Scaling law of internal run-up duration

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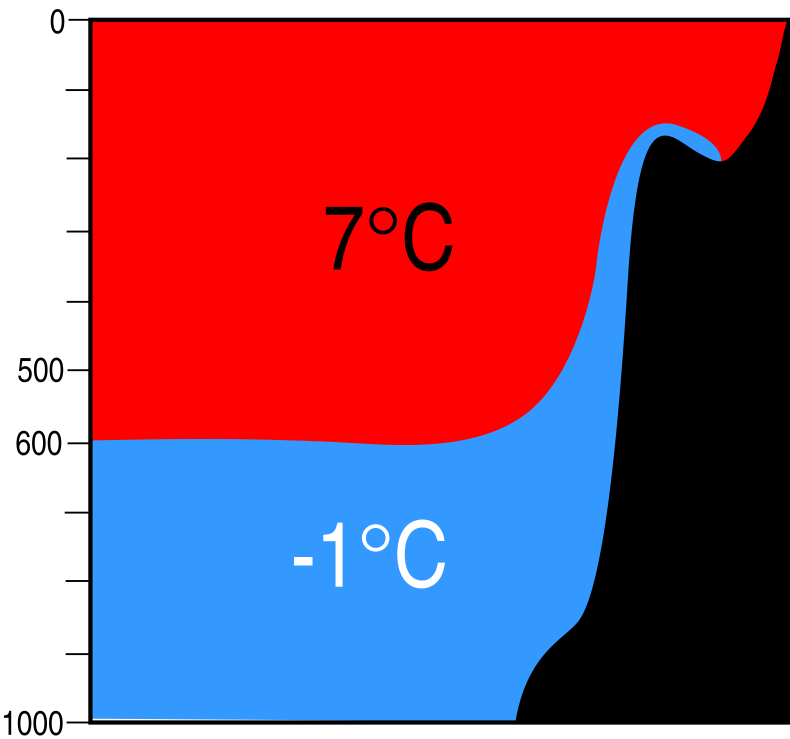
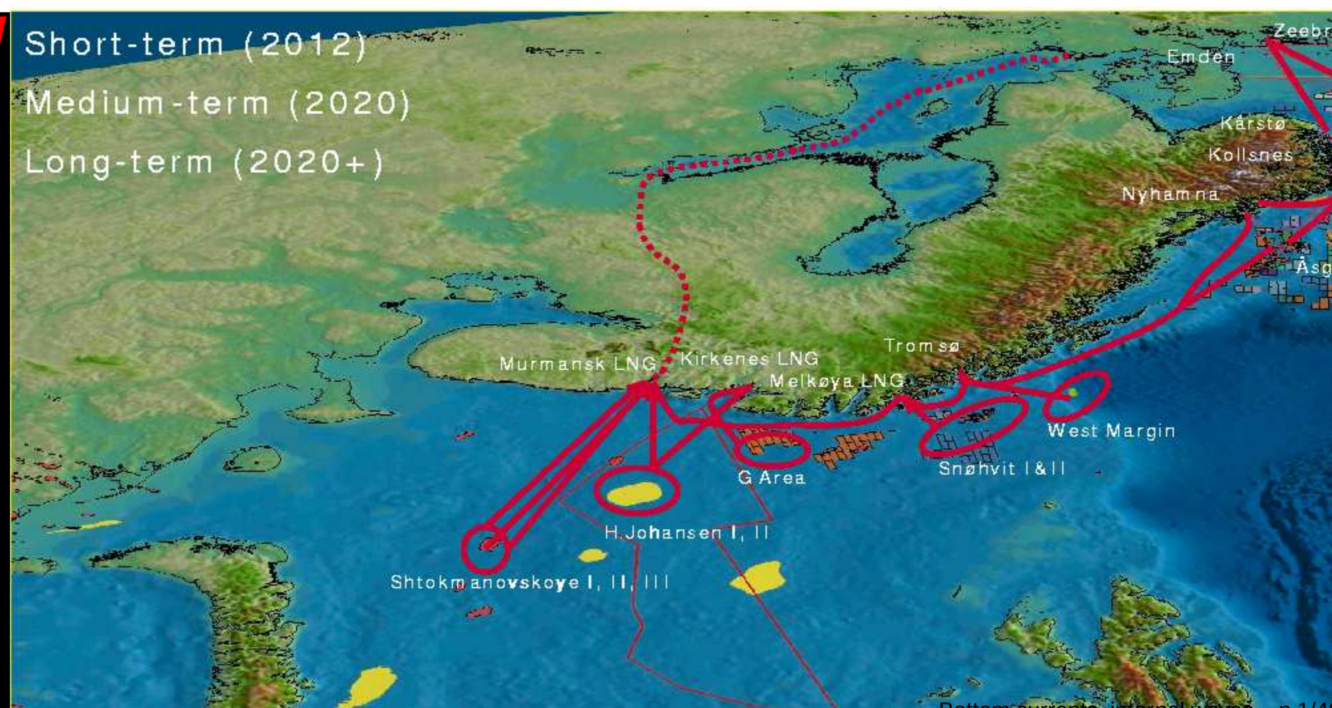
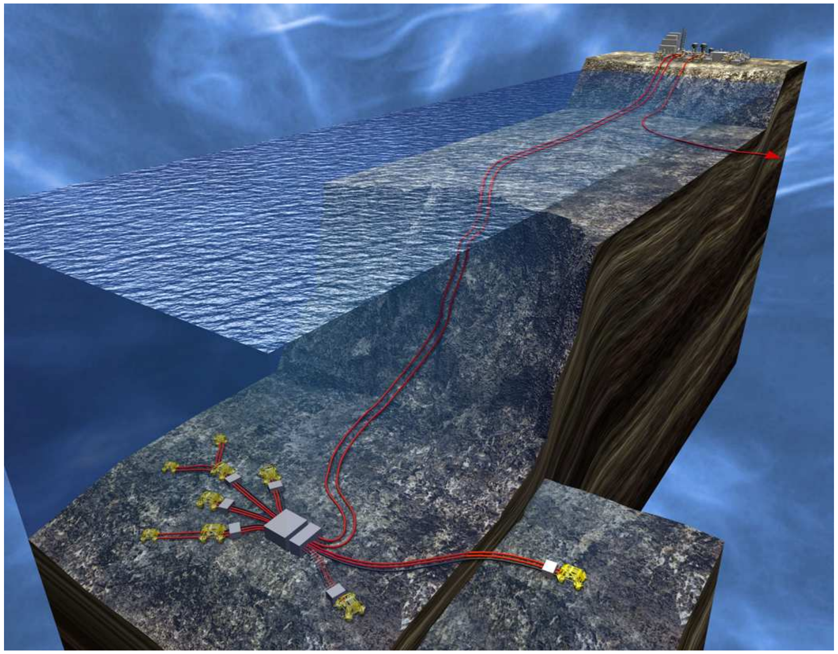
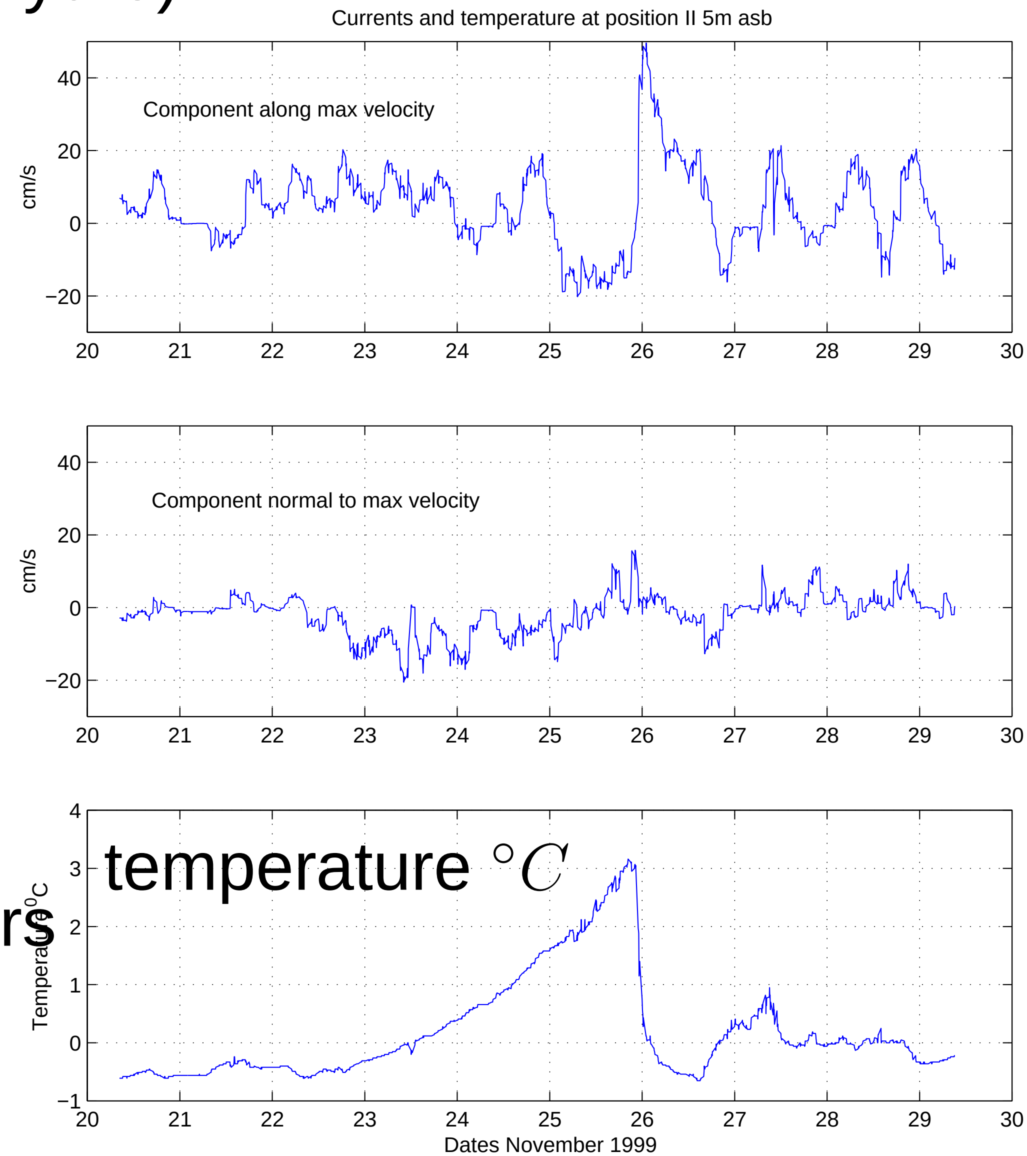




Main motivation: **STRONG BOTTOM CURRENT EVENT** measured at Ormen Lange gas field (StatoilHydro)





MAX VEL. 0.5 m s^{-1}

Current event, **DURATION** ~ 24 hrs

Initial down flow

Subsequent **ONSHORE FLOW**

Current event, at 850 m depth

Vertical excursion of pycno: 300 m (300 m / 550 m $\simeq \frac{1}{2}$)

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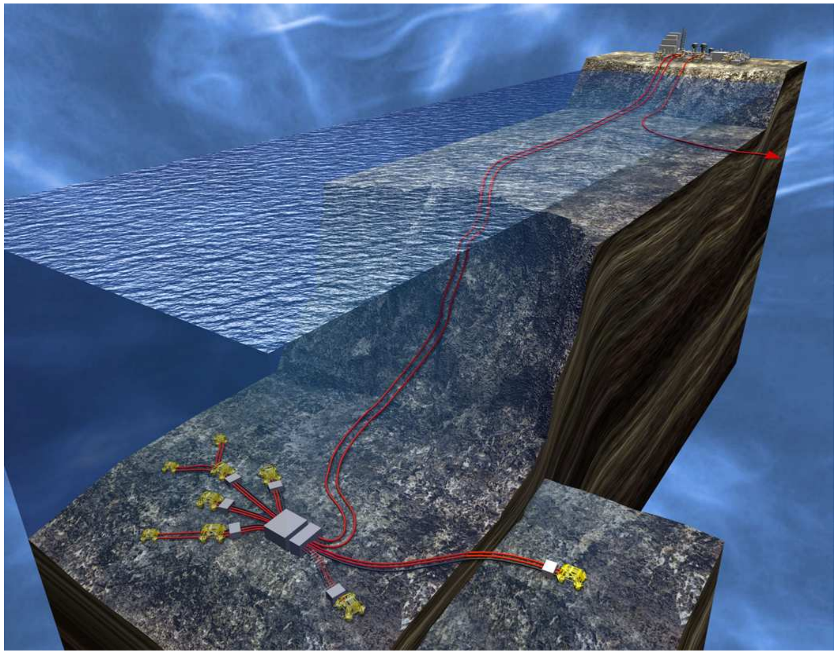

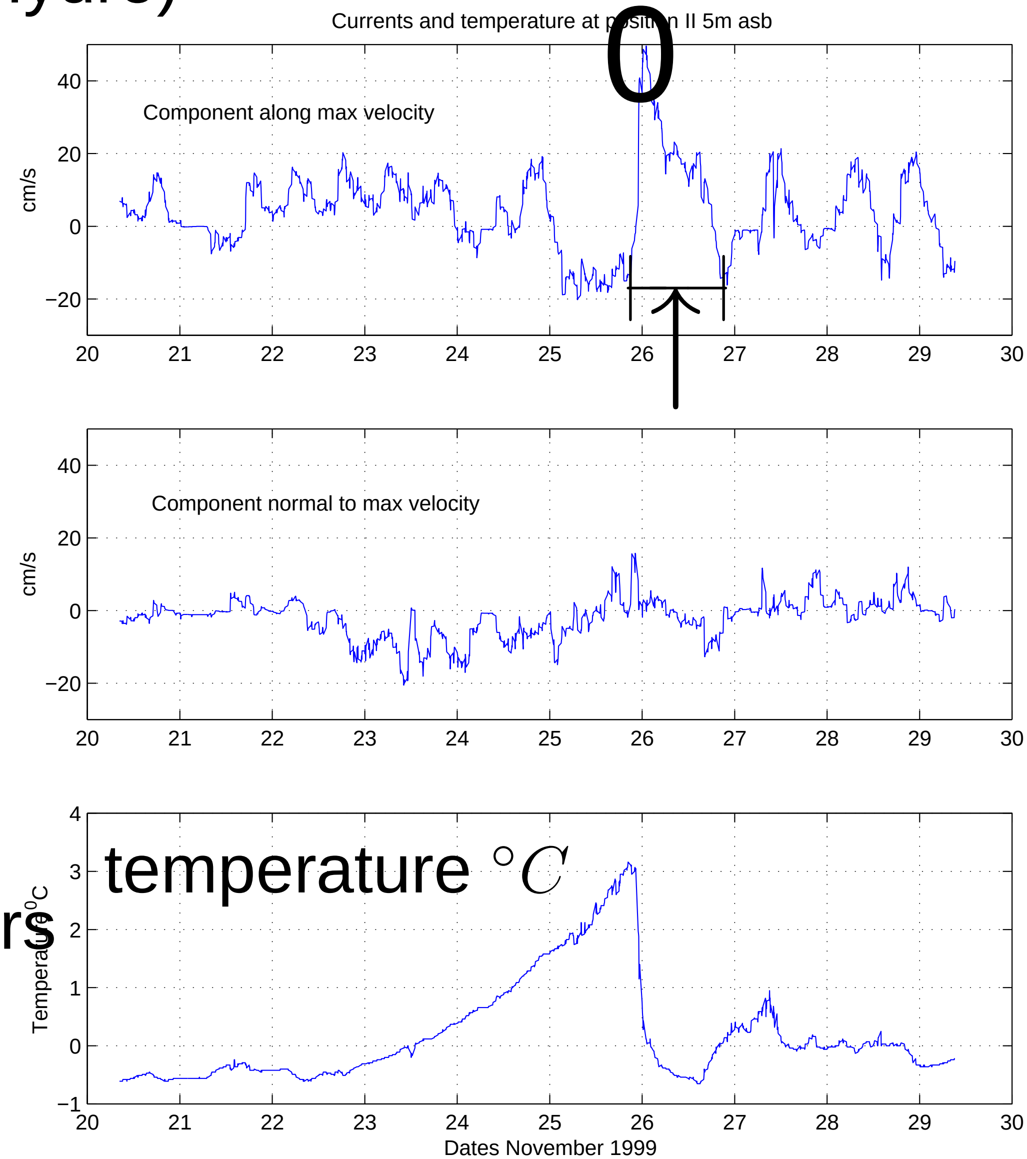

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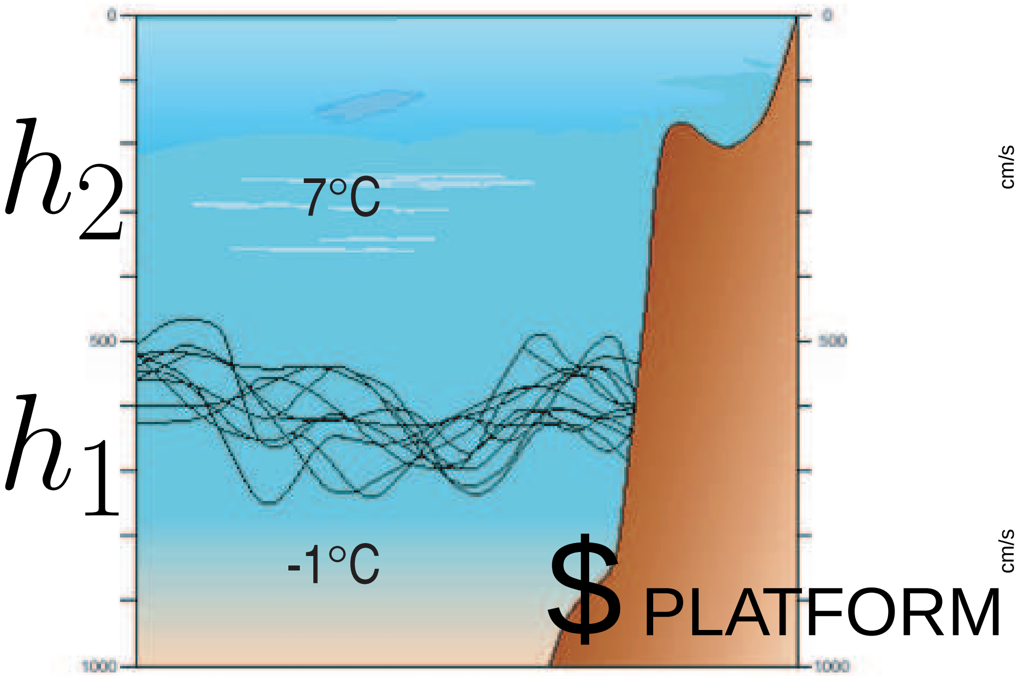

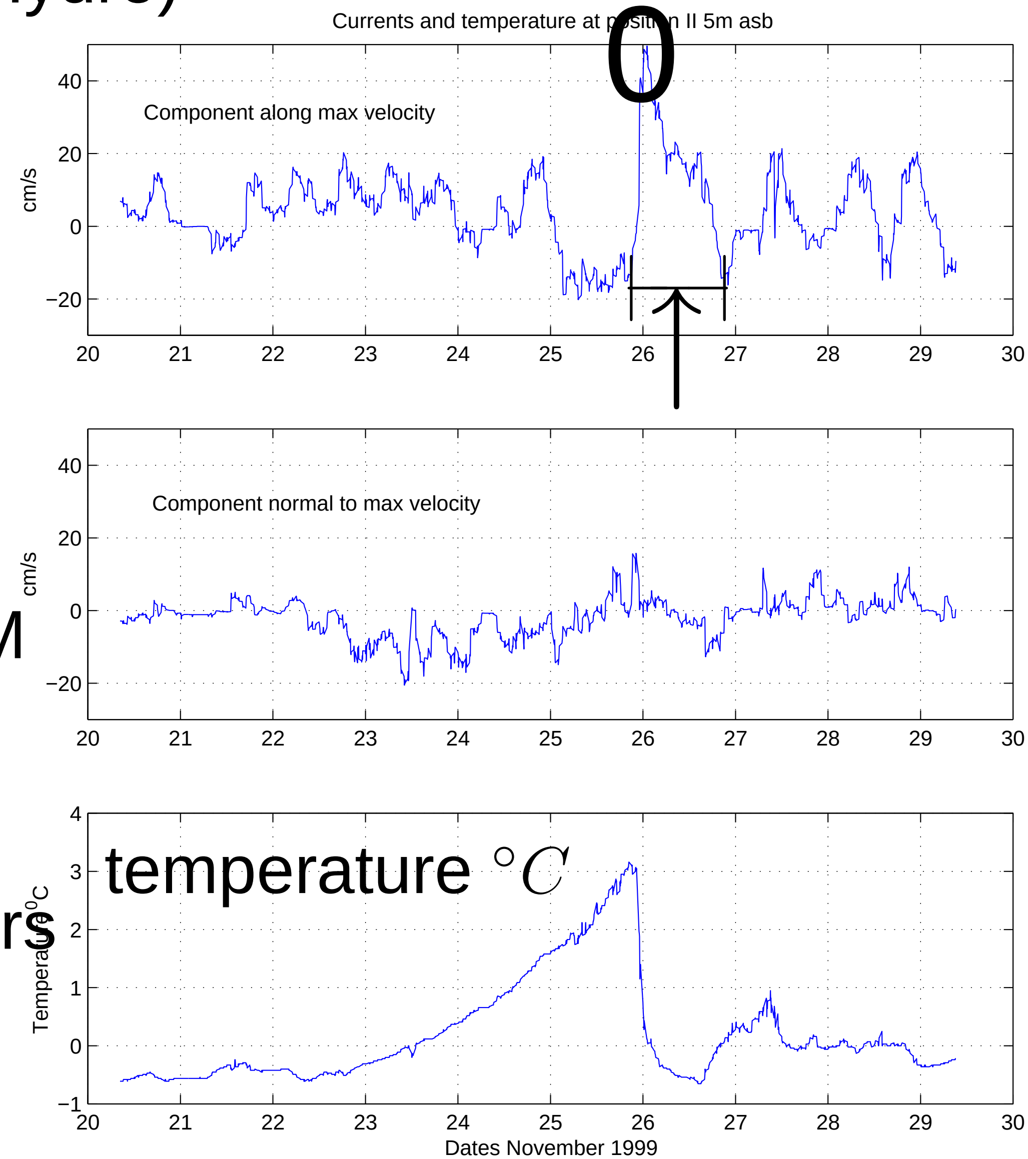

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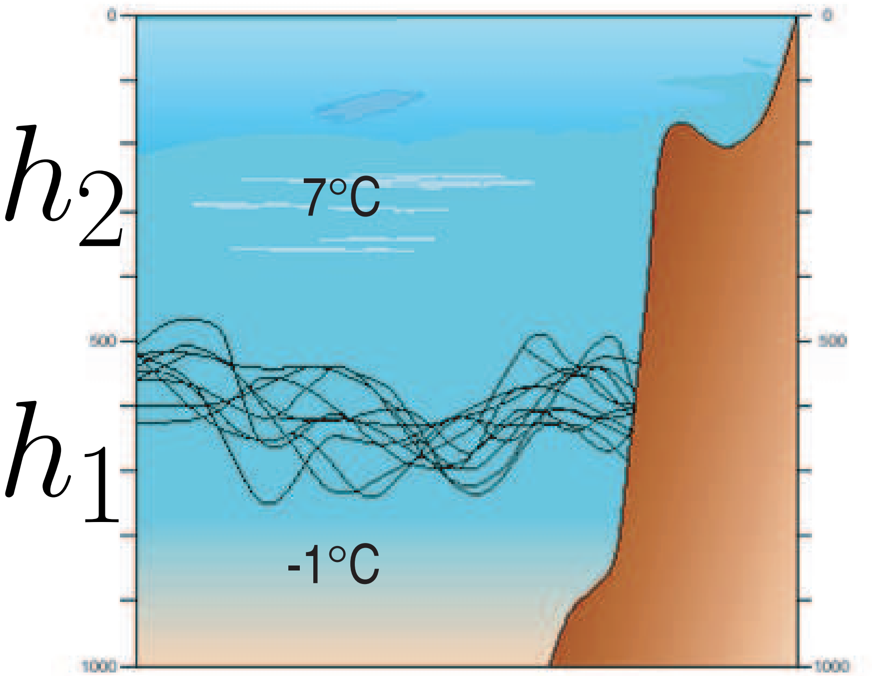
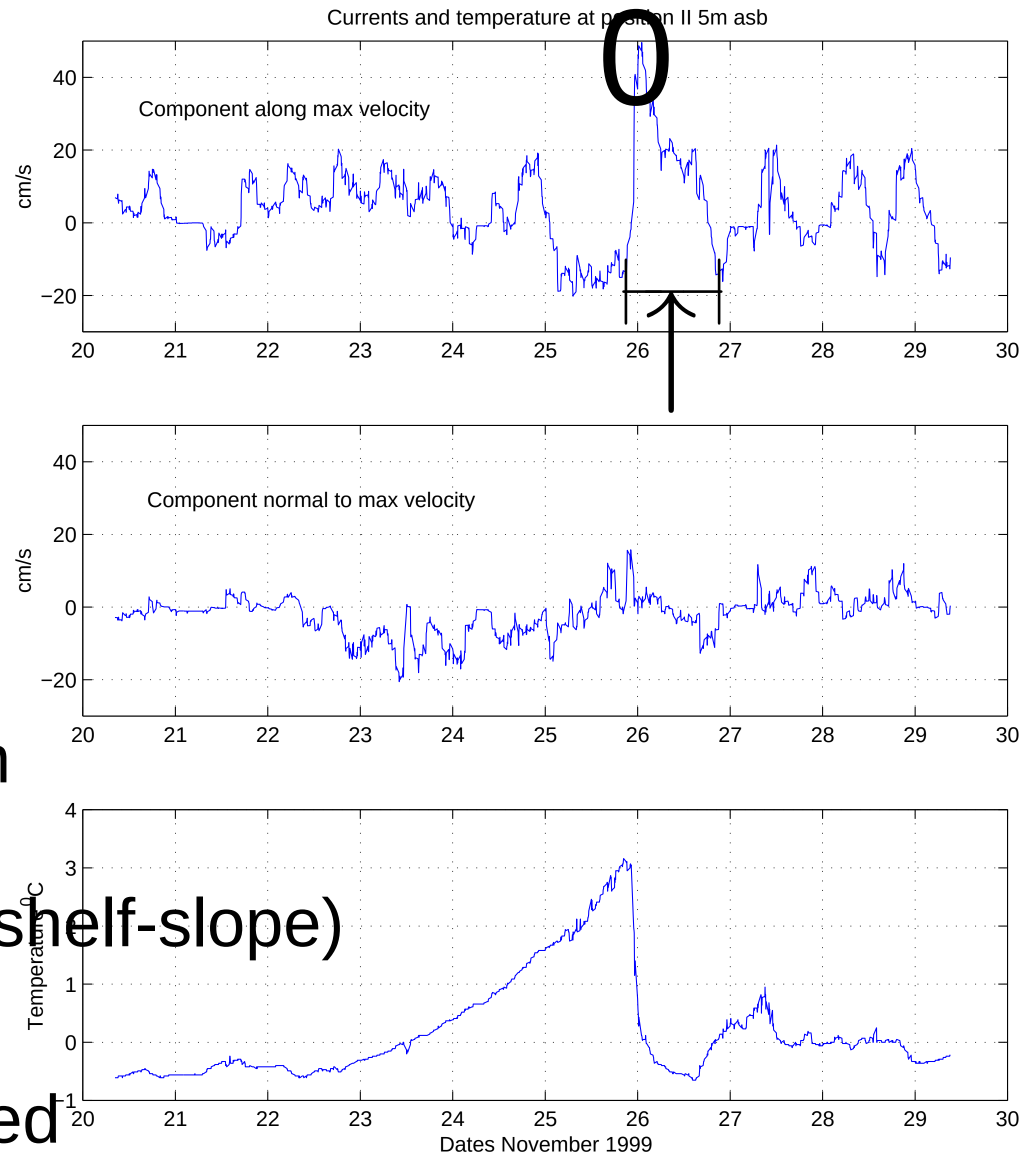
INTERNAL WAVE CHARACTERISTICS at Ormen Lange





thermocline at depth $h_2 = 550$ m

$\Delta\rho/\rho = 0.5 \times 10^{-3}$

depth ratio h_2:h_1 = 1:2 (outside shelf-slope)

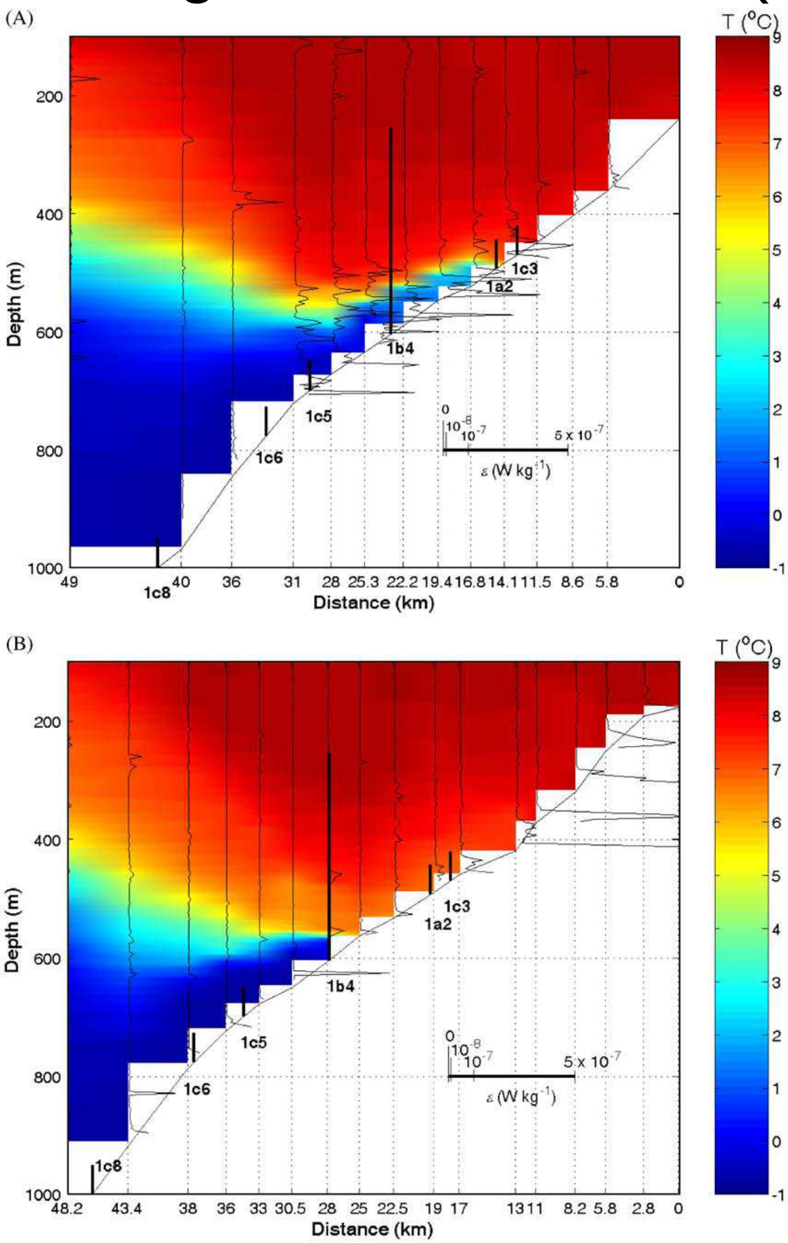
$c_0 = (\frac{g' h_2}{1+h_2/h_1})^{1/2} \simeq 1.35$ ms^{-1}

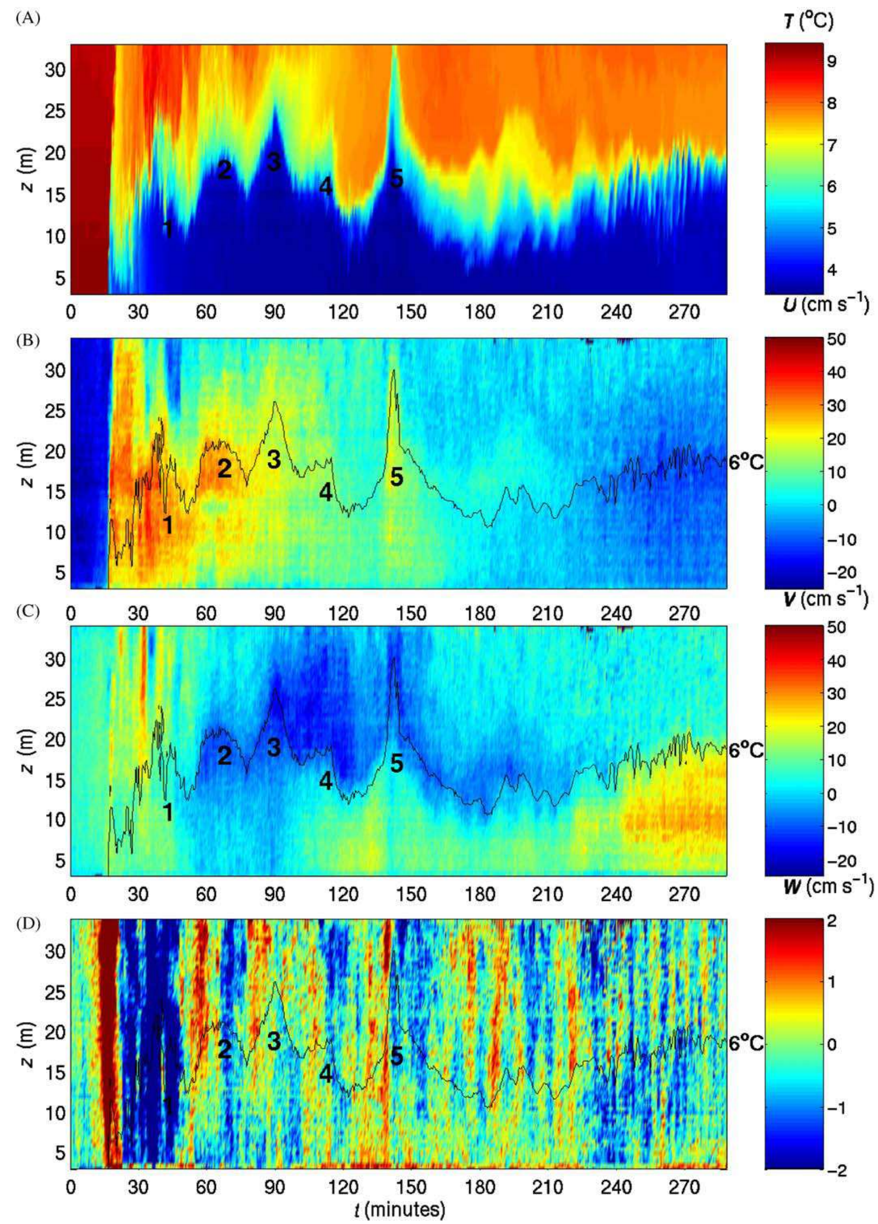
c_0 internal linear long wave speed

nondimensional maximal velocity $u/c_0 = 0.37$

nondimensional duration of current event $\Delta t c_0/h_2 = 212$

Internal run-up (solibores) in Faeroe-Shetland Channel
Hosegood & van Haren (2004)





Internal run-up and wavy bore

Internal run-up (solibores) in Faeroe-Shetland Channel
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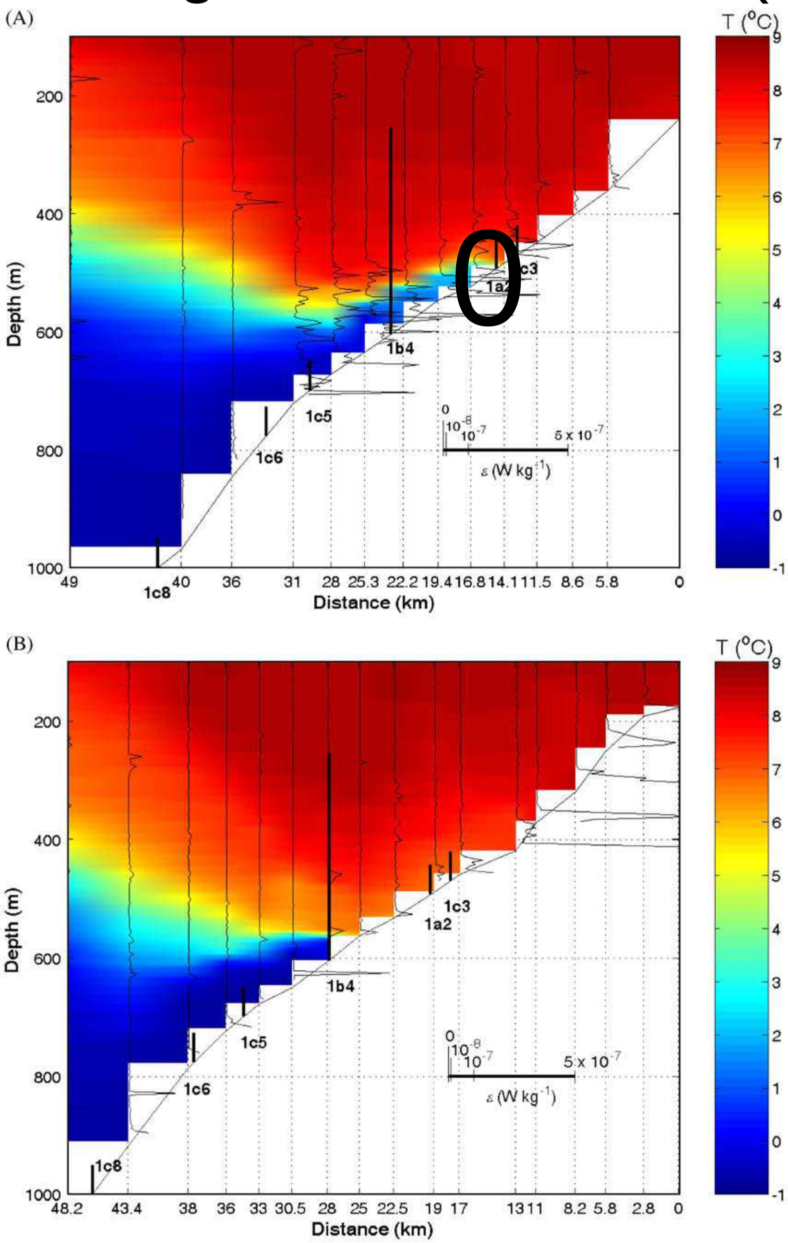
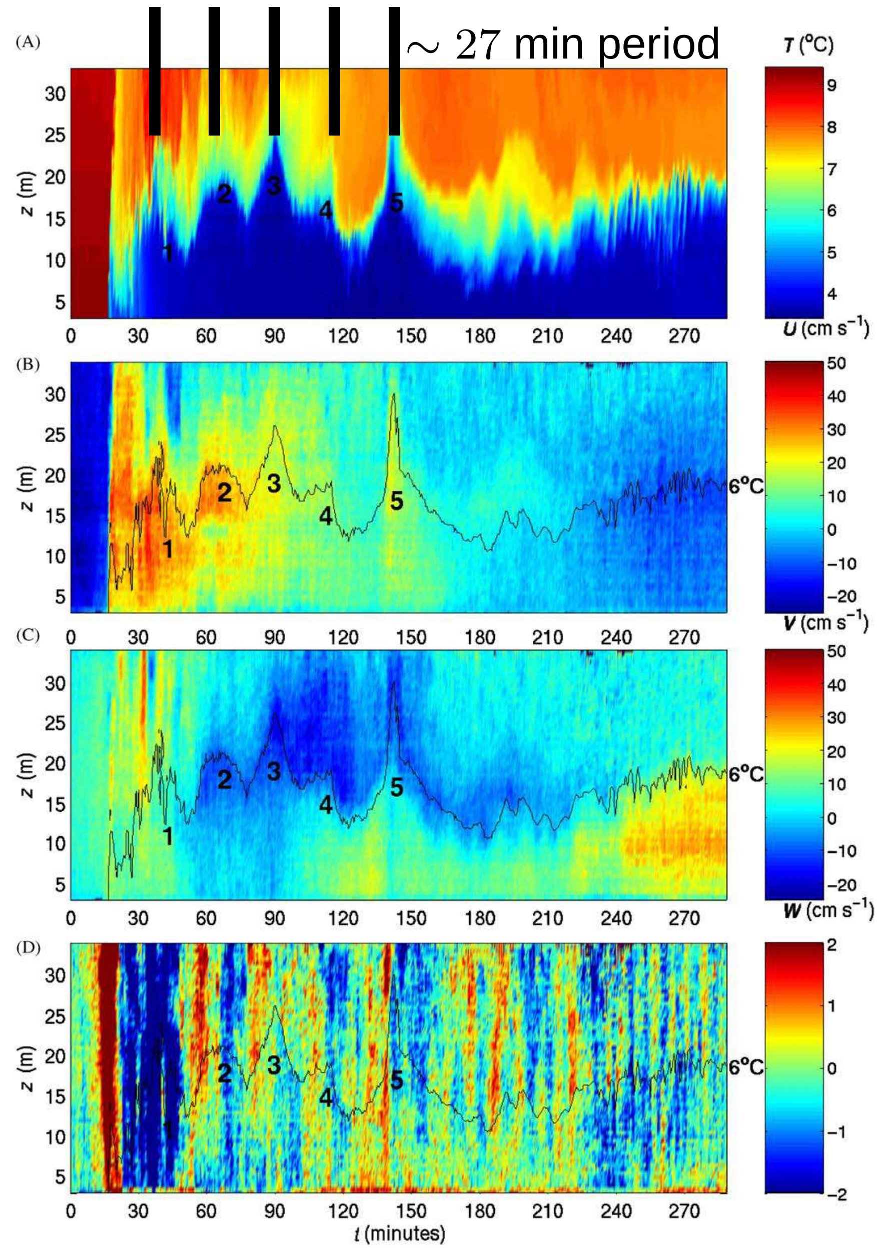




Internal run-up and wavy bore

Hosegood and van Haren's recordings;

- cause of run-up uncertain; not tidally driven

- leading edge velocity of 0.52 m s^{-1} $= 0.42c_0$

- c_0 internal linear long wave speed

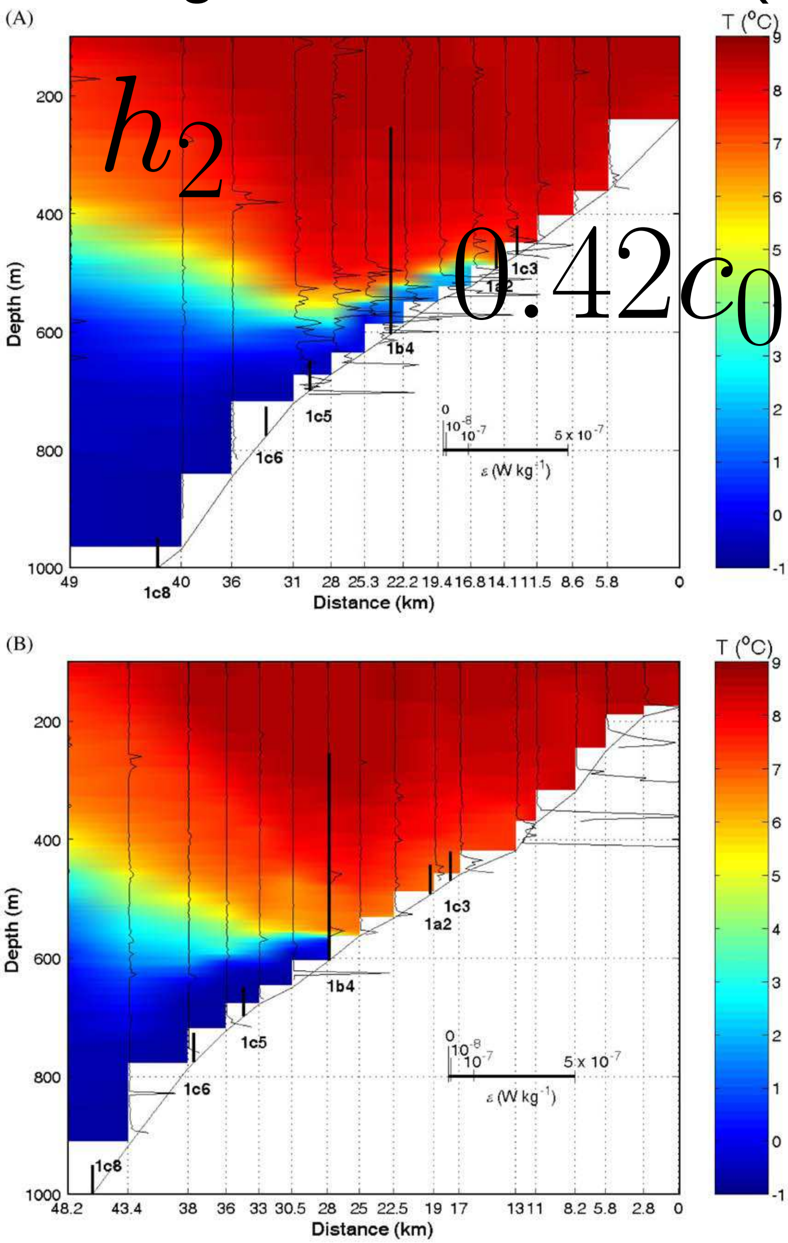
- vertical excursions of wavy pycnocline 10–19 m

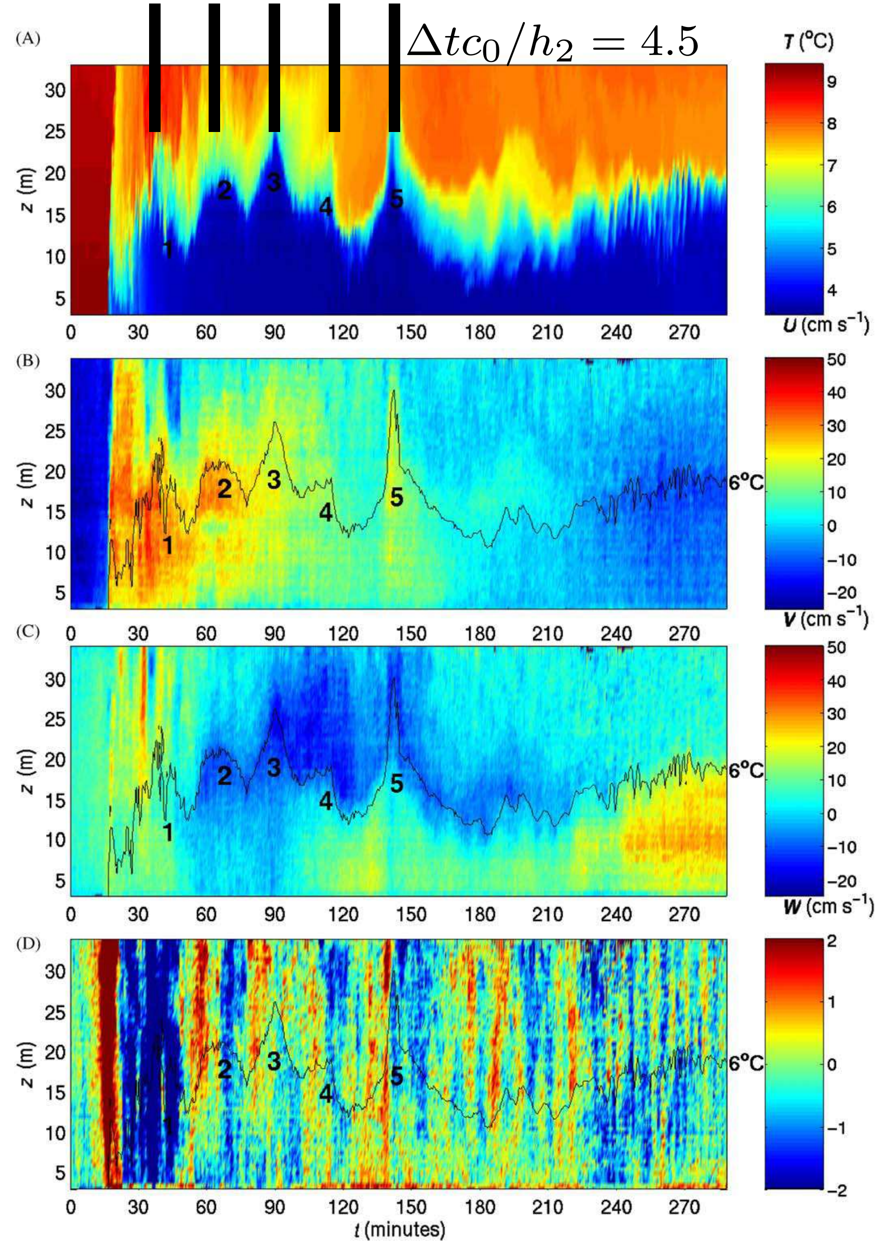
- period $\Delta t = 27$ min

- $\Delta t c_0/h_2 \simeq 4.5$, nondimensional period

- phase speed of bolus: 0.24 m s^{-1} $= 0.19c_0$

Internal run-up (solibores) in Faeroe-Shetland Channel Hosegood & van Haren (2004)





Internal run-up and wavy bore

Some studies on internal run-up

Cacchione and Southard (1974)

Kao, Pan and Renouard (1985)

Wallace and Wilkinson (1988)

Helfrich (1992)

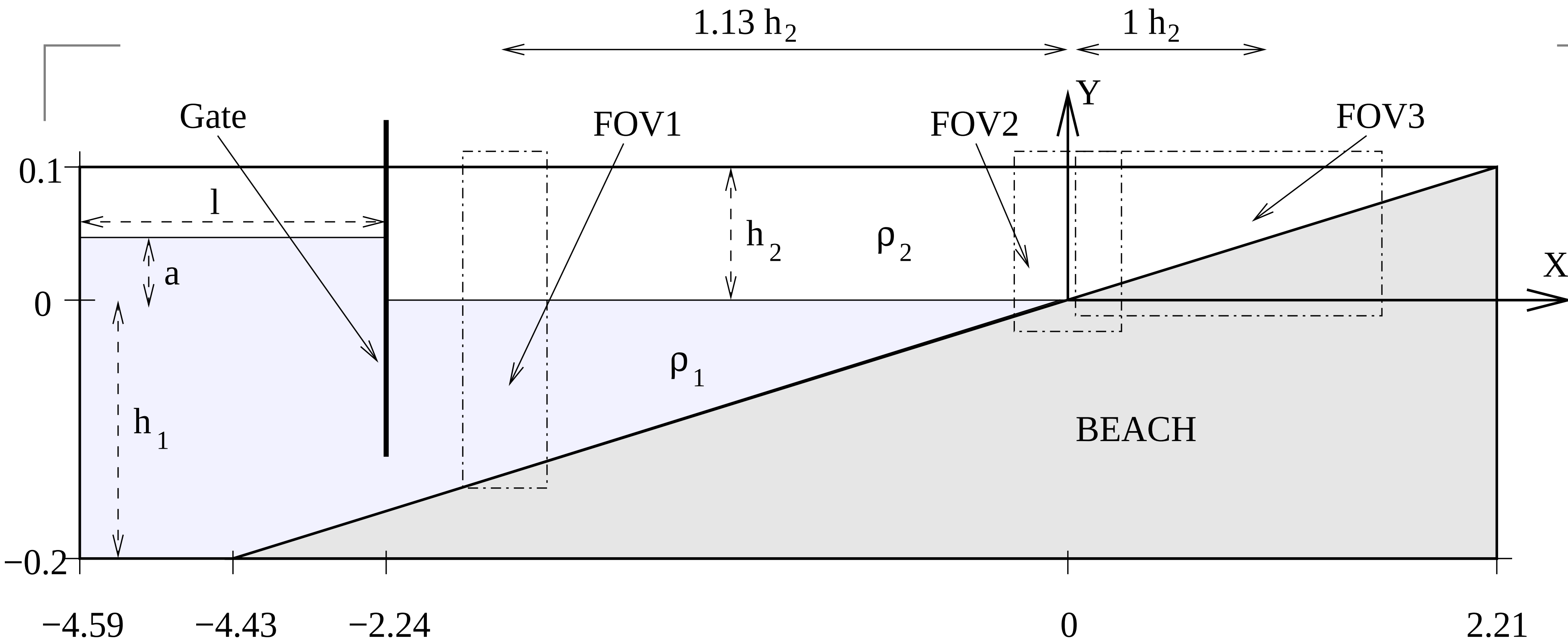
Michallet and Ivey (1999)

Sveen, Guo, Davies and Grue (2002)

Klymak and Moum (2003)

Hosegood and van Haren (2004)

Study internal run-up experimentally



- short $5h_2$ and long $21.9h_2$ initial elevation/depression
- $a = \pm 0.5h_2$
- small slope s=0.3/6.8=0.044
- FOV1, FOV2, FOV3
- scale 1:5000

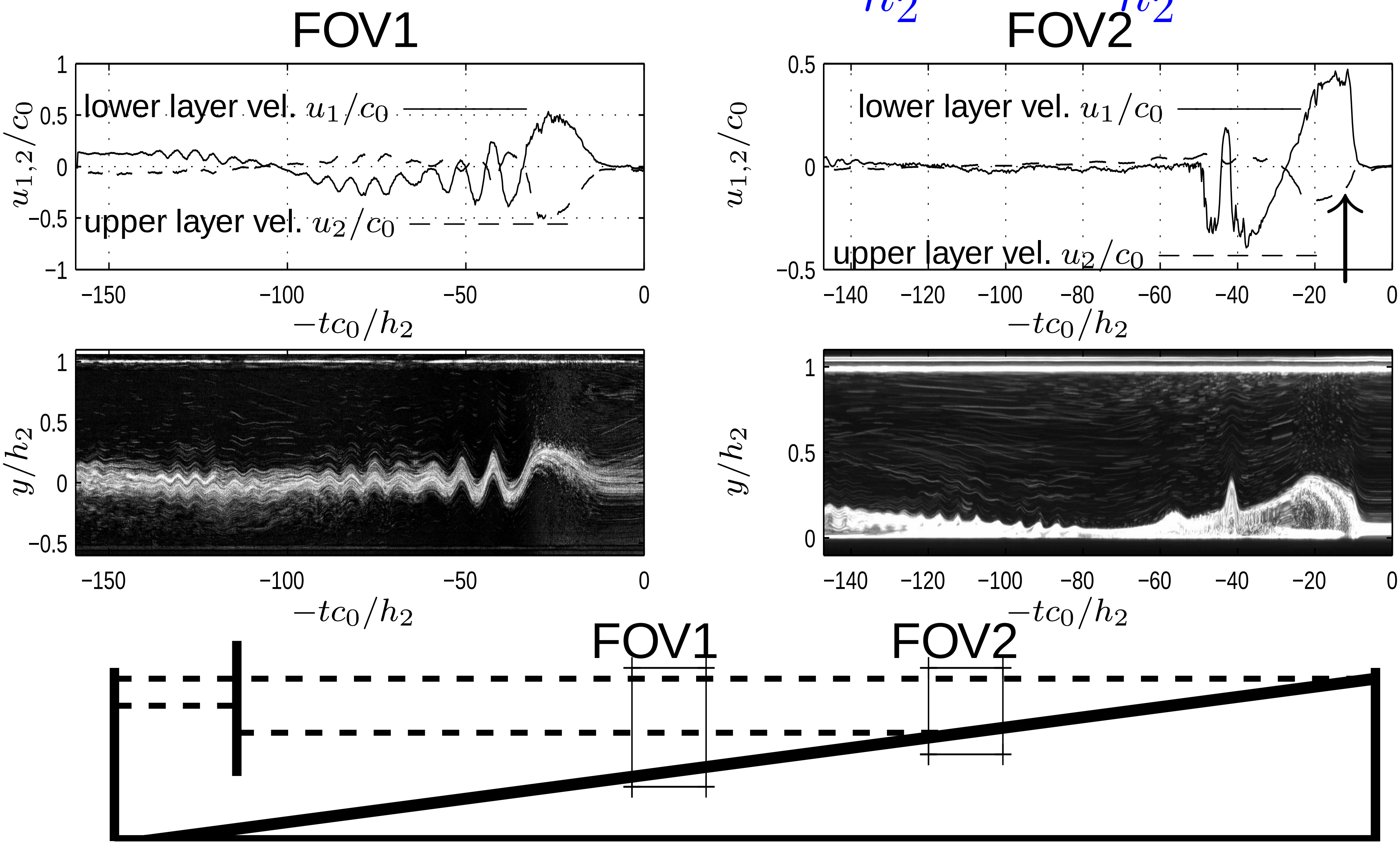
Focus

1. quantify internal wave induced velocities

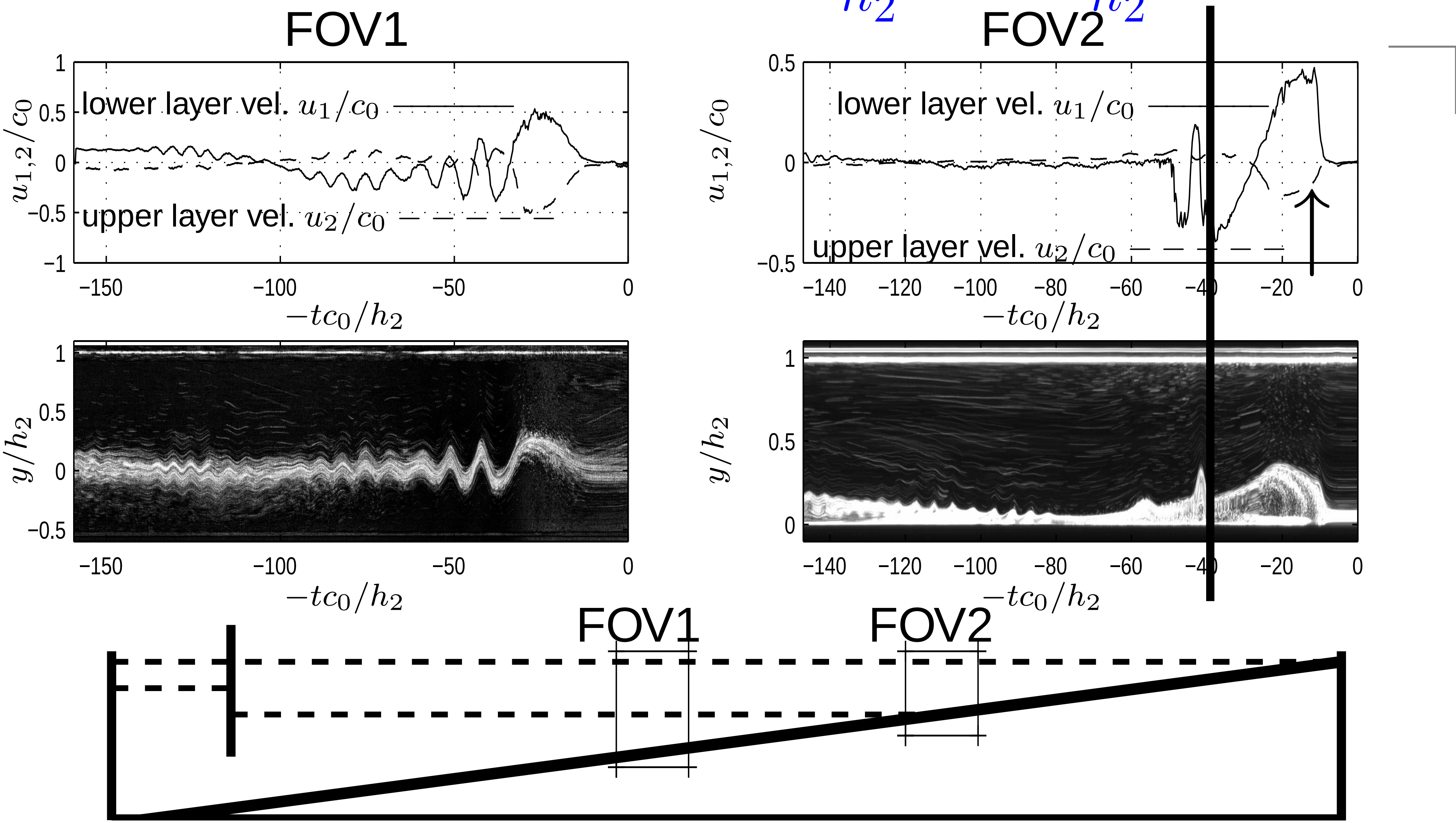
2. duration of onshore/offshore flow

3. internal run-up/gravity currents/boluses

Short ini. elevation, $\frac{l}{h_2} = 5$, $\frac{a}{h_2} = 0.5$



Short ini. elevation, $\frac{l}{h_2} = 5$, $\frac{a}{h_2} = 0.5$



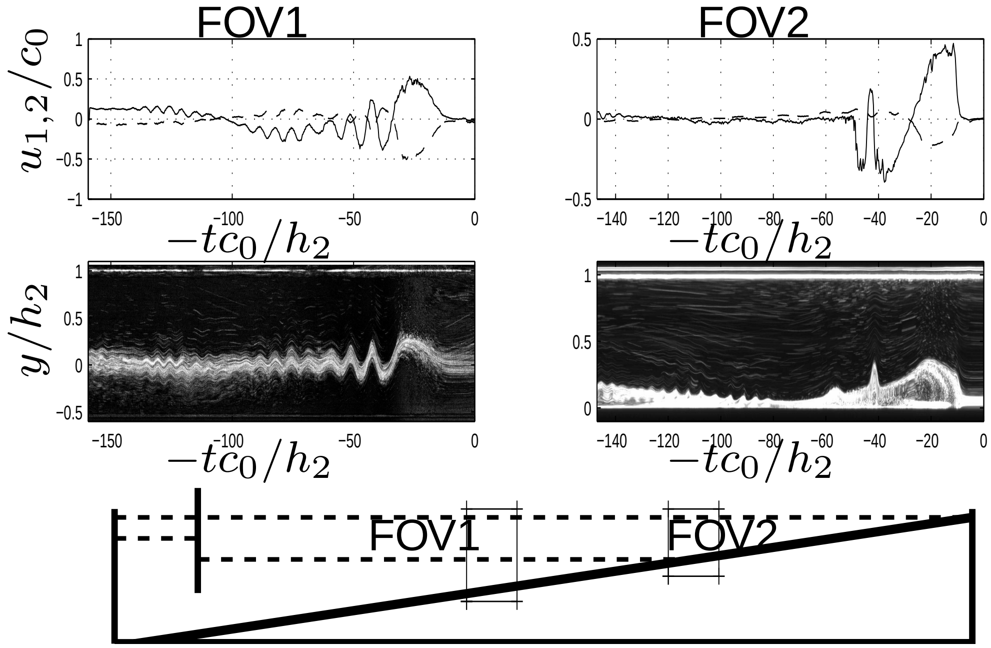
Observations, short initial elevation

- FOV1: leading elevation

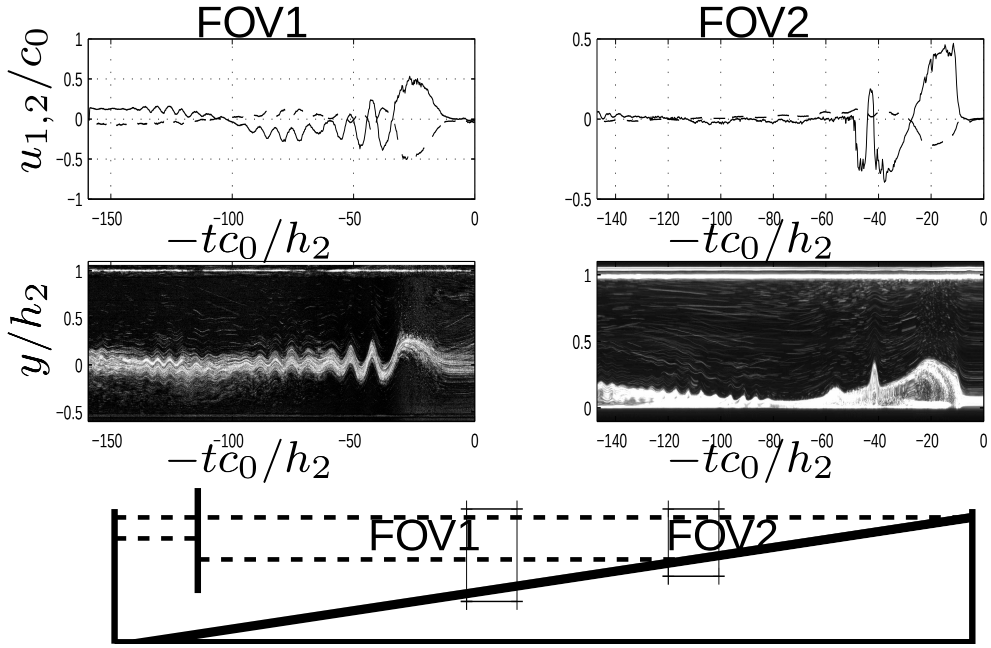
- dispersive wave train

- $u_{1,2}/c_0$ up to ± 0.5

- $\Delta t c_0 / h_2 = 20$



Observations, short initial elevation



- FOV1: leading elevation

- dispersive wave train

- $u_{1,2}/c_0$ up to ± 0.5

- $\Delta t c_0/h_2 = 20$

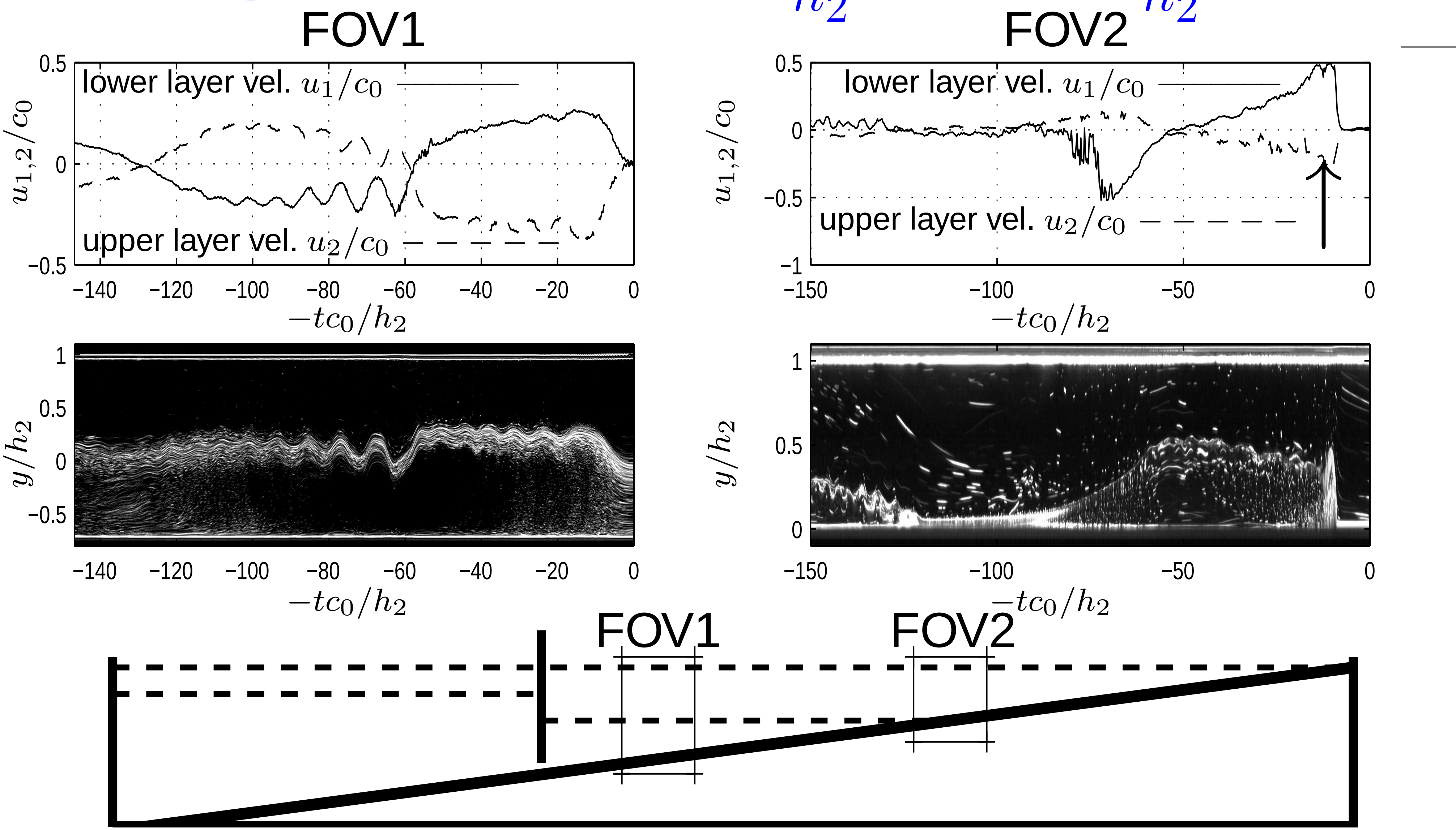
- FOV2: (intersection) leading elevation

- duration of event: $\Delta t c_0/h_2 = 20$

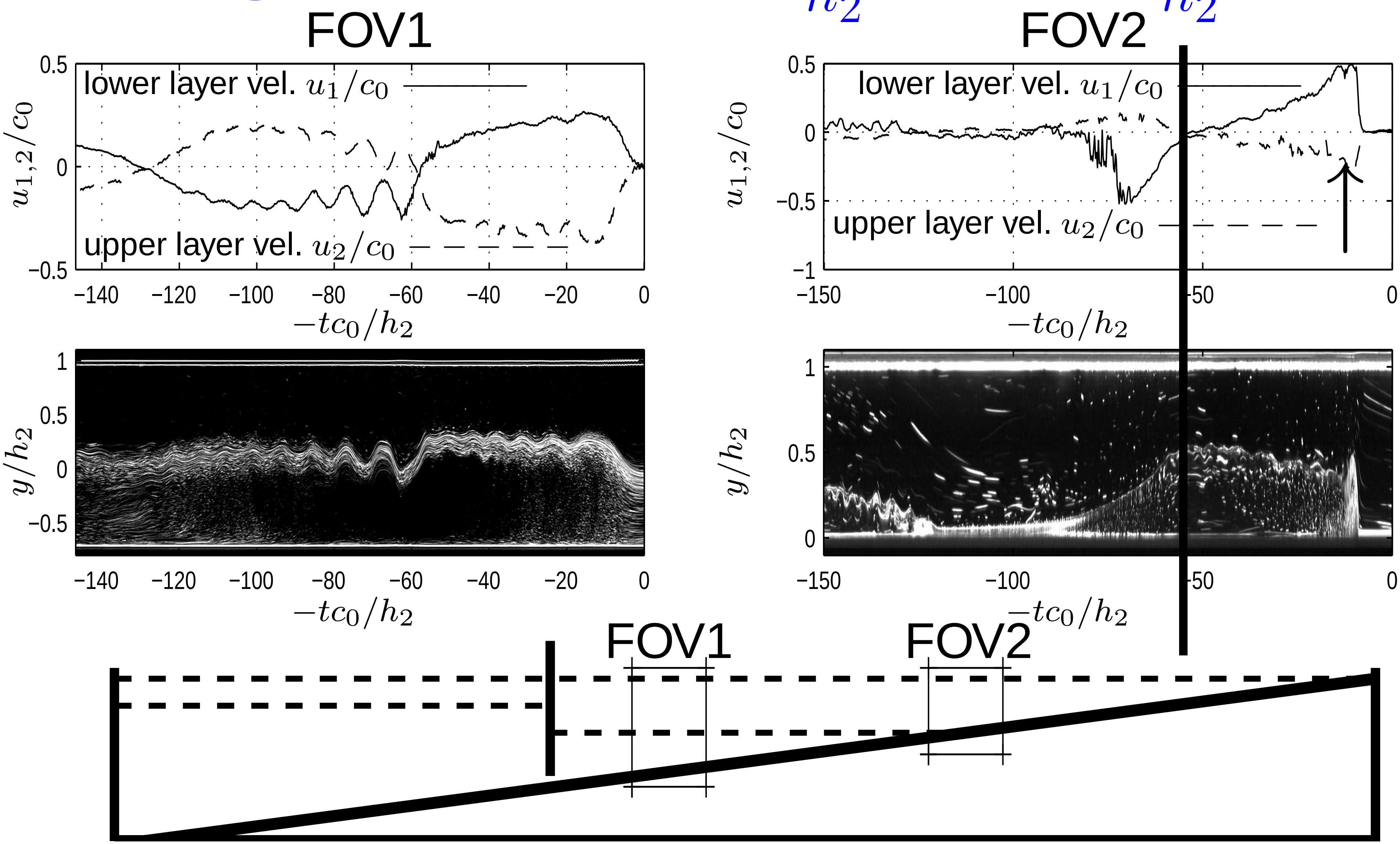
- u_1/c_0 up to 0.45 and down to -0.35 (lower layer)

- a bolus forms behind the bore; $\Delta t c_0/h_2 = 4.5$; about the same duration as measured by Hosegood & van Haren

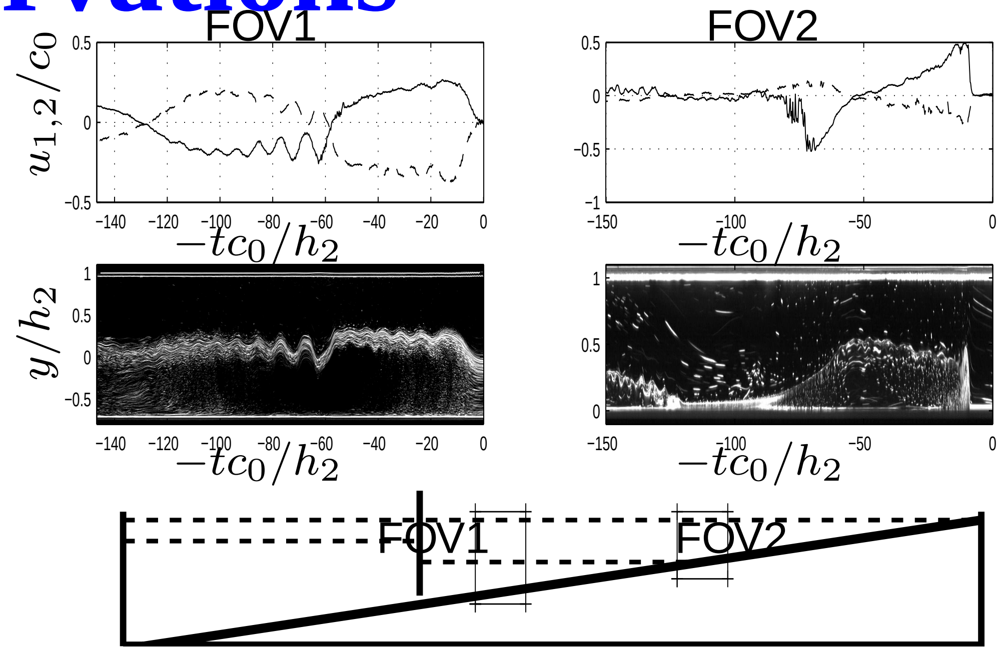
Long ini. elevation, $\frac{l}{h_2} = 21.9$, $\frac{a}{h_2} = 0.5$



Long ini. elevation, $\frac{l}{h_2} = 21.9$, $\frac{a}{h_2} = 0.5$



Observations



- FOV1: leading undular bore

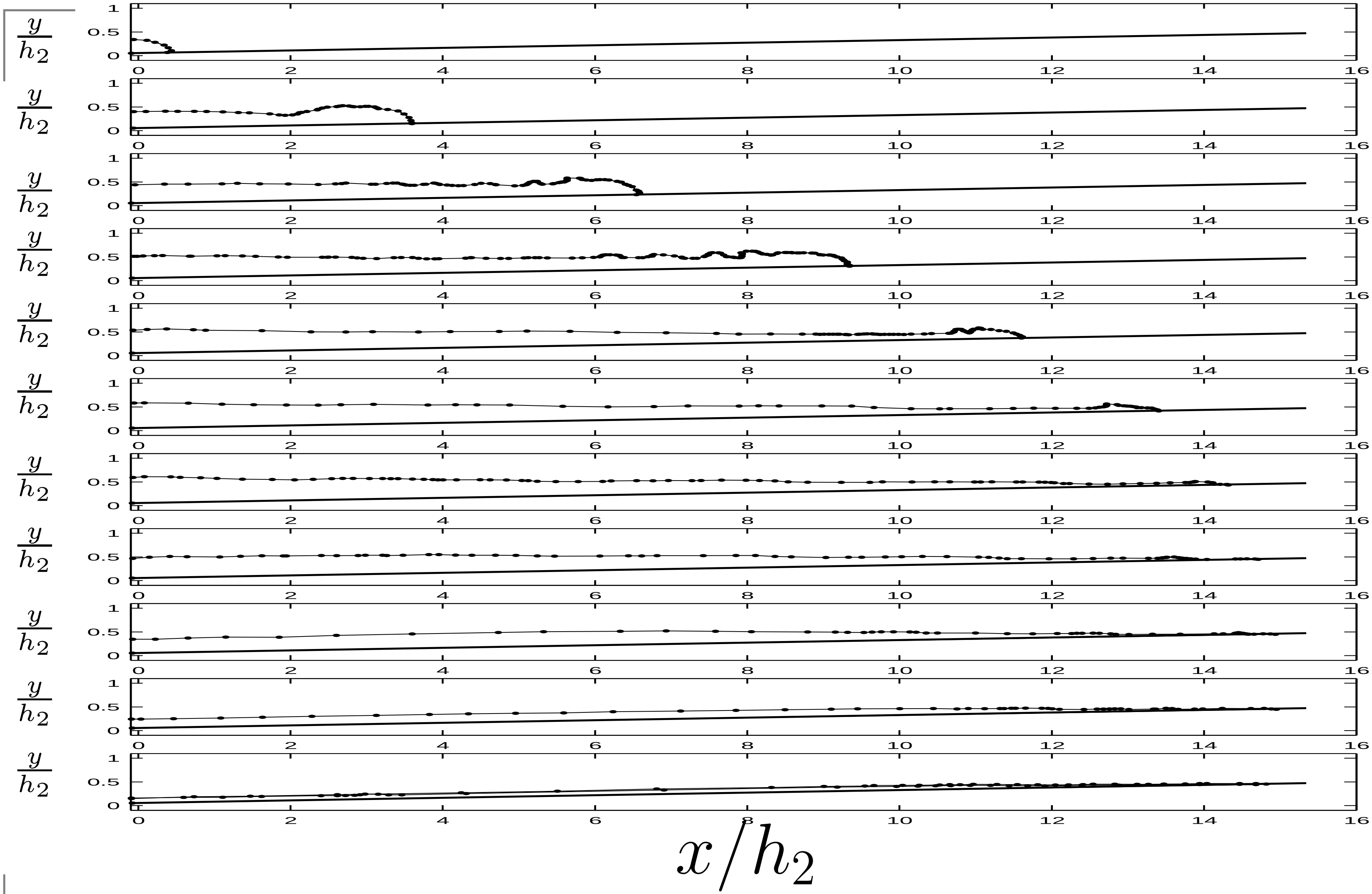
- duration of bore $\Delta t c_0/h_2 \sim 60$

- for the bore: u_1/c_0 up to 0.25, u_2/c_0 down to -0.4

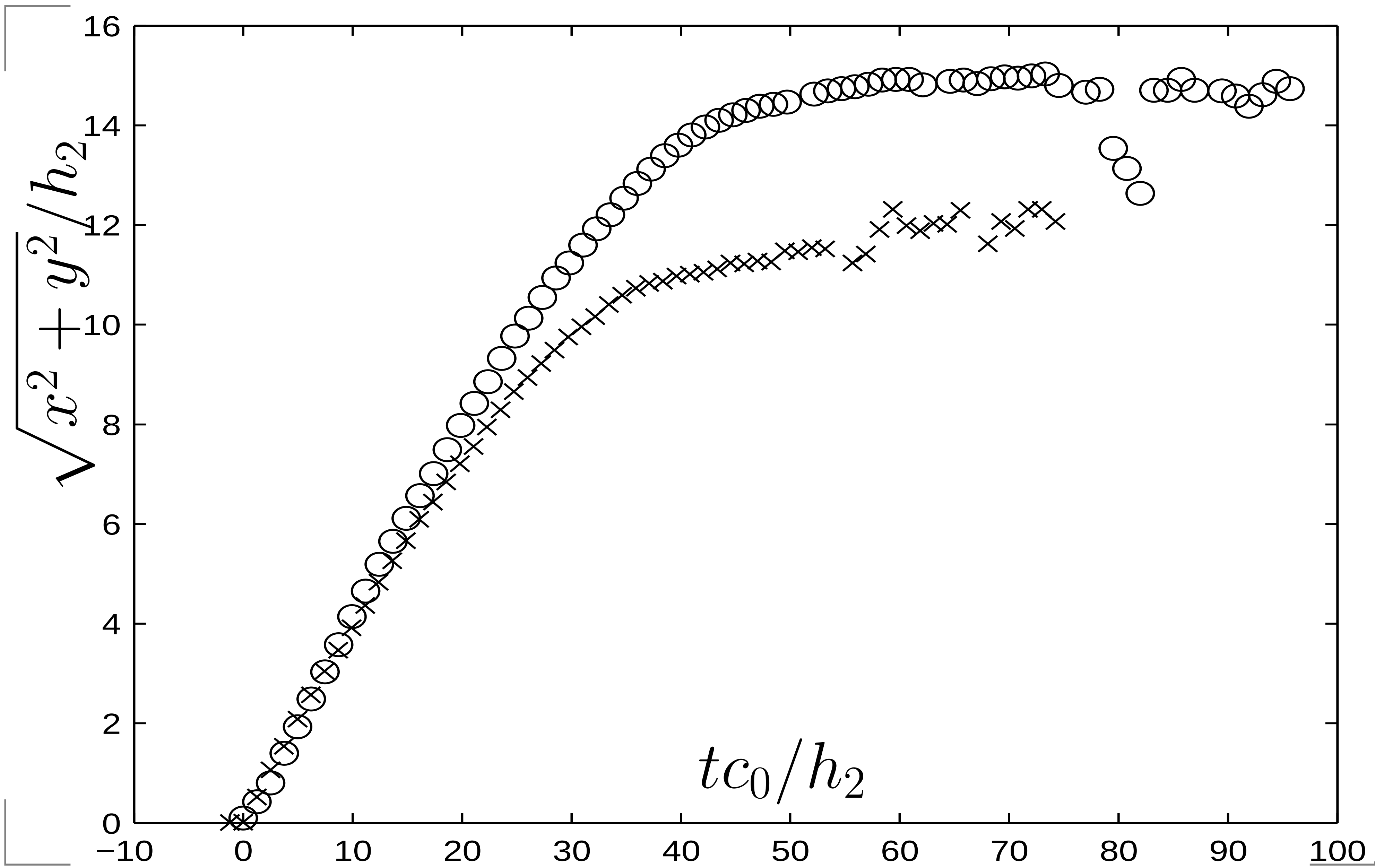
- FOV2: onshore flow of dense water; velocity u_1/c_0 of leading front slightly less than 0.5

- duration of onshore flow $\Delta t c_0/h_2 = 40$

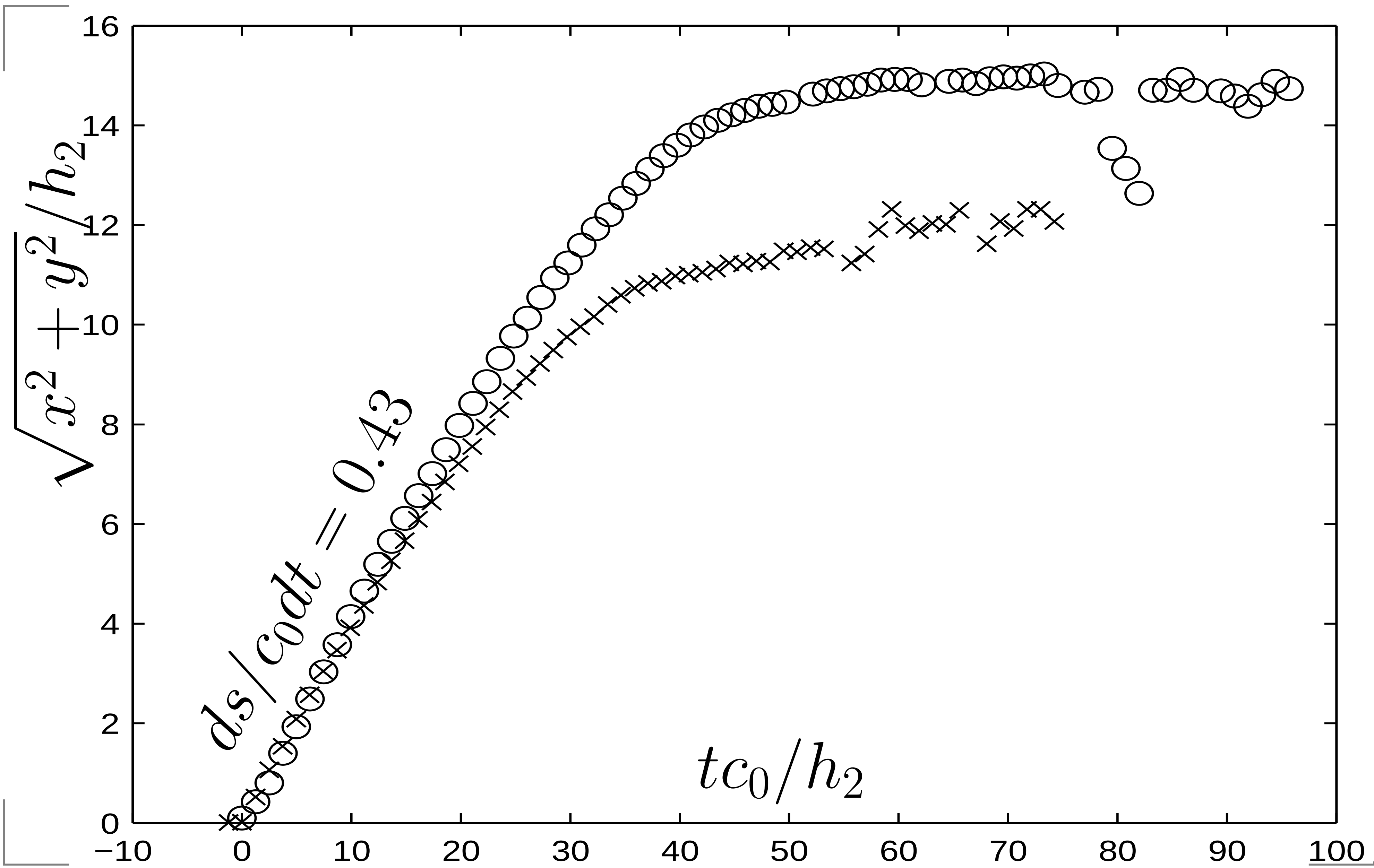
Run-up, long initial elevation, $\Delta t c_0/h_2 = 7.8$



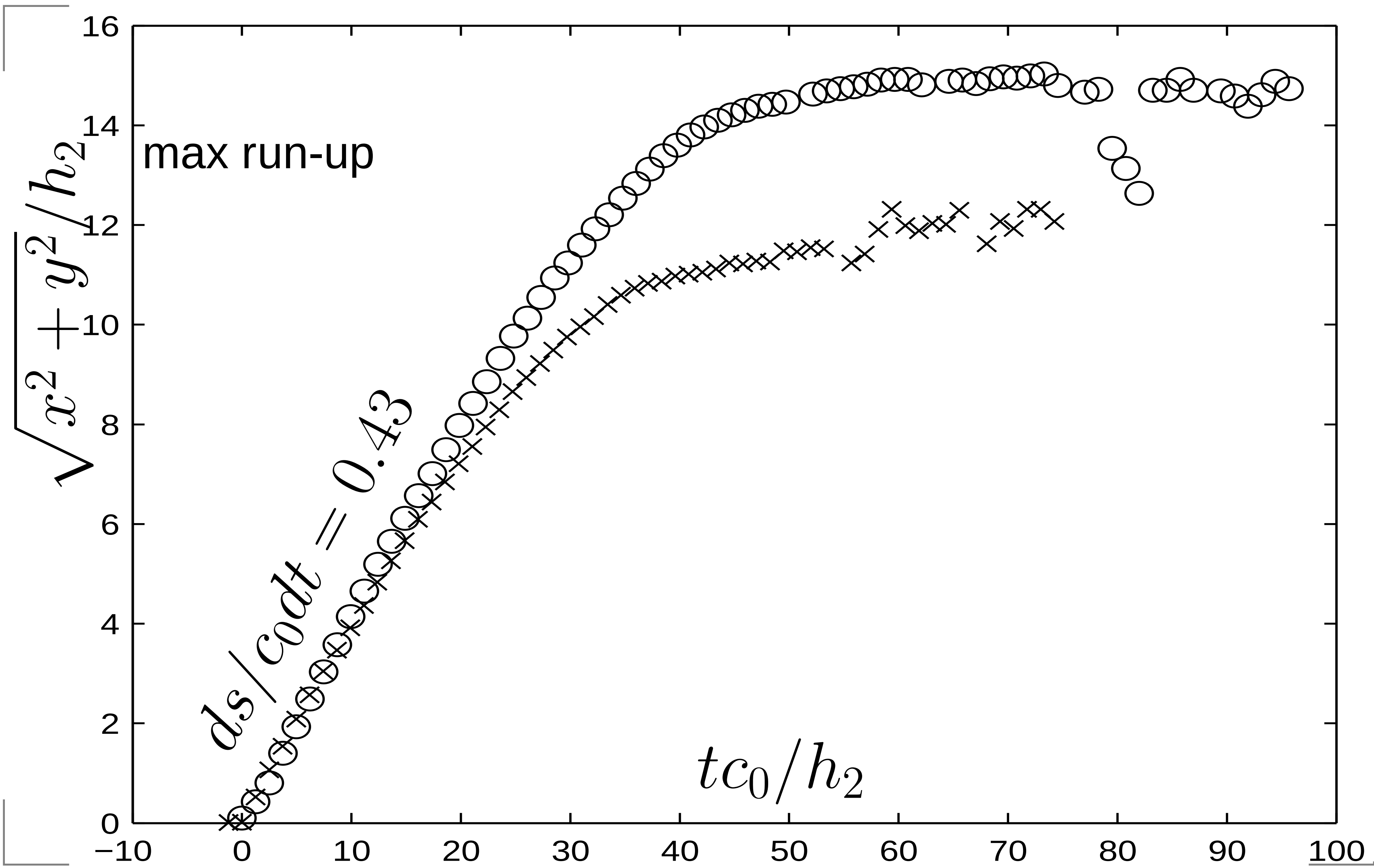
Position of front; $l/h_2 = 21.9$ ($\circ$), $l/h_2 = 5$ (x)



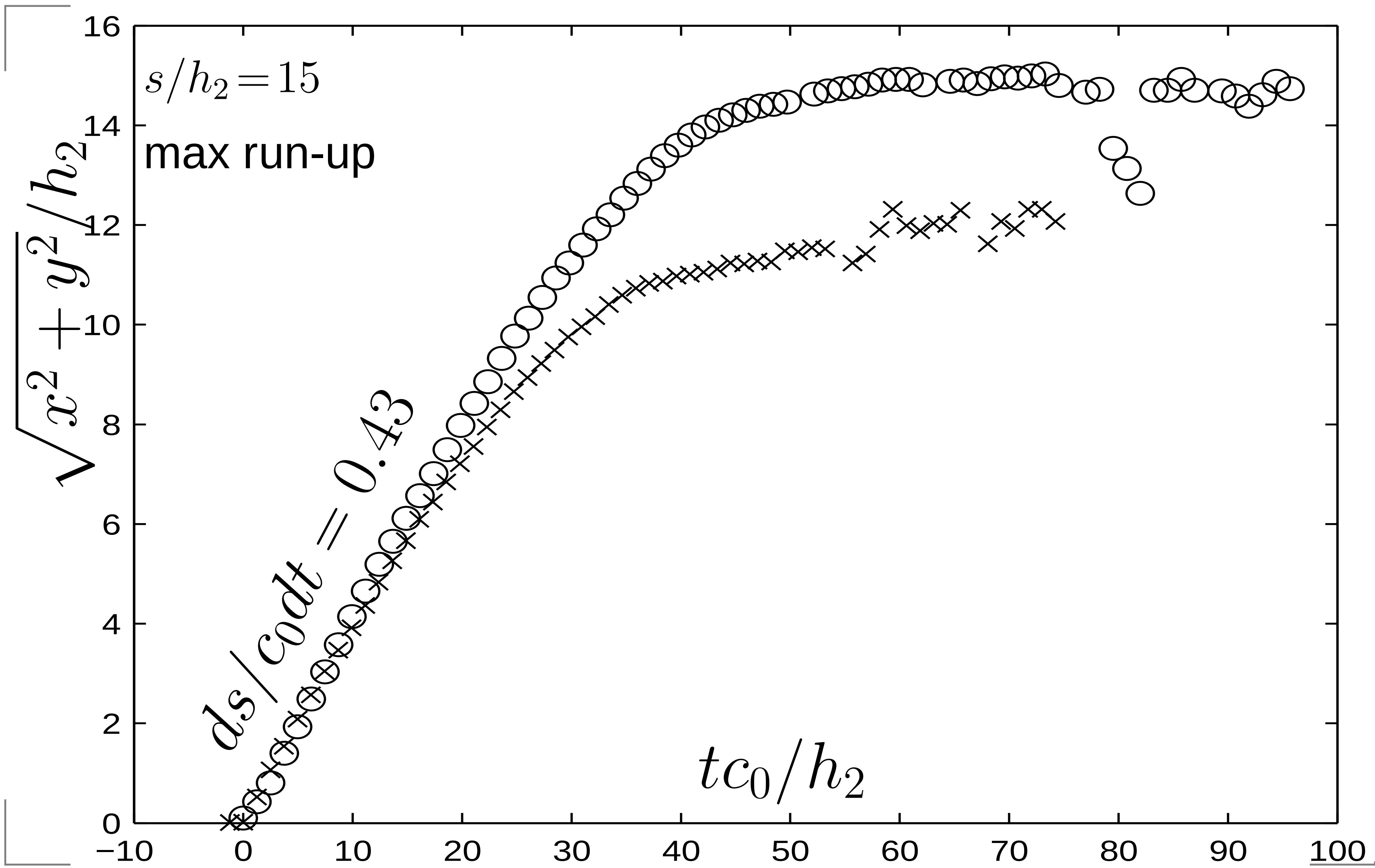
Position of front; $l/h_2 = 21.9$ (○), $l/h_2 = 5$ (x)



Position of front; $l/h_2 = 21.9$ (○), $l/h_2 = 5$ (x)



Position of front; $l/h_2 = 21.9$ **(○),** $l/h_2 = 5$ **(**x**)**



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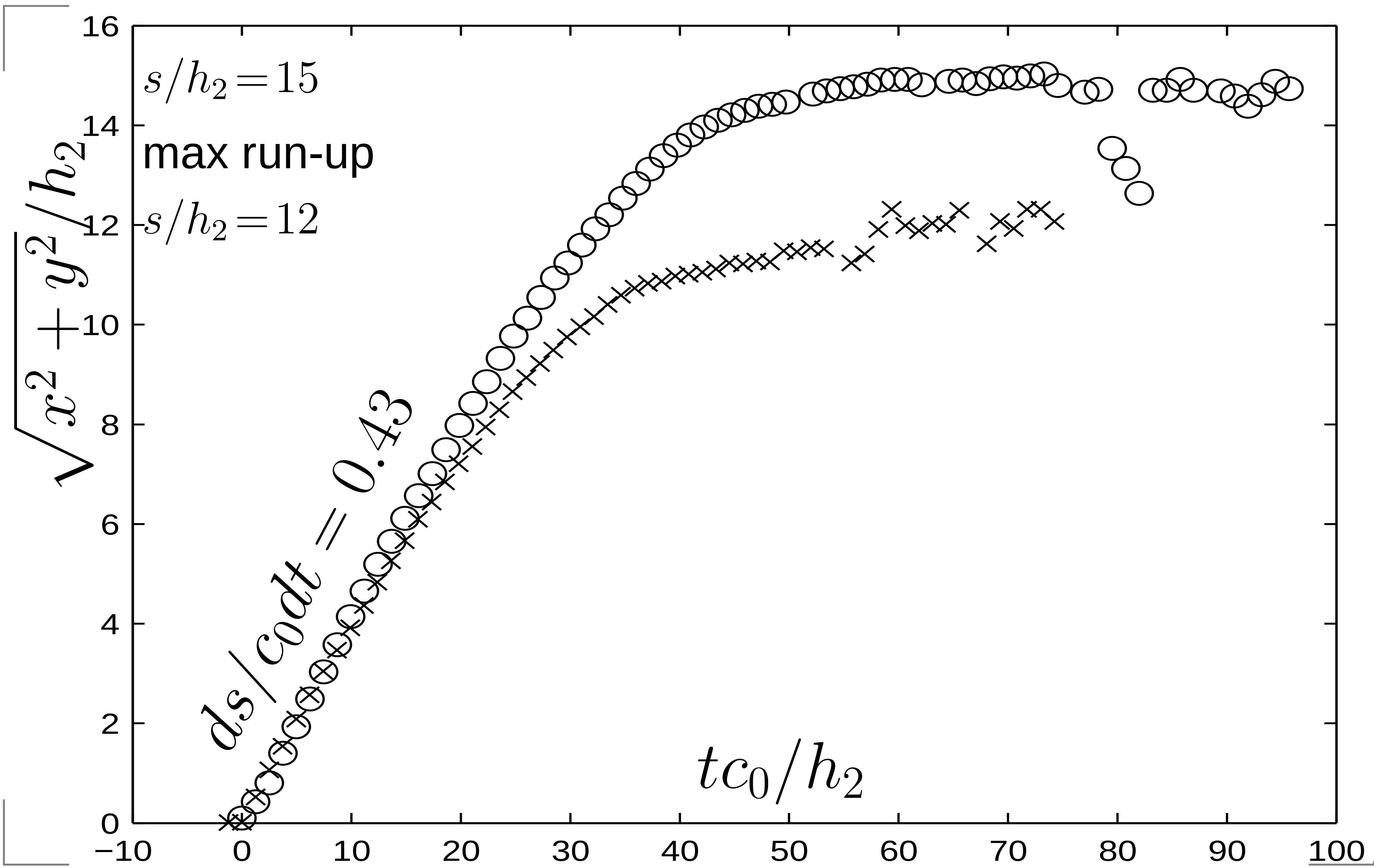
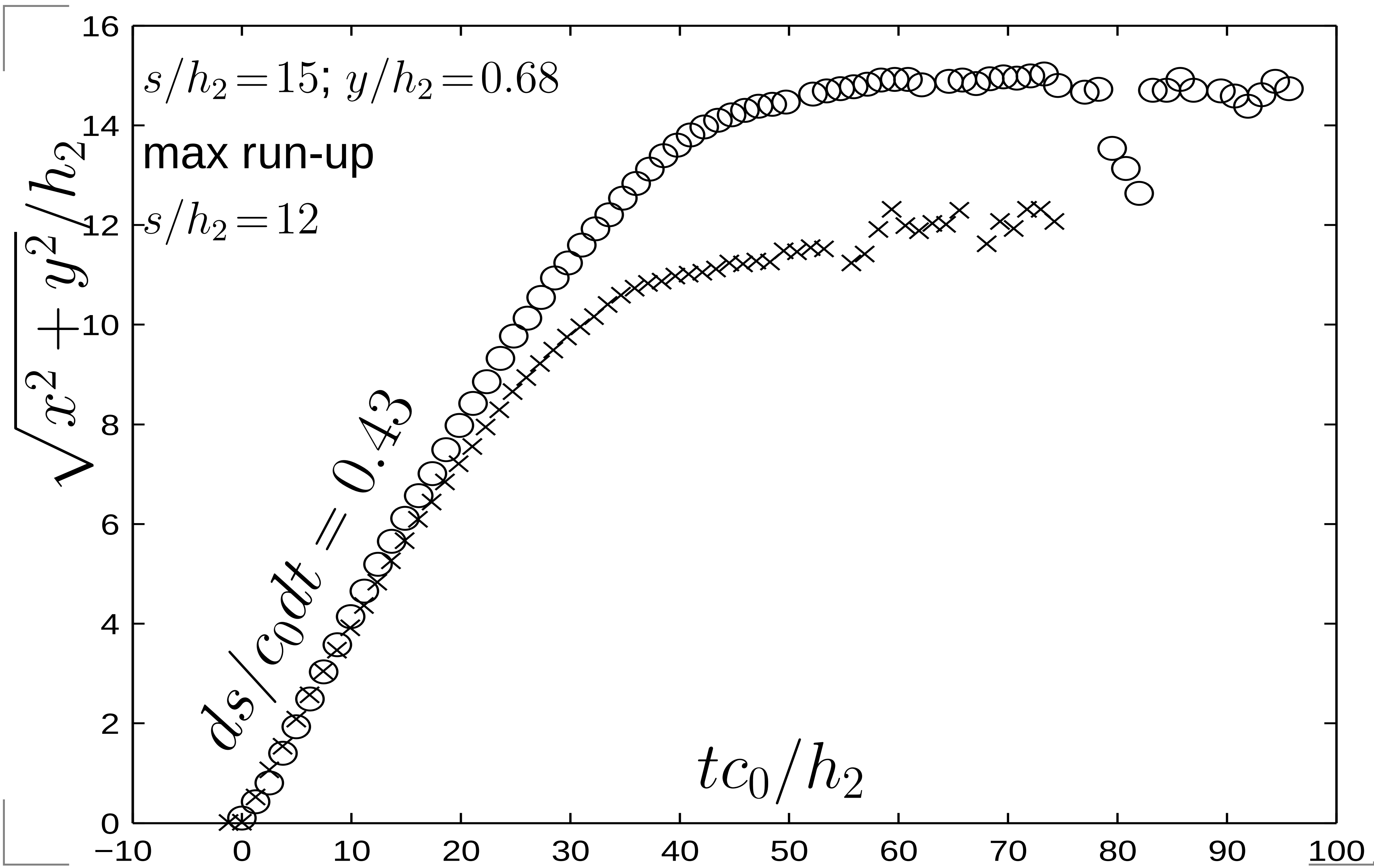
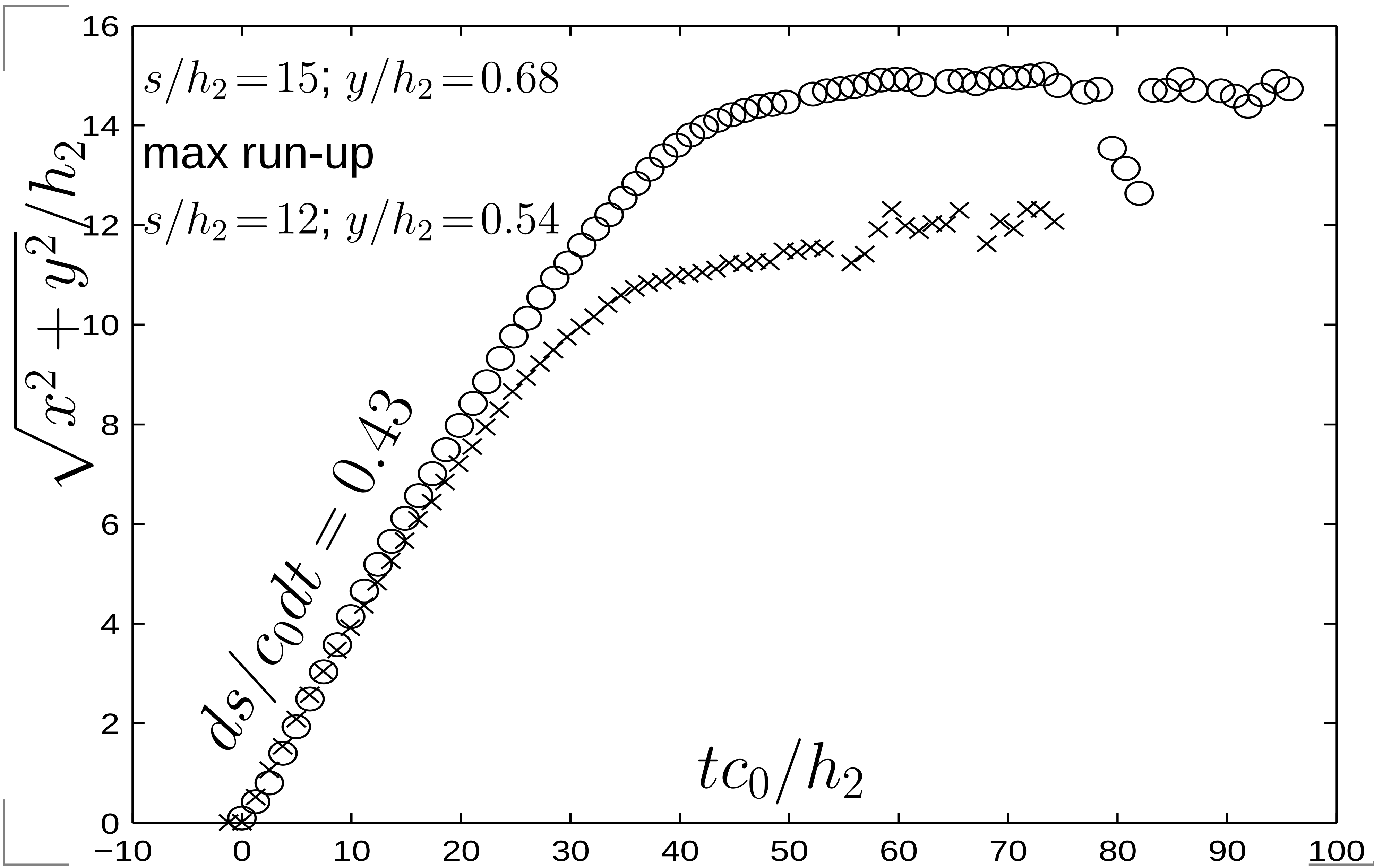


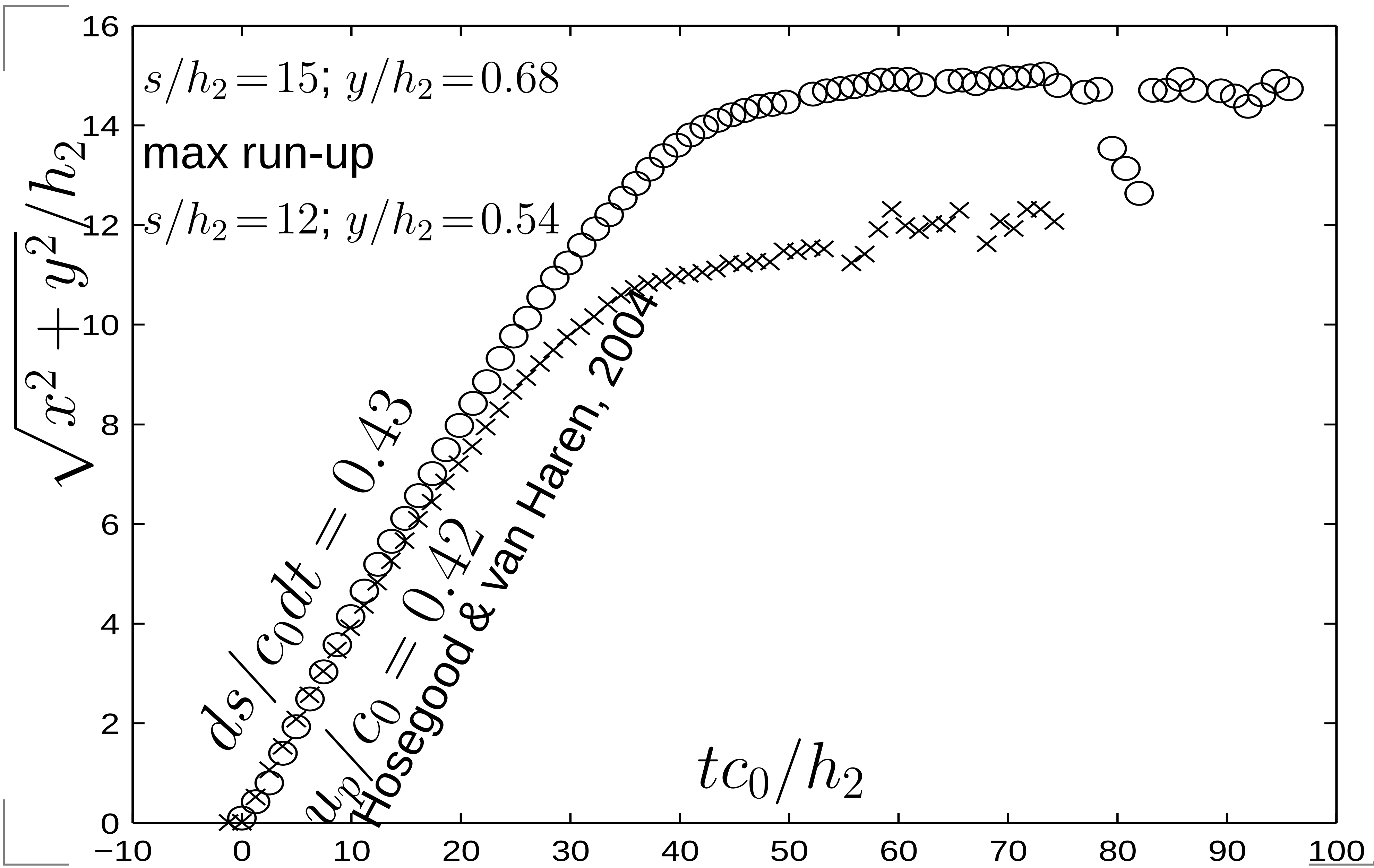
Position of front; $l/h_2 = 21.9$ (○), $l/h_2 = 5$ (x)



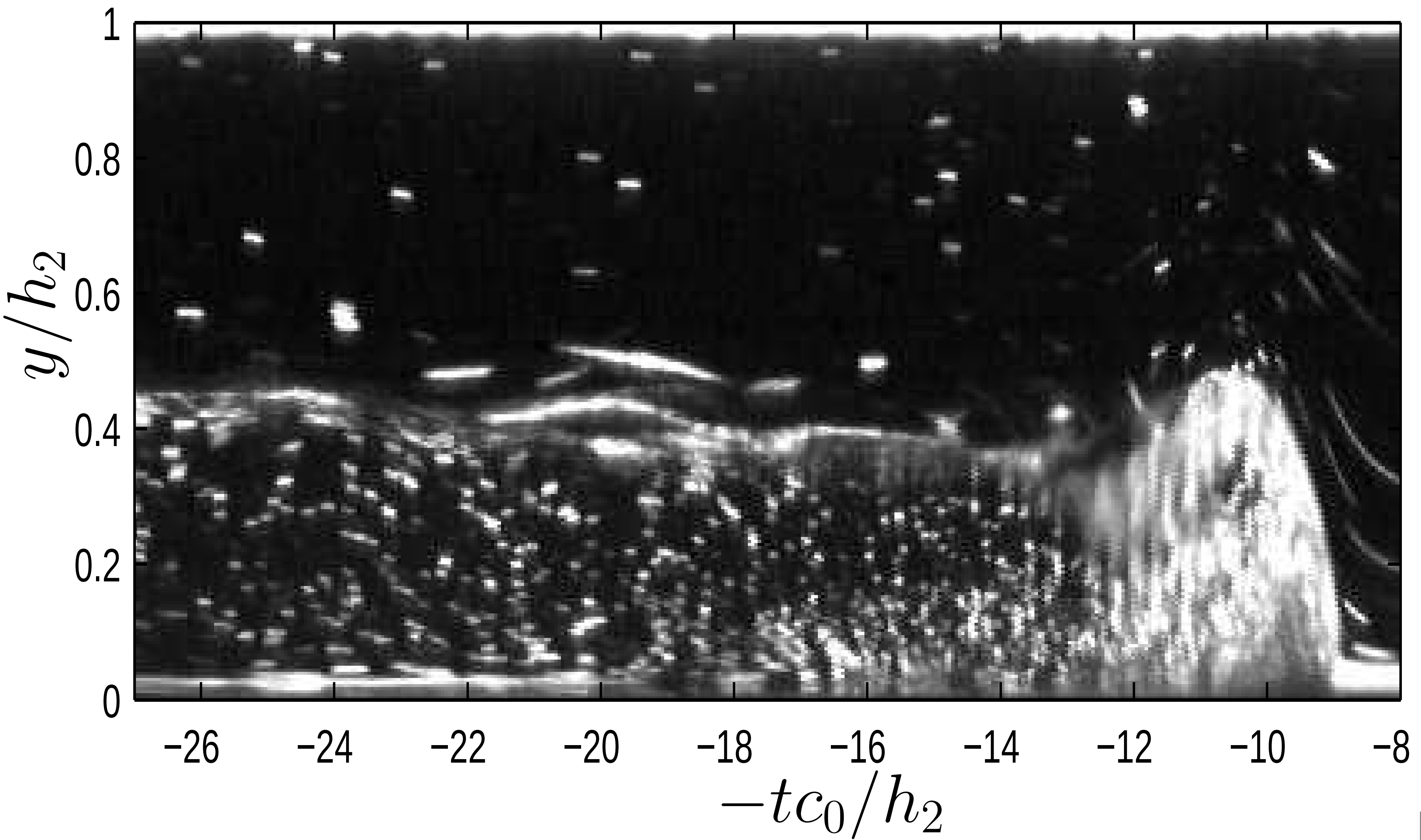
Position of front; $l/h_2 = 21.9$ (○), $l/h_2 = 5$ (x)



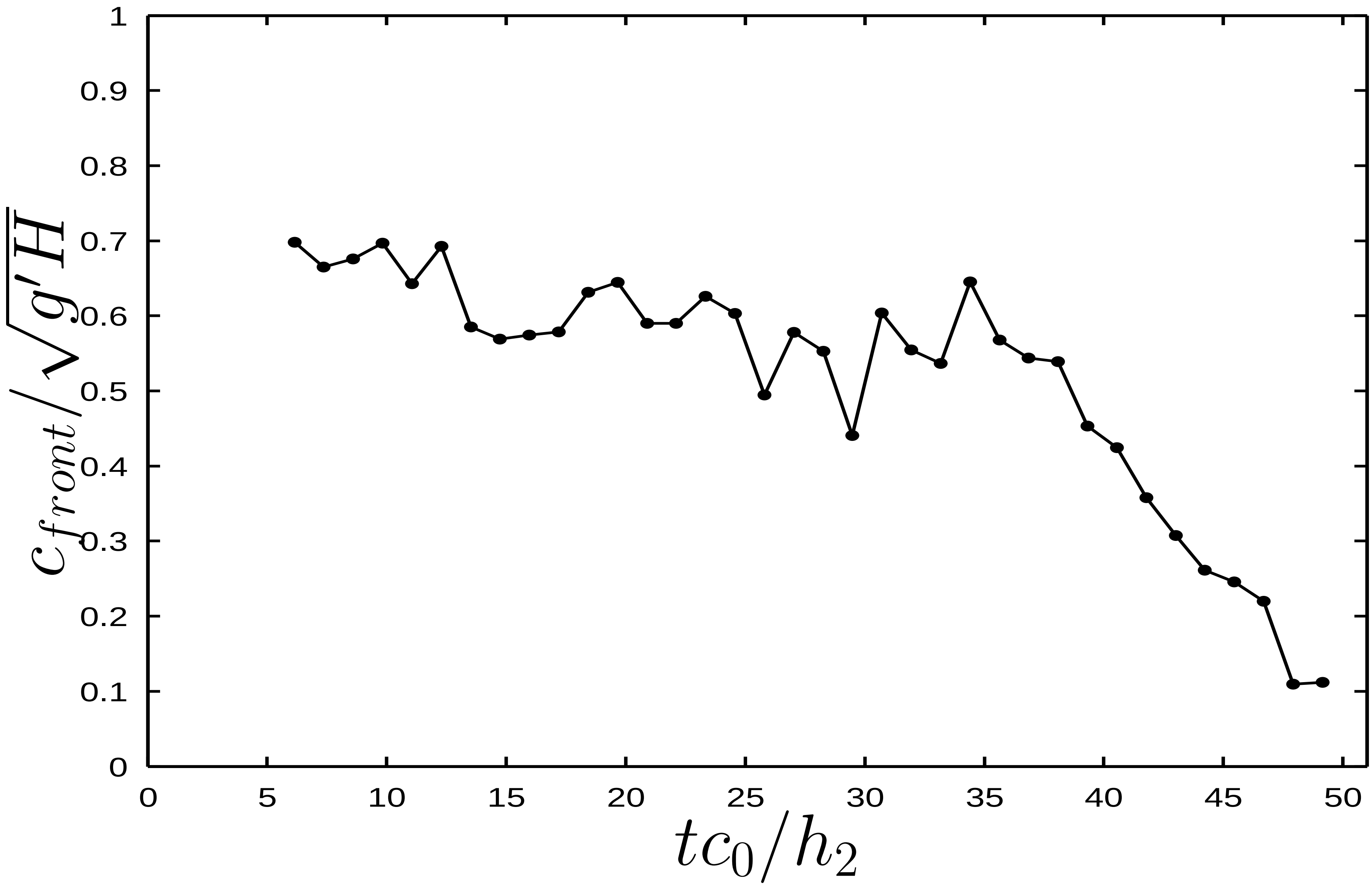
Position of front; $l/h_2 = 21.9$ (○), $l/h_2 = 5$ (x)



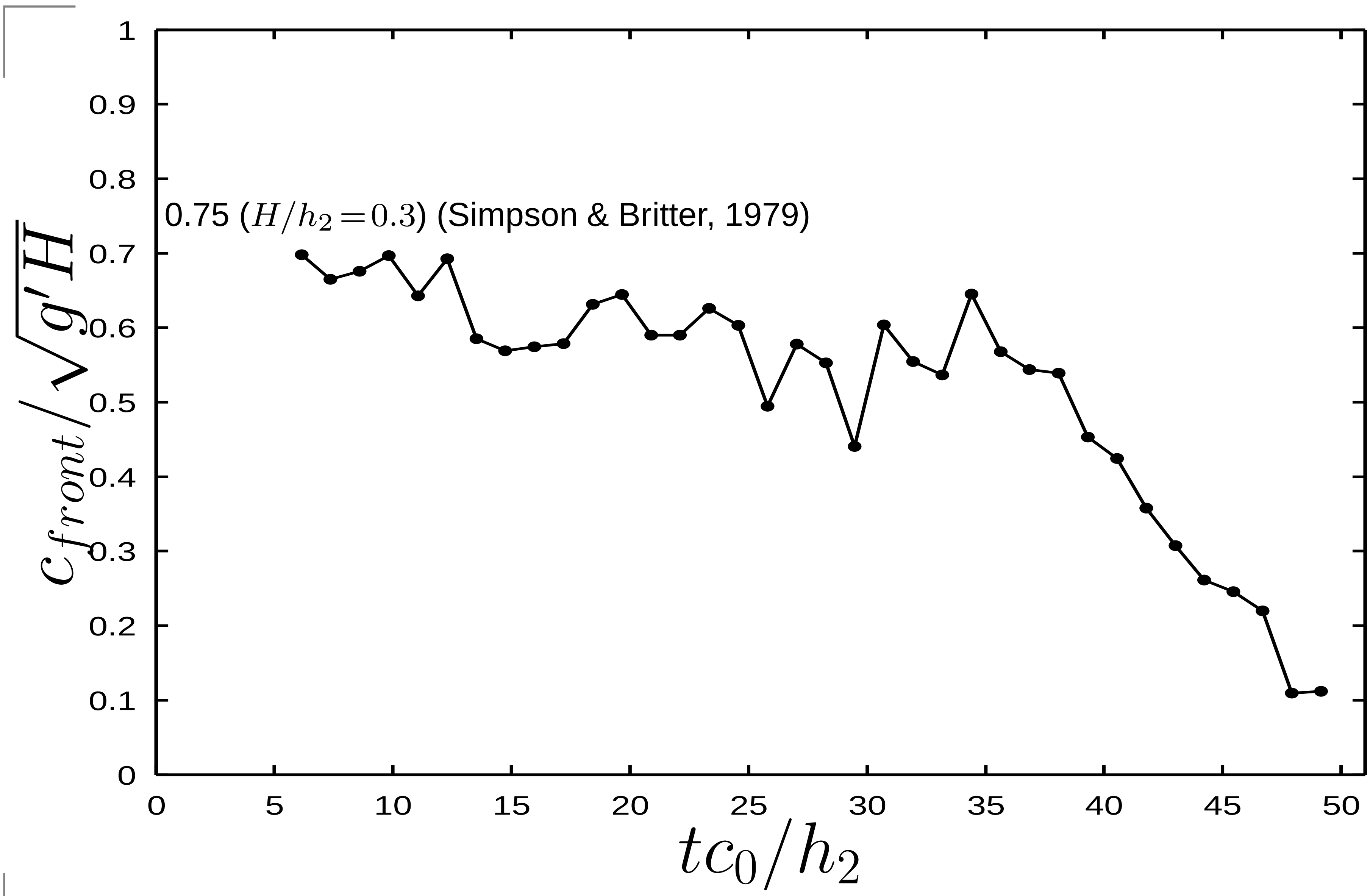
FOV2; gravity current



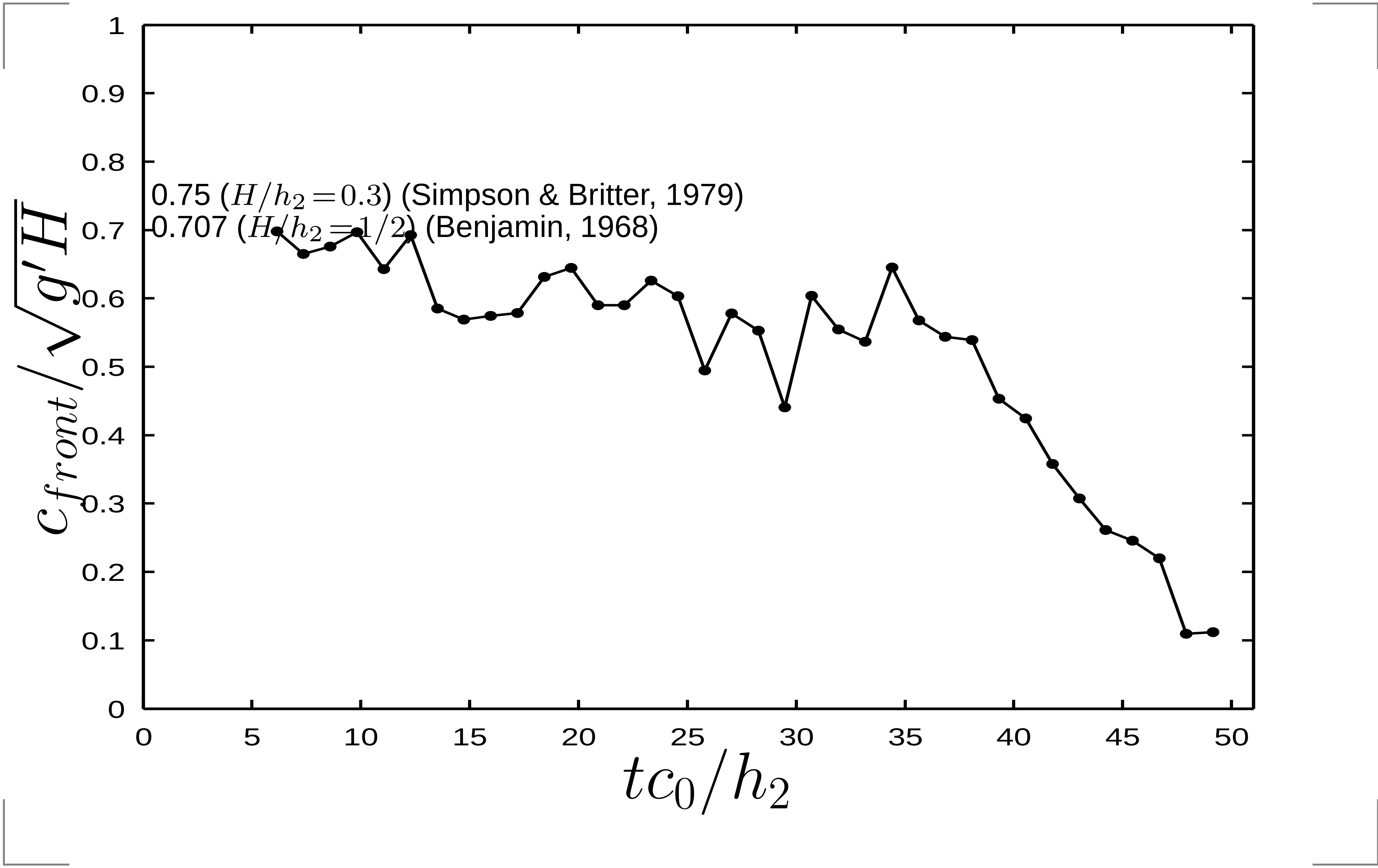
Gravity current; plot of $c_{front}/\sqrt{g'H}$; H thickness of tail



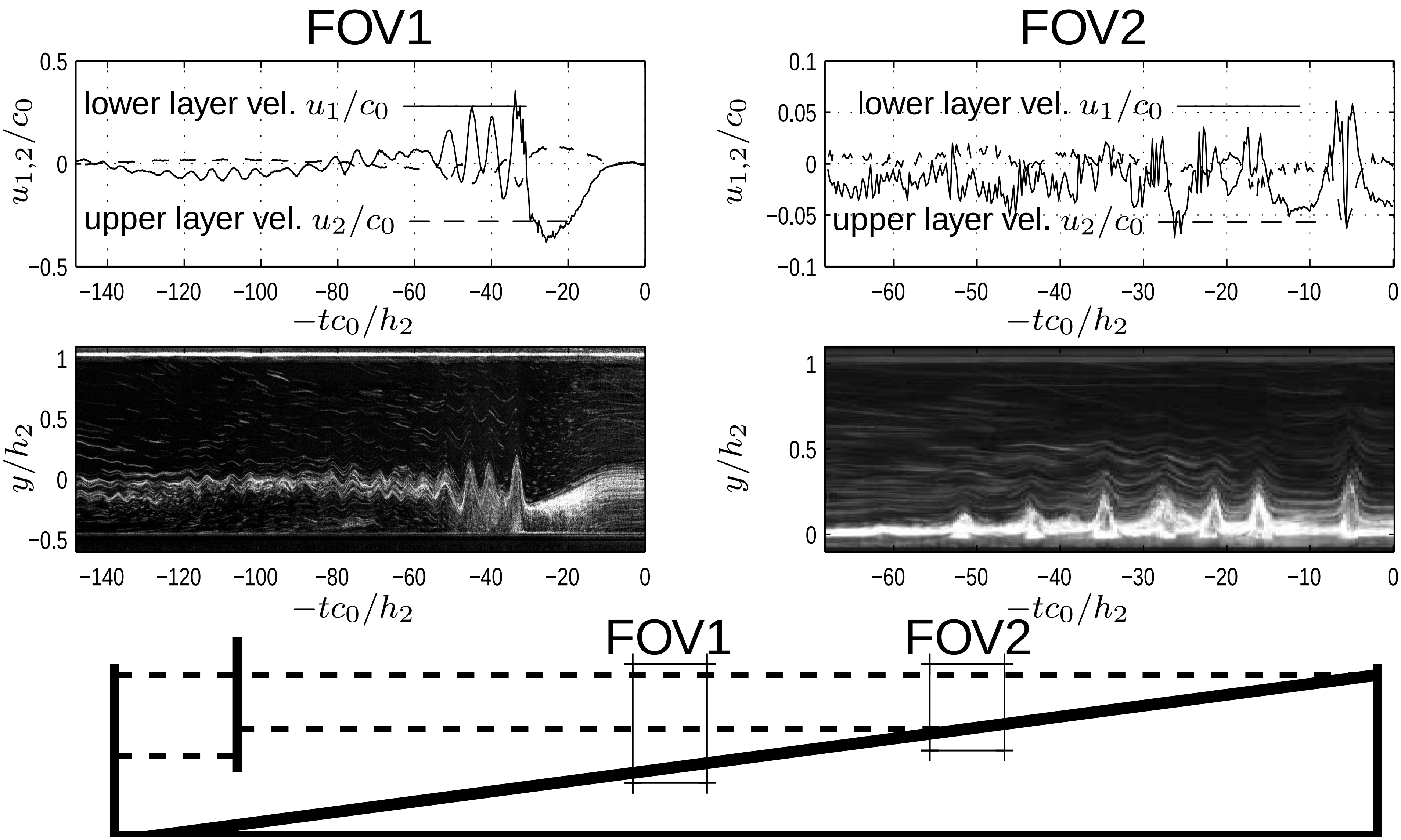
Gravity current; plot of $c_{front}/\sqrt{g'H}$; H thickness of tail



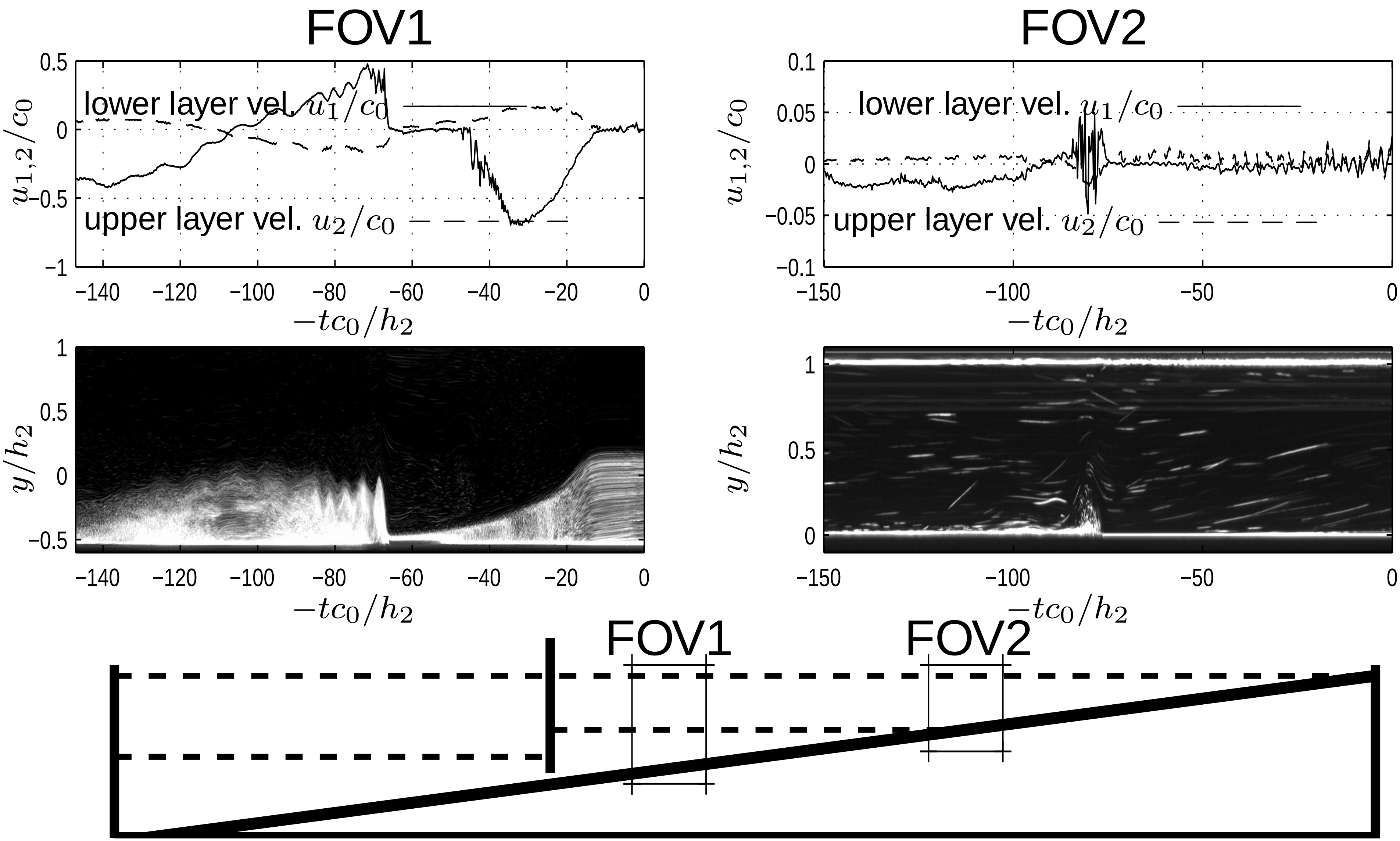
Gravity current; plot of $c_{front}/\sqrt{g'H}$; H thickness of tail



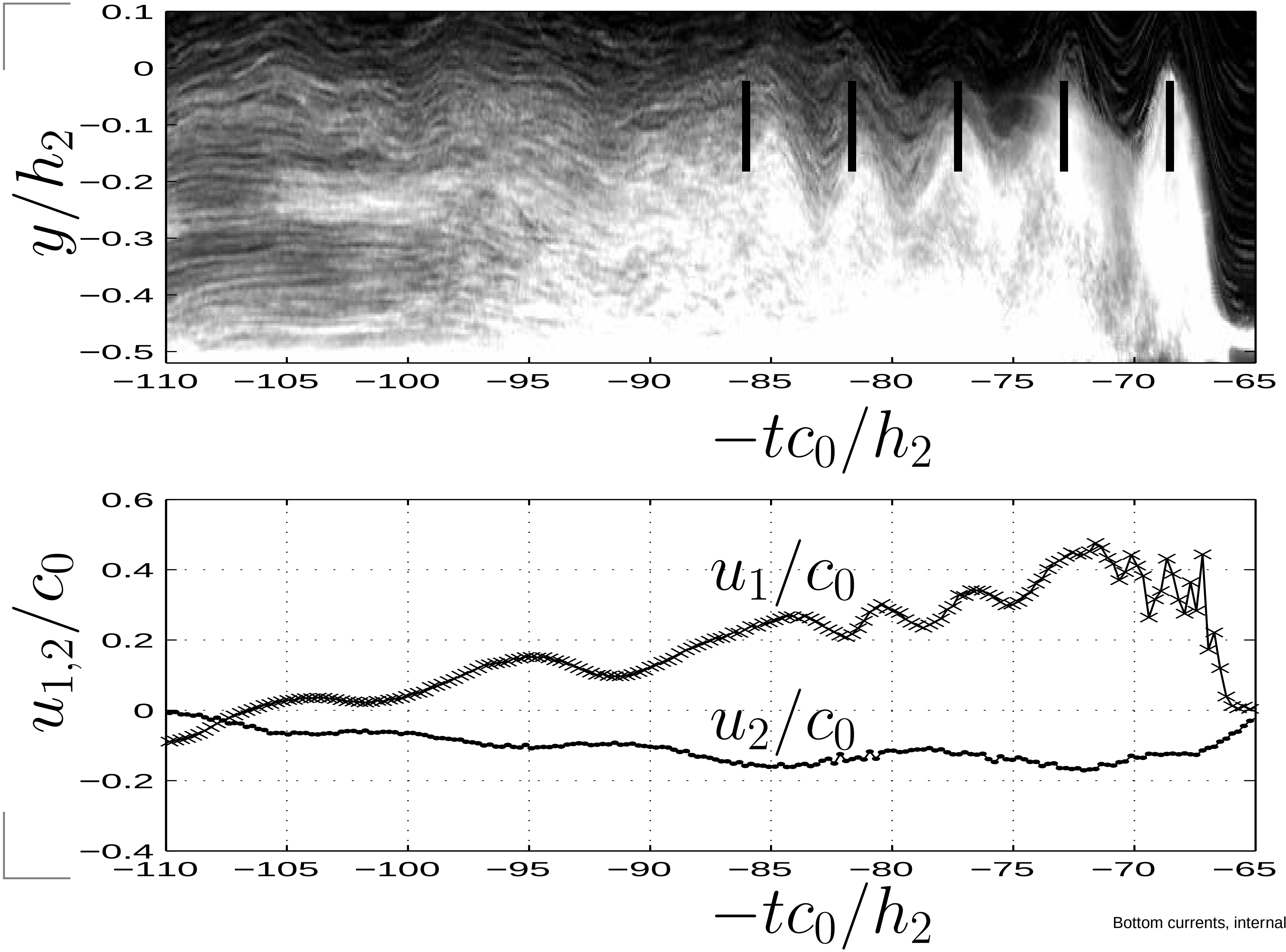
Short initial depression, $l/h_2 = 5$, $a/h_2 = -0.5$



Long initial depression, $l/h_2 = 21.9$, $a/h_2 = -0.5$



Long initial depression, leading waves



Onshore flow duration.

$\Delta t c_0/h_2 = 20$ for $l/h_2 = 5$ (short ini. elevation)

$\Delta t c_0/h_2 = 40$ for $l/h_2 = 21.9$ (long ini. elevation)

$\Delta t c_0/h_2 = 212$ field observation at ORMEN LANGE

Divide by $\sqrt{l/h_2}$ (l length of initial elevat.)

$\frac{\Delta t c_0/h_2}{\sqrt{l/h_2}} = 8.9$ for $l/h_2 = 5$ (short ini. elevation)

$\frac{\Delta t c_0/h_2}{\sqrt{l/h_2}} = 8.5$ for $l/h_2 = 21.9$ (long ini. elevation)

Divide by $\sqrt{l/h_2}$ (l length of initial elevat.)

$\frac{\Delta t c_0/h_2}{\sqrt{l/h_2}} = 8.9$ for $l/h_2 = 5$ (short ini. elevation)

$\frac{\Delta t c_0/h_2}{\sqrt{l/h_2}} = 8.5$ for $l/h_2 = 21.9$ (long ini. elevation)

How long should l be at Ormen Lange in order that $\frac{\Delta t c_0/h_2}{\sqrt{l/h_2}} \sim 9$?

Divide by $\sqrt{l/h_2}$ (l length of initial elevat.)

$\frac{\Delta t c_0/h_2}{\sqrt{l/h_2}} = 8.9$ for $l/h_2 = 5$ (short ini. elevation)

$\frac{\Delta t c_0/h_2}{\sqrt{l/h_2}} = 8.5$ for $l/h_2 = 21.9$ (long ini. elevation)

How long should l be at Ormen Lange in order that $\frac{\Delta t c_0/h_2}{\sqrt{l/h_2}} \sim 9$? Answer: $\sim$ 300 km!

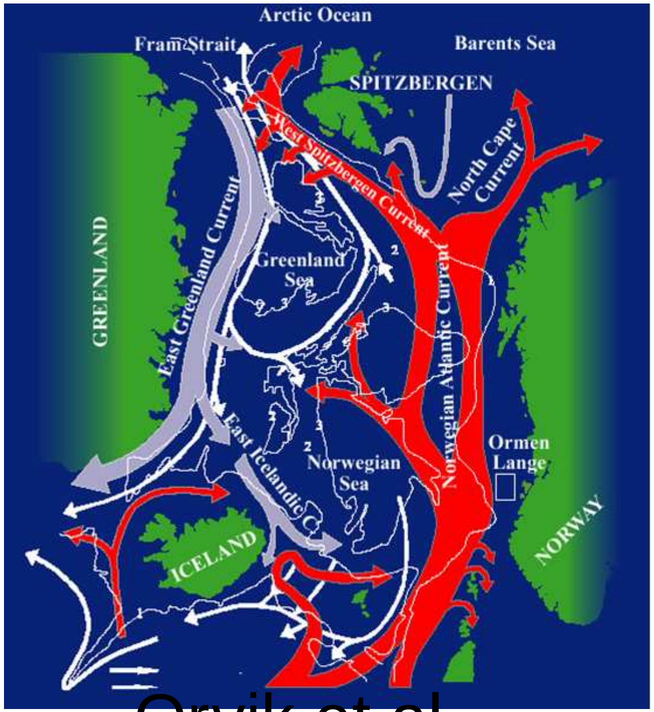
Divide by $\sqrt{l/h_2}$ (l length of initial elevat.)

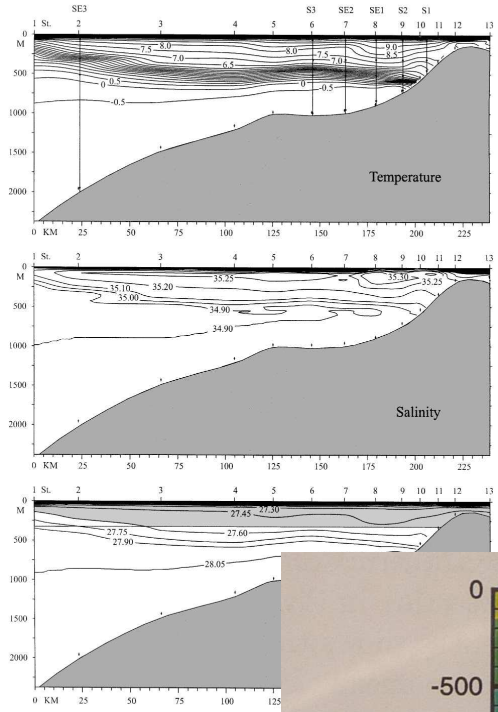
$\frac{\Delta t c_0/h_2}{\sqrt{l/h_2}} = 8.9$ for $l/h_2 = 5$ (short ini. elevation)

$\frac{\Delta t c_0/h_2}{\sqrt{l/h_2}} = 8.5$ for $l/h_2 = 21.9$ (long ini. elevation)

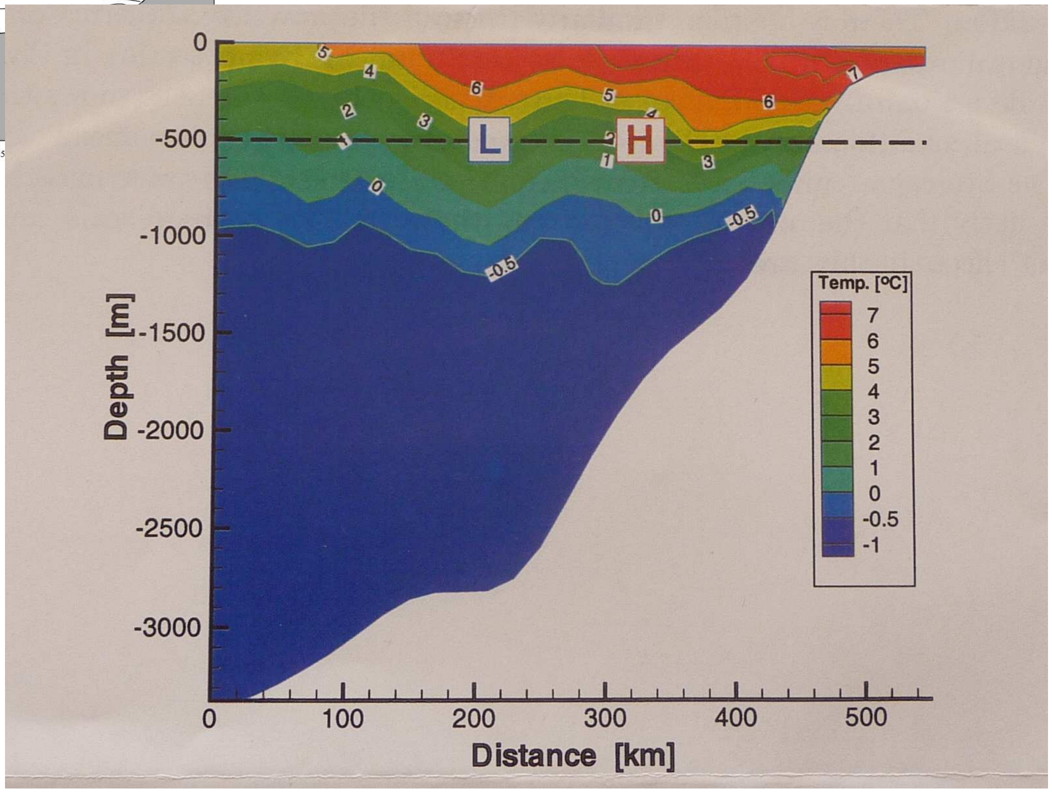
$\frac{\Delta t c_0/h_2}{\sqrt{l/h_2}} = 9.1$ for $l/h_2 = 300$ km/550 m (OL)

Width of Norwegian Atlantic Current?

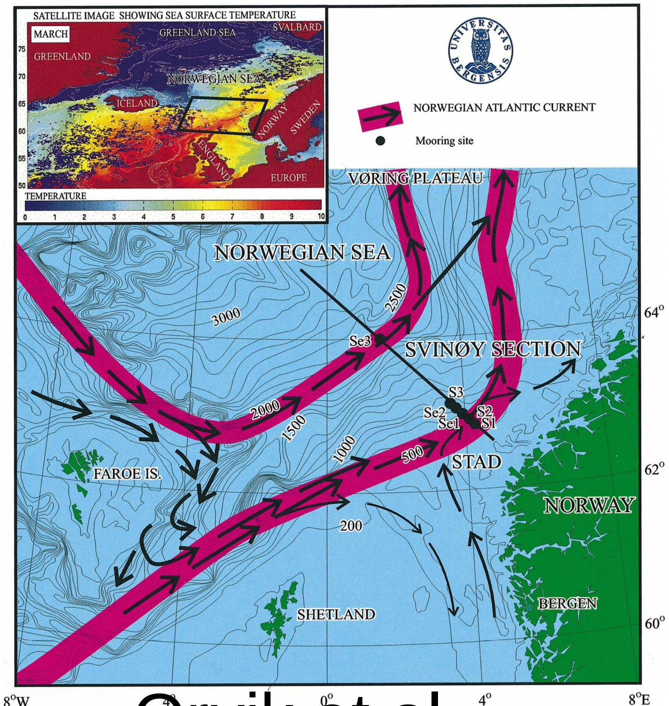




Orvik et al.



Width of Norwegian Atlantic Current?



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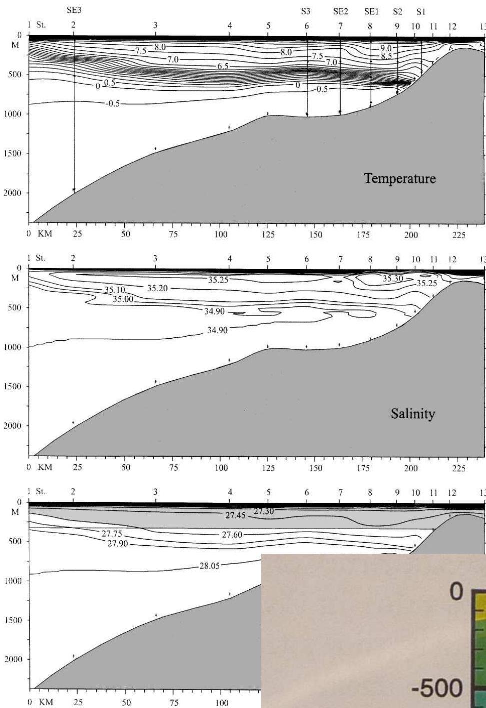
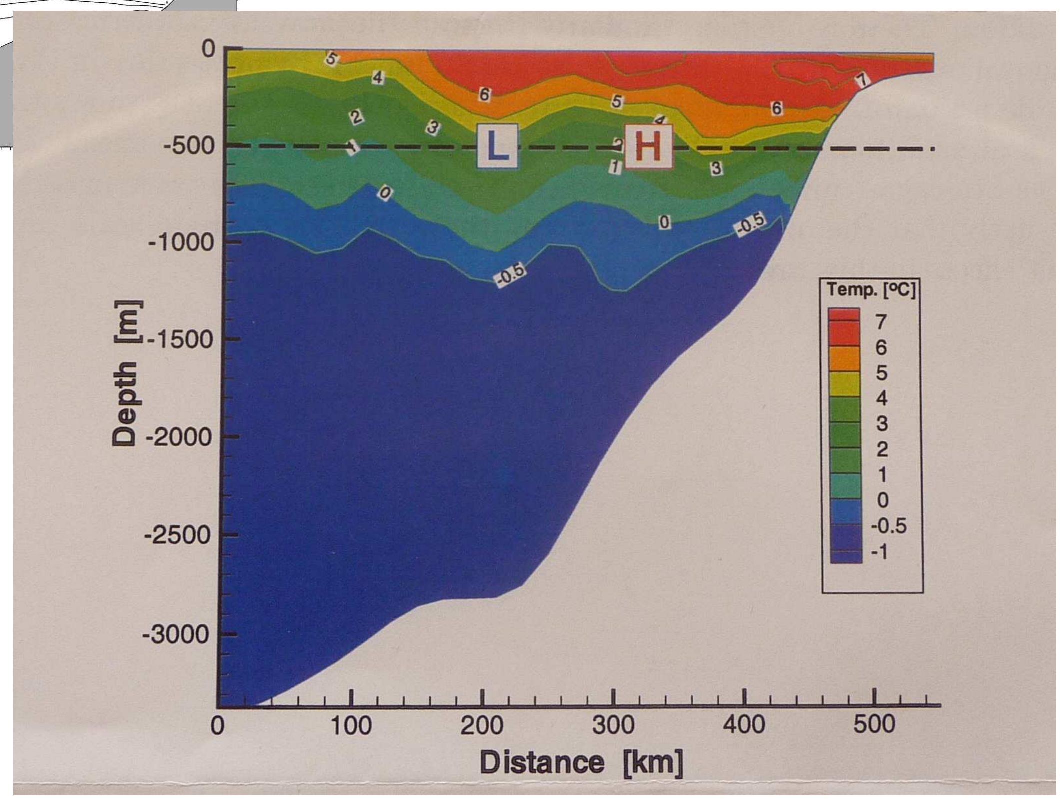


width ∼ 300 km



Conclusions I

Experiments show nondimensional velocity up to 0.5c_0

Current event in the field at Ormen Lange, velocity up to $0.37c_0$

Duration of event in laboratory and field: $\frac{\Delta t c_0/h_2}{\sqrt{l/h_2}} \simeq 9$

The onshore flow has a leading front velocity of $0.43c_0$

Hosegood & van Haren found leading front velocity $0.42c_0$

Onshore surge moves initially like a gravity current
$c_{front}/\sqrt{g'H}$=0.7 (here), 0.707 (Benjamin, 1968),
0.75 (Simpson & Britter, 1979) (H thickness of the tail)
Maximal run-up: $s/h_2 = 15$ and 12 ($y/h_2 = 0.68$ and 0.54) for long/short initial elevation

Conclusion II

Initial depression results in a train of boluses moving up slope

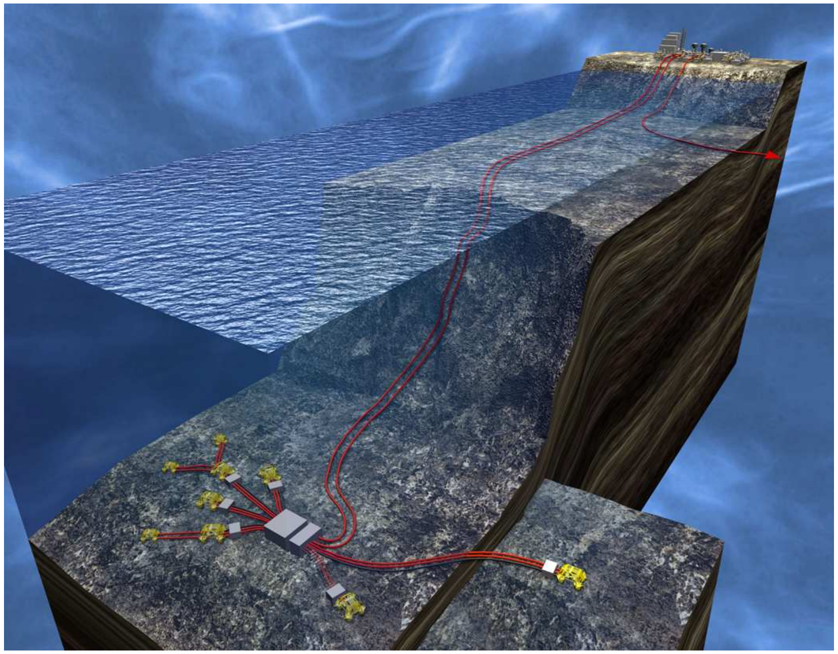
Number of boluses in agrees with present investigations

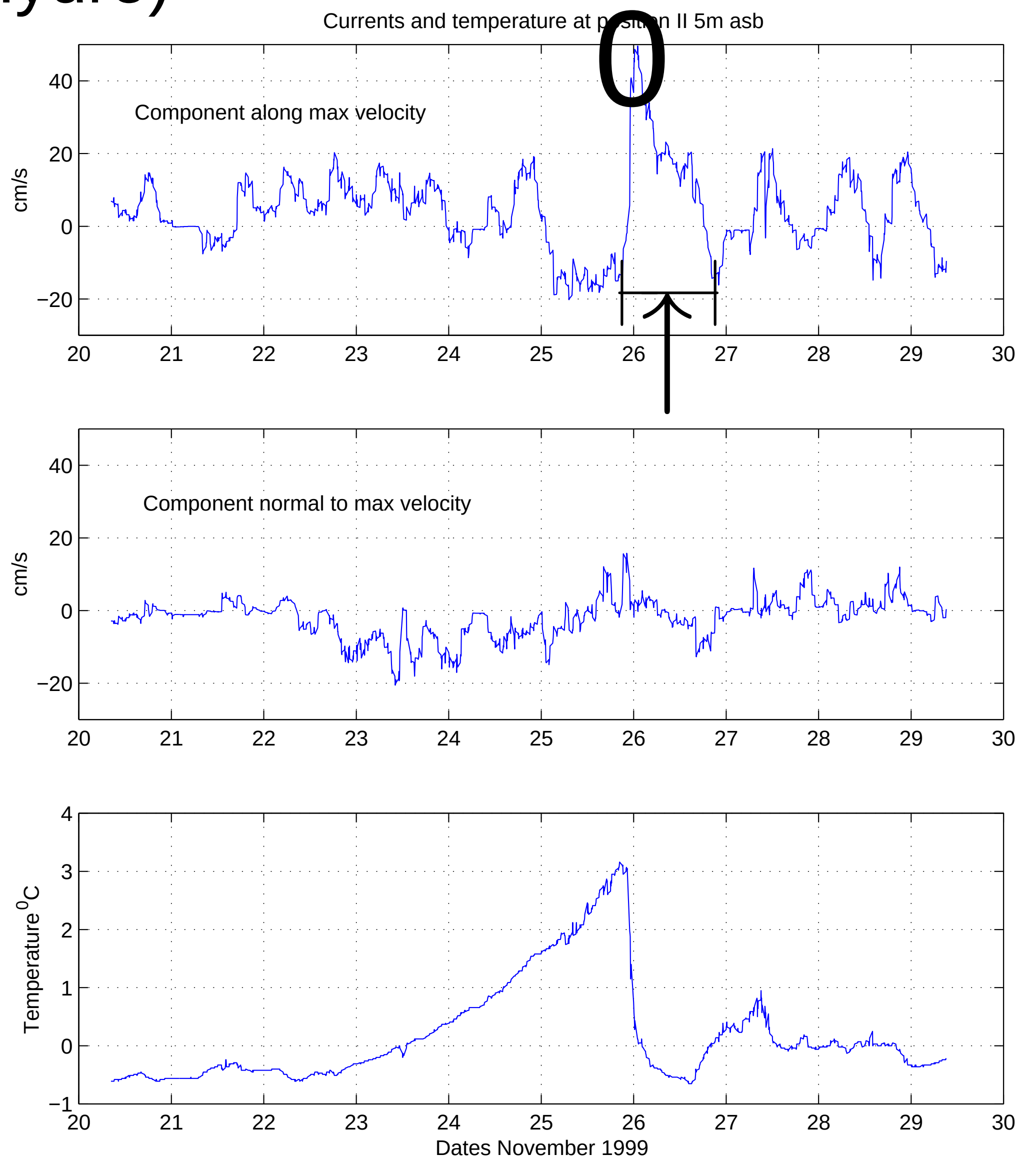
Period of bolus: $\Delta t c_0/h_2 \sim 4.5$; similar time as in Hosegood & van Haren's measurements in the Faeroe-Shetland Channel

Bolus induced velocity, up to $0.35c_0$. Phase velocity of bolus observed by Hosegood & van Haren is $0.19c_0$; by Klymak & Moum is $0.25c_0$ (but this depends much on the phase of motion along the slope)

Initial depression gives small run-up ($s/h_2 = 6.2$; $y/h_2 = 0.28$)

Main motivation: **STRONG BOTTOM CURRENT EVENT** measured at Ormen Lange gas field (StatoilHydro)

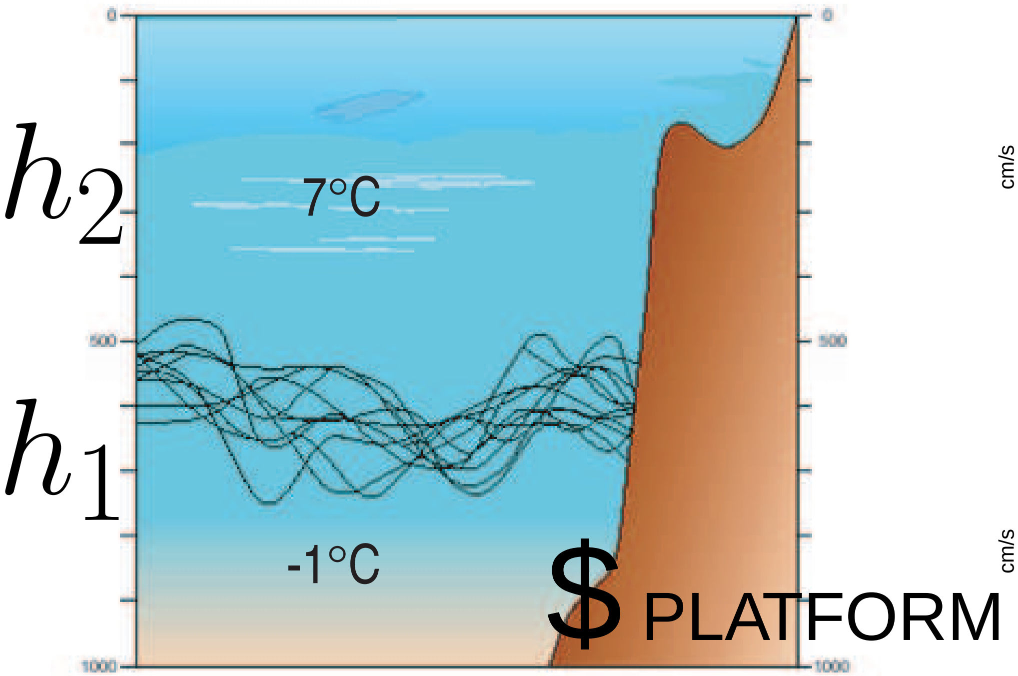


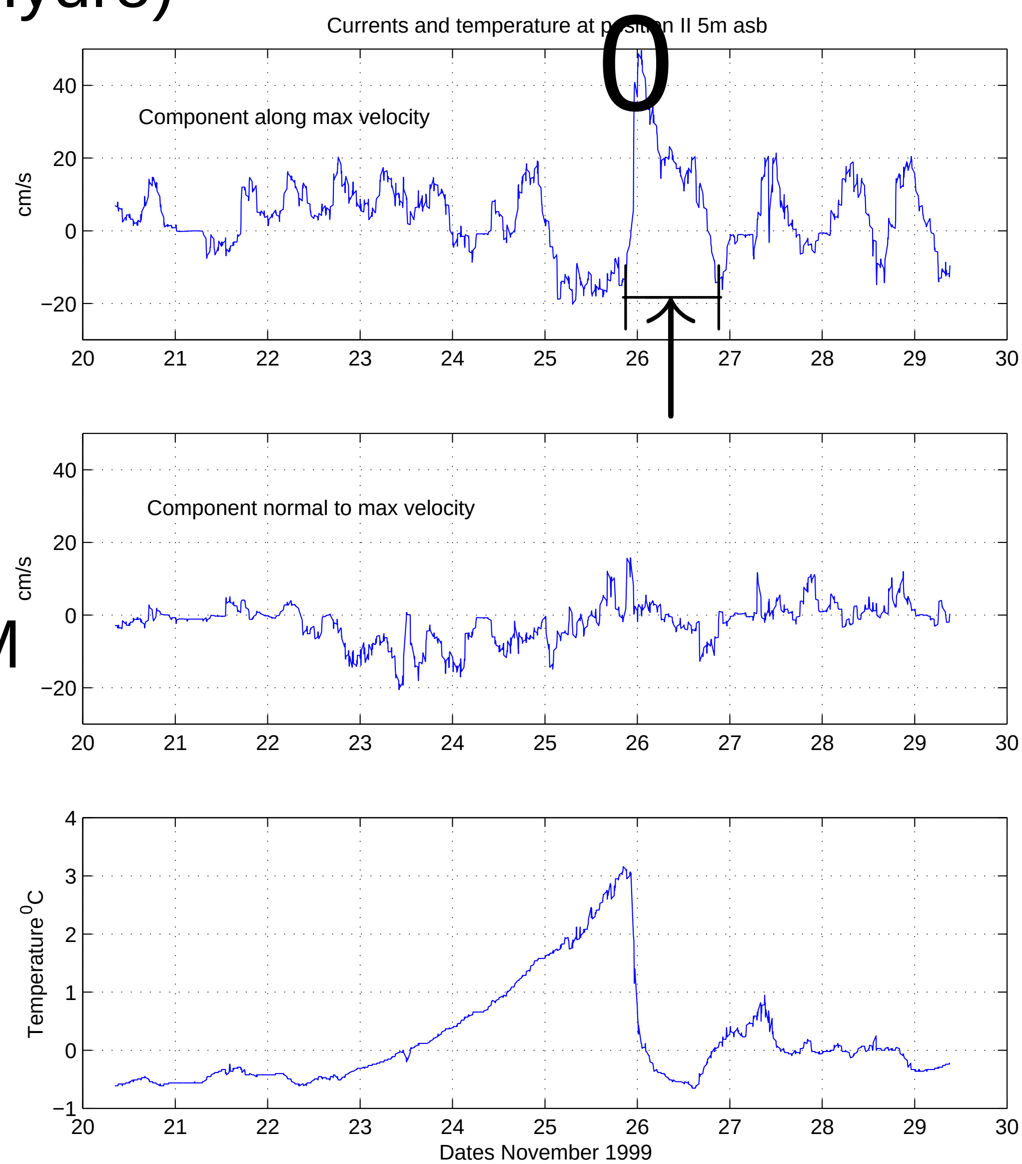


MAX VEL. $0.37c_0$

DURATION $\frac{\Delta t c_0/h_2}{\sqrt{l/h_2}} \simeq 9$

Main motivation: **STRONG BOTTOM CURRENT EVENT** measured at Ormen Lange gas field (StatoilHydro)





MAX VEL. $0.37c_0$

DURATION $\frac{\Delta t c_0/h_2}{\sqrt{l/h_2}} \simeq 9$

DURATION $\Delta t\sqrt{g'/l} \simeq 9\sqrt{1+h_2/h_1}$ $\quad [c_0 = \sqrt{g'h_2/(1+h_2/h_1)}]$