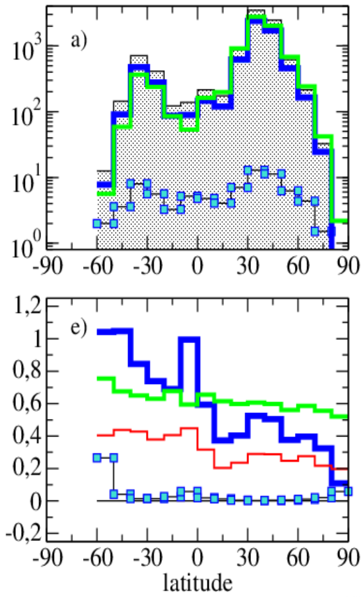
# *Cross-validating the impact of stochastic physics on ensemble covariances directly with observations*

Olaf Stiller and Christoph Schraff

Deutscher Wetterdienst

Using a new diagnostic tool:

**Aircraft u** *vs* **TEMP u**





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# Motivation

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

Ensembles ~~ forecast uncertainty

comprises uncertainty from
- initial conditions
- forecast model

Applications:

a) Probabilistic forecasting
   - ➢ ensemble variance (spread) ~~ forecast uncertainty

b) Covariances for data assimilation
   - ➢ ensemble covariance (short term forecast) ~~ background error covariance


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# Motivation

Parameter perturbations (e.g. physics parameters):

- ➢ improve ensemble spread
- ➢ improve ensemble covariances

Background-Error-Covariance → *distributes obs-info onto model space*

*AIM:* Compare ensemble covariances directly with observations:

Applications:

a) Probabilistic forecasting

➢ ensemble variance (spread) ~~ forecast uncertainty

b) Covariances for data assimilation

➢ ensemble covariance (short term forecast) ~~ background error covariance


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Parameter perturbations (e.g. physics parameters):

- improve ensemble spread
- improve ensemble covariances

Background-Error-Covariance → *distributes obs-info onto model space*

*AIM:* Compare ensemble covariances directly with observations:

observations: $y^o_\alpha$ and $y^o_v$

(obs – fg) : $\left(y^o_\alpha - y^b_\alpha\right), \left(y^o_v - y^b_v\right)$

*background error covariances in observation space:*

$$P^{b,loc}_{ens}[\alpha,v] = H_v \mathbf{B} \, (H_\alpha)^T$$
$$= P^b_{ens}[\alpha,v] * f_{loc}[\alpha,v]$$



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# Motivation

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$$\boxed{P_{ens}^{b,loc}[\alpha\,,v] = \left\langle \left(y_\alpha^o - y_\alpha^b\right)\left(y_v^o - y_v^b\right)\right\rangle}$$

$$\boldsymbol{H}\,\mathbf{B}\boldsymbol{H}^T + \boldsymbol{R} = \left\langle \left(\boldsymbol{y}^o - \boldsymbol{y}^b\right)\left(\boldsymbol{y}^o - \boldsymbol{y}^b\right)^{\boldsymbol{T}}\right\rangle$$

*AIM:* Compare ensemble covariances directly with observations:

$y_\alpha^o$ and $y_v^o$

(obs – fg) : $\left(y_\alpha^o - y_\alpha^b\right)$ , $\left(y_v^o - y_v^b\right)$

ensemble covariances in observation space:

$$P_{ens}^{b,loc}[\alpha,v] = H_v\mathbf{B}\,(H_\alpha)^T$$
$$= P_{ens}^b[\alpha,v] * f_{loc}[\alpha,v]$$


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# Motivation

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$$\boxed{P^{b,loc}_{ens}[\alpha, v] = \langle (y^o_\alpha - y^b_\alpha)(y^o_v - y^b_v) \rangle}$$

$$(H\,\mathbf{B}H^T)_{v\alpha} + \cancel{R_{v\alpha}} = \left\langle \left(\boldsymbol{y}^o - \boldsymbol{y}^b\right)\left(\boldsymbol{y}^o - \boldsymbol{y}^b\right)^{\boldsymbol{T}} \right\rangle_{v\alpha}$$

*AIM:* Compare ensemble covariances directly with observations:

$y^o_\alpha$ and $y^o_v$

(obs – fg) : $(y^o_\alpha - y^b_\alpha)$, $(y^o_v - y^b_v)$

ensemble covariances in observation space:

$$P^{b,loc}_{ens}[\alpha, v] = H_v\mathbf{B}\,(H_\alpha)^T$$
$$= P^b_{ens}[\alpha, v] * f_{loc}[\alpha, v]$$


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# Motivation



$$P_{ens}^{b,loc}[\alpha\,,v] = \left\langle \left(y_{\alpha}^{o} - y_{\alpha}^{b}\right) \left(y_{v}^{o} - y_{v}^{b}\right) \right\rangle$$

*from ensemble*

*from observations*

background error covariance



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# Straight forward test

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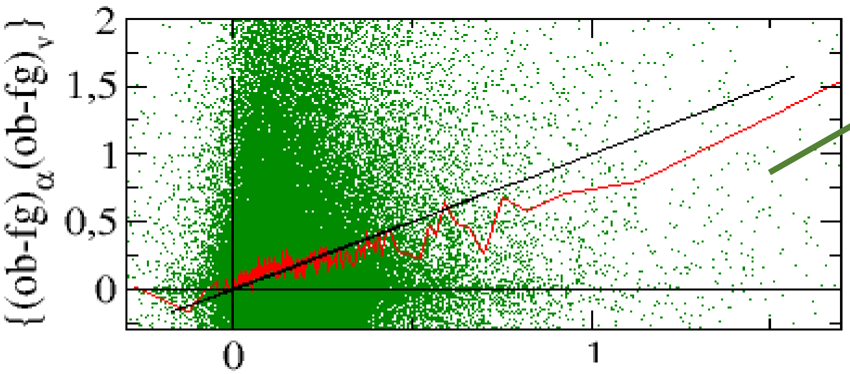
$$P_{ens}^{b,loc}[\alpha , v] = \langle (y_\alpha^o - y_\alpha^b)\,(y_v^o - y_v^b) \rangle$$

$y_\alpha^o$ : aircraft temperature

$y_v^o$ : radiosonde temperature




$P_{ens}^{b,loc}[\alpha , v]$

$$(y_\alpha^o - y_\alpha^b)(y_v^o - y_v^b)$$

Averaging (data per bin):

$N_{bin} = 500$



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# Straight forward test

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$$P_{ens}^{b,loc}[\alpha\,,v] = \left\langle \left(y_\alpha^o - y_\alpha^b\right)\left(y_v^o - y_v^b\right)\right\rangle$$

$y_\alpha^o$ : aircraft temperature

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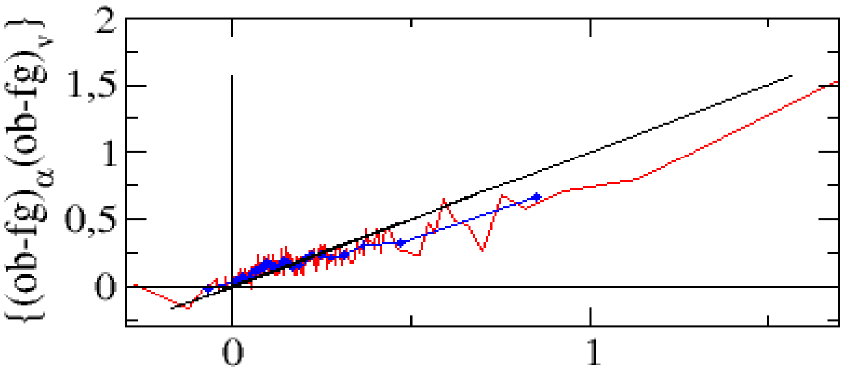


$P_{ens}^{b,loc}[\alpha\,,v]$

$$\left(y_\alpha^o - y_\alpha^b\right)\left(y_v^o - y_v^b\right)$$

Averaging (data per bin):

$N_{bin} = 500$

$N_{bin} = 5000$


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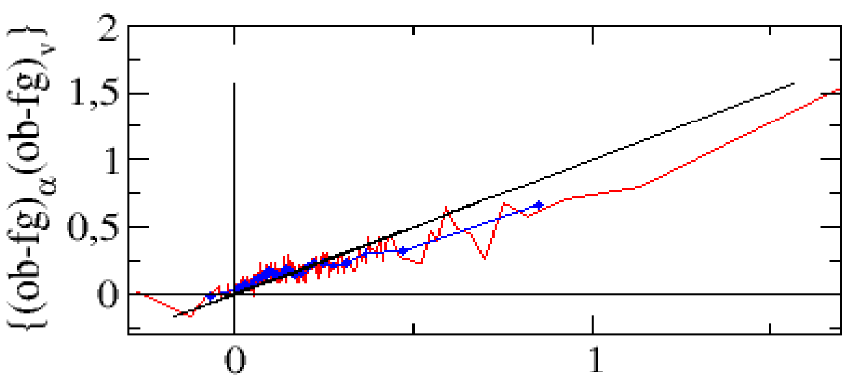
# Straight forward test



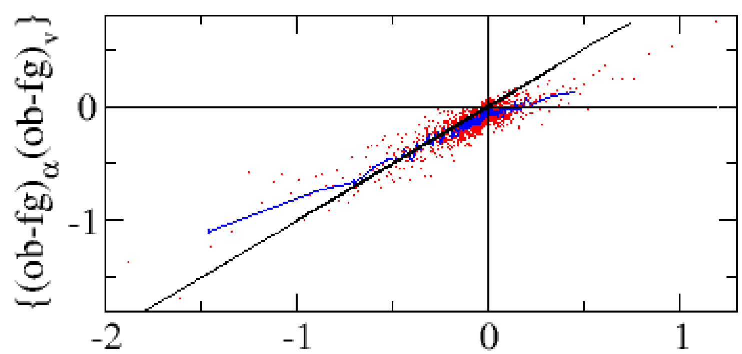
$$P_{ens}^{b,loc}[\alpha\,,v] = \langle (y_\alpha^o - y_\alpha^b)\,(y_v^o - y_v^b)\rangle$$

**aircraft *T*** *vs* **TEMP *T***




$P_{ens}^{b,loc}[\alpha\,,v]$

**aircraft *T*** *vs* **TEMP *RH***




$P_{ens}^{b,loc}[\alpha\,,v]$

# The cross-validation Diagnostic "$\mathcal{J}_\alpha^b$":

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$$\boxed{P_{ens}^{b,loc}[\alpha, v] = \left\langle \left(y_\alpha^o - y_\alpha^b\right)\left(y_v^o - y_v^b\right)\right\rangle}$$

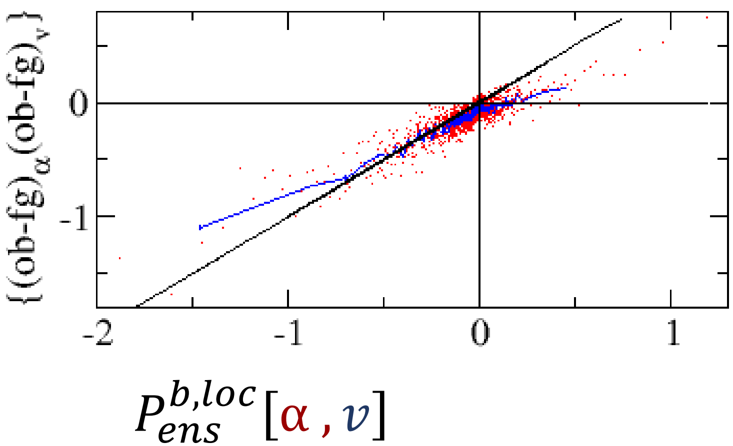
*Skill of ensemble "looks good"*

But what does that mean for DA?

The *new C-V diagnostics* "$\mathcal{J}_\alpha^b$" is:

- related to impact measure
  - (E)FSOI-type impact function
- more flexible
  - collect data in different kinds of bins

**aircraft *T*** *vs* **TEMP *RH***





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# *The cross-validation Diagnostic "$\mathcal{J}_\alpha^b$":*

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*(obs-fg) assimilation data* $\alpha$ : $\left(\boldsymbol{y}_\alpha^o - \boldsymbol{y}_\alpha^b\right)$

*good* *bad agreement*

*Verification data* $\boldsymbol{v}$ : $\boldsymbol{y}_v^o$ $\boldsymbol{y}_v^a \leftarrow \boldsymbol{y}_v^b \rightarrow \boldsymbol{y}_v^a$

(in this talk observations)

: *Model equivalent based on background*
(in observations space)

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# The cross-validation Diagnostic "$\mathcal{J}_\alpha^b$":



$$(y_\alpha^o - y_\alpha^b)$$

good   bad   agreement

$$y_v^o \qquad y_v^a \leftarrow y_v^b \rightarrow y_v^a$$

*Does the assimilation of* $(y_\alpha^o - y_\alpha^b)$

- *improve the fit to the verification data* $y_v^o$ *?*   FSOI
- *pull the model in the direction of the* $y_v^o$ *?*   *Cross-validation*

$$\boxed{\mathcal{J}_\alpha^b = \sum_{\alpha,v} s^{-1} P_{ens}^{a,loc}[\alpha,v]\,(y_\alpha^o - y_\alpha^b)(y_v^o - y_v^b) > 0}$$

# The cross-validation Tool

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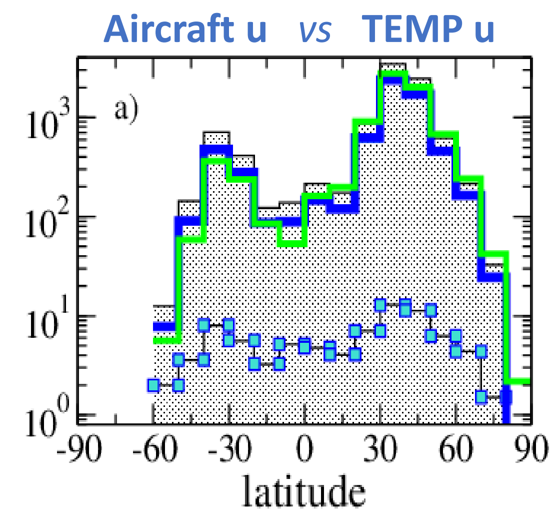
**blue curves** $\overset{?}{\sim}$ **green curves**

*from observations* — *from ensemble*

background error covariance




Consistency relation for model covariance:

$$P_{ens}^{b,loc}[\alpha, v] \overset{!}{=} \left\langle \left(y_\alpha^o - y_\alpha^b\right)\left(y_v^o - y_v^b\right)\right\rangle$$

$$\mathcal{J}_\alpha^b = \sum_{\alpha,v} s^{-1} P_{ens}^{a,loc}[\alpha,v] \left(y_\alpha^o - y_\alpha^b\right)\left(y_v^o - y_v^b\right) \overset{?}{>} 0$$

$$\left\langle \mathcal{J}_\alpha^b \right\rangle_{est} = \sum_{\alpha,v} s^{-1} P_{ens}^{a,loc}[\alpha,v] \qquad P_{ens}^{b,loc}[\alpha,v]$$

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# The cross-validation Tool

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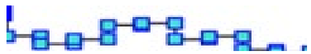
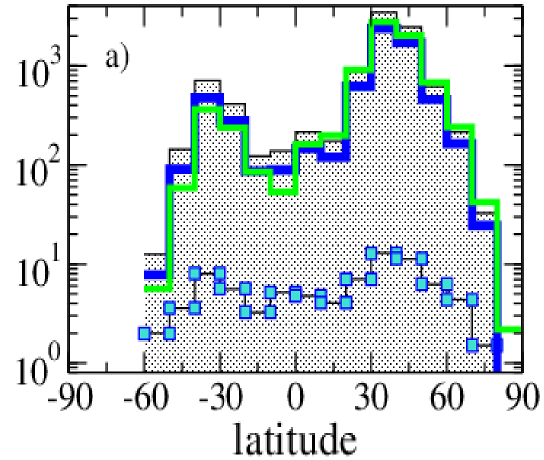
blue curves $\stackrel{?}{\sim}$ green curves

 : **Noise indicator** for blue curves

(Here: noise estimate for a sum $\sum_j A_j$ is $\sqrt{\sum_j A_j^2}$ )

Aircraft u *vs* TEMP u




Consistency relation for model covariance:

$$P^{b,loc}_{ens}[\alpha, v] \stackrel{!}{=} \langle (y^o_\alpha - y^b_\alpha)\,(y^o_v - y^b_v)\rangle$$

$$\mathcal{J}^b_\alpha = \sum_{\alpha,v} s^{-1} P^{a,loc}_{ens}[\alpha,v]\,(y^o_\alpha - y^b_\alpha)(y^o_v - y^b_v) \stackrel{?}{>} 0$$

$$\langle \mathcal{J}^b_\alpha \rangle_{est} = \sum_{\alpha,v} s^{-1} P^{a,loc}_{ens}[\alpha,v] \quad P^{b,loc}_{ens}[\alpha,v]$$

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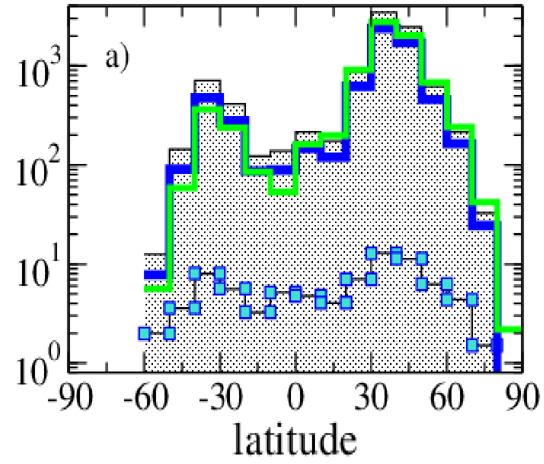
# The cross-validation Tool



## Single observation Experiments:

Aircraft u *vs* TEMP u




If only $y^o_\alpha$ is assimilated

$$P^{a,loc}_{ens}[\alpha,v] = P^{b,loc}_{ens}[\alpha,v]\,\frac{R'_{\alpha\alpha}}{P^{b,}_{\alpha\alpha} + R'_{\alpha\alpha}}$$

$$\boxed{\mathcal{J}^b_\alpha = \sum_{\alpha,v} s^{-1}\, P^{a,loc}_{ens}[\alpha,v]\,(y^o_\alpha - y^b_\alpha)(y^o_v - y^b_v)}$$

$$\boxed{\langle \mathcal{J}^b_\alpha \rangle_{est} = \sum_{\alpha,v} s^{-1}\, P^{a,loc}_{ens}[\alpha,v] \qquad P^{b,loc}_{ens}[\alpha,v]}$$

# The cross-validation Tool

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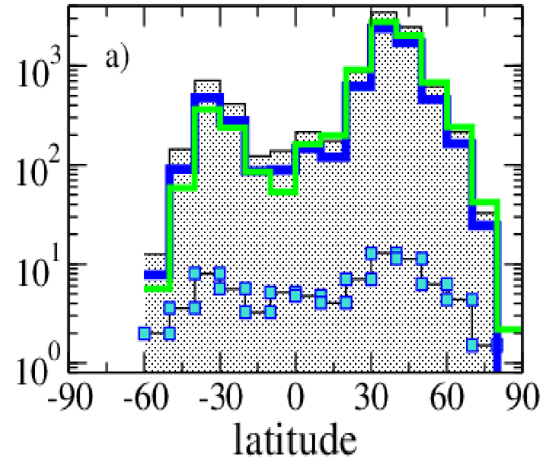
## Single observation Experiments:

If only $y^{o}_{\alpha}$ is assimilated

$$P^{a,loc}_{ens}[\alpha,v] = P^{b,loc}_{ens}[\alpha,v] \frac{R'_{\alpha\alpha}}{P^{b,}_{\alpha\alpha} + R'_{\alpha\alpha}}$$

Aircraft u vs TEMP u




$$\boxed{P^{b,loc}_{ens}[\alpha , v] \overset{!}{=} \langle (y^{o}_{\alpha} - y^{b}_{\alpha})\,(y^{o}_{v} - y^{b}_{v}) \rangle}$$

$$\boxed{\mathcal{J}^{b}_{\alpha} = \sum_{\alpha,v} ss^{-1} P^{b,loc}_{ens}[\alpha,v] (y^{o}_{\alpha} - y^{b}_{\alpha})(y^{o}_{v} - y^{b}_{v})}$$

$$\boxed{\langle \mathcal{J}^{b}_{\alpha} \rangle_{est} = \sum_{\alpha,v} ss^{-1} P^{b,loc}_{ens}[\alpha,v] \quad P^{b,loc}_{ens}[\alpha,v]}$$

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# The cross-validation Tool

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## Scaling/Normalizing graphs:

*Devide all curves by*
*the same (bin-dependent) function*

Choice may depend on

- type of data and bins
- purpose of statistics

For cross-validating observations:

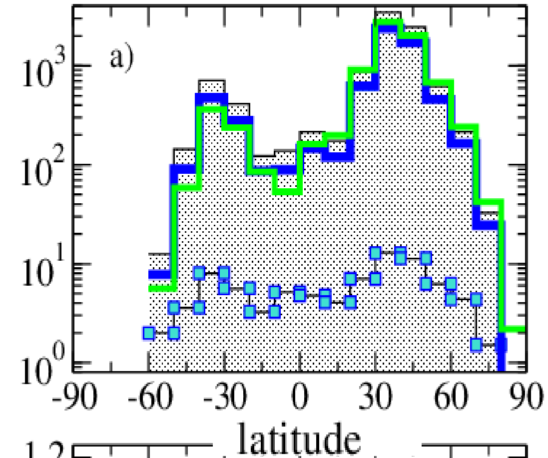
**blue curves** $\overset{?}{\sim}$ **green curves**

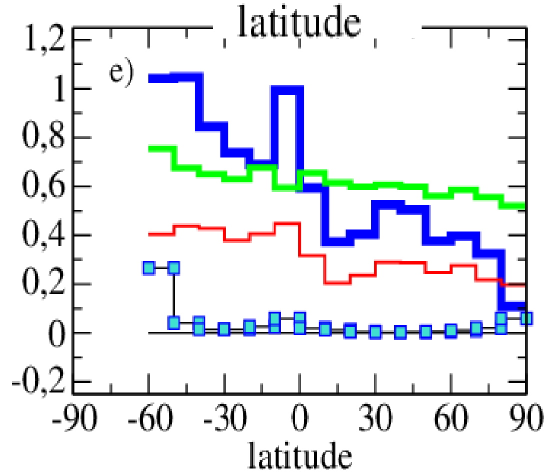
**green curves ~ [0, 1]**

Below for cross-validating covariances

- Scaling with number of observations

Aircraft u *vs* TEMP u

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# The cross-validation strategy for testing observations

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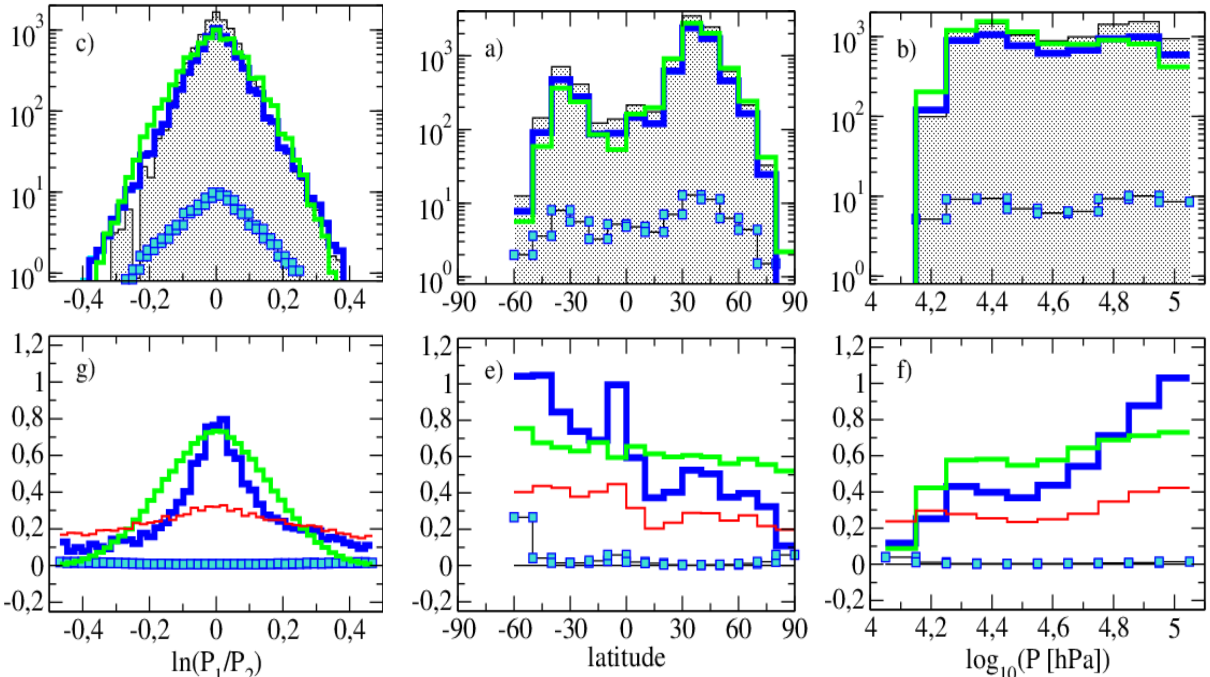


**Vertical Distance**
in log pressure levels

**latitude**

**Vertical height**
in log pressure

**And many others ….**

Collect statistics for many different types of bins and observations

……………………………………………

Paper is under review

*Please ask if interested!!*



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# Example: Testing AMVs

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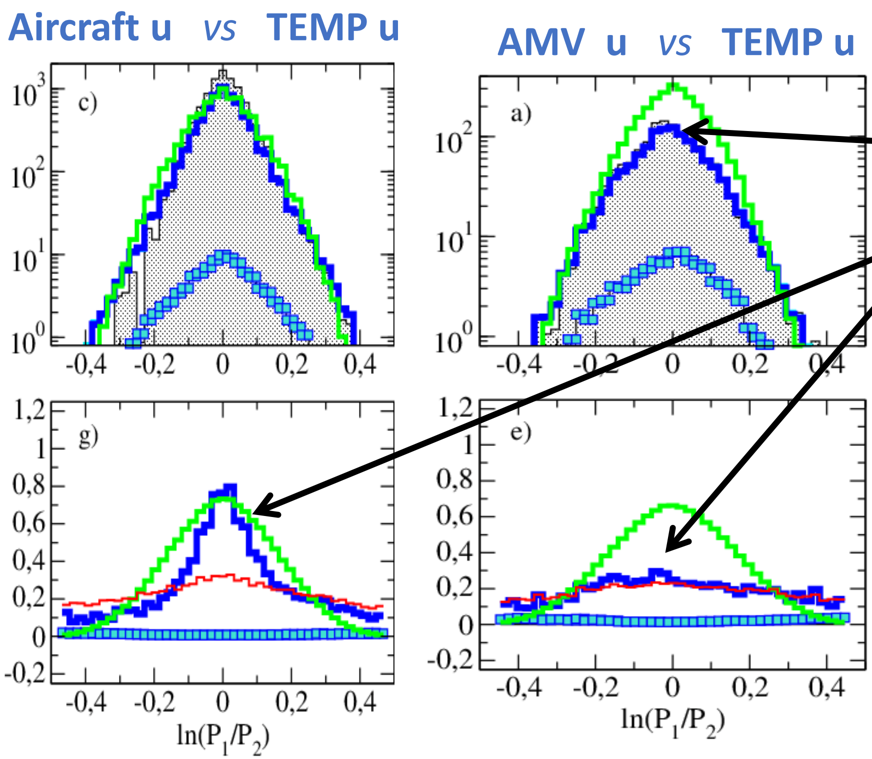


Two well established insitu observations

AMVs (Atmospheric Motion Vectors)

- are clearly "beneficial" ( $J_{\alpha}^{b}$ > 0)
- but significantly less optimal than

  Aircraft or TEMP wind

  - Less skill at small separation distances
  - (consistent with reported "height assignment problems")

Cross-validation diagnostic useful for testing/tuning height assignment methods



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# Example: AMSU A channel 7
# vs aircraft and TEMP

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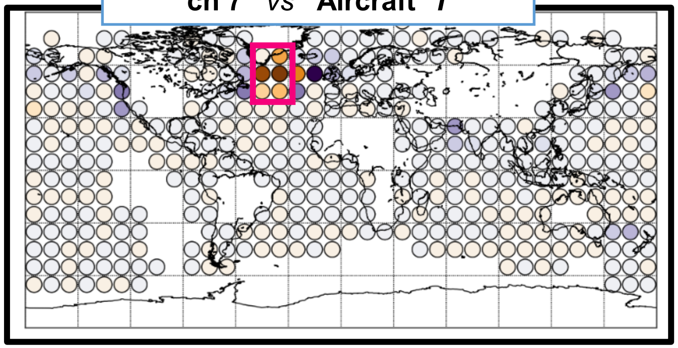
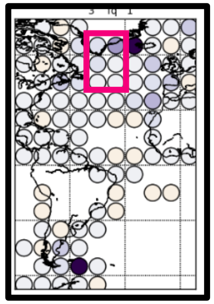
**Contributions to blue curves**

**June 2020**
**ch 7** *vs* **Aircraft *T***



*vs* **TEMP *T***

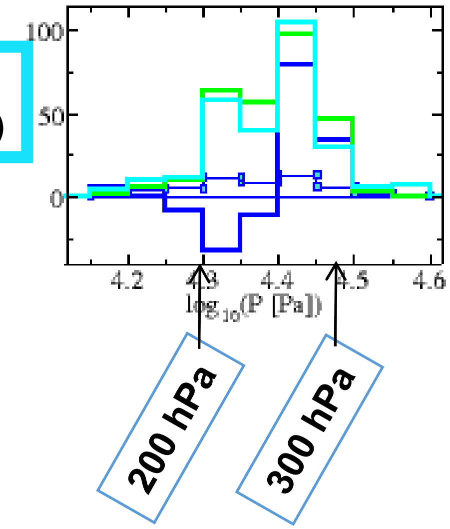


**(cyan curves)**

as blue - but w/o bias
(subtracted in each bin)

*It's a bias problem!*

**Aircraft *T*** *vs* **TEMP *T***




Conflicting results by cross-validating AMSU A channels helped identify region over the N Atlantic where

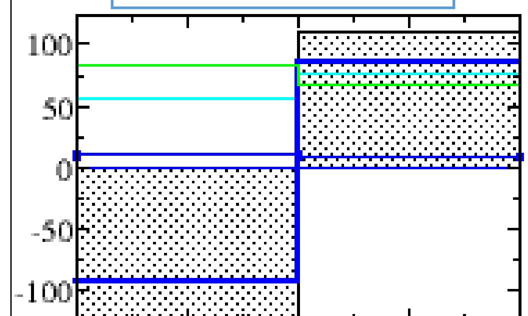
aircraft ***T*** inconsistent with TEMP ***T***

This could be traced back to
aircraft with codetype 141 ("AIREP data")
which had not been bias corrected at DWD

<u>After confirmation with denial experiments</u>

Oct 2021: assimilation of AIREP data stopped at DWD

**Aircraft *T*** *vs* **TEMP *T***




**AIREP** **AMDAR**

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# Cross-validating impact of Param. Pert. on Covariances

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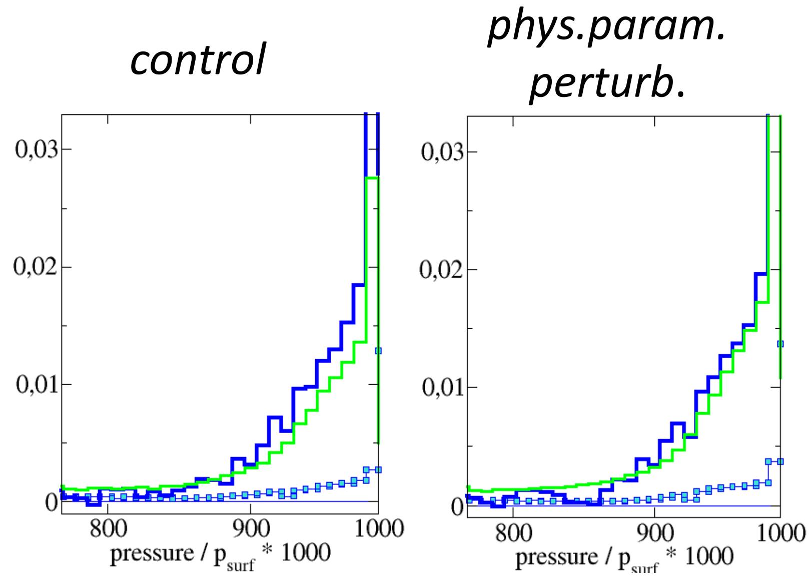
$$P_{ens}^{b,loc}[\alpha\,,v] = \langle (y_\alpha^o - y_\alpha^b)(y_v^o - y_v^b) \rangle$$

- Use trusted observations $y_\alpha^o$ and $y_v^o$ to test $P_{ens}^{b,loc}[\alpha\,,v]$
- Compare results for perturbed run with control (no perturbations)

radiosonde:
2m ***T***
*vs*
upper air ***T***




scaling: nb of obs in bin

no vertical localisation



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# Cross-validating impact of Param. Pert. on Covariances

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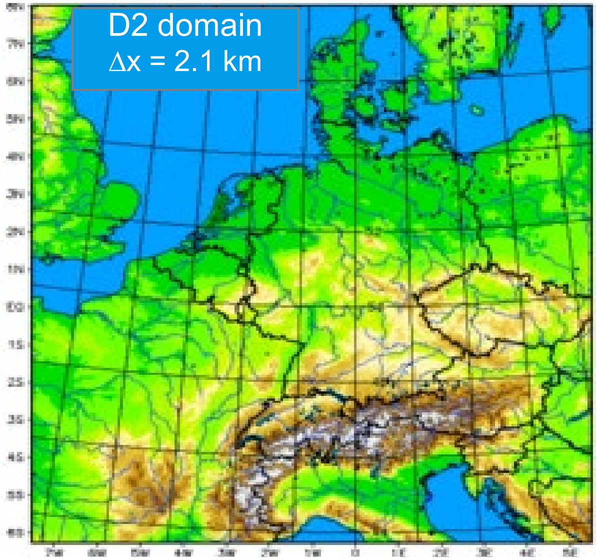
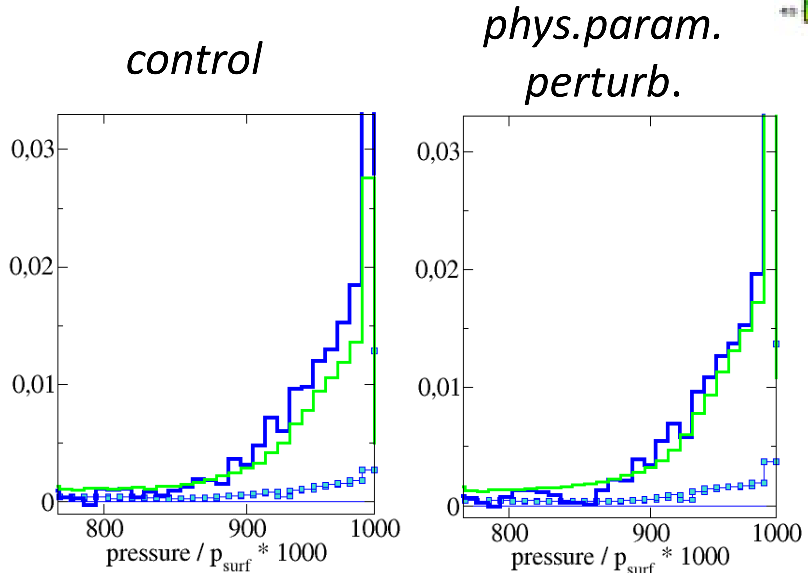
Wetter und Klima aus einer Hand

- Model: *ICON D2*
- Data assimilation: *KENDA* 40 member ensemble
  - LETKF + latent heat nudging
- Investigating:
  - Parameter Perturbations in DA cycle




radiosonde:
2m *T*
*vs*
upper air *T*




scaling: nb of obs in bin

no vertical localisation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# Cross-validating impact of Param. Pert. on Covariances



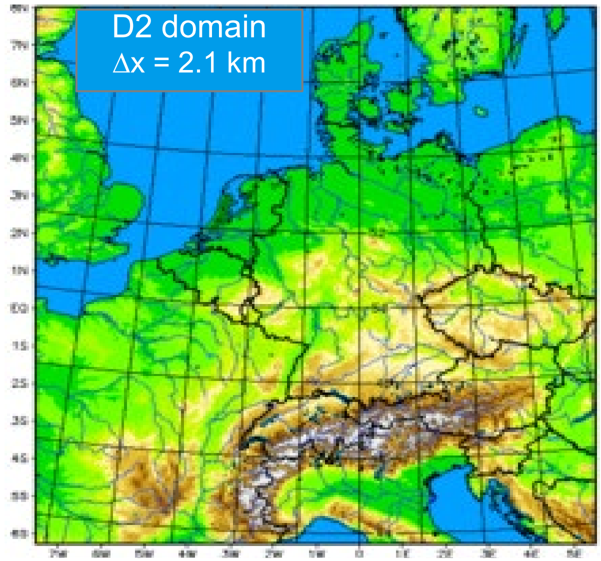
- Parameter Perturbations

  i. 17 physics parameters (as in fc ensemble)

  … designed to enhance spread mostly near surface where underdispersiveness is most severe

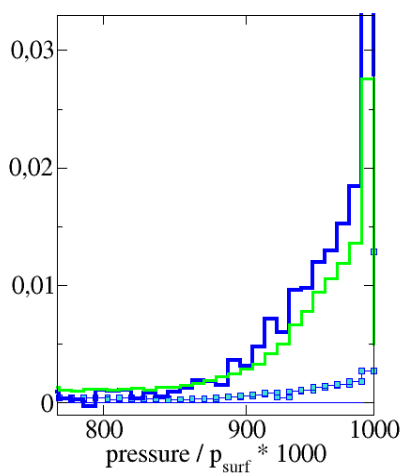
  ii. latent heat nudging parameters

sinusoidal variation in time with period of ~ 12 – 16 days, period / phase depends on member / parameter

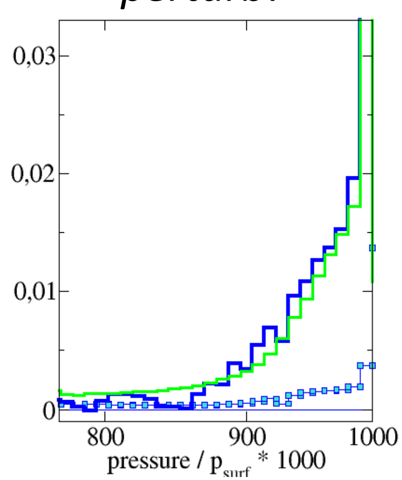



radiosonde:
2m ***T***
*vs*
upper air ***T***

*control*




*phys.param. perturb.*




scaling: nb of obs in bin

no vertical localization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# Cross-validating impact of Param. Pert. on Covariances

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

- Parameter Perturbations
  i. 17 physics parameters (as in fc ensemble)
  … designed to enhance spread mostly near surface where underdispersiveness is most severe
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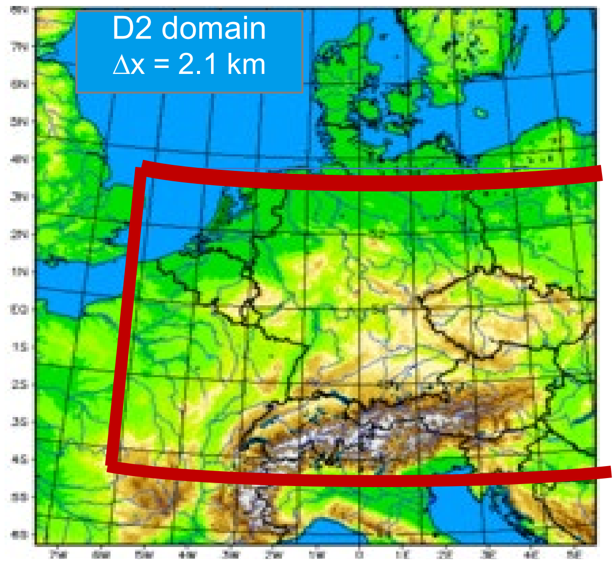
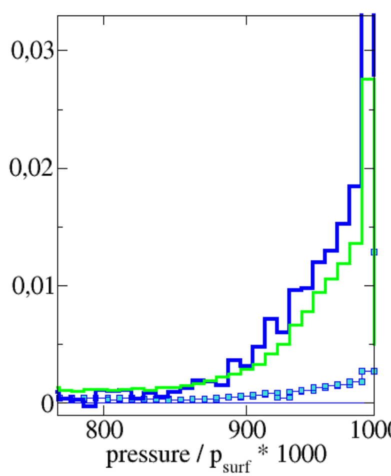



June 2021

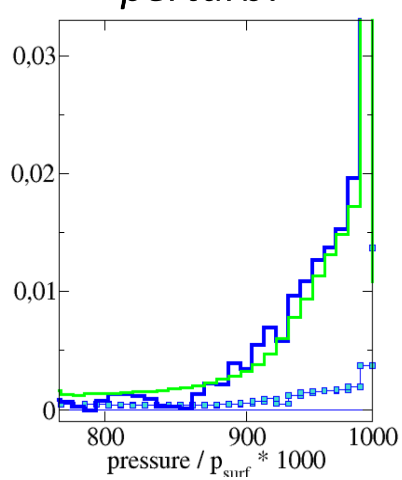
weeks 1+2
*weakly forced convection*

weeks 3+4
*forced convection*

*control*




*phys.param. perturb.*




scaling: nb of obs in bin

no vertical localization

only radiosonde data over land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# radiosonde:
# 2m *T* *vs* upper air *T*

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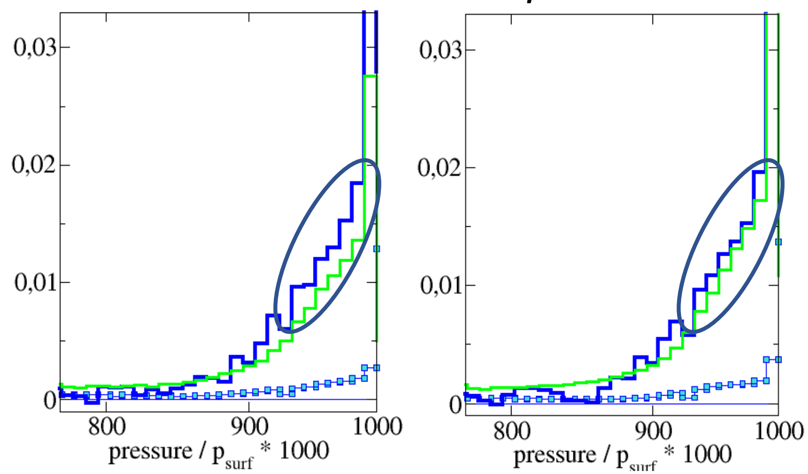
June 2021

*control* | *phys.param. perturb.*




In the perturbed run:

green curve higher

blue *vs* green curves better agreement

Parameter perturbations seem to slightly improve realism of covariance between 2m *T* *and* upper air *T*

**green curves ~ blue curves**

*from ensemble* | *from observations*

background error covariance

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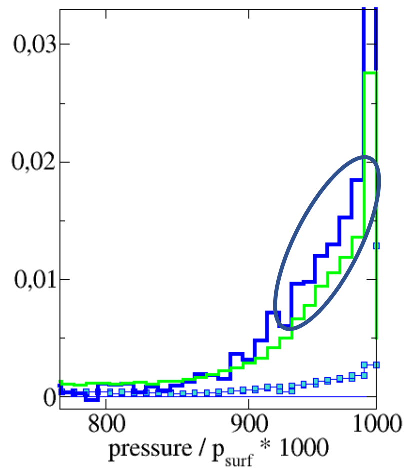
# radiosonde:
## 2m *T* *vs* upper air *T*

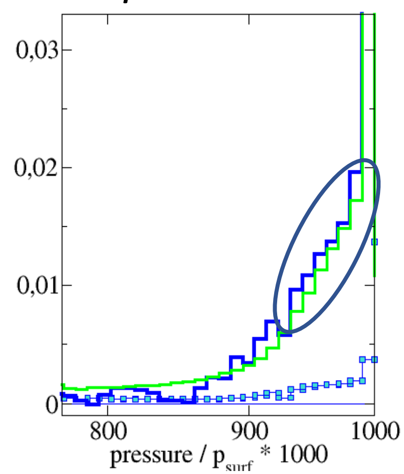
Deutscher Wetterdienst
Wetter und Klima aus einer Hand

June 2021

*control*




*phys.param. perturb.*



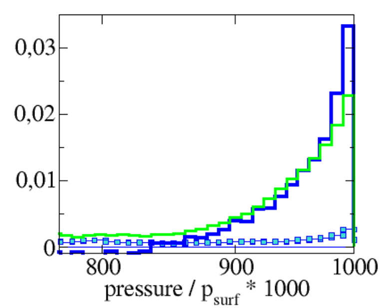

<u>In the perturbed run:</u>

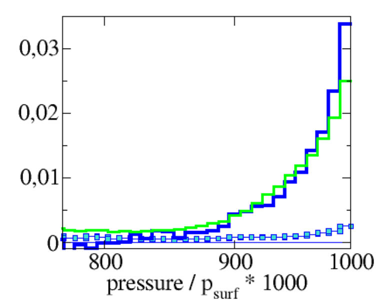
green curve higher

blue *vs* green curves better agreement

Parameter perturbations seem to slightly improve realism of covariance between 2m *T* *and* upper air *T*

2m ***RH***
*vs*
upper air ***RH***




very small differences but in the right direction

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# radiosonde:
## surface *p* vs upper air *T*

Deutscher Wetterdienst
*Wetter und Klima aus einer Hand*

June 2021,
weeks 1+2

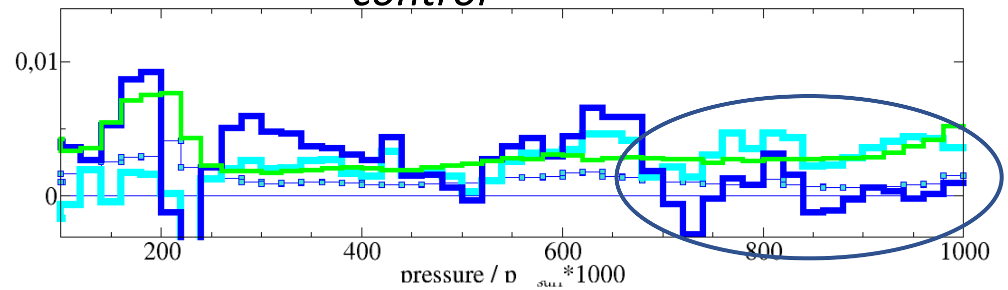
*weakly forced convection*

**cyan curve** : $p_{surf}$ bias subtracted

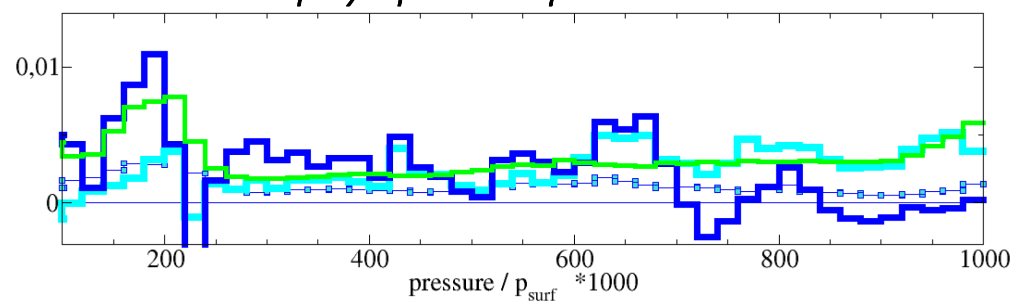
for p > 700 h Pa :
$p_{surf}$ & upper air ***T*** agree well
***only if*** $p_{surf}$ bias is subtracted

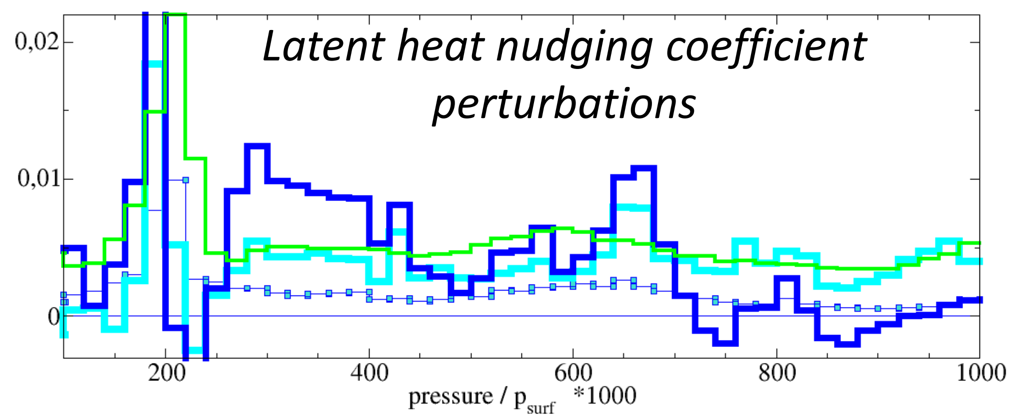
<u>LHN perturbations</u>
green curve:
ensemble covariances larger

*control*




*phys.param. perturb.*



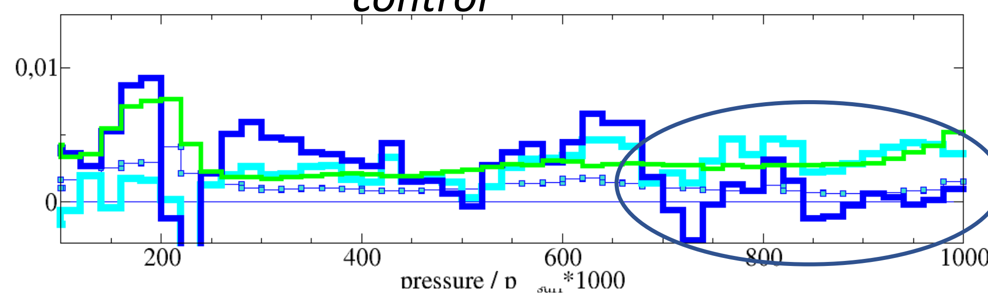
# radiosonde:
## surface *p* vs upper air *T*

Deutscher Wetterdienst
*Wetter und Klima aus einer Hand*

June 2021,
weeks 1+2

*weakly forced convection*

*control*

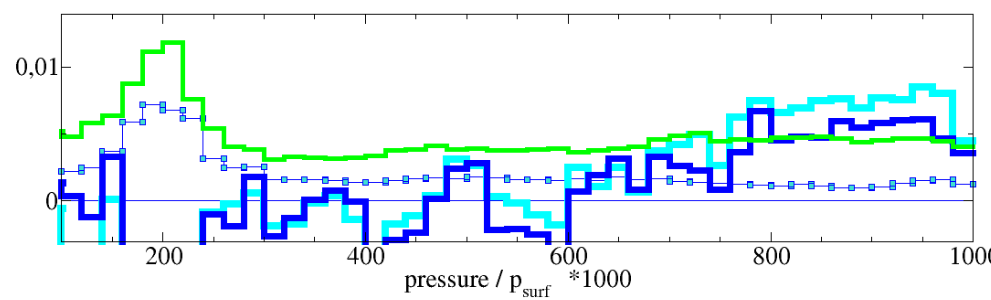



weeks 3+4

*forced convection*

correction of $p_{surf}$ bias
not essential for impact

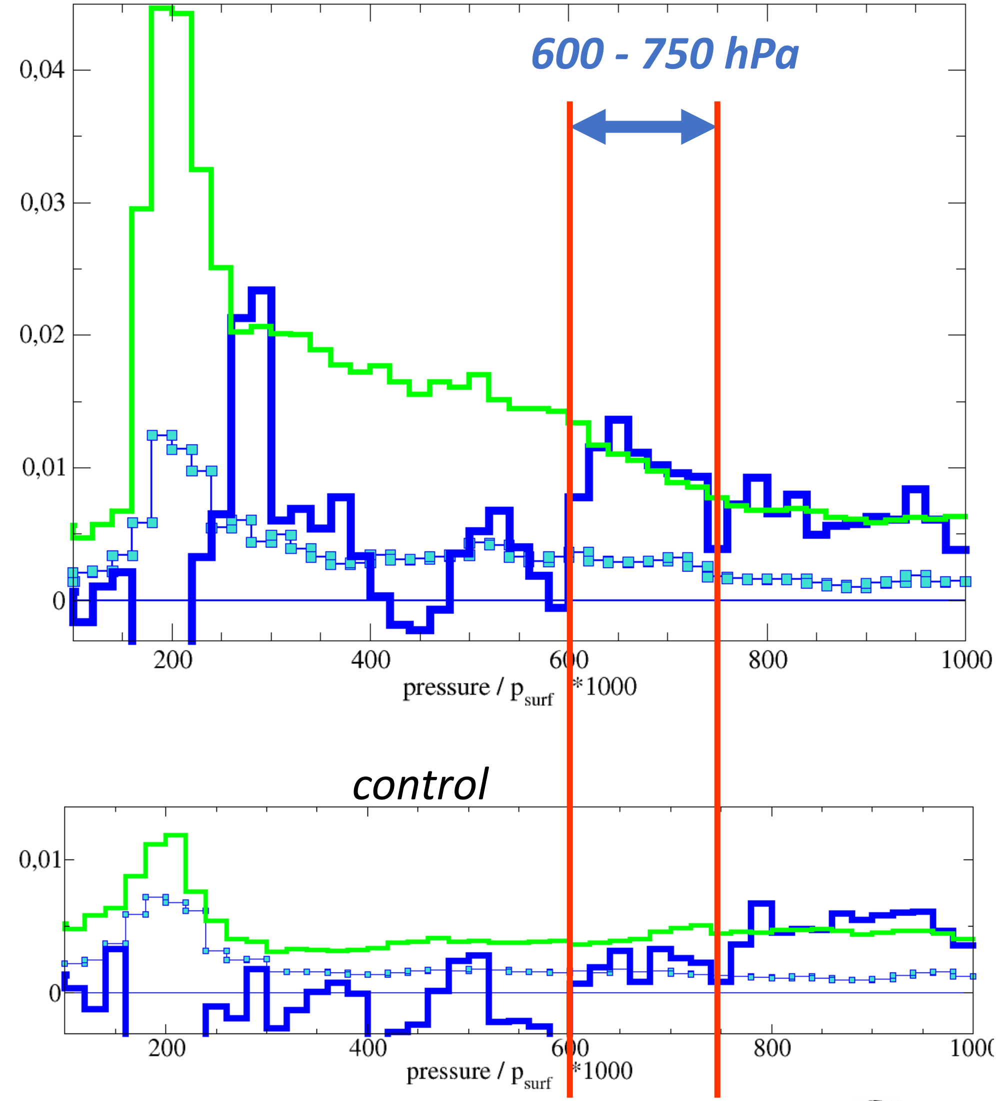
*control*



# radiosonde:
## surface ***p*** *vs* upper air ***T***

Deutscher Wetterdienst
*Wetter und Klima aus einer Hand*

*Experiment with perturbation of latent heat nudging coeffs*




June 2021
weeks 3+4

*forced convection*

correction of $p_{surf}$ bias not essential for impact

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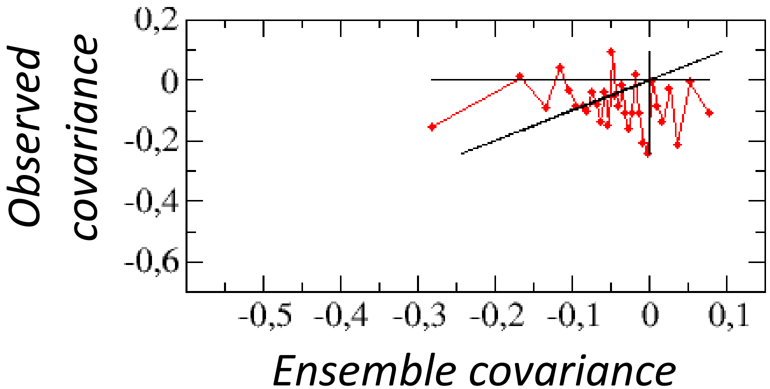
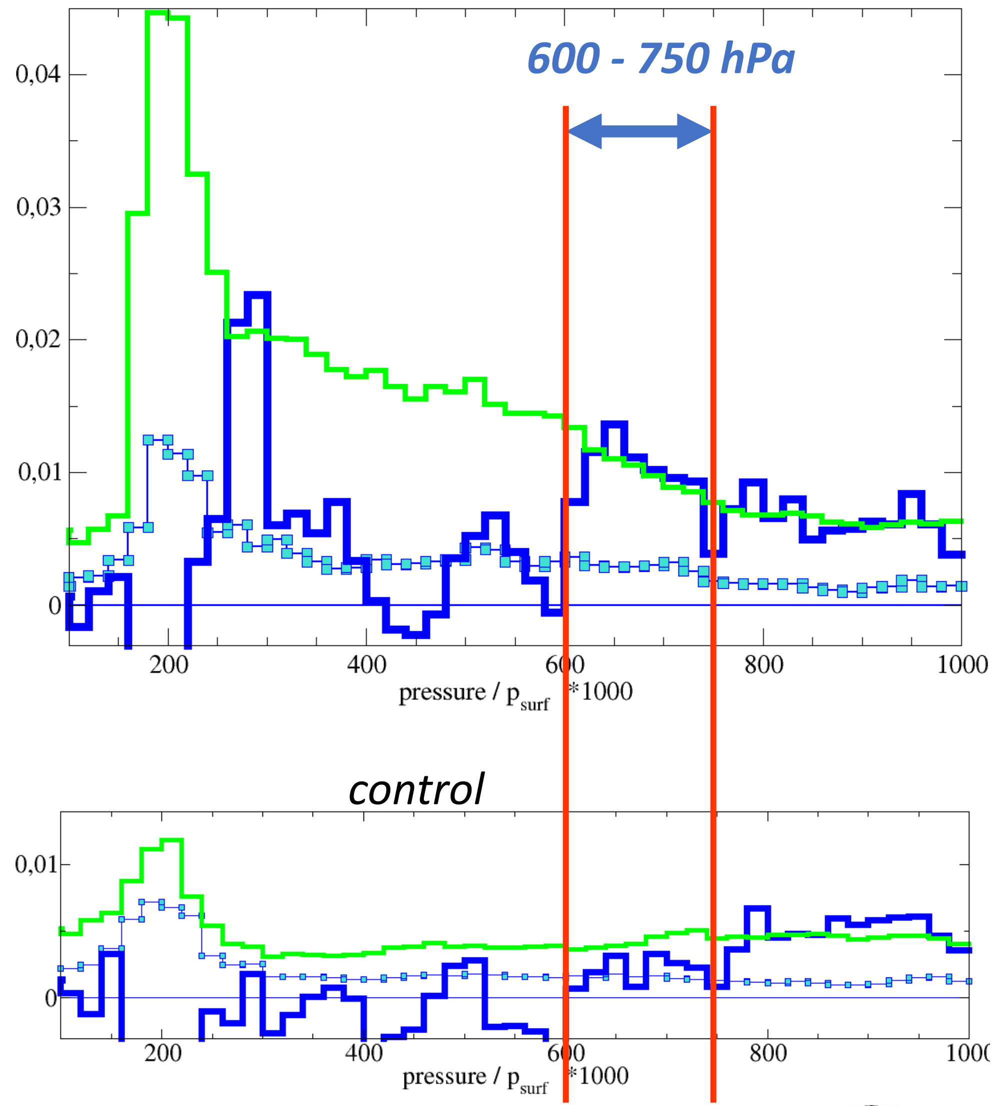
# radiosonde:
## surface *p* vs upper air *T*

### *(600 - 750 hPa)*

***control***

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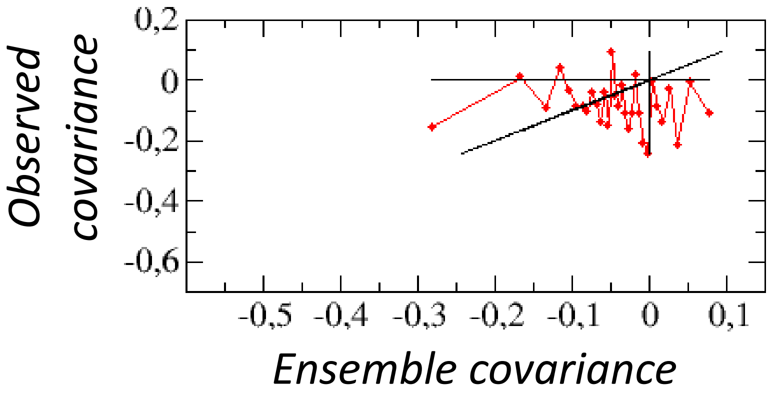
radiosonde:

surface ***p*** *vs* upper air ***T***

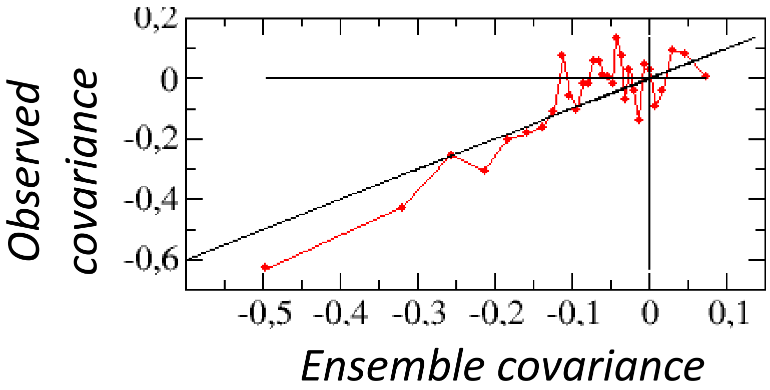


***(600 - 750 hPa)***

**control**




**perturbed**

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radiosonde:

## surface ***p*** *vs* upper air ***T***

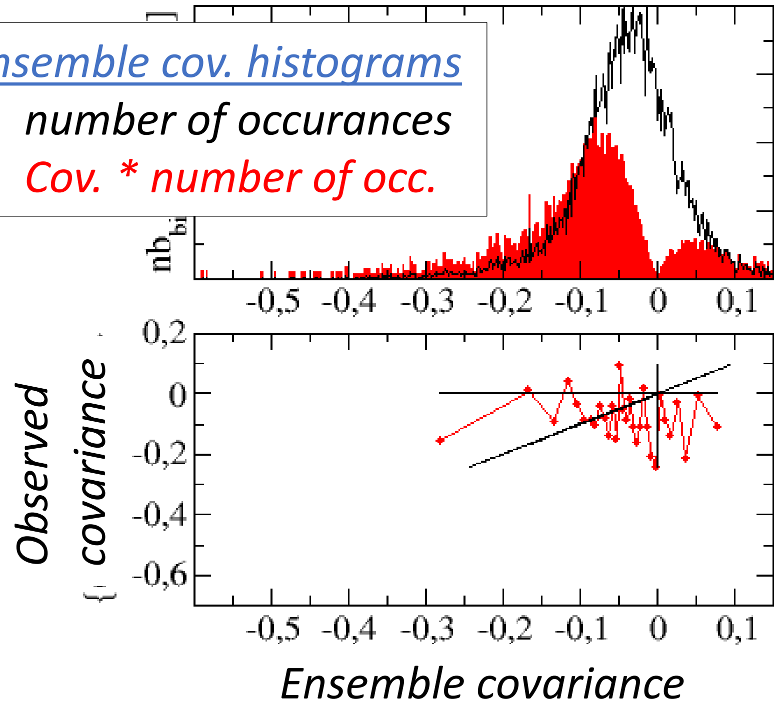


## *(600 - 750 hPa)*

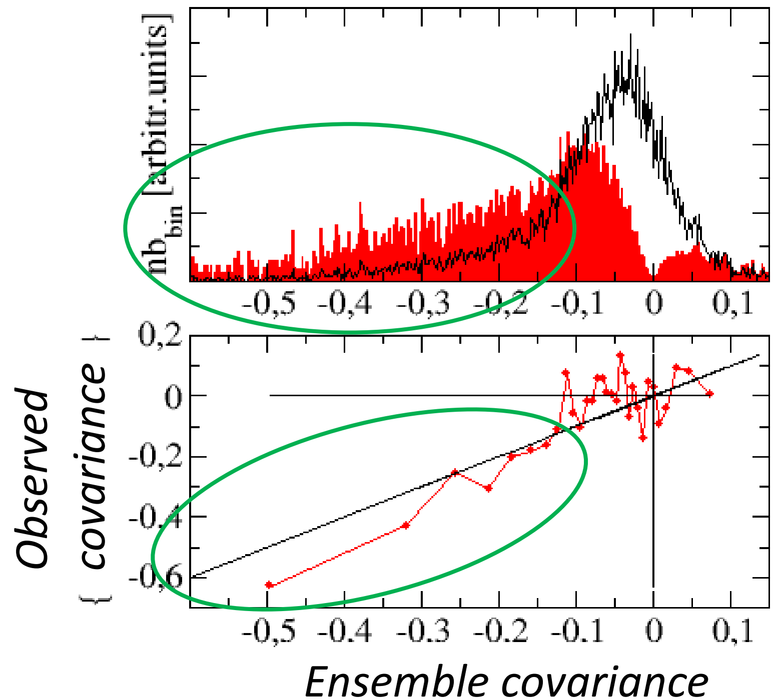
***control***

*Ensemble cov. histograms*

- *number of occurances*
- *Cov. * number of occ.*




***perturbed***




Parameter perturbation induces strong & realistic covariances.

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# Summary and conclusions



- Parameter perturbations modify ensemble (co-)variances
- Independent observations (with uncorrelated errors) allow testing
  - these covariances
  - the impact related to these covariances
- To evaluate these covariances we used
  i. a straightforward evaluation of

$$\boxed{P^{b,loc}_{ens}[\alpha\,,v] = \langle (y^o_\alpha - y^b_\alpha)\,(y^o_v - y^b_v) \rangle}$$

*from ensemble* *from observation*

background error covariance

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# Summary and conclusions

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

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  - these covariances
  - the impact related to these covariances
- To evaluate these covariances we used
  1. a straightforward evaluation of

$$\boxed{P_{ens}^{b,loc}[\alpha\,,v] = \left\langle \left(y_{\alpha}^{o} - y_{\alpha}^{b}\right)\left(y_{v}^{o} - y_{v}^{b}\right)\right\rangle}$$

  2. a new diagnostic tool with
     - diagnostics related to an impact measure (FSOI type)
     - allows search in different kinds of bins
     - indicates changes to ensemble covariance ("**green curves**")
     - and whether the observations agree with this ("**blue curves**")
- Examples show: Parameter perturbations can improve
  *different aspects of covariances and their impact*

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# Thank you for listening

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