The impact of SST on the weather forecast quality in the Bulgarian Antarctic Base area on Livingstone Island

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Introduction

The weather forecast of good quality is essential for the humans living and operating in the Bulgarian Antarctic Base. The numerical weather prediction models in southern high latitude regions still need improvement as the user community is limited, little test cases are documented and validation data are scarce. Not lastly, the challenge of distributing the output results under poor internet conditions has to be addressed.

Model configuration

The modeling system is based on the Weather Research and Forecasting (WRF) model, version 4.0, developed by the National Center for Atmospheric Research (NCAR) and the National Centers for Environmental Prediction (NCEP). The numerical model uses a staggered Arakawa C-grid [1] and the nesting is performed in a 3:1 ratio, with a finest resolution of 1 km. The domain configuration, shown on Figure 1, is centered over the Bulgarian Antarctic Base (BAB) and consists of three nested domains, namely d01, d02 and d03. The initial and boundary conditions for each forecast are taken from the GFS 0.25 Degree Historical Archieve [2] and the lateral boundary conditions are updated every 3 hours of the simulation. In order to quantify the importance of the sea surface temperature (SST), this variable is taken as a time varying boundary condition and is also updated every 3 hours into the simulation.

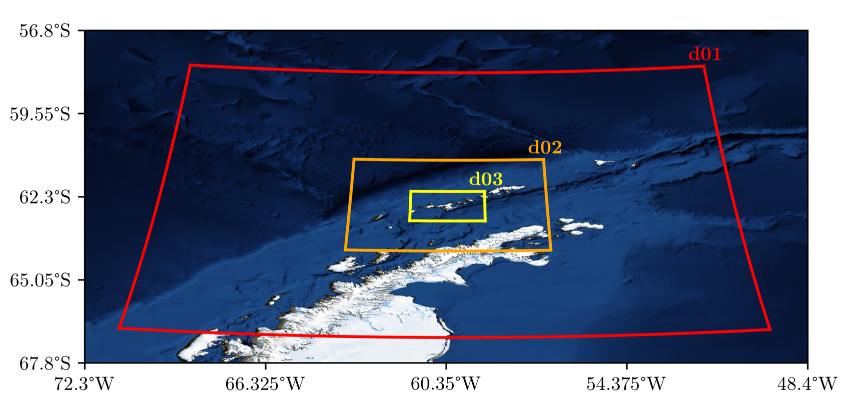

Figure 1: Area of covarage for the three domains - d01, d02 and d03. Background image from NASA Visible Earth - Blue Marble.

The topography data is taken from the GMTED2010 database and the land use data is from MODIS. A comparison with regional maps and photos show that both databases fail to represent accurately Livingston Island. The mountain range Tangra mountains, reaching heights over 2000 m, is represented as a flat surface with elevation of ~50 m and the whole island is described with a land type of snow and ice, while summer photos in the region indicate the presence of rock fields and even grasslands.

Terrain-following η-coordinates, distributed into 50 vertical levels are used. The physics parametrization is done in accordance with the Antarctic Mesoscale Prediction System (AMPS) [3].

The model configuration has been validated against measurements from an automatic meteorological station at BAB, synoptic measurements in the nearby stations and ERA-5 climatic hourly reanalysis data. It is found to represent satisfactory the temperature at 2 m, sea level pressure and wind at 10 m in the point of BAB during weather shift events.

Land use type sensitivity

Several cases with passing cyclones and shift of weather patterns are addressed in our study. The length of each simulation is 72 hours and the results are compared with measements at BAB, nearby synoptic stations and the ERA-5 reanalysis [4]. A side experiment with altering the land use type in one grid point (1 km^2) in the finest domain has been carried out. This grid point corresponds to the location of the base, where the snow melts completely during summer and reveals the rocky soil underneath. The land use type is included in the model equations with the following parameters: albedo $\alpha[\%]$, soil moisture availability $M[100\%]$, surface emissivity, $\epsilon[\%]$, roughness length $z_0[m]$, thermal inertia $\lambda_T[10^2 Jm^{-2}K^{-1}s^{-1/2}]$ and surface heat capacity $C[Jm^{-3}K^{-1}]$.

Table 1:MODIS land use type parameters for the summer, as in LANDUSE.TBL of WRF, v4.0.

Number	$\alpha[\%]$	$M[\%]$	$\epsilon[\%]$	$z_0[cm]$	λ_T *	C **	Name
10	19	15	92	7.5	2.37	$20, 8.10^5$	"Grasslands"
15	55	95	98	1	5	9.10^{25}	"Snow and Ice"
16	25	2	85	6.5	0.81	12.10^5	"Barren or Sparsely Vegetated"
17	8	100	98	0.01	6	9.10^{25}	"Water"
20	15	2	90	6	1.60	12.10^5	"Barren Tundra"

* $\lambda_T[4, 184.10^2 Jm^{-2}K^{-1}s{-}1/2]$; ** $C[10^5 Jm^{-3}K^{-1}]$

The Bulgarian Antarctic Base "St. Kliment Ohridski"

The Bulgarian Antarctic Base 'St. Kliment Ohridski' (BAB) is located on the Livingstone Island coast at 62.6414°S and 60.3647°W. Its elevation is 12 to 15 m above sea level. An average of 25 people work there during the austral summer, usually from late November until early March. The weather in the region is mostly influenced bu extratropical cyclones, which form and propagate as the Rossby planetary waves. The cyclones move west to east and begin to diminish over land, due to friction. Thus, the weather is highly variable with intense storms and strong winds events occurring regularly.

The experiment is carried out with four different land use types - snow and ice (as in MODIS data), barren or sparcely vegetated soil, barren tundra and grasslands. Their land use numbers and respective parameters values are given in Table 1. The results of the simulations for the finest domain are shown in Figure 2.

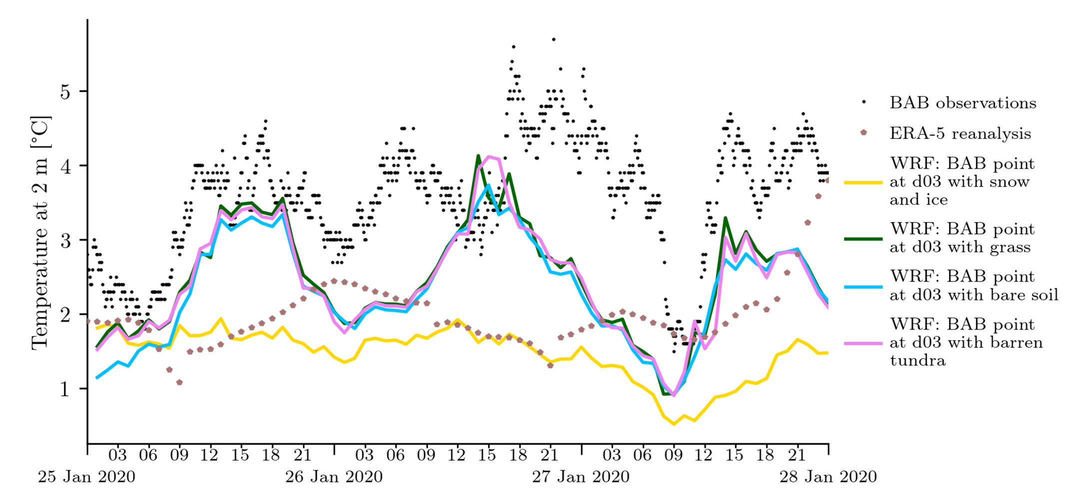

Figure 2: Timeseries of the temperature at 2 m with different land use types, compared to observational data and the ERA-5 reanalysis data.

The simulation of snow and ice is close to the ERA-5 reanalysis with a bias of -0.5°C and root mean square deviation (RMSD) of 0.75°C, which suggests that similar land parametrization is used in both models. The observational data, however, do not agree well with the initial snow and ice simulation - the respective bias and RMSD are -2.07°C and 2.23°C. The other land use types, with which we modified the land data, have a higher surface heat capacity, which differs with a factor of 10^{20} than the one for snow/ice. This results in the unlocking of diurnal variations of the 2 m temperature and reduces the difference between the simulations and observations. For barren tundra the bias compared to the observations is -1.1°C and the RMSD is 1.34°C. The model simulations comparison with data from synoptic observations on Livingstone Island gives similar results.

This comparisons show that the MODIS data, collected with satellite missions during 2005, does not adequately represent the current situation on places, affected by climate change, such as Livingstone Island. For accurate simulations in these regions, a revision of the land use type is advisory.

Experiments planning with different SST

The influence of the Southern ocean over the weather on small islands is significant, thus important to be correctly taken into account in the numerical forecast. The ocean mainly affects the weather on high latitudes through its sea surface temperature (SST) and the distribution and movement of sea ice by the currents. The initial simulations in our domains suggest that the numerical model predicts lower temperatures than those observed.

Two different datasets for SST forecasts are used in the simulations - the GFS 0.25 Degree Historical Archieve [2] and the Global Ocean 1/12°Physics Analysis and Forecast, available from the Copernicus Marine environment monitoring service (CMEMS) [5].

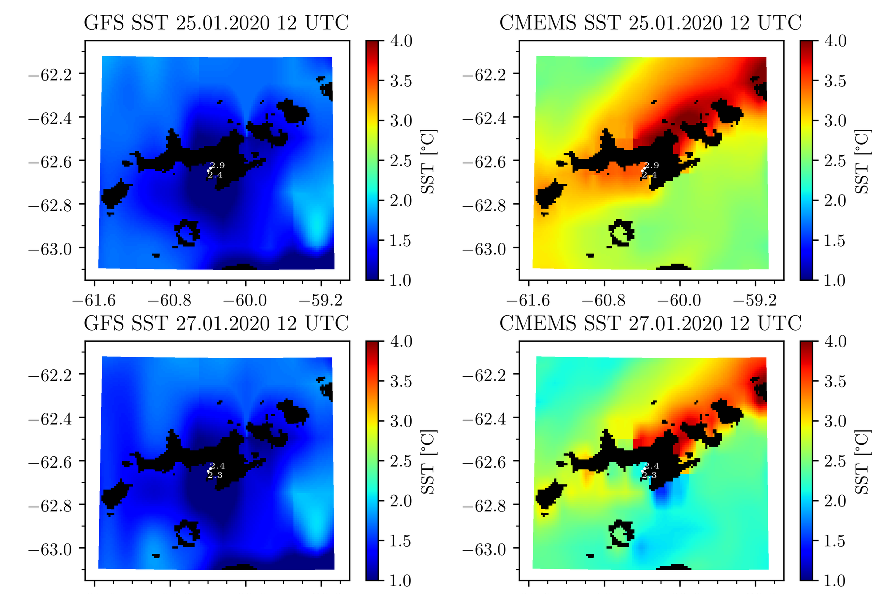

Figure 3: SST comparison with data from GFS and data from CMEMS and its evolution in time. The white points indicate measurements of the sea temperature in °C.

A visual representation of the difference in the SST field between the two datasets for one of our simulations is given in Figure 3.

Several differences can be noted in this comparison - the average SST, according to the GFS model is 2.5°C less compared to CMEMS; the distribution of cold water masses is different; the temporal evolution shows a significant decrease of about 2.5°C in the Southern part of the island in the CMEMS field and almost no change in the SST field by GFS. The in-situ measurements of sea temperature at 3 m depth are consistent with the large change in SST, predicted by the CMEMS model. Comparisons of other cases have shown less notable differences between the average temperatures by GFS and by CMEMS, but the temporal evolution of the GFS SST is not as profound as the CMEMS one. We have conducted experiments with both datasets. In order to make a quantitative assessment of the SST sensitivity, experiments with a modified SST are also conducted - the SST is modified with a fixed constant (with values of -3°C, -1°C, 1°C, 3°C) over the whole field.

SST sensitivity

A comparison of all our simulations for a test case in 2016 in the point, where BAB is located, are shown in Figure 4. The comparison of the simulations with unmodified GFS and CMEMS SST data show that the second tend to induce higher 2 m temperatures. The calculated values of bias and RMSD for the case study in 2016 and the case study in 2020 are minimal for the run with modified SST with a value of +3°C, which can also be seen in the graph, as the dark red curve is in the closest proximity to the observational points.

The comparison of unmodified data for both cases shows slightly better results with data from the CMEMS model - for the case study in 2016 the RMSD has values of 1.69 with GFS SST and 1.62 with CMEMS SST; for the 2020 case study, the respective values are 2.23 with GFS SST and 2.08 with CMEMS SST.

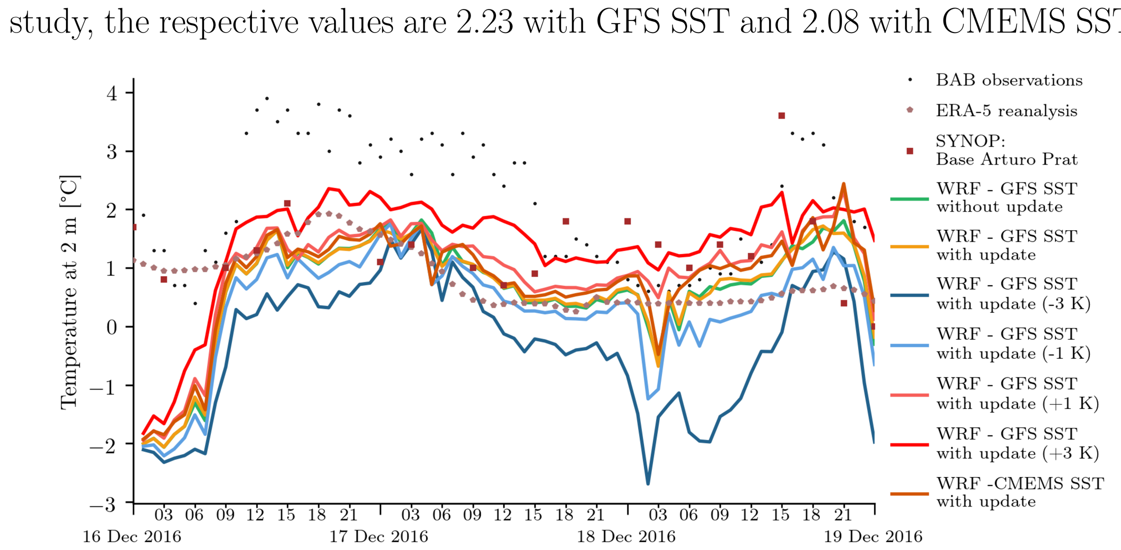

Figure 4: Timeseries of the temperature at 2 m with different land use types, compared to observational data, data from a nearby synoptic station, and the ERA-5 reanalysis data.

The experiments with symmetric modifications are used for a quantitative analysis. Let us introduce the measure of the modification $\Delta SST[°C]$, which takes discrete values of $\Delta SST \in [+3, -1, 0, 1, 3]$. We also introduce the variables T_{min}, P_{min} and V_{min} to represent the minimum values of the variables temperature at 2 m, sea level pressure and wind speed at 10 m for the 24-th forecast hour in the whole domain. The respective maximum values are denoted as T_{max}, P_{max} and V_{max}. The averaged values over the whole domain are calculated and written as T, P and V, the values in the point of BAB for the same hour are written as T_{BAB}, P_{BAB} and V_{BAB}.

Figure 5 shows the relation between these field characteristics and ΔSST for two of our test cases - Case 2016 and Case 2020. As expected, with an increase of SST, T also increases. The curve, which represents T_{max} is steeper than the curve representing T_{min}, in addition the temperature at BAB is most weakly affected by the change in SST. This suggests that points over land are less affected than points over sea.

The pressure graphs show a slight decrease of sea level pressure with an increase of the SST. The wind graphs suggest a decrease of V_{max} and V_{BAB} with raising SST, while V_{min} rises above 0 m/s after certain threshold of the SST value is reached.

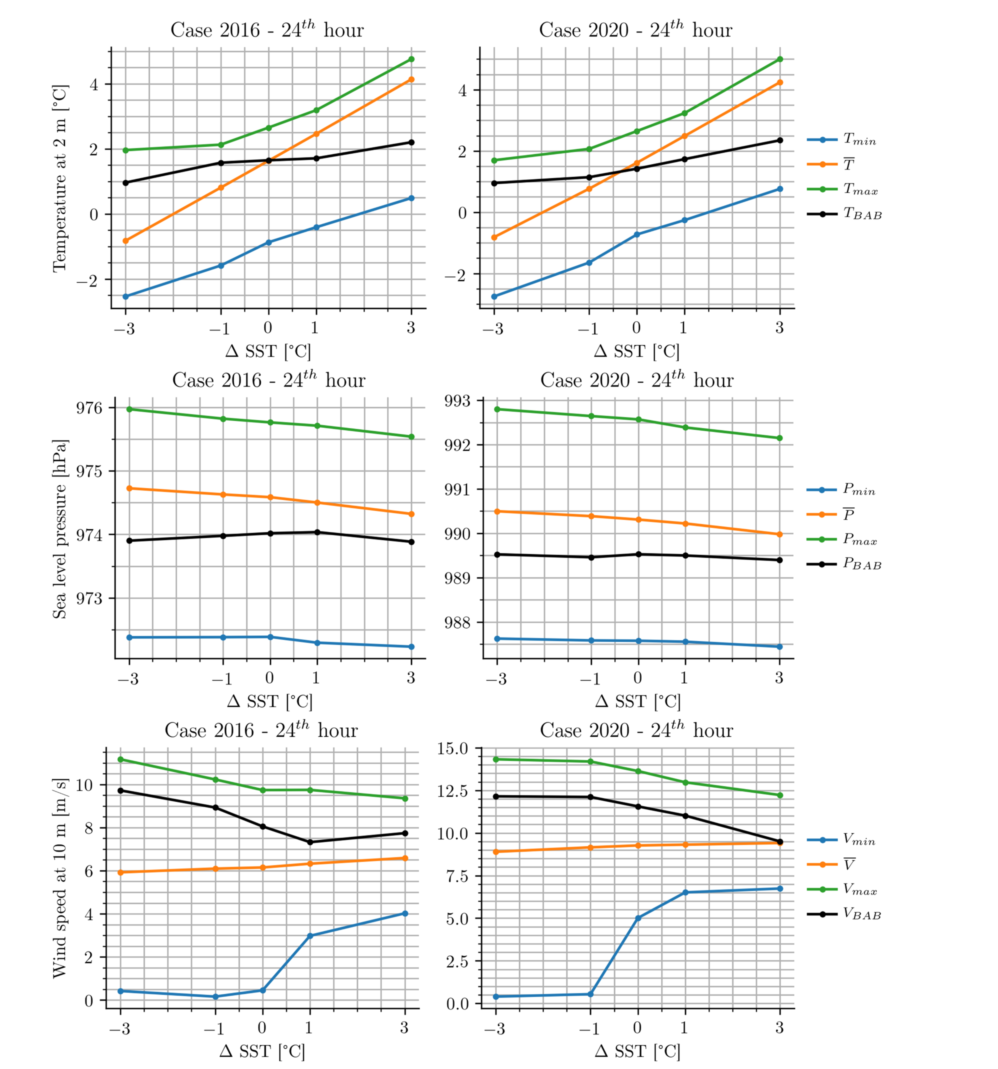

Figure 5: Relation between ΔSST and the field characteristics of T, P and V for the 24-th forecast hour for Case 2016 (left) and Case 2020 (right).

Conclusion

After configuring the WRF model for the area of Livingstone Island, an analysis of the SST fields from different sources and the conducted experiments, we have reached the following conclusions:

- The topography and land use datasets, available with WRF, do not represent adequately the area of study. A change in the land use type significantly increases the forecast quality.
- There are spatial and temporal differences in the SST fields provided by GFS and CMEMS, as the second tend to forecast higher values of SST with a sensible temporal evolution.
- The 2 m temperatures increase with rising SST. With $\Delta SST = 3$°C, the 2 m temperature at BAB rises with ~0.75°C. That is important to represent correctly the SST in the nearby ocean.
- With an increase of SST, the sea level pressure increases and the maximum wind speed decreases.

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Acknowledgements

The authors thank Assoc. Prof. Gergana Georgieva for the collection and systematization of the observational data, as well as the suggestions from her side during our study.

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