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Title: LANL ADM Protocol: TRACER AND COMPLEX TERRAIN STUDIES

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Los Alamos
NATIONAL LABORATORY

LANL ADM PROTOCOL: TRACER AND COMPLEX TERRAIN STUDIES

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2015 ADM PROTOCOL SUBMISSION 2017 NA-LA RESPONSE

- November 2, 2017: NA-LA Approved all 2015 ADM Protocol Elements Except Application of RG 1.145 Lateral Plume Meander Factors
  - Principal Concern: Applicability of MACCS2 to LANL Complex Atmospheric Flow Phenomena in a Mesa-Canyon Topographic Setting
  - Encouraged Submission of Further Research to Develop Technical Justification
- 2018-2021 Activities Focused on Developing Technical Justification
  - Literature Search and Review of 5 LANL-Specific Complex Dispersion Technical Studies
  - Comparison of MACCS2 with RG 1.145 Lateral Plume Meander Factors to Bowen-Draxler and ARCON96 Methodologies
  - Comparison of 3-D CAPARS Concentrations to Straight-Line Gaussian Model Concentrations (Lagrangian vs Eulerian Frames of Reference)
  - Development of Mesa-Canyon Opposing Wind Statistics Using 2005 NEWNET Data

NA-LA CONCERN: MACCS UNDERESTIMATES LANL DISPERSION

"The terrain surrounding many LANL source release points are extremely non-uniform…includes abrupt elevation drops into adjoining canyons...The proposed MACCS2 study cites the planned use of the plume meander even though it is unlikely that this is a valid modeling option unless the plume of interest in lofted well above the surrounding terrain.

…for ground releases there may be significant plume downwash and plume canyon channeling if the plume transits these canyon areas...Such phenomena could significantly increase offsite doses. However, MACCS2…cannot simulate these complex velocity currents that may enhance doses at the public boundary.

Therefore, to ensure that MACCS2 or other more generalized diffusion codes yields reasonably bounding results the use of plume meander…should not be used except for sensitivity studies."

WHY PURSUE PLUME MEANDER?
CONSERVATE BIAS OF GAUSSIAN MODEL AT 95% METEOROLOGY

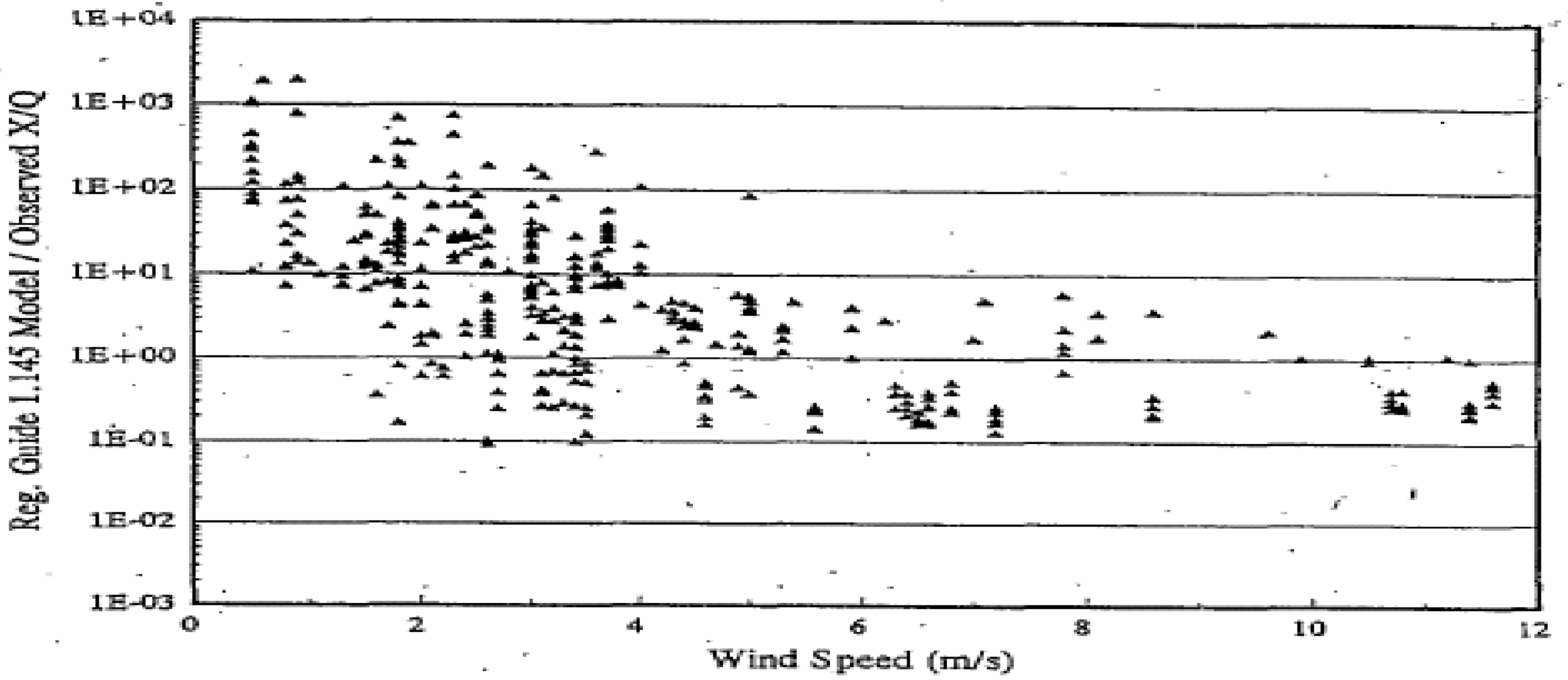
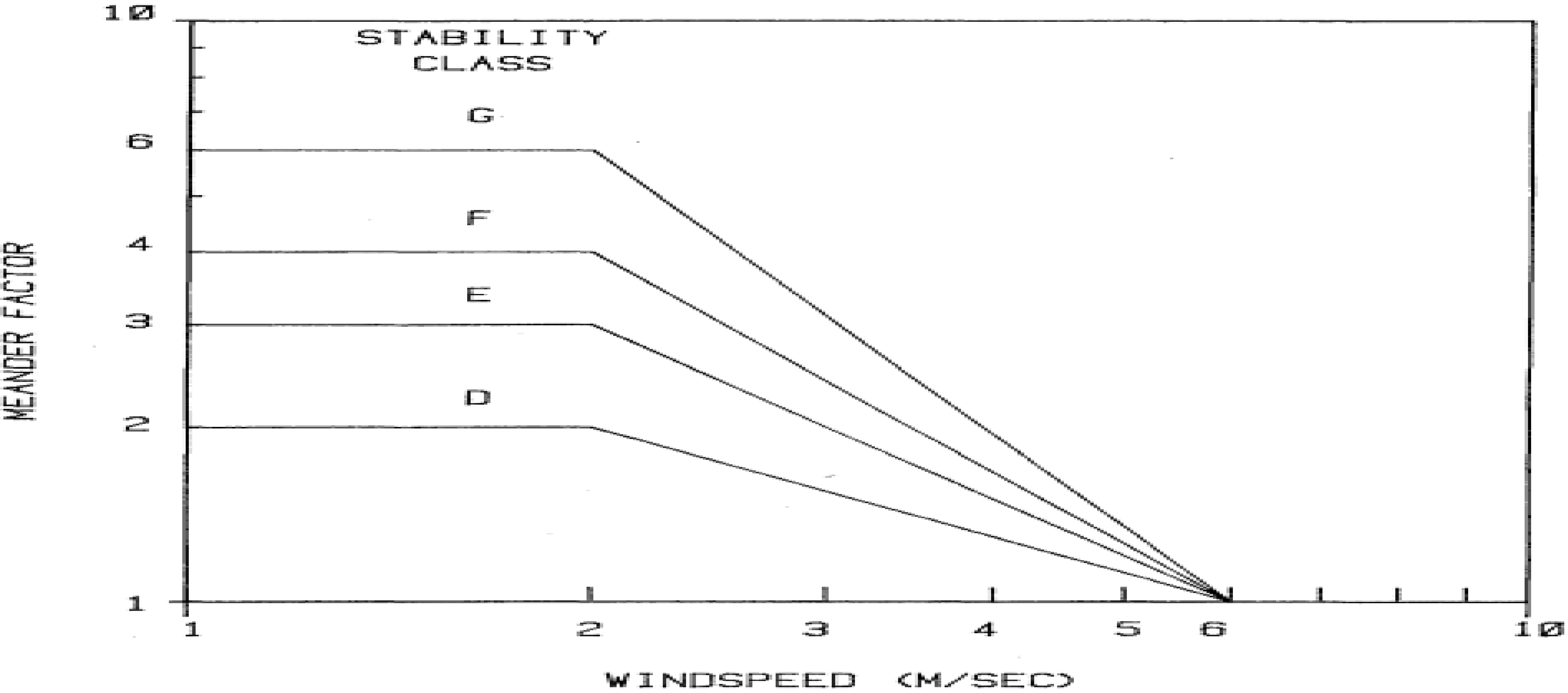


Figure 9. Bias in Regulatory Guide 1.145 Model Concentration Predictions

RG 1.145 LATERAL PLUME MEANDER FACTORS (1978)



TECHNICAL JUSTIFICATION FOR INCLUSION OF LATERAL PLUME MEANDER FACTORS IN MACCS2: DRAXLER METHODOLOGY

LAMPF "TRACER OF OPPORTUNITY" STUDY

- 1986-1987 Comprehensive "Tracer of Opportunity Study" Conducted at LANL to Evaluate Diffusion in Complex Terrain Topography
- Year 1: Array of 3 Portable Pressurized Ionization Chambers (PICs) Continuously Measured External Radiation Levels of Radionuclides Emitted from 30-m Los Alamos Meson Physics Facility (LAMPF) Stack
- WS/WD Measured at East Gate Tower Near Source, and at 700 Meters Downwind Across Deep Canyon
  - Horizontal WS and WD: 1.3-m, 4-m, and 12-m Levels
  - Vertical WS and WD at 4-m and 12-m Levels
  - Temperature, Solar Radiation, Relative Humidity, Precipitation

LAMPF STACK AND FIELD MONITORS

- LAMPF Stack Monitor
  - Routine LAMPF Operation of 800-MeV 1 mA-Intensity Linear Proton Accelerator, Activation Products (C^{11}, N^{13}, O^{15}), which served as Radionuclide Tracer Source
  - These Radionuclides do not Occur in Nature in Meaningful Quantities, thus a "Tracer of Opportunity": C^{11}, N^{13}, and O^{15} Monitored at LAMPF Stack
- Field Monitors
  - PICs Located 700-900 m N to NE of LAMPF Stack Across 120-m Deep Los Alamos Canyon and at Nearest Offsite Location
  - In 1987, 4 Additional PICs Deployed at Various Sites and Directions at Distances ranging from 550-2,800 m Downwind of LAMPF Stack

LAMPF METEOROLOGICAL MONITORING

➢ Meteorological Data Monitoring

- ➢ Wind Speed and Direction Measured at East Gate Tower Near Source, and at 700 Meters Downwind Across Deep Canyon.
- ➢ Horizontal Wind Direction and Wind Speed at Levels of 1.3 m, 4.0 m, and 12.0 m, and Vertical Wind Speed at Levels of 4.0 m and 12.0 m Measured, as well as Temperature, Solar Radiation, Relative Humidity, and Precipitation
- ➢ Tower Stands on Edge of a Smooth Sandy Mesa Top, while 600-m Wide and 120-m Deep Los Alamos Canyon Lies 50 m to S
- ➢ Second Meteorological Tower Located about 100 m NNW of LAMPF Stack on South Rim of Los Alamos Canyon Measured Horizontal Wind Direction and Wind Speed, and Vertical Wind Speed at 24 m Above Ground Level
- ➢ LAMPF Located as Close as 75 m to S and SE of Second Tower

DIFFUSION ANALYSIS AND CONFIRMATION OF MESA-CANYON FLOWS

- Diffusion Analysis
  - Comparison of Predicted Radiation Levels using Source and Receptor Wind Data at Sites Separated by a Canyon was Examined
  - External Radiation Levels **Determined by Direct Turbulence** Compared with Several Dispersion Methods
  - Atmospheric Diffusion Compared for Across-Mesa with Along-Canyon Transport
  - Transport into Canyon Also Studied
- Confirmation of Diurnal Mountain-Valley Winds
  - Comprehensive Analysis of Monitoring Data Confirmed a Predominant Mountain-Valley Wind up Rio Grande Valley During Evening

BOWEN-DRAXLER METHODOLOGY TO DETERMINE LATERAL AND VERTICAL DIFFUSION PARAMETERS

$$\sigma_y = \sigma_\theta x F_y\left(\frac{x}{\bar{u}T_y}\right) \approx \sigma_v t F_y\left(\frac{t}{T_y}\right)$$

$$\sigma_z = \sigma_\varphi x F_z\left(\frac{x}{\bar{u}T_z}\right) \approx \sigma_w t F_z\left(\frac{t}{T_z}\right)$$

where

σ_v = S.D. of transverse or crosswind wind speed [m/s]
σ_w = S.D. of vertical wind speed at effective release height [m/s]
t = downwind traveling time [s] = $x/\bar{u}$
x = downwind distance at [m]
$\bar{u}$ = average downwind speed effective release height [m/s]
F_y = transverse universal function = $(1 + 0.90\sqrt{t/5000})^{-1}$
F_z = vertical universal function = $(1 + 0.90\sqrt{t/1000})^{-1}$

BOWEN-DRAXLER MODEL CONCLUSIONS

- Bowen-Draxler Model, Modified for LANL Complex Terrain, using Direct Measurements of Turbulence Intensity, Best Represents LANL Diffusion using Gaussian Eulerian Frame of Reference Models
- Is more Representative of Atmospheric Diffusion at LANL than MACCS2 Methodology
- Documented in Two 1994 Peer-Reviewed AMS Journal of Applied Meteorology Publications

TECHNICAL JUSTIFICATION FOR INCLUSION OF LATERAL PLUME MEANDER FACTORS IN MACCS2: ARCON96 METHODOLOGY

ARCON96 LATERAL AND VERTICAL PLUME MEANDER EMPIRICAL EQUATIONS

- PNNL Developed Atmospheric Relative CONcentrations (ARCON96) (NUREG/CR-6331 R1) for NRC to Address Straight-line Temporally- and Spatially-Invariant Gaussian Model Biases and Limitations
- Developer Well-Recognized by Peers Relative to Understanding of Complex Flow Phenomena in Planetary Boundary Layer
  - ARCON96 Ramsdell-Fosmire Empirical Equations Quantify Lateral and Vertical Plume Meander as well as Lateral and Vertical Aerodynamic Effects of Buildings (Wake/Cavity)
  - Validated by Many in situ Atmospheric Tracer and Wind Tunnel Measurements over Various Topographic Locations
  - ARCON96 Equations Better Represent RG 1.145 Lateral Plume Meander and First Characterized Vertical Plume Meander
  - ARCON96 Endorsed by NRC in RG 1.194, "*Atmospheric Relative Concentrations in the Vicinity of Buildings*" for Application at All NPP Locations
  - Ramsdell-Fosmire Empirical Equations are now in MACCS Version 4.2

ARCON96 LATERAL AND VERTICAL PLUME MEANDER AND BUILDING WAKE

- Empirically-Derived ARCON96 **Horizontal and Vertical Low Wind Speed Plume Meander and Horizontal and Vertical Building Wake Corrections** Represented by Equations 2 and 3 per NUREG/CR-6331 Rev. 1, Technical Support Document

$$\sigma_y = [\sigma_y^2 + \Delta\sigma_{y1}^2 + \Delta\sigma_{y2}^2]^{1/2} \qquad \text{(Equation 2)}$$

$$\sigma_z = [\sigma_z^2 + \Delta\sigma_{z1}^2 + \Delta\sigma_{z2}^2]^{1/2} \qquad \text{(Equation 3)}$$

- First Term in Brackets Represents P-G Curves Turbulence Magnitude without Any Correction for Turbulence Generated by Low Wind Speed Plume Meander
- Second Term in Brackets Represents Turbulence Generated by Low Wind Speed Meander
- Third Term in Brackets Represents Turbulence Generated by Building-Induced Aerodynamic Effects on Wind Field

ARCON96 LATERAL AND VERTICAL PLUME MEANDER RAMSDELL-FOSMIRE EMPIRICAL

Lateral Plume Meander Correction

$$\Delta\sigma_{y1}^2 = 9.13\ E5\ [1 - (1+(x/1000\ u)\ \exp\ (-x/(1000\ u))]$$

Vertical Plume Meander Correction

$$\Delta\sigma_{z1}^2 = 6.67\ E2\ [1 - (1+(x/100\ u)\ \exp\ (-x/(100\ u))]$$

Horizontal Building Wake Correction

$$\Delta\sigma_{y2}^2 = 5.24\ E\text{-}2\ u^2 A\ [1 - (1+(x/10A^{1/2})\ \exp\ (-x/(10A^{1/2})]$$

Vertical Building Wake Correction

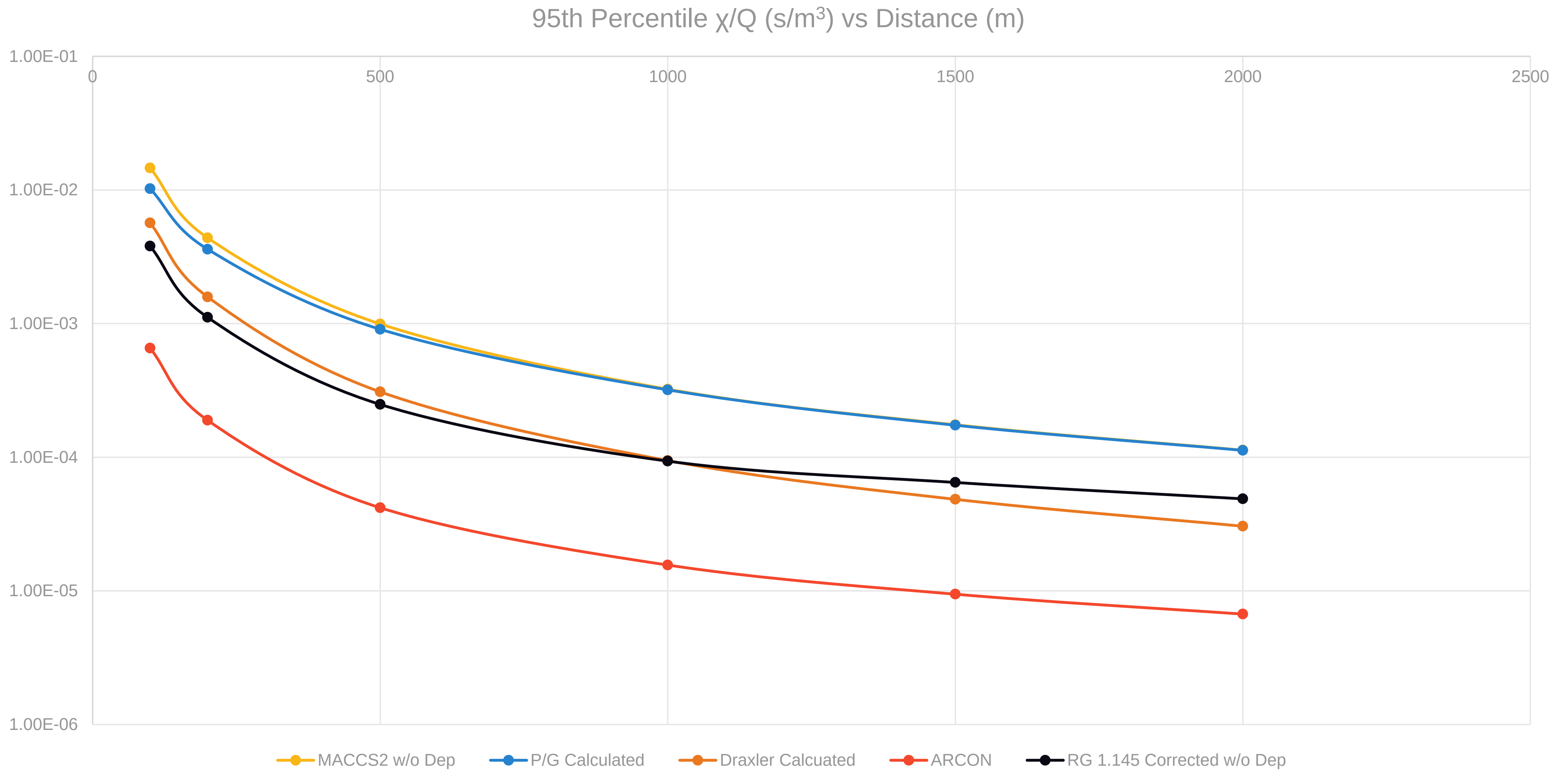
$$\Delta\sigma_{z2}^2 = 1.17\ E\text{-}2\ u^2 A\ [1 - (1+(x/10A^{1/2})\ \exp\ (-x/(10A^{1/2})]$$

x = downwind distance (m)

A = cross-sectional area of building (m^2)

RG 1.145 MEANDER FACTOR, BOWEN-DRAXLER, AND ARCON96 COMPARISONS TO MACCS2

MACCS2 COMPARISON WITH RG 1.145 LATERAL MEANDER FACTORS, BOWEN-DRAXLER, AND ARCON96 (95TH PERCENTILE)



LANL MESA-CANYON WIND FIELD STUDIES

LANL MESA-CANYON WIND FIELD CONCERNS

November 2017 NA-LA Questions on 2015 ADM Protocol Submission

1. Can LANL Canyons Trap Dispersed Mesa Releases and Increase Concentrations?
2. What is Fate and Transport of Mesa Plume after it Reaches a Canyon?

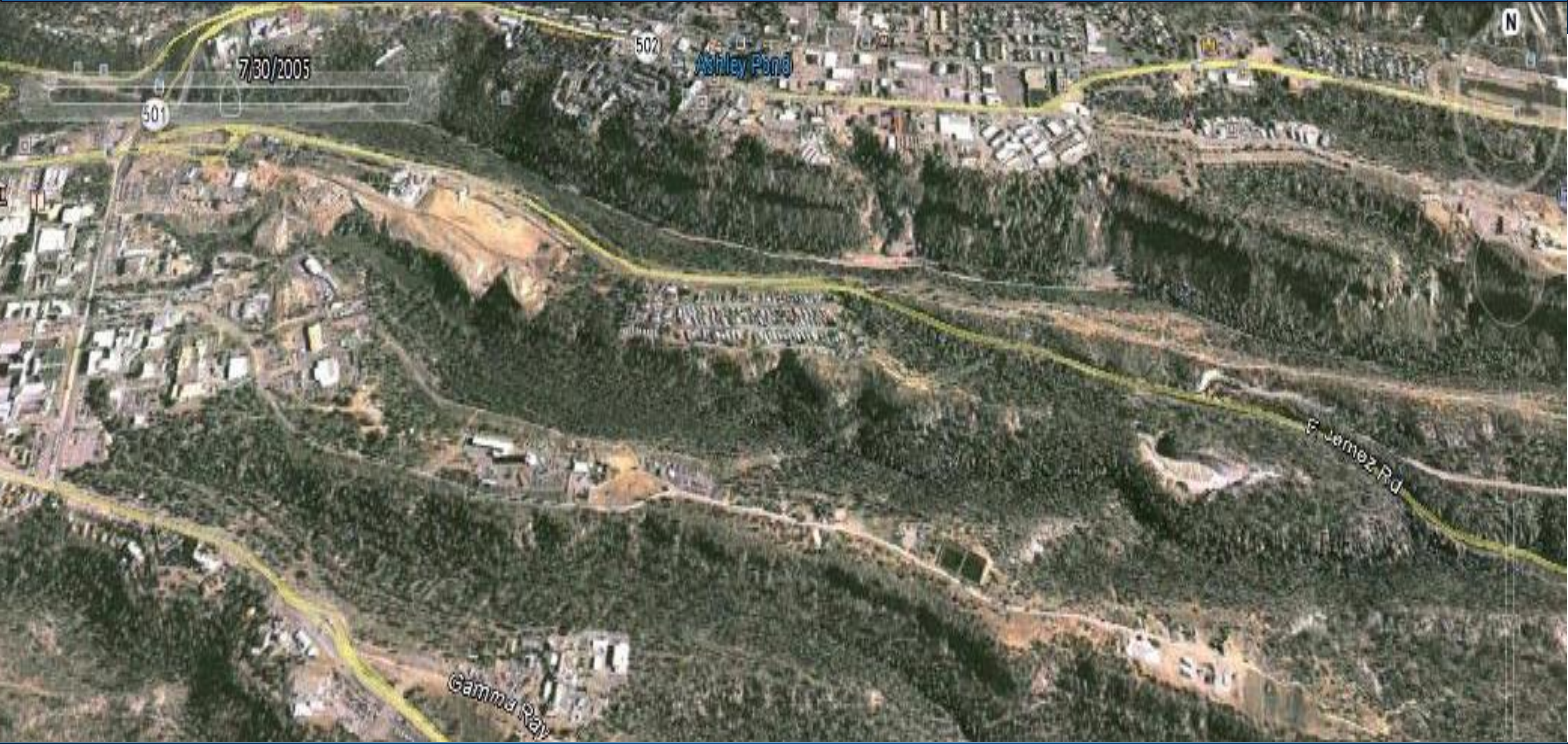
LANL MESA-CANYON STUDY OBJECTIVES

- Use Robust LANL Emergency Management CAPARS Modeling System
  - Time-Varying 3-Dimensional Mass-Consistent PIC Variable Trajectory Code
  - High-Resolution Nested Grid Cells (500 m, 60 m, 15 m)
  - Meteorological Data Needed to Develop 3-Dimensional Wind Field
    - 5 LANL Meteorological Towers (8 are now Operational)
    - Offsite Weather Observations and Surface Stations
    - Numerical Weather Prediction Model-Generated Vertical Profiles
- Examine Mesa-Canyon Flows
  - Determine if Complex Terrain Diffusion Supports Addition of RG 1.145 Lateral Plume Meander Factors to MACCS2
  - Determine Frequency and Duration of Canyon Wind Regime Flows
  - Establish that Canyon Flows Cannot Reconcentrate Plumes

LANL MESA-CANYON STUDY ELEMENTS

- Establish Canyon Wind Regime Frequency and Duration
  - –Mesa Top and Canyon Basin Observations from 2005 NEWNET Study
  - –Identify Winds in Opposite Directions to Determine Canyon Winds with Exception of Mountain-Valley Winds
  - –Catalogue Frequency and Durations of Canyon Winds that Oppose Mesa Winds
- Compare CAPARS 95th% EPHA Concentrations with Gaussian Model
  - –Compare Lagrangian CAPARS Downwind Concentrations to Eulerian Gaussian Model Applicable to All Transport Directions
  - –Determine at Mesa-Canyon Interfaces whether CAPARS Concentrations are Greater than or Less than Gaussian Model Concentrations

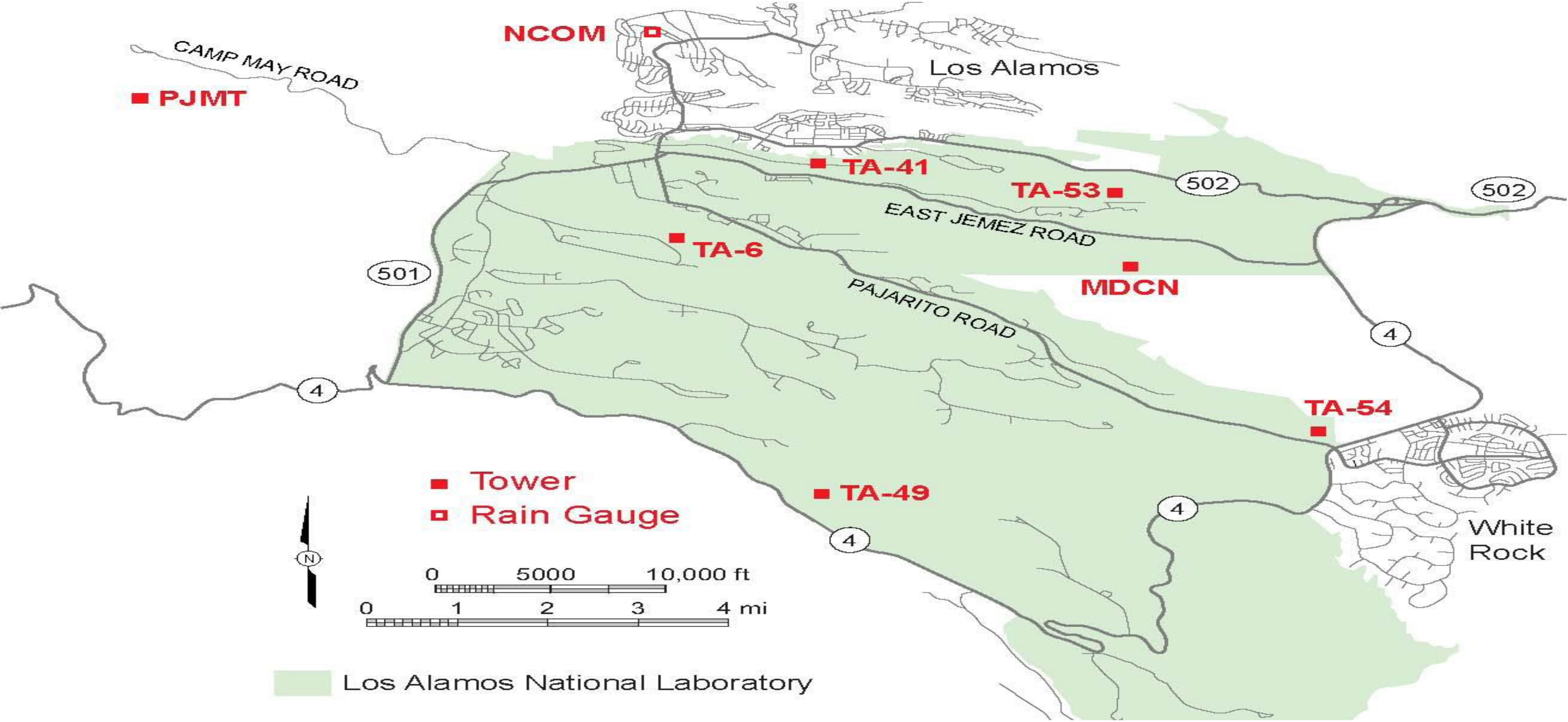
AERIAL VIEW OF LANL MESA-CANYON TOPOGRAPHY



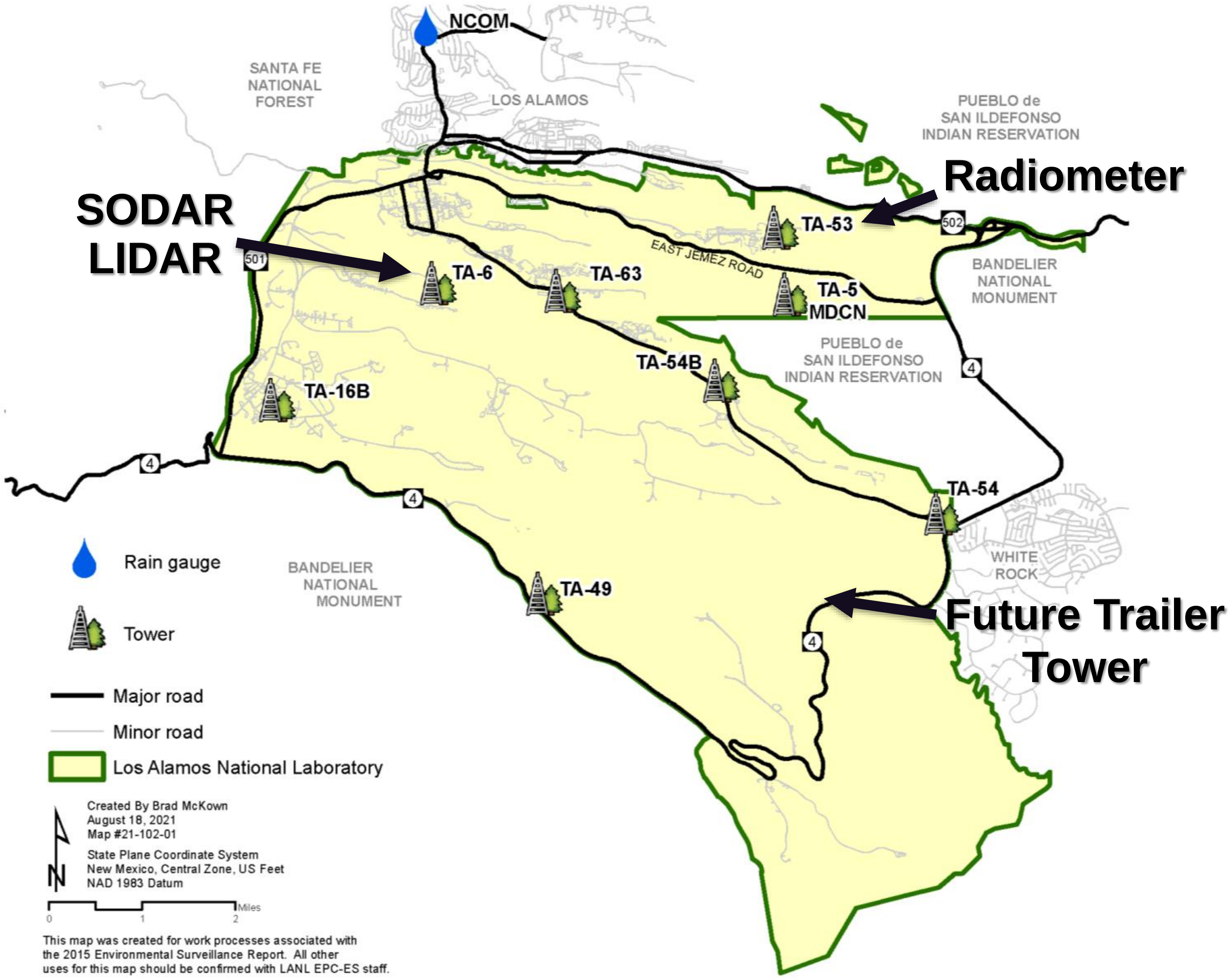
LANL MESA-CANYON DIFFUSION AND MODELING

- Diffusion Experiments Generally Show σ_y and σ_z in Complex Terrain are Factor of 2 to 10 Greater than Pasquill-Gifford Diffusion Equations
- MACCS2 Underestimates Diffusion throughout LANL Under 95th Percentile Meteorology Conditions
- Diffusion Underestimation Penalties are Expensive
    - DSA Unmitigated Analysis Radiological Consequences are Overly Conservative
    - Excessive SC/SS Controls, SACs and TSRs
    - MAR Limits Reducing Production Efficiency

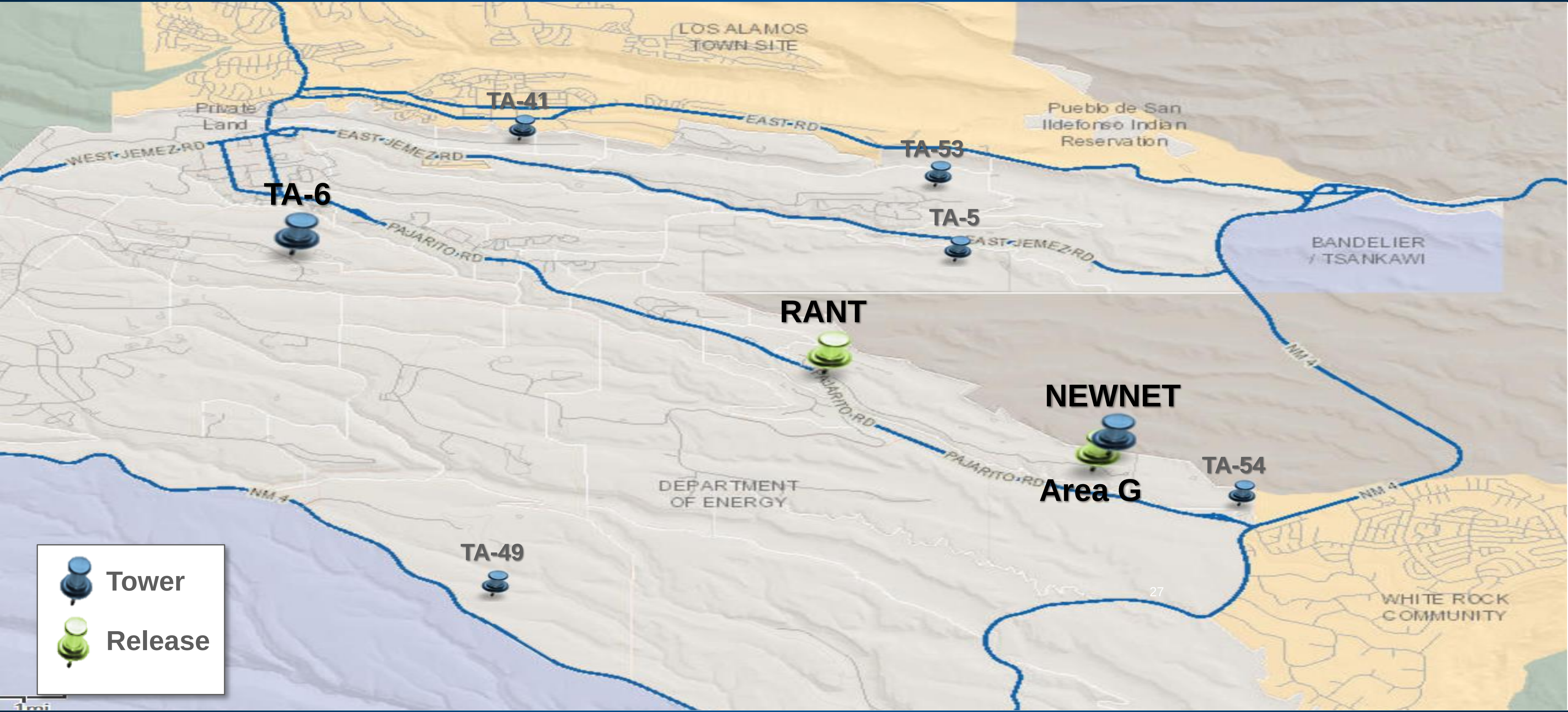
LANL METEOROLOGICAL MONITORING LOCATIONS



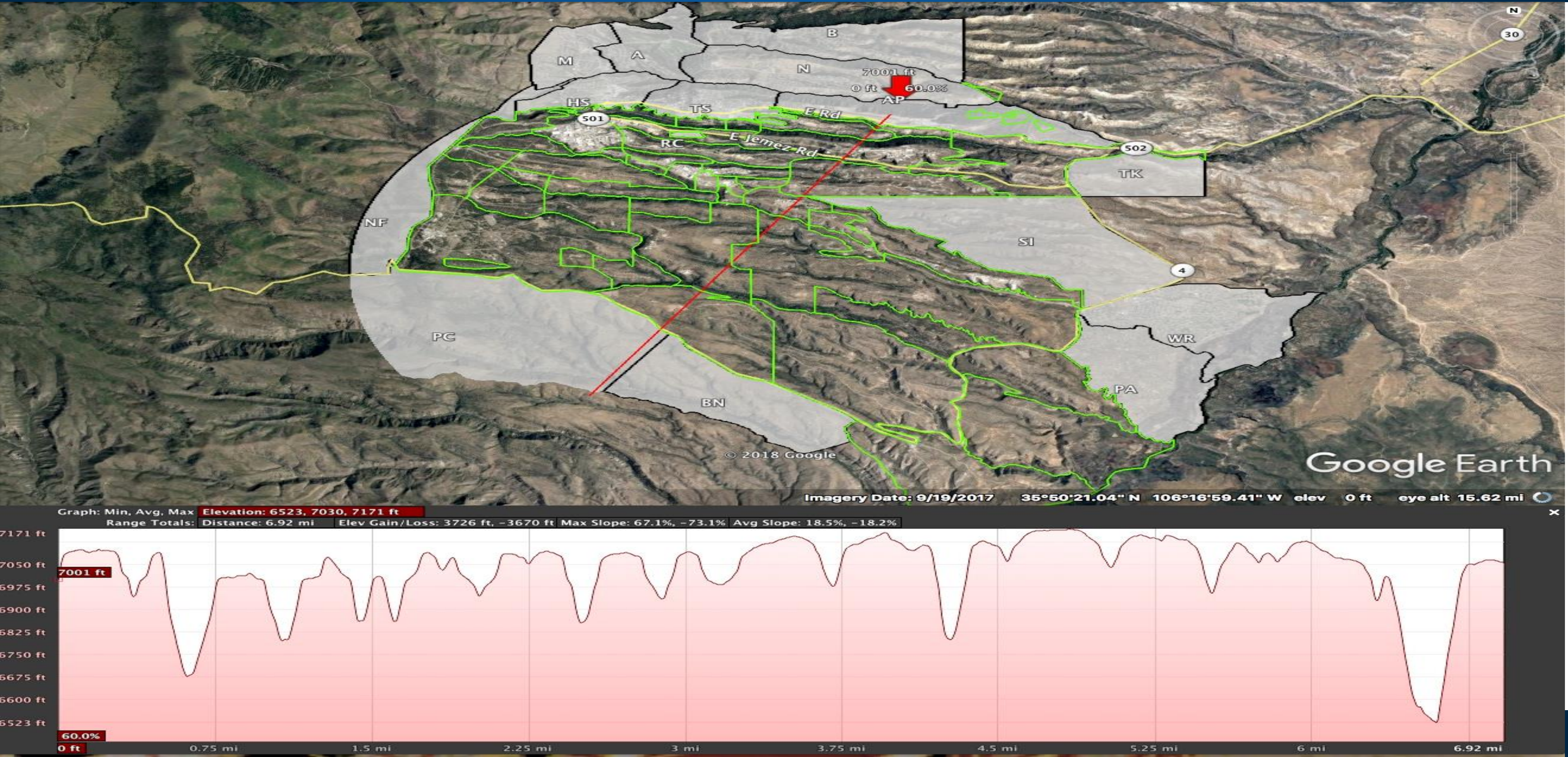
LANL METEOROLOGICAL MONITORING LOCATIONS



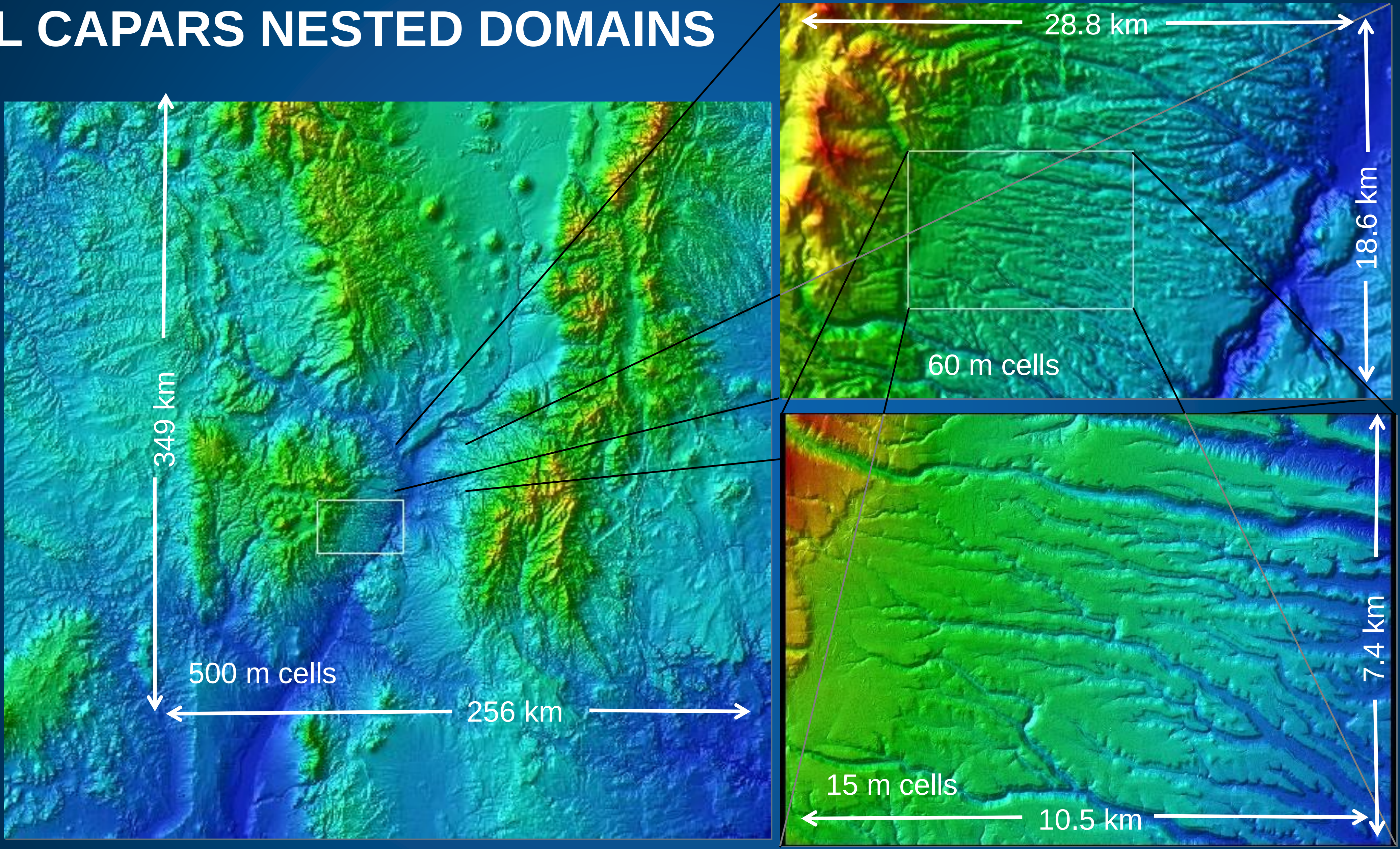
MODELING RELEASE AND MEASUREMENT SITES

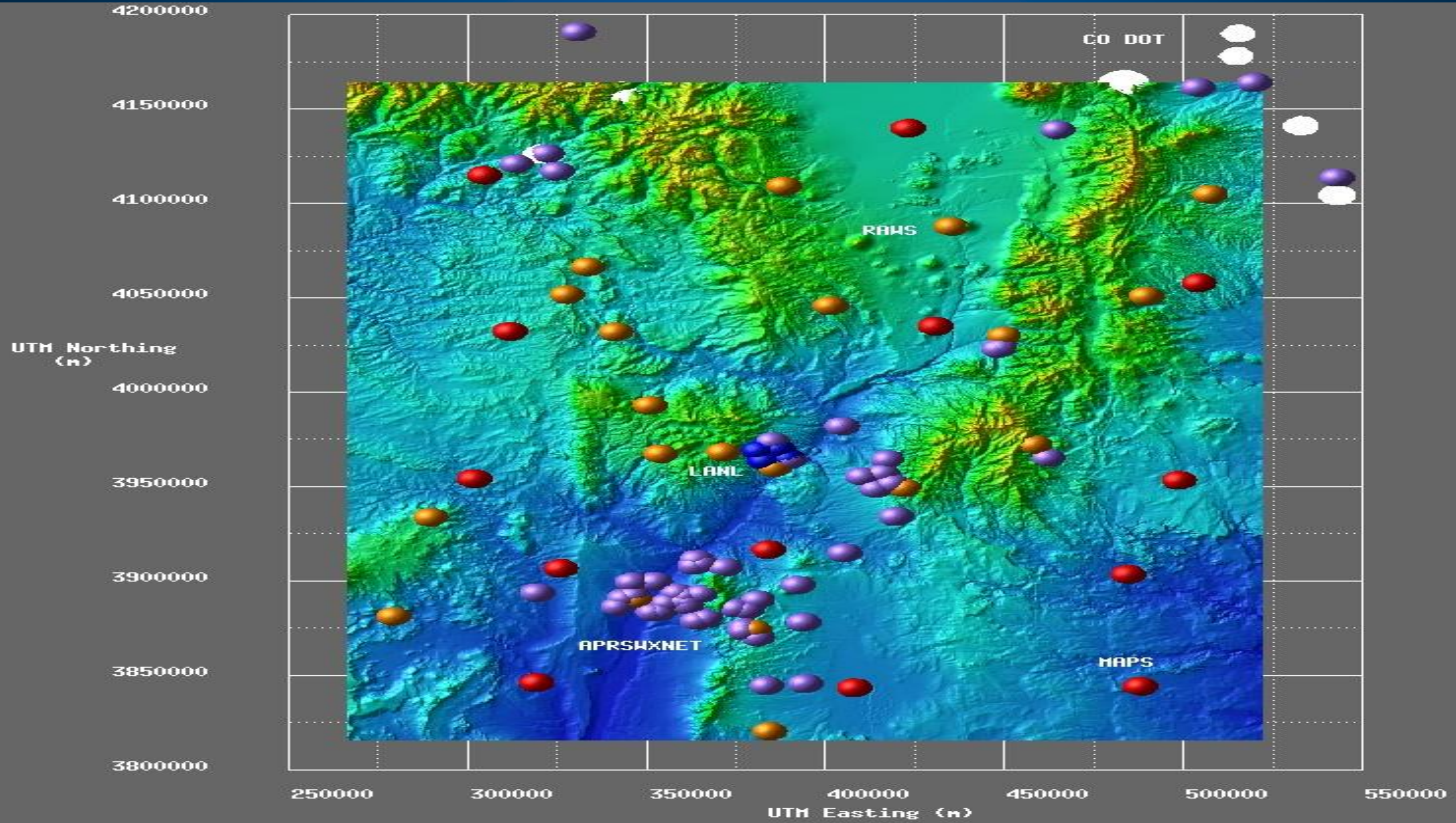


LANL CAPARS 3-D LAGRANGIAN DISPERSION MODEL

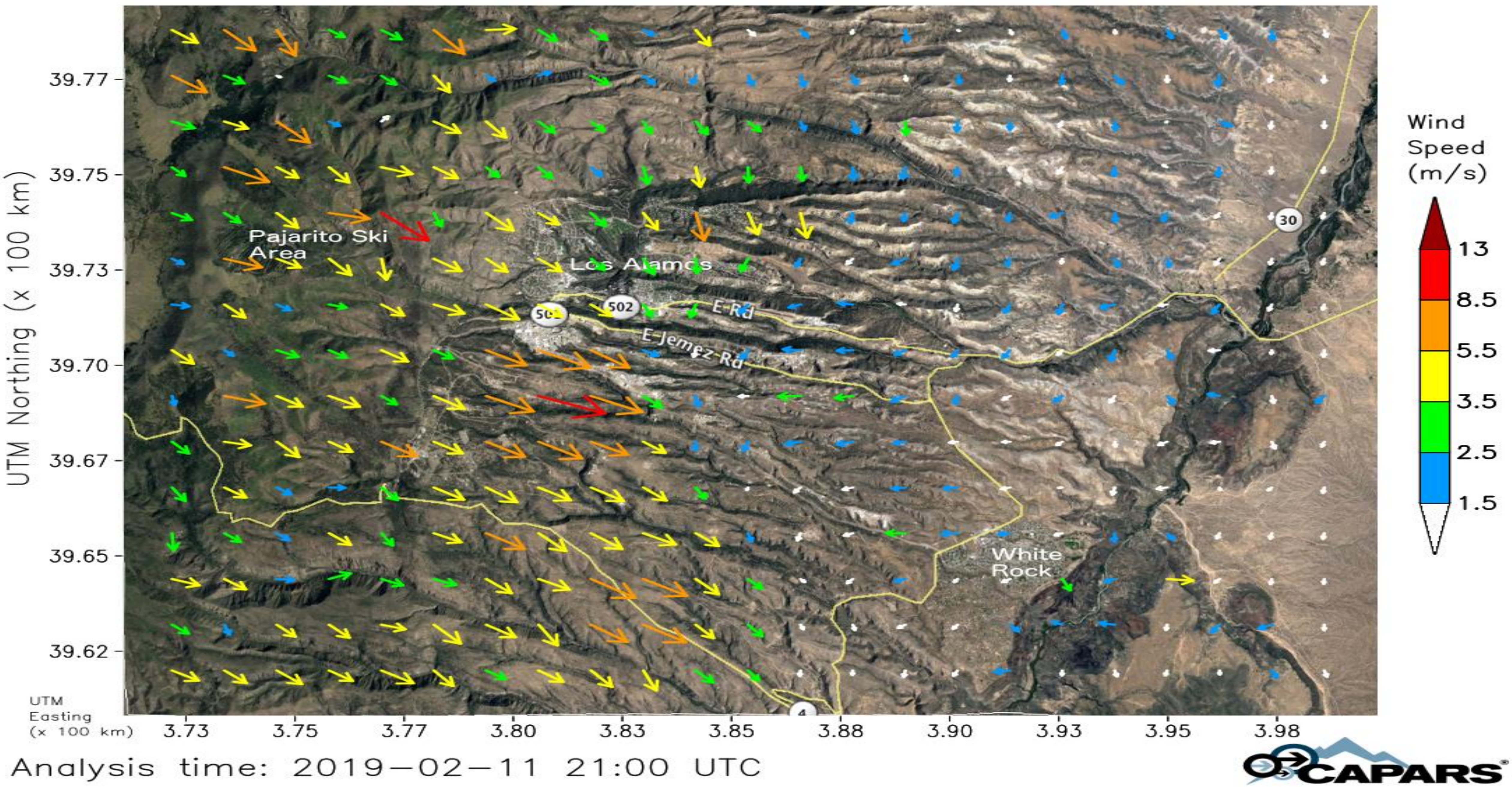


LANL CAPARS NESTED DOMAINS

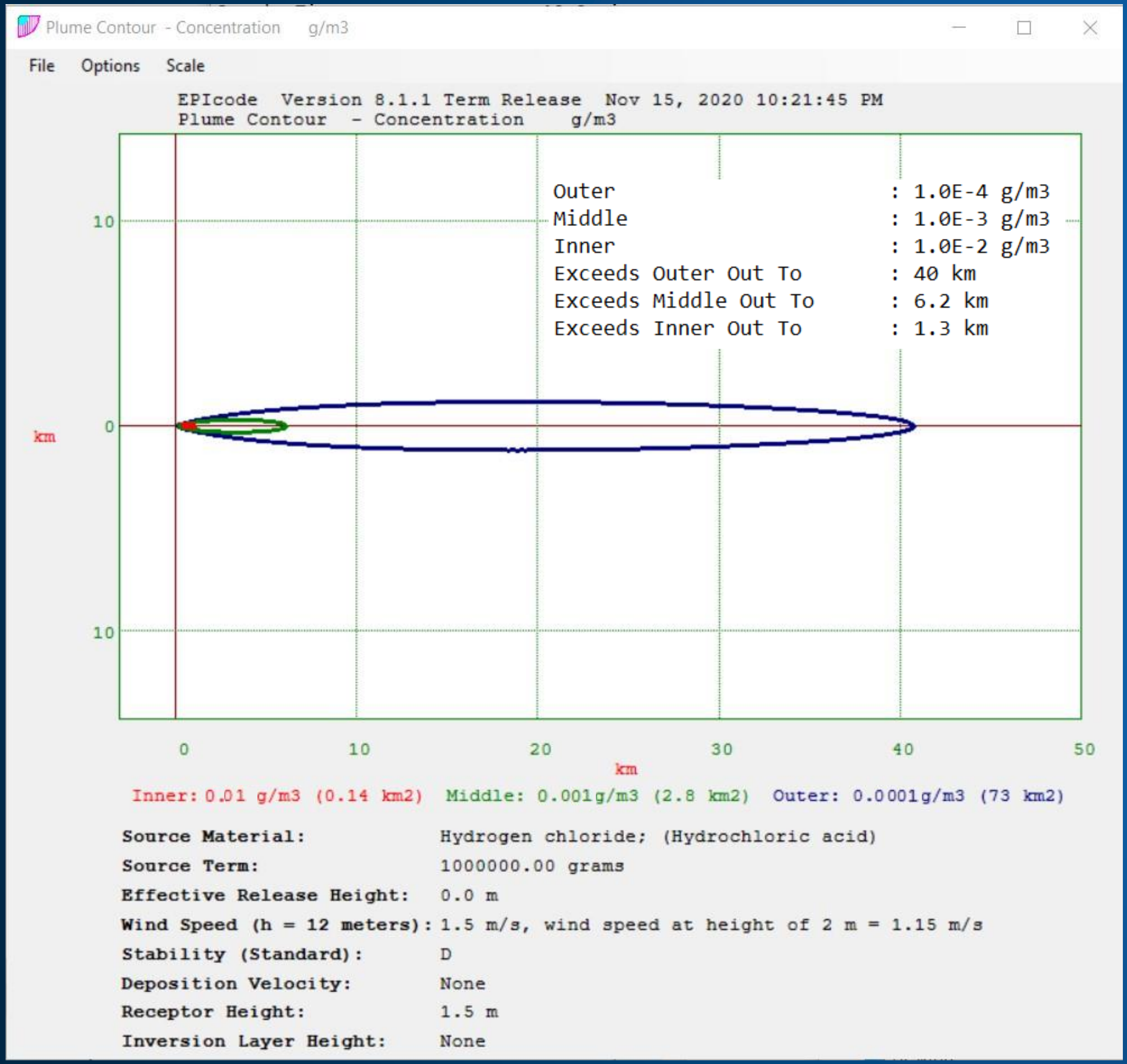




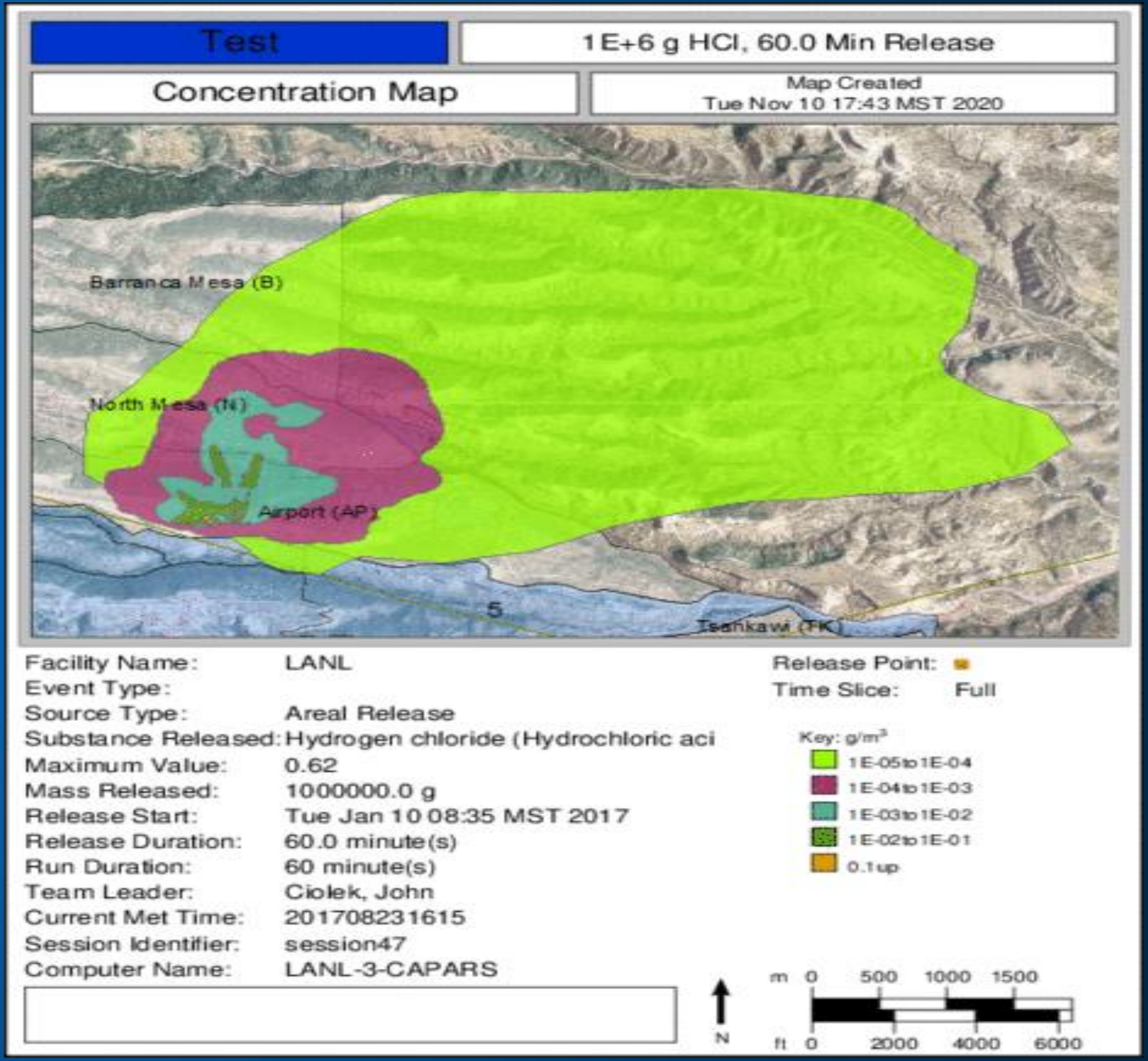
4200000
4150000
4100000
4050000
4000000
3950000
3900000
3850000
3800000
UTM Northing (m)
250000
300000
350000
400000
450000
500000
550000
UTM Easting (m)
CO DOT
RAWS
LANL
APRSWXNET
MAPS


Pajarito Ski Area
Los Alamos
502
501
E Rd
E Jemez Rd
30
White Rock
4
UTM Northing (x 100 km)
39.77
39.75
39.73
39.70
39.67
39.65
39.62
UTM Easting (x 100 km)
3.73
3.75
3.77
3.80
3.83
3.85
3.88
3.90
3.93
3.95
3.98
Wind Speed (m/s)
13
8.5
5.5
3.5
2.5
1.5
Analysis time: 2019-02-11 21:00 UTC
CAPARS

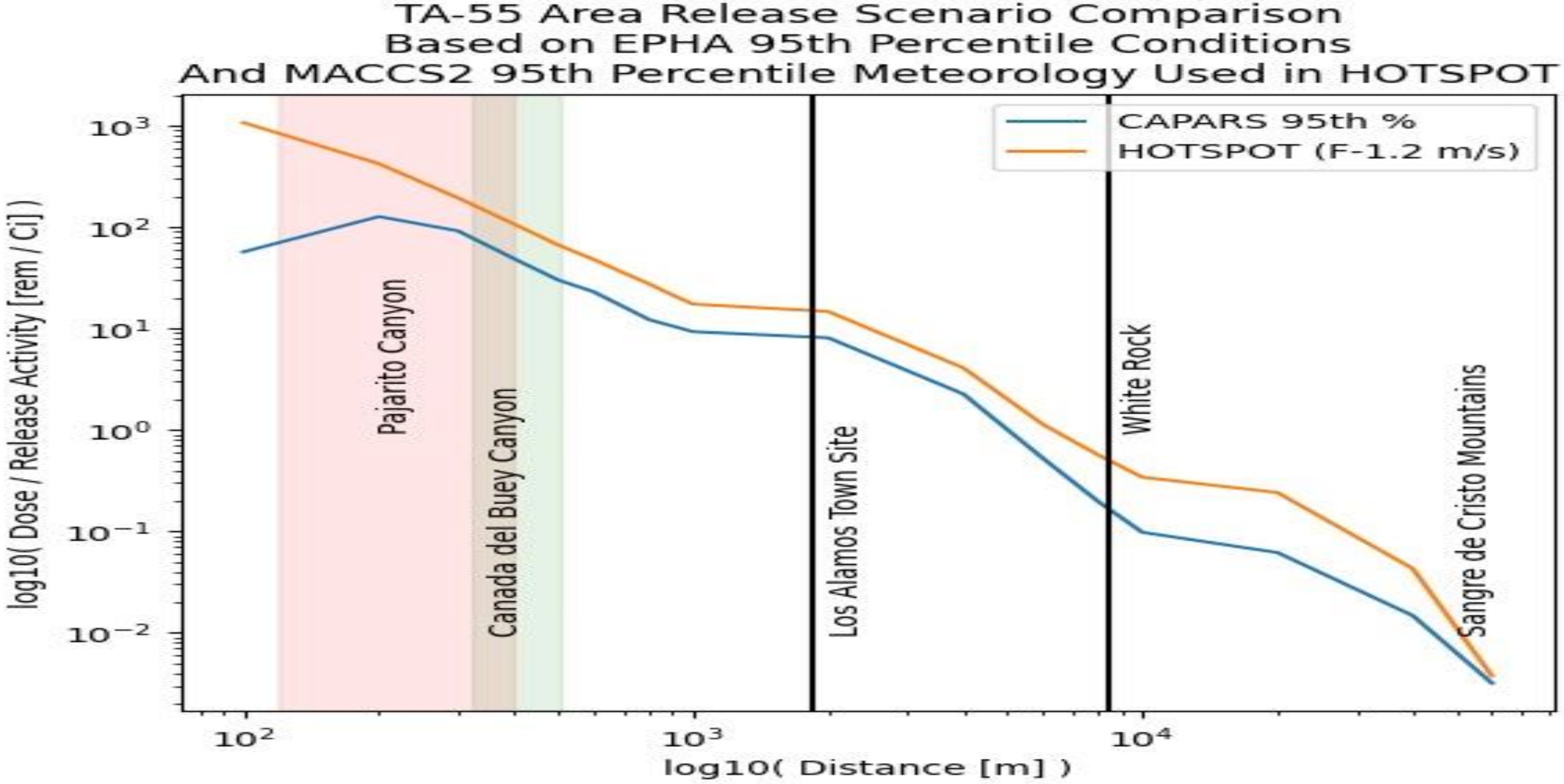
HOTSPOT: Eulerian Straight-Line Gaussian Model



CAPARS: Lagrangian Variable-Trajectory Model

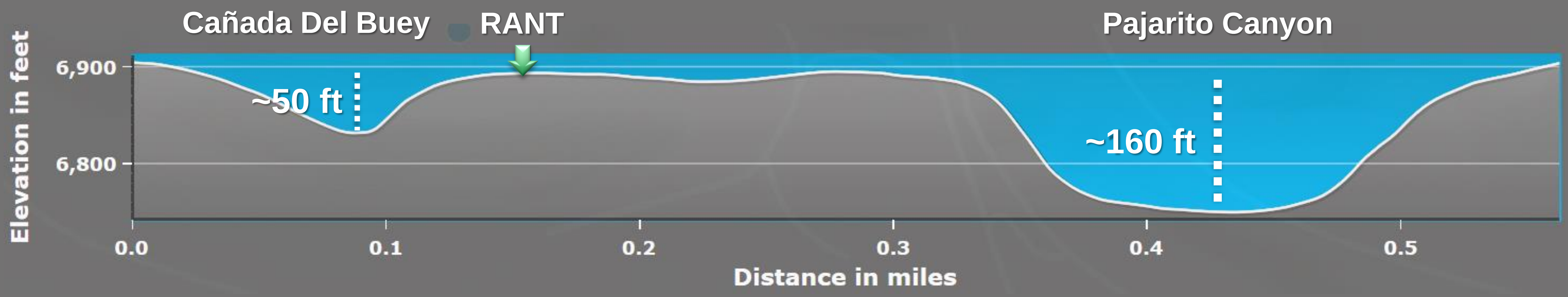


CAPARS-HOTSPOT EPHA COMPARISONS



MESA-CANYON TOPOGRAPHY AROUND RANT

ELEVATION PROFILE AROUND RANT



CANYON WIND REGIME FREQUENCY AND DURATION

- Identify Opposing Mesa-Canyon Wind Direction Conditions
  - –Mesa: TA-06 and TA-53 Meteorological Tower 12-Meter Level
  - –Canyon: NEWNET Station in Cañada del Buey
- Canyon Wind Regime from Southerly Winds Results
  - –Usually Occur when Mesa Wind Speeds < 2 m/s (Evening-Hour Katabatic Winds)
  - –Events are Rare and Transient
    - Several 15-Minute Events
    - Five 30-Minute Events
    - No Events > 30-Minutes
    - Most Events Lasted <15 Minutes Before Decaying when Mesa Winds Kicked Up
  - –Findings Consistent with 1976, 1983 and 2000 LANL Complex Terrain Studies
  - –Study Summaries Presented in Appendices B and D of ADM Protocol

MESA-CANYON STUDY SUMMARY

- Early Mesa-Canyon Wind Study Results Satisfy NA-LA Comment No. 1 in SO:26CMK-496203 Related to Hypothetical Mesa-Canyon Flow Concerns
  - 1976, 1983, & 2000 LANL Wind Field Studies: Canyon Winds (Katabatic) Occur Infrequently (After Sunset) and are of Short Duration
  - Comprehensive 4-D CAPARS State-of-the-Science Modeling Demonstrates Transport of a Mesa Plume into a Canyon does not Increase Concentrations
  - Plume Deformation from Wind Shear at Topographic Interface Meets Fluid Dynamics First Principles
- Future Mesa-Canyon Studies will Provide Additional Insights to be Shared with NA-LA, and EFCOG, DMSC, ANS and AMS Communities of Practice

OUTCOME

- February 2021: ADM Revision 1 (RPT-SBD-384-1) Transmitted to NA-LA for Review
- March 2021: ADM Presentation Well-Received by NA-LA, DNFSB, and AU-31
- April-July 2021: Informal Adjudication of Differences in Professional Opinion
  - MACCS Version 3.10 Became Available during Adjudication Period
  - Includes NRC RG 1.145 Plume Meander for Release Durations of Approximately 60 Minutes
  - NA-LA Concurred on 40-Minute Release Duration for LANL Spill and Fire Accident Analyses
  - ADM Revision 2 (RPT-SBD-384-2) Transmitted to NA-LA
  - Approved for All LANL Facilities on July 16, 2021
- August 2021: MACCS Version 4.1 with Ramsdell-Fosmire Equations Available
- ADM Protocol Revision to Justify this MACCS Version for LANL Accident Analyses to Access Lateral and Vertical Meander and Building Wake Dispersion Credit