Integrated Approach to Decision Support Services

Toward Explicit Hazard Impact Forecasts and Warnings

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Introduction

This paper looks at a conceptual workflow that incorporates risk management principles in the forecast process and decision support services. The individual stages of the workflow are not new ideas or practices. Some elements of the workflow are already practiced throughout the NWS but not uniformly. The main premise of this concept is that the NWS adopts a spectrum of solutions as the official forecast, and that a weighted consensus is the deterministic best guess. A deterministic solution can still be used in NWS legacy products. Tailored forecasts and services can deviate from the deterministic forecast as long as they don't extend beyond the bounds of the official spectrum of solutions. The conceptual workflow is illustrated in Figures 1 and 2.

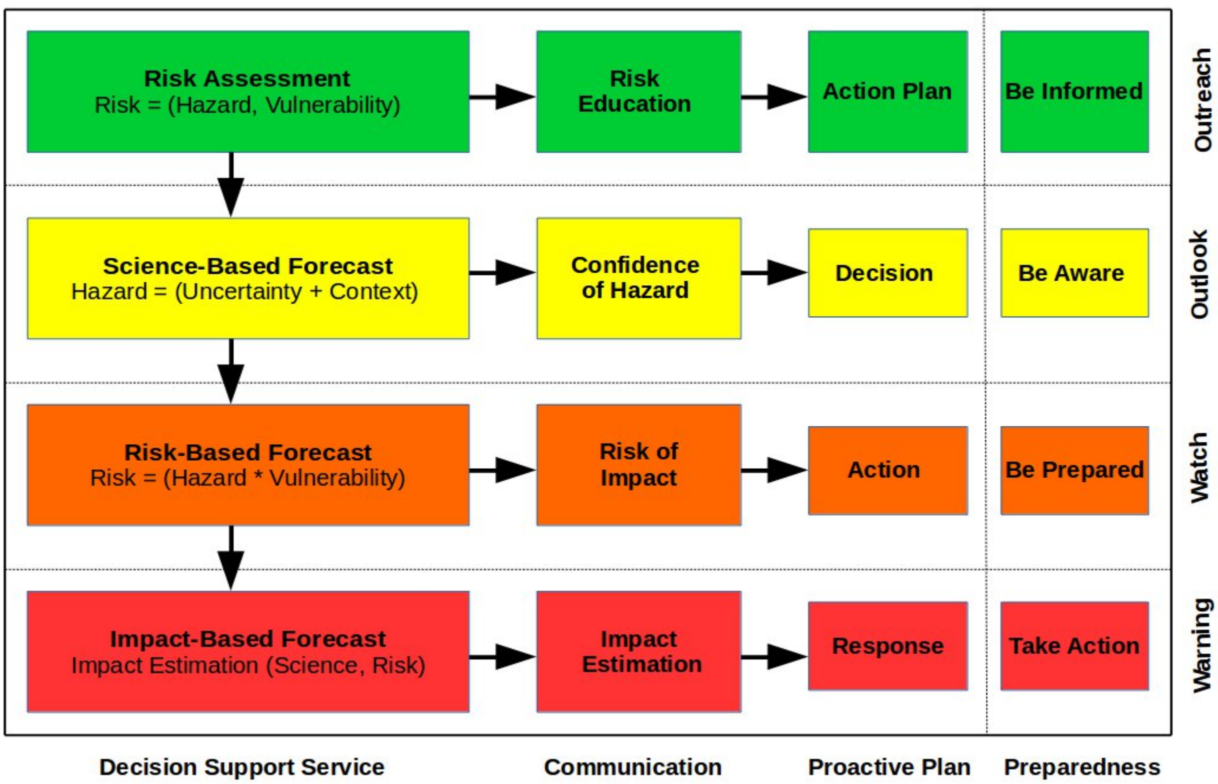


Figure 1. Abstract Concept of a Forecast Process for IDSS

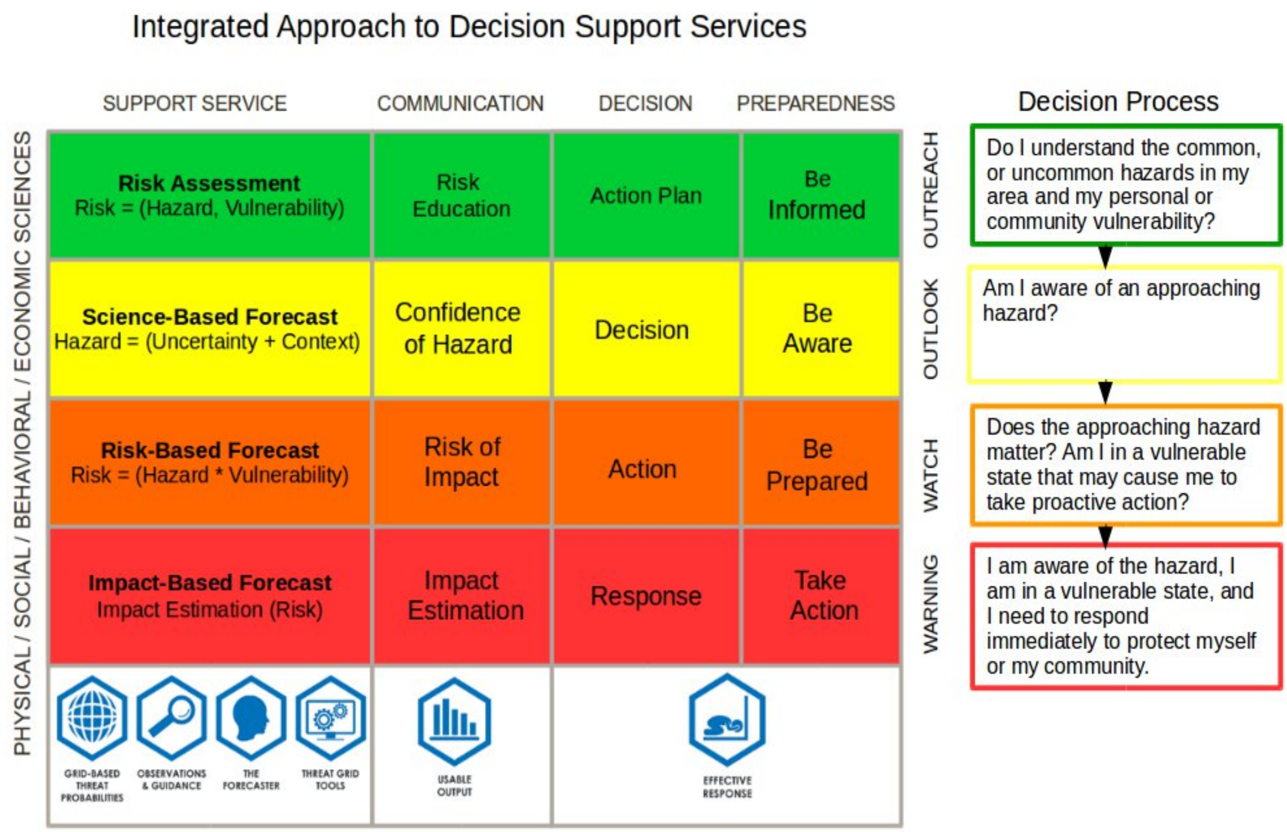


Figure 2. Integrated Approach to Decision Support Services

Currently, a weather forecaster uses less than approximately one-quarter of the information available to make a forecast decision. The vast amount of observational and model information has already exceeded the human forecaster's capacity to effectively use, especially under time constraints. Forecasters will be faced with more observational and deterministic models in the future that do not individually translate nicely to communicating the uncertainty of a hazardous weather, water, and climate event. However, a forecast process that relies mainly on an Ensemble Prediction System (EPS) and/or statistically derived information and data fusion methods does translate well to an Impact-Based Decision Support Service (IDSS).

The following is a conceptual description of a forecast process that is more aligned with risk management principles, and forms a direct link to explicit hazard impact forecasts and decision support services. The 4 stages in Figures 1 and 2 (left column) of the conceptual diagram as it applies to the Agricultural (AG) community in southeast Arizona is described with the end goal of providing IDSS. In particular, decision support for cold temperatures that have the potential to affect the health and subsequently the yield of crops. The additional columns related to communication of the forecast, proactive planning, and preparedness levels will not be discussed in detail. For additional information on terminologies and concepts used in risk management, particularly in risk modeling, please refer to the appendix.

Overview

The state of Arizona has one of the most diverse climates in the United States driven mainly by the elevation changes from near sea-level to over 10,000 feet. As a result, a variety of crops are grown across the state ranging from lettuce to fruits and nuts. This diversity in crops results in a variety of crop phenologies and vulnerabilities to weather, water, and climate. To complicate matters, each crop type has a different critical temperature at the various stages of growth from germination to flowering and fruiting (crop phenology). That said, the legacy NWS warning products for Freeze/Frost events are not useful to growers in Arizona when it comes to making decisions on whether or not to implement crop protection strategies.

Risk Assessment - Green Row

To provide a more meaningful and relevant service to the AG community, additional information beyond the weather, water, and climate need to be gathered and integrated in the forecast and decision support processes. Risk assessment provides this additional information. Risk assessment is a process of identifying hazards and vulnerabilities to these hazards for the purpose of determining the impacts. Understanding and quantifying these vulnerabilities is essential to cataloging the impacts in a GIS-based framework.

Hazard and Vulnerability Assessments

One successful framework for gathering and integrating this additional information comes from elements of NOAA's Community Vulnerability Assessment Tool Methodology (CVAT). The process is designed mainly for the Emergency Management (EM) community, but the overall concept can be applied to other types of communities, economic sectors, and core NWS partners.

Community Vulnerability Assessment Tool Methodology (CVAT)

This section describes the elements of the CVAT that apply to the southeast Arizona AG community. An in-depth description of this methodology can be found in the following article: https://coast.noaa.gov/data/docs/digitalcoast/cvat-nhr.pdf

The method provides the NWS field offices with a framework to engage and extract not only relevant but actionable information from partners. This information provides the basic building blocks for a GIS-based risk model, with the end goal of identifying and quantifying impacts from extreme weather, water, and climate events. Through this process, 4 key themes can be accomplished to better serve decision makers:

1. Building relationships with partners
2. Understanding the mission of partners

3. Learning critical impact thresholds and decision points of partners
4. Providing appropriate information based on the needs of partners

Initial Step: Community Engagement

The initial step in the methodology is to engage stakeholders and form a steering committee. In defining the AG community for southeast Arizona and forming the so called steering committee, the following key members are identified:

1. National Weather Service (NWS) in Tucson, AZ
2. University of Arizona, Cooperative Extension in the College of Agriculture and Life Sciences
3. Climate Assessment for the Southwest (CLIMAS) - One of NOAA's RISA teams
4. University of Arizona, School of Natural Resources and the Environment- Office of Arid Lands Studies

It should be noted that care must be taken in forming a community-based service and steering committee to avoid any violation of the Public-Private Partnership (National Research Council 2003) which was agreed to by NOAA. In this case, a state government (University of Arizona) entity is considered the primary partner for impact-based forecasts and decision support.
The partner's roles are as follows:

1. Facilitate building relationships with the NWS and growers.
2. Help identify, collect, and map critical temperature thresholds and decision points from crop growers.
3. Participate in an outreach program to educate growers of weather, water, and climate risks.
4. Collaborate in the messaging of confidence, risk of impact, and impact estimation forecasts from the NWS to the AG community as a whole.

Role's 1 and 2 are elements of the risk assessment in which the NWS forecaster plays a significant role in what can also be considered as a co-learning process with the community participants. The 3rd and 4th roles relate to the risk communication in all of the 4 processes of the conceptual diagram in Figures 1 and 2. In other words, Risk Education (green) involves an outreach program designed to educate the AG community of weather, water, and climate risks. The Confidence of hazard (yellow) involves communicating the confidence level of the forecast for cold temperatures followed by communicating the Risk of Impact (orange). The final process involves translating the forecast into a meaningful and actionable Impact Estimation (red).

Another example of this community engagement for AG has been established by the Midwestern Regional Climate Center with hosting the Vegetation Impact Program (VIP). See: http://mrcc.isws.illinois.edu/VIP/index.html

Step 1: Hazard Identification

The first step of the CVAT process involves ranking the different hazards that have occurred or have the potential to occur in the future. For this case, cold temperatures occurring during the different phases of a crop's growth pose the greatest risk. Other hazards such as drought, excessive heat, excessive rainfall, and hail are identified as potential risks. The process of ranking involves gathering and analyzing historical records, and in some cases just relying on the partner's subjective judgment.

Step 2: Creating Hazard Analysis Map

Once the hazards are ranked, the bulk of the work involves using a GIS software package to map the location of the hazards and identify any features (crops, houses, buildings, etc.) that fall within the hazard areas. This hazard area defines the area of greatest risk. Various GIS software packages like ArcGIS or open-source packages like QGIS and GRASS can be used to map the hazards and identify features that have the greatest risk of impact.

The historical records for the ranked hazards come from various sources and in a number of formats. Depending on the hazard, a significant amount of time is involved in gathering the needed information. Once the hazard information is collected, it is usually necessary to convert this information into a readable GIS format such as a shapefile, raster, or comma delimited file.

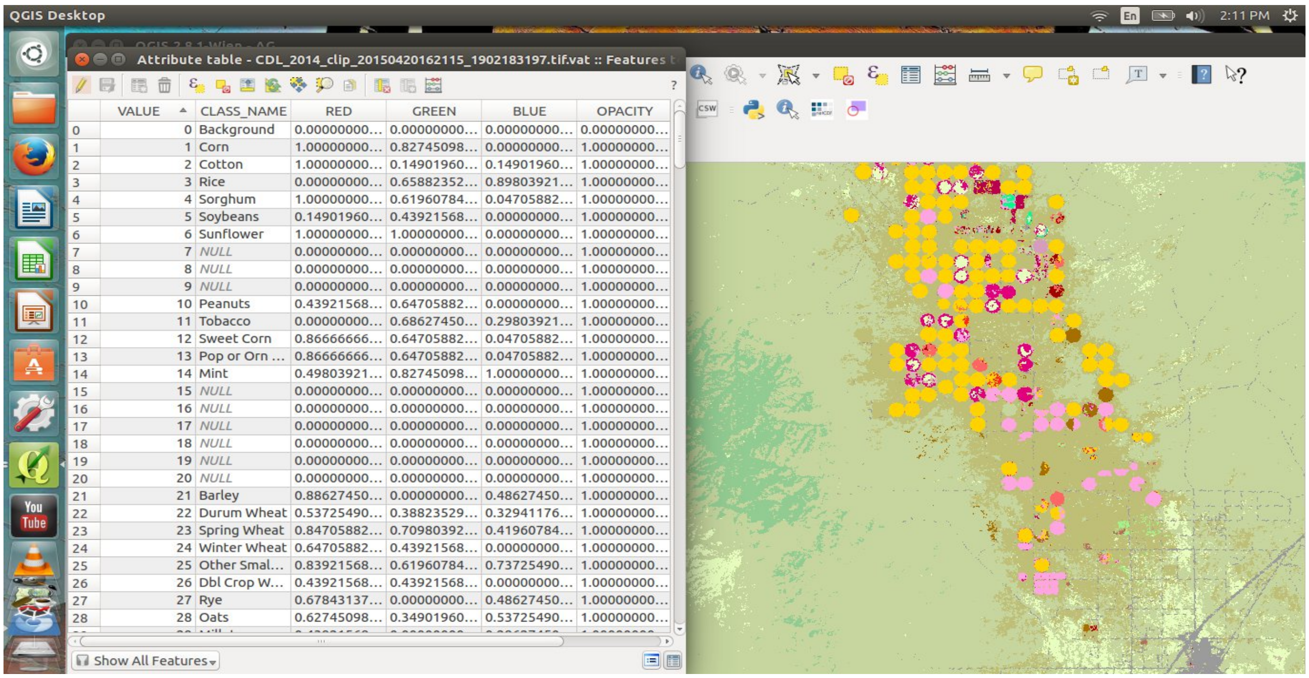
For most weather related hazards, the risk areas can change with the time of year and time of day. In this case, a climatology of the hazard in the form of historical frequencies or probabilities is created to identify the risk areas as a function of season and time of day. The initial work of this climatology is carried out in the first step of identifying hazards. Ideally, the GIS software or a similar method is used to create a gridded format (raster) of the hazard frequencies. The end product is a GIS raster layer of historical probabilities which can become the part of the risk model referred to as the hazard assessment. The Storm Prediction Center's (SPC) gridded climatology of severe local storms is an example of potential GIS layers. Refer to:
http://www.spc.noaa.gov/new/SVRclimo/climo.php?parm=anySvr

For the southeast Arizona AG community, weather station observations and high resolution gridded temperatures are used to compute historical Probabilities of Exceedance (POE) for several thresholds at and below freezing.

Steps 3 through 6: Vulnerabilities

To determine impacts from a hazard it is necessary to understand vulnerabilities. Steps 3 through 6 of the CVAT involve identifying and quantifying the vulnerabilities of critical facilities, societal, economic, and environmental categories using various GIS layers. These steps describe the methodology from the EM community and public safety perspective, but the same processes can be applied to other communities and partners. Overall, the goal is to determine the threshold which triggers some type of protection effort in hopes to minimize the impact.

For the AG community, it is first necessary to locate the different crops grown across southeast Arizona. A GIS cropland data layer called CropScape is used to locate and identify the crop types. Figure 3 shows the CropScape product with the associated attribute table. CropScape is a product of the USDA/NASS derived from a satellite remote sensing technique and quality controlled with ground-truth field observations. In southeast Arizona, the CropScape product does not identify all of the crop types correctly. Therefore, a dataset created by a USGS water usage group is used to cross reference and correct the CropScape product.



	VALUE	CLASS_NAME	RED	GREEN	BLUE	OPACITY
0	0	Background	0.00000000...	0.00000000...	0.00000000...	0.00000000...
1	1	Corn	1.00000000...	0.82745098...	0.00000000...	1.00000000...
2	2	Cotton	1.00000000...	0.14901960...	0.14901960...	1.00000000...
3	3	Rice	0.00000000...	0.65882352...	0.89803921...	1.00000000...
4	4	Sorghum	1.00000000...	0.61960784...	0.04705882...	1.00000000...
5	5	Soybeans	0.14901960...	0.43921568...	0.00000000...	1.00000000...
6	6	Sunflower	1.00000000...	1.00000000...	0.00000000...	1.00000000...
7	7	NULL	0.00000000...	0.00000000...	0.00000000...	1.00000000...
8	8	NULL	0.00000000...	0.00000000...	0.00000000...	1.00000000...
9	9	NULL	0.00000000...	0.00000000...	0.00000000...	1.00000000...
10	10	Peanuts	0.43921568...	0.64705882...	0.00000000...	1.00000000...
11	11	Tobacco	0.00000000...	0.68627450...	0.29803921...	1.00000000...
12	12	Sweet Corn	0.86666666...	0.64705882...	0.04705882...	1.00000000...
13	13	Pop or Orn ...	0.86666666...	0.64705882...	0.04705882...	1.00000000...
14	14	Mint	0.49803921...	0.82745098...	1.00000000...	1.00000000...
15	15	NULL	0.00000000...	0.00000000...	0.00000000...	1.00000000...
16	16	NULL	0.00000000...	0.00000000...	0.00000000...	1.00000000...
17	17	NULL	0.00000000...	0.00000000...	0.00000000...	1.00000000...
18	18	NULL	0.00000000...	0.00000000...	0.00000000...	1.00000000...
19	19	NULL	0.00000000...	0.00000000...	0.00000000...	1.00000000...
20	20	NULL	0.00000000...	0.00000000...	0.00000000...	1.00000000...
21	21	Barley	0.88627450...	0.00000000...	0.48627450...	1.00000000...
22	22	Durum Wheat	0.53725490...	0.38823529...	0.32941176...	1.00000000...
23	23	Spring Wheat	0.84705882...	0.70980392...	0.41960784...	1.00000000...
24	24	Winter Wheat	0.64705882...	0.43921568...	0.00000000...	1.00000000...
25	25	Other Smal...	0.83921568...	0.61960784...	0.73725490...	1.00000000...
26	26	Dbl Crop W...	0.43921568...	0.43921568...	0.00000000...	1.00000000...
27	27	Rye	0.67843137...	0.00000000...	0.48627450...	1.00000000...
28	28	Oats	0.62745098...	0.34901960...	0.53725490...	1.00000000...

Figure 3. CropScape product and attribute table for the different crop types.

The next step is to add to the attribute table for each crop type the critical temperatures for the different phenological stages. Corresponding to each critical temperature is a POE threshold value that represents a grower's risk tolerance. These critical temperatures and risk tolerance values define the vulnerability thresholds or decision points used to trigger freeze mitigation strategies by growers. Additional information deemed important by the steering committee and growers can be added to the attribute table at any time. This may include the optimum number of growing days, optimum temperatures, optimum rainfall, and etc. The main point here is that just about any type of vulnerability or decision point threshold can be an attribute of the crop.

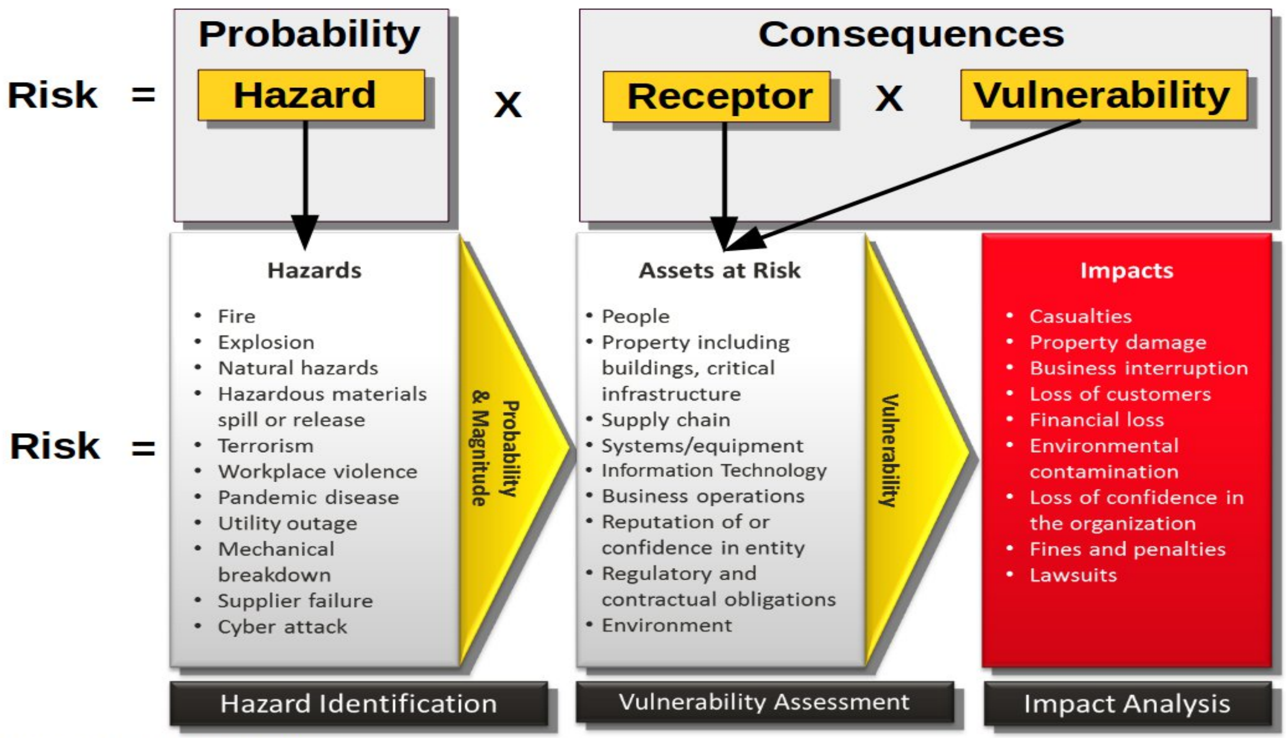
Once this information is populated, an optional analysis using the gridded temperature POEs created in steps 1 and 2 of the CVAT is done to identify the crops with the highest risk of a killing freeze. In some cases, historical frequencies from the nearest weather station may need to be used. At any rate, these crops are climatologically more vulnerable to freezing temperatures. This optional step helps in the identification of mitigation opportunities used by policy makers or individual growers.

Step 7: Mitigation Opportunities

The final step in the CVAT involves identifying mitigation opportunities by using the hazard and vulnerability assessments conducted in steps 1 through 6. This process helps community officials identify areas and measures for mitigation. In the case of the AG community, this may involve making policies to limit or restrict growing certain types of crops in vulnerable areas. That said, the NWS's role in this step is very minimal.

GIS-Based Risk Model

NOAA's CVAT methodology provides a framework for NWS field offices to deepen relationships with core partners and communities. The hazard and vulnerability assessments are essential to understanding impacts. These assessments are also key components that form the foundation of a GIS-based risk model. The basic formula for risk is shown in Figure 4 as a function of the probability of the hazard occurrence, magnitude, and vulnerabilities.



Source: www.ready.gov

Figure 4. Basic formula for Risk.

The way in which the vulnerabilities are expressed in the risk model will vary from hazard-to-hazard. Thus, there is no one-size-fits-all model. Vulnerabilities can be implemented in the model as vector and raster GIS layers or as values in attribute tables associated with shapefiles. In the AG case, the temperature vulnerability thresholds and the grower's risk tolerance probabilities (none, low, moderate, high) are defined in the attribute table of the modified CropScape shapefile. The risk tolerance probability thresholds are predefined, empirically derived, or computed using a simple cost-loss model. The fusion of the forecast temperature probabilities, vulnerability thresholds, and the grower's risk tolerance result in a risk value that can be presented as a probability or index value.

An example of social vulnerabilities in the risk equation shown in Figure 4 is the Social Vulnerability Index (SVI). The SVI refers to the socioeconomic and factors that affect the resilience of communities. Refer to the journal article on the SVI for more details: *"A Social Vulnerability Index for Disaster Management":* http://gis.cdc.gov/grasp/svi/A%20Social%20Vulnerability%20Index%20for%20Disaster%20Management.pdf

Further, the Center for Disease Control (CDC) hosts an interactive map of SVI. See: http://svi.cdc.gov/map.aspx

The following is a list of a few GIS-based risk assessment and modeling software packages:

1. CAPRA (Probabilistic Risk Assessment) : http://www.ecapra.org/
2. InaSAFE: http://inasafe.org/
3. United States FEMA HAZUS-MH: https://www.fema.gov/hazus-mh-overview#
4. OpenQuake: https://www.globalquakemodel.org/openquake/about/tools/risk-modelers/

Science-Based Forecast - Yellow Row

The science-based forecast process is a higher-level type of forecasting that relies on a weather and hydrological EPS to derive uncertainty information from which the most likely and worst cases can be assessed. This may include track probabilities for a tropical system, thunderstorm, tornado, hail swath, and etc. Probability of exceedance and joint probabilities of a multi-parameter event (ex. Red Flag) are other examples of uncertainty information. This initial phase of the forecast process differs slightly from the current practices of producing gridded forecasts of sensible weather elements. That said, the forecaster's attention is spent on the hazards that are of greatest concern by utilizing uncertainty and contextual information.

Uncertainty

Input for a risk model requires uncertainty information in the form of the probability of occurrence and the magnitude of a hazard. Therefore, it is necessary to have this ensemble or statistical model derived information readily available and in a format that is compatible with a GIS-based risk model. To support the AG community, a locally developed error-correction and downscaling methodology for each member of the SREF and GEFS ensemble systems is utilized. A brief summary of this methodology follows:

1. Hourly surface analysis using ARPS 3DVAR data assimilation. Use the 1st hour of the HRRR model forecast as the first-guess background field. Assimilate all surface observations from MADIS and Weather Underground.
2. Download each member (perturbation) from the SREF and GEFS ensemble systems and interpolate surface fields to a 3 km ARPS grid.
3. Apply the error corrections to each forecast hour, perturbation, and ensemble run using the ARPS 3DVAR objective analysis as ground-truth. Method taken from Stensrud and Yussouf (2007).

4. Compute summary statistics and probabilities of exceedance (POE) values for the SREF and GEFS.

A similar approach using the Graphical Forecast Editor (GFE) to support grape growers in California is described in the following article: *"Utilization of Real-Time Vineyard Observations to Produce Downscaled Temperature Forecasts for Frost Protection Operation"* http://nwafiles.nwas.org/jom/articles/2016/2016-JOM1/2016-JOM1.pdf

Figures 5 and 6 show examples of the probabilities and summary statistics, respectively.

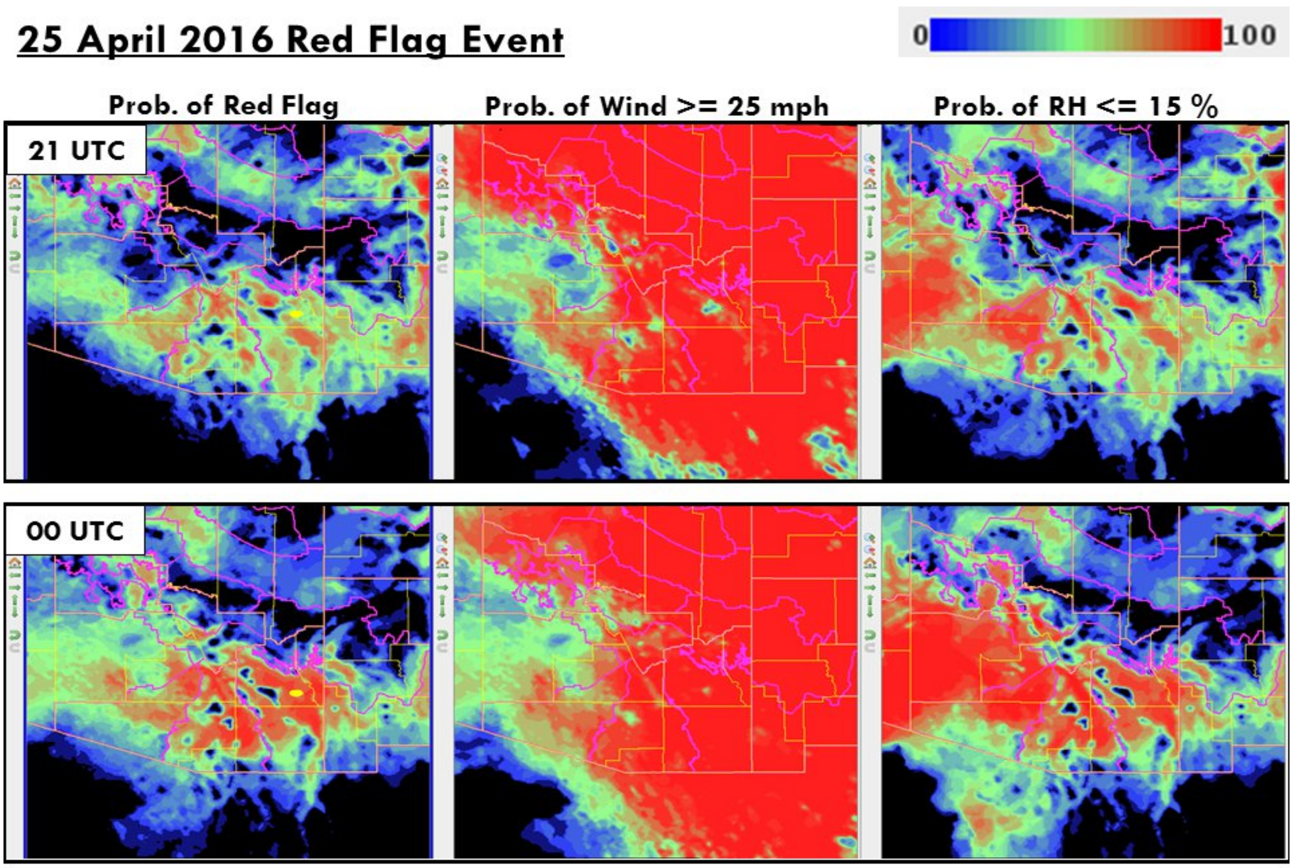
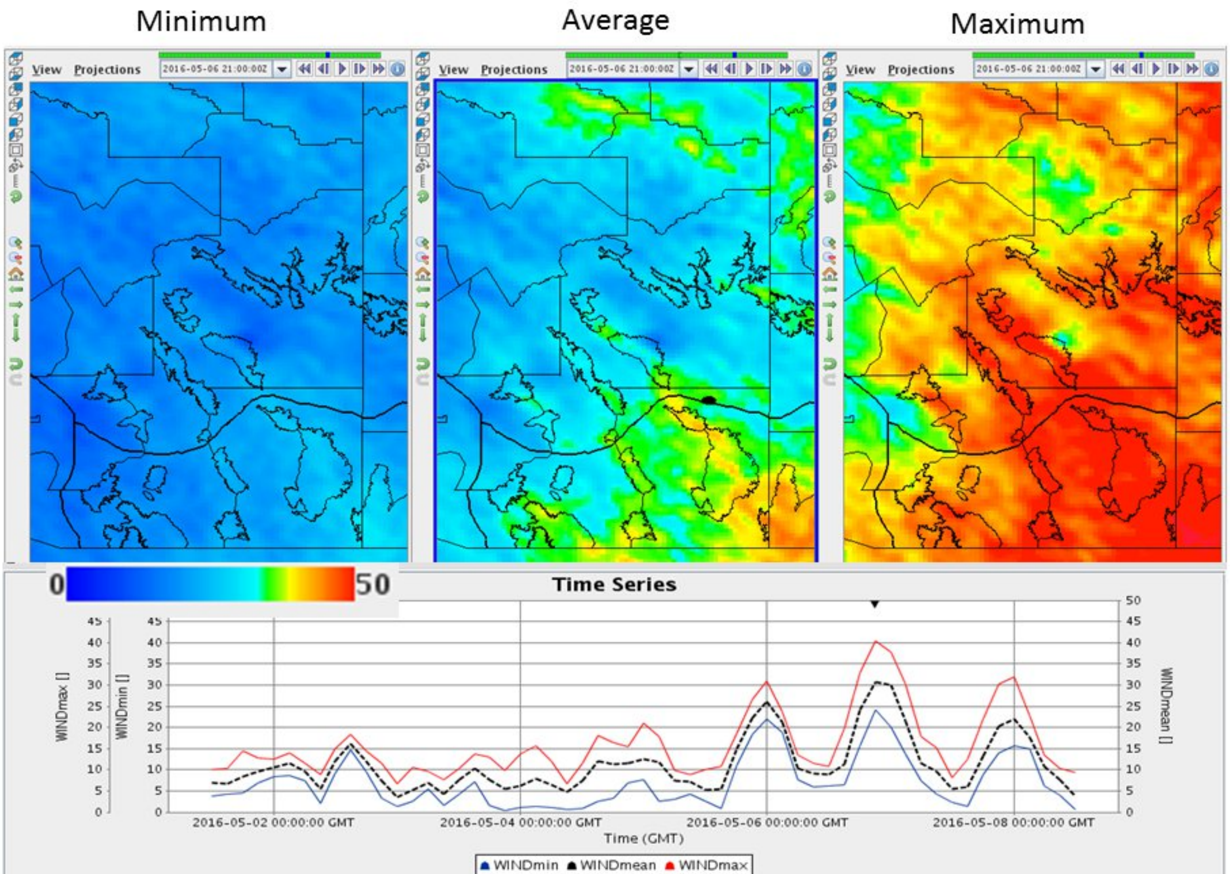


Figure 5. Probabilities for Red Flag conditions based on Wind and RH.



Parameter	Value	Min/Max/Avg	Level	Sampling
WINDmin	**24.1** []	.398/24.1/6.9	--	Weighted Average
WINDmean	**30.7** []	3.5/30.7/11.3	--	Weighted Average
WINDmax	**40.5** []	6.6/40.5/16	--	Weighted Average

Figure 6. Absolute Minimum, Average, and Maximum values for Wind Speed viewed in IDV.

This process will be replaced by the National Blend of Models (NBM). To support AG until then, probabilities for freezing and subfreezing temperature thresholds are computed along with probabilities for sky cover and wind speed thresholds. However, this uncertainty information by itself has limited applicability without incorporating some type of context.

Context

Context is a key link to applying information. Weather, water, and climate information is no different. The context provides meaning that can be used to make better decisions. This is especially true when it comes to rare events which by their nature have low frequencies of occurrence. The term context is used here to describe weather, water, and climate information that helps bring meaning to the hazard being forecast in terms of significance. This may come in the form of average return intervals, climate/model climate anomalies, or a ratio of the probability of occurrence to climate frequency. Some of the contextual information is gathered and derived during the risk assessment process such as the climatology of the hazard. Other types of contextual information come in the form of standard weather charts like height and surface fields. These charts provide some level of feature identification that provides context and compliments the uncertainty information.

The combination of **uncertainty** and **context** leads to some level of **awareness** that the hazard may or may not occur and be significant in terms of rarity. At this point in the forecast process, a level of **confidence** is gained. Excellent examples of uncertainty and contextual information used to build forecaster confidence can be found on the NWS Western Region Toolkit google sites page at: https://sites.google.com/a/noaa.gov/nws-wr-stid/projects/forecast-confidence

After some level of confidence is reached, the workflow leads to a **decision**. This decision may include staffing levels, deployment of resources or collaborative outlook messaging. The process is based on information needed to forecast the probability and magnitude of the hazard occurring. In other words, it provides no direct information related to the impact of the hazard, and is viewed as a level of "**Be Aware**" for decision makers. The workflow results in a seamless transition to the next step of determining and quantifying the impacts, if any, from the forecast hazard.

Risk-Based Forecast - Orange Row

Since the forecaster has gained some level of confidence that the hazard may occur, the next phase of decision support is to assess whether or not there will be any impacts. Therefore, this part of the forecast process involves the integration of the science-based forecast and the risk assessment information. The GIS-based risk model synthesizes this information to create a risk of impact for areas, features, etc. that could negatively be affected by the forecast hazard. For multiple hazards, a total risk can be computed by combining the risk of impacts from each hazard. In the case of the AG community, only one hazard (temperature) is forecast and used to compute the risk.

The risk model is the essential tool in this process for identifying and quantifying the risk of impacts. The GIS-based risk model allows the forecaster to create and run "what-if scenarios", with the most likely and worst cases. This process helps the forecaster quantify the significance of the scenarios and aids in targeting specific communities and partners with detailed information in the messaging of the **risk of impact**. The messaging of this information can be communicated in many different ways (verbal, textual, graphical, etc), but is viewed as a level of "**Be Prepared**" for decision makers. The end result leads to some type of **action** by the forecaster and targeted partner.

Figure 7 is an example of a Google Earth KML file used to display the color coded risk levels for crops in southeast Arizona. The risk model output is used to alert the forecaster of the crops that are at risk of impact by cold temperatures.

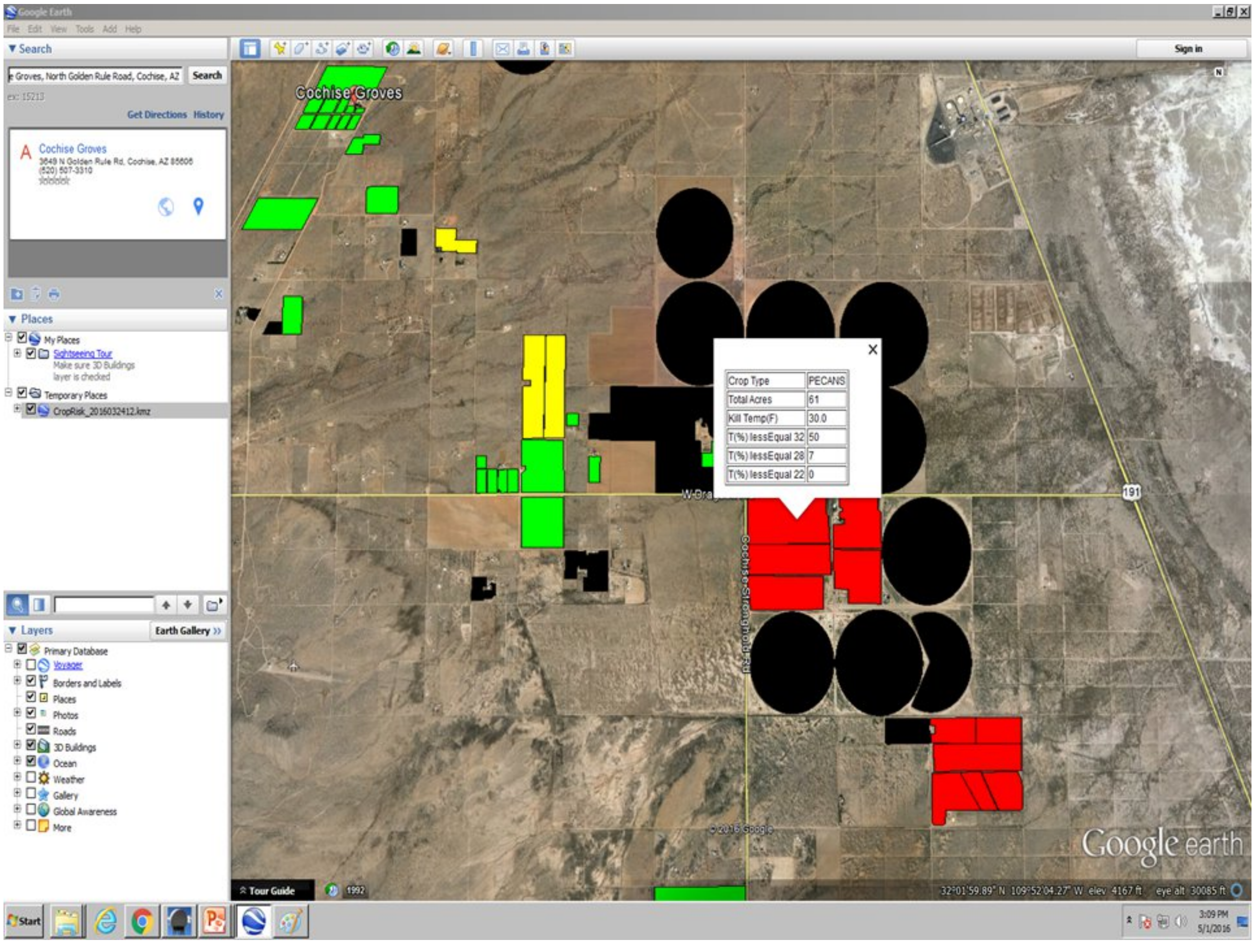


Figure 7. Color coded risk categories (Black=None, Green=Low, Yellow=Moderate, Red=High) for crops.

Impact-Based Forecast - Red Row

Each process of the conceptual workflow provides relevant intelligence for making decisions by including context at every stage. Without this contextual information, decision makers can find it difficult to apply the forecast information to a particular situation. In this case, each level of the workflow can stand alone as a type of decision support service. An impact-based forecast is considered a special type of decision support service that is triggered when a core partner and/or community (public or sector) will likely be impacted by a weather, water, or climate related event. In other words, the preparedness level is elevated to "**Take Action**". Because the **risk of impact is high** or the **risk tolerance is low,** the forecast needs to be translated and communicated in a different form that provides **impact estimates**. This is where an impact estimation model can be developed by reframing the **risk of impact forecast** to meet the needs of a community or partner. These impact estimates are what is referred to as an explicit hazard impact forecast which is at the heart of impact-based forecasts and warnings. Several benefits of explicit hazard impact forecast include the following:

- Improved contingency planning and decision-making
- Improved preparedness before the event
- Better situational awareness

- Improved understanding of natural hazard impacts
- Motivation for multidisciplinary collaboration

An example of an explicit hazard impact forecast is shown in Figure 8. This is an estimation of the fraction of the population forecast to lose power within the census tracts.

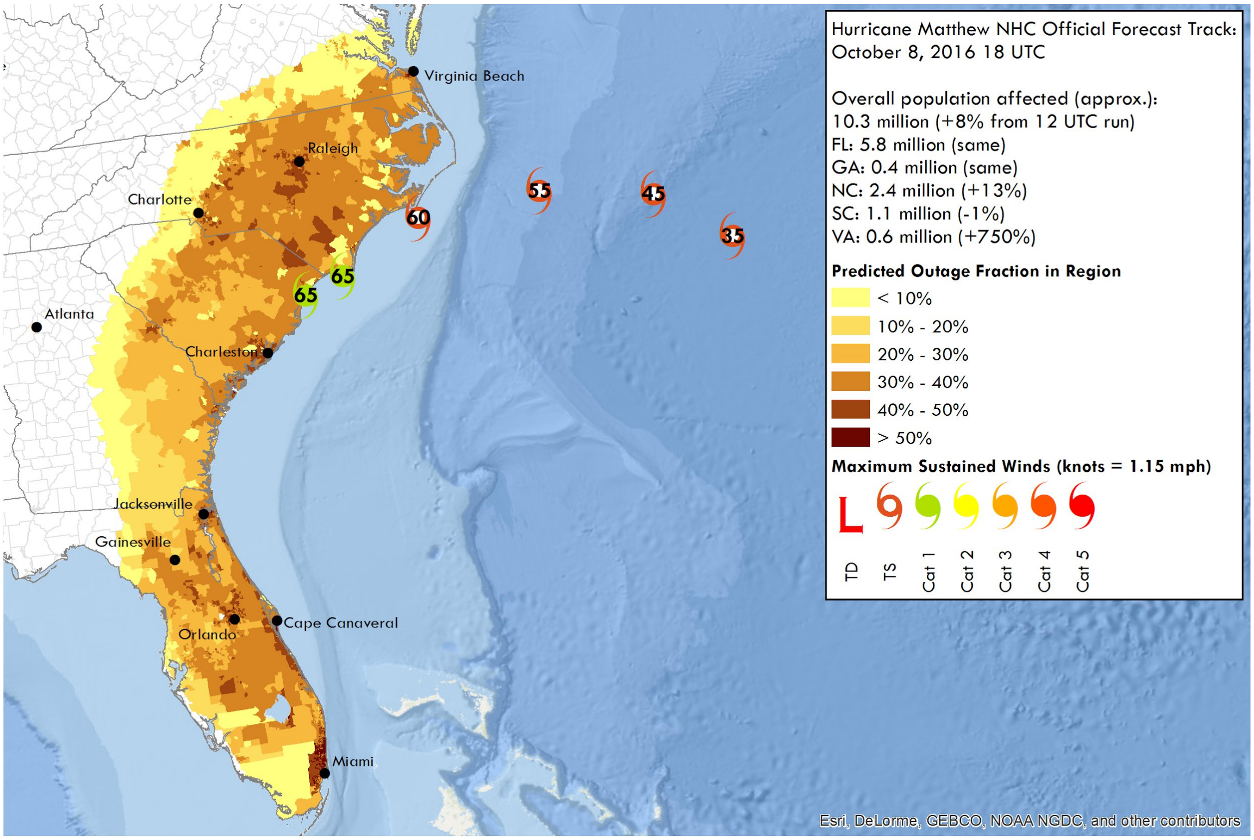


Figure 8. Prediction of the fraction of population affected by power outages caused by Hurricane Matthew at the census tract level. A detailed description of this product can be found: http://ieeexplore.ieee.org/xpls/icp.jsp?arnumber=6949604

The product shown in Figure 8 is a great illustration of the future direction for IDSS. Other examples of translation and integration concepts are outlined in the following presentation: *"Translating Weather Forecasts into Impact-Relevant information: Practice of Impact-Based Forecast in Operations"*: https://www.wmo.int/pages/prog/arep/wwrp/new/wwosc/documents/WOSCC-talk-.pdf

For a great summary of the concepts and motivations of hazard impact-based forecasting, please watch the following presentation by Gerald Fleming: https://www.youtube.com/watch?v=SQCoAnd0h3Q

For the AG community in southeast Arizona, current market value dollar amounts for partial and total crop losses using Yahoo Finance API is being developed.

Summary

This abstract concept of the forecast process and how it relates to risk management principles is designed to help guide and implement IDSS with the fully integrated field structure concept in mind. The individual stages that form the workflow are not new ideas or practices. In fact, components of the workflow are already practiced in some form throughout the NWS but not coherently. In addition, the concept is structured in a way to provide a seamless workflow from national centers to field offices by utilizing probabilistic forecast guidance produced by the centers. Likewise, the GIS-based risk assessments practiced at each field office are designed to provide an integrated, scalable, and seamless perspective of impacts at the local, county, state, regional, and national levels. For example, figure 9 illustrates how this approach is connected to the “Forecasting a Continuum of Environmental Threats” (FACETS) framework. FACETS is a conceptual framework based on gridded probabilities of hazards/threats spanning different time and space scales (minutes to months, and national to local). Currently, NSSL is working on the severe local storm capabilities and GSD is developing software for long-fused probabilistic hazards/threats.

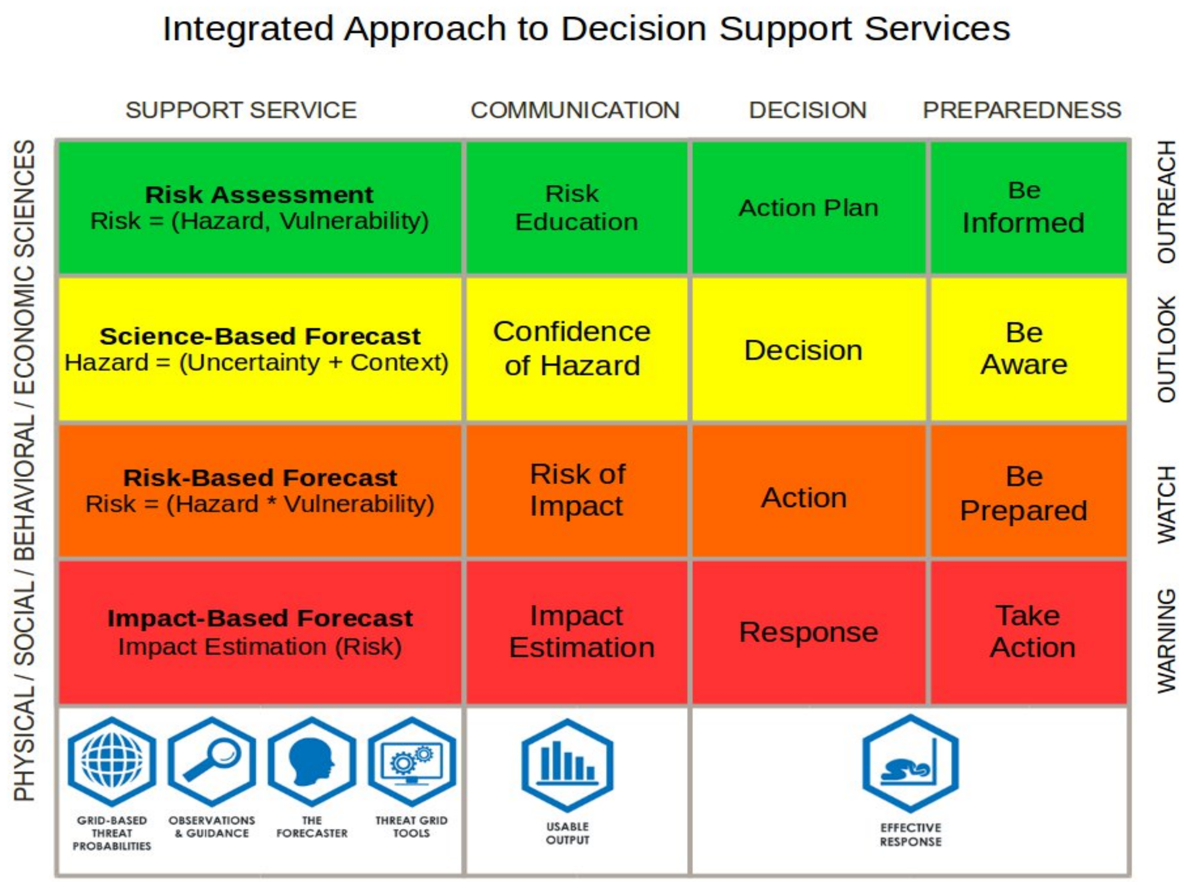


Figure 9. Integrated Approach to the FACETS Conceptual Framework.

The following is a summary of the main points of the conceptual diagram in Figures 1 and 8 :

1. The concept is designed to lead to decisions, actions or responses (by the human forecaster or the end user). The concept requires a subtle shift in the role of a human

forecaster and the weather, water and climate forecast processes. In this concept, the forecast becomes an input into the processes that tie more directly to human decision making.

   a. The concept demonstrates a tangible design to the "forecaster over the loop" concept.

2. The concept is scalable in both time and space, but is dependent on a local presence to produce local inputs. In other words, it strengthens the current NWS field structure.
   a. Such as "Deep Relationship Partner" defined thresholds or local weather expertise to properly contextualize a hazard.
3. The concept can be applied to event-based (venues, episodic), routine-based, sector-based, and community-based decision support.
4. The rows of the concept work together, or build off each other, and follow the human decision making process. For example:
   a. **Green row**: "Do I understand the common, or uncommon, hazards in my areas and my personal or community vulnerability?"
   b. **Yellow row**: "Am I aware of an approaching hazard?"
   c. **Orange row**: "Does the approaching hazard matter? Am I in a vulnerable state that may cause me to take protective action?"
   d. **Red row**: "I am aware of the hazard, I am in a vulnerable state, and I need to respond immediately to protect myself or my community."

Hopefully, this abstract concept of different levels of decision support and workflow will spark discussion and new ideas beyond the current focus on messaging, rapid deployment, on-demand and embedded services. Building trust through practicing elements of NOAA's Community Vulnerability Assessment Tool Methodology (CVAT) will be paramount to the success of decision support services. That said, human involvement will not be replaced by objective guidance, but the human role in the forecast process will undoubtedly change as the focus shifts from "what the weather will BE to what the weather will DO".

Acknowledgments

The author thanks John Brost (STSD Branch Chief with SRH) for the value-added edits and discussions which helped form this conceptual workflow. Lee Carlaw (NWS WFO Fort Worth/Dallas, TX) developed the local ensemble error-correction and downscaling system that is run operationally at NWS WFO Tucson, AZ. In addition, special thanks Michael Cantin (MIC Boise, ID) for supporting the project, and to all the participants of the team serving the AG community of southeast Arizona.

Appendix

Risk-Based Framework: An Integrated and Actionable Approach to the Weather-Ready Nation Initiative

"*To Understand consequences (impacts) it is necessary to understand vulnerability".*
SHIVA – The Seattle Hazard Identification & Vulnerability Analysis

Introduction

The new approach of providing IDSS is gaining in popularity worldwide (ex. UK Met Office services: https://www.youtube.com/watch?v=fxbHdmLyaSY), and there is a growing trend to try and understand the risks involved with extreme weather, water and climate events. There is also a growing awareness that there is no direct relationship between the impacts on society and the magnitude of a weather, water, or climate episode alone. In fact, this is a complex and highly nonlinear process much like weather, water, and climate prediction. Many organizations and industries practice risk management and communicate uncertainty in terms of risk. Some examples worldwide include:

- FEMA - http://www.fema.gov/risk-mapping-assessment-and-planning-risk-map
- USACE (US Army Corp of Engineers) - http://www.iwr.usace.army.mil/Missions/FloodRiskManagement/FloodRiskManagementProgram.aspx
- United Nations - http://www.unisdr.org/who-we-are/what-is-drr
- World Health Organization - http://www.who.int/management/general/risk/en/
- Department of Transportation - http://international.fhwa.dot.gov/scan/12030/12030.pdf
- Business and insurance industries - https://www.rims.org/Pages/Default.aspx
- Education industry - http://risk.arizona.edu/

These risk management practices strive to quantify the uncertainty of a hazard and the vulnerabilities of the asset or entity-at-risk being protected; thus, a more integrated approach to understanding and quantifying the potential impacts. This appendix will describe a risk-based framework which is believed to be a more structured and actionable approach to NOAA's Weather-Ready Nation initiative that **leverages and strengthens the NWS field structure.**

The strength of the NWS is in the 122+ field offices which are spread across the country and can apply risk management and GIS principles to better serve the decision makers at the local level. These local risk assessments and risk models can be combined and upscaled for a regional or national scale perspective (ex. bottom-up approach) for decision makers needing the bigger picture. Institutionalizing risk management principles in the NWS forecast, warning, and decision support services will help improve and protect the livelihoods of the communities served.

Risk Terminology

Risk management, in terms of natural or man made disasters, can be understood as the identification, assessment, and prioritization of risks (the potential loss of something valuable) followed by coordinated and economical application of resources to minimize, monitor, and control the probability and/or impact of unfortunate events. Risk management's objective is to assure uncertainty does not deflect the endeavor from the goals of decision makers. Risk management is a well vetted, well researched, well used, and a well understood framework to minimize the loss of people and/or their assets.

Risk Equation: In order to understand risk management, we must first understand risk and its associated terms. As mentioned earlier, risk is a function of more than just the direct relationship to the hazard magnitude as implied by the literal use of the words “impact-based”. Risk can be expressed as a mathematical formula and usually takes the form of a probability or index value, but takes on several forms based on the context in which it is being used. In simplest form, risk is the potential for an impact (negative consequence).

In the form of an equation, we start with:

Risk = Potential of Impact

Impacts are negative consequences to people and/or their assets. In the context of natural or man-made disasters, impacts typically fall into one of four categories: death, injury, asset damage or asset loss.

The potential for an impact, or risk, is dependent on two primary factors: the *Hazard* and the *Vulnerability* of the people or assets experiencing the threat.

Thus, our initial equation becomes:

Risk = Hazard x Vulnerability

The above equation will be referred to as “the Risk Model”.

The two primary components of the risk model can be broken down even further and are described below.

Hazard versus Threat: The distinction between a hazard and threat is subtle but important to understand. Both a hazard and a threat are the same source of a negative consequence (impact) but in different states. A hazard is a source in a harmless state, and a threat is the hazard in a harmful state. As an example, a river is a hazard but can become a threat when flooding occurs. A road is a hazard but becomes a threat when it is coated with ice or water.

For simplicity, the rest of this appendix will only use the term “hazard” in the context of the risk model. A hazard can be understood as having a probability of occurrence, probability of intensity, duration (described as the length of time a given threshold is exceeded), and areal coverage. These attributes combine to describe the hazards magnitude and can be mapped using a Geographic Information System (GIS).

Atmospheric hazards, such as rain, lightning, snow, wind, storm surge etc, are highly dynamic and vary in both space, time and severity. Other hazards, such as roads or rivers, are far more static and their variability is heavily dependent on external forces (like excessive rain or snow).

Vulnerability: Vulnerability is simply the weakness or gaps in the protection efforts of the asset or entity-at-risk. Oftentimes, vulnerability is understood in terms of “exposure” and “resiliency”.

By further understanding exposure or resiliency, we can classify vulnerability by using social, proximity, and threshold vulnerabilities that can be assessed and mapped using GIS.

Exposure: Exposure should be considered as the condition of being unprotected from the hazard. Exposure, in the risk model equation, has a positive sign indicating that as exposure increases, risk also increases.

Resiliency: Resiliency can be viewed as the person or asset's ability to spring back or rebound from the impact brought on by the hazard. Contrary to exposure, resiliency has a negative sign indicating that as resiliency increases, risk decreases.

Social Vulnerability: Social vulnerability tries to account for the inequality of groups and communities by looking at indicators that will affect their ability to cope and rebound from hazards. An index of social vulnerability to environmental hazards, called the Social Vulnerability Index (SoVI), has been developed that uses 11 census tract indicators such as age, income, race, employment, urban versus rural, etc. This index has been used as a GIS layer in many applications related to disaster management.

Vulnerability by Proximity or Susceptibility: Vulnerability by proximity generally refers to the relative location to the source of the hazard. For example, communities along a coastline tend to be more vulnerable to sea level rises and flooding from a hurricane or climate change than communities inland. Susceptibility is a function of the sensitivity of the asset at risk to a hazard or other properties such as the characteristics of a floodplain for flood/flash flood concerns. The Flash Flood Potential Index (FFPI) that uses GIS to map areas that will be more susceptible (thus, more vulnerable) to flash flooding based on static properties such as terrain slope, land cover, land use, soil type, and soil texture is another example.

http://www.crh.noaa.gov/Image/dmx/hydro/FFPI/FFPI_WriteUp.pdf

The vulnerability by proximity classification can also be a function of the climatology or the seasonality of the hazard in the area. In this case, a community in the central plains of the United States is more susceptible and vulnerable to tornadoes than one in the desert southwest. Vulnerability by time of day can also be lumped into this classification based on the climatology of the hazard. Or even the time of an outdoor event where a large number of people might be exposed and therefore more vulnerable to a weather hazard. This type of vulnerability can also be mapped and used in calculating risk.

Vulnerability Threshold: A vulnerability threshold can be viewed as the conditions in which a hazard typically becomes a threat to the asset or entity-at-risk. In other words, it is a derived quantity to which an asset becomes more susceptible to, or increasingly unable to cope with negative effects of a hazard. This type of vulnerability is at the heart of the WRN initiative which refers to it as an impact threshold that can be cataloged in a national database; hence, the use of the term "impacts catalog". The vulnerability threshold part of the risk equation is one of the most challenging and time consuming attributes to determine. It is also central to the evolution and success of IDSS and one that will require a three phase approach of gaining an understanding, co-learning, and implementing the operational aspect of IDSS to the target decision makers. The operational phase will continue to be evolutionary in the sense of maintaining relationships with decision makers and updating the vulnerability thresholds.

GIS-Based Risk Model

Hazards-United States (Hazus - https://www.fema.gov/hazus) is a nationally applicable standardized methodology that contains models for estimating potential losses from earthquakes, floods, hurricanes, and in 2013, tsunamis. Hazus uses Geographic Information Systems (GIS) technology to estimate physical, economic, and social impacts of disasters. Users can then visualize the spatial relationships between populations and other more permanently fixed geographic assets or resources for the specific hazard being modeled, a crucial function in the pre-disaster planning process.

GIS-based risk modeling is the process of combining various layers of information together to arrive at a mostly objective assessment of risk at various times and spatial scales. Consider each component of the risk model (hazard and vulnerability) as GIS layers. Putting these layers together forms the risk model. The number of layers will be dependent on the event or end user needs. Thus, the risk model is configurable or adaptable to many different circumstances and at all time scales.

Many of the layers for the risk model either already exist, or can be created with relatively minor variations in existing databases or practices. One example of this is the hazard grid in GFE. Unfortunately, this grid is not a one to one match with the hazard component of the risk model. However, NWS forecasters could produce a hazard grid that combines the probability of occurrence and probability of severity of some approaching hazard.

Other layers will need to be developed. For instance, humans are mobile. We travel to and from work, the store, the park, or entertainment activities. We can be inside a sturdy structure, or outside in an unprotected space. This mobility requires a dynamic vulnerability of proximity layer that will require development in order for the risk model to function at hyper local scales.

Content for some layers will require maintenance. The NWS will need to work intimately with partners and stakeholders to identify vulnerability of threshold content. Fortunately, this idea is currently being developed under the name “Impacts Catalog”.

The resiliency layer would require the NWS to work with communities to not only understand their current state of resiliency but also work with these communities in an advisory or consultant role to increase resiliency.

Thus, the risk model not only generates meaningful output for decision makers, including forecasters, spoken in their language, but also provides a framework for mitigating the risk of impacts.

Consistency Concerns: The GIS-based risk model approach, even when maintained at local levels, is inherently consistent at all time and spatial scales because it scales dynamically in both time and space. Since the risk model is not driven by top down, hazard only, one-size-fits-all information, the end user is allowed to decide if they want to see a map of risk on a CONUS scale, or the neighborhood scale. They can decide to assess risk for a one hour period, or a three day period, or some time frame five years into the future. True, two end users experiencing the same hazard may be presented with different levels of risk, but this is not inconsistency. Instead, the risk model is simply adjusting to the individual's vulnerability. Thus, the risk model is consistent spatially because it is tailored to the end user and their particular circumstance.

Since uncertainty is directly inputted into the risk model, the output scales with time. A certain risk level at time zero is equally meaningful as the same risk level ten years into the future. The difference is that the greater lead time events allow the end user to maximize their resiliency.

Additional Information and Resources

Understanding Risk (UR): https://understandrisk.org/

USA hosted UR for Boulder,CO 2015: https://understandrisk.org/wp-content/uploads/Boulder_Proceedings_WEB.pdf

CAPRA: https://ecapra.org/training-multi-hazard-risk-assessmentARPA: