Stochastic parametrisation
Reducing model error in the Community Earth System Model

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Why stochastic parametrisation?

• Stochastic parametrisation seeks to represent unresolved sub-grid variability
  • Grid-scale variables do not fully constrain sub-grid motions
  • Describe sub-grid tendency in terms of a probability distribution constrained by the resolved-scale flow
  • Include random numbers in our equations of motion
• Necessary in NWP to achieve reliable ensemble forecasts, in which the probability distribution accounts for all uncertainty in the forecast
Why stochastic parametrisation in climate models?

- Stochastic parametrisation can improve variability of small-scale ‘weather’, which can in turn improve statistics of the modeled climate
  - ‘slow changes of climate are explained as the integral response to continuous random excitation by short period “weather” disturbances’ (Hasselmann, 1976)
- noise-induced drift, noise-enhanced variability, noise-activated regime transitions

Fig: Judith Berner
Test SPPT scheme in coupled CAM4

• **Stochastically Perturbed Parametrisation Tendencies (SPPT)**
  – represents random errors due to the model’s physical parametrisation schemes
  – Multiplicative noise used to perturb the total physics tendencies (Palmer et al. 2009)
  – Noise follows spectral pattern, 6hr, 500km decorrelation scales

• **Simulations**
  – Community Atmosphere Model v4, 1°
  – Community Ocean model, 1°
  – Transient (historical) forcing
  – 1870-2004 (135 years)
SPPT has modest impact on mean state
SPPT has large impact on variability
SPPT has a large impact on El Nino-Southern Oscillation

- Dominant mode of climate variability in Tropical Pacific
- Coupled atmosphere-ocean phenomenon:

Weakening / collapse of westward winds

Relaxation of thermocline: warm water spreads east

Convection moves to central Pacific.

Increase of pressure in west, reduction in central

Walker circulation readjusts

cf. La Nina: Cold event (opposite feedbacks)
SPPT impact on ENSO amplitude

Box shows Nino 3.4 region
SPPT impact on ENSO variability
Untangling the mechanisms

Weakening of westward wind

Circulation readjusts

El Nino

Convection moves east

Warm water spreads east

Variance of U850

• Use atmosphere-only simulations to break feedback loop

Christensen et al., 2017, J. Climate
Untangling the mechanisms

- Use atmosphere-only simulations to break feedback loop
• In CCSM4, WWBs are too tightly correlated with SST
  – Overly periodic ENSO
• SPPT reduces correlation, increasing stochasticity of events
Compare to enhanced resolution

Observations

Christensen et al., 2017, J. Climate
Small et al., 2014, JAMES
What next? Test in ensemble of climate simulations

- CESM has too much internal variability
  - E.g. NCAR Large Ensemble (LENS)

- Could a stochastic scheme improve this?
  - Create sister experiment to LENS with stochastic parametrisation

Deser et al, J. Climate, 2016
SPPT impact on T2m variance

CTRL – OBS

T2m variance

SPPT – CTRL
LENS predictions of 20-yr trends

Following van Oldenborgh et al, 2013, ERL.
What next? Consider impact in EC-Earth

Coupled EC-Earth (T255, 1° Nemo), 160 years, 3 ensemble members

Yang, Christensen, Corti, von Hardenberg and Davini, in prep
Davini et al, 2017, GMD
Stochastic parametrisations can alleviate model bias in climate simulations

- Important to consider biases in mean and variability
- Some similarities with improvements on increasing resolution

Future work will consider impact of stochastic schemes on ensembles of climate simulations

CCSM4 and EC-Earth both show improvements, but in opposite direction

- What can we learn about deterministic model biases from the way stochastic schemes impact those models?
Thanks for listening

References:
Christensen, Berner, Coleman and Palmer, 2017, *J. Climate*
Yang, Christensen, Corti, von Hardenberg and Davini, in prep for *GRL*.
Davini et al, 2017, *Geosci. Model Dev*
Perturbation varies smoothly

\[ T = D + (1 + e) \sum_{i=1} P_i \]

- \( T \) – Total tendency
- \( D \) – Dynamics tendency
- \( P \) – Physics tendency

Pattern correlated in space: 500km length scale
AR(1) process in time: 6hr decorrelation

All schemes are perturbed using the same pattern.
All variables perturbed using the same pattern.
Pattern constant in height

ECMWF Tech Memo 598
Impact on El Nino smaller than on La Nina
SPPT vs enhanced resolution: mean U850
SPPT vs enhanced resolution: U850 variability
SPPT vs enhanced resolution: mean SST
SPPT vs enhanced resolution: SST variability
What next? Consider impact in EC-Earth

- Change in EC-Earth is in opposite direction to in CAM
- Impact of multiplicative noise in a simple DO model of ENSO can provide insights

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