Newly developed impact diagnostics for cross-validating satellite radiances with conventional observations

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

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1. Introduction:

The established impact diagnostic originally introduced by Langland and Baker (2004) have been further partitioned into **two components** related to different aspects of the observations and their use in the data assimilation (DA) system. Following largely Kalnay et al (2012), these components can be computed from the *model error covariances in observation space* which we estimate using the ensemble of our LETKF. This poster focuses on the **first component** (displayed below by the blue curves) which can be regarded as a **cross-validation diagnostic**, indicating the consistency between first guess departures (o-fg) of an observation type and those of the verifying data. Here we use observations for verification and restrict to the case of forecast time t=0 (impact on the analysis) which allows us to focus on issues related to the DA- rather then the forecast-system.

2a. Partitioning EFSOI type statistics in 2 components

using obs -- not using obs

a) Forecast Sensitivity to Observation Impact (FSOI) diagnostics are computed from a verification function J which reflects the impact of assimilated observations y^o_α on the fit to some verifying data y^v_v.
b) For this J is written as a sum over contributions J_α which are linked to the individual observations y^o_α.
c) In this work the terms J_α are further partitioned into 2 components.

a) $J = \frac{1}{2}\left(|y^v - y^{v|a}|^2_C - |y^v - y^{v|b}|^2_C \right)$

b) $J = -\sum_{\alpha \in Obs} J_\alpha$

c) $J_\alpha = 2 J^{t|b}_\alpha - J^{t|a}_\alpha$

Verifying against observations and using the diagonal R-matrix (elements : R_{vv} and $R_{\alpha\alpha}$) as metric, these components can be written in the form:

i. **(blue curves)** $J^{t|b}_\alpha = \sum_v \widehat{P}^a_{en[v,\alpha]}(t) \frac{(y^v_v - y_v^{v|b})(y^o_\alpha - y^b_\alpha)}{R_{vv} R_{\alpha\alpha}}$

ii. **(red curves)** $J^{t|a}_\alpha = \sum_v \widehat{P}^a_{en[v,\alpha]}(t) \frac{(y_v^{v|a} - y_v^{v|b})(y^o_\alpha - y^b_\alpha)}{R_{vv} R_{\alpha\alpha}}$

$(y^o_\alpha - y^b_\alpha)$	(obs – fg) of analysis obs α
$(y^v_v - y_v^{v|b})$	(obs – fc[fg]) of verifying obs v
$(y_v^{v|a} - y_v^{v|b})$	(fc[a] – fc[fg]) of verifying obs v
$\widehat{P}^a_{en[v,\alpha]}$	analysis error covariance matrix in obs space between: analysis obs α & verifying obs v

2b. Interpretation of $J^{t|b}_\alpha$ and $J^{t|a}_\alpha$

i. Consider $J^{t|b} = \sum_v \frac{(y^v_v - y_v^{v|a})(y^v_v - y_v^{v|b})}{R_{vv}}$ which can be written as the sum $J^{t|b} = \sum_{\alpha \in Obs} J^{t|b}_\alpha$

Note that $\langle J^{t|b} \rangle > 0$ has to hold if analysis pulls model towards verifying data

$\langle J^{t|b}_\alpha \rangle > 0$ **Q** : Are $(y^o_\alpha - y^b_\alpha)$ $(y^v_v - y_v^{v|b})$ and $\widehat{P}^a_{en[v,\alpha]}$ consistent?

ii. One can show that ***if either***

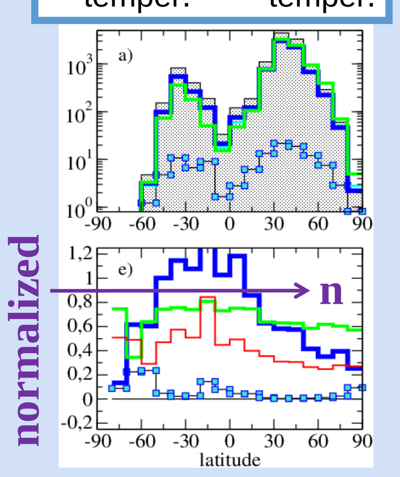
- analysis increments $(y_v^{v|a} - y_v^{v|b})$ are optimal w.r.t. the verification function J
- ***or*** covariaces used in Kalman gain matrix are all correct

then $\langle J^{t|a}_\alpha \rangle \approx \langle J^{t|b}_\alpha \rangle$ **Q** : Do the ana increments contain obs info "optimally"?

2c. Reference curves and normalisation

(green curves) $\langle J^{t|b}_\alpha \rangle_{estim} = \sum_v \widehat{P}^a_{en[v,\alpha]}(t) \frac{\widehat{P}^b_{en[v,\alpha]}}{R_{vv} R_{\alpha\alpha}}$

AIREP vs TEMP temper. temper.



: **Noise indicator** for blue curves
(Here: noise estimate for a sum $\sum_j A_j$ is $\sqrt{\sum_j A_j^2}$)

(bound of shaded areas**)** $J_\alpha = 2 J^{t|b}_\alpha - J^{t|a}_\alpha$ (~ „- total EFSOI")

If $\widehat{P}^b_{en[v,\alpha]}$ (ensemble background covariance in obs space) was the **correct** background error covariances, **then**:

$\langle (y^v_v - y_v^{v|b})(y^o_\alpha - y^b_\alpha) \rangle = \widehat{P}^b_{[v,\alpha]}$ so that **blue curves = green curves**

Normalization:

Orig.Idea: normalize with $\langle J^{t|b}_\alpha \rangle_{estim}$ directly (i.e., devide by green curve – theoretical reference).

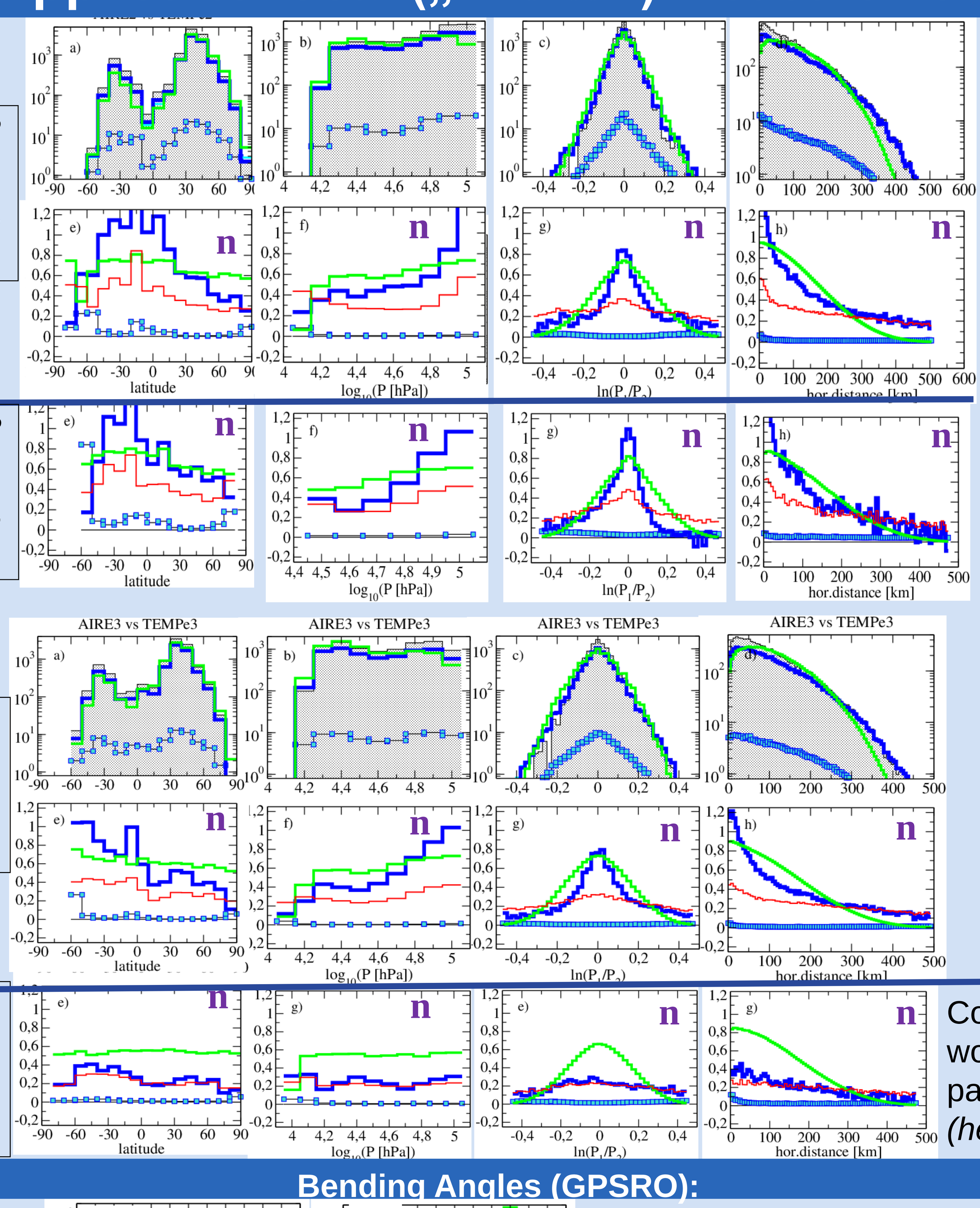
Problem: $\widehat{P}^b_{en[v,\alpha]}$ computed from ensemble+localization function η_{loc}

$\widehat{P}^b_{en[v,\alpha]}$ = *model spread* * η_{loc} ➡ large noise where η_{loc} is small

Chosen method

n : normalized graphs all curves devided by $\langle J^{t|b}_\alpha \rangle_{estim} / \eta_{loc}$

3. Applied to local („in situ") measurements (t=0)



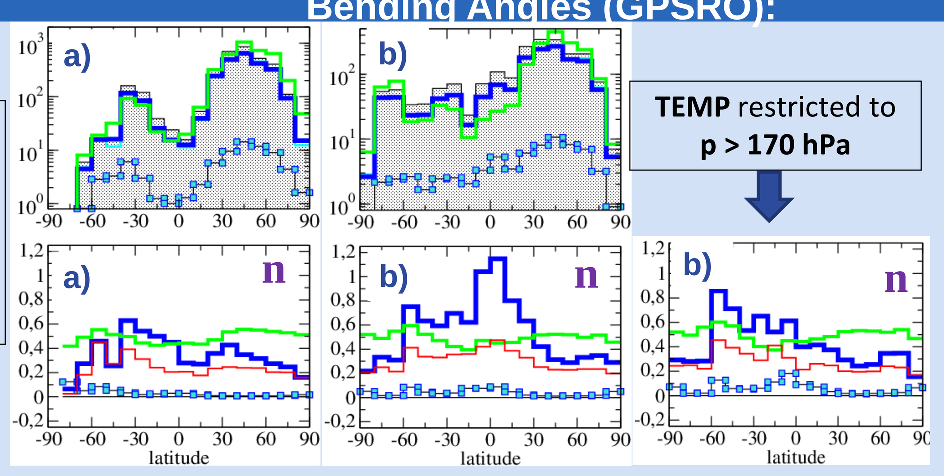
Blue curves always:
(i) "> 0",
(ii) mostly similar magnitude as green curves

I.e., in situ measurements generally show good agreement between (o-fg) departures and ensemble covariances.

Unless for large separation distances, ana incs contain less obs-info than "optimal" (red lines clearly below blue lines).
EnVar ana incs substantially more optimal (not shown).
Probable explanation: LETKF of global system is less able to capture small scale information than EnVar

Correspondance substantially worse for AMVs (SATOB) particularly at small scales *(height assignment problems!!)*

Bending Angles (GPSRO):



Mostly excellent agreement also for GPSRO (bending angles).

Differences of verification vs AIREPs and TEMPs are largely due to *stratospheric TEMPs.*
Covariances in stratosphere are larger

Metric depends on spatial and temporal distribution of verifying obs

4. Application to satellite radiances:

a) determination of localization height "plevel"

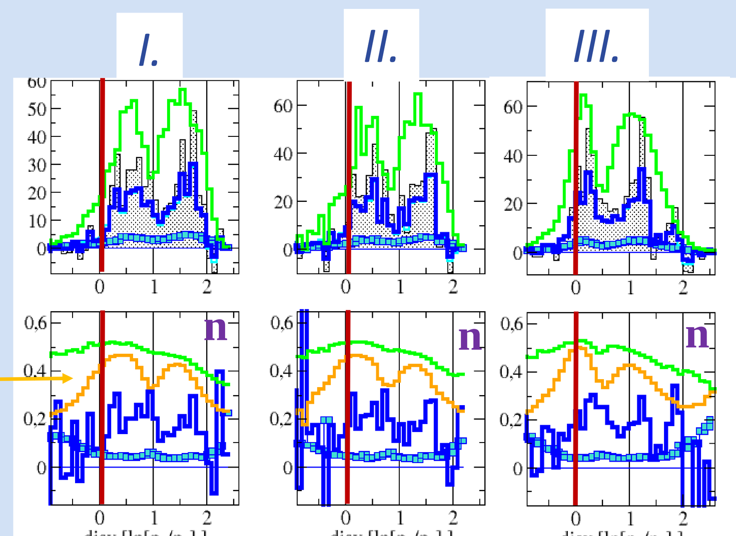
The first trials to apply the method to satellite radiances emphasized the importance of a good plevel assignment

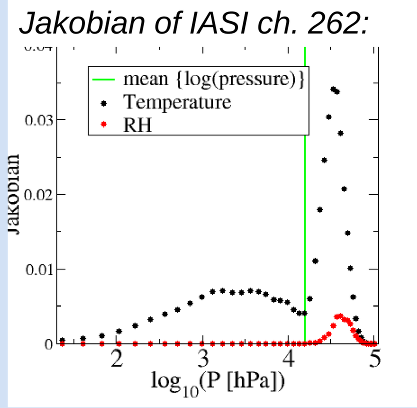
3 Methods to compute plevel (from the Jakobian **H**) have been tested:

I. *centre of mass of* **|H|**
II. *Take the maximum of* **|H|**
III. *Take* **BH**^{T} *instead of* **H**

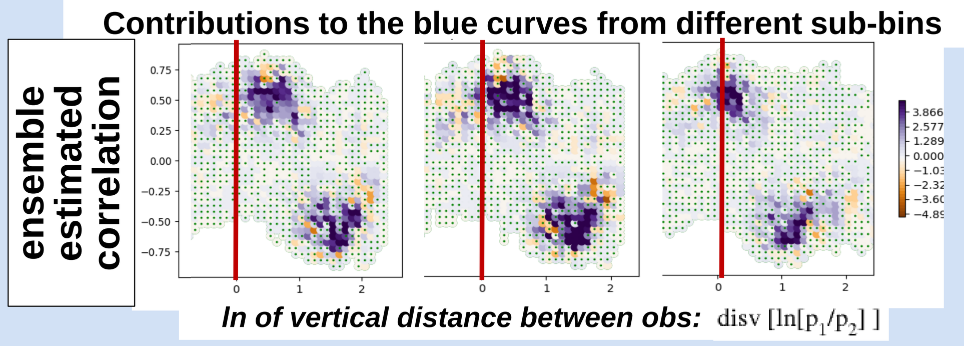
Here: Statistics are collected with vertical localization *"switched off"*

(orange curves) weighted mean of ensemble correlation



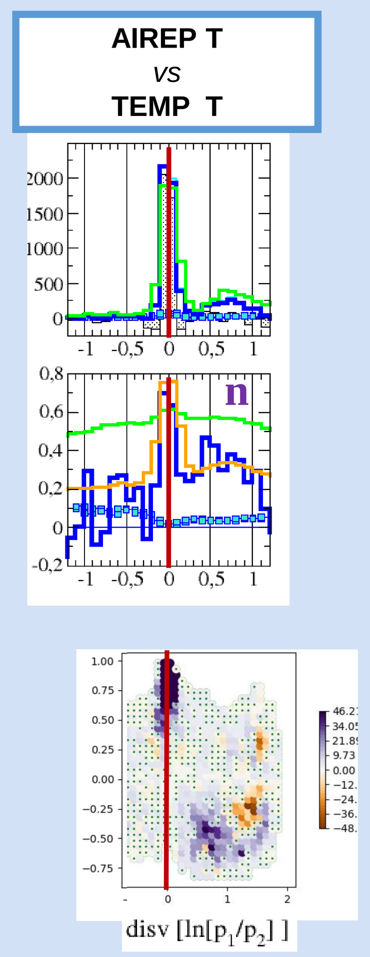


Contributions to the blue curves from different sub-bins

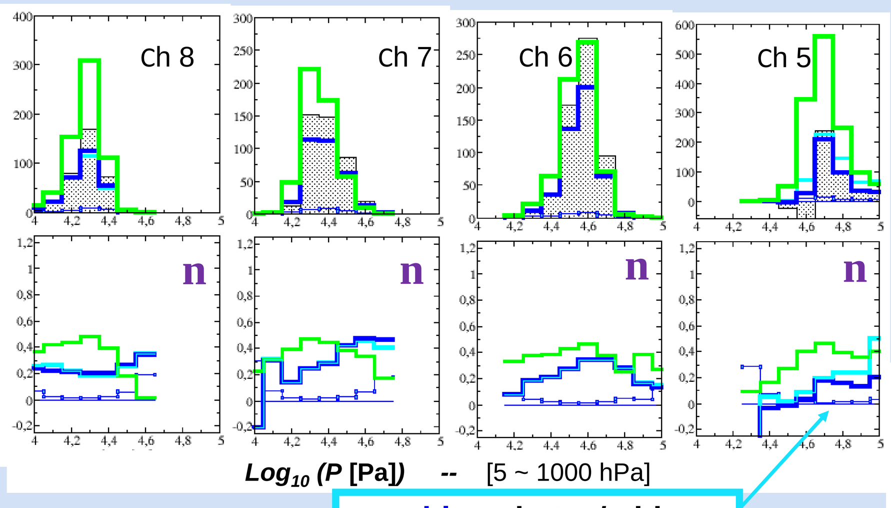


ln of vertical distance between obs: disv [ln[p1/p2]]

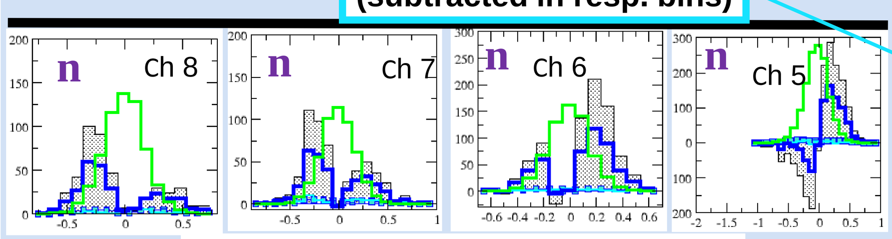
Secondary peak with neg. correlations also for:



4b. Tropospheric Channels of AMSU A



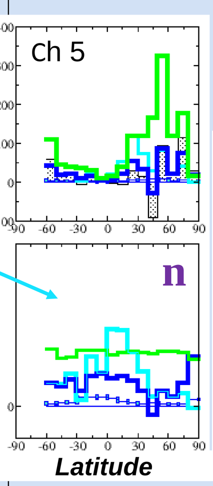
(cyan curves) as **blue** - but w/o bias (subtracted in resp. bins)



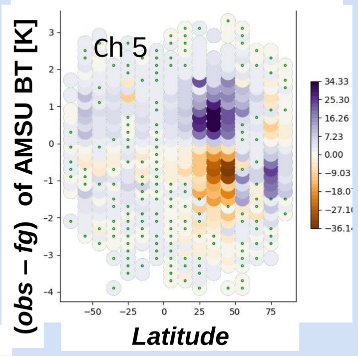
AMSU A shows **clearly beneficial** impact (though less ideal than in situ obs)

Channel 5 : bias problems
(obs-fg) bias opposite sign as for TEMPS or GPSRO (not shown)

Bias (particular model bias) strongly varies with:



Contributions to the blue curve



> location (e.g. latitude),
> season,
> weather regime,
> other conditions.

5. Concluding Remarks

A new **verification method** has been introduced

- for testing the **consistency of obs types** (i.e., individual channel)
- under **predefined conditions** (latitude, height, etc.)
- which is very sensitive to impact of **biases**
- and directly related to an **impact measure**
  - it divides established impact measure into parts related to different aspects of the data usage/quality
- most suitable for **testing new methods** / **tuning parameters.**

Interpreting statistics requires some experience / comparisons.
Starting with in situ observations permitted:
i) testing of method
ii) Benchmark for more complex observations

Testing consistency of:

(obs – fg) obs1 | (obs – fg) obs2 | ensemble covariances

Further work : t > 0
Check for ensemble covariances at different times.
Involves impact of dynamics (balances, spin up/down)

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