Assimilation and Impact of SMOS Wind Speeds in NWP

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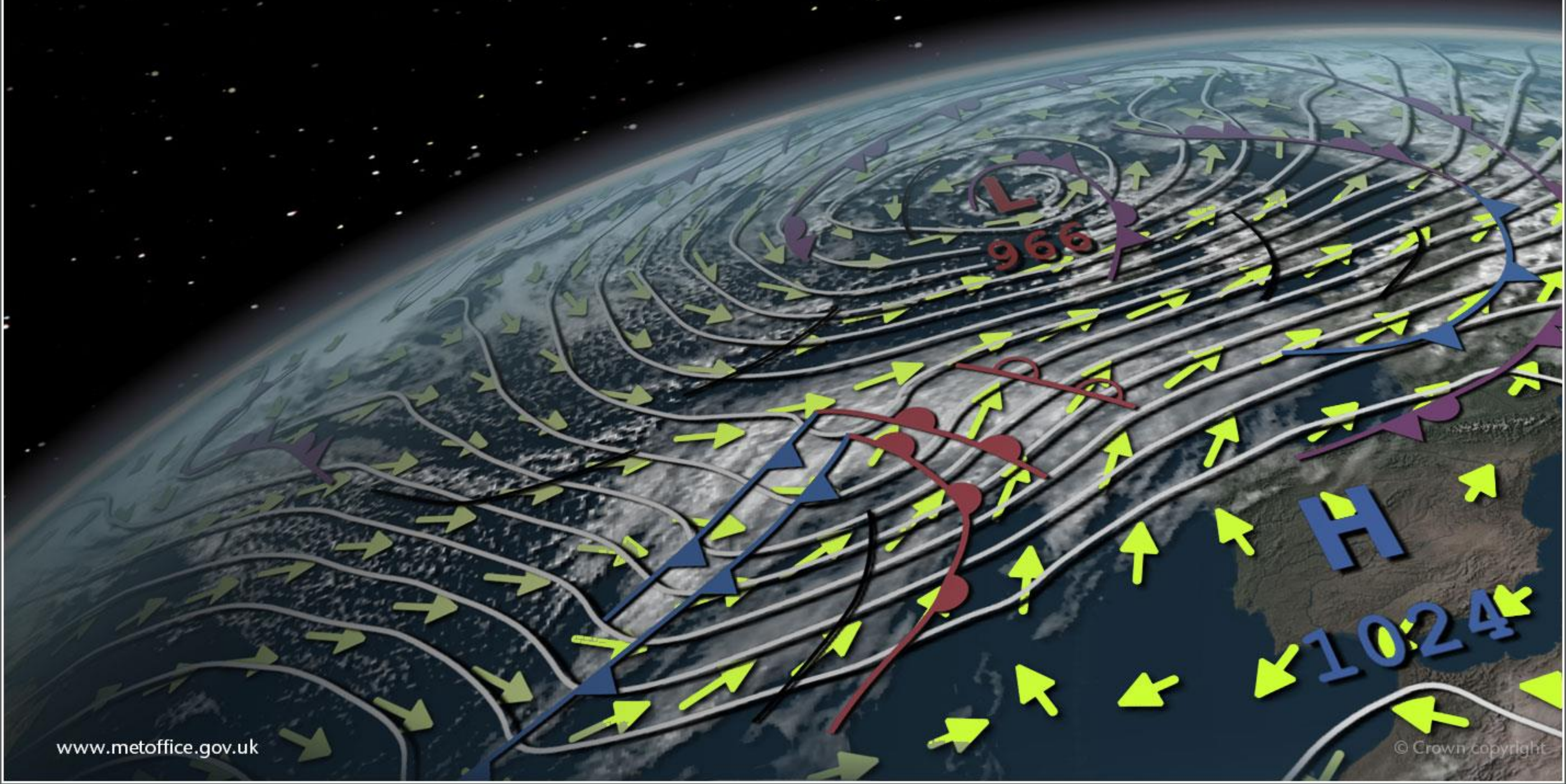

Overview

- Intro and motivation
- O-B statistics
- Assimilation Method
- Impact Experiments

.. demonstrate the performance, utility and impact of SMOS L-band measurements at high wind speeds over the ocean during Tropical and Extra-Tropical storm conditions.

Motivation

Old Model –

New Model –
(dynamical core, physics, resoln.)

TC Initialisation –
(central pressure estimates)

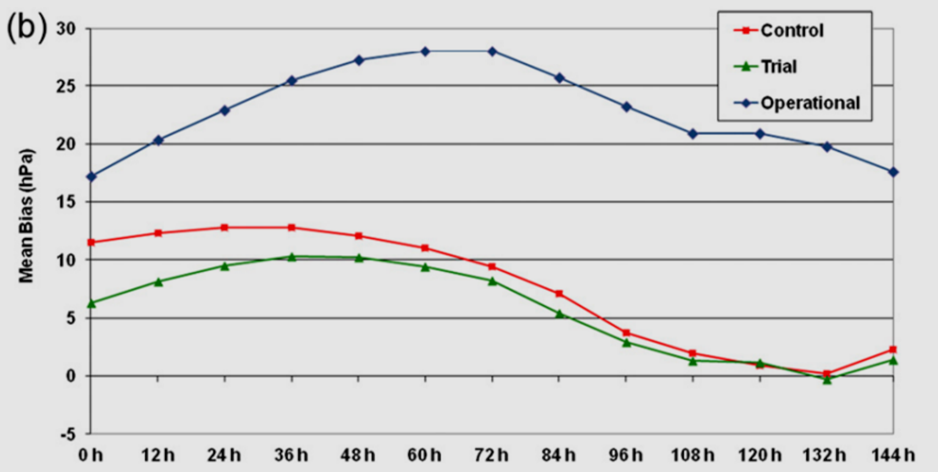

FIG. 8. (a) TC track forecast errors and (b) TC central pressure forecast bias during the trial of the 2015 scheme. The control and trial used the GA6 configuration of the MetUM. The trial included the 2015 scheme. The operational results were for an earlier model configuration.

- Upgrades in 2014 to model and 2015 to TC initialisation had large benefit on TC track and intensity forecast errors [ref. Julian Heming's talk]
- Remaining bias in analysis and short-range intensity (DA)
- ASCAT, RapidScat and WindSat provide high quality wind vectors below 25 m/s
- L-band MW radiometers have capability to complement in extreme conditions

SMOS Wind Speeds

- Capabilities: extreme conditions (complimentary), L-band (rain), 1000-km swath
- Limitations: RFI, resolution ~ 40-km (smoothing)
- Using IFREMER database of wind speeds retrieved following Reul et al. (2016) and quality flags

Reul et al. (2016). A revised L-band radio-brightness sensitivity to extreme winds under tropical cyclones: The 5 year SMOS-Storm database. Remote Sensing of Environment, 180, 274-291.

Flag	Meaning (when flag value =1)	Bit
1	Distance to coast ≤ 150 km	2
4	Temporal standard deviation of SSS > 0.8 pss	16
5	SST ≤ 0 C	32
7	Moderate RFI: average monthly RFI probability $0 < P_{RFI} \leq 25\%$	128
8	High RFI: average monthly RFI probability > 25%	256
9	Pixel multi-angular variability of Tb > 5 K	512

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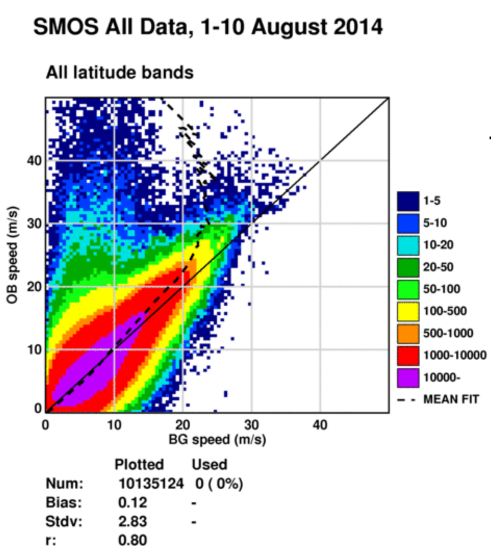
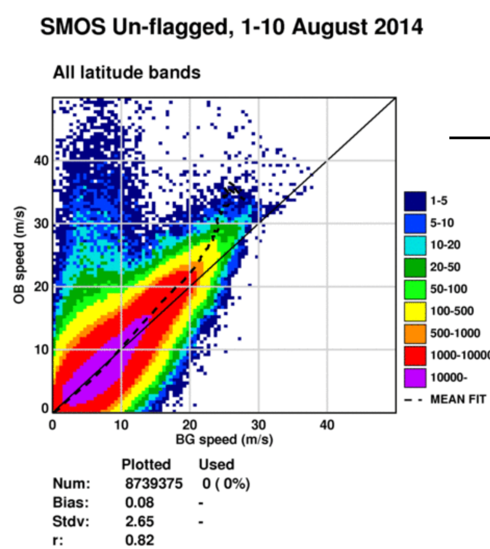
Observation – Background (O-B) Statistics

2D Histograms of OvB

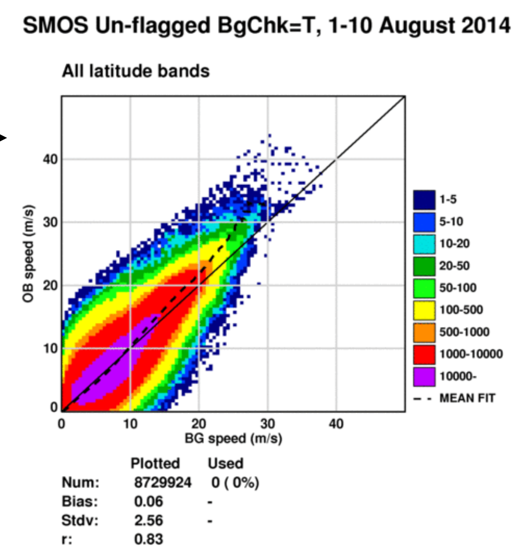
Data selection	N	%	Mean o-b m/s	STDV o-b m/s	r
All	10135124	100.0	0.12	2.83	0.80
Flagged	1395749	13.8	0.32	3.76	0.66
Un-Flagged	8739375	86.2	0.08	2.65	0.82
+ BgCheck	8729924	86.1	0.06	2.56	0.83



All Data



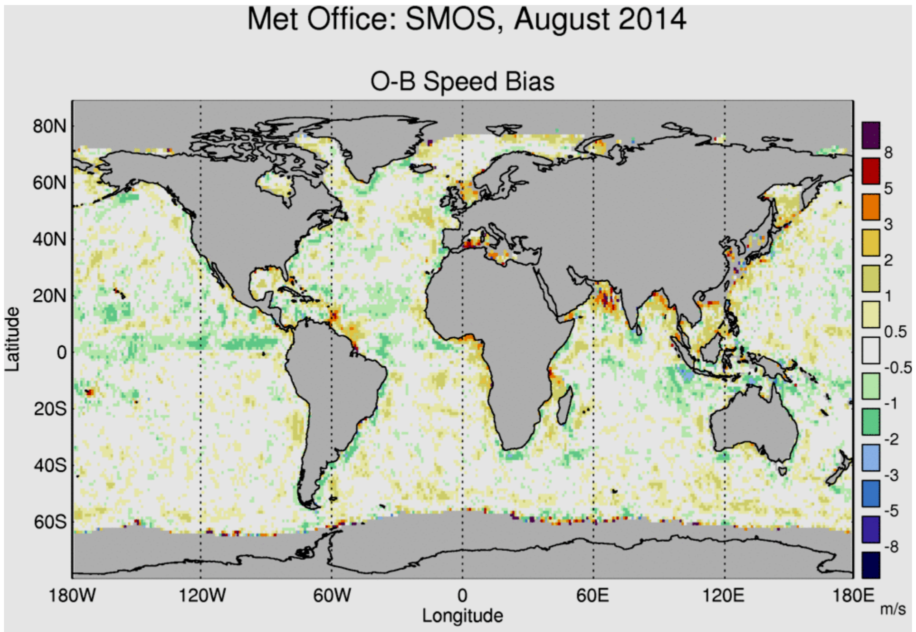
Quality Flags

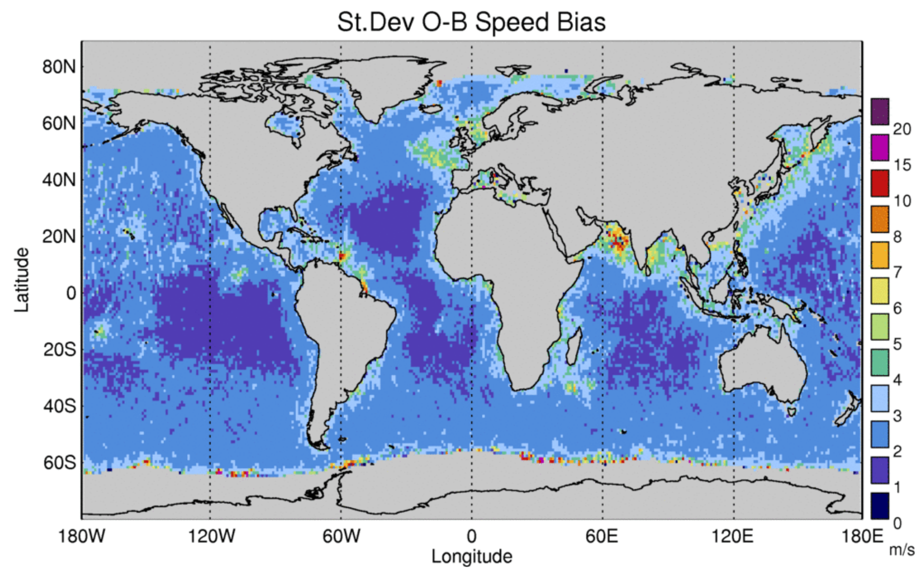


Background Check removes very large O-B innovations ('gross error')

Geographical Biases

Aug 2014, all data





Quality of SMOS retrievals reduced in the presence of,

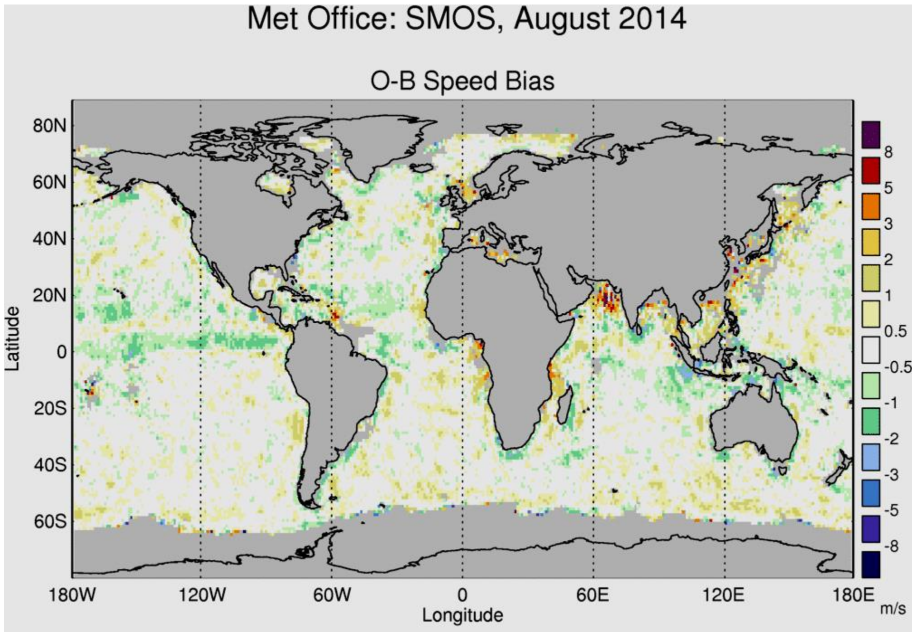
a) sea ice contamination,

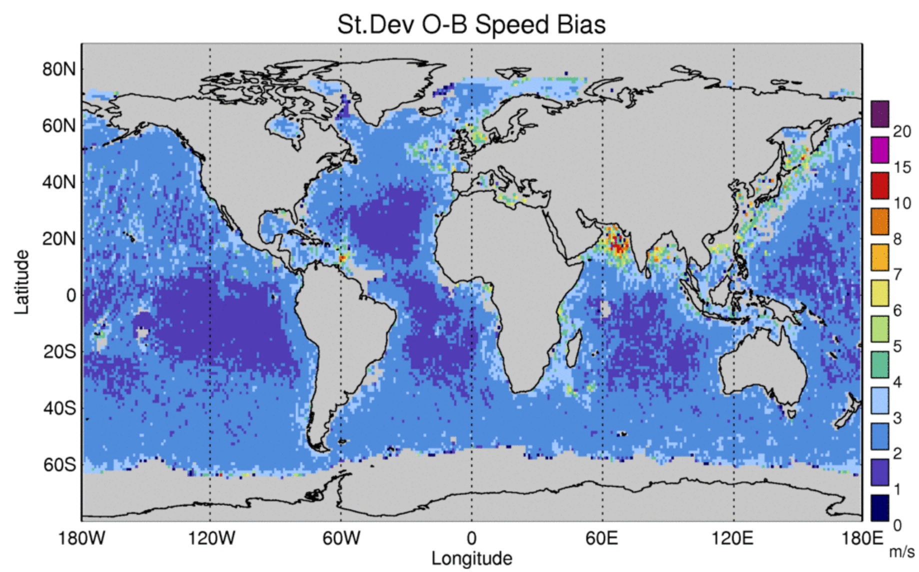
b) strong river plumes (e.g. Amazon),

c) RFI contamination (Arabian Sea, NE Atlantic and S&E Asia coasts, islands)

Geographical Biases

Aug 2014, un-flagged

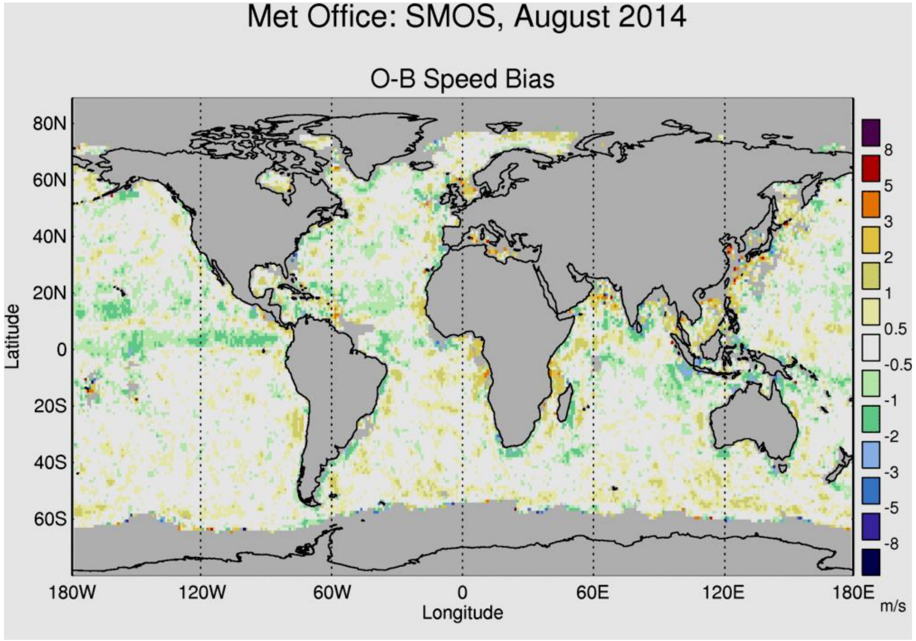


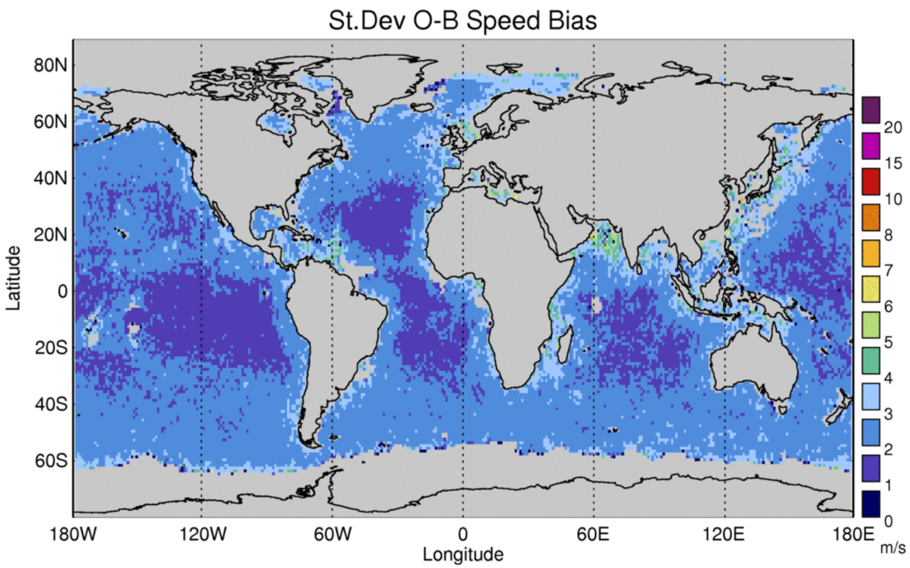


- Applying quality flag does a good job at screening for a) and b), some RFI remains (e.g. Arabian Sea)

Geographical Biases

Aug 2014, un-flagged + background check

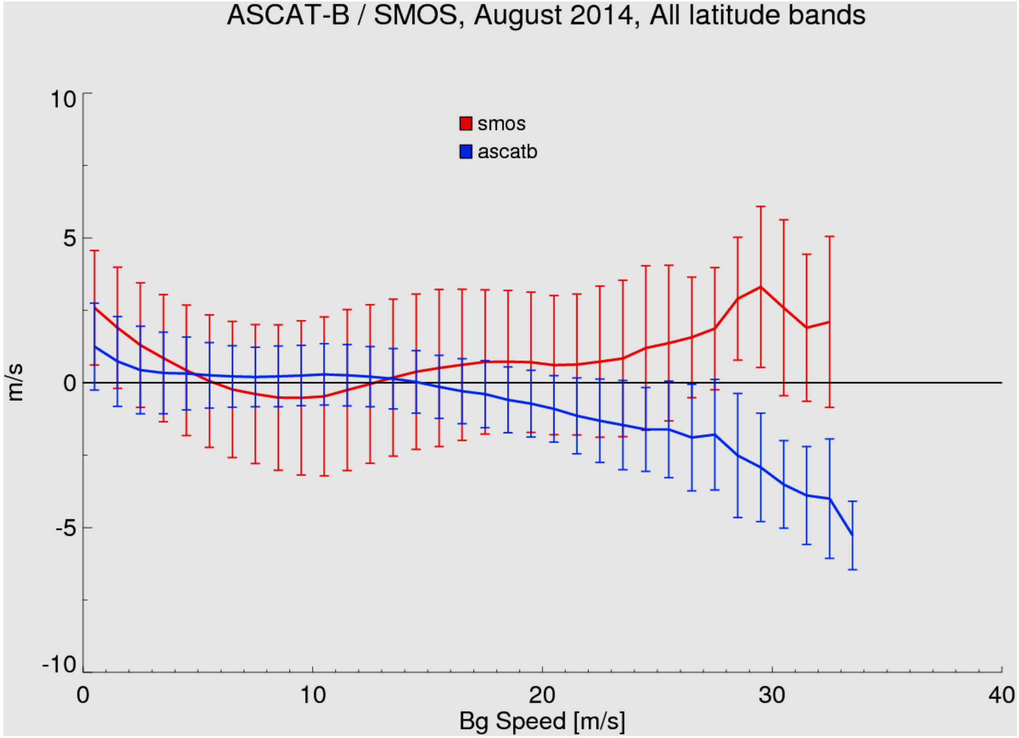




- Residual RFI contamination varies in extent by month, but can largely be cleaned up via the background check
- Spatial blacklist can also screen worst areas

O-B Wind Speed

Aug 2014, un-flagged + background check



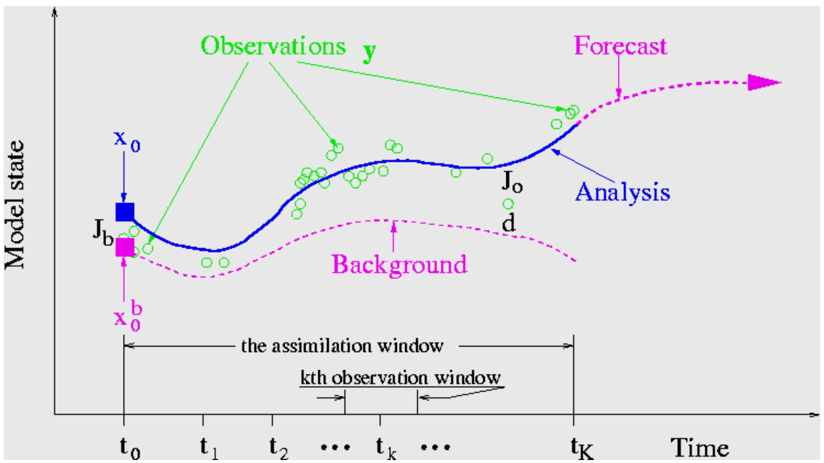
Speed	Sensor	N	Mean o-b m/s	STDV o-b m/s
< 15 m/s	ASCAT-B	13639952	0.28	1.16
	SMOS	25725754	0.02	2.44
15-20 m/s	ASCAT-B	588369	-0.32	1.12
	SMOS	1416451	0.62	2.60
20-25 m/s	ASCAT-B	47328	-1.09	1.28
	SMOS	134074	0.67	2.48
25-30 m/s	ASCAT-B	2164	-1.79	1.78
	SMOS	6837	1.65	2.39
30-35 m/s	ASCAT-B	97	-4.04	1.63
	SMOS	115	2.21	2.93
35+ m/s	ASCAT-B	8	-8.56	1.07
	SMOS	13	0.34	1.88

QC and Assimilation Method

Data assimilation

x - the model state vector
xb - the background state vector
y - the vector of observations
B - background error covariance matrix
R - observation error covariance matrix
H - observation operator

The Met Office's data assimilation scheme uses a variational method (4D-Var)



$$J = J_b + J_o$$

$$= \underbrace{\frac{1}{2}(x - x_b)^T B^{-1}(x - x_b)}_{\text{background cost}} + \underbrace{\frac{1}{2}(y - H(x))^T R^{-1}(y - H(x))}_{\text{observation cost}}$$

for departures from the model state, *x*

Finding, through successive iterations, an atmospheric state which minimises a global cost function, *J* .

Each observation to be used in forming the analysis contributes towards the minimisation of the total observation cost, J_o

SMOS WS penalty function

Observation operator, H

Surface WS is a non-linear function of the 10m zonal (u) and meridional (v) wind components

$$WS = \sqrt{{u_{10}}^2 + {v_{10}}^2}$$

Observation penalty

Quadratic function of the deviation from the latest atmospheric state, inversely weighted by the estimated observation error variance

$$J_{SMOS}(WS) = \frac{1}{2}\frac{(WS - WS_o)^2}{{\sigma_o}^2}$$

$WS =$ Latest atmospheric state of the 10m model wind speed.

Calculated using the observation operator (fully non-linear or tangent linear)

$WS_o =$ SMOS observed wind speed

$\sigma_o =$ observation error standard deviation

Impact Experiments

Experiments Overview

Each time period run a control (reference) plus several SMOS trial configurations

- Control (N320 L70 UM, N108/N216 4D-VAR, PS37 baseline, VarBC) assimilating conventional and satellite observations

Aug-Oct 2014

- Dates: 20140801 – 20141020, capture as many major TC's as possible
- TC central pressure switched **ON**
- Repeat with TC central pressure switched **OFF**

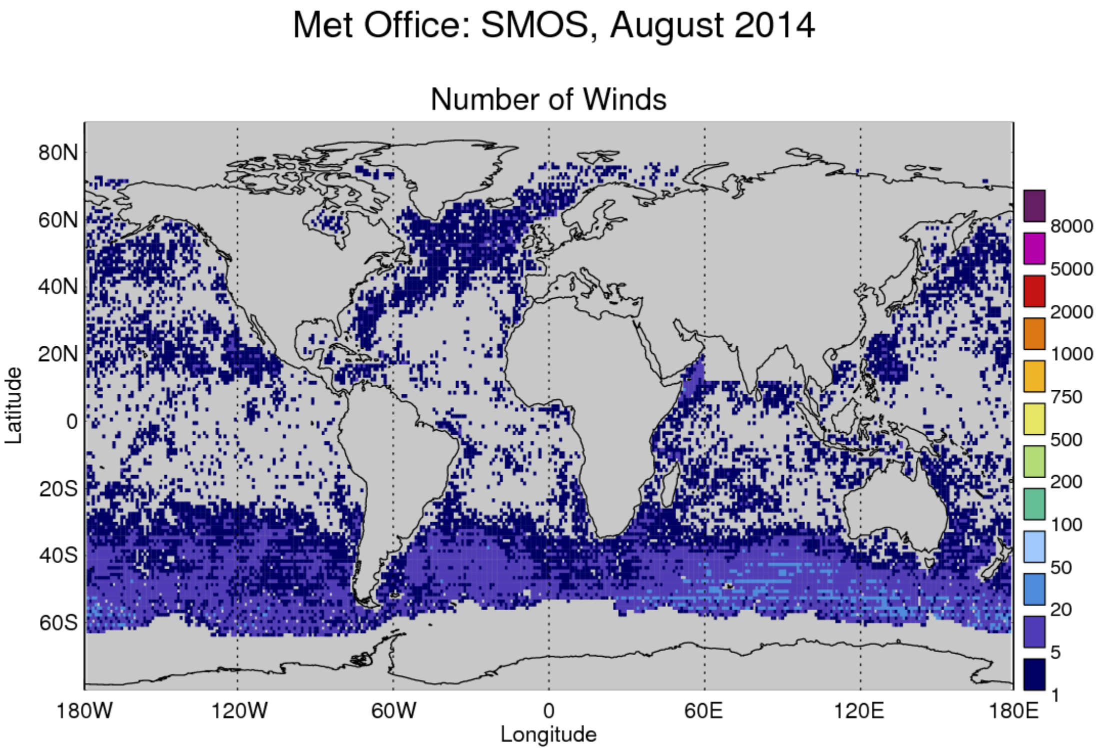
Dec 2014 – Jan 2015

- Dates: 20141201 – 20150131, NH winter

Aug-Sept 2015

- Dates: 20150820 – 20150920, Kilo/Ignacio/Jimena ('3 Brothers')
- TC central pressure switched **OFF**

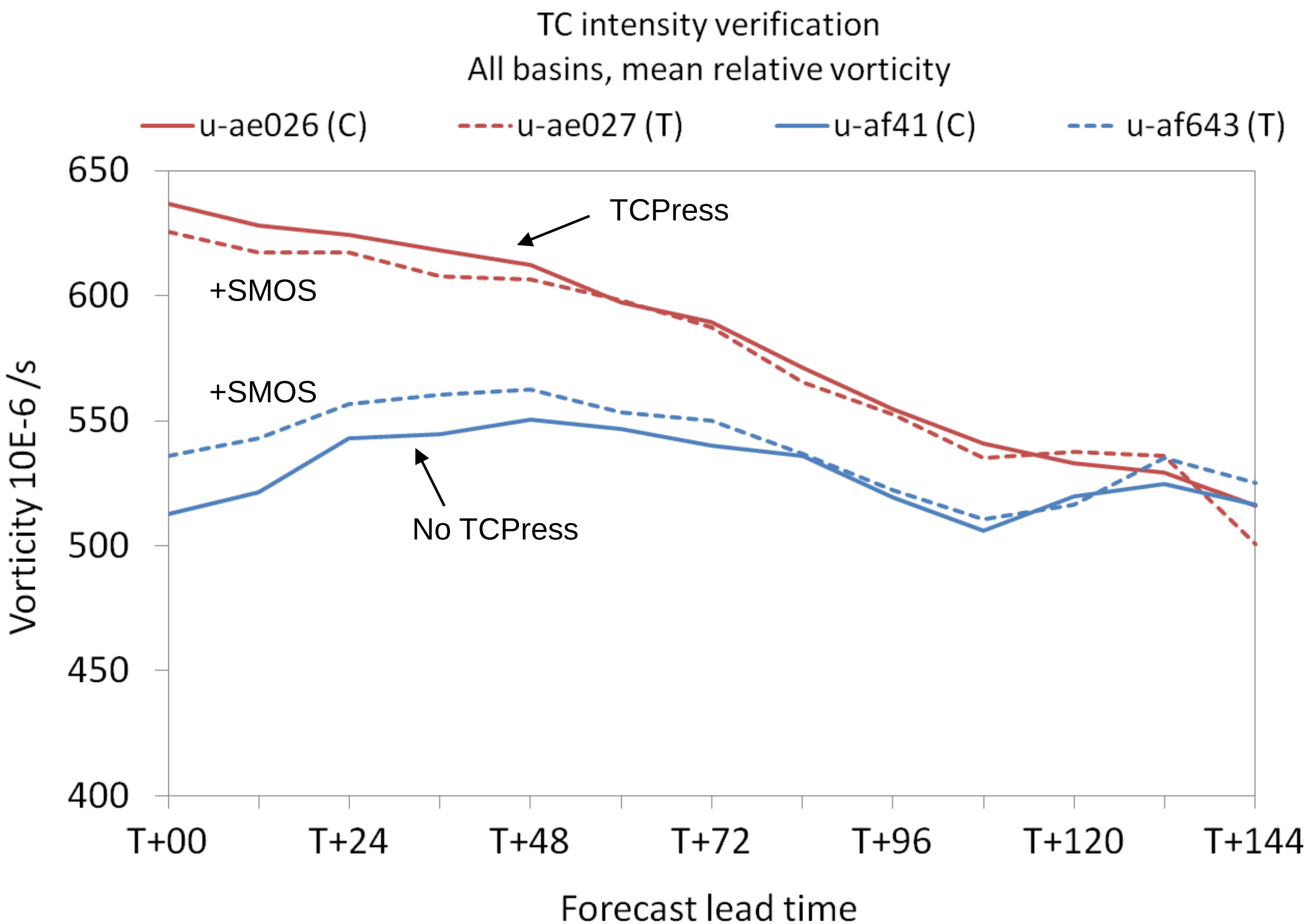
SMOS Data Use



- SMOS > 15 m/s, errors 2.25 m/s, thinning 80-km
- Average 661 SMOS wind speeds per 6-hr DA cycle

Aug-Oct 2014

SMOS impact with/without TC initialisation



vs No TCPress baseline

RV at T+0	
SMOS	+4.5%
TCPress	+24%

vs TCPress baseline

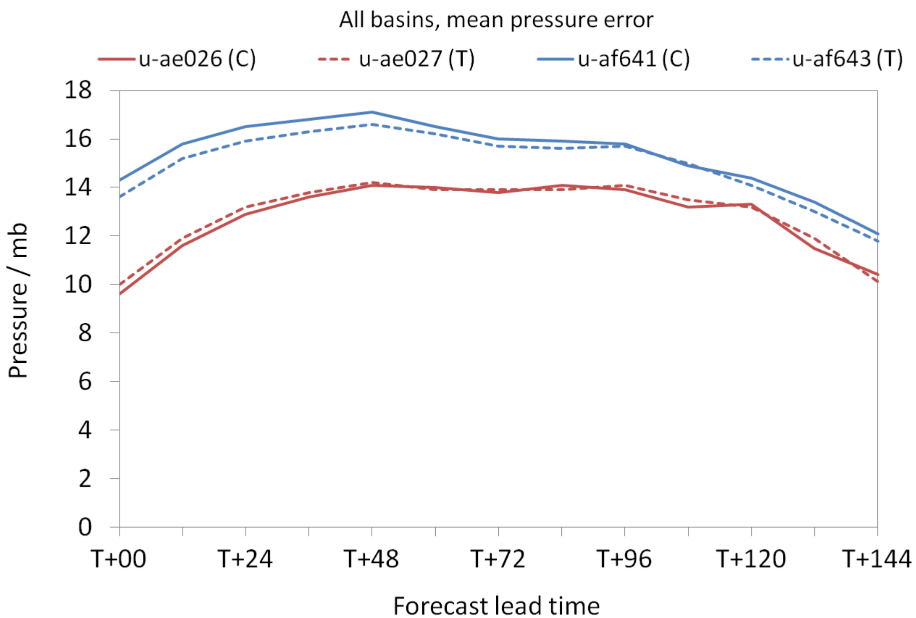
RV at T+0	
SMOS	-1.7%

MAE = mean absolute error

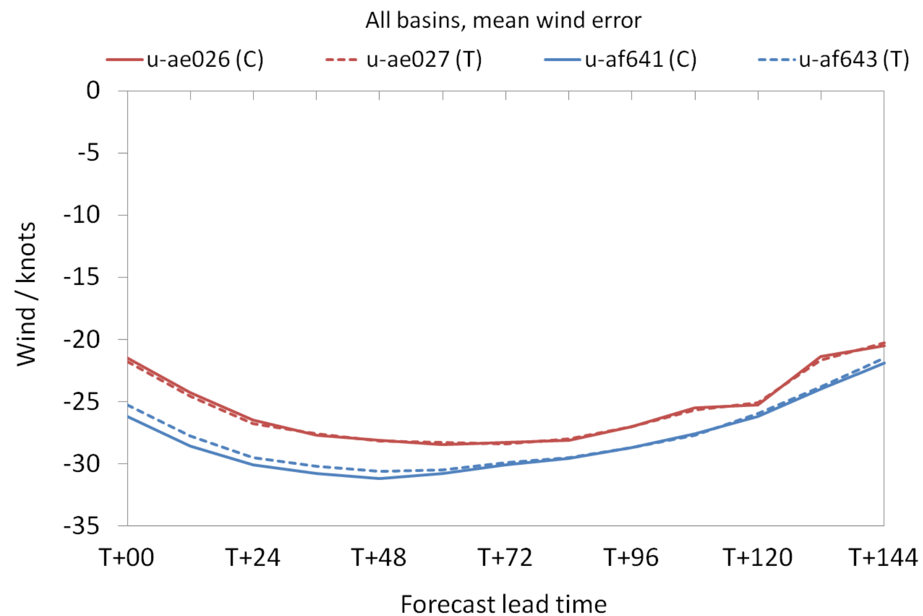
Aug-Oct 2014

SMOS impact with/without TC initialisation

Fc-Ob Pressure MAE



Fc-Ob 10m Wind MAE



	T+0
SMOS	-0.4 mb
TCPress	-3.5 mb

vs No TCPress baseline

	T+0
SMOS	-0.8 knots
TCPress	-4.5 knots

DPE = direct positional error

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Aug-Oct 2014

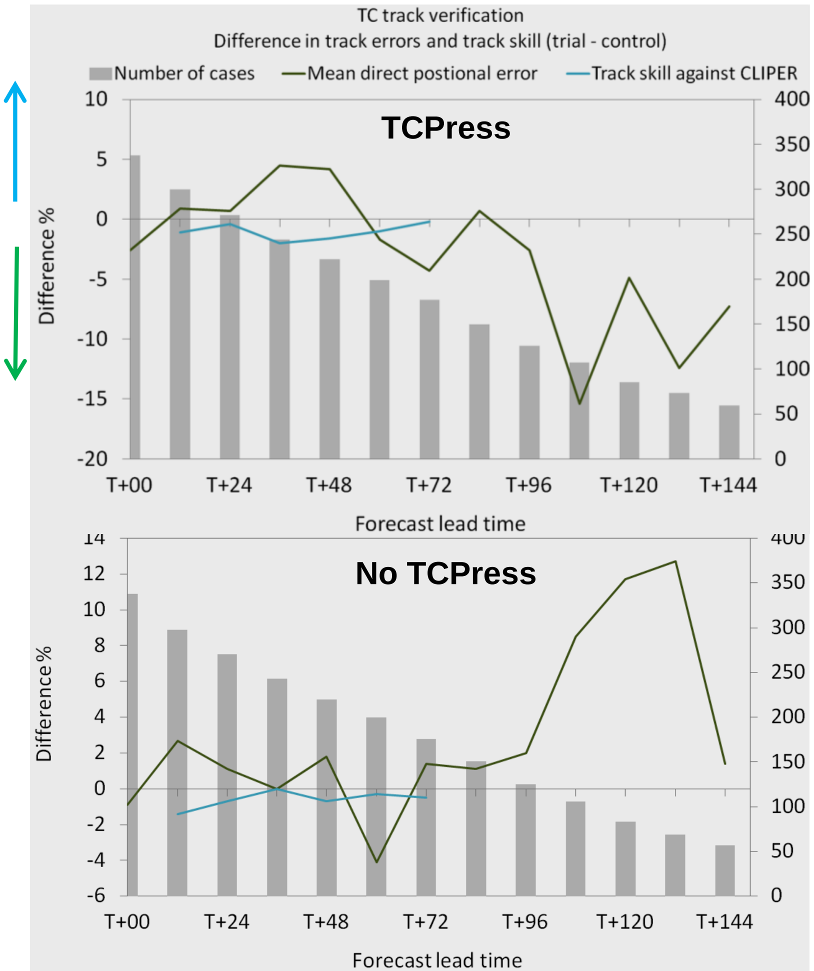
SMOS impact with/without TC initialisation

TC position/track errors

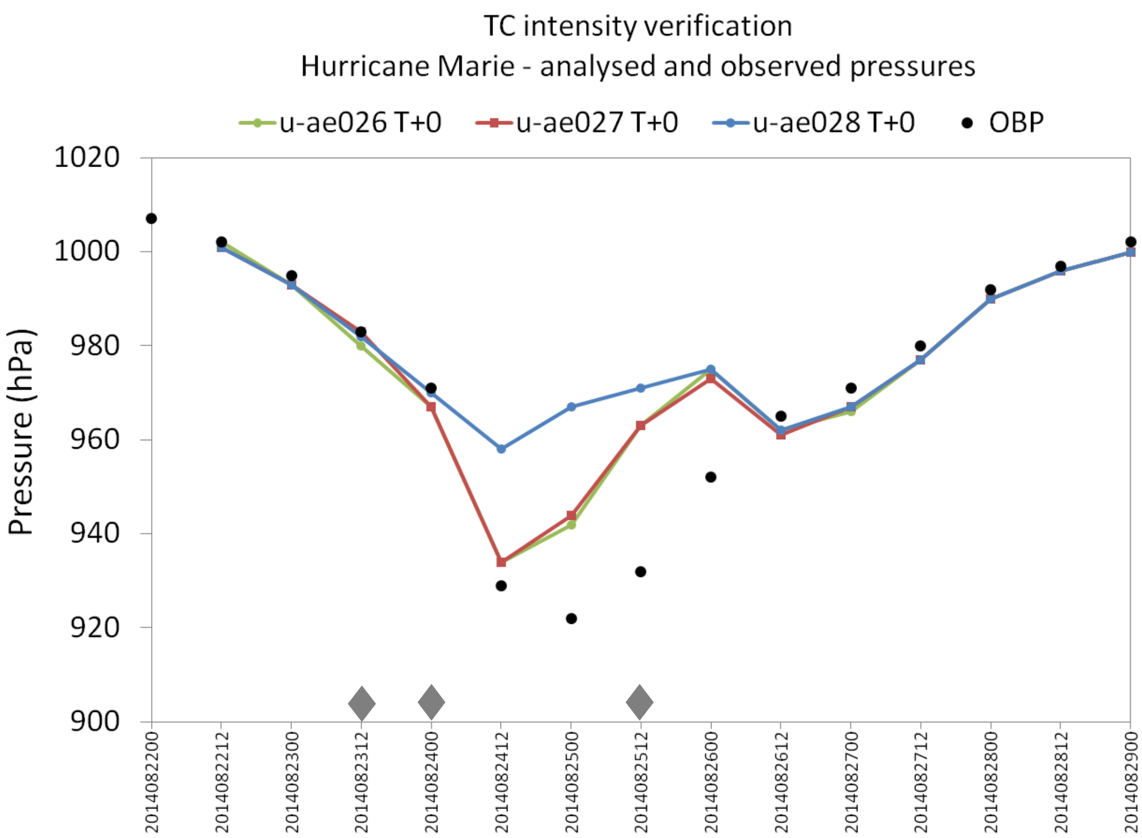
- Generally small improvement at T+0
- Worse at short range (impacts skill score)
- Long-range depend on assimilation of TCPress obs

Skill Improved

DPE Improved



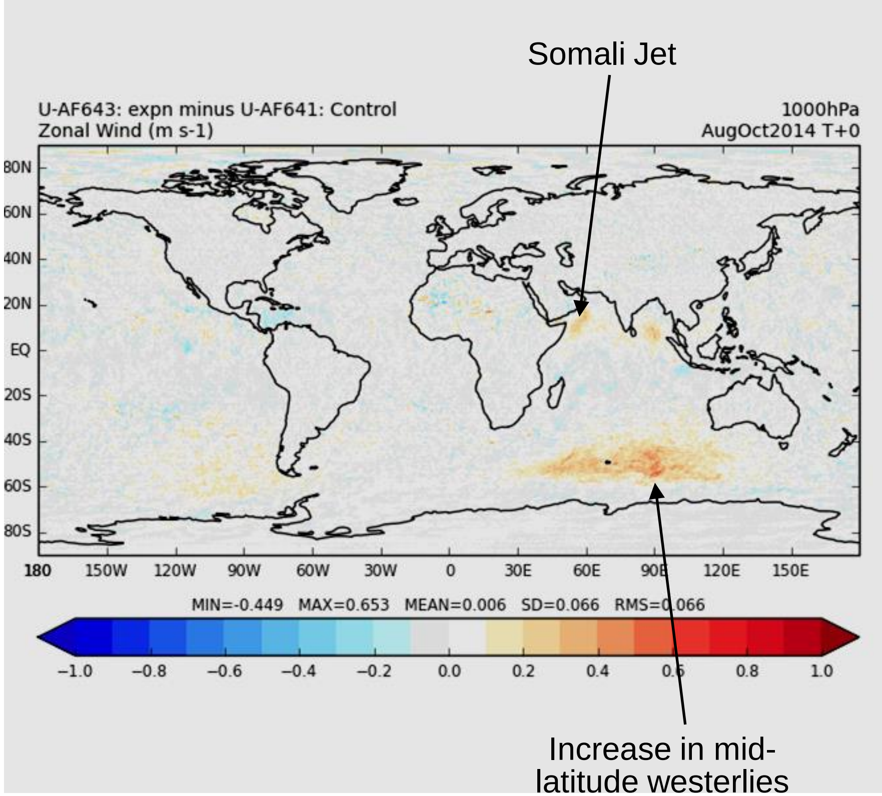
Sensitivity to TCPress QC – Hurricane Marie



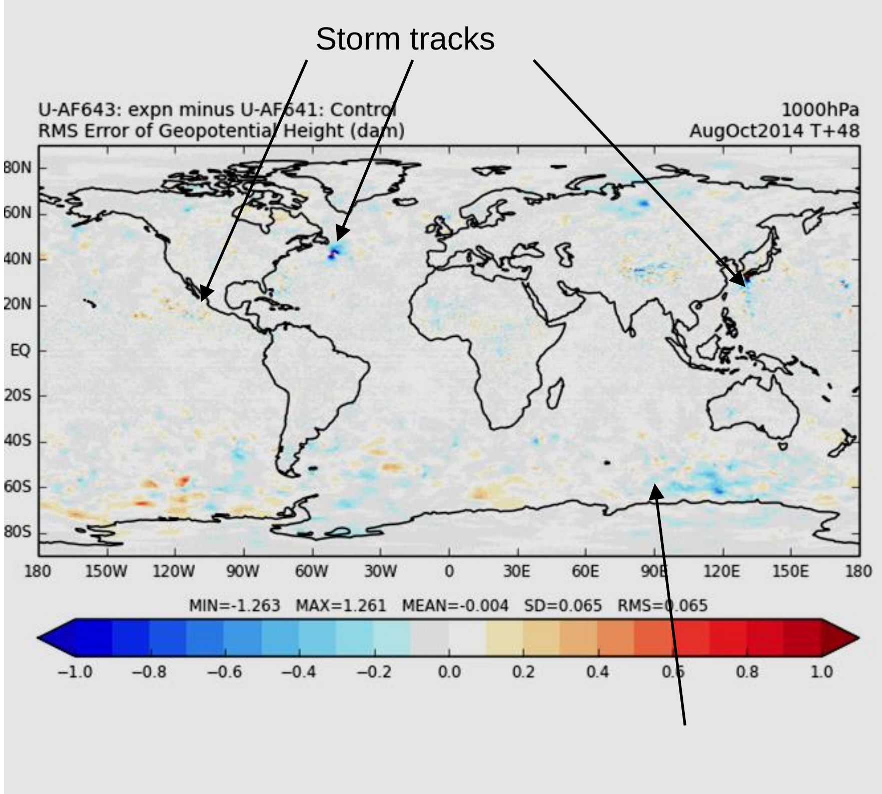
- U-ae028 fail background check from 24 / 0200z. Fails to intensify
- U-ae026 and u-ae027 accept until 24 / 1200z
- Small differences in background state can lead to v. large differences in analysis (and future forecast)

Aug-Oct 2014

SMOS impact without TC initialisation



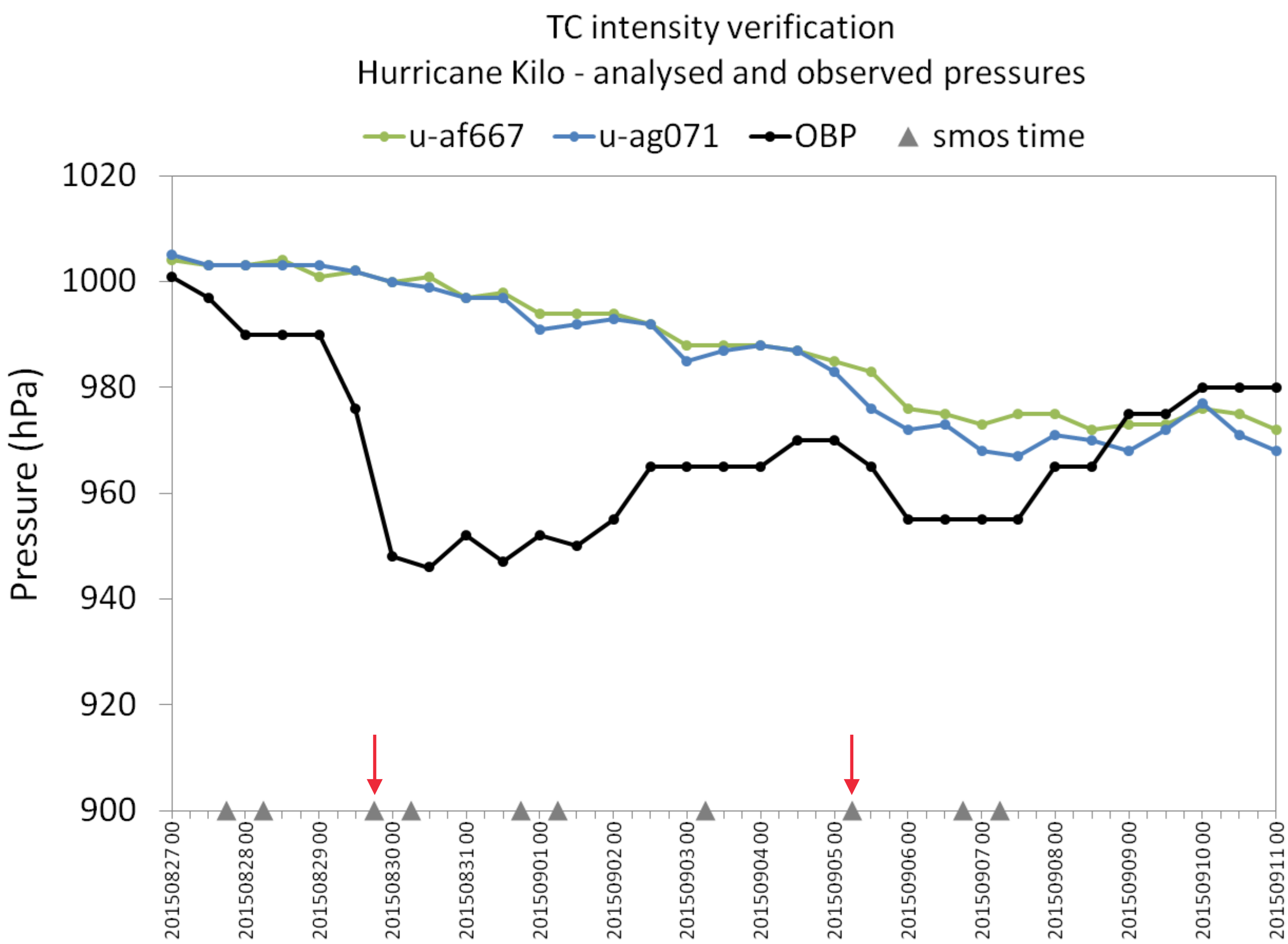
Difference Zonal Wind Analysis



Change in Z1000 RMSE at T+48

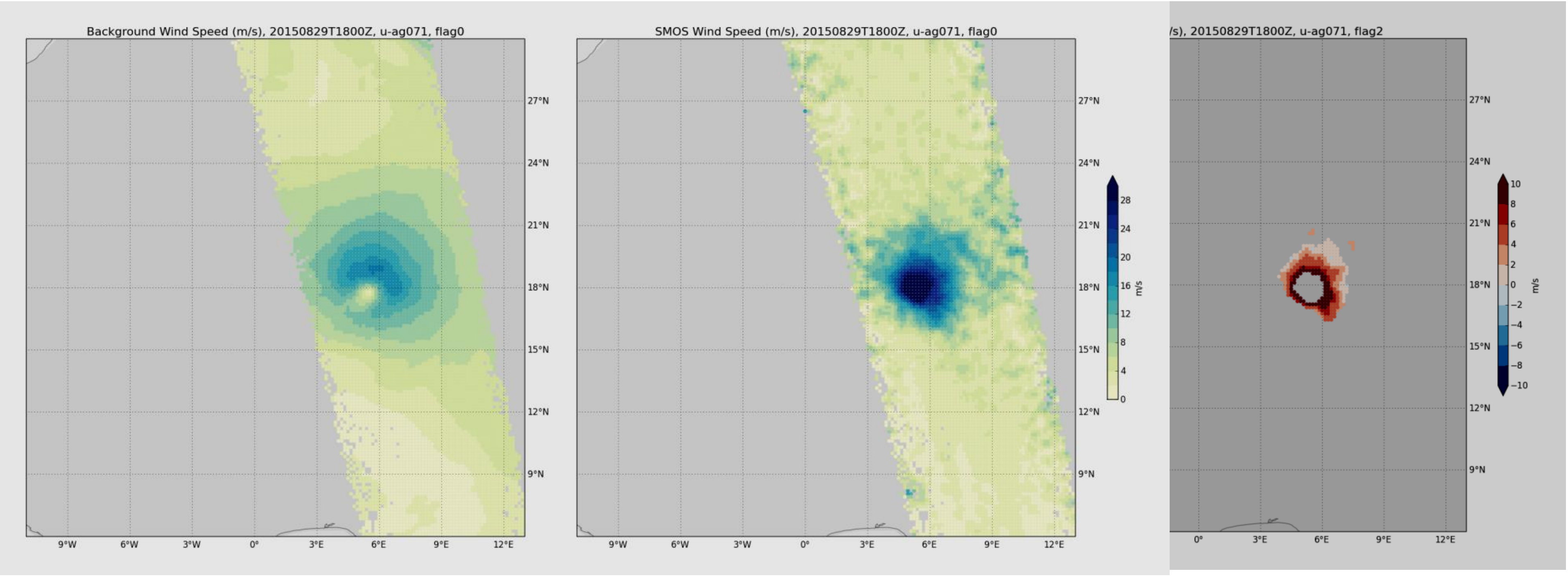
Kilo Analysed Pressure

SMOS impact without TC initialisation



Kilo – 29 Aug 2015

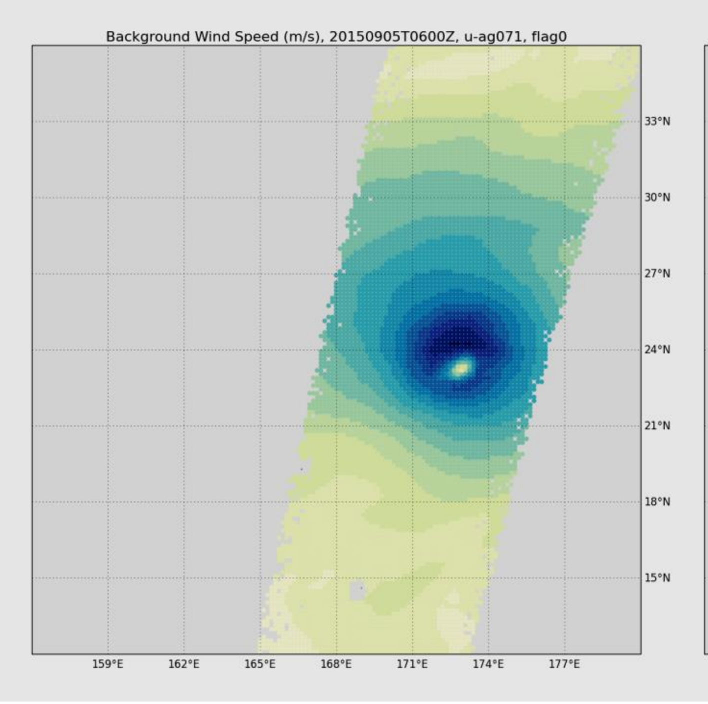
SMOS impact without TC initialisation



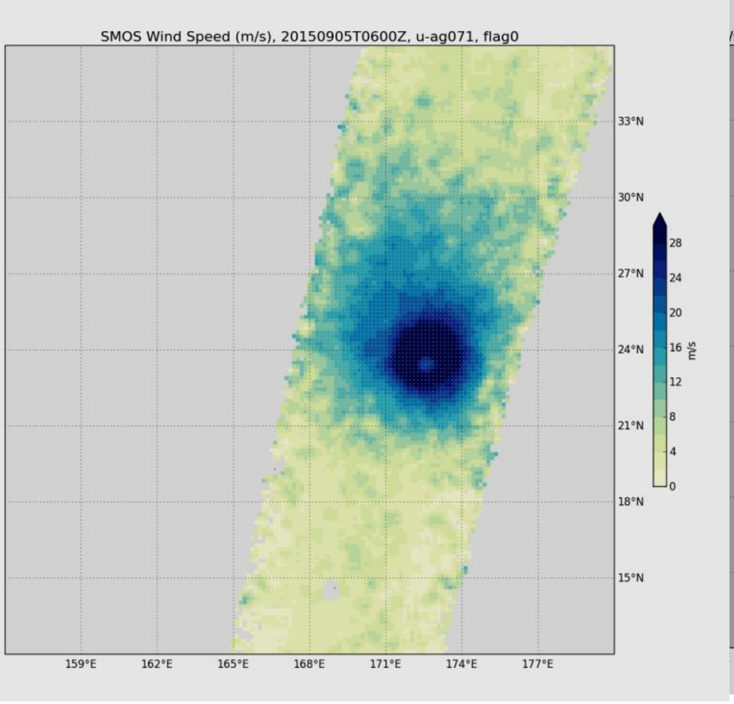
Background **SMOS** **O-B (after QC)**

Kilo – 5 Sept 2015

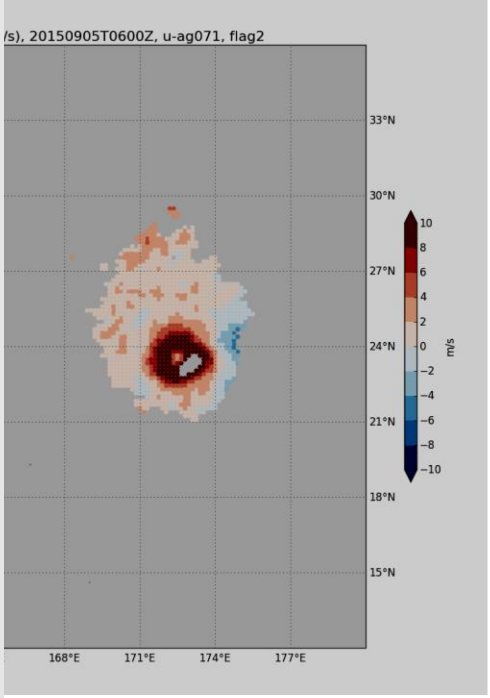
SMOS impact without TC initialisation



Background



SMOS



O-B (after QC)

Conclusions

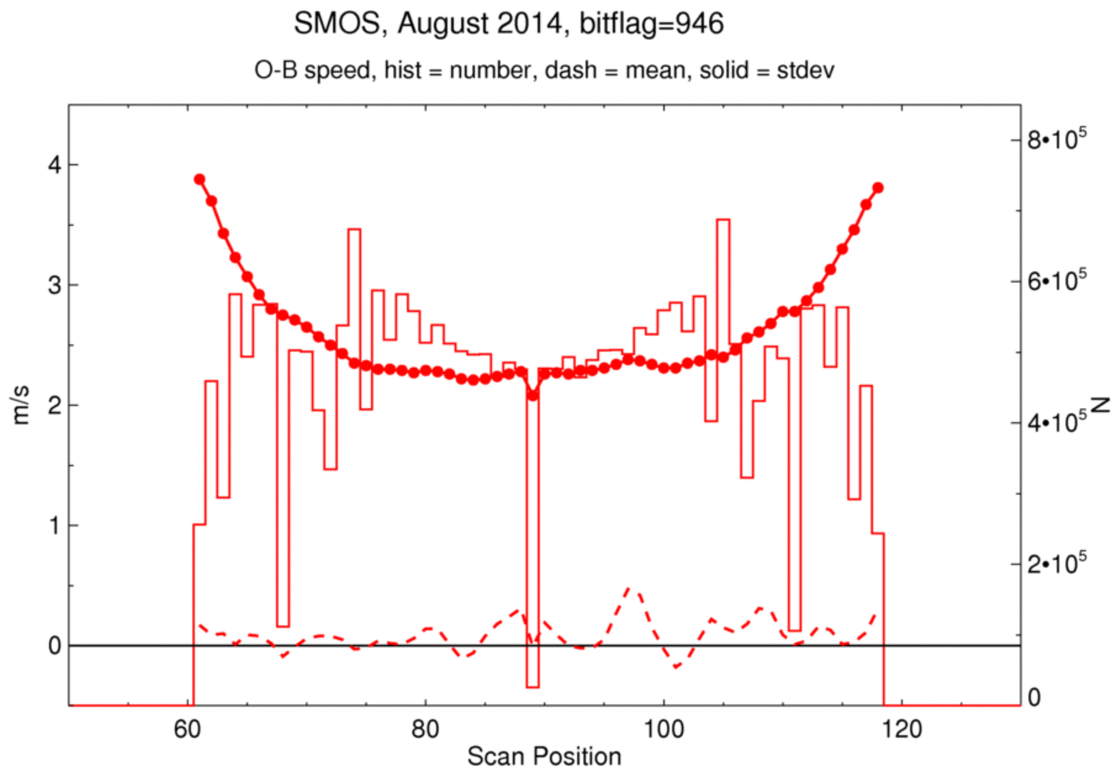
- SMOS QC flags are useful to screen the data, but RFI remains an issue (background check)
- Met Office TC initialisation scheme has large impact on TC intensity in analysis and forecast - results are very sensitive to QC rejections of this data
- Without initialisation, SMOS increases the analysed intensity of TC by 5% and leads to small reduction in pressure and wind errors at T+0 and short-range forecasts
- Impact on TC track errors is rather mixed
- SMOS resolution is an issue for small-radius storms – improvements in intensity for Kilo can be observed once storm radius larger and eye is resolved
- L-band measurements have potential to compliment exiting obs, but better agreement with scatterometers in overlap region needed

Met Office

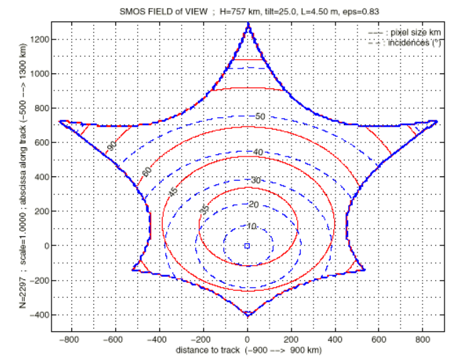
Thank you.

Questions?

Swath Position



- Speed bias modulation appears fairly small
- Higher STDV towards swath edges
- Fewer T_B measurements available (increased noise) and less variety of incidence angles

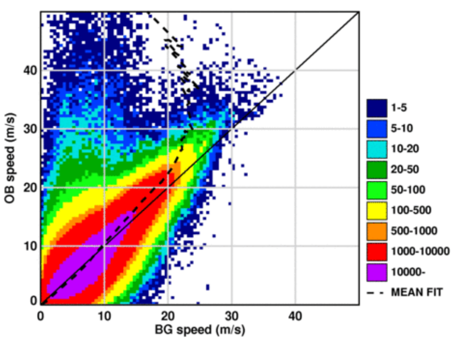


SMOS FOV

Flags as quality indicators: 1-10 Aug – all wind speeds

SMOS All Data, 1-10 August 2014

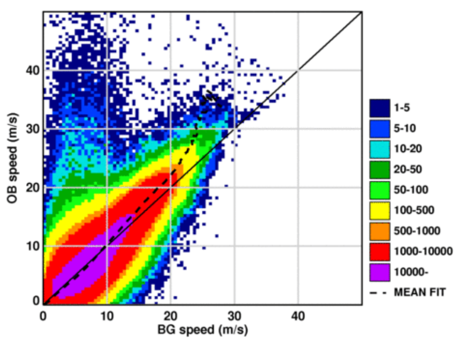
All latitude bands



	Plotted	Used
Num:	10135124	0 (0%)
Bias:	0.12	-
Stdv:	2.83	-
r:	0.80	

SMOS Un-flagged, 1-10 August 2014

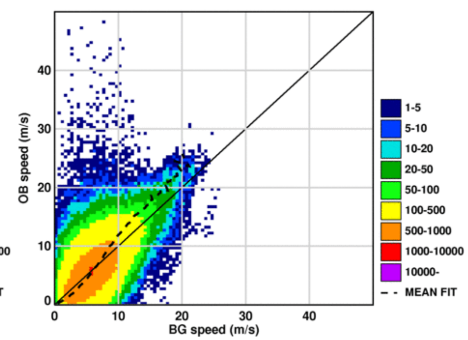
All latitude bands



	Plotted	Used
Num:	8739375	0 (0%)
Bias:	0.08	-
Stdv:	2.65	-
r:	0.82	

SMOS Quality Flag=1, 1-10 August 2014

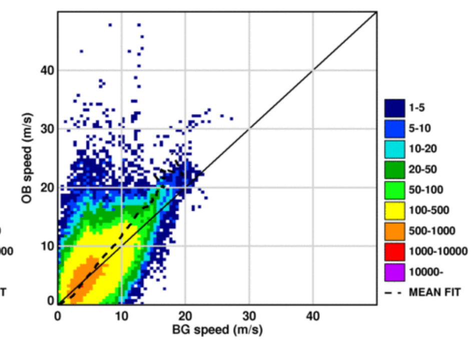
All latitude bands



	Plotted	Used
Num:	291216	0 (0%)
Bias:	0.31	-
Stdv:	3.69	-
r:	0.57	

SMOS Quality Flag=4, 1-10 August 2014

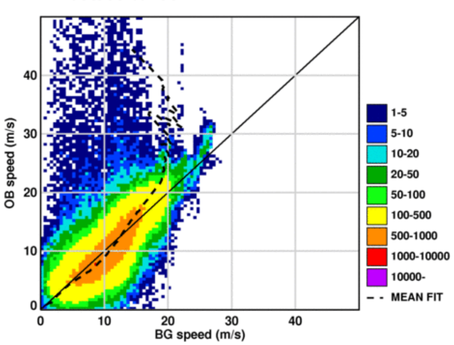
All latitude bands



	Plotted	Used
Num:	189020	0 (0%)
Bias:	0.53	-
Stdv:	3.41	-
r:	0.59	

SMOS Quality Flag=5, 1-10 August 2014

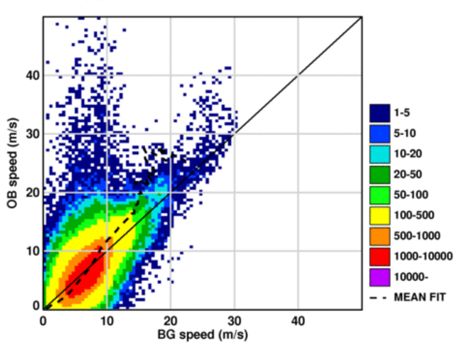
All latitude bands



	Plotted	Used
Num:	329819	0 (0%)
Bias:	0.13	-
Stdv:	4.35	-
r:	0.66	

SMOS Quality Flag=7, 1-10 August 2014

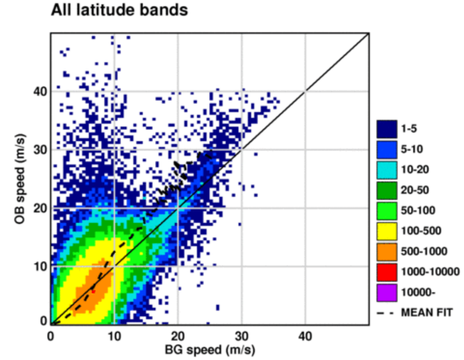
All latitude bands



	Plotted	Used
Num:	372949	0 (0%)
Bias:	0.07	-
Stdv:	3.22	-
r:	0.60	

SMOS Quality Flag=8, 1-10 August 2014

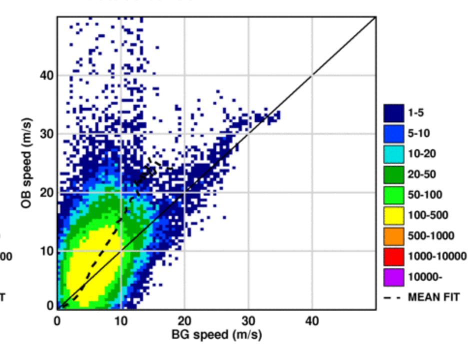
All latitude bands



	Plotted	Used
Num:	212162	0 (0%)
Bias:	0.28	-
Stdv:	3.61	-
r:	0.59	

SMOS Quality Flag=9, 1-10 August 2014

All latitude bands



	Plotted	Used
Num:	92475	0 (0%)
Bias:	2.37	-
Stdv:	4.75	-
r:	0.44	

SMOS Observation Processing

OPS to VAR

Ops_OceanWindsPre

Ops_OceanWinds

Input

L2 wind speeds

Wind speeds, cross-track distance, QC flags

- Read namelist variables
- QC flag – reject obs failing BitMask check

Namelist

- $Speed_{min}$
- SST_{min}
- Flag BitMask

Stationlist

- Observation errors, PGE
- Spatial blacklisting
- Spatial thinning

- Observation operator – background U10, V10 and WS10
- Min Speed - reject obs with WS_o/ WS_b less than $Speed_{min}$
- SST - reject obs with OSTIA SST less than SST_{min}
- Background check
- Produce monitoring files

Output

$$[WS]$$

Subset of QC'd wind speeds

O-B statistics

Overview of Bayesian background check

- 'Good' observations with normally distributed errors have Gaussian distribution with unbiased errors and variance V
- 'Bad' observations with gross errors have uniform density, k
- Background forecast assumed to have Gaussian errors

Let G denote the presence of gross errors, Ḡ denote the absence of gross errors

$$P(\overline{G}) = (1 - P(G))$$

The overall probability density of observed value y_o given background value y_b is

$$P(O) = P(O \mid \overline{G})P(\overline{G}) + P(O \mid G)P(G)$$

$$= N(y_o \mid y_b, V)(1 - P(G)) + kP(G)$$

$$= \frac{1}{\sqrt{2\pi V}} \exp\left(\frac{-(y_o - y_b)^2}{2V}\right)(1 - P(G)) + kP(G)$$

Variance of O-B values (excluding gross errors) $\mathrm{V} = \sigma^2 = {\sigma_o}^2 + {\sigma_b}^2$

Background check
Approximate limits

Let P_o be initial PGE, and P_2 be PGE after background check

$$x^2 = -2V\ln\left[(2\pi V)^{0.5}\frac{(1-P_2)}{P_2}\frac{kP_0}{(1-P_0)}\right] \qquad V = \sigma_o{}^2 + \sigma_b{}^2$$

To calculate example limits, set $P_2 = P_{crit} = 0.5$

Example

$$k = 0.0015 \ (\mathrm{ms})^{-2}, \quad P_0 = 0.1, \quad \sigma_o = 2.5ms^{-1}$$

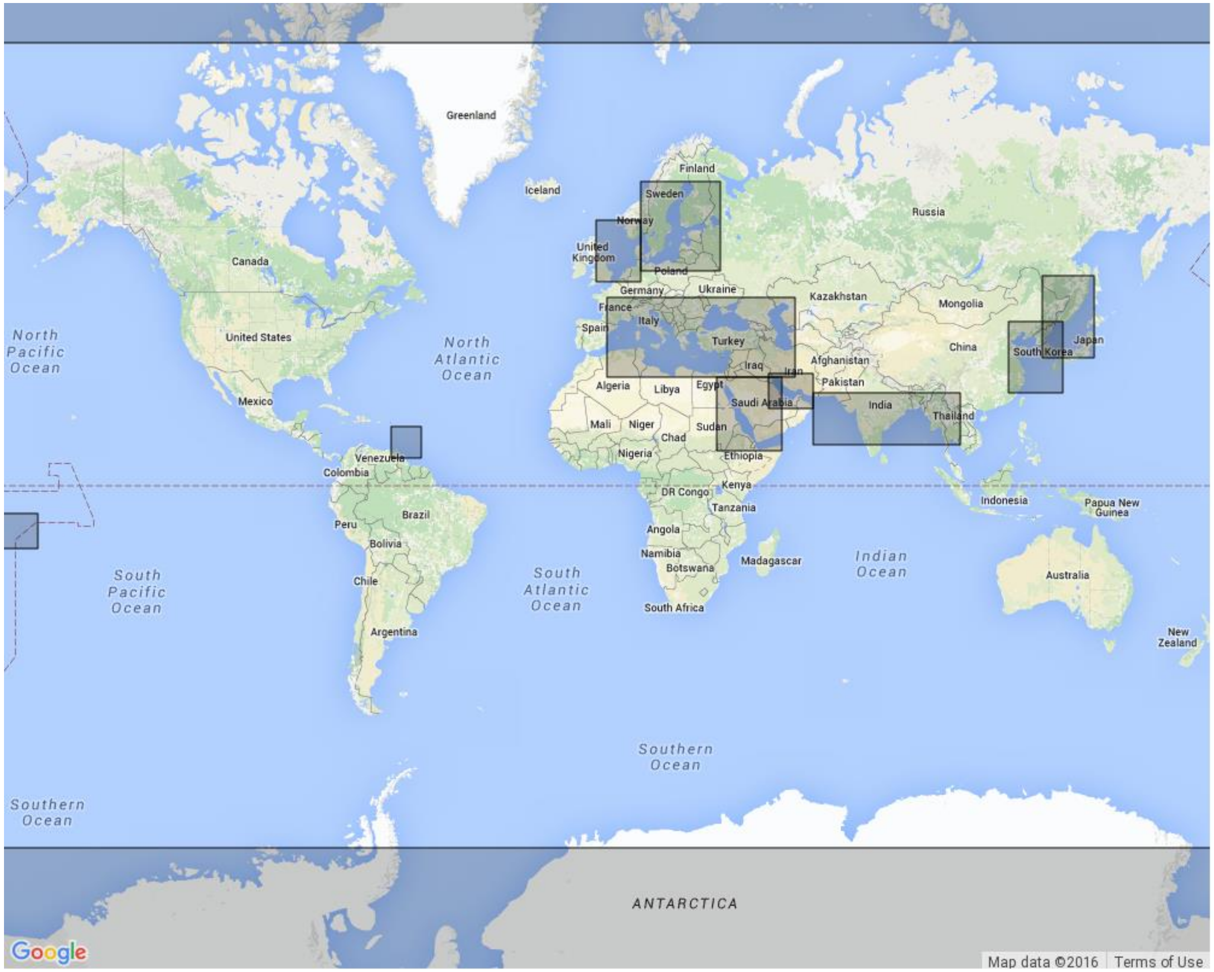
If σ_b = 1 m/s, then V = 7.25 $(m/s)^2$ and $x^2 = (9.9)^2$

If σ_b = 3 m/s, then V = 15.25 $(m/s)^2$ and $x^2 = (14.0)^2$

If σ_b = 5 m/s, then V = 31.25 $(m/s)^2$ and $x^2 = (19.5)^2$

Spatial blacklist areas

Aug-Oct 2014

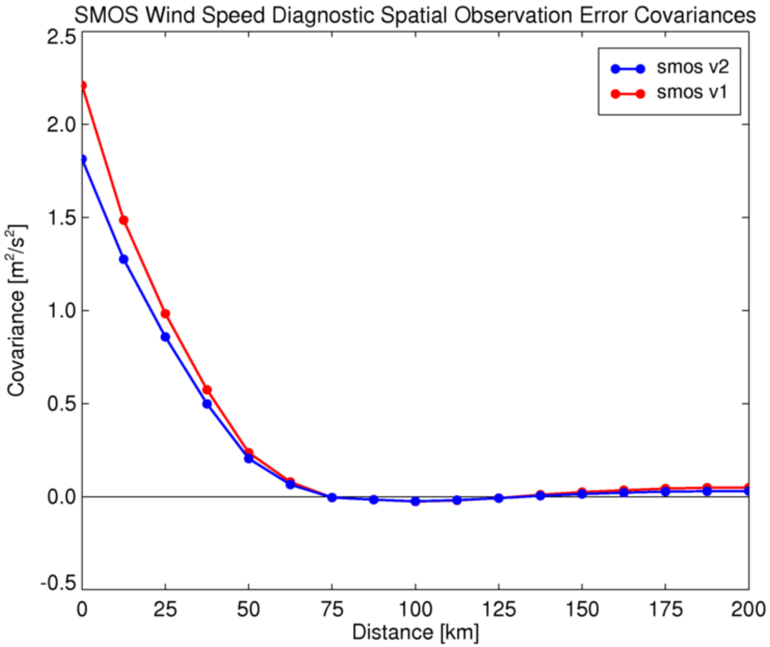


Desroziers' Diagnostic

- SMOS observation error covariances and horizontal error correlation diagnosed using Desroziers' method (Desroziers et al, 2005)
- Calculated using background innovations (O-B's) and analysis residuals (O-A's) from global model
- SMOS v2 wind speeds after passing quality flag, SST and background checks. Filtered for winds > 12 m/s
- 7 days from 20140822 00Z to 20140828 18Z
- Spatial thinning reduced to 10-km

Desroziers, G., Berre, L., Chapnik, B. and Poli, P. (2005), Diagnosis of observation, background and analysis-error statistics in observation space. Q.J.R. Meteorol. Soc., 131: 3385–3396.

Horizontal Error Covariances



σ^2

Diagnosed observation errors

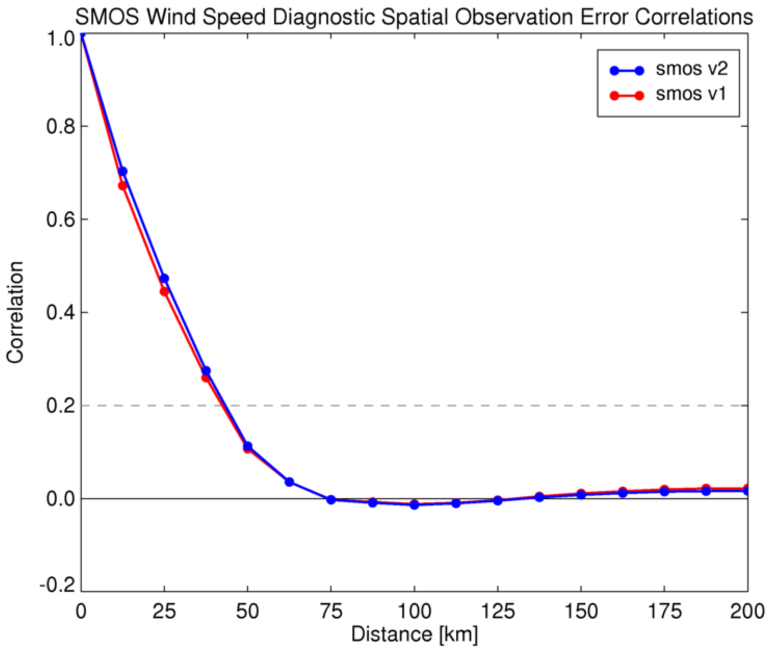
SMOS	Diagnosed σ^2 (m^2/s^2)	Diagnosed σ (m/s)	Assumed σ (m/s)
V1	2.21	1.49	2.5
V2	1.81	1.35	2.5

Some inflation needed from diagnosed values

For Scat diagnosed/reality ~ 0.6

Gives SMOS σ ~ 2.25 m/s

Horizontal error correlations



- Current assimilation scheme assumes errors are uncorrelated
- Correlated errors are indirectly accounted for by

  - Inflated observation errors
  - Thinning

- Distance to achieve a correlation value 0.2 is 43-km
- Around 80-km looks sensible for initial testing