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Supplementary material

An approach to integrated data management for three-dimensional, time-dependent fire behaviour model evaluation

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Supplementary Material 1: Lessons Learned from Integrating Data from the Camp Swift and RxCADRE Research Burns

This section briefly discusses lessons learned from our work with measurement data from the Camp Swift (McNamara and Mell 2018a) and RxCADRE (Ottmar et al. 2016) research burns. Our interest was to create integrated datasets suitable for evaluating three-dimensional, time-dependent fire behavior models (3D fire models). This experience led to a recognition of the importance of the best practices presented here, motivating the writing of this manuscript.

The USDA Forest Service Research Data Archive (the Archive) published data and metadata for the Camp Swift and RxCADRE efforts. We are more familiar with the Camp Swift effort, having performed quality control, documentation, integration, data derivation, and data analysis for this effort (McNamara and Mell 2018a). Consequently, we provide the complete list of data collected and published at Camp Swift in Table S1-1. Neither the Camp Swift nor RxCADRE research burn efforts implemented the full extent of the data management approaches presented in this manuscript. This absence of extensive data management practices resulted in a lack of documentation, quality control, availability of data, and other information that hindered data integration for 3D fire model evaluation. These missing items increased the time and effort required to integrate the data.

DQOs were needed in Camp Swift and RxCADRE to fully support mapping of pre-fire and post-fire vegetation (both the location and properties of the vegetation) and synchronization of ground and airborne measurements (e.g., Table 4). For example, we could not synchronize ground-based videos to other data. Field fuel samples outside the burn blocks were not always representative of burn block vegetation. Camp Swift did not have calibrated active fire thermal imagery, and the RxCADRE dataset (Ottmar et al. 2016) did not have high-resolution pre-fire visible imagery.

Some data quality issues (e.g., instrument malfunction or limitations in sensors) are unavoidable and part of any complex effort. Data quality issues are also common in unproven systems. However, not detailing errors and issues in the metadata increases integration challenges for all data users. Other challenges with data integration were avoidable, to some extent, with appropriate data management, geospatial practices, and data governance (supplemental materials two).

Camp Swift and RxCADRE data integrations provided us with valuable information to guide future efforts. It is encouraging that we were able to integrate data, demonstrating the possibility of such endeavors. However, the shared nature of the data management issues between the two burns supports the need for the practices presented here. We believe that implementing the data practices described in this manuscript supported by appropriate data governance (see supplemental section 2) will enable widespread effective use of research burn datasets and facilitate 3D fire model evaluations. Particularly for model comparisons, it is crucial to utilize the same integrated evaluation data, reducing costs overall as researchers are not separately integrating the same data.

We next provide examples of the importance of data integration. The vegetation at Camp Swift and RxCADRE varied in type and contiguity. Therefore, fire model evaluations require observations that support the fire model's ability to capture the influence of this variation on fire behavior. Such evaluations require spatially integrated active fire imagery, wind measurements, and vegetation characteristics. The active fire imagery's spatial and temporal resolution (i.e., DQOs) needs to be fine enough to capture the fire behavior variation as influenced by the vegetation. Similarly, the spatial resolution of vegetation characteristics (e.g., DQOs for vegetation type and location), which are model inputs, needs to be fine enough to support model fire behavior predictions and commensurate integration with the fire imagery. Achieving these DQOs requires careful site selection commensurate with measurement system capabilities and flexibility in experimental objectives.

The three figures, S1-1, S1-2, and S1-3, are examples of integrating active fire imagery and pre-fire vegetation for Camp Swift and RxCADRE. The influence of changes in the vegetation on fire behavior is apparent in all the figures. Spatial variation in the infrared fire imagery along the fire line corresponds to vegetation type variation at Camp Swift (Figure S1-1) and RxCADRE (Fig. S1-2). Note that the pre-fire imagery in Fig. S1-2 is not part of the RxCADRE dataset (Ottmar et al. 2016) and was obtained independently here and by Linn et al. (2021). Finally, Fig. S1-3 displays the influence of changes in vegetation on fire ignition at Camp Swift.

The data integrations shown in Figs. S1 1-3 are partial and do not account for the influence of the wind (see McNamara and Mell 2018a for more extensive integrations). However, the point here is that spatial variation of vegetation on fire behavior at RxCADRE and Camp Swift is shown in the integration of vegetation and colocated active fire imagery. These examples illustrate the importance of spatiotemporal integrated measurement data in fire model evaluation or observation-based fire research.

Table S1-1 Data collected from the 2014 Camp Swift Fire Experiment.

Dataset	Description
Anemometers (Butler et al. 2018a)	Forty-one cup-and-vane anemometers recording ambient and active fire wind direction and speed.
Fire Behavior Packages (Butler et al. 2018b)	In-situ measurements of heat fluxes, and wind speeds, ground videos, and range height poles.
Vegetation Map (McNamara and Mell 2018c)	Vegetation map derived from the pre-fire RPAS imagery.
Fuel Samples (Restaino 2018)	Pre-fire sampling of fuel loads occurred outside the burn blocks. Post-fire sampling only occurred in burn blocks.
Ignition Locations (McNamara and Mell 2018b)	Global positioning system (GPS) recorded locations of ignitions.
RPAS Pre-Fire Imagery (McNamara 2018a)	Pre-fire georeferenced digital visible imagery of the site.
RPAS Active fire Imagery (McNamara 2018c, McNamara 2018d)	Georeferenced infrared (IR) and electro-optical (EO) oblique georeferenced video frames of active fire conditions.
RPAS Post-Fire Imagery (McNamara 2018b)	Post-fire georeferenced digital visible imagery of the site.
RPAS Meteorological Data	Not published due to a correlation between meteorological data and the movement of the RPAS.
Instrument Locations (McNamara 2018d)	GPS recorded locations of instrument placement.
Sonic Detection and Ranging (Butler et al. 2018c)	One sonic detection and ranging (SODAR) device on the western edge of the three burn blocks.
Thermocouple rakes (Butler et al. 2018d)	Measurements of in-situ temperature from a set of thermocouples mounted on two rakes. Each burn block had four rakes placed end to end
Northern and Southern SODAR (Not Published)	Two SODAR instruments on the southern and northern end of the burn blocks. Data could not be published due to data quality and documentation issues

Northern and Southern Anemometers (Not Published)	Two ten-meter anemometer towers on the northern and southern end of the burn blocks. Data could not be published due to data quality and documentation issues

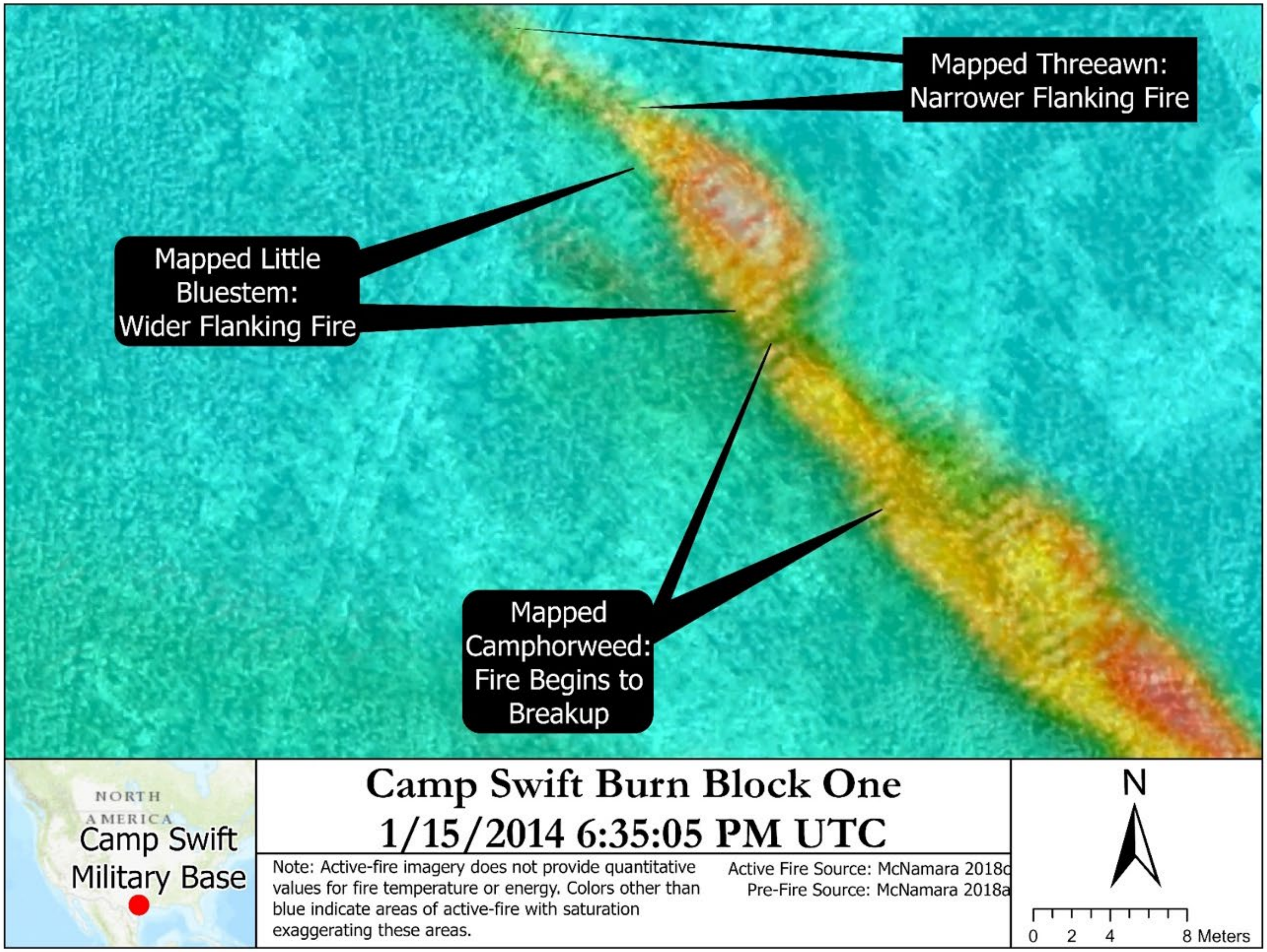

Figure S1-1: Qualitative active fire IR imagery from Camp Swift Burn Block 1 shows flanking fire behavior changes coincident with mapped vegetation changes (McNamara and Mell 2018b). We portray the IR imagery with some transparency, thereby highlighting the pre-fire imagery below the active fire imagery.

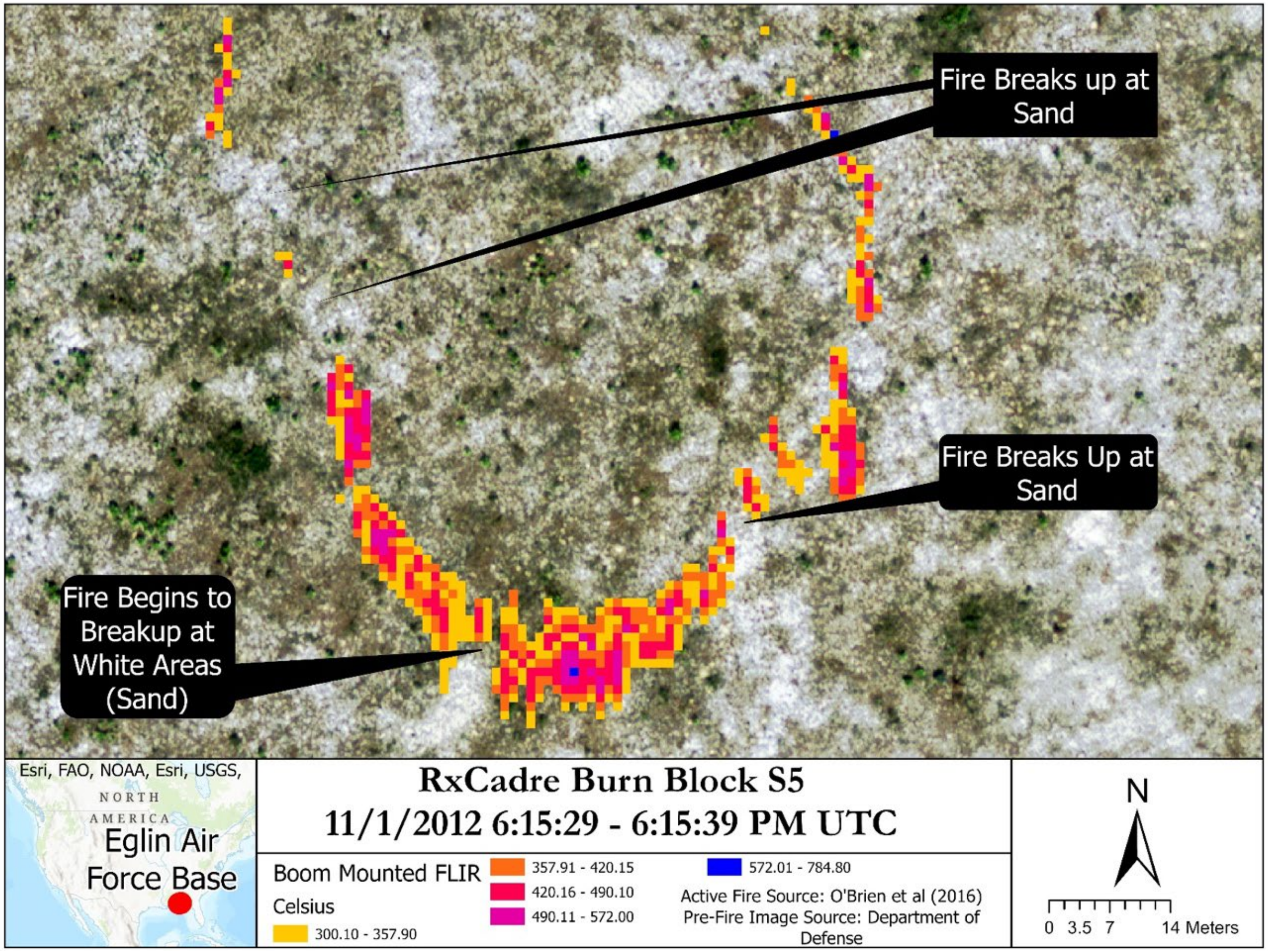

Figure S1-2: RxCADRE Burn Block S5 active fire imagery (O'Brien et al. 2016) overlaid with pre-fire imagery (described in Linn et al. 2020), showing the fire line shape and width affected by fuel breaks. Bright white areas in the imagery are sand. Grey areas, typically surrounding the white areas, are a mix of vegetation and sand.

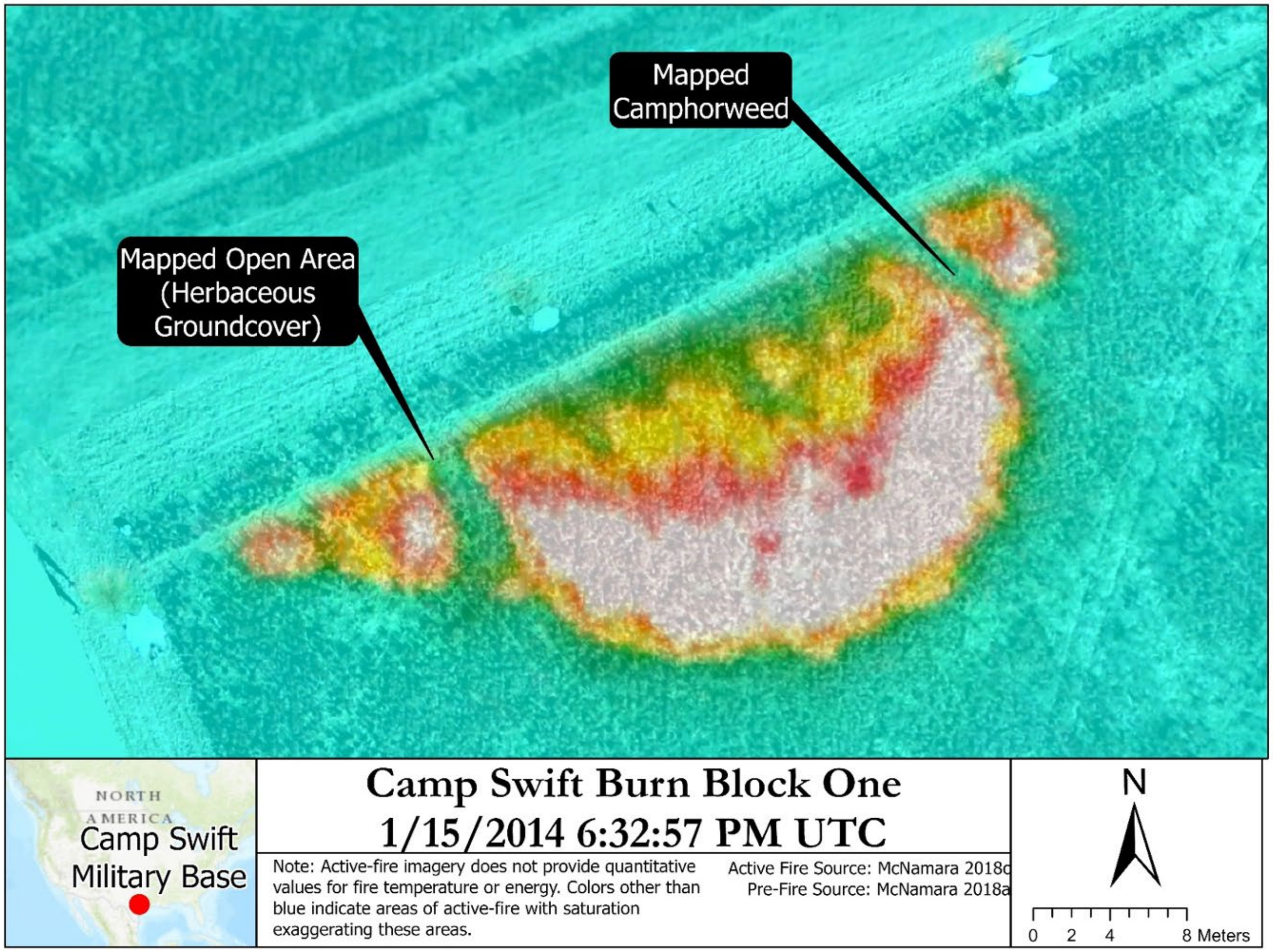

Figure S1-3: Mapped areas of open vegetation with herbaceous ground cover and Camphorweed (McNamara and Mell 2018b) breaking up the ignition of the fire. We portray the IR imagery with some transparency, thereby highlighting the pre-fire imagery below the active fire imagery. The break-up of the igniting fireline resulted in a head fire width the was significantly narrower than the 50 m ignition line.

Supplementary Material 2: Example Data Governance for Three-Dimensional, Time-Dependent Fire Behavior Model Evaluations

Neylon (2017) emphasized the importance of policy (i.e., data governance) in supporting cultural change regarding data sharing. Three-dimensional fire model evaluation efforts producing integrated datasets require data governance to empower and protect project participants, stakeholders, and data. We do not intend data governance to be compliance-oriented but rather foster a culture of data sharing and openness about data quality issues. The following are examples of policies that we believe would be conducive to fostering interdisciplinary efforts that produce integrated datasets for 3D fire model evaluation:

1. **The project will produce an integrated dataset at project completion.**

   Guidance for data delivery from research projects sometimes requires data to be delivered sometime after the final report for the project. This data governance is potentially counter-productive to producing an integrated dataset for fire model evaluation, but not for all experiments. First, it is not easy to track data delivery from complex projects if researchers deliver it piecemeal over multiple years and there is no accurate data catalog. Also, if researchers deliver the data as siloed assets over time, it is unclear how the project integrated it. Finally, this guidance provides a clear objective for the project team and stakeholders, providing the common understanding that the project's primary purpose is to deliver an integrated dataset to the OD repository.

2. **The project will track the lineage of all data during the data life-cycle**.

Data lineage includes tracking all individual and integrated data products, including collection, processing, QC, and publication. Both within individual data products and the integrated effort as a whole, the lineage of the data will be tracked and maintained throughout the data life-cycle. This policy will reduce operational friction as project participants understand the need to track data lineage. Also, this policy will alleviate the potential for data loss and provide the ability to trace errors back to the source.

3. **The project will conduct data quality assessments at specified points during the data life-cycle**.

Policies related to the quality assessment of the data will foster a culture of openness regarding data quality. Data management plans, QAPPS with associated DQOs and response actions, and ongoing metadata development are data governance procedures that help ensure researchers and data managers QC the data, document QC results appropriately, and take appropriate response actions. This data governance also reduces operational friction as requirements for data quality are transparent. Finally, this policy helps to develop repeatable processes and ensure transparency.

4. **Any use of the data produced for modeling or other purposes involves correct citation of the work by researchers**.

Including explicit use and access constraints can inform outside data users of appropriate actions to take with the data (e.g., dataset citation). Duke et al. (2013) provided a guide for including data providers as authors. Finally, published datasets should receive equal recognition as published papers. This governance reduces friction between data users, data collectors, data managers, and stakeholders as the DMP and initial metadata detail access and use constraints regarding the data at the beginning of the project.

The governance described above is designed particularly for projects producing integrated datasets for 3D fire model evaluations. This governance would be onerous for methodological studies where manuscripts about the methods and their appropriateness are of utmost concern. However, for 3D fire model evaluations, the data and documented quality control results are of utmost concern. We believe the above governance improves existing governance (e.g., Joint Fire Science Program 2021) for fire model evaluations because it clarifies the project's purpose, making data with the documented quality, and use and access constraints available to an international audience.

References

<bok>Butler BW, Jimenez DM, Teske CC (2018*a*) Camp Swift Fire Experiment 2014: in-situ anemometer measurements. Fort Collins, CO: Forest Service Research Data Archive. doi:10.2737/RDS-2018-0041</bok>

<bok>Butler BW, Jimenez DM, Teske CC (2018*b*) Camp Swift Fire Experiment 2014: fire behavior packages and videos. Fort Collins, CO: Forest Service Research Data Archive. doi:10.2737/RDS-2018-0042</bok>

<bok>Butler BW, Jimenez DM, Teske CC (2018*c*) Camp Swift Fire Experiment 2014: SODAR measurements. Fort Collins, CO: Forest Service Research Data Archive. doi:10.2737/RDS-2018-0051</bok>

<bok>Butler BW, Jimenez DM, Teske CC (2018*d*) Camp Swift Fire Experiment 2014: Thermocouple rakes. Fort Collins, CO: Forest Service Research Data Archive. doi:10.2737/RDS-2018-0052</bok>

<jrn>Duke CS, Porter JH (2013) The ethics of data sharing and reuse in biology. *Bioscience* **63**, 483–489. doi:10.1525/bio.2013.63.6.10</jrn>

<jrn>Linn RR, Winterkamp JL, Furman JH, Williams B, Hiers JK, Jonko A, O'Brien JJ, Yedinak KM, Goodrick S (2021) Modeling low-intensity fires: lessons learned from 2012 RxCADRE. *Atmosphere* **12**, 139. doi:10.3390/atmos12020139</jrn>

<other>McNamara DJ (2018*a*) Camp Swift Fire Experiment 2014: Pre-fire unmanned aerial vehicle (UAV) imagery. Fort Collins, CO: Forest Service Research Data Archive. doi:10.2737/RDS-2018-0049</other>

<other>McNamara DJ (2018*b*) Camp Swift Fire Experiment 2014: Active fire unmanned aerial vehicle (UAV) electro-optical imagery and video. doi:10.2737/RDS-2018-0046</other>

<other>McNamara DJ (2018*c*) Camp Swift Fire Experiment 2014: Post-fire unmanned aerial vehicle (UAV) imagery. doi:10.2737/RDS-2018-0048</other>

<other>McNamara DJ (2018*d*) Camp Swift Fire Experiment 2014: Active fire unmanned aerial vehicle (UAV) infrared imagery and video. doi:10.2737/RDS-2018-0047</other>

<eref>McNamara DJ, Mell WE (2018*a*) Camp swift fire experiment 2014: integrated data quality assessment. Available at https://usfs.maps.arcgis.com/home/item.html?id=aa3726577d9549a2a26b7d000fb98512 [Verified 12 December 2020]</eref>

<bok>McNamara DJ, William ME (2018*b*) Camp Swift fire experiment 2014: vegetation map. Fort Collins, CO: Forest Service Research Data Archive. doi:10.2737/RDS-2018-0043</bok>

<jrn>O’Brien JJ, Loudermilk EL, Hornsby B, Hudak AT, Bright BC, Dickinson MB, Hiers JK, Teske C, Ottmar RD (2016) High-resolution infrared thermography for capturing wildland fire behaviour: RxCADRE 2012. *International Journal of Wildland Fire* **25**, 62–75. doi:10.1071/WF14165</jrn>

<jrn>Ottmar RD, Hiers JK, Butler BW, Clements CB, Dickinson MB, Hudak AT, O’Brien JJ, Potter BE, Rowell EM, Strand TM, Zajkowski TJ (2016) Measurements, datasets and preliminary results from the RxCADRE project – 2008, 2011 and 2012. *International Journal of Wildland Fire* **25**, 1–9. doi:10.1071/WF14161</jrn>

<jrn>Neylon C (2017) Building a culture of data sharing: Policy design and implementation for research data management in development research. *Research Ideas and Outcomes* **3**, e21773. doi:10.3897/rio.3.e21773</jrn>

<bok>Restaino JC (2018) Camp Swift Fire Experiment 2014: field fuel samples. Fort Collins, CO: Forest Service Research Data Archive. doi:10.2737/RDS-2018-0044</bok>