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Northern Tornadoes Project 2018/19 Report

Northern Tornadoes Project
Western University, ntp@uwo.ca

Northern Tornadoes Project
2018/19 Report

THE NORTHERN TORNADOES PROJECT — Western Engineering

INDIGENOUS LAND ACKNOWLEDGEMENT

We acknowledge that Western University is located on the traditional lands of the Anishinaabek (Ah-nish-in-a-bek), Haudenosaunee (Ho-den-no-show-nee), Lūnaapéewak (Len-ah-pay-wuk) and Attawandaron (Add-a-won-da-run) peoples, on lands connected with the London Township and Sombre Treaties of 1796 and the Dish with One Spoon Covenant Wampum. This land continues to be home to diverse Indigenous peoples (e.g. First Nations, Métis and Inuit) whom we recognize as contemporary stewards of the land and vital contributors of our society.

THE NORTHERN
TORNADOES PROJECT
Western
Engineering

The Northern Tornadoes Project (NTP) is a partnership between Western University and ImpactWX that aims to better detect tornado occurrence throughout Canada, improve severe and extreme weather prediction, mitigate against damage to people and property, and investigate future implications due to climate change. Western University also collaborates with Environment and Climate Change Canada, and several international universities on this Project.

VISION

• That Canadians are better informed about tornadoes and are able to better protect their homes and communities.

• That NTP is an authoritative source on tornado documentation and research in Canada.

MISSION

• To better detect and document tornado occurrences throughout Canada.

• To improve communication of tornado science and risk to Canadians.

• To reduce damage to people and property.

• To better understand tornado climatology in Canada to identify trends due to climate change.

VALUES

Community driven

NTP is a community endeavour. It will take the efforts of the full severe weather community of scientists, emergency managers, media outlets, and storm enthusiasts to ensure the Project's success across Canada. All of our research is open access and freely available to the public and other researchers.

Education & Awareness

NTP is developing new methods and tools to increase our knowledge of tornadoes and push the boundaries of tornado research. It utilizes satellites, surveillance planes, drones and on-ground observations to capture and analyze tornado events and their damage. NTP is one of the most comprehensive tornado investigations ever undertaken in Canada and seeks to have a national and international impact.

Public empowerment

NTP is committed to saving lives, mitigating loss and strengthening knowledge and understanding of historic, recent and future tornado activity.

MESSAGE FROM NTP LEADERSHIP

Three years ago, we set our sights on finding at least a few undocumented tornado tracks in the remote forests of northern Ontario.

We have covered greater distances and nurtured bigger ambitions since then.

From northern Ontario to all of Canada, from aircraft surveys to drones and satellites, from on-the-ground damage investigations to artificial intelligence analyses, the Northern Tornadoes Project is one of the most comprehensive tornado research projects in the country. It aims to better detect tornado occurrences throughout Canada, improve communication of tornado science and risk, and mitigate against harm to people and property. NTP also seeks to increase knowledge of tornado climatology to better understand trends due to climate change.

This report is our journey through the past three years. It tells you where we have been, and where we are headed.

The Northern Tornadoes Project took off through generous donations from Toronto-based social impact fund ImpactWX and Western University. The funds got the project started, and helped expand it from one province to the whole nation. We also acquired cutting-edge technology, and built an expert team of researchers, engineers, and meteorologists. This includes collaborations with Environment and Climate Change Canada, and research groups in Canada, United States, and the United Kingdom.

As you read this report:

We are leveraging cutting-edge technology to increase our knowledge of tornadoes and push the boundaries of tornado research.

We are systematically collecting all possible tornado damage and tree-fall data in Canada and analysing it with a world-class team of engineers, meteorologists, and scientists. Our long-term vision is to cost-effectively automate detection and classification of all tornadoes in Canada. Our drone surveys and satellite images are giving us unparalleled capabilities to capture and analyze tornado events and their damage. We also plan on harnessing the power of artificial intelligence to automate our analysis of severe weather damage.

We are recruiting the right people. Our world-class researchers (including two Vanier Scholars), engineers and meteorologists are creating dynamic and innovative research environments. Our newly hired full-time Communications Specialist is busy communicating the Project's research impacts to national and international audiences and engaging with our dedicated weather-enthusiasts on social media.

We are community driven. We believe in the collective power and efforts of Canada's severe-weather community to raise awareness and help us grow bigger. Our Frequently Asked Questions page gives people a peek into the fascinating world of severe weather, and our team! Our Open Data site is a publicly accessible online database of historical and recent Canadian tornadoes with detailed satellite, aerial, drone and ground surveys and analysis. We are also leveraging the power of crowdsourcing via social media and citizen science to expand our reach. For the past three years, people have submitted reports of tornado sightings from across Canada to our Report A Tornado section and NTP social media accounts. The data are freely available to everyone.

Our report details all the above and much more. Take a walk through its pages. We are just getting started.

Greg Kopp & David Sills

ACKNOWLEDGEMENTS

NTP TEAM: LEADERSHIP

Dr. Greg Kopp is the ImpactWX Chair in Severe Storms Engineering and a professor in Western University's Department of Civil and Environmental Engineering. He received a B.Sc.M.E. from the University of Manitoba in 1989, a M.Eng. from McMaster University in 1991 and a Ph.D. in Mechanical Engineering from the University of Toronto in 1995. His expertise and research relate to mitigating damage to structures during extreme wind storms such as tornadoes and hurricanes. He works actively to implement research findings into practice, currently serving as Chair of the ASCE 49 Standards Committee on Wind Tunnel Testing For Buildings and other Structures, and as a member of various other Building Code committees. A former Canada Research Chair in Wind Engineering, he is also the lead researcher for the Three Little Pigs Project at The Insurance Research Lab for Better Homes.

Dr. David Sills is Executive Director of the Northern Tornadoes Project. He received a BSc in Atmospheric Science and Certificate in Meteorology from York University in 1993, as well as a PhD in Atmospheric Science from York University in 1998. He worked for more than 20 years as a severe weather scientist with Environment Canada, conducting research on Canadian tornadoes, severe weather nowcasting and mesoscale meteorology. He was awarded the CMOS Rube Hornstein Medal in Operational Meteorology and the Geoff Howell Citation of Excellence for Innovation. Dr. Sills serves as Associate Editor for the journals Atmosphere-Ocean and Monthly Weather Review. When not investigating the latest tornado, he also writes/performs indie folk-rock, is an avid photographer, and sails the Great Lakes with his wife Heather.

NTP TEAM: ENGINEERING

Aaron Jaffe's Master's thesis on tornadoes is a series of high pressure situations – but think data, not deadlines. During a tornado, flying debris often shatters windows and breaks doors. Wind rushes in, and internal pressures push the roof and walls outwards. Outside, external pressures from the tornado pull the roof up and apart. Using model houses, wind tunnels, and computer simulations, Aaron (BESc '17, Civil and Structural Engineering, Western University) is helping predict internal pressures of houses when they are in the midst of tornadoes. His study, one of the most comprehensive in his field so far, will help engineers and home-builders construct stronger, more resilient houses. "We can't stop tornadoes, but we can better predict their impacts, and design stronger houses to protect against them," he says. As the Northern Tornadoes Project's full-time research engineer and member of the Tornado Damage Survey Team, Aaron conducts engineering analysis of damaged and undamaged houses, analyzes aerial surveys of severe weather events, and summarizes the Team's damage reports.

Connell Miller's PhD thesis is all about protecting your home from the elements. The most common and popular types of cladding (like vinyl siding, and roof pavers) have air gaps for drainage and installation purposes. After wind storms, claddings often fail, even though they are designed to withstand that wind. Connell (BESc [Distinction] '14, Structural Engineering, Western University) uses full-scale experiments to better understand how wind interacts with air gaps in common types of residential cladding. His research will help create more accurate building codes for them. "Cladding wind loads in current building and manufacturing codes are either inaccurate or absent," he says. "That is why it is common to see failures of cladding where there shouldn't be." Connell is also a Northern Tornadoes Project's part-time research engineer and member of the Tornado Damage Survey Team. Apart from conducting damage surveys, he is also responsible for developing and conducting drone surveys. These map tornado paths at very high resolution, and allow better examination of damaged vegetation and man-made structures.

THE NORTHERN TORNADOES PROJECT — Western Engineering

NTP TEAM: METEOROLOGY

During warm summer months, Lesley Elliott (BSc [Hons] '04, Atmospheric Science, University of Alberta, MSc '06, Earth and Atmospheric Science, University of Alberta) is exploring nearby parks and trails with her young family, hitting up a local farmer's market, and also, tracking tornadoes with her keyboard and mouse. As the Project's main research meteorologist, Lesley is routinely checking radar imagery (and sometimes satellite imagery and lightning maps), and tornado-related hashtags on social media. She creates most of the Northern Tornadoes Project's tornado outlooks (daily during the peak season from June to August, and only as needed during the remaining months). The outlooks describe the risk of tornado formation (chance, likely or outbreak) based on meteorological observations and various weather model output and are intended to prepare the Tornado Damage Survey Team for possible action over the next several days. Lesley also creates event maps for the Team. The maps contain social media reports, radar-based storm tracks, ground survey observations, and sometimes, eyewitness accounts from locals. They also contain damage tracks observed with satellite imagery and flight plans for future high-resolution aerial imagery surveys. "I feel fortunate to be part of a group that is making sure that people are more aware of and better protected from tornadoes in Canada," she says.

Joanne Kunkel (BSc [Hons] '12, Atmospheric Science and Certificate in Meteorology, York University, MSc '16, Atmospheric Science, York University) roams Canada, almost 500 kilometres high with her keyboard and mouse. The country sprawls across her computer screen, from The Prairies to Southern Ontario to New Brunswick. The Northern Tornadoes Project's satellite analysis lead studies daily satellite images, scanning for telltale signs left in the wake of tornadoes and other severe weather events - fallen trees, razed structures, damaged crops, for example. She is also continuously scanning over the country, section by section, looking for historical tornadoes, and uses her meteorological skills to contribute to the daily tornado outlooks. Before heading out to the field, the Project's Tornado Damage Survey Team relies on Joanne's vital work and eye for detail to plan out survey routes and mark places of interest. As a meteorologist, she wishes people took tornado watches and warnings more seriously.

NTP TEAM: STRUCTURAL AND WIND ENGINEERING

Sarah Stevenson (BSc [Hons] '15, Civil Engineering, University of Manitoba, MESc '17, Wind Engineering, Western University) is tearing apart houses for her PhD. With the click of a mouse, and some computer code, she buffets them with high winds, rams them through thunderstorms, swirls them around in tornadoes. By studying how severe wind events weaken the bones and joints of a house - connections between ground to floor, floor to wall, wall to roof (and everything in between), for example - Sarah's research is helping develop stronger, more resilient houses. Currently, Canada's building codes rarely take severe wind effects into account. With climate change potentially affecting severe weather patterns in the coming decades, Sarah's research is helping develop newer, more improved building codes. She is also a member of the Northern Tornadoes Project's Tornado Damage Survey Team, where she investigates the devastating after-effects of tornadoes on people's homes. The field studies, in addition to site inspections of new houses under construction, often find their way into her computer models, making her findings more realistic and practical than anything being currently studied.

"Human impact in the wake of tornadoes and other severe weather events has always affected me,"says Emilio Hong (BESc '15, Civil and Environmental Engineering, Western University). "That's why we do what we do - to prevent this from happening again." The PhD scholar and Northern Tornadoes Project part-time research engineer is also a member of the Tornado Damage Survey Team. Following severe weather events, Emilio helps to analyze images obtained from drone and aerial surveillance that are used to determine the extent of tree damage and classify events into tornadoes, or downbursts, for example. The catch - he need to do it by eye. His solution - automate the procedure using computer modelling and artificial intelligence (AI) to drastically cut down analysis times. The AI program will also be able to scan drone or aerial photos of severe weather damage (tornado tracks, for example) in forests, and decide the type and severity of the event in seconds. The work will improve our knowledge on current risks and estimated effects of tornadoes.

Ibrahim Ibrahim (BSc '12, Civil and Environmental Engineering, Alexandria University, MSc '17, Civil and Environmental Engineering, Western University) is building maps out of numbers. For his PhD, the former civil engineer is combining and analyzing decades of meteorological data from multiple sources such as radars, satellites, and wind observations. His hope - build a database for a map of North America that estimates downburst frequency anywhere in the continent. Currently, no such map exists. Critically, the comprehensive dataset will help civil engineers understand how downbursts affect buildings. "We have very good records for 'everyday' winds, but there is little data for downbursts," he says. As part of the Northern Tornadoes Project's Tornado Damage Survey Team, Ibrahim will be tracking - you guessed it - downbursts.

NTP TEAM: GEOGRAPHIC INFORMATION SCIENCE TECHNICAL SPECIALIST

Geographic Information Science (GIS) is an incredible data collection tool that helps elevate what engineers do," says Liz Sutherland (BSc [Hons] '16, Geographic Information Science, Western University). As the GIS Technical Specialist for Northern Tornadoes Project (and Western Libraries Map and Data Centre), she is integral to correctly storing, cataloging, and maintaining massive amounts of information and data from the Project's aerial, drone, satellite, and ground surveys. Prior to Liz's arrival at the Project, team members would conduct ground surveys, come back to the laboratory, pore over field data, and manually combine it with photographs, and aerial and drone surveys. Liz's Survey123 app lets team members leverage the power of GIS to capture field locations and gives them a form to enter all descriptive data. "Within hours, I can turn those data into maps and application through GIS shortly after it is uploaded," she says. "The team can see all field data and important statistics, such as the number of damaged trees or maximum wind speed assessments right away." Her work has saved the team valuable time by moving away from tackling individual data points to combining it under one platform and analyzing it immediately. Another of Liz's contributions - the Project's Open Data Site - is a pioneering example of a university-driven open data platform being utilized by severe weather researchers.

NTP TEAM: COMMUNICATIONS SPECIALIST

Aniruddho Chokroborty-Hoque (MSc '10, Microbial Ecology, Western University, PhD '17, Genetics and Neuroscience, Western University) is a research communicator who has happily migrated from a fifteen-year stint conducting research to a lifetime of writing its stories. He is using multiple communication initiatives (e.g. commissioned op-eds, interviews, social media content, podcasts, videos shorts) to communicate the 'so what, who cares?' of NTP research to its various audiences - researchers, policy-makers, weather enthusiasts, and the general public. Aniruddho works with the NTP team to strategize and deploy storytelling strategies to raise the Project's visibility on national and international platforms. "I would like to help establish NTP as the authoritative source of open-access data and research on extreme weather events," he says.

NTP OPERATIONS: Daily Outlooks

Daily forecasts of tornado potential enables readiness of the NTP team, by both heightening the awareness of research staff observing events in real time (e.g., monitoring storms on radar for supercell thunderstorm features, checking social media for relevant witness or damage reports, etc.) and providing ground survey teams with advance notice of potential deployment. While only a small fraction of storms will produce a tornado, accurately identifying the areas at risk is an important step in the NTP methodology.

During the 2018 and 2019 NTP campaigns, tornado outlooks were produced daily starting in early June through to mid-September, and on an as-needed basis in the shoulder months.

Tornado potential on Day 2 (i.e., the following day) was identified by the forecaster, with updates to risk levels and areas issued for Day 1 when warranted. In the event there was model consensus of a possibly significant tornado event several days in advance, a Day 3 outlook would be produced as well.

During the 2018 NTP, with the focus solely on Ontario, the forecaster could confidently issue Day 3 and Day 4 outlooks that contained no apparent tornado risk (i.e., a map with no risk polygons) when synoptic weather patterns creating stable environments that would inhibit significant convective activity were anticipated several days in advance.

With the expansion nationwide in 2019, the forecaster would only invest time producing a Day 3 outlook if a significant tornado risk was apparent in a given region.

If a forecast was particularly challenging and/or tornado risk was elevated above 'chance', some discussion and collaboration typically occurred within the forecast team to refine risk areas and levels with the highest confidence possible.

In 2018, the tornado outlooks focused on the development of supercells and/or a quasi-linear convective system (QLCS), with polygons representing risk levels for each parent-storm type overlaid on a map of Ontario when a risk above marginal was identified by the forecaster (e.g., Figure 1).

A text summary of the anticipated storm environment accompanied the map. These outlooks also included additional graphics displaying forecasted synoptic scale weather features (e.g., frontal boundaries) and when applicable, relevant probabilistic model output fields.
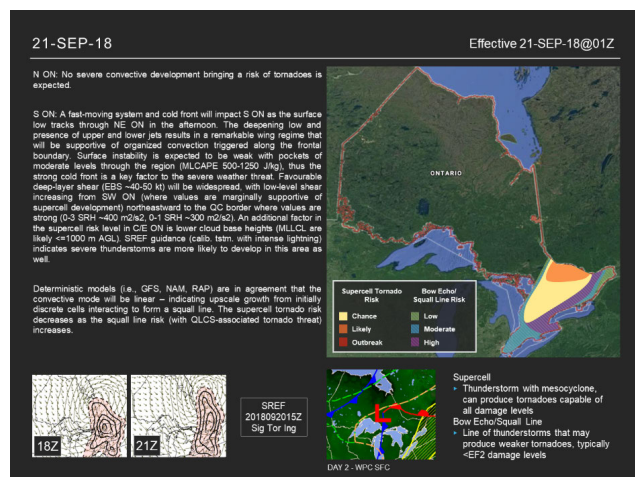

Figure 1: NTP Tornado Outlook for September 21, 2018.

NTP OPERATIONS: Daily Outlooks (continued)

The 2019 NTP expansion nationwide resulted in several refinements to the methodology and outlook template through discussion and feedback within the forecast team (which increased from two to three meteorologists). Changes to the tornado outlooks included removal of additional graphics and utilizing national maps and summaries with fewer details when tornado risk did not exceed 'chance'. Additionally, a new polygon was introduced on the national map that identified areas where any type of thunderstorm development (unorganized or organized) was possible (e.g., Figure 2).

When a tornado risk above 'chance' was identified, a regional map was included with an expanded summary discussing expected parent-storm type and key environmental parameters (e.g., Figure 3). This streamlined process was in place for the forecast team by early August 2019.

Upon completion of the tornado outlook, the forecaster saves a copy of the PowerPoint file as a PDF and uploads the files to an NTP shared folder on Google Drive. An email is sent to the NTP team that includes a Ground Survey Team Alert Level, which indicates the chance of deployment to the field within an identified risk area (low, moderate or high). Ideally, a Day 2 outlook is issued by the early afternoon, which gives the ground survey team advance notice of the potential for active weather and deployment within 48 hrs. If a Day 1 update is warranted, it is prepared and shared with the team by mid-morning.

After the revised outlook template was adopted in early August 2019, it was decided that the NTP Twitter account would post an outlook publically in the event that a 'likely tornado' risk (or higher) was identified by the forecast team. This occurred on two occasions: August 21 (the Day 2 outlook identified a likely tornado risk in south-central QC) and September 13 (a Day 1 updated identified a likely tornado risk in southwestern ON). On August 21,

three EF2s and one EF1 tornadoes developed in the 'likely tornado' risk area and one EF1 tornado developed in the 'chance tornado' risk area. On September 13, no tornadoes developed in the 'likely tornado' risk area, although an NTP ground survey confirmed an EF0 downburst caused damage in the 'chance tornado' risk area.
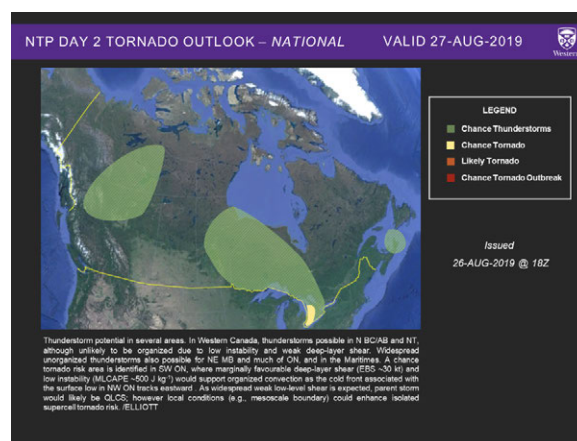

Figure 2: NTP Tornado Outlook for August 27, 2019.

Figure 3: NTP Tornado Outlook with regional map and expanded summary, August 21, 2019.

NTP OPERATIONS: Crowdsourcing

The principal source of witness and damage reports collected during the 2018 and 2019 NTP campaigns was public posts to popular social media platforms (i.e., Twitter, Facebook, Instagram, YouTube).

Social media users – ranging from individuals to public and private organizations – can quickly share information online through posts and/or comments (typically accompanied with a photo or video) during or after an event. Initial Twitter searches focus on posts with relevant hashtags (e.g. #onstorm for storm-related posts in Ontario, #ottweather for an Ottawa weather-related post). Searches are also completed for specific location tags (at times guided by review of storm location as seen by radar) and keyword combinations (e.g., 'Calgary' AND 'funnel cloud').

In spring of 2019, NTP introduced specific hashtags for posts that are directly related to possible tornado events in each province and territory of Canada (e.g., #bcNTP, #ykNTP, etc.). This helped NTP team members quickly track and follow up on events. A key source of information on Facebook are the Instant Weather regional community pages created for all areas in Canada. Some of these pages, particularly the Ontario and Prairie province pages, are very active during a severe weather event with witness accounts and/or reports of local damage incurred.

Several other public Facebook community pages operated by storm chasers in active regions are also accessed regularly. Additionally, NTP team members have joined several private Facebook groups discussing active severe weather in specific regions of Canada (e.g., the "Alberta Storm Chasers" group).

If there is doubt regarding the authenticity of a report, comparing images/video to street view in Google Maps and/or Google Images allows for quick verification of the validity of the report. In some instances, and especially when the NTP team is likely to complete a ground survey, contact is made with the account holder to request further information about eyewitness reports, additional details about location, timing and damaged incurred and/or copies of high-resolution images/video for analysis and archiving.

The research meteorologist saves relevant social media posts on the various platforms by taking screen captures and recording the link to the post. Additionally, posts on Twitter can be 'liked' and Facebook posts can be saved to a collection, allowing for quick recall on those platforms.

Additional sources of reports include information passed via email to NTP by contacts within ECCC, who receive many direct reports from the public and from trained spotters. Witnesses are also encouraged to submit reports via the NTP website. During the active months of 2019, eleven reports were submitted directly to the NTP team in this manner, including reports from five tornado events already under investigation and two previously unknown reports that were assessed as 'vortex-funnel cloud aloft' events. Additional reports included historical tornado damage, straight-line wind damage and witness photos of non-severe cloud features.

Information gleaned from the witness and damage reports collected by the NTP team are plotted on a map shared on Google Drive with all team members. A Google My Maps event map is created for each day with relevant reports (divided up into western and eastern regions). Data points are added to the maps for each area where damage is reported or a witness reported a tornado or potential tornado event.

A complete record includes a brief description of the report, an approximate time of event, the location (as specific as possible), a link information source, photo(s) of the post and additional media shared, and notes with other relevant information added by the research meteorologist.

NTP OPERATIONS: Ground Surveys

Ground surveys are a long-standing method of wind damage investigation. They are particularly useful when structures are damaged, and the details of construction can be captured. In fact, some details important to the rating of wind damage can only be obtained on the ground by well-trained surveyors.

Because damage is often cleaned up within a day or two of the event, including clues that may be key to understanding the type and intensity of the wind phenomenon, the ground survey team needs to be on site as soon as possible after the event.

The NTP tornado outlooks help to ensure that potential surveyors are ready to travel at a moment's notice.

Not all events warrant a ground survey. First, ground surveys can only be performed if the damage is accessible by road. In some cases, damage is very localized and photos or video available via news or social media provide sufficient evidence adequately characterize the event.

Ground surveys are most often used when there is significant structural damage or when the cause and/ or scope of damage is unclear.

Once on site, there can be different approaches for the survey depending on the scope of the damage. In some cases it may be sufficient to view the damage while driving the local road network, documenting more significant damage along the way. These are typically lower intensity events.

For larger events with higher intensity damage, surveyors may record data on a door-to-door basis.

In each case, the surveyors typically begin their work in the area of worst damage and work outwards until the threshold of damage (and therefore the length and width of the damage path) is identified.

The NTP damage survey app was developed to make the survey process quicker and more efficient. This app, installed on tablets and cell phones, is used by the surveyor to quickly record site information and take photographs, linking data to the GPS-derived location of the event with its name, degree of damage, estimated wind speed, type of damage, etc. Added benefits of this app include sending the information back immediately and a more standardized process, as opposed to the previous ad hoc approach.

The survey teams will also often talk with witnesses to the event, as they can provide critical information that helps to interpret damage details correctly. One example is noting whether doors to a farm building were left open, since this increases susceptibility to wind loading and therefore can affect the EF-scale rating.

For heavily damaged structures, the team undertakes an engineering analysis of the various connections (e.g., wall to roof) and other failures on the building. Pictures are taken of these connections and failures for further analysis.

These detailed studies help formulate solutions to mitigate against future structural damage to buildings due to tornadoes.

As the survey progresses, the route taken by the survey team is tracked to identify all areas surveyed. This improves the reliability of the survey, knowing which areas were accessible and which areas were not accessible but could possibly have damage that may be found later via aerial analysis.

In total, 54 ground surveys were conducted (26 in 2018 and 28 in 2019).

NTP OPERATIONS: Drone Surveys

Remotely piloted Unmanned Aircraft Systems (commonly known as drones) are aircraft without a human pilot on board. They are controlled from the ground either by remote control or autonomously with pre-programmed flight paths. In 2018, drones were used to take single aerial photographs of damaged structures. In 2019, our goal was to use them to improve the quality of data for research and classification purposes. We increased our drone fleet by adding two "Mavic 2 Pro" drones, which are equipped with a 20-megapixel camera with a one - inch sensor - the highest quality camera currently available on a commercially available drone.

For research-quality imagery with even higher resolution (order of centimetres), aerial photography is often used. However, aerial photography from traditional aircraft can take a significant amount of time to obtain, which can lead to delays in determining damage classification and rating, and may not capture the full scope of damage due to the area being cleaned up over those months. By flying drones over damaged areas using pre-programmed grids, high-quality data such as orthomosaic maps, 3D models, digital terrain models, and digital surface models can be generated.

Using and evaluating orthomosaic mapping was a focus for NTP in 2019 (e.g., Figure 1) . Orthomosaic maps are made up of a series of individual photos which have been merged to form one composite image that has been adjusted for topographic relief, lens distortion, and camera tilt. These corrected composite images allow for the same accuracy as satellite or aerial imagery, but with higher resolution and a faster deployment time.

One of our new Mavic 2 Pro drones was equipped with a near-infrared (all instances). The near infrared spectrum measures chlorophyll amounts in a plant by analyzing the quantity of near-infrared light it reflects. (The more near infrared light reflected, the more chlorophyll in the plant.) With this, we can generate normalized difference vegetation index (NDVI) maps. NDVI maps are used for determining overall plant health in grass and low-lying crops that may not show visible signs of tornado damage. For the 2020 tornado season, the goal is to have orthomosaic mapping for every ground survey we perform. To do this, research will go into finding drones that are capable of flying beyond visual line of sight for an extended period of time, to improve the speed at which we can do this mapping.
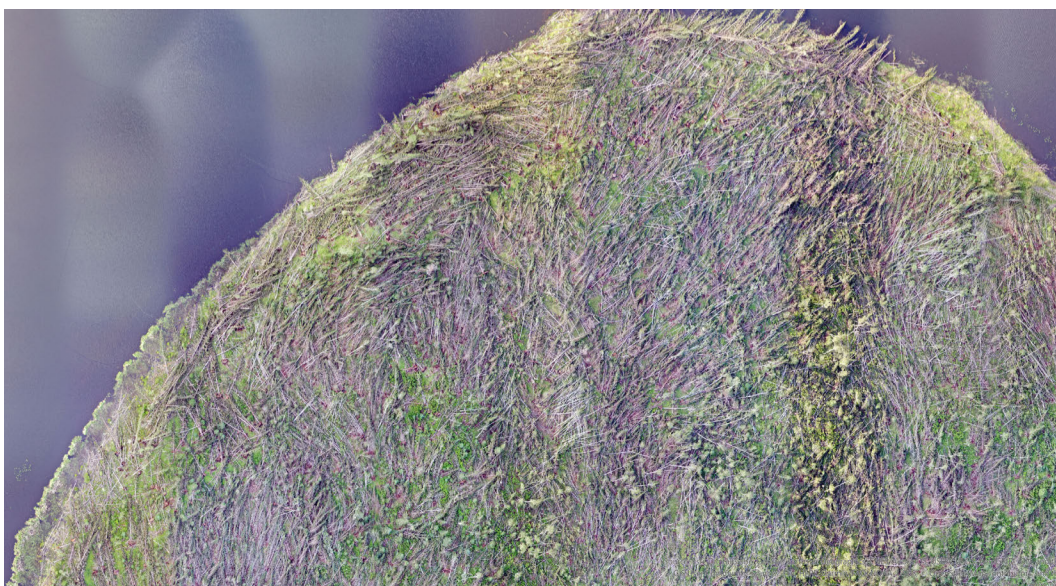

Figure 1:
Lac des Iles
SK, 2019
Drone-derived
orthomosaic map
(1.5 centimetre
resolution).

NTP OPERATIONS: Satellite Analysis

The Northern Tornadoes Project uses high-resolution (3-5 metre) satellite imagery (via planet.com) to to help identify tornadic damage paths, as well as damage associated with downbursts and hail swaths. Over forested regions, tree fall is generally straightforward to detect as it creates noticeable scars.

When possible, ground surveys, aerial and drone flights are also conducted over these forested areas to collect high-resolution data for research. However, over agricultural and treeless northern landscapes, tornado tracks are not as easily detected via satellite imagery.

Strong attention to detail is required while searching these landscapes, but even then, not all damage will be visible with satellite imagery. Therefore, it is essential to conduct ground surveys, aerial and drone flights.

Currently, Planet`s Surface Reflectance (SR) product is being researched as a potential means for identifying tornado tracks over these more challenging landscapes. The Surface Reflectance Product is often used in the agricultural industry for real-time monitoring of crop health. For NTP`s purposes, these day-to-day changes in the reflectance of crops and/or grass, may help us better determine whether a tornado had occurred over agricultural or treeless landscapes, especially when there are no additional sources of information to verify a tornado's occurrence.

Satellite analysis begins after supercell and QLCS storm tracks have been identified from radar analysis and crowdsourcing (weather office reports, posts from storm chasers and the public on Twitter and/or Facebook, for example). The storm tracks are created in Google Maps, and uploaded into Planet Explorer where the hunt for damage begins. Planet is the world's largest collector and distributor of Earth-imaging satellite data. It operates the largest fleet

(130+) of Earth imaging Doves (3 metre resolution) that line scan the Earth, as well as five RapidEye (5 metre resolution) satellites. Doves orbit the poles every 90 minutes, capturing Earth's entire landmass every day.

It is a pivotal tool for NTP damage analysis. Using Planet`s "Compare" tool, satellite images taken before and after the date of interest, most often at 3 metre resolution, are seen side-by-side for comparison. This tool makes satellite analysis much more efficient, as we can quickly see if there have been any noticeable changes to the landscape after the storm.

But, satellite analysis is not a quick task, as some search regions can be as large as 50,000 square kilometres (as was the case for the tornado outbreak in Alberta and Saskatchewan on June 28, 2019).

Additionally, cloud cover and smoke from wildfires can make the latest available imagery unsuitable for our needs and several days, sometimes weeks, can pass before clear imagery becomes available.

However, we can get lucky and cloud-free satellite imagery becomes available one or two days after an event. When we have survey teams on site conducting ground and drone surveys, having clear imagery available shortly after the event has been used to inform and direct the team to unreported locations of damage.

In 2019, NTP used Planet`s SkySat satellites for five storm damage events (Sapawe, ON on July 26, 2019 • Lac-des-Ecorces, QC on August 21, 2019 • Black Lake, MB on July 11, 2019 • Baie Saraana, QC on September 5, 2018 • Dakin Lake, SK on June 9, 2018). SkySat is a constellation of 15 high-resolution (0.8 metre) Earth imaging satellites with near infrared and video capabilities. It is used on a per-request basis and can visit any place above the Earth.

NTP OPERATIONS: Satellite Analysis (continued)

NTP requested the use of SkySat in order to obtain higher resolution imagery of the tornado tracks and treefall. Imagery collected helped more accurately detect locations of treefall, but the resolution was not high enough to see treefall direction and patterns, which is of interest to NTP for research. Therefore, the additional field methods continue to be important tools for analysis.

Satellite analysis can not only be used to detect recent storm tracks, it can also be used to search for tornadoes that occurred years, even decades ago.

While conducting analysis, sometimes we come across older tornado tracks. Once a tornado track is spotted in satellite imagery, it is cross-referenced with an extensive tornado database to determine whether it is a known tornado on record, or a previously unknown event. If it is determined to be an unknown event, the track is dated, classified and rated.

Planet`s Monthly Mosaic Images can be used to help date tornado tracks that occurred from 2016 onwards. Once a month is determined, Planet`s Daily Imagery is used to pinpoint a date range.

If the tornado occurred prior to 2016, Google Earth`s historical imagery is used to pinpoint a year and then Planet`s Daily Imagery is once again used to narrow down a date.

Using archived United States Storm Prediction Centre mesoanalysis data (available from 2005) and historical radar data from ECCC, we can determine a date and time the tornado likely occurred.

However, if the tornado occurred prior to 2009, Google Earth is currently our only data source and determining which storm the tornado belonged to and pinpointing a date is a difficult task.

When satellite analysis is our only tool to classify and rate tornadoes, a set of somewhat conservative guidelines has been developed to ensure consistency. Damage should be classified as tornadic if:

• Major areas of damage are aligned (line or gentle curve), with no along-path gaps greater than 2 km

• Aspect ratio of aligned damage path approaches or exceeds 10:1

• Path width less than 2 km, and total length at least 1 km

• Can be a wider area of minor non-tornadic damage in the vicinity but mostly to one side of the tornado damage path

If SkySat imagery is available and shows clear evidence of rotation in the tree damage, that can be also be used to assess the damage as tornadic.

For the EF-scale rating of damage, we rule out EF0 events as we have found that this weak damage is rarely captured via satellite imagery. If a track is evident, but the damage is spotty, the tornado is rated EF1.

A tornado is rated EF2 when a clear track is observed with large areas of trees uprooted and/or snapped (e.g., Figure 1 and 2). Currently, we do not rate tornadoes above EF2 using just satellite imagery.

Satellite analysis is an essential tool for improving the tornado database and is critical to advancing our understanding of the climatology of these events.

In the future, the Northern Tornadoes Project hopes to automate the detection of damage paths seen in high-resolution satellite imagery. However, this is an area of current research and development.

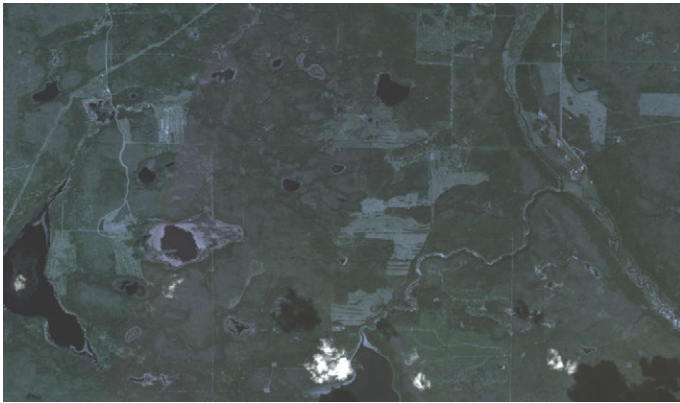# NTP OPERATIONS: Satellite Analysis (continued)

Figure 1: Satellite Imagery of Buffalo Lake Metis Settlement, AB captured (left) before the event on June 16, 2019, and (right) after the event on July 26, 2019. Rated EF2.
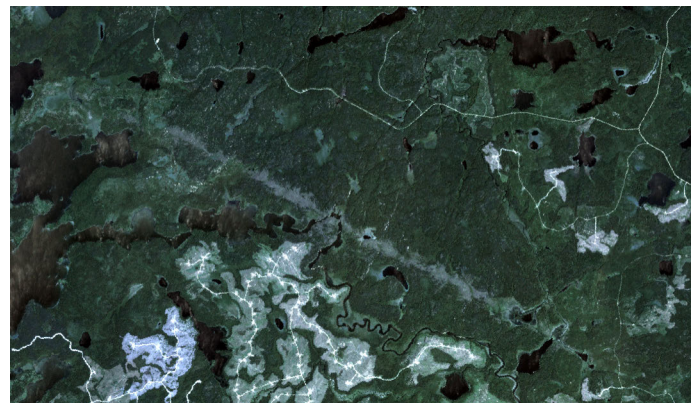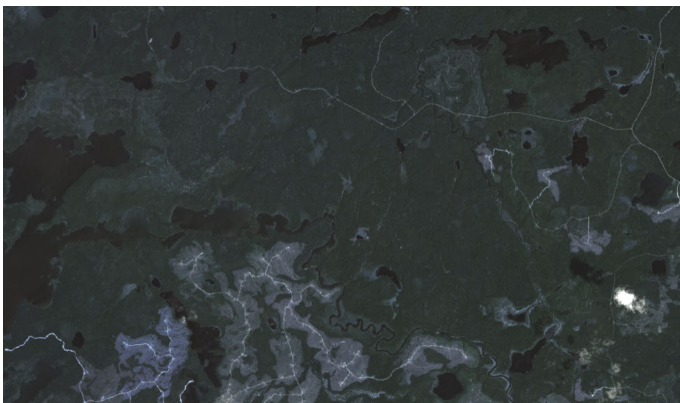

Figure 2: Satellite Imagery of Little Trout Lake, ON captured (left) before the event on July 3, 2019, and (right) after the event on July 28, 2019. Rated EF2.

NTP OPERATIONS: Aerial Analysis

The main goal of obtaining aircraft aerial imagery is to increase the quality of survey data and the subsequent analysis. This damage imagery, most often obtained in forested areas, captures aspects of the event that cannot be obtained from the ground. It also has much higher resolution (typically 5 centimetre) than what is available via satellite imagery (typically 3-5 metres).

Crewed aircraft can collect a series of high-resolution photographs (enough to capture most EF0 damage) of a given area. The photographs can then be stitched together (i.e., processed) to make a high-resolution, geo-referenced aerial map. NTP typically conducts aerial surveys for more significant tornadic events, especially those that include severe tree damage.

Unlike satellite analysis, aerial surveys are only conducted for confirmed tornado tracks with precisely known locations. There is often a significant period of time between the event and the time the flights are completed, and even longer before processed images are available. This means that preliminary event classifications and ratings must be made prior to the completion of the aerial survey.

NTP is investigating the processing of raw aerial data in-house in an effort to reduce this latency.

After the aerial imaging company delivers processed aerial data to NTP, it typically takes about a day – depending on the size of the event – to identify all the damage. Currently, this is done manually by combing through the imagery and outlining likely and potential tornadic damage (e.g., Figure 1). This process could become automated to a certain degree in the future. The vast majority of identified damage is snapped and/or uprooted trees, as the structural damage is often cleaned up by the time the aerial survey is flown and has typically already been assessed by an on-site ground survey.

Aerial analysis is actively contributing to NTP's long-term research goals. For example, large data sets of detailed tornado paths are critical in helping NTP develop automated treefall detection algorithms.

Aerial analysis also helps confirm tornadoes that would otherwise go unclassified. This is helping NTP paint a more accurate picture of actual tornado occurrence and risk in Canada, and contributing to improving tornado warning systems, and raising public awareness.

Aerial surveys will continue to improve in the next few years. NTP hopes to take advantage of improved resolution capabilities of up to 2.5 centimetre, in-house processing of raw aerial data, and automation of treefall detection in the near future. The surveys will continue to be used for large and difficult-to-access events.
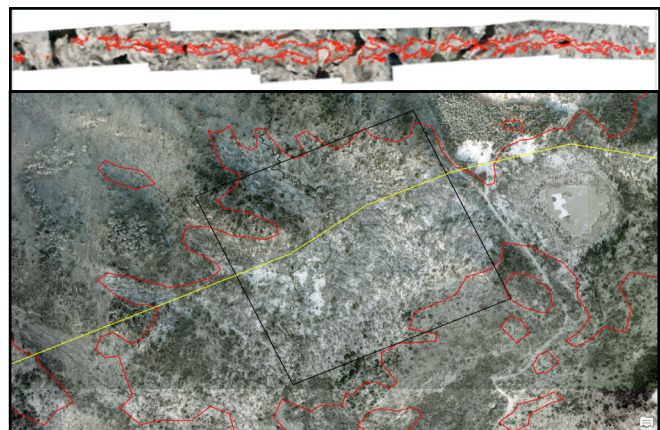
Figure 1: The figure strip on top outlines tornado damage occurring on September 21, 2018, at Val-des-Bois, QC. Bottom figure is a close-up of the worst damaged area along the tornado's path. The damage outline is shown in red and the tornado path 'centre line' is shown in yellow. A box with sides equal to half of the maximum width along the path is shown in black. The box is placed along the centre line of the area of worst damage, and the percentage of trees snapped and/or uprooted within the box determines the maximum wind speed, and subsequently, EF-scale rating. In this case, over 80% of the area of the box had trees down. Maximum wind speed was assessed at 190 km/h which is in the EF2 wind speed range.

NTP OPERATIONS: Classification & Rating

From the collected data, event classification and rating decisions must be made using the latest scientific understanding of severe weather phenomena for classification and the Canadian EF-scale for rating. The goal is to provide the most accurate event assessment possible.

When damage is present, the likelihood that the damage was caused by a tornado versus a downburst must be assessed. In cases where it is unclear which is more likely given the available evidence (usually only weaker events), then a classification of 'unclassified wind damage' is made. The damage is further characterized by estimating the damage path length and maximum width.

When only visual evidence of a vortex is available, the likelihood that it is a tornado or a non-tornadic vortex must be assessed. Non-tornadic vortices include vortices-funnel clouds aloft, gustnadoes, sub-tornadic vortices, and dust devils. In cases where the type of non-tornadic vortex is unclear given the available evidence or does not fit into an existing sub-category, it will be considered a general non-tornadic vortex with no sub-category and specific text details included.

Waterspouts, defined as tornadoes over water, have historically not been included in Canadian tornado data sets for large bodies of water (i.e., at least 10,000 sq km). This is mainly due to ECCC program jurisdiction issues (public versus marine programs). These tornadoes are now being included in NTP data sets on an experimental basis, but are not included in annual statistics for the time being.

The Canadian version of the EF-scale is used to rate the intensity of the damage caused by a tornado, from which estimates of maximum wind speed can be obtained. The Canadian EF-scale uses 31 different 'Damage Indicators' (from buildings to trees to electrical transmission structures). Each damage indicator has associated 'degrees of damage' that range from the threshold of visible damage to total destruction. Each degree of damage has an associated wind speed range from which a representative maximum wind speed is estimated. The EF-scale rating (between 0 and 5) is then assigned based upon the estimated maximum wind speed.

When damage is present, a ground survey is typically done within a few days, including aerial imaging using a drone. The field team recommends a preliminary EF-scale rating based on survey results. In cases where tornadoes are detected remotely using high-resolution satellite data, a preliminary EF-scale rating is based on the evidence of tree damage and the tree damage indicator included with the Canadian EF-scale.

When only visual evidence of a tornado is available, and no damage is caused to an EF-scale indicator, a rating of EF0-Default is assigned. This indicates that a wind speed of at least 90 km/h (the lower bound of EF0 using the Canadian EF-scale) is expected to have been associated.

After a tornado or downburst has occurred, preliminary assessment results are typically desired for media and public information purposes within 24-48 hours of an event.

Given ECCC distributes this type of information via storm summary bulletins, there is typically discussion between ECCC and NTP to reach consensus on the preliminary assessment before it is broadcast.

However, even after the preliminary assessment has been disseminated publicly, there is typically weeks to months more work for NTP collecting all possible evidence and re-assessing as new evidence comes in. For significant tornadoes, this often includes specially requested aircraft aerial imagery.

Once all evidence is considered, NTP determines a final assessment - with each approved by NTP's Executive Director.

NTP OPERATIONS: Results Summary (2018)

This section will highlight the results of the NTP event investigations for 2018 and 2019, focusing on events classified as tornadoes. The goal for the 2018 campaign was to detect every EF1+ tornado in Ontario and investigate significant tornado events in other parts of Canada.

Based on the success in 2018, the Project scope expanded to include the detection of every tornado in Canada in 2019.

2018 Events

Though the 2018 tornado season started quite late (first tornado of the season on June 13) and ended somewhat early (last tornado on September 25th), it was a busy one with a number of significant events (Figure 1).

Several of these events will be discussed below.

NTP verified the occurrence of 54 tornadoes in total, with 10 occurring outside of Ontario and Quebec (Fig.1). Since Quebec had such an active tornado season, the focus for 2018 ended up being split between Ontario and Quebec. Of the 44 tornadoes in those provinces, 32 of them were discovered by NTP and would otherwise have gone undocumented – an increase of 267%.

Appendix A has a detailed list of the 2018 tornado events.

NTP also documented a significant number of downbursts and non-tornadic vortices. When the cause of wind damage was not possible to verify, it was categorized as unclassified wind damage.

Waterspouts over large bodies of water such as the Great Lakes were verified and documented on an experimental basis.

Events verified by NTP in 2018, including tornadoes, tornadoes (experimental), downbursts, non-tornadic vortices, and unclassified wind damage

Event Type	2018
Tornado	54
Tornado (Experimental)	9
Downburst	28
NTV	38
Unclassified Wind Damage	8
Total	137

The following are brief summaries of three significant events investigated by NTP in 2018.

August 3 – EF4 tornado in Manitoba

On August 3, 2018, near 8 PM local time, a violent tornado developed in southern Manitoba affecting the small community of Alonsa (Figure 2). The tornado caused catastrophic damage along a path 15.1 km long and 1.2 km wide, resulting in one fatality and a few injuries. Insured losses were estimated by NTP to be over $2M.

In 2018, no NTP tornado outlooks were produced for areas outside of Ontario, but the team responded quickly with a two-person survey crew on the ground within 5 days. NTP survey teams performed detailed ground surveys, collected drone imagery and coordinated with ECCC staff from the Winnipeg office.

NTP OPERATIONS: Results Summary (2018) (continued)

Several homes were destroyed and moved off their foundations. While normally this would result in an EF5 rating, it was determined that the construction quality prevented a rating above EF4. NTP acquired additional high-resolution imagery from both satellite and aircraft platforms. All event data were synthesized and analyzed to characterize the event.

At an EF-scale rating of EF4, this was the highest-rated tornado in North America in 2018 (perhaps the world – a violent tornado was alleged to have occurred in South America but evidence is hard to come by). It was also the first tornado rated at EF4 under the new Canadian EF-scale, and the first EF4+ tornado in Canada since the 2007 EF5 tornado at Elie, MB (roughly 100 km away).

September 5th – Tornado outbreak in Quebec

During the afternoon and evening of September 5th, 14 tornadoes occurred over a large area in southern Quebec stretching from well north of Ottawa to north of Quebec City. Tornadoes of EF1 and EF2 strength caused mostly tree damage in this heavily forested region. There were no known injuries and insured losses are unknown.

As mentioned earlier, NTP tornado outlooks in 2018 covered only Ontario, but an area depicting the chance of supercell tornadoes was identified in eastern Ontario (and was implied for neighbouring parts of southern Quebec) a day in advance. Since thorough investigations during the summer of 2018 were limited to Ontario, the tornado damage from this outbreak was only discovered in 2019 while looking for damage from 2019 storms. There were no reports on social media about this event, during or after.

After the first eight damage tracks were identified, high-resolution aerial aircraft data were obtained (see Figure 3). A further six tornadoes were found using high-resolution satellite imagery only. Both aircraft

aerial and satellite imagery were used to characterize each of the 14 tornado damage paths.

The record for Quebec's largest recorded tornado outbreak was set on June 18, 2017 at 11 tornadoes. This 14-tornado outbreak in 2018 – the very next year – has broken this record. As with the 2017 outbreak, it ranks among the largest recorded in Canada.

September 21st – Tornado outbreak in Ontario / Quebec

During the afternoon and evening of September 21, seven tornadoes occurred across a large area from Sharbot Lake in eastern Ontario to Grand-Remous in southern Quebec. Three of the tornadoes ripped through urbanized areas, causing devastating damage up to EF3 in strength. Amazingly, there were no fatalities, though there were 23 injuries, a few serious. Hundreds of structures were damaged or destroyed, including homes, apartment buildings, commercial buildings, farm buildings, and electrical stations and towers, with insured losses estimated at over $300M.

The NTP tornado outlook identified an area of likely supercell tornado development in eastern Ontario nearly a day in advance. Given the 'likely' area ran along the border, the risk was implied for neighbouring parts of southern Quebec.

Four NTP team members joined six ECCC surveyors (from the Toronto, Montreal and Ottawa offices) in the Ottawa region over two days (Figure 4). Most of the time was spent on the EF3 damage path that stretched 47.6 km through Dunrobin, ON and Gatineau, QC, and on the EF2 path through Nepean on the southern edge of Ottawa. NTP surveyors also investigated damage between Calabogie and Kinburn. Drone imagery could not be collected for this event due to the many no-fly zones in the Ottawa area.

NTP OPERATIONS: Results Summary (2018) (continued)

Thorough aerial analysis was also conducted using high-resolution satellite and aircraft aerial imagery, and was instrumental to verifying changes to preliminary findings (Quebec tornadoes were upgraded to EF2, damage at Sharbot Lake was reclassified from downburst to EF1 tornado). This event affected a large population (perhaps the most of any tornado outbreak in Canada) in the nation's capital, making it meteorologically and politically significant.

For those reasons, it is likely the most thoroughly studied tornado outbreak in the country's history. The insured losses also make it one of the most expensive tornado events in Canadian history. Finally, this event occurred quite late in the season – there has been only one other recorded EF3 in Canada in September or later (Merritton, ON on September 26, 1898).
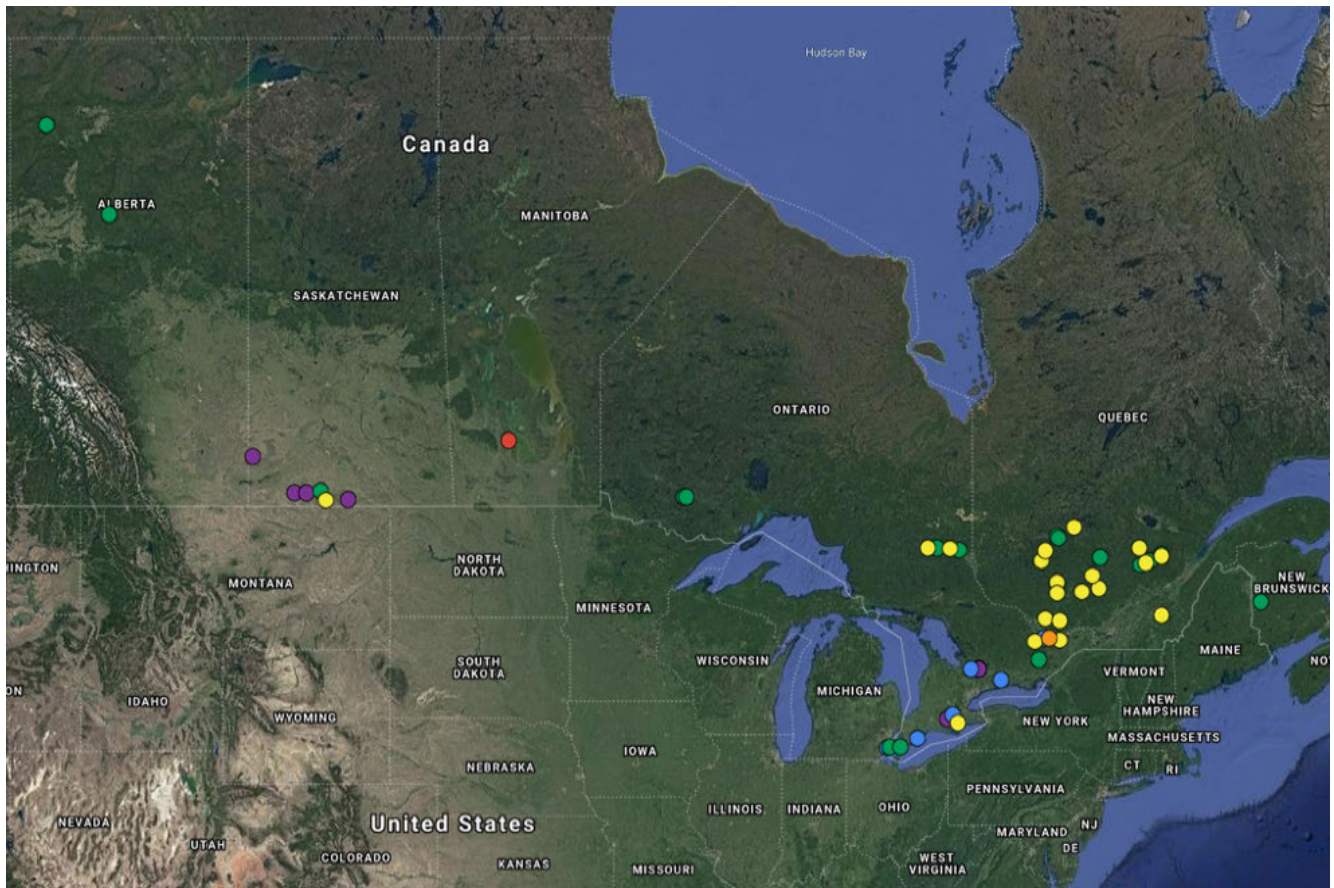
Figure 1: Map showing all tornado events confirmed by NTP in 2018.

NTP OPERATIONS: Results Summary (2018) (continued)
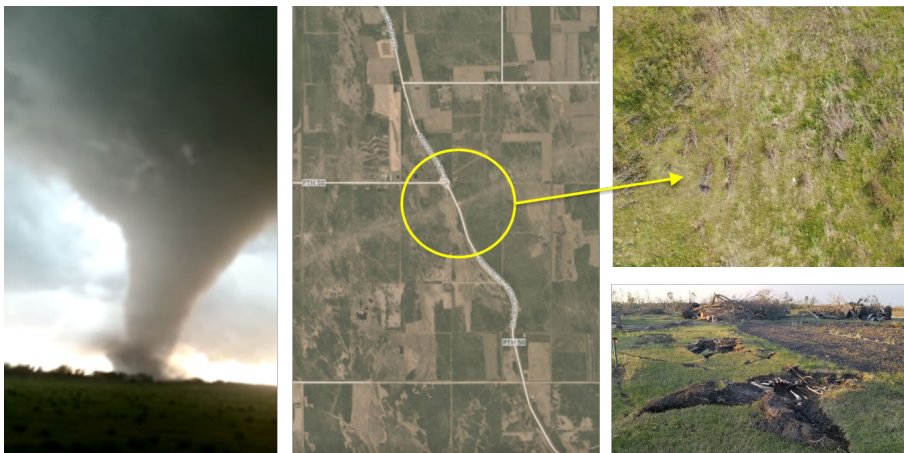
Shawn Cabak

Figure 2: (Left) Screen capture from Facebook video by Shawn Cabak showing the Alonsa tornado at its most intense. (Centre) Satellite imagery from planet.com showing the WSW-ENE tornado track. (Top Right) Drone imagery showing that the discolouration visible in the satellite imagery (yellow circle) is caused by both small uprooted trees and dead/dying grasses. (Bottom right) Photo from Kyle Brittain providing evidence that mature trees were ripped out of the ground and thrown downwind.

Lac Flocon – EF2 / 210 km/h
Length – 16.9 km
Maximum Width – 400 m

Name	Rating	Max Speed
Lac Minnie	EF2	190 km/h
Lac Kean	EF2	190 km/h
Lac Choiseul	EF1	145 km/h
Baie Saraana	EF2	190 km/h
Lac Leduc	EF1	145 km/h
Lac Gus*	EF2	190 km/h
Lac Hiya*	EF2	190 km/h
Lac Rouille*	EF2	190 km/h
Lac Laliberté	EF1	170 km/h
Lac du Batelet*	EF1	170 km/h
Lac Todd*	EF1	145 km/h
Sandford*	EF2	190 km/h
Lac Austin*	EF1	145 km/h
Lac Flocon*	EF2	210 km/h

Figure 3: Aircraft aerial imagery showing the entire path of the Lac Flocon tornado with red damage outlines and yellow centre line (top left), and an area along the path where every tree was flattened (bottom right). The name, EF-rating, and estimated maximum wind speed for each of the 14 tornadoes in the outbreak are shown at bottom left (asterisks indicates tornadoes for which aircraft aerial data were obtained).

NTP OPERATIONS: Results Summary (2018) (continued)
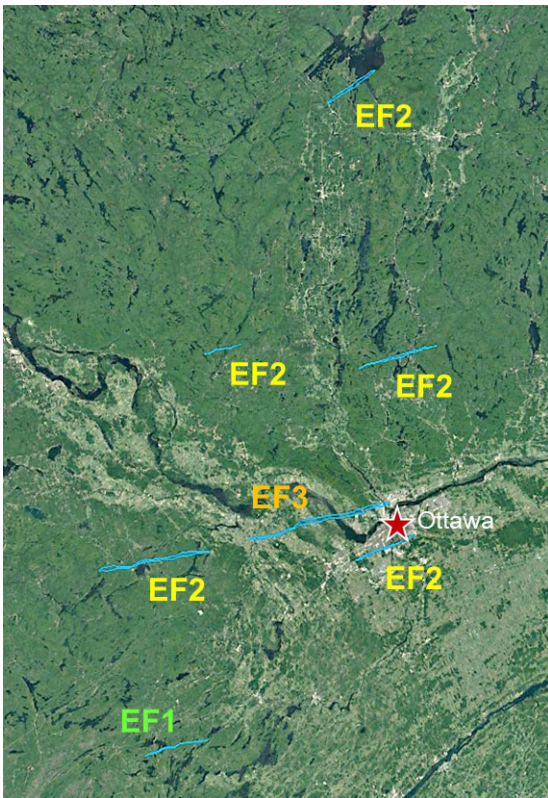
Figure 4: (Clockwise from top left) Tornado tracks and their ratings from the September 21, 2018 tornado outbreak • Radar showing the supercell thunderstorm with hook echo that produced the Dunrobin, ON EF3 tornado • NTP survey points where damage was recorded along the Ottawa (Nepean) tornado track (coloured pins with EF2 orange, EF1 yellow and EF0 green) plus the streets that were surveyed (in blue) • EF3 damage to a home in Dunrobin, ON.

NTP OPERATIONS: Results Summary (2019)

2019 Events

The length of the 2019 tornado season at roughly six months was far more typical than that for 2018, with the first tornado recorded on April 24 and the last on October 19. The most significant events occurred in Alberta and Saskatchewan on June 28 and 29, and those events will be discussed in more detail below.

NTP verified the occurrence of 66 tornadoes in total across Canada (Figure 1). Of these, 28 were discovered by NTP and would otherwise have gone undocumented – an increase of 78%.

Appendix B details 2019 tornado events and related meta-data.

As in 2018, NTP also documented a significant number of downbursts and non-tornadic vortices. When the cause of wind damage was not possible to verify, it was categorized as unclassified wind damage. Waterspouts over large bodies of water such as the Great Lakes were verified and documented on an experimental basis.

Events verified by NTP in 2019, including tornadoes, tornadoes (experimental), downbursts, non-tornadic vortices, and unclassified wind damage

Event Type	2019
Tornado	66
Tornado (Experimental)	5
Downburst	45
NTV	89
Unclassified Wind Damage	13
Total	218

The following is a brief case study of a significant tornado event investigated by NTP in 2019.

June 28/29 – Tornado outbreak in Alberta / Saskatchewan

On June 28 and 29, 11 tornadoes developed in Alberta and Saskatchewan, with the majority of activity occurring in the Cold Lake region near the AB/SK border. Eight of those tornadoes occurred on June 28th with up to EF2 damage. The remaining three occurred the following day, again with up to EF2 damage. This event was the most significant tornado event of the 2019 season across Canada. Damage occurred mostly in forested areas, though several farms were affected, and most of the trees in a provincial campground were flattened. The only known casualties were two farm animals, and insured losses were unknown.

NTP tornado outlooks leading up to this event did not include a tornado risk in this area, revealing a blind spot in Alberta for NTP forecasters. This will be investigated and addressed. Tornado forecasting in Alberta is quite challenging.

A two-person NTP ground survey team was sent to the area shortly after the days of the event, and there was coordination with the Edmonton ECCC forecast office. Drone imagery was collected in areas accessible by road and not covered by a no-fly zone. Aircraft aerial flights were made though not all tornado damage paths could be sampled due to military sensitivities in the area. High-resolution satellite imagery was, however, obtained for all damage paths. All data were analyzed in order to characterize the tornado damage.

Figure 2 is a satellite view of the tornado through Meadow Lake Provincial Park, beginning initially as a narrow damage path then turning right and becoming increasingly mixed with downburst damage as it crossed the lake. It also shows the Murray Doell campground within Meadow Lake Provincial Park, with every tree uprooted or in some cases snapped. Figure 3 is a video capture of the Cold Lake tornado.

NTP OPERATIONS: Results Summary (2019) (continued)
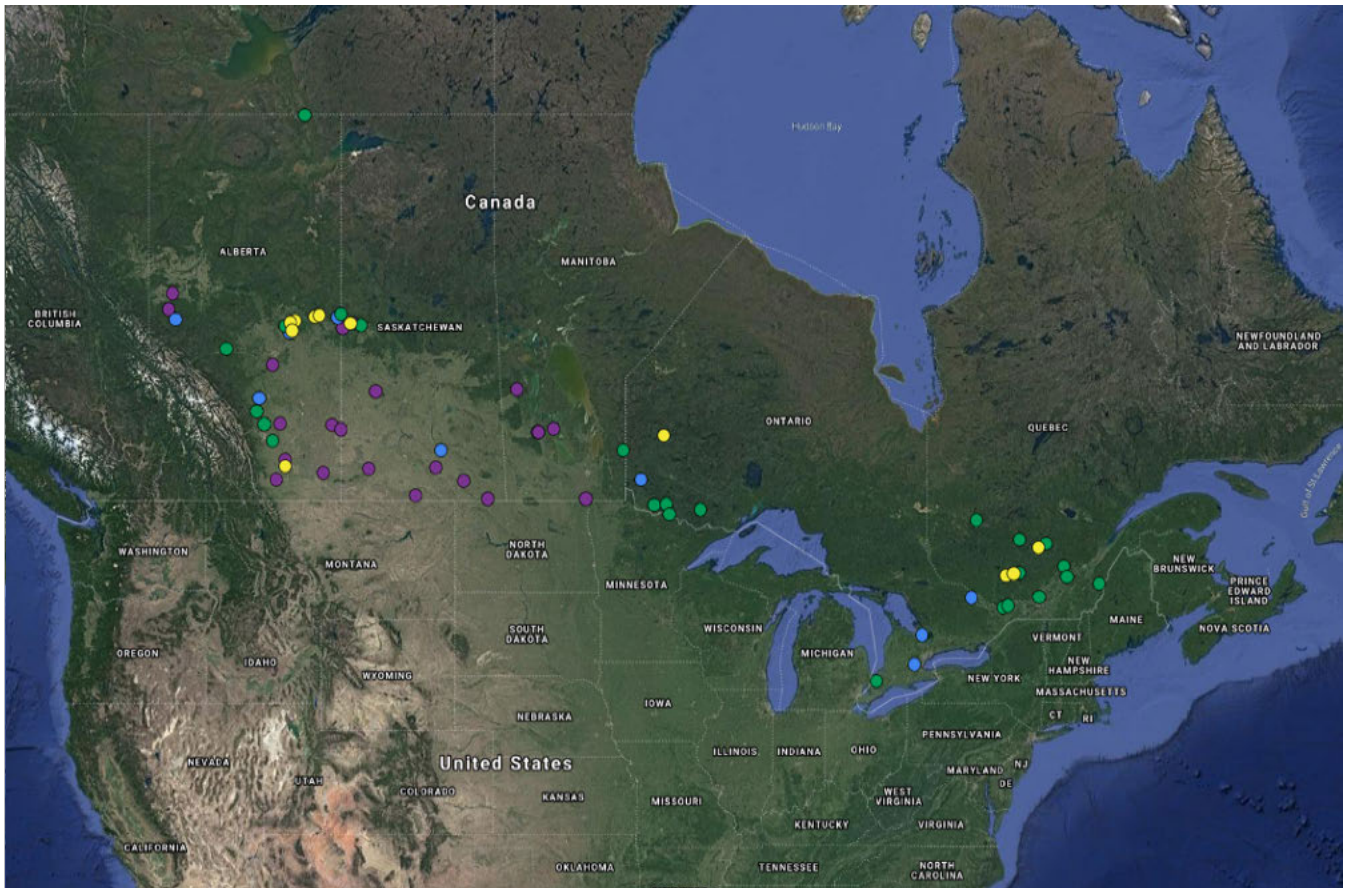
Figure 1: Map showing all tornado events confirmed by NTP in 2019.

NTP OPERATIONS: Results Summary (2019) (continued)

Figure 2: High-resolution satellite image (left) showing the Meadow Lake Provincial Park damage path, initially narrow, mainly tornadic and oriented toward the northeast, then widening as downburst damage increased and becoming directed toward the east (Data from planet.com). (Right) Drone imagery over the campground showing the near total destruction of trees around several campsites.

Figure 3: Image capture from video of the Cold Lake tornado, submitted to Twitter by Ryan Baldwin (@baldy_39).

NTP Research

NTP is globally unique in (i) systematically collecting all tornado and tree-fall data in Canada, and (ii) comprehensively analysing that data with a world-class team of engineers, meteorologists, and biologists.

The long-term vision of NTP is to cost-effectively automate detection and classification of all tornadoes in Canada.

There are many questions we are answering to achieve this vision – can we detect tornado occurrence and intensity by analyzing fallen trees? Will we be able to automatically detect and classify tornadoes using new, advanced tools? How do we lower research costs, while increasing research results? And, at the end of the day, can we leverage our improved understanding of tornadoes to build stronger houses and more resilient infrastructure for all Canadians?

To successfully answer these questions, we are hard at work to solve many technical issues such as improving the remote sensing of damage and automating the assessment of the EF-scale damage indicators and degrees of damage from imagery.

We are also improving the accuracy of wind speed estimation via damage observations – this will help us provide high-resolution maps of the tornado damage paths and wind speeds. All of these are topics of current research, involving many leading researchers around the world. Our strategy has been to tap into this expertise rather than developing our own from scratch in-house.

Cutting-edge questions require a cutting-edge team of researchers. "Right from NTP's beginning, I wanted to build a team of researchers who are defining the leading edge of tornado damage research and get them to work with us," Greg says. "These researchers are core to NTP."

For example, Dr. Ricky Wood (University of Nebraska) and Dr. Arn Womble (Insurance Institute for Business and Home Safety) carry out 3-D imaging of buildings destroyed by tornadoes. Based on multiple photographs of damaged structures, trees, or crops, they can reconstruct them as three-dimensional computer models with exceptionally high resolution. This allows researchers to quantify tornado damage accurately. For example, they can identify species of downed tree, and the size, direction of fall, and critically, separate these fromadjacent undamaged trees. Dr. Wood's team is now working to automate the process of damage identification using advance machine learning algorithms,which require the fastest supercomputers in North America to process the vast data files.

While large northern areas in eastern Canada are covered by trees, the prairies are covered with crops or grasslands. "If we are going to identify tree fall damage, we need a method to categorize them," Greg says. Dr. Frank Lombardo (The University of Illinois at Urbana-Champaign) and Dr. Chris Petersen (University of Georgia) are developing methods to estimate tornado windspeeds based on fallen trees, while Dr. Mark Sterling (University of Birmingham, UK) brings his expertise on tornado wind fields and the response and failures of crops under high wind speeds.

Crop and tree failures are made more complicated by the highly variable soil conditions in which they reside. Dr.Tim Newson (Western University) brings his expertise of both soil and foundations to understand how roots interact with the soil, a critical consideration when these fail.

Dr. Lombardo, for example, studies the patterns of fallen trees and damaged crops after tornado events. He uses statistical modeling and computer simulations to 'fit' tornado models to different patterns and determine wind speed and tornado intensity.

NTP Research (continued)

Dr. Sterling has taken a different approach with his models, which is important for NTP to understand the uncertainty of the wind speeds that cause this damage.

Lombardo, Newson, Peterson, Sterling, Womble, and Wood have unparalleled expertise in their fields -- and their collaboration with NTP is crucial for our success.

All of them are looking for data – be it tree fall data, aerial or ground imagery of damaged structures, or simply, a detailed quantitative and qualitative summary of tornado occurrences (dates, places, intensities, frequency) in Canada.

NTP can provide it all, and more.

"We want our collaborators to keep doing what they are doing – cutting-edge research on particular issues – but we want to support them with exceptional data collection and our own skills," Greg says.

By bringing these leading researchers together with the state-of-the-art NTP data, we can solve this problem together.

NTP is improving its ability to gather data through drone and satellite surveys, in this rapidly evolving field.

Prof. Mark Daley and NTP summer intern William Wang are utilizing the latest in machine learning to automatically detect and classify tornadoes – a goal we hope to achieve in the next decade.

"This is hard research that synthesizes all sorts of data and we need talented people for that," Greg says. "NTP is the perfect meeting place to bring all people together."

NTP leverages its expertise in data collection and synthesizing and bringing varied research under one roof, reaching out to these experts in their different fields.

In fact, the Montreal Expert Group Workshop was our second opportunity to bring everyone together, including leading experts and get everybody on board and up to date.

NTP also hopes to lower research costs by advancing its expertise in tornado analysis. For example, when satellite imagery improves its resolutions, NTP will not have to rely on drone or aerial surveys to gather data.

Critically, all data is open to the public. "It is right in our values – we are community-based for the public but also for researchers around the globe," Greg says. "Every data we collect is open for people to use. Right from the beginning, I wanted researchers who were into open access. It is better for society because we have tools open for all."

Western's wind engineering researchers have core expertise in wind tunnel testing, building aerodynamics, and the assessment of structural integrity and performance of buildings under extreme wind loads.

"We are amongst the world leaders in this," Greg says.

NTP researcher Sarah Stevenson, for example, is combining data from her own work, and data collected from Western's Boundary Layer Wind Tunnel Laboratory and the Three Little Pigs Project to create an accurate statistical model that captures our work with builders. Additionally, Western recently partnered with Doug Tarry Homes (St. Thomas, ON) and the Institute for Catastrophic Loss Reduction to incorporate research findings into building stronger homes.

NTP Research: Tornadic Storm Detection and Nowcasting Testbed

A long-term goal of the Northern Tornadoes Project is to help improve Canada's capacity to detect and nowcast (0 - 1 hour) tornadic storms.

There are a number of ways by which this can be pursued. One is establishing a monitoring testbed where detection and nowcasting techniques can be prototyped and evaluated. Successful prototypes can then be shared with Canadian partners via technical and knowledge transfer.

To that end, work has begun on assembling monitoring platforms that would form the core of the testbed. The testbed would be built with a research radar at its centre. A sophisticated Doppler C-band weather radar with dual-polarization capabilities has been acquired via an agreement with ECCC and is currently in storage. Work is now underway on a siting plan.

Other monitoring equipment that has been acquired via the same agreement includes a 14-station Lightning Mapping Array, a ten-station surface weather station network, and three vehicle-mounted mobile weather stations. Establishing and maintaining such a test bed will require significant resources and additional funding is currently being sought.

Dr. John Hanesiak at the University of Manitoba, a severe storms scientist and observationalist, is aiming to bring his expertise to the problem as well. His monitoring equipment includes atmospheric profilers and two vehicle-mounted mobile weather stations.

ECCC C-band radar at Exeter, ON being disassembled in order to be put into crates and moved to a Western Engineering facility.
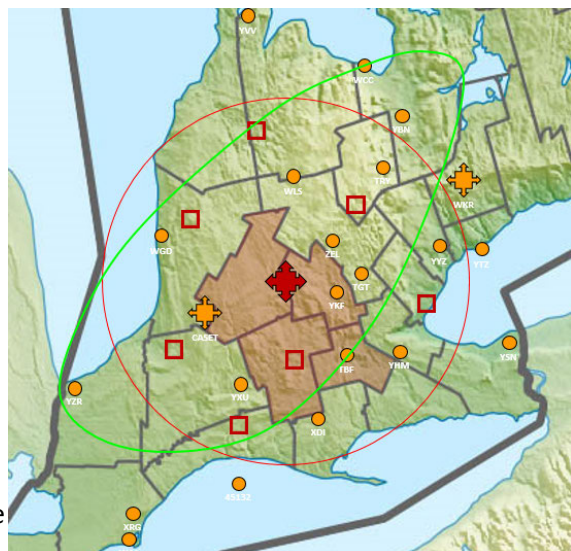
Map of southwestern Ontario showing possible siting for the C-band radar and the lightning / weather stations.

OPEN DATA SITE and REPORT A TORNADO

The Northern Tornadoes Project Open Data Site

https://ntpopendata-westernu.opendata.arcgis.com/

was created to serve as a public access portal for the project's research data.

The site is linked through GIS (Geographic Information Systems) - all data can be linked to other data through location information.

The Open Data Site provides access to information pertaining to all investigated tornadic events. It also contains information on downbursts, non-tornadic vortex events, and has specific icons showing unclassified events and non-events (i.e., storm tracks that revealed no damage). Currently the site has location data for the 2019 field season, and data for the 2018 field season (2017 data is coming soon). The next steps will be to incorporate historic data from previous field seasons and to ensure all data is uploaded and completed from the current season.

The Open Data Site recently incorporated the Event Summaries process. This was based on the creation of a Survey123 Form to track investigations undertaken by the team.

Survey123 is a GIS application available through Arc GIS Online and linked directly to the Open Data Site.

NTP team members use the form to enter each event that is being investigated. Throughout the event assessment process they update event details such as:

• Classification Status
• Preliminary classification (pending and completed)
• Final classification completed
• Rating Status
• Preliminary rating (pending and completed)
• Final rating completed
• Event Type (Tornado, Downburst, Classification pending, Tornado [Experimental], Non-Tornadic Vortex)

• Event Sub-Type (if there is one - Gustnado, Funnel Cloud, Aloft, Microburst, Dust Devil, Waterspout)
• Non-Event; currently hidden from public site), and
• Initial Data Sources.

The dashboard updates when a new record is added to the Survey123 form as well as any time information is updated within existing records. There is also a searchable dashboard within the *Events Investigation Maps* page, which allows users to browse and search through events.

Based on team and general-public feedback, we will be working on improving and updating this tool. For example, NTP has massively improved its data collection methods (case in point, Survey123).

The ground survey images and their associated information and photos are added into a web map of the investigated event along with any other data collected by the team. This could include drone photos/videos, aerial imagery, and other observations and media. Once the map has been created, the team uploads the completed event to the page where the public can view the data.

The satellite surveys are currently not loaded into the Open Data Site. We are working on a strategy for including imagery from Planet into the site and hope to see this data uploaded within the next few months. The high-resolution imagery collected through aerial surveys is managed through an *ArcGIS for Server* site. The data is linked through the Open Data Site. However it requires users to contact the team for access instructions. The setup allows us to control access to larger datasets and understand who is using the data for research projects.

OPEN DATA SITE and REPORT A TORNADO (continued)

Additional feedback forms as well as the *Report a Tornado* forms are also created using Survey123 and managed through ArcGIS Online.

The Open Data Site has the potential to host any data - reports, presentations, documents and procedures alongside spatial data and imagery, for example - the NTP team wishes to share with the public.

The idea is to create a seamless, easy-to-use public access point for all of NTP's associated data.

The Report A Tornado NTP initiative empowers the general public to become citizen scientists and report their observations to us through an online web form. All responses are forwarded to Environment and Climate Change Canada (ECCC).

Advancing our knowledge of tornadoes in Canada requires a better understanding of where and when tornadoes occur as well as their intensities.

The public plays a critical role in reaching our goal of recording every tornado in Canada. Their contributions, in the form of witness observations and damage reports, are invaluable.
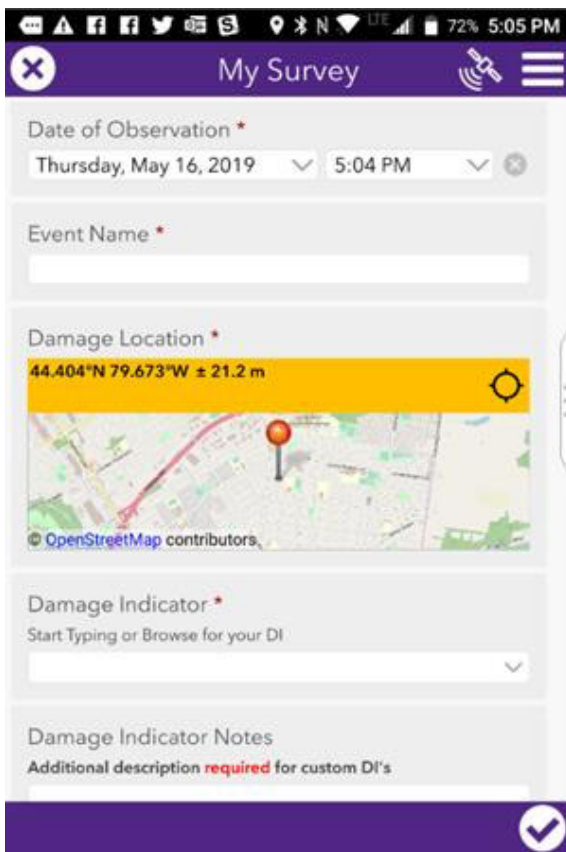
Survey123 app used by NTP damage survey team.
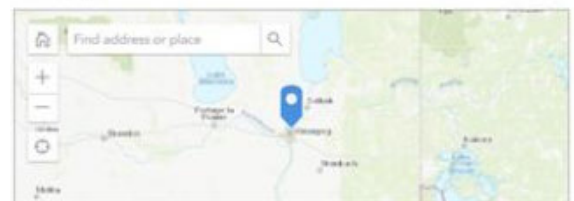
Screenshot of Report A Tornado webpage on NTP website.

OPEN DATA SITE and REPORT A TORNADO (continued)
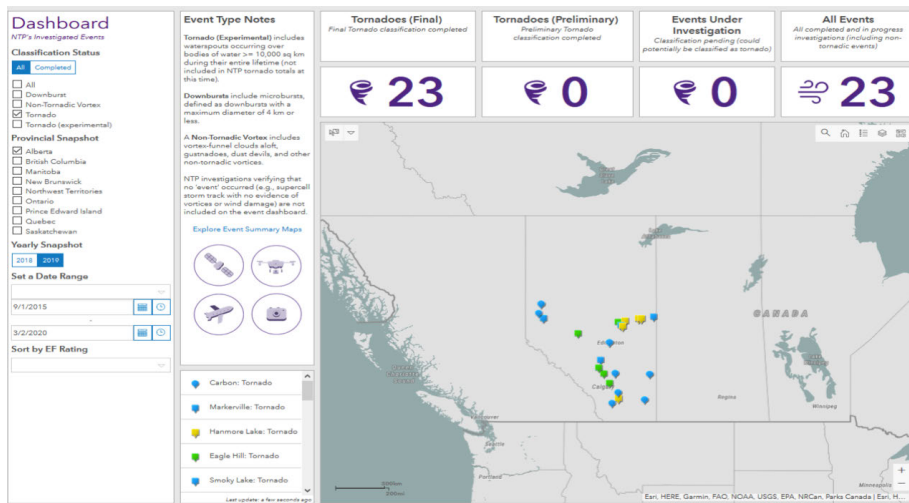
If a journalist wanted to grab a snapshot of the number of confirmed tornadoes in Alberta, they could do so by selecting the options above.

Event Investigation Map for Lac des Iles, SK.

OPEN DATA SITE and REPORT A TORNADO (continued)

2019 At a Glance

Tornadoes (Final)	Tornadoes (Preliminary)	Events Under Investigation	All Events
Final Tornado classification completed	Preliminary Tornado classification completed	Classification pending (could potentially be classified as tornado)	All completed and in progress investigations (including non-tornadic events)
🌪 66	🌪 0	🌪 0	💨 214

Learn More about NTP Investigated Events

Query, search and filter through all NTP investigated events in our interactive dashboard. Events are shown in a table and map view for you to explore!

Launch Interactive Dashboard

These main details and classification statuses allow events to be filtered into the Open Data Site's "At a glance" dashboard. Filters let the public know how many event invesitgations are in progress by NTP as well as how many final classifications have been made.

Each uploaded map uses the same basemap and layer symbology to maintain consistency across shared maps. There are currently 12 Event Investigation Maps uploaded to the Open Data Site along with an associated 37 data layers. As data becomes finalized through the Engineering team, it is uploaded onto the Open Data Site through ArcGIS Online.

Event Investigation Maps

Browse the gallery of the most recent maps below or explore all event investigation maps along with their associated datasets. Investigated events for 2019 counts are provided in a snapshot view which are updated by the team as events are reported. If you'd like to search by specific year, province or other category there is also a searchable dashboard.

View all Event Investigation Maps   Explore associated datasets

Hanmore Lake Event Investigation Map
Map of July 28 damage survey investigation of Hanmore Lake, AB from the July 26, 2019 event.
Explore

Lac des Iles (Meadow Lake) Event Investigation Map
Map of July 1-3 damage survey investigation of Lac des Iles (Meadow Lake), SK from the June 29,
Explore

Pembroke (Laurentian Valley) Event Investigation
Map of July 16 damage survey investigation of Pembroke (Laurentian Valley), ON from the July
Explore

Weslemkoon Lake Event Investigation Map
Map of July 16 damage survey investigation of Weslemkoon Lake, ON from the July 11, 2019 event.
Explore

Drone Surveys	Ground Surveys	Aerial Surveys	Satellite Surveys
26	46	34	329

Drones are used during Ground Surveys, where permitted, to identify damage in terrain with low accessibility, to gain a quick aerial snapshot of an entire neighborhood or property, to collect additional path information, and to provide additional points for comparison with aerial and satellite imagery.

Drone video can also be used as a preliminary means to capture the entire damage path, and is often reviewed after a survey to fill in gaps in mapped information.

Ground photos and associated metadata are collected, mapped, stored and preserved.

The NTP Storm Survey Team uses a customized web form to collect observations in the field of reported wind events. The form follows Environment Canada's specifications for classifying wind events based on the Enhanced-Fujita Scale (EF Scale).

Aerial Surveys are flown for select sites, the data is collected in high resolution geoTIFF format and uploaded to a mosaic dataset.

This dataset along with the associated files are available for researchers to access through the Northern Tornadoes Project ArcGIS for Server Site. KML downloads are available through the Open Data Site.

Request High-Resolution Data

The NTP Storm Survey Team uses high-resolution satellite imagery provided by Planet to review areas of interest for signs of damage following severe weather events.

Guided primarily by storm tracks, analysis is completed over large areas by comparing imagery from before and after an event, revealing any significant changes to trees or structures that can be attributed to severe wind damage, where a long, narrow path of damage is likely to be the result of a tornado.

As the Open Data Site is used more and more, we hope to incorporate different data applications and access points. For example, currently we are also summarizing the different datasets being collected.

THE ART OF SCIENCE: DO NOT TAKE THIS LIGHTLY

On January 10, 2019, the Department of Visual Arts and ArtLab Gallery at Western University hosted _Do Not Take This Lightly_ - a collaborative exhibition and _Tornado Store_ containing artist's multiples for sale.

The artistic undertaking - helmed under the leadership of Western Visual Arts professor Dr. Patrick Mahon - was linked with NTP.

It depicted effects of tornadoes on humans, and nature.

Third- and Fourth-Year Print Media students from Western Visual Arts collaborated with four guest artists over several months. They utilized multi-media art practices including printmaking, sculpture, video and sound.

Sales proceeds from the _Tornado Store_ were split between artists and donations to weather-related disaster relief funds.

The exhibition ran from January 10 to January 24, 2019.
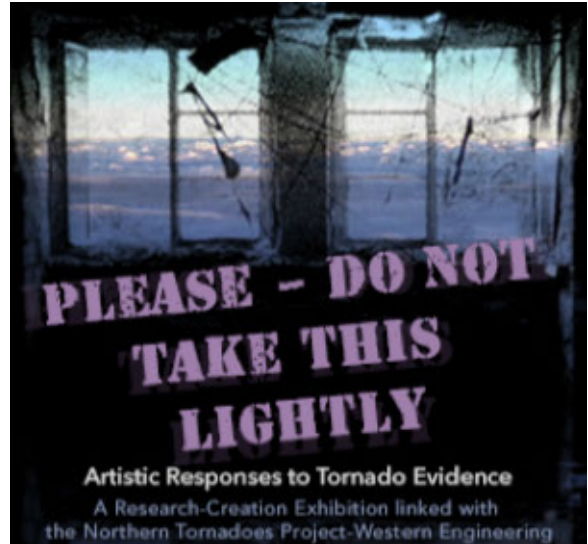
Do Not Take Lightly was realized under the leadership of Western Visual Arts professor Dr. Patrick Mahon.

MEDIA AND CONFERENCES

CBC • Earth and Space Science News • Global News • InstantWeather • London Free Press • Phy.Org • Radio Canada • Weather Geeks • Western Gazette • Western News • The Weather Network • TVO... covered us.

We presented NTP research at • 2018 AMS Severe Local Storms Conference • GIS Day 2019 (The Map & Data Centre and Western Libraries, Western University) • THWARTS Conference 2019 • ESRI Conference 2019 • 2019 CMOS Congress • 2019 Great Lakes Operational Meteorology Workshop • NTP workshops (2018/2019)

Western Engineering

IMPACT AT A GLANCE

• Created website FAQ section for public outreach

• Created Open Data Site + Report a Tornado section

• Investigated 519 potential events across Canada in two years, confirming 120 tornadoes

• Covered by media 11 times

• Presented NTP work at three conferences

• Expanded expertise in downbursts

• Developed communications initiative to raise NTP profile
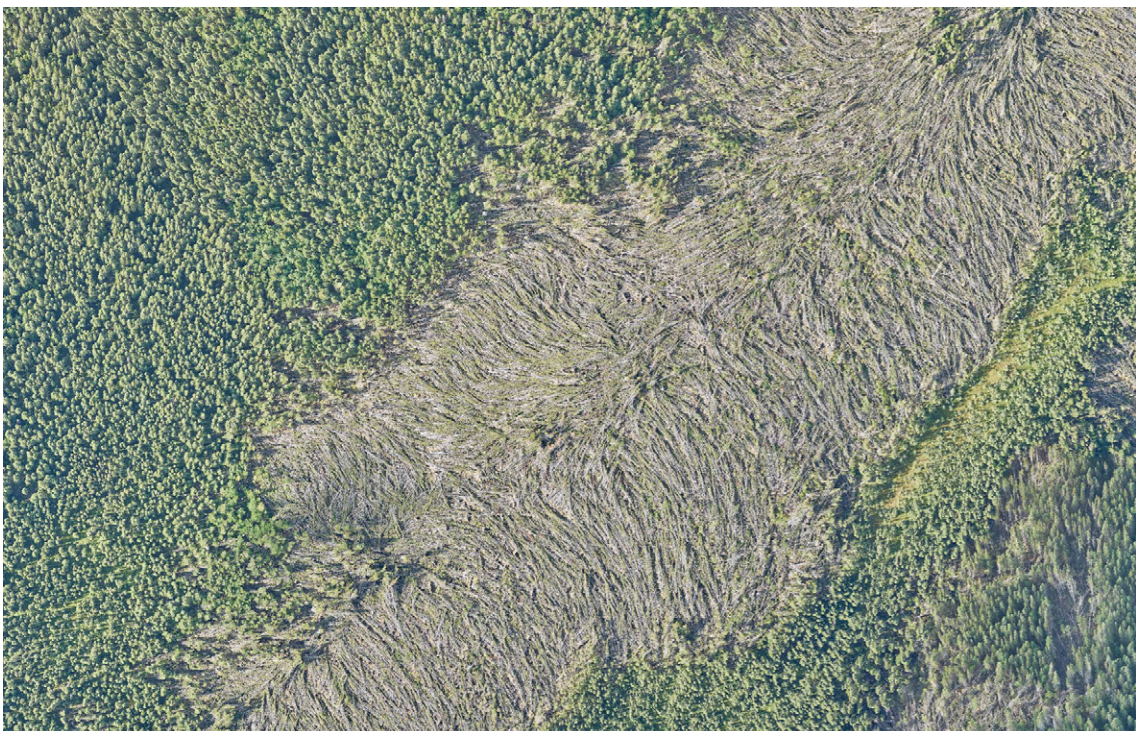
APPENDIX A: NTP VERIFIED EVENTS (2018)

Date	Location	Surveys Completed				EF-Scale Assessment	NTP Discovered	Track Length (m)	Max Width (m)	Max Wind (km/h)
		Satellite	Ground	Aerial						
				Drone	Aircraft					
2018-06-13	Norwich, ON	y	y			EF0 (def)		-	-	-
2018-06-13	Jarvis, ON	y	y			EF2		800	190	180
2018-06-17	Nursey Lake, ON	y				EF2	y	18500	700	190
2018-06-17	Midlothian Lake, ON	y				EF1	y	8800	300	145
2018-06-17	Matchewan, ON	y				EF2	y	10700	400	190
2018-06-17	Charlton, ON	y	y	y	y	EF1	y	9980	410	145
2018-06-25	Basset Lake, AB	y				EF1	y	3500	350	170
2018-06-25	Lubicon Lake, AB	y				EF1	y	2200	250	145
2018-07-04	McNamara Lake, ON	y			y	EF1	y	13900	1100	170
2018-07-04	Owl Lake, ON	y			y	EF1	y	11200	860	170
2018-07-10	Golden Prairie, SK	y				EF0 (def)		-	-	-
2018-07-10	Bracken, SK	y				EF0 (def)		-	-	-
2018-07-10	Val Marie, SK	y	y	y		EF0 (def)		-	-	-
2018-07-10	Ferland, SK	y	y	y		EF1	y	2000	100	145
2018-07-10	Macworth, SK	y	y	y		EF2		52000	700	190
2018-07-10	Fife Lake, SK	y	y			EF0 (def)		1000	50	-
2018-07-26	Lake Simcoe (SW of Lagoon City, ON)					EF0 (def)	y	-	-	-
2018-07-26	White Lake, ON	y				EF0	y	300	80	90
2018-07-29	Morpeth, ON	y	y	y		EF0		640	30	95
2018-08-01	Lac Barbe, QC	y				EF1	y	3200	300	145
2018-08-01	Lac Demerest, QC	y				EF2	y	7200	600	190
2018-08-03	Alonsa, MB	y	y	y	y	EF4		15100	1200	275
2018-08-07	Knowlesville, NB	y			y	EF1	y	37700	800	145
2018-08-08	Brantford, ON	y				EF0	y	-	-	-
2018-08-09	Lake Simcoe (NW of Beaverton, ON)					EF0 (def)		-	-	-
2018-08-09	Lake Simcoe (NW of Beaverton, ON)					EF0 (def)	y	-	-	-
2018-08-21	Bailieboro, ON	y	y			EF0	y	2420	100	120
2018-08-27	Oro Station, ON	y	y			EF0		8640	190	125
2018-08-28	Lac Borgia, QC	y				EF2	y	7700	350	190
2018-08-29	Saint-Julien, QC	y	y	y	y	EF2		15900	990	190
2018-09-05	Lac Minnie, QC	y				EF2	y	19000	450	190
2018-09-05	Lac Kean, QC	y				EF2	y	9300	650	190
2018-09-05	Lac Choiseul, QC	y				EF1	y	5700	250	145
2018-09-05	Baie Saraana, QC	y				EF2	y	6000	750	190
2018-09-05	Lac Leduc, QC	y				EF1	y	18700	550	145
2018-09-05	Lac Gus, QC	y			y	EF2	y	11400	450	190
2018-09-05	Lac Hiya, QC	y			y	EF2	y	5400	330	190
2018-09-05	Lac Rouille, QC	y			y	EF2	y	18300	480	190
2018-09-05	Lac Laliberte, QC	y				EF1	y	15400	600	170
2018-09-05	Lac du Batelet, QC	y			y	EF1	y	4290	260	170
2018-09-05	Lac Todd, QC	y			y	EF1	y	7020	330	145
2018-09-05	Sanford, QC	y			y	EF2	y	11900	960	190
2018-09-05	Lac Austin, QC	y			y	EF1	y	10500	660	145
2018-09-05	Lac Flocon, QC	y			y	EF2	y	16900	400	210
2018-09-21	Calabogie-White Lake, ON	y	y		y	EF2		37100	1210	190
2018-09-21	Kinburn - Dunrobin, ON / Gatineau, QC	y	y		y	EF3		47600	1500	245
2018-09-21	Grand-Remous (Baskatong Reservoir), QC	y	y		y	EF2		19200	1200	190
2018-09-21	Otter Lake, QC	y			y	EF2		12400	320	190
2018-09-21	Val-des-Bois, QC	y			y	EF2		26900	910	190
2018-09-21	Sharbot Lake, ON	y			y	EF1	y	21500	600	145
2018-09-21	Ottawa (Nepean), ON	y	y		y	EF2		21400	750	210
2018-09-25	Amherstburg, ON	y	y			EF0	y	125	100	95
2018-09-25	McGregor, ON	y	y			EF1	y	1600	150	150
2018-09-25	Staples, ON	y	y			EF1	y	2750	50	170

APPENDIX B: NTP VERIFIED EVENTS (2019)

Date	Location	Satellite	Ground	Aerial Drone	Aerial Aircraft	EF-Scale Assessment	NTP Discovered	Track Length (m)	Max Width (m)	Max Wind (km/h)
2019-04-24	McLeod Valley, AB	y				EF1		-	-	135
2019-05-03	Letellier, MB	y				EF0 (def)		-	-	-
2019-05-25	Gull Lake, SK	y				EF0 (def)		-	-	-
2019-06-02	Orleans, ON	y	y	y		EF1		11000	250	170
2019-06-02	Clarence Creek, ON	y	y			EF1		6800	250	160
2019-06-02	Fort Smith, NT	y	y	y		EF1		1500	120	155
2019-06-13	Carseland, AB	y				EF1		-	-	135
2019-06-13	Aberfoyle, ON	y	y	y		EF0	y	3200	50	115
2019-06-14	Seven Persons, AB	y				EF0 (def)		-	-	-
2019-06-23	Fort MacLeod, AB	y				EF0 (def)		-	-	-
2019-06-25	Sexsmith, AB	y				EF0 (def)		-	-	-
2019-06-26	Leduc, AB	y				EF0 (def)		-	-	-
2019-06-28	Newbrook, AB	y			y	EF1	y	4350	210	135
2019-06-28	Figure Lake, AB	y			y	EF2	y	4770	320	190
2019-06-28	Buffalo Lake Metis Settlement, AB	y	y	y	y	EF2		14200	1220	210
2019-06-28	Seibert Lake, AB	y			y	EF2	y	17800	1790	210
2019-06-28	Wolf Lake, AB	y			y	EF2	y	13300	960	210
2019-06-28	Cold Lake, AB	y	y	y		EF0		-	-	95
2019-06-28	Primrose Lake, SK	y				EF1	y	15500	1100	170
2019-06-28	Pierceland, SK	y				EF0 (def)		-	-	-
2019-06-29	Grovedale, AB	y				EF0 (def)		-	-	-
2019-06-29	Lac des Iles (campground), SK	y	y	y	y	EF2		13200	1550	210
2019-06-29	Lac des Iles, SK	y	y	y	y	EF0 (def)		-	-	-
2019-07-01	Avonlea, SK	y				EF0 (def)	y	-	-	-
2019-07-07	Lomond, AB	y				EF0 (def)		-	-	-
2019-07-08	Musreau Lake, AB	y				EF0		-	-	95
2019-07-11	Black Lake, MB	y				EF1	y	5000	300	145
2019-07-11	Pembroke, ON	y	y	y		EF0	y	1470	210	125
2019-07-11	Saint-Roch-de-l'Achigan, QC	y	y			EF1		2700	150	135
2019-07-11	Lac Pellerin, QC	y				EF1	y	3800	250	170
2019-07-12	Rockglen, SK	y				EF0 (def)		-	-	-
2019-07-13	Frobisher, SK	y				EF0 (def)		-	-	-
2019-07-14	Crossfield, AB	y	y	y		EF1		2000	25	135
2019-07-15	Lake Despair, ON	y				EF1	y	5700	550	145
2019-07-15	Tupman Lake, ON	y				EF1	y	21000	350	145
2019-07-15	Little Trout Lake, ON	y				EF2	y	13500	900	215
2019-07-16	Oyen, AB	y				EF0 (def)		-	-	-
2019-07-16	Alsask, SK	y				EF0 (def)	y	-	-	-
2019-07-17	Lake Manitoba, MB	y				EF0 (def)	y	-	-	-
2019-07-17	Lake of the Woods, ON	y				EF0		-	-	95
2019-07-17	Rainy Lake, ON	y				EF1	y	21300	700	170
2019-07-17	Craighurst, ON	y	y			EF0	y	-	-	-
2019-07-18	Carmangay, AB	y	y	y		EF2		5000	400	180
2019-07-18	Red Pheasant First Nation, SK	y				EF0 (def)		-	-	-
2019-07-18	Dauphin Lake (1), MB	y				EF0 (def)		-	-	-
2019-07-18	Dauphin Lake (2), MB	y				EF0 (def)		-	-	-
2019-07-24	Eagle Hill, AB	y				EF1	y	2200	100	160
2019-07-24	Smoky Lake, AB	y	y			EF0		9500	100	130
2019-07-24	Hanmore Lake, AB	y	y	y		EF2		9800	200	190
2019-07-24	Vivian Lake, SK	y				EF1	y	20500	350	170
2019-07-26	Sapawe, ON	y				EF1	y	1900	350	145
2019-07-29	Lac Jacques, QC	y				EF1	y	5800	300	145
2019-07-30	Lac-aux-Sables, QC	y				EF1		-	-	135
2019-07-31	Markerville, AB	y				EF0		-	-	90
2019-08-21	Lac-des-Ecorces, QC	y	y	y	y	EF2		23500	1220	190
2019-08-21	Lac Oat, QC	y			y	EF2	y	7050	400	190
2019-08-21	Lac Higginson, QC	y			y	EF1	y	6710	600	145
2019-08-21	Lac Murray, QC	y			y	EF2	y	14300	660	190
2019-08-21	Lac Lisleroy, QC	y			y	EF1	y	2790	360	145
2019-09-02	Lumsden, SK	y				EF0	y	-	-	100
2019-09-02	Hume, SK	y				EF0 (def)		-	-	-
2019-09-04	Saint-Pierre-les-Becquets, QC	y				EF1	y	-	-	150
2019-09-04	Sainte-Rose-de-Watford, QC	y				EF1		7200	300	170
2019-09-10	Carbon, AB	y				EF0 (def)		-	-	-
2019-09-11	Petrolia, ON	y	y			EF1	y	4500	200	140
2019-10-19	Indian Birch, MB	y				EF0 (def)	y	-	-	-