Development and Validation of a Rainfall Rate Algorithm Based on Hydrometeor Products Derived from Passive Microwave Satellite Observations

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Abstract

This work presents the development of a satellite-based rainfall rate algorithm that uses hydrometeors (cloud liquid water, rain water and ice water) derived by a 1D-VAR physical-based retrieval system (known as MIRS system) to retrieve surface precipitation amounts in mm/hr. The proposed algorithm is designed to facilitate its implementation on current and future satellite-based sensors. For the validation of the proposed surface precipitation algorithm (also known as MIRS rainfall rate algorithm), comparisons with state-of-the-art precipitation products derived from rain gauge, radar and satellite-based observations, performed over land and ocean, are presented as part of this work.

1. Introduction

Measurements of precipitation on different space and time scales are essential for the development of a variety of research areas that provide an inherent benefit to the human society and all living beings as part of the global ecological system. At present, accurate precipitation measurements rely on rain gauges and ground-based radar observations. One of the major disadvantages of these precipitation measurements is related to its intrinsic low spatial coverage. However, due to the associated global coverage of satellite-based observations and the strong physical relationship that exists between atmospheric microwave emissions and precipitation, there has been an increasing interest in the development of precipitation algorithms based on microwave satellite observations.

Rain Gauges cover a small portion of global land areas and are unable to be deployed over ocean

Satellite observation have good global coverage and are excellent compliment for rain gauge and radar observations

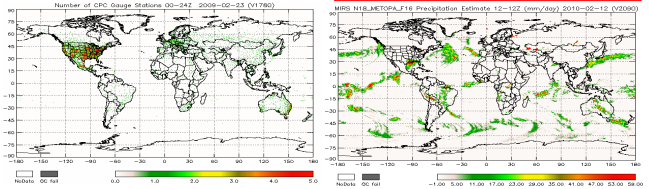


Fig. 1 Global distribution of rain gauge stations (*left*) and the global MIRS precipitation estimate composite in mm/day (*right*).

2. Description of the MIRS Rainfall Rate Algorithm

The Microwave Integrated Retrieval System (MIRS) rainfall rate algorithm is based on the physical relationship found between the amounts of hydrometeors in the atmosphere (cloud liquid water, rain water and ice water path) and surface rainfall rate. The MIRS rainfall rate algorithm uses a multi-linear regression approach that requires hydrometeor products and a set of regression coefficients corresponding to each hydrometeor in order to retrieve instantaneous rainfall rate in mm/hr.

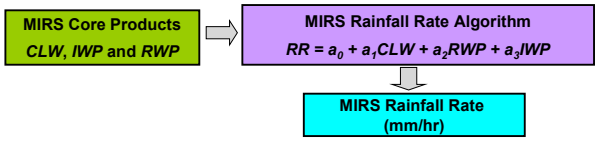


Fig. 2 Description of the MIRS Rainfall Rate algorithm.

The regression coefficients, a_0, a_1, a_2 and a_3, are static components in the algorithm that have been determined based on an off-line training using collocated sets of rainfall rate and hydrometeor products, both coming from the mesoscale model MM5. Therefore the algorithm can be applied to the hydrometeor products retrieved by the MIRS system. MIRS is a well-validated, integrated 1D-VAR retrieval system designed to operate effectively in all-weather conditions and over all surface types.

The MIRS rainfall rate algorithm is being applied operationally to AMSU and MHS sensors on board NOAA-18, NOAA-19 and Metop-A as well as to SSMI/S on board DMSP-F16.

3. Validation as part of the IPWG Project (rain gauge and radar)

For assessment purposes, a precipitation estimate composite, given in mm/day, has been generated using rainfall rate samples in mm/hr derived from microwave observation performed by three satellite sensors: NOAA-18, Metop-A AMSU and MHS, and DMSP-F16 SSMI/S. For more than one year, this precipitation composite has been validated on a daily basis as part of the International Precipitation Working Group (IPWG) project over three regions: *CONUS*, *South America* and *Australia*.

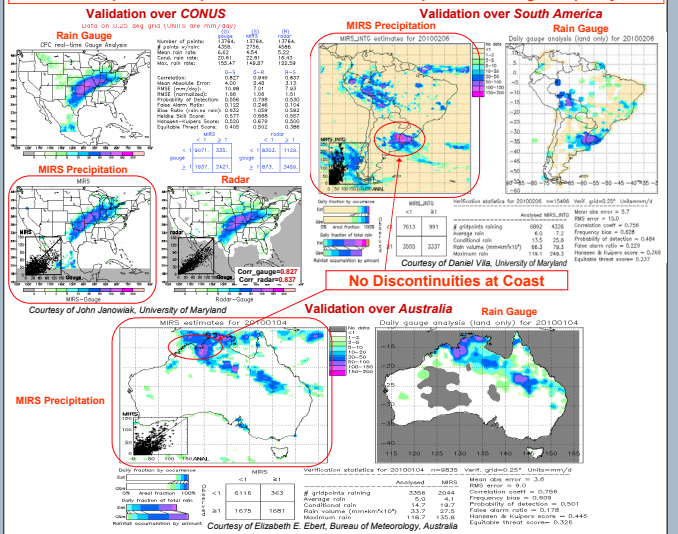


Fig. 3 Regions where the MIRS rainfall estimate algorithm is being validated as part of the IPWG project. Red squares show the daily MIRS precipitation estimate composite given in mm/day.

Upper Limit set by the Rain Gauge to Rain Radar Comparison

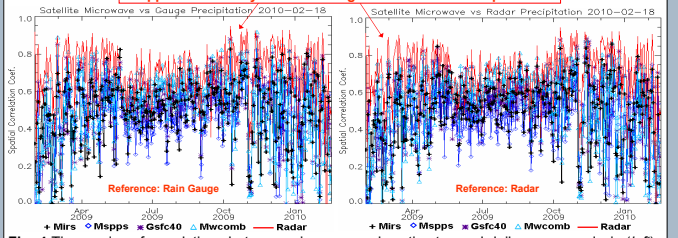


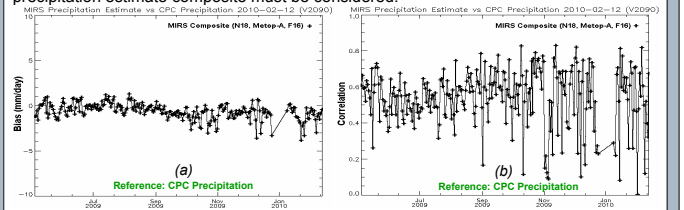
Fig. 4 Time-series of correlations between microwave-only estimates and daily gauge analysis (*left*) and radar observations (*right*). The MIRS precipitation estimate is the black line.

Microwave-Based Satellite Precipitation Estimate Algorithm	Responsible Organization	No. of Suites	Satellites/Instruments	Description
MIRS	NOAA/NESDIS/STAR	3	NOAA-18, Metop-A (AMSU-A and MHS) and F16-SSMIS	Sensor independent algorithm that depends on MIRS core products (RWP,IWP and CLW)
MSPPS	NOAA/NESDIS/STAR	2	NOAA-18 and Metop-A (AMSU-A and MHS)	Rain rate is computed based on an IWP and rain rate Relation
3B40RT	NASA	4	TRMM (TMI), F13, F14 and F15 (SSM/I)	Provides a merger of all available SSM/I and TMI microwave precipitation estimates into a high-quality estimate.
MWCOMB	CPC	8	TRMM (TMI), F13, 14, 15 (SSM/I), NOAA-15, 16, 17 (AMSU-B) and 18 (MHS)	Precipitation estimates are daily composites of precipitation estimates from SSM/I, AMSU-B and TMI.

Table 1 Precipitation estimate algorithms compared to rain gauge and radar precipitation estimates (mm/day) over *CONUS* as part of the IPWG.

4. Validation Using the CPC Precipitation (rain gauge)

For more than 10 months, the MIRS precipitation estimate composite based on rainfall rate samples from NOAA-18, Metop-A AMSU and MHS, and DMSP-F16 SSMI/S sensors has been compared to the daily Climate Prediction Center (CPC) rain gauge analysis precipitation product (given in mm/day). In this comparison, the limited temporal and spatial coverage associated with the satellite sensors used to generate the MIRS precipitation estimate composite must be considered.



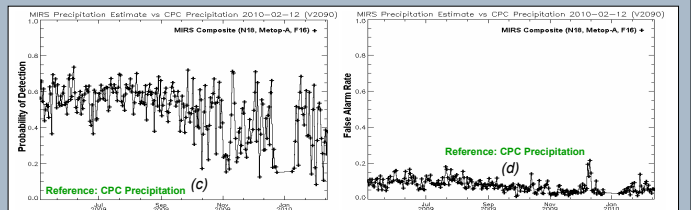


Fig. 5 Time-series of bias *(a)*, correlation *(b)*, probability of detection *(c)* and false alarm rate *(d)* of MIRS precipitation composite with respect to CPC rain gauge analysis.

5. Validation Using Stage IV Precipitation (rain gauge and radar)

The National Centers for Environmental Prediction (NCEP) Stage IV precipitation (4km resolution and given in mm/hr) has been used to validate, on a daily basis and over CONUS, the instantaneous rainfall rate derived from NOAA-18, NOAA-19, Metop-A AMSU and MHS, and DMSP-F16 SSMI/S sensors.

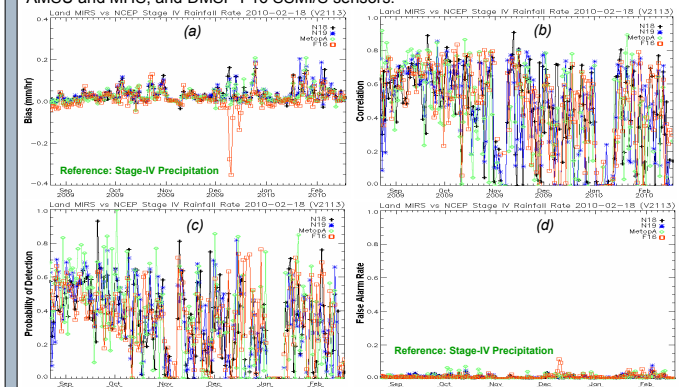


Fig. 6 Time-series of bias *(a)*, correlation *(b)*, probability of detection *(c)* and false alarm rate *(d)* of MIRS rainfall rate with respect NCEP to Stage IV rain gauge analysis given in mm/hr.

6. Comparison to Monthly MSPPS Rainfall Rate

Significantly Reduced False Alarms at the Sea-Ice Edges

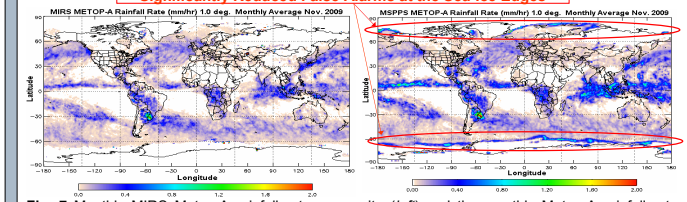


Fig. 7 Monthly MIRS Metop-A rainfall rate composite (*left*) and the monthly Metop-A rainfall rate composite estimated by the heritage MSPPS algorithm (*right*), given in mm/hr.

7. Summary and Future Work

- The MIRS rainfall rate algorithm is a *generic* algorithm that merely depends on hydrometeor products (not on a set of radiometric observations coming from specific set of channels). This characteristic has facilitated its transition from research to operations in a relatively short period of time.
- The MIRS rainfall rate algorithm has been successfully applied operationally to several satellite-based sensors, including *NOAA-18*, *NOAA-19*, *Metop-A AMSU and MHS*, and *DMSP-F16 SSMI/S* (and soon extended to *DMSP-F18 SSMI/S*).
- The MIRS rainfall rate algorithm has been extensively assessed over land and ocean, showing comparable capabilities and quality to state-of-the-art precipitation products derived from rain gauge, radar and satellite-based observations.
- Further improvement of the algorithm is being carried out by the development of a hydrometeor background covariance matrix for the MIRS system stratified by precipitation type and season.

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