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# Tub Toys Orbit the Pacific Subarctic Gyre

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In 1992, a cargo container of children's bath toys fell overboard in the middle North Pacific Ocean. Subsequently, 29,000 toys were tracked 4,000 kilometers to southeastern Alaska [*Ebbesmeyer and Ingraham,* 1994]. The spill's upcoming fifteenth anniversary has prompted an examination of the reports of toys stranded on shorelines around the Subarctic Gyre, a planetary vortex the size of the United States.

Previous articles have reported the drift of sneakers and toys for a year or so only along the southern edge of the Pacific Subarctic Gyre [*Ebbesmeyer and Ingraham,* 1992, 1994]. However, continuing reports of stranded toys have stimulated curiosity about how long it would take the currents that link the Gyre's perimeter between Asia and America to transfer flotsam around the Gyre, that is, its orbital period. These currents (Figure 1) are the North Pacific Drift Current, Alaska Current/Alaska Coastal Current, Alaskan Stream, Bering Slope Current and East Kamchatka Current, Oyashio Current, and Kuroshio. In the Bering Sea, the North Aleutian Current recurves north from Attu Island eastward along the north side of the Aleutians to merge with the Bering Slope Current.

This study supplements the toy sightings with those of other drifters [sandals, pumice, messages in bottles (MIBs)] and sequential measurements made over many years at two sites (water properties and computer drifters).

The new concept of being able to estimate the orbital period of a large gyre evolved from beachcombing and computer drift simulation, to confirmation with spectra. The orbital estimates from flotsam have been combined with those from water properties because the Gyre can be considered to be composed of discrete slabs of water resembling invisible tabular icebergs, each with differing temperature and salinity.

By C. C. Ebbesmeyer, W. J. Ingraham Jr., T. C. Royer, and C. E. Grosch

## *Sneakers, Toys, and Other Sources of Data*

Several items with the ability to float for long periods of time have been accidentally or purposefully released into the subarctic gyre. A container ship lost 80,000 Nike sneakers on 27 May 1990 at 48°N, 161°W (Figure 1). Each sneaker carried a unique code traceable to the originating container [*Ebbesmeyer and Ingraham,* 1992]. Media and beachcombers provided data on 2.5% of the lost sneakers. On 10 January 1992, 28,800 plastic turtles, ducks, beavers, and frogs, each of unique design, fell overboard from another container ship (44°N, 178°E; Figure 1). During August–September 1992, thousands of these items beached near Sitka, Alaska. During 1993–2005, beachcombers Dean and Tyler Orbison recovered 124 toys in the vicinity of Sitka (35% ducks, 26% beavers, 21% frogs, 18% turtles). The number of toys reported totaled 3.3% of those spilled, about the same as for the sneakers. On 22 January 2000, a cargo box with 10,224 Nike Baby Sunray II sandals with traceable codes went overboard up-current from the toy spill (47°N, 170°E). In June 2001 and June 2005, beachcomber L. Hanko reported 10 sandals on Kodiak Island, Alaska.

At Ocean Weather Station P (OWSP) located in the Gulf of Alaska (50°N, 145°W), oceanographers released 19,449 scientific forms in 12-ounce brown beer bottles during 1956–1959 [*Hollister and Dodimead,* 1962]. The final report of this study included recoveries as of 1962. An office copy of the final report listed 97 additional recoveries as of 1972.

On 6 June 1912, Mt Katmai erupted pumice into Shelikov Strait near Kodiak Island, Alaska. During 15–22 August 1914, a local newspaper reported odd-colored pumice covering the beaches in the Queen Charlotte Islands in British Columbia, Canada [*Queen Charlotte Islander,* 1914].

Windage, the effect of winds blowing directly on the drifters, was negligible on all of these items. For a quarter of the first orbit, the toys floated with substantial windage, but thereafter during multiple orbits the toys developed leaks and their specific gravity kept them barely afloat. The sandals floated upside down with their soles scarcely exposed, waterlogged pumice floated normally, and OWSP MIBs

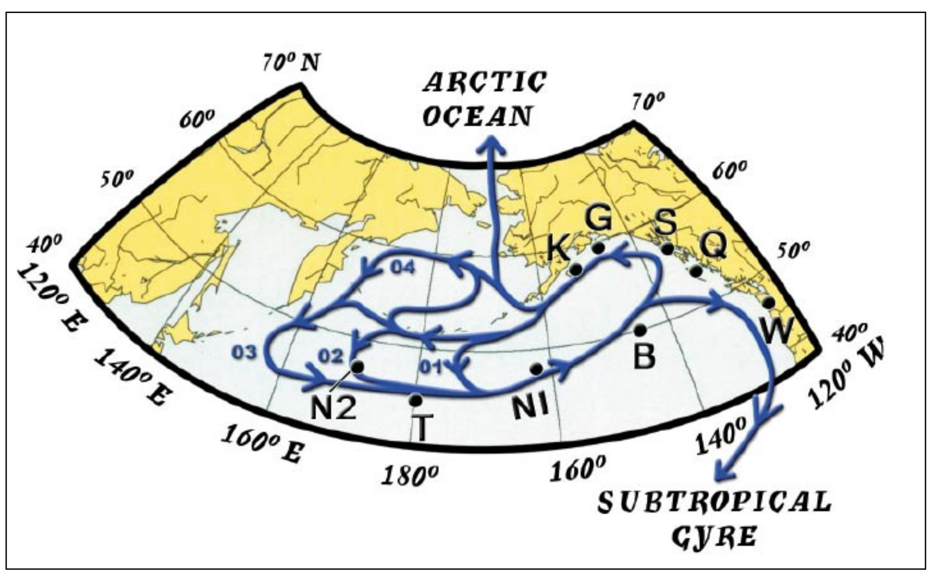


*Fig. 1. Orbits of the Subarctic Gyre derived from the Ocean Surface Current Simulator (OSCURS) computer program. Toys exit into the Arctic Ocean and the Subtropical Gyre (as evidenced by toys found in Washington state). Legend: B, drifters released at Ocean Weather Station P; G, temperature and salinity measurements; K, sandals at Kodiak and Katmai eruption; N1, 1990 sneaker spill; N2, sandals spilled in 2000; O1–O4, orbits 1–4; Q, toys in the Queen Charlotte Islands; S, toys at Sitka; T, 1992 toy spill; and W, toys in Washington.*

drifted on their sides mostly submerged [*Dodimead and Hollister,* 1958].

*Simulating the Movement of Drifters*

The computer program Ocean Surface Current Simulator (OSCURS) was used to generate trajectories of the toys and sandals. OSCURS calculates currents by adding the long-term geostrophic mean currents to those on a 90-kilometer grid over the North Pacific and Bering Sea calculated by applying empirical functions to sea level atmospheric pressure grids [*Ingraham et al.,* 1998]. In OSCURS simulations, 70 toys were released on the computer at the time and date of the spill and subsequently tracked day by day for 11.5 years (10 January 1992 to 19 July 2003). Positions of the toys were animated with video frames 10 days apart.

Temperature and salinity were measured several times annually during 35 years in the upper 100 meters at the mouth of Resurrection Bay, Alaska (1970–2005; 59.8°N, 149.5°W [*Royer,* 2005]). In OSCURS simulations, drifters were released at OWSP and tracked for 90 days during each winter since 1901 (1 December through 28 February; Figure 1). The end-point latitudes of the trajectories formed the OWSP time series used herein (designated PTI for OWSP Trajectory Index). The periods listed in Table 1 are averages of spectral peaks from the Lomb method and the maximum entropy method if both exceeded their 95% confidence limits [*Sarkar et al.,* 2005].

Low oceanic diffusion (1%) initially kept the group of toys together (from the spill to Sitka), which allowed calibration of OSCURS for initial toy windage and the strandings at Sitka. As time progressed and diffusion near the coast, with its more complex circulation than the offshore ocean, increased, several possible paths for portions of the group became evident with the OSCURS runs.

| Table 1. Orbital Periods of the Pacific Subarctic Gyre[a] | | |
|---|---|---|
| **Data Set** | **Orbit Number** | **Period, Years** |
| Toys, container spill | 1<br>2, 3, 4<br>3 | 2,<br>3, 3, 4<br>2.9 |
| Sandals, container spill | 3, 4 | 4 |
| Beer bottles, OWSP | 2, 3 | 3, 3, 3 |
| Pumice, Katmai eruption | 1 | 2.5 |
| Spectra, water temperature | 2<br>3, 4 | 2.73<br>3.50 |
| Spectra, water salinity | 1<br>2<br>3,4 | 2.11<br>2.72<br>3.63 |
| Spectra, OSCURS drifters | 1<br>2<br>3 | 2.16<br>2.80<br>3.30, 3.47 |

[a]Nineteen estimates from seven data sets: 10 from drifters; nine from spectra. Site codes B-S in Figure 1.

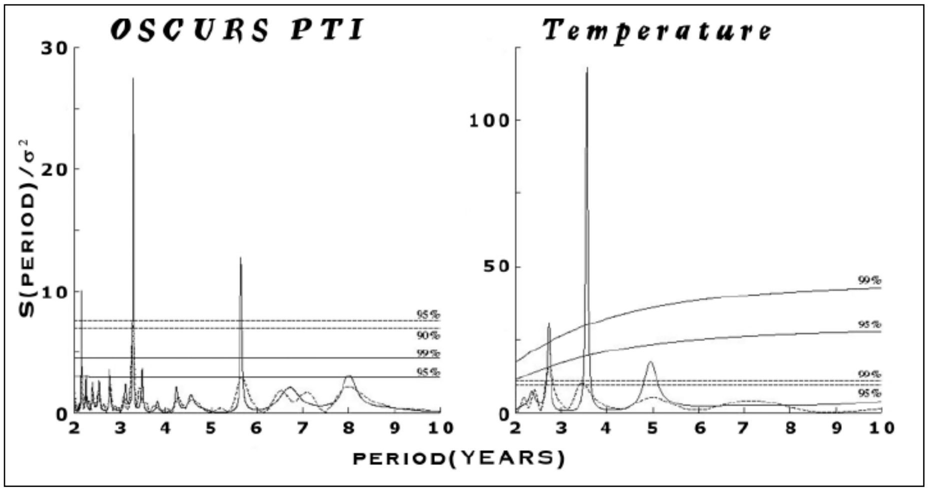


*Fig. 2. Spectra derived from: (left) OWSP Trajectory Index (PTI), the endpoint latitude of Ocean Weather Station P drifters; and (right) water temperature. The peaks between 2–4 years correspond to the orbital periods listed in Table 1, and the peaks between 5–6 years correspond to the orbital period of the North Pacific Subtropical Gyre, the next gyre to the south which adjoins the southern boundary of the Subarctic Gyre. Notation: solid lines, maximum entropy spectra; dashed lines, Lomb spectra; σ², variance; and 90%, 95%, and 99% confidence limits.*

| Table 2. Orbital Parameters of the Pacific Subarctic Gyre | | | |
|---|---|---|---|
| **Orbit Number** | **Period, Years** | **Orbit Length, Kilometers** | **Drift Speed, Centimeters per Second** |
| 1 | 2.11–2.16 | 7,400 | 10.9–11.1 |
| 2 | 2.72–2.80 | 10,200 | 11.5–11.9 |
| 3 and 4 | 3.30–3.63 | 12,600–13,500 | 11.0–13.0 |

OSCURS simulations, when cross-referenced with the locations and times at which toys were retrieved, indicated that groups of floats branched out into different orbits around and within the Gyre with the following circumferences (Figure 1): orbit 1, 7,400 kilometers; orbit 2, 10,200 kilometers; orbit 3, 12,600 kilometers; and orbit 4, 13,500 kilometers. The associated periods were taken as the intervals between peak recoveries at Sitka (toys), Kodiak (sandals), and southeastern Alaska (MIBs; Table 1). Recoveries of pumice and toys in the Queen Charlotte Islands were converted to orbital periods by applying their drift speeds to the respective orbital circumferences.

At Sitka, peak toy recoveries occurred at intervals of 2, 4, 3, and 3 years: 1992–1994, orbit 1; 1994–1998, orbit 4; 1998–2001 and 2001–2004, orbits 3 and 4 (orbit 2 could not be distinguished). By September 1995, the toys rounded the Gyre to the Queen Charlotte Islands (six toys; beachcomber G. Schweers), equivalent to 2.87 years around orbit 3. OSCURS showed the sandals treading eastward for 10 months, followed by a turn northward in the Alaska Current. Four years later, they again stranded on Kodiak Island, providing an estimate for the time duration of orbit 3 or 4. As suggested by ash scattered on the seafloor, Mount Katmai pumice drifted southwest through Shelikov Strait, then orbited to the Queen Charlotte Islands. The elapsed time and distance yielded 2.49 years around orbit 1. Peaks in the MIB recoveries along southeastern Alaska occurred at 3-year intervals 6, 9, and 12 years around orbits 2 or 3.

Spectra of hydrography and OSCURS OWSP drifters yielded 10 orbital periods in the range of two to four years (Table 1, Figure 2). Four orbits explain the multiple periods exhibited by the drifters and time series (Table 1). Ranking the spectral periods from lowest to highest partitioned them into three orbital ranges: orbit 1, 2.11–2.16 years; orbit 2, 2.72–2.80 years; and orbits 3 and 4, 3.30–3.63 years. Table 2 summarizes the time, distance, and speed at which drifters traveled once around the orbits.

*Orbiting the Gyre*

Seven data sets yielded orbital periods of the Pacific Subarctic Gyre. If flotsam drifts like slabs of water, drifters and spectra should yield comparable statistics. The data types were compared to test this assumption. Drifters and spectra yielded 10 and nine orbital estimates for which the means are 3.04 and 3.14 years, and the standard deviations are 0.60 and 0.85 years, respectively. Since these estimates were not statistically different, we combined them to obtain the aggregate orbital period: mean, 2.99 years, and standard deviation, 0.57 years. A drifter takes on average three years to circle the Gyre.

How long might the toys continue orbiting? A MIB released in 1975 in the Gulf of Alaska recently was recovered near Prince William Sound on the south coast of Alaska. The 31-year drift suggests that it completed 10 orbits of the Subarctic Gyre. The tub toys could complete 10 orbits by the year 2022.

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# Exaggerated Claims About Earthquake Predictions

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The perennial promise of successful earthquake prediction captures the imagination of a public hungry for certainty in an uncertain world. Yet, given the lack of any reliable method of predicting earthquakes [e.g., *Geller*, 1997; *Kagan and Jackson*, 1996; *Evans*, 1997], seismologists regularly have to explain news stories of a supposedly successful earthquake prediction when it is far from clear just how successful that prediction actually was. When journalists and public relations offices report the latest 'great discovery' regarding the prediction of earthquakes, seismologists are left with the much less glamorous task of explaining to the public the gap between the claimed success and the sober reality that there is no scientifically proven method of predicting earthquakes.

A striking example of this situation occurred when NASA posted a feature article on its Web site in 2004 in which an earthquake prediction project it funded was heralded as an "amazing success" (see http://www.nasa.gov/vision/earth/environment/0930_earthquake.html). Because this kind of hyperbole is a constant source of frustration for scientists at Weston Observatory (Boston College, Weston, Mass.), where seismologists try to accurately report the state of the art of research on earthquake prediction to the public, we decided to test just how amazing this particular success was.

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## *Analysis of NASA's method*

The NASA announcement claimed that a Rundle-Tiampo (RT) forecast [*Rundle et al.*, 2002; *Tiampo et al.*, 2002] has "accurately predicted the locations of 15 of California's 16 largest earthquakes this decade…." The Jet Propulsion Laboratory's QuakeSim Web site (http://quakesim.jpl.nasa.gov/) publishes updated 'scorecards' to illustrate how well the RT forecasts are performing [*Jet Propulsion Laboratory,* 2006]. Here, the scorecard that was posted at the time of the 2004 announcement is analyzed.

If the RT method is an amazing success, then it should perform much better than a reasonable ('least astonishing') null hypothesis. The success of the RT forecasts is evaluated here against the null hypothesis that future earthquakes will occur in the vicinity of past earthquakes. The number of forecast events discussed in the NASA announcement is given as 15 in one part of the announcement and 16 in another part. For the purpose of this analysis, the discussion is limited to the 15 events that are shown in the scorecard on the NASA Web announcement. These 15 events are referred to as the 'after' catalog because the earthquakes occurred after 1999.

We applied the 'cellular seismology' method of *Kafka* [2002, 2007] to investigate whether proximity to past earthquakes is a sufficient hypothesis to yield the same level of success as the RT method. To define the area of prior seismicity upon which this forecast is based (i.e., the 'before' catalog), the Advanced National Seismic System earthquake catalog from 1932 to 1999 with magnitude $M \geq 4.0$ was used, declustered of foreshocks and aftershocks following *Gardner and Knopoff* [1974]. The $M4.0$ cutoff was chosen based on inspection of the recurrence relation for this catalog, where we identified a change in slope for earthquakes with magnitude lower than 4.0, suggesting that this catalog is complete down to 4.0 since 1932.

This analysis used the 'before' catalog with $M4.0$ as the lower-magnitude cutoff. The QuakeSim scorecards show an 11-kilometer 'margin of error.' Applying the cellular seismology method using the 'before' catalog with $M \geq 4.0$, and circles of radius 11 kilometers, this analysis successfully forecast 14 of 15 (93%) of the 'after' earthquakes. The lower-magnitude cutoff was then systematically increased until 14 of the 'after' earthquakes (with an 11-kilometer radius) were no longer forecast. By using $M \geq 4.3$, only 13 of the 'after' earthquakes were forecast, but with $M \geq 4.2$ 14 of those earthquakes were forecast (Figure 1, left). In this case, the cellular zones cover 25% of the map area, and the locations of 14 of 15 of the future earthquakes were successfully forecast based on the simple assumption that they tend to occur near past earthquakes.

The cellular seismology method, as presented above, is purely statistical and is not based on any physical model of earthquake processes. To investigate the physical basis underlying the cellular seismology forecasts, the cellular method was revised to account for the distance surrounding a 'before' earthquake of a given magnitude within which future earthquakes might be governed by static stress triggering associated with that 'before' earthquake. This model uses the relationships between magnitude and fault size from *Wells and Coppersmith* [1994] to define a circular region around each epicenter where event triggering due to static stress changes might take place.

Applying this model to the entire 'before' catalog yields a map (covering 6% of the map area) that forecasts the locations of 11 of 15 (73%) of the 'after' earthquakes (Figure 1). If an additional five-kilometer margin of error is then added around the cellular zones for this case, the same 14 of 15 earth-