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Data Analysis: Statistical Modeling and Computation in Applications

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3. Modelling Flow Data

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Exercises due May 19, 2021 19:59 EDT
Modelling Flow Data

[Video player]

▶ 11:58 / 11:58   ▶ 1.50x   🔊 ⛶ CC ❞
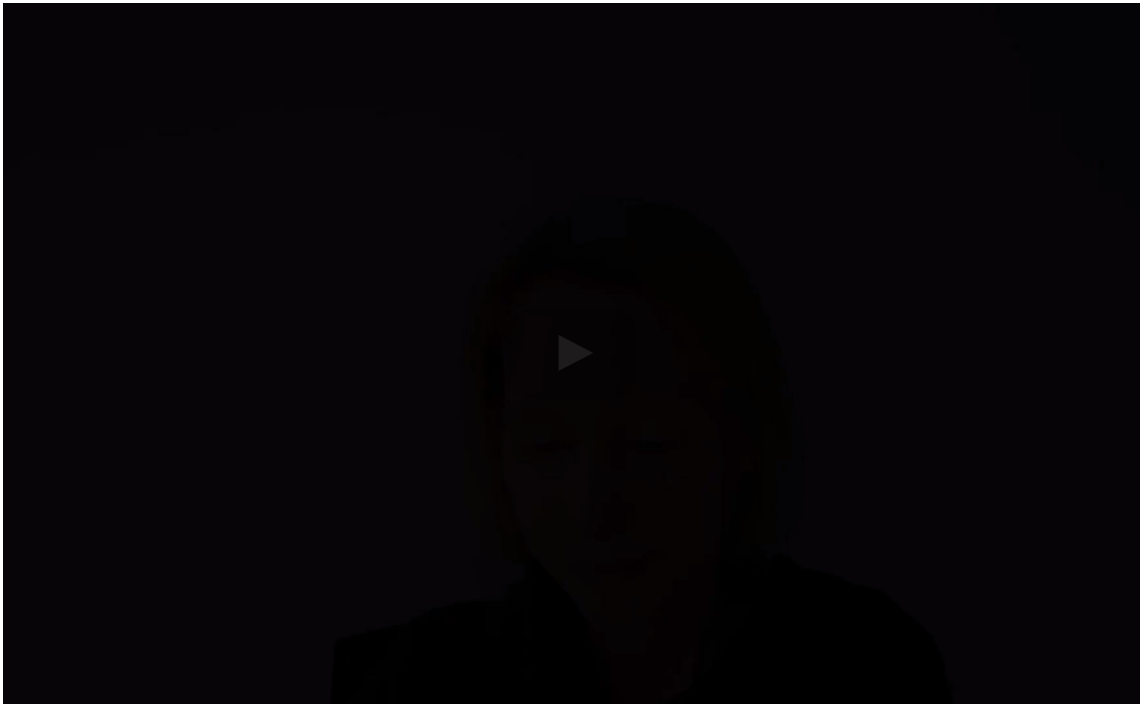
This was a real-world example of where actually simulations

of dynamics are used.

And if you look at [INAUDIBLE] guest lecture,

you will see many more examples of how, actually, simulations

and integration of statistical measurements

into these simulations can actually

help in many different applications

in understanding the ocean and in planning.

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Disclaimer: This section of the module is not a formal introduction to the analysis of flow data. We will not be discussing efficient computational approaches for modelling flows or their properties based on their partial differential equation representations. We provide a simple (maybe "naive") approach for the most basic setup on flow data.

We start by pointing to a great source for gaining a deeper understanding of flow dynamics and simulations. To the interested reader please see: Stam, Jos. "Stable fluids." Proceedings of the 26th annual conference on Computer graphics and interactive techniques 1999. Another interesting source for fluid simulations can be found in https://www.karlsims.com/flow.html

The below figure shows an example of the flow data we are going to work in this module. The data consists of water flow data around the Philippines with a number of attributes.
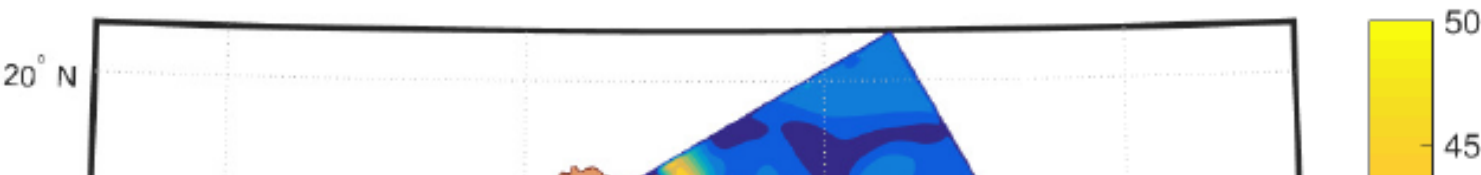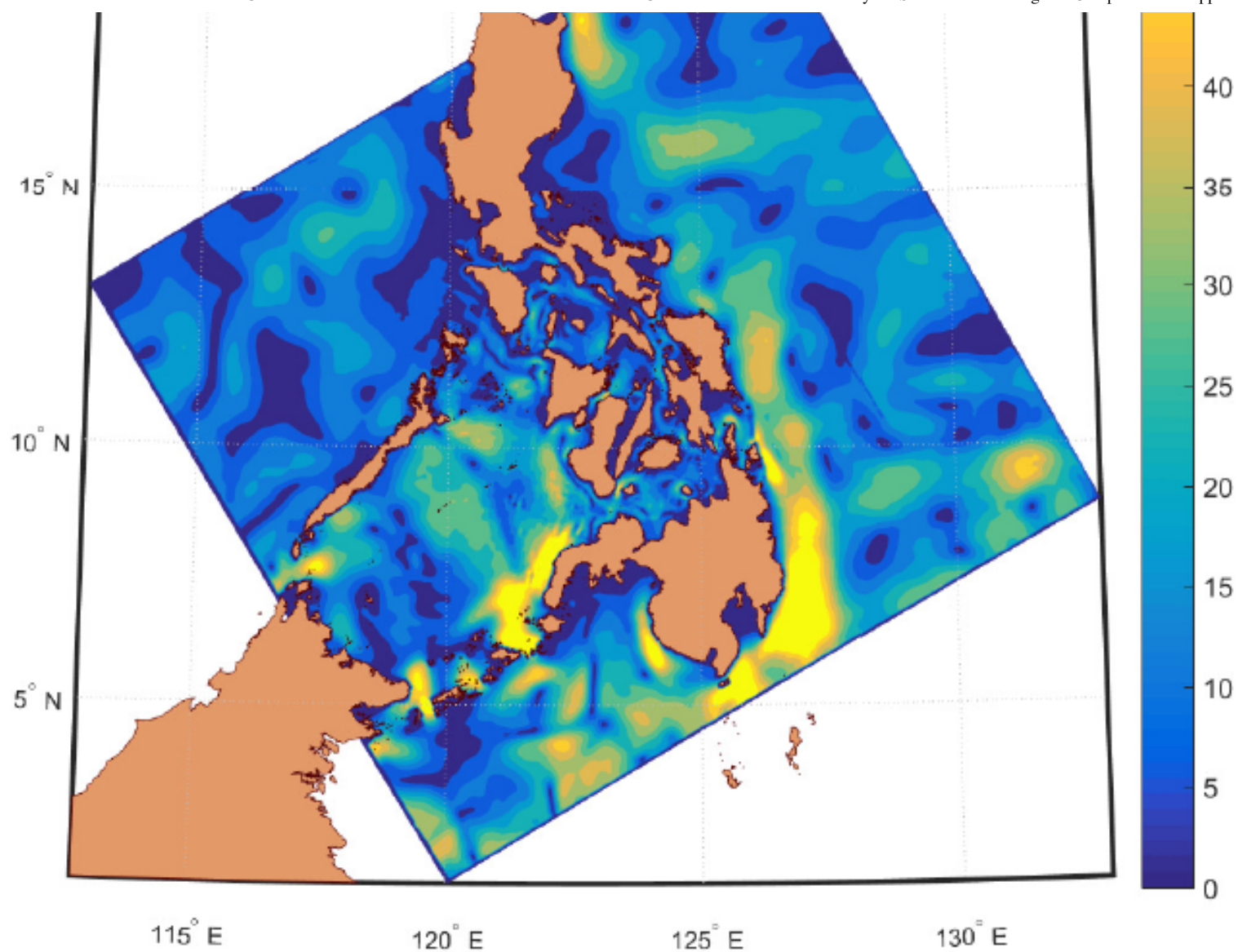
17: An example of flow data

The data is a flow field, which means that we have flow information for a number of discrete locations. Flow data means that we have a vector at each particular location that indicates the direction and magnitude of the flow, i.e., displacement in time, see the figure below.
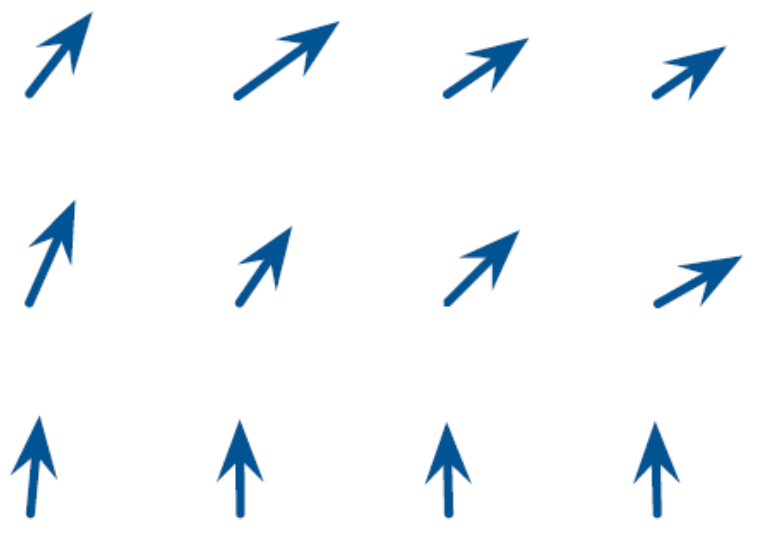
18: Example of flow dynamics

The flow refers to displacement in time, that is if $x(t)$ denotes the location of a particle at time t, then, we define the flow vector as

$$\frac{dx(t)}{dt} = V(x(t), t).$$

or similarly, their explicit Euler discretization as, for a small $\epsilon > 0$,

$$x(t + \epsilon) = x(t) + \epsilon V(x(t), t). \tag{7.1}$$

Lets discuss in more detail the meaning of this equation. Imagine that you are given flow information on a finite set of points, which might corresponds to different locations in a space, for example on a grid. This means that for each point you are given information about the flow direction and magnitude. If we constrain ourselves to the 2D space, this means that for each point of interest we are given a vector of two components, corresponding to the velocities in each of the axes. This creates a discrete vector field.

One important modeling assumption is that a particle in a specific location of a vector field will inherit the velocities of that particular location. Since we endow the particle with a particular velocity this causes some movement is induced. Lets say at time $t = 0$ we drop a particle at certain location $x(t = 0)$. Moreover, assume that we know the flow data says that a particle at location $x(t = 0)$ should be moving with velocity

$V(x(t=0), t=0)$. Now, we are interested in finding where will the particle be at some time instant $t + \epsilon$ for some small $\epsilon > 0$. We can simulate such movement and predict that $x(\epsilon) = x(0) + \epsilon V(x(0), 0)$.

Note that the velocity information not only depends on the location but in time as well, as the velocity of the flow might change with time. This means we have moved in time from $t = 0$ to $t = \epsilon$, and in space from $x(0)$ to $x(\epsilon)$. More importantly, now that the particle is at a new location $x(\epsilon)$ we need to check what the corresponding velocity is at that new location.

Also note that since the velocity or flow information might be given only for a discrete and finite number of points, a simple heuristic would be to find the closest point to $x(\epsilon)$ for which flow information is given, and assign this as the endowed velocity at that particular point. Some other more complex interpolating strategies could be used as well. If we repeat the process, we will generate a sequence of locations $\{x(k)\}$ for $k = 0, \epsilon, 2\epsilon, \cdots$, which will be the discretized simulated trajectory of the particle in the given flow.
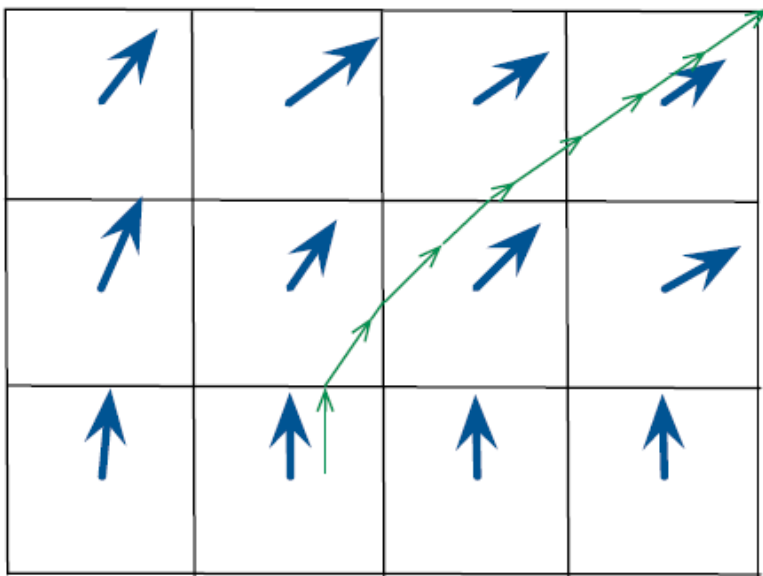
**19**: The evolution of a particle in the flow grid.

By simulating the dynamics of a particle on the flow vector field, we can obtain trajectories, as shown in the figure above.

The below figure shows some examples of a vector field with three different choices of grids.
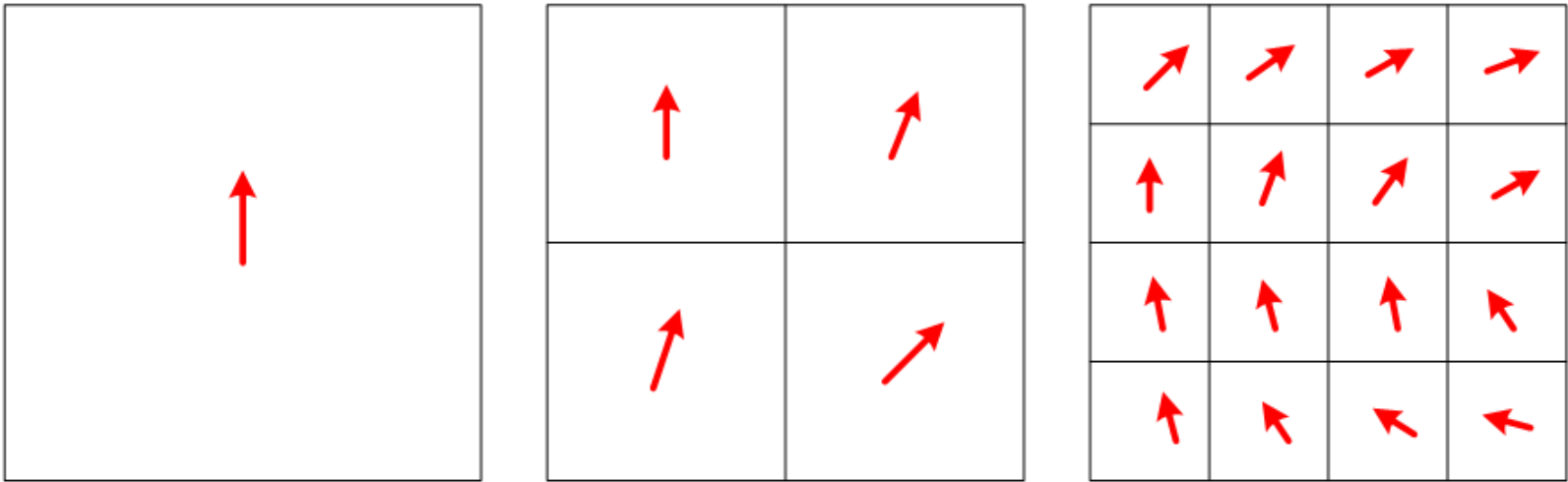
20: An example of three vector fields with different grids.

The below figure shows the simulated trajectories of a particle on the flow induced by the vector fields in the figure above. The starting points are shown as blue dots, and each of the green arrows represent the evolution of the particle over the vector field.
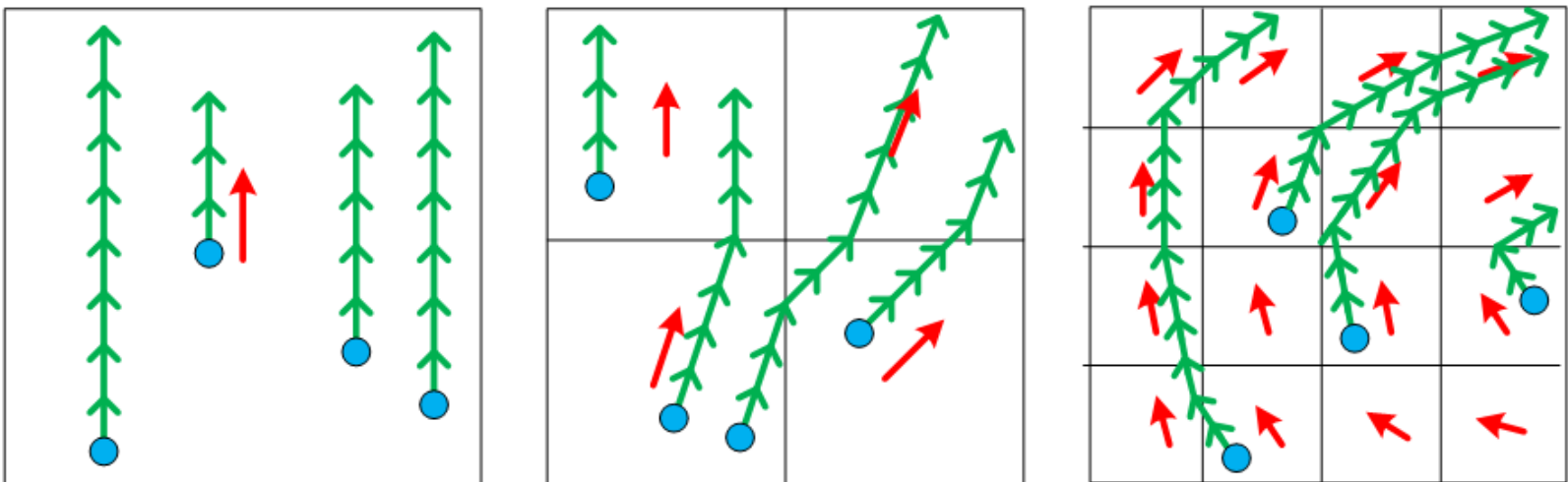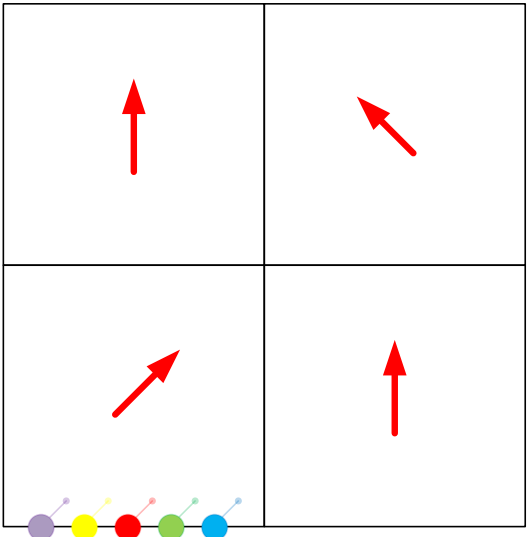

**21**: Examples of simulated trajectories.
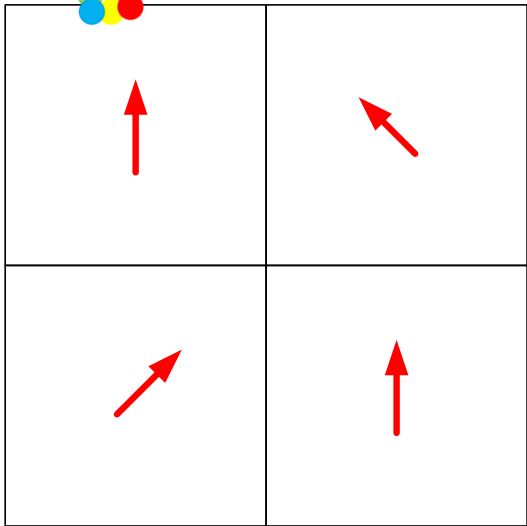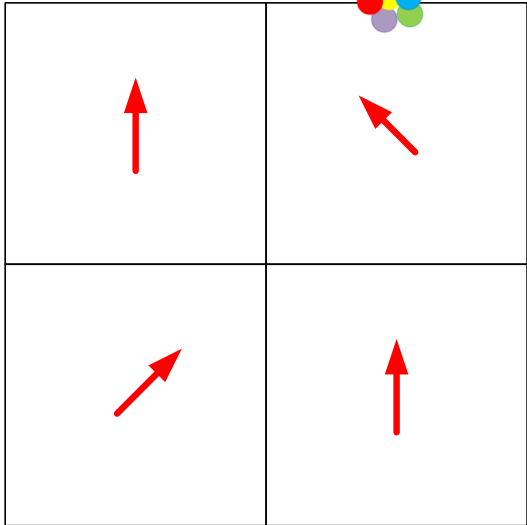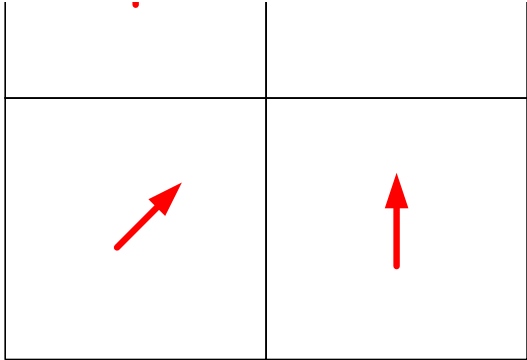
Flow Data

1 point possible (graded)

Consider the flow shown in the figure below, where a grid with four areas are shown with their respective flow data. Moreover, we are given the initial location of five particles shown as circles with different colors in the lower left hand corner.

22: An example of a flow and initial location of five particles

Which of the next options is the most likely location of the particles after some time has passed?
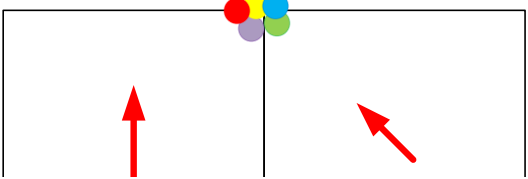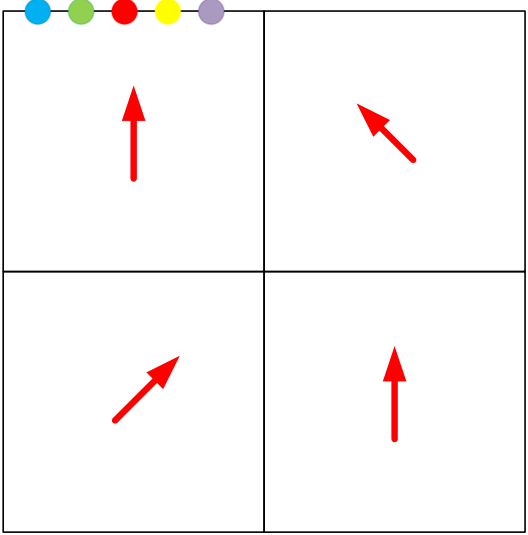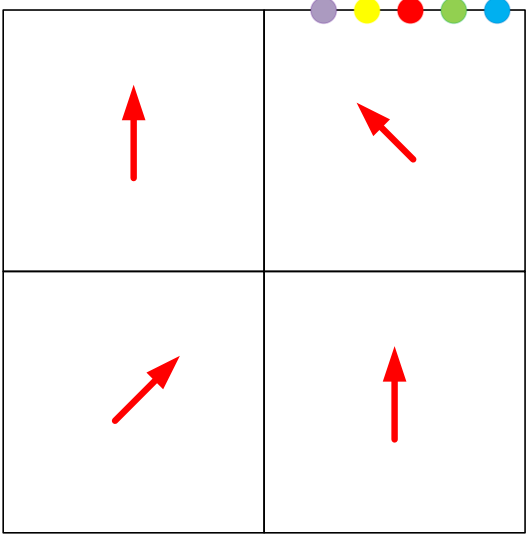
Submit   You have used 0 of 2 attempts

One particular use of simulating the dynamics of a particle given a flow data is for rescue operations. In this scenario, we are interested in finding the possible location of a particle-based on flow data and an estimated location at some timestamp. In this case, one might not have to evolve a single particle but a distribution. The computation of the evolution of entire distributions of over a flow field can be computationally expensive. Instead, one draws a number of samples from said distribution, and evolve their trajectories on the flow. Finally, one obtains a collection of trajectories, a sample of the new distribution based on the initial distribution.

Let us go a bit deeper into the uses of flow data in rescue operations. The figure below shows the original trajectory of the MH370 flight, which was set to go from Kuala Lumpur to Beijing. However, at some point, the plane took a turn and disappeared.

**23**: Planned route and actual route of MH370 according to radar.

About a year later, some pieces of the plane were found at a number of locations, as shown in the figure below.
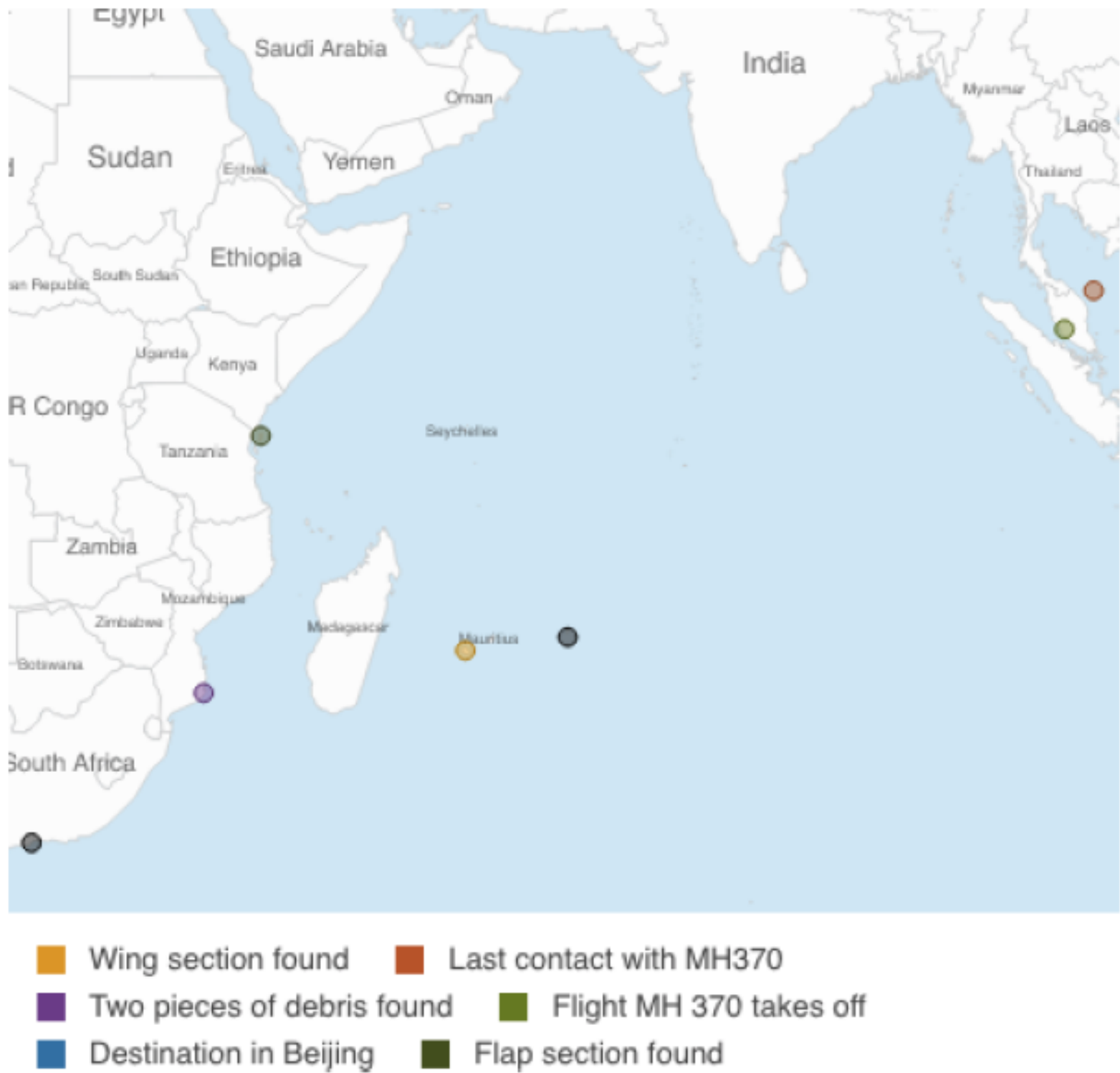

24: Locations of plane debris.

The question is: where can we target the search based on the locations of the found pieces, and time stamps? There are a number of uncertainties. Initially, one might not have exact time information about when the piece reached the location where it was found. Moreover, flow measurements and simulations are not exact, and several approximations and uncertainties are not taken into account. By sampling over time, one can obtain a number of trajectories, as shown in the figure below.

Simulated trajectories from combined CMEMS surface currents and ECMWF Stokes drift: objects were released in July 2015 around La Reunion and traced backwards in time

JV Durgadoo, S Ruehs & A Biastoch (GEOMAR), Mar 2016
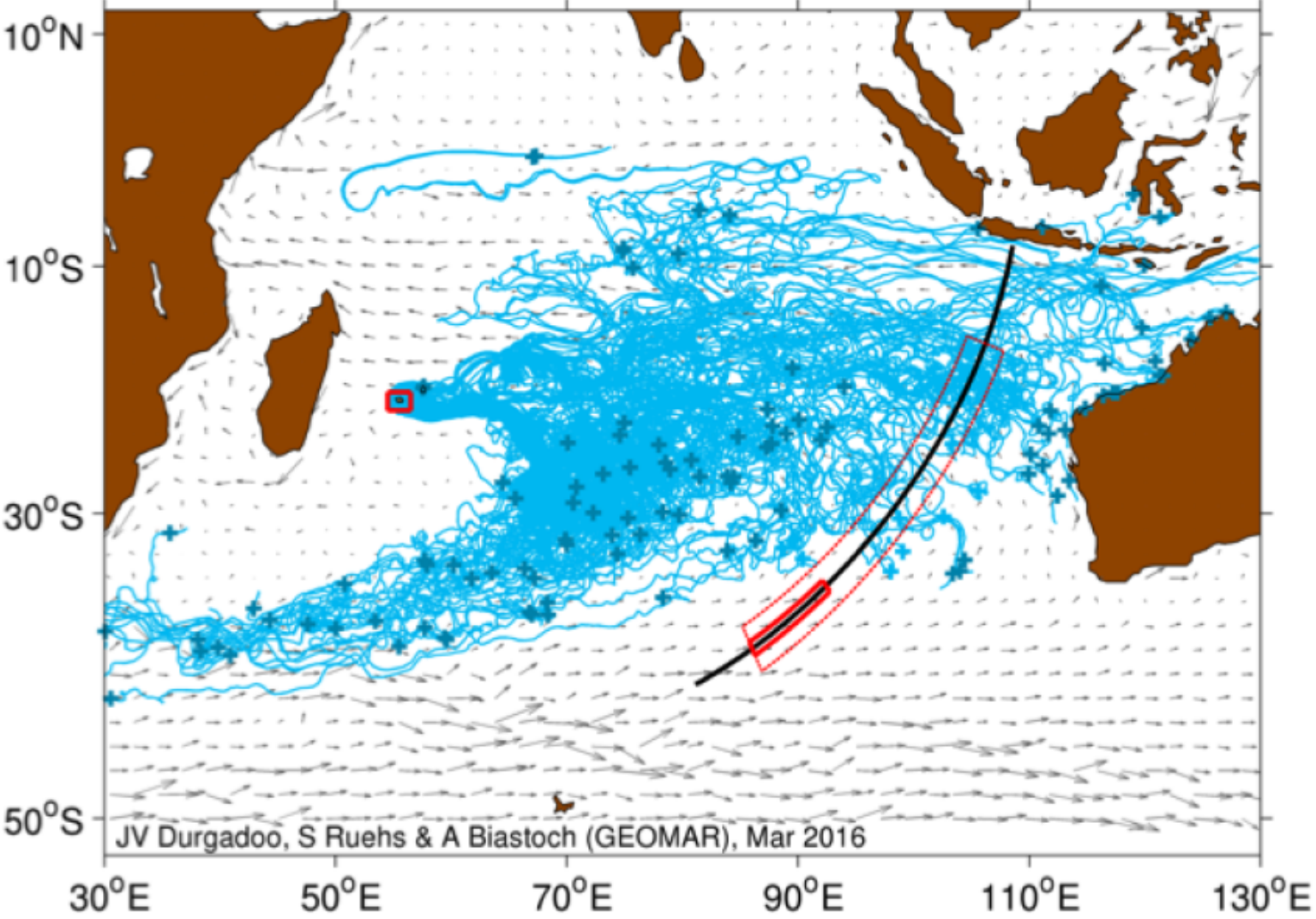
25: Each of the blue likes corresponds to a sampled trajectory. The arc is the likely position of the plane, based on fuel calculations. Red arc shows the original search area.

Subsampling of trajectories: consider only trajectories passing the 7th arc area in the timeframe 8-9 March 2014

JV Durgadoo, S Ruehs & A Biastoch (GEOMAR), Mar 2016
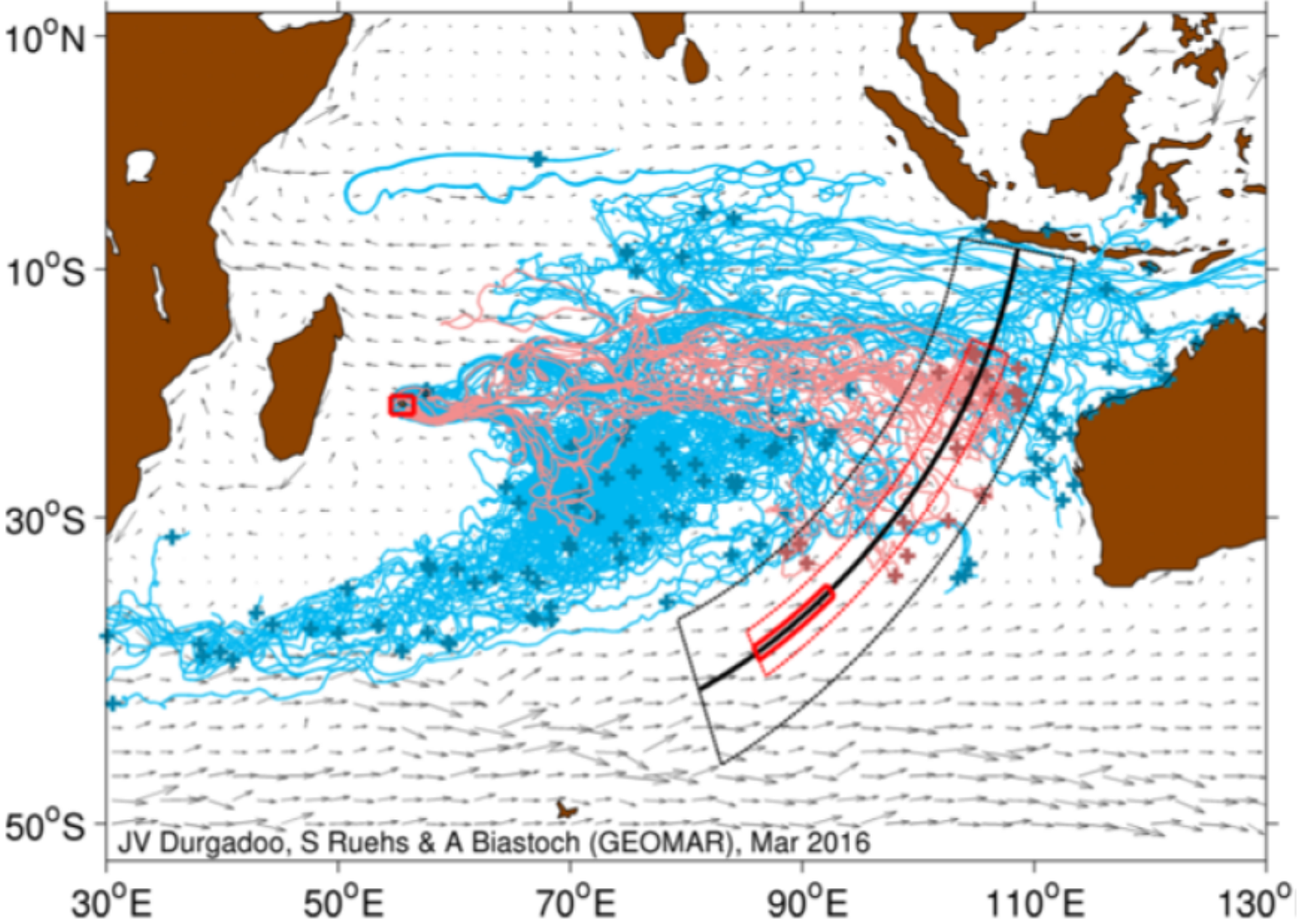
26: The red trajectories are those who intersect with the estimated plane location based on fuel. Decisions about where to look were based on the intersection between the likely position of the plane based on fuel and the simulated trajectories of the debris based on the flow and location of the found pieces. The trajectories for which such intersection is non-empty are shown in red in the figure above.

Discussion

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💬 Malaysia Air Flight 370, the "rest of the story"?
The example provided is both "good" and "bad" as the simulations shown were actually not successful at locating the crash site of M...   **2**

💬 Grab some basics here : Acoustic Doppler Current Profiler + "Flow Data" assumption
From my prior work, some background context as to how sea current velocity are collected. https://en.wikipedia.org/wiki/Acoustic_D...   **1**
     👤 Community TA

💬 [STAFF]: typo lines, not likes   **1**

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