A new methodology for physics perturbations

Michiel Van Ginderachter
Royal Meteorological Institute Belgium

ALARO 1 Working Days, Bratislava, 12/03/2019

EPS
model uncertainty of a forecast due to:

- Error in Initial (and boundary) conditions
- **Model error**
  - uncertainty of physical parameterization tendencies: **SPPT**
  - uncertainty of parameters inside parameterization: **RP, SPP**
- Stochastic nature of some physical processes
  - cellular automaton
  - multicloud model

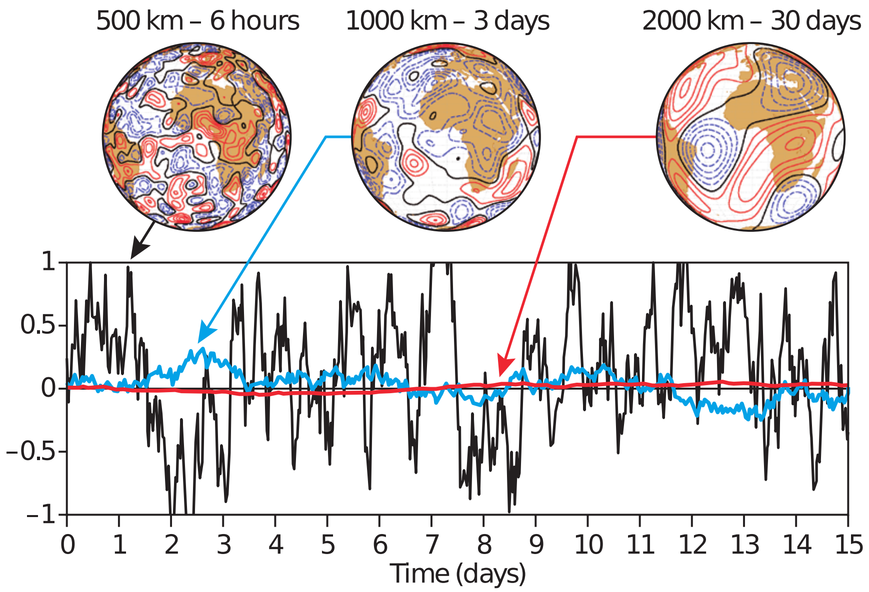
EPS
model uncertainty of a forecast due to:

- Error in Initial (and boundary) conditions
- **Model error**
  - uncertainty of physical parameterization tendencies: **SPPT**
  - uncertainty of parameters inside parameterization: **RP, SPP**
- Stochastic nature of some physical processes
  - cellular automaton
  - multicloud model

Stochastically Perturbated Parameterization Tendencies

$$\frac{\partial \psi}{\partial t}|_{\text{pert}} = (1+\alpha)\frac{\partial \psi}{\partial t}|_{\text{unpert}}$$

$$\alpha(\phi, \lambda, t) \in [-1, 1]$$



spatial, temporal correlation tuned for best skill

Introduction

Asses uncertainty of a forecast due to

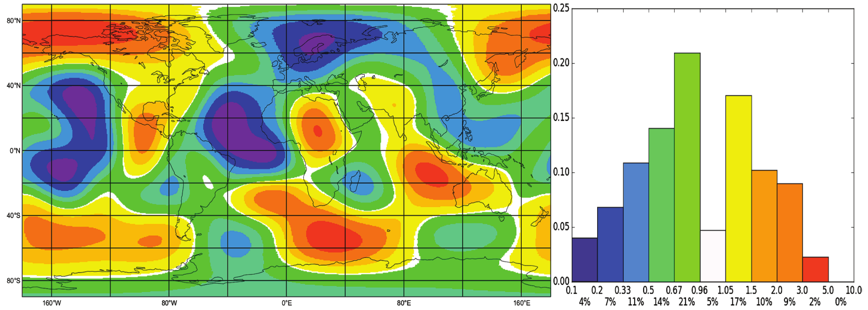
- Error in Initial (and boundary) conditions
- **Model error**
  - uncertainty of physical parameterization tendencies: **SPPT**
  - uncertainty of parameters inside parameterization: **RP, SPP**
- Stochastic nature of some physical processes
  - cellular automata
  - multicloud model

Random Parameter - Stochastically Perturbed Parameterizations

$$\frac{\partial \psi}{\partial t}|_{\text{pert}} = f(\mathbf{X}; \xi|_{\text{pert}})$$

$$\xi|_{pert} = \exp(\Psi)\xi|_{\text{unpert}}$$

$$\Psi \sim \mathcal{N}(\mu, \sigma)$$



σ determined by expert view

spatial, temporal correlation tuned for best skill

Scientific question

- Can the modularity of ALARO be used to characterize model error/uncertainty?
  - modularity: represent 1 physical process with different schemes
  - reference Model (most sophisticated/best results) vs approximate model (simpler/easier/faster)
  - lower bound for model error

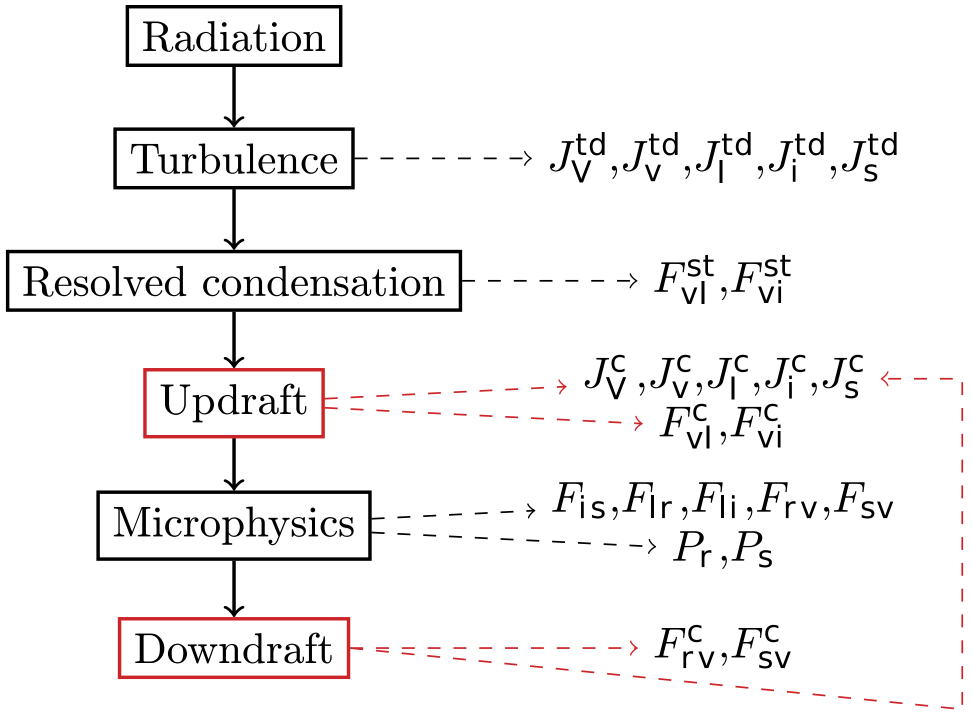
- What is the effect on the ensemble when using perturbations based on this characterization
  - can be applied to all physical process with multiple representations (cloud condensation, turbulence, radiation)
  - test case: deep convection at 4 km resolution

Practical application

- Deep convection at 4 km
  - **reference Model**
  - approximate Model
- Definition of model error
  - fluxes
  - time-scale
- Period - Domain

Deep Convection Parameterization

CP = ALARO - 3MT

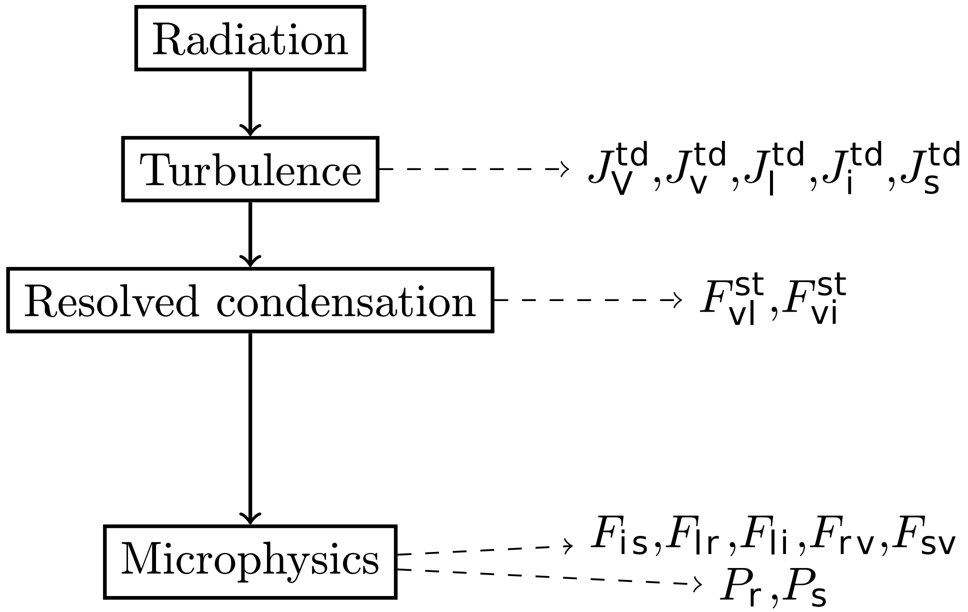


Practical application

- Deep convection at 4 km
  - reference model
  - **approximate model**
- Definition of model error
  - fluxes
  - time-scale
- Period - Domain

Explicit treatment of deep convection

NCP = ALARO - STRAPRO



Practical application

- Deep convection at 4 km
  - reference model
  - approximate model
- Definition of model error
  - **fluxes**
  - time-scale
- Period - Domain

- Transport:

$$\epsilon_{\psi}^{\text{trans}} = J^{c}_{\psi,\text{3MT}} + J^{td}_{\psi,\text{3MT}} - J^{td}_{\psi,\text{STRAPRO}}$$

$$\psi = q_v, q_l, q_i, h, u, v$$

- Condensation:

$$\epsilon_{\psi}^{\text{cond}} = F^{c}_{\psi,\text{3MT}} + F^{st}_{\psi,\text{3MT}} - F^{st}_{\psi,\text{STRAPRO}}$$

$$\psi = vl, vi$$

- Evaporation:

$$\epsilon_{\psi}^{\text{cond}} = F^{c}_{\psi,\text{3MT}} + F^{st}_{\psi,\text{3MT}} - F^{st}_{\psi,\text{STRAPRO}}$$

$$\psi = rv, sv$$

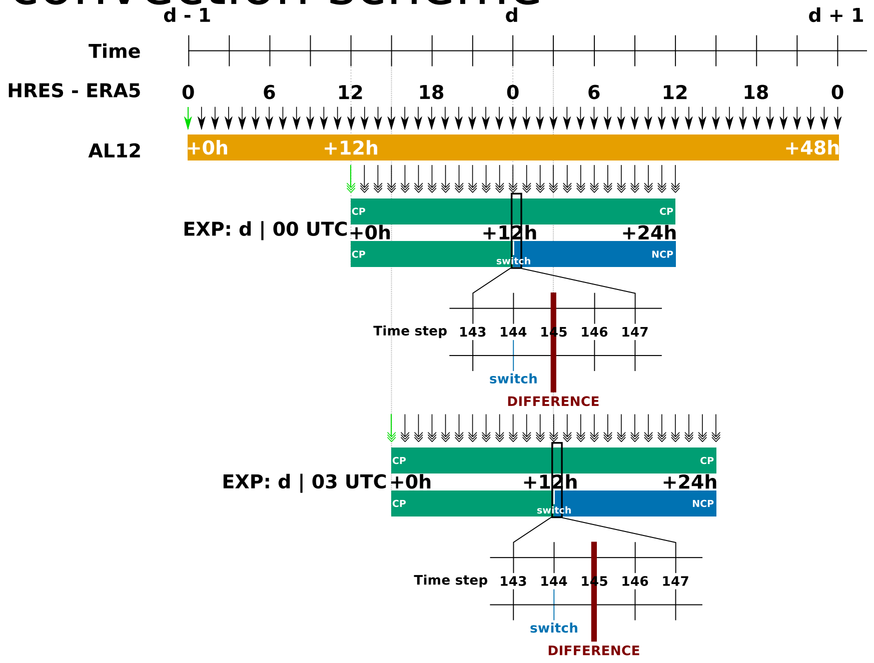
Practical application

- Deep convection at 4 km
  - reference model
  - approximate model
- Definition of model error
  - fluxes
  - **time-scale**
- Period - Domain

Error Source

- error made during 1 time step
- start from identical atmospheric state
- first timestep = problem with spin up fluxes

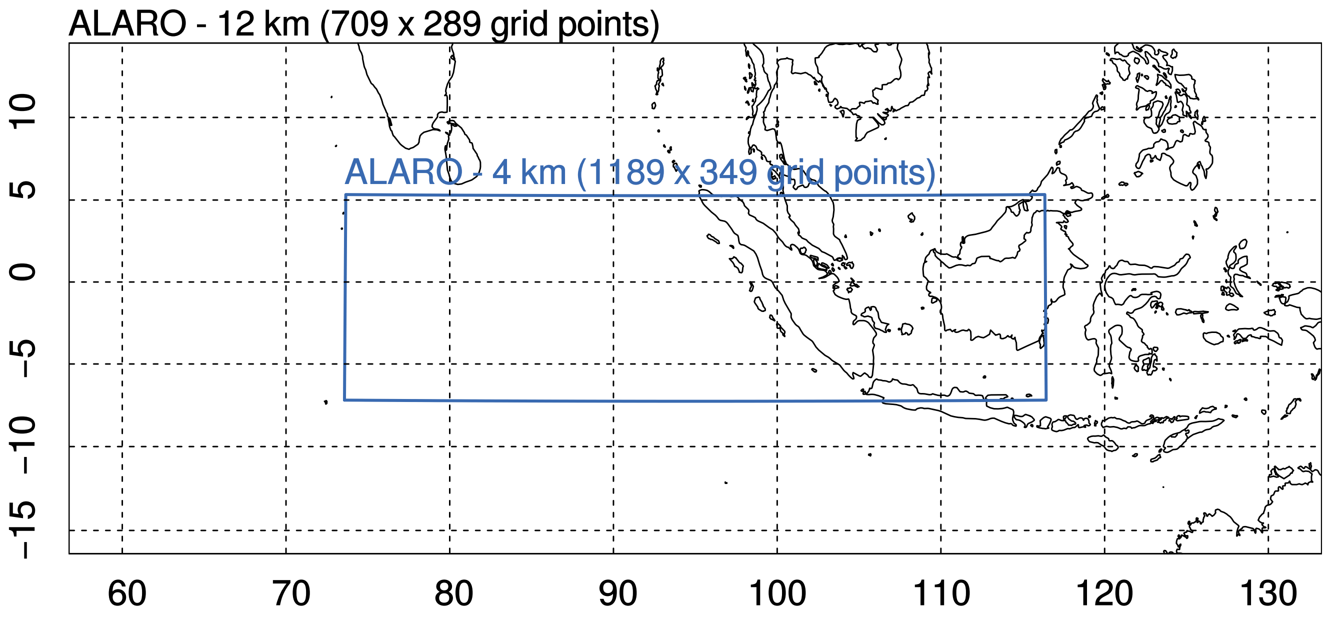
⟶ Let model spin up, then deactivate deep convection scheme



Practical application

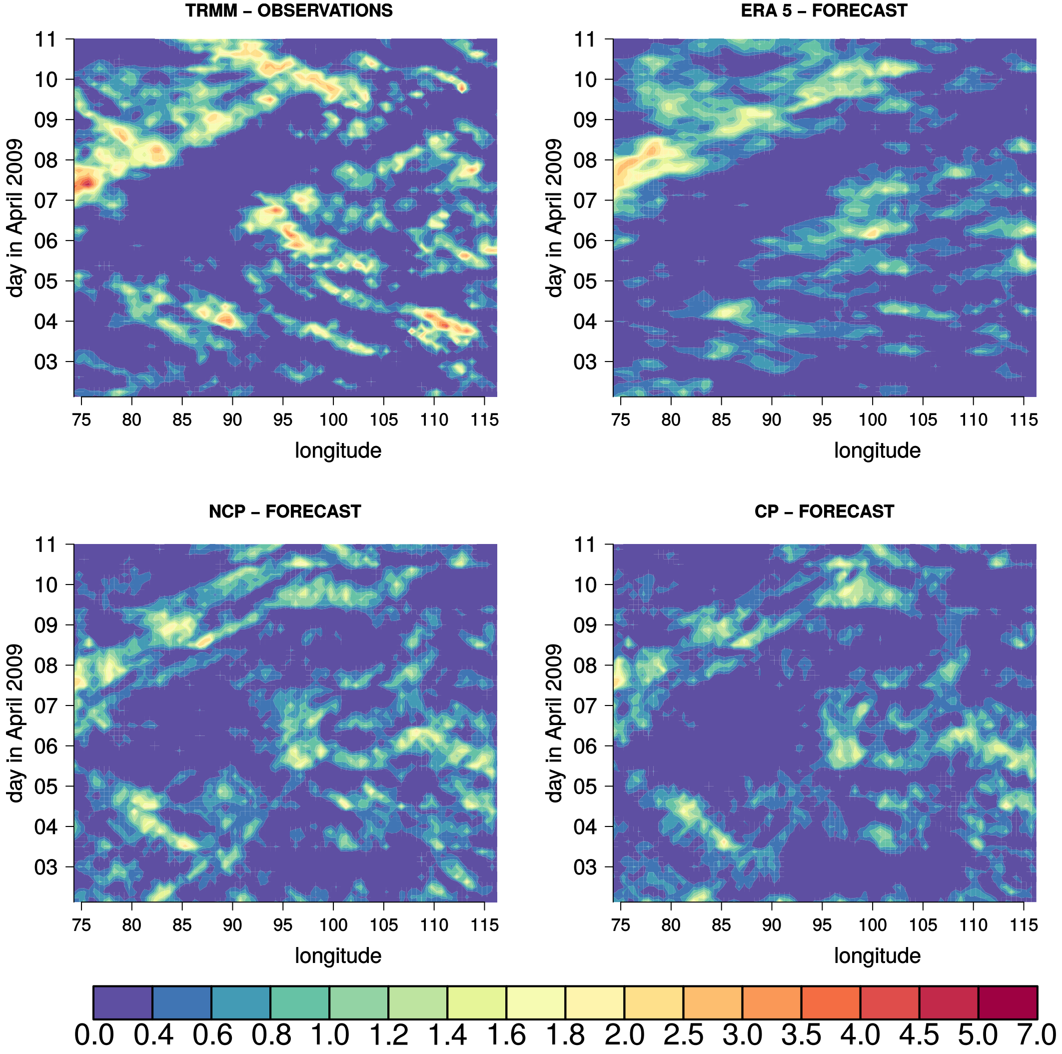
- Deep convection at 4 km
  - reference model
  - approximate model
- Definition of model error
  - Fluxes
  - Time-scale
- **Period - Domain**

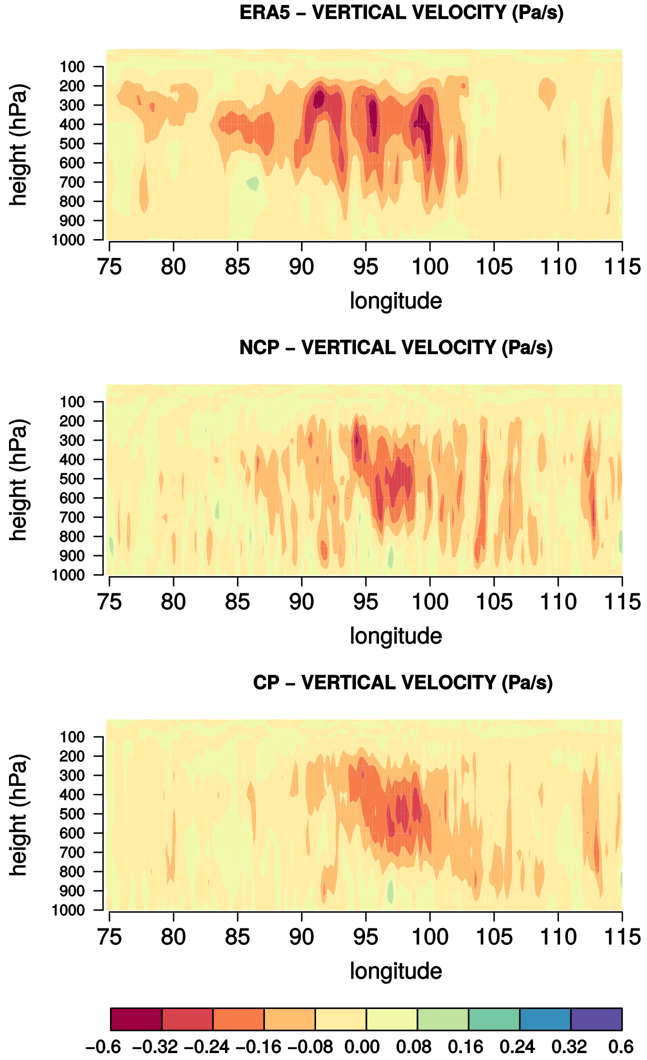
- Need (a lot of) convection
- No steep orography
  ⟶ Indian Ocean
  ⟶ Period of enhanced convective activity (active equatorial waves) 1 - 10 April 2009
- forced by ERA5 analysis

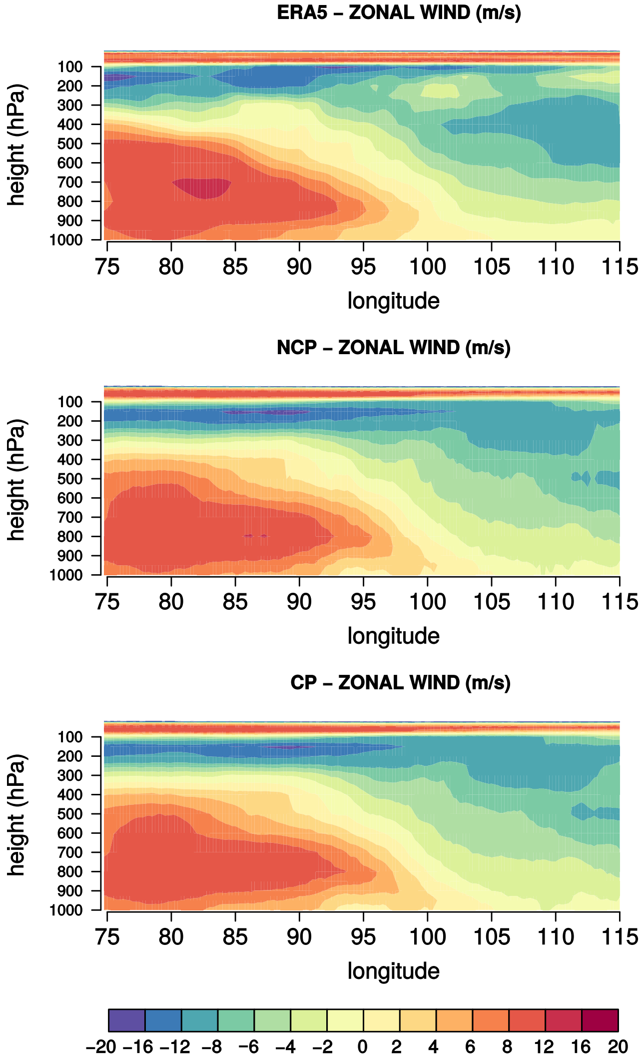


Intermezzo: ALARO in the Tropics

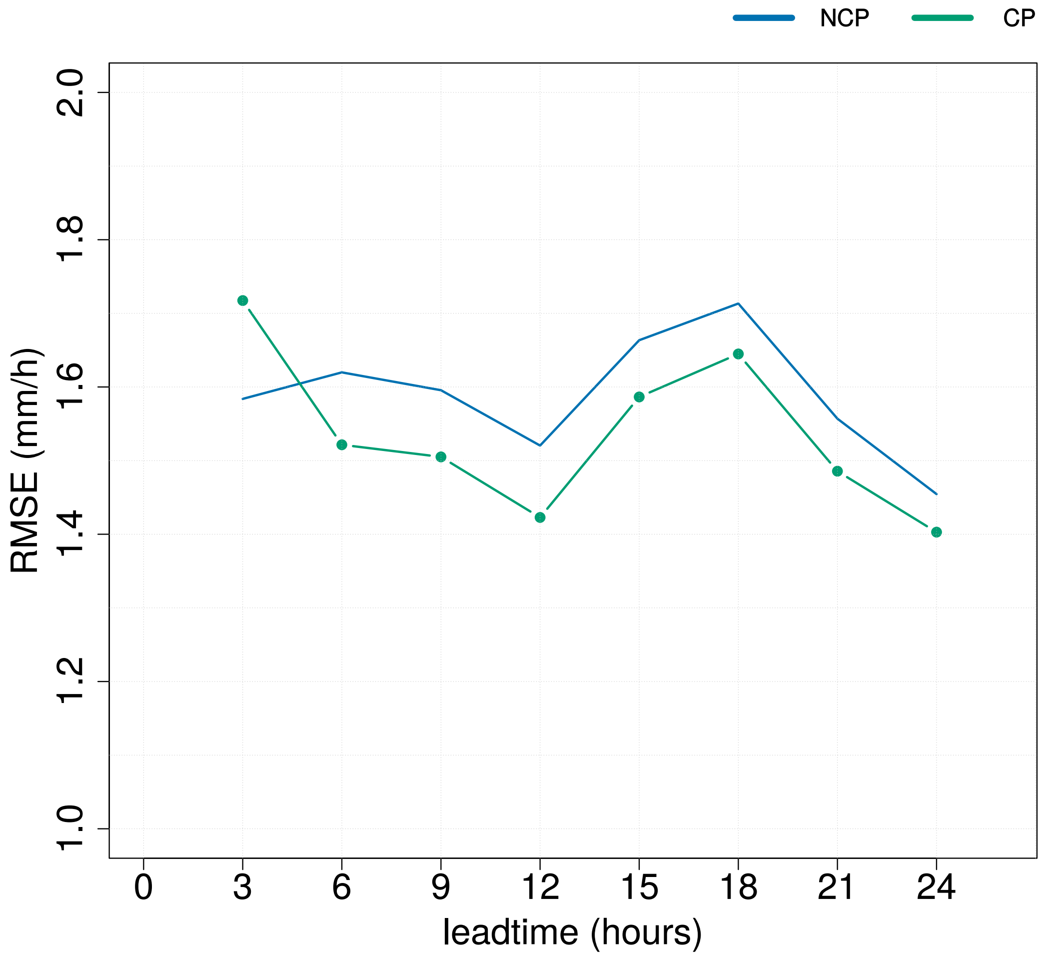
Representation of equatorial waves



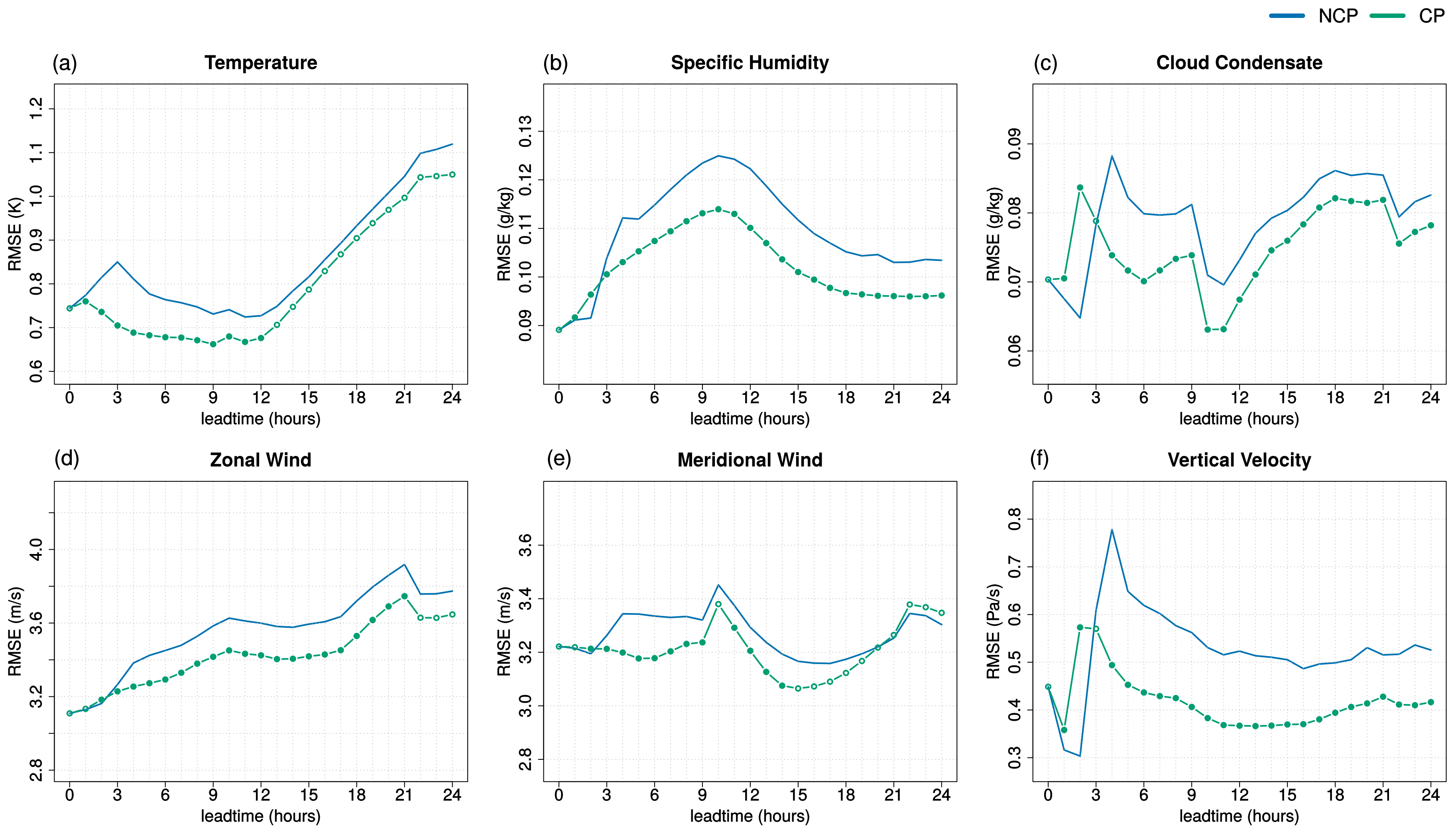




Scores - Precipitation

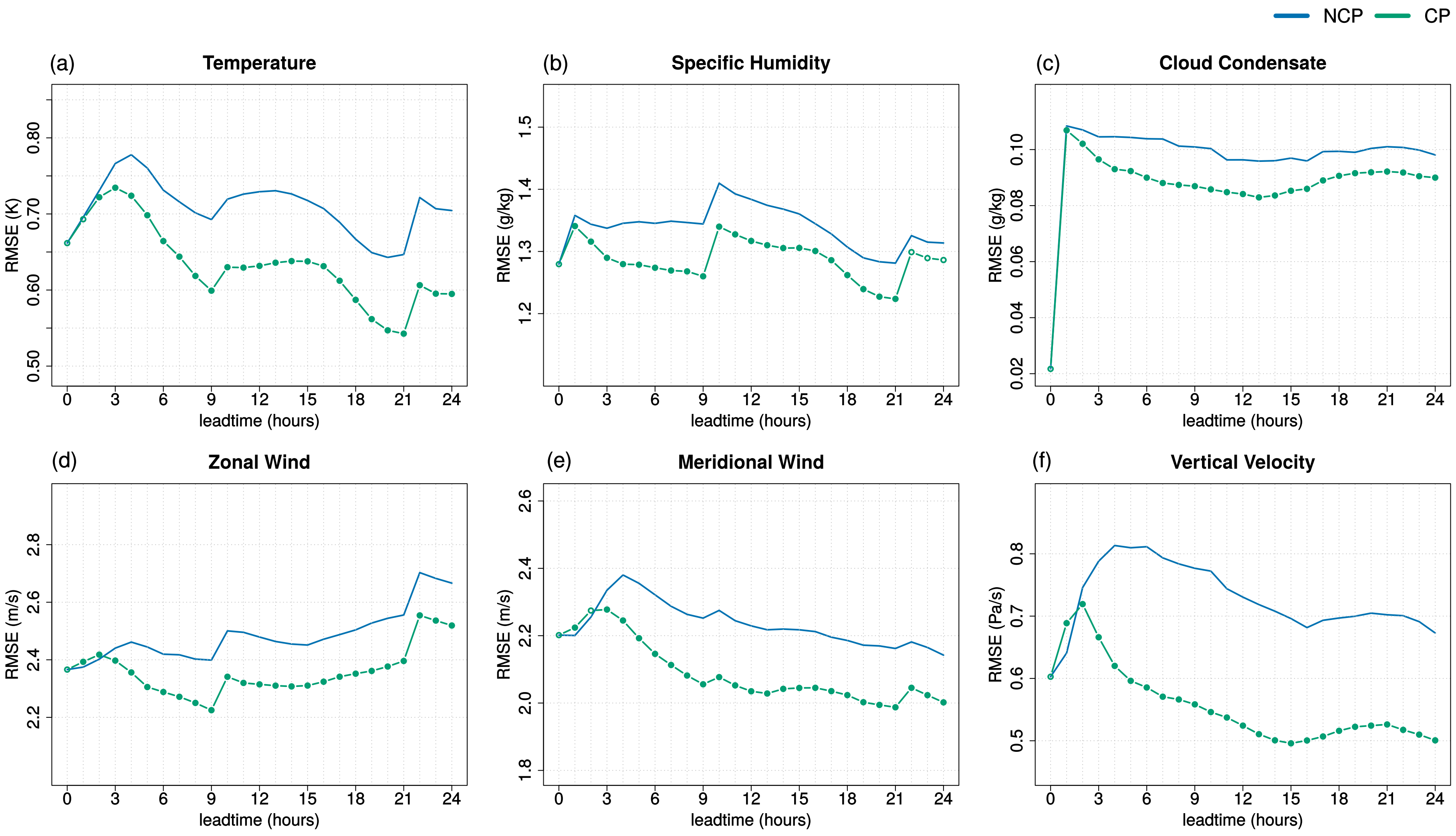


Scores - Atmospheric fields (250 hPa)



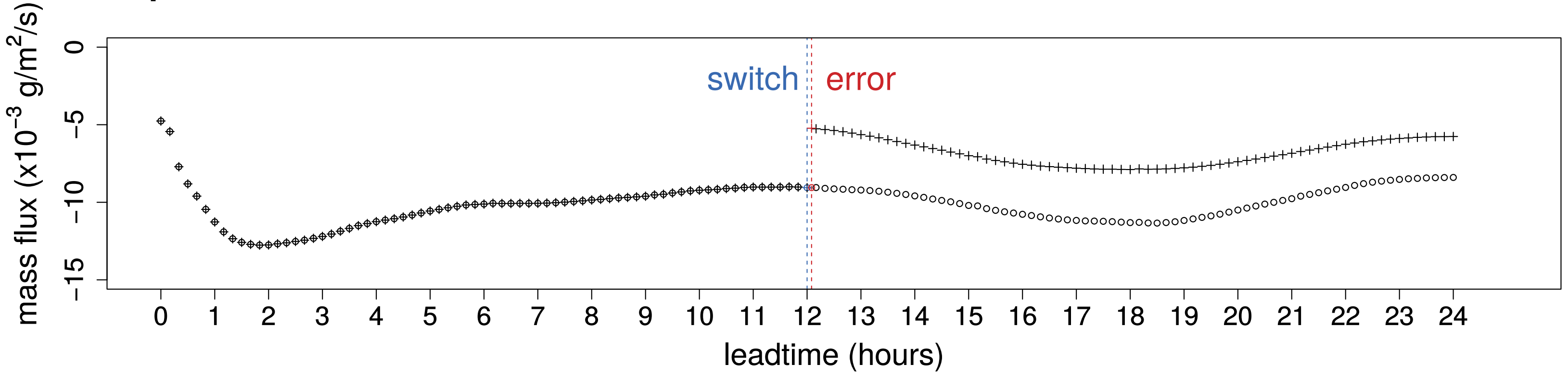
Intermezzo: ALARO in the Tropics

Scores - Atmospheric fields (850 hPa)

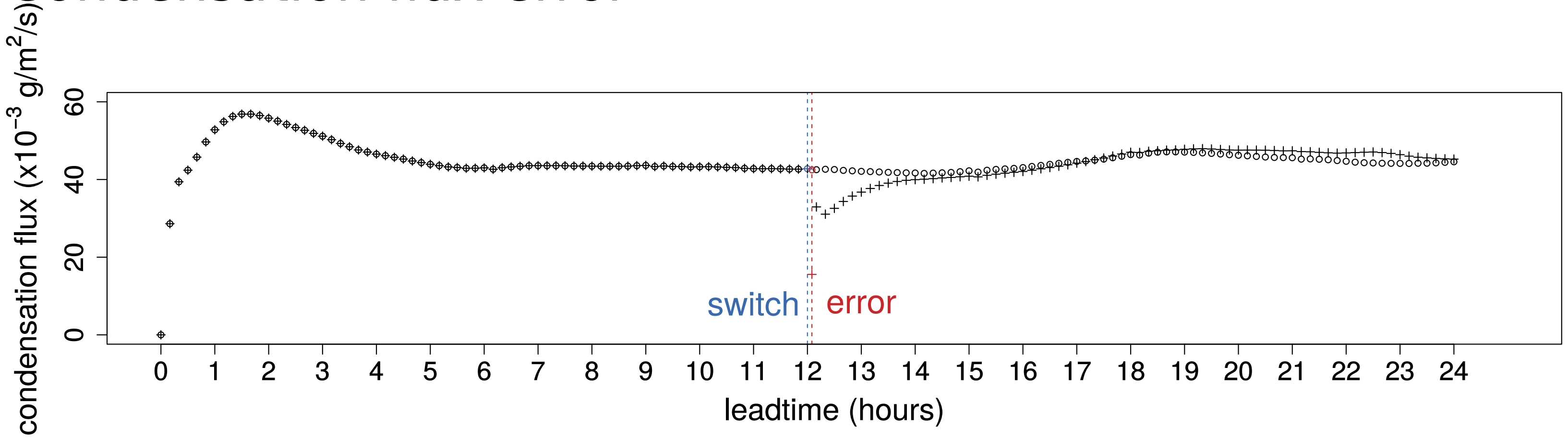


Deactivation of the deep convection scheme

- Transport flux error



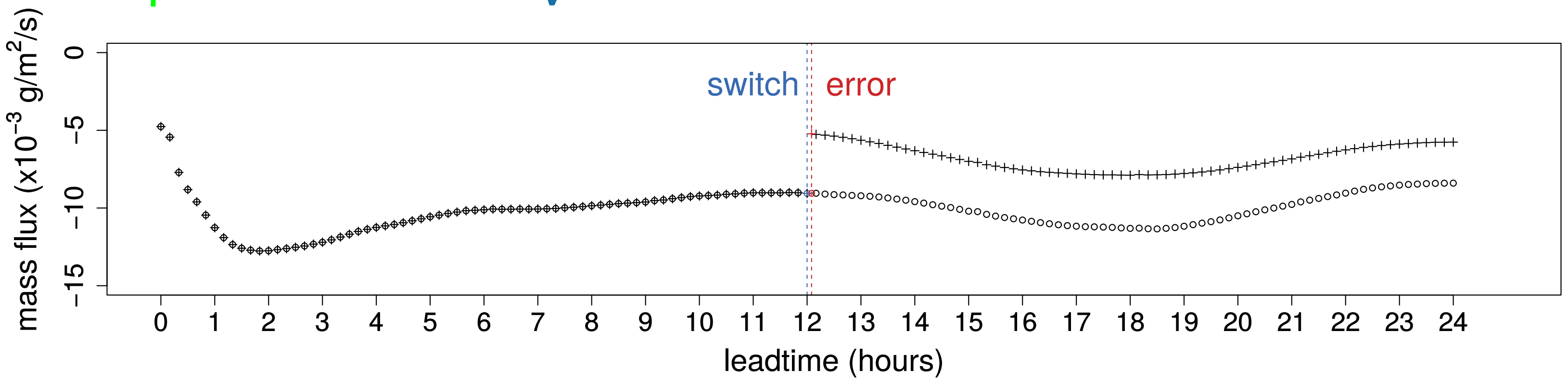
- Condensation flux error



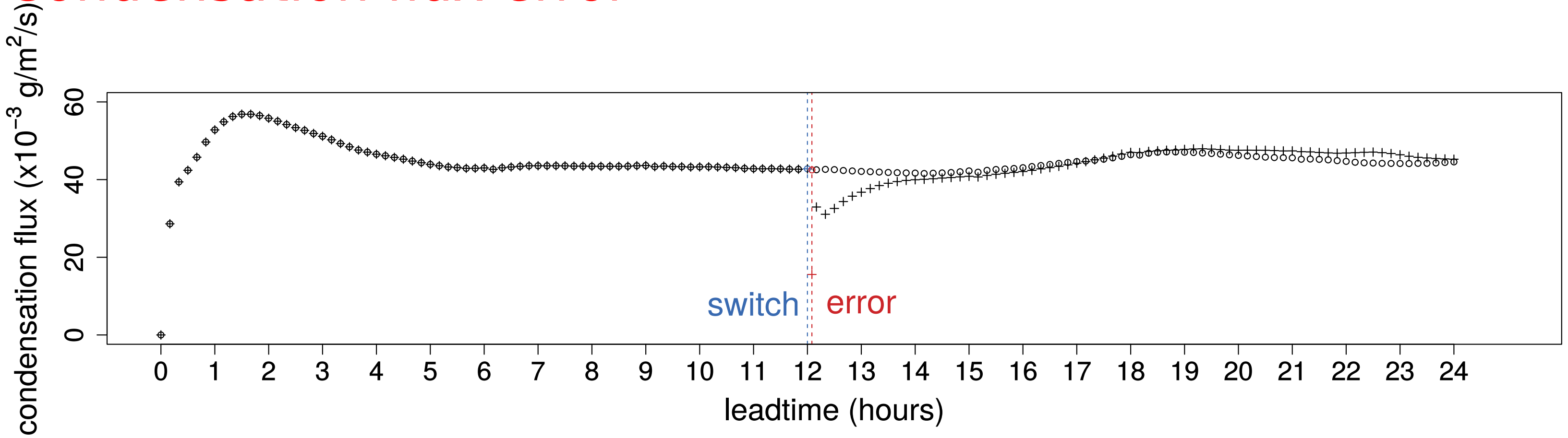
- Evaporation flux error

Deactivation of the deep convection scheme

- Transport flux error √



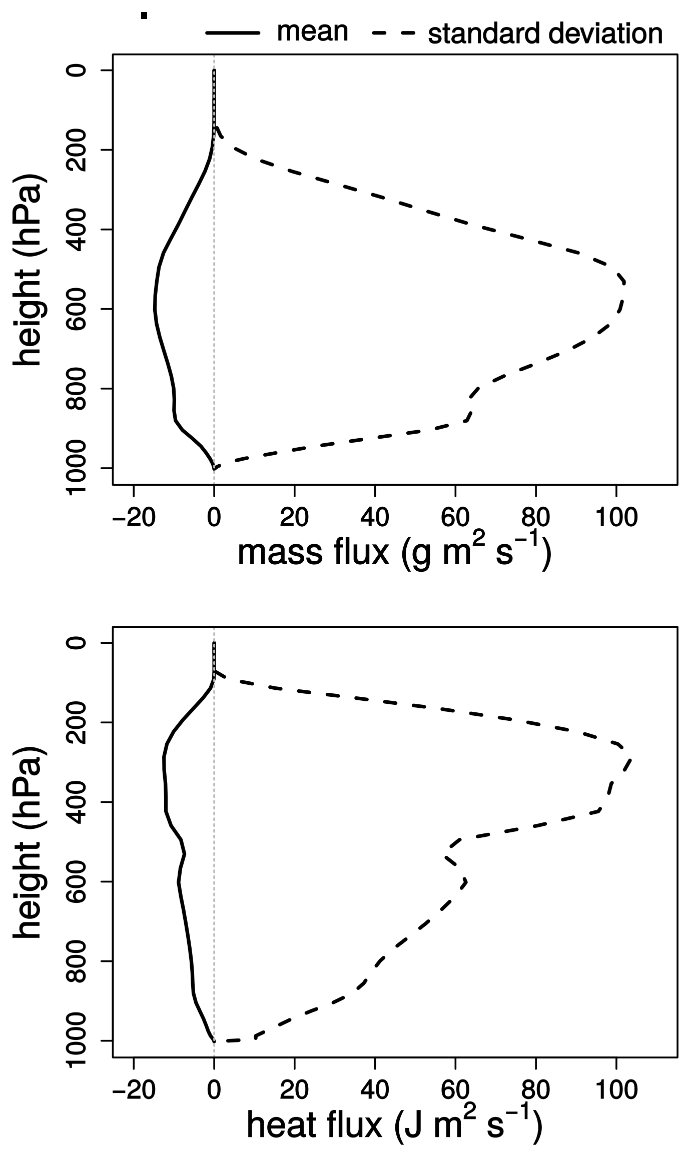
- ~~Condensation flux error~~



- ~~Evaporation flux error~~

Quantification of the transport flux error

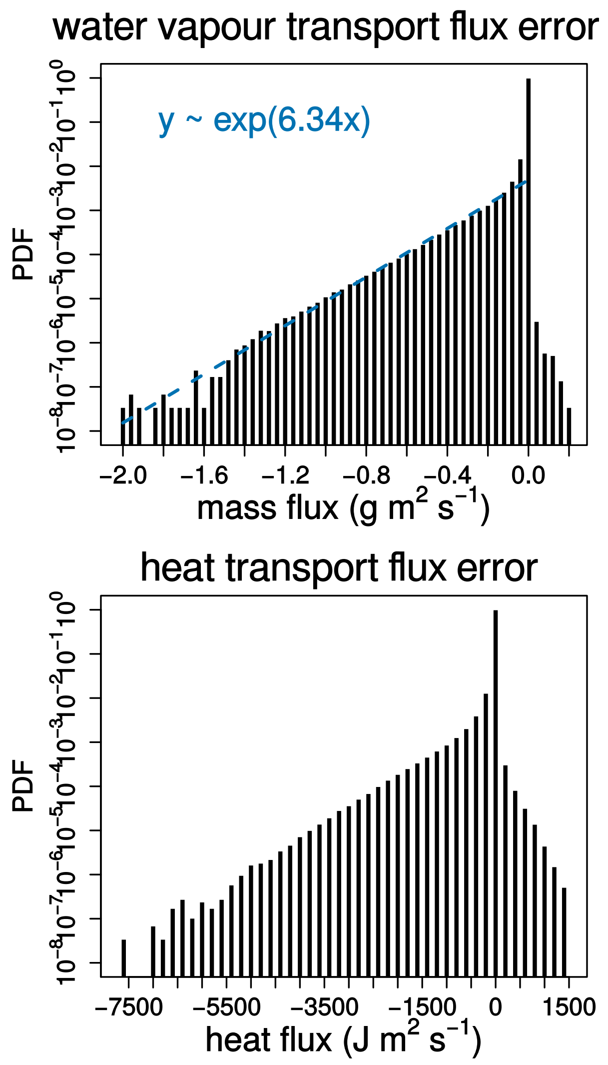
- **vertical profile**
- probability distribution
- intervariable correlation
- spatial autocorrelation
- temporal autocorrelation



Quantification of the transport flux error

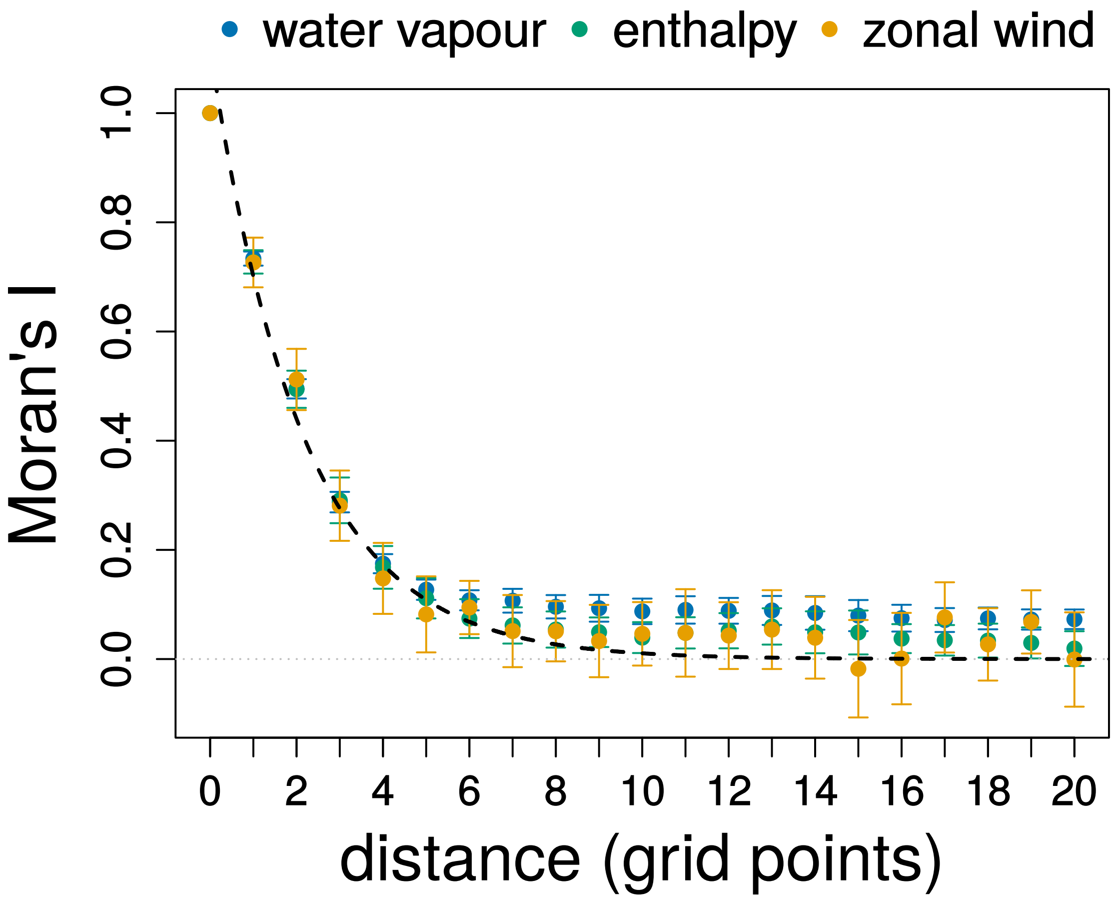
- vertical profile
- **probability distribution**
- intervariable correlation
- spatial autocorrelation
- temporal autocorrelation

transport flux error at l20



- mean and standard deviation
- probability distribution
- intervariable correlation
- **spatial autocorrelation**
- temporal autocorrelation

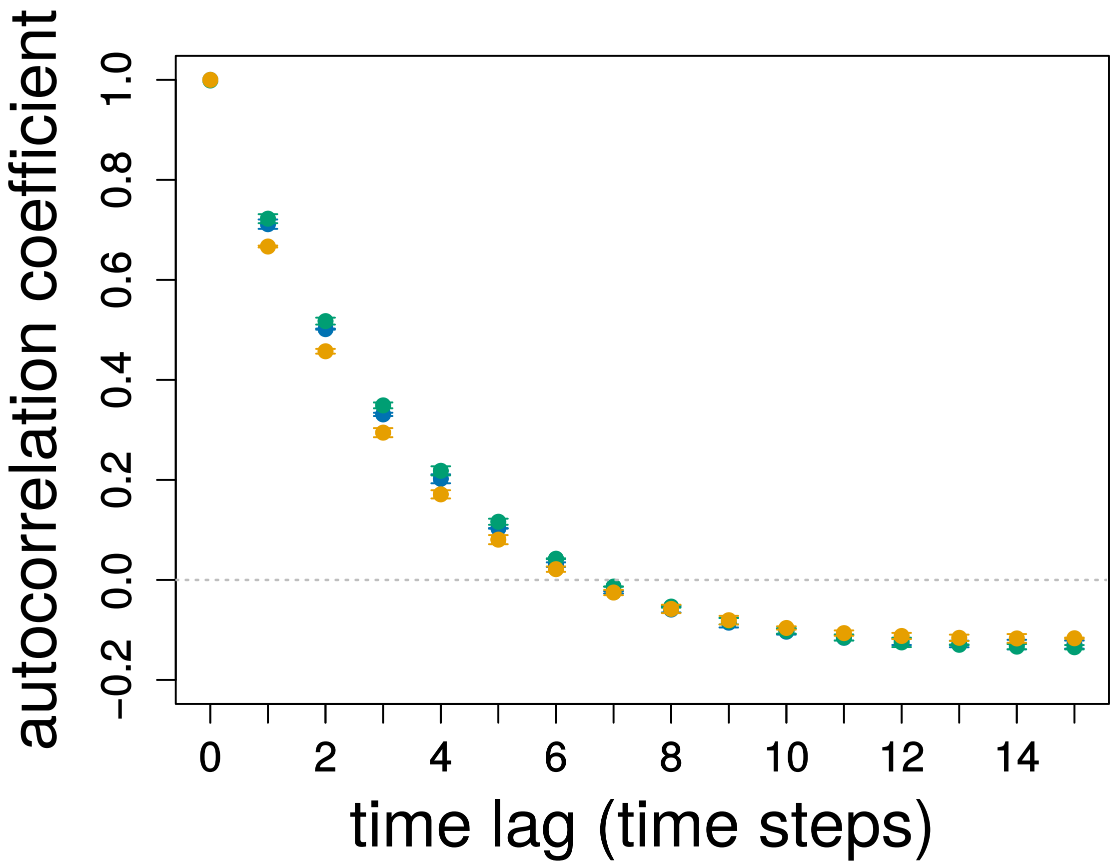
at level 20



Quantification of the transport flux error

- vertical profile
- probability distribution
- intervariable correlation
- spatial autocorrelation
- **temporal autocorrelation**

at level 20



Perturbation scheme

- vertical profile
- probability distribution
- intervariable correlation
- spatial autocorrelation
- temporal autocorrelation

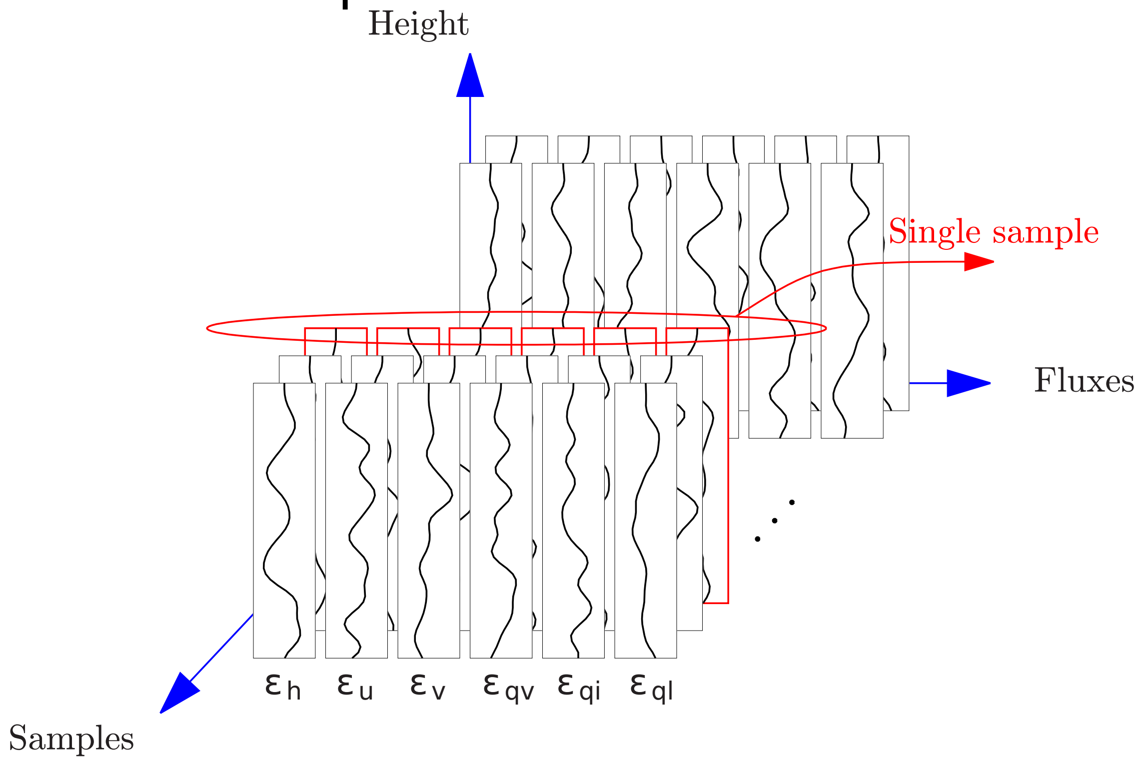
How to perturb the tendencies, keeping these correlations?

Perturbation scheme

- **vertical profile** $\surd$
- **probability distribution** $\surd$
- **intervariable correlation** $\surd$
- ~~spatial autocorrelation~~
- ~~temporal autocorrelation~~

How to perturb the tendencies, keeping these correlations?

$\longrightarrow$ Sample from a database



$$\frac{\partial \psi}{\partial t}|_{\mathrm{pert}} = -g\frac{\partial}{\partial p}\left(J_\psi|_{\mathrm{unpert}} + \epsilon_\psi\right)$$

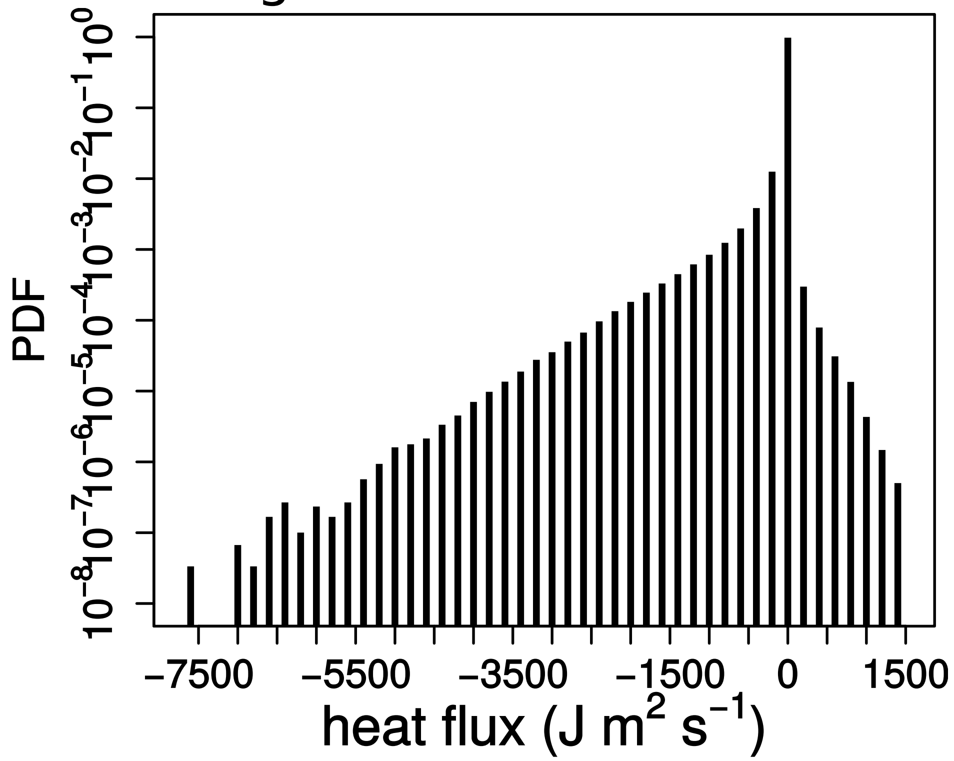
- vertical profile √
- **probability distribution** √
- intervariable correlation √
- ~~correlation with transport flux~~
- ~~spatial autocorrelation~~
- ~~temporal autocorrelation~~

How to perturb the tendencies, keeping these correlations?

What grid columns enter the database?

Only grid-columns with convective activity

⟶ Find a general selection criterion:



Perturbation scheme

- vertical profile √
- **probability distribution** √
- intervariable correlation √
- ~~spatial autocorrelation~~
- ~~temporal autocorrelation~~

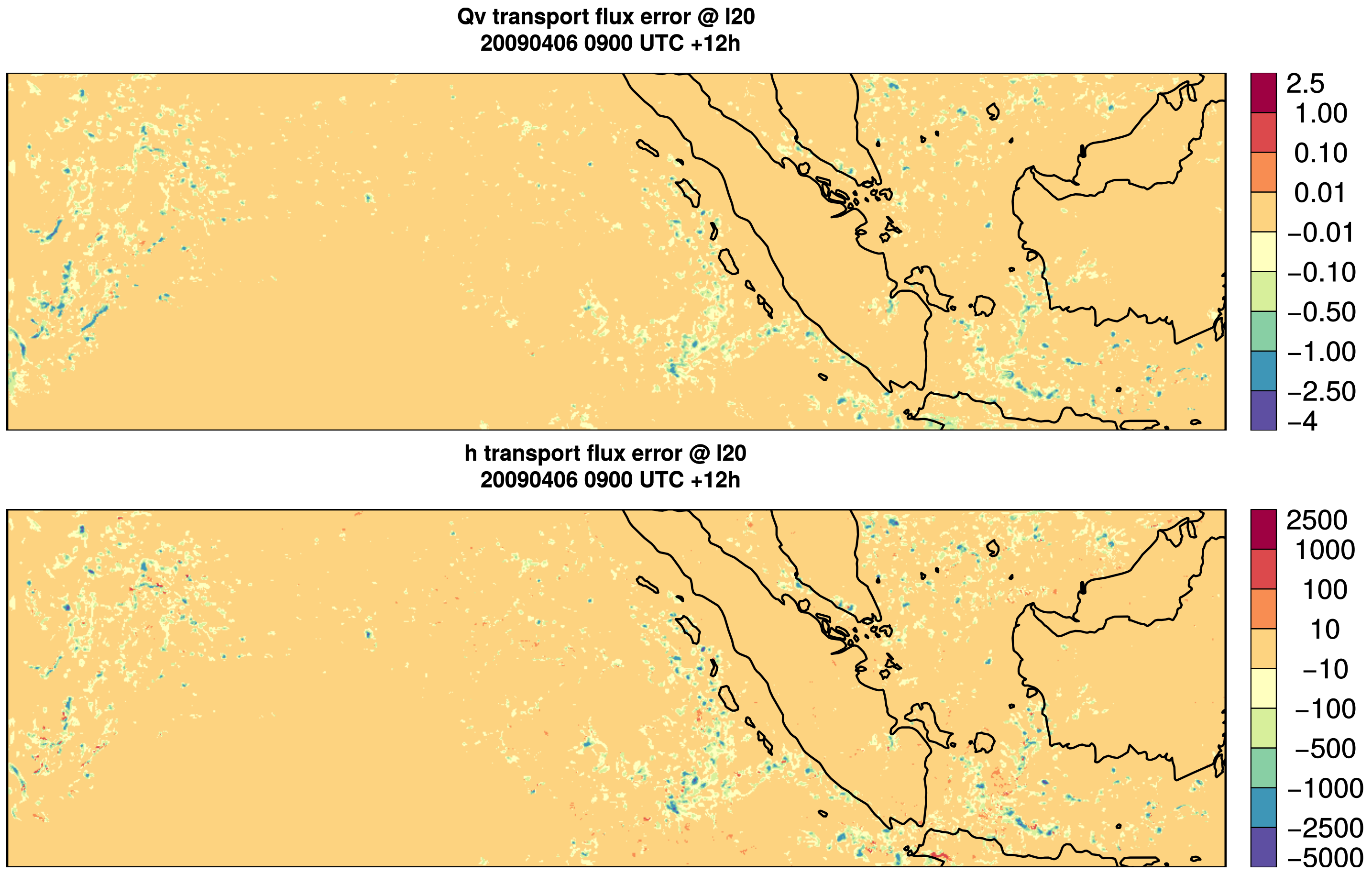
How to perturb the tendencies, keeping these correlations?

What grid columns enter the database?

Only grid-columns with convective activity

⟶ Find a general selection criterion:

$$\overline{\sigma_u \omega_u}$$



Perturbation scheme

- vertical profile √
- **probability distribution** √
- intervariable correlation √
- ~~spatial autocorrelation~~
- ~~temporal autocorrelation~~

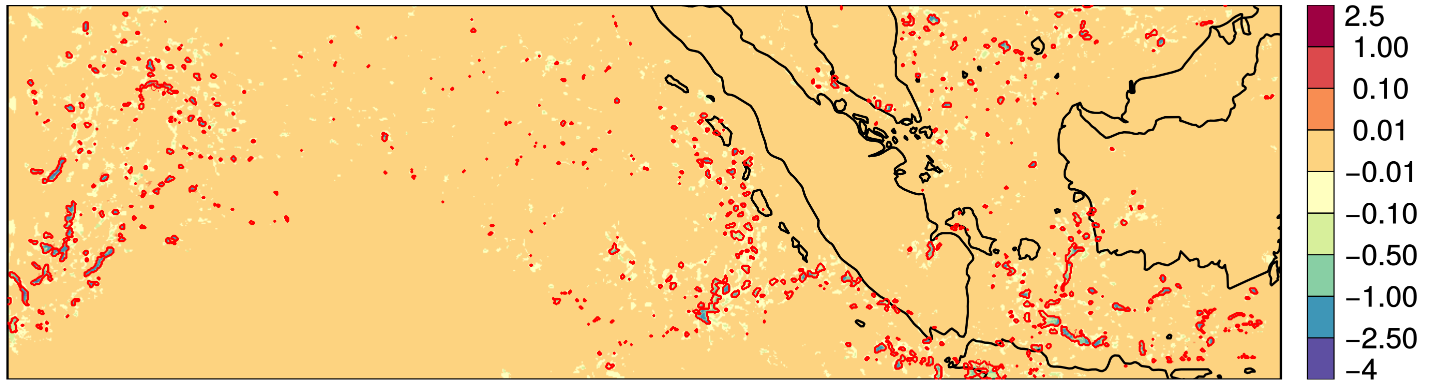
How to perturb the tendencies, keeping these correlations?

What grid columns enter the database?

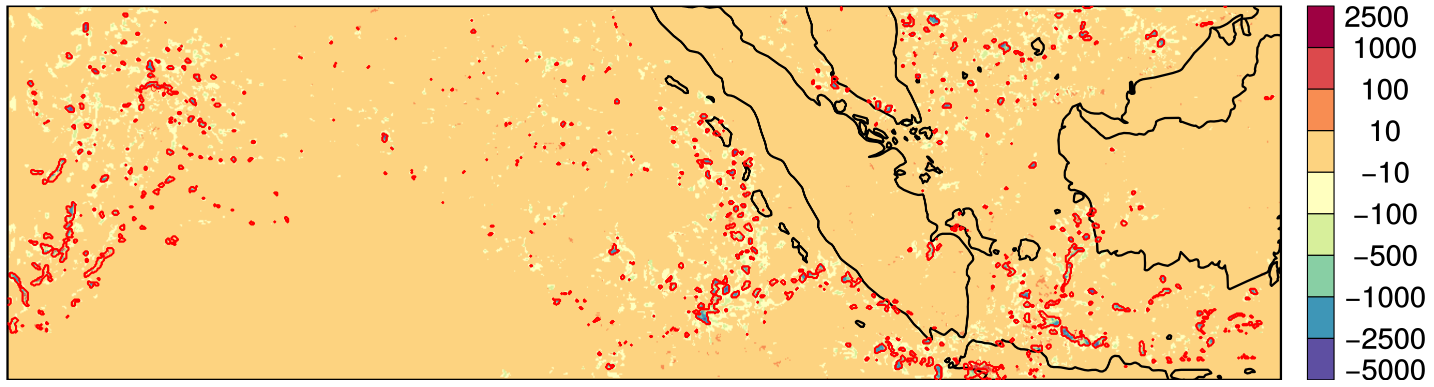
Only grid-columns with convective activity
⟶ Find a general selection criterion:

$$\overline{\sigma_u \omega_u} > 0.5 \text{ Pa/s}$$

Qv transport flux error @ l20
20090406 0900 UTC +12h



h transport flux error @ l20
20090406 0900 UTC +12h



Perturbation scheme

- vertical profile √
- **probability distribution** √
- intervariable correlation √
- ~~spatial autocorrelation~~
- ~~temporal autocorrelation~~

How to perturb the tendencies, keeping these correlations?

What grid columns enter the database?

When and where do we add perturbations?

Indications for convective activity:

- resolved vertical wind (vertically averaged) (OMEGA)
- moisture convergence (MOCON)

Simple YES/NO threshold
$\longrightarrow$ Tuned together with $\overline{\sigma_u \omega_u}$

- vertical profile √
- **probability distribution** √
- intervariable correlation √
- spatial autocorrelation (√)
- temporal autocorrelation(√)

How to perturb the tendencies, keeping these correlations?

What grid columns enter the database?

When and where do we add perturbations?

Indications for convective activity:

- resolved vertical wind (vertically averaged) (OMEGA)
- moisture convergence (MOCON)

Simple YES/NO threshold
$\longrightarrow$ Tuned together with $\overline{\sigma_u \omega_u}$

For **every grid point** at **every time step**:
if (MOCON/OMEGA > THRESHOLD) then:

- sample from database
- add profiles from sample to physical fluxes

Verification

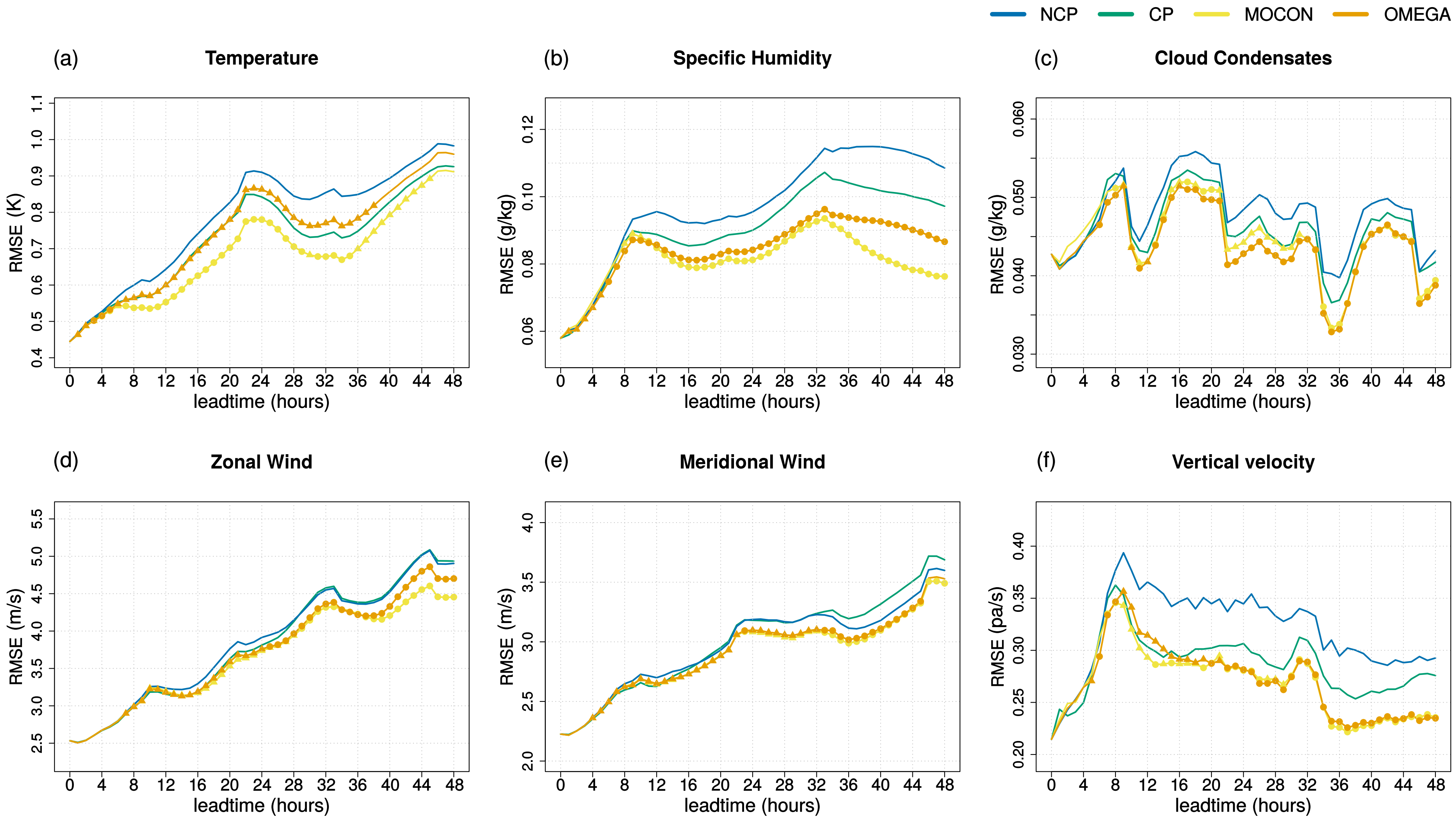
same domain during 11 - 20 April 2009

- flux perturbations only (ERA5)
- combined with IC and BC perturbations (ERA5 EDA)

Verification w.r.t ERA5

Results - Stochastic perturbations only

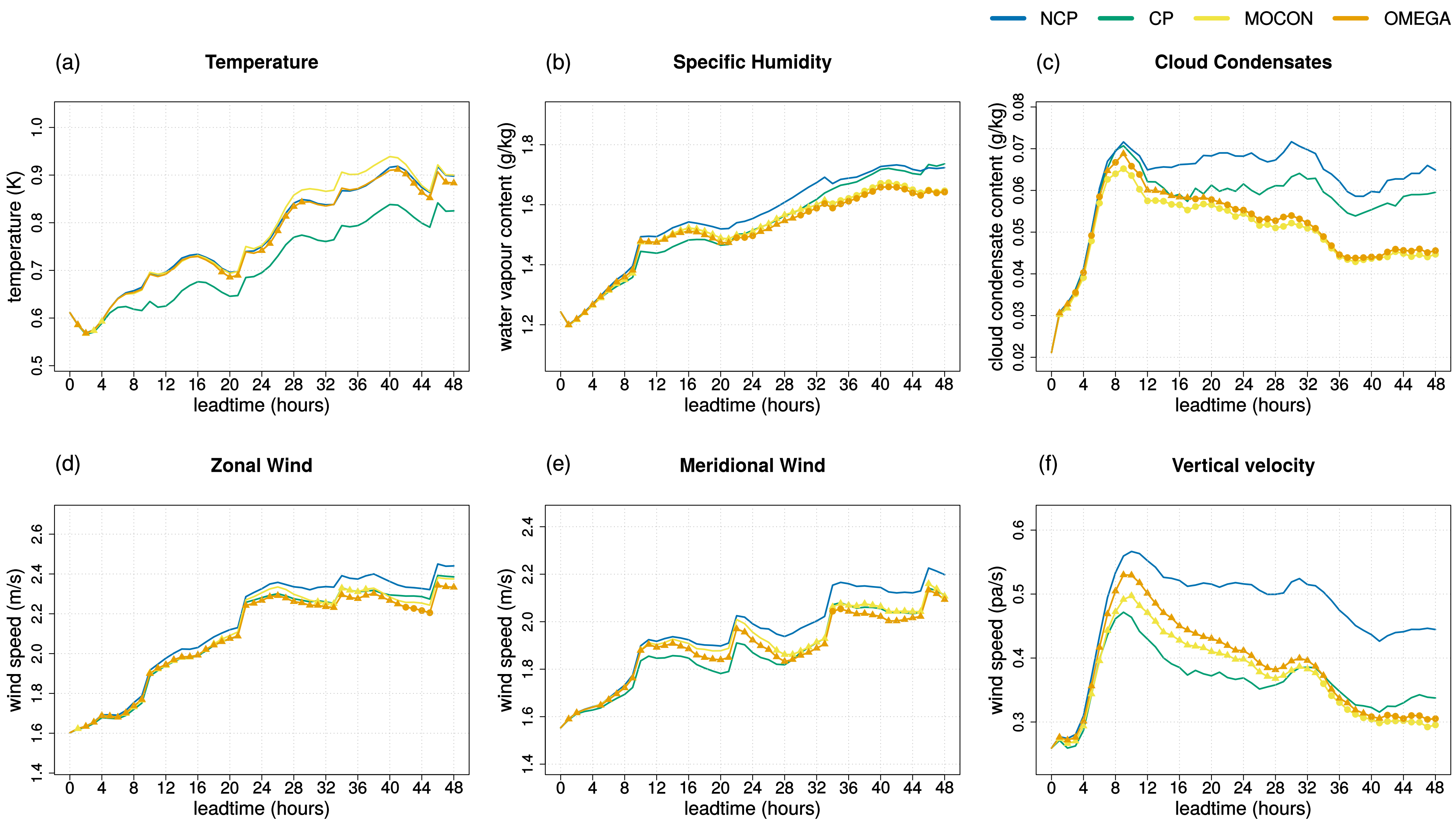
RMSE w.r.t. ERA5 HRES analysis: 10 member ensemble mean vs 3MT control vs STRAPRO control



(250 hPa)

Results - Stochastic perturbations only

RMSE w.r.t. ERA5 HRES analysis: 10 member ensemble mean vs 3MT control vs STRAPRO control

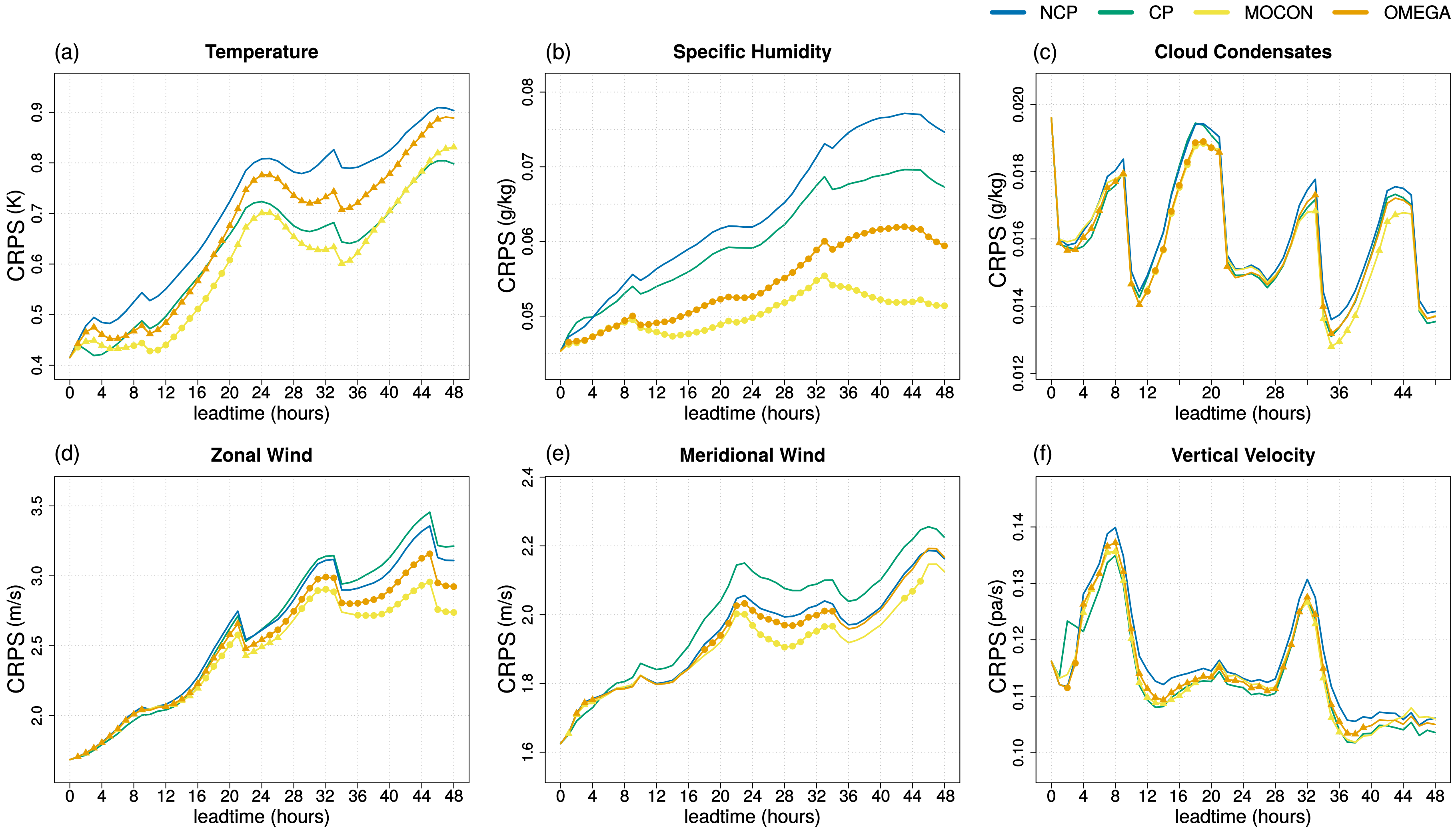


(850 hPa)

Results - Combination with IC and BC perturbations

IC and BC perturbations from ERA5 EDA

Continuously Ranked Probability Score (CRPS) = Brier score over all thresholds

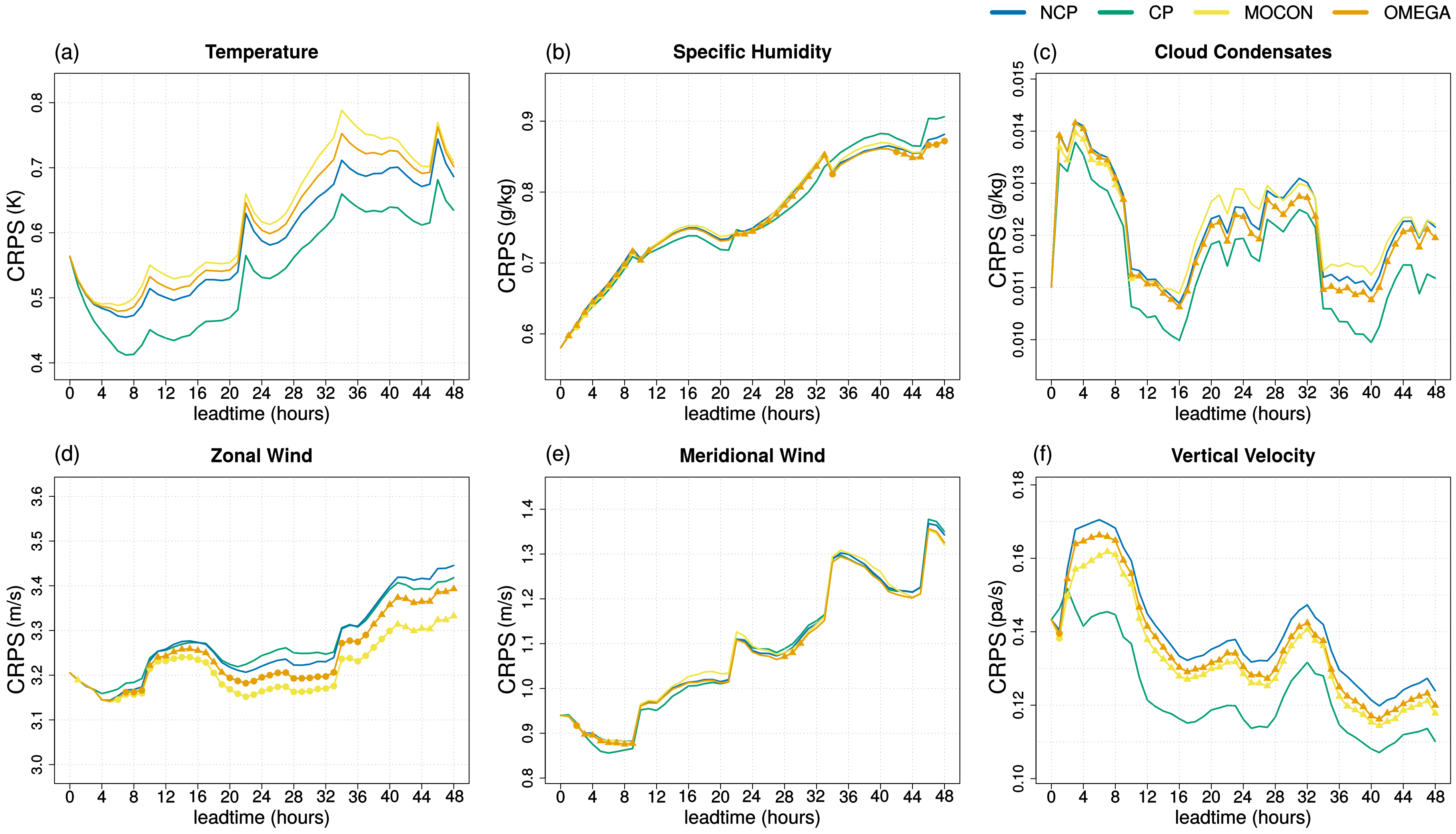


(250 hPa)

Results - Combination with IC and BC perturbations

IC and BC perturbations from ERA5 EDA

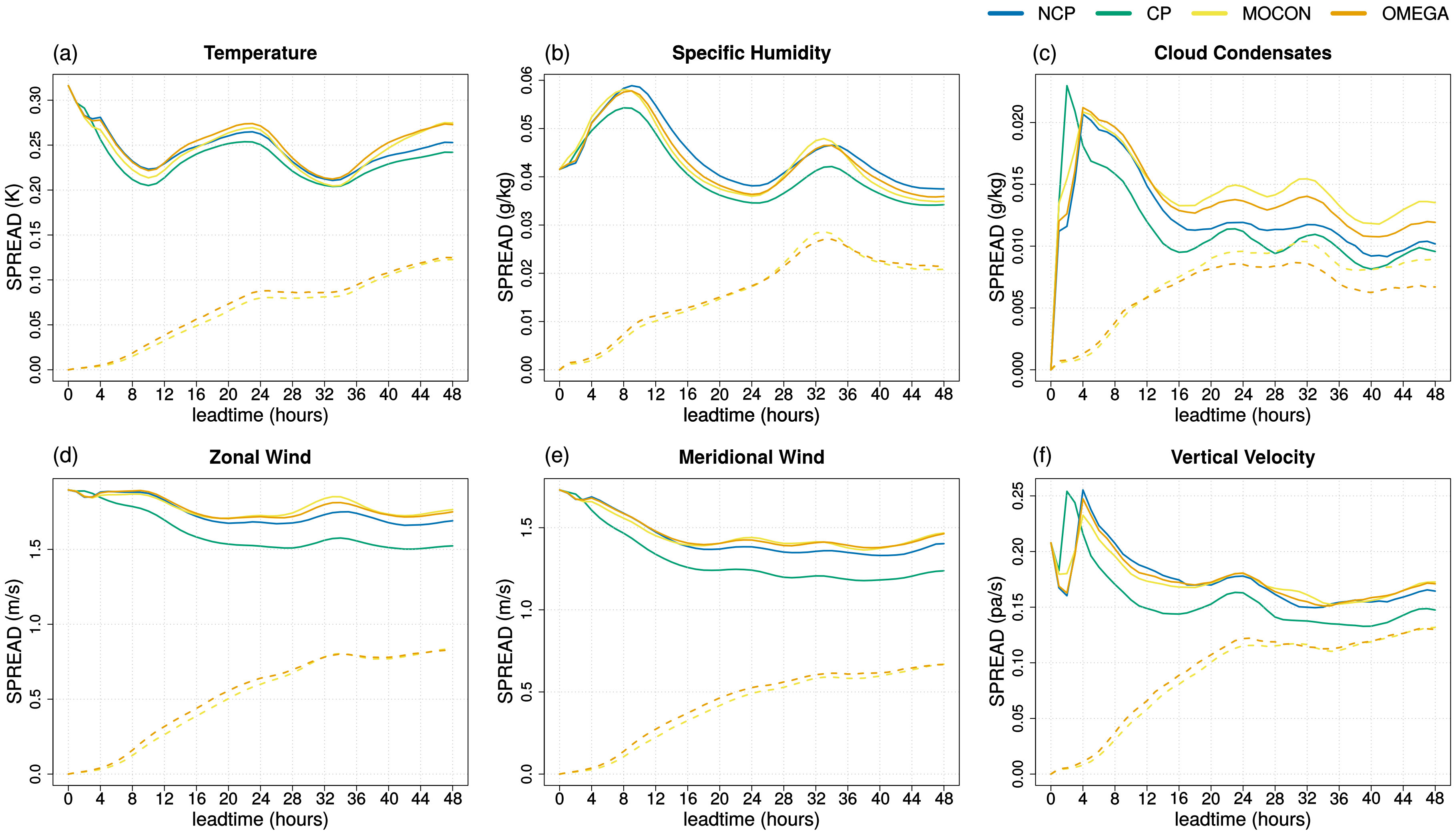
Continuously Ranked Probability Score (CRPS) = Brier score over all thresholds



(850 hPa)

Results

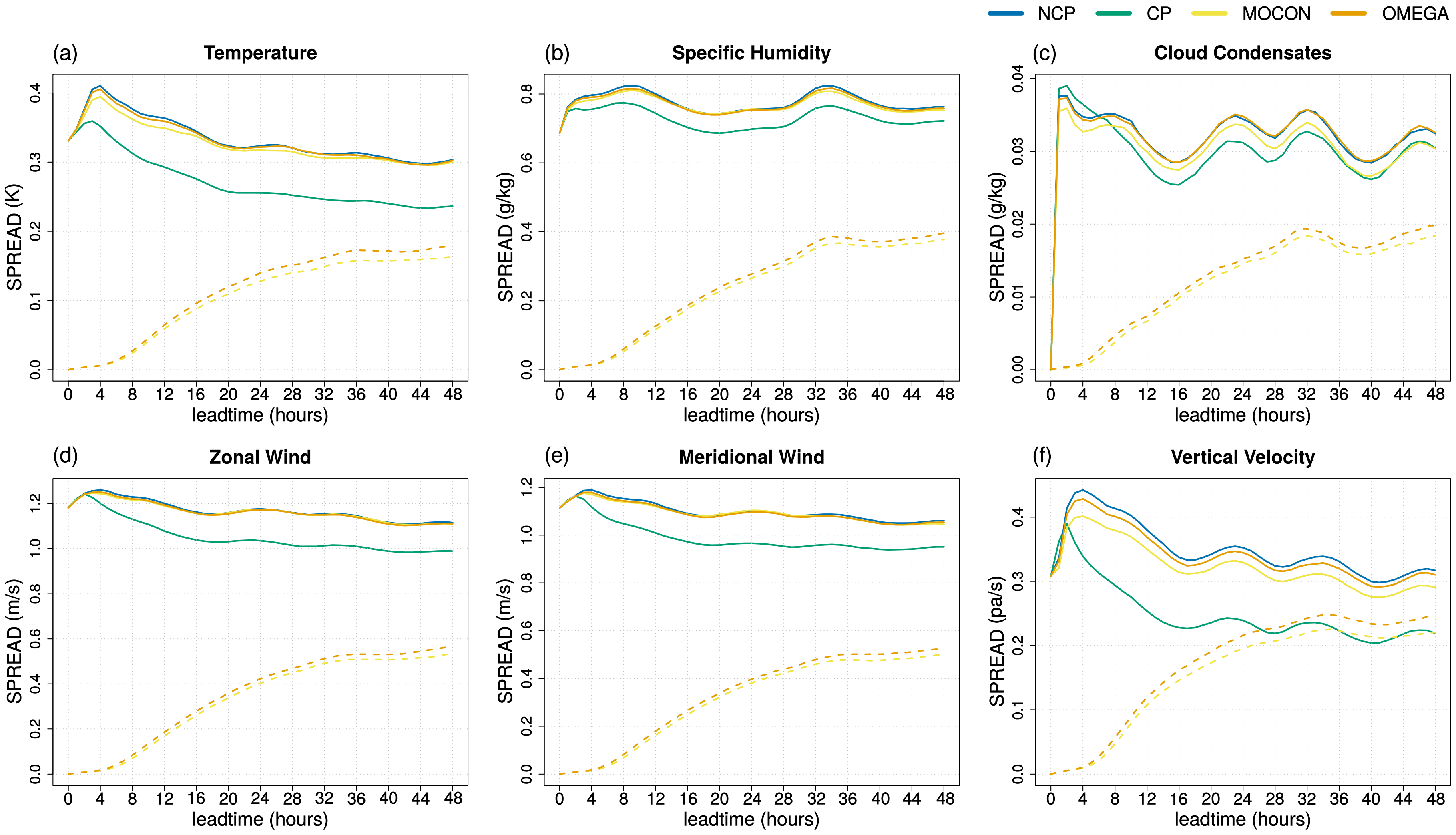
Spread



(250 hPa)

Results

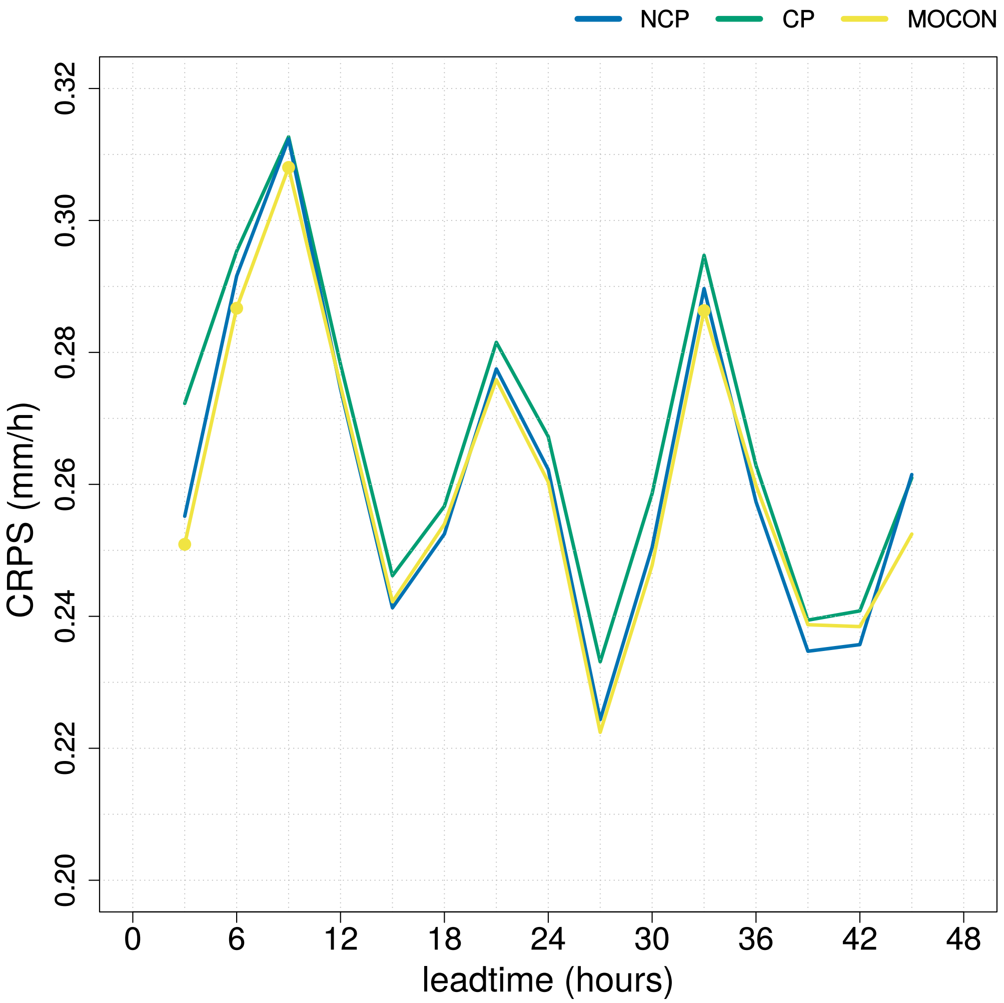
Spread



(850 hPa)

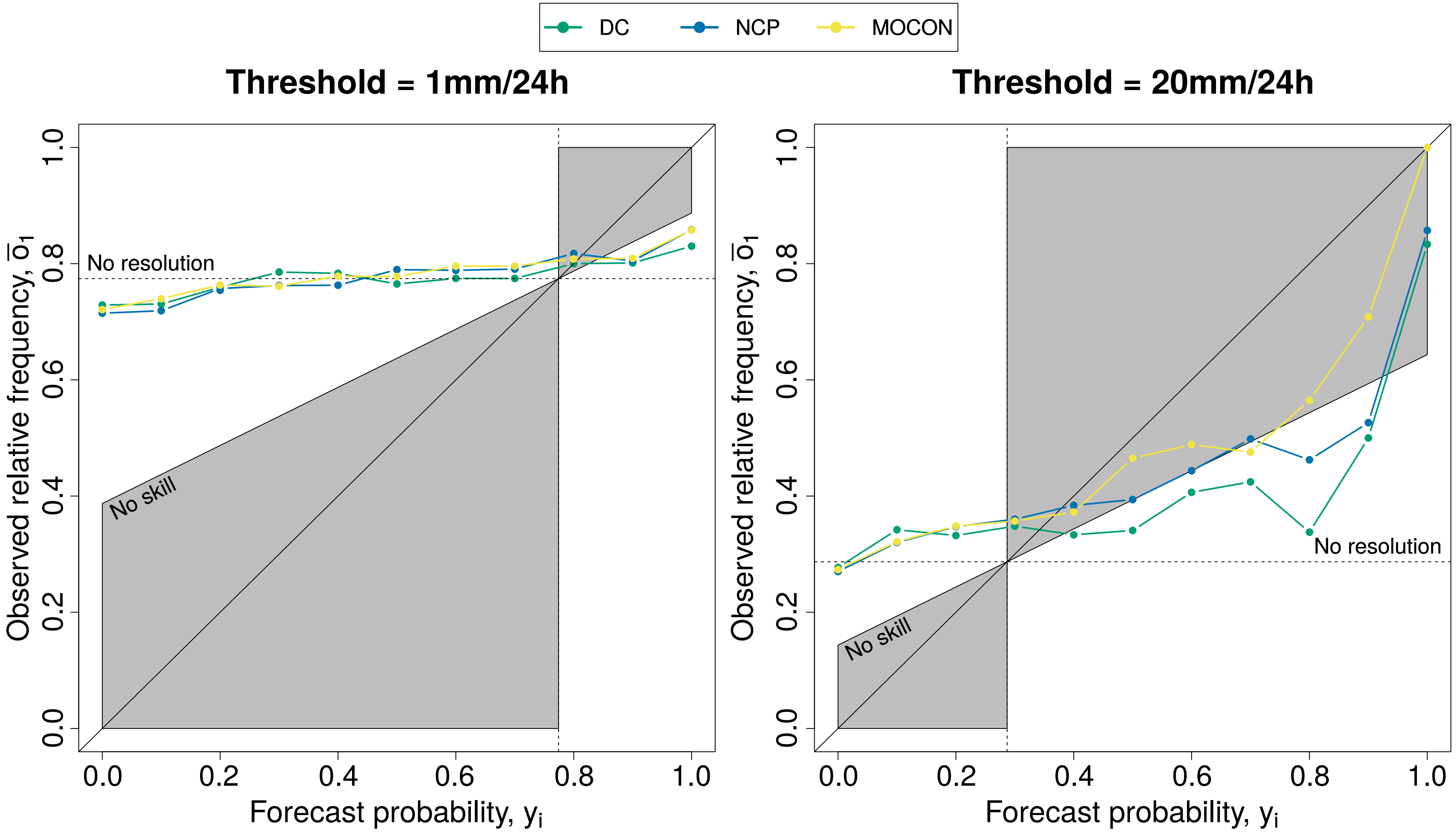
Results - Combination with IC and BC perturbations

Precipitation - CRPS w.r.t. TRMM (Satellite)



Results - Combination with IC and BC perturbations

Precipitation - Reliability



Conclusion

- New methodology for quantifying (lower bound on) model error
- Applied to deep convection (in tropics)
- Developed proto-type stochastic perturbation scheme
  - Takes into account PDF and vertical and multivariate correlations
  - Conserves total water, heat and momentum.
- largest positive impact in upper air
- small impact on precipitation

Outlook

- Find a way to quantify condensation-evaporation flux errors
- Take into account temporal autocorrelation
- Replace database by fitted distributions
- Test-case over Europe


Thank you
©Simon Schmitt - www.globalview.be