Toward uncertainty characterization for high-resolution near-shore models

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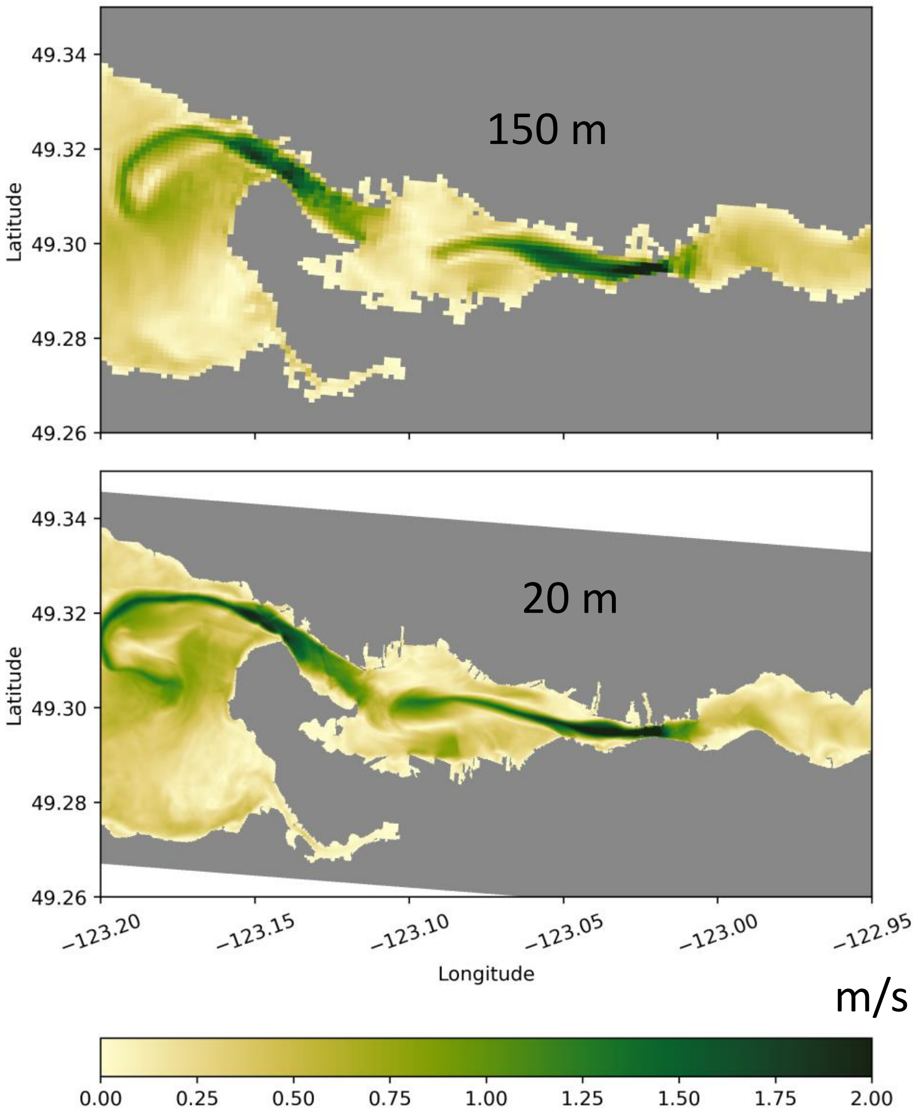
Introduction

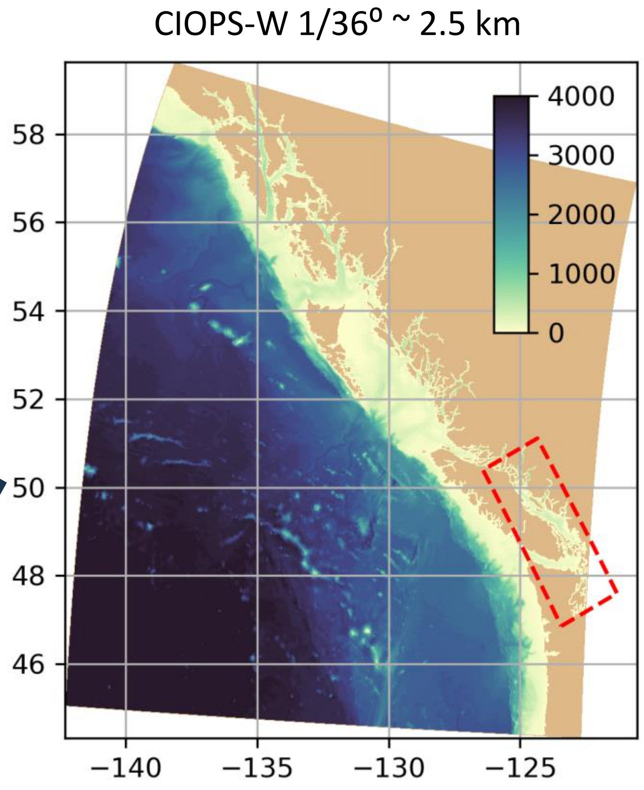
- We've built high-resolution ocean models for six Canadian ports & approaches
- Water level, near-surface current forecasts to support electronic navigation and drift prediction
- There is a need to provide uncertainty/error estimates with the forecasts
- *Ongoing* effort on uncertainty characterization:
  - Model setup
  - Ensemble-based approach
  - Some early results
  - Next steps

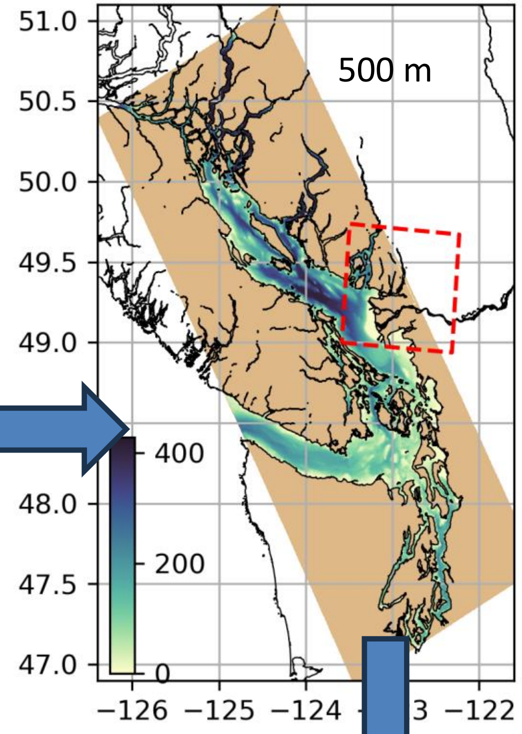
Vancouver Harbour surface currents

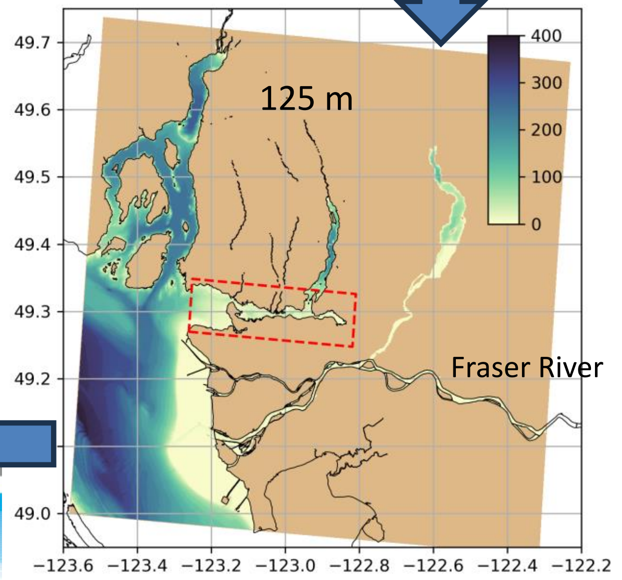


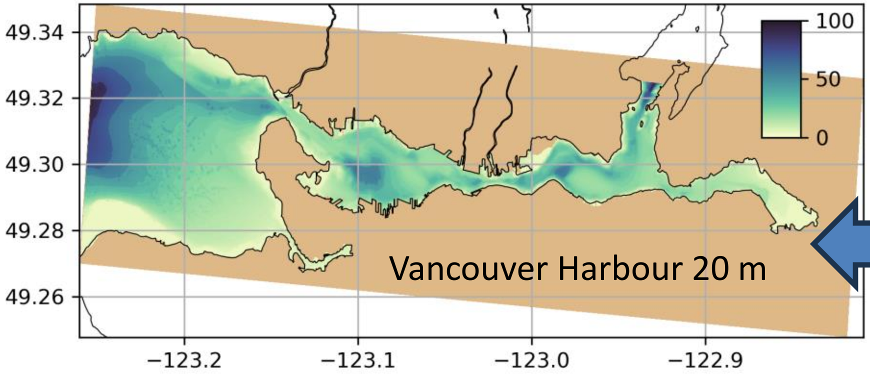
Model setup (one port)

- The port models are free runs without data assimilation or nudging
- GIOPS (1/4^o global)
  - → RIOPS (1/12^o regional)
    - → CIOPS-W (1/36^o Northeast Pacific)
      - → Salish Sea 500 m
        - → South Salish Sea 125 m
          - → Vancouver Harbour 20 m
- Surface forced by HRDPS (2.5 km) atmospheric model
- Gauged and climatological runoff
- NEMO v3.6



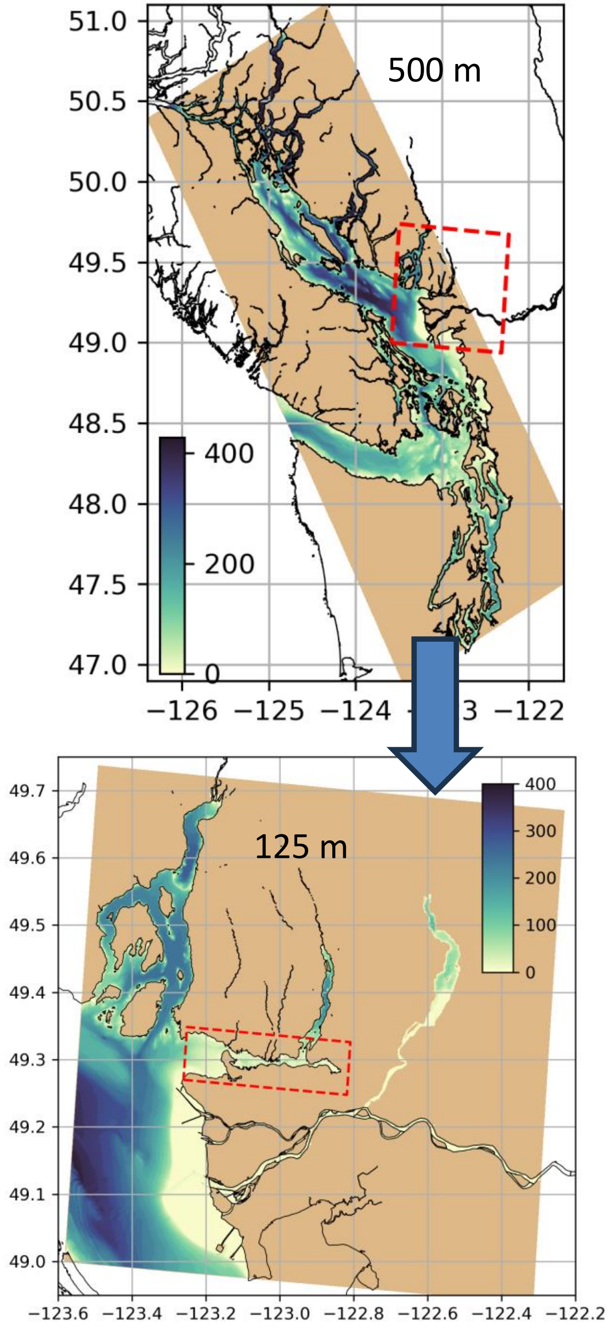






Characterizing uncertainty

- Use ensemble of hindcasts,
  - Derive "climatological" model uncertainty
  - May be pessimistic vs. an error-of-the-day estimate
  - Check consistency with model-observation error statistics
- Precursor to potential ensemble-data assimilation system
- From perturbation tests at the 125 m domain,
  - Found deterministic lateral boundary "removes" ensemble spread akin to restoring term
- Synthesize ensembles at 500 m, downscale for 125m & 20m



Physics perturbations

STOPACK for NEMO (Storto and Andriopoulos, 2021)

- Online injection of perturbations
- AR(1) process with time scale τ
- 2D smoothed noise in space

- SPP:
  - τ = 10 d, filter 100 passes

- SPPT:
  - τ = 6 h, filter 75 passes, std 0.25
  - momentum inflation 0.5, sppt_step 1

- Stochastic Kinetic Energy Backscatter (SKEB)
  - Not enabled

Stochastic Parameter Perturbations (SPP)	STD
Vertical mixing (avt, avm)	10%, 10%
Lateral diffusivity (ahtu, ahtv, ahtw)	10%, 10%, 10%
Lateral viscosity (ahm1, ahm2)	10%, 10%
Bottom friction (bfr)	5%
Solar radiation penetration (qsi0)	5%
Relative wind coefficient (relw)	10%

Stochastically Perturbed Parameter Tendency (SPPT)
Lateral diffusion (traldf)
Solar radiation (traqsr)
Lateral viscosity (traldf)

Surface forcing perturbations

- Lack ensemble atmospheric forcing at suitable resolution
  - Instead synthesize via an EOF-based method
- Used by numerous authors although details vary
  Ex: Jordà and De Mey (2010), Kim et al (2011), Ghantous et al (2020)
- Compute top N=40 modes, perturb the principal components with zero-mean AR(1) processes

$F = U\Sigma V^T$ $U\Sigma$: PCs, Σ: singular values, V: EOFs

$F \rightarrow F + \sum_N A_m U_m \Sigma_m V^T{}_m$ A_m: unique AR(1) process per mode

- A_m parameters: τ , σ
  - Same across modes
  - Set via model-observation analysis (autocorrelation, coherence)

Multivariate decomposition in three groups:

Surface forcing components	Time scale τ	Standard deviation σ
Surface winds u, v	18 hours	30%
Air temperature, air humidity, longwave radiation	12 hours	20%
Sea level pressure	48 hours	10%

Short wave radiation and precipitation not perturbed

- Could, but extra care needed to avoid negative values and retain zero-mean perturbations

Runoff perturbations

- Apply AR(1) process to the runoff

  → Repurpose the STOPACK SPP random field by applying it to the runoff data in NEMO

Stochastic Runoff Perturbations	Time scale	STD
Freshwater discharge	10d	8%
Freshwater discharge temperature	10d	3%

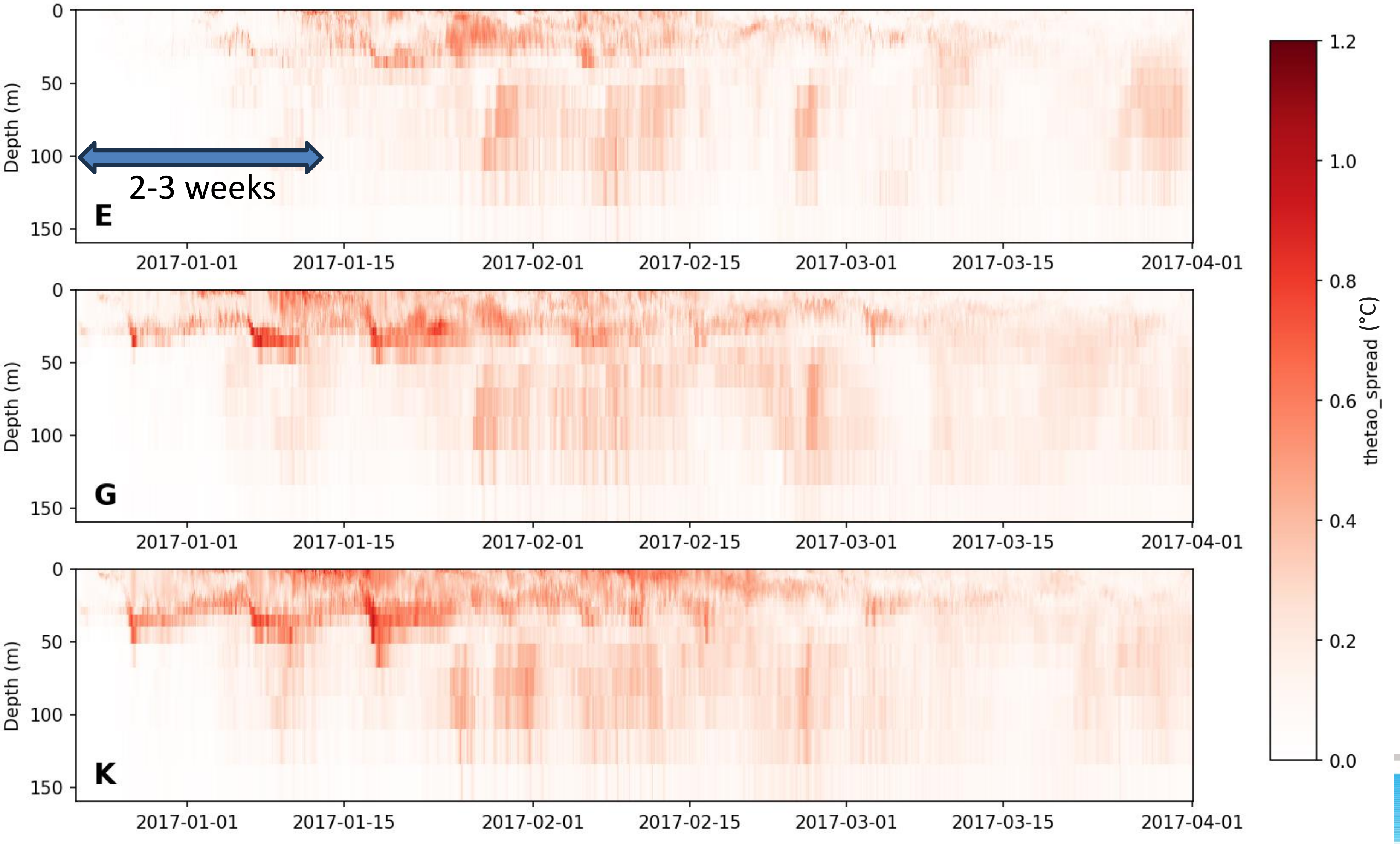
Ensemble experiments

- Three experiments with increasing level of perturbations
- 10 members, three years run (2017-19)

Ensemble set	Physics	Wind	Air temp, humidity, longwave and pressure	Runoff
E	X			
G	X	X		
K	X	X	X	X

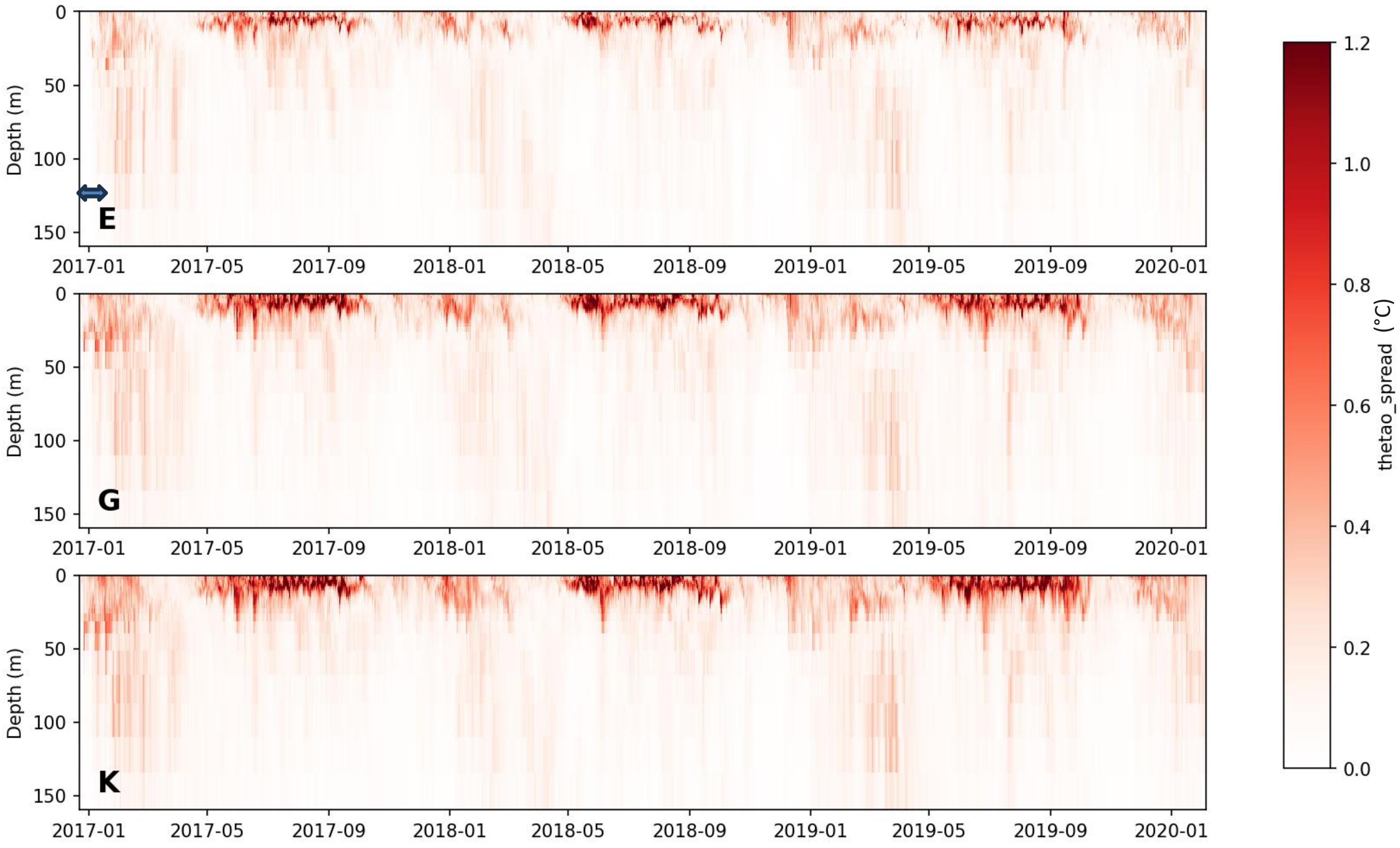
Spinup of ensemble spread (first 3 months)

- Temperature from a point in the middle of the domain
- 2016-12-22 start
- **E**: 2-3 weeks for STOPACK spread spinup
- **G,K**: less than a week
- **K** not very different from **G**
  → evidence that wind uncertainty is key



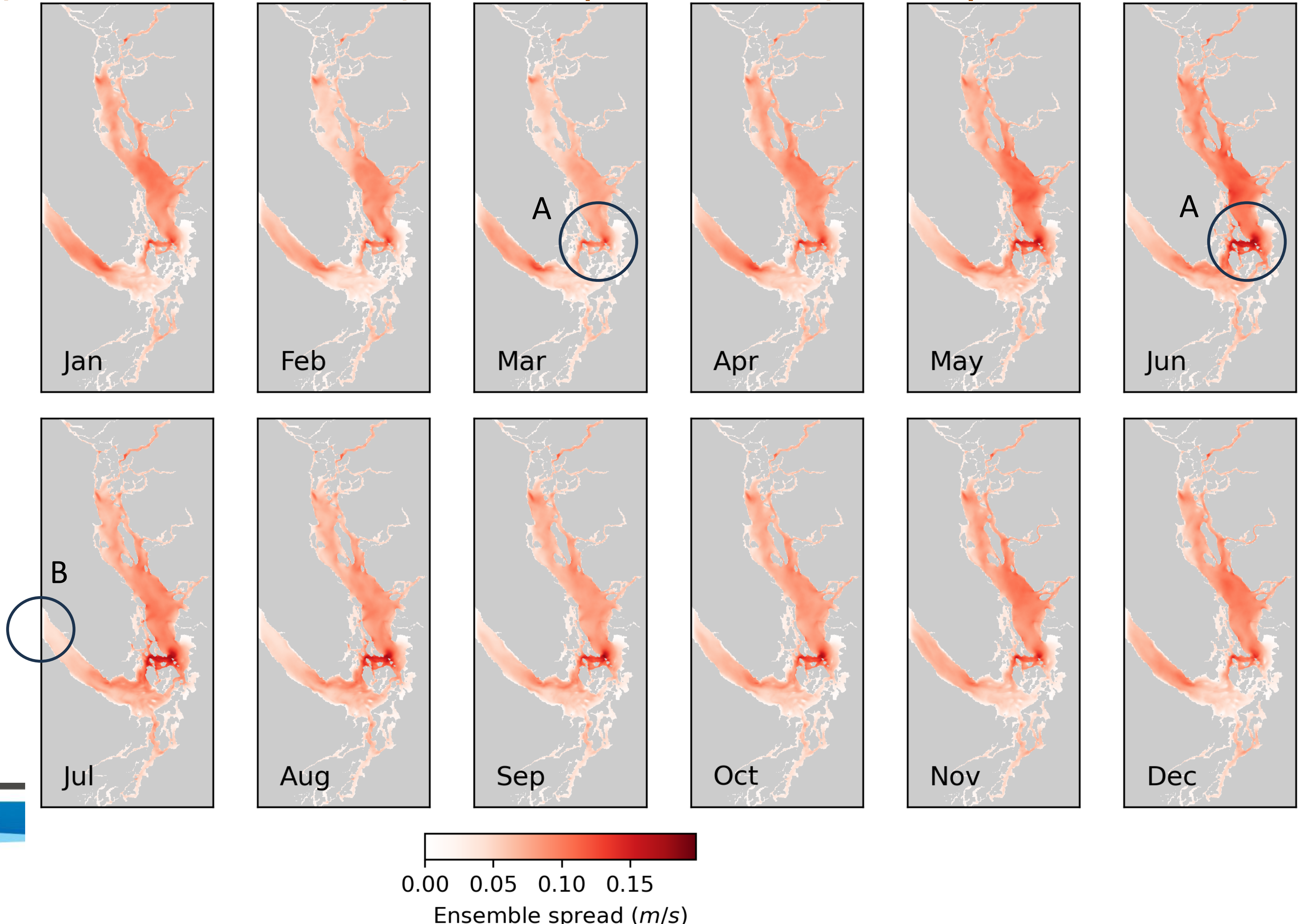
Spinup of ensemble spread (3 years)

- **E**: clear seasonal signal
- **G,K**: similar but stronger signal
- Large summer signal likely related to thermocline
- Similar spread spinup in other variables



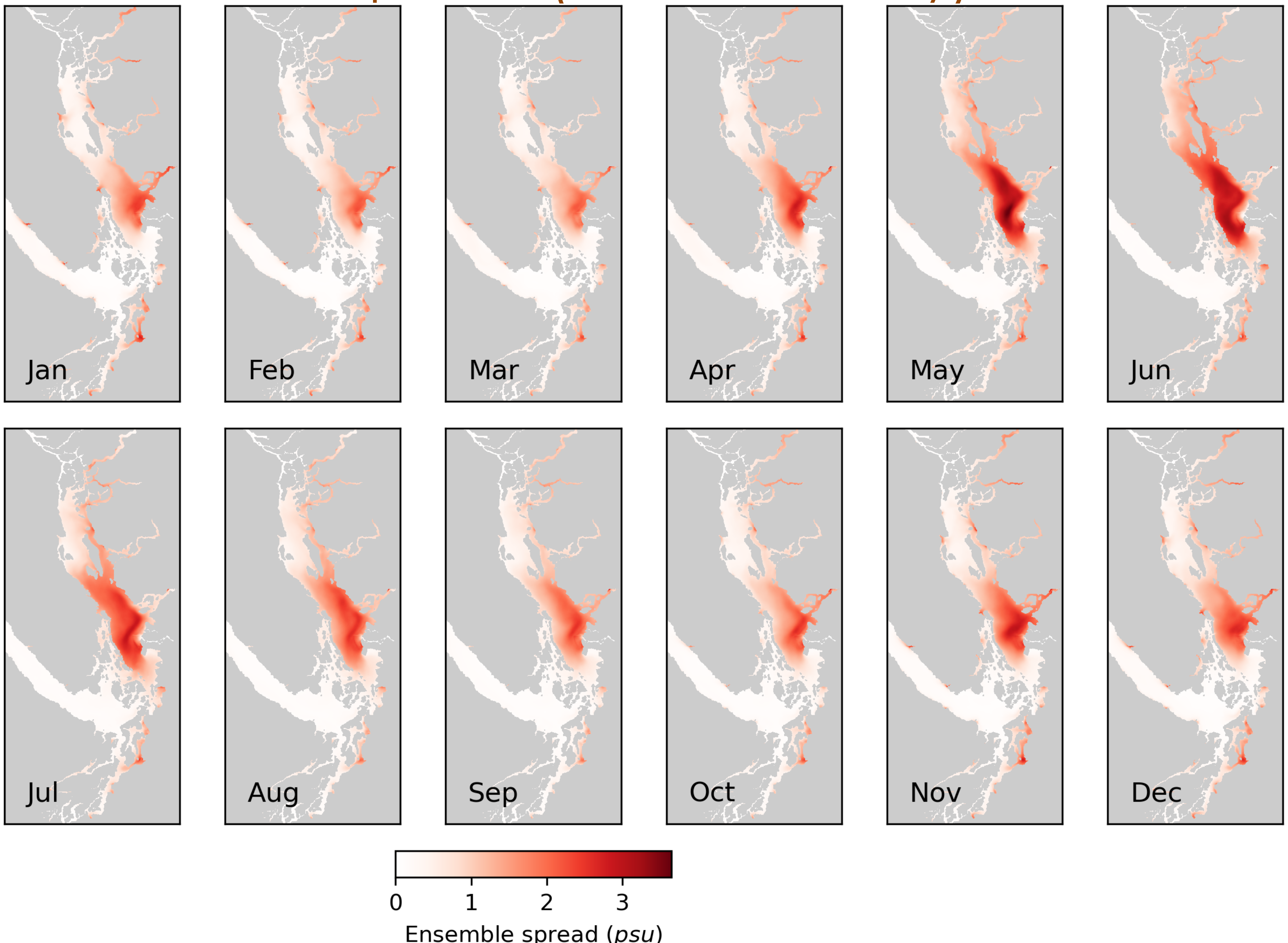
Spatial variability of ensemble spread (surface speed)

- Monthly means from K experiment over three years
- Hotspots of spread visible
- Increased spread in summer months at **A**
- Cold-spot of spread at open boundary **B**



Spatial variability of ensemble spread (surface salinity)

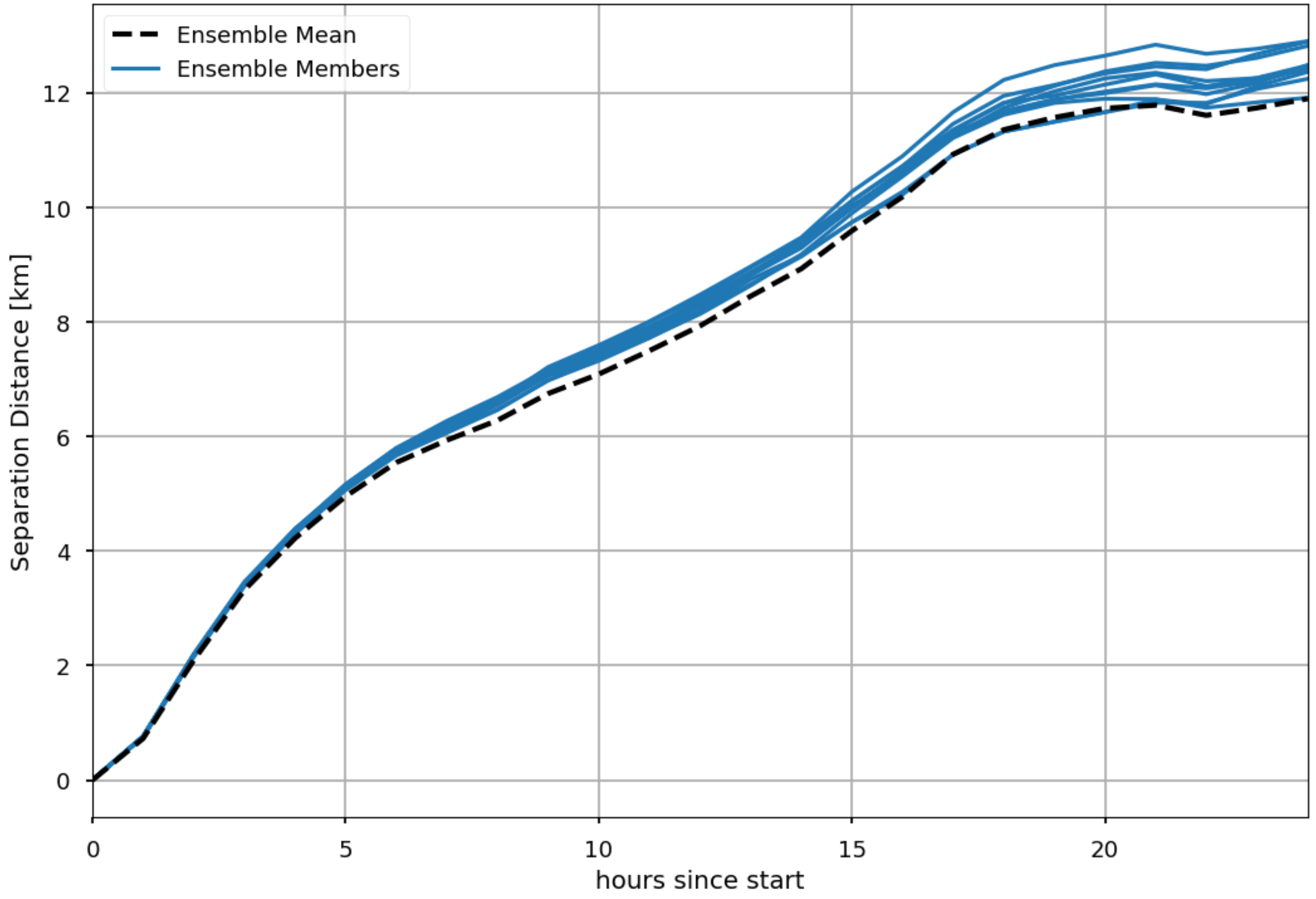
- Spread largest in central Strait of Georgia, much lower in Juan de Fuca strait
- Strong mixing region separates these regions



Ensemble drift experiment

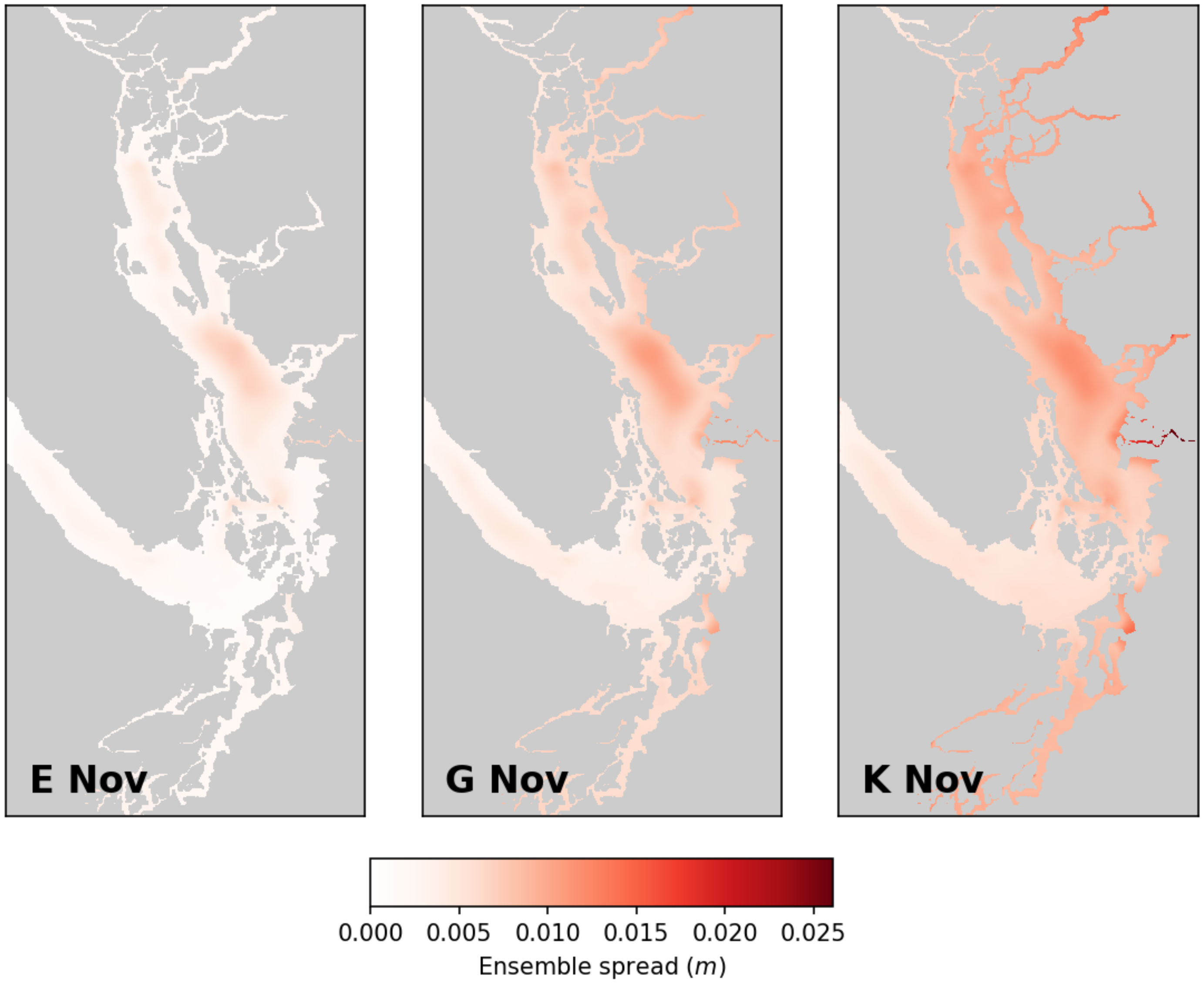
- 883 daily drift tracks Apr 2017 – Jan 2018 derived from 170 surface drifters
- OpenDrift with 2% windage (unperturbed wind)
- Tracked for K experiment members and mean
- → Drift performance improved with mean

Experiment	Separation Rates (km/day)
Worst ensemble member	12.90
Best ensemble member	11.91
Ensemble mean (forcing)	11.89
Mean over ensemble members drift scores	12.49



Water level ensemble spread

- CRMSE is order 5 cm for non-tidal water level at gauges
- Spread in ssh is order 1 cm for K experiment
- K experiment has sea level pressure perturbed
- Broadly underdispersive



Lateral boundary condition perturbations

- Lack ensemble forcing for lateral boundary
  - Apply the EOF-perturbing method

- Perturb principal components with AR(1) process, top N=40 modes

- Multivariate decomposition for
  - Non-tidal barotropic part
  - Baroclinic part

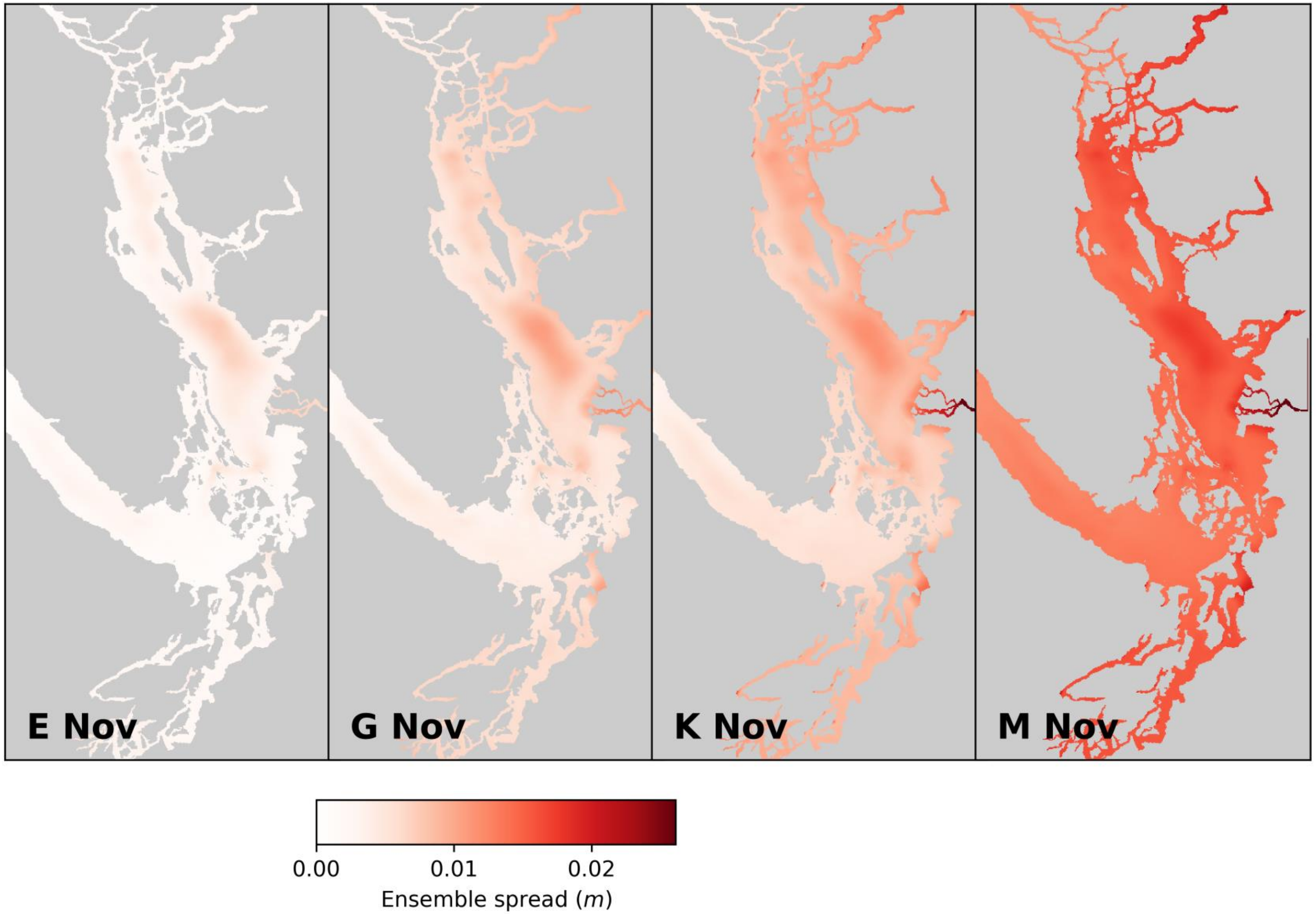
Stochastic LBC Perturbations	Time scale	STD
Barotropic non-tidal	1d	10%
Baroclinic	1d	10%

Ensemble set	Physics	Wind	Air temp, humidity, longwave and pressure	Runoff	Lateral boundary
E	X				
G	X	X			
K	X	X	X	X	
M	X	X	X	X	X

Water level ensemble spread

- Adding LBC perturbations raises spread from 1 to 2 cm
  - Still underdispersive

- Scant change in other variables
  - Consistent with seaward estuarine circulation at surface



Summary

- Initial set of ensemble hindcast experiments at 500 m domain
- Successively added perturbations for physics and for surface, runoff and lateral boundary forcing
- Wind perturbations appear important
- Spread underdispersive in water level

- Next steps
  - Systematic consistency analysis with observations
  - Revise perturbation parameters
  - Explore applying Stochastic Kinetic Energy Backscatter with STOPACK
  - Explore perturbing lateral boundaries with dynamically consistent perturbations
  - Longer simulation than 3 years
  - Downscale to 125 m and 20 m domains