GOBIERNO DE ESPAÑA

MINISTERIO PARA LA TRANSICIÓN ECOLÓGICA

Agencia Estatal de Meteorología

# SATELLITE DERIVED PRECIPITATING PRODUCTS BASED ON A PRINCIPAL COMPONENT ANALYSIS

EUMETSAT NWC SAF

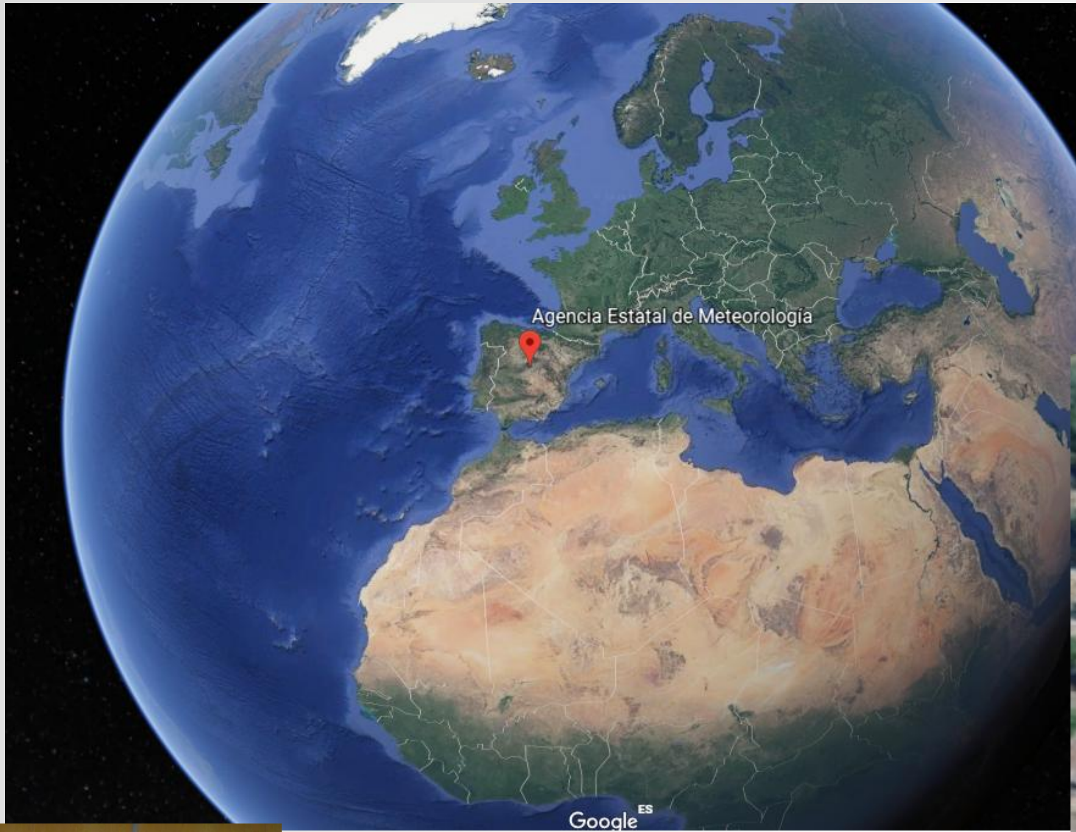
SUPPORT TO NOWCASTING AND VERY SHORT RANGE FORECASTING

NOWCASTING SAF USERS' WORKSHOP 2020

MADRID AEMET HQ

(10-12 MARCH 2020)

JOSÉ ALBERTO LAHUERTA





JOSÉ ALBERTO LAHUERTA
NWC SAF: PRECIPITATION
PRODUCTS DEVELOPER

# OVERVIEW:

1 NOWCASTING SAF, GENERAL VIEW

2 PRECIPITATING PRODUCTS:

- CONVECTIVE PRODUCTS: CRR , CRR-Ph
- OTHER PRECIPITATING PRODUCTS:
 PC , PC-Ph

3 NEW PROTOTIPE BASED ON A PRINCIPAL COMPONENT ANALYSIS

# 1. NOWCASTING SAF TEAM:

AEMet
Agencia Estatal de Meteorología
GOBIERNO DE ESPAÑA
MINISTERIO DE AGRICULTURA, ALIMENTACIÓN Y MEDIO AMBIENTE

METEO FRANCE

ZAMG
Zentralanstalt für Meteorologie und Geodynamik

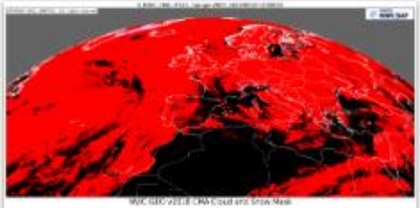
SMHI

METEO ROMANIA

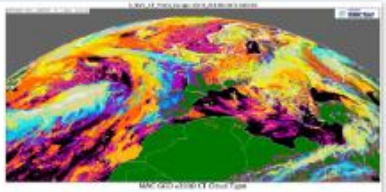
NWC/GEO Products v2018

www.nwcsaf.org

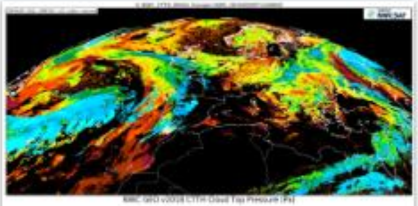
## Cloud Products



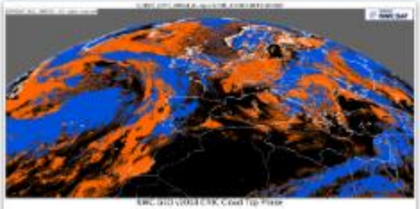
CMA: Cloud Mask



CT: Cloud Type

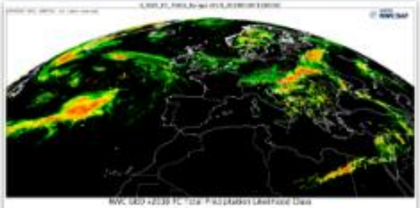


CTTH: Cloud Top Temperature and Height



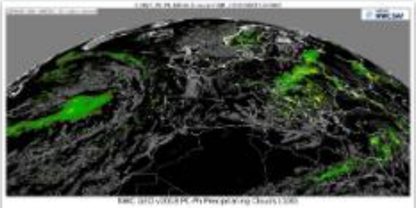
CMIC: Cloud Microphysics

## Precipitation Products

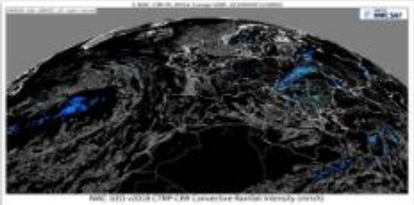


PC: Precipitating Clouds

CRR: Convective Rainfall Rate

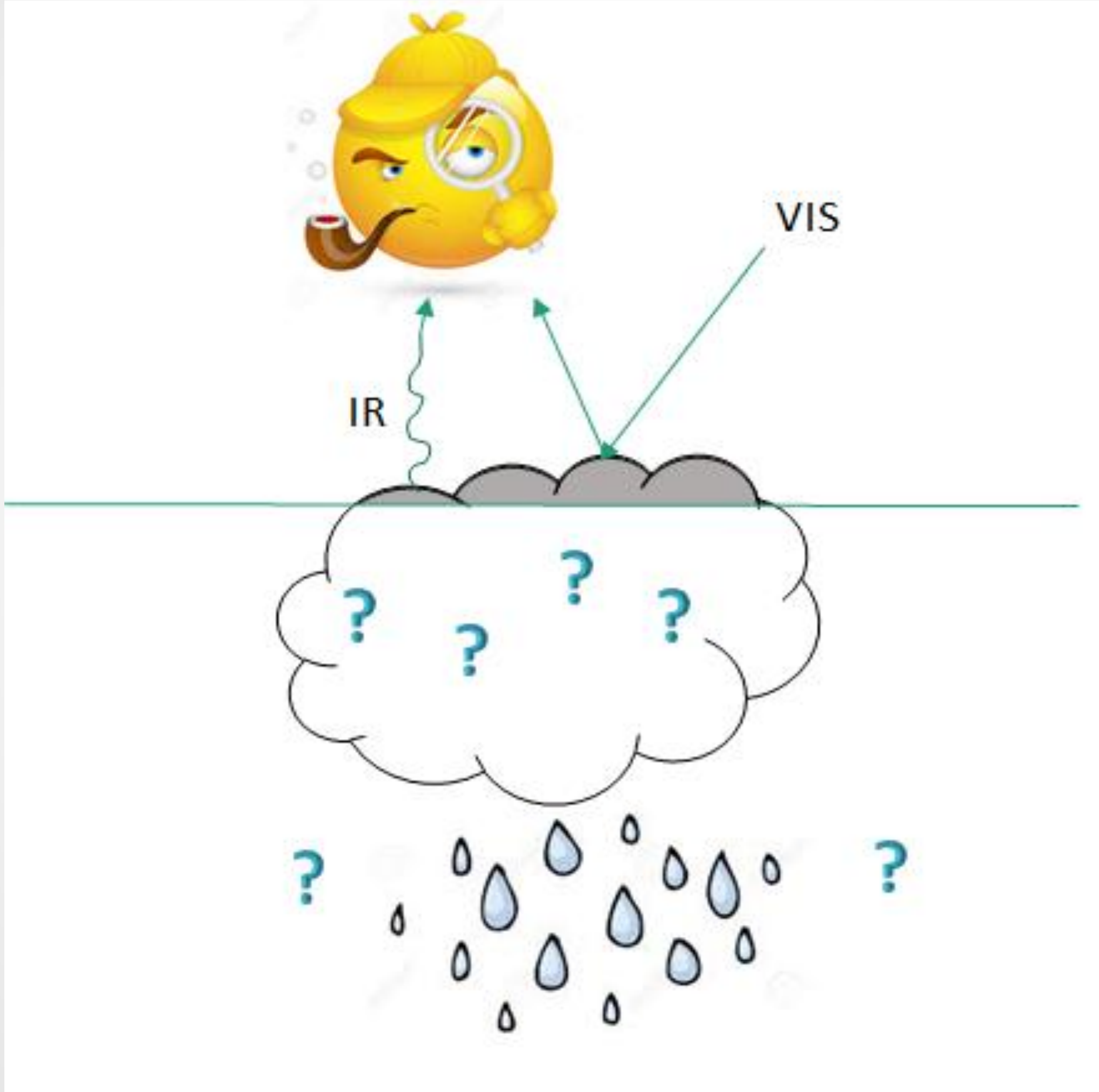


PC-Ph: Precipitating Clouds based on Cloud Physical Properties



CRR-Ph: Convective Rainfall Rate based on Cloud Physical Properties

# 2. PRECIPITATING PRODUCTS



- Rain drops are not visible from space. Visible and Infrared channels provide information of the upper part of the clouds . There is an indirect estimation of the precipitation.

- Despite this problem, it exits a kind of relation between the high of the cloud (IR channels), the density of the cloud (VIS channels) and the probability of rain and the rain rate.

- It also exits a connection between some microphysical properties such as the water content in the cloud, effective radius …. and precipitation.

# CONVECTIVE RAINFALL RATE (CRR)

INPUTS

**Satellite imagery:**
BT IR10.8 µm
WV 6.2 µm
VIS 0.6 µm

**NWP:**
Surface pressure ,T and dew point.
T at 1000,925,850,700,500 hPa.
HR at 1000,925,850,700,500 hPa.
Geopotencial (pressure levels)

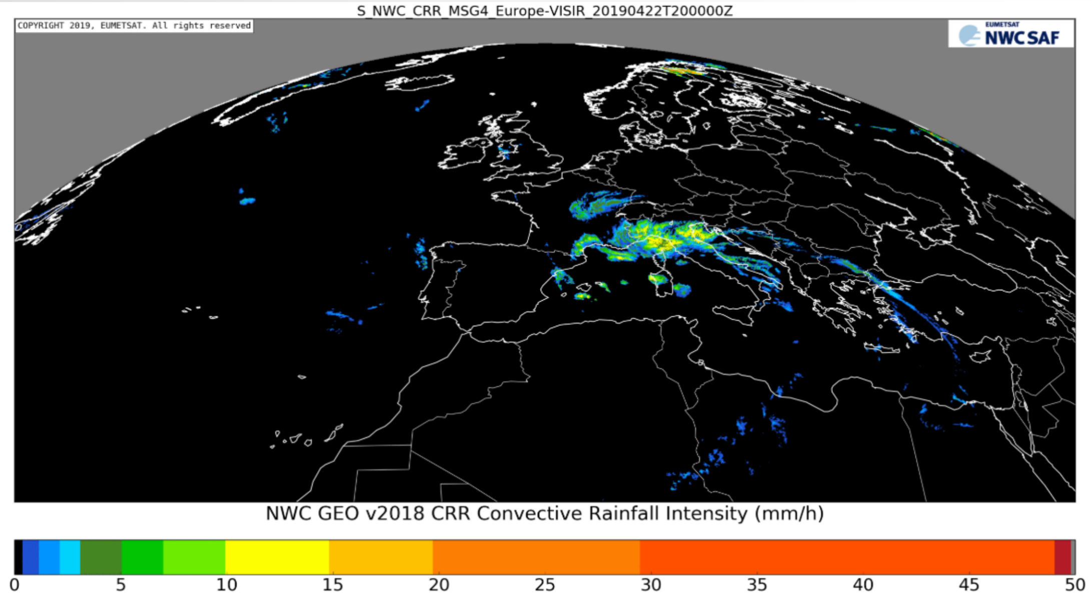
**Auxiliary data:**
Sun angles (Normalize VIS)
Saturation Vapour table (Moisture correction)
Terrain elevation (Orographic correction)
Climatological profile

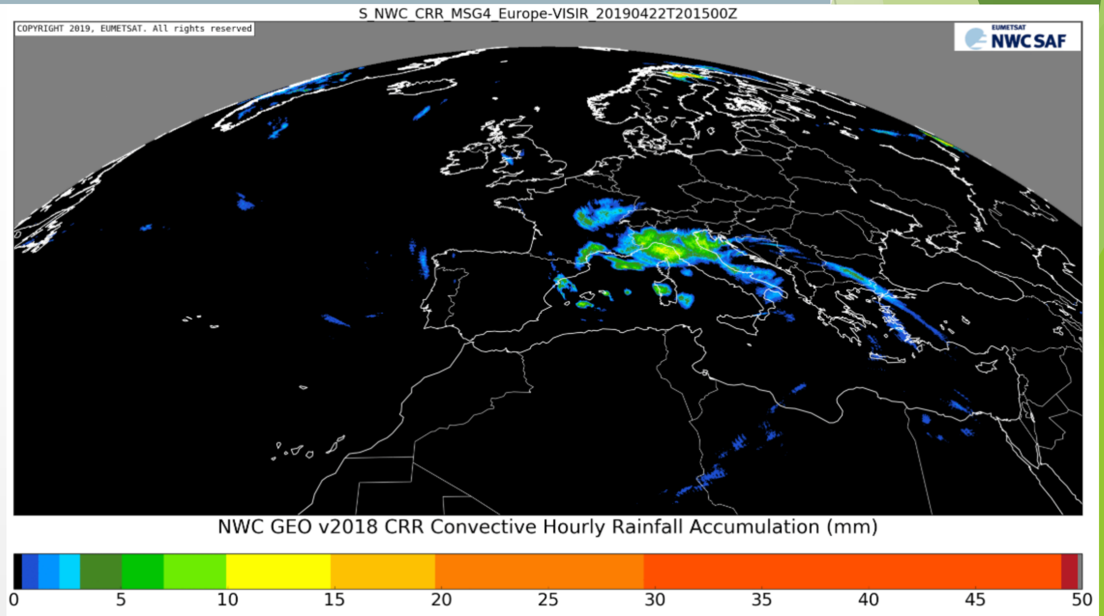
**Corrections:**

- Parallax (T,Z(mgp) different levels) or climatological profile.
- Orographic correction (u,v in 850hPa)
- Moisture correction (T,HR,p)
- Cloud evolution (2 IR images) or Cloud top Temperature gradient (1 image available)

Lighting information is optional

GEO-CRR-v401 2019-04-22T20:00:00Z Spain.cfg safnwc_CRR.cfm



RR(mm/h)=f(IR,IR-WV)

RR(mm/h)=f(IR,IR-WV,VIS-N)

$$RR = H(IR) * \exp\left[-0.5 * \left(\frac{(IR - WV) - C(IR)}{W(IR)}\right)^2\right]$$

$$H(IR) = 8 * 10^8 \exp[-0{,}082 * IR]$$

C(IR)=0,2*IR-45,0

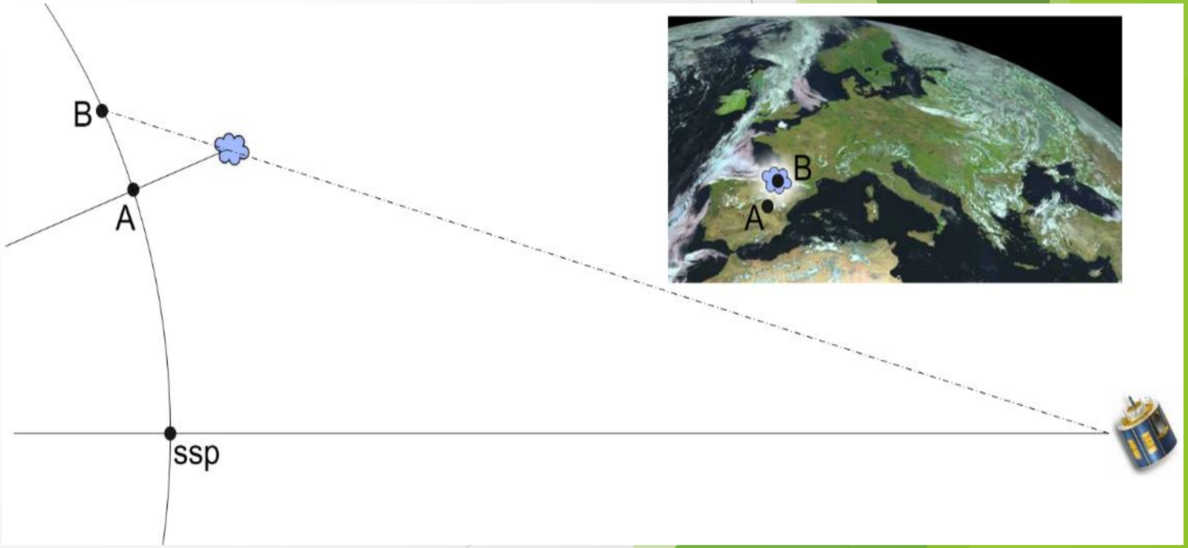
$$W(IR) = 1{,}5 * exp\left[-0{,}5 * (\frac{IR - 215{,}0}{3{,}0})^2 + 2{,}0\right]$$

# CRR CORRECTIONS

```
# MODEL CONFIGURATION FILE FOR GEO-CRR
# ------------------------------------

# 1. Identifier of the PGE
# ------------------------
PGE_ID GEO-CRR

# 2. Satellite bands to be used by the PGE
# ----------------------------------------
SAT_BANDS VIS06 WV62 IR108

# 3. Parameter used in the computation of zenith angle
# ----------------------------------------------------
DAY_NIGHT_ZEN_THRESHOLD 80

# 4.- Use of the Solar channel for DAY pixels (0: Not use / 1: Use)
# -----------------------------------------------------------------
USE_SOLAR_CHANNEL          1

# 5. Size of the window used in the filtering of the crr basic data
#   The size of the window will be:
#   (WIN_FILTER_SEMISIZE*2 + 1) x (WIN_FILTER_SEMISIZE*2 + 1)
# ---------------------------------------------------------------------
WIN_FILTER_SEMISIZE        3
FILTER_THRESHOLD           3

# 6. Corrections to be applied  (0: Not apply / 1: Apply)
# -------------------------------------------------------
APPLY_HUMIDITY_CORR        1
APPLY_EVOL_GRAD_CORR       1
APPLY_PARALLAX_CORR        1
APPLY_OROGRAPHIC_CORR      1
APPLY_LIGHTNING_CORR       1
```

It is the final user who decides which correction apply. It is possible to apply all corrections, none of them or whatever the user want.

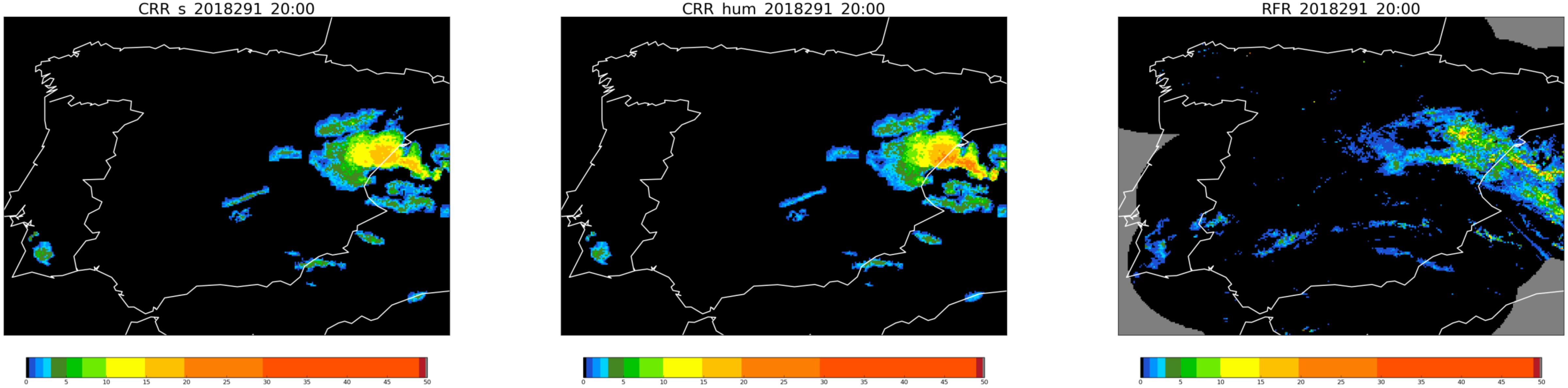
PARALAX CORRECTION



## MOISTURE CORRECTION FACTOR

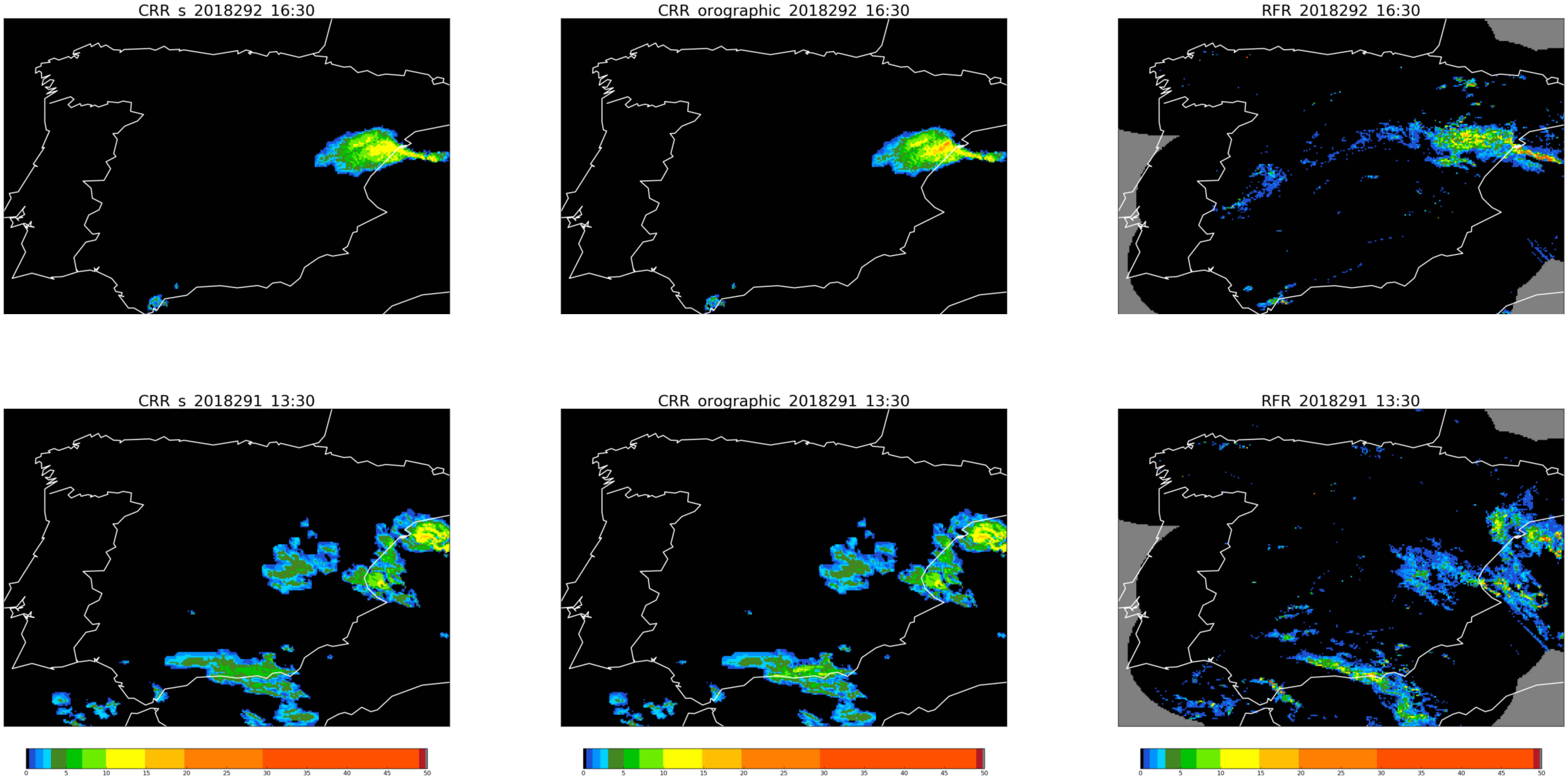
$$MCF = TOTAL\ PRECIPITABLE\ WATER_{SFC-500hPa} * \overline{RH}_{SFC-500hPa}$$

$$MCF \in [0,2] \quad MCF < 1 \ \ DRY\ ENVIRONMENT$$
$$MCF > 1 \ \ WET\ ENVIRONMENT$$



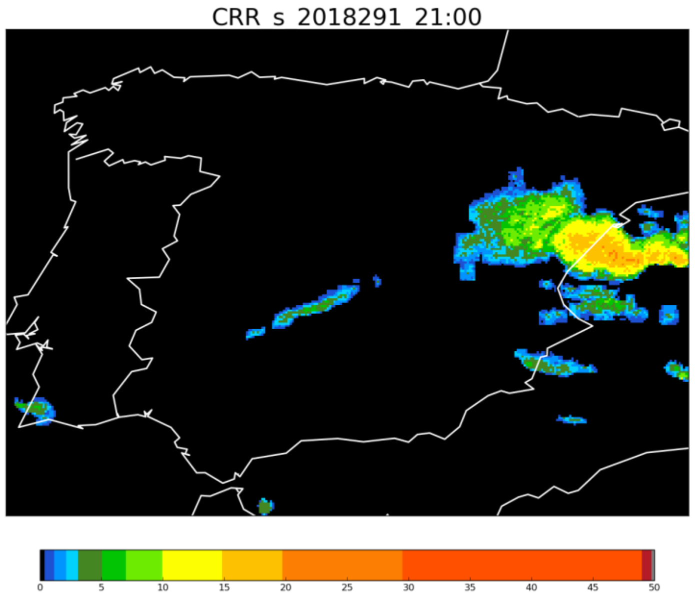
# OROGRAPHIC CORRECTION

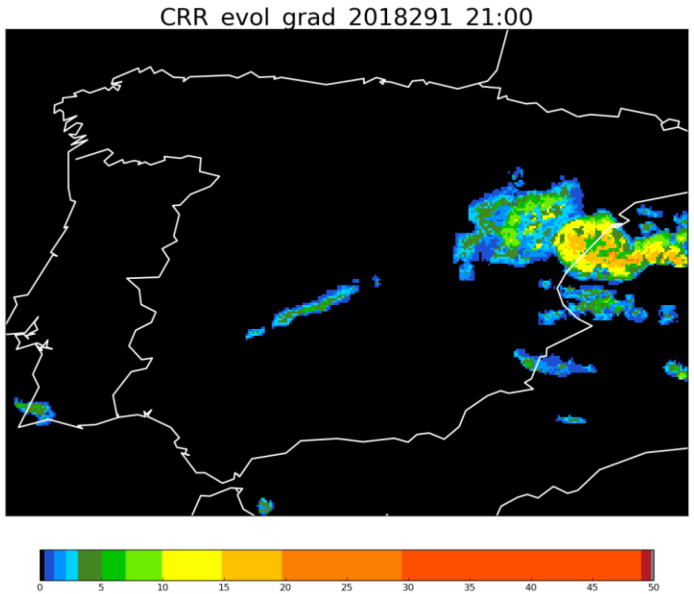
It is a correction that uses wind direction from the NWP and the topography to enhance or diminish the rain rate

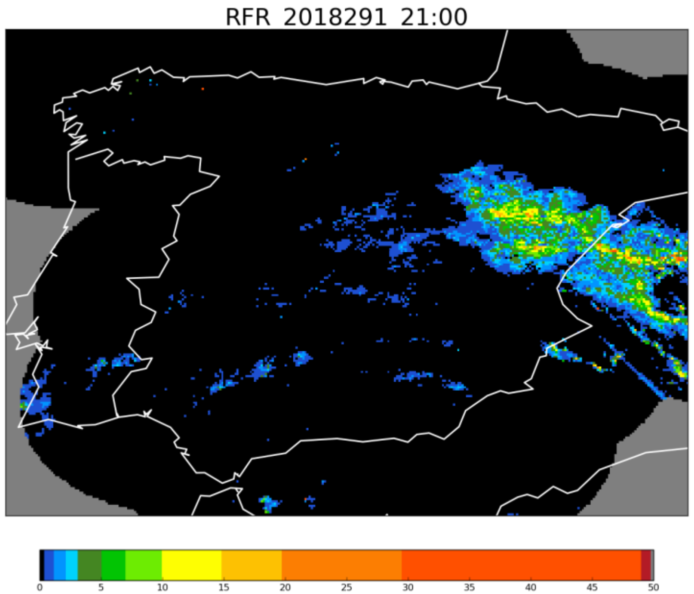


## CLOUD GROWTH RATE CORRECTION FACTOR

Consecutive IR satellite images are used to indicate vertically growing or decaying cloud systems.
When 2 consecutive images are not available an alternative correction is applied. This other correction tries to enhance precipitation in those pixels surrounded by warmer areas, so that colder pixels are more to prone to be being vertically growing.



# CONVECTIVE RAINFALL RATE FROM CLOUD PHYSICAL PROPERTIES (CRR-Ph)

The CRR-Ph product developed in the SAF contest is a nowcasting tool that provides information on convective and stratitorm associated to convection rain rate an hourly accumulations.

There is a **new calibration curve** at **day time** and a **new algorithm** for **night time**

INPUTS

- **CMIC Phase, COT and Reff** parameters are mandatory inputs to CRR-Ph.
- CMIC Phase is mandatory input to compute the CRR-Ph night algorithm

**CMIC products** need cloud products ad satellite imagery (**VIS0.6µm, VIS1.6µm** ,IR10.8 µm,IR8.7µm) as inputs to be computed

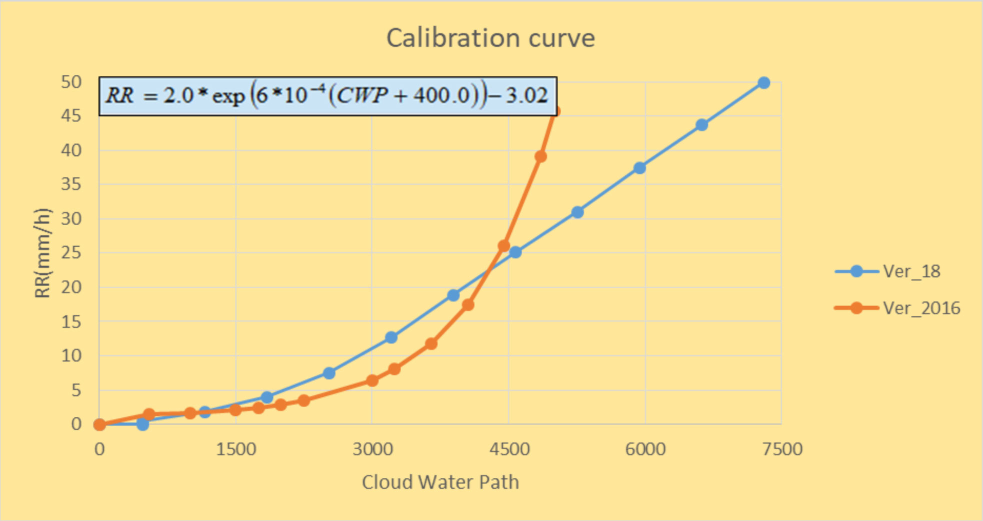
Satellite imagery
IR10.8 µm to compute Parallax correction
IR10.8 and WV6.2 to compute night algorithm.

NWP:
T and Geopotencial at 1000, 925, 850, 700, 500, 400, 300, 250 and 200 hPa.

Climatological profile to compute parallax correction when NWP no available

## CRR-Ph day

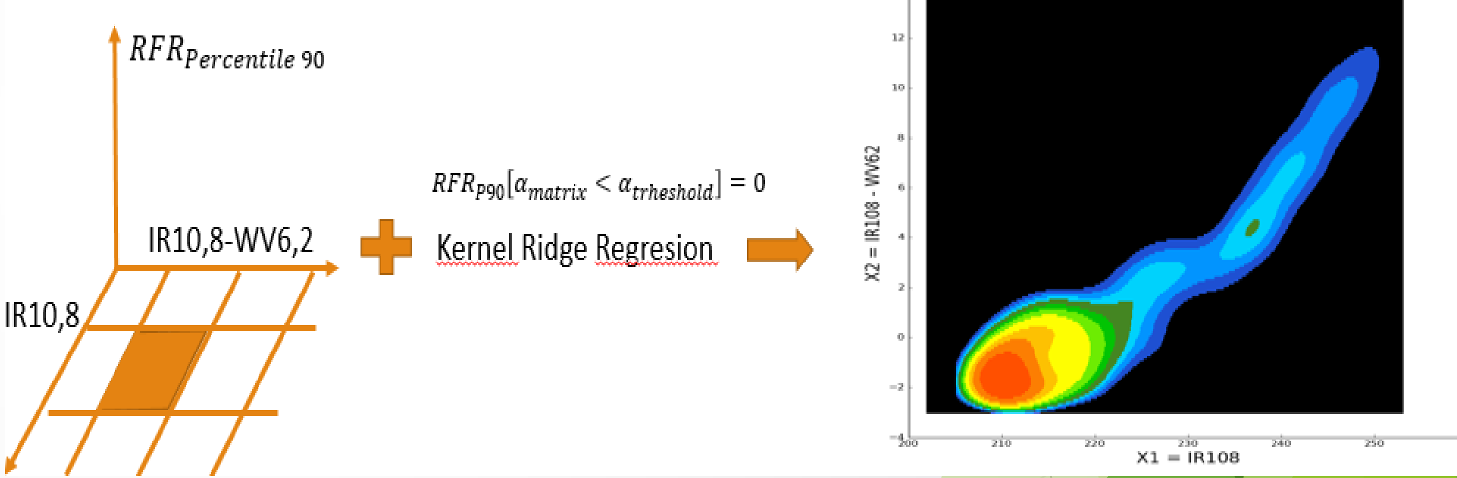
**New calibration curve** for the computation of the CRR-Ph (day) as a function of the CWP




## CRR-Ph night

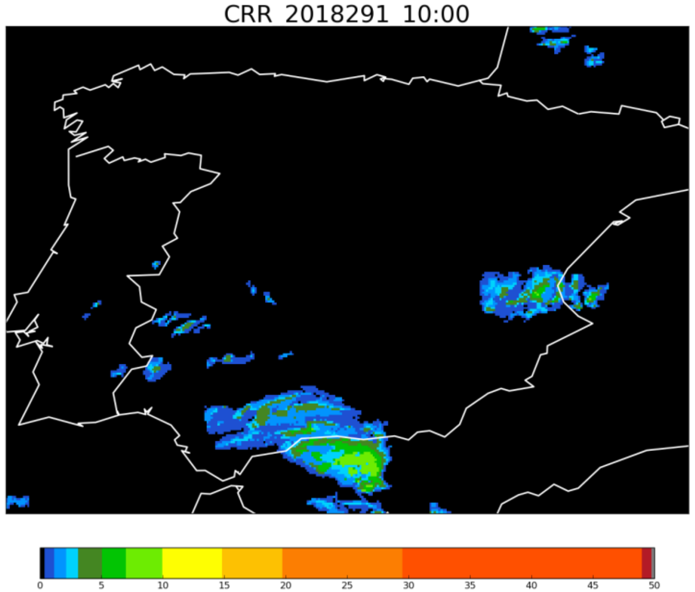
CRR-Ph night new algorithm
CRR-Ph in night conditions is computed as a function of IR10.8, IR10.8-WV6.2 using a 2D LUT

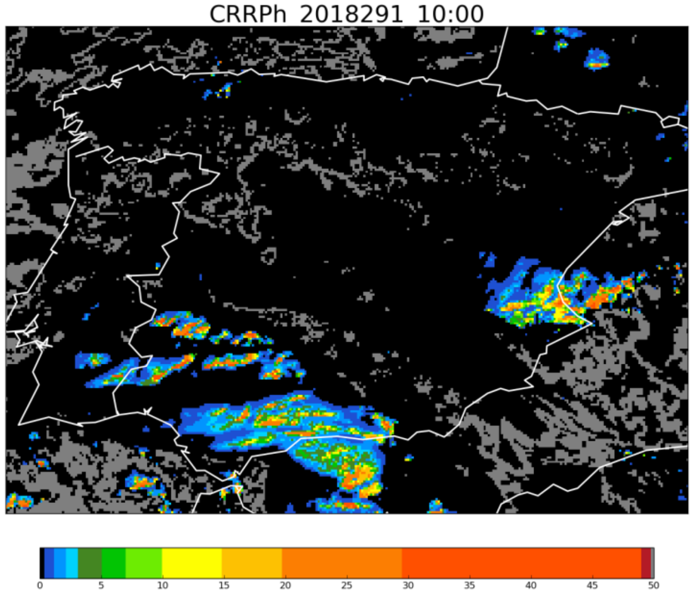
Cloud Water Path on a day time database is used to stablish thresholds used to exclude points where the product is going to be calculated

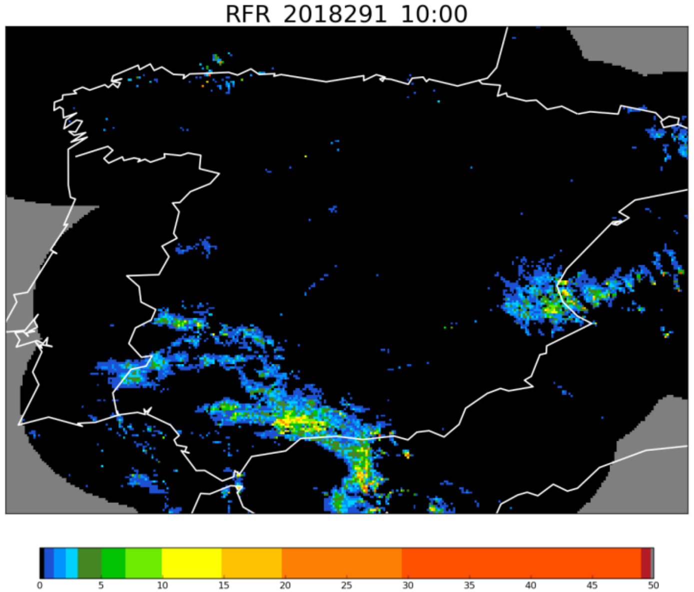



CRR-Ph is computed only in those pixels where CMIC PHASE is liquid, ice or mixed

# DAY ALGORITHM

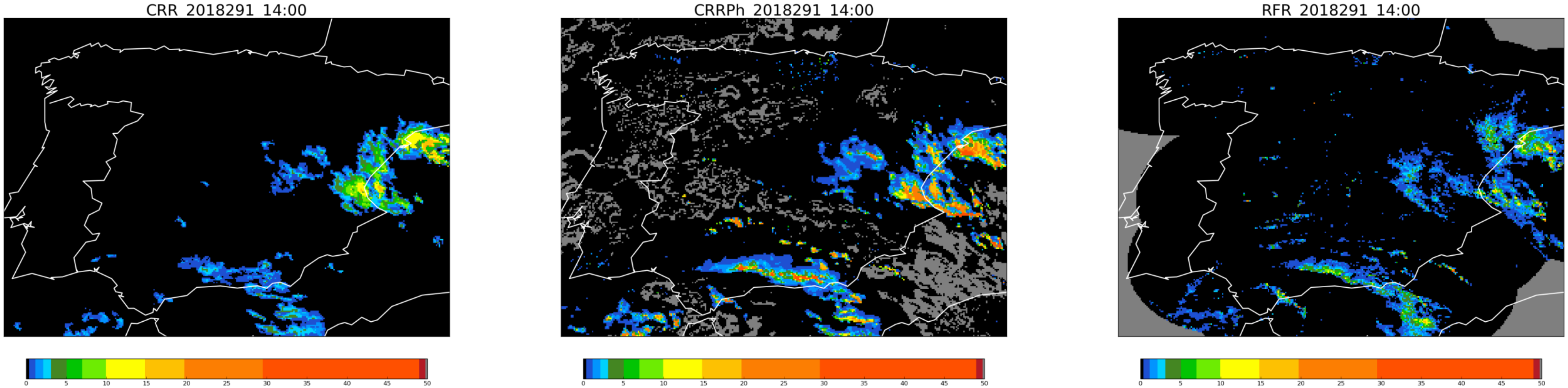



| | POD (%) | FAR (%) |
|---|---|---|
| CRR-Ph | 74 | 35 |
| CRR | 63 | 34 |

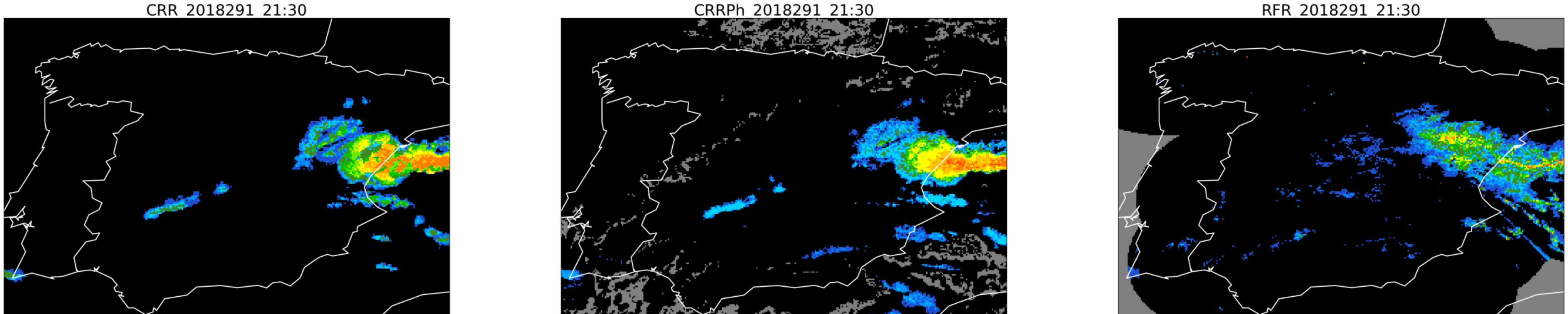
# DAY ALGORITHM




It performs better than the CRR night algorithm

# NIGHT ALGORITHM

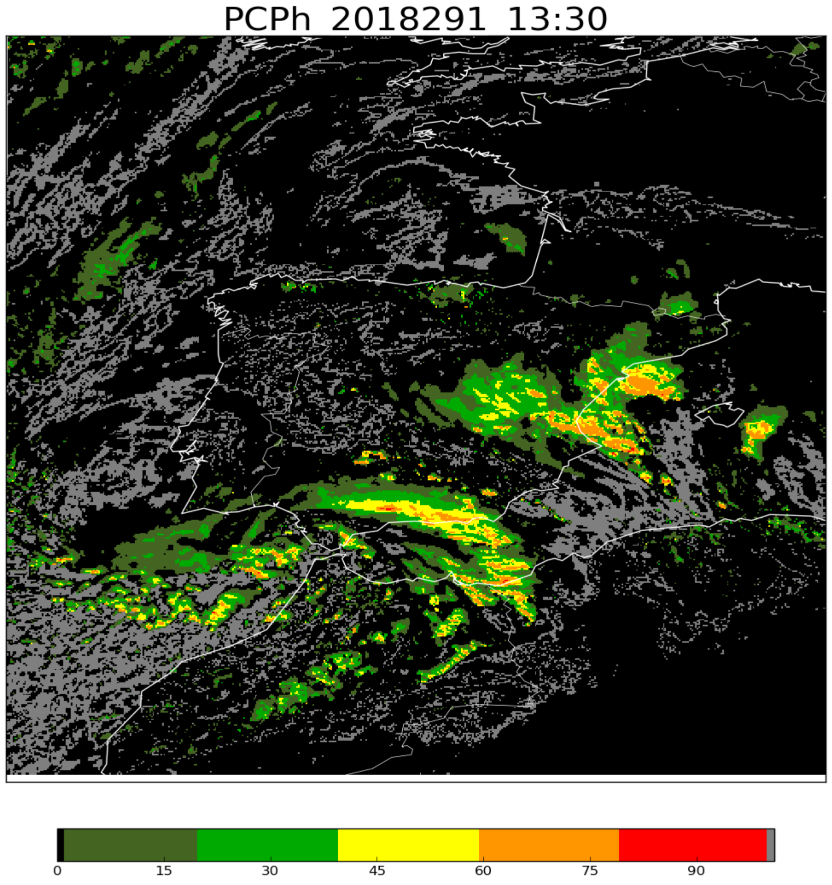
It performs similar to the CRR night algorithm

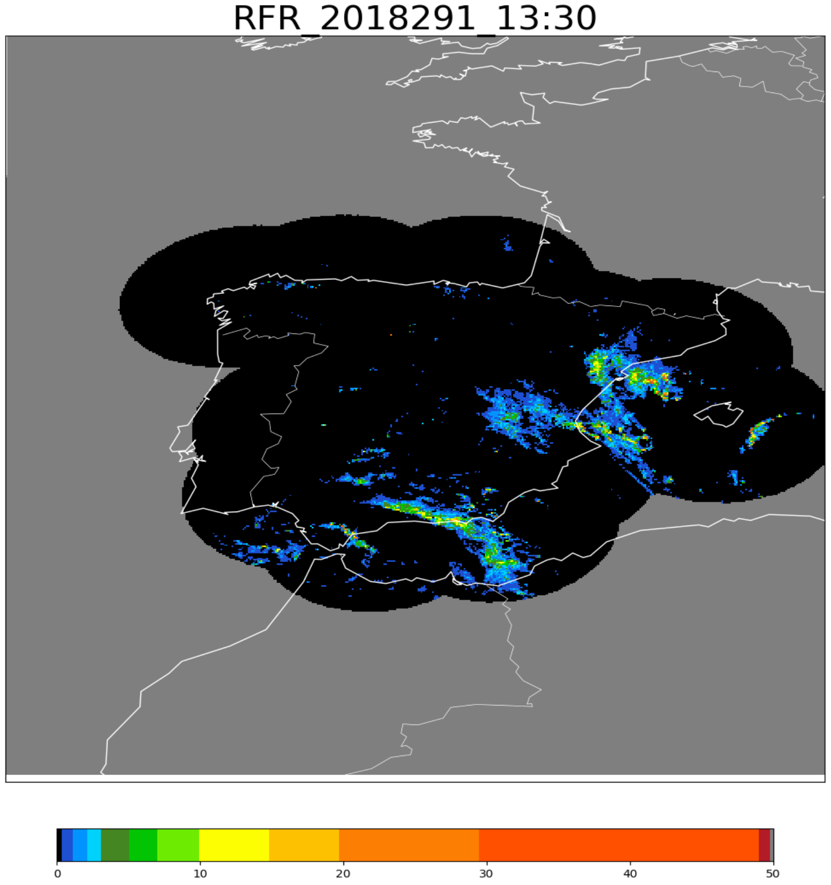


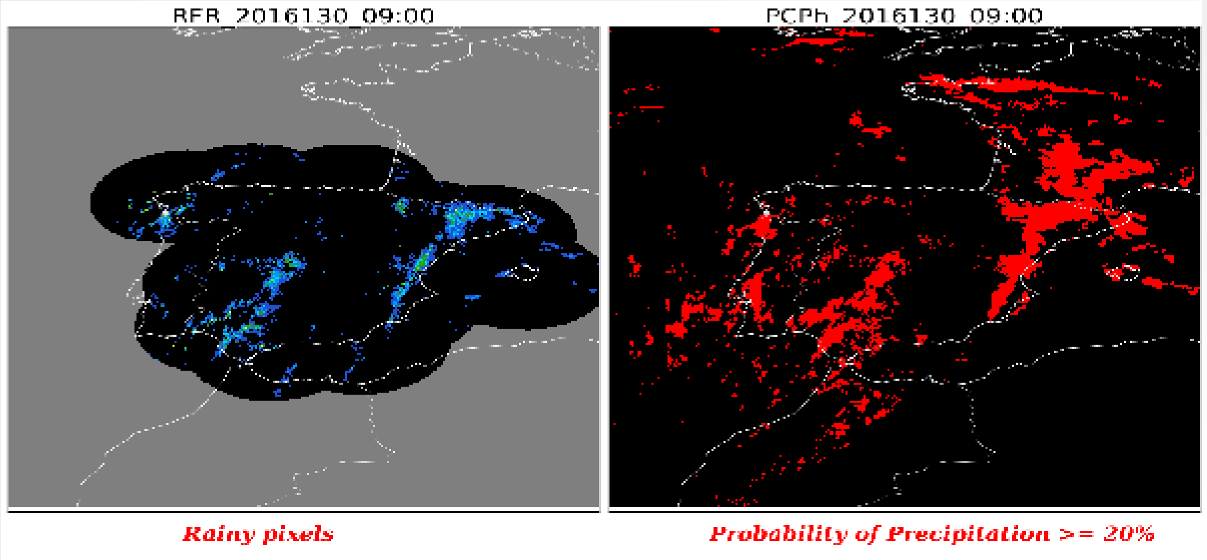
## OTHER PRODUCTS: PC and PC-Ph

PC-Ph provides with the probability of rain, for both day and night.
As CRR-Ph , it is based on microphysical properties

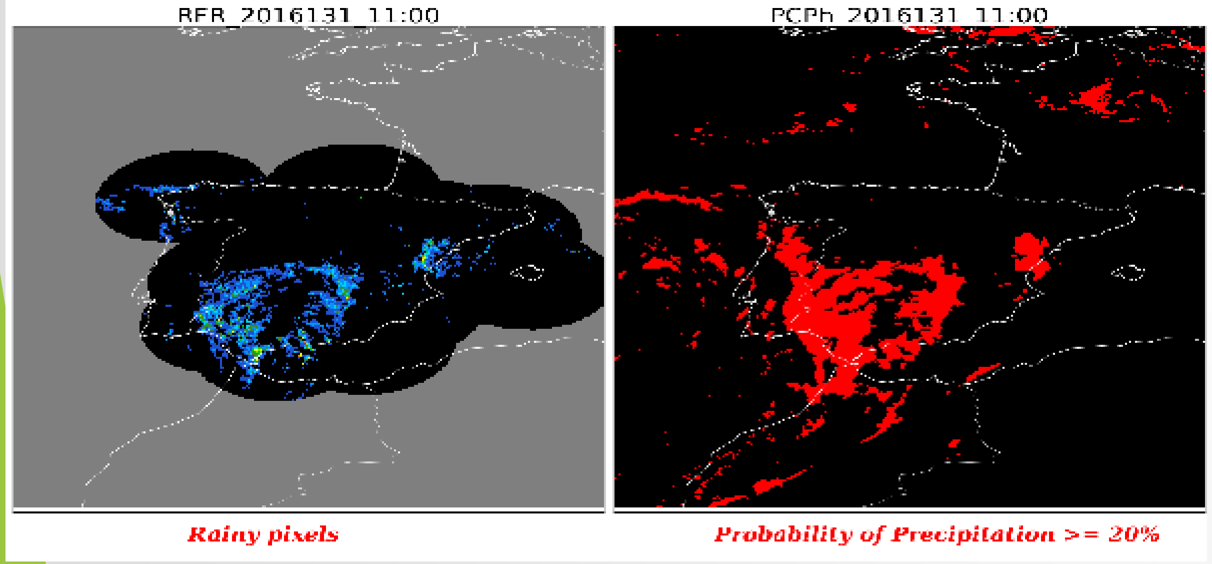
PC-Ph day time

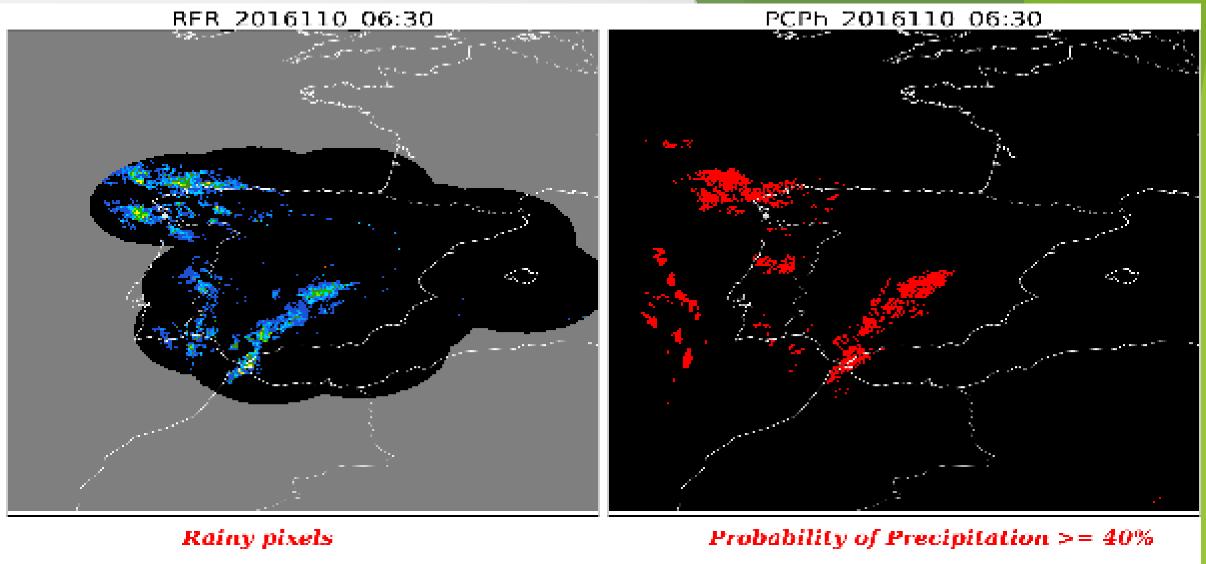


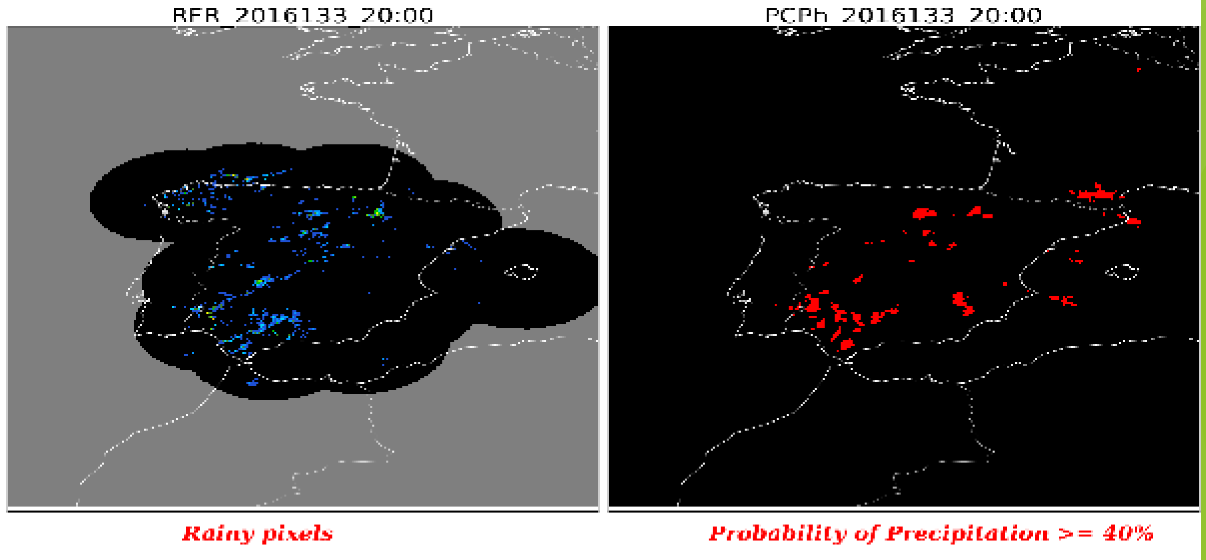



## PC-Ph day algorithm




## PC-Ph night algorithm



NEW PROTOTYPES BASED ON A PRINCIPAL COMPONENT ANALISYS:

**CRR-Ph based on PCA´s**
**PC-Ph based on PCA's**

¿What does PCA's stand for?

¿Have PCA's been used in other disciplines of meteorology or climatology?

Principal component analysis is a statistical method of **reducing the dimensionality** of a specific dataset that are correlated into a **lower** number of variables **keeping the same information**.

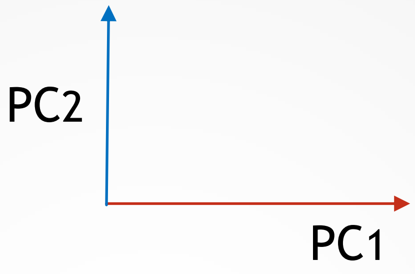
Principal Component Analysis belongs to a family of techniques known as ***unsupervised learning*** due to it doesn't want to predict a variable *(rainfall rate or probability of precipitation) otherwise it want to extract information from the predictors (Visible, infrared and water vapour channels)*.

PCA's have **been widely used in weather and climate research** to explain precipitating patterns, climatic variability, to compute climatological indices. It has also been used in remote sensing to extract information of the land , flood mapping, etc.

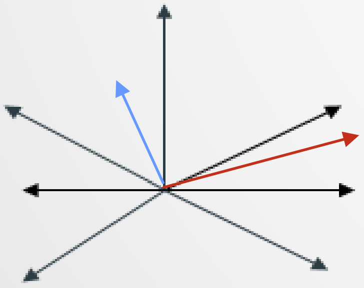
Large dataset

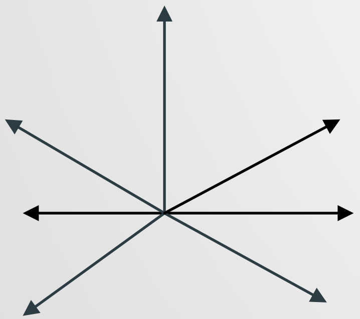
| IR10.8 | VIS0.6 | .... | .... | ... | WV6.2 |
|---|---|---|---|---|---|
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |

2D-plot




Reproject




Covariance matrix

$$\begin{pmatrix} * & * & \cdots & \cdots & * & * \\ * & & & & & * \\ * & & & & & * \\ * & & & & & * \\ * & & & & & * \\ * & * & \cdots & \cdots & * & * \end{pmatrix}$$

| Eigenvectors | Eigenvalues |
|---|---|
| V1 | λ1 |
| V2 | λ2 |
| V3 | λ3 |
| V4 | λ4 |
| … | … |
| Vn | λn |

Big

Small

CRRPh_Prototype

DAY TIME

1. Inputs

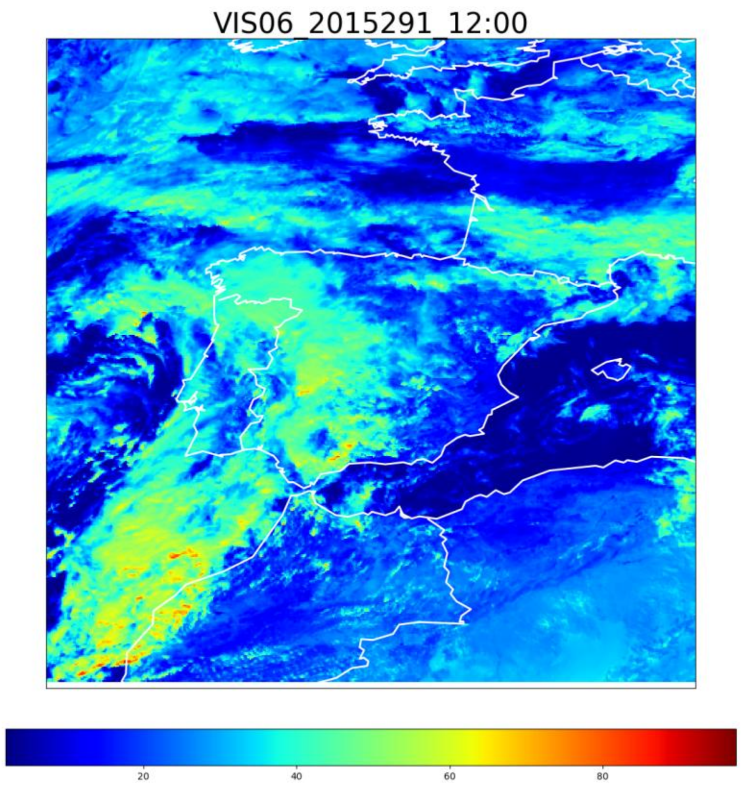
| IR10.8 | IR12.0 | IR13.4 | IR8.7 | IR9.7 | VIS0.6N | WV6.2 | WV7.3 | CWP |
|---|---|---|---|---|---|---|---|---|

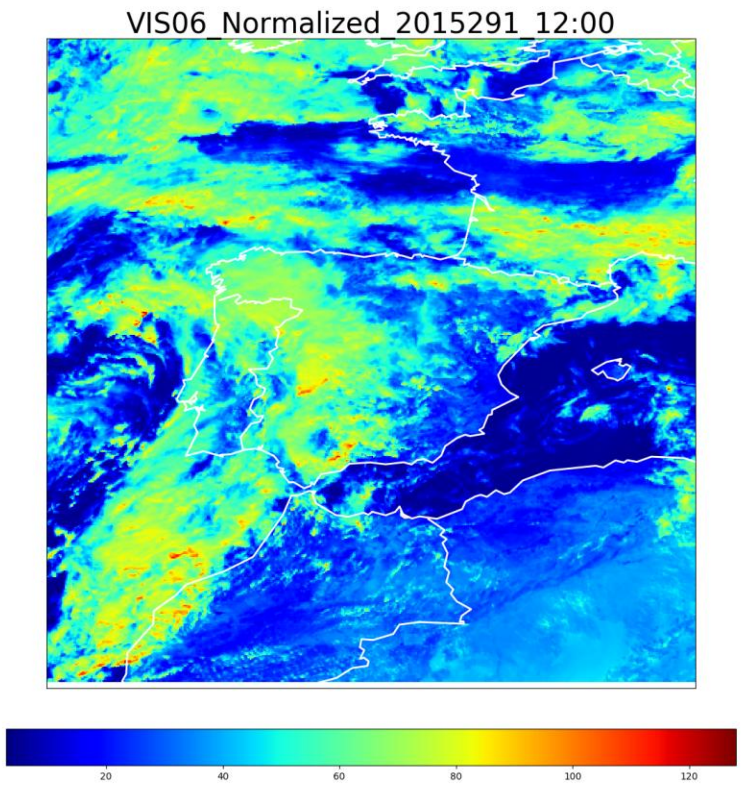
(μm)

COT: The cloud optical thickness  is a measure of a **beam atenuation** because of the **absortion and scatering** integrated to a whole column.
It is higly related to the **cloud top reflectances in the VIS0.6μm** and it is low dependent on the cloud size.

REFF: The effective radius is highly related with the cloud top reflectance at 1,6**μm** y 2,25**μm.**
It is well correlated with the probability of rain
CWP: The cloud water path is a measure of the **water content** integrated to a vertical column.

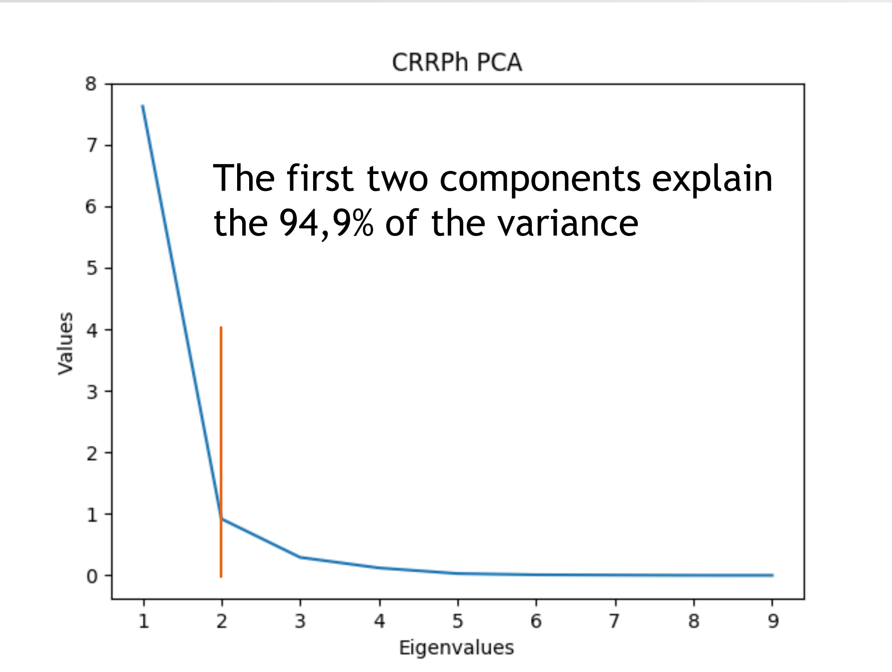
CWP= 2/3 * COT* REFF        *(Roebeling and Holleman,* 2009)




## 2. Normalization

Satellite channel normalization consists of subtracting a fixed value (mean value, previously calculated) from its brightness temperature and dividing it by another fixed value (standard deviation)



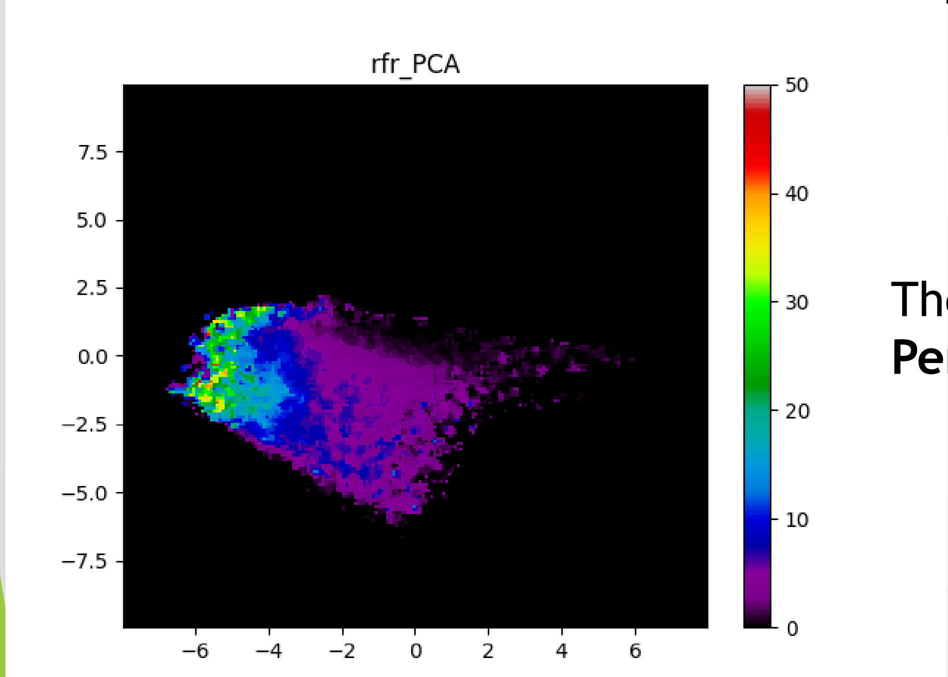

## 3. Projections

| Eigenvector_v1 | Eigenvector_v2 |
|---|---|
| v11 | v21 |
| v12 | v22 |
| v13 | v23 |
| v14 | v24 |
| v15 | v25 |
| v16 | v26 |
| v17 | v27 |
| v18 | v28 |
| v19 | v29 |

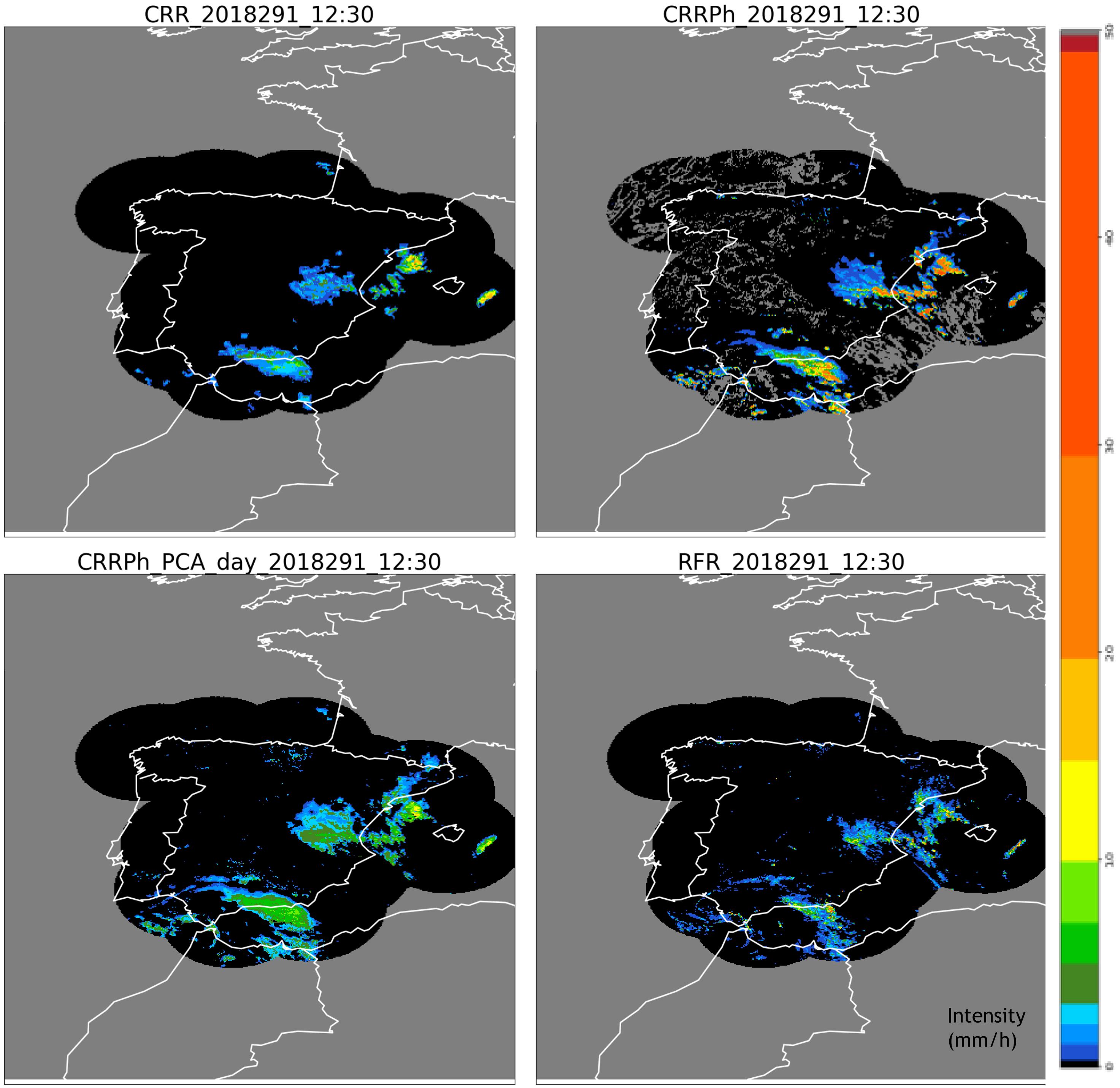
$$PC_1 = IR10.8_{normalized} * v_{11} + IR120_{normalized} * v_{12} + \ldots + CWP_{normalized} * v_{19}$$

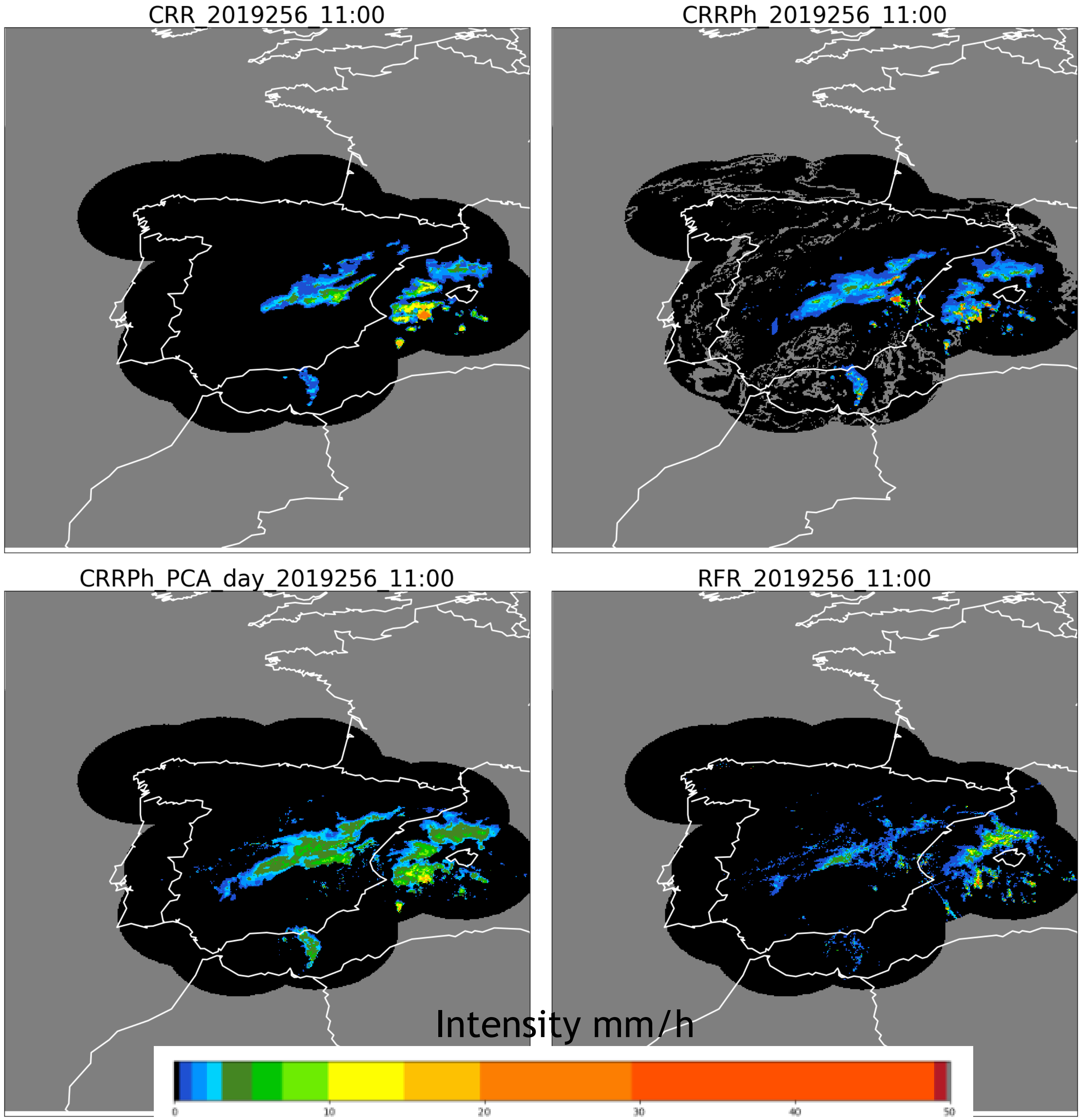
$$PC_2 = IR10.8_{normalized} * v_{21} + IR120_{normalized} * v_{22} + \ldots + CWP_{normalized} * v_{29}$$

## 4. Look up table

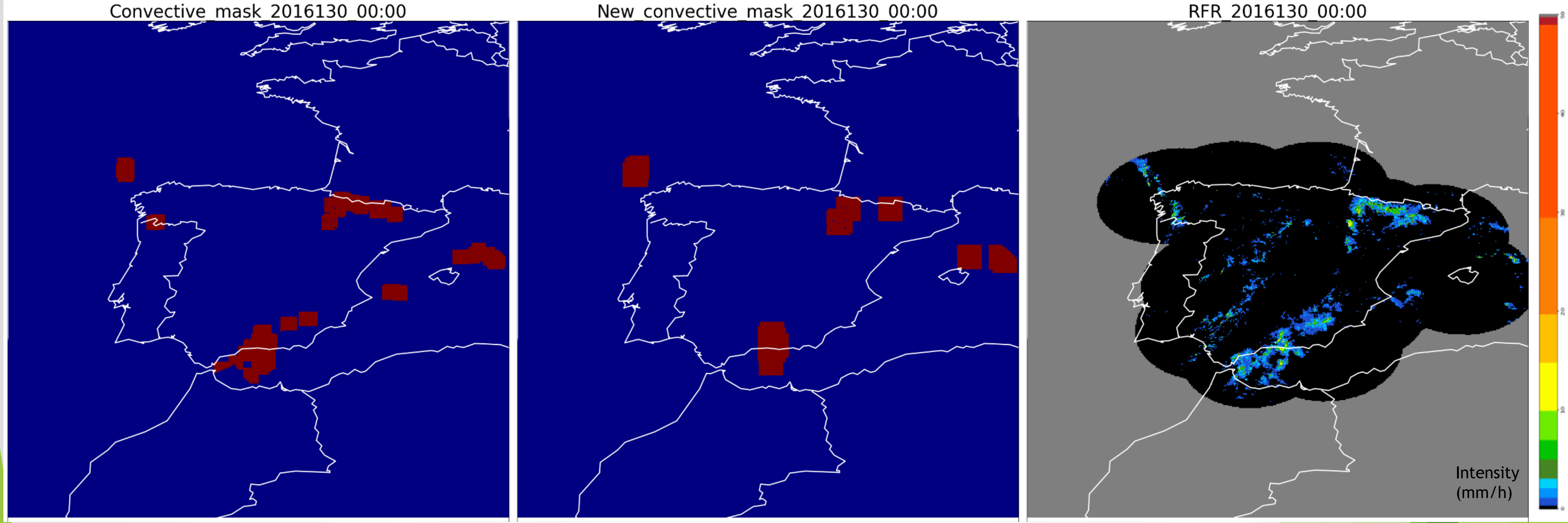



The colour represent the **ninety Percentile** of the Rainfall rate (mm/h)


CRR_2018291_12:30
CRRPh_2018291_12:30
CRRPh_PCA_day_2018291_12:30
RFR_2018291_12:30
50
40
30
20
10
0
Intensity
(mm/h)


CRR_2019256_11:00
CRRPh_2019256_11:00
CRRPh_PCA_day_2019256_11:00
RFR_2019256_11:00
Intensity mm/h
0
10
20
30
40
50

# CALIBRATING AREA:




Echotop > 6km
Rainfall rate>3mmh $^{-1}$
Box size = 15pix*15pix

**Echotop>6km**
**Rainfall rate>10mmh $^{-1}$**
**Box size = 25pix*25pix**

## NIGHT TIME

1. Inputs:

The same as day time

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| IR10.8 | IR12.0 | IR13.4 | IR8.7 | IR9.7 | VIS0.6N | WV6.2 | WV7.3 | CWP |

Not available at night time

**VIS06** and **Cloud Water Path** are needed so they are going to be "predicted" so as to use the same algorithm the whole day.

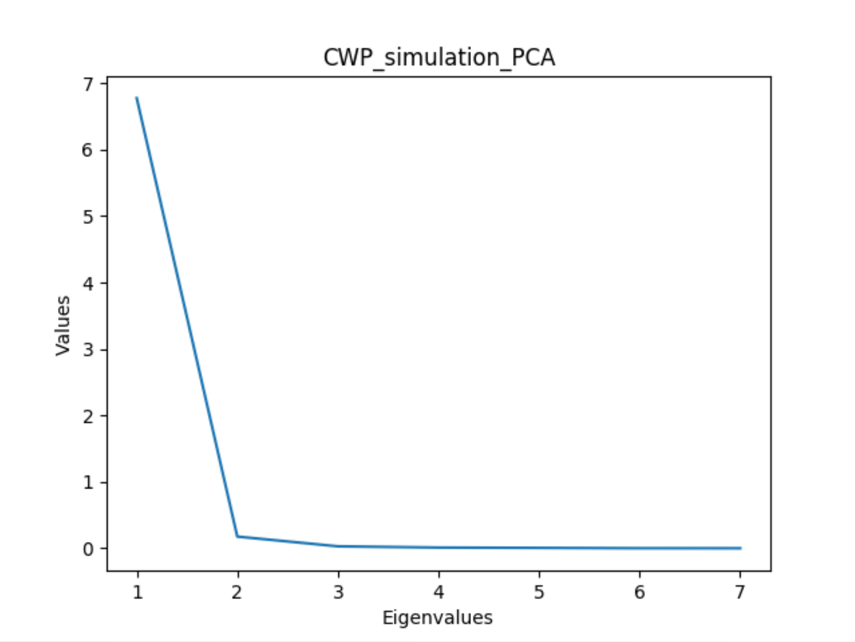
A concept of continuity want to be introduced

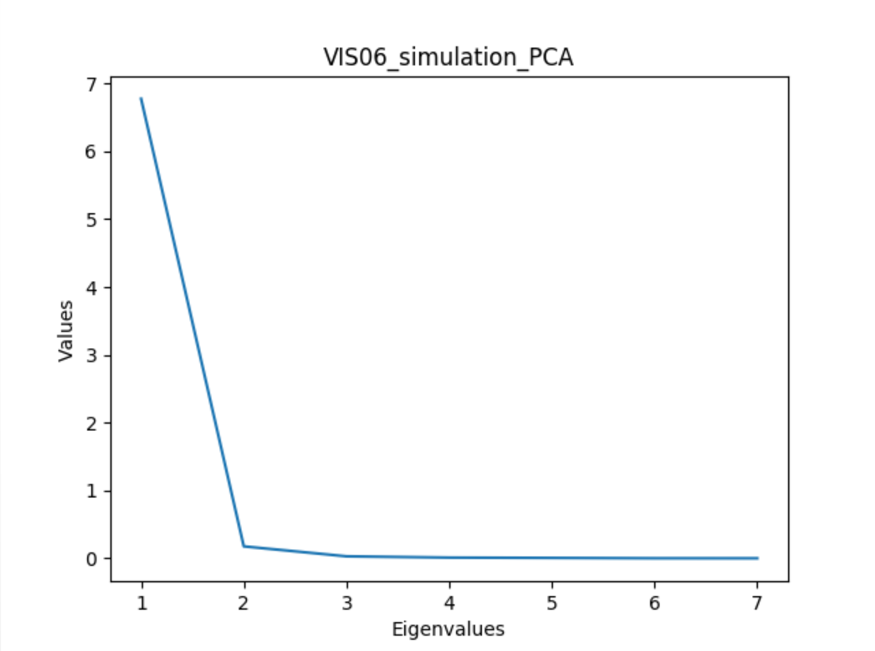
VIS06 and CWP simulation

Since VIS06 and CWP are compulsory at night time to compute the CRR-Ph new prototype, these channel are simulated at day time with the following channels, that are available at night time:

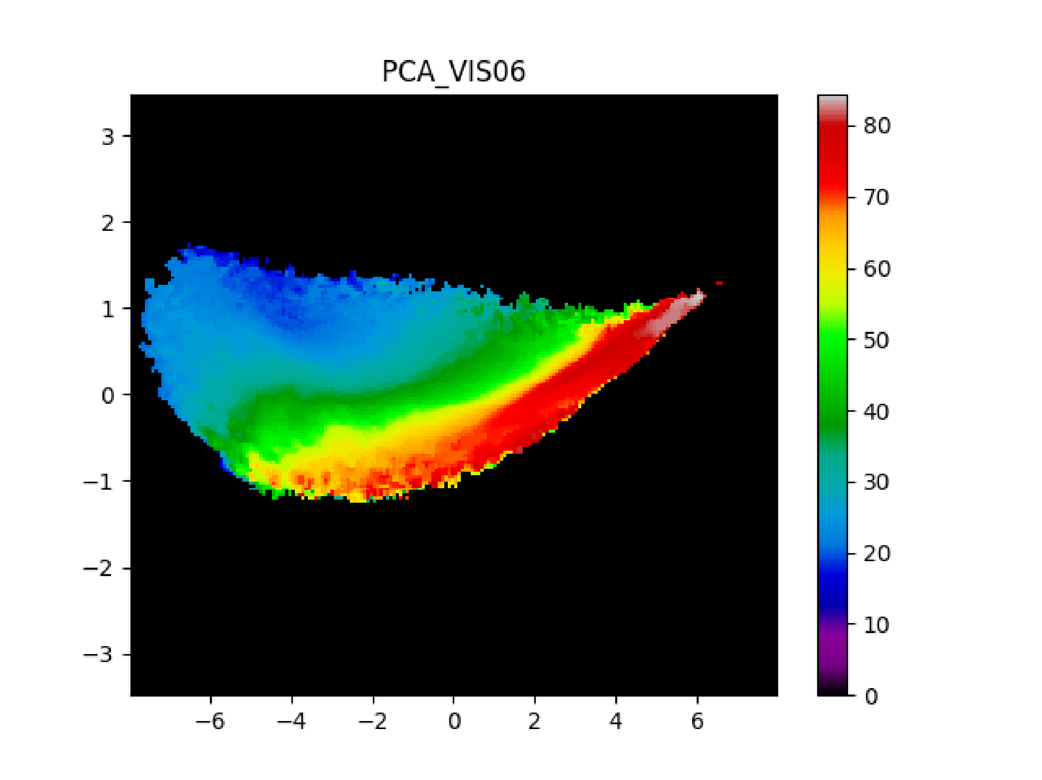
| | | | | | | |
|---|---|---|---|---|---|---|
| IR10.8 µm | IR12.0 µm | IR13.4 µm | IR 8.7µm | IR 9.7µm | WV6.2 µm | WV 7.3 µm |

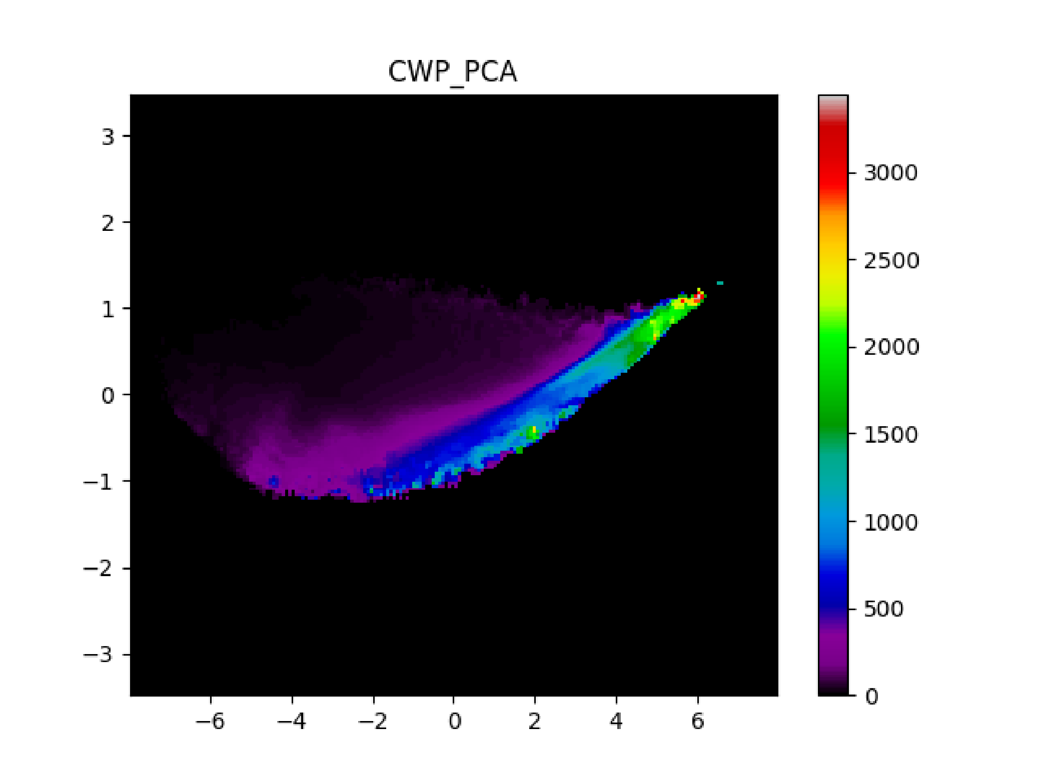
These simulations of the VIS06 channel and the Cloud Water Path are based in a Principal component analysis. To tackle this problem we use 2 eigenvectors that explain the 99,3% of the variance for the both channels.



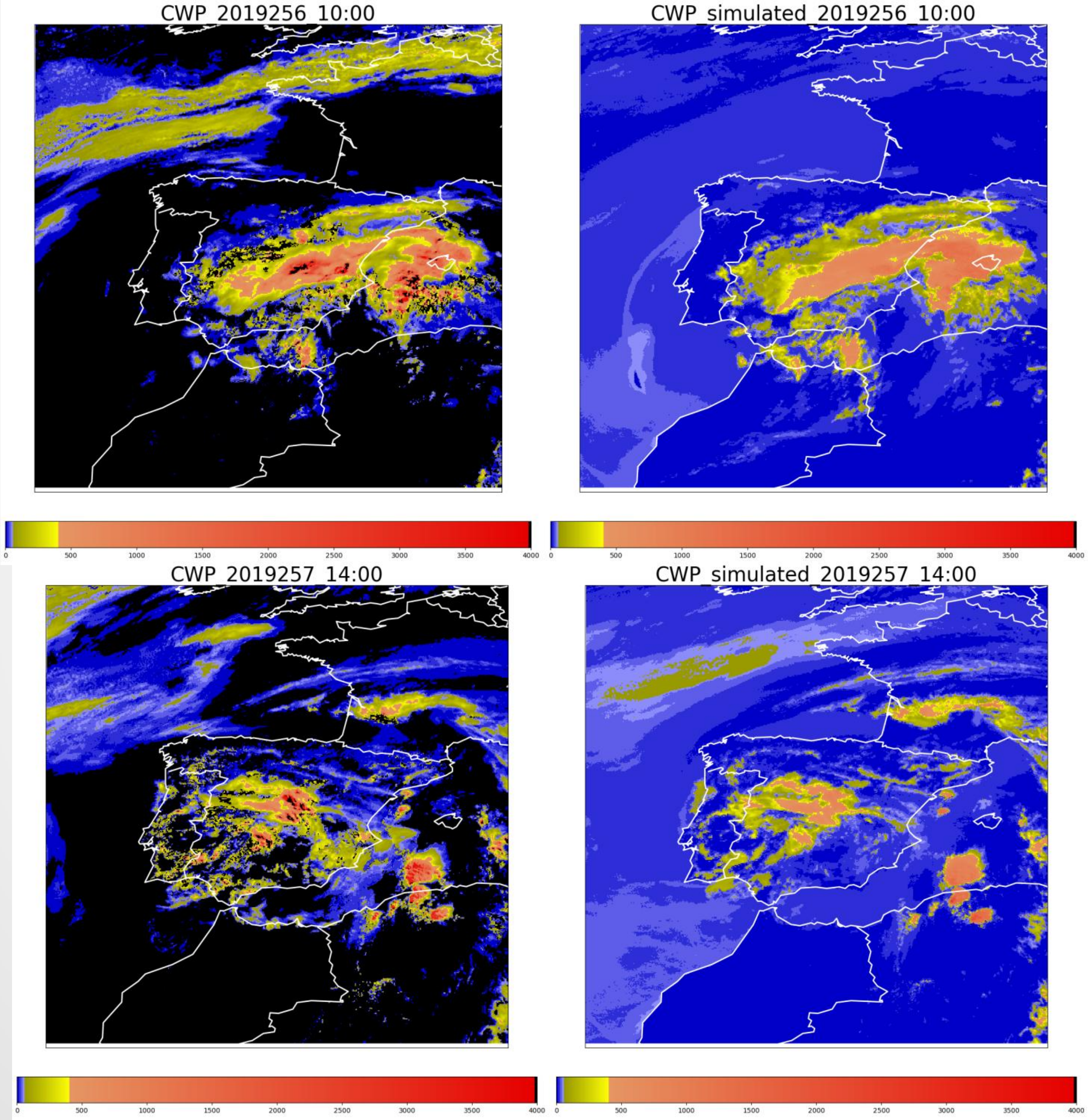



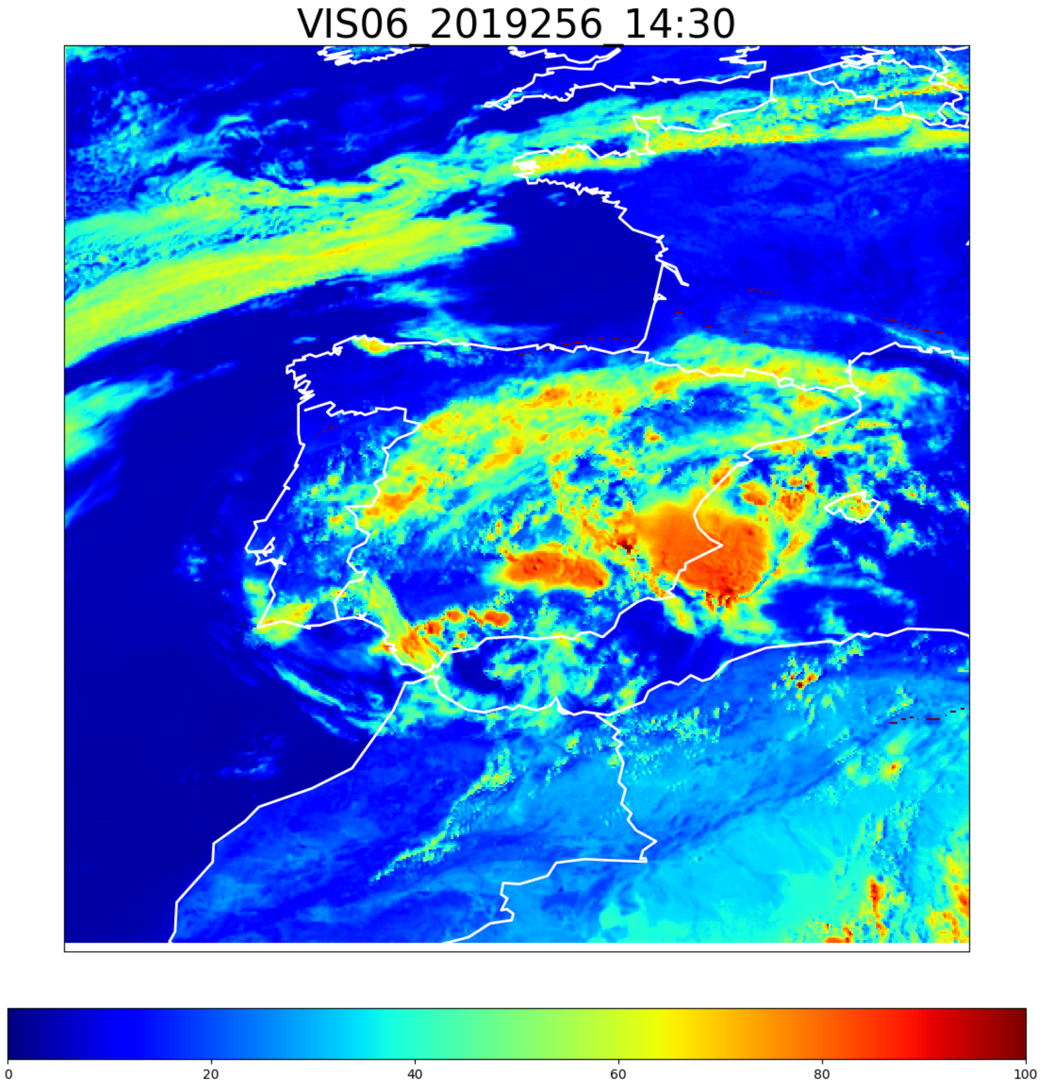

To simplify the problem there have been used the same eigenvectors to simulate the VIS06 channel and the CWP

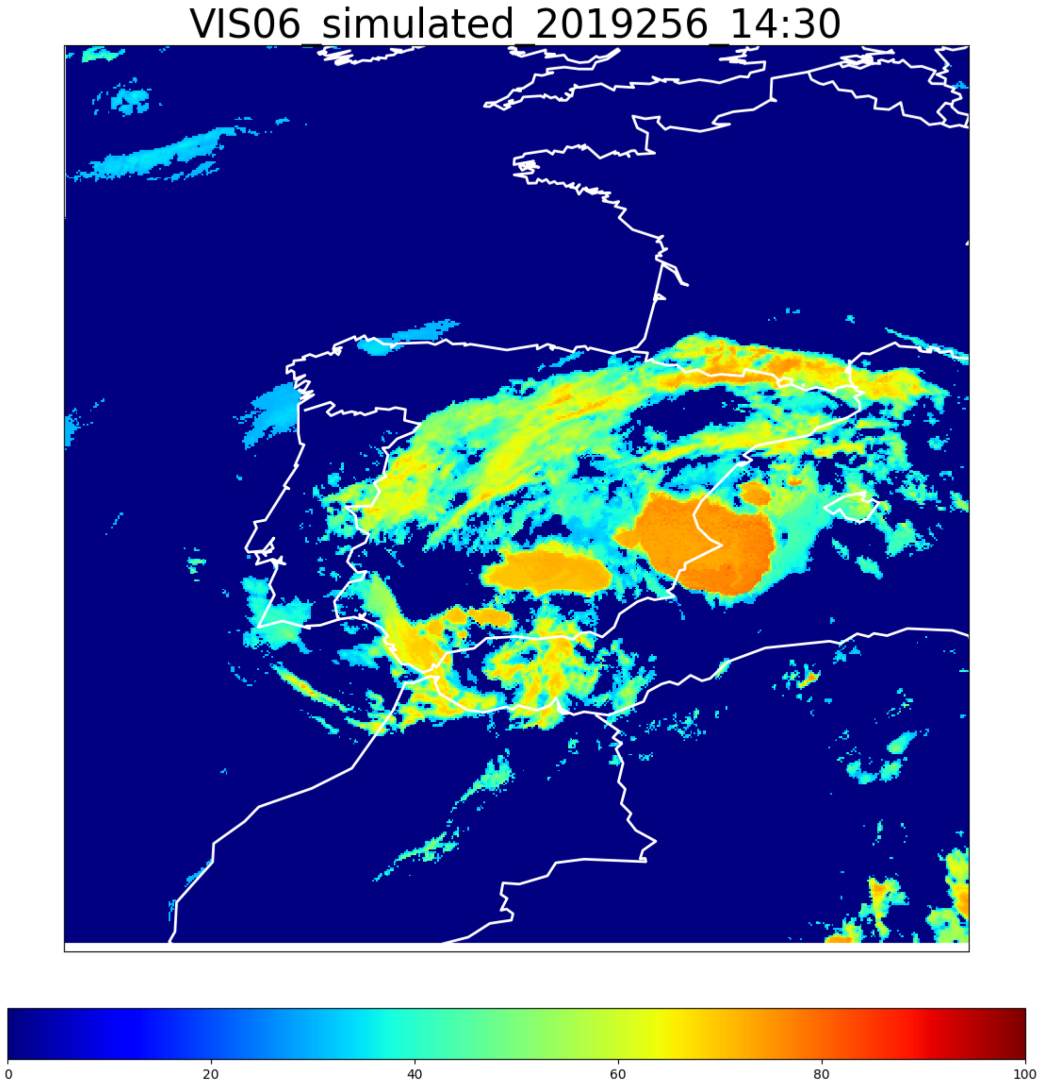


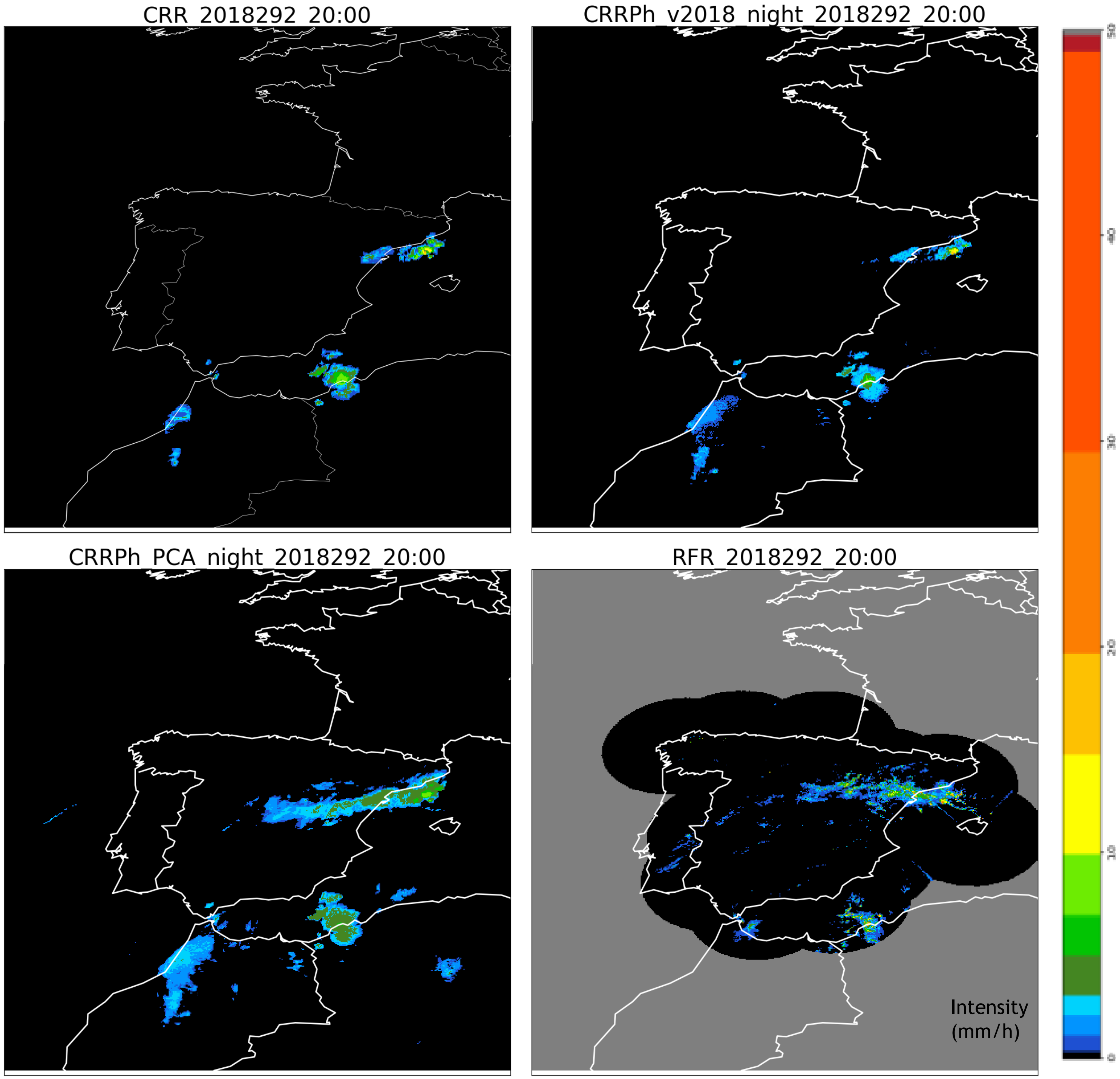

The simulation has been done with the mean value of the VIS06 and CWP. That explains it doesn’t reach so high values than the reality

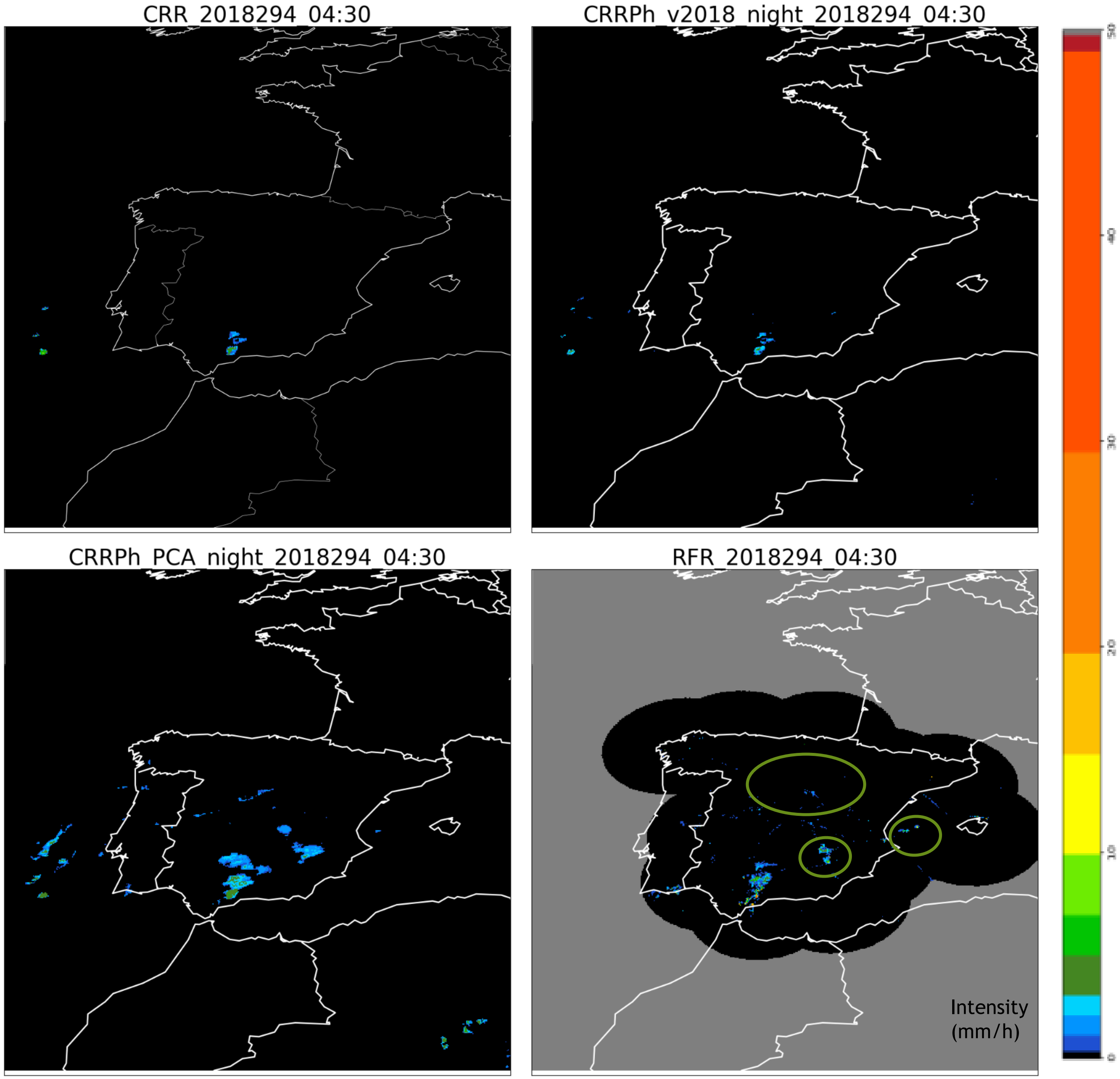

CWP_2019256_10:00
CWP_simulated_2019256_10:00
0 500 1000 1500 2000 2500 3000 3500 4000
0 500 1000 1500 2000 2500 3000 3500 4000
CWP_2019257_14:00
CWP_simulated_2019257_14:00
0 500 1000 1500 2000 2500 3000 3500 4000
0 500 1000 1500 2000 2500 3000 3500 4000

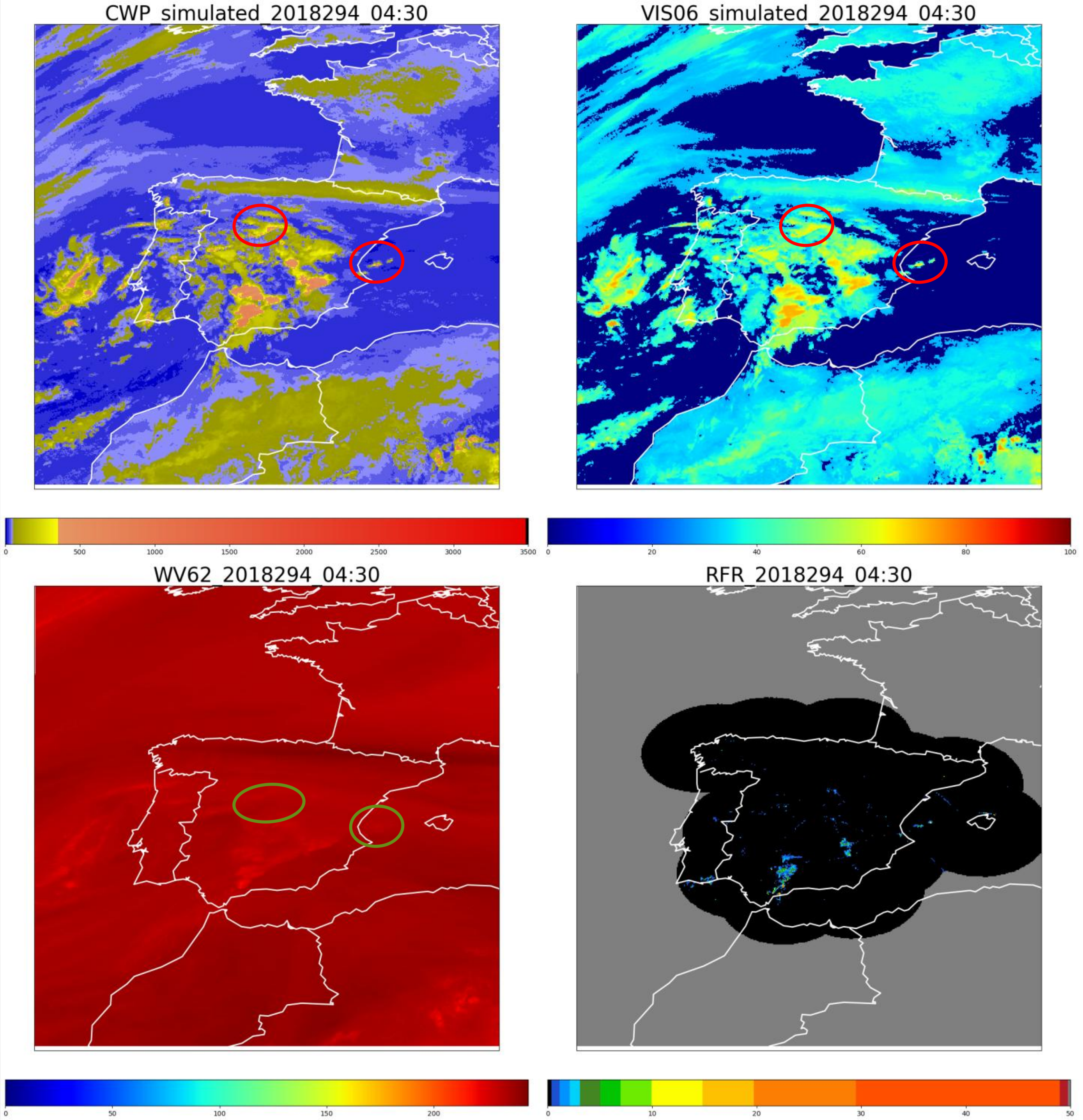

VIS06_2019256_14:30
0
20
40
60
80
100

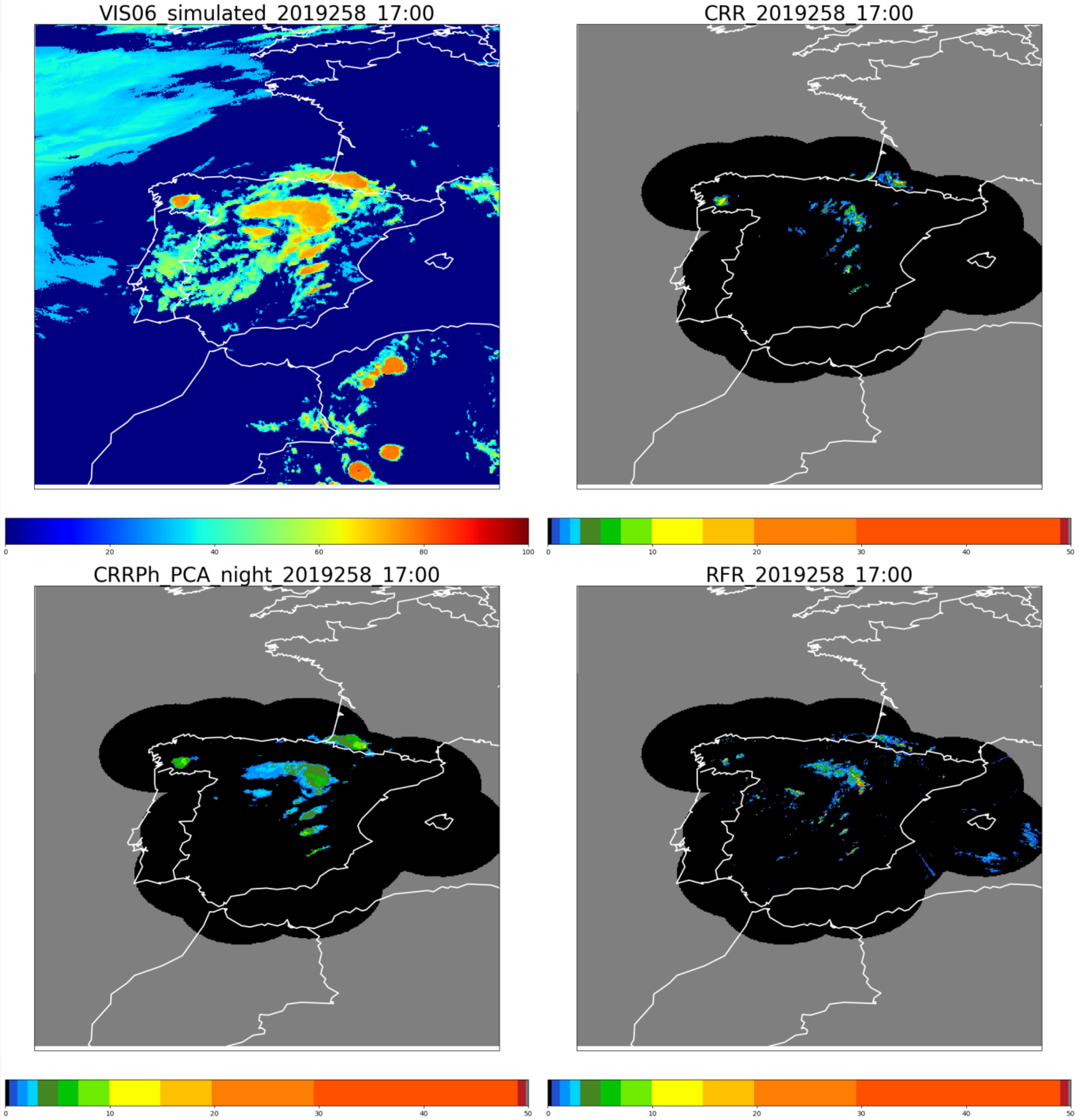

VIS06_simulated_2019256_14:30
0
20
40
60
80
100

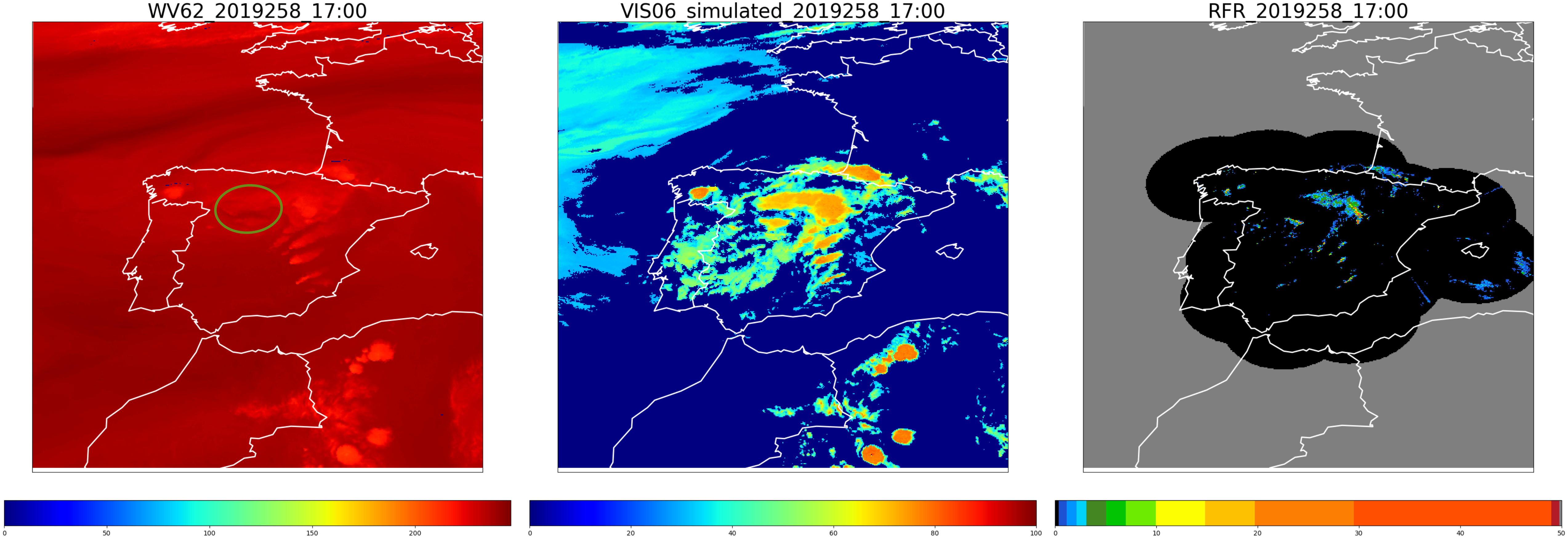
# NIGHT TIME EXAMPLES

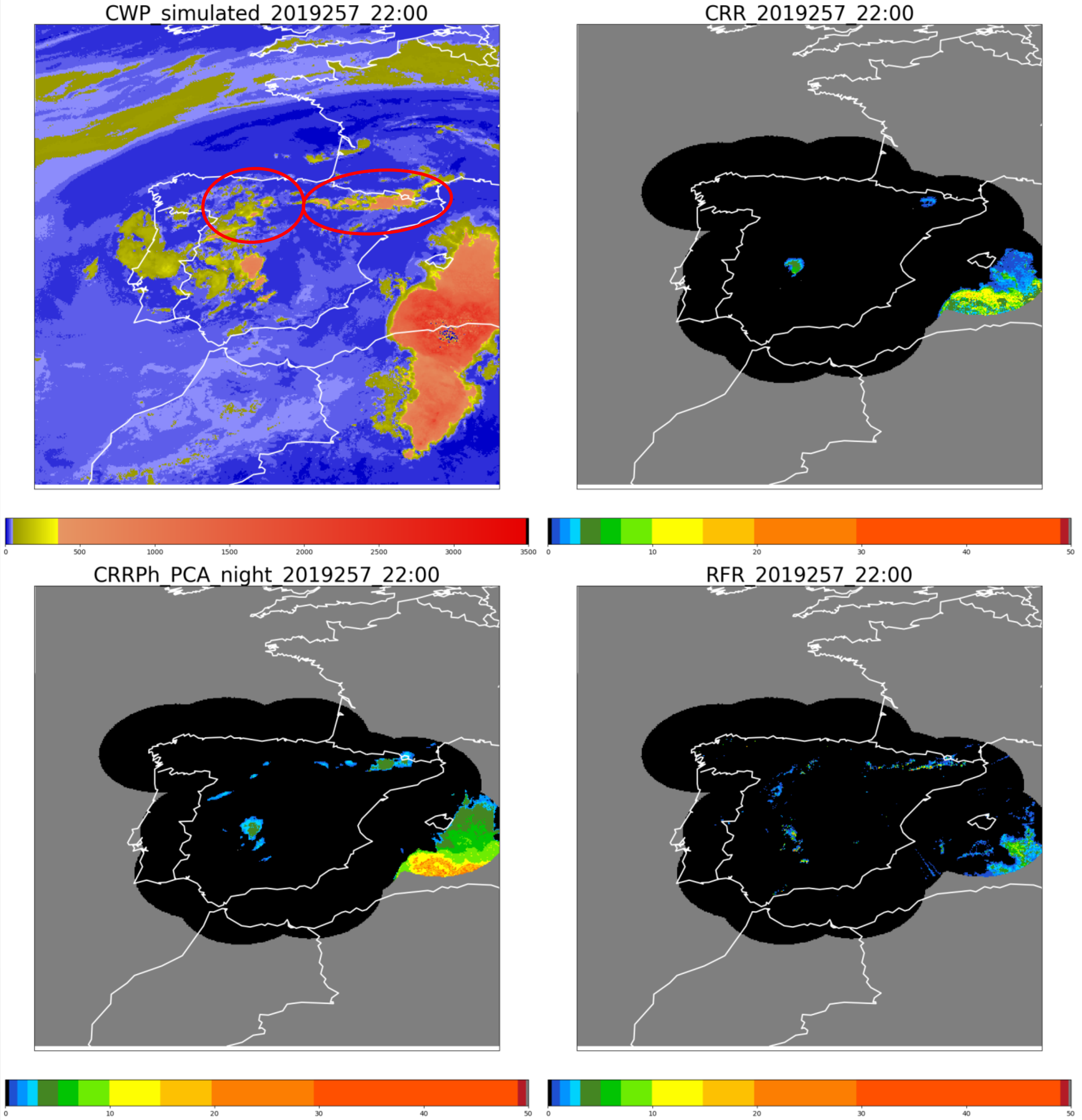



CRR_2018294_04:30
CRRPh_v2018_night_2018294_04:30
CRRPh_PCA_night_2018294_04:30
RFR_2018294_04:30
0
10
20
30
40
50
Intensity
(mm/h)


CWP_simulated_2018294_04:30
VIS06_simulated_2018294_04:30
0 500 1000 1500 2000 2500 3000 3500
0 20 40 60 80 100
WV62_2018294_04:30
RFR_2018294_04:30
0 50 100 150 200
0 10 20 30 40 50


VIS06_simulated_2019258_17:00
CRR_2019258_17:00
0
20
40
60
80
100
0
10
20
30
40
50
CRRPh_PCA_night_2019258_17:00
RFR_2019258_17:00
0
10
20
30
40
50
0
10
20
30
40
50


WV62_2019258_17:00
VIS06_simulated_2019258_17:00
RFR_2019258_17:00
0 50 100 150 200
0 20 40 60 80 100
0 10 20 30 40 50


CWP_simulated_2019257_22:00
CRR_2019257_22:00
0 500 1000 1500 2000 2500 3000 3500
0 10 20 30 40 50
CRRPh_PCA_night_2019257_22:00
RFR_2019257_22:00
0 10 20 30 40 50
0 10 20 30 40 50

CATEGORICAL VALIDATION IN CONVECTIVE AREAS

CALIBRATING : 2015
VALIDATING : 2016

DAY TIME

| CRR | N | POD (%) | FAR (%) | CSI (%) | PC (%) |
|---|---|---|---|---|---|
| | -------- | 62.82 | 34.13 | 47.64 | 64.55 |

| CRRPh | N | POD (%) | FAR (%) | CSI (%) | PC (%) |
|---|---|---|---|---|---|
| | 1160269 | 74.24 | 35.05 | 53.00 | 53.00 |

| CRRPh prototype | N | POD (%) | FAR (%) | CSI (%) | PC (%) |
|---|---|---|---|---|---|
| | 1481661 | **84.07** | **28.69** | 62.82 | 78.04 |

NIGHT TIME

| CRR | N | POD (%) | FAR (%) | CSI (%) | PC (%) |
|---|---|---|---|---|---|
| | -------- | 53.74 | 45.53 | 37.08 | 54.57 |

| CRRPh | N | POD (%) | FAR (%) | CSI (%) | PC (%) |
|---|---|---|---|---|---|
| | 3397658 | 42.29 | 36.42 | 34.05 | 34.05 |

| CRRPh prototype | N | POD (%) | FAR (%) | CSI (%) | PC (%) |
|---|---|---|---|---|---|
| | 1933738 | **76.03** | **36.80** | 52.70 | 71.34 |

**REQUIREMENTS**

| POD (%) | FAR (%) |
|---|---|
| 53 | 40 |

| POD (%) | FAR (%) |
|---|---|
| 75 | 35 |

| POD (%) | FAR (%) |
|---|---|
| 47 | 50 |

| POD (%) | FAR (%) |
|---|---|
| 47 | 50 |

FORMER CONVECTIVE AREA:

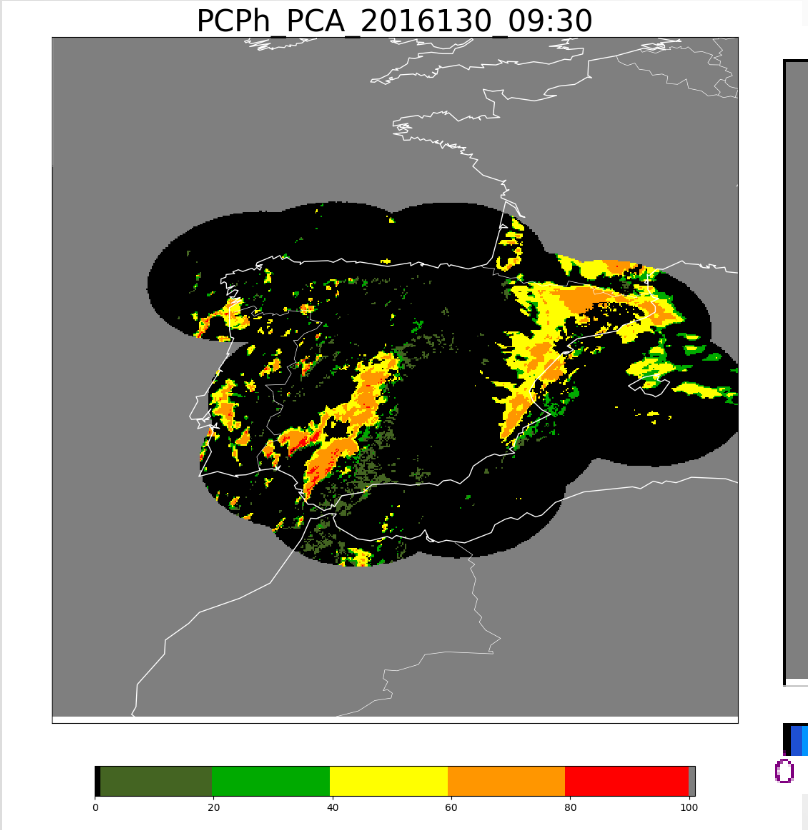
Echotop > 6km
Rainfall rate>3mmh $^{-1}$
Box size = 15pix*15pix

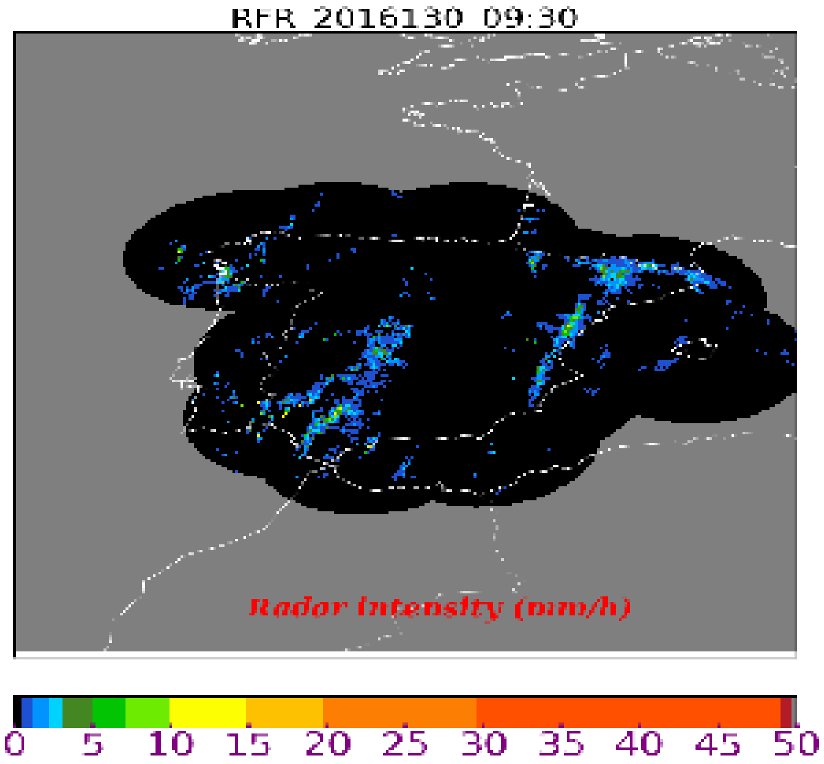
| CRRPh prototype | N | POD (%) | FAR (%) | CSI (%) | PC (%) |
|---|---|---|---|---|---|
| | 1573710 | 73.47 | 27.52 | 57.45 | 77.69 |

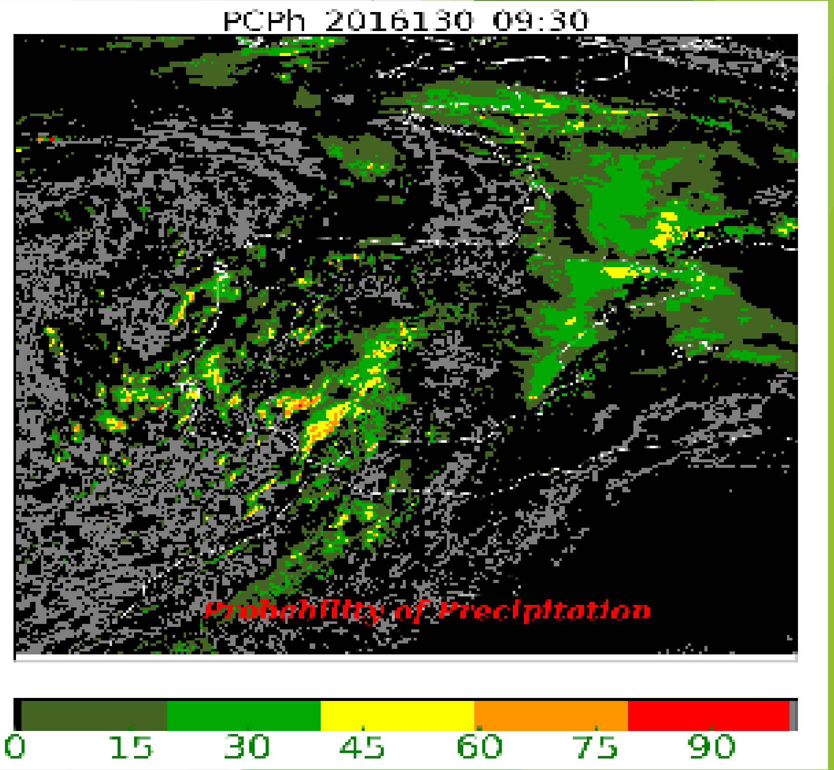
| CRRPh prototype | N | POD (%) | FAR (%) | CSI (%) | PC (%) |
|---|---|---|---|---|---|
| | 2938240 | 73.62 | 30.86 | 55.41 | 68.89 |

# PCPh_Prototype

PCPh prototype has the same inputs as the CRRPh prototype.
It is also based on a Principal component analysis.
It happens the same as the CRRPh prototype because there only exits one Look up it table for the whole day
At night the VIS06 channel and the Cloud Water path are simulated

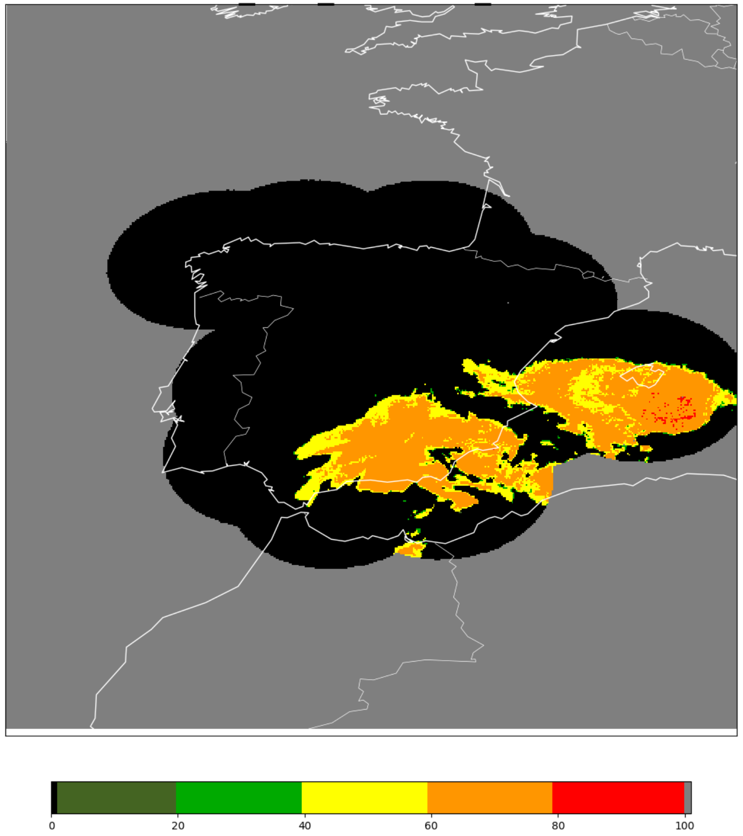


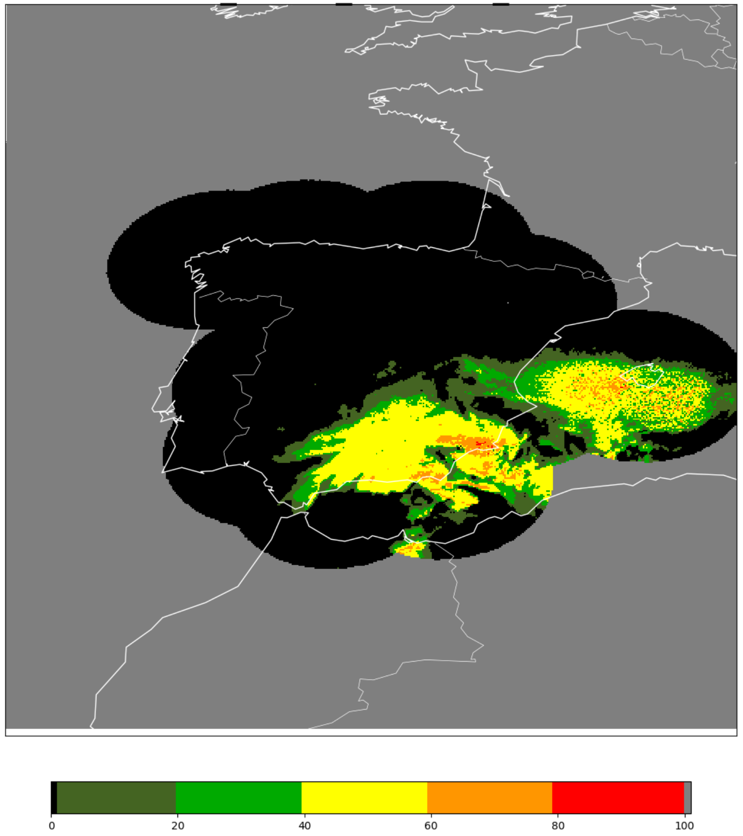



# PCPh night prototype

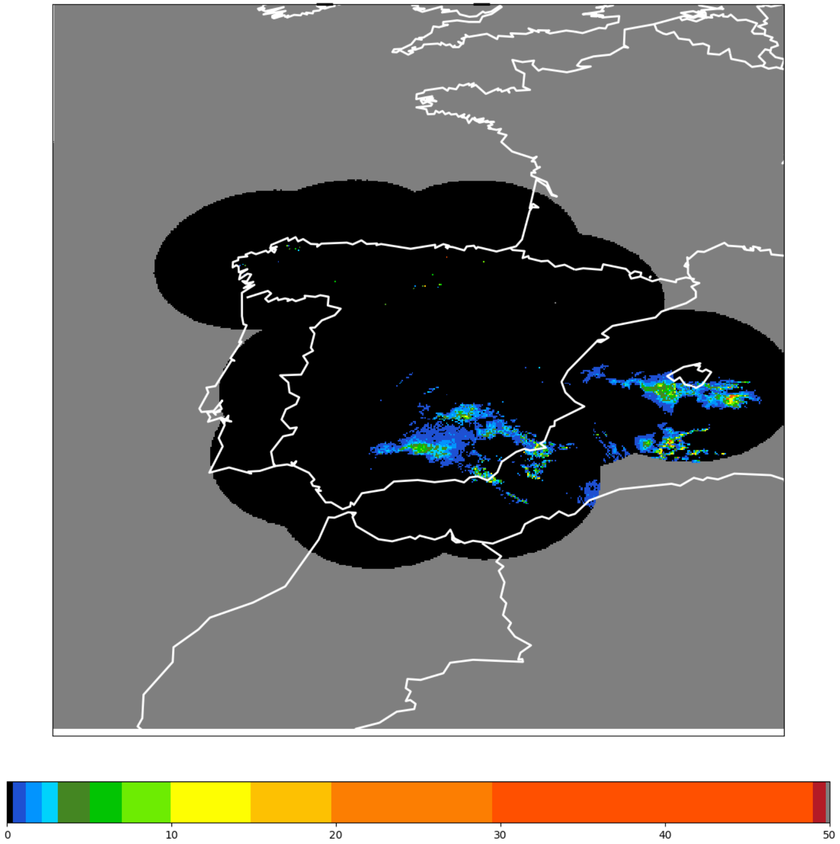
PCPh_PCA_2019256_02:00




PCPh_v2018_2019256_02:00




RFR_2019256_02:00



CONVECTIVE AREA:

Echotop > 6km
Rainfall rate>10mmh $^{-1}$
Box size = 25pix*25pix

| PCPh prototype | N | POD (%) | FAR (%) | CSI (%) | PC (%) |
|---|---|---|---|---|---|
| | 1487046 | 76.36 | 24.73 | 61.05 | 78.5 |

| PCPh prototype | N | POD (%) | FAR (%) | CSI (%) | PC (%) |
|---|---|---|---|---|---|
| | 1933738 | 73.36 | 34.74 | 52.76 | 72.41 |

- False Alarm Ratio:

$$FAR = \frac{false\_alarms}{hits + false\_alarms}$$

- Probability of Detection:

$$POD = \frac{hits}{hits + misses}$$

- Critical Success Index:

$$CSI = \frac{hits}{hits + misses + false\_alarms}$$

- Percentage of Corrects:

$$PC = \frac{hits + correct\_negatives}{hits + misses + false\_alarms + correct\_negatives}$$

| | | Estimated (CRR-Ph,PC-Ph) occurred[1] | Estimated (CRR-Ph,PC-Ph) no occurred |
|---|---|---|---|
| Observed (Radar) | occurred* | hits | misses |
| | no occurred | false alarms | correct negatives |