

Remote Sensing as a Tool for Integrated Water Cycle Management



Alberto Rodríguez Fontal

Chief of Area of Foreign Coordination

General Directorate of Water

Ministry of the Environment and Rural and
Marine Affairs

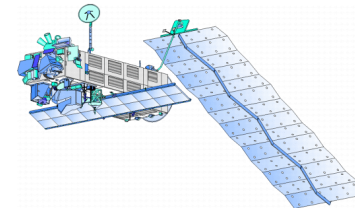
■ Landsat 5 Images

- Spanish National Plan of Remote Sensing (PNT)
National Geographic Institute (IGN)



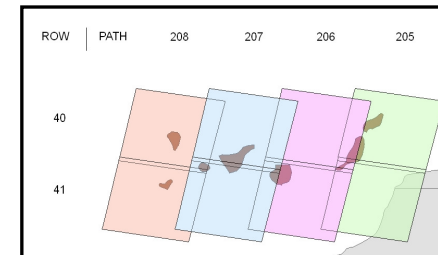
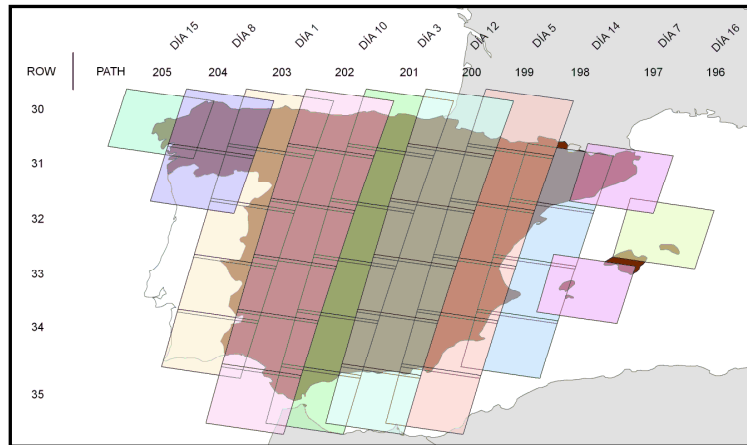
■ MERIS Images

- European Space Agency (ESA)
ESRIN Data Processing Center

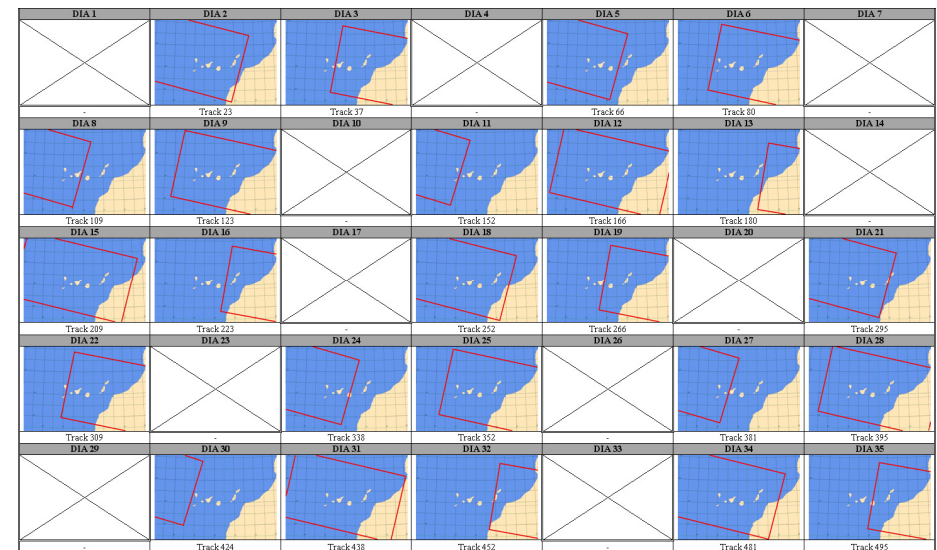
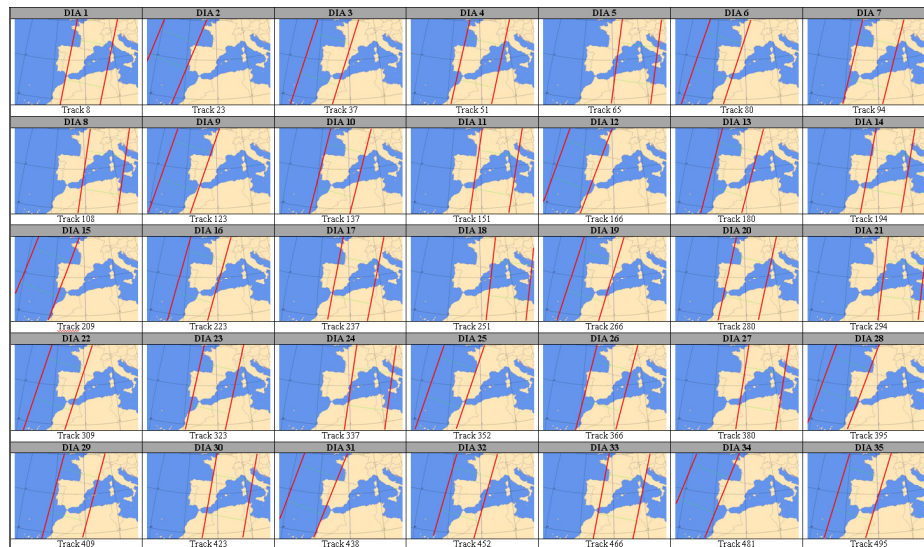


	LANDSAT 5	ENVISAT
Sensor	TM	MERIS
Spatial Resolution	30 m	300 m
Temporal Resolution	16 days	3 days
Spectral Resolution	7 bands	15 bands
Swath Width	185 km	1.150 km

■ Landsat 5 Images (16-day Earth coverage cycle)

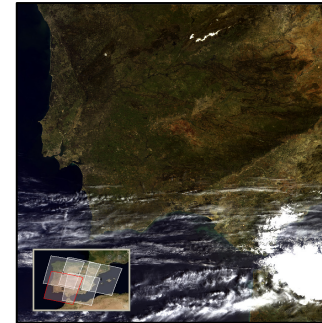


■ MERIS Images (35-day Earth coverage cycle)



■ **Geometric Correction**

- Landsat 5 Images (*Ground Control Points*) - PNT
- MERIS Images (*Ground Control Points*)



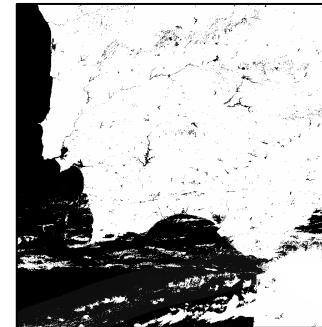
■ **Cloud Masks**

- Landsat 5 Images (*3 & 4 bands*)



■ **Water Masks**

- Landsat 5 Images (*Band 4*)
- MERIS Images (*Band 14*)



■ **Atmospheric Correction**

- Landsat 5 Images (*Gilabert Method*)
- MERIS Images (*ESA previous correction, unfit for studies of quality water*) - **ESA**
- MERIS Images (*Guanter Method, suitable for studies of quality water*) - SCAPE-M algorithm



- ***Water Quality***

- Landsat TM
 - o Suspended Solids Concentration (mg/l)
 - o Transparency (m)
 - o Chlorophyll-a Concentration (mg/m³)
 - o Surface Temperature (°C)
- MERIS
 - o Chlorophyll-a Concentration (mg/m³)
 - o Phycocyanine Concentration (mg/m³)
- Case study: The Albufera of Valencia

- ***Drought***

- o Normalized Difference Vegetation Index (*NDVI*)
- o Normalized Difference Water Index (*NDWI*)
- o Normalized Surface Drought Index (*NSDI* = *NDVI* & *NDWI*)

- ***Floods***

- o Delimitation of the flooded area. Analysis of episodes of flooding (SAIH test)

- ***Hydric Balance***

- o Evapotranspiration (SIMPA model, EWBMS project)

■ *Water Quality*

- o **Aim:** monitoring of the ecological state of surface water bodies (MASp) and assessing the eutrophication degree (EQR*)
- o **Scope:**
 - Landsat Images: Main Spain-Portugal cross border MASp and main lakes for each Spanish Hydrographic Confederations (CC.HH)
 - MERIS Images: Observable MASp in MERIS resolution and evolution of the main heavily modified MASp of each CC.HH.
- o **Achievements:** comparative with the requirements of the Technical Instruction of Planning (IPH)

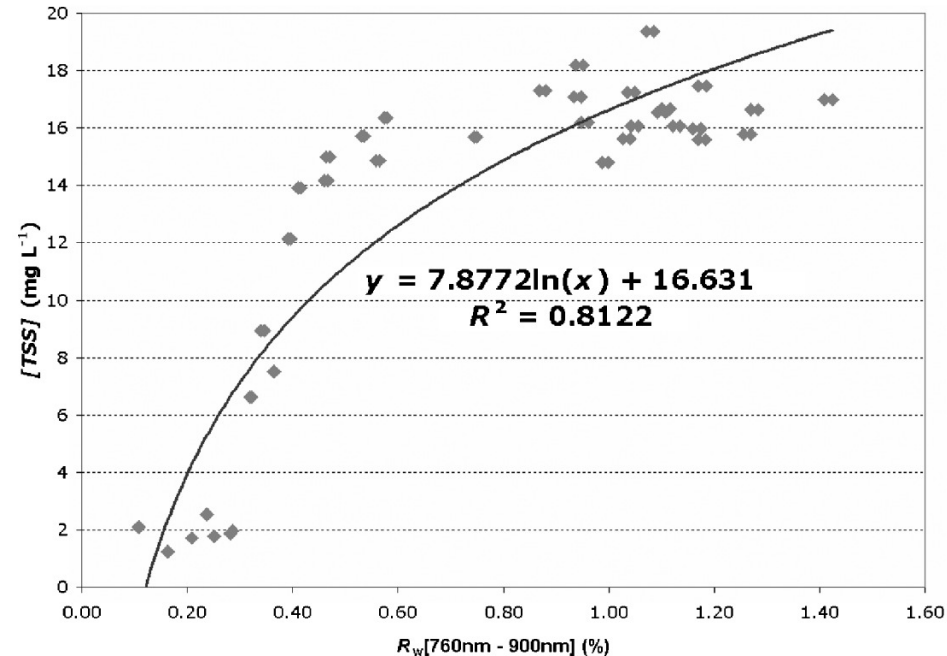
* EQR: Ecological Quality Ratio

$$\text{EQR} = \frac{\text{Observed Ecological Value}}{\text{Reference Ecological Value}}$$

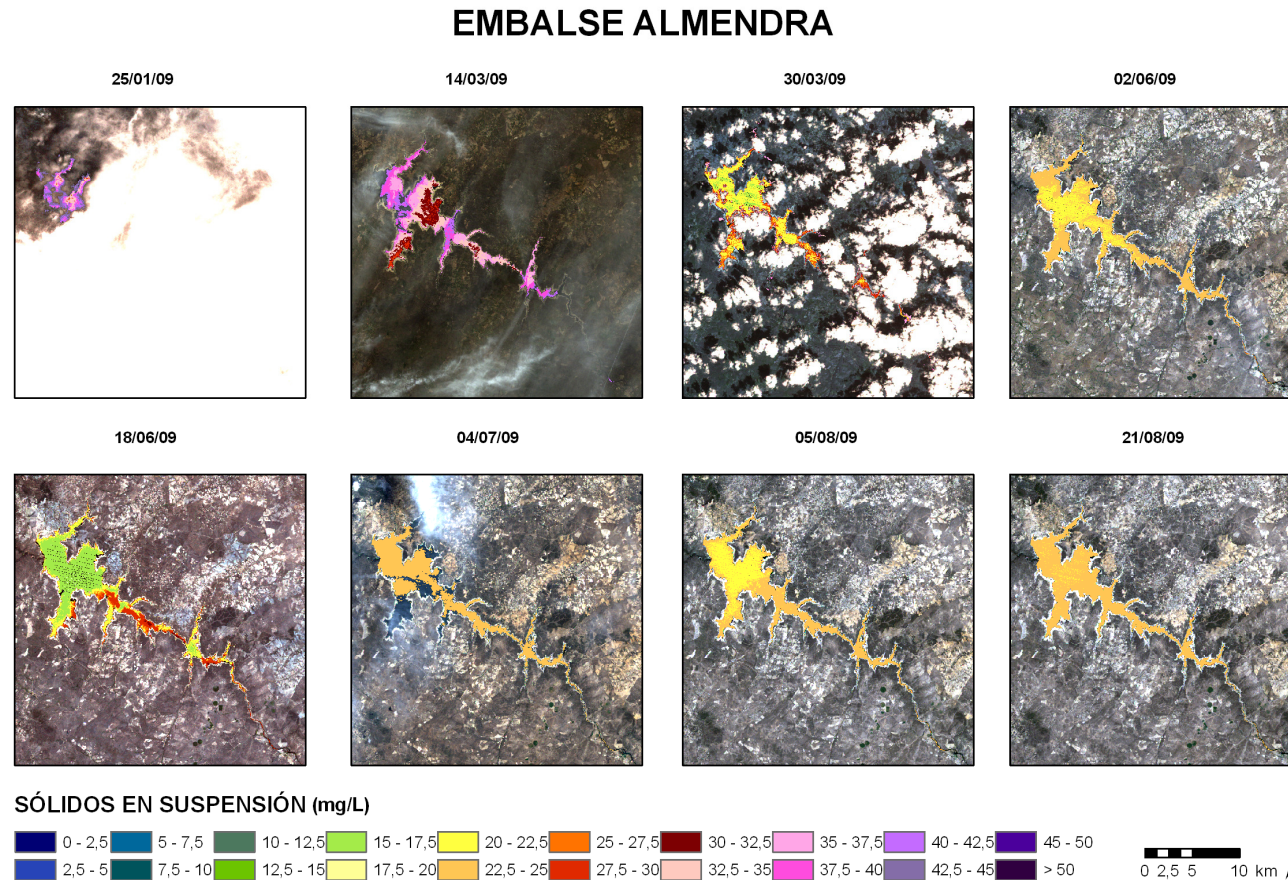
■ *Water Quality with Landsat (Methodology)*

○ Suspended Solids Concentration (mg/l)

Equation that relates the band 4 reflectance of the TM sensor with the suspended solids concentration.



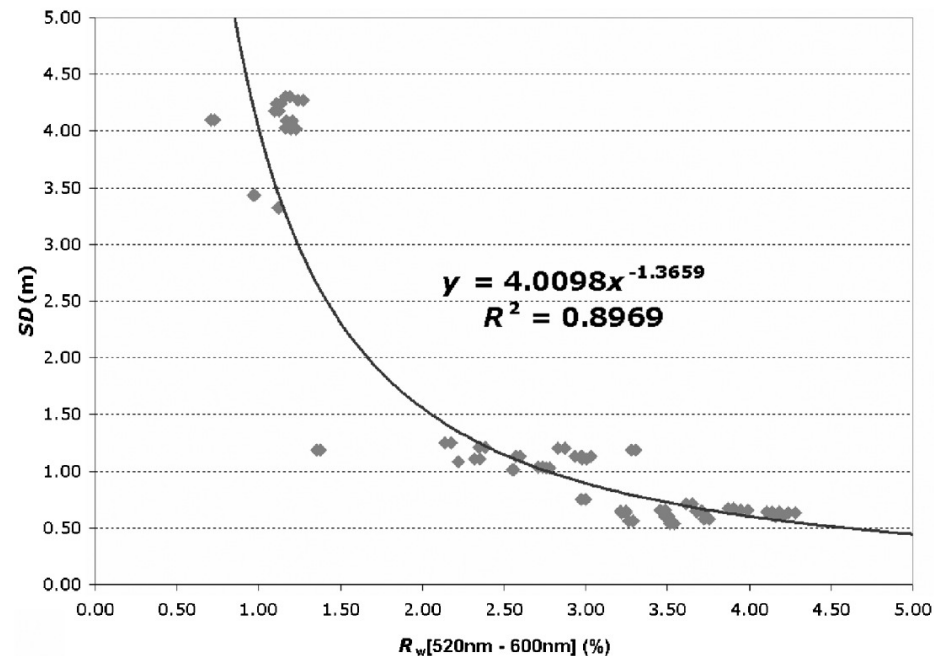
– **Example:** Suspended Solids Concentration (mg/l). Almendra Reservoir



■ *Water Quality with Landsat (Methodology)*

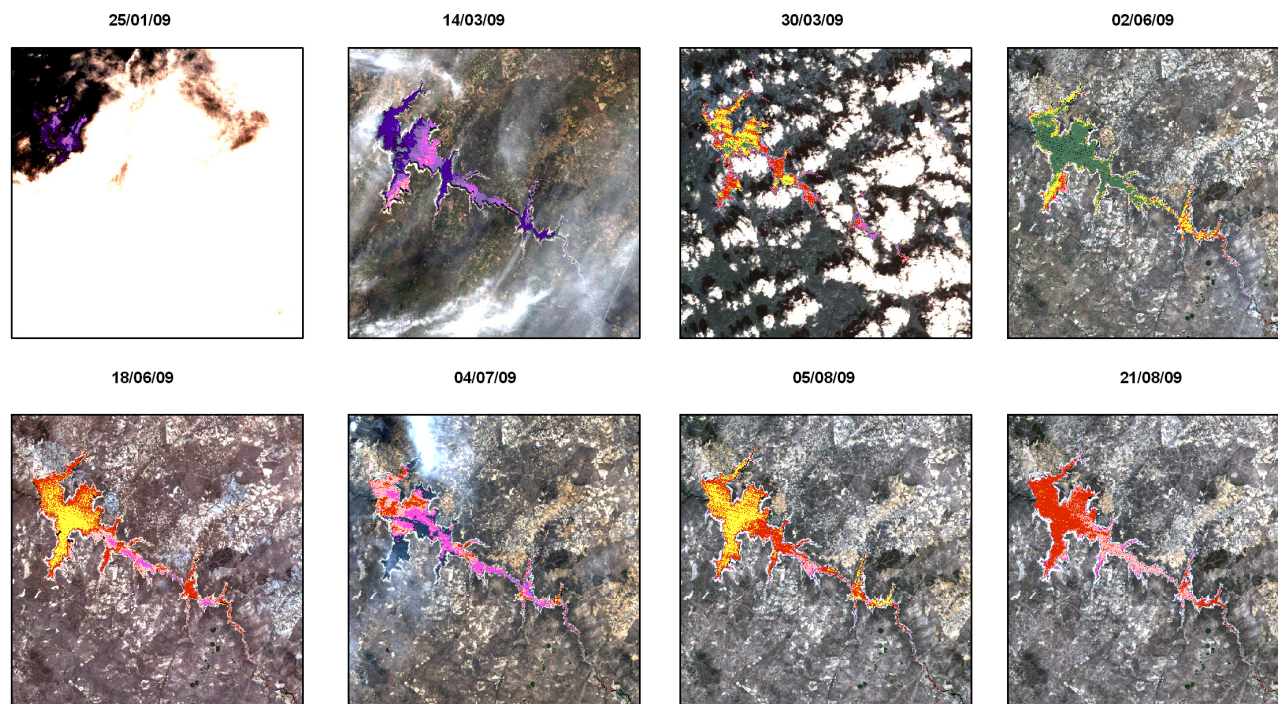
○ Transparency (m)

Equation that relates the band 2 reflectance of the TM sensor with the Secchi Disk transparency depth (SD).

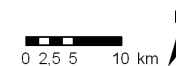


— Example: Transparency (m). Almendra Reservoir

EMBALSE ALMENDRA



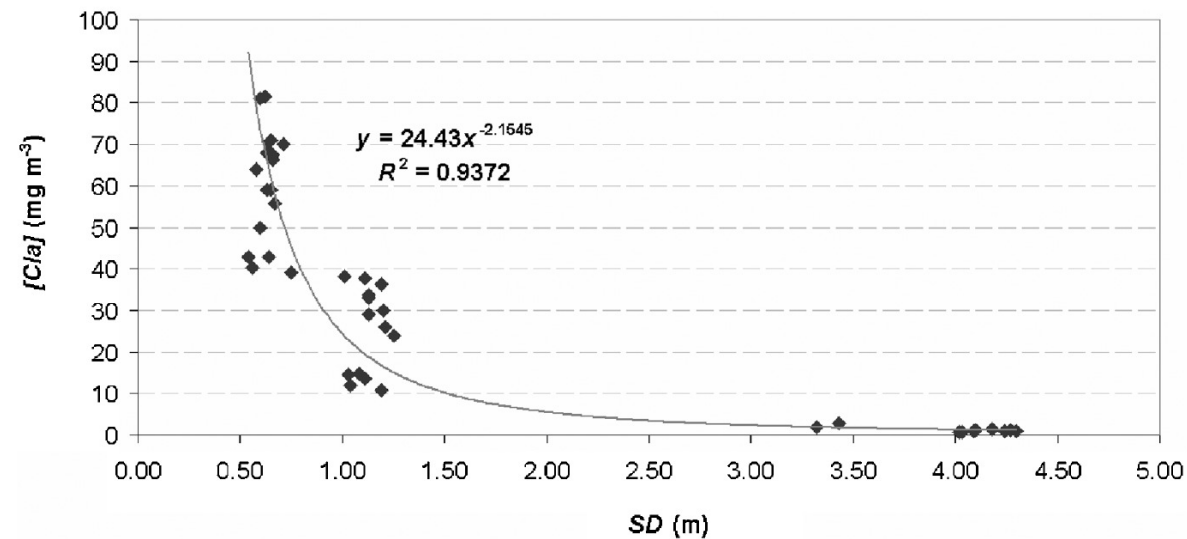
TRANSPARENCIA - Disco de Secchi (m)



■ *Water Quality with Landsat (Methodology)*

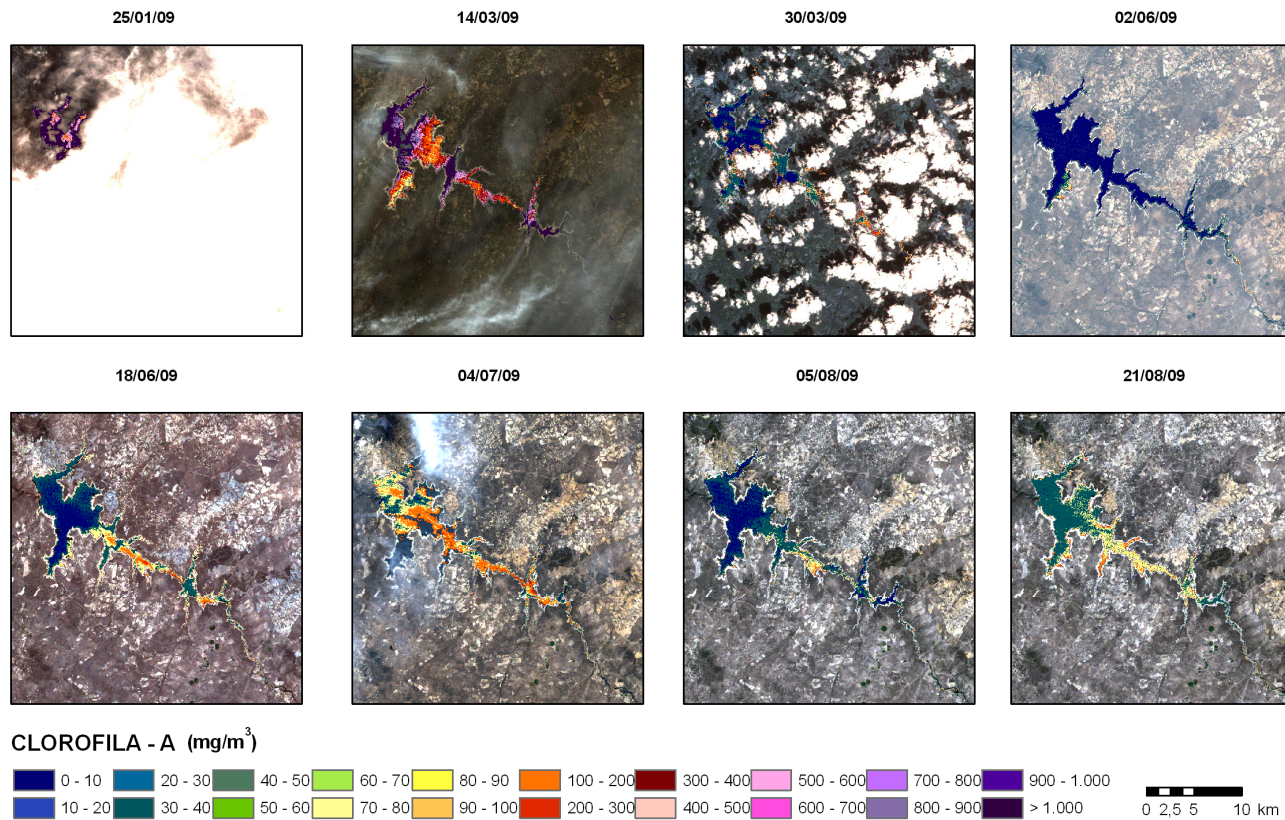
○ Chlorophyll-a Concentration (mg/m³)

Equation that relates the Chlorophyll-a values with the Secchi Disk (SD) values.



– **Example:** Chlorophyll-a Concentration (mg/m^3). Almendra Reservoir

EMBALSE ALMENDRA



■ *Water Quality with Landsat (Methodology)*

○ Surface Temperature (°C)

Simplified Plank Equation, developed by Markham and Barker in 1986 and revised in 2003. The expression of the equation is as follows:

$$T = \frac{K_2}{\ln\left(\frac{K_1}{R} + 1\right)}$$

Where:

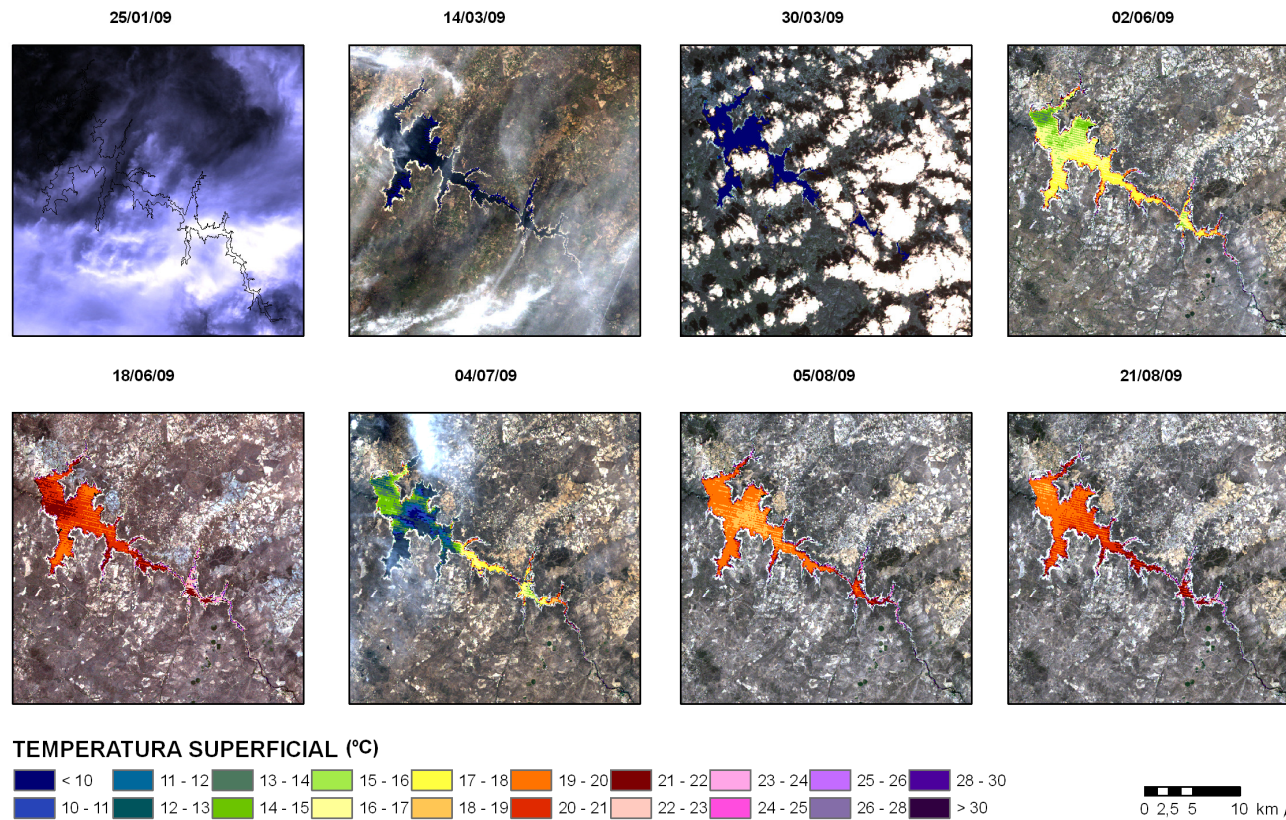
- *T: surface radiant temperature in Kelvin*
- *R: Band 6 spectral radiance*
- *K1 & K2: calibration constants* $\left\{ \begin{array}{l} K1 = 607,76 \text{ W} / (\text{m}^2 \cdot \text{sr} \cdot \mu\text{m}) \\ K2 = 1260,56 \text{ K} \end{array} \right.$

Being:

- *W: Watts; sr: steradians; μm : micrometers; K: Kelvin*

— Example: Surface Temperature (°C). Almendra Reservoir

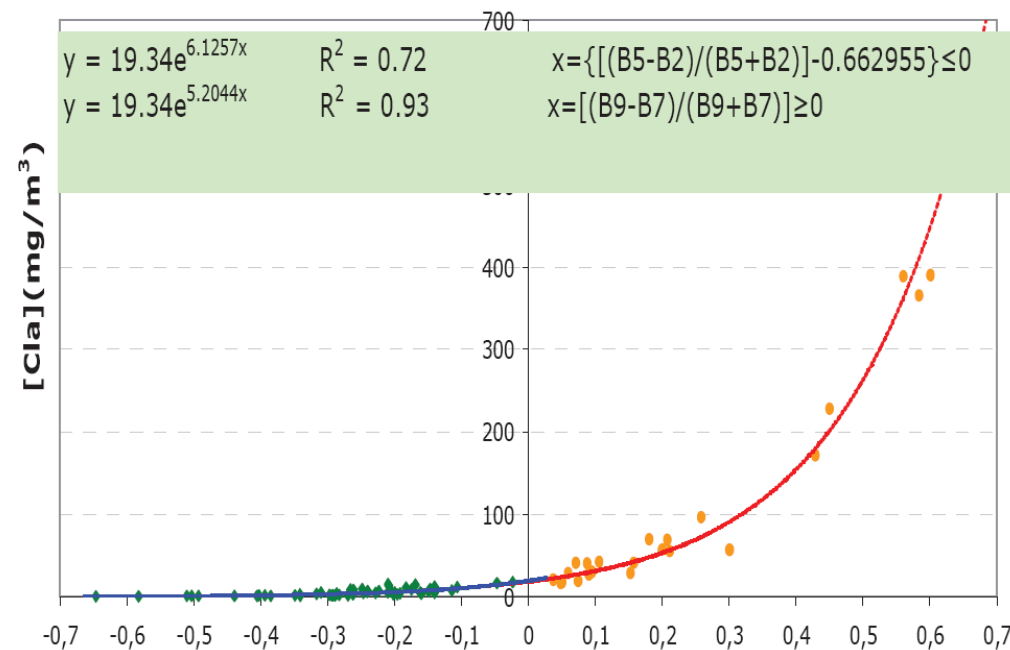
EMBALSE ALMENDRA



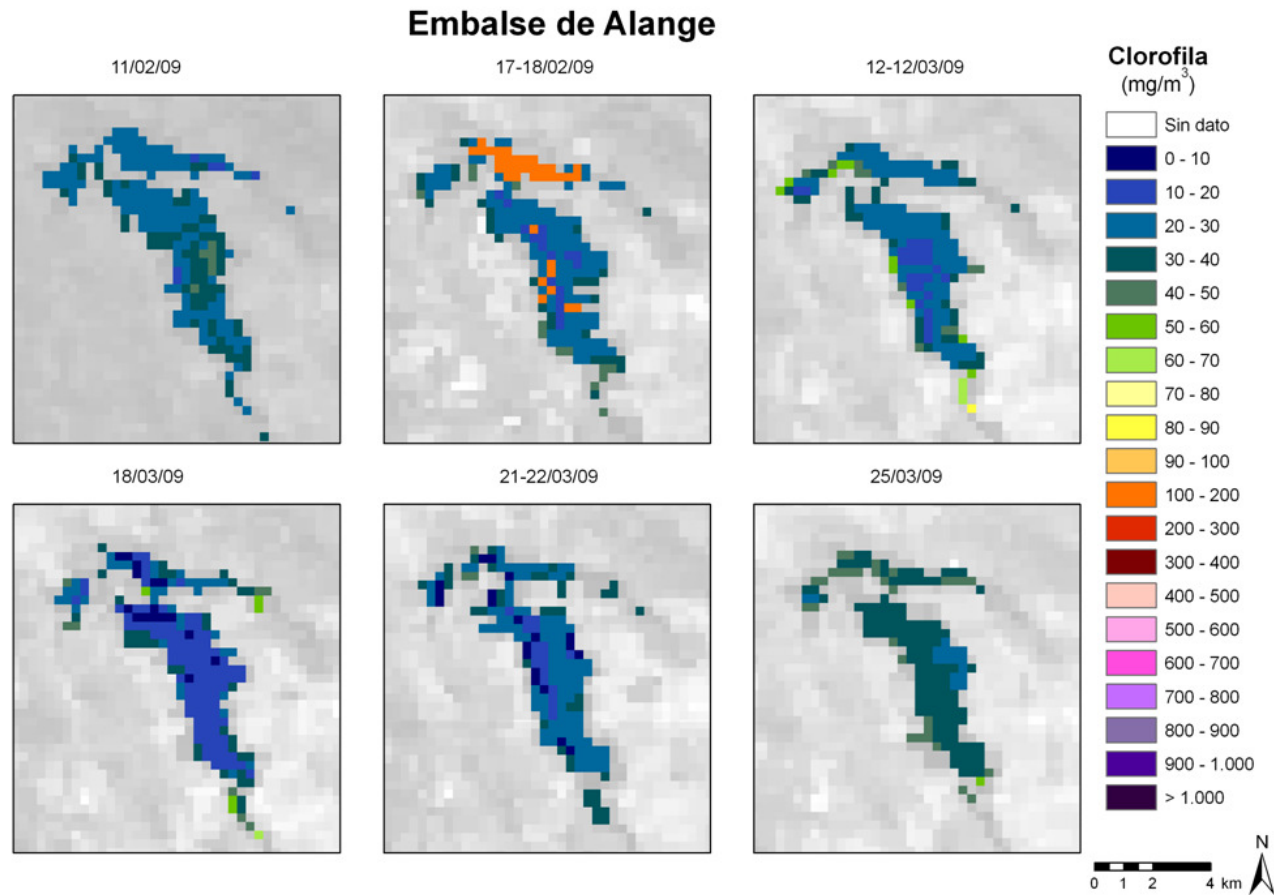
■ *Water Quality with MERIS (Methodology)*

○ Chlorophyll-a Concentration (mg/m³)

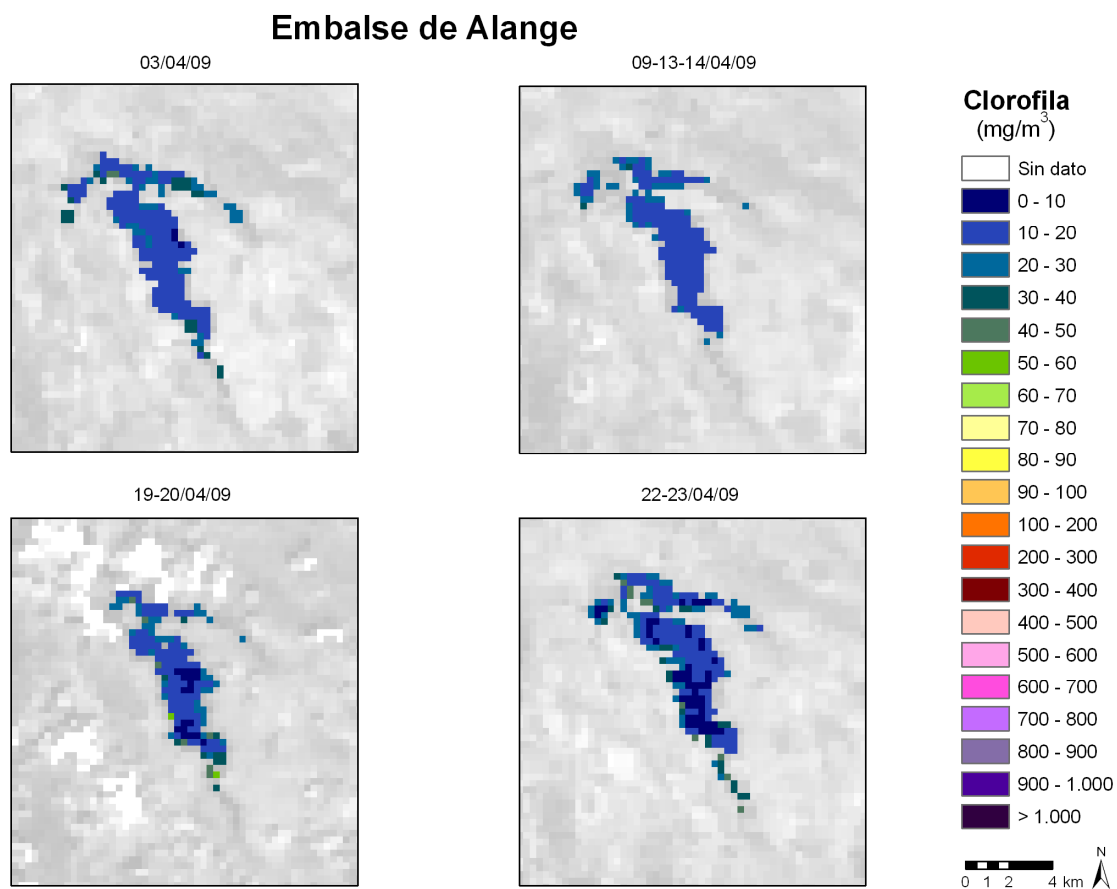
Equation that relates the Chlorophyll-a values with the MERIS bands reflectance.



- **Example:** Chlorophyll-a Concentration (mg/m^3). Alange Reservoir. January–March 2009.

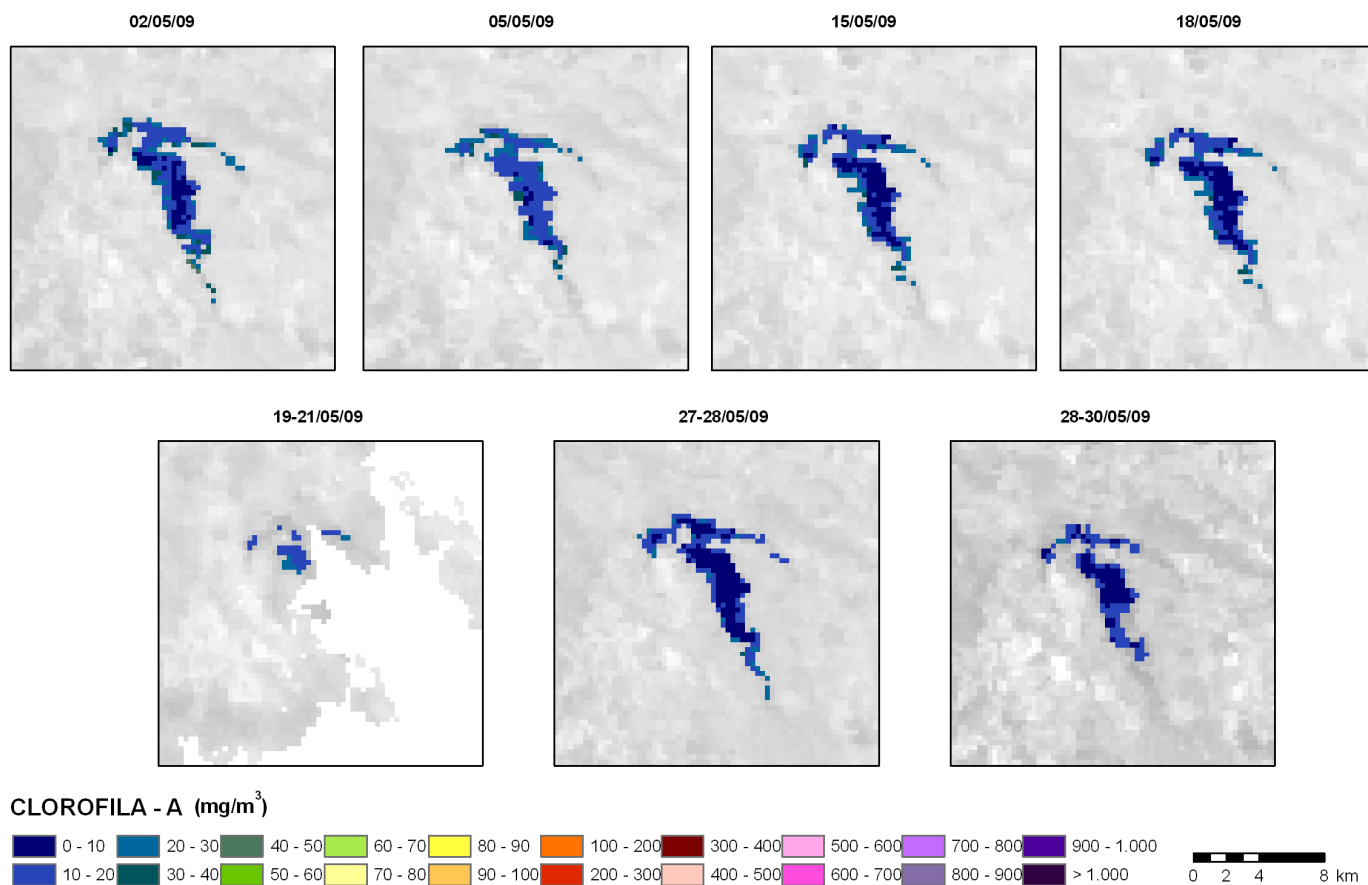


- **Example:** Chlorophyll-a Concentration (mg/m^3). Alange Reservoir . April 2009.



- **Example:** Chlorophyll-a Concentration (mg/m^3). Alange Reservoir . May 2009.

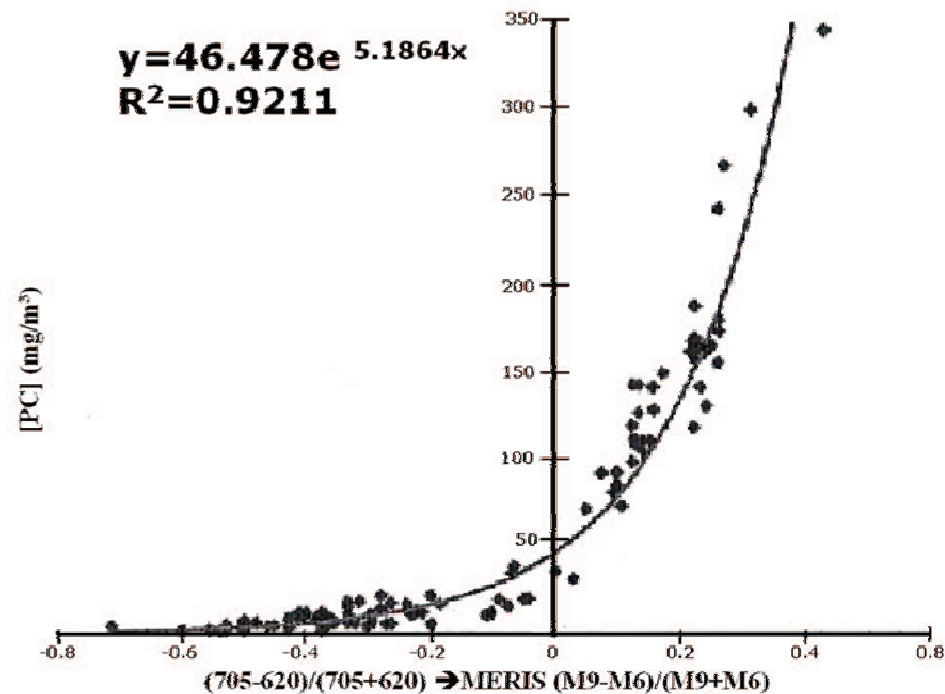
Embalse de Alange



■ *Water Quality with MERIS (Methodology)*

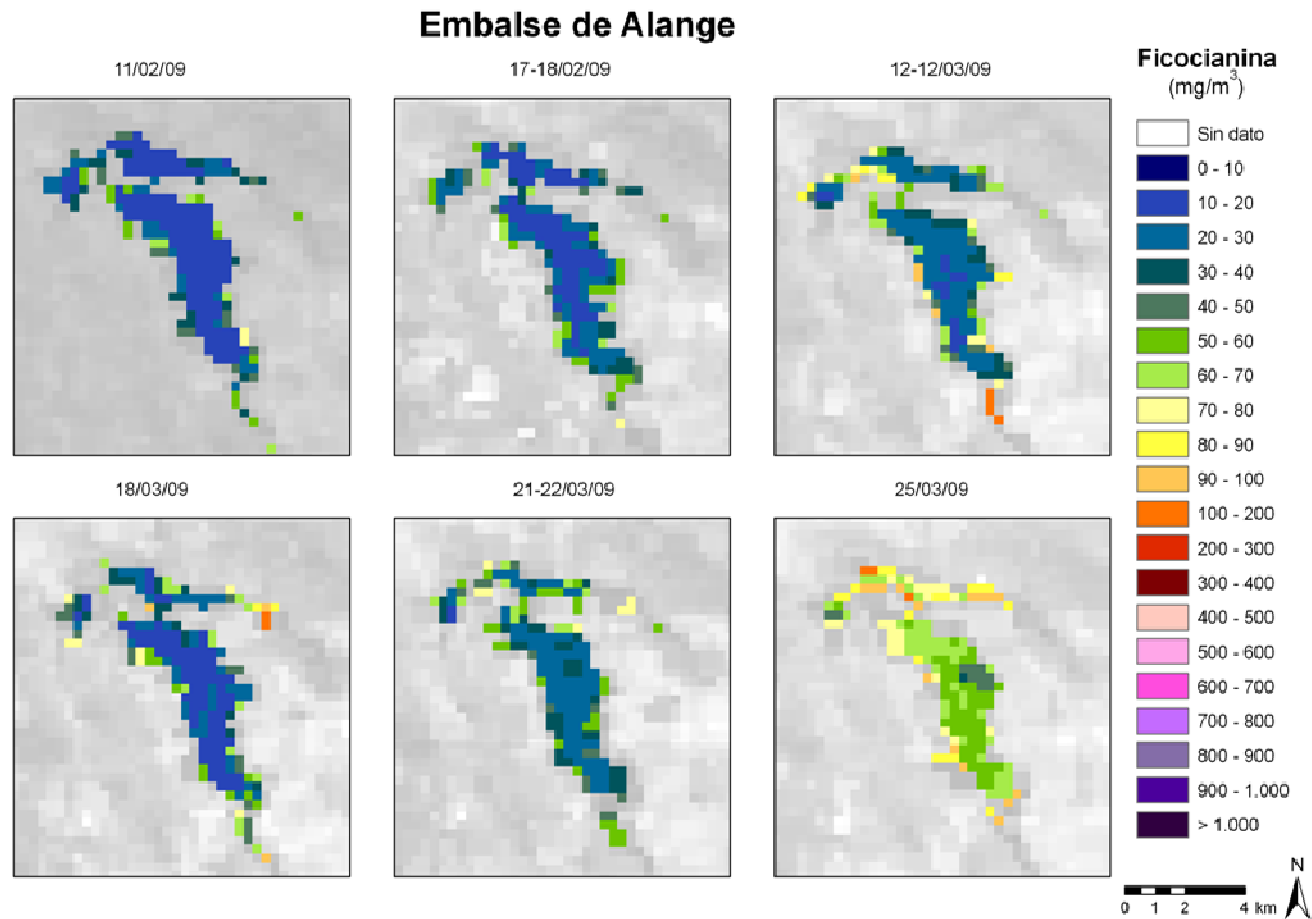
○ Phycocyanine Concentration (mg/m³)

Equation that relates the Phycocyanine values with the MERIS bands reflectance.



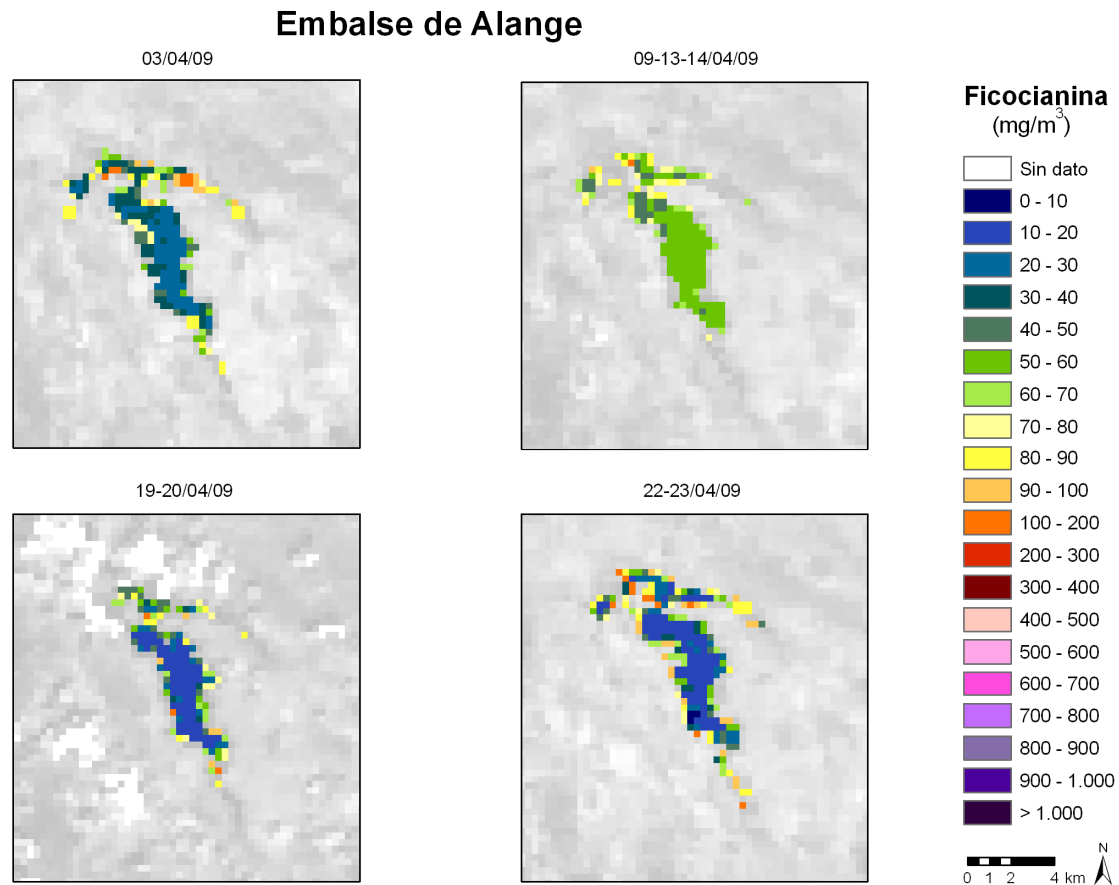
Achievements

- **Example:** Phycocyanine Concentration (mg/m^3). Alange Reservoir . January–March 2009.



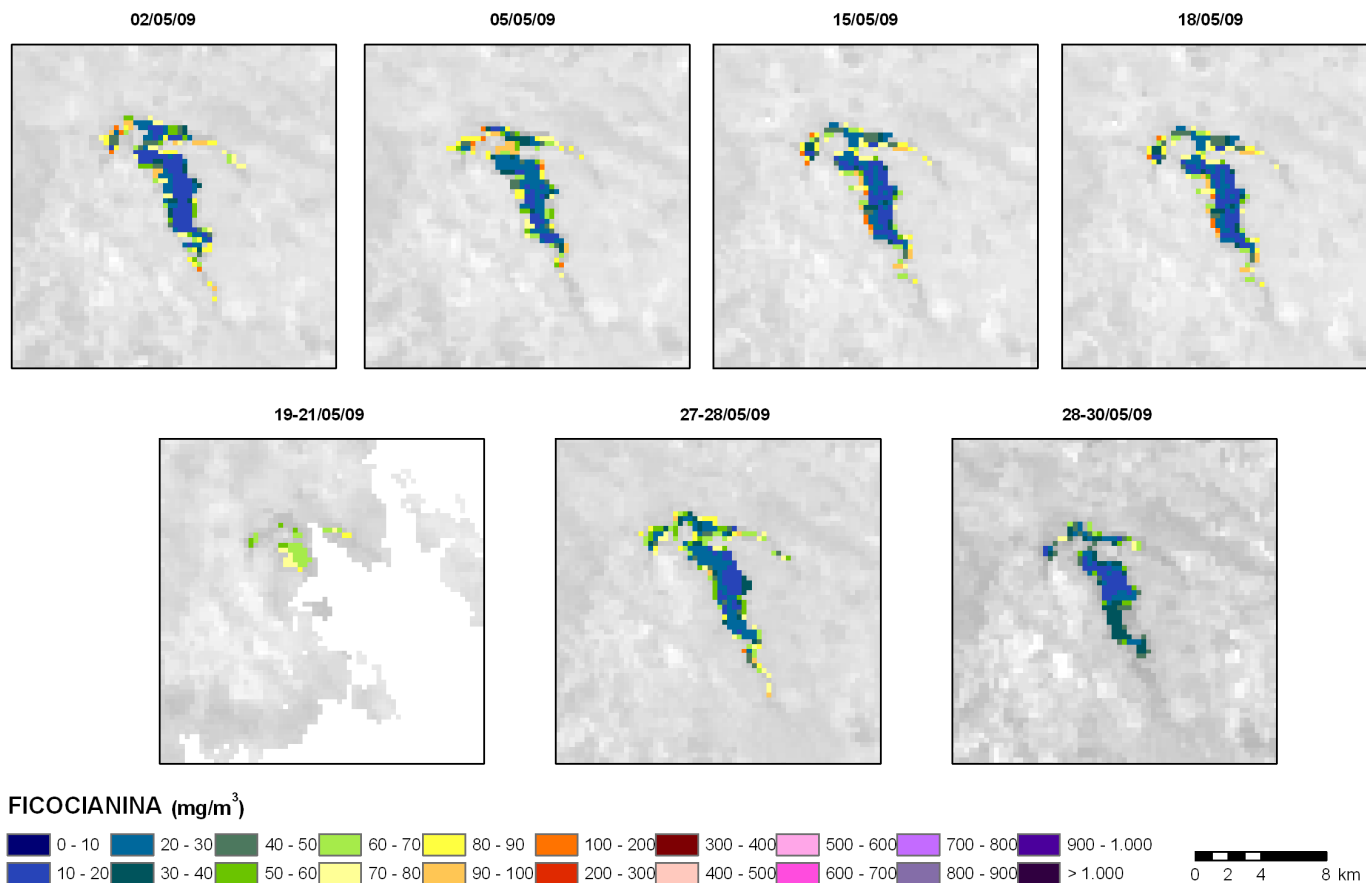
Achievements

- **Example:** Phycocyanine Concentration (mg/m^3). Alange Reservoir . April 2009.

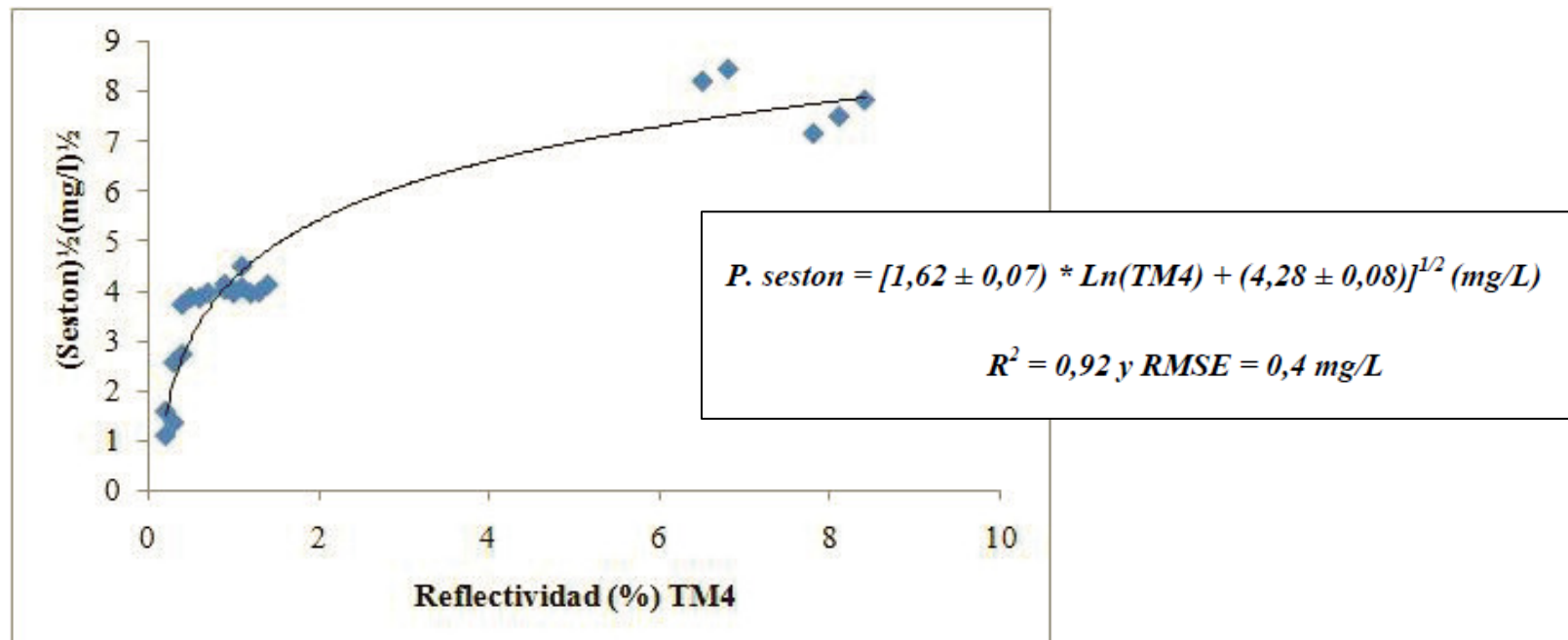


- **Example:** Phycocyanine Concentration (mg/m^3). Alange Reservoir . May 2009.

Embalse de Alange

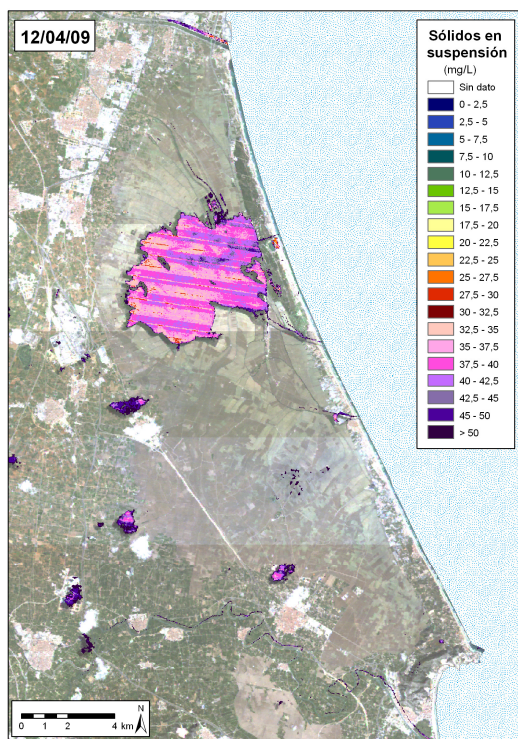


- **Water Quality with Landsat Images**
(Specific Methodology for The Albufera of Valencia)
 - **Suspended Solids Concentration (mg/l)**
Equation that relates the band 4 reflectance of the TM sensor with the suspended solids concentration.

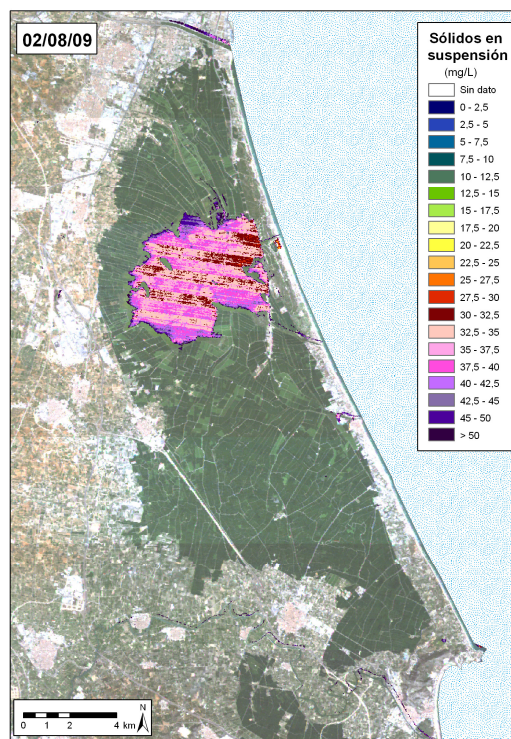


CASE STUDY: The Albufera of Valencia

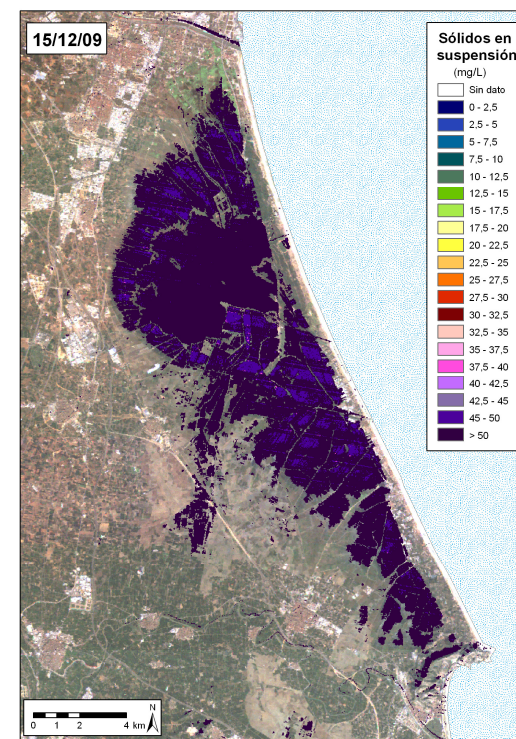
- **Example:** Suspended Solids Concentration (mg/l). Evolution for the lagoon of The Albufera of Valencia in 3 different moments of its hydrological cycle.



Dry paddy field without rice



Dry paddy field with high density of rice plants

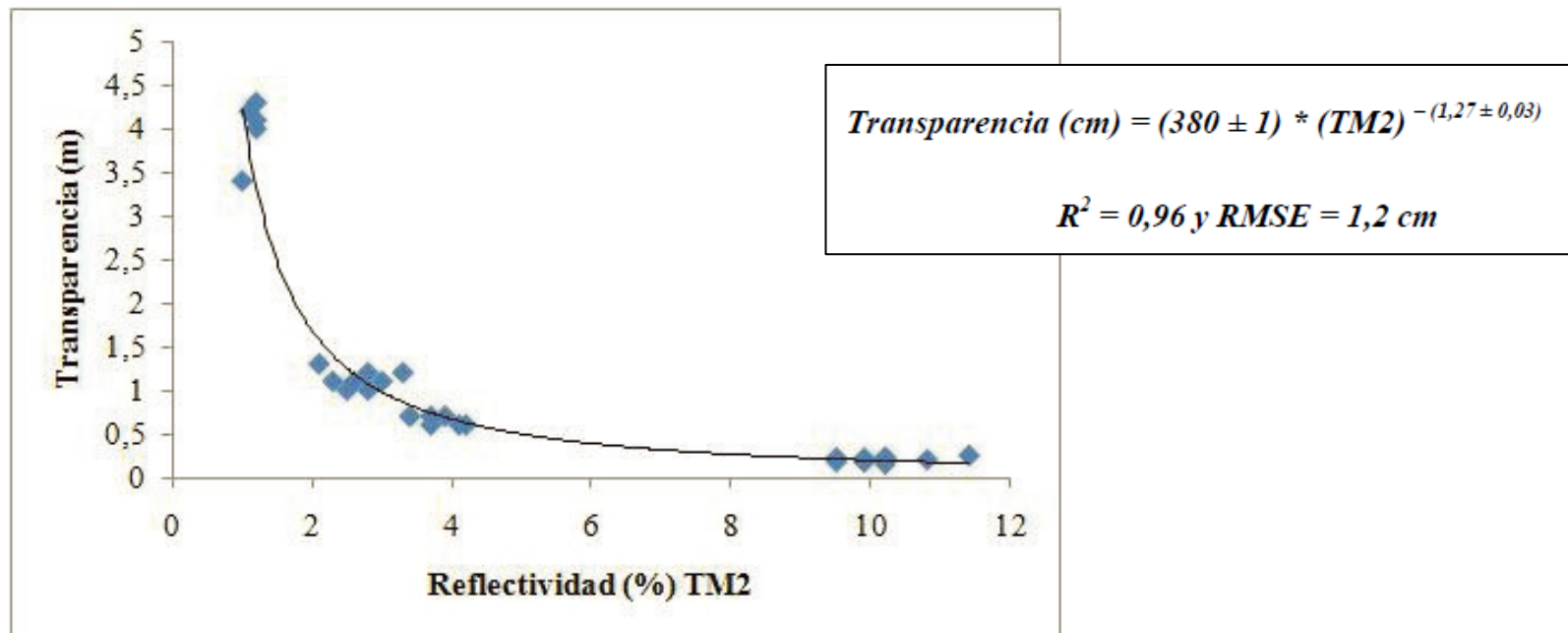


Flooded paddy field

- **Water Quality with Landsat Images**
(Specific Methodology for The Albufera of Valencia)

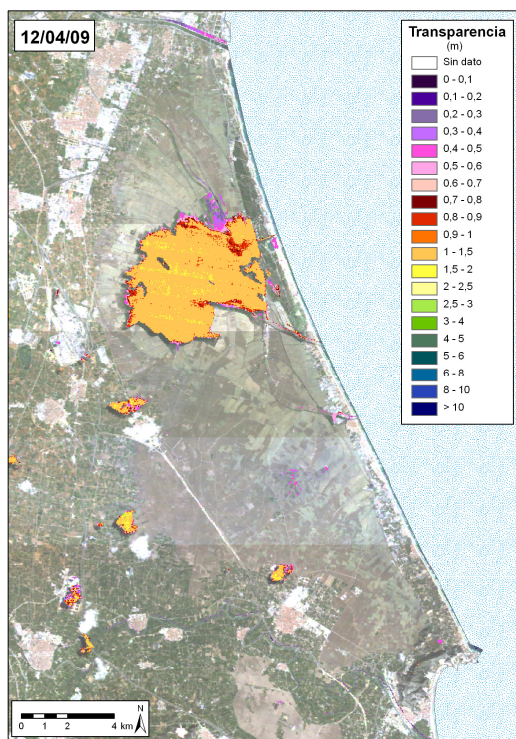
- **Transparency (m)**

Equation that relates the band 2 reflectance of the TM sensor with the Secchi Disk transparency depth (SD).

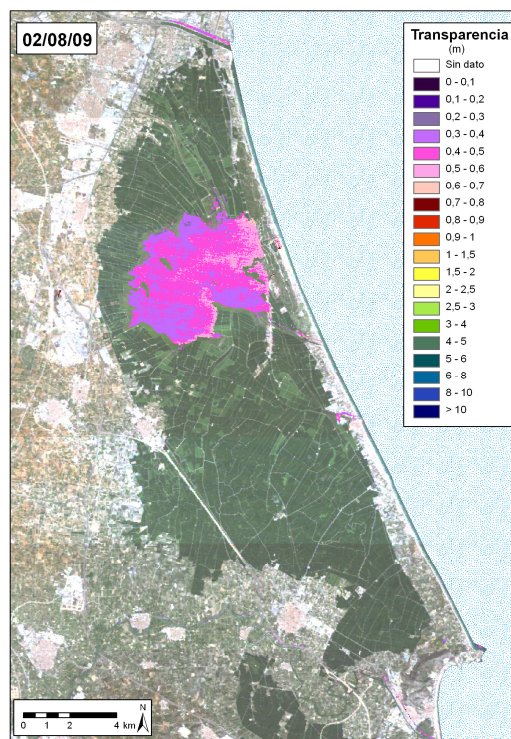


CASE STUDY: The Albufera of Valencia

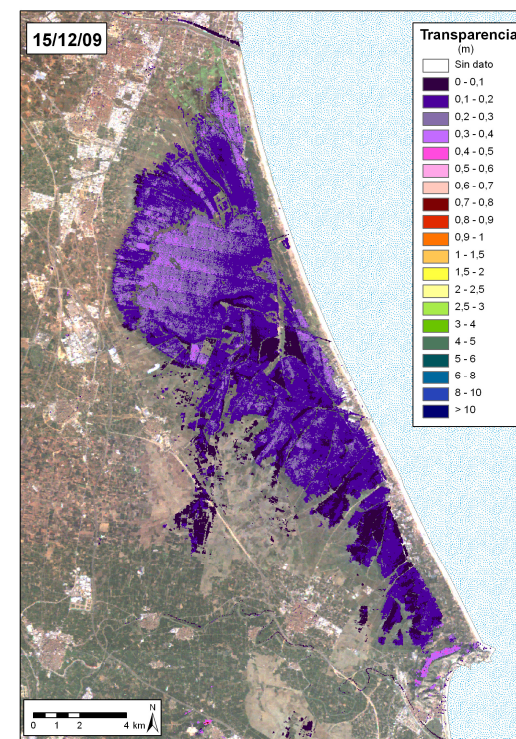
- **Example:** Transparency (m). Evolution for the lagoon of The Albufera of Valencia in 3 different moments of its hydrological cycle.



Dry paddy field without rice



Dry paddy field with high density of rice plants



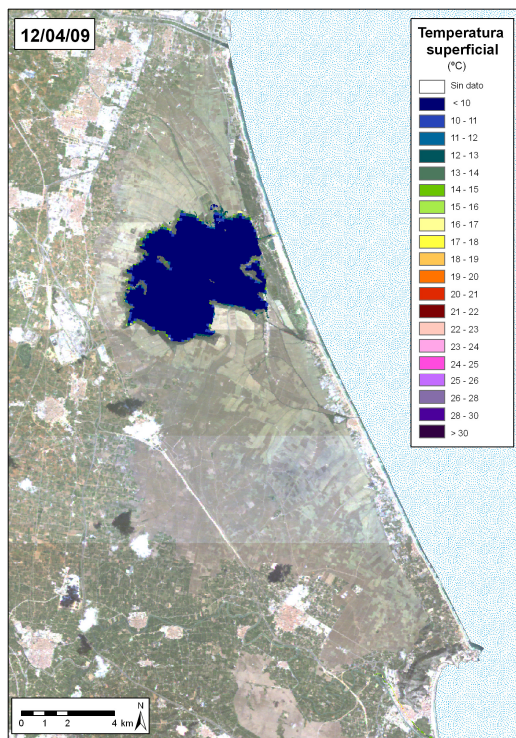
Flooded paddy field

CASE STUDY: The Albufera of Valencia

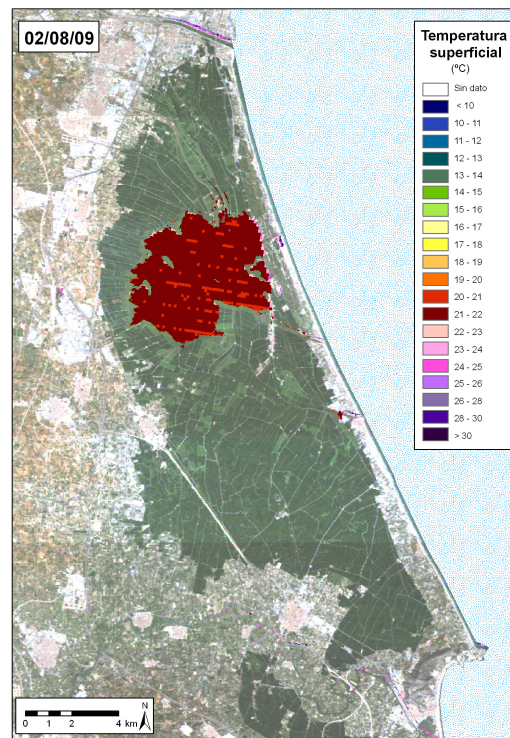
■ *Water Quality with Landsat Images*

○ Surface Temperature (°C)

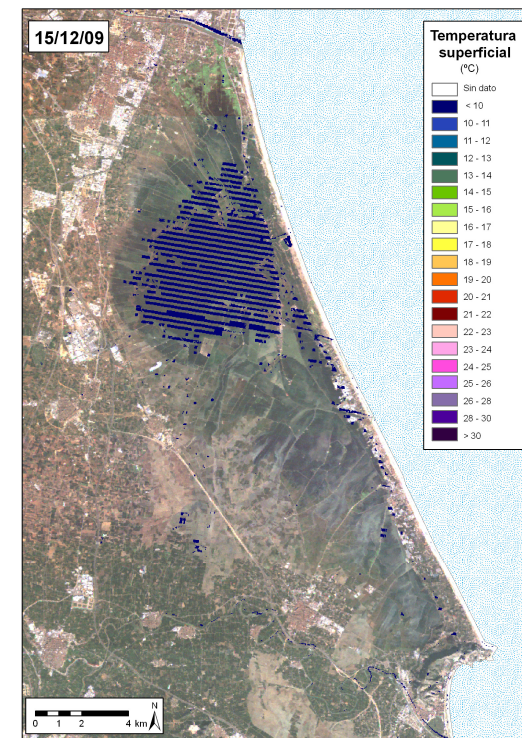
- **Example:** Surface Temperature (°C). Evolution for the lagoon of The Albufera of Valencia in 3 different moments of its hydrological cycle.



Dry paddy field without rice



Dry paddy field with high density of rice plants

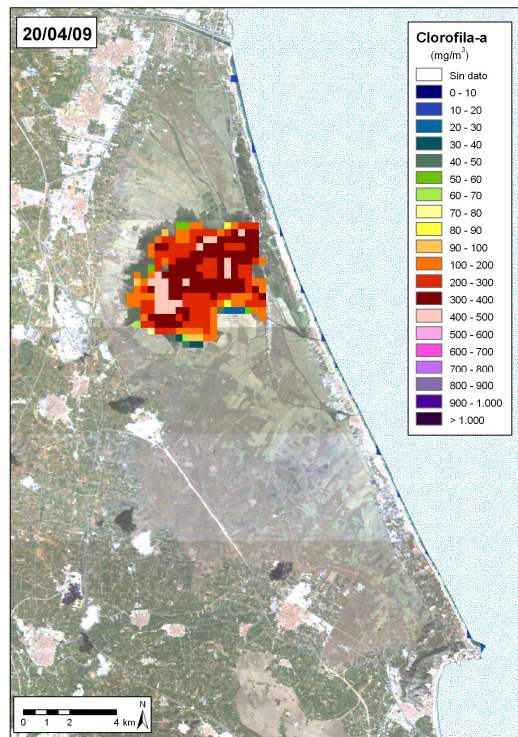


Flooded paddy field

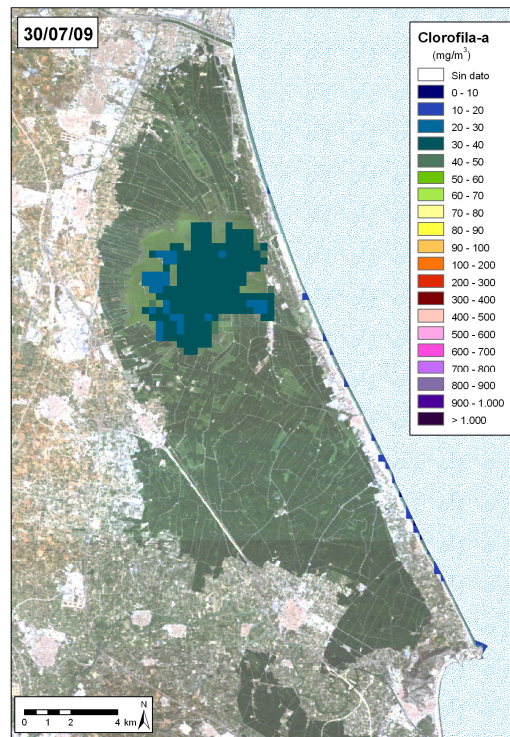
■ *Water Quality with MERIS*

○ Chlorophyll-a Concentration (mg/m³)

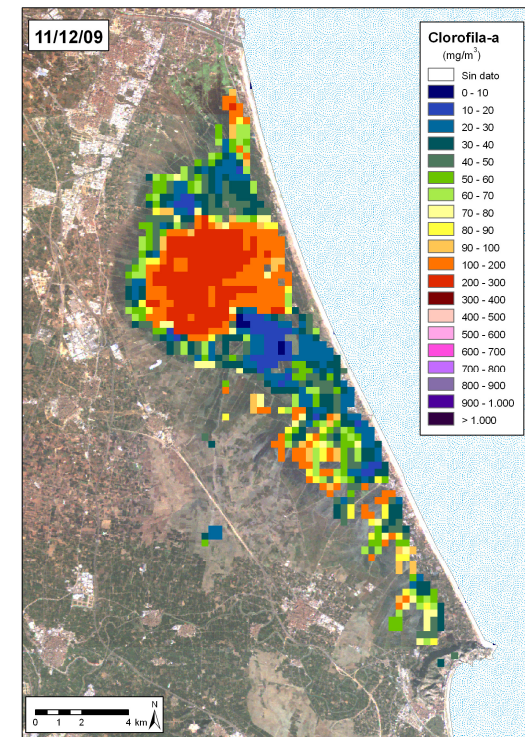
- **Example:** Chlorophyll-a Concentration (mg/m³). Evolution for the lagoon of The Albufera of Valencia in 3 different moments of its hydrological cycle.



Dry paddy field without rice



Dry paddy field with high density of rice plants

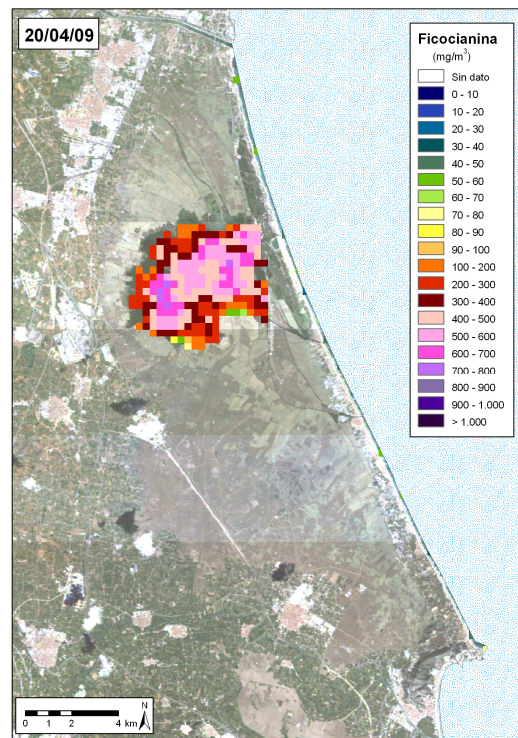


Flooded paddy field

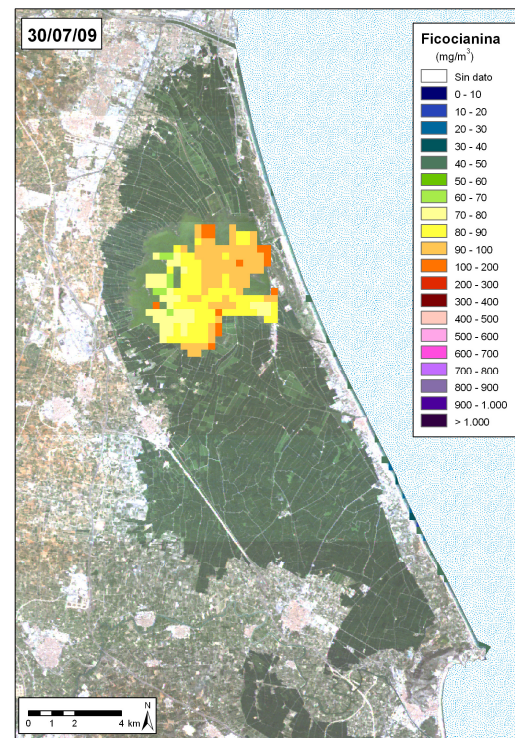
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○ Phycocyanine Concentration (mg/m³)

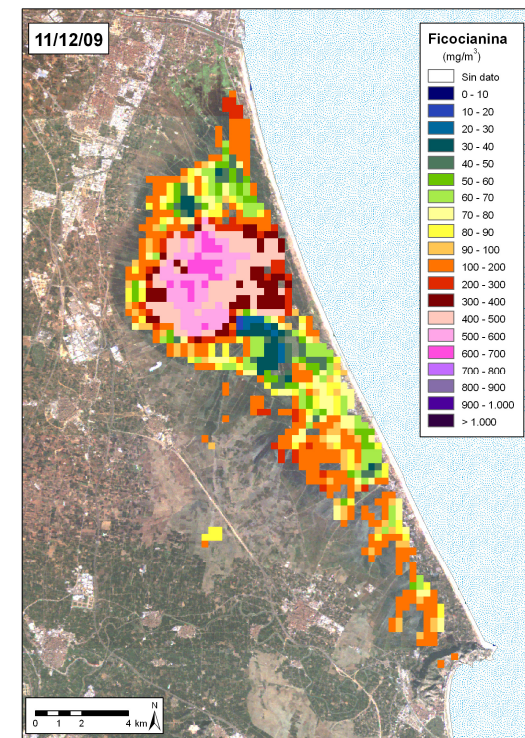
- **Example:** Phycocyanine Concentration (mg/m³). Evolution for the lagoon of The Albufera of Valencia in 3 different moments of its hydrological cycle.



Dry paddy field without rice



Dry paddy field with high density of rice plants



Flooded paddy field

■ *Drought*

- o **Aim:** development of a drought index that complements the drought indicators defined for the PES*
- o **Scope:** the whole national territory (168 Drought Management Systems defined in the PES*)
- o **Achievements:** provide support for the PES indicators. Monitor at the level of Drought Management Systems

* PES: Special Drought Plans

■ *Drought (Methodology)*

An index of drought in surface (NSDI), adapted from a model developed by the USA National Drought Mitigation Center (NDMC) with MODIS images (Normalized Difference Drought Index NDDI), is being validated for Spain.

The Spanish index is obtained from MERIS images, combining a water content index (NDWI) with a vegetation index (NDVI).

<i>MODIS Images (NDMC)</i>	<i>MERIS Images (NSDI)</i>
$\left. \begin{aligned} \text{NDVI} &= \frac{\rho_{\text{NIR}} - \rho_{\text{RED}}}{\rho_{\text{NIR}} + \rho_{\text{RED}}} \\ \text{NDWI} &= \frac{\rho_{\text{NIR}} - \rho_{\text{SWIR}}}{\rho_{\text{NIR}} + \rho_{\text{SWIR}}} \end{aligned} \right\}$	$\left. \begin{aligned} \text{NDVI} &= \frac{\rho_{\text{NIR}} - \rho_{\text{RED}}}{\rho_{\text{NIR}} + \rho_{\text{RED}}} \\ \text{NDWI} &= \frac{\rho_{\text{NIR}} - \rho_{\text{GRE}}}{\rho_{\text{NIR}} + \rho_{\text{GRE}}} \end{aligned} \right\}$
$\text{NDDI} = \frac{\text{NDVI} - \text{NDWI}}{\text{NDVI} + \text{MDWI}}$	$\text{NSDI} = \frac{\text{NDWI} - \text{NDVI}}{\text{NDWI} + \text{MDVI}}$

Where: GRE green, RED red, NIR near infrared y SWIR shortwave infrared

MERIS does not collect information in the SWIR region so, to implement the calculation of NDWI, an alternative band has been selected. The band used is situated around the 0.56 μm (green -band 5) where the absorption of the chlorophyll is minimum and the reflectance of water is maximum.

MODIS Images (NDMC)

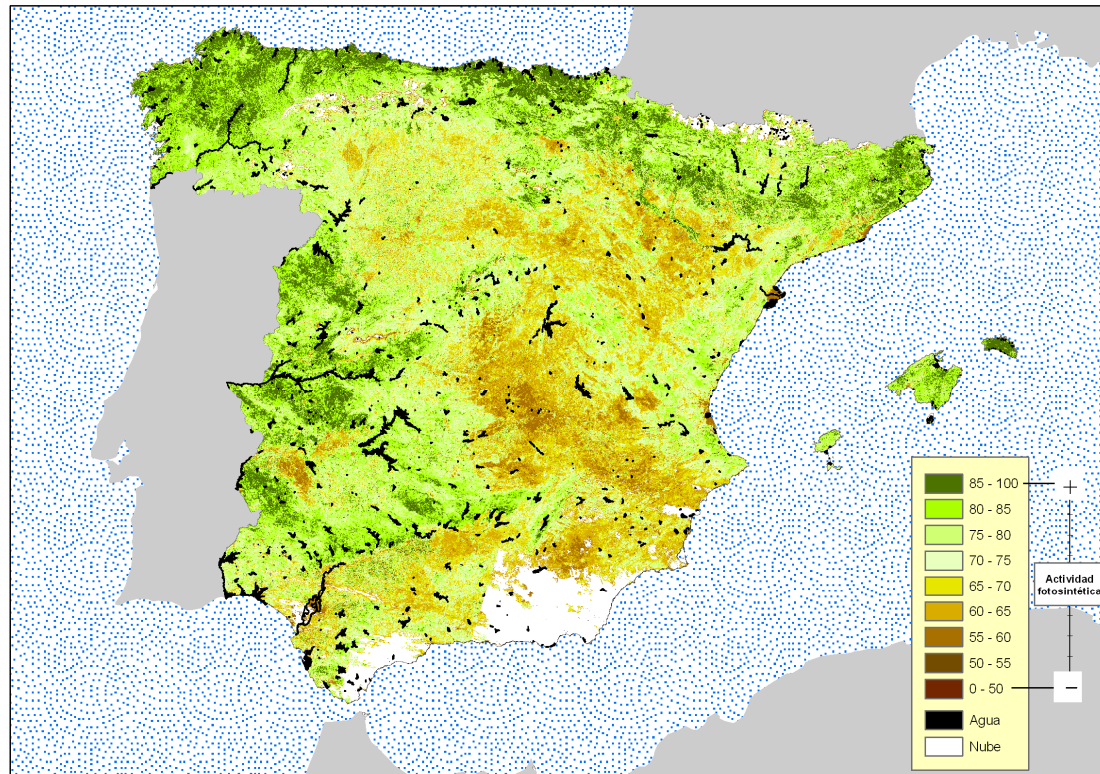
$$\left. \begin{aligned} \text{NDVI} &= \frac{\text{MO2} - \text{MO1}}{\text{MO2} + \text{MO1}} \\ \text{NDWI} &= \frac{\text{MO2} - \text{MO7}}{\text{MO2} + \text{MO7}} \end{aligned} \right\} \text{NDDI} = \frac{\text{NDVI} - \text{NDWI}}{\text{NDVI} + \text{NDWI}}$$

MERIS Images (NSDI)

$$\left. \begin{aligned} \text{NDVI} &= \frac{\text{ME13} - \text{ME8}}{\text{ME13} + \text{ME8}} \\ \text{NDWI} &= \frac{\text{ME11} - \text{ME5}}{\text{ME11} + \text{ME5}} \end{aligned} \right\} \text{NSDI} = \frac{\text{NDWI} - \text{NDVI}}{\text{NDWI} + \text{NDVI}}$$

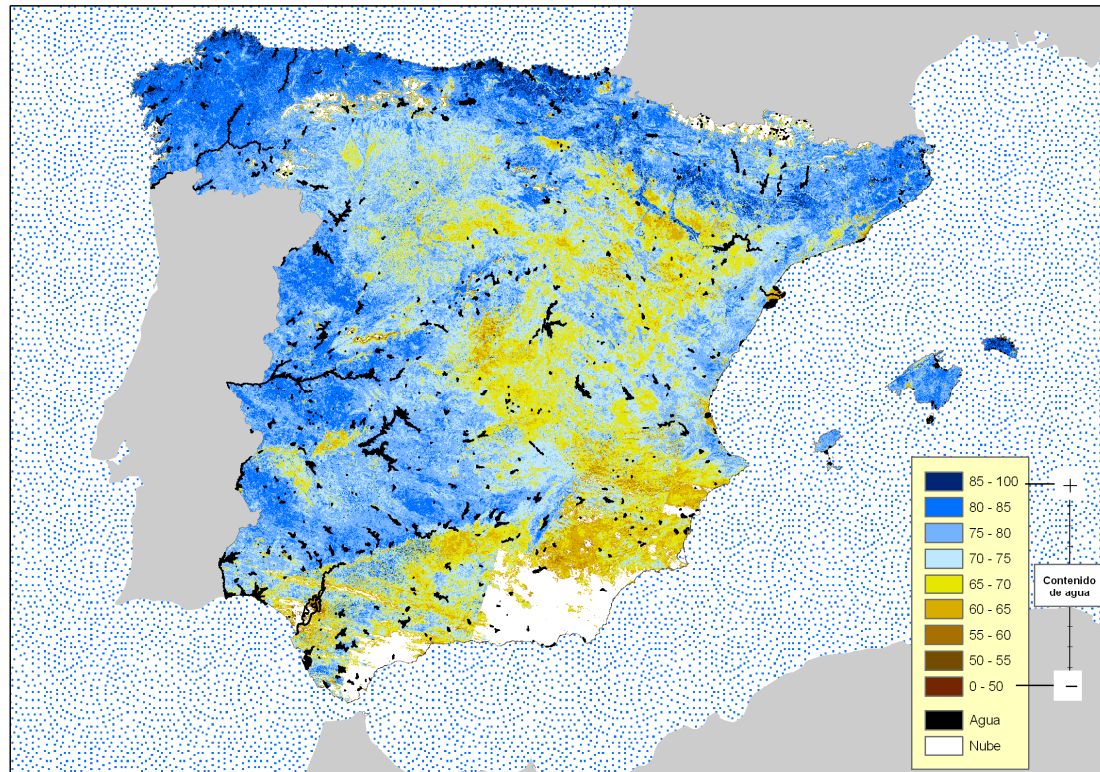
Achievements

- **Example:** Vegetation density of green index (NDVI).



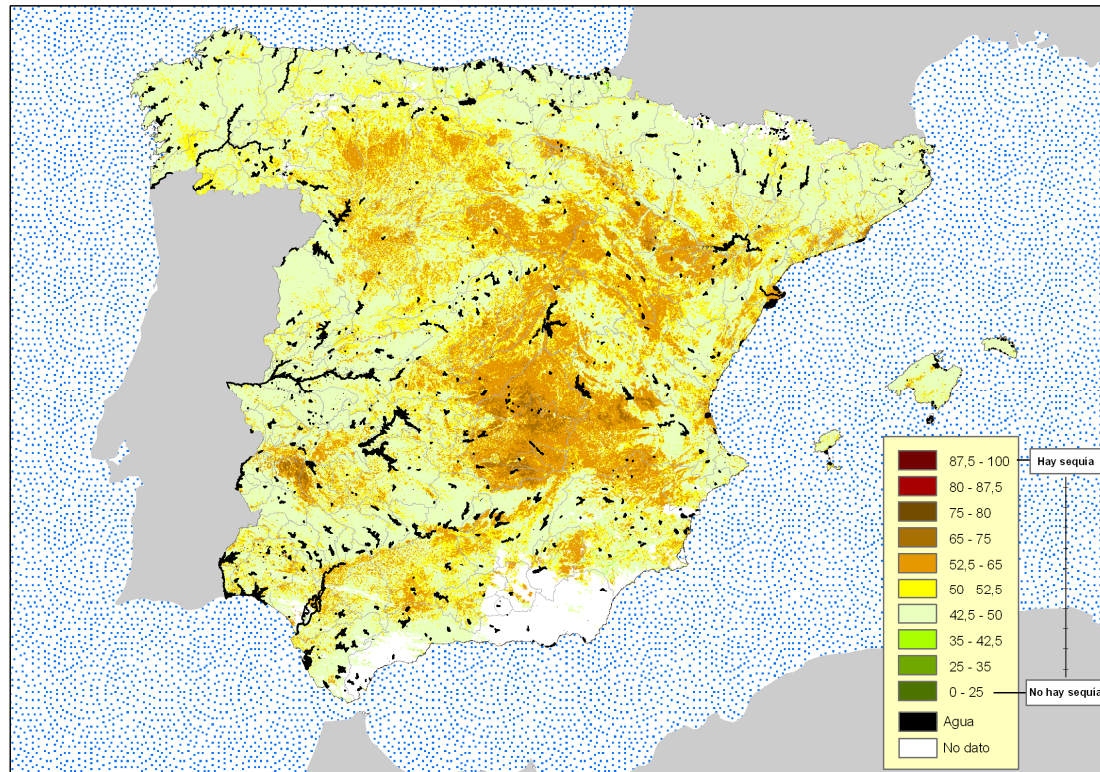
April 2010. Vegetation index

- **Example:** Vegetation water content index (NDWI)



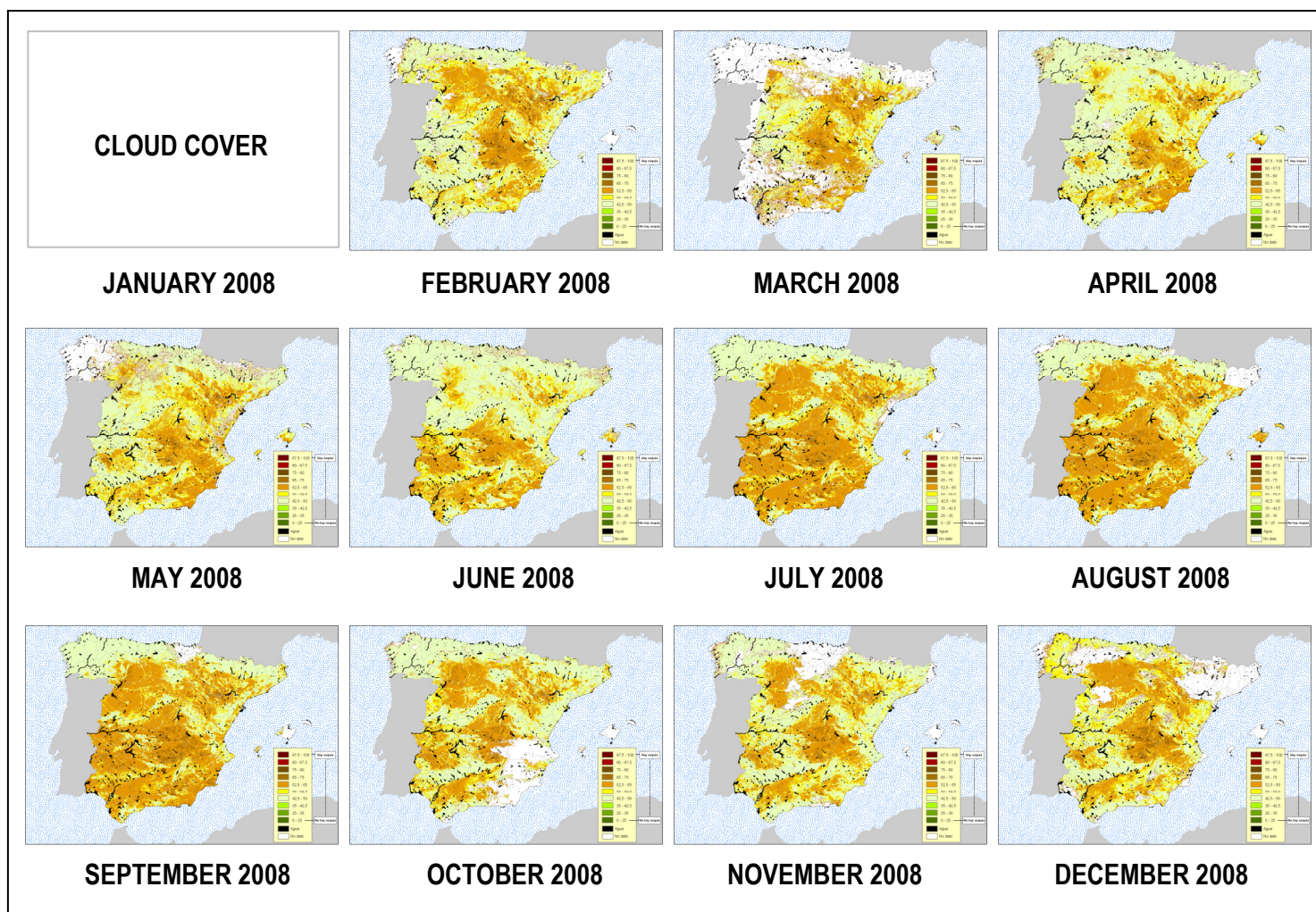
April 2010. Water index

- **Example:** Normalized Surface Drought Index (NSDI)

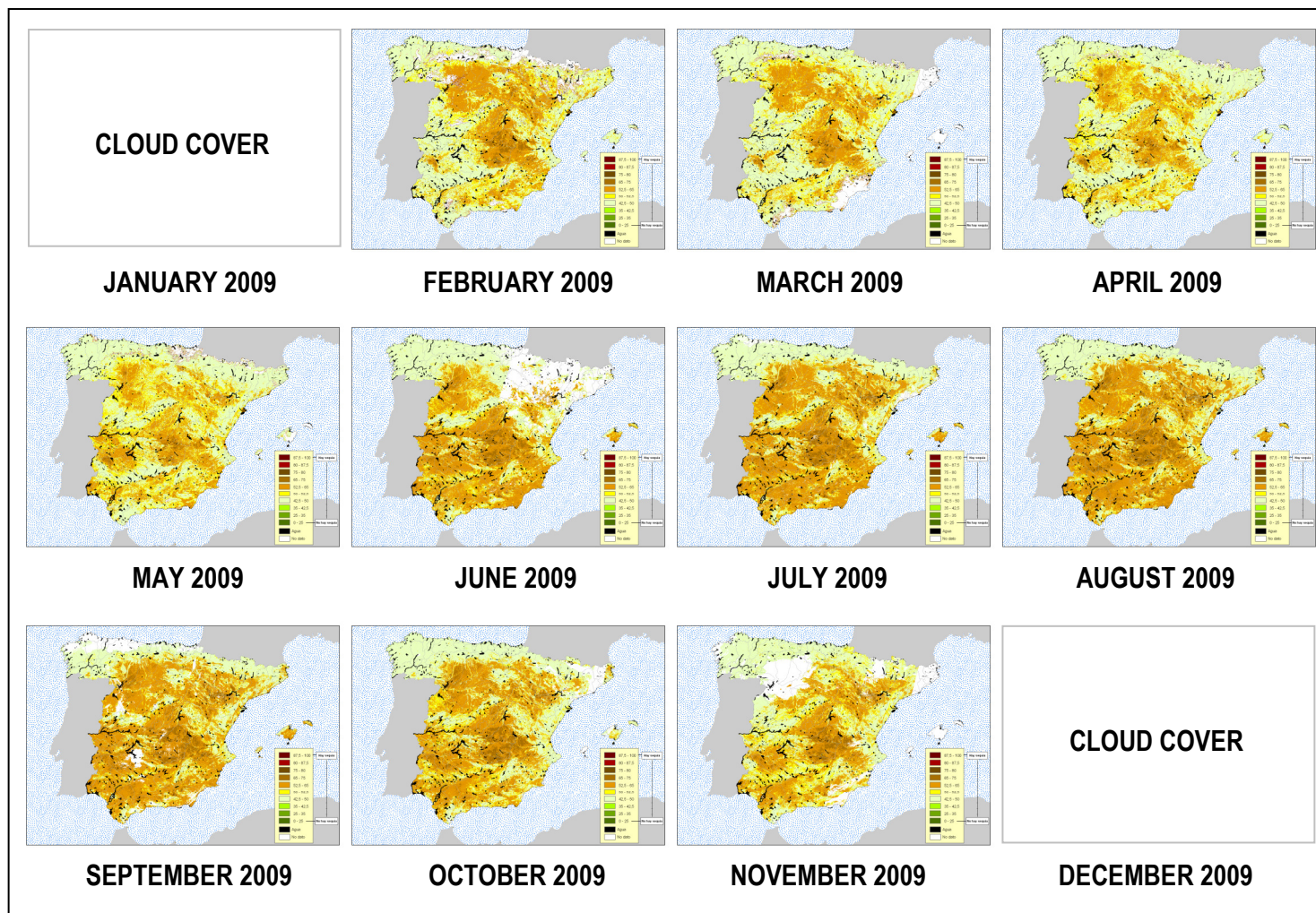


April 2010. Normalized Surface Drought Index

2008. Normalized Surface Drought Index

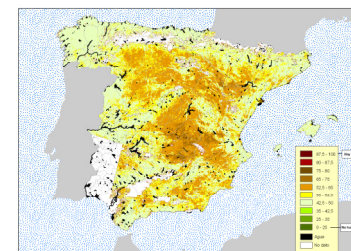


2009. Normalized Surface Drought Index

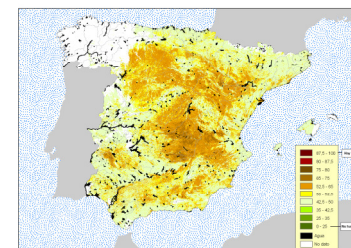


2010

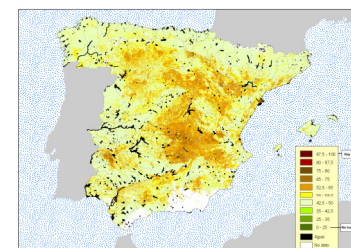
CLOUD COVER
JANUARY 2010



FEBRUARY 2010

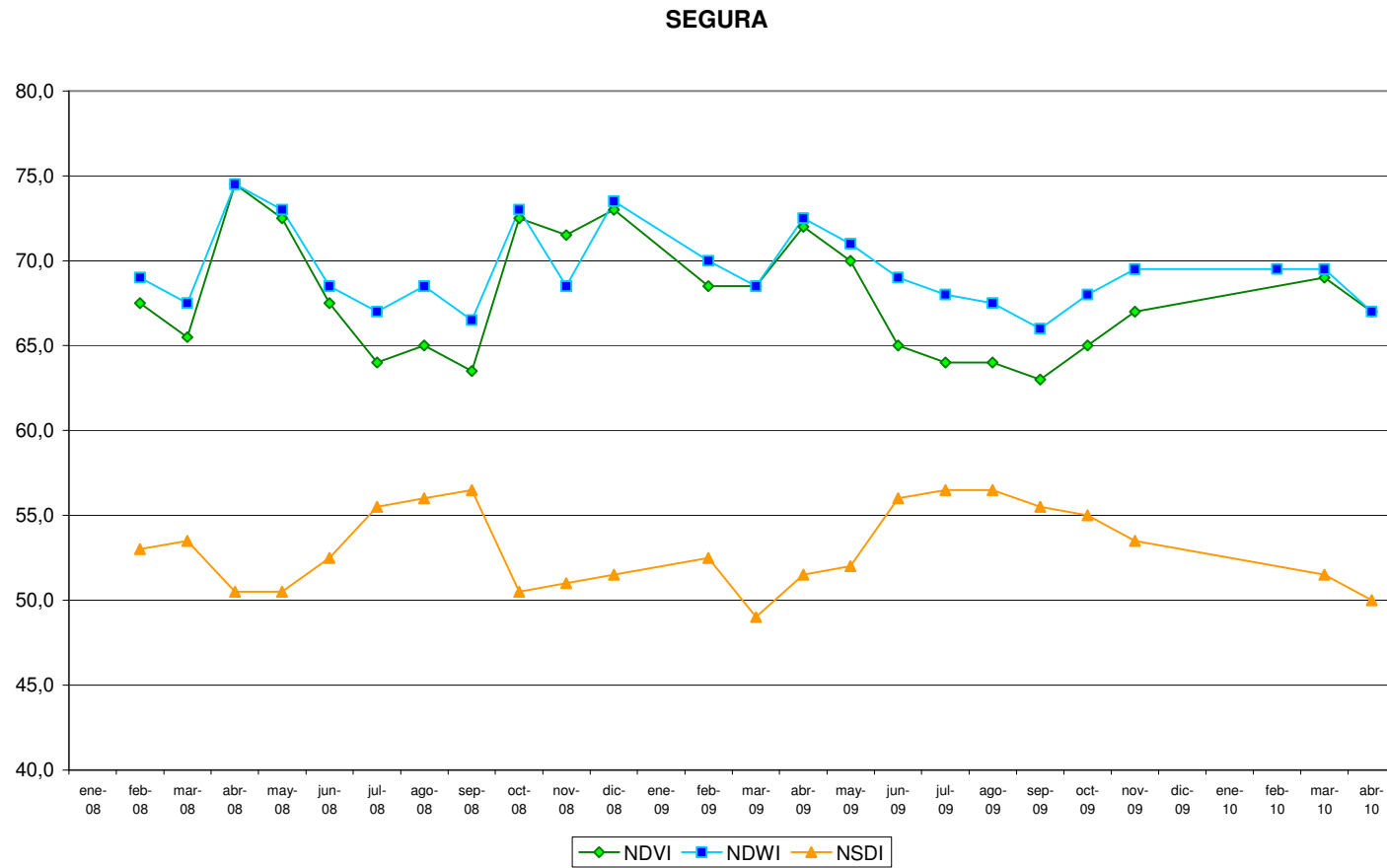


MARCH 2010



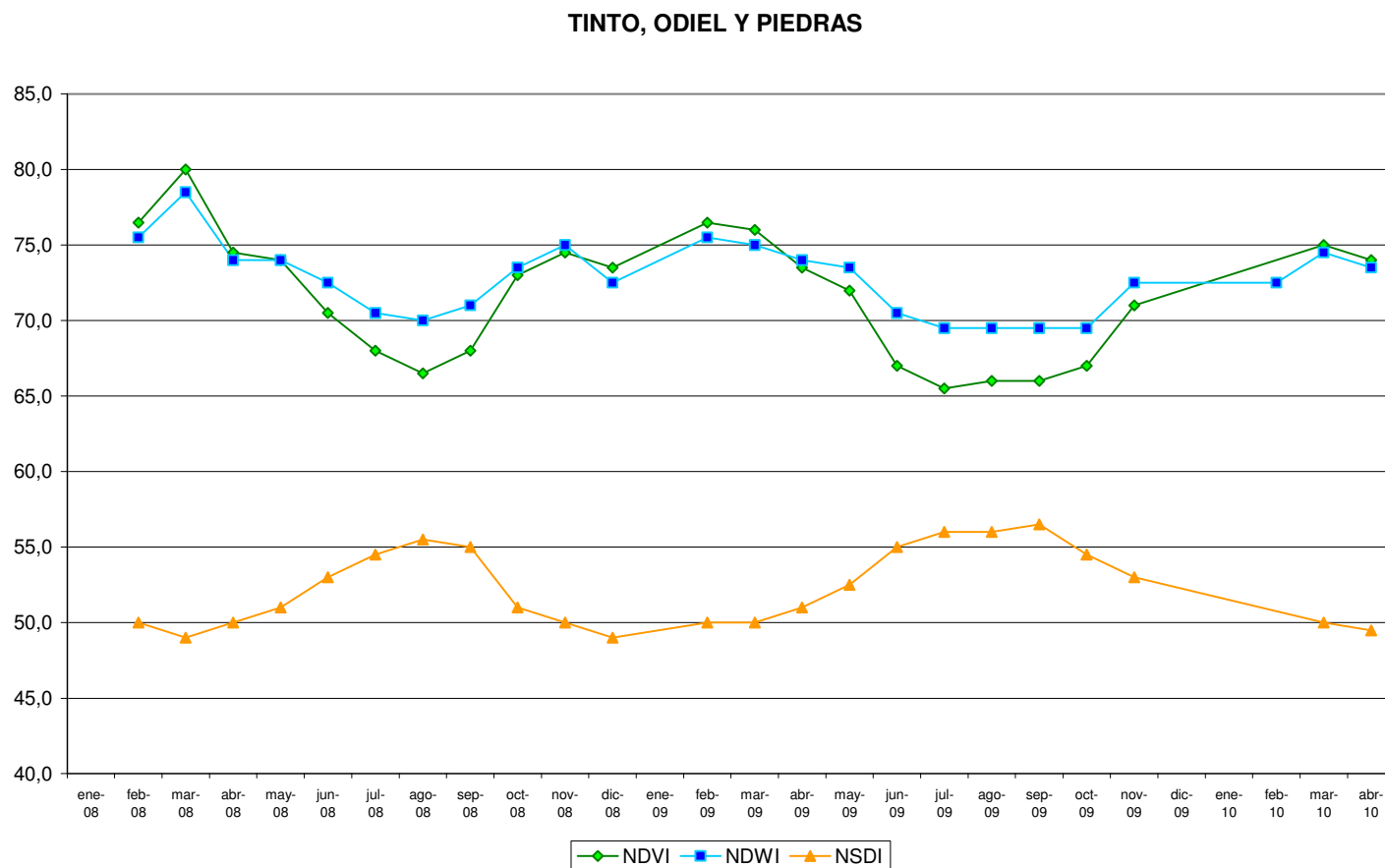
APRIL 2010

- **Drought.** (Monitoring at the level of Drought Management Systems of the Special Drought Plans).



October 2008 - April 2010. Drought Management System: Segura

- **Drought.** (Monitoring at the level of Drought Management Systems of the Special Drought Plans).



October 2008 - April 2010. Drought Management System: Tinto, Odiel y Piedras

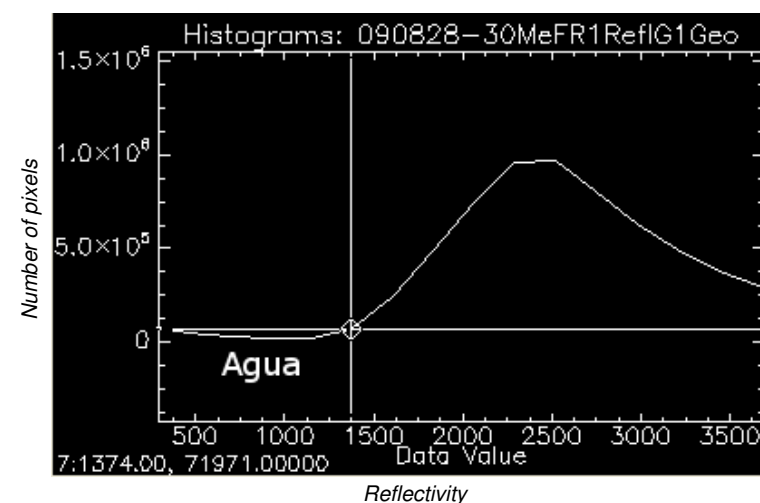
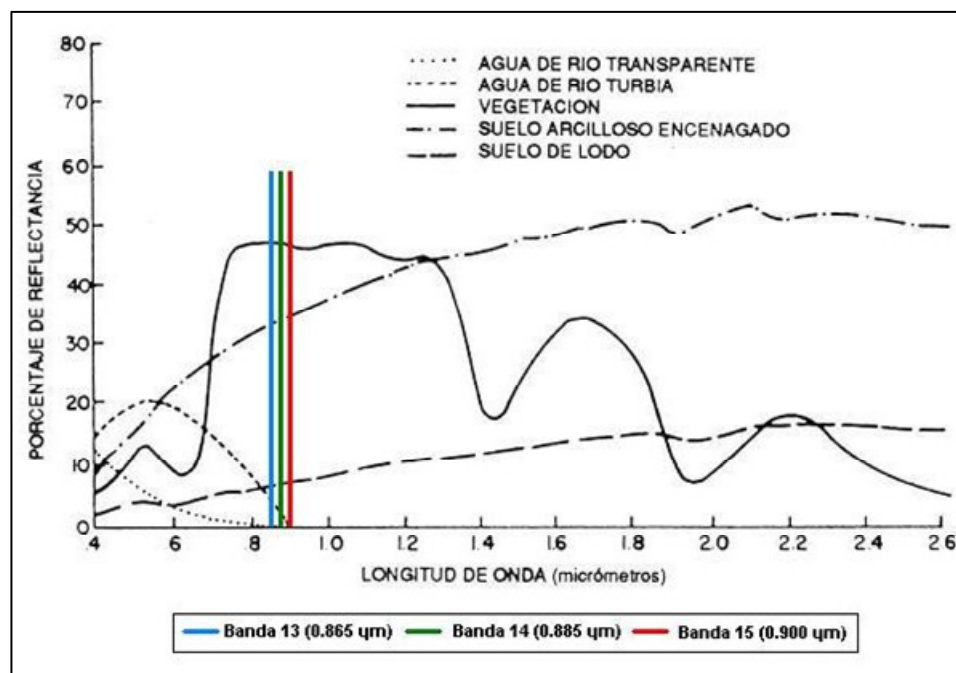
■ *Floods*

- o **Aim:** establishing methodological bases for the monitoring of flooding episodes, to obtain the area actually affected
- o **Scope:** relevant episodes for hydrological planning
- o **Achievements:** contrasting with records of the SAIH* network

* SAIH: Automatic System of Hydrologic Information

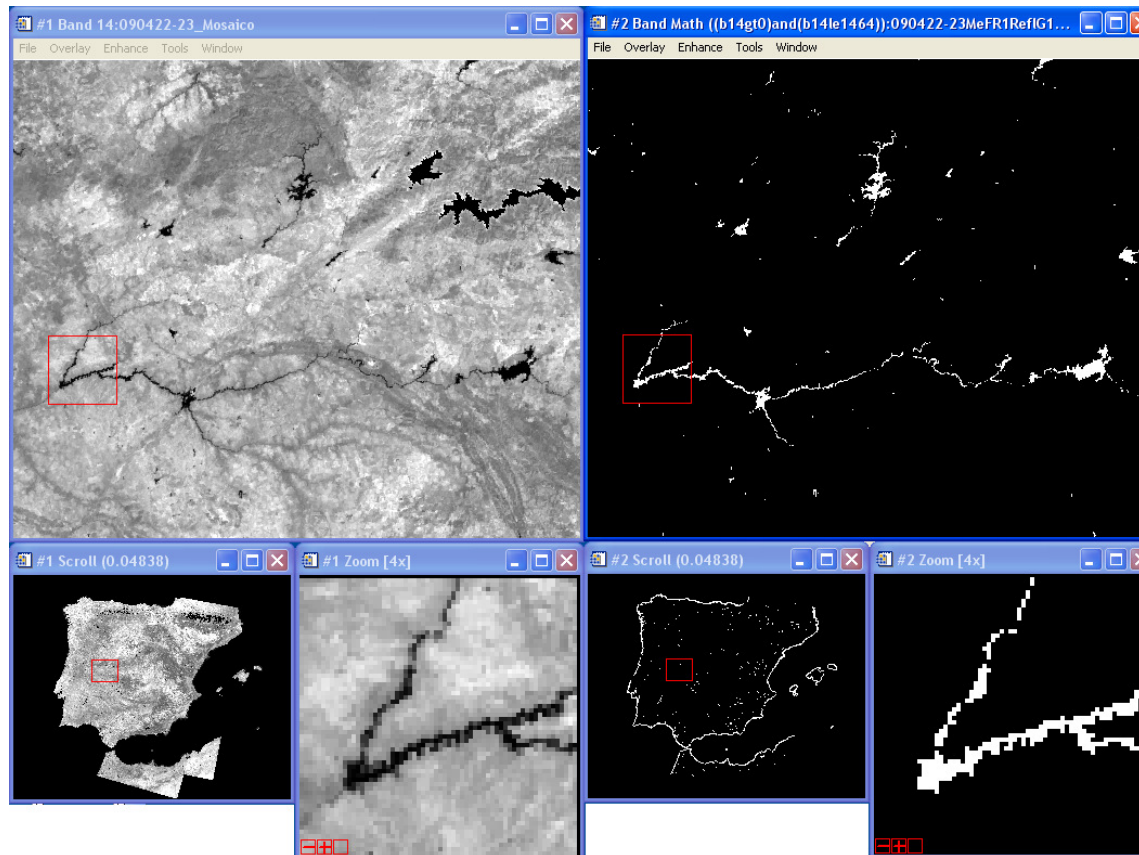
■ *Floods (Methodology)*

○ Spectral Analysis for band 14 of the MERIS sensor

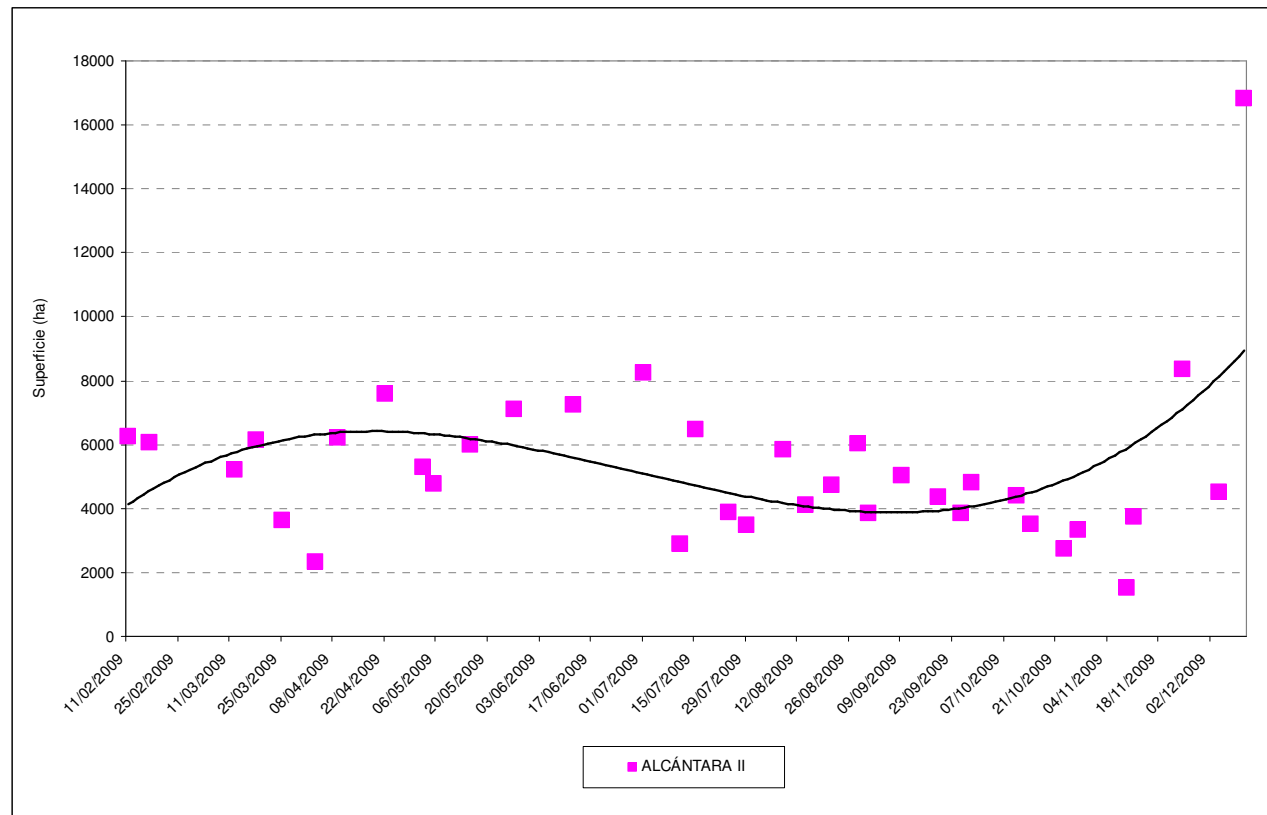


Histogram with the value selected as a threshold for the delimitation of water cover

- **Example:** Identification of water cover from band 14 reflectivity threshold. Alcántara II Reservoir

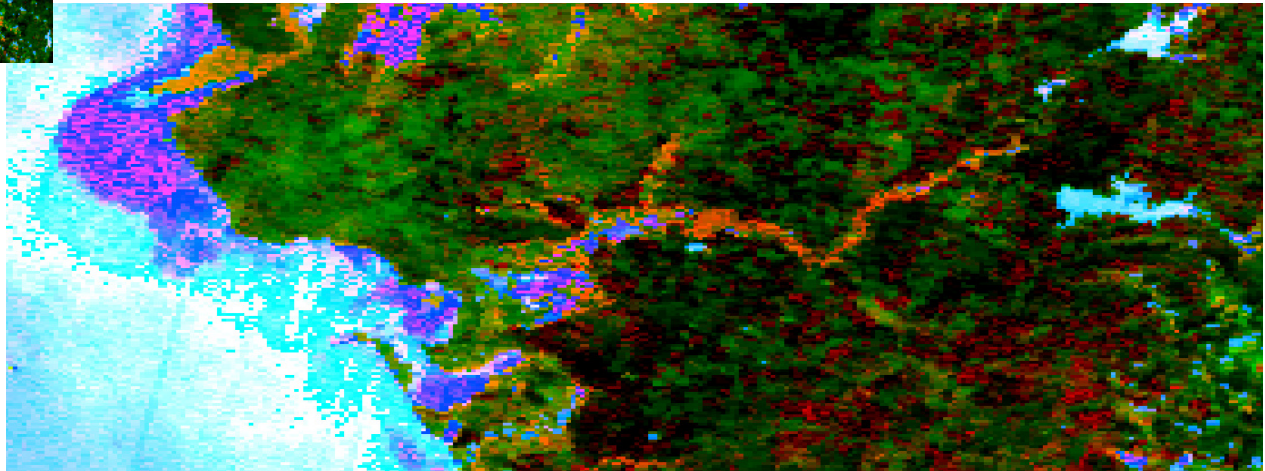
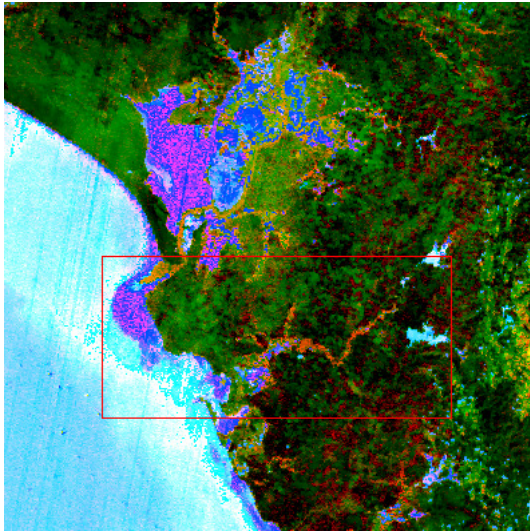


- **Example:** Evolution of the reservoir surface. Alcántara II Reservoir



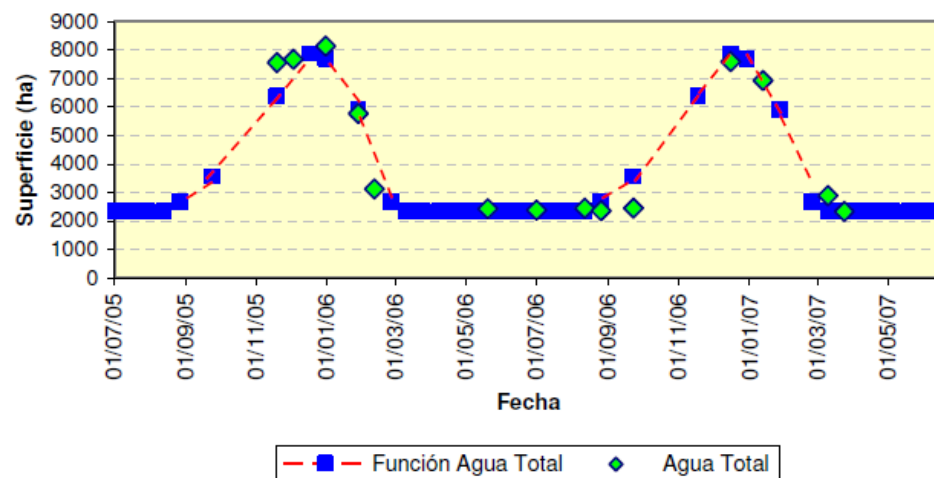
2009. Alcántara II Reservoir

- **Example:** Monitoring the Guadalete River flooding in February 2010. MERIS Sensor.



False colour composition of the flooding area. 19 February 2010

- **Example:** Evolution of the flooded area in the Natural Park of the Albufera along its hydrological cycle.



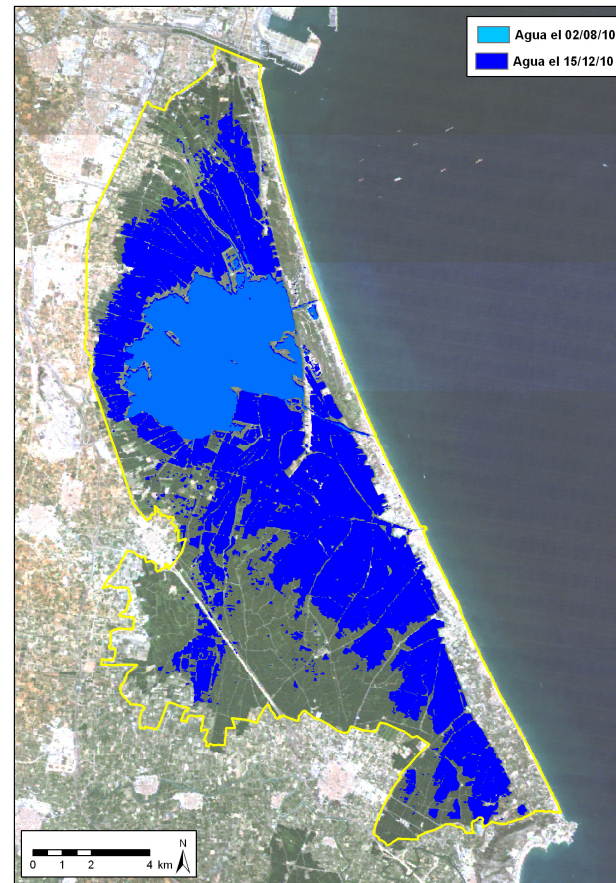
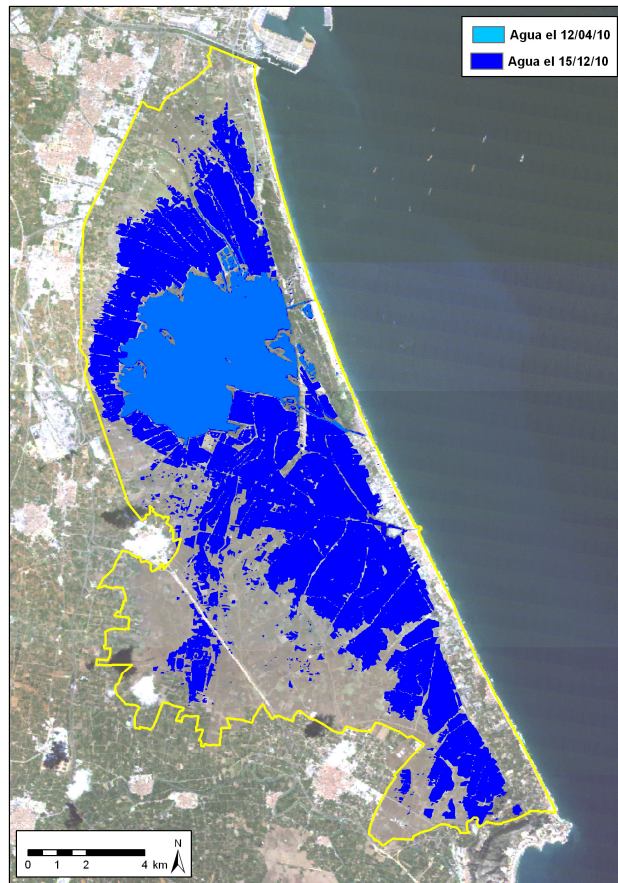
Total flooded area in the Park of the Albufera throughout 2005 and 2007.

	Natural Park (PN)	Flooded area		
		2009/04/12	2009/08/02	2009/12/15
Area (ha)	21.008	2.478	2.388	10.008
Percentage of the total PN area	100%	11,8	11,4	47,6
Perimeter (km)	95	51	46	71

Area and perimeter of the wetland flooded area in each date extracted from the water mask (Landsat 5)

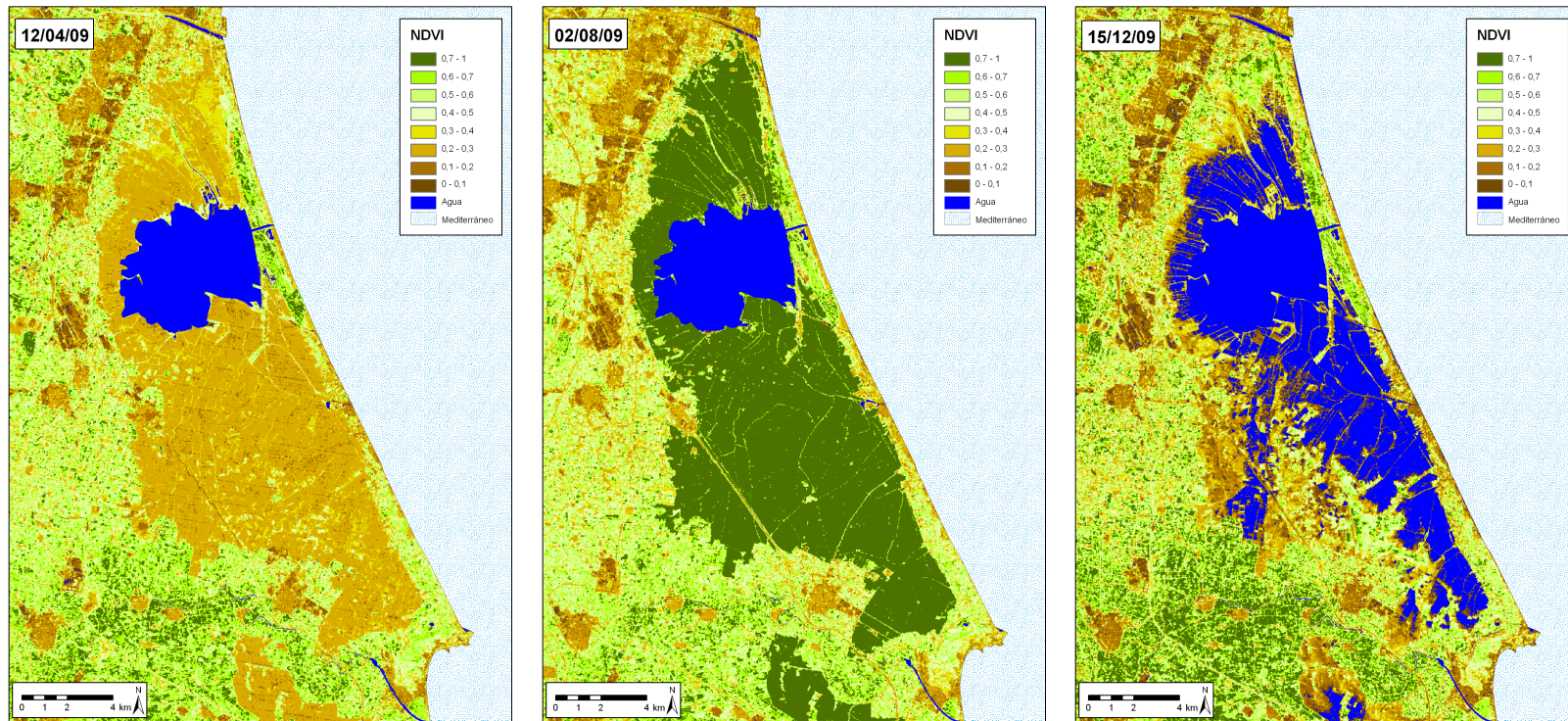
Achievements

- **Example:** Monitoring the flooded area in the Natural Park of the Albufera.



*Difference between the permanent water area 12 April - 02 August 2009
with regard to the temporarily flooded area 15 December*

- **Example:** Evolution of the Vegetation Index (NDVI) in the Natural Park of The Albufera of Valencia in 3 different moments of its hydrological cycle.



Dry paddy field without rice

Dry paddy field with high density of rice plants

Flooded paddy field

■ *Hydric Balance*

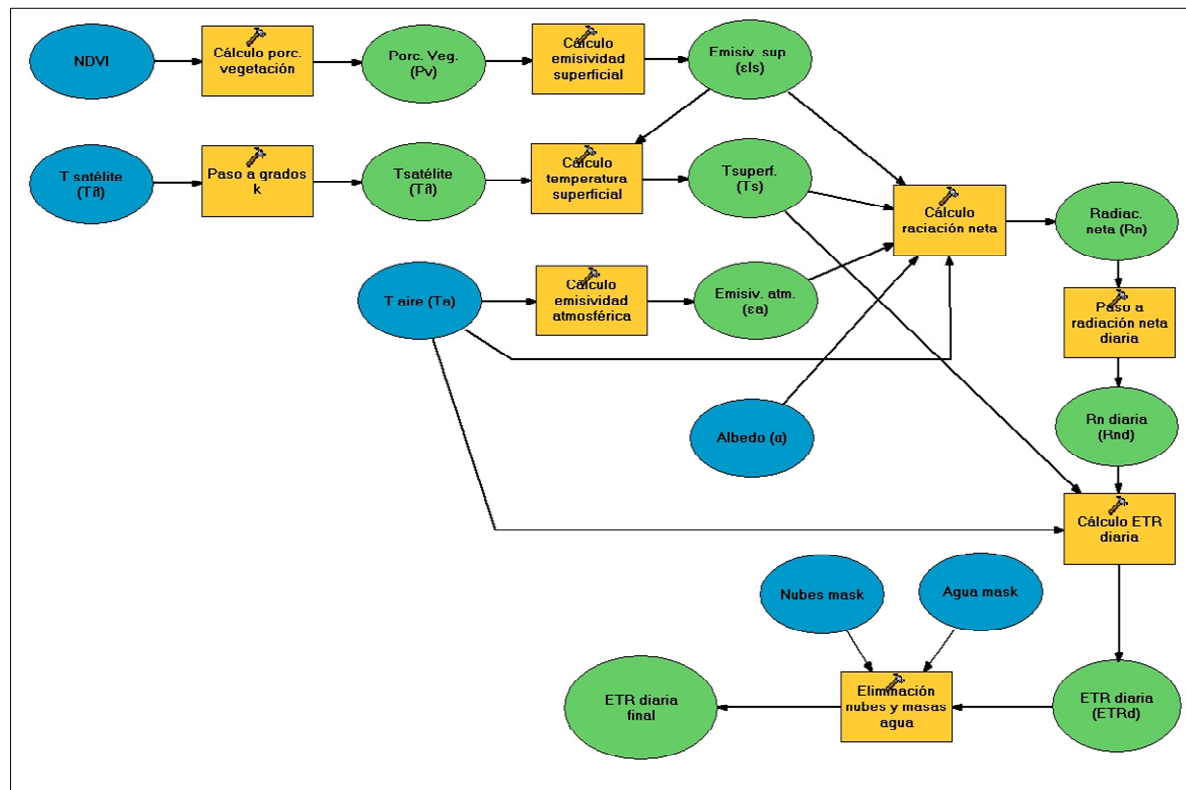
- o **Aim:** evapotranspiration estimation at different working scales
- o **Scope:** the whole national territory
- o **Achievements:** more precise data collection to feed existing models (SIMPA, EWBMS)

Where:

- { SIMPA: Integrated System for Rainfall-Runoff Modelling
- { EWBMS: *European Energy and Water Balance Monitoring System*. Estimation of precipitation and evapotranspiration with METEOSAT images

■ *Hydric Balance (Methodology)*

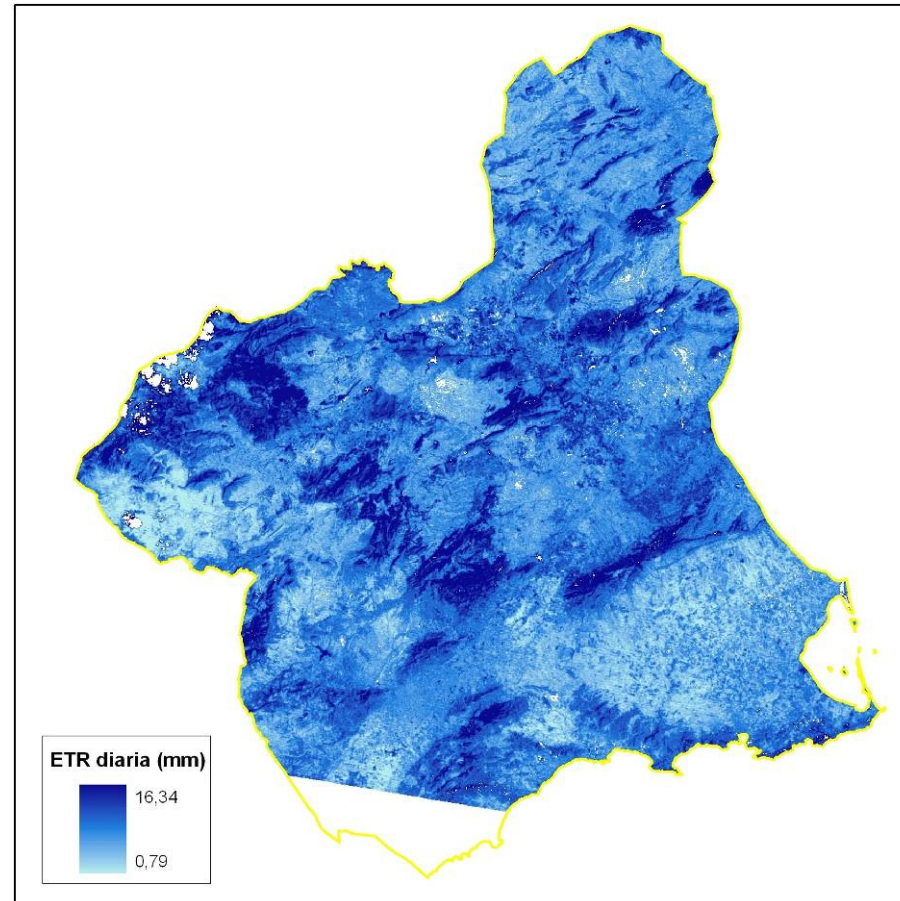
- o Method proposed by Seguin-Itier (1989) and Vidal-Perrier (1992), to calculate the evapotranspiration.



Model for the calculation of daily real evapotranspiration

Achievements

- *Example: daily evapotranspiration (mm).
13 July 2005. Autonomous Community of
the Region of Murcia.*



■ *Hydric Balance (Methodology)*

○ **FAO-56 Crop Coefficient Method .**

FAO-56 Manual (Allen et al. 1998)

$$ETR = ET_0 * (K_e + (K_{cb} * K_s))$$

Where:

- *K_e*: soil evaporation coefficient
- *K_{cb}*: basal crop coefficient
- *K_s*: soil water stress coefficient

The reference evapotranspiration (ET₀) is calculated by the equation of Penman-Monteith for 24-hour periods of time.

The rice crop coefficient is estimated from the equation of (Bausch and Neale, 1987):

$$K_{cb} = 1,36 * NDVI - 0,06$$

Achievements

- *Example: daily evapotranspiration (mm).
24 July 2009.
Paddy fields in The Natural Park of The
Albufera of Valencia.*

