Mediterranean subsurface circulation estimated from Argo data

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Outline

Determination of the float surface displacements :

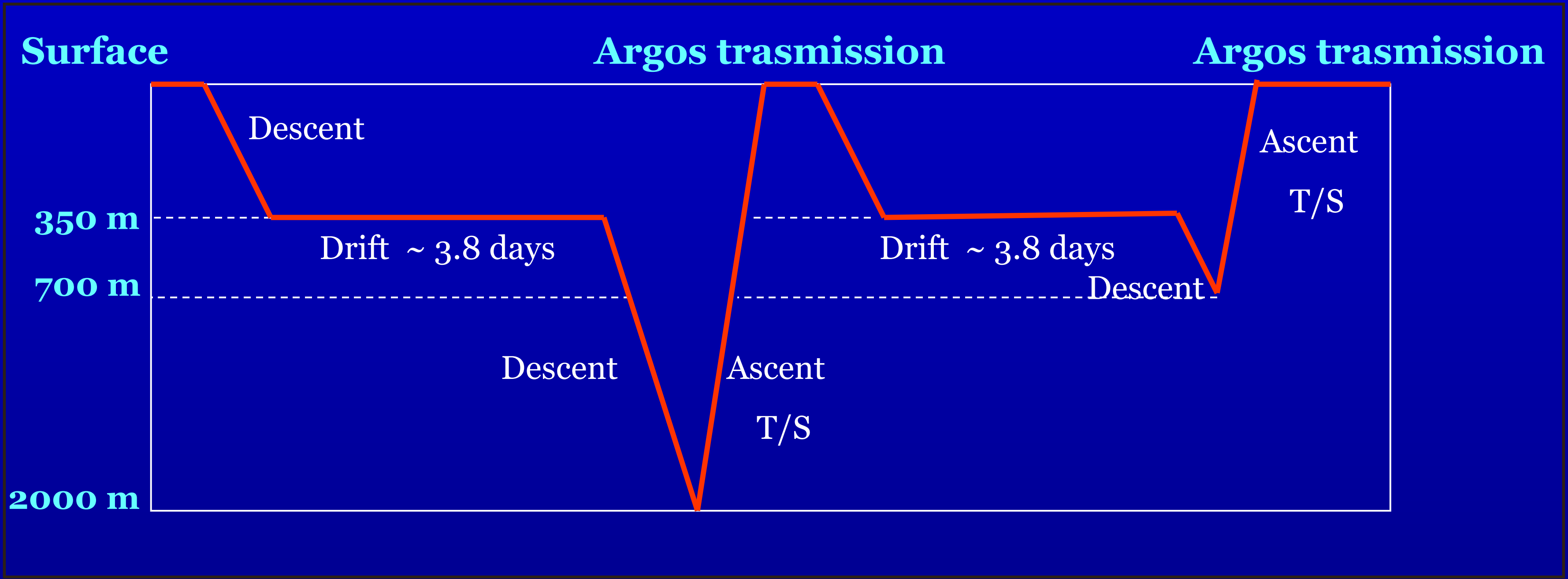
- Extrapolation of the diving *(X^{DS},Y^{DS})* and surfacing *(X^{AE},Y^{AE})* positions using estimated diving *(DS – Descent Start Time)* and surfacing *(AE – Ascent End Time)* times and a linear&inertial displacement model.

Determination of the float sub-surface displacements :

- Calculation of the extreme positions of the sub-surface drift using estimated arrival *(DE – Descent End Time)* and departure *(DPS – Desent to Profile Start Time)* times at parking depth, and a vertical current shear;
- Estimation of the sub-surface currents.

Computation of pseudo-Eulerian statistics of Mediterranean sub-surface circulation near 350 m depth.

MedArgo profilers : “Park and Profile” configuration



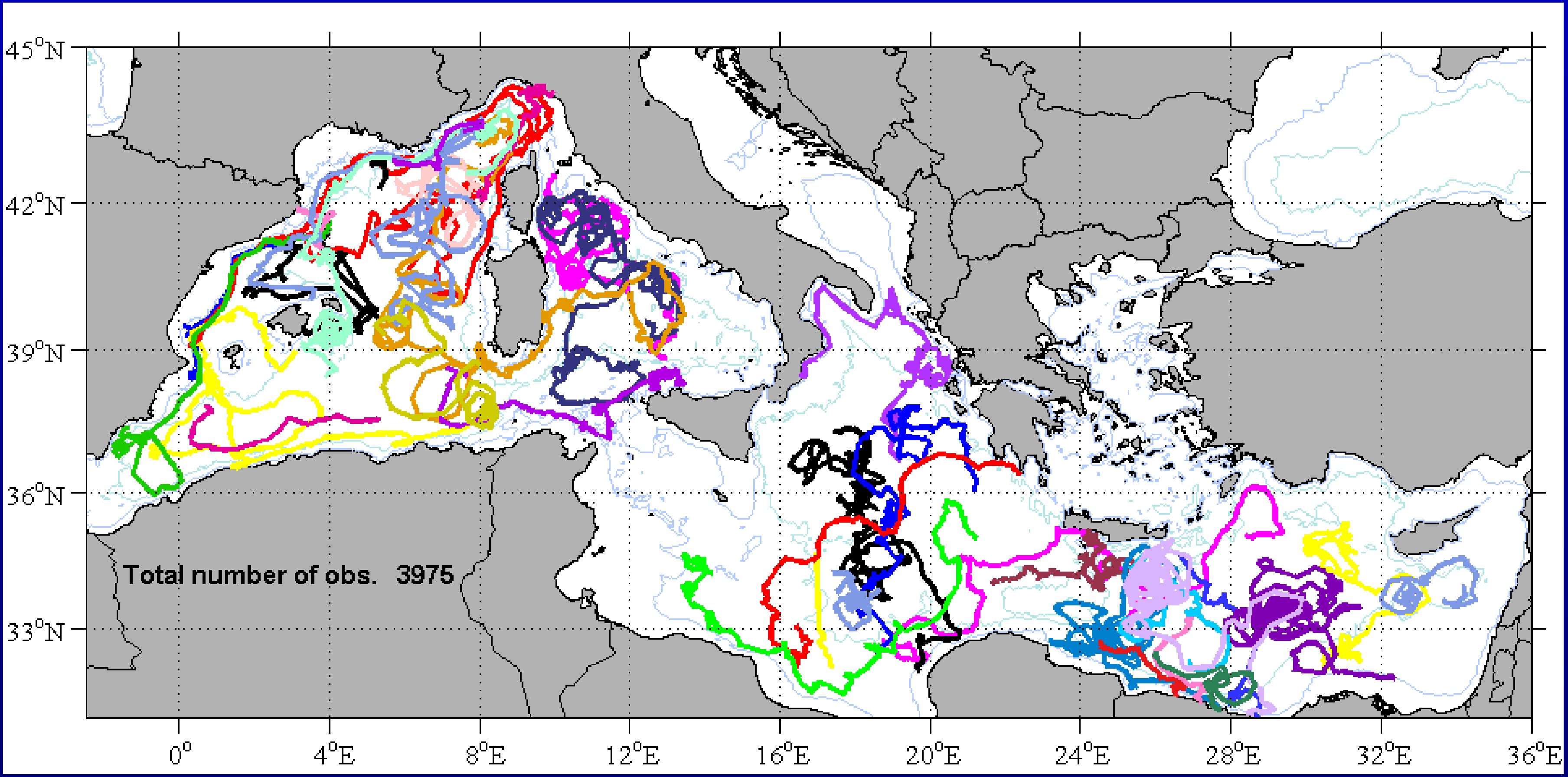
Trajectory files contain information on three dimensional movement of the float:

- set of coordinates of the float during its trasmissions from the sea surface to satellite;
- pressure recorded during the parked phase of the cycle;

It is possible to use the float subsurface displacements to measure the circulation parking depth

MedArgo surface trajectories

From October 2003 to April 2009

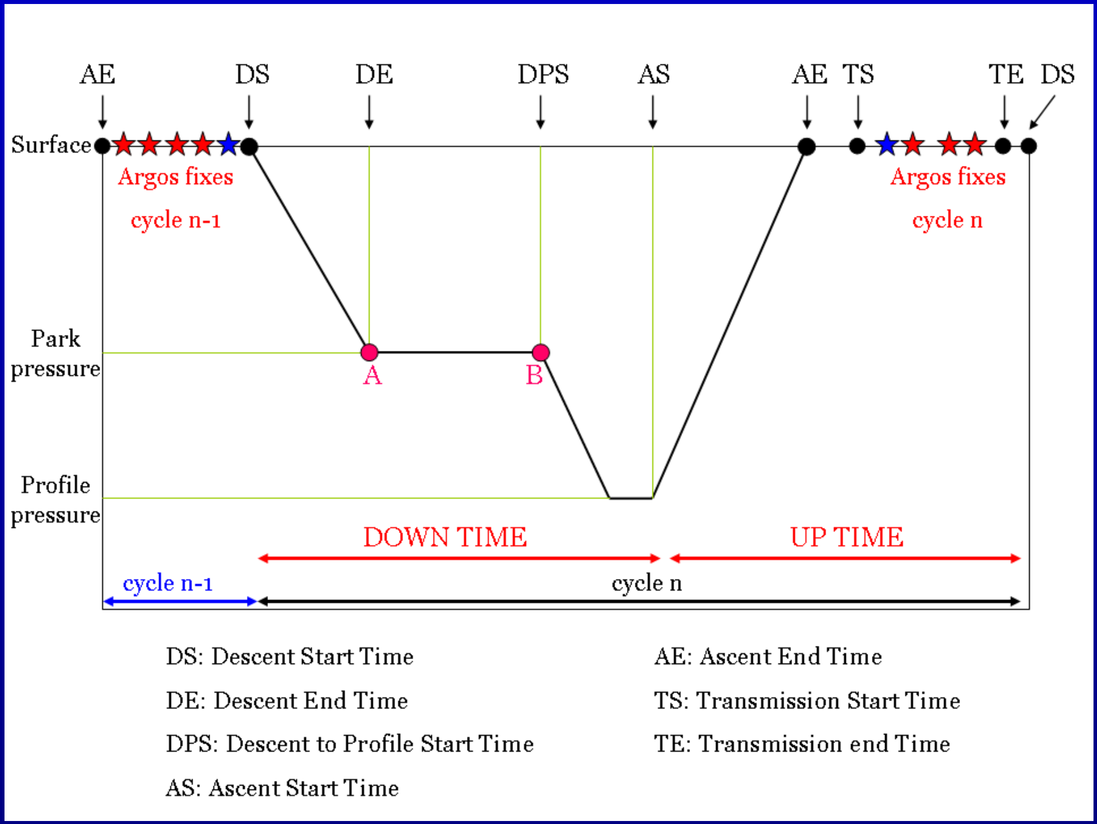


15 Apex

22 Provor

3975 cycles

Tecnical characteristics of Apex and Provor floats

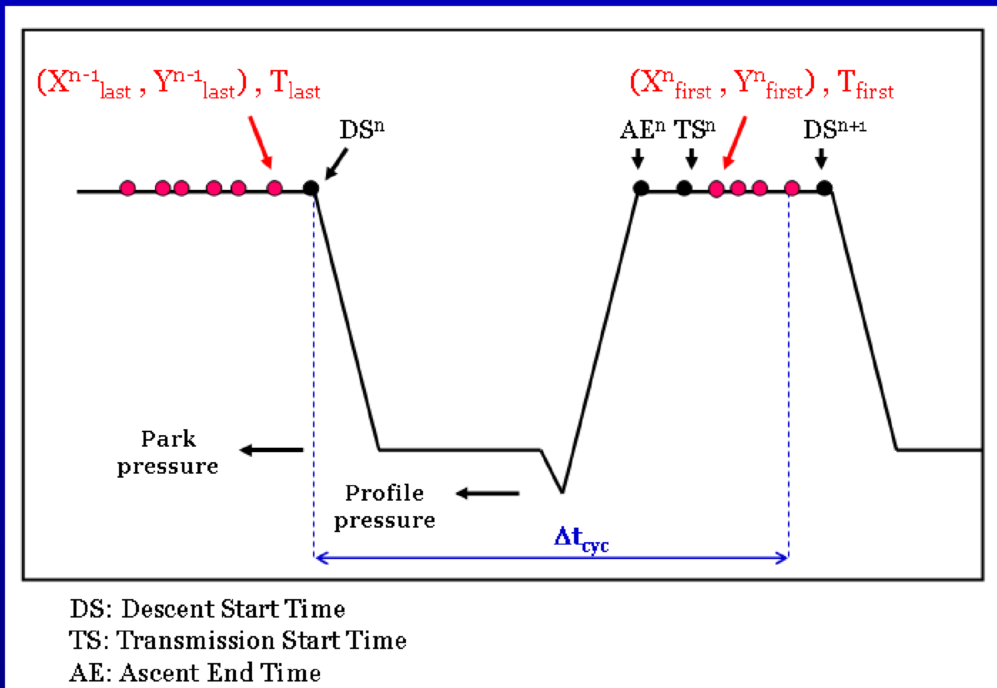


- First approximation: evaluate sub-surface position using the last position of the cycle n-1 and the first position of the cycle n (blue stars) (Lebedev et al.,2007);
- Second approximation: evaluate the best surface displacement through the estimation of diving (DS) and surfacing (AE) times and positions (Park & Kim, 2004);
- Third approximation: evaluate the best sub-surface displacement through the estimation of arrive (DE) and departure (DPS) times and positions at parking depth;

- Provor data contain the times AE, DS, DE, DPS, AS and TS
- Apex data contain only TS times, for this reason the evaluation of DS and AE times become necessary

Estimation of surfacing (AE) time - Apex

The surface arrival time (AE) can be determined from data in the Argos messages;



Determination of the start time of Argos transmission (TS):

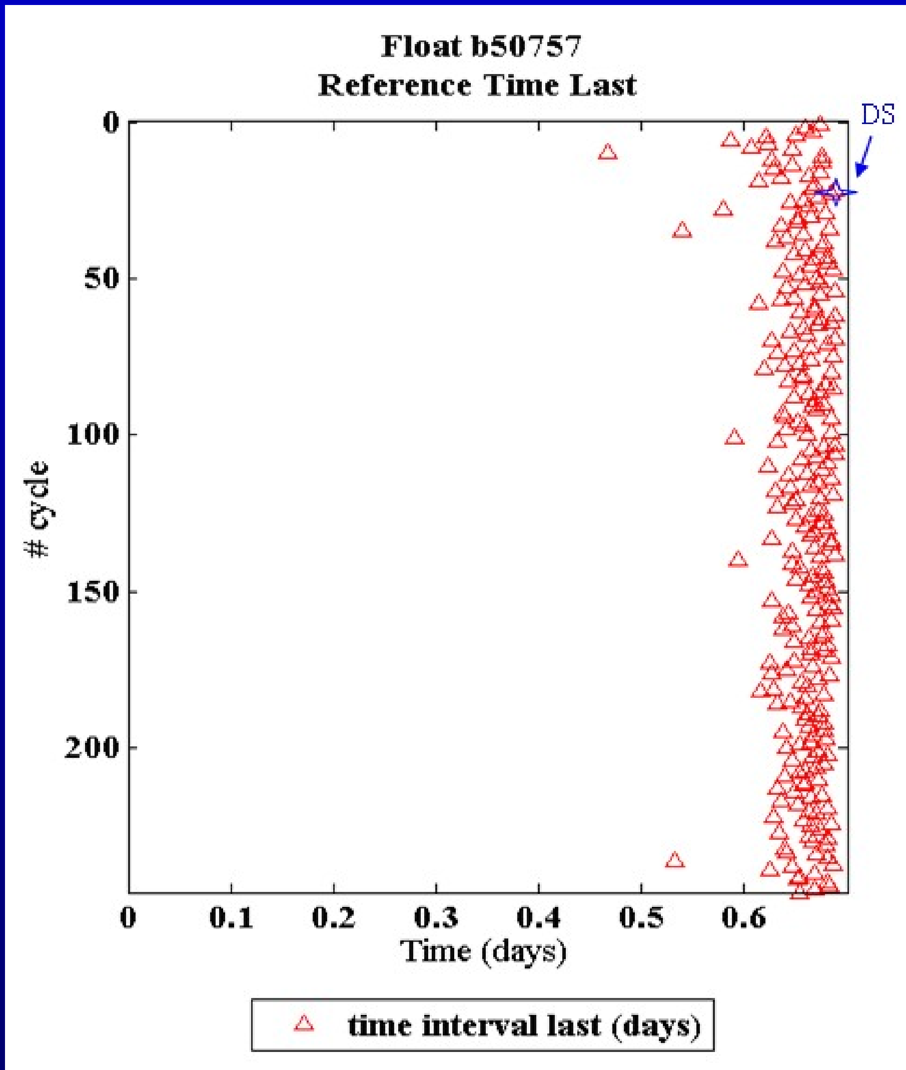
- the message #1 of an Apex transmission contain a counter of the number of measurements made during the CTD profile (number of triplet T,S,P);
- from the number of measurements is possible trace the number of messages (M) needed for trasmit all the profile;
- Apex repetition time (R) is 30 seconds;
- the N-th copy of message #1 is received at the time T;

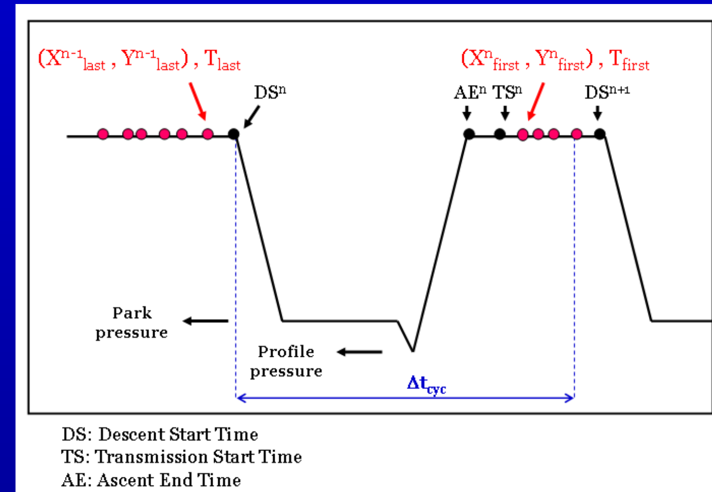
The time interval between TS and AE is 10 minutes:

AE = TS – 10 minutes

TS = T-(R*M)(N-1)

Estimation of diving (DS) time - Apex





- Consider the set of the last trasmission time (T^{n}_{last}) for each cycle;
- Consider the exact period of operation (Δt_{cyc}) ;

n = cycle number

Extrapolation of diving (X_{DS}, Y_{DS}) and surfacing (X_{AF}, Y_{AF}) positions

We assume that an Argo float surface displacement can be represented as:

Linear velocity + Inertial current + noise

Δ = t -t , (k=0,.....N-1)

$$J = \sum_{k}^{N} \frac{(x_{ex} - x_{obs})^2 + (y_{ex} - y_{obs})^2}{2\sigma_k^2} \qquad \frac{\partial J}{\partial (u_l, v_l, x_0, y_0, x_i, y_i)} = 0$$

Where :

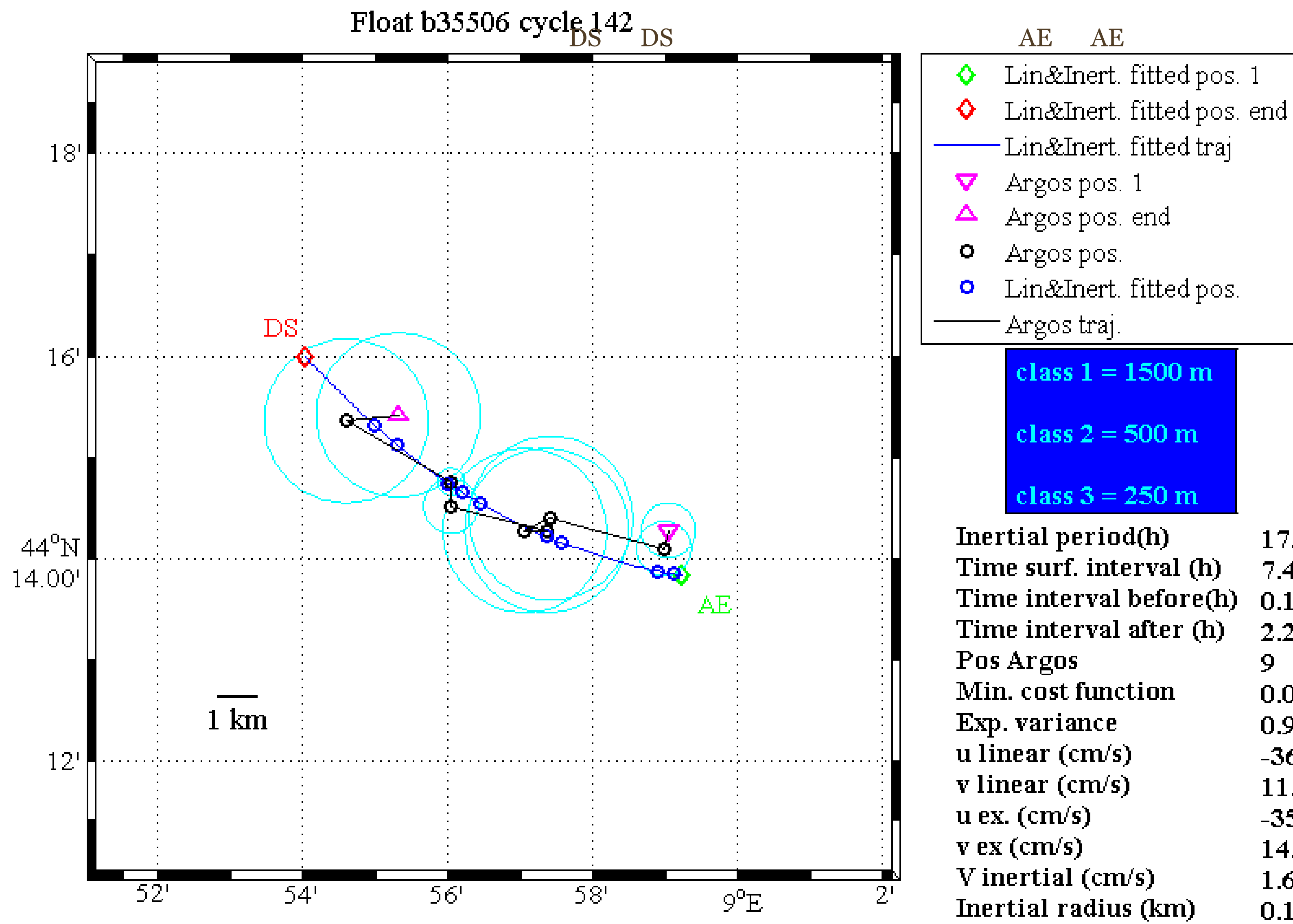
(x_{ex}, y_{ex}) extrapolated positions

(x_o, y_o) reference positions

(x_{ex}, y_{ex}) extrapolated positions

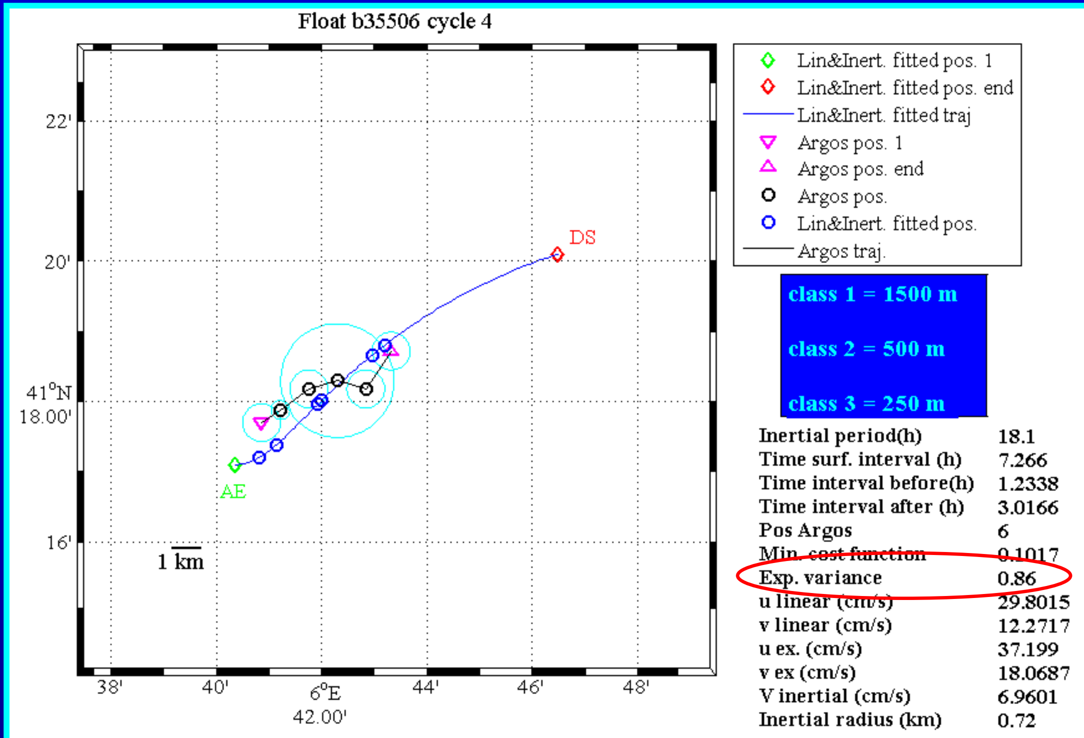
(x_{obs}, y_{obs}) observed positions

Extrapolation of diving (X_{DS}, Y_{DS}) and surfacing (X_{AE}, Y_{AE}) positions

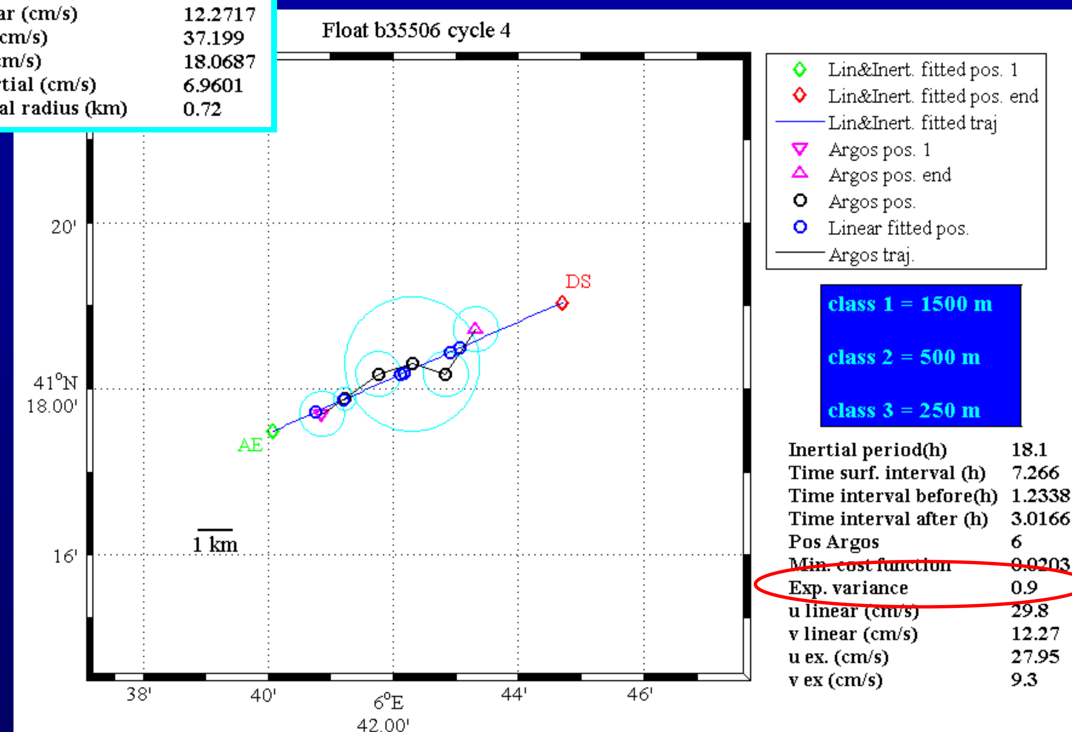


Inertial period(h)	17.2
Time surf. interval (h)	7.4662
Time interval before(h)	0.13392
Time interval after (h)	2.2159
Pos Argos	9
Min. cost function	0.03041
Exp. variance	0.97
u linear (cm/s)	-36.4747
v linear (cm/s)	11.0426
u ex. (cm/s)	-35.2528
v ex (cm/s)	14.4443
V inertial (cm/s)	1.6929
Inertial radius (km)	0.17

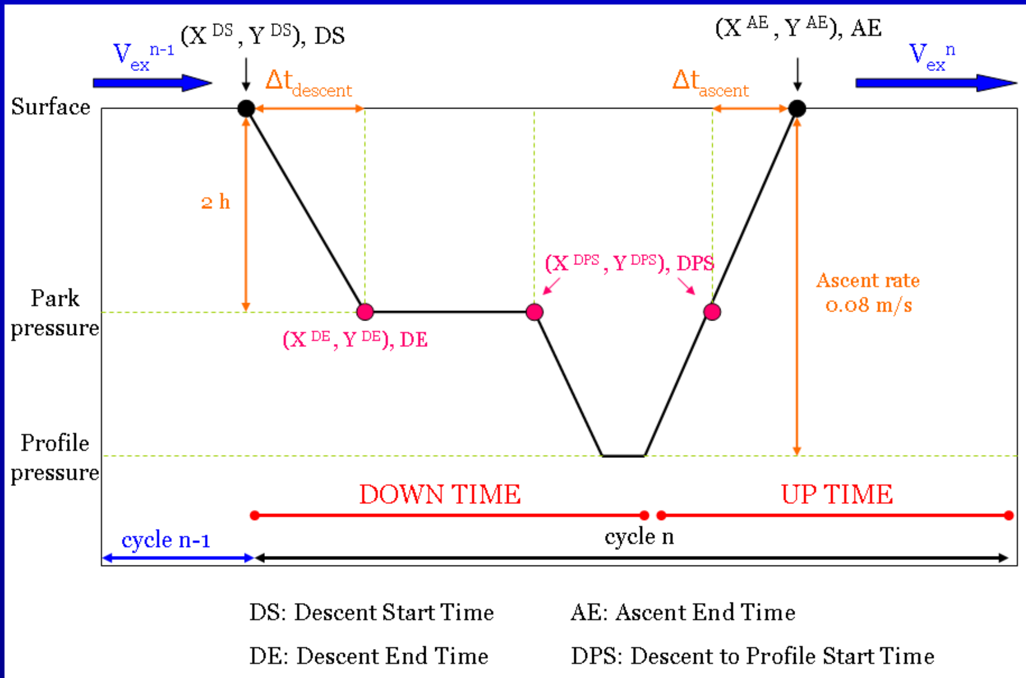
Comparison between *linear&inertial* and *linear* models



The Explained Variance or skill for the simple linear model (0.9) is higher then the combined linear&inertial model (0.86).



Evaluation of arrival times and positions at parking depth: *(X ,Y),DE*



Apex float

DE DE

From statistics results of Poulain et al. (2006):

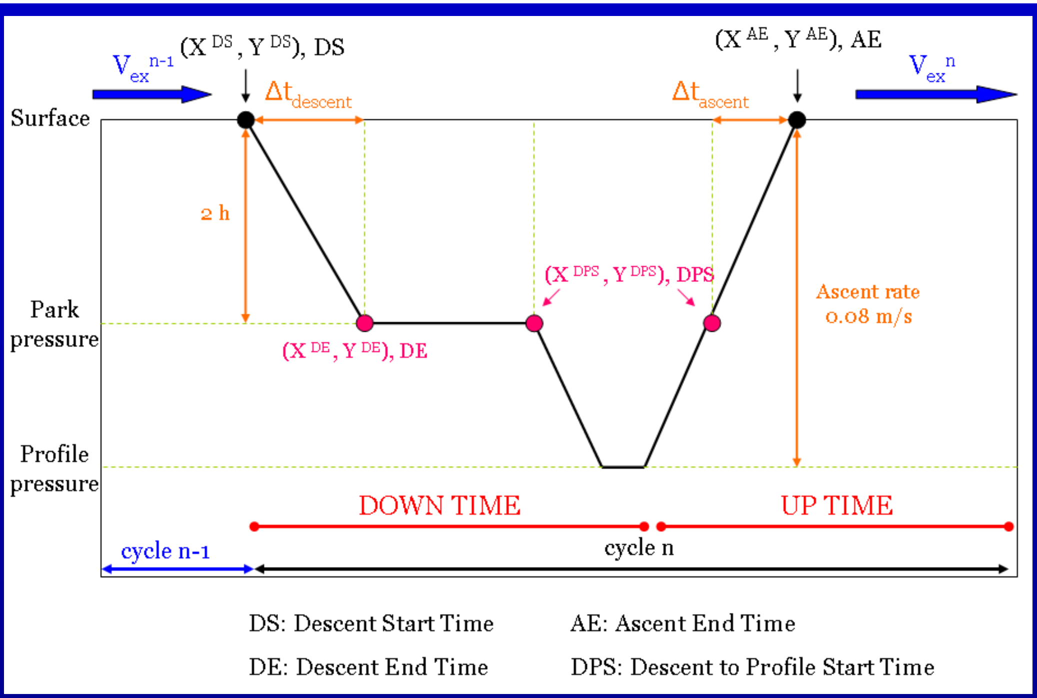
Δt = 2 h;

X = X + ΔX

$$\Delta X^{z}_{descent} = \Delta t_{descent} \frac{u^{n-1}_{ex}}{2}$$

$$\Delta Y^{z}_{descent} = \Delta t_{descent} \frac{v^{n-1}_{ex}}{2}$$

Evaluation of departure times and positions at parking depth : (X^{DPS}, Y^{DPS}), DPS



Ascent Average Speed (AAS):

Apex → 0.08 m/s

Provor CTS2 → 0.09 m/s

Provor CTS3 → 0.01 m/s

$\Delta t_{ascent} = 350m / AAS$

$$\Delta X^{z}_{ascent} = \Delta t_{ascent} \frac{u^{n}_{ex}}{2}$$

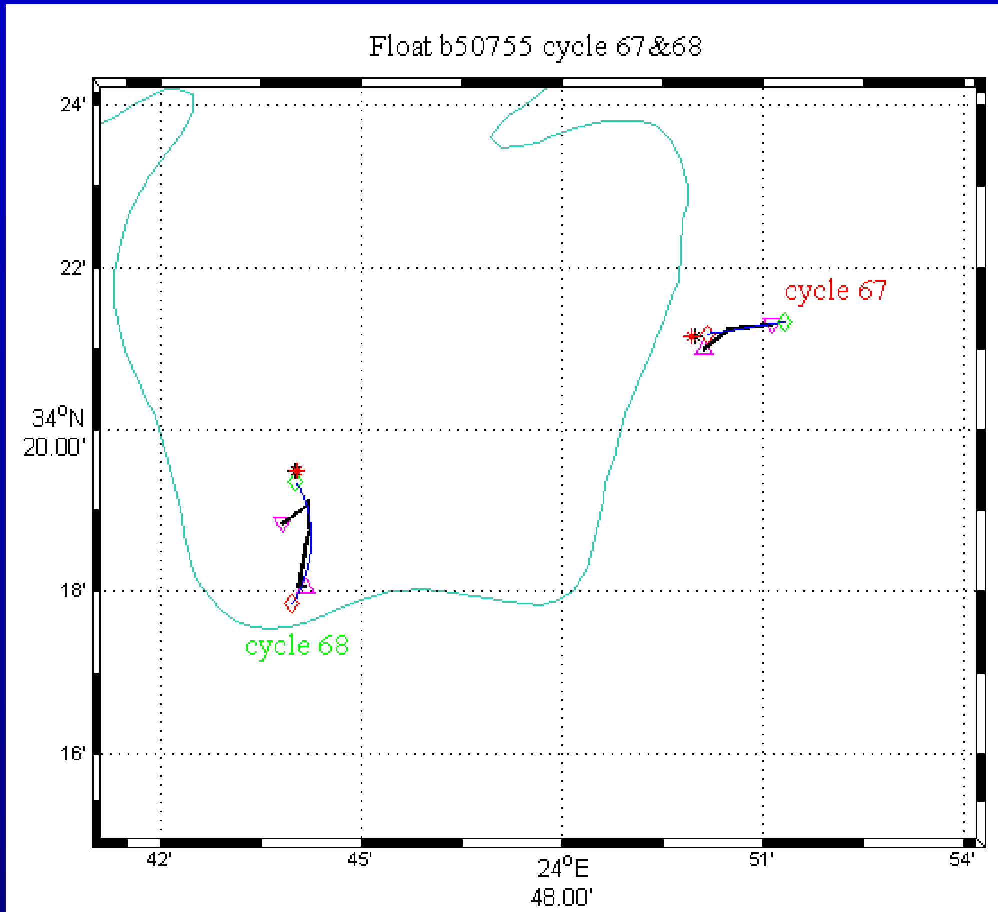
$$\Delta Y^{z}_{ascent} = \Delta t_{ascent} \frac{v^{n}_{ex}}{2}$$

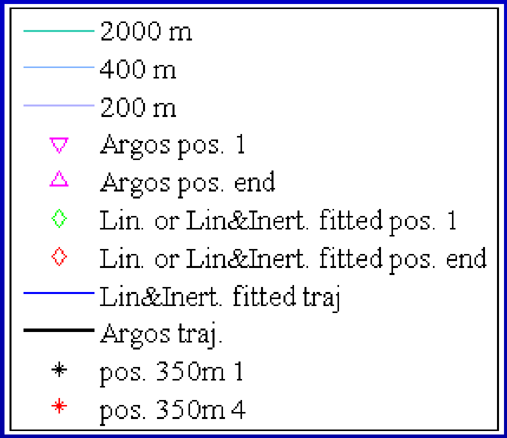
$$X^{DPS} = X^{AE} + \Delta X^{z}_{ascent}$$

$$Y^{DPS} = Y^{AE} + \Delta Y^{z}_{ascent}$$

- Use of times *DE-DPS* and positions $(X^{DE}, Y^{DE}) - (X^{DPS}, Y^{DPS})$ to evaluate velocity at 350m $(\vec{V}_{350})$;

Evaluation of times and positions at parking depth : Apex





ul cyc 67 (cm/s)	-11.8551
vl cyc 67 (cm/s)	-3.1644
ul cyc 68 (cm/s)	3.5872
vl cyc 68 (cm/s)	-7.0585
ul ex. cyc 67 (cm/s)	-9.658
vl ex. cyc 67 (cm/s)	-1.15
ul ex. cyc 68 (cm/s)	-0.31507
vl ex. cyc 68 (cm/s)	-11.0609
V350m 1	2.9466
V350m 2	2.903
V350m 3	2.9036
V350m 4	2.9036
V350m 0	3.0112
dtaf (h)	2
dtbe (h)	1.2153

(u ,v) components of surface average velocity;

(u ,v) components of extrapolated surface average velocity;

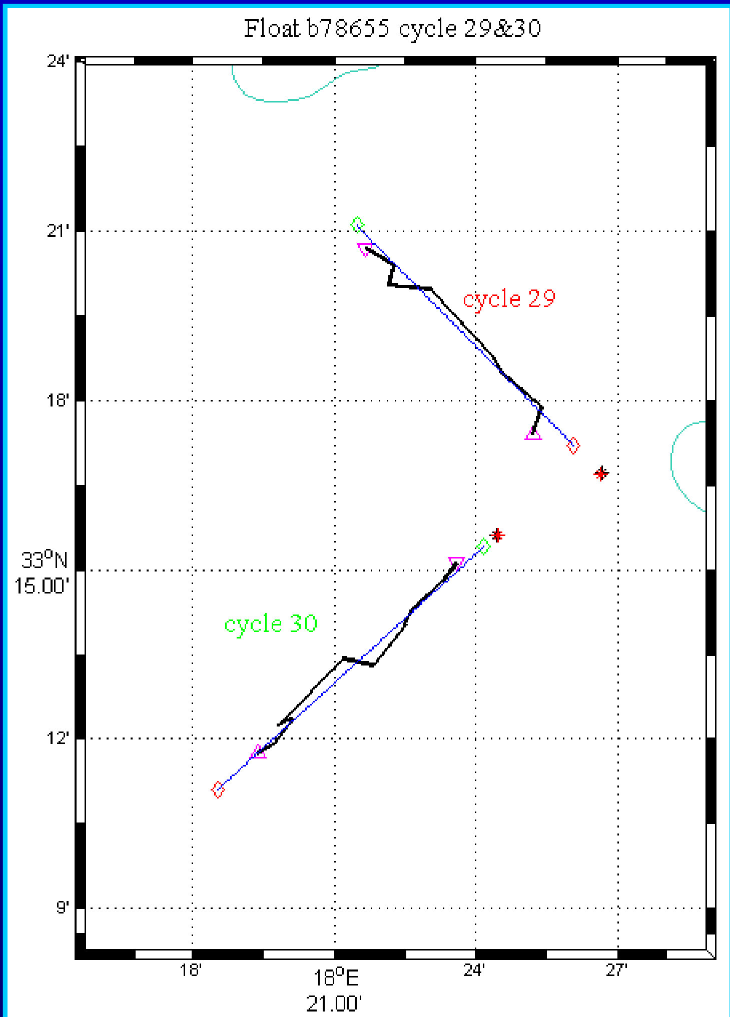
V (1,2,3,4) speed at parking depth in four subsequent reiterations;

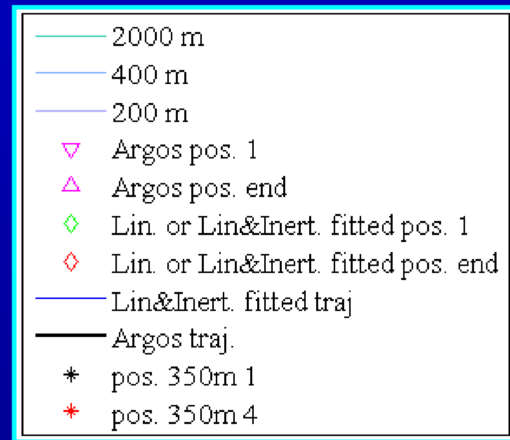
V 0 first approximations of speed at parking depth;

Dtaf descent time to parking depth;

Dtbe ascent time from parking depth.

Evaluation of times and positions at parking depth : Provor CTS3





ul cyc 46 (cm/s)	-13.8448
vl cyc 46 (cm/s)	-20.3475
ul cyc 47 (cm/s)	-28.3984
vl cyc 47 (cm/s)	-7.2182
ul ex. cyc 46 (cm/s)	-8.7715
vl ex. cyc 46 (cm/s)	-19.935
ul ex. cyc 47 (cm/s)	-30.0559
vl ex. cyc 47 (cm/s)	-6.7817
V350m 1	9.5019
V350m 2	9.3106
V350m 3	9.3145
V350m 4	9.3144
V350m 0	8.2503
dtaf (h)	2.5008
dtbe (h)	1.0802

(u ,v) components of surface average velocity;

(u ,v) components of extrapolated surface average velocity;

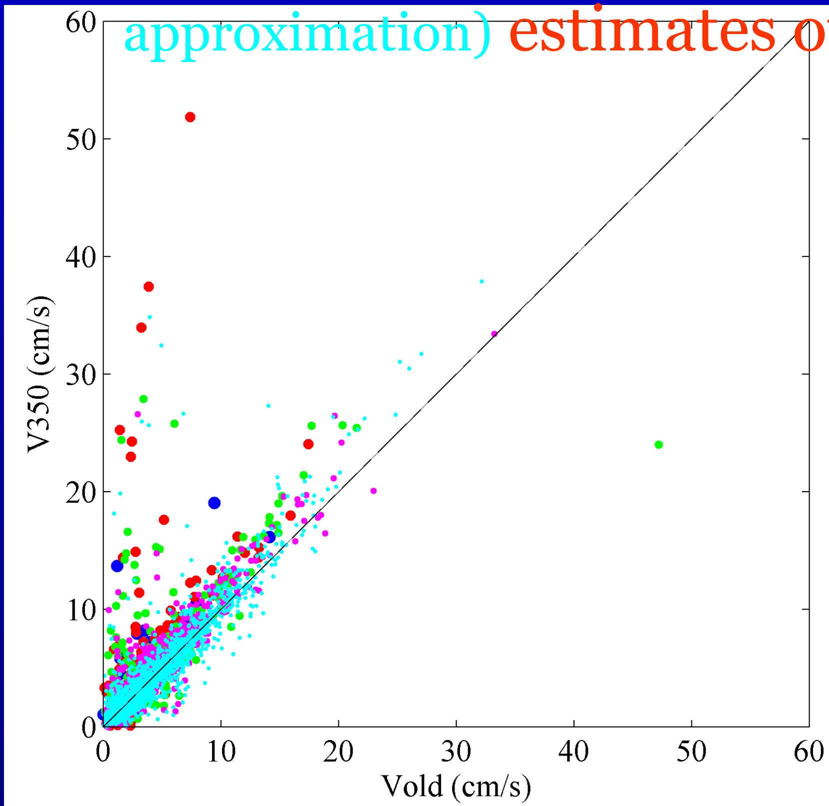
V (1,2,3,4) speed at parking depth in four subsequent reiterations;

V 0 first approximations of speed at parking depth;

Dtaf descent time to parking depth;

Dtbe ascent time from parking depth.

Comparison between rough (1th approximation) and fine (3th approximation) estimates of subsurface current near 350 m



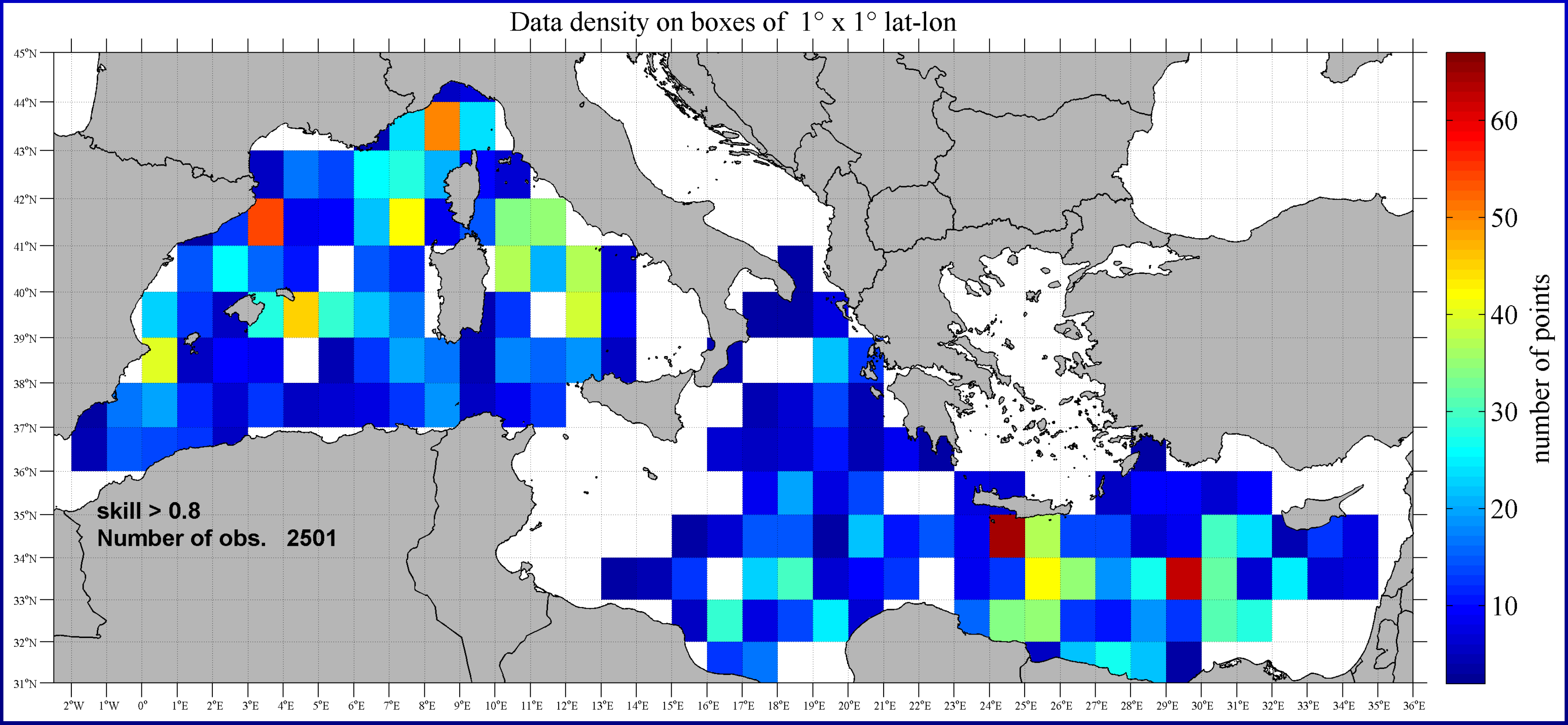
- Skill < 0.6 — N_{obs} = 63
- 0.6 ≤ Skill ≤ 0.7 — N_{obs} = 179
- 0.7 < Skill ≤ 0.8 — N_{obs} = 368
- 0.8 < Skill ≤ 0.9 — N_{obs} = 842
- Skill ≥ 0.9 — N_{obs} = 1449

For skills > 0.8 :

- Mean Difference is negligible
- Standard Deviation is < 6.1 cm/s
- Correlation Coefficient is ~ 0.85

Explain Varince	Number of observations	mean(V_{350}-V_{old}) (cm/s)	Standard Deviation (cm/s)	Correlation Coefficent
Skill ≥ 0.6	2838	0.67	6.50	0.74
Skill ≥ 0.7	2745	0.60	6.30	0.79
Skill ≥ 0.8	2505	0.49	6.09	0.85
Skill ≥ 0.9	1965	0.39	6.27	0.85

Pseudo - Eulerian statistics at 350 m



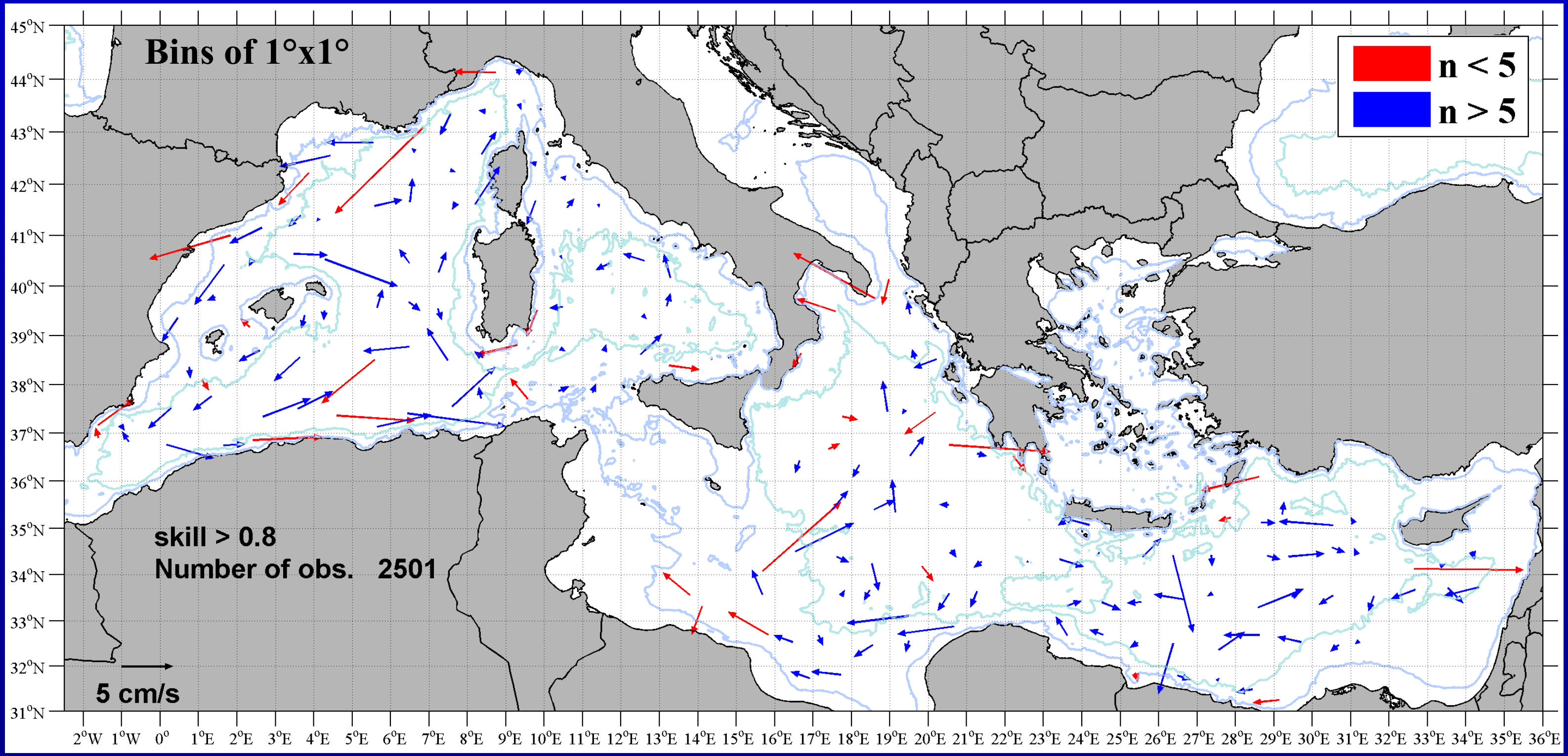
The bins with high number (> 30) of observations are localised :

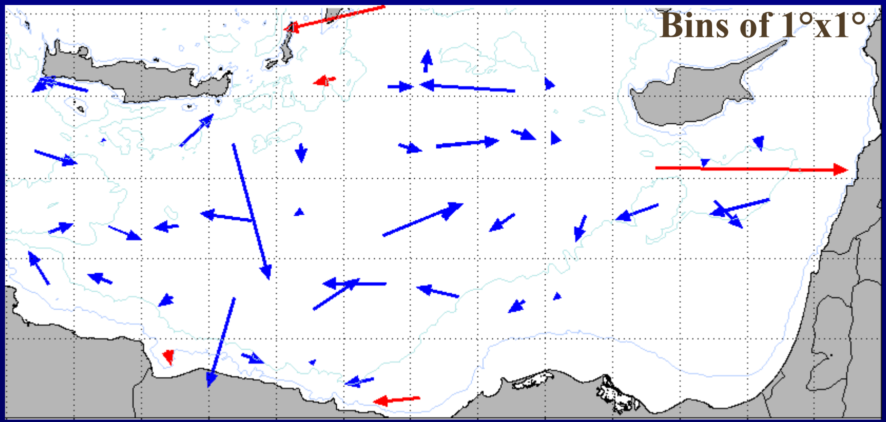
- in the western region: Tyrrhenian Sea and Liguro – Provençal Basin;

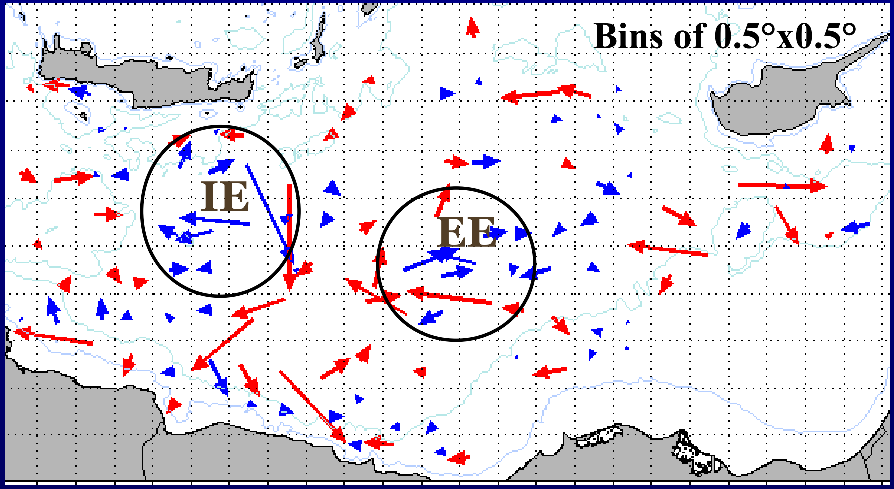
- in the eastern region: Levantine Basin.

Pseudo - Eulerian statistics of sub-surface circulation at 350 m

Mean flow: October 2003 - April 2009

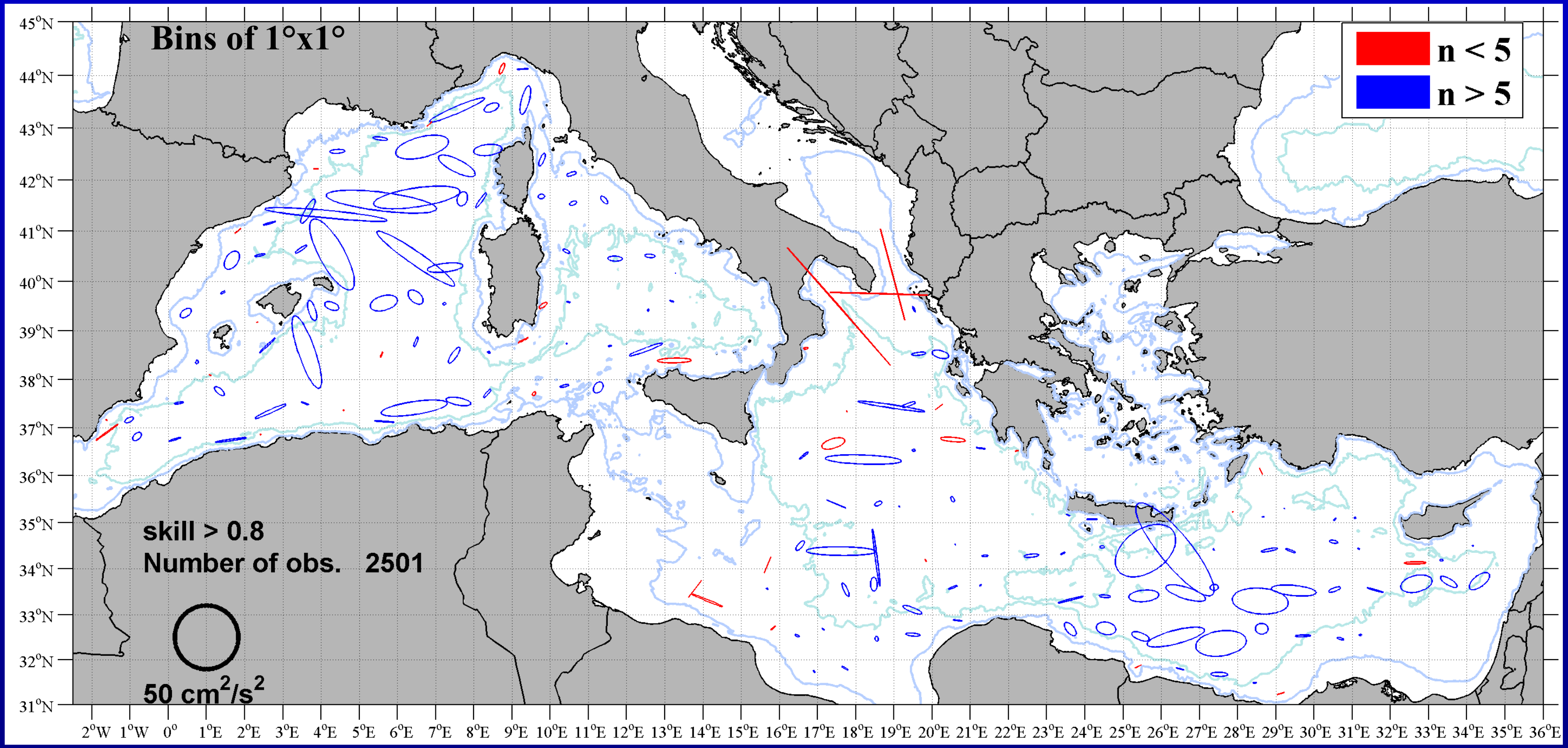


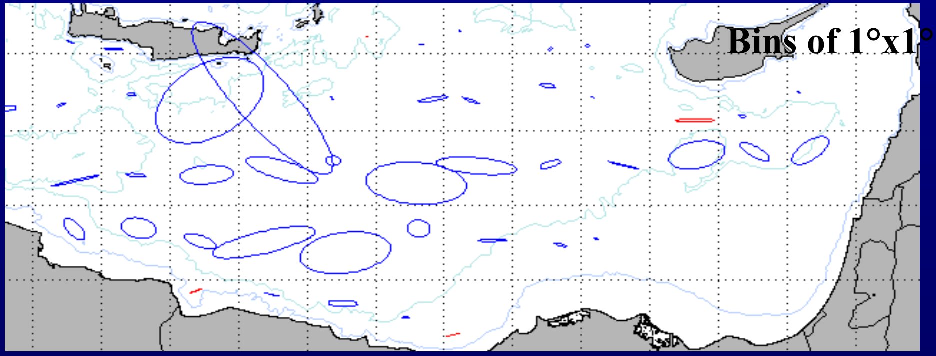


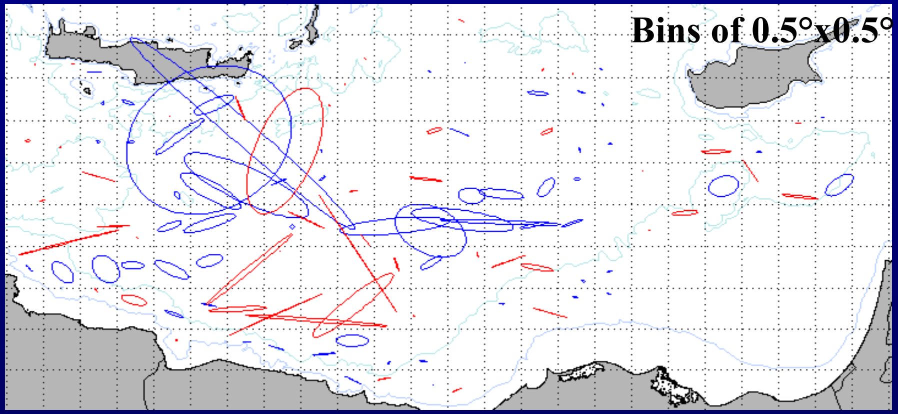


Pseudo - Eulerian statistics at 350 m

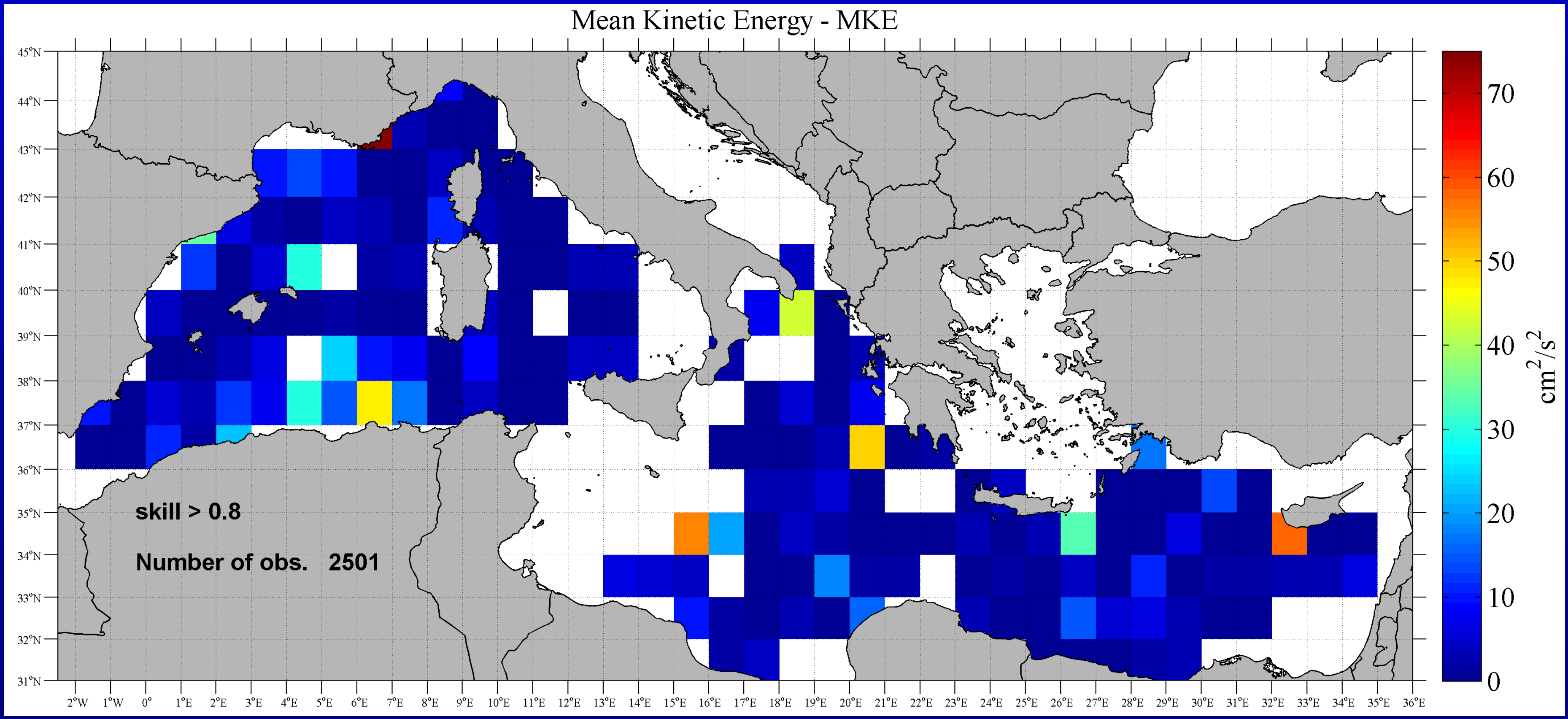
Velocity Variance: October 2003 - April 2009





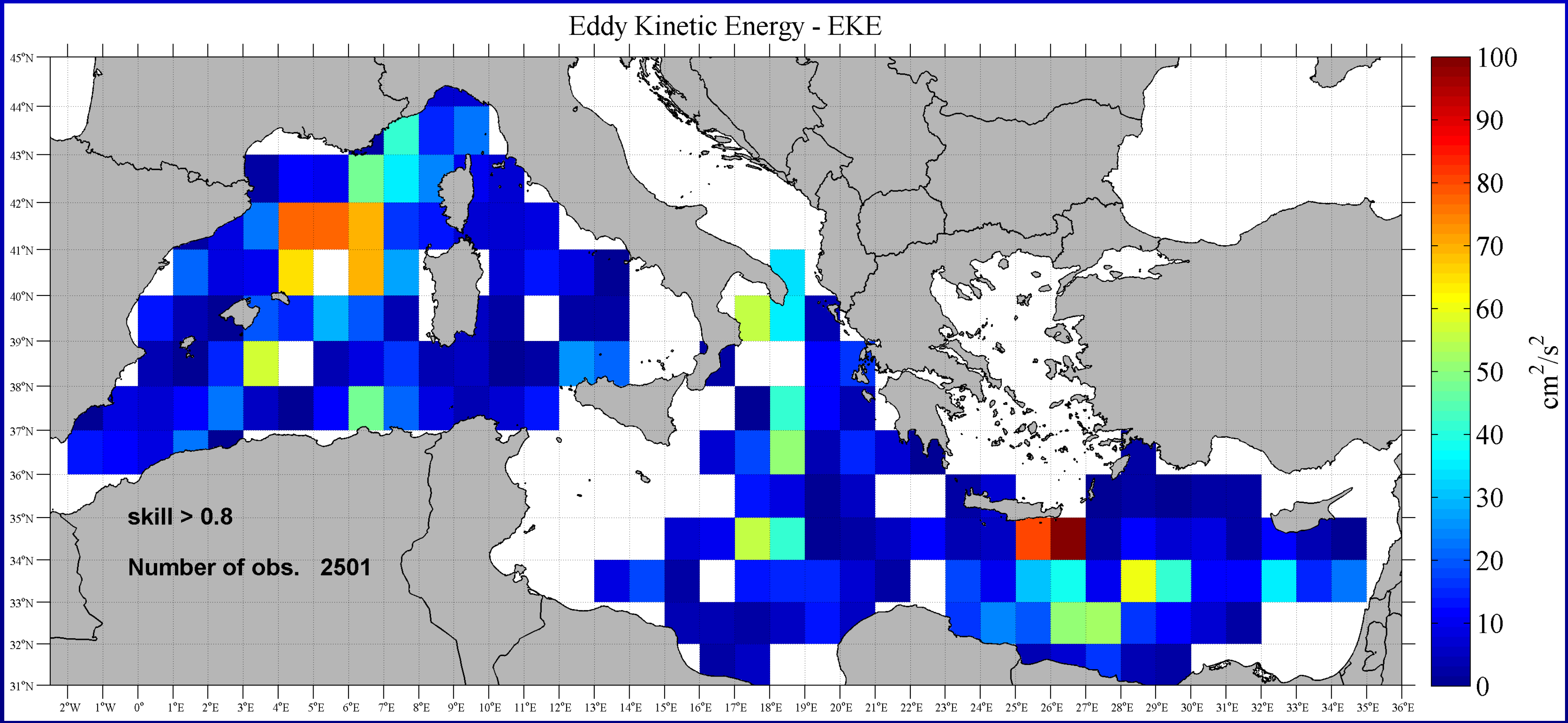


Pseudo - Eulerian statistics: Mean Kinetic Energy



- The MKE is maximum in some coastal regions, where the mean current vectors have higher values ;
- The maximum MKE (over 70 cm^2/s^2) is localised in the north-west basin;
- MKE is minimum (less than 10 cm^2/s^2) in most of the open sea.

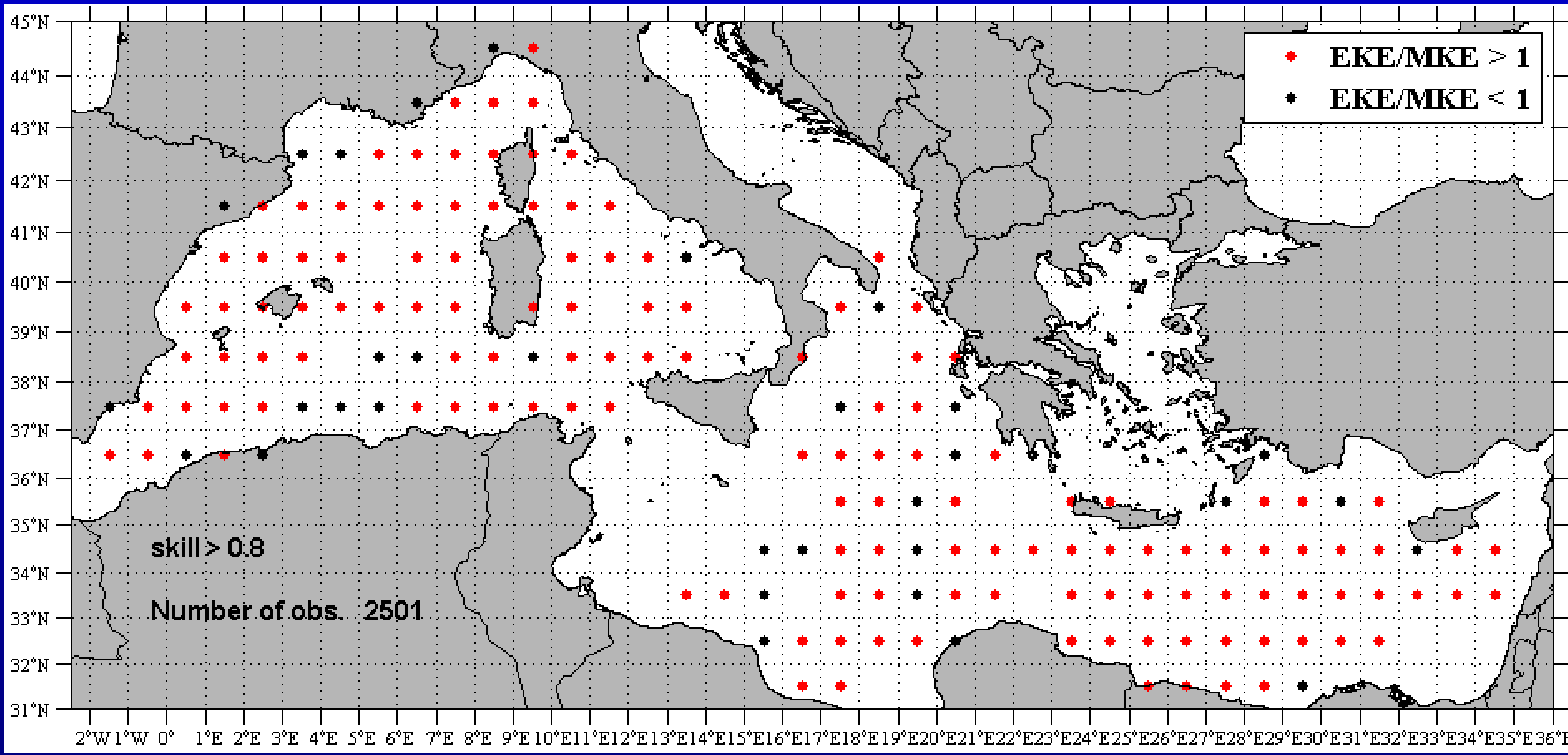
Pseudo - Eulerian statistics: Eddy Kinetic Energy



The EKE has strong gradients compared to MKE; it reaches values as large as about 100 cm^2/s^2 (rms velocity of 10 cm/s):

- in the centre of Levantine Basin, where there are several closed mesoscale and sub-basin scale circuits;
- in the Liguro-Provençal region, where the mean current has maximum values.

Pseudo - Eulerian statistics: ratio of EKE to MKE



For the most part of bins the ratio is major then 1;

The fluctuating velocity dominate the energy of sub-surface currents except in the strong currents;

Conclusion

Data from 37 Argo floats, deployed in the Mediterranean Sea between October 2003 and April 2009, are used to determine the float surface and sub-surface displacements;

The better sub-surface displacement velocity data-set (V_{350}), compared with the first approximation displacement data-set (V_{old}), shows a negligible mean difference, a standard deviation < 6.1 cm/s and a high correlation coefficient (~ 0.9);

The V_{350} data-set is used to investigate the sub-surface Mediterranean circulation.

In the best sampled regions, the Pseudo-Eulerian statistics show typical circulation pathways related to the LIW:

- in the Western region, the velocity field follows the Liguro-Provençal-Catalan and the Algerian currents; this area is characterised by high values of EKE and by principal axes of variance oriented in the direction of mean currents;

- in the Eastern region the mesoscale and sub-basin scale circulation is dominated by eddies (diameters of 100-150 km); the maximum value of EKE and variance is located south of Crete (Ierapetra eddy).