IMPACT OF FILAMENTS ON THE RELATIVE DISPERSION OF SURFACE DRIFTERS IN THE BENGUELA UPWELLING REGION

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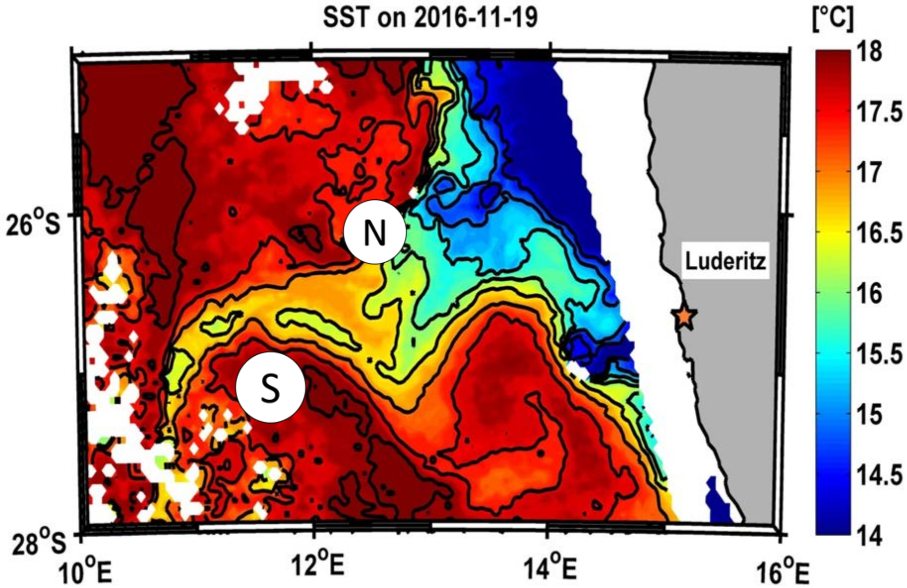
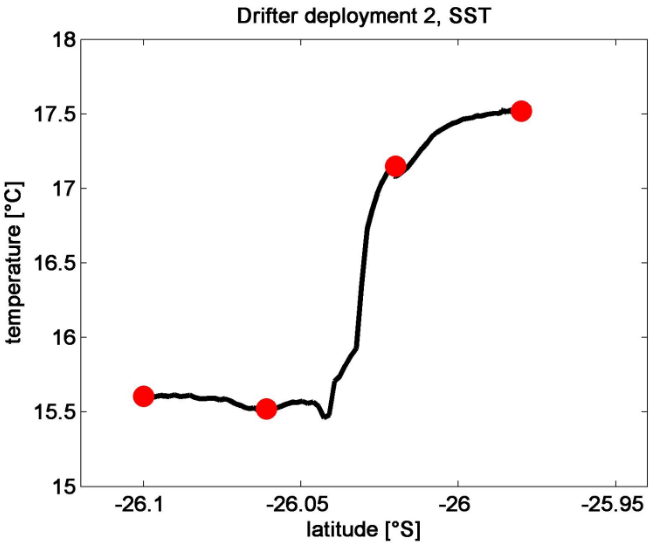
Overview

- Surface drifter experiment in the Benguela upwelling region
- (Relative) dispersion of pairs of drifters:
    - fixed times analysis: mean squared pair separations
    - fixed scale analysis: Finite Size Lyapunov Exponents (FSLEs)
- Mean squared pair separations: Different dispersion regimes
- Anomalous diffusion
- Do Finite Size Lyapunov Exponents yield consistent results ?
- Analysis of drifter subsets: dependence on deployment location
- Do our data show local (Richardson) dynamics?
- Conclusion

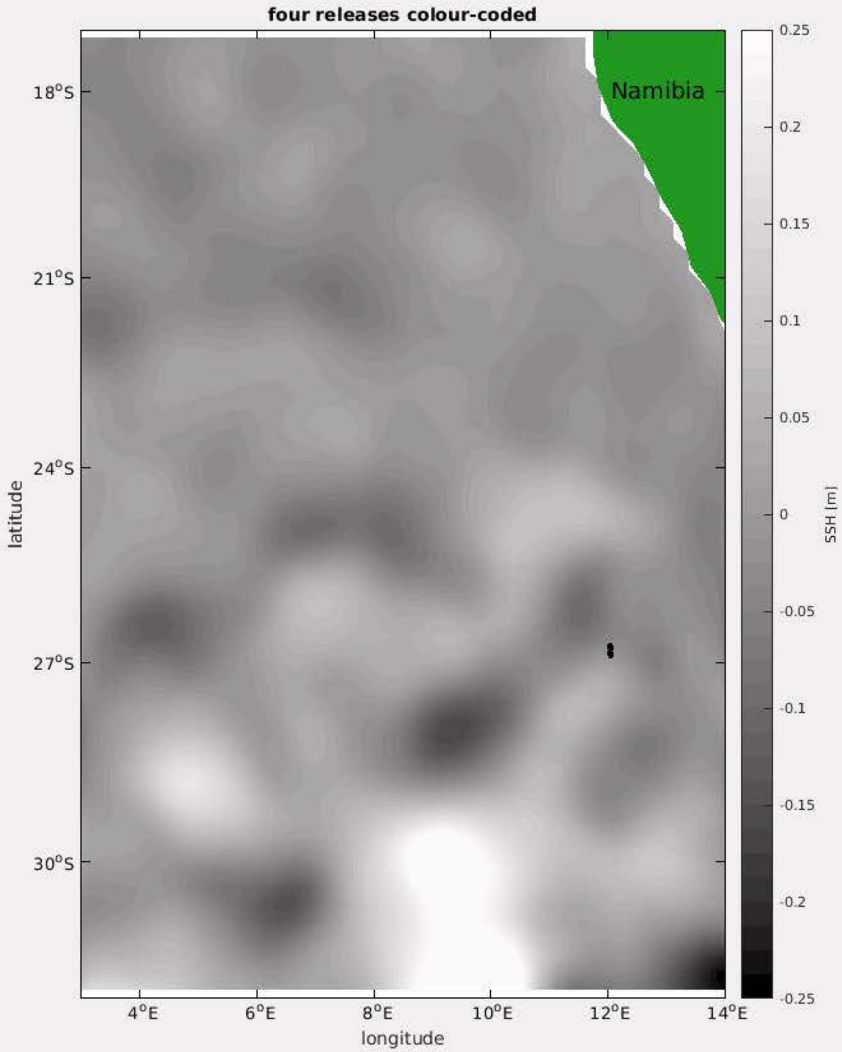
Upwelling water front off Namibia's coast with filament



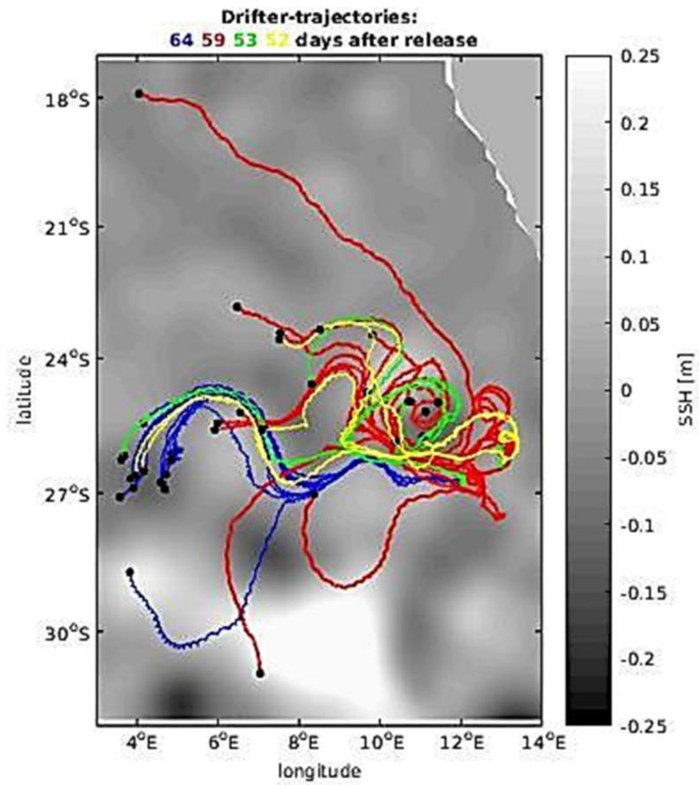


SST along ship track.
Red dots: triplet-deployments

36 surface drifters were released in 4 groups (12/12/6/6 drifters) of triplets, with initial distance of 100 m –500 m. *Deployment locations: southern boundary (27°S,12°E)* S, *northern boundary (26°S,13°E)* N


four releases colour-coded
Namibia
18°S
21°S
24°S
27°S
30°S
latitude
4°E
6°E
8°E
10°E
12°E
14°E
longitude
0.25
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
-0.25
SSH [m]

Drifter trajectories from cruise M132 in the area off Namibia‘s coast *in november/december 2016*



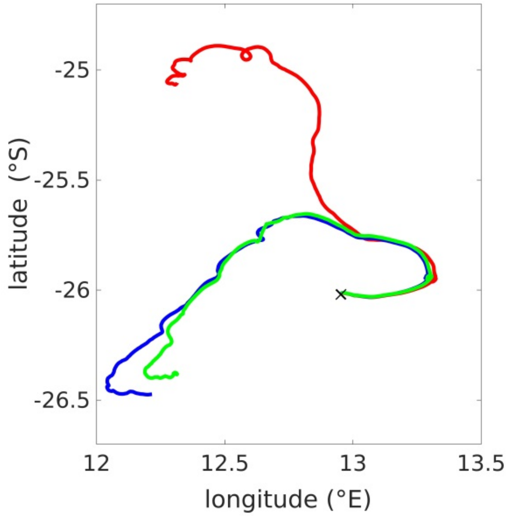
Lagrangian analysis

Pair separation statistics yield information about the dominant physical mechanisms acting at the different scales of motion (e.g. chaotic advection, turbulence, diffusion) in specific regions

- fixed time measure:
  Mean squared pair separation $< s^2\ (t) >$

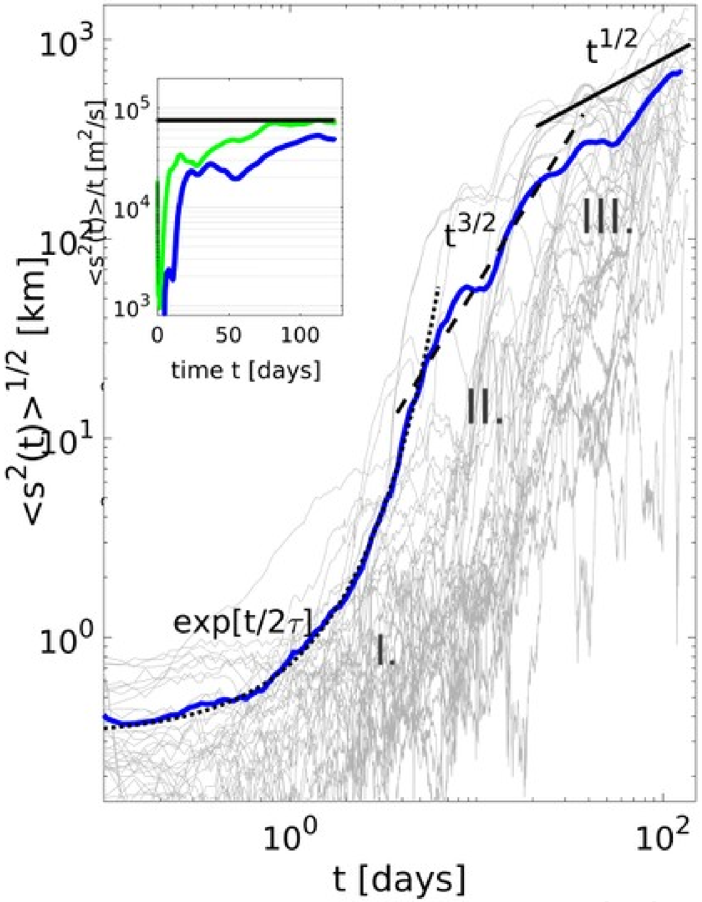
- Fixed scale measure:
  Finite size Lyapunov exponents $\lambda(\delta) = \frac{1}{\langle\tau(\delta)\rangle}\ln(\alpha)$

  $\langle\tau(\delta)\rangle$= averaged time for drifter-pairs, initially separated by distance δ, to reach distance $\alpha\delta$



What dispersion regimes can be detected (at what scales) ?
Do the two methods yield consistent results ?

Lagrangian root mean squared pair separation $< s^2(t) >^{1/2}$



	pair separations
I.nonlocal	$s{\sim}e^{t/\tau},\ \tau \cong 0.6\ days$
II. local	$< s^2 >= C\epsilon t^3$ $C\epsilon \cong 4.4\ x\ 10^{-9}\ W/kg$
III. diffusive	$< s^2 > = 2\kappa t,$ $\kappa \cong 3.7x10^4 m^2/s$

→ Nonlocal behavior for s < Rossby Radius R_1 (≅ 30 km)

Normal and anomalous diffusion

$$< r^2(t) >= 2\kappa\, t$$

- **Brownian motion** (Einstein, Ann. d. Phys., 1905)
- Deviation (diffusional anomalies)

  α > 1 (superdiffusion), κ(t) → t^{γ}

  α < 1 (subdiffusion), κ(t) → 0

$$< r^2(t) > \sim t^{\alpha}$$

experimentally observed in:

- α > 1 floating tracers in ocean (Osborne et al., Tellus ′ 89)
  rotating fluid flows (Solomon.. Phys. Rev. Lett.′ 93),
  sea ice (Gabrielsi, Badin, Kaleschke, J. o. Geoph. Res.′ 14)
- α < 1 polymer network (Amblard et al., Phys. Rev. Lett.′ 96)
  charge transport (Scher & Montroll Phys. Rev. B)

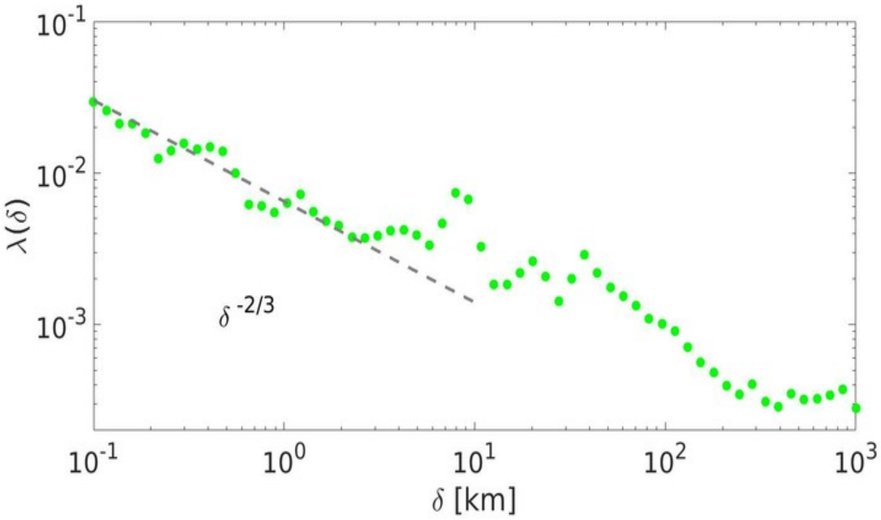
``Rules of thumb´´ for physical mechanism:

- α > 1: persistance of free paths (``Levy Flights´´)
- α < 1: geometric constraints (disorder or fractal)

→ strong diffusional anomaly $< r^2(t) > \sim \ln^{\alpha}(t)$ (Dräger & Klafter Phys. Rev. Lett.′ 00)

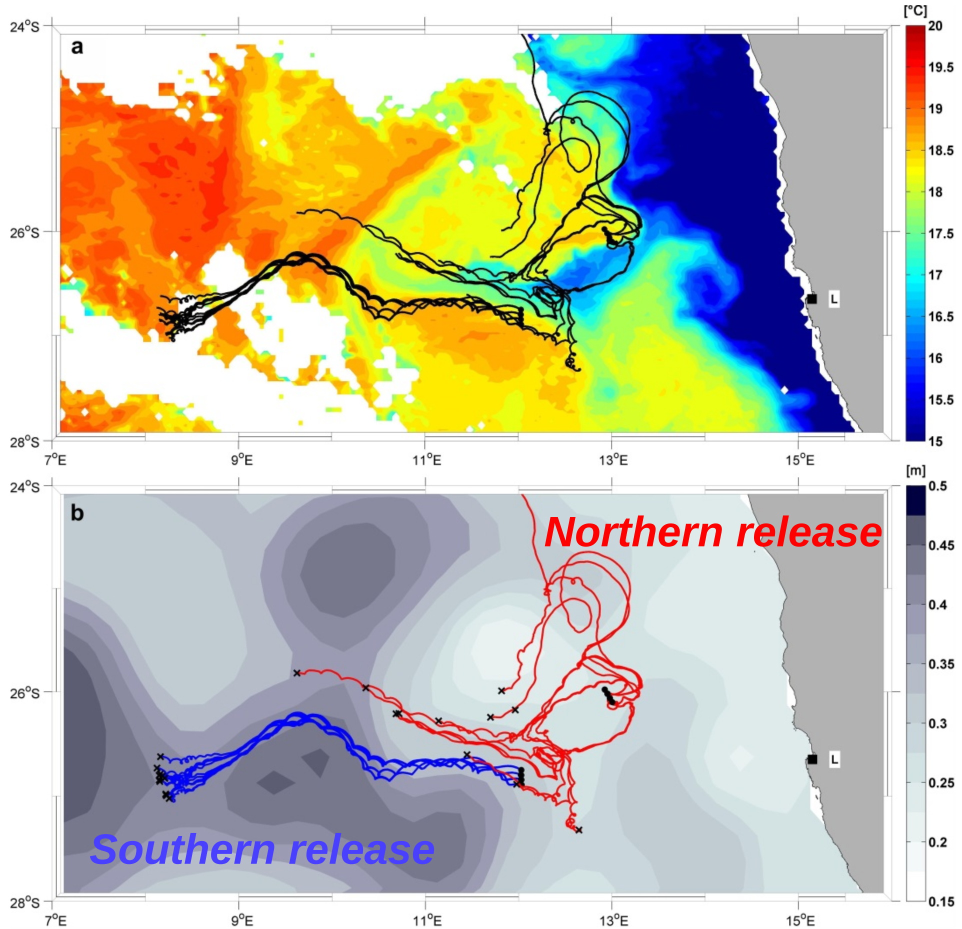
Finite Size Lyapunov Exponents

	pair separations	FSLE (expected)
I.Nonlocal	$s \sim e^{t/\tau}$	$\lambda(\delta) \sim const$
II.Local	$< s^2 > \sim t^3$	$\lambda(\delta) \sim \delta^{-2/3}$
III.Diffusive	$< s^2 > \sim t$	$\lambda(\delta) \sim \delta^{-2}$



Controversial results for small scales:
FSLEs $\lambda(\delta)$ point to local behavior, $<s^2(t)>$ to nonlocal behavior

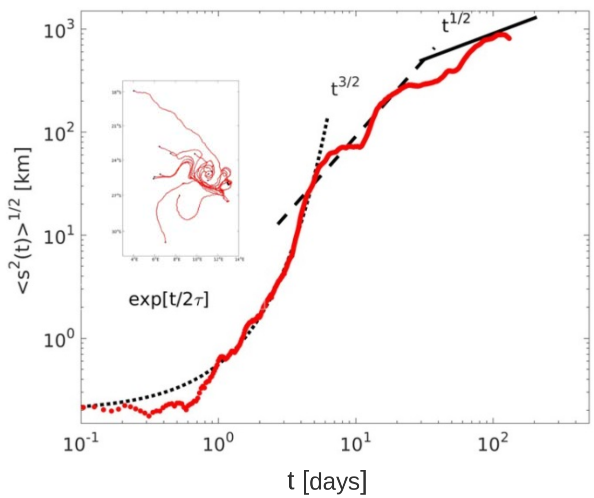
Different deployment scenarios:

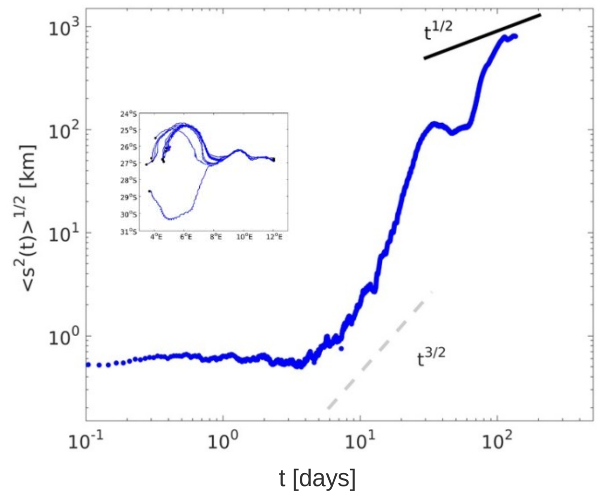


Dependence on deployment location

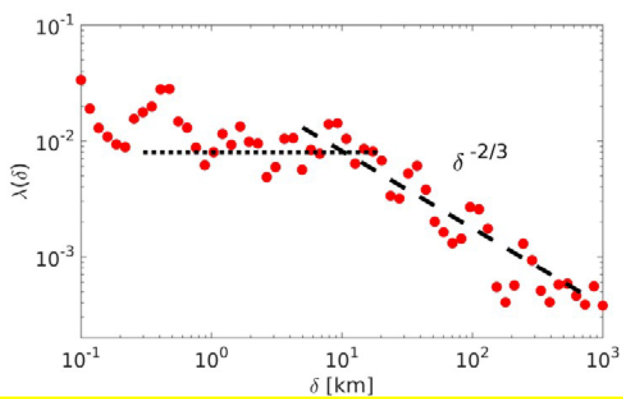
Northern release ***Southern release***

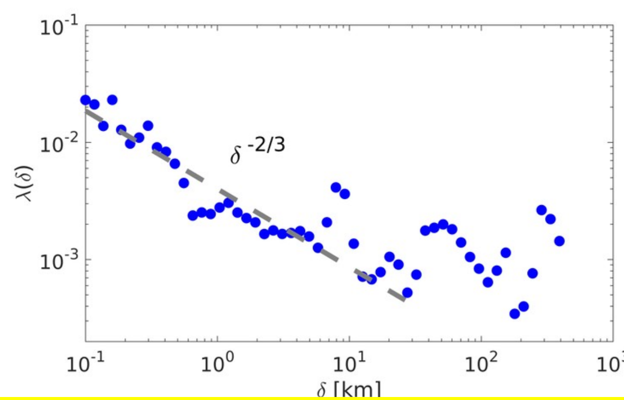
$< s^2\ (t) >^{1/2}$





FSLE
$\lambda(\delta)$





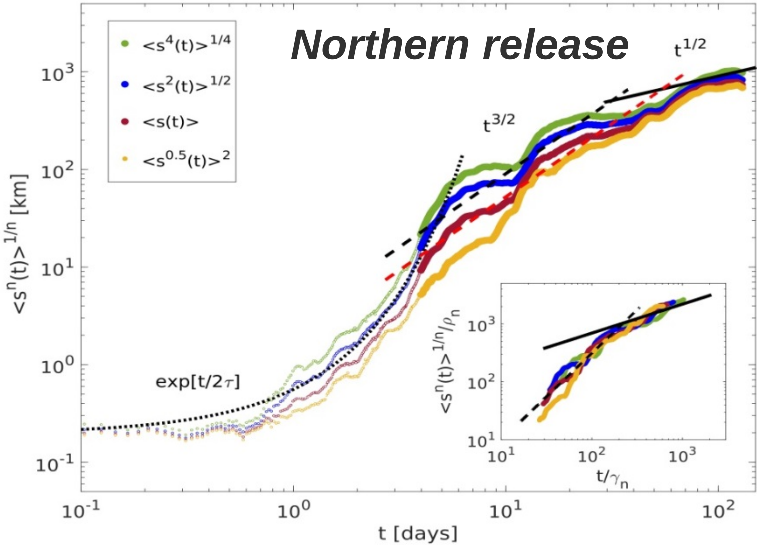
Consistent results for $< s^2\ (t) >$ and $\lambda(\delta)$,
when the methods are applied to the two releases ***separately***

Do our data show local (Richardson) dynamics? Below or above R_1? For both releases ?

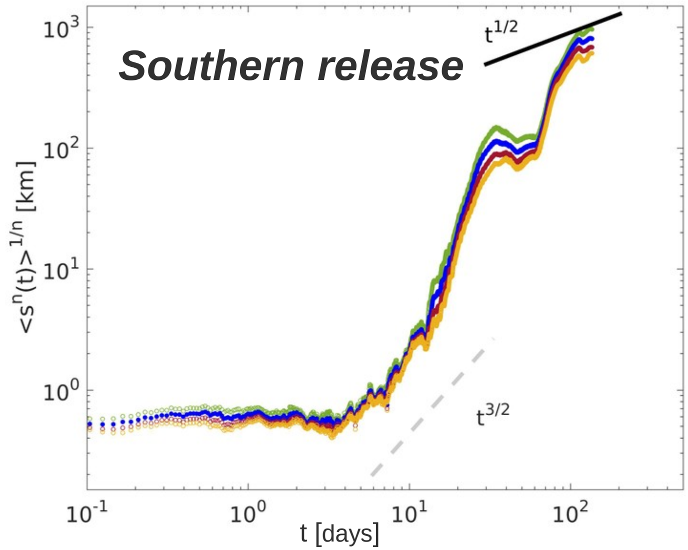
$<s^2(t)> \sim \epsilon t^3$ for s > R_1 (***northern release*** & whole ensemble)

$\lambda(\delta) \sim \delta^{-2/3}$ for $\delta \ll R_1$ (***southern release*** & whole ensemble)

Hallmark of local transport: anomalous broad distribution: $P(s|t) = \frac{s}{3}\left(\frac{b}{t}\right)^3 \exp\left[\frac{-bs^\beta}{t}\right]$, $\beta = 2/3$
Would be confirmed by datacollapse of moments $< s^n >$



YES



→ no intermittent Richardson dynamic

(Probably) No

Conclusions

- The Lagrangian squared pair separations $< s^2 >$ **averaged over all trajectories** show a nonlocal behavior for the first 4 days followed by a (local) Richardson regime (t^3- law) and a diffusive regime $< s^2 > \sim t$.

- In contrast the Finite Size Lyapunov-exponents (FSLE) $\lambda(\delta)$ are not constant for small δ, as expected for nonlocal transport, but decay as $\delta^{-2/3}$.

- The inconsistency originates in the strong influence of the location of deployment leading to a mixture of dynamics:
  $< s^2 (t) >$ is dominated by the northern (inertial) release due to scale separation
  $\lambda(\delta)$ reveals the small scale behavior ***within*** the filament (southern release)

- While the anomalous PDF (northern release) supports local transport for s > R_1 the narrow PDF (southern release) for small s questions submesoscale local dispersion.

J. Dräger, K. Jochumsen, A. Griesel and G. Badin submitted to Journal of Physical Oceanogrophy

Thank you!

The work presented here is a contribution to the project L3 (Diagnosing and parameterizing the effects of eddies) of the Collaborative Research Centre TRR 181 "Energy Transfer in Atmosphere and Ocean" funded by the German Research Foundation.

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The moments $\langle s^n(t)\rangle^{1/n}$ can be derived analytically straightforwardly from the theoretical forecast for $P(s|t)$ for the local (5)) and the diffusive regime (7), leading to

$$\langle s^n(t)\rangle^{1/n} = \begin{cases} i_n(t/b)^{3/2} & \text{for} \quad t < t_x(n) \\ k_n(2\kappa t)^{1/2} & \text{for} \quad t > t_x(n). \end{cases} \tag{8}$$

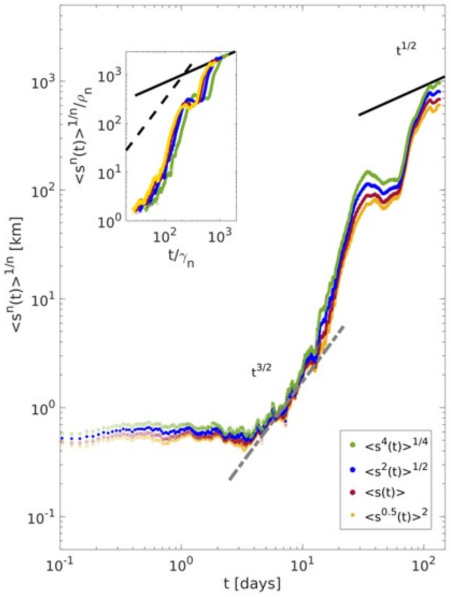
Here $i_n = (0.5\,\Gamma((\frac{n+2}{2})\ 3))^{1/n}$ and $k_n = \Gamma(\frac{n+2}{2})^{1/n}$ where $\Gamma(x)$ is the Gamma-function and with b defined in Eq. (5).

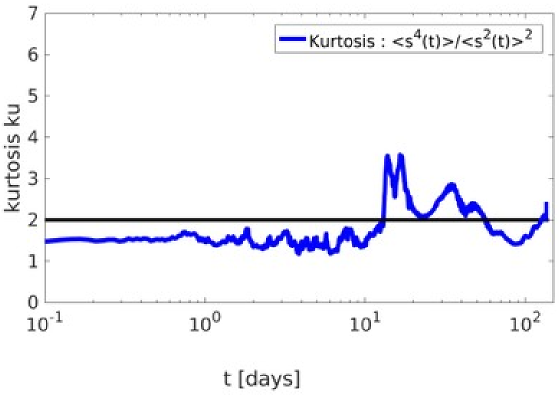
As the transition time $t_x(n)$ has to fullfill $i_n(t_x(n)/b)^{3/2} = k_n(2\kappa t_x(n))^{1/2}$, it is given by

$$t_x(n) = (2\kappa b^3)^{1/2}\gamma_n \tag{9}$$

with $\gamma_n = k_n/i_n$. Equations (8) and (9) indicate hat the transition time $t_x(n)$ from the local to the diffusive dispersion regime differs for the different moments $\langle s^n(t)\rangle^{1/n}$.

Local submesoscale features within the filament ?

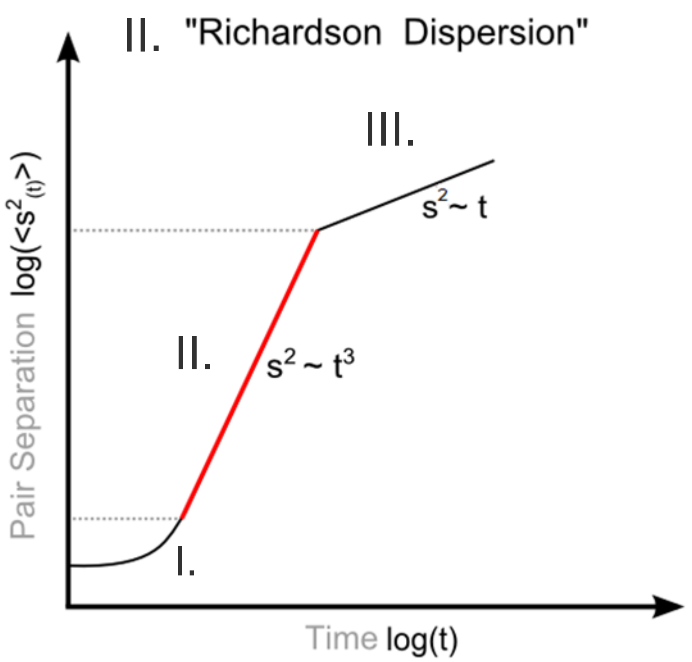




→ no intermittent Richardson dynamic

Mean squared pair separation: theoretical prediction

	fixed time measurement	fixed scale Measurement
I. nonlocal: s < eddies	$s \sim e^{t/\tau}$ τ =unfolding rate	$\lambda(\delta) = const$
II. local: (Richardson) s ≅ eddies	$< s^2 >= \epsilon t^3$ ϵ=energy transfer rate $P(s\|t) \sim e^{-bs^{2/3}/t}$	$\lambda(\delta) \sim \delta^{-2/3}$
III. diffusive s > eddies	$< s^2 > = 2\kappa t$ κ=relative diffusivity $P(s\|t) \sim e^{-cs^2/t}$	$\lambda(\delta) \sim \delta^{-2}$



$< s^2\ (t) >$: averaged squared separation of drifter-pairs, $\lambda(\delta)$: FSLE

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