The December 1-4, 2007 Storm Event over Northwest California

Jeffrey Lewitsky, Arlena Moses, Jeff Tonkin and Mel Nordquist

National Weather Service, Eureka, California

ABSTRACT

Starting Saturday, December 1 and continuing through Tuesday, December 4, 2007, a series of deep low pressure systems over the eastern Pacific Ocean moved toward the Pacific Northwest coast. Upon arrival these systems produced heavy rainfall, strong winds, and high seas. The greatest impact from these systems occurred in the northern portion of this region, along the coastlines of Washington, Oregon, and British Columbia. Northwest California experienced heavy rainfall, strong sustained winds, and long periods of high seas. Models were fairly accurate in predicting the strength and timing of this event for several days prior to the beginning of the event. Wave model guidance was also notable in forecasting the extended period of high ocean swell heights and corresponding swell periods.

1. Synoptic Situation

The first effects of these systems was felt along the Northwest California coast on December 1 as an area of low pressure and accompanying warm front moved into the region. The surface low would reach a minimum central pressure of 985 millibars (mb) at 06Z on December 2 while it was located near 45 N and 145 W. This low pressure center then moved off to the northeast and into Washington State by 00Z on December 3.

Northwest California experienced a period a high winds on December 1 through December 2 as the pressure gradient tightened ahead of this first surface low and warm front. Large southerly ocean swell, that was generated locally over the southern coastal waters due to the high winds, propagated through the coastal waters after the first low pressure system. Light stratiform rain also occurred with the warm front, with small accumulations across the region. The pressure gradient would then relax briefly after the warm frontal passage. Breezy, zonal onshore flow continued across the area ahead of the next area of low pressure.

A second and deeper area of low pressure brought heavy rain in addition to another period of strong winds to Northwest California December 3 through December 4. At 00z on December 3 this second area of low pressure deepened to a minimum central pressure of 952 mb, while it was located at approximately 40 N and 150 W. This low pressure center then moved off to the northeast and crossed Vancouver Island into mainland British Columbia on December 4. The highest winds and heaviest rain and snow accompanying this system occurred in the vicinity of the low center, across Oregon, Washington, and British Columbia. The trailing cold front associated with this low pressure moved through Northwest California on December 3 through early December 4. High winds occurred yet again as the pressure gradient tightened when the low pressure center moved through the Northeastern Pacific Ocean. Heavy rain took place across Northwest California ahead of this cold front, with post frontal showers continuing through most of December 4.

Large southwesterly swell propagated through the coastal waters December 4 through early December 5. The generation region of this swell differed from the first swell train as it originated out over the open Pacific Ocean during the most intense phase of the second area of low pressure.

2. Model Guidance and Performance

2.1 Precipitation

The GFS40, NAM12, and ECMWF high resolution models all displayed similar forecasts regarding quantitative precipitation forecast (QPF) amounts and timing of precipitation for this event. The three models also exhibited good run to run consistency as far as three to five days before the start of the event. The models forecasted that several ingredients would come together to lend themselves to a moderate-heavy precipitation event over the region. One, a semi-stationary boundary associated with the first low pressure system remaining over the region for two days and merging with the warm front from the second system. Two, a second surface low of subtropical origin was forecasted to entrain a precipitable water vapor plume exceeding 1 to 1.4 inches. Three, additional moisture would be supplied to this system from the remnants of a Western Pacific Ocean tropical cyclone that had been entrained in the upper level flow. Four, strong saturated southerly flow ahead of the main cold front which favors topographically enhanced precipitation for much of the region.

Models were depicting the majority of the QPF to be associated with the main cold frontal passage late on December 2 into December 3. Several instances of greater than 4 inches in 6 hours were forecasted for the Cape Mendocino and King Range region by the GFS40 and the NAM12 through this period. The GFS40 also depicted approximately 1 to 2 inches of QPF over the Siskiyou Mountains December 2 associated with the warm frontal passage. These numbers were supported by the November 29 and 30 HPC 3 and 5 day forecast totals of 6 to 8 inches in the Cape Mendocino region. Storm total amounts of near 1 inch were shown for southern and eastern Mendocino County by both models, with the bulk of the rain falling with the main cold front.

Model solutions were less consistent in forecasting the type of the precipitation. Cold air remained over the region from a system that occurred several days prior. Snow levels leading up to December 1 were around 3000 feet, with surface temperatures below freezing reported at stations above this elevation. 00Z November 29 model runs of the GFS40 kept surface through 850 mb layer temperatures relatively cold through early December 1, which, based on local studies, would keep snow levels at around 3000 to 3500 feet. The NAM12 differed slightly in that it indicated stronger warm air advection associated with the first warm front. The timing of the beginning of precipitation with this first warm front also differed between the models, which impacted precipitation type forecasts. Both models agreed that the strong southerly winds and warm air advection would raise snow levels above 7000 feet by late in the day on December 2.

Cloud cover from the approaching warm front overspread the region overnight on December 1 into the morning of December 2, limiting the amount of radiational cooling overnight. In addition, southerly flow and the associated warm air advection initiated stronger and earlier than indicated by the models. These factors would keep temperatures above freezing up to 4000 feet over the CWA through early on December 1 which was 500-1000 feet higher than earlier forecast. This was further compounded by a slower than forecast precipitation initiation, which allowed the warm air advection to further raise snow levels before the onset of precipitation.

2.2 Synoptic Pattern and Winds

As with the QPF forecasts for this event, the model indications of strong winds were present for several model runs prior to the start of the event. GFS40, NAM12, GEM (Canadian Global Environmental Model) and the ECMWF high resolution models were compared. The location of a long wave trough over the Northeast Pacific Ocean, as well as its timing was comparable in these four models. A deep 500 mb shortwave over the South-Central Bering Sea aided in the development of a strong baroclinic zone as it propagated through the long wave. This strong baroclinic zone developing over the Eastern Pacific Ocean off shore from California acted as a focus for surface cyclogenesis.

The models differed slightly in their depth, timing, and location of the shortwave associated with the resulting surfaces lows. At the surface, the GFS40 and GEM solutions both showed the second (and stronger) surface low deepening to 959 mb over the Pacific off shore from California near 40N 150W. The NAM12 and ECMWF high resolution indicated a similar location for the surface low, but did not forecast the low as deep.

With good upper level support, the forecast was for a quick intensification of the second surface low as it moved east of 140W. Though all the models were showing a rapid deepening trend, the GFS40 and GEM were the only models to capture the rapid cyclogenesis phase. These two models indicated a central pressure reaching 959mb while OPC analysis shows the second low deepening to 952mb (figure 1).

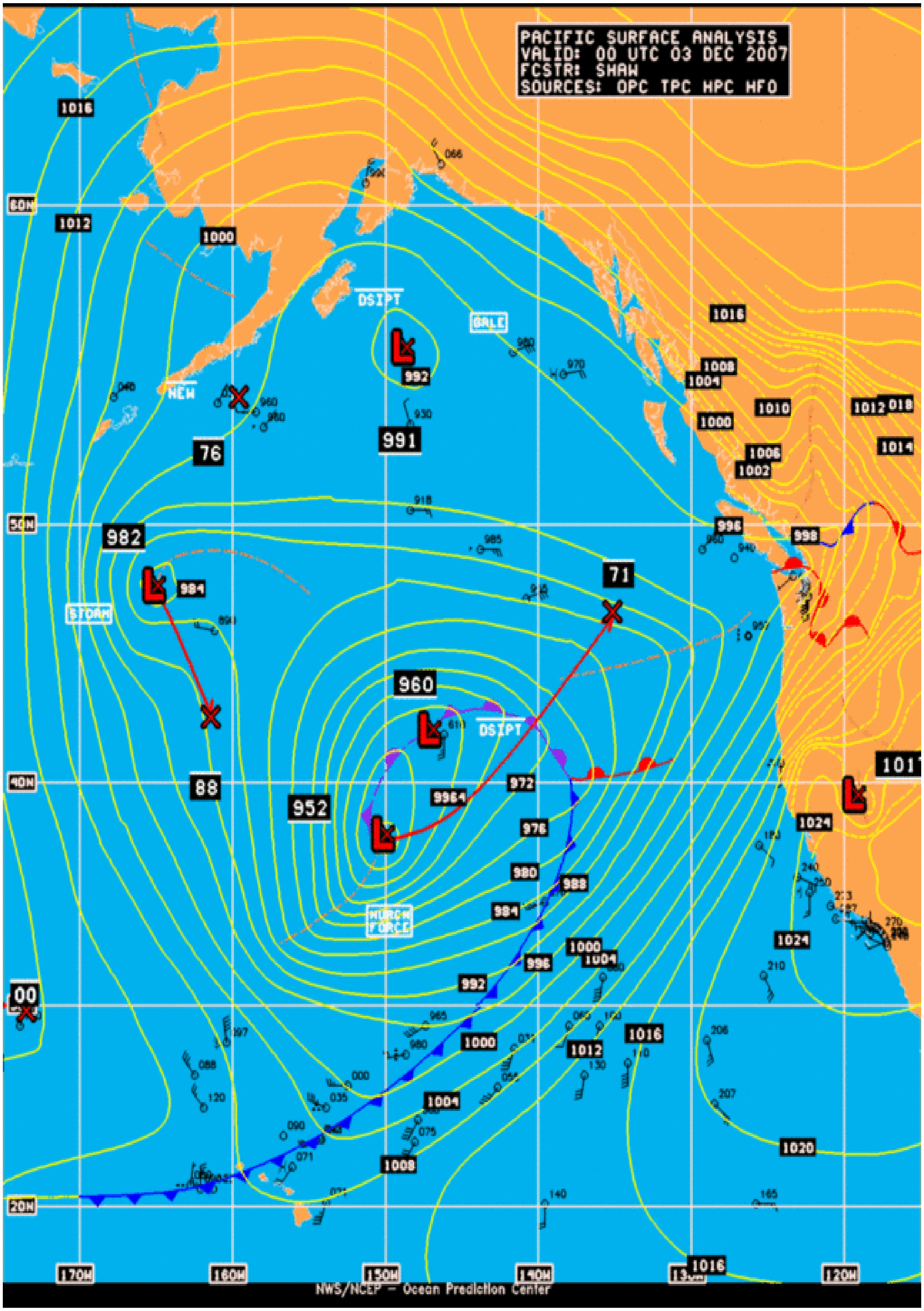


Figure 1. OPC Pacific Surface Analysis: 00z December 3, 2007.

Downstream from these surface lows over the Great Basin, a strong surface ridge was forecasted to develop in response to these deepening lows and associated upper level trough. The pressure gradient between the ridge and the low pressure over the East Pacific Ocean was shown to be strongest over the coastal regions of California and Oregon, including the WFO Eureka, California CWA. From this gradient, the GFS40 and the NAM12 were indicating 850 mb winds between 80 and 90 knots, with occasional speeds of 100 knots from December 1 through December 3. These winds were also present at the 925 mb surface, with forecasted winds of 70 to 80 knots, and boundary layer winds of up to 55 knots. At the surface, winds were forecast to be in the 40 to 50 knot range. The high winds were forecast for the entirety of Northwest California, including over the coastal waters, and were present for several forecast periods from December 1 through December 3 in the models.

2.3 Seas

Model runs on November 30 and December 1 of the Simulation Waves Nearshore (SWAN) model and the Eastern North Pacific (ENP) model both indicated seas increasing significantly with these systems. Maximum sea heights were forecasted to occur in two peaks, similar to the precipitation and maximum wind distributions. Seas would increase December 2, with the maximum heights of the event occurring on December 4, and remaining above 20 feet through December 6.

Hanson plots from the 03Z November 30 run of the SWAN model suggested that initially the seas would be primarily composed of short period, southerly wind wave. This trend was most notable over the offshore waters (20-60 NM from the coast), where the strongest winds were forecast to be present. In the northern offshore waters, a 10-12 foot, 10 to 12 second southerly fresh swell would also be present, commingled with the large wind waves (Figure 2). This fresh swell was thought to have originated from the southern offshore waters, generated by the storm force winds in that region.

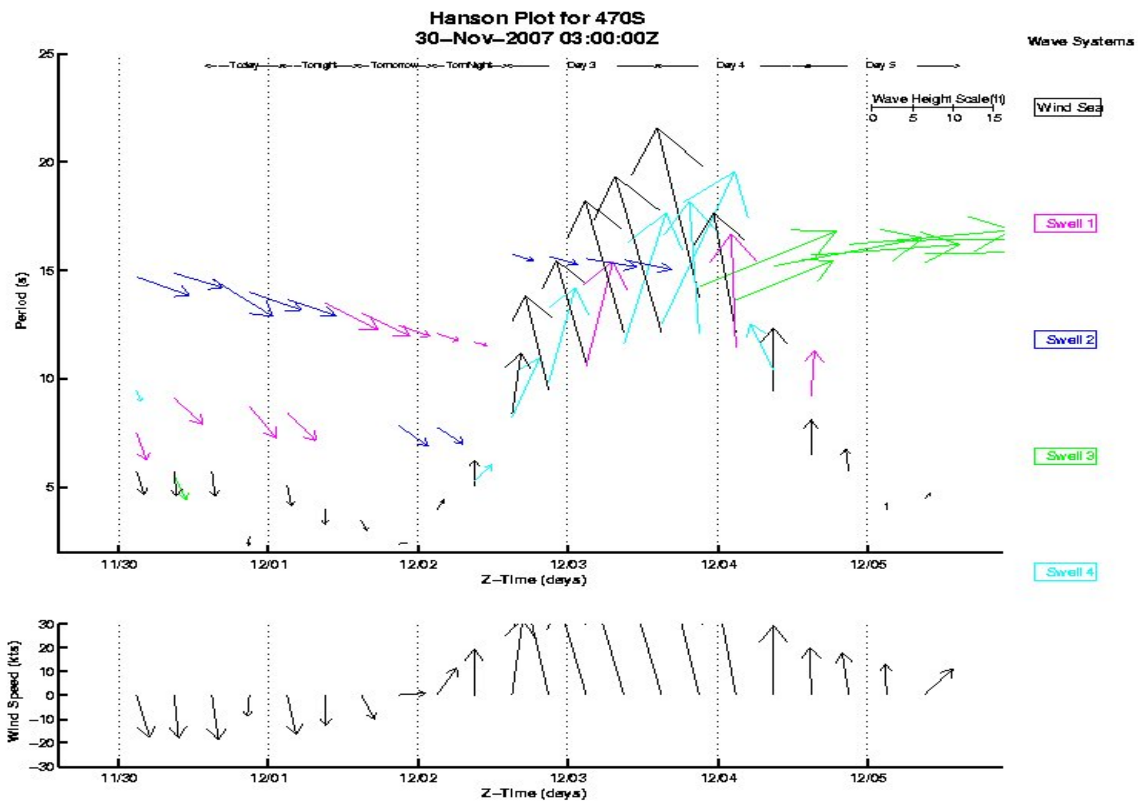


Figure 2: 30 November 2007 03z SWAN Model Hanson Output for Point 470S.

A similar trend was noted over the near shore coastal waters (0-20 NM from the coast), where much lighter sustained winds were forecast. Hanson plots from forecast points located in this region (Buoy 46022, 17 NM Southwest of Eureka, CA and Buoy 46014, 15 NM Northwest of Point Arena, CA) indicated seas would primarily be in the form of a 7-10 foot, 8 to 10 second fresh swell with smaller wind wave (Figures 3 and 4).

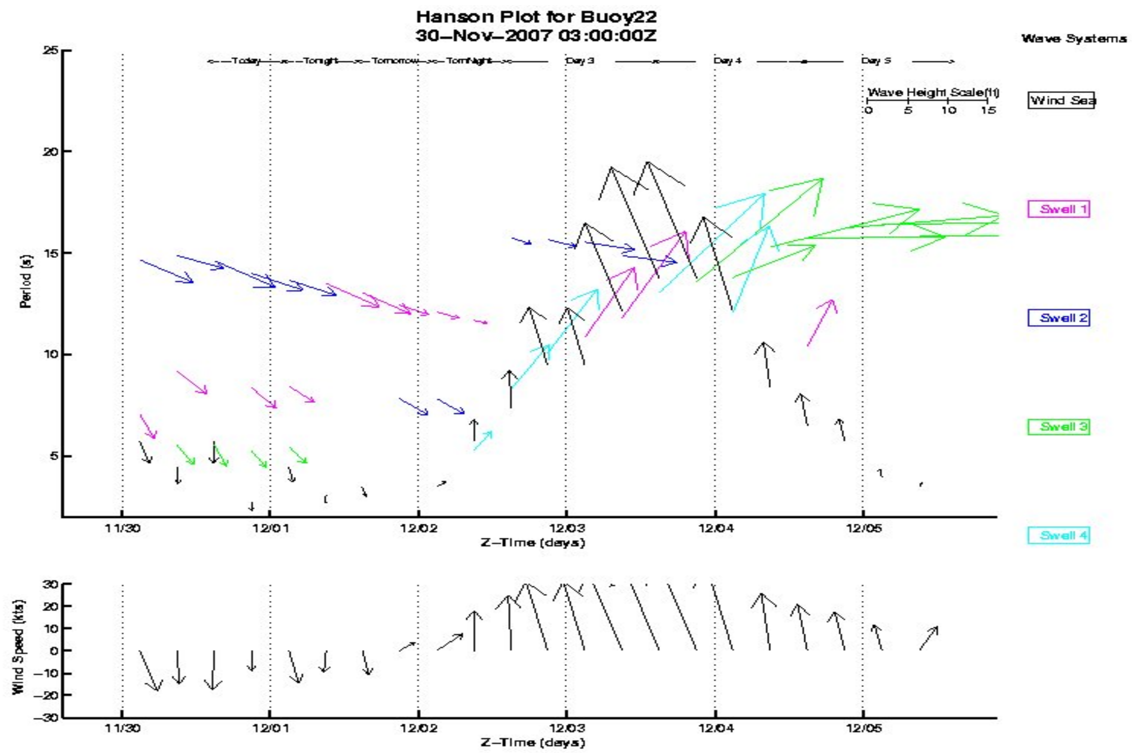


Figure 3: 30 November 2007 03z SWAN Model Hanson Output for NDBC Buoy 46022.

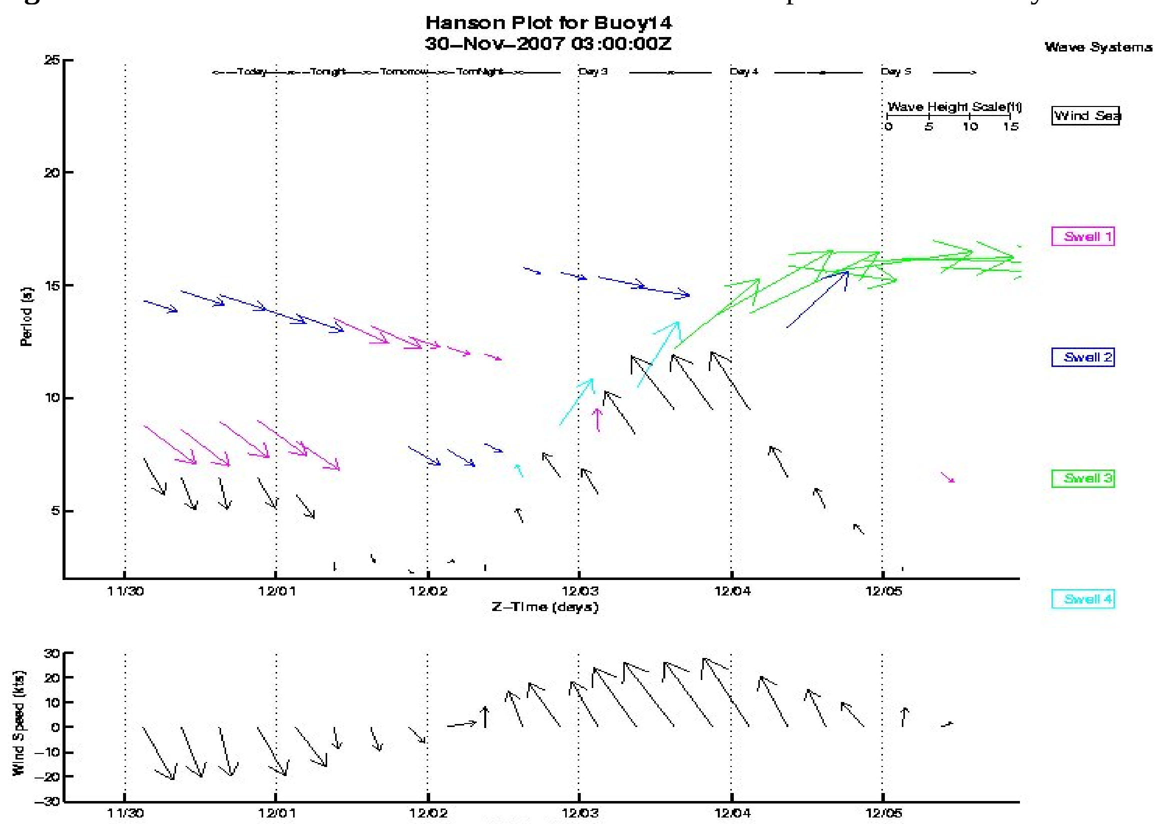


Figure 4: 30 November 2007 03z SWAN Model Hanson Output for NDBC Buoy 46014.

For all of the EKA waters, the initial dominant periods of 8 to 10 seconds would increase to 10 to 12 seconds as seas developed more through December 3. As the second surface low moved north of the region, a second increase in sea heights would take place on December 4, as the swell generated earlier over the Eastern Pacific Ocean by the second low moved into the waters. This is noted in all of the Hanson plots as the locally generated fresh swell and wind wave subside, the seas are dominated by a 16 to 17 second large westerly swell (figures 2-7).

The 03Z December 1 model run of the SWAN continued to indicate similar swell heights and directions as forecasted in the November 30 run for the offshore waters (Fig. 5). This model run did show higher wind waves at Buoy 46022 for December 2 and 3, reflective of the higher forecasted surface winds in the day's model run (Fig. 6). In addition to the higher wind waves initially at Buoy 46022, this SWAN run indicated that the longer period swell would reach the near shore waters sooner than the previous model run (Fig. 7).

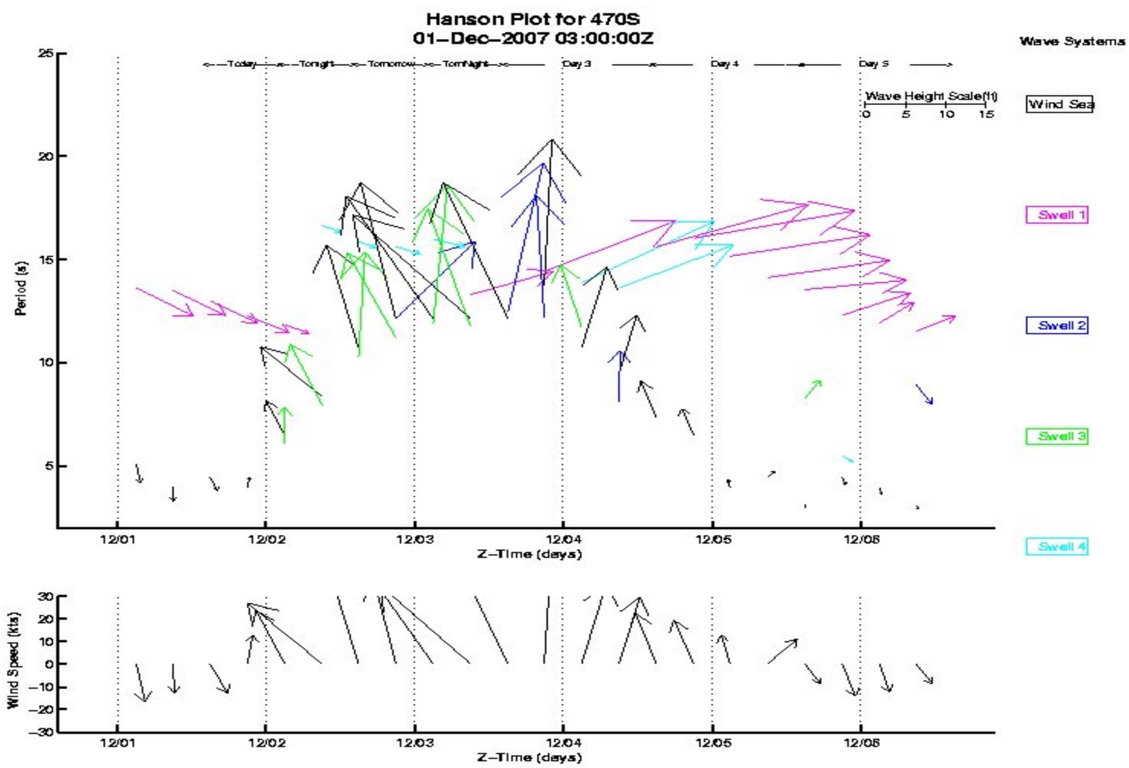


Figure 5: 01 December 2007 03z SWAN Model Hanson Output for Point 470S.

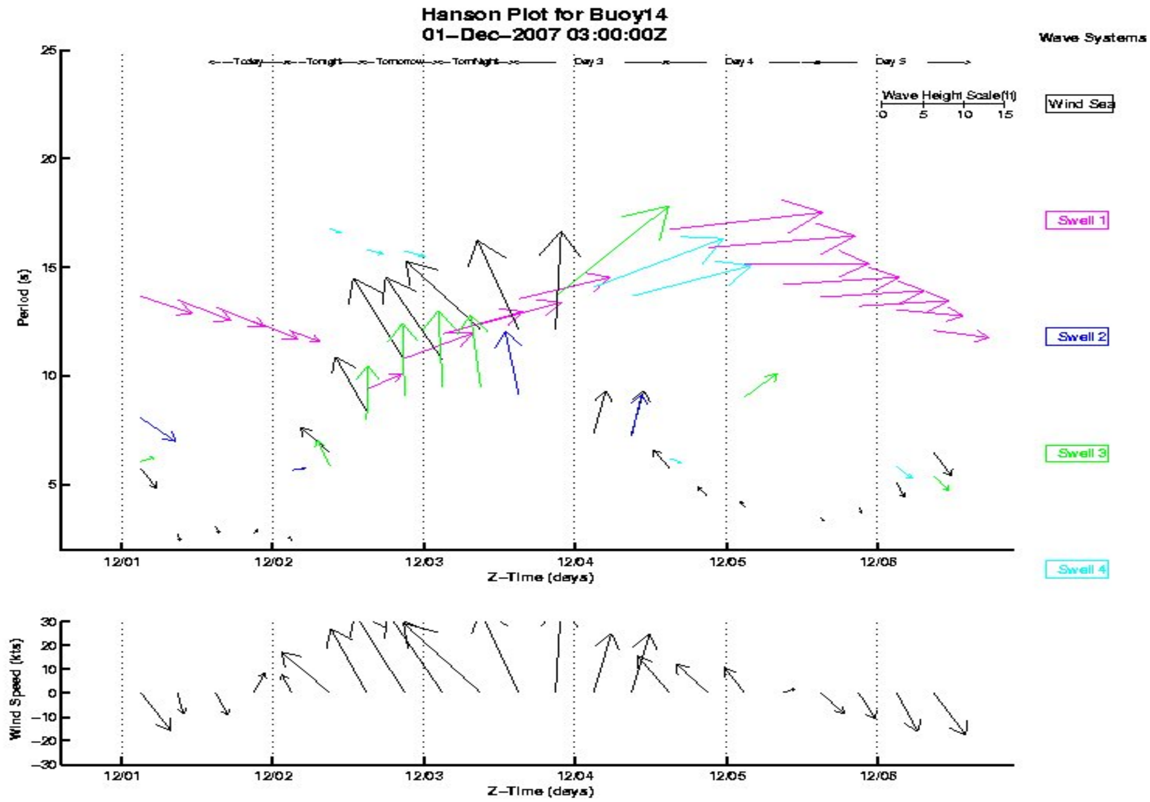


Figure 6: 01 December 2007 03z SWAN Model Hanson Output for NDBC Buoy 46014.

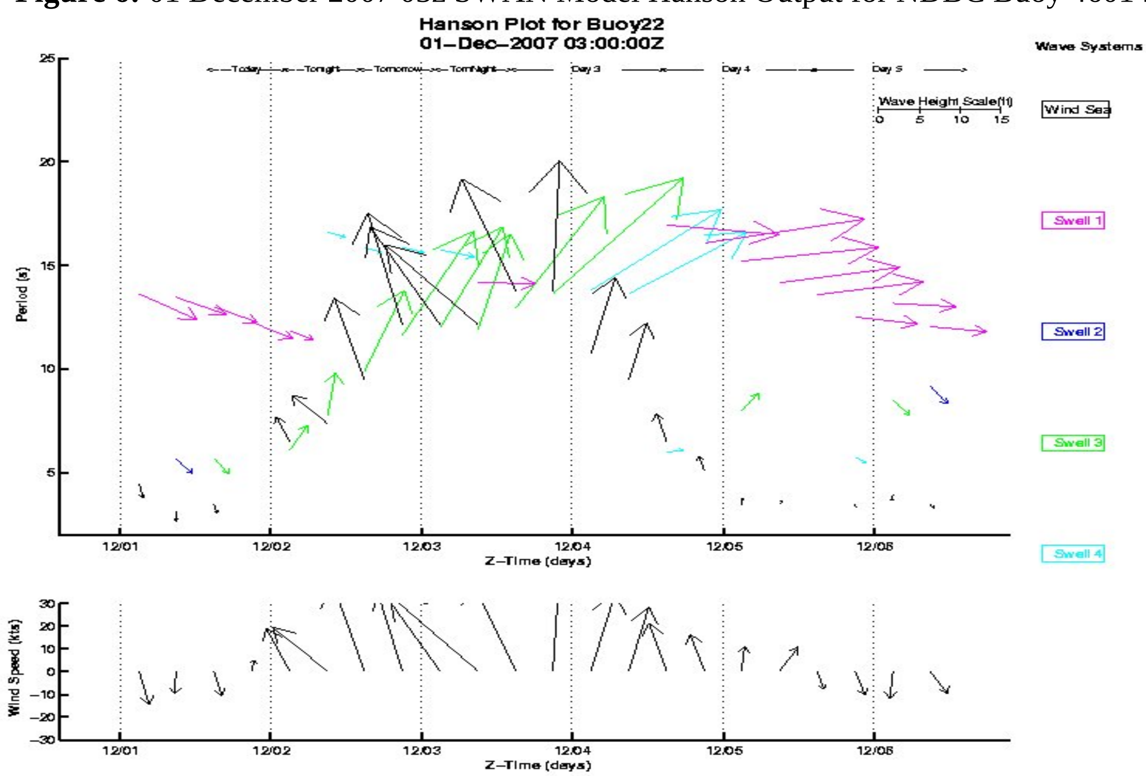


Figure 7: 01 December 2007 03z SWAN Model Hanson Output for NDBC Buoy 46022.

The 12Z run of the ENP on December 2 continued the trend as shown in the SWAN run on November 30 and December 1. Significant wave heights were forecasted to build to 20 to 30 feet early on December 3 (Fig. 8), with a primary wave direction from the southwest. It is important to point out that figure 8 and 9 have height contours in meters and the authors have converted them to feet in the text for ease of reading. The ENP also captured the second swell train (Fig. 9), with a primary wave direction from the west for December 4 and 5.

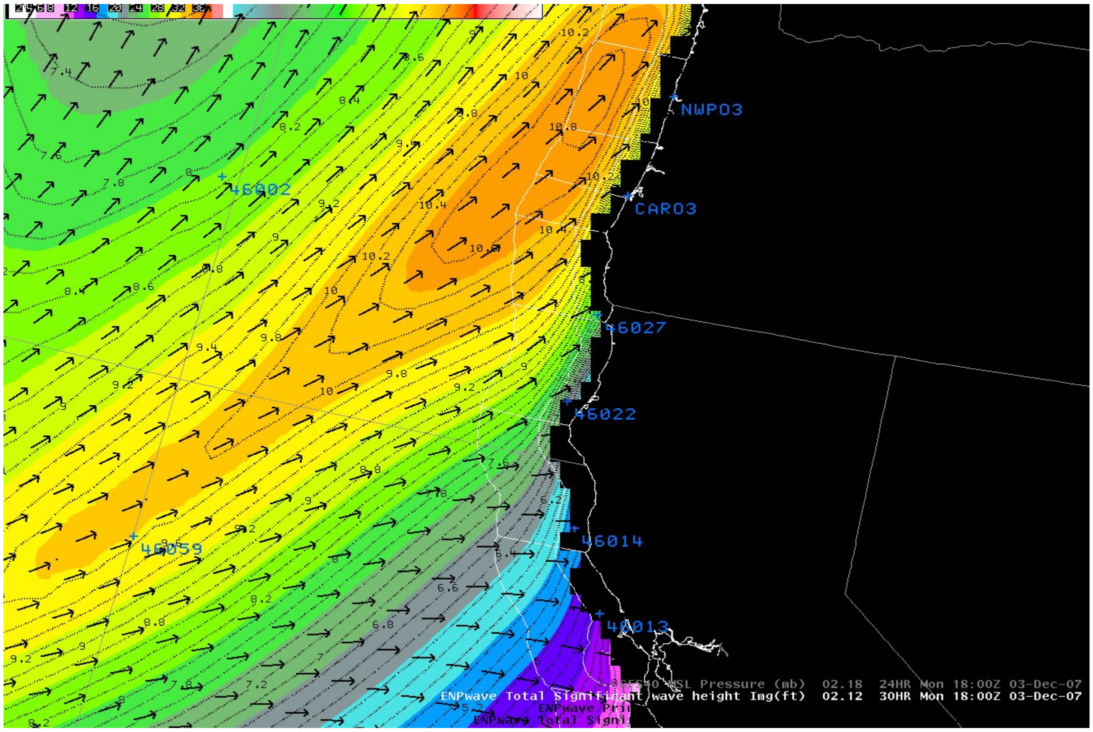


Figure 8: 03 December 2007 18z ENP Total Significant Wave Height and Direction.

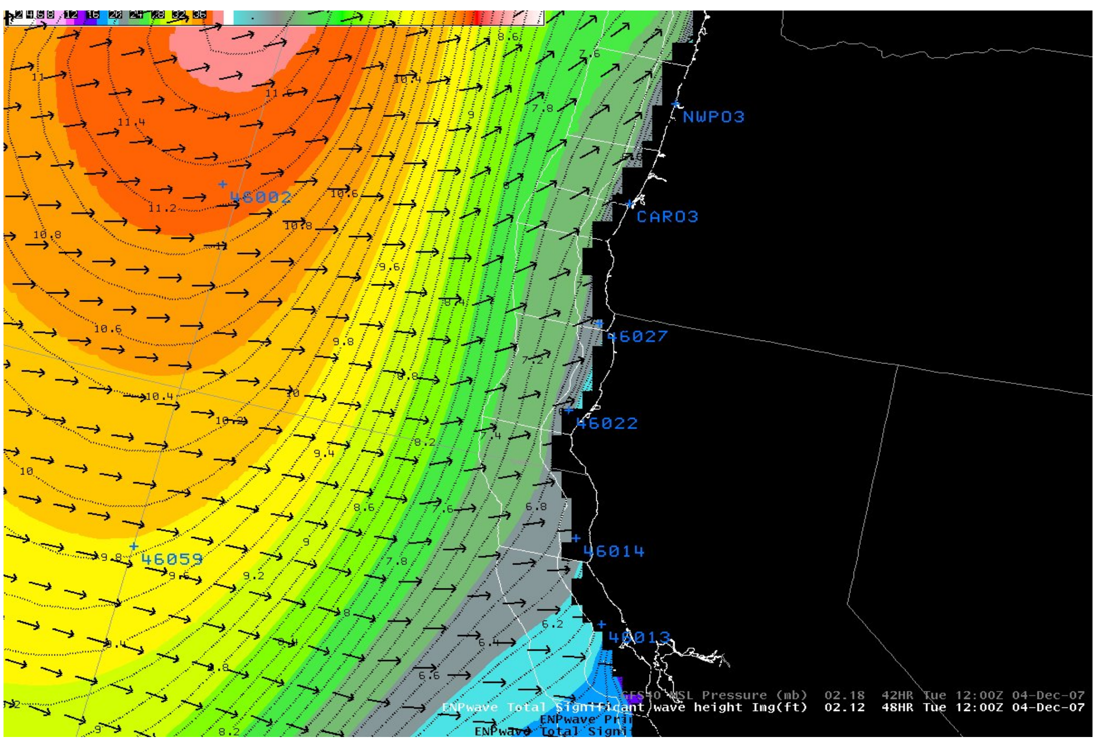
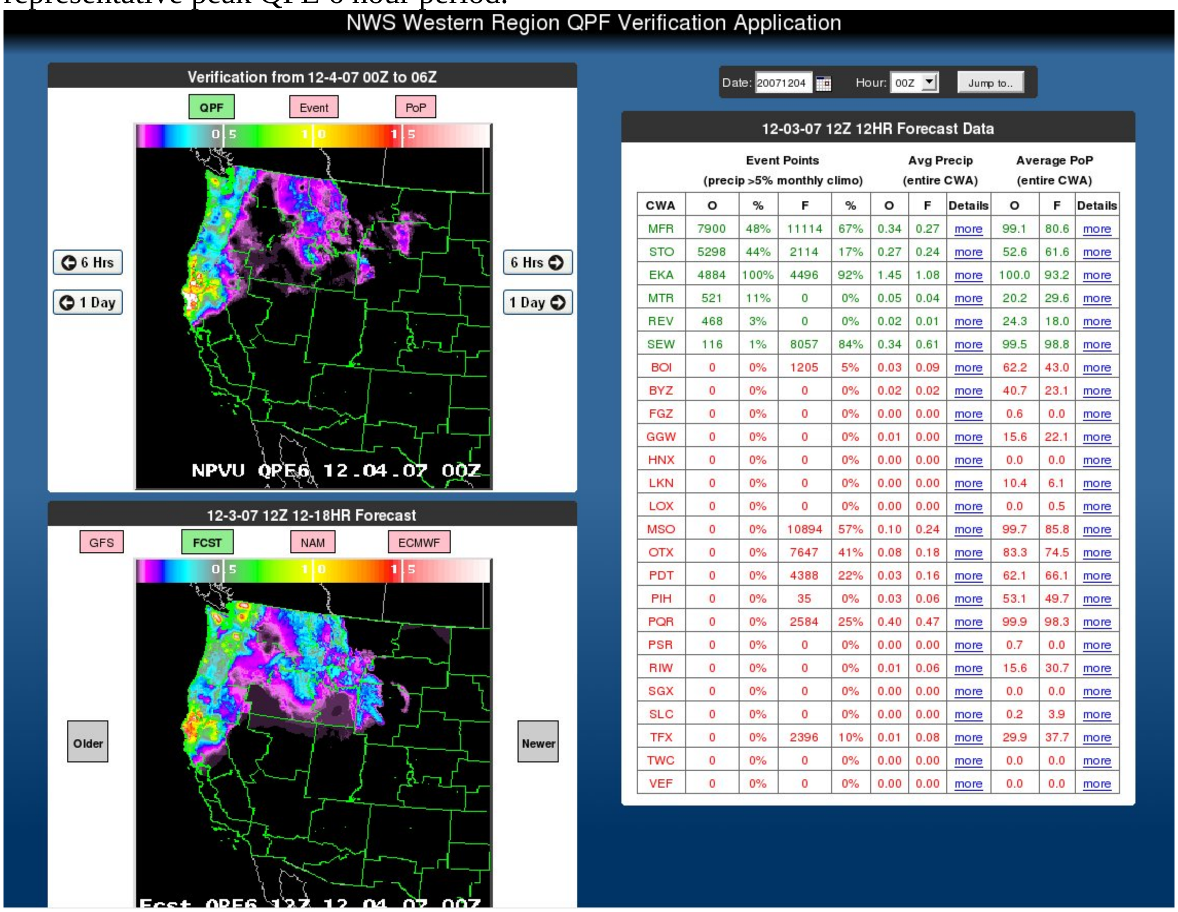


Figure 9: 04 December 2007 12z ENP Total Significant Wave Height and Direction.

3. Observations

3.1 Precipitation

A Hydrologic Outlook was issued by WFO Eureka prior to the event on November 30 to inform the public of the approaching heavy rain event and to warn them of the potential for significant rises of rivers and streams. Based on the forecast on November 30, QPF total amounts for the event were expected to generally range from 2 to 4 inches over Del Norte and Humboldt Counties with 5 to 6 inch totals in climatologically favored locations such as the King Range in Humboldt County and the higher terrain of Del Norte County. As an example, a six hour QPF and QPE grid are included to illustrate the distribution precipitation over the CWA (figure 10) during a representative peak QPE 6 hour period.



	Event Points (precip >5% monthly climo)				Avg Precip (entire CWA)			Average PoP (entire CWA)		
CWA	O	%	F	%	O	F	Details	O	F	Details
MFR	7900	48%	11114	67%	0.34	0.27	more	99.1	80.6	more
STO	5298	44%	2114	17%	0.27	0.24	more	52.6	61.6	more
EKA	4884	100%	4496	92%	1.45	1.08	more	100.0	93.2	more
MTR	521	11%	0	0%	0.05	0.04	more	20.2	29.6	more
REV	468	3%	0	0%	0.02	0.01	more	24.3	18.0	more
SEW	116	1%	8057	84%	0.34	0.61	more	99.5	98.8	more
BOI	0	0%	1205	5%	0.03	0.09	more	62.2	43.0	more
BYZ	0	0%	0	0%	0.02	0.02	more	40.7	23.1	more
FGZ	0	0%	0	0%	0.00	0.00	more	0.6	0.0	more
GGW	0	0%	0	0%	0.01	0.00	more	15.6	22.1	more
HNX	0	0%	0	0%	0.00	0.00	more	0.0	0.0	more
LKN	0	0%	0	0%	0.00	0.00	more	10.4	6.1	more
LOX	0	0%	0	0%	0.00	0.00	more	0.0	0.5	more
MSO	0	0%	10894	57%	0.10	0.24	more	99.7	85.8	more
OTX	0	0%	7647	41%	0.08	0.18	more	83.3	74.5	more
PDT	0	0%	4388	22%	0.03	0.16	more	62.1	66.1	more
PIH	0	0%	35	0%	0.03	0.06	more	53.1	49.7	more
PQR	0	0%	2584	25%	0.40	0.47	more	99.9	98.3	more
PSR	0	0%	0	0%	0.00	0.00	more	0.7	0.0	more
RIW	0	0%	0	0%	0.01	0.06	more	15.6	30.7	more
SGX	0	0%	0	0%	0.00	0.00	more	0.0	0.0	more
SLC	0	0%	0	0%	0.00	0.00	more	0.2	3.9	more
TFX	0	0%	2396	10%	0.01	0.08	more	29.9	37.7	more
TWC	0	0%	0	0%	0.00	0.00	more	0.0	0.0	more
VEF	0	0%	0	0%	0.00	0.00	more	0.0	0.0	more

Figure 10: Short term QPF and QPE images of 04 December 2007 valid at 00Z-06Z

These amounts were not expected to lead to flooding of main stem rivers across the region, but there was a possibility of localized flooding of low-lying areas and small creeks and streams. As forecast, major rivers and streams did report rises, but all remained well below monitor and flood stage.

Total rainfall amounts for both systems varied across the region from near 1.5 inches in the far southeastern corner of the WFO Eureka CWA to greater than 10 inches along the King Range Mountains (Fig. 11). This pattern is consistent with the climatological rainfall patterns across the region, and was enhanced by the prolonged southerly flow that intersects the King Range along the coast south of Cape Mendocino. In this pattern, the Humboldt Bay region north of the King Range is considerably rain shadowed. This is evidenced by the tight gradient between Fortuna, which received 1.93 inches of rain, and Honeydew which received 8.60 inches, the two locations being approximately 40 miles apart. The bulk of these amounts fell as the second surface low approached the region late in the day on December 2, and with the cold front through December 3. Additional light rainfall also continued in a showery regime behind the main cold frontal passage on December 4.

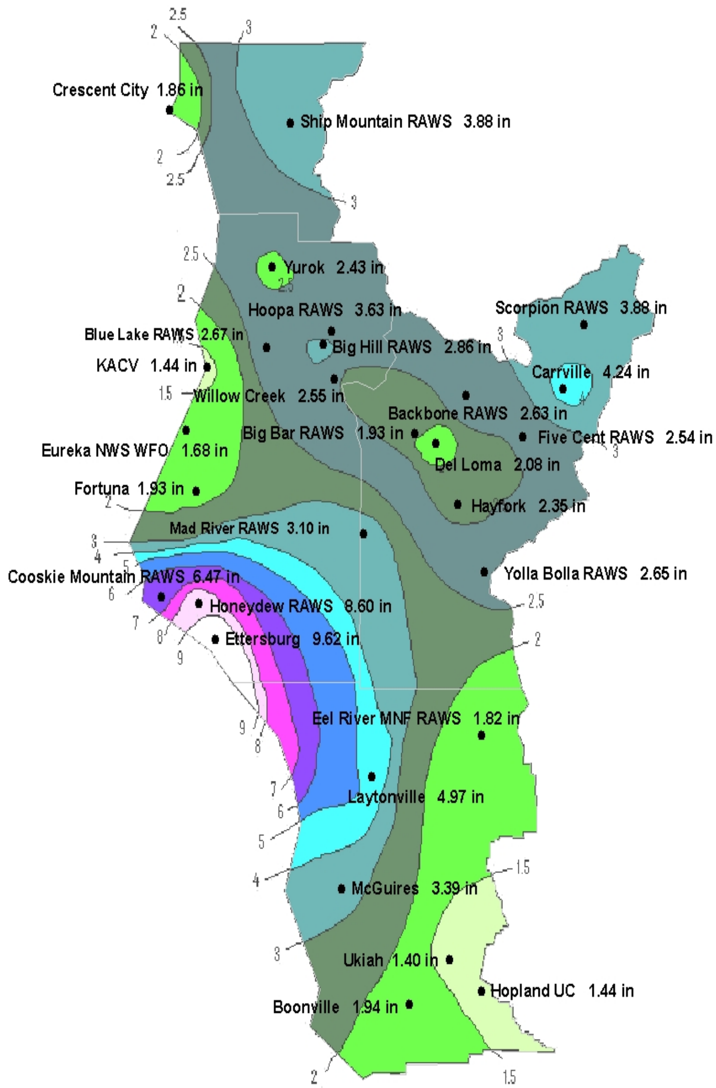
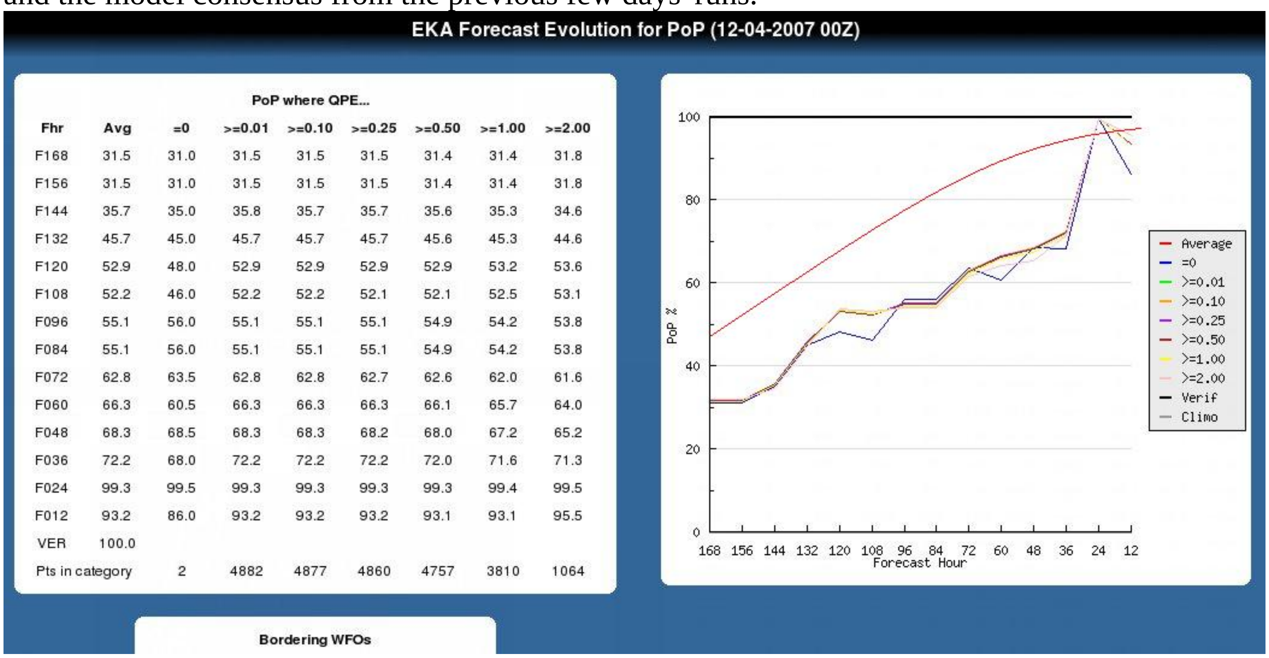


Figure 11. Storm Total Rainfall Amounts: December 1-4, 2007.

POP grids leading up to this event were generally well forecast by the local office as indicated by the graph in figure 12. Even as early as 7 days in advance POP forecasts were near the average climatological values of 35-40% for this time of year. As the figure indicates our local POP forecast steadily ramped up to categorical values by day 2. Two possible areas for improvement include: starting with higher POPs at day 7 for a high impact event such as this when the medium range models show consistent solutions as indicated earlier; and ramping up the POPs to categorical levels more rapidly, by day 3-5 as indicated by the redline curve on the graph in figure 12. It is important to note that these suggestions pertain to high impact events where SREF and operational models are generally in good agreement. Where there is a large spread in model solutions a climatologically consistent value is more appropriate. Local office QPF grids verified well although 6 hour QPF grid values may have been shifted temporally from the corresponding QPE values. In other words, storm total values of the grid forecasts performed well but there may have been a slight temporal shift of a few hours, the forecast QPF being late of the observed QPE (figure 13). Observed precipitation amounts, spatial distribution, and timing were all close to both the local QPF forecasts and the model consensus from the previous few days' runs.



EKA Forecast Evolution for PoP (12-04-2007 00Z)

		PoP where QPE...						
Fhr	Avg	=0	>=0.01	>=0.10	>=0.25	>=0.50	>=1.00	>=2.00
F168	31.5	31.0	31.5	31.5	31.5	31.4	31.4	31.8
F156	31.5	31.0	31.5	31.5	31.5	31.4	31.4	31.8
F144	35.7	35.0	35.8	35.7	35.7	35.6	35.3	34.6
F132	45.7	45.0	45.7	45.7	45.7	45.6	45.3	44.6
F120	52.9	48.0	52.9	52.9	52.9	52.9	53.2	53.6
F108	52.2	46.0	52.2	52.2	52.1	52.1	52.5	53.1
F096	55.1	56.0	55.1	55.1	55.1	54.9	54.2	53.8
F084	55.1	56.0	55.1	55.1	55.1	54.9	54.2	53.8
F072	62.8	63.5	62.8	62.8	62.7	62.6	62.0	61.6
F060	66.3	60.5	66.3	66.3	66.3	66.1	65.7	64.0
F048	68.3	68.5	68.3	68.3	68.2	68.0	67.2	65.2
F036	72.2	68.0	72.2	72.2	72.2	72.0	71.6	71.3
F024	99.3	99.5	99.3	99.3	99.3	99.3	99.4	99.5
F012	93.2	86.0	93.2	93.2	93.2	93.1	93.1	95.5
VER	100.0							
Pts in category		2	4882	4877	4860	4757	3810	1064

Figure 12: Graph of POP values for the 7 days leading up to 04 December 2007 00Z

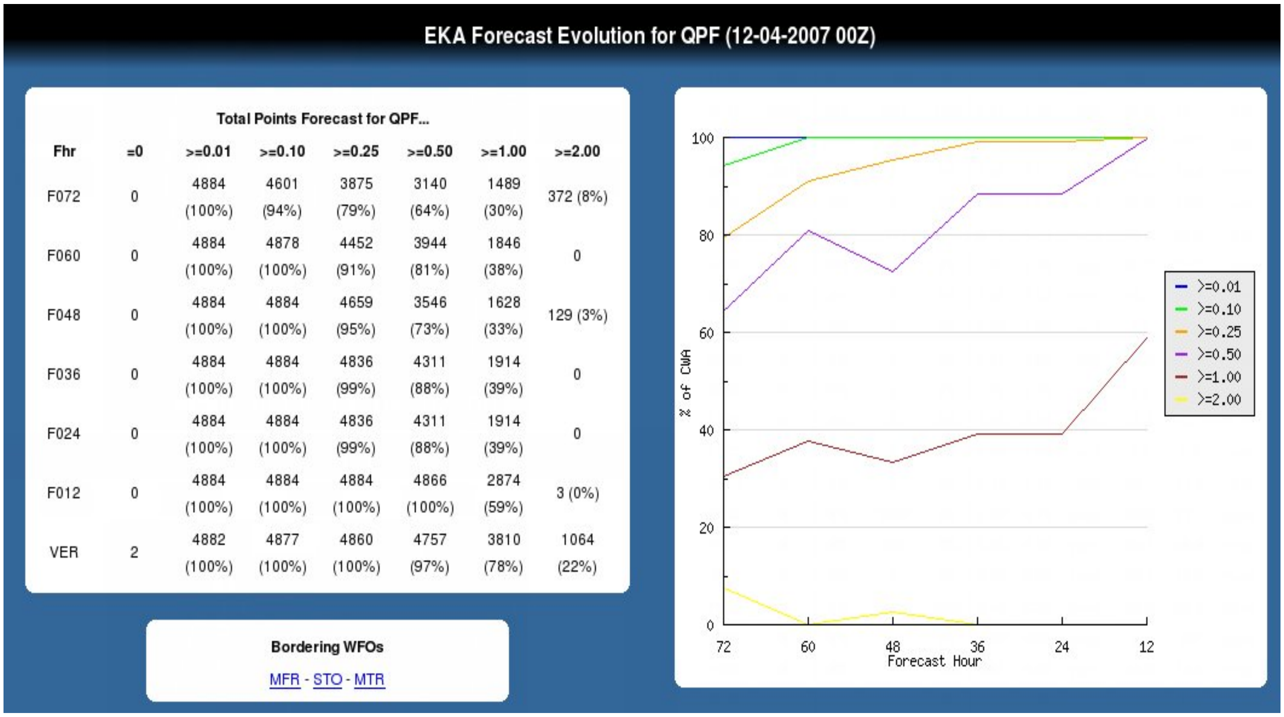


Figure 13: Graph of QPF values for the 72hrs leading up to 04 December 2007 00Z

3.2 Wind

A High Wind Watch was issued for Zones 1 (Del Norte and Humboldt County coasts) and 3 (Interior portions of Del Norte and Humboldt Counties) on November 30. The High Wind Watch was upgraded to a High Wind Warning for these locations on December 1, with the addition of Zone 2 (Coastal Mendocino County) to the warning. Widespread warning level conditions were experienced during the day on December 2 and continuing through December 3, verifying the issuance of the High Wind Warning for Humboldt and Del Norte Counties. The Coastal Mendocino zone however did not experience any recorded advisory or warning level conditions throughout the event. The highest observed peak wind through the event occurred at Ship Mountain during the afternoon hours of December 3. A selected list of high peak wind values across the CWA is displayed in Table 1.

Location	Peak Wind (mph)
Ship Mountain RAWS	101
Shoolhouse RAWS	88
5 ENE Capetown	79
Cooskie Mountain RAWS	78
Kneeland RAWS	73
Samoa Coast Guard	68
Arcata Airport ASOS	55
Crescent City Airport ASOS	52
Eureka WFO	39
Ukiah Airport ASOS	29

Table 1. Peak Wind Gusts: December 1-4, 2007.

Over the coastal waters, a Storm Warning was issued and verified for all of EKA's marine zones on December 1 for sustained winds and/or frequent wind gusts of 48 to 63 knots (55 to 73 mph). As expected the strongest winds with this event occurred mainly north of Cape Mendocino, the region closest to the main area of low pressure.

From a historical perspective, this event produced the longest duration of sustained wind speeds of 40 knots or greater over the coastal waters within the past 25 years. Sustained winds of 40 knots or greater were observed for two, nearly consecutive, ten hour periods at Buoy 46022. The most recent long duration wind event at Buoy 46022, that meet the same speed criteria, occurred in January of 1995. The 1995 event however, only recorded the sustained speeds of greater than 40 knots for 6 hours. The rarity of these conditions is further evidenced by the fact that the majority of years from 1982 to 2006 show no record of these conditions existing for even 1 hour at Buoy 46022.

3.3 Seas

Based on the model forecast of seas reaching 25 to 30 feet, a Hazardous Seas Warning was issued for all of the EKA coastal waters zones from December 1 through December 5, primarily for seas reaching 18 feet or greater regardless of the primary period. In addition, a High Surf Warning, indicating wave heights of 24 feet or greater expected at EKA's coastal shores, was issued for the coasts of Del Norte, Humboldt, and Mendocino counties.

Wave heights associated with the first round of higher seas occurred on December 2, lasting through the morning of December 3 (see Table 2 for Peak Wave Heights). The primary period associated with the peak wave heights was longer than predicted by the SWAN model, indicating more influence from the fresh swell than the locally generated wind waves. The second, longer period southwesterly swell arrived on the afternoon of December 3, and continued through December 4 (see Table 3 for Peak Wave Heights). These wave heights verified both the Hazardous Seas Warning and the High Surf Warning issued for the event.

Location	Peak Wave Height, Period
Buoy 46022, 17NM SW of Eureka	28.5 ft @ 15 sec.
Buoy 46212, Humboldt Bay South Spit	21 ft @ 14 sec.
Buoy 46213, Cape Mendocino	Not Available
Buoy 46014, 19NM N of Point Arena	21 ft @ 14 sec.

Table 2. Peak Wave Height and Period: December 3, 2007.

Location	Peak Wave Height, Period
Buoy 46022, 17NM SW of Eureka	26 ft @ 19 sec.
Buoy 46212, Humboldt Bay South Spit	23.3 ft @ 17 sec.
Buoy 46213, Cape Mendocino	30.2 ft @ 18 sec.
Buoy 46014, 19NM N of Point Arena	24.6 ft @ 16 sec.

Table 3. Peak Wave Height and Period: December 4, 2007.

The duration of the long period swell observed at Buoy 46022 was one of the more significant long period swell durations of the past 25 years. From the evening of December 3 through the early morning of December 5, there were 30 hours of 16 seconds or longer swell periods. For 7 of those hours, the swell reached heights of 26 feet or more. To give the reader historical context, in January of 1990 a comparable swell event occurred in which there were 15 hours of 26 feet or higher swell with a corresponding period of 16 seconds or longer. The peak wave height during that event, 34 feet, was observed for 2 hours. Prior to the 1990 event, a significant storm occurred in February of 1984 in which swell of 26 feet or higher with a period of 16 seconds or longer was observed for 15 hours. Swell heights reached 39 feet for 2 hours during that historic event.

4. Conclusion

Only minor damage was reported from this storm, primarily as the downing of small trees and limbs. There were also widespread reports of short-duration power and communication outages during the period of peak winds. The duration of the high seas and long period swell did result in beach erosion along the Northwest California coastline. Local authorities reported several people were swept off the North Jetty of Humboldt Bay on December 3. Those people were swept into the cold Pacific Ocean during the peak wave heights associated with the event. Thankfully they were successfully rescued.

With the models in good agreement as to the duration and severity of this event as much as a week in advance, long lead times with several days of advance notice was achieved in informing the public of the impending hazards. As this storm occurred during the crab season in the region, a weather briefing was held for local crabbers at the EKA WFO. The advance warning of the high seas and winds allowed the crab fleet to remove or adjust the crab pots which prevented the pots from being sanded in. As crab pots are valued at approximately $150 per pot, this advance notice potentially saved the fleet millions of dollars of possible damage. Without a doubt the December 1-4, 2007 storm was a high impact weather event with heavy rains and strong winds occurring over land. But of greatest significance, it ranks as one of the most intense, long duration wind and high seas events observed at Buoy 46022 and over the coastal waters as a whole, in the past 25 years.