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COUPLED FIRE-ATMOSPHERE MODELLING

ANNUAL REPORT 2018-2019

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Cover: Waroona fire. Credit Neil Bennet, Bureau of Meteorology

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ACKNOWLEDGMENTS

We thank our colleagues at the Bureau and the UK Met Office for their advice on using ACCESS system. Many colleagues have helped us understand modelling developments, as well as encouraged us with the importance of our work. We also acknowledge the helpful feedback from our End Users on the practical implications of what we do, and for guidance on the direction of the project. We also thank the BNHCRC for the ongoing support of our work and appreciation for related outreach activities.

EXECUTIVE SUMMARY

The project goal is to improve understanding of fire and atmosphere interactions and feedback processes through running a coupled fire-atmosphere simulation model. Planned project outcomes include: preparation of meteorological and simulation case studies of significant fire events, installation and testing of the ACCESS-Fire coupled model on the National Computing Infrastructure (NCI) and preparation of training material to support operational implementation of research findings.

The project started in March 2016, and progress over the past three years has been on several fronts; 1) publication of a case study of the Waroona fire and related outreach activities 2) implementing, developing and testing the coupled fire-atmosphere model ACCESS-Fire 3) operational support during high-impact events and 4) draft of the paper ' Lessons learned from coupled fire-atmosphere research and implications for operational fire modelling'.

Progress with the coupled model ACCESS-Fire (ACCESS is the Australian Community Climate and Earth-System Simulator) has been slower than anticipated due to several unforeseen IT and model configuration challenges. In the past 12 months, significant testing and development has been required to adjust the settings in the meteorological boundary layer scheme to ensure model stability in response to the large fire-generated heat fluxes. The IT setbacks have been resolved and ACCESS-Fire high-resolution nested suites are now running on NCI. Importantly, the development effort means that the modelling framework can be easily re-configured to relocate and run for a 'new' event anywhere in Australia and brings the model closer to being available to other research groups.

Initial runs of two fire case studies have been completed and simulation results are very promising. We anticipate that further simulations and analysis of the two case studies in the coming year will produce high quality research findings and produce two valuable publications

The two case studies being run are the Waroona fire in Western Australia in January 2016 and the Sir Ivan fire in NSW in February 2017. Both were major fires that exhibited extreme fire behaviour and had significant impact on local communities. A detailed paper on the Waroona fire has been published in Journal of Southern Hemisphere Earth Systems and Science (JSHESS) and supporting engagement and training activities have been provided to a wide group of End Users in the Australian fire management community.

The manuscript 'Lessons learned from coupled fire-atmosphere research and implications for operational fire modelling' is well progressed and will be co-authored by Mika Peace, John Bally (AFAC, retired BoM) and Jay Charney (US Forest Service). We anticipate it will provide a valuable publication describing coupled-fire atmosphere modelling to benefit CRC stakeholders. It will also contribute towards discussion on the future directions of fire modelling in Australia.

Our project has continued to participate strongly in outreach activities, including media outreach through extended radio interviews and collaboration on print and online news articles. Panel participation has been invited on topics including fire science, STEM careers and Women in Leadership. Operational

support was provided on request during the 2018 Queensland fire campaign and that contribution was commended by the QFES Commissioner and Queensland Premier.

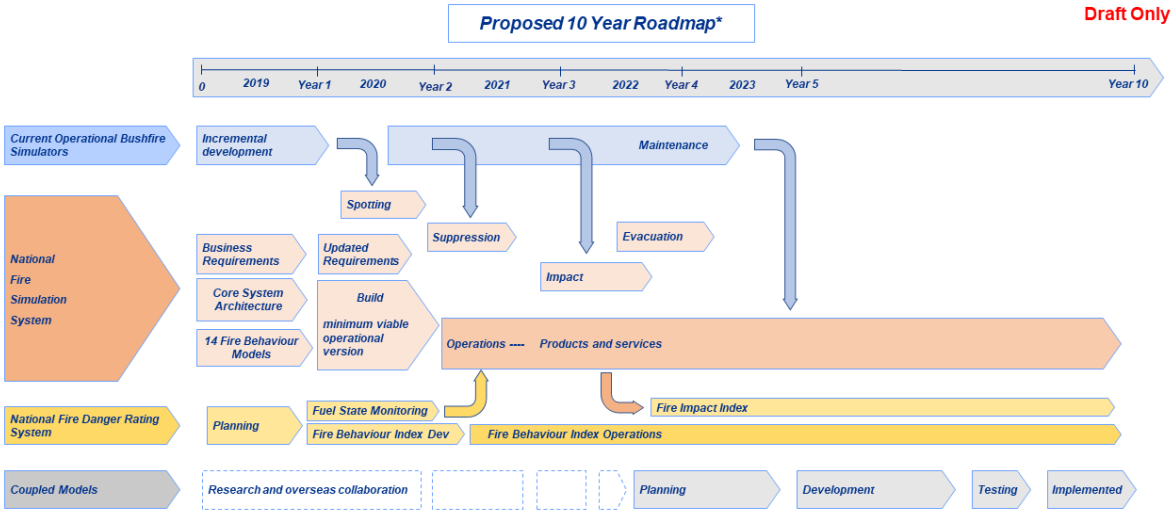
END-USER PROJECT IMPACT STATEMENT

John Bally, *Fire Prediction Services Ltd (AFAC)*

Bushfire simulation has become an important function in most fire agencies and contributes to many critical fire agency functions. It is a complex and rapidly evolving enterprise bringing together weather, fire behaviour, fuel and land surface models. Although simulation models have existed for several decades, model accuracy, IT system capacity and input data good enough to make models reliable in an operational context have only recently become available. Indeed, many industry experts do not yet consider current models sufficiently reliable for critical operations without thorough manual validation.

Bushfires are driven by weather but they also generate heat, moisture, smoke and air movement that can in turn change the weather that is driving them. Incorporating this two-way feedback between fires and weather is very complex, but is attempted by a number of "coupled" dynamical fire atmosphere models. Coupled models may be needed to predict the behaviour of very large fires that have a large impact on the weather around them, but with current technology are very slow and expensive to run.

For these practical reasons, apart from a single experimental trial in the US, all fire simulation models in operational use ignore the influence of bushfires on the atmosphere.



A draft (not endorsed) roadmap for bushfire simulation currently being discussed by the industry predictive services community clearly flags the vision for incorporating coupled fire-atmosphere models in the operational suite in less than 10 years. This research project supports that industry lead vision by developing an understanding of the fire conditions that are best understood and predicted by coupled modelling systems. To that end, it is great to see the ACCESS-fire system running, after many difficult IT hurdles have been overcome.

Coupled fire modelling is a technically complex field, and there are many dependencies on other large software systems and infrastructure that are well

outside the ability of any small research team to control. Mika's and the team's persistence in overcoming these significant hurdles should be recognised.
This project has already developed good insights into the role played by smaller scale atmospheric effects on fire behaviour, using fire observations and very high-resolution weather modelling. Now that the coupled model is running, we look forward to new insights from fire-atmosphere feedbacks in the two case studies being run.
This is primarily a research project. Given the likely future strategic importance of coupled models for operations, it would be beneficial to see opportunities taken where possible to make the first steps towards routine running of the system. These steps could include:

- Using operational fuel and other input datasets where permitted;
- Measuring model execution speed and reporting on the gap between current model cost and performance and what would be required for operational use
- Developing output products and displays that may be useful to a wider operational audience, in addition to outputs needed to support research
- Applying the methods used to archive and verify weather models to coupled fire models to support the methods of continuous improvement that has been so successfully applied to weather prediction.

I understand that there may be limited opportunity in the current project, even with time extensions, to make much progress on these ambitious goals. They could, however, be used to frame a successor project, which in my view would have strong industry support.
I note the strong statements from Andrew Sturgess (QFES) in appreciation of Mika's help during the recent Qld fire emergency. This is a great example of the application of knowledge gained in research to real world needs, and illustrates a great benefit from research and operational communities working closely together, resisting the natural temptation to each stay in their own silos.

PRODUCT USER TESTIMONIALS

Andrew Sturgess, *Queensland Fire and Emergency Services*

Southern Australia is recognised as one of the most fire prone parts of the planet and events like 1983 Ash Wednesday fires in Victoria and SA, and the 2003 Canberra fires are etched in the memories of fire agencies. Bushfires have always been part of the natural Queensland environment but they have traditionally been of a lower priority compared to the impacts of Tropical Cyclones. This was turned on its head in 2018 when Queensland saw extreme fire conditions that were unprecedented and more akin to what our southern counterparts experience. Emergency managers aim to make evidence based decisions and in our Predictive Services Unit we are committed to bringing science to operations. When the long term climate drivers brought hot dry conditions, that aligned with a series of low pressure systems in late November 2018, it became clear that we were facing extraordinary bushfire potential and it was imperative that we delivered on this commitment. With this in mind I reached out to Dr Mika Peace and the BoM/BNHCRC for assistance. Mika provided expert advice and direct input to our operational Fire Behaviour Analysts as they built their predictions that gave increased confidence exactly when the consequences of the decisions required it. This was what I imagined the support would look like but as it turned out the input extended to providing advice directly to the Queensland Premier and the State Disaster Managers.

No lives were lost and property damage, given the conditions, were relatively low. The value of having an operational/researcher directly involved in operational decision making exceeded expectations and likely set a standard for future events.

INTRODUCTION

Large bushfires release substantial amounts of energy into the surrounding atmosphere. This energy release modifies the structure of the surrounding wind, temperature and moisture profiles in space and time. The changes driven by the fire can manifest as winds that are similar in speed but opposite in direction to the prevailing winds, pyrocumulus clouds and, in extreme cases, pyro-cumulonimbus clouds. The dynamic feedback loops produced by the fire-atmosphere coupling process can have a dramatic influence on how a fire evolves. Fire-atmosphere feedbacks can also be enhanced by local topographic influences.

In current operational fire simulation models, simple meteorological values are provided as inputs to an algorithm for fire spread used to predict how a fire perimeter will evolve across a two-dimensional landscape. This approach does not incorporate any three-dimensional interactions between the fire and atmosphere and, in many cases, will provide a limited depiction of how a fire may evolve, particularly in a dynamic environment in high terrain. This project explores the ability to examine fire-atmosphere interactions through use of a coupled model.

The project uses the premier operational Australian high-resolution weather prediction model ACCESS, coupled to a fire-spread model. The ACCESS model (uncoupled) has been used to examine several high impact fire events and has provided detailed insights into the meteorological processes impacting a fire environment. Coupling ACCESS to a fire model builds on previous expertise in the BoM research team and provides opportunity for future development of a coupled modelling capability in Australia.

The coupled fire-atmosphere model ACCESS-Fire has been installed and tested on Australian National Computing Infrastructure (NCI) for research application, with future potential for operational use. The model is being used to run a set of case studies. Detailed examination of high impact events and verification against available meteorological and fire behaviour data will highlight the importance of assessing and predicting the likelihood of fire-atmosphere interactions in anticipating fire evolution. The close links of the project team with operational and training groups in meteorology, fire behaviour and fire management provide a clear pathway for implementing research findings.

The Waroona fire in southwest WA in January 2016 is the first case study. Over a two-day period, there were four periods of extreme fire behaviour; two separate pyro-convective thunderstorm events and two evening ember storms.

The Sir Ivan fire in NSW is the second case study. The fire occurred on a day of 'catastrophic' fire danger and produced a pyrocumulonimbus, when the environmental wind direction changed from northwest to southerly. An unprecedented set of observations were collected during the event by NSW RFS and these will be a valuable component in the analysis.

BACKGROUND

The project examines case studies and uses high resolution coupled modelling to better understand and predict fire-atmosphere feedback processes. Fire-atmosphere feedback is important because it often reflects a transition from steady-state fire spread to rapidly fluctuating, dynamic and more intense fire activity, which is inherently more difficult to predict. Blow-up fires, extreme fire behaviour and dynamic fire behaviour are all terms that may be used to describe fire activity that is erratic and potentially dangerous to fire fighters and destructive to communities. Coupled modelling will assist in identifying and understanding the triggers and ingredients that lead to non-linear fire activity. This knowledge will enable risk mitigation activities to be undertaken; both at bushfires and fuel reduction burns.

Coupled models (e.g. WRF-Fire) have previously been used in Australia by several researchers, and extensively overseas to examine fire-atmosphere coupling processes. This project uses the ACCESS-Fire model, which links directly to high-level operational and research Australian meteorological computing capability. ACCESS-Fire represents an important opportunity for future development, as well as potential to provide a fire prediction tool to international partners through the overarching UK Met Office Unified Model framework.

Coupled fire-atmosphere models are being used increasingly internationally in both research and operational spheres. The most progressive operational implementation is in the USA state of Colorado, where the WRF-Fire model is a component of a new capability for fire prediction in the state. Other USA work includes using the WRF-Fire model for predicting particulate trajectories in fire plumes. A coupled fire-atmosphere model has also been used to analyse fire behaviour in Mediterranean fires. As Australia has one of the most fire-prone landscapes in the world, our requirement for developing capability in this space is unparalleled.

The strong links between the project team and training and operational activities present a clear pathway to implement research findings and produce training materials from this and related projects. The project focusses on case studies of real events, from which learnings can translate directly into operational practice.

RESEARCH APPROACH

CASE STUDIES

In both meteorology and bushfire management, it is well established that examining events in detail retrospectively following a case study approach provides insights that were not available in real time, and these insights can translate into lessons learned which may be applied during future events. Therefore, our research approach is to make a detailed analysis of past, high-impact events. We do this through examination of data that was available in real time, as well as running ACCCESS-Fire and examining the output with the objective of understanding how the energy released by the fire modified the surrounding atmosphere and infer how this process subsequently affected the fire behaviour. The two case studies in preparation are the Waroona and Sir Ivan fires.

Waroona

The Waroona event was suggested as a case study by End Users Lachie McCaw and Neil Burrows, who were co-authors on the publication (Peace et. al. 2017). The Waroona event was selected because during the first two days of the fire there were four episodes of extreme fire behaviour: two pyrocumulonimbus events and two evening ember storms. The drivers for the extreme fire behaviour were not fully understood at the time, particularly because the extreme fire behaviour did not coincide with the diurnal maximum in fire danger calculated by traditional measures of fire risk.

Sir Ivan

The Sir Ivan fire burnt on a day of 'catastrophic' fire risk in NSW at the end of a heatwave and during extended drought. Fire risk was enhanced by an unstable atmosphere and a northwest to southerly wind change during the afternoon. Pyrocumulonimbus developed coincident with the passage of the wind change. RFS NSW collected an unprecedented set of observational data during the event, which presents an opportunity for detailed verification against simulation results.

ACCESS-FIRE DEVELOPMENT

Coupling a fire model to the ACCESS model was a project originally conceived in a collaboration between Melbourne and Monash universities with the objective of simulating the Black Saturday fires. The fire code that was written during the Monash project was provided to BoM and has been installed on our NCI project space. The original code was configured for a single event and implemented in the now-retired UMUI ACCESS model interface. Significant effort has been invested in modifying the code to run on multiple events and in transitioning to the new Rose-Cylc model user interface. Ongoing development work will continue to develop the model's functionality, capability and predictive skill. In its current form ACCESS-Fire can be run to produce valuable simulation output for past events. Jeff and Mika have both visited the UK Met Office to hold

discussions with UK developers of the overarching UM (Unified Model). International interest in the project activities is high and offers of assistance in reviewing aspects of the model configuration and coding have been made by UK developers.

ACCESS-FIRE SIMULATIONS

Simulations are in progress for the Waroona and Sir Ivan fires. The current model configuration has a series of nested domains at 4 km, 1.2 km and 300m. Tests have been run that include another nest to 100 m and a combination of the 300m and 100m configurations will be used.

Simulations to date have used constant fuel grids across the domain, however the options for including variable fuel grids are being assessed.

Current runs implement the fire grid at 1:1 on the inner atmospheric nest, and a zoom function has been developed allowing the fire grid to be run at variable resolution (ie 1:2, 1:10) within the inner atmospheric mesh.

Initial results show the model is producing features such as fire-modified winds and some plume dynamics as well as resolving interesting dynamical processes in the wind regime adjacent to downslope topographic features.

KEY MILESTONES

Key milestones in the original project plan were unavoidably delayed due to IT delays with the changes to the ACCESS model framework and required developments to the fire code. These delays have been discussed with End Users and the BNHCRC and the original project plan has been revised to meet a new timeline. No deliverables have been removed, only the timing has been changed. The Waroona case study has been included in the updated project plan, which represents a major additional deliverable that was not in the original project. Engagement and implementation activities stemming from the Waroona case study have also been included.

WAROONA CASE STUDY

The Waroona case study has been published in JSHESS:

Meteorological drivers of extreme fire behaviour during the Waroona bushfire, Western Australia, January 2016 Peace, M., McCaw, L., Santos, B., Kepert, J., Burrows, N. and Fawcett, R.

http://www.bom.gov.au/jshess/papers.php?year=2017

SIR IVAN CASE STUDY

The Sir Ivan fire has been selected as the second case study and initial simulations have been made. The case study will proceed in collaboration with End Users at NSW RFS and BoM NSW, with a focus on comparison of the simulations and observations, particularly the linescan images and fire heat flux output.

ACCESS-FIRE DEVELOPMENT

Considerable progress has been made by Harvey in developing components of the ACCESS-Fire framework, making refinements to the fire code and adjusting the meteorological boundary layer settings to accommodate the heat fluxes released by the simulated fire.

Nesting suite: Runs at 300 m are producing valuable results and experiments at 100 m have required additional computational resources and the benefit realized by the additional computational expense will be subjectively assessed.

Fuel settings: No variable fuel maps have been implemented as yet; settings for Waroona will remain as constant and variable fuel maps will be investigated for Sir Ivan. The project team have held discussions with the National Fire Danger Ratings System (NFDRS) team regarding implementing the National Fuel Grids (as developed by the NFDRS project) in ACCESS-Fire.

ACCESS-FIRE SIMULATIONS

Sir Ivan:

Initial simulations have been run over the Sir Ivan domain with constant fuel with a "false" ignition time. In our next runs, the inner domain will be expanded, fire

ignition described as a polygon prior to the fire 'escape' and variable fuel included if appropriate. The Sir Ivan case study will progress in collaboration with NSW partners in BoM Severe Weather and RFS, with an emphasis on verification and comparison between the simulations and available observations.

Waroona:

Simulations of the Waroona fire with the CSIRO forest (Vesta) fire behaviour model are comparing favourably to reconstructions of the fire's perimeter. Refinements to the fire model interaction with the atmospheric component are expected to produce further improvements. The focus of the analysis will be on the interaction between the fire plume and the hydraulic jump and downslope winds in order to thoroughly test the hypotheses surrounding this aspect of the event. This will provide scientific evidence towards the broader questions of prediction and understanding of fire behaviour in downslope wind regimes around Australia and internationally.

COUPLED FIRE-ATMOSPHERE MODELLING DISCUSSION PAPER

A manuscript has been drafted on 'Lessons learned from coupled fire-atmosphere research and implications for operational fire modelling'. The manuscript is well progressed and will be co-authored by Mika Peace, John Bally (AFAC, retired BoM) and in international collaboration with Jay Charney (US Forest Service).

Initial feedback on the breadth and depth of the drat has been favourable and we anticipate it will provide a valuable publication documenting and providing context for the contribution of coupled-fire atmosphere modelling to fire research. It will also contribute towards discussions on the future directions of fire modelling in Australia in coming decades.

UTILISATION AND IMPACT

SUMMARY

The project has been widely recognized for our outreach activities through engaging and communicating research findings with End Users, internal and external stakeholders, local and national media and the broader community.

QFES REQUEST FOR SUPPORT

In November and December 2018, the state of Queensland responded to an unprecedented fire campaign, with hundreds of fires burning across the state and the first occurrence of 'Catastrophic' fire conditions in the state. QFES Fire behaviour analyst Andrew Sturgess requested support from the project team in the Queensland Disaster Management Centre, which was filled by a three-day deployment (Mika) to provide science and meteorological interpretation support to the Queensland FBANs. Recognition of the contribution was through: an invited presentation to AFAC 2019 with Andrew Sturgess; a letter of appreciation from QFES Commissioner; invitation to the Premier's Christmas function and publication of an article in Fire Australia (authored by Gabriele Colgan-Zito).

HAZARD NOTE

Following publication of the Waroona case study, a Hazard Note was requested by the BNHCRC and NSW RFS. The Hazard Note was prepared in collaboration with Nathan Maddock and Kay Ansell and published in June 2018.

OUTREACH AND ENGAGEMENT

The project team have responded to numerous invitations to present at a range of external forums to both specialist and non-specialist audiences.

Distribution of presentation and other research material and science support to Embedded Mets, EWD, BMTC and other internal fire interests.

Extended radio interviews.

CSIRO program "STEM Professionals in Schools". See "Conferences and Engagement Activities" above.

INTERNAL COLLABORATIONS

- Fire Weather Working Group
- Embedded Met Working Group
- Input to the National Fire Danger Rating System trial
- Input to internal fire meteorology training material

CONFERENCES AND ENGAGEMENT ACTIVITES

Australian Conferences

AFAC 2018. Waroona ACCESS Simulations, Sir Ivan poster and panel session.

Fire Behaviour and Fuels Conference 2019. Oral presentation (Waroona simulations), Panel Session (Women in Fire) and poster (Coupled modelling)

BNHCRC Events.

Mount Macedon International Study tour presentation (August 2018)

End User Events

FBAN training NSW RFS August 2018 (include email excerpt).

Talk at BoM WA (pre-AFAC) August 2018.

Extended Radio Interviews

ABC WA from AFAC (August 2018).

ABC 891, Adelaide. Interview on Fire Tornadoes. (Sept 2018)

ABC National program BoM – fire expert (August 2018)

Print and online media articles

Advertiser story 'Feel the Heat'. (Dec 2019)

Advertiser article ' Fire Fury' double page spread with Clare Peddie (Feb 2019)

Online ABC NEWS story (Kate Doyle) on Fire Weather conditions in Australia and what makes a bad day (Jan 2019)

Workshops

Fire Weather Workshop: Downslope Winds section host, with follow-up implementation project to CRC in collaboration with Jason Sharples (May 2019)

NFDRS project workshop (August 2018)

AMOS 10 years since Black Saturday, organizing committee, session chair and panel member/speaker at evening public session. (Feb 2019)

Fire prediction workshop (invited by John Bally/AFAC) (March 2019)

BARRA workshop, organizer and facilitator, Adelaide (April 2019)

Climate Change Workshop: Informing Climate Change response in SA. Adelaide (DEW) (March 2019)

Other Activities

STEM Professionals in Schools CSIRO program at Mitcham Primary School, South Australia (ongoing)

Science in the Pub – Fire (August 2018)

Invitation to ' Early Career Research' panel at Adelaide University 'Women in Mathematics' day and poster promoting 'Women in Mathematics'.

Mika: ~2-month a/Supervising Meteorologist SA Forecasting Centre.

'Science Conversations', Bureau of Meteorology internal talk (July 2018)

NEXT STEPS

The project is currently pending formal approval for extension to June 2020.

ACCESS-Fire is now running successfully, therefore efforts over the coming 12 months will focus on the Waroona and Sir Ivan simulations, analysis and write-up. Recruiting an intern will accelerate the analysis phase of the two case studies and contribute towards producing valuable visualisations of the simulation output. The case studies will be the primary activity for the project in the next 12 months.

The manuscript 'Lessons learned from coupled fire-atmosphere modelling and implications for operational fire modelling' is well advanced and feedback from co-authors has (mostly) been included. The paper will be moved through review and into publication as soon as practicable.

Two oral presentations have been accepted for AFAC 2019; one on our simulations with ACCESS-Fire and the second (invited) on the response to the Queensland fires (co-presented with Andrew Sturgess).

An internal BoM seminar has been requested on our simulations with ACCESS-Fire, this will occur late 2019, with invitation extended to our external stakeholders in Victoria.

The project team will attend the Fire and Forest Meteorology Symposium May 2020 in USA and UM workshop (UK) (pending international travel approval).

PUBLICATIONS LIST

1 Meteorological drivers of extreme fire behaviour during the Waroona bushfire, Western Australia, January 2016 Peace, M., McCaw, L., Santos, B., Kepert, J., Burrows, N. and Fawcett, R. Journal of Southern Hemisphere Earth Systems Science, 2017.

http://www.bom.gov.au/jshess/papers.php?year=2017

2 Extreme Fire Behaviour: Reconstructing the Waroona Fire Pyrocumulonimbus and Ember Storms., Peace, M., Kepert, J., BNHCRC Hazard Note, June 2018.

TEAM MEMBERS

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