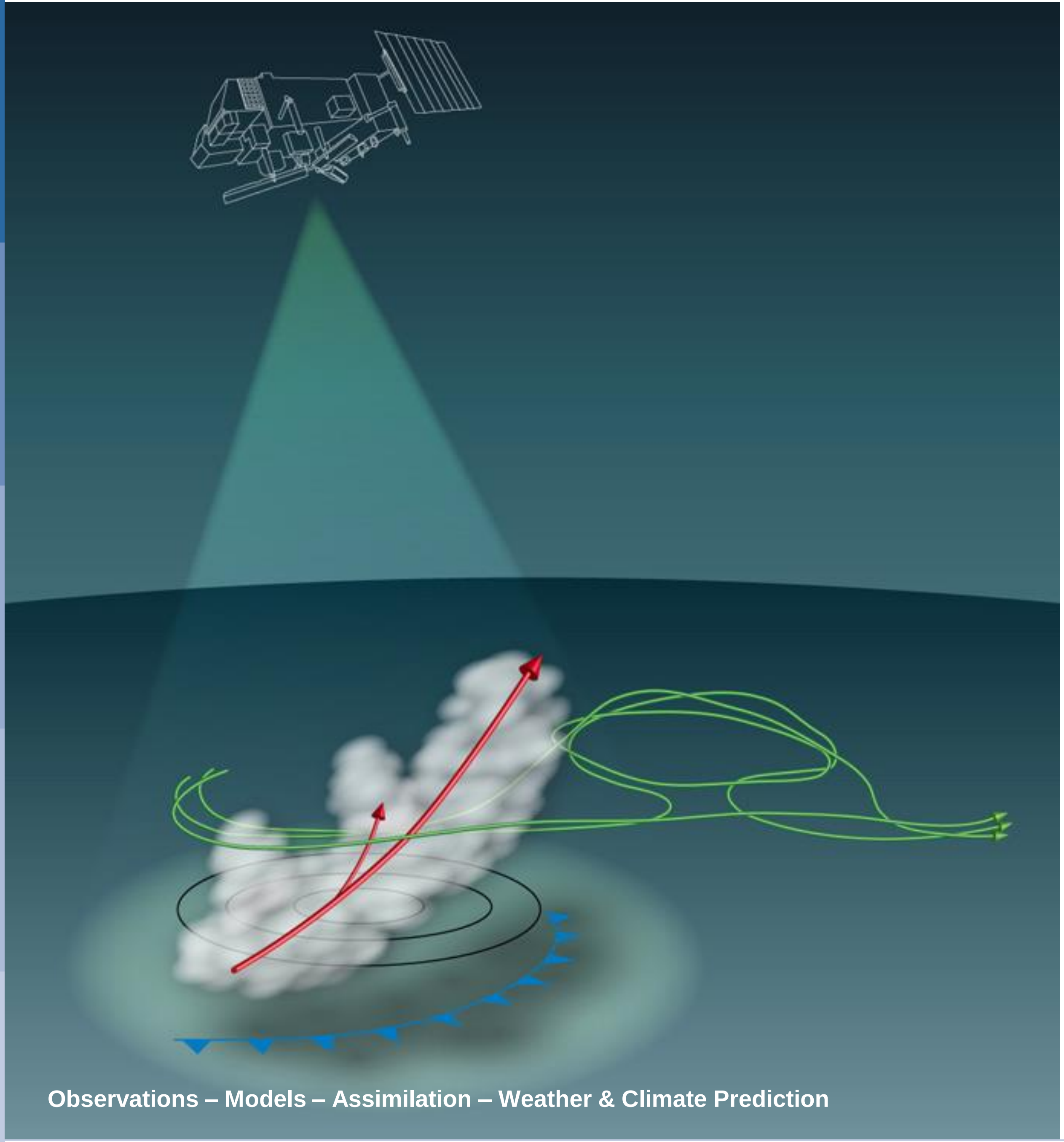


Aspirations for the Workshop - Bringing WCB understanding into forecast system development

Mark Rodwell

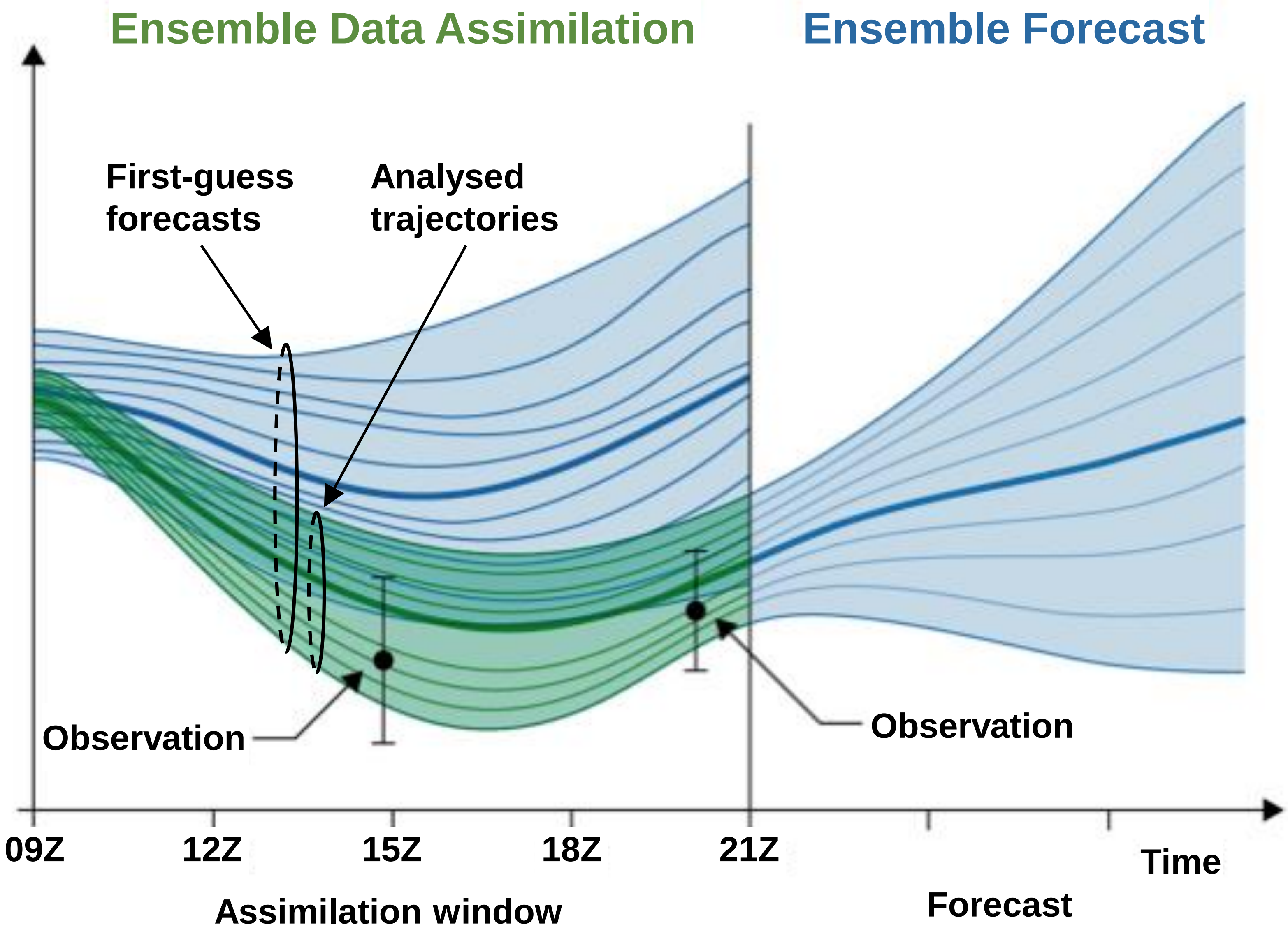
In collaboration with:

Heini Wernli, Richard Forbes, Alan Geer, Elias Hólm, Bruce Ingleby, Simon Lang

Warm conveyor belts – a challenge to forecasting

10 March 2020, ECMWF virtual workshop

What we wish to improve: the Ensemble Prediction process



Lorenz (1963) … **Chaos** and the "**Butterfly Effect**"

Molteni and Palmer (1993) … **Fastest growing initial uncertainties**; "singular vectors"

Buizza, Miller and Palmer (1999) … **Model uncertainties**; "stochastic physics"

<u>**Goal of Forecasting**</u>

Increase "**sharpness**" (decrease spread) of the ensemble while maintaining statistical (flow-dependent) **reliability**

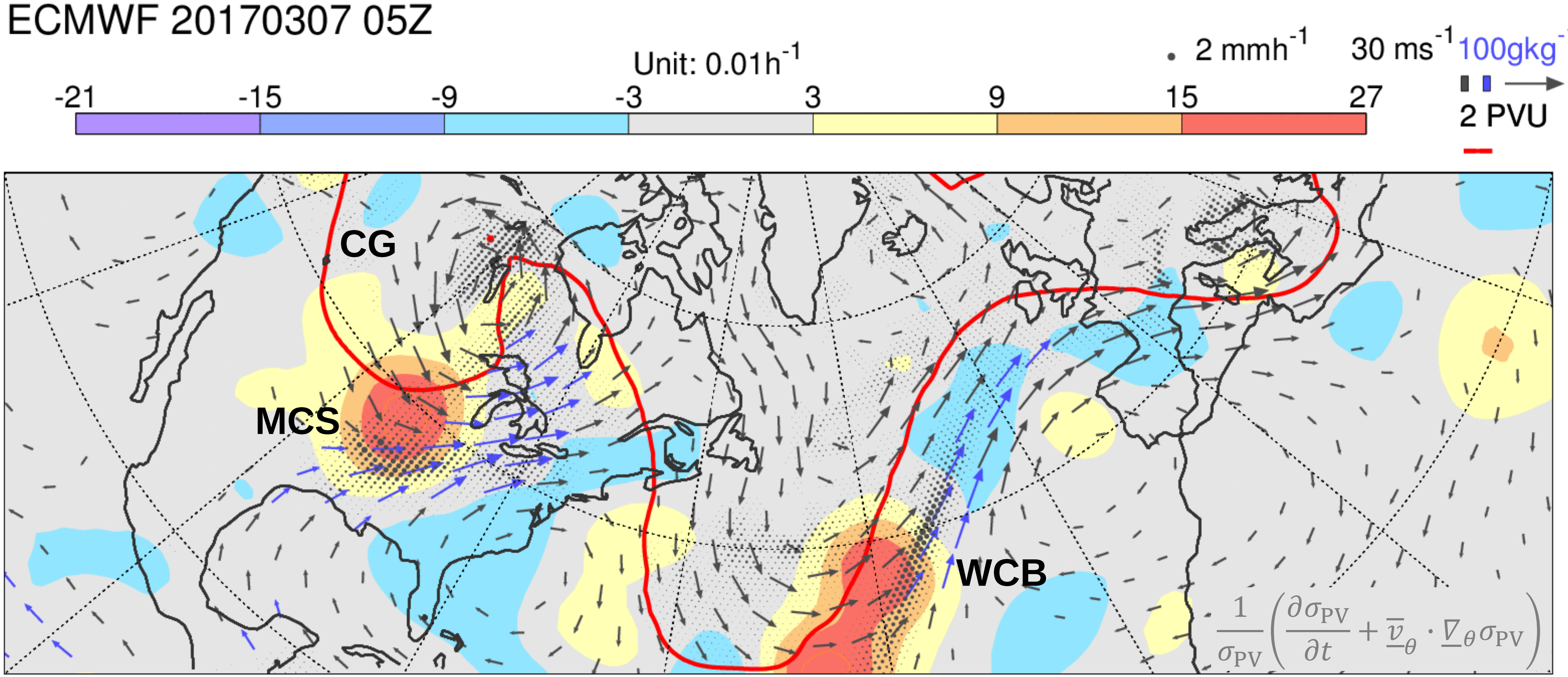
Searching for Butterflies: Uncertainty growth-rate in EDA background $\sigma_{PV_{315}}$

Much uncertainty growth associated with moist processes: **W**arm **C**onveyor-**B**elts, and **M**eso-**S**cale **C**onvection

Interaction of uncertain features, large ENS spread & poor prediction of Euro blocking at D+6

Aim: Evaluate short-range synoptic flow-dependent representation of uncertainty

Q: Is sensitivity to moist processes real or due to deficiencies in model uncertainty representation? TIGGE?

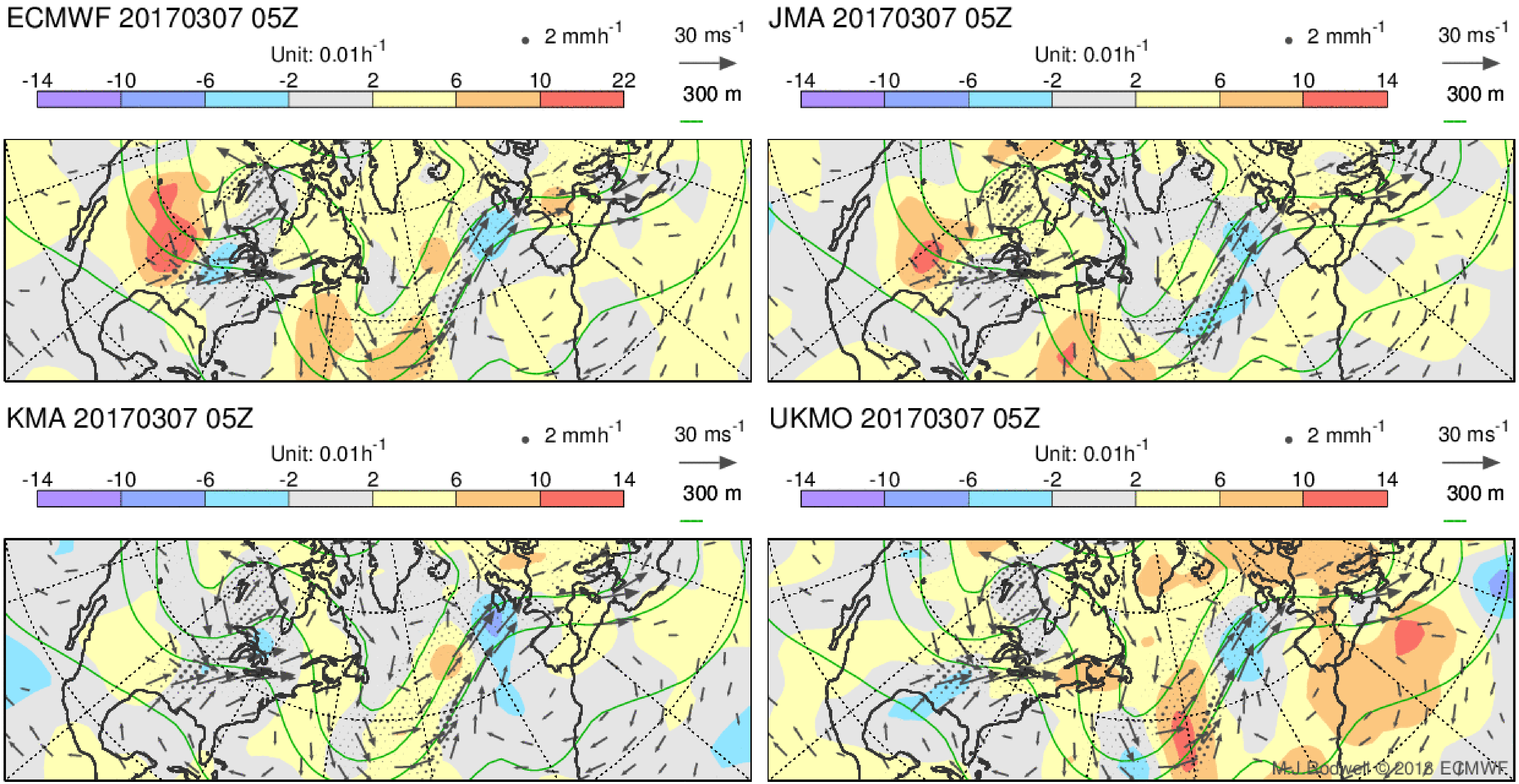


$$\frac{1}{\sigma_{PV}}\left(\frac{\partial \sigma_{PV}}{\partial t} + \underline{v}_\theta \cdot \underline{\nabla}_\theta \sigma_{PV}\right)$$

Control forecast PV_{315}=2, $\underline{v}_{850}$ and $q|\underline{v}|_{850}$, Ensemble-mean precipitation. Synoptic filter:1d, T21.

Rodwell, Richardson, Parsons and Wernli (2018)

TIGGE models have different butterflies: Uncertainty growth-rate in 12h ENS Z_{250hPa}



Control forecast Z_{250} (CI=300m) and $\underline{v}_{850}$, Ensemble-mean precipitation. Synoptic filter:1d, T21.

ECMWF:

EDA(PV_{315K}) ≈ ENS(Z_{250hPa}) ≈

JMA:

≈ ECMWF

UKMO:

Stronger growth-rates over Europe/Africa

KMA:

Weaker everywhere

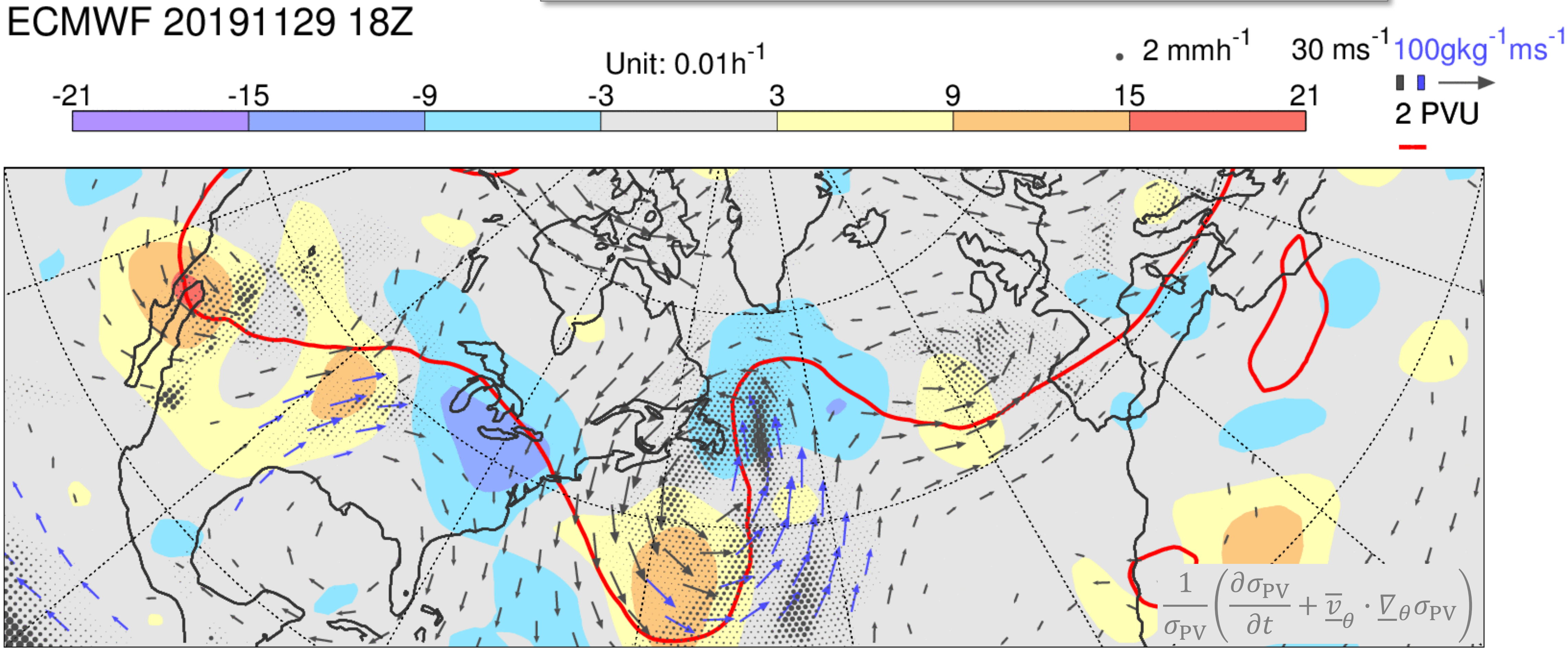
Which is best?

What makes a butterfly in a model?

$$\frac{1}{\sigma_Z}\left(\frac{\partial \sigma_Z}{\partial t} + \underline{\overline{v}}_p \cdot \underline{\nabla}_p \sigma_Z\right)$$

Case study of east coast cyclogenesis: Uncertainty growth-rate in EDA $\sigma_{PV_{330}}$

Will investigate:
- Reliability: What aspects lead to enhanced forecast uncertainty?
- Sharpness: ENS sensitivity to observations and initial conditions?



$$\frac{1}{\sigma_{\mathrm{PV}}}\left(\frac{\partial \sigma_{\mathrm{PV}}}{\partial t}+\overline{\underline{v}}_{\theta}\cdot\underline{\nabla}_{\theta}\sigma_{\mathrm{PV}}\right)$$

Control forecast PV_{330}=2, $\underline{v}_{850}$ and $q|\underline{v}|_{850}$, Ensemble-mean precipitation. Synoptic filter:1d, T21.

Case study: ENS with model uncertainty (as in operational forecast)

Boxes used in experiments discussed later

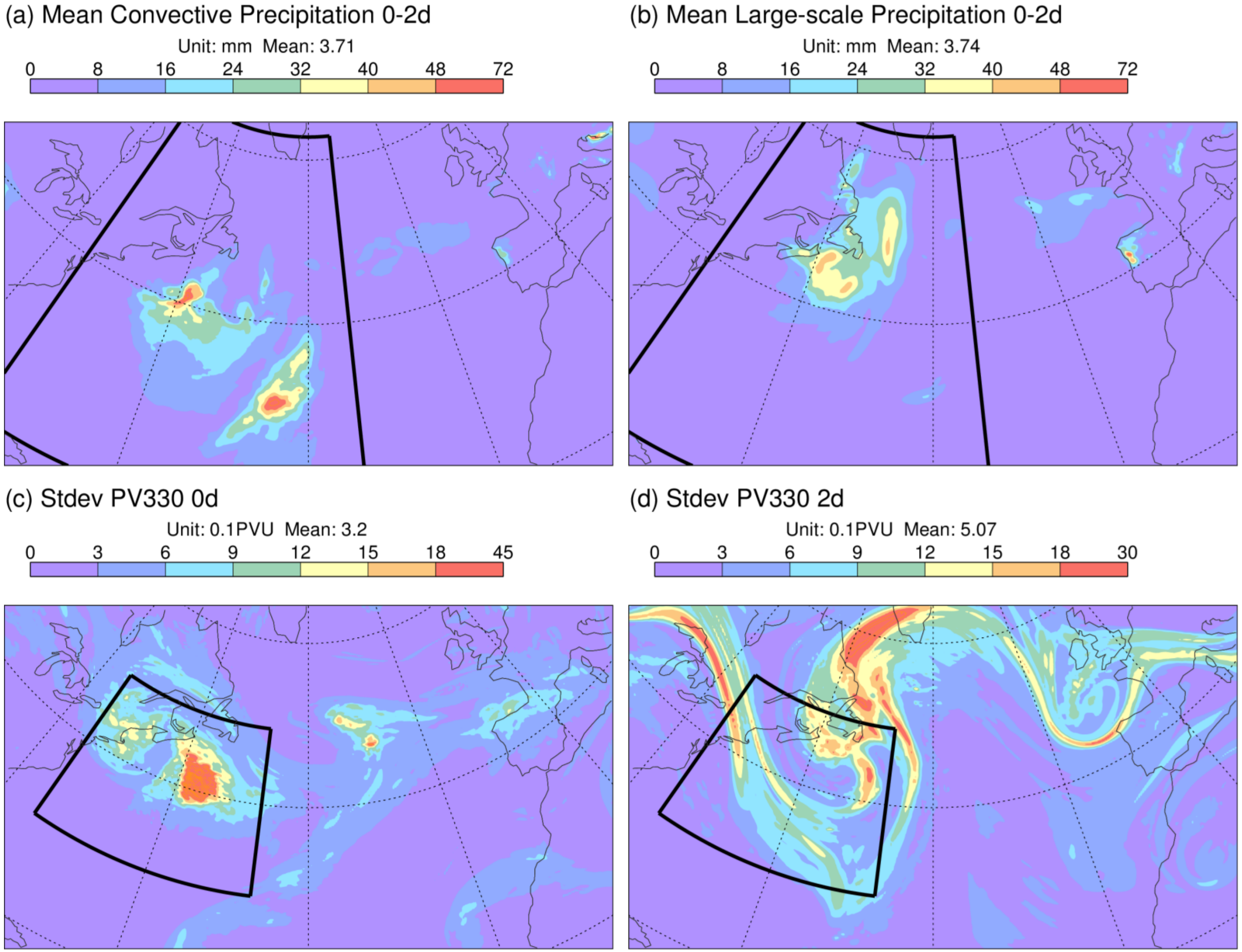
2 day ENS-mean precipitation

- Convection at foot of WCB
- Cloud (large scale precipitation) towards head of WCB

Initial and 2 day spread (PV_{330})

- Large initial uncertainty in the baroclinic wave
- Large 2 day uncertainty in downstream ridge

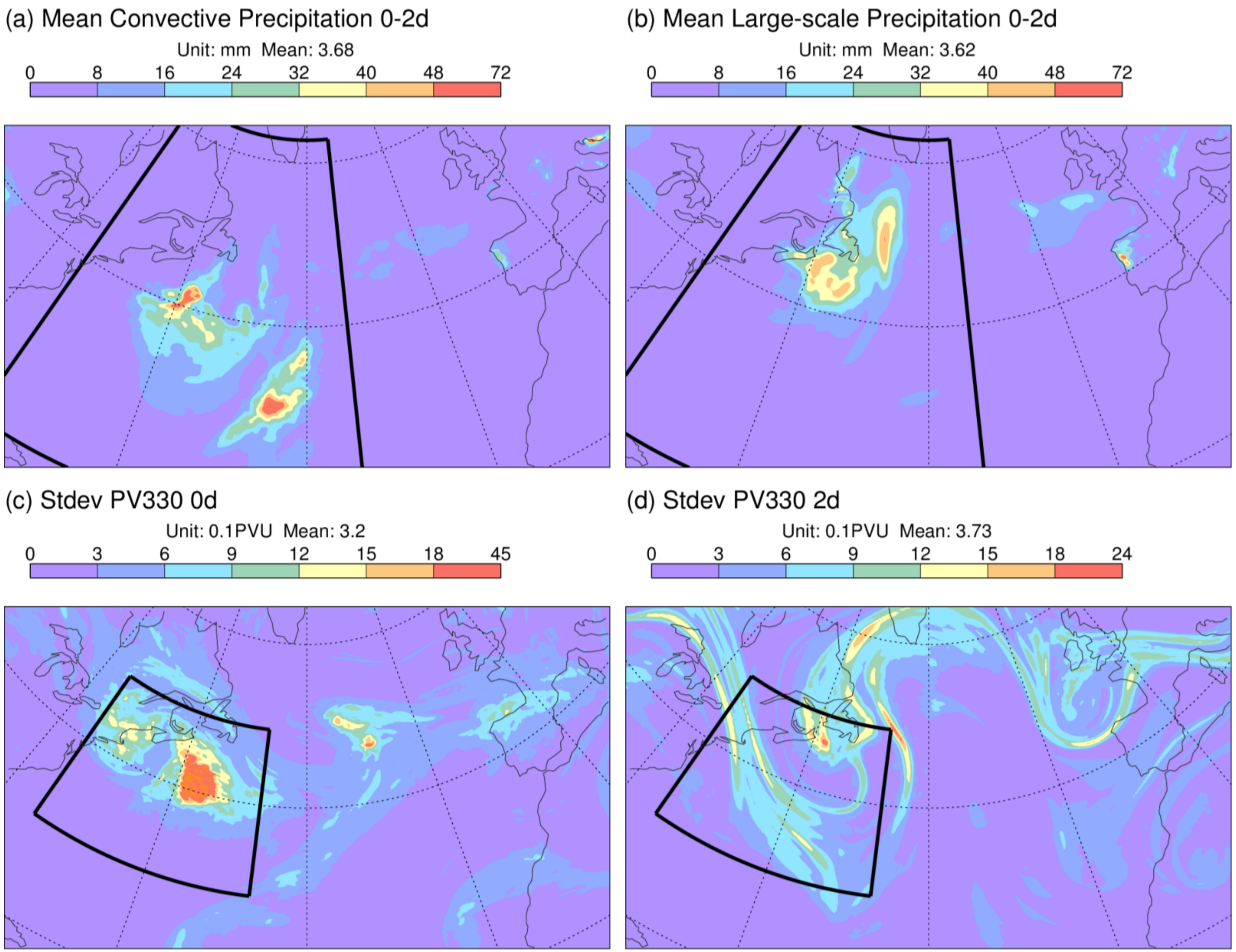
ENS start date: 20191128 at 12UTC. Differences from operational setup include no singular vectors, no re-centring on the control



Case study: ENS without model uncertainty

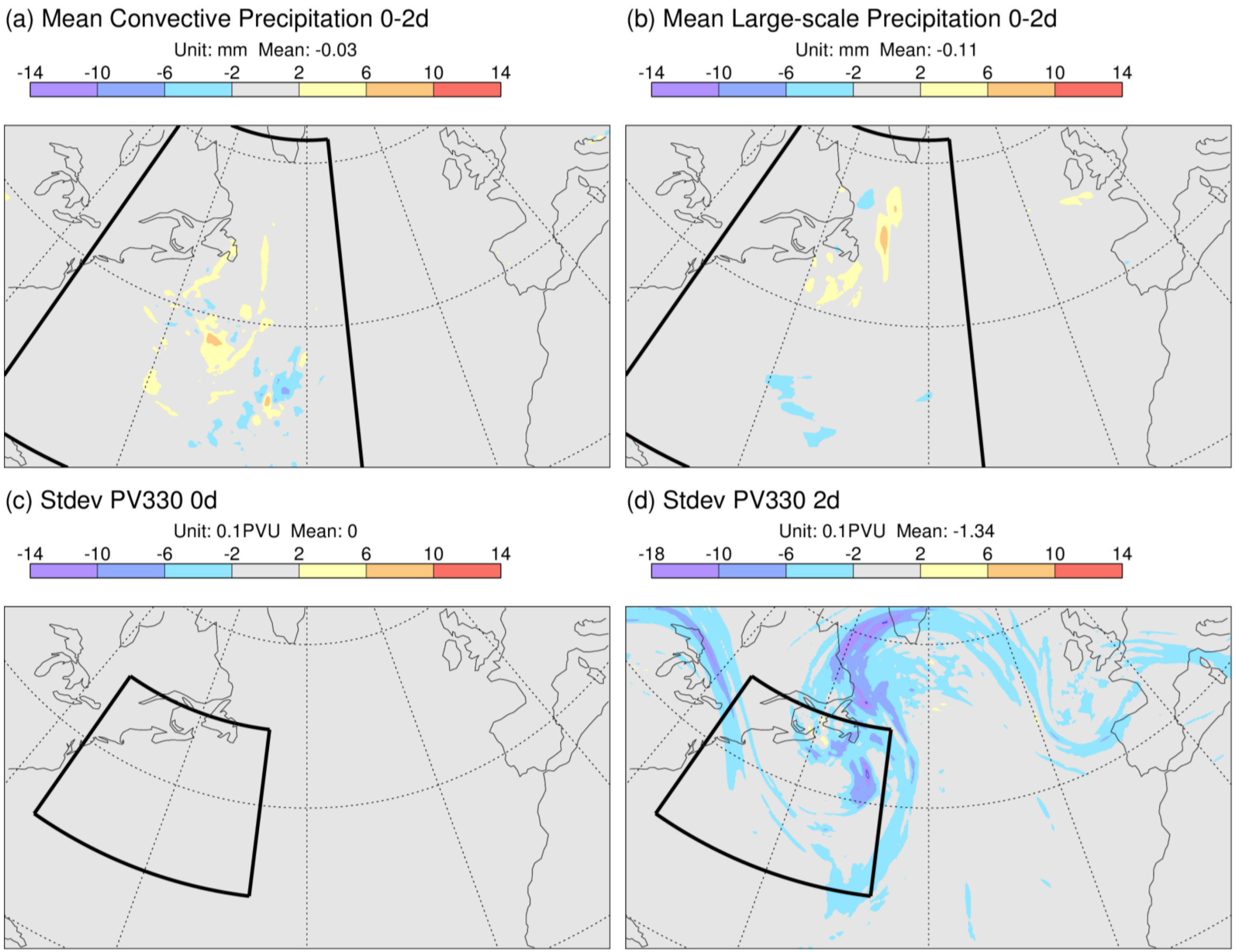
Little change in ensemble-mean precipitation

Large reduction in ridge uncertainty



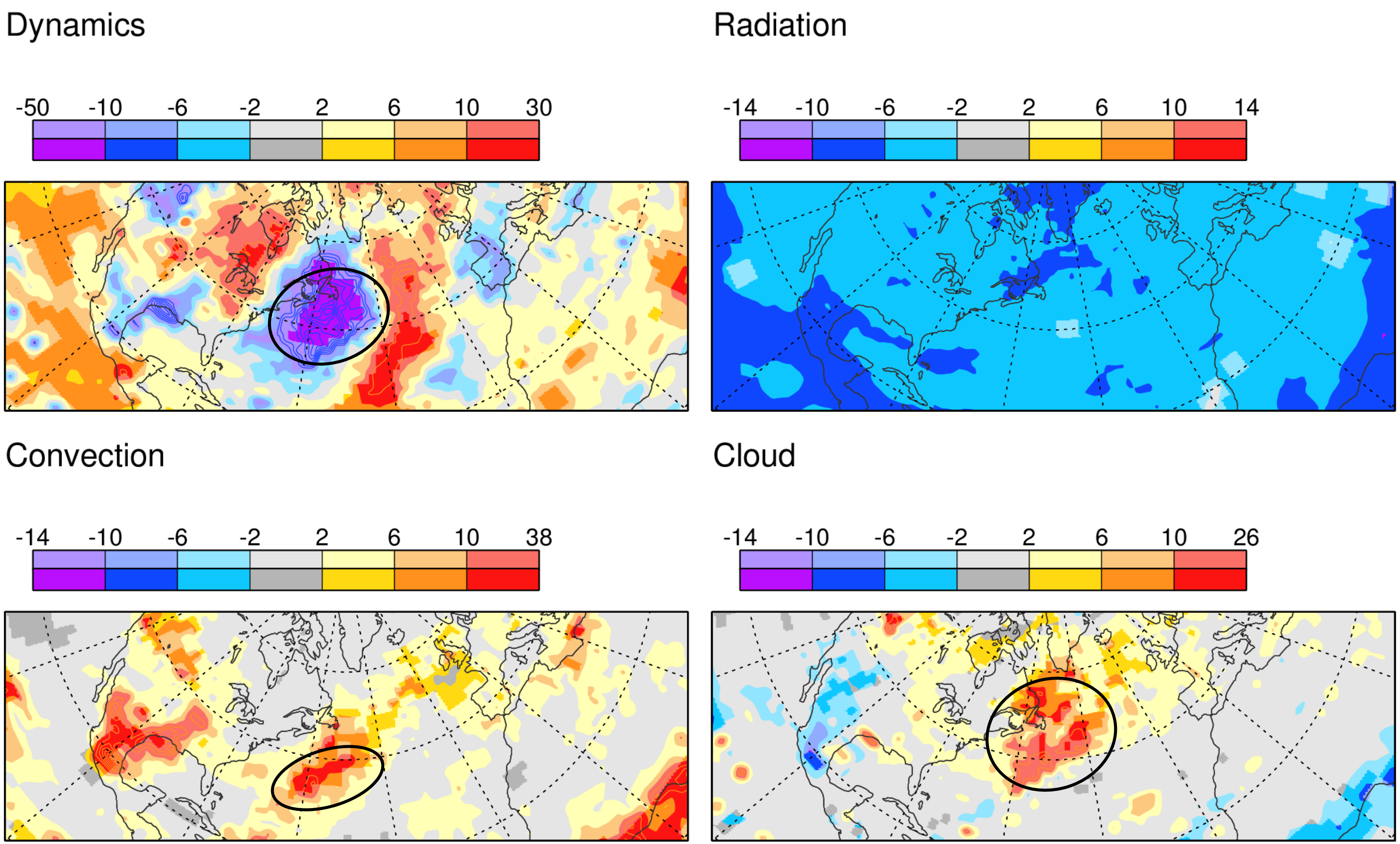
ENS start date: 20191128 at 12UTC. Differences from operational setup include no singular vectors, no model uncertainty, no re-centring on the control

Case study: Impact of removing model uncertainty



- Model uncertainty representation is important.
- Helps explains "butterfly" differences between models.
- How to assess butterflies against reality?

Warm Conveyor Belt cluster – Mean T_{500} process tendencies, EDA control



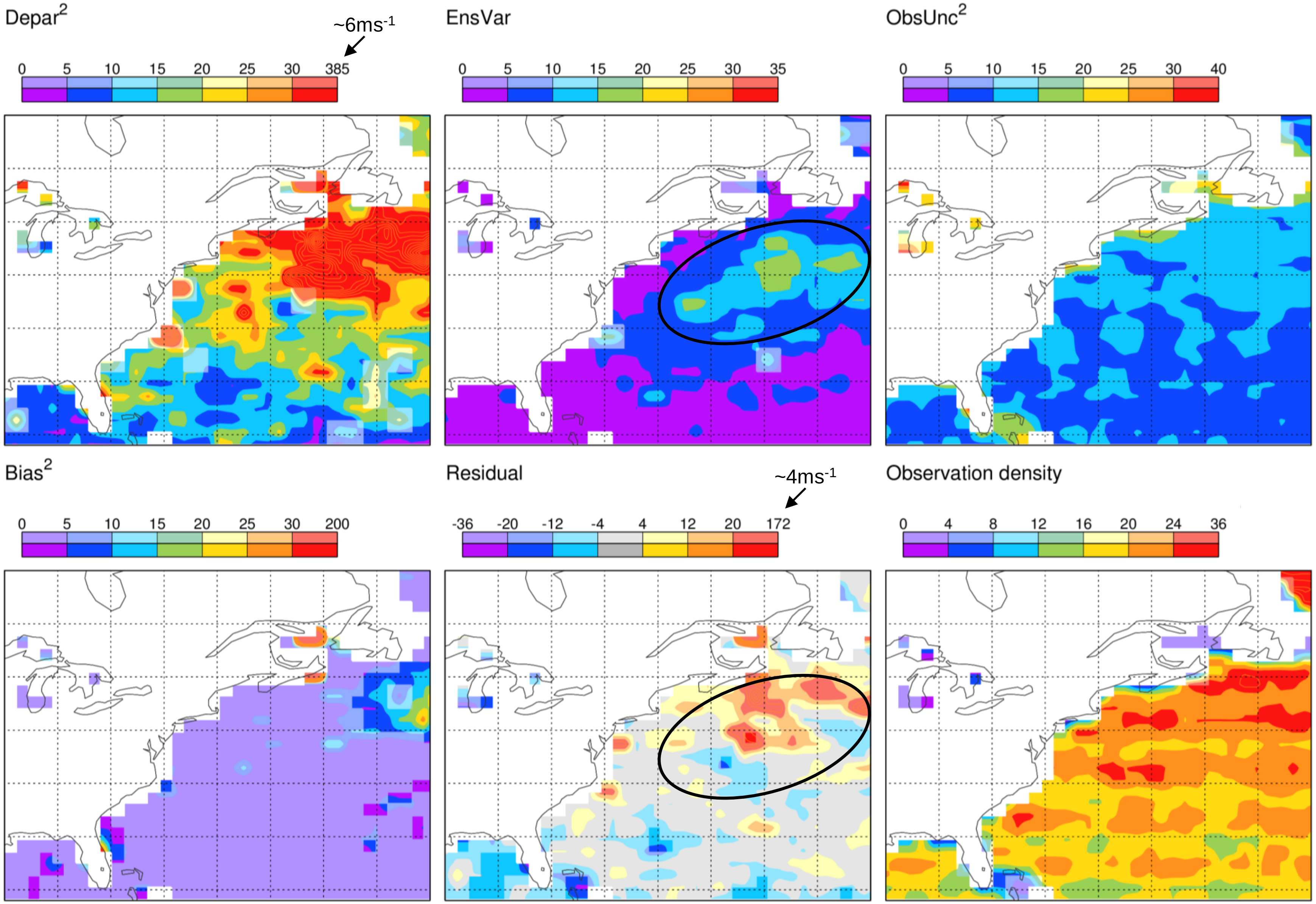
For the Warm Conveyor Belt cluster, the ascent leads to a dynamical cooling tendency

The physical processes are particularly active and counter-act some of this cooling

At 500hPa, we see strong warming due to cloud microphysics and embedded convection (as in case study)

Tendencies (Rodwell and Palmer 2003) from the unperturbed EDA control background forecast for the 29-member WCB cluster. Unit is 0.1K. Bold colors = 5% significance

EDA variance budget for WCB cluster based on scatterometer **surface wind**



~~Error ≈ Spread~~

Depar^2 = EnsVar + ObsUnc^2 + Bias^2 + Residual
(on average)

- Large surface wind Departures^2
- Partly reflected in ENS variance
- Still a positive Residual
- Observation uncertainty^2 is over-estimated
- Little Bias^2
- +ve Residual ⇒ EnsVar too small
- Extending model uncertainty (of *e.g.* convective momentum flux) down into boundary layer helps

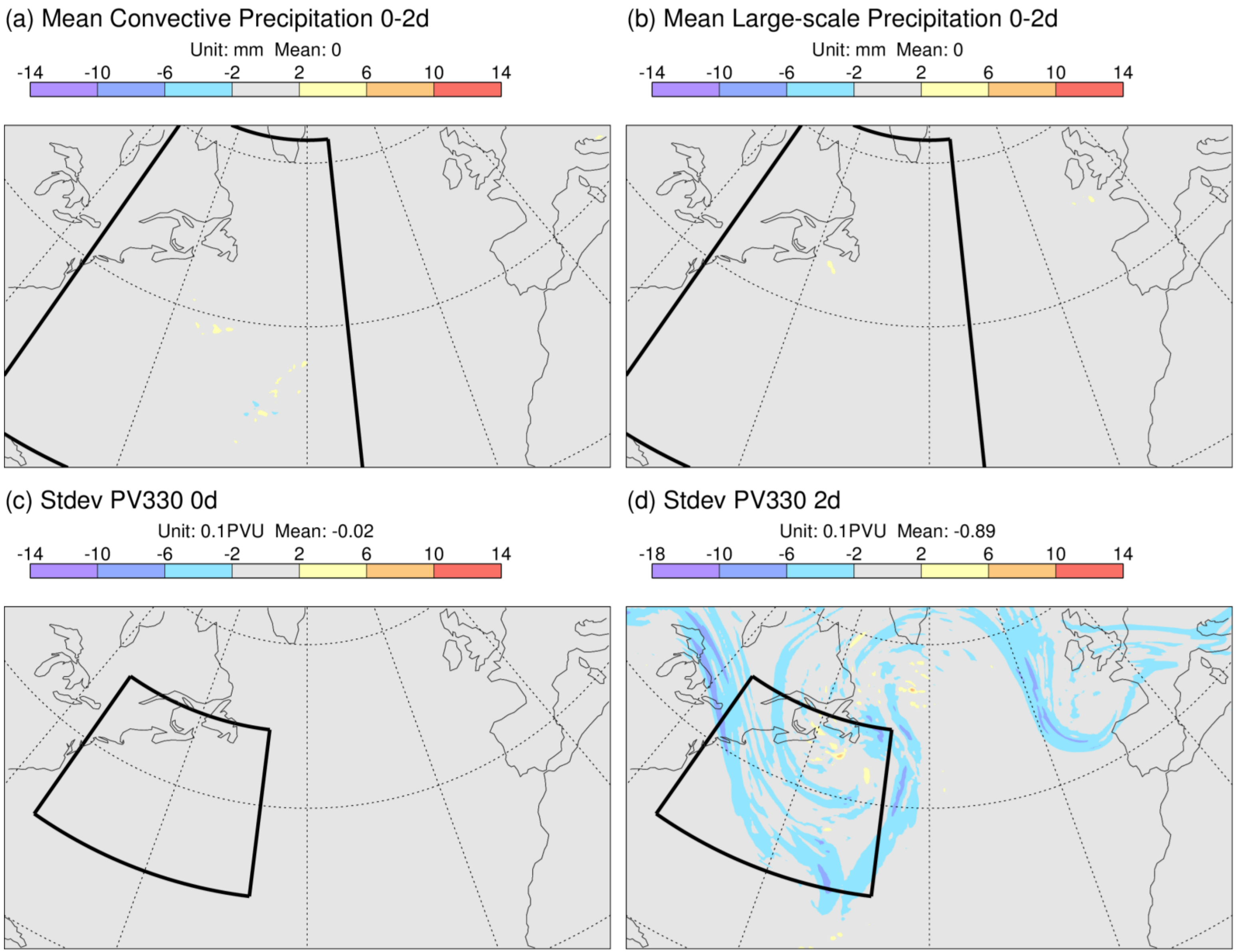
Composite of 29 EDA cycles within MAM 2017. Units are 0.1 (ms^{-1})^2 and 0.1 (O80 cell)$^{-1}$ (12h cycle)$^{-1}$. Budget as in Rodwell, Lang, Ingleby, Bormann, Hólm, Rabier, Richardson and Yamaguchi (2015)

Case study: Impact of turning-off initial (singular vector) perturbations

Little impact on ensemble-mean precipitation

Decrease in Jetstream 2 day uncertainty

Singular vector perturbations probably improve initial growth-rates



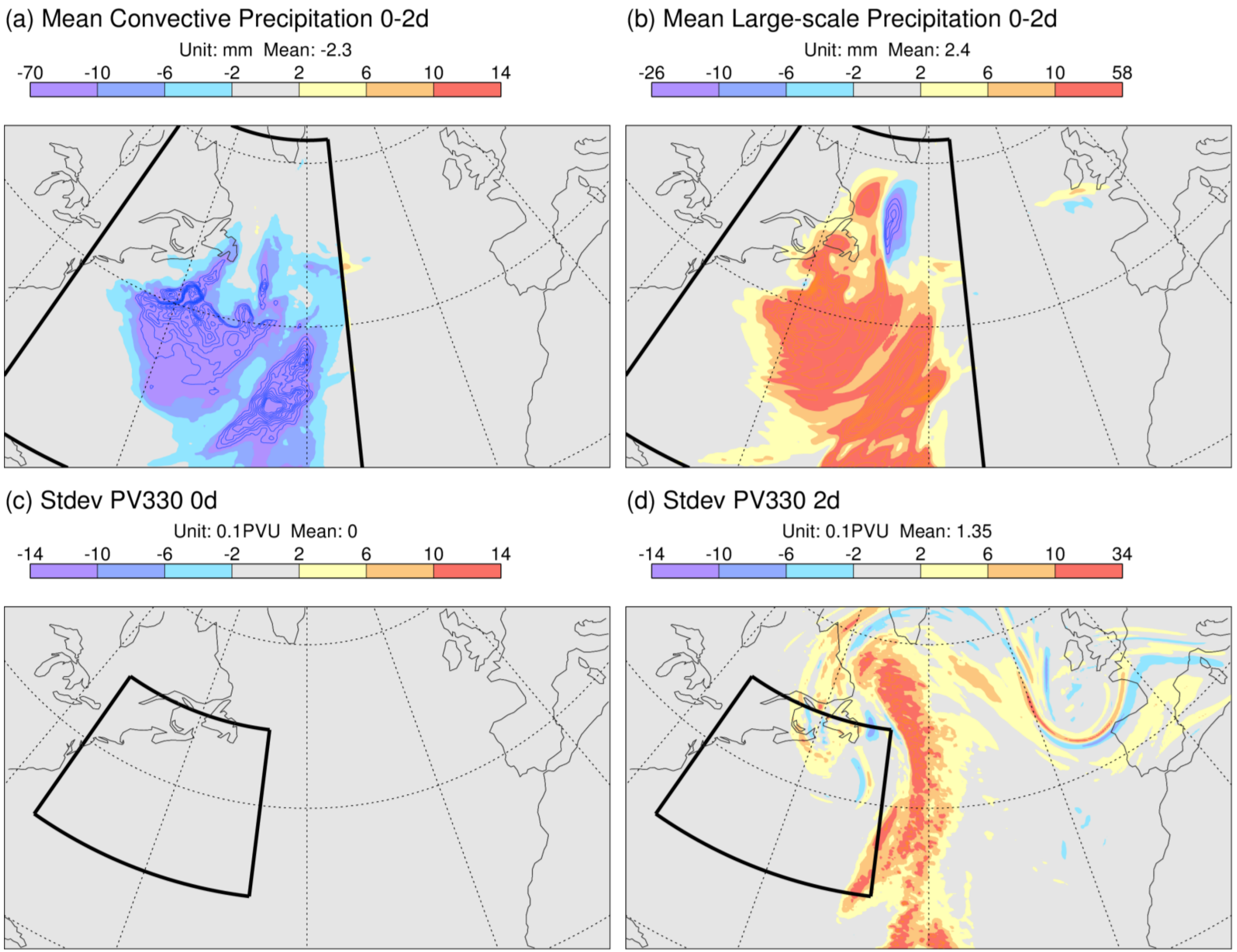
Case study: Impact of turning-off convective parametrization (in large box)

Large-scale cloud scheme takes up the work of the convective parametrization

Leaves ensemble-mean total precipitation largely unchanged

Does cloud scheme short-circuit upscale error growth process?

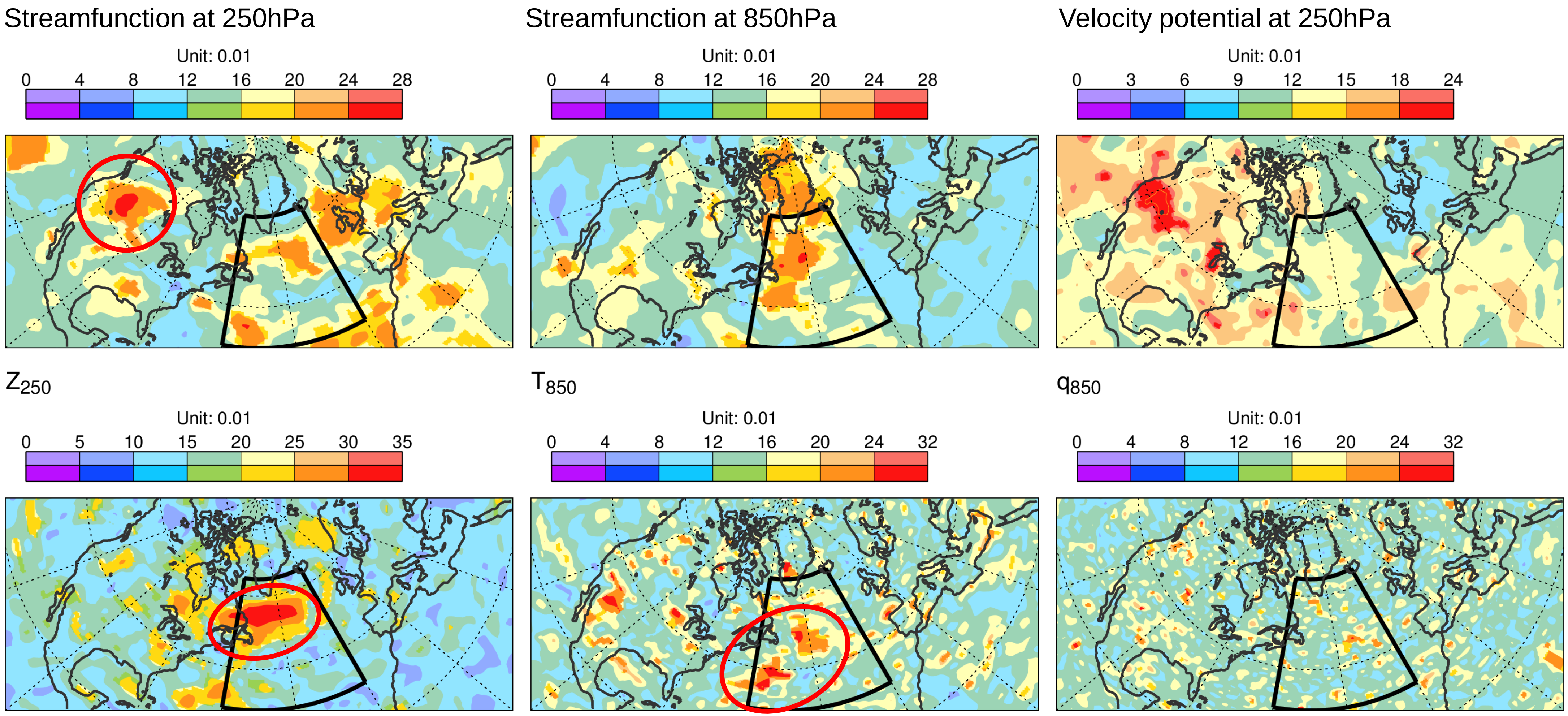
Maybe some height sensitivity?



Case study: Large-scale & local uncertainties important for ridge uncertainty at day 2

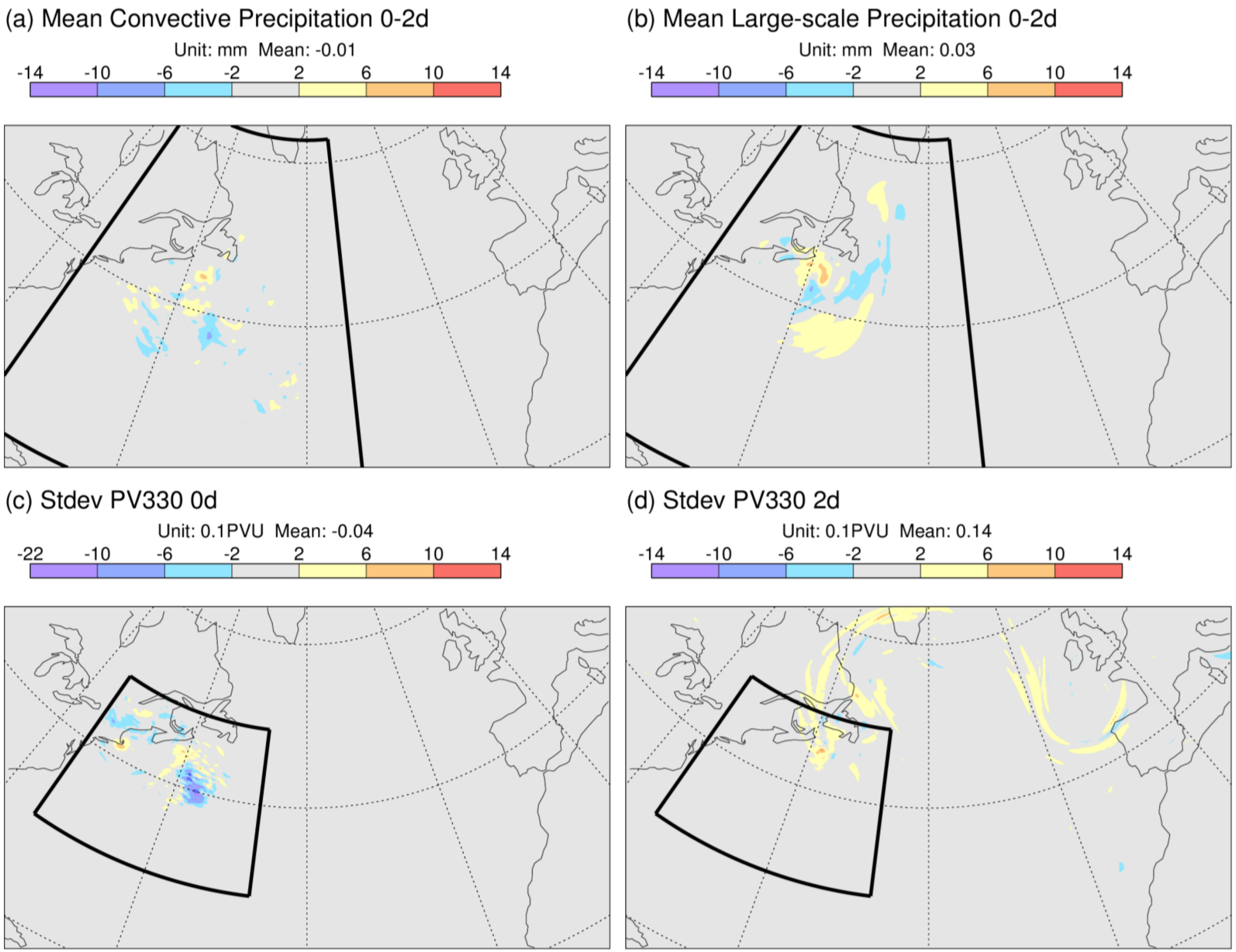
Ensemble forecast sensitivity of day 2 streamfunction at 250hPa in indicated box to global initial uncertainties in various fields

Sensitivities to large-scale waves (including upstream trough over western North America) as well as local uncertainties



Fraction of StDev of one parameter explained by one StDev deviation in the other. Bold colors indicate 10% significance.

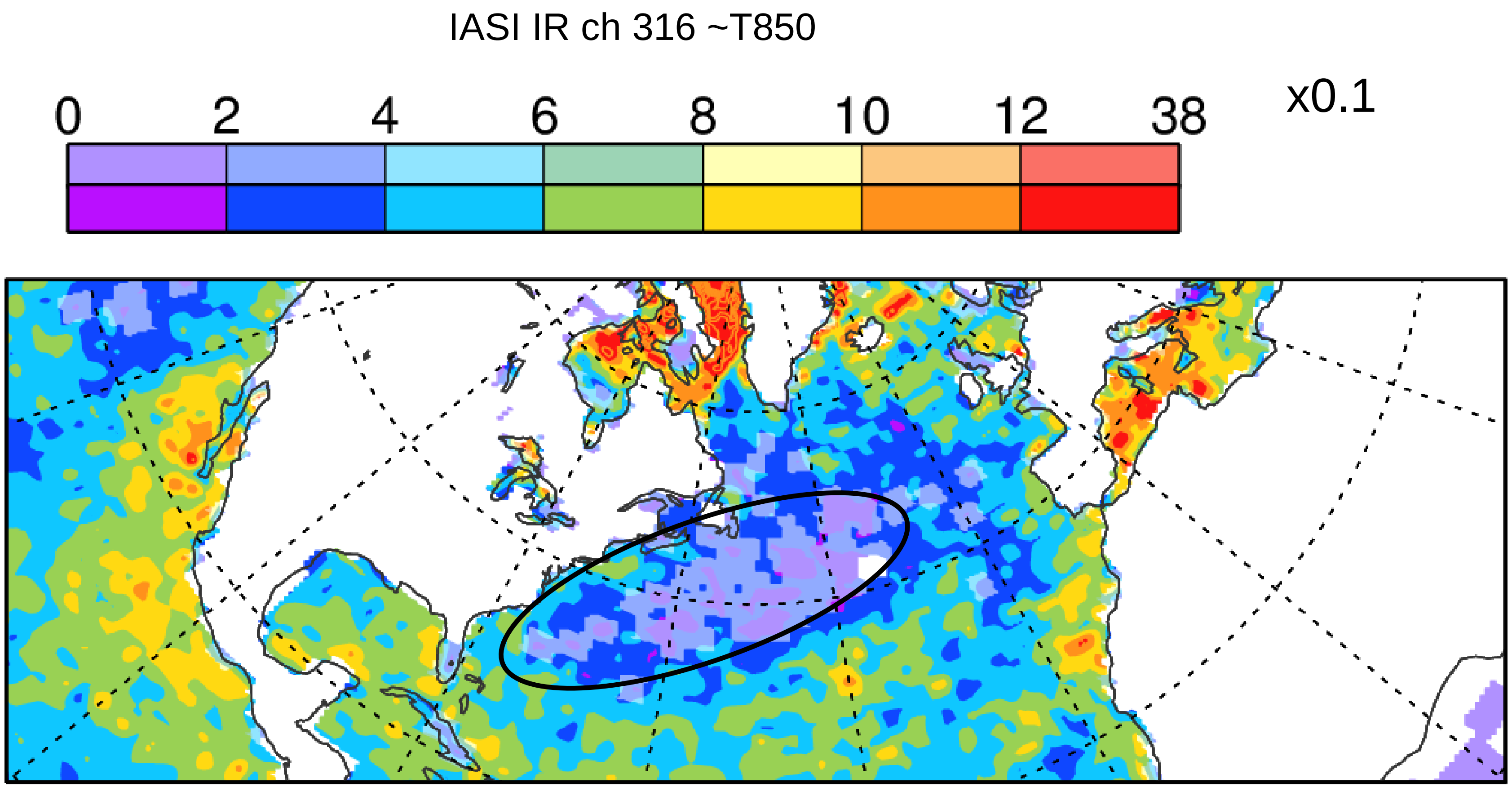
Case study: Impact of not assimilating local observations (in small box)



Small impact. Slightly reduced initial uncertainty, but slightly increased spread at day 2

Initialisation of the larger scale waves and background (first guess) information likely to be important

Density of observations assimilated during WCB cluster MAM 2017



Difficulties in assimilating observations in WCB cluster just when we need them most!

Even when assimilated ‘all-sky’ observations are assumed to have very large uncertainties (*e.g.* due to highly non-linear observation operators).

unit=cell^{-1}cycle^{-1}≈(125km)$^{-2}$(12h)$^{-1}$

Warm conveyor belts – a challenge to forecasting

Hopefully these brief results highlight some of the challenges we need to overcome if WCB understanding is to help improve forecast performance, and that they provide some justification for the key questions of the workshop:

Predictability

What are the key aspects of WCBs which lead to enhanced forecast uncertainty, and the implications for development strategy?

Observations

How well do we observe and initialise WCBs in our forecasts, and would new observation sources help?

Models

How well do we represent the complex set of physical processes within a WCB, and what aspects deserve particular attention?

Impacts

What role do WCBs play in weather extremes, regime transitions, and global climate?

Thank you