**In-situ** data and NCEP reanalysis: A comparative study in the Southern Ocean and Antarctic Ocean

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A special expedition was launched by the National Center for Antarctic and Ocean Research (NCAOR), India on board R/V Akademik Boris Petrov during 25 January to 1 April 2006 passing the Southern Ocean and reaching the Larsemann Hills area of East Antarctica. The surface layer **in-situ** data generated from the cruise are compared with that obtained from the NCEP reanalysis during the same period along the track of the vessel. It is concluded that the NCEP reanalysis sea surface temperature and air temperature have some discrepancies as the vessel enters the sea ice zone near the Antarctic coast. The air pressure is well modeled but the relative humidity shows high variability throughout the period of the study. The wind speed is poorly correlated with that obtained from the NCEP due to the use of “Course over the ground” in place of ship “heading” while calculating the true wind.

**Key words:** In-situ data, surface layer, NCEP reanalysis, Southern Ocean, Antarctic Ocean, sea level pressure, air temperature, wind speed, relative humidity, SST

1. **Introduction**

The Southern Ocean is the only ocean, which circles the globe without being blocked by land and affects the climate in many ways. The strong Antarctic Circumpolar Current from west to east around Antarctica connecting the Pacific, Indian and Atlantic Ocean basins and their currents redistribute heat and other properties affecting temperature and rainfall patterns. The Southern Ocean plays an important role in the formation of two global-scale water masses: Antarctic Intermediate Water (AAIW) and Antarctic Bottom Water (AABW). The AABW is formed along the margins of the Antarctic continent where salinity of water increases due to release of brine as a result of sea ice build up. This salinification makes the water dense and it sinks to the bottom. On the other hand AAIW is less saline forming at depths of about 500 -1200 m when cold surface water sinks beneath warmer ones.

The deep and bottom waters produced by the polar oceans form a part of the global thermohaline circulation. Therefore, sea ice processes contribute to the driving of the global distribution of water mass characteristics, the ventilation of the deep world ocean and the transport of natural and anthropogenic substances (tracers) from the ocean surface to the abyss where these are stored for centuries. The latter is of climatic relevance in view of the increasing concentrations of greenhouse gases in the atmosphere, which are assumed to have caused the 0.5 K increase in global temperatures during the last century. Also the extent and thickness of sea ice has an influence on the earth’s climate. Global climate change is expected to be amplified in polar regions because of the feedback effects associated with the high albedo of ice and snow.

To address some of these issues India is planning to open a new center in the Larsemann Hills area of East Antarctica to carry out scientific research in the fields of physical, chemical and biological oceanography. A special scientific expedition on board R/V Akademik Boris Petrov (ABPetrov) was launched from Goan (India) on January 25, 2005, which reached the Larsemann Hills area on February 25, 2006 to obtain surface, atmospheric and oceanic data.

Modeling the ocean circulation requires faithful representation of the atmosphere-ocean interaction. The data that goes as input into the models should be precise and accurate to generate proper results. This is more critical in the data void remote polar regions which suffer due to lack of ship data and the tendency for prolonged cloud cover which reduce the amount of satellite data. In this study, a time series of observations from the cruise of the ABPetrov during 27 January to 31 March 2006 is compared with the
reanalysis data from the National Centers for Environmental Prediction (NCEP)-National Center for Atmospheric Research (NCAR) project. NCEP reanalysis is one of the most common choices for comparison and validation as NCEP is one of the leading numerical weather prediction centers of the world besides European Centre for Medium-Range Weather Forecasts (ECMWF) for providing surface flux fields to drive ocean models.

2. Datasets
2.1 Observational data
A 66-day cruise was launched from 25 January to 1 April 2006 on board ABPetrov passing the Southern Ocean and reaching the Larsemann Hills area of East Antarctica (Fig. 1). The expedition collected water samples for analyzing its carbon content. Oceanographic CTD and XBT operations were launched as the ship stopped at pre-determined stations. At times the Gravity Corer was deployed to collect core samples from the seabed topography. In-situ surface layer data such as sea level pressure, air temperature, relative humidity, SST and wind speed were obtained in the Southern Ocean.

Throughout the cruise the ship’s Automatic Weather Station (AWS) logged standard meteorological variables, which form the main dataset used in this study. These included sea level pressure, air temperature, relative humidity, thermostalinograph temperature, wind speed, wind direction, ship speed and ship direction which were displayed on real-time basis. The ship’s motion, as determined by the GPS navigation system was subtracted from the anemometer-measured wind vector to obtain the true wind speed. “Course over the ground” is defined as the direction (relative to true north) the vessel actually moves over the fixed earth while “heading” is defined as the direction to which the bow of the vessel is pointing relative to true north. The data obtained from ABPetrov had the “heading” data missing, so for estimating the true wind the “course over the ground” (ship direction) was used in place of “heading” and the course-estimated wind speed was calculated. The accuracy of this estimate is questionable at low ship speeds where the calculated wind direction deviates wildly from the true wind.

The above parameters were recorded every three hours, for each day starting from 08 00 hrs IST (02 30 UTC) on 27 January 2006 to 20 00 hrs IST (14 30 UTC) on 31 March 2006. The bucket thermometer (make: Theodor Friedrichs, Germany) was used to record the sea surface temperature (SST) along the ship route. The bucket was lowered down to a depth of around 2 m and kept there for a few seconds and then picked up to record the readings. Wherever the SST data is missing due to heavy storm or bad climate, the gap has been filled with the thermostalinograph data from the AWS of the ship, which is almost equal to SST data.

2.2 Model data
The ABPetrov data are compared with the 4 times daily, surface or near surface (0.995 sigma level) data for the year 2006 obtained from the NCEP–NCAR reanalysis. These are 6-h averages accumulated over a model forecast. The NCEP routinely produces 2.5°×2.5° gridded data with spatial coverage of 90°N-90°S, 0°E-357°30’E, and temporal coverage of 4-times daily and monthly values from 1 January 1948 to present. The idea behind the reanalysis project was to generate a dataset, which is suitable for input in the models and carry out short-term climatological studies. The NCEP reanalysis data have been extracted from the global analyses every 6h, from 00 00 UTC 27 January 2006 to 18 00 UTC 31 March 2006 at the exact position of the ABPetrov. To compare with the in situ data, the NCEP data was
interpolated to the corresponding IST for which the data was collected by using the Grads software. The movement of the vessel during this time period does not greatly affect the results since it is very small (over any 6-h period) compared to the size of the model grid. The NCEP reanalysis U-wind speed and the V-wind speed at 0.995 sigma level were extracted at the exact position of the ship and the square root of the sum of squares of the two values were used to compare with the *ABPetrov* course-estimated wind speed.

### 3. Surface Layer Data Comparison

The time series of *ABPetrov* and NCEP surface layer data every 6 hours, from 18 00 hrs IST 27 January 2006 to 14 00 hrs IST 31 March 2006 are shown in Figure 2 (A-E). Figure 2 shows sea level pressure (SLP), air temperature (T<sub>a</sub>), wind speed (WS), relative humidity (RH) and sea surface temperature (SST) at the surface or near surface (0.995 sigma level for the NCEP reanalysis). The sea surface temperature (SST) from *ABPetrov* has been compared with the 4 times daily observation of the

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![Fig. 2—Data obtained from *ABPetrov* and NCEP reanalysis from 27 January to 31 March 2006 (A = sea level pressure, B = air temperature, C = wind speed, D = relative humidity and E = sea surface temperature)](image-url)
skin surface temperature from NCEP for the year 2006. The model analyses are able to capture the magnitude and variability of SLP, \( T_a \), SST and WS accurately except for some differences near the coast of the Antarctic continent when the ship is inside the marginal ice zone (MIZ) close to what can be defined as the ice edge. There are coincident large differences between observed and NCEP data in case of \( T_a \) and SST (Figure 2 B, E). The model SSTs are too cold in this region (MIZ) and this may be due to the interpolation error between the sea ice edge and nearest available observations. When the nearest observation is far from the MIZ, the interpolation will blur the SST gradient over that distance when in reality, the gradient is strong in the immediate vicinity of the sea ice edge. There are many differences between the observed and NCEP reanalysis relative humidity, with the model often showing supersaturation (Figure 2 D). Such differences were also reported by Renfrew et al.\(^7\) in the Labrador Sea area of Arctic region.

A detailed comparison of the observed and NCEP surface layer data is summarized in Tables 1 and 2. The scatter plots of SLP, \( T_a \), WS, RH and SST are shown in Figure 3 (A-E). A linear regression line is also overlaid on these plots where the \( ABPetrov \) observations are treated as the independent variable and the NCEP reanalysis as the dependent variable. Table 2 summarizes some comparison statistics. The correlation coefficient (CC) and the slope of the linear regression line indicate how well the data pairs match in a linear sense. The slope error quantifies the departure from a linear relationship. The random error quantifies the random scatter in the comparison. The

<p>| Table 1—Summary of surface layer meteorological data from the ABPetrov and the NCEP reanalysis |
|---|---|---|---|---|---|</p>
<table>
<thead>
<tr>
<th>Data</th>
<th>SLP (mb)</th>
<th>( T_a ) (°C)</th>
<th>WS (m s(^{-1}))</th>
<th>RH (%)</th>
<th>SST (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( ABPetrov )</td>
<td>1002.32</td>
<td>14.12</td>
<td>8.48</td>
<td>80.06</td>
<td>14.96</td>
</tr>
<tr>
<td>NCEP</td>
<td>1003.97</td>
<td>13.27</td>
<td>7.30</td>
<td>82.09</td>
<td>13.77</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Standard Deviation</td>
<td></td>
</tr>
<tr>
<td>( ABPetrov )</td>
<td>15.00</td>
<td>12.66</td>
<td>4.68</td>
<td>4.61</td>
<td>11.94</td>
</tr>
<tr>
<td>NCEP</td>
<td>14.05</td>
<td>13.63</td>
<td>4.53</td>
<td>9.77</td>
<td>14.75</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Maximum</td>
<td></td>
</tr>
<tr>
<td>( ABPetrov )</td>
<td>1022.30</td>
<td>29.80</td>
<td>21.70</td>
<td>87.00</td>
<td>30.00</td>
</tr>
<tr>
<td>NCEP</td>
<td>1023.35</td>
<td>29.14</td>
<td>20.58</td>
<td>100.00</td>
<td>29.74</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Minimum</td>
<td></td>
</tr>
<tr>
<td>( ABPetrov )</td>
<td>947.70</td>
<td>-9.90</td>
<td>0.70</td>
<td>66.00</td>
<td>-1.85</td>
</tr>
<tr>
<td>NCEP</td>
<td>955.35</td>
<td>-19.41</td>
<td>0.28</td>
<td>46.00</td>
<td>-30.16</td>
</tr>
</tbody>
</table>

| Table 2—Comparison of surface layer meteorological data from the \( ABPetrov \) and the NCEP reanalysis |
|---|---|---|---|---|---|
| \( ABPetrov \) vs NCEP | SLP (mb) | \( T_a \) (°C) | WS (m s\(^{-1}\)) | RH (%) | SST (°C) |
| Correlation Coefficient | 0.97 | 0.98 | 0.53 | 0.39 | 0.96 |
| Slope | 0.91 | 1.06 | 0.51 | 0.83 | 1.19 |
| Bias error | 1.65 | -0.85 | -1.18 | 2.03 | -1.20 |
| Slope error | 13.62 | 13.36 | 2.40 | 3.81 | 14.15 |
| Random error | 15.34 | 12.90 | 6.04 | 10.09 | 12.59 |
| Total RMS error | 20.58 | 18.59 | 6.60 | 10.97 | 18.98 |
bias error quantifies any systematic model error. The total error is the square root of the sum of squares of the component errors, which is equal to the root-mean-square (RMS) error. If X is the independent variable and Y the dependent variable having n individual components represented by x_i and y_i respectively, then the error (e_i) and bias error (b) is given by e_i = x_i - y_i.

Fig. 3—Scatter plot of ABPetrov data versus NCEP reanalysis data (A = sea level pressure, B = air temperature, C = wind speed, D = relative humidity and E = sea surface temperature)
where \( i = 1 \) to \( n \) and \( b = \frac{\sum_{i=1}^{n} e_i}{n} \). If the linear regression line between \( X \) and \( Y \) is given by \( Y = c + mX \) where \( c \) is the intercept and \( m \) is the slope of the regression line then the slope error \((s)\), the random error \((r)\) and the total error \((t)\) is given by

\[
s = \sqrt{\frac{\sum_{i=1}^{n} (b - Y_i)^2}{n}}, \quad r = \sqrt{\frac{\sum_{i=1}^{n} (e_i - Y_i)^2}{n}} \quad \text{and}
\]

\[
t = \sqrt{b^2 + s^2 + r^2}.
\]

Also the total error \((t)\) is equal to the r.m.s error given by

\[
t = \sqrt{\frac{\sum_{i=1}^{n} (x_i - y_i)^2}{n}}.
\]

It is clear from Tables 1 and 2 along with Figures 2A and 3A that SLP is well modeled with \( CC = 0.97 \) and slope of 0.91. The model-analyzed SLP has small positive bias of 1.65. A good correlation between the in-situ observational data and model output is due to the fact that pressure field is inherently more predictable and less affected by mesoscale and microscale variability.

The mean NCEP air temperature has a cold bias of –0.85 but a high correlation coefficient of 0.98 and a regression slope of 1.06. Comparing the SSTs from the model and the observed data we get a cold bias of –1.20. The difference is primarily noted in the MIZ near the Antarctic coast where the NCEP reanalysis, forecasts very low SSTs than the permissible limit of –1.8°C (the freezing temperature of seawater). SST and sea-ice play an important role in determining the behavior of the overlying atmosphere. Sea-ice has a significant impact on the exchange of energy between the atmosphere and the underlying surface, with a dramatic effect on the surface temperature. It is difficult to retrieve SST from space in the marginal ice zone due to the rapid development and retreat of sea ice depending on the season. Sea ice can also affect satellite radiances retrievals and an incorrect distribution of sea-ice may influence the model tropospheric state. Thus, the problem arises due to the error associated with interpolation of satellite-determined SSTs (which are very few in the region) over the MIZ region. The mean SSTs for \( ABPetrov \) and NCEP are 14.96 °C and 13.77 °C respectively.

The NCEP reanalysis wind speed has a correlation coefficient and regression slope of 0.53 and 0.51 respectively when compared with the course-estimated wind speed and shows a lot of scatter compared to other variables. The under estimation of high wind speeds over the ocean by the model is due to high temporal and spatial variability of the wind field. A possible reason for such low values could also be attributed to the use of “Course over the ground” in place of ship “heading” while calculating the true wind, mainly at low ship speeds. However the mean wind speed and the standard deviation compare well with the NCEP values (Table 1).

The NCEP relative humidity is the most poorly correlated variable with that of the \( ABPetrov \) as the model often shows super saturation of 100% with a high positive bias of 2.03. Several possible reasons could be such as too much water vapor transport into the region, too great a moisture flux out of the sea, or too little condensation and precipitation of water vapor in the boundary layer. Correct parameterization and frequent application of the Bergeron-Findiesen process in the model was also suggested to improve the model overestimation in RH.

In short the atmospheric surface layer in the NCEP reanalysis corresponds reasonably well with that observed from the \( ABPetrov \) except for the relative humidity and some differences arising in the sea surface temperature and air temperature, when the vessel enters the marginal ice zone near the Antarctic coast.

4. Conclusion

A comparison of several meteorological observations from a cruise of the R/V \( ABPetrov \) to the Larsemann Hills area of East Antarctica was carried out with the 0.995 sigma level surface layer or near surface layer data, from the NCEP-NCAR reanalysis project. Significant errors are observed in the NCEP reanalysis relative humidity with a high standard deviation of 9.77% and is least correlated with that obtained from \( ABPetrov \). The NCEP reanalysis produces very low sea surface temperatures and air temperatures as the vessel enters the MIZ near the Antarctic coast. Given the sparse distribution of Antarctic weather stations, it is desirable to further examine Antarctic climate with satellite data. The gridded products, such as the NCEP reanalysis data, are significantly less reliable for Antarctic climate studies, especially for surface conditions. It appears
that the NCEP reanalysis is not able to simulate meteorological fields properly in the marginal ice zone \(^7,9,11\). The sea level pressure is well modeled with a high correlation of 0.97. Since the ship “heading” data was missing the “course-estimated” true wind speed was calculated from the ABPetrov, which is poorly correlated with that obtained from the NCEP. Caution needs to be exercised while using the NCEP data in the Southern Ocean and Antarctic region to get proper results.

5. Acknowledgement

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References

6 Reanalysis information and selected output available online at http://www.cdc.noaa.gov/cdc/data.ncep.reanalysis.surface.html