SEA, SWELL AND SURF FORECASTING FOR D-DAY AND BEYOND
THE ANGLO-AMERICAN EFFORT, 1943-1945

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"History with its flickering lamp stumbles along the trail of the past trying to reconstruct its scenes, to revive its echoes, and kindle with pale gleams the passion of former days."

Winston Churchill
(1874-1965)

***Operation Neptune** was the most complicated and most difficult that has ever taken place. It involves tides, winds, waves, visibility both from the air and the sea stand-point, and the combined employment of land, air and sea forces in the highest degree of intimacy and in contact with conditions which could not and cannot be fully foreseen.*

Prime Minister Winston Churchill to the House of Commons during 6 June 1944

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Late in 1943, the British Admiralty became responsible for preparing the sea, swell and surf forecasts for Operation OVERLORD, the world's largest amphibious assault. To do so, as of 1 February 1944, the Admiralty's Naval Meteorological Service activated a Swell Forecast Section. There follows a first-hand account of how this unit prepared the requisite wave predictions for D-Day (6 June 1944), the Big Storm (19-22 June 1944), and over-the-beach supply operations following the destruction of the artificial harbor at the OMAHA beachhead. The same British and American meteorologists were then posted to the Joint Meteorological Centre, Colombo, Ceylon to assist in the invasion of Rangoon, Burma (Operation DRACULA).

The Military Requirement for Accurate Wave Forecasting

Soon after the United States of America (USA) entered World War II, British and American leaders contemplated whether the two countries should capture a modest cross-channel bridgehead by late 1942 (Operation SLEDGEHAMMER). Upon further deliberation, the respective British and American heads of state, Winston Churchill and Franklin D. Roosevelt, chose as of 24 July 1942 to substitute Operation TORCH, a far simpler joint invasion of French-controlled North Africa.[1] Because TORCH was scheduled for early November, 1942, rapid capture of the port city of Casablanca would depend heavily upon the local surf conditions.

As Roosevelt noted in a message of 3 September 1942 to Churchill, "... bad surf on the Atlantic beaches is a calculated risk." This proved to be a valid worry. By the end

of the assault's second day, 9 November 1942, 64% of the 378 landing craft and lighters deployed at Casablanca's Fedala beachhead had broached, stranded or sunk in breakers soon reaching six feet or more in height, a condition persisting for the next two months (Atkinson, 2002).

As a consequence of the TORCH operation, the same allied task force still under the command of General Dwight D. Eisenhower, USA, invaded Sicily (9-10 July 1943) and southern Italy (3 September 1943). Back in London, however, plans for the ultimate cross-channel attack remained stagnant until 7 September 1943 when the office of the Chief of Staff, Supreme Allied Commander (COSSAC), was finally authorized to flesh out the paper-work needed to implement what was now called Operation OVERLORD. As conceived, three Allied seaborne divisions would land at low tide shortly after dawn along a 20-mile wide beachhead in Normandy. To ensure their safe arrival, two airborne divisions would be dropped ahead of the "ground-pounders." However, it was also anticipated that these Allied forces would be quickly counter-attacked by 13 near-by German divisions followed by additional counter-attacks from another 44 German divisions already stationed within northern France, Belgium and the Netherlands. To negate such attacks, the COSSAC plan called for the Allies by D-plus 15 to land another 16 divisions (500,000 troops), bring in nearly 100,000 vehicles, capture a major port (Cherbourg), and create two artificial harbors (MULBERRY-A and MULBERRY-B).

For accomplishing this major marine transfer of a million men and their materiel thousands of newly developed landing craft would be utilized despite the fact that their shallow draft and blunt pop-open bows made them extremely sensitive to wave action (Appendix A). To a large degree they looked like and behaved like floating shoe boxes. After viewing an underway Landing Craft Tank (LCT) from the side, one wag claimed it resembled "a tin shed… traveling upside down and backwards through the water." Thus, for such a convoy to assemble, travel across the 100-mile wide English Channel, unload, and return to port meant it needed a four-day period of low seas. Then if an assault planner added in other requisite attack features such as moonlight, minimal low cloud, and low tide near dawn, the Meteorological Office's climatologists determined that the chances for such a four day interval occurring near Normandy during June months were 1-in-13.

Despite the extreme sensitivity of complex amphibious operations to local weather conditions, during mid-November, 1943, the COSSAC agreed to the Air Ministry's choice of a dour civilian, Dr. James M. Stagg, as Operation OVERLORD's Senior Weather Adviser. However, Stagg's last stint of military forecasting dated back to a decade before while on desert duty with the Royal Air Force in Iraq. To overcome this deficiency in maritime knowledge, the Admiralty's Captain Leonard G. Garbett, CBE., RN, reached an agreement during the same month with the COSSAC and the Meteorological Office's director, Sir Nelson K. Johnson, for the Royal Naval Meteorological Service to have the sole responsibility in generating the sea, swell and surf forecasts required by what, as of 17 January 1944, would transition into being the Supreme Headquarters, Allied Expeditionary Force (SHAEF).

With this assignment in hand and as Director of the Royal Navy's "Met Service," Garbett must now determine how to fulfill this function. To ascertain the American viewpoint, Garbett invited to his Berkeley Square office two American military meteorologists who thought oceanographically. Commander Richard Steere, USN, the staff aerologist for the pending Western Naval Task Force, had, in fact, developed a surf reporting code utilized in Operation TORCH. Colonel Thomas Moorman, Jr., AC, the regional control officer for the Ninth Air Force's 21st Weather Squadron, had already assigned an oceanographer, 2nd Lt. John C. Crowell, AC, to the Assault Training Center at Devon's Woolacombe.[2] As for the team's Officer-in-Charge, the logical choice was Instructor Commander John Fleming, RN, who had specialized in English Channel weather while serving as the Home Fleet's staff meteorologist a year before. When apprised of this new responsibility, Fleming had only one request—that it be called the "Swell Forecast Section" to provide an aura that OVERLORD might occur in a region exposed to large amounts of ocean swell.

The Section's Implementation

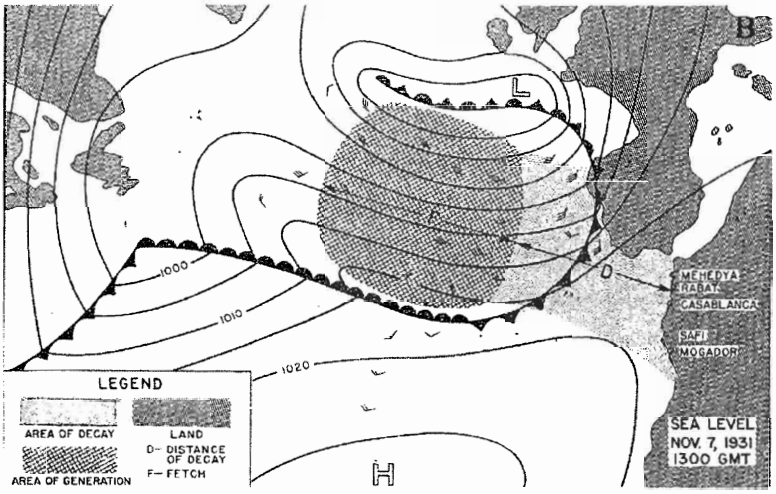
Although the decision to create the unit was made late in November, 1943, its activation within the New Admiralty's sub-basement waited until the following February. During the interim, Captain Garbett's senior climatologist, Cdr. C.R. Burgess, RN, and Lt. Crowell visited Casablanca, Morocco, to study its infamous ocean swell conditions.

From there, Crowell proceeded to the Azores but found none of its weather stations suitable for reporting sea state. Meanwhile, after helping sink the dreaded German battle cruiser, Scharnhorst, during 26, December 1943, Commander Fleming returned to London to become the Staff Meteorological Officer for Admiral Sir Bertram Ramsay, KCB, KBE, RN, the Allied Naval Commander-in-Chief, Expeditionary Force (ANCXF).[3]

To man the Swell Forecast Section, the Royal Navy provided two meteorological officers, two meteorological ratings, and two members of the Women's Royal Navy Service ("Wrens"). On the American side, the 21st Weather Squadron provided 1st Lts. Crowell and Bates plus two enlisted men (Appendix B). Furthermore, to prove to the raw Americans that London was still a military target, during the early evening of 20 February 1944 as part of Operation STEINBOCK a German Messerschmitt 410 bomber deposited a 250 kilogram (750 pound) bomb next to the New Admiralty's southern exit even as Lieutenants Cauthery, Crowell and Bates were utilizing the building's northern exit.[4]

As it so happened, back in mid-1942 both countries had begun developing independently quantitative prediction methods for sea, swell and surf that would be far better than relying on the seamen's eye. Attempts to create such methods dated back many decades to estimable breakwater designers like Thomas Stevenson and David Gaillard and the renowned geographer, Vaughan Cornish (Stevenson, 1864; Gaillard, 1904, and Cornish (1934). Nonetheless, their research did not adequately describe how a wave train decayed within distance from its generating area and then, in shallow water, changed into a plunging breaker.[5]

To remedy the situation, Garbett had assigned Instructor Commander Claude Suthons, RN, to this task. Working on his own and utilizing only empirical data and relationships, Suthons was able to provide the British assault force for Operation TORCH with useful graphs for relating wave height and period to wind speed and associated fetch and duration, as well as an estimate of their decay rate (Suthons, 1945). Meanwhile, during the same time frame, the estimable Professor Harald Sverdrup and his 26-year old protégé, Walter Munk, under a U.S. Army Air Force contract had developed an equally rudimentary swell forecasting scheme for Operation TORCH (Munk and Day, 2002). Then, after adding aerodynamic and hydrodynamic concepts, in May, 1943 Sverdrup



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Work Sheet for Experimental Sverdrup-Munk Swell Forecast **Scripps Institution of Oceanography**	
Preparation Date:	16 June 1943
Forecaster:	Charles C. Bates, 2nd Lt., AC
Locale being Forecast for:	Moulay Youssef Breakwater, Casablanca, Morocco
Weather Map in Use:	1300 GMT 7 November 1931 Surface Chart
Characteristics of Wave Generation Area:	
Wind Velocity:	17 meters/second (33 knots) (Determine Geotropically)
Fetch:	1,000 Kilometers (540 nautical miles)
Duration:	16 hours
Wave Height:	5.6 meters (18.5 feet)
Period:	7 seconds
Wave Length:	75 meters (250 feet)
Characteristics of Ocean Swell at Breakwater:	
Arrival Time:	2300 GMT, 11 November 1931
Travel Time:	80 hours
Height:	1.8 meters (6 feet)
Period:	12 seconds
Wave Length: (Deep Water)	222 meters (738 feet)

Figure 1. Wave forecasting at Scripps Institution of Oceanography, La Jolla, California, May-August, 1943 A. Initial class of military oceanographers. B. Surface weather map of 11/7/1931. C. Experimental swell forecast for Casablanca, Morocco.

began instructing Air Corps meteorologists in this new method. (Figure 1; Sverdrup and Munk, 1944, Munk and Day 2002).[6]

Nonetheless, neither the Sverdrup-Munk nor the Suthons wave forecasting method had undergone rigorous field testing. Thus, the Garbett-Steere-Moorman trio decided that the Admiralty should create a jointly-manned team charged with dual missions. First, the team would determine which was the better wave forecasting technique—that of Suthons or that of Sverdrup-Munk. After that was known, as a component of the Citadel-based Admiralty Weather Forecasting Centre, the team would generate the requisite sea, swell and surf forecasts needed by Dr. Stagg. The U.S. Navy had no personnel to spare so the Section's staffing came from Garbett's and Moorman's commands (Figure 2).

Because of the exigencies of wartime, the Section's members were run-of-the-mill. Even so, a war remained to be won. Thus, much of the Section's efforts were technical in nature. For readers interested in such detail, reference should be made to John C. Crowell's master's thesis (1946) and to the author's papers published by the New York Academy of Sciences (1940) and the American Meteorological Society (1990). As for the Section's wave forecasting accuracy, it depended heavily upon the scientific interplay among the nine primary meteorologists involved in SHAEF's convoluted weather forecasting system. Thus, to understand the full scope of such interplay, as a minimum the reader should refer to the somewhat biased books written by the participants themselves (Krick and Fleming, 1954; Stagg, 1971; Petterssen, 2001).

As for the Swell Forecast Section, its first task led by Lieutenant J.H.C. Fulford, RNVR, was establishing a synoptic network of 58 wave observations stations (Table 1 and Figure 3). Of these, only four provided measurable analog data. The other 54 stations relied on "Mark-I eyeball observations" made by His Majesty's Coast Guard beach watchers thrice daily who noted the height of every wave over a three minute interval. That done, each station then reported by code to the Admiralty the average and maximum wave heights observed plus the average wave period. Although highly subjective, the sheer mass of 1,100 wave reports weekly overcame that deficiency. In addition, having received TOP SECRET-BIGOT clearances, the wave forecasters

familiarized themselves via SECRET aerial photographs of what the surf zones were like at the designated beachheads. Then, after three months in existence, the Section issued

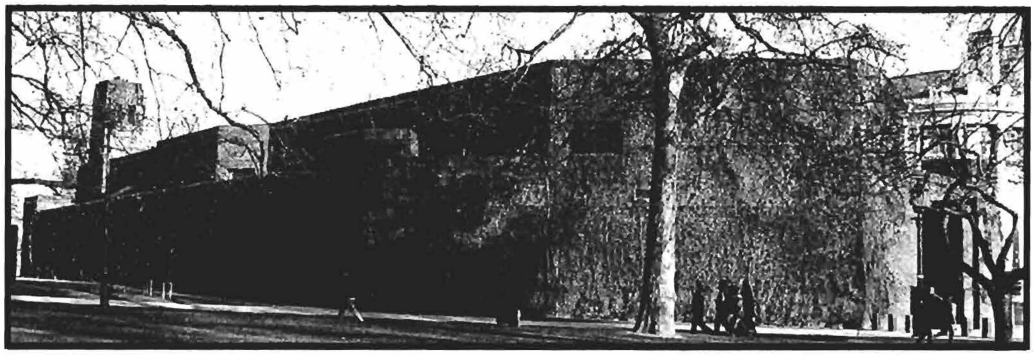

Figure 2. The Citadel, home of the Admiralty Weather Forecasting Centre. By virtue of being on temporary duty from Newfoundland, the author lived within its bunk room for the three weeks centered on D-Day, 1944.

Table 1. Wave Reporting Stations and Assault Beaches

Number	*Station*	*Number*	*Station*
1	Sennen	45	Selsey Bill
2	Cape Cornwall	46	East Beach
3	Godrevy	47	Bognor Regis
4	Fistral Beach	48	Littlehampton
5	Prah Sands	49	Worthing
6	Loe Bar	50	Newhaven
7	Woolacombe	51	Kemp Town
8	Constantine Bay	52	Cuckmere Haven
9	Pendeen	53	Birling Gap
11	Blackwood Point	54	Holywell
12	Atherfield Point	55	Eastbourne
13	St. Catherine's Point	56	Pevensey Bay
14	Woody Point	60	Sizewell
15	Foreland	61	Dunwich
21	Seven Rock Point	62	Benacre
22	Charmouth	63	Lowestoft
23	West Bay	64	Gorleston
24	Abbotsbury	65	Southwold
25	Langton Herring	66	Polling
26	Fortuneswell	67	Mundesley
27	Osmington	68	Cromer
28	Osmington Mills	69	Cley
29	Lulworth Cove		*Assault Beaches*
30	Orcombe Point	A-1	Utah, American
31	Budleigh Salterton	A-2	Omaha, American
32	Ladram Bay	B-3	Gold, British
33	Sidmouth	B-4	Juno, Canadian
34	Beer Head	B-5	Sword, British
35	Weston		

Table 2. Technical Conclusions by the Swell Forecast Section *	
Technical Issue	**Technical Conclusion**
What is meant by the term, "Wave Height"	Statistical analysis by Cauthery and Lochner indicate "Effective Height" is an appropriate value lying half way between average and maximum wave heights over a 3-minute interval.
Could Atlantic ocean swell affect the Normandy beachheads?	Observation network observes no important ocean swell beyond Start Point. Diffraction theory also suggests no notable swell in the Bay of the Seine.
When waves approach a beach at an angle, what happens to their wave height?	Based on East Anglia data, if waves refract 90 degrees, their height is reduced by 50%.
If wave trains must advance against strong tidal currents, how is the wave height affected?	Opposing 2 knot tidal streams cause early breaking and reduce surf height by 20%.
How accurate are the Section's forecast values for wave heights?	For waves under five feet in height, one foot accuracy if surface wind value is known to within a single Beaufort force and 22.5 degrees of correct direction.

*Findings as of April 1944.

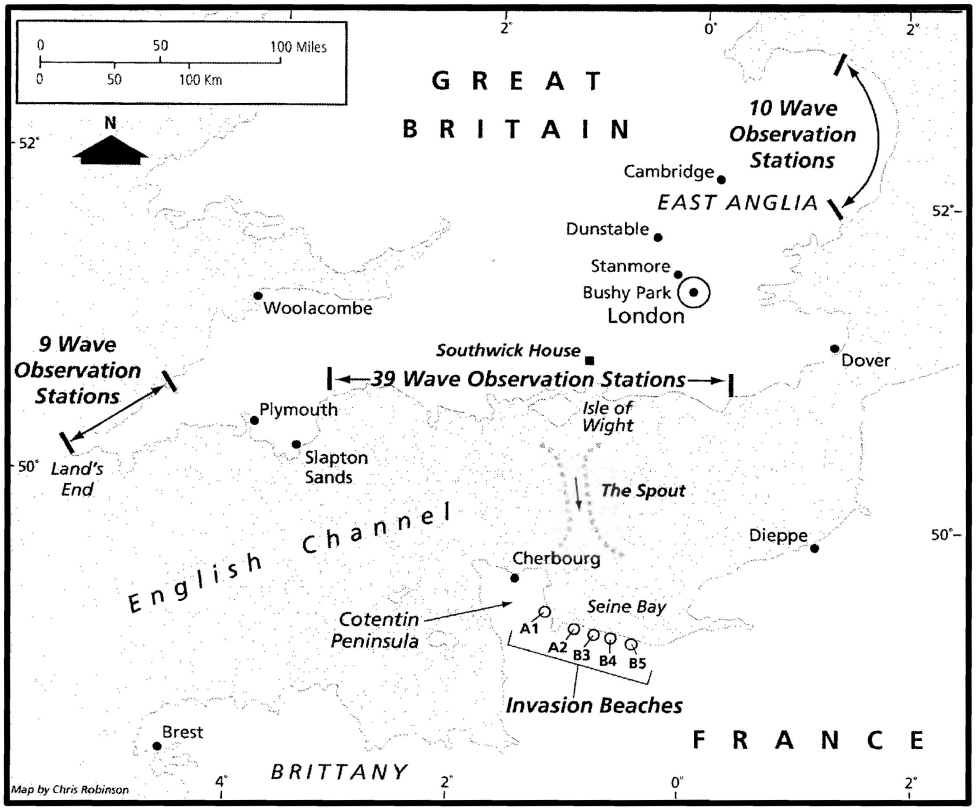

Figure 3. Map indicating key locations of sites involved in wave forecasting for Operations NEPTUNE/OVERLORD between March- August, 1944. As for "The Spout", it consisted of 10 mine-swept channels each a mile wide and all leading to Normandy.

its first CONFIDENTIAL report, "Notes on the Sea, Swell, and Surf in the English Channel," for use by staff meteorologists Fleming and Steere (Table 2).

Sea, Swell and Surf Forecasting for D-Day

Once General Eisenhower became the Supreme Allied Commander (SAC) at SHAEF, he persuaded the Combined Chiefs of Staff and its superiors, President Roosevelt and Prime Minister Churchill, that the initial OVERLORD assault required five beachheads spread over 50 miles of Normandy coastline rather than the original three beachheads. This expansion brought about three changes worth noting here. First, the maritime assault phase now had its own name, NEPTUNE. Second, the launch date for NEPTUNE/OVERLORD was postponed from early May to early June. Third, as of early April, the SHAEF complex of 1,300 personnel would move from central London's Norfolk House into a newly constructed cantonment within the 1,100 acre Bushy Park located next to the four-century old palace known as Hampton Court.

During this interim period, much of note occurred concerning how the challenging 5-day weather prognoses would be prepared for the Supreme Allied Commander. Complicating this issue was the American military revolting over an Air Ministry civilian serving as Eisenhower's senior meteorological adviser. As a consequence, during 29 March 1944, Stagg was replaced in that senior role by Colonel Donald Yates, AC, a West Pointer (Class of 1931), a pilot, and a graduate meteorologist. However, in rebuttal during 18 April 1944 the Air Ministry converted Dr. Stagg into Group Captain Stagg, RAFVR, thereby allowing him to become SHAEF's ranking meteorologist once again.

Within the next three days the new group captain ran into another hornet's nest at the Admiralty. As Stagg's SECRET diary records for Friday, 21 April 1944:

> Cmd. Fleming created a rumpus because I had asked his "Swell Section" for S.&S. forecast yesterday.... They had put me into "Swell Section." I asked Crole [Crowell] to provide and be good enough to remind the Lieutenant Commander in the[daily] Conference that I would need one each day in case I forgot. Fleming said I had no right to order his men about, that I was the most tactless man he had met, etc. It is for consideration whether speaking as he must have before all his juniors, he was not (in service courtesy) far more tactless.

Minutes of meeting held at Widewing at 3 p.m. on Tuesday, 25th April 1944, to discuss the procedure to be followed on the SHAEF Daily Conferences on Long Range Forecasts, the issue and coordination of the forecasts to be issued to the various units of the Allied Expeditionary Force, and other relevant matters.

Col. D.N. Yates			- U.S.S.T.A.F – Chairman		
Mr. E. Gold			- D.D.M.O.		
G/Capt. J. M. Stagg			- S.H.A.E.F.		
Inst/Cdr. Fleming			- A.N.C.X.F.		
Col. C.N Spencer Dr. R. C. Sutcliffe	)	A.E.A.F.	Mr. C.K.M. Douglas Dr. S. Petterssen	)	ETA [Dunstable]
Lt. Col. I.P Krick Lt. Col. B. Holzman	)	U.S.S.T.A.F. [Widewing]	Inst/Cdr. Wolfe Inst/Lieut Hoghen	)	Admiralty

It was agreed that

a. The actual SHAEF forecast should be issued, and that it should normally be issued only to those meteorological sections at the Naval, Air Force and Army C-inC Headquarters.

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2. Procedure in the Conferences:

It was explained that the participants in the conference were the Admiralty Meteorological Section,, Air Ministry Weather Central (ETA), and U.S. Weather Central (Widewing), with the Chief Meteorologist, SHAEF, acting as chairman and having the responsibility for decisions arising from the conferences.

The Naval Staff Weather Officer and Chief Meteorological Officers of the Air Commander-in-Chief participate in the conference primarily as specialists for their own Services, though their contributions to the general discussions are invited.

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4. Conference procedure and the means of achieving agreement on basic factors in the forecasts.

a. Definition of main pressure systems and fronts.
b. Timing of processes.
c. Intensities of phenomena associated with fronts.

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G/Capt Stagg explained that the decision to lay on an operation on D day would be made on the advice given on D-3, that the necessary operational orders would be issued on D-2, and that no postponement would be possible after D-1. In order to meet the requirements of the Supreme Commander, therefore, he had to give a five day forecast regularly.

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During a further discussion, ...it was agreed that... each member should act as conference opener for 2 days at a time.

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2000B (Double British Summer Time) has been provisionally fixed as the regular time for the [customary] day conference for the present.

Figure 4. Declassified abstract of key SHAEF weather conference of 25 April 1944.

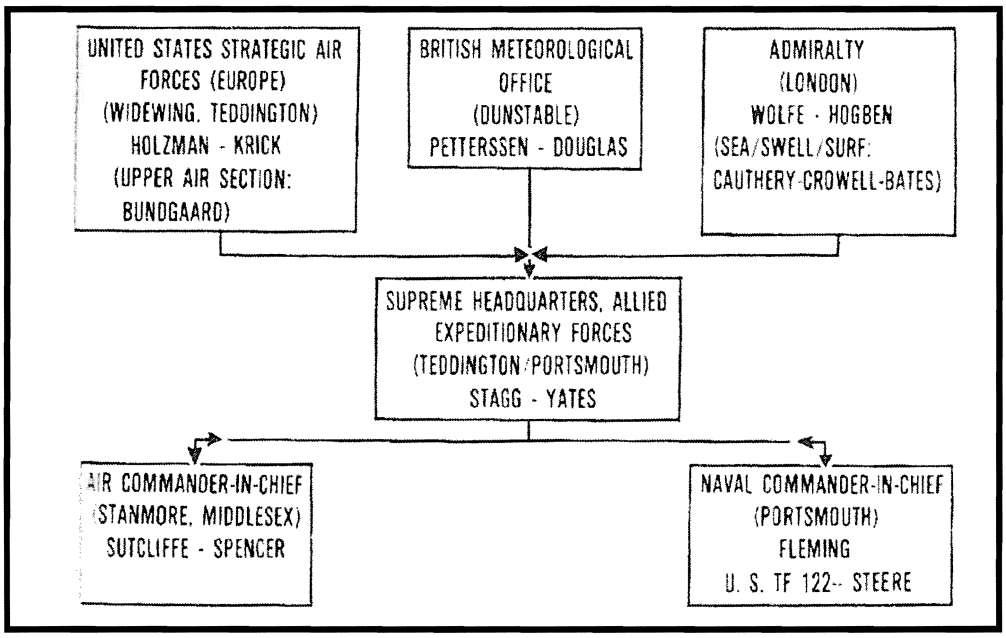


Figure 5. Schematic diagram for 6-way telephonic weather conferences used to prepare five day weather and wave predictions for Operations NEPTUNE/OVERLORD during April-July, 1944. Note: Key participants are listed by given name.

In practice, Group Captain Stagg had far more to worry about. During the subsequent Tuesday's session at the adjacent WIDEWING complex hosted by Colonel Yates, the two of them needed to finalize the final ground-rules wherein they and the three contributing weather centers would jointly generate via a scrambled telephone circuit an *agreed upon* 5-day weather forecast for any potential D-Day. Once that had been achieved, Stagg and Yates would then present the prognoses to General Eisenhower and his key staff members upon request (Figures 4 and 5; Appendix C).

General Eisenhower was noted for allowing his staff members to perform their "dog work" without interruption from above. Even so, after being reared on the stark Kansas prairie, he was a "weather worrier" with a tendency to pop in informally and personally inspect the weather charts.[7] Furthermore, during Monday, April 17th, "Ike" announced to the admirals, generals and air marshals assembled for the regular weekly command briefing (Stagg, 1971):

> ...when the time comes to start OVERLORD, we are going to have to rely very much on the weather forecast, so I want to hear what our weather experts can do. Each Monday until then Group Captain Stagg will tell us what he thinks the weather will be for the rest of the week... [Appendix D].

Then in strode the shambling six-foot seven inch tall Scot followed by a very dapper, Yates who, although he stood 13 inches lower than Stagg, was still a near look-alike to the famed movie star, Clark Gable.

By now, the Admiralty Forecast Centre's scrambled telephone circuit was operational. As a matter of routine one or two of the Section's wave forecasters listened in to each SHAEF forecasting session. As a courtesy to us, as soon as the duty forecasting team agreed upon the 5-day general prognosis, it then developed the associated surface wind forecasts. With that information at hand and by the use of specialized nomographs, the lead wave forecaster jotted down the predicted sea, swell and surf heights and passed the chit to the Admiralty's spokesman to be read back to all at the end of the 6-way conference.[8]

This system of environmental forecasting came under close scrutiny early in May 1944. During May 3rd, components of the 1st and 29th U.S. Infantry Divisions were to conduct a practice dawn landing at Devon's Slapton Sands comparable to the actual Normandy assault against OMAHA beach a month later. Following long-winded weather conferences late in April 30th and early in May 1st and despite an innocuous wave forecast, Stagg advised Eisenhower that May 3rd's weather was iffy while the following day's would be much better. "Ike" therefore postponed Operation FABIUS-1 by 24 hours. By now, all of the SHAEF command was weather sensitive. Just a week before in darkness and with waves two feet in height, 42-knot E-boats out of Cherbourg had intercepted Operation TIGER's practice convoy off Portland Bill. The result—two LSTs sunk, one LST damaged, and 749 service personnel lost in what was supposed to be a simple training exercise.[9]

Long before the Operation TIGER fiasco, Admiral Ramsay knew it would be impossible to control from London an invasion fleet of 1,213 naval combatants, 4,126 landing craft/ships, 736 naval auxiliaries, and 864 merchant vessels. Instead, he must be close to Fort Southwick's Underground Headquarters (UGHQ) located on the down above Portsmouth Harbor. There, a British complement of 450 naval, 125 army, and 125 air force communicators plus liaison personnel would maintain the master plot of what was taking place within the English Channel and over on the beachheads prior to, during and after D-Day.[10]

For his surface headquarters, Ramsay ordered HMS Dryad, the Royal Navy's Navigation School, evicted by no later than 3 April 1944 from a nearby 295 acre tract known as Southwick Park. Ramsay also mentioned the site to his fellow occupant of St. Paul's School, General Bernard Montgomery, GCB, DSO, RA. By mid-February, 1944, Montgomery, too, had decided to move his 21st Army Group Headquarters into tentage next to Ramsay's ANCXF headquarters for the D-Day operation. Eventually, although it meant living in a caravan, Eisenhower also made the 3-story Southwick House his own field headquarters for initiating Operations NEPTUNE/OVERLORD (Figure 6). Meanwhile by the time Admiral Ramsay and his staff meteorologist, Commander Fleming, came to Southwick Park during 26 April 1944, the facility had been notably upgraded. Nonetheless, out of 100 new Nissen huts, Fleming's meteorological unit rated only half of a hut, i.e., a near-windowless working space of 16x16 feet housing printers, map-spotting tables, desks, chairs, filing cabinets and vertical map-boards. (Figure 6).

During the first four weeks of May, 1944, English weather was unusually benign. Over the North Atlantic Ocean, the upper atmosphere featured a "high index zonal flow" pattern with only minor north-south perturbations embedded therein. Thus, even during May 28th, the day that Stagg and Yates were moving from London to Southwick Park, Stagg's five-day forecast stated "mainly quiet wind conditions would continue for the coming week," i.e., through Sunday, June 4th, or the day just prior to launching the long awaited invasion of France.

After arriving at the closely guarded encampment, Stagg and Yates found their living quarters to be a tent. Without any supporting staff of their own, they had to foist themselves upon the hospitality of frosty Commander Fleming. Nonetheless, Fleming considered his prime responsibility to be to Admiral Ramsay, not to General Eisenhower. Thus, if Ramsay needed to inspect a particular weather map, that chart disappeared no matter how badly Stagg wished to study it. Then, as of June 1st, additional inspections became the order of the day. What had been labeled the "Polar Front" by Dr. Jacob Bjerknes back in 1919 now featured a series of cyclonic disturbances stretching as far back as the Rocky Mountains that were certain to affect the British Isles adversely within the coming week (Bates and Fuller, 1986).[11] Moreover, spaced roughly 1,200 nautical miles apart, these wavelets increased in size and intensity as they moved eastwards over

Commander Fleming's weather shack utilized half of a "Nissen hut."

Southwick House during 1944.

STAFF METEOROLOGISTS

DONALD YATES
Colonel, USAF

JAMES STAGG
Group Captain, RAF

JOHN FLEMING
Instructor Commander, RN

The SHAEF commanders. Left to right: General Bradley, Admiral Ramsay, Air Chief Marshal Tedder, General Eisenhower, General Montgomery, Air Chief Marshal Leigh-Mallory, and Lt. General Bedell Smith.

Figure 6. The site and key participants associated with what has been termed "The Most Important Weather Forecast in the History of the World", i.e., the SHAEF forecast of 0400 DBST during 5 June 1944.

the North Atlantic Ocean with a speed of roughly 700 nautical miles per day.

General Eisenhower made the tense situation worse during Friday, June 2nd. With the proposed D-Day just three days away, "Ike" advised Stagg that he now required weather briefings during both morning and evening hours. Yates recalled:[12]

> At periodic intervals each day Stagg and I reported to the Supreme Commander who in every case had assembled his Deputy, Chief of Staff, the Commander in Chief of Army, Navy, and Air and their deputies, and his G-3. During these briefings, Admiral Ramsay... had present his meteorological officer for personal advice. No other meteorologists were present. The normal procedure was for Stagg to present with appropriate aids an analysis of the synoptic situation and then in general terms present the forecast for the period in question. I followed with more specific information on the impact of the forecast on the operations of the strategic and tactical units of the Air Force, troop carriers, paratroop units, and, if any, the impact upon the Army operations. Admiral Ramsay's Met officer usually volunteered information on the operational implications of the sea and swell portions of the forecast. We were then queried at length by all members of the group. The briefings to Supreme Commander usually lasted from thirty minutes to an hour.

From Saturday morning, June 3rd, onwards for 48 hours, the forecasters' duty time became a blur. At the 1930 DBST conference that evening Dunstable and Admiralty argued that the warm sector of a deepening cyclonic area west of the Shetland Islands would cause adverse weather over the English Channel on the proposed D-Day. WIDEWING *steadfastly* claimed the opposite. Upon pondering over Stagg's briefing Eisenhower asked that Stagg come back at 0430h the next morning with a finalized opinion. As the author listened to the telephonic weather conference at 0300 DBST, Sunday, June 4th, the weary Stagg sounded totally exhausted, Yates somewhat better, and Fleming ice-cold. Privately, however, Yates had ordered WIDEWING'S Irving Krick to join the majority's prognosis that the proposed D-Day of June 5th would feature rain, high seas, and low clouds within the assault area. Then, after listening to this updated forecast, as of 0430 DBST Eisenhower ordered this massive invasion involving 500,000 personnel postponed for 24 hours.[13]

However, within just a few hours the forecasters were beginning to revise their line of thinking. By noontime, the HMS Hoste, a weather observing frigate requested earlier by Commander Fleming for posting 600 nautical miles west of northern Ireland, was reporting by MOST SECRET MOST IMMEDIATE 3-hourly messages that

atmospheric surface pressure was rising steadily. Then at noontime stations on Ireland's west coast reported a major cold front moving eastwards at 30 knots that was certain to pass through the Normandy assault area during early Monday, June 5th. Thus, when the Centrals reconvened during the early evening, all of them were projecting with various degrees of confidence that the offending cyclone off the Shetlands would move towards Norway, the Polar Front's following cyclones deepening off Newfoundland would track northeastwards towards southern Greenland, and a modicum of high atmospheric pressure might return to the English Channel sometime thereafter. Accordingly, at the SHAEF 1930 DBST weather conference, the new 5-day forecast postulated that a stormy Monday would be followed by 36 hours of steadily improving weather. Even so, arrival of the next band of inclement weather following mid-day, Wednesday, June 7th, remained uncertain.

So on Sunday night at 2130 DBST as the harried SHAEF commanders once again were questioning the Stagg-Yates-Fleming trio, Southwick Park's officer-in-charge observed (Schofield, 1977):

> "...the trees in the copse were swaying in the rising wind and the clouds were scudding across."

Table 3. SHAEF 5-Day Wave Forecast for 5/9 June 1944*

Swell: In western approaches to English Channel, and south of 50 degrees N up Channel as far as the Cherbourg Peninsula: 6 to 7 feet Monday, decreasing to 4 to 5 feet Tuesday, 3 to 4 feet remainder of period, westerly direction throughout.	
Sea:	**Monday, 5 June:** (a) Western approaches to English Channel: 8-10 feet mixed sea and swell. (b) Near the English Coast, in the Channel: 3-4 feet west of Portland Bill, 2-3 feet in the east. (c) French Coast (except western Cherbourg Peninsula): 5-6 feet decreasing to 3-4 feet. (d) Southernmost North Sea: 5-7 feet.
	Tuesday, 6 June, D-Day, Areas as above. (a) 3-4 feet wind waves. (b) 2-3 feet becoming 3-4 feet in the west. (c) and (d) 3-4 feet except for 2-3 feet in southwestern Bay of Seine
	Wednesday to Friday, 7, 8, and 9 June. (a) 5-7 feet mixed sea and swell. (b) 2-3 feet, risk of 4 feet (c) 3-5 feet, but 2-4 feet in Bay of Seine

* Prepared at 2200 DBST, Sunday, 4 June 1944, by 1st Lt. John Crowell, AC.

Even so, based on Stagg's optimistic outlook and understanding that the wind field would still be strong enough for landlubbers making the cross-channel passage extremely seasick, Eisenhower chose a provisional "WE GO" compared to his "NO GO" of 24 hours before (Table 3).[14] Then after obtaining some rest, "Ike" six hours later would listen to the updated weather prediction and make a final operational decision.

As he reported later (Eisenhower, 1948):

> At three-thirty the next morning our little camp was shaking and shuddering under a wind of almost hurricane proportions and the accompanying rain seemed to be traveling in horizontal streaks... It seemed impossible that in such conditions there was any reason for even discussing the situation.

Thus, it was not until 0400 DBST on Monday, 5 June 1944, that the SHAEF meteorological team offered up "The Most Important Weather Forecast in the History of the World" (Hogben, 1994). Later, Commander Fleming described what occurred:[15]

> After Stagg had given his forecast and answered questions arising from it, Eisenhower asked each of his C's-in-C for his views. First, Ramsay indicated that he was prepared to resume the operation—he had no misgivings at all. Then Montgomery said he was ready to go as long as the Navy could get him there; Leigh-Mallory was, however, by no means happy and stated that in some ways conditions would be borderline, if not worse. Finally, Eisenhower, having considered all the pros and cons, closed the conference and launched the invasion with three simple words: "Okay! Let's go!

Immediately, via scrambled telephone Admiral Ramsay signaled the commanders of his Western and Eastern Naval Task Forces, i.e., Rear Admirals Alan Kirk, USN, and Philip Vian, RN, for them to begin full scale operations as of 0610 and 0654 DBST respectively, i.e., within the next two hours.

Although Admiral Ramsay believed the impending weather of June 6th provided a suitable invasion window, Admiral Theodor Kranke, his Paris-based German counterpart responsible for defense of France's Atlantic coastline, did not. So the Britisher later reported (Ramsay, 1944):

> As our forces approached the French coast without a murmur from the enemy or from their own radio, the realization that once again almost complete tactical surprise had been achieved slowly dawned.

Meanwhile, as the duty wave forecaster within the Admiralty's Citadel, the author

visited Flag Plot at 0330 DBST on D-Day morning. EXUBERANCE! Successful drops had already been made by three airborne divisions. As for the naval forces, personnel manning the Chain Home radar screens on the Isle of Wight were reporting myriads of ships moving steadily along "The Spout" on their way to Normandy. Upon going topside at 0515 DBST, he found the clearing sky full of 1,425 B-17 and B-24 bombers on their way hopefully to demolish OMAHA's beach defenses. As for the Section's 36-hour wave forecasts made late in June 4th, they were reasonably accurate. However, for actual wave conditions in the assault area, refer to Table 4.

Table 4. Observed Wave Conditions at NEPTUNE Beachheads, 6-7 June 1944*

Date	*Observation and Its Location*	
6 June 1944 (D-Day) 0300 DBST	OMAHA:	Troop unloading area 10 nautical miles offshore experiences gusty northwesterly winds of 12-18 knots. Wave heights of 3-4 feet with occasional interference waves up to 6 feet. Choppiness makes personnel transfer difficult.
0540-0640 DBST	ALL BEACHES:	Skirted Sherman tanks (DD-Dual Drive, treads and propellers) launched even though operational limit is 1-foot high waves. Consequences: UTAH: Launched 0.6 miles offshore into 2-foot waves. 27 out of 28 tanks reach shore. OMAHA: Launched 3.5 miles offshore into 3-4 foot waves. 27 out of 29 tanks sink. GOLD & JUNO: Launched 0.4 miles offshore into 3-foot waves. 42 out of 58 tanks reach beach. SWORD: Launched 2.2 miles offshore into waves less than 2 feet high. 24 out of 24 tanks reach beach.
1200 DBST	UTAH OMAHA	Surf less than 2 feet high. Transport unloading area continues with choppy waves 3 to 4 feet high; surf 2 feet high.
1800 DBST	OMAHA	Surf 1 to 2 feet high; offshore waves 2-3 feet high. Wind remains northwesterly 12-18 knots.
7 June 1944 (D-plus-One) 1200 DBST	OMAHA	Offshore waves still 2-3 feet high… northwesterly wind speed of 10 knots or less. Surf 1-2 feet high.

* Pritchard, D.W., 1st Lt., AC. Memorandum to Regional Control Officer, 21st Weather Squadron dto 30 June 1944.
Fletcher, David. *Swimming Shermans: Sherman DD Amphibious Tank of World War II.* Oxford: Osprey Publishing, 2006.

Wave Forecasting for the "Big Storm" (19-22 June 1944)

Following June 6th, Section activities were quiescent for the next 11 days with one exception. During D-plus-8 (14 June 1944), Lt. Crowell reported for duty complaining of shrapnel rattling around his wash basin in Half Moon Street because of low-flying

German aircraft during the night. These aircraft, of course, were the pesky "doodle-bugs" with 850 kilogram (1,870 pound) warheads that soon would be impacting Greater London an average 80 times per day. Even so, denizens of the Citadel had nothing to fear for their windowless structure was capped with 20 feet of concrete. Unknown to us, however, was the War Office's ongoing use of 600,000 tons of the same material for building artificial harbors off the OMAHA and GOLD beachheads by D-plus-21 (27 June 1944).

Termed a "MULBERRY," such a harbor would be approximately the size of Dover Harbor and enclose a square mile of beach front featuring a 21 foot change in sea level during spring tides. On the deep water side, three lines of barriers would suppress incoming waves. Furthest out were a row of Admiralty-designed BOMBARDONS comprised of 24 free-floating but anchored steel cruciforms with a 19 foot draft. At mid-point and firmly emplaced in a low tide water depth of 30 feet were 26 PHOENIXs consisting of massive free flooding concrete caissons each 200 feet in length. Then close in for the protection of small craft were "CORNCOBS," a string of antiquated ships intentionally scuttled into 10 feet of water at low tide. Finally, for rapid ship-to-shore transfers several miles of floating roadways extended out to Lobnitz pierheads that moved upwards or downwards with the tide level. As for a MULBERRY's ability to withstand wave action, its prime designer, Brigadier Bruce White, CBE, RE, assumed it would stay intact throughout a conventional summer storm featuring Beaufort Force 6 winds (approximately 24 knots) (White, 1980).

All told, 35 convoys moving as slowly as 3 knots were required to bring the MULBERRY paraphernalia across the Channel. Scheduling such convoys fell within the purview of Admiral Ramsay. Accordingly, Commander Fleming noted later:[15]

> It was decided that the most important convoy of all carrying very large quantities of essential heavy equipment should, if possible, be held back until there were prospects of a period of 48 hours with little or no wind and calm seas. By 17th June (D plus 11), it appeared that ideal conditions would prevail for the next two or three days.... On the strength of my forecast to this effect, the [100 tug] convoy was ordered to sail on 18th June.

Unfortunately, at this very time, both Fleming and Stagg's SHAEF team of meteorologists fell into a "sucker's hole." Based on prior episodes, they predicted a lobe

of 1,030 millibars pressure would extend northeastwards from the Azores into the English Channel area, thereby allowing calm seas. Instead this lobe's center paused near southern Ireland while a low pressure zone moved up from southern France. Consequently, from June 19th through June 22nd near gale force winds blew from the northwest directly down the Channel for 120 miles. Thus, Ramsay's special convoy became a total wreck. Fleming further remembers:

> If previously I had never experienced sheer misery, I certainly did now, and the fact that I was living in close contact with those responsible for ordering the operation was as salt in my wounds… the feel that one had been, however inadvertently, the main contributor to what was almost a major disaster is something not easily put aside."

Because the onset of the storm was not predicted, pandemonium reigned throughout the beachheads. Fortunately, northwesterly winds offered only a glancing blow to the British sector so its MULBERRY-B, now called Port Winston, and associated small craft suffered only moderate damage. Off OMAHA, however, aboard the U.S. flagship USS AUGUSTA, Commander Steere was reporting maximum wave heights of 12 feet and wind gusts up to 32 knots. Inshore, chaos. With inadequate holding tackle, 800 landing craft collided with each other or stranded on the beach. Early on, five break-away LCTs hit the floating roadways and caused them to buckle badly, thereby dooming the pierheads from future use. Even worse, the 200-foot long BOMBARDONs broke loose and struck the embedded PHOENIXs, damaging 21 out of 31 of those vital blockships beyond repair (Figure 7).

At the time, it did not seem possible but all storms must end. In anticipation, during the mid-afternoon of June 21st (D-plus-15), Portsmouth's convoy dispatcher called Admiralty for advice as to when beachhead surf heights would drop to a tolerable level, i.e., to four feet or lower. As the wave specialist on duty, the author indicated 24 hours hence. In the storm's aftermath, after inspecting the American's MULBERRY-A, Rear Admiral Kirk recommended its abandonment. During 2 July 1944 (D-plus 26), General Eisenhower concurred even though Cherbourg was still nearly useless and Breton's ports of Brest, St. Nazaire, and Lorient were far from being captured. In other words, the requisite 20,000 tons of daily supplies for what was now the 1st and 3rd U.S. Armies must continue primarily arriving over the beachheads.

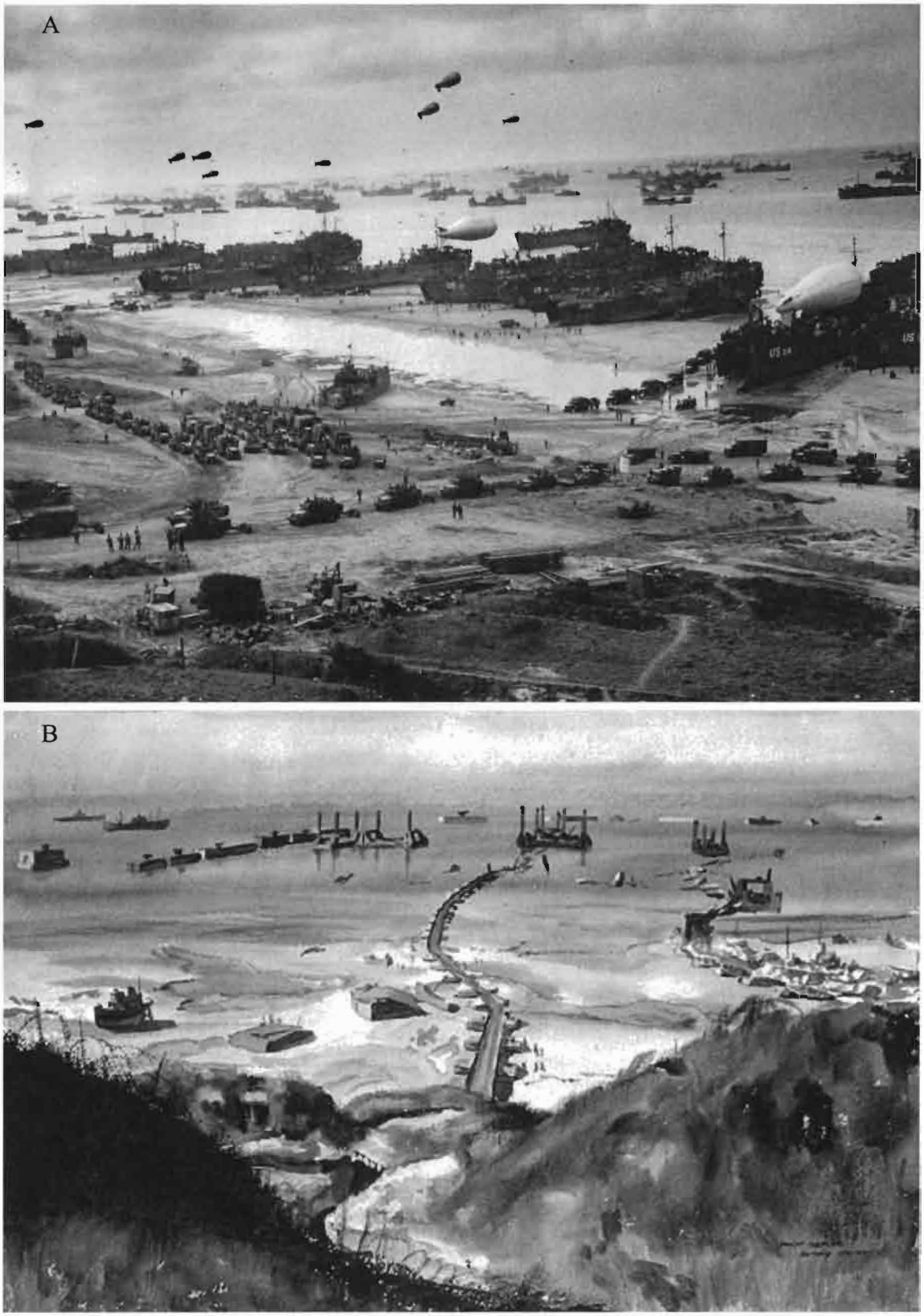
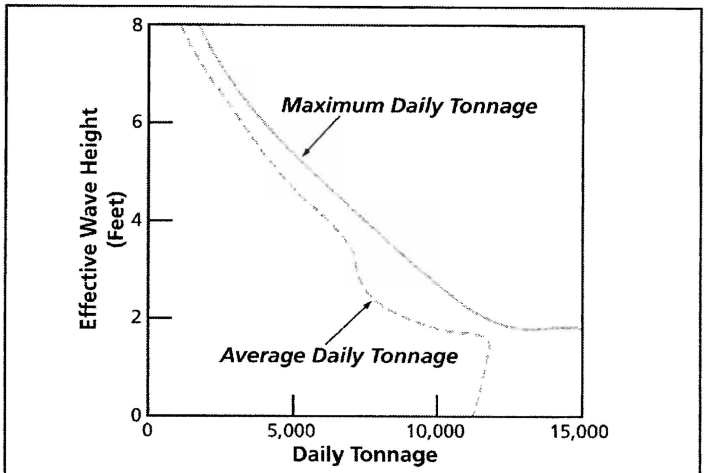


Figure 7. OMAHA Beachhead before and after "The Big Storm". A: D-plus-9 (15 June 1944)--9,000 tons of cargo successfully offloaded. (US Army photo). B. D-plus-17 (23 June 1944)—MULBERRY-A wrecked beyond repair (Naval Historical Center).

The Swell Forecast Section's Post-NEPTUNE Interlude

Operation NEPTUNE ended during D-plus 24 (30 June 1944), while Operation OVERLORD ended with the capture of Paris during D-plus-80 (25 August 1944). However, for the wave forecasters 28 July 1944 became an informal "Freedom Day" for thereafter the Admiralty Forecast Centre no longer participated in SHAEF's daily telephonic conferences. Instead, the main issue of the day became: "Are our daily wave forecasts of value to the field commands uploading supplies over the Normandy beaches?" To that end, Lts. Crowell and then Bates visited the Normandy beaches to learn the answer. At the British 1st Assault Force near Honfleur, our former cohort, Lieut. (Sp) J. H. C. Fulford, RNVR, advised that Admiralty wave forecasts were of interest but not vital. Over at OMAHA, the Naval Officer in Command, Captain Chauncy Camp, USN, advised that our prognoses were of little value for he preferred "... to keep a sharp eye on the glass."

However, during a late afternoon visit in 29 July 1944 to the Headquarters, 5th



Wave Height	Work Status
0–2	Ideal for small craft and ship-to-shore transfers.
2–4	Modest difficulty in ship-to-shore operations and for small craft.
4–6	Major difficulty in ship-to-shore transfers and for small craft.
6 plus	Dangerous inshore operations. Open sea tows difficult.

Figure 8. Relationship between effective wave height and rate of offloading cargo, OMAHA Beachhead, 11 June-31 July 1944.

Engineer Special Brigade, Lt. Bates found a much different situation. Unannounced four foot high waves induced by local sea breezes were about to suspend the entire 250 DUKW ship-to-shore transfer process because of safety issues until the following dawn. Moreover, no advance planning had been made for utilizing what would soon be wasted downtime. To ameliorate the situation, in a nearby apple orchard Colonel Moorman directed the author to return to London and determine, if possible, the definitive correlation between wave height and offloading rate. To do so, the lieutenant acquired the SECRET daily offloaded tonnage numbers for OMAHA's first 50 days of operation and plotted them against existing wave heights. The relationship was clear-cut. Should wave heights be below two feet, other factors controlled the unloading rate. Above that, however, efficiency steadily declined to about 10% when waves became six feet high (Figure 8).

With this relationship at hand, Eisenhower's Chief Engineer, Major General Cecil R. Moore, CE, and Colonel Moorman agreed that Moorman's roving oceanographers, 1st Lts. Donald W. Pritchard and Robert O. Reid, should have their own beachhead weather unit, Detachment YK, at Carentan.[18] It was a decision well taken. Even during 7 September 1944 when YK was activated, the port of Cherbourg was delivering only 3,000 tons of cargo per day while OMAHA and UTAH could jointly provide 25,000 tons daily under optimal conditions. Moreover, it remained mandatory that beach operations continue at that rate because Antwerp did not open to ocean shipping until November 28th. Once that took place, Detachment YK then left for a plush new posting close to the Arc de Triomphe in Paris, France. Meanwhile, back at the Admiralty, Captain Garbett with Colonel Moorman's concurrence was transferring the Swell Forecast Section to the Joint Meteorological Centre, Colombo, Ceylon [Sri Lanka] to forecast wave conditions for the Southeast Asia Command and the Commander-in-Chief, East Indies Fleet.

The Swell Section in Southeast Asia

During the Section's reconstitution in Colombo during mid-January, 1945, its title became simply "Swell Section." It was also told to prepare for the upcoming invasions of Burma (Operation DRACULA), and of Malaya (Operations ROGER and ZIPPER). After two months of extensive travel and negotiations, the Section's synoptic network of wave reporting stations might, on a good day, consist of 16 collaborative stations spread

over an area of 3,000 miles. Of these, 14 were Mark-I eye-ball stations manned by native civil servants. However, by mid-summer Teddington's Admiralty Research Laboratory (Group W) planned to be operating bottom pressure recorders at Addu Atoll and Colombo (Table 5 and Figure 9).

Table 5. Wave Reporting Stations for Bay of Bengal Wave Forecasting, June, 1945

Number	Station	Number	Station
			India
1	Cocos Island		
2	Diego Garcia	8	Negapatam
3	Addu Atoll	9	Madras
		10	Coconada
Ceylon (Sri Lanka)		11	Vizagapatam
		12	Puri
4	Colombo	13	Sandheads Lightship
5	Kogalla	14	Sangor Island
6	Hambantota	15	Chittagong
7	Trincomalee	16	Cox's Bazar

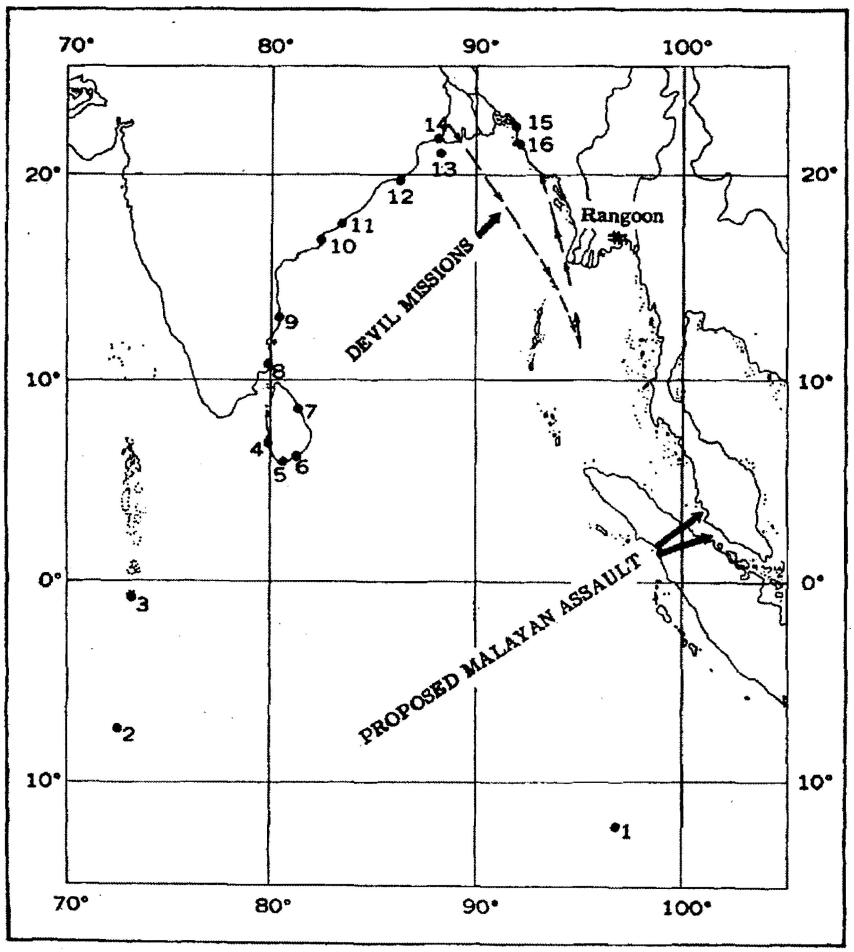


Figure 9. Map indicating place-names of wave reporting stations established to assist in wave forecasting for Allied amphibious operations within Southeast Asia during May-September 1945.

The Southeast Asia Command was a catch-as-catch-can operation spread over an some 1,200 miles by 1,500 miles. Even so, Lord Louis Mountbatten, its Supreme Allied Commander, intended that DRACULA would be a miniature version of NEPTUNE. To ensure there would be no weather surprises, during 22 April 1945 the USAAF's 2nd Weather Reconnaissance Squadron began flying B-25s on daily DEVIL missions with wave observer Technical Sergeant Lochner on board over the Andaman Sea to a point 300 miles south of Burma. Simultaneously, the submarine, HMS Strongbow started loitering off the western tip of Sumatra. For local meteorological coverage, Lieut. Cauthery joined the naval task force's HMS Blackmore, a destroyer accompanying two battle ships, six escort carriers, six cruisers, 14 other destroyers, and numerous troop transports containing the 26th Indian Division.

As an extra fillip, the 10th Weather Squadron's Colonel Richard Ellsworth, AC, flew down from Calcutta [Kolkata] with a jeep for Crowell's and Bates's personal use. Behind this donation was Ellsworth's urgent need for knowing well in advance whether the naval task force would or would not be about their mission. In a different role, Moorman was the staff weather officer for the 10th U.S. Air Force. Thus, he must also advise Major General Howard Davidson, AC, whether the 1st and 2nd Air Commando Group's C-47s could safely drop the 3rd Gurkha Parachute Battalion into the outskirts of Rangoon 30 hours ahead of the naval support craft's arrival. This proved to be a valid issue for just as the invasions of Morocco, Sicily, and Normandy began, adverse weather conditions appeared locally during D-2. In this instance, Lieut. Cauthery decided that although there was a small but intense low pressure area only 100 miles across to the south of the assault force, the storm would move rapidly to the northwest. Fortunately, it did. DRACULA thereby proceeded on schedule, allowing Rangoon to be captured on the same day that Berlin, Germany fell, i.e., during 2 May 1945.

Then, even as Lieut. Cauthery returned from HMS Blackmore, his American co-workers were under immediate orders to proceed to Chengtu, China to prepare for a coastal invasion of that country. Once in Kunming, however, they were diverted to the Headquarters, Far East Air Force, in Manila, the Philippines.[19] Then, while aboard the USS El Dorado in Manila Bay planning the invasion of Kyushu, Japan (Operation OLYMPIC), Crowell and Bates listened to the loudspeaker blare that an atomic bomb

had exploded over Hiroshima during 8 August 1945. As for the Swell Section's British component, it, too, disbanded when Lord Louis Mountbatten accepted the surrender of Japan's 680,000 member armed force in Southeast Asia in 12 September 1945.

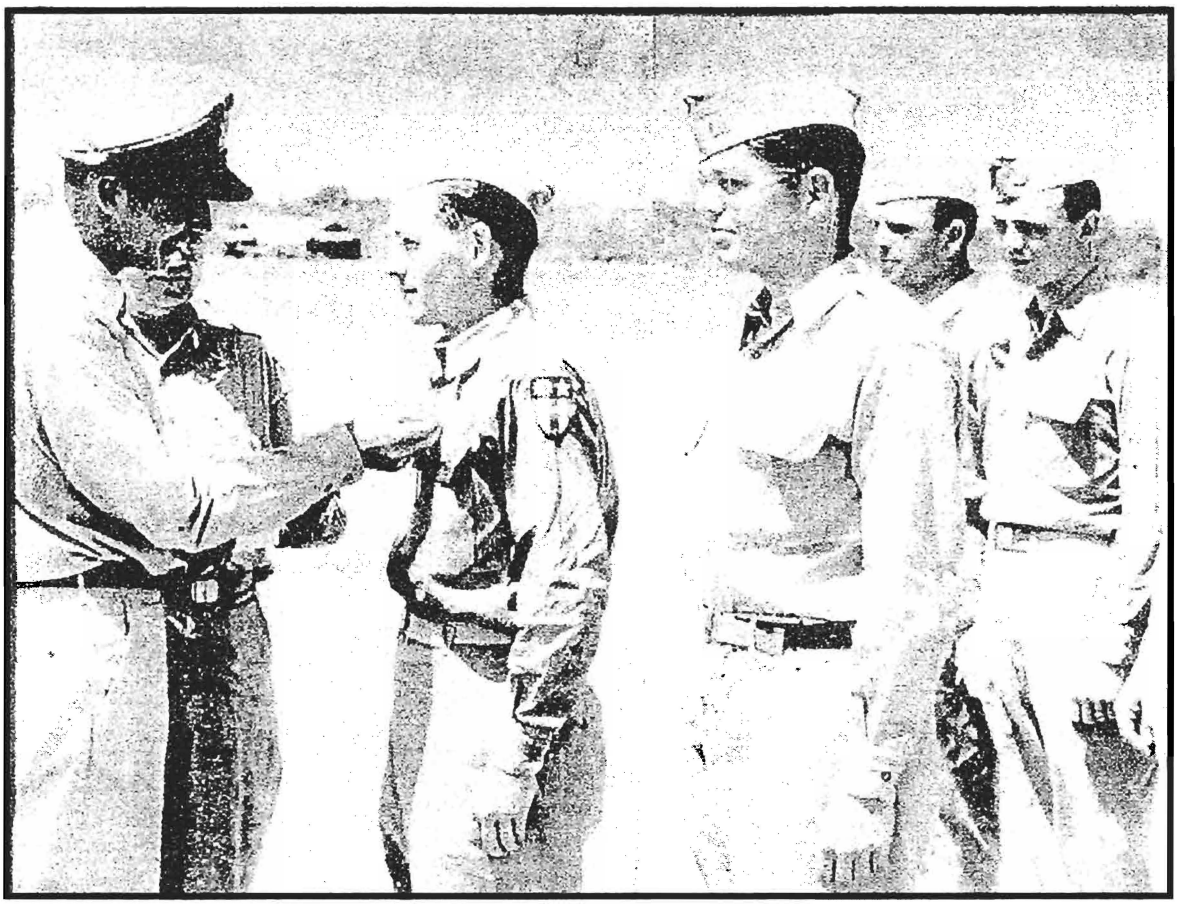


Figure 10. Ceremony at Ratmalana AFB, Ceylon, during February, 1945, awarding Captain Charles C. Bates, AC, the Bronze Star Medal per a Ninth Air Force General Order dating back to November, 1944. Awaiting receipt of a similar award is Captain John C. Crowell, AC.

EPILOGUE

Even as Captains Crowell and Bates were changing from the European to the China-Burma-India theatre of war the 21st Weather Squadron presented them with a citation which read in part:

> "… for sharing a great deal of the responsibility for making the science of oceanography a significant factor in an assault landing."

Formalizing this kudo even further came during 7 November 1944 when General Orders #260 of the Ninth Air Force awarded them Bronze Star medals "For meritorious service in connection with military operations against the enemy in June 1944." (Figure 8).

In contrast, in his book, *Forecast for Overlord, June 6, 1944*, Group Captain Stagg never mentions the Swell Forecast Section. On the other hand, in Professor Petterssen's memoir, *Weathering the Storm: Sverre Petterssen, the D-Day Forecast, and the Rise of Modern Meteorology,* the nautically aware Norwegian notes:[20]

> Since so much has been said and written about the weather aspect of the work, it seems appropriate to mention that there was also a marine problem… The marine part of the work was handled with skill and convincing professionalism by the Admiralty center; only rarely did Widewing and Dunstable contribute to the discussions. At least one part of the [forecasting] problem remained noncontroversial.

With respect to the Section's decision to define predicted and/or effective wave height as the mid-point between the average and maximum wave heights observed over a three-minute interval, this concept became quickly outmoded post-war.[21] By 1948, engineers of the Admiralty Research Laboratory were using frequency analyzers to scan electrical analog recordings of ocean wave trains. As a consequence, they found that a given wave train could best be described by two parameters—its peak frequency and its total energy.[22] Nonetheless 39 years later the esteemed Professor Henry Charnock, FRS, could still report (Charnock, 1987):

> Certainly modern observations agree rather well with those of Sverdrup-Munk 45 years ago. Both they and Suthons made a major contribution not only to the war effort but to our knowledge of seawaves and swell.

As for those early inventors of modern day sea, swell and surf forecasting, Suthons survived into his 90s. Back in Norway, Sverdrup, unfortunately, died at age 68. Meanwhile, his protégé, Walter Munk, became the "Grand Old Man of American Oceanography" with the receipt of awards such as the Kyoto Prize of $446,000 (1999) and the Crafoord Prize of $550,000 (2010) along the way. The key forecasters involved in Operations NEPTUNE/OVERLORD also pursued notable careers (Appendix E). Even so, all clearly remembered General Eisenhower's response to Dr. Stagg when the latter called the general's attention to the group's inaccurate forecast of D-plus-13:[23,24]

"I thank the gods of war we went when we did."

Acknowledgments

This unit history has been prepared 65 years after the fact. To do so, the author utilized technical critiques and British documents provided by Brian Booth, Devizes, Wiltshire; upon extracts with permission from *Surf Forecasting for Invasions during World War II* by Santa Barbara, California's Professor John Crowell; upon Bushy Park recollections by Colonel Robert Bundgaard, USAF (Retired), of Madison, Connecticut, and upon editorial suggestions plus word processing by Dr. Thomas Mitchell of Georgetown, Texas. The American Meteorological Society's permission to quote from Sverre Petterssen's *Weathering the Storm* is also appreciated.

Notes

1. During 19 August 1942, the Allied 6,033 man raid against German-held Dieppe, France incurred 55% casualties over an eight hour interval. In contrast, between 8-10 November, 1942, the 125,000 men attacking the Vichy French in northern Africa experienced a 1.2% casualty rate.
2. An US Army Air Force weather squadron consisted of multiple units scattered over areas hundreds to thousands of miles across. In view thereof, its ranking officer was a colonel termed the "Regional Control Officer." As for Moorman's 21st Weather Squadron, it consisted of 40 mobile weather units scheduled for deployment to the Far Shore at the earliest possible moment. Contemporaneously, he was also the Staff Weather Officer to the Ninth Air Force and to the 1st US Army.
3. Highly organized, Admiral Bertram Ramsay, RN, was equally adaptable. Thus, by using an additional armada of small volunteered vessels, Operation DYNAMO under his command evacuated 198,229 British and 139,977 French troops from Dunkerque, France between 27 May-4 June 1940.
4. During 23 February 1944 Churchill wrote a longhand note to Roosevelt concerning the second of the three-bomb release. Upon detonating within the garden of Number 10 Downing Street, that bomb caused the plaster ceilings within the Prime Minister's residence to fall. As "WC" reported: "It is surprising what curious blast effects have followed from these few bombs. Places as much as 500 yards away have been affected, while others quite close to have been missed out."
5. Today's Beaufort Wind Force Scale dates back to 1806 when Commander Francis Beaufort, RN, began standardizing an empirical method for describing wind speed keyed primarily to observed sea conditions.
6. In his book, *Problems of Water Waves* (1935), Dr. Hans Thorade of the Deutsche Seewarte (German Naval Observatory) advised: "Complete agreement between theory and observation is seldom found, and where it is found, it seems suspicious."

7. Bundgaard RC. Personal communication 29 August 2010; Checketts, HJ, Ltr to Bates dtd 14 November 1994; Stagg, *Forecast*, pg. 46.
8. By and large, the six way SHAEF telephonic weather conferences occurred during evening hours, primarily circa 0130 and 2000 DBST. On the other hand, Lieut. Cauthery resided in northern London with a wife and small daughter. Accordingly, his co-workers mandated that he spend nighttime hours with them.
9. During practice operation TIGER, 749 men lost their lives. As for D-Day, 179 troops were killed at UTAH Beachhead and 2,000 men at OMAHA Beachhead.
10. The Underground Headquarters consisted of a mile of tunnels reached by stairways of 167 steps. Over 80 percent of the staff were women auxiliaries wearing bell bottom trousers. Work shifts lasted 12 hours with only one 10-minute break for obtaining a smoke or breath of fresh air topside.
11. Crowell and Bates were taught meteorology not only by the famed Professors Jacob Bjerknes and Harald Sverdrup but also by the equally famed Carl-Gustav Rossby at the University of Chicago. In contrast, forecasters at the Royal Navy and the Meteorological Office were trained in-house. During early 1946, Bates also was Professor Rossby's personal assistant for issues pertaining to the American Meteorological Society.
12. Yates DN. Ltr to Merewether A. dtd 2 March 1953.
13. Ibid. 1980. Oral history interview 10 June 1980. Hasdorff JC, Oral History Division, USAF. Pg. 87-88.
14. Dunstable's and WIDEWING's aeronautically oriented forecasters often smudged wind forecasts by issuing statements like "Winds will be Beaufort 3-4." As a result, wave forecasters had to utilize considerable judgment in converting that prediction to wave height for it could indicate heights somewhere between two and four feet, i.e., "Go" to "Marginal".
15. Fleming J. Ltr to Bates C. dtd 21 September 1981.
16. Ibid.
17. Ibid.
18. Second Lieutenants Pritchard and Reid were November, 1943 graduates from Scripps' second class in military oceanography. For their oceanographic skills, both were ultimately elected to the National Academy of Engineering, Reid in 1985 and Pritchard in 1993.
19. For Crowell, Bates and Lochner to travel from Colombo to Manila was a saga in itself. The first leg, Colombo to Chabua, India, was by multiple hops via C-47 aircraft. Next came the leg, Chabua-Kunming, China, involving leading the 10th Weather Squadron's first vehicle convoy over the Ledo-Burma Road. Finally, the China-Philippines leg utilized a secret flight from Kweilin to Manila over 700 miles of Japanese held territory.
20. Petterssen, *Weathering the Storm*, p. 217.
21. Although the Swell Forecast Section utilized its dual concept of "predicted wave height" and "effective wave height" throughout WWII, Munk at the Scripps Institution developed a comparable value known as "significant wave height." His particular term in use even today consists of averaging the heights observed of the one-third largest waves within a specific wave train.

22. Barber NF and Ursell F. 1948. The Generation and Propagation of Ocean Waves and Swell. *Phil Trans R Soc A* **240(824)**: 527-580.
23. Stagg JM. 1944. Report to the Supreme Commander on the Meteorological Implications in the Selection of the Day for the Allied Invasion of France, June 1944. SHAEF. 22 June 1944.
24. Stagg JM. 1971. *Forecast*, pg. 126.

Appendices:

APPENDIX A
New Types of Landing Craft Utilized in World War II's European Theatre

Name/Abbreviation	Originator & Introductory Year	Length (Feet)	Tonnage (Loaded)	Stranding Depth (Feet)	Transport Ability
Landing Craft Assault, LCA	United Kingdom 1939	42	13	2	36 troops. Wood construction.
Landing Craft Tank (Mark 1)-LCT(1)	United Kingdom 1940	117	286	4	4 Medium Tanks.
Landing Craft Vehicular/Personnel LCVP	United States 1941	36	12	2	36 troops or 1 vehicle (Jeep). Wood construction.
Landing Craft Mechanized, Mark III, LCM(3)	British, 1942	50	52	3	1 medium tank or 50 troops.
Amphibious Truck DUKW	United States 1942	31	8	3	2 tons cargo for 58 miles water; 400 miles road.
Ferry, Self-Propelled. RHINO	United States 1942	70 to 100	Up to 900	2	Various. Navy pontoons lashed together. Two stern outboard motors.
Landing Ship Tank LST	British/United States, 1942	327	3,880	4	20 medium tanks, 27 other vehicles, 191 troops.
Landing Craft Infantry, Large LCL-L	British/United States, 1943	158	389	5	180 troops offloading via narrow side-ramps.

Appendix B. Swell Forecast Section's Biographical Backgrounds

Name/Rank	*Life Span*	*Education*	*Remarks*
THE INSTIGATORS			
Garbett, Leonard Captain, RN	1879- 1974		1909: Lieut. Royal Navy 1919: Cdr.; returns HMS *Mersey* (monitor) to Plymouth from E. Africa 1921: Superintendent, Naval Services, Meteorological Office 1937: Capt., RN (Ret) appointed Superintendent Naval Meteorological Branch, Admiralty
Moorman, Thomas Colonel, AC	1910- 1997	US Mil. Acad. BS-1933 CalTech (Meteor.) MS-1938	1934: Pilot Rated 1941: Asst. Director, Air Corps Weather Research Center 1943: Regional Control Officer, 21st Weather Region
Steere, Richard Commander, USN	1909- 2001	US Naval Acad. BS-1931 MIT (Meteor.) MS-1940	1931: Duty USS Pennsylvania (BB-38) 1932: Bronze Medal, Fencing, Olympic Games 1936: Commander, USS Porter (DD-356) 1940: Staff Weather Officer for COMPHIBLANT (USS Augusta,)
THE STAFF MEMBERS			
Fleming, John Inst. Commander, RN	1904- 1994	Cambridge Univ. BA, 1926	1926: Instructor Lieut., RN 1940: Instructor Cdr (Meteorology) 1941: Posted Home Fleet, Nore 1943: Posted Home Fleet, Scapa Flow
Cauthery, Harold Instructor Lieut., RN	1914- 1987	Cambridge Univ. (Christ's College) BA (Math)-1935 BA (History)-1936	1936: Inland Revenue Service 1939: Asst. to Minister of Housing 1942: Inst. Lieut., Royal Navy
Fulford, J.H.C. Lieut. (Sp), RNVR			1941: Tobruk, Libya (siege of) 1944: Installed wave observation network.
Crowell, John C., AC	1917-	Univ. Texas (Austin) BA (Geology)-1938	1938: Geologist, Shell Oil. Co. 1942: Aviation Cadet (UCLA/Chicago) 1943: 2nd Lt. (Scripps Inst. Oceanography, May-August
Bates, Charles, AC	1918-	DePauw Univ. BA (Geology)-1939 UCLA-MS (Meteorology)-1944	1939: Geophysical Trainee, Standard Oil (NJ) 1941: Sgt., 2nd Field Artillery Observation Bn. 1942: Aviation Cadet (UCLA/Chicago) 1943: 2nd Lt. (Scripps Inst. of Oceanography, May-August) 1944: 1st Lt., Forecaster, Stephenville, Newfoundland AFB
Lochner, Ernest Tech. Sgt., AC	1915- 1996	Penn. State Univ. MS (Ichthyology), 1940	1944: Statistician
Hynes, E.L., Sgt., AC			1944: Clerical support (Feb.-Nov.)
Two ratings, Women's Royal Naval Service			1944: Data compilation and map plotting
Two ratings, Royal Navy Volunteers			1944: Dan buoy observing station, Sidmouth, Devon
THE TECHNIQUE INVENTORS			
Suthons, Claude T. Inst. Commander, RN	1895-	BA (University unknown)	1942 – 1945: Author, *Forecasting of Sea Swell Waves, Naval Met. Branch Memo 135/45*
Sverdrup, Harald U. Prof. Scripps Inst. of Oceanography	1888- 1957	Ph. D. Leipzig, 1917 (Meteorology)	1936: Director, Scripps Inst. Oceanography 1944: Author, *Wind, Waves and Swell. Principles in Forecasting. H.O.* Misc. 11,275 (Confidential)
Munk, Walter H. Staff Assistant	1917-	MS, Univ. Calif. Los Angeles, 1940 (Geophysics)	1944: Co-author, *Wind, Waves and Swell, Principles in Forecasting. H.O.* Misc. 11,275 (Confidential)

Appendix C. Key Participants in SHAEF Telephone Weather Conferences for NEPTUNE/OVERLORD

OFFICER (Life Span)	*EDUCATIONAL HIGHLIGHTS*	*REMARKS*
SHAEF Headquarters		
James M. Stagg Group Captain (1900-1975)	Ph. D. (Physical Sciences), Edinburgh (1924)	Although Stagg's specialties were geomagnetics and radiation, Met Office posted him to be SHAEF'S top meteorologist—and in civilian status.
Donald N. Yates Colonel, USAAF (1909-1993)	B.S., U.S. Military Academy, (1931); Pilot Rating (1932); M.S. (Meteorology), CalTech (1939)	Although a gymnast small in stature, his military bearing was highly evident as was his no-nonsense personality.
ANCFX Headquarters		
John Fleming Instructor Cdr, RN (1904-1994)	B.S., Cambridge (1926)	Despite being a "schoolie", Fleming was a very proper naval officer awarded the Distinguished Service Cross for helping sink the Scharnhorst (12/26/1943).
KEY SUPPORTING METEOROLOGISTS		
METEOROLOGIST	*EDUCATIONAL HIGHLIGHTS*	*REMARKS*
British Met Office, Dunstable		
C.K.M. Douglas Civilian, OBE, AFC (1893-1982)	RAF pilot in France (1918)	Dean of Met Office forecasters with total recall of prior synoptic weather situations dating back two decade. Inarticulate.
Sverre Petterssen Civilian (1898-1974)	Ph. D., Oslo (1933)	MIT professor (1939-1942) reared north of the remote Lofoten Islands. Skilled forecaster of Scandinavian weather.
U.S. Strategic Air Forces in Europe (Widewing, Bushy Park)		
Benjamin G. Holzman Lt. Colonel, USAAF (1910-19)	Ph. D., CalTech (1934)	Articulate former Chief Meteorologist, American Airlines (1940-1942)
Irving P. Krick Lt. Colonel, USAAF (1906-1996)	Ph. D., CalTech (1934)	Brilliant but a bombastic and devious meteorologist famed for offering forecasts further into the future than merited by the existing data.
Admiralty Forecast Center, the Citadel, London		
Geoffrey Wolfe Instructor Lt. RN (1911-2008)	B.S., Cambridge	Urbane, level headed forecaster. One of 424 survivors when battleship HMS Barham exploded violently off Libya (11/25/1941).
G. Lawrence Hogben Instructor Lt, RNZN (1916-200)	Ph. D., Oxford (1939) (Mathematics)	Feisty Rhodes Scholar. First naval instructor to earn the Distinguished Service Cross. (Battle of the Barents Sea, 12/31/1942).

APPENDIX D
Time Line: Ocean Wave Advisories for the Supreme Commander Allied Expeditionary Force

Date	Remarks
1943	
Late November	Captain L. Garbett, RN, Director, Naval Meteorological Service, meets with Col. T. Moorman, USA, and Cdr. R. Steere, USN. Wave forecasting for NEPTUNE will be joint effort with Royal Navy as lead agency.
1944	
Monday, 17 January	Supreme Headquarters, Allied Expeditionary Forces (SHAEF) activated under General Eisenhower. His G-3 (Operations) Division includes Dr. James Stagg's Meteorological Section.
Tuesday, 1 February	Admiralty Swell Forecast Section activated under Instructor Cdr. John Fleming, RN.
Tuesday, 15 February	Col. Donald Yates, USA, Director of Weather Services, US Strategic Air Forces Headquarters, Bushy Park, assigned collateral duty as Dr. Stagg's SHAEF deputy.
Monday, 6 March	SHAEF's G-3 queries Stagg re sea and swell forecasts. Advised Admiralty not yet linked by scrambled telephone to SHAEF.
Monday, 13 March	Swell Forecast Section activates coastal wave observation network.
Monday, 17 April	After evening/morning telephone conferences with Dunstable, WIDEWING and Admiralty, Stagg/Yates begin weekly Monday morning practice of presenting comprehensive 5-day weather forecast to Eisenhower and key staff members.
Thursday, 20 April	Stagg contacts Swell Forecast Section directly for wave information, thereby causing Fleming to complain.
Wednesday, 26 April	Admiral Ramsay and his ANCXF staff move to Southwick House close to Portsdown's combined Underground Headquarters. Instructor Cdr. C. Young becomes Chief, Swell Forecast Section.
Sunday, 28 May	General Eisenhower and key staff members move to Southwick House from Bushy Park. For weather charts, Stagg/Yates must utilize those posted in Fleming's cramped weather shack.
Monday, 29 May	1000 DBST: SAC weather briefing by team of Stagg-Yates-Fleming.
Friday, 2 June	1000 and 2130 DBST: SAC weather briefing as above.
Saturday, 3 June	2130 DBST: SAC weather briefing as above for proposed D-Day of pending Monday but meteorological conditions appear doubtful.
Sunday, 4 June	0430 DBST: SAC weather briefing as above. D-Day postponed 24 hours. 2130 DBST: SAC weather briefing advises improving situation during pending Tuesday so SAC offers a tentative "Go."
Monday, 5 June	0415 DBST: SAC weather briefing confirms improving weather pattern so Eisenhower orders full "Go" for NEPTUNE on 6 June. 1915 DBST: Eisenhower visits Fleming's weather shack. Stagg advises: "I hold to my forecast!"
**********	
The Big Storm	
Saturday, 17 June	1000 DBST: SHAEF telephonic weather conference agrees calm weather for the next 72 hours favorable for major cross-channel tow of key Mulberry Harbor components.
Monday, 19 June	0900 DBST SHAEF weather forecast incorrect. For next 78 hours Normandy beaches exposed to onshore winds gusting up to 32 knots.
Wednesday, 21 June	1900 DBST: Swell Forecast Section issues special wave forecast advising waves to be 4 feet or less at beachhead after next 23 hours.
Saturday, 29 July	1000 DBST: Admiralty ceases participation in SHAEF weather conferences.

APPENDIX E
Career Highlights of SHAEF Forecasters after World War II

Forecaster	Remarks
	BRITISH
Group Captain James Stagg, RAFVR	1954: Awarded KBE (Knighthood) 1959: Elected President, Royal Meteorological Society
Instructor Cdr. John Fleming, RN	1950: Deputy Director, Naval Weather Service 1956: Rear Admiral, Director, Naval Educational Service 1960: Awarded KBE (Knighthood)
Instructor Cdr. Geoffrey Wolfe, RN	1960-80: Chairman, Wolf Electric Tools, London, England (approximate)
Instructor Lieut. Lawrence Hogben, RNZN	1950-90: Public Relations, Imperial Chemicals, Europe (approximate)
Instructor Lieut. Harold Cauthery, RN	1969: Awarded Companion of Order of the Bath 1971-72: Deputy Under Secretary of State (Air) 1972-75: Deputy Under Secretary of Local Government Commissions
Mr. CKM Douglas	1919-54: World famed synoptic meteorologist at Meteorological Office Awarded Order of the British Empire Continued until retirement as a world-class synoptic meteorologist
Dr. Sverre Petterssen	1940s Meteorology Chair, Det. Geofysiske Institute, Bergen Norway 1950-52: Director, Scientific Services, U.S. Air Force Weather Service
	AMERICANS
Col. Donald Yates, Air Corps	1945-50: Director, Air Weather Service 1954-60: Commander, Air Force Missile Test Center (Rank of Major General) 1960-63: Deputy Director of Defense Research & Engineering (Rank of Lt. General)
Lt. Col. Benjamin Holzman, Air Corps	1958-60: Commander, Air Force Office of Scientific Research (Rank of Brigadier General) 1960-64: Commander, Air Force Cambridge Research Laboratories
Lt. Col. Irving Krick, Air Corps	1948-90: President, Irving P. Krick & Associates engaging in long-range weather forecasting and cloud seeding—and controversial throughout.
First Lt. John Crowell, Air Corps	1959 Chairman, Dept. Geology, Univ. Calif. Los Angeles 1981: Elected National Academy of Science 1995: Awarded Penrose Medal, Geological Society of America
First Lt. Charles Bates, Air Corps	1964-68: Technical Director, U.S. Naval Oceanographic Office 1968-79: Science Advisor to Commandant, U.S. Coast Guard
Technical Sgt. Ernest Lochner, Air Corps	1968-81: Curator, Division of Fishes, National Museum of Natural History

Glossary

AEAF	Allied Expeditionary Air Force
AFB	Air Force Base
ANCXF:	Allied Naval Commander Expeditionary Force
B-25	"Mitchell" twin-engined bomber used for weather reconnaissance
C-47	"Skytrain/Dakota" twin-engined transport aircraft
C-54	"Skymaster" long-range transport aircraft (four engines)
COSSAC	Chief of Staff to Supreme Allied Commander
D-Day	Date of Allied invasion of Normandy (Operations NEPTUNE/OVERLORD), 6 June 1944
DBST	Double British Summer Time (Two hours in advance of Greenwich time)
DDMO	Deputy Director, Meteorological Office
E-Boat	German fast attack boat 120 feet in length capable of peak speed of 42 knots. In German, known as a "Schnell boot."
ETA	Teleprinter designator, Weather Forecast Centre, Dunstable, Bedfordshire
Far Shore	Section of Normandy occupied by Allied troops
FRS	Fellow of the Royal Society (scientific organization)
Honours System (British)	CB: Companion, Order of the Bath CBE: Commander, Order of the British Empire DSC: Distinguished Service Cross (gallantry at sea) DSO: Distinguished Service Order (gallantry on land) KBE: Knight Commander, Order of the British Empire KCB: Knight Grand Cross, Order of the Bath
Instructor, Naval	"Instructor Officers," once known as "Schoolmasters or "Schoolies" and especially proficient in mathematics, dated back to 1836 when they became responsible for training midshipmen at sea. Over time, new sub-specialties were created including navigation (1906) and meteorology (1937).
Military Ranks (ascending):	
Royal Navy	Midshipman, Sub-Lieutenant, Lieutenant, Lieutenant Commander, Commander, Captain
US Army and its Air Force	2nd Lieutenant; 1st lieutenant, Captain, Major, Lieutenant Colonel, Colonel
US Navy	Ensign, Lieutenant (junior grade), Lieutenant, Lieutenant Commander, Commander, Captain
Military Specialty:	
British Air Force	RAF, Royal Air Force; RAFVR, Royal Air Force Volunteer Reserve
British Army	RA, Royal Army; RE, Royal Engineers
British Navy	RN, Royal Navy; RNVR, Royal Navy Volunteer Reserve
US Army	AC, Air Corps; CE, Corps of Engineers
US Navy	USN, US Navy; USNR, US Navy (Reserve)
MO	Meteorological Office (civilian component), Air Ministry
SAC	Supreme Allied Commander of the Allied Expeditionary Force
SHAEF	Supreme Headquarters, Allied Expeditionary Force
TF 122	US Naval Task Force 122 (also known as Western Naval Task Force) commanded by RADM Alan Kirk, USN
USAAF	US Army Air Forces
USSTAF	US Army Strategic Air Forces in Europe
Widewing	Telephonic designator, Bushy Park (Camp Griffis)

References

Atkinson R. 2002. An Army at Dawn, p. 132. *Holt.*

Bates CC. 1948. Utilization of Wave Forecasting in the Invasions of Normandy, Burma and Japan. *Annals NY Acad. Sci.* 51(3): 545-569.

Op. cit. 1990. Sea, Swell and Surf Forecasting for Operation Overlord. D-Day monograph, *Amer. Met. Soc.* Pp. 30-38.

Bates CC and Fuller JF. 1986. America's Weather Warriors, 1814-1985. *Texas A&M University Press.*

Charnock H. 1987. Sea and Swell Forecasting for Operational Planning, p.9. *Royal Met Soc Proc.* "Meteorology and World War II" Symposium. Typescript.

Cornish V. 1934. Ocean Waves and Kindred Geophysical Phenomena. *University Press, Cambridge.*

Crowell JC. 1946. Sea, Swell and Surf Forecasting Methods Employed for the Allied Invasion of Normandy, June 1944. MA thesis, Univ. Calif. Los Angeles, 15 Feb. 1946. Scripps Inst. Oceanography archives.

Op. cit. 2010. Surf Forecasting for Invasions during World War II. *Marty Magic,* Santa Cruz, California.

Eisenhower DD. 1948. Crusade in Europe, p. 250. *Doubleday*, Garden City.

Gaillard DD. 1904. Wave Action in Relation to Engineering Structures. US Army Prof. Paper 31. *Govt. Printing Office.*

Krick IP and Fleming R. 1954. Sea and Sky: Weather in our world and in our lives. JP Lippincott.

Hogben L. 1994 Diary: The most important weather forecast in the history of the world. *London Review of Books* 16(10):21.

Munk H and Day D. 2002. Harald U. Sverdrup and the War Years. *Oceanography* 15: 7-29.

Petterssen S. 2001. Weathering the Storm: Sverre Petterssen, the D-Day Forecast, and the Rise of Modern Meteorology, *Amer. Met. Soc.* Monograph.

Ramsay B. 1944. Operation Neptune: Report by ANCXF: Lessons Learned and Recommendations. 15 September 1944. *ADM File 199/1663.* Vol. 1, p. 10.

Schofield BB. 1977. Navigation and Direction: The Story of HMS DRYAD. *Kenneth Mason.*

Stagg JM. 1971. Forecast for Overlord, June 6, 1944. *Ian Allan.*

Stevenson T. 1864. Design and Construction of Harbours. *Adam & Black.*

Suthons CT. 1945. The Forecasting of Sea and Swell Waves. *Naval Met. Branch* Memo No. 135/45.

Sverdrup H and Munk W. 1944. Wind Waves and Swell. Principles and Forecasting. *Hydro Office* Misc. Rept. 11,275. CONFIDENTIAL. Issued unclassified, 1947. Wind Waves and Swell: Theory of Relations for Forecasting. *Hydro. Office* Pub. 601.

Sverdrup H and Munk W. 1944. Breakers and Surf: Principles in Forecasting. *Hydro Office* Pub. 234.

White B. 1980. The Artificial Invasion Harbours Called MULBERRY. *Private publication.*