6A.4 THE NATIONAL WEATHER SERVICE UNIFIED SURFACE ANALYSIS

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1. INTRODUCTION

The Unified Surface Analysis is a near-hemispheric surface analysis created every six hours at the four synoptic times and produced by four different offices within the U. S. National Weather Service—the Hydrometeorological Prediction Center (HPC), the Ocean Prediction Center (OPC), the National Hurricane Center (NHC), and the Honolulu Weather Forecast Office (HFO). While each office produces separate analyses to suit their own operational needs and objectives, a process is in place whereby a collaboration between the four offices results in one seamless analysis covering an area of 177,106,111 km^2 , or about 70% of the Northern Hemisphere.

Users of any of the various surface analyses produced within the NWS may not be aware that all contain contributions from the other three analysis centers. For example, the portions of the HPC North American surface analysis covering the Atlantic and Pacific Oceans, Florida, the Gulf of Mexico, and Mexico are actually produced by NHC and OPC and then are attached to the HPC analysis. The purpose of this paper is to describe the overall process and content of the Unified Surface Analysis, as well as the various tools used to construct the analysis.

The Unified Surface Analysis process is guided by the Unified Surface Analysis Manual (the main reference for this manuscript), produced by forecasters from all four analysis centers to streamline the analysis process. The manual is available through the HPC website at http://www.hpc.ncep.noaa.gov/sfc/UASfcManualVersion1.pdf

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2. HISTORY

For several decades, various offices within the NWS and its predecessor the U. S. Weather Bureau produced separate surface analyses which covered geographic areas important to their forecast and warning operations. These analyses usually overlapped and led to a duplication of effort by the offices—and often brought confusion to users who would see features analyzed differently from office to office. To remedy this redundancy, the various analysis centers agreed to limit their analyses to their respective areas of responsibility and to combine them to create one seamless Unified Surface Analysis covering much of the Northern Hemisphere (Figure 1). This effort was intended to make the entire process more efficient and to allow each center to bring its own particular regional and meteorological expertise to the analysis process. The plan was initiated in 2001 by HPC, OPC, and NHC, with HFO joining the collaboration effort in 2003. An example of the Unified Surface Analysis is shown in Figure 2.

HPC and its predecessor the National Meteorological Center (NMC) began creating surface analyses in 1946 spanning from the equator to the North Pole. OPC and its predecessors created surface analyses for the open waters of the Atlantic and Pacific Oceans generally north of 18°N. NHC was concerned with tropical surface analysis over the waters of the Atlantic and East Pacific Oceans from Hawaii eastward from the equator to 50°N. HFO also produced tropical and subtropical surface analyses of the Pacific Ocean extending from 30°S to 50°N. In addition to these four offices, the Anchorage Forecast Office (ANC) also drew surface analyses for the northeast Pacific Ocean, eastern Asia, and the state of Alaska. Obviously, these analyses led to significant duplication of effort over portions of the Northern Hemisphere.

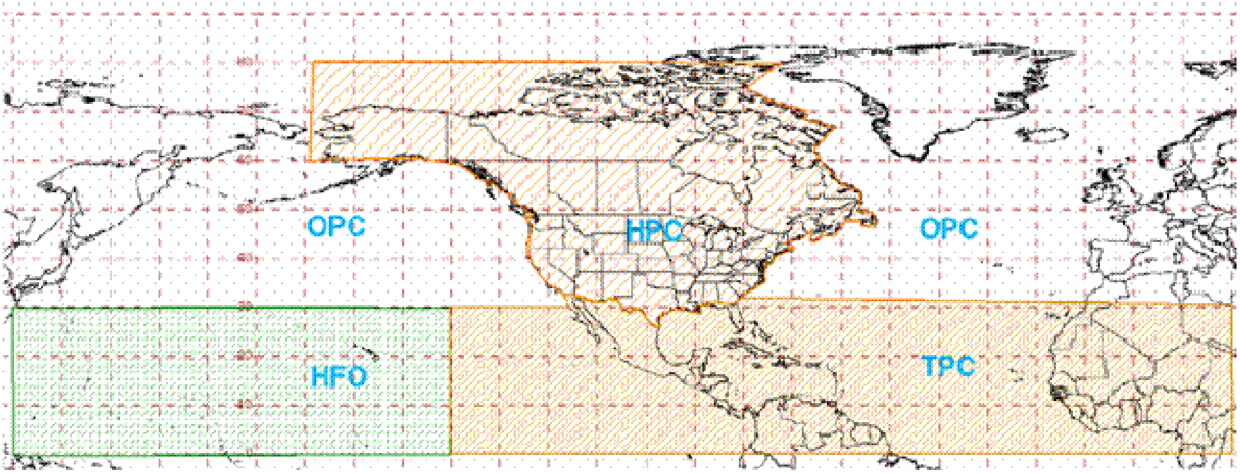

Figure 1. Map showing the area covered by the Unified Surface Analysis and the areas of responsibility of HPC, OPC, TPC (NHC), and HFO.

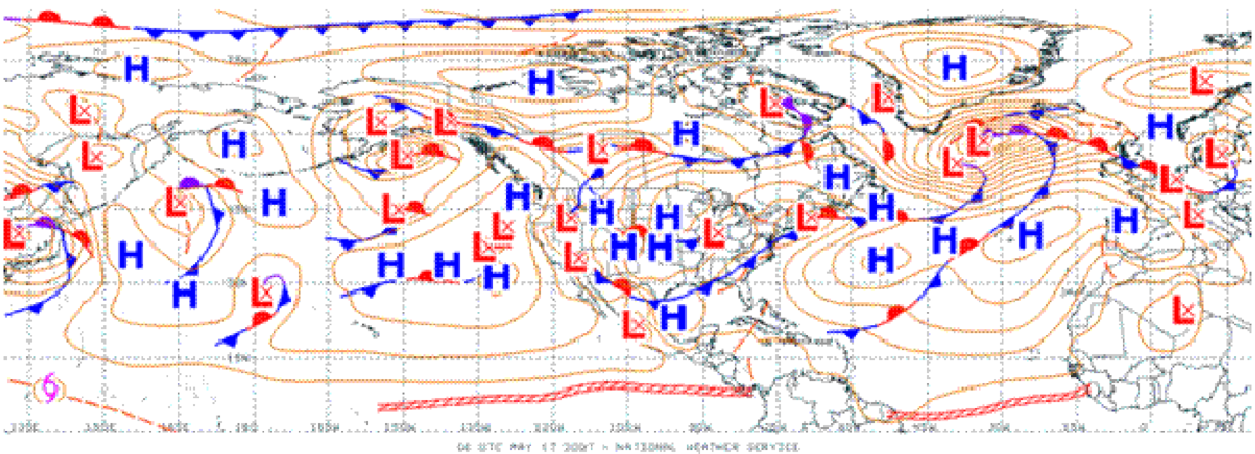

Figure 2. Example of the National Weather Service Unified Surface Analysis from 0600 UTC 17 May 2007.

In 2001, the various centers decided to limit their analyses to their areas of responsibility (AOR) and combine each of these separate analyses to create one seamless surface map for much of the Northern Hemisphere. This collaboration was intended to save time and allow each center to concentrate more fully on their respective regions of expertise, ideally producing an overall analysis that was more precise and meteorologically sound than could have been done by any one analyst.

While each center still produces its own surface analyses separate from the Unified Surface Analysis, analyses of the other centers are used for the parts that lie outside of their AOR. For example, even though NHC produces an area-wide surface analysis which covers the region from 20°S to 50°N between 0° and 160°W, the part which lies outside of the NHC AOR consists of the analyses from HPC, OPC, and HFO. Figures 3a-3d show examples of the separate analyses produced by NHC, HPC, OPC, and HFO.

Currently, HPC provides the surface analysis roughly from 30°N to 85°N, including much of mainland North America, the Canadian Archipelago, and the Arctic Ocean. NHC produces the analysis for the tropical and subtropical areas from the equator northward to 30°/31°N between 20°E westward to 140°W, including overland areas of Florida, Mexico, South America, Central America, Africa, and the Caribbean. HFO also produces an analysis for tropical and subtropical areas from the equator to 30°N between 140°W and 130°E. OPC is unique in that it produces two separate analyses: an Atlantic and Pacific analysis which stretch from NHC and HFO's boundaries northward to Eastern Asia, the Aleutians, Greenland, Western Europe, and the Mediterranean Sea. The two analyses are split along 105°W.

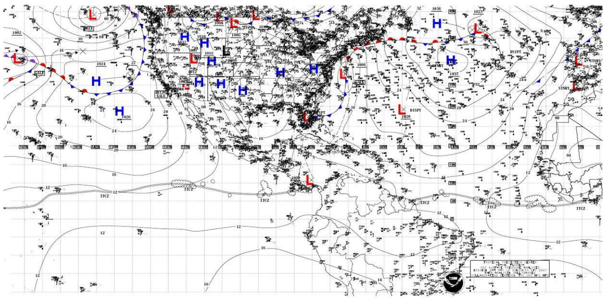

Figure 3a. Surface analysis produced by NHC.

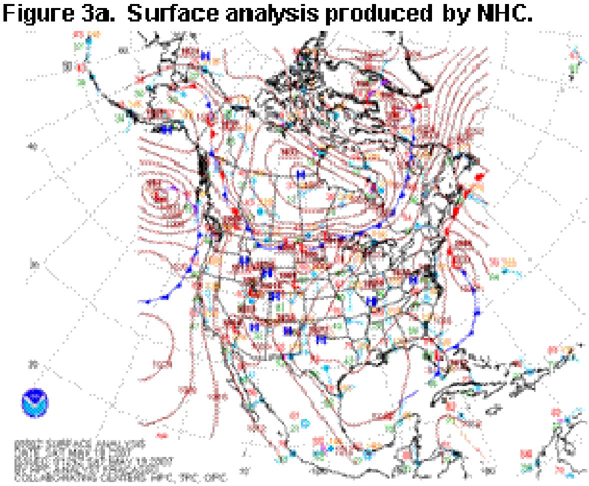

Figure 3b. Surface analysis produced by HPC.

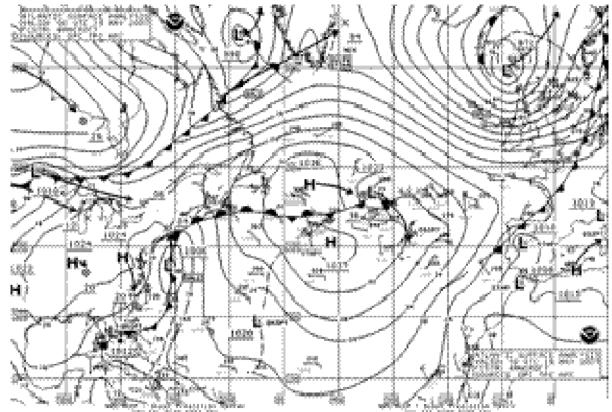

Figure 3c. Atlantic surface analysis produced by OPC. A similar analysis is produced by OPC for the North Pacific Ocean.

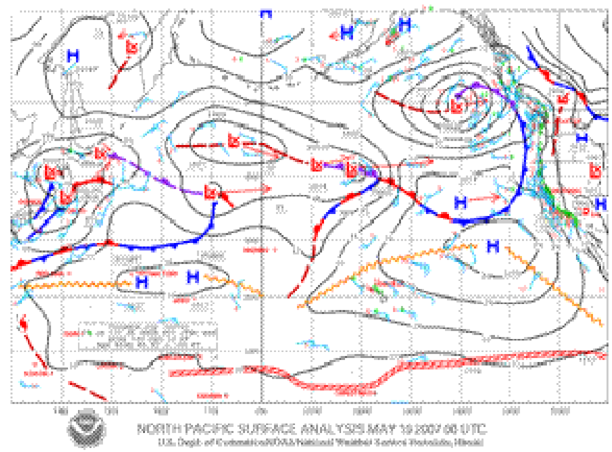

Figure 3d. Surface analysis produced by HFO.

3. CONTENT

The Unified Surface Analysis includes all synoptic-scale systems and isobars every four millibars. Mesoscale features are depicted in the data-rich contiguous United States and in other locations where data permits, mainly in the HPC AOR but also sometimes over the immediate coastal waters of the United States when features are in radar range. Intermediate isobars (every one to two millibars) are sometimes included in areas of weak pressure gradients, especially within the HPC, NHC, and HFO areas.

The various synoptic and mesoscale features depicted on the Unified Surface Analysis are shown in Figure 4. Some features are used by all four centers in their analyses while others, such as tropical waves or the ITCZ, are only used by particular centers because of their specific geographic characteristics.

Frontal boundaries are one of the most important features depicted on the analysis. For operational purposes, the four centers have agreed to define a front as a density discontinuity in which there is a temperature difference of about 6°C (10°F) over a distance of 500 km (300 nautical miles) (Bluestein 1986). This temperature gradient can be smaller over the open oceans where air masses have been modified by the underlying sea surface. Cold, warm, and stationary fronts are fairly straightforward in their definitions. Occluded fronts come in two varieties. Cold occlusions occur when the coldest air surrounding the cyclone is behind its cold front and are normally seen on the west sides of ocean basins and with clipper systems descending from the arctic. Warm occlusions form when the coldest air surrounding the cyclone is ahead of its warm front and are normally seen on the east sides of ocean basins and just to the lee of the U.S. portion of the continental divide (Glickman 2000).

When cold fronts reach the subtropical and tropical waters, they often transition into a shearline. Lying equatorward of the subtropical ridge, these boundaries have lost all temperature contrast over the warm ocean and have minimal dewpoint contrast across them. However, they delineate an area where wind speed quickly

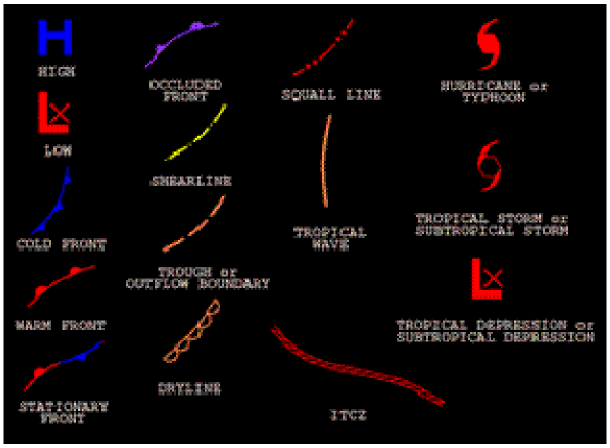

Figure 4. A schematic showing the various features plotted on the Unified Surface Analysis.

increases on the poleward side by at least 5 m/s (10 knots) but from nearly the same direction as on the equatorward side. They lie in pressure troughs although due to the lack of observations over the tropical and subtropical waters, the trough may not be recognizable.

HPC uses three features primarily in its mesoscale analysis which are predominantly related to severe weather. A dryline is the leading edge of a significant density or dewpoint discontinuity forced by downslope winds off the Rocky Mountains and Mexican Plateau, usually ahead of a significant synoptic-scale system moving through the Western or Southwest United States. They usually progress eastward during the heating of the day due to mixing processes and then retreat westward at night once mixing ceases. A dryline is usually associated with a dewpoint difference of 14°C (25°F) or more, usually located where the gradient is strongest.

Outflow boundaries and squall lines are also sometimes depicted on the surface analysis as mesoscale boundaries associated with thunderstorms. An outflow boundary is formed by the horizontal spreading of thunderstorm-cooled air and can last for more than a day (Glickman 2000). A squall line is a solid line of convection, usually associated with rapid pressure fluctuations and high winds. It is normally placed at the leading edge of a wind shift and inside the leading pressure trough.

In the tropics, tropical waves are tracked by NHC usually beginning in May and lasting roughly until November. A tropical wave is a trough or cyclonic curvature maximum in the trade wind easterlies that usually reaches maximum amplitude in the lower to middle troposphere. Tropical waves are often difficult to analyze due to a lack of surface and upper air data over the open waters of the Atlantic Ocean. In general, a diagnosis of the vertical shear pattern can help determine if the surface reflection of a tropical wave axis lies ahead of, on top of, or behind a cluster of convection.

Tropical cyclones are depicted on the surface analysis using positions given by the various tropical cyclone forecasting centers (NHC, the Central Pacific Hurricane Center [CPHC], and the Joint Typhoon Warning Center [JTWC]). The usual symbols for hurricanes, tropical storms, and tropical depressions are used—with the hurricane symbol also used for typhoons over the Western Pacific. Subtropical storms are depicted with a tropical storm symbol since marine warnings associated with these systems are issued as tropical storm warnings.

More recently, NHC and HFO have analyzed the Intertropical Convergence Zone (ITCZ) for inclusion into the Unified Surface Analysis. Defined for operational purposes, the ITCZ is a zonally elongated axis of surface wind confluence in the tropics, due to a confluence of northeasterly and southeasterly trade winds, and/or confluence at the poleward extent of cross-equatorial flow into a near-equatorial “heat trough” (partly from Glickman 2000). Breaks and discontinuities are often denoted within the ITCZ in areas where surface confluence is very weak or non-existent and also in the vicinity of tropical waves.

4. **TOOLS**

a. Surface Observations

The most obvious tool for producing a surface analysis is surface observations. The four centers rely on three types of surface observations when analyzing surface meteorological data: METAR, SYNOP, and SHIP observations. Most METAR observations are available at least once per hour and are most numerous across the United States. There are almost 2000 METAR sites across the United States alone and an additional 12,000 sites available through the U.S. mesonet at the Global Systems Division (GSD). Most METAR observations are available to the analyst by H+0:05 while those from the military and from Canada are usually available by H+0:15.

SYNOP observations are international observations taken every three or six hours, depending on the site. SHIP observations include ships, buoys, and C-MAN stations. SHIP observations are perhaps the most unreliable observations given the unsteady and often hostile conditions in which the observations are taken. In addition, some meteorological sensors aboard ships may not be calibrated as frequently as other observation platforms and are subject to more severe environmental conditions. However, every ship and buoy observation is vital to the analysis centers when the general lack of observations over the oceans is taken into account. SHIP data are typically analyzed carefully for inconsistencies in reported pressures and wind speeds and are always quality controlled against some benchmark (usually a numerical model).

In general, SHIP observations are generally available by H+0:20 but some can lag by as much as H+1:00 or H+1:30. Whereas HPC benefits from a dense network of METAR and SYNOP observations over the United States and Canada which arrive in a timely fashion, NHC, OPC, and HFO rely more heavily on ship and buoy observations and thus require more time to produce a comprehensive analysis.

Because the network of surface observations over parts of the oceans is not very dense (especially over the tropical areas), it is often beneficial to use observations which are up to a couple of hours old, especially in regions of the tropics where the change in pressure is relatively small. The semi-diurnal pressure tide does become a factor, however, and must be accounted for at all times.

b. Upper air soundings/cross sections

Often, analyzing the vertical structure of the atmosphere can provide clues as to the state of the atmosphere at the Earth's surface. For example, a cross section plot of potential temperature (θ) or equivalent potential temperature (θ_e) can indicate the slope of a front and where the front intersects the Earth's surface. Even the inspection of a single upper air sounding can provide clues as to the conditions at the surface. Wind veering (backing) with height can indicate warm (cold) advection and can therefore help to define frontal passage across a station.

The use of upper air soundings is also extremely important in the analysis of tropical waves. NHC uses upper air time sections from individual stations to decipher when and if a tropical wave passed its location since the maximum amplitude of a tropical wave typically occurs near 700 hPa. The time sections present a vertical picture of the atmosphere at each station over a 12 day period, such that changes in zonal and meridional wind, relative humidity, and θ_e can be observed with wave passage. Figure 5 shows an example of the anomalous wind field from Dakar, Senegal—an important radiosonde station when it comes to deducing when a tropical wave moves off the coast of Africa. Wave passage is usually apparent when the anomalous wind shifts from a northerly direction to a southerly direction (blue to pink shading on the diagram).

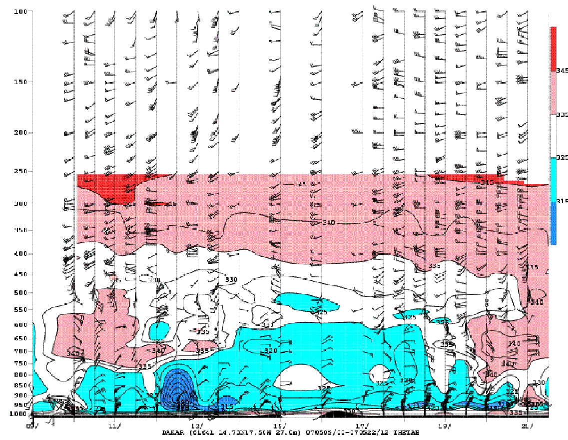

Figure 5. A vertical time section of the anomalous winds from Dakar, Senegal.

c. Satellite imagery

Satellite imagery is one of the most important tools for surface analysis in regions where surface observations are lacking (especially over the oceans). Visible imagery is preferred in order to see the movement of low clouds, although infrared imagery can also be quite useful in locating certain features. Water vapor imagery is also a beneficial tool in defining middle and upper level features and relating them to surface features.

Sometimes even microwave satellite imagery can be helpful. One of the most invaluable tools for the marine analyst is satellite-derived winds, specifically from QuikSCAT. QuikSCAT wind vectors cover nearly 90% of the world's oceans every day but since the satellite is a polar-orbiting platform, only two useful wind swaths are produced over a particular area each day. Also, there are gaps between each swath outside of the polar regions (largest gaps lie within the tropics), making it impossible to see every area of the world's oceans. Winds from QuikSCAT can help identify frontal boundaries, tropical cyclones, the ITCZ, tropical waves, as well as areas of high and low pressure. Increases in wind speed are usually observed poleward of occlusions and warm fronts and behind cold

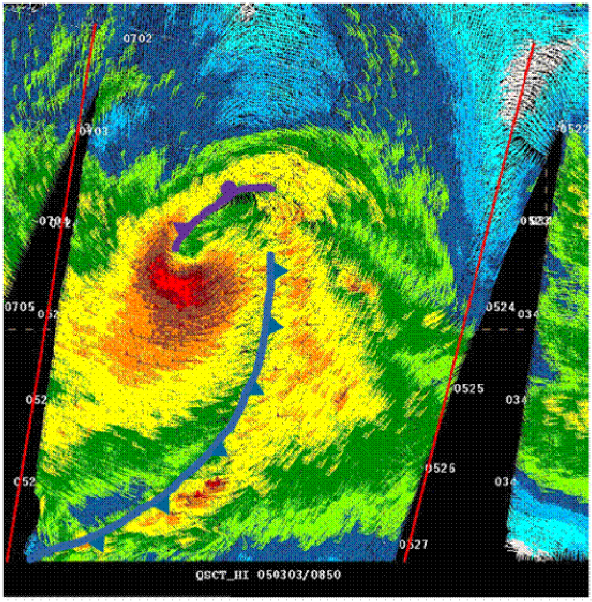

Figure 6. Analysis of a cold front and occluded front based on the wind speed and wind direction from a QuikSCAT image.

fronts. The pressure gradient can also be inferred from QuikSCAT wind estimates, allowing an analyst to infer the proper spacing between isobars. Figure 6 shows an example of a QuikSCAT image and the subsequent analysis of a cold and occluded front based on the wind direction and gradient in wind speed.

d. Radar imagery

Primarily used by HPC, radar imagery from the WSR-88D network can help with the placement of frontal zones and squall lines over the United States and its adjacent coastal waters. When in clear-air mode, the radar can help reveal thin discontinuities for the analysis of frontal zones or outflow boundaries. The intensity of precipitation can also be of use, where linear convection with heavy rainfall is usually associated with cold fronts whereas warm fronts usually lie on the equatorward side of a broad area of stratiform rain. Although not as extensive and having lower resolution, radar imagery from several Caribbean and Central American countries is consulted to help with the placement of tropical cyclones and tropical waves.

e. Model-derived fields

Numerical models are extremely useful in diagnosing the type and placement of synoptic features on the Unified Surface Analysis—but they are just that—models which must be used in accordance with other real-time observations or data. Many different model-derived fields are employed at each of the centers to analyze the particular features specific to their area of responsibility. For the analysis of fronts, most centers use not only basic sea level pressure and wind vectors but also low-level thickness pattern fields and boundary layer moisture convergence. The 1000-850 hPa thickness pattern is helpful in placing frontal zones over bodies of water and flat terrain, with fronts lying at the leading edge of the thickness packing. In areas of higher terrain, more elevated layers are needed to deduce frontal placement, such as the 850-700 hPa thickness field over western North America.

Since the Unified Surface Analysis inherently attempts to denote frontal boundaries at the Earth's surface, an important field to inspect is the pattern of equivalent potential temperature (θ_e), which takes into account the temperature and moisture surrounding frontal boundaries. In particular, a plot of the gradient of θ_e can clearly show not only the location of a frontal boundary, but also how strong or weak the front is and if it has lost most of its baroclinicity. Figure 7 shows an example of a field of the gradient of θ_e from the Global Forecast System (GFS) model. Note that some areas, such as the Canadian Maritimes and the Pacific coast of Mexico have gradients which are not related to frontal boundaries. The analyst must use this field as guidance when he or she knows that a front may exist but needs help with the exact location or strength of the boundary.

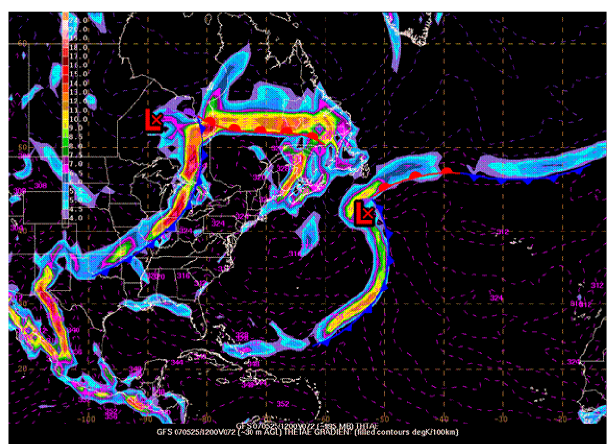

Figure 7. An example of the gradient of equivalent potential temperature (θ_e) from the Global Forecast System (GFS). Units are in K/100 km with coloring beginning above 4.0 K/100 km.

5. COORDINATION

The entire process of producing the Unified Surface Analysis takes about three hours from start to finish and involves all four analysis centers (NHC, HPC, OPC, and HFO). As shown in Figure 1, each center produces analyses within their respective AOR. Each center must then exchange their analyses electronically and coordinate features along the boundaries. Ultimately, the four separate analyses are appended together to form the final seamless analysis. The timeline is as follows (where H is the synoptic hour):

Time	Action
H	HPC, NHC, OPC, and HFO begin analysis
H+1:00	HPC, NHC, and OPC all exchange preliminary files and begin coordination
H+1:30	HPC completes coordination with NHC and OPC and transmits final North American analysis
H+1:00-2:00	NHC and OPC finalize their analyses
H+2:00	HFO completes their preliminary analysis and sends to NHC and OPC for coordination
H+2:15	NHC appends the HFO analysis for the Unified Surface Analysis
H+2:30	OPC completes their analyses and sends to NHC for coordination
H+2:45	NHC appends the OPC/HPC merged analysis to the already existing NHC/HFO merged analysis, then transmits the completed analysis
H+3:00	Final deadline for NHC if tropical cyclones are present—OPC finalizes the Unified Surface Analysis and transmits the product

It is well-known and even documented that there can be marked differences of opinions concerning the placement of surface features or the identification of features even among knowledgeable analysts (Uccellini et al. 1992). The four analysis centers must handle differences in opinion on these issues on an almost daily basis, but methods are in place to make a final decision. First and foremost, each analysis center respects the integrity of the analysis of the other three centers over their respective AORs, realizing that each has its own expertise in the analysis of uniquely geographic and meteorological scenarios. Coordination and collaboration are primarily limited to the boundaries of the AORs, where surface features and isobars cross from one center's analysis to another. It is usually simplest to "meet in the middle" with most features, since the difference in opinion is rarely of great significance. On the rare occasion where the differences are more significant, the centers will attempt to come to a mutual agreement, with each having alternating priority on the final decision. This scenario is only used in the rarest of cases, and only if the disagreement occurs within a few degrees of the AOR boundaries.

The Unified Surface Analysis is currently hosted on the OPC website at http://www.opc.ncep.noaa.gov/UA.shtml (Figure 8). A full analysis is shown on the page, but there are two ways to access regional portions of the map. The user can click on the map itself or use one of the links located below. In addition, the full-scale analysis can be looped over a period of 3, 7, or 14 days—and the regional maps can be looped over 3 or 7 days.

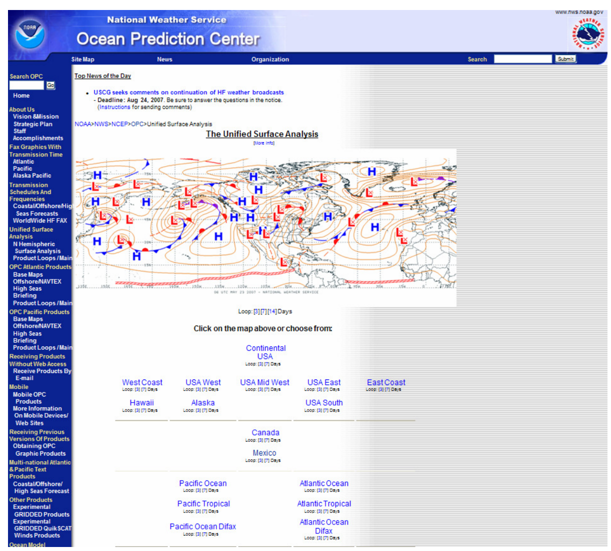

Figure 8. Screenshot of the Unified Surface Analysis website hosted by OPC.

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