Postprint: Application of the WQSRTP Method for Objective High and Low Temperature Forecasting in Gansu Province

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Abstract

Utilizing ECMWF high-resolution numerical weather prediction products and national-level verification station temperature observation data, the Weighted Quasi-Symmetric Rolling Training Period method (WQSRTP) was employed to generate objective intelligent grid maximum (minimum) temperature products for Gansu Province. The forecast performance of this product was evaluated and compared with the China Meteorological Administration's intelligent grid guidance forecast product (SCMOC) and Gansu Province's urban grid forecast product (SPCC). The results demonstrate that the WQSRTP correction method significantly improves the 24-hour maximum (minimum) temperature forecast capability of the ECMWF high-resolution numerical model, with forecast accuracy increasing by 32.16% and 15.48% for maximum and minimum temperatures, respectively. The WQSRTP correction product exhibits positive correction skill relative to SCMOC, SPCC, and ECMWF maximum (minimum) temperature products, and the correction capability for maximum temperature exceeds that for minimum temperature. Spatial error verification reveals that the WQSRTP correction method effectively enhances forecast accuracy for maximum (minimum) temperature in complex terrain regions such as the Qilian Mountains and Gannan-Min Mountains, substantially reducing the mean absolute error.

Full Text

Application of the WQSRTP Method in Objective Forecasting of High and Low Temperatures in Gansu Province

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Abstract

Based on ECMWF fine-grid numerical prediction products and temperature observation data from national assessment stations, the Weighted Quasi-symmetric Running Training Period (WQSRTP) method was used to generate objective maximum (minimum) temperature products for the intelligent grid in Gansu Province. The forecast performance of these products was evaluated and compared with the China Meteorological Administration's intelligent grid guidance forecast product (SCMOC) and Gansu Province's urban grid forecast product (SPCC). The results show that the WQSRTP correction method can significantly improve the forecasting capability for maximum (minimum) temperature. The forecast accuracy of WQSRTP maximum and minimum temperature products increased by 32.16% and 15.48% respectively compared to ECMWF. The WQSRTP correction products show positive correction skills relative to SCMOC, SPCC, and ECMWF maximum (minimum) temperature products, and the correction capability for maximum temperature is better than that for minimum temperature. The WQSRTP correction method can effectively improve the forecast accuracy of maximum (minimum) temperature in complex terrain areas such as the Qilian Mountains and the Gannan-Min Mountains, and significantly reduce the mean absolute error.

Keywords: high and low temperature forecasting; correction skill; accuracy; Gansu

Introduction

Temperature forecasting is an important component of refined forecast products and is one of the key forecast elements focused on by the government and the public. Improving the refined forecasting level of temperature is a demand for refined weather forecasting services in many industries []. Intelligent grid forecasting business has emerged under the requirements of modern meteorological operations, with objective quantification being its notable characteristic []. The China Meteorological Administration's "Meteorological Forecasting Business Development Plan (2016-2020)" points out that meteorological forecasting business should always aim at improving forecast accuracy as the core goal. Therefore, when intelligent grid forecasting products achieve high spatial and temporal resolution, the improvement of forecast accuracy is equally important. The accuracy of intelligent grid forecasting products depends on one hand on the development of numerical forecasting models, and on the other hand on the research and development of techniques for interpreting numerical forecasting model products. Under the condition of stable numerical weather forecasting capability, in-depth development of model product interpretation technology is an effective way to improve forecast accuracy.

In recent years, many scholars have conducted numerous explorations in the interpretation of temperature numerical model forecasting products. To eliminate systematic biases in model forecasts, scholars have proposed Model Output Statistics (MOS) [], Kalman filtering methods [], analog methods [], and machine learning methods [] to correct numerical model forecast biases and improve the accuracy of forecast results. Different scholars have studied the applicability of these methods for temperature correction in different regions. For example, research on objective correction methods for daily maximum and minimum temperatures in Shaanxi Province found that the simple linear regression algorithm works well for daily maximum temperature correction, while the decaying averaging algorithm works well for daily minimum temperature correction []. The quasi-symmetric sliding training period correction method can effectively improve the forecast accuracy of daily maximum and minimum temperatures in Shandong Province, and the bias sliding correction algorithm has good correction effects on the central Shandong mountainous area and national assessment stations within 72 hours []. In Jiangxi Province, the sliding dual-weighted average correction method can effectively correct model errors and improve forecast accuracy, while the spatial error gradual correction method can compensate for the instability of the sliding dual-weighted average correction method during seasonal transition periods []. In addition, some scholars have proposed effective methods to improve temperature accuracy based on numerical model error characteristics. For instance, Cai Ninghao et al. [] incorporated historical average errors, initial field errors, and Kalman filter inversion errors of numerical model forecast maximum and minimum temperatures into the correction method and found that forecast accuracy improved significantly, outperforming both the Central Meteorological Observatory's guidance product and the forecaster's subjectively corrected urban grid forecast product. Liu Xinwei et al. [] used wavelet analysis methods to incorporate numerical model forecast errors into the correction of the Central Meteorological Observatory's guidance product, effectively improving the accuracy of maximum and minimum temperature forecasts in Gansu Province.

To effectively improve MOS correction methods, scholars have also explored optimal training periods for temperature correction. For example, Wu Qishu et al. [] found through designing different training period comparison schemes that the optimal training days for maximum and minimum temperatures are 30 days, and symmetric mixed sliding training periods can obtain better correction results. In recent years, with the development of China's multi-source fusion actual products [], research on intelligent grid temperature correction methods using multi-source fusion actual products as the background field has achieved good correction results. Zeng Xiaoqing et al. [] used multiple different error regression correction methods to correct temperature forecast products, and the results showed that the sliding error regression method is optimal for short-term forecasts.

Gansu Province has complex topography and landforms, with significant regional climate differences, large biases in numerical model temperature forecast products, making temperature forecasting difficult and forecast accuracy low []. To meet the needs of intelligent grid business, Lanzhou Central Meteorological Observatory has developed targeted temperature objective correction technology in recent years, which has improved model forecast effects. However, forecast accuracy in relatively complex terrain areas remains low and still cannot meet actual forecasting business needs. Therefore, this paper uses the Weighted Quasi-symmetric Running Training Period method (WQSRTP) to correct ECMWF maximum and minimum temperature forecast products commonly used in business, aiming to provide technical support for intelligent grid temperature forecasting business under complex terrain conditions, and further improve Gansu Province's high and low temperature forecasting service capabilities, laying a foundation for objective forecasting to replace subjective forecasting.

1. Data and Methods

1.1 Data Sources and Processing

The observed temperature data used were daily maximum and minimum temperature observations from 70 national assessment stations in Gansu Province (Fig. 1). Numerical forecast data included the China Meteorological Administration's intelligent grid guidance forecast product (SCMOC) and the European Centre for Medium-range Weather Forecasts (ECMWF) maximum and minimum temperature grid forecast products, both with a horizontal resolution of 0.125°$×0.125°. The forecast products were issued at 08:00 Beijing time with a forecast period of 0−240 hours. The Gansu Province urban grid forecast product (SPCC) ha
with a forecast period of 0-24 hours. The training samples used data from 2018-2020, while the verification samples used data from 2021. The ECMWF maximum and minimum temperature forecast products were processed into daily maximum and minimum temperature products using the daily maximum/minimum value method. The grid forecast products were interpolated to stations using the neighborhood method, which selects the grid point closest to the station as the station forecast. When multiple grid points have equal distance, the northeast corner grid point is selected.

1.2 Research Methods

1.2.1 WQSRTP Method The WQSRTP method uses a quasi-symmetric sliding training period [], sliding sequentially to select n days before the forecast day in the current year and n days after the forecast day in the previous year as training sample data. Based on the weighted linear regression method, a forecast model for ECMWF maximum and minimum temperatures is established for each station. Using the weighted linear regression method, the t-time forecast value and the t-time observed actual value are weighted linearly regressed (formula), resulting in a weighted linear regression model. According to the model, forecasts are made to obtain corrected results. In the formula, aYt + 't is the t-time corrected value ( ); Yt is the t-time model forecast value ( ); a is the regression coefficient; b is the constant term ( ). Using the quasi-symmetric sliding training period, the forecast values and observed actual values at different times within the training period are used to fit a and b using the least squares method, minimizing the objective function value (formula). In the formula, wi is the i-th weighting coefficient, determined by the distance of the sample date from the forecast day and the same period forecast day. Samples closer to the forecast day or the same period forecast day are given higher weights, and vice versa. The weight distribution is shown in Fig. 2.

1.2.2 Verification Methods

1) Forecast Accuracy The forecast accuracy rate is calculated as: Nt × 100%, where Fa is the percentage of samples with temperature forecast errors not exceeding 2°C; Na is the number of samples with errors not exceeding 2°C; and Nt is the total number of forecast samples.
2) Root Mean Square Error and Mean Absolute Error RMSE = MAE = 1N i |Oi - , where RMSE is the root mean square error; MAE is the mean absolute error; N is the number of forecasts; Oi is the observed value at the i-th station; and Pi is the predicted value at the i-th station.
3) Forecast Skill The forecast skill score is calculated as: mean - meanf × 100%, where Fss is the forecast skill score; mean is the MAE of SCMOC maximum/minimum temperature; and meanf is the MAE of ECMWF maximum/minimum temperature.

2. Results

2.1 Assessment Station Verification Results

The ECMWF fine-grid maximum and minimum temperature forecast products were interpolated to stations, and the WQSRTP method was used to correct the maximum and minimum temperatures at each station, obtaining corrected maximum and minimum temperature products for each station. A comparative analysis was conducted on the forecast results of the four products (SCMOC, ECMWF, WQSRTP, SPCC) at 70 national assessment stations during the above time period.

All four forecast products have certain forecast capabilities for maximum and minimum temperatures at the 70 national assessment stations (Table 1). As the forecast lead time increases, forecast accuracy gradually decreases, and both RMSE and MAE gradually increase. The WQSRTP corrected product shows significantly better forecast performance than the other three products. The forecast accuracy for maximum temperature is 65.74%-72.76%, which is 20.12%, 25.52%, and 32.16% higher than SCMOC, SPCC, and ECMWF products, respectively. The forecast accuracy for minimum temperature is 62.94%-69.37%, which is 14.76%, 15.48%, and 13.51% higher than the other three products, respectively. The maximum temperature forecast performance is better than the minimum temperature forecast performance.

To better understand the forecast capabilities of the four products in different months, Fig. 3 shows the monthly average forecast accuracy of maximum and minimum temperatures for the four forecast products at 24 h, 48 h, and 72 h. The monthly average forecast accuracy of WQSRTP corrected maximum and minimum temperature products is higher than the other three products in all months, with a slight decrease in forecast accuracy as forecast lead time increases. From the perspective of monthly forecast accuracy for maximum temperature, the inter-monthly variation is relatively insignificant for WQSRTP, while it is more significant for the other three products. The maximum values of forecast accuracy for WQSRTP and SCMOC maximum temperature products appear in August-September, at 80.04% and 68.72%, respectively, while the minimum values appear in December-January, at 54.68% and 36.64%, respectively. The forecast accuracy of ECMWF and SPCC maximum temperature products is 53.89%-62.88% and 44.85%-47.20%, respectively. From the monthly forecast accuracy distribution of minimum temperature, the inter-monthly variation is more significant, being higher in August-September and lower in December-January of the following year. The forecast accuracy of WQSRTP minimum temperature is 55.44%-81.17%, which is significantly higher than the other three forecast products. The maximum temperature forecast accuracy is relatively higher in summer, while the minimum temperature forecast accuracy is relatively higher in winter.

To more intuitively understand the correction effect of WQSRTP products, Table 2 shows the correction skills of WQSRTP corrected products relative to the other three products for maximum and minimum temperature forecasts at different lead times. It can be seen that within different lead times, WQSRTP corrected products show positive correction skills relative to ECMWF and SCMOC maximum and minimum temperature forecast products, indicating that WQSRTP corrected products have obvious advantages over the other three maximum and minimum temperature products, and the correction effect for maximum temperature is better than that for minimum temperature. As forecast lead time increases, the correction skill for maximum temperature increases, while the correction skill for minimum temperature decreases. Within different lead times, WQSRTP corrected products show the highest correction skill relative to ECMWF maximum and minimum temperature products, with the correction skill for maximum temperature being 42.84%-43.65% and for minimum temperature being 24.33%-30.26%. The correction skill relative to SCMOC products is slightly lower.

Fig. 4 shows the monthly MAE distribution of maximum and minimum temperatures for the four forecast products at 24 h, 48 h, and 72 h. Within different lead times, the MAE of WQSRTP maximum and minimum temperature forecast products is significantly lower than that of the other three products. The MAE for maximum temperature is 1.9-2.4°C, which is reduced by more than 0.61°C compared to the other three products. The MAE for minimum temperature is 1.2-1.9°C, which is reduced by more than 0.79°C compared to the other three products. The MAE of SPCC forecast products is the smallest, but it should be noted that SPCC products only have a 24 h forecast period.

2.2 Spatial Error Distribution

From the above analysis, it can be found that WQSRTP has the best forecast effect among the four products (Fig.). Therefore, further analysis was conducted on the spatial distribution of forecast accuracy and MAE of the four products for temperature in Gansu Province to more intuitively understand their forecast capabilities.

The 24 h maximum temperature forecast accuracy of the four products shows that WQSRTP maximum temperature forecast accuracy is above 60% in most areas of the province, especially above 80% in the eastern part of the Gannan-Min Mountains, but below 60% at individual stations in western Gannan Prefecture and southeastern Longnan. The minimum temperature forecast accuracy is above 60% in most of the province, with improvements above 80% in some areas of the Gannan-Min Mountains. Compared with SPCC, the accuracy of maximum and minimum temperatures of WQSRTP products has improved in most areas of the province, with maximum temperature accuracy improving significantly in the eastern Qilian Mountains and parts of the Gannan-Min Mountains, with only individual stations in southeastern Longnan showing negative correction effects. The improvement range of minimum temperature forecast accuracy is smaller than that of maximum temperature accuracy.

Compared with ECMWF, the WQSRTP correction product improves temperature forecast accuracy by more than 20% in some areas, with individual stations reaching 40%. The improvement is more significant in the complex terrain areas of the Gannan-Min Mountains and Qilian Mountains. The WQSRTP maximum temperature correction product has higher forecast accuracy in the Hexi region of Gansu Province than in the Hedong region, while the minimum temperature correction product shows the opposite pattern. The large value areas with maximum temperature forecast accuracy above 70% are mainly distributed in the Hexi region, while the forecast accuracy is relatively low in the Gannan-Min Mountains and parts of southeastern Longnan. The large value areas with minimum temperature forecast accuracy above 70% are mainly distributed in the central Hexi region and parts of the Hedong region, with relatively low forecast accuracy in the eastern Gannan-Min Mountains.

The spatial distribution of 24 h maximum temperature MAE for the four products shows that the MAE of WQSRTP maximum and minimum temperature products is less than 2.5°C in most areas of the province, which is significantly lower than the other three products. The MAE of ECMWF maximum temperature products is above 3.0°C in most areas of the province, with some stations above 4.0°C. The MAE of WQSRTP maximum temperature products is less than 2.0°C at 93.52% of stations, and the MAE of minimum temperature products is less than 2.0°C at 85.29% of stations. Some stations in the Gannan-Min Mountains have MAE above 3.0°C. Compared with SPCC, the MAE of WQSRTP maximum and minimum temperature correction products is smaller at 90.88% and 86.47% of stations, respectively, with the difference being less than 0.1°C. Compared with ECMWF, the MAE of WQSRTP products is significantly reduced, especially in the complex terrain areas of the Qilian Mountains and Gannan-Min Mountains, with some stations showing reductions above 1.5°C, indicating that the WQSRTP correction product has more significant correction effects in complex terrain areas.

In summary, WQSRTP correction products significantly improve temperature forecasting capabilities in Gansu Province, especially in the Qilian Mountains and Gannan-Min Mountains where model temperature products have large forecast biases and low accuracy. The correction effect for maximum temperature is better than that for minimum temperature. Additionally, in some areas of southeastern Longnan where the correction effect of WQSRTP products is relatively poor compared to SPCC products, targeted correction technology research needs to be continuously conducted to improve temperature forecast accuracy.

3 Discussion

The WQSRTP method effectively achieves the goal of improving the forecast accuracy of maximum and minimum temperatures in Gansu Province, with significant improvements in forecast accuracy in most areas and obvious reductions in MAE. However, there are still individual stations with relatively low forecast accuracy. The WQSRTP method implements the idea of forecasters' daily operational forecast bias correction through weighted linear regression, transforming the simple linear regression in the MOS method into weighted linear regression. All stations in the WQSRTP method use a quasi-symmetric sliding training period of 30 days, which is related to the optimal training days proposed by Wu Qishu et al. []. To further improve forecast accuracy, the next step could involve adjusting the length of the quasi-symmetric sliding training period for different stations in Gansu Province.

Compared with the temperature objective correction product for Gansu Province generated by Liu Xinwei et al. [] based on the wavelet low-frequency period moving average correction method for ECMWF fine-grid temperature numerical forecast products, the WQSRTP maximum temperature correction product has higher accuracy in most areas of Gansu Province, while the minimum temperature correction product has higher accuracy in the complex terrain areas of the Gannan-Min Mountains and Qilian Mountains, indicating that different objective correction methods have different correction capabilities for the same numerical forecast product. The forecast accuracy of WQSRTP corrected products decreases less with increasing lead time compared with Wu Qishu et al. [], demonstrating certain advantages of the WQSRTP method. The fact that the corrected temperature forecast accuracy in Fujian Province by the WQSRTP method is higher than that in Gansu Province is closely related to the forecast performance of numerical model products in different regions, fully illustrating that objective correction methods can only correct numerical forecast biases to a limited extent.

In recent years, domestic numerical models have developed rapidly and the forecasting system has been continuously improved []. This paper does not conduct correction analysis on domestic numerical model products, but subsequent work could compare and analyze the differences in correction capabilities of the same correction method for different model forecast products in the same region. With the continuous development of numerical model products and objective correction methods, research on integration methods for multiple correction products has made some progress []. It is also possible to optimally integrate numerical model temperature forecast products corrected by different methods to improve the level of objective forecast fusion applications and further enhance temperature forecast accuracy.

4 Conclusions

To address the problem of low accuracy of numerical model temperature forecasts under complex terrain conditions in Gansu Province, this study developed a WQSRTP correction technique for maximum and minimum temperatures at national assessment stations in Gansu Province based on commonly used ECMWF maximum and minimum temperature numerical forecast products in operational business, generated corresponding objective forecast products, and compared them with SCMOC, SPCC, and ECMWF forecast products. The main conclusions are as follows:

1) The WQSRTP correction products have certain forecast capabilities for maximum and minimum temperatures at national assessment stations in Gansu Province. However, as the forecast lead time increases, forecast accuracy gradually decreases, and both RMSE and MAE gradually increase. The WQSRTP correction method can effectively improve the accuracy of objective temperature forecasts, with the 24 h maximum and minimum temperature forecast accuracy increasing by 32.16% and 15.48% respectively compared to ECMWF fine-grid forecast products. The WQSRTP products show positive skills relative to the other three maximum and minimum temperature forecast products, with the correction skill for maximum temperature being higher than that for minimum temperature.
2) The monthly average forecast accuracy of the four products shows no obvious inter-monthly variation for maximum temperature, while the inter-monthly variation for minimum temperature forecast accuracy is more significant, being higher in August-September and lower in December-January of the following year. The monthly forecast accuracy of WQSRTP products is the highest among the four products in all months, and the decrease in forecast accuracy with increasing lead time is relatively small.

3) The spatial error distribution shows that ECMWF fine-grid maximum and minimum temperature products have large forecast biases and low accuracy in the complex terrain areas of the Qilian Mountains and Gannan-Min Mountains. The WQSRTP correction products significantly improve the forecast accuracy of maximum and minimum temperatures in these areas, effectively reducing MAE, with the correction effect for maximum temperature being better than that for minimum temperature.

References

[] Jiao Meiyan. Modernization process of weather forecast[J]. Meteorological Monthly, 2010, 36(7): 1-4.

[] Jin Ronghua, Dai Kan, Zhao Ruixia, et al. Progress and challenge of seamless fine gridded weather forecasting technology in China[J]. Meteorological Monthly, 2019, 45(4): 445-457.

[] Wei Qing, Dai Kan, Lin Jian, et al. Evaluation on the 2016-2018 fine gridded precipitation and temperature forecasting[J]. Meteorological Monthly, 2020, 46(10): 1272-1285.

[] Zhao Bin, Zhang Bo. Application of a bias correction scheme for 2-meter temperature levels over complex terrain[J]. Transactions of Atmospheric Sciences, 2018, 41(5): 657-667.

[] Liu Huanzhu, Zhao Shengrong, Lu Zhishan, et al. Objective element forecasts at NMC——a MOS system[J]. Journal of Applied Meteorological Science, 2004, 15(2): 181-191.

[] Tong Hua, Guo Pinwen, Zhu Yuejian, et al. Bias correction and statistical downscaling meteorological parameters forecast technique based on large scale numerical model products[J]. Meteorological Monthly, 2014, 40(1): 66-75.

[] Zhi Xiefei, Huang Wen. Multimodel ensemble forecasts of surface air temperature and precipitation over China by using Kalman filter[J]. Transactions of Atmospheric Sciences, 2019, 42(2): 197-206.

[] Cai Ninghao, Yu Jianwei. Temperature forecasting method based on numerical model bias analysis[J]. Transactions of Atmospheric Sciences, 2019, 42(6): 864-873.

[] Liu Xinwei, Duan Bolong, Huang Wubin, et al. Application of objective prediction method based on wavelet analysis in intelligent grid high and low temperature prediction[J]. Transactions of Atmospheric Sciences, 2020, 43(3): 577-584.

[] Wu Qishu, Han Mei, Guo Hong, et al. The optimal training period scheme of MOS temperature forecast[J]. Journal of Applied Meteorological Science, 2016, 27(4): 426-434.

[] Liu Xinwei, Liu Na, Duan Mingkeng, et al. Test and evaluation of northwest intelligent grid temperature objective prediction method based on wavelet analysis[J]. Transactions of Atmospheric Sciences, 2020, 43(4): 673-686.

[] Li Haochen, Yu Chen, Xia Jiangjiang, et al. A model output machine learning method for grid temperature forecasts in the Beijing Area[J]. Advances in Atmospheric Sciences, 2019, 36(10): 1156-1170.

[] Shi Chunxiang, Pan Yang, Gu Junxia, et al. A review of multi source meteorological data fusion products[J]. Acta Meteorological Sinica, 2019, 77(4): 774-783.

[] Chen Yuwen, Huang Xiaomeng, Li Yi, et al. Ensemble learning for bias correction of station temperature forecast based on ECMWF products[J]. Journal of Applied Meteorological Science, 2020, 31(4): 494-503.

[] Zeng Xiaoqing, Xue Feng, Zhao Ruixia, et al. Comparison study on several grid temperature rolling correction forecasting schemes[J]. Meteorological Monthly, 2019, 45(7): 1009-1018.

[] Zhi Xiefei, Wang Tian, Ji Yan. Multimodel ensemble forecasts of surface air temperature over China based on deep learning approach[J]. Transactions of Atmospheric Sciences, 2020, 43(3): 435-446.

[] Shen Xueshun, Wang Jianjie, Li Zechun, et al. China's independent and innovative development of numerical weather prediction[J]. Acta Meteorological Sinica, 2020, 78(3): 451-476.

[] Glahn H R, Lowry D A. The use of model output statistics (MOS) in objective weather forecasting[J]. Journal of Applied Meteorology and Climatology, 1972, 11(8): 1203-1211.

[] Wang Dan, Wang Jianpeng, Bai Qingmei, et al. Comparative correction of air temperature forecast from ECMWF model by the decaying averaging and the simple linear regression methods[J]. Meteorological Monthly, 2019, 45(9): 1310-1321.

[] Zhang Hongli, Han Fuqiang, Zhang Liang, et al. Analysis of spatial and seasonal variations in climate warming and humidification in Northwest China[J]. Arid Zone Research, 2023, 40(4): 517-531.

[] Yang Weitao, Sun Jianguo, Ma Hengli, et al. A multi scale integrated classification method for landforms[J]. Arid Zone Research, 2022, 39(2): 638-645.

[] Zhou Hai, Qin Hao, Ji Luying, et al. Research progresses of multimodel ensemble forecast of surface meteorological elements[J]. Transactions of Atmospheric Sciences, 2022, 45(6): 815-825.

[] Tong Hua, Zhang Yutao, Qi Qianqian, et al. The multi model blending forecasts of near surface parameters based on CMA model system[J]. Meteorological Monthly, 2022, 48(12): 1539-1549.

Note: Figure translations are in progress. See original paper for figures.