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ARCTIC UPPER-LEVEL WINDS FROM REANALYSES AND TOVS SATELLITE RETRIEVALS

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1. INTRODUCTION

Over regions of the world where conventional data are sufficiently dense, products from reanalyses are generally faithful to reality. In high-latitudes, however, where observations are sparse (fewer than 5 observations per 2.5° lat-long box per month [Kistler *et al*, 2001]) the accuracy of reanalysis products is uncertain. We present results from an effort to assess the accuracy of upper-level wind fields from both the NCEP/NCAR (National Centers for Environmental Prediction/National Center for Atmospheric Research) and ECMWF (European Center for Medium Range Weather Forecasting) Reanalysis data sets over the Arctic Ocean, as well as from a new upper-level wind data set derived from TOVS (TIROS Operational Vertical Sounder) satellite temperature retrievals. One of the major difficulties in validating reanalysis products is that almost all available conventional data are assimilated into the system, thus independent data sets are few. By comparing the time and location of rawinsonde data ingested into the reanalyses with the locations of rawinsondes from field campaigns in the Arctic region, however, we were able to ascertain that observations from two field programs were not assimilated, and therefore constitute independent data. The Coordinated Eastern Arctic Experiment [CEAREX, 1990] was conducted northeast of Spitsbergen in fall/winter 1988, and the Lead Experiment [LeadEx Group, 1993] took place in the Beaufort Sea in spring 1992. While these data are independent, the sites are relatively near to coastal stations (100 to 300 km), thus the results presented here (and more thoroughly in Francis [2002]) may be optimistic, and differences between reanalysis and measured winds may be larger farther from the coasts. New retrievals of TOVS-derived winds are compared to data from the SHEBA (Surface Heat Balance at the Surface) field program that occurred in the Beaufort Sea for a year beginning in October 1997 [Uttal *et al*, 2002]. SHEBA data are not compared to reanalysis winds because the data were assimilated into the models. Approximate locations of the CEAREX, LeadEx, and SHEBA field sites are shown in Fig. 1.

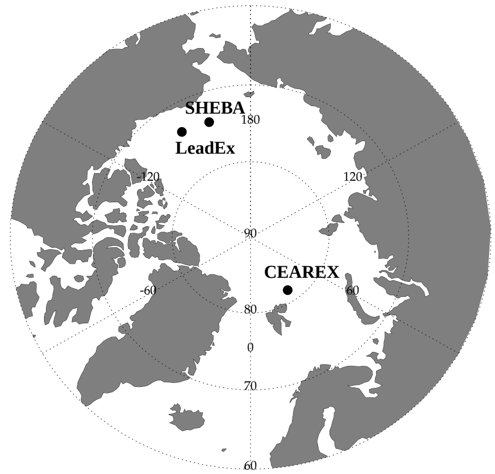


Figure 1: Arctic map showing approximate locations of the CEAREX, LeadEx, and SHEBA field programs from which rawinsondes were used in this study.

2. VALIDATION OF REANALYSIS WINDS

Here we summarize results of a study that were recently published in Francis [2002]. We compared mean-layer winds for five layers bounded by 300, 400, 500, 700, 850, and 1000 hPa from the NCEP/NCAR reanalysis, the ECMWF reanalysis, and from CEAREX and LeadEx rawinsondes. Approximately 180 collocations were obtained, although about half of the rawinsondes had no wind data above 400 hPa. Figure 2 presents comparison statistics of *u* and *v* wind components from the NCEP/NCAR reanalysis with rawinsonde data. The ECMWF Reanalysis results are very similar and are not shown.

Biases are calculated as the mean difference between reanalysis and rawinsonde *u* and *v* winds. The biases in NCEP/NCAR winds are statistically significant (> 95%) at all levels except for the *u* component in layer 5 (1000 to 850 hPa). The means of both wind components from the reanalysis are approximately double (more westerly and northerly) those from rawinsondes in all but the lowest layer. Root-mean-square errors (RMSE) exhibit further evidence of the wind differences, with values similar in magnitude to the rawinsonde total mean wind speed in each layer. Much of the RMSE is likely attributable to the fact that a spatially interpolated and gridded value is being compared to a point measurement. The bias in total speed represents approximately 65% of the mean speed from rawinsondes above 500 hPa and 35% below (Fig. 2d). One might expect, however, that the rawinsonde winds would be larger in absolute magnitude than interpolated gridded values owing to smoothing of small-scale circulation features by the reanalyses, but our results show the opposite relationship. Further analysis reveals that both reanalysis data sets have the wrong sign for *u* approximately 20% of the time (30% in the lowest layer), and slightly less frequently for the *v* component. These discrepancies are not a function of wind speed.

The implications of these errors may be important. Overly strong westerlies imply that the meridional temperature gradients near the experiment sites are too strong, possibly leading to an overly intense, narrow jet

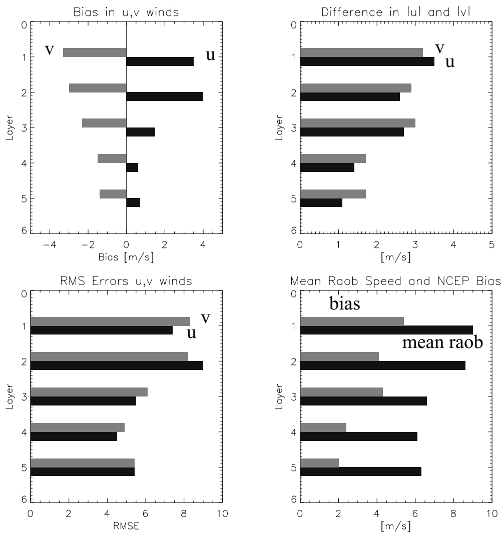


Figure 2: Comparison of NCEP/NCAR Reanalysis upper-level winds to measurements by rawinsondes during the CEAREX and LeadEx Arctic field programs. Layers 1 through 5 are bounded by the following pressure levels: 300, 400, 500, 700, 850, and 1000 hPa. The *u* wind is dark gray and *v* is light gray. (a) shows the bias in *u* and *v*, (b) is the difference in mean absolute magnitudes of *u* and *v* (NCEP-rawinsonde), (c) shows RMS errors in *u* and *v*, and (d) is the mean wind magnitude from rawinsondes and bias in the NCEP/NCAR speed.

stream and/or misplaced cyclonic disturbances. Alternatively the jet axis may be rotated clockwise from its actual alignment, which for a constant speed, could cause the u component to be too positive and the v component to be too negative. Winds that are too frequently from the north may imply that semipermanent features in the upper-level circulation may be misplaced and that reanalyses may not properly capture the synoptic-scale features that tend to cause fluctuations in especially the north-south wind component. Further, if one used reanalysis winds to calculate advective transport of energy or moisture, for example, values would likely be too small in the poleward sense, as the meridional wind is too strong from the north, and transport would be too large in the zonal direction owing to the wind being too strong from the west on average. Models using these winds to calculate surface fluxes or to force sea ice motion may produce patterns with unrealistic features, although errors near the surface are smaller.

Realistic wind fields are essential for studying the Arctic climate, both for process studies and for understanding long-term changes, and clearly the data sets presently available have limitations that will contribute large uncertainties to calculations of advected quantities, such as sensible heat and moisture transport.

3. UPPER-LEVEL WINDS FROM TOVS

In an attempt to improve upon the present situation, we have generated a new upper-level wind data set for the Arctic using temperature profiles retrieved from the TOVS instrument and from NCEP/NCAR 10-meter wind fields. We also employ the mass conservation technique developed by Zou and Van Woert [2002] (hereafter abbreviated ZVW), which improved their upper-level winds derived from TOVS retrievals in the Southern Ocean.

3.1 *Method*

The wind retrieval algorithm begins by obtaining temperature profiles retrieved from the TOVS instrument using a modified version of the Improved Initialization Inversion ("3I") algorithm [Scott *et al*, 1999]. Twenty years of TOVS profiles were produced as a part of the so-called Path-P project [Francis and Schweiger, 2000; Schweiger *et al*, 2002], although in this study we use the orbital retrievals (Level-2) rather than the gridded product that is available from the National Snow and Ice Data Center as the Path-P data set. Temperatures at 9 standard levels and the surface are then interpolated to a 1° x 1° grid over the region north of 60°N, filtered zonally and meridionally to remove high-frequency noise, and interpolated to fill in small areas of missing data. Layer-mean temperatures are then calculated between the surface, 1000, 900, 850, 700, 600, 500, 400, 300, and 100 hPa. The 10-meter winds produced by the NCEP/NCAR Reanalysis are also obtained from NCAR via ftp and interpolated to this grid. The NCEP/NCAR 10-meter winds were compared to measurements from Russian "North Pole" drifting ice stations and were found to be very close to observations. It was later discovered, however, that the NP winds were assimilated by the reanalysis, so areas far from NP stations may contain significant uncertainties. The degree of this uncertainty could not be quantified owing to the lack of independent data.

Thermal winds $\vec{V}_T$ are computed in the standard way from layer-thickness gradients ∇Z_T in the zonal and poleward directions:

$$\vec{V}_T = \frac{g}{f}\nabla Z_T, \qquad (1)$$

where

$$Z_T = \frac{R\bar{T}_v}{g}\ln\frac{p_2}{p_1}, \qquad (2)$$

R is the dry gas constant, $\bar{T}_v$ is the mean-layer virtual temperature, *g* is gravity, *f* is the Coriolis parameter, and *p* is the pressure at layer boundaries. Because the polar atmosphere contains so little water vapor, we use actual temperature in place of virtual temperature. Thermal winds are added sequentially to the 10-meter *u* and *v* winds to create a first-guess wind profile. Over Greenland where TOVS profiles are not retrieved, we insert NCEP/NCAR Reanalysis winds for levels above 700 hPa. We then use the two methods of ZVW to correct wind fields by conserving mass both zonally and meridionally. Consistent with the results of ZVW, we found that their Method #1 produced wind fields that most closely matched rawinsonde data from SHEBA. This method calculates the *u* and *v* component winds separately by using the mass flux conservation equation across a latitudinal wall as a constraint to derive the *v*-component wind first. The vertically-integrated mass conservation equation is then used to infer the zonal wind.

3.2 *Results*

Figure 3 shows statistics comparing *u* and *v* component winds without mass conservation correction (thermal winds only) with rawinsonde measurements during the entire year of SHEBA. Similar to the reanalysis winds, biases in the *u* component are positive, indicating that retrieved winds are too strong from the west, although unlike the reanalyses, the biases do not increase with height. The retrieval biases are near zero at the surface and approximately constant at 3 m s^{-1} with height above 800 hPa. The biases in *v* component winds also exhibits the same sign but are about half those of reanalyses above 700 hPa. Rank correlation coefficients are approximately 0.7 for both components with RMS errors increasing with height from 2 m s^{-1} to about 10 m s^{-1} near the tropopause. Note that RMS errors in rawinsonde winds are generally estimated to be approximately 2 to 3 m s^{-1} below the jet stream level [http://www.eumetsat.de/en/dps/mpef/products/windsuse.html].

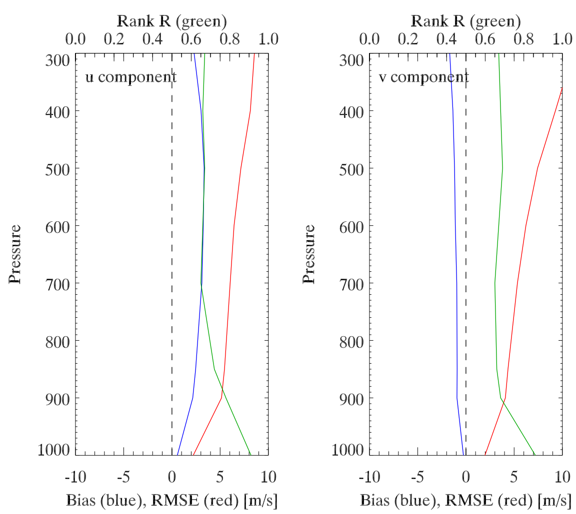


Figure 3: Error statistics for comparisons of satellite-derived wind profiles (no mass conservation correction) with rawinsonde measurements during SHEBA. Blue lines are biases, red lines are RMS errors, and green lines are rank correlation coefficients.

We then applied the mass conservation procedure developed by ZVW for the Southern Ocean. They found that this correction significantly decreased the bias in *u* from near 4 m s^{-1} to approximately 1 m s^{-1}, and the *v* bias from about 1.5 m s^{-1} to about -0.3 m s^{-1}. Applying their method to the Arctic is somewhat more complicated, however, owing to the existence of Greenland in many of the latitude zones. This is particularly of concern in applying their technique to the *u* component, as Greenland acts like a wall below about 700 hPa. We attempt to resolve this issue by linearly interpolating retrieved winds on either side of Greenland at each level below 700 hPa. Above 700 hPa we use NCEP Reanalysis winds, as there are no retrievals from TOVS over high elevation areas. We tested several other methods to solve this problem, and the results do not appear to be overly sensitive to the technique.

Figure 4 presents *u* and *v* winds corrected with method #1 of ZVW. The effect of the mass conservation correction on our results is not as striking as ZVW's in the Southern Ocean. In fact, the rank correlation and RMS error in the *u*-component winds are affected adversely while the bias is improved slightly. We attribute this result to the effects of Greenland in the zonal flow. Note that ZVW's method #2 was less successful in our and ZVW's study, and those results are not shown. The most significant effect of the correction is that the bias in *v* is reduced to near zero, which bodes well for using these winds to calculate poleward advection of heat and moisture. In addition, we find a major improvement in the comparison of the bias in TOVS-derived total wind speeds to rawinsonde total wind speeds. While reanalyses exhibited biases whose magnitudes were over half of the actual wind speeds, the TOVS-derived biases are only about 10% of total wind speeds.

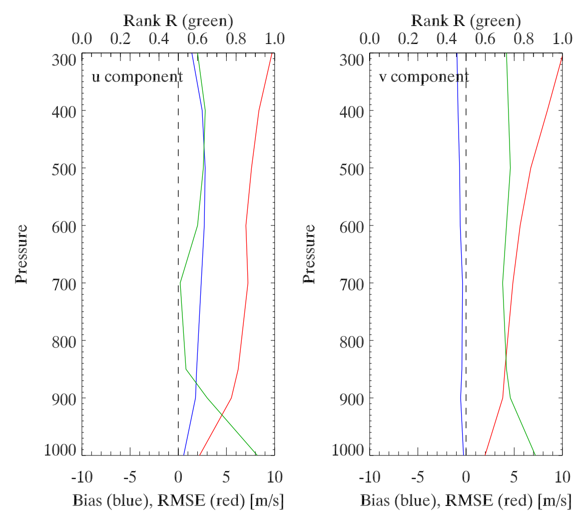
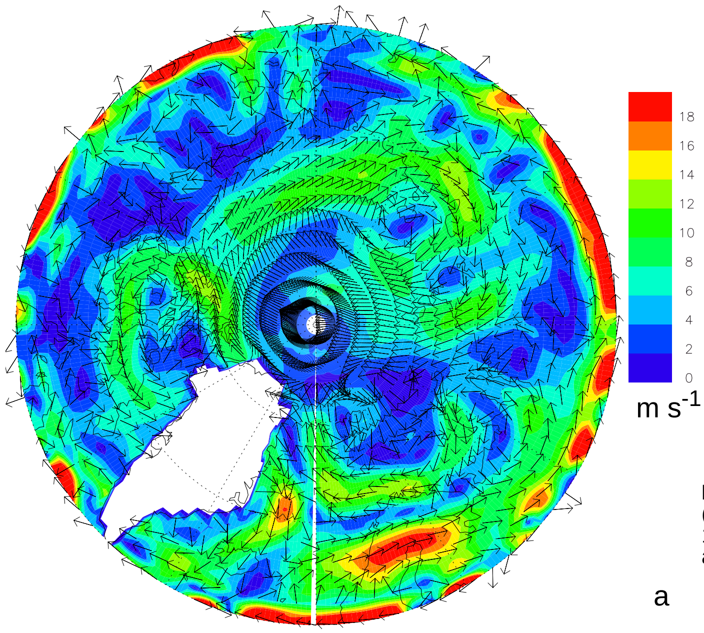


Figure 4: Same as Fig. 3 but winds include mass conservation correction according to Zou and Van Woert [2000] Method #1.

4. CONCLUSIONS

While these results are still somewhat preliminary, we are very encouraged that a 20-year data set of improved 3D wind fields for the Arctic can be produced from TOVS temperature retrievals. An example of the retrieved wind field (with ZVW's method #1 mass conservation correction applied) for 10 January 1998 at 850 hPa is shown in Fig. 5a. The corresponding sea level pressure field from NCEP is also presented in Fig. 5b for reference. The retrieved winds are consistent with expectations given isobar alignment and gradient strengths. After further validation, we expect to produce



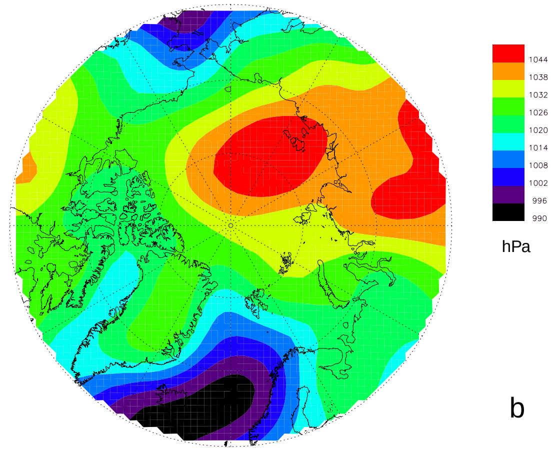


Figure 5: Example of TOVS-derived 850 hPa wind field (a) and NCEP sea level pressure field (b) for 10 January 1998. The mass-conservation method #1 of ZVW was applied.

a 20-year data set of 3D winds for the Arctic region using this method. We intend to archive the data at the National Snow and Ice Data Center for use by the entire scientific community.

5. REFERENCES

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Acknowledgements. This work was supported by NSF Grant no. OPP-0105461 and a grant from NOAA and the University of Alaska: UAF02-0032. The authors would also like to thank Dr. C.-Z. Zou for his helpful consultations.