

Cooperative Demonstration of Technology

Next-Generation NATO Reference Mobility Model

NG-NRMM Motivation, Goals, and Architecture

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Off-Road Mobility Challenges



Military Challenges are Unique

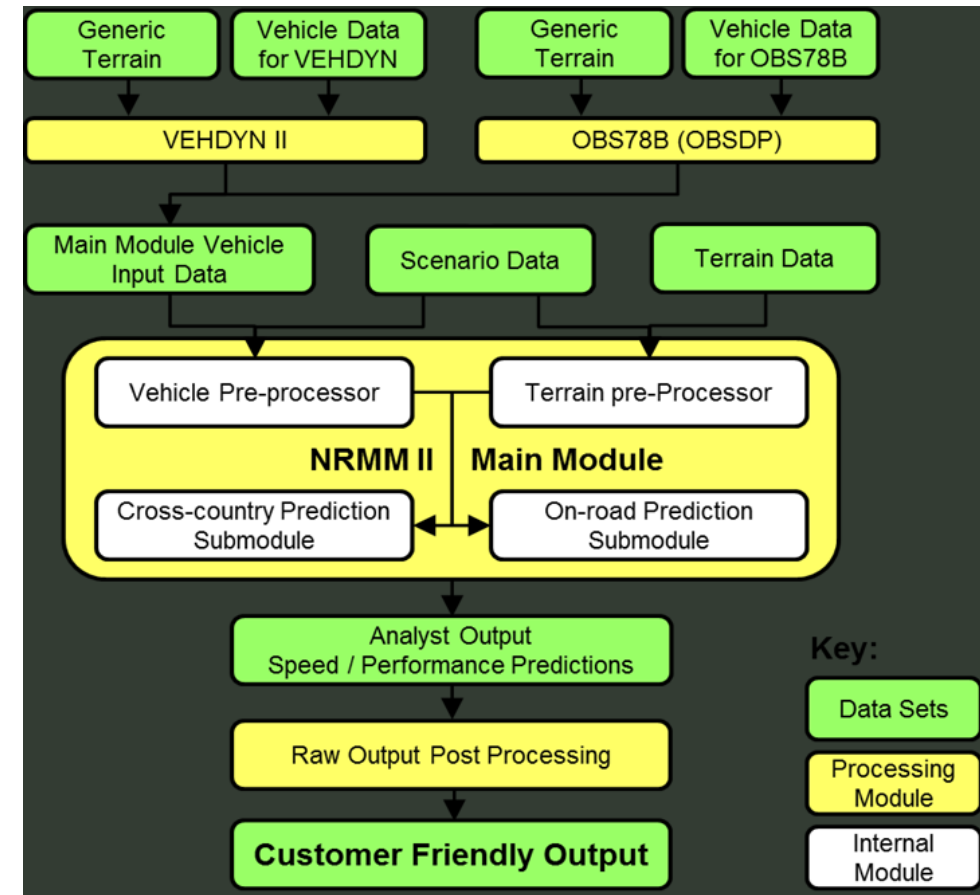


Presentation Outline

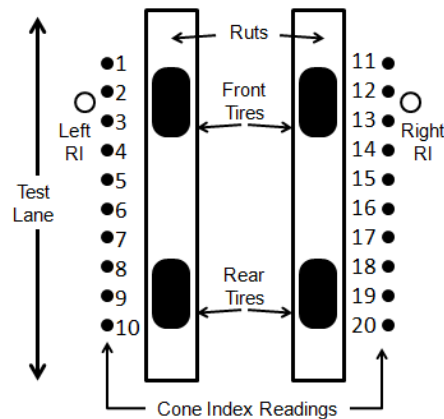
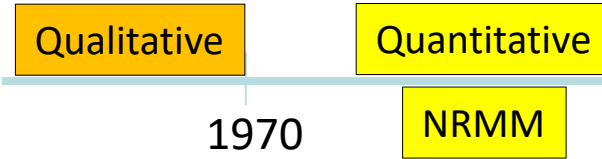
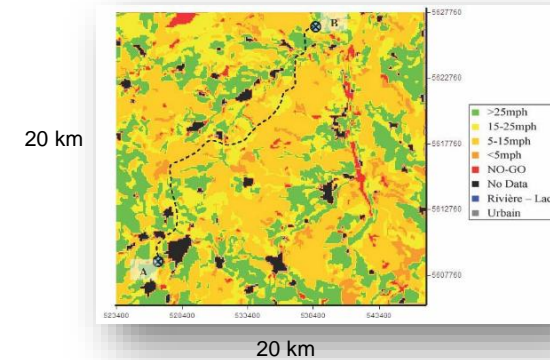
- What is NRMM?
- Why is NRMM outdated?
- What is NG-NRMM?
- Why use NG-NRMM?
- NG-NRMM, New NATO Standard

NRMM Overview

- FORTRAN code
- **2D pitch plane vehicle dynamic models for ride quality and obstacle performance**
- Terrain data are maps of soil, slopes, vegetation, roads, obstacles for specific world regions
- Scenario data overlays weather effects
- Main operational module considers seven major speed limiting factors
- **Empirical soft soil trafficability models based on rating and vehicle cone index (RCI / VCI)**
- **Widely used for**
 - **operational analysis**
 - **acquisition**
 - **design**



NRMM, An Empirical Approach



NATO Reference Mobility Model (NRMM)

- Dr. M. G. Bekker of TARDEC is the “Father of Terrain-Vehicle Systems”
- NRMM was developed in 1970’s by TARDEC and ERDC
- Worked towards NATO standardization in 1977-78
- US Army TACOM issued a policy adopting NRMM as mobility standard in 1981
- Methodology relied on empirical relationships and **not** physics-based
- Does **not** extrapolate to contemporary vehicle designs and technologies
- Does **not** benefit from advances in simulation and computational capabilities

What NRMM Can't Do

- Methodology **not** physics-based – relies on empirical, in-situ soil measurements
- Does **not** support 3D models
- Does **not** consider steering performance and lateral vehicle dynamics
- Does **not** extrapolate to contemporary vehicle designs and technologies
- Does **not** predict mobility for systems dissimilar to past systems (weight, power, suspension system, controls, etc.)
- Does **not** benefit from advances in simulation and computational capabilities
- Does **not** cover uncertainty, intelligent vehicles, or data sets for urban areas

NG-NRMM Research Thrusts

1. GIS Terrain and Mobility Map

Identify a GIS-based mapping tool that implements and integrates existing valid mobility metrics (%NOGO and Speed-Made-Good) in an open architected environment.

2. Simple Terramechanics

Identify most promising existing terramechanics methods supporting NG-NRMM requirements that provide a possible means of correlating the requisite terrain characteristics to remotely sensed GIS data.

3. Complex Terramechanics

Establish a vision for the long term terramechanics approaches that overcome the limitations of existing models.

NG-NRMM Research Thrusts

4. Intelligent Vehicle Mobility

Identify unique mobility metrics and M&S methods necessary for mobility assessments of intelligent vehicles over a sliding scale of data and control system resolutions.

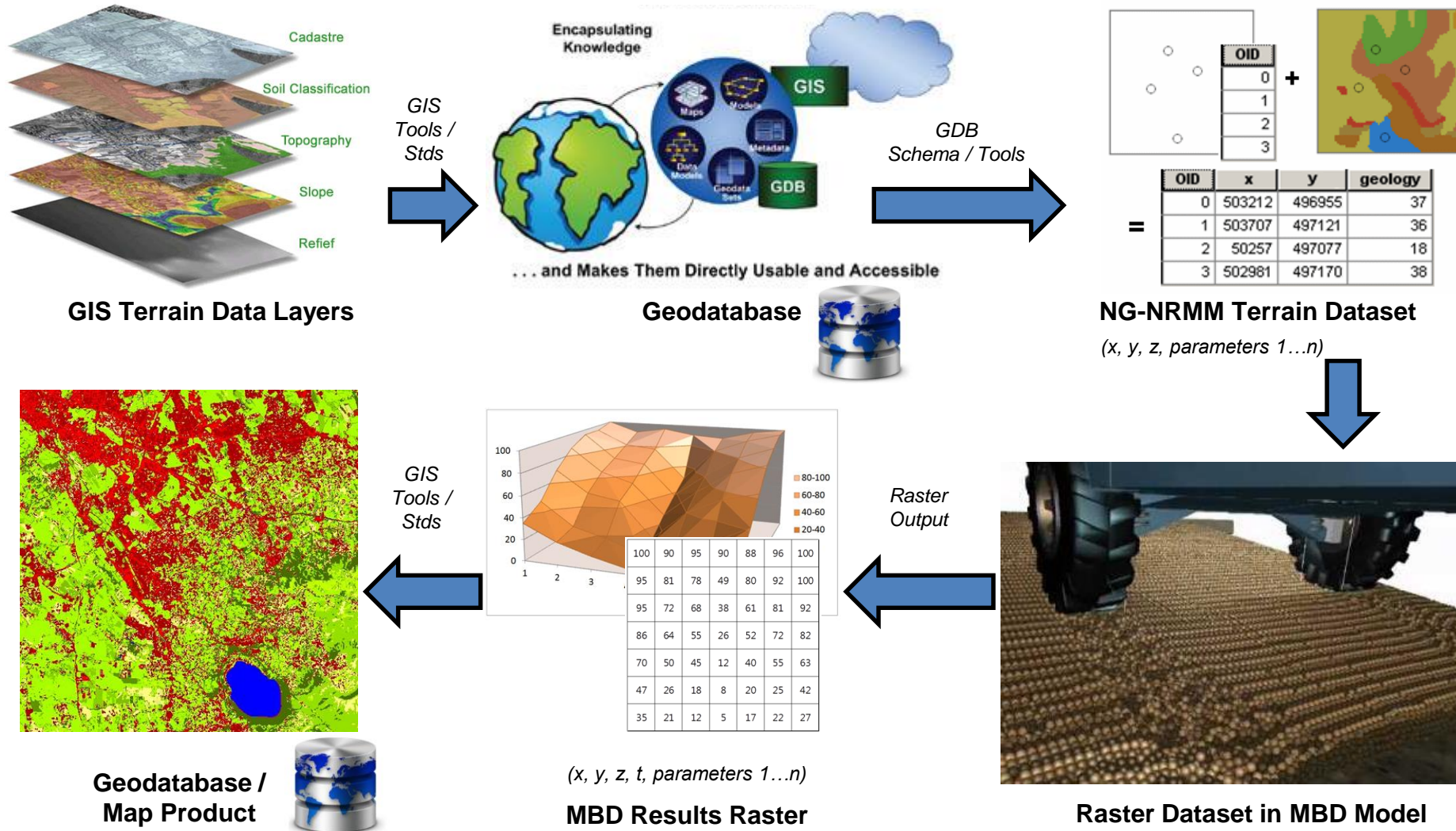
5. Uncertainty Treatment

Identify the practical steps required to embed stochastic characteristics of vehicle and terrain data to extend and refine the current deterministic mobility metrics.

6. Verification & Validation (V&V)

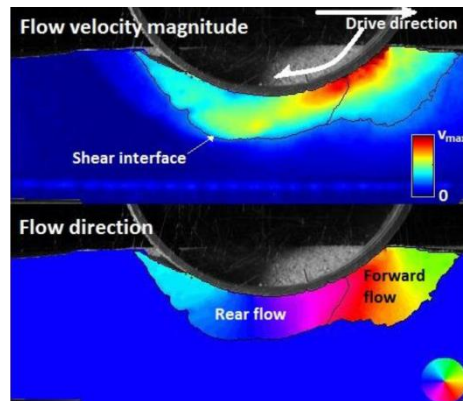
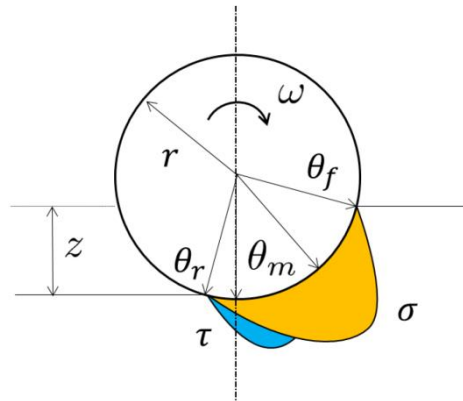
Implement near-term vehicle-terrain interaction benchmarks for verification of candidate NG-NRMM M&S software solutions and lay the groundwork for long-term validation data through cooperative development with test organizations standards committees.

Thrust Area 1: GIS Terrain and Mobility Map



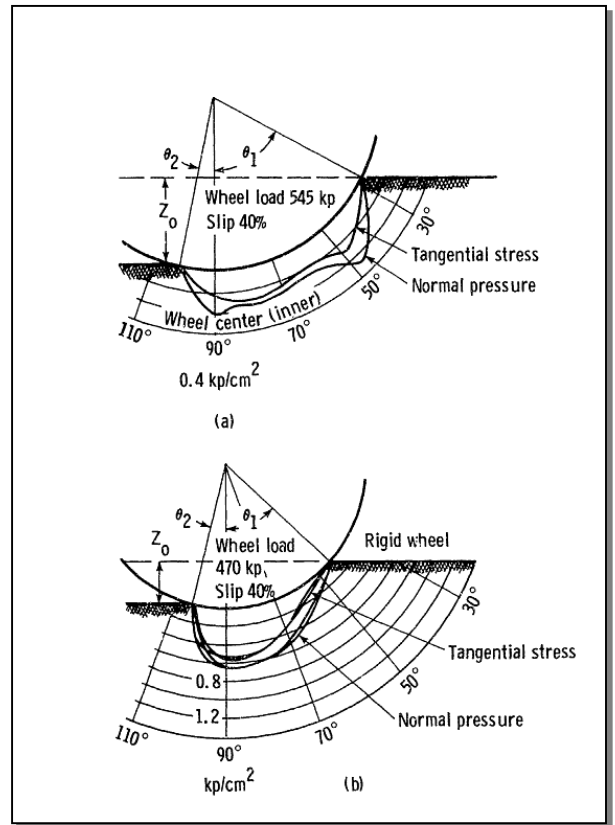
Thrust Area 2: Simple Terramechanics

Bekker-Wong-Janosi Models

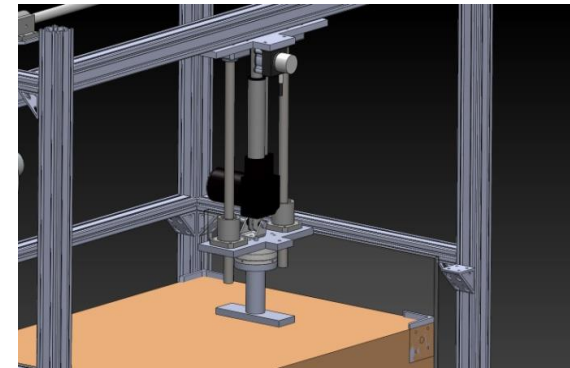


Particle Image Velocimetry

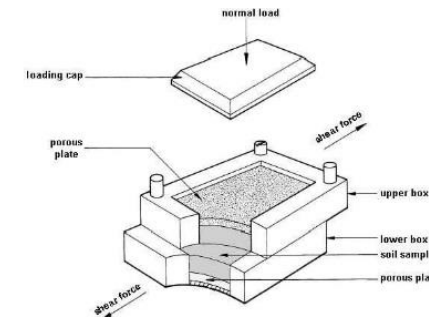
Stress Distribution



Laboratory Identification

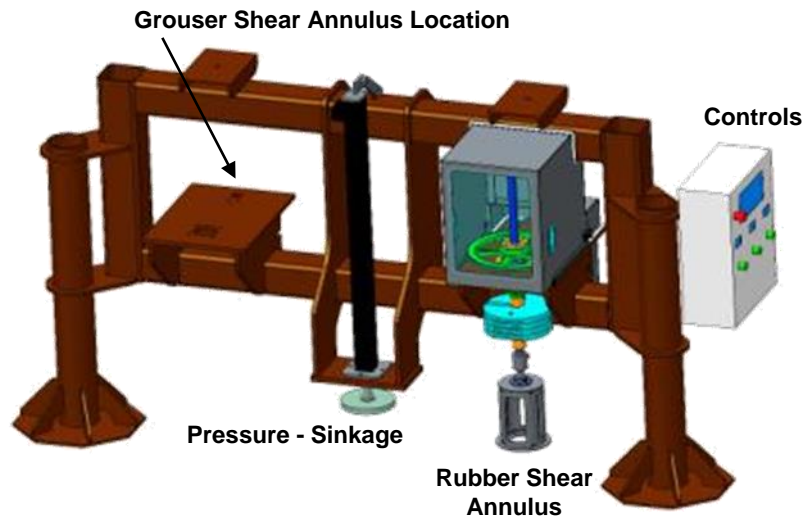


Pressure – Sinkage Test

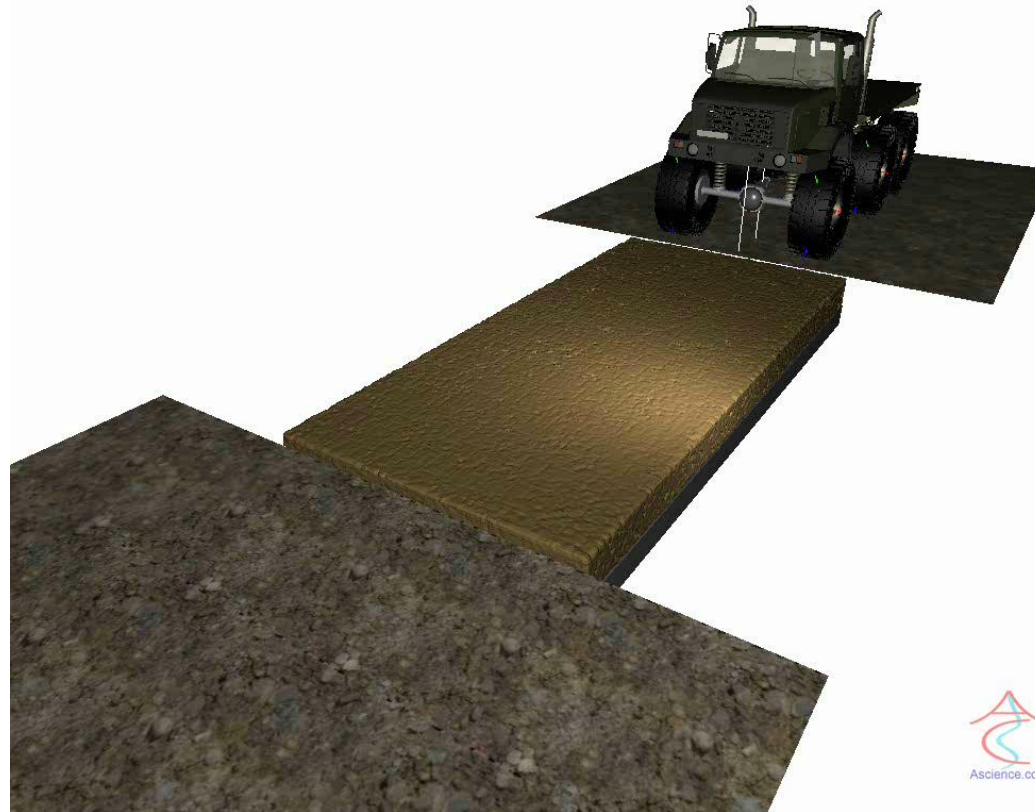
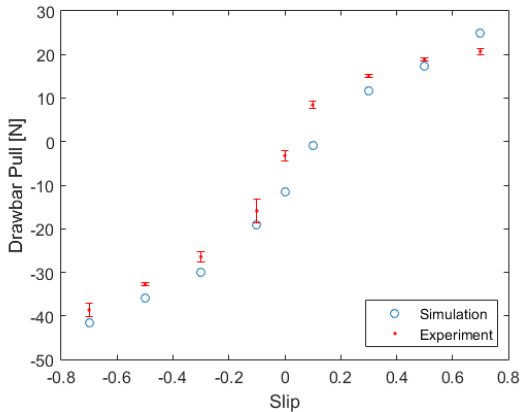
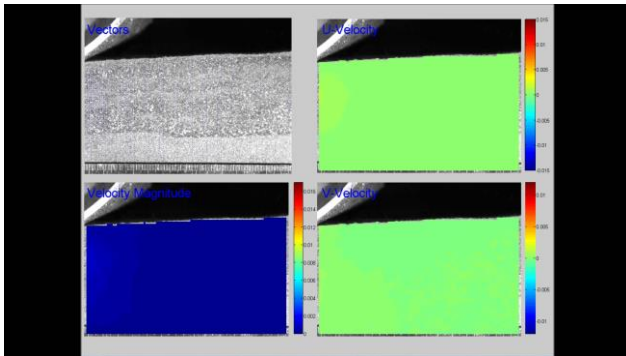
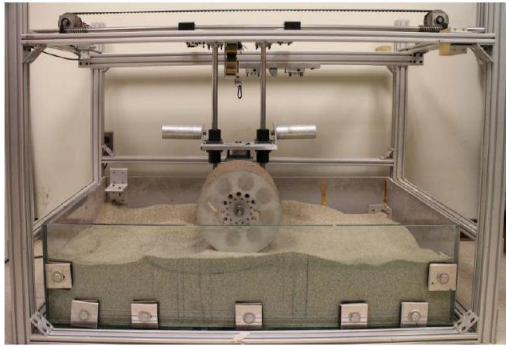


Direct Shear Test

Soil Characterization Using Bevameter



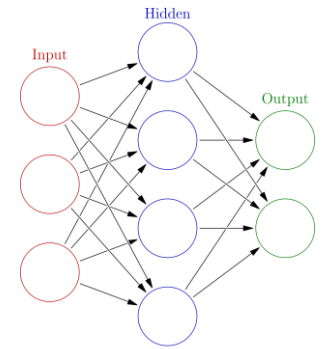
Thrust Area 3: Complex Terramechanics



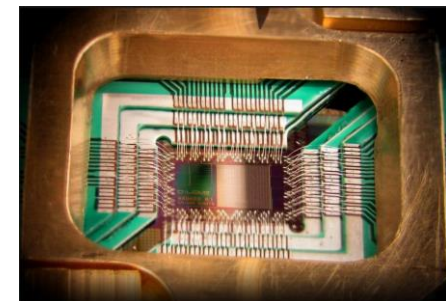
High-Performance Computing



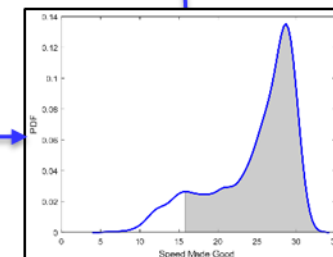
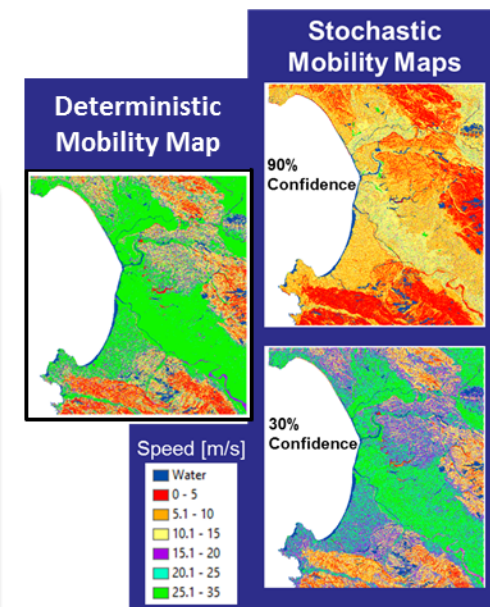
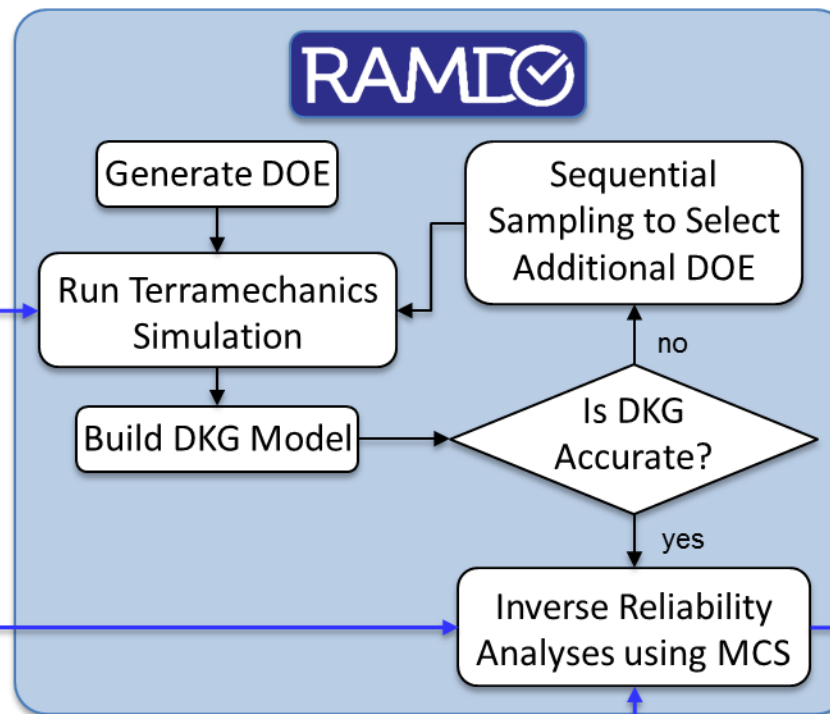
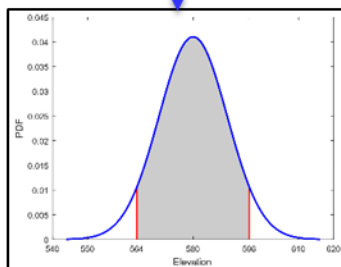
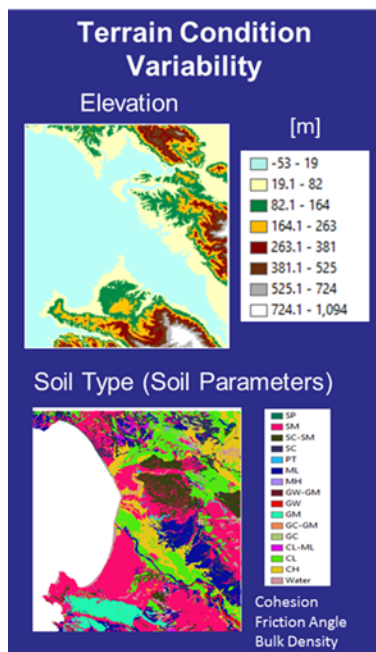
Machine Learning



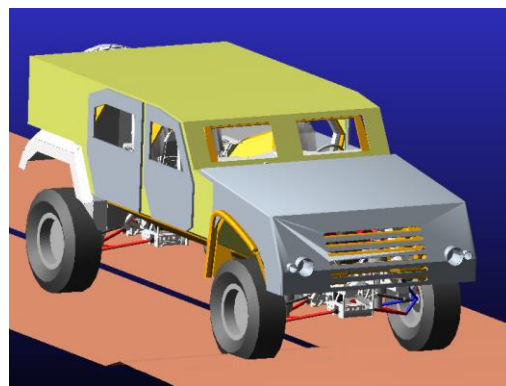
Quantum Computing



Thrust Area 5: Uncertainty Quantification



Thrust Area 6: Verification and Validation



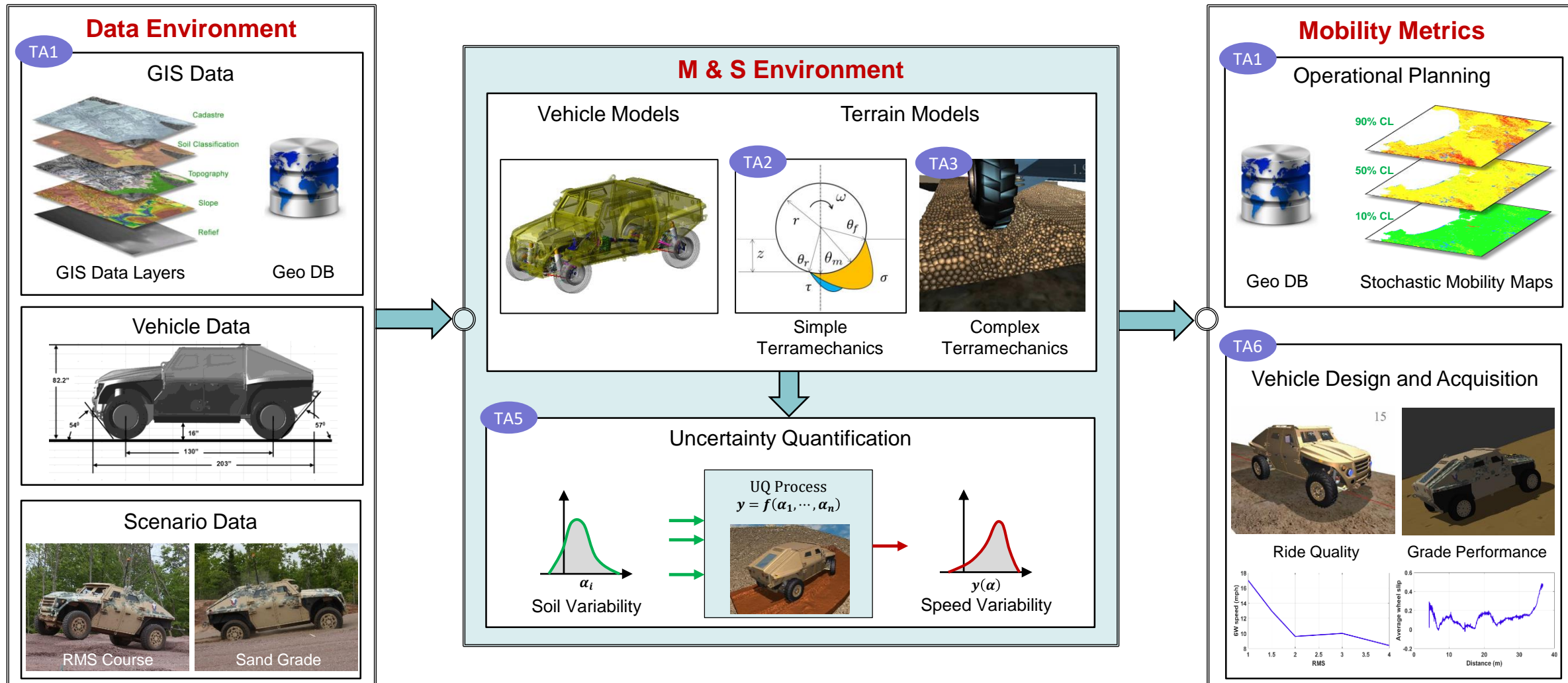
NG-NRMM Software Maturity Level

1. **DEMONSTRATION:** Demonstration of a correct implementation of a theoretically and conceptually consistent model.
2. **PARAMETER SENSITIVITY DEMONSTRATION:** Verification that performance change with a change in system parameter such as GVW or terrain deformability is consistent with theory and physics principles.
3. **INDEPENDENT USER VERIFICATION:** Independent user demonstration and correlation to vendor results
4. **CROSS CODE VERIFICATION:** Cross verification with another accepted mobility simulation code
5. **CALIBRATION:** Calibration to a real vehicle test data set
6. **VALIDATION:** Blind correlation to a real vehicle test data set
7. **PARAMETER VARIATION VALIDATION:** Blind correlation to a real vehicle test data set with a change in system parameter(s).

Participating Tool Developers

- United States
 - Advanced Science and Automation Corp.
 - MSC Software Corp.
 - University of Wisconsin – Madison
 - RAMDO Solutions
- Canada
 - CM Labs Simulations Inc.
 - Vehicle Systems Development Corp.
- South Korea
 - FunctionBay Inc. / MotionPort LLC
- South Africa
 - Council for Scientific and Industrial Research
- Denmark
 - Aarhus University

NG-NRMM Architecture



Why Use NG-NRMM?

- NG-NRMM captures decades of advancements since the development of NRMM.
- Modern methods available in NG-NRMM can significantly improve our ability to make mobility predictions and assessments. These hold the promise of improving prediction errors by an order of magnitude.
- Simplified NG-NRMM solutions, running in real time or better, can replace NRMM for use in operational planning, training, and field deployment.
- High-fidelity NG-NRMM solutions are suitable for research and development work at the technology and procurement levels.
- Accounting for uncertainties, especially in terrain properties, improves confidence in mobility maps.

NRMM vs. NG-NRMM: Mobility Traverse Speed Comparison



Traverse Loop Summary			
	Method		
AVG. Speed	NG-NRMM	TEST	NRMM
(m/s)	7.4	7	11.5
(km/hr)	26.6	25.3	41.4
(miles/hr)	16.5	15.7	25.7

- NG-NRMM over predicts S-M-G by 10% while NRMM over predicts by 60%

Section	Description	Speed Variance (%)	
		NRMM	NG-NRMM
B1	RMS 1.0 with Exit onto Gravel Pad	14.0	23.4
B2	Up Slope on Gravel Pad with Down Slope through 2NS Sand Grade	31.3	1.9
B3	Construction Site Road to Gravel Access Road & Loop 2, Rink Field Traverse with setup for OEF	18.6	-1.4
B5	Gravel Road to Stability Side Trail, Sinusoidal Side Slope with Setup for Moisture Dependent Area	54.4	49.0
Y1	Stability Field Traverse with Sinusoidal Side Slope, Loop 2 with Panic Stop	26.9	-5.4
Y2	Loop 2 with Rink Field Traverse & Setup for Wadi	38.8	5.0
Y3	Wadi	264.9	-20.2
Y4	Rink Field Traverse with Setup For Coarse Grain Pit	85.9	32.8
Y5	Sinusoidal Coarse Grain Pit	97.2	4.7
Y6	Rink Field Traverse with Loop 2 & Access Road to VDA 2 Field Traverse & Setup for Fine Grain Soil Pit	38.5	-8.8
Y7	Fine Grain Soil Pit - Up slope into pit then 90 degree turn in pit with accelerated exit	142.2	3.8
Y8	Construction Site Road to Side Slope, Obstacle avoidance on Side Slope, then RMS 2.0	88.0	-10.1

NRMM

- Consistently over predicts S-M-G for ALL segments
- Over predictions range from 14% to 265%
- Average over prediction error is 75%

NG-NRMM

- Both over and under predicts S-M-G
- Over predictions range from 2% to 49%
- Under predictions range from -1% to -20%
- Average error is +6%

NG-NRMM Speed-Made-Good (S-M-G) prediction is an order of magnitude improved over NRMM.

NRMM *vs.* NG-NRMM: Automotive Event Simulation Capability

Test	NRMM	NG-NRMM	Comments
Wall To Wall	✗	✓	No 3D Steering Mechanism in NRMM
Steady State Cornering	✗	✓	No Steering, Load Transfer Capability in NRMM
Straight Line Acceleration	✗	✓	NRMM over-predicts acceleration performance
V-Ditch	✓	✓	
Step Incline (12",18",24")	✓	✓	
Double Lane Change (Paved and Gravel)	✗	✓	No Steering, Roll and Lateral Dynamics in NRMM
Side Slope Obstacle Avoidance	✗	✓	No Steering and Lateral Load Transfer in NRMM
60 % Grade Paved	✓	✓	
Half Round (4", 8", 10", 12")	✓	✓	No enveloping tire model in NRMM
Symmetric RMS (1",1.5",2",3",4")	✓	✓	No enveloping tire model in NRMM
Asymmetric RMS (1"-1.5", 1.5"-2")	✗	✓	No Roll Dynamics in NRMM

NRMM *vs.* NG-NRMM: Limiting Terrain Identification

- **NRMM:** Empirical relations exist for Vehicle Cone Index (VCI) that defines minimum soil strength required for trafficability on a level wet heavy clay (CH) terrain. A vehicle with lower VCI can traverse more terrain area and hence more mobile than a vehicle with higher VCI.
- **NG-NRMM:** There is no direct identification of the limiting soil strength for a given vehicle. However, **for any soil**, the fundamental soil strength parameters such as cohesion and friction can be incrementally reduced to identify the conditions when Drawbar Pull (Coefficient, DPC) reduces to zero. Further, DPC is also directly predictive of **slope** trafficability as well.

Performance Metrics Conformance with NG-NRMM

Test Event	Performance Metric
Straight Line Acceleration	Speed vs. time
Wall-to-Wall Turn Circle	Minimum turn circle radius
Steady State Cornering	Understeer gradient, Max speed
Double Lane Change, Paved & Gravel	Max speed
Side Slope Stability with Sine Steer	Max side slope
Longitudinal Grade Climbing, Paved	Max grade
Obstacle Crossing, Step and V-Ditch	Go/NoGo
Ride Quality	6W speed vs. Road rms, sym & asym
Shock Quality	2.5g speed vs. Half-round height
Off-Road Trafficability	Drawbar pull vs. Slip
Longitudinal Grade Climbing, Sand	Max sand grade
Mobility Map Generation	Speed-Made-Good % Go % Reliability

NEW

Ride Quality Demonstration

Symmetric Road: 3 in RMS



Asymmetric Road: 1.5 & 2.0 in RMS

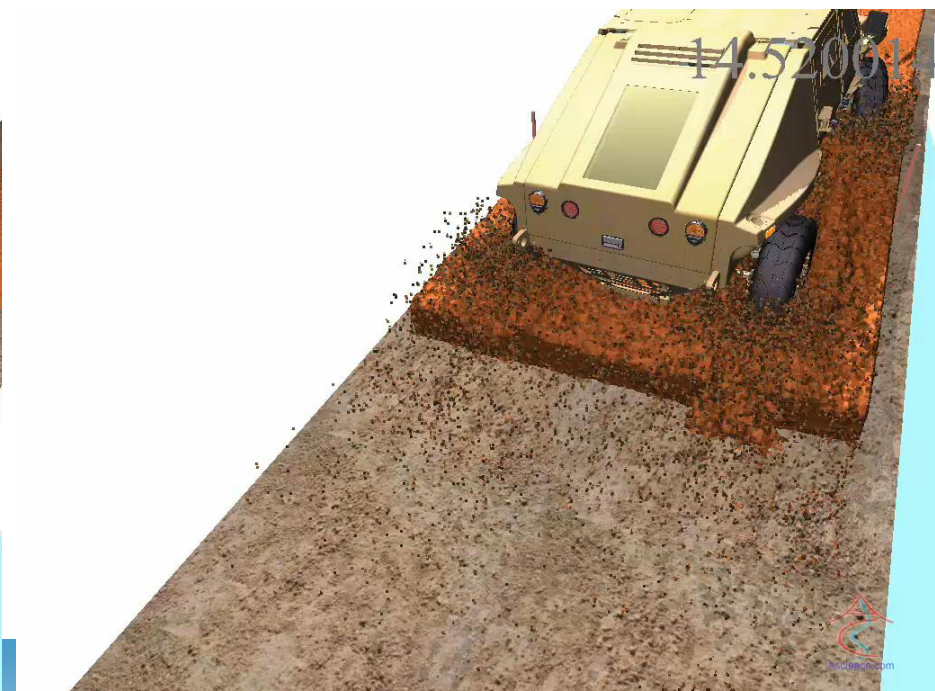
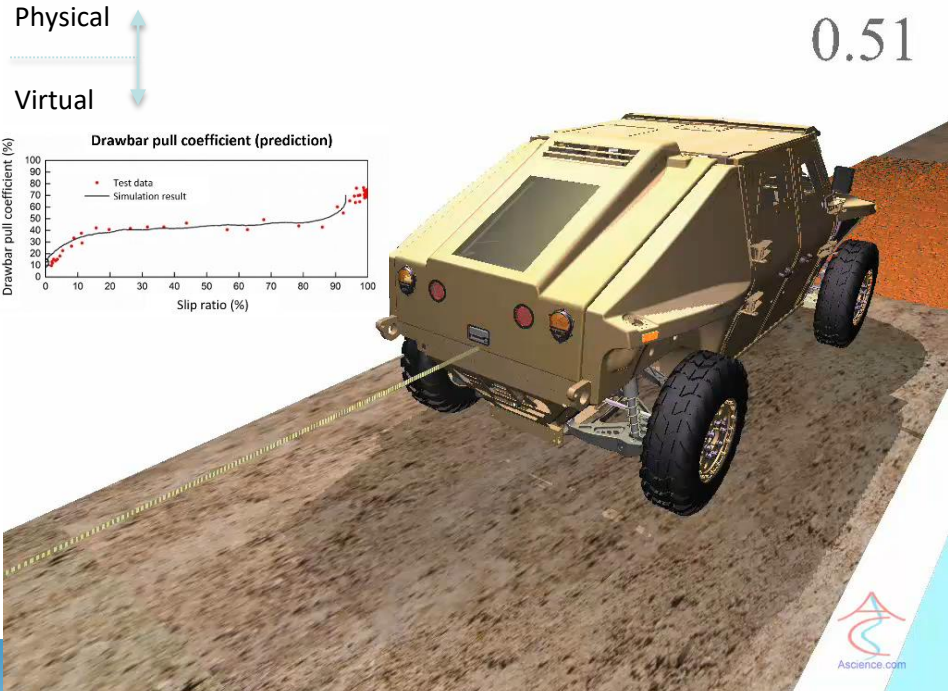


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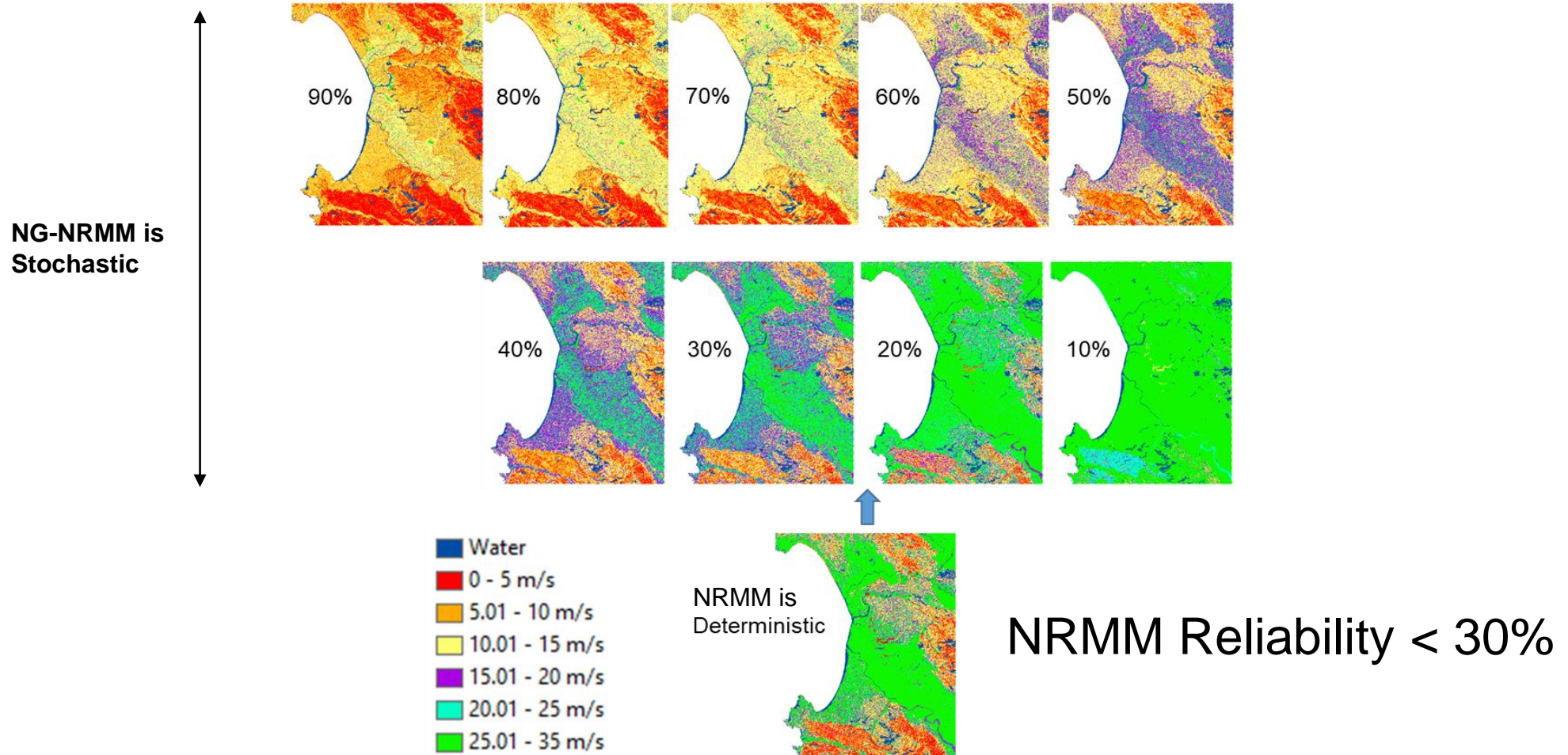


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Soft Soil Mobility Demonstration



Reliability of Speed-Made-Good Map



NG-NRMM, New NATO Standard

- **STANREC 4813:** Guidance for M&S Standards Applicable to the Development of Next-Generation NATO Reference Mobility Model (NG-NRMM).
- NG-NRMM is a Standard, not a specific computer code.
- NG-NRMM compliant tools can be government or commercial software.

NG-NRMM Architecture

