An intercomparison of two reanalysis datasets CAMS vs. ERA5

Kaffashzadeh Najmeh[1], Aliakbari-Bidokhti Abbas-Ali[2]

[1] *Postdoctoral Fellowship, Space Physics Department, Institute of Geophysics, University of Tehran, Iran*
n.kaffashzadeh@ut.ac.ir
[2] *Professor, Space Physics Department, Institute of Geophysics, University of Tehran, Iran*
bidokhti@ut.ac.ir

ABSTRACT

Although reanalysis products cover various variables on a global scale, their performance is different across regions. This study evaluates two reanalysis datasets, namely CAMS and ERA5, based on an in situ measured temperature over Tehran for three successive years of 2016, 2017, and 2018. The results show that both reanalysis datasets capture the general pattern of daily and monthly variability. Both datasets contain a cold bias. Despite the enhanced spatial resolution of ERA5, it turns out that ERA5 is more biased than CAMS. Furthermore, a detailed assessment of model performance indicates that more than 80% of the error is associated with bias.

Keywords: reanalysis, evaluation, bias

INTRODUCTION

Reanalysis data provides a global picture of past weather and climate (ECMWF, 2020). These data are constructed by combining atmospheric observations such as satellite, radar, and in-situ measurements with a detailed computer simulation of the atmosphere, using data assimilation methods. Reanalysis data have been widely used as an initial condition for the daily forecast of the atmosphere or boundary conditions in regional models, for the study of climate change, and as proxies to complement insufficient in-situ measurements.

The European Centre for Medium-Range Weather Forecasts (ECMWF) has been producing various reanalysis products for over two decades. The Copernicus Atmosphere Monitoring Service (CAMS) and the ECMWF Reanalysis fifth Generation (ERA5) have been developed in recent years, and in spite of having some similarities, they have some major differences. CAMS is mainly developed to assimilate the chemical compositions such as tropospheric ozone and aerosol concentrations, but it also holds outputs for several meteorological variables. ERA5 has been created to estimate more accurate meteorological conditions by upgrading toward fine temporal and spatial resolutions.

Several studies have been dedicated to analyze various assimilated products. For instance, Liu et al. (2020) evaluated multi-reanalysis products, including ERA5, with in situ records over the Tibetan Plateau and found that all reanalysis systems provide highly correlated but cold biased of air temperature. Jiao et al. (2021) found that the accuracy of ERA5 precipitation is strongly correlated with topographic distribution in China. A slight cold bias of ERA5 sea surface temperature around the Pacific and the Atlantic has been reported by Yao et al. (2021). ERA5 surface temperature was assessed using buoy observations over the Arctic. The comparisons showed that ERA5 surface temperature data contains a negative bias, up to $-11.18 \pm 3.08\ ^{\circ}C$ in December (Yu et al., 2021). CAMS shows an improved performance in free-tropospheric ozone, but it shows bias at the surface of many parts of the globe (Huijnen et al., 2020). An inter-comparison of tropospheric ozone from seven reanalysis datasets in East Asia reported that CAMS depicts more reasonable spatial-temporal variability than ERA5 (Park et al., 2020).

This study evaluates the assimilated temperature products from CAMS and ERA5 over Tehran. We use a surface-based measured data series for the years of 2016, 2017, and 2018. Moreover, a relatively new statistical metric is used to quantify the error in terms of bias and variance. This paper is outlined as follows: the used datasets in this study are introduced in Section 2. The methodology is described in Section 3. Results are given in Section 4. And lastly, the conclusions and discussion are provided in Section 5.

DATASETS

In situ observation. Measured data series of the atmospheric temperature variable were obtained at one synoptic station. The station is named Mehrabad locating at the latitude of 35.7°N and longitude of 51.3°E, with an altitude of 1191 m. The data series was retrieved for three successive years as 2017, 2018, and 2019 in a 3-hourly time interval.

Reanalysis data products. The first reanalysis datasets used in this study contains CAMS, which is the most recent European Centre for Medium-range Weather Forecast (ECMWF) global reanalysis data of atmospheric compositions (Innes et al., 2019). CAMS also provides data for several meteorological variables. The spatial resolution of CAMS is a reduced Gaussian grid at a spectral truncation of T255, i.e., 0.75°× 0.75° globally, approximately 80 km. The vertical resolution consists of 60 hybrid-sigma vertical model levels with the top level of 0.1 hPa. CAMS covers a long-term period of data from 2003 onwards. The reanalysis fields are available at a 3-hourly time interval and accessible from the Copernicus atmospheric data store.

At the ECMWF, there are several meteorological reanalysis products such as ERA-40 (Uppala et al., 2005), ERA- Interim (Dee et al., 2011), and ERA-5 (Hersbach et al., 2020). In this study, we selected the most recent one, i.e., ERA5, which is the fifth generation of the ECMWF atmospheric reanalysis covering the period of 1970 to the present. This dataset provides an hourly estimation of a large number of atmospheric, land, and oceanic climate variables. ERA5 covers the globe with the spatial resolution of 0.25°× 0.25°, approximately 31 km grid, and resolves atmosphere up to the height of 80 km or 0.01 hPa using 137 vertical model levels. This product is constructed by the Copernicus Climate Change Service at the ECMWF.

METHODOLOGY

In this study, the mean square error (MSE) was used as a statistical metric to evaluate the reanalysis performance. The MSE is defined as the squared mean of the difference between an assimilated (X_a) and observed (X_o) variables:

$$MSE = \frac{\sum_{i=1}^{n}(x_a^i - x_o^i)^2}{n} \tag{1}$$

The MSE can be modified to include all relevant model evaluation indicators, i.e., bias, variance, and correlation as (Solazzo and Galmarini, 2016):

$$MSE = (\bar{x}_a - \bar{x}_o)^2 + (\sigma_a - r\,\sigma_o)^2 + \sigma_o^2(1 - r^2) \tag{2}$$

where σ_a and σ_o refer to the standard deviation of the assimilated and observed data, respectively, and *r* is the coefficient of correlation between the observed and assimilated datasets. In Eq. (2), the first term (hereafter E1) shows the deviation between average assimilated and measured datasets and refers to the model accuracy. The second term (hereafter E2) contains the variance error, i.e., the discrepancy in amplitude or phase between the variability of the assimilated and observed values, that determines the precision of the model. And the third part (hereafter E3) refers to unsystematic errors related to the associativity between observed and assimilated datasets. In other word, the E2 indicates an explained error which reveals the variance error arising from the variability of the assimilated variables not observed in measurements. The E3 represents an unexplained error reflecting the lack of observed variability in the assimilated data.

RESULTS

To obtain the data series at the station location, the reanalysis temperature fields were interpolated at the station location-nearest grid point method, at the surface vertical model level. Daily and monthly mean cycles of observed time series (obs) versus two assimilated datasets, i.e., CAMS and REA5, are overlaid in Figure 1. The daily cycles are given by the average of the values at each hour, i.e., 00, 03, 06, 09, 12, 15, 18, and 21 UTC, over a year. Figure 1.a shows the daily variation of the temperature at the station in 2016. In this figure, the maximum and minimum of the observation are 296.14 °*K* and 288.09 °*K* that occur at the time of 12:00 and 03:00, respectively. From this figure, it appears that both reanalysis products capture the daily cycle, although they underestimate the temperature values. For instance, the maximum temperature in CAMS and REA5 are 290.81 °*K* and 287.26 °*K*, respectively. So, there is less discrepancy between CAMS and observation compared to that for ERA5. Figure 1.b illustrates the monthly mean temperature in which maximum and minimum values are associated with the month of July (7) and December (12). As can be seen in this figure, both reanalysis datasets underestimate the measured values where the maximum of 304.68 °*K* are given by 299.43 °*K* and 298.43 °*K* in CAMS and REA5, respectively. In contrast to the hourly mean, there are slightly small discrepancies between the monthlv mean of CAMS and ERA5.

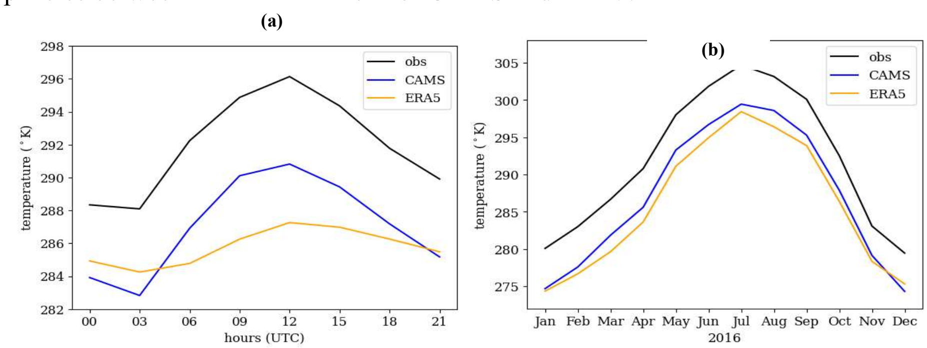

Figure1. (a) Hourly and (b) monthly average of the temperature at the station for the year 2016.

To assess the performance of the reanalysis systems, the MSE of the data series was calculated based on Eq. (2). Table 1 lists all the MSE terms of the assimilated temperature for the years 2016, 2017, and 2018. From this table, it appears that the MSE of the assimilated temperature via CAMS and REA5 systems are 27.74 and 46.63, respectively. This indicates that the overall performance of the CAMS is better than the ERA5. As can be seen in this table, in the year 2016, E1for CAMS is 24.19 which contributes to 87.22% of the MSE. And the reaming portion, 12.78%, refers to the variance error in which 0.05% and 12.73% are associated with E2 and E3, respectively. This indicates that the explained error makes only a negligible part of the MSE. A similar behavior appears for the ERA5 datasets in which E1, E2, and E3 contribute to 82.2, 0.46 and 17.34 percent of the MSE, respectively. So, in both reanalysis systems, E1 contributes to the largest portion, more than 80%, of the MSE, while the variance errors make less than 20% of that. The square root of the MSE for CAMS and ERA5 datasets are 5.27 °*K* and 6.83 °*K*, respectively. This confirms a better agreement between CAMS and measured temperature in comparison to that of ERA5. Similar patterns are found for the years 2017 and 2018 in which CAMS has lower MSE than ERA5. That reflects the robustness and consistency of these results.

Table 1. The results of the statistical evaluation metrics, including MSE and its components, i.e., E1, E2, and E3, of the assimilated temperature by the CAMS and ERA5 systems.

Years	Datasets	E1	E2	E3	MSE	$\sqrt{MSE}$
2016	CMAS	24.19 (87.22%)	0.01 (0.05%)	3.53 (12.73%)	27.74	5.27
	ERA5	38.33 (82.2%)	0.21 (0.46%)	8.09 (17.34%)	46.63	6.83
2017	CMAS	23.56 (88.28%)	0.05 (0.18%)	3.08 (11.54%)	26.68	5.16
	ERA5	38.67 (83.89%)	0.32 (0.7%)	7.1 (15.41%)	46.09	6.8
2018	CMAS	24.81 (87.63%)	0.03 (0.1%)	3.47 (12.27%)	28.32	5.32

	ERA5	39.79 (85.34%)	0.34 (0.73%)	6.49 (13.93%)	46.63	6.83

CONCLUSIONS AND DISCUSSION

This study evaluated two reanalysis data products, i.e., CAMS and ERA5, versus an in situ temperature time series. Daily and monthly cycles illustrate that both reanalysis systems underestimate the observed temperature. This result is supported by former studies as described in Section 1. A possible reason for the cold-biased assimilated temperature can be related to an altitude error of the stations located at the relatively flat or the mountain valley (Wang et al., 2014).

Less than 20% of the total error is associated with the non-systematic error. That can be due to the over-simplifications, such as linearization, turbulence closure, and representativeness. They lead to an under-fitting issue and likely a high bias and low variability in models (Hastie et al., 2008). It is noteworthy that only less than 1% of the total error arises from the explained model error; the remaining portion is attributed to the unexplained error. That can be caused by small-scale phenomena, such as cloudiness, boundary layer transition, and vertical mixing, that are not well captured in the coarse resolution models.

Despite the finer resolution of the ERA5, there was more agreement between CAMS and observed temperature than that of the ERA5. This feature could be associated with the online coupled chemistry and transport models and their interaction in CAMS.

The results of this study reveal that both assimilated temperature datasets are cold-biased. So, calibrating these data (bias correction methods) could be necessary for some studies.

ACKNOWLEGEMENT

This study has been supported by the National Vice-Presidency for science and technology affairs. The measured temperature data was obtained from the Iran Meteorological Organization. The authors would like to thank the ECMWF for providing ERA5 and CAMS reanalysis data.

REFERENCES

1. Hastie, T., Tibshirani, R., and Friedman, J.: The Elements of statistical learning, data mining, inference, and prediction. Springer Series in Statistics, 2nd edition, (2008), 764 p.

2. Hersbach, H. et al.: The ERA5 global reanalysis. 1999–2049 (2020) doi:10.1002/qj.38.

3. Huijnen, V. et al.: An intercomparison of tropospheric ozone reanalysis products from CAMS, CAMS interim, TCR-1, and TCR-2. Geosci. Model Dev. 13, 1513–1544 (2020).

4. Inness, A. et al.: The CAMS reanalysis of atmospheric composition. Atmos. Chem. Phys. 19, 3515–3556 (2019).

5. Jiao, D., Xu, N., Yang, F., and Xu, K.: Evaluation of spatial - temporal variation performance of ERA5 precipitation data in China. 1–13 (2021) doi:10.1038/s41598-021-97432-y.

6. Liu, L.: How well do the ERA-Interim, ERA-5, GLDAS-2 .1 and NCEP-R2 reanalysis datasets represent daily air temperature over the Tibetan Plateau ? 1484–1505 (2021) doi:10.1002/joc.6867.

7. Park, S. et al.: Evaluation of tropospheric ozone reanalyses with independent ozonesonde observations in East Asia. Geosci. Lett. 7, (2020).

8. Solazzo, E., and Galmarini, S.: Error apportionment for atmospheric chemistry-transport models – a new approach to model evaluation. 6263–6283 (2016) doi:10.5194/acp-16-6263-2016.

9. Wang, S. et al.: Comparison of surface air temperature derived from NCEP / DOE R2 , ERA Interim , and observations in the arid northwestern China : a consideration of altitude errors. (2014) doi:10.1007/s00704-014-1107-1.

10. Yao, L., Xia, X., and Jing, W.: Evaluation of the ERA5 Sea Surface Temperature Around the Pacific and the Atlantic. (2021), doi:10.1109/ACCESS.2021.3051642.

11. Yu, Y. et al.: Evaluation of 2-m Air Temperature and Surface Temperature from ERA5 and ERA-I Using Buoy Observations in the Arctic. (2021).

12. ECMWF, https://www.ecmwf.int/en/about/media-centre/focus/2020/fact-sheet-reanalysis.