



Hungarian  
Space Office



# → 7th ADVANCED TRAINING COURSE ON LAND REMOTE SENSING

4–9 September 2017 | Szent István University | Gödöllő, Hungary



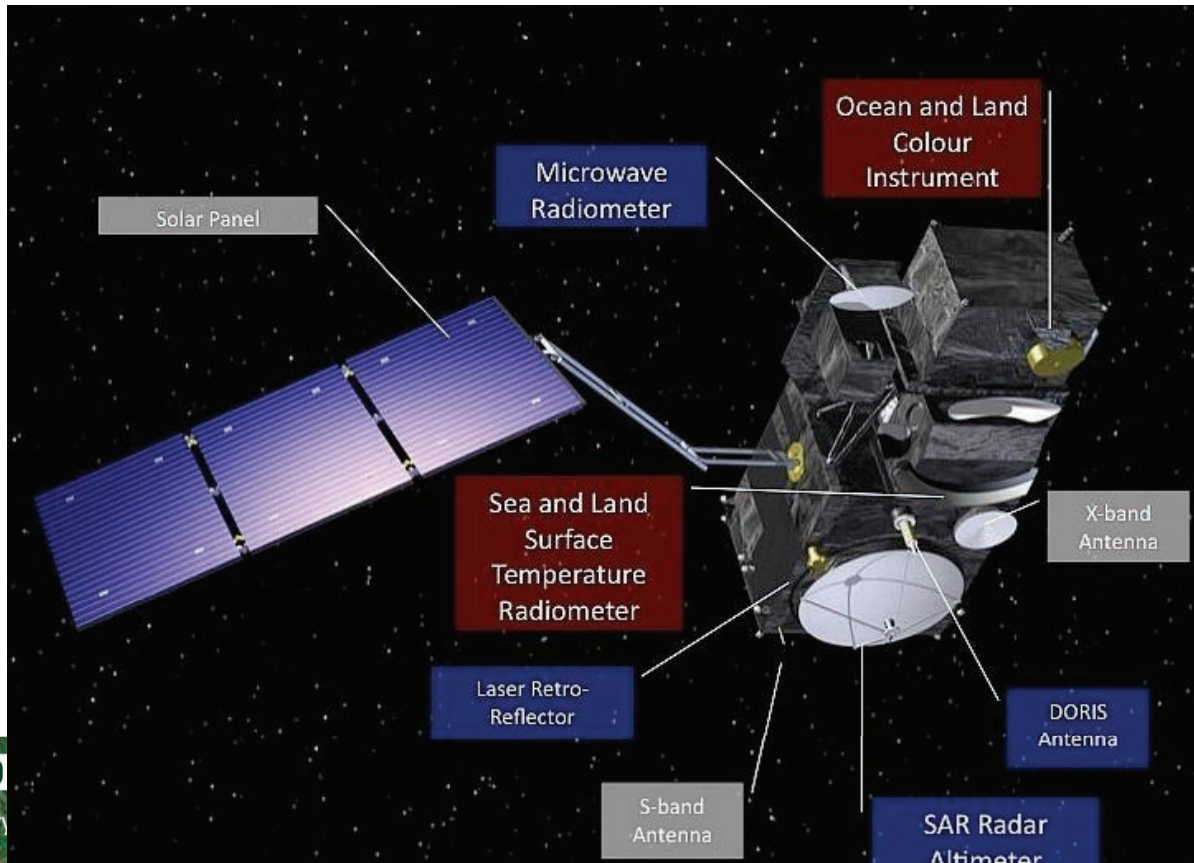
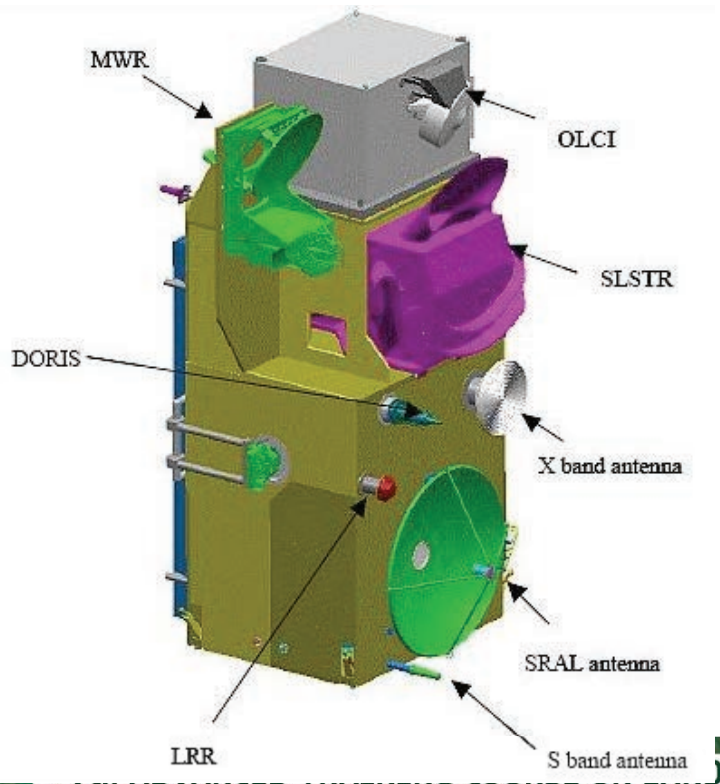


# LST RETRIEVAL USING THE SYNERGY OF S3-OLCI AND SLSTR

Prepared by Ana B. Ruescas and Juan C. Jimenez-  
Muñoz

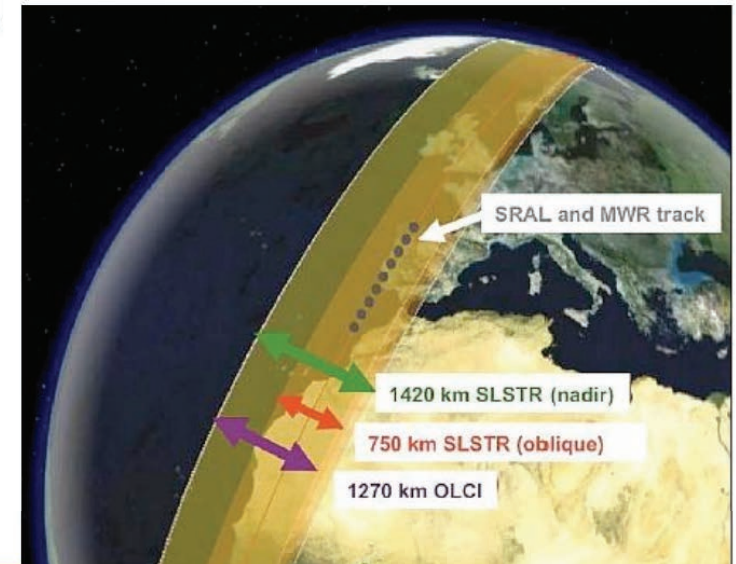
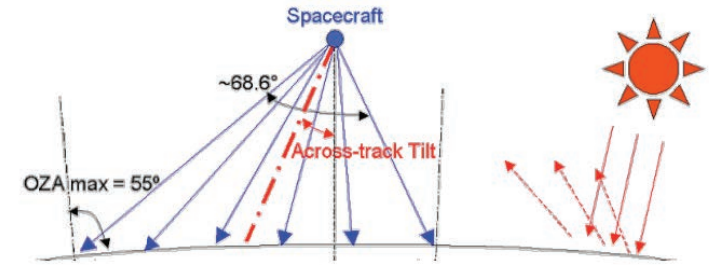
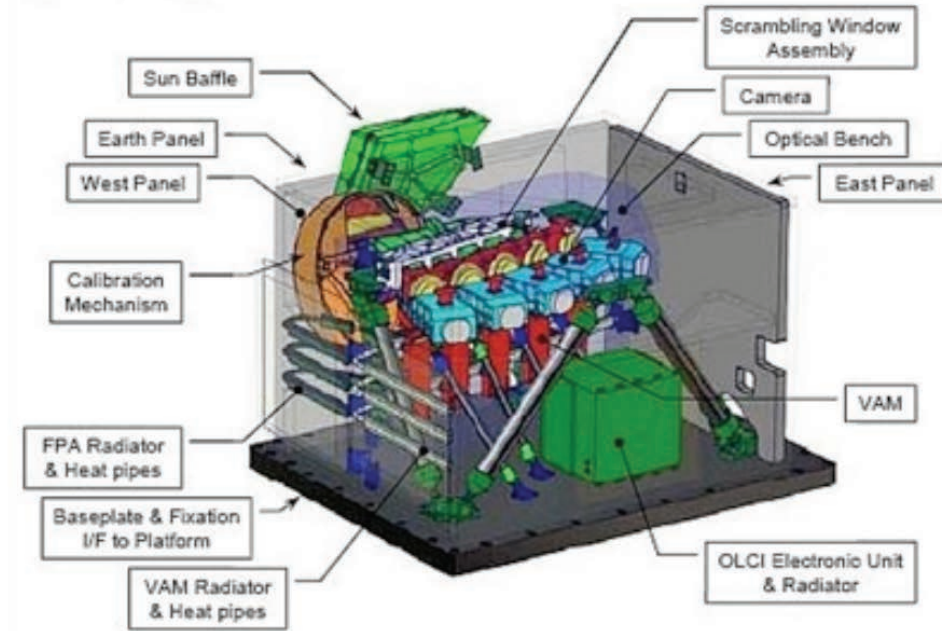
Brockmann Consult (Germany) + Image Processing  
Laboratory (UV, Spain)

# SENTINEL-3 SATELLITE OLCI & SLSTR SENSORS





# Ocean and Land Colour Instrument: OLCI



Images credit: ESA

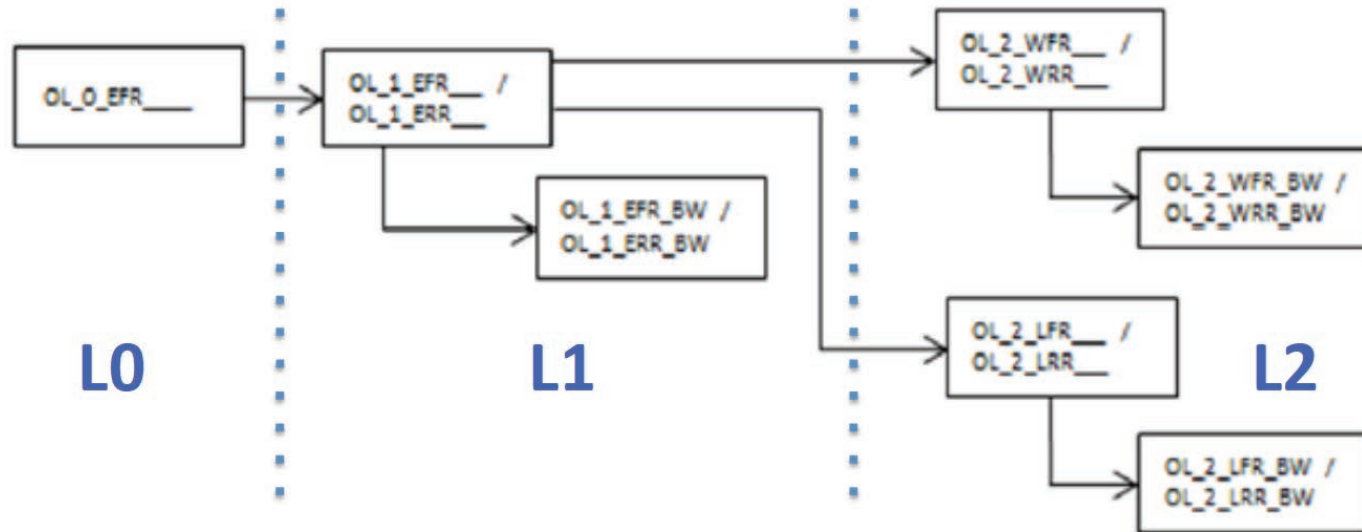
# Ocean and Land Colour Instrument: OLCI

Swath	1 440 km
SSI at SSP (km)	300 m
Calibration	MERIS type calibration arrangement with spectral calibration using a doped Erbium diffuser plate, PTFE diffuser plate and dark current plate viewed approximately every 2 weeks at the South Pole ecliptic. Spare diffuser plate viewed periodically for calibration degradation monitoring
Detectors	ENVISAT MERIS heritage back-illuminated CCD55-20 frame-transfer imaging device (780 columns by 576 row array of 22.5 $\mu\text{m}$ square active elements).
Optical scanning design	Push-broom sensor. Five cameras recurrent from MERIS dedicated Scrambling Window Assembly (SWA) supporting five Video Acquisition Modules (VAM) for analogue to digital conversion
Spectral resolution	1.25 nm (MERIS heritage), 21 bands.
Radiometric accuracy	< 2% with reference to the sun for the 400-900 nm waveband and < 5% with reference to the sun for wavebands > 900 nm. 0.1% stability for radiometric accuracy over each orbit and 0.5% relative accuracy for the calibration diffuser BRDF.
Radiometric resolution	< 0.03 $\text{W m}^{-2} \text{sr}^{-1} \text{mm}^{-1}$ (MERIS baseline)
Mass	150 kg
Size	1.3 $\text{m}^3$
Design lifetime	7.5 years

MERIS Bands	$\lambda$ center	Width
<b>Yellow substance/detrital pigments</b>	<b>412.5</b>	<b>10</b>
<b>Chl.. Abs. Max</b>	<b>442.5</b>	<b>10</b>
<b>Chl &amp; other pigments</b>	<b>490</b>	<b>10</b>
<b>Susp. Sediments, red tide</b>	<b>510</b>	<b>10</b>
<b>Chl. Abs. Min</b>	<b>560</b>	<b>10</b>
<b>Suspended sediment</b>	<b>620</b>	<b>10</b>
<b>Chl. Abs, Chl. fluorescence</b>	<b>665</b>	<b>10</b>
<b>Chl. fluorescence peak</b>	<b>681.25</b>	<b>7.5</b>
<b>Chl. fluorescence ref., Atm. Corr.</b>	<b>708.75</b>	<b>10</b>
<b>Vegetation, clouds</b>	<b>753.75</b>	<b>7.5</b>
<b>O<sub>2</sub> R-branch abs.</b>	<b>761.25</b>	<b>2.5</b>
<b>O<sub>2</sub> P-branch abs.</b>	<b>778.75</b>	<b>15</b>
<b>Atm corr</b>	<b>865</b>	<b>20</b>
<b>Vegetation, H<sub>2</sub>O vap. Ref.</b>	<b>885</b>	<b>10</b>
<b>H<sub>2</sub>O vap., Land</b>	<b>900</b>	<b>10</b>
New OLCI bands	$\lambda$ center	Width
<b>Aerosol, in-water property</b>	<b>400</b>	<b>15</b>
<b>Fluorescence retrieval</b>	<b>673.75</b>	<b>7.5</b>
<b>Atmospheric parameter</b>	<b>764.375</b>	<b>3.75</b>
<b>Cloud top pressure</b>	<b>767.5</b>	<b>2.5</b>
<b>Atmos./aerosol correction</b>	<b>940</b>	<b>20</b>
<b>Atmos./aerosol correction</b>	<b>1020</b>	<b>40</b>

# OLCI product types

## OLCI PRODUCT TYPES



### LEVEL 0

EFR Earth observation Full Resolution

### LEVEL 1

EFR Earth observation Full Resolution (calibrated)

ERR Earth observation Reduced Resolution (cal.)

EFR\_BW EFR browse product

### LEVEL 2

WFR Water and atmosphere Full Resolution

WFR\_BW WFR Browse Product

WRR Water and atmosphere Reduced Res.

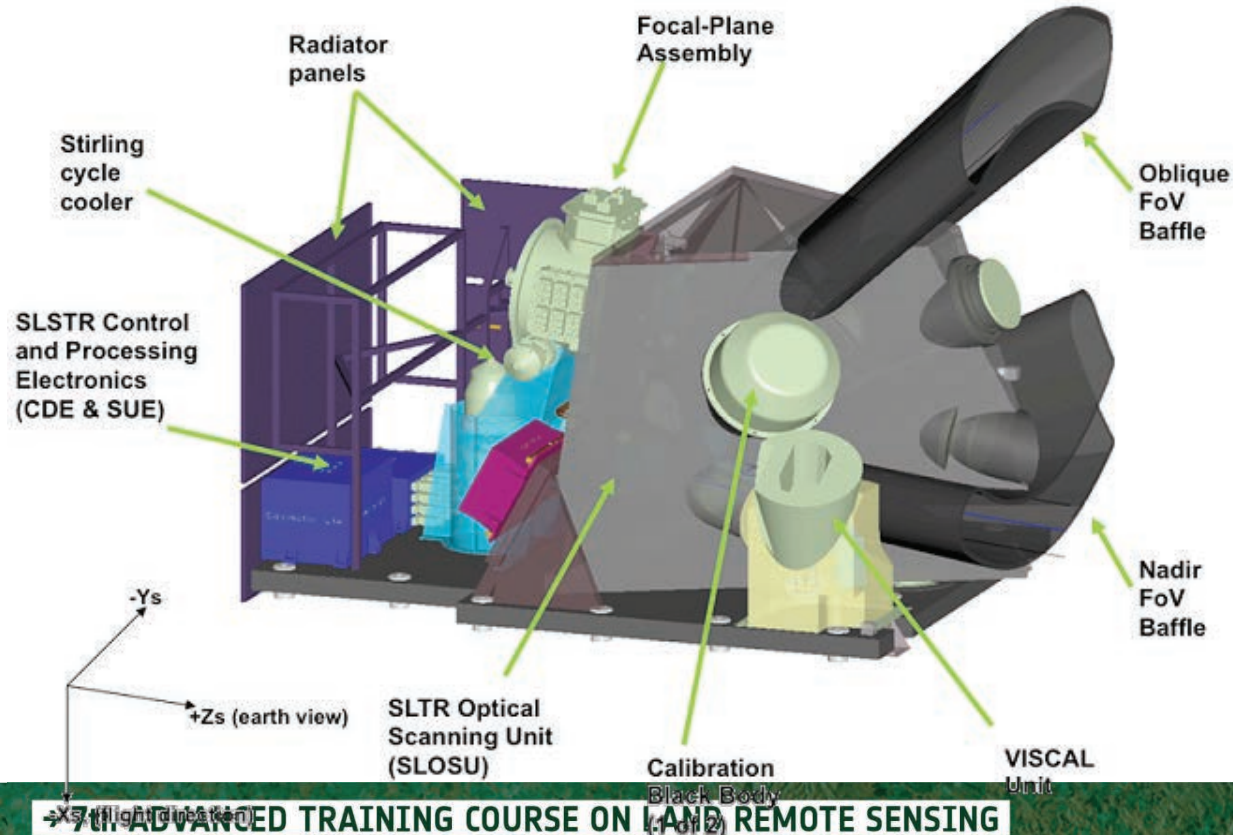
LFR Land Full Resolution

LRR Land Reduced Resolution

Etc.

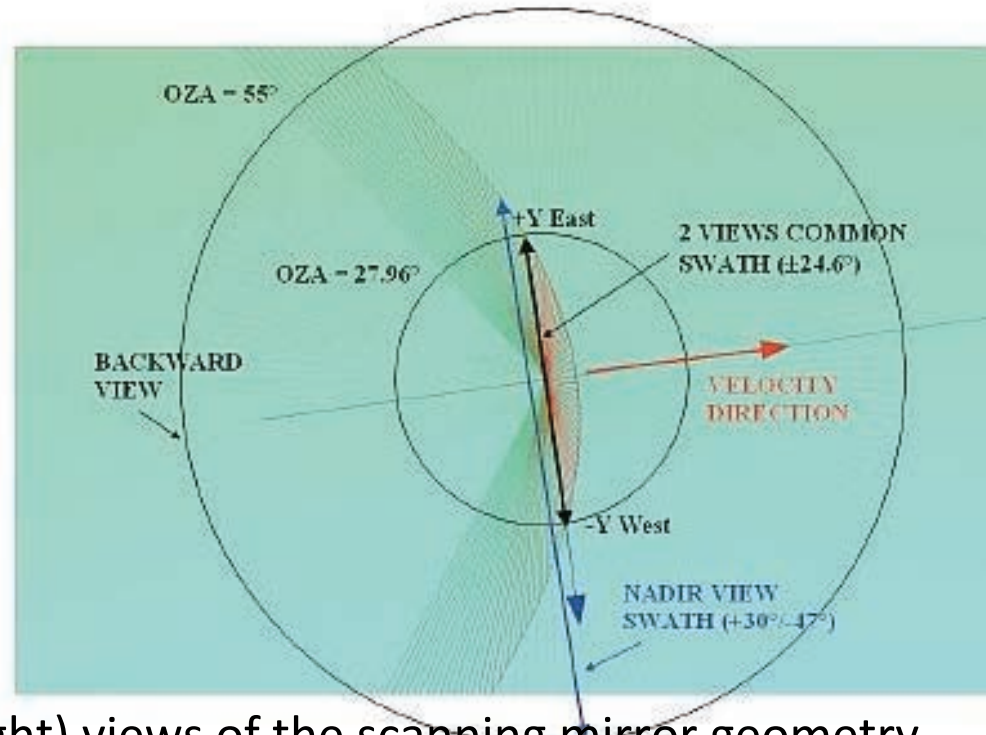
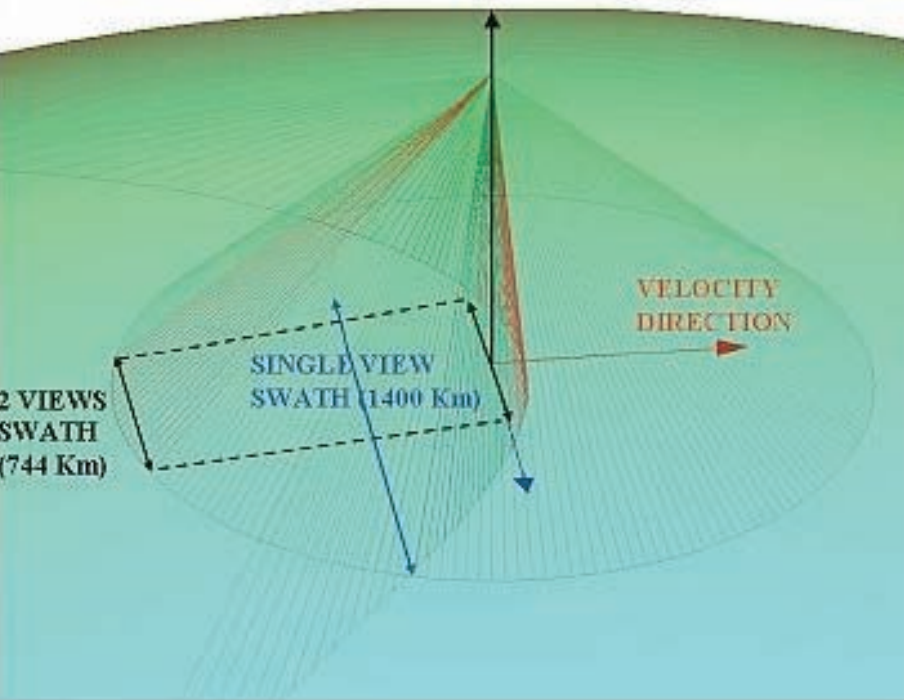


# Sea and Land surface temperature radiometer (SLSTR)



→ **AN ADVANCED TRAINING COURSE ON LAND REMOTE SENSING**

# Sea and Land surface temperature radiometer (SLSTR)



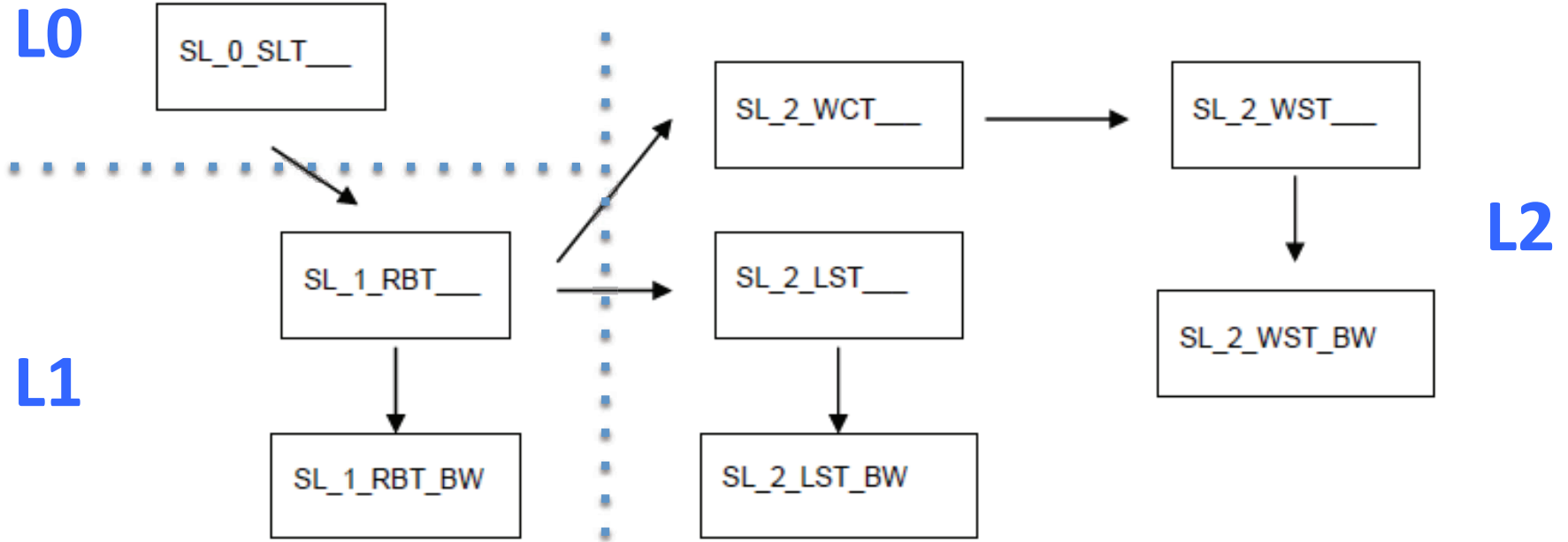
Backward inclined (left) and near nadir (right) views of the scanning mirror geometry



# DATA AND PHYSICAL UNITS of SLSTR

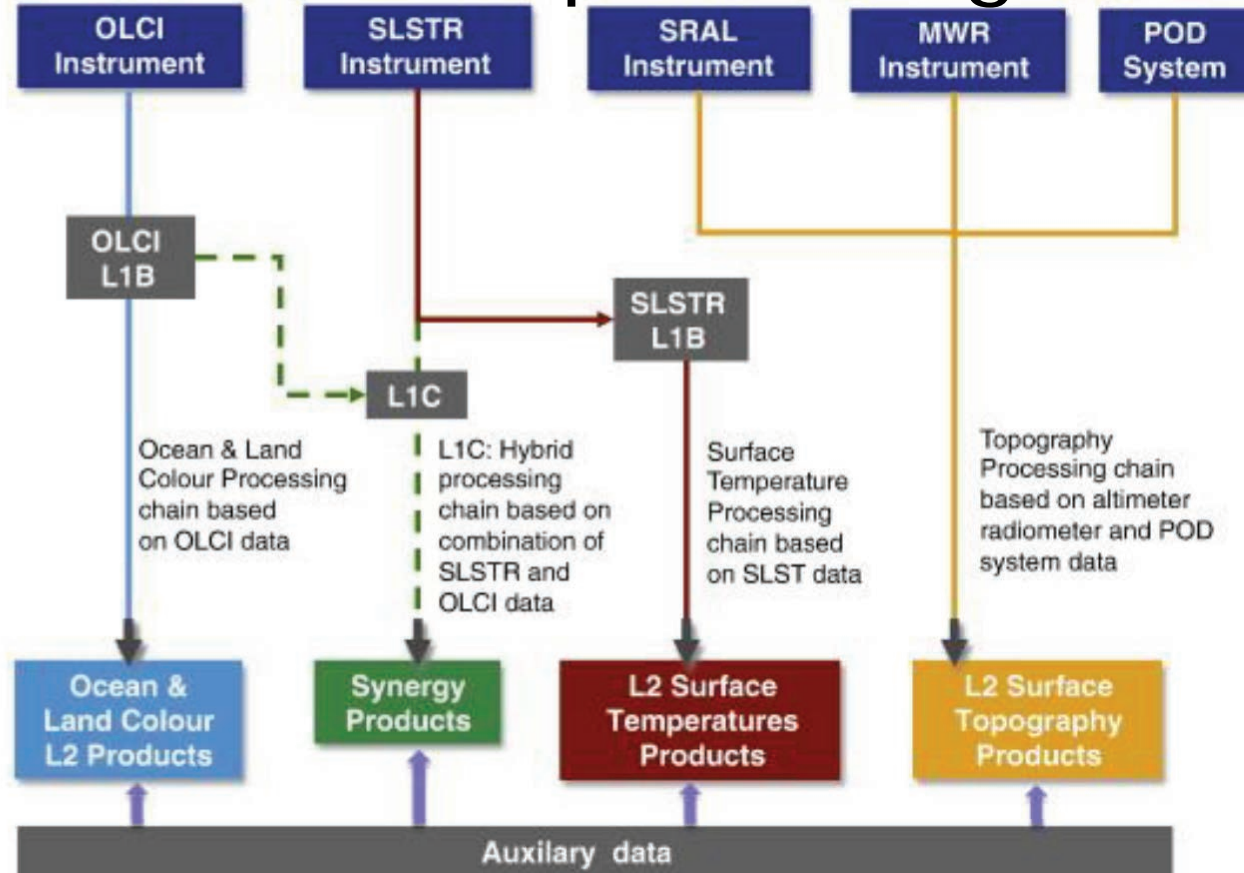
Performance	Parameters	SLSTR	AATSR & ATSR-1/2
Swaths	Nadir view	1 400 km	500 km
	Dual view	740 km	500 km
Global coverage revisit time	1 S/C (dual view)	1.9 days	7-14 days
		0.9 days	-
		1 day	7-14 days
		0.5 days	-
SSI at SSP (km)		0.5 km VIS-SWIR 1 km IR-fire	1 km
Spectral channels centre $\lambda$ ( $\mu\text{m}$ )	VIS (not ATSR-1): SWIR: MWIR/TIR: Fire-1/2:	0.555; 0.659; 0.865; 1.375; 1.610; 2.25; 3.74; 10.85; 12; 3.74; 10.85	0.555; 0.659; 0.865; 1.610; 3.74; 10.85; 12; -
Radiometric resolution	VIS ( $\alpha=0.5\%$ ): SWIR ( $\alpha=0.5\%$ ):	SNR > 20 SNR > 20	SNR > 20 SNR > 20
	MWIR (T=270K): TIR (T=270K): Fire-1 (<500 K): Fire-2 (<400 K):	Ne $\Delta$ T < 80 mK Ne $\Delta$ T < 50 mK Ne $\Delta$ T < 1K Ne $\Delta$ T < 0.5 K	Ne $\Delta$ T < 80 mK Ne $\Delta$ T < 50 mK
Radiometric accuracy	VIS-SWIR: ( $\alpha=2-100\%$ )	< 2% (BOL) < 5% (EOL)	< 5%
	MWIR-TIR (265-310K): Fire (<500K):	< 0.1 K (goal) < 3 K	< 0.1 K
Life time (in orbit)		7.5 years	AATSR: 5 year design, operative since 2002; ATSR-2: 3 year design, operating from 1995 to 2008; ATSR-1: 3 year design, operating from 1991 to 2000

# SLSTR PRODUCT TYPES





# Sentinel-3 data processing chains





LAND

Coast

SEA

Ocean and Land Colour Instrument

OLCI

Level 0

OLCI Level 1B

OLCI L2 Marine Parameters for Coastal areas

OLCI L2 Parameters for Atmosphere

OLCI L2 Marine

OLCI L2 Land

SYN Level 1C

SYN L2 Land

SYN L2 Parameters for Atmosphere

SLSTR Level 1B

Level 0

SLSTR

SLSTR L2 Marine

Sea and Land Surface Temperature Radiometer

SRAL

Level 0

SRAL Level 1B

SLSTR L2 Land

SRAL L2 Marine and Land Parameters for Coastal areas

SRAL L2 Marine Parameters for Sea-Ice areas

SRAL L2 Marine

SRAL L2 Land Parameters for Rivers & Lakes

SRAL L2 Land

MWR

Level 0

Micro Wave Radiometer

# OCLI/SLSTR SYNERGY PRODUCTS

Legenda

SRAL	Level 0	Internal products or parameters
MWR		
OLCI		Products
SLSTR		Sensor combined
SYN		

Image credit: ESA



# OVERVIEW OF SENTINEL 3 TOOLBOX IN SNAP

ESA has developed a common architecture for all Sentinel Toolboxes call the **Sentinel Application Platform** (SNAP)

- The project is carried out by Brockmann Consult, Array Systems Computing and C-S called.

The SNAP architecture is ideal for Earth Observation processing and analysis due the following technological innovations: Extensibility, Portability, Modular Rich Client Platform, Generic EO Data Abstraction, Tiled Memory Management, and a Graph Processing Framework.

<http://step.esa.int/main/toolboxes/snap/>

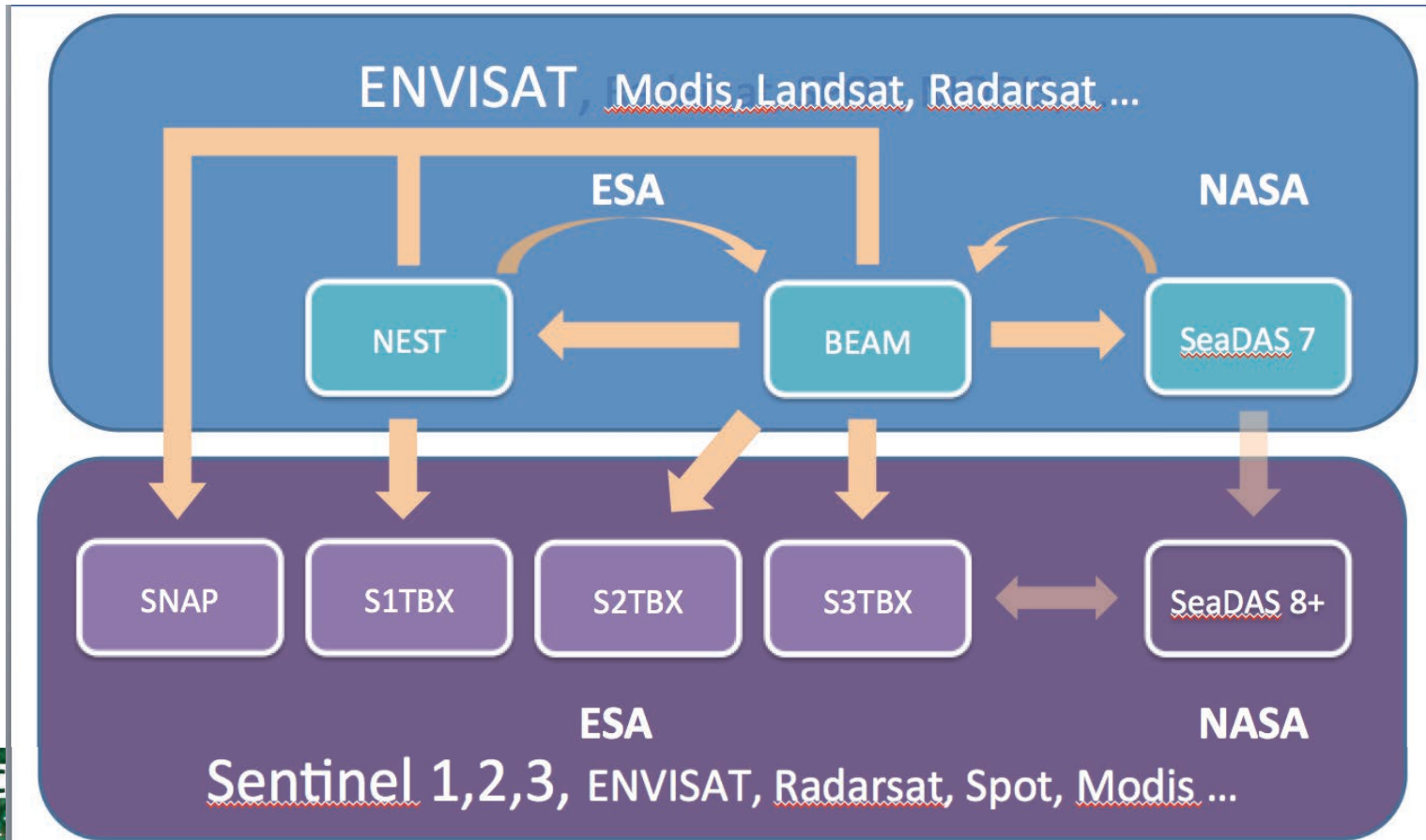
# Sentinel Toolboxes Consortia



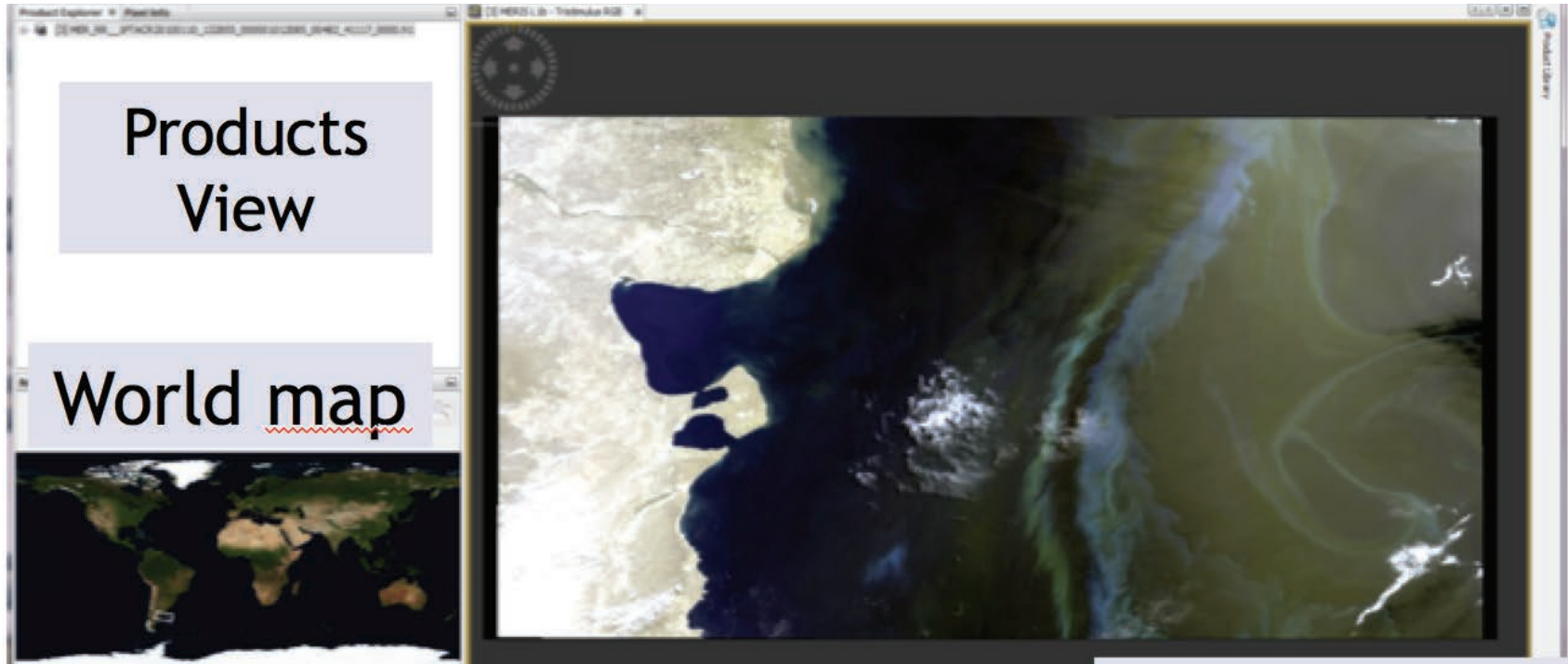
driven by user requirements, guided by user expertise,  
implemented by a experienced technical team



# Heritage and Evolution



# SNAP overview



# Land surface temperature using a split-window algorithm

$$T_S = T_i + c_1 (T_i - T_j) + c_2 (T_i - T_j)^2 + c_0 + (c_3 + c_4 W) (1 - \varepsilon) + (c_5 + c_6 W) \Delta \varepsilon \quad (1)$$

where  $T_s$  is the LST (in K),  $T_{i,j}$  are at-sensor brightness temperatures (in K),  $W$  is the atmospheric water vapor content (in  $\text{g}\cdot\text{cm}^{-2}$  or cm),  $\varepsilon$  is the mean LSE  $0.5\cdot(\varepsilon_i + \varepsilon_j)$ , and  $\Delta\varepsilon$  is the LSE difference ( $\varepsilon_i - \varepsilon_j$ ). Subindices 'i' and 'j' refer to two different TIR bands, thus leading to the SW algorithm, or to one TIR band but two different view angles (e.g. nadir 'n' and oblique 'o' views), thus leading to the DA algorithm. Coefficients  $c_0$  to  $c_6$  are obtained from statistical regressions performed over simulated data.

J.A. Sobrino, J.C. Jiménez-Muñoz, G. Soria, A.B. Ruescas, O. Danne, C. Brockmann, D. Ghent, J. Remedios, P. North, C. Merchant, M. Berger, P.P. Mathieu, F.-M. Göttsche, Synergistic use of MERIS and AATSR as a proxy for estimating Land Surface Temperature from Sentinel-3 data, Remote Sensing of Environment, Volume 179, 2016, Pages 149-161, ISSN 0034-4257, <http://dx.doi.org/10.1016/j.rse.2016.03.035>.  
(<http://www.sciencedirect.com/science/article/pii/S0034425716301158>)  
Keywords: Land Surface Temperature; MERIS; AATSR; OLCI; SLSTR; Sentinel 3



# OVERVIEW OF EXERCISE

1. OLCI L1 radiance to reflectance
2. Collocate OLCI-L1+ OLCI L2
3. Emissivity calculation based on NDVI /OGVI thresholds method →using band math (8 steps)
4. Water vapour band selection
5. Collocate SLSTR (master) / OLCI (slave) →from 300 m to 1000 m pixel
6. Apply the LST split window algorithm with the band math tool only on valid pixels → definition of “valid pixel” using masks and flags of the products
7. Validate with simulated in situ data: import of csv file, correlative plots, pixel information extraction demo
8. Comparison with S3 LST standard product using scatter plots
9. Batch processing: how to apply the processing chain to a bunch of products

# 1. RADIANCE TO REFLECTANCE

Open the scene:

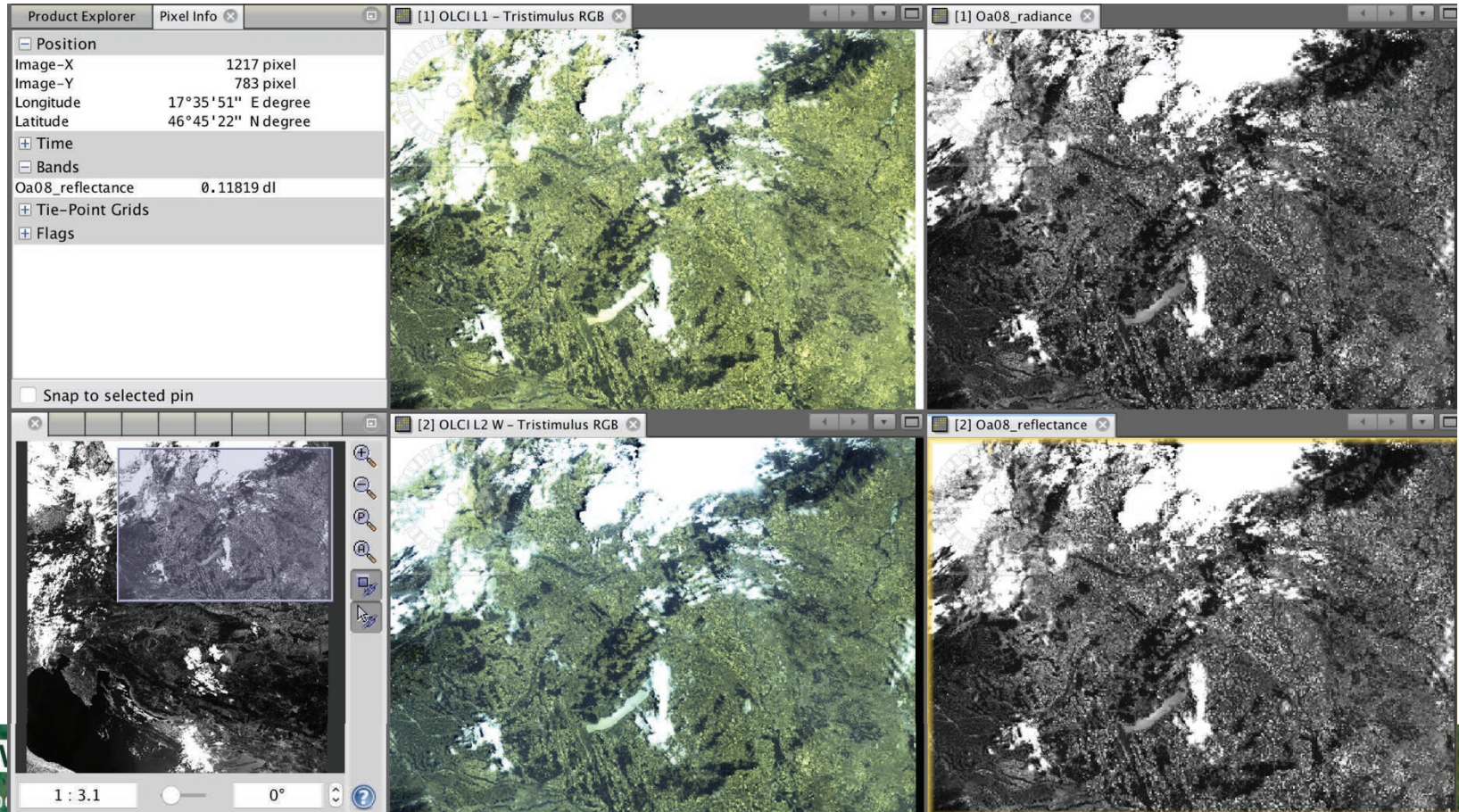
```
"subset_0_of_S3A_OL_1_EFR_____20170710T093144_20170710T093444_20170711T134744_0179_019_364_2159_LN1_0_NT_002.dim"
```

Right click on the product in the Product Explorer and select "Open RGB Image Window". Stretch the histogram for a better visualization in the "Colour Manipulation" window.

In the Optical label click on Preprocessing/Radiance-to-Reflectance Processor:

$$R_{TOA}(\lambda) = \frac{\pi L_{TOA}(\lambda)}{E_0(\lambda) \cos(\theta)}$$

# 1. RADIANCE TO REFLECTANCE





## 2. OLCI L1/L2 COLLOCATION

Use layer stacking to group the “radrefl” L1 and L2 OLCI bands in one product with the same spatial resolution and geo-location:

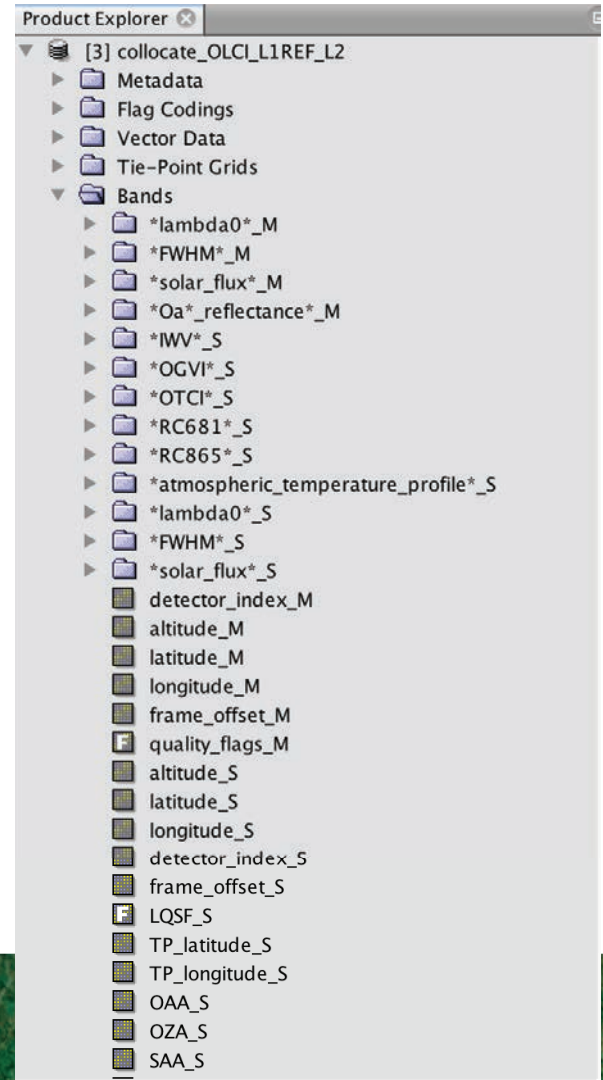
Raster/Geometric Operations/Collocation

Master file:

```
subset 0 of S3A_OL_1_EFR_____20170710T093144_20170710T093444_20170711T134744_0179_019_364_215_9_LN1_0_NT_002_radrefl.dim
```

Slave file:

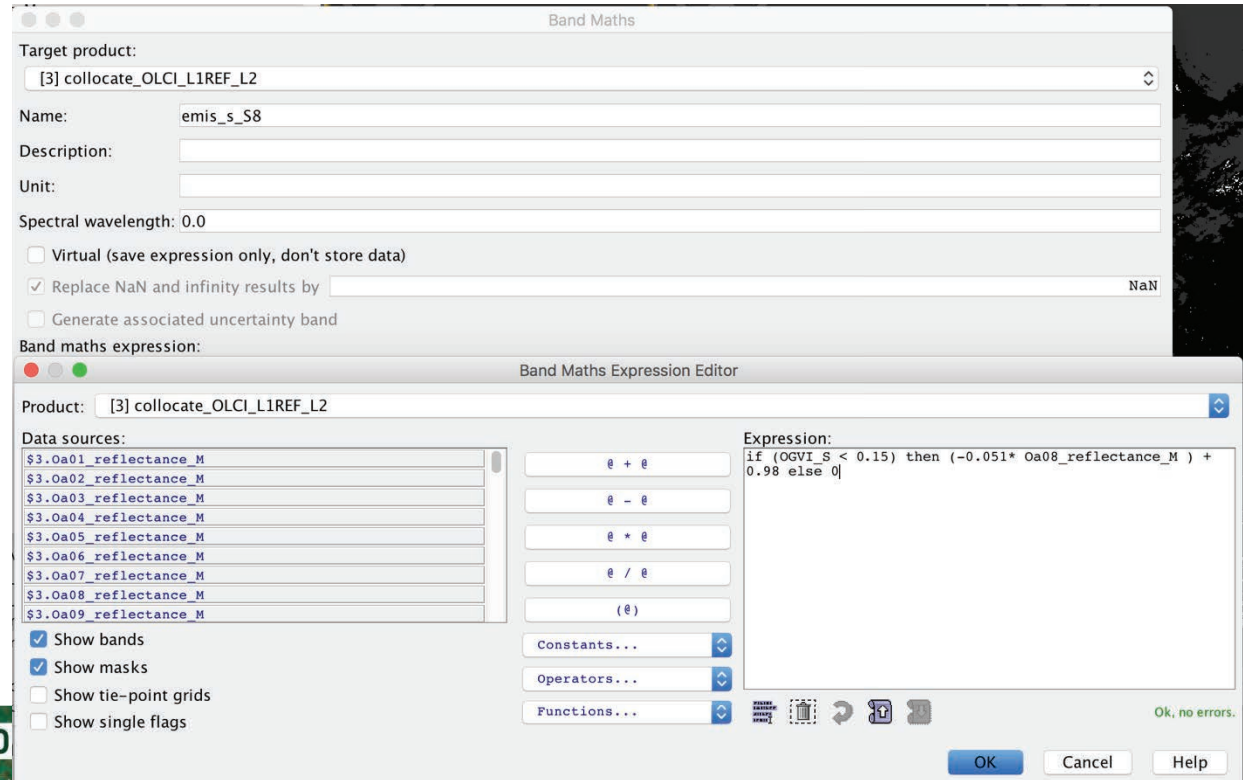
```
subset 1 of S3A_OL_2_LFR_____20170710T093144_20170710T093444_20170711T140642_0179_019_364_215_9_LN1_0_NT_002.dim
```



### 3. EMISSIVITY FROM VEGETATION INDICES

Using the collocated product, start calculating the several variables needed for the LST algorithm.

Raster/Band Maths



# Definition of emissivity

The emissivity,  $\epsilon$ , at a given wavelength  $\lambda$  (units,  $\mu\text{m}$ ) and temperature  $T$  (units, K), is defined as the ratio of the radiance  $R_\lambda(T)$  emitted by a body at temperature  $T$  and the radiance  $B_\lambda(T)$  emitted by a black body at the same temperature  $T$ , that is,

$$\epsilon_\lambda(T) = \frac{R_\lambda(T)}{B_\lambda(T)}, \quad (1) \quad (1)$$

where  $B_\lambda(T)$  refers to Planck's law, which is defined as

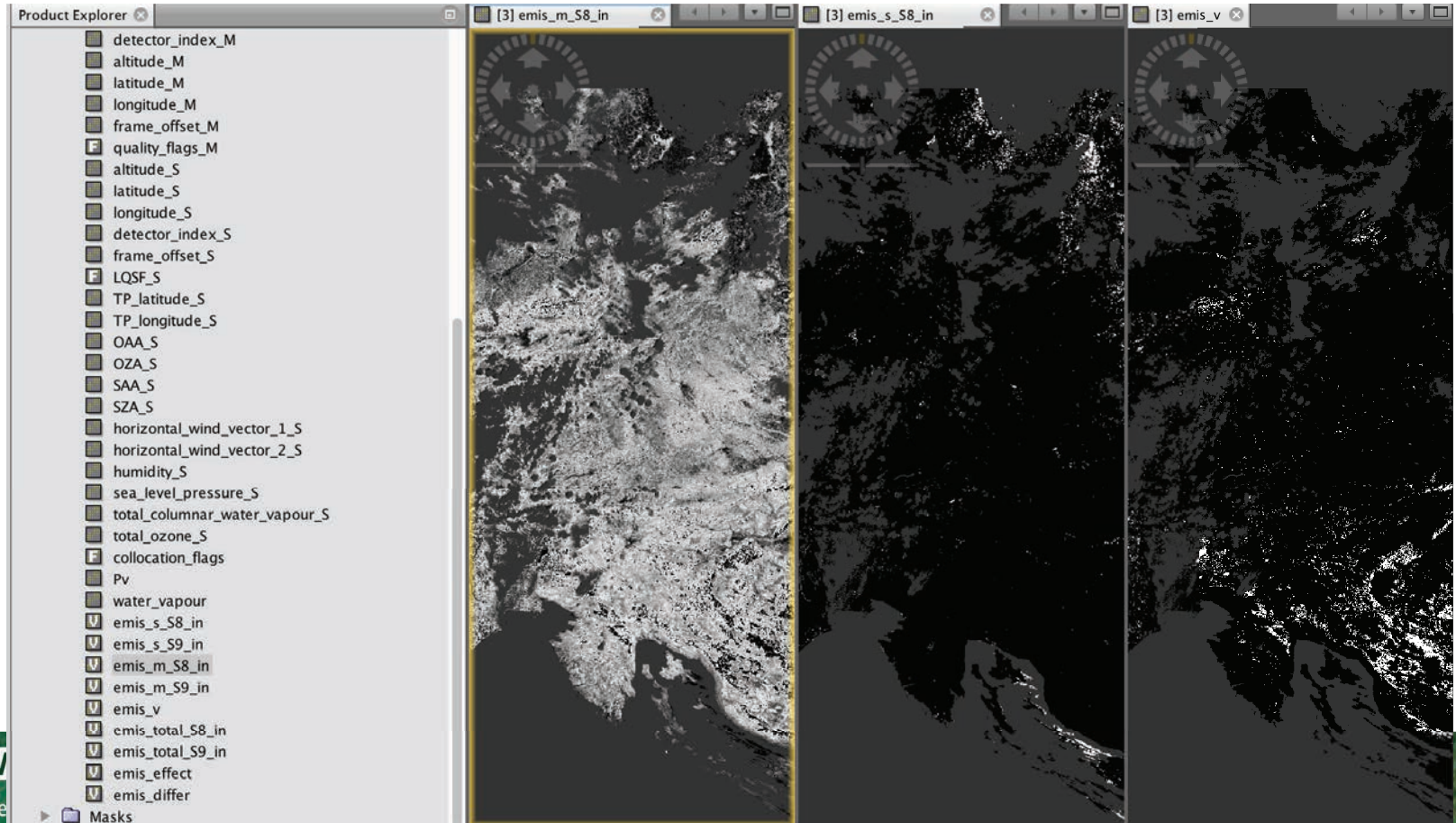
$$B_\lambda(T) = \frac{C_1 \lambda^{-5}}{\exp(C_2/\lambda T) - 1}, \quad (2) \quad (2)$$

in which  $C_1$  and  $C_2$  are constants ( $C_1 = 1.191 \times 10^8 \text{ W } \mu\text{m}^4 \text{ sr}^{-1} \text{ m}^{-2}$ ,  $C_2 = 1.439 \times 10^4 \mu\text{m K}$ ).

Land surface emissivity retrieval from satellite data  
Li et al., 2013, IJRS, <http://dx.doi.org/10.1080/01431161.2012.716540>



### 3. EMISSIVITY FROM VEGETATION INDICES



Pv

$(OGVI - 0.15) / (0.9 - 0.15)$

Soil emissivity

$emis\_s\_S8\_in = \text{if } (OGVI < 0.15) \text{ then } (-0.051 * \text{reflec\_band8\_OLCI}) + 0.98 \text{ else } 0$

$emis\_s\_S9\_in = \text{if } (OGVI < 0.15) \text{ then } (-0.032 * \text{reflec\_band8\_OLCI}) + 0.983 \text{ else } 0$

Mixed vegetation emissivity

$emis\_m\_S8\_in = \text{if } (OGVI > 0.15) \text{ and } (OGVI < 0.99) \text{ then } 0.969 * (1 - Pv) + (.99 * Pv) \text{ else } 0$

$emis\_m\_S9\_in = \text{if } (OGVI > 0.15) \text{ and } (OGVI < 0.99) \text{ then } 0.977 * (1 - Pv) + (.99 * Pv) \text{ else } 0$

Vegetation emissivity

$emis\_v = \text{if } (OGVI > 0.99) \text{ then } 0.99 \text{ else } 0$

Total emissivity

$emis\_total\_S8\_in = \text{if } (emis\_s\_S8\_in \neq 0) \text{ or } (emis\_m\_S8\_in \neq 0) \text{ then } (emis\_s\_S8\_in + emis\_m\_S8\_in) \text{ else NaN}$

$emis\_total\_S9\_in = \text{if } (emis\_s\_S9\_in \neq 0) \text{ or } (emis\_m\_S9\_in \neq 0) \text{ then } (emis\_s\_S9\_in + emis\_m\_S9\_in) \text{ else NaN}$

Effective emissivity

$emis\_effect = emis\_total\_S8\_in + emis\_total\_S9\_in / 2$

Differential emissivity

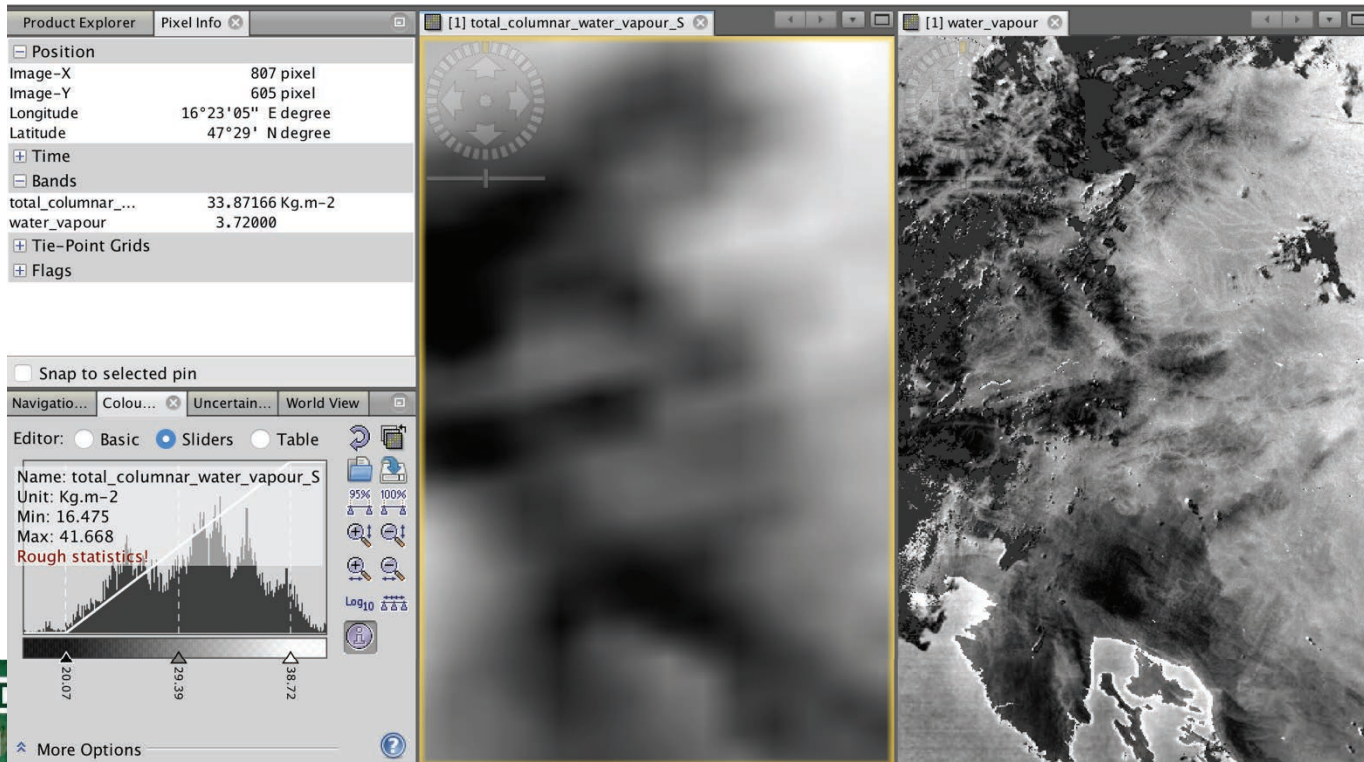
$emis\_diff = emis\_total\_S8\_in - emis\_total\_S9\_in$

Water vapour to g\*cm2

$water\_vapour = IWS\_S / 10$

## 4. WATER VAPOUR BAND SELECTION

Take the IWV (Integrated Water Vapour) band of OLCI L2 and pass from Kg/m<sup>2</sup> to g/cm<sup>2</sup> using Band Maths:  $IWV/10$





## 5. SLSTR-OLCI COLLOCATION

Use layer stacking to group the SLSTR and OLCI bands in one product with the same spatial resolution (1km) and geo-location:

Raster/Geometric Operations/Collocation

Master file:

*subset\_2\_of\_S3A\_SL\_1\_RBT\_\_\_\_20170710T093144\_  
20170710T093444\_20170711T141258\_0179\_019\_364  
\_2159\_LN2\_0\_NT\_002.dim*

Slave file:

*collocate\_OLCI\_L1REF\_L2.dim*



## 6. THE SPLIT WINDOW ALGORITHM

The screenshot displays the QGIS interface with a satellite map of a coastal region. Two dialog boxes are open:

**LST - Properties**

Product Node Properties	
Name	LST
Description	
Modified	<input type="checkbox"/>

Raster Band Properties	
Unit	<null value>
Data Type	float32
Raster size	1097 x 1293
Pixel-Value Expression	$S8\_BT\_in\_M + (1.084 * (S8\_BT\_in\_M - S9\_BT\_in\_M)) + (0.2771 * (S8\_BT\_in\_M - S9\_BT\_in\_M)^2) + (-0.268) + ((45.1 + (-0.73 * water\_vapour\_S)) * (1 - emis\_effect\_S)) + (((-125 + (16.7 * water\_vapour\_S))) * (emis\_differ\_S))$
Valid-Pixel Expression	$(S8\_BT\_in\_M.raw \neq -32768.0)$
No-Data Value Used	<input checked="" type="checkbox"/>
No-Data Value	NaN
Spectral Wavelength	0.0
Spectral Bandwidth	0.0
Ancillary Variables	
Ancillary Relations	

**Pixel-Value Expression**  
Mathematical expression used to compute the raster's pixel values

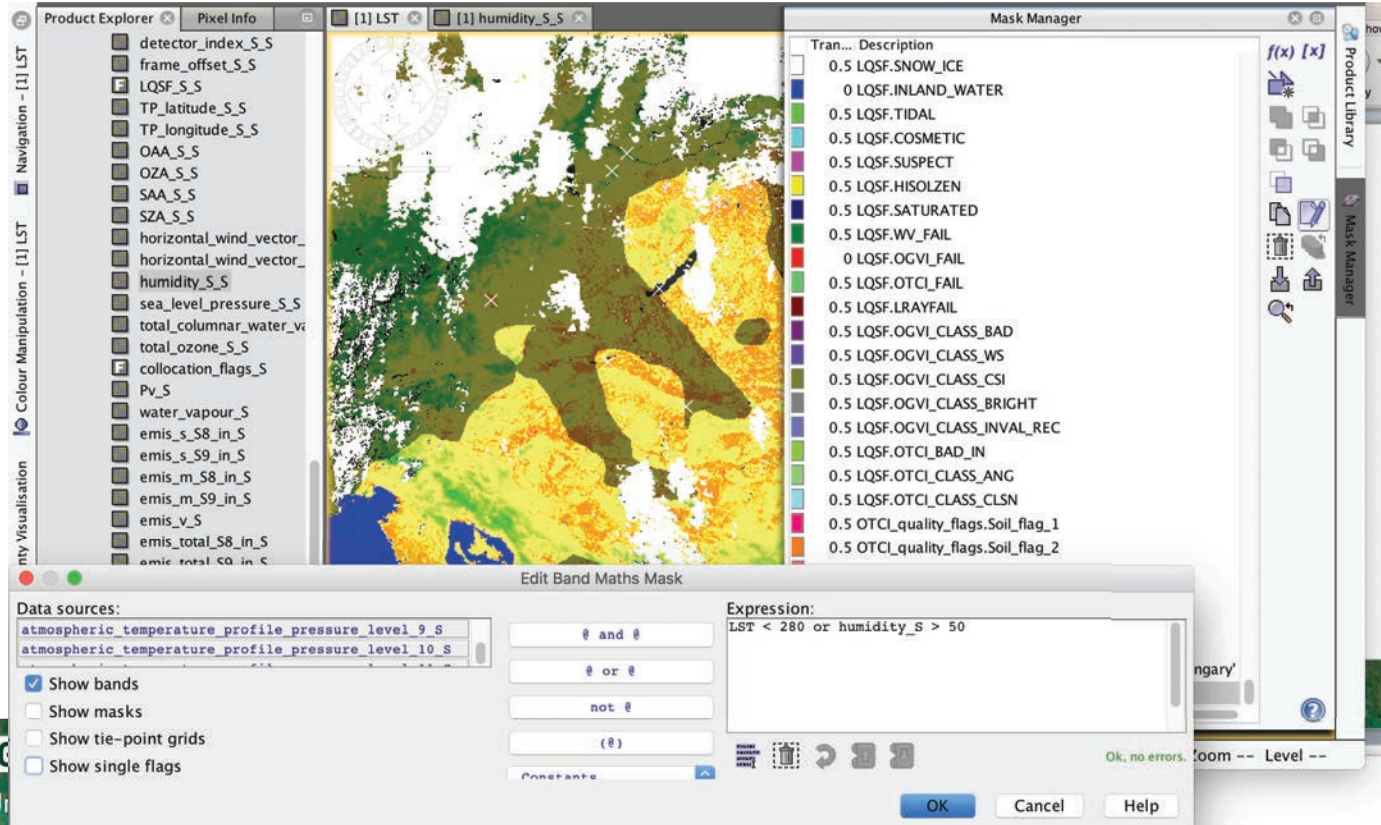
**LST - Pixel-Value Expression**

$$S8\_BT\_in\_M + (1.084 * (S8\_BT\_in\_M - S9\_BT\_in\_M)) + (0.2771 * (S8\_BT\_in\_M - S9\_BT\_in\_M)^2) + (-0.268) + ((45.1 + (-0.73 * water\_vapour\_S)) * (1 - emis\_effect\_S)) + (((-125 + (16.7 * water\_vapour\_S))) * (emis\_differ\_S))$$

The background map shows a coastal area with a color scale from green (low values) to yellow/orange (high values). The LST Properties dialog is on the left, and the Pixel-Value Expression dialog is on the right.

## 6. FLAGS AND MASKS

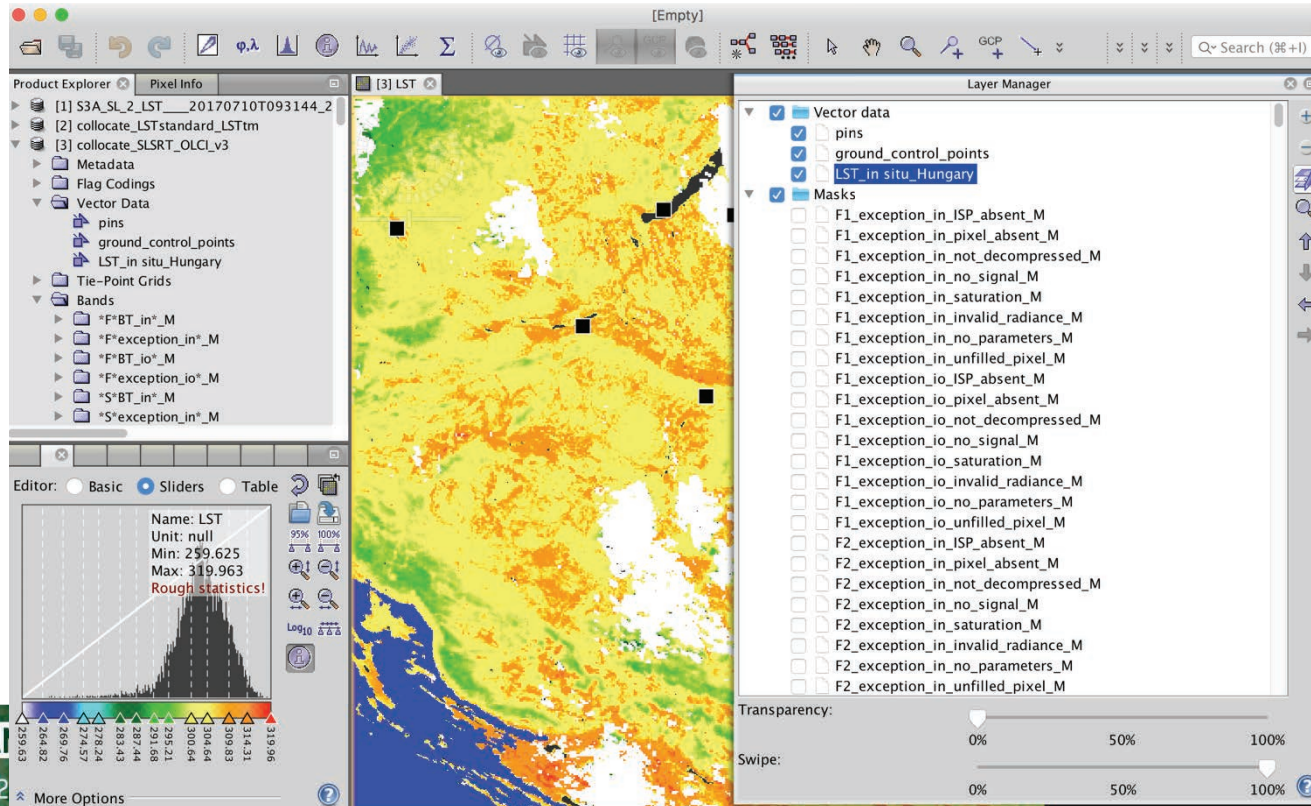
- Use the Mask Manager to visualize, change and created new masks from flags or bands.





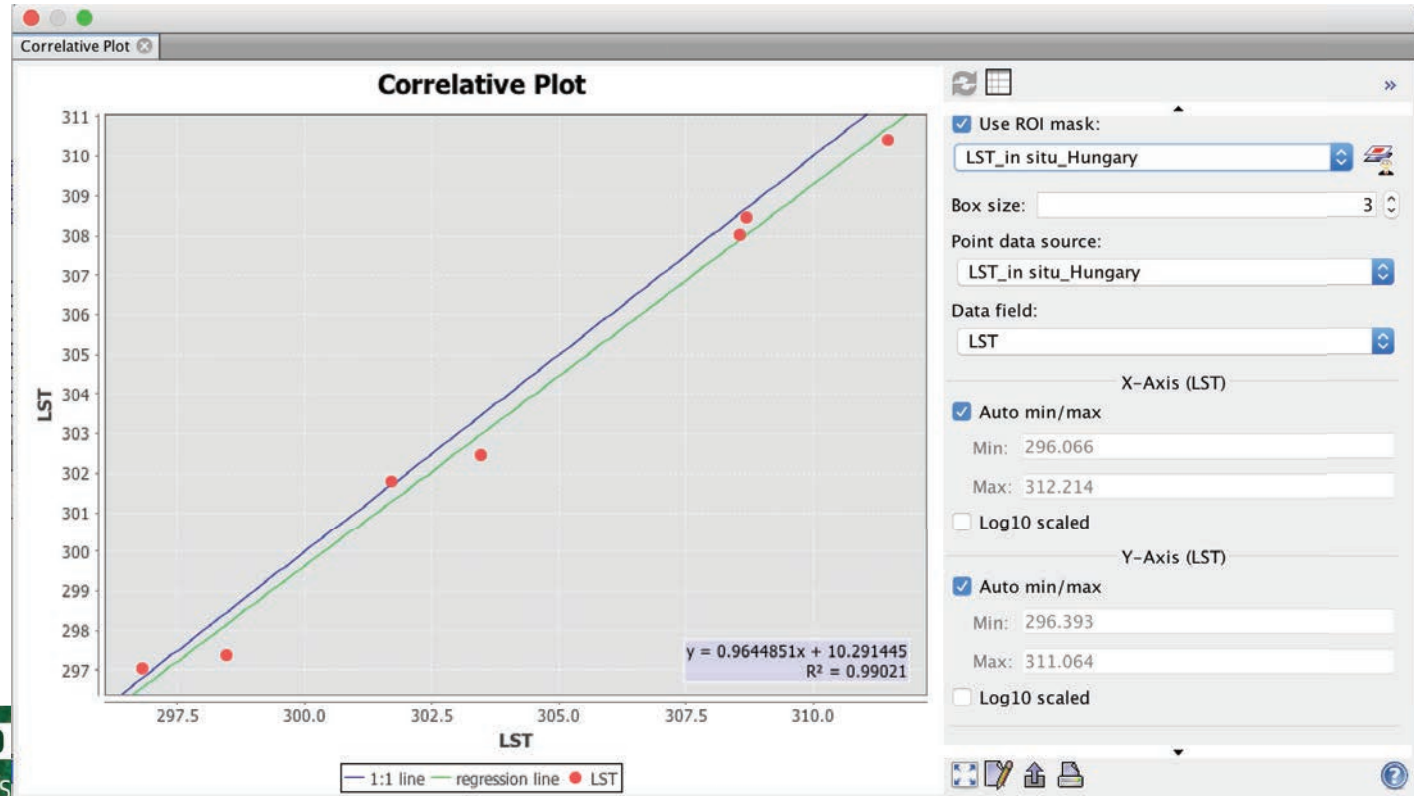
# 7. VALIDATION TOOLS: USING IN SITU DATA

## 1. Import file with in situ data: File/Import/Vector Data/Vector from CSV



# 7. VALIDATION TOOLS: USING IN SITU DATA

## 2. Make correlative plot: Analysis/Correlative plot



# 8. COMPARISON WITH OTHER PRODUCTS

Comparison of LST product with LST standard product:

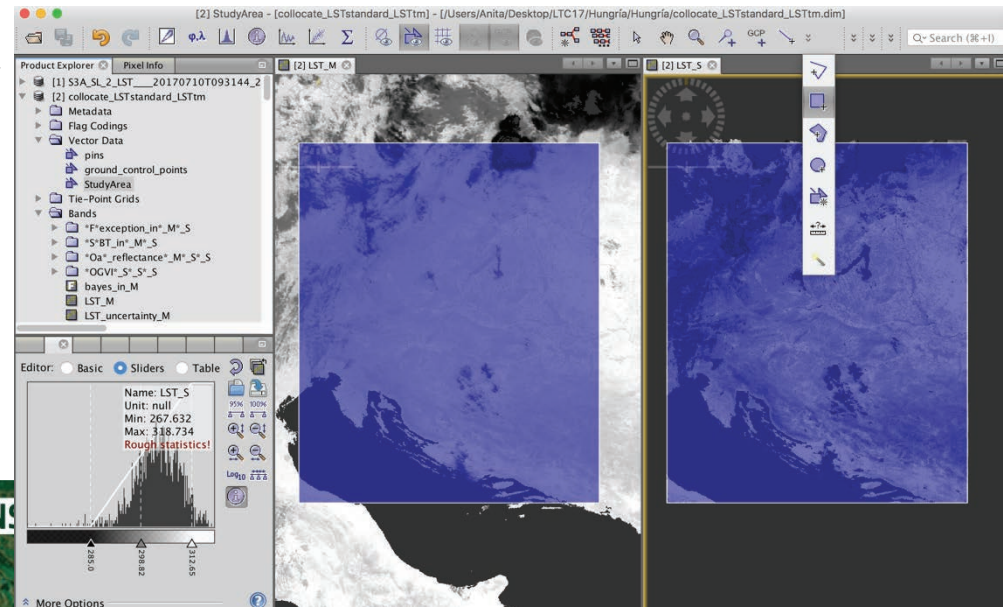
1. Collocate products using Raster/Geometry Operations/Collocation:

Master product:

***subset\_1\_of\_S3A\_SL\_2\_LST\_\_\_\_20170710T093144\_20170710T093444\_20170710T113909\_0179\_019\_364\_2159\_SVL\_O\_NR\_002.SEN3***

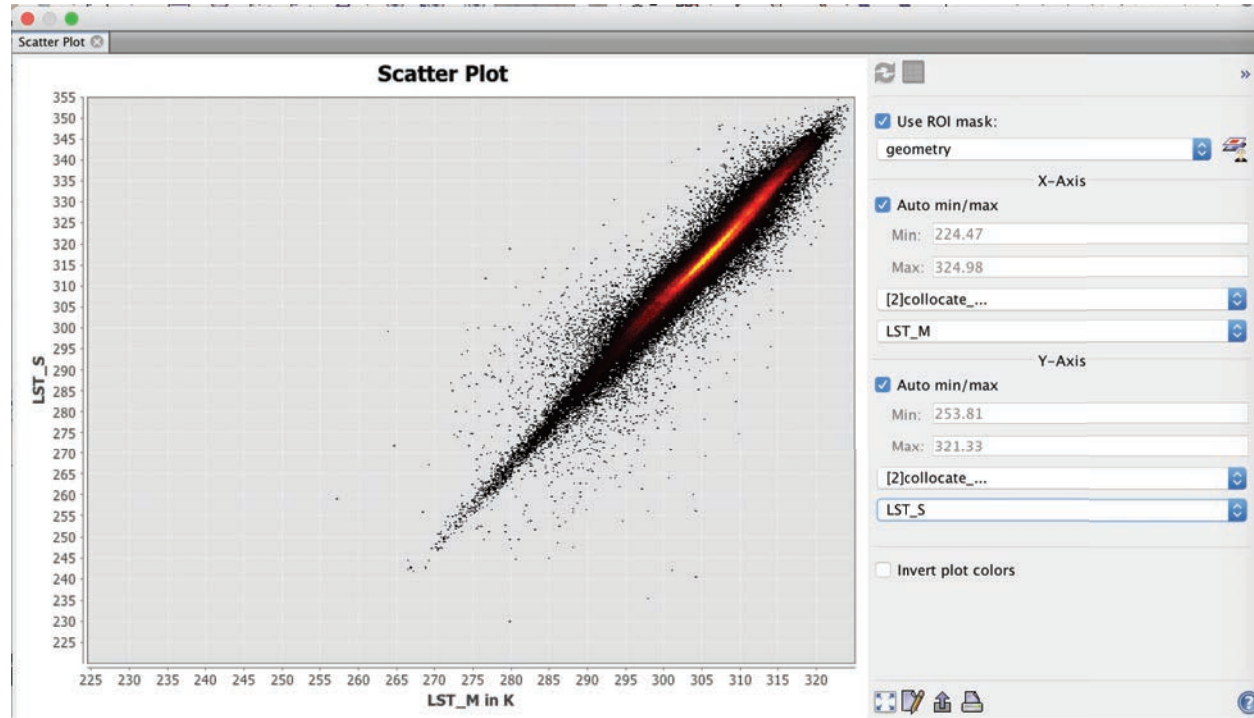
Slave product: ***subset\_0\_of\_collocate\_SLSRT\_OLCI\_v3.dim***

2. Mask study area with geometry tools:  
Vector/New Vector Data Container



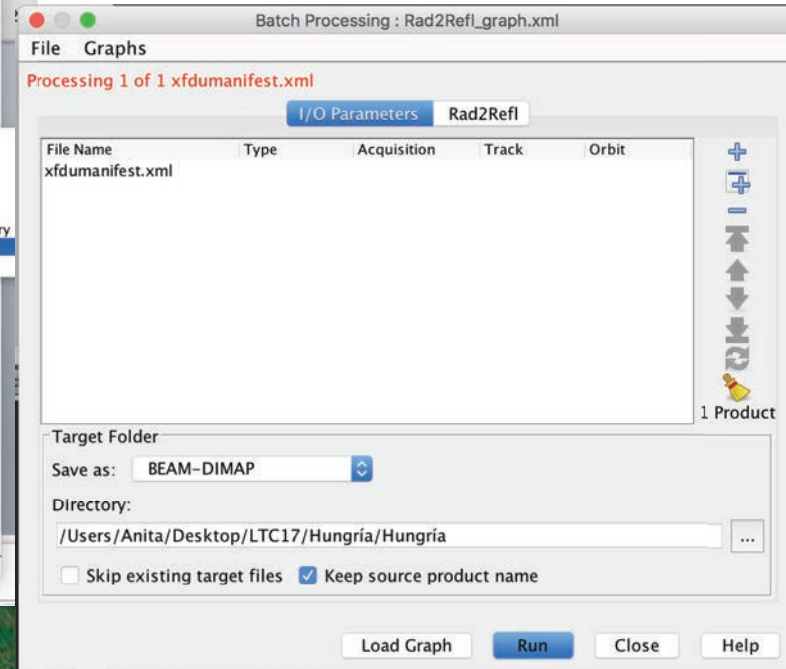
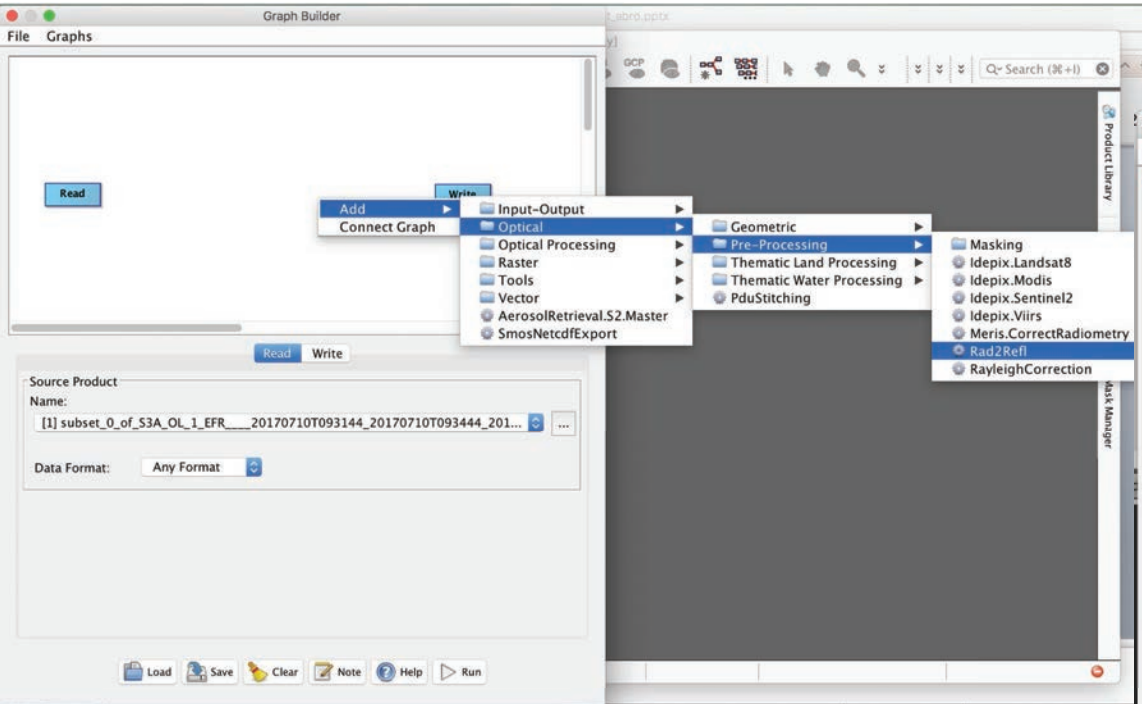


## 8. SCATTER PLOT of both bands using the mask of the study area



# 9. PREPARING FOR BATCH PROCESSING

## Tools/Graph Builder



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4-9 September 2017 | Szent István University | Gödöllő, Hungary

# SEN4LST processor in BEAM-VISAT

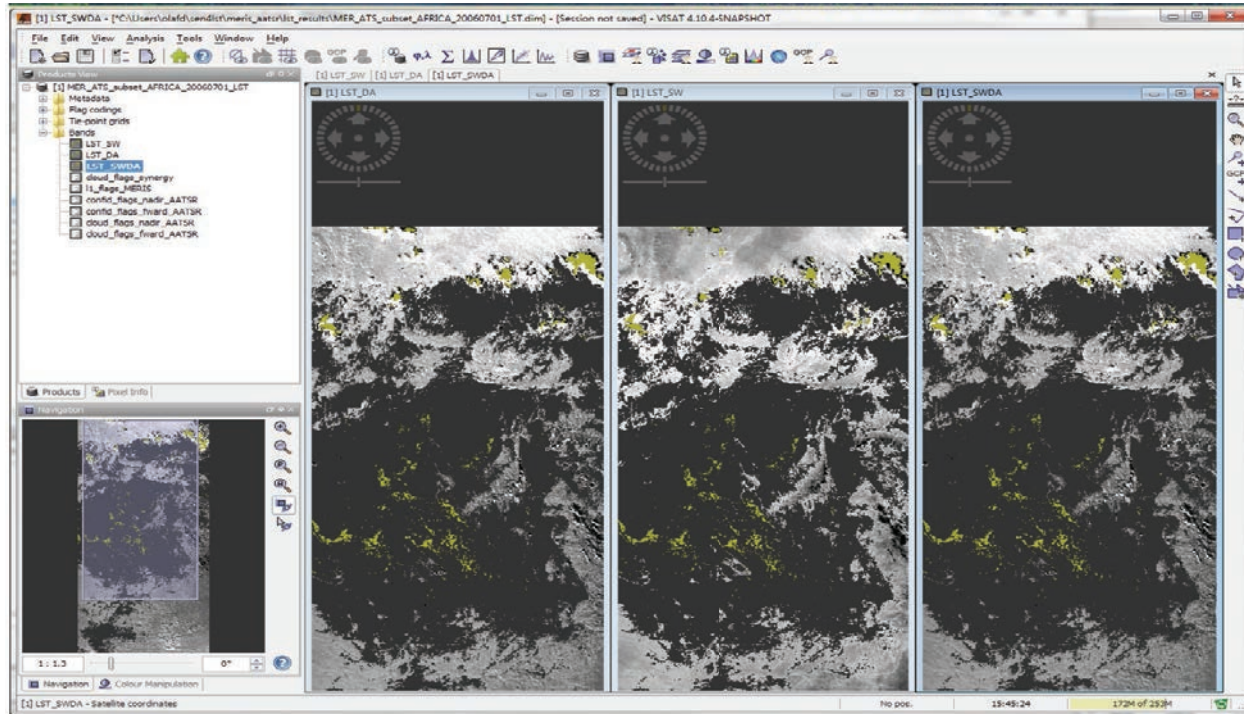
- Synergistic Use of the Sentinel Missions for Estimating and Monitoring Land Surface Temperature
- 2014 ESA Support to Science Element Project
  - Univ. Valencia
  - Brockmann Consult GmbH
  - Univ. Swansea
- Project objectives:
  - **Development of an improved LST retrieval concept** for the Sentinel-2 and Sentinel-3 missions, including its validation with a detailed analysis of the spectral, spatial and temporal synergistic aspects provided by the Sentinel-2 and Sentinel-3 mission
  - **Adaptation and BEAM 4.11 implementation of the algorithm** to Envisat MERIS and AATSR data followed by a detailed assessment based on multi-temporal LST analysis and comparison with the standard AATSR LST product



# LST processor specifications

- 2 Processor modules
  - Synergy Surface Directional Reflectance (SDR) retrieval including atmospheric correction and cloud screening
  - LST retrieval using split-window (SW), dual-angle (DA) and a combined (SW-DA) algorithm
- Input
  - Overlapping L1B products (MERIS/AATSR or simulated OLCI-SLSTR)
- Outputs
  - (Synergy SDR)
  - Three LST products for SW, DA, SW-DA

# Example of several LST algorithms of the Sen4LST sensor



# TAKE HOME MESSAGE

- Overview on Sentinel-3 OLCI and SLSTR sensors, including synergy products and applications
- Overview of SNAP Sentinel-3 Toolbox
- Exercise of Land Surface Temperature Calculation using the Vegetation Threshold Method
- Training using validation data and tools
- Introduction on batch processing
- Example of products from the SEN4LST processor in BEAM