P9.18 APPLICATION OF REMOTELY SENSED OCEAN VECTOR WINDS TO DETERMINE WAVE GENERATION AREAS

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1. INTRODUCTION

Ocean waves propagate unimpeded thousands of miles from their generation areas across oceans and hemispheres. Southern Hemisphere swell born south of New Zealand creates surfing conditions along the Southern California coast. Waves generated in the southeasterly winds west of South Africa impact the Long Island and New Jersey beaches. According to the American Lifeguard Association rip currents kill approximately 100 Americans annually. Long period swells from far off storms can cause dangerous bar conditions to erupt instantly as swell fronts arrive and shoal and for low lying beaches and villages to be inundated.

NWS forecasters have more wave information at their finger tips than ever before. Offshore and coastal buoys report a variety of wave parameters and serve as offshore guardians providing critical information concerning changing conditions and potential threats to beaches, inlets and coastlines. Numerical wave models such as the NOAA WAVEWATCH III (NWW3) (Tolman et al. 2002) provide detailed estimates of sea state parameters well into the future including the character of significant wave height, dominant waves, and first and second swell period, direction and height. Numerical wave models have well known biases such as the inability to raise wave heights quickly and high enough in areas of strong cold advection. Swell dominated domains such as the eastern North Pacific (Hanson et al. 2009) have a wave height high bias. It was surmised that dissipation source terms, wave-wave interaction, and atmospheric drag coefficient were the source of this high bias in swell dominated regimes. Wind forcing such as from the NCEP Global Forecast System (Moorthi et al. 2001) for the NWW3 can be a key error source in the prediction system. Cyclone intensity, motion, shape, and scale all factor into wave generation. Any error such as weaker maximum winds will result in an error in wave generation and propagation.

Until now NWS forecasters have not been able to determine discrete wind fetch areas or wave generation areas in extratropical and tropical cyclones. Fetch were often eyeballed using projected Great Circle (GC) rays and estimated based on NWP wind fields. The goal of this project is to develop an objective technique, through GEMPAK functionality to mathematically estimate the size and intensity of areas of fetch relative to coastal and offshore sites of interest. A second goal is to apply this functionality to NWP based wind analyses/predictions and gridded ocean surface vector wind (OSVW) from remotely sensed sources from scatterometers such as the QuikSCAT(Chelton et al. 2006), ASCAT on METOP-A (Verspeek, 2007), or India’s OSCAT on OceanSat-2.

Scatterometers provide the full wind vector and have been shown to be very useful in operations as a diagnostic to estimate the accuracy of NWP analyses, for short-term predictions, to define wind warning categories and areas, and serve as basis for verification of warnings. (Von Ahn et al 2006, Brennan et al. 2009, 2010, Leslie et al. 2008).

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The methodology will be described in Section 2, two in depth case studies will be detailed in Sections 3 and 4, discussion will given in Section 5, and a summary and future work will be presented in Section 6.

2. METHODOLOGY

Ocean waves propagate along great circle paths from the point of origin or generation (Barber and Ursell, 1948). Hanson and Phillips 2001 discussed wave propagation and stated that in deep water ocean swell does indeed propagate in general accordance with deep water linear gravity wave theory. They also stated that distant ocean storms could be thought of as point sources and that automated approaches to determining point sources from wave measurements are quite labor intensive. Rather than develop a rigorous objective method to determine point sources of ocean swell as suggested by Hanson and Phillips 2001, the approach is to identify potential fetch generation areas by determining the wind component favored along specific GC paths. The GC paths originate at points offshore of islands, headlands, harbor entrances, bars, or beaches and are projected seaward. The goal of this project is two-fold, 1) give forecasters a visual tool that can be used to compare wind components (fetch) from remotely sensed OSVW and NWP; 2) develop a tool that can be used with NWP near surface wind output and wave model swell information as an education tool. This second goal is to help educate forecasters as to how discrete wind fetches evolve in cyclonic storms and generate specific wave systems. The first goal is to develop a diagnostic to determine the validity of NWP analyses and predictions by comparing wind field components from NWP output and remotely sensed OSVWs. Based on these comparisons forecasters could estimate whether a greater or lesser threat for wave development and propagation exists as compared to NWP fields.

We developed developed two GEMPAK (desJardins et al. 1991) functions to determine the wind component along predefined GC rays. The first function (dv_gcir) computes for every gridpoint on a global grid, a unit vector, pointing in the direction away from the point of interest and towards the antipodal point along a GC arc. The second function (dv_gcvw) is similar to dv_gcir but additionally sets to missing the u and v components of the unit vectors of all land gridoints on the grid and all water gridpoints on the grid whose view of the home or origin point is blocked by land. In dv_gcwv, for each water gridpoint, the following is done. The water gridpoint currently being processed is called the "current gridpoint". The function examines each gridpoint along the GC arc from the current gridpoint to the home point. We can call these "arc gridpoints". As each arc gridpoint on the GC arc is examined, the four corner gridpoints surrounding that arc gridpoint are computed. The current gridpoint is marked as being in a land shadow if the following are true:
(a) All four of this arc gridpoint's corner points are on the grid, AND
(b) At least one of these corner points is a land gridpoint.

If the above condition is not true for all of the arc gridpoints, then the current gridpoint is considered to have a clear water view of the home point. Otherwise the current gridpoint is considered to be in a land shadow and is set to missing value. Each GC grid with land shadowing is pre-calculated before being applied. The GC grid is calculated at the resolution of the gridded NWP winds (0.5 degree) or OSVW (0.33 degree).

To determine the wind component opposing the GC ray unit vectors we simply calculate and display the dot product of the full wind vector (from either NWP or QuikSCAT gridded wind field) and the GC ray unit vectors. Shown in Fig. 1 are both the GC Rays (red arrows) and wind component (filled contours, color coded to wind scale in lower left) for GC rays extending from a point off of Cape Flattery, WA. The red arrows are void extending southwest of the Hawaiian Island and Aleutian Chain due to the blocking effect of the islands. The wind components show two significant fetch areas, the first fetch area extends from southeast to northwest in the southern Gulf of Alaska with a maximum wind of 49 knots. The second significant fetch area is west of the International

Dateline with a large area of winds of GALE force (yellow) and higher with a maximum of 52 knots (brown filled contours).

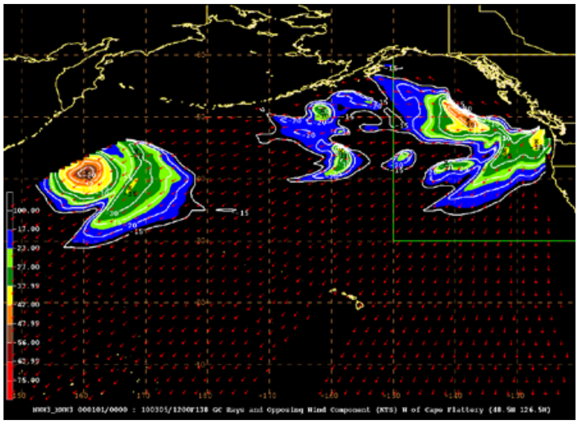

Figure 1. Plot of GC rays (red arrows) and wind component (color coded as shown in the lower left corner) opposing the rays from Cape Flattery, WA.

3. CASE STUDY 1

We have applied this new functionality to two examples with the goal of exploring and assessing the application to OSVW from QuikSCAT and the NCEP GFS model. The first case is from mid-March 2008 of a large intense slow moving ocean storm south of Newfoundland. In Fig. 2 the operational Surface Analysis from 0000 UTC 18 March 2008 is shown. The storm of interest is centered at 41 degrees North latitude, 56 degrees West longitude at 964 hPa. The pressure gradient suggests the strongest winds lie to the west and northwest of the center. Winds associated with the intense low were of HURRICANE force intensity based on QuikSCAT and ship observations.

A quick eyeball estimate suggests that the fetch of strongest winds were optimized for waves to propagate southward. For this first case we determined the wind

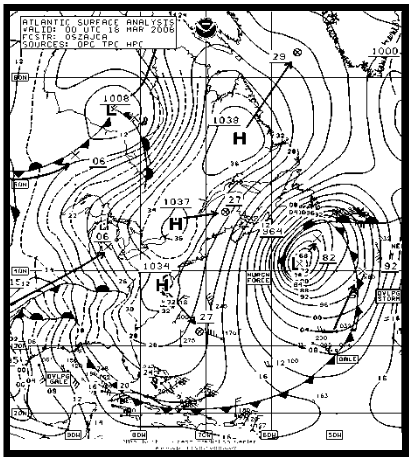

Figure 2. Ocean Prediction Center surface analysis valid 0000 UTC 18 MAR 2008 for the western North Atlantic.

components optimized for the north coast of Puerto Rico from the 00 UTC 16 MAR 2008 run of the NCEP GFS 48 hour forecast valid 0000 UTC 18 Mar. Shown in Fig. 3 are the GC rays emanating from just north of Puerto Rico and the GFS wind components.

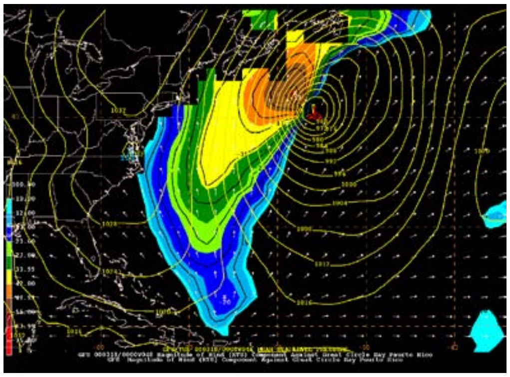

Figure 3. Wind component opposing GC rays from a point north of Puerto Rico for the 48 hour forecast of the NCEP GFS valid 00 UTC 18 MAR 2008. Wind components are depicted by filled colored contours as per the scale in the lower left. Dark brown winds are 48 kn and higher.

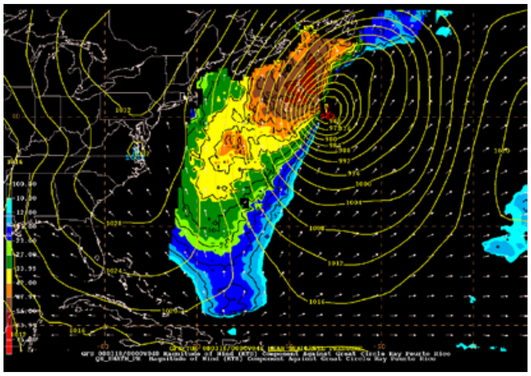

Figure 4. As per Fig. 3 except showing the wind component from the QuikSCAT scatterometer from 0000 UTC 18 MAR 2008 and 48 hour sea level pressure forecast from the NCEP GFS model.

Comparing the two wind component fields in Figs. 3 and 4 we see that the GFS in essence had a similar wind field to the QuikSCAT based field although the maximum wind speed of 57 knots was slightly weaker than the 61 knots by QuikSCAT. More importantly the areal coverage of the area of winds of 48 and 56 knots was much larger in the QuikSCAT derived wind components as compared to the GFS.

We compared eight QuikSCAT passes to matching GFS short term forecasts and found similar results as presented here. In essence the GFS wind fields with the exception of relatively subtle differences compared well to the QuikSCAT wind components. The fact that only subtle differences existed between GFS and QUikSCAT suggest that the NWW3 wave predictions (based on the GFS winds) would offer useful guidance concerning the timing of the propagation of the wave field and height of the wind wave and swell fields generated by this intense late winter cyclone.

4. CASE STUDY 2

Our second case study examines the application of the GC ray technique to a very slow moving, low latitude, very intense western North Pacific extratropical cyclone from early December 2008. This cyclone produced a very strong swell front that propagated into the South Pacific causing inundation to the islands of the north coast of New Guinea. According to newspaper reports north facing coastal towns experienced a six hour period of very high waves and associated inundation up to 4.5m in height. Combined inundation and wave action caused considerable destruction to exposed coastal villages. Shown in Fig. 5 is the OPC surface analysis from 1200 UTC 5 December 2008 with a very intense low of 992 hPa near 29.5 degrees North latitude, 153 degrees East longitude with HURRICANE FORCE winds.

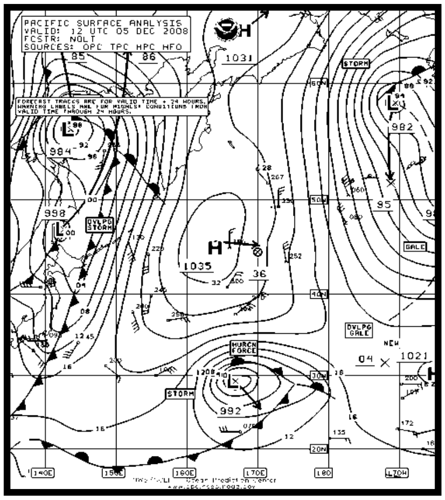

Figure 5. OPC surface analysis valid 1200 UTC 05 DEC 2010. The cyclone of concern can be seen near the southern portion of the analysis.

Applying the GC ray technique to forecasts of the GFS and QuikSCAT gridded fields yields some remarkable differences. Shown in Fig. 6 is a 45 hour forecast from the GFS of the wind component relative to GC rays originating from the north coast of New Ireland, New Guinea. The GFS forecast shows an elongated fetch area of GALE force (yellow) winds to 45 knots (light brown filled contours).

The QuikSCAT wind component for 2100 UTC 5 December 2008 in Fig. 7 shows a far different wind field than the GFS 45 hour forecast in Fig. 6. The shape and character of the relative wind components are similar, however, rather than maximum winds of moderate GALE force as the GFS, the QuikSCAT wind components show a long fetch of STORM (dark brown) to HURRICANE force (red) winds suggesting the cyclone was much more intense than the

GFS predicted. Not shown are a series of four comparisons over three days of QuikSCAT versus GFS wind fields (at varying forecast hours). Over that period QuikSCAT showed significantly stronger winds than the GFS forecasts and analyses with persistent HURRICANE to strong STORM force winds along the favored fetch and wave generation area for the South Pacific Island of New Guinea.

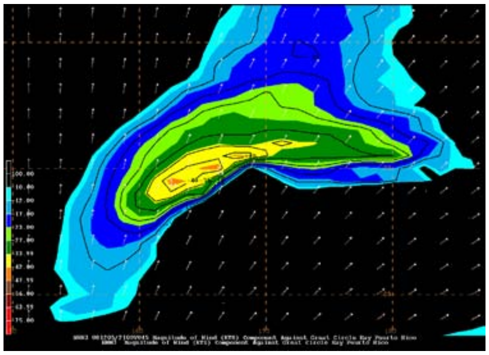

Figure 6. Wind component relative to GC Rays from New Ireland, New Guinea from a GFS 45 hour forecast valid 2100 UTC 5 December 2008. Wind speeds contoured according to the scale in the lower left of image. Yellow contours represent GALE force winds.

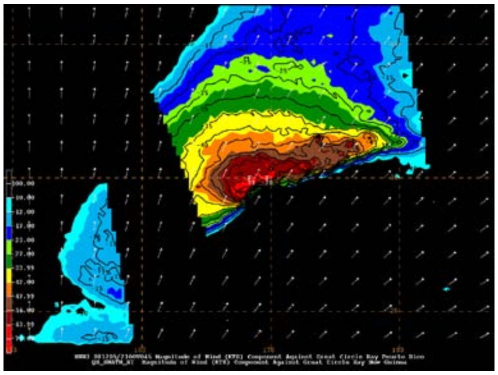

Figure 7. As for Figure 6 except QuikSCAT wind component relative to New Ireland, New Guinea valid 2100 UTC 5 December 2008. Dark brown contours represent winds of STORM force and red of HURRICANE FORCE.

6. DISCUSSION

Ocean surface vector winds from scatterometers such as the NASA QuikSCAT have been shown to be of significant use to marine forecasters in defining areas of high winds, areal extent of winds, and helping to define surface circulations and fronts. In this paper we have described a technique to further the utility of remotely sensed ocean surface vector winds by identifying areas of potential wave development and as a diagnostic to determine the accuracy of NWP predicted wind fields. Deep water ocean wave propagation agrees well with theory as energy primarily moves along Great Circles. We have developed a means to generate gridded unit vector fields through a GEMPAK function (GCIR) of GC rays emanating from an origin point such as a coastal location. Using a simple dot product we then determine the wind field component of either remotely sensed OSVW or NWP model predictions. The dot product yields an approximation of the fetch oriented toward the coastal location.

In case study one, we saw an example of excellent NWP forecast guidance as compared to QuikSCAT based OSVW. Using the technique described here forecasters would have had confidence in wave predictions from the NWW3 not only for intensity of the event but also timing of the swell front to Puerto Rico.

Case study two is a different matter. In all comparisons, the QuikSCAT winds showed a significantly stronger wind field and wind field component than any GFS forecasts and therefore a greater threat for destructive wave generation. Using the scatterometer based OSVW as ground truth, forecasters would have been suspect of the timing and height of NWW3 based wave predictions.

7. SUMMARY and FUTURE WORK

Simple GEMPAK functionality was developed to define a grid of unit vectors whose direction aligns with Great Circles emanating from an ocean point of interest. A second function truncates the projection of GC rays beyond land masses and islands and defines the GC paths towards the point of interest. Waves generated by winds aligned with the GC paths will propagate to the point of interest. The wind fetch is the wind component aligned with the GC rays and can be estimated by a simple dot product of the wind vector and unit vector

GC rays. The functionality was applied to both NWP wind fields and scatterometer based remotely sensed OSVWs. In the two case studies shown, the utility of applying this technique to wide swath OSVW from QuikSCAT as a diagnostic to determine the validity of NWP based winds was successfully demonstrated. The Atlantic case showed reasonable agreement between QuikSCAT OSVW and NCEP GFS based winds. The Pacific example highlighted a significantly weak cyclone in NWP guidance as compared to the QuikSCAT OSVW fields. The second example clearly demonstrates the potential for this technique to be used as both a diagnostic and threats assessment and bolsters the utility of global wide swath remotely sensed ocean surface vector winds.

The rotating antenna aboard QuikSCAT seized in November 2009 and wide swath OSVW are no longer available. OSVW from the European ASCAT scatterometer have been added to the technique for U.S. coastal and territorial sites and are presently under evaluation. The one drawback ASCAT has compared to QuikSCAT OSVW is the limited swath width (two 550 km swaths with a 720 km inherent nadir gap). The ASCAT OSVW rarely gives forecasters the ability to see the entire wind field associated with extratropical cyclones. India's OSCAT scatterometer on the OceanSat-2 satellite is presently in orbit and under evaluation. We hope to apply this technique to OSCAT OSVW once they become available in near real-time.

In addition to application to remotely sensed OSVW, the technique has clear applications as a training tool for coastal and ocean marine forecasters. By applying the algorithm to NWP wind and wave fields favored fetch windows are explicitly defined and forecasters can build knowledge concerning the generation and evolution of storms, fetch, and associated waves. For instance, when viewing wind components along specific fetches it is clear that storm motion is critical to the generation of longer period swell. In the future. the OPC will be working with NWS coastal Weather Forecast Offices (WFOs) to distribute GC path grids and bring this application into wider NWS operations.

Ackowledgements. The authors wish to extend our gratitude to Keith Brill of the Development training Branch of the NCEP Hydrometeorological Prediction Center, Scott Jacobs and Dave Plummer of the NCEP Central Operations Systems Integration Branch, for their suggestions, patience, and persistence in making this technique possible and to Frances Achorn of the Ocean Prediction Center for providing the gridded NWP and QuikSCAT fields from archive.

7. ***References***

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