GAW Report No. 235

Vegetation Fire and Smoke Pollution Warning and Advisory System (VFSP-WAS): Concept Note and Expert Recommendations

WEATHER CLIMATE WATER

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The Global Fire Monitoring Center (GFMC)

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Vegetation Fire and Smoke Pollution Warning and Advisory System (VFSP-WAS): Concept Note and Expert Recommendations

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WORLD METEOROLOGICAL ORGANIZATION

GLOBAL ATMOSPHERE WATCH

IBBI Interdisciplinary Biomass Burning Initiative

GFMC

UNISDR IWPM International Wildfire Preparedness Mechanism

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PREFACE

This concept note contains the expert recommendations resulting from discussions at the international workshop on Forecasting Emissions from Vegetation Fires and their Impacts on Human Health and Security in South-East Asia, which was hosted by the Indonesian Agency for Meteorology, Climatology and Geophysics (BMKG), Jakarta, from 29 August to 1 September 2016. The workshop was organized by the World Meteorological Organization (WMO) and the Interdisciplinary Biomass Burning Initiative (IBBI) in collaboration with the United Nations Office for Disaster Reduction/International Wildfire Preparedness Mechanism (UNISDR/IWPM), United Nations University (UNU), Global Wildland Fire Network (GWFN) through the Global Fire Monitoring Center (GFMC), Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, and the International Global Atmospheric Chemistry (IGAC) Project. Arising from the keen interest of WMO Members in several impacted regions, the note provides guidance for addressing the issues of vegetation fire and smoke pollution. It also proposes the establishment of a Vegetation Fire and Smoke Pollution Warning and Advisory System (VFSP-WAS) and to support the potential foundation of regional centers on the topic. Although most of the examples described here focus on the South-East Asian region, the concepts remain applicable to other regions (e.g. for Africa, Latin America, Northern Asia). “South-East Asia” as referred to in this note includes WMO Members from both Regional Associations II and V (Asia and South-West Pacific).

1. BACKGROUND: RATIONALE AND GOALS OF THE WORKSHOP

The scope of the international workshop "Forecasting Emissions from Vegetation Fires and their Impacts on Human Health and Security in South-East Asia" was to:

1. Provide an opportunity to share experience and knowledge between South-East Asian and international scientists, representatives of national agencies and practitioners on the underlying reasons, meteorological, environmental and human health impacts of vegetation fires and smoke pollution.
2. Provide initial overview of the tools for forecasting vegetation fire smoke emissions, smoke transport, related air quality changes and impact on human health and train personnel of responsible agencies in the use of those tools.
3. Explore the interest in and feasibility of setting up Regional Facilities that can assist WMO Members in the region in forecasting vegetation fire smoke emissions, smoke transport and consequences for air quality and health and to evaluate the capacity of coutries in the area in supporting/providing such facilities.

While the workshop provided an important opportunity to share experiences among different experts and institutions in the region, it also evaluated the requirements for improved services for fire smoke warning, and how these requirements could be integrated in an operational context.

The workshop did not tackle issues related to institutional aspects of implementation of the discussed system, neither did it discuss the logistic elements. Should countries in a region consider the development of regional services as a priority, further discussions in an appropriate framework such as a corresponding WMO Regional Association meeting are required, and formal WMO procedures should be followed (similar to the ones established for the Sand and Dust Storms Warning and Advisory System (SDS-WAS), see Annex I).

2. INTRODUCTION TO THE REGIONAL SITUATION IN SOUTH-EAST ASIA

Since the 1990s, South-East Asia and neighbouring regions of Asia have been increasingly affected by excessive use of fire in the land use and land-use change and by recurrent human-cause wildfires. The use of fire has resulted in ecosystem degradation and environmental damage including extended smoke pollution affecting human health and the composition of the regional and global atmosphere (Field et al., 2009). In South-East Asia traditional slash-and-burn agriculture (swidden land cultivation) during the past millennia has provided livelihood for indigenous forest and rural communities, in many cases based on traditional principles of sustainability. However, since the beginning of the twentieth century population growth, migration and economic development has resulted in extended conversion of native forests and wetlands (peat biomes) to agricultural lands as well as to forest and other tree plantations. The use of fire as the most economic tool for clearing native vegetation has become a driver of change in the region. Biodiversity- and carbon-rich pristine forest and peat-swamp ecosystems have been replaced by agro-industrial systems. The periodic recurrence of the El Niño-Southern Oscillation (ENSO) favours the spread of land-use fires to uncontrolled wildfires, which has caused additional, non-intended loss of native ecosystems.

During the El Niño droughts in 1982-83 fires affected more than 5 million hectares of land in the Indonesian province of East Kalimantan, Borneo. While these events remained largely unnoticed globally, during the early and late 1990s, particularly during the El Niño of 1997-98, the availability of satellite observation systems allowed the monitoring and assessment of damage of large areas burned on insular South-East Asia, leaving behind more than 10 million hectares of fire-affected lands in Indonesia alone. Despite the scientific evidence for the negative environmental consequences of large-scale fire application and international assistance in building fire management capacities and offering advisory support for the development of environmental and land-use policies, the situation remained largely unchanged (Goldammer, 2006).

With the onset of the next strong El Niño in 2015, the drought-supported acceleration of fire use resulted in the spread of fire on more than 2.6 million hectares. According to the World Bank the damages to the national economy caused by fires in 2015 amounted to Rp 221 trillion (US$16.5 billion) (Glauber and Guanwan, 2016). Apart from the economic damage and the intangible (or difficult to assess) losses of biodiversity and ecosystem services, the fires burning in September and October 2015 until the onset of the rainy season are estimated to have released about 11.3 Tg CO_2 per day (Huijnen et al., 2016). For comparison: The daily release of CO_2 from fossil fuel burning in the European Union Member States is 8.9 Tg. In total, the CO_2-equivalent emissions from the burning in 2015 were in between the mean annual fossil-fuel emissions of India and Japan (Field et al., 2016), and contributed to the 400pm Mauna Loa ‘threshold’ being crossed (Betts et al., 2016).

At the eve of the United Nations Climate Change Conference (COP 21) held in Paris, France, (30 November-12 December 2015) the magnitude of emissions contributing to anthropogenic climate change was alerted by international fire scientists, managers and policymakers at the 6th International Wildland Fire Conference (Pyeongchang, Korea, October 2015) and called COP 21 for action:[a]

International policies and concerted action*: Collective international efforts are needed to address impacts of vegetation fires that are of transboundary nature and currently affecting at an unacceptable level common global assets such as atmosphere and climate, natural and cultural heritage, and human health and security. Systematic application of principles of Integrated Fire Management (IFM), based on the wealth of traditional expertise and advanced fire science, contributes to sustainable land management, ecosystem stability and productivity, maintenance and increase of terrestrial carbon stocks, and reduction of unnecessary emissions of pollutants that affect human health and contribute to climate change. The COP 21 is encouraged to acknowledge the role and endorse the support of IFM as an accountable contribution to reduce greenhouse gas emissions, maintain or increase terrestrial carbon pools in all vegetation types and ensure ecosystem functioning.*

[a] Outcomes of the Conference: The Pyeongchang Declaration “Fire Management and Sustainable Development” and the annexed Conference Statement – http://gfmc.online/allgemein/korea-2015.html

3. IMPACTS OF SMOKE FROM VEGETATION FIRES ON HUMAN HEALTH

Vegetation fires release large amounts of particulate matter (PM) and toxic gases including carbon monoxide, nitrogen oxides, and non-methane organic compounds into the atmosphere. Large and frequent wildfires impact local and regional air quality and are a threat to human health (Bowman and Johnston, 2005). Recent studies estimate that around 180,000 to 340,000 premature deaths could to be attributed to exposure from wildfire smoke (Lelieveld et al., 2015; Johnston et al., 2012). Studies have clearly and consistently demonstrated that wildfire smoke PM is associated with respiratory (Henderson et al., 2011) and cardiovascular effects (Dennekamp et al., 2015) and that exposure to fire emissions represents the highest risk to vulnerable subsets of the population i.e. people with existing respiratory or cardiovascular illnesses, infants and the elderly (e.g. Statheropoulos et al., 2013). Health studies have primarily focused on PM so that the effects of other smoke components remain unclear, particularly effects with longer latencies (Reisen et al., 2015).

The health effects of the fires in Indonesia are their most immediate impact (Tacconi, 2016). As argued in *The Lancet Respiratory Medicine*: "If the 2015 Indonesian fires were not the worst air pollution event of the past few decades, it is only because they were surpassed by the 1997 fires" (Burki, 2017). In parts of Sumatra and Kalimantan during September and October of 2015, PM_{10} concentrations hovered at 1000 $\mu g/m^3$ for weeks, frequently exceeding concentrations 3500 $\mu g/m^3$; for comparison, the European Union PM_{10} standard is fewer than 35 days per year exceeding 50 $\mu g/m^3$. Official government statistics indicate that 43 million Indonesians were affected by the smoke, with half a million requiring medical attention for upper-air respiratory conditions (Burki, 2017). Model-based estimates of premature mortality due to smoke exposure during the episode vary widely, but range from 11 880 (Crippa et al., 2016) to 100 300 excess deaths (Koplitz et al., 2016) depending on different model assumptions and whether the effects on neighbouring countries are included. For much of September and October, visibility in southern Sumatra and southern Kalimantan was reported as 5-10% of normal (Field et al., 2016).

The health effects of smoke from vegetation fires on human health in South-East Asia were, in fact, addressed by the United Nations and partners in the aftermath of the 1997-98 fire smoke episode. The World Health Organization (WHO) produced Health Guidelines for Vegetation Fire Events (Schwela et al., 1999; Goh et al., 1999) shortly after this episode. A comprehensive approach in reducing the risk that emissions from vegetation fires pose to human health should include (Goh et al., 1999):

- Characterization of the magnitude and composition of the emissions and their transformations during transport.
- Quantification of resulting concentrations of ambient air pollutants in populated areas.
- Evaluation of likely exposure scenarios for affected populations (both indoors and outdoors).
- Assessment of consequent health risks posed by such human exposures.

Satellite-derived products offer real-time fire observations, which provide information and data on active fires, burned areas, and smoke emissions. Active fire observations are better at detecting flaming fires rather than low-temperature smouldering fires.

4. TOOLS FOR FIRE AND VEGETATION SMOKE MANAGEMENT AND EARLY WARNING

Integrated fire management includes social, economic, cultural and ecological evaluations for planning and operational systems in order to minimize the damage and maximize the benefits of fire.

Identifying and mapping areas at risk of fires is crucial to integrated fire management in the region. This includes areas presenting significant fire risks and potential for generating transboundary haze pollution events. This mapping should be transparent and shared between all actors involved in the region.

The nature of fires in South-East Asia, with large fire emissions and their impacts on population centers, requires an approach that integrates both fire and smoke management.

Fire early warning systems are a key component to increase resilience against the increasing severity of future fire regimes under climate change (de Groot and Flannigan, 2014). Following the Third UNISDR International Conference on Early Warning (EWC III) and related consultations[b], it was recommended that smoke early warning system used in the South-East Asia region and elsewhere would to be based on early warning systems such as the Global Fire Early Warning System (Global Fire EWS) (de Groot and Goldammer, 2013) and/or the EC Joint Research Center Global Wildfire Information System (JRC-GWIS)[c] which could be complementary to the fire danger rating systems used by Indonesia, Malaysia, and the Association of Southeast Asian Nations (ASEAN) (de Groot et al., 2007).

The foundation of both the Global Fire EWS and the GWIS platform is the Canadian Forest Fire Weather Index (FWI) System, which has been shown to provide useful information globally (Di Giuseppe et al., 2016) and is the most widely used fire danger rating system around the world (de Groot et al., 2015). The FWI danger rating system only relies on weather variables to assess fire danger. Traditionally, for its calculations, forestry agencies have relied on observations measured at synoptic stations, which are sparsely distributed in the most fire prone regions of equatorial South-East Asia. Under GWIS, progress is being made on enhancing FWI information in Indonesia using weather data inputs from satellites under NASA's Group on Earth Observations Work Programme.

Furthermore, by using predicted conditions from advanced numerical weather prediction models, much longer-range assessments can be achieved (for example 1 to 2 weeks in advance), enabling better planning and resource sharing within and between countries. Both the Global Fire Early Warning system and GWIS approach.

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[b] For the rationale and history of the Global Fire Early Warning System see http://canadawildfire.ualberta.ca/gfews/ and http://gfmc.online/gwfews/index.html

[c] The Global Wildfire Information System is a joint initiative of the GEO and the Copernicus Work Programmes. GWIS builds on the ongoing activities of the European Forest Fire Information System (EFFIS), the Global Terrestrial Observing System (GTOS) Global Observation of Forest Cover - Global Observation of Land Dynamics (GOFC-GOLD) Fire Implementation Team, and the associated Regional Networks. The development of GWIS is supported by the partner organizations and space agencies such as NASA. See also http://gwis.jrc.ec.europa.eu/static/gwis_current_situation/public/index.html

The Global Fire EWS uses the deterministic Canadian Meteorological Centre forecast, while GWIS uses both a deterministic weather forecast and the European Center For Medium Range Weather Forecasts (ECMWF) ensemble prediction system and provides probabilistic fire weather indices calculations up to 15 days ahead. Of course, the use of weather forecasts instead of observations means that FWI values might be affected by model biases, which may be amplified or damped by nonlinear transformations in the fire model. For example, a dry bias in the model in a certain region will lead to the persistent prediction of relatively high fire danger values. If warning levels are defined on the basis of local observations, this may result in a high false alarm rate.

Good post processing tools could minimise these errors by, for example, defining "model based" warning levels. To support the use of fire forecast data, ECMWF has developed a freely available post-processing tool called CaliVer (Calibration and Verification) to define warning levels from model outputs at regional level (Vitolo et al., 2017).[d] Others such as the "ranking" of FWI indices as compared to historical time series of FWI values provide as well information on the local variability of fire danger.

Similarly, regional calibration of the FWI System has recently been updated for South-East Asia, and is in the process of being implemented in the Global Fire EWS. Investigations to further strengthen the calibration with new datasets are ongoing and is seen as an important aspect to improve the usability of the systems in the region.[e] For more details on the Fire Early Warning Systems available see Annex III. Furthermore, in the context of GEO, NASA has funded a project for "Enhancements to the Global Wildfire Fire Information System: Fire Danger Rating and Applications in Indonesia", in order to enhance the potential support of GWIS at regional level. GWIS already provides daily information on fire emissions derived by Copernicus Atmospheric Services[f] (Annex IV).

Sub-seasonal to seasonal weather forecasts have been shown to be skilful in predicting fire activity in South-East Asia (Spessa et al., 2015). As the proposed fire early warning systems are based on weather forecasts it is straightforward to also consider to extending the prediction to seasonal lead times. There is a growing interest across the scientific community in exploring the benefit of merging weather and climate forecasts as showcased by the ongoing joint WMO World Weather Research Programme (WWRP) – World Climate Research Programme (WCRP) Sub-seasonal to Seasonal Prediction Project (S2S). The benefits from the point of view of the final users is that forecasts in the S2S range are not only informative of anomalous conditions like seasonal predictions but can also provide "actionable" information as short range forecasts (White et al., 2017). ECMWF has been particularly active in promoting the S2S timescale with the recent extension up to 46 days of its extended range ensemble prediction system and it is planning to provide also fire forecast up to two months ahead. At longer lead times the role played by model uncertainties becomes relevant and should be quantified. This can be achieved thanks to the availability of the information provided by the 51 runs of the ensemble prediction system which can be translated in probability of occurrence.

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[d] Caliver is a free R-package https://github.com/ecmwf/caliver
[e] See http://data.giss.nasa.gov/impacts/gfwed/
[f] https://atmosphere.copernicus.eu

Global early warning systems can provide a useful overview of cross-boundary fire danger conditions, and initial and boundary conditions for further downscaling. From our experience, we know that at local level the utility of these global systems can be limited due to their too coarse calibration. Therefore, the development of specific regional and national fire early warning systems, which are tailored to specific national to local needs and that are "bridging the last mile" to the end user, must be prioritized.

5. RECOMMENDATIONS FOR ESTABLISHING A VEGETATION FIRE AND SMOKE POLLUTION WARNING AND ADVISORY SYSTEM (VFSP-WAS)

The proposed warning and advisory system should build upon the experience acquired through comparable initiatives: the Copernicus Atmospheric Monitoring Services (CAMS), WMO Specialized Regional Meteorological Centres (e.g. ASMC in Singapore), the Sand-and Dust Storms Warning and Advisory System (SDS-WAS; e.g. its regional center in Barcelona), and the International Cooperation for Aerosol Prediction (ICAP). These initiatives demonstrated that small efforts can add significant value to the end user by making use of existing products. The required efforts lie in the following areas:

1. Collecting the existing fire-related products and providing a centralized data access.
2. Calculating simple ensemble statistics, mostly generating a median product.
3. Performing a centralized verification (in near-real time if possible).
4. Creating accessible and comprehensive graphical products.
5. Making the products from different fire-related information systems (e.g. GWIS, CAMS, etc.) available on a central website.

And more specifically for the purpose of fire and smoke:

6. Sharing fire products amongst the different producers, e.g. satellite observation products, emission inventories, on-site ground observations (including Global Atmosphere Watch (GAW) stations).
7. Taking boundary conditions for regional atmospheric composition models from global models (e.g. CAMS).

Points 1 to 5 could be applied to fire danger forecasting, active fire detection, burnt area mapping and smoke forecasting. The role of the warning system is to provide interpretation to the user community, as experience has shown that the mere collation and publishing of existing products would not in itself lead to their optimal use by stakeholders.

A Vegetation Fire and Smoke Pollution Warning and Advisory System (VFSP-WAS) should have a federation structure with regional nodes and involve a programme of research activities aimed at providing information needed to reduce uncertainty in the forecasting of impacts of smoke from vegetation fires. The areas of research to be covered include

1. Studies of the impact of peat burning on air quality. Research interests include detailed mapping of peatland areas, further studies of the emission factors (Putra et al., 2016) and the composition of smoke from the combustion of peat. Improved parametrization of peat combustion in regional chemical transport models is also

required. Results of these studies could later be applied to other areas posing substantial fire emissions risk (e.g. deforestation areas).

2. Skill evaluation of climate and fire danger forecasts at synoptic, sub-seasonal and seasonal time scales that are specific to fire-prone regions in South-East Asia.
3. Detailed data-based information on fire danger and near-real-time information on the present situation.
4. Assimilation of near-real-time air quality observation data from GAW and other stations into smoke forecasting systems.
5. Generation of information products regarding smoke impacts that are user friendly and accessible. This would require harmonization of information from many diverse sources synchronized across applications, regions and disciplines. These products could include:
    a. Detailed maps of seasonal forecasts of fire severity
    b. Near-real-time maps of fire activity derived from new satellite information e.g. Himawari-8, MODIS, VIIRS, Sentinels.

The VFSP-WAS is suggested as an international network of research, national operational centers and users organized through regional nodes (similar as it is realized for SDS-WAS, see SDS-WAS, 2015) assisted by VFSP-WAS regional centers (Figures 1-2). It will be coordinated by the VFSP-WAS Steering Committee.

At the level of regional nodes, VFSP-WAS can be structured as a federation of regional partners. A federated approach allows flexibility, growth and evolution, while preserving the autonomy of individual institutions. It involves a variety of participants (universities research organizations, meteorological services, emergency management bodies, health organizations, etc.) gathered to cooperate and benefit without requiring changes to their own internal structures and existing arrangements.

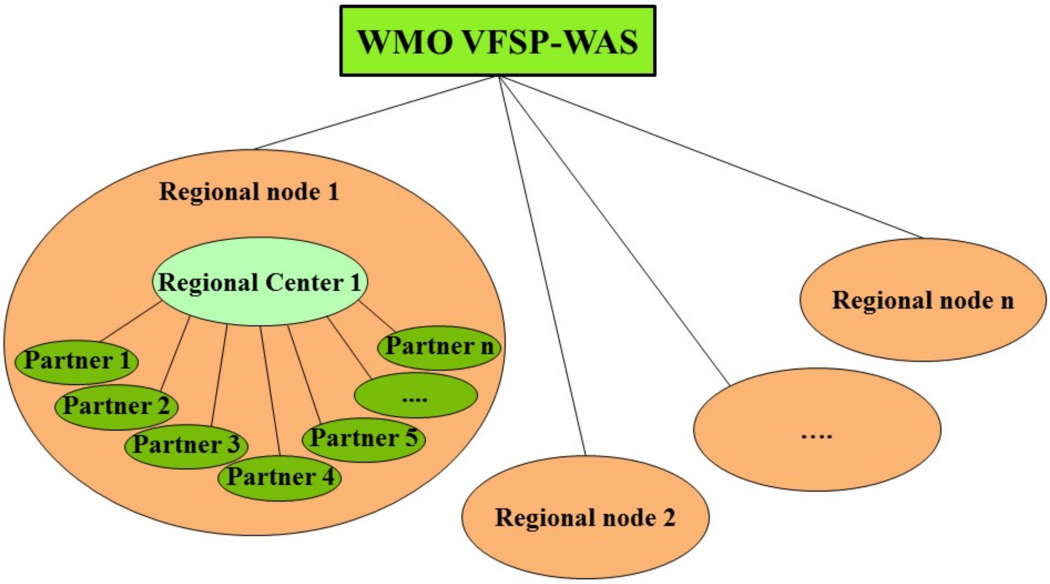

Figure 1. Suggested structure of the Vegetation Fire and Smoke Pollution Warning and Advisory System

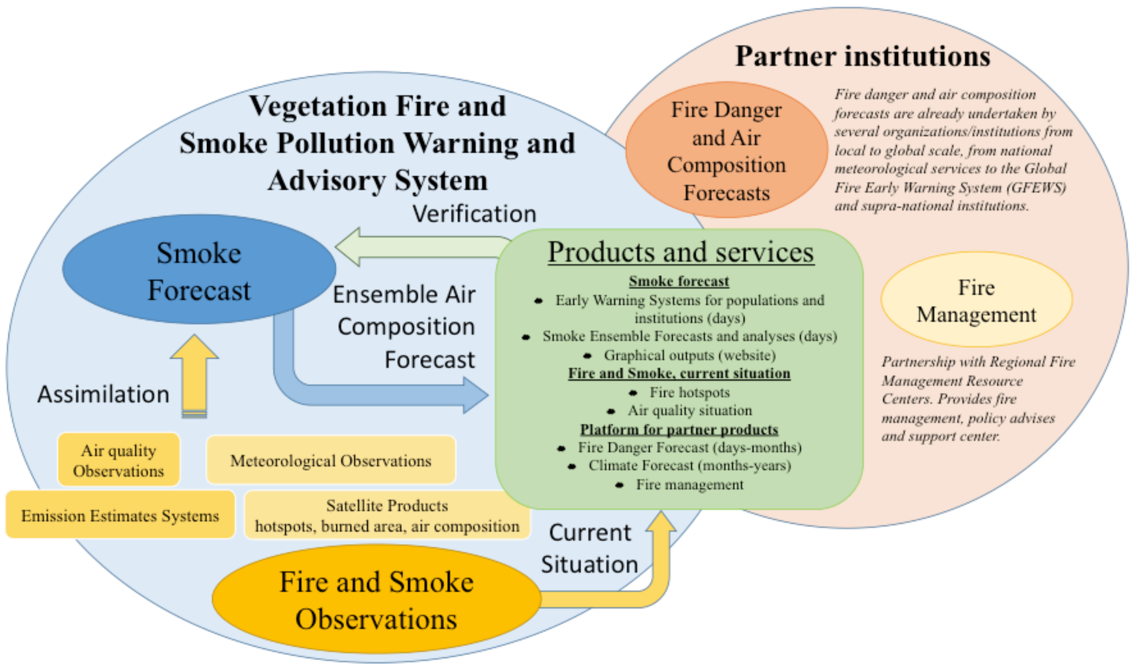

Figure 2. Overview of a potential Vegetation Fire and Smoke Pollution Warning and Advisory System

6. RECOMMENDATIONS FOR ESTABLISHING A REGIONAL FIRE AND SMOKE POLLUTION WARNING AND ADVISORY CENTER (RVFSP-WAC)

At the regional level, VFSP-WAS can be organized as a federation of regional partners and realized through regional activity Nodes and Regional Vegetation Fire and Smoke Pollution Warning and Advisory Centers (RVFSP-WAC). The organization of regional nodes research, development and forecasting activities within each node can be defined and led by a VFSP-WAS Regional Steering Group (RSG) and coordinated by a Regional Center. The Node is an open federation of different partners from interested countries of the region with equal votes of each partner involved (see the previous section). The Center can be hosted by one or several countries/organizations (on the agreement of the Node members and its RSG) and focus more on technical realization of the RVFSP-WAC and providing the RVFSP forecast. Schematic structure of such a Regional Fire and Smoke Pollution Warning and Advisory Center (RVFSP-WAC) is presented in Figure 3.

The establishment of a VFSP-WAS for a specific region would require existing providers of related services to collaborate with one central unit hosting the VFSP-WAS – the Regional Vegetation Fire and Smoke Pollution Warning and Advisory Center (RVFSP-WAC) – in which several people would be dedicated to collecting, analysing and publishing the products with producers of the primary information being adequately acknowledged. A common verification system would provide credibility and will facilitate further research and continued improvements of operational systems. Such set-up arrangements would ensure acknowledgement of product producers and allow linkages with existing regional activities in a flexible way.

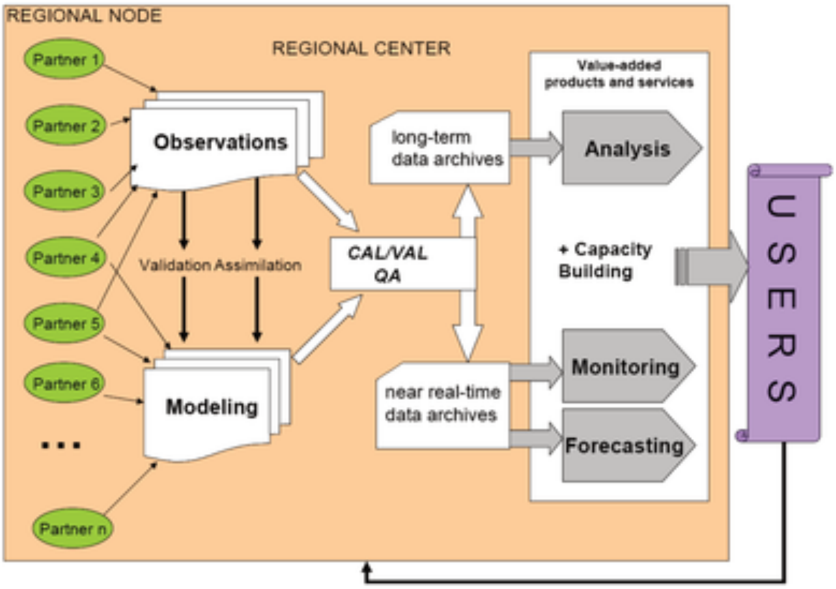

Figure 3. Schematic structure of a WMO Regional Node and Fire and Smoke Pollution Warning and Advisory Center (RVFSP-WAC)

The strength of such a center will be a production of ensemble forecasts based on the already available products, e.g. by ASMC and NHMSs in the South-East Asian region as well as partners outside of the region willing to contribute to the center. Lateral and surface boundary conditions for regional forecasts could be provided by external partners with advanced capabilities (for instance, CAMS).

An RVFSP-WAC for South-East Asia could provide information in support of fire and emergency management. Because of the disastrous impact of fire and smoke pollution in the region, provision of much-needed data that can inform the health sector and the other users of the air pollution information should form a cornerstone of the center's mission and guide the developments of the user relevant products and services. However, the RVFSP-WAC would not itself lead on policy advice but instead contribute to collaborating entities.

Mapping the potential partners interested in RVFSP-WAC should occur first and foremost, followed by the organization of a dialogue with these partners. This could occur through the organization of a stakeholder roundtable, or a workshop. This step should ensure that relevant actors from the global, to the regional, national and local level (cf. Partnerships section) are involved in the dialogue. The following stakeholders and beneficiaries ought to be consulted: meteorological departments, land (including peatland) and forestry management, fire management and firefighters, and health management and health practitioners. Understanding user needs is key to determine the type and quality of products and services required. This process would also be key for finalizing a statement of the goals an RVFSP-WAC would achieve (workshop experts' recommendations for such mission statements are included in Annex V).

Once a set of user-focused and impact-based products and services has been identified, as well as the accuracy needed for their operational use, the implementation plan should follow comprehensive steps from initial research and validation efforts to impact-based services (Figure 4). Any implementation plan for an RVFSP-WAC should contain a more informed and detailed sequence of steps leading to operational use.

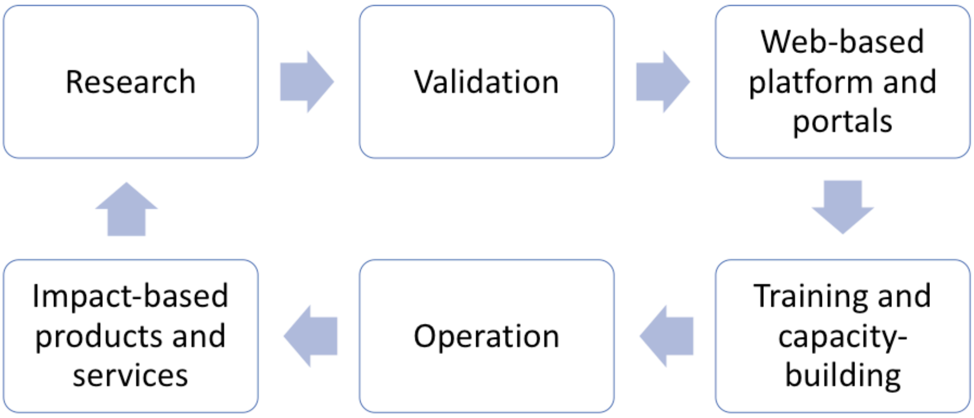

Figure 4. A conceptual series of steps to the implementation of a Regional Vegetation Fire and Smoke Pollution Warning and Advisory Center. Once a step is completed, attention should be maintained on the preceding ones to ensure sustained improvement and applicability.

RVFSP-WAC should aim to ensure partners appropriately and systematically use the center's warning and advice to ensure harmful fire episodes are reacted upon appropriately. Because fire and smoke predictions still need considerable development, any center should also aim to breach the gap between research and operational work.

Structure of a regional center for South-East Asia

The proposed RVFSP-WAC in the region would maintain strong links with partner institutions that provide Fire Danger forecasts and Early Warning (the ASEAN centers for South-East Asia), and national and regional institutions that support fire management, e.g. the Regional Fire Management Resource Center – South East Asia (RFMRC-SEA). The center would provide centralized access to products and services aimed at stakeholders and the public. Regional partners would contribute these products while the center would facilitate their availability (website and data access). The center would be responsible for providing multi-model ensemble of atmospheric composition forecasts and analyses and longer-term fire danger forecasts (e.g. sub-seasonal or seasonal). It would also perform a common verification of all of these.

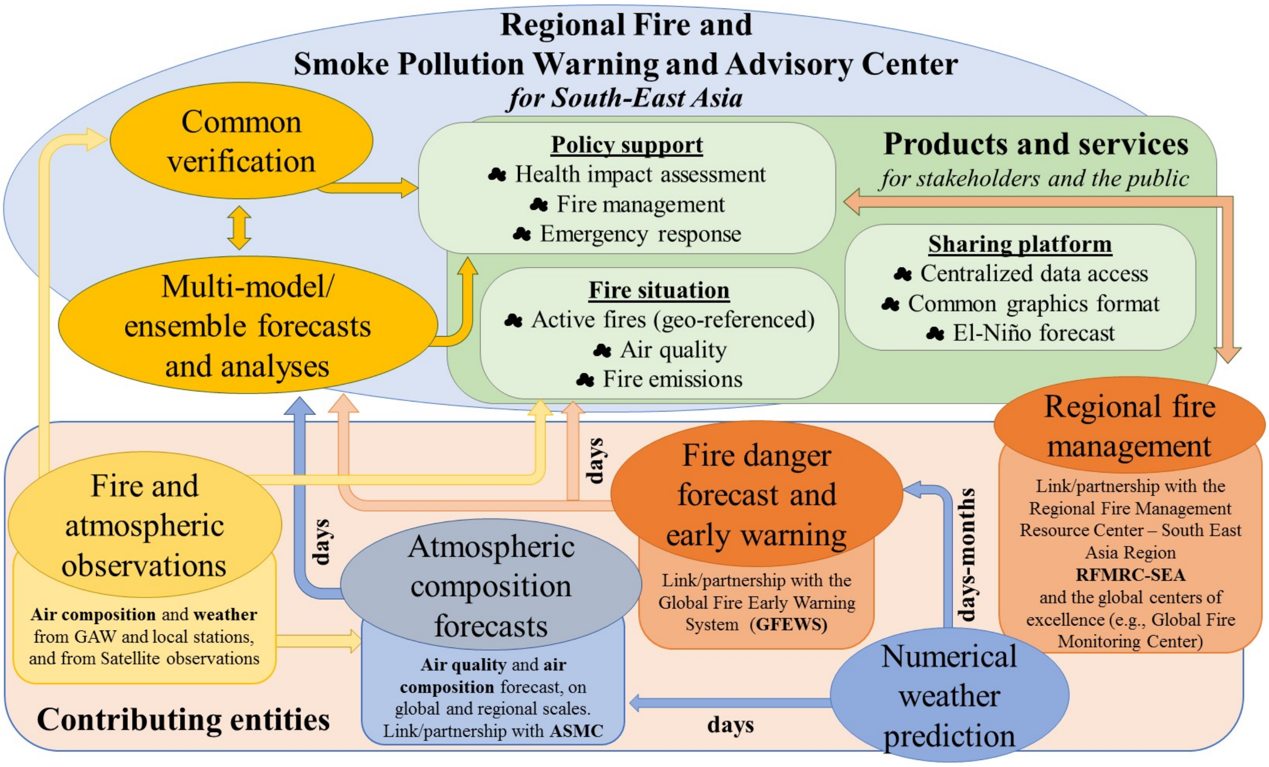

Figure 5. Workflow of a potential Regional Fire and Smoke Pollution Warning and Advisory Center: example for South-East Asia

Existing regional institutions and framework

The Association of Southeast Asian Nations (ASEAN) has agreed upon policies and technical measures towards reducing regional haze pollution:

1. The ASEAN Agreement on Transboundary Haze Pollution (AATHP) was signed on 10 June 2002 in Kuala Lumpur, Malaysia. AATHP entered into force in 2003 and has now been ratified by all ASEAN member states. The agreement gives effect to the 1997 Regional Haze Action Plan (see below) and contains legally binding measures on monitoring and assessment, prevention, preparedness, national and joint emergency response, procedures for deployment of people, material and equipment across borders, as well as technical cooperation and scientific research. The 2016 AATHP Implementation Roadmap updates ASEAN's role in haze reduction, focusing on early warning and regional cooperation.[g]
2. The ASEAN Regional Haze Action Plan was endorsed in 1997 by the ASEAN Ministers of the Environment.[h] Under the section "Regional Monitoring Mechanisms", the plan strengthens the role of the ASEAN Specialised Meteorological Centre (ASMC)[i], hosted under the Meteorological Service Singapore, in the monitoring and assessment of vegetation fires and the occurrence of transboundary smoke haze, as well as in provision of seasonal forecasts for the

[g] http://haze.asean.org/wp-content/uploads/2017/10/Roadmap-ASEAN-Haze-Free_adoptedbyCOP12.pdf
[h] https://cil.nus.edu.sg/wp-content/uploads/formidable/18/1997-Regional-Haze-Action-Plan.pdf
[i] See: http://asmc.asean.org/home/

ASEAN region. These forecasts feed into a larger network of actions taken at ground level and policy level by Governments in ASEAN. The Fire Danger Rating System (FDRS)[j] for South-East Asia was also developed as part of this action plan and is operated by the Malaysian Meteorological Services (MetMalaysia).[k]

3. Within the framework of AATHP, the ASEAN Peatland Management Strategy (APMS), covering the period 2006-2020 was developed to guide member states to sustainably manage peatlands and reduce fires and associated haze. The strategy calls for an integrated fire management, where resources are focused on prevention.

Indonesia also contributes to the international activities related to reducing haze caused by vegetation fires and BMKG hosts the newly designated WMO Information System – Data Collection or Production Center (WIS-DCPC) on 'Transboundary Forest Fires', which is closely linked with the GAW atmospheric pollution observations in the region. On a national level, with an increasing international recognition of the problem prior to and at COP 21, additional measures have been taken in Indonesia to enforce existing laws regulating the use of fire and to enhance governance in fire management at all levels. It is important to note that the concept of DCPC contradicts the GAW data management structure as GAW data have to be submitted to the GAW Data Centres, hence being DCPC does not make BKMG an immediately legitimate body for collection of GAW data. To solve this problem other functions outlined at the WMO Information System (WIS)[l] should be implemented. Following the WIGOS technical regulations GAW data should go to the GAW data centres.

The responsibilities for fire management in Indonesia and neighbouring South-East Asian countries are distributed between different agencies, notably the Indonesian Ministry for Environment and Forestry (KLHK) and Board for Disaster Management (BNPB, specialized agencies such as those responsible for protected areas, or the newly established Peat Restoration Agency (BRG) in Indonesia. The President of Indonesia issued the Directive on Forest and Land Fire Control in January 2017, which codifies Indonesia's responsibilities under the AATHP. The Directive consists of six components with measures at national, provincial, district and village levels:

1. Preparedness and early detection.
2. Community involvement in fire prevention and mitigation.
3. Aerial patrols and initial suppression.
4. Law enforcement.
5. Improvement in land and forest governance.
6. Enhancing coordination from national to field level.

During large wildfire situations or emergencies these agencies are supported by ministries responsible for emergency situations/disaster management and the military.

Inter-agency coordination is critical for the success of strategic, long-term planning and implementation of fire management as an integral element of managing forests, protected

[j] FDRS was adapted from the Canadian Forest Fire Danger Rating System, see: http://haze.asean.org/fire-danger-rating-system-fdrs-for-southeast-asia-2/

[k] For more national and regional fire danger rating / early warning systems: See Early Warning Portal of the Global Early Warning System for Wildland Fire: http://gfmc.online/fwf/fwf.html

[l] https://www.wmo.int/pages/prog/www/WIS/centres_en.html

areas, agricultural lands, plantations and other vegetation at the risk of wildfire (i.e. at landscape level), and addressing the excessive, illegal and inappropriate application of fire in land use practices, the safe and benign use of fire, the prevention of and preparedness for wildfire situations.

To facilitate the development of informed dialogue and building of institutional capacities and the participation of civil society (notably at local community level, NGOs, etc.) Regional Fire Management Resource Centers have been established in four regions of Europe, Central Asia and South-East Asia (cf. section "Partnerships" below).

Partnerships

The proposed regional center would partner with the Regional Fire Management Resource Center – South East Asia Region (RFMRC-SEA), which has been established in Bogor, Indonesia, in March 2017 (official inauguration: 10 July 2017). The RFMRC-SEA is serving as the 4th Regional Fire Management Resource Center.[m] The RFMRCs are associated with and operate under the Global Fire Monitoring Center (GFMC)[n] and the Global Wildland Fire Network (GWFN)[o] (the first three regional centers have been established between 2010 and 2015 in South-East Europe[p], Eastern Europe[q], and Central Asia[r]). These centers of excellence provide the following services:

- Provision of science-based advisory service for sustainable forestry and land management and relevant policies ("Science-Policy Interface – SPI").
- Creation of an interface and promotion of the dialogue between services of specialized governmental institutions and civil society organizations.
- Promotion of regional cooperation through networks such as the Regional South East Asia Wildland Fire Network under the Global Wildland Fire Network.
- Training and continuing vocational training in fire management (main task: information, training, education and the promotion of human resources and institutional capacities).
- Development of an internet-based information portal, which will include the science of vegetation fires and related scientific disciplines.
- Development of a web-based documentation and information portal on the practices, which are prerequisite for the application of scientific principles in informed fire management.

and serve the goals of the United Nations International Strategy for Disaster Reduction (UNISDR) in fulfilment of the past "Hyogo Framework for Action 2005-2015: Building the Resilience of Nations and Communities to Disasters" and in the implementation of the

[m] https://rfmrc-sea.org
[n] http://gfmc.online/
[o] http://gfmc.online/globalnetworks/globalnet.html
[p] http://www.rfmc.mk/
[q] http://nubip.edu.ua/en/reefmc
[r] http://rcafmrc.num.edu.mn/

voluntary follow-up "Sendai Framework for Disaster Risk Reduction 2015-2030".[s] In 2017, the process has been initiated to establish the 5th and 6th regional center in Central Eurasia (Russian Federation) and South America (joint hosts: Brazil and Chile), which will become fully operational in 2018.

To fully realize an effective regional service, the proposed system should acknowledge and complement existing formalized structures and agreements within ASEAN, to circumvent potentially contradictory warnings and assessments during periods of high risk. One mechanism is for WMO to work within the comprehensive Memorandum of Understanding between WMO and ASEAN (WMO-ASEAN MOU, 2002), which was signed by the two organizations' Secretary-Generals in 2002. The MOU has provisions for deepening cooperation across ASEAN member states in mitigation of natural disasters and environmental monitoring. Another related mechanism is for the eventual system to flow its products and assessments into the ASMC, which under its ASEAN mandate[t] is the official source of transboundary haze advice for its member states. This would enable the system to have maximum reach and not be primarily associated with one country.

As a WMO center, the RVFSP-WAC would work in close collaboration with all WMO Members in the region and with the corresponding Regional Association (RA) (for South-East Asia, RA II and RA V).

Workshop experts stressed the value of offering a user-friendly platform to disseminate products from partners, which could represent a significant part of any center's responsibilities. This would provide users with a centralized database for regional products related to fire and smoke, including observations and predictions, and their history.

Context within WMO

During the 68th Executive Council (EC-68)[u], WMO discussed the establishment of a regional center related to fire activities in two instances. First, in Agenda Item 5.2: WMO Information System, a center for 'Transboundary Forest Fires' based in Jakarta (Indonesia) was designated as a WIS-DCPC (WMO Information System - Data Collection or Production Center). This center is to be further evaluated and supported in order to comply with the WIS manual before being endorsed by the Commission for Basic Systems (CBS). At the same time, it should be noted that data collections and dissemination on atmospheric composition is coordinated through the GAW Programme, which has within its structure several data centers, that have also been designated as DCPCs. In addition, EC-68's Agenda Item 8 would be relevant should the proposed center aim to constitute part of the seamless Global Data-Processing and Forecasting System (GDPFS). In particular Agenda Items 8.1 and 8.2 cover the implementation of seamless data processing and forecasting, and weather forecast including verification and high-resolution impact-based forecasting.

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[s] http://www.unisdr.org/we/coordinate/sendai-framework
[t] https://cil.nus.edu.sg/wp-content/uploads/formidable/18/1997-Regional-Haze-Action-Plan.pdf
[u] http://ec-68.wmo.int/

The 16th World Meteorological Congress (Cg-XVI) (2011) adopted the outline for a revised Manual on the GDPFS (WMO-No. 485) through Resolution 6 (Cg-XVI), wherein it decided that this Manual is the single source of technical regulations for all operational data-processing and forecasting systems operated by WMO Members. The GDPFS aims to enable member states and partners to support decision-makers by providing impact-based forecasts and risk-based warnings, taking into account vulnerability and exposure information to support risk-based decision-making. A seamless GDPFS builds upon the original system that aims to be more agile and adaptable to support Application Programmes (e.g. AeM, AgMet, MMO, and PWS) and provides not only weather-related predictions, but also products that support impact-based forecasts and warnings. The vision for a seamless GDPFS was endorsed by WMO during EC-68 and described in the revised manual on GDPFS (WMO GDPFS, 2017). EC called for the development of the Implementation Plan for the seamless GDPFS which is currently at the stage of development. Only after adaptation of this plan will it be possible to put the proposed fire smoke forecasting centers in the context of seamless GDPFS. The methodology and research needs for realization of the Seamless Prediction Systems were published in the World Weather Open Science Conference (WWOSC) book "Seamless Prediction of the Earth System: From Minutes to Months".[v]

Further WMO-relevant information is included in Annex I, listing the steps which were undertaken by the SDS-WAS nodes to be recognized as Regional Specialized Meteorological Centers (RSMC) with a global coordination by the SDS-WAS Steering Committee. Similar procedures may be used for the establishment of the regional centers related to fire activities. Note that there is no WMO global coordination of the warning and advisory system for fire and smoke pollution equivalent to SDS-WAS hence the concept of such system requires further development and adaptation by WMO Constituent Bodies. However, the ASEAN Specialised Meteorological Centre (ASMC, http://asmc.asean.org, see Annex VI) can be used as an initial prototype for other vegetation fires and smog pollution centers, but with extended responsibilities and closer integrations with atmospheric composition observations of the WMO Global Atmosphere Watch.

7. TOPIC-SPECIFIC RECOMMENDATIONS

Fire danger and seasonal forecast

Currently a variety of fire danger indices are being provided at the global and regional levels. In the case of South-East Asia, the workshop highlighted the existence of operational products providing up-to seven days forecast of fire danger. These products include the Indonesian Fire Danger Rating System, the ASEAN Fire Danger Rating System (developed and produced by Met Malaysia), the Global Fire Early Warning System and the Global Wildfire Information System. All systems are based on the Canadian Fire Danger Rating System, which has been calibrated for equatorial South-East Asia in a broad sense (de Groot et al., 2007). The systems provide index information on fire danger, while they do not reflect potential/current level of atmospheric pollution associated with fire activities. Evidence suggests that ENSO (Barnston et al., 2017) and regional precipitation (Spessa et al., 2015; Setiawan et al., 2017) can be reasonably captured a couple of months ahead, with other relevant modes such as the Indian

[v] http://library.wmo.int/opac/index.php?lvl=notice_display&id=17276#.VZ6N5mPTDWG

Ocean Dipole (Shi et al., 2012; Zhu et al., 2015) and the Madden Julian Oscillation predictable at varying lead times (Li and Robertson, 2015).

Research and development needs

The initial FWI calibration of de Groot et al. (2007) was exclusive to equatorial South-East Asia, and is known to over-estimate fire danger in the "Upper ASEAN" region. The FWI system therefore requires a separate calibration for Thailand, Vietnam, Laos, Cambodia and Myanmar. Further calibration of the FWI system within Indonesia is also needed to account for differences in fuel types and land use intensity. The 2013 episode in Riau province in Central Sumatra, for example, indicates that acute fire emissions events affecting Singapore occur under less severe drought conditions than in other fire prone regions (Gaveau et al., 2014), likely related to the intensity of land use (Hansen et al., 2013), suggesting that the drought code (DC) may not be the best overall emissions potential indicator in that region, or that the DC requires a different calibration. A more detailed calibration will also benefit from longer records of space-based fire and pollution data than were available when the initial calibration of de Groot et al. (2007) was conducted.

Research and development is also required for supporting long-term fire management planning through seasonal predictions, emphasizing the risks and usefulness to local actors. Shawki et al. (2017) demonstrated the potential for combining seasonal climate forecasts with Indonesia's calibrated FWI system in operationalizing long-lead fire danger forecasts, but emphasized that further research is needed to determine how skill at different lead times, in different fire-prone regions, and for different models translates into predictions of fire danger. A regional center should work together with the World Weather Research Programme's (WWRP) Sub-seasonal to Seasonal project (S2S) (Vitart et al., 2017) for regional downscaling and facilitating the development of sub-seasonal to seasonal predictions of fire severity in the area. To this end there could be a clear benefit in accessing fire danger forecast produced by ECMWF at the S2S time scale.

In addition to the seasonal prediction of anomalous dry conditions, the sub-seasonal to seasonal time range can also provide actionable information with great potential for advance planning. ECMWF has already implemented a "seamless" forecasting system for floods and drought which provides frequent forecast updates with up to six months horizon and performs well at the S2S time scale. The same approach can be implemented for fire forecasting in the region.

Fire emissions and haze forecast

Reasonably fast and comprehensive estimates of smoke constituent emissions are derived from satellite observations of fires. There are three fundamentally different approaches:

Fire Radiative Power
The thermal radiation of a fire can be observed in real time in the middle infrared (MIR) spectral range. Such observations are called "active fire" observations. If a quantitative signal is recorded, then it can be interpreted as "fire radiative power" (FRP) product. FRP has been shown to be proportional to the biomass combustion rate under certain conditions. Subsequently, instantaneous emission rates of various smoke constituents can be calculated with published emission factors (Wooster et al., 2005). The advantages of this approach are

the immediate availability of the observations and emission estimates (even while the fires are still burning) and the relatively weak dependence on the fire type for above-ground burning. Also, a quantitative characterization of the fires with a spatial resolution to 375 m (e.g. with NPP-VIIRS) and a temporal resolution 10 minutes (e.g. from Himawari-8) is possible when all available satellite data are used. This approach is used, for instance, by Copernicus Global Fire Assimilation System (GFAS) (Kaiser et al., 2012) and Integrated System for wild-land fires IS4FIRES (Sofiev et al., 2009; Soares et al., 2015).

Smoke detection
Smoke plumes can be readily detected in the atmosphere using remote sensing tools. Aerosol optical depth and carbon monoxide are relatively well observed by satellites, and are used to infer fire emissions with "inversion" methods. While the atmospheric effect is relatively directly constrained for the observed species and the effect of any unobserved fire is also included, this methodology cannot distinguish the sources of observed constituents, e.g. from fire or from other sources (e.g. urban emissions) and has limited temporal and spatial resolution.

Burned area
The detection and quantification of burned area using satellite products is well established. Scaling burned area with fuel load and combustion completeness yields burned biomass, from which smoke emission can be calculated as in the FRP-based method described above. In addition to being a commonly used method, the similarity to in situ methods employed locally by foresters on the ground means that significant validation and calibration has been carried out. In addition, since area burned is persistent, it can be detected even after an observation gap, due to cloud cover for example. The spatial resolution is also relatively high (down to 250 m for global coverage). However, since the area burned can only be observed after a burn has occurred, it is not suitable for true real-time applications. Active fire satellite observation that can only distinguish between "fire" and "no fire", e.g. due to its MIR channel saturation the satellite can only produce binary "high-temperature event" (HTE) products. Sometimes, relatively simple assumptions are used to estimate burned area from such products and emissions can subsequently be calculated as described above. This approach is being used to correct for missing small fires in the Global Fire Emissions Database (GFED) (Randerson et al., 2012) or to calculate emissions in real time, e.g. with FINN (Fire Inventory from NCAR; Wiedinmyer et al., 2011) and to estimate emissions in EFFIS.

These emission estimates are a key input to atmospheric composition and transport models that represent a main tool for haze and air pollution forecasts. A RVFSP-WAC could coordinate multi-model ensemble forecasts of air pollutants dispersion in the region through atmospheric transport using regional expertise and capacities. To support this, WMO Members outside of the region informally proposed during the workshop to contribute to such a multi-model ensemble forecast and analysis (e.g. sharing outputs of the lower resolution global aerosol models).

Within the International Global Atmospheric Chemistry (IGAC) project, there is at present about half a dozen advanced global aerosol models that include emissions from vegetation fires and could be included in a multi-model ensemble forecast. Only half of the IGAC-participating models are now operational, the others remaining in a research and development stage (for some, only the vegetation fire component is not operational).

Several real-time smoke forecasting products exist. The most established global aerosol forecasts are represented in the International Cooperative in Aerosol Prediction (ICAP). Four models include dedicated smoke treatment: (i) the Copernicus Atmosphere Monitoring Service (CAMS)[w] (European Center For Medium Range Weather Forecasts (ECMWF) and partners), (ii) MASINGAR: Model of Aerosol Species IN the Global AtmospheRe (Meteorological Research Institute, Japan Meteorological Agency, MRI-JMA, see Tanaka et al., 2003), (iii) GEOS-5: Goddard Earth Observing System model, version 5 (NASA, see: Rienecker et al., 2008), (iv) NAAPS: Navy Aerosol Analysis and Prediction System[x] (US Navy), and System for Integrated modeLling of Atmospheric coMposition SILAM[y]; where the first two use emissions from the Global Fire Assimilation System (GFAS)[z], the third one - from a similar fire radiative power (FRP)-based inventory of the Quick Fire Emissions Dataset (QFED)[aa], the fourth - from the active fires detected by the Fire Locating and Modeling of Burning Emissions (FLAMBE)[bb] system and the fifth one – from IS4FIRES[cc].

The ICAP initiative itself has demonstrated that simply collecting different forecasts in a single database and generating web pages with common plotting conventions is an effective tool for the developers to assess and improve their forecasting systems.

EU’s Copernicus Atmosphere Monitoring Service (CAMS) is using its global atmospheric composition forecasts and GFAS fire emissions as common boundary conditions for an ensemble of seven operational regional air quality forecasting systems for Europe, including smoke (Marecal et al., 2015). A common real-time verification with station data greatly helps the interpretation and further developments of the individual models and the median of all models has been shown to benefit from the individual strengths of the seven models, as this statistical “analysis” is thus more accurate than any single forecast.

ASMC provides operational and regularly updated information and products on the weather and smoke haze situation in the ASEAN region at http://asmc.asean.org (see Annex VI). By using the fire distribution from CAMS-GFAS, it is already similar to a member in the CAMS ensemble of European air quality models. The Bluesky Modelling Framework is a possible approach that has been successfully applied in North America, and in which the testing of different emissions scenarios as input to transport models is relatively straightforward.

Truly prognostic smoke forecasts require emissions forecasts. The simplest possible approach is to better understand the relationship between historical emissions and simple meteorological or fire weather parameters. Forecasts of those parameters can subsequently be used to produce emissions forecasts. Despite the role of non-weather factors in controlling fire activity, this approach is likely to be useful in Indonesia because of the strong climatic controls on fire activity and emissions relative to other fire-prone regions in the world (Bedia et al., 2015).

[w] http://atmosphere.copernicus.eu
[x] https://www.nrlmry.navy.mil/aerosol_web/Docs/globaer_model.html
[y] http://silam.fmi.fi
[z] http://apps.ecmwf.int/datasets/data/cams-gfas/
[aa] https://geos5.org/wiki/index.php?title=Quick_Fire_Emission_Dataset_(QFED)
[bb] http://acmg.seas.harvard.edu/geos/wiki_docs/emissions/FLAMBE4ARCTAS.pdf
[cc] http://is4fires.fmi.fi

Research and development needs

Despite its application in other regions, the implementation of ensemble forecasts for transboundary haze events in South-East Asia still requires substantial development. Since all CAMS services are freely available, the CAMS concept of implementing an ensemble of forecasts with common boundary conditions, presentation and verification could relatively easily be applied to the smoke situation in South-East Asia with ASMC already providing the first operational, high-accuracy ensemble member.

Observation gaps that may occur due to cloud cover or lack of satellite coverage create gaps in the emission estimates. At the same time, consistent merging of FRP from different satellites still represents an open research topic. Furthermore, the signal from peat fires is relatively small and the proportionality to fuels consumed is less certain for these fires than for above-ground fires. Finally, the emission factors vary for individual fires so that estimates on a small scale have a limited accuracy. The CAMS-GFAS (Kaiser et al., 2012) inventory is a widely used (e.g. by ECMWF, NASA, JMA, ASMC and GWIS) example of such a combined inventory.

The uncertainties in emission estimates from smoke observations are still large due to variable and relatively poorly known optical properties of aerosols, the poorly characterized errors in atmospheric chemistry and transport models, and noise in the satellite observations. A recent example of an inversion of South-East Asian fire emissions is given in Huijnen et al. (2016).

Observations and data production for verification and assimilation

Global atmospheric composition observations in WMO are coordinated through the GAW Programme. To support the assessment of fire impacts, measurements of the combustion species (aerosols, reactive and greenhouse gases) are needed. There are several stations in the South-East Asian region operated under both GAW and the other networks arrangements (e.g. AERONET) that can support verifications of haze forecast, but their number and timeliness of data delivery are very limited.

An RVFSP-WAC would help member states utilize measurements of ambient air pollutants (including the Indonesian GAW stations at Bukit Koto Tabang, Sorong and Danum Valley). Such a center could provide centralized data access to a variety of observations, from satellite observations to ground observations of fire and smoke. Although it would not necessarily be involved in producing data itself, it should encourage the regional use and dissemination of these observations.

Research and development needs

Beyond a regional increase in number and coverage of observations, near-real-time access to in situ observational data for assimilation and verification was stressed during the workshop as key to the improvement of chemical transport model. Some gaps in observations can be filled by the Acid Deposition Monitoring Network in East Asia (EANET) monitoring sites. However, EANET is not a contributing network to WMO GAW at this stage and even if it was, remaining data gaps may have to be filled by suitably placed new stations.

Editorial note: terminology

This concept note includes terms that are widely used in fire ecology as well as in scientific disciplines and related technologies, such as atmospheric sciences, satellite remote sensing or early warning. The terms “landscape fire” and “vegetation fire” are increasingly replacing the terms “wildland fire” (which is less understood outside of the English-speaking fire management community), “forest fire” (which is representing only one of many vegetation types), “land fire” (a term uniquely used in South-East Asia) or “wildfire” (which is an uncontrolled fire that could be started by lightning and any human cause or fire application). The term “peat fire” is clearly restricted to a specific type of organic terrain. Biomass burning is the general term that encompasses all of these terms and others (e.g. prescribed burning). For particular applications (management and scientific) it is important to specify which aspect of biomass burning is being addressed.

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ANNEX I

DESIGNATION PROCEDURE FOR RSMC AND GDPFS CENTERS

Establishing a Regional Vegetation Fire and Smoke Pollution Warning and Advisory Center (e.g. for South-East Asia) as a formal Regional Specialized Meteorological Center (RSMC) may require a rather long consultative process, especially if this involves operational duties. A WMO Information System – Data Collection or Production Center (WIS-DCPC) involves information exchange and is not automatically a GDPFS Center, which also deals with products and services. As realized within the WMO Sand and Dust Storm Warning Advisory and Assessment System (SDS-WAS) programme[dd] with designations of the RSMC for sand and dust storm forecasts for Northern Africa-Middle East-Europe (NA-ME-E) with the SDS-WAS Regional Node and RSMC in Barcelona[ee] (and now preparing the next one for Asia in Beijing)[ff] (see: SDS-WAS, 2015), there is a need to develop the functions and designation criteria for a new type of Center. The proposed transition from the research phase to operational activities for SDS-WAS is described by the Commission for Basic Systems in the 'Standard designation procedure as Regional Specialized Meteorological Center with activity specialization in Atmospheric Sand and Dust Forecasting (RSMC-ASDF)' and included as Annex 2 (pages 27-28) in the Science and Implementation Plan for the Sand and Dust Storm Warning Advisory and Assessment System (SDS–WAS) (SDS–WAS, 2015).[gg]

Establishing requirements for Regional Vegetation Fire and Smoke Pollution Warning and Advisory Centers should involve a close collaboration between the WMO's Commission for Atmospheric Sciences (CAS), Commission for Basic Systems (CBS) and corresponding Regional Associations. This follows the process followed for building, e.g. regional dust storm forecast centers for SDS-WAS. The research phase/background for such a programme can be coordinated by the IBBI and WMO GAW and WWRP together with region's National Meteorological and Hydrological Services (NMHSs) (e.g. BMKG, ASMC and Meteorological Service Singapore (MSS), MetMalaysia, etc.), the transition to operational activities has to be coordinated by the WMO DPFS and regional NMHS together with other interested regional and international organizations.

[dd] http://www.wmo.int/sdswas
[ee] http://sds-was.aemet.es/ and http://dust.aemet.es/
[ff] http://eng.nmc.cn/sds_was.asian_rc/
[gg] https://www.wmo.int/pages/prog/arep/wwrp/new/documents/Final_WWRP_2015_5_SDS_IP.pdf

ANNEX II

BACKGROUND ON FIRES BURNING IN PEATLAND BIOMES AND OTHER ORGANIC TERRAIN

South-East Asian peatlands cover about 23 million hectares, or 60% or the world's tropical peatlands and 6% of the global peatlands. In the region, the majority (70%) of peatlands is in Indonesia, but peatlands can also be found in Malaysia, Brunei, the Philippines, Cambodia, Lao PDR, Myanmar and Singapore. With depth of peat between 0.5 and 10 m, peatlands are usually located in low elevation, sub-coastal areas. Peatlands only cover 2 to 3% of the Earth's land surface, but store around 25% of its terrestrial carbon (Turetsky et al., 2015). This makes peatland management, and prevention of peat fires, a critical part of carbon sequestration and storage.

Fires burning in peat and other organic terrain are predominantly characterized by smouldering combustion. Such fires are spreading slowly, flameless and burn at low temperatures. Smouldering is dominated by pyrolysis and heterogeneous oxidation while flaming requires gas-phase oxidation. In their natural state, peatlands are too humid to burn. In South-East Asia peat fires are commonly the result of human intervention. The key characteristics of peat and smouldering fires are:

- Peat is particularly sensitive to drought conditions: the severity of peatland fires is foremost related to soil moisture, second to the mineral content of the peat. This means peat drainage makes the soil more flammable; not only does it reduce the moisture available, it also creates channels whereby atmospheric oxygen can follow, thus encouraging smouldering at depth. Because smouldering fires transfer heat at depth, the fuel consumption of peat fires can be two orders of magnitude larger than flaming fires.
- Smouldering fires are hard to suppress, requiring large amounts of water. Moreover, the nature of smouldering (as opposed to flaming fires), means lower oxygen concentrations are needed (about 10% rather than 16% for flaming fires) and oxygen removal is inefficient until the fuel bed is cooled enough to prevent re-ignition. Finally, because lower temperatures are involved (450 to 700°C rather than 1500°C), dry peat is much more susceptible to smouldering fires and ignition is easier; dry peat is also at risk of self-ignition. The main issue when combating smouldering fires is that standard firefighting techniques which work for flaming fires (e.g. fire-breaks) cannot be relied upon to extinguish peat fires: prevention is much more efficient.
- Flaming and smouldering interact, such that smouldering fires typically succeed flaming fires, and under the right conditions, smouldering fires can also provide an ignition source for flaming fires to emerge. This means an integrated fire management approach is required for locations at risks of smouldering fires such as dry peatlands.
- The chemical composition of emissions from peat fires significantly differs from that of typical flaming fires. Incomplete combustion is prevalent, with more reduced compounds emitted. For instance, the CO/CO_2 ratio in smouldering fires is about 0.4 (about 0.1 for flaming combustion). Because little heat is generated, pollutants are generated and accumulated close to the surface, which encourages their transport to population centers where they seriously threaten health.

ANNEX III

EARLY WARNING SYSTEMS

Fire early warning systems are a key component to battling the increasing severity of future fire regimes under climate change (de Groot and Flannigan, 2014). Following the Third UNISDR International Conference on Early Warning (EWC III) and related consultations[hh] it was recommended that smoke early warning system used in the South-East Asia region and elsewhere would to be based on early warning systems, such as the Global Fire Early Warning System (Global Fire EWS) (de Groot and Goldammer, 2013) and /or the Global Wildfire Information System (GWIS). Both these systems could provide information that are complementary to the fire danger rating systems used by Indonesia, Malaysia, and ASEAN (de Groot et al., 2007).

The Global Wildfire Information System is a joint initiative of the GEO and the Copernicus Work Programmes. The Global Wildfire Information System (GWIS) builds on the ongoing activities of the European Forest Fire Information System (EFFIS), the Global Terrestrial Observing System (GTOS) Global Observation of Forest Cover- Global Observation of Land Dynamics (GOFC-GOLD) Fire Implementation Team (GOFC Fire IT), and the associated Regional Networks, complementing existing activities that are ongoing around the world with respect to wildfire information gathering. The development of GWIS is supported by the partner organizations and space agencies. Support to GWIS was just launched by NASA through its ROSES programme.

The foundation of both the Global Fire EWS and the Global Wildfire Information System (GWIS) is the Canadian Forest Fire Weather Index (FWI) System, which is the most widely used fire danger rating system around the world (de Groot et al., 2015).

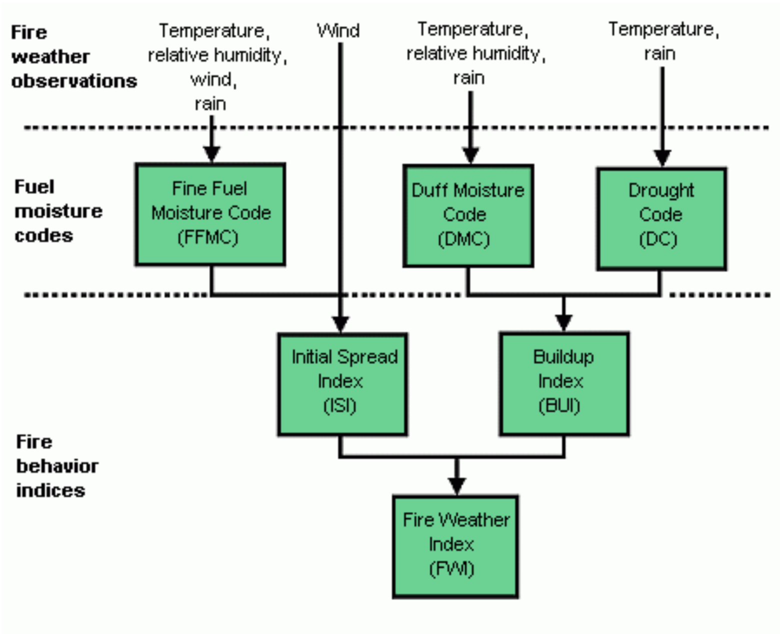
The FWI System is comprised of 6 components to assess fuel dryness and potential fire behaviour:

- The Fine Fuel Moisture Code (FFMC) is an indicator of the moisture content of litter and other cured fine fuels. Often used as a predictor of human- and lightning-caused fires, it indicates the relative ease of ignition and the flammability of fine fuel.
- The Duff Moisture Code (DMC) indicates the dryness of loosely compacted, upper organic layers of the forest floor. It is often used as a predictor of lightning-caused fires.
- The Drought Code (DC) is a numeric rating of the average moisture content of deep, compacted organic layers. It is a useful indicator of seasonal drought effects on forest fuels and the amount of smouldering in deep organic soil layers.
- The Initial Spread Index (ISI) is an indicator of rate of fire spread.

[hh] For the rationale and history of the Global Fire Early Warning System see http://gfmc.online/fwf/EWS.html

- The Build-up Index (BUI) indicates the dryness of medium and large dead fuels.
- The Fire Weather Index (FWI) combines the other components to give a general indicator of fire danger and fire intensity.

As part of the 1999-2004 Southeast Asia Fire Danger Rating System Project (Canadian International Development Agency), the FWI System was calibrated to regional fire weather conditions and the unique fire problems in this part of the world. This included adjusting the amount of daily fuel drying due to day length in the equatorial region, and calibrating specific codes and indices of the FWI System to regional fuel moisture and ignition patterns, smoke and haze production, and potential fire intensity in grassland fires. The FFMC was calibrated using historical active fire data in South-East Asia, and using laboratory fuel moisture and ignition studies conducted in Sumatra with local grass fuels (de Groot et al., 2005). As such, the FFMC serves as a regional ignition predictor and early warning indicator of new fire starts. The DC was calibrated to provide advanced warning of up to 30 days of potential haze disaster conditions from peatland fires by analysing historical DC and airport visibility data in the region (Field et al., 2004). The ISI was calibrated as an indicator of potential for fast-spreading, high intensity wildfire in grasslands, which represents the most serious fire control issue in this very common and open vegetation fuel type (de Groot et al., 2007).



The FWI System is used across the entire region, sometimes with varying local calibration (e.g. recent new calibration in Thailand) and variable forecast period of 0-3 days, depending on agency standard operating procedures.

Predictions of fire severity and of haze conditions can be provided by combining mid-range weather forecast with fire danger rating and assessment of ground conditions. The Global EWS provides 1-10 day forecasted FWI System data based on the Canadian Meteorological Center's Global Deterministic Forecast System. The severity of fires in South-East Asia (and particularly in the islands) is mainly related to drought conditions. Meanwhile precipitation in the region is predictable with good skill on sub-seasonal to seasonal timescales. This implies that fire severity should be predictable with reasonable accuracy in mid-to-long range timescales, beyond the existing 1-10 day forecast.

Nevertheless, establishing a reliable sub-seasonal to seasonal fire early warning system would require holistic assessment, which could be based on established methods (e.g. for the European region). Proof-of concept exists, but establishing such a system would require:

- Quantifying and verifying forecast skills at predicting drought level and peat conditions.
- Identifying a lead time with which forecasts reliably capture fire severity.
- Assessing atmospheric transport of pollutants, including for transboundary haze events.
- Facilitating communication between the regional center, land management and fire management.

Establishing standard operating procedures can take a long time, but ensuring a skilled mid-to long-range fire prediction system is critical to long-term management of fire and haze in the region.

ANNEX IV

GLOBAL INITIATIVES ON WILDFIRE MONITORING OF THE EUROPEAN COMMISSION AND THE GROUP ON EARTH OBSERVATION

The European Commission established the Earth Observation and Monitoring Programme, the so-called Copernicus Programme in 2014[ii], which includes the launching and operation of the Sentinel satellites and the establishment of Thematic Services. Several of these services contribute to the monitoring of wildfires in different ways.

The Copernicus services include two fire dedicated systems, the European Forest Fire Information System (EFFIS) and the Global Wildfire Information System (GWIS). These systems are supported in their operation and further development through the Copernicus Regulation 2014-2020 and will be further funded in the new Copernicus Regulation 2020-2028. They thus guarantee the support of the European Commission to the monitoring of wildfire effects in Europe and globally.

Both EFFIS and GWIS support the Emergency Response Coordinating Centre (ERCC) of the European Commission Humanitarian Office (ECHO), which provides humanitarian support worldwide in the case of natural and man-made disasters.

In addition to being a component of the Copernicus services, GWIS constitutes one of the Global Initiatives under the GEO Work Programme 2017-2019 (http://www.earthobservations.org/activity.php?id=126). The GWIS work programme is implemented in close cooperation with the Global Observation of Forest Cover (GOFC) Fire Implementation Team and its regional networks worldwide (http://gofc-fire.umd.edu/meeting/static/GOFC_Fire_IT_2016/index.php). As part of its operational activities, meetings of GWIS partners and networks take place annually.

[ii] Regulation (EU) No. 377/2014 of the European Parliament and the Council of 3 April 2014 establishing the Copernicus Programme.

ANNEX V

SUMMARY OF FURTHER EXPERT RECOMMENDATIONS FOR THE MISSION STATEMENTS AND GOALS OF A REGIONAL VEGETATION FIRE AND SMOKE POLLUTION WARNING AND ADVISORY CENTER

Mission 1 – To provide data and information that can be used to capacitate relevant actors regionally, nationally and locally to reach informed decisions as they work to prevent destructive fires.

Mission 2 – To provide data and information that is relevant and helpful for specific agencies in individual countries that are tasked with dealing with (emergencies) in the context of public health, fire management and law enforcement.

Mission 3 – To provide data and information that can be used by the Regional Fire Management Resource Centers in the effort to advise and capacitate relevant actors regionally, nationally and locally to develop fire management policies and implementation strategies and reach informed decisions in fire management.

Mission 4 – To facilitate the use of fire and smoke prediction at the regional level, to protect health, economic activities and the environment.

Mission 5 – To facilitate the use of fire and smoke observations by users regionally, nationally and locally.

Mission 6 – To provide centralized expertise to regional WMO Members, providing advises and training to support the establishment and improvement of fire and smoke observations and predictions.

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ANNEX VI

ASEAN SPECIALISED METEOROLOGICAL CENTRE (ASMC)

The ASMC was established in January 1993 as a regional collaboration among the National Meteorological Services (NMS) of ASEAN member countries. ASMC is one of twelve official centers/facilities under the ASEAN framework[jj], and is hosted in Singapore.

The main objective of ASMC is to enhance regional capacity and strengthen support in the provision of meteorological services. Under the ASEAN Regional Haze Action Plan[kk] endorsed by the ASEAN Ministers of the Environment and implemented in 1997, the ASMC was appointed to monitor and assess land and forest fires and the occurrence of transboundary smoke haze affecting the ASEAN region. The countries initially monitored covered Brunei Darussalam, Indonesia, Malaysia and Singapore, and were later extended in 2003 to cover the whole ASEAN region (Cambodia, Lao PDR, Myanmar, the Philippines, Thailand and Vietnam).

The main roles of ASMC are to:

- Detect, monitor and assess land and forest fires, as well as the occurrence of transboundary smoke haze for the ASEAN region.
- Provide alert level warnings to ASEAN member states for occurrence of transboundary smoke haze.

Complementarily, ASMC also:

- Conducts seasonal and climate predictions for the ASEAN region.
- Serves as a technical advisor and provides updates on the regional smoke haze situation to ASEAN ministerial/inter-agency committees.
- Provides technical training such as interpretation of satellite images to agencies in the region.

ASMC provides operational and regularly updated information and products on the weather and smoke haze situation in the ASEAN region at http://asmc.asean.org/home/. The website utilizes GIS technology for more efficient analysis of the geospatial data. Available information includes regional meteorological and air quality observations, satellite products from polar orbiting and geostationary satellites, active fire detections, seasonal forecasts and advisories for stakeholders in ASEAN. End users include the environment, forestry, meteorological and related agencies of ASEAN member states.

ASMC routinely runs a dispersion model to inform advisories and aid stakeholders to hone their risk assessment and response. ASMC's current dispersion modelling system was developed in collaboration with various regional and international centers, and draws inputs from the Global Fire Assimilation System (GFAS) of the Copernicus Atmospheric Monitoring Service (CAMS). Research and development into the system is an ongoing effort at ASMC with the aim to enhance predictions of transboundary smoke haze affecting the ASEAN region.

[jj] http://asean.org/asean/asean-centres-facilities/
[kk] https://cil.nus.edu.sg/wp-content/uploads/formidable/18/1997-Regional-Haze-Action-Plan.pdf

ANNEX VIIa

FORECASTING EMISSIONS FROM VEGETATION FIRES AND THEIR IMPACTS ON HUMAN HEALTH AND SECURITY IN SOUTH-EAST ASIA

Indonesian Agency for Meteorological, Climatology and Geophysics (BMKG)
(Jakarta, Indonesia, 29 August – 1 September 2016)

Workshop agenda

Monday, 29 August 2016: Day 1 – Advanced Seminar on Fire Management for Decision Makers

07.45-08.15 Registration of participants

08:20-09:45 Opening of the workshop
Announcer: Master of Ceremony

- Welcome remarks by the Director General of BMKG (Mr Andi Eka Sakya)
- Welcome remarks by WMO (Mr Alexander Baklanov)
- Opening speech and Inauguration of Indonesia GAW by Ministry of Environment and Forestry (Ms Siti Nurbaya Bakar)

10:00-11:15 Session I: Occurrence and impacts of vegetation fires in the region
Moderator: Ms Melita Keywood (C.S.I.R.O., Australia)

- State of wildfire and land-use fire application in the Maritime Continent (Mr Bambang Hero Saharjo, Bogor Agricultural University, Indonesia)
- Impact of vegetation fire emissions on human health (Mr M. Kamaruzzaman, Ministry of Health, Indonesia)
- Impact of vegetation fire emissions on human health and security: 20 years of observations in South-East Asia and neighbouring regions of Asia (Central, Northeast and Western Asia – Mongolia, Russia and Ukraine) and results of global modelling (Mr Johann G. Goldammer, GFMC)
- Impact of vegetation fire emissions on the regional and global atmosphere: Contribution to climate change (Mr Johannes Kaiser, MPICh)
- Impact of fire application and fire-induced ecosystem degradation and destruction on biodiversity and ecosystem services (Mr Budi S. Wardhana, BRG)

11:20-13:00 Session II: Fire management and environmental governance
Moderator: Mr Bambang Hero Saharjo, Bogor Agricultural University, Indonesia
- Reduction of unnecessary use of fire and prevention & control of wildfires: Lessons identified during the last 20 years and implications for the future of

- Integrated Fire Management (IFM) measures in Indonesia (Mr Georg Buchholz, GIZ)
- Environmental governance: Land-use and fire management policies, legislation and law enforcement in Indonesia (Mr Raffles B. Panjaitan, Ministry of Environment and Forestry, Indonesia)
- The ASEAN Agreement on Transboundary Haze Pollution: Review and prospects of implementation (Mr Saroj Srisai, ASEAN Secretariat, Jakarta)
- International concerted action: Considerations, initiatives and status of building an "International Fire Regime" (Mr Johann G. Goldammer, GFMC)

14:00-14:45 **Session III: State of the science and technologies in early warning, forecasting, monitoring and impact assessment**
Moderator: Mr Alexander Baklanov

- Utility and use of satellite sensors in depicting and quantifying vegetation fire occurrence, impacts on the ground and emissions (global to regional) (Mr Martin Wooster, King's College, London)
- Fire early warning: Status of development and use of Fire Danger Rating Systems (national, regional and global) (Mr Bill de Groot, Canadian Forest Service)
- The Indonesian Fire Information System (Mr Agus Haryanta, Ministry of Forestry, Indonesia)

14:50-16:00 **Session IV: Towards building regional vegetation fire smoke pollution forecast center – experiences and needs**
Moderator: Mr Johannes Kaiser, Max Planck Institute for Chemistry, Germany

- Regional Fire Management Resource Centers – Achievements and visions (Mr Johann G. Goldammer, GFMC)
- Possible role and functioning of regional vegetation fire smoke pollution warning centers (Mr Dodo Gunawan, BMKG Indonesia)
- ASEAN Specialised Meteorological Centre (Mr Christopher Gan, Singapore Meteorological Service)
- Relationships to and potential contributions of WMO programmes (GAW App SAG, WWRP S2S and HIW, Agriculture Meteorology, DPFS) (Mr Alexander Baklanov, WMO)

16:30-17:30 **Discussion**
Moderator: Moderator: Mr Johann G. Goldammer, Global Fire Monitoring Center (GFMC), Max Planck Institute for Chemistry, Germany

- General thematic recommendations: Initial thoughts for the final Workshop Day (Mr Johann G. Goldammer, GFMC)
- Presentation of a concept paper for a potential "Regional Vegetation Fire Smoke Warning Center" (Mr Alexander Baklanov and Mr Stéphane Mangeon WMO)
- Other
- Closing

Tuesday, 30 August 2016: Day 2 – Training Course (I): Observations
Training programme by Ms Melita Keywood (Australia), Ms Puji Lestari (Indonesia), Ms Fabienne Reisen (Australia) and Mr Iqbal Mead (UK)

09:00-09:30 **Opening**
- Opening speech by Deputy of Climatology
- Introduction (Ms Melita Keywood)

09:30-11:00 **GAW measurements and observations of fire**
Moderator: Ms Melita Keywood

- GAW stations in Indonesia (Mr Dodo Gunawan, BMKG Indonesia)
- The chemistry of smoke (Ms Fabienne Reisen)
- Peat fires: Field measurement and lab-scale observations (Ms Puji Lestari)
- Close-to-source fire emissions measurements in Indonesia (Mr Martin Wooster)

11:30-13:00 Case Study Investigation: 2015 Southeast Asian haze event
Moderator: Ms Puji Lestari

- Part 1 Background, tools, data required

14:00-15:30 Case Study Investigation: 2015 Southeast Asian haze event
Moderator: Ms Melita Keywood

- Part 2 QA/QC, analysing and presenting data

16:00-16:30 **Summing up and next steps**
Moderator: Ms Melita Keywood

Wednesday, 31 August 2016: Day 3 – Training Course (II): Modelling Fire Impacts on Air Quality and Health

09:00-09:15 **Opening**
- Introduction by the facilitator (Mr Johannes Kaiser)

09:15-10:15 **Presentations: Fire danger forecasts**
Moderator: Mr Dodo Gunawan

- Near term fire danger forecasting with Global Fire Early Warning System (Mr Bill de Groot)
- Medium-range fire danger forecasting at ECMWF (Mr Mark Parrington)
- Seasonal and historical fire danger (Mr Robert Field)

10:15-11:15 **Presentations: Fire observations & emissions**
Moderator: *Mr Christopher Gan*

- Satellite Fire Observations (Mr Martin Wooster)

- GFAS Emissions (Mr Mark Parrington/Mr Johannes Kaiser)
- IS4FIRES Emissions (Mr Mikhail Sofiev)

11:45-12:45 Presentations: Smoke forecasts
Moderator: Mr Martin Wooster

- Copernicus Atmosphere Monitoring System (Mr Mark Parrington)
- MASINGAR at MRI-JMA (Mr Taichu Tanaka)
- Regional Specialized Meteorological Center (RSMC) (Mr Anton Muscat)
- Mr Christopher Gan/Ms Felicia Shaw (ASEAN Specialised Meteorological Centre, Singapore Meteorological Service)

14:00-16:00 Practicals
Moderator: Mr Johannes Kaiser

- Participants use the introduced systems to copy plots from the web, download and plot data, or download and use data in their own applications (in groups of 2-3)
- Presenters of the morning are around to assist.

16:15-16:45 2-minute presentations by participants
Moderator: Mr Martin Wooster

Thursday, 1 September 2016: Day 4 – Training Course (III): Drafting Report/Recommendations

09:00-09:30 Introduction
Moderator: Mr Bill de Groot

- Topics to be addressed
- Formation of breakout groups

09:30-11:00 Breakout Group Sessions

- Breakout Group I: Fire danger and seasonal forecast
- Breakout Group II: Fire emissions and haze forecast
- Breakout Group III: Observations and data production
- Breakout Group IV: Fire information and management systems

11:30-12:30 Reporting back of Breakout Groups
Moderator: Ms Melita Keywood

12:30-13:30 Final discussion and workshop recommendations
Moderator: Mr Alexander Baklanov, WMO

13:30 Adjourn

ANNEX VIIb

FORECASTING EMISSIONS FROM VEGETATION FIRES AND THEIR IMPACTS ON HUMAN HEALTH AND SECURITY IN SOUTH-EAST ASIA

Indonesian Agency for Meteorological, Climatology and Geophysics (BMKG)
(Jakarta, Indonesia, 29 August – 1 September 2016)

List of workshop participants
This list includes main co-organizers, hosts and resource persons

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