the TMI has a conical scan and scans ahead of the sub-satellite point, while the radar scans across the sub-satellite point. Given the altitude of the satellite and its speed, each pixel is scanned by the radar about 1 minute later. Most probably a one minute delay does not introduce relevant changes in the size and position of the raining cells. But the altitude of the TRMM satellite is lower compared to the one of the SSM/I radiometer and the spatial resolution is increased from 15 to about 5 km in the 85 GHz channel, enhancing the effect of the rain cells displacement.

An evaluation of the effect of this time lag can be obtained by modifying the data acquisition sequence of the TMI, which requires also that the antenna should be located under the satellite.

In the present configuration the data are taken only in the area ahead of the satellite and the useful swath is about 720 km. The radar scans across the sub-satellite point with a swath of about 220 km. Assuming that the quality of the rain rate estimate obtained from the radar data is satisfactory, it is possible to validate the algorithms developed for the TMI data and extend the retrieved information to a full 720 km swath.

With the TMI antenna under the satellite and a new data acquisition sequence, some data in a limited swath of about 100 km in the backward direction can be included. Given the altitude and speed of the TRMM satellite, all the pixels within this limited swath will be scanned twice in a time interval of about 2.2 minutes, giving a possible way to quantify the differences in size and location of the raining cells.

Using this new approach, it is also possible to have an evaluation of the wind speed and direction. Moreover, when the raining cell is steady in the same position and relatively stable, a stereographic image of the cloud can be analysed in order to give some new insight on the cloud structure.

3. – Conclusion

Any validation process requires that the corresponding data are comparable. Inside a thunderstorm the wind can peak to a velocity sufficient to displace a raining cell to an adjoining field of view. The time-lag between the radar rain and the satellite rain can result in a real change in the precipitation on a single pixel, making the entire validation process questionable. Raining cells can change so rapidly in size and location, that even comparing two successive radar images taken ten minutes apart can give a correlation coefficient as low as 0.5.

Some improvements are expected from the TRMM mission, since both radar and microwave radiometer are on the same satellite. However, we recommend to check the time-lag effect using the same type of data. This can be obtained by taking some microwave radiometric data in the backward direction and by comparing them with the corresponding data taken in the forward direction.

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