Estimation of the error covariance matrix for IASI reconstructed radiances and its impact at ECMWF

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with thanks to collaborators at ECMWF, EUMETSAT and the Met Office including

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Thomas August, Tim Hultberg, Dorothée Coppens (EUMETSAT)
Nigel Atkinson (Met Office)

EUMETSAT study: Assimilation of PC-reconstructed radiances in NWP

- Assuming a scenario where the EUMETSAT baseline dissemination system will only carry PC-products and the Level 1C spectrum of original radiances will not be available in NRT (e.g., IRS):

  - Establish whether ECMWF could replicate L1C radiance assimilation impact using radiances reconstructed from truncated PCs with no modification of the DA system
    - Address NWP concerns about the DA system configuration / adaptation: channel selection, bias correction, observation error specification…

  - Establish the effects on radiance reconstruction when changing the PC scores eigenvector basis.
    - While such updates are expected to be infrequent, they may be necessary to take account of instrument changes or significant changes in the atmosphere.
    - Address NWP concerns that long lead time will be required if a change in the eigenvector basis is proposed.

IASI Reconstructed radiances were generated locally at ECMWF

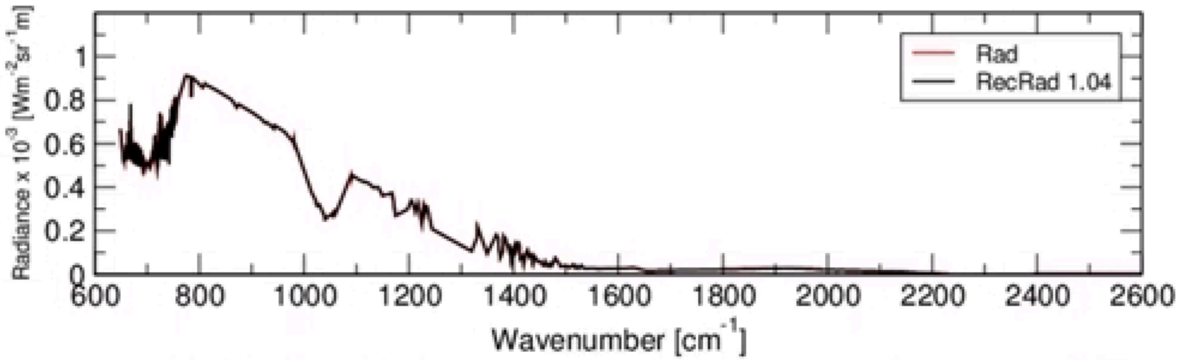
PC scores: $\mathbf{p}=\mathbf{P}(\boldsymbol{y}-\bar{\boldsymbol{y}})$

IASI PC
300 scores

= Compression operator **P** x IASI Level 1C 8461 chs.

Reconstructed radiances: $\boldsymbol{y}_{rr} = \mathbf{RP}(\boldsymbol{y}-\bar{\boldsymbol{y}}) + \bar{\boldsymbol{y}}$
where **R** – reconstruction/decompression operator;
$\boldsymbol{y}$ – original Level-1C radiances and $\bar{\boldsymbol{y}}$ - mean

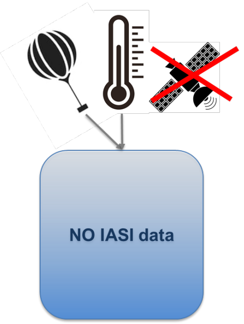
Comparable radiances/brightness temperature amplitude are found for both Rad/RecRad datasets after this pre-processing step.



- IASI PC-products have been processed/disseminated by EUMETSAT since 2011, but no operational experience has been established at NWP centers, as users continued using the original Level 1C radiances.
  - PC-products retain the geophysical information needed for NWP and achieve a significant data volume reduction.
- EUMETSAT PC compressed IASI L1C data
  - **v1.04** currently operational;
  - **v2.01** next planned release in the upcoming IASI L2 processor v6.7;
- The eigenvectors used for compression are characterized by:
  - <u>the noise normalisation matrix</u> (v1.04 - diagonal noise-normalisation matrix applied to centred radiances; v2.01 - full noise-normalisation matrix and the radiances haven't been centred)
  - <u>the training set of spectra</u> which consists of real L1C IASI spectra
  - <u>the number of eigenvectors to retain</u> (300 PC).

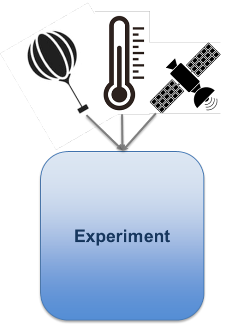
Observing system experiments

- Carried out assimilation runs in the context of full system experiments using a state-of-the-art assimilation system represented by the current operational version of the ECMWF.



CY47R3.1; TCo399 horizontal resolution (25 km); Periods: 2^{nd} June – 31^{st} Aug 2020 & 2^{nd} Dec – 28^{th} Feb 2021;

NO_IASI – It uses all operational observations, except for IASI data



RAD – It is identical to NO_IASI, but additionally assimilates MetOp-A/B/C IASI radiances.

REC_RAD _v104 – It is identical to NO_IASI, but additionally assimilates MetOp-A/B/C IASI reconstructed radiances generated using EUMETSAT v1.04 eigenvectors basis

REC_RAD_v201 – It is identical to NO_IASI, but additionally assimilates MetOp-A/B/C IASI reconstructed radiances generated using EUMETSAT v2.01 eigenvectors basis

REC_RAD_COMB – Evaluate the sensitivity to "on-the-fly" changes to the eigenvector basis; It is identical to NO_IASI, but additionally assimilates MetOp-A/B/C IASI reconstructed radiances generated using EUMETSAT v1.04 eigenvectors basis until 4^{th} July 2020 / 3^{th} Jan 2021 and using EUMETSAT v2.01 eigenvectors basis after that.

The use of radiances reconstructed from PCs exploits existing science and infrastructure developed for L1C radiance assimilation.

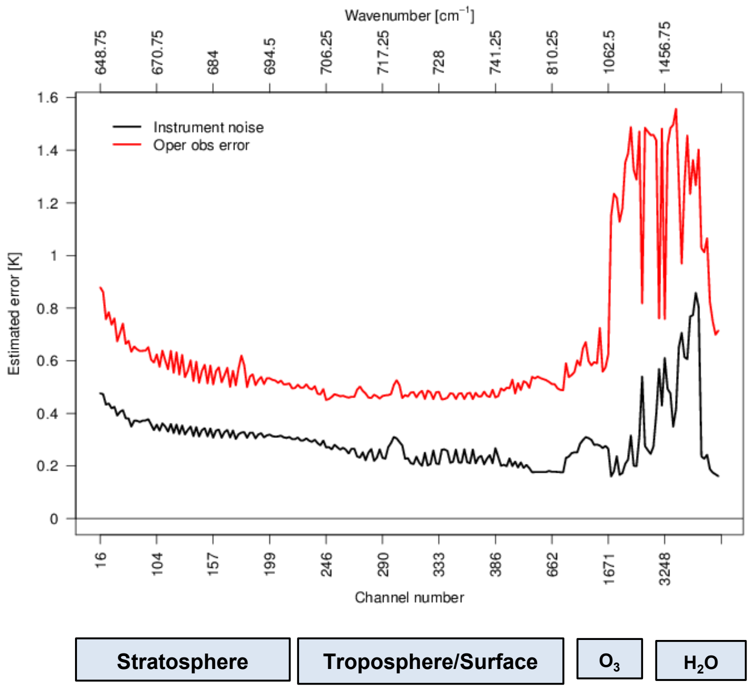
- Use the REC_RAD equivalent of our current operational: channel selection (e.g., 220 assimilated channels), cloud and aerosols screening, VarBC and **with no modification of R_{IFS} (observation error matrix) and RTTOV**.
- **R_{IFS}** : use the operational full IASI observation error covariance matrix estimated from real IASI measurements (Bormann et al., 2010);

<u>Stratospheric / Upper tropospheric T sounding channels</u>: error standard deviations larger than the instrument noise estimate, with little error correlations;

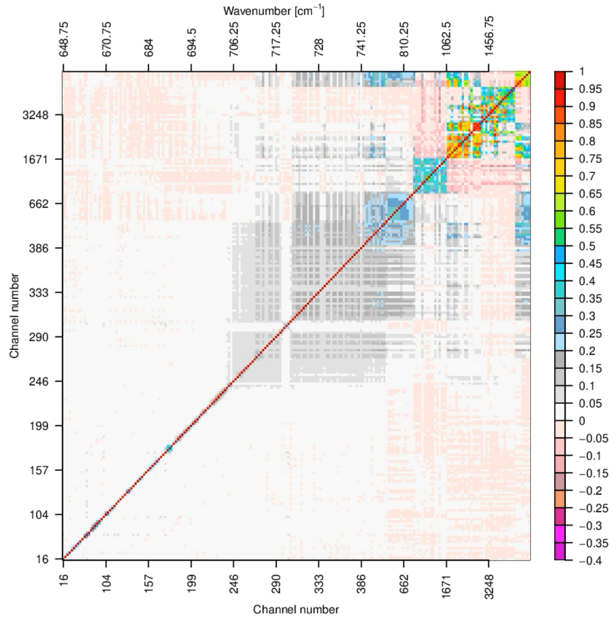
<u>Water vapour channels</u>: error standard deviations much larger than the instrument noise with significant inter-channel error correlations;

<u>Lower T sounding, window, and O_3 channels:</u> error standard deviations larger than the instrument noise with weaker, but still significant inter-channel error correlations.

Error standard deviation



Inter-channel observation-error correlation matrix

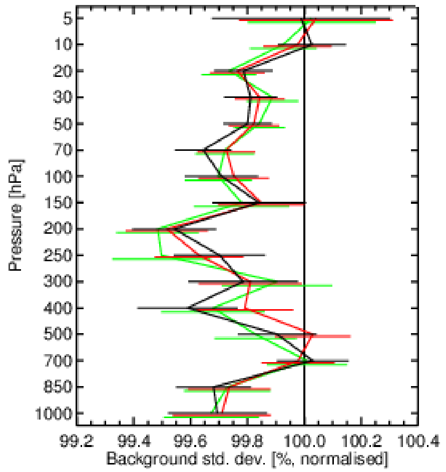


No indications of performance loss switching from RAD to REC_RAD in the full system

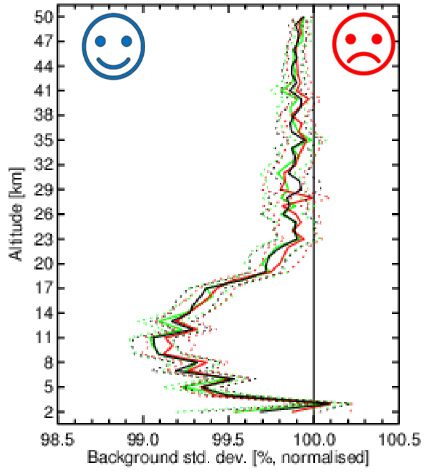
- IASI radiances, reconstructed from PC-products can be seamlessly assimilated in an operational system designed for Level-1C radiances, without DA system retuning and without forecast skill loss.

Short-range forecast impact

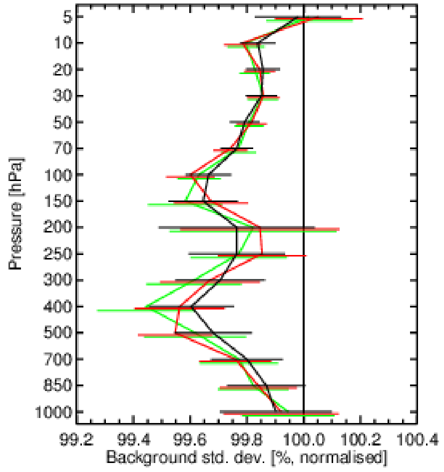
TEMP-Temperature



GPS-RO

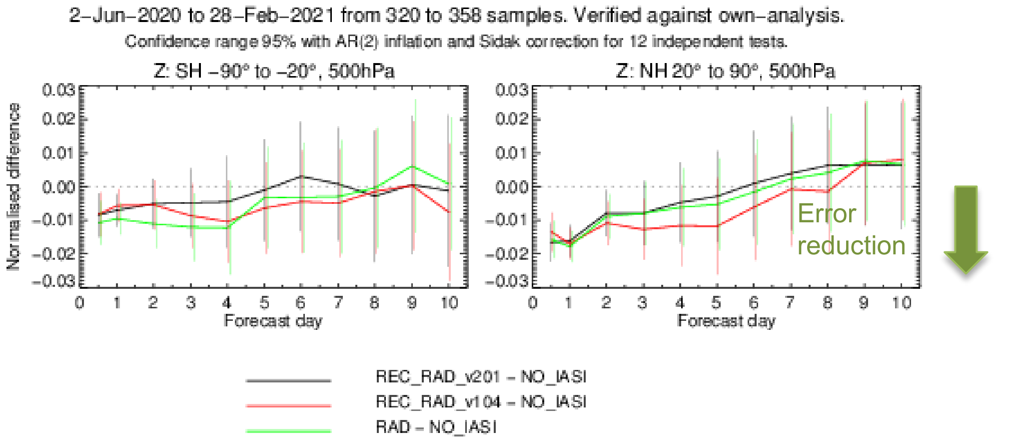


Conv. Wind



Forecast impact: Z500 hPa

Verified against own analysis



Periods: 2nd Jun – 31st Aug 2020 &
2nd Dec – 28th Feb 2021

REC_RAD_v201
REC_RAD_v104
RAD

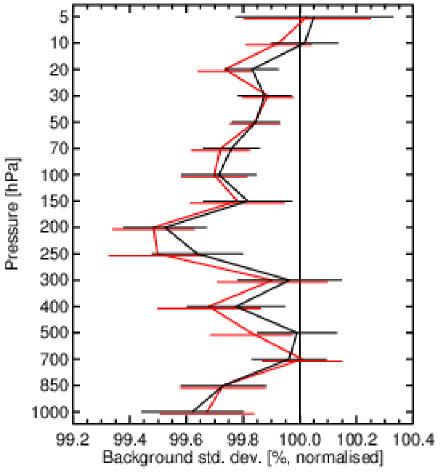
100% = NO_IASI

No indications of performance loss switching between REC_RAD eigenvectors basis

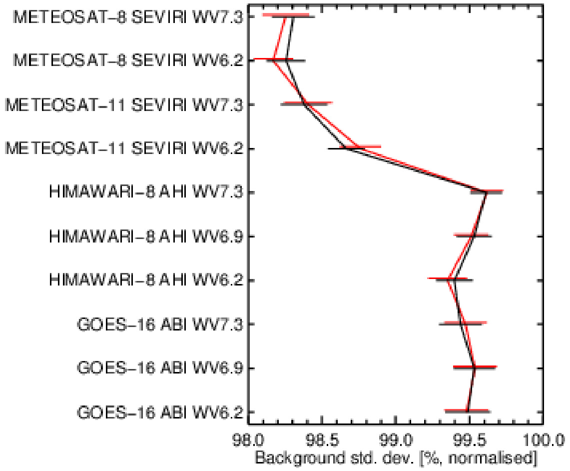
- The eigenvector basis of the PC-products can be seamlessly updated over time, without any system recalibration, ensuring operational continuity and preserving the NWP forecast skill. This is an important result with respect to operational constraints on PC products if a maintenance or updates are is needed.

Short-range forecast impact

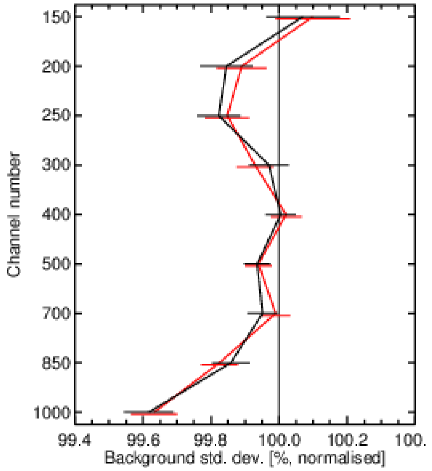
TEMP-Temperature



GEOS



AMVs



Forecast impact: Z500 hPa

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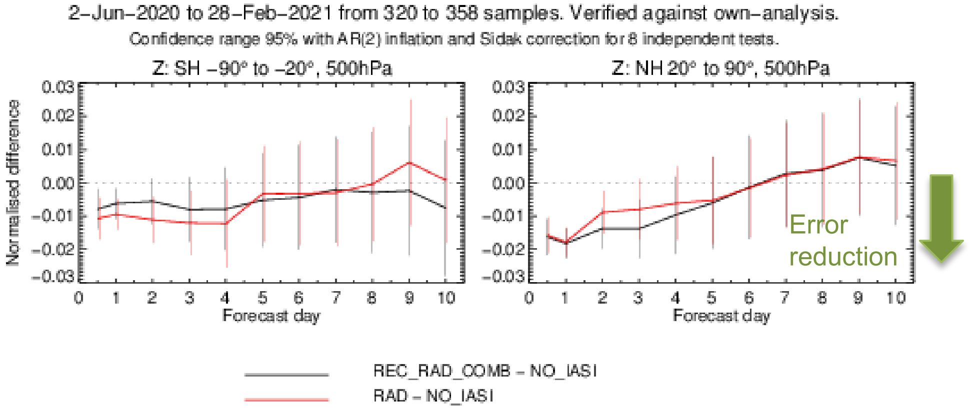


Periods: 2nd Jun – 31st Aug 2020 &
2nd Dec – 28th Feb 2021

REC_RAD_COMB
RAD

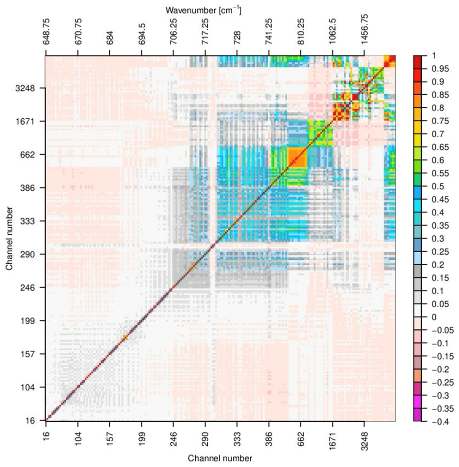
100% = NO_IASI

Estimating a dedicated observation error covariance for REC_RAD

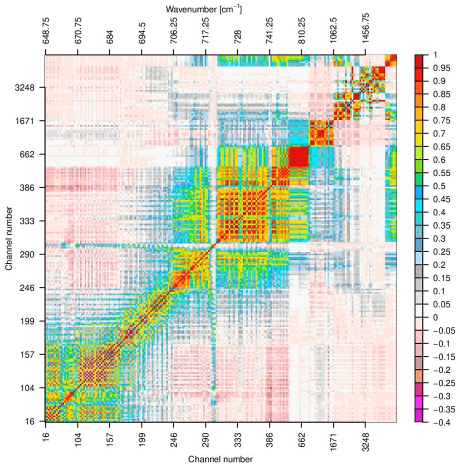
- Was the success of assimilating REC_RAD facilitated by the pre-existing suitable, well-tuned operational observation error matrix for IASI Rad?
  - The initial task in this study was to take the REC_RAD and pretend they are real radiances. The observation error covariance matrix that was used in the assimilation experiments was derived from real IASI measurements;
  - Next step was to derive a dedicated error covariance appropriate to these REC_RAD: Observation error covariance matrices have been derived from a **passive IASI REC_RAD monitoring run** using the **departure-based diagnostic methods.** These unscaled diagnosed matrices were used then in an assimilation experiment (IASI REC_RAD active) and their performance compared with respect to a NO_IASI control.
  - Considering $\mathbf{x}_t=\mathbf{x}_a$, then the observation error is $\mathbf{e}_o = \mathbf{y}\text{-}H(\mathbf{x}_t) = \mathbf{y}\text{-}H(\mathbf{x}_a)$

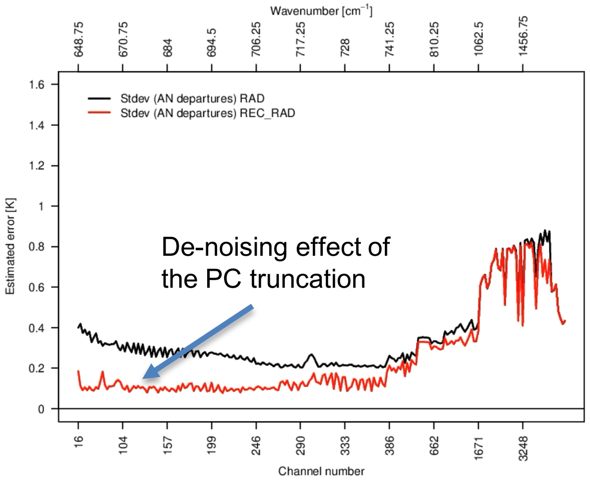
$$\mathbf{R}=<\mathbf{e}_o\mathbf{e}_o^T>=<(\mathbf{O}-\mathbf{A})(\mathbf{O}-\mathbf{A})^T>$$

Use RAD departures



Use REC_RAD_v201 departures





- De-noising effect of the PC-truncation: the random noise in the REC_RAD is being reduced, so that the the reconstruction process can introduce spectral correlation of the observation errors not seen in the original data.
- Observation uncertainty depends on the instrument noise, observation operator, model resolution and is state dependent.
- The residual noise must be added to the reconstructed radiances before the derivation of the covariance matrix!

Estimating a dedicated observation error covariance for REC_RAD

- Was the success of assimilating REC_RAD facilitated by the pre-existing suitable, well-tuned operational observation error matrix for IASI Rad?
  - The initial task in this study was to take the REC_RAD and pretend they are real radiances. The observation error covariance matrix that was used in the assimilation experiments was derived from real IASI measurements;
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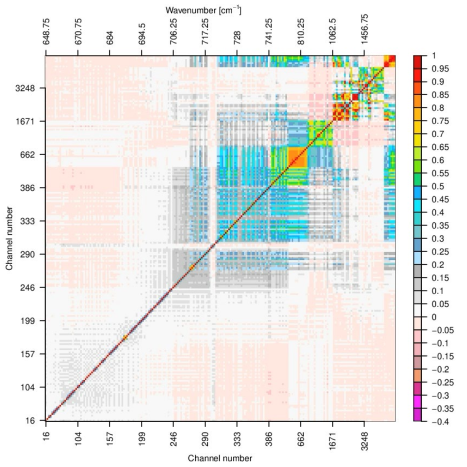
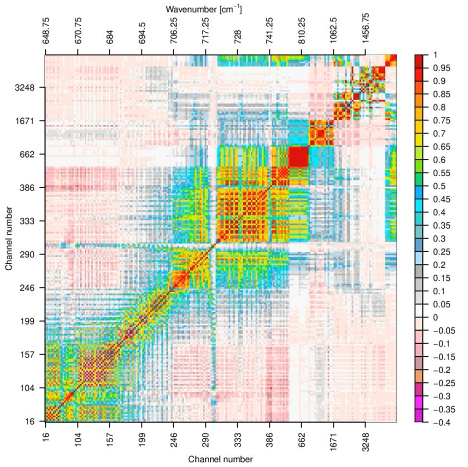
  - Considering $\mathbf{x}_t=\mathbf{x}_a$, then the observation error is $\mathbf{e}_o = \mathbf{y}\text{-}H(\mathbf{x}_t) = \mathbf{y}\text{-}H(\mathbf{x}_a)$

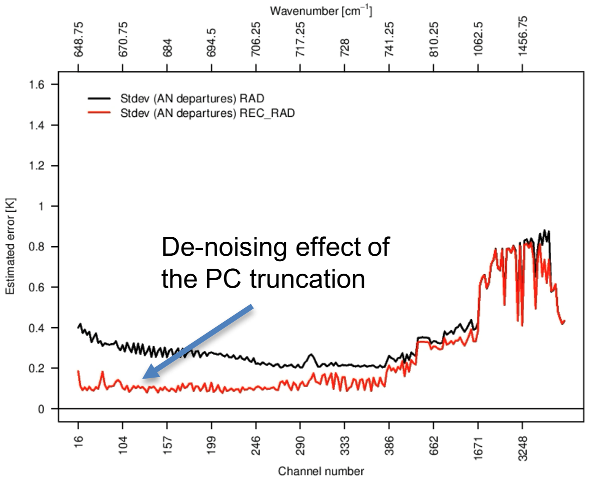
$$\mathbf{R}=\langle \mathbf{e}_o\mathbf{e}_o^T\rangle=\langle(\mathbf{O}\text{-}\mathbf{A})(\mathbf{O}\text{-}\mathbf{A})^T\rangle$$

Use RAD departures

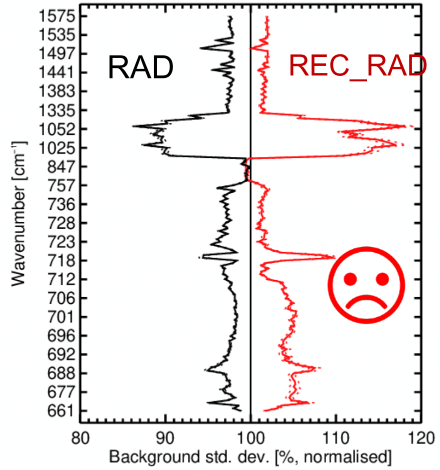


Use REC_RAD_v201 departures



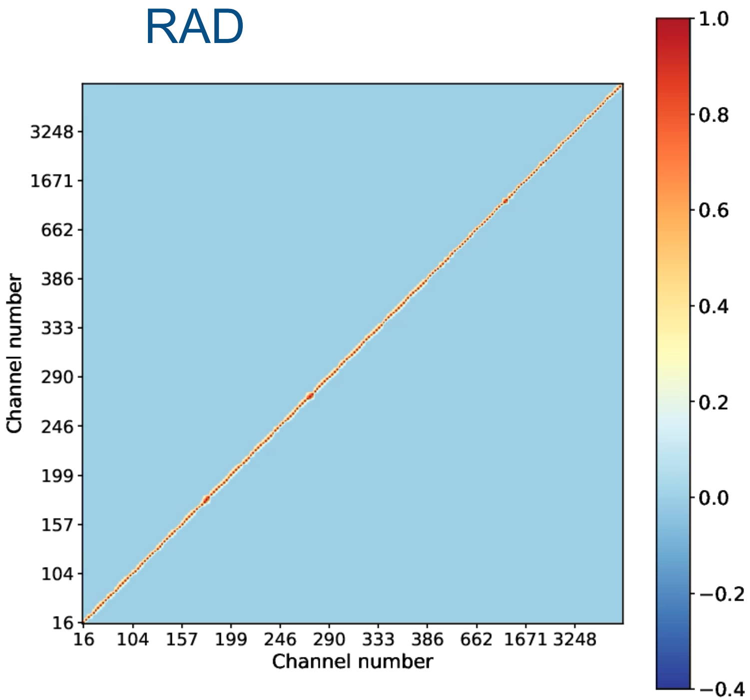


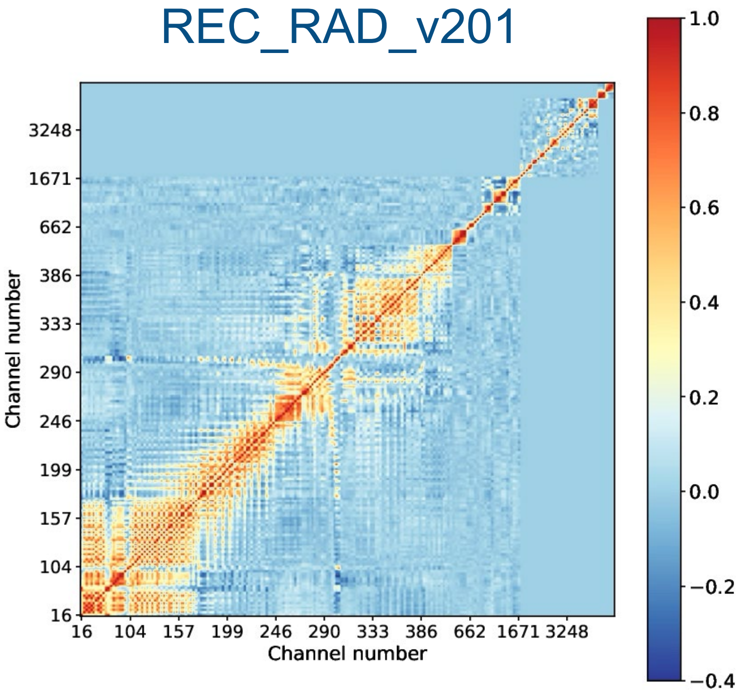
CrIS

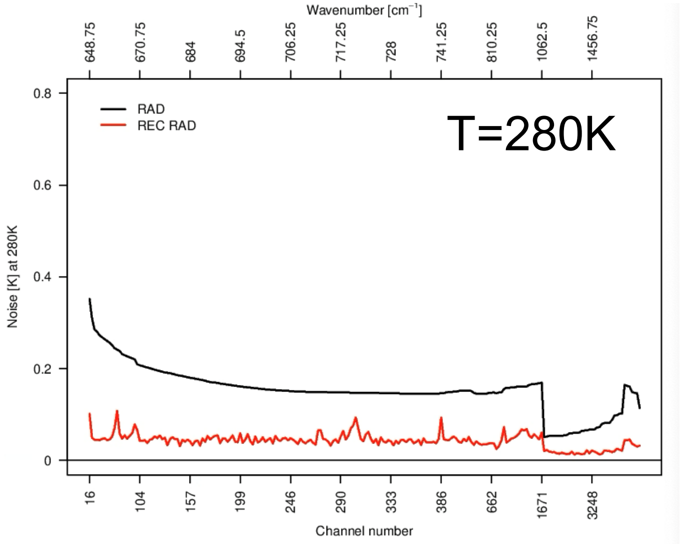


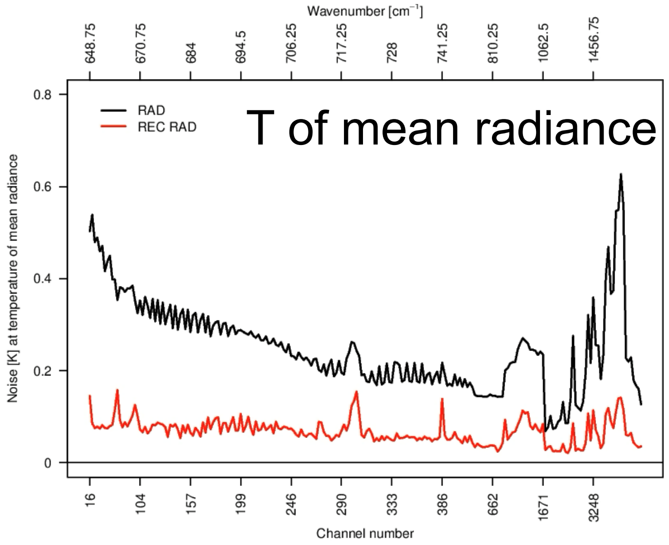
IASI instrument **noise** correlation matrices & std dev – ECMWF OPS used channels

- The instrument noise covariance (RAD and REC_RAD) can be calculated from data supplied by EUMETSAT.







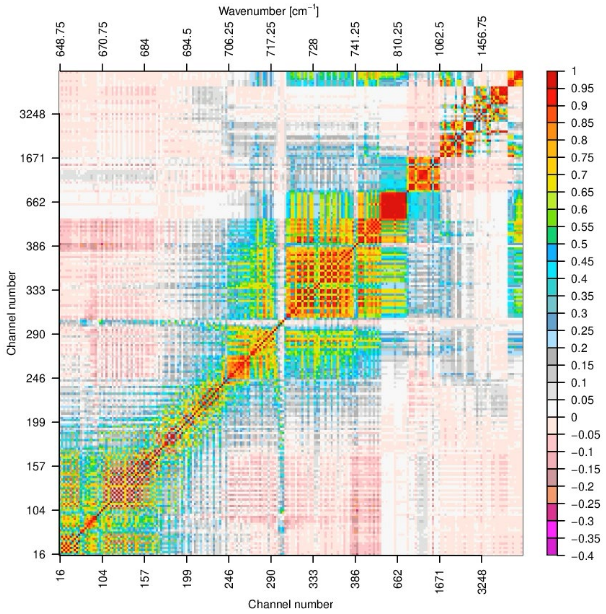


REC_RAD noise covariance= $\mathbf{N\ E\ E^T\ E\ E^T\ N}$

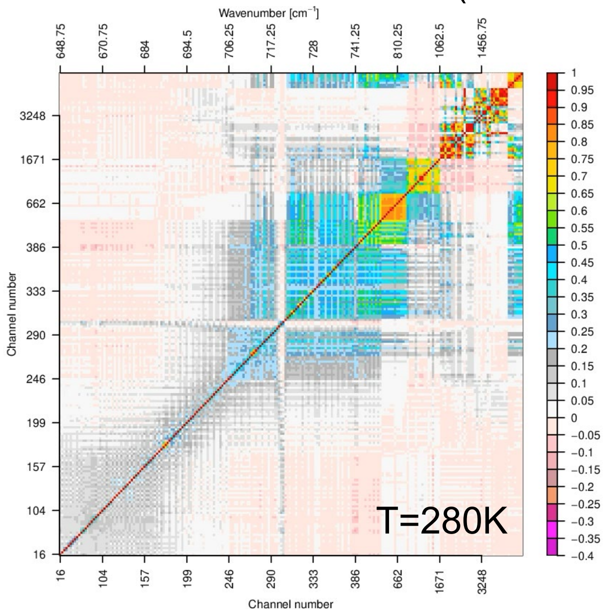
N is the matrix square root of the L1C noise covariance
E eigenvectors, the PC-basis vector

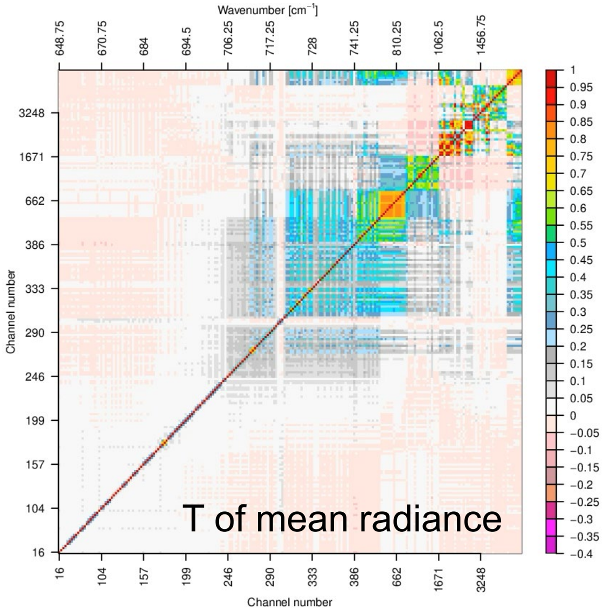
IASI REC_RAD_v201 error covariance estimate

1) Estimate $\mathbf{R} = \langle \mathbf{e}_o \mathbf{e}_o^T \rangle = \mathbf{\langle (O\text{-}A)(O\text{-}A)^T \rangle}$

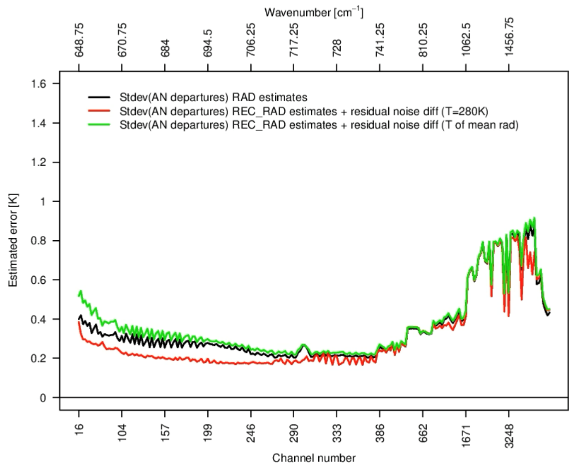


2) Add + the difference between the instrument noise covariance for RAD and that for REC_RAD (both converted to BT at 280K or T of mean radiance)





Error standard deviation



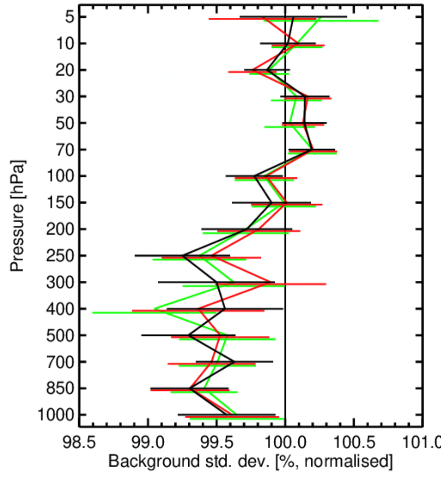
3) Run OSEs with REC_RAD_v201

Observation error matrix estimates:

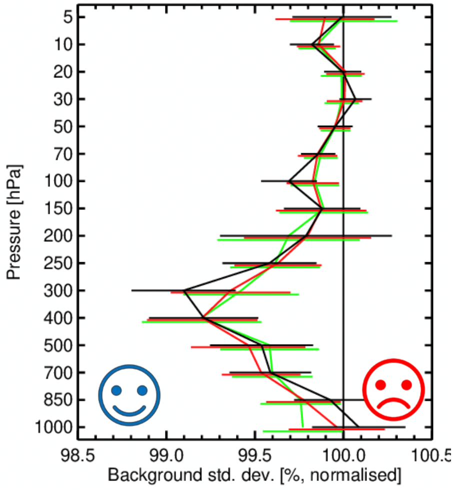
- R=$\mathbf{\langle (O\text{-}A)(O\text{-}A)^T \rangle}$ from passive IASI RAD departures
- R=$\mathbf{\langle (O\text{-}A)(O\text{-}A)^T \rangle}$ from passive IASI REC_RAD_v201 departures + residual noise diff (T=280K)
- R=$\mathbf{\langle (O\text{-}A)(O\text{-}A)^T \rangle}$ from passive IASI REC_RAD_v201 departures + residual noise diff (T of mean radiance)

Short-range impact evaluated against observations (REC_RAD_v201)

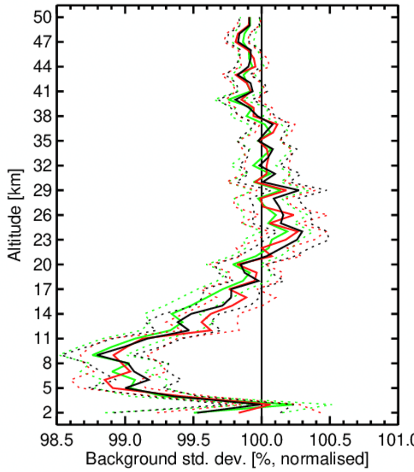
TEMP-Temperature



Conv. Wind



GPS-RO



Periods: 3rd Jun–21st Jun 2020 &
3rd Dec–25th Dec 2020

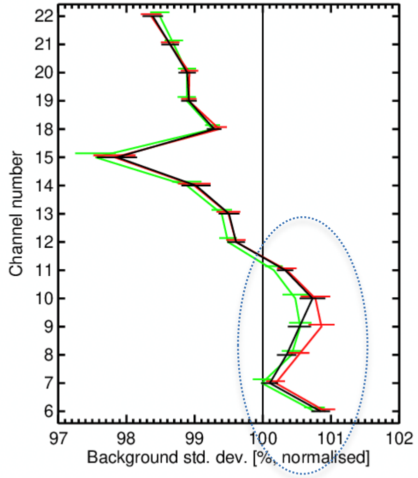
REC_RAD_v201 (AN dep from REC_RAD + noise mean)

REC_RAD_v201 (AN dep from REC_RAD + noise 280K)

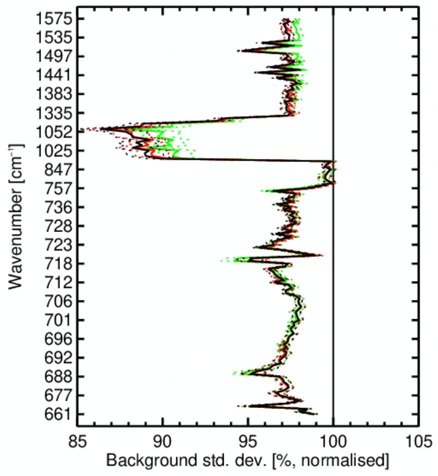
REC_RAD_v201 (AN dep from RAD)

100% = NO_IASI

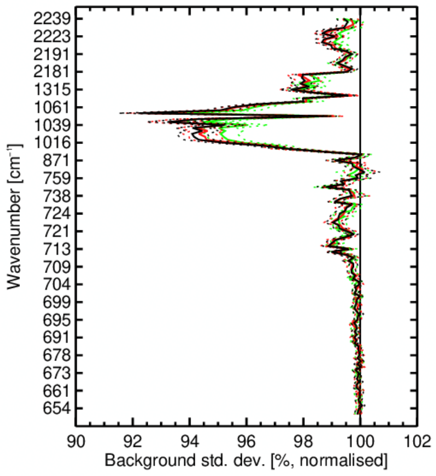
ATMS



CrIS



AIRS



Overall summary

- IASI was used as a proxy for IRS to address a priori assumptions within the NWP community regarding the utilisation of Radiances Reconstructed from PC-products.
    - At least in the context tested, Reconstructed Radiances can replace raw Radiances with no loss of NWP skill which confirms that the day-1 dissemination baseline for MTG-IRS is safe for users.
    - On-the-fly changes to the eigenvector basis preserved operational continuity and forecast skills.
- An improved understanding and refinements of the methodologies to estimate the observation error covariance will accelerate the operational uptake of MTG-IRS in NWP after commissioning.
    - When users receive RR from IRS, they will not be able to follow the usual practice of deriving an a posteriori departure-based type observation error covariance matrix.
    - Promising results from REC_RAD_v201 by appropriately modifying the diagnosed observation errors to account for the instrument noise component.
    - Scope to further optimise the observation error specification for IASI reconstructed radiances. This is an area where efforts will continue at ECMWF.