

Assimilation of Transformed Retrievals from IASI radiances at the Met Office

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Met Office Passive atmospheric temperature/humidity sounding: current instruments



https://airs.jpl.nasa.gov/mission/overview/





https://www.nesdis.noaa.gov/oursatellites/currently-flying/joint-polar-satellite-system

https://www.eumetsat.int/iasi

- A wealth of data from IR sounders available in NRT for NWP applications
- IASI: 3 satellites, 8461 channels, 30 cross-track samples with 2x2 FOVs
- AIRS: 2378 channels, 90 cross-track samples
- CrIS: 3 satellites, 1305 (NSR) / 2211 (FSR) channels, 32 cross-track samples

Met Office Passive atmospheric temperature/humidity sounding: forthcoming instruments

- IASI-NG: 3 satellites (first launch in 2025), 16921 channels, 14 earth-viewing crosstrack samples with 4x4 FOVs
- MTG-IRS: 2D detector acquires 160 x 160 spectra (1960 spectral channels) over a dwell, for 4 local area coverage (LAC) zones. Full disk acquired every 60 mins, LAC4 (Europe) every 30 mins



https://www.eumetsat.int/mtg-infrared-sounder



https://www.eumetsat.int/eps-sg-iasi-ng

Assimilation of satellite data for NWP

- Satellite data make up for most observations that are routinely assimilated at the Met Office
- Huge amount of data are discarded due to operational/computational constraints, imperfect knowledge of spatial correlations, shortcomings in NWP models and observation operators.
- Recent work at the Met Office shows that it is possible to assimilate a reduced set of obs components Transformed Retrievals (TRs) and achieve comparable results as when assimilating radiances directly.

Transformed Retrievals

• Linearized and normalized measurements $\hat{\mathbf{y}} = \mathbf{y}^o - H(\mathbf{x}^a) + \hat{\mathbf{H}}\mathbf{x}^a \cong \hat{\mathbf{H}}\mathbf{x}^t + \mathbf{\epsilon}^o$ $\hat{\mathbf{y}}' \cong \mathbf{R}^{-1/2}\hat{\mathbf{H}}\mathbf{x}^t + \mathbf{R}^{-1/2}\mathbf{\epsilon} \equiv \hat{\mathbf{H}}'\mathbf{x}^t + \mathbf{\epsilon}'$

$$\operatorname{cov}(\mathbf{\epsilon}^o) = \mathbf{R}$$
 $\operatorname{cov}(\mathbf{\epsilon}') = \mathbf{I}$

• Projection onto signal-to-noise basis (in obs space)

$$\mathbf{S} = \mathbf{R}^{-1/2} \widehat{\mathbf{H}} \mathbf{B}^{1/2} = \widehat{\mathbf{H}}' \mathbf{B}^{1/2} = \mathbf{U}_r \mathbf{\Lambda}_r \mathbf{V}_r^T$$
$$\mathbf{y'}_{ret} = \mathbf{U}_r^T \widehat{\mathbf{y}}' \qquad \mathbf{H'}_{ret} = \mathbf{U}_r^T \widehat{\mathbf{H}}' = \mathbf{\Lambda}_r \mathbf{V}_r^T \mathbf{B}^{-1/2}$$

- signal-to-noise matrix **S**, with $r = rank(S) \le min(m,n)$
- y'_{ret} is assimilated with H'_{ret}

Information content of observations

• From S we can calculate degrees of freedom for signal (DFS)

$$d_{s} = \sum_{i=1}^{r} \frac{\lambda_{i}^{2}}{1 + \lambda_{i}^{2}} = \sum_{i=1}^{r} d_{si}$$

$$\mathbf{B} = \mathbf{\Sigma}^{1/2} \mathbf{C} \mathbf{\Sigma}^{1/2} \qquad \tilde{\mathbf{S}} = \mathbf{R}^{-1/2} \widehat{\mathbf{H}} \mathbf{\Sigma}^{1/2} = \widehat{\mathbf{H}}' \mathbf{\Sigma}^{1/2} = \widetilde{\mathbf{U}}_{r} \widetilde{\mathbf{\Lambda}}_{r} \widetilde{\mathbf{V}}_{r} \qquad \tilde{d}_{s} = \sum_{i=1}^{r} \frac{\tilde{\lambda}_{i}^{2}}{1 + \tilde{\lambda}_{i}^{2}} = \sum_{i=1}^{r} \tilde{d}_{si}$$

• DFS weighting function (DFSwf): $\mathbf{s}_{i} = \frac{d_{s}}{\tilde{d}_{s}} \widetilde{d}_{si} \widetilde{\mathbf{v}}_{i} \circ \widetilde{\mathbf{v}}_{i} \in \mathbb{R}^{r \times n}$

• Cumulative DFS weighting function: $\mathbf{s} = \frac{d_s}{\tilde{d}_s} \sum_{i=1}^{r} \tilde{d}_{si} \, \tilde{\mathbf{v}}_i \circ \tilde{\mathbf{v}}_i$

DFS weighting functions

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Temperature DFS: 2.695

0.000 0.025 0.050 0.075 0.100 0.125 0.150 0.175

Temperature DFS weighting function

- TR 1

- TR 2

- TR 3

- TR 4

Humidity DFS: 1.098

0.000 0.025 0.050 0.075 0.100 0.125 0.150 0.175

Humidity DFS weighting function

TR 1 TR 2

- TR 3

- TR 4

- TR 5 - TR 5 - TR 6 - TR 6 - TR 7 - TR 7 ----- TR 8 ----- TR 8 - TR 9 - TR 9 - TR 10 - TR 10 - TR 11 10-1 10^{-1} - TR 11 - TR 12 _____ TR 12 - TR 13 - TR 13 - all TRs - all TRs **Cloud-free location** 106 sure [hPa] Ě 10 101 10 103

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Assimilation trials

- Three-month trial with hybrid 4D-Var (no VarBC) from 1st December 2019 to 28th February 2020 using same observations (except for SSMIS and MWRI to avoid orbital bias) as those used in the Met Office operational DA scheme for the same period (in-situ or ground based, satellite products and satellite radiances including IASI – up to 175 radiances – on Metop-1(B) and Metop-3(C)): CTRL trial
- Same as CTRL except for replacing IASI rads with TRs: TR trial
- Same as TR trial but only assimilating y'_{ret_i} with $\lambda_i > 0.1$: TR_L0p1 trial

TR obs components



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-20

TR innovation components

90°N 80°N E sers 70°I 60°I 50°N 40°N 30°N 20°N ~ 1 10°N 0 10°5 20°S 30°S 40°5 50°S 60°S 70°S 80°5 90°S 180° 160°W 140°W 120°W 100°W 80°W 60°W 20°W 20°E 40°E 60°E 80°E 100°E 120°E 140°E 160°E 180° 40°W 0°W



Analysis increments: potential temperature



TR minus CTRL potential temperature analysis increments at 5220.0 - 2019-12-01 0300 UTC

Analysis increments: specific humidity



Analysis increment distrib: potential temperature



analysis increment

Analysis increment distrib: specific humidity TR minus CTRL TR_LOp1 minus CTRL



analysis increment

Information content of TR components

- Partial sums D_k of the k largest normalised degrees of freedom for signal for an ensemble of 3344 out of 13061 IASI observations in the first assimilation cycle with S with max rank (=140).
- Histogram of the number of TRs for the 3344 IASI obs with $\lambda_i > 0.1$
- no more than 17 TR components with largest λ_i values are required to express from 97.9% up to 99.3% of the total number of DFS from each observation.



Trial results: TR vs. CTRL score cards

- Relative RMSE diffs for various fields and fcst lead times
- Overall results: +0.03% (obs); +0.01% (ECMWF analyses)
- TR trial seems to perform better in SH where we have more sat obs
- Overall abs diffs < 0.1% (Met Office threshold for significant change)

% Difference (static bias TransRets vs. static bias control) - overall 0.03%, RMSE against observations for Equalized, 2019/1215 00:00 to 20200228 12:00 % Difference (static bias TransRets vs. static bias control) - overall 0.01%, RMSE against ecanal for Equalized, 2019/215 00:00 to 20200228 12:00

							ma	ax =	20							
NH_PMSL	-		•			1	۲	•	٧	۲	1		۲	۷		surf
NH_W250									•	۳	٠	•	٠	•		AMDARS
NH_W500									٠	۳	*			•		sondes
NH_W850								۷								Satwind
NH_W10m													٠	٠		surf
NH_T250							•							٠		sondes
NH_T500										۳						sondes
NH_T850											٠	•	٠	•		sondes
NH_T_2m										٠	٠	٠		•		surf
NH_Z250							•		٠	•	٠	٠	۷	۷		sondes
NH_Z500									٠	٧	٠	٠	۷	۷		sondes
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TR_W250																AMDARS
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SH_W500																sondes
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SH_Z500	•															sondes
SH_Z850																sondes
	1+0	7+6	T+12	T+24	T+36	T+48	T+60	T+72	T+84	T+96	T+108	T+120	T+132	T+144	T+168	

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Z850														

Trial results: TR_L0p1 vs. CTRL score cards

- Overall results: +0.01% (obs); -0.04% (ECMWF analyses)
- More uniform score results for different fields and lead times
- Overall abs diffs deemed not significant.
- Assimilation of fewer TR components does not change significantly comparison results

% Difference (static bias lambda > 0.1 TransRet vs. static bias control) - overall 0.01%, RMSE against observations for Equalized, 20191215 00:00 to 20200228 12:00 % Difference (static bias lambda > 0.1 TransRet vs. static bias control) - overall -0.04%, RMSE against ecanal for Equalized, 20191215 00:00 to 20200228 12:00

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NH_PMSL	Γ		1.	1		1	۲	•						1		surf
NH_W250																AMDARS
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NH_W10m				•												surf
NH_T250		•		•									•			sondes
NH_T500							٠									sondes
NH_T850														•		sondes
NH_T_2m														•		surf
NH_Z250																sondes
NH_Z500													٠	•		sondes
NH_Z850														•		sondes
TR_W250														•		AMDARS
TR_W500	•															sondes
TR_W850					•	٠	٠	٠								Satwind
TR_W10m																surf
TR_T250								•		٠			۲	٧		sondes
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TR_T850											•					sondes
TR_T_2m																surf
SH_PMSL											٠		۲			surf
SH_W250								•						•		AMDARS
SH_W500																sondes
SH_W850																Satwind
SH_W10m						•										surf
SH_T250			•											•		sondes
SH_T500	•											•		•		sondes
SH_T850													۷			sondes
SH_T_2m																surf
SH_Z250	٠								•		٠	٠				sondes
SH_Z500	•		٠									٠				sondes
SH_Z850										•			•			sondes
	T+0	T+6	T+12	T+24	T+36	T+48	T+60	T+72	T+84	T+96	+108	+120	+132	+144	+168	

H, WS00 H, W10m NH, T250 NH, T250 NH, Z500 NH, Z		T+0	1+6	T+12	T+24	T+36	T+48	T+60	T+72	T+84	T+96	T+108	T+120	T+132	T+144	T+168
H, WS00 H, W100 NH, T250 NH, T	SH_Z850			•						+)		1	*	•	٠	
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H, WS00 H, WS00 NH, T250 NH, T	SH_T500															
H, WS00 H, WS07 H, W107 NH, T250 NH, T250 NH, T250 NH, Z500 NH, Z5	SH_T250			1	٠	٠	•									
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H, WS00 H, WS07 H, W107 NH, T250 NH, T250 NH, T250 R, W250 R, W250 R, W1280 R, W1280	SH_W500													•		
H, WS00 H, W1750 NH, T250 NH,	5H_W250			E									•	•		
H, WS00 H, WS07 H, WS07 H, WS07 H, WS07 H, T7250 H, T7250 H, T250 F, W250 F, W	TR_T_2m							6		•		•				
H, WS00 H, WS07 H, W100 NH, T250 NH, T250 NH, T250 H, W220 R, W250 R,	TR_T850			v	v	*										
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H_W500	NH T250															
H_W500	H W10m															
H W500	H W850															
	H W500															

Met Office Trial results: CTRL / TR / TR_L0p1 vs. **CTRL NOIASI**

- New control trial where IASI obs are removed: CTRL NOIASI
- Test of capability of TRs to extract information from satellite instrument that is not assimilated
- No significant difference wrt assimilation of satellite radiances

RMSE against observations for Equalized, 20191215 00:00 to 20200228 12:00

% Difference (static bias lambda > 0.1 TransRet vs. static bias control no IASI) - overall 0.14%, % Difference (static bias lambda > 0.1 TransRet vs. static bias control no IASI) - overall 0.38% RMSE against ecanal for Equalized. 20191215 00:00 to 20200228 12:00

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NH_W250																AMD
NH_W500				•	٠											sond
NH_W850									٠.							Satw
H_W10m												•	•			surf
NH_T250	•	•	•													sond
NH_T500	•															sond
NH_T850														•		sond
NH_T_2m	-							•								surf
NH_Z250	•		٠			٠										sond
NH_Z500	•	•	•			٠										sond
NH_Z850																sond
TR_W250	1								•			٧	۷	٠		AMD
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TR_T250																sond
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5H_W10m					4			4		4		4	
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Exploiting more information from IR sensors

• DFSwfs for one cloud-free obs: 175 vs. 4432 IASI channels





Summary

- First detailed assessment of results from assimilation of Transformed Retrievals against direct assimilation of radiances using operational NWP system
- No significant differences in statistical distribution of analysis increments
- Information content of set of rads can be condensed in much fewer TR components
- Overall forecast skill differences from set of three-month trials < 0.05%
- Comparable skill gains when assimilating radiances or TRs from a "new" instrument (IASI)
- First tests with large number of channels indicate significant information gains can be achieved (esp. for humidity in clear sky) when considering ten-fold more channels
- Paper under review in QJRMS