# EXTENSIVE ANALYSIS OF POTENTIALITIES AND LIMITATIONS OF A MAXIMUM CROSS-CORRELATION TECHNIQUE FOR SURFACE CIRCULATION BY USING REALISTIC OCEAN MODEL SIMULATIONS

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# Research Problem

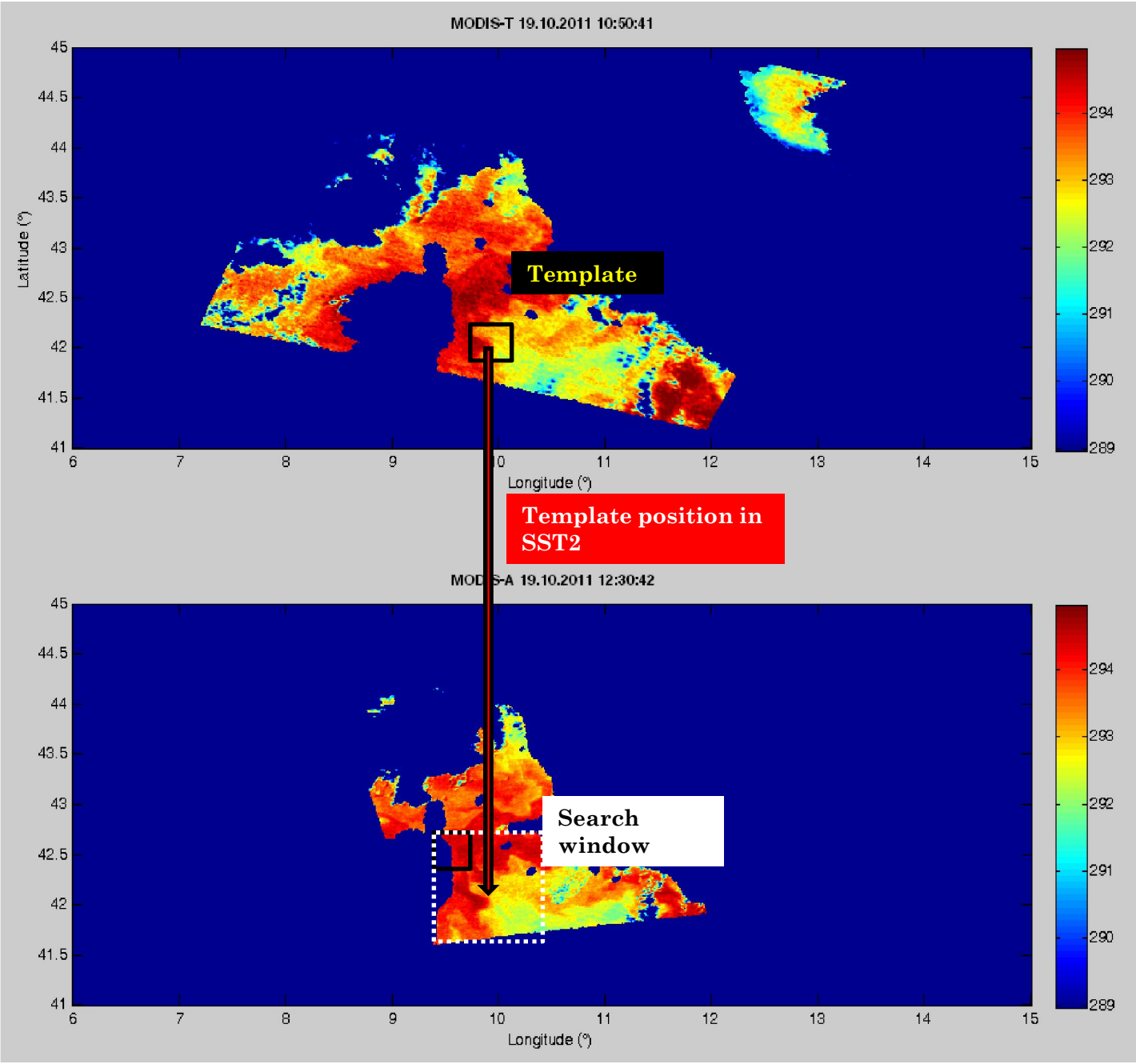
Moored instruments provide high resolution in time but limited spatial coverage.

Ocean surface circulation estimation from sequential satellite imagery give us a synoptic-scale coverage of the surface currents on a quasi-continuous temporal basis.

Here the Maximum Cross-Correlation (MCC) technique, based on processing of an increasingly higher resolution satellite images, is shown.

# CONTENTS

- Maximum Cross-Correlation technique
- Some improvements and algorithm calibration
- Anlysis of potentialities and limitations of MCC working on synthetic thermal image
- MCC application to satellite imagery


MODIS-T 19.10.2011 10:50:41
Template
Template position in SST2
MODIS-A 19.10.2011 12:30:42
Search window
Latitude (°)
Longitude (°)
45
44.5
44
43.5
43
42.5
42
41.5
41
6
7
8
9
10
11
12
13
14
15
294
293
292
291
290
289

# MAXIMUM CROSS-CORRELATION TECHNIQUE

Velocity measured: $V = \frac{\Delta S}{\Delta T}$

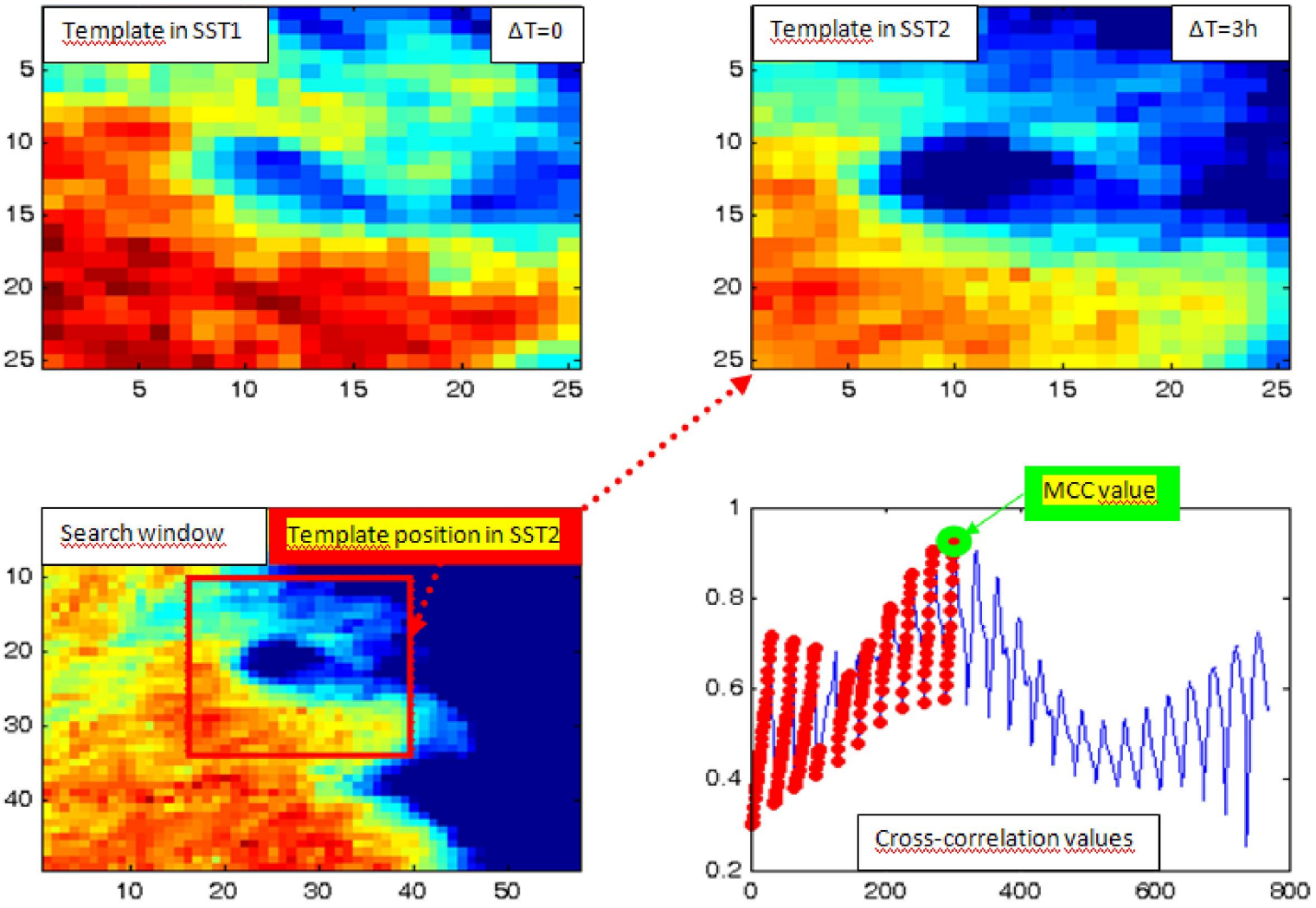
Search window amplitude: $\Delta\, pixel = \frac{\Delta T \bullet Vmax}{r}$

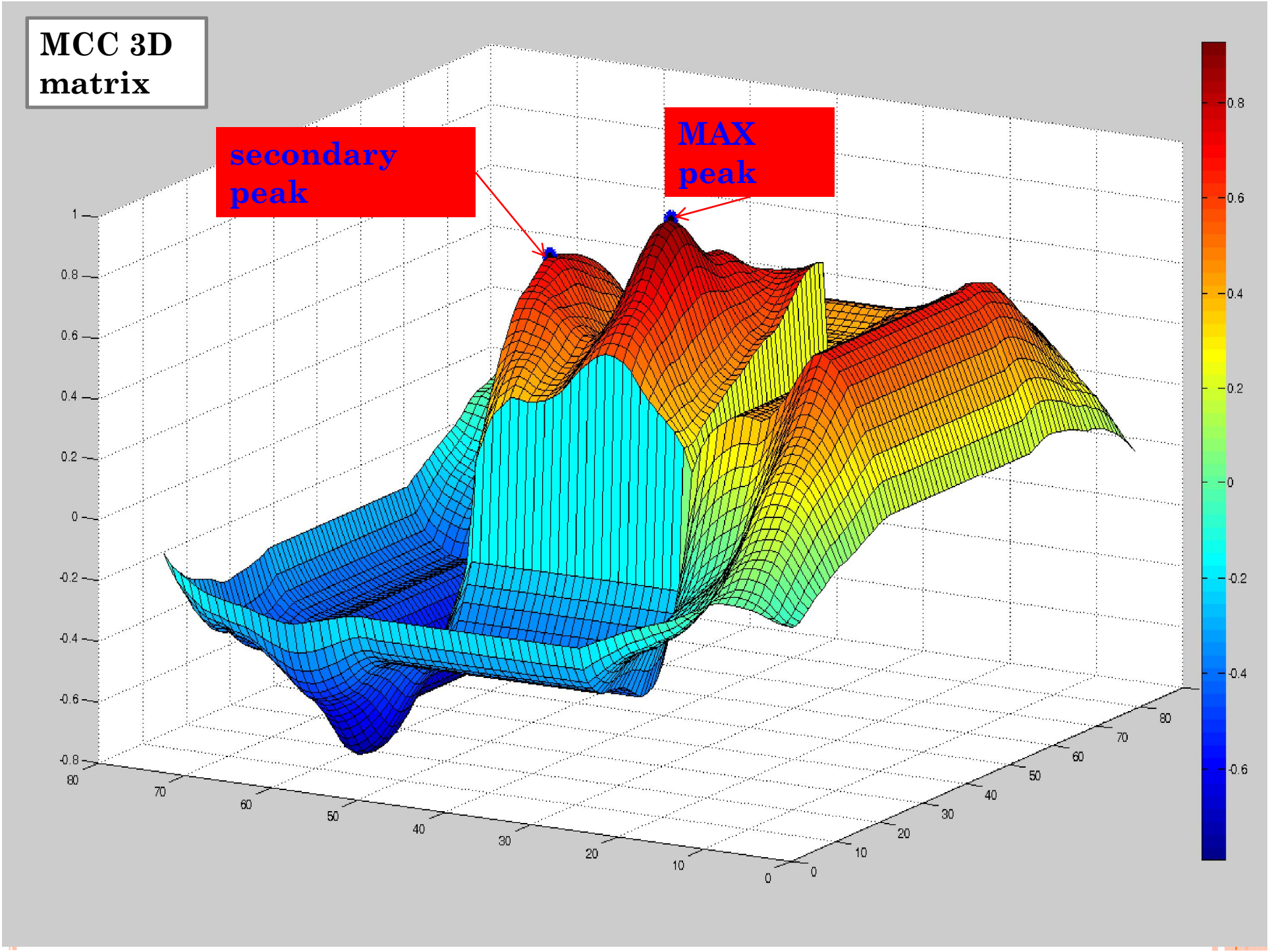
Velocity measurable: $Vmin = \frac{r}{\Delta T}$

*Vmax= typical max speed current in that area*
ΔT= SST interval
ΔS= template dispacement
*r= image resolution*

The smallest velocity measurable with 1.1 km of resolution, for 3h time separation, is 9.2 cm/sec, that decreases to 4.6 cm/sec for 6h!

# Maximum Cross-Correlation technique




MCC 3D matrix
secondary peak
MAX peak
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
80
70
60
50
40
30
20
10
0
0
10
20
30
40
50
60
70
80
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6

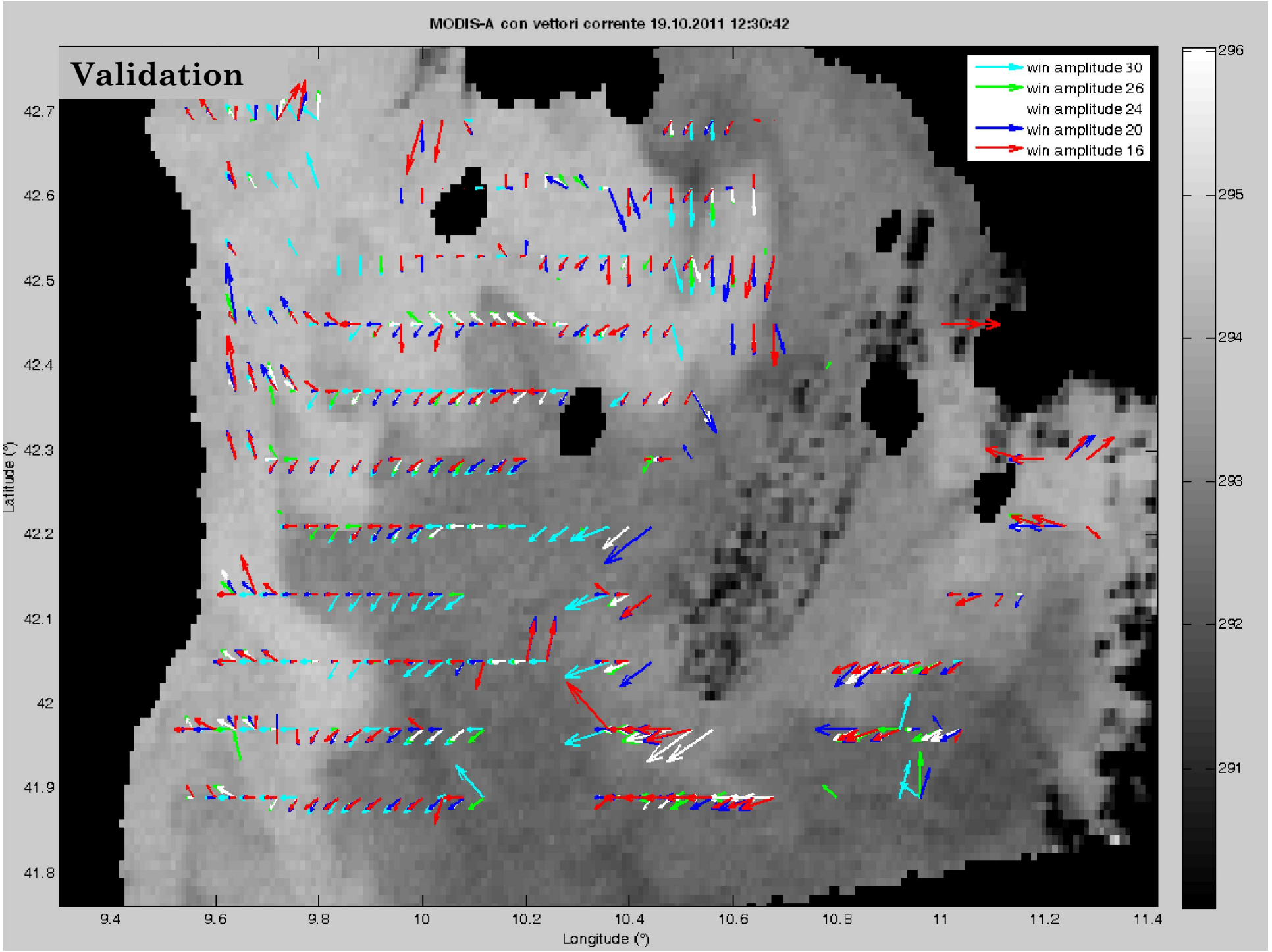
# LIMITATIONS OF THE MCC

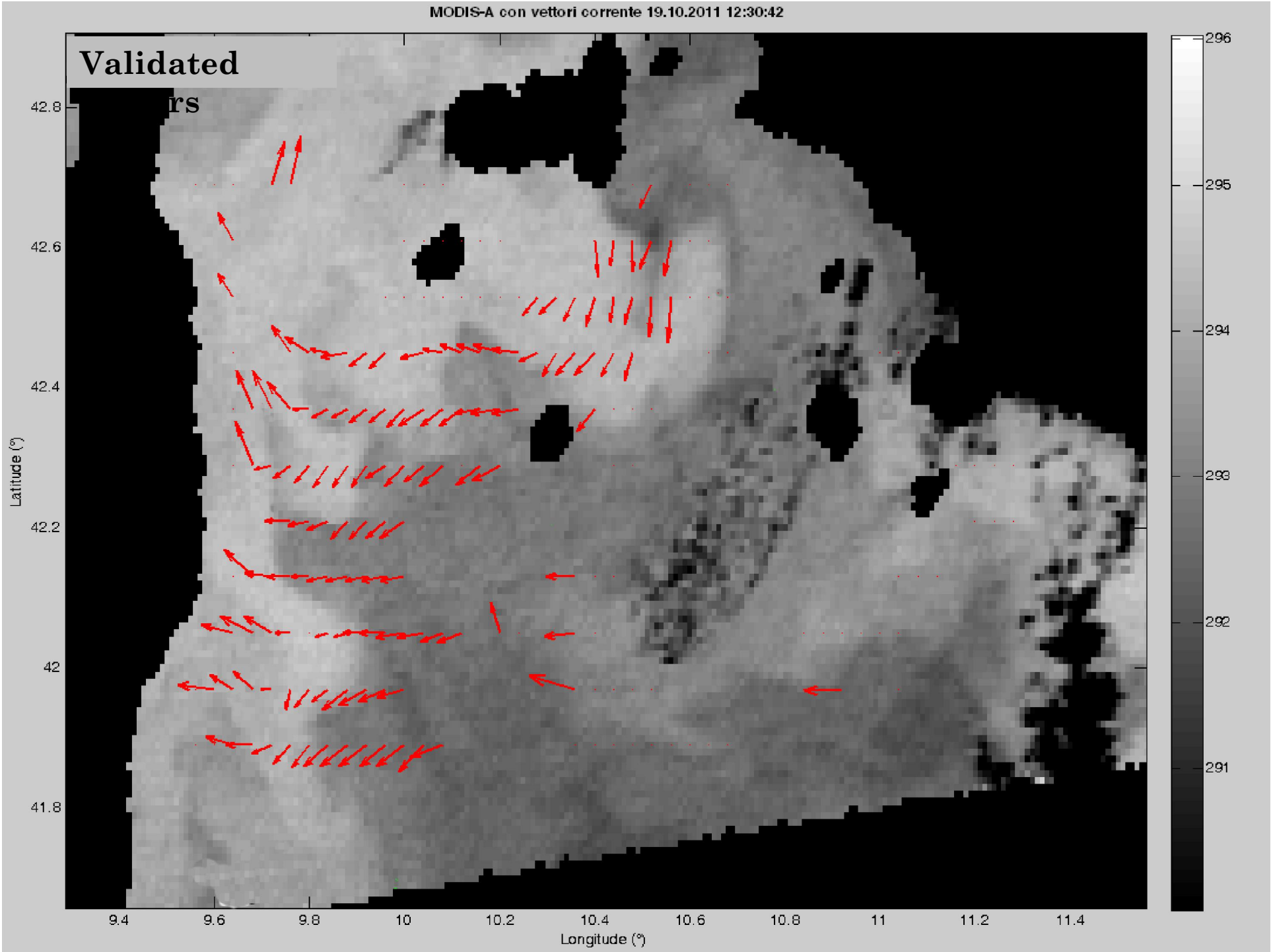
- Limitations of the algorithm implementation
- MCC is suitable to detect flows moving along thermal gradient
- Patterns are advected (or uniformly translated) without changes (or with little changes)
- Many satellite images are necessary
- Cloud coverage
- SST or other surface parameter from satellite imagery are passive tracers
- Could not work properly in shallow water

# MCC TECHNIQUE AND SOME IMPROVEMENTS

*MCC algorithm improvements may be implemented during each phases:*

- Preprocessing (noise reduction filters, unsharp contrast filter, background analysis, cloud and land masking)
- Processing (using multiple template windows, MCC-FFT with pixel clouds masked, selection values over adaptive thresholds, pattern rotation, reciprocity algorithm)
- Post-processing (temporal and spatial validation of current vectors)

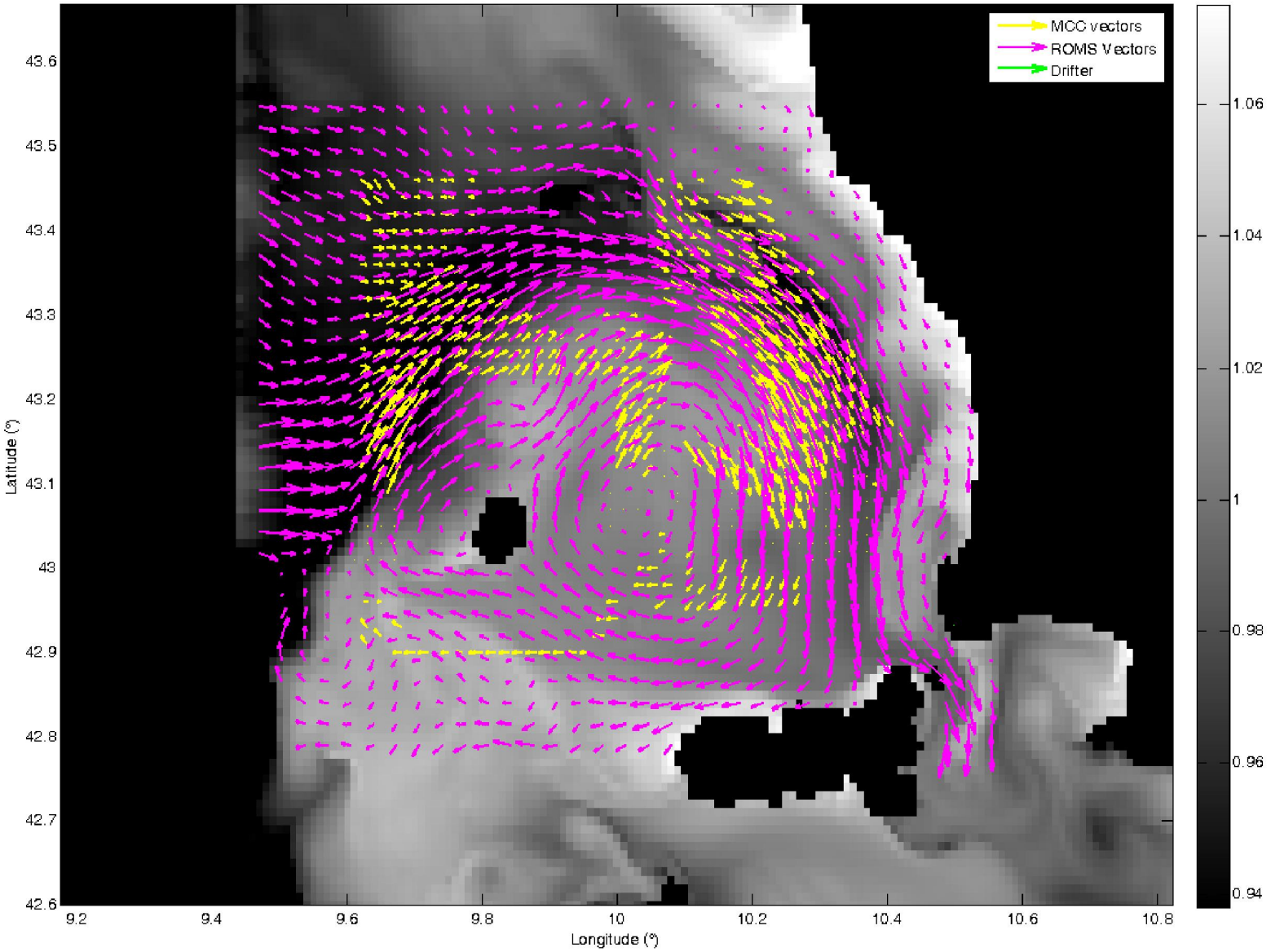

MODIS-A con vettori corrente 19.10.2011 12:30:42
Validation
win amplitude 30
win amplitude 26
win amplitude 24
win amplitude 20
win amplitude 16
Latitude (°)
42.7
42.6
42.5
42.4
42.3
42.2
42.1
42
41.9
41.8
Longitude (°)
9.4
9.6
9.8
10
10.2
10.4
10.6
10.8
11
11.2
11.4
296
295
294
293
292
291


MODIS-A con vettori corrente 19.10.2011 12:30:42
Validated
rs
42.8
42.6
42.4
42.2
42
41.8
Latitude (°)
9.4
9.6
9.8
10
10.2
10.4
10.6
10.8
11
11.2
11.4
Longitude (°)
296
295
294
293
292
291

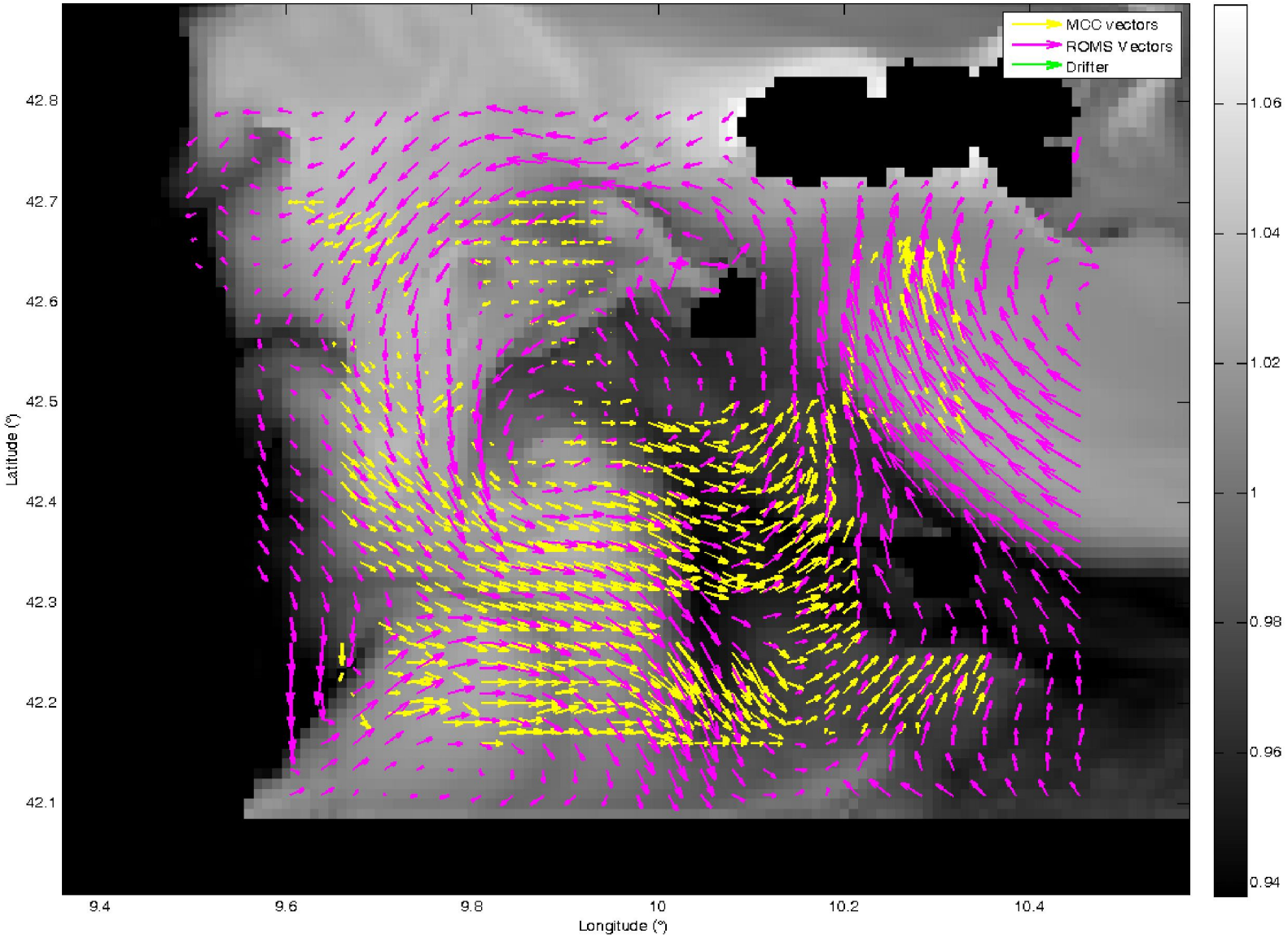
# MCC: Synthetic thermal image analysis

*In the past many authors used numerical model to validate the MCC technique by mean synthetic data.*

For the first time, an extensive analysis of reliability of the MCC from realistic numerical ocean model ROMS is carried out


MODIS multi-banda, con vettori corrente validati e drifter 03.07.2012 03:00:00
MCC vectors
ROMS Vectors
Drifter
Latitude (°)
Longitude (°)
43.6
43.5
43.4
43.3
43.2
43.1
43
42.9
42.8
42.7
42.6
9.2
9.4
9.6
9.8
10
10.2
10.4
10.6
10.8
1.06
1.04
1.02
1
0.98
0.96
0.94

ANALYSIS


MODIS multi-banda, con vettori corrente validati e drifter 03.07.2012 03:00:00
MCC vectors
ROMS Vectors
Drifter
Latitude (°)
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9.4
9.6
9.8
10
10.2
10.4
1.06
1.04
1.02
1
0.98
0.96
0.94

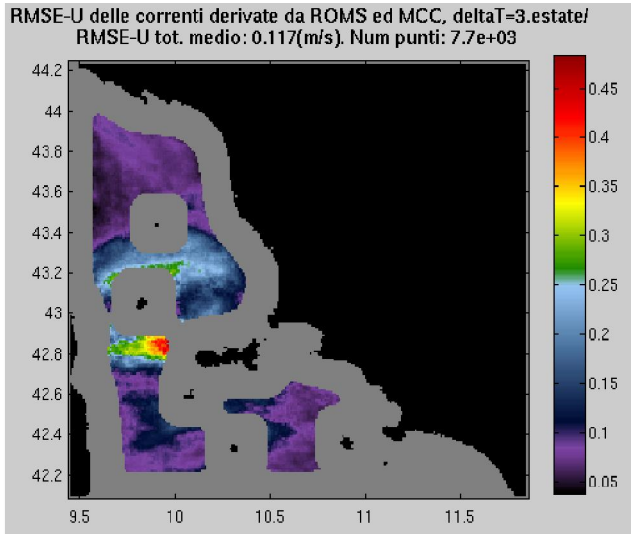
ANALYSIS

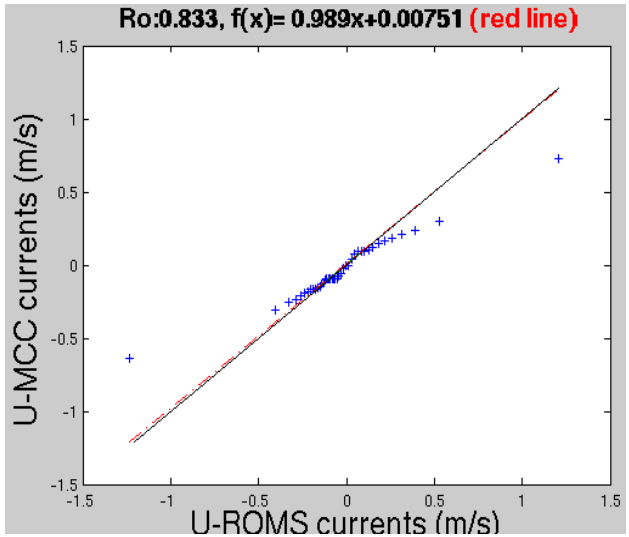
# MCC: Synthetic thermal image analysis

- Seasonal analysis
- Diurnal and Nightime cycles
- Windows template amplitude effects
- Time step effects
- Effects of averaging data currents (spatial and temporal)
- *Test noise effect on the synthetic images and real images simulation (work in progress)*

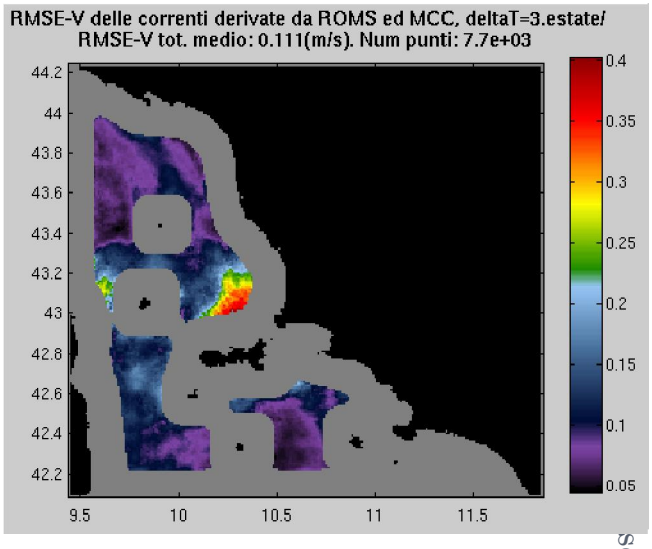
# MCC: SYNTHETIC THERMAL IMAGE ANALYSIS

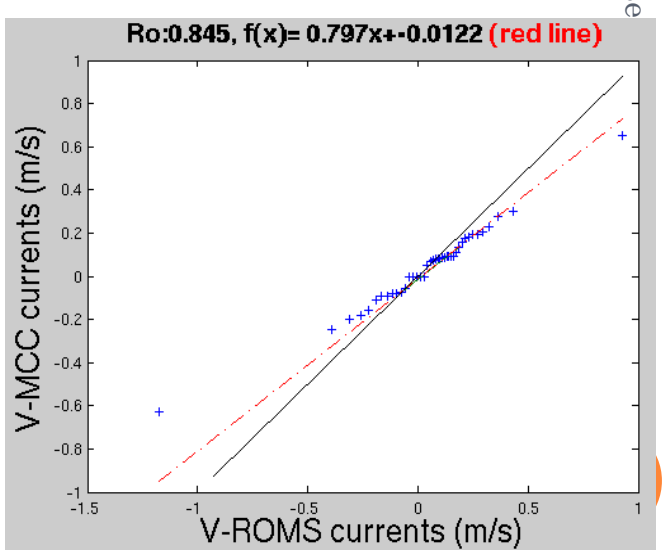
## *SEASONAL ANALYSIS*




RMSE for each pixel value and quantile plot in the summer season



# MCC: SYNTHETIC THERMAL IMAGE ANALYSIS

*SEASONAL ANALYSIS*

| Season | RMSE Ucomponent | RMSE Vcomponent | Corr. Ucomponent | Corr. Vcomponent | RMSE Angle | Template Amplitude (pixel) |
|---|---|---|---|---|---|---|
| Summer | 0.117 | 0.111 | 0.833 | **0.845** | 33.4 | 16 |
| Autumn | 0.107 | 0.148 | 0.728 | 0.758 | 34.6 | 16 |
| Winter | 0.108 | 0.125 | 0.71 | 0.68 | 41 | 16 |
| Spring | **0.083** | **0.099** | **0.839** | 0.833 | **33.2** | 16 |

# MCC: Synthetic thermal image analysis

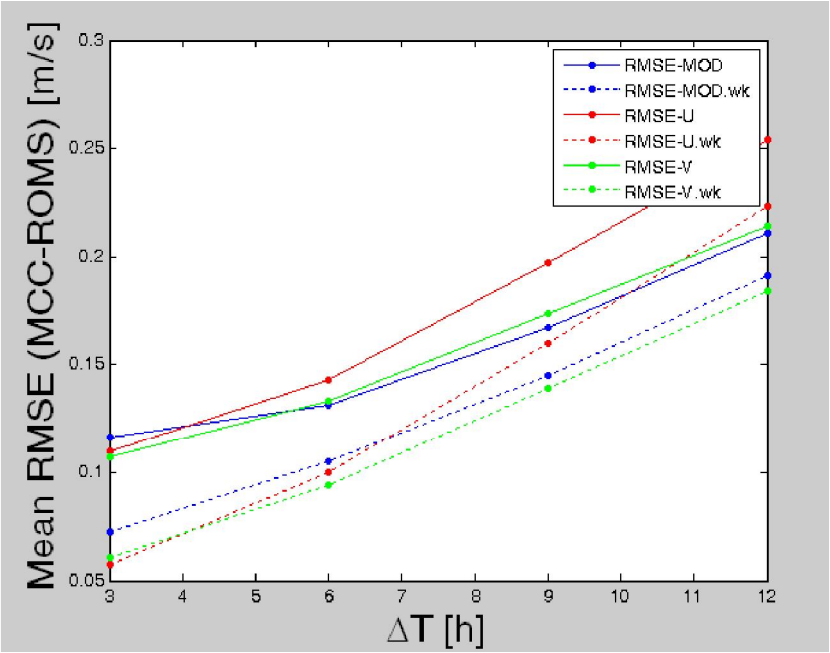
*Nighttime and Daytime analysis*

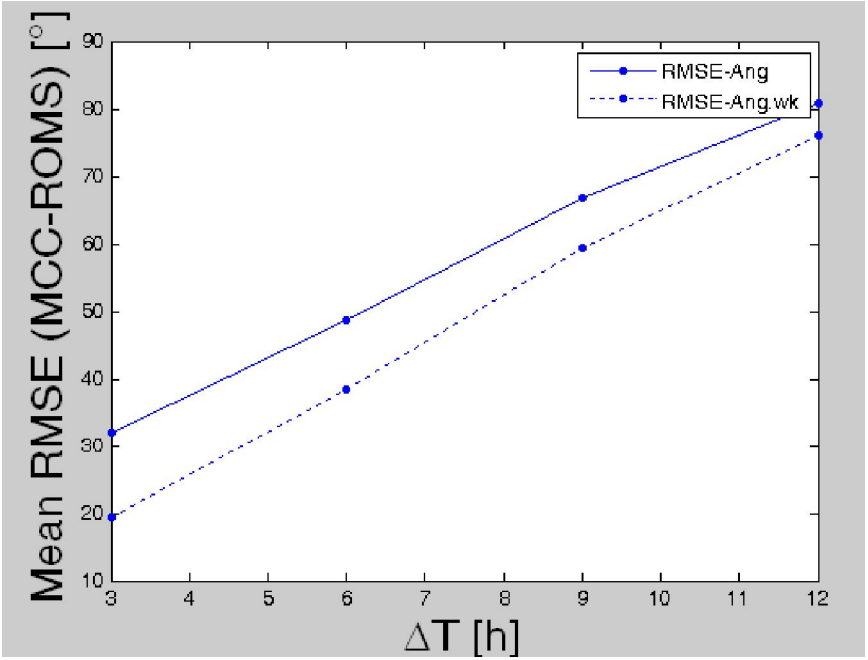
| Nighttime | | | | | | |
|---|---|---|---|---|---|---|
| Season | RMSE Ucomponent | RMSE Vcomponent | Corr. Ucomponent | Corr. Vcomponent | RMSE Angle | Template Ampl. (pixel) |
| Summer | 0.113 | 0.106 | **0.846** | **0.841** | **30.4** | 16 |
| Autumn | 0.107 | 0.143 | 0.737 | 0.742. | 32.8 | 16 |
| Winter | 0.106 | 0.119 | 0.685 | 0.686 | 40.2 | 16 |
| Spring | **0.079** | **0.091** | 0.84 | 0.83 | 31.3 | 16 |

| Daytime Warming | | | | | | |
|---|---|---|---|---|---|---|
| Season | RMSE Ucomponent | RMSE Vcomponent | Corr. Ucomponent | Corr. Vcomponent | RMSE Angle | Template Ampl. (pixel) |
| Summer | 0.121 | 0.117 | 0.811 | **0.853** | 35.2 | 16 |
| Autumn | 0.105 | 0.149 | 0.728 | 0.775 | 34 | 16 |
| Winter | 0.109 | 0.13 | 0.728 | 0.678 | 38.1 | 16 |
| Spring | **0.084** | **0.11** | **0.837** | 0.838 | **32.2** | 16 |

# MCC: SYNTHETIC THERMAL IMAGE ANALYSIS

*TIME STEP AND EFFECTS OF AVERAGING DATA CURRENTS*

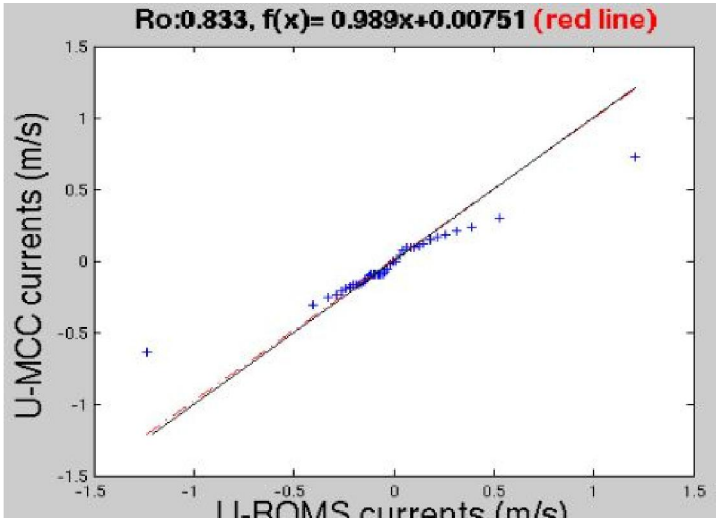


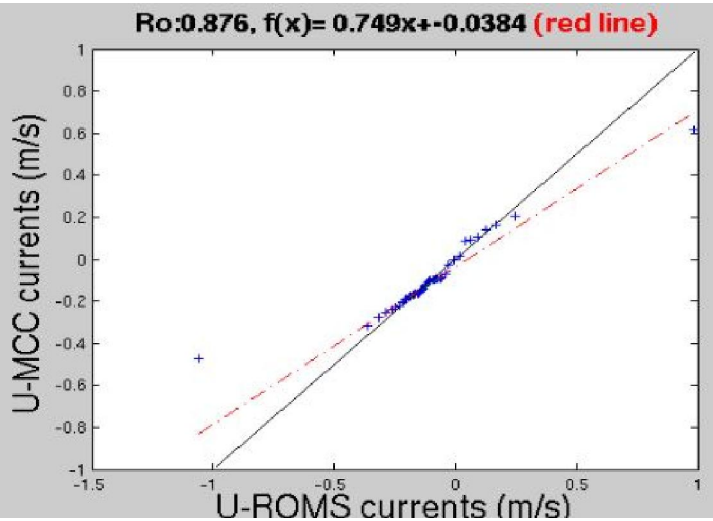



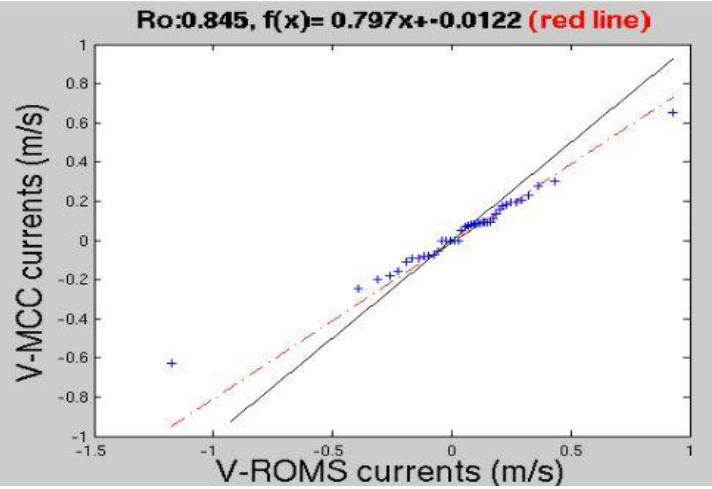

*Temporal mean effects*

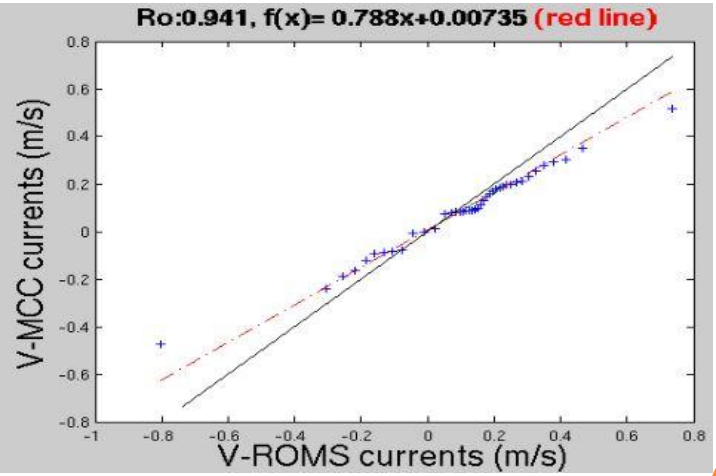
# MCC: SYNTHETIC THERMAL IMAGE ANALYSIS

*EFFECTS OF AVERAGING DATA CURRENTS*



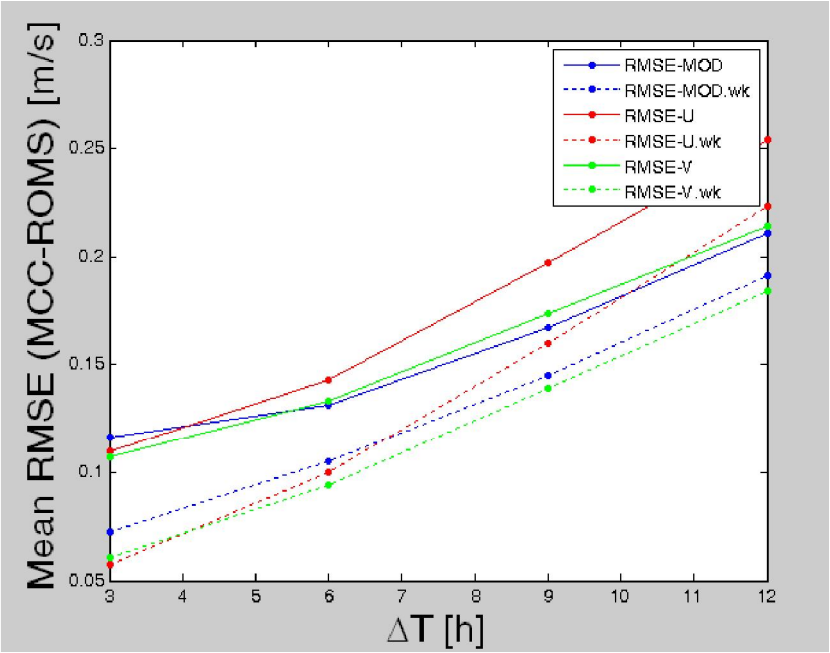



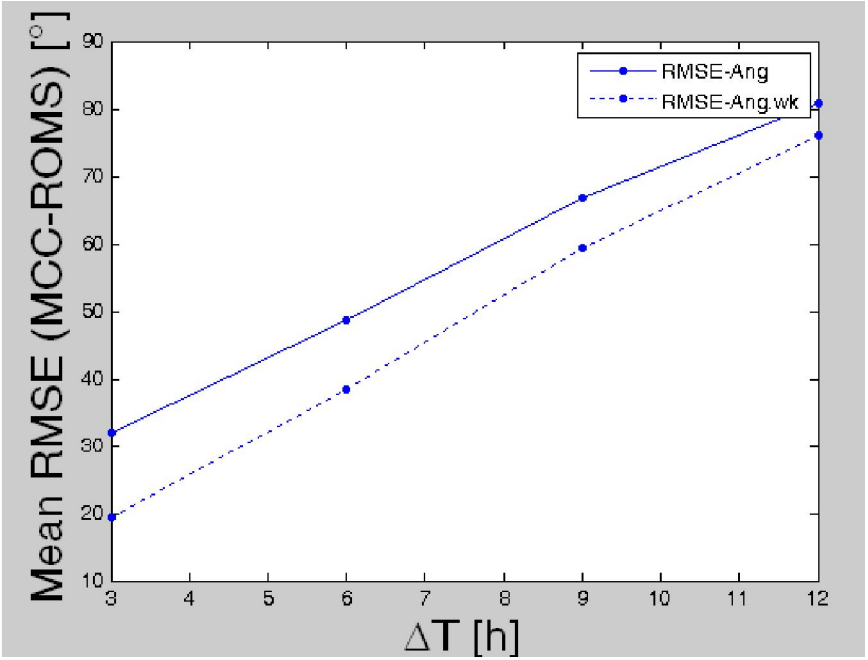




*Spatial mean effects*

# MCC: SYNTHETIC THERMAL IMAGE ANALYSIS

*TIME STEP AND EFFECTS OF AVERAGING DATA CURRENTS*




*Temporal mean effects*

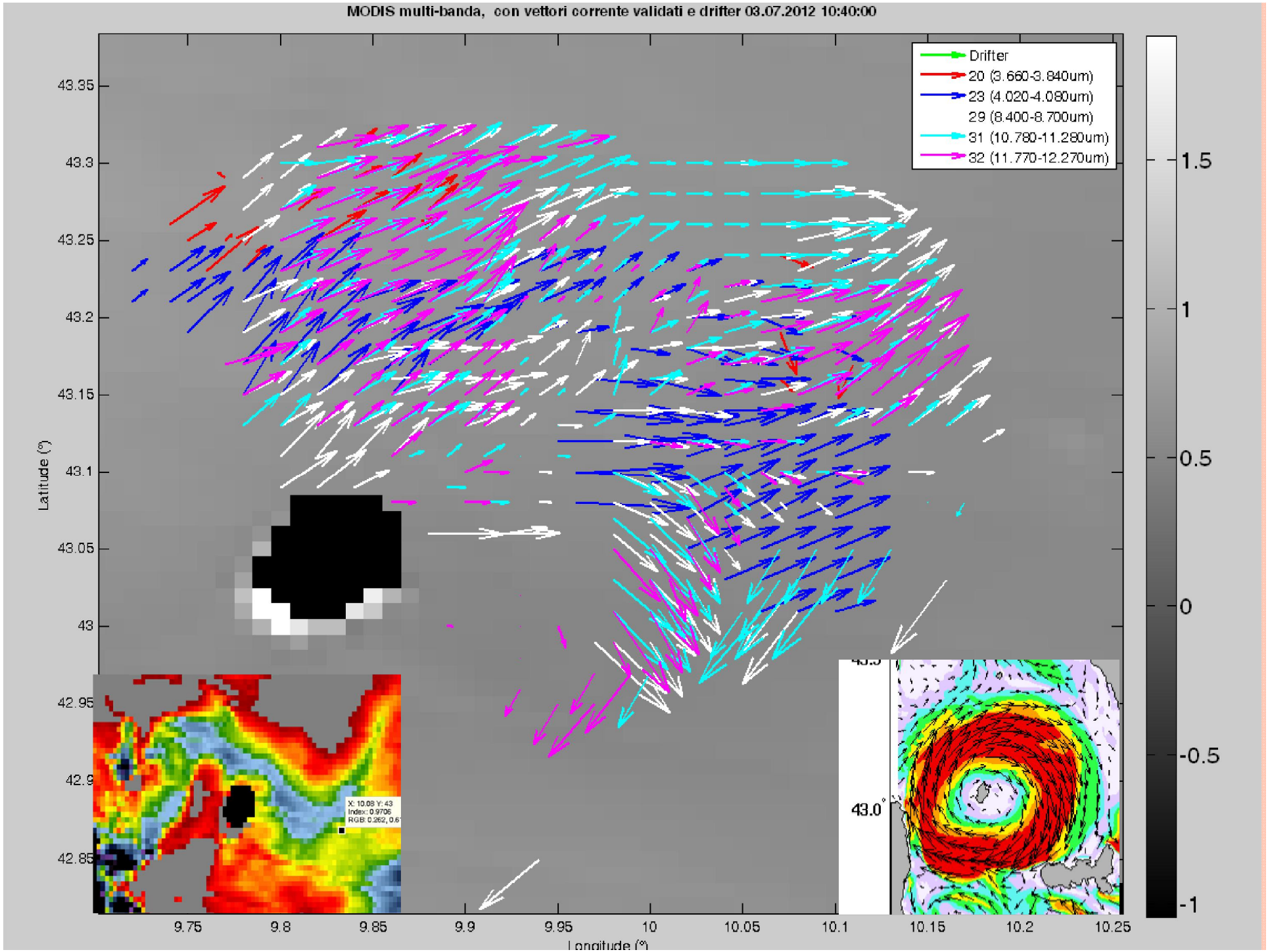
# SYNTHETIC ANALYSIS - CONCLUSIONS

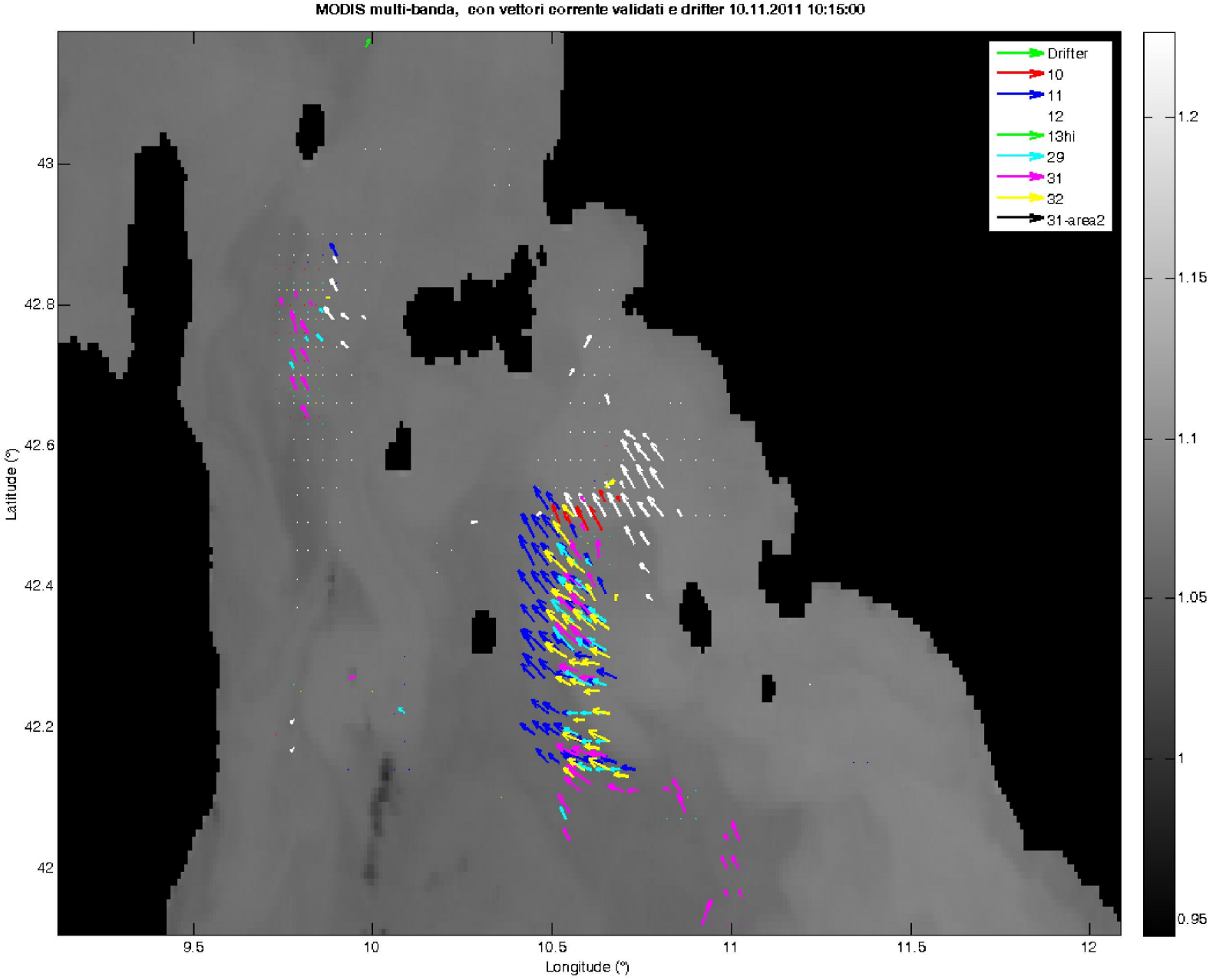
- High MCC seasonal variability (good results in summer and spring) due to SST gradient and clouds presence
- Diurnal and nightime variability (warming and cooling fluxes)
- Existence of an optimal windows template amplitude (not shown here) and critical choice of interval time
- Beneficial effects of averaging data currents (spatial and temporal)
- Necessity to analyze beahavior of other tracers and real satellites data

# APPLICATION TO SATELLITE IMAGERY

*Real tests with AQUA/TERRA (MODIS), METOP-A (AVHRR) SST and single band signal.*

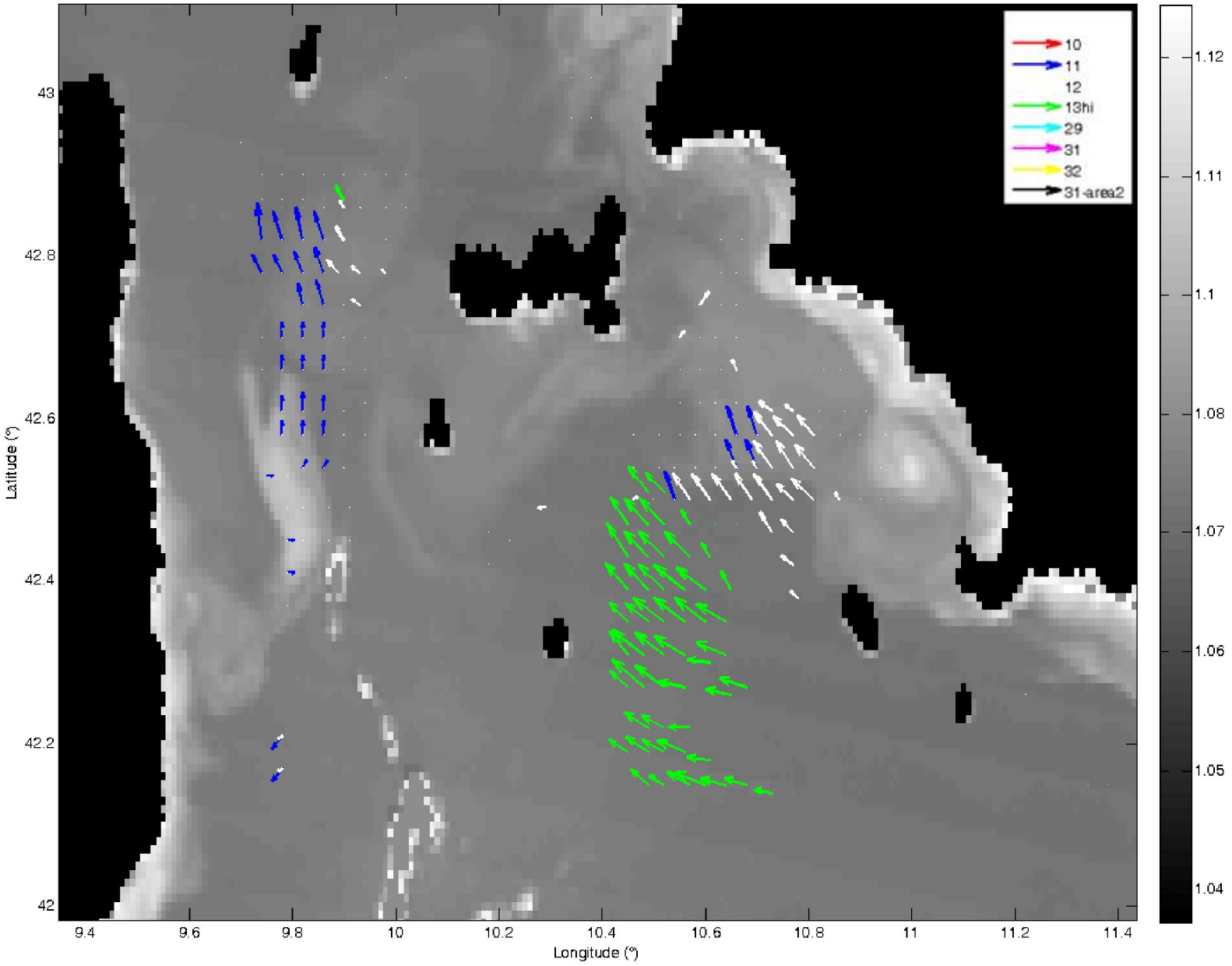
- *SST global 1.1 km from GHRSST L2P distribution*
- *Chlorophyll from OceanColor MODIS L2*
- *Single band calibrated radiances at 1 km in reflected (phytoplankton and biogeochemical bands ) and emissive solar bands from MODIS L1B (MOD021).*


MODIS multi-banda, con vettori corrente validati e drifter 03.07.2012 10:40:00
Drifter
20 (3.660-3.840um)
23 (4.020-4.080um)
29 (8.400-8.700um)
31 (10.780-11.280um)
32 (11.770-12.270um)
Latitude (°)
Longitude (°)
43.35
43.3
43.25
43.2
43.15
43.1
43.05
43
42.95
42.9
42.85
9.75
9.8
9.85
9.9
9.95
10
10.05
10.1
10.15
10.2
10.25
1.5
1
0.5
0
-0.5
-1
43.0°

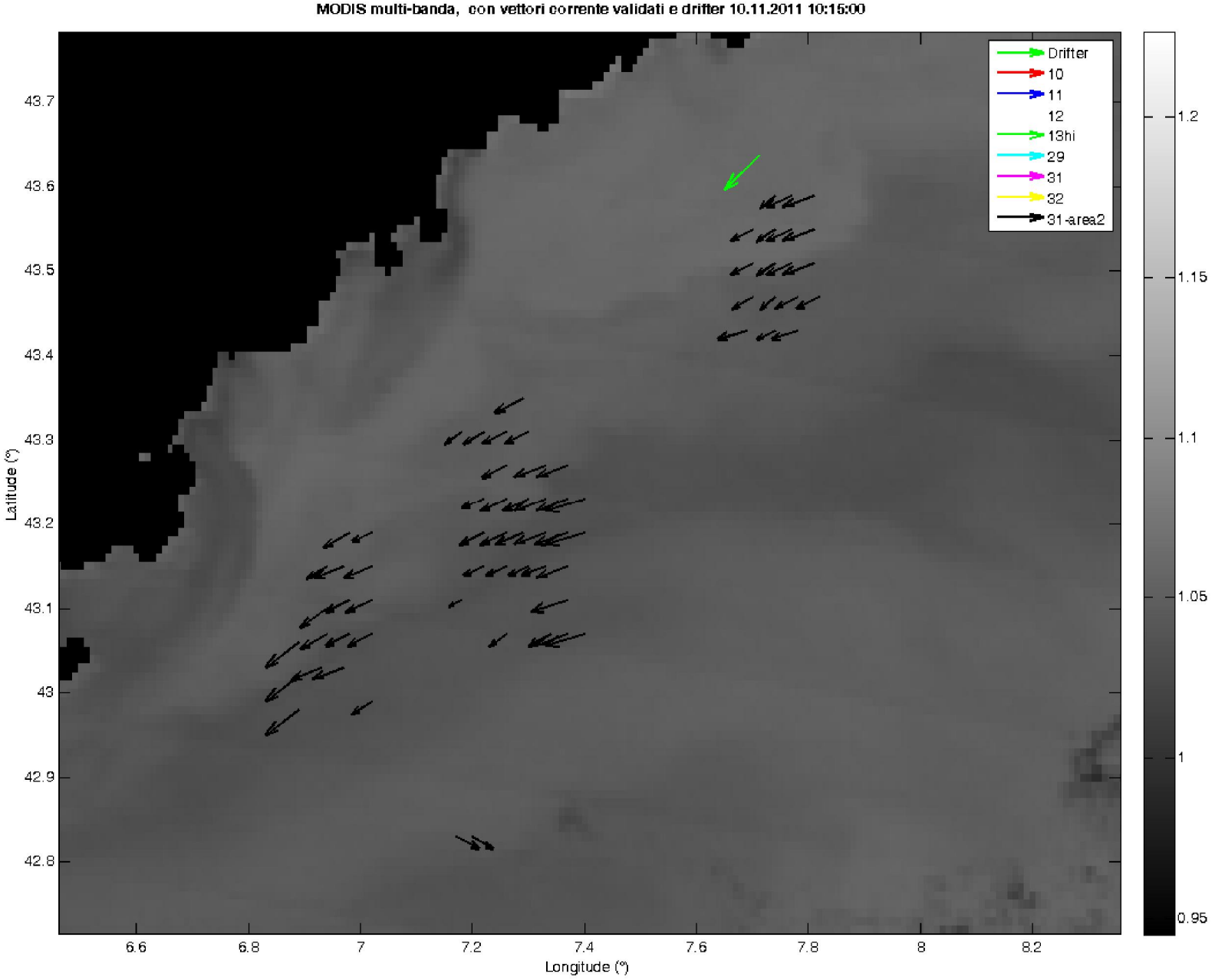

MODIS multi-banda, con vettori corrente validati e drifter 10.11.2011 10:15:00
Drifter
10
11
12
13hi
29
31
32
31-area2
Latitude (°)
43
42.8
42.6
42.4
42.2
42
Longitude (°)
9.5
10
10.5
11
11.5
12
1.2
1.15
1.1
1.05
1
0.95

ANALYSIS

MODIS-T-band-5 con vettori corrente validati e drifter 10.11.2011 10:15:00




ANALYSIS


MODIS multi-banda, con vettori corrente validati e drifter 10.11.2011 10:15:00
Drifter
10
11
12
13hi
29
31
32
31-area2
Latitude (°)
Longitude (°)
43.7
43.6
43.5
43.4
43.3
43.2
43.1
43
42.9
42.8
6.6
6.8
7
7.2
7.4
7.6
7.8
8
8.2
1.2
1.15
1.1
1.05
1
0.95

ANALYSIS

# Thank you!