RELATIVE DISPERSION ANALYSIS OF GLAD SURFACE DRIFTERS IN THE GULF OF MEXICO

Agnese Pini [1], Giovanni Leuzzi [1] & Paolo Monti [1]

(1) Dipartimento di Ingegneria Civile, Edile e Ambientale, Università degli Studi di Roma "La Sapienza, Roma, Italia

KEY POINTS:

- *Relative dispersion analysis of the Lagrangian dataset derived from the GLAD drifter campaign in the Gulf of Mexico was computed on pairs derived from actual triplets*
- *The results show that an exponential growth of the relative dispersion begins and occurs within the first two days of deployment*
- *The influence of inertial motions should be taken into account in order not to overestimate turbulence diffusivities*

1 INTRODUCTION

Dispersion and transport of pollutants in the marine environment are governed by turbulence. Specifically, at the surface boundary layer, dispersion phenomena are determined by the interaction of different forcings as currents, waves and winds. An accurate prediction of pollutant pathways and concentrations is fundamental in the planning of search-and-rescue activities in case of accidental release of pollutants. At present, the study and simulation of dispersion processes is mainly carried out using Lagrangian stochastic models (*Monti & Leuzzi*, 2010; *De Dominicis .et al*, 2012). In the Lagrangian approach, particle transport is due to an average motion produced by the advection of the mean current field and a fluctuating contribution due the sub-grid scale diffusion. Data obtained from field campaigns realized with drifters is widely used and recognized useful in order to follow the Lagrangian analysis. Drifter trajectories are, in fact, a direct Lagrangian datum, they are representative of whole turbulent dispersion phenomena and reflect all forcing contributions. In particular, drifter campaigns set with a large number of satellite-tracked instruments allow to evaluate turbulence parameters derived from statistical analysis of absolute and relative dispersion. In numerous previous studies (*La Casce & Ohlmann*, 2003; *La Casce*, 2008), the absolute and relative dispersion analysis of various dataset was conducted providing a good comprehension of dispersion dynamics for large spatial scales (mesoscale). On the contrary, investigation of turbulence dispersion for smaller spatial and temporal scales remains an open issue.

In the present work the statistical analysis, based on the relative dispersion theory, of the dataset derived from the GLAD campaign in the Gulf of Mexico is conducted in order to obtain turbulence parameters useful to the implementation and development of Lagrangian dispersion models. The analysis was carried out to verify the accordance with the different dispersion regimes known in the literature, focusing on the earliest phase of dispersion. The aim was to confirm the usefulness of Lagrangian experiments realized with satellite-tracked drifters and, at the same time, to highlight advantages and limitations of these campaigns concerning the way they were conducted. In this work, information about the GLAD campaign (release, instruments, data processing) was presented as well as results concerning relative dispersion and diffusivity of the dataset.

2 DATA

The data used in the present work derived from the GLAD campaign conducted in the Gulf of Mexico in 2012 by CARTHE Consortium. The GLAD experiment consisted of deployment of about 300 surface drifters in the northern Gulf of Mexico in the same area (De Soto Canyon) and period of the year when the Deepwater Horizon's accident occurred in 2010. Drifters were released through three different launches within 20 and 31 July 2012 and followed for about three months. For the first two launches (S1 and S2) a S-configuration realized within an area ~ 8x10 km and made up of 10 nodes spaced at 2 km was used. Each node of the scheme consisted of nine drifters organized in nested triplets. The S-shaped deployment allowed to obtain a roughly initial distance between drifters of about 100 m and a near-simultaneous release of 90 drifters for each launch. The release duration for the first launch (S1) was ~ 5 h, while for the second one

(S2) was ~ 4 h.

Drifters of the GLAD campaign were CODE-type, similar to those used in the COastal Dynamics Experiment (CODE) in the early 1980s (*Davis*, 1985), designed to follow the surface circulation in the presence of wind and surface waves, with submerged sails ~1 m deep by 1 m wide. Each GLAD drifter was equipped with a SPOT GPS unit programmed to sample position every δt=316 s on average, with a nominal position accuracy of 6.4 m. The data positions were collected at 5 min intervals (*Poje et al.*, 2014). Post-processing operations were applied to 5 min-trajectories to eliminate outliers in position, velocity and rotation of drifters. Valid data were spline-interpolated to obtain uniform 5 min interval data then filtered with a Butterworth forth-order low pass with 1-h cut-off period. At last interpolated to 15 min intervals. GLAD dataset, publicly available and used in this work, hence reports: drifter identification number, date, time, position, velocity and estimates errors at 15 min intervals (*Ozgokmen*, 2012).

3 THEORY

Dispersion and transport of a tracer in a turbulent flow can be studied both through absolute or relative dispersion theory. The dispersion of a pollutant depends on the size of the cloud with respect to the integral time scale of turbulence. Relative dispersion takes into account of this behaviour. In the present work the GLAD dataset was investigated considering the relative dispersion of drifter triplets.

Relative dispersion theory is closely linked to the turbulence theory, it originates from experimental studies of *Richardson* (1926) in which he observed that the relative diffusivity was scale-dependent as it increases with the plume width. This relation, described by Richardson's Forth-Thirds Power Law was later proved to be consistent with Kolmogorov's turbulence theory.

The relative dispersion (mean square pair separation) gives information about how particles separate as a function of time and is defined as:

$$\left\langle r^2 \right\rangle = \frac{1}{N_p} \sum_{i \neq j} (x_i - x_j)^2 + (y_i - y_j)^2 \quad (1)$$

where the sum is over all pairs of particles and *Np* is the number of pairs.

The relative diffusivity can be defined as:

$$K = \frac{1}{2} \frac{d}{dt} \left\langle r^2 \right\rangle \quad (2)$$

At last, the relative velocity variance (mean square separation velocity) is defined as:

$$\left\langle v^2(t) \right\rangle = \frac{1}{N_p} \sum_{i \neq j} (u_i(t) - u_j(t))^2 \quad (3)$$

where u_i and u_j are the individual velocities. It represents the separation velocity of particles pairs undergoing relative dispersion as a function of time.

It is widely known in the literature (*La Casce*, 2008) that relative dispersion is a function of time and pair separation. As observed by other authors (*Koszalka et al.*, 2009) the relative dispersion as well as diffusivity exhibits different growth phases depending on pair distance. In an initial phase, when pair separations between particles are greatly smaller in size than turbulent eddies that dominate dispersion, the relative dispersion increases exponentially in time and the diffusivity exhibits a quadratic grown. Then, when pair separation increases and is similar in size with the turbulent scales, individual velocities are still correlated but the relative dispersion increases cubically in time, and the relative diffusivity grows as the Richardson's Forth-Third Power Law. At last, when particle separations are larger than the size of dominant eddies, velocities are uncorrelated, the dispersion increases linearly with time and the diffusivity is constant.

4 RESULTS

The relative dispersion analysis of the GLAD dataset was conducted by examining separately the two launches, S1 and S2. Also zonal and meridional directions were distinguished in order to find out a possible anisotropy of the dispersion.

Relative dispersion and diffusivity were directly computed from drifters pairs derived from triplets actually realized in S1 and S2 launches. Each identified triplet, once determined its center of gravity, provided three pairs made up of an actual drifter and its center of gravity at every time step (Δt=15 min). This "chance pair" was analytically verified to be in accordance with theoretical relations valid for pairs and allowed to obtain smaller initial separation distance (~31 m and ~18 m for pairs of S1 launch in zonal and meridional direction respectively, ~48 m and ~36 m for S2 launch in zonal direction and meridional direction). The entire flying time of the GLAD dataset was investigated (~50 days for S1 launch, ~80 days for S2 launch), considering different time intervals in order to catch different dispersion regimes. The focus was carried out on the first 25 days of the trajectory development to guarantee a fair density of data. From the release up to day 10, 84 pairs for S1 statistics and 84 pairs for S2 statistics were available, then pairs decrease up to 48 for the S1 launch and to 78 for the S2 one until day 25.

Relative dispersion is presented in Fig.1, results for S1 and S2 launches both zonal and meridional directions are shown in panel (a). In panel (b) the relative dispersion is highlighted for zonal direction and both launches for the first two days of deployment. In this initial phase the dispersion exhibits an exponential growth, as shown by the exponential curve which well fits both curves. This result, differently from previous works (*La Casce & Ohlmann*, 2003; *Koszalka et al.*, 2009), confirms quantitatively that the dispersion exponential growth begins and occurs within these first two days. In panel (c) the relative dispersion growth is pointed out, for S1 and S2 launches in the zonal direction, from day 2 up to the last day considered. In this phase the relative dispersion shows a cubic growth with time that evidences the occurrence of the Richardson's regime. These results are similar to what observed by *La Casce & Ohlmann* (2003) except for the best-fit exponent of the power-law that was here found of about 3.1 instead of about 2.2. Furthermore, in the time period considered, it was not found the evidence of a dispersion growth decrease to a linearly growth with time as predicted for the diffusive regime.

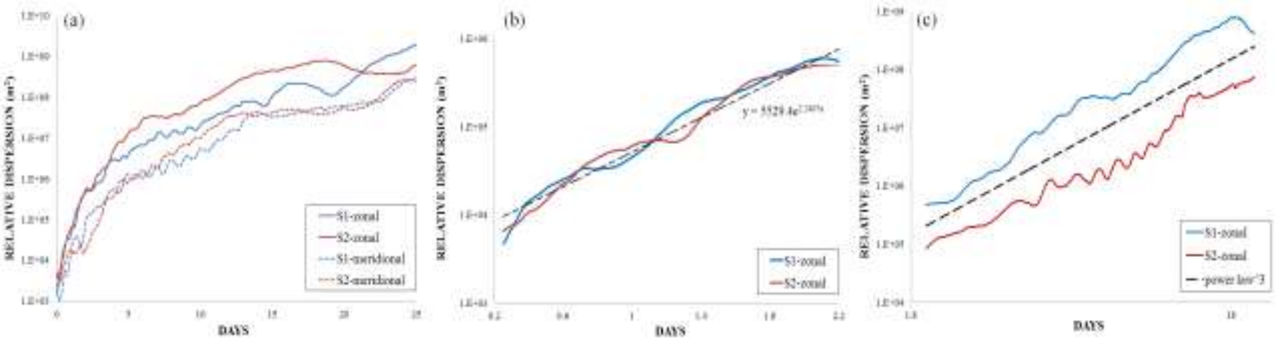

Figure 1 : relative dispersion for S1 (blue) and S2 (red) launch in zonal (solid) and meridional (pointed) direction, panel (a); relative dispersion for S1 (blue) and S2 (red) launch in the zonal direction for the first two days in panel (b) and from day 2 up to day 22 in panel (c).

Relative diffusivity is presented in Fig. 2. Results for the zonal direction of both launches are shown in panel (a) referring to the first 25 days; in panel (b) and (c) for the first two days of deployment and from day 2 up to day 25, respectively. During the initial phase the relative diffusivity presents a nearly quadratic growth as a function of the average pair distance of the drifters. In contrast, in the subsequent phase, when relative dispersion was found to increase cubically with time, the relative diffusivity grows nearly as Richardson's Forth-Third Power Law. This results is similar to what observed by other authors in different domains (*La Casce*, 2008; *Koszalka et al.*,2009).

The relative velocity variance (not shown) exhibits a linear growth with pair separation distance.

All the turbulence parameters inferred by the GLAD dataset analysis show the clear influence of inertial oscillations. Investigation of the possible dispersive contribution of these motions is a crucial issue for both numerical and experimental studies, as it is at present unclear and requires further study.

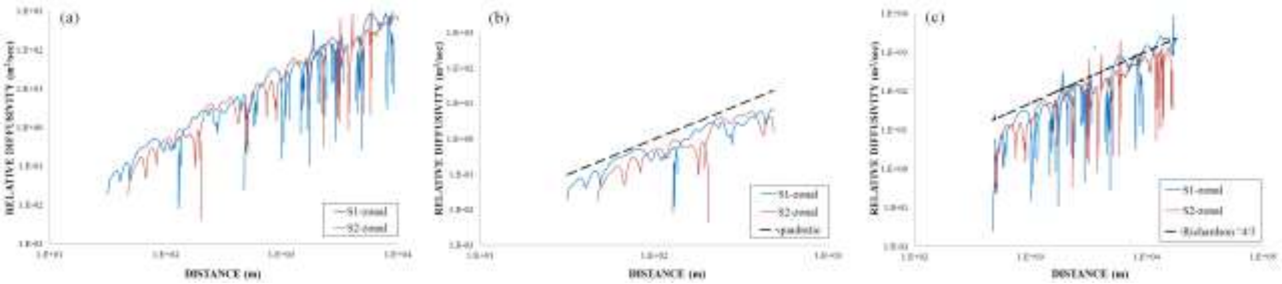

Figure 2 : relative diffusivity vs. pair distance for S1 (blue) and S2 (red) launch in zonal direction in panel (a); relative diffusivity for S1 (blue) and S2 (red) launch in the zonal direction for the first two days in panel (b) and from day 2 up to day 22 in panel (c).

5 CONCLUSIONS

In the present work the statistical analysis of the GLAD experiment dataset was conducted focusing on the pair dispersion of drifters. The principal aim was to confirm the usefulness of Lagrangian experiments as tools of analysis in the study of turbulence and dispersion. Specifically it is worth noting the value added by the way the GLAD campaign was conducted. The near-simultaneous release of such a large number of instruments allowed to investigate smaller turbulence scales otherwise detectable. The choice to evaluate dispersion through the relative approach allowed to focus on sub-mesoscale turbulence that, at present, is not completely clear and resolved. We carried out the analysis of the dataset in order to obtain estimates of the relative dispersion, the relative diffusivity and the relative velocity variance. Statistics were computed over all the pairs (drifter-triplet center of gravity) deducted from S1 and S2 triplets. Experimental observations were compared with the dispersion regimes predicted by the relative dispersion theory. Different growth regimes with related time scales and growth's laws were pointed out. The presence and influence of inertial motions on turbulence parameters was observed. This suggests the need for further analysis in order to properly take into account the dispersive contribution of these motions in numerical modelling as well as to evaluate algorithms, efficiently and physically based, for filtering inertial oscillations. This could allow to catch in the experimental data smaller turbulence structures whose contribution to dispersion is otherwise shaded by the inertial motion.

REFERENCES

Monti, P. & Leuzzi, G. Lagrangian models of dispersion in marine environment, Environ. Fluid. Mech., 2010, 10, pp.637-656.

De Dominicis, M., Leuzzi, G., Monti, P.,Pinardi, N. & Poulain, P. M. Eddy diffusivity derived from drifter data for dispersion model applications, Ocean. Dynam., 2012, 62, pp.1381-1398.

La Casce, J. H. & Ohlmann, C. Relative dispersion at the surface of the Gulf of Mexico, J. Mar. Res., 2003, 61, pp. 285-312.

La Casce, J. H. Statistics from Lagrangian observations, Progr. Oceanogr., 2008, 77, pp.1-29.

Davis, R. E. Drifter observations of coastal surface currents during CODE: the method and descriptive view, J. Geophys. Res., 1985, 90, pp.4741-4755.

Poje, A. C., Ozgokmen, T. M., Lipphardt, B. L., Haus, B. K., Ryan, E. H., Haza, A. C., Jacobs, G. A., Reniers, A. J. H. M., Olascoaga, M. J., Novelli, G., Griffa, A., Beron-Vera, F. J., Chen, S.S., Coelho, E., Hogan, P. J., Kirwan, A. D., Huntley, H. S. & Mariano, A.J. Submesoscale dispersion in the vicinity of the *Deepwater Horizon* spill, Proc. Natl. Acad. Sci. U.S.A., 2014, 111, pp. 12693-12698.

Ozgokmen, T. CARTHE: GLAD experiment CODE-style drifter trajectories(low-pass filtered, 15-min interval records), northern Gulf of Mexico near DeSoto Canyon, July-October 2012, Gulf of Mexico Research Initiative, 10.7266/N7VD6WC8. Available at https://data.gulfresearchinitiative.org/data/R1.x134.073:0004, 2012.

Richardson, L. F., Atmospheric diffusion on a distance-neighbour graph, Proc. R. Soc. Lond. A, 1926, 110, pp. 709-737.

Koszalka, I., La Casce, J. H, Orvik, K. A. Relative dispersion in the Nordic Seas, J. Mar. Res., 2009, 67, pp. 411-433.