

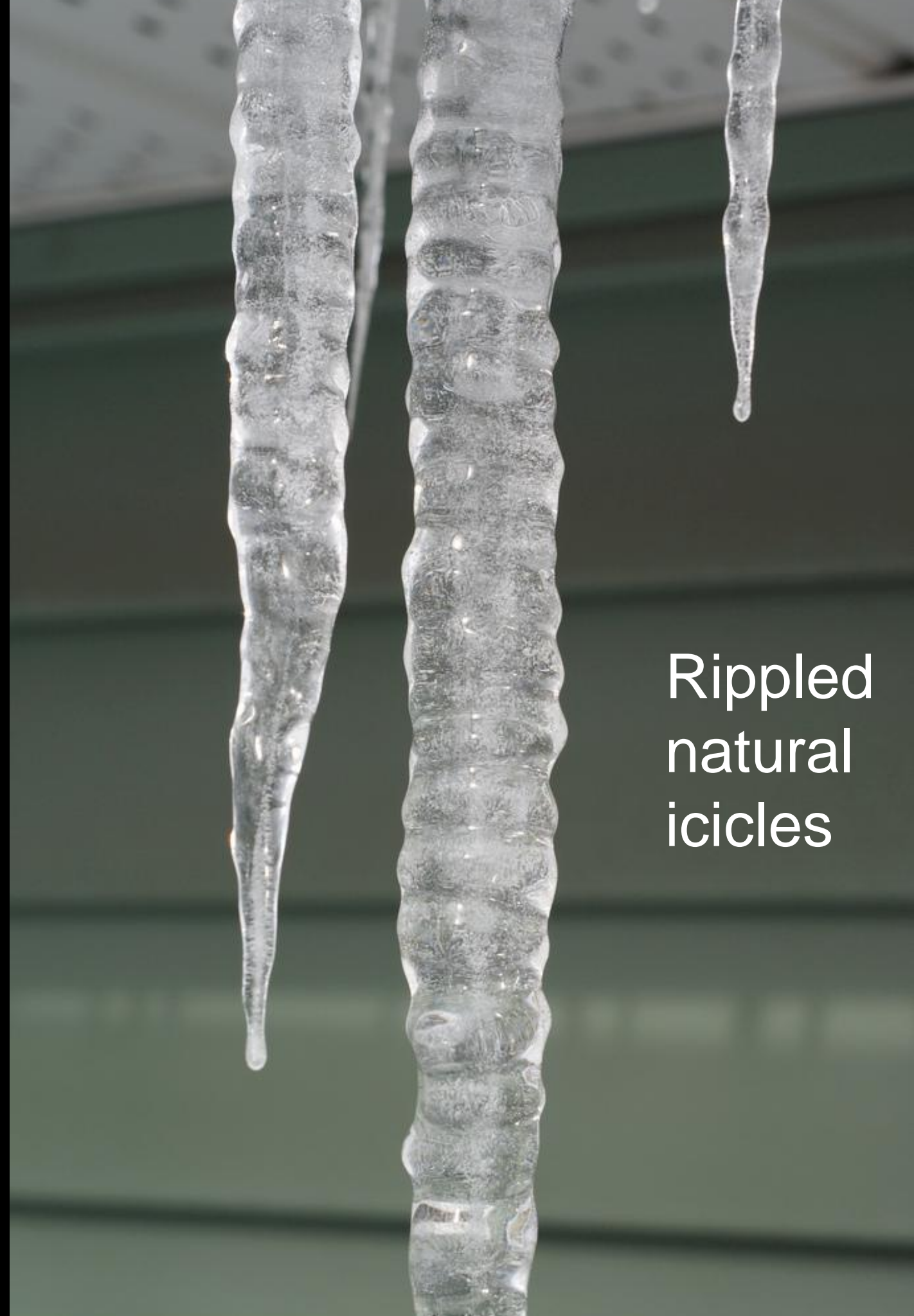
# Ripples on icicles

Antony Szu-Han Chen  
Stephen Morris

*University of Toronto,  
Canada*

Lasse Makkonen  
*VTT, Finland*

Rippled  
natural  
icicles





SLOWENIEN FEBRUAR 2014 / DANKE DEN FEUERWEHREN AUS ÖSTERREICH !!!







Rippled  
icicles  
on  
insulators



a.  $150 \mu\text{S}/\text{cm}$ , 20 kV



b.  $750 \mu\text{S}/\text{cm}$ , 20 kV



c.  $1500 \mu\text{S}/\text{cm}$ , 20 kV



d. hollow ice layer,  $1500 \mu\text{S}/\text{cm}$ , 20 kV

Y. Deng *et al.*, *IEEE Trans. Dielectric and Electrical Insulation*, Vol. 22, p. 1613 (2015).





Rippled  
natural  
icicles



# Icicle ripples

“Michelin Man” ring-like ridges are often seen on the surface of natural icicles.

Ripples are always observed to have a wavelength very close to 1 cm, independent of flow rate, undercooling *etc.*

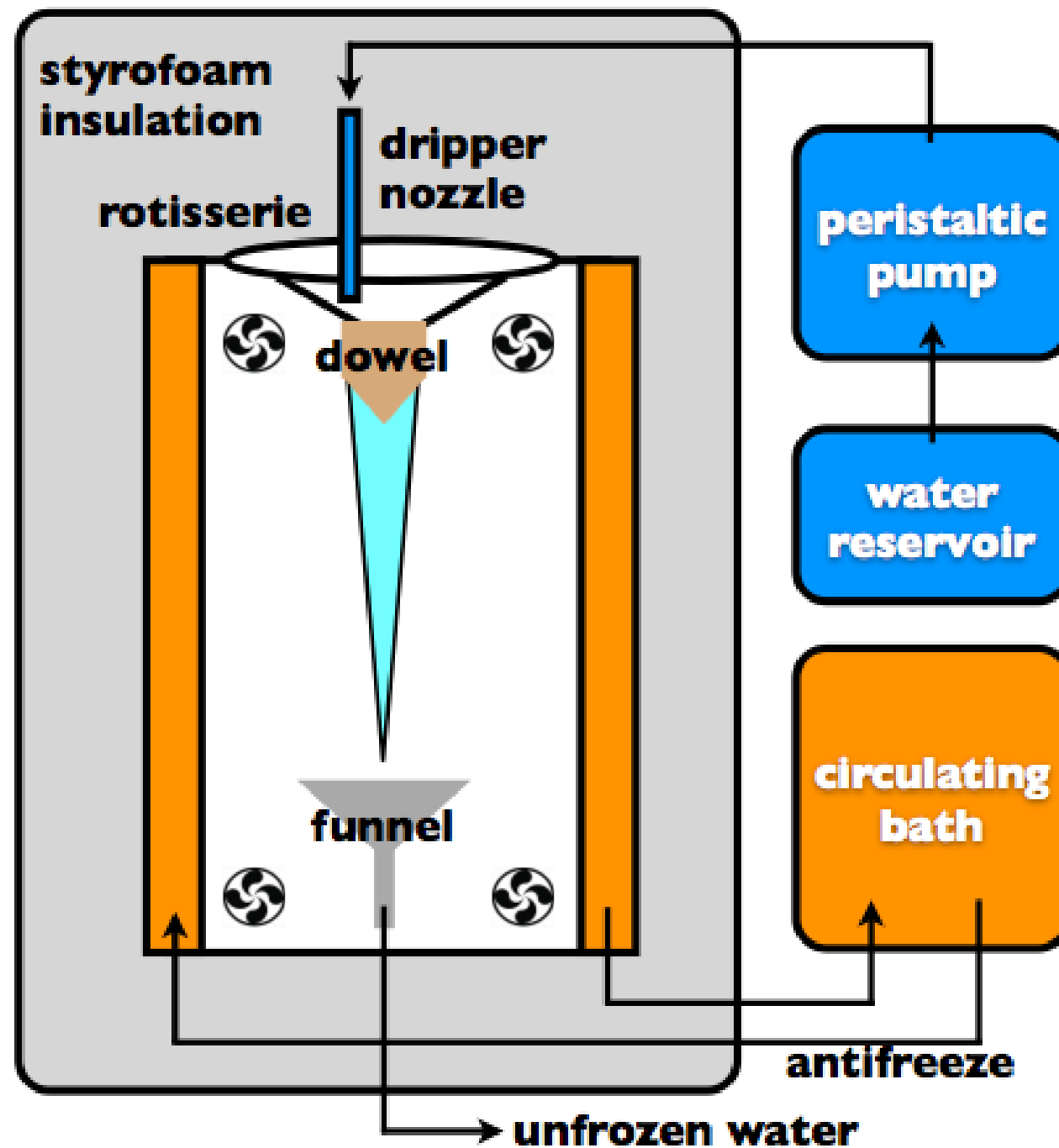
Rippling instability theory claims surface tension effects at air-water interface lead to ripples

*K. Ueno, Phys. Fluids 19, 093602 (2007)*

However, ripples are not observed on distilled water icicles.

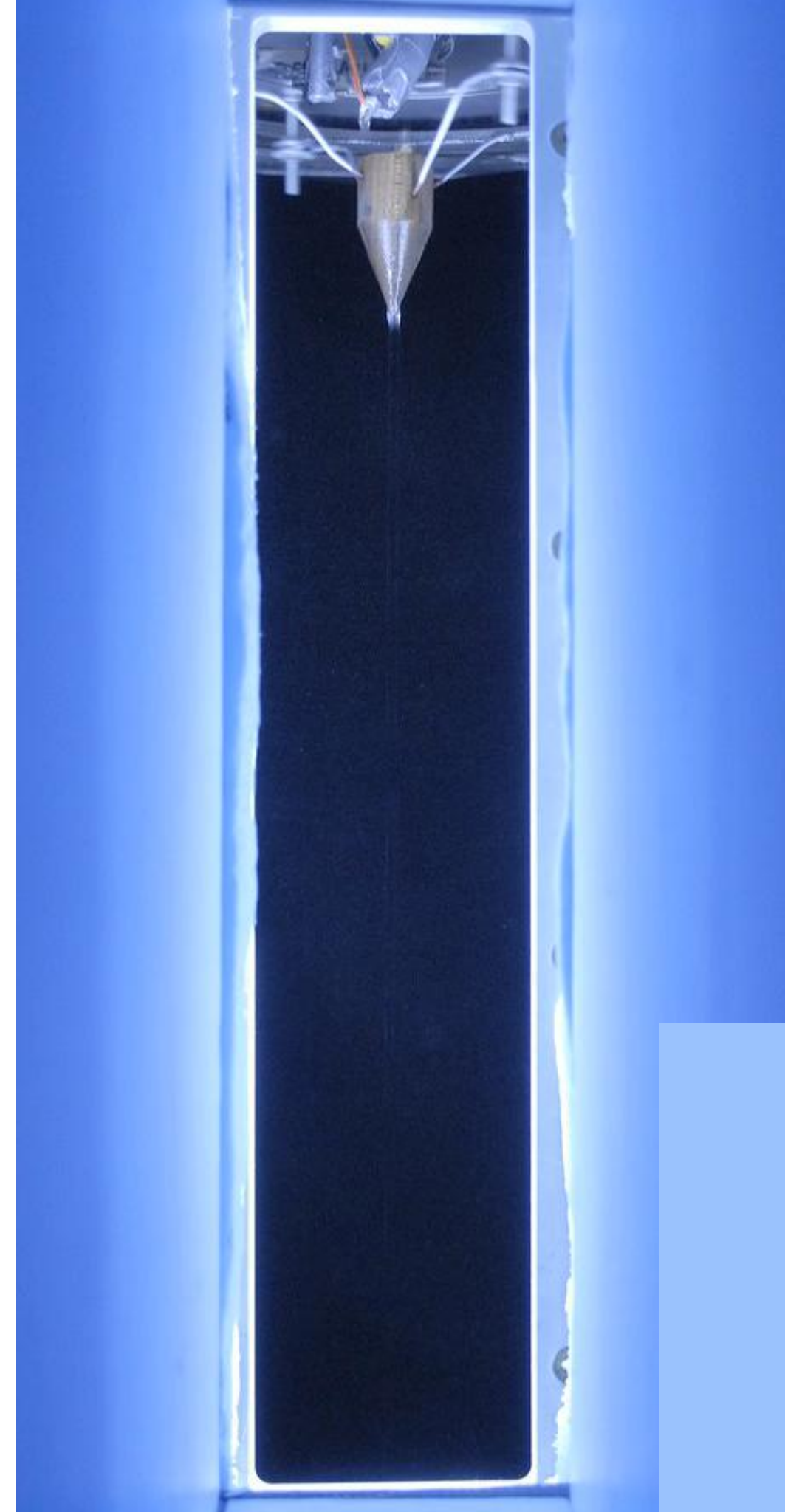


# The icicle machine



Using time-lapse photography, we can make movies of the icicle's evolving morphology.

**8 rotational views of the same ripply icicle.**





*distilled water*

*40 mg NaCl per kg H<sub>2</sub>O*

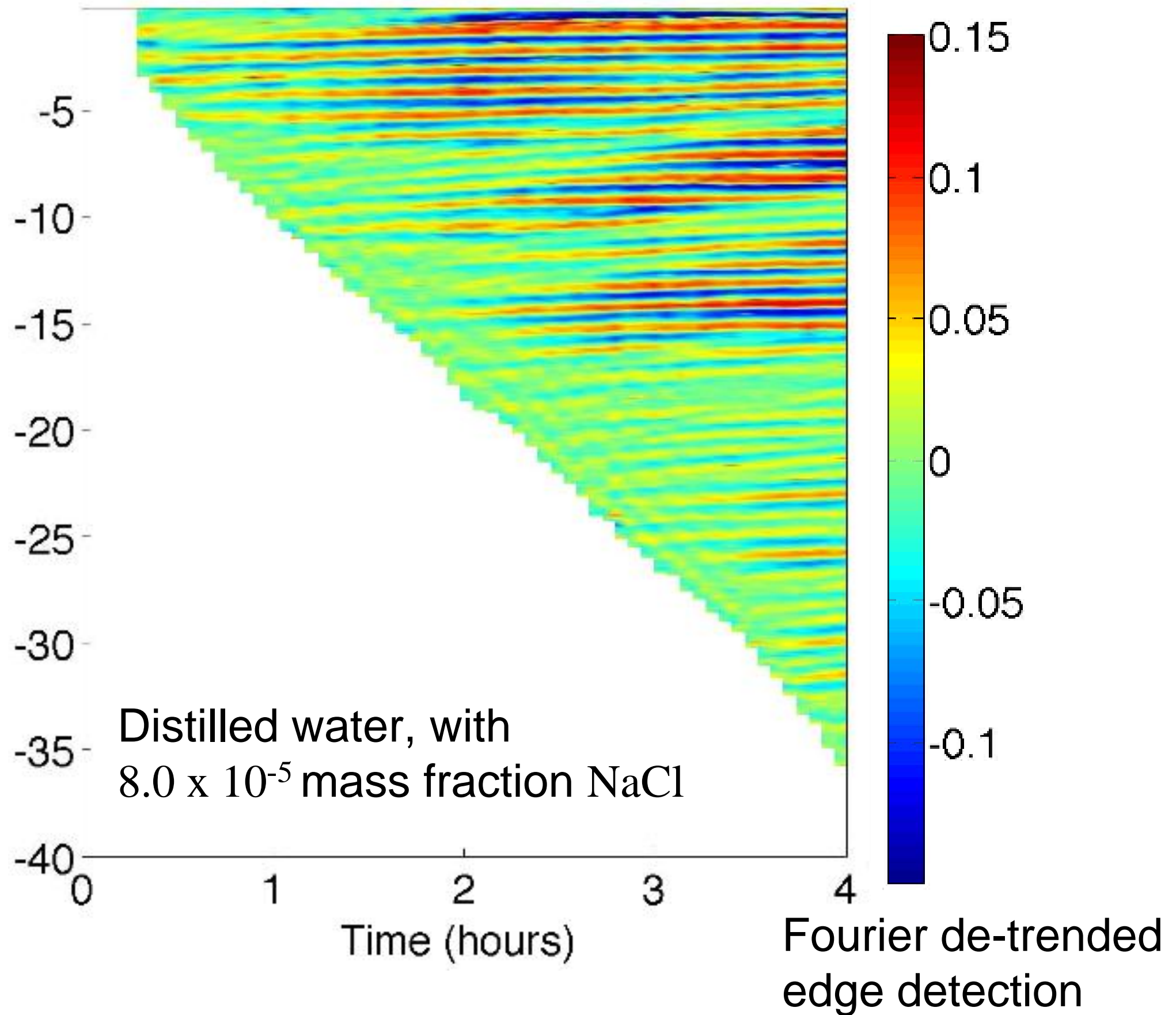
*1.28 g NaCl per kg H<sub>2</sub>O*



*-12.3 deg C, 2.0 g/min*

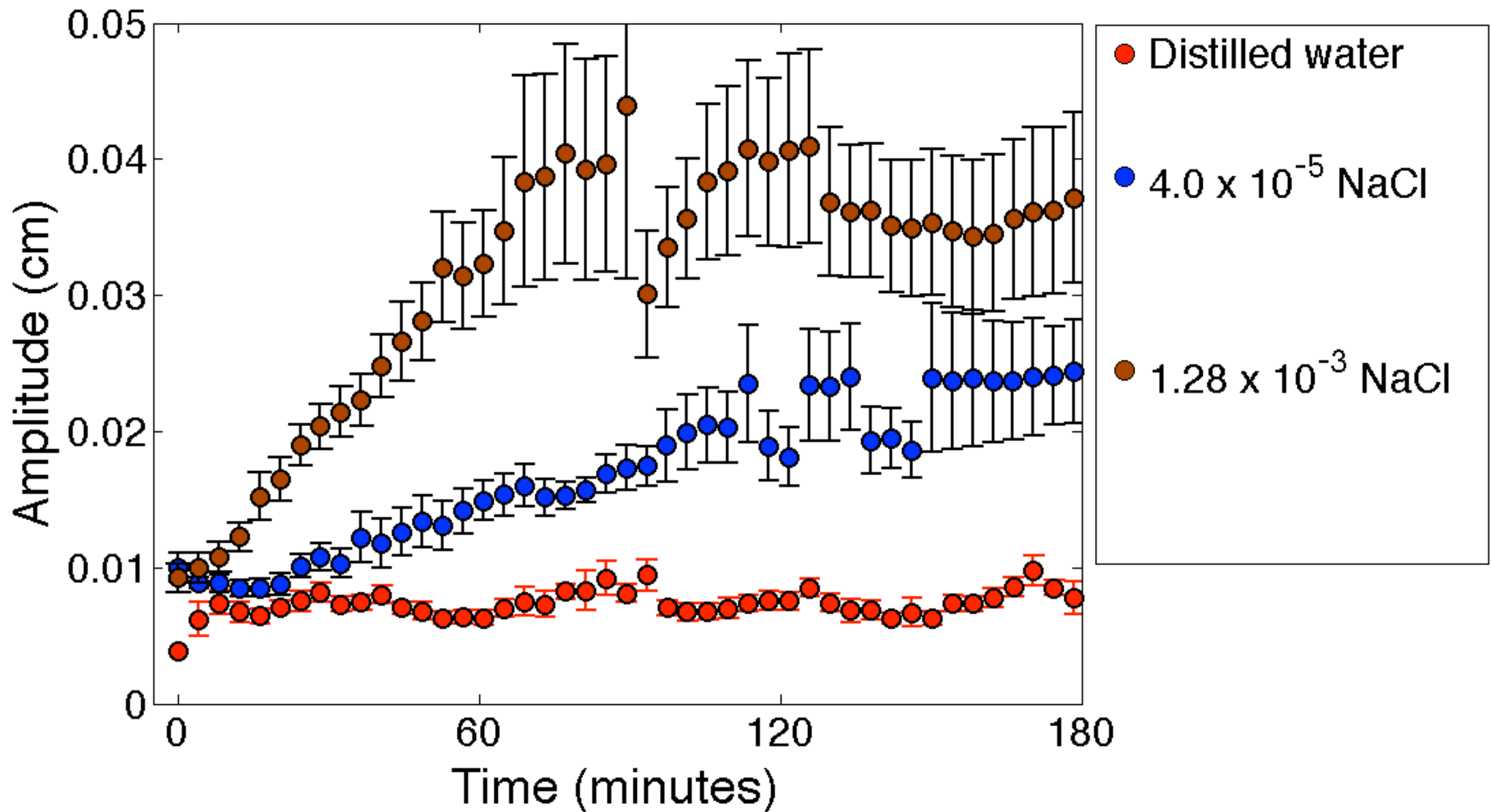


# Icicle topography vs time





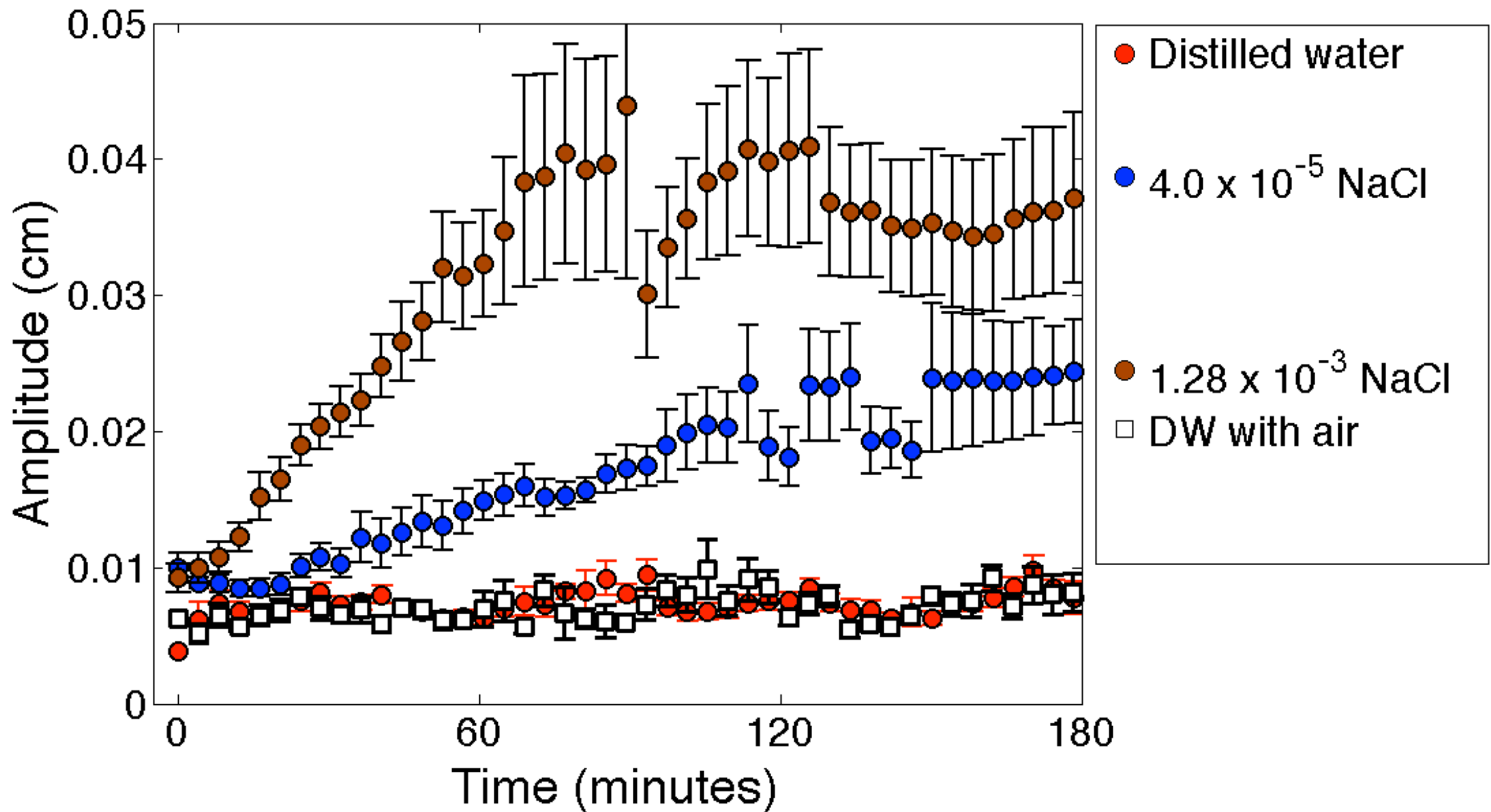
# Growth and saturation of ripples vs time



Amplitudes averaged over 1 rotation of icicle and over repeated runs.  
 $t = 0$  when icicle reaches 10 cm, topography data from top 10 cm only.



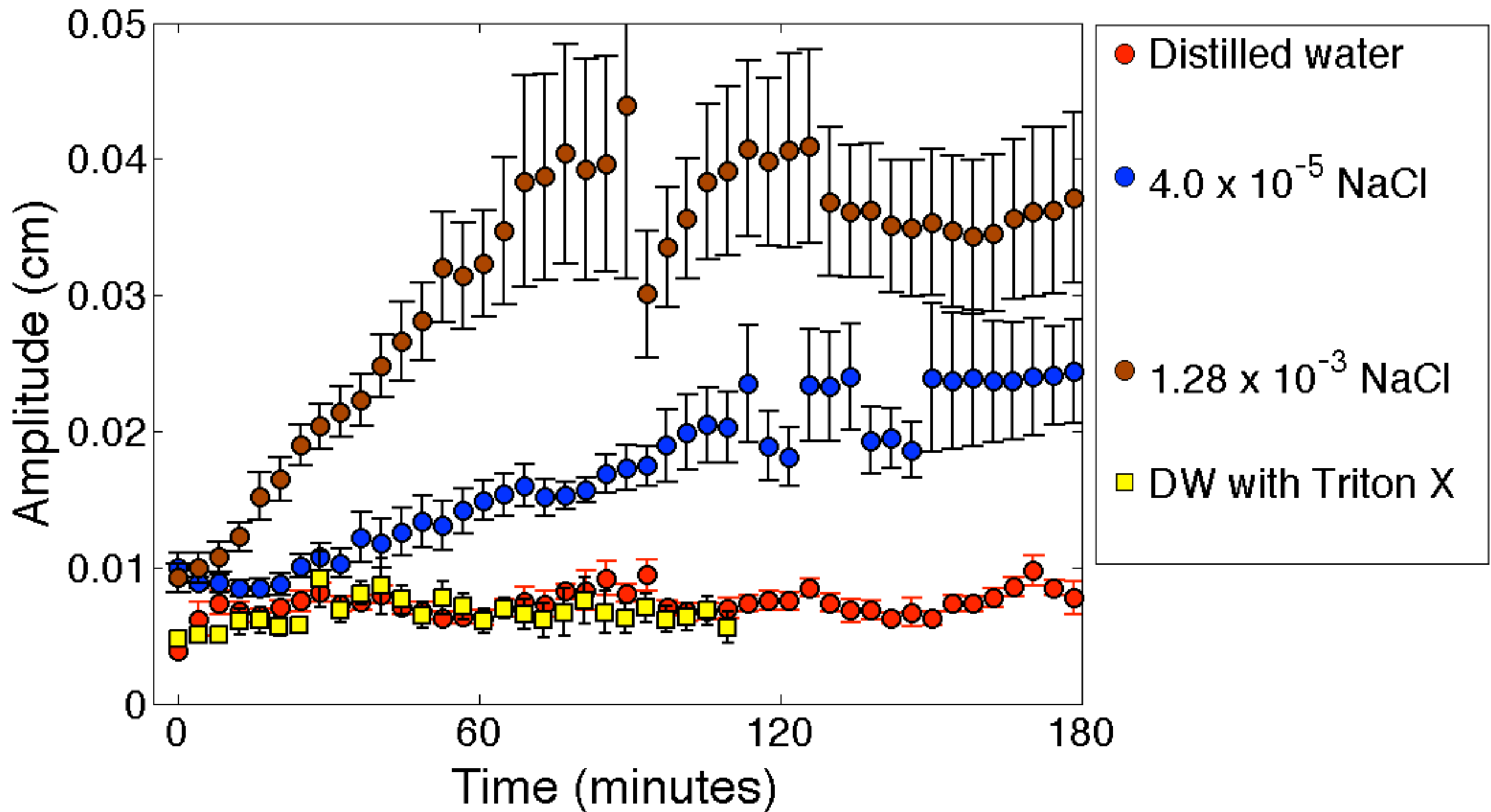
# Growth and saturation of ripples vs time



Bubbling air through the distilled water for a long time does not produce ripples. All samples are likely saturated with dissolved air.

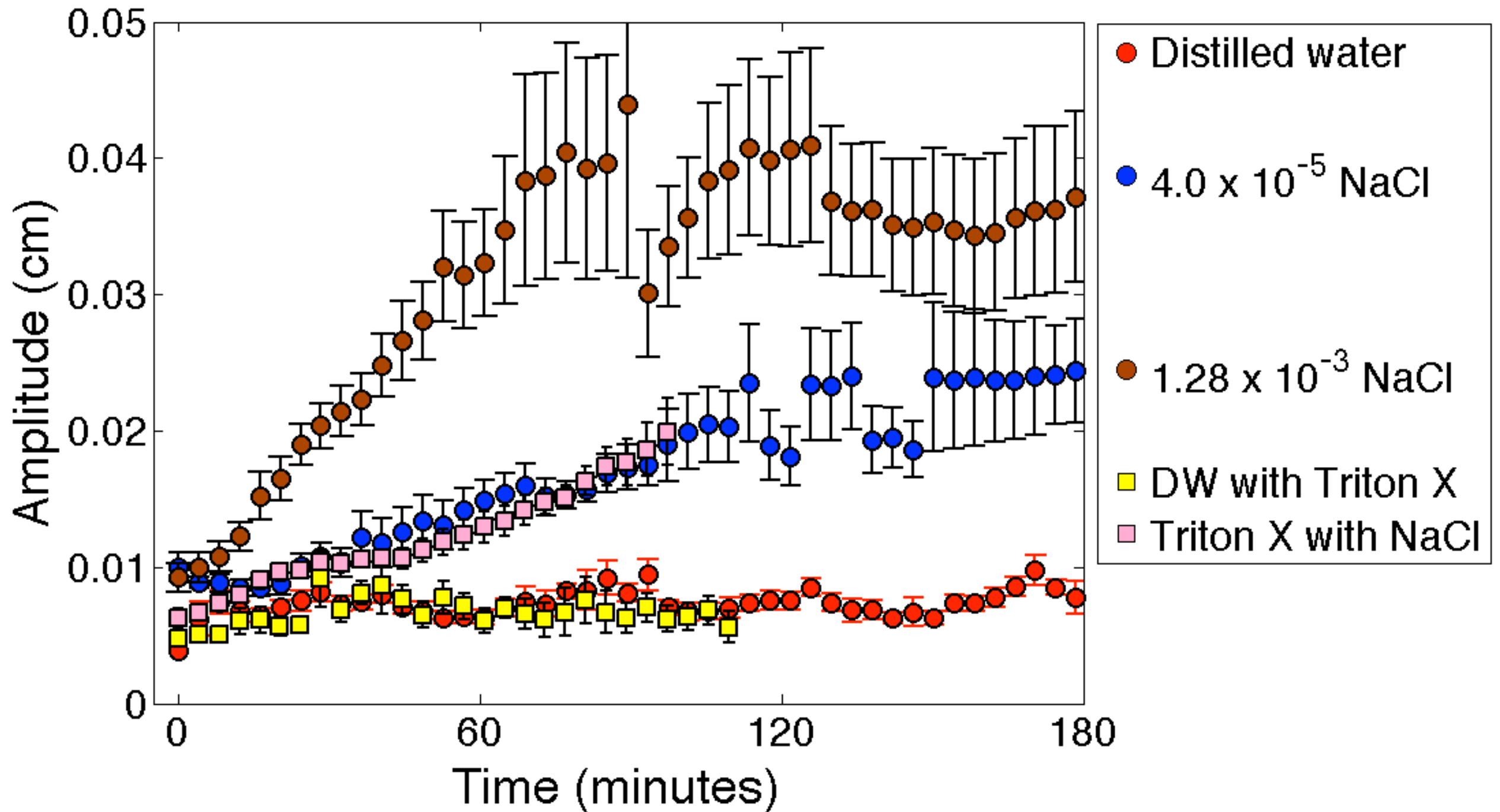


# Growth and saturation of ripples vs time



Adding a strong surfactant, Triton X, to distilled water does not produce ripples, even though the surface tension is reduced by 47%.

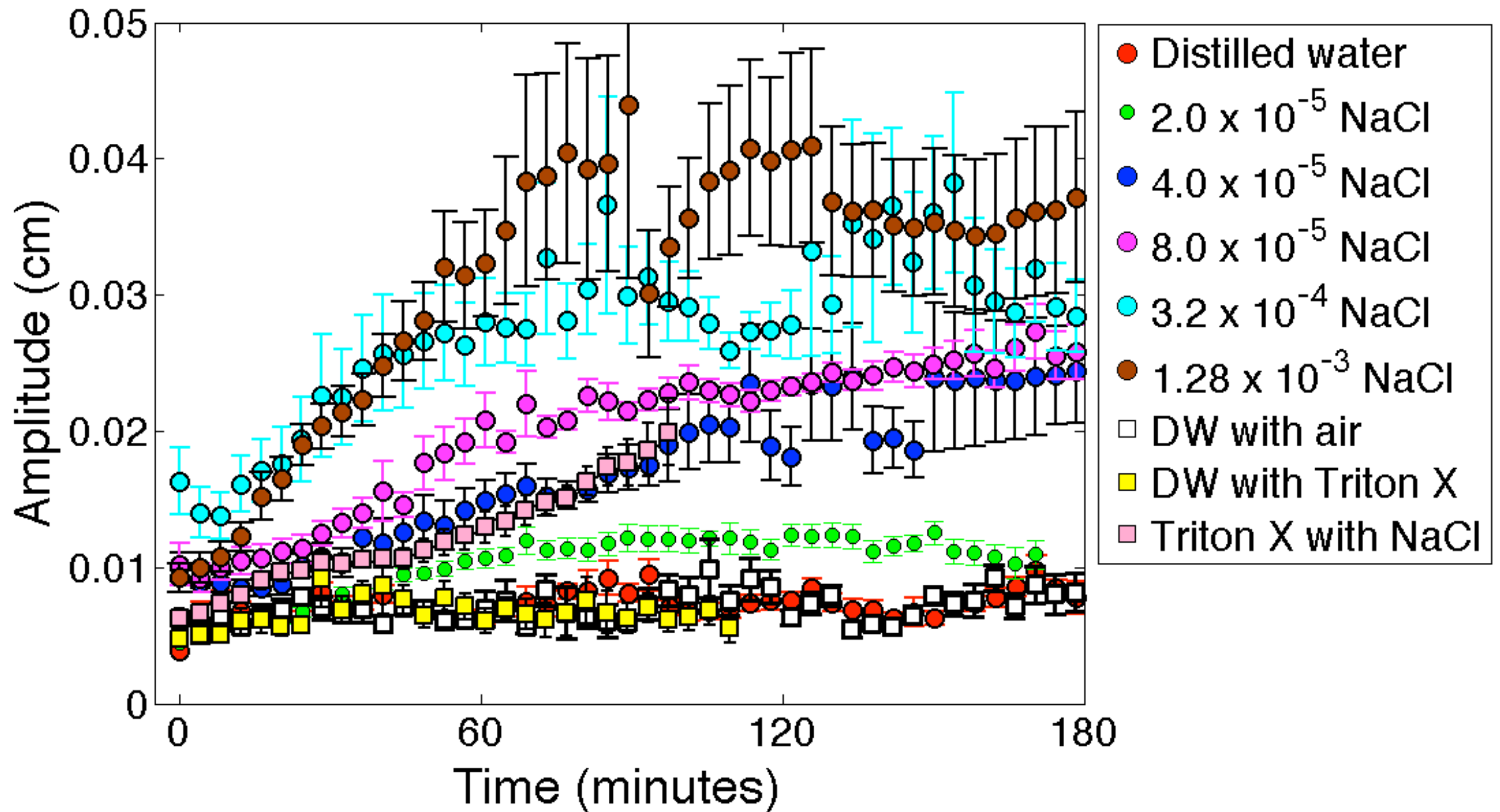
# Growth and saturation of ripples vs time



Adding a small concentration of salt *and* the Triton X, does produce ripples.

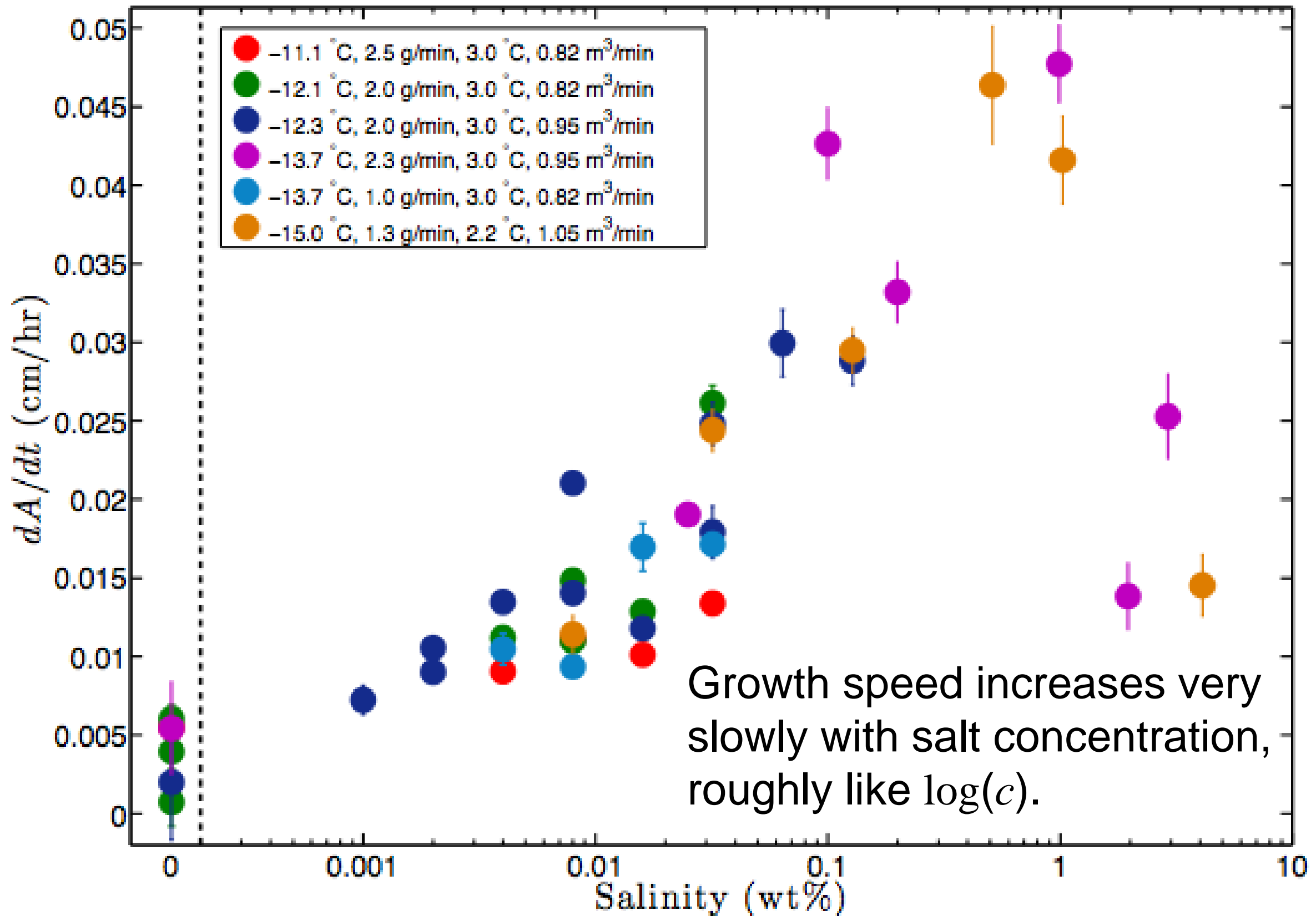


# Growth and saturation of ripples vs time



Both ripple amplitude and growth rate increase with salt concentration, but surfactant and dissolved air do not produce ripples.

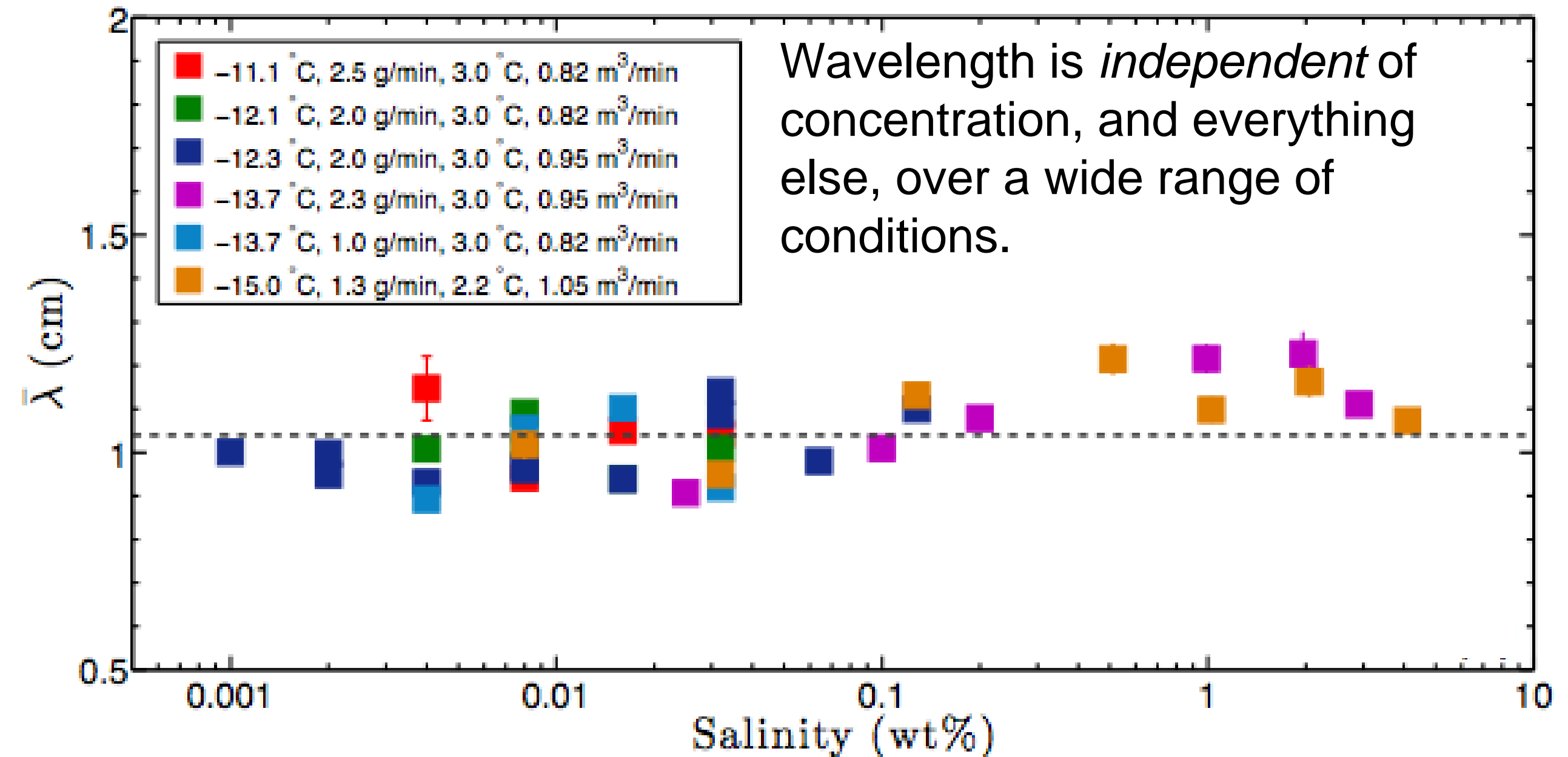
# Growth speed of ripples vs salt concentration



Averaged over time after 1 hour of growth, top 10 cm



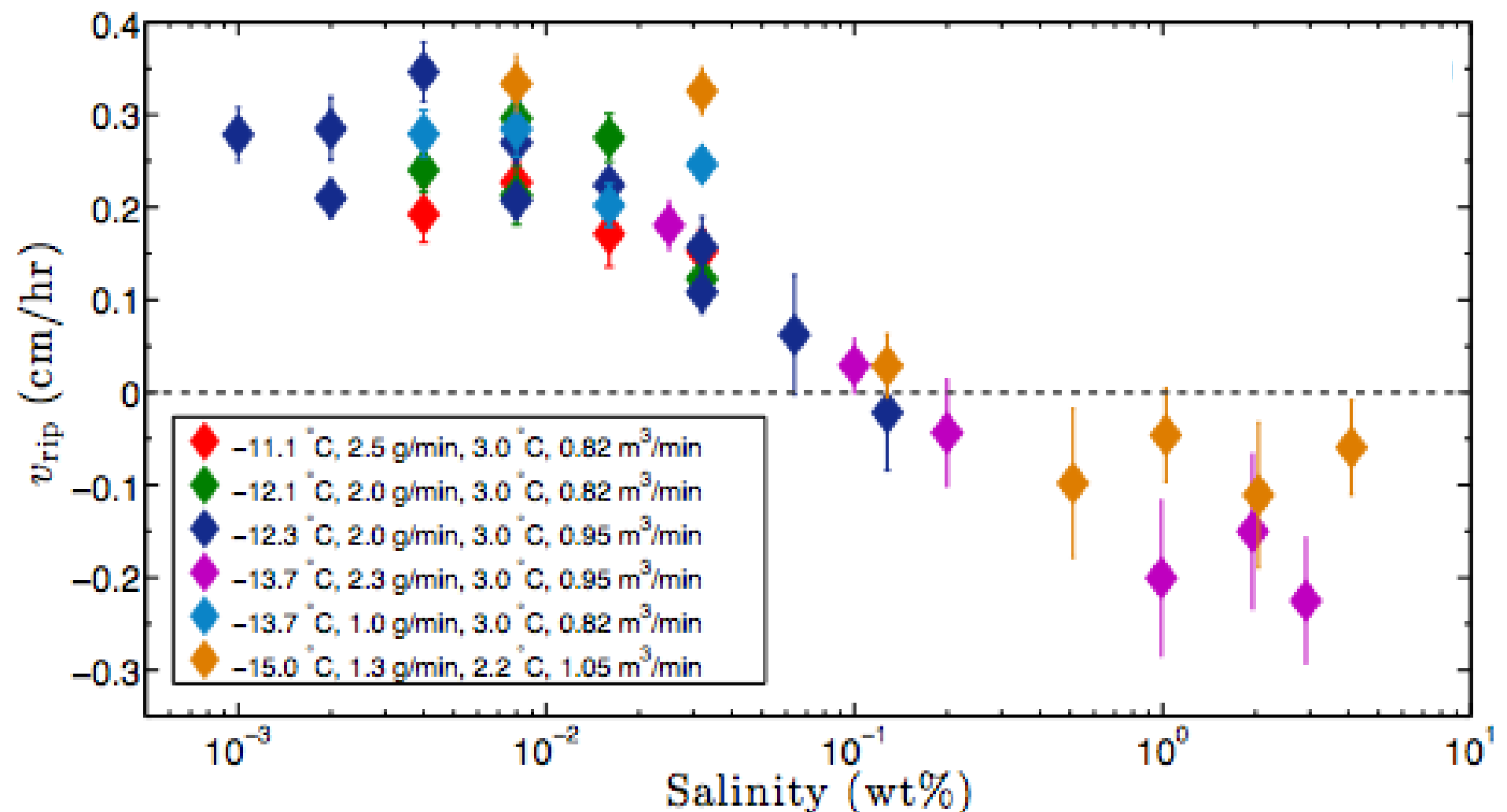
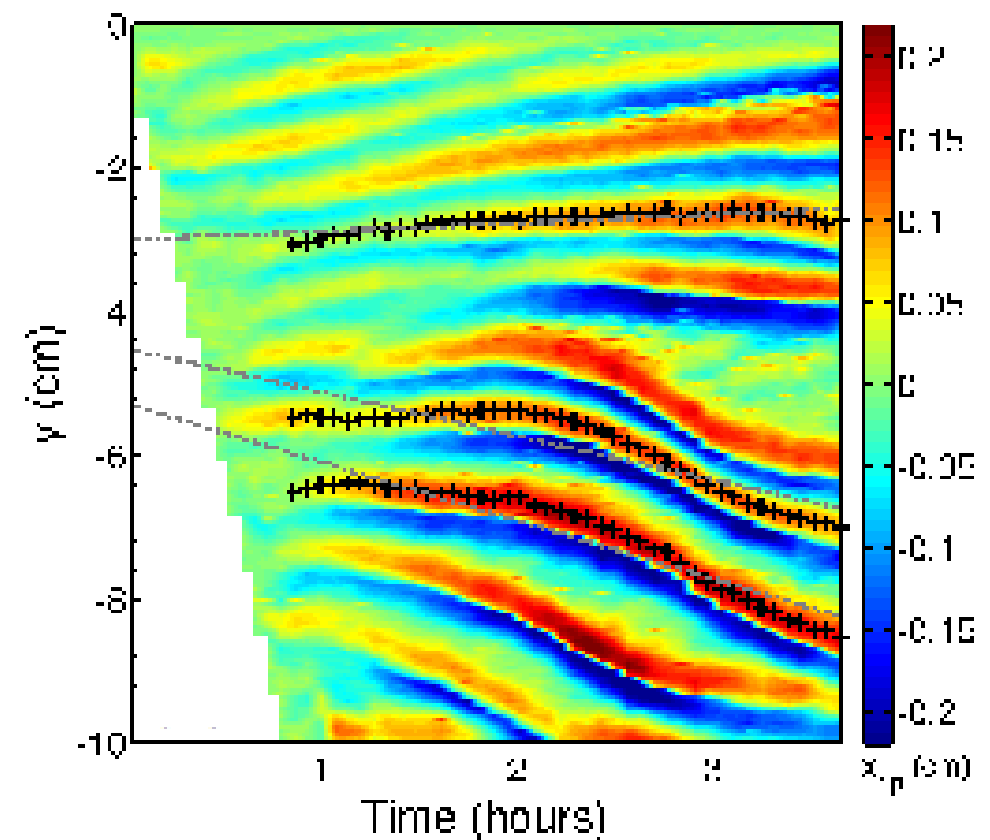
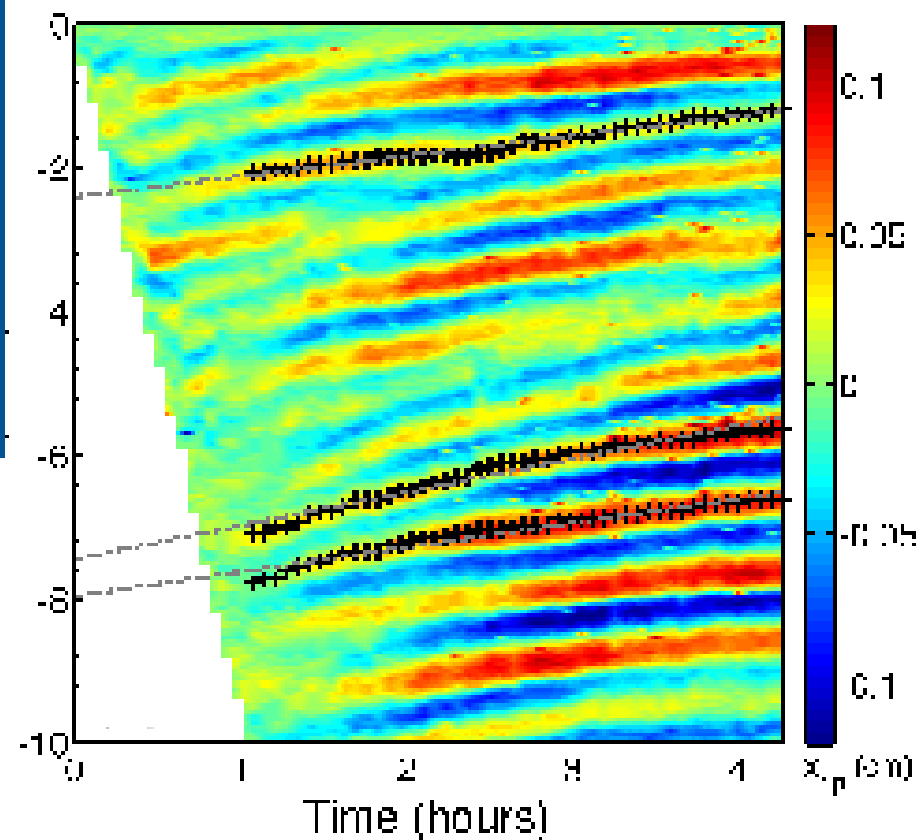
# Mean wavelength of ripples vs salt concentration



# Traveling speed vs salt concentration

Traveling speed *changes sign* with salt concentration.

Positive is *up* the icicle, negative is *down*.







## Composition of natural icicles

We collected about a dozen “wild type” natural icicles and measured their compositions. They are consistent with rippled laboratory icicles, only somewhat purer.

	Conductivity
This icicle:	$19\mu\text{S}/\text{cm}$
Typical lab salty icicle:	$200\mu\text{S}/\text{cm}$
Ripple threshold:	$7\mu\text{S}/\text{cm}$
Distilled water:	$2\mu\text{S}/\text{cm}$





# The end

## Conclusions:

- Ripples are due to impurities and *not* to surface tension
- We don't have a good theory for the rippling instability
- Need to do more experiments!
- All data available online in the *Icicle Atlas*.