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Developing a global early warning system for wildland fire

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Abstract: Wildland fires burn several hundred million hectares of vegetation every year, and increased fire activity has been reported in many global regions. Many of these fires have had serious negative impacts on human safety, health, regional economies, global climate change, and ecosystems in non-fire–prone biomes. Worldwide fire suppression expenditures are rapidly increasing in an attempt to limit the impact of wildland fires. To mitigate fire-related problems and costs, forest and land management agencies, as well as land owners and communities, require an early warning system to identify critical periods of extreme fire danger in advance of their potential occurrence. Early warning of these conditions allows fire managers to implement fire prevention, detection, and pre-suppression plans before fire problems begin. Fire danger rating is commonly used to provide early warning of the potential for serious wildfires based on daily weather data. Fire danger information is often enhanced with satellite data, such as hot spots for early fire detection, and with spectral data on land cover and fuel conditions. Normally, these systems provide a 4- to 6-hour early warning of the highest fire danger for any particular day that the weather data is supplied. However, by using forecasted weather data, as much as 2 weeks of early warning can be provided. This paper presents a proposed Global Early Warning System for Wildland Fire to provide advanced early warning capabilities at local to global levels.

Keywords: fire weather forecasting, international fire danger rating, remote sensing

1. Introduction

Fire is an increasingly prevalent disturbance on the global landscape with several hundred million hectares of vegetation burning every year. Land and forest fires (collectively referred to as wildland fires) occur annually in all vegetation zones (Figure 1), and most global fire is unmonitored and undocumented. Increasing trends in wildland fire activity have been reported in many global regions. Wildland fires can have many serious negative impacts on human safety (Viegas, 2002), health (Schwela *et al.,* 1999; Heil and Goldammer, 2001; Kunii *et al.,* 2002; Sastry, 2002), regional economies (e.g., Glover and Jessop, 1999), and global climate change (Crutzen and Goldammer, 1993; Kasischke and Stocks, 2000). To mitigate these fire-related problems, forest and land management agencies, as well as land owners and communities, require an early warning system to identify critical periods of extreme fire danger in advance of their occurrence. Early warning of these conditions with high spatial and temporal resolution, incorporating measures of uncertainty and the likelihood of extreme conditions, allows fire managers to implement fire prevention, detection, and pre-suppression plans before fire problems begin. Considering that most uncontrolled and destructive wildfires are caused by humans as a consequence of inappropriate use of fire in agriculture, pastoralism, and forestry, it is crucial that international wildland fire early warning systems are developed to complement relevant national fire danger warning systems where they exist, to provide early warning where national systems do not exist, and to enhance warnings applied or generated at the local community level. This will ensure delivery of targeted information reflecting specific local conditions and allowing the involvement of local communities in wildland fire prevention.

Fire danger rating is a mature science and has long been used as a tool to provide early warning of the potential for serious wildfires. Fire danger rating systems (FDRS) use basic daily weather data to calculate wildfire potential. FDRS early warning information is often enhanced with satellite data, such as hot spots for early fire detection, and with spectral data on land cover and fuel conditions. Normally, these systems provide a 4- to 6-hour early warning of the highest fire danger for any particular day that the weather data is supplied. However, by using forecasted weather data, as much as 2 weeks of early warning can be provided, depending on the length of the forecast. Ensemble weather prediction systems through multiple realizations of forecasts provide distributions of weather forecasts and capture their inherent predictability and uncertainty associated with such forecasts.

FDRS tools for early warning are highly adaptable and have demonstrated their application to a wide range of users, from independent remote field stations (for making local fire suppression and preparedness decisions) to global and regional fire information centres (for large-scale decision making, such as multinational resource sharing). There are many examples of current operational systems using GIS technology and computer modeling of landscape-level fire danger (Lee *et al.,* 2002) that process and transfer early warning information very quickly via the World Wide Web.

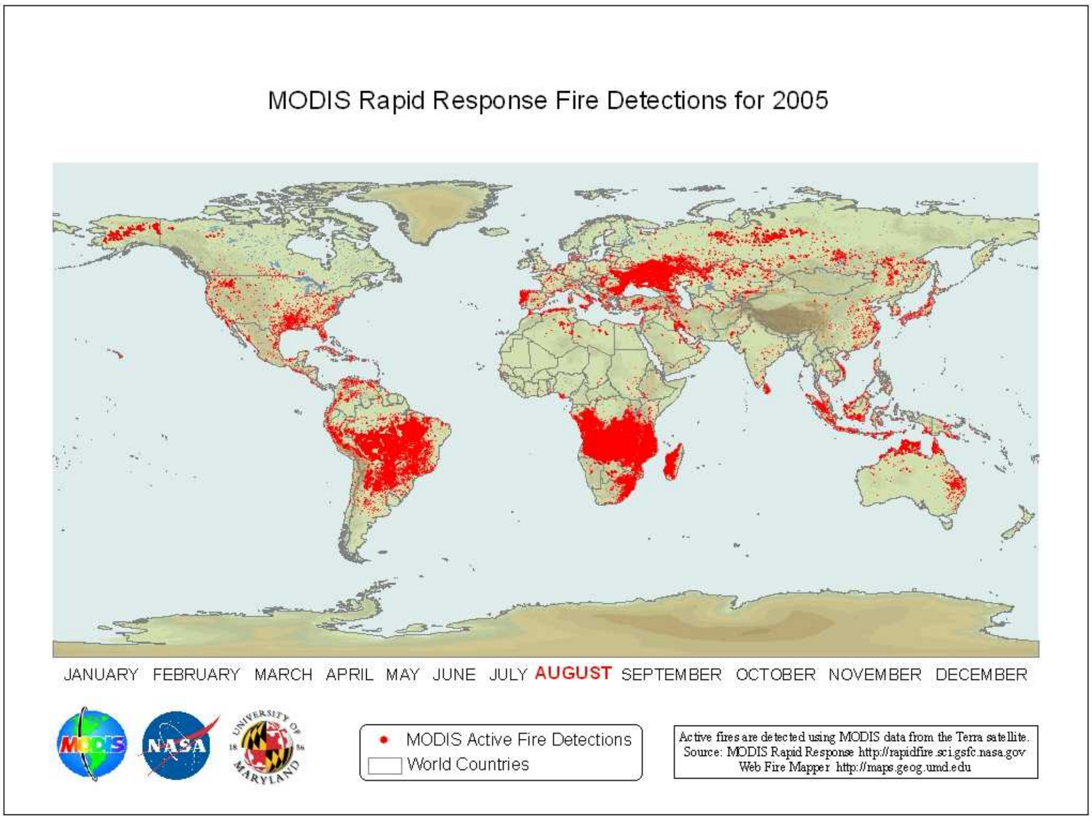


Figure 1. Global vegetation fires depicted by the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument (on Terra) for August 2005 (provided by University of Maryland).

2. Objectives

The goal of the proposed global early warning system for wildland fire (EWS-Fire) is to provide a scientifically supported, systematic procedure for predicting and assessing international fire danger that can be applied from local to global scales. The system is not intended to replace the many different national fire danger rating systems currently in use, but rather to support existing national fire management programs by providing:

- new longer term predictions of fire danger based on advanced numerical weather models; and
- a common international metric for implementing international resource sharing agreements during times of fire disaster.

As a byproduct, the EWS-Fire also provides a fire danger rating system for the many countries that do not have the financial or institutional capacity to develop their own system. Because the system can be used at the local level, it can support local capacity-building by providing a foundation for community-based fire management programs (Moore *et al.,* 2002).

It is intended to develop the EWS-Fire using existing demonstrated science and technologies. Many examples of spatial fire management systems providing fire danger information are currently in operation (see the Global Fire Monitoring Center website www.fire.uni-freiburg.de/fwf/fwf.htm). The EWS-Fire will build on that expertise and provide enhanced products by incorporating the predictive power of new weather forecasting models. For practical fire management applications, the system will require rapid and wide dissemination of products, and an extensive technology transfer program to provide training in the operation of the system and development of fire management decision aids.

3. System Development

Development of an operational EWS-Fire is proposed through three phases. The overall system structure, including information technology and fire and weather science, is prepared during the system design phase. Establishment of standard operating procedures to provide and distribute daily early warning products will occur during the operational implementation phase. Finally, a technology transfer phase will facilitate sustainability of system operations and ensure applicability of the system to practical fire management through training programs.

3.1 *System Design*

The EWS-Fire needs to address two distinct issues: 1) to establish a methodology to use forecasted weather to provide predicted fire danger, and 2) it must also provide a means of interpreting the fire danger in practical and locally relevant fire management terms. These criteria imply that the fire danger rating system used for the EWS-Fire must have fairly simple and reasonably predictable weather inputs over the forecasted range, and it must be possible to locally calibrate the fire danger indices.

Many fire danger rating systems and indices are in use around the world, and several reports compare methods in different global regions (e.g., Valentine, 1978; Viegas *et al.,* 1999; Lin, 2000). Research and development of fire danger rating in Australia (Luke and McArthur, 1978), US (Deeming *et al.,* 1977), and Canada (Stocks *et al.,* 1989) have been ongoing for about 80 years, resulting in established national systems. Fire management agencies developing new systems in other countries often use or adapt existing systems. Components of the Canadian Forest Fire Danger Rating System (CFFDRS) have been applied widely around the world. In particular, the Canadian Forest Fire Weather Index (FWI) System (Van Wagner, 1987), a subsystem of the CFFDRS, has been adopted or adapted for use in North, South, and Central America, Europe, northern and eastern Asia, and the south Pacific (Taylor and Alexander, 2006). Codes and indices of the FWI System have been calibrated across a wide range of global vegetation including northern boreal and temperate forests (others in Taylor and Alexander, 2006), the northern Mediterranean region (Viegas *et al.,* 1999), and tropical forests of Southeast Asia (Field *et al.,* 2004; de Groot *et al.,* 2005). Because the FWI System requires only four weather parameter inputs once each day, its simple operational procedure lends itself well to application and use at the local level. For these reasons, the FWI System is a pragmatic choice as the basis for the global EWS-Fire.

The proposed structure of the EWS-Fire (Figure 2) is largely based on existing spatial fire danger rating systems. The system is expected to provide both current and forecasted fire danger information, because both are important for fire management decision-making. Current fire danger indicates the actual fire potential and provides a quantitative method to compare and prioritize areas when suppression resources are limited. Forecasted fire danger provides early warning of future trends in fire potential, allowing fire managers to plan and implement fire management strategies in advance.

Current and forecasted fire danger products will use actual and forecasted weather data (respectively) to calculate FWI System component values (Figure 2). Overlaying current fire danger maps with hot spot data (e.g., AVHRR, MODIS) will indicate areas where ongoing fires combine with high fire danger to create the greatest current priority. Combining forecasted fire danger maps with hot spot data will indicate critical areas where serious fire problems will occur if current fire activity persists. This is referred to as future fire threat in the structure diagram. The international panel for Global Observation of Forest and Land Cover Dynamics (GOFC-GOLD) has developed several fire monitoring and mapping products that make use of hot spot data and are available for use in the EWS-Fire. Depending on the purpose and application of the system, a range of EWS-Fire products are possible; several examples are shown in Figure 3.

The traditional approach to weather prediction uses a single realization of the atmosphere as the forecast. However, uncertainty in the analyzed initial conditions, limits to atmospheric predictability, and uncertainty in the model representation of the atmosphere always place limits on the certainty of the prediction (i.e., single forecasts are in fact only one realization of a number of possible outcomes). Multiple model runs, based on slightly different initial conditions and/or using slightly different model configurations, parameterizations, and so on, can be undertaken and provide distributions of possible outcomes. These so-called ensemble forecasts provide a mechanism to provide measures of the forecast uncertainty or accuracy, including possible extreme behaviour not available with a single realization.

These techniques can be applied directly to fire weather situations. Figure 4 presents an example using the Forest Fire Danger Index (FFDI), which is used in Australia to assess the likelihood and severity of bushfires. Using an ensemble-based approach, Figure 4 illustrates three realizations of the forecast FFDI. It can be seen that the possible outcomes do vary significantly. To this end, these ensemble-based forecasts can be used to derive the probability distribution of FFDI at each location. In this way, the likelihood of low or high FFDI at each location can be derived. By way of example, the 75% percentile value of the forecast FFDI is shown in Figure 4. The probability of FFDI values at each location and at each forecast interval can be derived in this manner. Simple or more complex products are readily derived, providing additional ways to undertake risk assessment.

Historical fire, weather, and hot spot databases will be used to calibrate EWS-Fire products for different regions. Calibration procedures are subjective to the calibration purpose and therefore differ for each application. For example, calibrating a fire danger index for local fire detection scheduling would be very different from calibrating an index for mobilizing international suppression resources. Data availability is also an issue in many parts of the world. However, as a first step, regional historical weather can be used to categorize fire danger levels based on frequency of occurrence (e.g., de Groot *et al.,* 2006). Hot spot data is also valuable for calibration because of its frequent global coverage (see Csiszar *et al.,* 2005) and rapid availability, and its demonstrated potential for fire danger calibration (Dymond *et al.,* 2005). In particular, hot spot data has demonstrated robust capacity to calibrate the Fine Fuel Moisture Code of the FWI System as a predictor of fire ignitions (de Groot *et al.,* 2006) and holds promise as a global calibration tool for this important fire environment parameter. Collection of actual fire danger values will also be

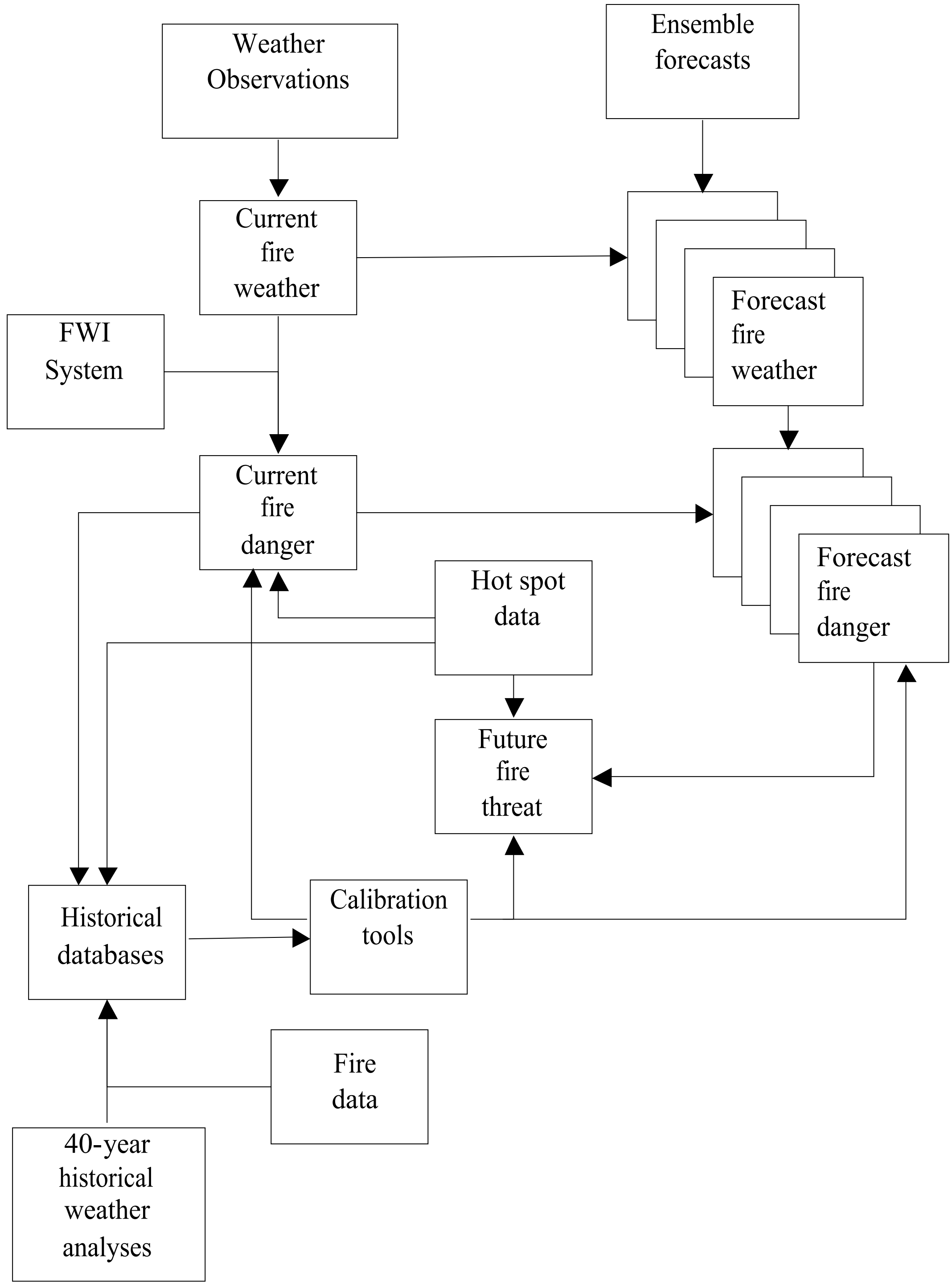
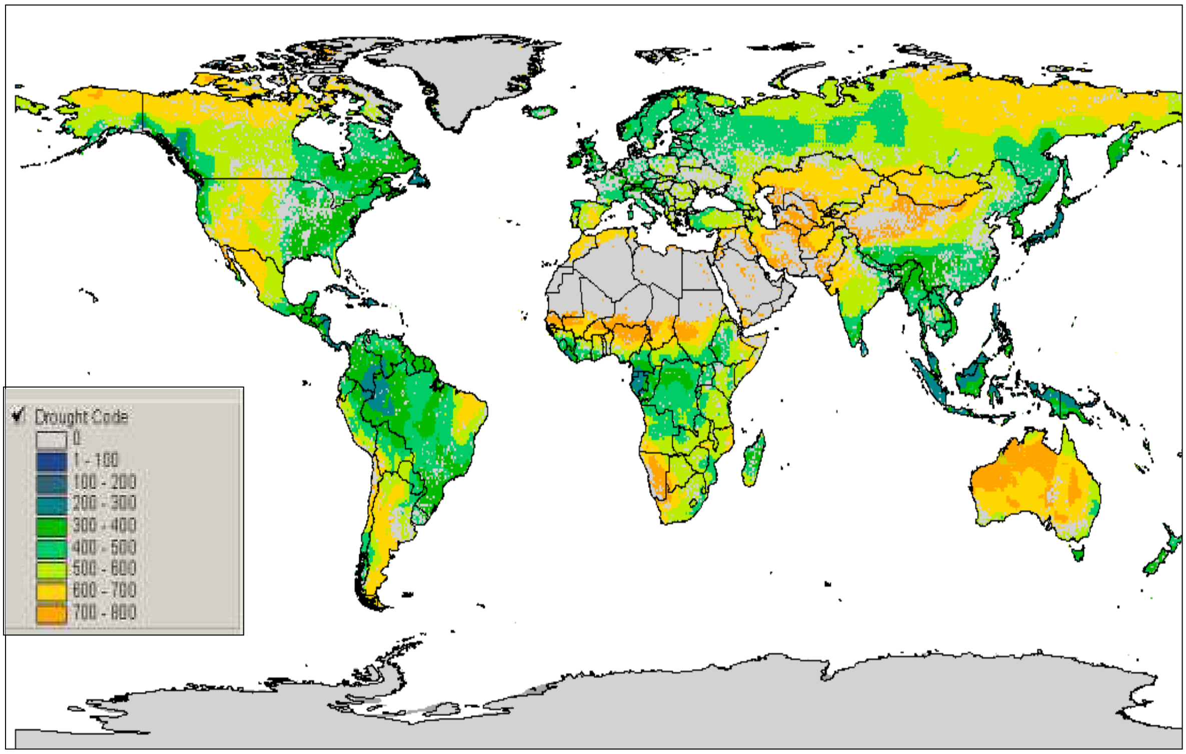


Figure 2. Basic structure of the proposed early warning system for wildland fire (EWS-Fire). Solid lines indicate daily procedures; dashed lines indicate periodic recalibration of fire danger levels based on updated databases.

a)



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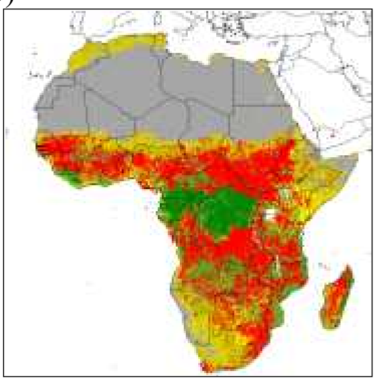

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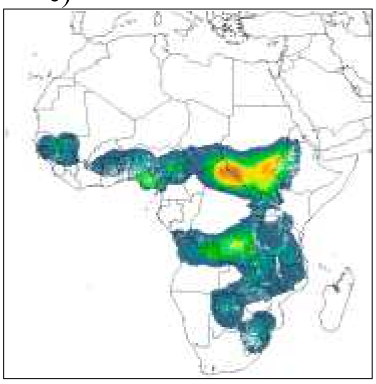

Figure 3. Examples of potential EWS-Fire products, including a) global fire danger using the Drought Code (DC) component of the FWI System; b) DC overlaid by hot spot data (red); and c) spatial fire threat as assessed by DC and hot spot density.

useful for validating the forecasted fire danger products. Undoubtedly, other calibration techniques will become evident as fire danger rating science advances.

3.2 *Operational Implementation*

Daily (actual) FWI products are already being generated for many countries and some global regions on an operational basis. Linking or networking these agencies would provide a significant start to compiling a global product of current fire danger. An

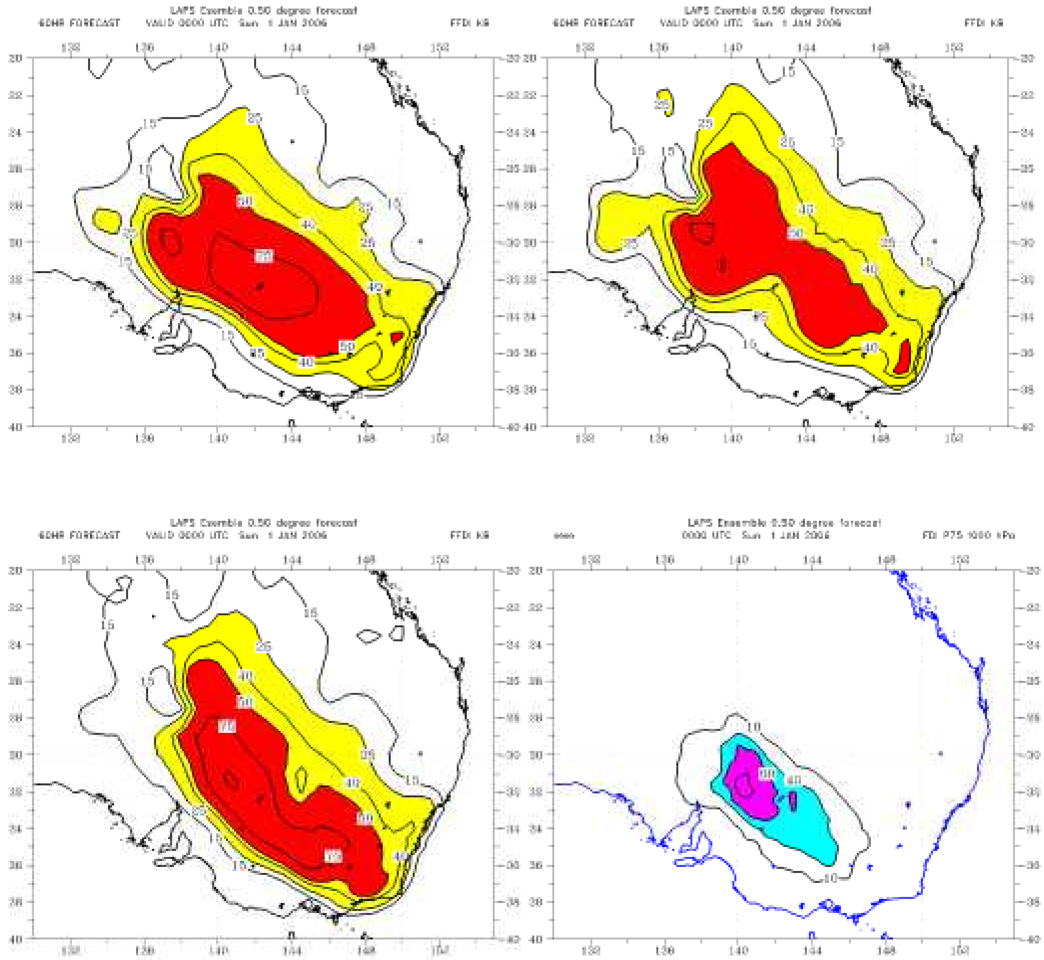

Figure 4. Three sample realizations from a 26-member ensemble, providing 36-hour predictions of Forest Fire Danger Index (FFDI) over southeastern Australia. Note the variation in possible outcomes and different locations potentially impacted. The likelihood of FFDI values is based on the 75-percentile values of forecast FFDI.

advantage of building on existing national and regional systems is that it will ensure direct connection and applicability of the EWS-Fire from local to global scales. Provision of a complete global product of current fire danger will require a coordinating agency or facility to compile existing spatial data, to produce fire danger maps for regions where there currently are none, and to integrate the current fire danger maps with hot spot data (and possibly other remotely sensed data in the future, such as vegetation and rainfall). This will be a large task and may need the assistance of a number of regional agencies. The overall structure and procedures for this will depend on many factors, including the range and scale of products, availability of data, facilities, etc.

Regarding forecasted fire danger, the generation and dissemination of the FWI products based on numerical weather predictions will be undertaken by a national meteorological service operating within the World Meteorological Organization (WMO) framework. The WMO National Meteorological Services in each country have been established and have the authority to provide meteorological and hydrological services relevant to the protection of life and property, safeguarding the environment, national security, and development and promotion of capacity building. They have established operational and robust global links for sharing and disseminating data and information locally, nationally, and internationally. Using these established procedures was considered a priority within EWC-III, and the approach will be:

1. To develop procedures within the robust framework of the World Weather Watch (global network of operational meteorological services) to run the early warning system on a daily operational basis, including analysis, production, and dissemination of fire danger assessments; and
2. To establish procedures with operating services to maintain and update the system as new tools and products are developed.

Dissemination of wildland fire early warning products must be directed to various user levels from global to local using multiple channels. A dedicated web portal on global wildland fire early warning, such as the Global Fire Monitoring Centre (GFMC) Wildland Fire Early Warning Portal (www.fire.uni-freiburg.de/fwf/fwf.htm), will provide access to global, regional, and national early warning systems. These users, however, must have regular access to the Internet.

Advance information tools must be developed to disseminate fire warning alerts to targeted users. This technology is already in use for rapid alerts of satellite-detected wildland fires, such as the Advanced Fire Information System (AFIS). AFIS is the first near real-time operational satellite fire monitoring system in southern Africa. The system is based on technology developed at the University of Maryland and NASA over the last few years. Funding for the development, installation, and operational running of the system has been made possible through Eskom, the Department of Agriculture, and the Council for Scientific and Industrial Research (CSIR) Satellite Application Centre (SAC). The CSIR SAC is in the process of customizing and further developing AFIS to enable not only the detection of fires but also the prediction and assessment of future fire events (www.fire.uni-freiburg.de/GlobalNetworks/Africa/Afrifirenet_4e.html).

3.3 *Technology Transfer*

Training on the operational and application aspects of the system will occur through established institutions specializing in technology and information transfer. The WMO framework will be used to provide technical training in the daily operational procedures to provide early warning products. Key objectives of this program are:

- To ensure the availability of adequately trained staff to meet WMO members' responsibilities.
- To promote high quality continuing education in meteorology, climatology, hydrology, and related disciplines to keep the knowledge and skill of relevant staff of WMO members up-to-date with the latest scientific advances and technological innovations, and to provide the competence and skills needed in additional fields.

Global regional training centres have been established to facilitate these objectives.

Technical training in the application of early warning information to fire management planning and actions will be done through the United Nations University (UNU), now associated with GFMC (www.fire.uni-freiburg.de/programmes/un/unu/unu.htm). The Global Wildland Fire Network, through the participation of government and nongovernment institutions of countries organized in Regional Wildland Fire Networks, is offering a suitable platform for regional training (www.fire.uni-freiburg.de/GlobalNetworks/globalNet.html). The first fire technology transfer programs in Africa (www.fire.uni-freiburg.de/GlobalNetworks/Africa/Afrifirenet_3.html) and Southeast Asia (Buchholz and Weidemann, 2000; de Groot and Field, 2004) have been very successful. For the EWS-Fire, training would include course instruction on basic fire weather, fire behaviour, fire danger, and early warning, and calculation of FWI System components using simple computer programs and manually with FWI tables.

Finally, assistance in the development of local fire management decision-aids based on EWS-Fire products is critical to the ultimate success of the system. This can be done through facilitated workshops that help local communities develop criteria for determining when specific fire prevention, detection, and suppression actions are taken based on early warning information. Technology transfer through workshops like these are key to the success of community-based fire management. The United Nations International Strategy for Disaster Reduction (UN/ISDR), Global Wildland Fire Network and the GOFC-GOLD Regional Fire Implementation teams and networks would jointly work in technology transfer and training to develop local expertise and capacity building in wildland fire management.

4. EWS-Fire Proposal

Following the recommendations of the UN World Conference on Disaster Reduction (WCDR) in Kobe, Japan, January 2005, and the proposal of the UN Secretary General to develop a Global Multi-Hazard Early Warning System (GEWS), a call for project proposals for building a GEWS was issued in preparation for the 3rd International Conference on Early Warning (EWC-III) (27–29 March 2006, Bonn, Germany), sponsored by the United Nations International Strategy for Disaster Reduction and the German Foreign Office (www.ewc3.org/). An international consortium of institutions cooperating in wildland fire early warning research and development submitted a proposal for the EWS-Fire, and it was selected for presentation at EWC-III. The outcomes of the discussions, which are documented on the GFMC Early Warning Portal (www.fire.uni-freiburg.de/fwf/EWS.htm), reveal the high interest in and endorsement by government and international institutions. The early warning system is also included as a yet-to-be-funded task in the 2006–2007 work plan of the Global Earth Observation System of Systems (GEOSS), an international initiative involving more than 150 countries and 35 international organizations. Regionally, it was presented at the Conference on Promoting Partnerships for the Implementation of the ASEAN Agreement on Transboundary Haze Pollution, 11–13 May 2006 in Hanoi, Vietnam. What is needed now is a financial and operational plan to implement the necessary research and development for setting up the system. The consortium that submitted the proposal to UNISDR is currently seeking funding from various sources to overcome the lack of single-source funding of such an international cooperative project.

5. Conclusions

A global early warning system for wildland fire will affect fire management internationally in several ways. On a global basis, it will provide international agencies, national governments, and local communities with an opportunity to mitigate fire damage by advanced assessment of fire danger and the possibility of extreme behaviour. This will enable implementation of appropriate fire prevention, detection, preparedness, and fire response plans before wildfire problems begin. It will provide the foundation with which to build international resource-sharing agreements, and a means to implement those agreements during times of extreme fire danger. Finally, it will provide a fire danger rating system for many fire-prone countries that do not have an operational national system.

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