551.509.313.43 (99)

Real-time mesoscale modeling for short range prediction of weather over Maitri region in Antarctica

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सार – इस शोध पत्र का मुख्य उददेश्य भारत मौसम विज्ञान विभाग (आई. एम. डी.) में संचालित भूमंडलीय पूर्वानुमान प्रणाली टी–382 की आरंभिक और परिसीमा की स्थितियों का उपयोग करते हुए 15 कि. मी. के क्षैतीज विभेदन पर मैत्री क्षेत्र (अक्षांश) 70 डिग्री, 45 मिनट दक्षिण, देशांतर 11 डिग्री, 44 मिनट पूर्व) के लिए ध्रुवीय डब्ल्यू. आर. एफ. निदर्श को कार्यान्वित करना है। इस अध्ययन में मामले के अध्ययनों के पारम्परिक अभिगम का उपयोग करते हुए निदर्श के निष्पादन कर मूल्यांकन किया गया। इस शोध पत्र में उदाहरण सहित बताए गए मामले के अध्ययनों के परिणामों से यह पता चला है कि इस निदर्श में सिनॉप्टिक और मेसोस्केल मौसम प्रणालियों को अभिग्रहण करने की क्षमता है। पूर्वानुमान के क्षेत्र अनुरूपी विश्लेषण क्षेत्रो के अनुकूल पाए गए हैं। प्रीटोरिया में दक्षिण अफ्रीका के मौसम सेवा द्वारा तैयार किए गए माध्य समुद्र दाब के सिनॉप्टिक चार्टों का उपयोग निदर्श वैधता के लिए किया गया है। अनुरूपी प्रेक्षणों की तुलना में माध्य समुद्र स्तर दाब के मीटियोग्राम इस निदर्श से प्राप्त किए गए। इस अध्ययन में मैत्री क्षेत्र में मौसम के अल्प अवधि पूर्वानुमान के लिए पूर्वानुमान उत्पादों की उपयोगिता को दर्शाया गया है। पूर्वानुमान की सूचनाओं को भारत मौसम विज्ञान विभाग की राष्ट्रीय वेबसाईट www.imd.gov.in में वास्तविक समय विधि में उपलब्ध कराया गया है। इस अध्ययन से मैत्री में मौसम पूर्वानुमान को लाभ मिल सकता है।

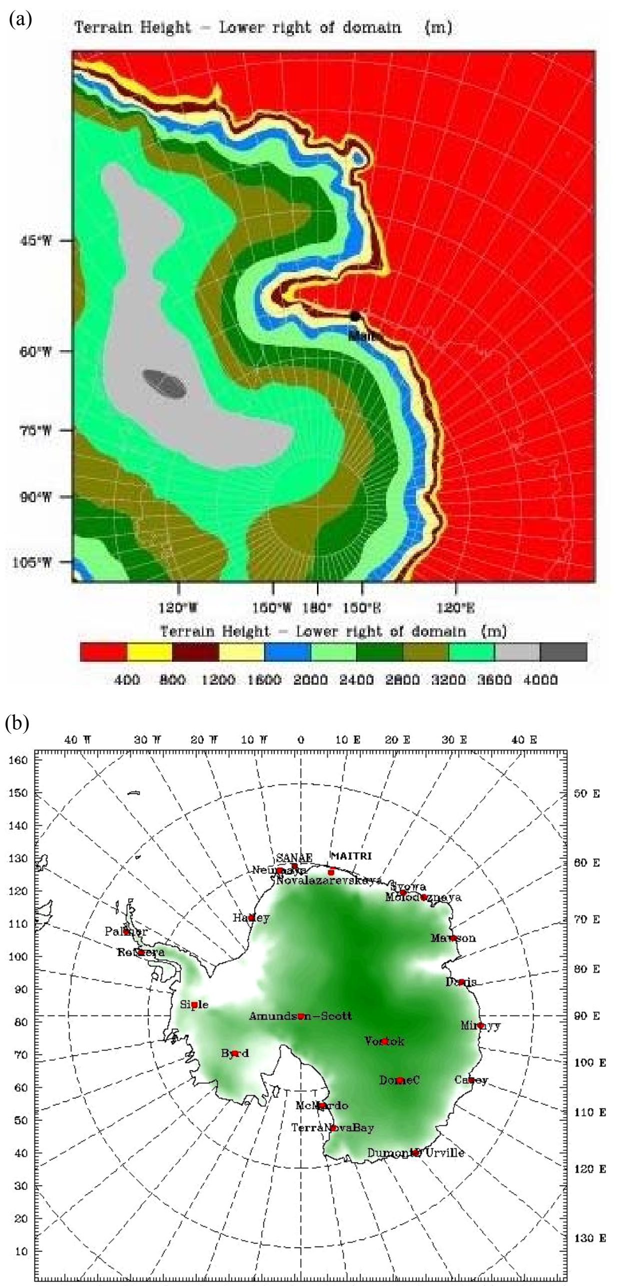
ABSTRACT. The main objective of this paper is to implement Polar WRF model for the Maitri (Lat. 70° 45′ S, Long. 11° 44′ E) region at the horizontal resolution of 15 km using initial and boundary conditions of the Global Forecast System T-382 operational at the India Meteorological Department (IMD). The study evaluates the performance of the model using the conventional approach of case studies. The results of the case studies illustrated in this paper reveal that the model is capable of capturing synoptic and meso-scale weather systems. Forecast fields are consistent with the corresponding analysis fields. Synoptic charts of mean sea level pressure prepared by the Weather Service of South Africa at Pretoria are used for the model validation. The model derived meteograms of mean sea level pressure are compared against the corresponding observations. The study demonstrates the usefulness of the forecast products for short range forecasting of weather over the Maitri region. The forecast outputs are made available in the real-time mode in the national web site of IMD www.imd.gov.in. The study is expected to benefit weather forecasters at Maitri.

Key words – Numerical Weather Prediction, Polar WRF, Polar Meteorology.

1. Introduction

With the commissioning of High Performance Computing System (HPCS), National Centre for Environmental Prediction (NCEP) based Global Forecast System (GFS T382) has been made operation at the HQ of IMD, incorporating Global Statistical Interpolation (GSI) scheme as the global data assimilation for the forecast up to 7 days. There are number of other global Numerical Weather Prediction (NWP) models operated at various NWP Centres. Some of them are: (a) European Centre for Medium Range Weather Forecasting (ECMWF) Global Model (25 km), (b) United Kingdom (UK) Met Office Global Model (40 km), (c) National Centre for Environmental Prediction – Global Forecast System (NCEP-GFS), (d) Arpege (Meteo France) (20-250 km), (f) Japan Meteorological Agency (JMA) Global Spectral Model (20 km) etc. All these models cover weather forecasts for the Antarctica region at the medium range time scale. But these models are developed primarily for the tropics and mid latitudes in the Northern Hemisphere and are not suitable for the Antarctica region.

As such, it is necessary to implement a mesoscale NWP model with appropriate physics options. For the operation of real time mesoscale NWP modeling over Antarctica, the challenges include poor first guess and boundary conditions, shortage of conventional meteorological observations and the polar atmosphere itself. Antarctica lacks the dense data network needed to provide mesoscale NWP model with an accurate representation of the large scale circulation. For skillful



Figs. 1(a&b). (a) Model domain and (b) Some important stations in Antarctica

forecasts the model must accurately represent the Antarctic katabatic winds that are governed by the balance of gravity, thermal stability and synoptic forcing (elevated ice sheet), Sea ice that impacts the atmosphere ocean interactions (Cassano and Parish, 2000, Cassano *et al*., 2001; Parish and Cassano, 2003; Pavolonis *et al*., 2004). A polar-optimized version of the state-of-the-art Weather Research and Forecasting model (WRF) was developed for the Greenland region by the Polar Meteorology Group of Ohio State University's Byrd Polar Research Center (Powers, 2007; Hines and Bromwich, 2008).

The main interest in this study is to implement a meso-scale model - Polar WRF for the Maitri region over the Antarctica. A version of the Polar WRF adapted from Polar Meteorology Group is configured for the Maitri region with the use of initial and boundary conditions of Global Forecast System (GFS) operational at India Meteorological Department (IMD). After necessary testing and validation, the model is made operational and products are made available in the real-time mode in the IMD web site : www.imd.gov.in. Validation results of these experiments are presented in this paper.

2. Configuration of Polar WRF for Maitri

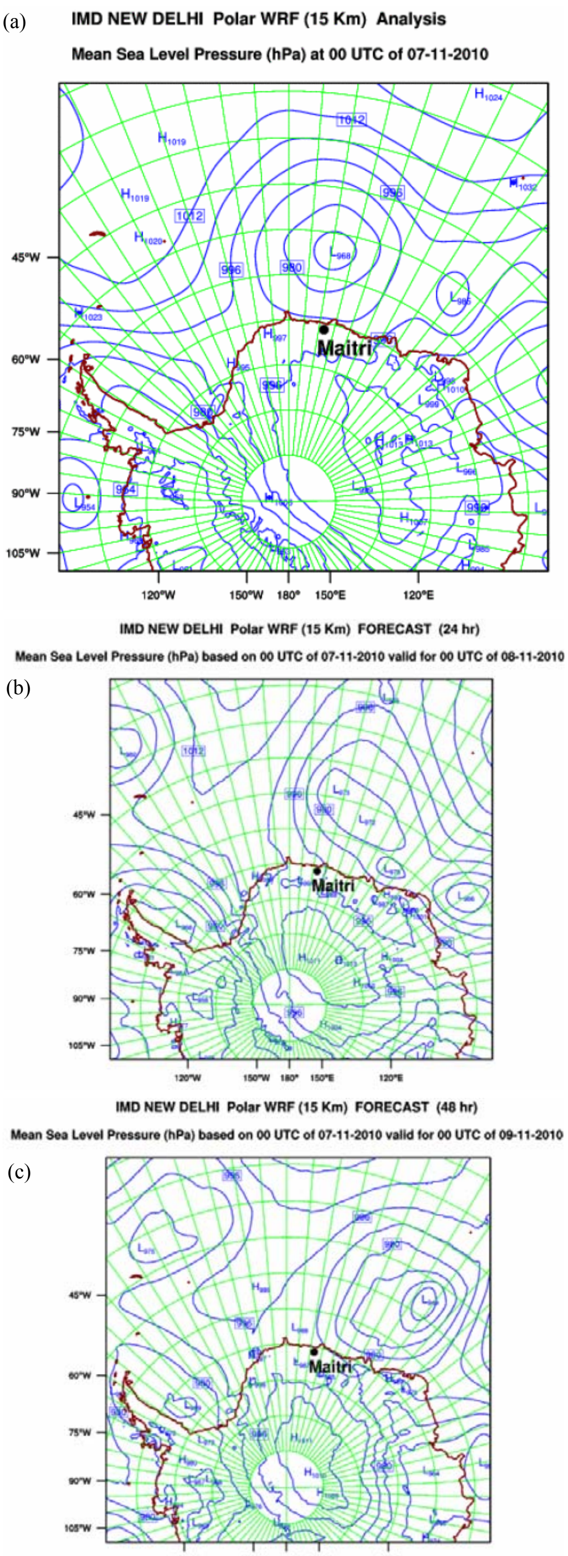
Antarctic Meso-scale Prediction system (AMPS) is providing real-time mesoscale NWP products for the Antarctic region since September 2000 (Powers *et al*., 2003). This system was built around the Polar Meso-scale Model - Polar MM5. Polar MM5 was used until June 2008 to make the forecasts, but currently more advanced mesoscale models like Polar WRF is used (Hines and Bromwich 2008). In the present study, Polar WRF model (version 3.1.1) is configured for the forecast up to 48 hours over the Maitri region. A single static domain with 400×400 grids at the 15 km horizontal spatial resolution and 39 vertical is used. Maitri (Lat. 70° 45′ S, Long. 11° 44′ E) is kept at the centre of the model domain. The model domain is presented in Fig. 1(a). Some important stations that are located in this model domain are shown in Fig. 1(b). The model is run with the initial and six hourly boundary fields from GFS-T382 operational at IMD.

Physics options of the Polar WRF used in this study are: (a) Micro physics-WSM 5-class scheme, (b) Goddard shortwave, (c) RRTM Long wave, (d) Noah Land-surface, (e) Planetary boundary layer-Mellor Yamada-Janjic and (f) Cumulus convection-Grell-Devenyi.

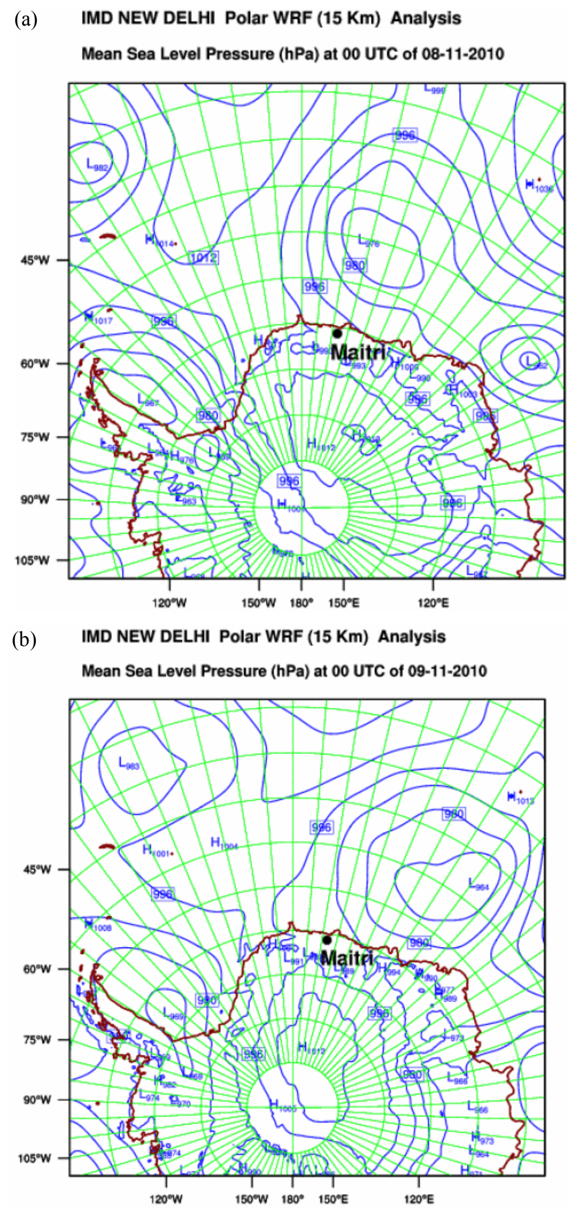
3. Results of validation and discussion

3.1. *Comparison of model forecast fields with the corresponding model analysis fields*

In order to validate the model forecasts against the corresponding analysis fields, a case study of 7 November 2010 is illustrated when a series of low pressure areas lay around Maitri region. Forecast parameters considered for this exercise are : (a) mean sea level pressure, (b) surface (2 m height) relative humidity, (c) surface (10 m height) wind - super imposed 2 m height temperature and (d) snowfall.

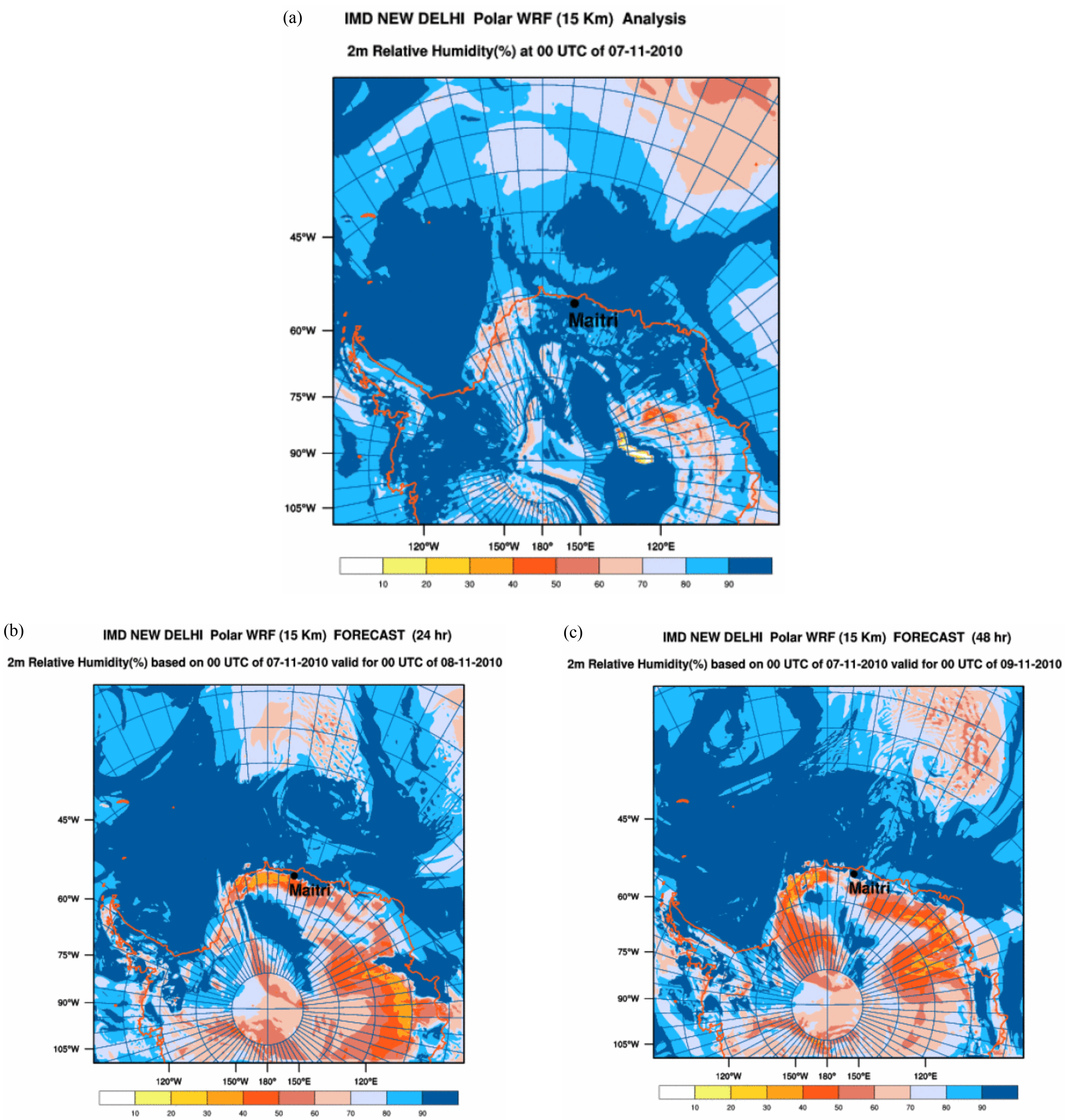


Figs. 2(a-c). (a) Analysis field of mean sea level pressure valid at 0000 UTC of 7 Nov 2010, (b) 24 hours forecast field of mean sea level pressure valid at 0000 UTC 8 November 2010, (c) Same as (b) except for the 48 hours forecast valid at 0000 UTC of 9 Nov 2010



Figs. 3(a&b). (a) Analysis field of mean sea level pressure valid at 0000 UTC of 8 November 2010, (b) same as (a) except for 9 November 2010

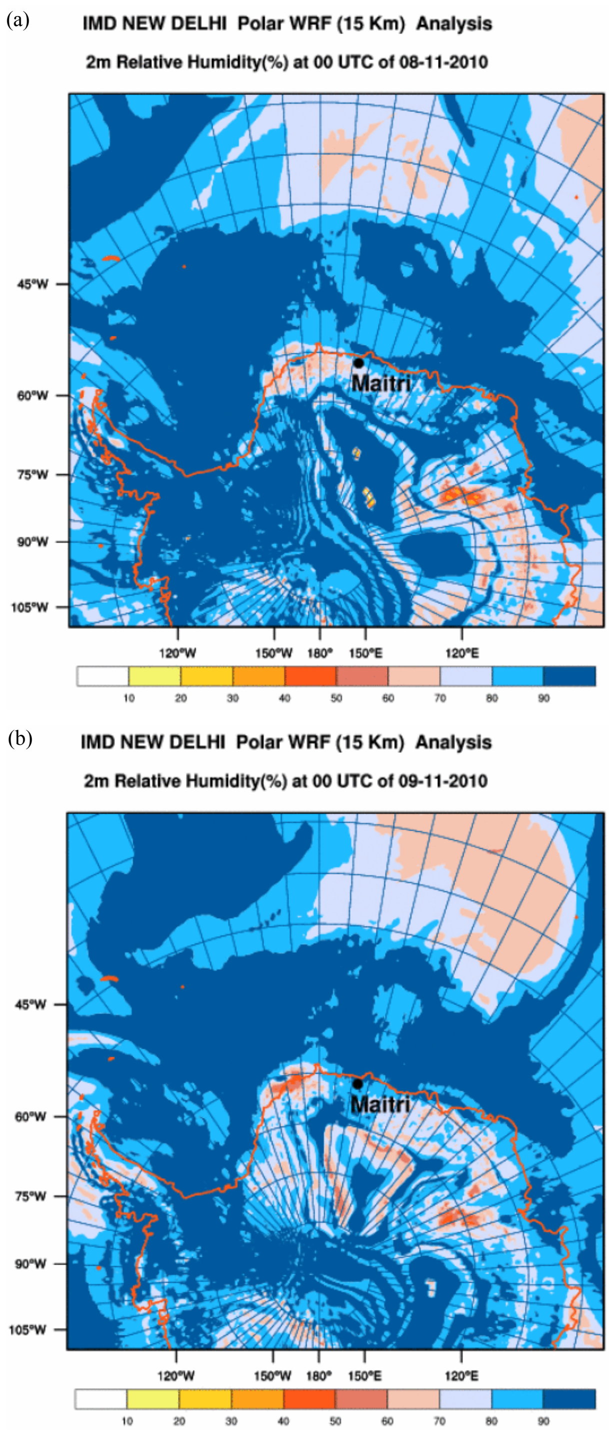
Analysis of mean sea level pressure field valid at 0000 UTC of 7 November 2010 and the 24 hours and 48 hours forecast fields valid at 0000 UTC of 8 November and 9 November 2010 are presented in Figs. 2(a-c) respectively. In the analysis of 7 November an well marked low pressure area is seen to the north of Maitri. Another two low pressure areas are located respectively to the north east and east of Maitri. In the 24 hours forecast valid at 0000 UTC of 8 November, the first low pressure system is well captured with a slight eastward movement.



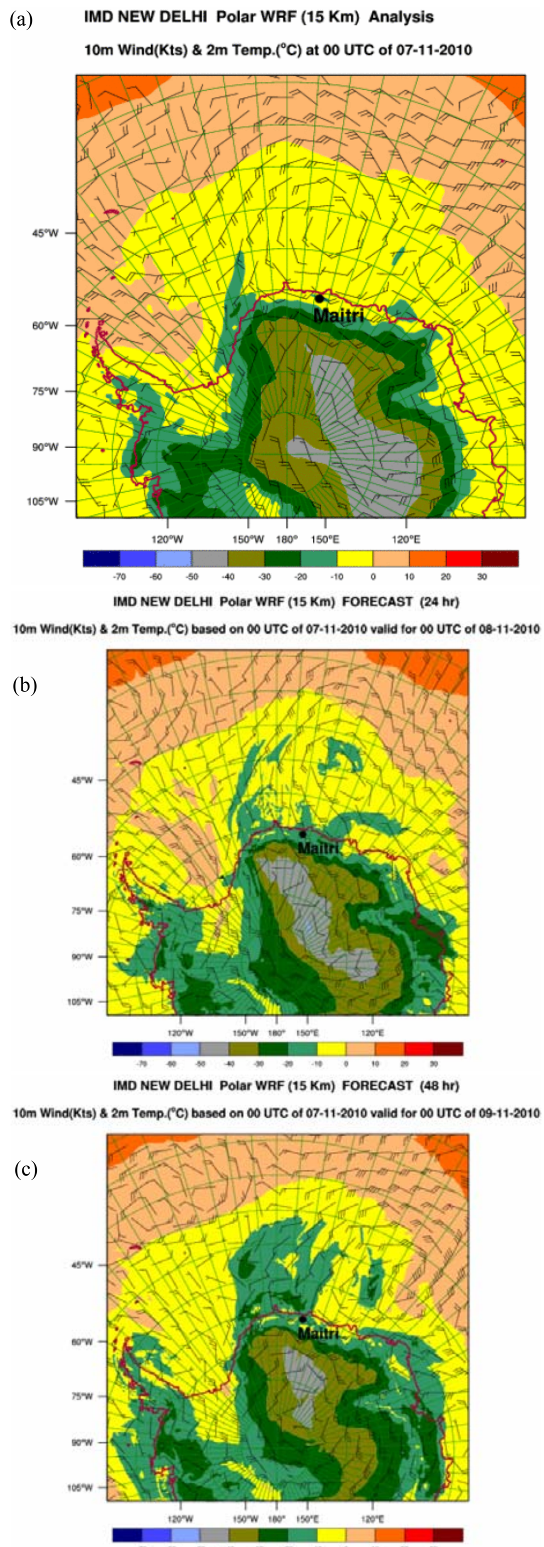
Figs. 4(a-c). (a) Analysis field of 2 m height relative humidity valid at 0000 UTC of 7 November 2010, (b) 24 hours forecast field of 2 m height relative humidity valid at 0000 UTC of 8 November 2010 and (c) Same as (b) except for the 48 hours forecast valid at 0000 UTC of 9 November 2010

The other two low pressure systems are respectively seen to the northwest and southwest of Maitri. In the 48 hours forecast valid at 0000 UTC of 9 November, these systems persisted and moved east wards. In order to compare the forecast fields, the corresponding analysis fields of 8 November and 9 November are shown in Figs. 3(a&b) respectively. The inter-comparison reveals that the forecast fields are in well agreement with the corresponding analysis field.

The analysis field of 2 m height relative humidity for 0000 UTC 7 November 2010 is shown in

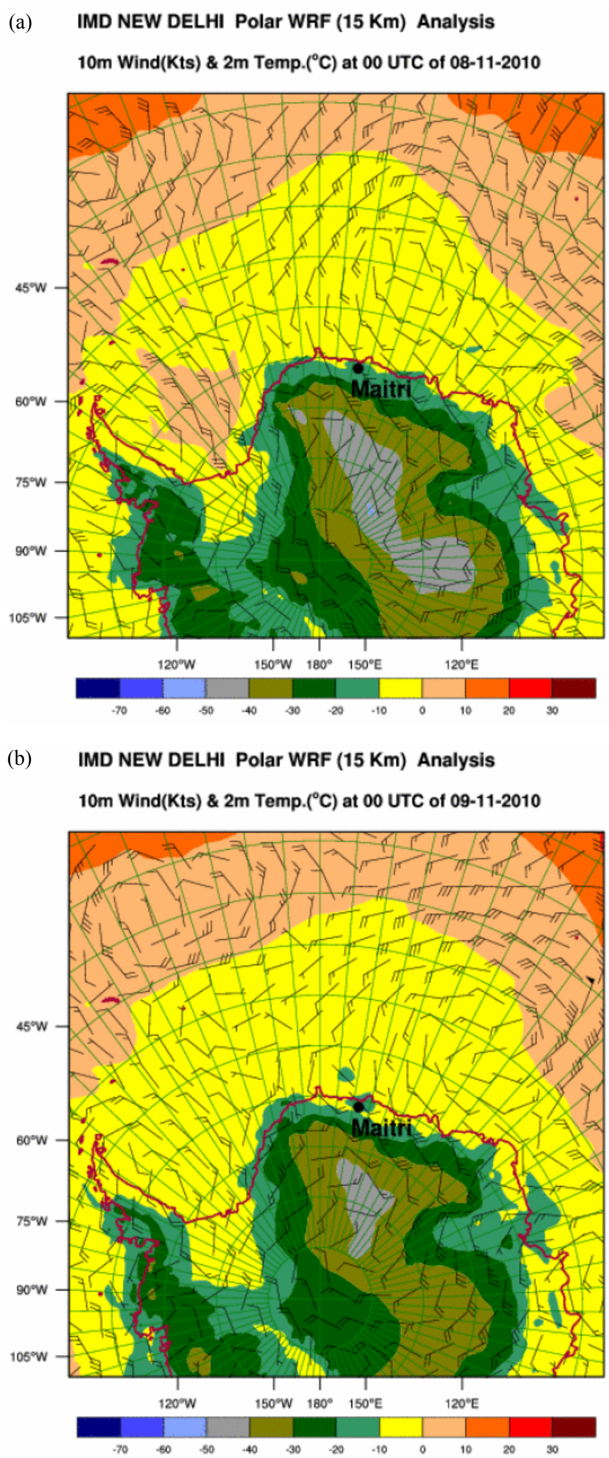


Figs. 5(a&b). (a) Analysis field of 2 m height relative humidity valid at 0000 UTC of 8 November 2010 and (b) same as (a) except for 9 November 2010

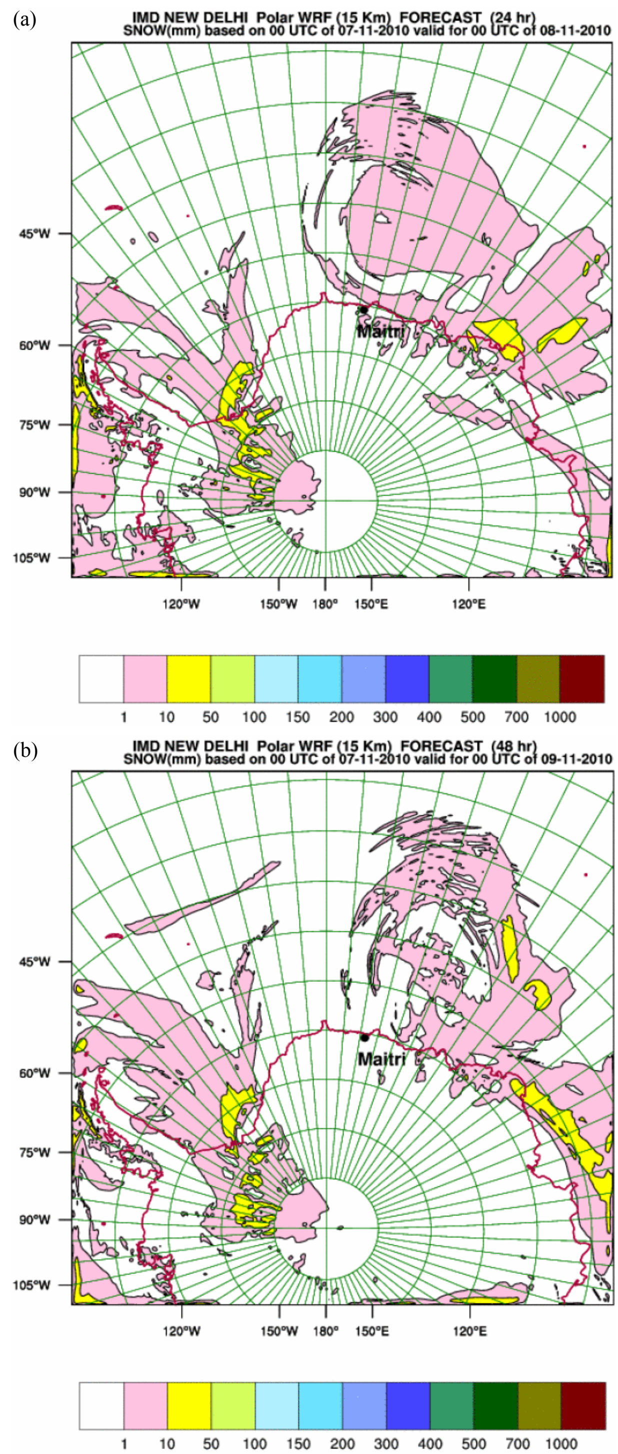


Figs. 6(a-c). (a) Analysis field of 10 m height wind and 2 m height temperature valid at 0000 UTC of 7 November 2010, (b) 24 hours forecast field of 10 m height wind and 2 m height temperature valid at 0000 UTC of 8 November 2010 and (c) Same as (b) except for the 48 hours forecast valid at 0000 UTC of 9 November 2010

Fig. 4(a). Figs. 4(b&c) represent the forecast fields of 2m height relative humidity at 24 hours (*i.e.*, 0000 UTC of 8 November) and 48 hours (*i.e.*, 0000 UTC of 9 November)

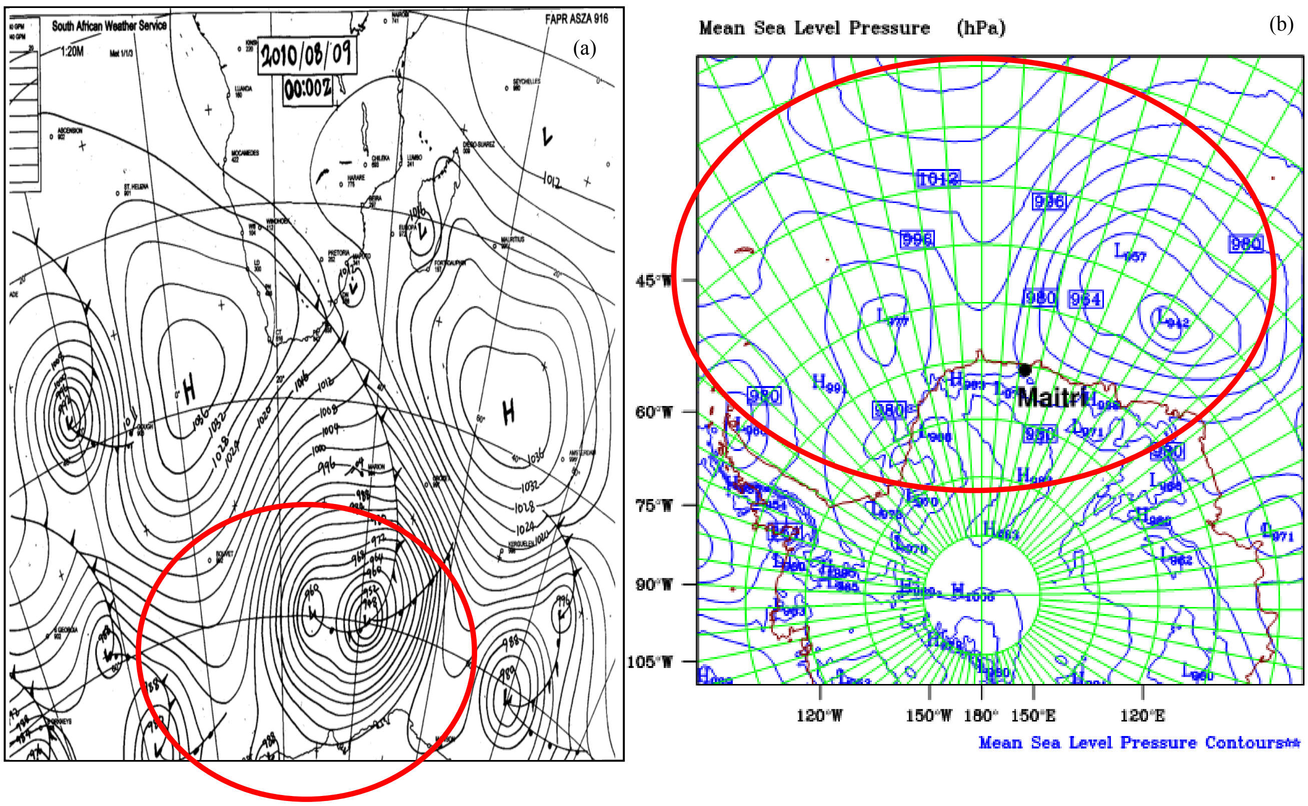


Figs. 7(a&b). (a) Analysis field of field of 10 m height wind and 2 m height temperature valid at 0000 UTC of 8 November 2010 and (b) same as (a) except for 9 November 2010

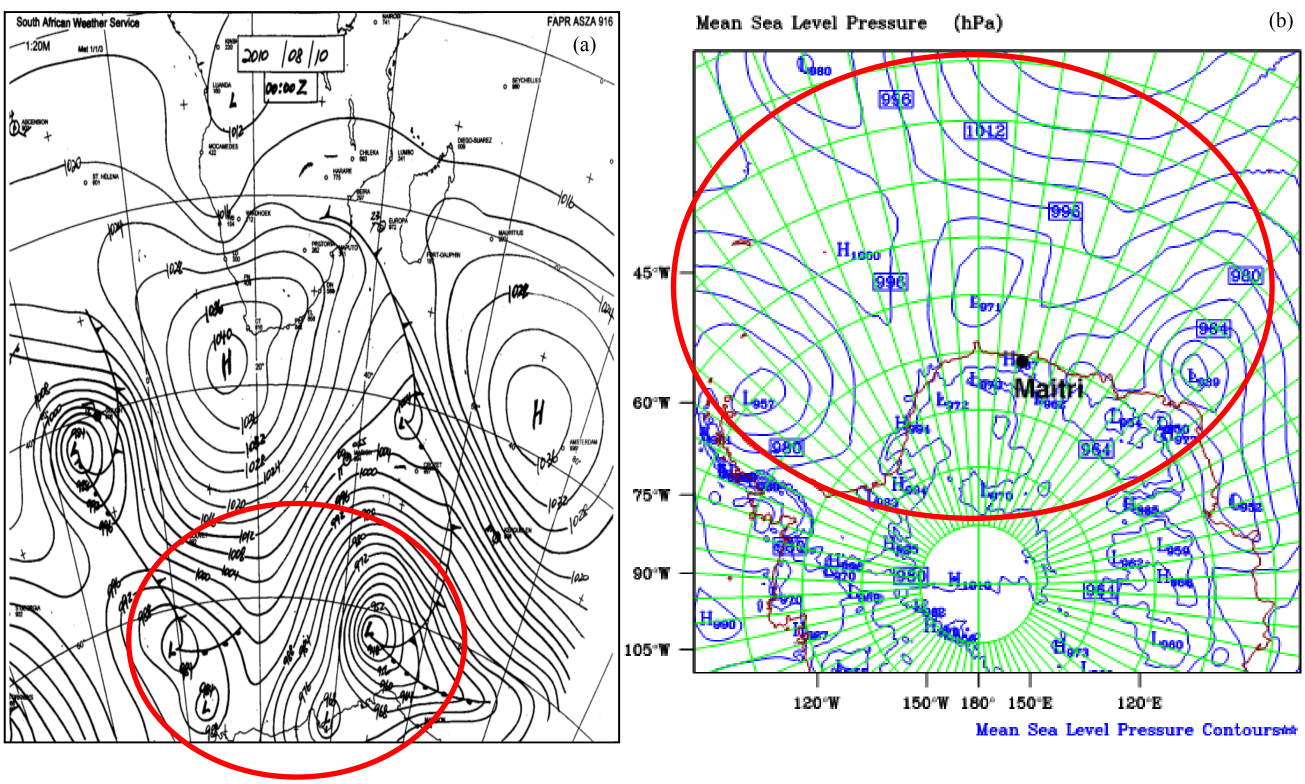


Figs. 8(a&b). (a) 24 hours forecast field of snowfall (mm) valid at 0000 UTC of 8 November 2010 and (b) Same as (a) except for the 48 hours forecast valid at 0000 UTC of 9 November 2010

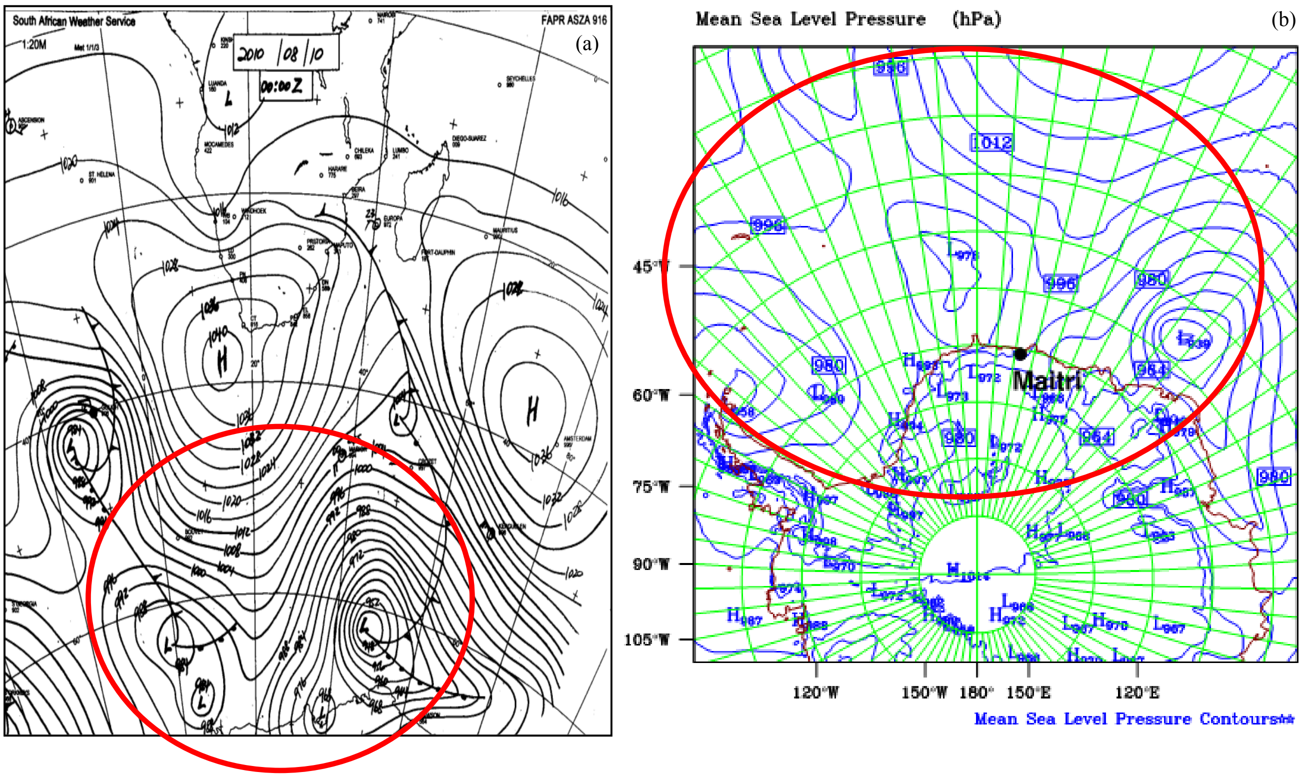
respectively. In order to compare the forecast fields, corresponding analysis fields are shown in Figs. 5(a&b) respectively. The east-west oriented larger regions of higher relative humidity (90%) are noticed in the 24 hours and 48 hours forecast fields. These features are broadly matches with that of the corresponding analysis fields. The locations of higher relative humidity justify the presence of low pressure systems over these areas.



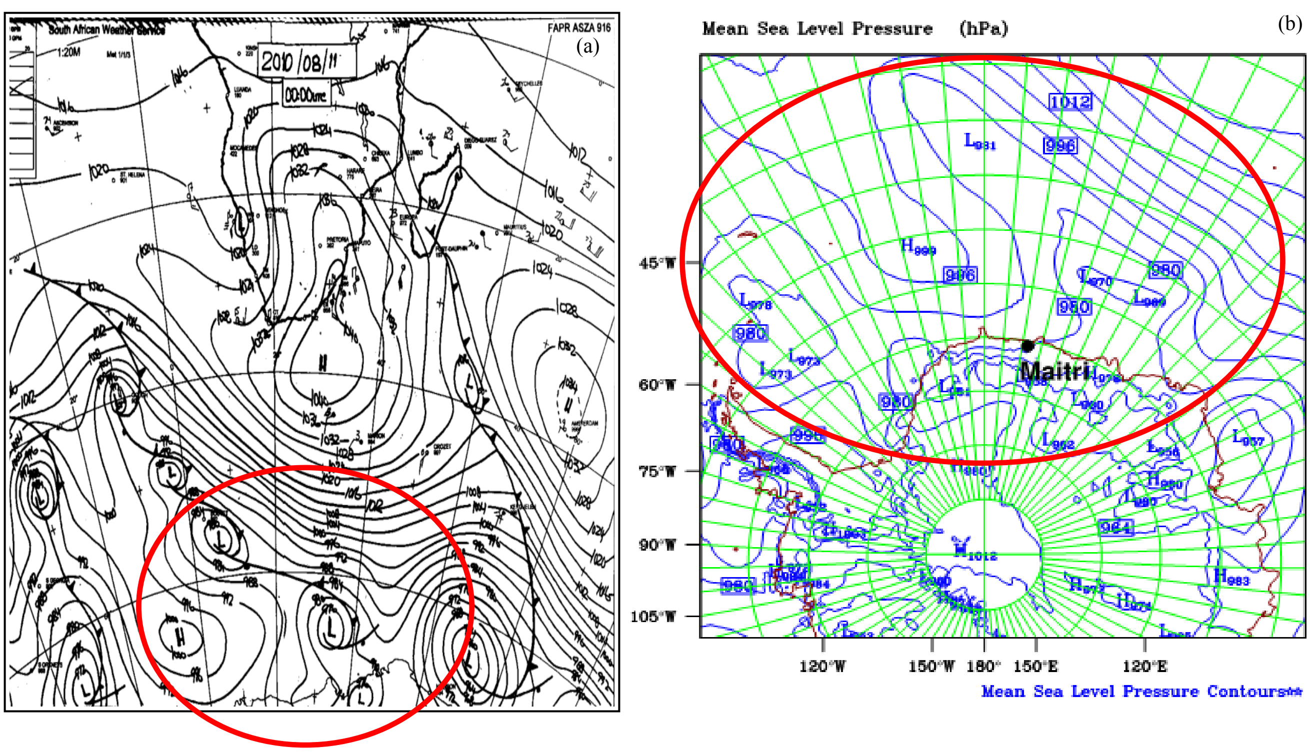
Figs. 9(a&b). (a) Observed synoptic chart of Pretoria showing mean sea level pressure field at 0000 UTC of 9 August 2010 and (b) Corresponding 24 hours forecast field based on initial condition of 0000 UTC of 8 August 2010



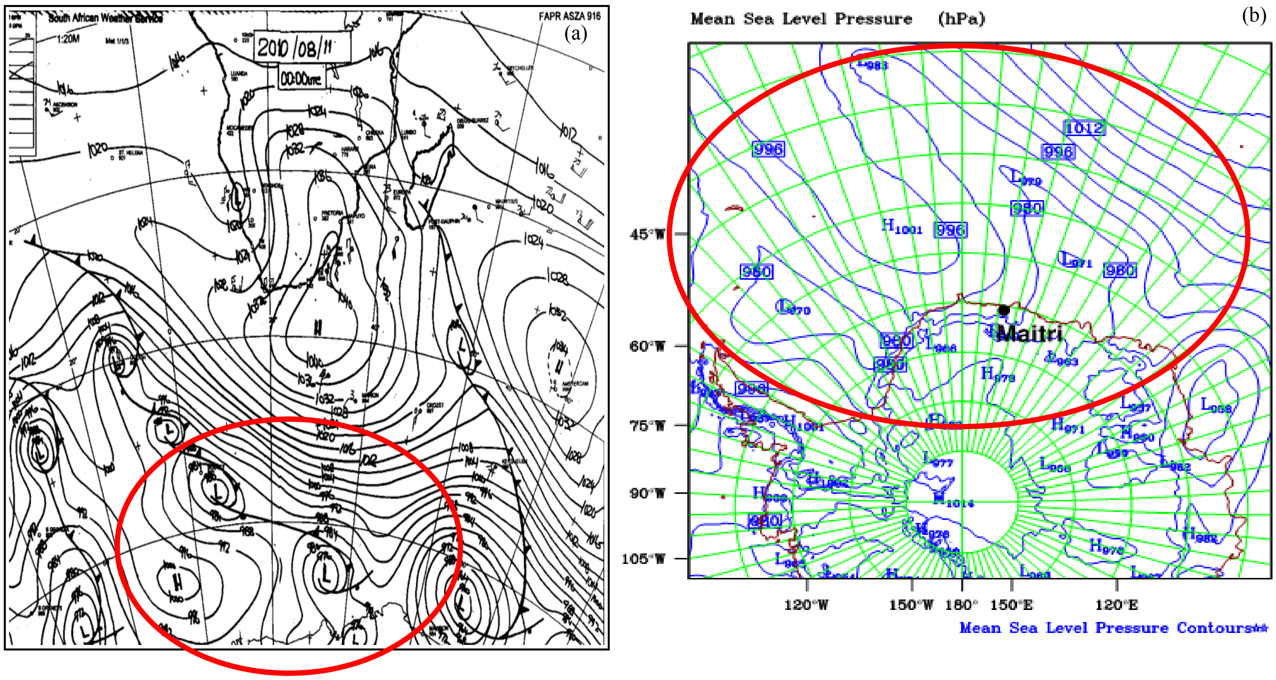
Figs. 10(a&b). (a) Observed synoptic chart of Pretoria showing mean sea level pressure field at 0000 UTC of 10 August 2010 and (b) Corresponding 48 hours forecast field based on initial condition of 0000 UTC of 8 August 2010



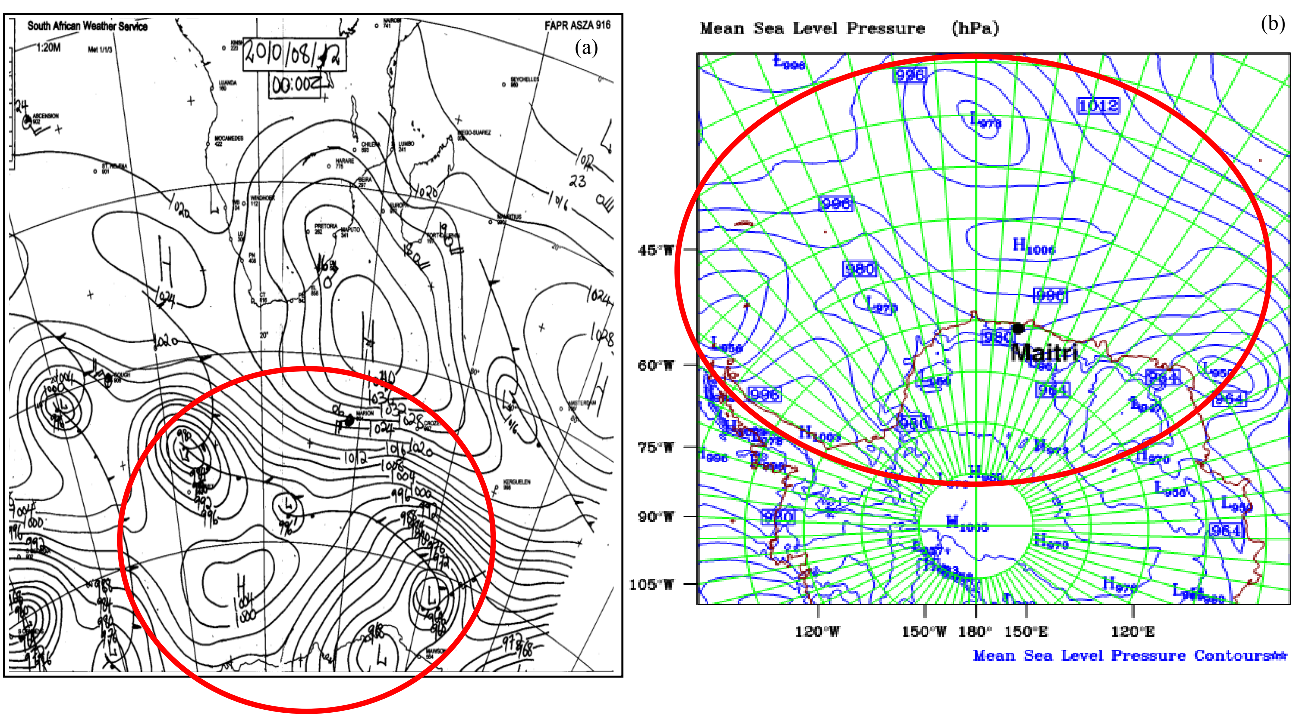
Figs. 11(a&b). (a) Observed synoptic chart of Pretoria showing mean sea level pressure field at 0000 UTC of 10 August 2010 and (b) Corresponding 24 hours forecast field based on initial condition of 0000 UTC of 9 August 2010



Figs. 12(a&b). (a) Observed synoptic chart of Pretoria showing mean sea level pressure field at 0000 UTC of 11 August 2010 and (b) Corresponding 48 hours forecast field based on initial condition of 0000 UTC of 9 August 2010



Figs. 13(a&b). (a) Observed synoptic chart of Pretoria showing mean sea level pressure field at 0000 UTC of 11 August 2010 and (b) Corresponding 24 hours forecast field based on initial condition of 0000 UTC of 10 August 2010



Figs. 14(a&b). (a) Observed synoptic chart of Pretoria showing mean sea level pressure field at 0000 UTC of 12 August 2010 and (b) Corresponding 48 hours forecast field based on initial condition of 0000 UTC of 10 August 2010

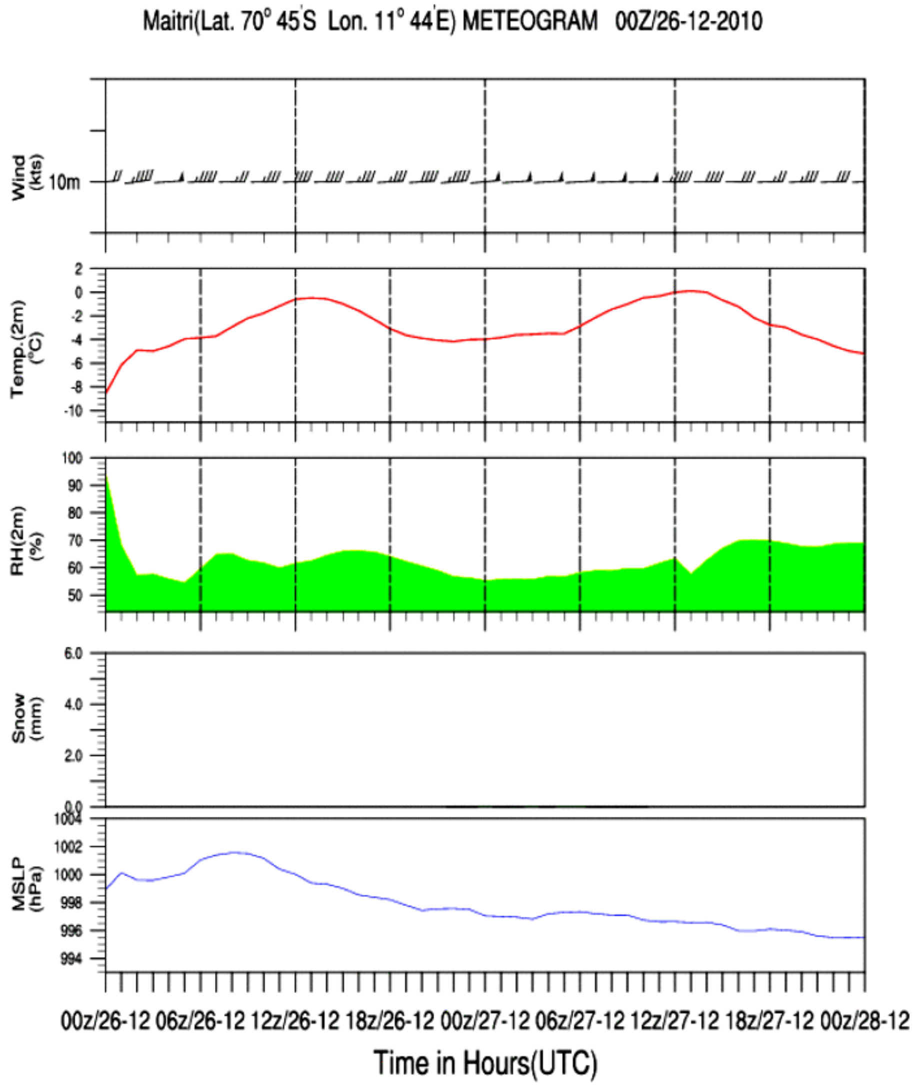
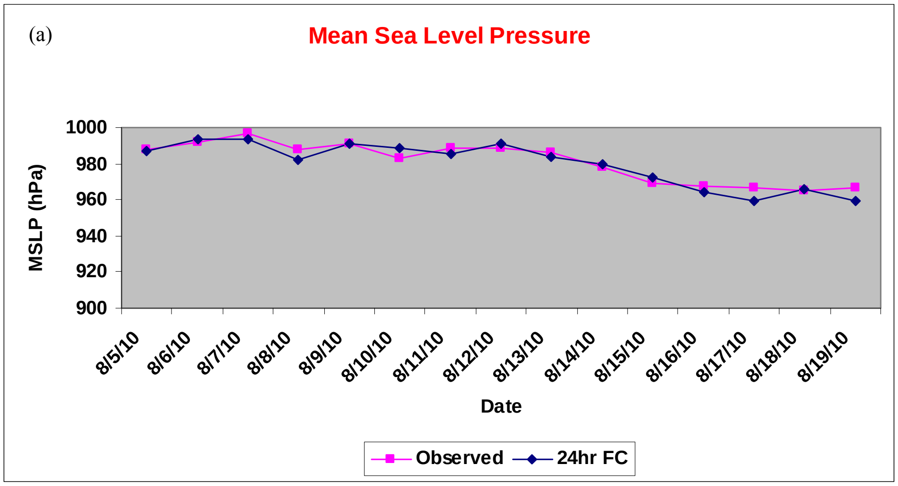
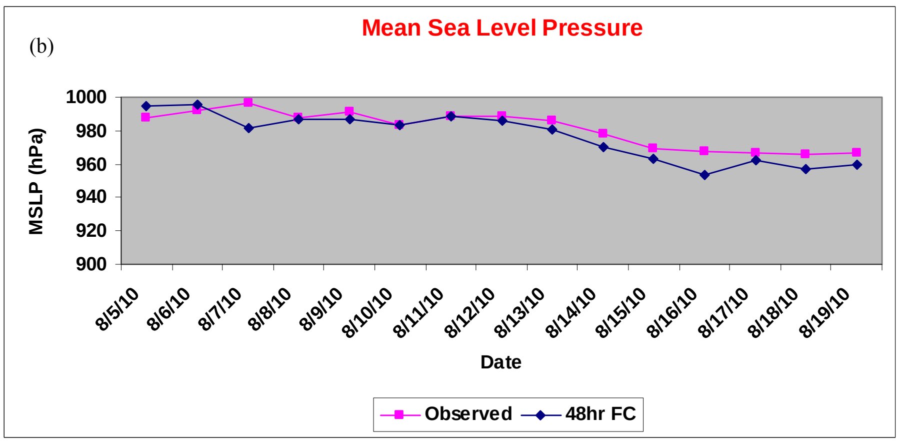


Fig. 15. Example of meteogram of Maitri, prepared based on the initial condition of 0000 UTC of 26 December 2010

Fig. 6(a) shows the analysis field of 2 m height temperature at 0000 UTC of 7 November and the wind fields at 10 m height for the same time are superimposed on it. Figs. 6(b&c) represent the forecast fields for 0000 UTC of 8 November and 9 November respectively.

A cyclonic circulation is seen to the north of Maitri with a trough extending south-east wards on 7 November. After 24 hours it is found that the circulation moved east wards and another circulation is developed to the north west of Maitri. After 48 hours it is found that the developed cyclone intensifies and moves in the same direction decreasing the temperature in the surrounding areas of Maitri. Though the analysis result shows similar feature in the wind field for 8th and 9th November 0000 UTC but the temperature fields only shows the evolution signature [Figs. 7(a&b)]. The location of circulation features is consistent with the location of the low pressure areas. Distribution of temperature in the forecasts is comparable with the corresponding analysis fields. In the Figs. 8(a&b), 24 hours and 48 hours forecast fields of snowfall valid at 0000 UTC of 8 November and 9 November respectively are shown. The occurrence of snowfall over the belt to the north of Maitri is caused due to the presence of low pressure system there.





Figs. 16(a&b). (a) An inter-comparison of daily 24 hours forecast mean sea level pressure of 0000 UTC and corresponding observed mean sea level pressure of Maitri during 5 August 2010 to 19 August 2010 and (b) same as (a) except for the 48 hours forecast

The inter-comparison reveals that the forecast fields are comparable with the corresponding analysis fields and all these forecast fields are consistent internally.

3.2. *Comparison of model forecast fields with the corresponding observed synoptic weather charts*

Synoptic charts of mean sea level pressure prepared by South Africa Weather Service at Pretoria are used for the validation corresponding forecast fields. As the map scale and domain of the synoptic charts prepared at Pretoria is different from the model domain and map scale used in this study, the common area of synoptic features are shown using a circular mark. The case studies illustrated are for the period from 9 August to 12 August 2010, during the passage of two low pressure systems.

Fig. 9(a) presents synoptic mean sea level chart of Pretoria valid at 0000 UTC of 9 August 2010. Corresponding 24 hours forecast field based on initial condition of 0000 UTC of 8 August is shown in Fig. 9(b). In the synoptic chart a low pressure area is seen to the north east of Maitri and another to the southwest, separated by a north-south oriented ridge line. These features are very clearly captured in the forecast fields. The systems persisted [Figs. 10 (a&b)] on 10 August both in the synoptic chart as well as in the 48 hours forecast field, with a slight eastward movement. Similar pattern is also captured in the 24 hours forecast valid at 0000 UTC of 10 August [Fig. 11(b)]. On 11 August, in the synoptic chart [Fig. 12(a)] a low pressure area is noticed extending from south-east to north-west ward with a high pressure area located to the west of this system. The pattern is well predicted both in the 48 hours and 24 hours forecasts

[Fig. 12(b) and Fig. 13(b)]. The synoptic chart of 12 August 0000 UTC and corresponding 48 hours forecast with the initial condition of 0000 UTC of 10 August are presented in Figs. 14 (a&b). The inter-comparison reveals the two low pressure areas separated by a high pressure area around the Maitri region as seen in the synoptic chart is well captured in the forecast field.

The validation results of these case studies demonstrated the potential of the model to capture synoptic scale low pressure systems.

3.3. *Verification of daily location specific forecast fields*

An example of meteograms prepared for Maitri on the basis of six hourly 48 hours forecast outputs with the initial condition of 0000 UTC of 26 December 2010 is illustrated in Fig. 15. The parameters included in the meteogram are: (*i*) mean sea level pressure, (*ii*) snow, (*iii*) surface (2 m height) relative humidity and (*iv*) surface (10 m height) wind.

For verification of the model derived pressure field, Figs. 16 (a&b) illustrates the time series of the observed and corresponding 24 hours and 48 hours forecast mean sea level pressure of Maitri for the period from 5 August to 19 August 2010. The time series of the observed and modeled pressure shown in this comparison indicates a high level of agreement between the modeled and observed pressure. The observed pressure values are found to be very close to the forecast values both in the 24 hours and 48 hours forecast field.

4. Concluding remarks

The main objective of this study has been to implement the Polar WRF for Maitri region over the Antarctica using IMD GFS as initial and boundary conditions. This task has been successfully accomplished. Validation results of the study show that the forecast fields are consistent with the corresponding analysis fields. The inter-comparison with the synoptic chart of Pretoria showed the potential of the model to capture synoptic scale low pressure systems. The time series of the observed and modeled pressure of Maitri indicates a high level of agreement between the modeled and observed pressure. The results obtained from this validation exercise clearly demonstrate the usefulness of these numerical products to meet the operational requirement of near real-time weather forecasting over the Maitri region. The study is expected to benefit weather forecasters at Maitri.

However, these results being preliminary, further investigations are needed for a variety of different weather conditions during winter and summer months for identifying shortcomings of the model and aspects of the model that require additional development work in the future. The present work demonstrates the validity of the direction taken to utilize NWP applications in the operational weather forecasting and for the Antarctica research.

Acknowledgements

Authors are grateful to the Director General of Meteorology, India Meteorological Department, New Delhi for his keen interest in this study and providing all facilities and support to complete the work. Authors thankfully acknowledge the Meteorology Group of the Byrd Polar Research Center at the Ohio State University for use of the Polar WRF in this work and technical guidance through e-mail interactions.

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