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Seasonal Effects on Vehicle Mobility

High-Latitude Case Study

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Matthew F. Bigl, and Michael W. Parker

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Preface

This study was conducted for the Assistant Secretary of the Army, Acquisition, Logistics and Technology under Program Number 62784, Project Number AT40 and Task 48. The technical monitor was John Rushing.

The work was performed by the Terrestrial and Cryospheric Sciences Branch and by the Force Projection and Sustainment Branch of the Research and Engineering Division, U.S. Army Engineer Research and Development Center, Cold Regions Research and Engineering Laboratory (ERDC-CRREL).

At the time of publication, Dr. John Weatherly was Chief, Terrestrial and Cryospheric Sciences Branch; Mr. Justin Putnam was Acting Chief, Force Projection and Sustainment Branch; Mr. Jimmy Horne was Division Chief and Dr. Bert Davis, was the Technical Director for Geospatial Research and Engineering/Military Engineering. The Deputy Director of ERDC-CRREL was Mr. David B. Ringelberg, and the Director was Dr. Joseph L. Corriveau.

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Seasonal Effects on Vehicle Mobility: High-Latitude Case Study

ABSTRACT

Seasonality plays a key role in altering the terrain of many military operating environments. Since seasonality has such a large impact on the terrain, it needs to be properly accounted for in vehicle dynamics models. This work outlines a variety of static and dynamic seasonal terrain conditions and their impacts on vehicle mobility in an austere region of Europe. Overall the vehicles performed the best in the dry season condition. The thaw season condition had the most drastic impact on mobility with all but the heavy tracked vehicle being almost completely NOGO in the region. Overall, the heavy tracked vehicle had the best performance in all terrain conditions. These results highlight the importance of incorporating seasonal impacts on terrain into NRMM or any vehicle dynamics model. Future work will focus on collecting more data to improve the empirical relationships between vehicles and seasonal terrain conditions, thereby allowing for more accurate speed predictions.

1. INTRODUCTION

Many military operating environments experience a wide range of seasonal conditions which can have a significant impact on the ground terrain. This impact is perhaps the greatest in high-latitude regions where seasonal climatic changes are more pronounced. Off-road vehicle mobility is of particular concern in these regions as vehicles can be hindered by the degraded ground conditions. Thus, delivering accurate predictions of vehicle capabilities in these conditions can provide the warfighter with crucial information for route planning analyses. Previous work relating to off road mobility has focused primarily on static, or preset, terrain parameters to assess the impacts of base terrain on off road vehicle mobility. However, since seasonality has a large impact on the terrain, it needs to be properly accounted for in vehicle mobility models. Several studies conducted by researchers at the Cold Regions Research and Engineering Laboratory (CRREL) have attempted to characterize seasonal impacts on a suite of vehicles [1-4]. These focused on the generation and incorporation of new high resolution winter terrain datasets including: frost depth, thaw depth, snow depth/density, and river/lake ice thickness.

This particular work outlines a variety of common static and new dynamic seasonal terrain conditions and their impacts on vehicle mobility in an austere region of Scandinavia. A static terrain input dataset was used to establish a baseline for vehicle mobility in the region. These static terrain parameters include: soil class, land usage, and slope. To highlight the effects of seasonality, three separate terrain conditions were modeled: dry season soil conditions, average winter season conditions, and thaw season conditions. In addition to the static terrain parameters that were used, each terrain condition had one or several additional seasonal parameters added. These parameters include: soil moisture (for unfrozen conditions), snow depth/density and frost depth (for winter season condition), and thaw depth (for thaw season condition). In addition to the varied terrain conditions, a suite of vehicles was used for this analysis to assess the performance of common military vehicles. The performance of the test vehicles will be outlined in the Results section of this report.

2. PREVIOUS WORK

As mentioned in the previous section, many previous analyses focused primarily on assessing vehicle performance in static terrain conditions. However, research conducted at CRREL over the past several decades has focused on developing new algorithms for seasonal predictions with the North Atlantic Treaty Organization (NATO) Reference Mobility Model (NRMM) [5-9]. NRMM is a vehicle mobility platform that combines several mobility-related technologies into a single comprehensive model to predict on and off road mobility capabilities [10]. Winter mobility algorithms were developed for NRMM from extensive vehicle testing to characterize the relationships between a suite of vehicles and varied seasonal terrain. These algorithms predict the motion resistance and maximum available traction for vehicles on winter terrain, including: snow, ice, and frozen/thawing ground. In addition to field testing, several studies have been conducted using vehicle simulators to assess vehicle and driver performance in winter conditions [8 and 9].

While these studies provided crucial insight into the relationships between vehicles and the underlying winter terrain, many of the analyses utilized uniformly distributed seasonal parameters, which does not effectively capture the variability of the terrain [5 and 11]. More recently, studies have focused on developing new models and methods to provide geospatially and temporally varying predictions of these winter season parameters. These new additions allow for more robust seasonal terrain inputs to be generated for the NRMM, thereby providing more accurate mobility predictions.

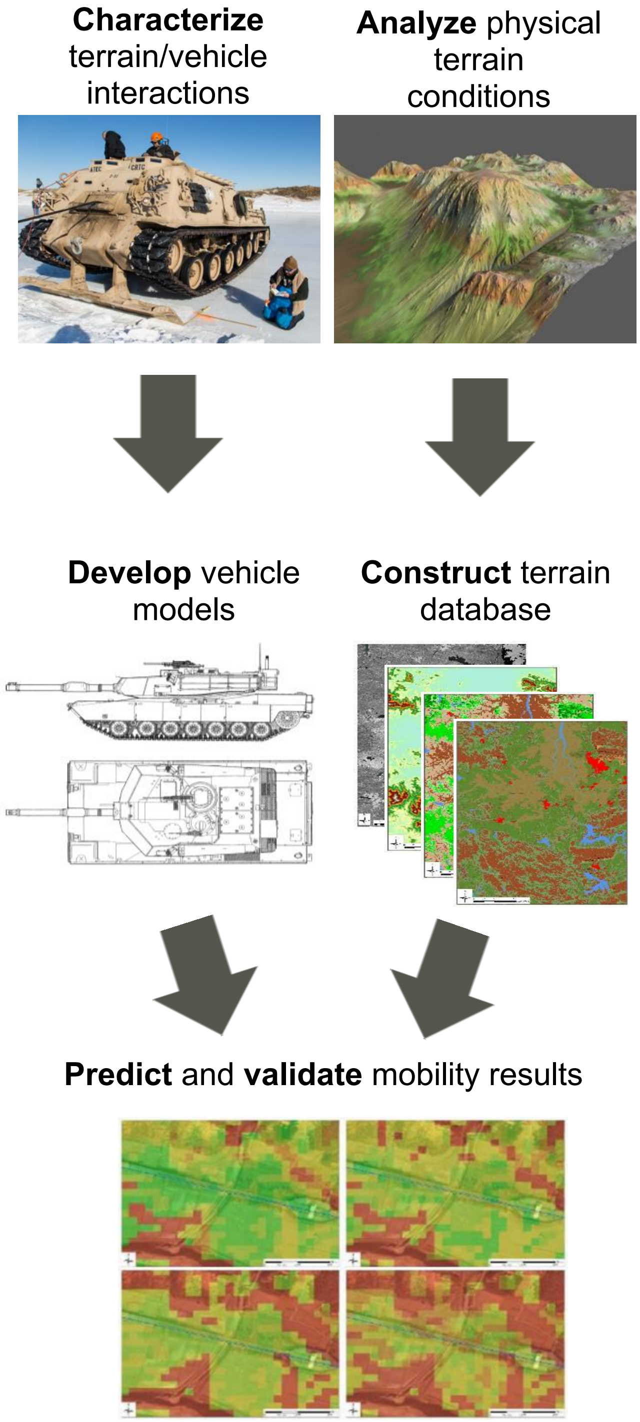
3. METHODOLOGY

In order to generate robust predictions for vehicle performance in a variety of cross country conditions several steps are required (Figure 1). These steps include:

1) Field Testing to characterize the relationships between vehicles and the underlying terrain.
2) Analyzing the climatology for an area of interest to inform selection of the appropriate seasonal parameters.
3) Conducting geospatial analyses to generate the input terrain parameters and construct a representative digital terrain database.
4) Modeling vehicle performance using the input terrain databases and geospatially distributing the results.

Steps 1-3 in this methodology will be outlined in further detail in the following subsections of the report. The modeling in step 4 was conducted using NRMM II – CRREL Beta Version 3.0.

Figure 1: Overview of seasonal cross country mobility workflow. Including: characterizing terrain/vehicle interactions, analyzing the physical terrain, developing vehicle models, constructing terrain databases, and predicting/validating mobility results



3.1 FIELD TESTING

For this analysis, researchers at CRREL have assessed vehicle performance in winter conditions at several field sites. These studies included: testing heavy tracked recovery vehicle capabilities in Alaska, assessing over snow performance of light tracked vehicles in Norway and Vermont, and characterizing wheeled vehicle abilities in deep snow conditions in Montana. To assess vehicle performance, a variety of tests are used which include: motion resistance, drawbar pull, coast down, and slope testing. The motion resistance test is used to gauge a vehicles resistance to motion for a given surface condition. The drawbar pull test provides an estimate of the possible net tractive force for the ground conditions. The coast down test is another setup that is used to test the motion resistance of a vehicle. Finally, the slope testing determines how capable a vehicle is on different grades; both perpendicular and side slop capabilities are tested. Vehicle performance in thawing soils was previously characterized by [8, 12-14], but no further field analyses were conducted as part of this study.

In addition to the vehicle testing, there are also extensive measurements taken of the underlying terrain. For measuring the strength of the soil, a shear vane tester (shear strength), Clegg impact hammer (bearing capacity), and dynamic cone penetrometer (bearing capacity) are used. In addition to soil strength, volumetric soil moisture is measured using a Field Scout moisture meter. To characterize the snow properties tests are conducted to measure common parameters such as: density, moisture content (Finnish snow fork and Denoth moisture meter), and depth (Magnaprobe). The strength of the snow is also measured using the same instruments as the soil tests, in addition to: the Rammsonde penetrometer, Yamaha Drop Cone, CTI snow compaction gauge, and the Snow Micro penetrometer depending on the amount of compaction.

3.2 CLIMATOLOGY ANALYSIS

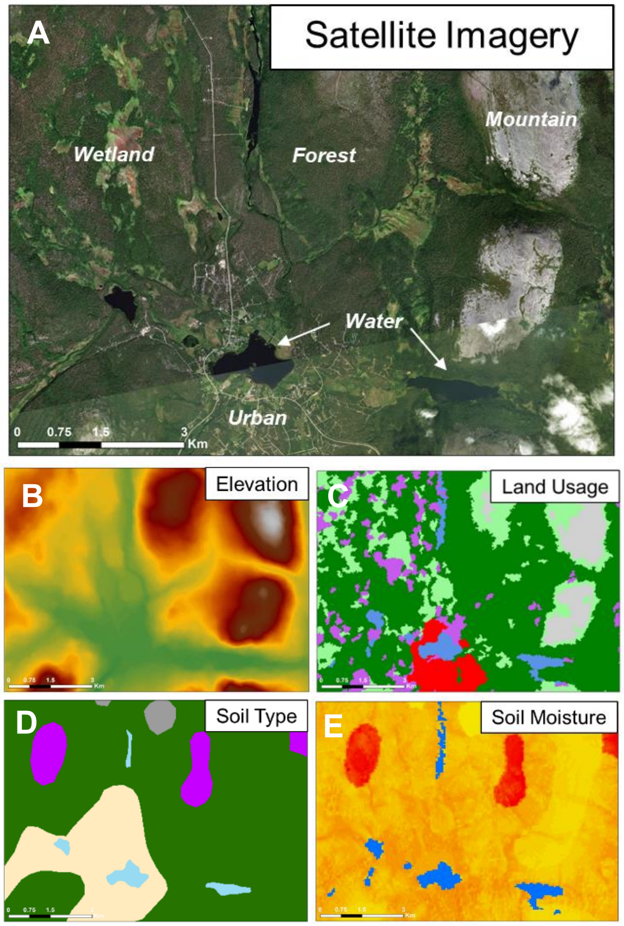
Climatology analyses play a key role in these studies as they allow for the proper identification of representative seasonal terrain conditions. The analysis for this study used weather data from the World Bank Climate Change Knowledge Portal (CCKP) and National Centers for Environmental Information (NCEI) which include: The Global Summary of the Day (GSOD), the Global Historical Climatology Network (GHCN), and the Integrated Surface Database (ISD). These databases provide statistical information relating to temperature, precipitation, and a suite of other climatological parameters at a fine temporal resolution over a large period of record (POR). For this analysis a POR was analyzed from 1961-1990 and another from 1991-2016. This step was crucial to see if there were significant differences in more recent years due to globally changing climate. Generally, both the average air temperature and the total precipitation are higher in the more recent POR.

This analysis provided insight into the timing of key seasonal changes in northern Scandinavia. These records indicate that the wettest months tend to be July and August, with the driest month being May. The freezing season was found to occur between Mid-October and Early-April with the thaw season reaching its peak in Mid-April. The greatest snow depths were observed during the beginning of March, with the depths increasing as elevation increased.

3.3 GEOSPATIAL ANALYSIS

For each area of interest, geospatial data (such as satellite imagery, slope, land usage, and soil type) was gathered to provide a baseline terrain condition (Figure 2 a-d). Once the baseline was established, varying seasonal conditions were then incorporated. One example of this is soil moisture, which can fluctuate depending on the season, and is a crucial indicator of soil strength (Figure 2e). The soil moisture data was generated by Creare LLC [15]. This dataset provides daily global 30-meter volumetric moisture predictions, which allows it to be used for any area of interest.

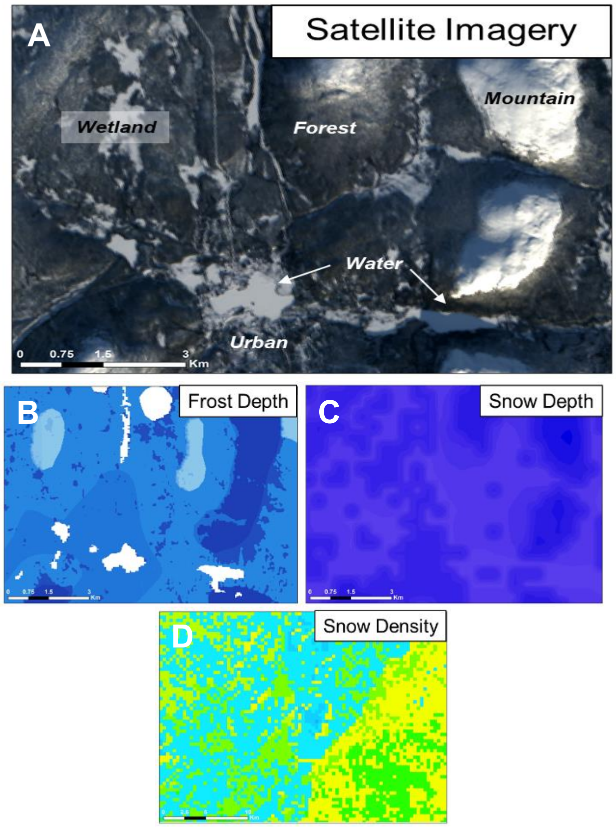
Figure 2: Examples of the parameters that are used to construct a terrain database. A: Satellite image of the test area in northern Scandinavia, B-D: Static terrain parameters, and E: soil moisture example of dynamic seasonal inputs.



Winter plays a significant role in vehicle mobility, so new methods had to be developed for generating terrain datasets in winter conditions. These datasets typically include frost depth, snow depth, ice thickness and snow density (Figure 3). These geospatially distributed seasonal datasets are generated using a variety of models developed at CRREL. SnowModel [16] is used to predict the snow depth and density for a given area and time period. This model was selected as it is a snow evolution modeling platform that allows for spatially distributed results with high spatial (1-200-meter cell size) and temporal resolution (10 min-1 day). Required inputs to SnowModel include: topography and land cover (vegetation type) as well as time dependent climatic fields such as precipitation, wind speed, air temperature, and relative humidity. The climatic inputs are typically obtained from meteorological stations or an atmospheric model.

In addition to snow characterization, the strength of the underlying soil is also crucial for correctly preceding vehicle capabilities. The depth of frost can change the competency of soil considerably. The MODBERG (Modified-Berggren) model [17] is used to calculate estimated maximum frost depth. This model takes into account the surficial soil type and estimated gravimetric soil moisture, as well as the average air freezing degree days and snow depth for a particular region. These parameters are used with the Modified-Berggren equations to calculate the maximum frost depth. This model does not inherently produce geospatially distributed results. However, the results were able to be mapped following a modified geospatial distribution process. Before MODBERG is run, the input parameters are geospatially mapped in the region of interest. These parameters are spatially joined into a single raster dataset, with unique numeric identifiers created for each combination of input parameters. This process is similar to the generation of Numbered Terrain Units (NTU's) for which NRMM is required to run. The attribute table of this spatially joined raster dataset is exported, and its contents are used as the input parameters to MODBERG. A maximum estimated frost depth is calculated for each combination of input parameters and the results are mapped back by matching the unique identifiers to the input raster dataset. Another equally important factor affecting soil competency is the depth of thawing ground. The FROSTB model [18] was used to estimate the average thaw depth for a particular point in time. This model is not setup in a manner to accept geospatial inputs thus, to represent the thaw depth, a value of 5.5 inches (calculated using FROSTB) was uniformly distributed across the area of interest. This value was selected as a proxy to represent the average depth of thawing soil in the test region. The majority of the static and dynamic datasets in this study had a spatial resolution of 30 meters, with the exception of the snow depth/density which had a 400 meter resolution.

Figure 3: Examples of seasonal parameters used. A: Satellite image of the northern Scandinavia test area in winter, B: modeled maximum frost depth, C and D: modeled snow depth and density.



Once all of the seasonal inputs were generated they were spatially combined to the static terrain database. The seasonal condition being modeled dictated which data layers would be used to generate the input file for NRMM. The output attribute table generated from the spatial combine was used as the input into NRMM.

4. RESULTS AND ANALYSIS

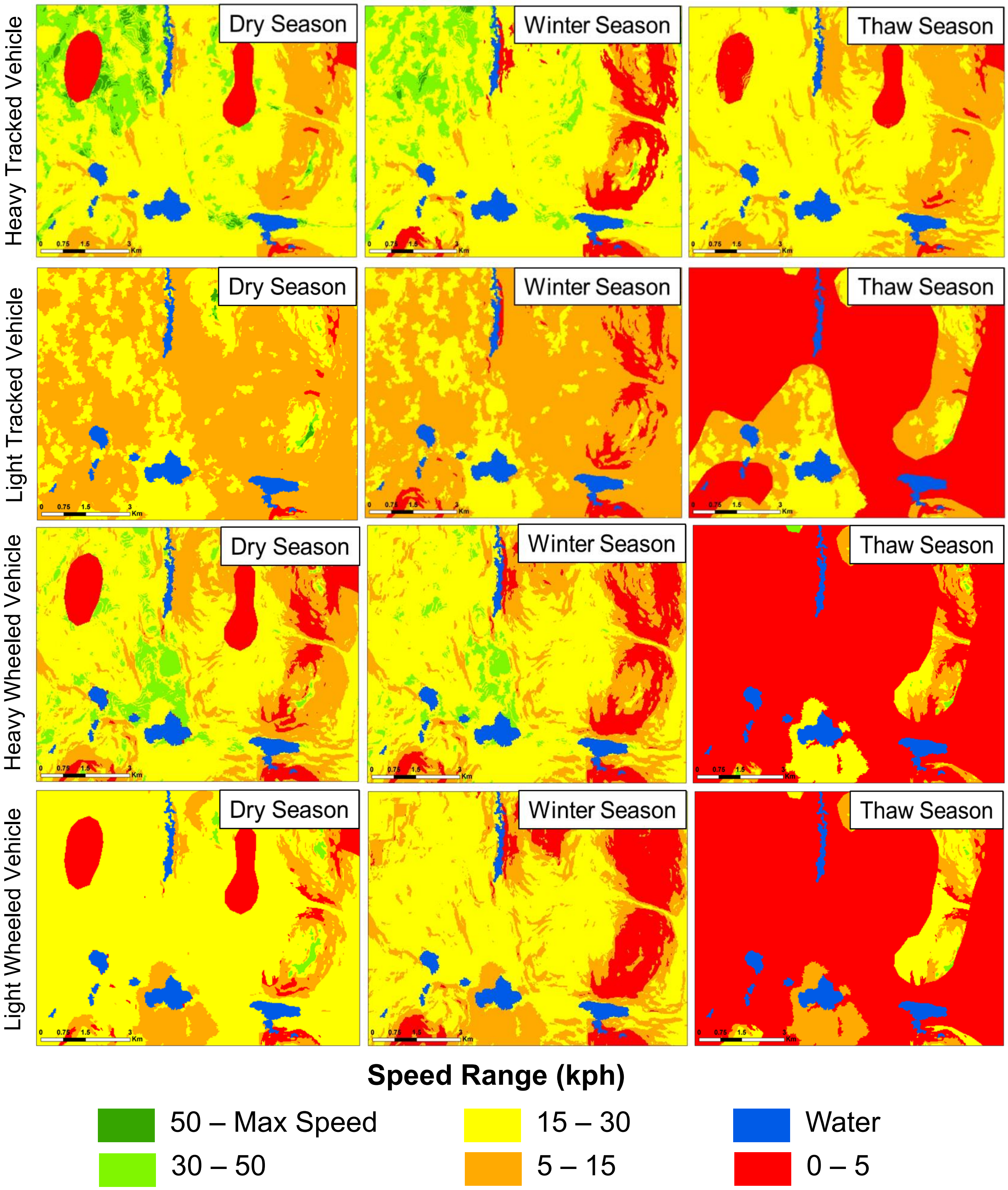
The results of this analysis indicate that there is a drastic impact on vehicle speed depending on the season (Figure 4). Overall the vehicles performed the best in the dry season condition, which is to be expected since the terrain is generally more competent. In the dry season, there is lower volumetric soil moisture, which increases the strength of the soil. The exception to this is with sand-dominated soils, where the strength increases with increasing moisture content. The thaw season condition had the most drastic impact on mobility, with all but the heavy tracked vehicle being almost completely NOGO in the region. The winter season showed the slightly hindered vehicle performance due to the snow on the terrain. However, all of the vehicles were able to traverse peat soils due to the fact that most of the ground under the snow was frozen.

Overall, the heavy tracked vehicle had the best performance in all terrain conditions. In the dry season condition, the heavy tracked vehicle was hampered by peat soils. However, the greatest hindrance to speed for the heavy tracked vehicle was the slope of the terrain, the effect of which was exacerbated in the winter season. This decrease in slope mobility is due to there being less traction between the vehicle and the underlying terrain. The performance of the light tracked vehicle seemed to be hampered mostly by the amount of vegetation due to its low push-over force compared to the other vehicles. However, this vehicle was the only one capable of traversing peat soils in the dry season condition. Similar to the heavy tracked vehicle, the light tracked vehicle was mostly hampered by the slope of the terrain, especially in winter conditions. The light and heavy wheeled vehicles had similar performance to one another in all conditions. While performance of both vehicles was impacted by the slope of the terrain, the light wheeled vehicle performed better on slopes in the dry season than the heavy wheeled vehicle. However, the opposite was true for the winter season condition. This is likely due to the larger snow depths at higher elevations. The heavy wheeled vehicle has a higher ground clearance and was likely not experiencing as much drag as the light wheeled vehicle.

5. CONCLUSIONS

These results highlight the importance of incorporating seasonal impacts on terrain into NRMM and Next Generation NRMM. All of the test vehicles experienced impacts to performance in both the winter and thaw season conditions compared to the dry season. Overall, the greatest hindrance to speed for all four test vehicles was the 5.5 inches of thawing soil. In winter season conditions, the ground beneath the snow was frozen enough to allow vehicles to safely traverse across the areas of peat. Future vehicle technology needs to be adapted to be suited for the terrain of austere northern regions. These updates include: reviving deep and over snow vehicle capabilities, addressing current science and technology gaps, applying new modeling and simulation techniques, and developing autonomous vehicle capabilities. In addition to updating vehicle technology, future modeling and geospatial work must focus on: quantifying and incorporating uncertainty into speed predictions, adding capabilities for peat and highly organic soils, addressing vegetation effects on terrain strength, and validating updated algorithms that quantify the effects of seasonally changing terrain conditions on vehicle mobility.

Figure 4: Seasonal speed maps for the dry season, winter season, and thaw season, for all four test vehicles.



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14. ABSTRACT

Seasonality plays a key role in altering the terrain of many military operating environments. Since seasonality has such a large impact on the terrain, it needs to be properly accounted for in vehicle dynamics models. This work outlines a variety of static and dynamic seasonal terrain conditions and their impacts on vehicle mobility in an austere region of Europe. Overall the vehicles performed the best in the dry season condition. The thaw season condition had the most drastic impact on mobility with all but the heavy tracked vehicle being almost completely NOGO in the region. Overall, the heavy tracked vehicle had the best performance in all terrain conditions. These results highlight the importance of incorporating seasonal impacts on terrain into NRMM or any vehicle dynamics model. Future work will focus on collecting more data to improve the empirical relationships between vehicles and seasonal terrain conditions, thereby allowing for more accurate speed predictions.

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