

Met Office highlights using GNSS-RO for NWP

Neill Bowler

Owen Lewis, Mary Forsythe, Gemma Halloran Hailing Zhang (COSMIC / JCSDA)

Crown Copyright 2017, Met Office

www.metoffice.gov.uk

Contents

- NRT monitoring
- Visiting scientist quality control
- Observations with greatest impact
- ROMEX
- Vertical smoothing
- Conclusion



NRT monitoring



- Provides monitoring graphs of a variety of satellites
- Main work has been in reforming parallelism
 - Previously parallel in python
 - Now separate tasks in workflow
 - More reliable, better with large data

https://rom-saf.eumetsat.int/monitoring/index.php

Visiting scientist – Quality Control

- Hailing Zhang visited Met Office in Oct-Nov 2023
 - Continued working part-time over winter / spring
 - Report ready for review
- Variety of QC methods coded into JEDI
- Common framework for testing QC methods
 - Background forecast from Met Office operations
 - Using Met Office operator (modified)
 - Same observations for all QC methods
 - Common preliminary QC checks
- Focused on super-refraction

S1	Check for sharp refractivity gradients and its second derivative in the observations	$\frac{dN}{dz} > -0.05 \text{ N m}^{-1}$ $\frac{dN}{dz} < -10^{-6} \text{ N m}^{-1}$ $\left \frac{d^2N}{dz^2}\right < 10^{-4} \text{ N}^{-2} \text{ m}^{-2}$ $\frac{dN}{dz} \neq 0$	MF	Any threshold is violated
S2	Check difference between the maximum and minimum of simulated bending angles in a 1 km layer.	max(α _{model}) – min(α _{model})	NRL	> 0.005 rad
S3	2-step methods based on the modelled refractivity gradient	at level k, and IH _{obs} \leq 5km <i>a.</i> $\left \frac{dN}{dx}\right > 0.75 \text{ CRV}$ <i>b.</i> $\left \frac{dN}{dx}\right > 0.5 \text{ CRV}$ and max(α_{obs}) \geq 0.03 rad	NCEP	 a. reject observations whose impact parameter ≤ IH_{model}(k+5) b. reject observations below the profile maximum
S4	Check the vertical difference of the modelled impact parameter between a given layer and the one below	dx	ECMWF /UKMO	> 10 m
S5	Check the vertical gradient of the modelled refractivity is above some thresholds.	$\frac{dN}{dz}$		< –0.08 N m ⁻¹ +500m 0 5 CRV

Super-refraction – average SR height



- MF and NRL give highest average SR height
- NBAM and MO similar
- Impact parameter check gives lowest SR heights
- Observations from COSMIC-2

Super-refraction – observation rejection rate



- NBAM, Impp and MO all show maximum rejection in marine stratocumulus regions
- MF and NRL reject most observations over broader area

Super-refraction – average SR height



- Similar patterns seen for Metop
 - Noisier, since fewer observations
- Increased SR height over Greenland & Antarctica

Effect of refractivity gradient threshold







- Control: assimilate operational GNSS-RO observations
- Experiment 1: add high-volume Spire observations
- Experiment 2: add high-volume Spire observations, excluding 15-25 km

Experiment 1

Experiment 2





- Third experiment
 - Add all Spire observations above 7km
- Impact similar to allobs experiment, but degraded RMSE in certain regions

Experiment 1

Experiment 3

Wind (m/s) @ 500hPa, Northern Hemisphere (CBS area 90N-18.75N), Equalized and Meaned between 20211022 00:00 and 20220122 12:00, Analysis, 1.5deg grid



± 1 standard error bars calculated assuming independent observations

- Almost no impact from adding lots of Spire observations below 15km and above 25km
- Removing tropospheric obs also causes degradation
- Tropospheric obs: useless on their own, but helpful in combination?



ROMEX

ROMEX – all obs

	SH_Z850	SH 2500	SH 2250			SH_T850	SH_T500	SH_1250	SH_T100	SH_T50	SH_W10m	058M_HS	SH_W200	SH_W250	OLM_HS	SH_M20	TR_T_2m	TR_T850	TR_T500	TR_T250	TR_T100	TR_T50	TR_W10m	TR_W850	TR_W500	TR_W250	TR W100	TR W50	NH_2820	NH_2200	NH 2250	001Z HN	NH Z50		NH_1500	UCZI HN	NH_T100	NH_T50	NH_W10m	NH0	NH W500	NH W250	NH W50	
T+0							1																-												1	1 1 2	-							1
T+6		-	1																											_	4													
1+12	▶ <	4	Ķ	<		P.,	Þ		•	4			•		⊲	-		Þ	►	►	•	Þ		n il molite			> 1		< <				◄	Þ		►		٩			4	4 .	•	
1+24	• <	<<	<	<		Þ		4	•	⊲		•	•	-		4		►	►	•		•				۱.	> I		۹ •	٩.	4		◄	1	•		1 1	٩			•	4 •		
T+36	•	< <	<<	<		►	.4	4		4		-	Þ	٩	-	1		►	►	٩	٩	•				• 1	Þ :	•	4	◄	<	\triangleleft	⊲		 - Jame	4	4	4		- 1	•	۹ ۲		
T+48	•	< <	<	1<		►	đ	\triangleleft	4	4		0.	•	4	•	4		►	►	۹	4	•		0	-	1	•	•	⊲	۹	◄	\triangleleft	⊲		- 1	4	4	٩			•	4	•	
T+60		⊲ ∘	<<	1<		►	a	<	4	-		P	8	4	4	•		►	₽	۹	۹	•		•	4	4	•		<	۹.	◄	<	◄			4	4	4		4	-10	4	1.0	l la
T+72		-	<<	1<		Þ	4	4	4			1		4	-	4		►	Þ	4	4				4	• 1	•		4		4	<	4		1	4	4	4		-		4		1×.
T+84	• • • •)•••	4	< <	1<	1	Þ		4	4	4			ñ •	4	- 41	4			•	4	4			-	4	4	•		<	4	4	<	⊲	-	1 1	4	4	4			-	<	4 4	N.
T+96	e e a ber	4	< <	1 <			9		4	4		0000 0		(i	4	•				4	4			4	4	4			4	4	4	<	4	1	-loor 4	4	4	4		4	4	4	4 4	0
T+108	n m njeme	- 2		1 <		-		•	•	4		8 0 0 F		loor A	4	-		•		⊲	•	1 m r		-	4	4			<	4	4	<	<	-		4	•	•		4	4	4	4 4	1
T+120	nanjer	- in the second se	~ <	1 -			france and	4	4			nmn Pr	P	lan na na	-	în mini		•		4	4			-		4			4	4	4	<	4	1	4	4	4	•		-			4	1
T+132	o n allere	nolle		1			-	4	4				li enere	000	leen	000 •		•		<	4	0 m c -11		-	4	4	-			n oộc 4 8	4	<	4	105			•	4			00 0000 00 000		4	1
T+144	onnije.	-		1			fre me	1000	-				hrame b	1	home	in mn				•	4			n nfhe	4	4			- dia	aobr	4	4	4		1000	hom		4		- al	n often nije			
T+168																																-												
100																																				_			_			_		1
	an		an	a	an	ar	ar	ar	ar	an	ar	ar	ar	an	an	ar	ar	ar	ar	ar	ar	ar	an	2	2	n n	מ ע	n a		n r	P I		ם יי	an	ar	an	ar	ar	ar	an	2 2	1 9	an	

% Difference (ROMEX all obs vs. ROMEX control) - overall -1.37%, RMSE against ecanal for Equalized, 20220902 00:00 to 20221201 12:00

- Change in RMSE measured against ECMWF operational analyses
- Assimilating all observations, compared with control

Stratosphere bias correction



- Global statistics indicate -0.05% bias in lower stratosphere
- Add 0.05% to all observed bending angles
- Additional x2 experiment

Bias – geopotential 500 hPa

Geopotential Height (m) @ 500hPa, Northern Hemisphere (CBS area 90N-18.75N), Equalized and Meaned between 20220901 00:00 and 20221201 12:00, ECMWF_Analysis, 1.5deg grid



± 1 standard error bars calculated assuming independent observations

- No change in bias from:
 - Applying bias correction in lower troposphere
 - Applying vertical smoothing
- Effective bias correction from:
 - Applying bias correction to all bending angles (increase by 0.05% or 0.1%)
- Expect similar effect from reducing k₁ coefficient

רר

ROMEX – all obs (bias correction x2)

– – – – –

כככ

ככ

	0587_HS			SH 7350		SH Z50						WDT M HS	DGRM_HS	SH_W200		ODT M HS		TR_T_2m	TR_T850	TR_T500	TR_T250	TR_T100	TR_T50	TR_W10m	TR_W850	TR_W500	TR_W250	TR W100	TR W50	NH 7850			NH Z50	NH_T_2m	NH T850	NH_1200	NH_T250	NH_TI00	NH T50	MH W10m	NH W/850	NH W500		NH W50	
T+0										1																													1		1			1	1
T+6																																													
T+12		-	Þ		< >			►	►	►	<	1	٠	•	•	<	-		Þ	~	▶		►		•	Þ	•	Þ	•		e ĝ. 🖷	-	\leq	1	•	> 1	>	4	4			• •		►	
T+24	◄	₽	Þ	•	۹.		Þ	►	►	►	<	٩	٠	►	►	-	•		►	٠	►	4	►		•	•	•	• •	•	• •	•	►	<		•	>	>		۹			•			
T+36	4	►	Þ		<	4	Þ	►		•		•	٠	►	•		-		►	4	►	۹	•		•	Þ	•	Þ	•	•		: e	\triangleleft		•	•	>		٩			•	•		
T+48	٩	►	Þ		◄	٩	Þ	►				•	٠	►		•	1		►	٩	►	٩	•		•	•	•	• •		►		<	\triangleleft		•	•	•	۹	۹			•	4	1	
T+60	4	₽	Þ	•	9 °	•	Þ	►	-	•	1		Þ	₽		1.	-		Þ	۹	►	۹	•			•	-	•	•		1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	<	\triangleleft		P 0		•	4	۹		1.0	- 10 - 10	4 ⁰ / ₀ ·	8 8	na
T+72	٦	•	Þ		•	-4	Þ	Þ		1.	1			₽	•		1		•	۹	Þ		•		•		4	• •				<	\triangleleft		•	•	N	4	4		•	•			lĩ.
T+84	×.	<u>}</u>	2.	n n		-	Þ	₽		n -				₽	٠	ñ.,	-		•	۹	►	4	•		*	•		•		÷.	n n •	<	\triangleleft		•	, n n	•	4	۹		- 1 -	- 6 -		й п. н	N
T+96	•	٠	i e		•	4	•		1	4	-			٠	ŀ	4	1 4		•	٩	►	٠			• [•	•	•		-		<	\triangleleft		Þ	• [4	۹		. [•	•	4 A	•	10
T+108	•		2.0	п п п	•		•	-		п -1				٠		10000				٩	۲	4	4		 n n	•	4	•			п. н.		<		•	•	-	4	٩					•	
T+120	۳	٠	1		•	F.		•					Þ	Þ			i P			٩	Þ	•			•	•	-9					1 4	◄		₽ Î	•	•	4	•				1		
T+132		ê 🕨		8	0	•		0 1 ►		8				►		ê 🕨	: -			٩					* 0 0	*	41 B B				8		◄		P 8	• B B	•	æ	•			н 8 н	1	8	
T+144	•	•	1		1	•			•				-	۲						4	٠	-	٠				4					1.4	⊲		•	•	• [,	٩			• •		4	
T+168																																													
		0						01	01	01	01	01	01	01		01	n,	01		01	01	01	01	01	01	01 0	51 0	11 0		ເດ	0	01	01	01	51 0			01							

- Change in RMSE measured against ECMWF operational analyses
- Assimilating all observations, compared with control

(ROMEX all obs bias corect everywhere 2 vs. ROMEX control) -RMSE against ecanal for Equalized, 20220902 00:00 to 20221201 12:00

overall 0.07%

 Applying bias correction to all bending angles (increase by 0.1%)

Temperature (radiosondes, T+12)

Temperature (K), Northern Hemisphere (CBS area 90N-20N), T+12,

Equalized and Meaned between 20220901 00:00 and 20221201 12:00. Sondes

ROMEX control ROMEX all obs bias corect everywhere ROMEX all obs ROMEX all obs bias corect everywhere 2 Difference vs. ROMEX control Root Mean Square Error (Forecast - Observations) Root Mean Square Error (Forecast - Observations) 200 400 600 800 Pressure (hPa) 1000 1.0 1.5 2.0 -0.03-0.02-0.010.00 Mean Error (Forecast - Observations) Difference vs. ROMEX control Mean Error 200 400 600 800 1000 -0.20.0 0.2 0.4 -0.100.15 -0.050.00 0.05 0.10

± 1 standard error bars calculated assuming independent observations

 RMSE increased with normal observations

- RMSE reduced everywhere with bias-adjusted obs
- Temperature bias in troposphere affected
 - No change in stratosphere



Vertical smoothing

% Difference (0.75x model levels vs. Add Spire reprocessed) - overall 0.48%. Vertical smoothing – pre-processing

- Developed smoothing within Met Office preprocessing
- Applied to BUFR data, all satellites
 - Local polynomial regression with cubic polynomial
 - Cannot have too little smoothing, as LPR will not work on too few points
- Smoothing length-scale in proportion to Met Office model level spacing
- Experimented with smoothing BA and log(BA)
 - Smoothing in BA seems better

				•									
N100				•	٠	•	٠	•				1	
N250				•	٠	•	٠						
N200		•	•				•					*	
V850	•	•	•	•	•	•				٢.	Ľ.	۰.	
10m											1	۲	
_T50													
F100					٠		٠						
250													
500												ç ¢	
850							4		4				
2m													
250												77	
100											iee i t	(T	
250											iv.	Ŧ	
500									20.00		iae T	(
850		1	1				1				i.e		
N50			1		÷		-						
100		1	1		÷		÷				÷	÷	
250		-								£	ļ		
500	-				-	-	÷				ļ.	-	
250											-	L.,	
0		-	÷.,										
T50	•		ļ.,	-	-	-		-		ļ.,	ų,	÷	
130						-		-			1		
				•	۸		۸		٠	•		*	
230	A	-	•	•	•				۸		•		
500				•		•					100		
850										1.		4	
2m		Ŀ.	<u>.</u>										
V50					٠		•	•				1.	
100	4	4		٠	٠	٠		٠	4			1	
250				•	1					1			
500	•	•								<u>.</u>	1.	4	
850	•												
.0m			1.										
T50	4	-											
100	4	4	4										
250													
500											1		
350											1		
2m													
250									4		9 m m 5 . 4	5 4	
100				4							11	1	
250		-									1	[
500					÷	-					Ċ.	17	
850			1									÷	

RMSE against ecanal for Equalized, 20211023 00:00 to 20220122 00:00

Vertical smoothing – next steps

- Write up report
- Follow-on project
 - Apply smoothing to high-resolution bending angle observations
 - Would avoid "minimum" smoothing scale
 - May help to reduce biases
 - ROMEX data?
 - Experiment with super-obbing
 - Confirm results with ECMWF model
- Ultimately may want operational delivery of high-resolution data

Further work in CDOP-4

- Analysis of GS2 data from EUMETSAT Secretariat
- Provision of observation uncertainty estimates
- Testing and review Spline and PRO code
- FY-3E assessment
- Ongoing activities
 - NRT monitoring
 - Support for GBGP software

Some suggestions

- Observations in lower stratosphere have largest impact
 - Why do we not get more from tropospheric observations?
- ROMEX work packages
 - Covering current work?
 - Future experiments?
 - How valuable are observations with different equator crossing times?