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A comparison of aircraft-based surface-layer observations over Denmark Strait and the Irminger Sea with meteorological analyses and QuikSCAT winds

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Abstract

A compilation of aircraft observations of the atmospheric surface layer are compared against several meteorological analyses and QuikSCAT wind products. The observations are taken during the Greenland Flow Distortion Experiment (GFDex), in February and March 2007, during cold-air outbreak conditions and moderate to high wind speeds. About 150 data points spread over six days are used, with each data point derived from a 2-minute run (equivalent to a 12km spatial average). The observations were taken 30-50m above the sea surface and are adjusted to standard heights. Surface-layer temperature, humidity and wind, as well as sea surface temperature (SST) and surface turbulent fluxes are compared against co-located data from the ECMWF operational analyses; NCEP Global-Reanalyses; NCEP North-American-Regional-Reanalyses (NARR); Met Office North-Atlantic-European (NAE) operational analyses; two MM5 hindcasts; and two QuikSCAT products.

In general, the limited area models are better at capturing the mesoscale high windspeed features and their associated structure – often the models underestimate the highest windspeeds and gradients. The most significant discrepancies are a poor simulation of relative humidity in the NCEP-Global and MM5 models; a cold bias in 2-m air temperature near the sea-ice edge in the NAE model; and an overestimation of wind speed above 20 m s^{-1} in the QuikSCAT wind products. In addition, the NCEP Global, NARR and MM5 models all have significant discrepancies associated with the parameterization of surface turbulent heat fluxes. A high-resolution prescription of the SST field is crucial in this region, although these were not generally used at this time.

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1. Introduction

The objective of this study is to assess the quality of a selection of such NWP models and analyses during high wind speed wintertime conditions using a compilation of surface-layer observations from an aircraft-based field campaign. The aims are to quantify typical errors in the NWP analyses; uncover any systematic model biases; ascertain the resolution required to model the mesoscale features; and evaluate the QuikSCAT wind products for this region. High quality surface-layer meteorological observations for the subpolar seas are relatively rare, and so despite the importance of such validation for ocean studies, there have been relatively few in this region.

The observations used in this comparison are compiled from the low-level components of six flights from the Greenland Flow Distortion experiment (GFDex). GFDex centered around an aircraft field campaign, based out of Keflavik in Iceland, during February and March 2007. The objectives of the field campaign were to obtain comprehensive observations of a number of mesoscale weather systems associated with interactions between the synoptic-scale atmospheric flow and the high topography of Greenland, such as tip jets, barrier flows and lee cyclones, as well as including a targeted observing component aimed at targeting sensitive area predictions. The six flights compiled here were flown to observe a reverse tip jet case (B268), a polar mesoscale cyclone (B271) and various barrier flow events (B274, B276, B277 & B278). Further details of individual flights can be found in the GFDex overview paper (Renfrew et al. 2008). The meteorological conditions during the six flights can be categorised simply as 'cold-air outbreaks' associated with moderate to high wind speeds in northerly or northeasterly flows. In general the atmospheric surface layer was slightly unstable and the atmospheric boundary layer (ABL) close to moist neutral, i.e. conditions typical of such cold-air outbreaks (e.g. Brümmer 1997, Renfrew and Moore 1999).

2. Data Sets

Flight-level measurements from the Facility for Airborne Atmospheric Measurement's (FAAM's) BAE-146 have been used to derive an observational 'database' for this comparison study. The database comprises numerous variables at approximately 150 separate times and locations, spread over six days (Figs. 1, 2; Table 1). The flight-level observations have been divided into 2-minute (~12 km) runs, and run-averages are used for the comparison. The flight-level meteorological observations have been adjusted to "standard" levels by using well-established stability-dependent surface-layer similarity theory. The model data for the comparison are ECMWF operational analyses (at T511/N400 resolution); NCEP Global Reanalyses; NCEP North American Regional Reanalyses; Met Office North-Atlantic-Europe (NAE) operational analyses and MM5 Hindcasts. In addition QuikSCAT winds are compared using the RSS and NASA-DIRTH retreival algorithms.

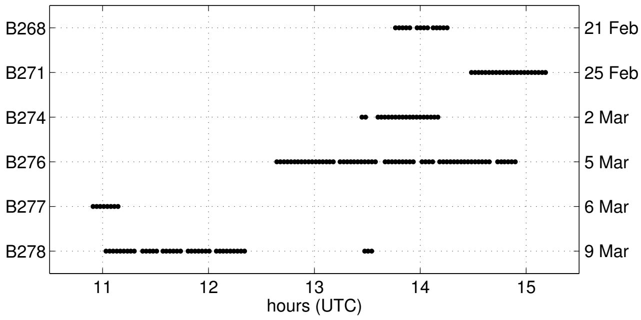


Figure 1 Times and dates of the GFDex observational database used in the comparison.

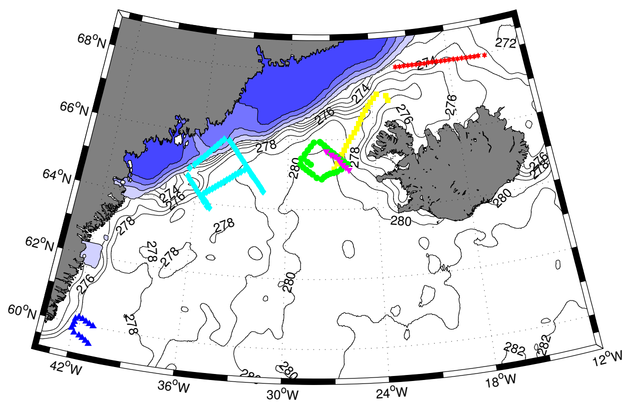


Figure 2 Locations of the observational database points. Data are from the low-level legs of flights B268 (blue triangles), B271 (red stars), B274 (yellow squares), B276 (cyan diamonds), B277 (magenta triangles) and B278 (green circles). Sea surface temperature (contours) and sea-ice concentration (shading) from the OSTIA data set on the 5 March 2007 is also shown.

3. Methodology

The strategy employed in this study has been to assess each model or satellite-derived product in the best way for that product, i.e. to compare at the best temporal and spatial resolution available. In other words, we are assessing the quality of each product against the observational 'truth', rather than carrying out a strict intercomparison. The basic methodology has been to extract model and satellite-derived 'timeseries' by matching in time and space against the observational data. Figure 1 illustrates the temporal range of the observational data – betweeen 1100-1500 UTC over six days; while Fig. 2 illustrates the spatial domain of the observations – the data points cover approximately 2000 km of the atmospheric surface layer.

3. A summary of model performance

(a) ECMWF operational analyses

The ECMWF model does not capture the highest windspeeds observed, despite a horizontal resolution equivalent to ~40 km in the T511/N400 truncation. This suggests mesoscale atmospheric flow features are being 'smoothed out' in some way. A result that is in line with the spectral analysis and conclusions of Chelton et al. (2006). At T511/N400 the model produces good estimates for the surface-layer temperature and humidities, despite a large scatter in the SST. But at lower resolution (1.125 deg) a bias of -0.7 K in T_{2m} is introduced. The ECMWF surface turbulent fluxes correspond reasonably well with the observations – the statistical comparison is in line with previous studies (Renfrew et al. 2002; Josey 2001; Josey et al. 2002). Overall the correspondence is comparable to that of Renfrew et al. (2002)[1] for similar cold-air outbreak conditions over the Labrador Sea.

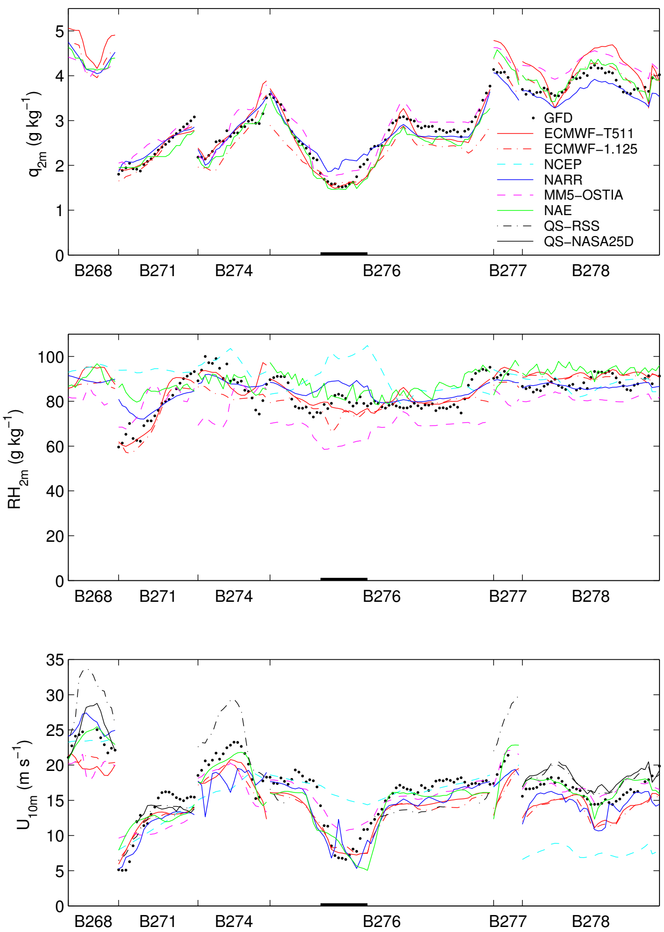
(b) NCEP Global Reanalyses

The NCEP global reanalyses are simply too coarse to adequately resolve the mesoscale flow features observed in this data set. In particular the correspondence in U_{10m} is very poor. The T_{2m} and SST correspondences are reasonable for the model's resolution, but there is still a positive bias in RH as discussed in Renfrew et al. (2002). The flux correlations are poor. The

[1] Note Renfrew et al. (2002) present bias, slope, random and total errors in their Tables 2 and 4. They state on p. 389 that the "total error" is equal to the r.m.s. error, but unfortunately this is incorrect (they do not tabulate the r.m.s. errors).

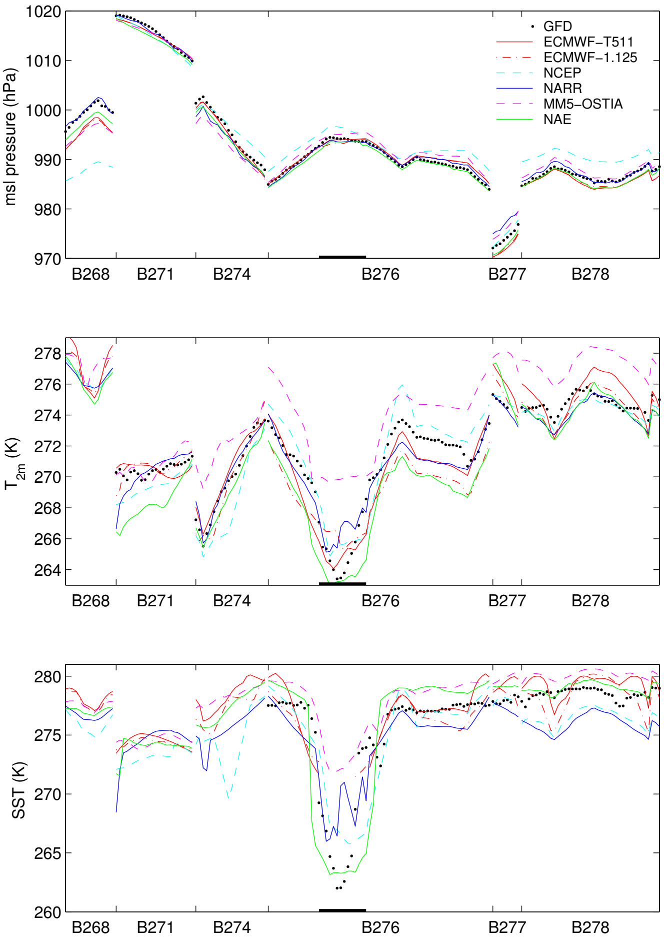
inappropriate scalar roughness length parameterisation that has been discussed in previous studies (Zeng et al. 1998; Renfrew et al. 2002) is evident on occasion, but the generally poor correspondence in other variables means it is less obvious in this study.

Figure 3 Spatial "timeseries" plots showing observations (dots) and model or satellite products (see legend) for the 6 low-level flights. Recall each observation is a 2 minute (~12 km) average. The variables shown are mean-sea-level pressure (mslp), 2-m air temperature (T_{2m}), sea surface temperature (SST), 2-m specific humidity (q_{2m}), 2-m relative humidity (RH_{2m}), and 10-m wind speed (U_{10m}). A bold horizontal line on each panel marks where the data are from over observed sea ice.



(c) NCEP NARR

The NCEP NARR comparison is generally good. At this horizontal resolution (32 km) the highest wind speeds can be simulated, although overall there is a negative bias (-1.5 m s^{-1}) in U_{10m}. The correspondence in surface-layer temperature and humidities is relatively good, compared to the other models, suggesting that the ABL parameterizations are adequate; with the caveat that the slope in the RH_{2m} comparison is too low (the model is too moist at lower RHs) and ΔT is rather low. The r.m.s. errors for T_{2m} and q_{2m} are similar to the comparison against buoy data of Moore et al. (2008). Given the above, the correspondence of the surface heat fluxes is disappointing, suggesting the bulk flux algorithm is *not* optimal. The NARR bulk flux algorithm employs a viscous sublayer, which becomes negligible for high wind speeds, whereupon flux transports are simply set by the ABL parameterization, which is based on Mellor and Yamada (1974)'s level 2 scheme (see Janjić 1994). Evidence from this comparison suggests this set up can, but does not always, lead to fluxes much larger than either the observations or the other models.



(d) Met Office NAE

The NAE operational model does well at capturing the observed high winds associated with the barrier flows and jets – there is only a small bias (-0.7 m s^{-1}) in U_{10m}. However adjacent and over areas of sea ice there is a pronounced cold bias in T_{2m} (-1.3 K on average), which is *not* explained by a +1.1 K bias in the SST. This problem may be explained by the model's sea ice being set at a uniform 2 m, which is perhaps, too thick on average for this region. The NAE RH_{2m} has a similar low-slope problem to that of the NARR model. The surface turbulent fluxes are generally well-modelled, but the relatively large biases in ΔT and Δq result in relatively large biases in the sensible and latent heat fluxes.

(e) MM5 hindcasts

The MM5 simulations are able to capture the high windspeed jets, but some times do not. A +1.7 K bias in the OSTIA SST used in the second hindcast leads to a positive bias in T_{2m} (2.3 K) and in q_{2m} (0.24 g kg^{-1}). The RH_{2m} corresponds poorly to the observations, suggesting little skill for this field during these conditions. The MM5 default bulk flux algorithm results in a poor regression slope and large bias, which leads to large overestimates in the sensible and latent heat fluxes. In line with Pagowski and Moore (2001), this suggests the algorithm is inappropriate for high heat flux conditions.

(f) QuikSCAT winds

The QuikSCAT wind comparisons are poor for both retrieval algorithms: the linear regression slopes are too large and the r.m.s. errors – at 3.3 and 1.9 m s^{-1} for the RSS and NASA-DIRTH retrievals respectively – are higher than the instrument's design specifications. The NASA DIRTH algorithm is more conservative, with data only available for 3 flight comparisons, while the RSS algorithm appears to be more problematic at high wind speeds.

4. Conclusions

To simulate the high winds associated with extratropical mesoscale weather systems – such as tip jets, barrier flows and polar lows – a model resolution of order 20 km is necessary, but is not sufficient, as appropriate ABL and surface flux parameterizations are also crucial. In regions of the subpolar and polar seas, relatively close to the sea-ice edge, the current generation of NWP models still have problems in accurately simulating ABL temperature and humidity, perhaps being unable to transit from stable to unstable conditions quickly enough? An accurate prescription of the SST is essential, but at the time of GFDex these were generally prescribed at a relatively coarse resolution compared to the atmospheric model grid. The operational use of a new generation of high-resolution SST products (e.g. Donlon et al. 2007) will no doubt improve the quality of SST fields, but there are still likely to be relatively high discrepancies in cloudy areas of high SST gradients. The use of surface turbulent fluxes from NWP models is *not* recommended without an investigation of the surface flux algorithm used and validation against observations.

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