How should we represent unresolved processes in climate models?

A data-driven approach for Rayleigh-Bénard convection

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School of Physics and Climate Change Research Centre

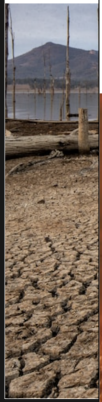
Tuesday 14 November 2023

SCIENCE

Climate change: 1.5C warming threshold to be passed in 9 years as emissions hit record high

ABC Science / B

Posted Fri 11 No

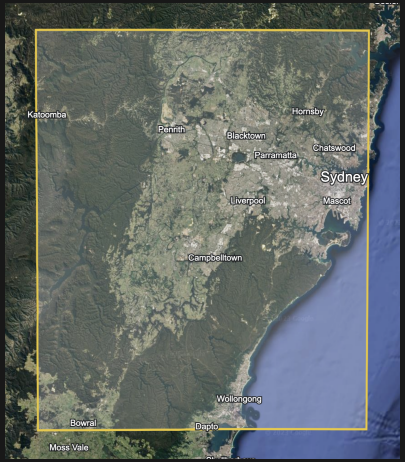


Climate change report from IPCC a 'code red for humanity', United Nations chief warns

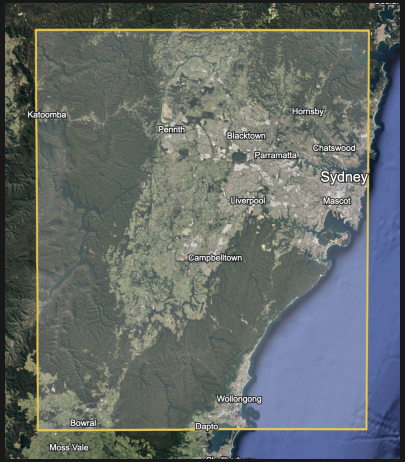
By national science, technology and environment reporter Michael Slezak and the Specialist Reporting Team's Penny Timms

Posted Mon 9 Aug 2021 at 6:01pm, updated Tue 10 Aug 2021 at 7:28am

$1^\circ \times 1^\circ$, L $\sim$ 100 km

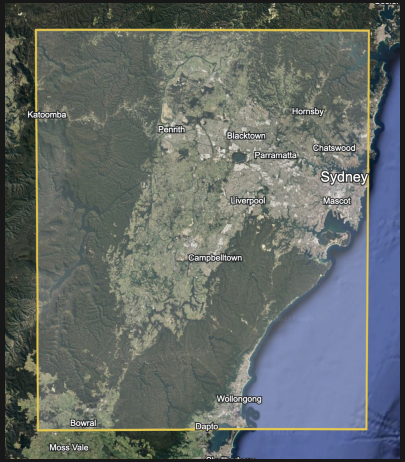


$1° \times 1°$, L $\sim$ 100 km



L $\sim$ 100 m

$1^\circ \times 1^\circ$, L $\sim$ 100 km

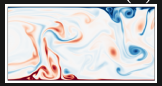


Favourable or unfavourable conditions

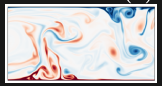
Moisture, heat transports

L $\sim$ 100 m

Fine state (t)

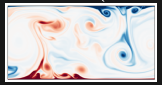


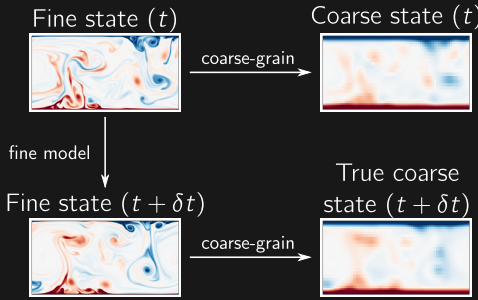
Fine state (t)

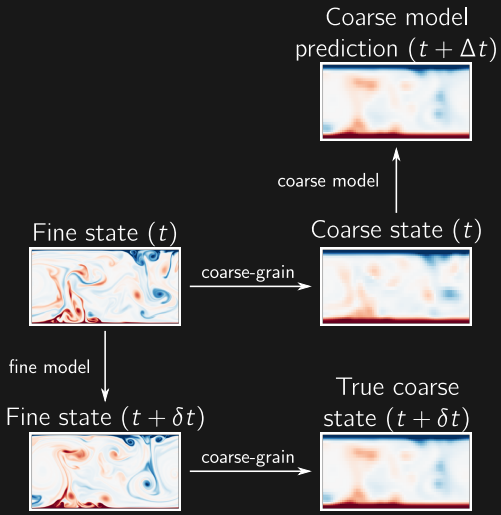


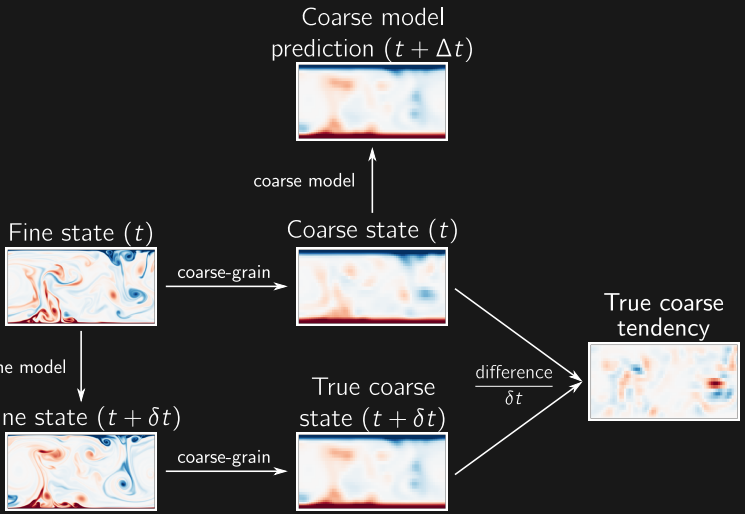
fine model

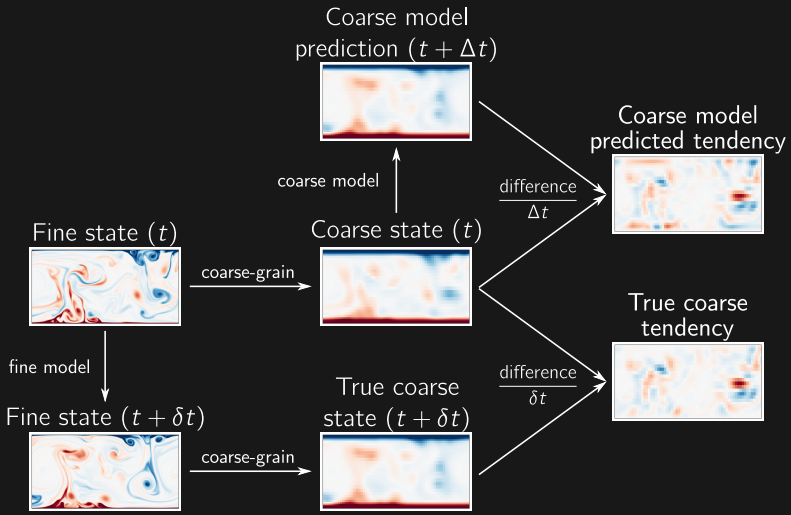
Fine state $(t + \delta t)$

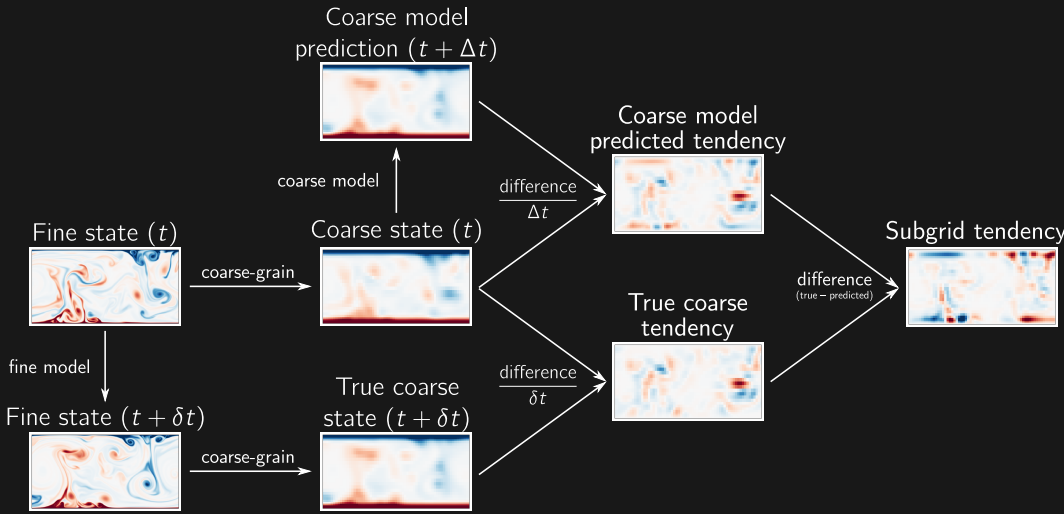


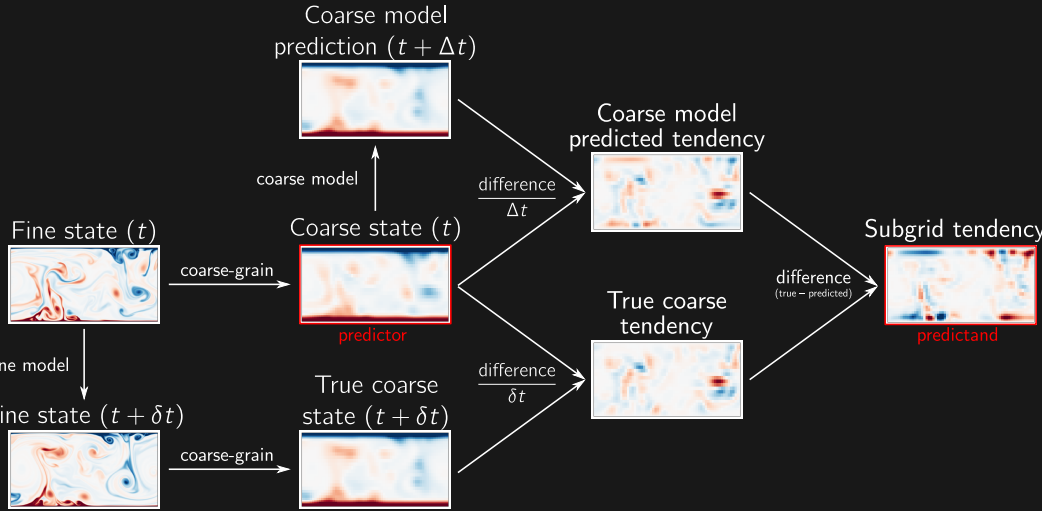

Fine state (t)
coarse-grain
Coarse state (t)
fine model
Fine state $(t + \delta t)$
coarse-grain
True coarse state $(t + \delta t)$

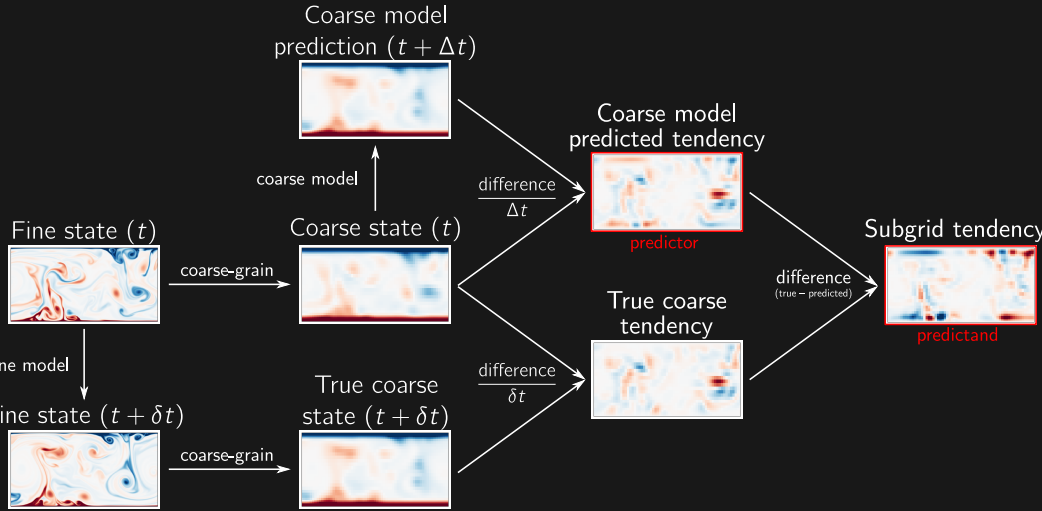

Coarse model prediction $(t + \Delta t)$
coarse model
Fine state (t)
coarse-grain
Coarse state (t)
fine model
Fine state $(t + \delta t)$
coarse-grain
True coarse state $(t + \delta t)$

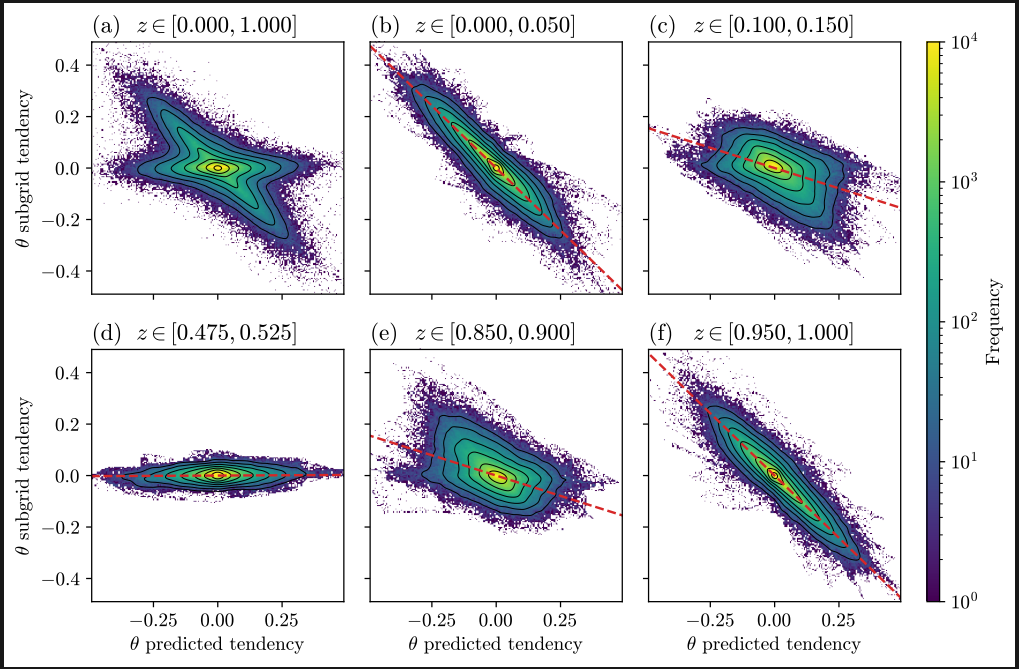

Coarse model prediction $(t + \Delta t)$
coarse model
Fine state (t)
coarse-grain
Coarse state (t)
True coarse tendency
fine model
difference
δt
Fine state $(t + \delta t)$
coarse-grain
True coarse state $(t + \delta t)$


Coarse model prediction $(t + \Delta t)$
Coarse model predicted tendency
coarse model
difference
Δt
Fine state (t)
Coarse state (t)
coarse-grain
True coarse tendency
fine model
difference
δt
True coarse state $(t + \delta t)$
Fine state $(t + \delta t)$
coarse-grain


Coarse model prediction $(t + \Delta t)$
coarse model
Coarse model predicted tendency
difference
Δt
Fine state (t)
coarse-grain
Coarse state (t)
Subgrid tendency
difference
(true − predicted)
True coarse tendency
fine model
difference
δt
Fine state $(t + \delta t)$
coarse-grain
True coarse state $(t + \delta t)$


Coarse model prediction $(t + \Delta t)$
coarse model
Coarse model predicted tendency
difference
Δt
Fine state (t)
coarse-grain
Coarse state (t)
predictor
Subgrid tendency
difference
(true − predicted)
predictand
True coarse tendency
fine model
difference
δt
Fine state $(t + \delta t)$
coarse-grain
True coarse state $(t + \delta t)$

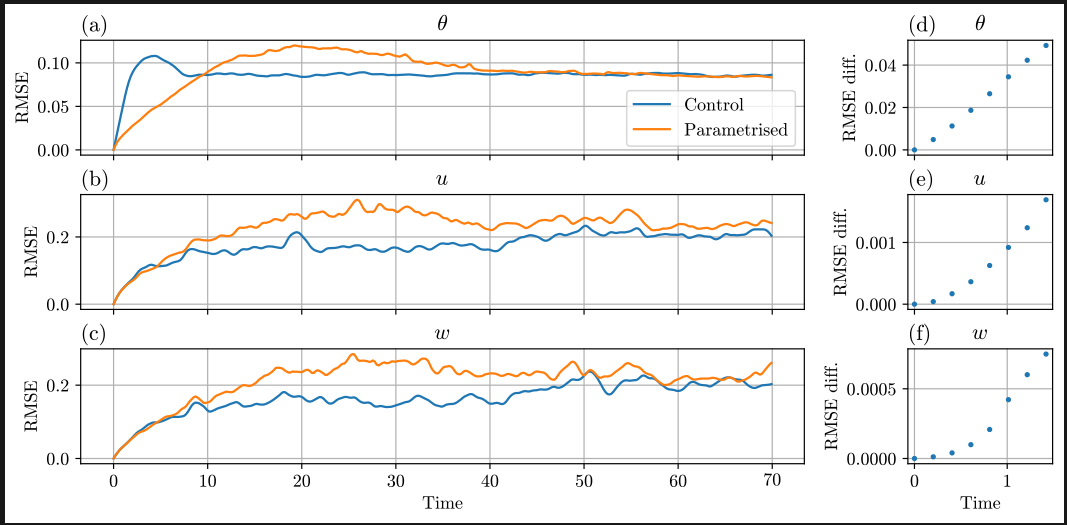

Coarse model prediction $(t + \Delta t)$
coarse model
Coarse model predicted tendency
difference
Δt
predictor
Fine state (t)
coarse-grain
Coarse state (t)
Subgrid tendency
difference
(true − predicted)
predictand
True coarse tendency
fine model
difference
δt
Fine state $(t + \delta t)$
coarse-grain
True coarse state $(t + \delta t)$

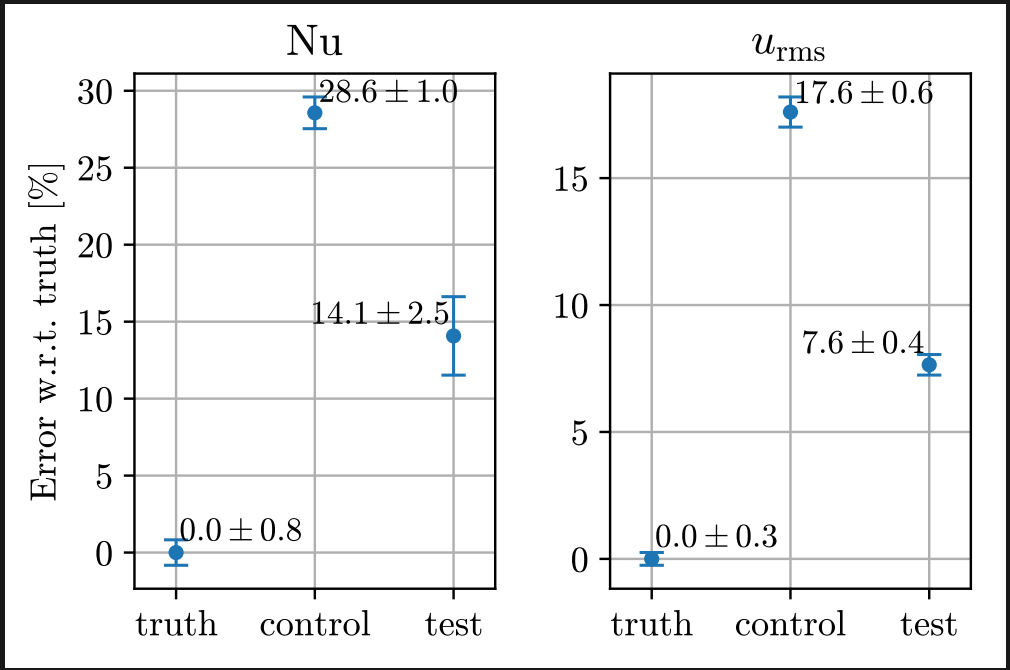

(a) $z \in [0.000, 1.000]$
(b) $z \in [0.000, 0.050]$
(c) $z \in [0.100, 0.150]$
(d) $z \in [0.475, 0.525]$
(e) $z \in [0.850, 0.900]$
(f) $z \in [0.950, 1.000]$
θ subgrid tendency
θ predicted tendency
0.4
0.2
0.0
−0.2
−0.4
−0.25
0.00
0.25
Frequency
10^0
10^1
10^2
10^3
10^4

$$\frac{\partial \boldsymbol{u}}{\partial t} = \cdots$$
$$\frac{\partial \theta}{\partial t} = \cdots$$

$$\frac{\partial \boldsymbol{u}}{\partial t} = \cdots$$
$$\frac{\partial \theta}{\partial t} = \cdots + \text{subgrid tendency model}$$

Truth	2048×256, no forcing
Control	256×64, no forcing
Parametrised	256×64, with forcing


(a)
θ
RMSE
0.10
0.05
0.00
Control
Parametrised
(b)
u
RMSE
0.2
0.0
(c)
w
RMSE
0.2
0.0
0
10
20
30
40
50
60
70
Time
(d)
θ
RMSE diff.
0.04
0.02
0.00
(e)
u
RMSE diff.
0.001
0.000
(f)
w
RMSE diff.
0.0005
0.0000
0
1
Time


Nu
u_{rms}
Error w.r.t. truth [%]
30
25
20
15
10
5
0
15
10
5
0
28.6 ± 1.0
14.1 ± 2.5
0.0 ± 0.8
17.6 ± 0.6
7.6 ± 0.4
0.0 ± 0.3
truth
control
test
truth
control
test

- Implemented a test bed for data-driven parametrisation
- Constructed a proof of concept by:
    1. Calculating subgrid tendencies
    2. Fitting a statistical model to predict them
    3. Using predicted subgrid tendencies to force a coarse model
    4. Demonstrating improved short-term forecast and long-term statistical ("climate") accuracy
- Future work: machine learning, stochasticity, memory