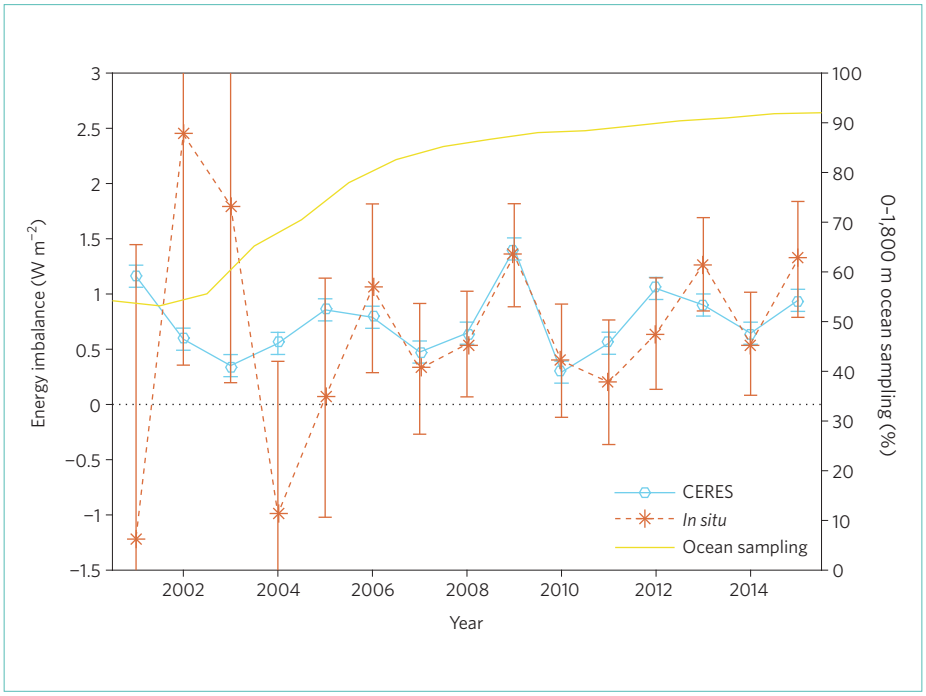

Figure 1 | Comparison of year-to-year net top-of-the-atmosphere annual energy flux from the CERES Energy Balanced and Filled (EBAF) Ed2.8 product with an *in situ* observational estimate of uptake of energy by Earth's climate system. The *in situ* estimate (orange asterisks joined by an orange dashed line) is composed of first differences of annual 0–1,800 m ocean heat content anomalies estimated from Argo float profiles and other sources[5], adding a constant heating rate of 0.1 m^{-2} based on the sum of the multi-decadal rates of deep (>2,000 m) ocean warming[4], as well as land warming, ice melt, and atmospheric warming and moisture uptake[1]. *In situ* uncertainties (orange error bars) are shown at one standard error of the mean[5]. CERES data (blue circles joined by solid blue line) are adjusted to agree with the 2005 through 2015 *in situ* heat uptake rate of 0.71 ± 0.10 W m^{-2} (5–95% confidence intervals). CERES annual random errors (blue error bars) are shown at one standard deviation (0.1 W m^{-2}). The percentage volume of the 0–1,800 m global ocean sampled for annual ocean heat uptake[5] (yellow line) shows substantial improvement over time with implementation of Argo.

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Acknowledgements

Argo data are collected and made freely available by the International Argo Programme and the national programs that contribute to it. We also thank the CERES science, algorithm and data management team. G.C.J. and J.M.L. are supported by the Climate Observation Division, Climate Program Office, National Oceanic and Atmospheric Administration (NOAA), US Department of Commerce and NOAA Research. N.G.L. is supported by the NASA Science Mission Directorate. PMEL Contribution 4461.

Author contributions

All authors contributed equally to the formulation and revisions of this study. G.C.J. created the figure and drafted the text. J.M.L. calculated the 0–1,800 m ocean heat content anomaly estimates. N.G.L. provided the CERES top-of-the-atmosphere energy flux estimates.

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COMMENTARY:

Preventing fires and haze in Southeast Asia

Luca Tacconi

Indonesian peatlands need to be protected and restored to prevent fires and the health, environmental and economic impact that they have on the wider region.

During September and October 2015, Southeast Asia was engulfed in a toxic haze emanating from forest and peatland fires in Indonesia. Every year fire is used for agricultural purposes, but droughts such as that of 2015 — associated with the El Niño–Southern Oscillation and Indian Ocean Dipole — create the conditions that allow extensive fires to burn in disturbed tropical forests and peatlands, which are normally highly resistant to fire in their undisturbed state[1–3]. The 2015 fires were the second worst of the past two decades (after the 1997–1998 event) in terms of greenhouse gas (GHG) emissions[4]. The Indonesian Government estimates that between June and October, fires affected about ~2.61 million hectares[5] (Table 1), of

which peatlands may have accounted for about 618,574 hectares[6]. Peatland fires are the primary source of the toxic haze and GHG emissions[3,7].

The rain that started falling at the end of October had dowsed most of the fires by early November and cleared the skies. But millions of people in Indonesia were exposed to haze (Table 2), which causes respiratory problems, mostly due to the inhalation of fine particulate matter ($PM_{2.5}$)[8]. Over half a million people in Indonesia suffered health effects (there were at least nineteen deaths) during the fire and haze event[9]. More deaths can be expected due to mortalities among the foetal, infant, child, and elderly population. There were 527 reported deaths from the 1997–1998 fire and haze event. However, total excess mortality was assessed for the whole population of Indonesia at 15,000 by applying the World Health Organization's formula for pollution to a sample of 539 individuals (whose health was assessed during the event)[8]. A more recent assessment of the health impacts of fires (with a health response equation developed exclusively for an adult population: >30 years), combines satellite-derived fire estimates and atmospheric modelling to quantify health effects from fire emissions for the population of countries within the Association of Southeast Asian Nations (ASEAN) from 1997 to 2006. It derives an average annual mortality of 14,900, but attributes 10,800 deaths to $PM_{2.5}$ and 4,100 to ozone[10]. That order of magnitude of excess mortality is comparable to the earlier study[8], given that: (1) Indonesia experiences the highest concentration of fire related pollution; (2) it accounts for about 40% of the ASEAN population; and (3) about half of the ASEAN population is below the age of 30 and it was not appropriately covered by the second study[10]. Another assessment based on 'missing children' in census data, estimates deaths in Indonesia from the 1997–1998 fire and haze event at around 15,600 (ref. 11). Despite the different methods used, the order of magnitude of excess mortality is comparable. However, the fire and haze's toll on children and young adults should be further assessed to ensure that whole-population studies[8,10] do not underestimate the number of mortalities.

The 2015 fires and haze affected the economy of Indonesia and the region. Oil production in Indonesia was negatively affected — although to an uncertain extent — as the haze caused oil facilities to reduce production (or close completely) for several days due to the ill health of workers[12]. Thousands of flights in the region were cancelled or delayed[13], disrupting business and tourism as far as Thailand[14]. Timber was lost to fire in natural forest and plantations. As haze reduces solar irradiance, which in turn reduces yields[15], agricultural crops may also have been affected. Although a full assessment has not yet been made, the fires are also expected to have affected biodiversity[16].

Greenhouse gases appear to have been emitted on an extraordinary scale. First estimates suggest[17] daily emissions of around 22 $MtCO_2e$ during September and October 2015, compared to the normal daily average of 2 $MtCO_2e$ in years without significant fires. At that level, Indonesia's emissions would have exceeded those of China for a total of about two weeks over the two months, as well as of the US's total over the same period[17]. The total emissions from the fires, which started in early July, have been in the order of 1.75 $GtCO_2e$, with significant uncertainty involved[4]. Those emissions are about 43% greater than the country's annual emissions from land use change and forestry (~1.22 $GtCO_2e$ in 2012) and just 13% less than its total annual emissions (~1.98 $GtCO_2e$ in 2012)[18].

The economic cost of the recent fire and haze event to Indonesia has been provisionally estimated at US$16.124 billion[5], or about 1.8% of Indonesia's GDP in 2014. However, the total economic cost of the fires is likely to be much higher. The provisional assessment estimates the cost of additional carbon emissions at US$3.966 billion. But it would amount to US$16.3 billion, if it were calculated using the November 2015 price of carbon on the European market of about US$9.35 per tonne. The economic costs to the other countries in the region further adds to the economic toll.

Table 1 | Area burnt by land use type during the 2015 fire event.

Land use	Area (hectares)	Percentage (%)
Total area burnt	2,611,000	
a. Food crops	346,039	13.25
b. Estate crops	72,763	2.79
c. Palm oil concessions	505,887	19.38
d. Forestry concessions	233,414	8.94
e. Swamp forest	176,179	6.75
f. Natural forest	259,376	9.93
g. Other	807,369	30.92
h. Mining	24,183	0.93
i. Total accounted	2,425,210	92.88
j. Unaccounted area	185,790	7.12
k. Fire affected area not allocated to specific stakeholders (e+f+g+j)	1,428,714	54.72

Ref. 5 reports total area burnt and allocation to land-use types a–h. i–k and percentage allocation calculated by the author.

Table 2 | Area burnt by fire in 2015 and total population in the fire affected provinces.

Island/province	Burnt area (×10^3 hectares)	Population
Sumatra, of which:	870	
South Sumatra	608	7,450,394
Riau	139	7,217,530
Jambi	123	3,092,265
Borneo, of which:	1,287	
Central Kalimantan	429	2,212,089
East Kalimantan	388	3,553,143
South Kalimantan	292	3,626,616
West Kalimantan	178	4,395,983
Papua	268	3,593,803
Other	186	
Total	2,611	27,119,224

Data sources: provincial burnt area from ref. 5; population from Indonesian Department of Statistics Census 2010.

Fire causes

Fires are caused by a range of activities[7,19], including: land clearing by companies

A canal on peatland. Canals such as this, located in the area of the former Mega Rice Project (Central Kalimantan province, Indonesia), were used to drain the peatlands. They will need to be dammed to re-flood the peat and rehabilitate it. © Luca Tacconi.

and individual small-scale farmers; other livelihood activities; and unintentional, escaped fires. Whether companies or smallholders cause the most fires is unlikely to be answered in the immediate future. This is illustrated by the fact that the land-use allocation to specific stakeholders (who may be responsible for fires) in the majority of areas burnt during the 2015 and 2006 fire events (the third worst of the past twenty years in terms of greenhouse gas emissions[4]) is unknown. In 2015, almost 55% of the burnt area was not allocated to defined stakeholders, or it was unaccounted for (Table 1); the holders of concessions for estate crops, palm oil and forestry account for only about one-third of the total burnt area. In 2006, companies' concessions for oil palm, timber plantations and logging accounted only for 20.8% of the area burnt (40.9% of fire emissions) in Sumatra island, and 49.2% of the area burnt (26.8% of fire emissions) in Kalimantan[20]. The total area affected by fire in drought years such as 2006 and 2015 is so vast that it would be extremely expensive to verify satellite imagery on the ground, to fully assess the causes of fires that occur outside concessions areas. Moreover, there is limited capacity across the country, at the local level to collect the data[21]. To address the problem, the Government of Indonesia therefore needs to influence the behaviour of all stakeholder categories, and to prioritize both relatively pristine and degraded peatlands.

Prevention of peatland fires

Peatlands need to be protected and restored to prevent the recurring fire and haze events[3,7,22]. Previous governments and parliaments of Indonesia have lacked political commitment to address the problem. Indonesia was the last country in the region to ratify the ASEAN Agreement on Transboundary Haze Pollution. However, the current Indonesian President, Joko Widodo, appears to be committed to action. Widodo cut short a trip to the US, and set up office for several days in South Sumatra, one of the most affected provinces, to oversee relief efforts. He is staking his presidency on a political programme that gives priority to improving livelihoods, including the allocation of 12.8 million hectares of forest land to communities (which should be carefully managed to avoid worsening the fire problem). And unlike during previous fire and haze events, the people made themselves heard: there were street protests calling on the government to address the fires[23].

State institutions must now deliver on the will of the President and people. Peatlands are moving centre stage: companies' licenses to operate in peat areas will be reviewed; no new licenses are supposed to be given to companies to operate on peat. But will good intentions, and possibly some new regulations to completely ban development of peatlands lead to effective action? Indonesia has many, sometimes contradictory, laws and regulations that all too often are not (fully) implemented. As a case in point, environmental regulation prohibited the development of peatlands deeper than three metres, yet many logging and plantations concessions overlapped with those areas. Former President, Susilo Bambang Yudhoyono, decreed the rehabilitation of the Mega Rice Project, the largest degraded area of peatland in Indonesia. But little has been done to implement that decree, apart from international donors' projects that have laid some of the foundations for rehabilitation work to commence. The Indonesian government needs to commit significant financial resources to protect and rehabilitate peatlands, and provide appropriate incentives to provincial governments[24].

Law enforcement should be ramped up to ensure company compliance. In October 2015, the Indonesian police reported that they were investigating more than 40 companies and about 80 individuals for fire-related offences[25]. The question is whether those investigations will be brought to a successful end, and whether the courts will bring the law to bear on those found to be guilty. There is considerable public distrust of the police and the courts due to widespread corruption[26]. These institutions therefore need to be more transparent in their processes, and to make information on the cases investigated fully available, to the maximum degree allowed by the law.

In relation to small-scale farmers, the government is considering the repeal of an article of the law that allows farmers to burn up to two hectares for agricultural purposes. Smallholders' fires do need to be addressed, but an outright ban is unlikely to be effective. Farmers are often poor, they cannot afford (or do not have access to) mechanical land clearing options. A more nuanced approach would allow farmers to burn during periods when fire risk is relatively low. Such a fire danger rating system has already been developed for Indonesia and Malaysia[27]. This nuanced approach, and firefighting preparedness, can also be supported by fire risk forecasting, which can alert people about severe fire and haze events months in advance[28]. When the fire risk is too high, the government would need to have in place a system that allows farmers to access mechanical land clearing[29]. This will not be easy or cheap, but it would contribute to reducing the extremely high costs resulting from fires and haze. Increased mechanization of smallholder agriculture would also contribute to efforts aimed at increasing the implementation

of sustainability certification among smallholders in specific sectors, such as the Indonesian Sustainable Palm Oil system (http://go.nature.com/TGw9go).

International support

Over the past decades, the Indonesian government has only sought to suppress fires. It has had limited success, at least when they burnt peatlands. Preventing peatland fires in Indonesia and the toxic haze that it produces contributes to improved regional health and economic outcomes. But it also reduces globally significant GHG emissions. Other countries, beyond the ASEAN region, should therefore contribute to the prevention effort. They should not follow the example of Australia. It closed down its Kalimantan Forest Carbon Project, which was about to block canals to demonstrate how to rehabilitate deep peat in order to minimize fire recurrence and peat oxidation that also results in significant emissions.

In its intended nationally determined contribution statement, submitted to the United Nations Framework Convention on Climate Change for the 2015 Conference of the Parties in Paris, Indonesia pledged an unconditional reduction in emissions of 29%, compared to a business as usual scenario of 2.881 GtCO2e in 2030. An additional 12% could be cut with international support. The 2015 fires have released the equivalent of about two years of unconditional reductions. Without making very significant progress on preventing fires, Indonesia is unlikely to deliver on its climate change pledge. The credibility of Indonesia's commitment to reduce emissions is certainly at stake, but so is that of its President and the whole government. Emissions from the Indonesian peatland fires are also a great risk to the global carbon budget. When they burn as they did in 2015, their emissions surpass those of Japan and more than double Germany's.

The credibility of the international community's commitment to implementing the Paris climate agreement is also at stake, as is support for Reducing Emissions from Deforestation and Forest Degradation (REDD+). As the climate changes, droughts are likely become more frequent[30] and the fire risk will become greater, particularly if the winds of political change do not bring about the implementation of strict and extensive fire prevention measures. ❐

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Acknowledgements

This research benefited from support from project ACIAR FST-2012-040.

COMMENTARY:

Soft but significant power in the Paris Agreement

Jennifer Jacquet and Dale Jamieson

The success of the Paris Agreement relies on a system of 'pledge and review', and the power of shaming laggards. This puts much of the burden for holding countries accountable on civil society.

The twenty-first Conference of the Parties (COP21) of the United Nations Framework Convention on Climate Change (UNFCCC) in Paris ended with an agreement that some call "the world's greatest diplomatic success", while others insist it is "too weak" and full of "false hope". The Paris meeting created a pathway for success, but the Agreement itself cannot ensure it. Here, we outline some of the challenges ahead.

Climate change is the world's most difficult and complex collective action problem[1]. The central challenge is to motivate actors to do more in response to climate change than they would under a 'business as usual' scenario. There are two broad approaches to this challenge. One is a 'top-down' approach that solves assurance problems through legally binding substantive obligations. This is, for