Cornell University

# Modeling 3D Hydrodynamics and Shelf Flushing

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Edwin (Todd) Cowen
Seth Schweitzer

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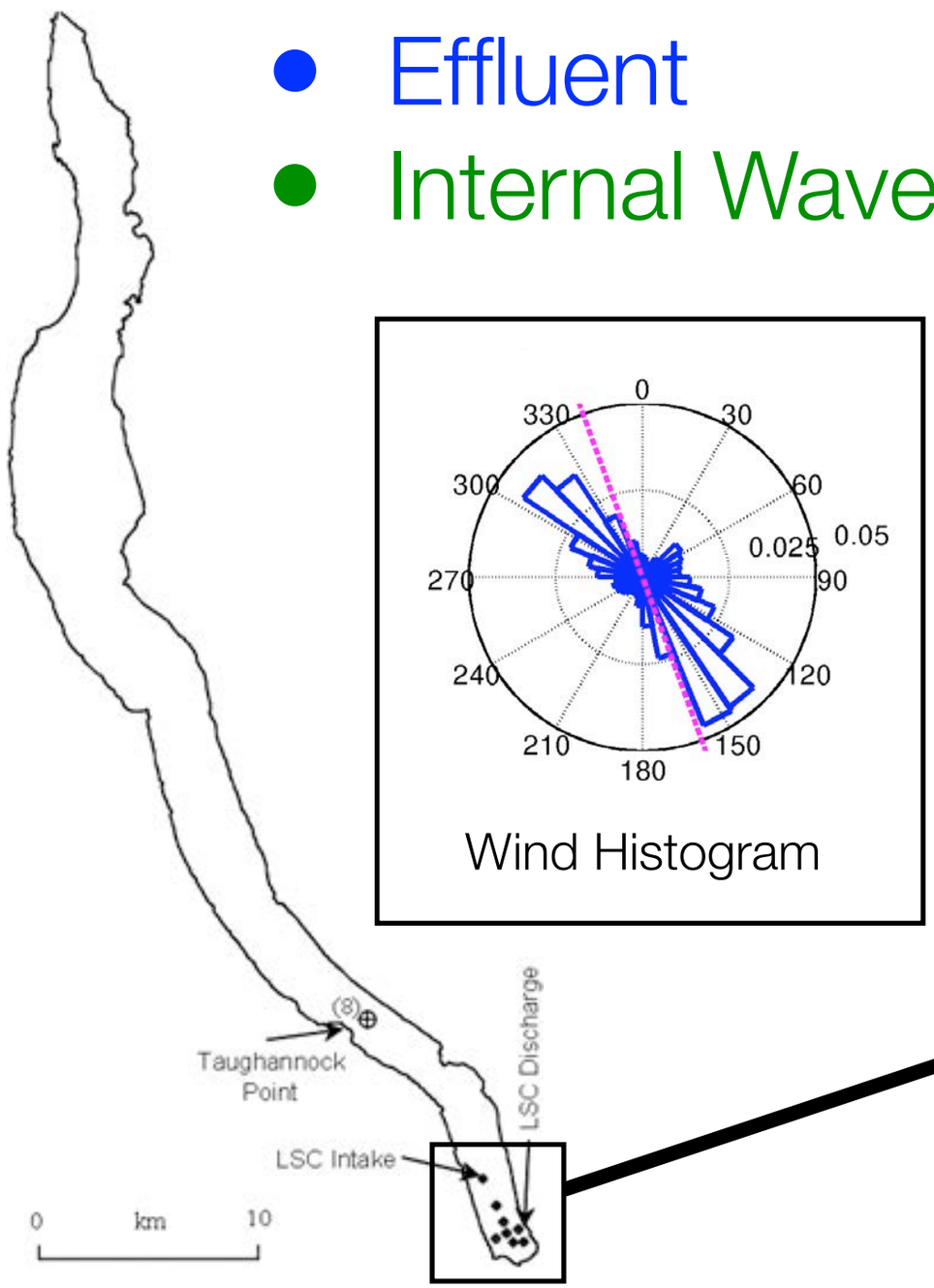
*Instituto del Agua & Departamento Ingeniería Civil, Universidad de Granada, Granada, Spain*

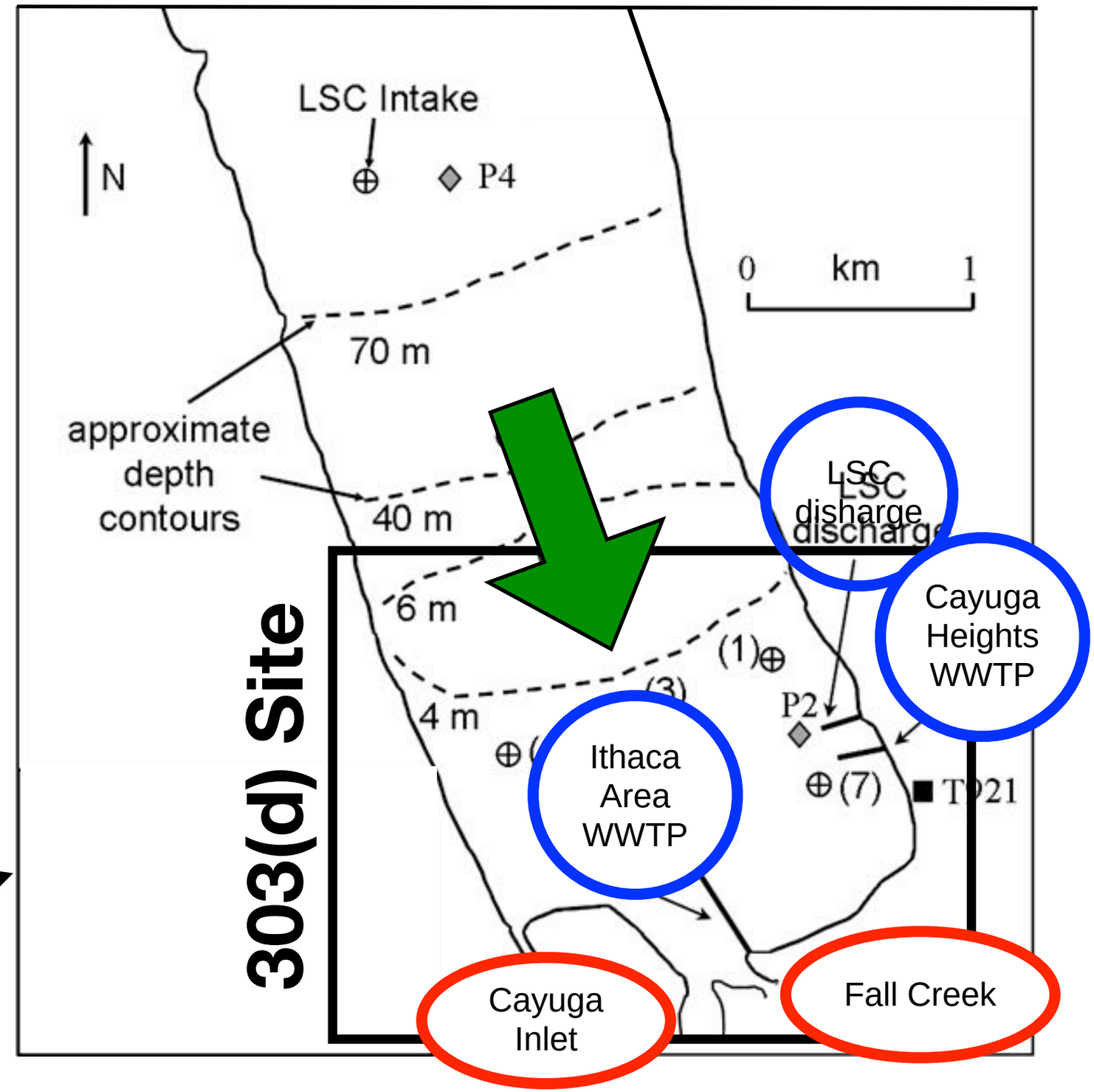
# Outline

- Physical processes impacting the southern shelf
- Background on 3D hydrodynamic model
- Adding point sources to 3D model
- Using 3D model to compute flushing time and residence times on southern shelf

# Physical Processes

- Tributaries
- Effluent
- Internal Waves

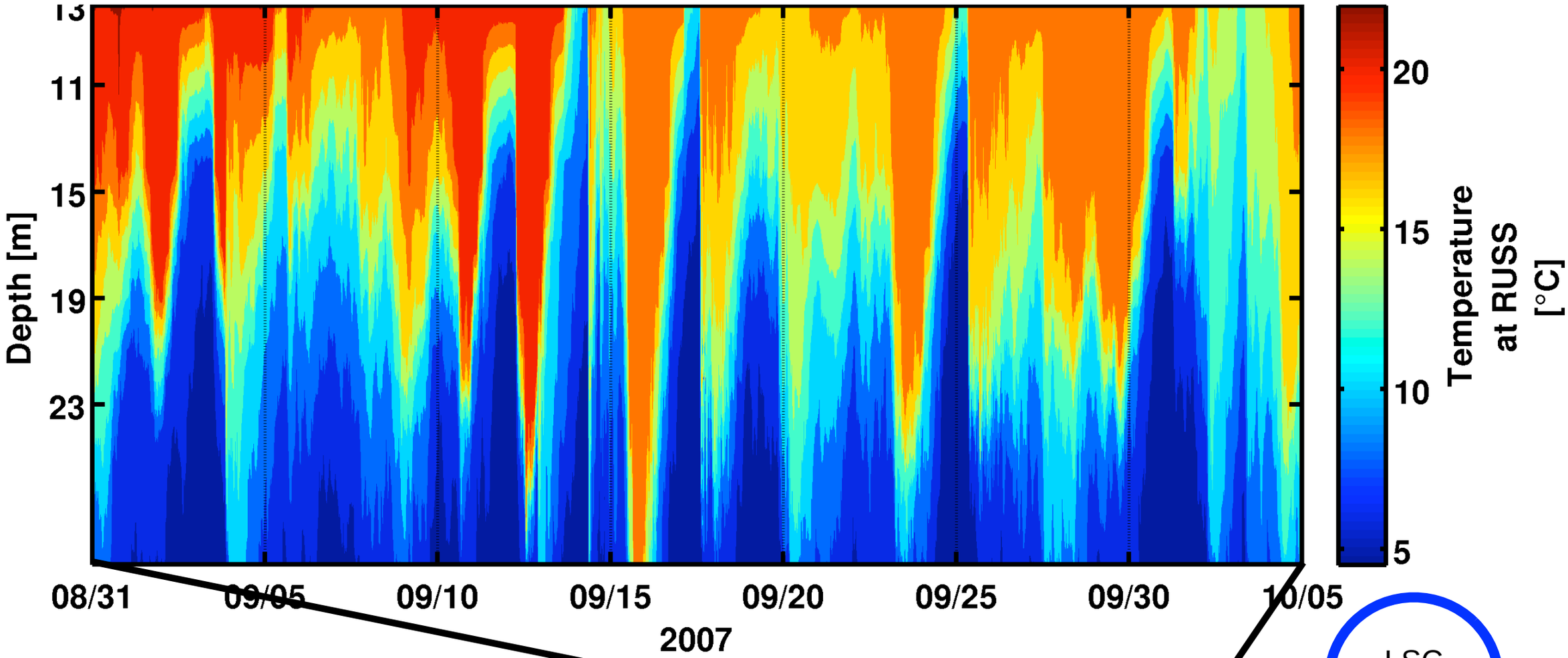


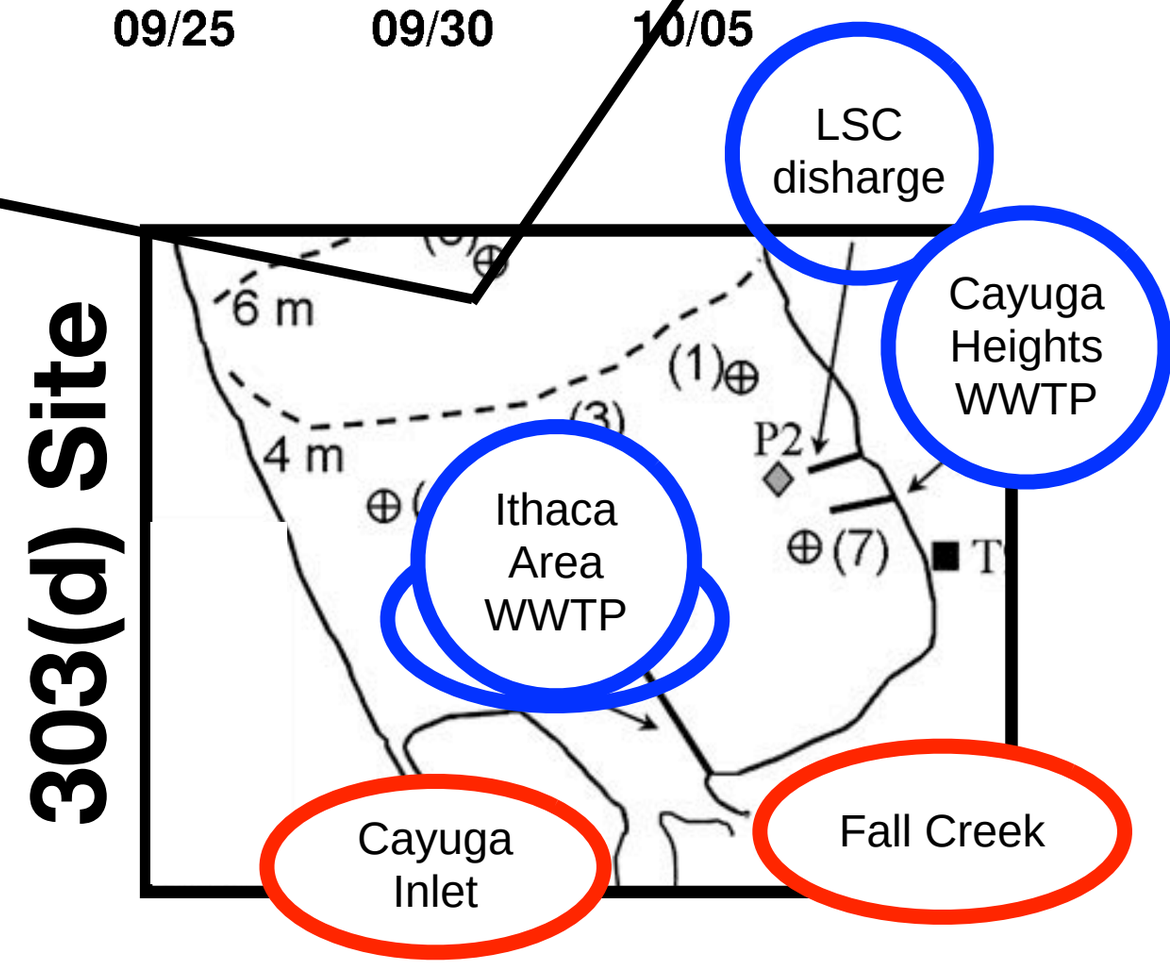
# Conditions after a Rainfall Event

April 5, 2005 CAYUGA LAKE view north from Ithaca photo by Bill Hecht

April 5, 2005 Cayuga Lake south end Rt 13 in upper right. photo by Bill Hecht




# Internal Waves Impact the Southern Shelf



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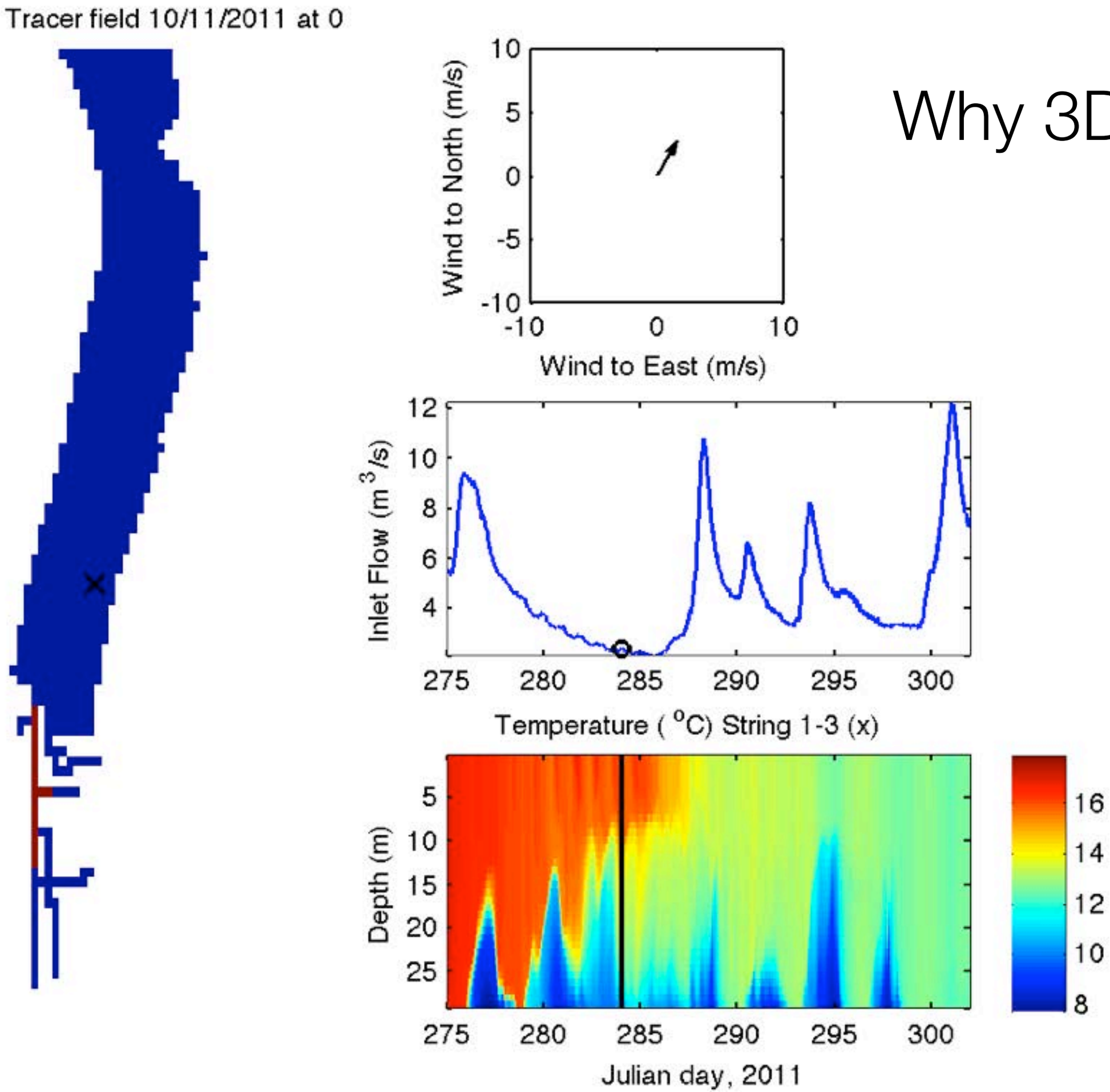
Tracer field 10/11/2011 at 0
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Inlet Flow (m$^3$/s)
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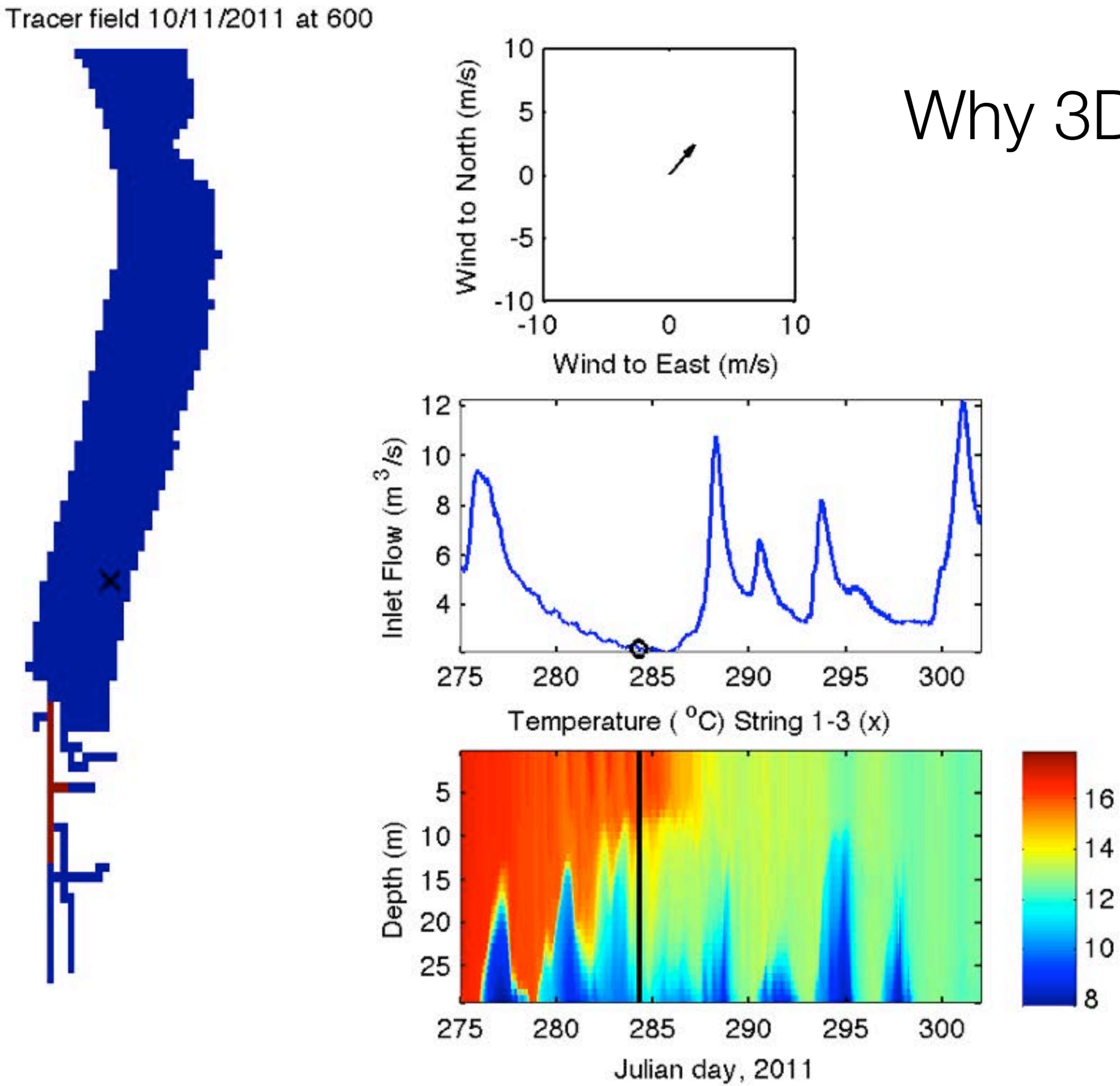
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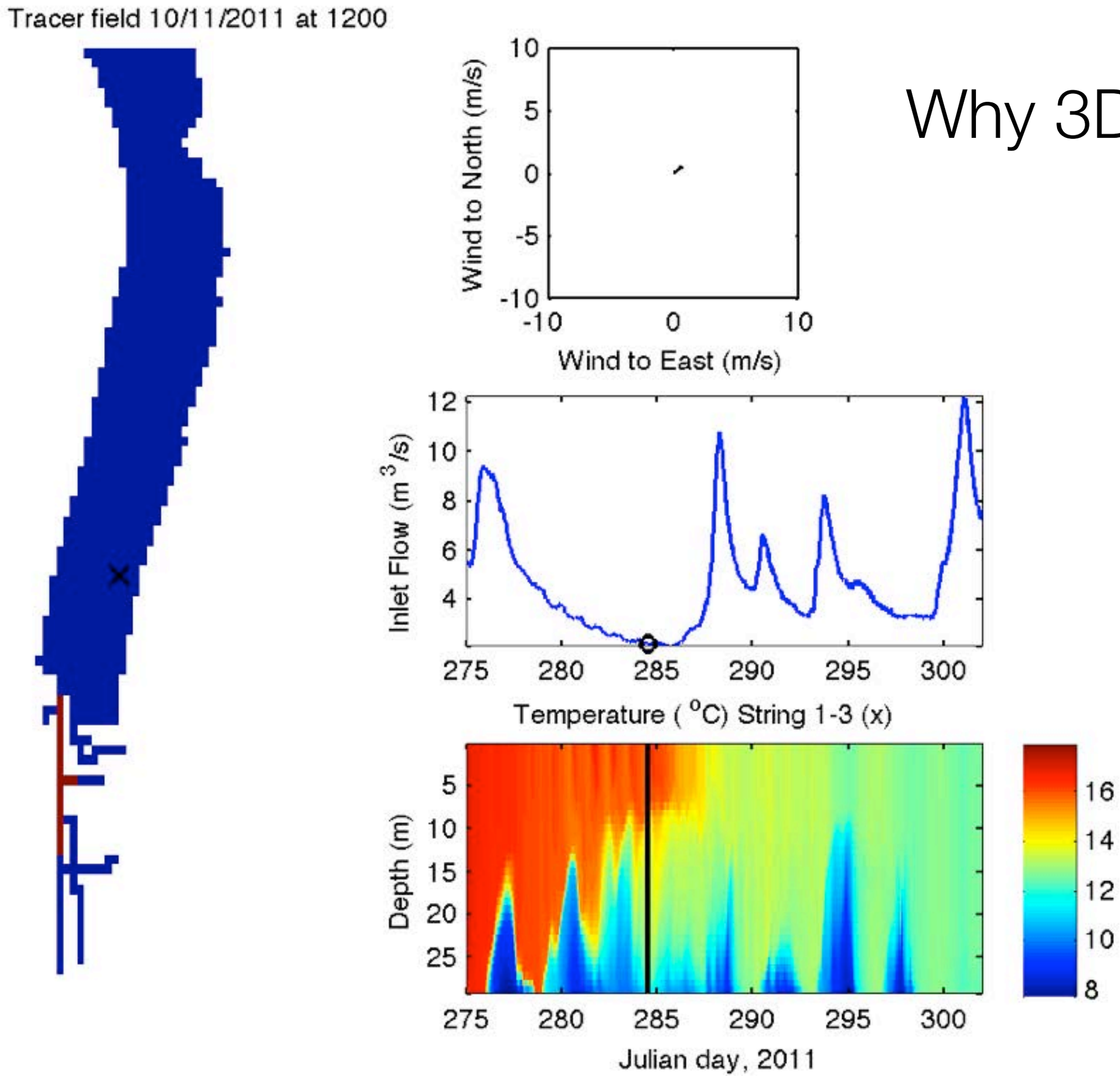
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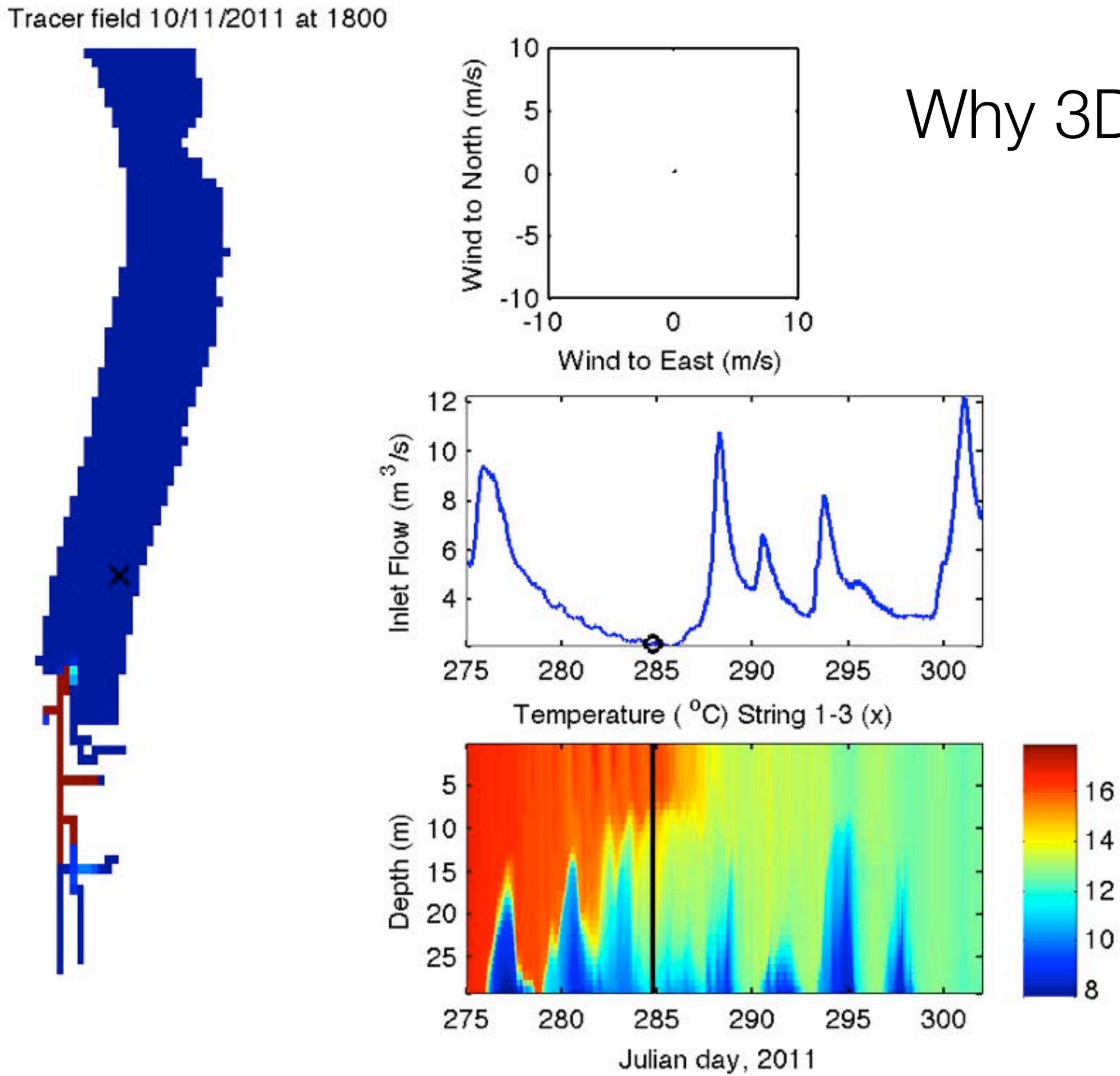
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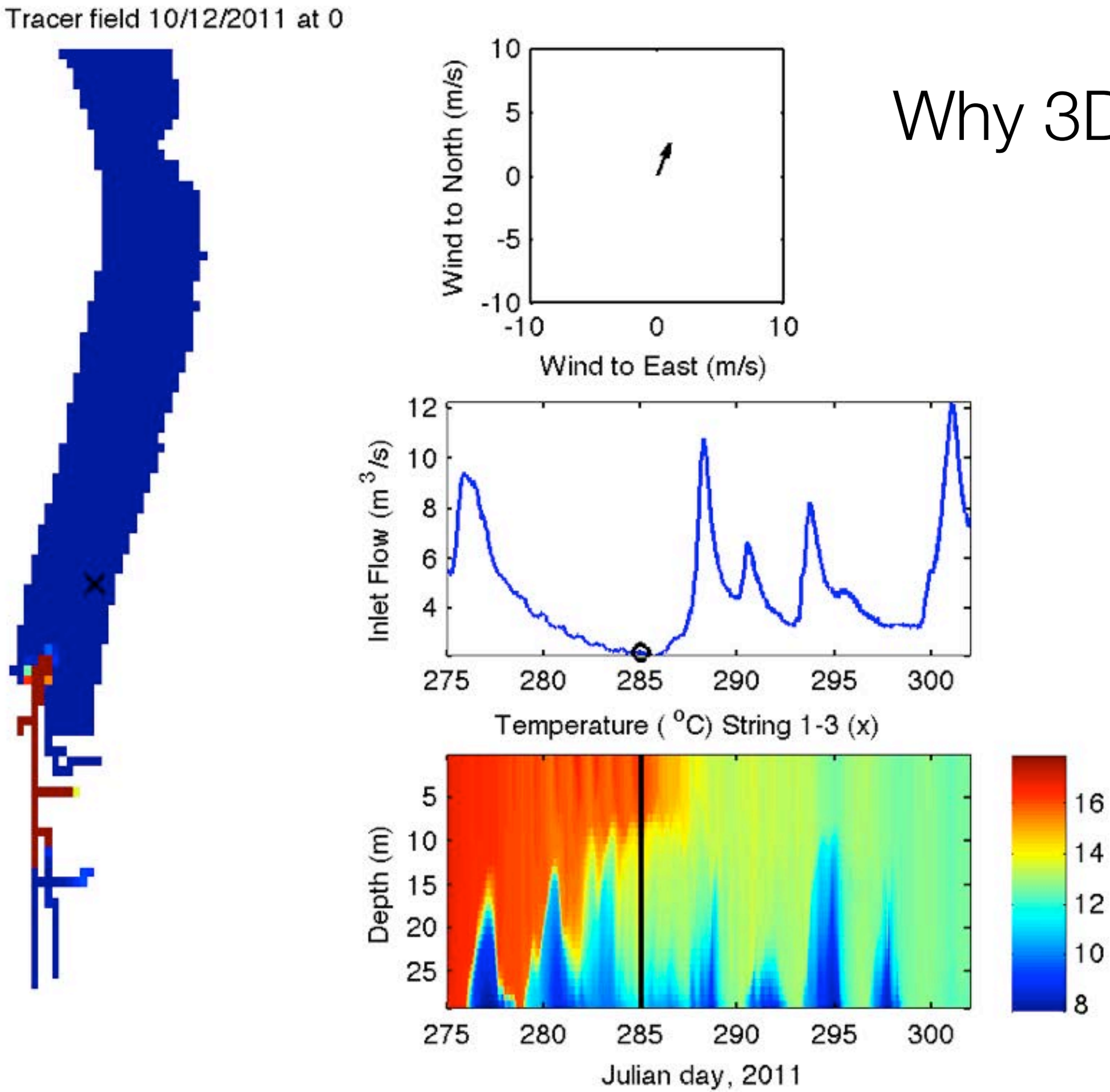
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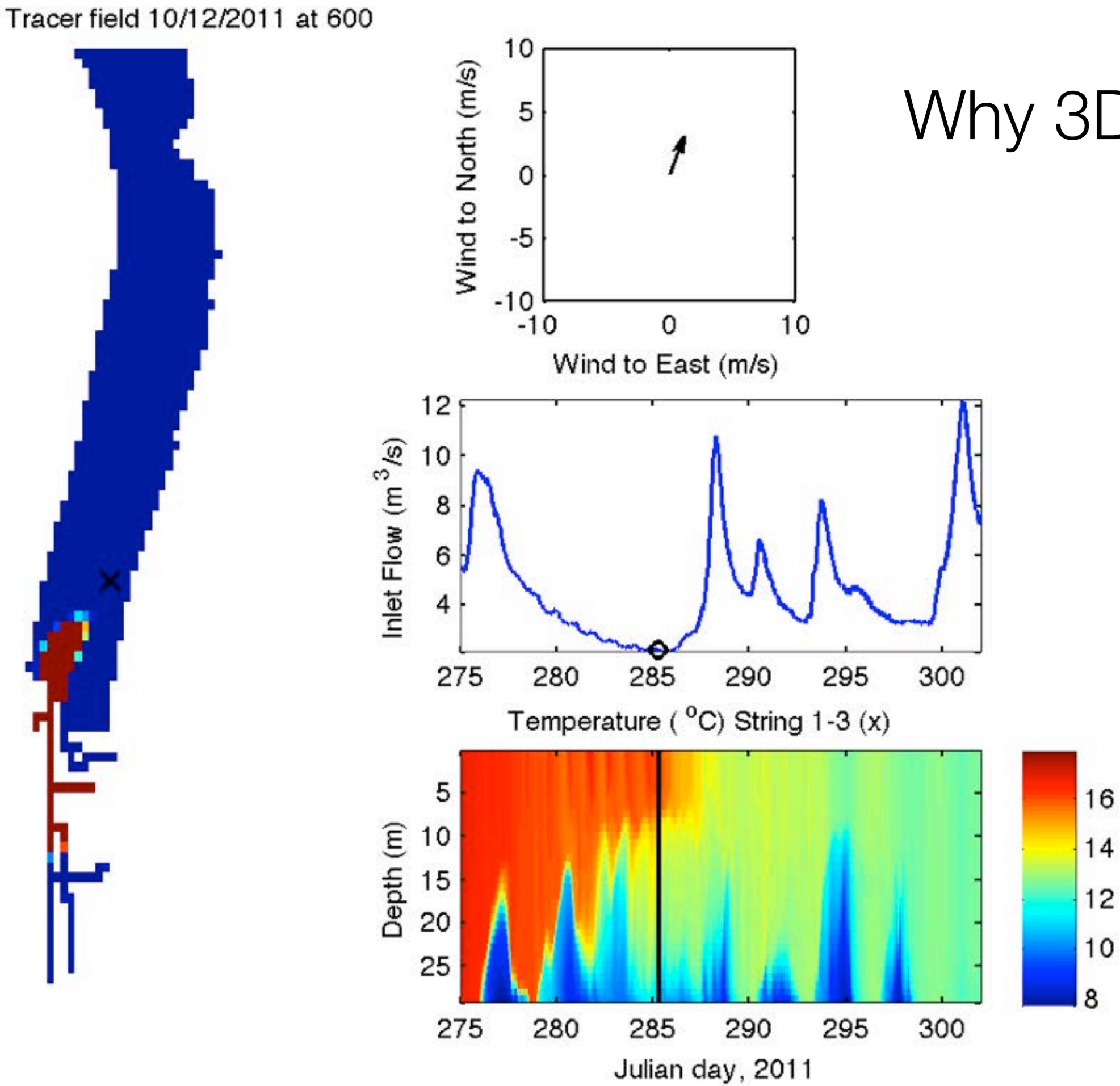
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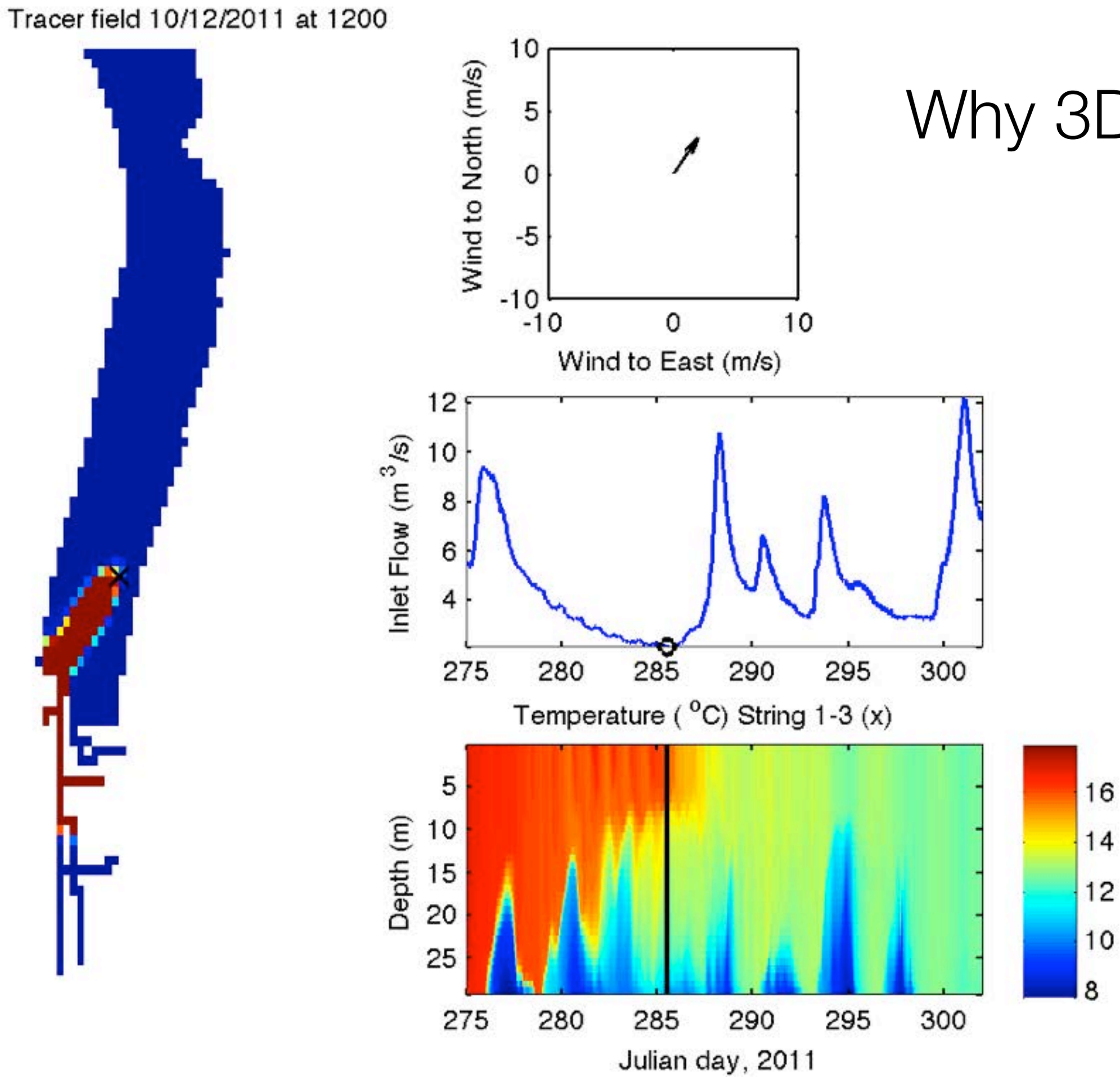
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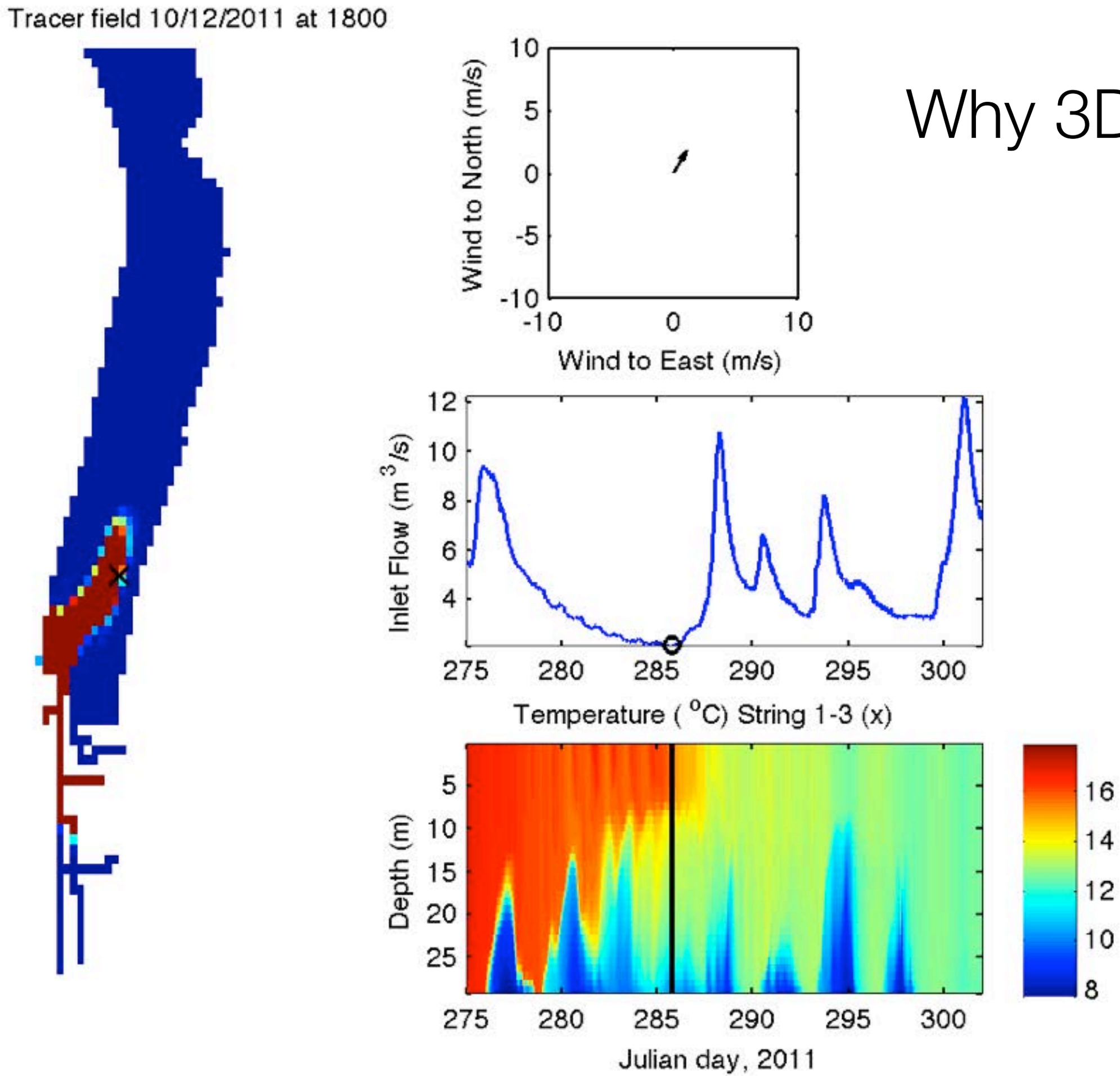
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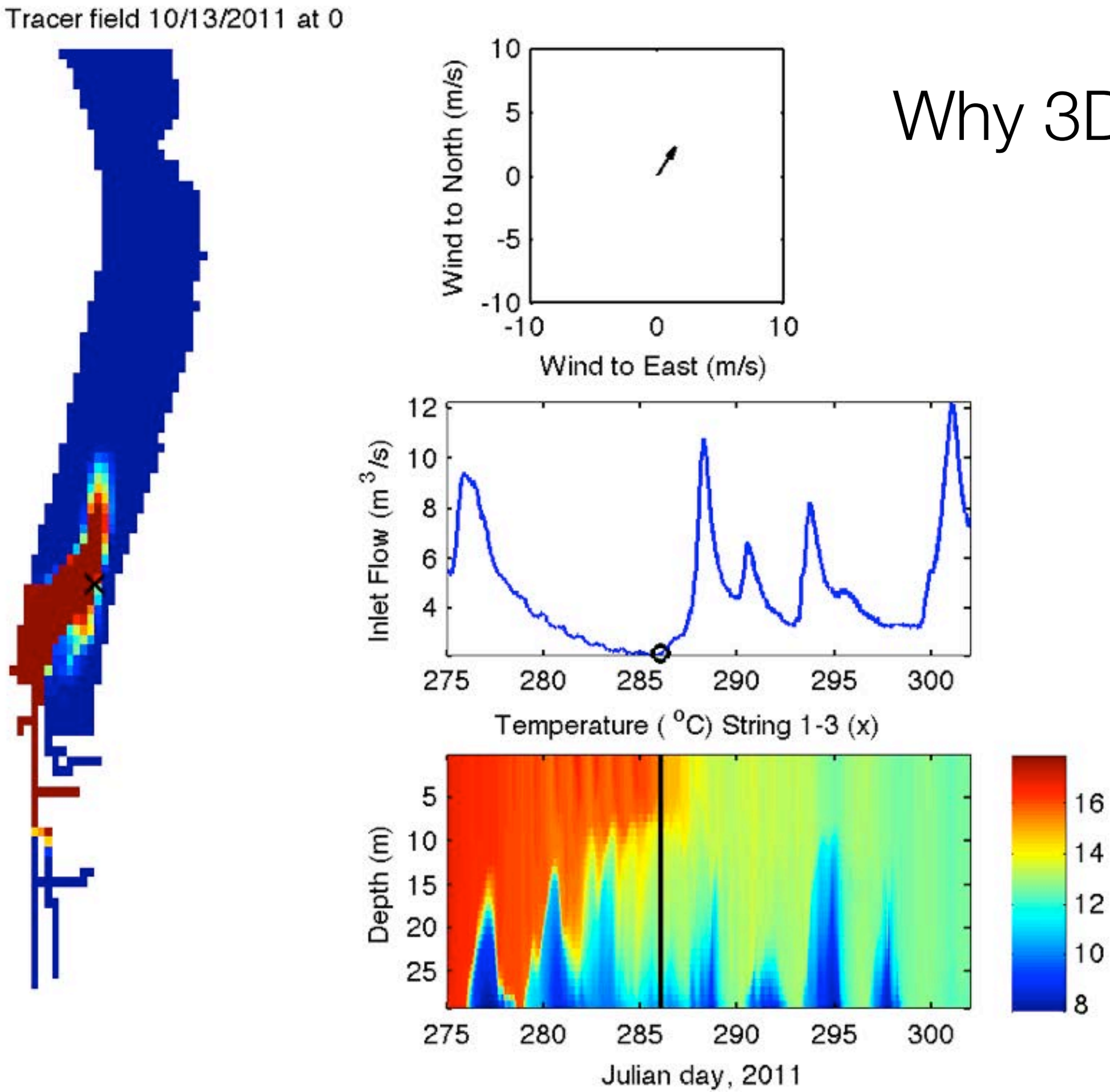
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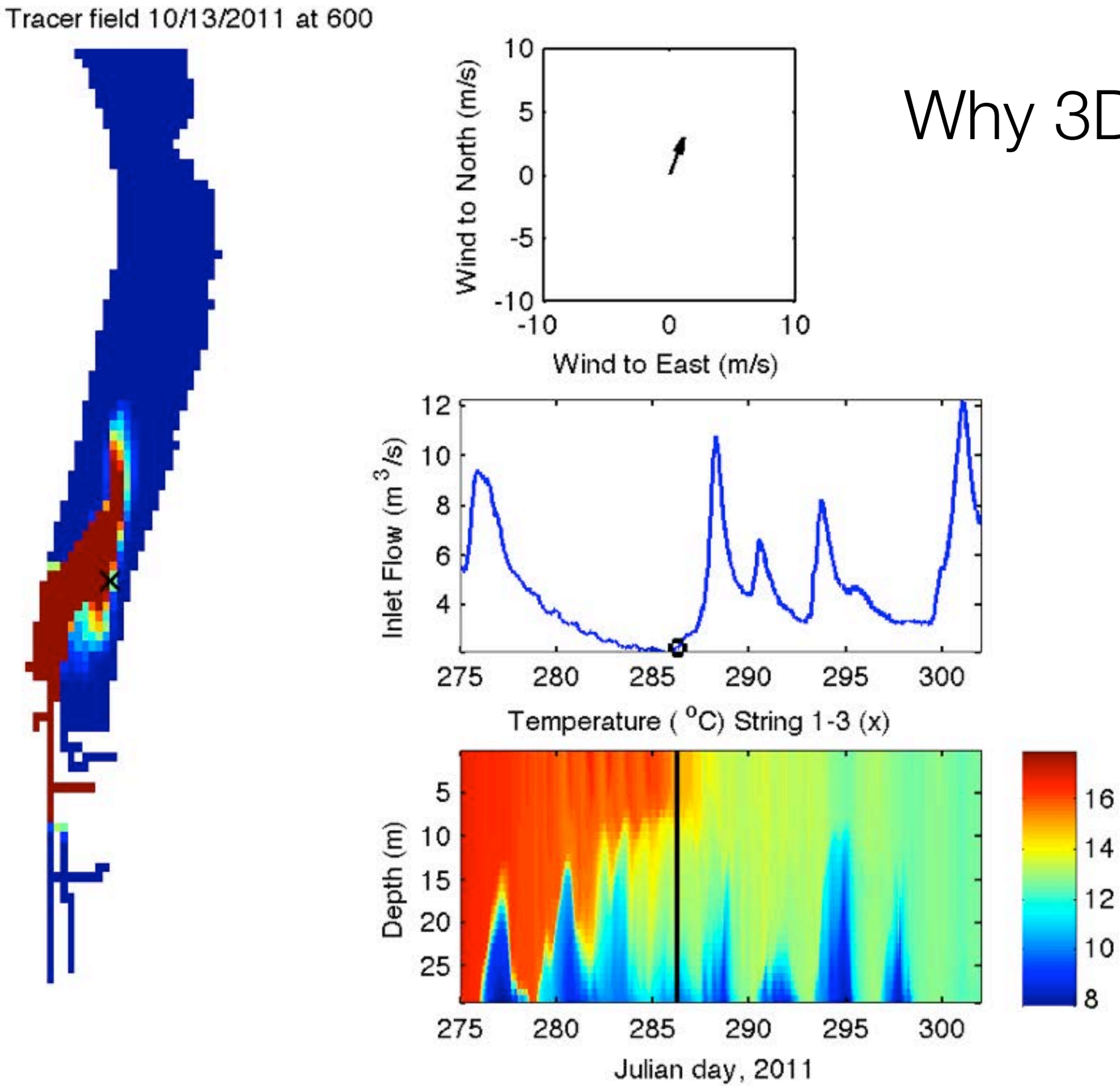
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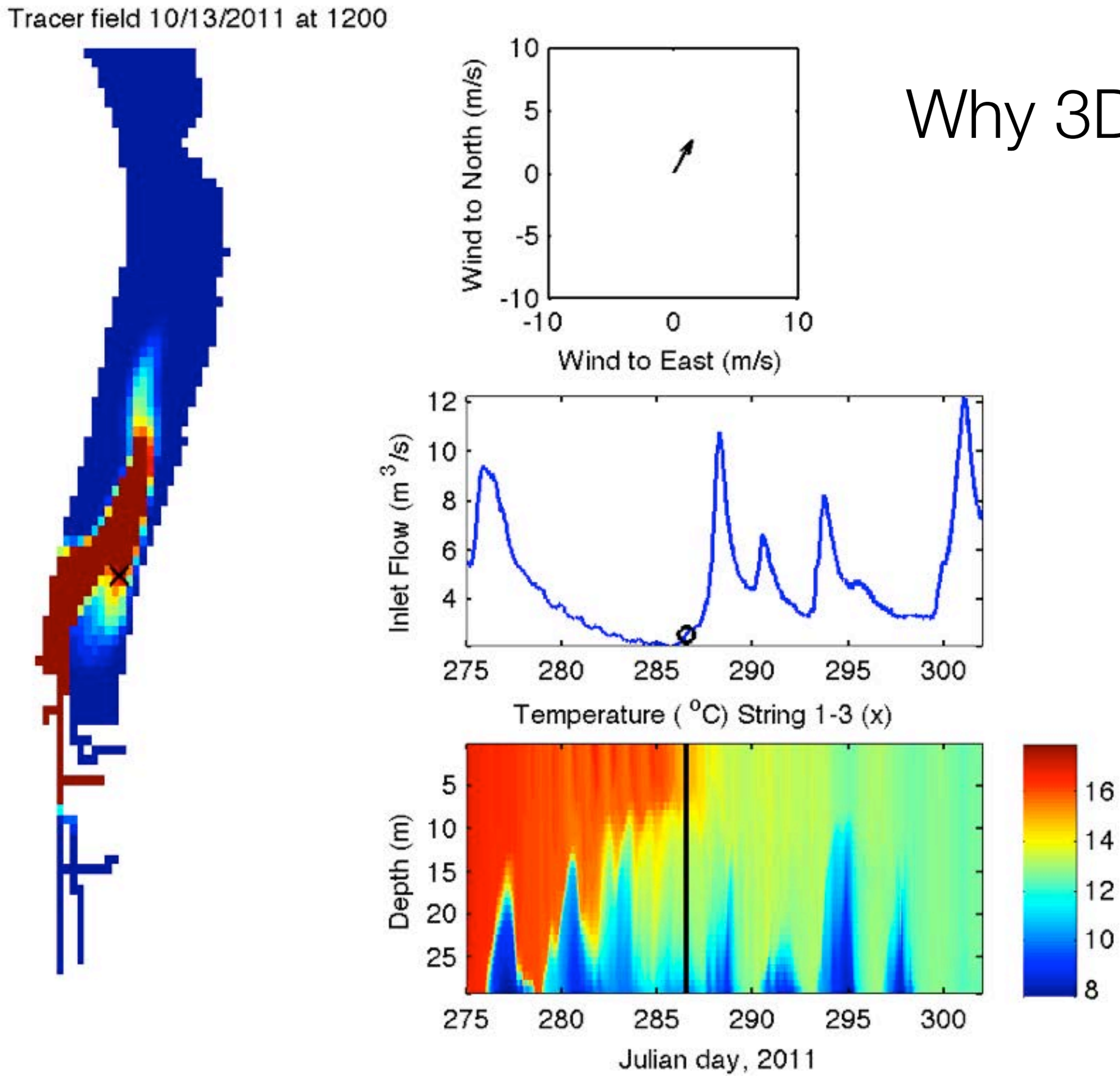
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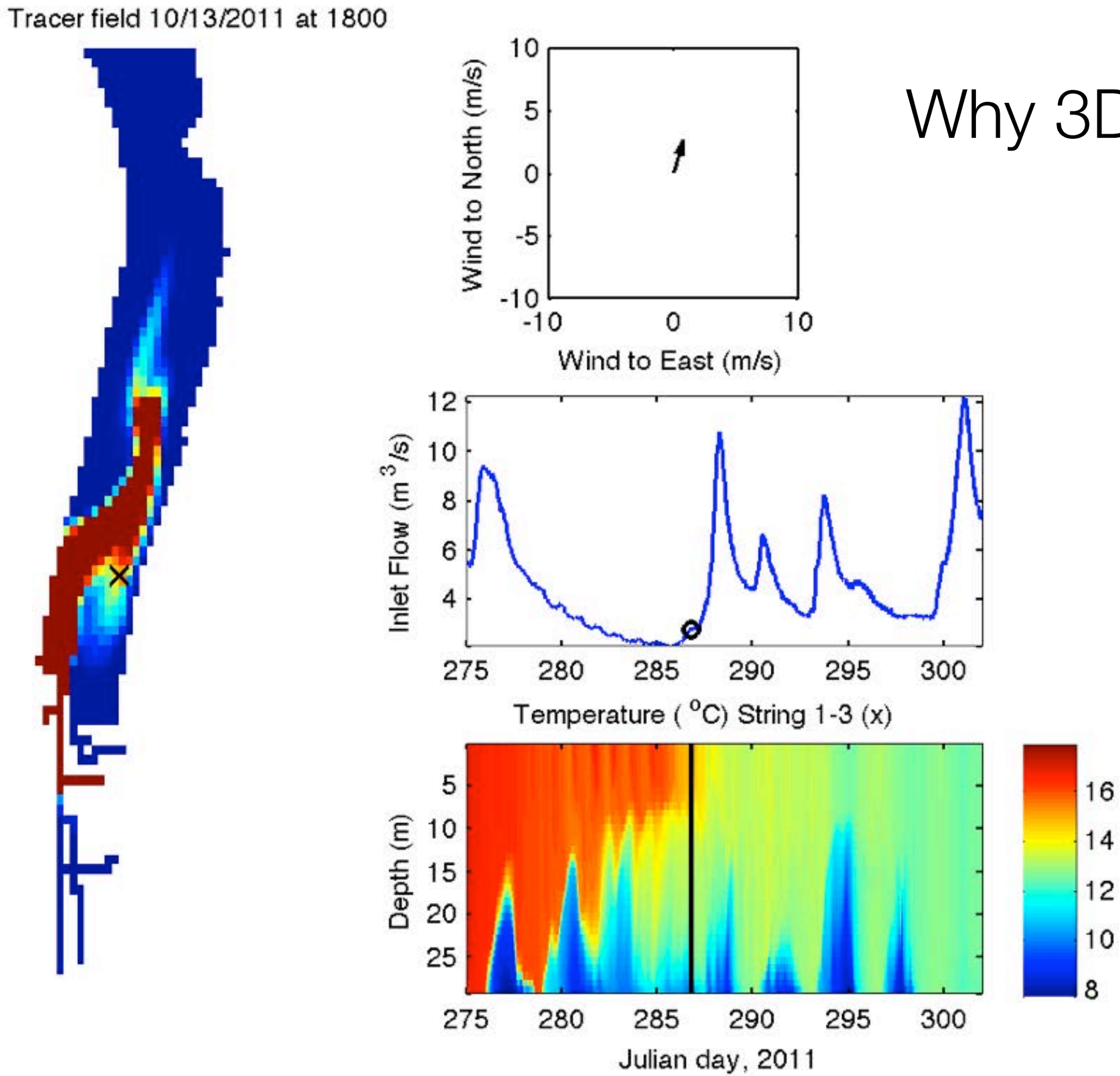
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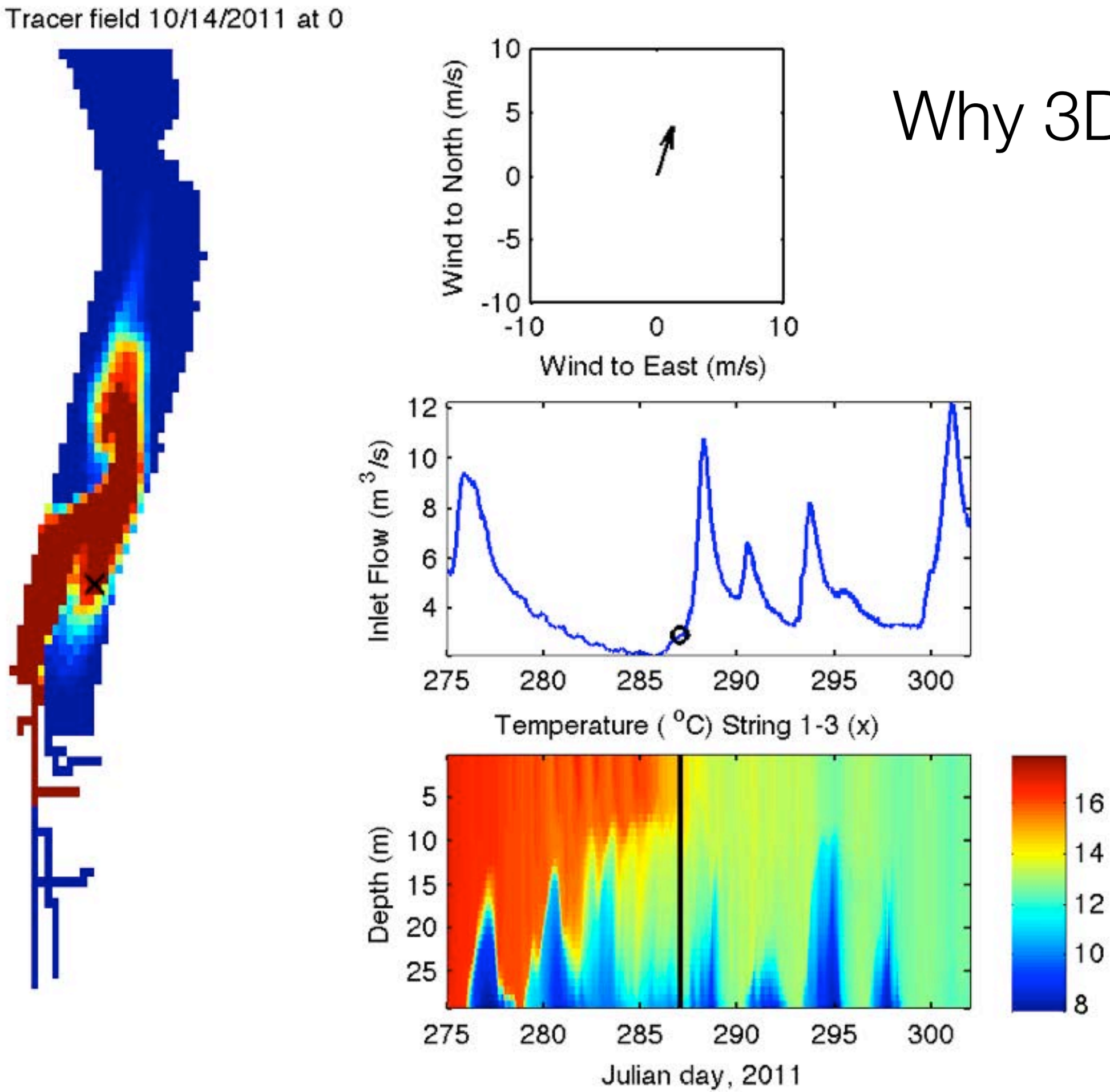
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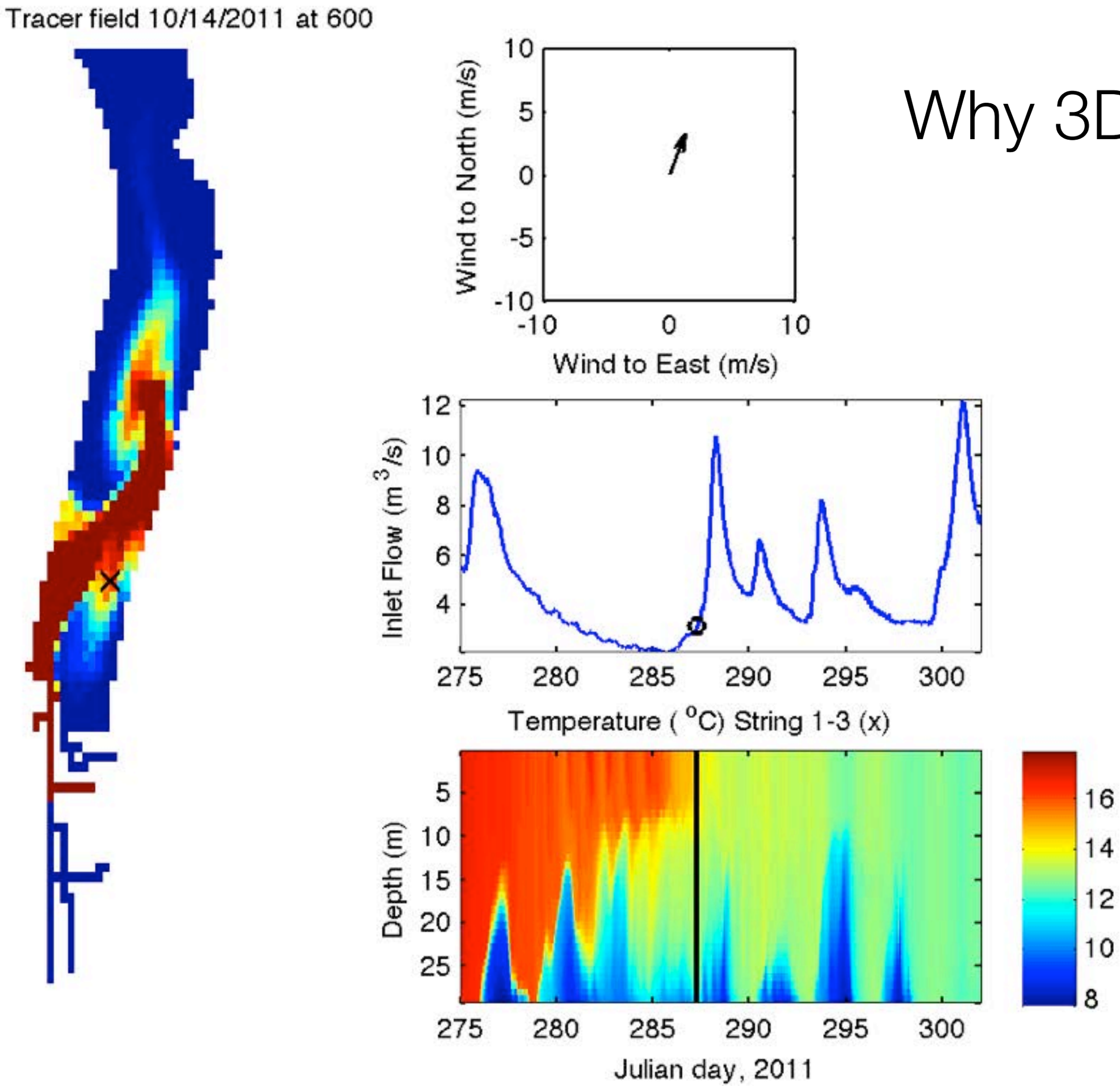
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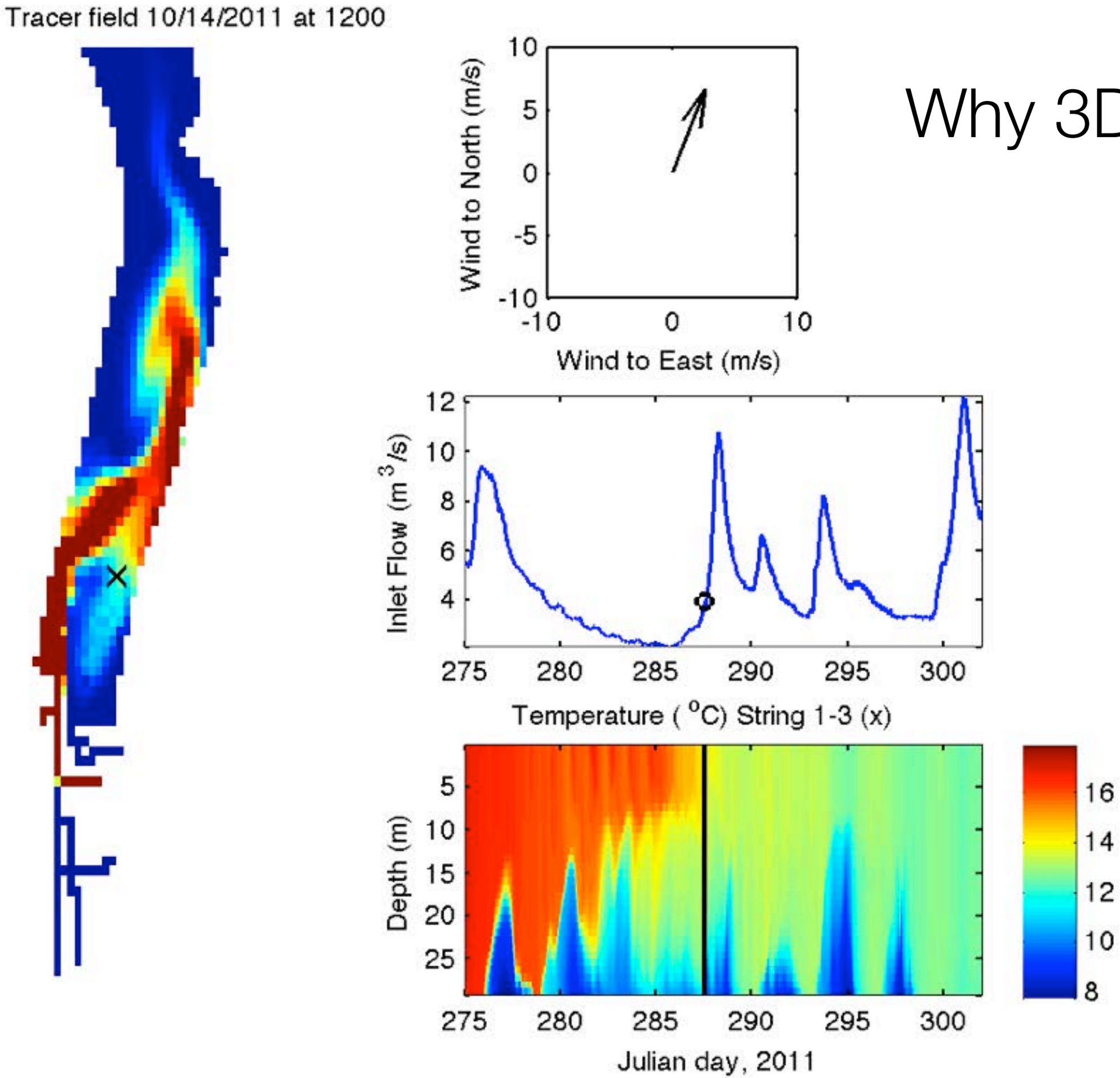
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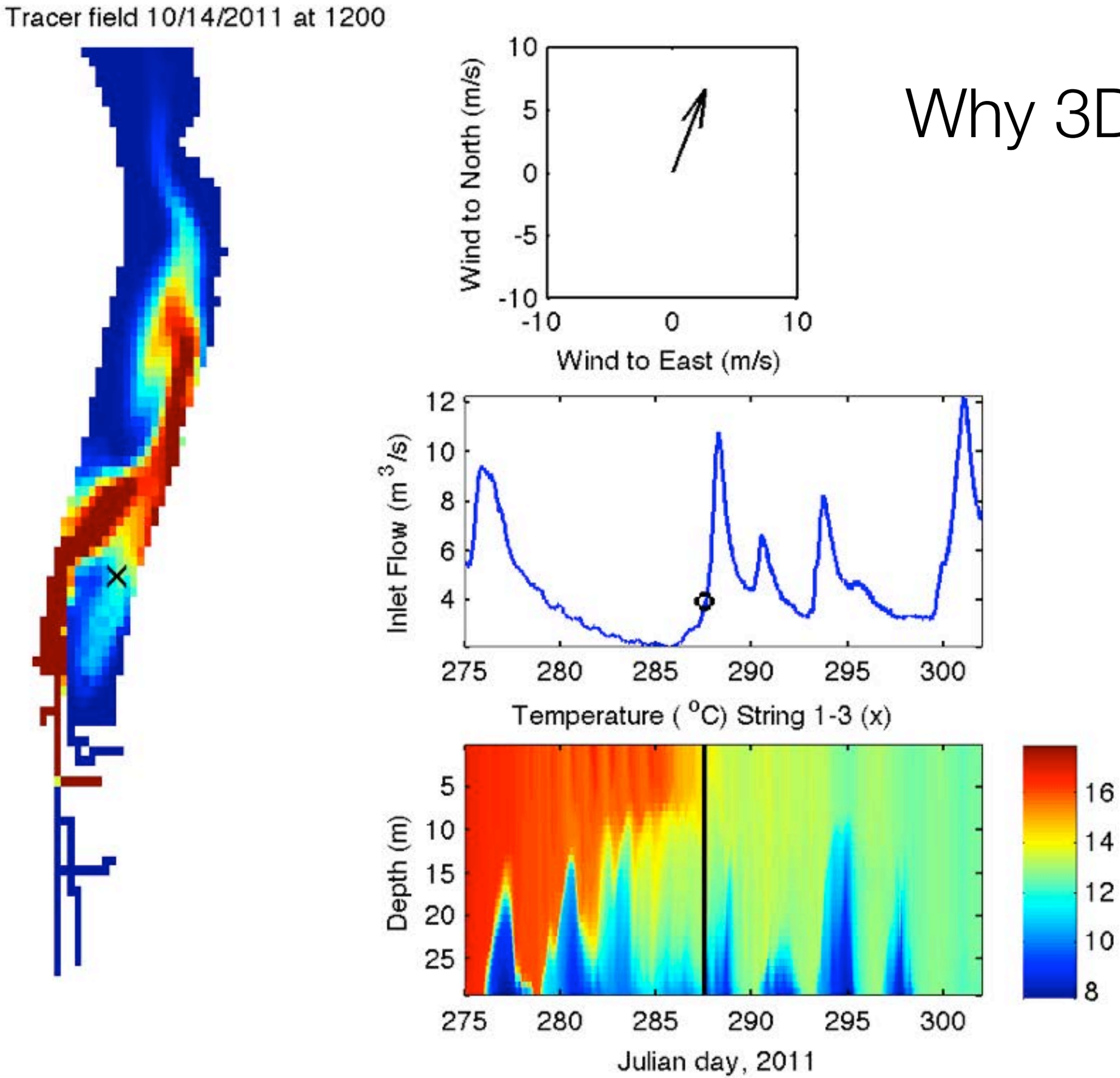
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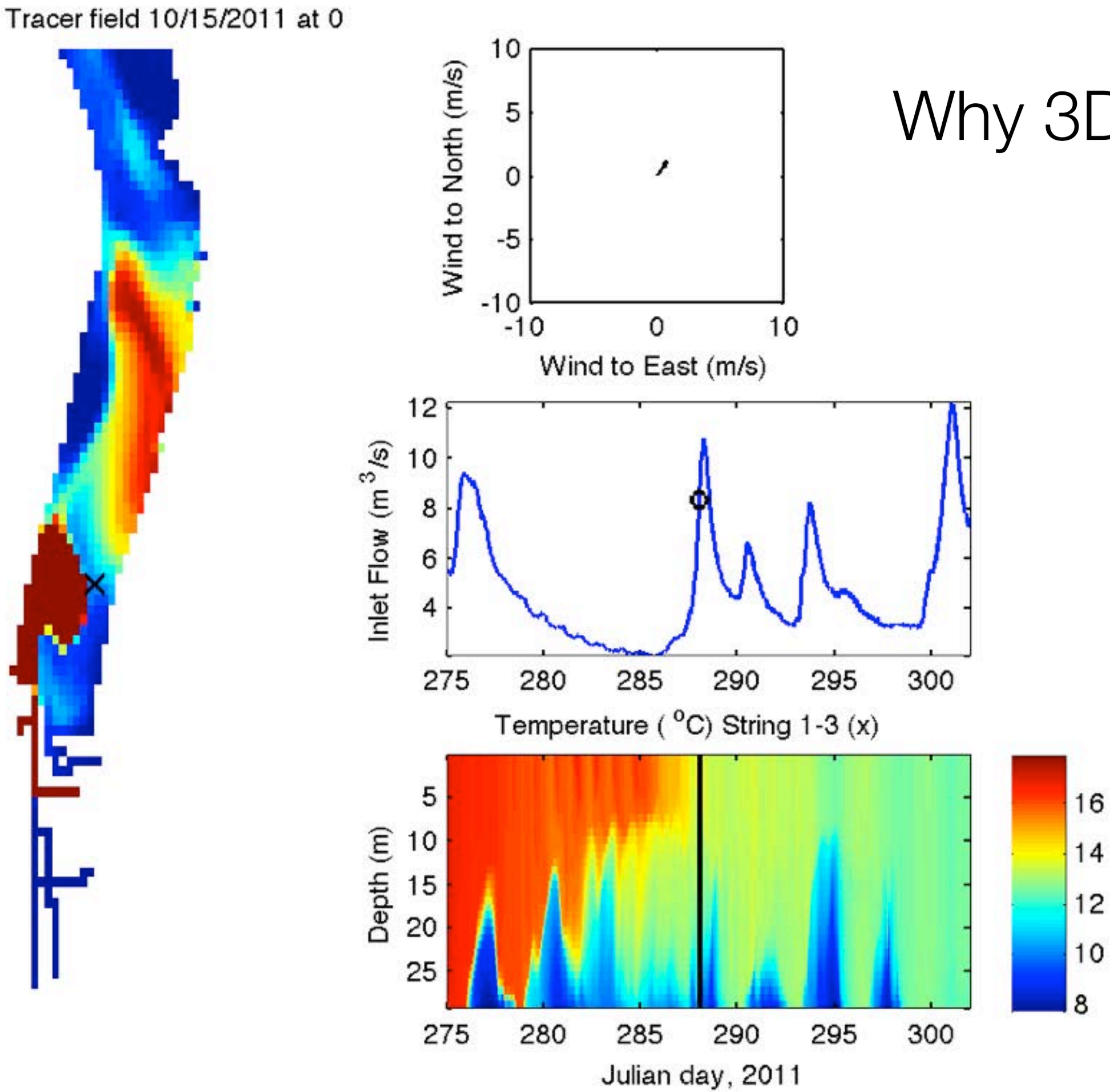
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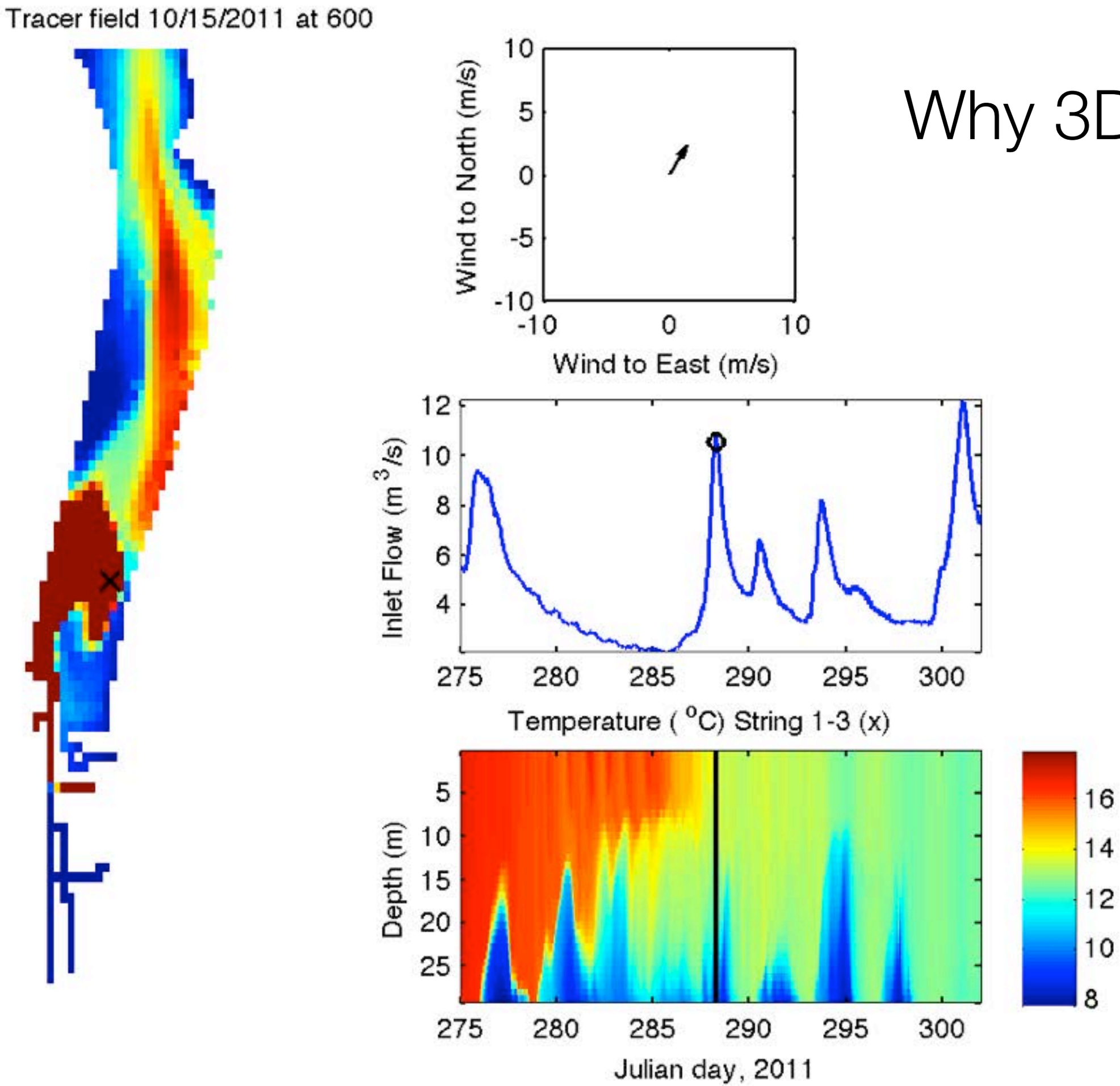
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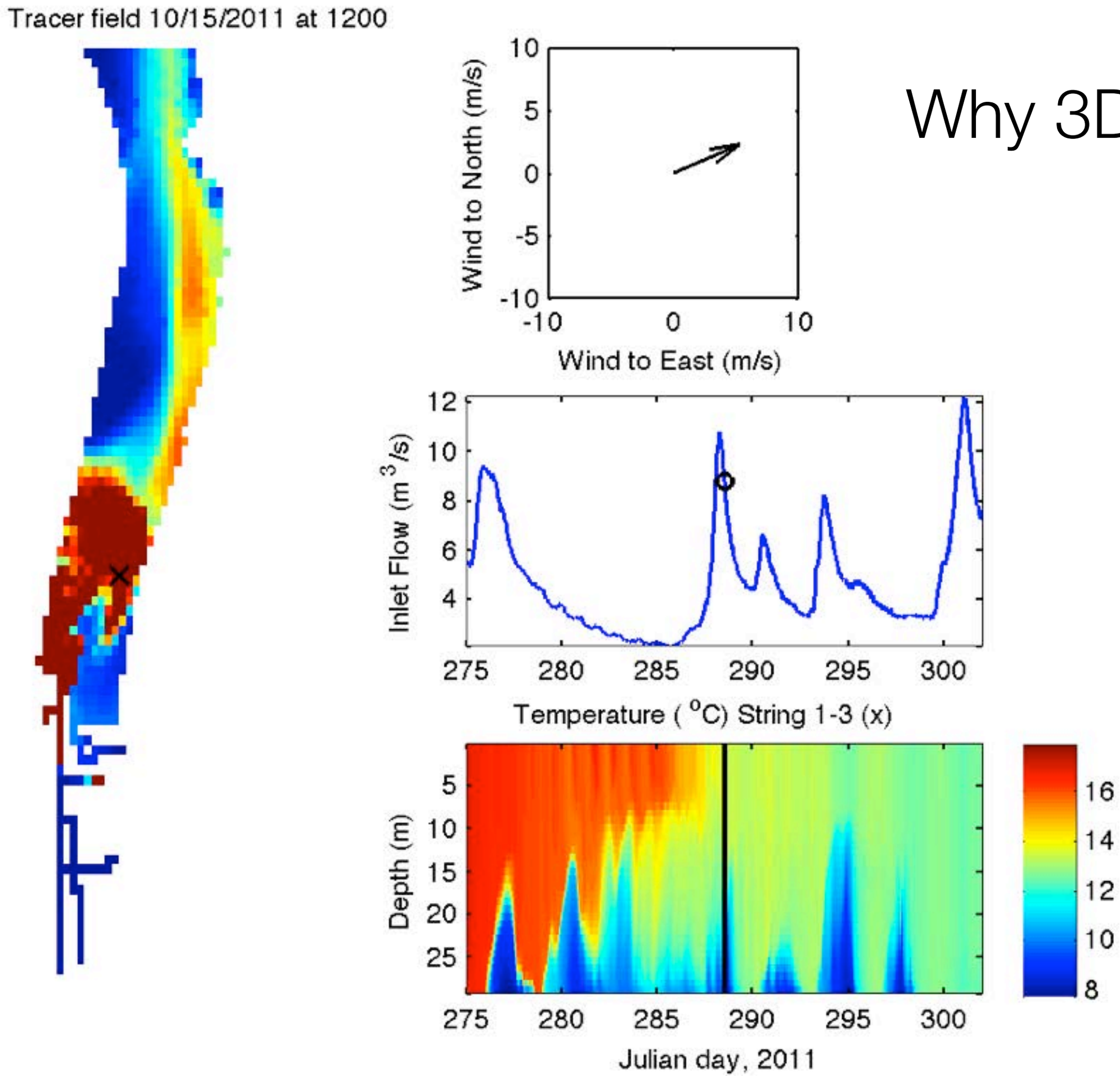
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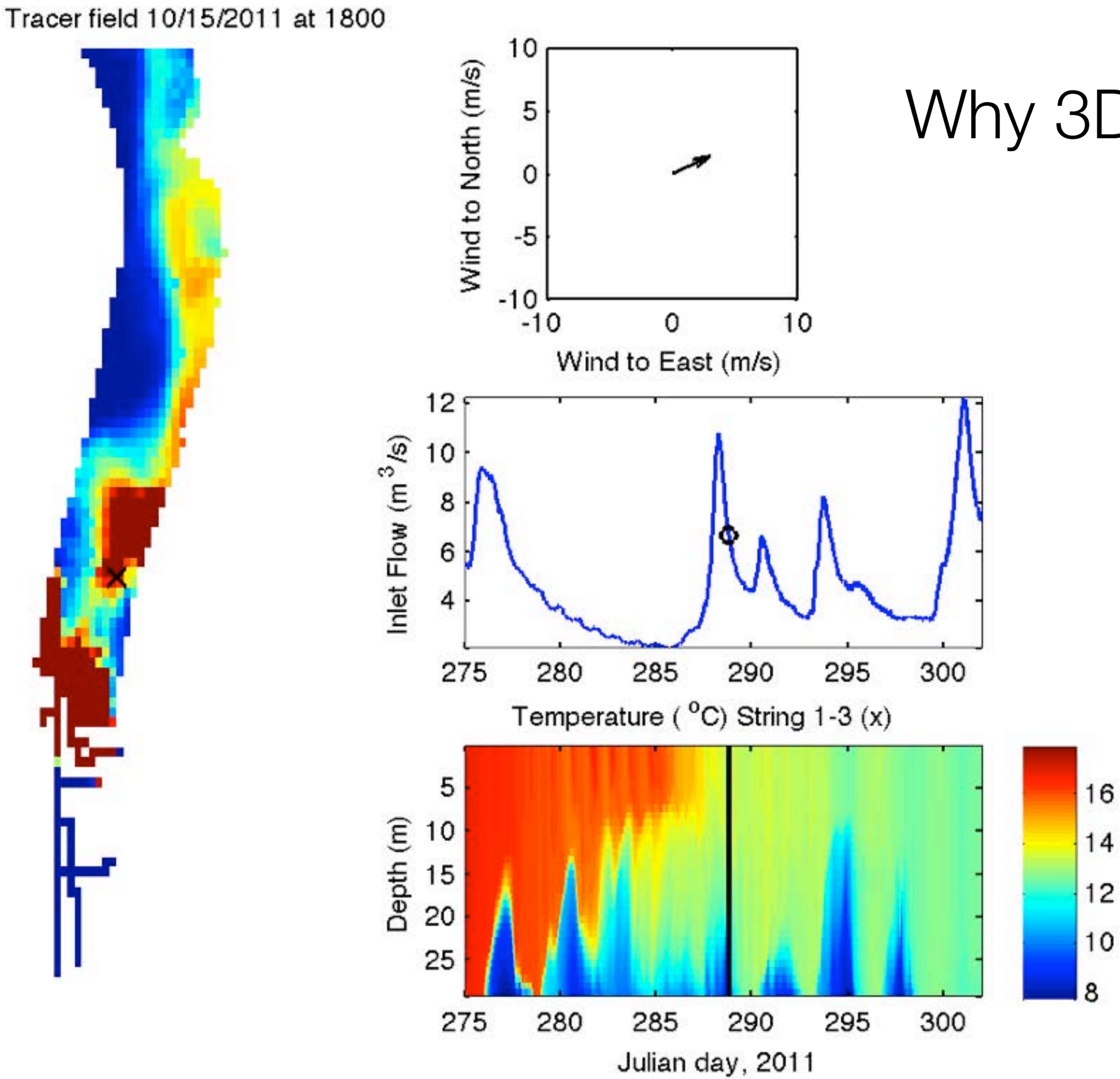
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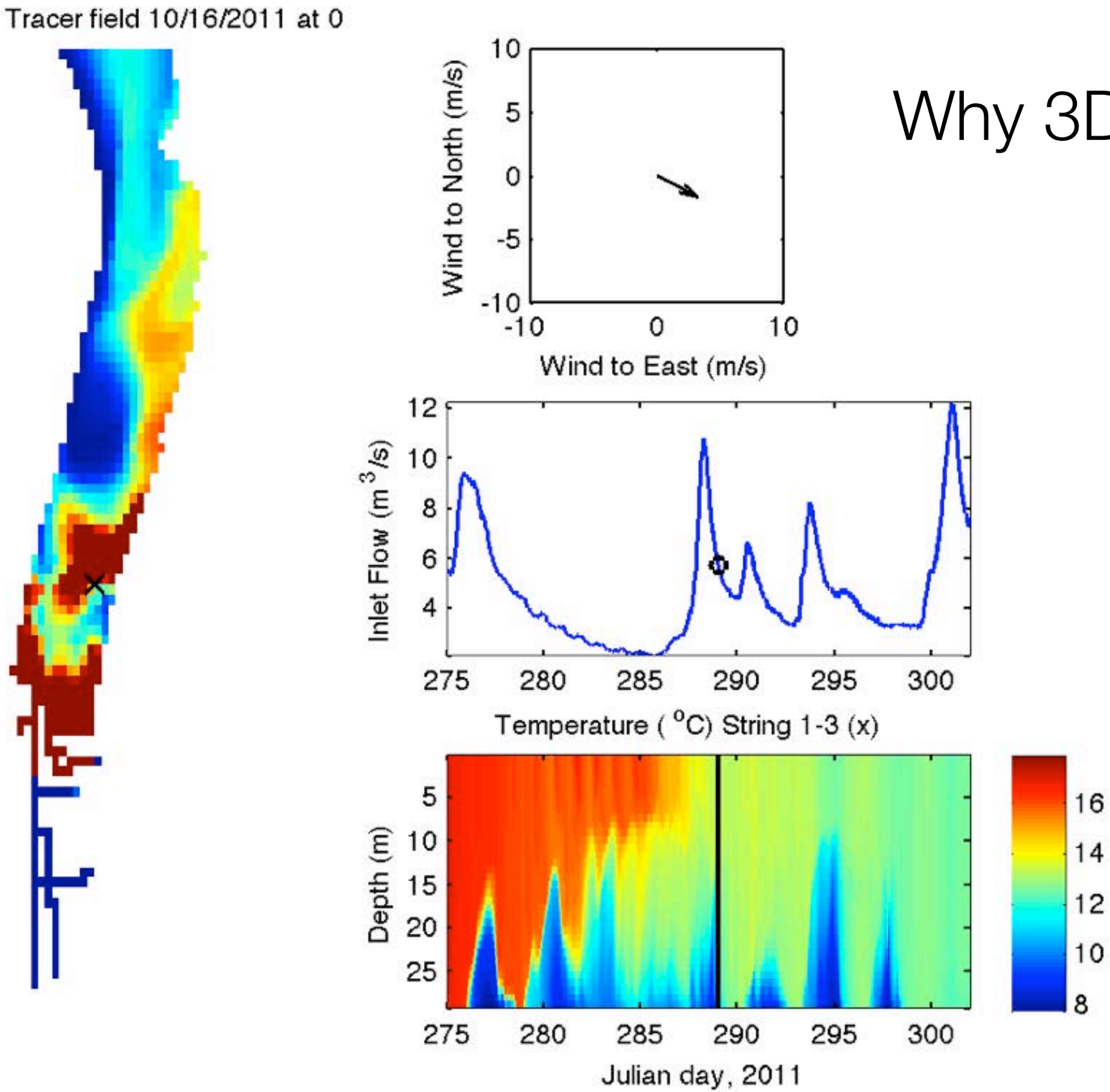
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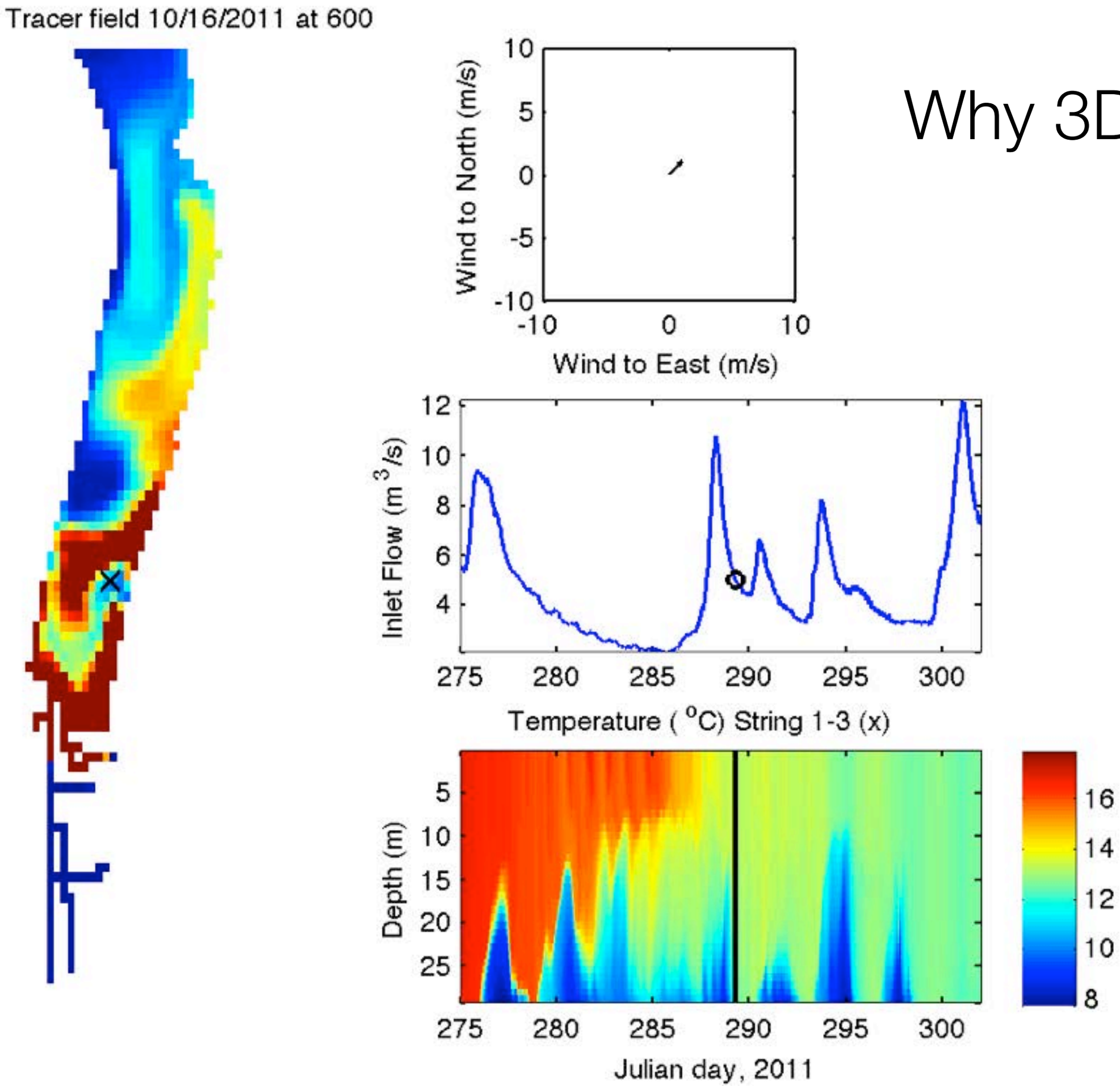
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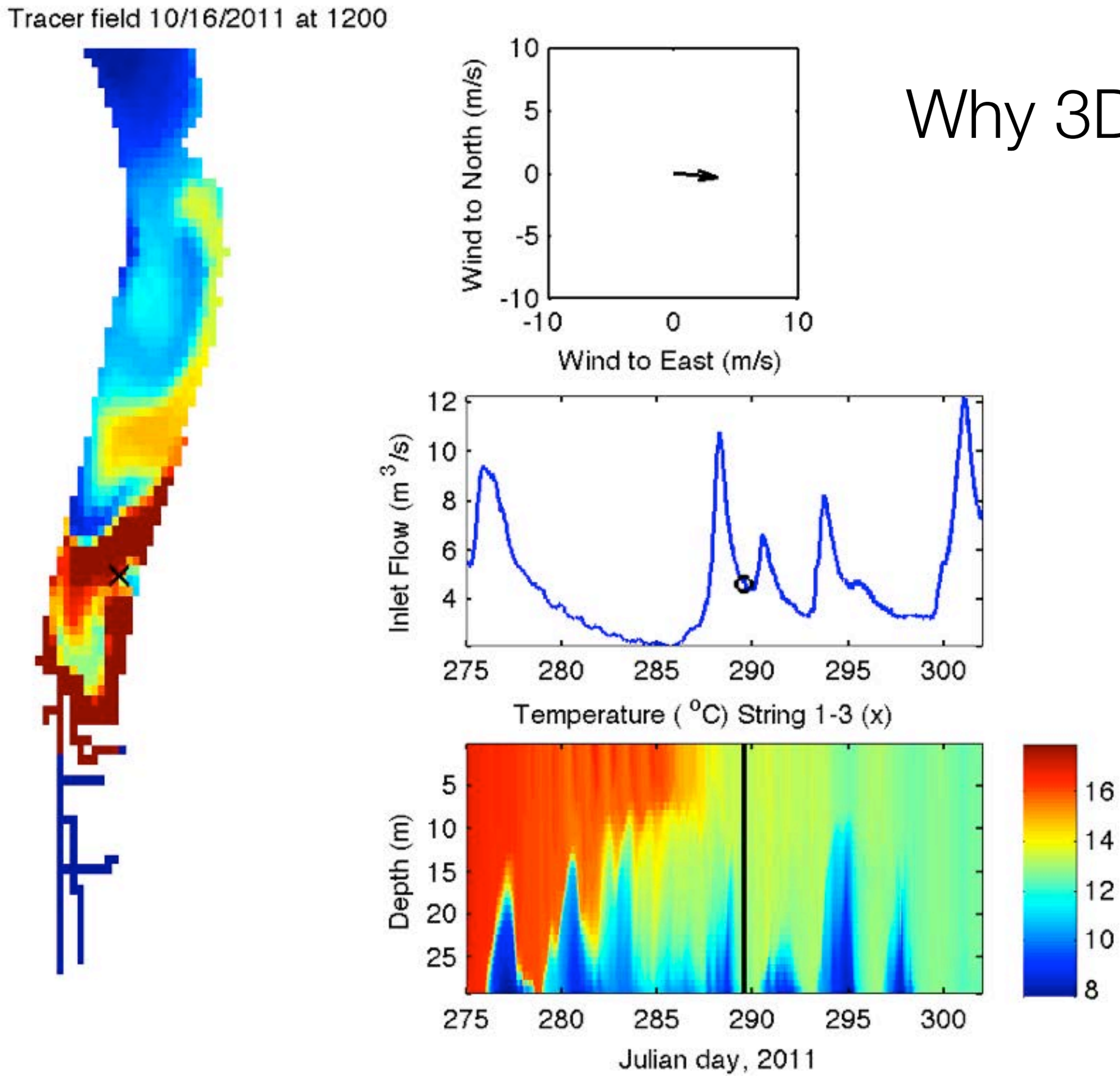
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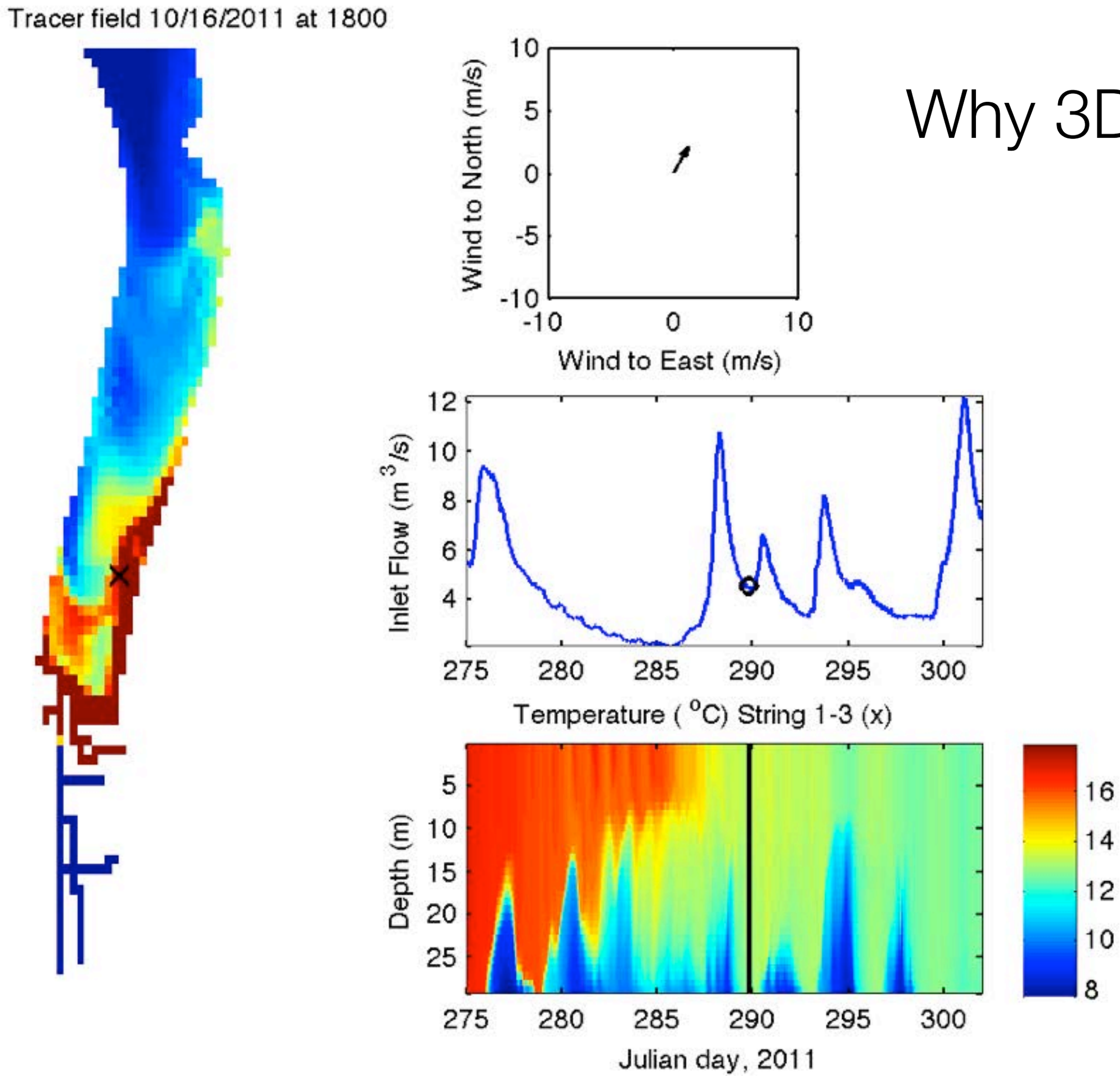
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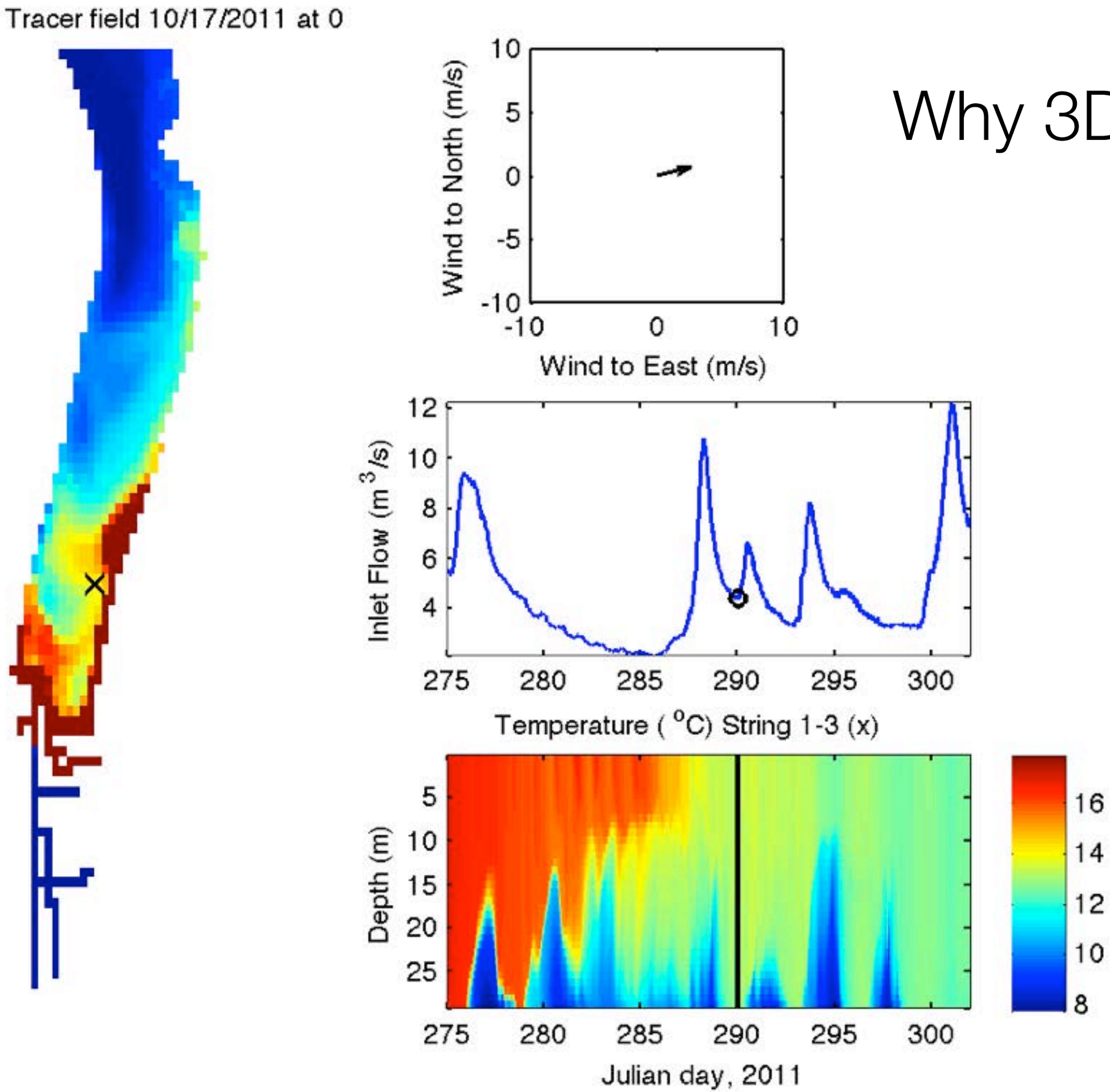
# Why 3D?


Tracer field 10/17/2011 at 0
Wind to North (m/s)
Wind to East (m/s)
10
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0
-5
-10
-10
0
10
Inlet Flow (m$^3$/s)
12
10
8
6
4
275
280
285
290
295
300
Temperature ( $^o$C) String 1-3 (x)
Depth (m)
5
10
15
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25
275
280
285
290
295
300
Julian day, 2011
16
14
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10
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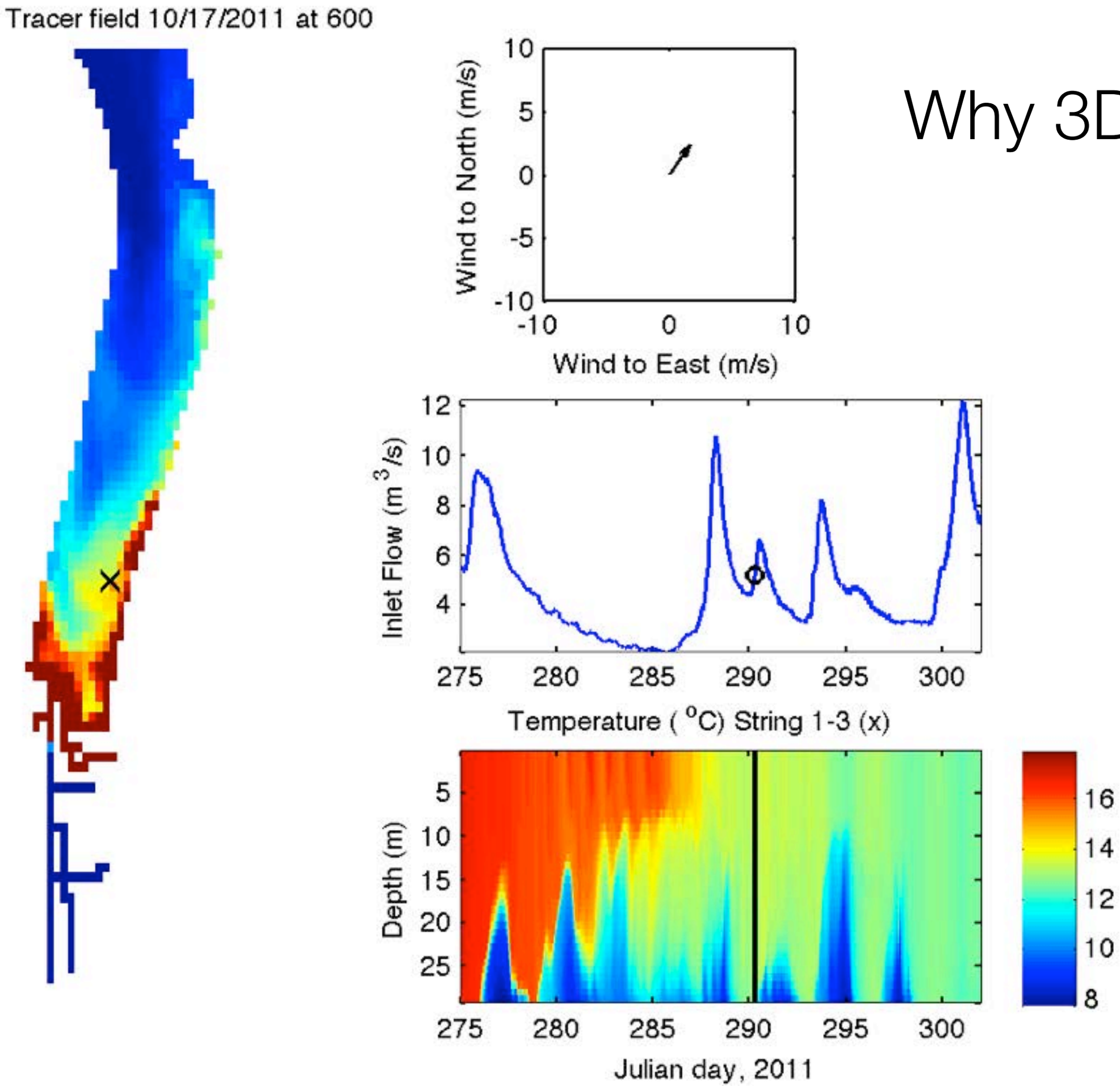
# Why 3D?


Tracer field 10/17/2011 at 600
Wind to North (m/s)
Wind to East (m/s)
10
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-5
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-10
0
10
Inlet Flow (m$^3$/s)
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8
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275
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Temperature ( $^o$C) String 1-3 (x)
Depth (m)
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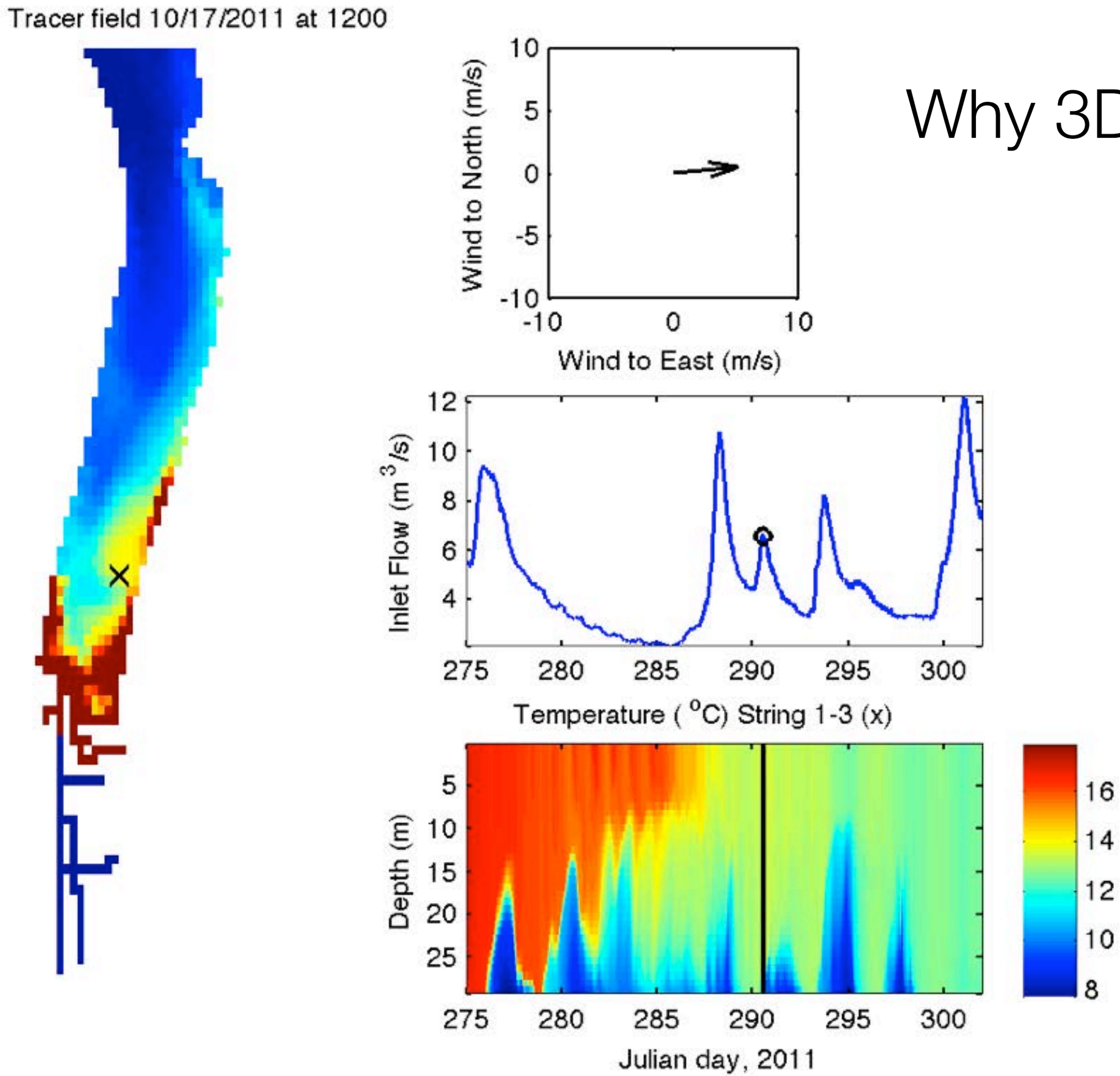
Julian day, 2011

# Why 3D?


Tracer field 10/17/2011 at 1200
Wind to North (m/s)
Wind to East (m/s)
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Inlet Flow (m3/s)
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Temperature ( °C) String 1-3 (x)
Depth (m)
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25
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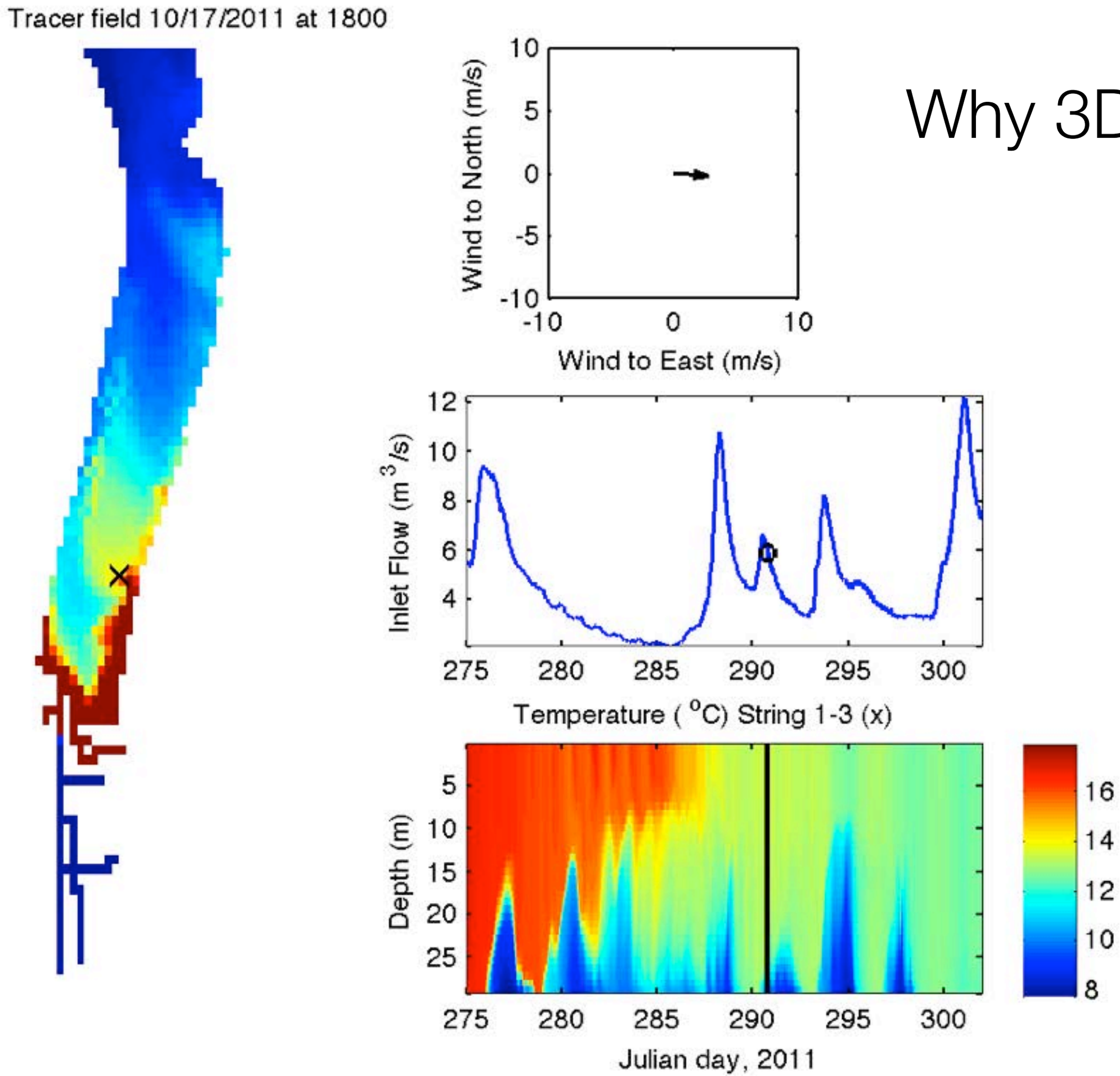
Julian day, 2011

# Why 3D?


Tracer field 10/17/2011 at 1800
Wind to North (m/s)
Wind to East (m/s)
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Inlet Flow (m3/s)
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Temperature ( °C) String 1-3 (x)
Depth (m)
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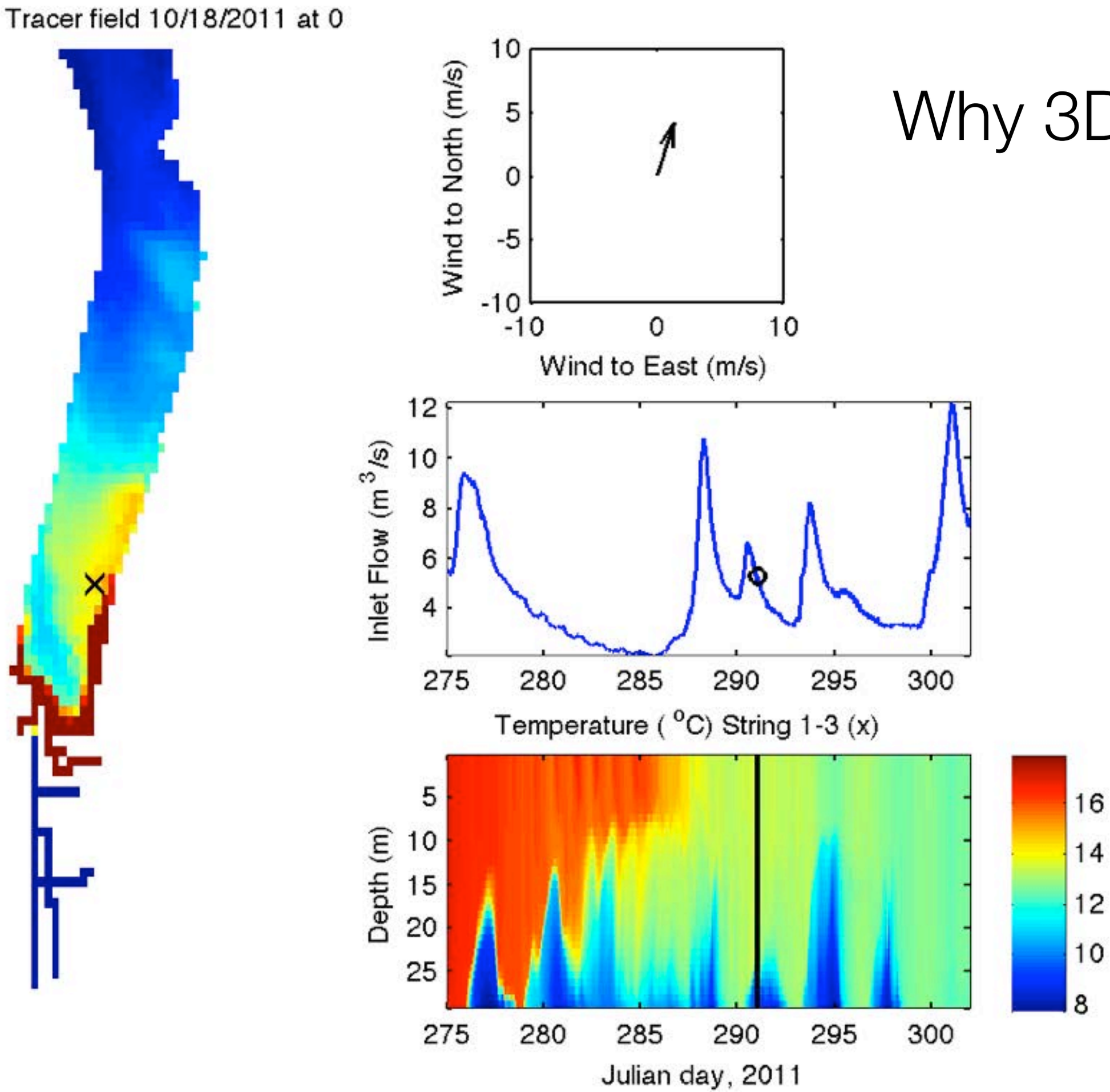
Julian day, 2011

# Why 3D?


Tracer field 10/18/2011 at 0
Wind to North (m/s)
Wind to East (m/s)
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Inlet Flow (m$^3$/s)
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Depth (m)
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Julian day, 2011
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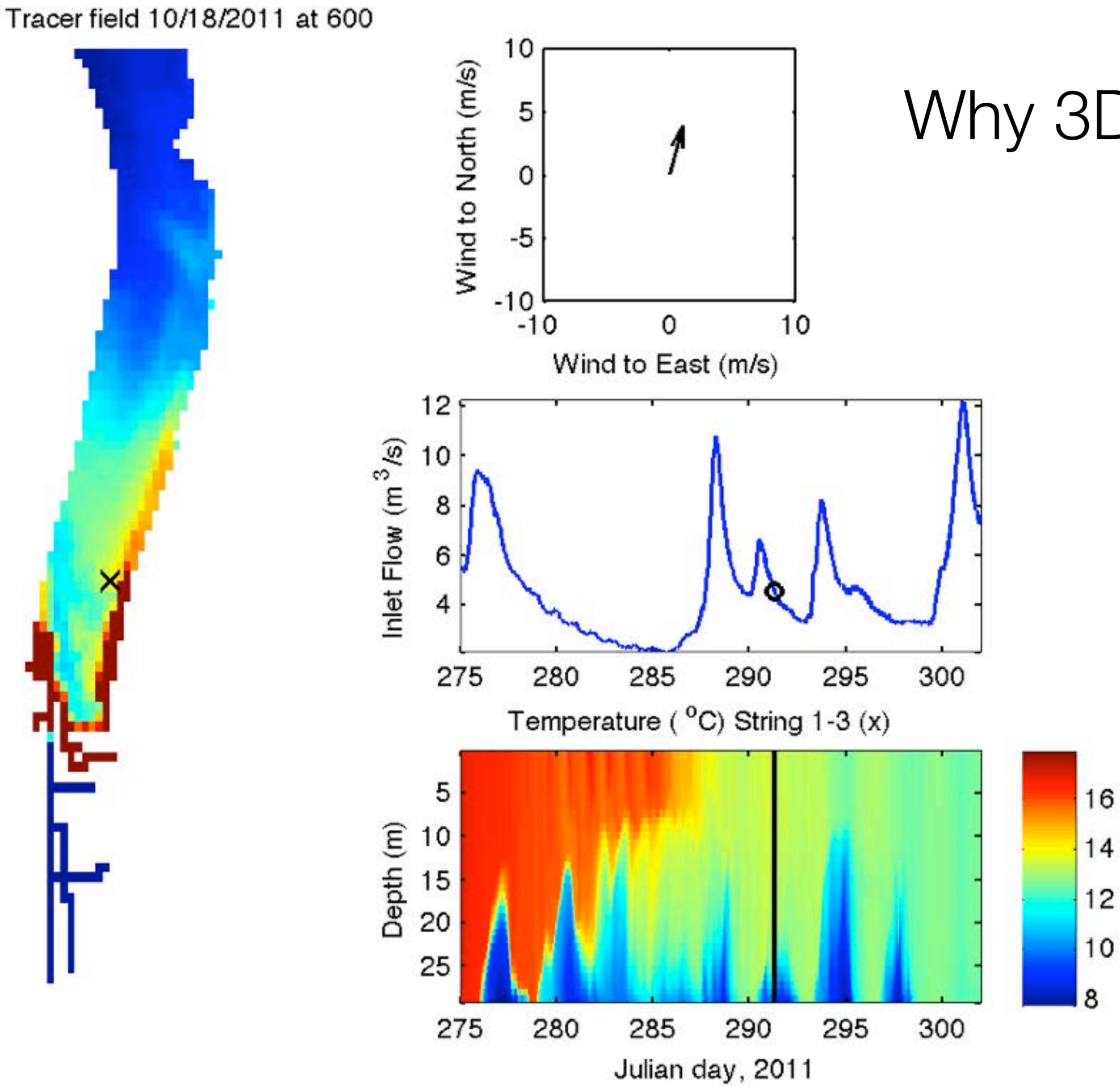
# Why 3D?


Tracer field 10/18/2011 at 600
Wind to North (m/s)
Wind to East (m/s)
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Inlet Flow (m$^3$/s)
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Julian day, 2011
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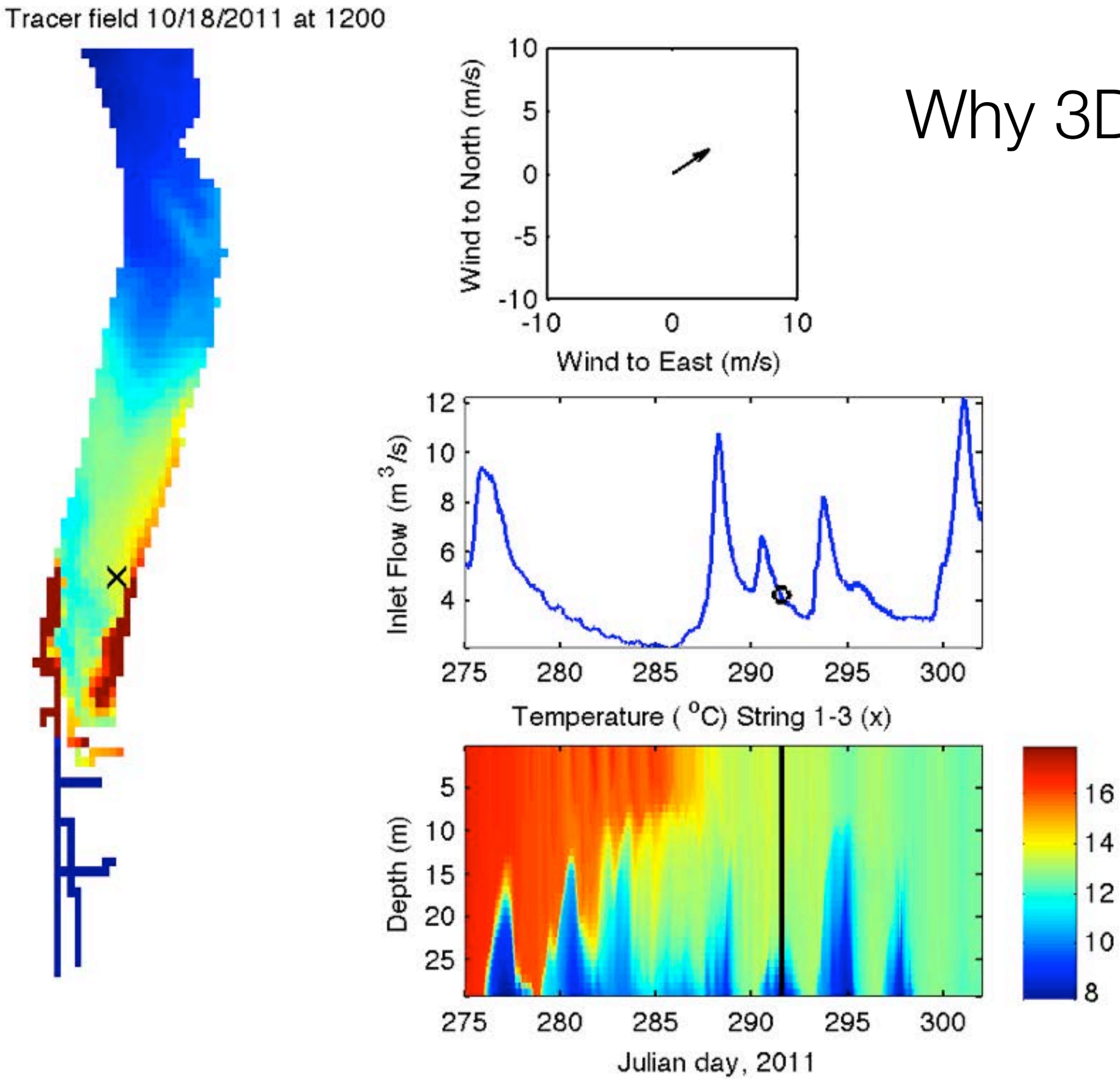
# Why 3D?


Tracer field 10/18/2011 at 1200
Wind to North (m/s)
Wind to East (m/s)
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Inlet Flow (m$^3$/s)
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Julian day, 2011
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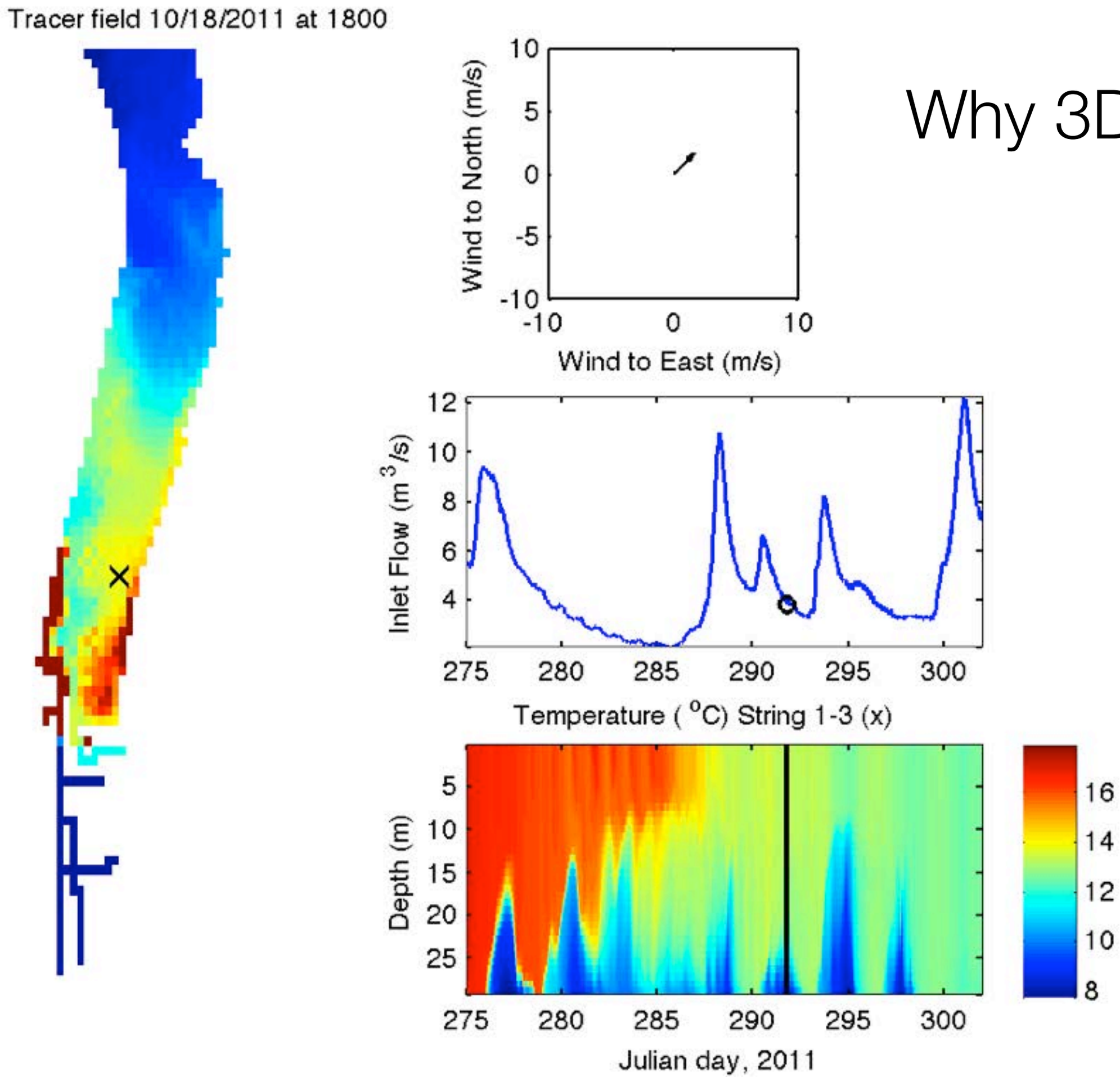
Tracer field 10/18/2011 at 1800
Wind to North (m/s)
Wind to East (m/s)
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Inlet Flow (m3/s)
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Julian day, 2011
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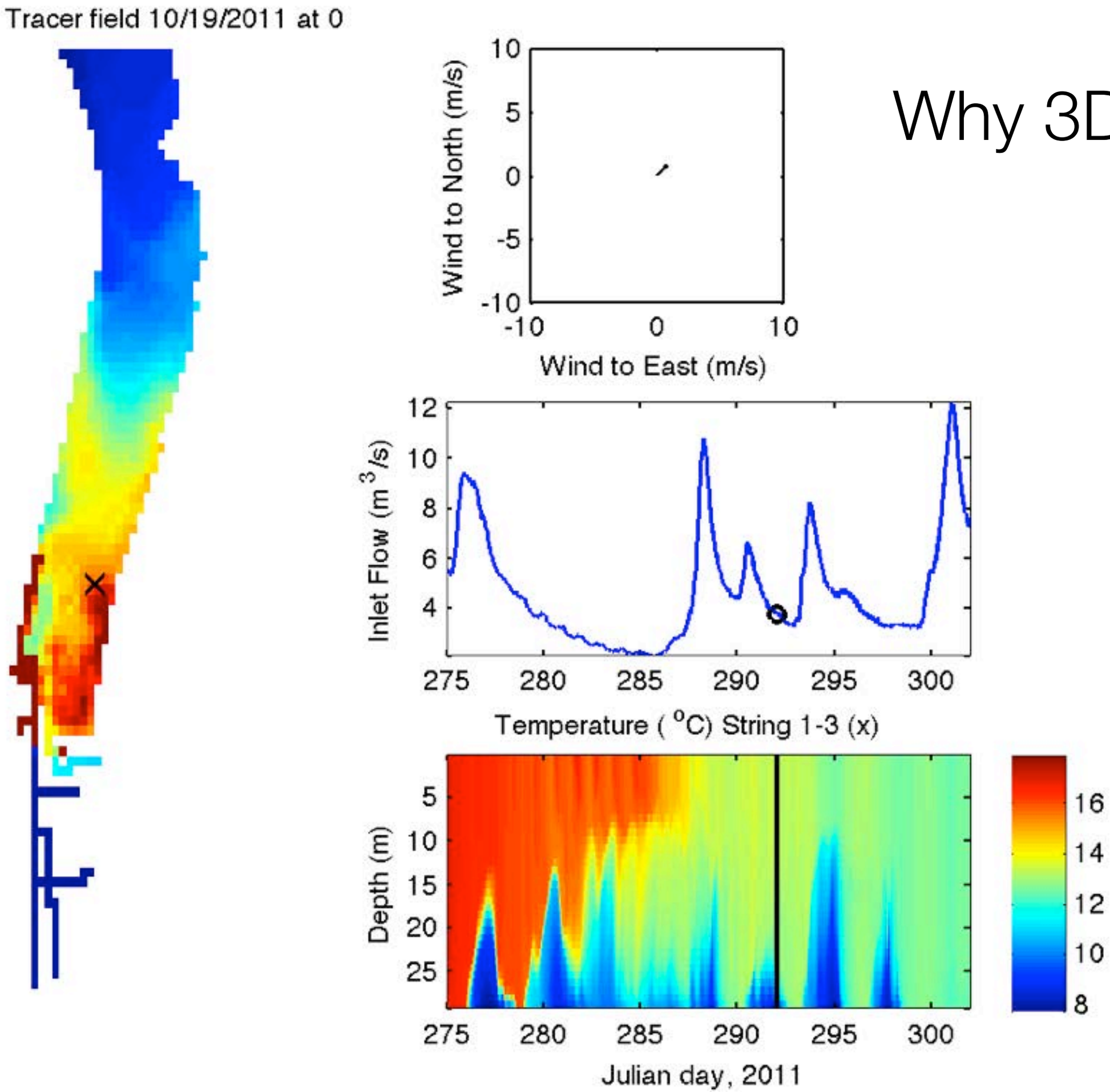
# Why 3D?


Tracer field 10/19/2011 at 0
Wind to North (m/s)
Wind to East (m/s)
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Inlet Flow (m$^3$/s)
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Temperature ( $^o$C) String 1-3 (x)
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Julian day, 2011
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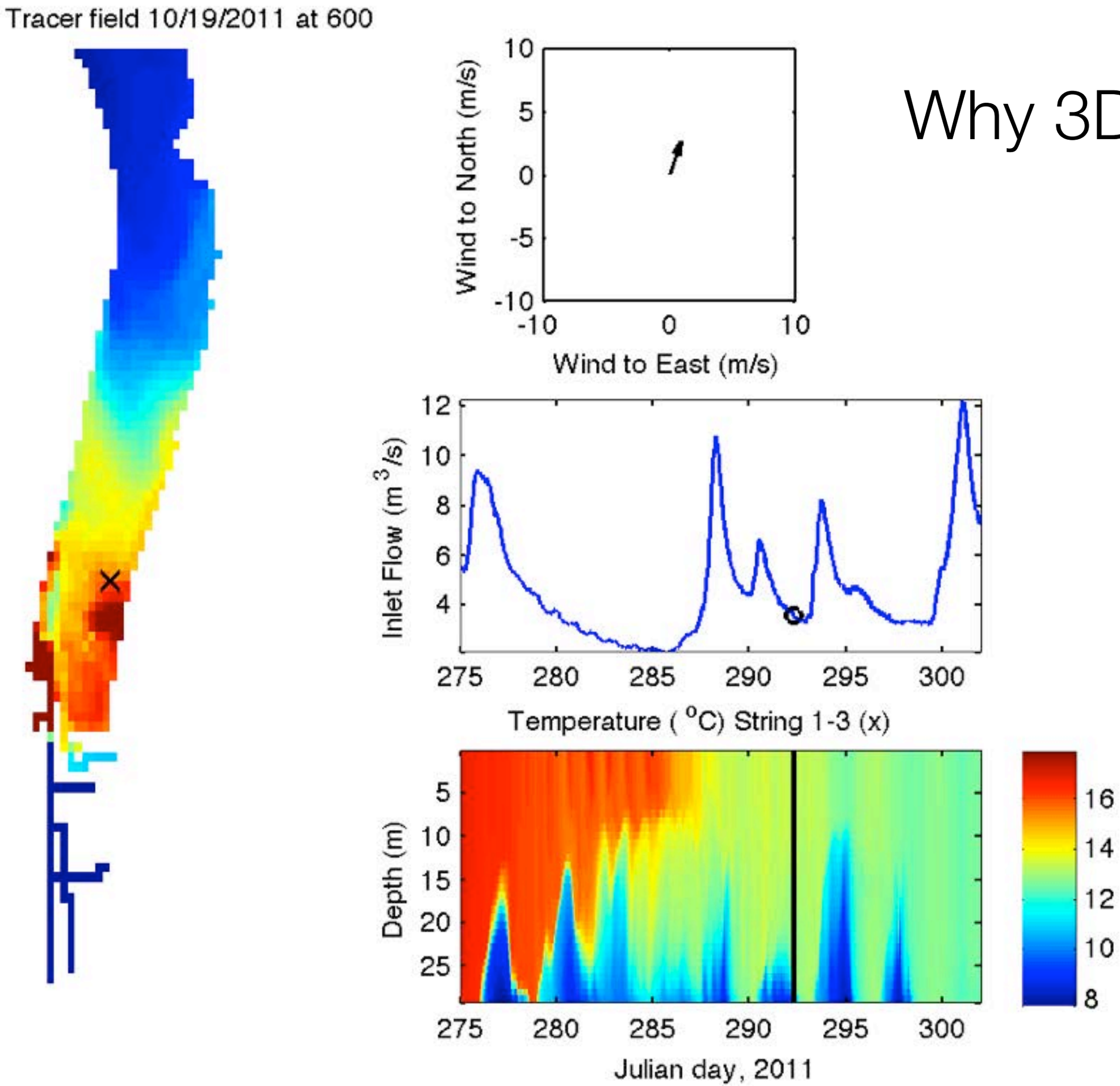
Tracer field 10/19/2011 at 600
Wind to North (m/s)
Wind to East (m/s)
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Julian day, 2011
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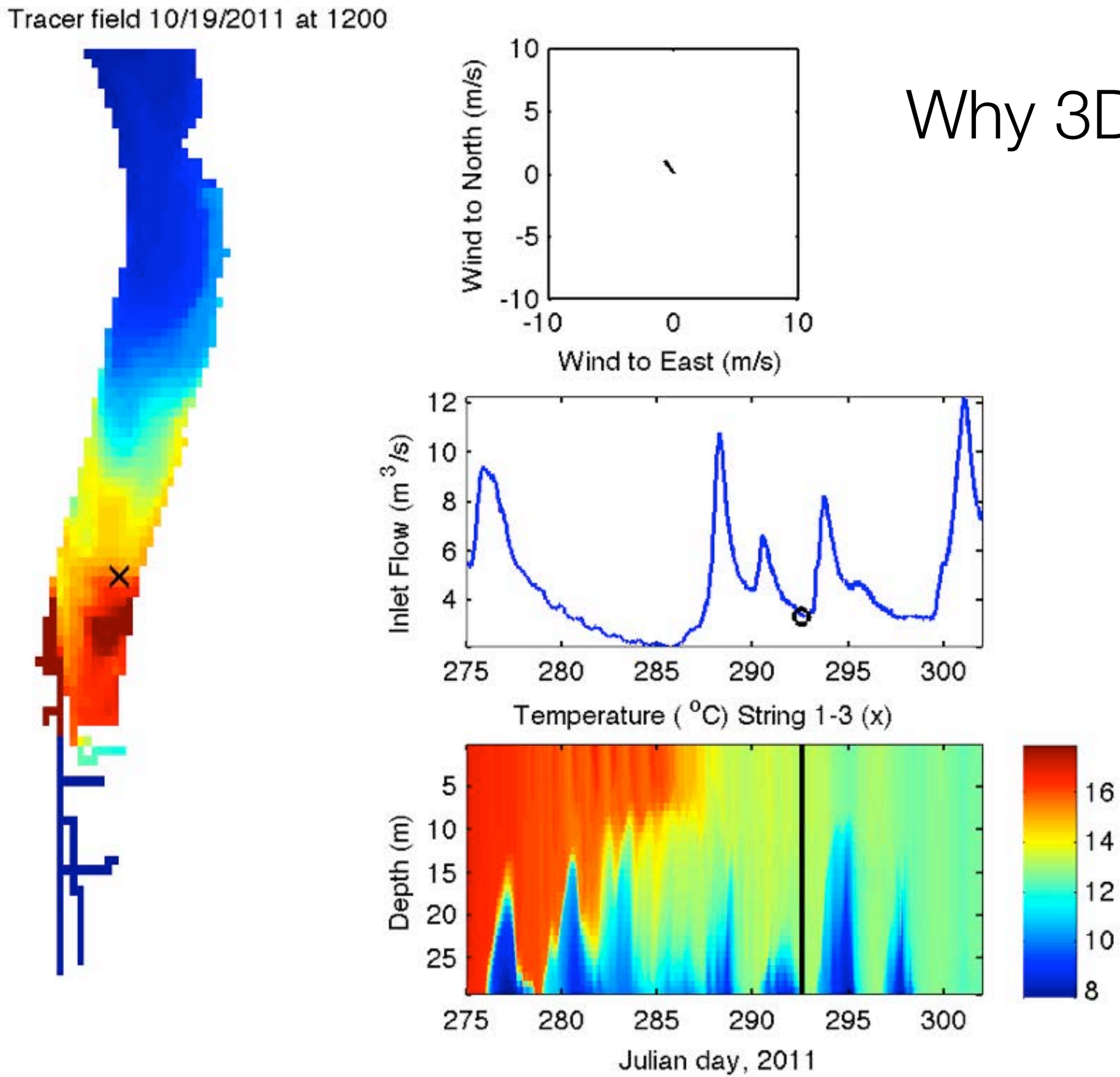
Tracer field 10/19/2011 at 1200
Wind to North (m/s)
Wind to East (m/s)
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Inlet Flow (m$^3$/s)
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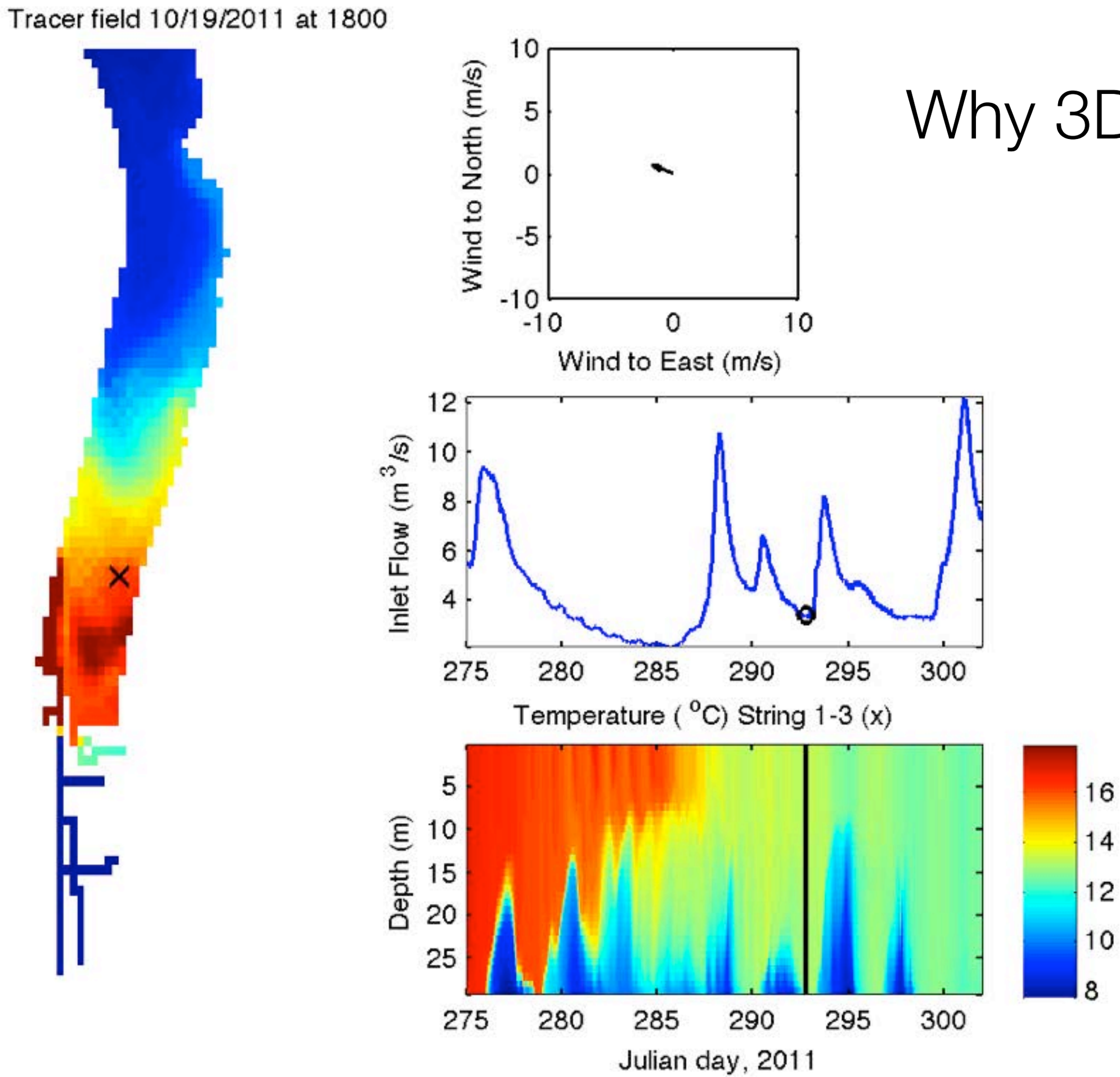
Julian day, 2011

# Why 3D?


Tracer field 10/19/2011 at 1800
Wind to North (m/s)
Wind to East (m/s)
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Inlet Flow (m$^3$/s)
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Julian day, 2011
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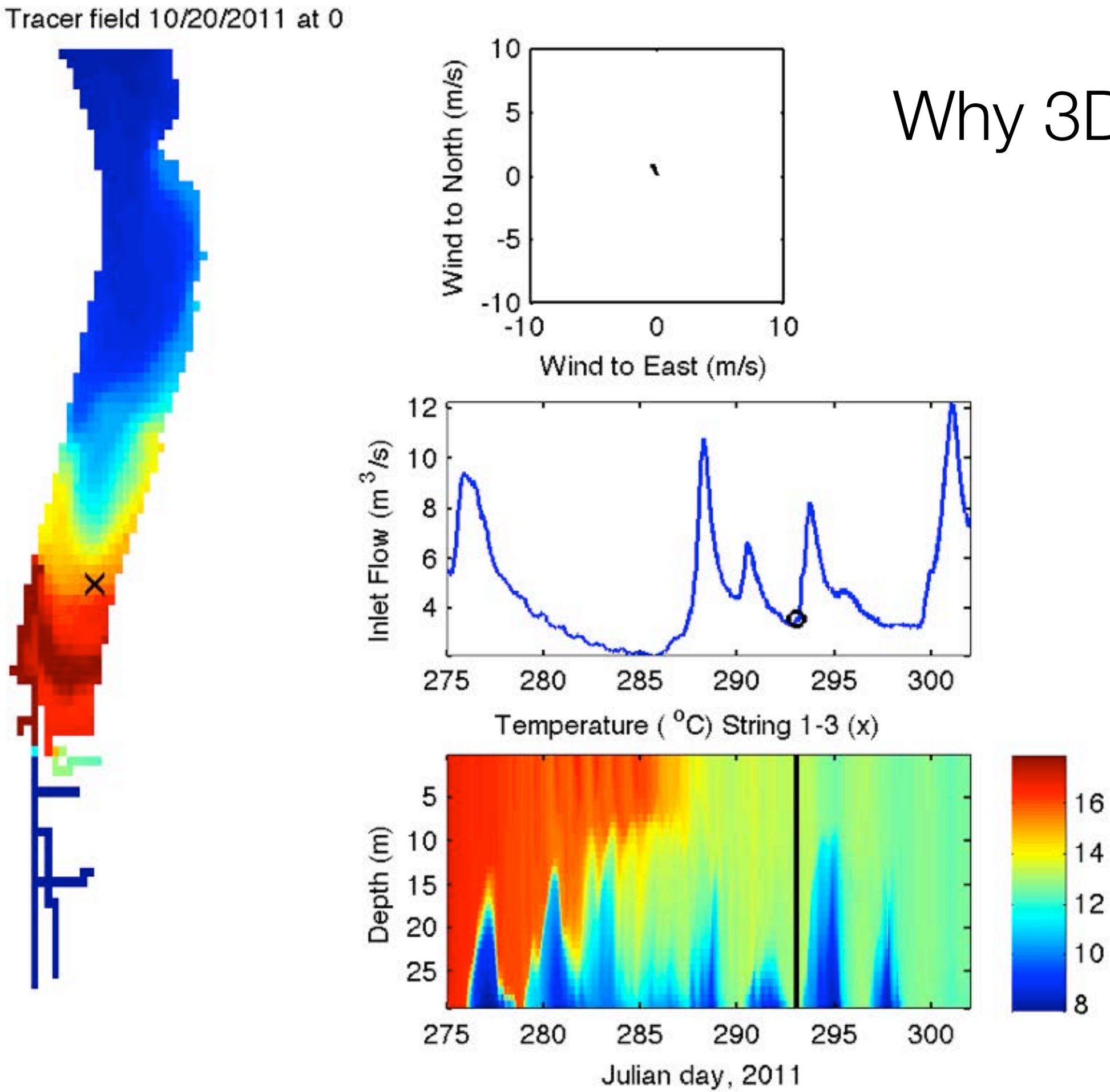
# Why 3D?


Tracer field 10/20/2011 at 0
Wind to North (m/s)
Wind to East (m/s)
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Inlet Flow (m3/s)
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Temperature ( °C) String 1-3 (x)
Depth (m)
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Julian day, 2011

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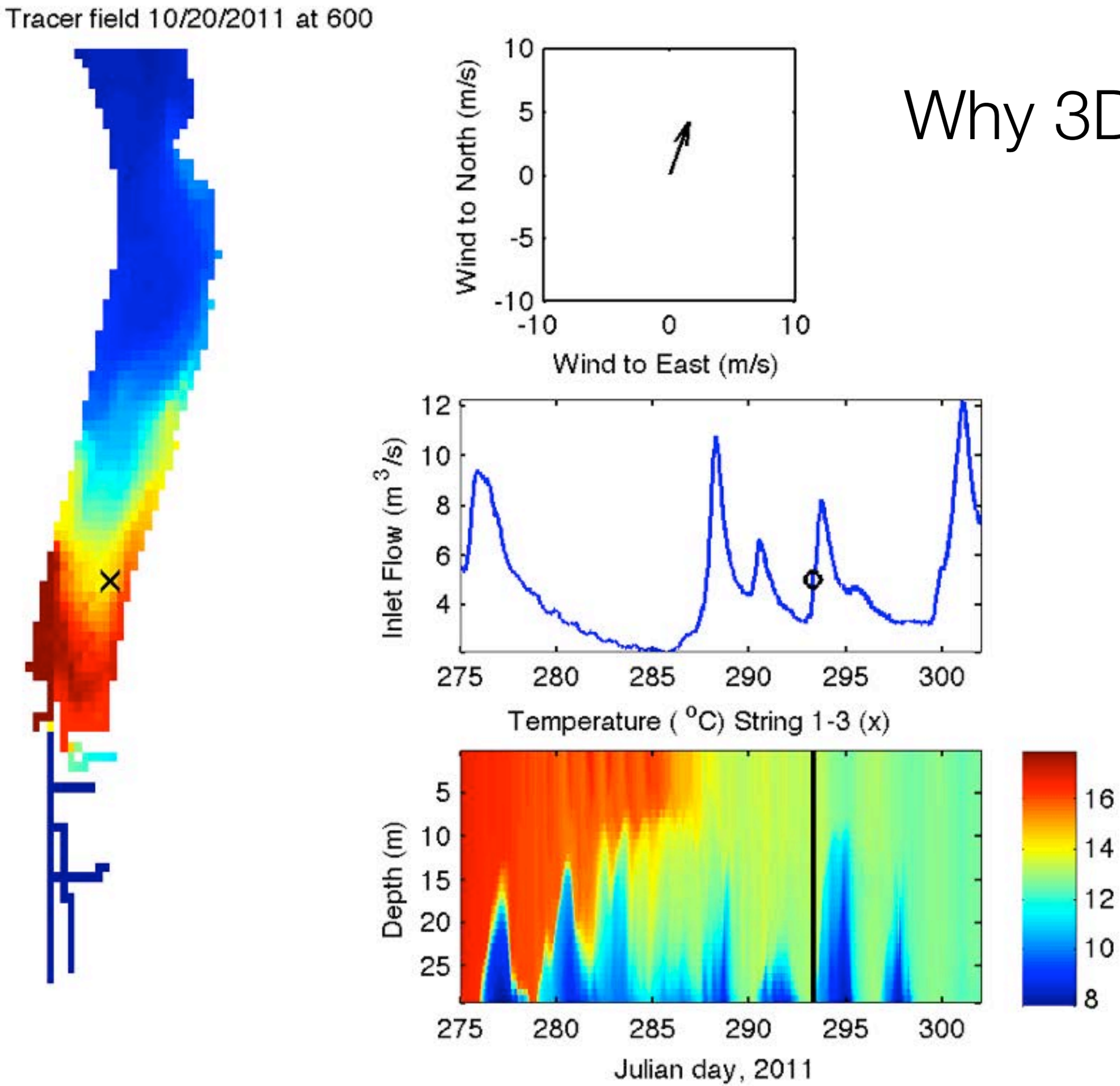
Tracer field 10/20/2011 at 600
Wind to North (m/s)
Wind to East (m/s)
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Inlet Flow (m3/s)
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Temperature ( °C) String 1-3 (x)
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Julian day, 2011
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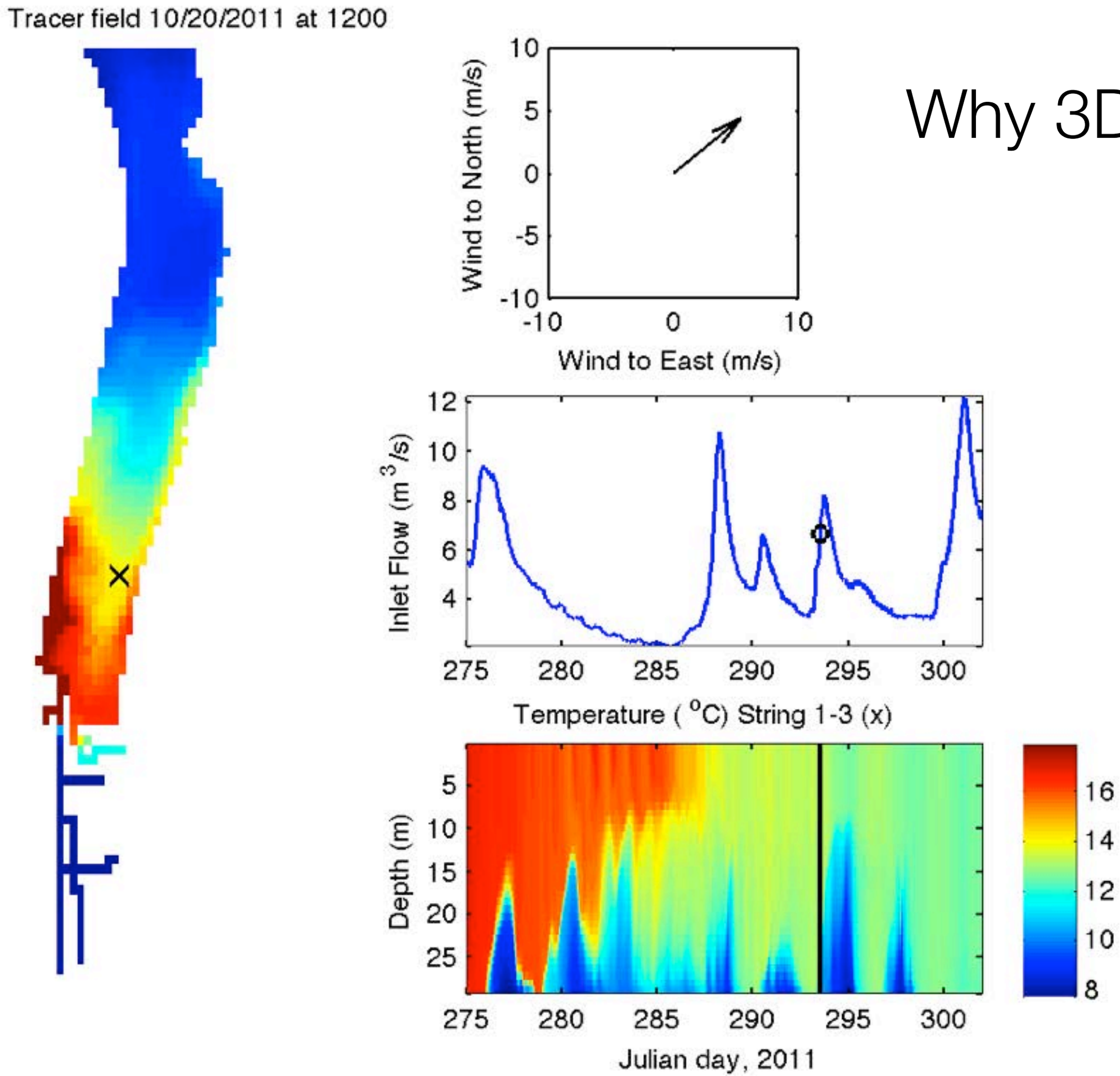
Tracer field 10/20/2011 at 1200
Wind to North (m/s)
Wind to East (m/s)
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Inlet Flow (m$^3$/s)
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Julian day, 2011
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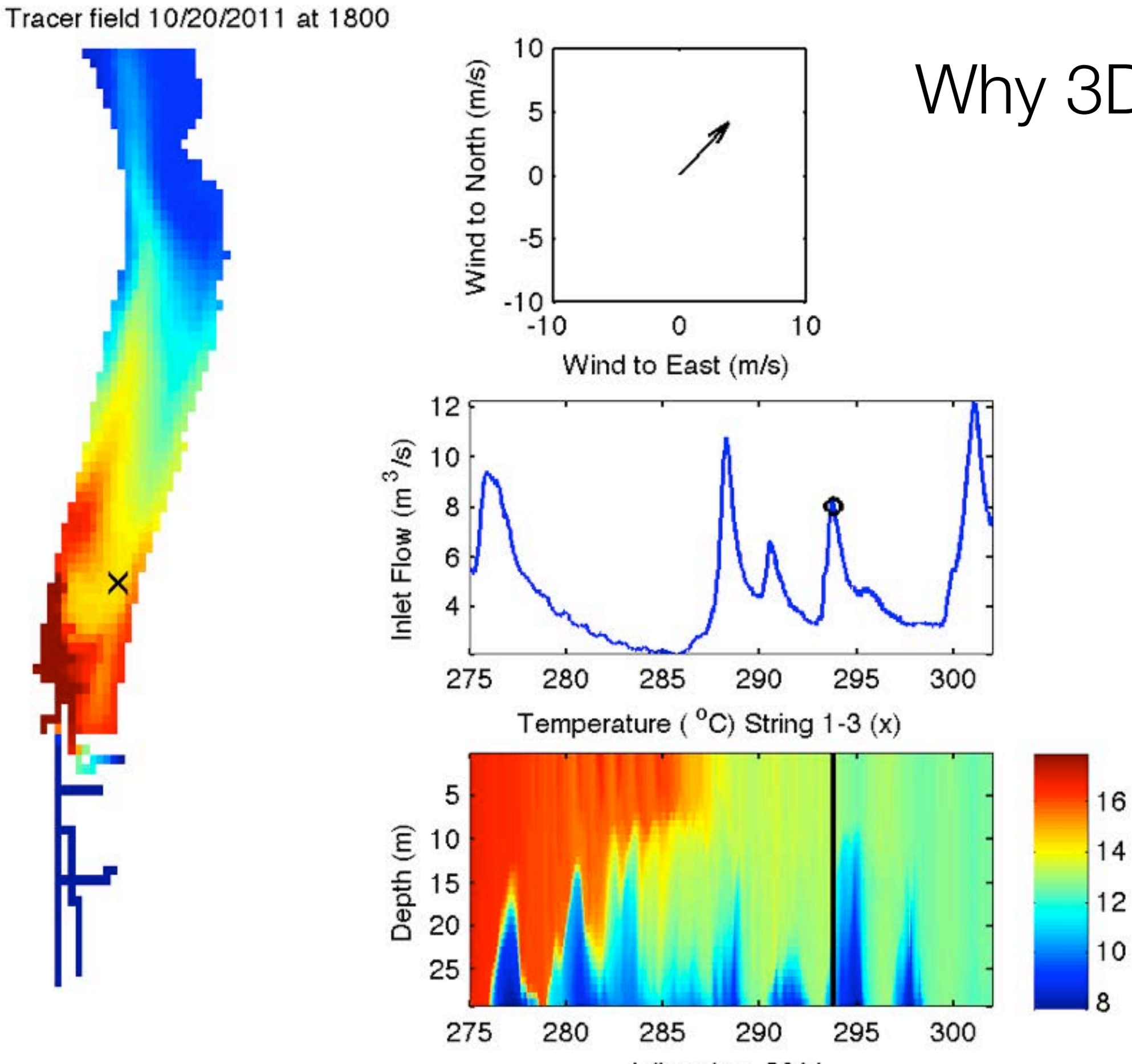
Tracer field 10/20/2011 at 1800
Wind to North (m/s)
Wind to East (m/s)
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Inlet Flow (m3/s)
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Temperature ( °C) String 1-3 (x)
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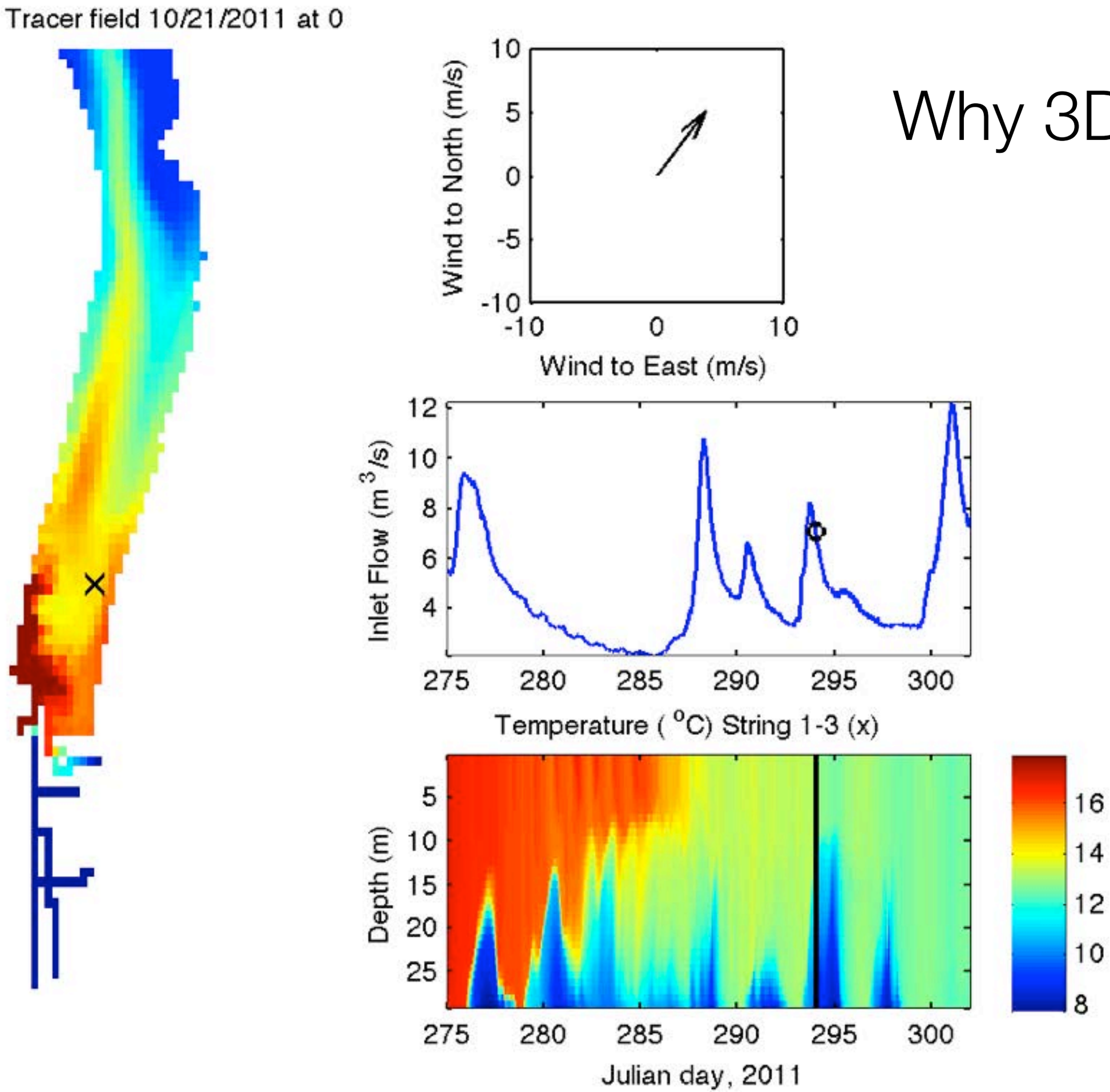
# Why 3D?


Tracer field 10/21/2011 at 0
Wind to North (m/s)
Wind to East (m/s)
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Inlet Flow (m$^3$/s)
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Temperature ( $^o$C) String 1-3 (x)
Depth (m)
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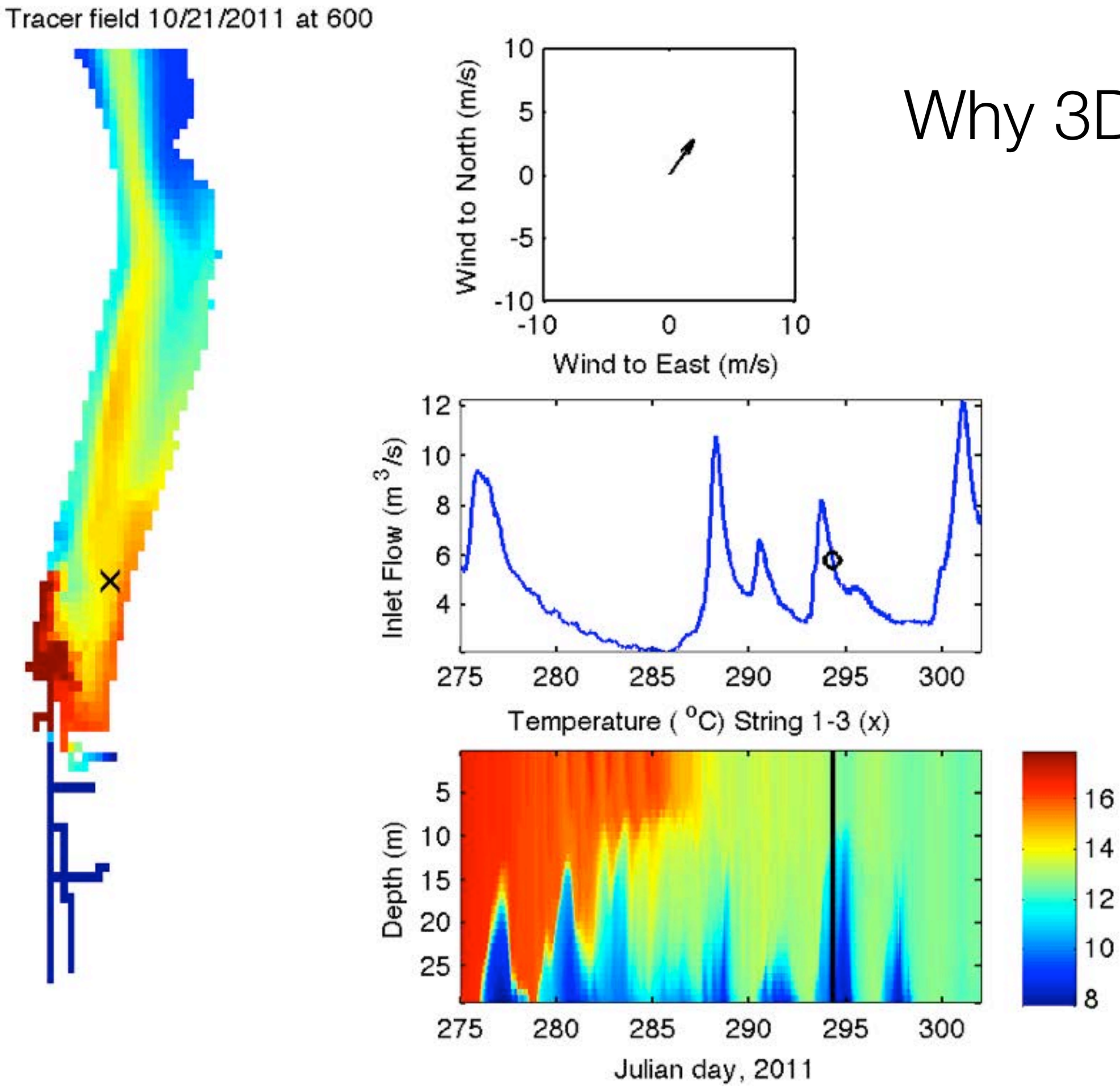
Julian day, 2011

# Why 3D?


Tracer field 10/21/2011 at 600
Wind to North (m/s)
Wind to East (m/s)
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Inlet Flow (m$^3$/s)
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Temperature ( $^o$C) String 1-3 (x)
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Julian day, 2011
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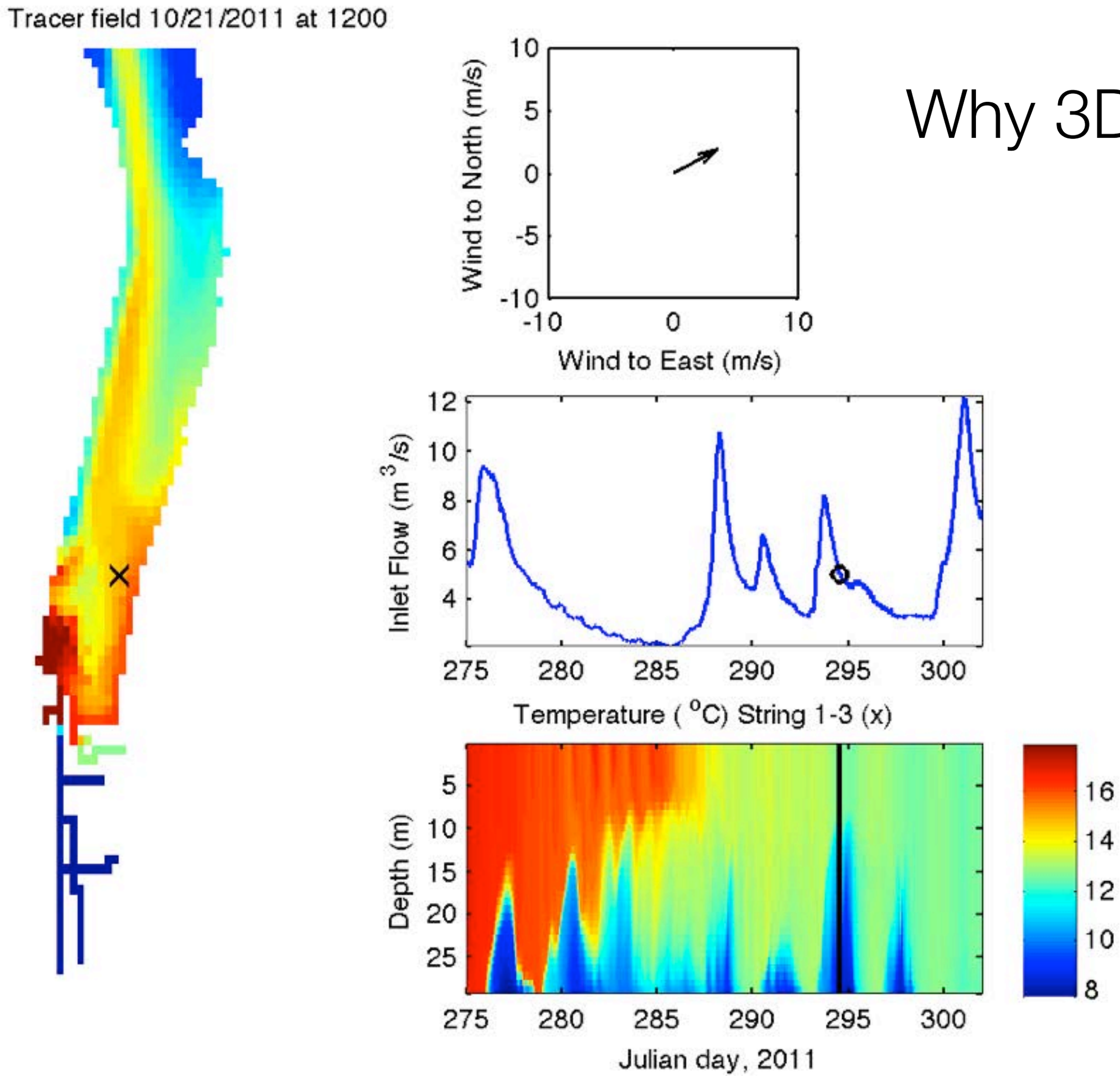
# Why 3D?


Tracer field 10/21/2011 at 1200
Wind to North (m/s)
Wind to East (m/s)
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Inlet Flow (m$^3$/s)
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Temperature ( $^o$C) String 1-3 (x)
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Julian day, 2011
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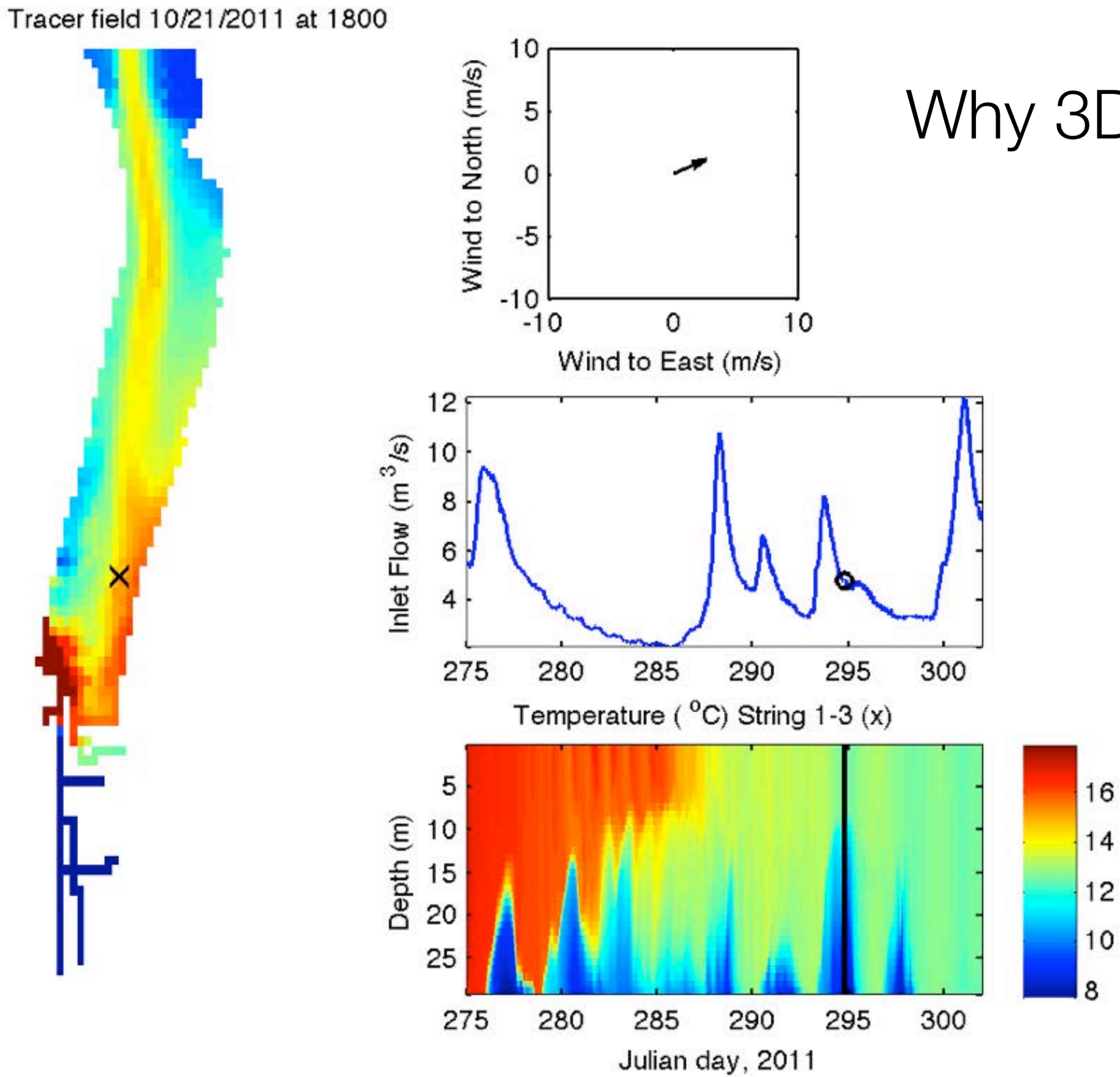
# Why 3D?


Tracer field 10/21/2011 at 1800
Wind to North (m/s)
Wind to East (m/s)
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Julian day, 2011
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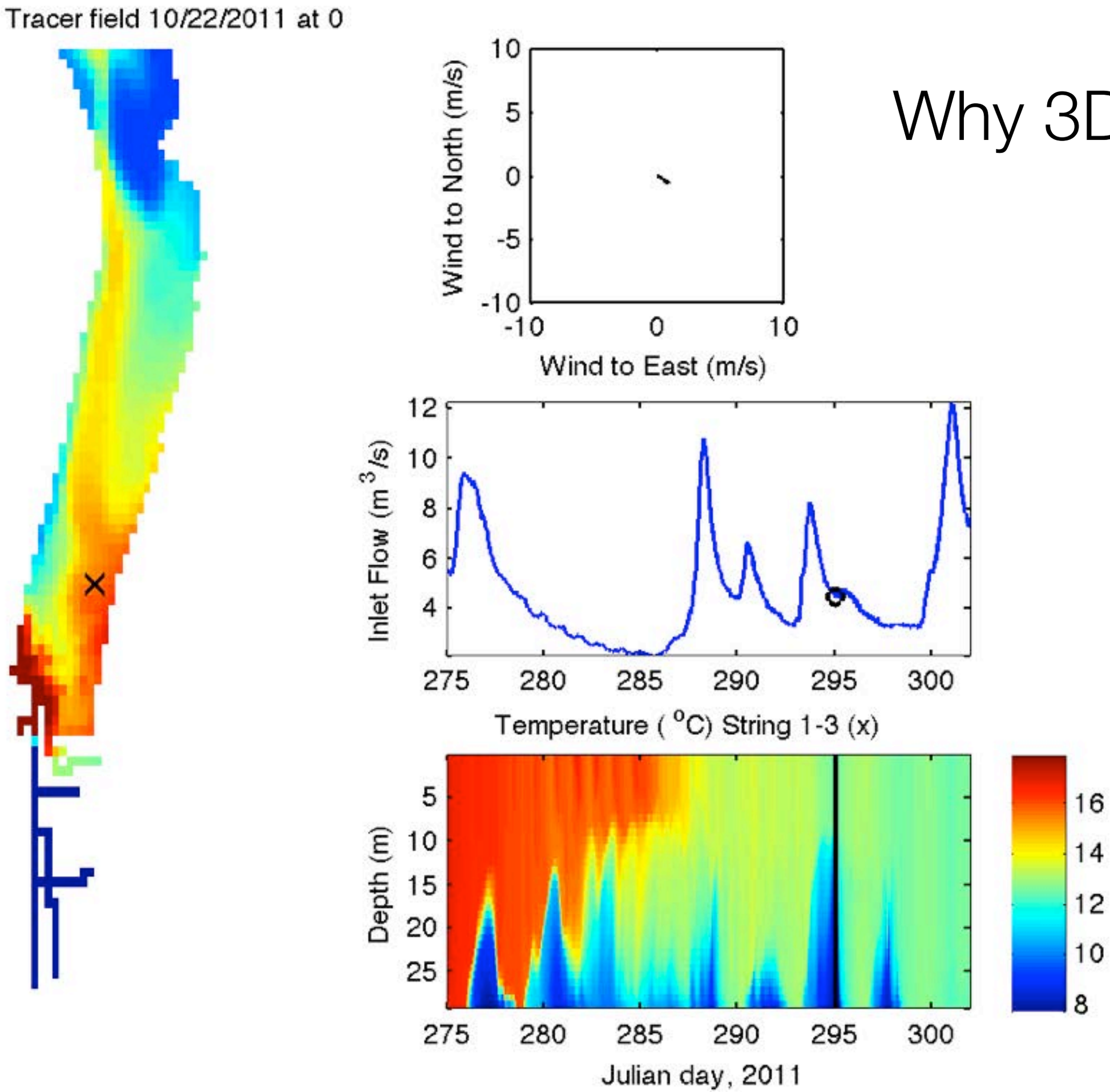
Tracer field 10/22/2011 at 0
Wind to North (m/s)
Wind to East (m/s)
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Julian day, 2011

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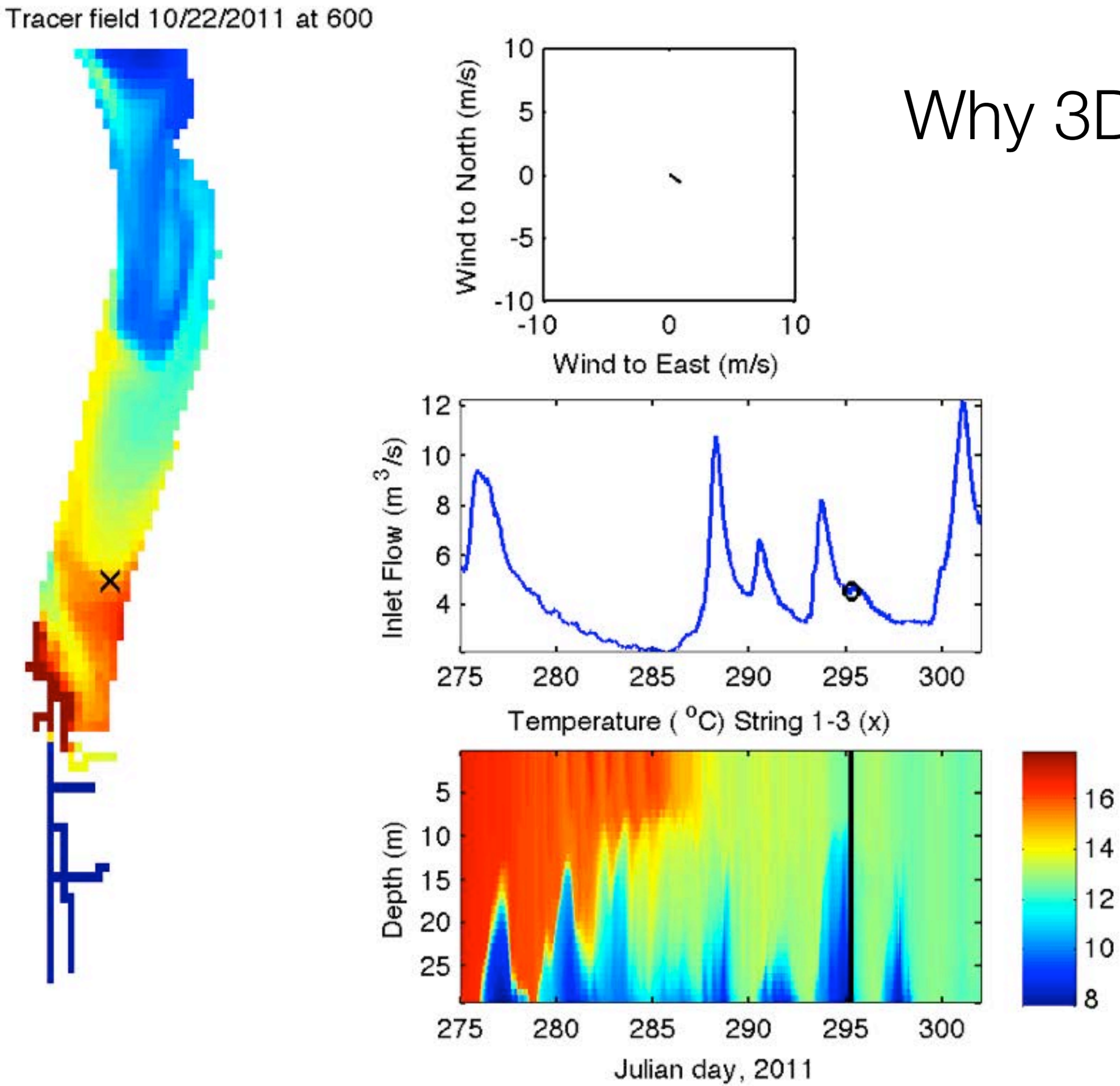
Tracer field 10/22/2011 at 600
Wind to North (m/s)
Wind to East (m/s)
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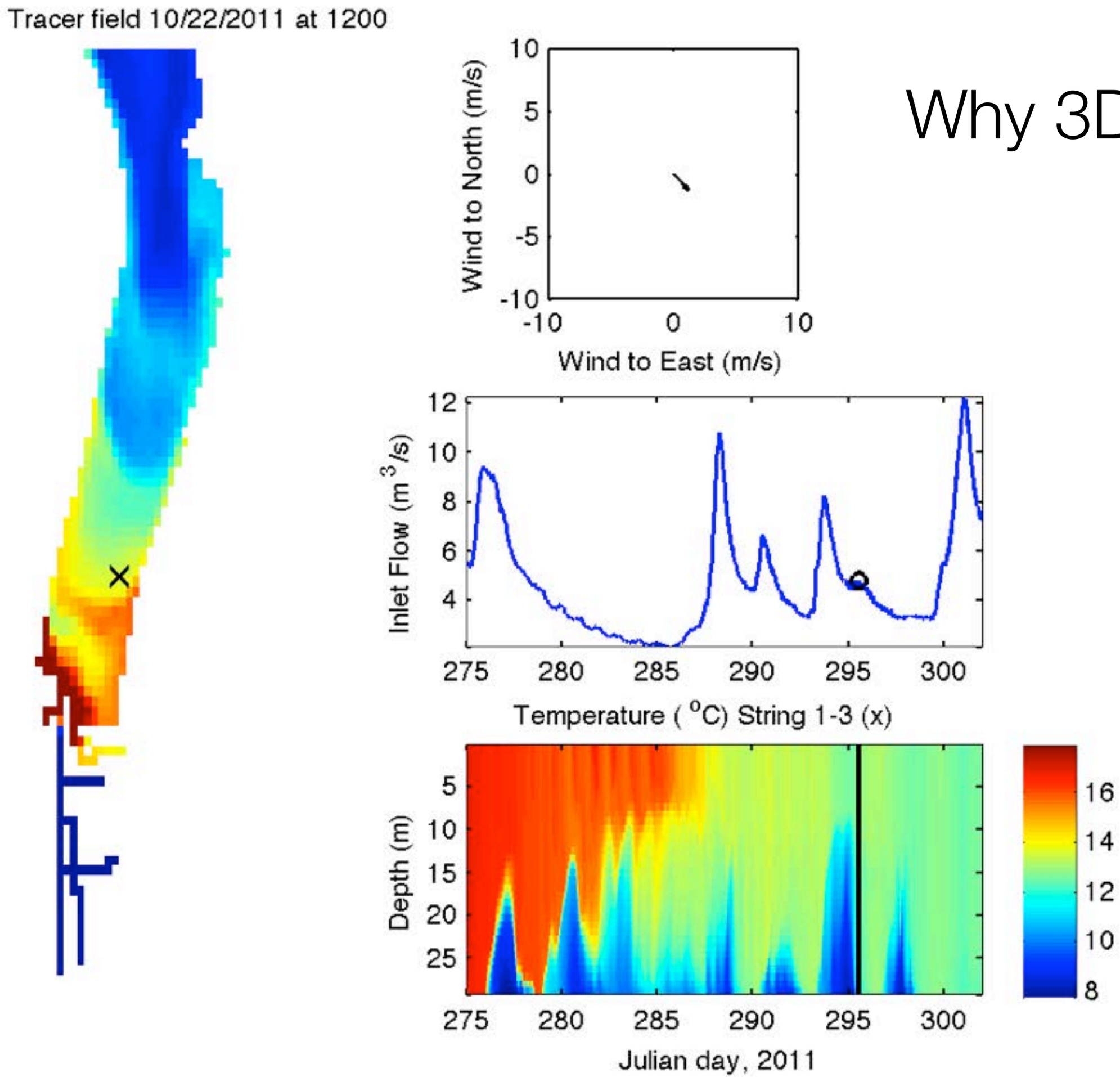
Tracer field 10/22/2011 at 1200
Wind to North (m/s)
Wind to East (m/s)
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Julian day, 2011
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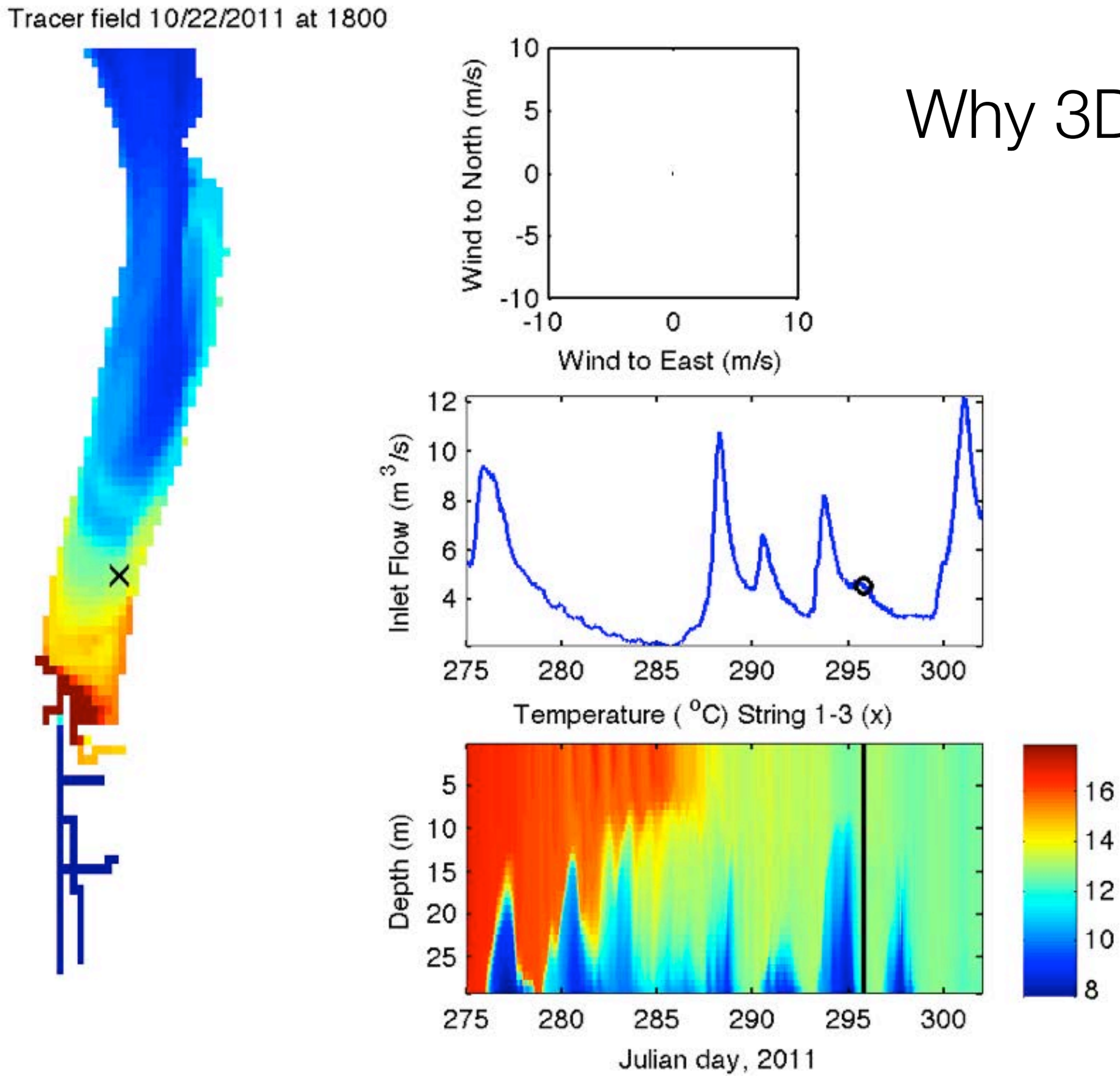
Tracer field 10/22/2011 at 1800
Wind to North (m/s)
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Julian day, 2011

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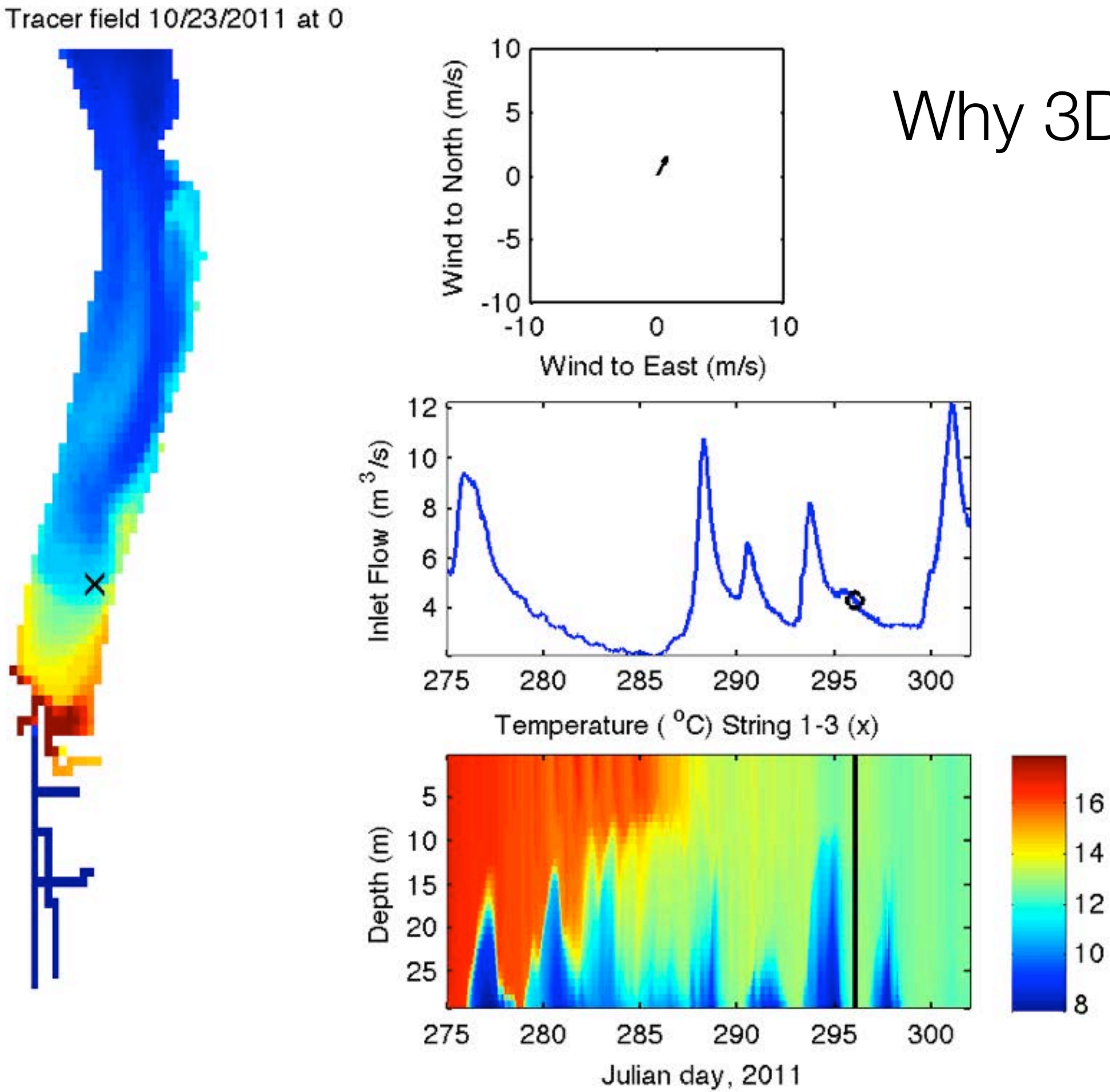
Tracer field 10/23/2011 at 0
Wind to North (m/s)
Wind to East (m/s)
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Inlet Flow (m$^3$/s)
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Julian day, 2011

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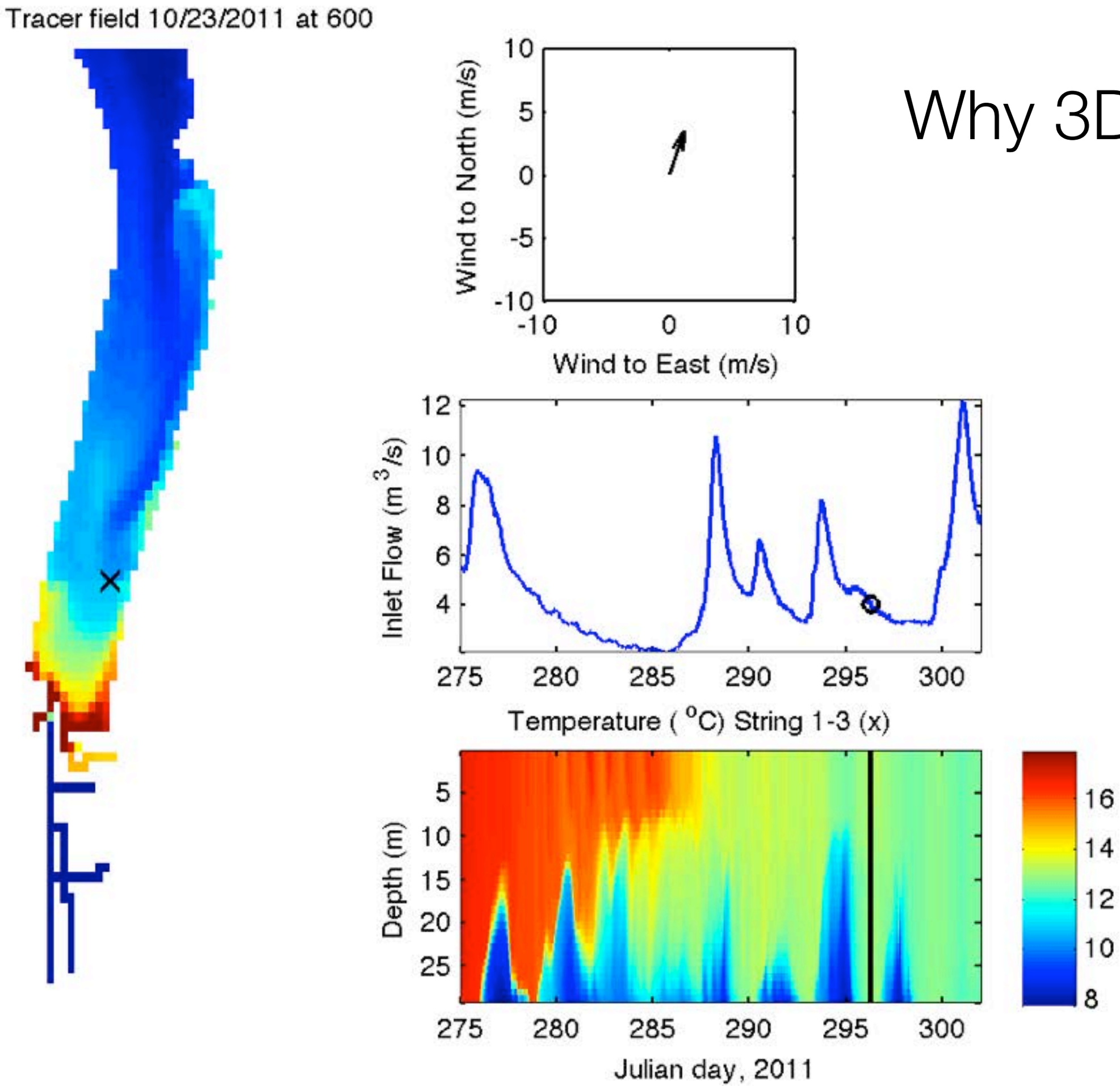
Tracer field 10/23/2011 at 600
Wind to North (m/s)
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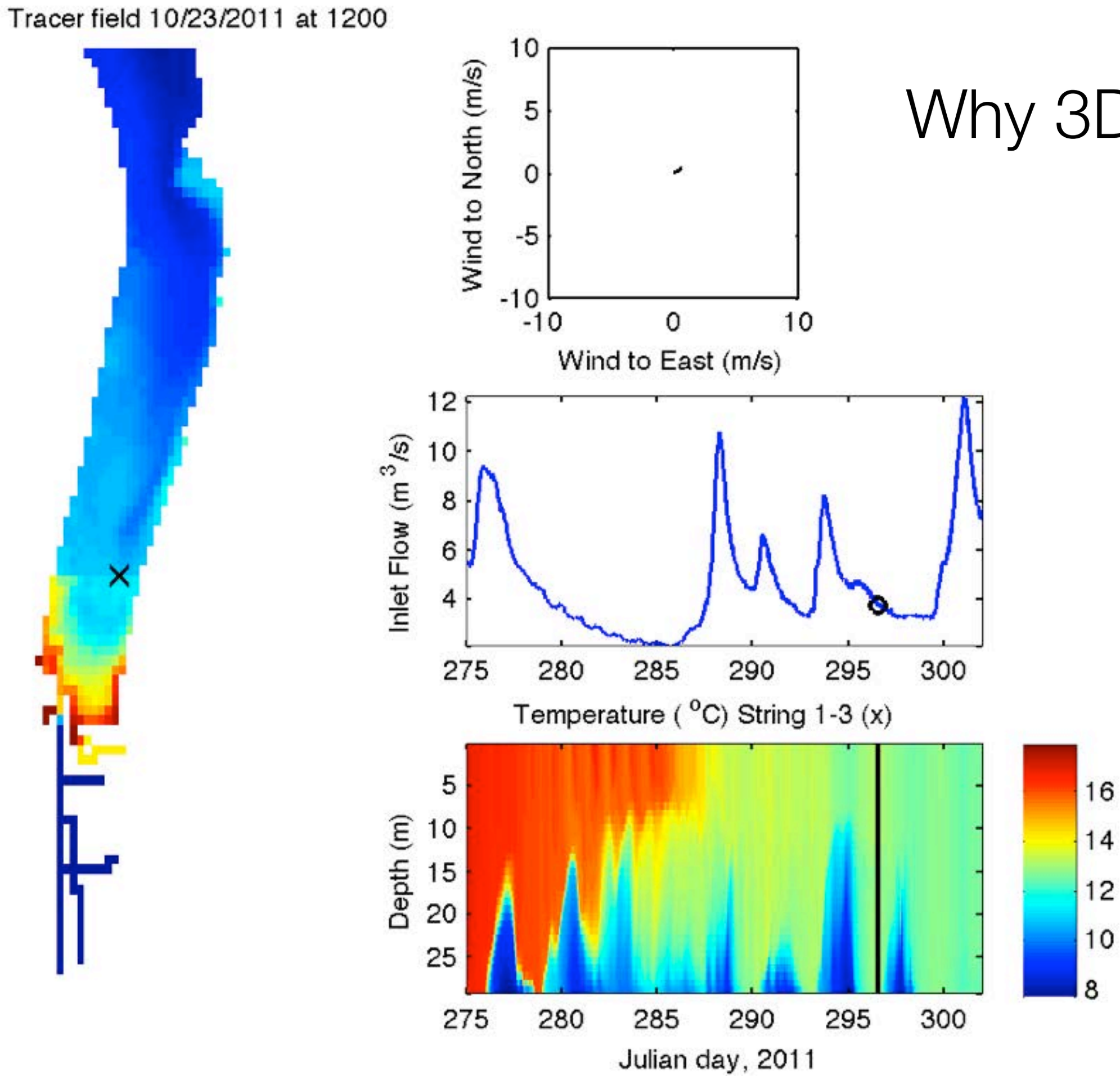
Tracer field 10/23/2011 at 1200
Wind to North (m/s)
Wind to East (m/s)
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10
Inlet Flow (m$^3$/s)
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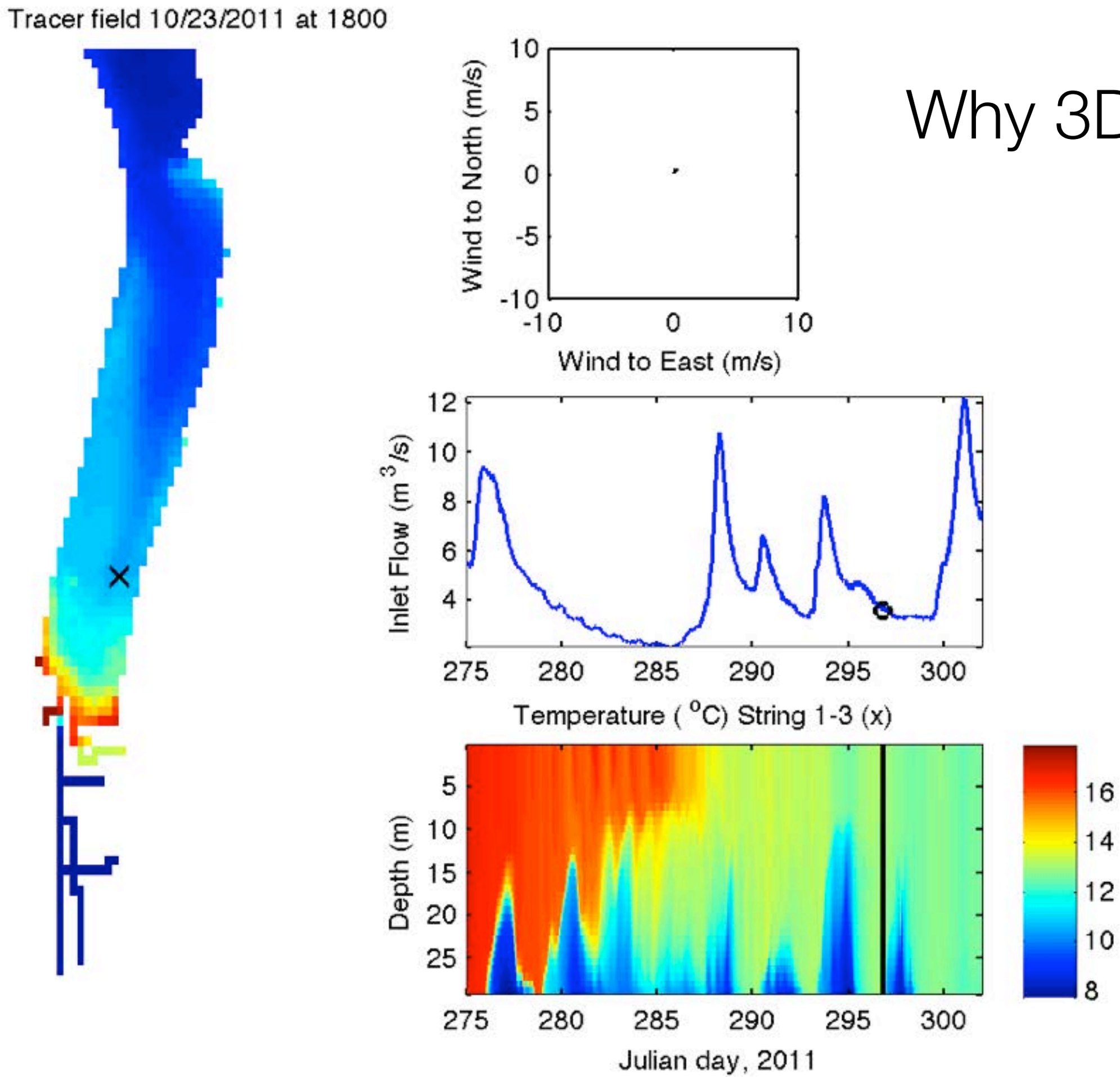
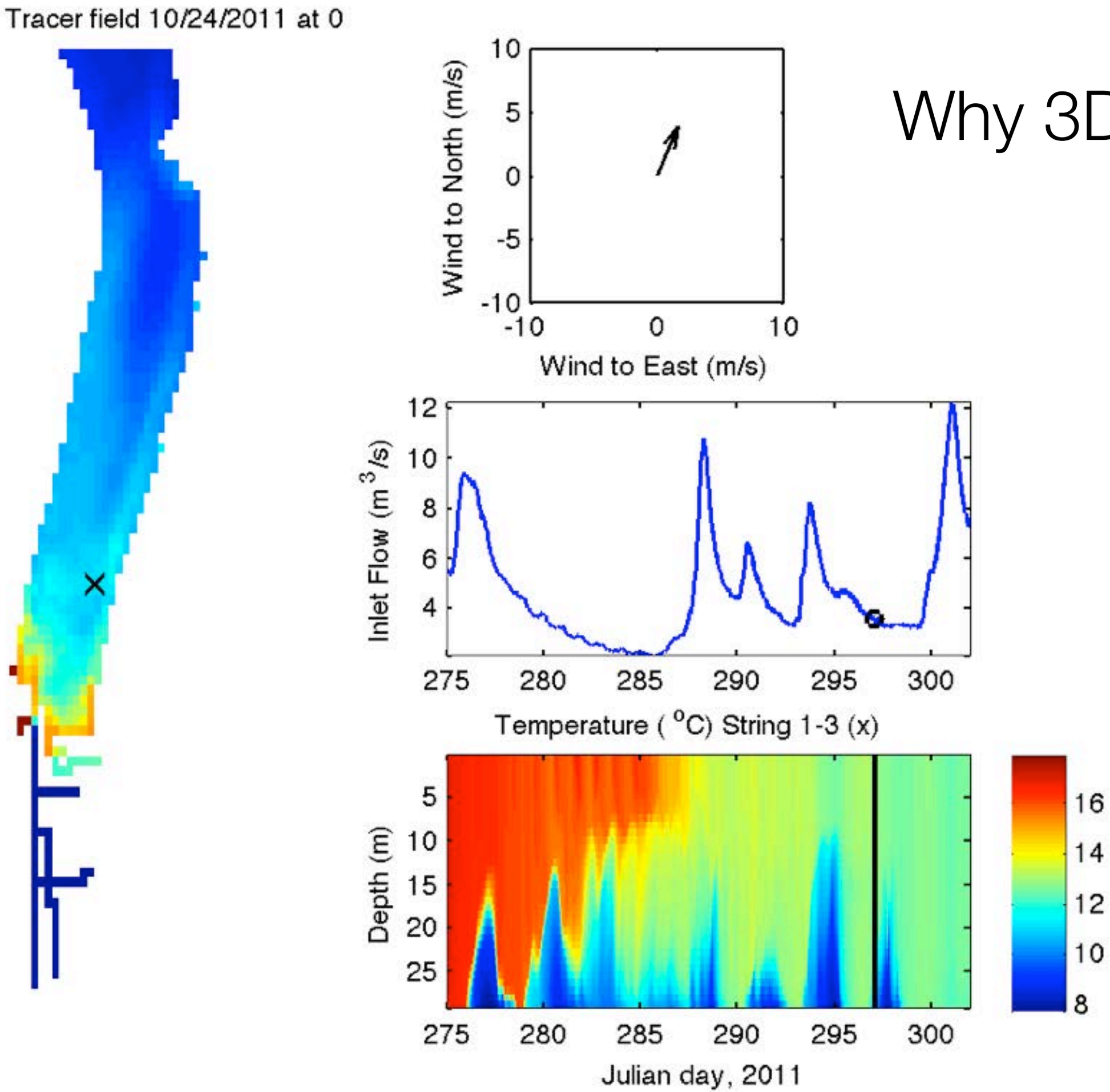
6
4
275
280
285
290
295
300
Temperature ( $^o$C) String 1-3 (x)
Depth (m)
5
10
15
20
25
275
280
285
290
295
300
Julian day, 2011
16
14
12
10
8

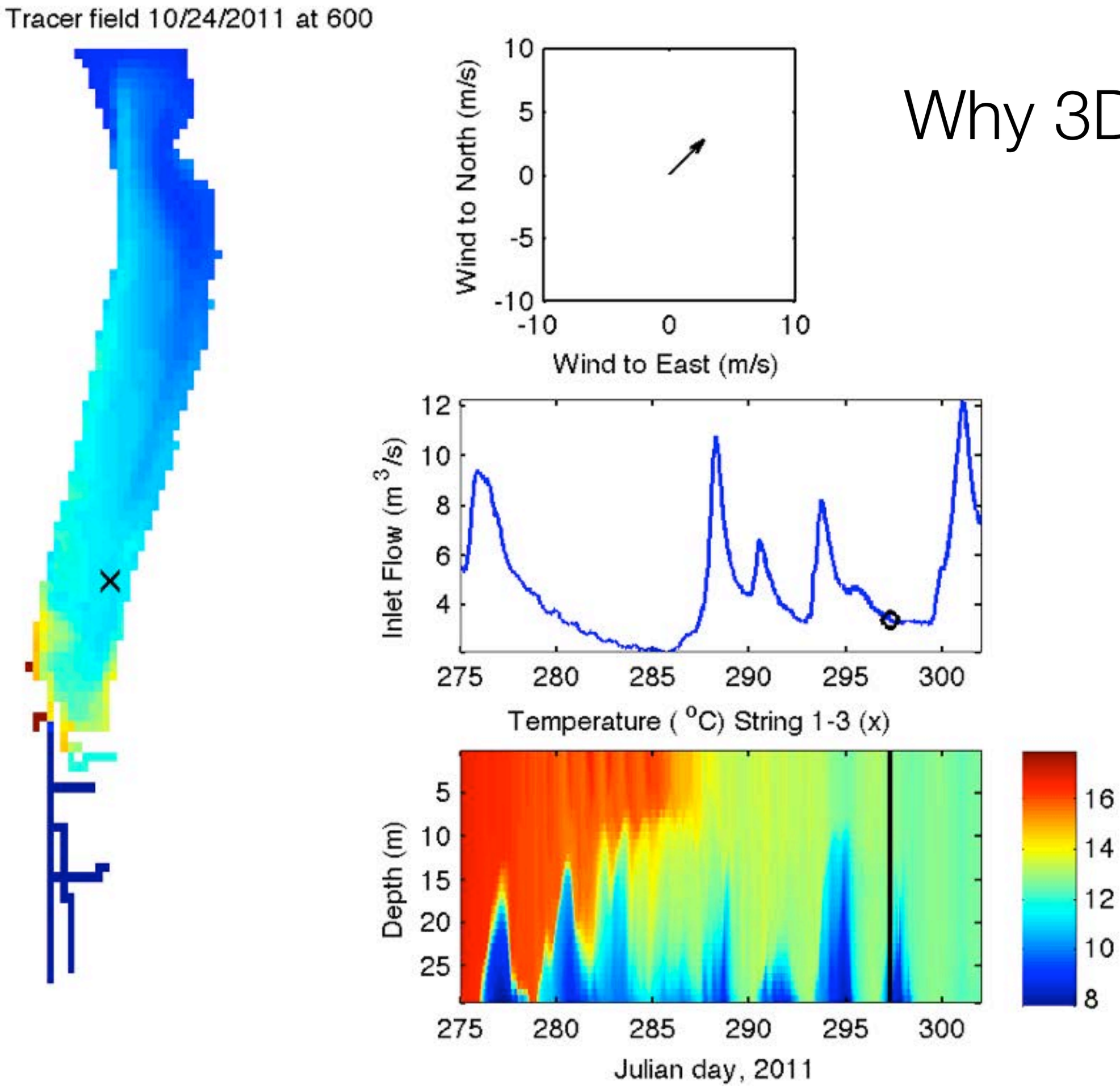
# Why 3D?


Tracer field 10/23/2011 at 1800
Wind to North (m/s)
Wind to East (m/s)
10
5
0
-5
-10
-10
0
10
Inlet Flow (m$^3$/s)
12
10
8
6
4
275
280
285
290
295
300
Temperature ( $^o$C) String 1-3 (x)
Depth (m)
5
10
15
20
25
275
280
285
290
295
300
Julian day, 2011
16
14
12
10
8

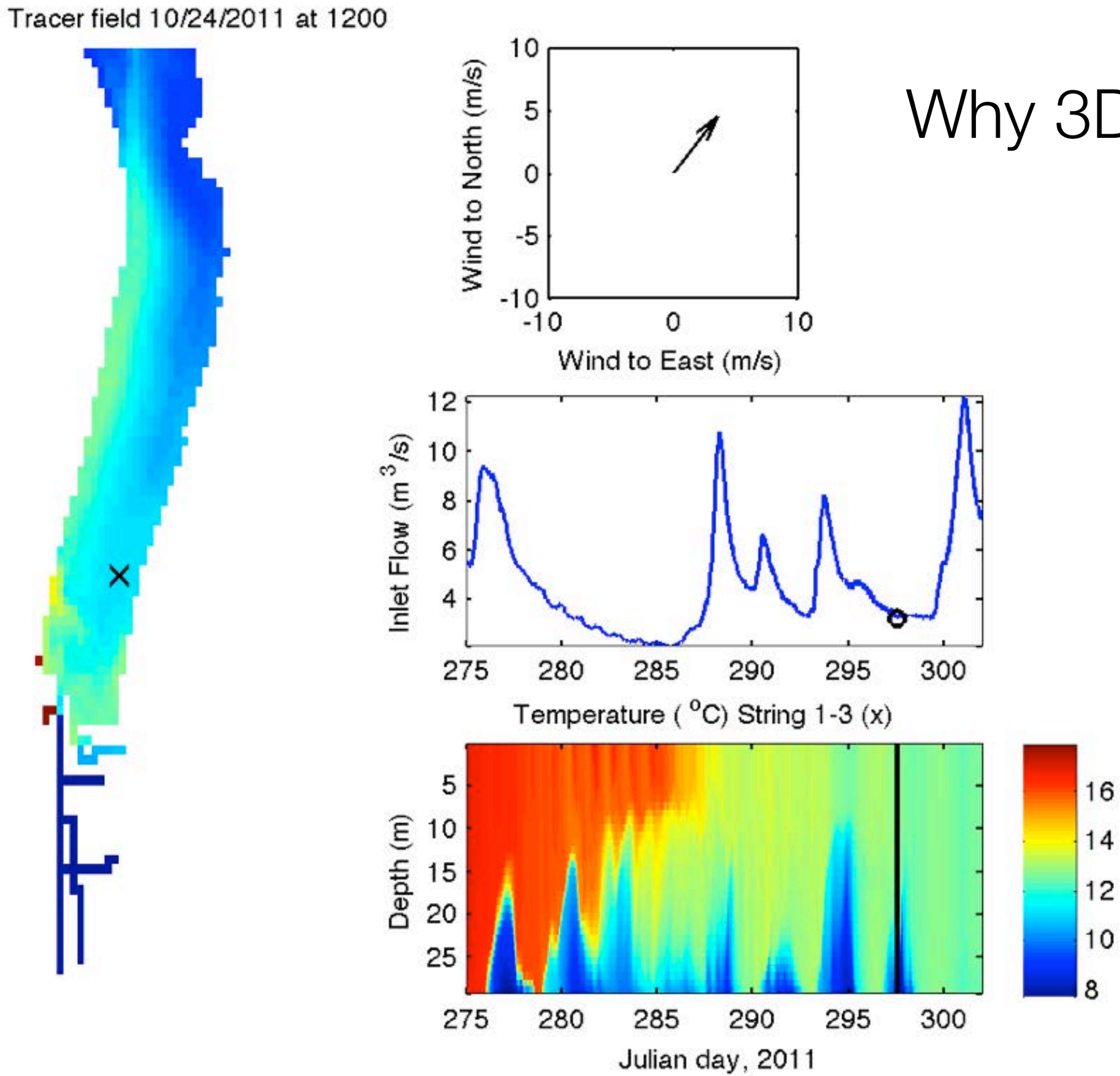
# Why 3D?


Tracer field 10/24/2011 at 0
Wind to North (m/s)
Wind to East (m/s)
10
5
0
-5
-10
-10
0
10
Inlet Flow (m3/s)
12
10
8
6
4
275
280
285
290
295
300
Temperature ( °C) String 1-3 (x)
Depth (m)
5
10
15
20
25
16
14
12
10
8
Julian day, 2011

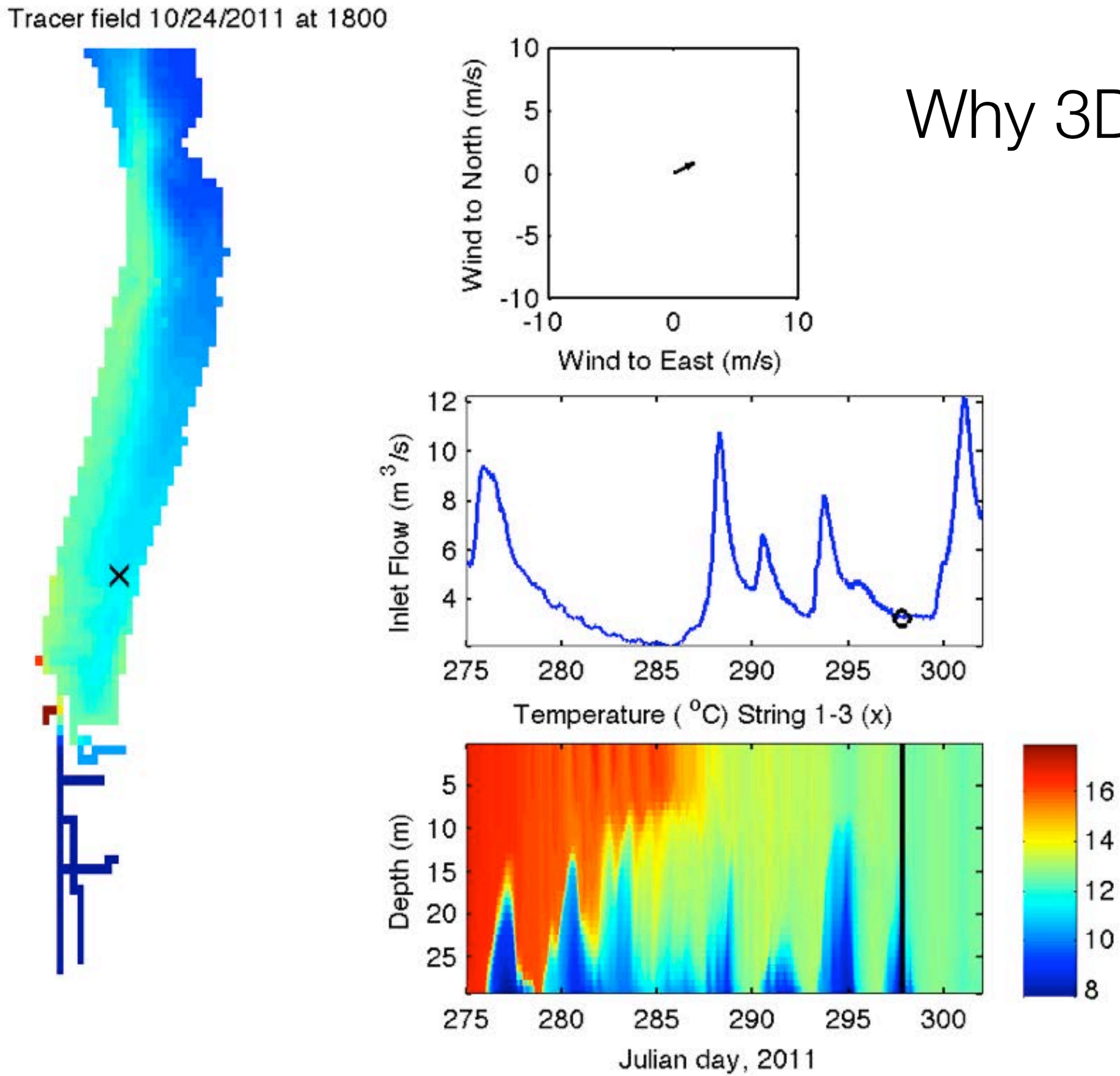
# Why 3D?


Tracer field 10/24/2011 at 600
Wind to North (m/s)
Wind to East (m/s)
10
5
0
-5
-10
-10
0
10
Inlet Flow (m$^3$/s)
12
10
8
6
4
275
280
285
290
295
300
Temperature ( $^o$C) String 1-3 (x)
Depth (m)
5
10
15
20
25
16
14
12
10
8
Julian day, 2011

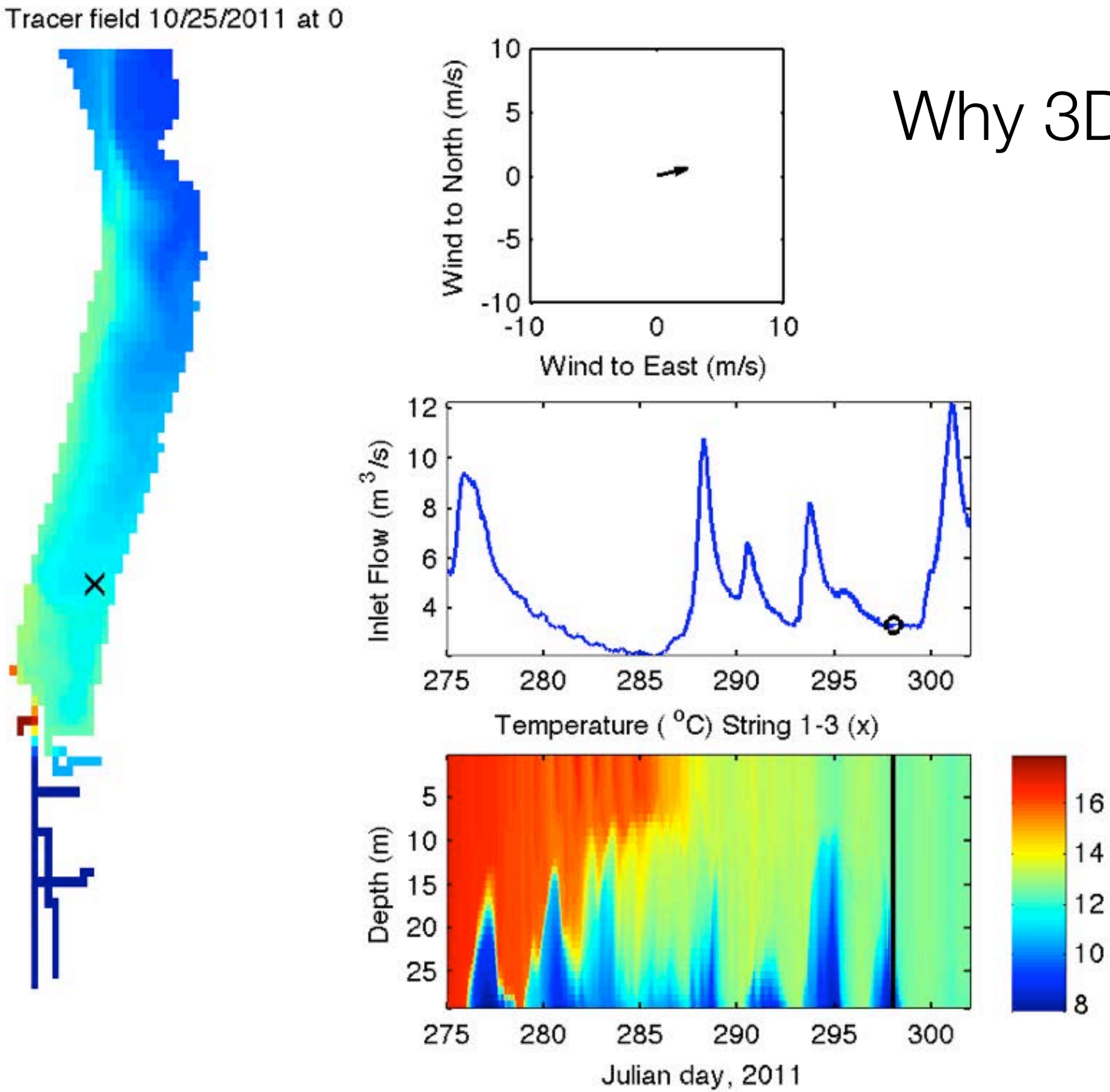
# Why 3D?


Tracer field 10/24/2011 at 1200
Wind to North (m/s)
Wind to East (m/s)
10
5
0
-5
-10
-10
0
10
Inlet Flow (m$^3$/s)
12
10
8
6
4
275
280
285
290
295
300
Temperature ( $^o$C) String 1-3 (x)
Depth (m)
5
10
15
20
25
16
14
12
10
8
Julian day, 2011

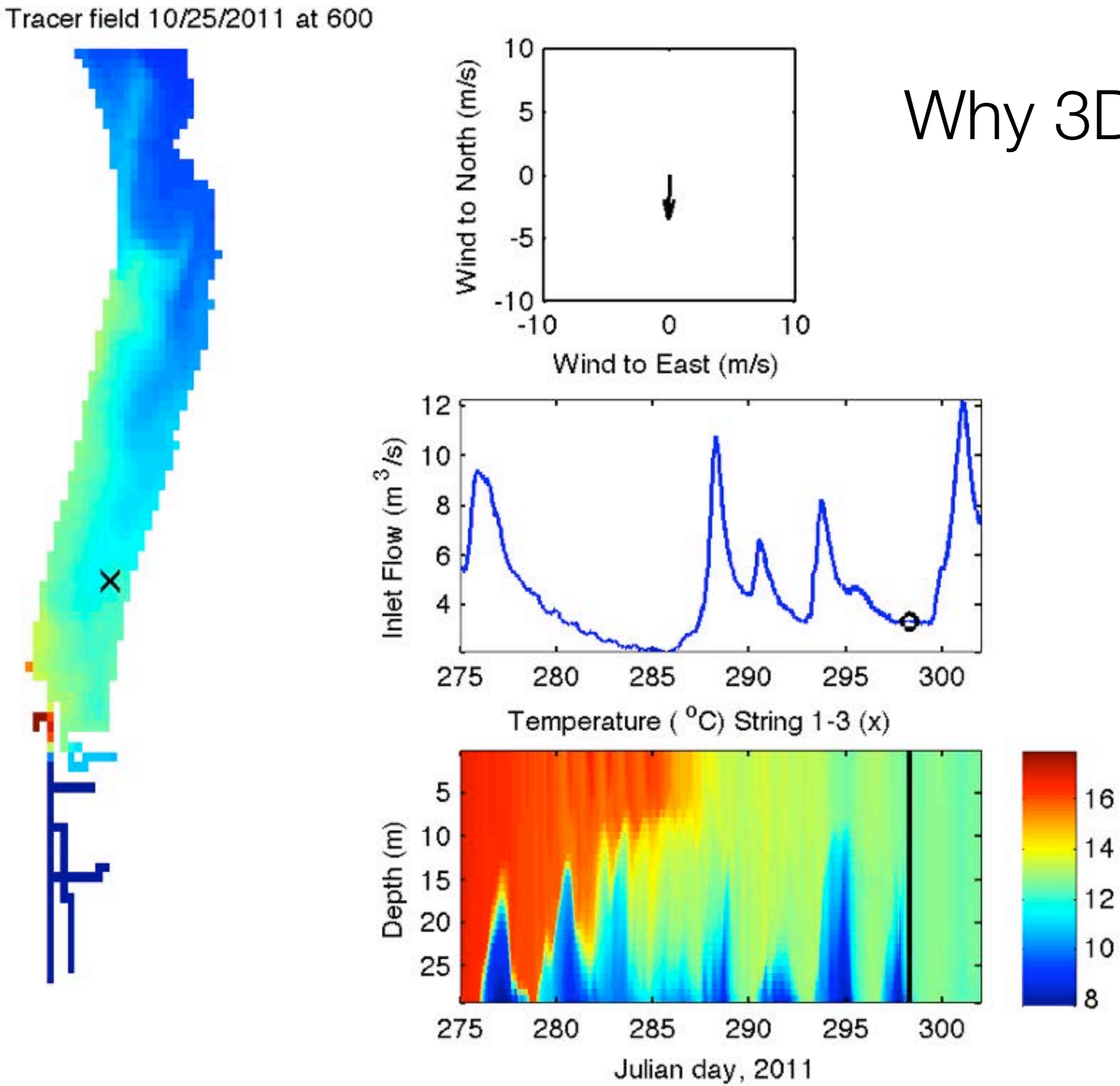
# Why 3D?


Tracer field 10/24/2011 at 1800
Wind to North (m/s)
Wind to East (m/s)
10
5
0
-5
-10
-10
0
10
Inlet Flow (m$^3$/s)
12
10
8
6
4
275
280
285
290
295
300
Temperature ( $^o$C) String 1-3 (x)
Depth (m)
5
10
15
20
25
16
14
12
10
8
Julian day, 2011

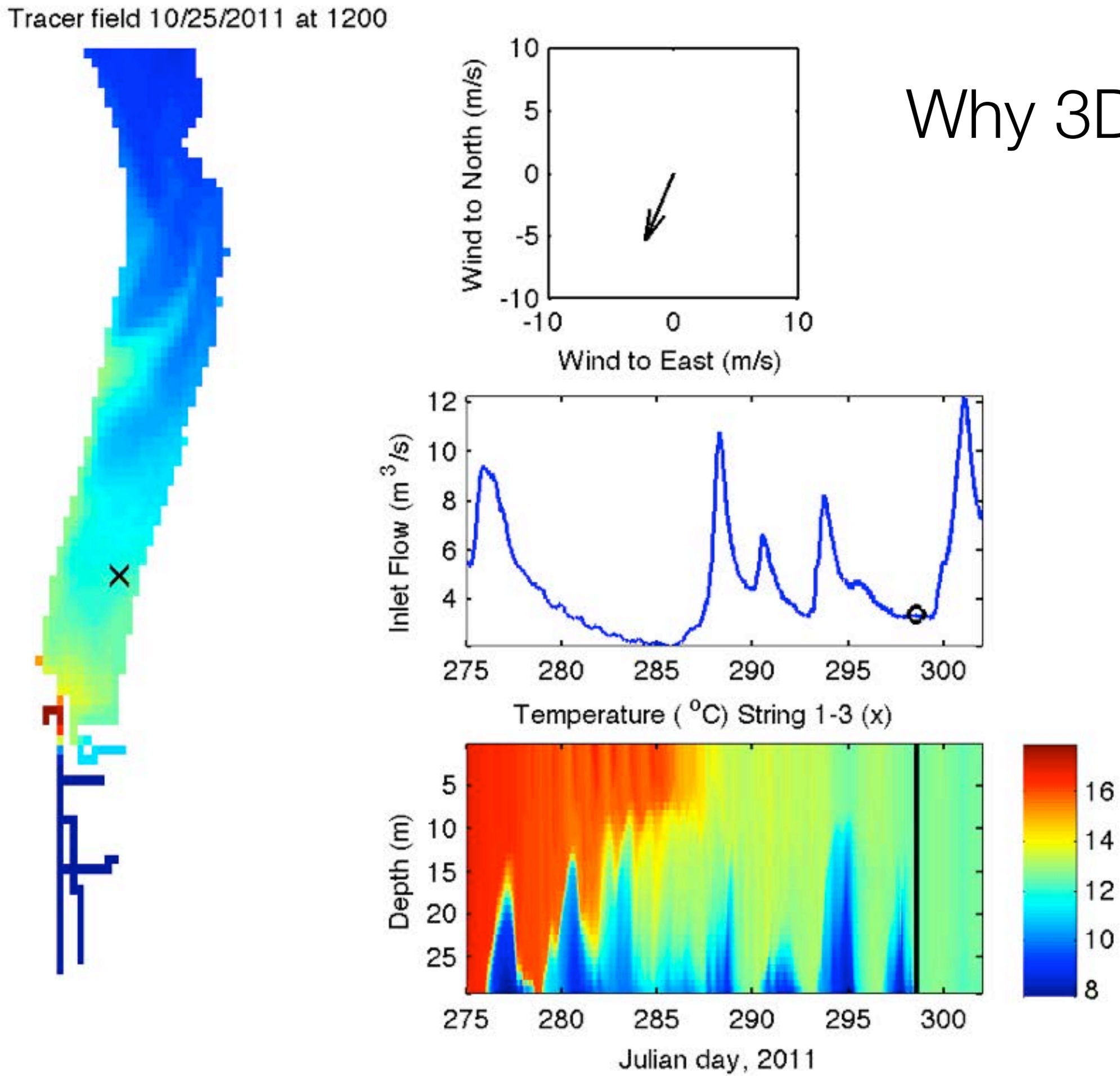
# Why 3D?


Tracer field 10/25/2011 at 0
Wind to North (m/s)
Wind to East (m/s)
10
5
0
-5
-10
-10
0
10
Inlet Flow (m$^3$/s)
12
10
8
6
4
275
280
285
290
295
300
Temperature ( $^o$C) String 1-3 (x)
Depth (m)
5
10
15
20
25
16
14
12
10
8
Julian day, 2011

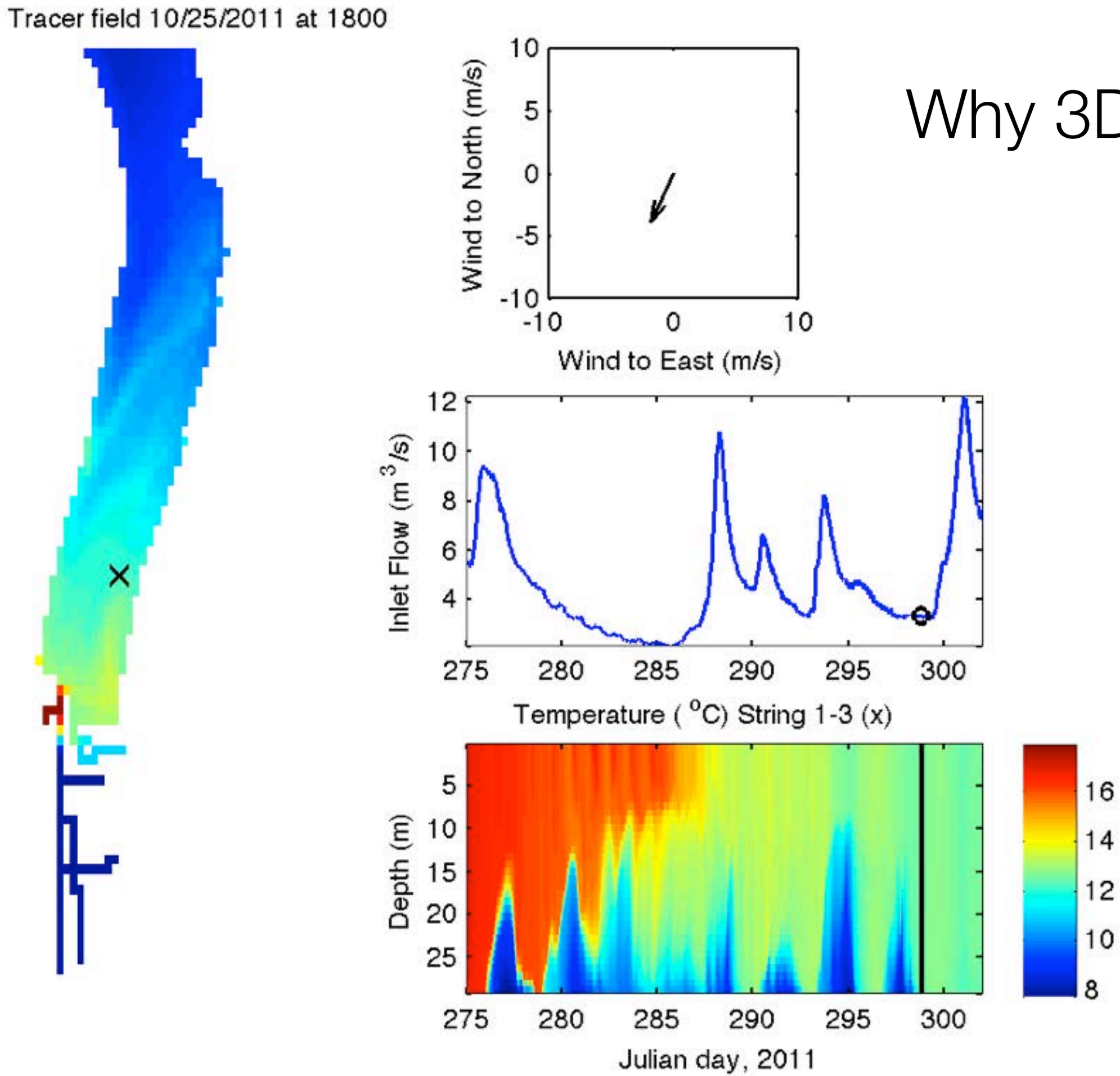
# Why 3D?


Tracer field 10/25/2011 at 600
Wind to North (m/s)
Wind to East (m/s)
10
5
0
-5
-10
-10
0
10
Inlet Flow (m$^3$/s)
12
10
8
6
4
275
280
285
290
295
300
Temperature ( $^o$C) String 1-3 (x)
Depth (m)
5
10
15
20
25
275
280
285
290
295
300
Julian day, 2011
16
14
12
10
8

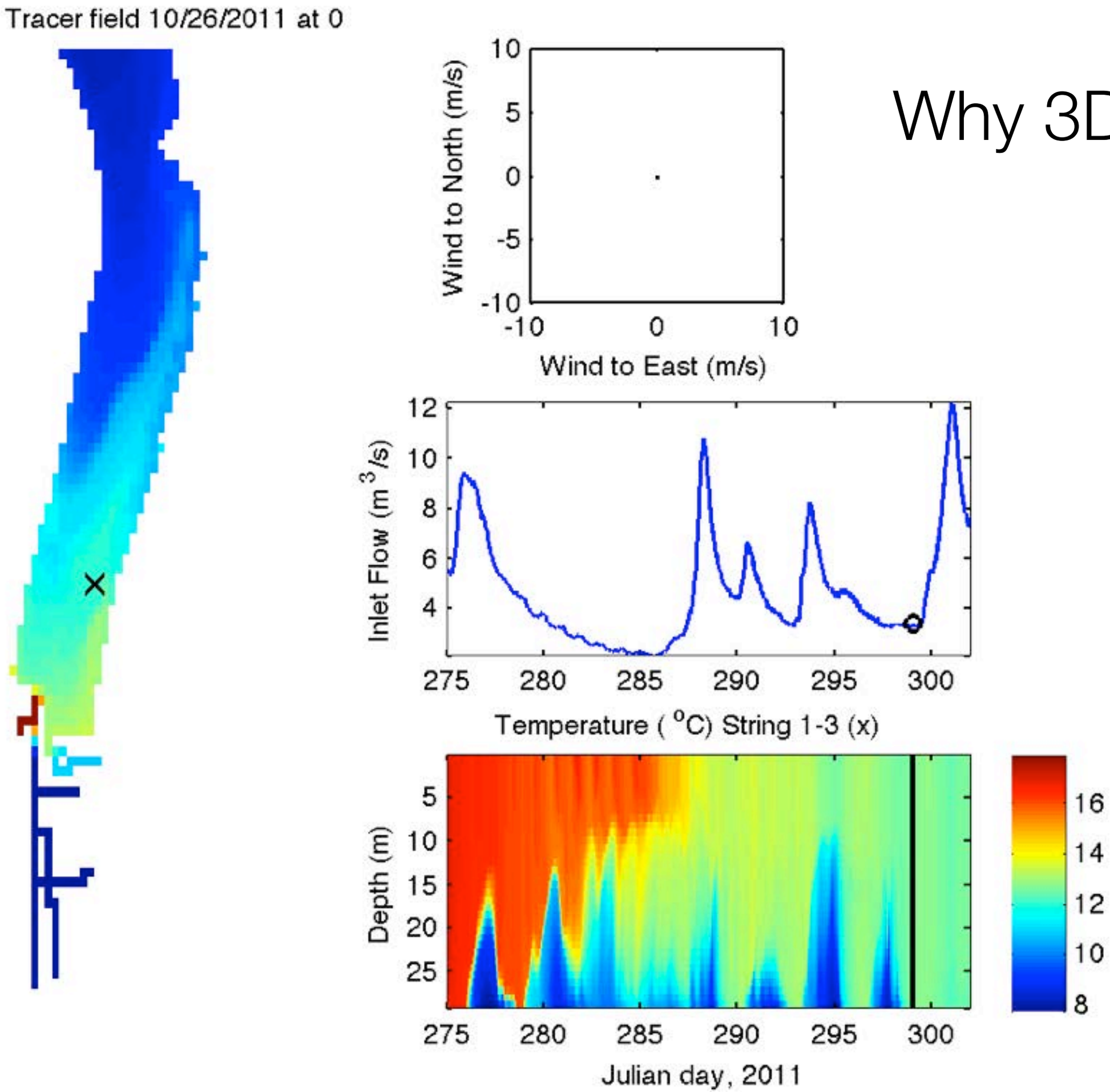
# Why 3D?


Tracer field 10/25/2011 at 1200
Wind to North (m/s)
Wind to East (m/s)
10
5
0
-5
-10
-10
0
10
Inlet Flow (m$^3$/s)
12
10
8
6
4
275
280
285
290
295
300
Temperature ( $^o$C) String 1-3 (x)
Depth (m)
5
10
15
20
25
16
14
12
10
8
Julian day, 2011

# Why 3D?


Tracer field 10/25/2011 at 1800
Wind to North (m/s)
Wind to East (m/s)
10
5
0
-5
-10
-10
0
10
Inlet Flow (m$^3$/s)
12
10
8
6
4
275
280
285
290
295
300
Temperature ( $^o$C) String 1-3 (x)
Depth (m)
5
10
15
20
25
16
14
12
10
8
Julian day, 2011

# Why 3D?


Tracer field 10/26/2011 at 0
Wind to North (m/s)
Wind to East (m/s)
10
5
0
-5
-10
-10
0
10
Inlet Flow (m$^3$/s)
12
10
8
6
4
275
280
285
290
295
300
Temperature ( $^o$C) String 1-3 (x)
Depth (m)
5
10
15
20
25
275
280
285
290
295
300
Julian day, 2011
16
14
12
10
8