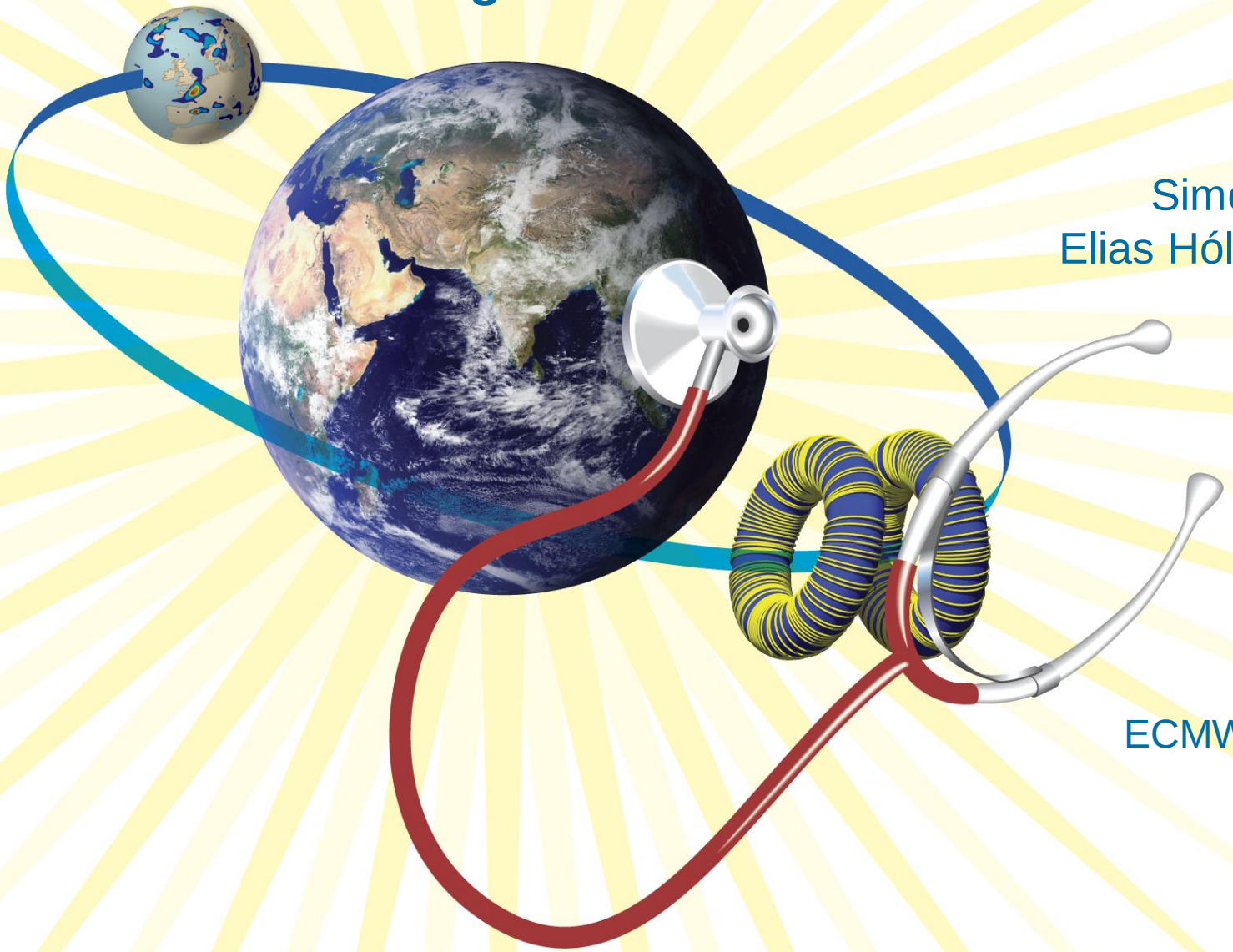
Using ensemble data assimilation to diagnose model uncertainty



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ECMWF/WWRP Workshop on Model Uncertainty

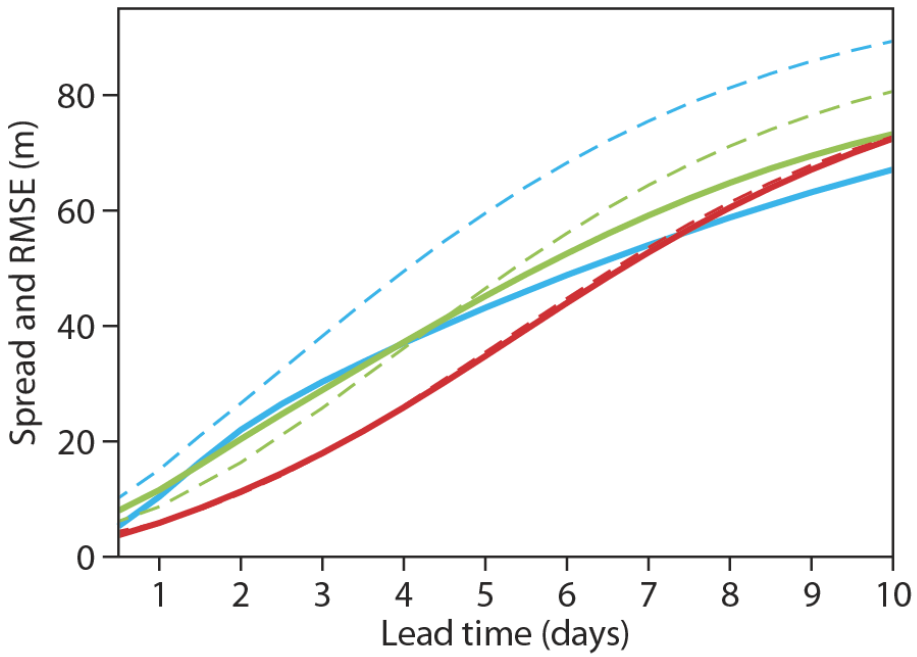
12 April 2016, ECMWF Reading

Ensemble spread and error

Z500

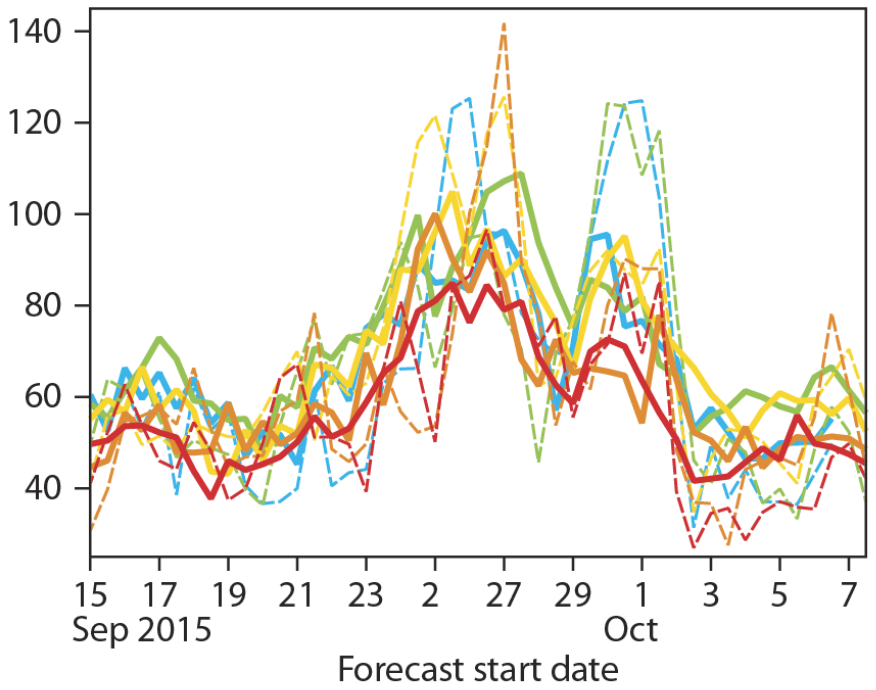
Rodwell 2016, ECMWF Newsletter

Northern Hemisphere, annual mean



	1996	2005	2014
Spread			
RMSE			

Europe, day 6



	ECMWF	UKMO	JMA	CMC	NCEP
Spread					
RMSE					

Improvements in sharpness and reliability. Due to:

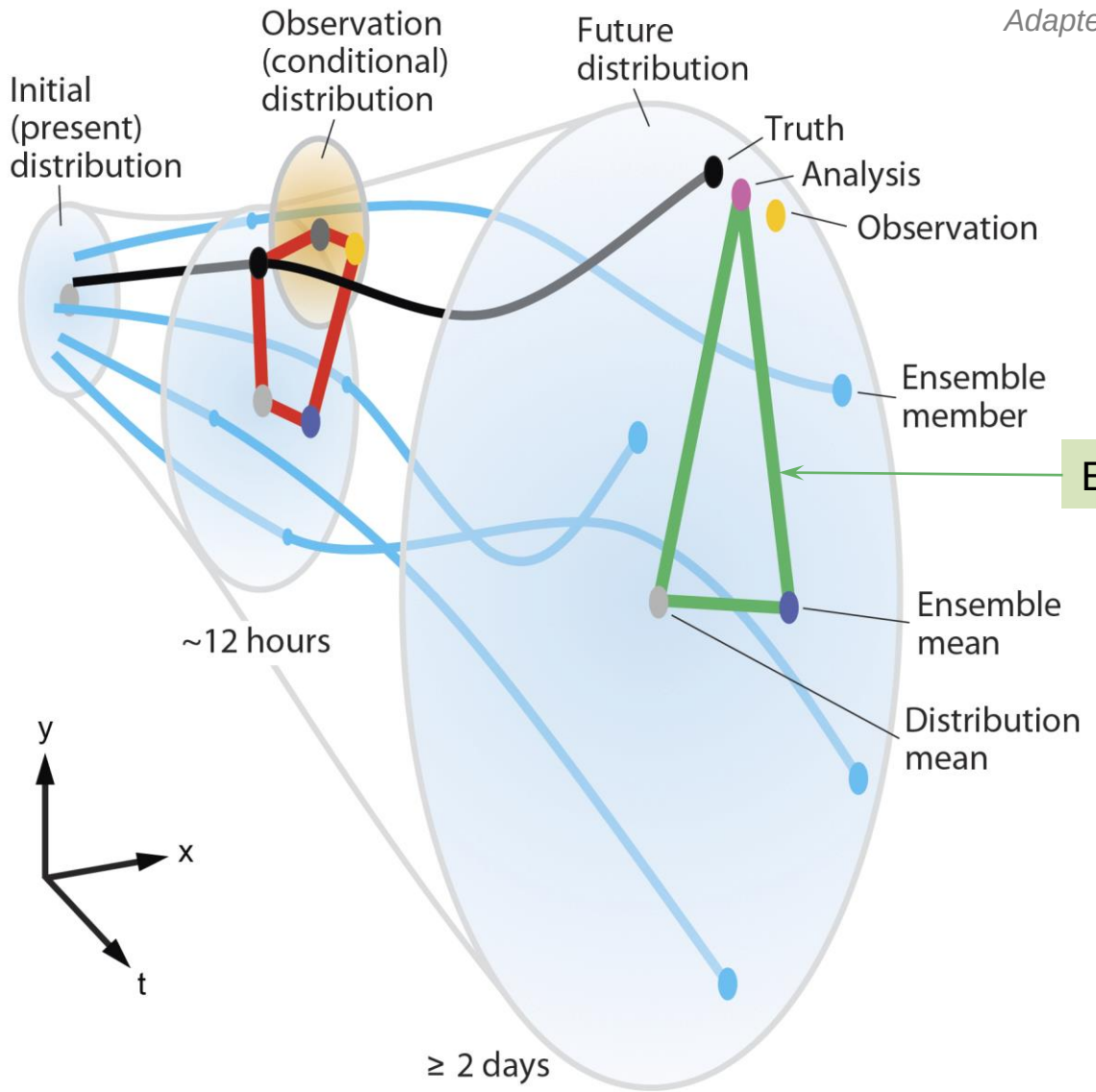
- Ensemble of data assimilations
- Stochastic physics
- Observations and modelling of observation error

- Spread agreement between centres indicates flow-dependent fluctuations in underlying predictability (reason for ensemble forecasting!)
- Need to assess flow-dependent reliability

500 hPa geopotential height (Z500). RMSE is of ensemble-mean error. Spread = ensemble standard deviation (scaled to take account of finite ensemble size).

Reliability in ensemble forecasting

Adapted from Rodwell et al. (2015) QJRMS



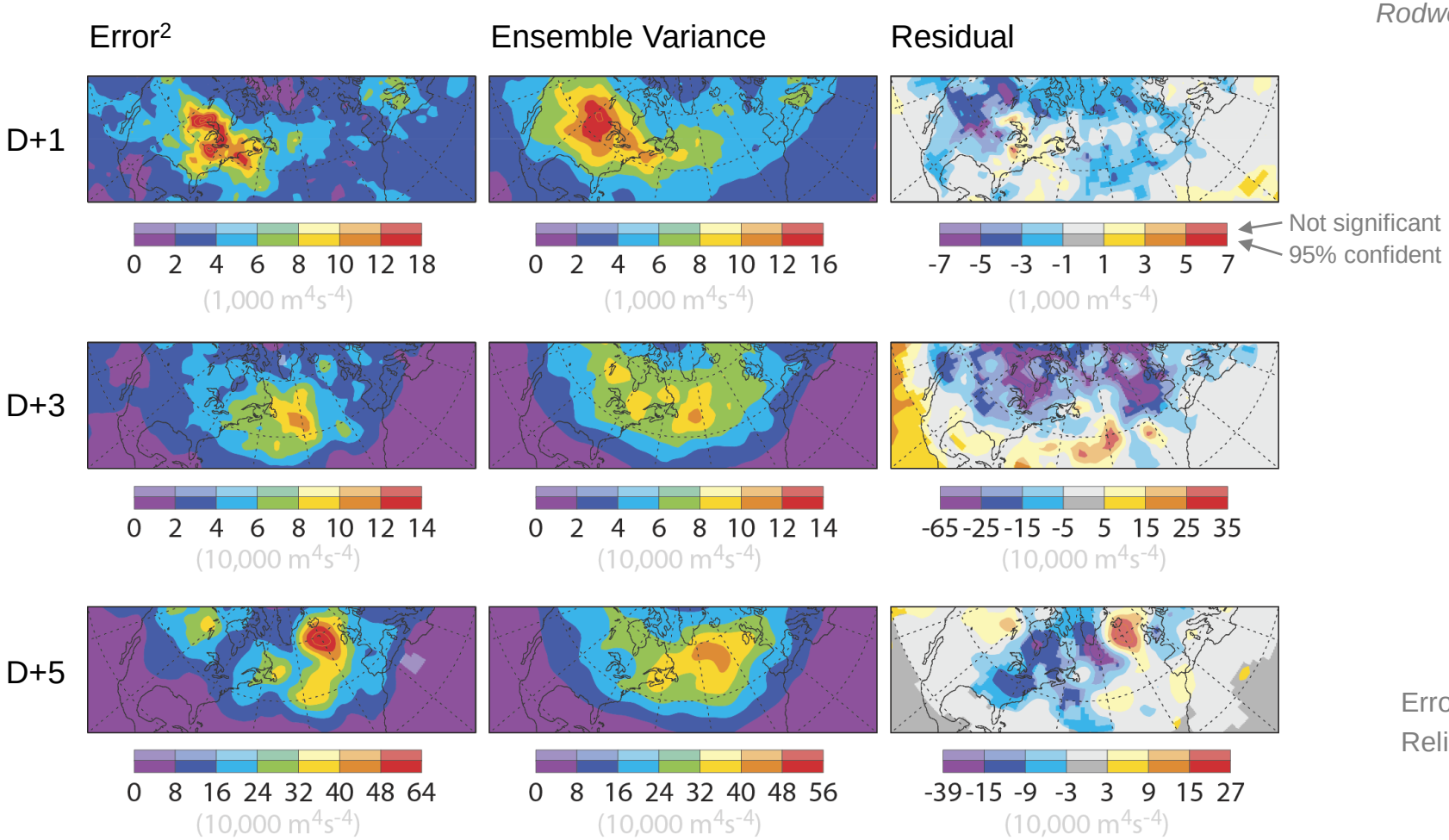
$Error^2 = EnsVar + Residual$

(Cross-terms on squaring have zero expectation. EnsVar is scaled variance to account for finite ensemble-size)

Composite with North American trough & CAPE (⇒ Mesoscale convective systems)

Z200, 54 cases

Rodwell 2016, ECMWF Newsletter



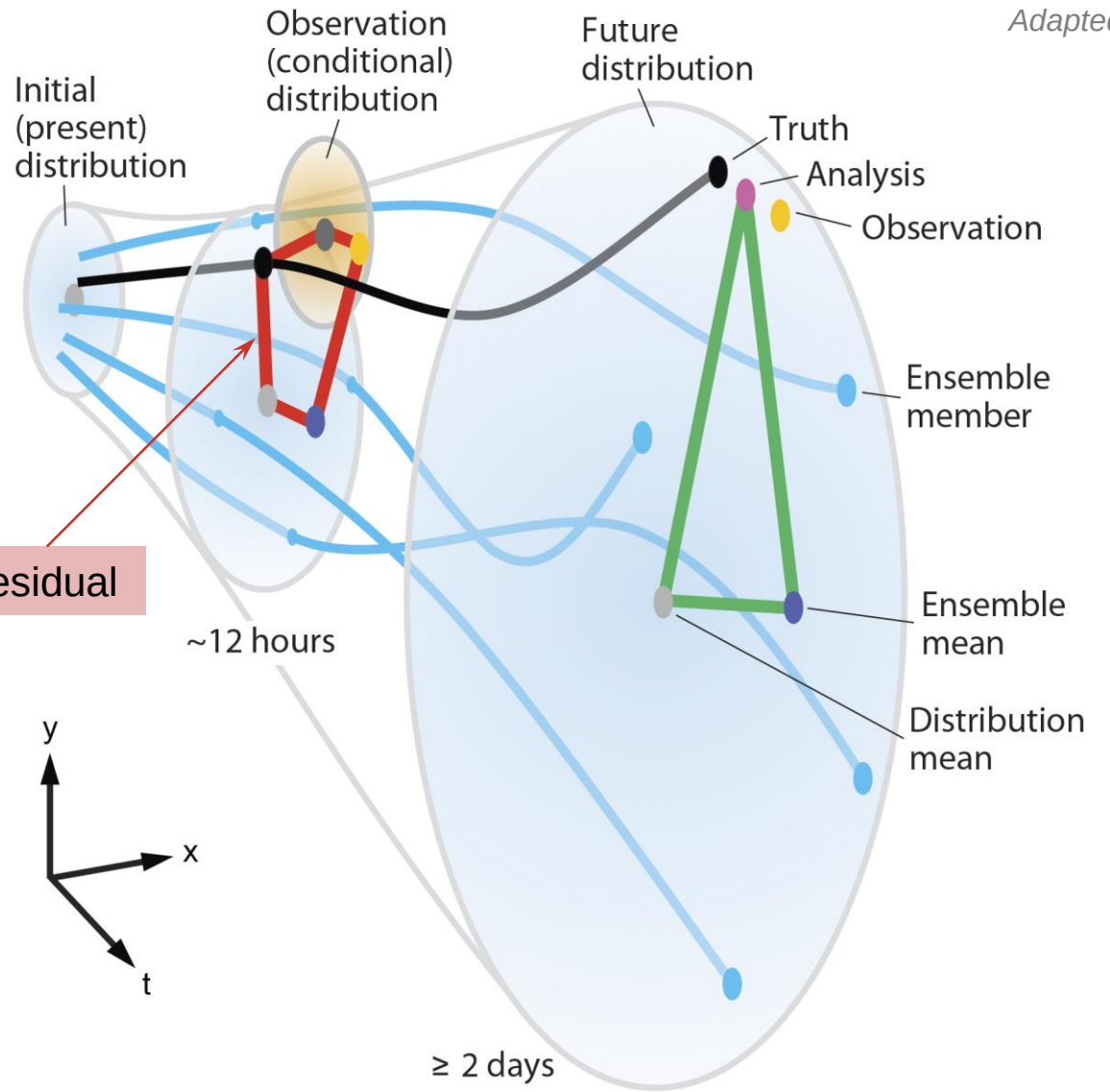
Error² = EnsVar + Residual

Reliability ⇒ E[Residual]=0

- *Following conditions conducive to MCS development, enhanced errors and spread propagate east towards Europe → 'Busts'* ✓
- *Note: -ve residuals occur in non-trough/CAPE situation too.*
- *+ve residual at D+5 is not significant (Chaos? → use bigger sample or shorter leadtime? But analysis uncertainty at D+1?)* ✗

Reliability in ensemble data assimilation

Adapted from Rodwell et al. (2015) QJRMS



$Depar^2 = Bias^2 + EnsVar + ObsUnc^2 + Residual$

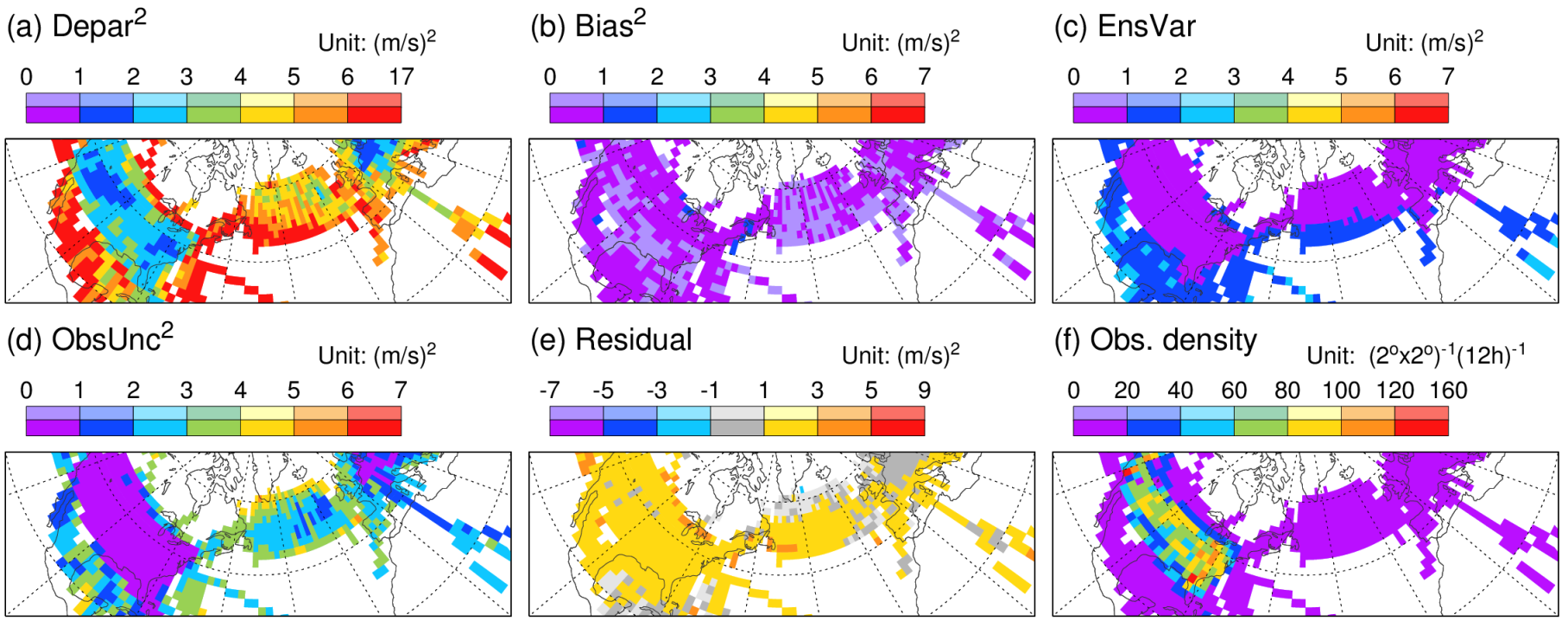
(Cross-terms on squaring have zero expectation. EnsVar is scaled variance to account for finite ensemble-size)

EDA reliability budget: Non-trough/CAPE comp.

u200, ~1000 cases

Rodwell 2016, ECMWF Newsletter

Relative to aircraft observations of zonal wind 200hPa (±15)



$Depar^2 = Bias^2 + EnsVar + ObsUnc^2 + Residual$

Reliability $\Rightarrow$ E[Residual]=0

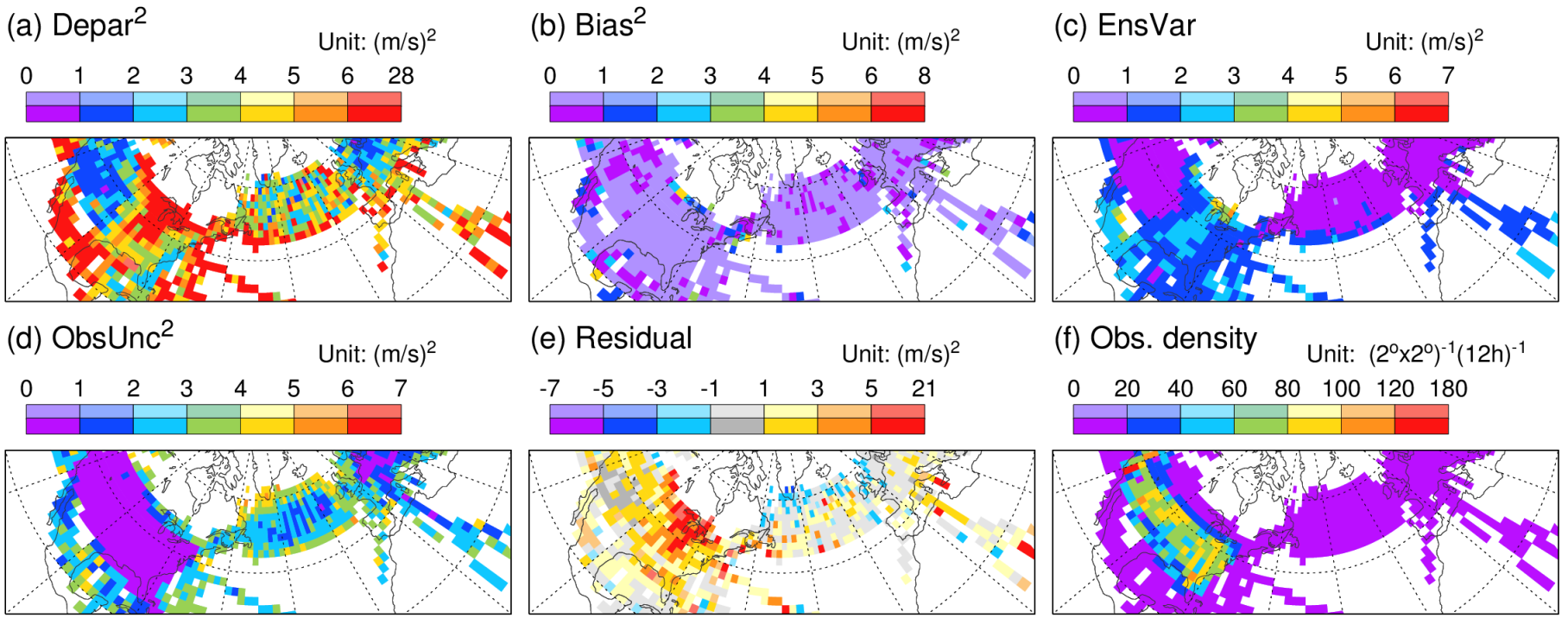
- Residual suggests general underestimation of background variance or observation uncertainty
- Not interested in this here as we are interested in flow-dependent reliability

EDA reliability budget: Trough/CAPE comp.

u200, 54 cases

Rodwell 2016, ECMWF Newsletter

Relative to aircraft observations of zonal wind 200hPa (±15)



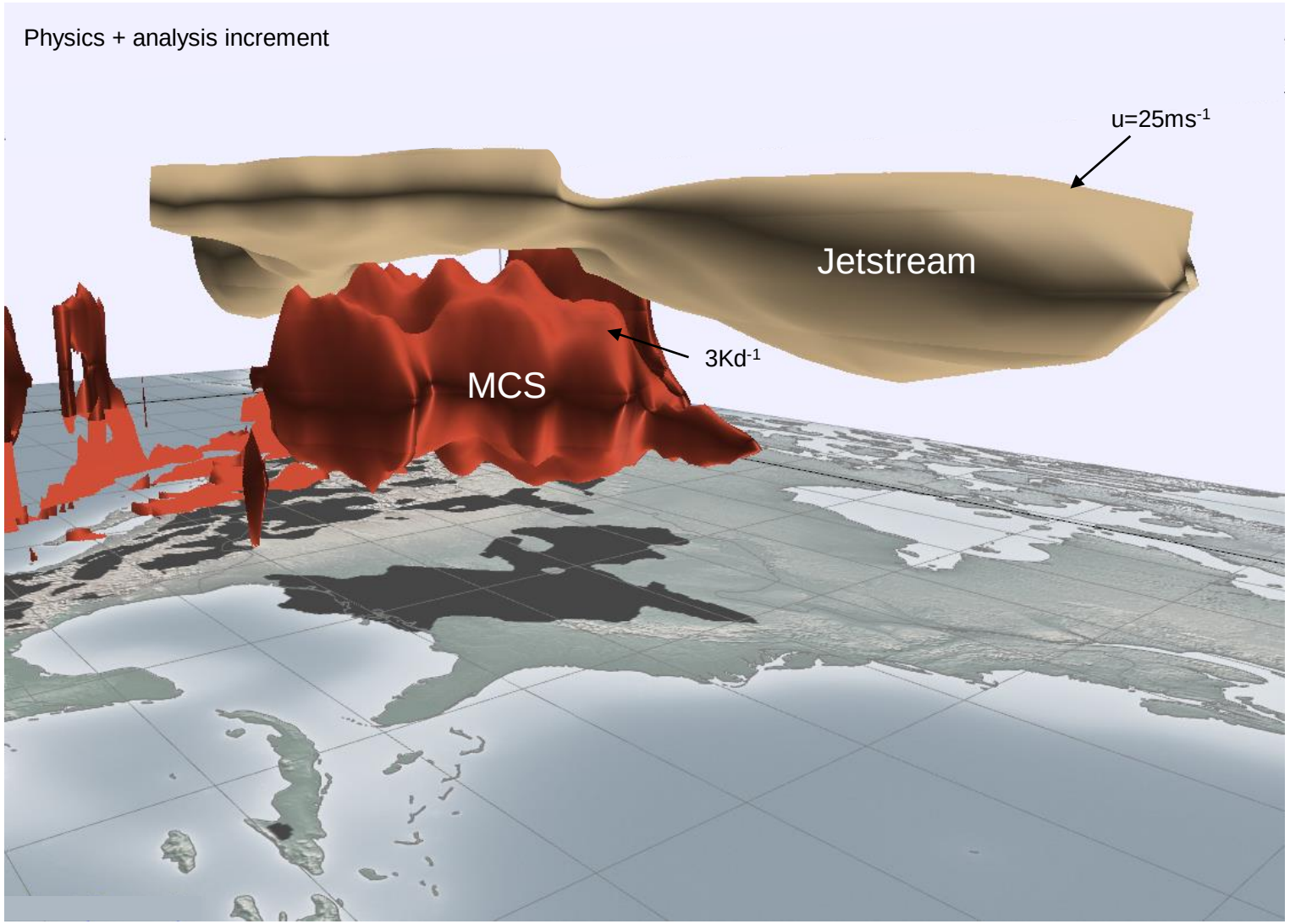
Depar^2 = Bias^2 + EnsVar + ObsUnc^2 + Residual

Reliability $\Rightarrow$ E[Residual]=0

- **Key result: Residual in trough/CAPE regime highlights MCS, and suggests lack of background variance**
- (Observation uncertainty changes should be a second-order effect for this large-scale wind field)
- One interpretation: The inherent un-predictability of the existence, intensity and location of MCS events is not adequately reflected in Jetstream uncertainty (with downstream consequences)

A role for systematic model error?

54 cases

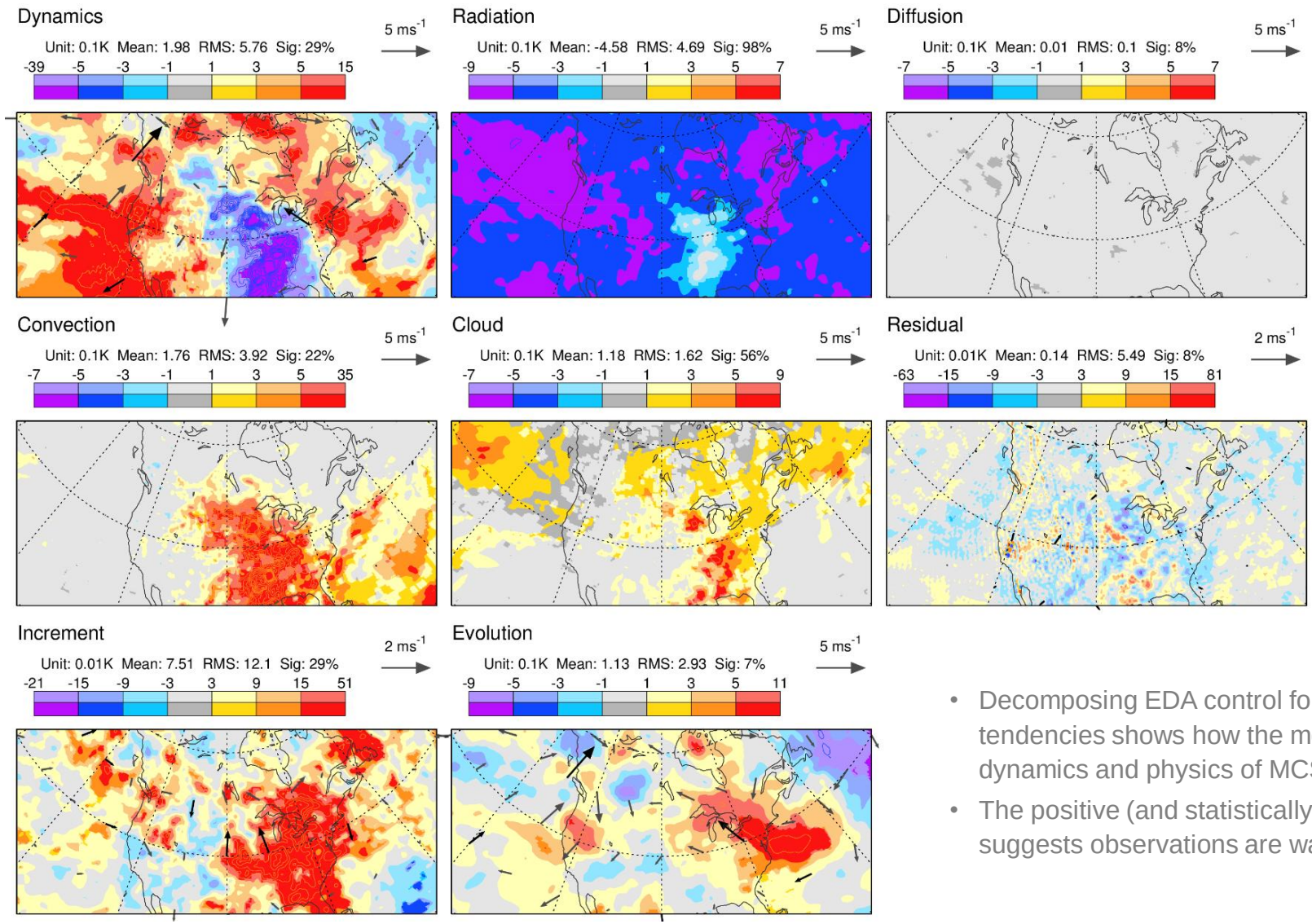


Met3D: Marc Rautenhaus

- *Increments highlight a role for model systematic error: MCS does not interact enough with Jetstream*
- *Also need to strengthen stochastic physics to increase background variance?*

Initial tendency budget from control forecast: Trough/CAPE comp.

T300, 54 cases



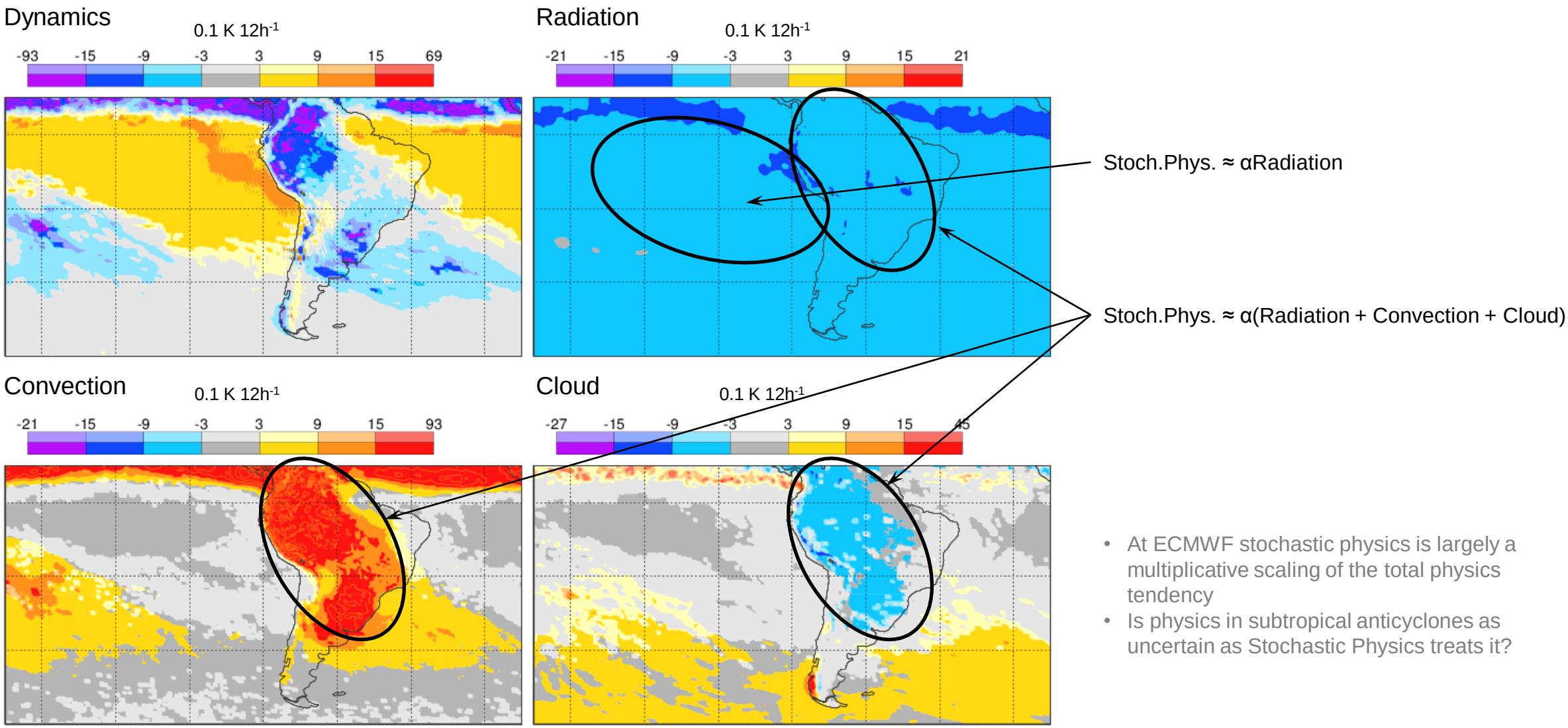
- Decomposing EDA control forecast into process tendencies shows how the model represents dynamics and physics of MCS
- The positive (and statistically significant) increment suggests observations are warmer than the model

Process tendencies accumulated over 12hr background, the analysis increment, and evolution of the flow

Sensitivity to representation of model uncertainty

Initial tendencies from control forecast: SON 2014

T500, SON 2014

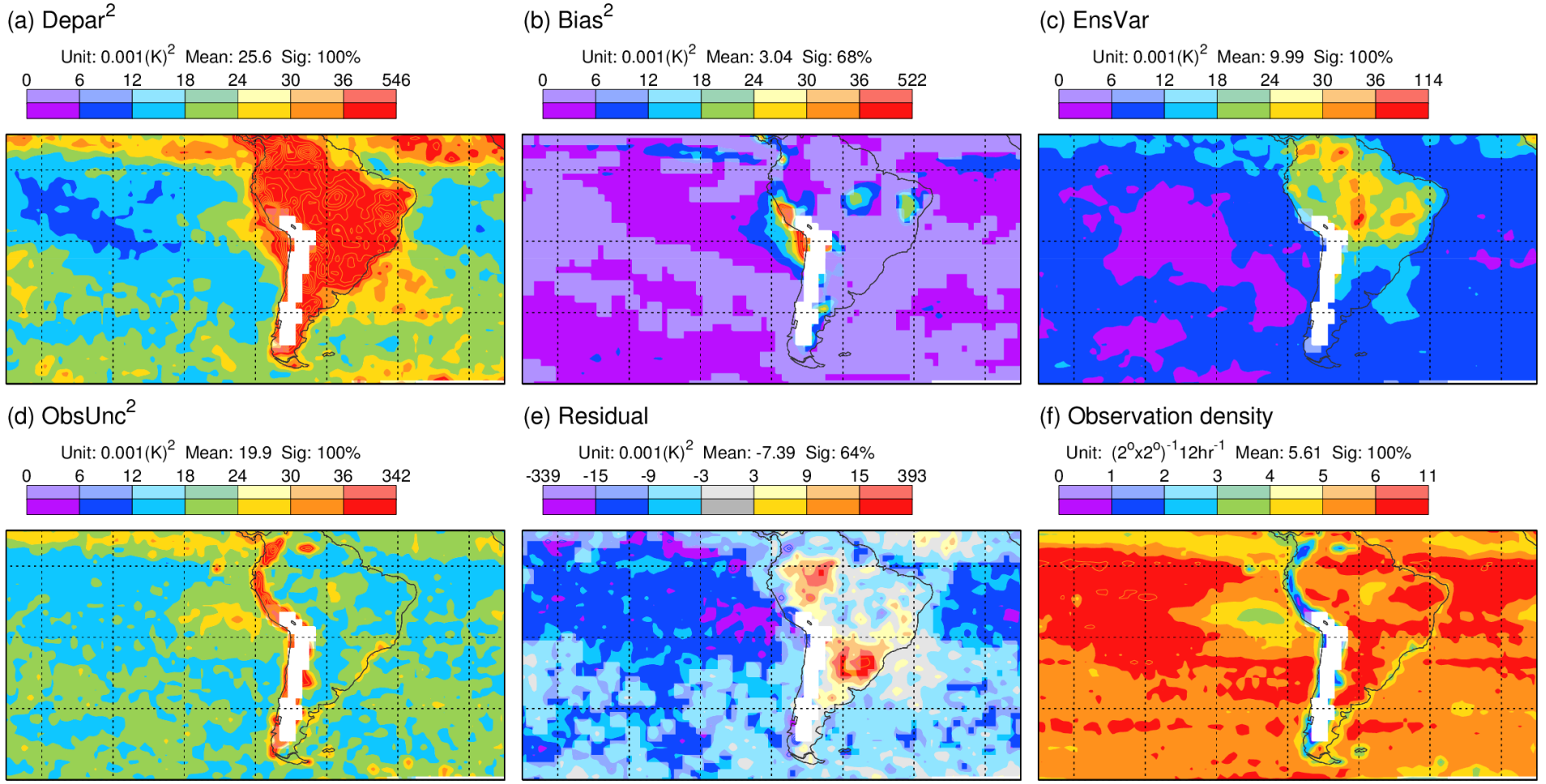


- At ECMWF stochastic physics is largely a multiplicative scaling of the total physics tendency
- Is physics in subtropical anticyclones as uncertain as Stochastic Physics treats it?

EDA reliability budget: Satellite microwave (~T500)

Rodwell et al. (2015) QJRMS

Relative to AMSUA channel 5 microwave brightness observations of mid-tropospheric temperature



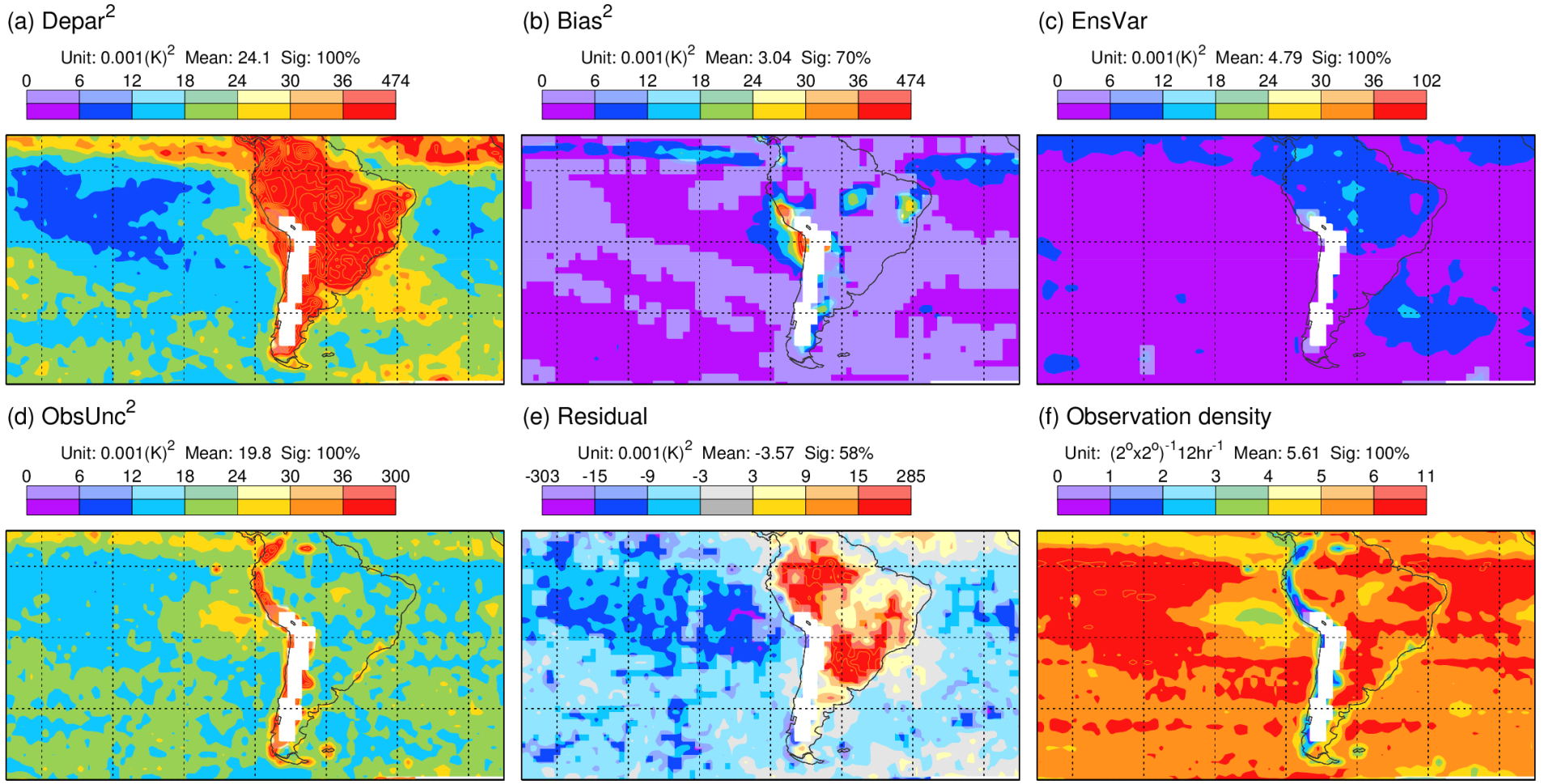
- Largest departures and ensemble variance in convective regions
- Large bias off west coast (associated with errors in cloud detection?)
- ObsUnc^2 is sometimes larger than Depar^2 off west coast
- Residual consistent with too much stochastic physics in subtropical anticyclones, too little in convective regions

2 members, 20110812-20111116

EDA reliability budget: Satellite microwave (~T500) No Stochastic Physics

Rodwell et al. (2015) QJRMS

Relative to AMSUA channel 5 microwave brightness observations of mid-tropospheric temperature



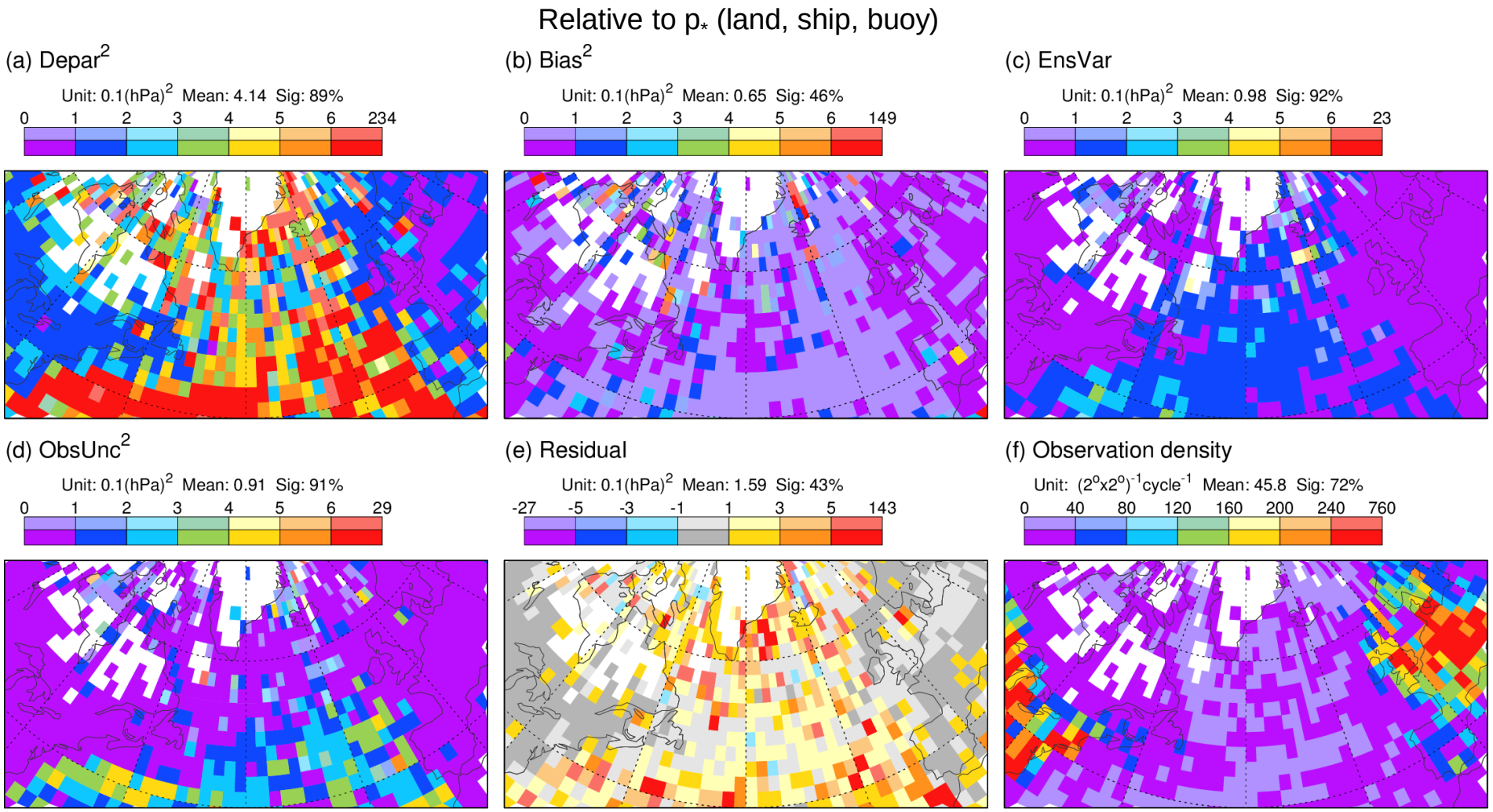
- Reduction in ensemble variance
- Improved diagnosed reliability within subtropical anticyclones, but convective regions worse
- **Key result: EDA reliability budget *is* sensitive to *local* changes in Stochastic Physics**
- Should help development of stochastically-formulated process parametrizations
- Note that Obs Error assignment also likely to be an issue in this budget

2 members, 20110812-20111116

A role for errors in the modelling of observation uncertainty? (Different situation)

EDA reliability budget: Surface pressure SON 2014

Rodwell et al. (2015) QJRMS

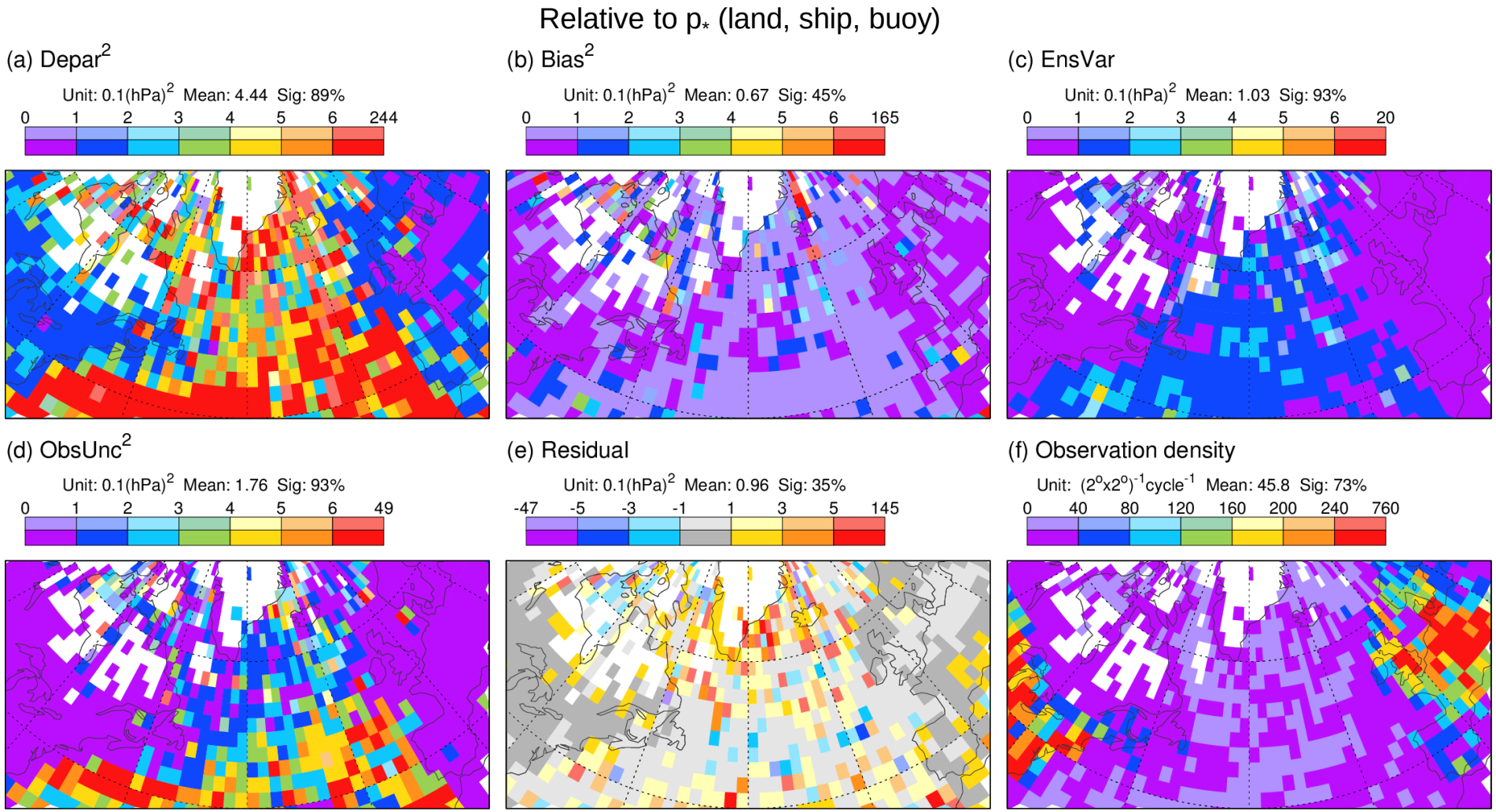


- Marine observation errors not large enough?

Reference experiment (3 members, 20140901-20141130)

EDA reliability budget: Larger marine Observation Uncertainties

Rodwell et al. (2015) QJRMS



- Larger marine observation errors consistent with better reliability
- Modelling of observation uncertainty and representation of model uncertainty are key to reliability

Perturbed experiment (3 members, 20140901-20141130)

Summary

- Difficult to assess flow-dependent reliability in the medium-range
  - Error propagation and interaction means we cannot highlight specific issues
  - Chaos means that large samples are required
- Approach here is to look at short timescales
  - Need to include uncertainty in our knowledge of the truth
  - “EDA reliability budget” (focuses on reliability, not sharpness)
  - **Can assess local and flow-dependent sensitivity to model uncertainty representation**
- Ambiguities with (e.g.) observation error a “mixed blessing”
  - Reliable ensemble initiation requires good modelling of observation error
  - “Desroziers statistics” (etc) can inform on observation errors
  - Initial tendency budget can inform on systematic model errors
- Tool can now be readily applied by developers to the IFS