On Ensemble Variability in 3D Ocean Modeling

Bjarne Büchmann
Johan Söderkvist

Defence Centre for Operational Oceanography , FCOO

Motivation

- **Ocean dynamics is stochastic & chaotic**
  - inherently
  - by nature

- **In the nature**

- **In the models**

Turbulence, Meso-scale, etc.

Motivation (2)

Nature

- **Stochastic process**
- **SINGLE outcome**
- **Can’t repeat**

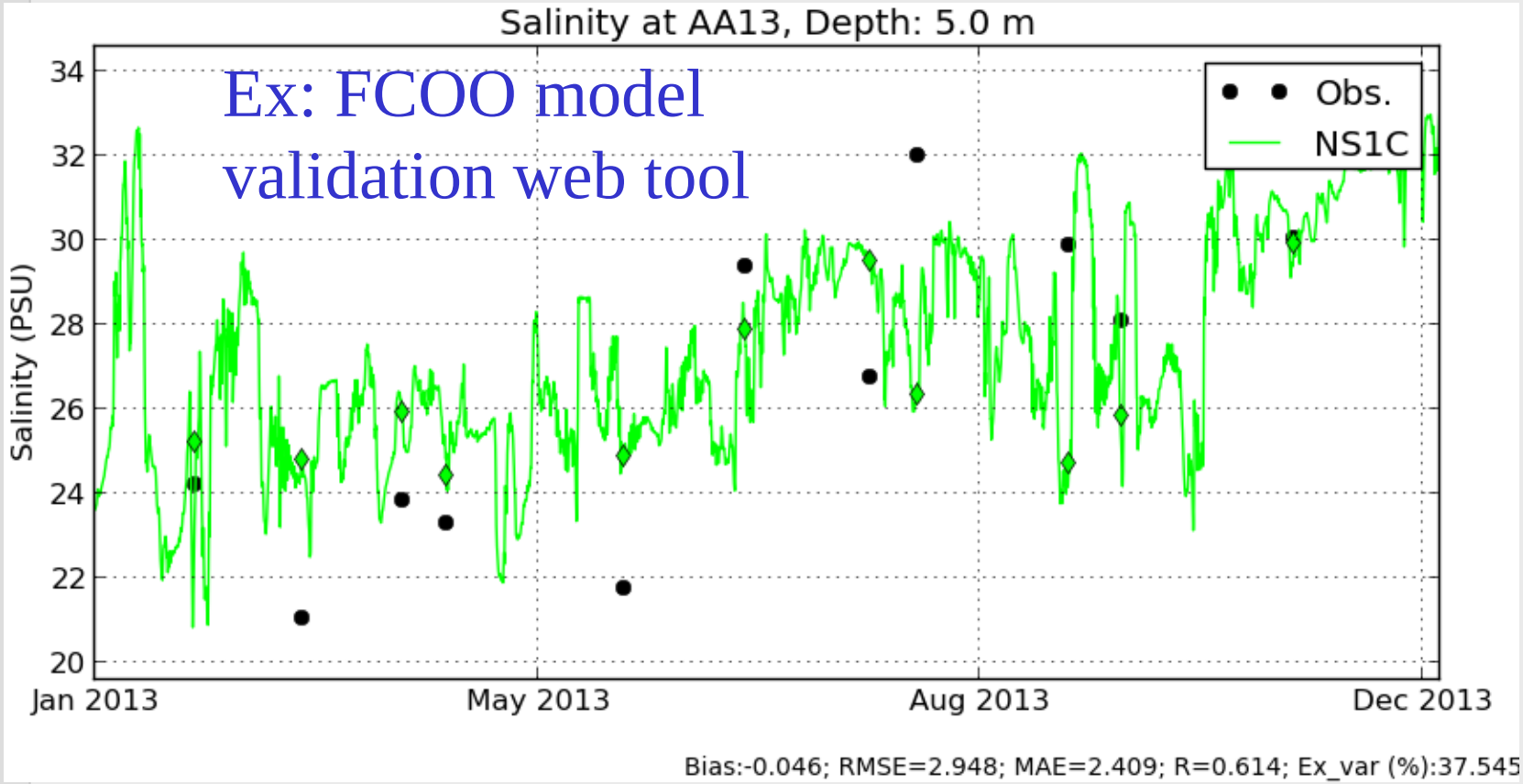
Model

- **Stochastic process (we hope)**
- **SINGLE outcome (normally)**

Motivation (3)

How to compare?

Nature vs Model



Motivation (4)

How to compare?

Nature vs Model

- **Are model skills random?**
  If so, how much?
- **Model tuning:**
  When is a model ”improved”?
  Which of two is ”better”?

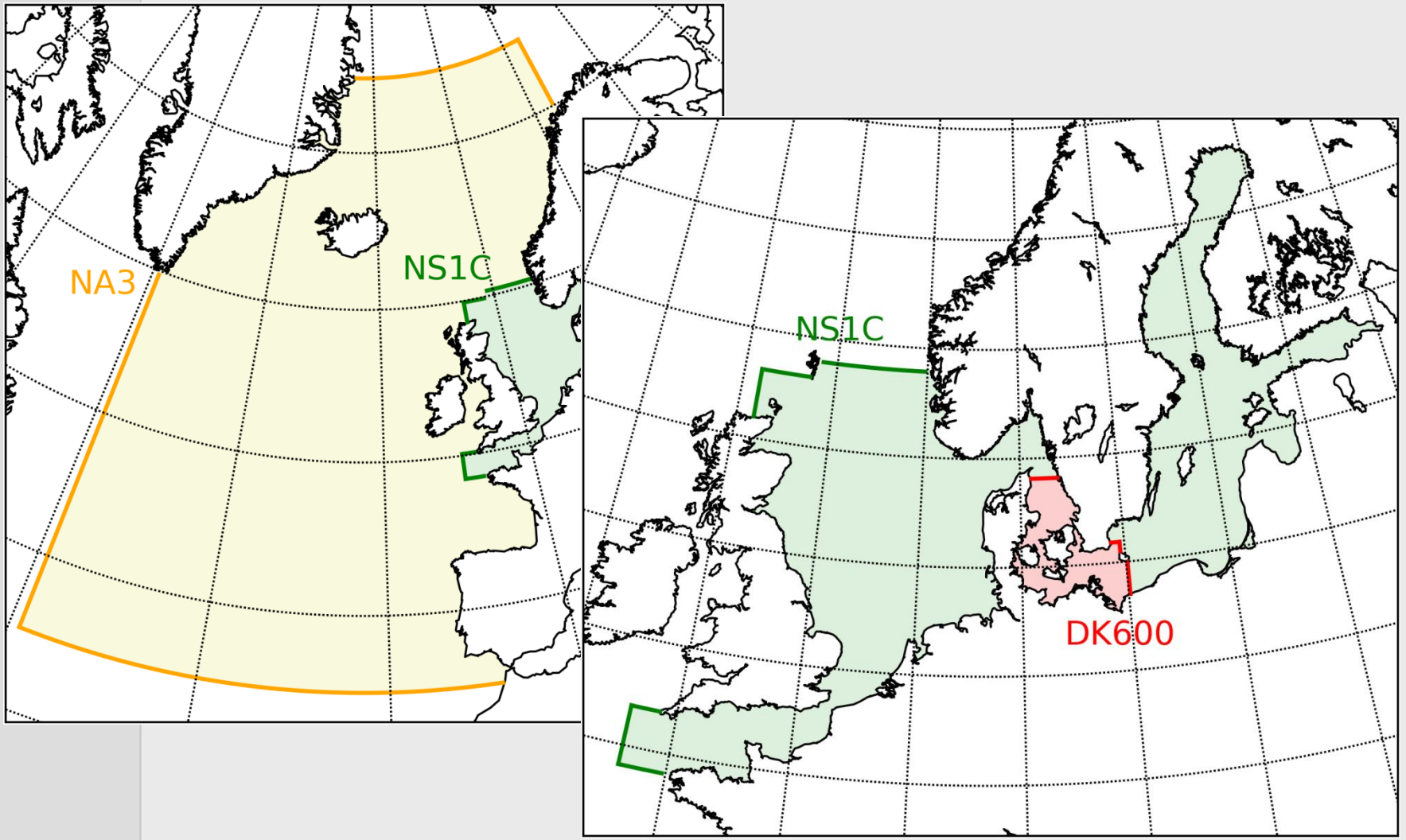
FCOO GETM[1,2] Setup

Middle of three nested models[3]

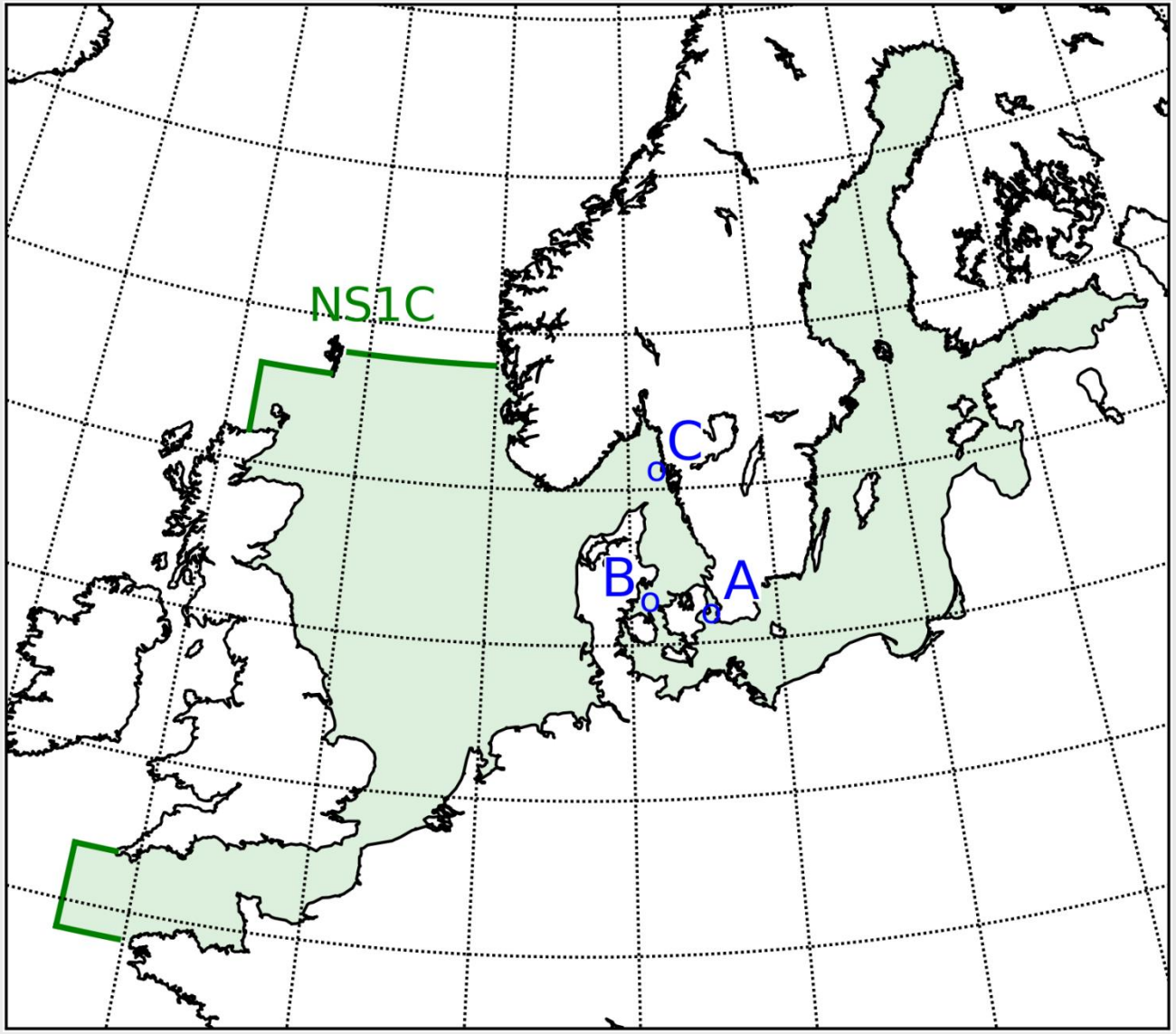
- 3D, 60 layers, sigma-coords (terrain-following)
- 1nm horizontal resolution
- 261 subdomains
- Repeatable compilation
- Repeatable execution

1: General Estuarine Transport Model
2: Burchard and Bolding (2002), Tech. Rep. EUR 20253 EN
3: Büchmann et al. (2011) Ocean Dynamics

Operational Model Setup



Examined Model Setup



Ensemble concept

Run 20 times ”identical” NS1C

- Identical setup
- Identical parameters
- Identical forcing

So identical output… !!!

- **Perturb initial conditions slightly**

Experiment A:

- **Want different results**
- **How much perturbation needed?**

Experiment A: Principles

- Perturbation
- Modify initial condition: SALT
- Each column gets a change
- Change: $\varepsilon_{salt} \cdot p$,
  p: p.d.f: uniform [-0.5:0.5]

Experiment A:

case	ε_{salt}	Perturb?		
a00	Baseline	No/zero		
a01	10^{-4}PSU	Yes		
a09	10^{-12}PSU	Yes		
a11	10^{-14}PSU	Yes		
a14	10^{-17}PSU	Yes		
a15	10^{-18}PSU	No		
a33	10^{-16}rel.	Yes		
a34	10^{-17}rel.	Yes		
a35	10^{-18}rel.	Yes		
a36	10^{-19}rel.	No		

Total: 21 5-day simulations

Experiment A:

case	ε_{salt}	Perturb?	Branch?	
a00	Baseline	No/zero	N/A	
a01	10^{-4}PSU	Yes	Yes	
a09	10^{-12}PSU	Yes	Yes	
a11	10^{-14}PSU	Yes	Yes	
a14	10^{-17}PSU	Yes	Yes	
a15	10^{-18}PSU	No	No	
a33	10^{-16}rel.	Yes	Yes	
a34	10^{-17}rel.	Yes	Yes	
a35	10^{-18}rel.	Yes	Yes	
a36	10^{-19}rel.	No	No	

Total: 21 5-day simulations

Experiment A:

case	ε_{salt}	Perturb?	Branch?	Salt moved
a00	Baseline	No/zero	N/A	
a01	10^{-4}PSU	Yes	Yes	≈1M ton
a09	10^{-12}PSU	Yes	Yes	≈10kg
a11	10^{-14}PSU	Yes	Yes	≈100g
a14	10^{-17}PSU	Yes	Yes	<0.1g
a15	10^{-18}PSU	No	No	0
a33	10^{-16}rel.	Yes	Yes	
a34	10^{-17}rel.	Yes	Yes	
a35	10^{-18}rel.	Yes	Yes	<1μg
a36	10^{-19}rel.	No	No	0

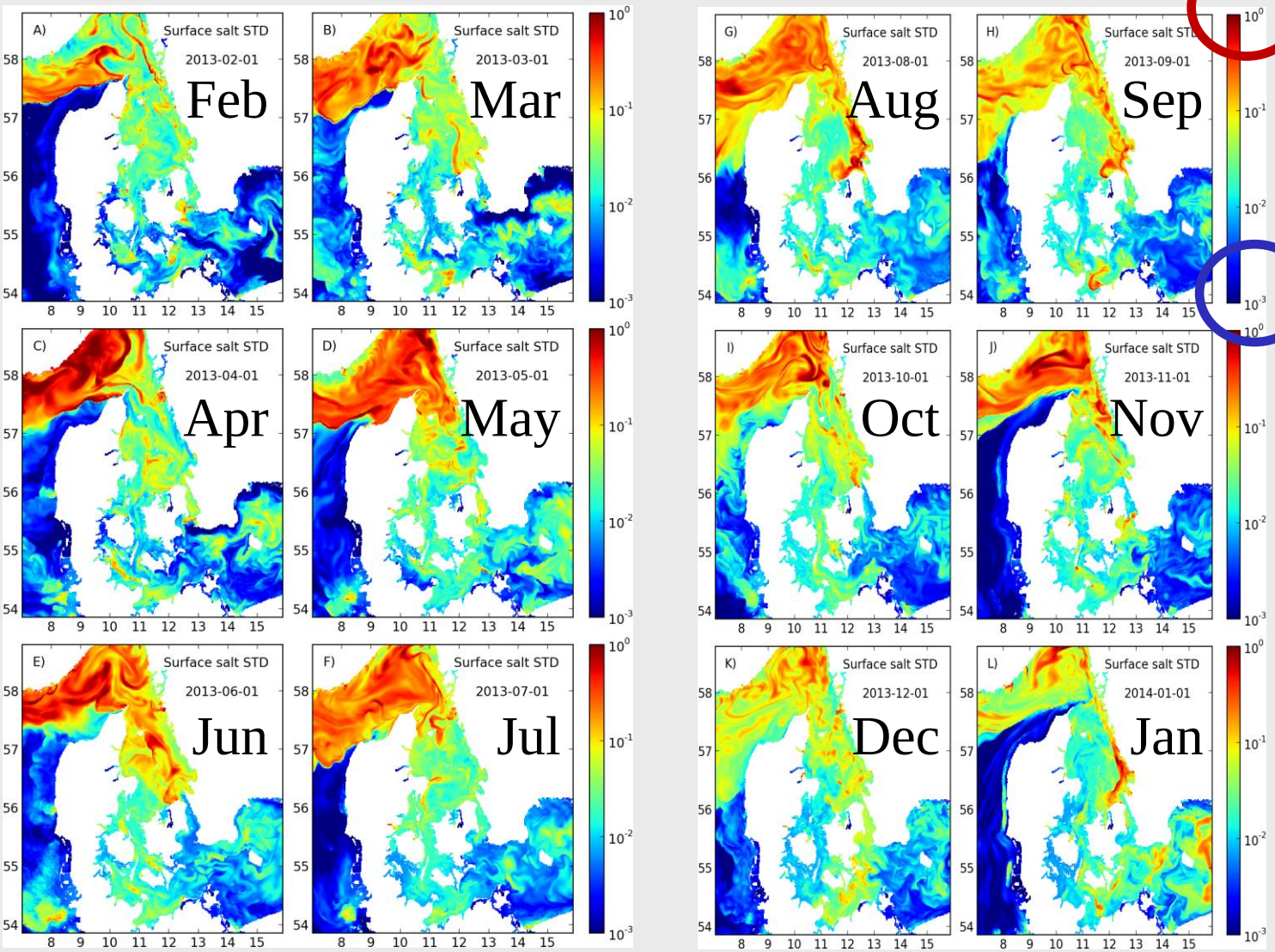
Total: 21 5-day simulations

Total SALT: order of Tera tons

Experiment B: Principles

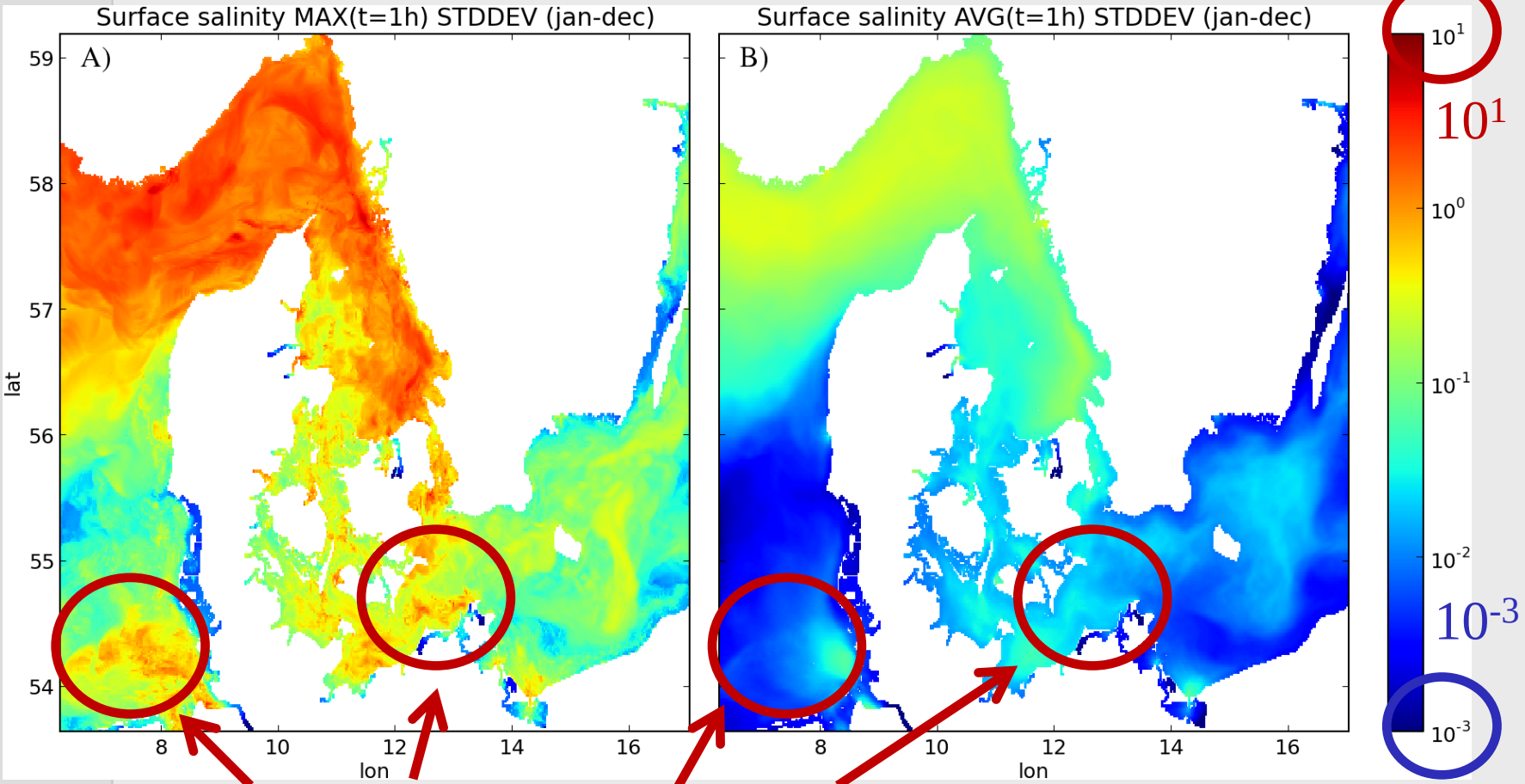
- 20 ensemble members
- $\varepsilon_{salt} = 10^{-12}$PSU
  (redistribute ≈10kg salt)
- Vary random seed for prob.
- Simulate for 1 year

SSS STDDEV Snapshots
1st day of month



FULL YEAR STDDEV(x,y)

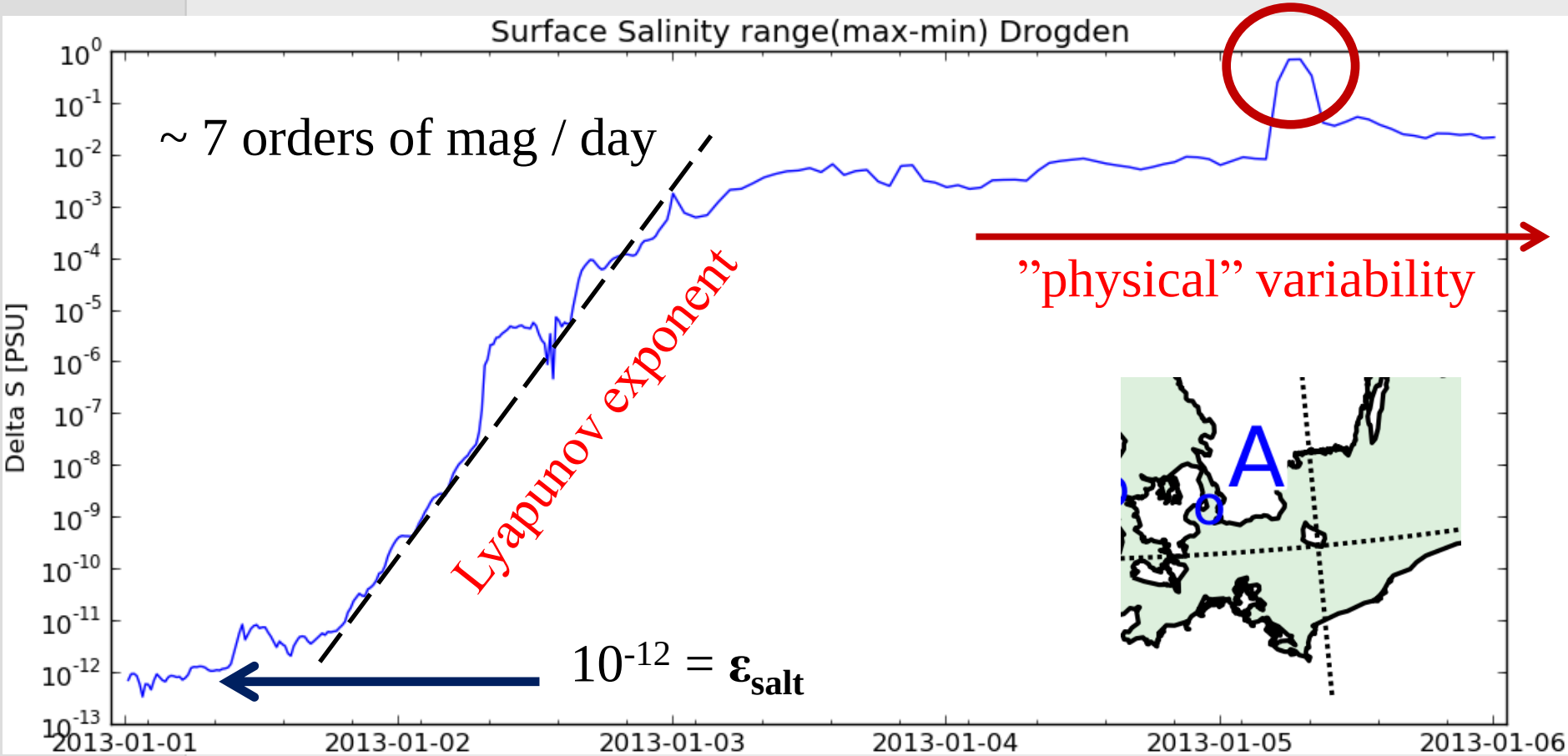
MAX_t AVG_t Changed scale



High MAX_t / AVG_t ratio => Near-max-events rare

Initial development

Drogden range=max(SSS) – min(SSS)

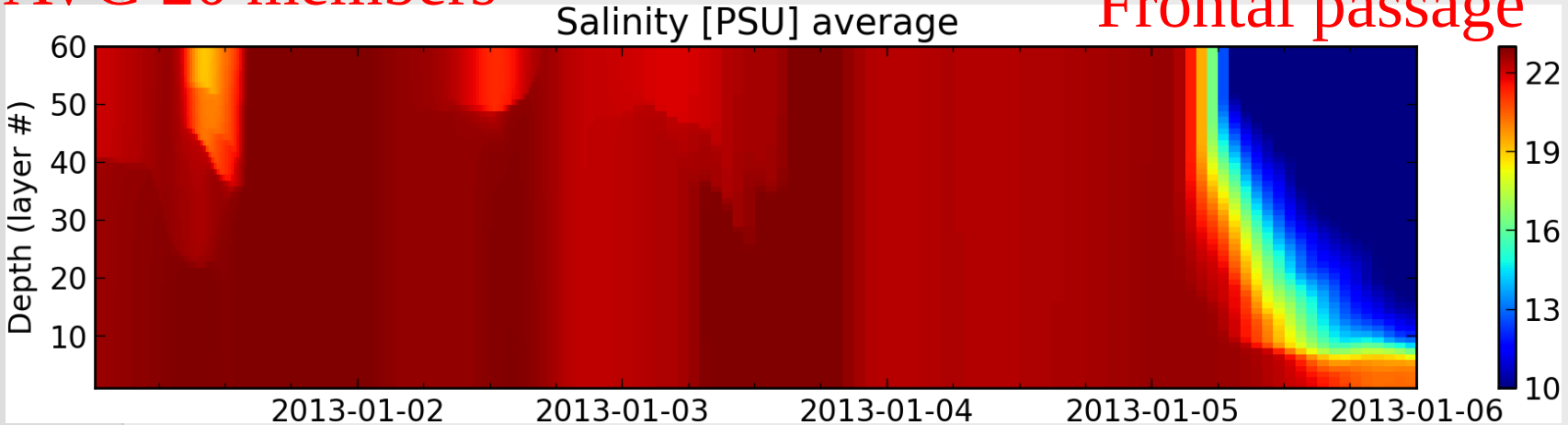


Initial development

Drogden

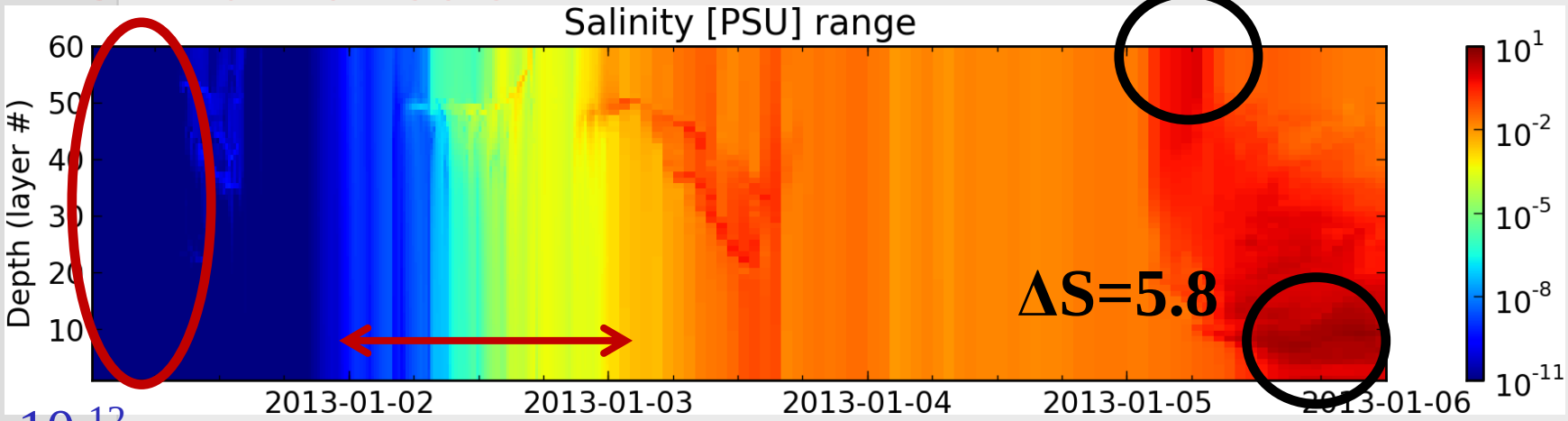
AVG 20 members

Frontal passage



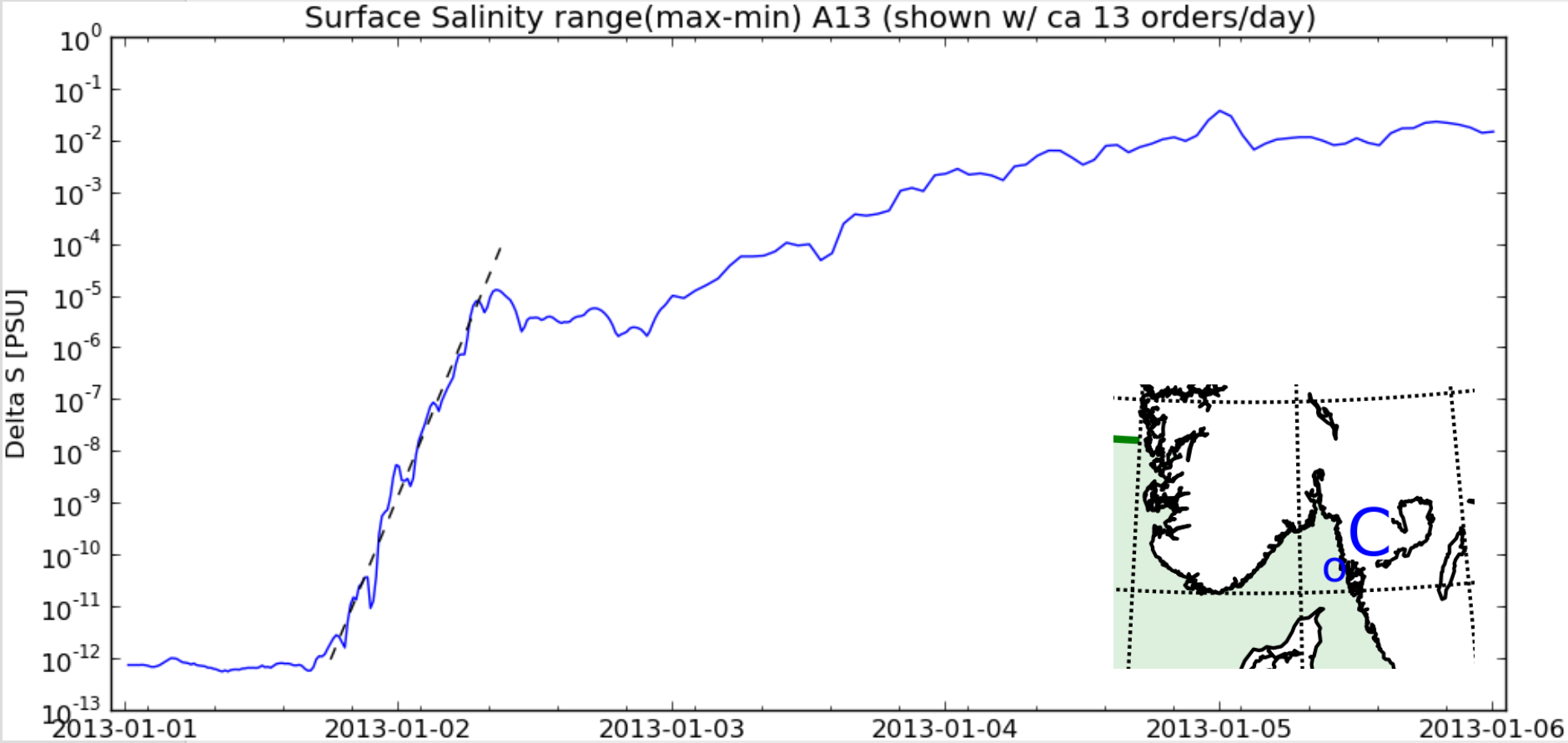
RANGE 20 members

ΔSSS=0.97

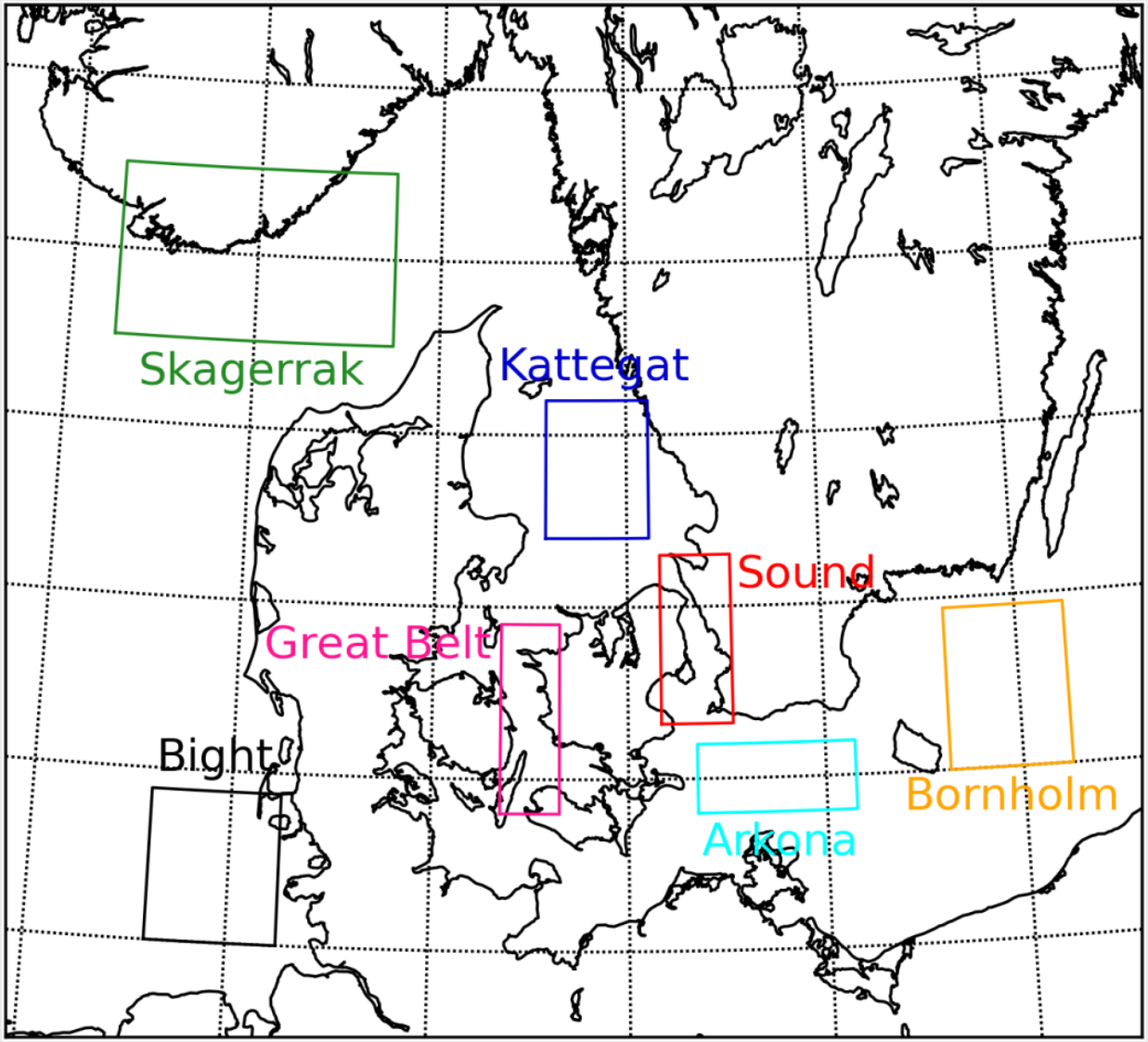


$10^{-12} = \varepsilon_{salt}$ EXP growth

Initial development

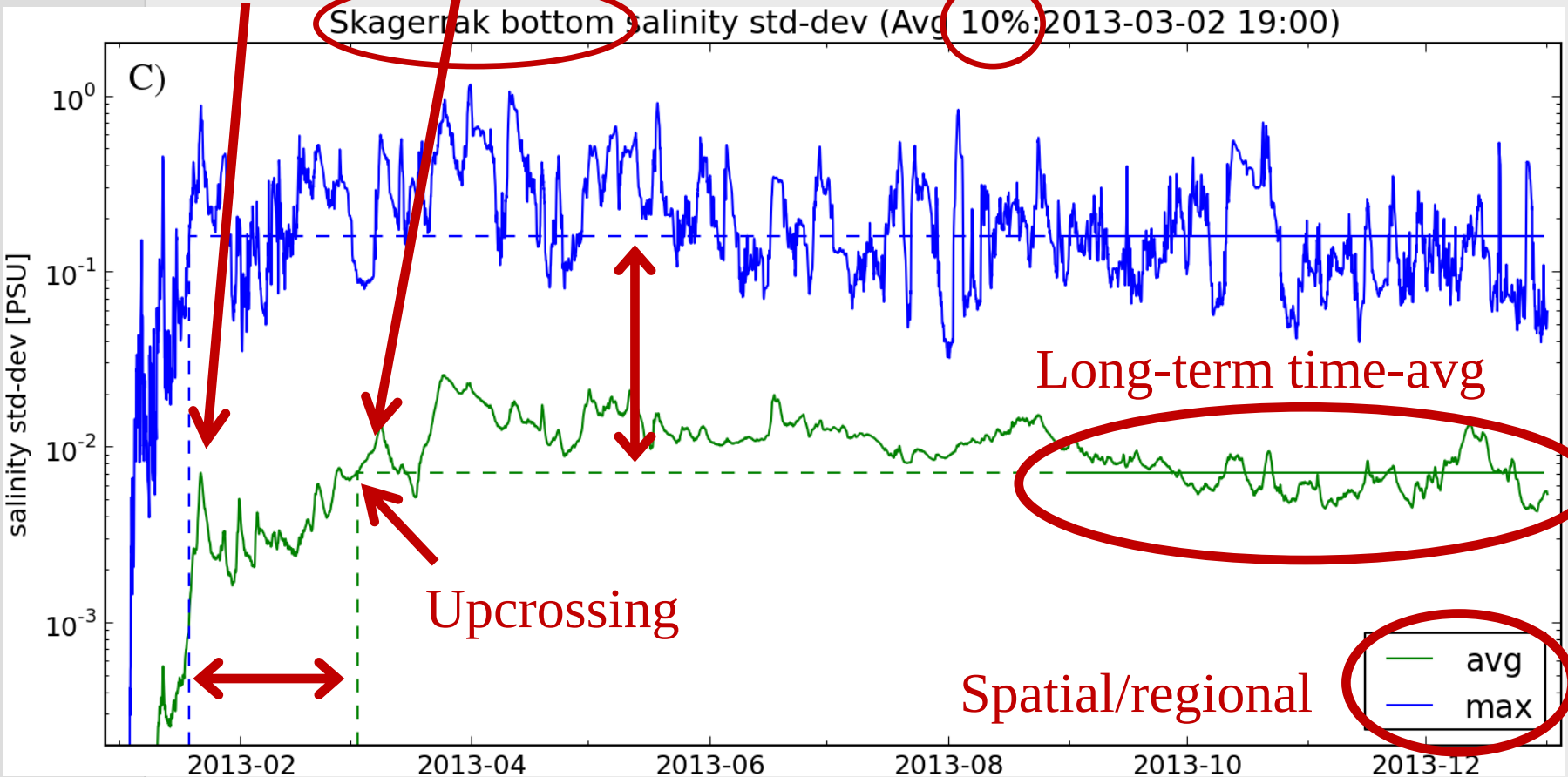


Longer time scales? Regional differences!



Long-term development

Magnitude and time scale



Salt STD-DEV per region

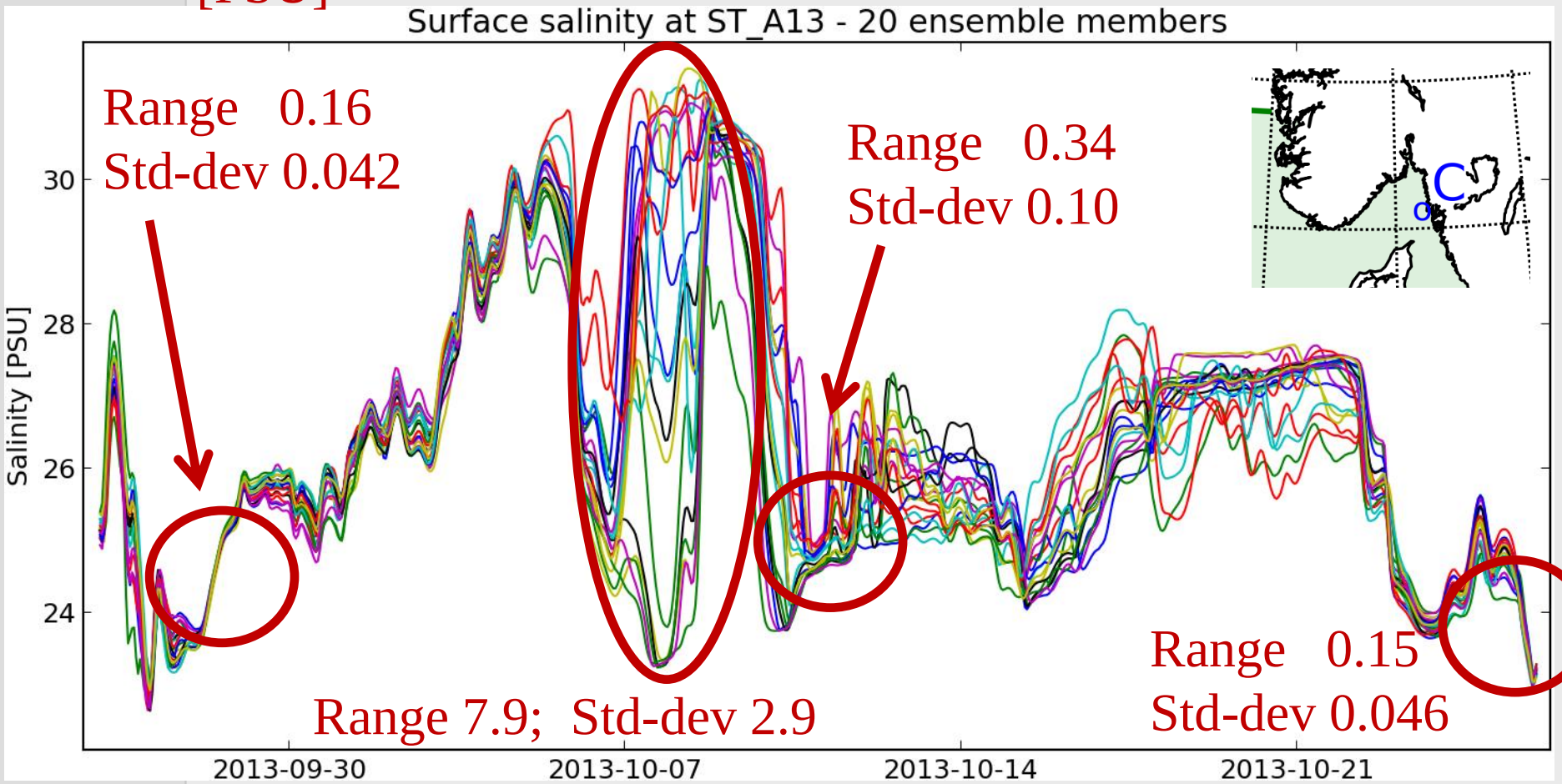
AVG (time, area)

Region		STD-DEV [PSU]	Time-scale [days]
Great Belt	Surface	0.02	~ 5
Great Belt	Bottom	0.02	~ 7
German Bight	Surface	0.007	~ 10
German Bight	Bottom	0.005	~ 13
Skagerrak	Surface	0.14	~ 21
Skagerrak	Bottom	0.07	~ 61
Arkona	Surface	0.02	~ 43
Arkona	Bottom	0.05	~ 24

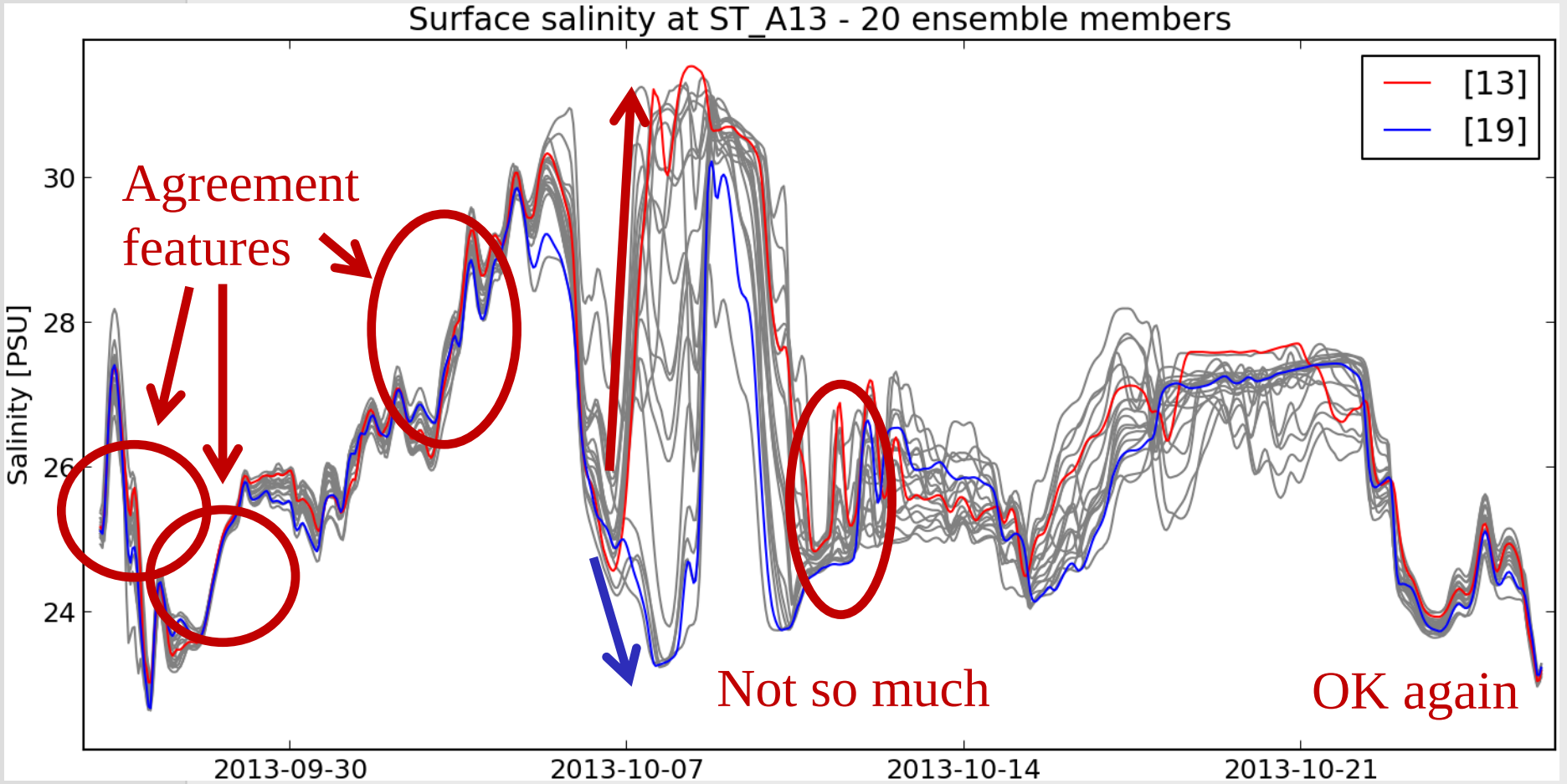
~ factor 30 ~ factor 10

Event in Eastern Skagerrak

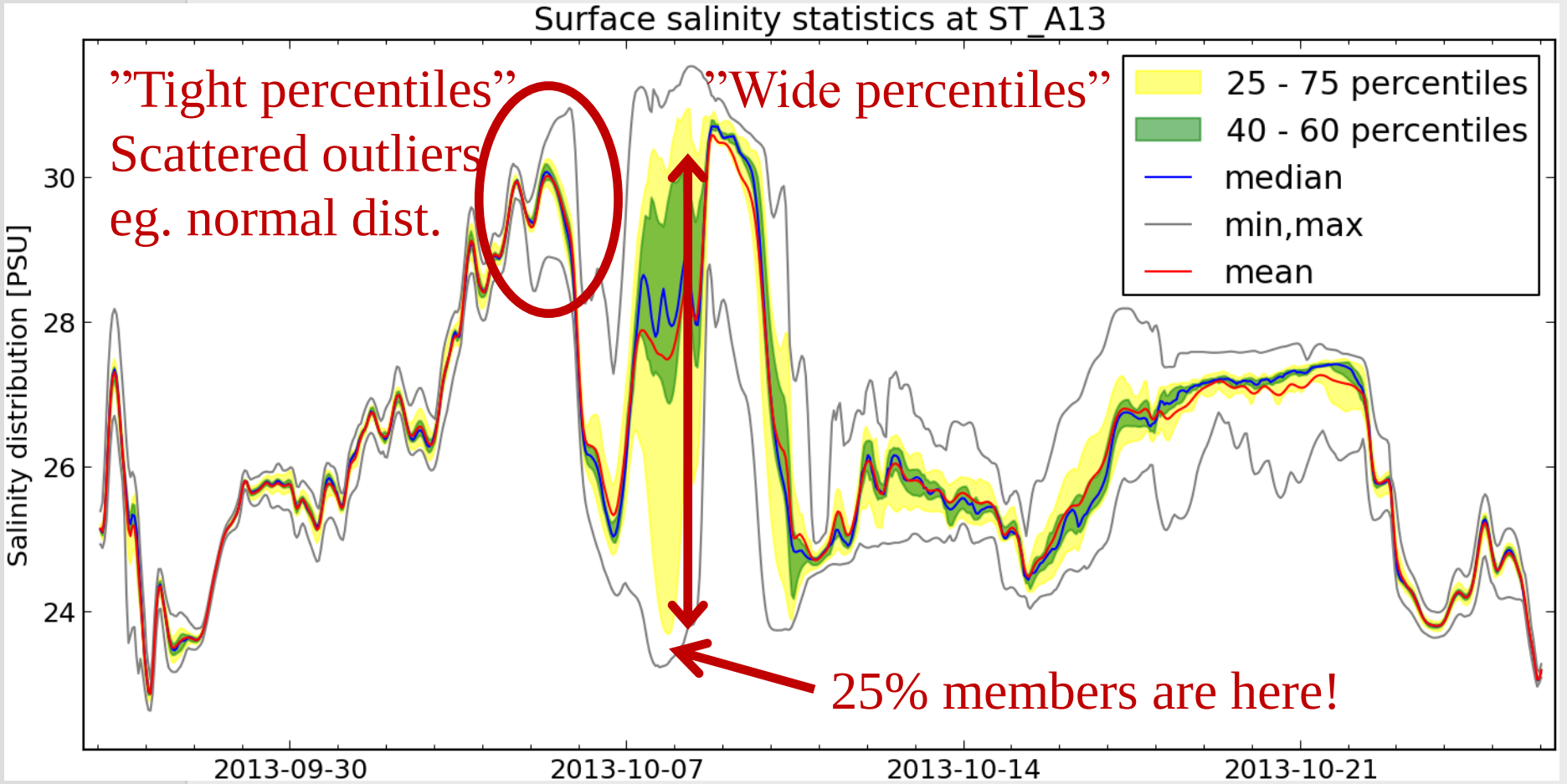
[PSU]



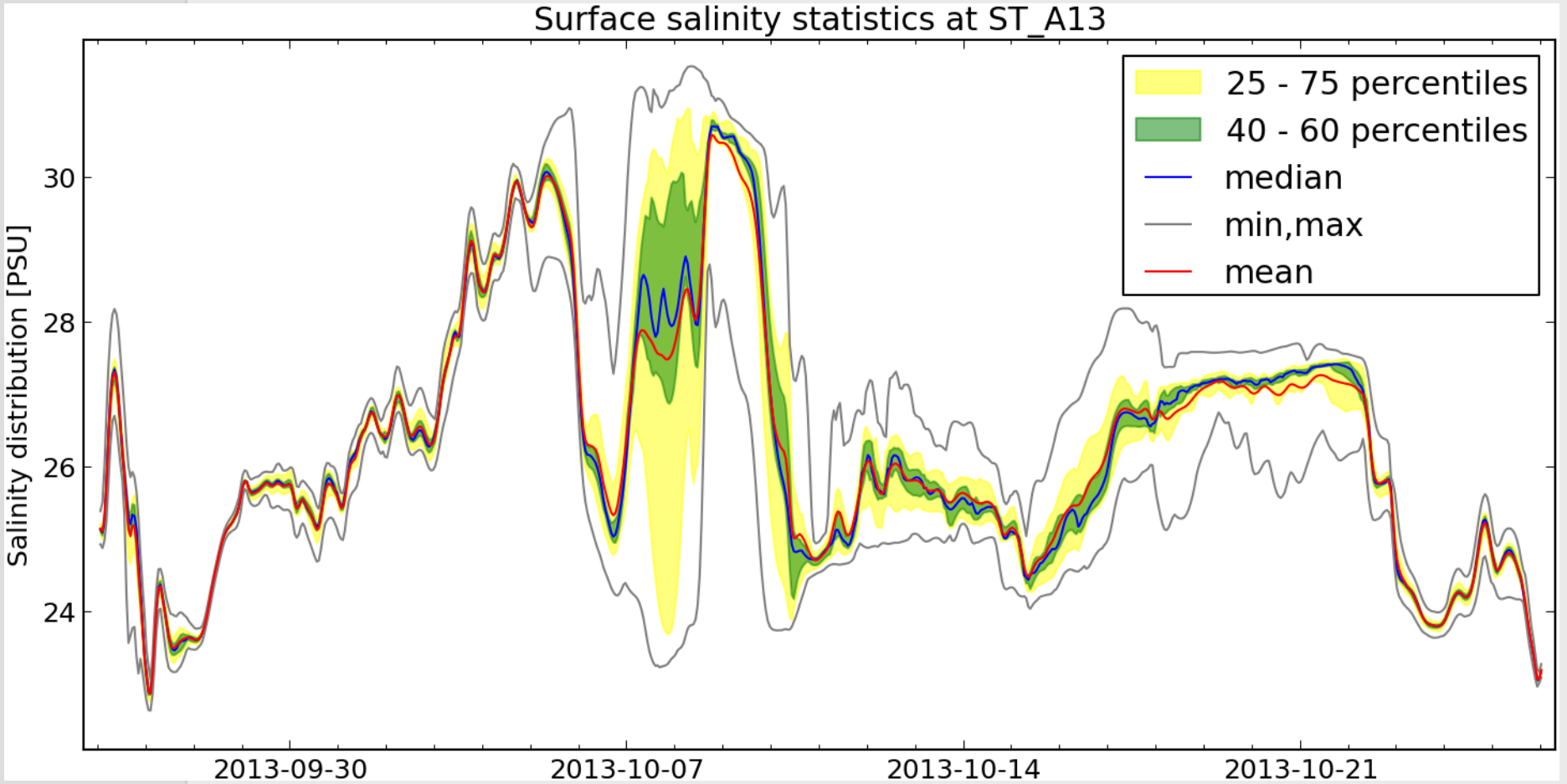
Two members (example)



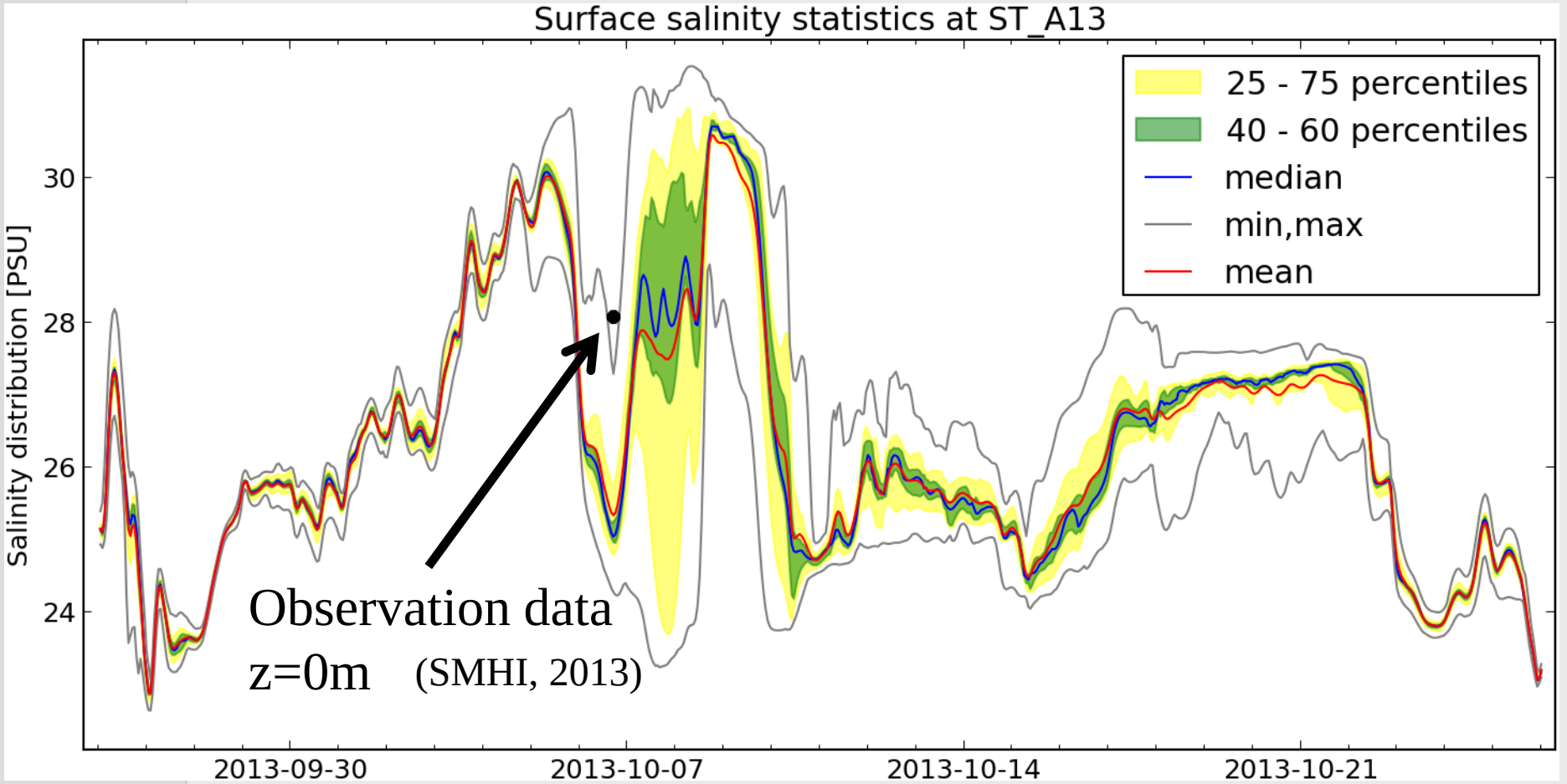
Statistics (example)



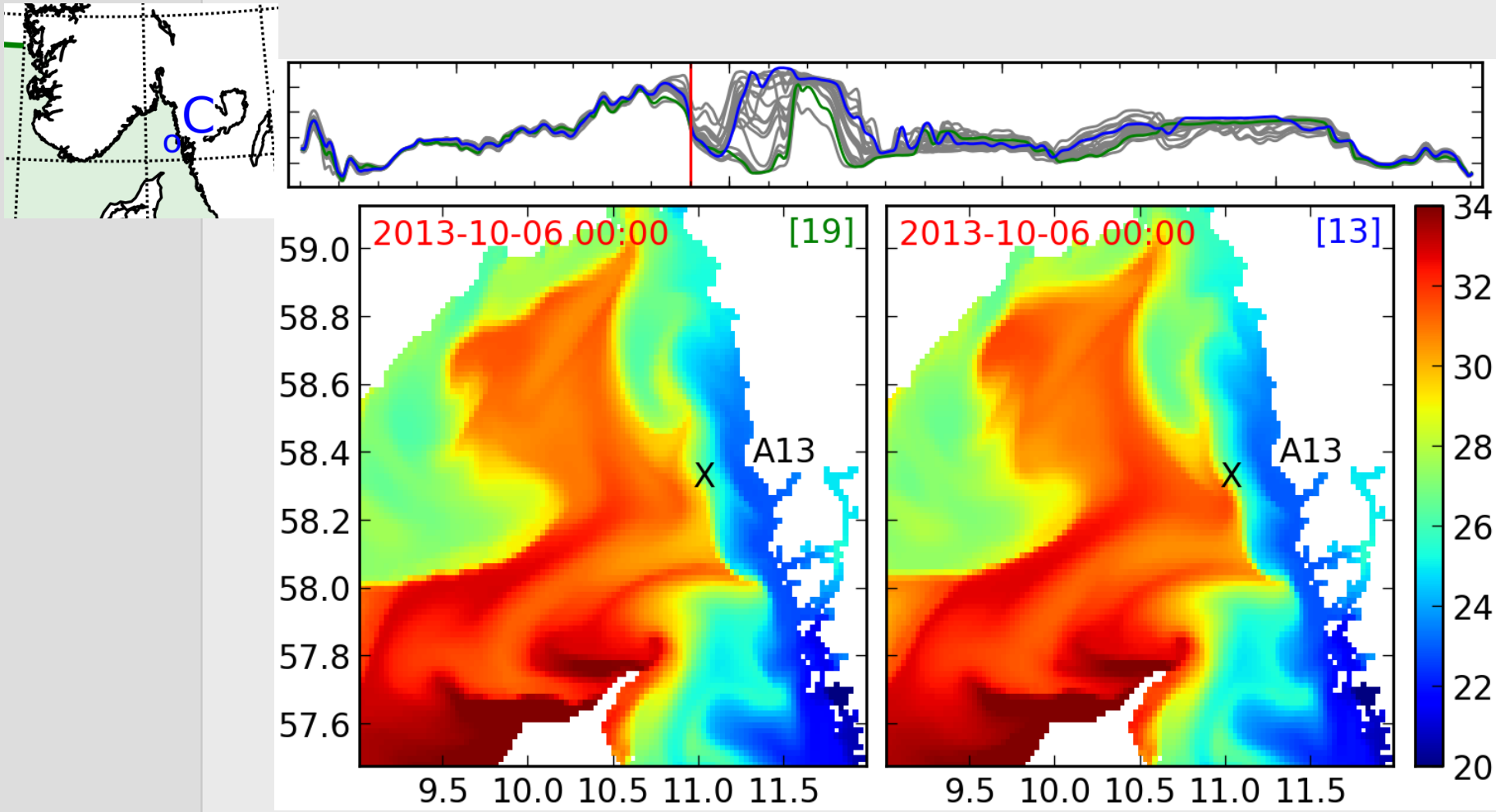
Statistics (example)



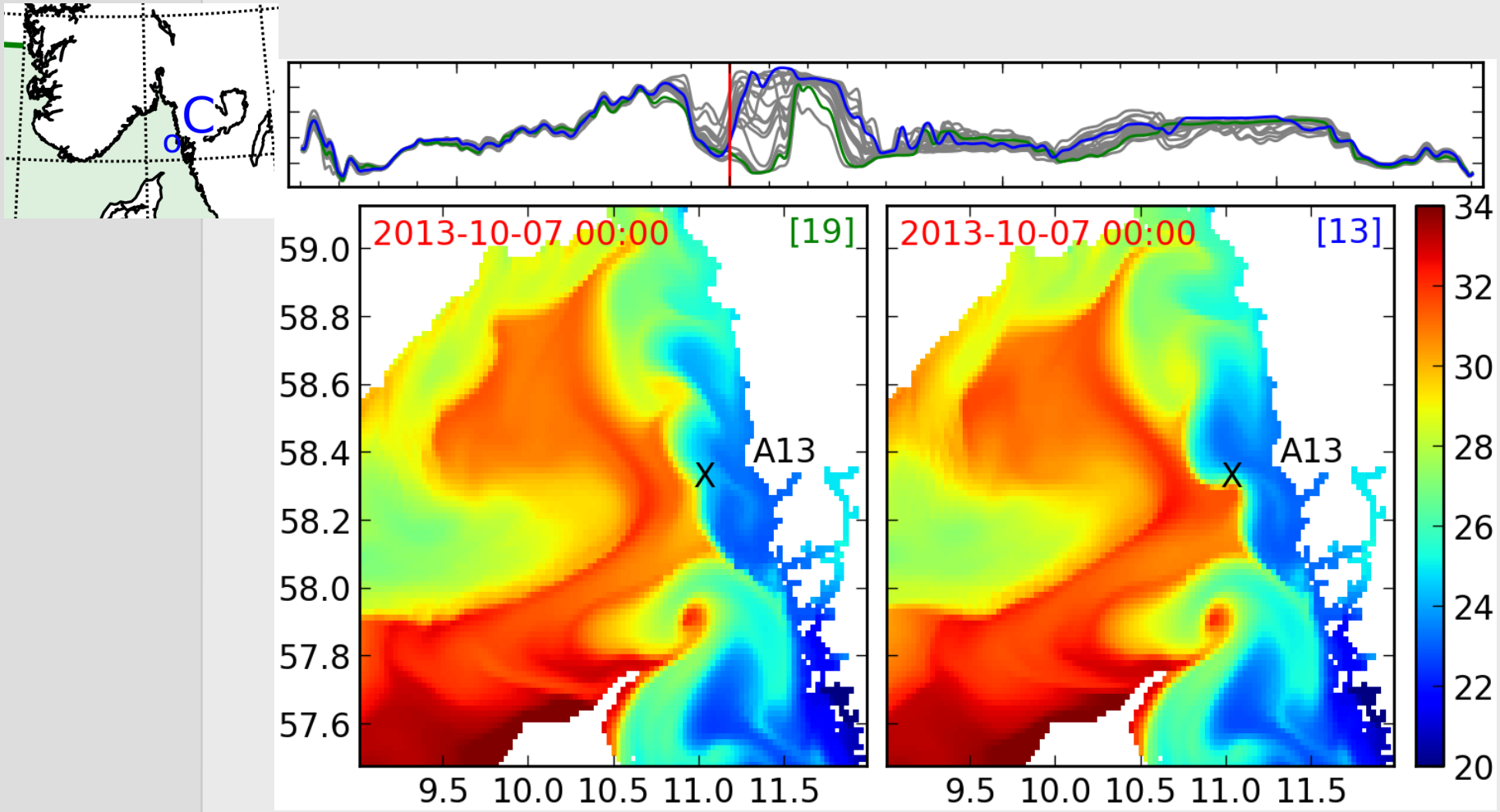
Statistics (example)



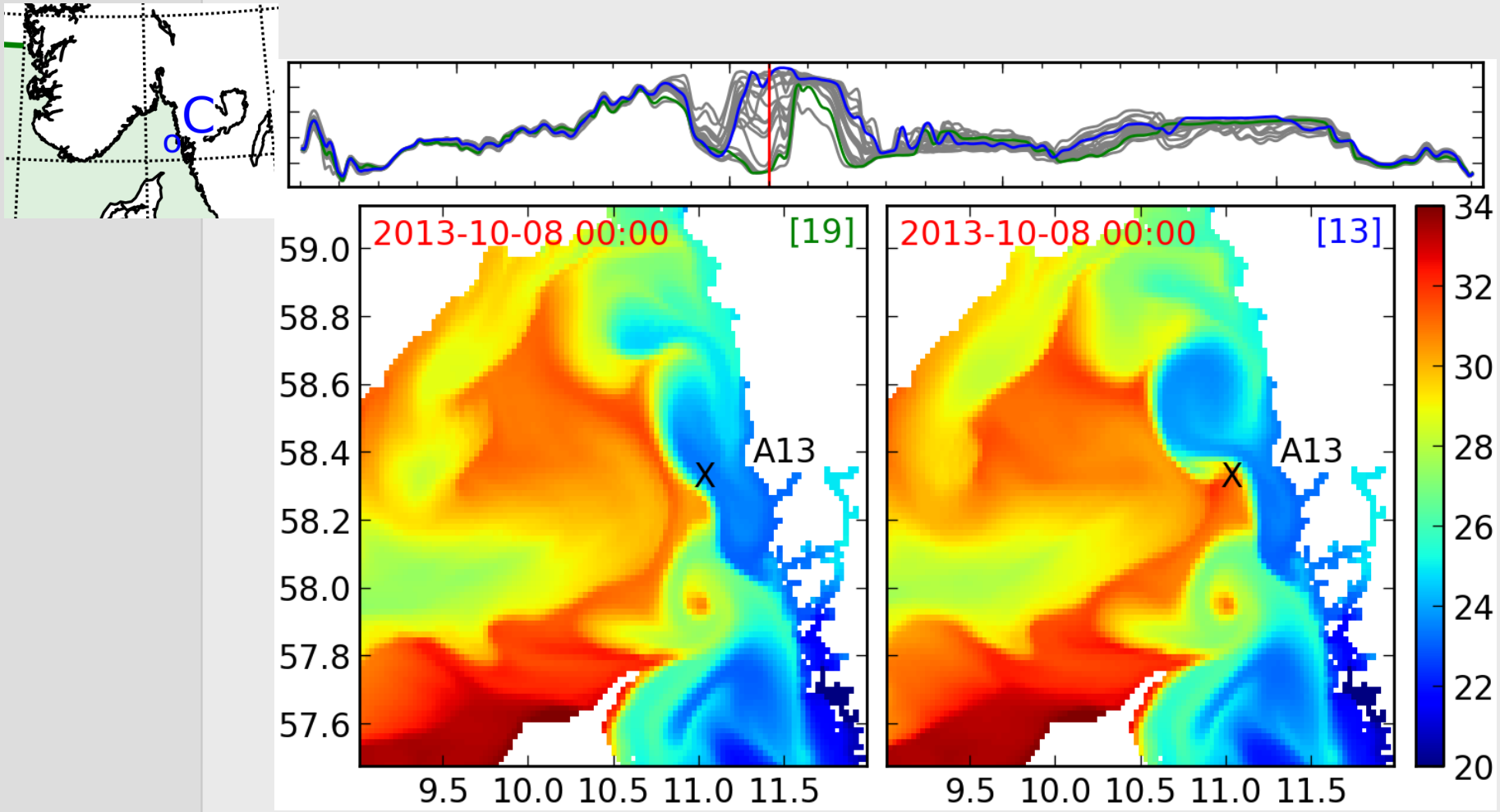
Surface Salt variation



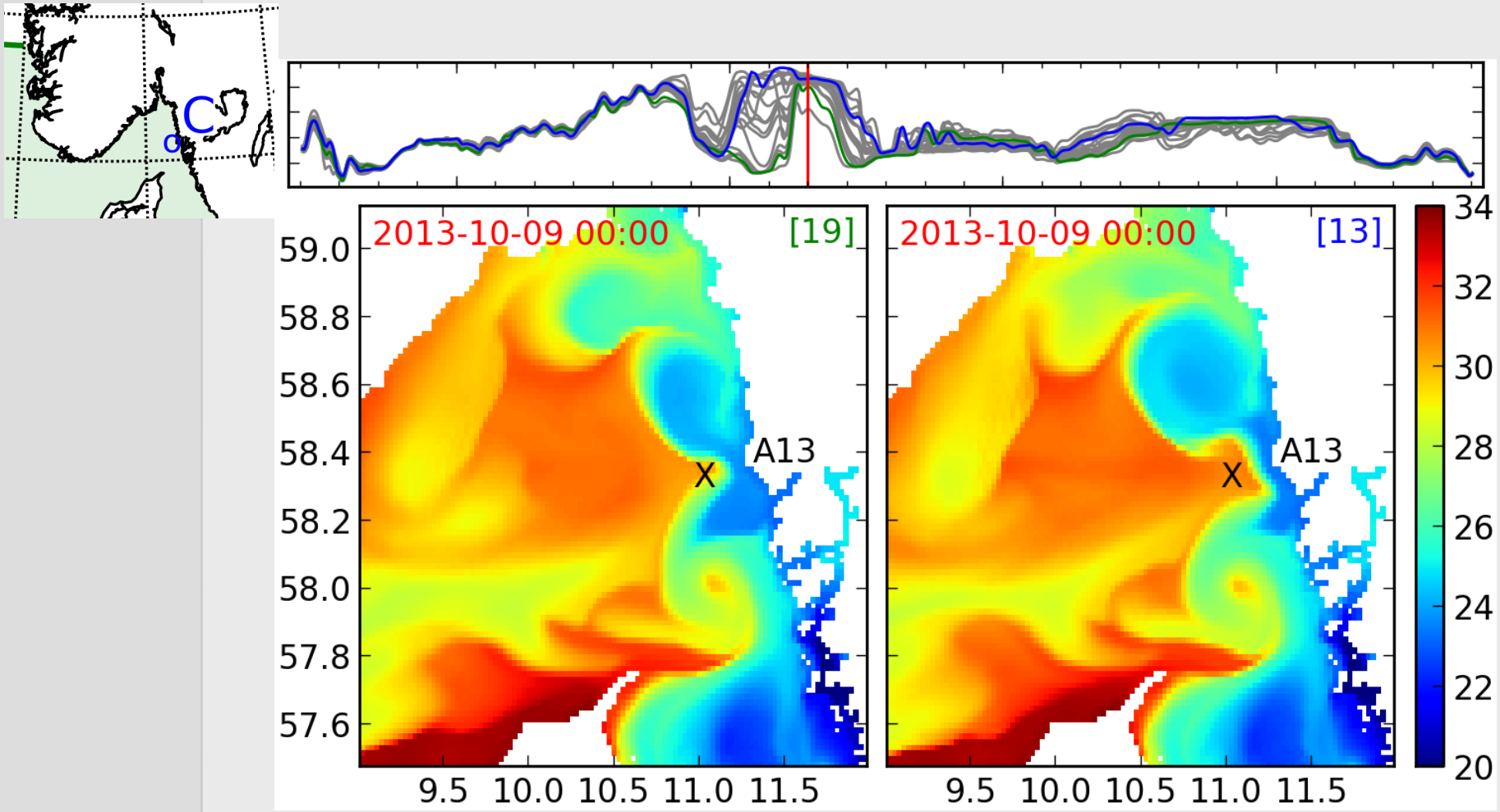
Surface Salt variation



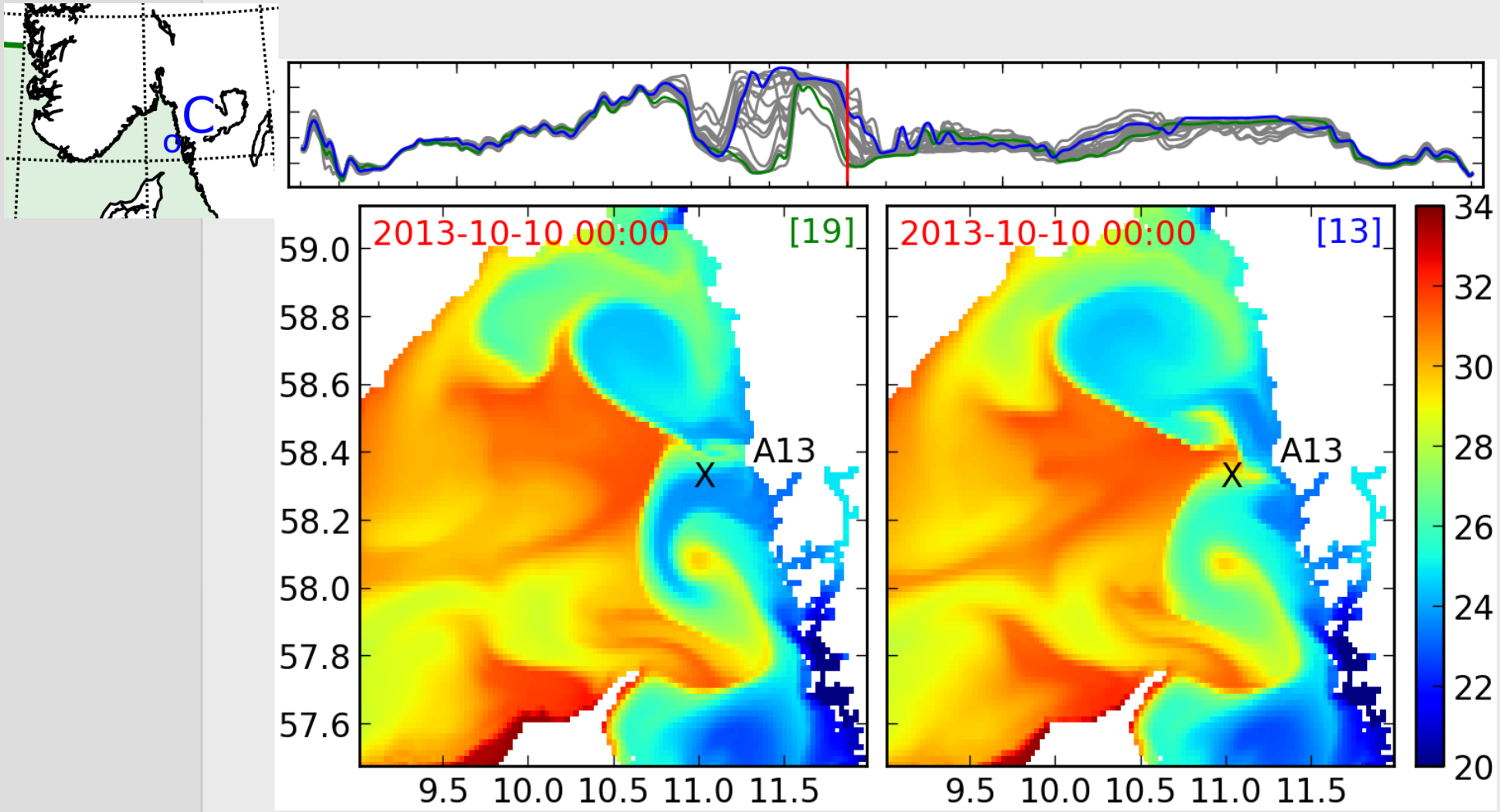
Surface Salt variation



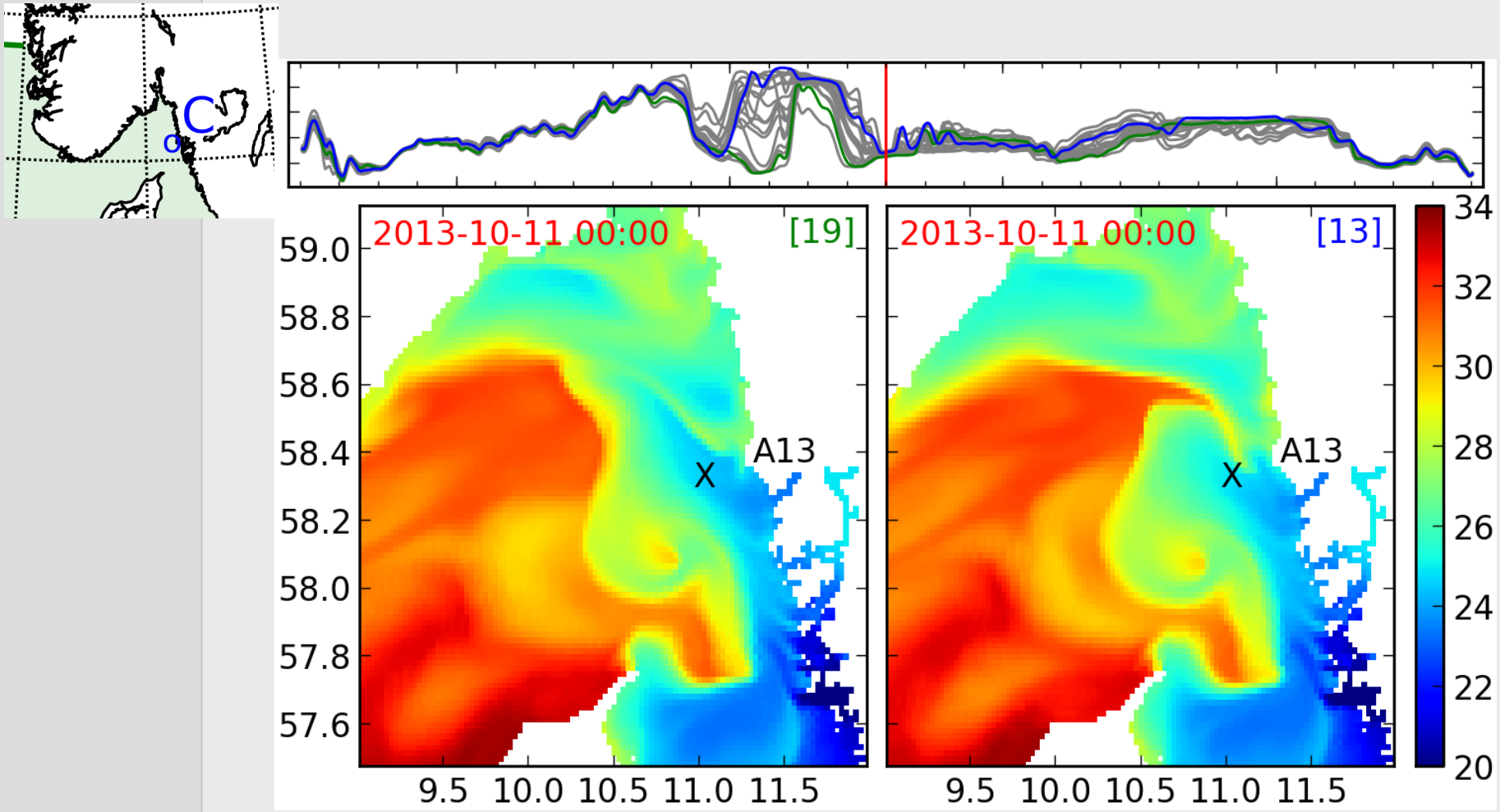
Surface Salt variation



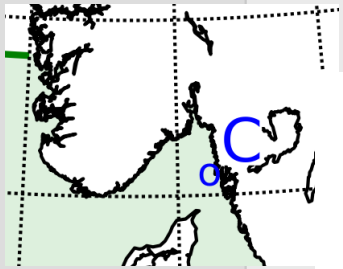
Surface Salt variation



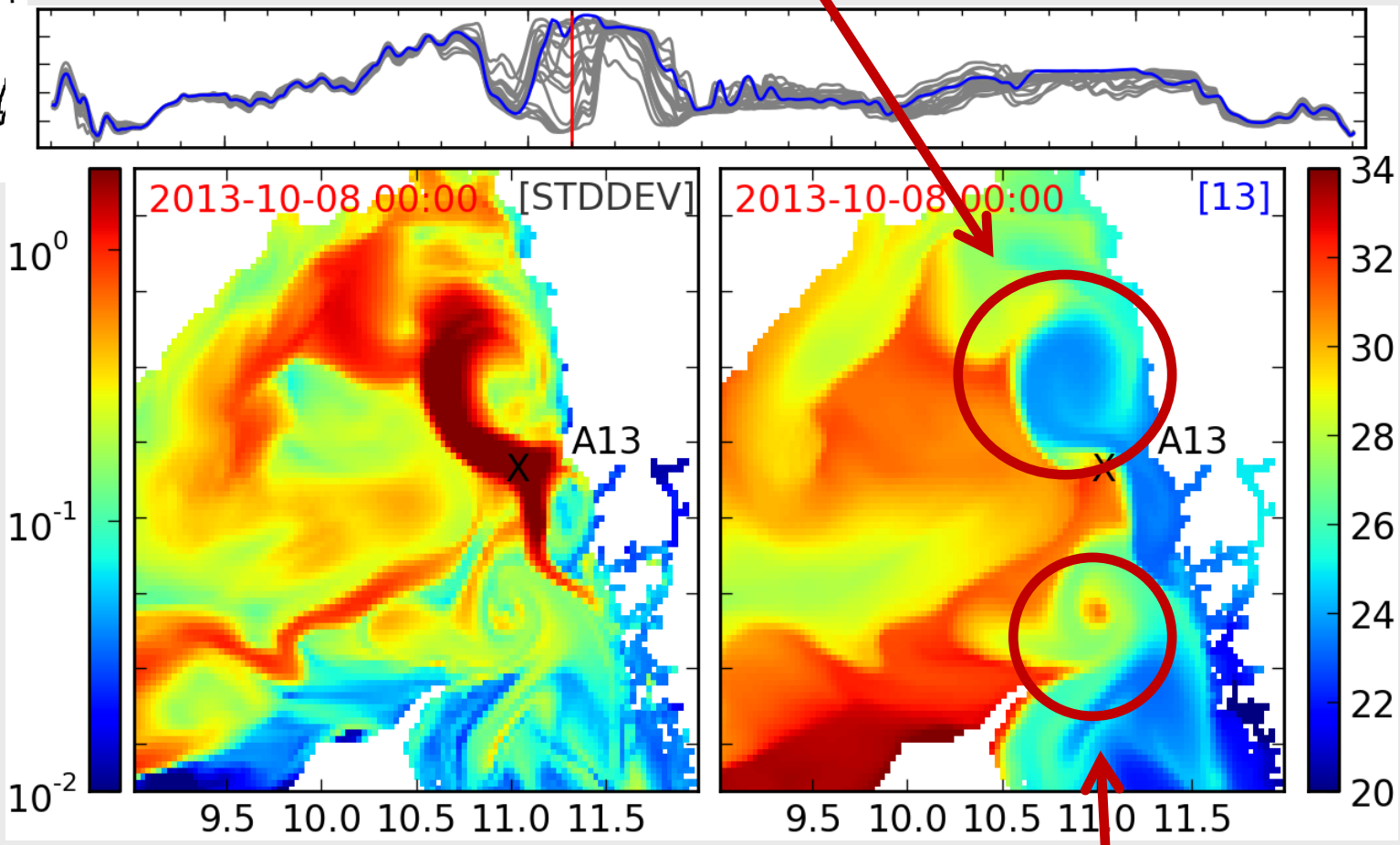
Surface Salt variation



Surface Salt variation



”Stochastic” eddy

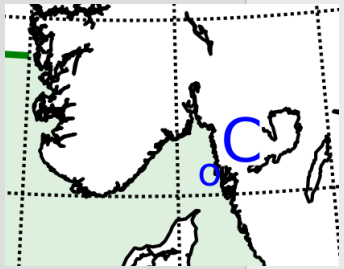


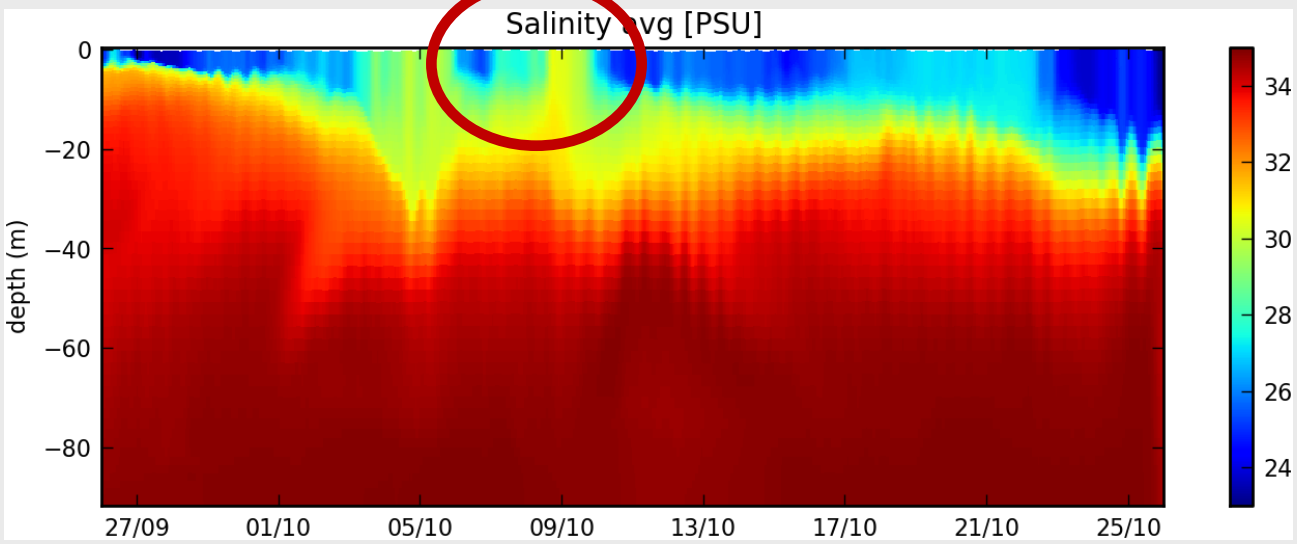
”Free” vs. ”Forced” meso-scale activity

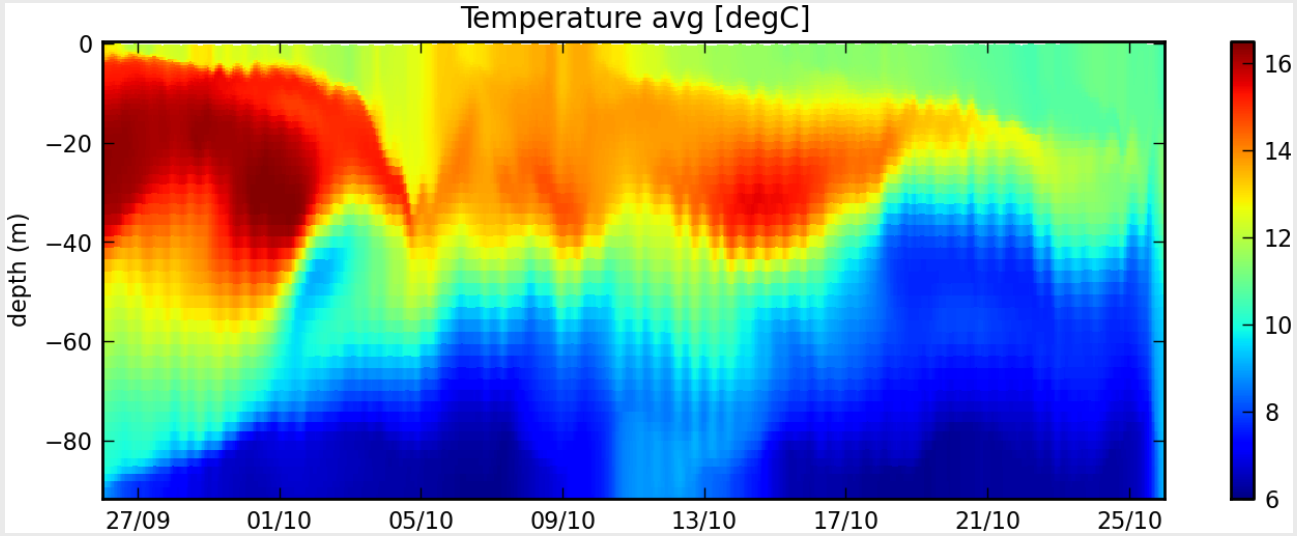
”Deterministic” eddy

Time-depth variation

High SSS variability

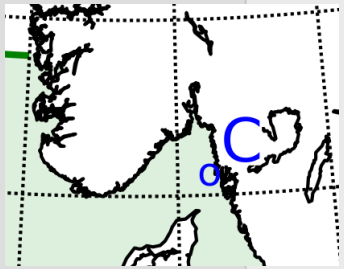


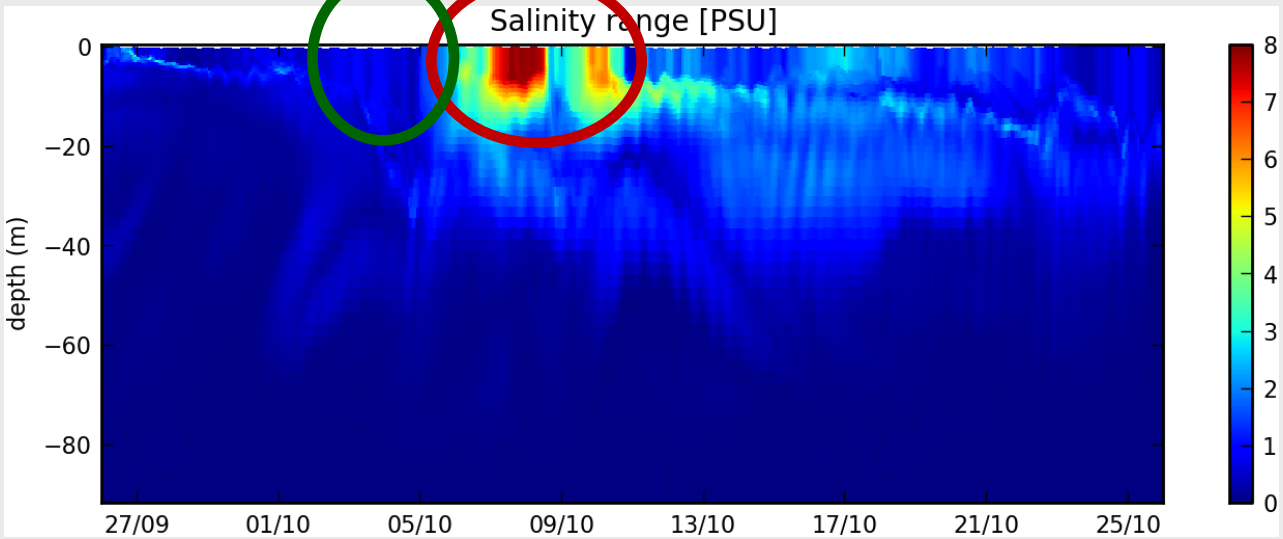




Time-depth variability

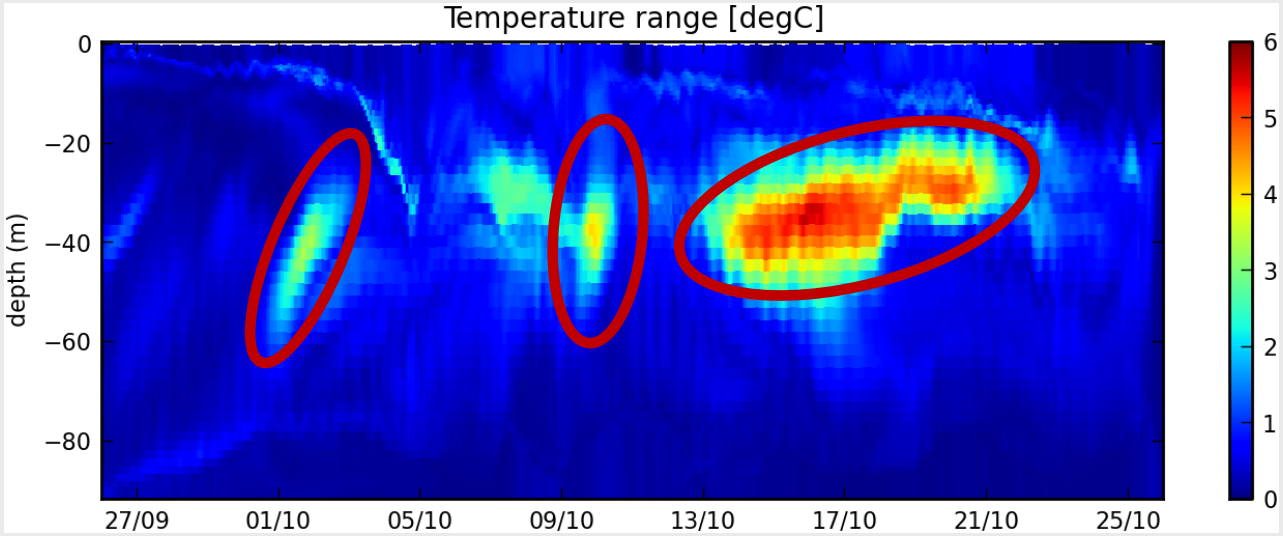
RANGE Low High





SALT

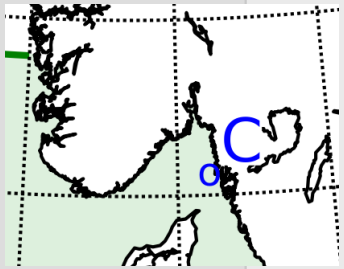
High TEMP variability



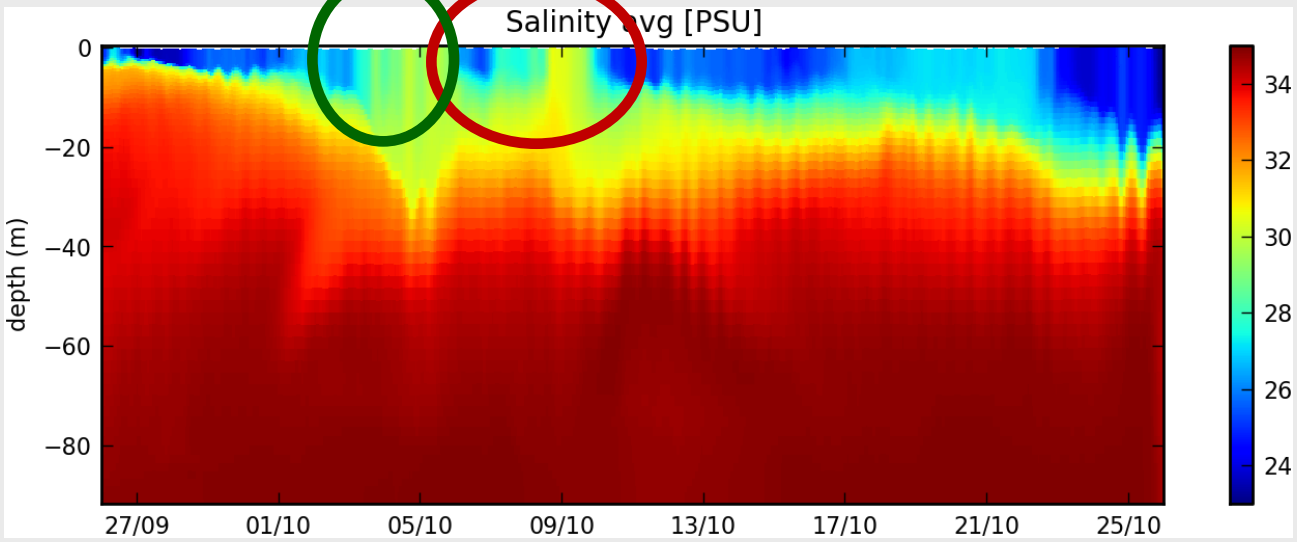
TEMP

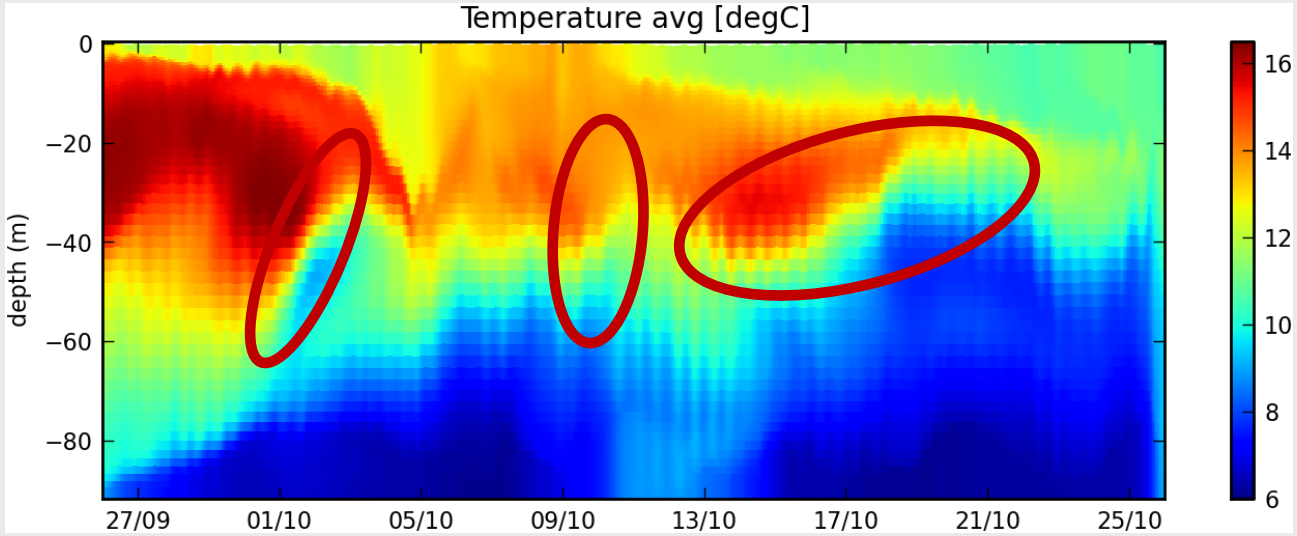
Time-depth variation

Low High

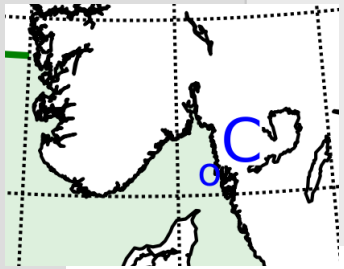


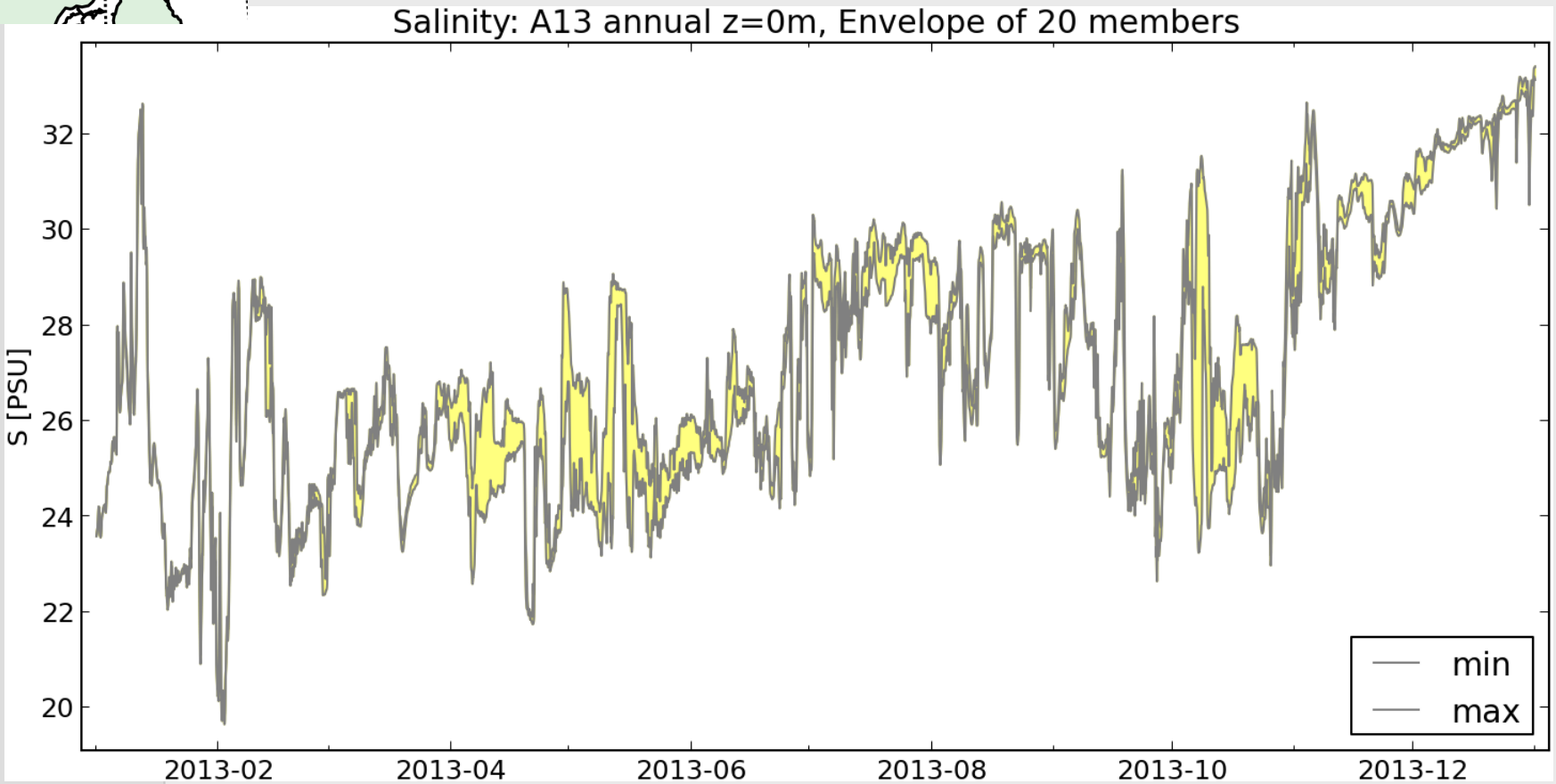
Not easy to guess(?)



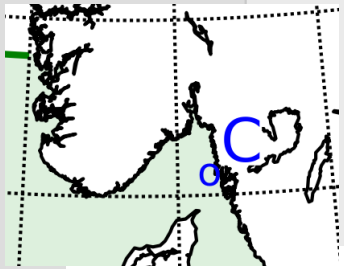


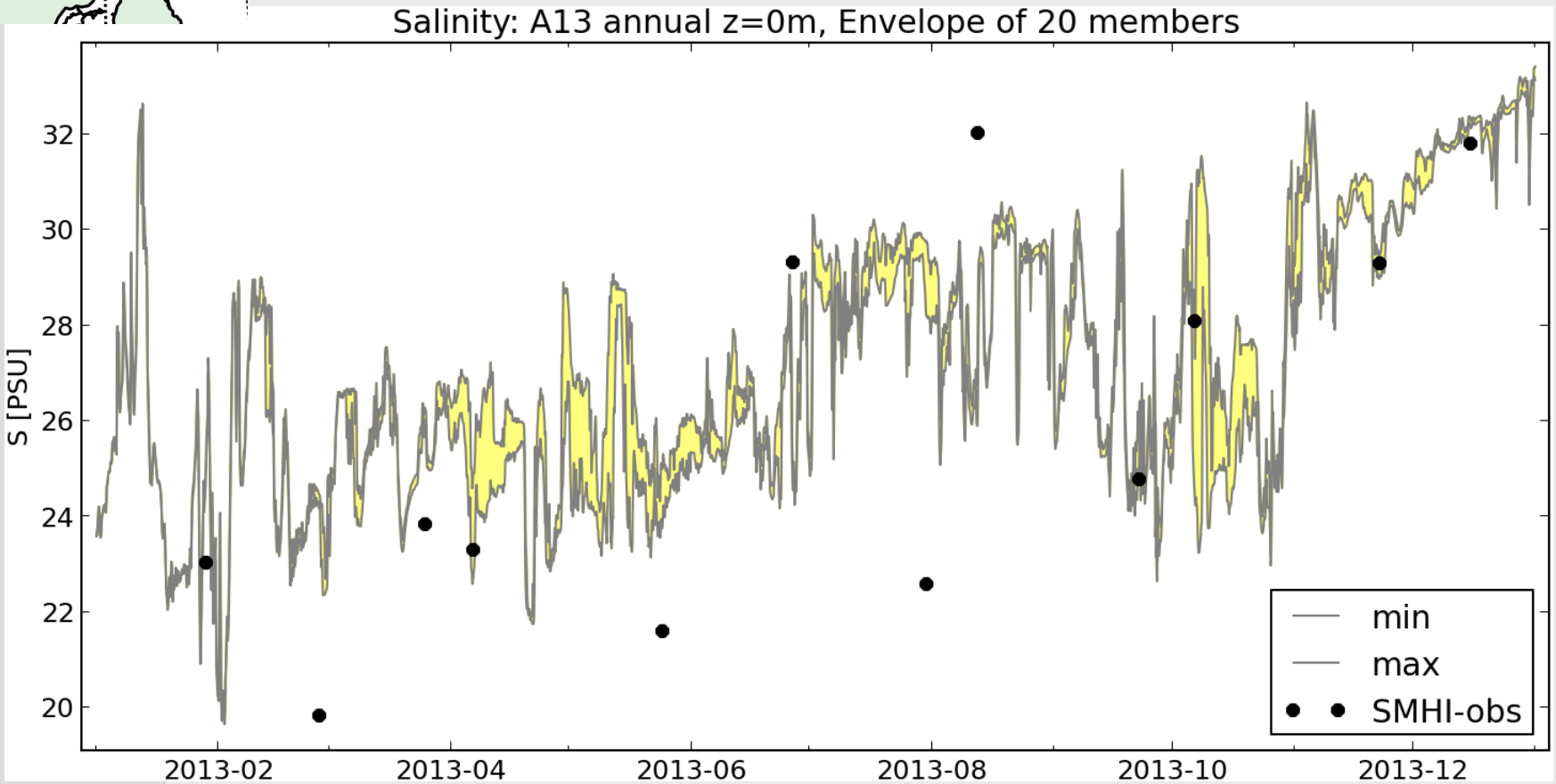
Back to compare w/ obs



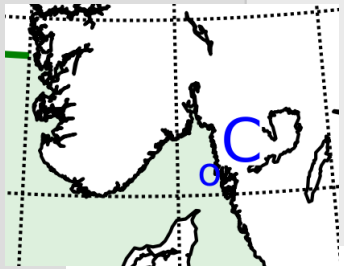


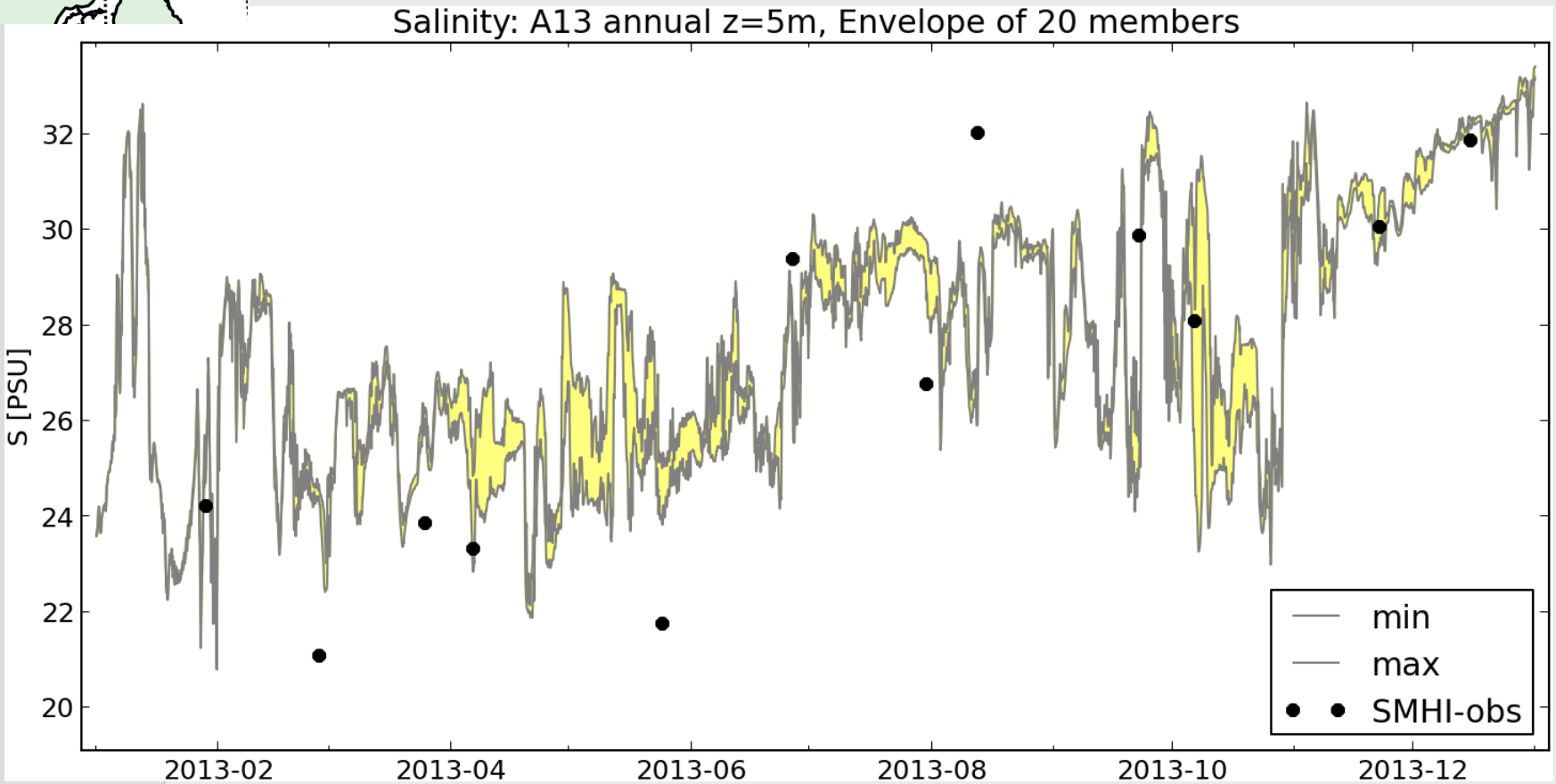
Back to compare w/ obs





Back to compare w/ obs





Conclusions

- **Stochastic/chaotic system**
  Nature and model BOTH

- **Single model setup**
- **Infinitesimal perturbations**
- **Large ensemble variabilty**

- **Time scale of evolution**
- **Model validation**
  vs. Solution validation

Conclusions

- **Difference (ensemble range) WITHIN a setup:**
  O(10PSU)
  O(10degC)

- **Same time and position**
- **IDENTICAL settings**
- **IDENTICAL forcing**

- **Infinitesimal initial perturb.**