ANDRO: An Argo-based deep displacement atlas

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Argo float displacements

Since 2000, data from ~ 6000 Argo floats have been collected, worldwide, generating ~ 400000 profiles in the ocean main thermocline (between 2000m depth and the surface).

With their cycling periods of 10 days (generally), Argo floats subsurface displacements can also be used as a direct and absolute measure of the ocean mesoscale motions, at their drifting depths (1000m mostly).

Estimation of Argo deep displacements

We need reliable estimates of Argo deep displacements.

The simplest estimates use the first Argos fix from the present cycle and the last Argos fix from the previous cycle.
This was done by Lebedev et al. (2007) for their YoMaHa'07 displacement/velocity file.
However, due to errors in the data processing and/or archiving several float cycles have missing or erroneous data, in the NetCDF public files.
YoMaHa'07 preserves some of the erroneous float cycles.
In particular park pressures may be wrong.

We have, over the last three years, almost fully corrected the AOML, Coriolis, JMA and INCOIS DAC data.
This was possible because we had access to the original raw Argos messages received.

ANDRO

We have created a displacement/velocity ASCII file (named ANDRO for Argo New Displacements Rannou Ollitrault) along the same lines and with the same format as YoMaHa'07, but with AOML, Coriolis, JMA and INCOIS DAC corrected data.

An Dro is a traditional celtic dance of Brittany (Vannes county), meaning a round, a turn, a swirl.

We are presently planning (if financial support is available) to extend our procedure to the whole Argo data set, i.e. for all the other DACs, beginning with CSIRO, then BODC, MEDS, KORDI, KMA and CSIO.

AOML, Coriolis, JMA and INCOIS have kindly given us access to their Argos raw data files so that we have been able to do our own decoding. We hope this will also be possible for the other DACs.

All the errors detected and most corrections have been communicated, on a regular basis, to AOML Coriolis and JMA (soon to INCOIS), so that they can progressively update the NetCDF files, if they think it is worth. We shall also proceed similarly with the other DACs.

Example of corrections done in 2007, on the Coriolis data set

- Check and correction of the correspondence between one ARGOS file and one float cycle ~ 6000 new or modified links (10% of total)
- Correction of time shifts for PROVOR, due to false day number determination
- Updating of the 25 different APEX formats.
- Check and correction of the version number for all the APEX floats
- Software updating for the APEX processing (still in progress at Coriolis)
- Check and correction of meta data (mainly REPETITION_RATE, CYCLE_TIME, PARKING_PRESSURE and DEEPEST_PRESSURE) e. g. 68 double missions created over a total of 753.

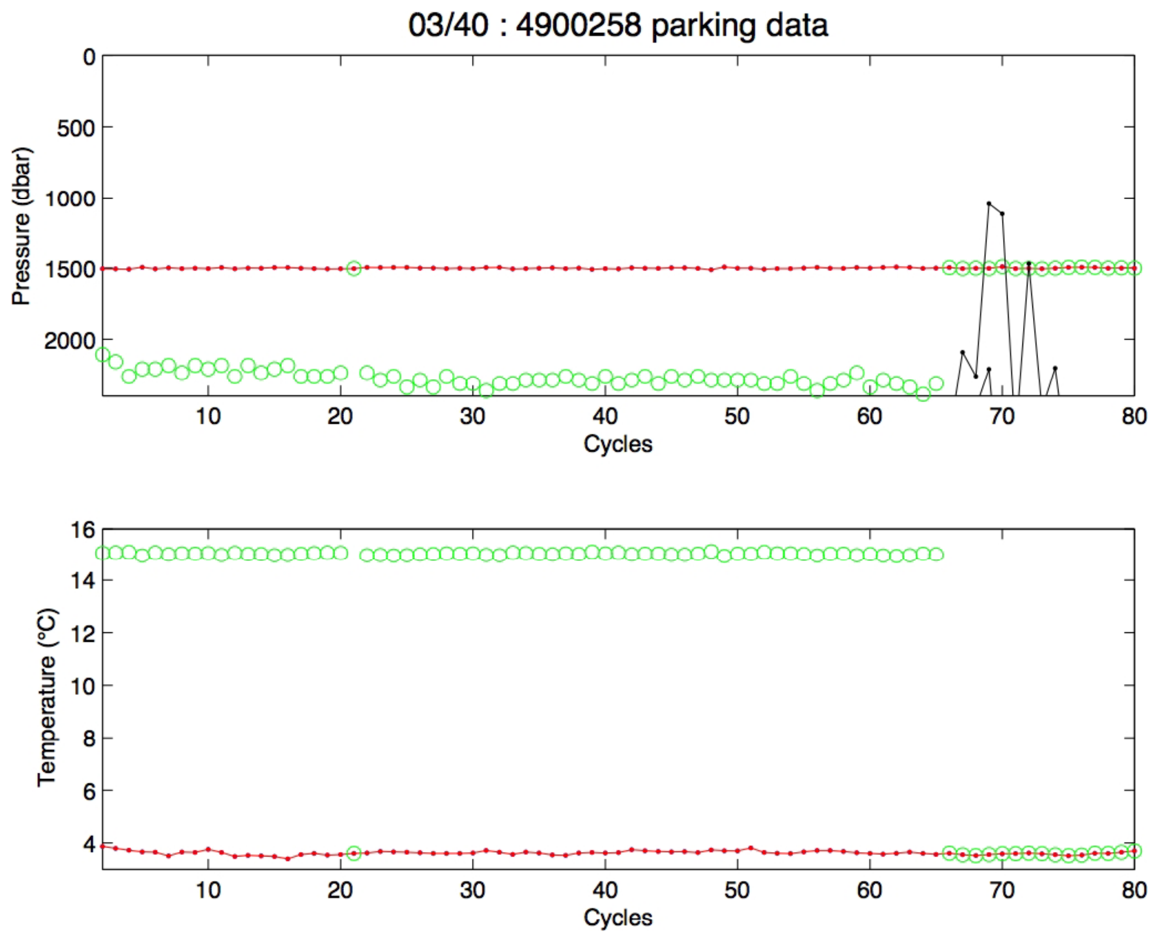
Similar checks were done in 2009 on the AOML and JMA Argos data set and results communicated back to the DACs

Processing done in 2008, 2009 and 2010, to produce our ASCII ANDRO file

- Regeneration of the most complete ARGOS data set from the DAC archived raw data
- Recovering of ARGOS fixes not found in NetCDF files
- PROVOR
  - Recovering of P,T, S measurements at drifting depth from ASCII decoded files
  - Correction of the remaining time shifts
  - A new decoder is now available at LPO
- APEX, SOLO and NINJA
  - Decoding anew of all the ARGOS raw message files
- Parking pressure for each cycle is given as:
  - Mean of P measurements at drifting depth, if they are available,
  - Otherwise, the one Parking pressure measured
  - Or, the Parking Pressure found in the meta file
- Visual validation of the Parking pressure
- Implementation of Nakamura, Ogita & Kobayashi test
- Exclusion of grounded cycles

Example of an erroneous decoding

APEX (type 1.2) in the North-West Atlantic



As found in the NetCDF files before our work

After a new decoding of Argos raw data

ANDRO update

AOML, JMA & Coriolis data until January 1 2009:

- AOML:2823 floats corresponding to ~270000 cycles
  (1428 SOLO, 1377 APEX, 16 ALACE & 2 PROVOR)
- JMA: 811 floats corresponding to ~75000 cycles
  (681 APEX, 93 PROVOR, 18 NINJA, 19 ALACE & misc.)
- Coriolis: 949 floats corresponding to ~ 70000 cycles
  (448 PROVOR, 449 APEX, 50 NEMO, 2 misc.)

These data represent 80% of the world Argo data set.

Presently, ANDRO contains 75% of the world Argo data set

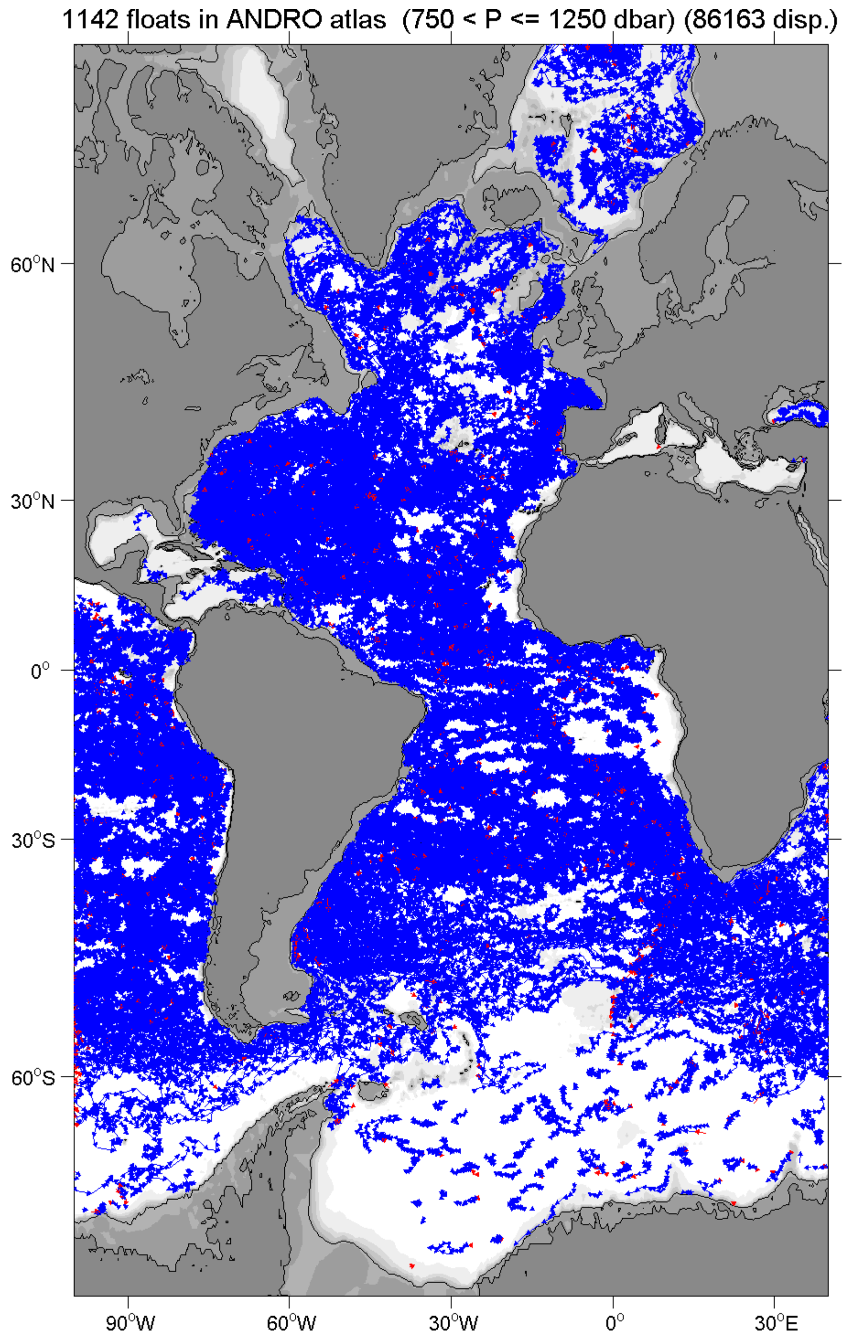
INCOIS data(and AOML and JMA complementary data) will be included in the July 14 (Bastille day) 2010 ANDRO version

Contents of the ANDRO file (January 15 2010)

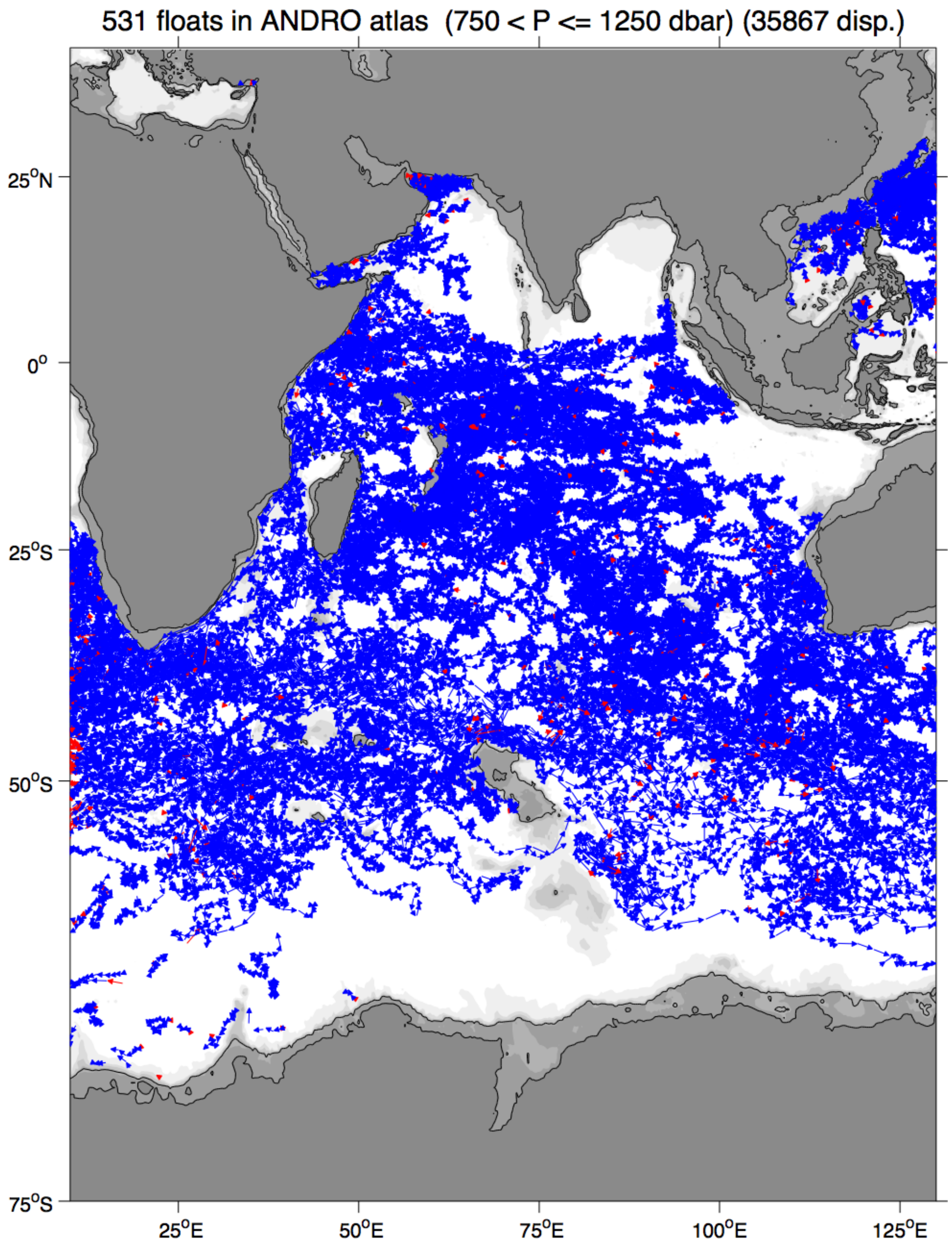
All Coriolis data covering the period July 11 1999 to April 7 2008
AOML data (all SOLO and 75% of APEX floats until December 31 2008)
JMA data (85% of APEX floats until December 31 2008)

- Data span the period July 11 1999 to December 31 2008
- ASCII file, same format as YoMaHa'07 (updated '09)
- 3624 floats, 315820 displacements

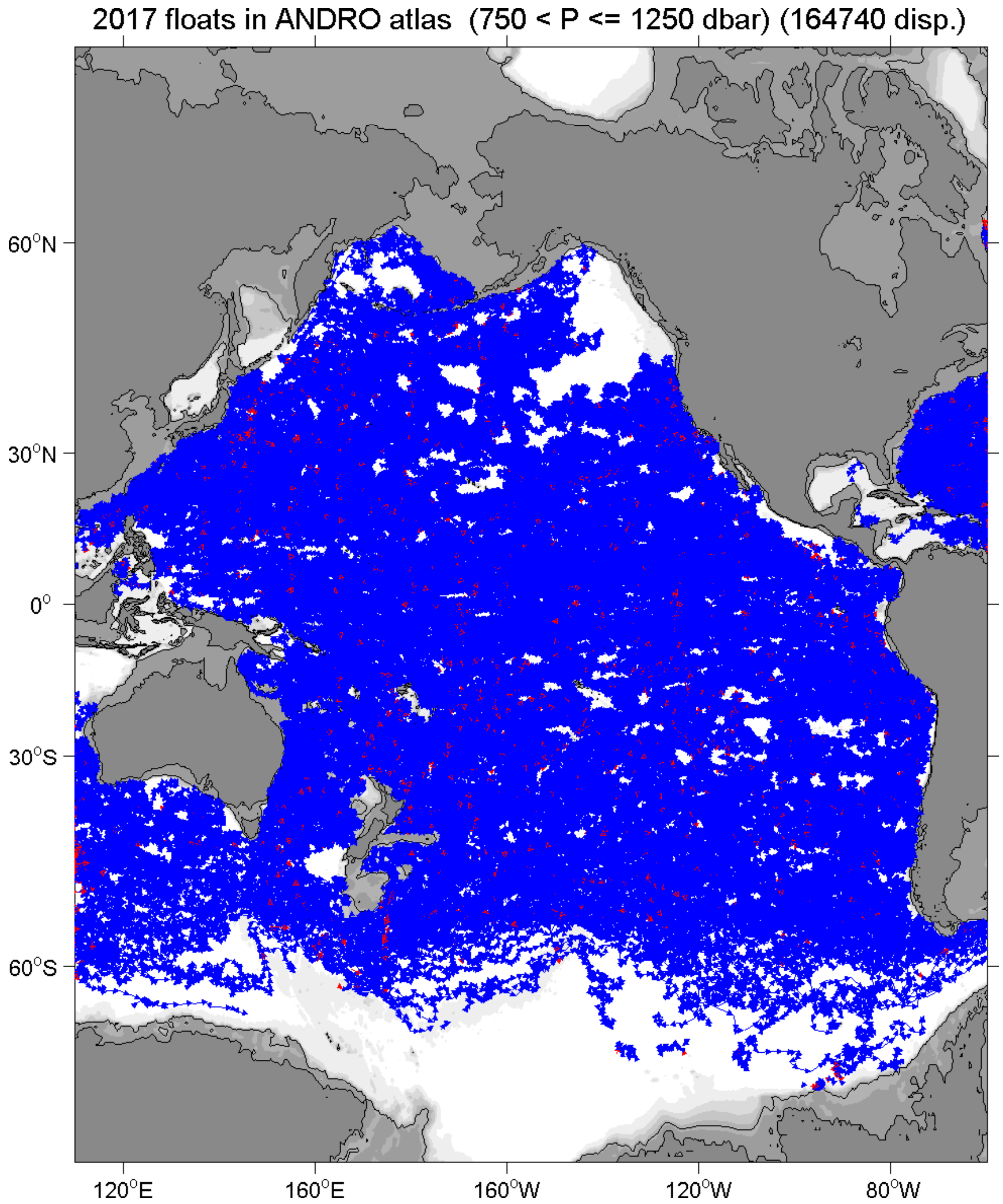
  4 % at depths less than 250 dbar
  3 % between 250 and 750 dbar
  79 % between 750 and 1250 dbar
  10 % between 1250 and 1750 dbar
  3 % between 1750 and 2250 dbar
  1 % undefined



Present status of the ANDRO atlas in the Atlantic and for the Layer [750, 1250[dbar



Present status of the ANDRO atlas in the Indian ocean and for the the
Layer [750, 1250[dbar



Present status of the ANDRO atlas in the Pacific and for the Layer [750, 1250[dbar

Comparison between ANDRO and YoMaHa’

Comparison between the contents of ANDRO and YoMaHa’09 over the same period, that is from July 11 1999 to December 28 2008 and the same floats (PROVOR and APEX from Coriolis, SOLO and 55% of the APEX from AOML)

Note that it is the updated YoMaHa’09 version dated January 3 2009 which has been used in this comparison.

Pressure interval (dbar)	P < 750	750<P<1250	1250<P<1750	1750<P<2250	total
ANDRO	18895	202517	21226	7537	250175
YoMaHa’09	13777	209539	22772	7336	253426

What are the differences and why?

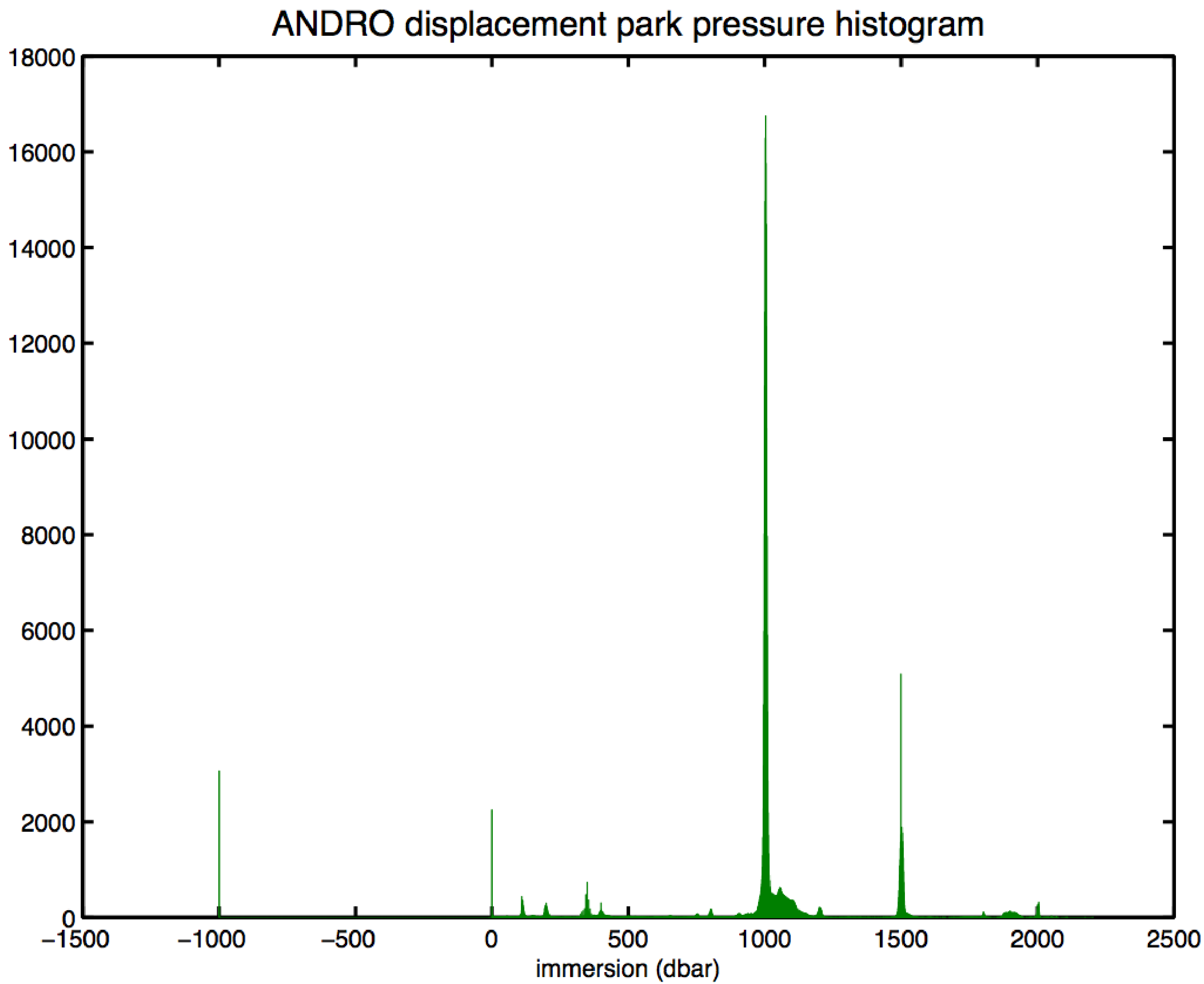
Between ANDRO and YoMaHa

The main difference between these two data sets is that ANDRO parking pressures are **measured** values (except for 29 floats).

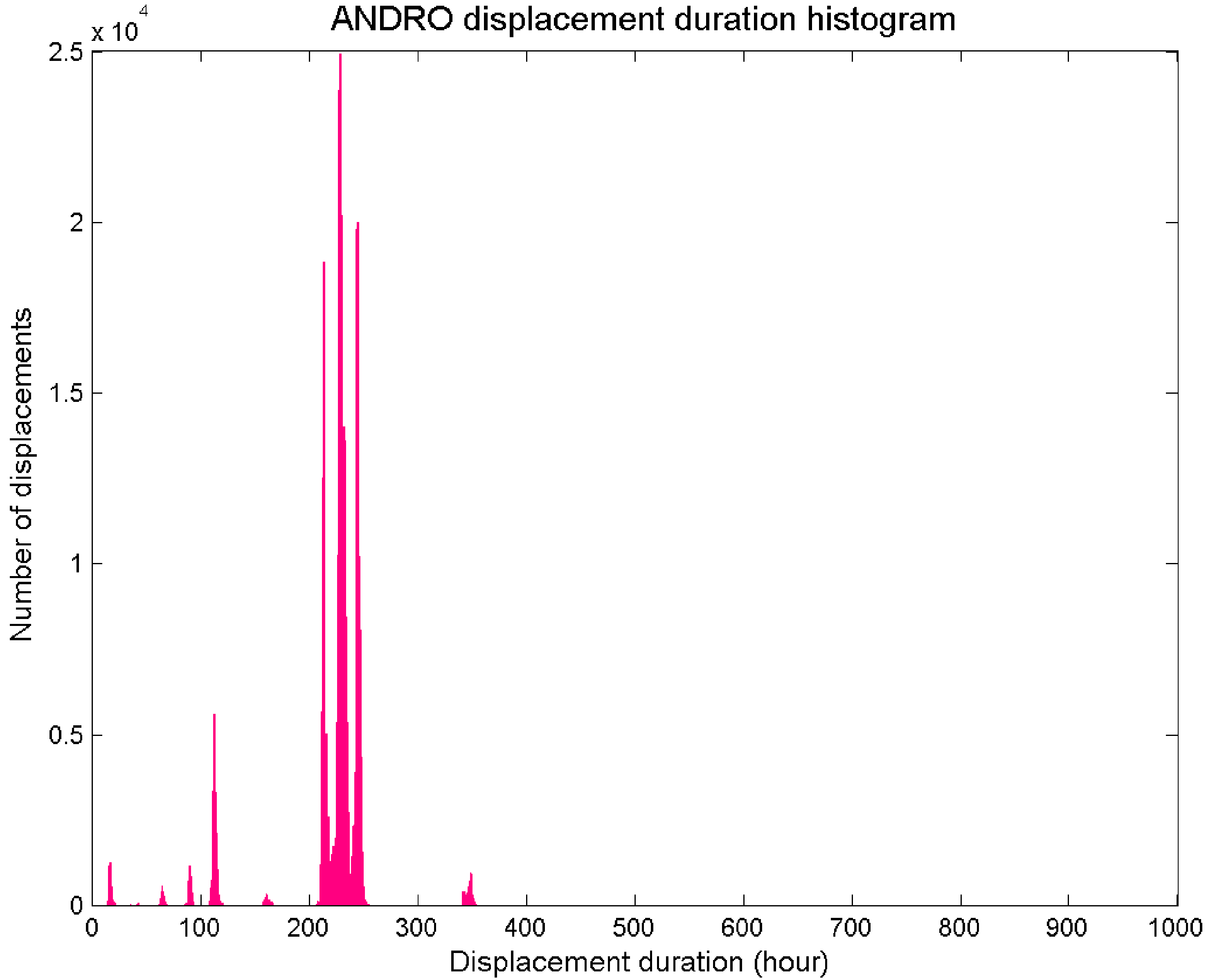
Many floats have apparently grounded during part of their lives. 3260 corresponding cycles have been excluded in ANDRO.

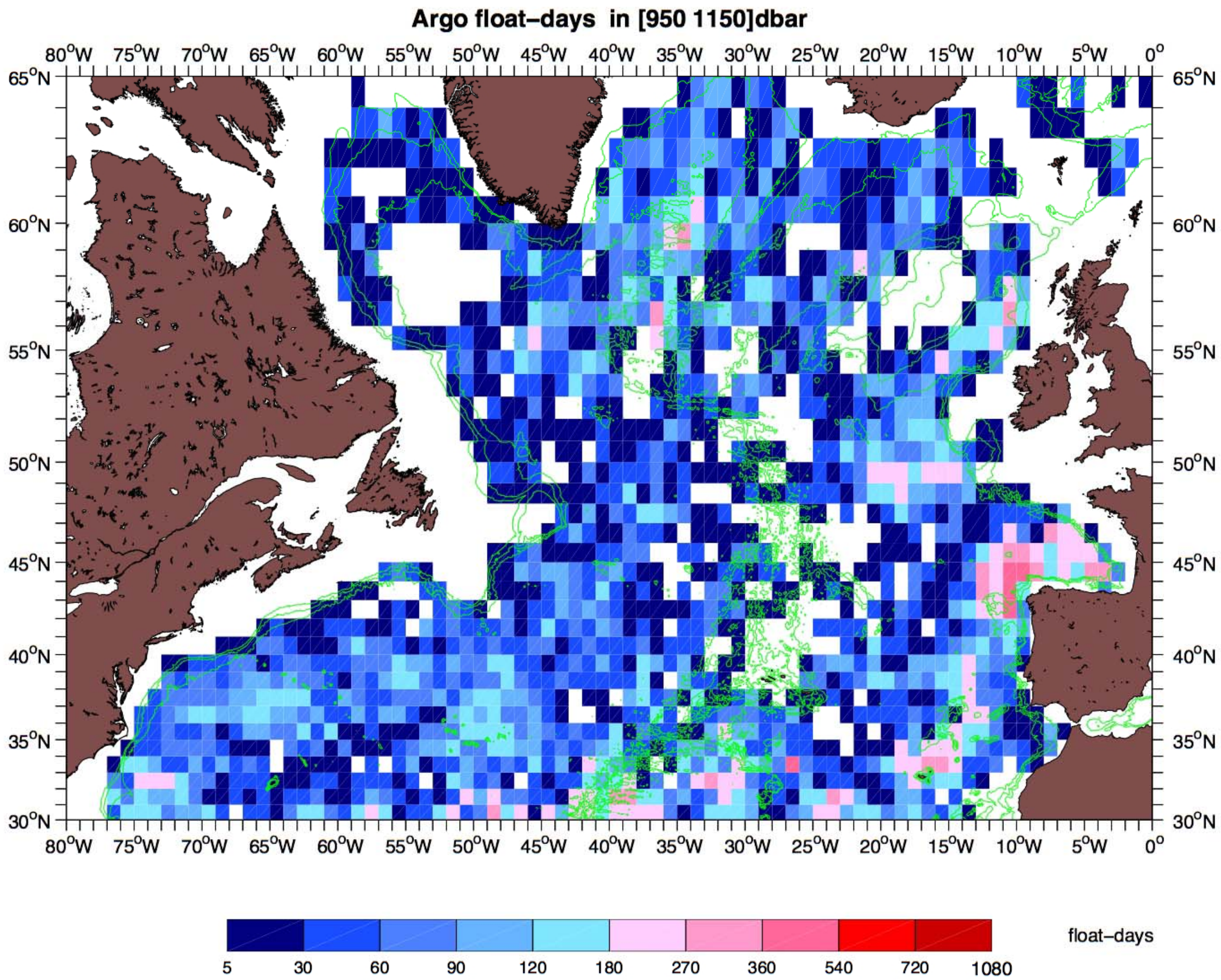
A few floats have also transmitted bad pressure measurements, mainly because of ill functioning of their pressure transducer. For 2451 cycles where the temperature does not indicate clearly that the float is at the surface, we have defaulted the parking pressure in ANDRO.

Pressure distribution in ANDRO



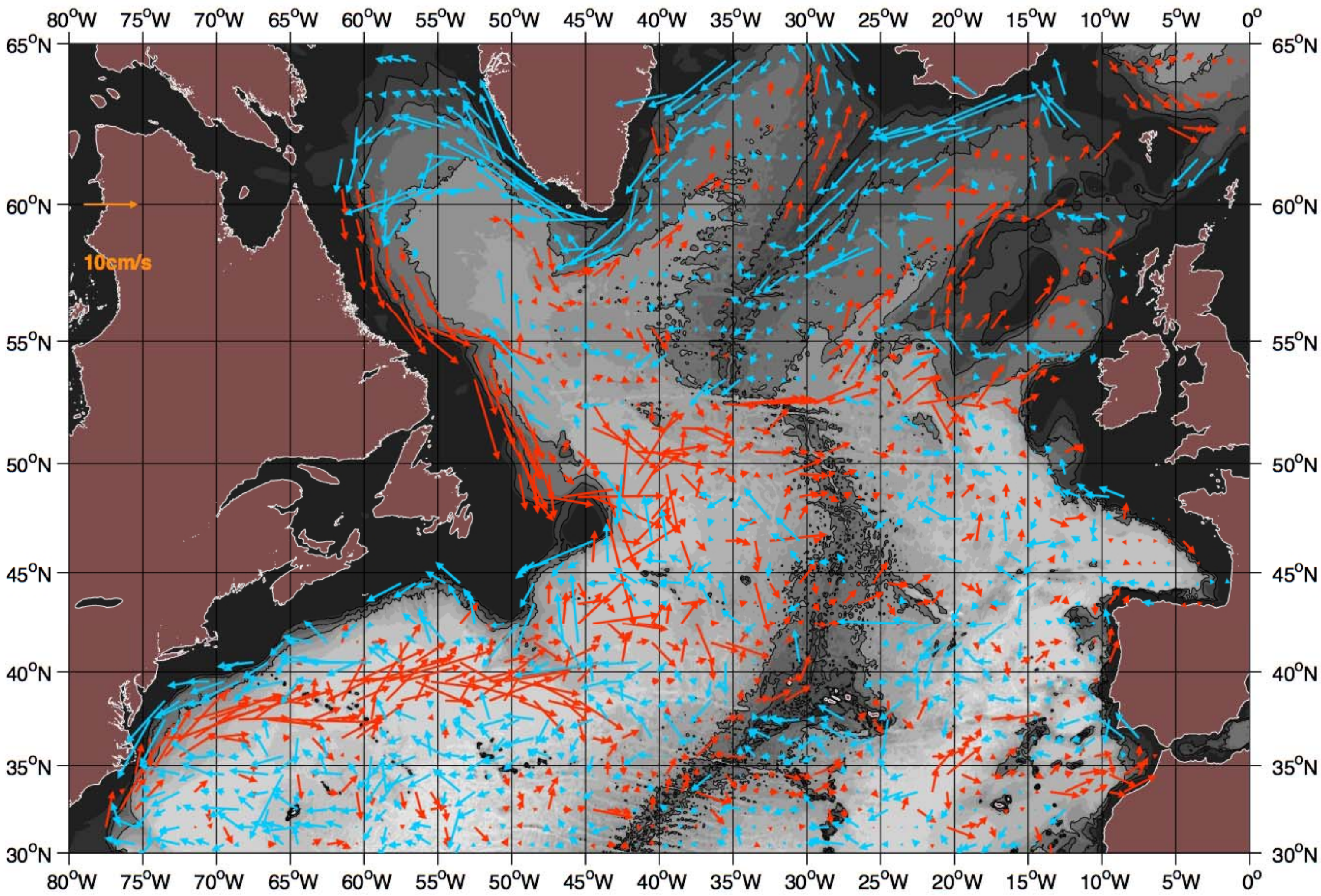
Displacement Duration distribution in ANDRO

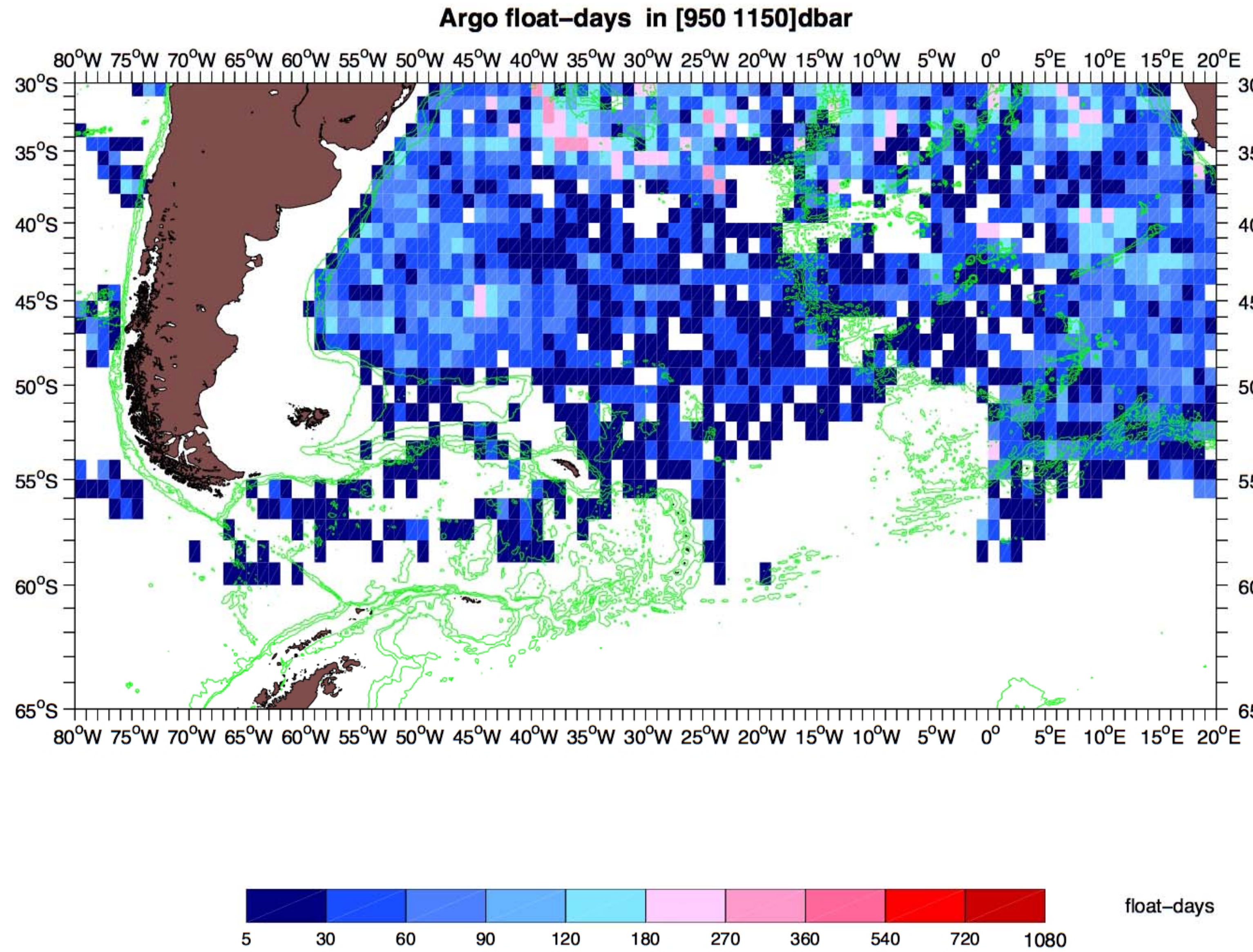




Argo float-days in [950 1150]dbar
80°W 75°W 70°W 65°W 60°W 55°W 50°W 45°W 40°W 35°W 30°W 25°W 20°W 15°W 10°W 5°W 0°
65°N 60°N 55°N 50°N 45°N 40°N 35°N 30°N
5 30 60 90 120 180 270 360 540 720 1080
float-days

Argo floats : mean 1° x 1° currents in [950 1150]dbar

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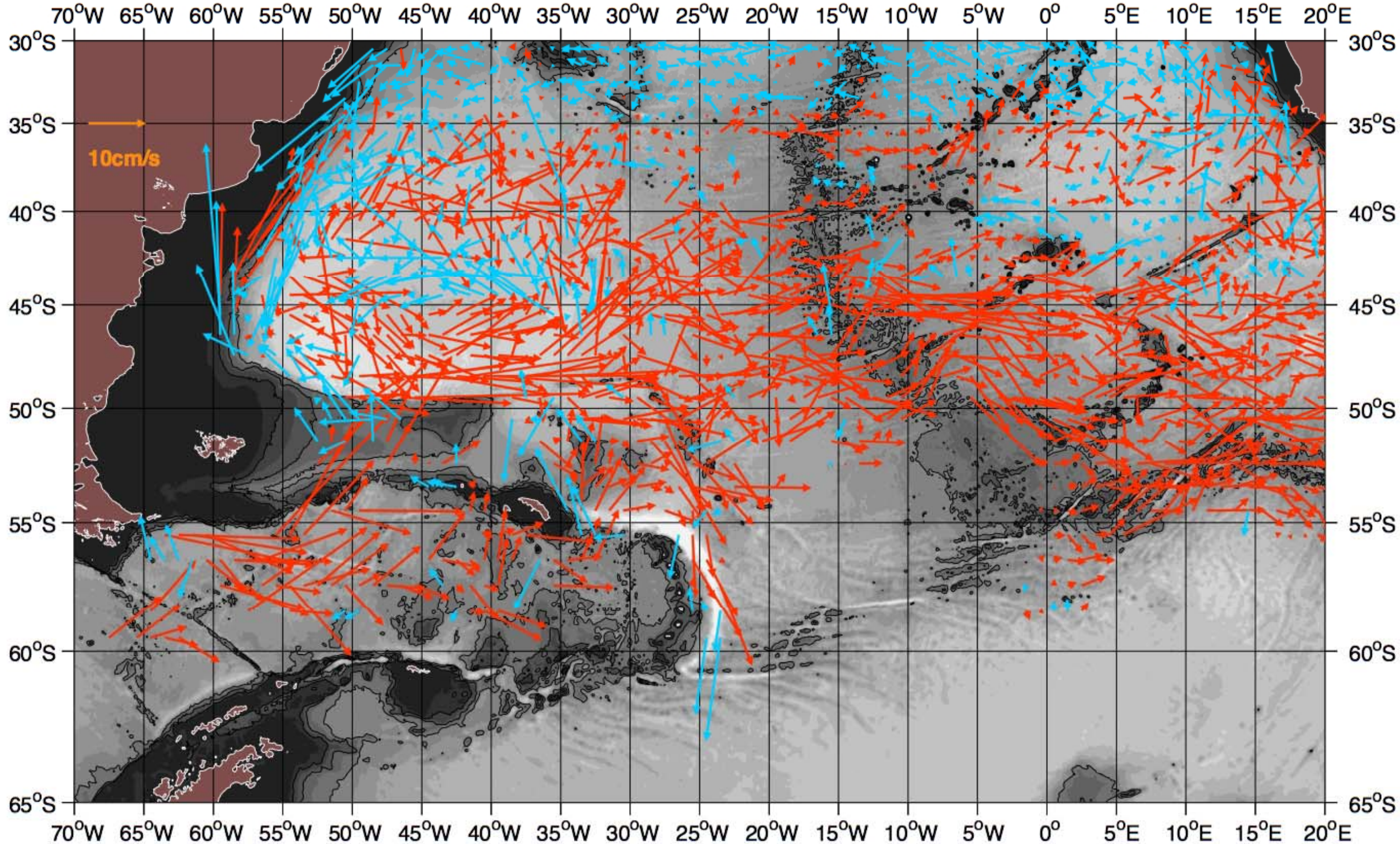
80°W 75°W 70°W 65°W 60°W 55°W 50°W 45°W 40°W 35°W 30°W 25°W 20°W 15°W 10°W 5°W 0° 5°E 10°E 15°E 20°E
30°S
35°S
40°S
45°S
50°S
55°S
60°S
65°S
5 30 60 90 120 180 270 360 540 720 1080
float-days

Argo floats : mean 1° x 1° currents in [950 1150]dbar



Surface Displacement Extrapolation

To estimate the true surface displacement of a float, one need to know its times of surfacing and diving, to which one must extrapolate the actual ARGOS fixes.

For PROVOR, these 2 times can be normally calculated from technical data.

For APEX, surfacing time can be calculated from transmission start date, and diving time can be estimated with an envelope method (maximum time of the last Argos messages). Note that the two-envelope method by Park, Kim, King & Riser, 2005 doesn’t work for APEX floats profiling deeper that their parking depths.

For SOLO, we haven’t done any time estimation yet.

The extrapolation proper is done by fitting a uniform velocity and a circular inertial motion to the ARGOS fixes (Park, Kim & Crawford, 2005)

If we can trust the surface extrapolations, we’ll get more accurate subsurface displacements.

This has been done for Coriolis data (753 floats, 57999 cycles), but with partial

Extrapolation algorithm

We have N surface positions X_k^{obs}, Y_k^{obs} (with associated errors ε_k) and we look for $\mathbf{M}(k)$=(X_k, Y_k) k=1,…, N such that

$$\mathbf{M}(k) = \mathbf{M}(1) + \mathbf{u}_L \cdot \Delta t_k + \int_0^{\Delta t_k} \mathbf{u}_I(0) \cdot e^{-ift} dt$$

We have to minimize the functional J:

$$J = \sum_1^N ((X_k - X_k^{obs})^2 + (Y_k - Y_k^{obs})^2) / \varepsilon_k^{\ 2}$$

There are 6 unknowns: u_L, v_L, X_1, Y_1, x_i, y_i where (x_i, y_i) is the cer
of the inertial circle, on the assumption that f=2Ω sinφ is constant.

With b =[X_1^{obs}, X_2^{obs}, …, Y_1^{obs}, Y_2^{obs}, …]^t , Z=[u_L, v_L, X_1, X_2, x_i, y_i]^t ,
C the diagonal matrix with elements ε_k^2, J is given as $(AZ-b)^t C^{-1}$(A
Where A is a 2Nx6 matrix, function of f and the Δt_k.

The solution is then straightforward and given by $Z = (A^t C^{-1} A)^{-1} A^t C$

Selection criteria

- Initial selection: only Argos location classes 1, 2 or 3 are used (with position errors ε of order 1 km, 350m and 150m respectively).
- The cycle is kept as such if the distances between all pairs of points are smaller than 300m.
- Nakamura, Ogita and Kobayashi test:

  If $dist(M_k^{obs}, M_{k+1}^{obs}) > (\varepsilon_k^2+\varepsilon_{k+1}^2)^{1/2}$ and if the speed on the segment

  is greater than 3 m s^{-1}, the poorer location is suppressed (if the two positions have the same Argos class, the one inducing the greatest speed is suppressed).
- If $dist(M_1, M_1^{obs}) > 2 \bullet RM$ where

$$RM = \sqrt{\frac{1}{N}\sum_{k=1}^{N} dist(M_k, M_{k+1})^2}$$

  the first position is suppressed before a second iteration. Similarly, if some class 1 Argos position satisfies this criterium, i suppressed before a further iteration.
- Only cycles with at least 6 surface positions are considered.

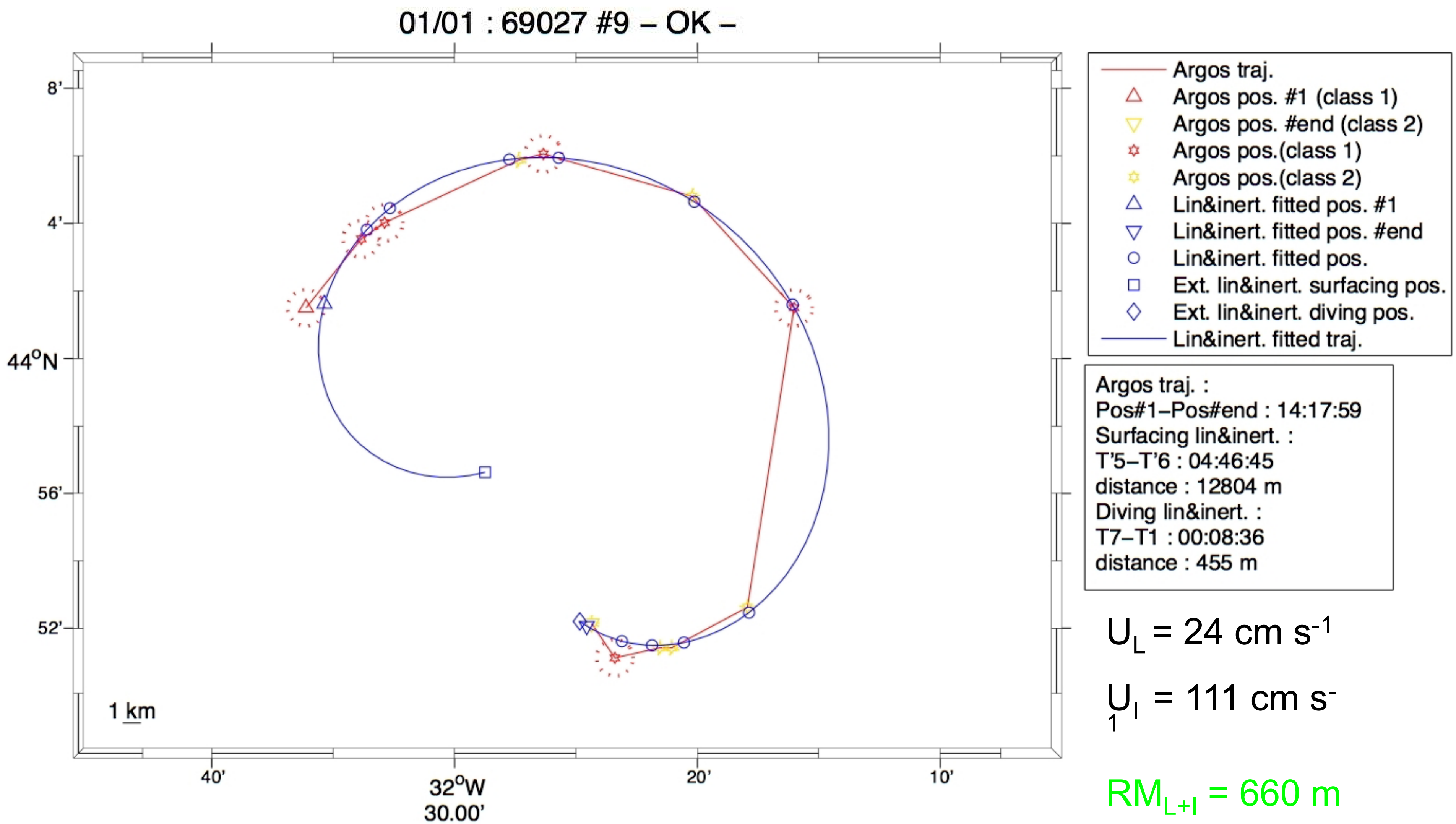
Results for the Coriolis data

- The extrapolated positions are estimated only if the times of extrapolation (whether between the surfacing and first Argos fix times, or between the last Argos fix and diving times) are smaller than 2/3 of the time span of the Argos fixes, and only if RM ≤ 750 m
- NB: A linearity coefficient CL= RM/dist(M_1, M_N) of 10% at most has also been used, but is valid only for low latitudes.

	Worldwide	Between 6°S and 6°N
	753 floats, 57999 cycles	123 floats, 8159 cycles
Extrapolation OK for	35890 cycles (62%, but see NB)	5787 cycles (71%)
Not enough Argos fixes (before or during iterations)	5546 (9.5%)	1072 (13%)
All fixes within a 1km (or 150 m initially) radius	2189 (3.7%)	125 (1.5%)
Criteria not verified or method not valid	14374 (24.8%, but see NB)	1175 (14.5%)

Excellent fit on the Argos fixes

Note however the almost 5h delay between surfacing and first Argos fix, implying a 13 km distance between the two positions



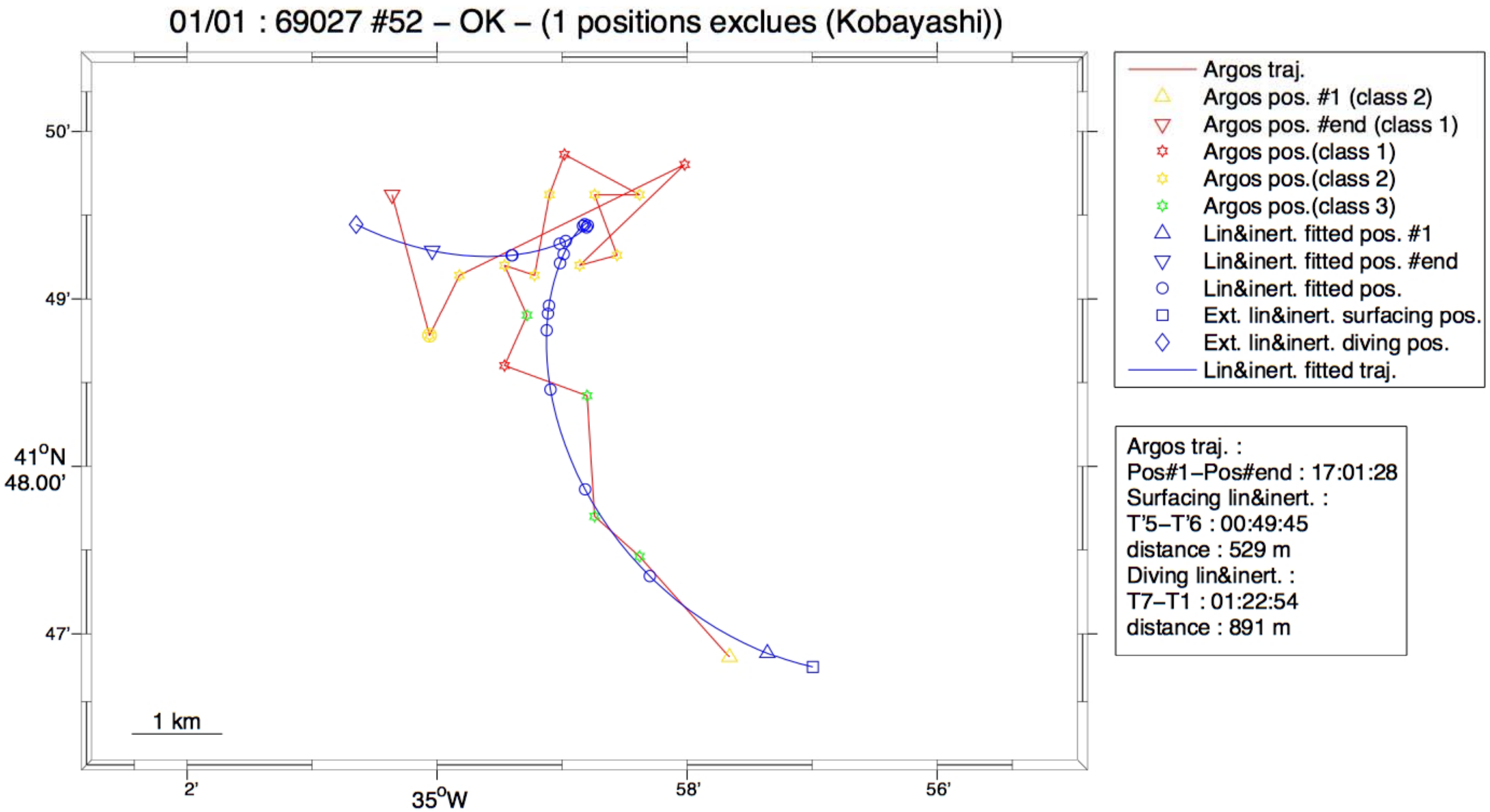
$U_L = 24$ cm s^{-1}

$U_I = 111$ cm s^{-1}

$RM_{L+I} = 660$ m

CI = 2.8%

Acceptable fit on the Argos fixes



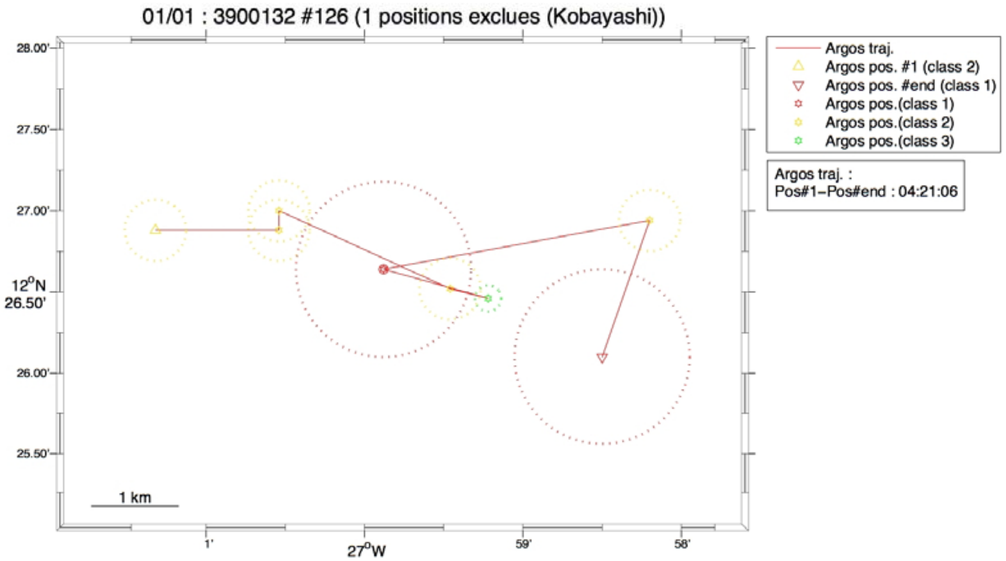
U_L = 10 cm s^{-1}

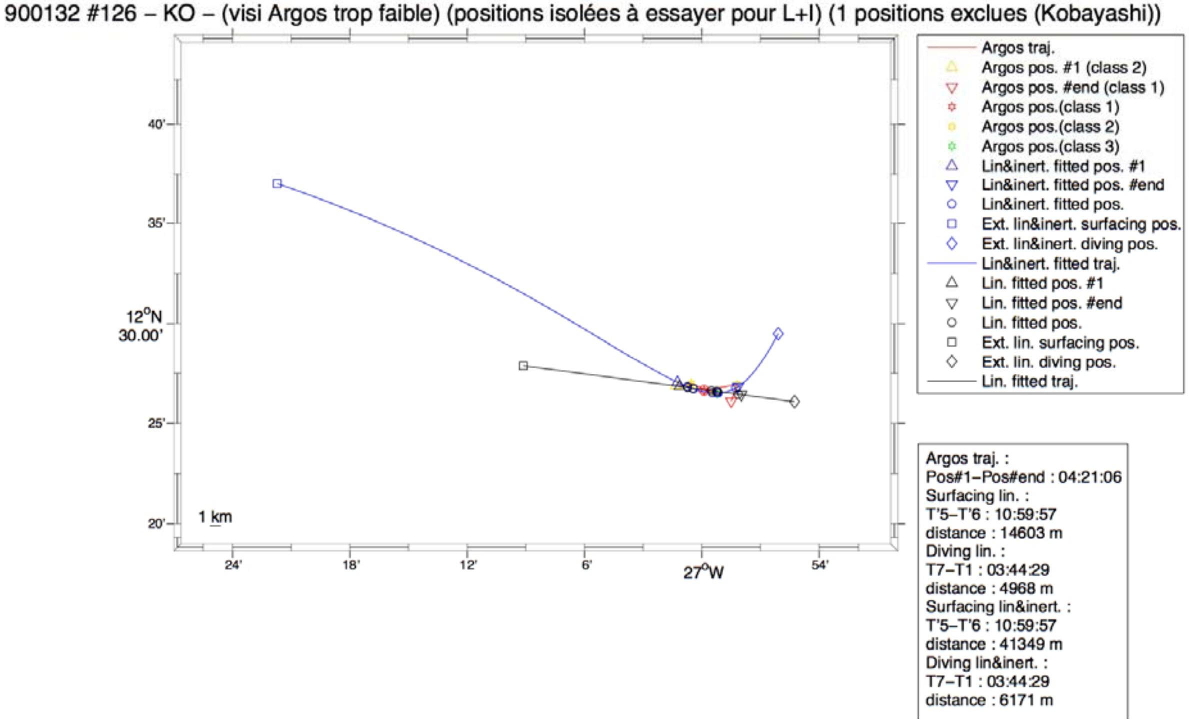
U_I = 10 cm s^{-1}

RM_{L+I} = 527 m

CL = 8.3%

Poor adjustment on Argos fixes





- Argos fix times span only 4h21mn, whereas inertial period is 55h.
- Poor adjustment on Argos fixes. There is a 11h delay between surfacing and first Argos fix times, which makes the extrapolation even more unreliable!

U_L =121 cm s^{-1}

U_I =89 cm s^{-1}

RM_{L+I} =643 m

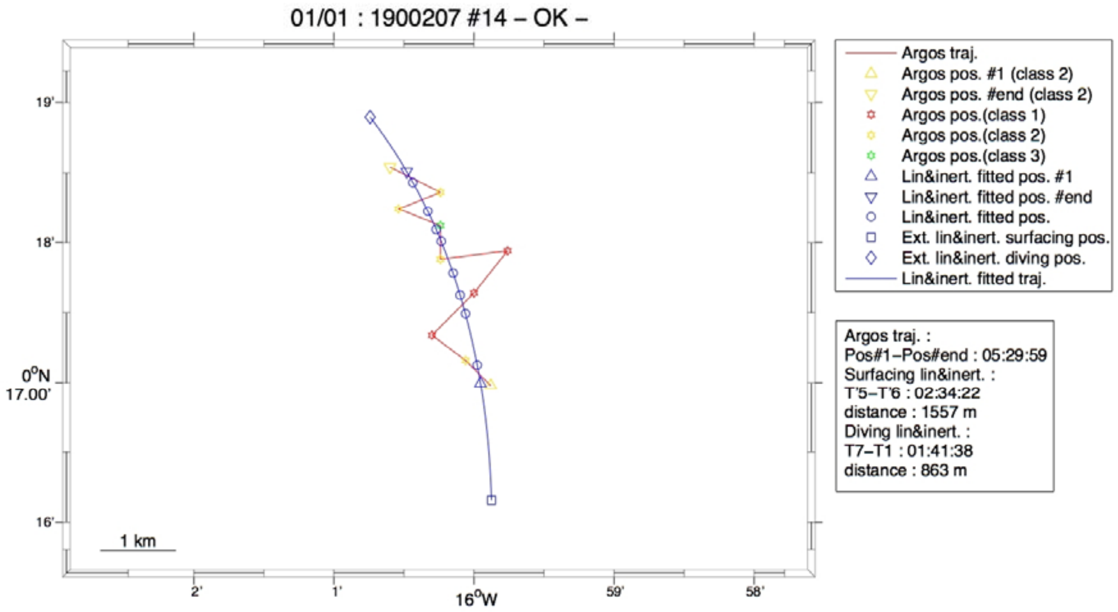
CL_{L+I} = 12.1%

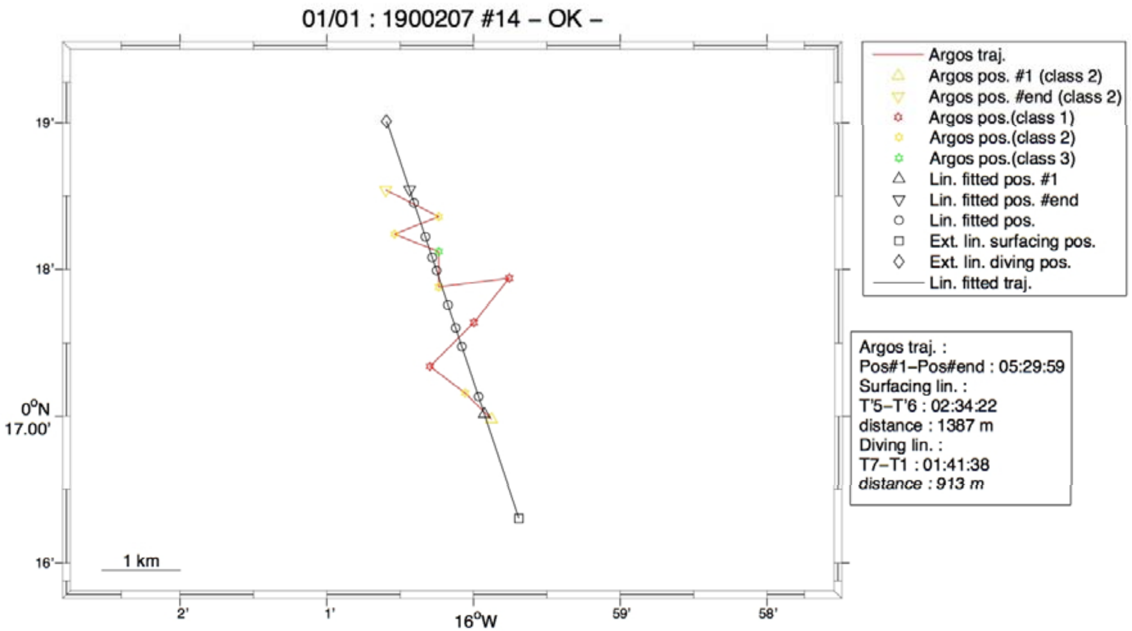
RM_L = 621 m

CL_L =11.7%

U_L = 37 cm s^{-1}

Linear adjustment near the Equator





- Matrix A is ill conditioned: $\sin(f\Delta t_k)$ terms are << 1

RM_{L+I} = 293 m

CL_{L+I} = 9.2%

U_L =424 cm s^{-1}

U_I =410 cm s^{-1}

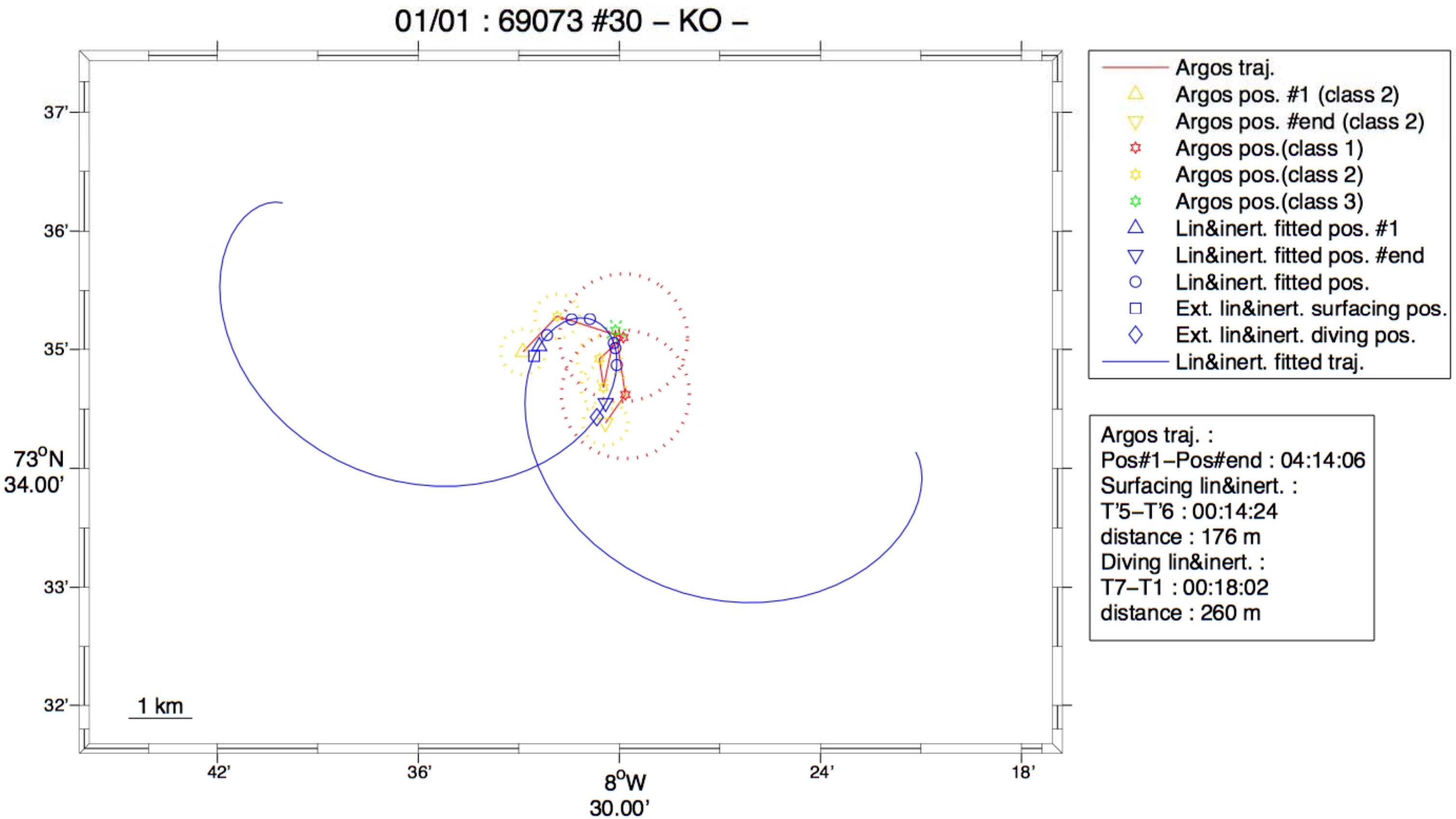
- Linear fit is better and should be used near the Equator!

U_L =15 cm s^{-1}

RM = 289 m

CL = 9.1%

Good fit on the Argos fixes at high latitude



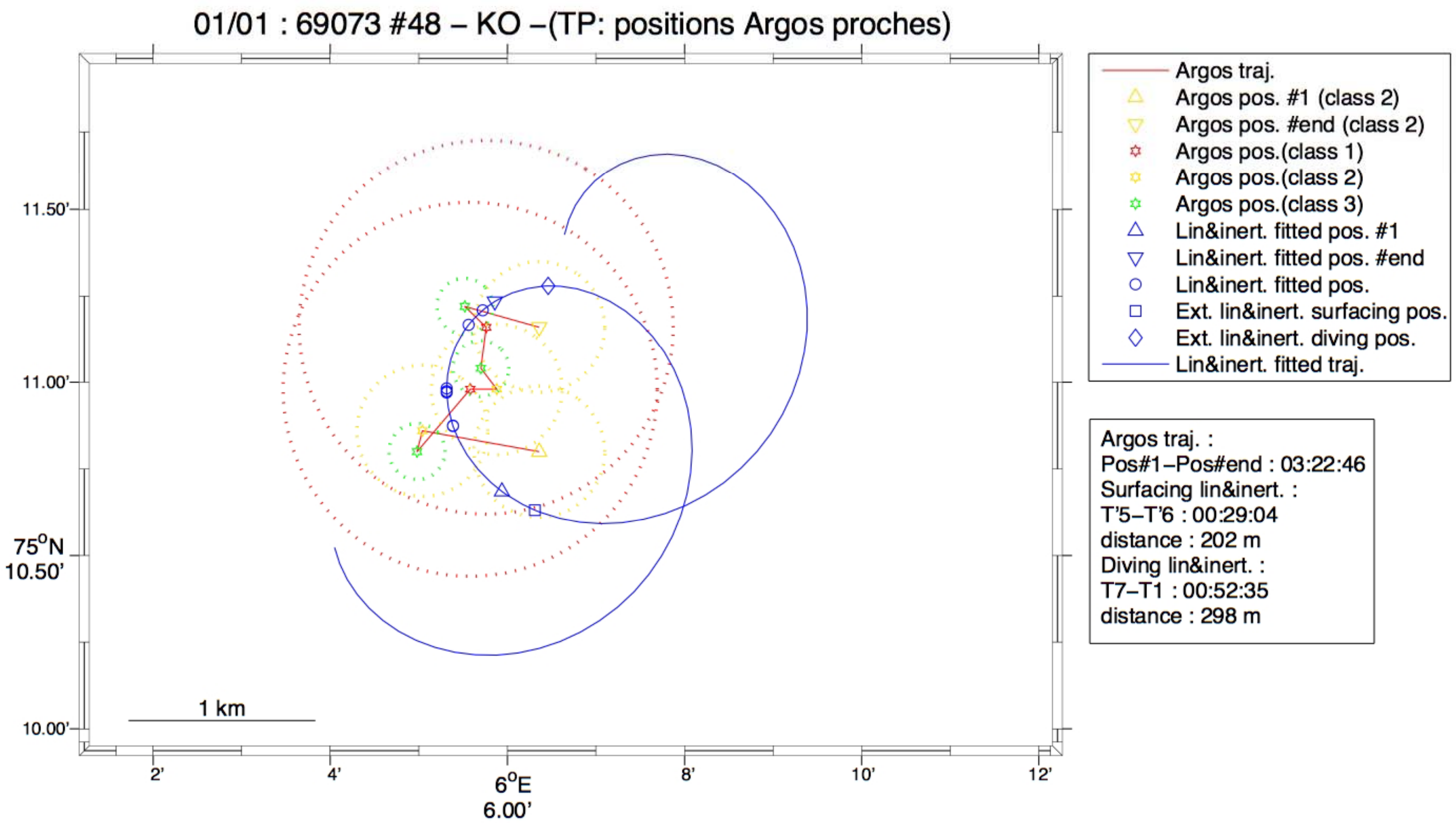
U_L =11 cm s^{-1}

U_I =24 cm s^{-1}

RM_{L+I} = 532 m

CL = 31.1%

Approximate fit on Argos fixes at high latitude



U_L =2 cm s^{-1}

U_I =11 cm s^{-1}

RM_{L+I} = 210 m

CL = 31.4%

Some statistics from the Coriolis data

For one cycle:

- Number of Argos locations (only classes 1,2 and 3): 11.8 ± 12
- Time span between first and last Argos locations : 8.6 ± 6 h
- Distance between the last Argos and diving positions: 1.8 ± 1.7 km

  (Time between last Argos and diving positions : 86 ± 72 mn)
- Distance between the surfacing and first Argos positions: 1.6 ± 1.5 km

  (Time between surfacing and first Argos positions: 66 ± 51 mn)

Measurement errors on deep velocity

- Time delay after surfacing and before diving 80±60 mn corresponding to $\delta \mathbf{x} \approx 1.5 \pm 1.5$ km implies $\varepsilon_U \approx 3$ mm s^{-1} with 10 days cycles
- Current shear during ascent and descent: $\Delta U < 50$ cm s^{-1} over the upper 400 m and with vertical float velocity 10 cm s^{-1}, implies $\varepsilon_U \approx 2$ mm s^{-1}
- Argos position errors are O(1 km) adding a $\varepsilon_U \approx 2$ mm s^{-1}

Total measurement error is < 1 cm s^{-1}

Sampling error for the deep mean circulation

With EKE ≈ 50 cm^2 s^{-2} and $T_L \approx 10$ d implies $\varepsilon_{<U>} \approx 1$ cm

CONCLUSION 1

•At high latitudes, the Coefficient of Linearity CL< 10% is not adequate. We need to do some more tests.

• We may expect at best reliable extrapolations for 3/4 of the data

• For the 1/4 left, one can try other methods, e.g. an estimation of an angular frequency different from the inertial frequency, or as suggested by Brian King, a weighting function of the time span between the data and the looked for position.

• We propose that other Argo users do their own extrapolation, or a given float data set, we can provide.

CONCLUSION 2

• Generally, instruments (PROVOR, APEX and SOLO) give very good data as far as subsurface displacements are concerned.

• A better version of ANDRO is possible with estimates of actual diving and surfacing positions: this needs to get the surfacing and diving times and then to extrapolate the corresponding positions from the actual Argos locations (for example using a least square fit of a uniform velocity and a circular inertial motion, see Park et al., 2004).

• Argo subsurface displacements are an unprecedented data base of direct and absolute measurements of the ocean circulation (but one needs their exact drifting depths).

• Deep (depth greater than 2000 m) and bottom water displacements remain unknown

•ANDRO extended worldwide, i. e. to all the Argo DACs, should be completed by the end of 2010 (with data until January 1 2009). There is a lack of financial support for the next 6 months, however.

Thank you

We acknowledge the continual financial support of IFREMER for this project