Model Uncertainty – MIP

Constraining stochastic parametrisations using high resolution simulations

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How should we represent model uncertainty?

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- Why MY chosen **stochastic parametrisation**?
  - Practical performance vs. theoretical underpinning
  - Should every model use the same scheme?
    - Different modeling assumptions
    - Different resolutions
    - Different regional foci
  - To what extent can one scheme ‘mop up’ all uncertainty
    - Do we need multiple schemes or will this lead to double counting?

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- What about the climate modelling community?
  - Do **multiple models**/parametrisations span model uncertainty?
  - How much of structural errors can we attribute to poor **tuning**?
  - How can **stochastic** approaches complement multi-physics?

How can we begin to answer these questions?

→ **Require a large database of model error**

- For different models
- For different global regions
- For different seasons
- For different model resolutions

Ideally accompanied by

- Information on model parametrised tendencies

Model Uncertainty - MIP

- Joint initiative of WWRP's PDEF and WCRP's WGNE
    - model error identification
    - Aim: intercomparison of random and systematic error characteristics across many models

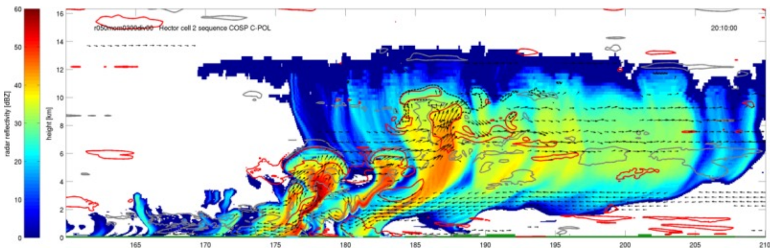
- Will provide new database of model error

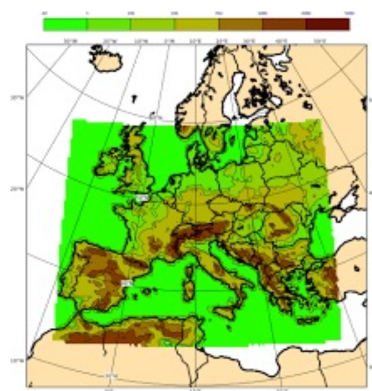
- **Funding secured to support work**
    - NCAR/NOAA DTC – June 2021-June 2025
    - Leverhulme Trust: Oxford (with ECMWF), Exeter (with UK Met Office), Météo France – Sept 2023-Sept 2026

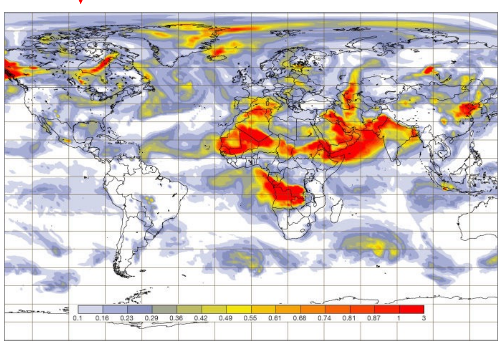
https://mumip.web.ox.ac.uk

Use a high resolution simulation as 'truth'

- Use high resolution simulation, that resolves process of interest, to inform parametrisation at lower resolution
- "nature run" should be extended in space and time -> learn spatio-temporal correlations needed by stochastic parametrisations







E.g. LES → inform stochastic parametrisation for LAM

E.g. convection permitting LAM → inform stochastic parametrisation for global EPS

- Caveat: **the high resolution benchmark is not the real atmosphere**
  - ➢ Compare model to multiple benchmarks, including those from other models

Image credits: (L) M. Herzog (C) COSMO (R) ECMWF

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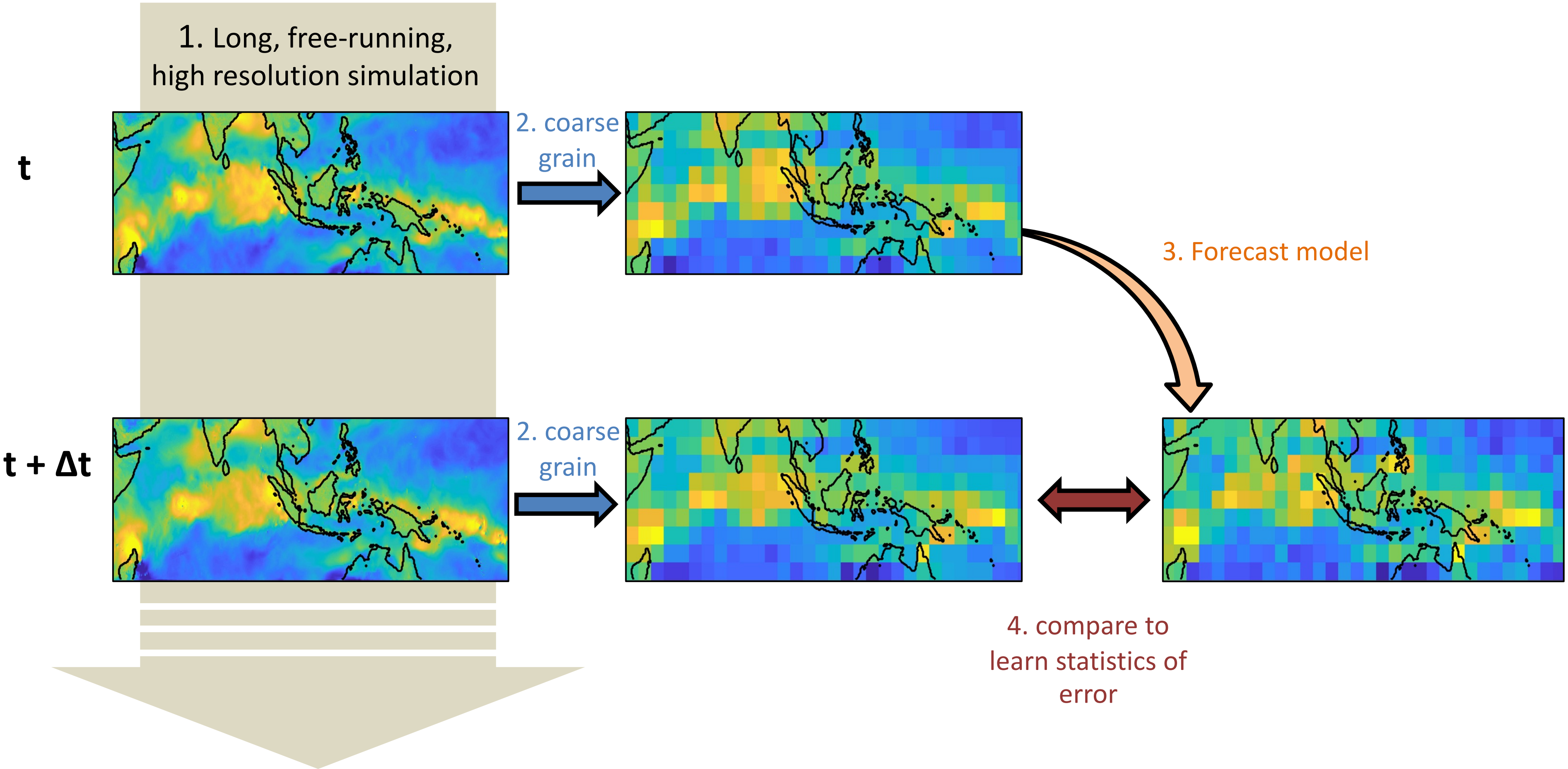


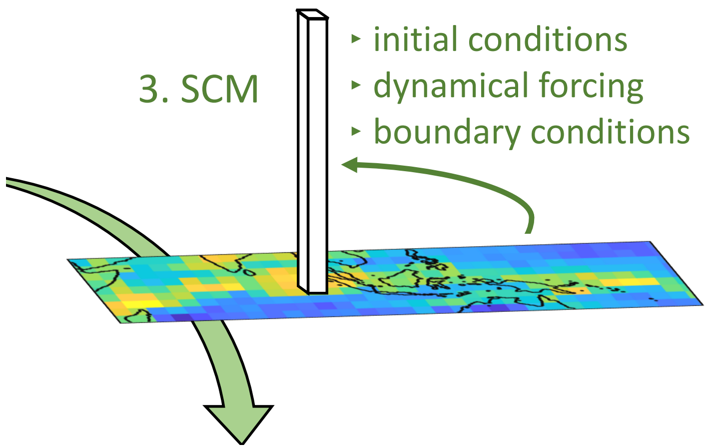
Christensen et al, 2018, JAMES.
Christensen, 2020, QJRMS

Single Column Model (SCM) as Forecast Model

- A SCM consists of:
  - subgrid parametrisations from parent model
  - forced with dynamical tendencies

- How do we use an SCM?
  - Use coarsened high-res simulation to prescribe Initial conditions, Dynamical forcing and Boundary conditions

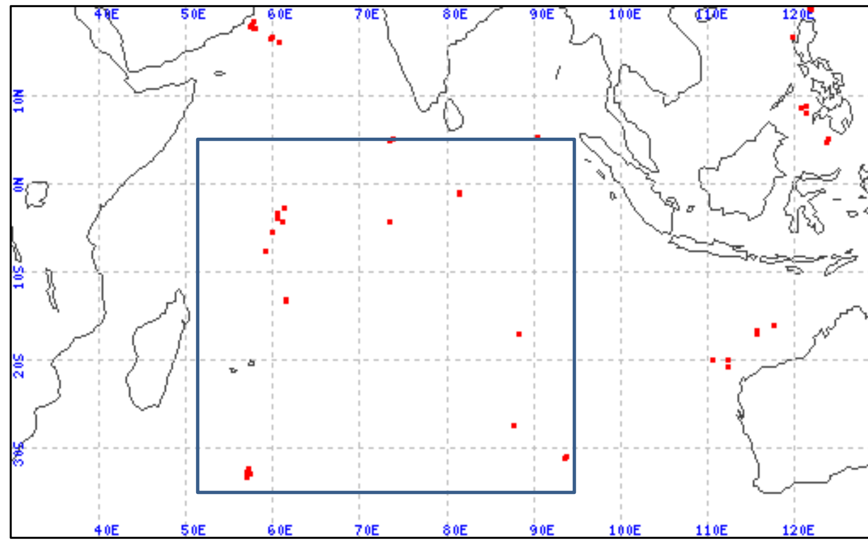
- Benefits of using SCM?
  - Supply dynamical tendencies targets uncertainty in the parametrisation schemes
  - SCM portable and cheap
  - Tile many SCM to cover domain
  - New DEPHY format facilitates sharing of SCM driver files



Christensen, Dawson and Holloway, 2018, JAMES

First MUMIP experiment: Indian Ocean domain

- Last 30 days of **ICON 2.5km Dyamond Summer** simulation
- Data archived 3 hourly
- CG to resolution of 0.2 degrees (~22 km)
- Domain in Indian Ocean: (51-95E,5N-35S)
- See website: mumip.web.ox.ac.uk



Rapid progress over recent months!

Complete datasets from four models!

- CCPP SCM + Global Forecast System (GFSv17) physics (X. Sun, NOAA/DTC, K. Newman, NCAR/DTC)
- CCPP SCM + Rapid Refresh (RAP) physics (X. Sun NOAA/DTC, K. Newman, NCAR/DTC)
- ECMWF OpenIFS CY48r1 (E. Groot, U. Oxford)
- Météo France ARPEGE-Climat SCM (W. Lfarh, Météo France)

UK Met Office runs in production, available shortly (K. Singh, Univ Exeter)

Analysing the data: multiplicative noise?

SPPT:

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

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Calculate ‘true’ total tendency from coarsened ICON

Assume SCM dynamics tendency is ‘correct’

Assess error in SCM physics tendencies

$$\underbrace{T - D}_{} = (1+e)\underbrace{\sum_{i=1} P_i}_{}$$

Compare ‘true’ physics tendency …

… to parametrised physics tendency

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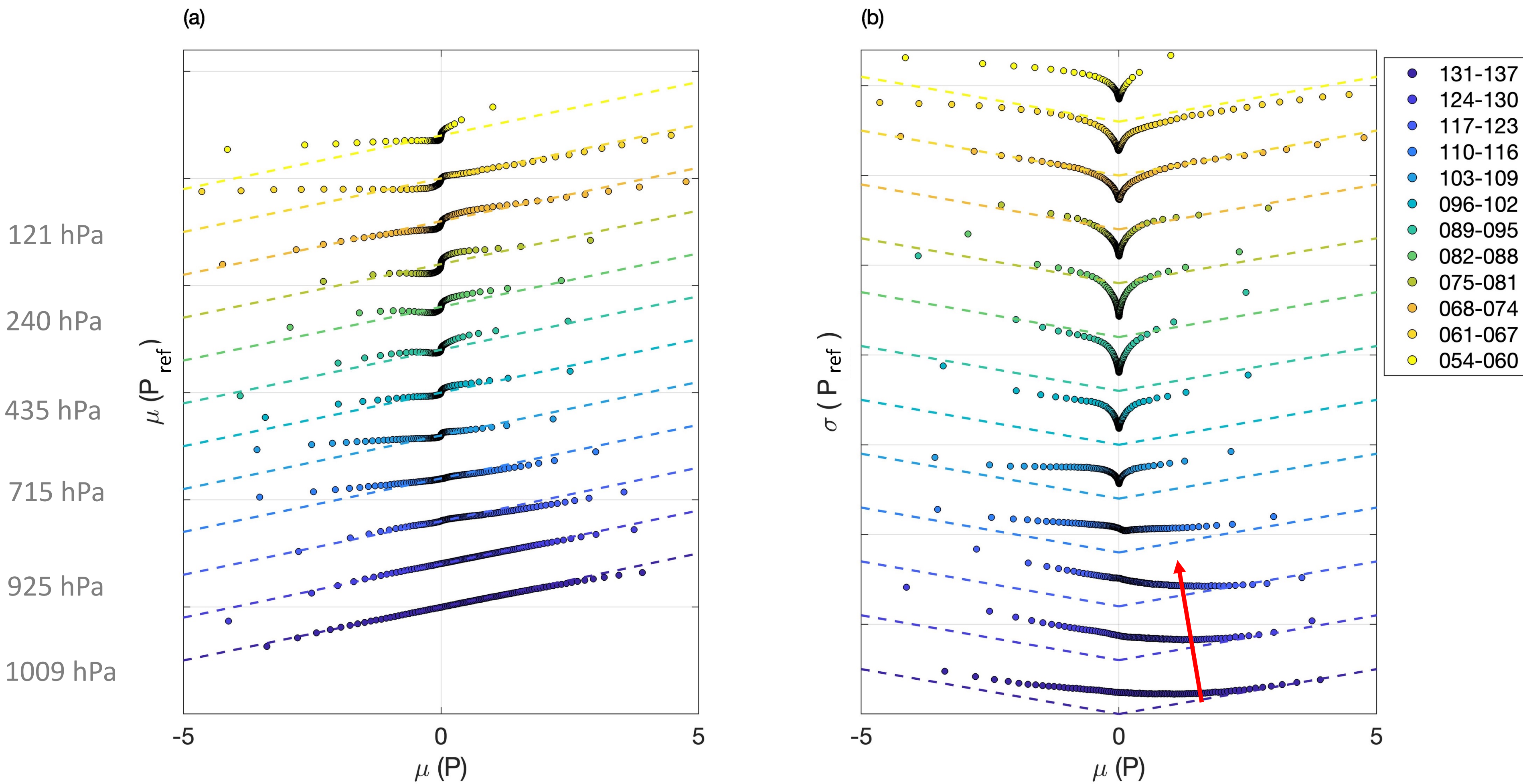
Very preliminary analysis so far!
- 3 models
- 5 days simulation considered:
= 1.8 million simulations

U tendencies

IFS

mean and standard deviation of reference conditioned on SCM prediction



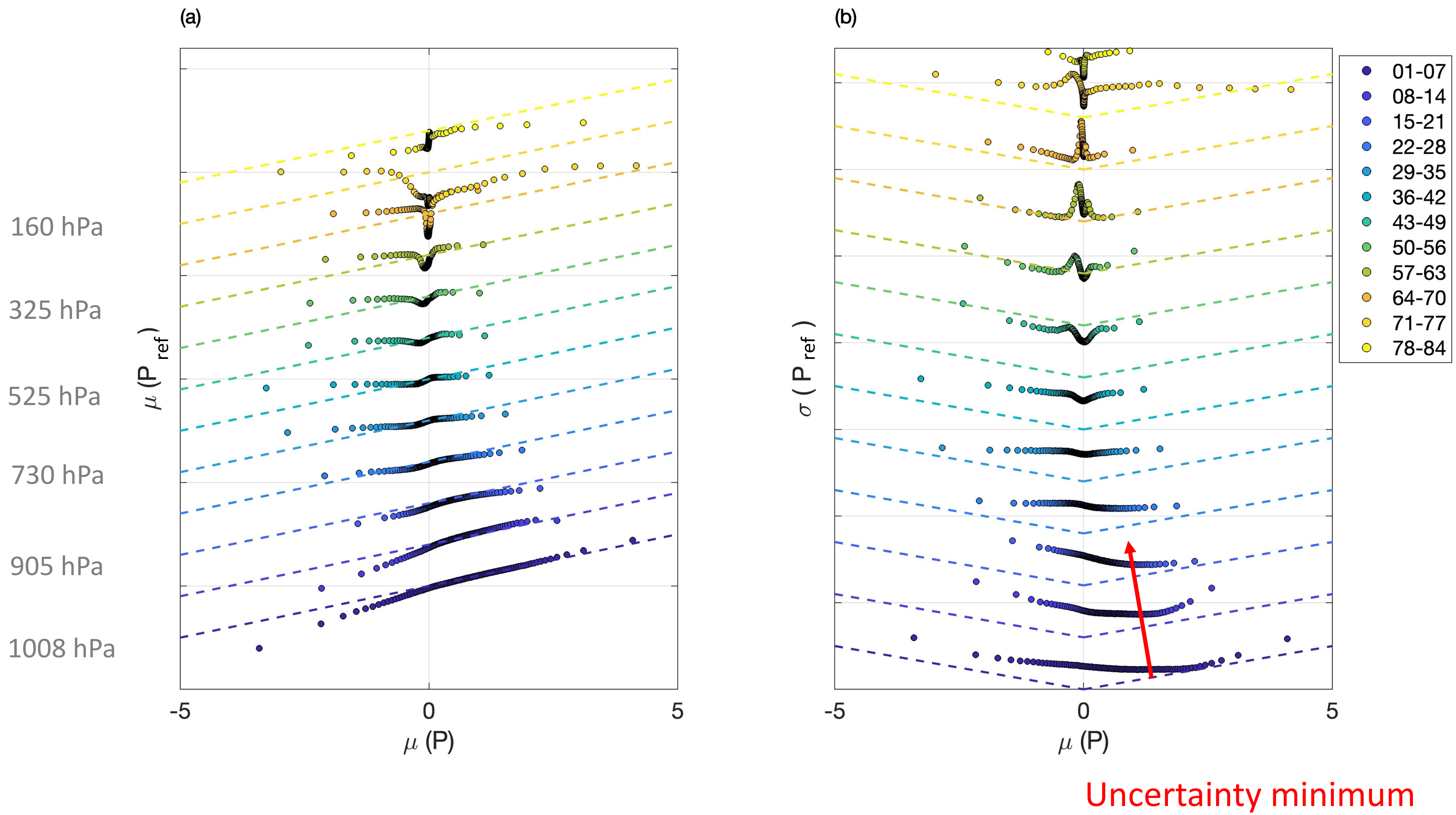
Well calibrated, especially near surface

Uncertainty minimum

GFS

U tendencies

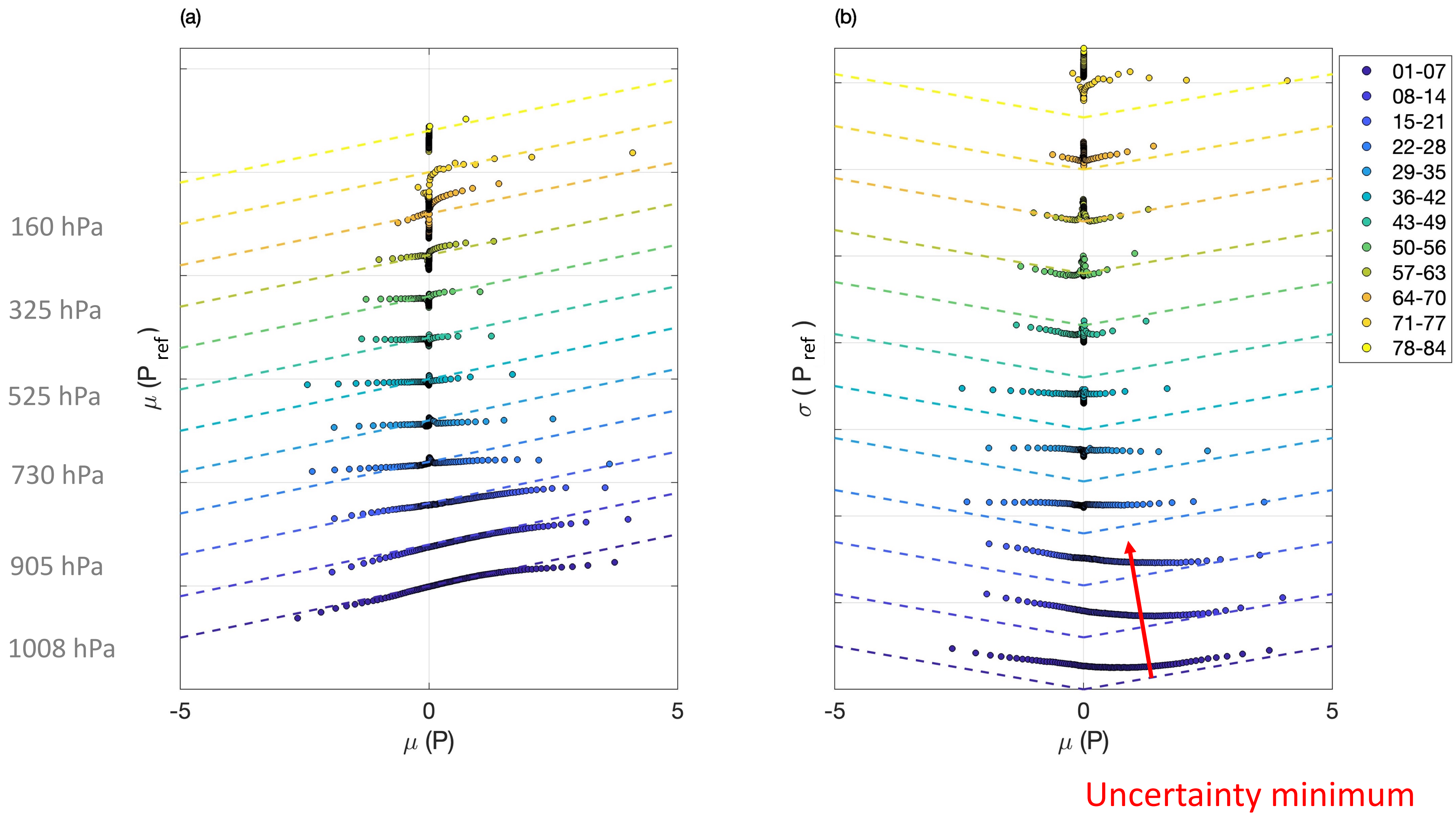
mean and standard deviation of reference conditioned on SCM prediction



RAP

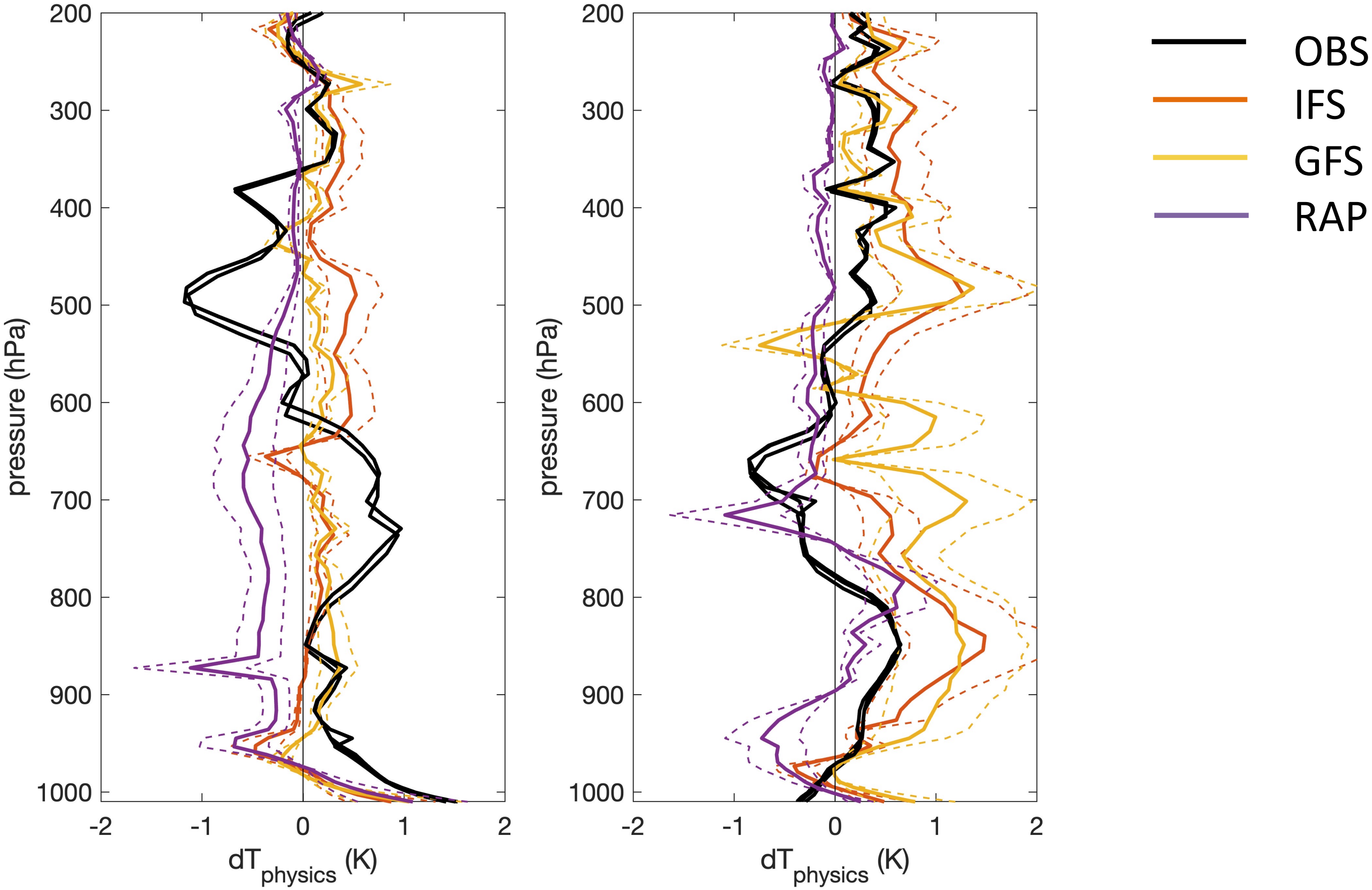
U tendencies

mean and standard deviation of reference conditioned on SCM prediction



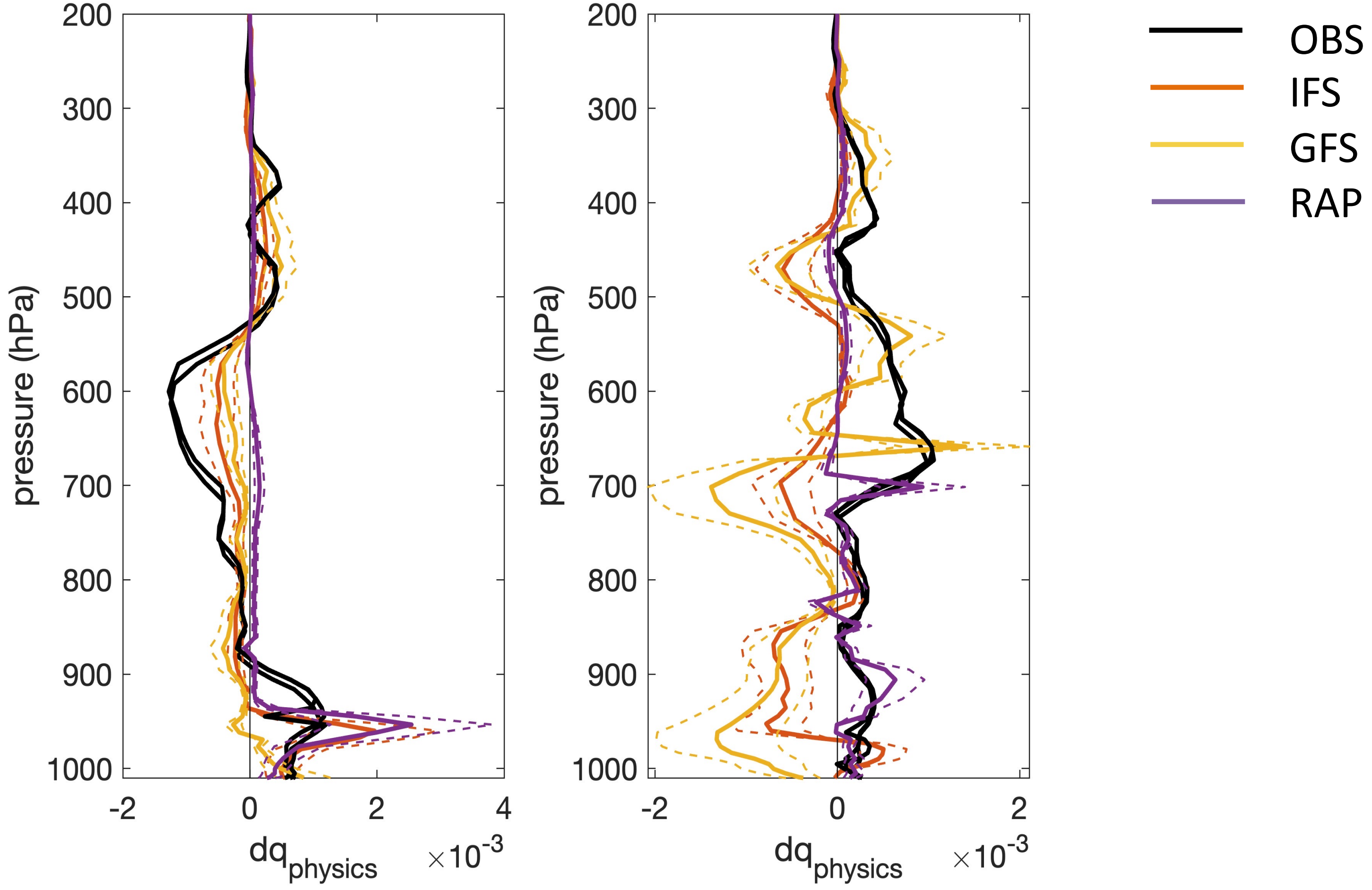
Multi-model vs SPPT

- Consider vertical profiles of physics T tendency in two sample columns



Multi-model vs SPPT

- Consider vertical profiles of physics q tendency in two sample columns



MU-MIP plans

- Assess structural error across different models
  - Exeter lead: H. Lambert and K. Singh
- Assess parametric uncertainty
  - Meteo France lead: R. Roehrig and W. Lfarh
- Assess random error, foundations of stochastic parametrisations
  - Oxford lead: H. Christensen and E. Groot

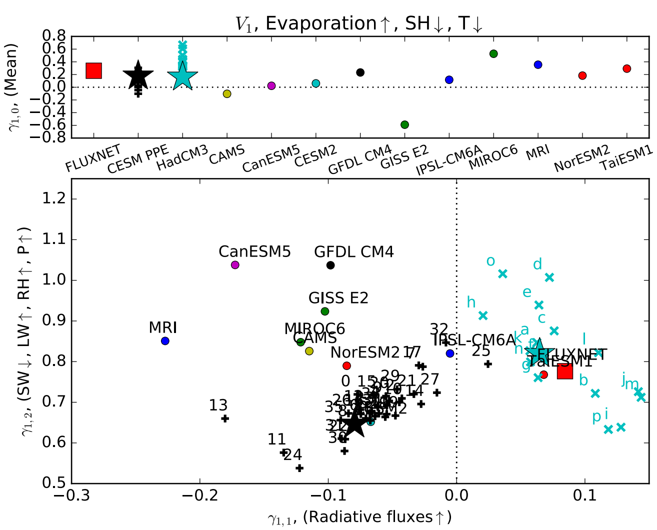


Fig: Hugo Lambert

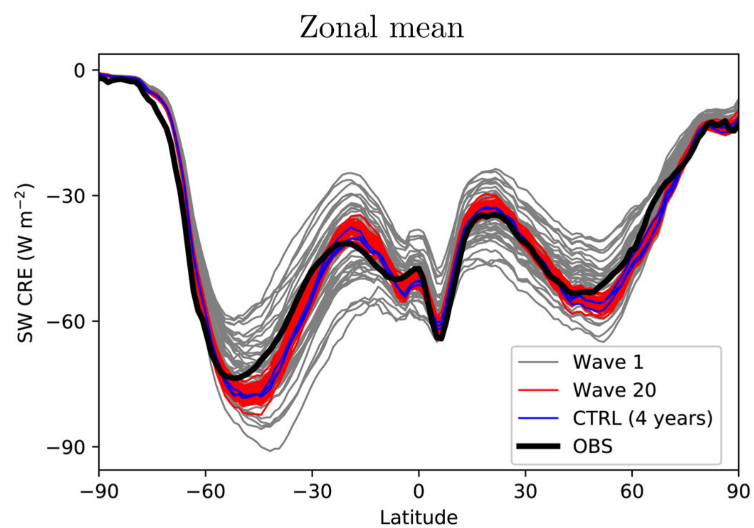
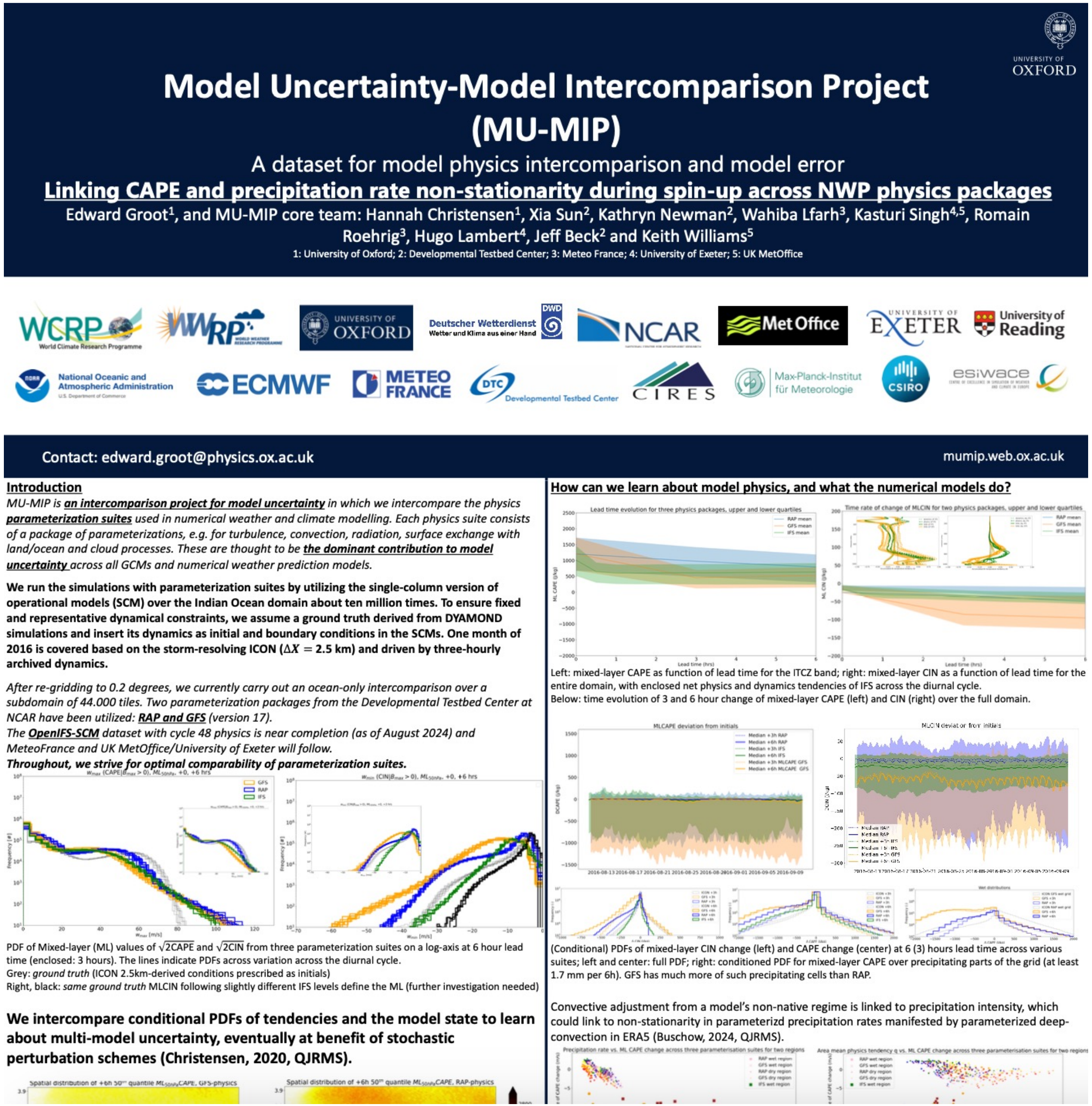


Fig: Hourdin, …, Roehrig, et al, 2020, JAMES

Please see Edward Groot’s poster for more analysis



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Model Uncertainty - MIP

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Home

Welcome to the Model Uncertainty - Model Intercomparison Project (MUMIP)

An initiative of the WCRP Working Group for Numerical Experimentation and the WWRP Predictability, Dynamics and Ensemble Forecasting Working Group

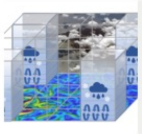
Introduction

MU-MIP is an international project which seeks to characterise systematic and random component of model error across many different climate models. This is the first coordinated intercomparison of random model error, and will be used to inform stochastic parametrisation development.

Some key questions:

- How should we best represent model uncertainty/random error using stochastic approaches?
- To what extent should this representation be model specific or a fundamental property of atmospheric models?
- Are current approaches justified? How can they be improved?
- Can a coarse-graining approach be used to validate and compare high-resolution simulations and their behaviour across scales?

News



New MUMIP data available for analysis

29 August 2024

Oxford Workshop on Model Uncertainty, 23-26 Sept

10 June 2024

MUMIP Meeting 5

29 April 2024

Leverhulme Trust Research Project Team Meeting 2

21 February 2024

Leverhulme Trust Research Project team meeting 1

12 January 2024

MUMIP Meeting 4

4 October 2023

1 | 2 | 3 | next | last

Contact

The MU-MIP team consists of scientists from 10+ institutes spanning three continents. Please get in touch bv emailing Hannah Christensen on hannah.christensen 'at' physics.ox.ac.uk if

Thanks for listening

Hannah.Christensen@physics.ox.ac.uk

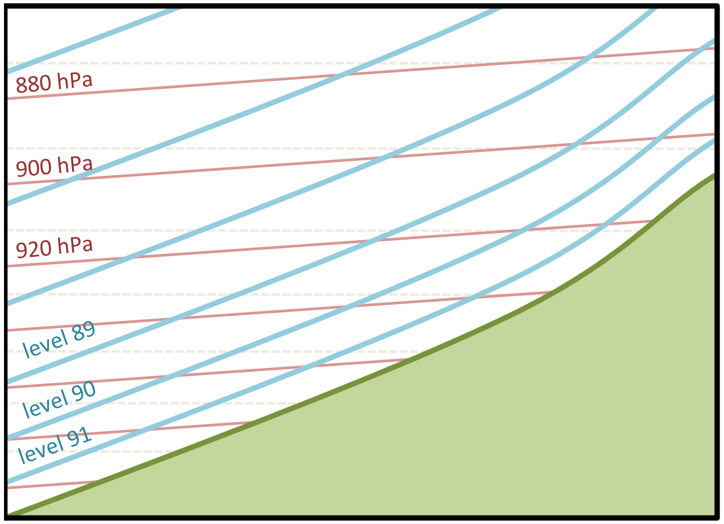
Extra Slides

Coarse graining details

1. Local area averaging for coarse graining

$$\overline{\psi}_{n,k} = \sum_{i}^{I} W_{n,i} \psi_{i,k}$$

2. Linearly interpolate in time
3. Vertical interpolation
   - Evaluate coarse-scale grid box mean p_{sfc}
   - Coarse-grain other fields along model levels
   - Interpolate from native model levels to target model levels



4. Above high-resolution model top, pad data using ECMWF analysis
5. Advective tendencies estimated from the coarsened fields

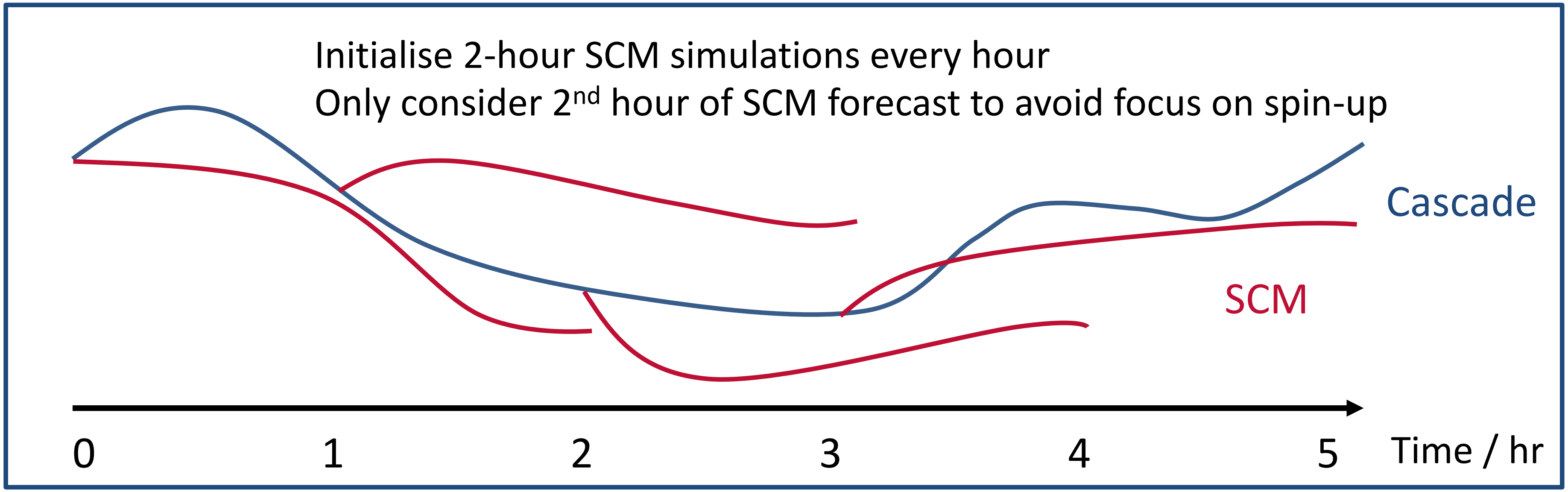
$$\mathrm{adv}(\psi)|_{n,k} = -\overline{\mathbf{u}}_{n,k} \cdot \overline{\nabla}_k(\overline{\psi_{n,k}})$$

6. Specify sensible and latent heat fluxes from high-resolution dataset, but take static boundary conditions from operational ECMWF model at T639

Christensen et al, 2018, JAMES.

What we do

- Coarse-grain Cascade to T_L639
- Run an independent SCM simulation, initialised every hour, from every lat-lon point (>68,000) in the coarse-grained domain
- Run each SCM simulation for two hours, discard the first hour to avoid focus on spin up
- Repeat for entire 9-day Cascade simulation



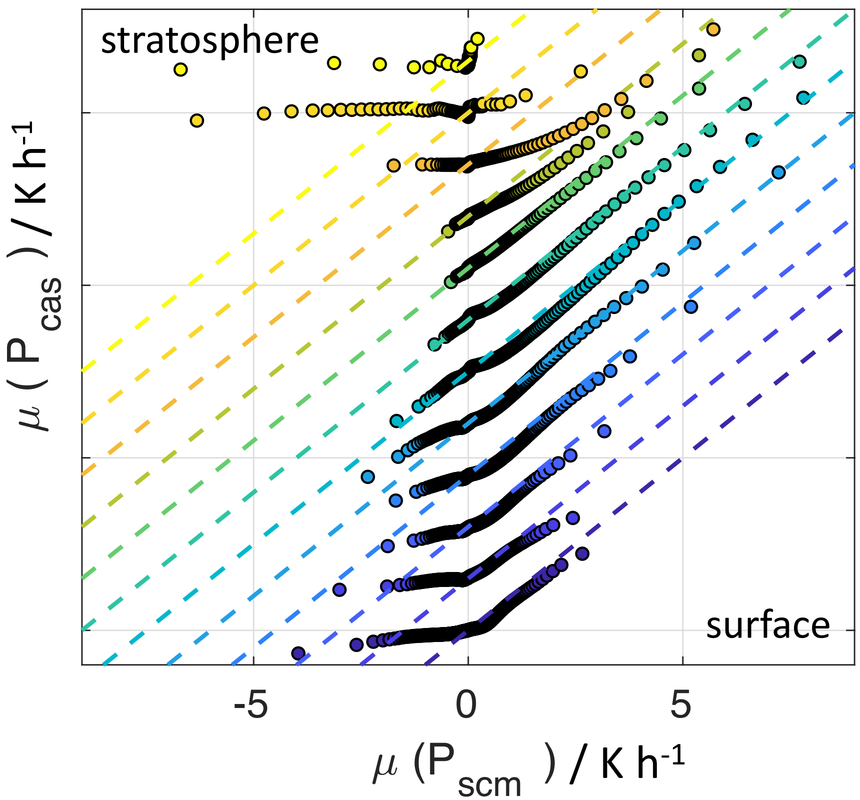
Cf. existing approaches to identify model error

- **E.g. Initial tendency approach** in which physics tendencies in data assimilation cycle are compared to the analysis
- **E.g. Transpose AMIP** in which climate models are run in weather forecasting mode from common initial conditions

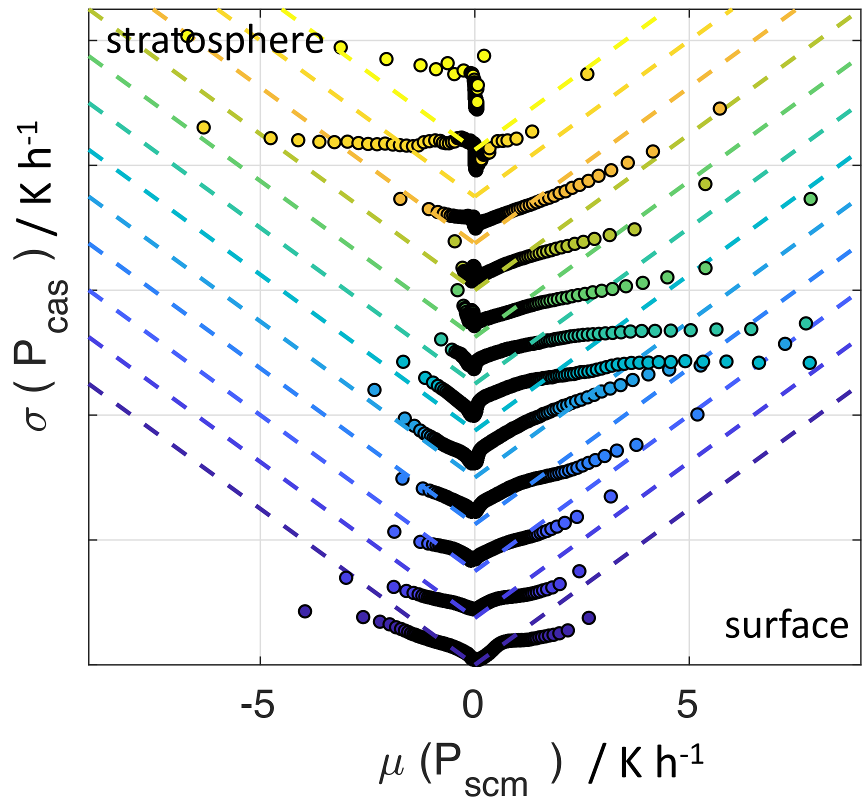
	Initial tendency	Transpose AMIP	My SCM approach
Decompose model evolution (& error) into single processes	☺		☺
No data assimilation capabilities needed to evaluate forecast model		☺	☺
Comparison of model with its native analysis may mask errors	☹		
Inconsistencies in IC can lead to systematic drifts		☹	☹

Consider T tendency

Mean tendency



Uncertainty in tendency



Data grouped by level.
Dark blue: levels 91—87 (ground—995 hPa)
Yellow: levels 32—36 (86—60 hPa)