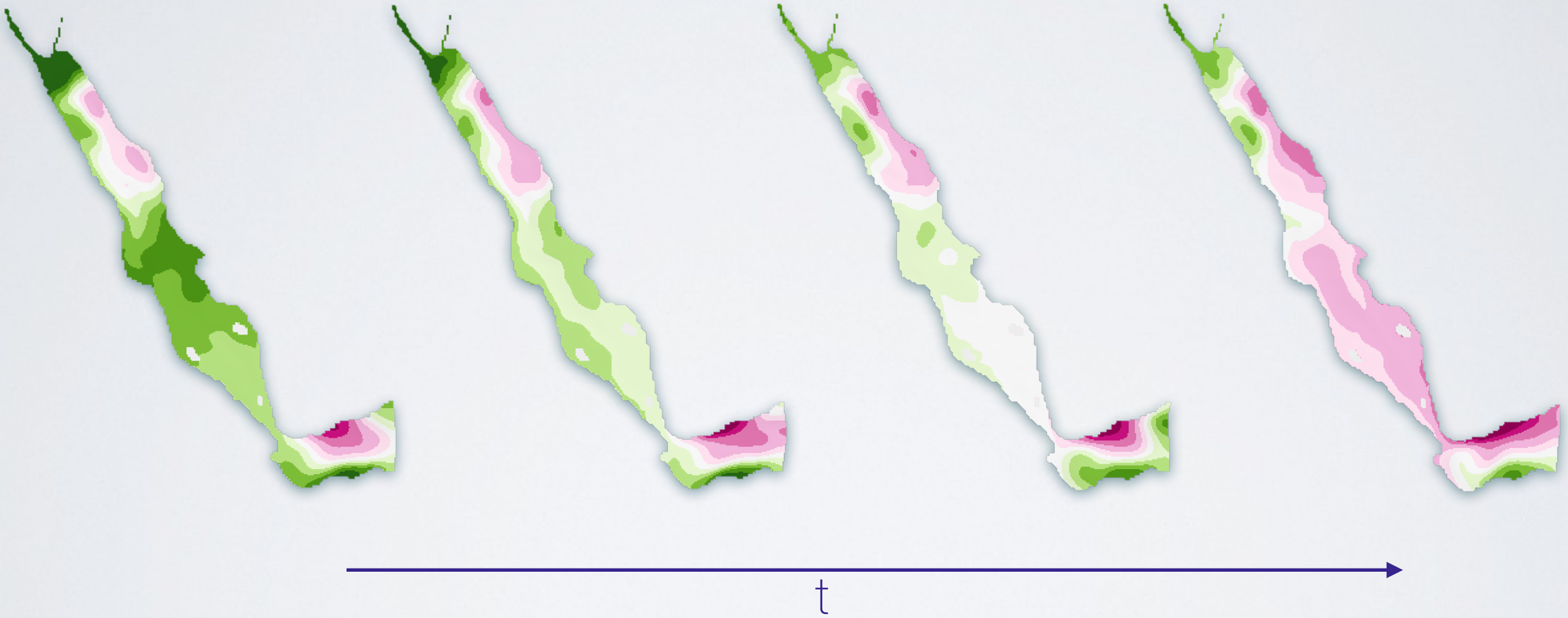
T. Höllt[♦♣], M. Hadwiger[♣], O. Knio[♣], I. Hoteit[♣]

[♣] King Abdullah University of Science and Technology
[♦] Computer Graphics & Visualization, TU Delft

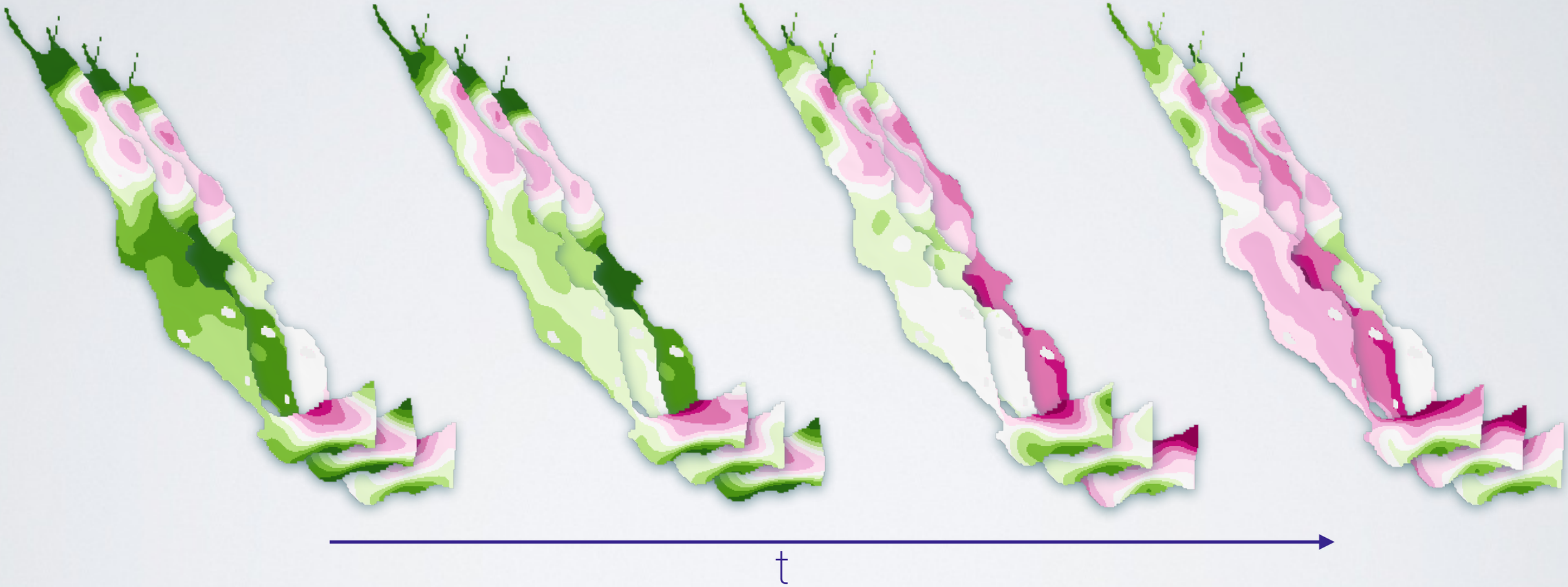
Probability Maps for the Visualization of Assimilation Ensemble Flow Data

TU Delft

Motivation



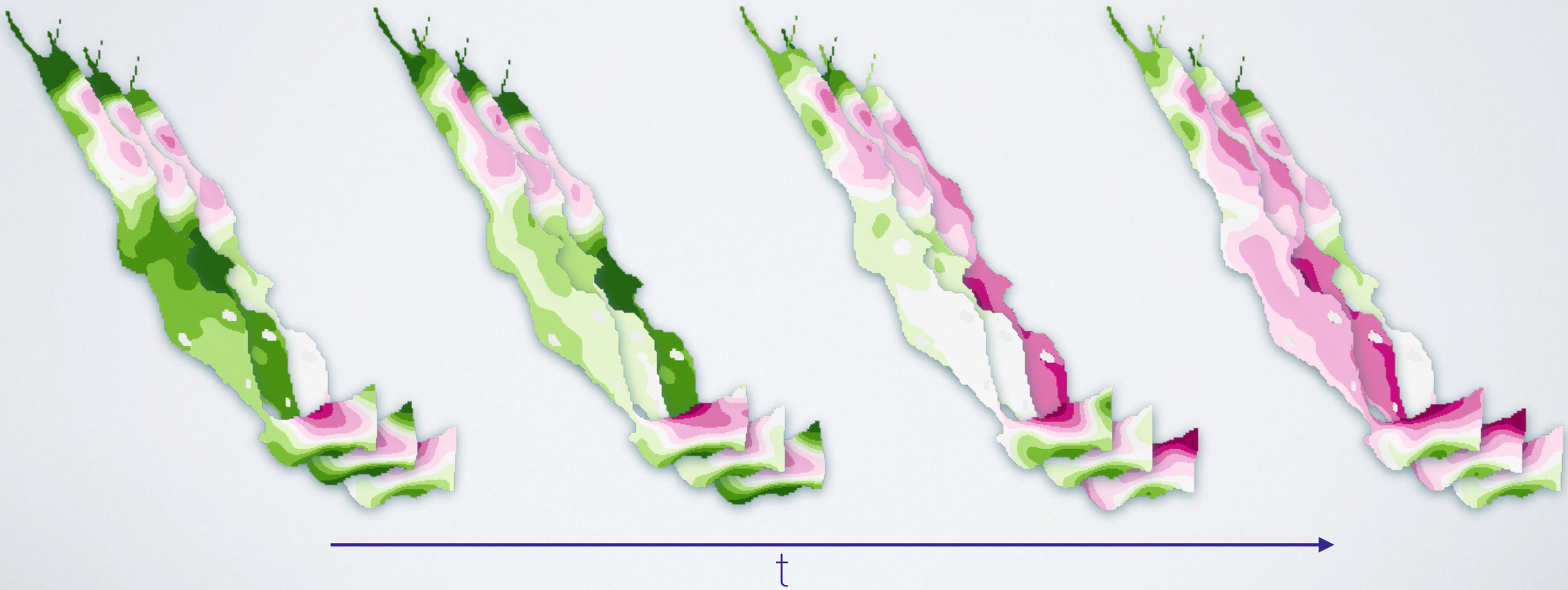
Motivation



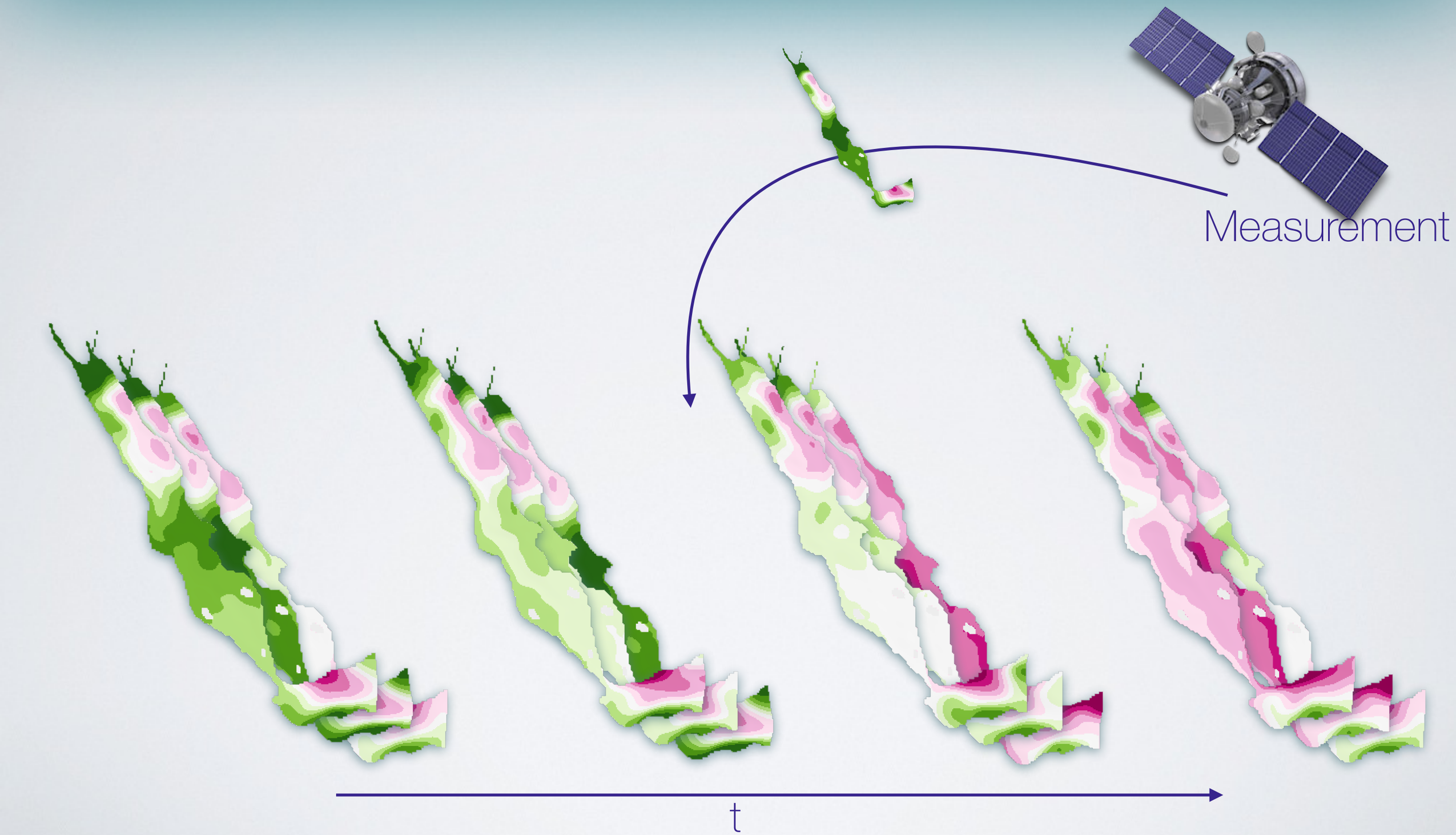
Ensemble Simulation

- Uncertainty in model + model parameters
- Uncertainty in boundary conditions
  - measurement errors, low resolution…
- Random sampling of uncertainty space
  - tens to hundreds of samples

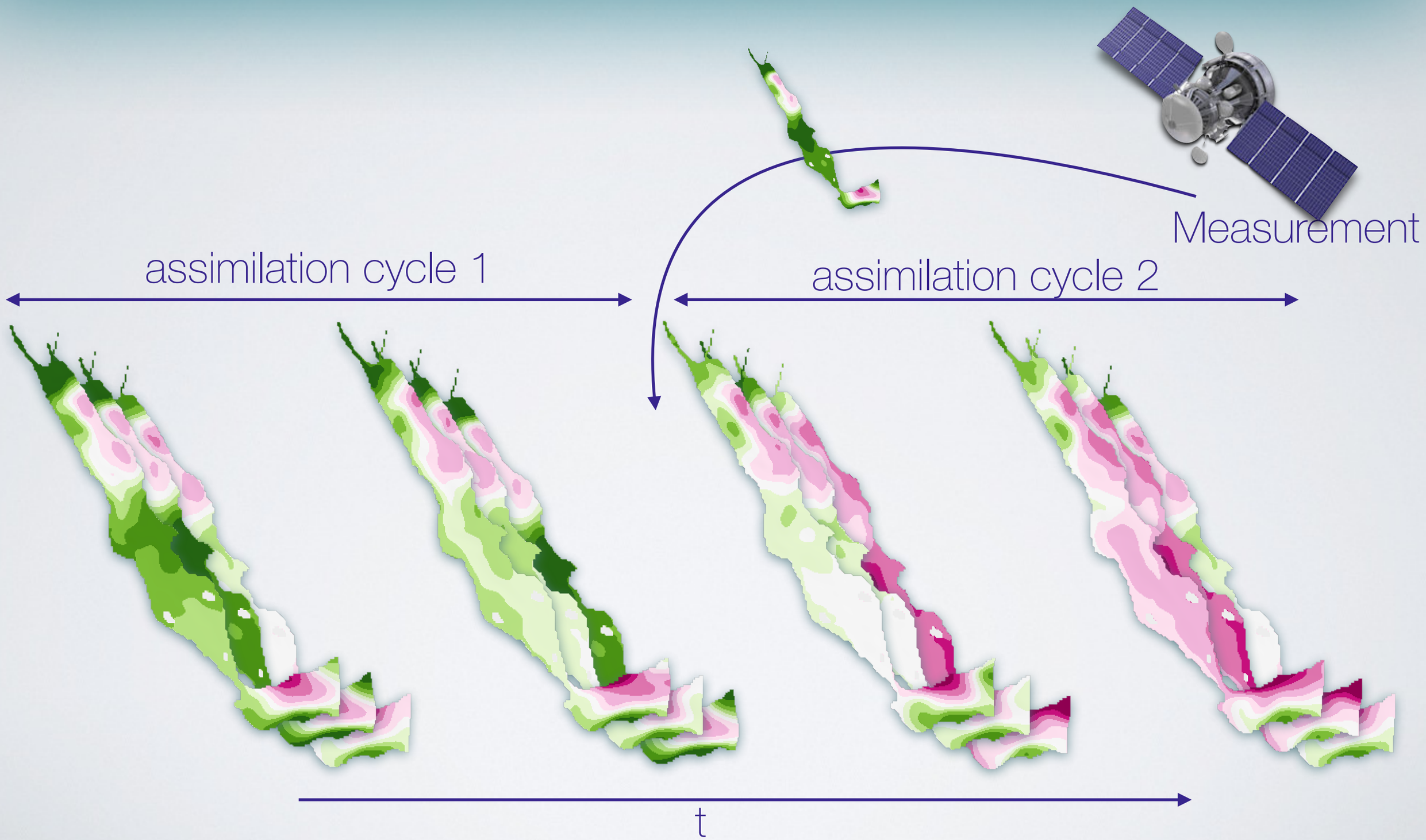
Motivation



Motivation



Motivation

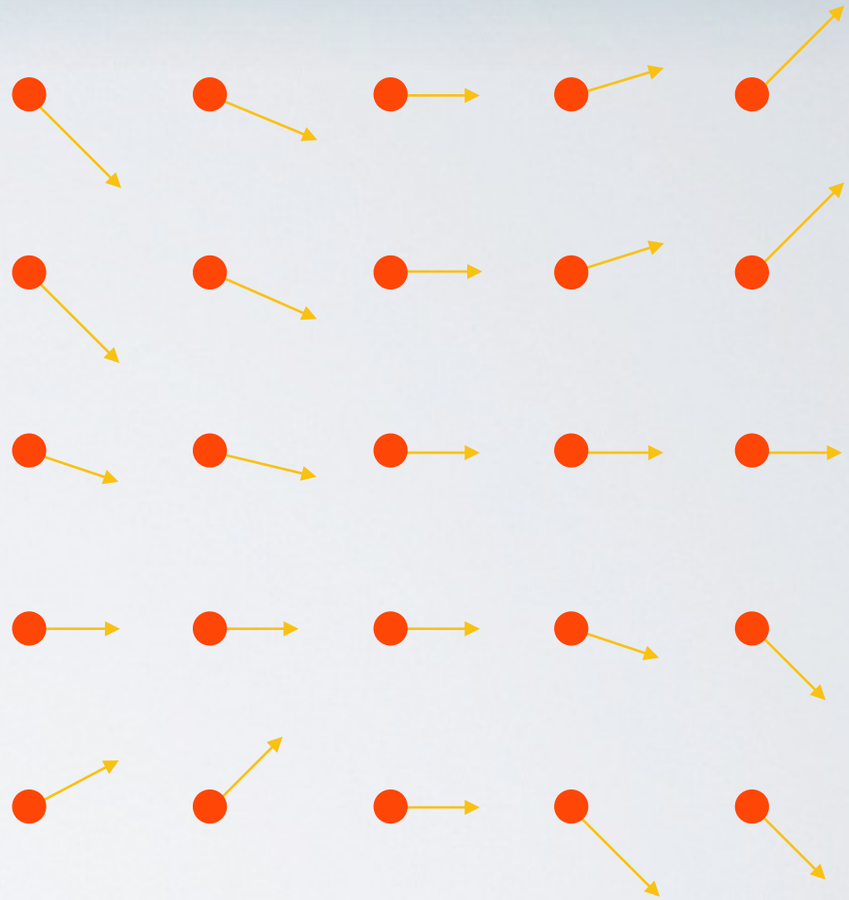


Assimilation

- Simulation steered by measured data
    - not all simulated data is also measured
- Ensemble resampled after assimilation
    - unclear correspondences between cycles
    - hard to track behavior over time
    - follow all possible combinations?

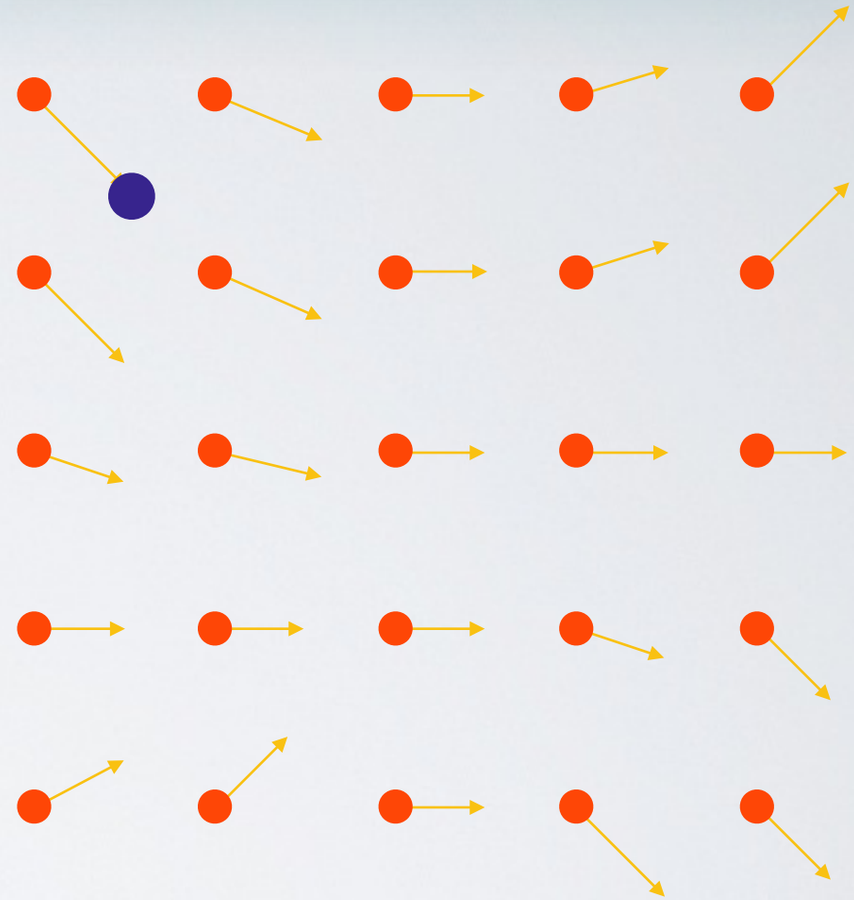
Pathline Tracing

- Input
  - regular sampled domain
  - flow direction + magnitude



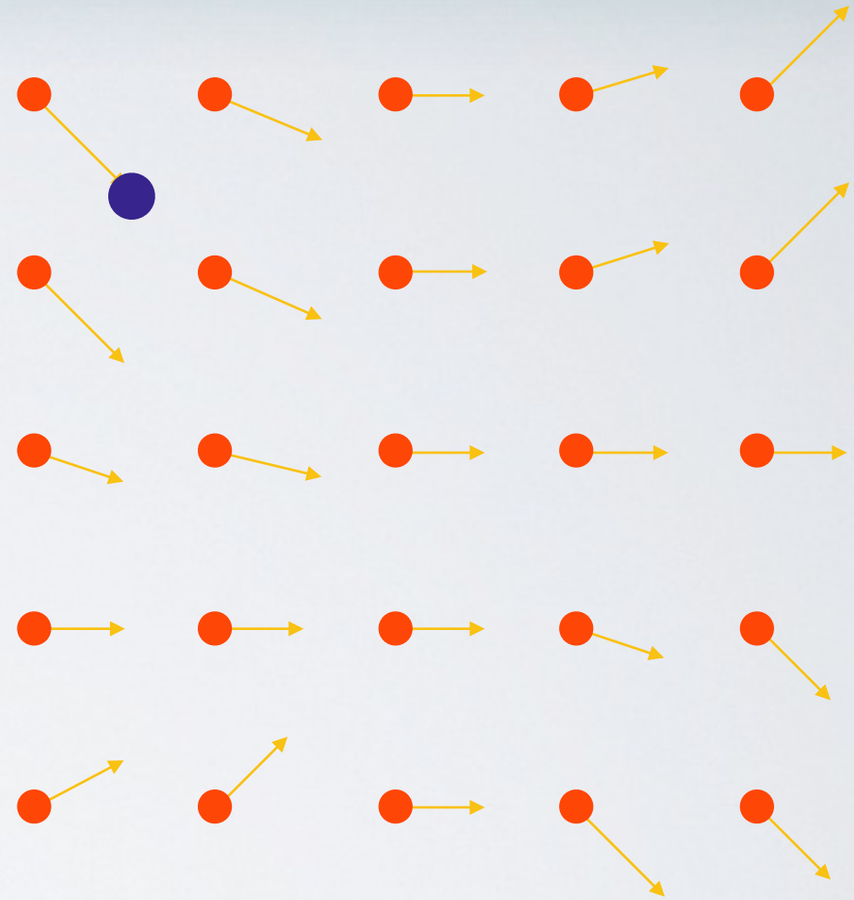
Pathline Tracing

- Input
  - regular sampled domain
  - flow direction + magnitude
  - inject particle



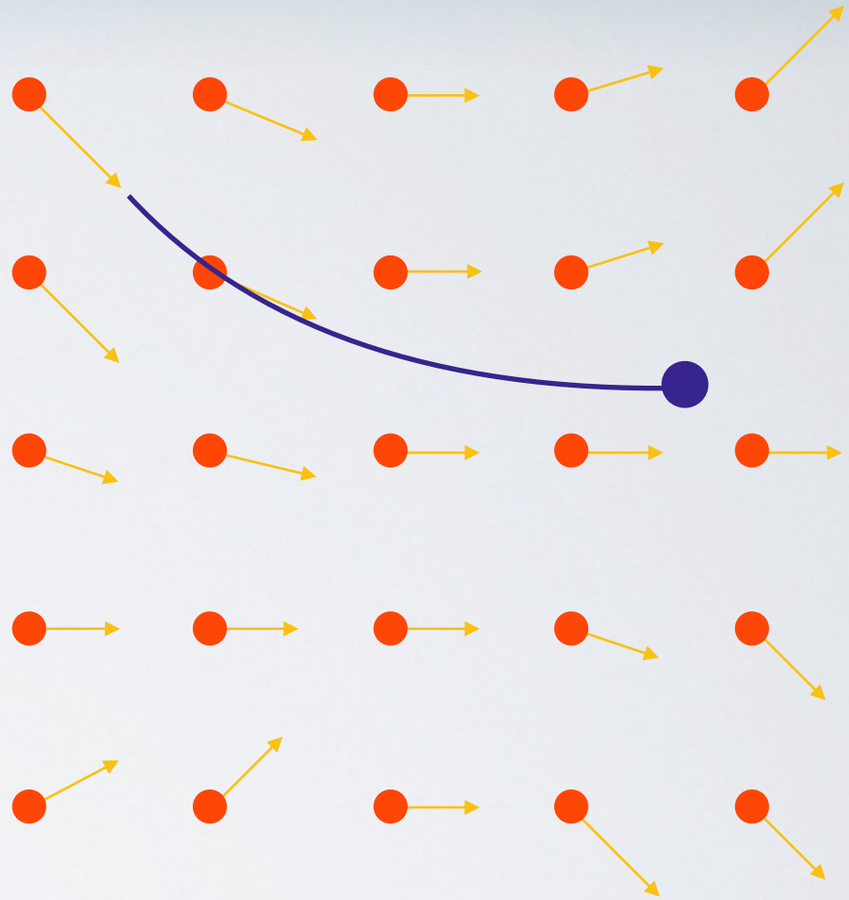
Pathline Tracing

- Input
  - regular sampled domain
  - flow direction + magnitude
  - inject particle
- Integrate path



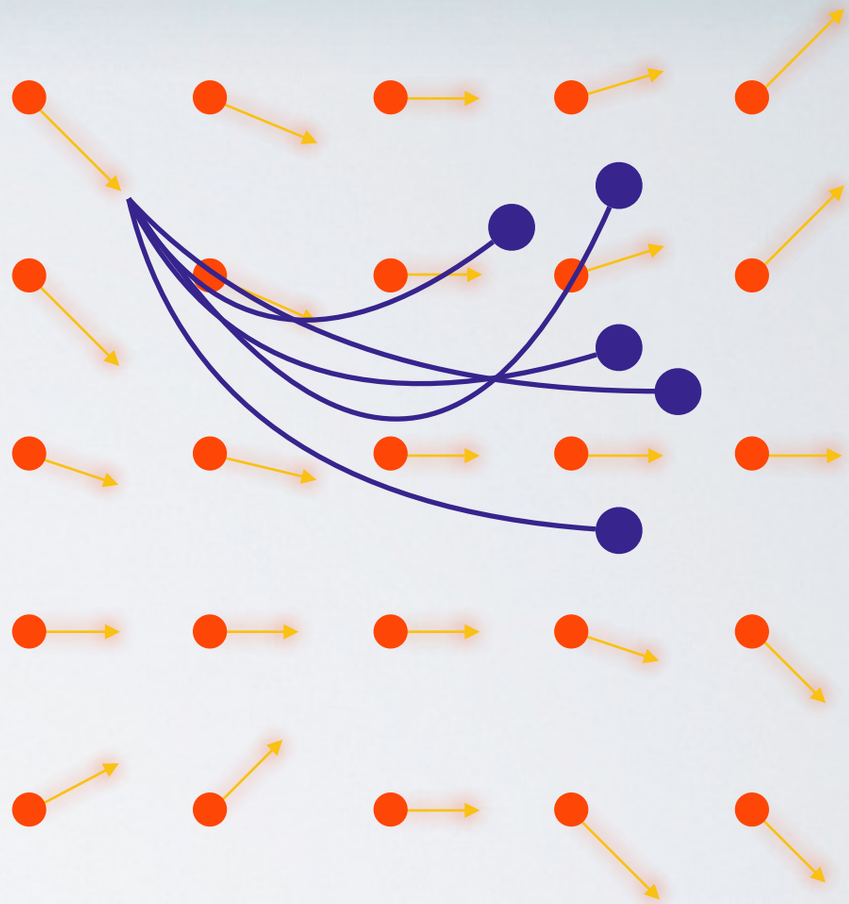
Pathline Tracing

- Input
  - regular sampled domain
  - flow direction + magnitude
  - inject particle
- Integrate path



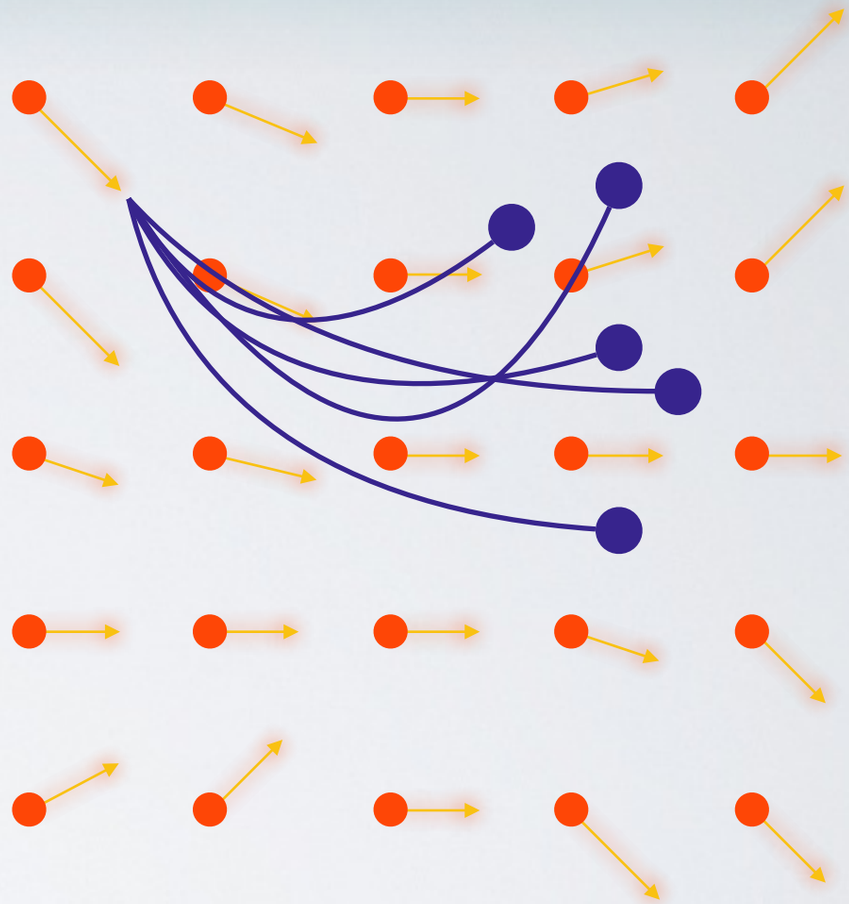
Ensemble Tracing

- Multivalued vectors
- Trace multiple “sub-particles” (1 per member)



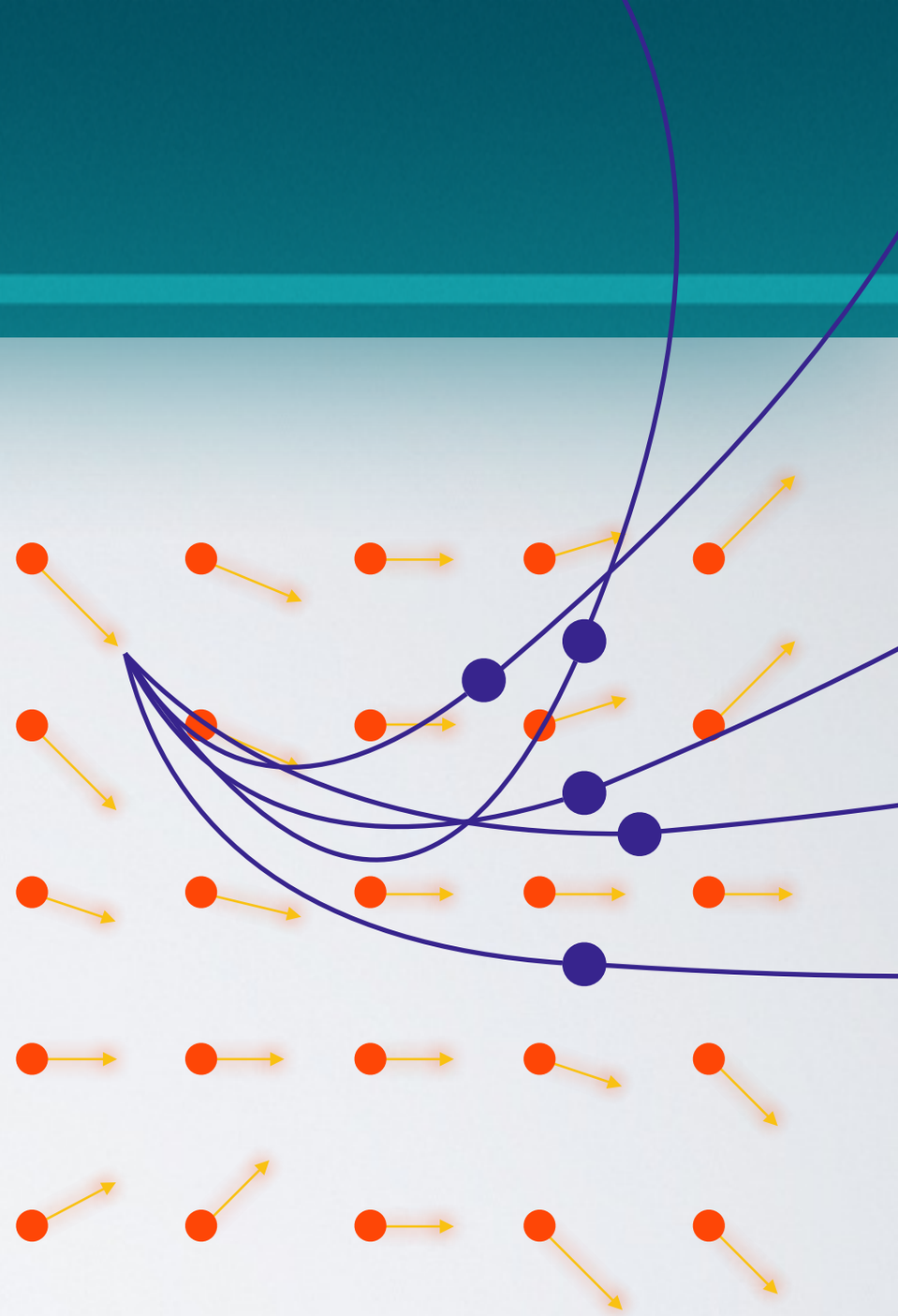
Ensemble Tracing

- Multivalued vectors
- Trace multiple “sub-particles” (1 per member)
- Well defined temporal correspondences
  - ⇨ 1 trace/member for complete time series



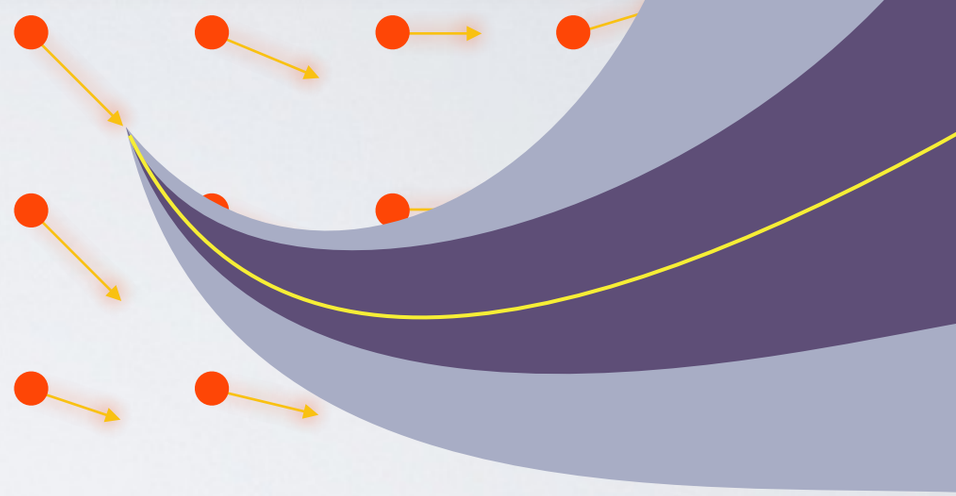
Ensemble Tracing

- Multivalued vectors
- Trace multiple “sub-particles” (1 per member)
- Well defined temporal correspondences
  - ⇨ 1 trace/member for complete time series

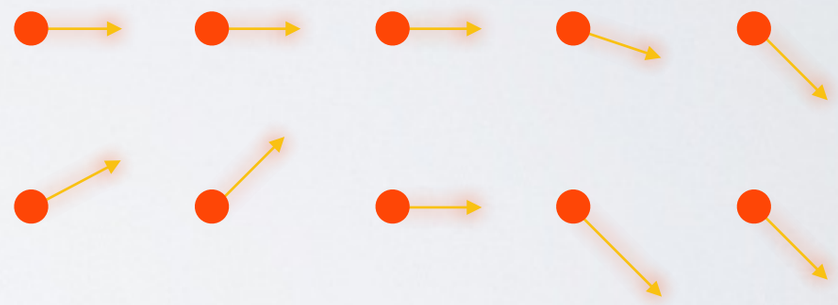


Ensemble Tracing

- Trace multiple “sub-particles”
- Well defined correspondences
  - one “sub-particle”/ member



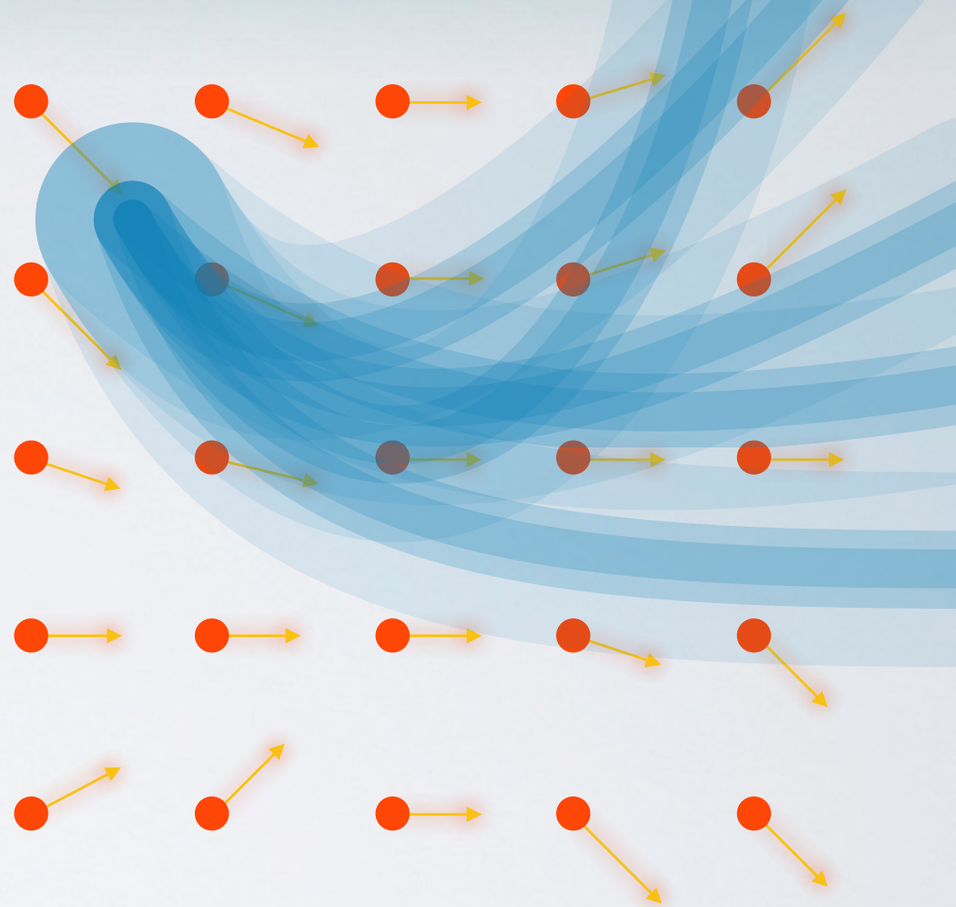
- Mirzargar et al: Curve Boxplot[1]



[1] Mirzargar et al, *Curve Boxplot: Generalization of Boxplot for Ensembles of Curves*, IEEE TVCG 20(12), 2014

Ensemble Tracing

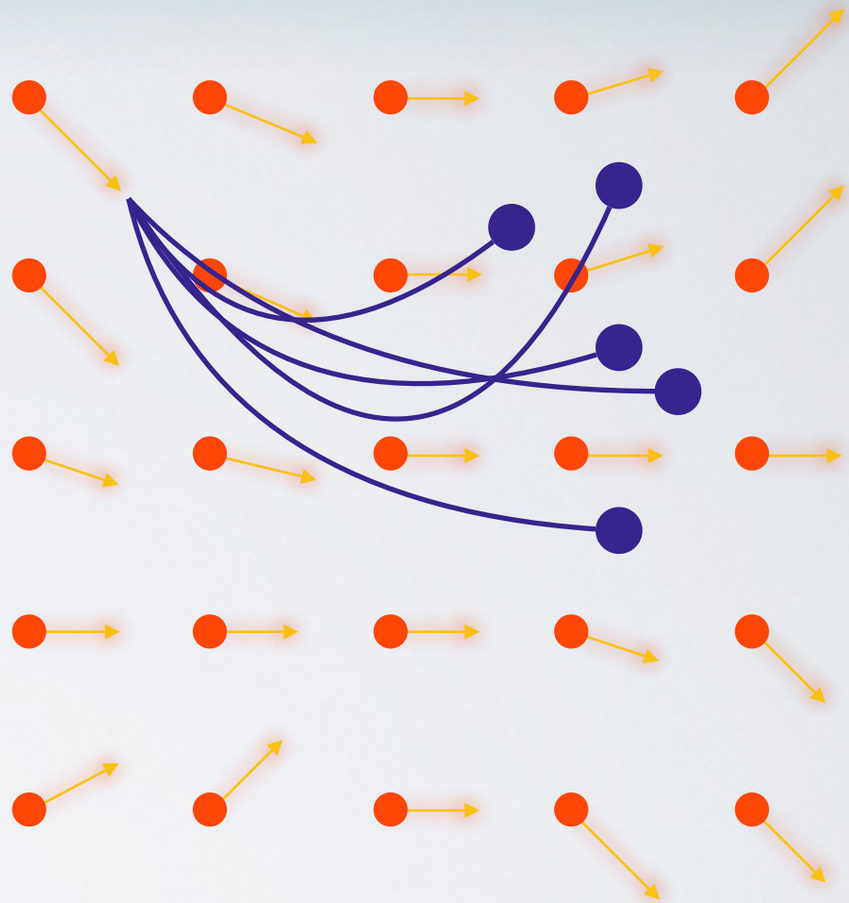
- Trace multiple “sub-particles”
- Well defined correspondences
    - one “sub-particle”/ member
- Mirzargar et al: Curve Boxplot[1]
- Lampe & Hauser: Curve Density Estimate[2]



[1] Mirzargar et al, *Curve Boxplot: Generalization of Boxplot for Ensembles of Curves*, IEEE TVCG 20(12), 2014
[2] Lampe & Hauser, *Curve Density Estimate*, CGF 30(3), 2011

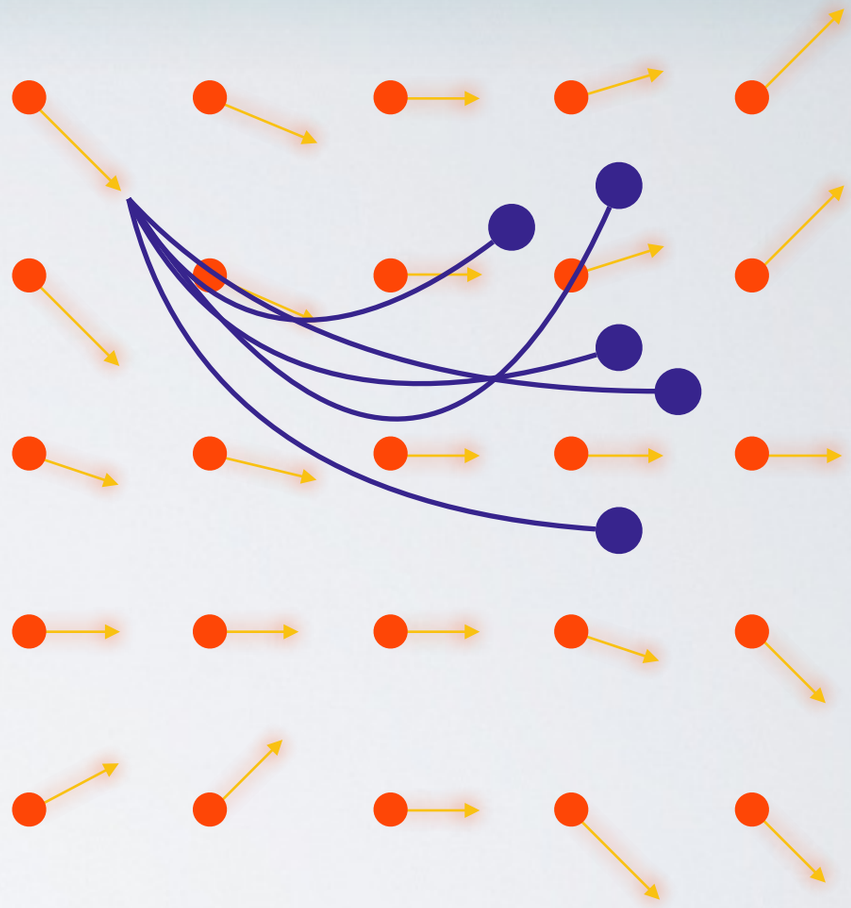
Assimilation Tracing

- Trace multiple “sub-particles”



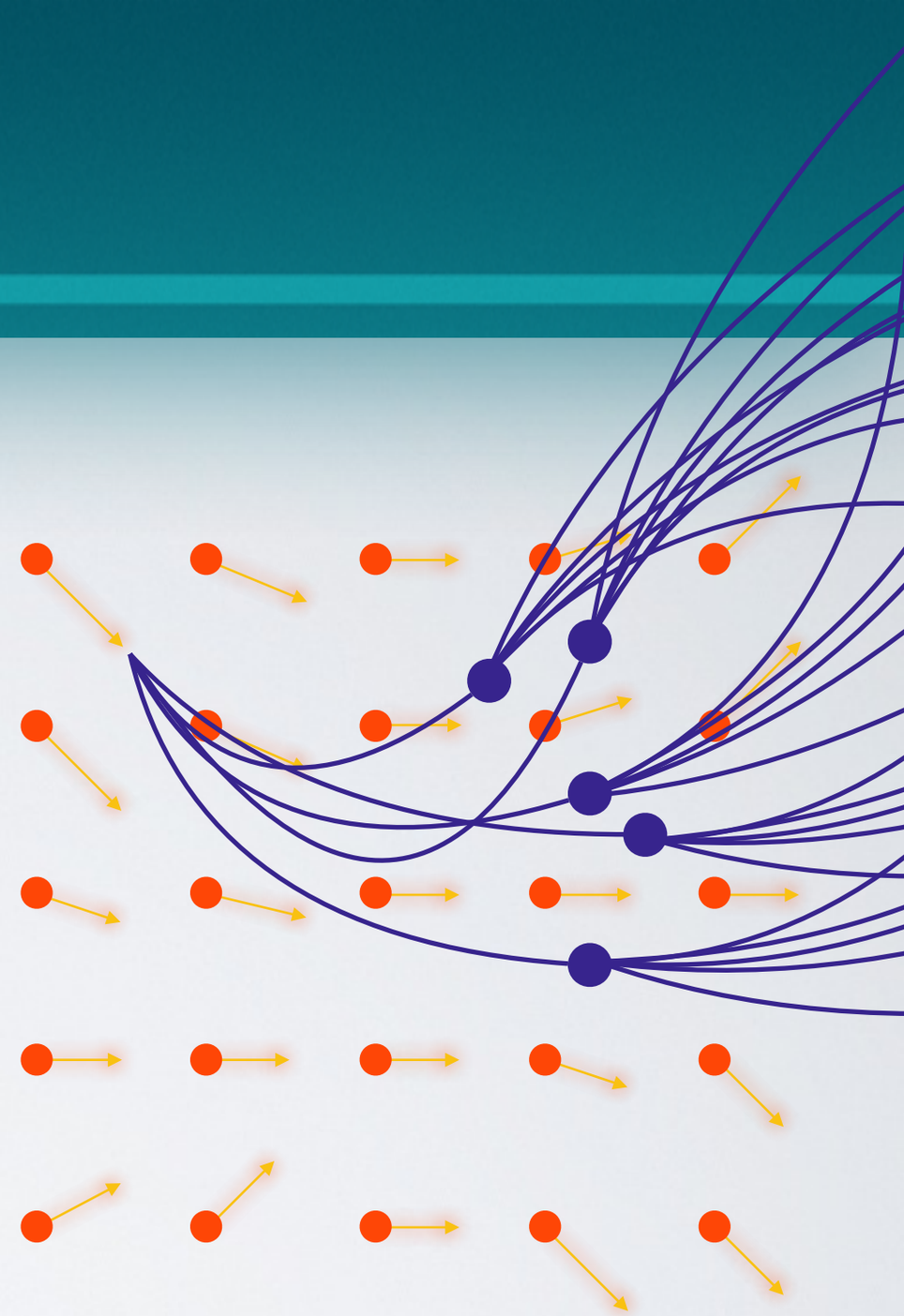
Assimilation Tracing

- Trace multiple “sub-particles”
- Brute force all combinations
- After assimilation cycle
  - new sub-particles per trace
  - eg. 5 members ⇨ 5*5 traces



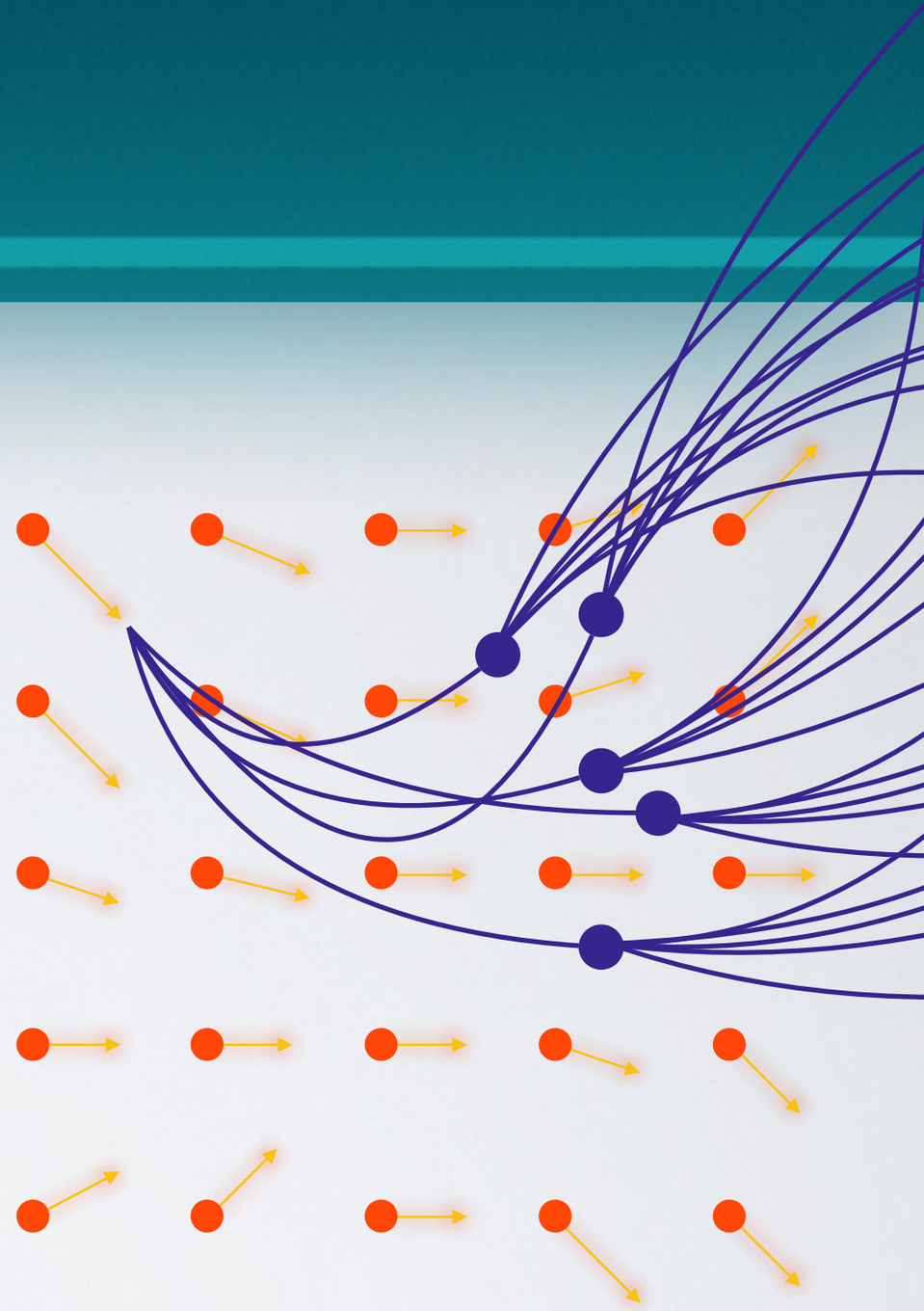
Assimilation Tracing

- Trace multiple “sub-particles”
- Brute force all combinations
- After assimilation cycle
  - new sub-particles per trace
  - eg. 5 members ⇨ 5*5 traces



Assimilation Tracing

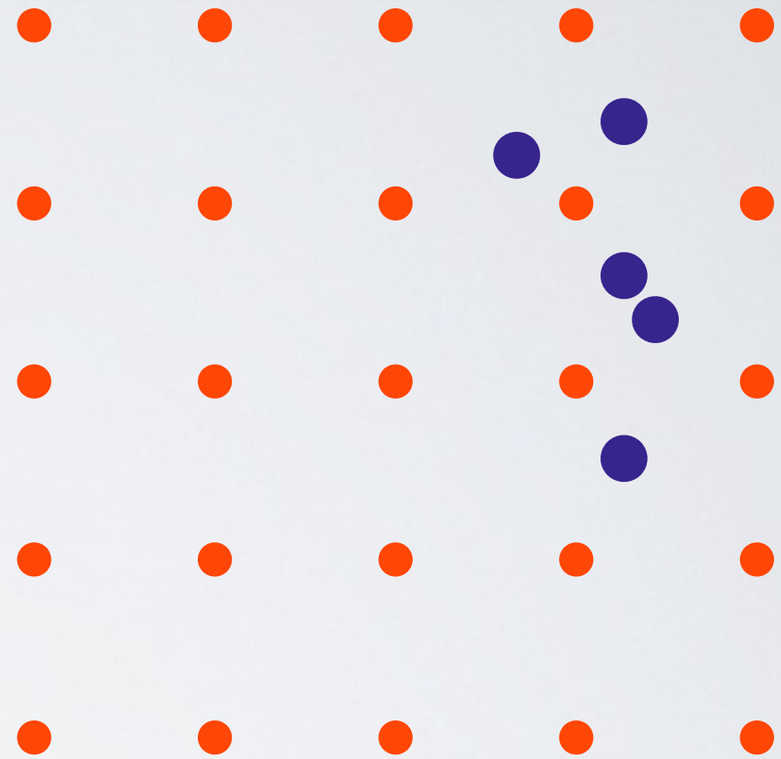
- Brute force all combinations
  - m members, c cycles
  - m^c combinations



- Red Sea dataset: ~1E17(!)

Binned Tracing

- Idea: discretize/bin domain
- Count particles per bin after each cycle

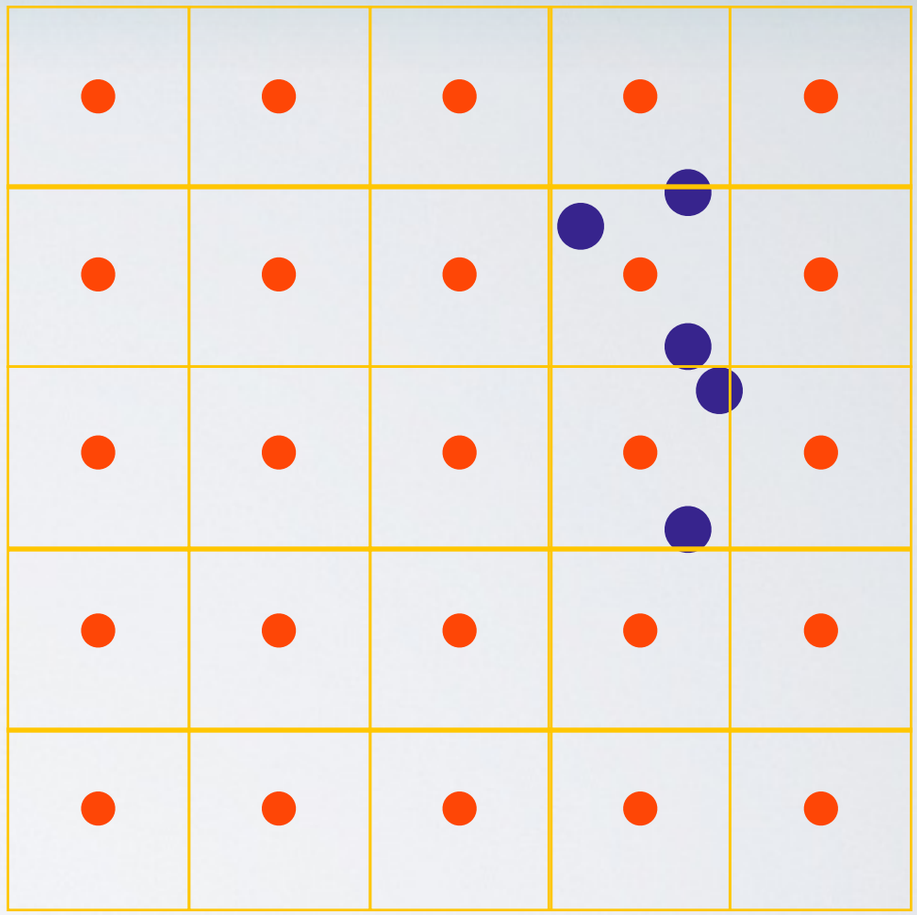


➪ Probability-weight

Binned Tracing

- Idea: discretize/bin domain
- Count particles per bin after each cycle

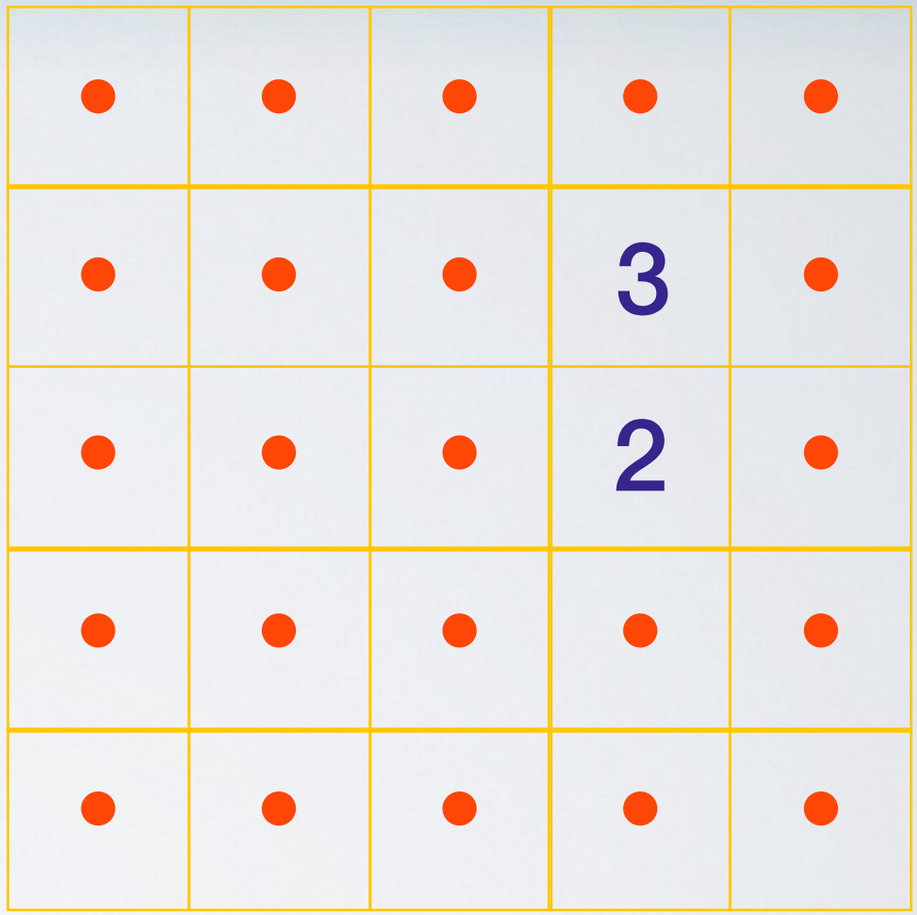
⇨ Probability-weight



Binned Tracing

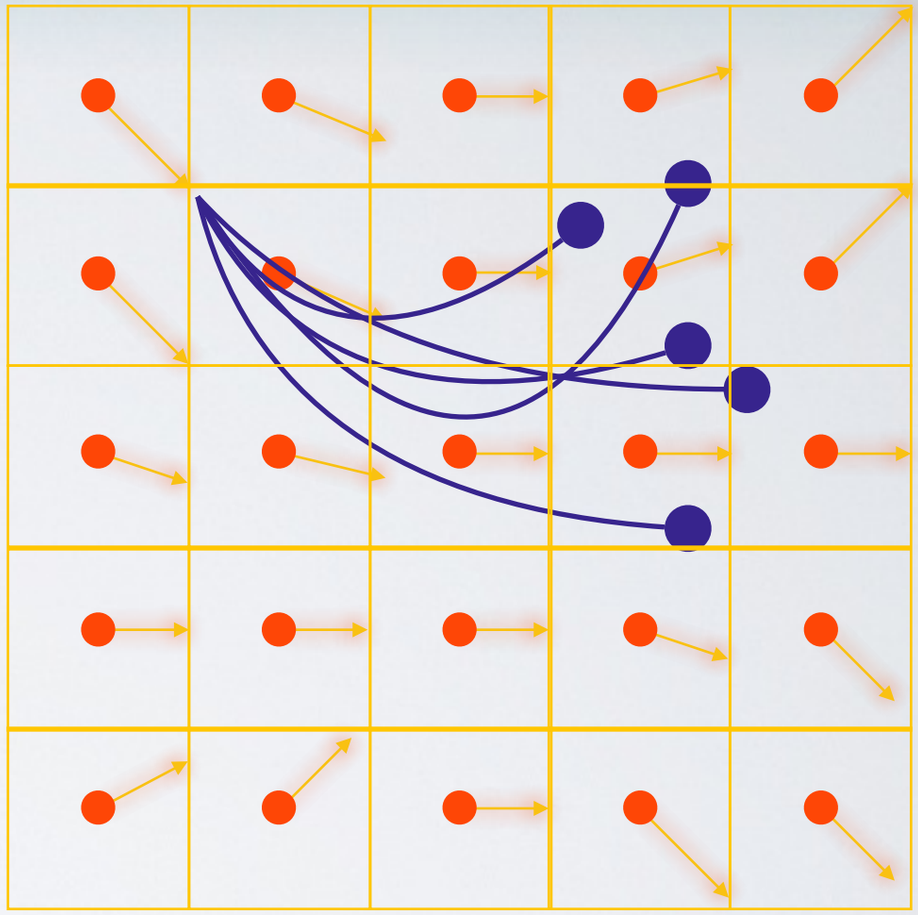
- Idea: discretize/bin domain
- Count particles per bin after each cycle

⇨ Probability-weight



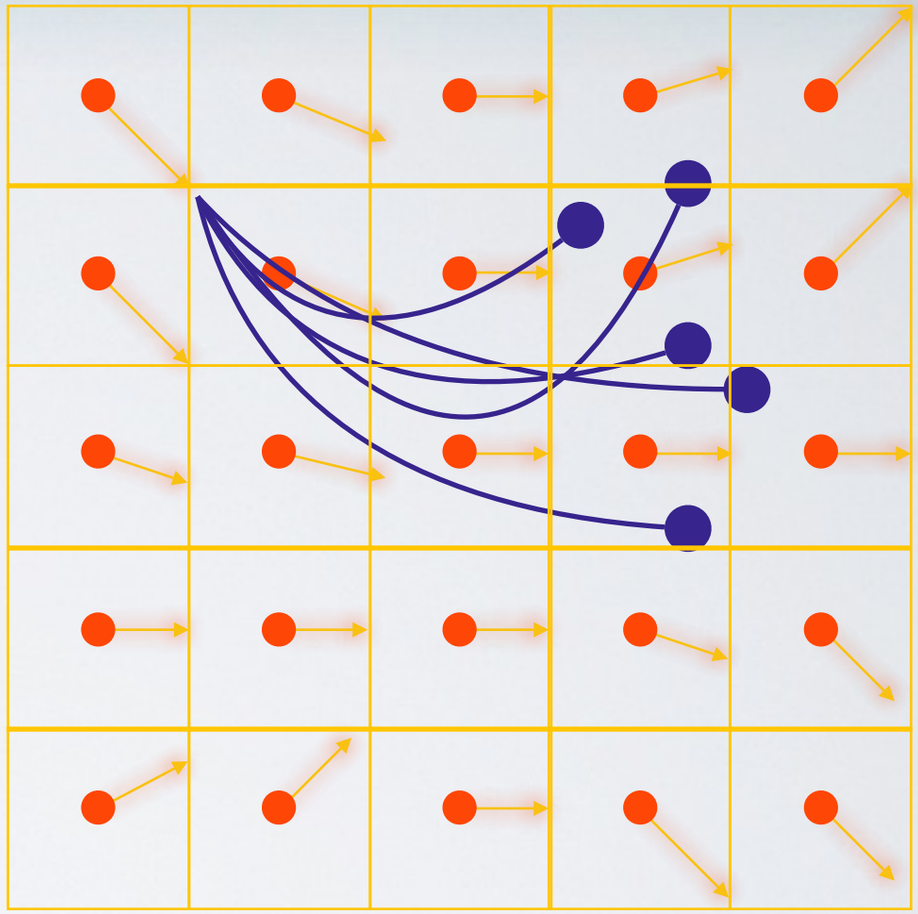
Binned Tracing

- Trace multiple “sub-particles”



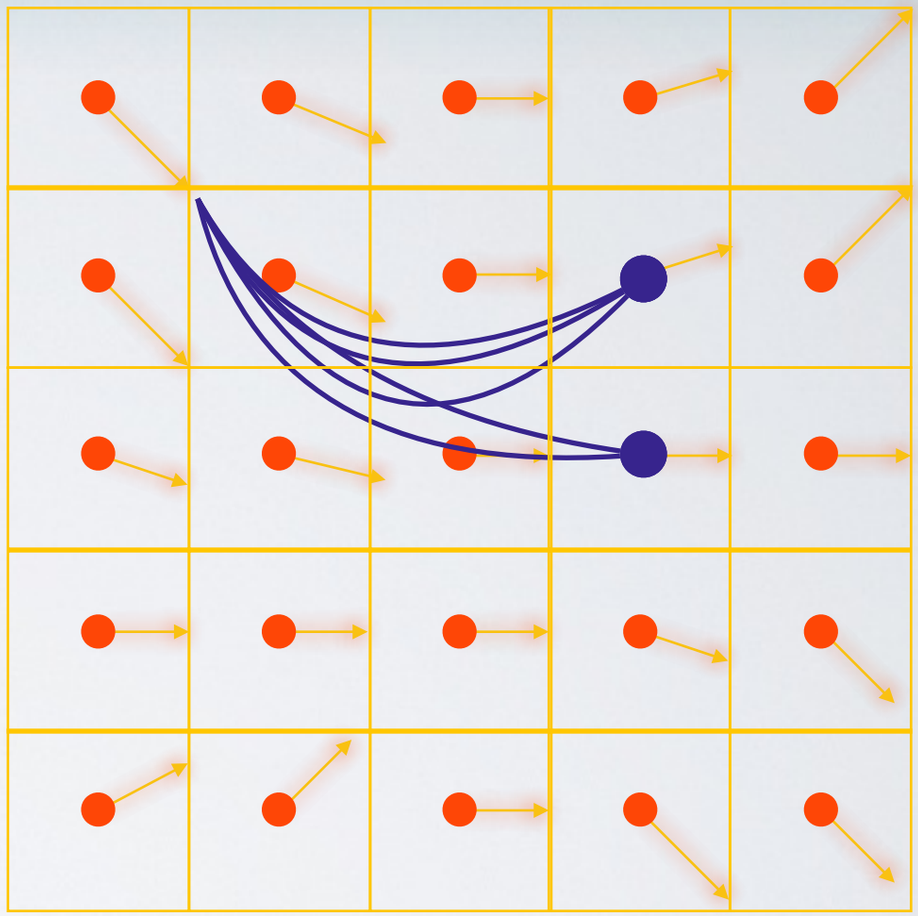
Binned Tracing

- Trace multiple “sub-particles”
- Adjust end to bin center



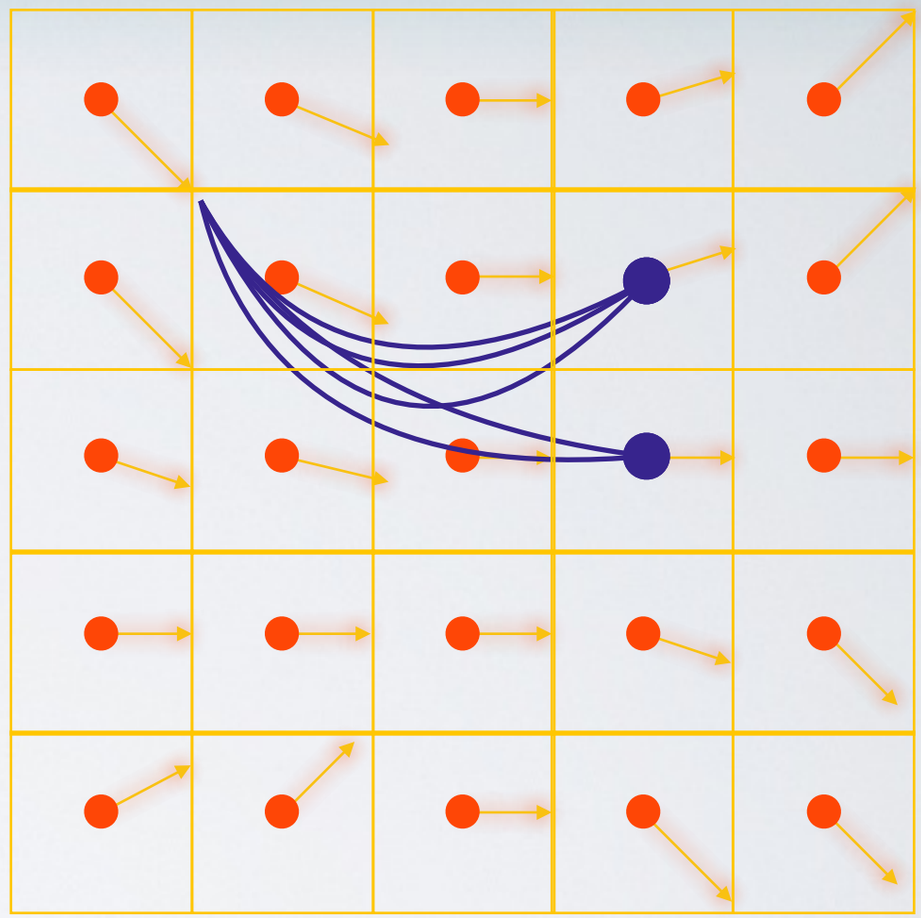
Binned Tracing

- Trace multiple “sub-particles”
- Adjust end to bin center



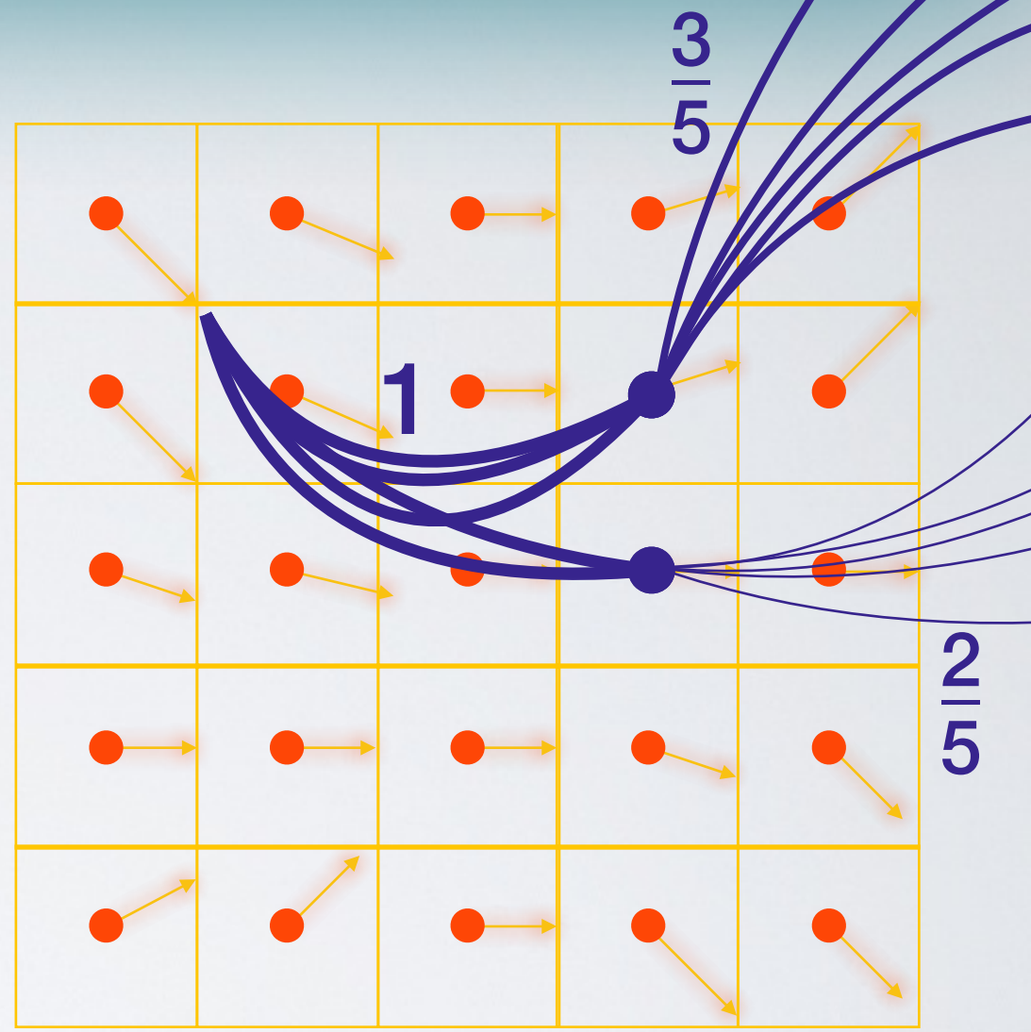
Binned Tracing

- Trace multiple “sub-particles”
- Adjust end to bin center
- Continue tracing from bins
- Attach probability-weights



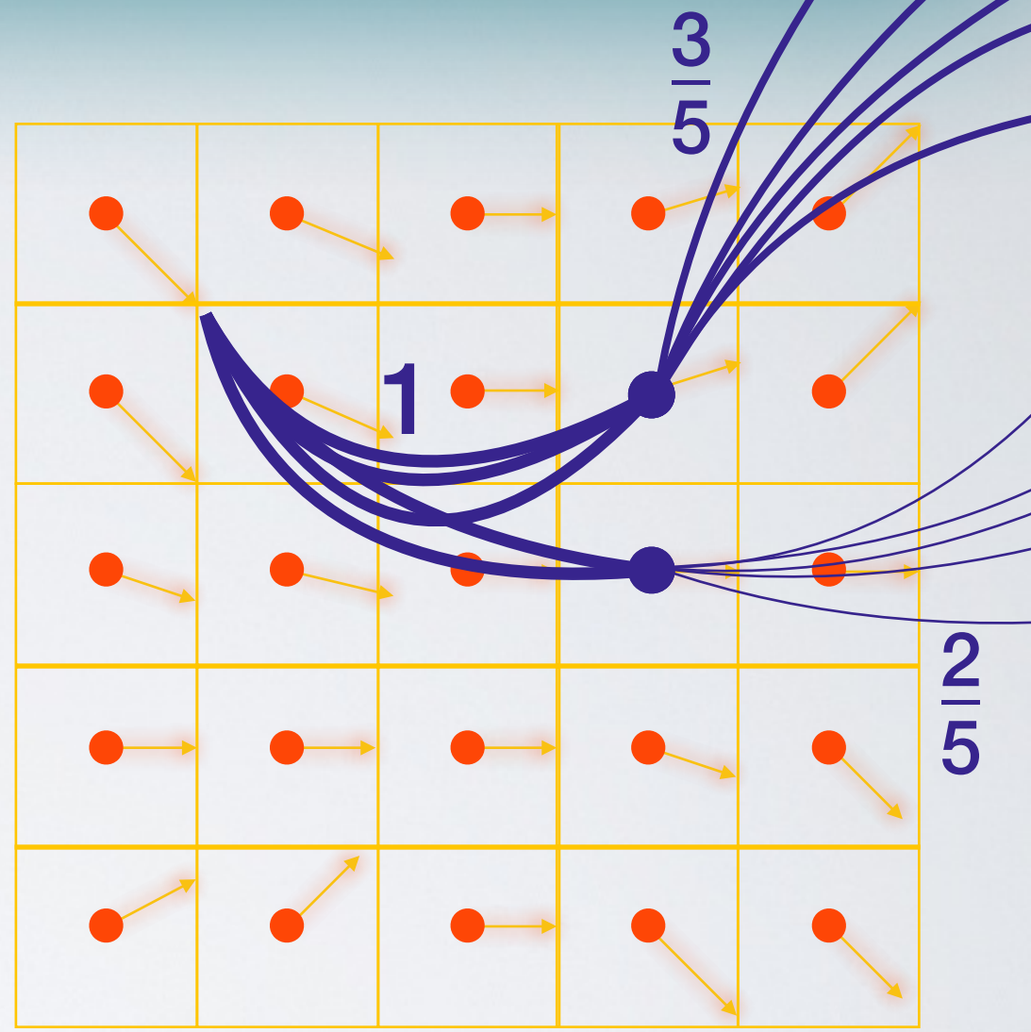
Binned Tracing

- Trace multiple “sub-particles”
- Adjust end to bin center
- Continue tracing from bins
- Attach probability-weights



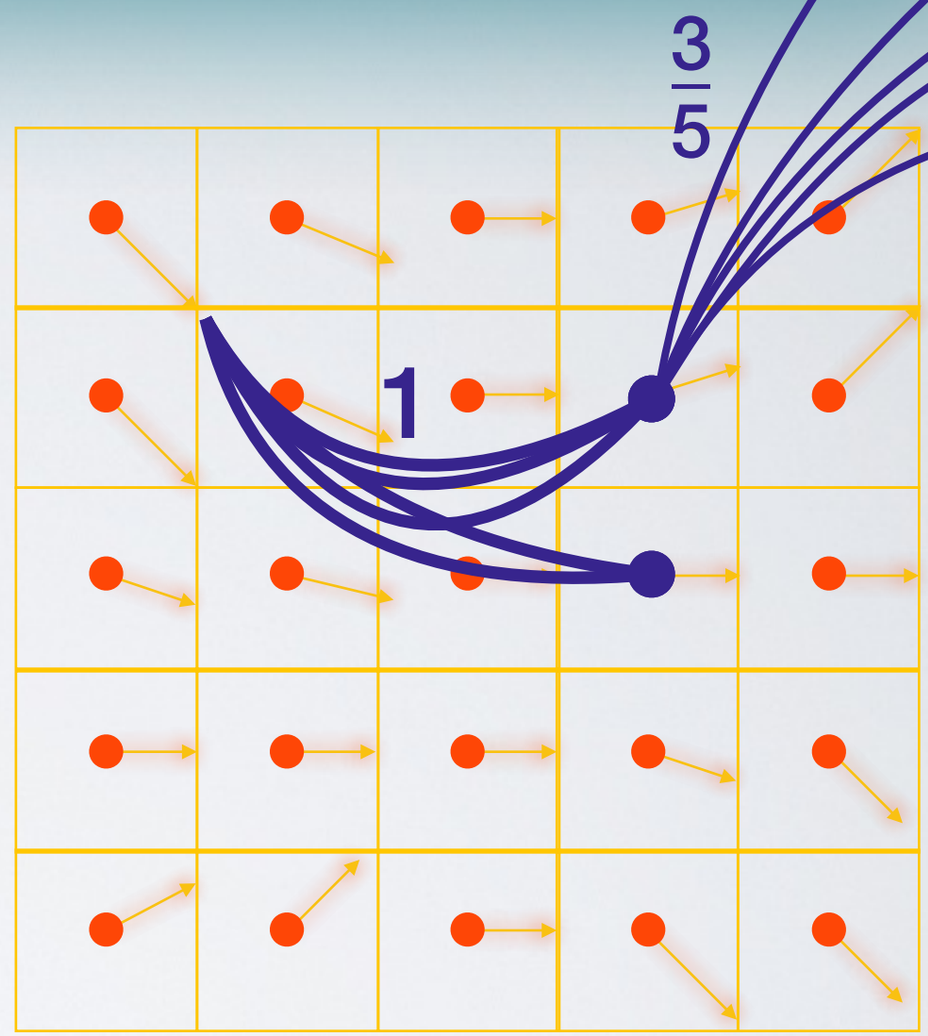
Early Termination

- Terminate early if probability below threshold
  - user defined
  - conservative default

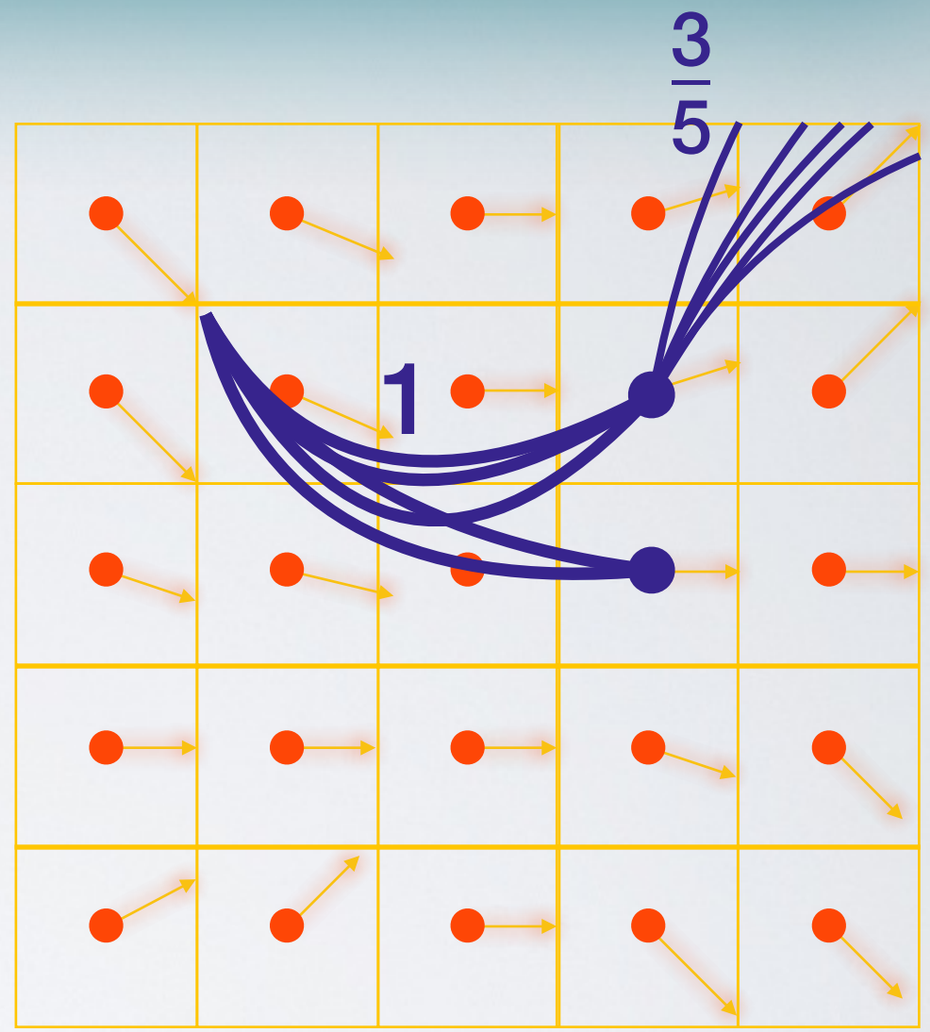


Early Termination

- Terminate early if probability below threshold
  - user defined
  - conservative default



Probability Map Creation



Probability Map Creation

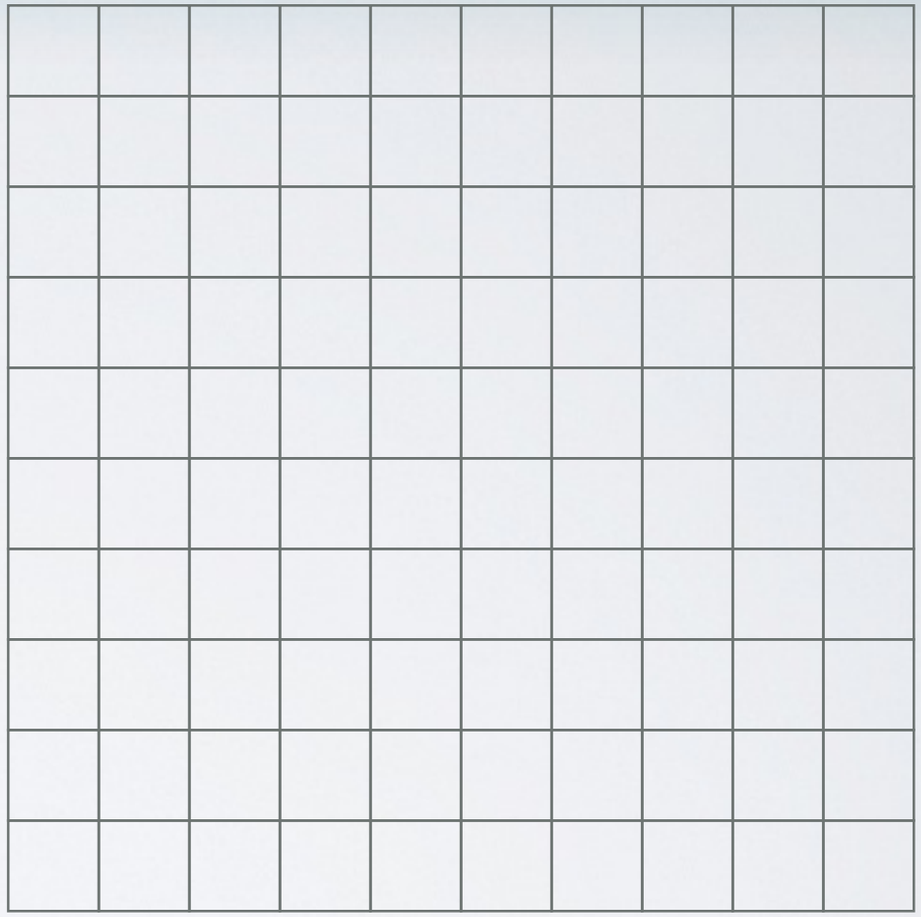
cycle 1

cycle 2

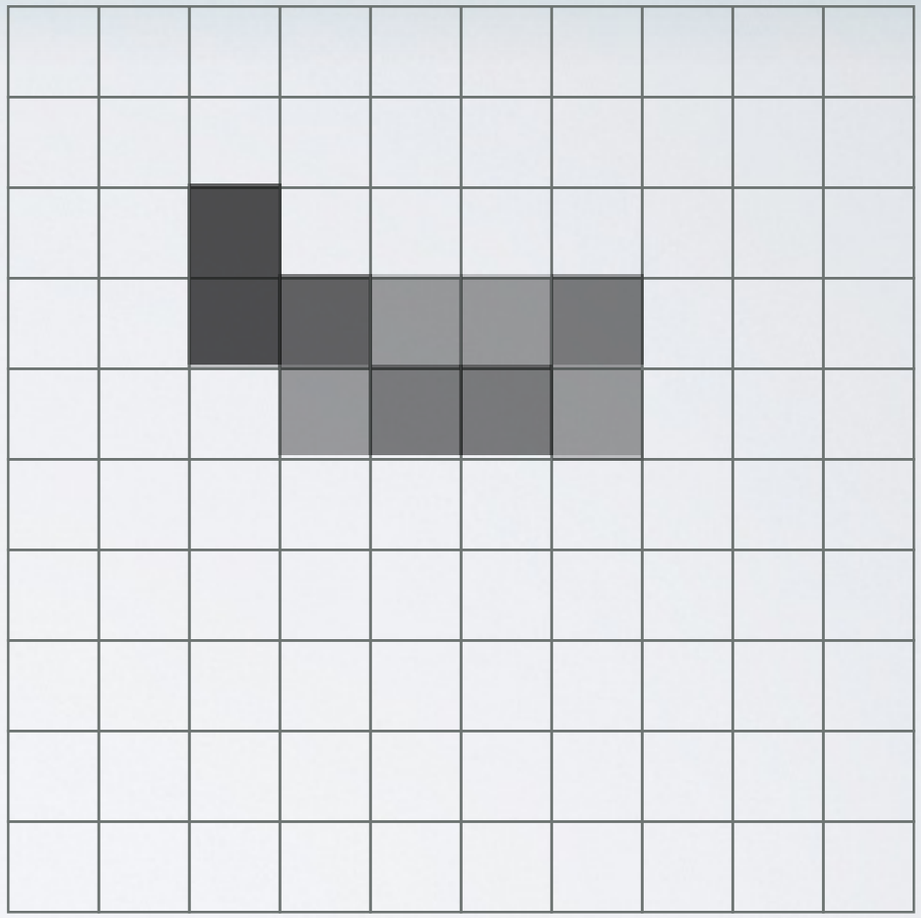
Probability Map Creation

cycle 1

cycle 2



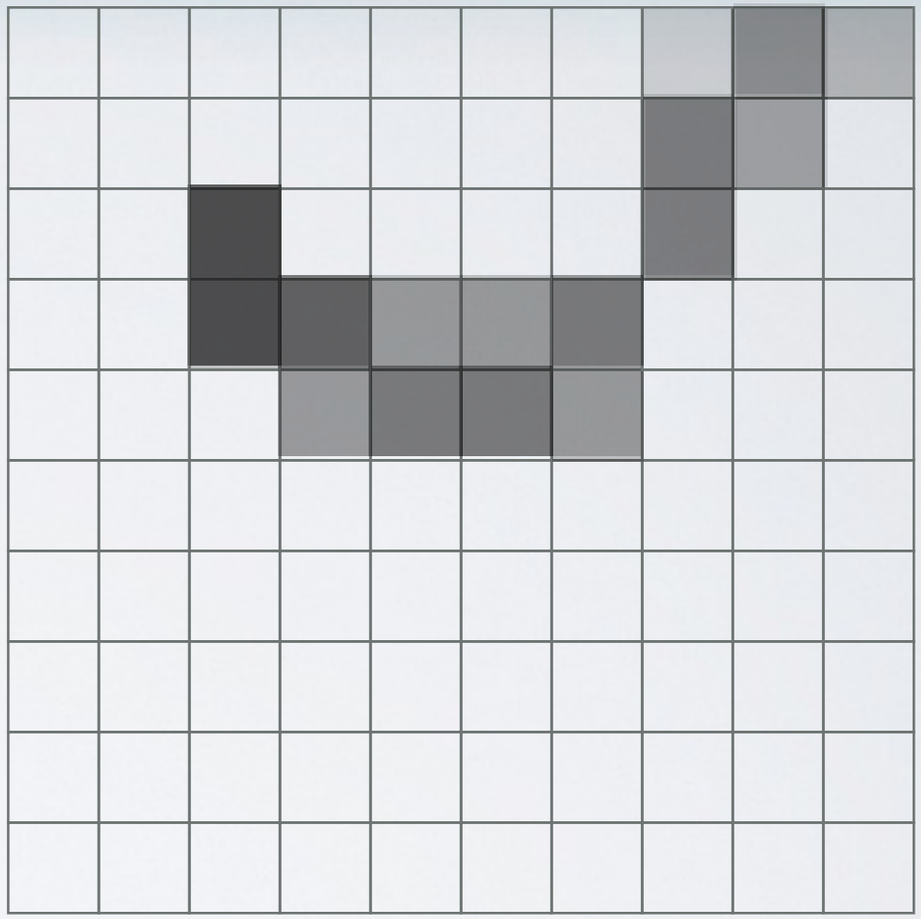
Probability Map Creation



cycle 2

- Rasterize pathlines, probability as alpha

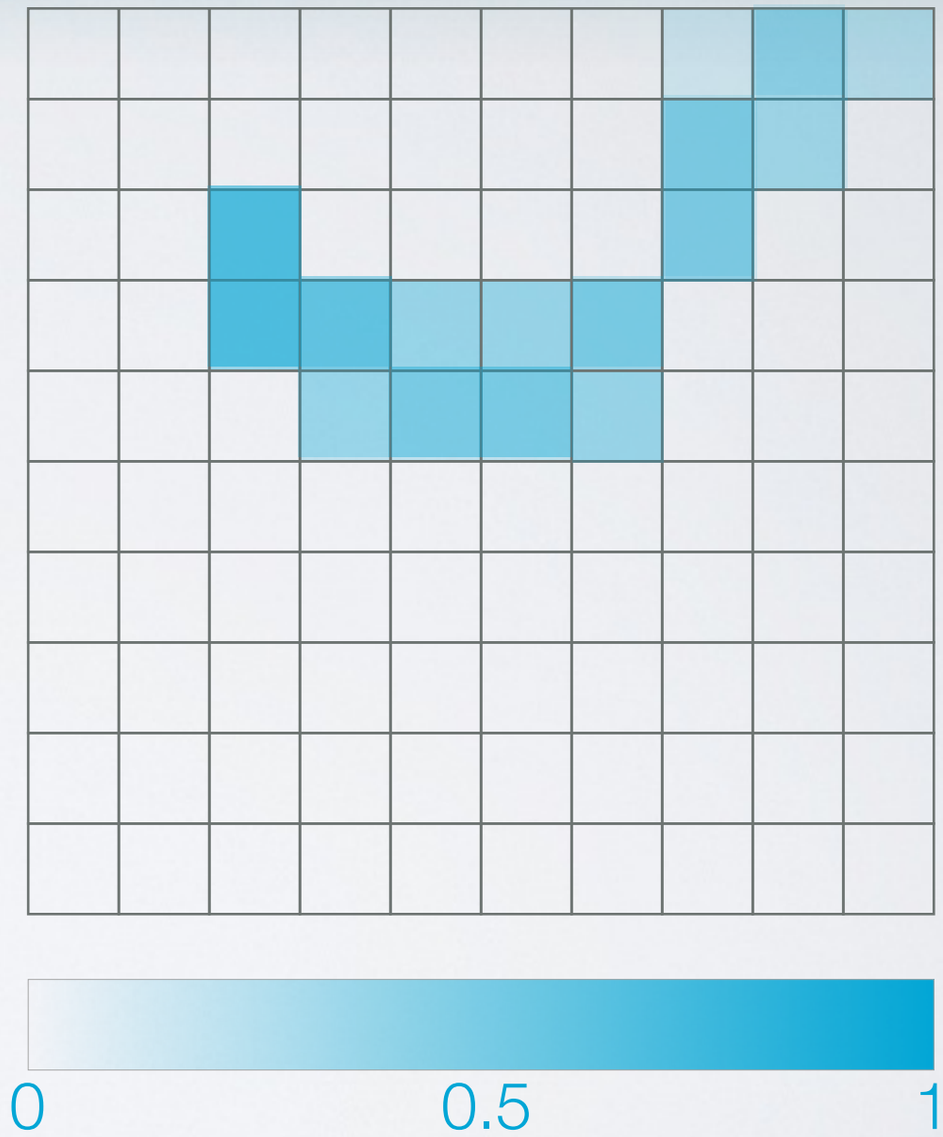
Probability Map Creation



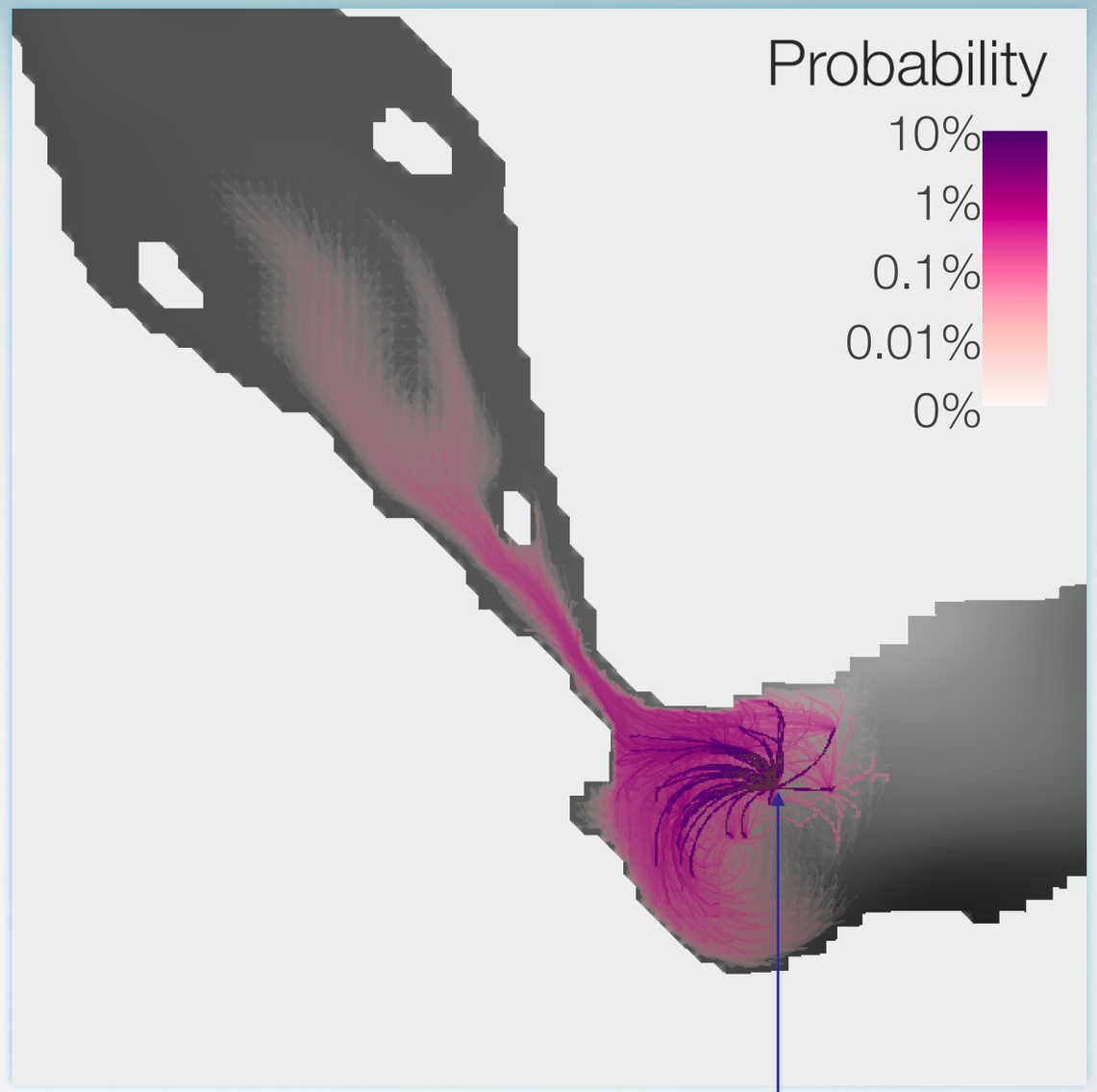
- Rasterize pathlines, probability as alpha

Probability Map Creation

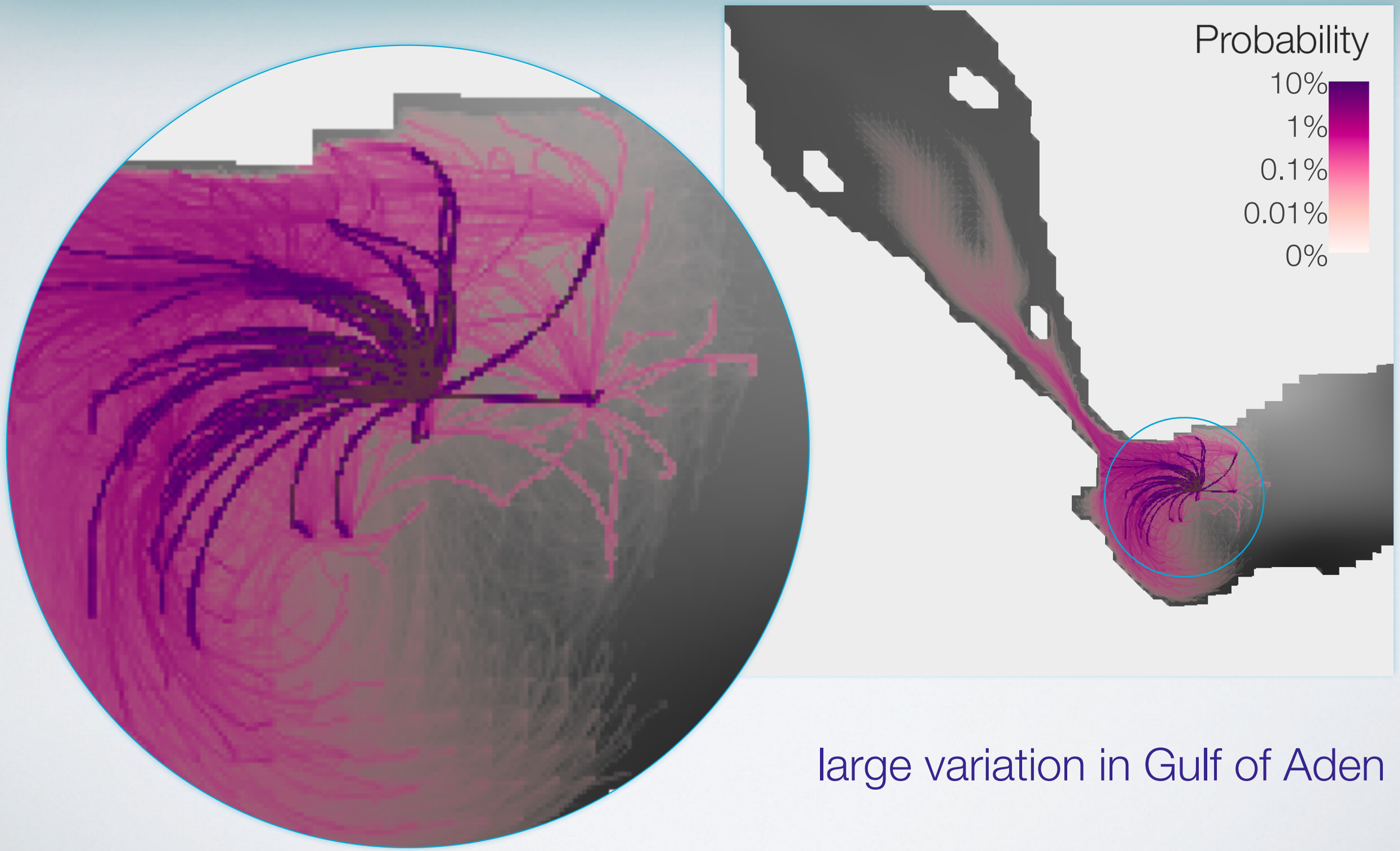
- Simple alpha lookup in texture
- Per pixel probability
- Apply colormap in fragment shader



Results

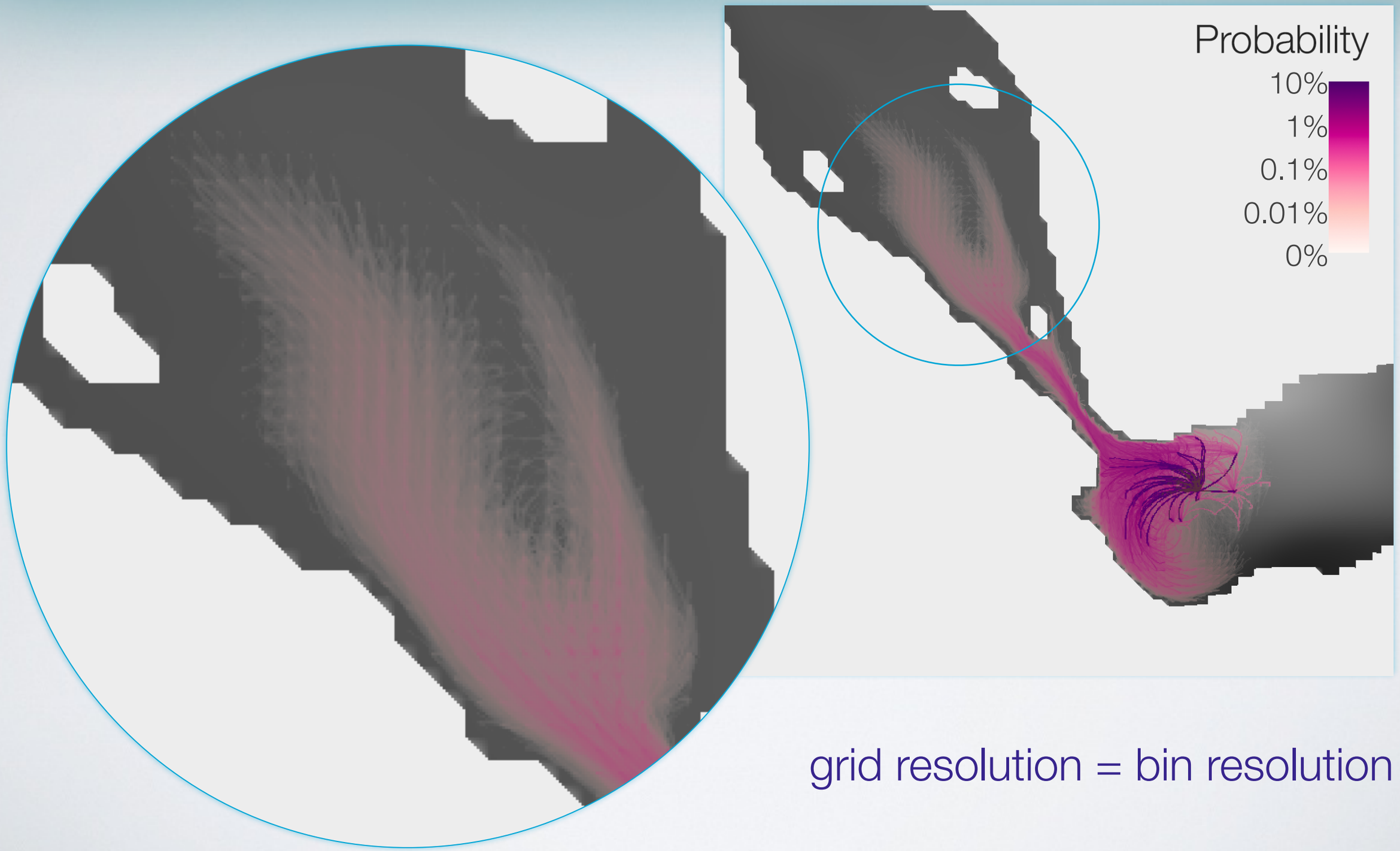


Results



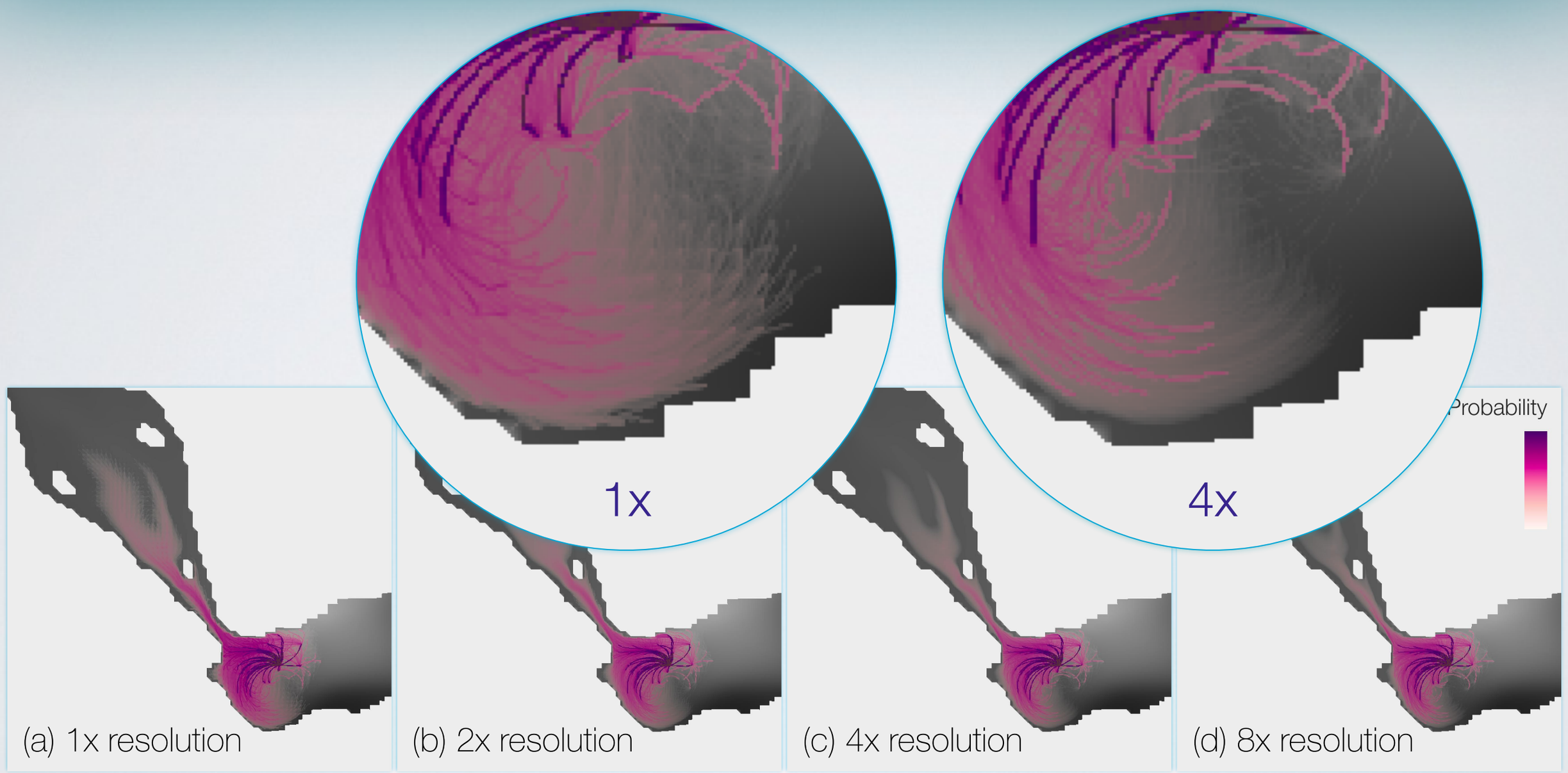
large variation in Gulf of Aden

Results



grid resolution = bin resolution

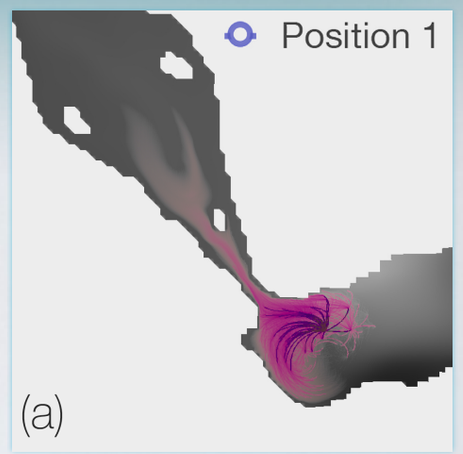
Results



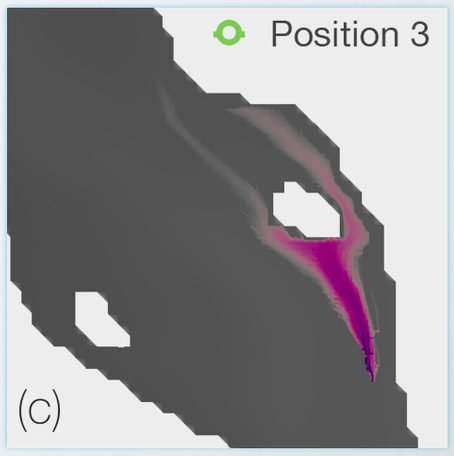
Higher bin resolution gives better precision, larger computational cost

Results

18000
13500
9000
4500
0
computation time in ms
1x
2x
4x
8x
bin resolution

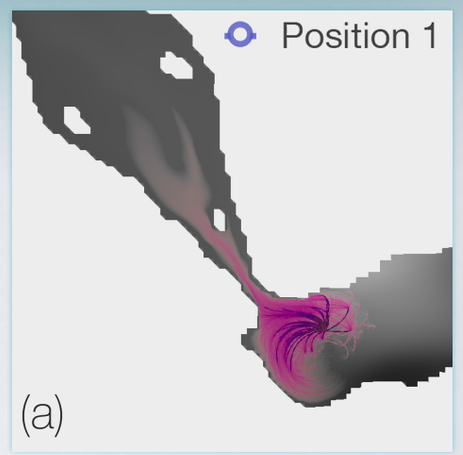

Position 1
(a)

Position 2
(b)

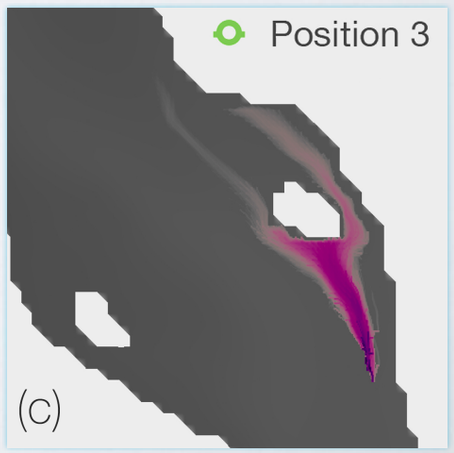

Position 3
(c)

Results

Performance at 2x Resolution
pathline segments traced
1E+09
1E+08
1E+07
1E+06
1E+05
1E+04
1E+03
1E+02
1E+01
1E+00
1
2
3
4
5
6
7
8
9
assimiliation cycle

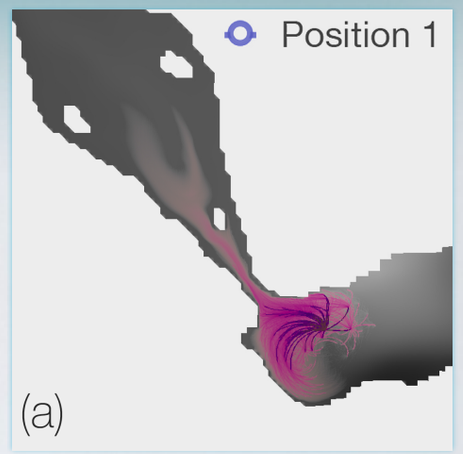

Position 1
(a)

Position 2
(b)

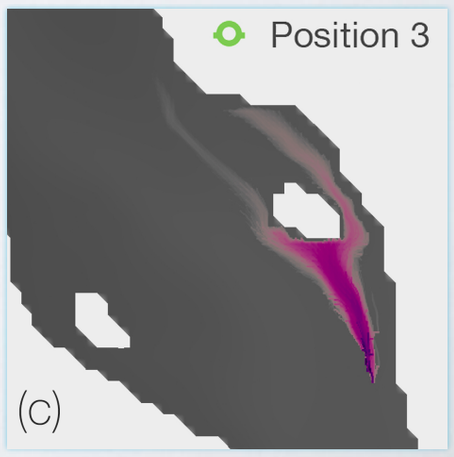

Position 3
(c)

Results

Performance at 2x Resolution
1.600
1.200
800
400
0
particles dropped
1
2
3
4
5
6
7
8
9
assimiliation cycle

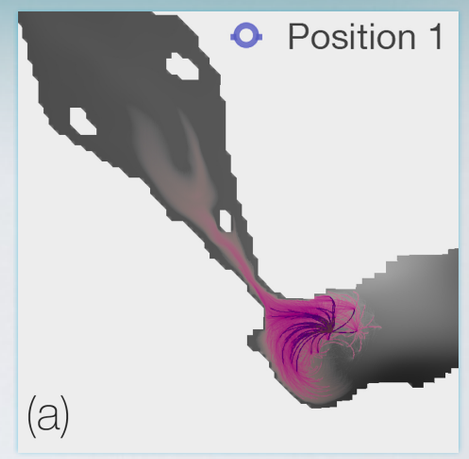

Position 1
(a)

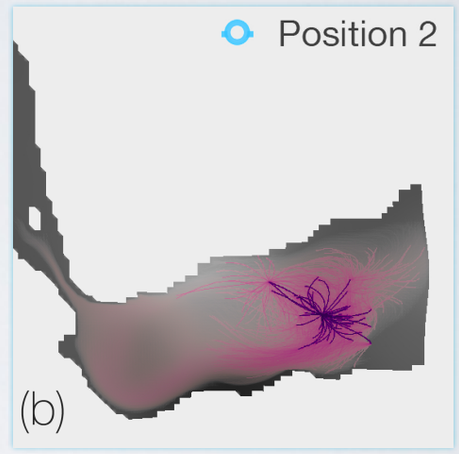
Position 2
(b)

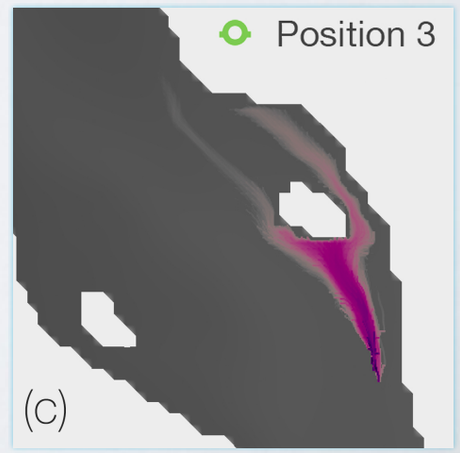

Position 3
(c)

Results

Performance at 2x Resolution
particles dropped
1.600
1.200
800
400
0
1
2
3
4
5
6
7
8
9
segments traced
1E+07
1E+06
1E+05
1E+04
1E+03
1E+02
1E+01
1E+00
assimiliation cycle

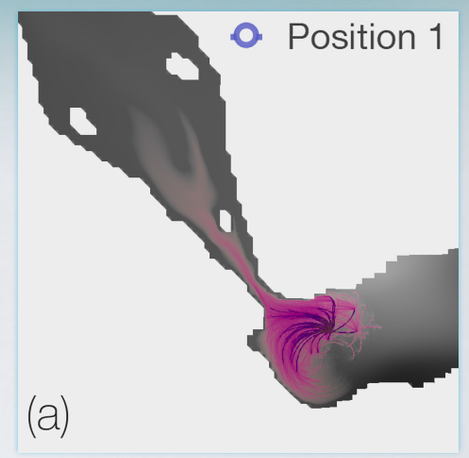

Position 1
(a)

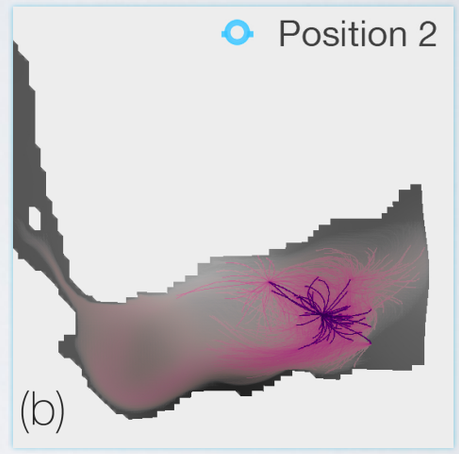

Position 2
(b)

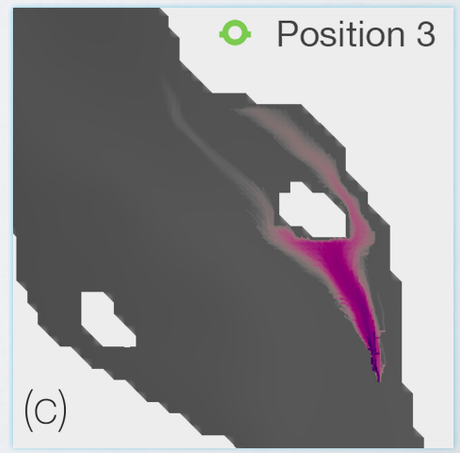

Position 3
(c)

Results

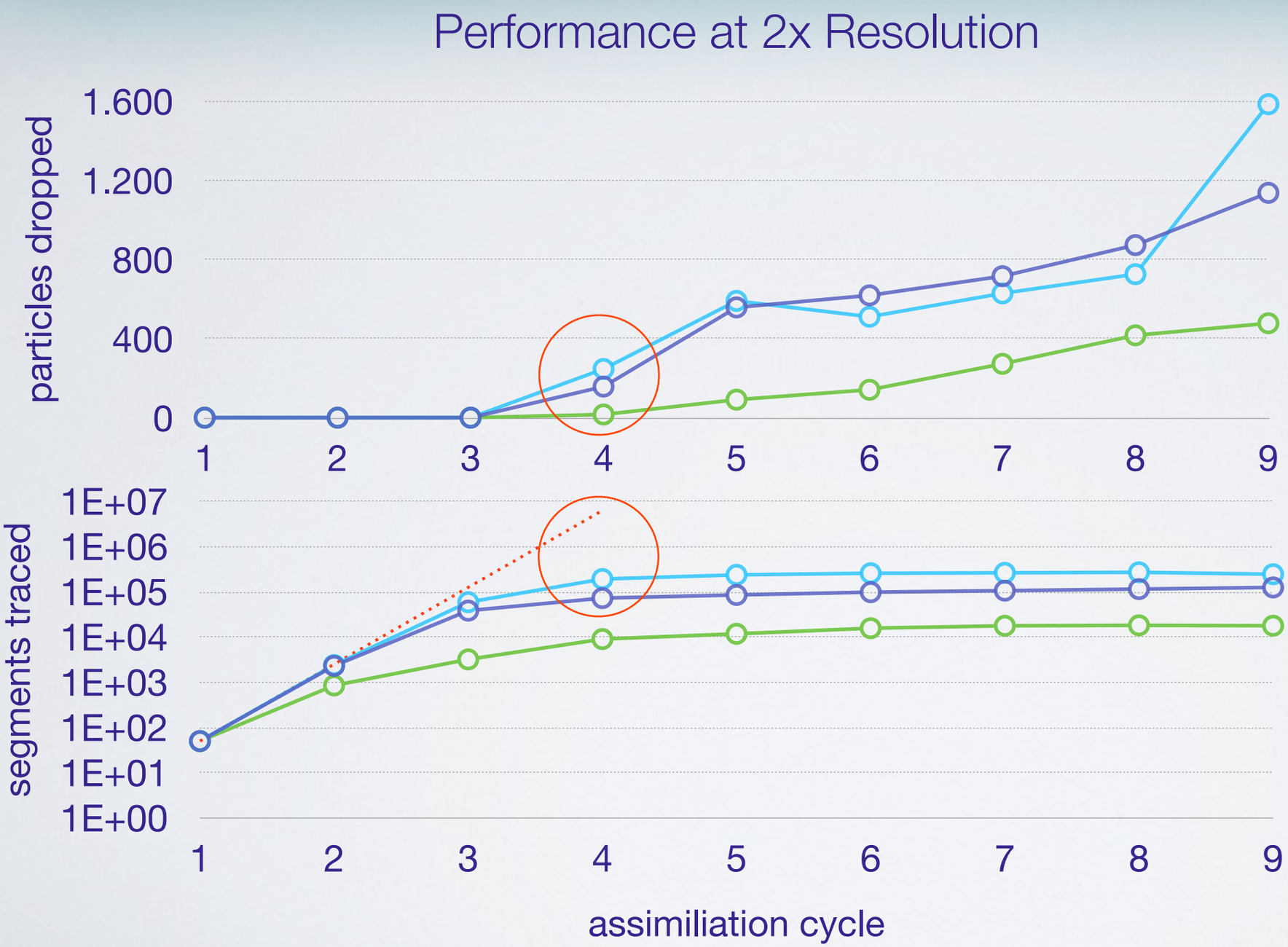
Performance at 2x Resolution
particles dropped
1.600
1.200
800
400
0
1
2
3
4
5
6
7
8
9
segments traced
1E+07
1E+06
1E+05
1E+04
1E+03
1E+02
1E+01
1E+00
assimiliation cycle

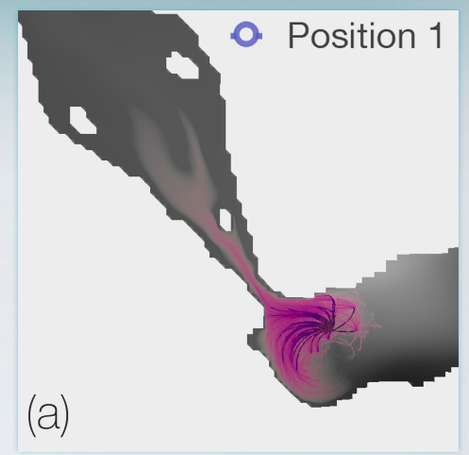

Position 1
(a)


Position 2
(b)

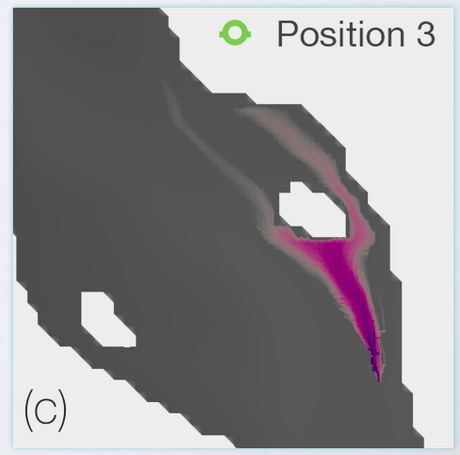

Position 3
(c)

Results

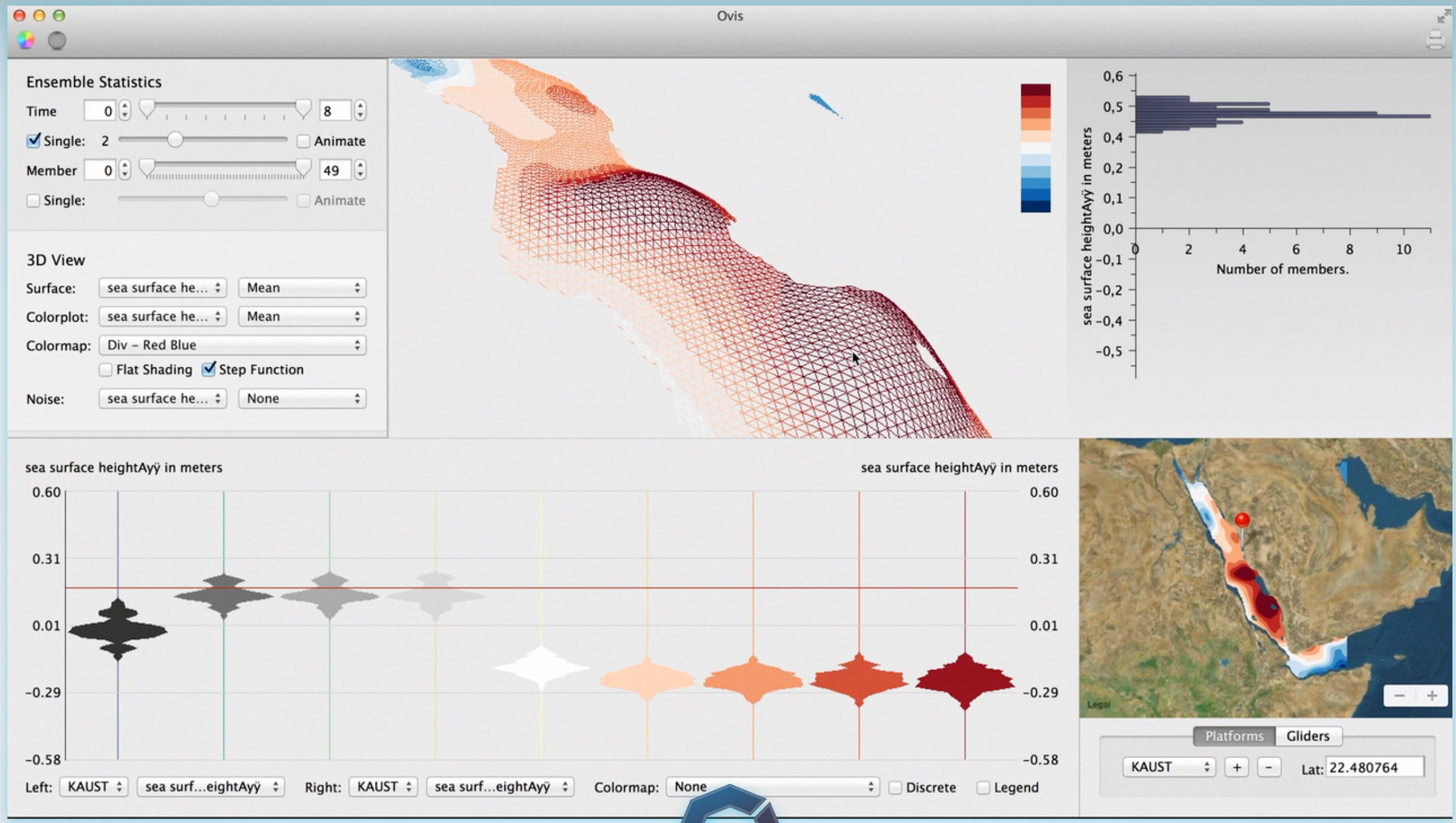

Performance at 2x Resolution
particles dropped
1.600
1.200
800
400
0
1
2
3
4
5
6
7
8
9
segments traced
1E+07
1E+06
1E+05
1E+04
1E+03
1E+02
1E+01
1E+00
assimiliation cycle


Position 1
(a)

Position 2
(b)


Position 3
(c)

Questions?


Ovis
Ensemble Statistics
Time 0 8
Single: 2 Animate
Member 0 49
Single: Animate
3D View
Surface: sea surface he... Mean
Colorplot: sea surface he... Mean
Colormap: Div – Red Blue
Flat Shading Step Function
Noise: sea surface he... None
sea surface heightAyÿ in meters
Number of members.
sea surface heightAyÿ in meters
sea surface heightAyÿ in meters
0.60
0.31
0.01
-0.29
-0.58
Left: KAUST sea surf...eightAyÿ
Right: KAUST sea surf...eightAyÿ
Colormap: None
Discrete
Legend
Legal
Platforms
Gliders
KAUST
Lat: 22.480764