Met Office

Meteorology Research and Development

The impact of an improved QuikSCAT wind product on Met Office global forecasts and analyses

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Contents.

Abstract.

An assimilation trial has been conducted in the Met Office to evaluate the impact of the new SeaWinds near real time (NRT) product with enhanced rain flagging on Met Office forecasts compared to the impact of the original NRT SeaWinds product.

Results from the assimilation study demonstrate modest forecast improvements in all areas of the globe with larger impacts in the tropical 850hPa wind skill scores, particularly at short range (T+24). These areas of improved wind skill correlate with rainfall patterns observed in SSMI data, indicating that enhanced rain flagging is helping with the quality control of the data. It is the conclusion therefore from this report that the new NRT product is suitable for assimilation into NWP models.

1. Introduction.

1.1 QuikSCAT

NASA's Quick Scatterometer (QuikSCAT) was launched into space at 7:15 p.m. Pacific Daylight Time on Saturday (6/19/99) atop a U.S. Air Force Titan II launch vehicle from Space Launch Complex 4 West at California's Vandenberg Air Force Base. The satellite is now in orbit with an altitude of about 800 kilometers (500 miles) above Earth's surface.

The SeaWinds on QuikSCAT mission is a "quick recovery" mission to fill the gap created by the loss of data from the NASA Scatterometer (NSCAT), when the satellite it was flying on lost power in June 1997. The SeaWinds instrument on the QuikSCAT satellite is specialised microwave radar that was designed to measure near-surface wind speed and direction under all weather and cloud conditions over Earth's oceans. However, rain contamination of the backscattered radar signal proves to be a problem that prevents the all-weather capability of the instrument being fully realised.

The Met Office has been assimilating a near real time (NRT) BUFR product from QuikSCAT since 2002 and has being undertaking its own quality control to eliminate as much rain contaminated data as possible. In recent times, a new NRT product with enhanced rain flagging (developed by JPL) has been released by NESDIS for testing to address some of these long standing rain contamination issues.

1.2 The Met Office global forecast model

The Met Office global forecast model used for these experiments has the following main characteristics:

- Resolution of ~40km in mid-latitudes
- 640 x 481 grid size
- 50 vertical levels
- Lid at ~63km
- Forecast out to 120 hours.

ASCAT, QuikSCAT and ERS-2 scatterometers are already assimilated into the model. The reader is referred to [1] and [2] for further details of the assimilation methodology.

1.3 Assimilation of SeaWinds data at the Met Office

SeaWinds wind data has been assimilated into the Met Office global forecast model since December 2002 and has provided positive forecast impacts, particularly for tropical cyclone forecasting [2].

A recent assimilation trial for the June 2007 period has however shown that the performance of the current SeaWinds product is reduced in the tropics leading to an overall slightly negative impact on Met Office tropical wind forecasts when verified against analyses [3]. The impact on the NWP index can be seen in table 1 below and in a more detailed breakdown in figure 1. It is demonstrated later in this report that these negative impacts do not occur to the same extent in the new SeaWinds product making it a viable alternative for NWP assimilation applications.

Table 1. Skill scores against NOSCAT control for trials (summarised from [3]).

Trial compared with NOSCAT control	Score against observations (+/- 0.05)	Score against analysis (+/- 0.05)
ALLSCAT	+0.97	-0.07
ASCAT only	+0.61	+0.29
QuikSCAT only	+0.66	-0.08

2. QuikSCAT surface wind product description.

The new SeaWinds product (NSW) and the original SeaWinds product (OSW) will be abbreviated from now on in this report. The original SeaWinds near real time (NRT) product is described in detail in [4] and [5].

2.1 Changes to the original SeaWinds product.

The eight years of availability of ocean surface vector wind data from SeaWinds instrument, for data assimilation and weather forecasting and warnings, have yielded significant improvements in product services for many forecasting offices around the world. However this same experience revealed the shortcomings in the wind products that limited their operational use. A few of known issues with OSW are: larger retrieval uncertainties at the swath edges, over-flagging of winds due to possible rain contamination, and under estimation of the high wind speeds. To address these shortcomings in the OSW retrievals, using lessons learned from coincident scatterometer (SeaWinds) and radiometer (AMSR) measurements on board of ADEOS-II satellite, JPL implemented several changes in the science level QuikSCAT processing system [5] that were then adapted to near-real time processing products produced and disseminated by NOAA/NESDIS.

The major changes implemented in the NSW product are:

- Refinement of geophysical model function that relates measured backscatter to near surface wind field
    - The OSW processing algorithm uses an empirically derived model function (referred to as QSCAT-1) that was obtained using collocated scatterometer measurements with numerical weather forecast models and buoy measurements ([6] and [7]). The NSW model function is re-adjusted for wind speed ranges between 16-30m/s to match high wind speed retrievals from SSMI/F13 passive microwave measurements

- Retrieval algorithm modification
    - Distance to the cone values are used as one of the flagging parameters in many data assimilation schemes. They are obtained as a minimum on an objective function that relates measured and modeled backscatters (σ_0) during wind vector retrieval process. In NSW retrieval algorithm the additional logarithm term was added to the original OSW objective function. The main consequence of this change is that distance to the cone values and previously used data assimilation scheme has to be re-adjusted in order for NSW to be used effectively.
    - For the Met Office to take advantage of the NSW product the following modification was made to the solution likelihood parameter (P_{NSW}) in order to reverse engineer a solution likelihood ($P_{delogged}$) that behaves in a non-logarithmic fashion (equation 1). Note, the aim is not to retrieve the original value (P_{OSW}) but rather to produce a value that behaves in a similar way as wind speed (U) is varied;

$$P_{delogged} = P_{NSW} - \beta \, [\, \log(U^2) + \alpha \,] \qquad \text{[Equation 1]}$$

where β is merely a switch (either 0 or 1) that allows the same code to run for the old product (β = 0) and new product (β = 1). α is an empirically determined constant that best fits the compared OSW and NSW product data. The U^2 term was assumed because the logarithmic term being incorporated into P_{NSW} is related to the backscatter, which in turn is related to the surface stress $\underline{T}$ given by equation 2;

$$\underline{T} = \rho C_d(\underline{U}-\underline{U}_s)^2 \qquad \text{[Equation 2]}$$

where ρ is the air density, C_d is the drag coefficient and $\underline{U}$ and $\underline{U}_s$ are the ocean surface wind and current velocities respectively.

The distance to cone values calculated using the new $P_{delogged}$ were found to behave in a way that allowed them to be easily threshold-checked in a similar way to the method used for the OSW product [2].

- Development of new rain impact flag
    - In an attempt to reduce the rain flagging of good retrievals an impact-based autonomous multidirectional histogram (MUDH), or impact-based multi-dimensional histogram (IMUDH), rain flagging scheme was developed and implemented for NWS processing [5]. This new impact based flag was developed utilizing SeaWinds scatterometer σ_0 measurements and AMSR derived rain rates on board of ADEOS-II satellite. For the IMUDH flag, "rainy" WVCs were defined by how much wind vector retrieval within the cell was contaminated by rain rather than particular rain rate. Rain impact was defined if wind speed bias was >2m/s and across track wind direction bias was >15°. The probability for a rain impacted measurement is set when the AMSR rain rate exceeded approx 4 mm/h. The table developed to flag SeaWinds data on board of ADEOS-II satellite was successfully transferred to QuikSCAT data. This new flag represents an indicator that rain signal dominated σ_0 measurement, and that subsequent wind retrieval can not be trusted. Although rain flagging of the data has been reduced from 4.2% (old) to ~1.8% (new) of data, this flag doesn't negate the presence of precipitation in cases that were flagged previously. The flag only indicates that σ_0 measurements were severely affected by precipitation. This change makes the largest impact on NSW product. Figure 2a and 2b clearly demonstrate the impact of the SeaWinds rain flag changes for a case of high winds in the North East Atlantic, where more winds are available for assimilation for the NSW product (figure 2b).

- Improved retrievals at the swath edge
    - In the edge regions of the SeaWinds measurement swath only vertically polarized beam measurements are available for wind vector retrievals. To complicate retrievals further the azimuth angle between the fore and aft looks between these two measurements approaches zero. This poor measurement geometry results in a substantially degraded retrieval performance in the edge regions. In the OSW processing system all measurements within edge wind vector cells (WVC) are averaged to form a single fore and aft σ_0 that were then used in the retrieval. The new data processing system sorts all of fore and aft σ_0 measurements into two azimuth angle ranges based on the minimum and maximum azimuth angle for that particular WVC. The availability of four σ_0's in the WVC's at edges of the measurement swath in the retrieval process resulted in a substantial improvement in wind retrieval performance. This result in up to 4 σ_0's instead of 2 being used for the wind retrieval which consequently leads to overall better retrieval algorithm performance at the swath edge. The retrieval error was reduced by ~20% for directions and ~15% for wind speeds in this region of the measurement swath.

2.2 QuikSCAT data coverage

Figure 3 shows the swath usage by Met Office. Only the sweet part of the swath is of use for operational NWP. This is due to the larger observation error associated with wind product data in the inner and outer swath. Although some data in the inner swath will correlate well with data from other sources, these data do not have sufficient directional skill to have meaningful information content from which the assimilation scheme can add correct increments to the background state.

2.3 Quality of wind speed data

The Met Office utilises wind speeds in the range 2-25m/s. Wind speeds greater than 25m/s are not trusted due to the lack of validation of the performance of scatterometers at extreme wind speeds. In addition, the QuikSCAT wind speeds (both OSW and NSW) are bias corrected [2] because the higher wind speeds appear to be consistently too high compared to NWP data. There is a mathematical and practical need for observations to be bias free for assimilation so both the NSW and OSW wind products were bias corrected before being used in this study.

2.4 Rain contamination checks

Rain contamination is dealt with using three independent checks

- BUFR rain flag
- Rain probability value
- Distance to cone check

In the case of the new NRT product the rain flag has been changed. In addition, the solution likelihoods that feed into the distance to cone calculation were also changed so code had to be adapted to cope with the characteristics of these new data.

3. Forecast trial evaluation of QuikSCAT products.

3.1 The trial configuration

The forecast trial was configured as N216 (half the operational resolution) with 50 vertical levels and used 4D Var. The period of the trial was 16th March – 18th April 2008.

The following quality checks in addition to the quality control flagging in the BUFR product:

- Lower Sea Surface Temperature threshold set to 273.15K to help avoid sea ice
- Nodes 1-11, 29-48, 66-76 were blacklisted due to lower directional quality
- Upper absolute distance to cone threshold set to 1.8 (OSW) or 3.0 (NSW)
- Bias correction of both wind products, which tend to overestimate wind speeds

Three experiments were run. One for each SeaWinds product and a third trial (NOSCAT) that had no scatterometer data assimilated in it. None of these trials included any ERS-2 or ASCAT scatterometer data.

3.2 Headline index results

The headline results of the trials were as follows:-

Table 2. Summary of trials results.

Trial comparison	**Main results**
NSW vs OSW	Headline NWP index improvements of +0.17 against observations and +0.76 against analyses (figures 4 and 5) Tropical skill score improvement in 850hpa at T+24 to T+72 and small improvement in 250hpa winds at T+24 range (figure 6)
OSW vs NOSCAT	General good performance all around but poor verification against tropical analyses with reduced skill scores and increased RMSE in 850hpa and 250hpa winds (figure 7)
NSW vs NOSCAT	General good performance all around but with no reduced performance against tropical analyses (figure 8)

3.3 Tropical cyclone tracking performance.

Two storms of interest occurred during the period. These were TC Lola and TC Pancho, which both occurred in the Australian Basin. The performance of the new product compared to the old product is as follows:-

Table 3. Improvements in cyclone track errors by forecast range.

Forecast range	**Improvement in track position**
T+0 Analysis	19%
T+24	0%
T+48	20%

It must be stressed that this is only for two tropical cyclone cases so the results are meant only to be an indicator of the performance rather than presenting any definitive metric. These results are nevertheless encouraging and do give an indication that the new product is expected to improve tropical cyclone forecasts.

4. Discussion and further work.

4.1 Comparison of forecast scores for QuikSCAT products.

The Renniegram shown in figure 9 shows a comprehensive breakdown of the skill scores for major forecast parameters for trial – control (NSW forecast – OSW forecast differences) for the March 2008 period. It is clear from this breakdown that pressure at mean sea level (PMSL), winds and low level temperature and humidity are all improved in the tropics. Scores are more modest in the northern hemisphere due to the heavy constraints on the data assimilation system placed by the wealth of observations being ingested. The southern hemisphere shows a broad range of improvements, the most significant of which occur at longer range (T+144).

The vertical dotted lines in figure 9 show the 2% significance lines. Coloured bars which cross these lines are regarded as either significantly good (crossing to the left) or significantly bad (crossing to the right). None of the bars crossed the 2% line to the right. The T+24 850hpa scores for wind, temperature and humidity all cross the 2% significance line to the left indicating significant short range forecast improvement in these fields.

4.2 Tropical wind improvements.

It is clear from the index statistics presented above that there are improvements in the tropical wind scores from assimilating the NSW product in place of the OSW product. To visualise this in another way, figure 10 shows the vertical profile of forecast – analysis RMS vector error at T+24 forecast range in the tropics for the entire trial period. The lower plot in figure 10 shows that the RMS vector error is lower for the trial than for the control for the 600-1000hpa range. This demonstrates both the usefulness of the NSW product for improving the surface winds and the ability of 4D var to propagate meaningful information from the surface up through the planetary boundary layer.

The lower time series in figure 11 shows how the 850hpa wind RMS vector error (forecast – analysis) for the trial is consistently lower than that for the control in the tropics throughout the trial period. This demonstrates that the NWS product is having a consistent modest short range impact in the tropics rather than having a small number of very large impacts.

4.3 The influence of rainfall on forecast wind improvements.

If one has a good data assimilation system then it is logical that improved scatterometer wind measurements will result in improved surface wind forecasts. The new JPL rain flagging is an attempt to address one shortcoming of Ku band scatterometer measurements, their susceptibility to rain contamination. The effect of rain contamination on scatterometer measurements of backscatter is that the backscatter is increased by backscatter from the atmosphere. This increase in backscatter makes the surface winds appear faster than they really are. It would therefore be expected that if a more effective QuikSCAT rain flag was used prior to assimilation then the resulting forecast winds ought to be slowed down in rainy regions compared to forecasts generated after the assimilation of QuikSCAT using a less effective rainflag. This would mean that the global mean forecast wind speed shown in figure 12 for the NSW product (for 850hpa at T+24) would contain some slower mean winds than the OSW assimilation case in regions where rain was present.

To test this hypothesis, the T+24 850hpa winds differences (trial – control) shown in figure 13 were compared with precipitation maps generated by both the forecast model and SSMI [8]. Rainfall data from SSMI were obtained from Remote Sensing Systems (www.ssmi.com) in daily file format and were aggregated into a data set spanning the period of the March 2008 trial. Figure 14 shows the number of F13 platform SSMI overpasses during the trial period that reported rain rates in excess of 0.1mm/hr. This is a useful proxy for “rainfall activity” or better, “Ku band sigma0 contamination potential.”

The SSMI and Met Office forecast model rain fields are shown in figure 14 and figure 15 respectively. The results of the comparison are summarised in table 4 in which regions of slower winds (circled in figure 16) are qualitatively correlated with regions of frequent/intense rainfall. It does appear that there is a link between the slowing down of the tropical winds in the Pacific Ocean (region B and C figure 16) and the precipitation in figures 14 and 15.

Table 4. Precipitation in regions of lower wind forecasts.

Region where slower 850hpa winds are forecast at T+24	Model precipitation?	SSMI derived precipitation?
A Indian Ocean	Slight	Slight
B Tropical Western Pacific	Slight	Yes
C Tropical Eastern Pacific	Yes	Yes
D South West Atlantic	No	Yes
E North Atlantic (Greenland)	Slight	Yes
F West Tropical Atlantic	Yes	Yes

4.4 Conclusions.

The June 2007 SeaWinds trial demonstrated that the OSW wind product had a great benefit to Met Office forecasts. However, this trial also showed deficiencies in the tropical wind forecasts that resulted from assimilation of this product. These deficiencies are not observed in the March 2008 assimilation trial using the NSW product instead of the OSW product. In the June 2007 trial the index score verified by analyses was -0.08 for a SeaWinds only (OSW) versus NOSCAT trial. In the March 2008 trial the NSW product performed +0.76 better than OSW for the same period. This indicates that the NSW product does not have some of the drawbacks of the OSW product.

Outside of the tropics the OSW and NSW products perform in a comparable way and little difference in forecast performance is observed in the March 2008 assimilation trial.

The March 2008 trial results demonstrate that the NSW product makes a suitable replacement for the OSW product in the Met Office global model assimilation system. The new product results in improved tropical winds, particularly in ocean areas where there is significant rainfall.

5. Acknowledgements.

The authors would like to acknowledge Mike Thurlow for suite support and Malcolm E. Brooks for support with post-processing of the forecast trials. The authors would also like to thank Mike Rennie for the software to produce the Renniegram in figure 9 and Sreerekha Thonipparambil for advice on obtaining a suitable SSMI precipitation data set.

6. References.

[1] Candy, B., 2001: The Assimilation of Ambiguous Scatterometer Winds Using a Variational Technique: Method and Forecast Impact. Forecasting Research Tech. Rep. 349.

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[5] “QuikSCAT Science Data User Product Manual” JPL, 2006 ftp://podaac.jpl.nasa.gov/ocean_wind/quikscat/L2B/doc/QSUG_v3.pdf

[6] Wentz, F. J. and D. K. Smith 1999: "A model function for the ocean-normalized radar cross section at 14 GHz derived from NSCAT observations." J. Geophys. Res., 104, 11,499-11,514.

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[8] Wentz, F.J. and Spencer, R.W., “SSM/I Rain Retrievals Within a Unified All-Weather Ocean Algorithm”, RRS Tech. Report 120196, December 1996. ftp://ftp.ssmi.com/ssmi/articles/rain.doc

Figures.

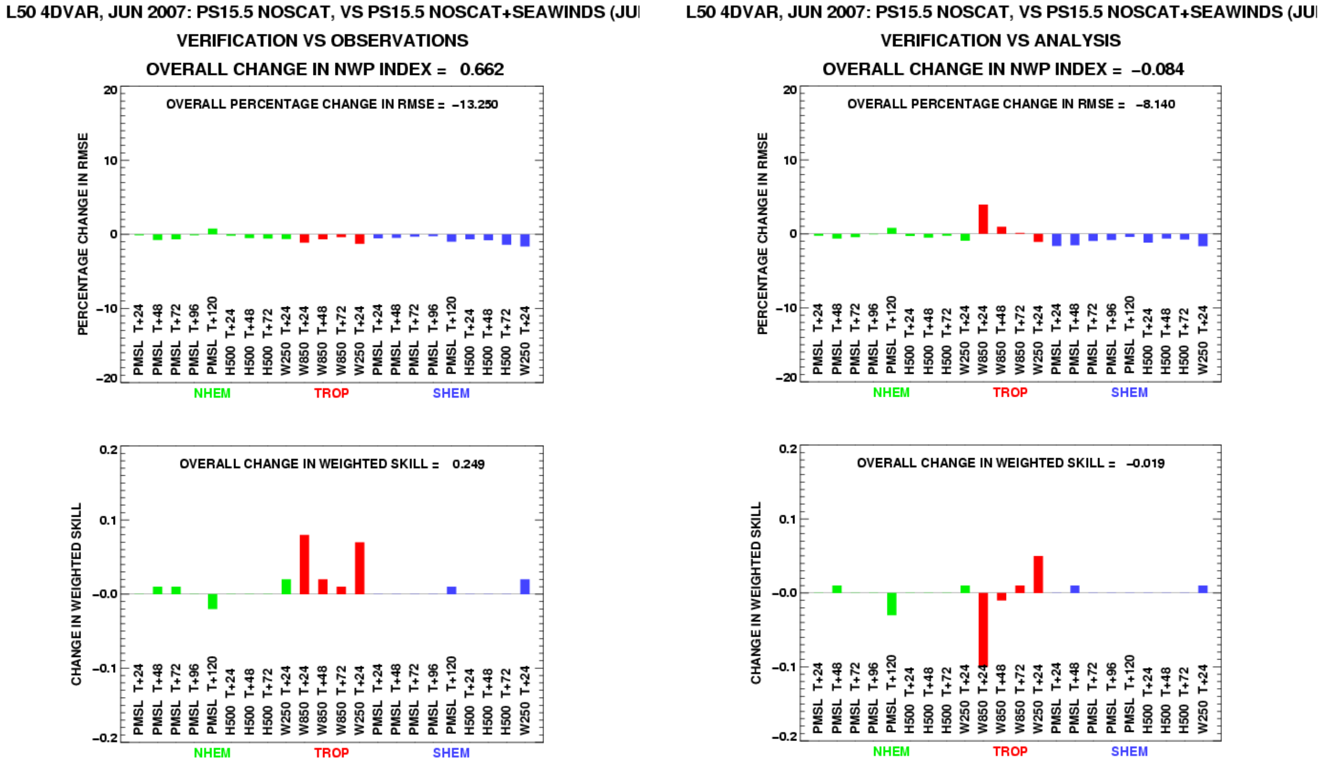

Figure 1. Forecast impact parameters for SeaWinds only trial versus no-scatterometer trial run for June 2007 trial season [3]. Note how the scores verified against observations and analyses are very different in the tropics. The (weighted) negative impact in the tropics drags down the SeaWinds impact to -0.08 when verified against analyses relative to the no-scatterometer case.

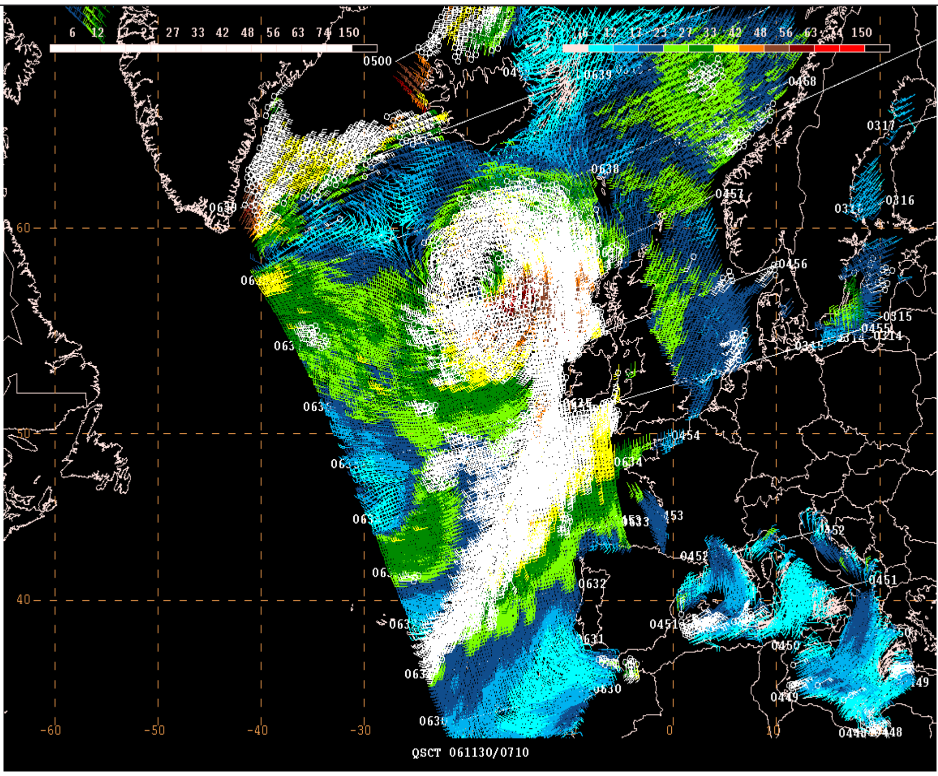

Figure 2a. Example of difference in rain flagging of data for OSW product. White barbs are rain flagged.

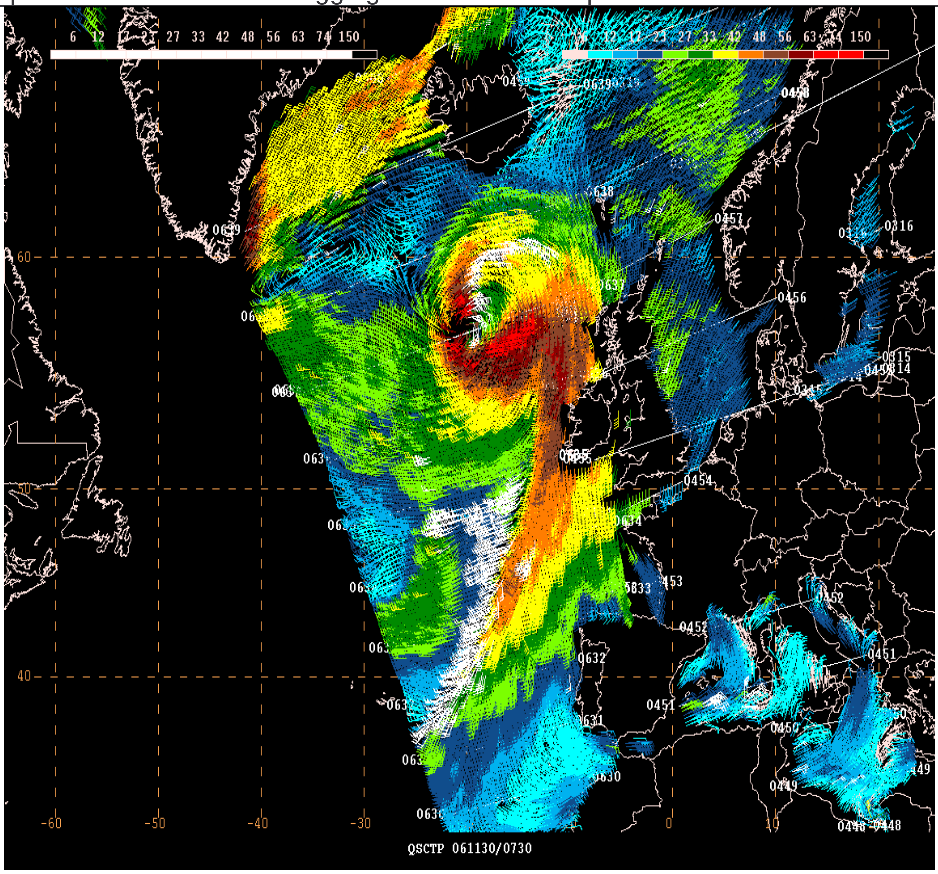

Figure 2b. Example of rain flagging of data for NSW products. White barbs are rain flagged.

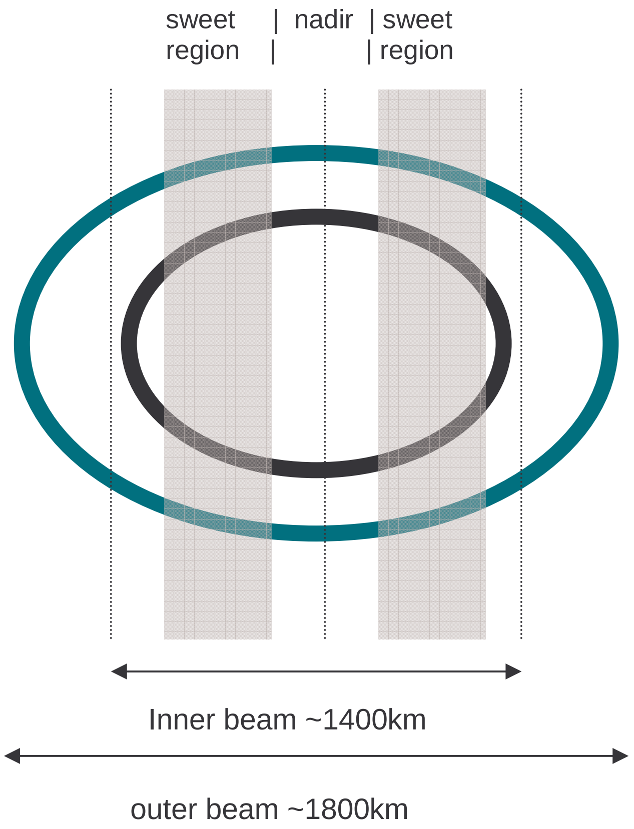

Figure 3. The QuikSCAT swath. The inner and outer beams are shown in black and blue respectively. The sweet parts of the swath are shown as grey stripes. Only the sweet part of the swath is used (cells 12-28 and 49-65) in Met Office NWP due to the higher quality of the data.

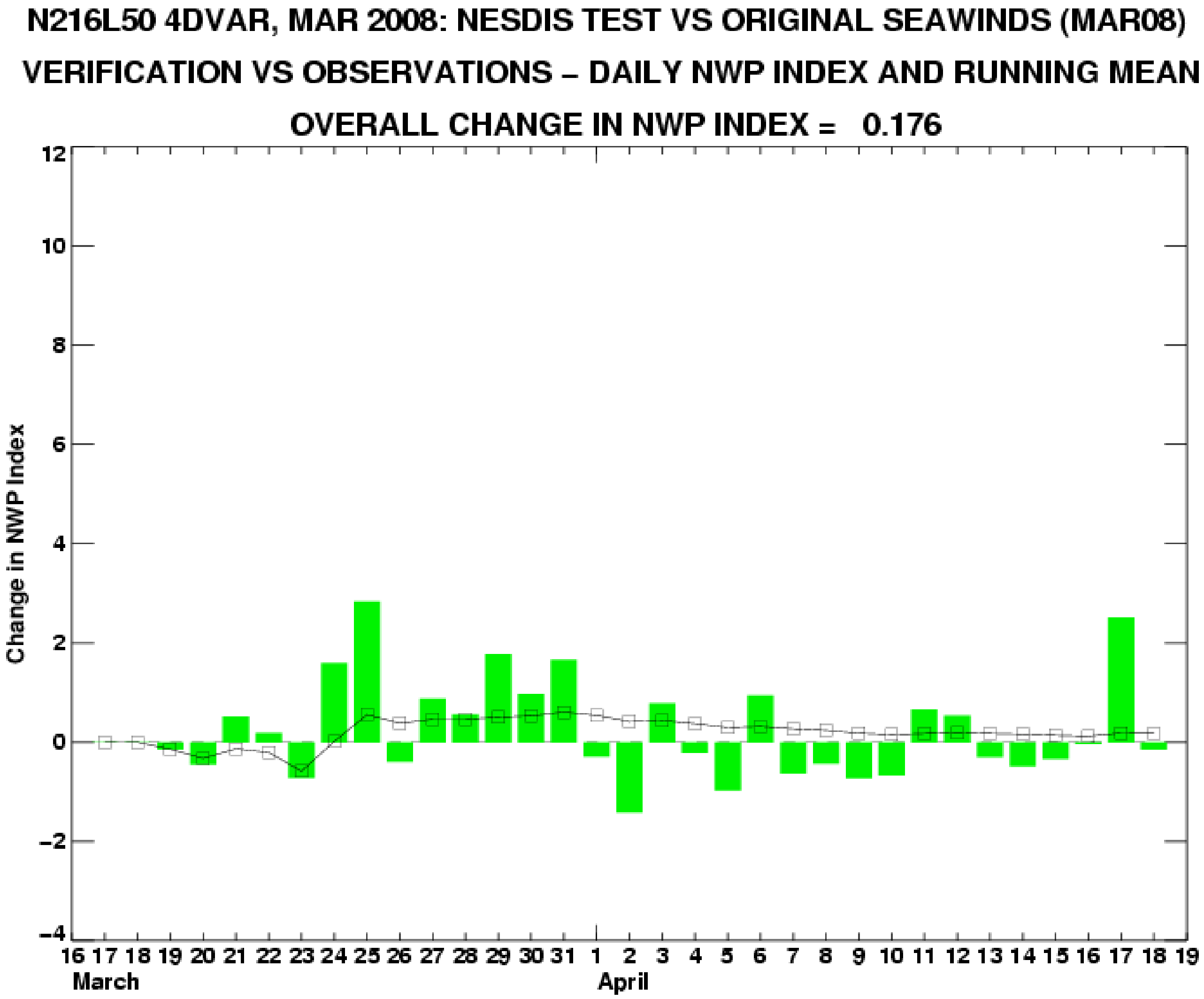

Figure 4. The NWP index verified against observations varies over the trial but has some strong positive signals over the period. Overall a positive impact of +0.176 is measured when the trial forecasts are verified against observations.

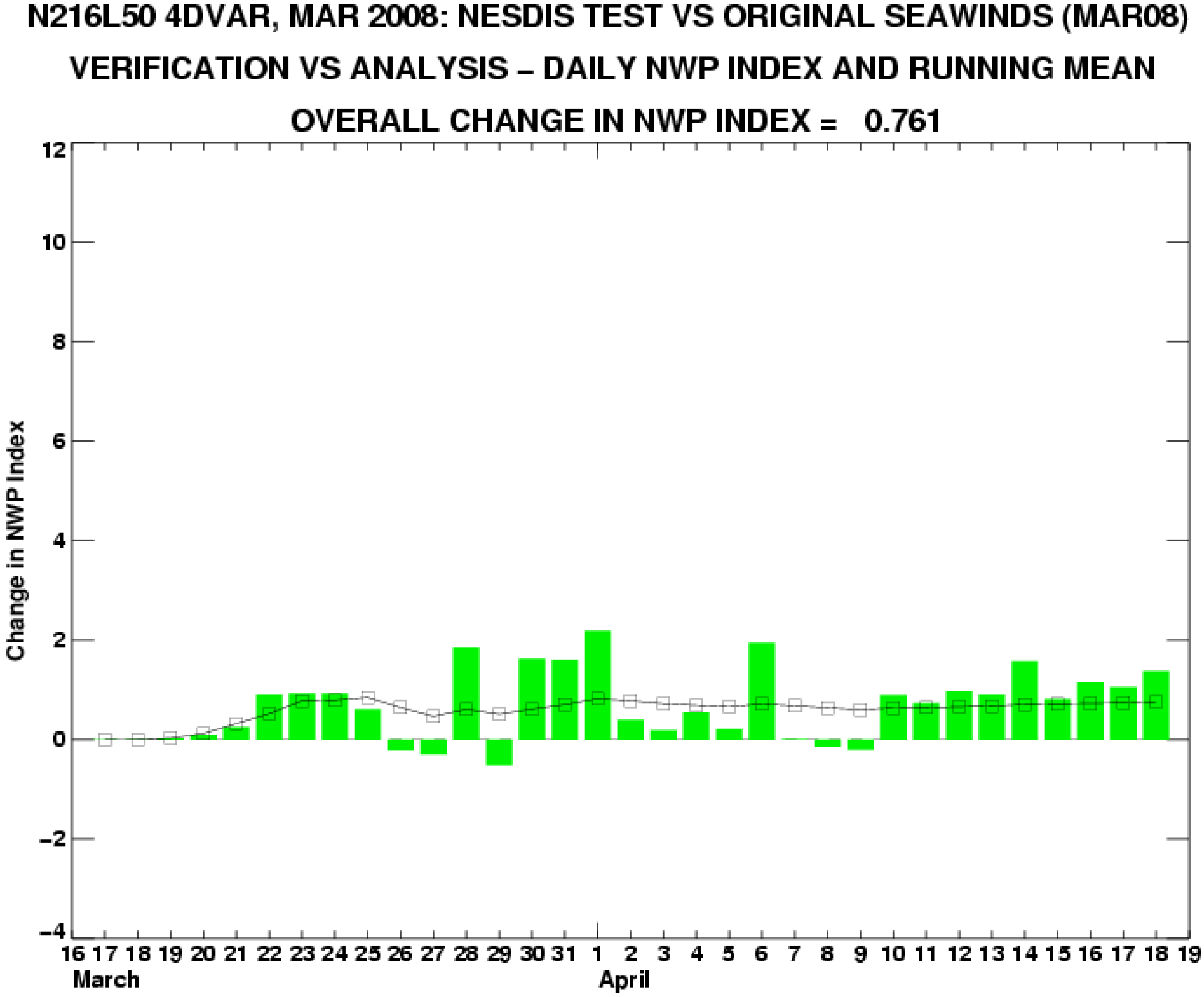

Figure 5. The NWP index verified against analyses has strong positive signals over almost the whole trial period. An overall NWP index improvement of +0.761 is measured in the trial forecasts when verified against analyses.

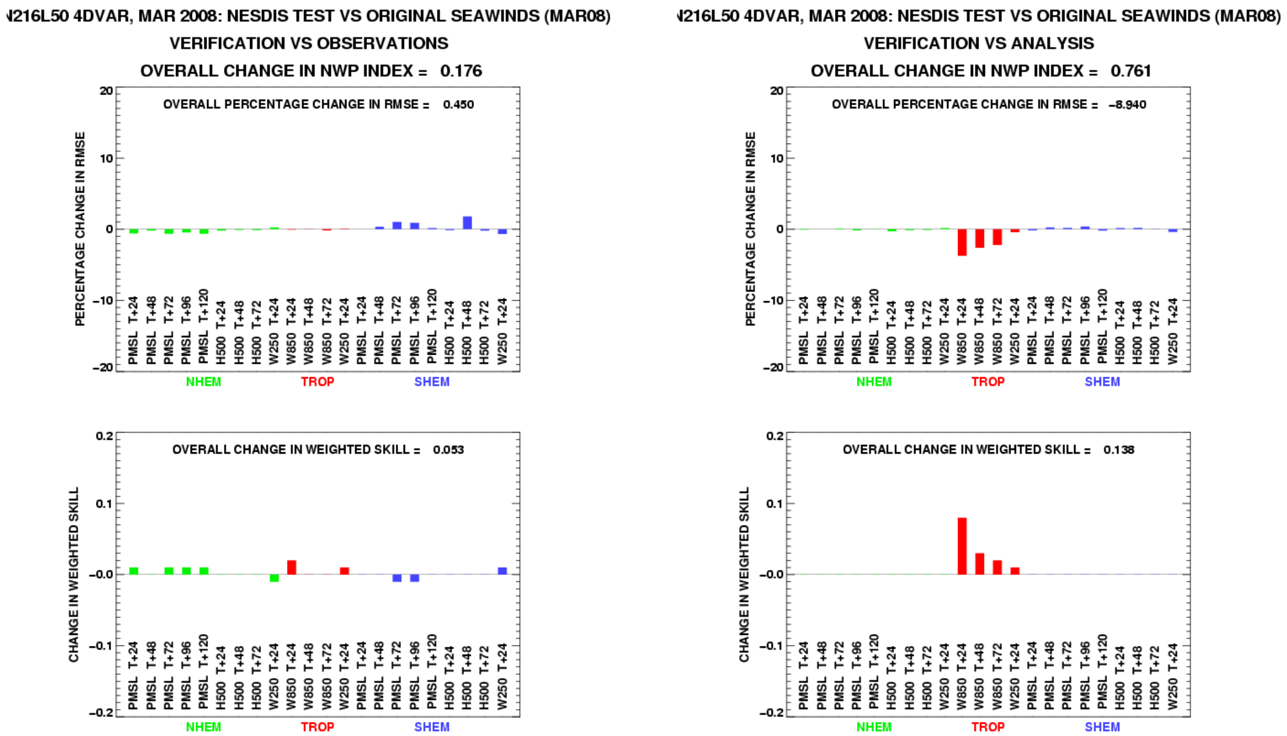

Figure 6. Individual parameter trial skill scores demonstrate large improvements in tropical wind scores when forecasts from the new SeaWinds product trial are verified against March 2008 analyses.

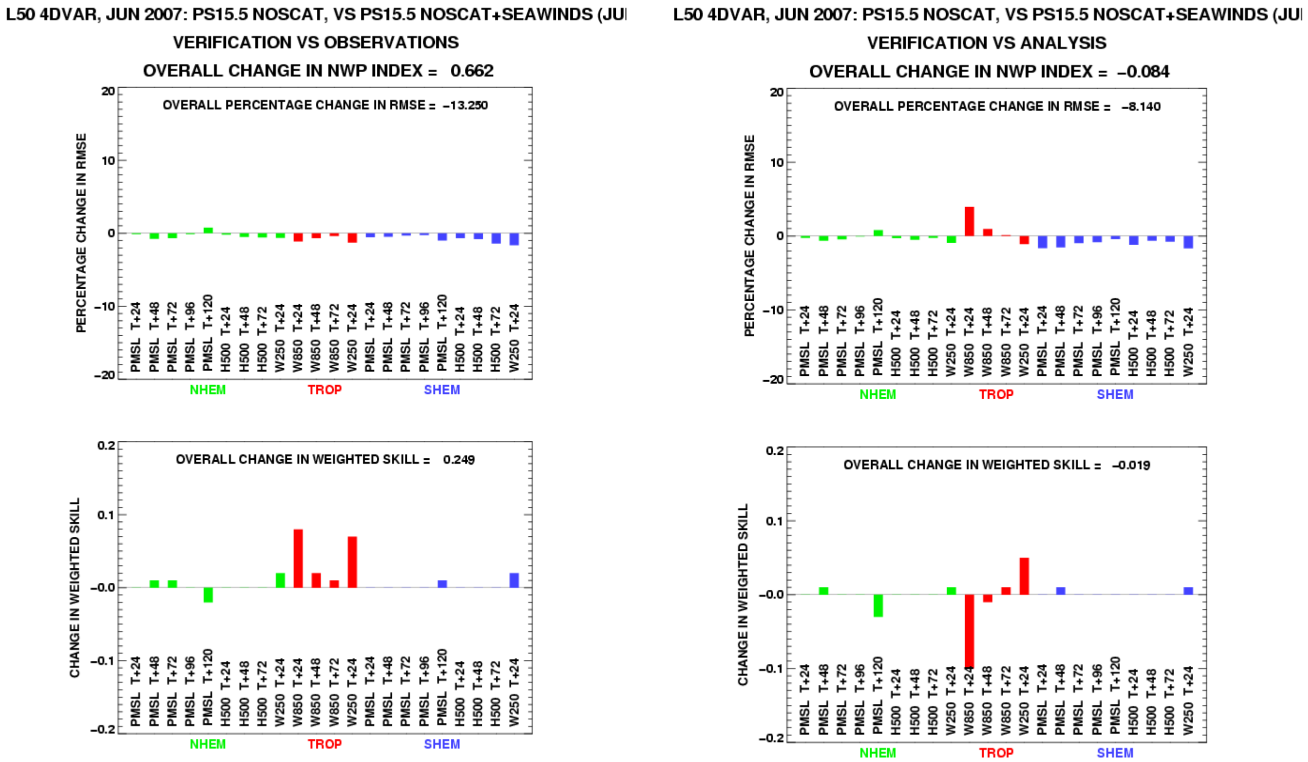

Figure 7. Original SeaWinds product versus NOSCAT control. Reduction in weighted skill are observed against March 2008 analysis winds in the tropics.

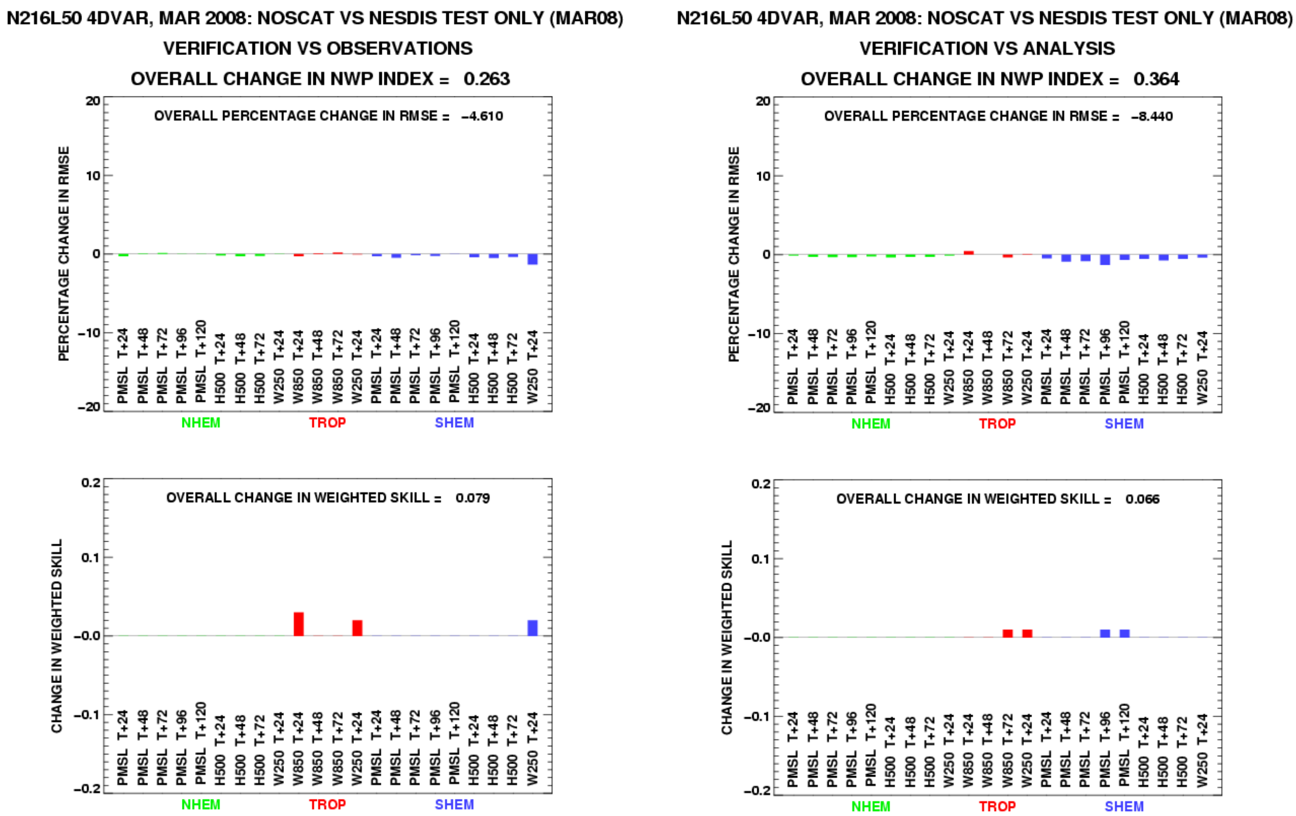

Figure 8. New NESDIS SeaWinds product versus NOSCAT control. Modest improvements in weighted skill are observed in the tropical winds when verified against March 2008 analyses.

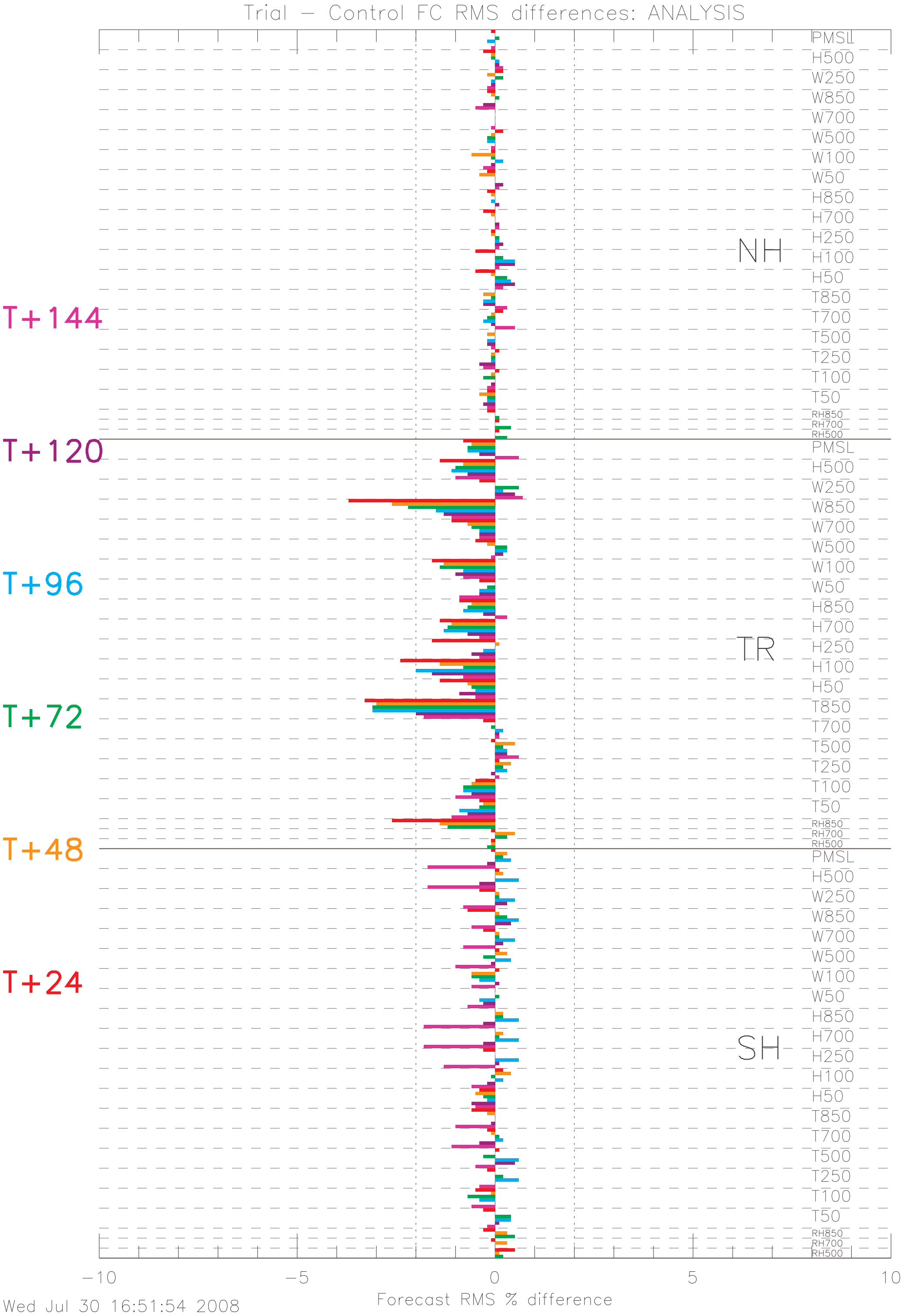

Figure 9. Renniegram showing the change in forecast error for the trial (NSW forecasts) versus control (OSW forecasts). Note that coloured lines to the left are good. The most significant impacts are in the tropics for 850hpa wind and temperature.

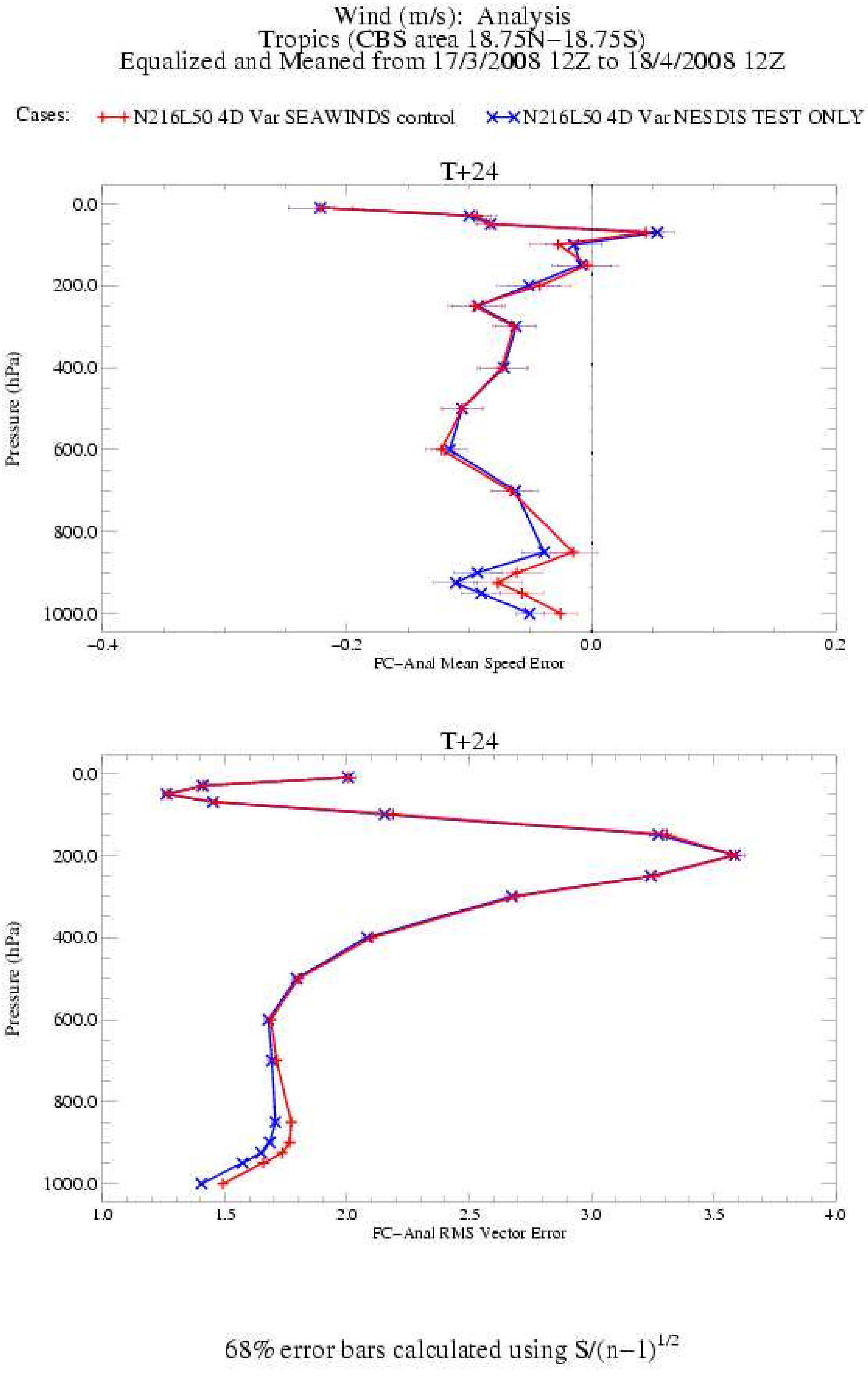

Figure 10. Improvement in RMS vector wind error in the tropics. Trial = blue line, Control = red line. Note how trial RMS vector error is significantly lower between 600 – 1000hpa.

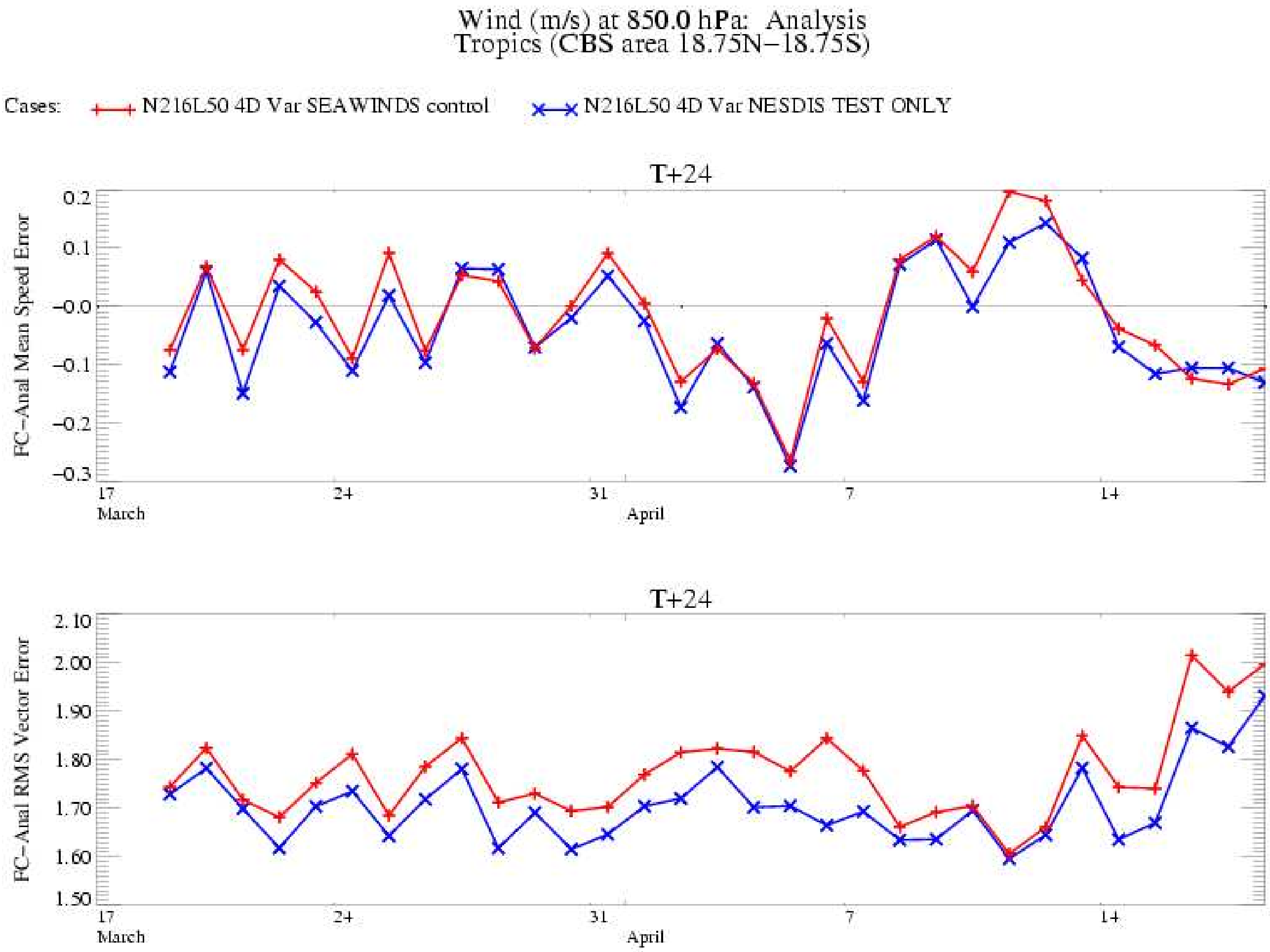

Figure 11. Time series of RMS vector error in the tropics. It is readily seen from the lower plot that the RMS vector error was lower for the trial (blue) than for the control (red) throughout the trial period.

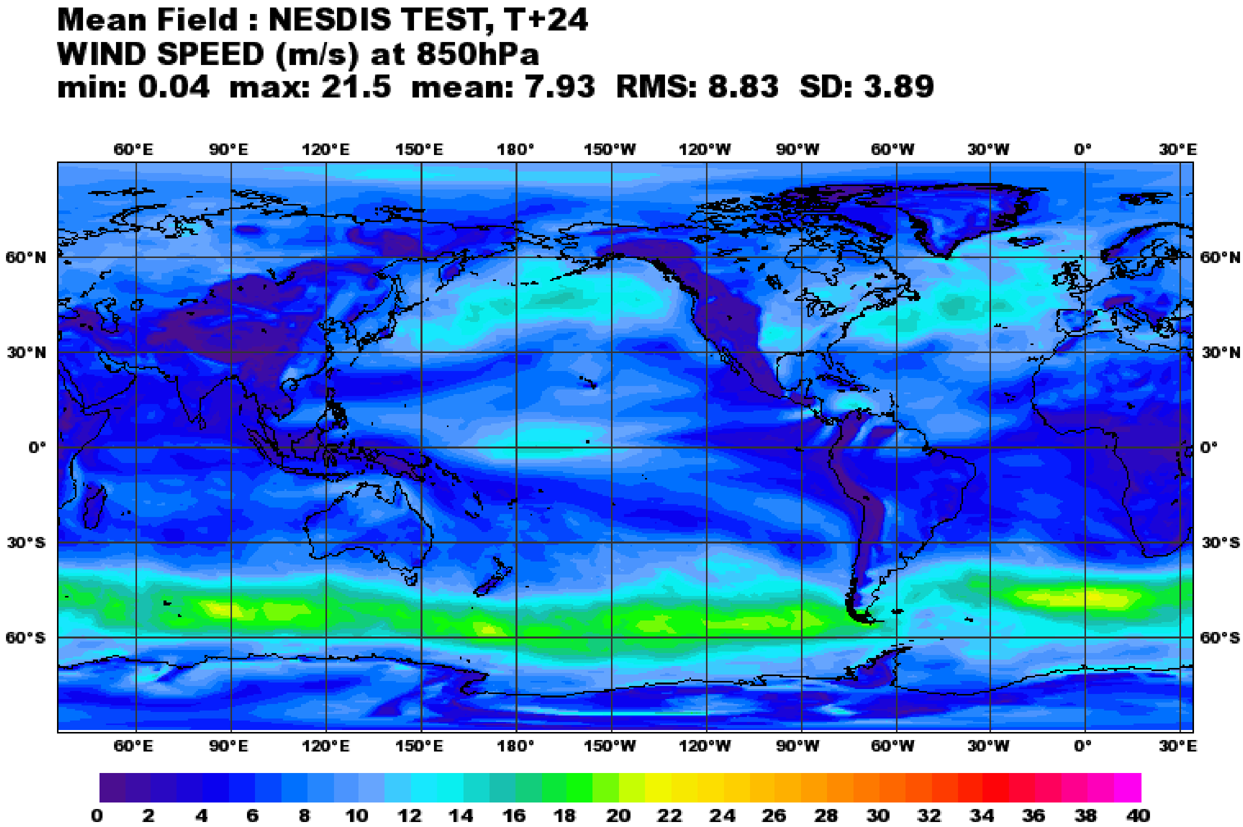

Figure 12. Trial wind speeds at 850hpa for T+24 forecast range.

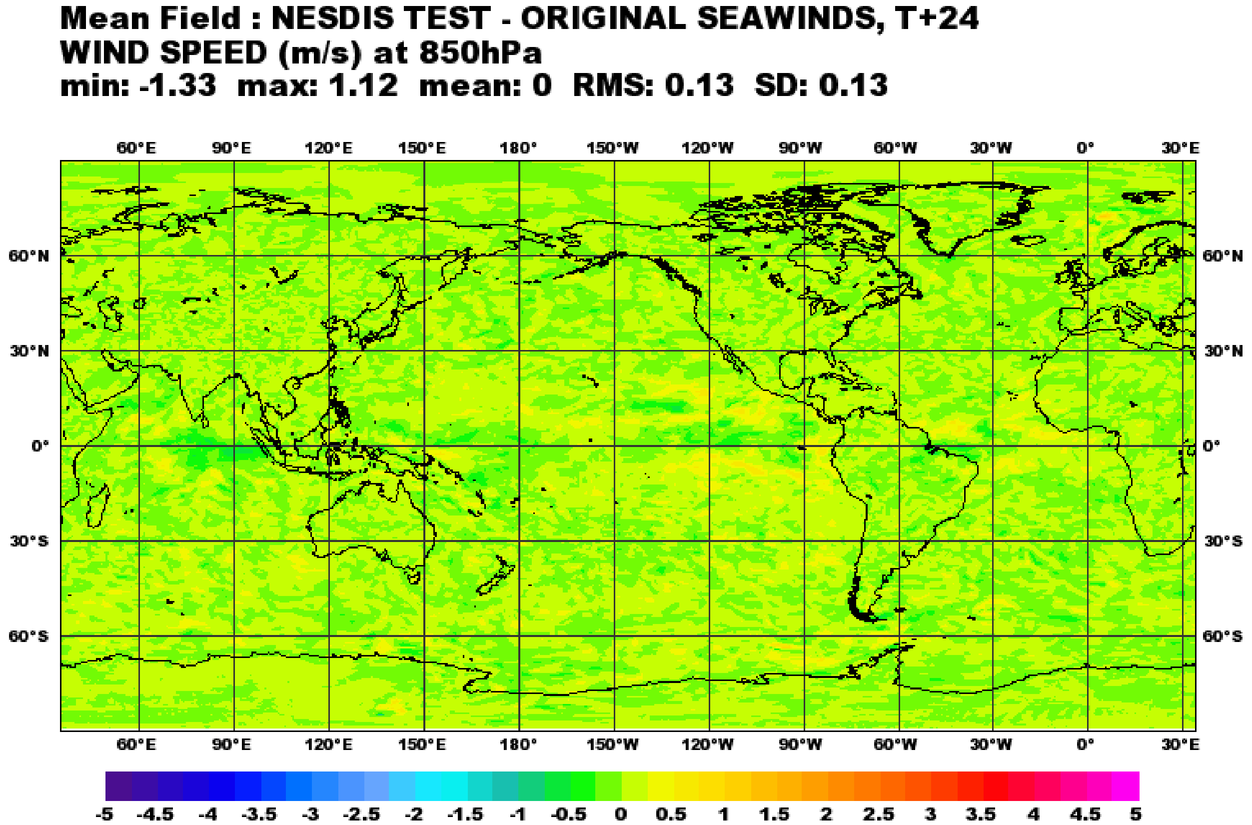

Figure 13. Trial – Control for 850hpa wind speeds at T+24 range.

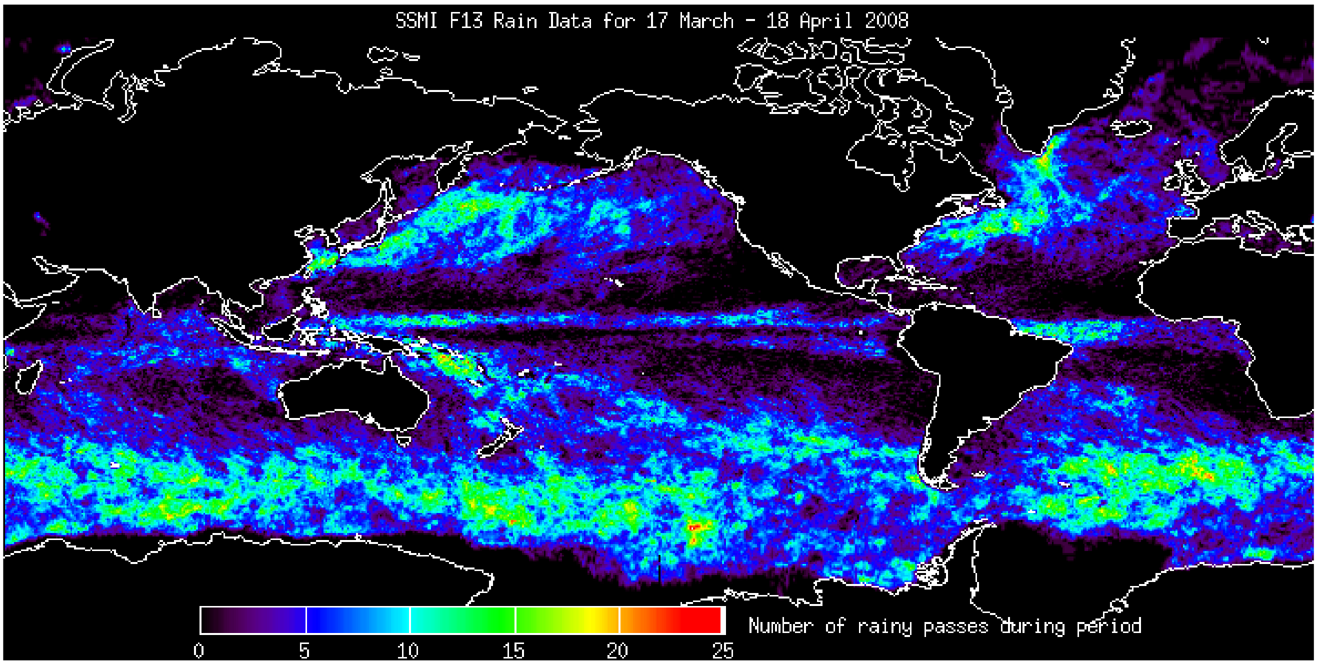

Figure 14. Number of rainy overpasses (ascending and descending) throughout the trial period as measured by SSMI on F13.

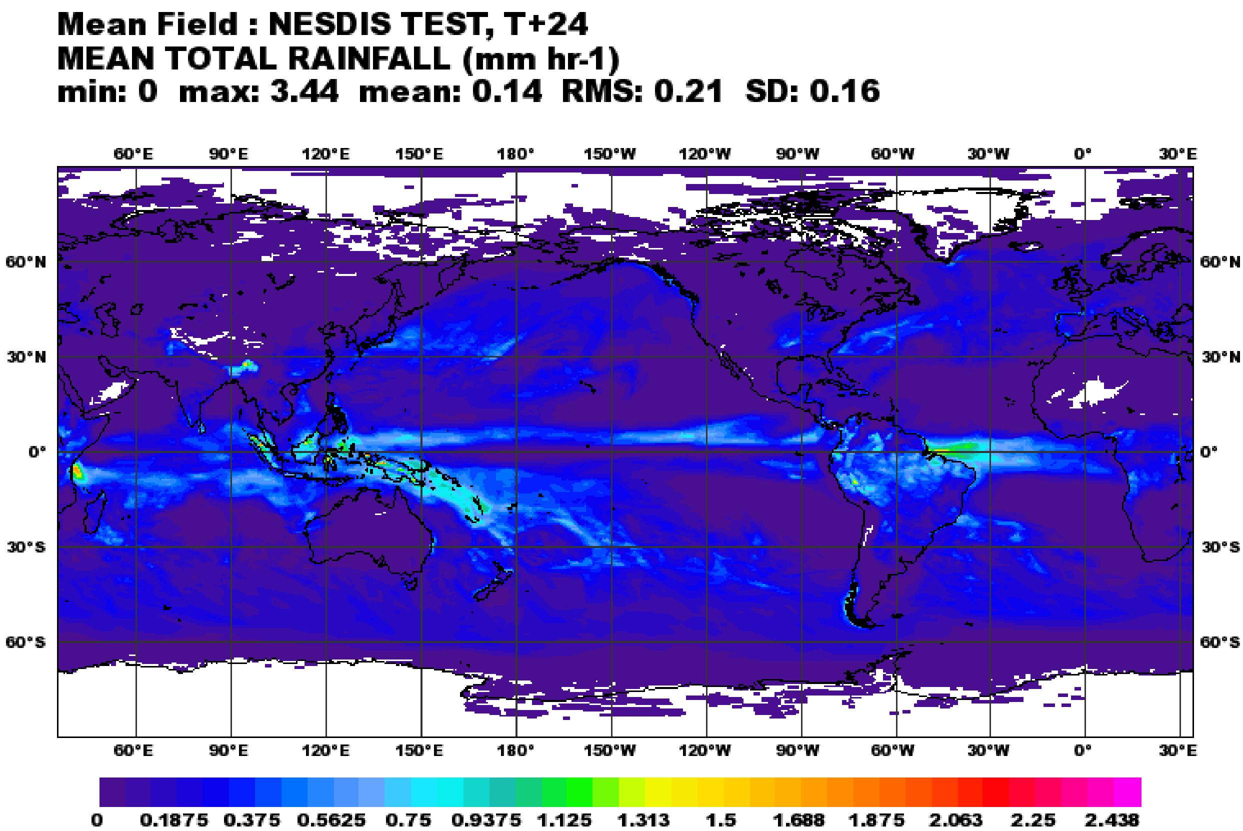

Figure 15. Mean rainfall rate (mm/hr) forecast at T+24 range by trial. This is not significantly different to the forecast from the control.

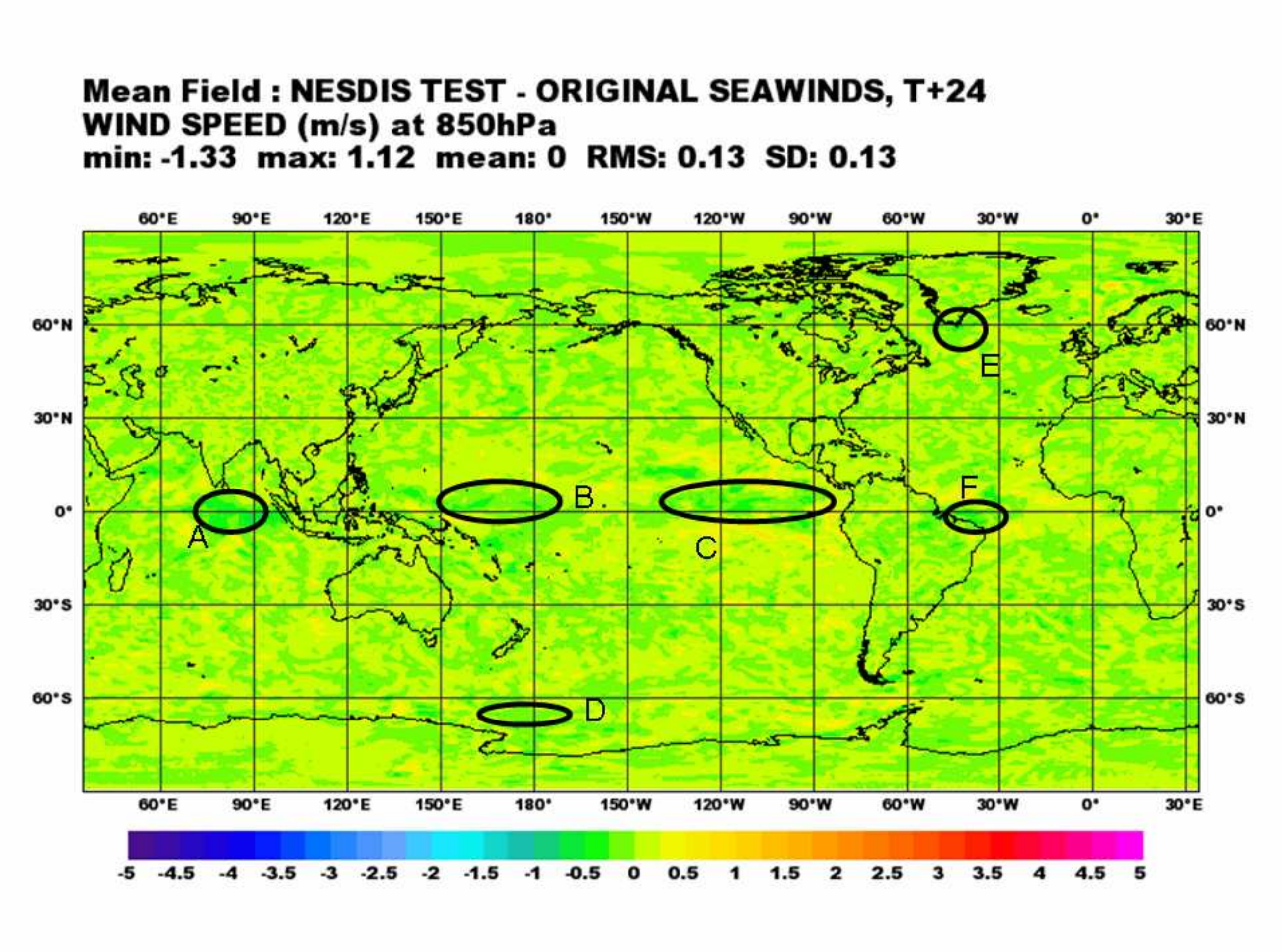

Figure 16. As for figure 12 above but with regions of interest marked by circles. Trial – Control for 850hpa wind speeds at T+24 range. Regions A-F are circled to show areas where forecast winds are slowed down (by up to 1m/s) in the trial compared to the control.