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UPDATE ON SURFACE WIND ACTIVITIES AT THE MET OFFICE

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Abstract

This paper gives an overview of recent activities to improve the assimilation of satellite surface wind products at the Met Office. This includes the assessment of new scatterometer winds from the ScatSat-1 mission, the migration to a neutral stability wind observation operator, an updated scatterometer bias correction scheme, and evaluation of wind speeds retrieved from TechDemoSat-1 (TDS-1) Global Navigation Satellite System-Reflectometry (GNSS-R) measurements.

NEUTRAL WIND OPERATOR

Currently scatterometer wind components are assimilated as “real” 10m winds. The observation operator simply interpolates the stability-dependent model background 10m wind fields in space and time to the observation location. However, the products we assimilate from KNMI/ OSI-SAF (ASCAT-A/B, ScatSat-1) and the Naval Research Laboratory (WindSat) are all “equivalent neutral” 10m winds. This means that atmospheric stability affects are ignored in the transformation from roughness to 10m wind and leads to a discrepancy in the way the winds are treated in the data assimilation system. Here we outline the method for a neutral wind observation operator (see also Hersbach, 2010).

If we integrate the gradient of the model wind between the roughness height (for momentum) $z = z_{0m}$ and the observation height z_{ob} then we obtain the interpolation formula

$$\mathbf{v}_{\mathrm{ob}} = \mathbf{v}_0 + \frac{C_D}{v_* k}\Phi_m\left(L, z_{\mathrm{ob}} + z_{0m}, z_{0m}\right)\left(\mathbf{v}_1 - \mathbf{v}_0\right) \tag{1}$$

where L is the Monin-Obukhov length scale, v_* is the surface scaling velocity, $\mathbf{v}_1$ wind vector at lowest model level, $\mathbf{v}_0$ motion vector at the model surface, $\mathbf{v}_{\mathrm{ob}}$ wind vector at observation height, and k Von Kármán constant. Φ_m is the integrated form of the Monin-Obukhov stability function for momentum, and C_D the surface exchange coefficient for momentum**.**

For scatterometer winds, we set z_{ob} =10 and the 10m wind components are given by

$$\mathbf{v}_{10} = \mathbf{v}_0 + C_{DR10\mathrm{m}}\left(\mathbf{v}_1 - \mathbf{v}_0\right) \tag{2}$$

where $C_{DR10\mathrm{m}}$ are the interpolation coefficients for 10m winds:

$$\begin{aligned} C_{DR10\mathrm{m}} &= \frac{C_D}{v_* k}\Phi_m\left(L,\ 10 + z_{0m}, z_{0m}\right) \\ &= \frac{\Phi_m\left(L, 10 + z_{0m}, z_{0m}\right)}{\Phi_m\left(L, z_1 + z_{0m}, z_{0m}\right)} \end{aligned} \tag{3}$$

The 10m equivalent neutral wind vector is the wind calculated from the surface stress where the effects of atmospheric stability are neglected. If we assume standard Monin-Obukhov theory in the surface boundary layer ($v_* = u_*$, where u* is the friction velocity) and ignore the effects of surface currents ($\mathbf{v}_0 = 0$), then from Equation (2) the 10m neutral wind $\mathbf{v}_{10\mathrm{n}}$ can be written

$$\begin{aligned}\mathbf{v}_{10\mathrm{n}} &= C_{DR10\mathrm{m}} \mathbf{v}_1 \\ &= \frac{\Phi_{mn}(10 + z_{0m}, z_{0m})}{\Phi_m(L, z_1 + z_{0m}, z_{0m})} \mathbf{v}_1\end{aligned} \tag{4}$$

Substituting the neutral form of the 10m stability function for Φ_{mn} gives

$$\mathbf{v}_{10\mathrm{n}} = \frac{\ln((10 + z_{0m})/z_{0m})}{\Phi_m(L, z_1 + z_{0m}, z_{0m})} \mathbf{v}_1 \tag{5}$$

where Φ_m is dependant on the stability function formulations.

On average the marine boundary layer is weakly unstable and the global average difference in wind speed between neutral and real winds is around 0.17 m/s. However in strongly stable or unstable conditions the mean difference can be of the order of 1 m/s (Figure 1a). Using a neutral wind operator for ASCAT generally leads to smaller mean absolute errors in O-B wind speed (Figure 1b). Comparing mean O-B for neutral and real backgrounds (Figure 1c,d) we find a reduction in positive speed bias in the winter hemisphere, and a reduction in negative speed bias in strongly stable areas (e.g. Gulf Stream).

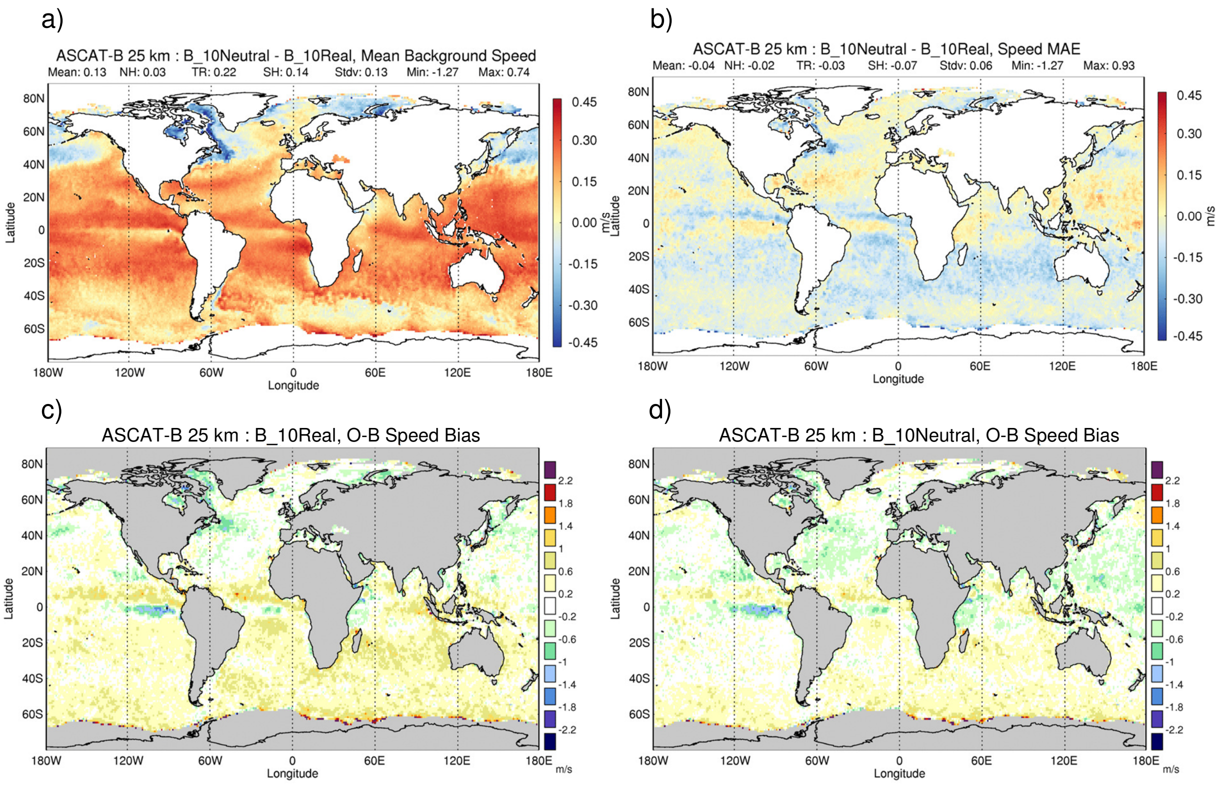

***Figure 1*: (a) Neutral minus real model background wind speed, (b) neutral mean |O-B| minus real mean |O-B|. (c) Mean O-B wind speed using a real background, d) mean O-B wind speed using a neutral background. Data are 25 km ASCAT-B for July 2016.**

WIND SPEED BIAS CORRECTION

With the neutral operator, there remains a large negative O-B difference at higher wind speeds with ASCAT biased low compared to the model (Figure 2, green line). This bias should be corrected before the data are assimilated to improve the speed scale match between the observations and the model. For ASCAT using the real operator we simply subtracted 0.2 m/s to account for the global average difference between neutral and real 10m winds (orange line). Instead, we now use regression of O-B versus the mean wind speed (MWS)

$$MWS = \frac{O+B}{2} \tag{6}$$

To obtain a non-linear calibration curve. Using regression against MWS we assume that O and B have the same random error distribution, which is more realistic than assuming all the error lies within the observation alone (Vogelzang and Stoffelen, 2011). Bias correction coefficients are calculated in MWS intervals of 1 m/s using 6 months of quality-controlled data. Applying the correction gives a much-improved fit between ASCAT and the model for MWS above 15 m/s (Figure *2*, blue line).

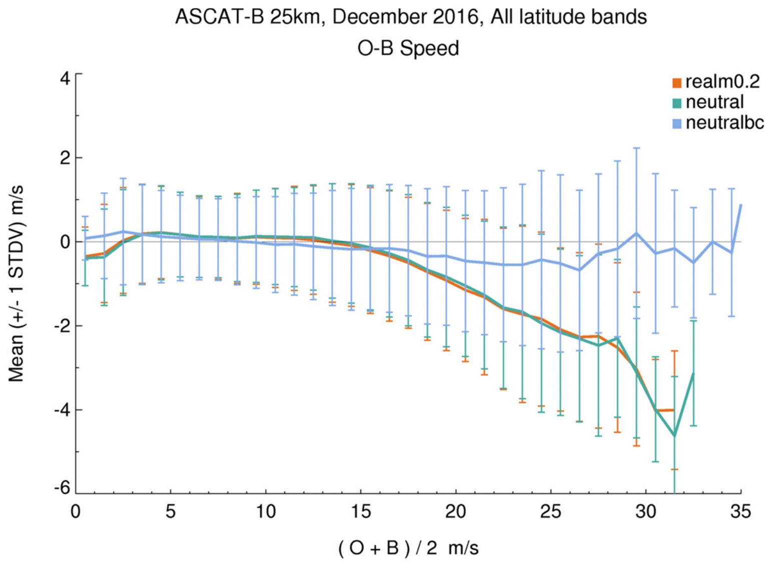

***Figure 2*: ASCAT-B wind speed O-B as a function of the mean of the observed and model wind speed. Solid lines show the mean O-B and the error bars denote +/- 1 standard deviation O-B. The orange line is the real operator with a uniform subtraction of 0.2 m/s, the green line is the neutral operator, and the blue line is the neutral wind with a MWS bias correction.**

FORECAST IMPACT

The impact of using the neutral wind operator and the MWS bias correction has been assessed with assimilation experiments across two seasons. The winter season runs from 2016/11/15 – 2017/02/20 (~90 days) and the summer season from 2017/06/20 – 2017/09/30 (~95 days). Experiments are based on an OS40 configuration with UM forecasts at low resolution (N320 ~40 km), 70 vertical levels, N108/N216 4D-Var with hybrid background error covariances. The reference experiment uses the real wind operator with the old bias correction scheme (subtract 0.2 m/s for ASCAT, and a polynomial speed-dependent correction for WindSat). The trial experiment uses the neutral wind operator and the MWS bias correction. An additional experiment used the neutral operator alone, but here we focus evaluation on the combined operator and bias correction experiment.

Forecast Root Mean Square error (RMSE) against independent ECMWF analyses shows a number of significant positive and negative impacts (Figure 3). In the winter season, there are some detrimental impacts for short-range forecasts in the northern hemisphere at days 1 and 2. In the same season in the southern hemisphere there are statistically significant positive impacts for 10m winds across most lead times, as well as PMSL, 850 hPa winds and 500 hPa geopotential height for lead times longer than day 3. In the summer season, there are no clear signals but again the majority of significant impacts are beneficial. The number of statistically significant positive/negative impacts overall is 48/21 in winter and 37/12 in summer.

For the low-level winds, we can see the benefit provided by the MWS bias correction scheme on top of the neutral operator alone in reducing RMS vector errors (Figure 4).

Considering the background forecast (T+6) fit to all scatterometer winds combined, we see a reduction in mean absolute O-B of 35-46% for U (zonal wind) and 6-27% for V (meridional wind). Most of the reduction comes from the use of the neutral operator, but the MWS bias correction also contributes some of the improvement.

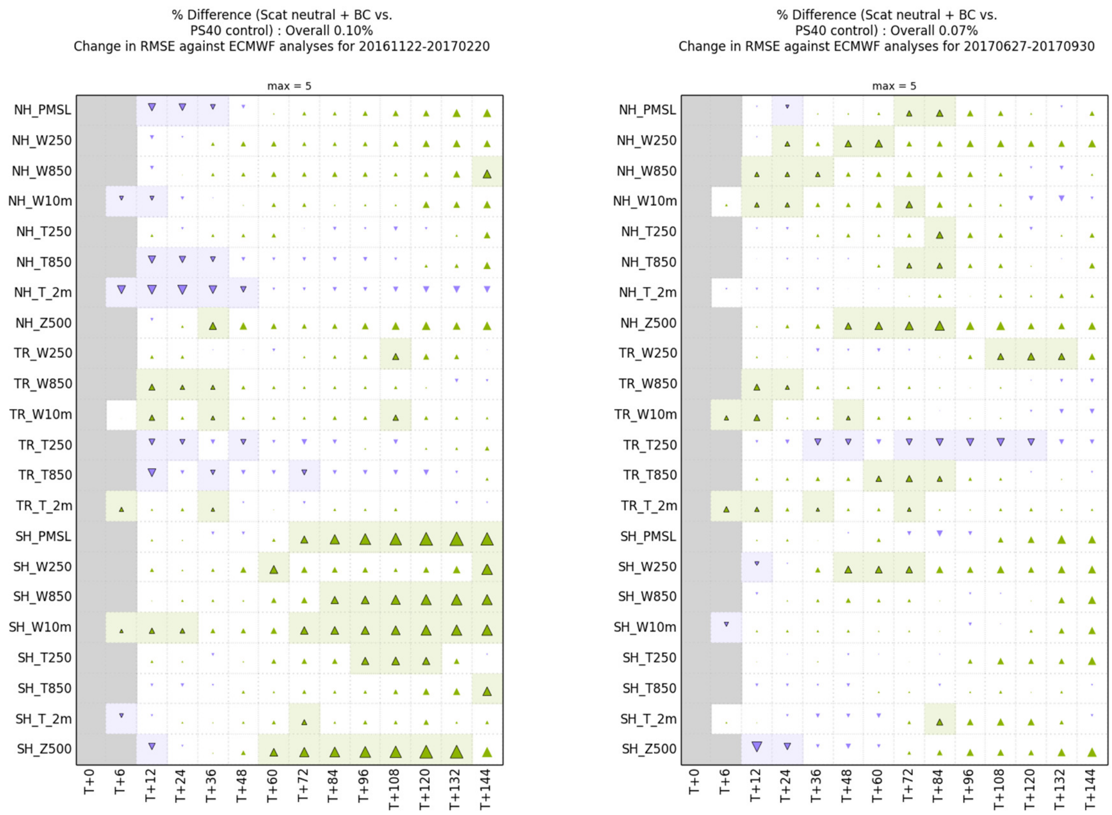

Figure 3**: Forecast RMS error scorecards against ECMWF analyses for the neutral wind and MWS bias correction experiment. These show the change in RMS error for various forecast parameters on the y-axis, ordered by northern hemisphere (90°N-20°N) in the top third, tropics in the middle third, and southern hemisphere (20°S-90°S) in the bottom third. On the x-axis is the forecast lead time, from T+0 to T+144 hours. Green triangles denote a positive impact (i.e. reduction in RMSE) and purple a negative impact. Impacts that are statistically significant at the 95% level are denoted by a shaded box. Winter season (left) and summer season (right).**

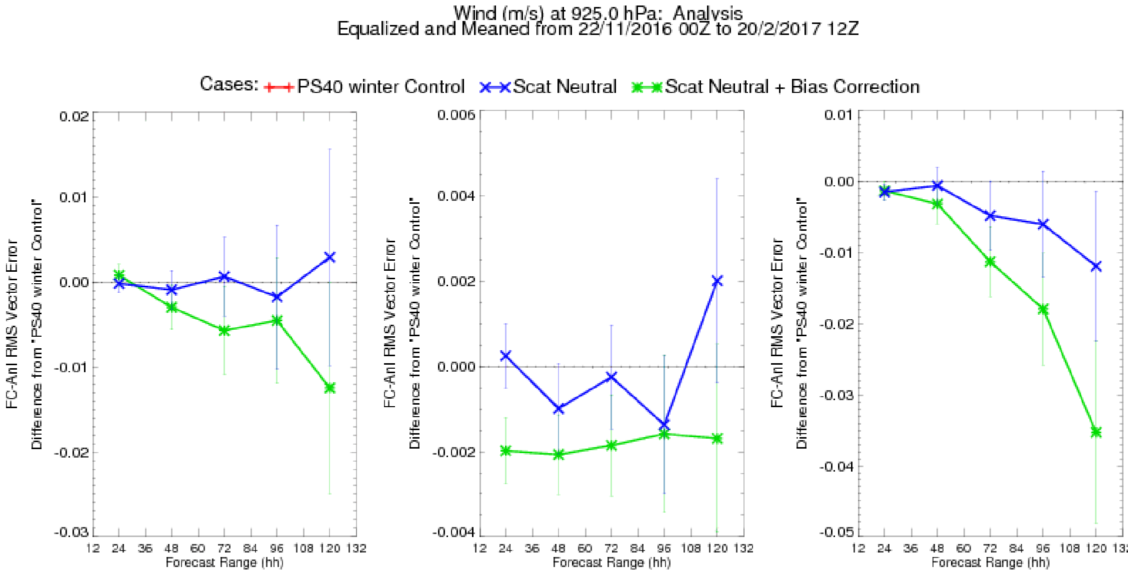

***Figure 4*: The change in forecast RMS Vector error for winds at 950 hPa compared to the reference experiment. The blue line is for use of the neutral operator alone, the green line is for the neutral operator combined with the MWS bias correction. Plots are for northern hemisphere (left), tropics (middle), and southern hemisphere (right) for the winter trial season.**

SCATSAT-1 IMPACT

The ScatSat-1 satellite was launched by the Indian Space Research Organization (ISRO) on 26 September 2016. The satellite is a gap-filling mission for the OceanSat-2/3 series and carries the same OSCAT scatterometer instrument operating in the Ku-band. The EUMETSAT Ocean and Sea Ice Satellite Application Facility (OSI SAF) have developed a 50 km OSCAT wind product that makes use of the level 2a OSCAT backscatter data made available by ISRO. Routine monitoring of the ScatSat-1 winds shows that the quality of the data is very good and compares well to ASCAT.

The impact of ScatSat-1 is assessed over a single trial season from 2017/12/01 – 2018/02/21 (~89 days) in which ScatSat-1 winds are assimilated in addition to ASCAT-A, ASCAT-B and WindSat. Adding ScatSat-1 slightly improves the background (T+6) forecast fit to ASCAT and WindSat observations. Considering the background fit to other observation types, we see small improvements for several instruments, but most notably a 0.5% reduction in O-B for CrIS temperature sounding channels in the lower troposphere (Figure 5). Changes in forecast RMSE are fairly neutral but there are some statistically significant positive impacts at days 1 and 2, e.g. PMSL in the extra-tropics, and 10m winds in the tropics and southern hemisphere (Figure 6). The number of statistically significant positive/negative impacts is 33/9 so the majority of changes are beneficial.

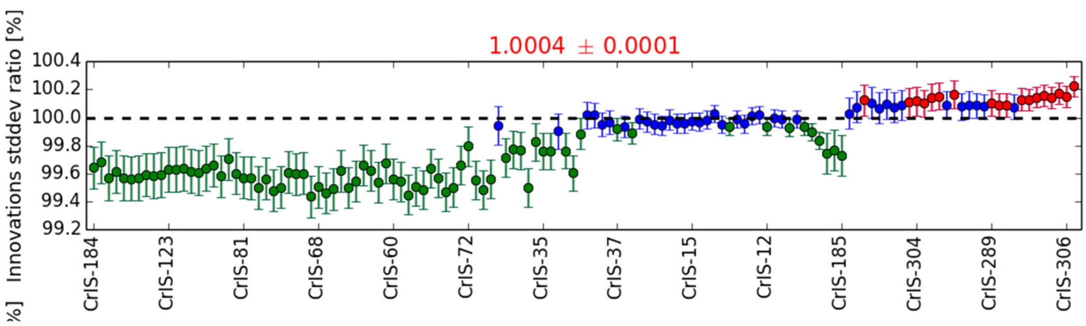

***Figure 5*: O-B standard deviation ratio for CrIS on Suomi-NPP. CrIS channels are ordered from left to right, first block for temperature sounding channels, second block for humidity sensitive channels. Within each block, channels are ordered by their weighting function peak, from lower troposphere on the left to the stratosphere on the right.**

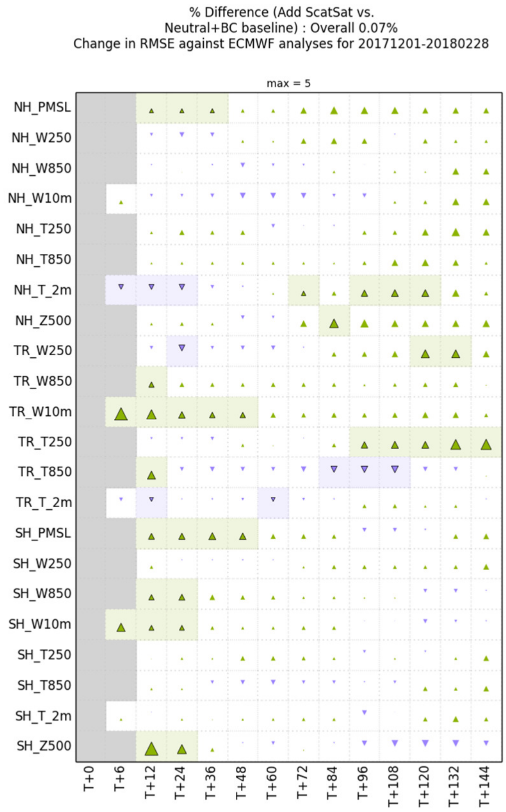

***Figure 6*: Same caption as Figure 3, but for the ScatSat-1 winter experiment verified against ECMWF analyses.**

EVALUATION OF TDS-1 WIND SPEEDS

The UK TechDemoSat-1 (TDS-1) satellite was launched in July 2014 and carries the first GNSS Reflectometry (GNSS-R) instrument able to measure ocean surface winds globally using reflected signals of opportunity from Global Navigation Satellite Systems (e.g. GPS). The Met Office are a partner in the TGSCATT project, funded by the European Space Agency, to perform a scientific assessment of TDS-1 measurements, from establishing the physical relationship through to developing and assessing level 2 products. Our role in the project is to evaluate TDS-1 wind speed data in NWP in order to understand their error characteristics and potential impact. A full description of the methods, evaluation, conclusions and recommendations can be found in Cotton et al. (2018).

We evaluate the level 2 wind speed product developed by the National Oceanography Centre (NOC) in Southampton. The winds are based on the retrieval algorithm of Foti et al. (2015) and using the Bistatic Radar Equation for radiometrically calibrated observables (CBRE). Overall we find that the O-B wind speed standard deviation (STDEV) difference is around 2 m/s on average, but errors are strongly wind speed dependent (Table 1). The original data set is capped at wind speeds below 20 m/s and this causes an artificial reduction in STDEV at higher values of MWS.

MWS m/s	Mean O-B m/s	STDEV O-B m/s	Number
0 ≤ MWS < 4	-0.22	1.40	109,831
4 ≤ MWS < 8	-0.11	1.86	149,184
8 ≤ MWS < 12	-0.05	2.80	65,581
12 ≤ MWS < 16	+0.47	4.01	14,737
16 ≤ MWS < 20	+0.44	3.13	2,288

***Table 1*: TDS-1 departure statistics versus the Met Office model background as a function of the mean wind speed (MWS). Data are from May-June 2015 using the NOC CBRE algorithm.**

Since the GNSS-R instrument on TDS-1 has only been operating 2 days out of every 8, we use case studies to compare TDS-1 wind speeds with ASCAT. On 3 June 2015 we observe two specular point tracks from TDS-1 west of Australia which overlap with an ASCAT-A pass just 15 mins later (Figure 7). Comparing wind speed trends along one of the specular point paths shows generally good agreement between ASCAT and TDS-1 (Figure 8). There are instances where ASCAT agrees better with the model than it does with TDS-1 (e.g. 33-34ºS), and instances where TDS-1 agrees better with ASCAT than the model (e.g. 27-28ºS). It is clear that TDS-1 is much noisier for wind speeds above around 8 m/s. Further work has shown that TDS-1 benefits from spatial averaging in the along-track in order to reduce the noise.

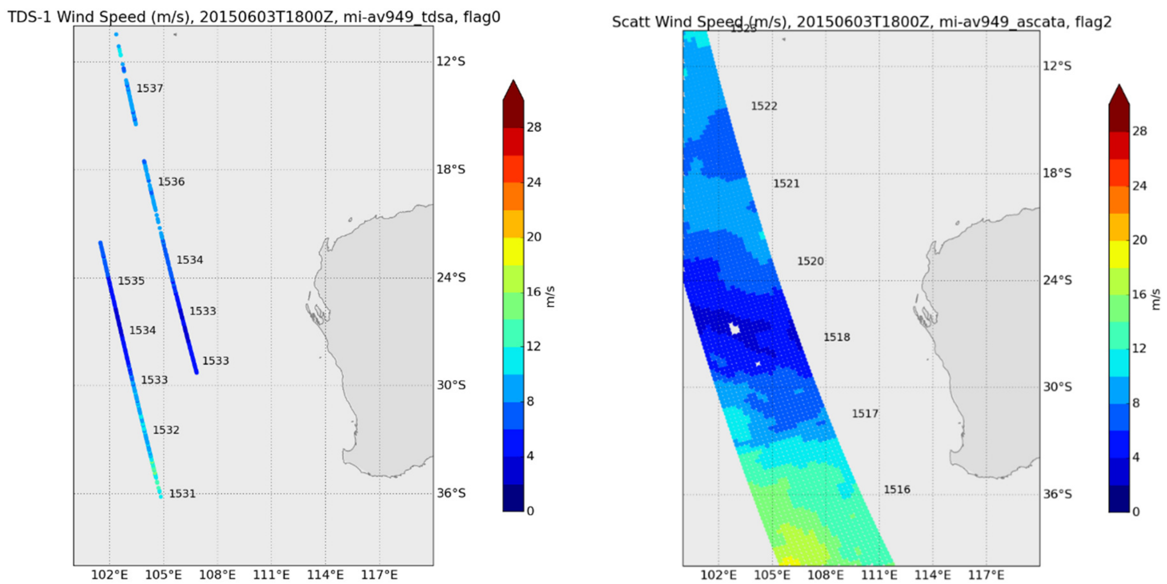

***Figure 7*: Overpasses from TDS-1 (left) and ASCAT-A (right) 15 mins apart on the 3 June 2015, west of Australia. The TDS-1 image shows winds speeds from two specular point tracks, whilst the ASCAT image shows wind speeds from one of the two swaths.**

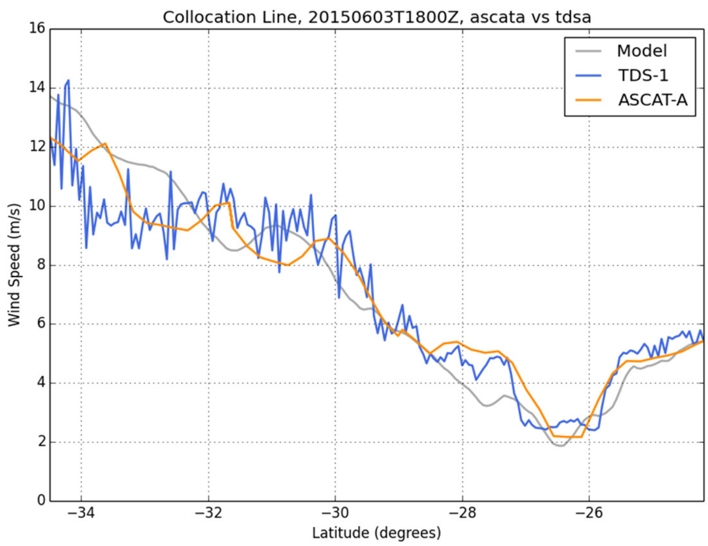

***Figure 8*: Wind speed trend for TDS-1 (blue line) taken along the specular point track in the lower left of Figure 7. The trend is plotted ascending from south to north in latitude. Also shown are the wind speed trend from the model background (grey) and the nearest collocated ASCAT wind speed (blue).**

SUMMARY

The observation operator has been updated to allow the assimilation of scatterometer winds as neutral stability 10m winds rather than real 10m winds. Using a neutral wind operator for ASCAT leads to smaller absolute errors in O-B wind speed. A new bias correction scheme based on regression against the mean wind speed improves the negative bias between ASCAT and the model, particularly at mean wind speeds greater than 15 m/s. Experiments combining the neutral operator with the updated bias correction give mostly small impacts on forecast RMSE, but the impacts that are statistically significant are mostly beneficial. In the winter trial season there are statistically significant positive impacts in the southern hemisphere for 10m winds across most lead times, as well as PMSL, 850 hPa winds and 500 hPa geopotential height for day 3 onwards.

The addition of scatterometer winds from ScatSat-1 gives some benefit at short lead-time (days 1 and 2) for PMSL and 10m winds. The background forecast fit to other observations is improved, particularly for CrIS temperature sounding channels in the lower troposphere.

The implementation of the neutral operator, updated bias correction, and ScatSat-1 assimilation are planned for operational implementation at OS41, around September 2018.

The evaluation of GNSS-R wind speeds from TDS-1 shows an average STDEV O-B of around 2 m/s, but errors are strongly wind speed dependent. Along-track averaging of the data is beneficial to help reduce the noise in the measurements.

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