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# H-SAF Passive microwave precipitation retrieval algorithms: current status overview and analysis of results

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# H-SAF Precipitation Products developed by ISAC-CNR

| | Area | Description | Main features |
|---|---|---|---|
| H01 v1.7 (CDRD Algorithm) | H-SAF (25-75ºN / 25ºW-45ºE ) | **Precipitation rate at ground from MW conical scanners (with indication of phase)** | **Bayesian approach<br>Quality Index, Precipitation Phase<br>Coherent with H02** |
| H02A v2.4 (PNPR Algorithm) | H-SAF (25-75ºN / 25ºW-45ºE ) | **Precipitation rate at ground from MW cross-track scanners (with indication of phase)** | **Neural Network<br>Quality Index, Precipitation Phase<br>Coherent with H01** |
| H03 | H-SAF (25-75ºN / 25ºW-45ºE ) | **Precipitation rate at ground from GEO/IR supported by LEO/PMW** | **Operational product (quality flag)<br>Use of H01 v1.7 and H02 v2.4<br>Use PMW rainfall map to calibrate MSG IR brightness temperatures** |
| H04 | H-SAF (25-75ºN / 25ºW-45ºE ) | **Precipitation rate at ground from LEO/PMW "advected" by GEO/IR.** | **Non-real time product<br>Use of H02 v2.4<br>Use of MSG IR brightness temperatures to advect the rain fields as retrieved by the PMW** |
| H01 v2 (CDRD Algorithm) | Full MSG Disk | **Precipitation rate at ground from MW conical scanners (with indication of phase)** | **Uses a new cloud radiation database over Full Disk area<br>Improved detection over arid surface** |
| H02B (PNPR Algorithm) | Full MSG Disk | **Precipitation rate at ground from MW cross-track scanners (with indication of phase)** | **Combined use of two neural network<br>Improved detection over arid surface** |
| H03B | Full MSG Disk | **Precipitation rate at ground from GEO/IR supported by LEO/PMW** | **Operational product (quality flag)<br>Use of H01 v1.7 and H02 v2.4<br>Use PMW rainfall map to calibrate MSG IR brightness temperatures** |

# PMW precipitation retrieval in H-SAF: Goal and Motivations

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**The goal is to provide precipitation products optimized for Europe/Mediterranean areas and other regions in MSG full disk area (Africa and Southern Atlantic) and achieve *accuracy* and *consistency* of precipitation retrieval from *all* the available cross-track and conically scanning radiometers, for all precipitation regimes and surface/environmental conditions**

**Outcomes:**

- **Optimal precipitation monitoring;**
- **Improvement in products based on morphing/blending techniques of MW/IR observations** for monitoring precipitation at higher spatial/temporal resolution (strongly dependent on quality, consistency, and number/frequency of PMW observations);
- Impact on **hydrological applications** (relying on MW/IR combined products).

**New Opportunities:**

**GPM**: PMW satellite observations has now reached optimal configuration (< 3 hour time interval globally) with best available instruments (GMI+DPR) which needs to be exploited;

**Collaboration between EUMETSAT H-SAF and GPM**: No-cost proposal approved by NASA PMM Program on:

- ***precipitation retrieval algorithm development***: interaction on several critical aspects of interest both to H-SAF and GPM (i.e., snow/light precip. at high latitudes, impact of orography)
- ***validation activity***: connection between the well established H-SAF product validation and hydrological validation programs and the Ground Validation/Calibration activity of GPM

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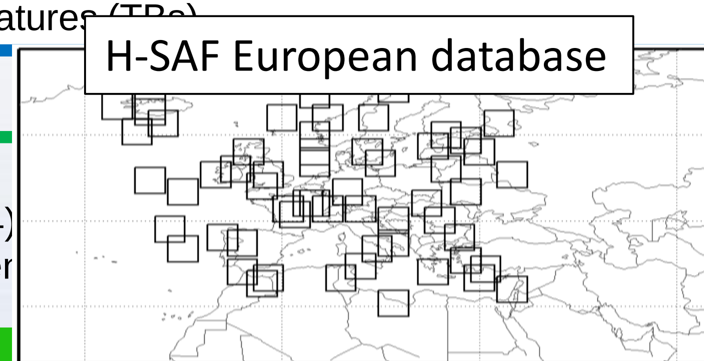
# H01 and H02 common features

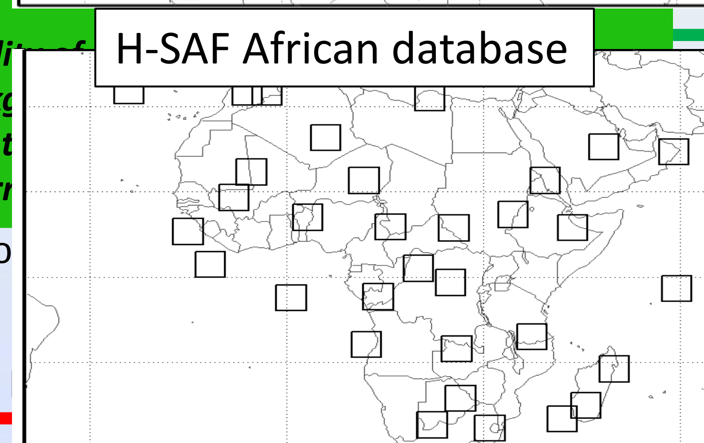
## The H01 and H02 algorithms are based on the same physical foundation

- Both algorithms use a **common database** made up of millions of microphysical-meteorological profiles derived from high resolution simulations (three nested grids; third grid at 2.5 km resolution) over the regions of interest (H-SAF area, Africa, Southern Atlantic) produced by a cloud resolving model (UW-NMS);
- A radiative transfer model is used to calculate brightness temperatures (TBs).




- Screening procedure (based on Chen and Staelin, 2003);
- New screening procedure for arid surfaces (Casella et al. 2014)
- Phase flag determination procedure (Grody et al. (2000), Roser (2009).
- Quality index determination procedure.

Based on:
***Quality of***
***Backg***
***Event***
***Interr***




**Main differences between H01 and H02:**

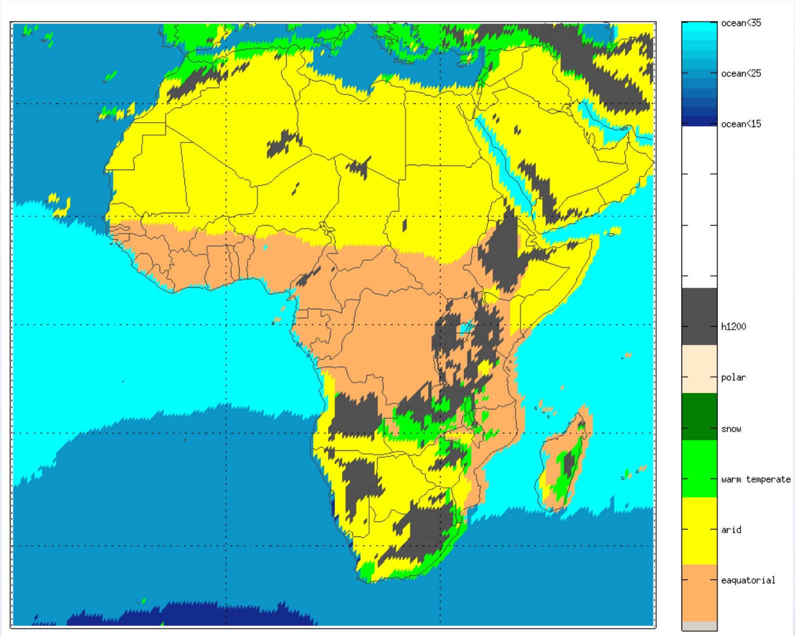
- Retrieval technique;
- Radiometer characteristics (i.e. scan geometry, spatial resolutio
  - Product spatial resolution:
    - H01: ≅15 km (SSMIS 89 GHz channel resolution);
    - H02: from 16 x 16 km$^2$ / circular at nadir to 26 x 52

94 simulations (60 for European Db and 34 for African DB)

# H01 (CDRD) and H02 (PNPR): Extension to MSG full disk

In order *to cover as much as possible* the climatic variability of the African continent with a limited number of simulations, we have identified different climatic regions, and we have used TRMM PR observations (2006-2007, for consitency with European DB) TRMM PR overpasses we have used “Rain Type” and “Freezing Level Height” in order to select specific events over a specific climatic region.

Climatic Regions




- Simulation of 34 events with NMS Cloud Resolving Model over Africa
- Modification of the emissivity model to include desert
- Creation of a Database (Cloud Dynamics and Radiation Database) for conical scanner SSMIS and for Cross track AMSU-MHS radiometers
- Every Simulation has been compared with LEO-PMW, GEO-IR and with TRMM-PR observations.
- New Neural Network trained with the extended database
- Improvement of the precipitation detection algorithm over arid surface in both full disk PMW products

# New Precipitation Detection Algorithm over Arid Surface

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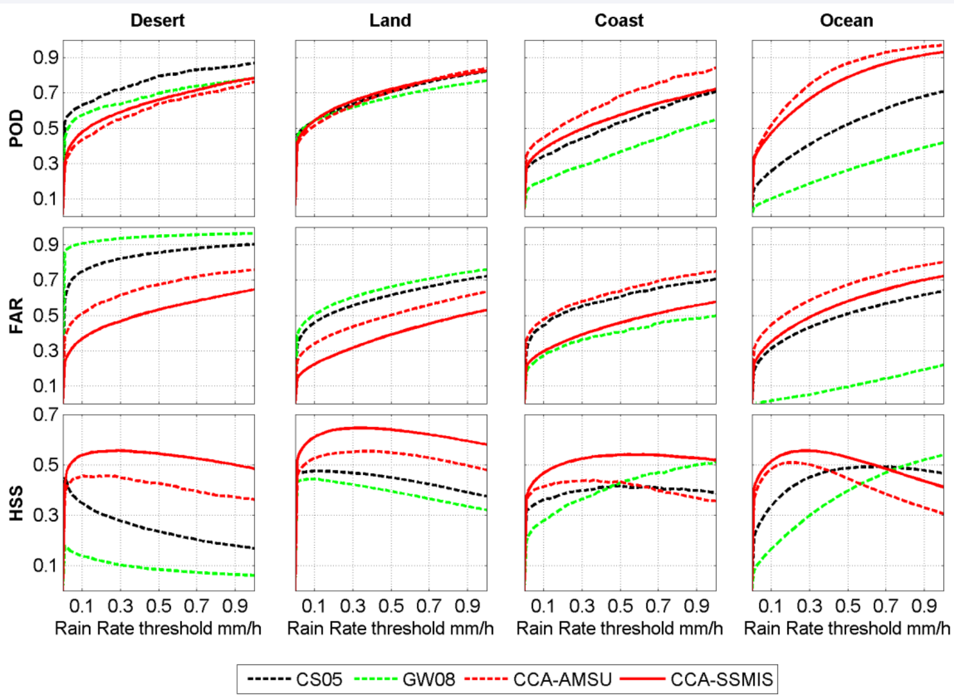
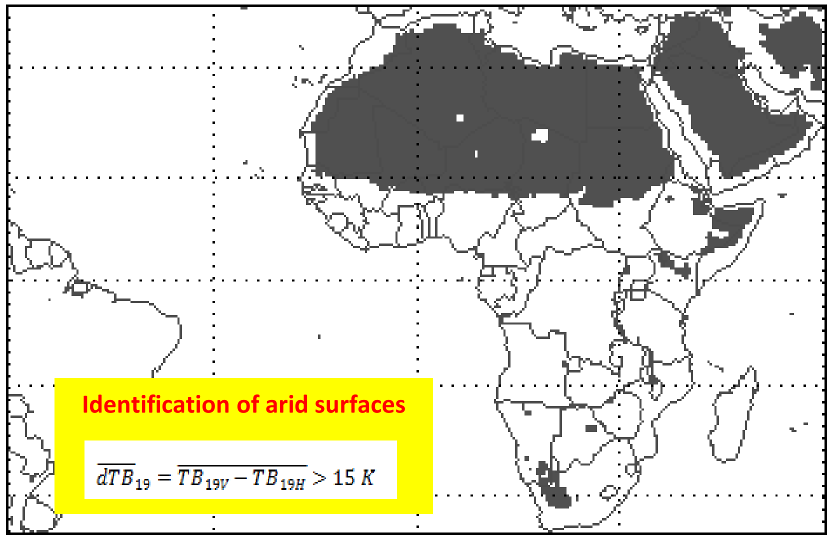
Algorithm based on the application of canonical correlation analysis (**CCA**), in order to select the linear combination of TBs which has the **maximum correlation with rain rate**, and on the **definition of a threshold to discriminate rain/ no rain pixels**.




$$HSS = \frac{2(hc - fm)}{(h+m)(m+c)+(h+f)(f+c)}$$

***h, m, f, c* are the fractional *hits*, *misses*, *false detections*, and *correct rejections***

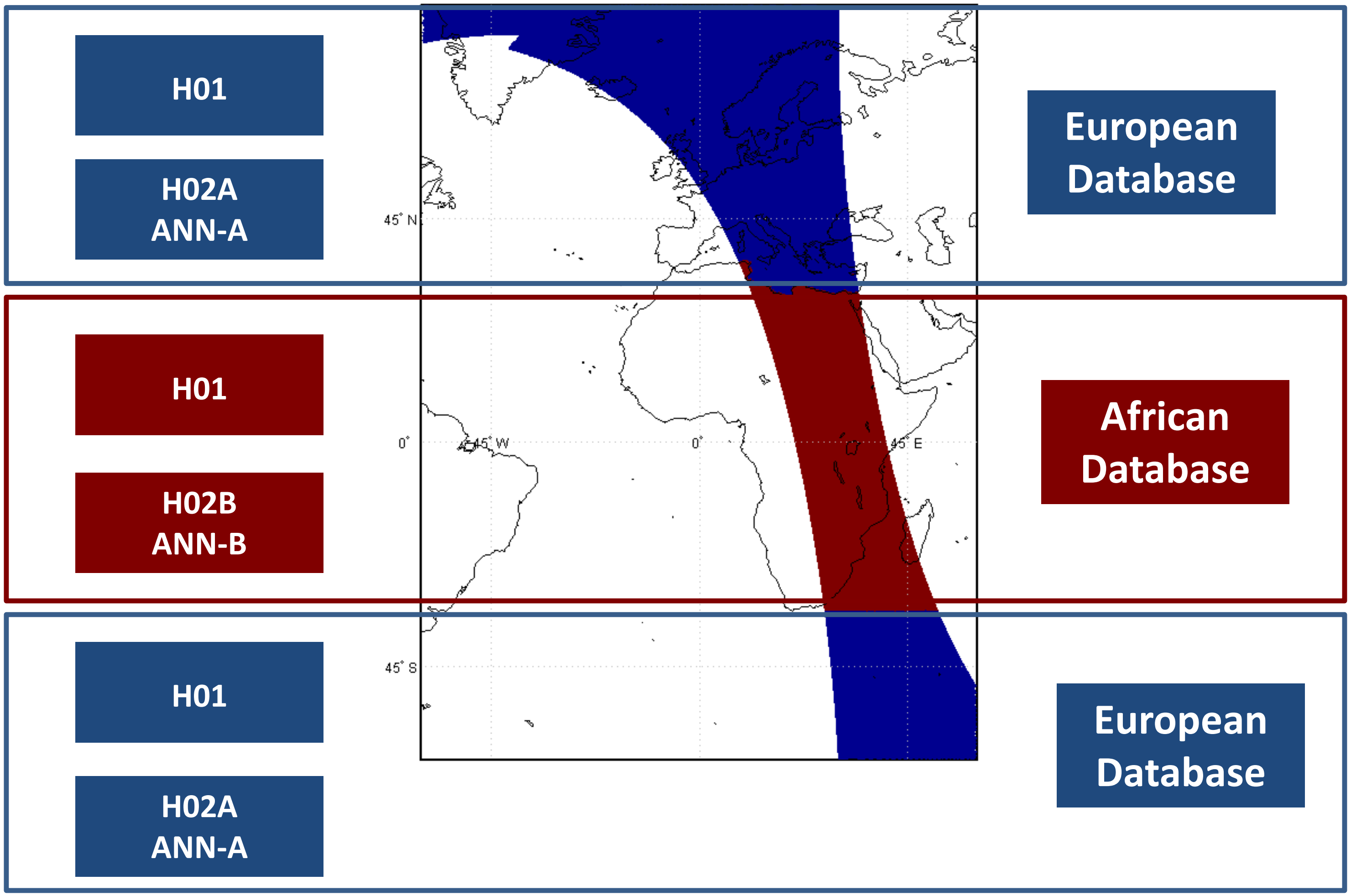



Comparison of the CCA-SSMIS and CCA-AMSU algorithm with other similar algorithm for the detection of precipitation using as ground truth for the precipitating pixels the PR- rain rate with a variable threshold (represented in the x axis).

**CS05**
Chen and Staelin (TGRS, 2003)
**GW08**
Grody and Weng (TGRS, 2008)

D. Casella, G. Panegrossi, P. Sanò, L. Milani, M. Petracca, and S. Dietrich, A novel algorithm for detection of precipitation in tropical regions using PMW radiometers, Atmos. Meas. Tech. Disc, doi:10.5194/amtd-7-9237-2014.

# H01 & H02 :
# Algorithms and Databases Optimization over full disk area



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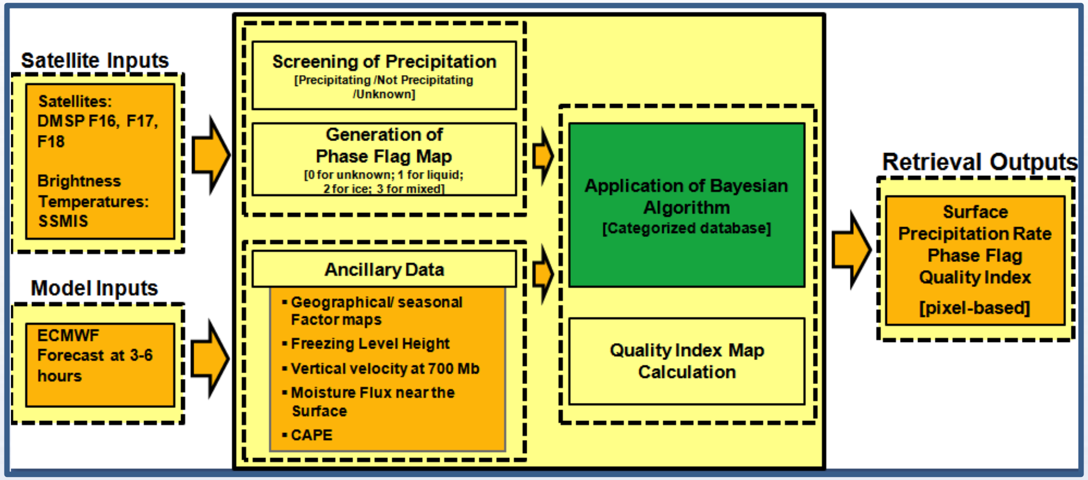
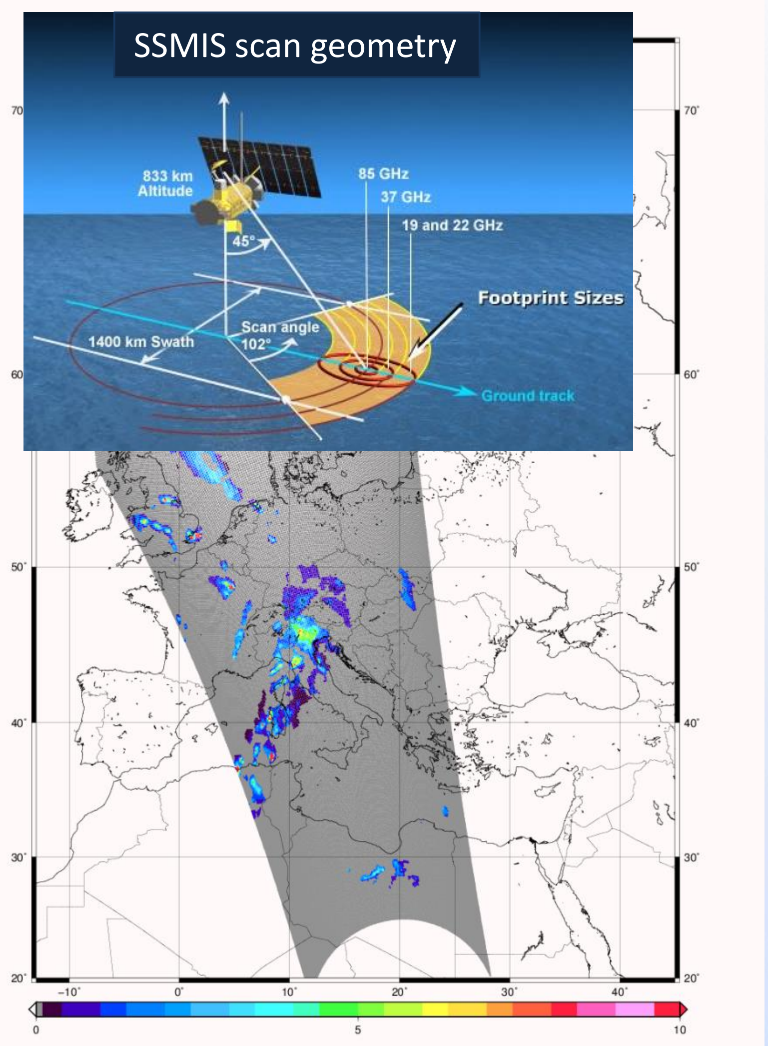
# H01: Cloud Dynamics and Radiation Database (CDRD)
# Bayesian Algorithm for conical scanners

(Sanò et al., TGRS, 2013, Casella et al., TGRS, 2013; Smith et al., Mugnai et al., NHESS, 2013)




- Use of MW conical scanners (Tb) (DMSP-SSMIS);
- Physically-based Bayesian technique;
- *A synthetic a-priori* database built from cloud model generated microphysical profiles coupled to RTE model;
- Use of dynamical-thermodynamical-hydrological (DTH) model-derived variables to reduce *ambiguity* problem of retrieval solution; DTH variables from ECMWF forecast/analysis are used as additional input;
- Precipitation phase and Quality index evaluation.
- Proc. Time: < 2 min (H-SAF area), Hor. Res.: ≅15 km

# Internal Validation: 24 H-SAF Case Studies

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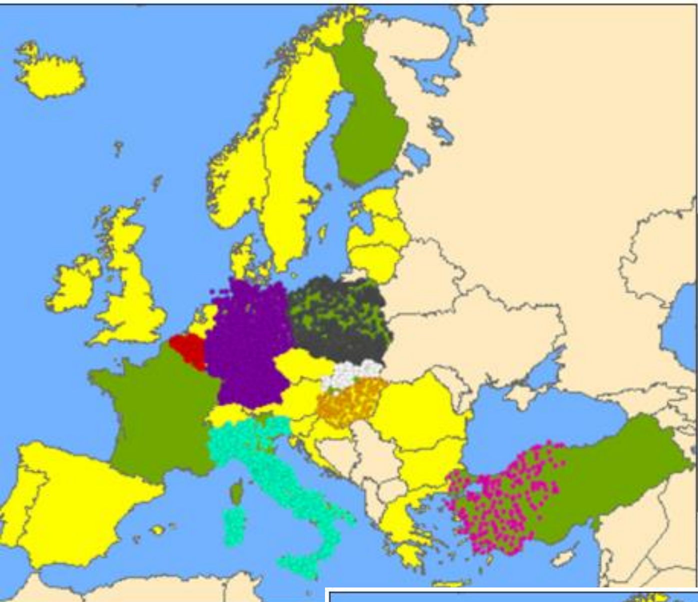
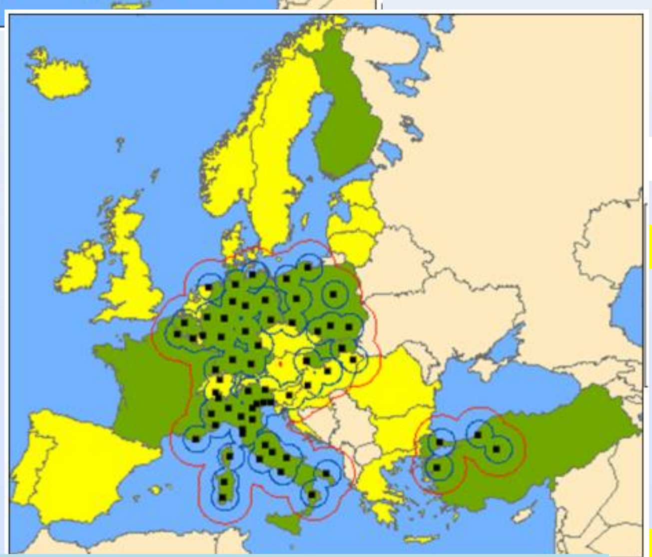


**H-SAF rain gauges network**

| date | region | Brief description |
|---|---|---|
| 10/20/2011 | Italy | Rome Flood |
| 10/25/2011 | Italy | 5 Terre Flood |
| 11/4/2011 | Italy | Genoa Flood |
| 03-04/02/2012 | Italy | Snow storm - Central Italy |
| 10-11/02/2012 | Italy | Snow storm – Central Italy |
| 21-22/12/2009 | Italy | Snow storm Northern Italy |
| 1/20/2009 | Italy | Stratiform |
| 6/20/2009 | Italy | Convective |
| 1/14/2009 | Italy | Frontal precipitation event-rain/snow |
| 1/12/2009 | Hu | Frontal precipitation-rain |
| 10/2/2009 | Hu | Snowfall |
| 17/9/2009 | Hu | Light stratiform |
| 10/9/2010 | Hu | Severe Thunderstorm/Convection |
| 23/6/2011 | Hu | Convective |
| 30/7/2011 | Hu | Severe Thinderstorm |
| 11/5/2009 | PL | Convective |
| 23/6/2009 | Pl | Convective |
| 7/6/2011 | SK | Orografic Precipitation |
| 23/12/2009 | SK | Melting snow on frozen soil |
| 28/11/2010 | SK | Snowfall |
| 13/11/2010 | BE | Winter stratiiform heavyy rain event |
| 7/8/2010 | GE | Convective |
| 3/6/2010 | GE | Convective |
| 05-06/12/2010 | GE | Winter frontal precipitation |

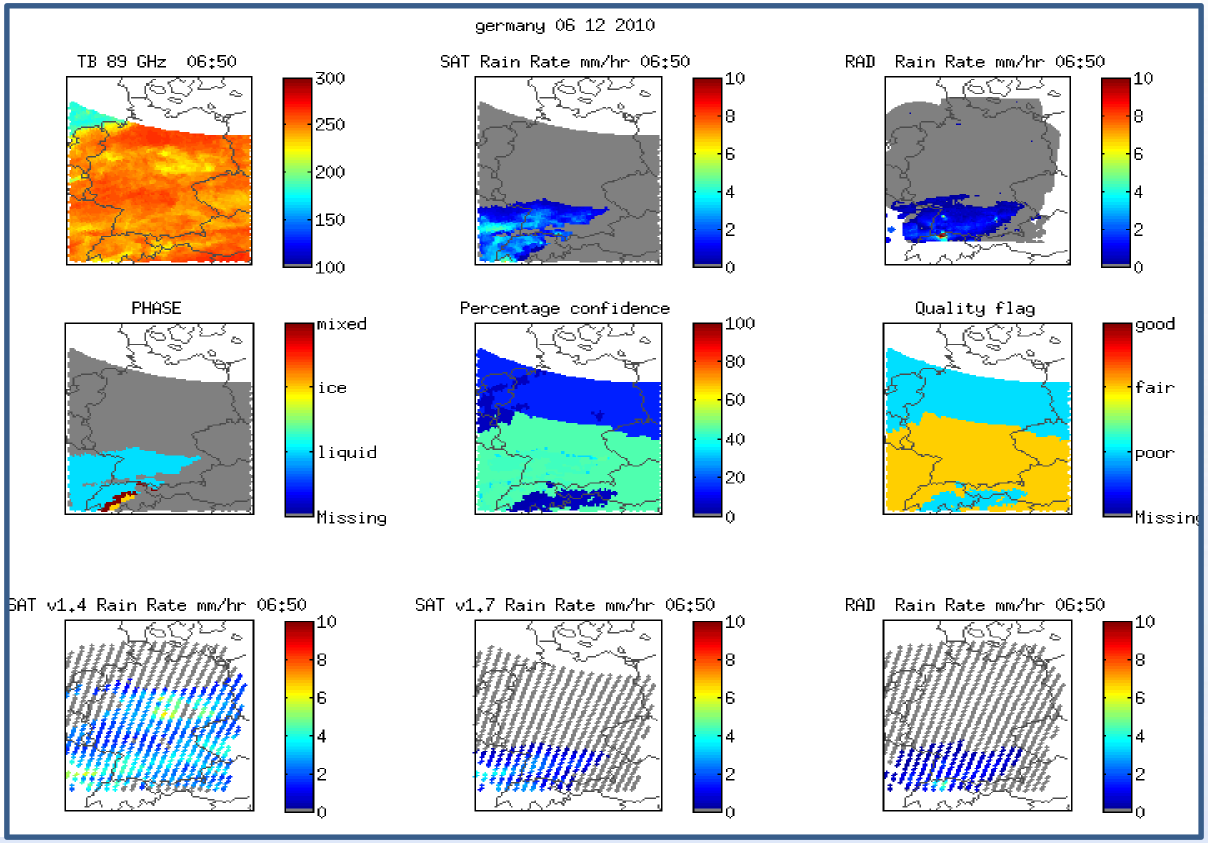


**H-SAF radar network**

**H-SAF area (25°N to 75°N lat - 25°W to 45°E lon)**

# H01 - CDRD Algorithm

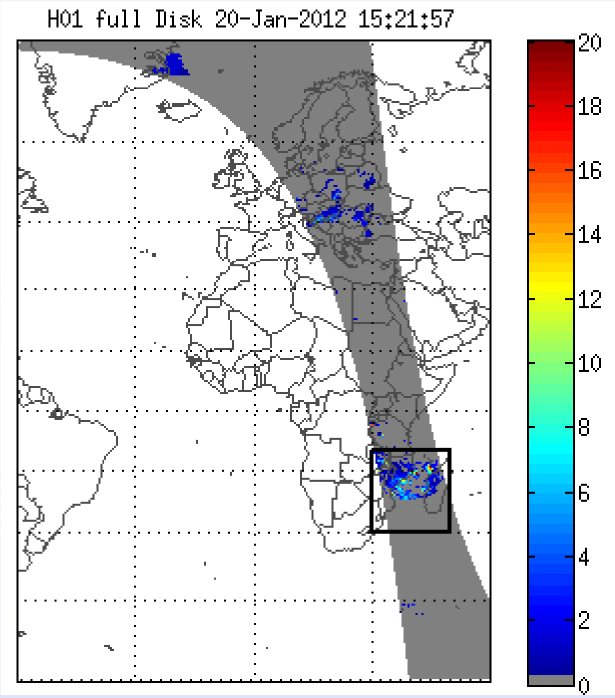
## GERMANY 6 December 2010 – Winter frontal precipitation

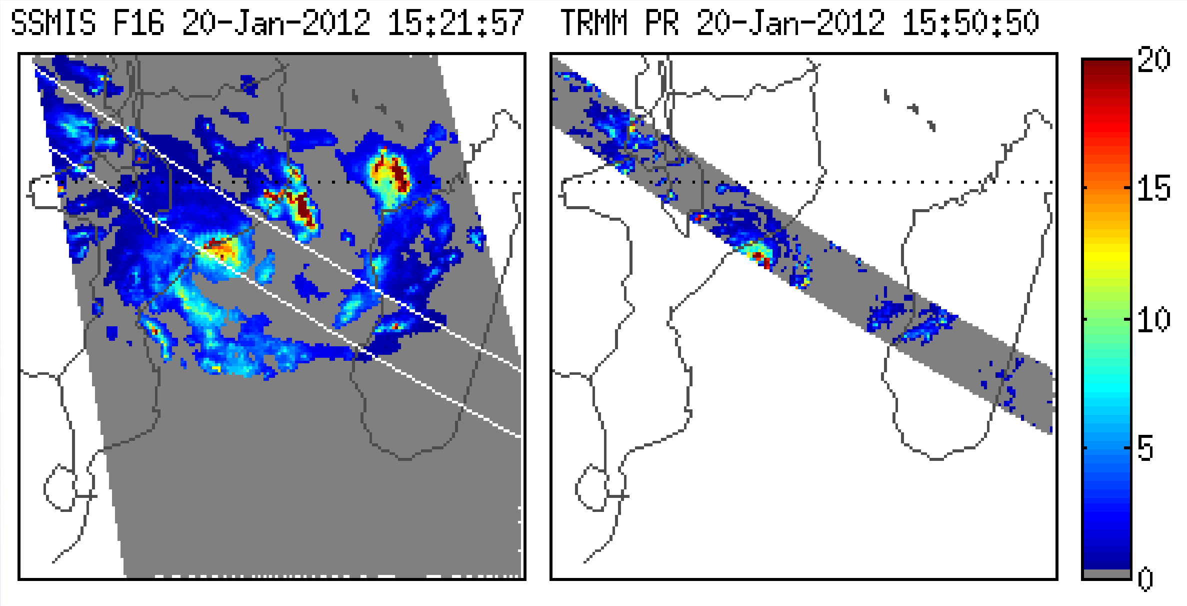



**H01: improvement of screening and snow detection**

| | GE3 05-06/12/2010 | |
|---|---|---|
| | RAD | |
| | v1.4 | v1.7 |
| NUM | 1330 | 1327 |
| ME | 1.06 | 0.03 |
| SD | 2.57 | 0.74 |
| RMSE | 1.80 | 0.74 |
| FSE% | 262.52 | 108.56 |
| CC | 0.20 | 0.45 |
| POD | 0.64 | 0.66 |
| FAR | 0.74 | 0.54 |
| CSI | 0.23 | 0.37 |

# CASE STUDY: Tropical Cyclone FUNSO
# Algorithm: H01 (CDRD)




Tropical cyclone Funso formed in the Mozambique channel off the coast of Mozambique on 19 January 2012. Storms and floods from Funso have killed at least 22 people and forced tens of thousands from their homes in Mozambique.

# H02: PMW Neural-net Precipitation Retrieval (PNPR) Algorithm for cross-track scanners

(Mugnai et al., NHESS, 2013b, Sanò et al., AMTD, 2014)

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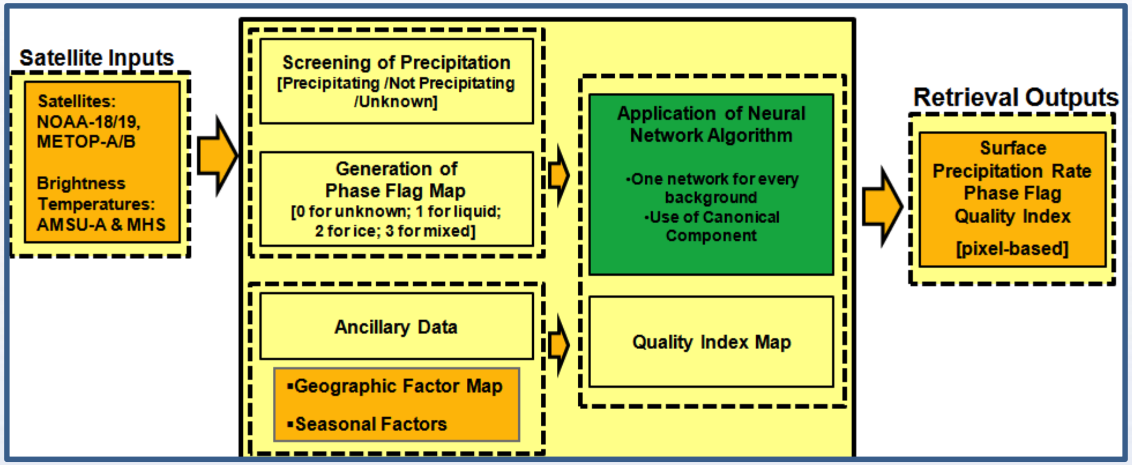
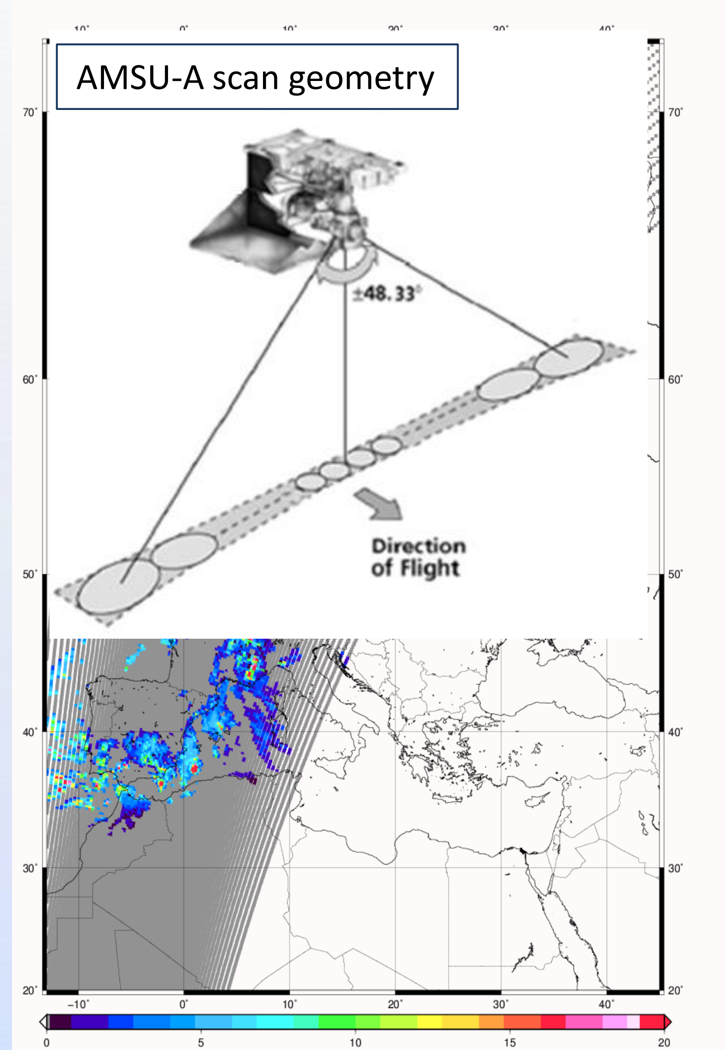
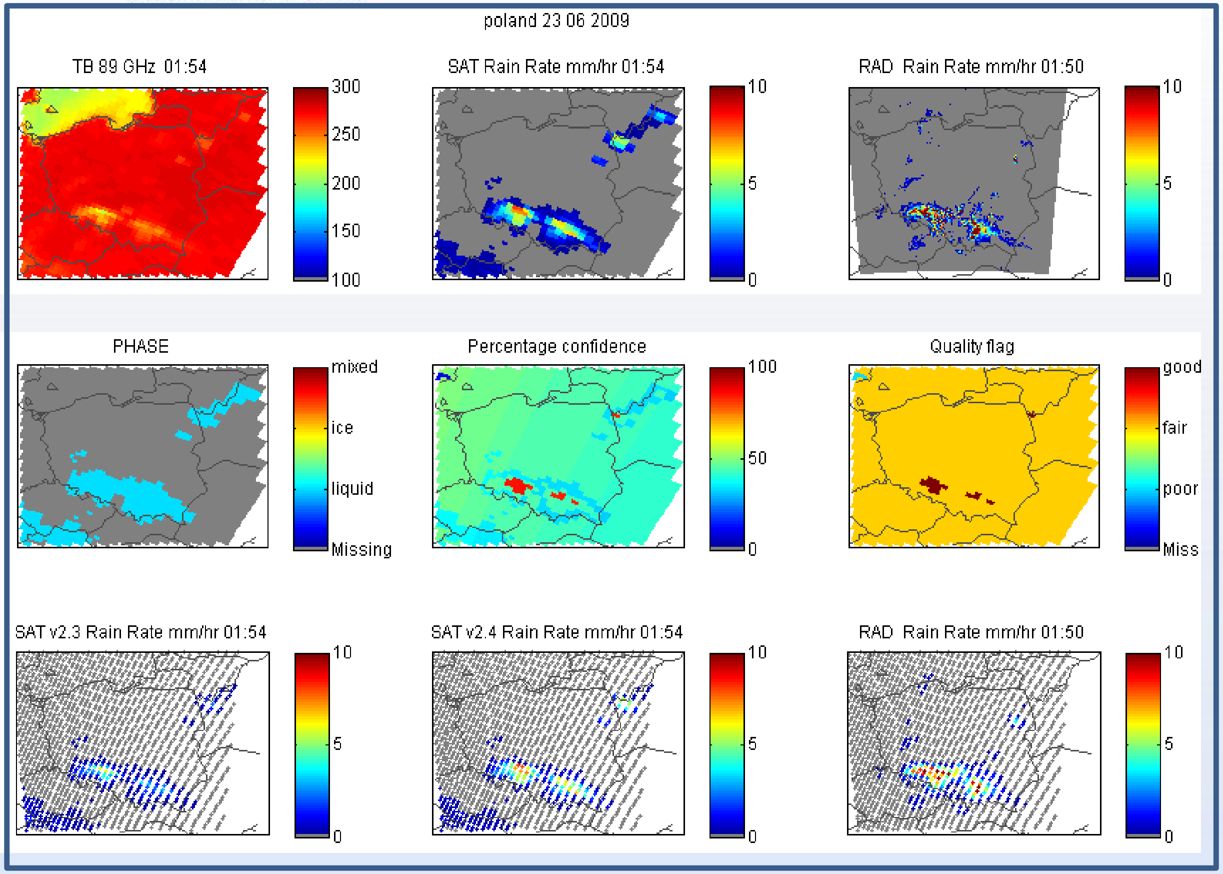



- Use of MW cross-track scanners (Tb) (NOAA and MetOp);
- Training database built from same cloud resolving simulations as CDRD;
- New optimal Artificial Neural Network (ANN) algorithm, one ANN for all surface backgrounds;
- The Full Disk Algorithm uses two ANNs (ANN-A for European Area, ANN-B for African Area) trained by the two Databases.
- Correction of MetOp-A channel [AMSU-A Channel 7 (54 GHz)] using a specific ANN.
- Input: AMSU-A/MHS channels, additional channel derived variables;
- Geographycal inputs (i.e., latitude, season, topography) used as additional input;
- Precipitation phase and Quality index evaluation
- Proc. Time: < 30 sec (H-SAF area), Hor. Res.: ≅16-50 km



# H02 - PNPR Algorithm
# POLAND 3 June 2009 – Convective precipitation




**H02: improvement of detection and retrieval for convective cells**

| | PO2 23/6/2009 | |
|---|---|---|
| | RAD | |
| | v2.3 | v2.4 |
| NUM | 403 | 403 |
| ME | -1.46 | -0.52 |
| SD | 3.54 | 2.36 |
| RMSE | 2.48 | 2.18 |
| FSE% | 101.76 | 89.73 |
| CC | 0.70 | 0.73 |
| POD | 0.79 | 0.79 |
| FAR | 0.56 | 0.56 |
| CSI | 0.39 | 0.40 |

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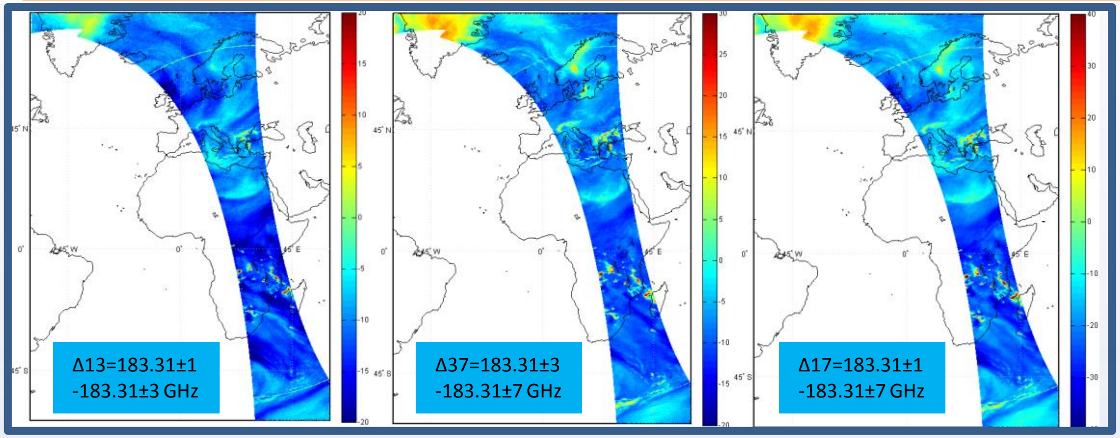
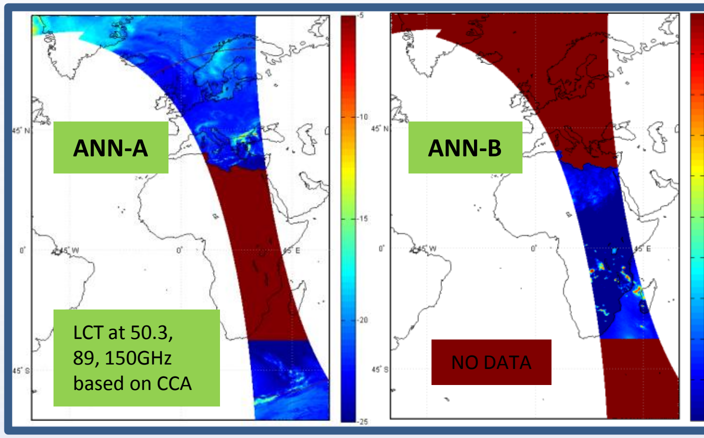
# CASE STUDY: 06-Jan-2012 18:09 Satellite: METOP-A
# Convective event over Mozambique and Madagascar Regions

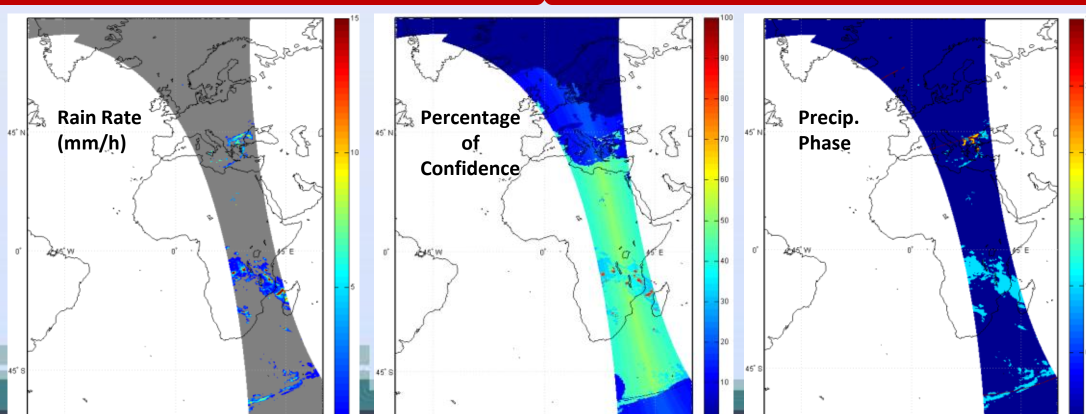
**H02 Input**




**Additional Inputs: Surface type, Latitude, Season, Surface height, Zenith angle.**

H02




**H02 Output**

# CASE STUDY: 06-Jan-2012 18:09 Satellite: METOP-A Algorithm: H02 (PNPR)

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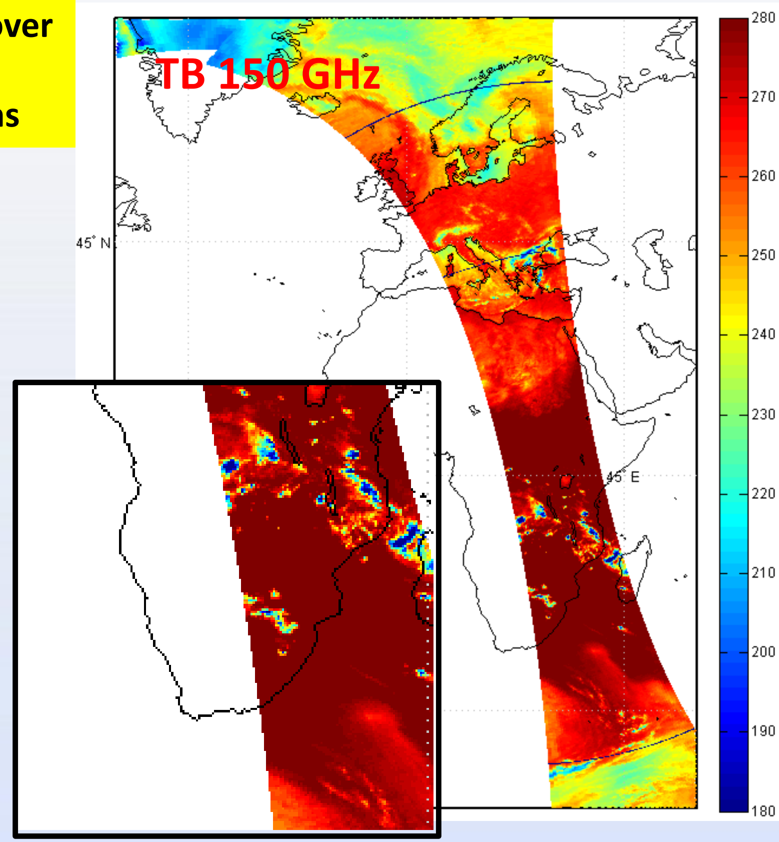
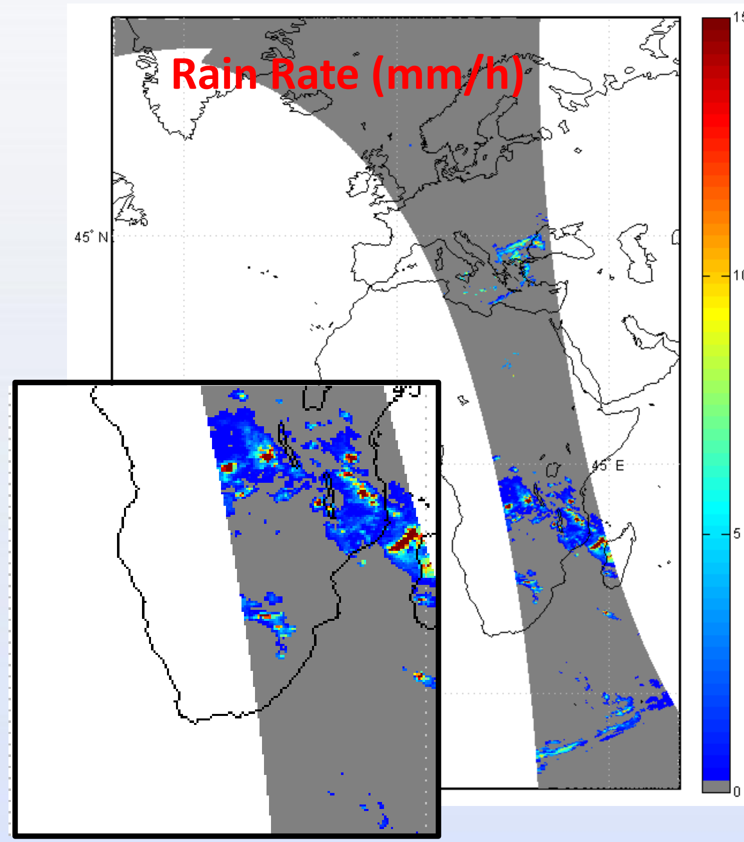
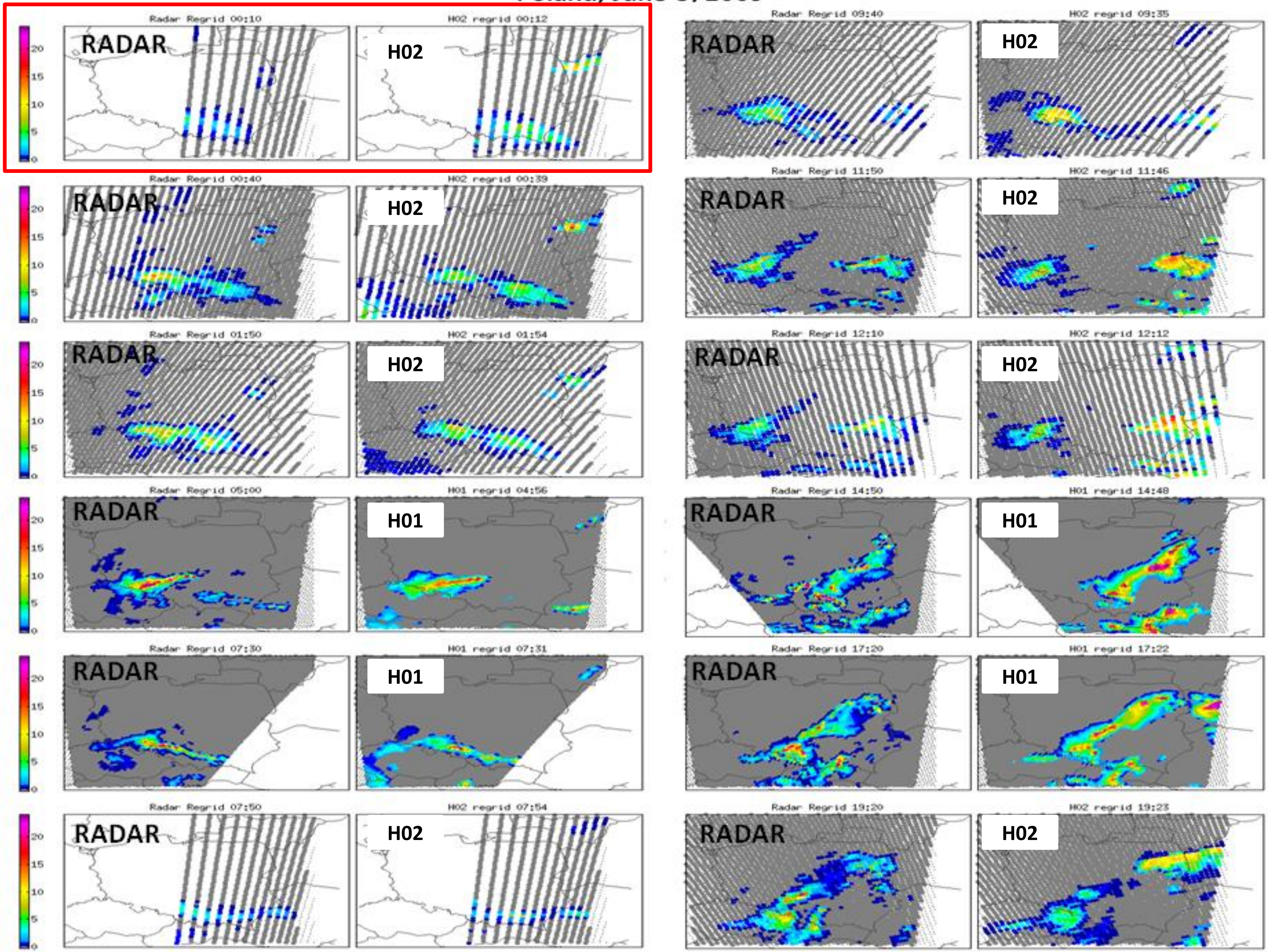
**Convective event over Mozambique and Madagascar regions**



Poland, June 3, 2009



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# Validation over Africa using TRMM PR

- The study was carried out in the area between 36° S–36° N in latitude and 60° E–60° W in longitude, covering the African continent, part of the Arabian Peninsula, part of the Southern American continent and part of the Atlantic and Indian Ocean.

- The analysis was performed considering coincident observations (15 min time window) of the Tropical Rainfall Measuring Mission (TRMM) precipitation Radar (PR) with observations from SSMIS and AMSU/MHS radiometers in the years 2011 and 2012.

- Two datasets have been created (SSMIS-PR and AMSU/MHS-PR coincidences) with a total of 5247 (AMSU/MHS) and 2149 (SSMIS) coincident overpasses.

- To obtain co-located vectors of SSMIS or AMSU/MHS brightness temperatures (TBs) and PR rainfall estimates (TRMM product 2A25), we have downscaled the TRMM-PR data to the MW radiometers nominal resolutions (the IFOV size of the 91GHz/89GHz channel for the SSMIS/MHS radiometer respectively).

**The downscaling to the radiometer nominal resolution, varying with the scan angle for AMSU/MHS, and not to a common grid (i.e. 0.5°x0.5° regular grid), is due to our goal of obtaining a pixel based (i.e., precipitation product resolution) validation and a more accurate assessment of the algorithms performance.**

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# H02 (PNPR) Algorithm – Preliminary validation results

## CONTINGENCY TABLES

The percentages shown in a given column are computed with respect to the total number of H02 samples (2.2 million) and represent how the H02 product classifies the events assigned to that class by the TRMM-PR.

- H02 correctly identify pixels with no rain.
- There is a general tendency of the H02 to underestimate the precipitation.

H02/PNPR

### TRMM-PR

| Total | Rad < 0.25 (NO Rain) | 0.25≤ Rad < 1.0 | 1.0≤ Rad < 10.0 | Rad ≥10.0 |
|---|---|---|---|---|
| 0.00≤ Sat < 0.25 | **98.3%** | **70.2%** | 32.1% | 2.5% |
| 0.25≤ Sat < 1.0 | 0.7% | 6.4% | 6.2% | 1.3% |
| 1.0≤ Sat < 10.0 | 0.9% | 21.9% | **50.6%** | **49.3%** |
| Sat ≥10.0 | 0,0% | 1.4% | 11.0% | 47.0% |
| **Land** | **0.00≤ Rad < 0.25** | **0.25≤ Rad < 1.0** | **1.0≤ Rad < 10.0** | **Rad ≥10.0** |
| 0.00≤ Sat < 0.25 | **98%** | **56.8%** | 22.7% | 2.0% |
| 0.25≤ Sat < 1.0 | 1.3% | 15.3% | 11.4% | 2.5% |
| 1.0≤ Sat < 10.0 | 0.6% | 26.9% | **55.7%** | **48.0%** |
| Sat ≥10.0 | 0.0% | 0.9% | 10.1% | 47.4% |
| **Coast** | **0.00≤ Rad < 0.25** | **0.25≤ Rad < 1.0** | **1.0≤ Rad < 10.0** | **Rad ≥10.0** |
| 0.00≤ Sat < 0.25 | **97,8%** | **68.2%** | 37.6% | 1.5% |
| 0.25≤ Sat < 1.0 | 1.3% | 8.7% | 5.9% | 0.0% |
| 1.0≤ Sat < 10.0 | 0.9% | 22.2% | **47.6%** | 27.7% |
| Sat ≥10.0 | 0.0% | 0.8% | 8.9% | **70.8%** |
| **Ocean** | **0.00≤ Rad < 0.25** | **0.25≤ Rad < 1.0** | **1.0≤ Rad < 10.0** | **Rad ≥10.0** |
| 0.00≤ Sat < 0.25 | **98.4%** | **78.8%** | 42.5% | 2.9% |
| 0.25≤ Sat < 1.0 | 0.3% | 0.8% | 0.5% | 0.0% |
| 1.0≤ Sat < 10.0 | 1.2% | 18.7% | **45.0%** | **51.8%** |
| Sat ≥10.0 | 0.0% | 1.6% | 12.1% | 45.2% |
| **Desert** | **0.00≤ Rad < 0.25** | **0.25≤ Rad < 1.0** | **1.0≤ Rad < 10.0** | **Rad ≥10.0** |
| 0.00≤ Sat < 0.25 | **99.6%** | **71.6%** | 32.8% | 4.3% |
| 0.25≤ Sat < 1.0 | 0.1% | 4.0% | 3.3% | 0.0% |
| 1.0≤ Sat < 10.0 | 0.3% | 23.4% | **51,4%** | **54.3%** |
| Sat ≥10.0 | 0.0% | 0.9% | 12,5% | 41.3% |

# H02 Algorithm – Preliminary validation results

## Continuous statistical scores

The scores show a quite good agreement between H02 and TRMM-PR data (values of CC ranging from 0.58 for desert surface to 0.71 for coast area).
Mean Error 0.08 -0.21mm/h and RMSE of 1.91-2.21mm/h are obtained.

| | Land | Ocean | Coast | Desert |
|---|---|---|---|---|
| PIXEL N. | 1182872 | 1019600 | 31120 | 328301 |
| ME | 0,14 | 0,21 | 0,146 | 0,08 |
| RMSE | 2,21 | 2,19 | 2,09 | 1,91 |
| SD | 2,23 | 2,22 | 2,1 | 1,92 |
| CC | 0,64 | 0,62 | 0,71 | 0,58 |

# H02 (PNPR) Algorithm – Preliminary validation results

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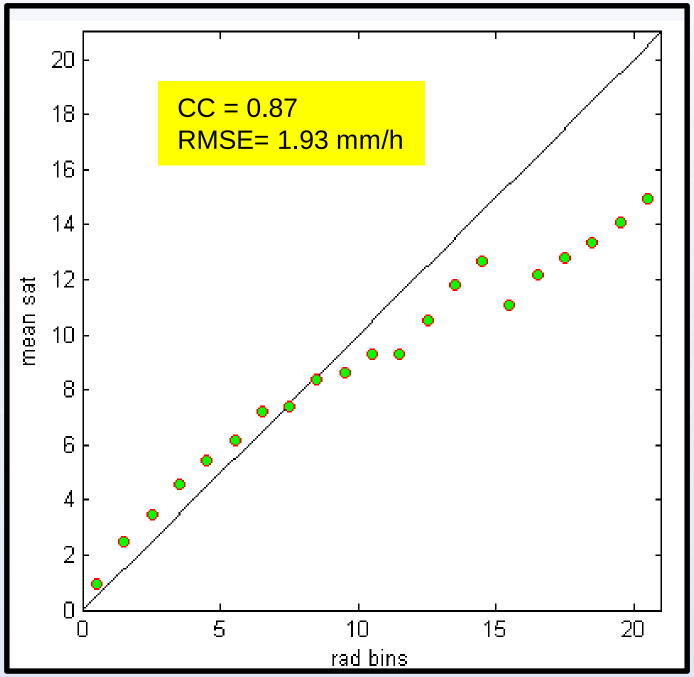
## Binning Analysis

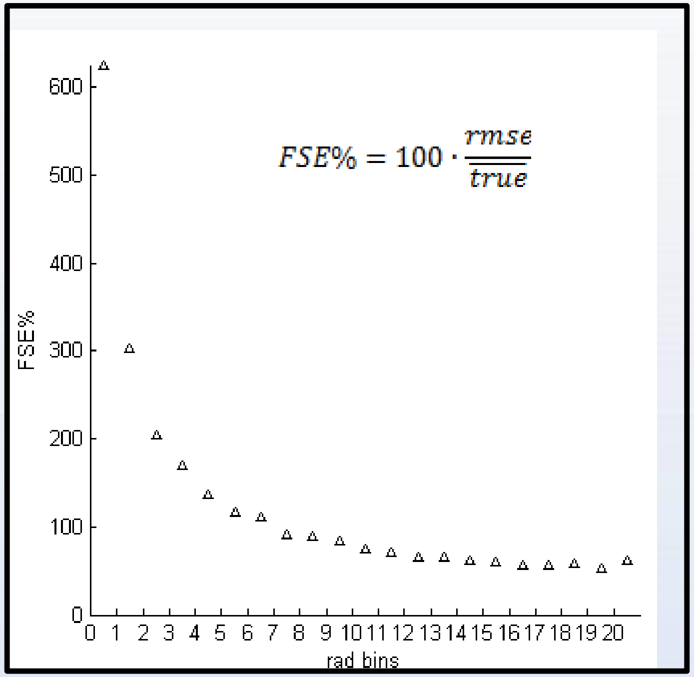
**Only pixels classified as rainy by the TRMM-PR (RR> 0.25 mm/h) are considered.**

The analysis shows very good agreement for RR < 10 mm/h, slightly worse at higher RR (CC = 0.87, RMSE= 1.93 mm/h.

FSE < 100% for RR > 7 mm/h.




Mean H02 (PNPR) retrieved values reported as a function of the 1 mm/h rain rate bins of TRMM-PR measurements.



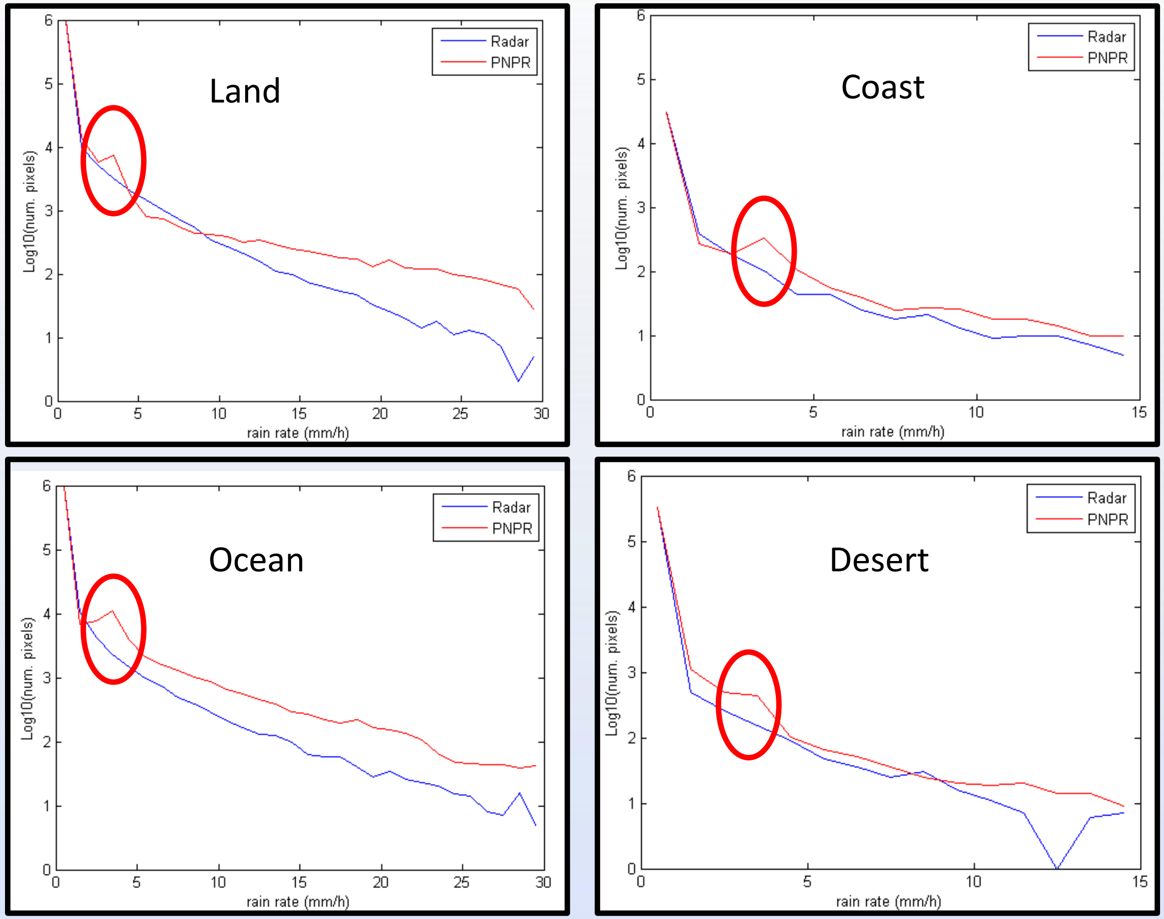

Fractional standard error percentage (FSE%) values obtained for the retrievals within each bin.

# H02 (PNPR) Algorithm – Preliminary validation results

## PDF H02 and TRMM-PR

The PDFs show a fairly similar trend between H02 (PNPR) and TRMM-PR.

We are currently analyzing the reason for the peak around 3 mm/h



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# Conclusions

- H01 (Bayesian) and H02 (ANN) are our two different approaches used respectively for conical and cross-track scanning PMW radiometers for Europe/Mediterranean areas, recently extended to Africa and Southern Atlantic;
- Our priorities:
  1) achieve consistency (and accuracy) of retrievals among different sensors;
  2) exploit the full constellation of PMW radiometers for precipitation monitoring and to improve satellite-based products for hydrological applications;
  3) Promote international collaborations aimed at development/validation of PMW retrieval algorithms (H-SAF/GPM)

- Validation over Africa of H02 for AMSU/MHS using TRMM PR (2011-2012 ) (validation of CDRD for SSMIS in progress):
  - Pixel-based comparison (at high freq. channel resolution (16-50 km) dependent on scan viewing angle)
  - Very good ability to identify precipitation pattern variability;
  - Very low false alarm over all types of surfaces (including desert); Difficulty to detect very low precipitation; good statistics for medium/high precip.;
  - Over the all period;  ME 0.08 -0.21mm/h and RMSE of 1.91-2.21mm/h;
  - "Binning" analysis shows very good agreement for RR < 10 mm/h, slightly worse at higher RR (CC = 0.87, RMSE= 1.93 mm/h, FSE < 100% for RR > 7 mm/h.

H SAF
Support to Operational Hydrology and Water Management

# Future development

**Further Analysis of validation results**:
Dependence on type of event;
Dependence on orography;
Comparison with H01;
Consistency between H02 and H01;

- **Algorithms in development:**
  - **H17** - Bayesian algorithm (using European and African DBs) for GCOM-W1 AMSR-2
  - **H18** - ANN algorithm (using European and African DBs) for NPP Suomi ATMS
  - **H19** - ANN algorithm (using European and African DBs) for GMI and use of DPR as additional input
  - **H20** - ANN trained using GMI and DPR global coincident observations (one year time period)

- **Further development in H01 and H02 algorithms (within H-SAF and in collaboration with NASA PMM)**
  - Improve detetection/retrieval of light precipitation (solid and liquid);
  - Impact of orography;
  - Evaluation of Bayesian vs. Neural Network approach for MW radiometers.
  - Evaluation of consistency of retrieval from different sensors (GPM constellation).

**Recent publications**


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- Sanò, P., et al.: Transitioning from CRD to CDRD in Bayesian retrieval of rainfall from satellite passive microwave measurements, Part 1: Algorithm description and testing, IEEE Trans. Geosci. Remote Sens., Vol. 51, no. 7, 4119-4143, doi: 10.1109/TGRS.2012.2227332, 2013
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- D. Casella, G. Panegrossi, P. Sanò, L. Milani, M. Petracca, and S. Dietrich, A novel algorithm for detection of precipitation in tropical regions using PMW radiometers, Atmos. Meas. Tech. Disc., doi:10.5194/amtd-7-9237-2014.
- P. Sanò, D. Casella, G. Panegrossi, F. Di Paola, L. Milani, A. Mugnai, M. Petracca, and S. Dietrich, The Passive microwave Neural network Precipitation Retrieval (PNPR) algorithm for AMSU/MHS observations: description and application to European case studies, submitted to Atmos. Meas. Tech. Disc. , doi:10.5194/amtd-7-1-2014.
- D. Casella, Sanò P., Panegrossi G., Mugnai A., Dietrich S., Extension of the CDRD algorithm over African continent within the H-SAF project. (in discussion).


# Thank you !!!


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