

MODEL VALIDATION USING A DIAGRAM COMPARING OBSERVED AND SIMULATED TIDES AND TIDAL CURRENT ELLIPSES IN TOKYO BAY

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INTRODUCTION

Numerous regional models have been developed to provide information on ocean conditions, such as temperature, salinity, and currents for the coastal engineering design, aquaculture, and oil spill prediction. Model validation through comparisons between observed and simulated tides is necessary, because tides are relatively dominant and tidal currents affect the vertical mixing. We investigate the usefulness of a diagram (Tsubono, 2022) similar to the Taylor diagram (Taylor, 2001), which shows the amplitudes and phases of observed and simulated tidal constituents simultaneously with the complex distance in terms of the root mean square difference and the correlation coefficient between the two time-series, to evaluate the model performance for reproducing tides and tidal currents in , for example, Tokyo Bay.

MODEL AND OBSERVED DATA

The Regional Ocean Modeling System (ROMS) was used to simulate tides and tidal currents in Tokyo Bay. The model domain covered Tokyo Bay (Figure 1) with zonal and meridional resolutions of $1/240^\circ$ and 20 vertical layers. To validate the simulated tides, we used the hourly tidal heights recorded at seven tide gauges (0, Kurihama; 1, Yokosuka; 2, Daini-Kaiho; 3, Yokohama; 4, Kaihin; 5, Tokyo; 6, Chiba in Figure 1) in Tokyo Bay, which were obtained from the Japan Oceanographic Data Center website. The tidal harmonic constants (M2, S2, N2, K2, K1, O1, P1, and Q1) were calculated from the one-year time series of observed and simulated tidal levels at all tide gauges in 2020, with the phase of the constants from 2020/01/01/0:00 (JST).

The time series of the observations or the model tide are calculated from the harmonic constants as follows:

$$Z_{o_k}^j = A_{o_k}^j \exp(i \theta_{o_k}^j), \quad Z_{m_k}^j = A_{m_k}^j \exp(i \theta_{m_k}^j),$$

$$z_o(t)^j = \text{Re}(Z_{o_k}^j) \cos \omega t + \text{Im}(Z_{o_k}^j) \sin \omega t, \quad (1)$$

$$z_m(t)^j = \text{Re}(Z_{m_k}^j) \cos \omega t + \text{Im}(Z_{m_k}^j) \sin \omega t.$$

where $A_{o_k}^j$ and $A_{m_k}^j$ are the amplitudes and $\theta_{o_k}^j$ and $\theta_{m_k}^j$ are the phases of constituent j (M2, ..., Q1) at the k -th gauge in the observation (o) and model (m), respectively, i is the imaginary number $\sqrt{-1}$ and $\text{Re}(Z)$ and $\text{Im}(Z)$ are the real and imaginary parts of Z .

We also used current data recorded at Chiba (gauge 6 in Figure 1) and compared the tidal currents between the observation and the model with the diagram.

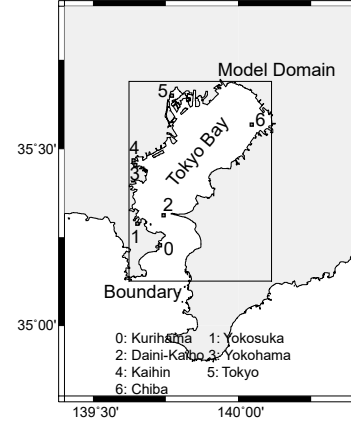


Figure 1 - The domain of the model and the locations of the seven tide gauges in the Bay of Tokyo.

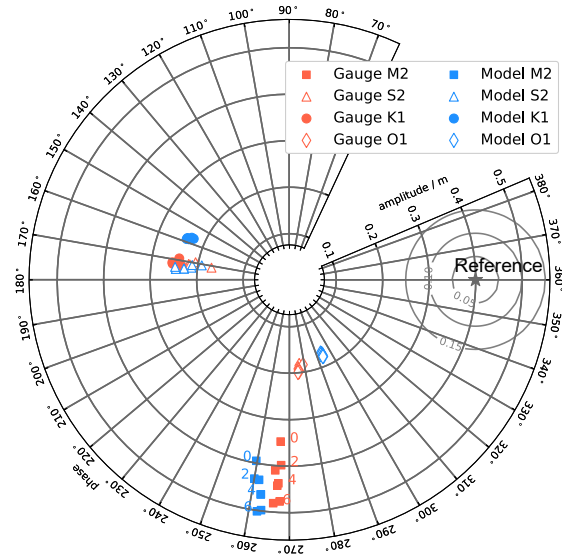


Figure 2 - Comparison of tidal harmonic constants M2, S2, K1, and O1 between observed and simulated tides in Tokyo. The orange symbols represent the observed constants, and the blue symbols represent the simulated constants.

TIDES USING DIAGRAM

Figure 2 shows a diagram of the M2, S2, K1, and O1 harmonic constants at the seven gauges in Tokyo Bay. On the diagram, the radial distance represents the amplitude of the constituent, and the angle between the observed and simulated constituents represents the phase lag $\Delta\theta$. The circular arcs and radial lines represent iso-magnitudes of the amplitudes and phases, respectively. Radial lines with negative and positive angles relative to

the observed constants indicate whether the simulated tides precede or follow the observation, respectively. The Pearson correlation coefficient (R) is calculated using the phase lag as $R = \cos \Delta\theta$. The simulated phases of the M2, K1, and O1 constituents show shifts of about 5° to 10° from the observed phases, implying an R value of 0.996 to 0.985 between the observed and simulated time series; the simulated peaks of M2 and K1 are slightly earlier, and that of O1 is slightly later, compared to their observed peaks. In contrast, the peak of S2 is almost the same in the observed and model. The three contours (concentric circles) around the reference point (black star) show the complex distances of 0.05, 0.1 and 0.15 m, which are the distances of the tidal harmonic constant of the model from the observation. The distance of the tidal harmonic constant between the model and the observations is between 0.05 and 0.1 m. By comparing the complex distance $\Delta Z (= |Z_{o_k}^j - Z_{m_k}^j|)$ with these contours, the model performance for this tide can be evaluated, because the distance is a function of the RMSD: $\Delta Z = \sqrt{2} \text{RMSD}$.

A diagram (not shown here) for the harmonic constants normalized to the constant at the Chiba gauge, which is in the innermost part of the Tokyo Bay, shows the following: the observed phases are nearly the same at all gauges, while the simulated phases lag from the mouth to the inner part; the observed and model amplitudes increase from the mouth to the inner part, indicating the standing wave. Except for the 0; Kurihama and 2; Daini-Kaiho gauges near the bay mouth, the normalized harmonic constants are clustered. The results showed that the simulated tides near the bay mouth differed from the observed ones because the boundary conditions set near the bay mouth affected the node of the simulated standing wave there, although the tides in the inner part were in good agreement with the observations.

TIDAL CURRENT ELIPSES

The semi-major axes (MA) of the simulated and observed M2 tidal current ellipses at Gauge 6 (Chiba) were compared using a diagram plotting the clockwise and counterclockwise vectors (CV and CCV) and MA (Figure 3). The magnitudes of simulated and observed CV and CCV were almost identical, indicating that both tidal current ellipses become a simple harmonic oscillation rather than elliptical. The observed MA (2.1cm/s) was smaller than the simulated MA (3.1cm/s) and rotated about 15° clockwise. In Fig. 3, the simulated CCV and CV are plotted when the observed CCV and CV overlap, that is, when the observed M2 velocity is equal to the magnitude of the MA. The simulated CCV and CV are 26.2° (pink dotted line in Fig. 3) behind the simulated MA. The 26.2° inclination gap between the CCV and MA, or the CV and MA, corresponds to the phase lag of the model from the observation. This means that the simulated peak occurred 26° later than the observed. Thus, not only the magnitude and inclination of the MA but also the shape of the tidal current ellipse and the phase lag of the harmonic constant for the MA constituent between the observation and the model are shown on the MA diagram (Fig. 3) by plotting the CCV and CV.

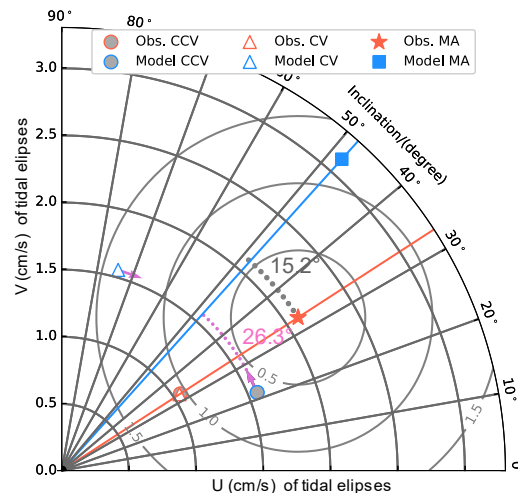


Figure 3 - Semi-major axes (MA) of tidal ellipses of observed and simulated M2 tidal currents.

CONCLUSIONS

In this study, the model performance for tides and tidal currents in Tokyo Bay was investigated using a diagram that shows the amplitude and phase of the observed and simulated tidal constituents. The diagram also shows the complex distance in terms of the RMSD and correlation coefficient between the time series of the observed and simulated tidal constituents. The diagrams illustrated the improvement in the phase and amplitude of the tidal level for the K1 and O1 constituents. The harmonic constants normalized to the tidal harmonic constant at the innermost gauge were plotted on a diagram to investigate whether the model reproduced the standing wave of the tide in Tokyo Bay. The diagram displaying the semi-major axes (MA) of the tidal ellipses and the radii of the counterclockwise and clockwise vectors was able to show the phase lag of the MA constituent between the observation and the model as the angular gap between the simulated MA and CCV, or MA and CV, when the observed CCV and CV overlap.

ACKNOWLEDGMENTS

Python codes for the diagrams plotting the constants of tides and tidal ellipses in this study can be accessed at https://github.com/takakitsubono/APAC2023_demo.

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