ALFRED-WEGENER-INSTITUT
HELMHOLTZ-ZENTRUM FÜR POLAR- UND MEERESFORSCHUNG

Fast ~~and furious~~ EVP solutions in a high-resolution sea ice model

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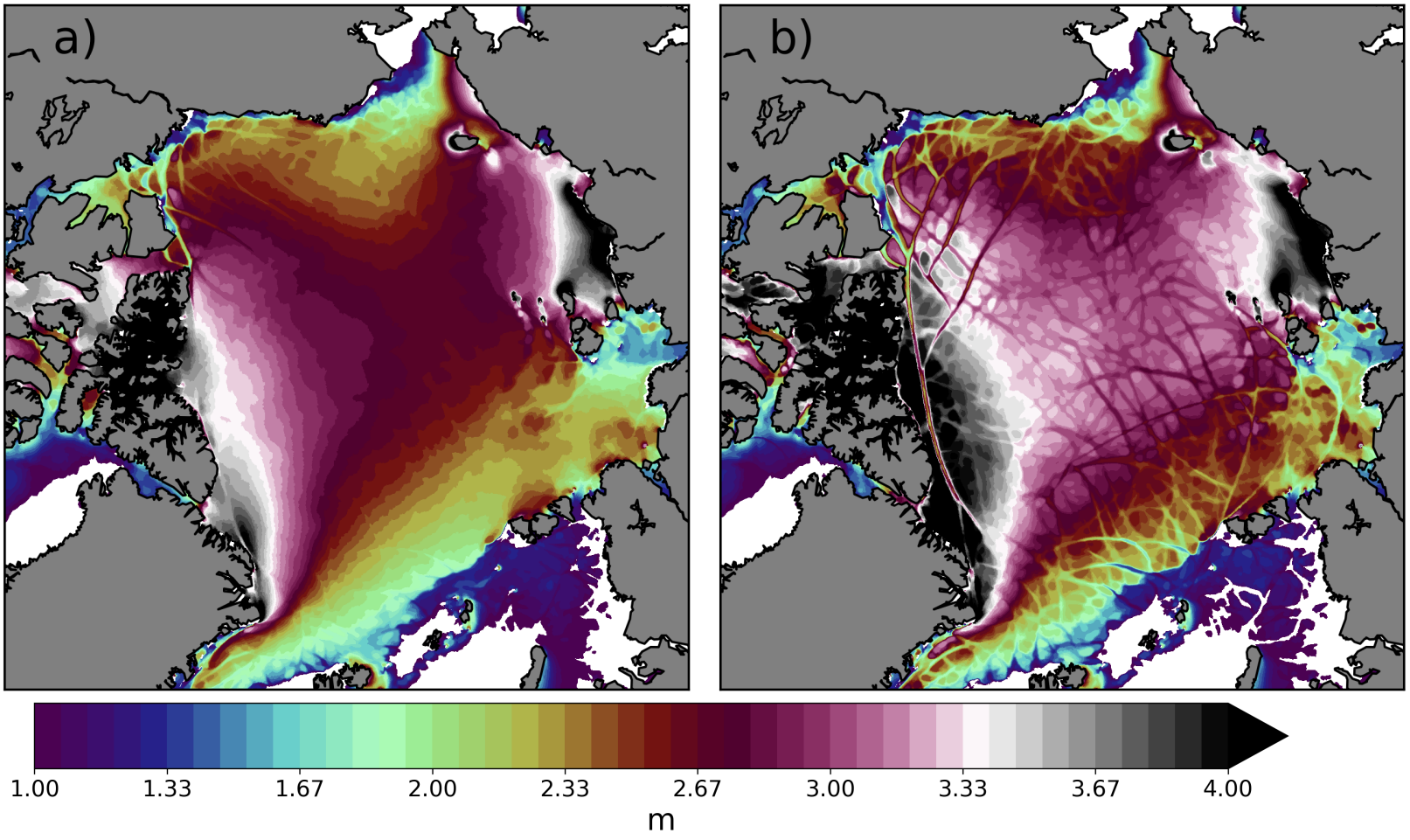
TRR181

FESOM

HELMHOLTZ ASSOCIATION

Ice thickness, 4.5 km resolution Arctic setup

From this → Same computational cost → To this



Sea ice dynamics

$$\frac{D(m\boldsymbol{u})}{Dt} = \underbrace{-mf_C\boldsymbol{k}\times\boldsymbol{u}}_{\text{Coriolis force}} + \underbrace{\boldsymbol{\tau_a}+\boldsymbol{\tau_w}}_{\text{a/s and ocean drag}} - \underbrace{mg\Delta H}_{\text{Sea Surface tilt}} + \underbrace{\nabla\cdot\boldsymbol{\sigma}}_{\text{Ice interaction}}$$

Ice Rheology

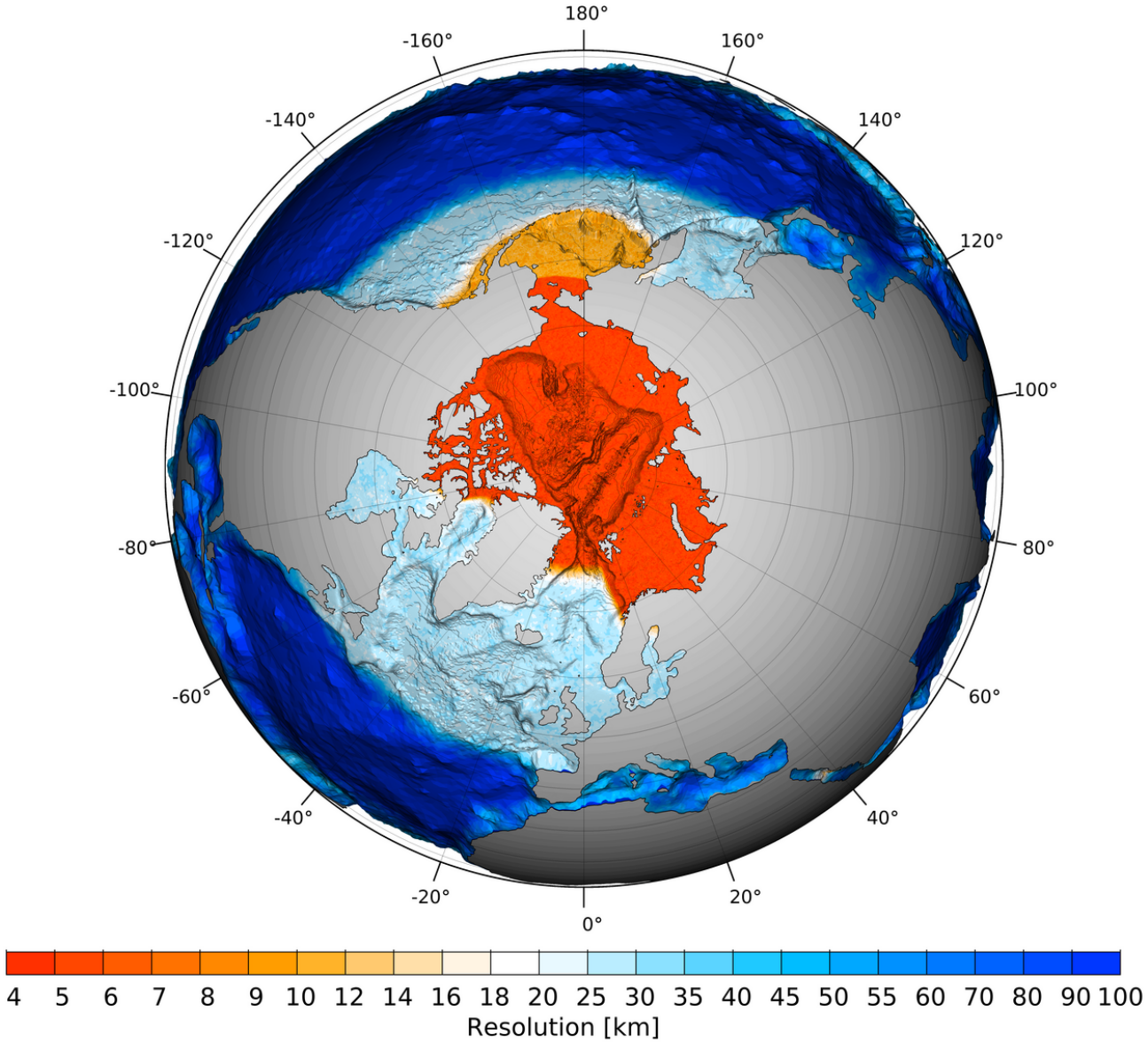
Relationship between sea ice internal **stress** ($\boldsymbol{\sigma}$), to the deformation of the sea ice cover (**strain**, $\boldsymbol{\varepsilon}$), material properties of the sea ice (**strength**, $\boldsymbol{P}$) and the state of ice cover (e.g **thickness**, $\boldsymbol{h}$, and **coverage area**, $\boldsymbol{A}$).

Rheology

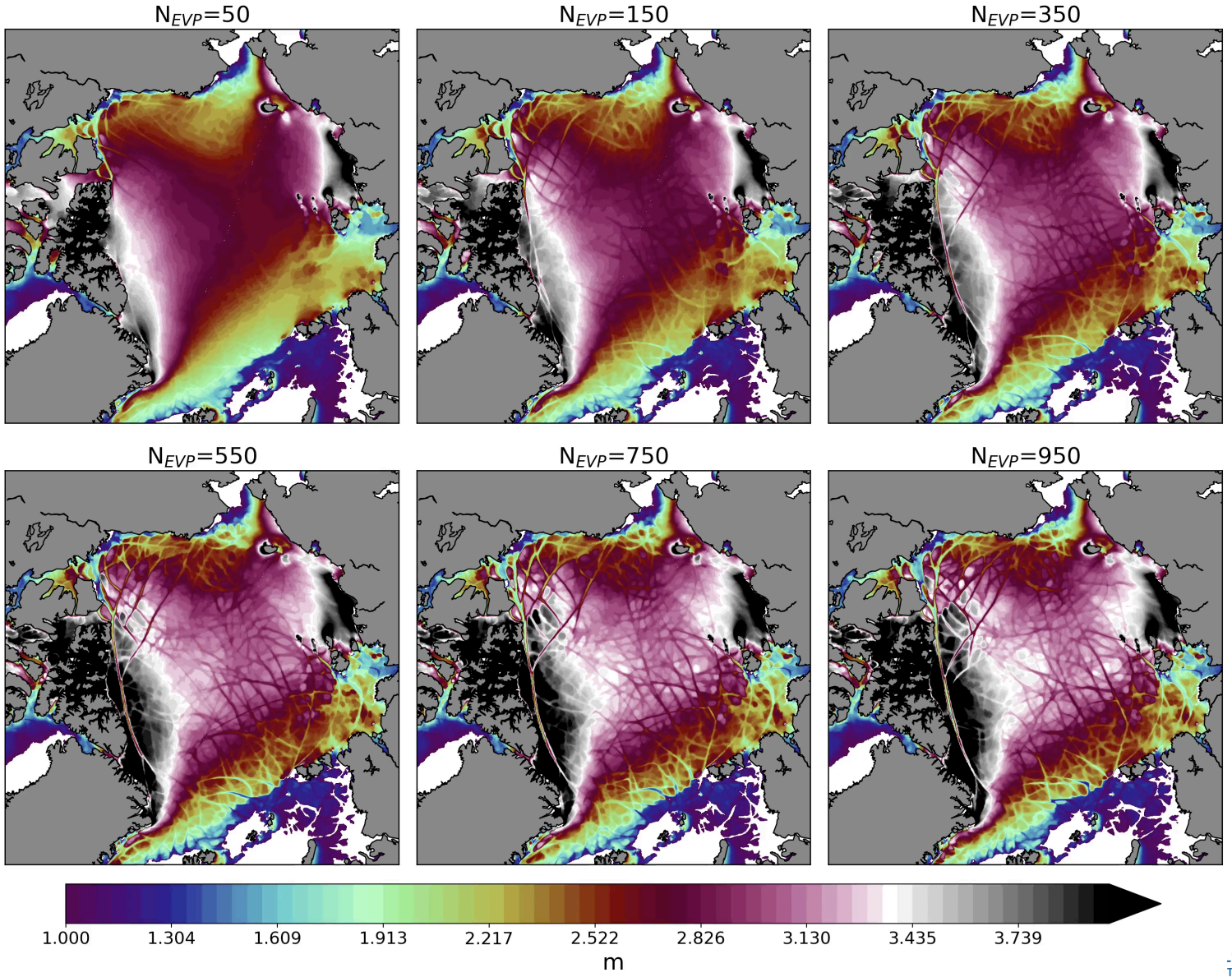
Viscous **P**lastic rheology solved with **E**lastic **V**iscous **P**lastic (**EVP**) method

- Used in many of ocean and climate models
- Requires sub-cycling steps (N_{EVP}) within ocean model time step
- The higher the model resolution the larger the N_{EVP} should be $=>$ more expensive the model is computationally.

Global FESOM2 setup with 4.5 km Arctic Ocean

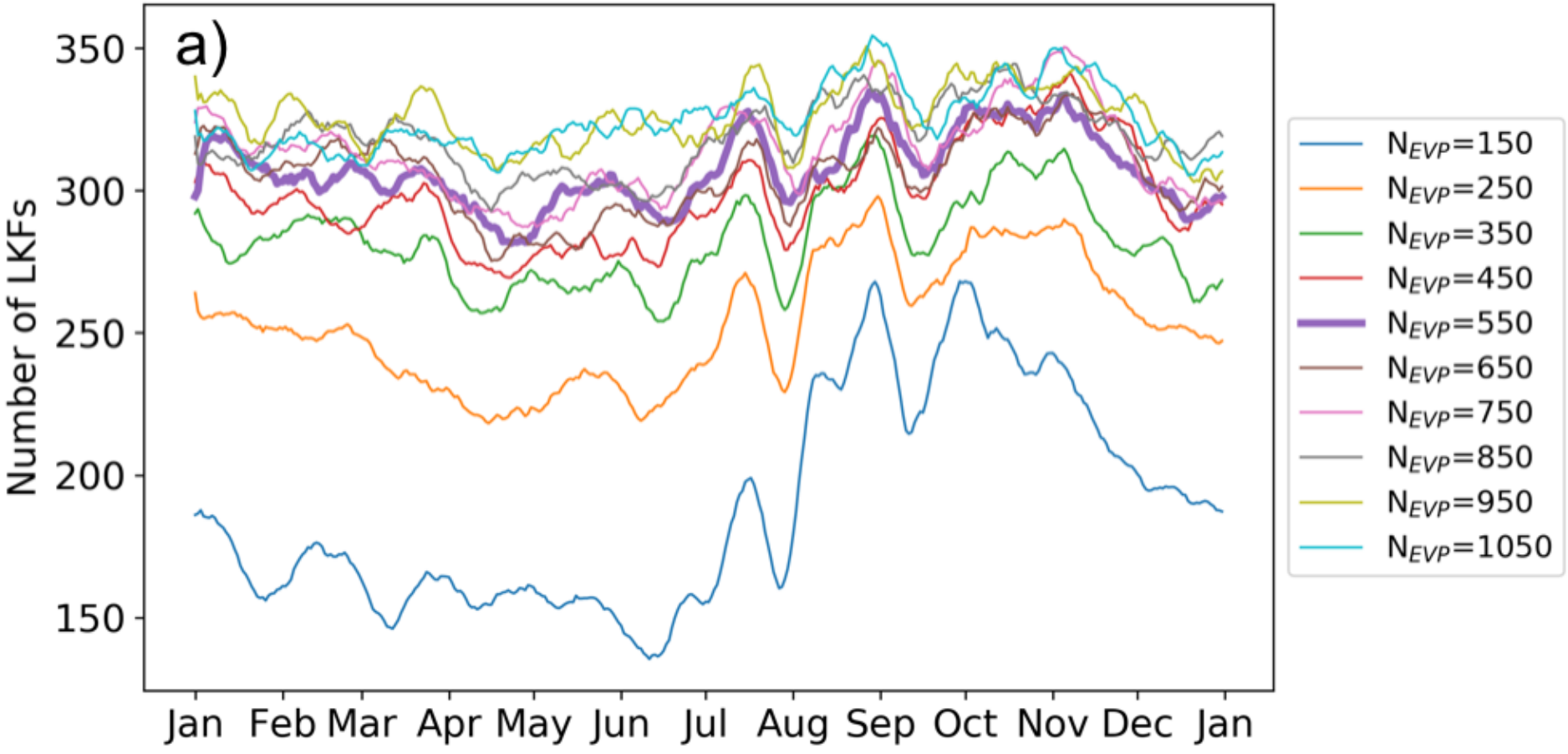


Larger N_{EVP} → More cracks



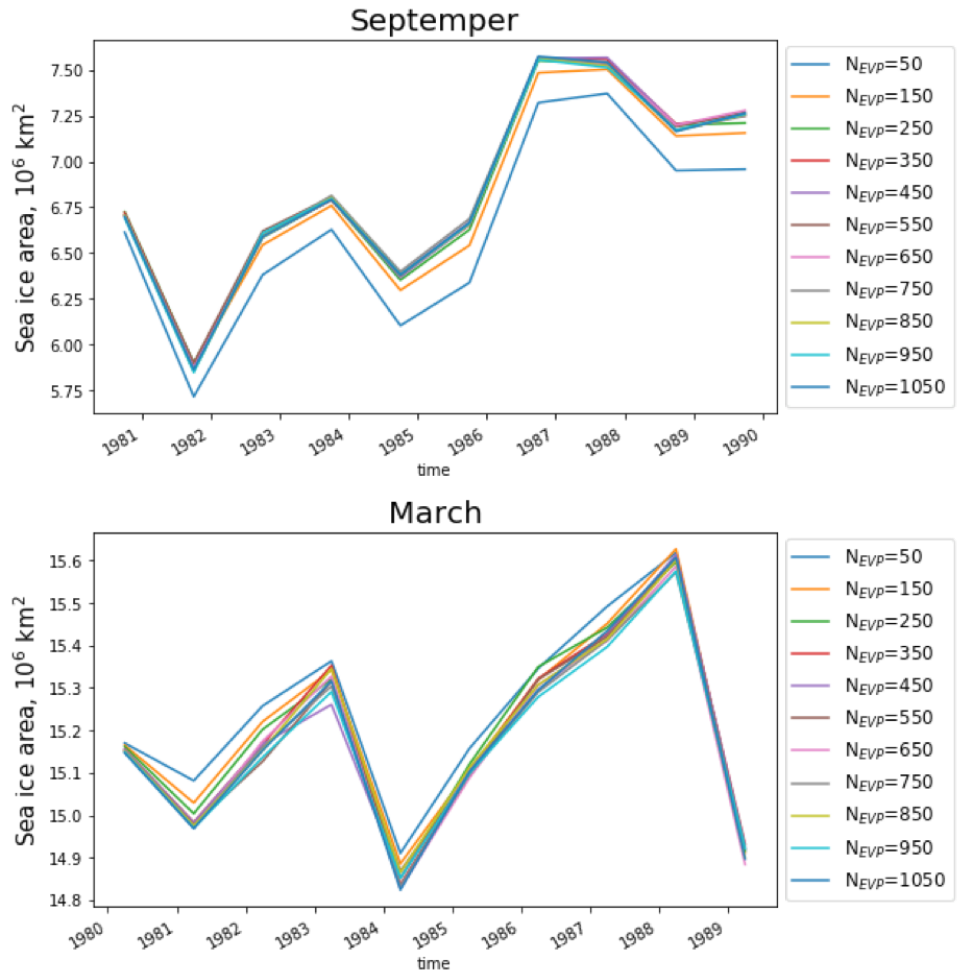
We need to quantify differences between runs

Daily number of detected LKFs

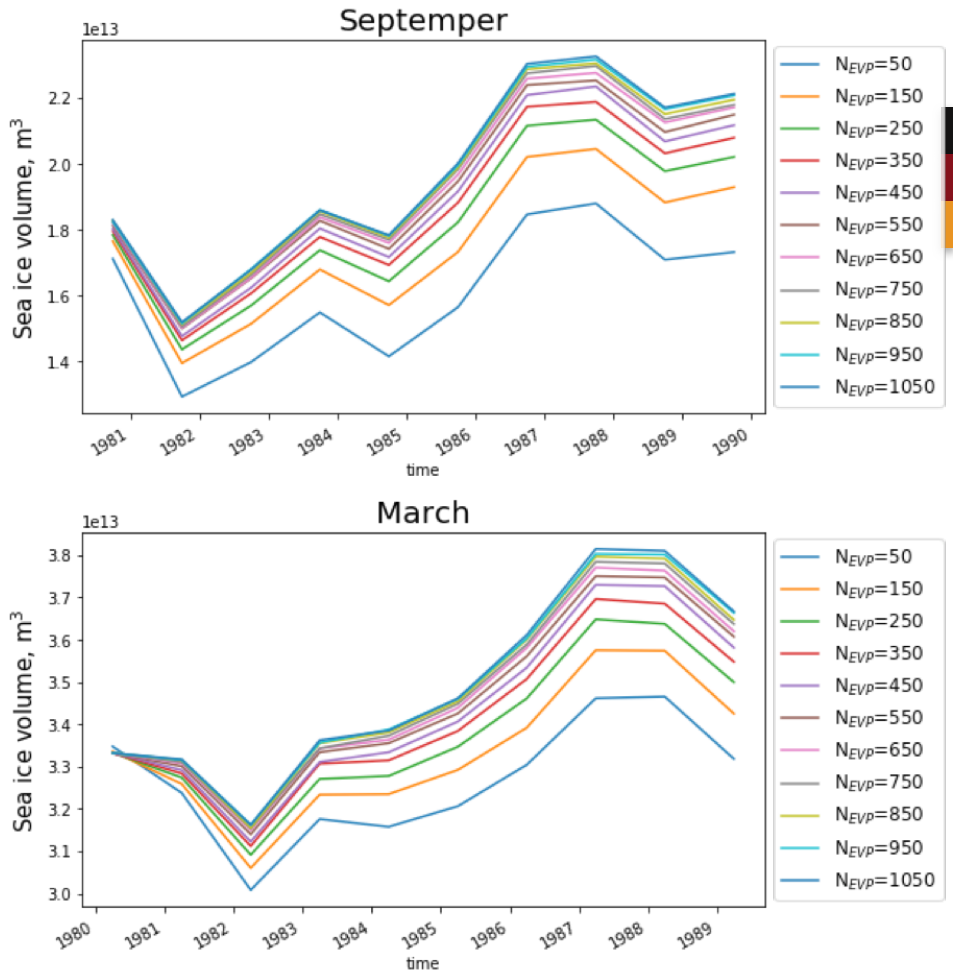


We need to quantify differences between runs

Sea ice area



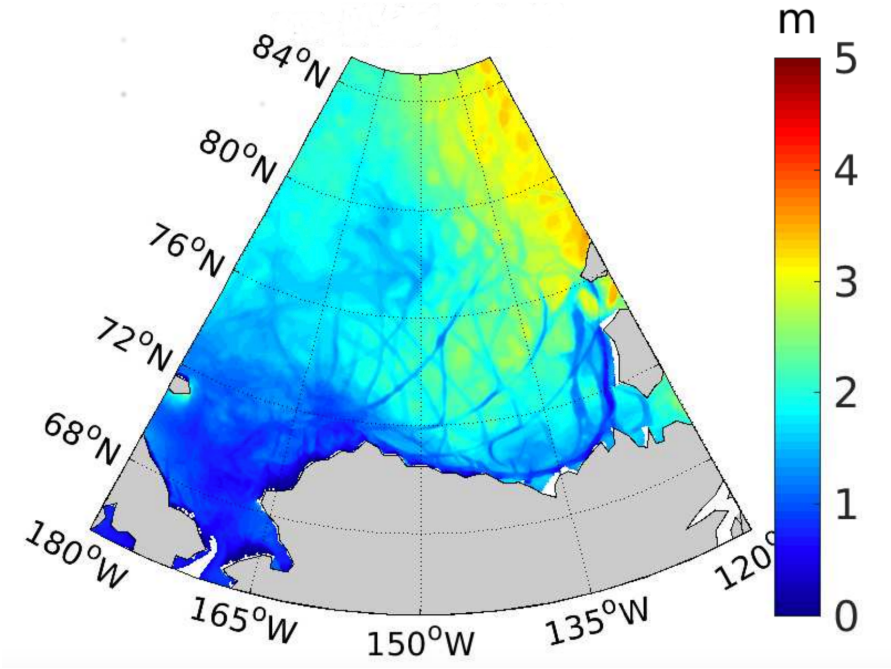
Sea ice volume



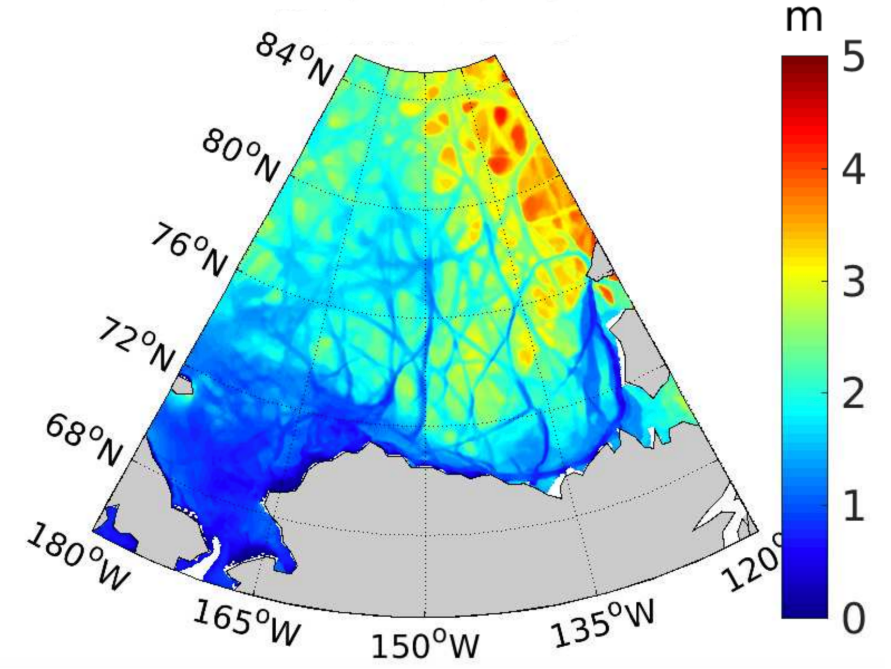
Larger N_{EVP} → More cracks

Sea ice is similar to what is used in many ocean and climate models (zero layer thermodynamics, EVP dynamics).

$N_{EVP} = 200$



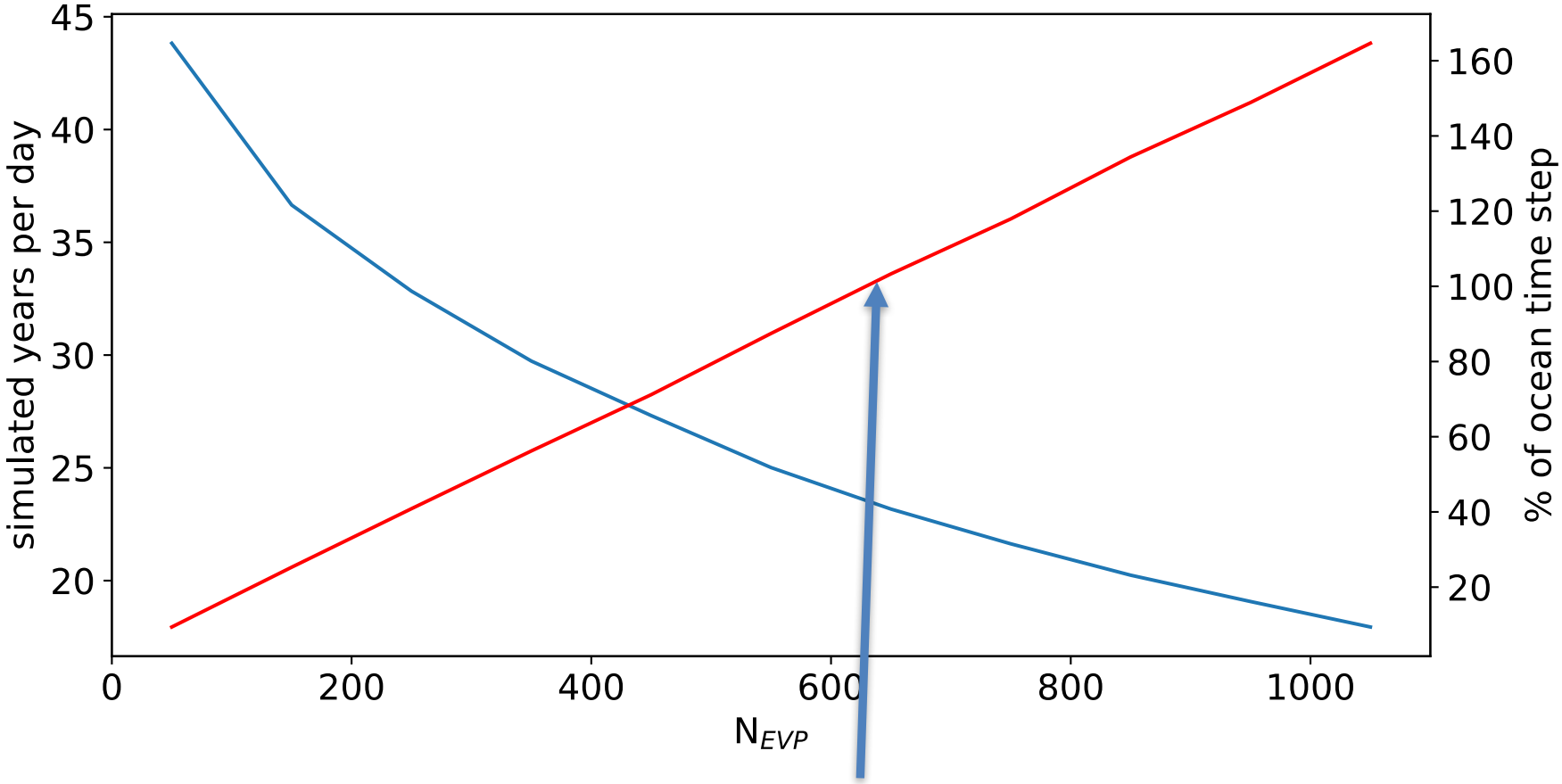
$N_{EVP} = 800$



Wang, et al, 2016

But it's expensive and do not scale well

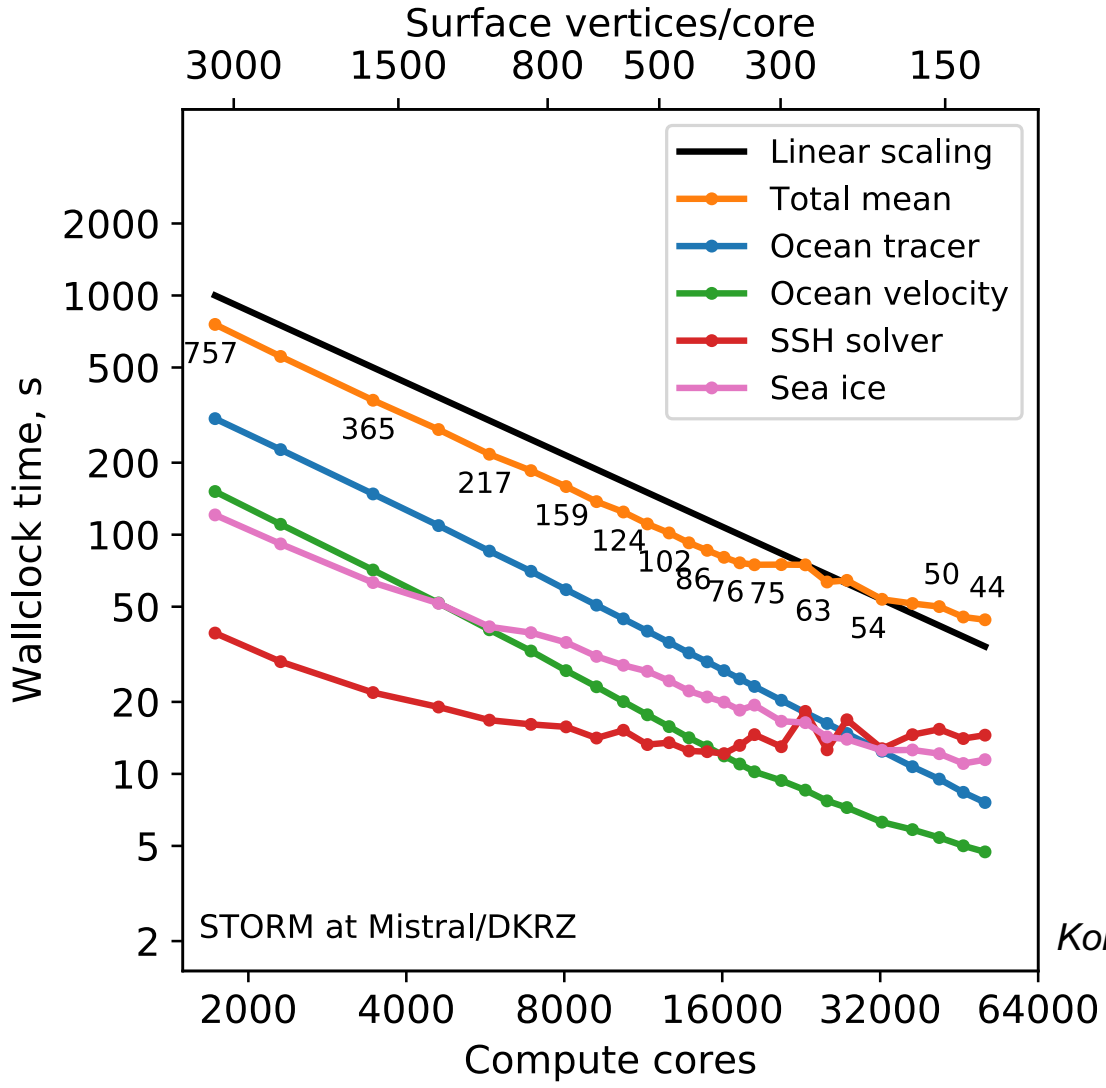
FESOM2 throughput depending on N_{EVP}
(4.5km Arctic Ocean setup, 1728 cores)



At about 650 N_{EVP} the sea ice code cost as much as ocean code.

But it's expensive and do not scale well

Scalability of different model computational cores



Koldunov et al., 2019, GMDD

New EVP options in FESOM 2

mEVP (modified)

- "Fixed" EVP version after Lemieux et al. (2012), Bouillon et al. (2013) and Kimmritz et al. (2015).
- Separates the issue of numerical stability from the number of N_{EVP} sub-cycles.
- numerical stability is governed by two parameters α and β (constants, resolution dependent)

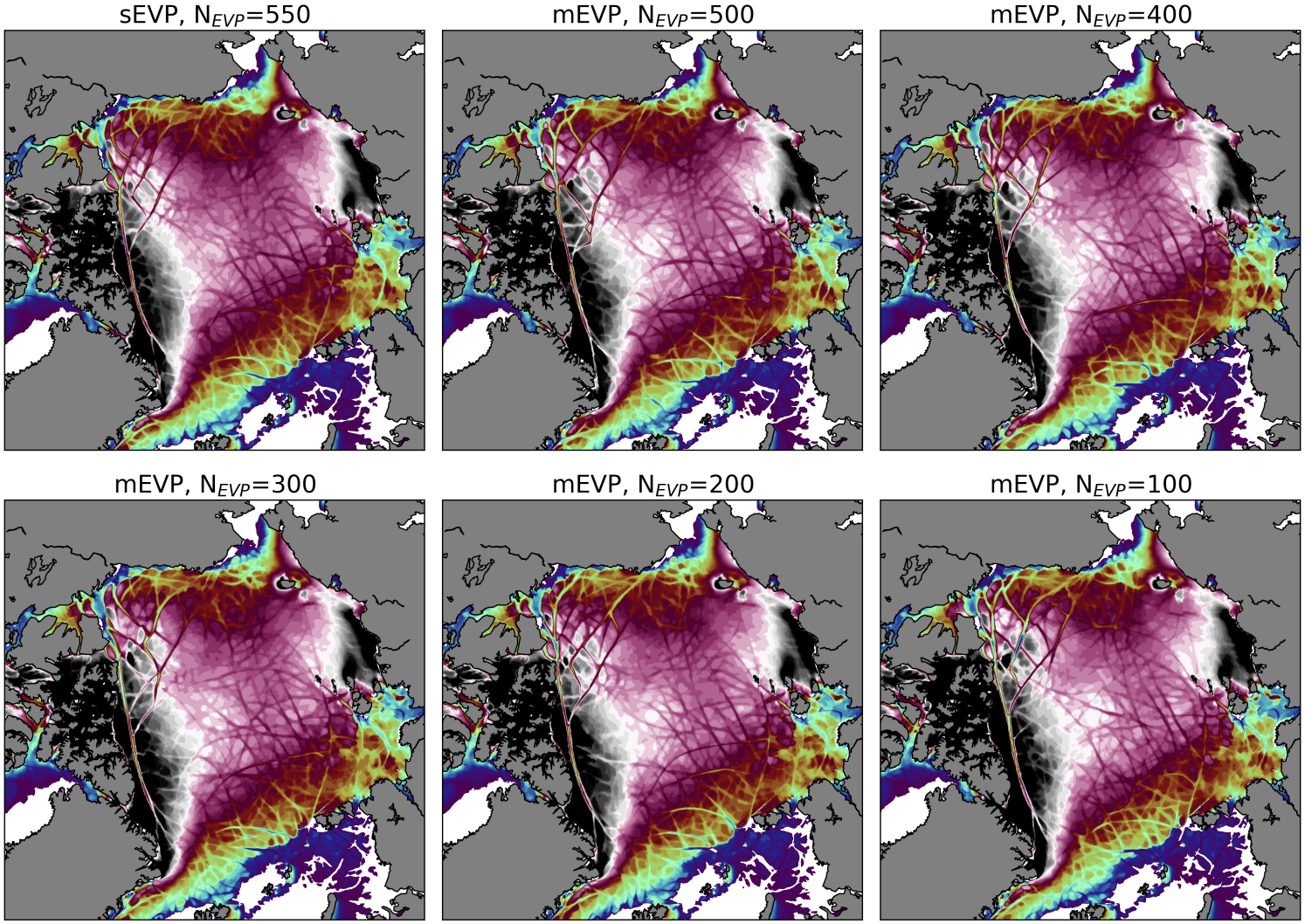
Allows considerable reduction in the number of N_{EVP} sub-cycles

aEVP (adaptive)

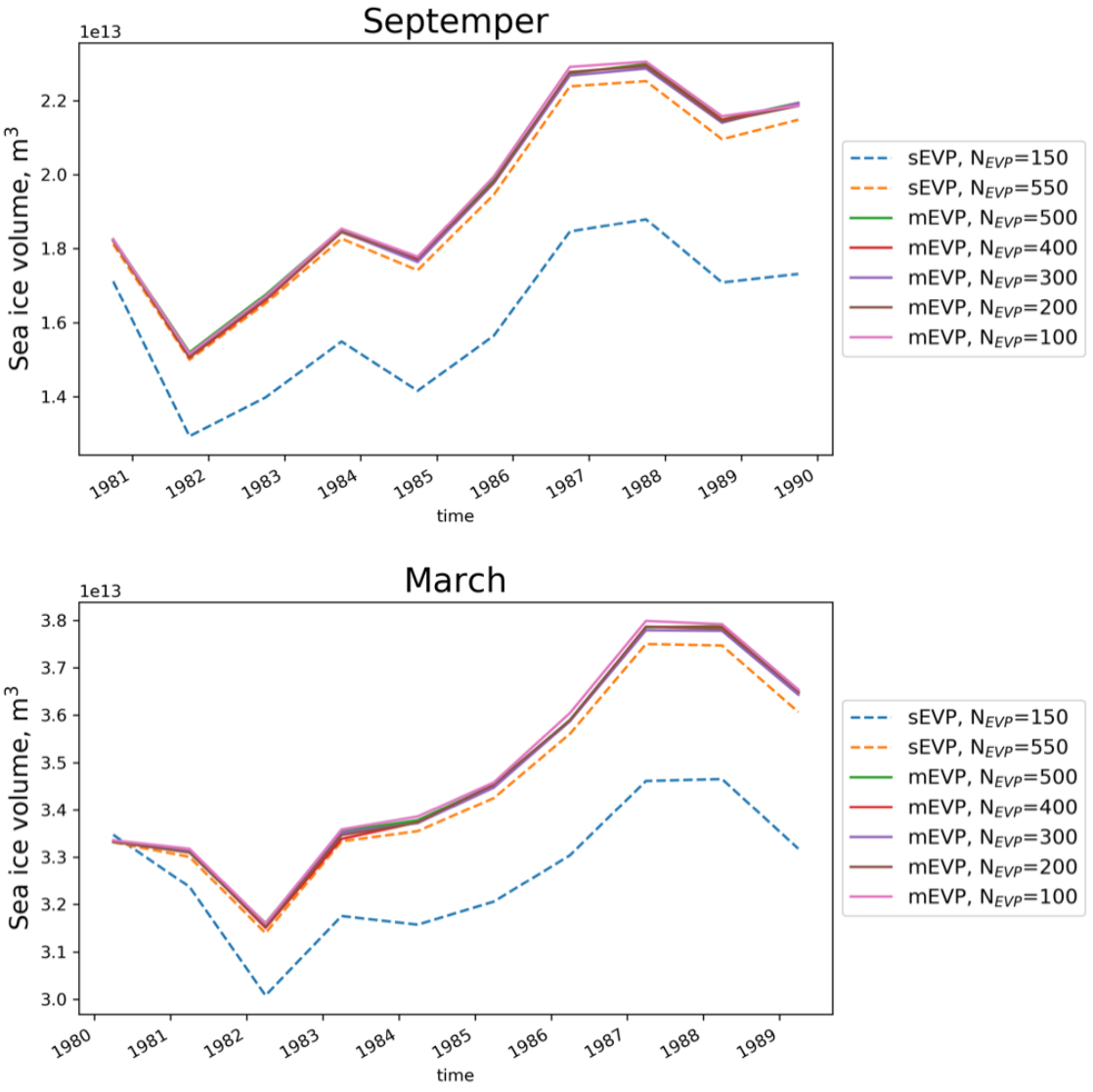
- Estimate α and β at each particular location in run time (Kimmritz et al., 2016)
- improved convergence in areas with smaller α and β

Potentially very important for multi-resolution areas.

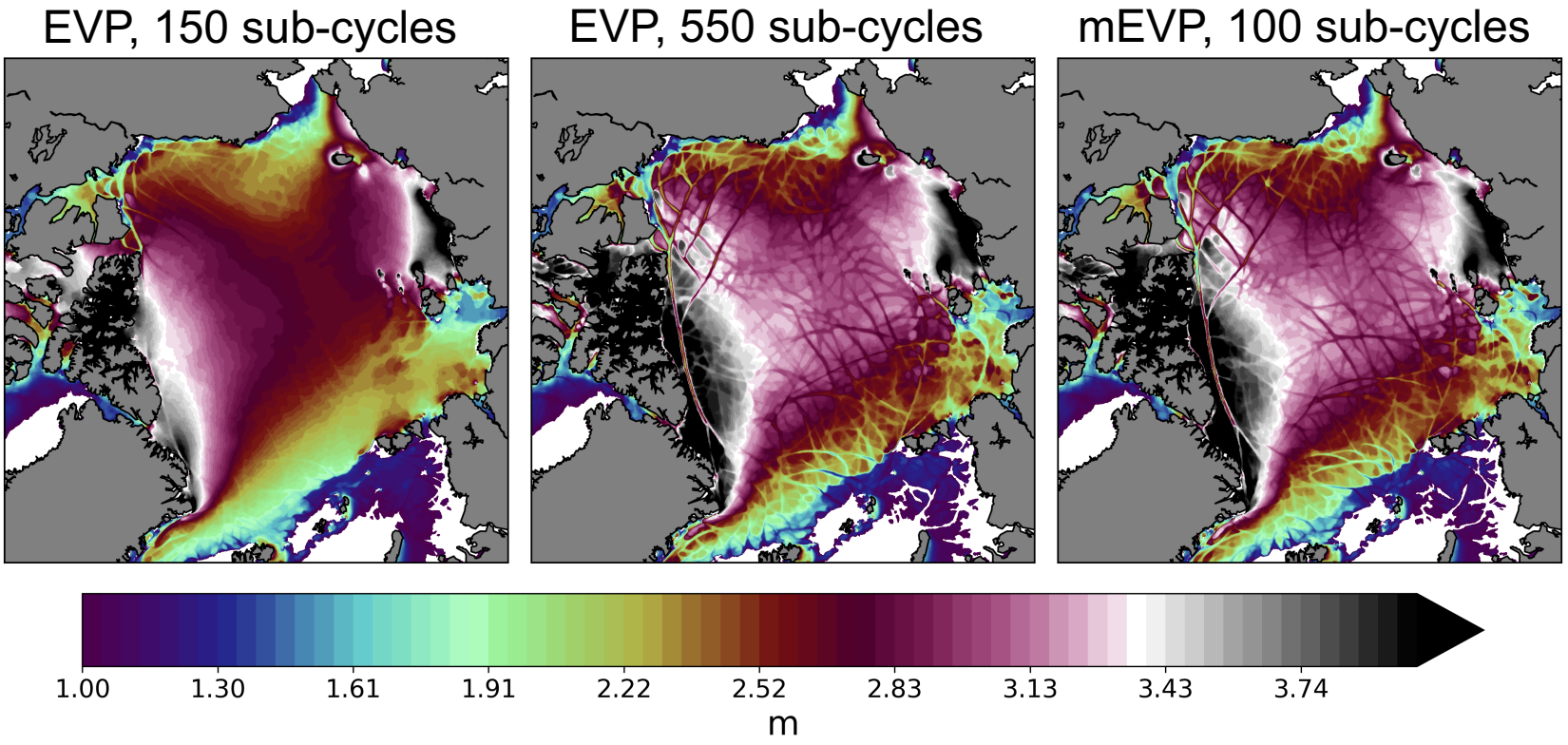
mEVP sea ice thickness, α=β=500



mEVP mean sea ice volume



New mEVP(modified) option in FESOM 2



Conclusions

- Using mEVP and aEVP solvers improves the overall performance of sea ice model (x6 times in 4.5km case) while retains the properties of the simulated sea ice fields.

- Makes it possible to perform climate simulations with more realistic sea ice dynamics with throughput of about 40 simulated years per day on the 4.5 km resolution mesh.

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