

All-sky assimilation of microwave sounders at the Met Office

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Motivation

- Microwave sounding radiances are an important source of information to constrain short range forecasts
- AMSU-A radiances provide the second highest impact as measured by the FSOI over a two month period over last summer
- Obs from low peaking channels (Ch 4 and Ch 5) are discarded when significantly affected by cloud
- Strong motivation to move to all-sky assimilation of microwave sounders



Cloud-affected radiances

Cloud flags are currently rejecting most of AMSU-A channel 4 data and a significant portion
 of channel 5 data



Moisture in VAR

- Model variables: u, v, w, θ , Π , ρ , q, q_{cl} , q_{cf} , C_{l} , C_{f} , C_{t}
- Perturb. forecast (PF) model vars: (u', v', w', θ ', Π ', ρ ', q_c ') = w'
- w' components not independent: we need uncorrelated v_p and transform U_p such that w' = $U_p v_p$
- Met Office CVs: $\mathbf{v}_p = (\psi', \chi', p^{A'}, \mu') =$ stream function, velocity potential, unbalanced pressure, humidity variable
- μ' proportional to rh'_ (q'_) close to (away from) saturation: temperature-sensitive obs preserve cloud when $\mu'{=}0$
- Parameter transform \mathbf{U}_{p} determines q'_{T} from μ'

Partitioning the moisture increments (1/2)

Single moist CV requires an operator to distribute total water increments so as to pass them to obs
operator and prognostic models: liquid increments

$$q_{cl}' = C_l(q_T' - q_{cf}' - q_s') \cong C_l(q_T' - q_{cf}' - q_s \frac{\partial \ln e_s}{\partial T}T')$$

$$q_{cl}' \cong \frac{C_l(1-C_f)}{1-C_lC_f} \left(q_T' - q_s \frac{d\ln(e_s(T))}{dT} T' \right)$$

$$C_l^{eff} \equiv \frac{C_l(1 - C_f)}{1 - C_l C_f}$$

$$(q_{cl}')_{diag} \cong a(z_l, \delta_{rh})q_{cl}'$$

Migliorini, Lorenc and Bell (2017), QJRMS

1.0 1.0 0.5 0.5 0.0 -0.5 -1.0-1.0-1. -1.5-2.0-4 -3 -2 -1 0 1 $0.6 < rh_T < 0.65$; a = 0.160 -4 -3 -2 -1 0 10.65 < $rh_T < 0.7$; a = 0.143 -4 -3 -2 -1 0 1 $0.7 < rh_T < 0.75$; a = 0.145 1.0 0.5 -0.5 -1.0-1.0 -1.5-1.5 -1. q_{ci} -4 -3 -2 -1 0 1 0.75 $< rh_T < 0.8$; a = 0.139 -4 -3 -2 -1 0 10.8 < rh_T < 0.85; a = 0.141 -4 -3 -2 -1 0 10.85 $< rh_T < 0.9$; a = 0.145 1.0 1.0 0.5 0.5 0.0 0.0 -0.5-0.5 -0. -1.0-1.0-1.0-1.5-2.0 -4 -3 -2 -1 0 1 0.9 $< rh_{T} < 0.95$; a = 0.156 -4 -3 -2 -1 0 1 0.95 $< rh_T < 1.0$; a = 0.199 -3 -2 -1 0 $rh_T > 1$; a = 0.487 1.0 1.0 0.5 0.5 0.5 0.0 0.0 -0.5 -0.5 -0.5 -1.0-1.0-1.0-1.3 -1.5 $C_l^{eff}(q_{I'}' - q_s \frac{d \ln(e_s(T))}{dT} I')$ -4 -3 -2 -1 0 -4 -3 -2 -1 Ô

Partitioning the moisture increments (2/2)

Single moist CV requires an operator to distribute total water increments so as to pass them to obs
operator and prognostic models: ice increments

$$q'_{cf} = C_{f}(q'_{T} - q'_{cf} - q'_{s}) \cong C_{f}(q'_{T} - q'_{cf} - q_{s}\frac{\partial \ln e_{s}}{\partial T}T')$$

$$q'_{cf} \cong \frac{C_{f}(1 - C_{l})}{1 - C_{l}C_{f}} \left(q'_{T} - q_{s}\frac{d\ln(e_{s}(T))}{dT}T'\right)$$

$$C_{f}^{eff} \equiv \frac{C_{f}(1 - C_{l})}{1 - C_{l}C_{f}}$$

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Migliorini, Lorenc and Bell (2017), QJRMS

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 (q'_{ct})

Uncertainties in the presence of cloud

- A monitoring experiment was set up to evaluate errors for AMSU-A Ch 4 and Ch 5 observations affected by cloud. To this end, the data assimilation system was modified to perform radiance calculations on model rather than on standard levels.
- LWP retrieved from both real and simulated AMSU-A Ch1 and Ch2 observations (Weng et al., 2003)







0.000

0.025

0.050

0.075

0.100

0.125

0.150

0.175

0.200

0.225

Cloud-dependent errors

- · Evidence of non-linear dependence of the innovation distributions on average LWP
- Also significant biases esp. at low LWP values (but no VarBC corrections on data)
- · Stddev of innovations are still well approximated by piece-wise linear relationship in avg LWP



Innovation distribution

- Innov distrib for non-raining scenes noticeably non-Gaussian (K-L distance from Gaussian: d_{KL}= 0.1681) compared to clear-sky only (d_{KL}= 0.0336).
- Normalization by cloud-dependent errors still does not ease non-Gaussianities (d_{KL}= 0.1629)
- Significant improvements for clear plus cloudy scenes with 0.1 kg/m2 \leq LWP \leq 0.375 kg/m2 (d_{KL}= 0.0288)



Single-ob experiment

- Analysis increments from assimilation
 of a single cloudy scene
- Radiances from MHS Ch3 and Ch4, AMSU-A Ch6 and Ch8 to Ch14 on Metop-B (CTRL) compared to those obtained when AMSU-A Ch4 and Ch5 radiances (normally discarded in the presence of cloud) were also assimilated (Exp)



Trial experiment

- Trial experiment from 15 November 2016 0600 UTC to 20 February 2017 1200 UTC
- RTTOV on model levels; new moisture incrementing operator; non-zero jacobian wrt clw for ATOVS; all-sky (nonprecipitating) AMSU-A Ch5; Ch4 with 0.1 kg/m2 < LWP < 0.375 kg/m2



Trial experiment

Total number of obs



Trial experiment

Satellite data innovations



Trial experiment

• In situ data innovations



Score cards

- Change in RMSE (green: smaller than control) against EC analyses (left) and against obs (right)
- Max RMSE diff = max triangle area: 20%
- Shading when diff
 significant at 0.05 level
- Meso: over the UKV domain

% Difference (all-sky modlevs vs. OS39) Change in RMSE against observations for 20161125-20170220

							max	= 2	0					
NH_PMSL	•	•	•				•					•	•	
NH_W250							÷				•	٠	•	
NH_W850	•											•	*	
NH_W10m	*	•	•					•			•	•	•	•
NH_T250	•	•	۷	٣					•		•		•	•
NH_T850	•								•			•	•	
NH_T_2m														
NH_Z500							4					•	•	
TR_W250	•								•	٠				
TR_W850	▼													
TR_W10m														
TR_T250	•						4	4						
TR_T850	▼	•	•						•	•	•		٠	
TR_T_2m	•		•											
SH_PMSL	•	v							٠	۲	•	•		
SH_W250	•	•	۲	▼	▼	▼	•	•		•		۲	٠	
SH_W850	•	•					•			*	•	•	•	
SH_W10m	۷	•									•			
SH_T250	▼	•	•				•		•			•	•	
SH_T850	•			•	•	•			٠	٠	۲	٠	۲	
SH_T_2m	•		•		•	•					•		•	
SH_Z500	4	4	4	4	4				•		٠	•	•	
Meso_PMSL	*	•		*				۲	۲	▼	▼	۲	٠	٠
Meso_W250	•	•	۷				۲	•		۲	•	۲	۲	
Meso_W850	▼	•								۲	۲	۲	۲	٠
Meso_W10m				•					•		۲	۲	•	•
Meso_T250	▼	▼	▼	•		•		٠	▼	۲	۲		۲	▼
Meso_T850	•			4					۷			۲		•
Meso_T_2m	•		•					٠	•		۲	▼	٠	
Meso_Z500			4		4	4		•	▼	▼	▼	•	۲	•
	T+0	T+6	T+12	T+24	T+36	T+48	T+60	T+72	T+84	T+96	T+108	T+120	F+132	Γ+144

% Difference (all-sky modlevs vs. OS39) Change in RMSE against ECMWF analyses for 20161125-20170220

							max	= 2	0					
NH_PMSL													1	1
NH_W250													*	
NH_W850						•								
NH_W10m														
NH_T250			۸					÷			•		•	
NH_T850								•	•				•	
NH_T_2m														
NH_Z500			•										•	•
TR_W250			٠						•	•				
TR_W850														
TR_W10m							٠						•	
TR_T250												4		
TR_T850			4				4	۸	4	۸				
TR_T_2m		▼	۷	▼	•	۷	۷			٠	•	٣	٠	v
SH_PMSL			٠									•	٠	۲
SH_W250			•									·	•	•
SH_W850										•	•	·	•	٠
SH_W10m										•	•	•	•	٠
SH_T250			1.		•	۷	۷		•	٠	•	٠	•	٠
SH_T850			4			•	۲		·	•	•	÷	•	
SH_T_2m		٣		٣		•	٠	•	·					
SH_Z500			۷						÷	•	•	٠	۲	۲
Meso_PMSL								٠	▼	▼	•	۲	•	•
Meso_W250			۷			•	۲	٠	٠	۲	٠	٠	٠	
Meso_W850			•			•	•	•	÷	۲	•	۲	•	•
Meso_W10m						٠	•	•		٠	V	V	•	•
Meso_T250			▼			•	۲	▼	۲	۲	•	٠	۲	▼
Meso_T850							•	•	٠	۲	٠	۲		
Meso_T_2m								+	•		¥	▼	٠	
Meso_Z500			٠	•			٠	▼	▼	V	▼	V	۲	
-	T+0	T+6	T+12	T+24	T+36	T+48	T+60	T+72	T+84	T+96	T+108	T+120	T+132	Γ+144

Verification

• Global NWP index: +0.126% (obs) +0.187% (EC ana)

VAR TRIAL: all-sky modlevs against CTRL (winter trial) VERIFICATION VS OBSERVATIONS FROM 20161125 TO 20170220 SOUTHERN HEMISPHERE



	СН	AN	GE n	IN na:	1 S K =	KIL = 0.	L S	SCO	ORE
PMSL	Г								
H500	•								•
W250									•
W850									
W700									•
W500									•
W100									•
W50	•								
H850						•			•
H700									•
H250	•								•
H100			•	•		•			
H50	•	٠			٠				•
T850	•			•					
T700									
T500						•			•
T250									•
T100	•								•
T50	•								•
RH850	•								
RH700	•		÷						
RH500	•	÷	·			•			
	T+12	T+24	T+36	T+48	T+60	T+72	T+96	T+120	T+144

VAR TRIAL: all-sky modlevs against CTRL (winter trial) VERIFICATION VS ANALYSIS FROM 20161125 TO 20170220 SOUTHERN HEMISPHERE

PER	CE	NI	AG	iE (СН	AN	GE		I R	MSE
	_	ma	X =	= 5	(g	re	y =	= 2)	
PMSL	۰							۲		
H500	۲		۲	۲	۲		۲			
W250	۲			۲	۲	۲		٠	٠	
W850	۲			۲				٠	۲	
W700								٠	•	
W500					٠				٠	
W100	•			٠	۲		٠			
W50						۲			٠	
H850	•					•				
H700	•									
H250						۲				
H100	٠						۲	٠		
H50										1
T850				•	٠	٠	•	٠	•	
T700	•		•					٠		
T500					۲			٠	•	
T250			۲	۲	۲	٠	۲	۲	۲	
T100										
T50		Ö			Ъ			۲	٠	
RH850				۲	٠					1
RH700										
RH500	۲									
	L2	54	36	8	00	22	90	20	4	
	Ŧ	±	ž	ž	ž	£	£	Ŧ	+17	
								É.	É.	

	СН	AN	GE	IN na:	15		L S 1	SCO	ORE
PMSL	Г						-		•
H500									
W250									
W850									
W700									
W500	-								
W100									
W50	•								
H850									•
H700									
H250									
H100									
H50					•	-	٠		٠
T850	Ŀ	÷				•			
T700									
T500	•								
T250								•	•
T100	•						÷		
T50					•	•			
RH850	•	•							
RH700	•								
RH500									
	T+12	T+24	T+36	T+48	T+60	T+72	T+96	+120	+144

Verification: EC (NH)







68% error bars calculated using S/(n-1)**

68% error bars calculated using S/(n-1)**

68% error bars calculated using S/(n-1)"

Verification: EC (TR)



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Verification: EC (SH)



68% error bars calculated using S/(n-1)"





68% error bars calculated using S/(n-1)"

68% error bars calculated using S/(n-1)**

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Verification: MSLP (v own analyses)



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Verification: in situ (NH)



Verification: in situ (TR)



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Verification: in situ (SH)



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Conclusions and future work

- A pre-operational system that allows cloud affected radiances from AMSU-A to be assimilated alongside those in clear sky is being developed at the Met Office
- Results from a three-month trial show that the assimilation of non-precipitating radiances form AMSU-A Ch 4 and Ch5 has an overall neutral impact on the control run
- There are, however, consistent RMSE reductions in key indicators (TR T250, TR W850, NH PMSL, NH T2m, NH/SH H500).
- We are also planning to test the assimilation of MHS Ch 4 and Ch 5 in all-sky conditions in the UKV limited area model using hourly 4D-Var cycles, with radiances simulated using RTTOVSCATT.
- On a longer timescale we will consider minimization tests with a succession of linearization states (i.e. the so-called "outer loop") for all-sky trials.