6th Workshop on Coupling Technologies
for Earth System Models – CW2023
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Time schemes at the ocean-atmosphere interface : diagnostics using a mathematically consistent Schwarz iterative method

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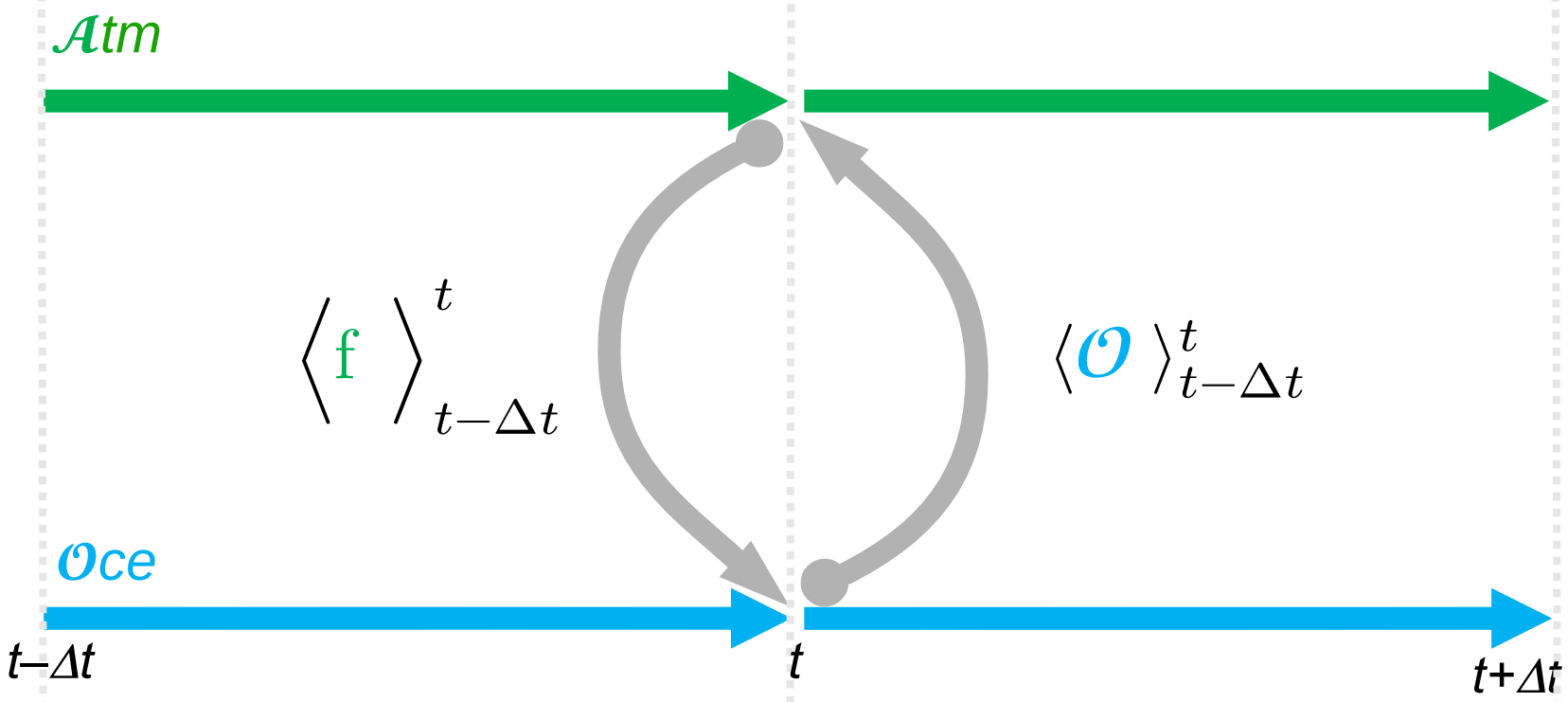
Time stepping between ocean and atmosphere is mathematically inconsistent

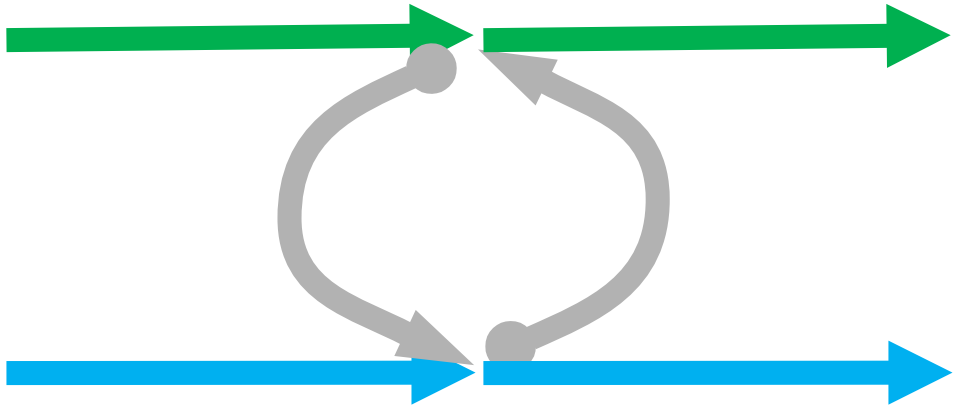
Models are not synchronised with boundary conditions



Redrawn from Fig. 5.4, Lemarié et al. (2008)

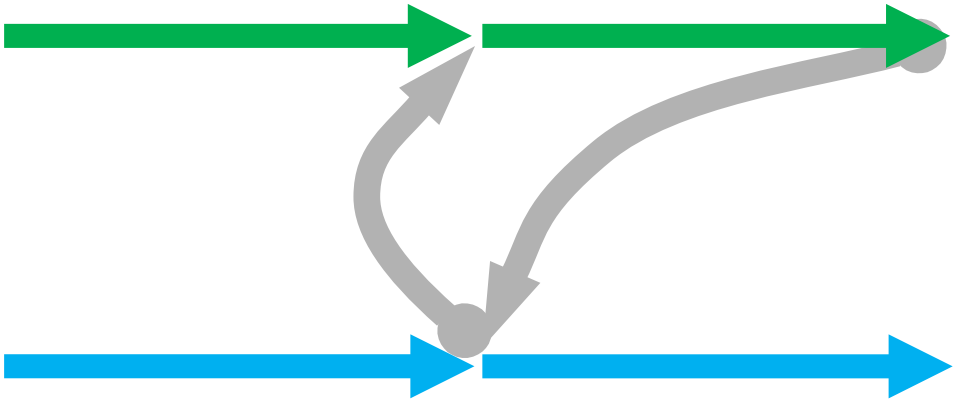
Our community uses 2 mostly time schemes

Parallel



IPSL-CM6, CNRM-CM6-1, EC-Earth3, MPI-ESM, HadGEM3-GC31, ?

Sequential Atmosphere First



ECMWF, RPN, ?

Schwarz iterative procedure during one coupling time step [t, t+Δt]

- Iterations from k=1 to convergence
- For each iteration, initial state of $\mathcal{A}$ and $\mathcal{O}$ are the solutions at the end of the previous time step [t-Δt, t], when interface values of $\mathcal{O}_\Omega$ and $\mathbf{f}_\Omega$ have converged.
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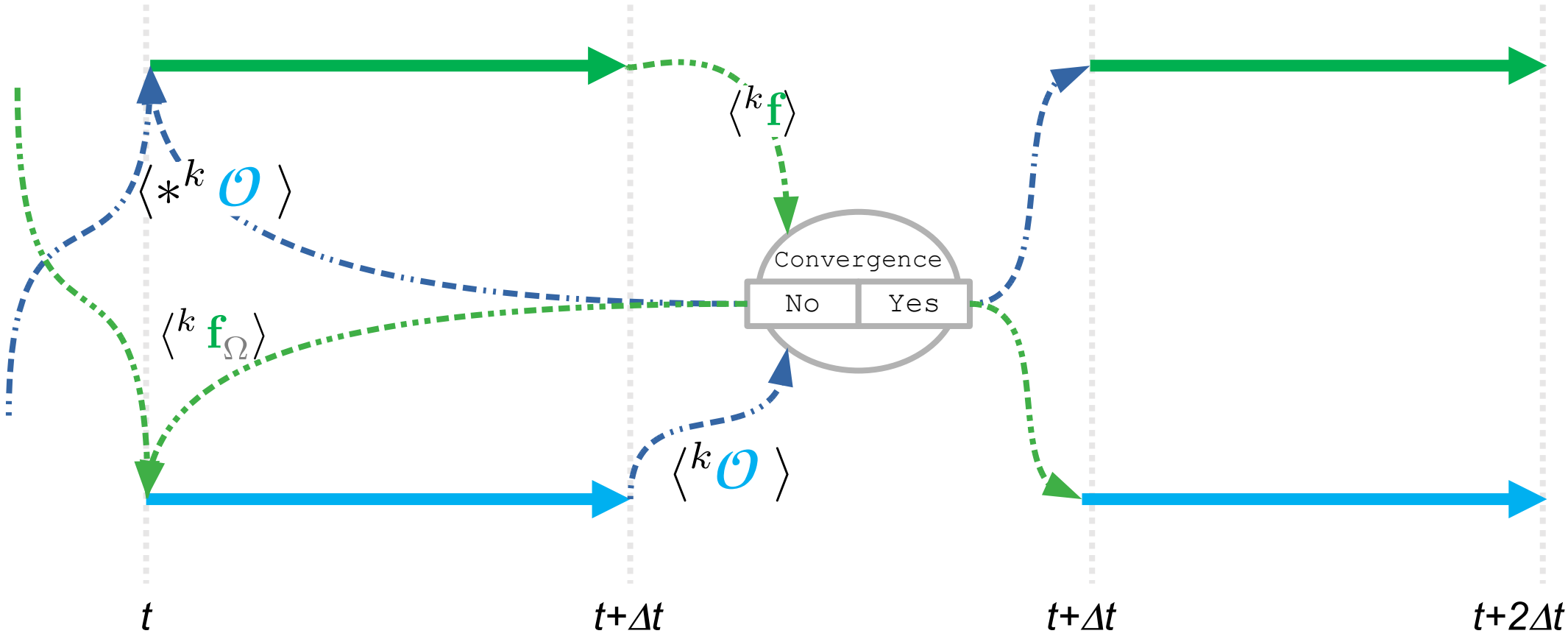


The Schwarz iterative method : a reference solution

Re-synchronize models and boundary conditions

Mathematically consistent

Tremendous computing cost

Reference solution

Schwarz in IPSL-CM

Model

Earth System Model IPSL-CM at low resolution (ocean 2°, atmosphere 96x95x39).

Simplified land surface model (bucket)

Sea-ice model : LIM3 monocategory

6 experiments :

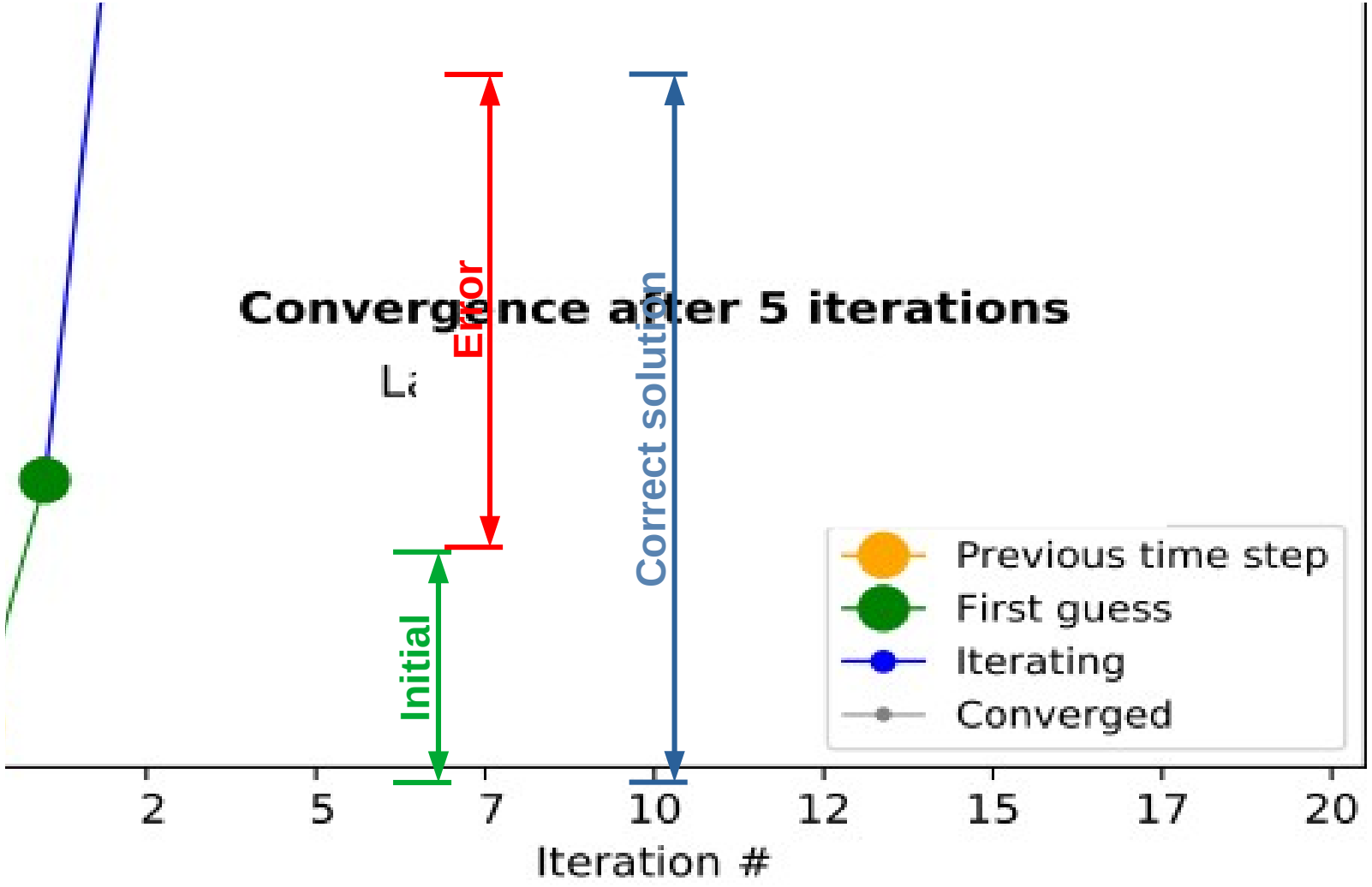
Parallel, Sequential atmosphere first, Sequential ocean first

Coupling time step : Δt = 1h, Δt = 4h

5 days runs

50 iterations

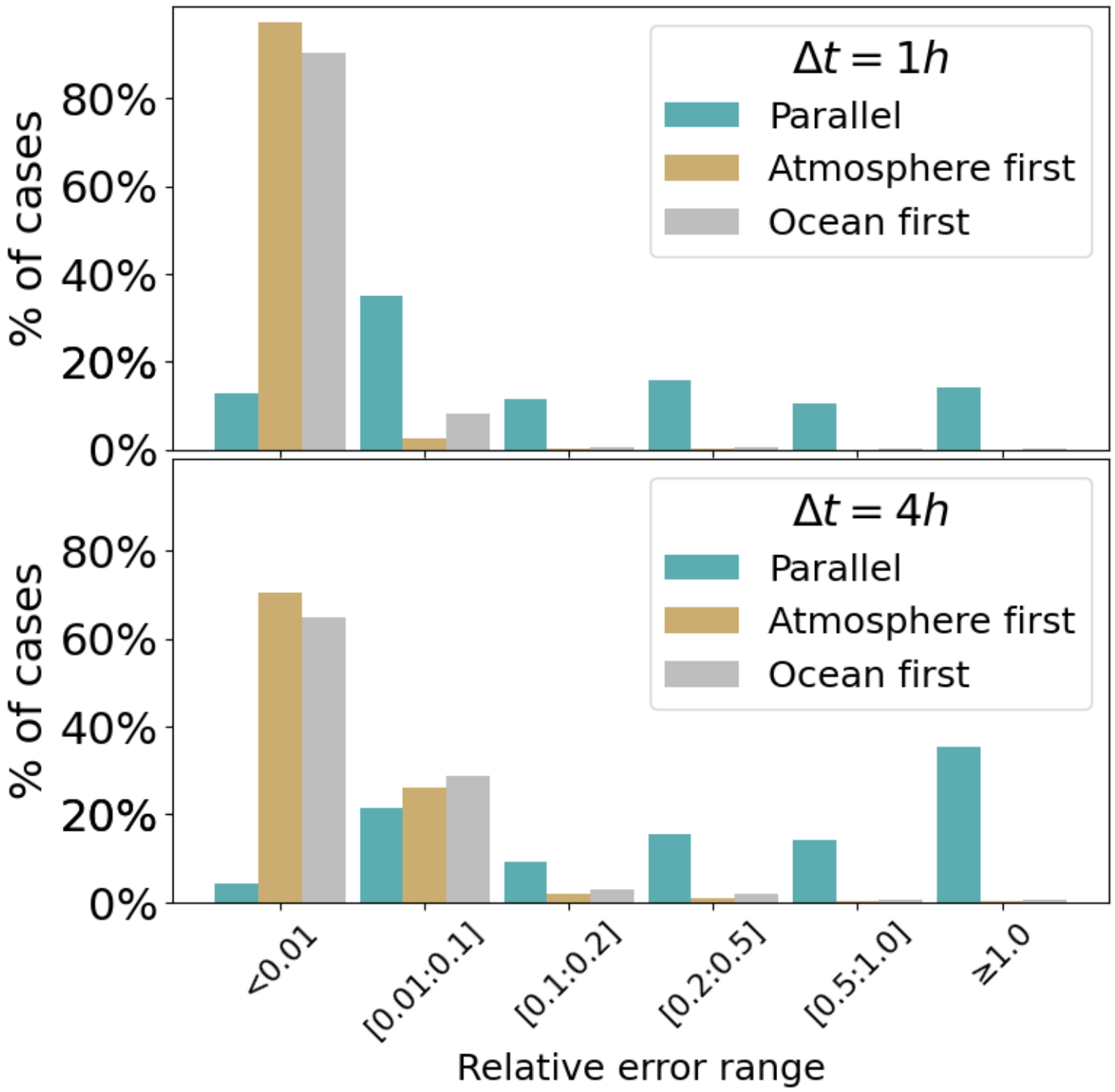
Diagnosing the relative error on SST



Relative error

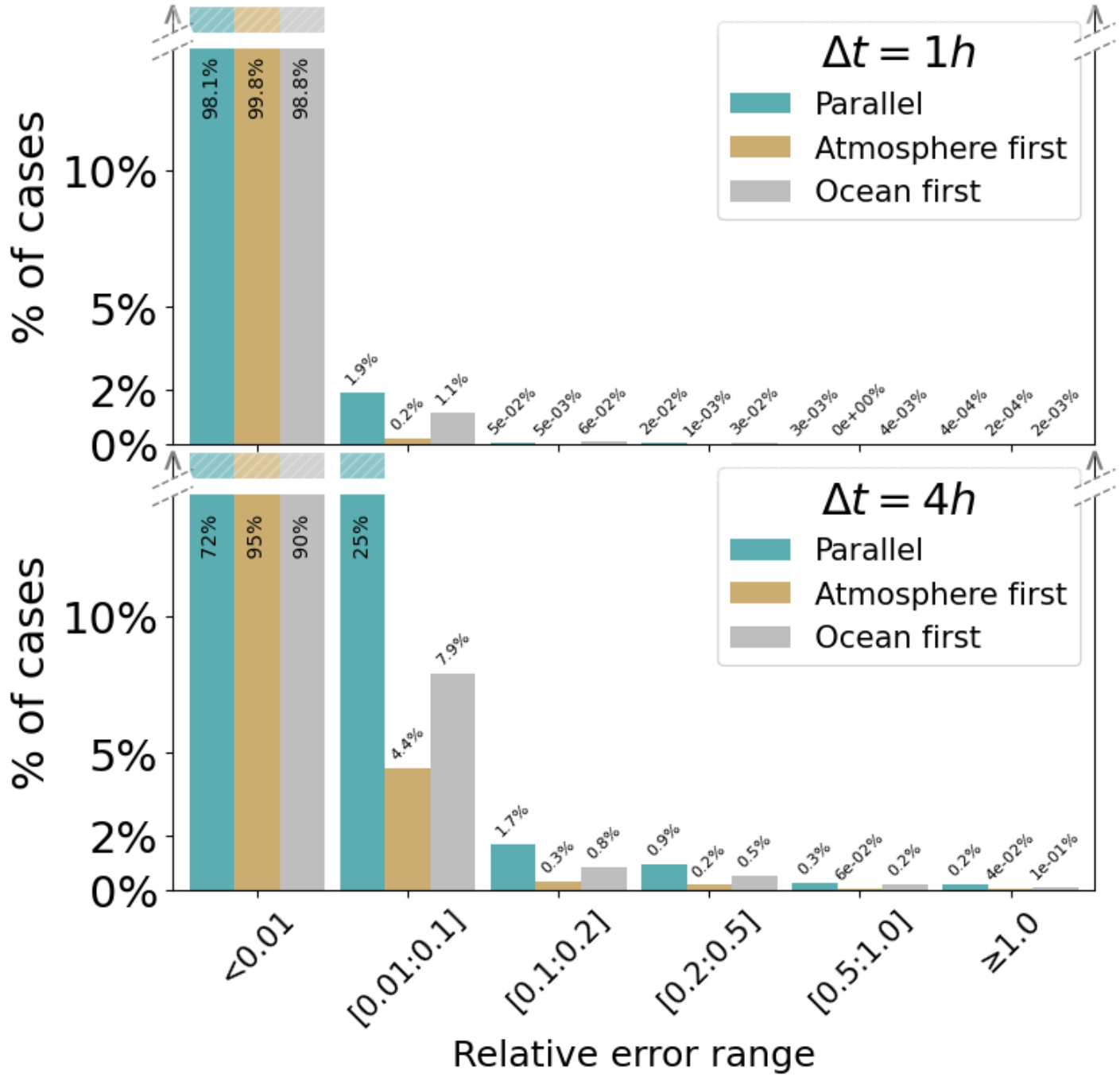
4 688 points x
120 steps =
562 643 cases

4 688 points x
30 steps = 140 k-cases

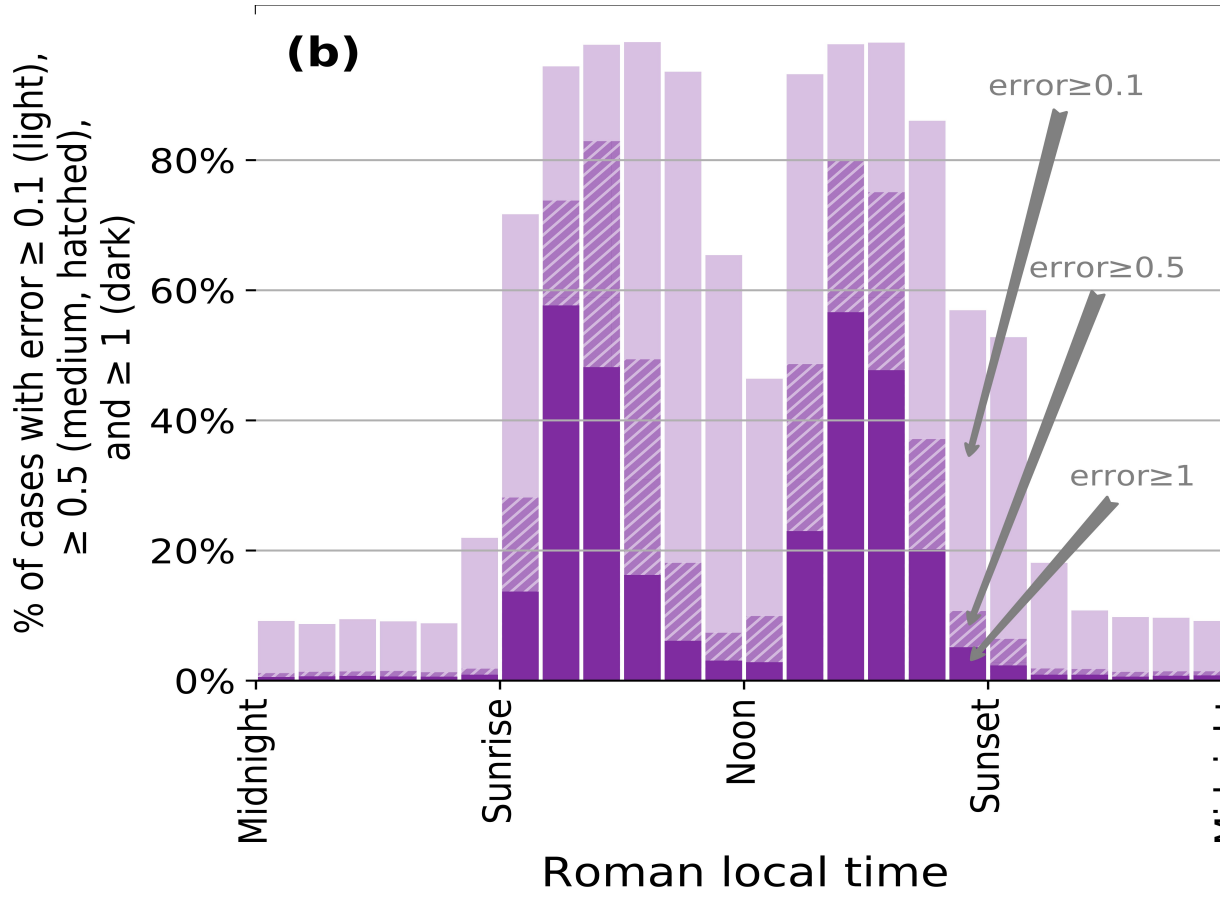


Points with sea-ice are excluded

2 iterations give a low error in most cases



Error peaks after sun rise and before sunset



Histograms of errors in function of the local time

Number of cases in each error range (% of total for each local time). Δt = 1h - Parallel

First conclusions

Current time schemes in state-of-the-art Earth System Model are mathematically inconsistent.

A Schwarz iterative has been implemented in the IPSL coupled model. It is mathematically consistent.

Schwarz iterative method is used as a reference to quantify the error done with the legacy scheme.

This error is quite large.

With a coupling time step Δt = 1, 2 Schwarz iterations can almost cancel the error.

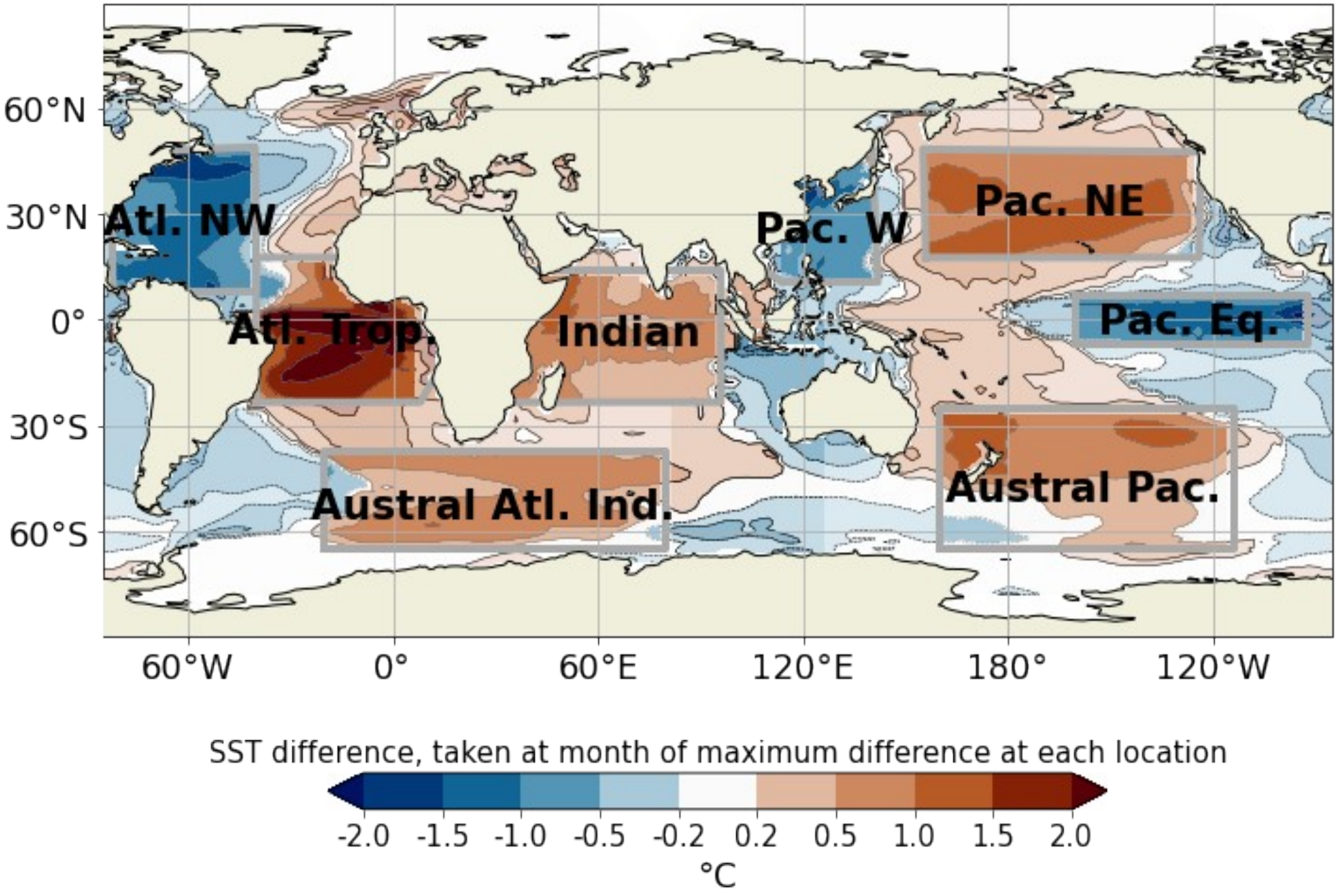
*Sequential atmosphere firs*t has the smaller errors

Marti, O., Nguyen, S., Braconnot, P., Valcke, S., Lemarié, F., and Blayo, E.: A Schwarz iterative method to evaluate ocean–atmosphere coupling schemes: implementation and diagnostics in IPSL-CM6-SW-VLR, Geosci. Model Dev., 14, 2959–2975, https://doi.org/10.5194/gmd-14-2959-2021, 2021.

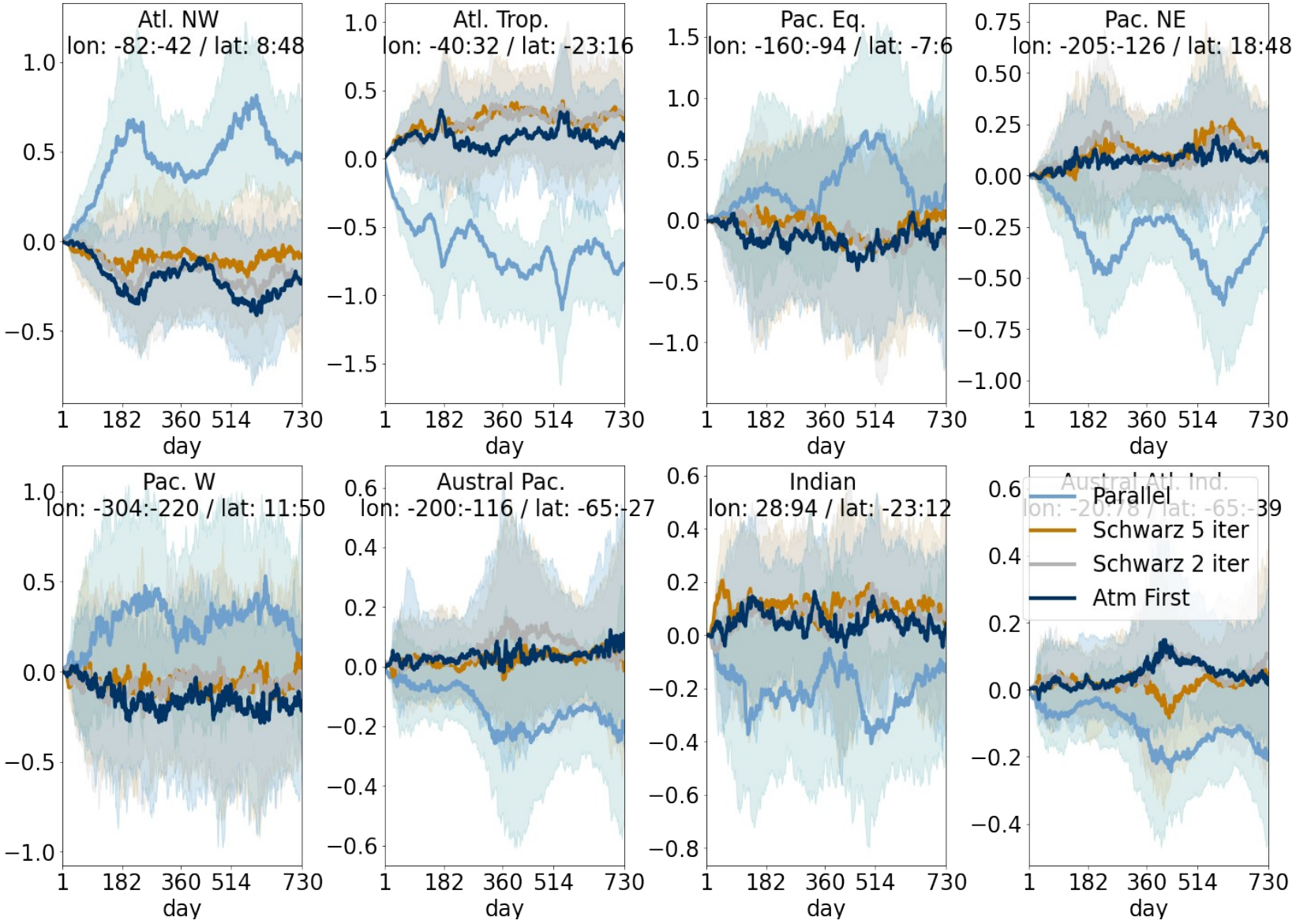
And for « real » simulations ?

Impact on short experiments

Difference between Schwarz and Parallel
2 year runs – 50 members



Daily SST : Parallel, Schwarz 2 iterations, Schwarz 5 iteration, Atmosphere first



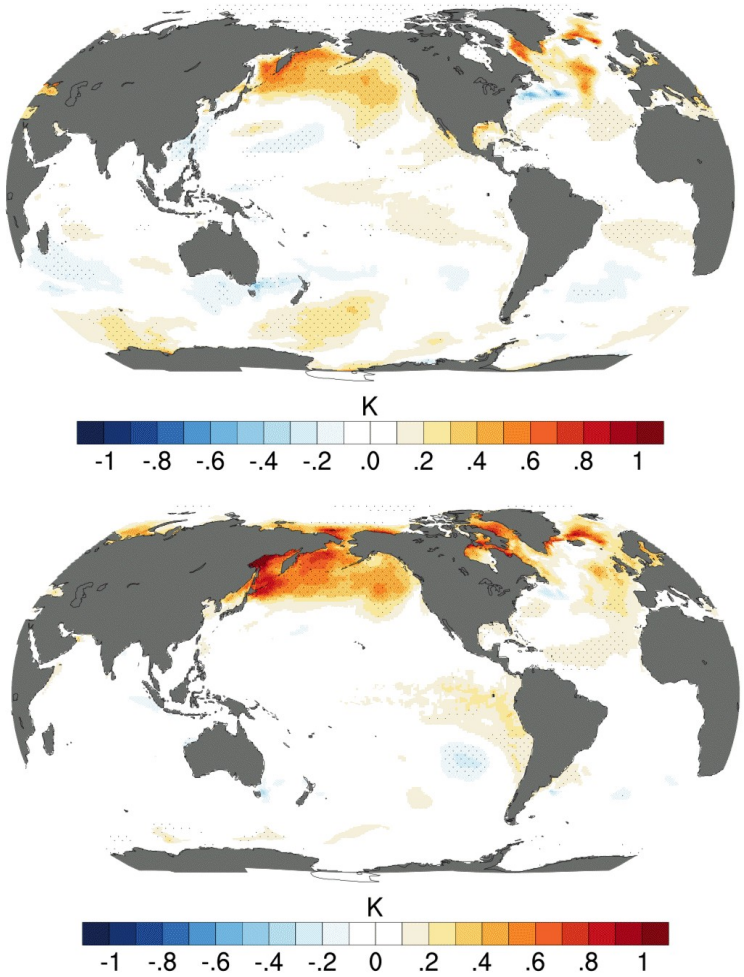
Anomaly with the average of all experiments

Shading - strong: 80% of experiments, light : 90%

Significant differences in 300 year runs ...

SST : difference **Seq. Atmosphere first** minus **Parallel**

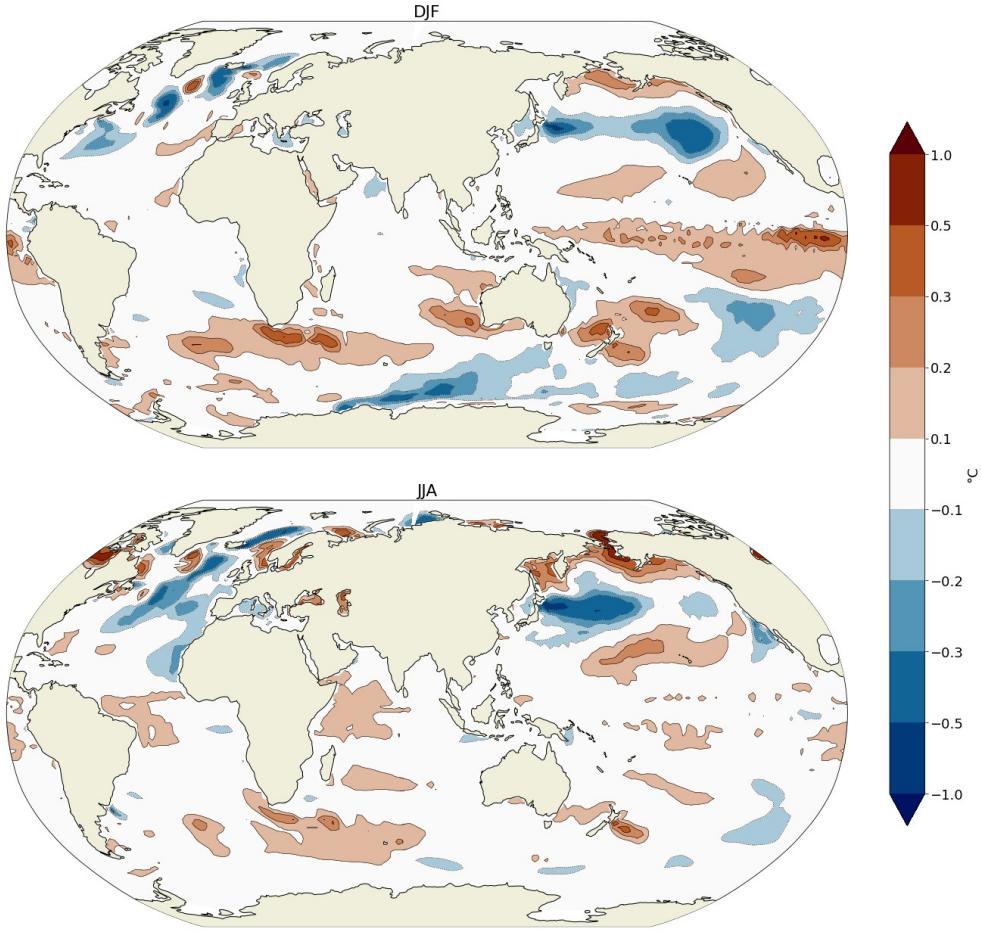
CNRM-CM6-1



DJF

JJA

IPSLCM5A2



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IPSL

Conclusions

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A Schwarz iterative has been implemented in the IPSL coupled model. It is mathematically consistent.

Schwarz iterative method is used as a reference to quantify the error done with the legacy scheme.

This error is quite large.

With a coupling time step Δt = of 1 hour, 2 Schwarz iterations can almost cancel the error.

*Sequential atmosphere firs*t has the smaller errors

The effect on real experiments is also quite large

And now … ?

2 Schwarz iterations doubles the cost : unacceptable

Some ideas ?

Use *Sequential atmosphere first*.

- Increase the time to solution.
- Lot of work to optimize this scheme : memory, load-balancing

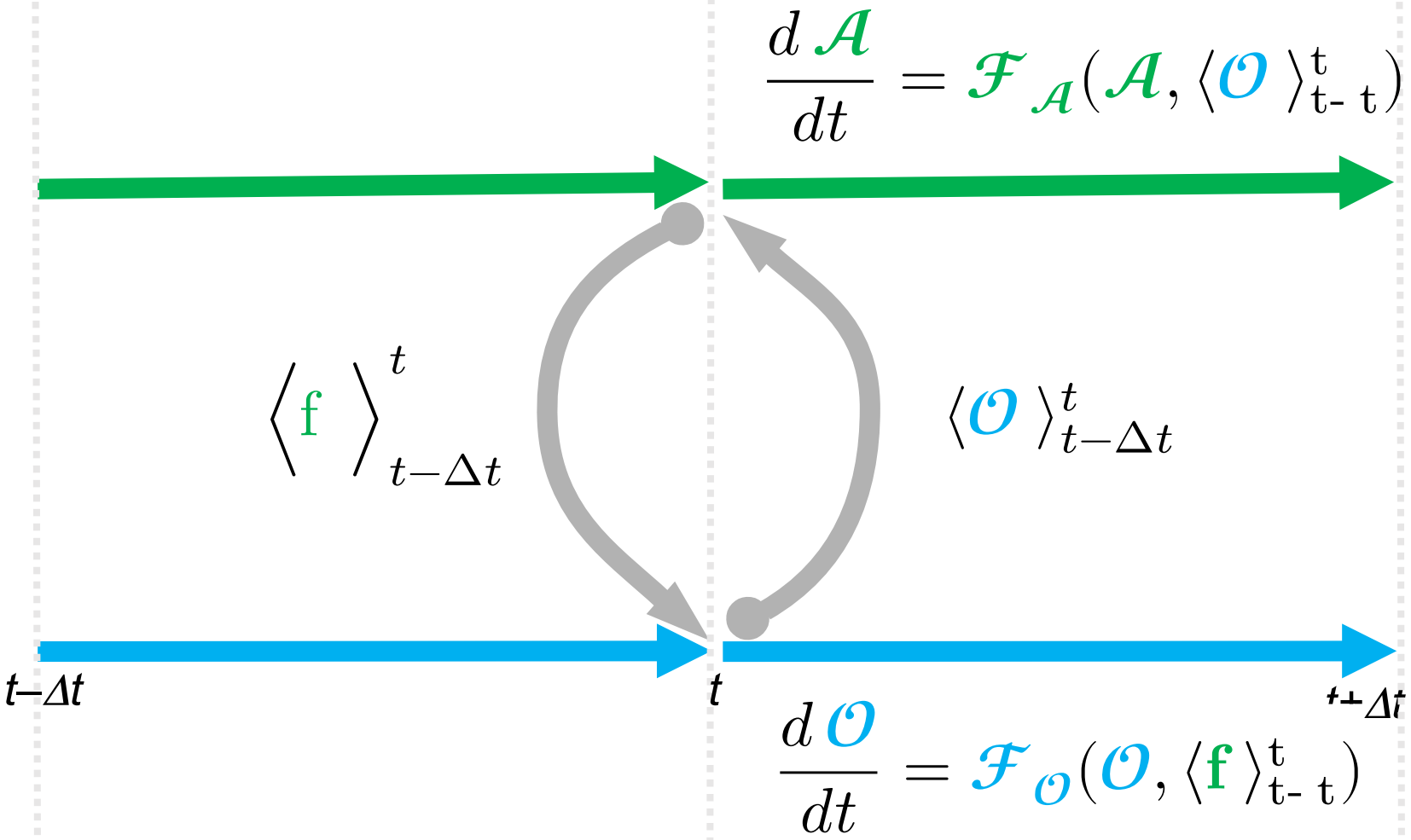
Improve the first guess to increase the convergence speed to **1 iteration**

- Deep Learning ?

Time steping between ocean and atmosphere is mathematically inconsistent

Models are not synchronised

[t, t+Δt] is the coupling time step. $\langle \bullet \rangle$ is the time average between to times



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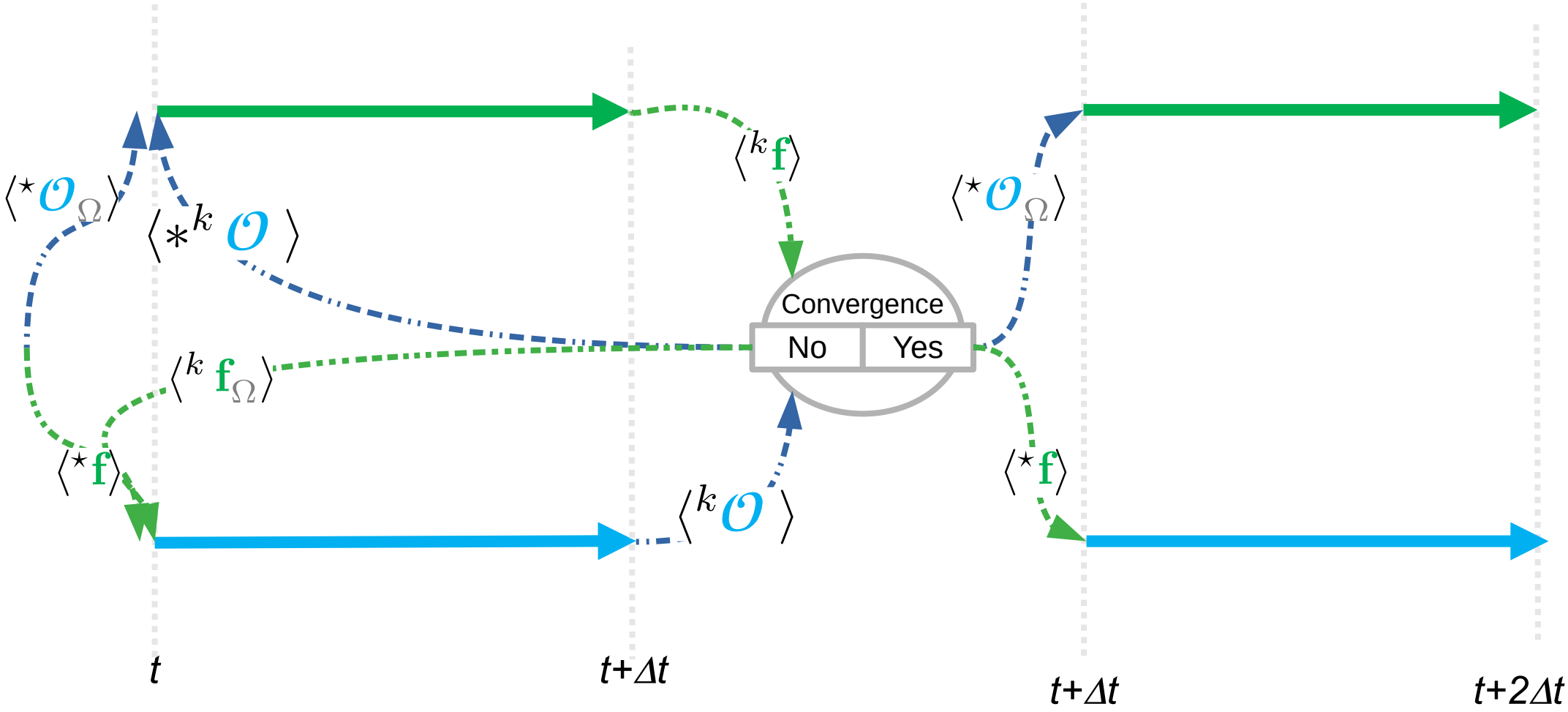

4 experiments

- 2 Years - 50 members
  - Small random pertubation of SST in initial state
- Time schemes
  - Parallel
  - Schwarz 5 iterations
  - Schwarz 2 iterations
  - Sequential Atmosphere First