DYNAMIC MODELLING OF FIRE COALESCENCE

Spot Fire Project

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Department of Industry and Science
Business Cooperative Research Centres Programme

SPOT FIRES AND FIRE COALESCENCE

- Fire behaviour in Australian vegetation is often characterised by the occurrence of spot fires.

- Spotting can be the dominant process under extreme fire conditions, and adds a considerable dynamic element to the overall propagation of fires – the resulting spread should not be considered as quasi-steady!

- Multiple individual fires grow and merge into larger ones – this can result in increases in fire intensity and spread!

- Such effects are currently not accounted for in operational models.....!!!

- Implications for fire power and pyro-convective budget.

SPOT FIRE PROJECT - AIMS

- Investigate the potential of simple geometric methods to model the complicated processes involved in fire coalescence

- Develop computationally efficient models for spot fire coalescence – effectively 2D models of 3D processes

- Examine the effects of dynamic enhancement of fire spread on the pyroconvective budget of mass spotting events

SPOT FIRE PROJECT - METHODS

- Mathematical modelling of fire perimeter evolution
  - Level set methods
  - Fire line curvature

- Experimentation: laboratory (Pyrotron) and field cases

- Coupled fire-atmosphere modelling
  - Understanding the role of pyroconvective coupling in fire-fire interactions
  - Models of ember fall distribution (incorporating evolving fire source)

- Simulation models of fire coalescence
  - Fire spread simulator incorporating dynamic fire spread and spotting (able to run in operational time frames)
  - Simulation of notable fire events and plume development

MATHEMATICAL MODELLING – TRADITIONAL APPROACH

Huygen's principle

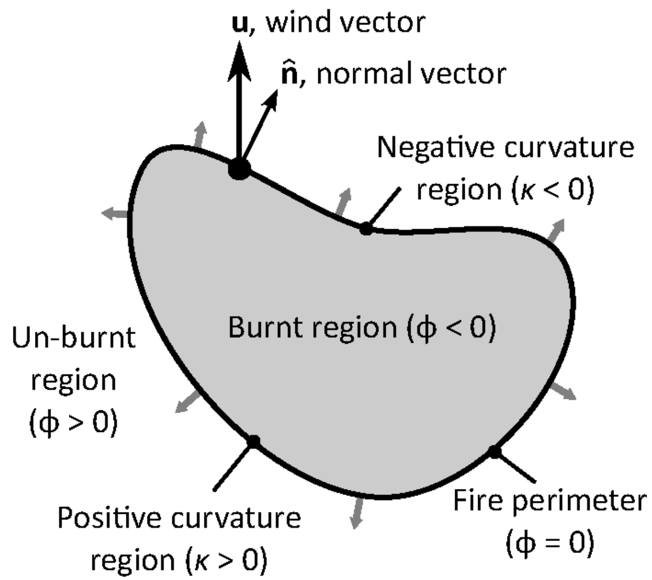
- based on quasi-steady rate of spread model; e.g.

$$R_0 = 0.024\exp(-0.45 + 0.987\ln D + 0.0338T - 0.0345H)$$

MATHEMATICAL MODELLING – OUR APPROACH

Level set method

- based on normal flow
- no predefined template
- PDE foundation
- permits incorporation of intrinsic effects



$$\frac{\partial \phi}{\partial t} + s|\nabla \phi| + \mathbf{u} \cdot \nabla \phi = 0$$

$$\hat{\mathbf{n}} = \frac{\nabla \phi}{|\nabla \phi|}$$

$$\frac{\partial \phi}{\partial t} + (\alpha\kappa + \beta)|\nabla \phi| + \mathbf{u} \cdot \nabla \phi = 0$$

$$\kappa = -\nabla \cdot \frac{\nabla \phi}{|\nabla \phi|}$$

MATHEMATICAL MODELLING – OUR APPROACH

Level set method

- The equation that is solved is two-dimensional (in space)

$$\frac{\partial \phi}{\partial t} - \alpha \nabla^2 \phi + N(\phi) = 0$$

$$N(\phi) = \alpha \frac{\nabla \phi}{|\nabla \phi|} \cdot \nabla(|\nabla \phi|) + \beta |\nabla \phi| + \mathbf{u} \cdot \nabla \phi$$

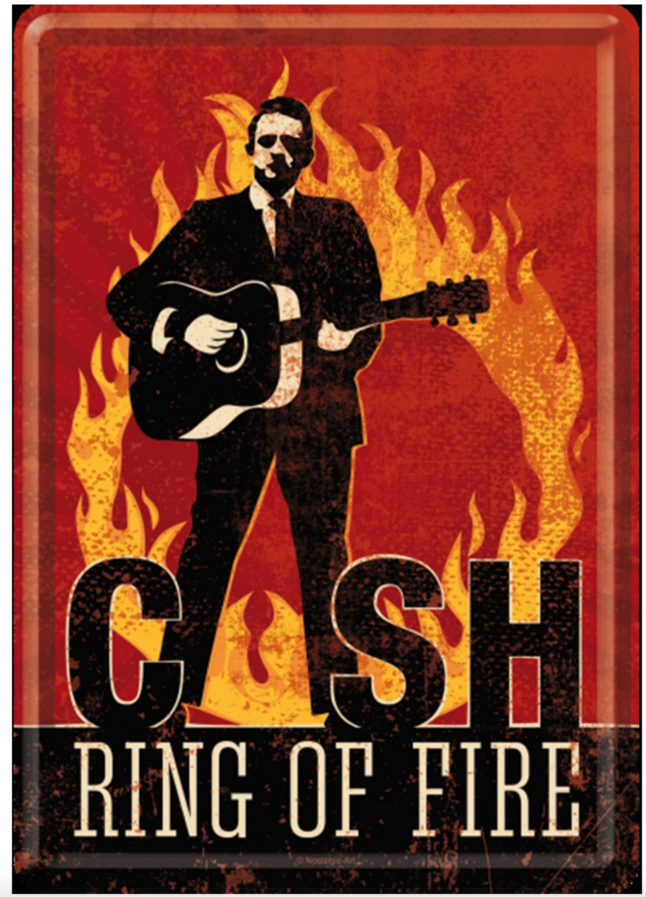
$$\mathbf{u} = \begin{cases} \gamma(\hat{\mathbf{w}} \cdot \hat{\mathbf{n}})\hat{\mathbf{w}} & \hat{\mathbf{w}} \cdot \hat{\mathbf{n}} > 0 \\ 0 & \hat{\mathbf{w}} \cdot \hat{\mathbf{n}} \leq 0 \end{cases}$$

There are a number of technical issues that have to be overcome to implement computationally efficient numerical solution of this equation!

MATHEMATICAL MODELLING – OUR APPROACH

Level set methods with and without curvature dependence

- “Ring of fire” tests



MATHEMATICAL MODELLING – OUR APPROACH

Level set methods with and without curvature dependence

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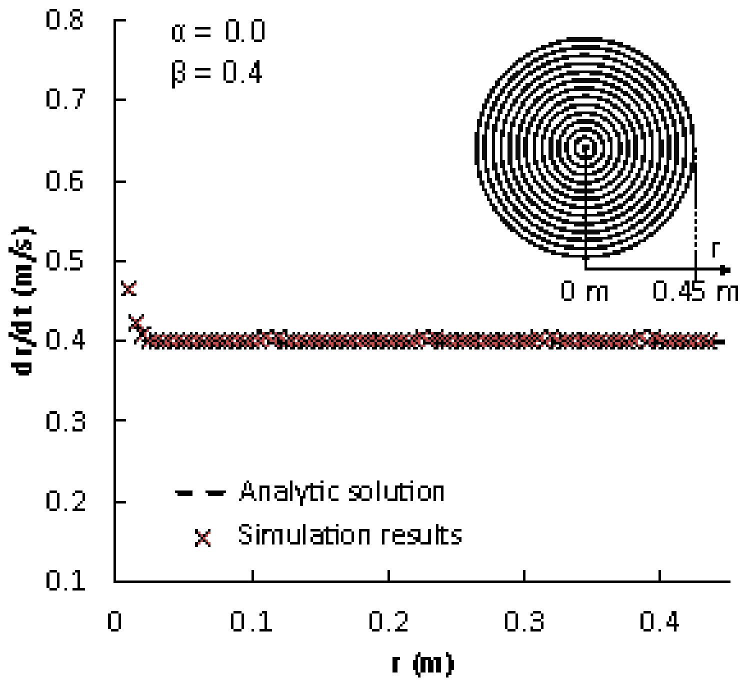
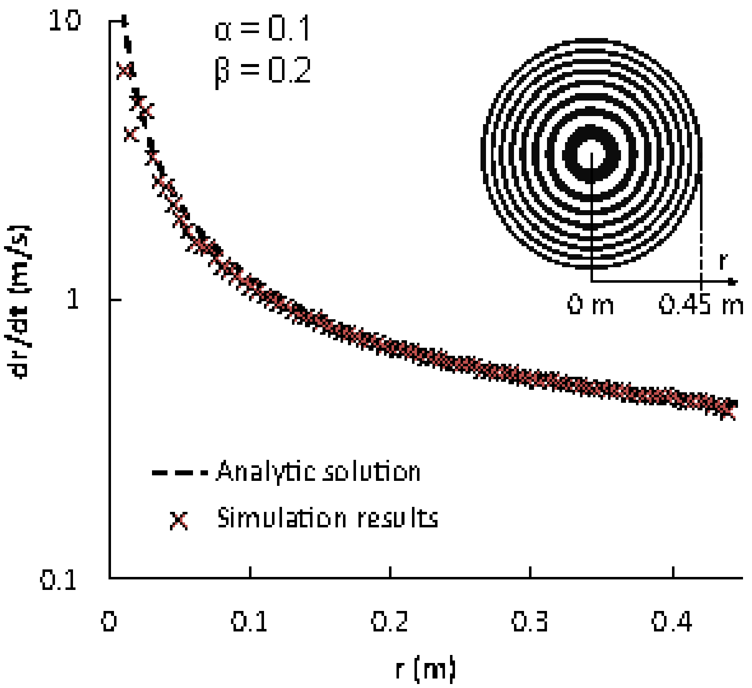


No curvature dependence

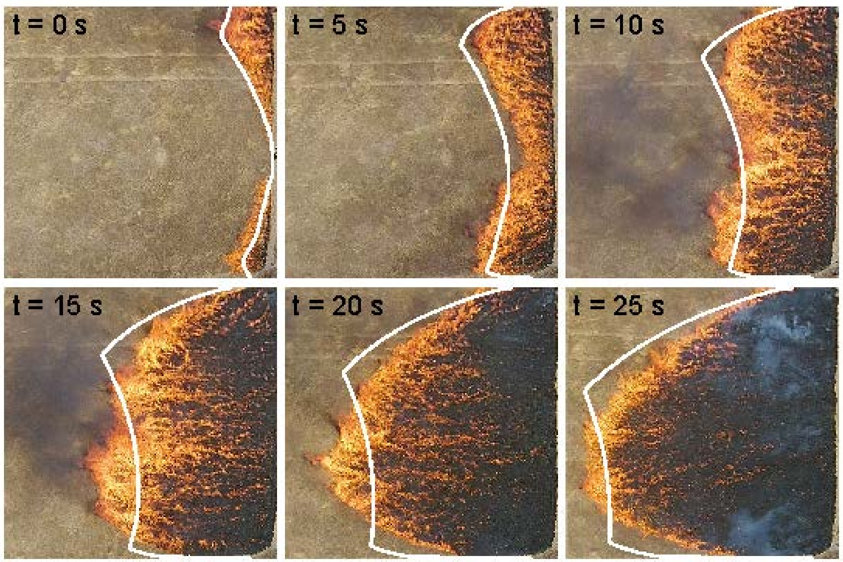


Curvature dependence

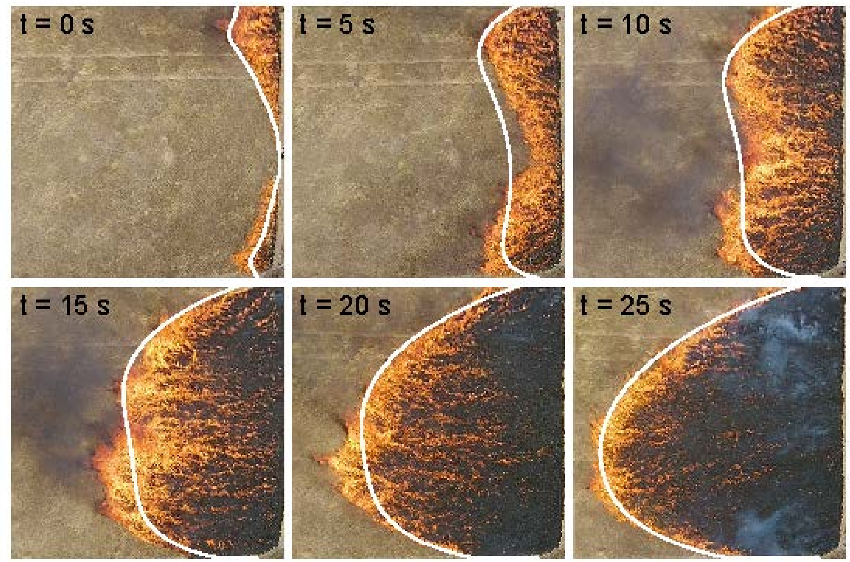
MATHEMATICAL MODELLING – OUR APPROACH

Level set methods with and without curvature dependence

- Wind driven fires (CSIRO/CFA grassfire experiments)



No curvature dependence



Curvature dependence

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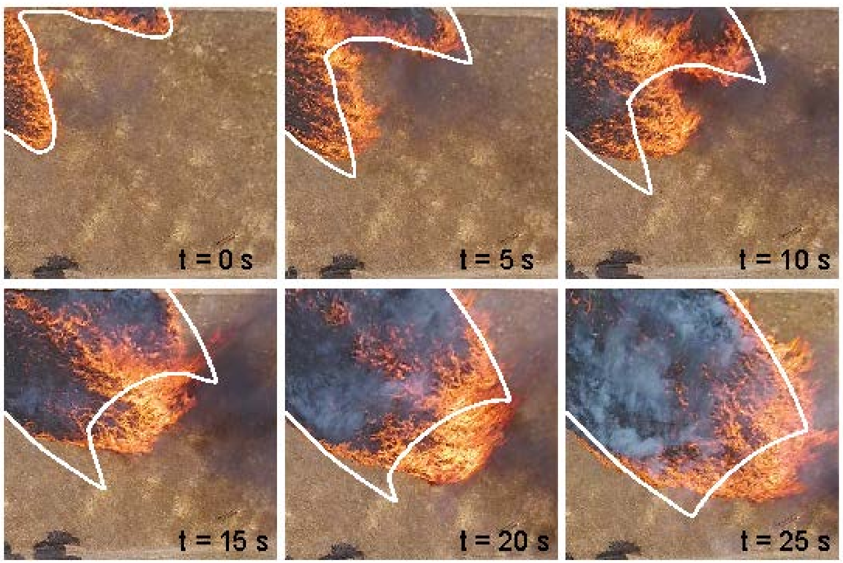

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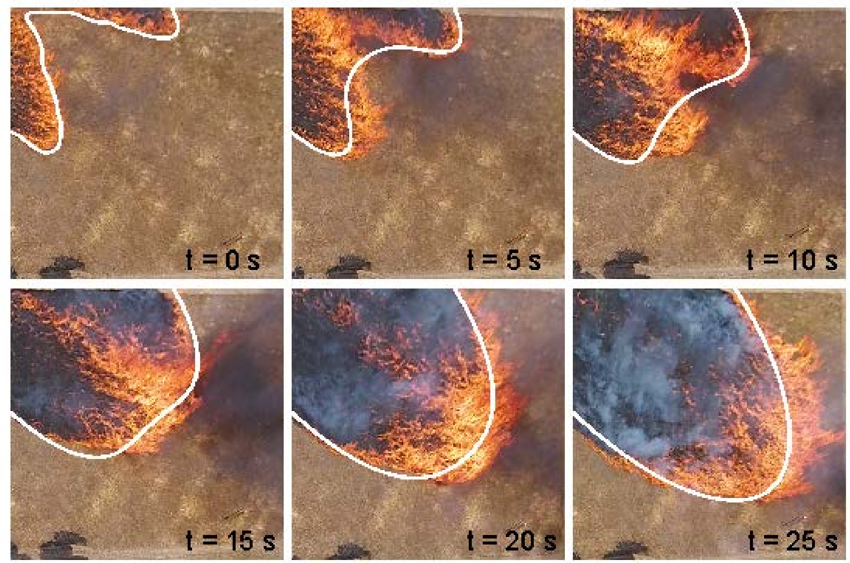
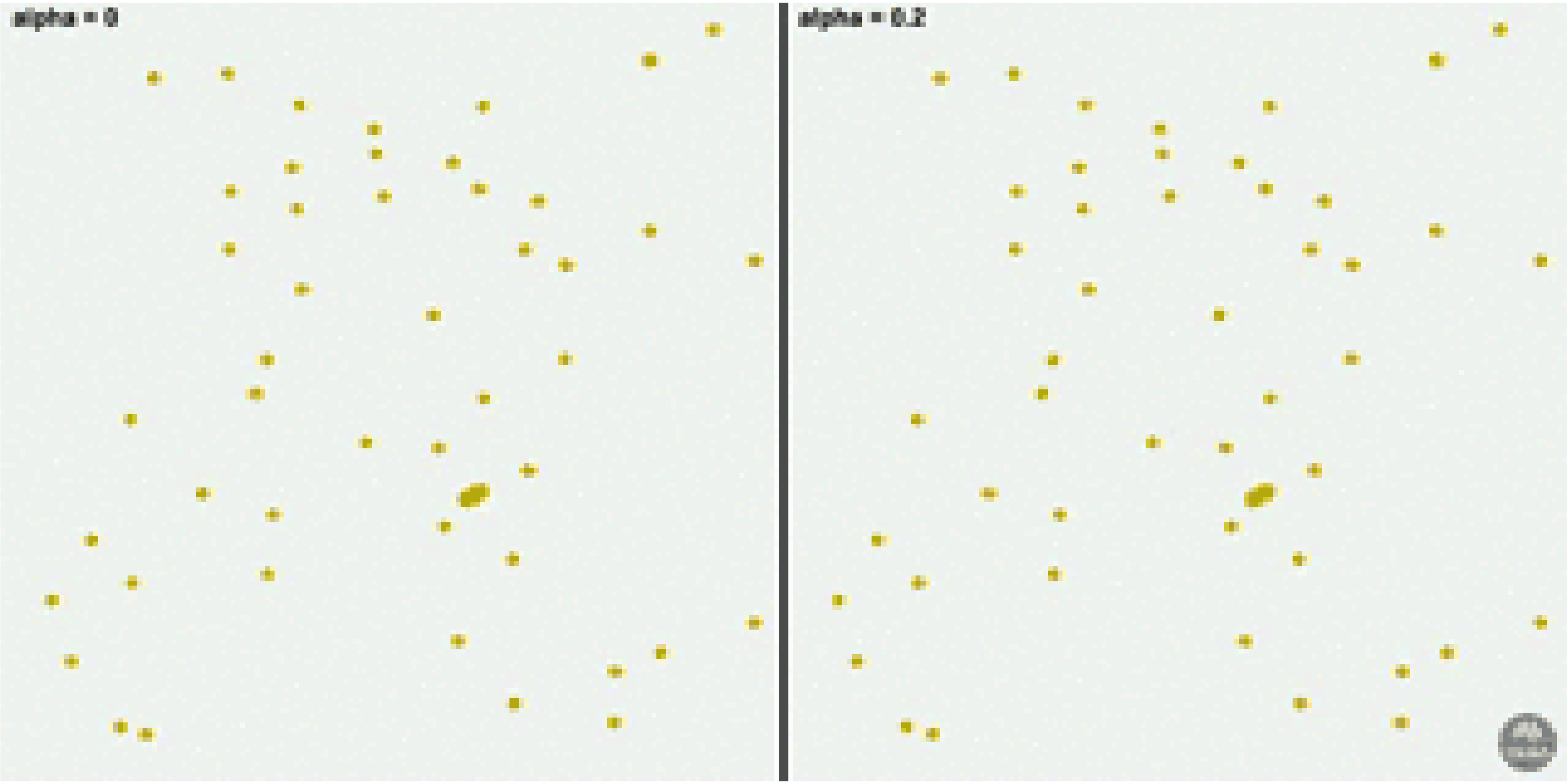


Curvature dependence

FIRE COALESCENCE FROM MULTIPLE IGNITIONS



EXPERIMENTAL PROGRAM

To better understand how curvature might be better parameterised in order to capture the dynamic effects involved in fire coalescence, we will conduct a range of experiments:

- ❑ **Oblique fire line intersections**
- ❑ **Parallel line fires**
- ❑ **Ring fires**
- ❑ **Other geometries**
- ❑ **Project Aquarius data...**

COUPLED FIRE-ATMOSPHERE MODELLING

To better understand the dynamics and physical mechanisms driving the dynamic spread we used an atmospheric model coupled with a model for surface fire spread (WRF-Fire).

Atmospheric model:

- Weather Research and Forecasting model
- Navier-Stokes equations + thermodynamics

Surface fire model:

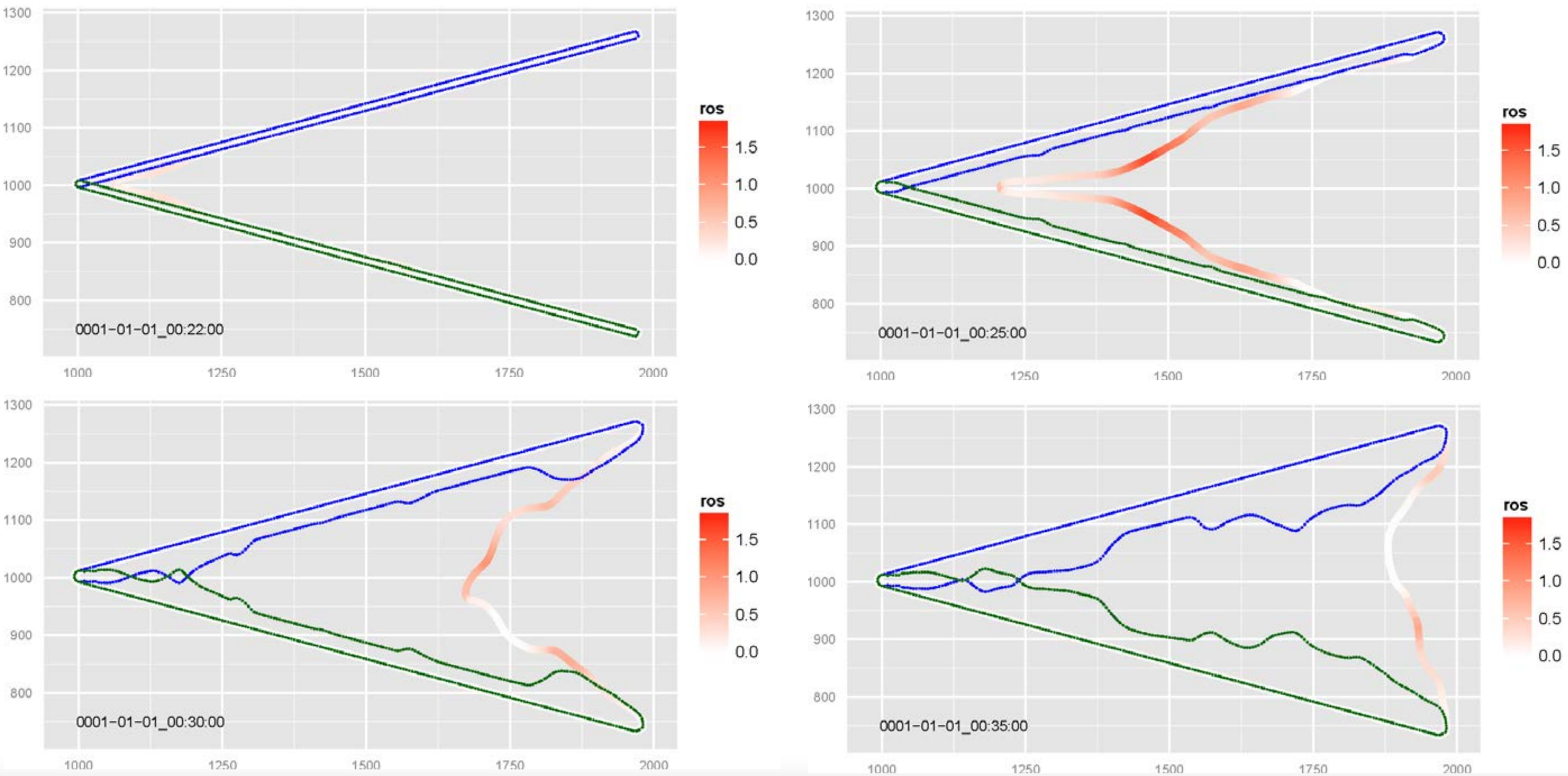
- Rothermel:

$$R(w, \gamma_s) = R_0(1 + \phi_w + \phi_s)$$

COUPLED FIRE-ATMOSPHERE MODELLING

Pyroconvective coupling in fire-fire interactions

- Fire line merging



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Pyroconvective coupling in fire-fire interactions

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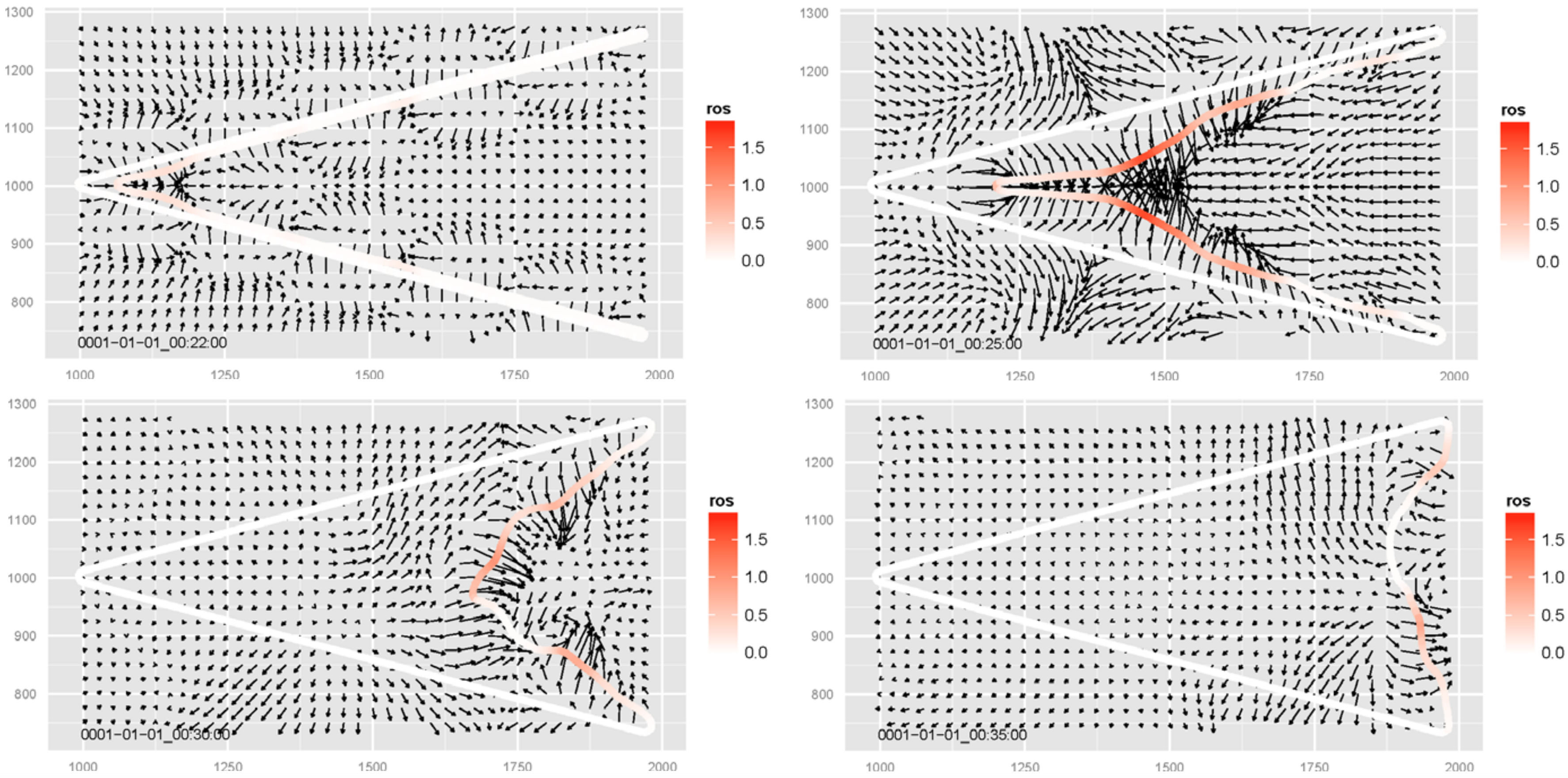
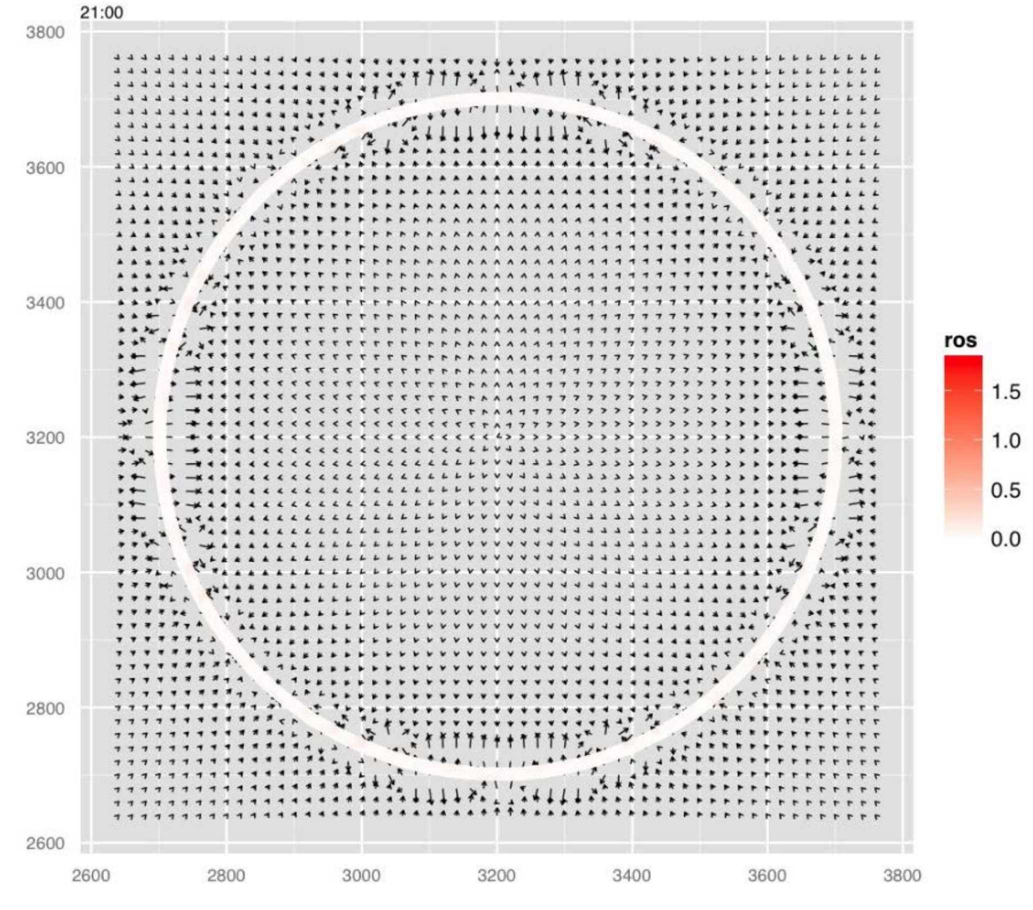


COUPLED FIRE-ATMOSPHERE MODELLING

Pyroconvective coupling in fire-fire interactions

- Ring fires



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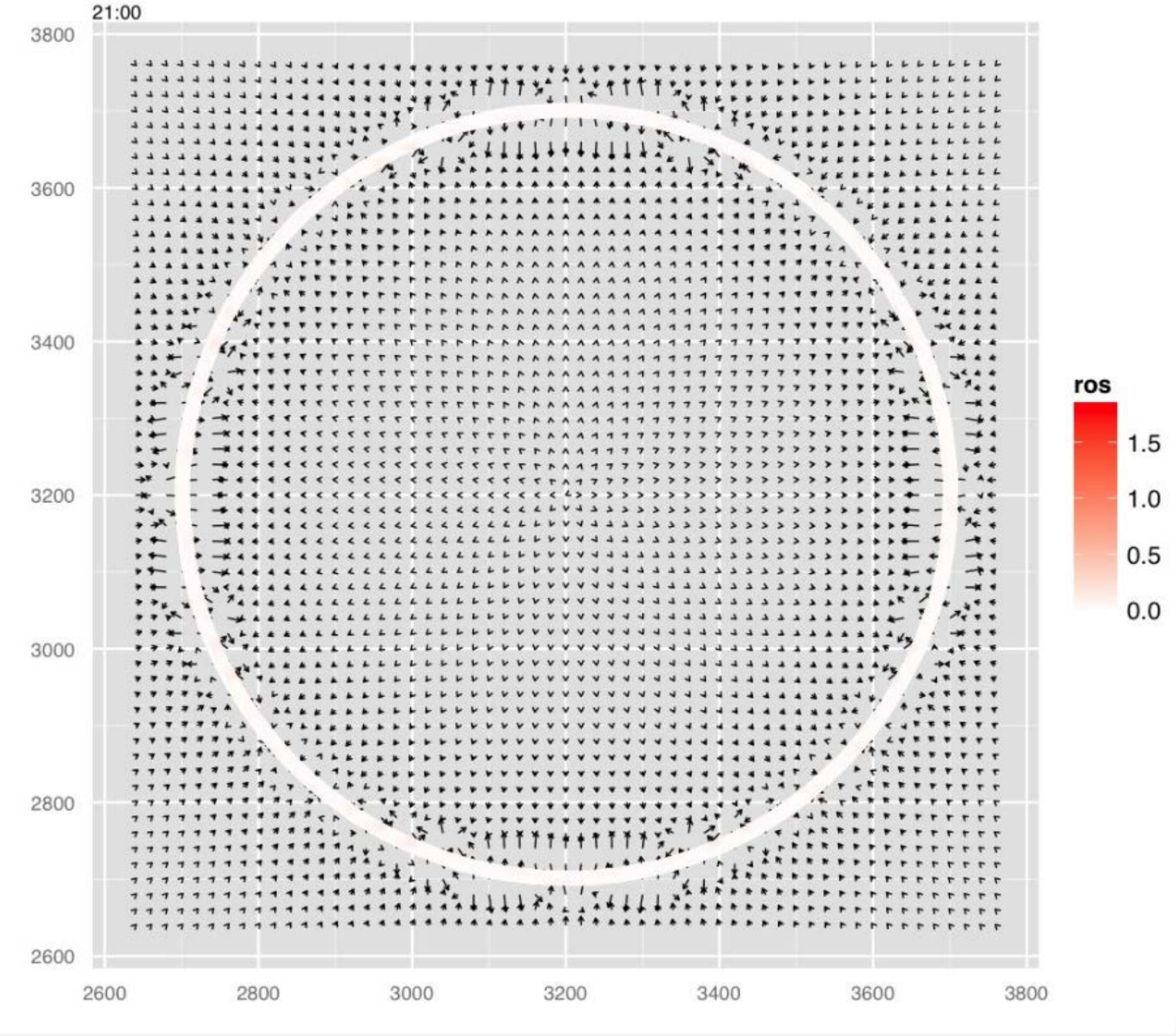

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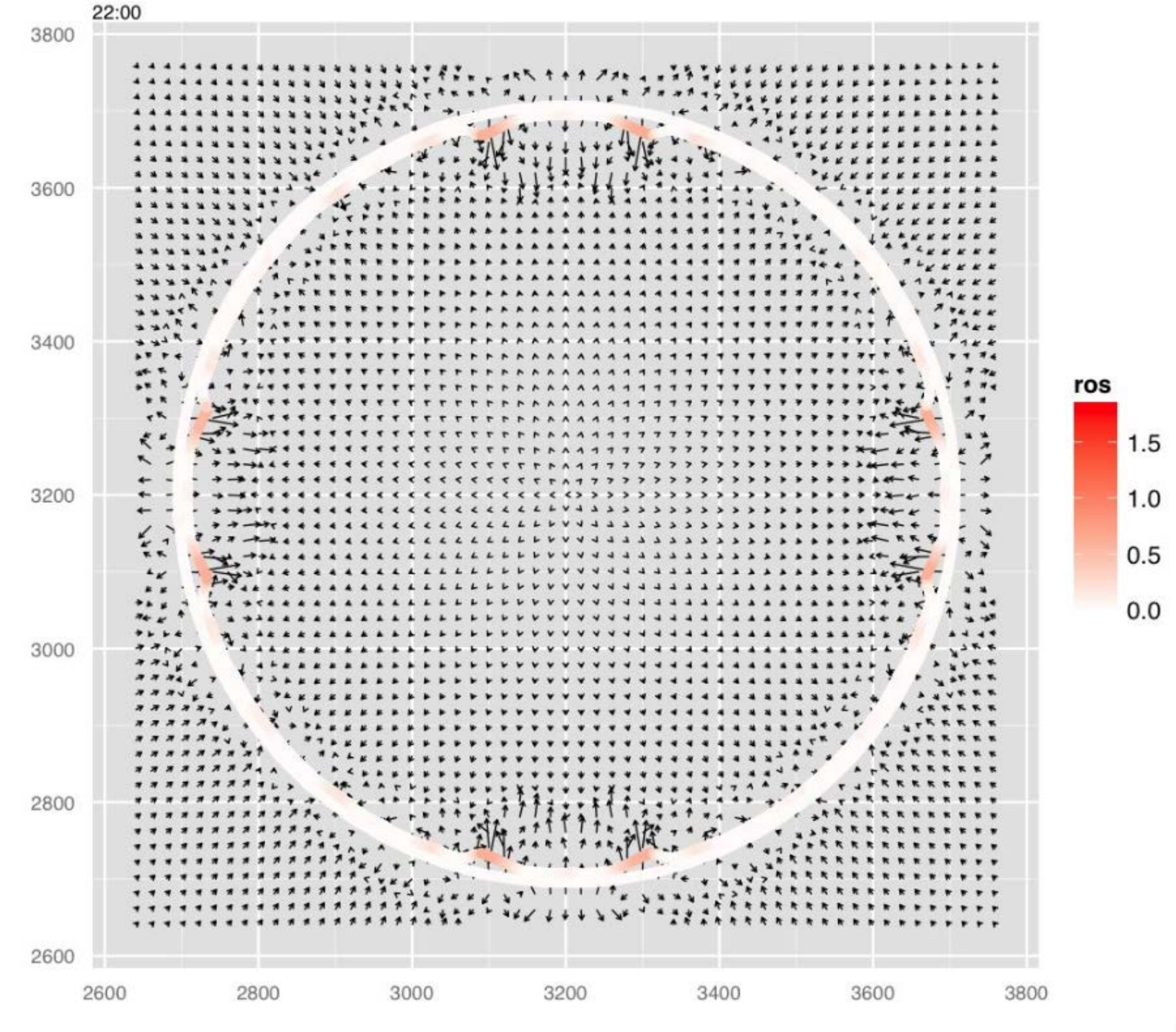

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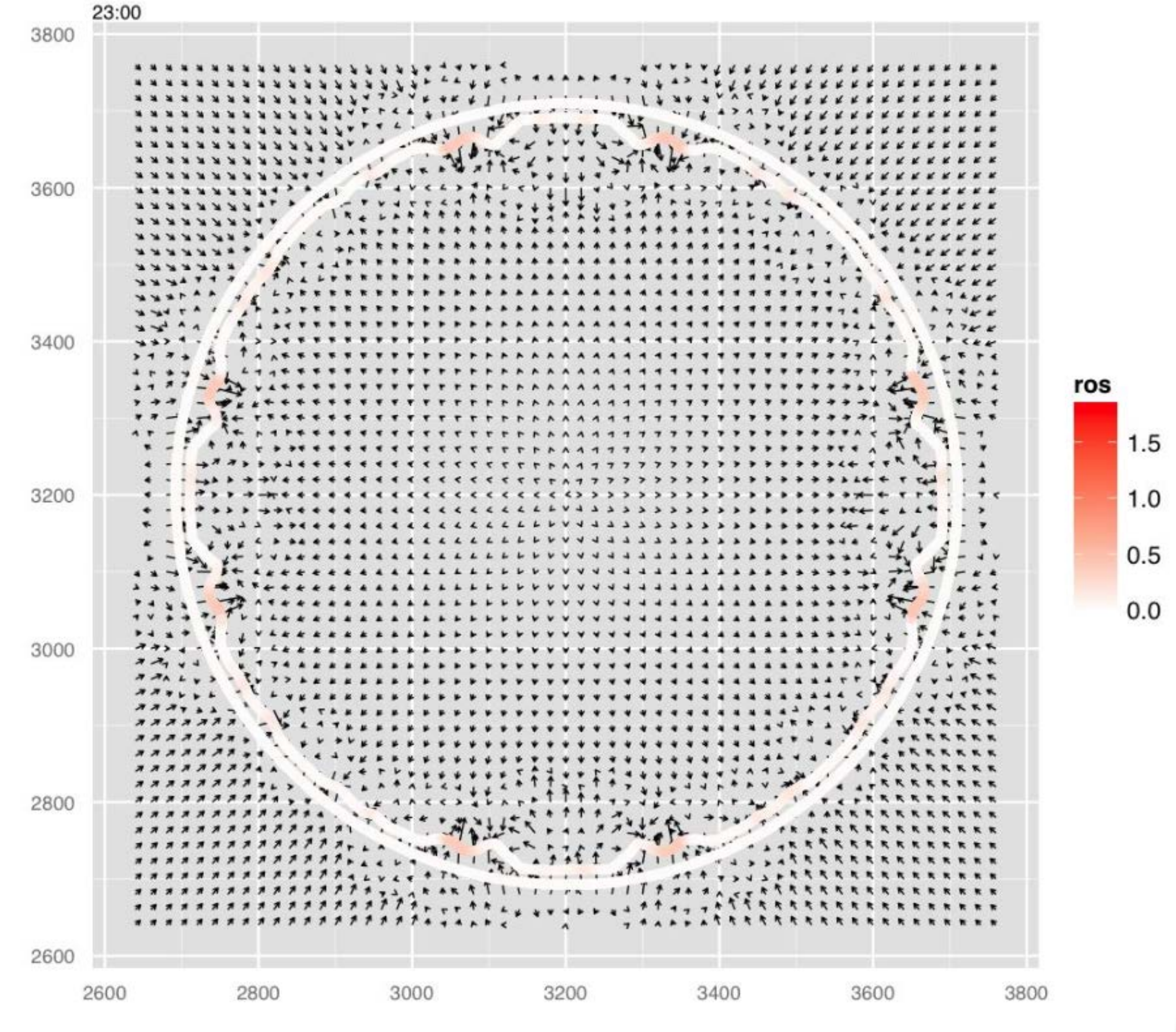

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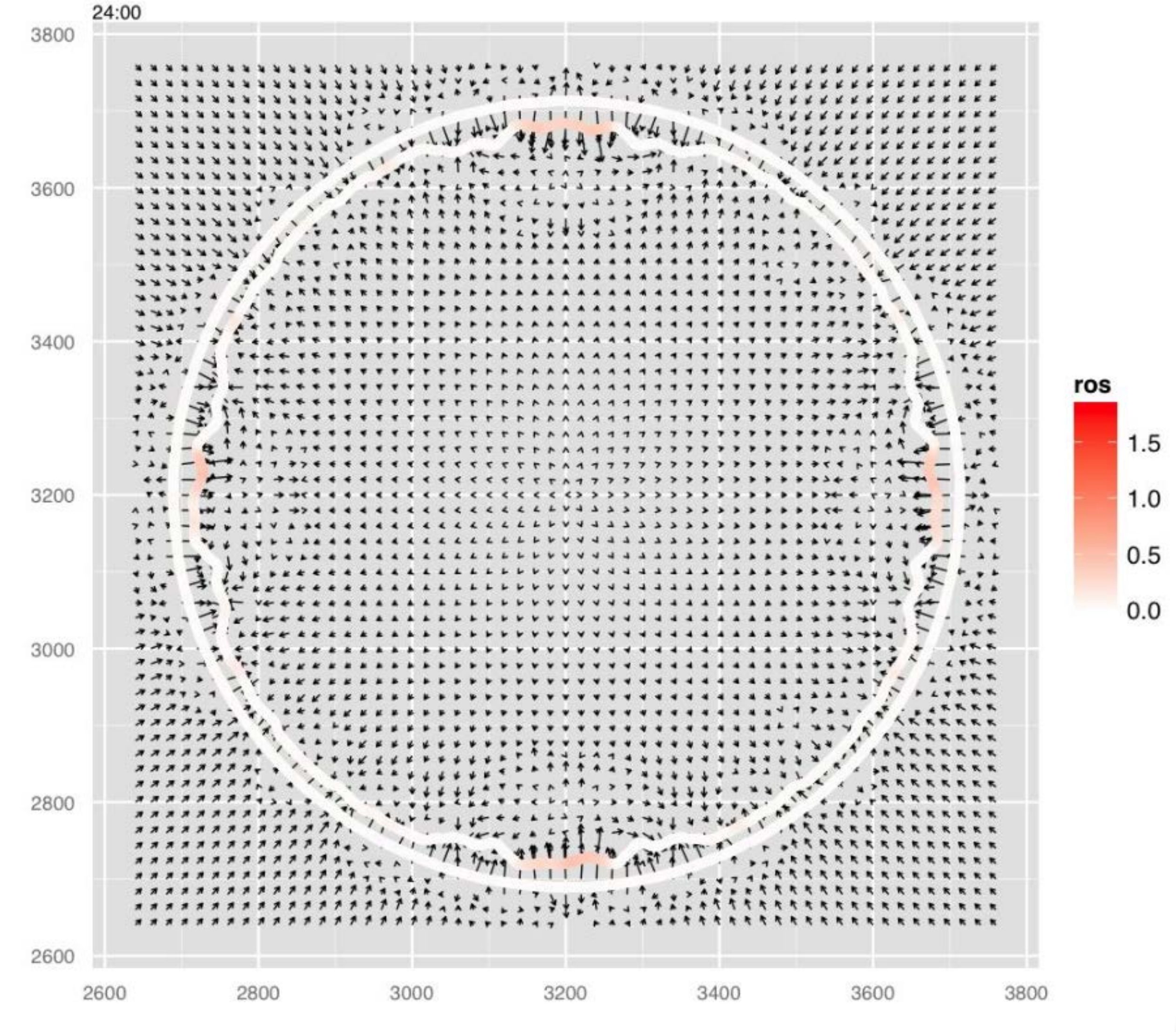

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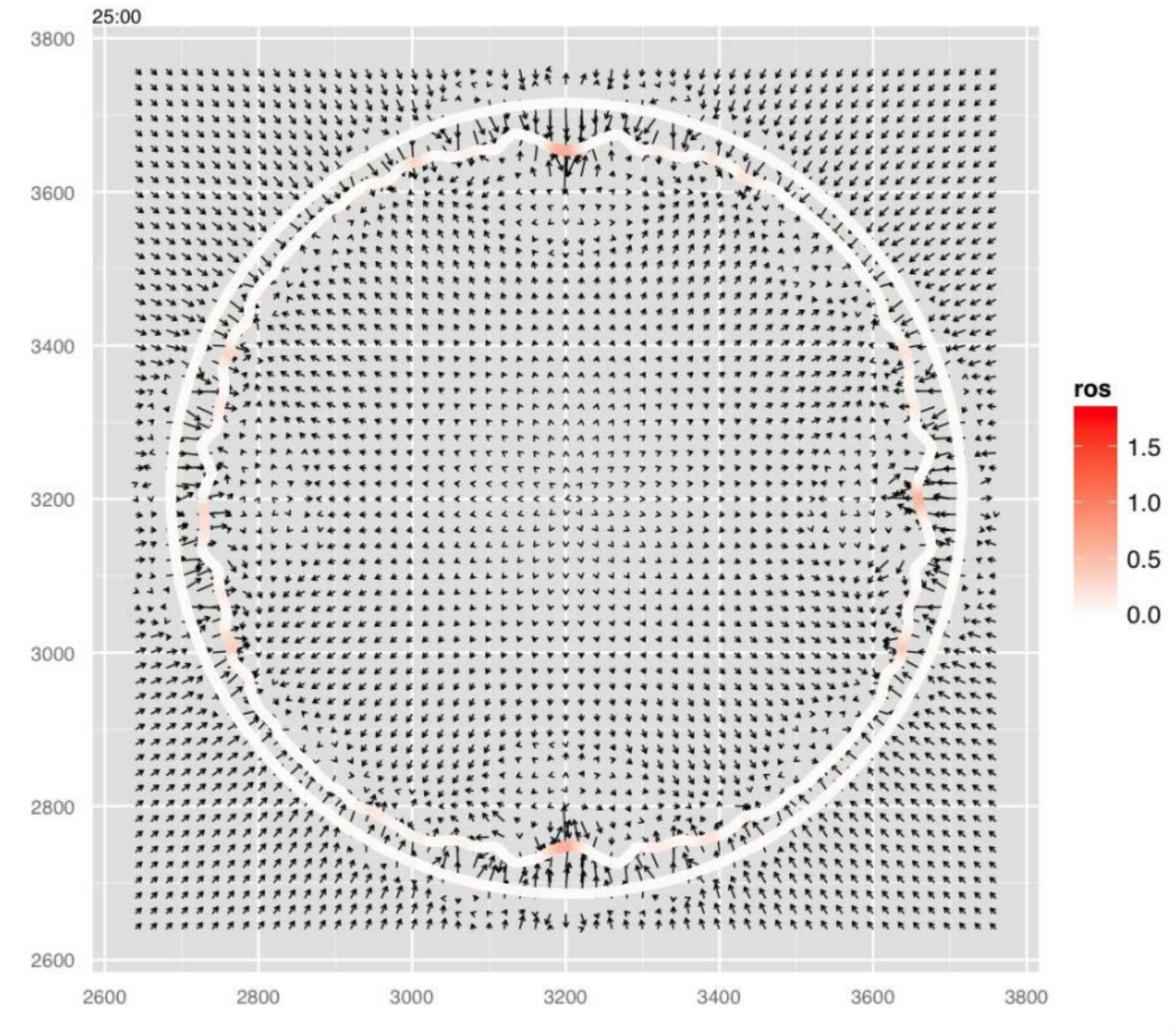

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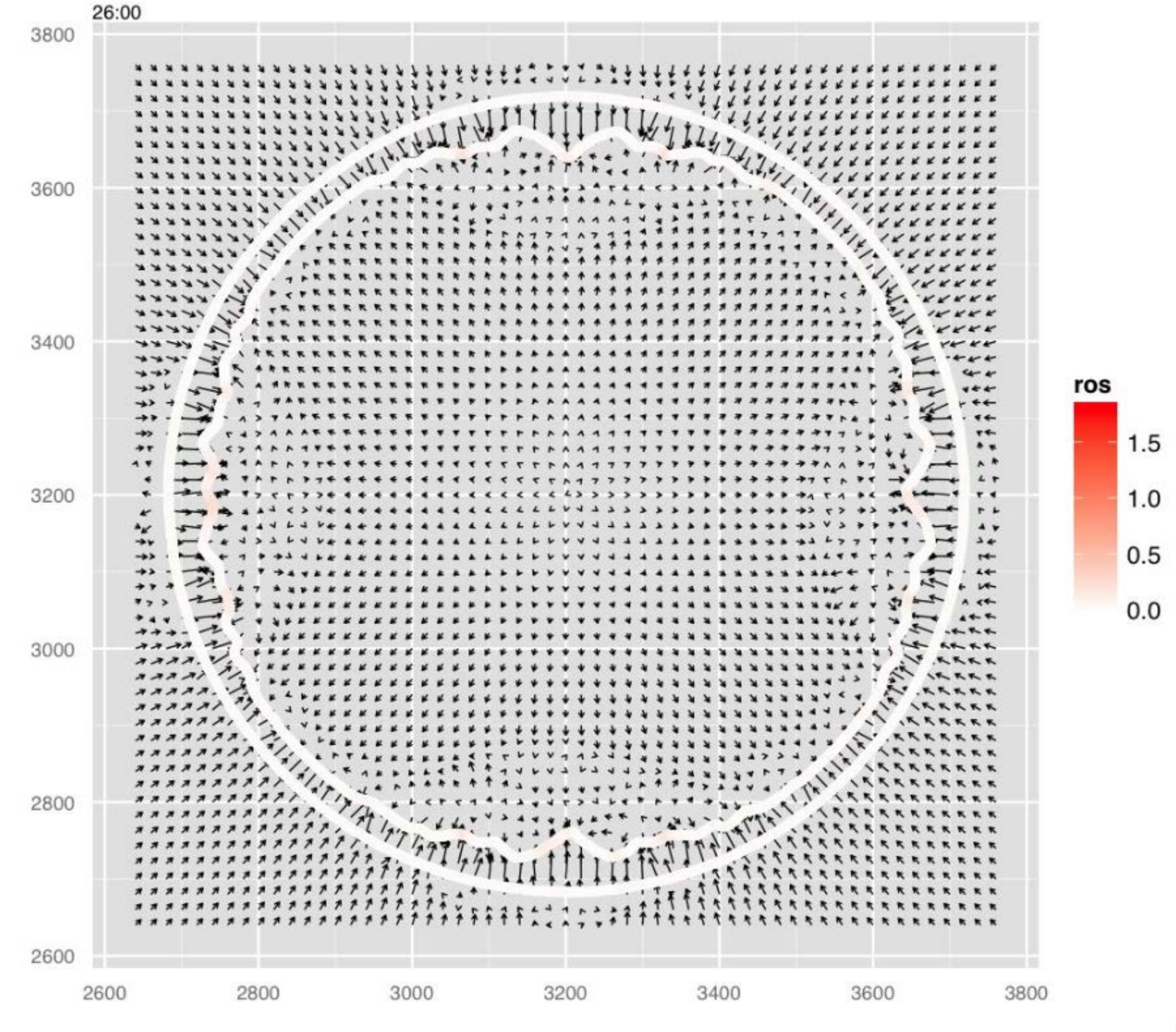

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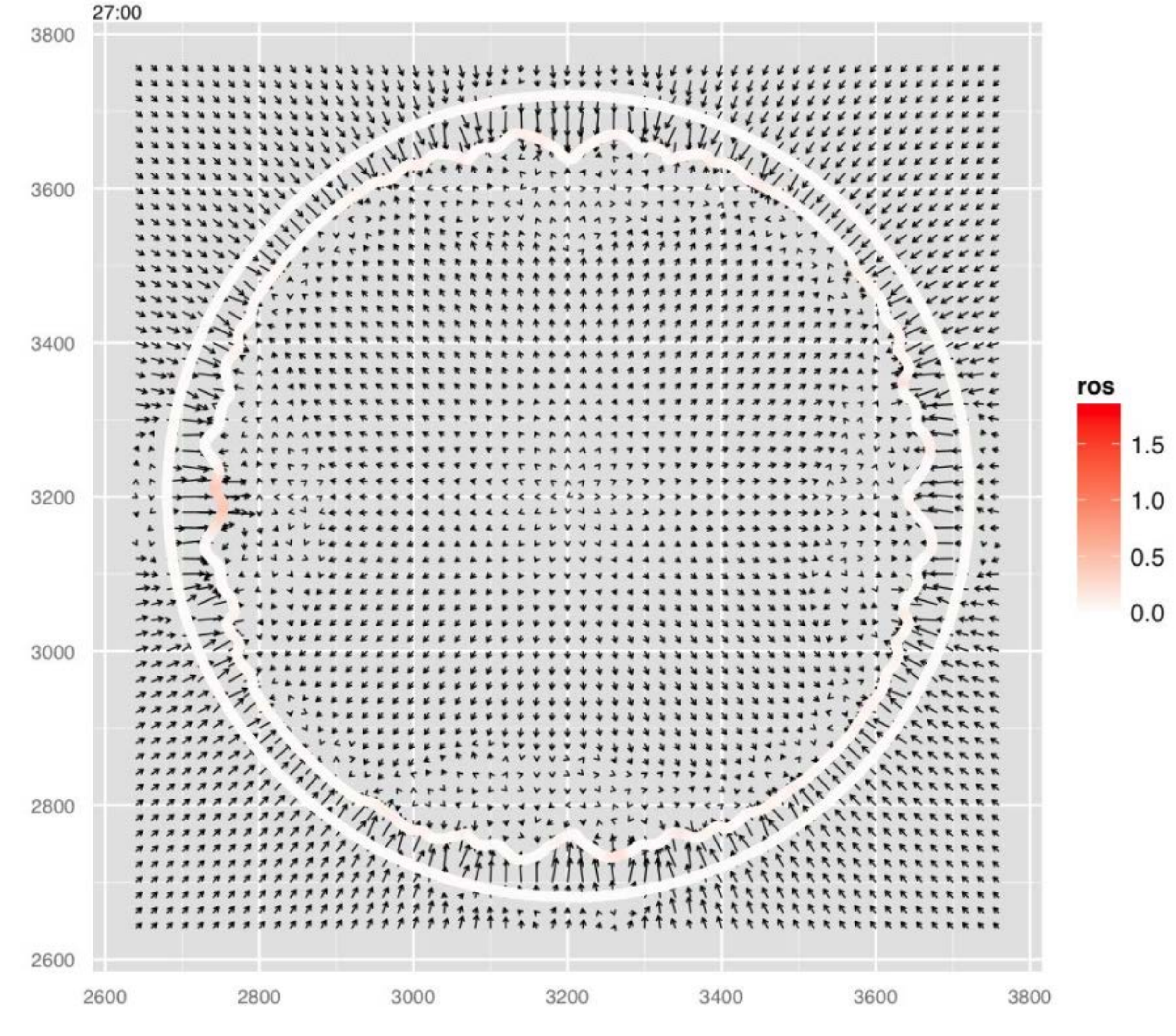

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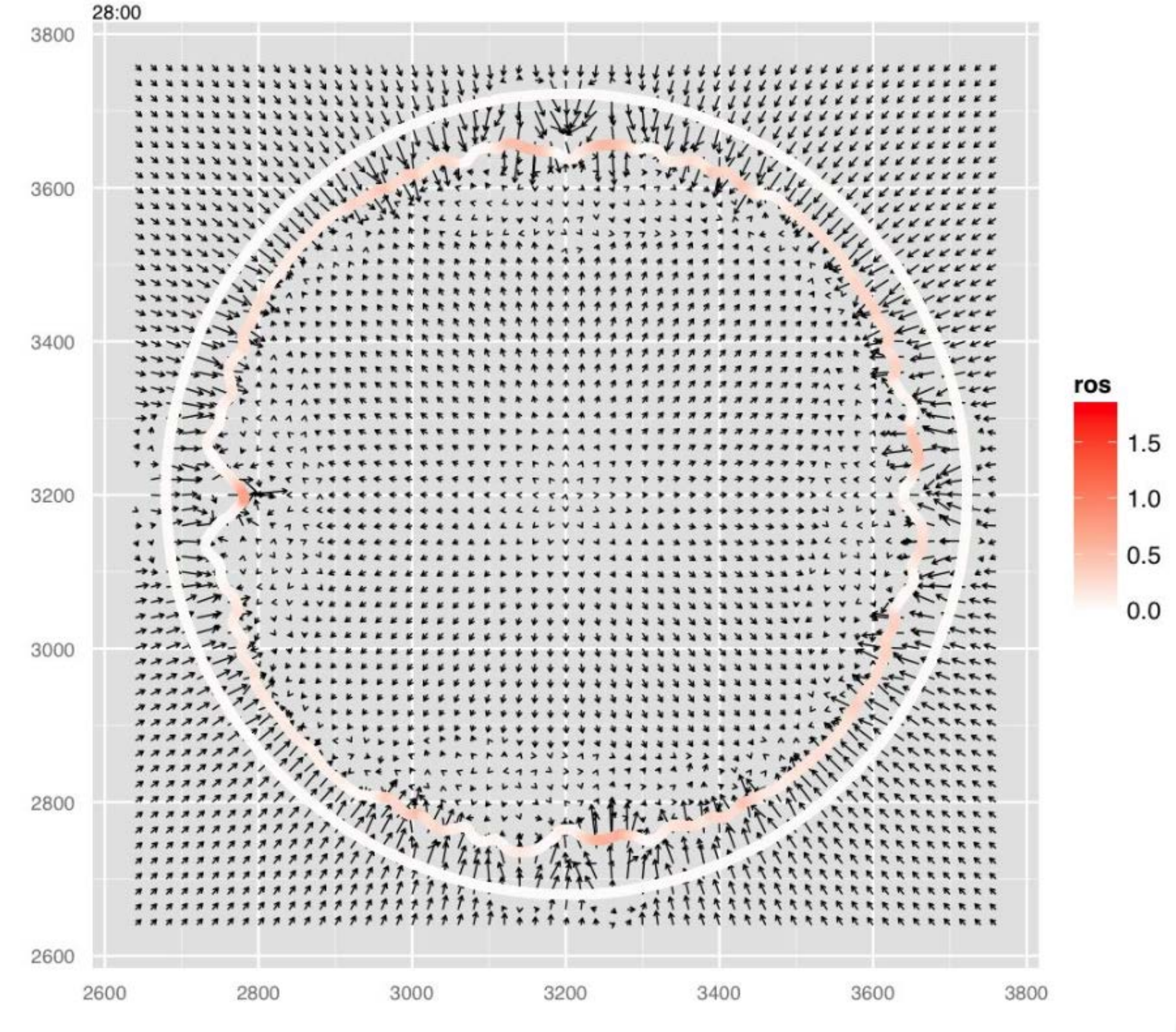

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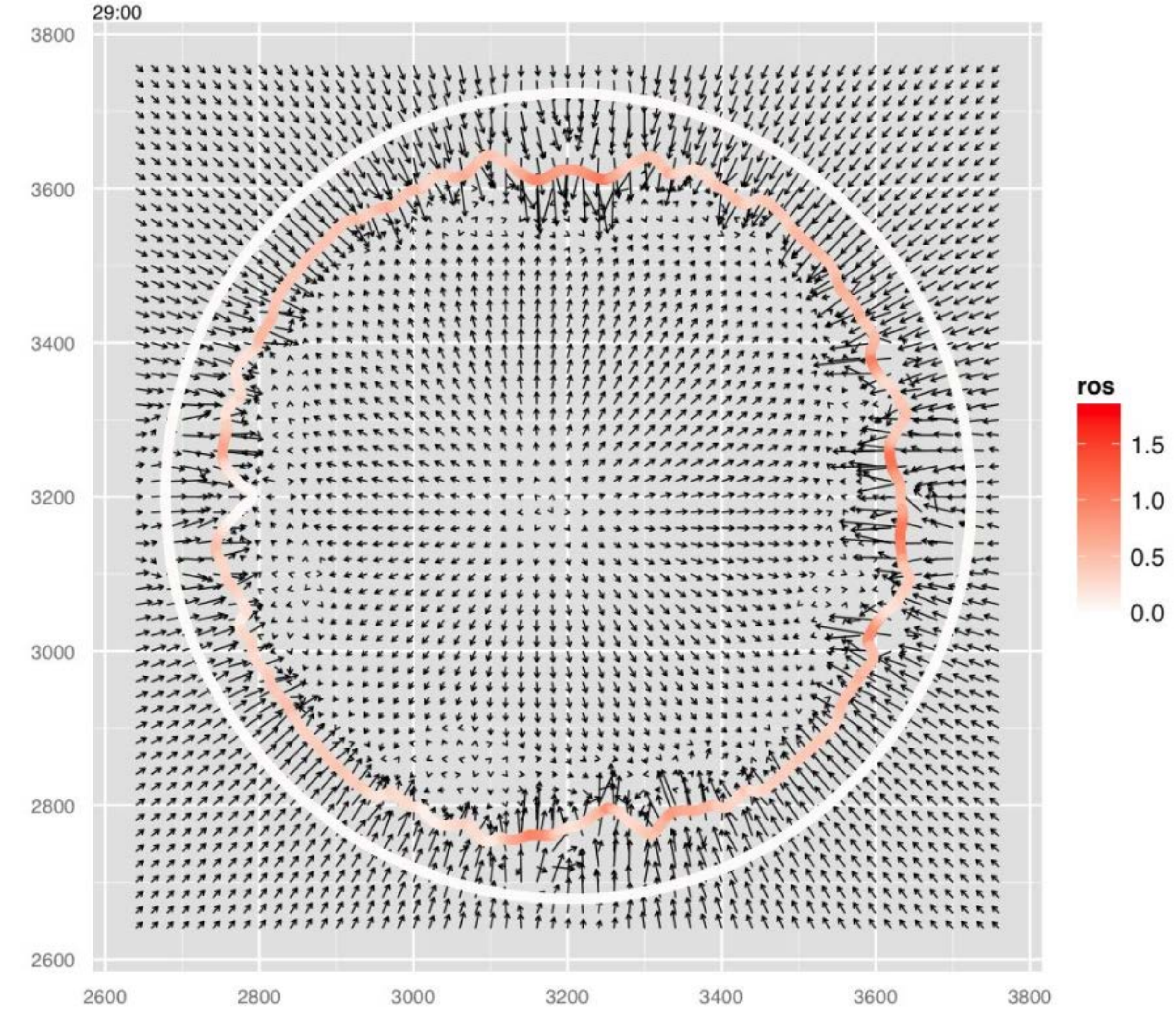

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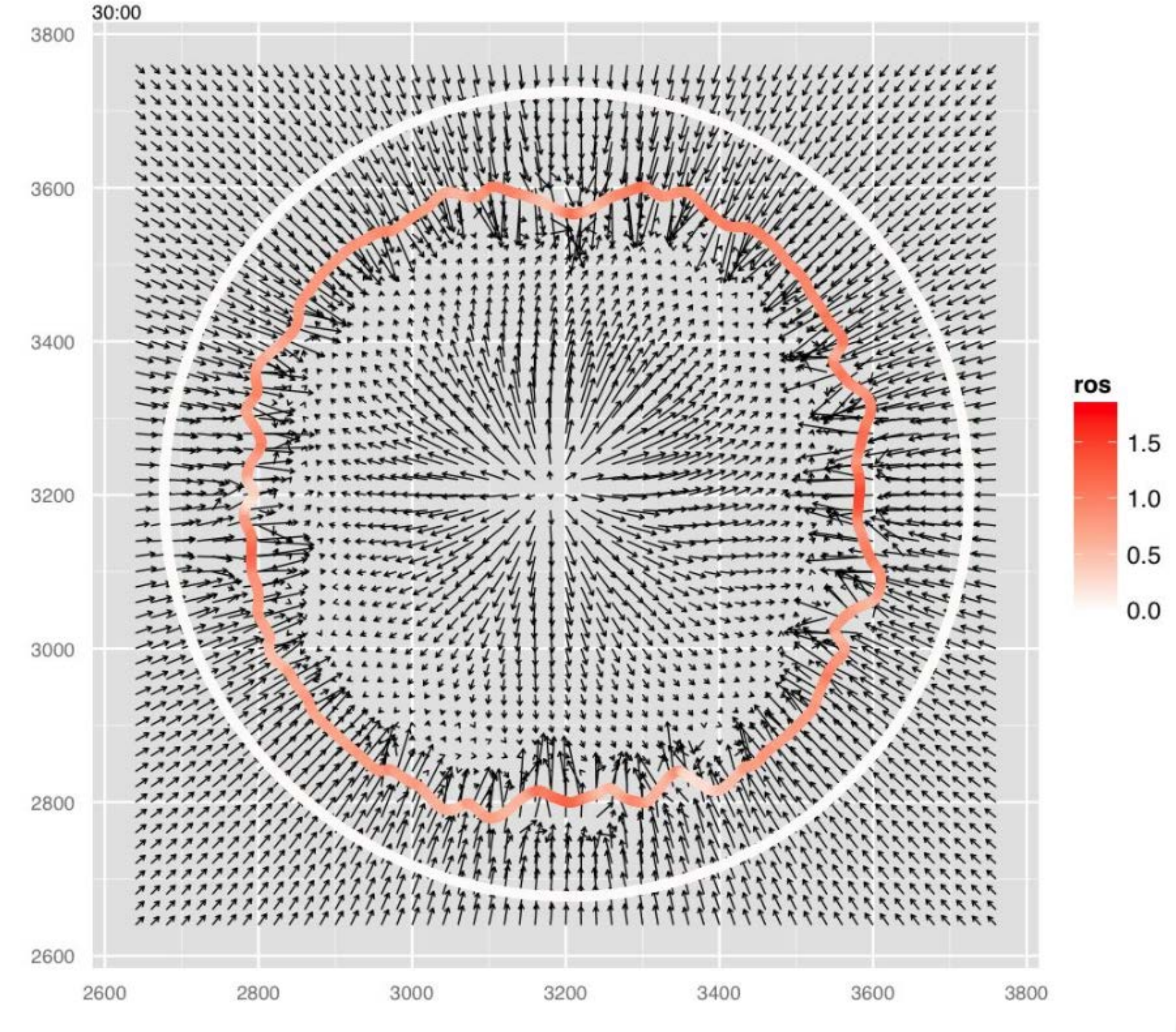

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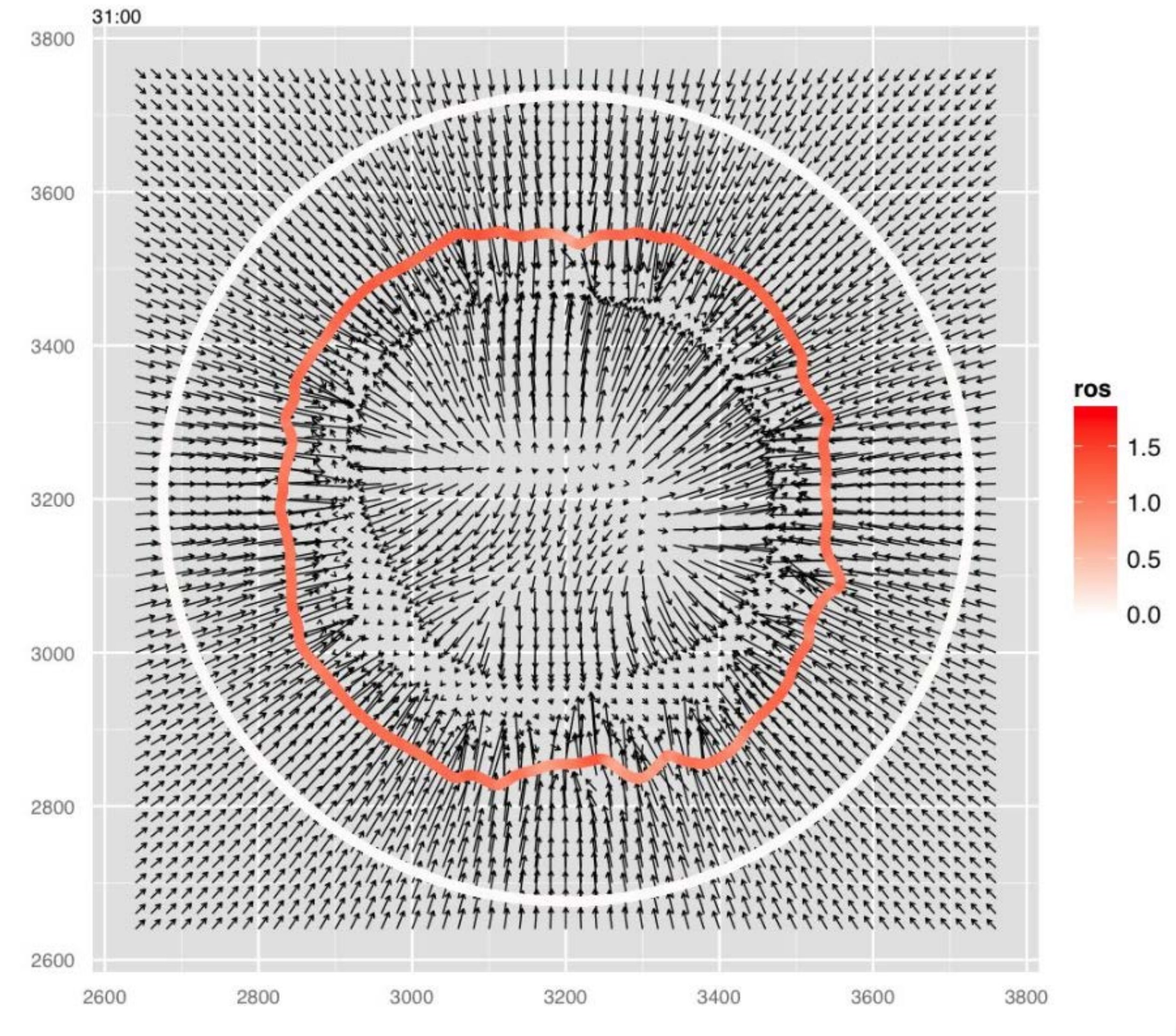

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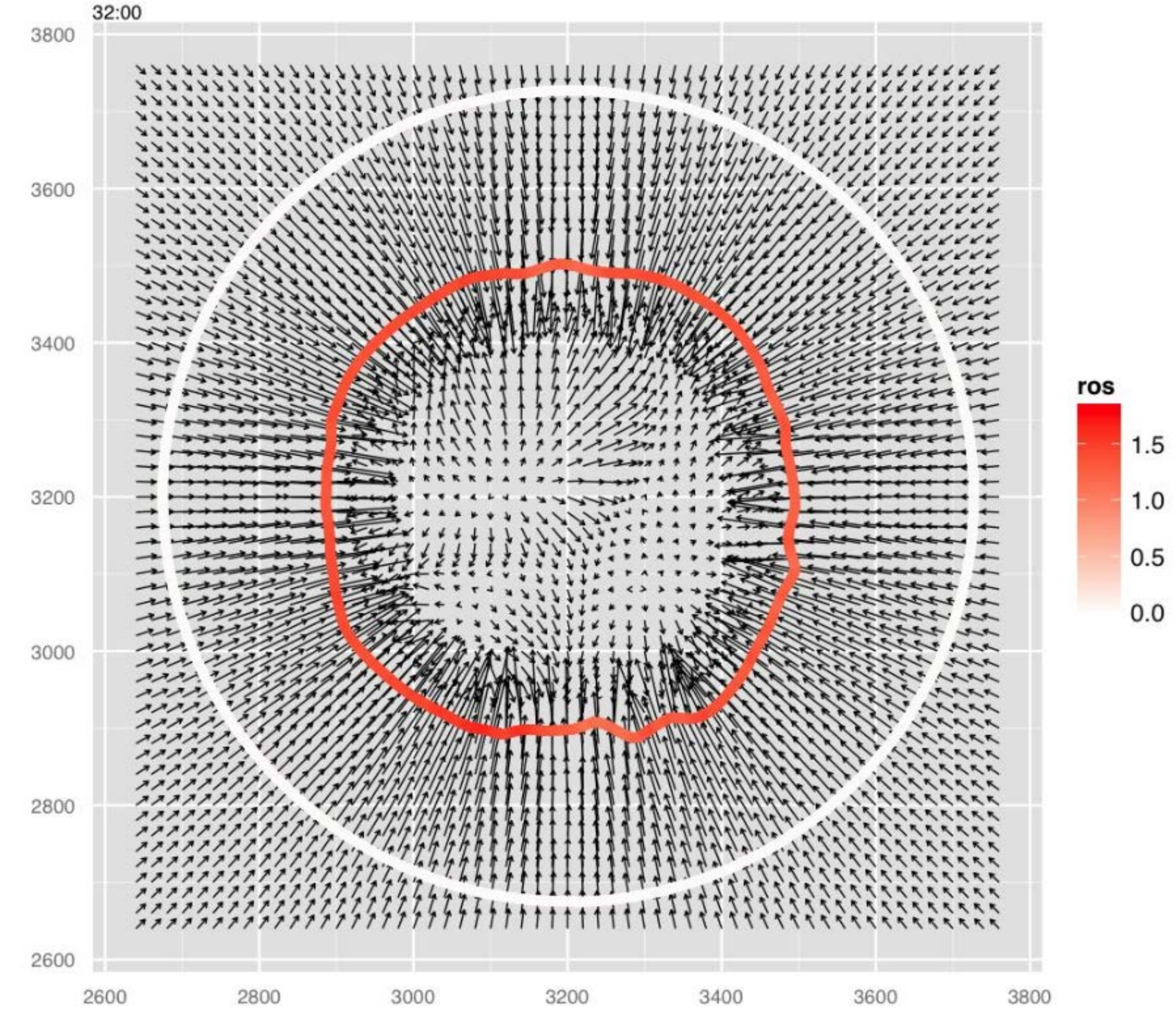

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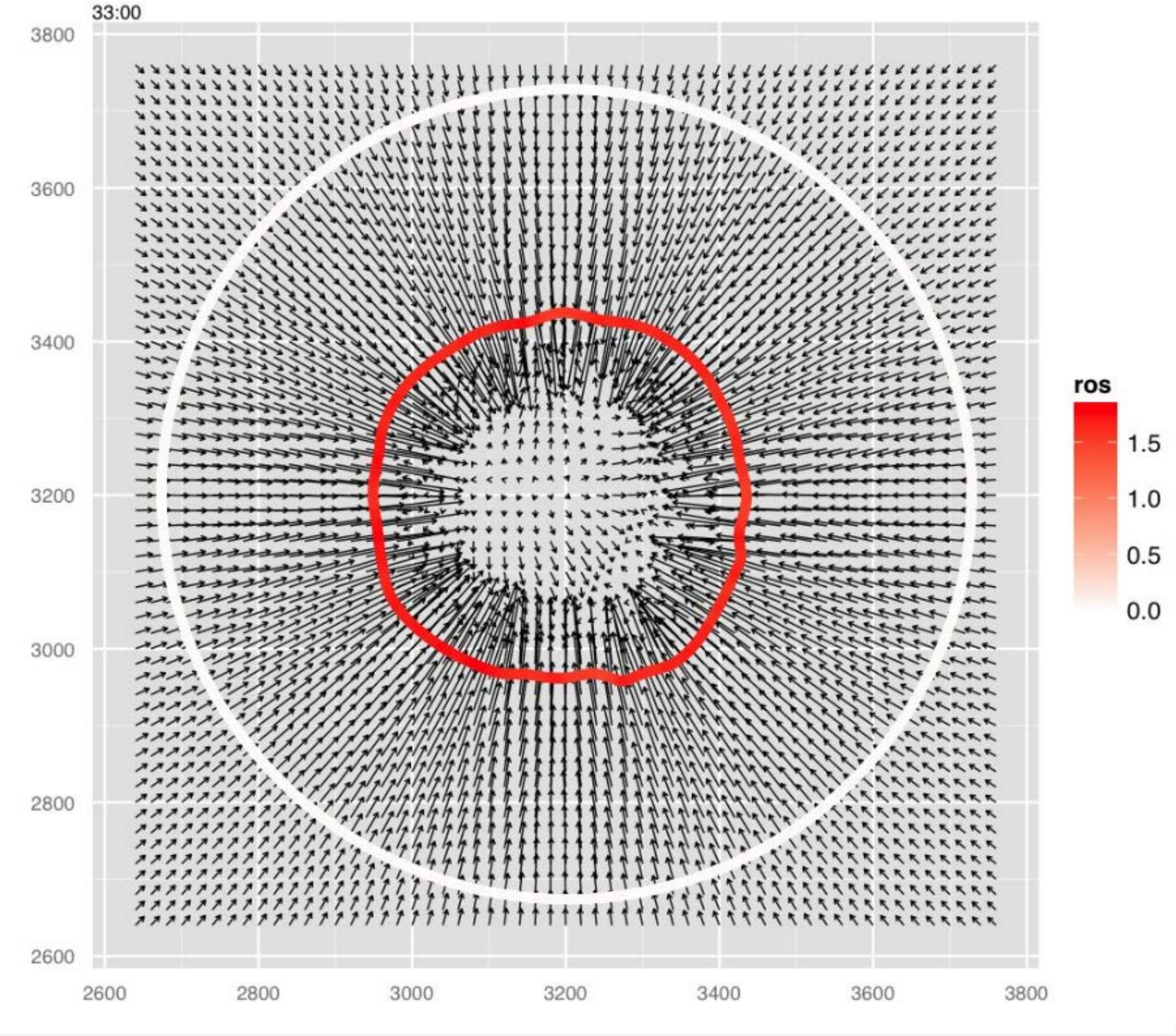

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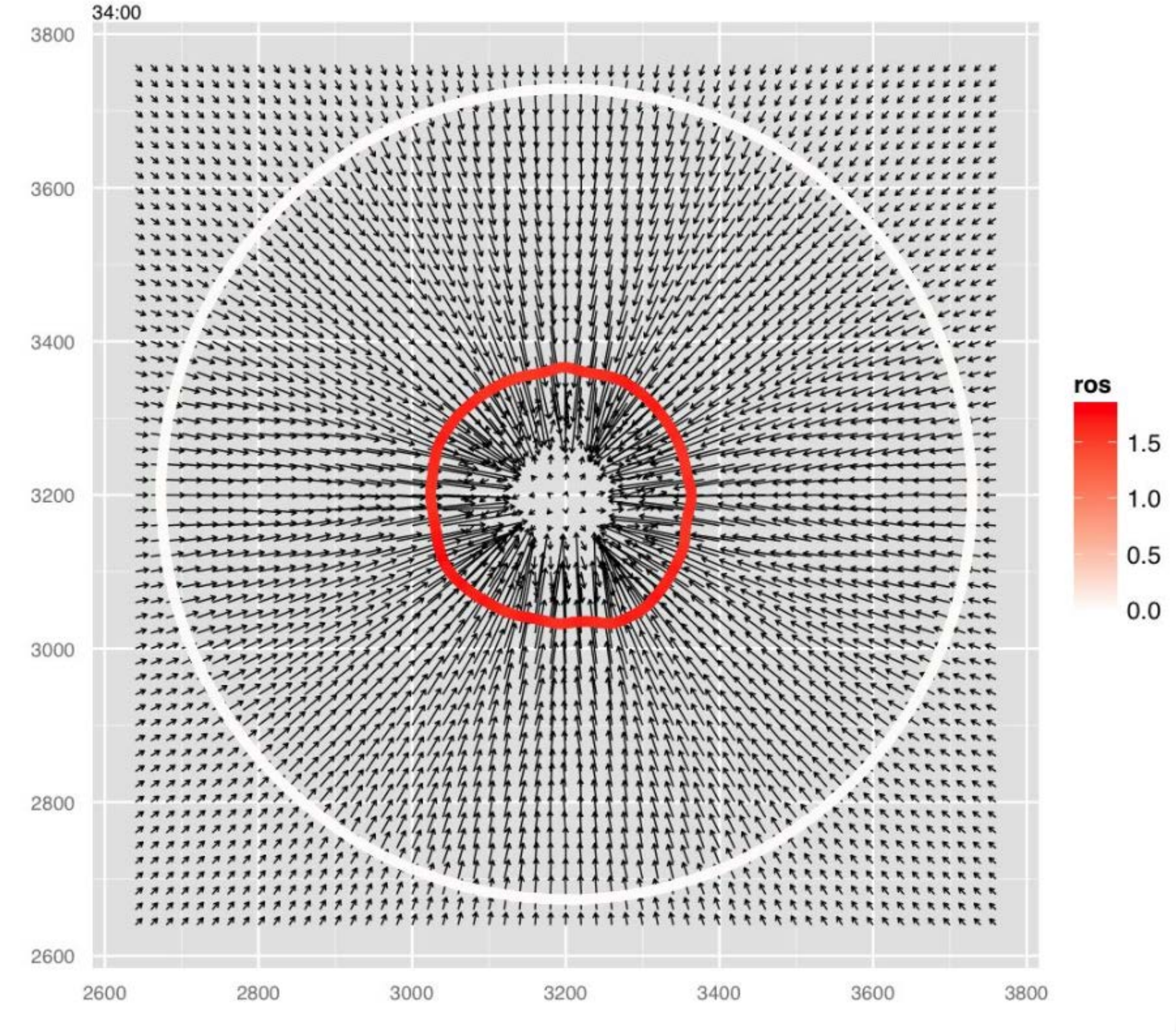

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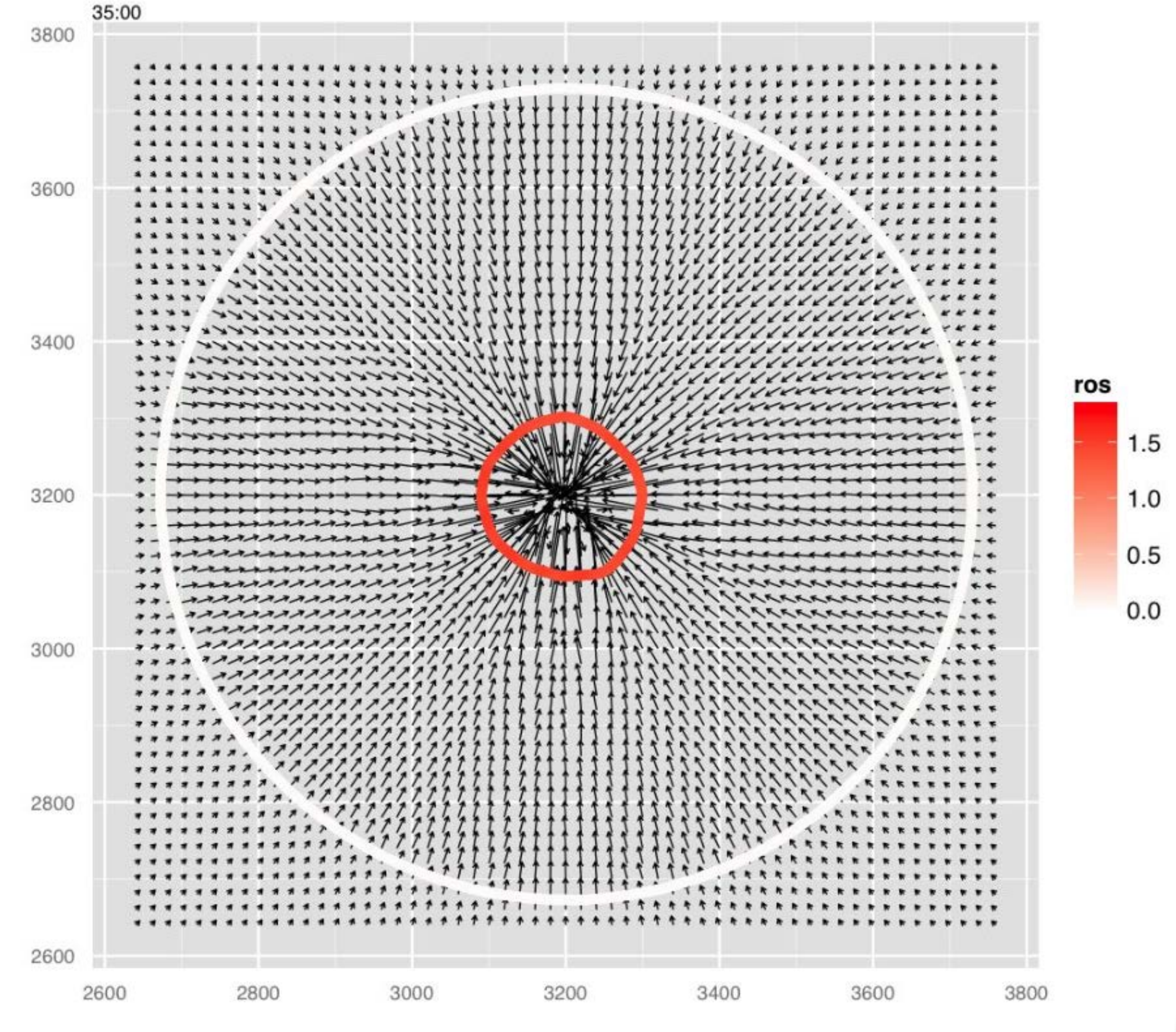

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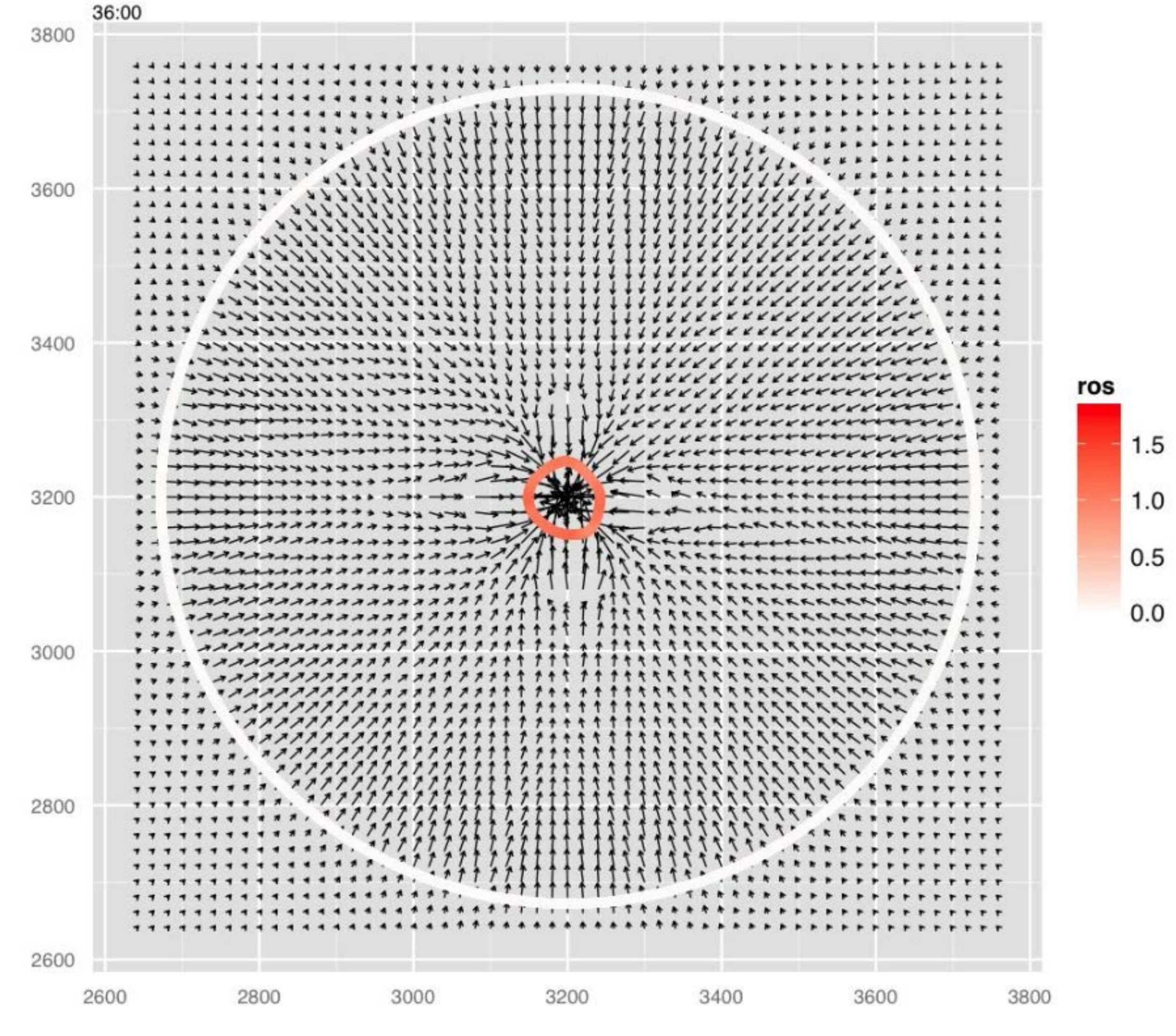
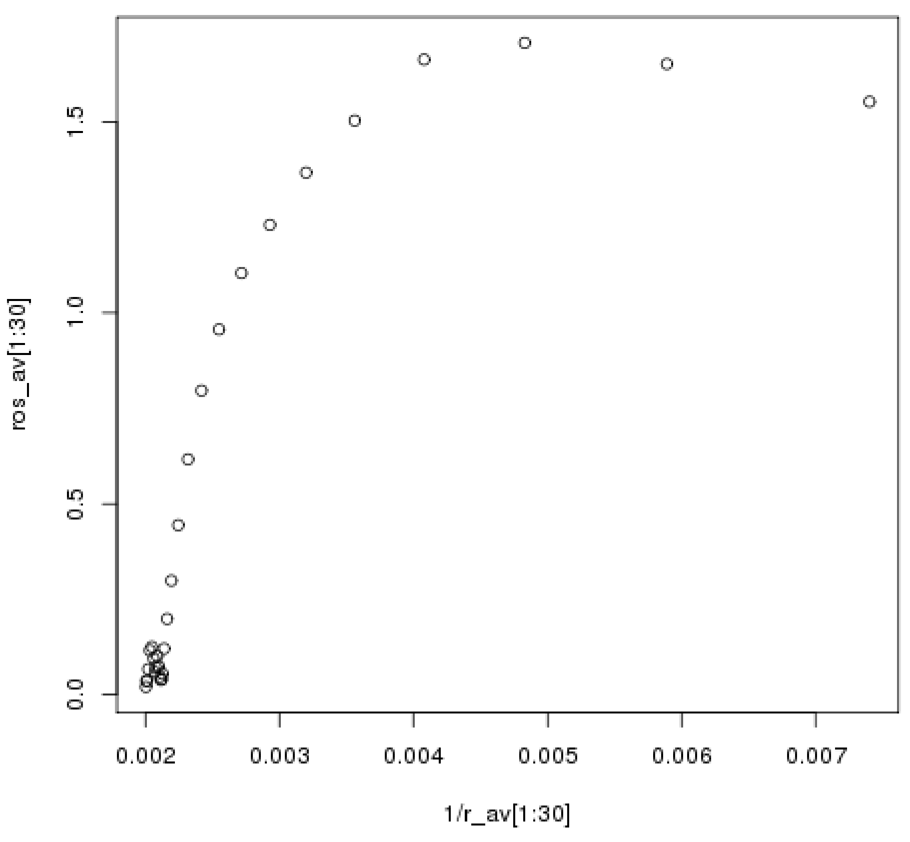
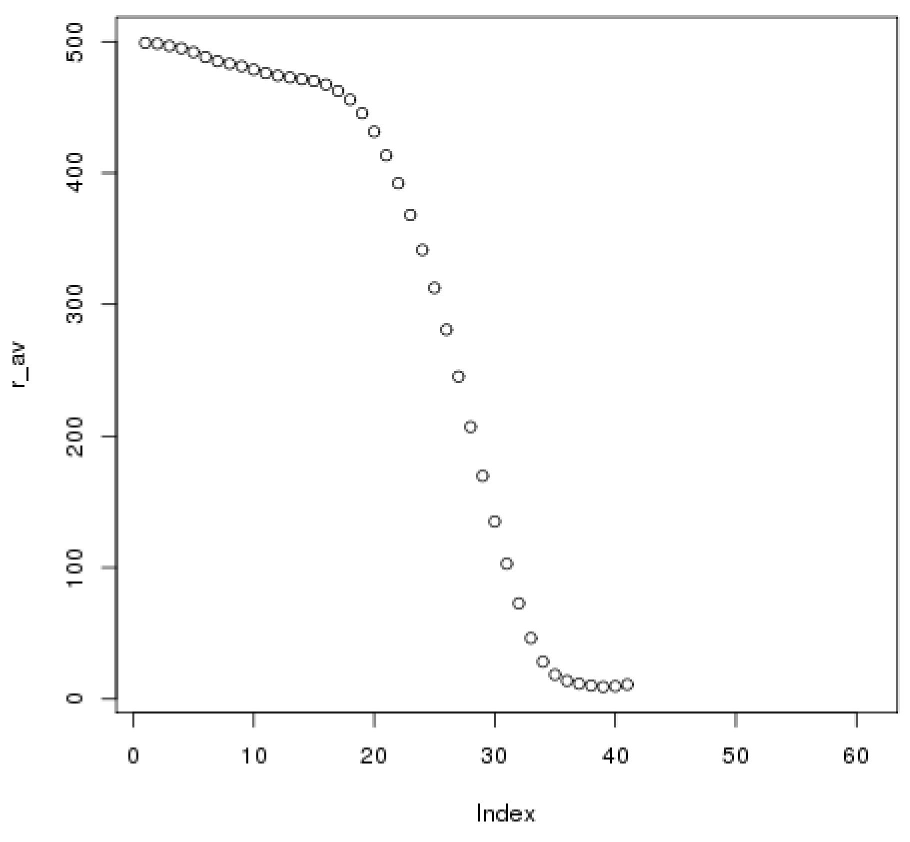


COUPLED FIRE-ATMOSPHERE MODELLING

Pyroconvective coupling in fire-fire interactions

- Ring fires





ACCOMPLISHMENTS TO DATE…

- **Contracts signed!**
  Head contract between BNHCRC and UNSW signed in March 2015. Subcontract between UNSW and CSIRO was subsequently signed in June 2015. Project is now officially active!

- **Science plan finalised (including experimental plan)**
  After consultation with the Advisory Committee the plan was finalised in July 2015. The plan will be formally submitted next quarter.

- **Collaboration with University of Coimbra (Portugal)**
  Auxiliary experimental program focusing on fire line merging incorporating wind and slope effects. Also experiments of relevance to other Next Generation Fire Behaviour Modelling Cluster projects.

ACCOMPLISHMENTS TO DATE…

- **Invited conference presentation**
  UNDERSTANDING EXTREME BUSHFIRE DEVELOPMENT. New South Wales Rural Fire Service Association Conference, Mudgee NSW, June 2015. Delivered by J. Sharples.

- **PhD student scholarship awarded to Christopher Thomas**
  An investigation of the dynamics of fire-fire interactions using a coupled fire-atmosphere model.

- **Conference paper in press**
  Thomas, C.M., Sharples, J.J., Evans, J.P. (2015) Pyroconvective interaction of two merged fire lines: curvature effects and dynamic fire spread. Proceedings of MODSIM2015.

ACCOMPLISHMENTS TO DATE...

- **Journal article under internal (CSIRO) review**
  Hilton, J.E., Miller, C. Sharples, J.J., Sullivan, A.L. (2015) Curvature effects in the dynamic evolution of wildfires. In preparation. To be submitted to *International Journal of Wildland Fire*, or *Combustion Theory and Modelling*.

- **Journal article in final stages of preparation**
  Sharples, J.J., Hilton, J.E., Sullivan, A.L. (2015) On the interaction of two oblique fire fronts. To be submitted to *International Journal of Wildland Fire*, or *Combustion Theory and Modelling*.

- **Conference poster presented/published**
  Sharples, J.J., Hilton, J.E., Miller, C., Sullivan, A.L. (2015) Nature abhors curvature – fires included! Poster presentation at AFAC/Bushfire and Natural Hazards CRC Conference.

ADDITIONAL OPPORTUNITIES…

Connection with Australian Research Council projects

J.J. Sharples & J.P. Evans (2013-2016) Investigation of atypical bushfire spread driven by the interaction of wind, terrain and fire.

J.J. Sharples & J.P. Evans (2016-2019) Understanding the role of deep flaming in violent pyroconvective events.

Both of these projects have strong links with spotting and fire coalescence. Combining findings of these projects with those of our BNHCRC funded research has the potential to provide new and significant insights into extreme and dynamic fire propagation!

ADDITIONAL OPPORTUNITIES…

Collaboration with the Fire Weather Research Laboratory at San Jose State University

A/Prof. Craig Clements, who is in the audience (*I hope!*) directs a program of research specifically aimed at collecting fire plume and fire weather data.

For example, some of these data pertain to merging fires that are also affected by wind and slope.

ADDITIONAL OPPORTUNITIES…

Connection with Manchester University, UK

Prof. John Dold has conducted a number of large scale fire experiments under 30-30-30 conditions.

Many of these experiments involved fire coalescence, and as such provide a further source of experimental data for model development and validation!

Prof. Dold will visit A/Prof. Sharples in February 2016 in connection with ANZIAM 2016.

ADDITIONAL OPPORTUNITIES…

Savannah veld fires in Kruger National Park, South Africa. September 2010.

Multiple line fires

Image copyright: Prof. John Dold

ADDITIONAL OPPORTUNITIES...

Savannah veld fires in Kruger National Park, South Africa. September 2010.

Spiral fire

Image copyright: Prof. John Dold

ADDITIONAL OPPORTUNITIES…

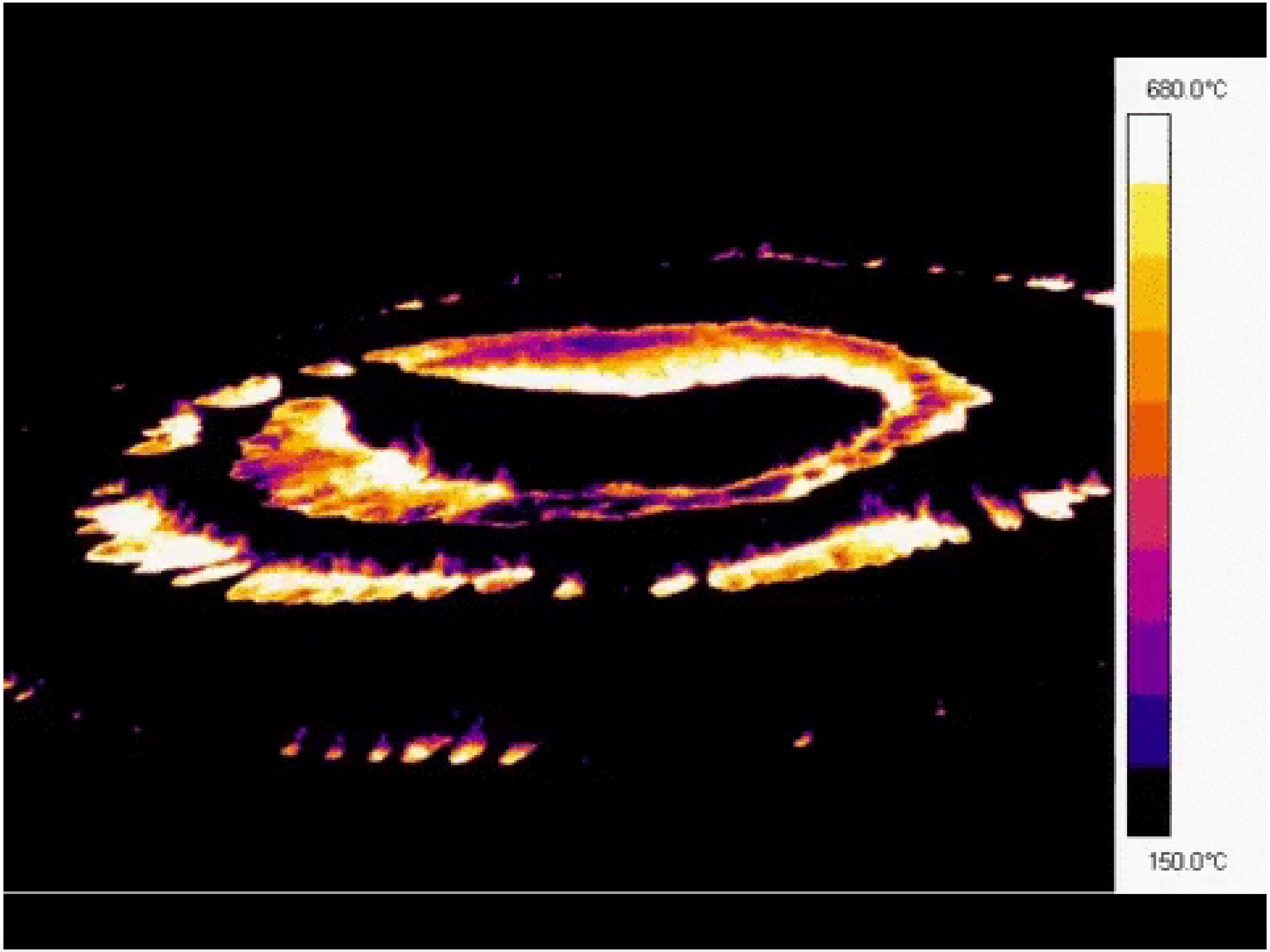


Image copyright: Prof. John Dold

ADDITIONAL OPPORTUNITIES…

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