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VALIDATION OF ARCTIC SEA ICE DRIFT WITH IABP BUOYS

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Abstract

Satellites enable daily and global coverage of the polar oceans, providing an unique monitoring capability of sea ice dynamics over Arctic and Antarctic. Available geophysical parameters include ice concentration, extent, type and sea ice drift.
Backscatter map from SeaWinds/QuikSCAT and brightness temperature maps from Special Sensor Microwave Imager (SSM/I) are available at a pixel resolution of 12,5 km from which ice drift can be estimated for each sensor. Since 1999, IFREMER makes available a "Merged" sea ice drift data set based on the combination of these drifts at 3 and 6-day lags at the grid resolution of 62,5 km. It has been demonstrated that combining these drifts increases the number of valid vectors.
In this paper, the validation of this Merged product is presented in comparison with drifting buoys of the International Arctic Buoy Programme (IABP) over five winters (1999-2004), enabling an estimation of drift accuracy as a function of drift speed.
In the second part, the accuracy of the Advanced Microwave Scanning Radiometer (AMSR-E) drift products based on 89 GHz brightness temperature maps at 6,25 km pixel resolution is assessed. Drift data are compared with the buoys positions and with the Merged product during the 2002-2003 winter. AMSR-E provides a better vector accuracy compared with that of the Merged product because of its enhanced ground resolution but the information is available only during the cold season.

I. Introduction

Since 1979, buoys are moored on ice each year in the framework of the IABP, providing continuous local measurements. Since the 1990's, sea ice drift measurements are estimated from satellites data, which enable daily and global coverage of the polar oceans, providing an unique monitoring capability of sea ice dynamics over Arctic and Antarctic. Available geophysical parameters are sea ice concentration, extent, type and sea ice drift.
This paper deals with the sea ice drifts estimate from satellite using several sensors. SeaWinds/QuikSCAT scatterometer data have been combined with SSM/I radiometer data to provide sea ice drift. This product, called "Merged", is validated with buoys data (§II). In a second part, AMSR-E radiometer measurements are validated with buoys and compared with the Merged product (§III). The advantages and shortcomings of these measurements are discussed in the conclusion (§IV).

II. Merged sea ice drift validation

II.1. The Merged product

Since 1991, SSM/I data are available at the frequency of 85,5 GHz; these data are available at horizontal and vertical polarizations with a pixel size of 12,5 x 12,5 km (Ezraty et al., 2004). SeaWinds/QuikSCAT

provides backscatter maps at a pixel resolution of 12,5 km from which sea ice drifts are also derived (Ezraty and Piollé, 2004a).
IFREMER makes available a “Merged” product since 1999, based on the combination of SSM/I and SeaWinds/QuikSCAT drifts at 3 and 6-day lags. Drift vectors are estimated every five pixels of the polar stereo projection NSIDC grid (drift grid resolution is 62,5 x 62,5 km). The benefits to combine these two drifts are in three points :

1) The geometry ground swath and orbit enable backscatter measurement very near the North Pole, the data gap is only 40 km for QuikSCAT compared with 254 km for SSM/I.
2) The combination increases by 12 to 15% the drift data density, in particular at early fall and early spring (see Figure 7).
3) Merging process enables discrimination of the few vector outliers remaining in the individual products (Ezraty and Piollé, 2004b).

II.2. Comparison with buoys

Merged drifts are compared with buoys drifts over five winters (1999-2004) at 3 and 6-day lags. Buoys have been selected in order to have trajectories duration from 4 to 7 months.
At 3 day-lag, distribution of buoys and Merged drifts show mean drift of 17,7 km for buoys and 16,9 km for Merged, and similar standard deviation of 14,4 km. This is highlighted by figure 1 where Merged and buoys drifts are presented with probability in logarithmic scale, showing a slight dissymmetry towards the strong values for the buoys drifts.

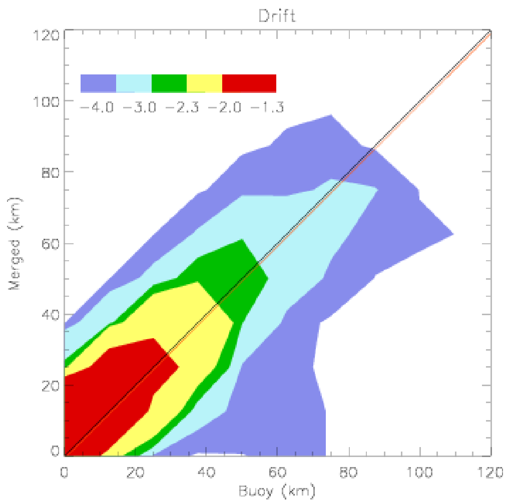

Figure 1 : Comparison of buoys and Merged drifts for 3 day-lag, winters 1999-2004. Colors are probability expressed in logarithm scale.

The mean bias (obtained from the difference between buoys and Merged drifts) is 0,3 $\pm$ 0,1 km in a 95% confident interval, which is compatible with the large samples (13660 comparisons). The standard deviation of the difference is 7,5 $\pm$ 0,1 km of which 5,1 km are uncorrelated noise. The quantification effect accounts for $\delta^2/6$ with δ the pixel size (in variances). In this case, this corresponds to 5,1 km, the uncorrelated noise is thus totally explained by the quantification effect.

Drifts data are converted into ice speed in order to compare drifts at 3 and 6 day-lags. The standard deviation of the difference of ice speeds is 2,91 $\pm$ 0,04 cm/s, which is comparable with standard deviation of 2,96 cm/s with SSM/I and 2,80 cm/s with NSCAT at 4 day-lag on two winter months (Liu et al., 1999), 2,6 to 2,9 cm/s at 1 day-lag (Liu and Cavalieri, 1998), 6 cm/s for SSM/I at 1 day-lag (Emery et al., 1997). Kwok et al. (1998) and Zhao et al. (2002) compare buoys and satellite drifts with and without small drifts. Their results show smaller standard deviation when small drifts are dismissed (lower than one pixel) : 2,32 cm/s for QuikSCAT and 2,27 cm/s for SSM/I for Zhao et al. (2002). Kwok et al. (1998) improve their comparison with SSM/I at 3 day-lag : from 4,28 cm/s down to 2,58 cm/s with vertical polarization and 4,52 cm/s down to 2,89 cm/s with horizontal polarization. Our results are not comparable : there is no improvement excluding small drifts. One problem to exclude small drifts is that drifts lower than one pixel may have a strong weight

(24% of the Merged drifts in our study), statistics on the samples are then strongly modified, but what are their meaning ?

Angles of Merged drift vectors present a strong uncertainty : for small drifts (lower than two pixels in component) the angle is 0, 45 or 90° whereas angles of buoys drift vectors are more accurate. Mean angle difference between buoys and Merged is 3,9 ± 0,8° and the standard deviation is 39,2 ± 0,5° of which 33,5° are uncorrelated noise. If drifts less than one pixel are excluded, the standard deviation of the difference decreases down to 29,4 ± 0,4°. Excluding small drifts seems to improve significantly the angular accuracy.
These results are in agreement with the comparison of buoys vector angles with SSM/I by Liu and Cavalieri (1998) with standard deviation about 25,9° and 18° over two months, 34,4° with SSM/I and 28,6° with NSCAT at 4 day-lag on two winter months (Liu et al., 1999), and 29,8° with QuikSCAT and 35,5° with SSM/I for Zhao et al. (2002) without small drifts. Kwok et al. (1998) improve also strongly the angle comparison between buoys and SSM/I at 3 day-lag excluding small drifts : from 46,5° down to 30,6° for vertical polarization and from 50,4° down to 32,8° for horizontal polarization. Figure 2 shows the angle difference between the Merged product and buoys as a function of Merged drifts : the angle difference sharply decreases (smaller than 45°) for drifts higher than 40 km (about 3 pixels), this was also noticed by Liu et al. (1999).

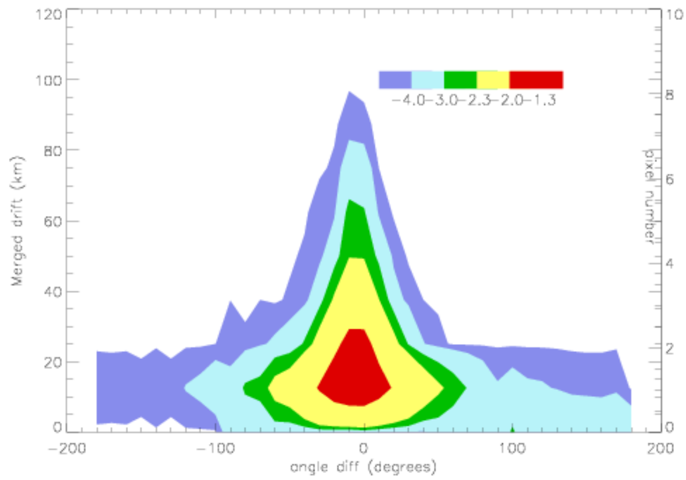

Figure 2 : Angle difference between Merged and buoys as a function of Merged drift for 3 day-lag, winters 1999-2004. Colors are probability expressed in logarithm scale.

Using 6 day-lag is more adequate to small drifts. Mean drifts are 28,5 km for buoys and 27,0 km for Merged, with a standard deviation of 20,4 km for buoys and 19,6 km for Merged. Mean ice speed at 6 day-lag is lower than that at 3 day-lag due to the better accuracy of small drifts measured at this day-lag. The standard deviation of drifts difference is 8,9 ± 0,1 km of which 6,5 km are uncorrelated noise. In order to compare this value with that of 3 day-lag, they must be converted in ice speeds. With 6 day-lag, the standard deviation of the difference is lower than with 3 day-lag (2,91 ± 0,04 cm/s at 3 day-lag and 1,72 ± 0,02 cm/s at 6 day-lag). This delay is better for small drifts, consequently, the angle data have a better resolution with a standard deviation of the difference of 29,6 ± 0,4°.
Comparing buoys and Merged drifts in North/East components frames enables independent estimate of uncertainties. North and East components standard deviation of the difference are 7,0 ± 0,1 km of which 4,0 km and 4,3 km respectively are uncorrelated noise. For each component, the quantification effect accounts for $\delta^2/12$, with δ the pixel size (Ezraty and Piollé, 2004b) : thus 3,6 km of the uncorrelated noise are explained by this effect.

The Merged drift is validated with buoys drifts over five winters. Merged drifts at 3 day-lag are constraint by the ability to measure small drifts, the 6 day-lag is more adapted to small drifts but is constraint by the 6 pixels maximum drift set in the algorithm. The day-lag must be chose in function of the value of the drifts.

III. AMSR-E sea ice drift validation

III.1. The AMSR-E product

Since 2002, AMSR-E at 89 GHz provides temperature brightness maps with a pixel resolution of 6,25 km, which is interesting to detect small drifts. From these maps, drifts are inferred, grid spacing of the drift map is 31,25 km.

AMSR-E drifts are compared with buoys over the 2002-2003 winter, these results are also compared with Merged/buoy drifts comparison over this winter.

III.2. Comparison with buoys

Figure 3 shows the comparison between buoys and AMSR-E drifts. Compared with figure 1 for Merged drifts, this diagram shows a better agreement between the AMSR-E and buoys than that for Merged/buoys. The mean bias of the difference AMSR-E/buoys is about 0 km, the standard deviation is 6,7 $\pm$ 0,2 km (of which 4,8 km are uncorrelated noise), lower than the 8,1 $\pm$ 0,2 km (of which 5,8 km are uncorrelated noise) for the Merged/buoys comparison over the same winter. This induces an improvement of 3,3 km on the drift noise level with AMSR-E drifts (calculated with variances additivity).

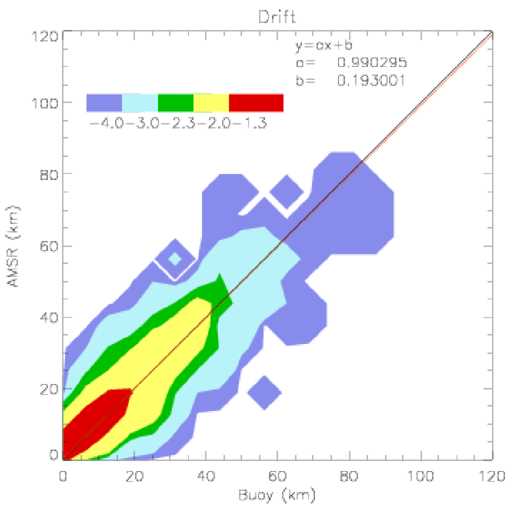

Figure 3 : Comparison of buoys and AMSR-E drifts for 3 day-lag, winter 2002-2003. Colors are probability expressed in logarithm scale.

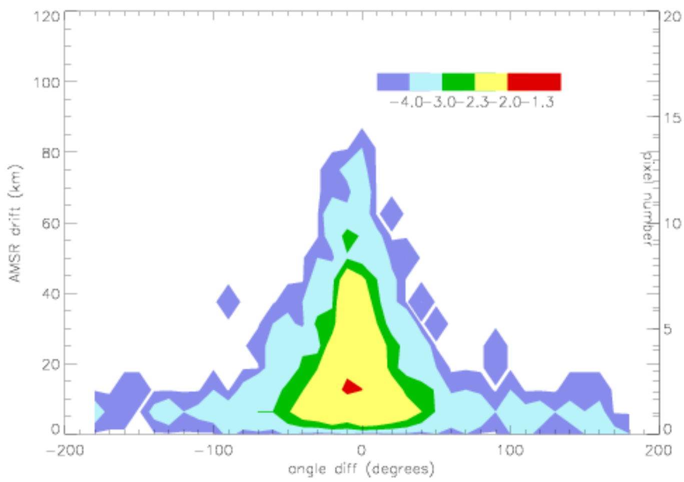

Figure 4 : Angle difference between AMSR-E and buoys as a function of AMSR-E drift for 3 day-lag, winter 2002-2003. Colors are probability expressed in logarithm scale.

In ice speeds, standard deviations of the difference between AMSR-E and buoys are lower than that of the Merged/buoys comparison :

- at 3 day-lag : 2,60 $\pm$ 0,08 cm/s for AMSR-E/buoys and 3,14 $\pm$ 0,09 cm/s for Merged/buoys
- at 6 day-lag : 1,59 $\pm$ 0,05 cm/s for AMSR-E/buoys and 2,08 $\pm$ 0,06 cm/s for Merged/buoys

The angle difference between AMSR-E and buoys has a mean bias of 0,9 $\pm$ 1,5°, the standard deviation is the same order (35,2 $\pm$ 1,1°) than that of Merged/buoys (35,1 $\pm$ 1,0°). Figure 4 shows the angle difference as a function of AMSR-E drifts, angle difference is important since drifts are lower than 30 km (about 5 pixels). A comparison over several winters is needed in order to show the benefit of AMSR-E on the angle comparison which is not obvious on this winter.

North and East components comparisons show a standard deviation of the difference of 6,4 $\pm$ 0,2 km for AMSR-E/buoys whereas it is about 7,2 $\pm$ 0,2 km for the Merged/buoys.

These results show that AMSR-E drifts are in agreement with buoys drifts, mean biases and standard deviation of the AMSR-E/buoys difference are lower than that of Merged over the same winter.

IV. Discussion and conclusion

These comparisons are performed along the buoys trajectories : essentially Fram Strait, the Beaufort gyre and the North pole. Figures 5 and 6 present AMSR-E and Merged drift maps for 3 day-lag (2nd-5th February 2005), an eulerian comparison can be made on the whole Arctic. The two maps present similar drift pattern, in particular a strong southward drift in Fram strait, ice exit of Kara area, drift from Laptev sea to central Arctic. AMSR-E map shows more vectors to the North of Alaska and to the Canadian archipelago. Due to the pixel size, AMSR-E grid resolution is increased by a factor of four compared with that of the Merged, but also more data gaps patches and no data at the North Pole. At this day-lag, Merged drifts are often lower than one pixel (crosses on figure 5) or are about one to two pixels inducing angles of 0, 45 or 90°, whereas AMSR-E drifts present a better angular resolution due to the pixel size.

Figure 7 shows drift data density during the 2002-2003 winter for AMSR-E and Merged data for several day-lags. AMSR-E provides 60 to 85% data density from December to mid-April, and decreases for early fall and early spring down to 25 to 60% whereas the Merged product has a data density higher than 85% for the period December-mid April and higher than 60% for early fall and early spring.

The Merged product, which is a combination of SSM/I and SeaWinds/QuikSCAT measurements, is validated with buoys drifts over five winters. This product is more appropriated than SSM/I or SeaWinds/QuikSCAT independently since merging process enables discrimination of the few vector outliers remaining in the individual products. This also increases the time period when data can be estimated. The main limitation of this product is its angular resolution for small drifts : the ice vector direction on slow motion areas have a larger uncertainty.

AMSR-E provides a better vector accuracy compared with that of the Merged product because of its enhanced ground resolution. Thus time lag can be reduced to two days. Yet this product is limited by patches of missing data and present less drifts data density, in particular for early fall and early spring.

Noise level is dominated by sensor ground resolution and pixel size, advantages and shortcomings of each product depend on pixel sizes, period and magnitude of drift.

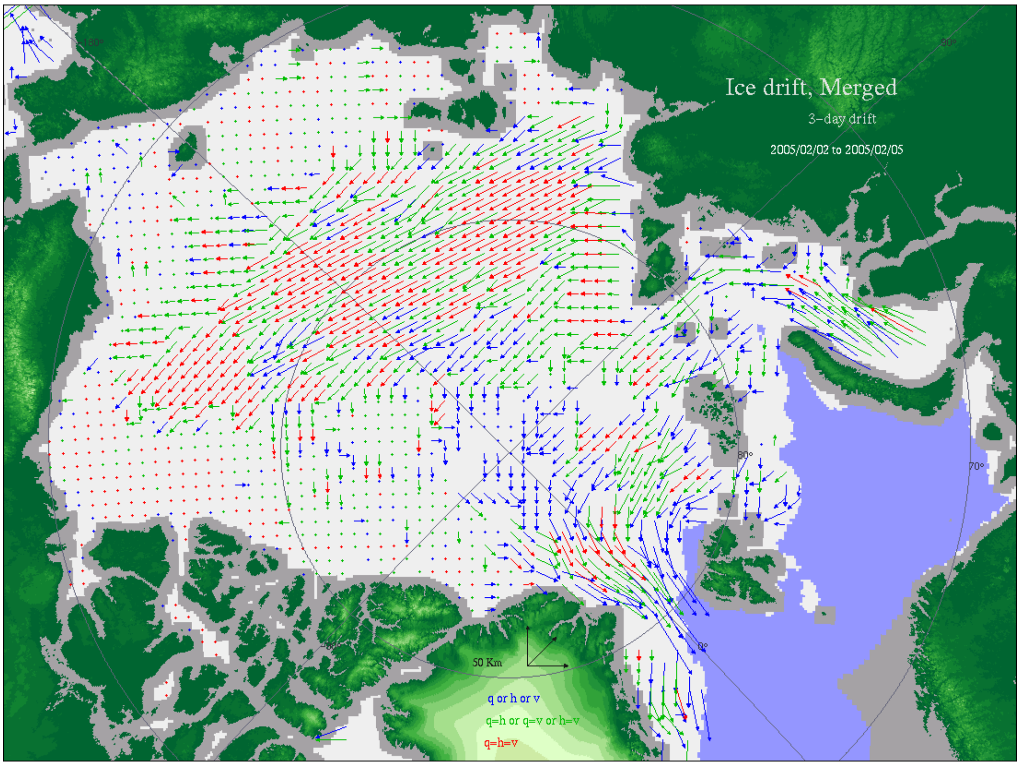

Figure 5 : Arctic sea ice drift from the combination of SSM/I (h and v polarizations) and SeaWinds/QuikSCAT at three day-lag February 2nd-5th, 2005. Drift vectors less than one pixel are marked with a cross. In red : identical drift for the 3 products, in green : identical drift for two of the products, in blue : selection or validation of one product.

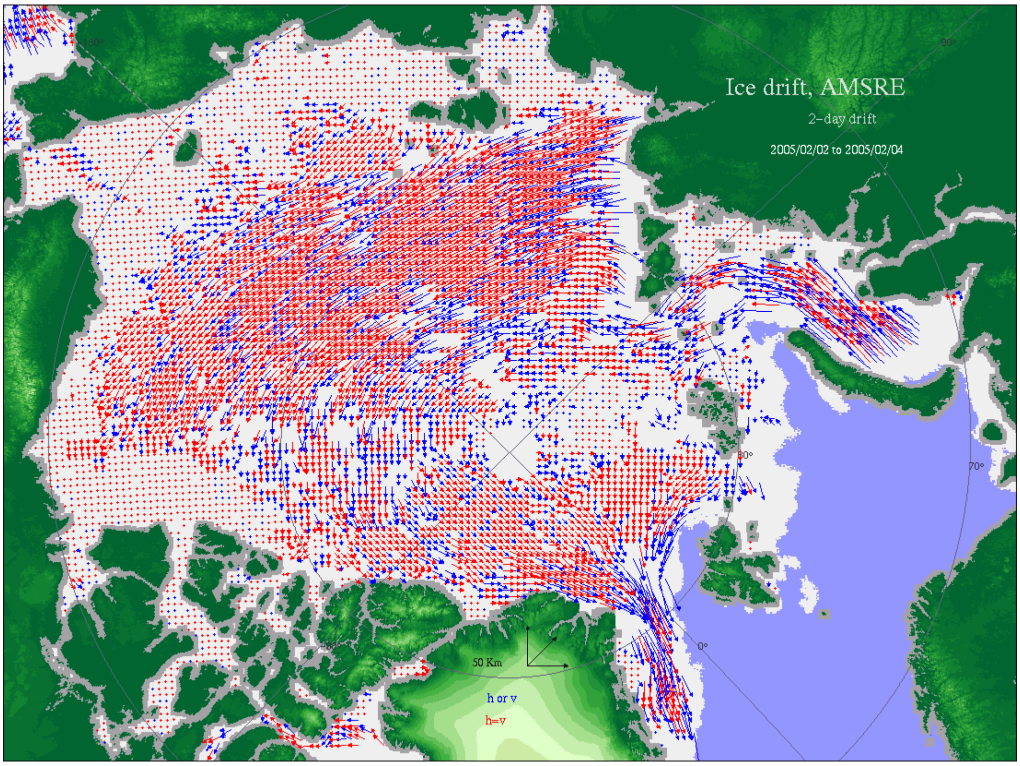

Figure 6 : Arctic sea ice drift from AMSR-E at 3 day-lag February 2nd-5th, 2005. Drift vectors less than one pixel are marked with a cross. In red : identical drift for horizontal & vertical polarizations, in blue : selection or validation of one polarization.

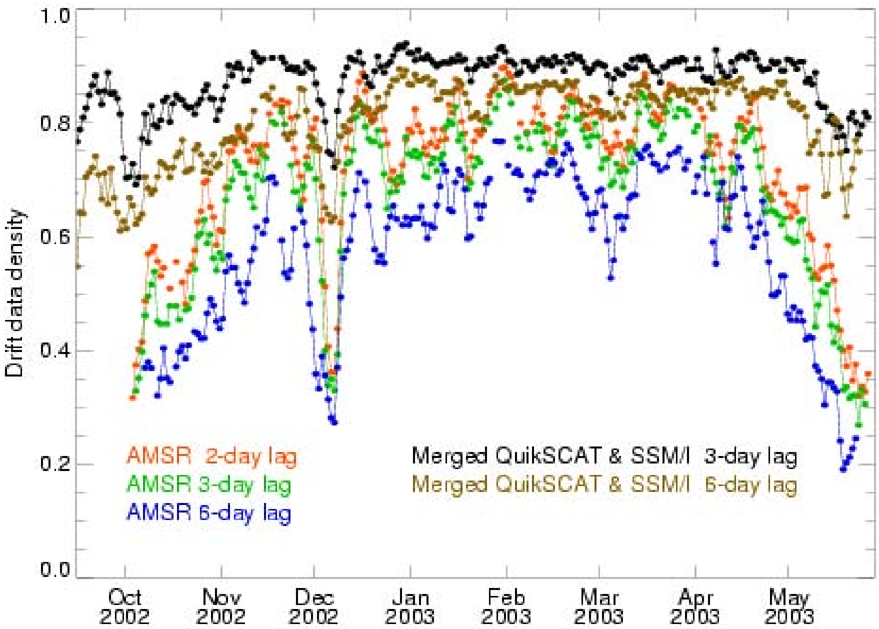

Figure 7 : Times series of drift data density for the 2002-2003 winter for AMSR-E and Merged at 2, 3 and 6 day-lags.

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