NATIONAL ICE CENTER VISITING SCIENTIST PROGRAM

Summary of Research

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1. LONG TERM GOALS

The long-term goal of the University Corporation for Atmospheric Research (UCAR) Visiting Scientist Program at the National Ice Center (NIC) is to recruit the highest quality visiting scientists in the ice research community for the broad purpose of strengthening the relationship between the operational and research communities in the atmospheric and oceanic sciences.

The University Corporation for Atmospheric Research supports the scientific community by creating, conducting, and coordinating projects that strengthen education and research in the atmospheric, oceanic and earth sciences. UCAR accomplishes this mission by building partnerships that are national or global in scope. The goal of UCAR is to enable researchers and educators to take on issues and activities that require the combined and collaborative capabilities of a broadly engaged scientific community.

2. OBJECTIVES

The objectives of the UCAR Visiting Scientist Program at the NIC are:
- Manage a visiting scientist program for the NIC Science Center in support of the mission of UCAR.
- Provide a pool of researchers who will share expertise with the NIC and the science community.
- Facilitate communications between the research and operational communities for the purpose of identifying work ready for validation and transition to an operational environment.
- Act as a focus for interagency cooperation.

The NIC mission is to provide worldwide operational sea ice analyses and forecasts for the armed forces of the U.S. and allied nations, the Departments of Commerce and Transportation, and other U. S. Government and international agencies, and the civil sector. The NIC produces these analyses and forecasts of Arctic, Antarctic, Great Lakes and Chesapeake Bay ice conditions to support customers with global, regional and tactical scale interests. The NIC regularly deploys Naval Ice Center NAVICECEN Ice Reconnaissance personnel to the Arctic and Antarctica in order to perform aerial ice observation and analysis in support of NIC customers. NIC ice data are a key part of the U.S. contribution to international global climate and ocean observing systems.

3. APPROACH

The UCAR Visiting Scientist Program works with participating Federal agencies to recruit scientific visitors and recent PhDs who are interested in conducting applications-oriented research and product evaluation of relevance to UCAR and the NIC ice-monitoring mission. The UCAR visiting scientists are a source of expertise for the NIC as well as mentors to the recent PhDs.

Participating agency representatives in this visitor program have been:
- Waleed Abdalati: NASA program sponsor
- Tony Beesley: UCAR Visiting Scientist
- Cheryl Bertoia: National Ice Center liaison to UCAR
- Michael Chase: Product Development/Programming Support/Web development
- Dennis Conlon: Office of Naval Research, program sponsor
- CDR Michael D. Foster, PhD: former Executive Officer, Naval Ice Center (visitor program sponsor/advisor)
- Jörg Haarpaintner: UCAR Postdoctoral Fellow
- Phil Hovey: NOAA physical science technician
- LCDR Doug R. Lamb: Director, Science and Applied Technology National Ice Center/Naval Ice Center
- Eric Lindstrom: NASA program sponsor
- John Marra: NASA program sponsor
- Ted Maksym: UCAR Visiting Scientist
- Walt Meier: UCAR Visiting Scientist
- CDR Gary M. Mineart: Director, National Ice Center & Commanding Officer, Naval Ice Center (visitor program advisor)
- Kim Partington: NIC Chief Scientist, then served as a NASA Polar Programs Manager (NASA advisor to program)
- John Powell: Executive Officer, Naval Ice Center (visitor program sponsor & advisor)
- Juanita Sandge: NRL Stennis Space Center program sponsor
- Eric Sogard: NRL Stennis Space Center program sponsor
- CDR Zdenka Willis: Director, National Ice Center & Commanding Officer, Naval Ice Center (visitor program advisor)
- Michael VanWoert: NIC Chief Scientist
- Cheng-Zhi Zou: UCAR Visiting Scientist

4. WORK COMPLETED

ZONAL WIND RETRIEVALS FROM SATELLITE SOUNDINGS FOR PRECIPITATION ESTIMATES OVER THE SOUTHERN OCEAN

A. PROJECT OBJECTIVES

Precipitation estimates over the Antarctica and Southern Oceans have become an important component in studies of the influence of the Antarctic ice sheets on global climate change (e.g., Bromwich et al., 1995; Cullather et al., 1996, 1998; Slonaker and Van Woert, 1999; Zou and Van Woert, 2000a,b). However, direct precipitation measurement using rain-gauges over Antarctica are extremely difficult to make due to the lack of weather observation stations, large errors caused by small rainfall amounts, and drifting snow (Bromwich, 1988). Because of the observation difficulties, an indirect method that uses atmospheric moisture budget has been developed for precipitation estimates over high Southern latitudes (Bromwich, 1988; Bromwich et al., 1995). In this method, moisture fluxes are first estimated using radiosonde-observed or model-calculated atmospheric wind and moisture profiles, and then long-term averaged net precipitation is calculated as the convergence of the moisture fluxes.

Three types of data have been used in the moisture flux estimates. Peixóto and Oort (1983) and Bromwich (1988) used radiosonde observations (RAOB) to determine the zonal and meridional moisture fluxes. However, this method is limited by the sparseness of the radiosonde stations over the Antarctic continent and its surrounding ocean. Bromwich et al. (1995) and Cullather et al. (1996, 1998) performed comprehensive studies of the net precipitation and its long-term change in Antarctica using ECMWF (European Center for Medium-Range Weather Forecasts), NMC (National Meteorological Center), and ABM (Australian Bureau of Meteorology) model analyses. Broad disagreement in the estimates of net precipitation and moisture fluxes has been observed between these various analyses. The third type of such studies is to use satellite data to estimate the moisture fluxes. Recently, Slonaker and Van Woert (1999) and Zou and Van Woert (2000a,b, hereafter refereed to as ZVW00) sought to use TIROS (Television Infrared Observational Satellite) Operational Vertical Sounder (TOVS) satellite temperature and moisture data to estimate the meridional moisture fluxes and net precipitation over Antarctica and the Southern Oceans. This approach requires a wind model to retrieve the three-dimensional wind fields from the satellite temperature soundings. Slonaker and Van Woert (1999) used thermal wind equation plus the surface wind fields obtained by Atlas et al. (1993) as the tie-on wind. ZVW00 further extended the method by applying conservation of mass to the wind obtained by Slonaker and Van Woert (1999) and produced mean meridional winds and moisture fluxes comparable to the radiosonde observations and reanalysis data.

This project at the National Ice Center is to derive the zonal wind profiles from satellite observations based on the approach of ZVW00's. In ZVW00, only meridional wind was derived from the satellite soundings. With meridional wind, only poleward moisture flux and zonally averaged net precipitation can be inferred. In order for the satellite method to estimate the longitudinal distribution of net precipitation, three-dimensional zonal wind fields are also needed. In this study, the wind derivation approach of using thermal wind relationship plus a

mass conservation constraint developed in ZVW00 is applied to the zonal wind derivation. The obtained zonal wind is then compared with the ECMWF and NCEP/NCAR reanalysis data and RAOB data at Macquarie Island for validation.

B. PROJECT APPROACH

B.1. Data

The temperature data are the 1988 TOVS Pathfinder A dataset (Susskind et al., 1997). The surface wind velocity is taken from Atlas et al. (1993) who optimally blended SSM/I surface wind speed with in situ observations and ECMWF analyses using a variational method. These surface wind vectors, which are referred to as VAM winds, exhibit higher accuracy than values from the ECMWF analyses alone when compared against independent buoy data (Atlas et al., 1996).

B.2 Methodology

The method for zonal wind retrieval is based on the thermal wind relationship plus a mass conservation constraint. The thermal wind relation is written as

$$\frac{\partial u_g}{\partial \ln p} = \frac{R_d}{f} \frac{\partial T_v}{a \partial \varphi}$$

(1)

where f is the Coriolis parameter, R_d the dry air gas constant, u_g the geostrophic zonal wind speed, and T_v the virtual temperature. Integrating (1) over p from the surface $p = p_0$ to any level p, we obtain the first-guess zonal wind,

$$\tilde{u} = u_0 - \int_p^{p_0} \frac{R_d}{f} \frac{\partial T_v}{a \partial \varphi} d \ln p ,$$

(2)

where $\tilde{u}$ is the Slonaker and Van Woert (1999) type of *pseudo-geostrophic* zonal wind, and u_0 is the VAM surface wind (Atlas, et al., 1993). This first-guess zonal wind does not conserve mass, therefore, a mass conservation correction is applied by using variational methods. In the atmosphere, the horizontal wind fields should satisfy the mass conservation in a vertical column of the atmosphere, which is written as

$$\int_0^{p_0} \left(\frac{\partial u}{a\cos\varphi \partial\theta} + \frac{\partial(v\cos\varphi)}{a\cos\varphi \partial\varphi} \right) dp = 0$$

(3)

The variational formalism using Eq. (3) as a strong constraint is written as

$$E = \int_0^{2\pi} \int_0^{p_1} (u - \tilde{u})^2 \, dpa\cos\varphi d\theta + \int_0^{2\pi} \lambda_1 \int_0^{p_0} \left(\frac{\partial u}{a\cos\varphi\partial\theta} + \frac{\partial(v\cos\varphi)}{a\cos\varphi\partial\varphi} \right) dpa\cos\varphi d\theta$$

(4)

where p_1=850 mb is the first level above the surface on which the zonal wind field needs to be corrected. Solving Eq. (4) will yield the final satellite-retrieved zonal wind field.

C. PROJECT WORK COMPLETED

The project is the collaborative efforts of Dr. Cheng-Zhi Zou and Dr. Mike Van Woert at the National Ice Center. They have completed solving the zonal wind retrieval equation (4) theoretically. They used the theoretical solution and the data described in Section 3 to actually retrieve the zonal wind field and compare it with the ECMWF and NCEP/NCAR reanalyses as well as radiosonde observations. A detailed description of how to solve Eq. (4) and some preliminary results have been presented as a conference proceeding article at the 11th International TOVS Study Conference held at Budapest, Hungary, September 20 to 26, 2000.

D. PROJECT RESULTS

D.1 Zonally and monthly averaged zonal wind

Fig. 1 shows the monthly-averaged zonal-mean zonal wind derived in this study for January and July, 1988, in the region from 50^0S to 76^0S, and Fig. 2 shows the same field from ECMWF reanalysis. From the ECMWF reanalysis, it is seen that the main feature in the zonal wind field is the movement of the jet stream positions associated with the seasonal change of the atmospheric thermal structure. Comparing Fig. 1 with Fig. 2, it is seen that equatorward of 63^0S the satellite-derived zonal wind basically captures the tendency of the jet stream movement. In January, 1988, Fig. 1 (a) shows an almost closed jet stream near 300 hPa equatorward of 50^0S, resembling the jet stream structure observed in the ECMWF reanalysis. During July, 1988, the satellite-derived zonal wind shows much weaker horizontal shear near 50^0S, indicating that it is far away from the jet stream position. This is consistent with the jet stream position located near 30^0S in the reanalysis data. Poleward of 63^0S the satellite-derived zonal wind yields an anomalously strong vertical wind shear. This difference is due to the fact that the satellite wind is an average over the ocean area while the ECMWF data are averages over the whole latitude circle, which contains both ocean and land. The continental elevation is approximately 2 km above sea level, which could lift the boundary layer and affect the thickness of the boundary layer easterlies.
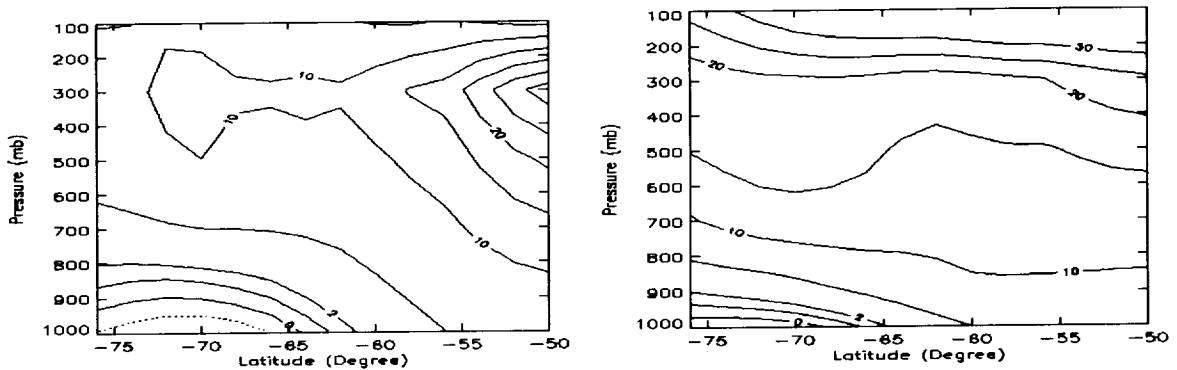
(a) Satellite, January, 1988
(b) Satellite, July, 1988

Fig. 1 Satellite-derived zonal-mean zonal wind in this study. (a) January, 1988, and (b) July, 1988.
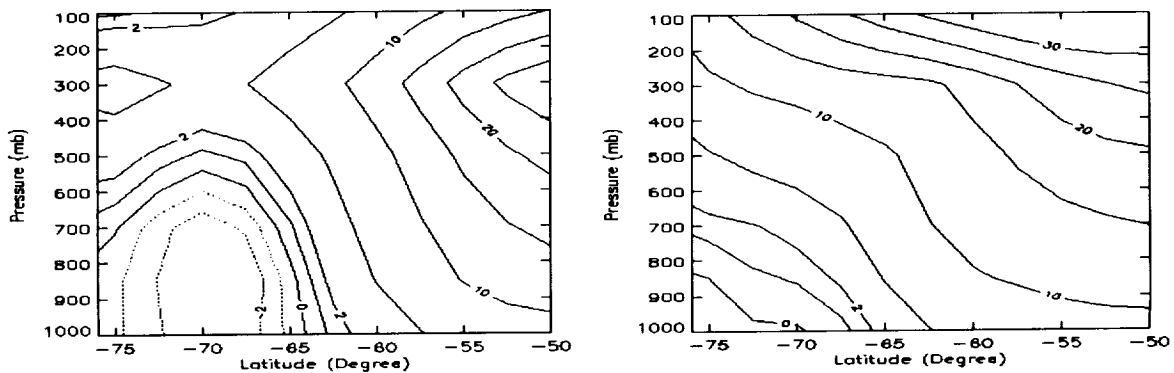
(a) ECMWF, January, 1988
(b) ECMWF, July, 1988

Fig. 2 Same as Fig. 1 (a) and (b) except for ECMWF reanalysis. (a) January, 1988, and (b) July, 1988.

D.2 Comparisons at Macquarie Island

Radiosonde data can be used to assess the overall quality of the satellite-derived data products. In particular, twice-daily wind and moisture soundings are available for 1988 at Macquarie Island (54.5^{0}S, 158.9^{0}E). ZVW00 used this dataset to validate the satellite-derived meridional wind and moisture fluxes. A similar comparison between the satellite-derived zonal wind product and the radiosonde observations is performed in this study.
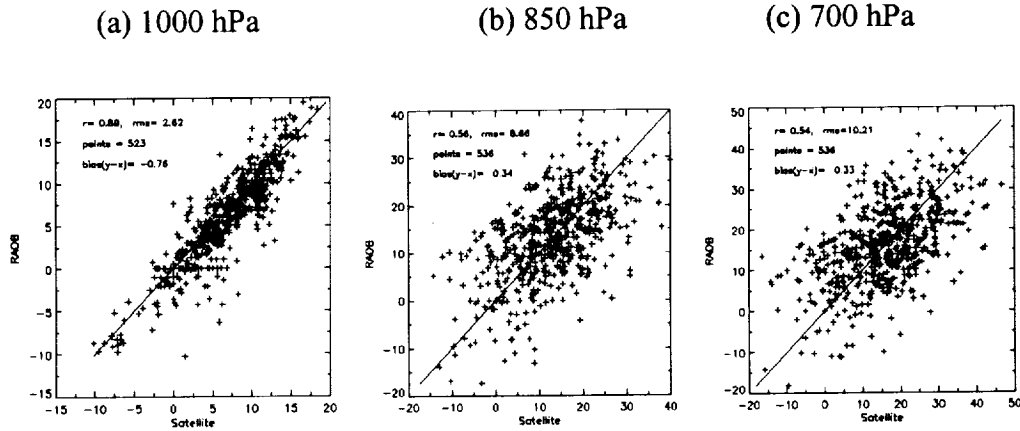
(a) 1000 hPa   (b) 850 hPa   (c) 700 hPa

Fig. 3 Scatter plots of the satellite-derived zonal wind vs. the radiosonde-observed at Macquarie Island for 1988. (a) 1000 hPa; (b) 850 hPa; (c) 700 hPa.

Fig. 3 shows the scatter plots between the RAOB and satellite winds at Macquarie Island for 1000, 850, and 700 hPa levels. Table 1 lists the detailed statistics of the comparison between the RAOB zonal wind and the satellite-derived zonal wind at all available levels for both non-mass-conserved and mass-conserved. Table 1 and Fig. 3 show that the zonal wind fields compare most favorably near the surface, where the correlation between the satellite wind and radiosonde observation is 0.89 and the

Table 1 Zonal wind statistics between the RAOB data and satellite-derived at Macquarie Island for 1988, where u is the mass-conserved zonal wind by the variational method while $\tilde{u}$ represents the non-mass-conserved zonal wind as defined in the text.

Height	1000 mb	850 mb	700 mb	500 mb	300 mb	100 mb
Points	523	536	536	532	510	409
RAOB mean of u (m/s)	6.02	13.17	16.15	21.68	28.11	24.87
Satellite mean of u (m/s)	6.77	12.83	15.81	20.96	27.50	22.42
Satellite mean of $\tilde{u}$ (m/s)	6.77	9.64	12.62	17.83	25.23	20.55
RAOB std (m/s)	5.48	9.02	9.81	12.71	16.58	12.60
Satellite std for u (m/s)	4.98	9.41	11.20	14.26	16.32	16.95
Satellite std for $\tilde{u}$ (m/s)	4.98	5.63	7.71	11.03	14.83	19.37
Correlation (RAOB, Satellite u)	0.89	0.56	0.54	0.54	0.58	0.73
Correlation (RAOB, Satellite $\tilde{u}$)	0.89	0.74	0.64	0.64	0.63	0.70
Rms (RAOB, Satellite u) (m/s)	2.62	8.66	10.21	13.06	15.16	11.89
Rms (RAOB, Satellite $\tilde{u}$) (m/s)	2.62	7.01	8.48	11.03	13.91	14.46
Bias(raob- Satellite u) (m/s)	-0.76	0.34	0.33	0.72	0.62	2.45
Bias (raob- Satellite $\tilde{u}$) (m/s)	-0.76	3.54	3.53	3.85	2.89	4.31

The rms (root-mean-square) error is 2.6 m sec^{-1}, comparable with the accuracy estimation of ± 2 m sec^{-1} for the VAM surface wind (Atlas et al., 1993). For the available data, the VAM annual

mean surface wind speed is 6.8 m sec^{-1}, which is very close to the RAOB value of 6.0 m sec^{-1}. This good agreement between the RAOB and satellite winds may be due to the fact that Atlas et al. (1993) have already incorporated the RAOB data into their VAM surface wind field.

The correlation between the RAOB and satellite-derived mass-conserved zonal wind is around 0.55 over the range 850 hPa and 300 hPa. This is slightly less than the correlation between the RAOB wind and the non-mass-conserved satellite wind. The rms errors between the RAOB and mass-conserved satellite winds are approximately 1 to 2 m sec^{-1} larger than that of the RAOB and non-mass-conserved satellite wind.

The annual means of the non-mass-conserved satellite zonal wind have a typical bias greater than 3 m sec^{-1} compared to the RAOB data. Below 300 hPa, however, the annual means of the mass-conserved winds are within 0.7 m sec^{-1} of the RAOB data. This reduction in the bias appears to be the most important improvement resulting from the application of the mass conservation.

E. PROJECT IMAPACT AND APPLICATIONS

The zonal wind retrievals from satellite soundings will provide an effective method to acquire wind profile information over the regions where radiosonde stations are sparse, such as the vast ocean area. It will have significant impact upon the climate modeling and predictions. As mentioned earlier in the Introduction, a direct application of this zonal wind field will be in the area of estimating moisture flux and net precipitation over the Southern Ocean based on purely satellite observations.

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