Exploring model uncertainty representation in the IFS transport scheme
Stochastic perturbations to the semi-Lagrangian scheme

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Exploring model uncertainty representation in the IFS transport scheme

Part I

• Including model uncertainty representations in ensemble forecasting systems: where / how / why?
• Current model uncertainty representation in the IFS
• Introducing a new model uncertainty scheme: STOCHDP

Part II

• STOCHDP: a case study
  – Typhoon Neoguri
  – Scheme sensitivities
Background: building a reliable ensemble forecasting system

In a reliable ensemble, **ensemble spread** acts as a predictor of **ensemble error**

Averaged over many ensemble forecasts:

\[
\sigma(x) \approx |e(\bar{x})| \]

⇒ Ensemble spread indicates the expected magnitude of the error of the ensemble mean
Background: representing model uncertainty in an ensemble forecast

Each ensemble member sees a different realisation of the forecast model.
Dynamics

- Discretisation
- Time-integration
- Transport
- Stabilisation

Physics parametrizations

- LW/SW Radiation
- Convection
- Clouds & microphysics
- Composition
- Boundary layer
- Turbulent mixing
- Gravity wave drag

Coupled processes

- Land-surface
- Ocean
- Sea-ice

Background: model uncertainty representation in the IFS
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SPPT
Stochastically Perturbed Parametrisation Scheme (e.g. Lock et al., 2019, QJRMS)
Background: how SPPT operates in the IFS

Physics tendencies:
T tendencies (K/3h), 0-3h, model level 64

Random pattern:
\( r \sim N[0, 0.44] \), time/spatial correlations

e.g. member #1
red, solid: 0 < r < +1
blue, dash: -1 < r < 0

\[ X' = (1 + r)X \]
Background: how SPPT operates in the IFS

Physics tendencies:
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Random pattern:
r~N[0,0.44], time/spatial correlations

e.g. member #1
red, solid: 0<r<+1
blue, dash: -1<r<0

Ensemble standard deviation
(20 perturbed members)
Background: how SPPT performs in the IFS

**ENS:**
- **Including SPPT vs Excluding SPPT**

*Fair CRPS (see Leutbecher 2019, QJ)*

- 212 cases *(JJA2018 + NDJF2018/19)*
- TCo399 L91 *(approx. 30km resol)*
- 8+1 members

Colours => significance at 99.7%
How about model uncertainty in the dynamical core...?

- Discretisation
- Time-integration
- Transport
- Stabilisation

Semi-Lagrangian advection

Physics parametrizations

- LW/SW Radiation
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Coupled processes

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X

Dynamics

P_X

C_X
STOCHDP: stochastic departure points

- Semi-Lagrangian scheme: Departure Point (DP) estimates
STOCHDP: stochastic departure points

- Semi-Lagrangian scheme: Departure Point (DP) estimates
- Diamantakis & Magnusson (2016): slower convergence $\Leftrightarrow$ strong shear/curvature
STOCHDP: stochastic departure points

- Semi-Lagrangian scheme: Departure Point (DP) estimates
- Diamantakis & Magnusson (2016): slower convergence ⇔ strong shear/curvature

Model uncertainty scheme: guided by the rate of convergence for the DP estimate

\[ D^* = D^{(5)} + r(D^{(5)} - D^{(5-i)}), \quad i = 1 \ldots 4 \]

where \( D^* \) is the perturbed DP and \( r \) is a random number
**STOCHDP: parameters**

\[
D^* = D^{(5)} + r(D^{(5)} - D^{(5-i)}), \quad i = 1..4
\]

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Details</th>
<th>Defaults</th>
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<tr>
<td>(i)</td>
<td>Perturb the difference btw 5(^{th}) and (5-(i))(^{th}) DP estimate</td>
<td>3 (i.e. \ r(D^{(5)}-D^{(2)}))</td>
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<tr>
<td>(r)</td>
<td>Random number:</td>
<td>(\mu=0,\sigma)</td>
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<td>(N(\mu,\sigma))</td>
<td>Normal distribution</td>
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<td>{(x,\tau)}</td>
<td>2D spectral pattern – correlation scales</td>
<td>{500km,6h} ((SPPT))</td>
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<td>(r_j)</td>
<td>Perturb LAT/LON/VER independently?</td>
<td>(j=1 \ i.e. \ r_{LAT}=r_{LON}=r_{VER})</td>
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| \(r(\ldots)\) | Apply a limiter to the perturbations:  
- Vertical: to prevent unphysical overturning  
- Horizontal: prevent U/V exceeding width of halos | \(\max|r(\ldots)| = |A-D^{(5)}|\) |
STOCHDP: early results (ENS scorecard)

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**ENS:**
STOCHDP + Initial Perturbations vs Initial Perturbations only

42 cases (Nov/Dec 2018)
TCo399 L91, t+360h
8+1 members

- ▲ => improved skill (fCRPS)
- ▼ => degraded skill (fCRPS)
- ▲ => increased spread
- ▼ => decreased spread

Solid triangles => significance at 95%
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Part I

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Part II

- STOCHDP: a case study
  - Typhoon Neoguri
  - Scheme sensitivities
STOCHDP case study: TC Neoguri

Diamantakis & Magnusson (2016):
- TC Neoguri
- HRES forecast
- Initialised: 2014-07-05, 00UTC
- t+96h, 850hPa windspeeds (Figure 1c)
- DP estimate: slowest convergence in TC vicinity (Figure 3)
STOCHDP case study: TC Neoguri

Control forecast

Windspeed

max(windspeed) = 49.8 ms⁻¹

ten of STOCHDP
TCo639L91, dt=720s
20+1 members

ENS:
STOCHDP only
TCo639L91, dt=720s
20+1 members
STOCHDP case study: TC Neoguri

Control forecast  
Windspeed  
Ensemble stdev

ENS:  
STOCHDP only  
TCo639L91, dt=720s  
20+1 members
STOCHDP case study: TC Neoguri

Control forecast

Windspeed

Ensemble stdev

ENS:
STOCHDP only
TC0639L91, dt=720s
20+1 members

max(windspeed) = 38.6 ms⁻¹
max(Sdev) = 3.2 ms⁻¹
STOCHDP case study: TC Neoguri

Control forecast

Windspeed

max(\text{windspeed}) = 41.6 \text{ ms}^{-1}

Ensemble stdev

ENS:
STOCHDP only
TCo639L91, \ dt=720s
20+1 members
STOCHDP case study: TC Neoguri

Control forecast

Windspeed

Ensemble stdev

ENS:
STOCHDP only
TC0639L91, dt=720s
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STOCHDP case study: TC Neoguri

Control forecast

Windspeed

Ensemble stdev

ENS:
STOCHDP only
TC0639L91, dt=720s
20+1 members
STOCHDP case study: TC Neoguri

Control forecast

Windspeed

max(windspeed) = 40.8 ms⁻¹

Ensemble stdev

ENS:
STOCHDP only
TCo639L91, dt=720s
20+1 members

max(Sdev) = 8.3 ms⁻¹
STOCHDP case study: TC Neoguri --- sensitivities

STOCHDP (dt=720s) Ensemble std dev - windspeed

ENS:
STOCHDP only
TCo639L91, dt=720s
20+1 members
STOCHDP case study: TC Neoguri --- sensitivities

Shorter timestep:
- smaller spread (overall)
- location of max spread differs

ė faster convergence of SL scheme
ė (reduced) phase speed errors

ENS: STOCHDP only
TCo639L91, dt=720s
20+1 members
**STOCHDP case study: TC Neoguri --- sensitivities**

Using \(D^{(5)} - D^{(1)}\) to construct the perturbation:
- amplitude of perturbations tuned for similar spread in global/regional analysis
- TC Neoguri: much greater spread

\(D^{(1)}\) least accurate where flow most complex

**STOCHDP** \((D^{(5)} - D^{(2)})\)

**Ensemble stdev - windspeed**

**STOCHDP** \((D^{(5)} - D^{(1)})\)

**ENS:**
- STOCHDP only
- TCo639L91, dt=720s
- 20+1 members
STOCHDP case study: TC Neoguri --- sensitivities

Longer correlation scales in the random patterns:
• much greater spread
• extending over much larger area
Summary: Exploring model uncertainty representation in IFS transport scheme

Part I
STOCHDP:
• introduces stochastic perturbations to the SL departure point (DP) calculation in ENS
• uses convergence rate of unperturbed DP estimate to modulate size of perturbations
• ENS medium-range experiments show promise in terms of probabilistic skill

Part II
Typhoon Neoguri case study:
• STOCHDP generates ensemble spread close to the source of uncertainty
• Scheme sensitivities to timestep and DP calculation appear consistent with SL numerics
Exploring model uncertainty representation in the IFS transport scheme

Stochastic perturbations to the semi-Lagrangian scheme

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Thank you for your attention!