EVOLUTION OF THE PRODUCTS OF THE NAUTICAL ALMANAC OFFICE

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Introduction

My career of nearly 37 years has been spent almost entirely in the Nautical Almanac Office, and I now head the small division that still proudly bears the name. The invitation to review the products that the office has produced gave me the opportunity to step back from the details and look at a broad perspective. Rather than define the history in terms of the products, I'd like to look at some parallel factors in astronomy and navigation, their interaction with the Nautical Almanac Office, and the products that resulted.

Most of you are familiar with either *The Astronomical Almanac* or the navigational almanacs. The first product of the office, *The American Ephemeris and Nautical Almanac for 1855,* superficially bears little resemblance to *The Astronomical Almanac for 2000*, its direct descendant published last month. That first edition was the only product of the office, whereas *The Astronomical Almanac* is just one of several products. The concept of a product, especially within a mission-oriented institution, also means there has to be a demand or requirement for it.

Figure 1 displays the parallel timelines and significant milestones. The lines in the top part show the evolution of annual printed products. The middle part shows some important people and electronic products. The bottom part shows some of the trends and requirements driving the evolution of the products. This paper will describe the relationships among them.[1]

National Almanac Offices

"Almanac" and "ephemeris" have imprecise definitions. "Almanac" derives from the concept of calendar and almanacs have existed for centuries. It now commonly refers to similar information in an annual publication. The earliest almanacs often had two components, a calendrical one for listing dates and festivals, and an astronomical one for configurations of the Sun, Moon, planets, stars, phases of the Moon, weather predictions, and other such

"useful" information. "Ephemeris" derives from the Greek for something lasting a very short time. The current usage is in the sense of tabular representations of the positions of celestial bodies as a function of time. The distinction between an almanac and an ephemeris is therefore somewhat blurred.[2]

In the 15th century, great voyages of exploration and discovery out of the sight of land made the determination of longitude a problem of paramount importance. Many methods were proposed, but few were practical. The most notable schemes required observations of events that could be observed simultaneously from many locations: solar and lunar eclipses, occultations of stars, and the eclipses of the satellites of Jupiter. The drawback was that these events occurred at wide intervals, rarely at times convenient to a navigator, and were difficult to observe because of inadequate instruments and the motion of a ship. The method known as lunar distances was the most attempted, but rarely successful because the lunar theory was so inaccurate.[3]

National offices were intended to assure that accurate information was reliably available to navigators for that country. In France, a private almanac called *Connaissance des Temps* was taken under the auspices of the French Academy beginning in 1679. That publication provided the earliest explanations of finding longitude using the Moon. The British Nautical Almanac Office was established with the main purpose of providing the information for the application of the method. The first issue appeared in 1767. The time was right, as Tobias Mayer had just completed a new, more accurate, theory of the Moon. Germany and Spain soon established their own similar offices and publications.[4]

The United States Nautical Almanac Office

There were, inescapably, political considerations behind the founding of the American Nautical Almanac Office and its development.[5]

The young United States of America used the British Nautical Almanac for navigation and surveying, as well as astronomical purposes. As the country grew geographically and also became a maritime power, there was increasing need felt for a national almanac. Even before establishment of a national observatory in 1842 there was talk in the astronomical community of a federally supported national almanac. In 1844, John Y. Mason, Secretary of the Navy, noted our dependence on foreign nations. There was a dilemma, however. Matthew Fontaine Maury, the Superintendent of the new national observatory, was of the opinion that an

American almanac should be wholly American in both calculation and observations. There was fear that such a product might be so inaccurate as to be dangerous. On the other hand, if the product merely duplicated the British work, why expend the funds? There was also a division between those who thought a national almanac should be solely for navigational purposes, and those who wanted to do a service to astronomy in general.[6]

At last, on Saturday, 3 March 1849, the last day of the administration of James K. Polk, an appropriations bill passed by Congress for the Naval Service provided

> ...That a competent officer of the navy, not below the grade of lieutenant, be charged with the duty of preparing the Nautical Almanac for publication, and that the Secretary of the Navy may, when in his opinion, the interests of navigation would be promoted thereby, cause any nautical works that may, from time to time, be published by the hydrographical office, to be sold at cost,...[7].

Despite the wording, this authorization was not construed as placing the almanac under the hydrographical office. A Nautical Almanac Office was established at the beginning of the next fiscal year, 1 July 1849. Separate from the national observatory, it was located in Cambridge, Massachusetts, next to the Harvard College Observatory, the best research observatory in the United States. Benjamin Peirce was there, and served as *de facto* scientific director. The first Superintendent of the Nautical Almanac Office was Navy LT Charles Henry Davis. He had experience with navigation, but also strong ties to the scientific community. He was a protégé of Peirce.[8] Davis' view was that the almanac should serve for both navigation and astronomy. In navigation, it would make the United States independent of Britain, and in science it would be more perfect than any existing almanac.

Production of the American almanacs was, for at least the first century, considered to be extremely important for the government and for astronomy. Eventually the missions of the Nautical Almanac Office and the Naval Observatory intertwined. The Nautical Almanac Office was moved to Washington in 1866, and then located on the new grounds of the Observatory in 1893. Administratively, it was separate until sometime between 1897 and 1907, when it was taken under Observatory administration.[9]

When CAPT W. J. Barnette assumed the duties of Superintendent of the Naval Observatory in December 1907, wishing to have more information on the workings of the department of Astronomical Observations, he appointed a board to evaluate staff suggestions on the plan and scope of work. The board worked from May to July 1908, and its recommendations

were issued as an instruction by Thomas Newberry, Secretary of the Navy, in March 1909:[10]

> There is hereby formed an astronomical council composed of the following members: The Superintendent (ex officio), the Assistant Superintendent, such assistants in charge of the astronomical divisions as the Superintendent may designate, and the Director of the Nautical Almanac.
>
> The council should be guided by the fact that the most important astronomical duty of the Government is the publication of a nautical almanac, and as that is intended not only for the use of navigators, but also of astronomers in the most delicate investigations known to their science, it should be kept up to the highest attainable pitch of accuracy. To that end, continuous fundamental meridian observations upon the Sun, Moon, planets, and stars are absolutely necessary and constitute the astronomical essentials.
>
> The astronomical work of the Naval Observatory shall be so planned and executed as best to subserve the following purposes, and no others, to wit:
>
> To furnish to the Nautical Almanac Office, as far as may be possible, such observations and such data as may be needed for carrying out the purpose of the law under which the appropriations for that office are made from year to year, which is as follows:
>
> > For * * * [*sic*] preparing for publication the American Ephemeris and Nautical Almanac and improving the tables of the planets, moon, and stars * * *.
>
> The principal work of the observatory shall be in the field of the astronomy of position as distinguished from astrophysical work, and shall be the continued maintenance of observations for absolute positions of the fundamental stars and of stars which are to be made fundamental, and in addition the independent determination by observations of the Sun, of the position of the ecliptic, and of the equator among the stars, and of the positions of the stars, Moon, and planets with reference to the equator and equinoxes.

Creating and Managing an Almanac.

In starting up a new product, Davis was faced with basic questions that are still valid today: What is its application, what information should it offer, how should information be presented, how should it be calculated and by whom, what medium should be used, how should the product be

produced, how should it be distributed, and so forth.

Management of change after creating a product is a policy decision. As Eckert[11] reports, many suggestions on change are received by an almanac office. A decision on which improvements to adopt and when to adopt them is difficult and can be made only on the basis of all the factors involved, and in accordance with a consistent long-range policy. The almanacs cannot be used lightly for experimentation or to reflect personal whims. Each modification must be examined not only for intrinsic worth, but also for consistency with the almanac as it exists or is planned for the future. The saving brought about by an alteration must more than offset the inconvenience caused by the change. There is a history in the office of consulting outside experts for advice, or for comments on proposed changes, both in existing products or new ones.

There is an inherent time lag in making changes. From the establishment of the office, a goal was to have the navigational information available for use three years in advance, to supply ships going on the longest voyages. This means that preparation must begin even earlier, the amount depending on the methods. Consequently, this defines the time lag between making a decision and seeing the result appear in the finished product.

In the first edition, as mentioned earlier, for navigational purposes the almanac had to provide at minimum sidereal time for the Greenwich Meridian, lunar distances, and ephemerides of the Sun, Moon, and planets. For astronomical purposes and surveying, and observations for improvements of the theories, it contained transit ephemerides of the Sun, Moon, planets, and many stars for Washington. Occultations of stars by the Moon and eclipses of the Sun provided important opportunities for checking the accuracy of the ephemerides. This was the basic content for several years.

Examples of the most important changes in the navigational portion and their justification are as follows. Ephemerides of more planets were introduced in 1882 as part of a group of changes suggested by Newcomb and approved by the National Academy of Sciences.[12] As altitude-intercept methods were introduced, the method of lunar distances fell into disuse. That portion of the almanac was removed in 1912 after an investigation conducted by the Chief of the Bureau of Equipment in 1907 showed it was little used.[13] When the navigation portion changed from a reprint into a separate publication for navigators in 1916, tabular data were given hourly instead of daily. Rising and setting phenomena of the Sun and Moon first appeared in 1919. From 1929 content and arrangement was influenced by the needs of aerial navigators, as we shall see later. In 1934 the Greenwich Hour Angle

of Sun, Moon, and stars was included solely for navigators. Page layout for air navigation influenced the layout for surface navigation.

Examples of changes in the part for astronomy and geography include the following. Davis wanted to include full ephemerides of all minor planets, but as the number grew rapidly, this was impracticable. A century later, a selected few were included for special projects. As more satellites of planets were discovered, better dynamical ephemerides were included. Physical ephemerides of planets and the Moon were added. Longer lists of star positions were always in demand, such that a separate publication was created for them. Pluto was added in 1950, minor planets 1-4 in 1952 for use in studies of the equinox, the ephemeris for the Washington meridian was removed, and so forth. We will not delve deeper into details.

International Cooperation

Let us consider the timeline of Figure 1 for international meetings and other influences.

Today, the American and British Nautical Almanac Offices strive to comply with recommendations of the International Astronomical Union (IAU). There were efforts at some international coordination, if not cooperation, from the beginnings of the American office. Davis, wanting to publish ephemerides of all the minor planets, suggested to the European almanac offices a joint program. They never responded, but the idea was impractical anyway as the number grew rapidly. In 1896 a meeting of directors of national ephemerides was called in Paris. The matter of common planetary ephemerides was somewhat delicate because all the European offices used the work of Leverrier, which in Simon Newcomb's opinion did not incorporate enough observational data.[14] There were some agreements made on which constants to use for the fundamental reference system. They were incorporated into the almanacs for 1901. Newcomb continued to introduce his own theories into the American almanacs.

The next international conference was called in 1911, again in Paris. Although the Conference was primarily concerned with obtaining a greatly increased list of apparent places of stars, it extended its attention to all the ephemerides of bodies in the solar system. The most significant of its comprehensive recommendations was to reduce redundant calculation by distribution of calculations among the five principal ephemeris offices (France, Germany, Great Britain, Spain, United States). It also specified standards of calculation and presentation, arranged for publication of additional data, and fixed the values of some constants to be used in the

ephemerides.

Official approval was in some cases necessary for the adoption of these recommendations. The resolutions were distributed to American astronomers, and 84 responded, generally favorably. The naval appropriations act passed by Congress on August 12, 1912 had three provisions that influenced the American almanacs. The one of interest for international cooperation authorized exchange of data with foreign almanac offices. The Nautical Almanac Office expressed willingness to adopt the program of exchanges of data recommended by the Congress, with understanding that it could be terminated upon one year's notice, and with the conditions that it was not committed to printing extra decimals of precision in the ephemerides of stars, nor to cease publishing ephemerides for the meridian of Washington. The changes accepted were introduced into the volume for 1916, at the time that *The Nautical Almanac* became a separately prepared publication.

In 1919 the IAU was established. Commission 4 on Ephemerides provided the formal contacts by which the previous agreements could be continued and extended. The agreements made in 1911 had been directed to reduction of the total amount of work by avoiding duplicate calculation. In 1938 Commission 4 recommended that the principle should be extended to the avoidance of duplicate publication. As a first step the apparent places of stars then printed in all the principle ephemerides would be collected into a single volume. This was implemented in 1941 by the publication of the Apparent Places of Fundamental Stars. That material was removed from the national almanacs, relieving the office of some burden of calculation.

After the disruption of World War II, the Director of the Paris Observatory convened a conference in Paris in March 1950 to discuss the fundamental constants of astronomy. The most far-reaching consequence was in the recommendation that defined ephemeris time and brought the lunar ephemeris into accord with the solar ephemeris. These recommendations were adopted in 1952 and implemented in the almanacs for 1960.

In 1963 at IAU Symposium 21 in Paris, it was concluded that a change in the conventional IAU system of constants could no longer be avoided. At the Twelfth General Assembly in 1964 a list of constants proposed by a working group was adopted and recommended for use at the earliest practicable date in the national and international astronomical ephemerides. This was done in the almanacs for 1968. Further study by IAU groups led to recommendations for far more substantive changes in the constants, reference system, and ephemerides. The recommendations were

adopted in 1976 and fully implemented in the volumes for 1984. The volumes for 1981 were united under a single title, and the format was changed.

The selection of a standard reference system for stars was always an important topic at these international conferences. Newcomb was pleased with the work of Arthur Auwers at Berlin, but noted a systematic difference in the right ascensions from the stars used in the *American Ephemeris*. Therefore he decided to construct his own catalogue for right ascensions, while adopting the work of Lewis Boss for declinations.

In 1938, the German office finished the FK3, about the same time that the U.S. Naval Observatory finished its zodiacal catalogue. The latter was not printed for lack of funds, and in 1941 the FK3 was adopted as an international standard.[15]

Source of Theory

It is frequently supposed, even these days, that our ephemerides are the direct result of a set of formulas evaluated as functions of time. In fact, they are the concluding step in a sequence of three distinct processes. The first is construction of a theory, defining the problem in mathematical terms and solving the equations of motion. This includes comparison to observations for refinement. The second is construction of an intermediate device that reduces the evaluation of a theory to a series of arithmetic operations. Until mid-20th century, that was a set of tables. Nowadays it is most often the output of a numerical integration. The third is extraction of the data, conversion of coordinates, and arrangement of numerical results.[16]

There have been few major changes in the basic ephemerides of the almanacs, but they occurred more frequently over time. By directing the attention of American astronomers to the need for improved theories of the lunar and planetary motions, the *American Ephemeris* became an important factor in the contributions to celestial mechanics and astrometry made in America.[17]

At the founding of the office, the theories and tables employed at the several national almanac offices were a patchwork collection, with additions, corrections, and adjustments which enabled predictive accuracy for only a few years in advance. They were based on only 50 years of accurate observations. Davis had to use the best and most recent theories, while starting work to produce new ones. Even before the first volume was begun, special new theories and tables were worked out for several bodies. As a test,

predictions for the solar eclipse of 28 July 1851 were prepared from the American, British, French, and German ephemerides and compared to observed timings. Davis was obviously proud to report that the American calculations were far superior to the others in accuracy. The British almanac was the furthest off, with an error up to 85 seconds of time, corresponding to an error in longitude of 15-20 miles.

Davis laid out a plan for development of new tables, and his successors kept it up. However, Davis and Winlock both noted in their annual reports, in a theme that continues to this day: [18]

> While the importance of such investigations are admitted in the work of the office, they are subordinate to the current duties necessary for the preparation of the annual volume, and the almanac must be indebted to the devotion of the astronomers to their science for the voluntary contribution of much time and labor to the class of subjects here referred to; the gentlemen engaged upon these are also actively employed on the current duties of the office.

Simon Newcomb was appointed Superintendent in 1877, and in his first annual report, he states "The most urgent want of the office at the present time is a set of tables of the Moon and planets, corresponding in accuracy to the present state of practical astronomy, and founded on entirely homogeneous data."[19]

He began a program to determine fundamental astronomical constants from all available observational data, and to discuss all the observations of the Sun and planets made worldwide since 1750. From this, he and G. W. Hill constructed new planetary theories and tables, and a catalogue of 1,596 fundamental stars. Through the Secretary of the Navy, in December 1877 Newcomb submitted a proposal of fifteen suggested changes in the astronomical ephemeris to the astronomers of the country that were referred to a committee of the National Academy of Sciences. Most were sustained, some modified, and they were incorporated into the volume for 1882. After the international conference in 1896, his new theories were introduced into the American and other almanacs starting with 1901. At the time, he predicted that they would only be good for 70-100 years.

Another provision of the Act of Congress in 1912, referred to earlier, authorized personnel to conduct this research if time permitted.

Starting in 1938, extensive discussions of accumulated observations of the Sun and planets indicated appreciable discordances. Gerald Clemence, Director of the Nautical Almanac Office, reported that the various defects and inadequacies indicated that a new attack on the whole problem of the

motions of the principal planets was needed. The accumulation of observations since Newcomb's time was massive, and extensive theoretical and computational work was needed to utilize it and to improve the form of the theory.[20] In 1947-50, Wallace Eckert, former director of the NAO, Dirk Brouwer of Yale, and Gerald Clemence, then current director of the NAO, undertook to reconstruct all the planetary theories, based on still more observations, using computers to do a numerical integration for comparison. The principal result was a numerical integration of the outer planets that covered the span 1653-2060. In 1952-54, Brown's lunar theory was evaluated from theory rather than the tables. The results were incorporated into the almanacs starting with 1960.

After the war, more observations flowed in, including the new dimension of distance and using non-optical detectors. Driven by requirements of the space age, the Jet Propulsion Laboratory (JPL) developed extensive new theories of planets and satellites, based on but not completely conforming to IAU guidelines adopted in 1976. Their development and lunar ephemerides DE200/LE200 were taken as the basis of the almanacs starting with 1984.

In 1994 the IAU adopted a new International Celestial Reference System (ICRS). JPL has a new Development Ephemeris that conforms to the ICRS, and we contemplate introducing it into our almanacs for 2002 or 2003.

Time and the Almanacs

Davis stirred up another controversy when he was planning the first issue of the *American Ephemeris*. He asked what meridian to use — Greenwich, or one in North America? It had not been specified in the Act that authorized the office. To use the Greenwich meridian would be to redo the British Almanac, and surely an American product was wanted.[21] The question was taken to the American Association for the Advancement of Science and referred to a committee of eminent astronomers and mathematicians. In February 1850 the House Naval Affairs Committee took up the issue. On 2 May it proposed a joint resolution that was adopted in an appropriations bill on 23 September:

> that hereafter the meridian of the Observatory of Washington shall be adopted and be used as the American meridian for astronomical and geographical purposes, and such part of the computations of the Nautical Almanac as may be designed for the exclusive use of navigators, shall be adapted to the meridian of Greenwich.[22]

This was a compromise, but also recognition by the Congress that the Almanac was not only for navigators, but also astronomers and geographers. The division of material into parts for navigation and astronomy permitted a reprinting of the first part separately, which commenced in 1858 The provision for two meridians was repealed by the previously mentioned Act of Congress of August 12, 1912. Nonetheless, despite international pressure to use the Greenwich meridian, two meridians were used in *The Nautical Almanac* until 1934 and the *American Ephemeris* until 1950.

Until 1925 there was continued international effort to standardize on the use of a common term for the time argument of the ephemerides. The astronomers wanted to use Greenwich Mean Time with the day starting at noon, but some places still used Greenwich Civil Time with the day starting at midnight, and there was confusion over whether the day started at midnight or noon. In 1925 everyone agreed that the day would start at midnight. In the volumes for 1939-1952 time is listed as both Greenwich Civil Time and Universal Time. In 1953, the term Greenwich Civil Time was discontinued. The term Universal Time was adopted for astronomical use, while the term Greenwich Mean Time was adopted for navigational use. The latter was converted to Universal Time over 1985-1990. Meanwhile, in 1950, Clemence proposed the introduction of Ephemeris Time as the independent argument, separate from Universal Time. This was adopted in 1952 and implemented in 1960 with the Ecker-Brouwer-Clemence integrations. That was superseded in 1984 by the introduction of Dynamical Time with the JPL ephemerides, and that concept is still being refined.

Presenting the Data: Calculation, Typesetting, and Proofreading.

We mentioned earlier that there are three distinct steps in preparing an ephemeris for presentation. Clemence wisely observed that there is also a fourth: keeping out mistakes.[23]

During its earliest years, the NAO had no permanent staff beyond the Superintendent and a few clerks and proofreaders. The superintendent contracted with various astronomers and mathematicians throughout the country for the computations. Some of the most eminent American astronomers of the time took part in this work, and without their cooperation it is doubtful whether the project could have been successfully accomplished. Davis felt that it also created general interest in the character and prosperity of the work. Newcomb, early in his tenure as Superintendent, noted that two-thirds of the ephemeris calculations were done by piecework. This took extra lead time in the preparation of copy. He thought it would be more efficient

to have the planetary work done by one expert. Newcomb also noted in an early annual report that typographical and other errors in the published *American Ephemeris* were frequently reported. Knowing that he had to maintain trust in the integrity of the publications, he put proofreading under the supervision of a single responsible assistant, Mr. D. P. Todd. Only in 1950 was the use of pieceworkers outside the office entirely discontinued.

The naval appropriations act passed by Congress on August 12, 1912, provided

> That any employee of the Nautical Almanac Office who may be authorized in any annual appropriation bill and whose services in whole or in part can be spared from the duty of preparing for publication the annual volumes of the American Ephemeris and Nautical Almanac may be employed by said office in the duty of improving the tables of the planets, moon, and stars, to be used in preparing for publication the annual volumes of the office.

It was a continuing thread of comment throughout the annual reports that it was difficult to find competently trained staff, and even more difficult to hire them when the authorized pay was so low — lower than that of a common clerk. The annual report for 1938 laments the loss by retirement or death of experienced astronomers all over the world, and adds:[24]

> At the last three meetings of the IAU, decisions were made over the protest of experienced astronomers, and then had to be reversed at the next meeting. Many observatories have ceased fundamental astronomical work, as the younger generation seeks something more attractive, less monotonous, and less arduous. Maintaining staff for fundamental work is expensive.

Astronomers welcomed any development that promised to relieve the amount of calculational labor and increase the reliability of the results. L. J. Comrie, Director of the British Nautical Almanac Office, started working with calculating printers as early as 1929, and Wallace J. Eckert was working with punched card equipment by 1933. He was brought in as Director of the American Nautical Almanac Office in 1940, to introduce punched card equipment and apply it to the production of the newly created *Air Almanac*. The machines helped compensate for a wartime shortage of staff. Machines calculated the data and generated tables; the tables were photo reproduced and also proofread by machine methods. The resulting almanac was the most reliable and accurate yet produced. By the time war urgency passed, there was a commitment to continue using tabular equipment to produce the

almanacs. Starting in 1945, a specially built card-operated typewriter was producing camera copy for *The Air Almanac*, a method later applied to *The American Nautical Almanac* and other publications. Introduction of the same equipment into the British office in the 1950s enabled unification of the British and American Nautical Almanacs from 1958. The Air Almanacs had already been unified in 1953. Similarly, the Ephemerides were unified in 1960, with each office preparing half the publication. We are now working with HMNAO to make it look like a uniform product.

Programmable computers were installed and utilized from the late 1950s onward, and used for both calculation and typesetting. In the mid-60s, the Government Printing Office began using typesetting equipment driven by computer-generated tapes, and went through several generations until the late 80's. Though they were generally more accurate than the old conventional methods of setting cold type, they weren't always any faster or easier! Right up until 1995-1996, preparing copy for an annual volume for reproduction and printing might be spread out over several years. Now, all the camera copy is produced right in our office and delivered to the printer ready to reproduce. Unfortunately, overconfidence in the reliability of computers without considering the human factors had led to some embarrassing errors and oversights, and we are paying particular attention to proofreading and examination again.

Distribution

The mainline printed products of the office produced as directed by law and through congressional appropriations have not generally been aggressively marketed in the United States. As a result, there was no incentive to make changes to appeal to a wider audience. For the first 60 years or so, the office itself handled sales, either directly or through designated agents. The Bureau of Equipment handled distribution to the Navy and other military components. Around 1908-1910, public sales were turned over to the Government Printing Office, but distribution to the Navy, military units, and exchange libraries came back to the office. In 1980, an agreement was reached with the Defense Mapping Agency to have them do distribution for the Department of Defense, and this has been passed on to the Defense Logistics Agency as of last year.

The office has distributed data in camera copy since the 1940's, and in machine readable forms for special purposes ever since computers were introduced. Participation in international exchanges tended to discourage changes. Since about 1986, we have been exploring the use of computer

disks, the Internet, and the World Wide Web for distribution of not only products, but also services.[25]

Special Considerations for Navigational Almanacs

The Nautical Almanac was a reprint of the nautical portion of *The Astronomical Ephemeris and Nautical Almanac* from 1855 to 1915. In 1916, because the speed of ships had increased enough that the process of taking sights had to be expedited, the presentation of the data was completely redesigned. The original book had to be opened to too many different places to collect all the information required. The new arrangement reduced the number of openings required, and with accuracy only to the number of places required.

Development of an air almanac began in the late 1920's. As aircraft began making long flights, it was discovered that it took too long to extract data from the American Nautical Almanac to get a fix. P. V. Weems suggested that a big burden of computation could be transferred from the navigator to the almanac office if the Greenwich Hour Angle in arc replaced the right ascension in time.[26] In spite of limited staff, the office published supplements and made minor additions into the American Nautical Almanac beginning with 1929 and continuing through 1934. An experimental air almanac was issued in 1933. In 1940 permission was given to increase the staff of the NAO and start a crash program to design and publish an almanac to meet the needs of air navigators. There had been enough aerial navigation to find out what was required of an almanac, and the aerial navigators were in general a small group of carefully selected and highly educated young men. It was therefore possible to make an almanac on the basis of what was then considered the ideal almanac without much regard to the past. The desirable features included having all the astronomical data for a single day on a single sheet, tabulated at a suitable short time interval, and with convenient interpolation tables. The emphasis was always on doing as much calculation for the navigator as possible. When the American and British Air Almanacs were unified in 1953, there were some minor adjustments that did even more.

An annual Air Almanac was issued starting in 1941. It was first issued in three volumes per year of four months each (with patriotic red, white, and blue bindings[27]); in 1977 it was issued in two volumes per year for six months each, and as of 1987 it has been issued as one annual volume. Sky Diagrams were issued separately for a few years, and were so enthusiastically received that they were incorporated into the volume.

Surface navigators quickly adopted *The Air Almanac* because of its ease of use.[28] This suggested that a changed design might improve the ease with which *The Nautical Almanac* could be used. In order to study this subject, the Naval Observatory included in the *Nautical Almanac for 1947* a questionnaire for mariners. The U.S. Institute Of Navigation had an Almanac Committee. It considered the comments received and a sample of pages from the Observatory. In October it sent a report to the Naval Observatory. In December the USNO began to prepare a preliminary sample of current ideas for a 1950 Nautical Almanac. This was sent to as many members of the ION as were deemed interested, for reaction, constructive criticism, and suggestions. Clemence was in charge.[29]

As a result, *The Nautical Almanac for 1950* and onward was designed along the same lines as *The Air Almanac*: all the data for three days presented on facing pages, lookup tables to reduce the GHA in a separate section, and correction tables in critical value format on the inside covers.

As of 1998, at the direction of the RAF, HMNAO ceased publication of *The Air Almanac* for navigation and created a new one that serves an entirely different purpose, providing information on illumination and light levels.

Other Products: Printed

We have now discussed our three "mainline" continuing annual products. There is currently a fourth printed annual publication entitled *Astronomical Phenomena*. According to the annual report for 1951, "extracts from The American Ephemeris, with a small amount of supplementary material, are now published separately under the title Astronomical Phenomena. The contents consist primarily of material of interest to the general public, which was formerly supplied in mimeographed form or by correspondence; the separate publication is primarily for economy, permitting the users instead of the Observatory to bear the cost of distribution." The first issue was for 1951 and coincided with the revision of *The Nautical Almanac*. The intent has been to publish it three years in advance of the cover date for planning purposes, but right now it is just two years ahead. It was for some time a joint publication with HMNAO, but they have now stopped marketing it separately.

There are other products with a significant lifetime, but are issued irregularly or have been discontinued.

When Newcomb began his grand project to redo all the planetary theories and to redetermine all the astronomical constants, in 1879 he started

a series to publish the results, titled *Astronomical Papers Prepared for the Use of the American Ephemeris and Nautical Almanac*. Generally known as "The Astronomical Papers", the most recent part was published in 1987, and while it is not officially terminated, it seems unlikely to continue. In parallel, *Publications of the United States Naval Observatory, Second Series* started in 1900 to publish astrometric observations and data, the most recent part appearing in 1992.

The Coaster's Nautical Almanacs were devised as an experiment by Newcomb to meet a perceived need, but are so obscure that they are mentioned only in a few annual reports.[30] Before the American Nautical Almanac Office was established, American ships used reprints of the British Nautical Almanac made by a Mr. G. W. Blunt. It had many errors in it, which was one reason justifying establishing an official American office. In 1857, a contract was made with him to cease publication of his almanac and become an exclusive agent of our official one. When he retired in 1867, sales agents were appointed in major seaports, and later sales were opened up to any dealer, although keeping the accounts was a major burden to the NAO. Sales fell off by a third from 1876 to 1883, supposedly because fewer American ships were in service, but Newcomb suspected it was actually because numerous companies were reprinting portions of the official almanac to sell cheaply for advertising purposes, and they were popular on ships plying a coastal trade.

Newcomb felt that since the Government had established the Hydrographic and Nautical Almanac Offices for the purpose of supplying navigators with all necessary scientific data for navigation, an almanac for the coastal trade should be issued. But in order not to compete with private enterprise, all known publishers of private almanacs had to agree to cease publication if an official almanac were issued. All but one did, that one being John Bliss & Co. of New York, nevertheless in 1884 an experimental American Coaster's Nautical Almanac was issued, followed by separate Atlantic Coaster's and Pacific Coaster's Nautical Almanacs in 1885. In addition to astronomical data, they contained information on tides, lists of lighthouses, and other information of use for coastal navigation. By 1891, it appeared that the experiment had failed, as the private publishers continued to produce cheap or free reprints for advertising and sales of the official almanac were never the great quantity expected. They were never discussed in the annual reports after 1891, though they appeared in the annual publications list until 1907 or 1908. The story is of interest to us now because we are today in a similar situation where copies of *The Nautical Almanac* are

being reprinted and sold privately even though British authorities hold the copyright.

The Ephemeris for the Bureau of Land Management (BLM), Department of the Interior, is the next discontinued publication. The annual report for 1959 stated that the Nautical Almanac Office had undertaken its preparation beginning with the issue for 1960. This was a publication founded in 1909-1910, and formerly prepared within that agency. Federal cadastral surveyors using solar attachments needed the data contained in *The Ephemeris* for determining bearings from astronomical observations. The BLM asked the NAO to take it over, apparently because their expert retired or died. In 1985, changes in our computer systems required major changes in the computational software, and the BLM decided that since use had declined so far, and other devices and calculator software on the market (such as *The Almanac for Computers* described later) could do the job, they would no longer support it. The last edition was for 1987-88.

Supplements and Circulars on solar eclipses are the final discontinued series. Even before the first volume of the Ephemeris was published, the NAO published predictions of a solar eclipse in 1851. Solar eclipses were of great value because the observations gave valuable information on the orbital elements of the Moon, up until the mid-1950s. After that, they gave valuable information on the limb of the Moon and the diameter of the Sun. The Navy sent expeditions to all total solar eclipses that could be profitably observed before World War II, and some afterwards. The American Nautical Almanac Office had charge of the eclipse work for all the almanac offices of the world until recently. Before the era of personal computers, the calculations for predictions were quite long and tedious, but a natural outgrowth of the work of the NAO. To encourage observations, supplements to the *American Ephemeris* were issued. The USNO began an irregular series of Circulars in July 1949, and many of them contained the information on solar eclipses previously issued in the supplements. The number of eclipse Circulars and the quantity of detail therein increased over the years, then they were discontinued in 1989 as a cost-saving measure. Only the basic information still appears in the annual almanacs.

There have also been important publications for navigators and astronomers that are not periodical, such as the two sets of Sight Reduction Tables for Marine Navigation (H.O. 229) and for Air Navigation (H.O. 249)[31], done for the Hydrographic Office in cooperation with the British Nautical Almanac Office, and *Planetary and Lunar Coordinates* that is done every 20 years or so.

Other Products: Electronic

In consideration of the availability of computers and the Internet, we have started rethinking how we supply not just information, but services to the community. Other speakers will cover this in more detail, but for completeness I want to include here a mention of some of them. A more thorough discussion will be the topic of other papers in this Symposium.[32]

Since the introduction of mechanical calculators, the NAO had distributed data on punched cards, and then magnetic tape. We also did some types of specialized calculations. As personal calculators and computers began to appear, there was a need to provide information tailored for them. The *Almanac for Computers*, 1977-1990, was designed to facilitate the applications of digital computers and small calculators to problems of astronomy and navigation which require coordinates of celestial bodies.[33] Fixed-interval tables, requiring interpolation, are replaced by concise mathematical expressions for direct calculations. The expressions were polynomial approximations fit to the tables, both navigational and astronomical. In the second edition, expressions were introduced to allow calculation of certain quantities for intervals greater than the current year. It was primarily a printed product, but the coefficients were also available on floppy disk or magnetic tape. It was discontinued when technology permitted the distribution of data and an executable file together.

The first computer almanacs of this form were introduced around 1986-1988, and were designed to do calculations using a supplied ephemeris that defined the valid time interval. The Floppy Almanacs,[34] good for just a few years each, were first, followed by the Interactive Computer Ephemeris (ICE) that had a longer ephemeris. Although they are still available from private sources, the NAO ceased supporting them when we introduced better products in 1993 and 1995. Two products were developed for certain microcomputer systems. MICA (Multi Year Interactive Almanac)[35] is the computerized complement to *The Astronomical Almanac*, while STELLA, (System To Estimate Longitude and Latitude Astronomically),[36] for DoD use only, is a counterpart to *The Nautical Almanac*. Each has a limited ephemeris.

As of 1996, the Astronomical Applications Department has a public Web site that provides information on our products and services, and can automatically handle many of our correspondence requests. As this seems to be an important future medium of communication both for DoD and general

use, we are investigating ways to expand and tailor our site to complement our printed publications.

In the continuing spirit of consulting with our customers before making changes, we enclosed a mail-back survey with *The Astronomical Almanac for 1999*, and also had a very detailed version up on the Web. We were interested not only in what portions of the publication are being used, but also whether an electronic complement or substitute would be acceptable. The results from several hundred responses indicate an overwhelming desire to retain the printed version no matter what. The respondents do not yet trust electronic media for ease of use, nor stability of the technology, in particular for archival purposes.

Conclusion.

The products of the Nautical Almanac Office have changed quite a lot over the long run. The evolution of our products is accelerating, and we are often asked whether we are keeping up with the evolution of technology. We place our mission at the highest priority. I close with some words from my predecessor, LeRoy Doggett:

> By the 1980s some people regarded ephemeris offices as obsolete producers of paper products in an age of electronic information. Electronic methods of navigation were becoming much easier and, in many cases, more reliable than traditional celestial navigation. But at the same time, the offices were facing ever increasing public demands for information.
>
> Today, with the market awash in astronomical software, someone needs to set a standard for scientific excellence. It is a role the ephemeris offices are uniquely qualified to fulfill.[37]

Notes

1 Unless otherwise noted, all information on the almanacs and their contents is taken from annual reports of the Nautical Almanac Office, annual reports of the U.S. Naval Observatory, prefaces in the annual volumes, or reports of Commission 4 on Ephemerides within the Transactions of the International Astronomical Union that are published after each General Assembly.

2 David A. Kronick, "Almanacs and Annuals", in A History of Scientific

& Technical Periodicals, The Origins and Development of the Scientific and Technical Press 1665-1790, Second Edition, Scarecrow Press, Inc., 1976.

3 See "Finding the Longitude" in *Greenwich Time and the discovery of longitude*, Derek Howse, Oxford University Press, 1980, Appendix I, pp. 192-198. Also, Seymour L. Chapin, "A Survey of the Efforts to Determine Longitude at Sea, 1660-1760, Part II: The Use of Celestial Bodies", NAVIGATION, *Journal of the Institute of Navigation*, March 1953, p. 242.

4 P. K. Seidelmann, P. M. Janiczek, and R. F. Haupt, "The Almanacs - Yesterday, Today and Tomorrow", NAVIGATION*: Journal of The Institute of Navigation*, Vol. 24, No. 4, Winter 1976-77, pp. 303-312.

5 Craig Waff, "Navigation vs. Astronomy: Defining a Role for an American Nautical Almanac, 1844-1849", These proceedings.

6 Ibid.

7 9 Stat. L., 374, 375, CHAP. CLII. - An Act making Appropriations for the naval Service for the year ending the thirtieth of June, one thousand eight hundred and fifty. Text and background taken from "U. S. Naval Observatory [1809-1948]", a typescript first narrative prepared by Commodore J. F. Hellweg. QB82 U7U8 in the U. S. Naval Observatory Library.

8 Marc Rothenberg, "Observers and Theoreticians: Astronomy at the Naval Observatory, 1845-1861", *Sky With Ocean Joined*", Proceedings of the Sesquicentennial Symposia of the U.S. Naval Observatory, Edited by Steven J. Dick and LeRoy E. Doggett, U. S. Naval Observatory, Washington, D.C. 1983.

9 According to Hellweg, *op. cit.*, "On September 20, 1894, the Secretary of the Navy, availing himself of the authority granted in the act of March 3, 1857, issued a regulation making the Nautical Almanac Office a branch of the Naval Observatory. In a departmental decision rendered January 19, 1905 (File 9449-04 and 17626 Navy Department), it was held that the Nautical Almanac Office is not a separate shore station, and since that time its status has been that of a department of the Naval Observatory."

10 Synopsis of the Report of the Superintendent of the United States Naval Observatory for the Fiscal Year Ending June 30, 1909.

11 Wallace J. Eckert, "Air Almanacs", *Sky & Telescope*, Vol. IV, No. 1,

Nov. 1944.

12 Edgar W. Woolard, "The Centennial of the American Nautical Almanac Office", *Sky and Telescope*, Vol. XI, No. 2, pp. 27-29, Dec. 1951.

13 Synopsis of the Report of the Superintendent of the United States Naval Observatory for the Fiscal Year Ending June 30, 1908, p. 14.

14 Arthur L. Norberg, "Simon Newcomb's Role in the Astronomical Revolution of the Early Nineteen Hundreds", *Sky With Ocean Joined*", Proceedings of the Sesquicentennial Symposia of the U.S. Naval Observatory, Edited by Steven J. Dick and LeRoy E. Doggett, U. S. Naval Observatory, Washington, D.C. 1983.

15 Report of the Office of "The American Ephemeris" to Commission 4, Transactions of the International Astronomical Union, Vol. VII, Seventh General Assembly held at Zurich, August 11 to August 18, 1948. Cambridge University Press, 1950.

16 Seidelmann, Janiczek, and Haupt, *op. cit.*

17 Woolard, *op. cit.*

18 Annual Report of the Secretary of the Navy,. Nautical Almanac Office. November 10, 1857

19 Arthur L. Norberg, "Simon Newcomb's Role in the Astronomical Revolution of the Early Nineteen Hundreds", *Sky With Ocean Joined*, Proceedings of the Sesquicentennial Symposia of the U.S. Naval Observatory, Edited by Steven J. Dick and LeRoy E. Doggett, U.S. Naval Observatory, Washington, D.C. 1983.

20 G. M. Clemence, Report of the Office of "The American Ephemeris" to Commission 4, *op. cit.*, p. 78-79.

21 Craig Waff, "Charles Henry Davis, The Foundation of the American Nautical Almanac, and the Establishment of an American Prime Meridian," *Vistas in Astronomy,* Vol. 28, pp. 61-66, Pergamon Press, 1985.

Also, "Astronomy and Geography vs. Navigation: Defining a Role for an American Nautical Almanac, 1844-1850," invited paper presented at the Historical Astronomy Division's LeRoy E. Doggett Memorial Session, American Astronomical Society, Washington, D.C. 6 January 1997.

22 U.S. Congress, House, "The American Meridian" debate, 31st Congress, 1st Session, 2 May 1850, Congressional Globe, XIX, 891.

23 G. M. Clemence, "Time and Almanacs", NAVIGATION *Journal of the Institute of Navigation*, Vol. 2, No. 6, p. 152. In proceedings of Symposium: The Federal Government and Navigation, Eastern Regional Meeting of the Institute, Washington, D.C., Feb. 9-10, 1950.

24 Report of the Superintendent of the Naval Observatory for the fiscal year ending June 30, 1939, a typescript memorandum to the Chief of the Bureau of Navigation.

25 John A. Bangert, "The Future of Almanac Data in the United States", these proceedings.

26 Seidelmann, Janiczek, and Haupt, *op. cit.*

27 Hellweg, *op. cit.*

28 George W. Mixter, "American Almanacs", NAVIGATION, *Journal of the Institute of Navigation*, Vol. 1, No. 3, pp. 53-56, September 1946.

29 Ramon A. Williams, "A 'New Look' for the *Nautical Almanac*", NAVIGATION, *Journal of the Institute of Navigation*, Vol. 1, No. 11, pp. 235-237, September 1948.

30 The last and most complete description, from which this material is taken, appeared in The Report of the Director of the Nautical Almanac, Bureau of Equipment, in the "Annual Report of the Secretary of the Navy for the Year 1891". Newcomb was the Director.

31 John Dohm, "H.O. 249 and the New Air Almanac", NAVIGATION, *Journal of the Institute of Navigation,* March 1953, p. 239.

32 John A. Bangert, "The Future of Almanac Data in the United States", and "The Astronomical Applications Department Today", both elsewhere in these Proceedings.

33 Seidelmann, Janiczek, and Haupt, *op. cit.*

34 G. H. Kaplan, T. S. Carroll, L. E. Doggett, P. K. Seidelmann, S. E. Deustua (1986): "A 'Floppy Almanac'", *Bull. AAS* **18**, pp. 664-665.

35 J. A. Bangert and G. H. Kaplan (1992): "MICA: A High-Precision

Almanac for Small Computers", *Bull. AAS* **24**, p. 740.

36 J. A. Bangert (1996). "Set Your Sight on STELLA: New Celestial Navigation Software from USNO," *Chips* XIV, No. 5, 5-7. Also, P. M. Janiczek (1996): "STELLA: Toward Automated Celestial Navigation", *Surface Warfare* 21, No. 2 (March/April 1996), pp. 34-37.

37 LeRoy E. Doggett, "Primus inter pares: The Place of the Bureau des Longitudes Among the National Ephemeris Offices", paper given at IAU Symposium 172, Dynamique, Éphémérides et astrométrie du système solaire, Paris, 3-8 July 1995.