I am the daughter of Earth and Water,
And the nursling of the Sky;
I pass through the pores of the ocean and shores;
I change, but I cannot die.
For after the rain when with never a stain
The pavilion of Heaven is bare,
And the winds and sunbeams with their convex gleams
Build up the blue dome of air,
I silently laugh at my own cenotaph,
And out of the caverns of rain,
Like a child from the womb, like a ghost from the tomb,
I arise and unbuild it again.

Percy Bysshe Shelley “The Cloud”

Representation of Atmospheric Transport – A function of Wind field

Where wind field is *spatially varying* in latitude, longitude, and vertically ascending in the atmosphere (in reality, wind fields are spatially varying on a <u>local</u> scale because of geographical effects, on a <u>regional</u> scale because of synoptic scale variation).

Where movement of an 'air parcel' in this domain, occurs along the wind vectors in the 'x ,y plane' (east-west, north-south) axis.

Where determination of which x-y plane in the vertical transport occurs at is determined by 'mixing height'.

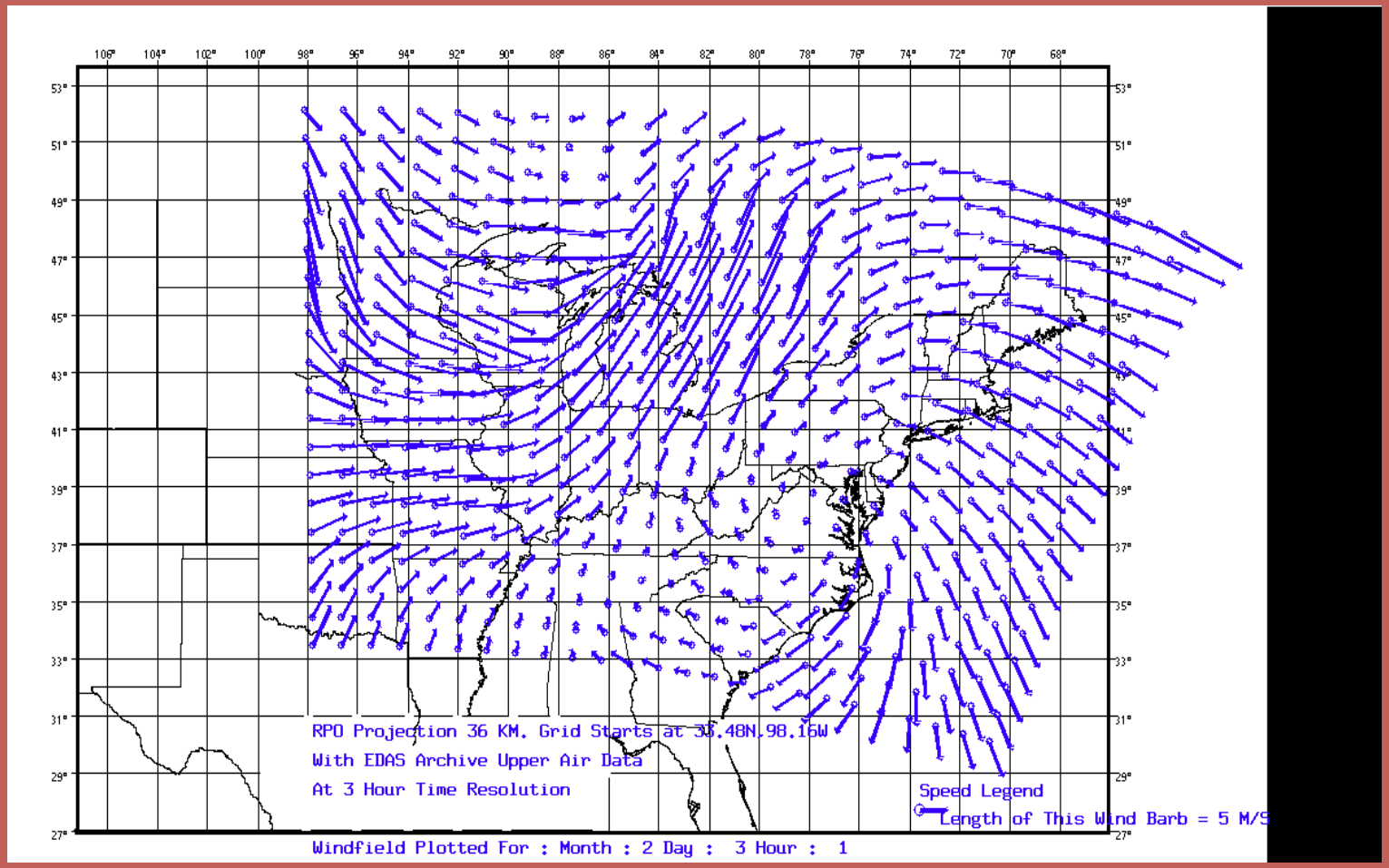
Making a Wind Field With CALMET

CALMET Allows you to *Interpolate Measured Meteorological Data* Read by the Model (Measured Data includes Surface ASOS data, Upper Air radiosonde measurements).

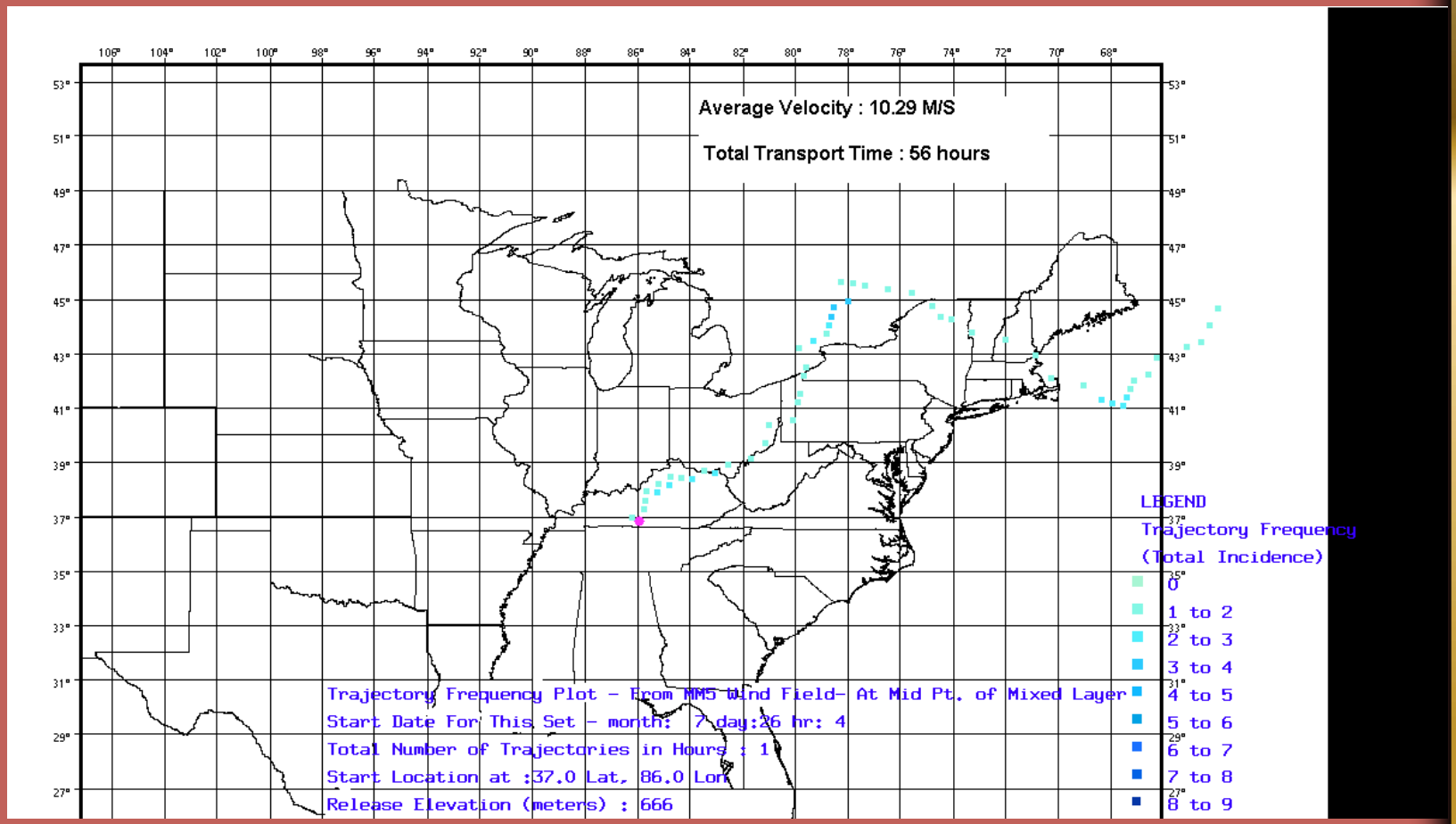
Subsequently, one may apply model physics to account for smaller scale effects on the wind field than represented by the Meteorological Observations

A Third alternative with CALMET is reliance on modeled Wind fields from a Prognostic model

Horizontal Depiction of Winds from CALMET



Travel of an ‘Air Parcel’ along the wind field.

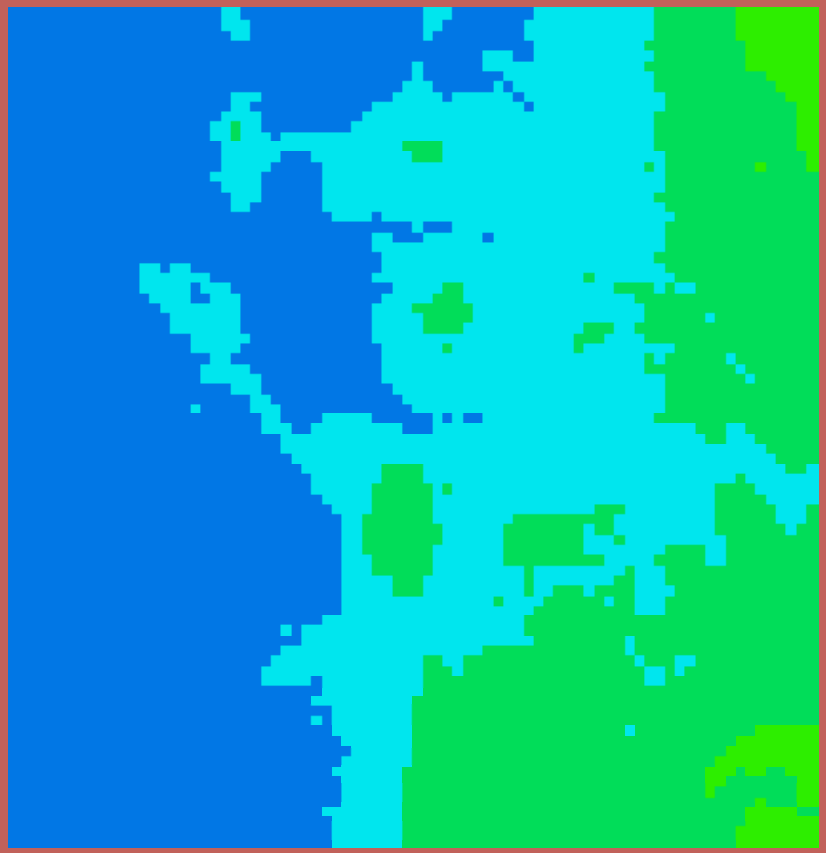


Calpuff Modeling – Complex Winds Applications

- Meteorological field representation : Use one surface station as a ‘driver’ to produce a spatially varying wind field over a local scale domain accounting for geographical effects

Primary Needs to Produce Accurate Meteorological Fields for the Burlington, Vermont Area.

1) Establish horizontal resolution of domain.
2) Select and prepare meteorological inputs.
3) Ensure that various meteorological field quantities produced by model are reasonable.
4) Tweak CALMET option settings to allow best performance in Burlington area – involves comparing modeled to measured meteorological fields as CALMET is rerun.



0.2 KM. Resolution CALMET Domain in Normal Projection
Terrain Heights
Terrain Derived from USGS and Smoothed for Domain

LEGEND
Terrain Height
(Meters)

- 0 to 10 m.
- 10 to 50 m
- 50 to 100 m
- 100 to 200 m
- 200 to 300 m
- 300 to 400 m
- 400 to 500 m
- 500 to 600 m
- 600 to 700 m

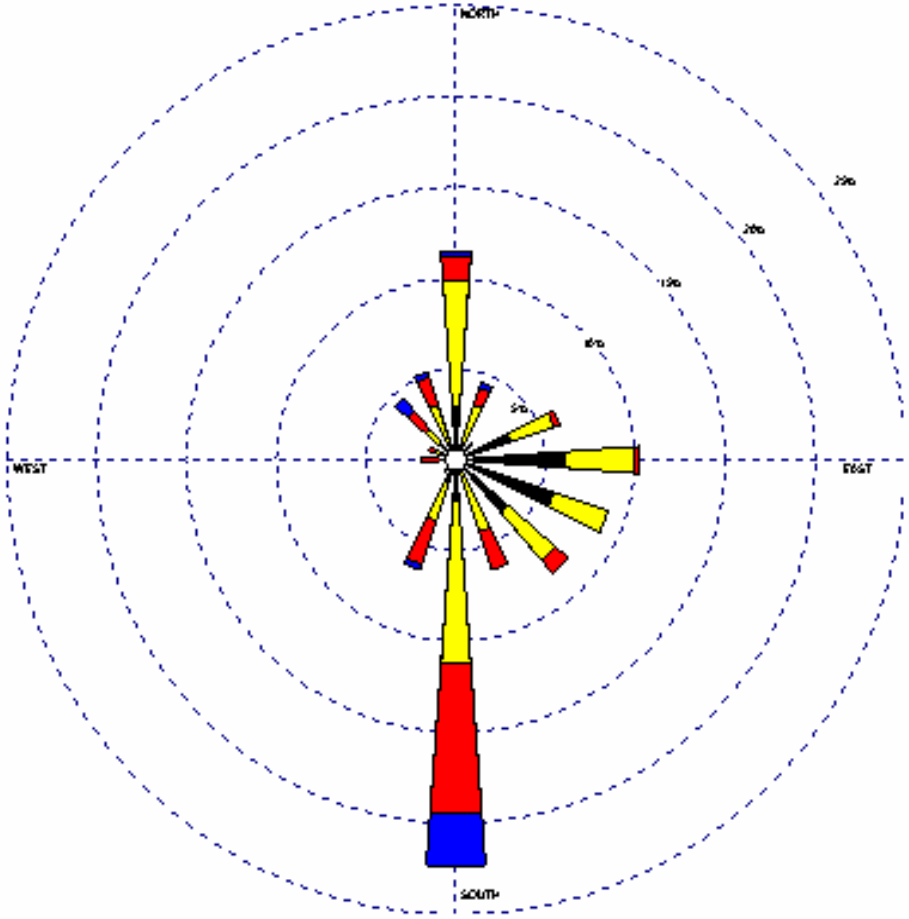
Examining the domain to ensure model simulation accurate

1. inspection of the geographical characteristics of the domain is essential so that the model runs may properly simulate atmospheric flow in the situation at hand.

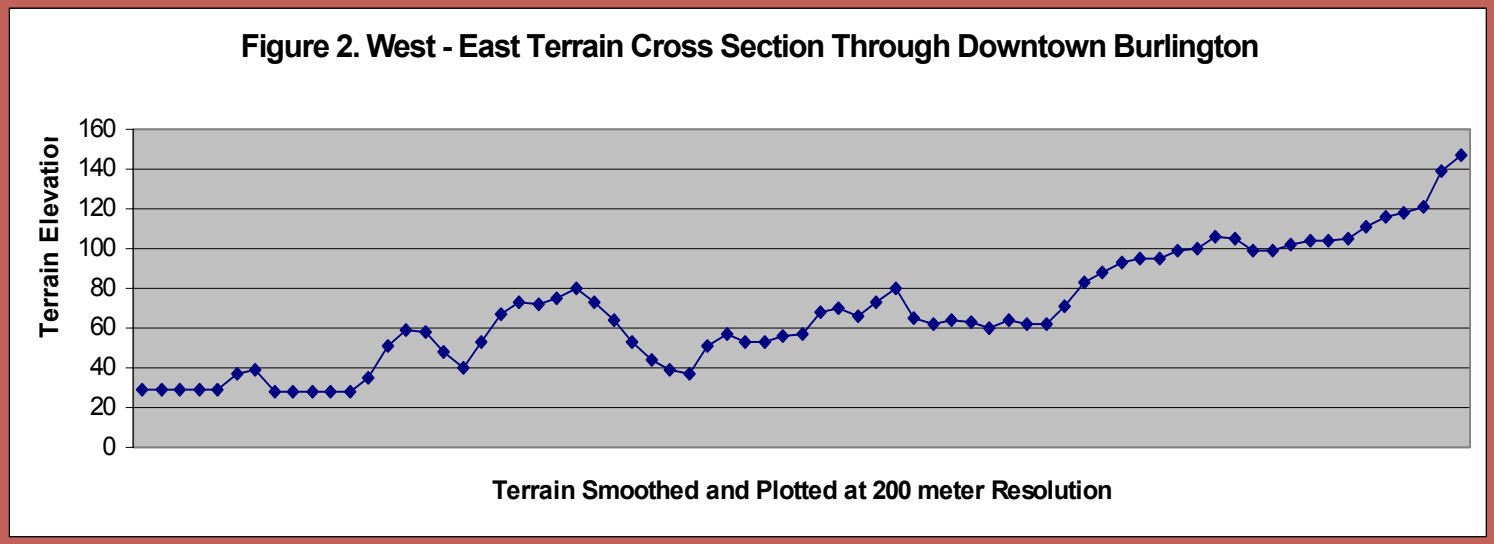
2. Primary Characteristics of the Domain Include :

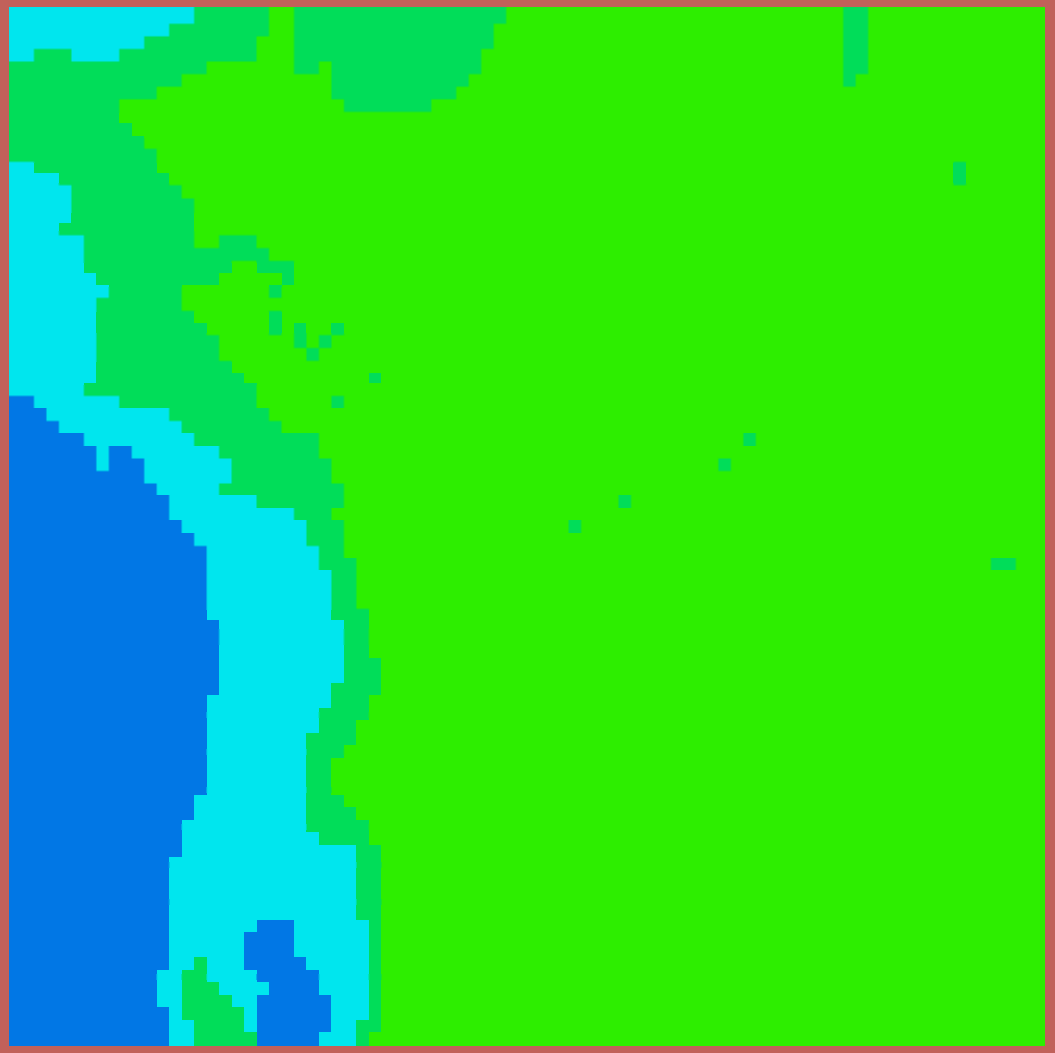
- Lake Champlain
- and the terrain gently sloping downwards to the lake (westwards), over about 10 kilometers distance.

Burlington, VT - Measured Windfield Stable Conditions



Determination of Horizontal Model Resolution



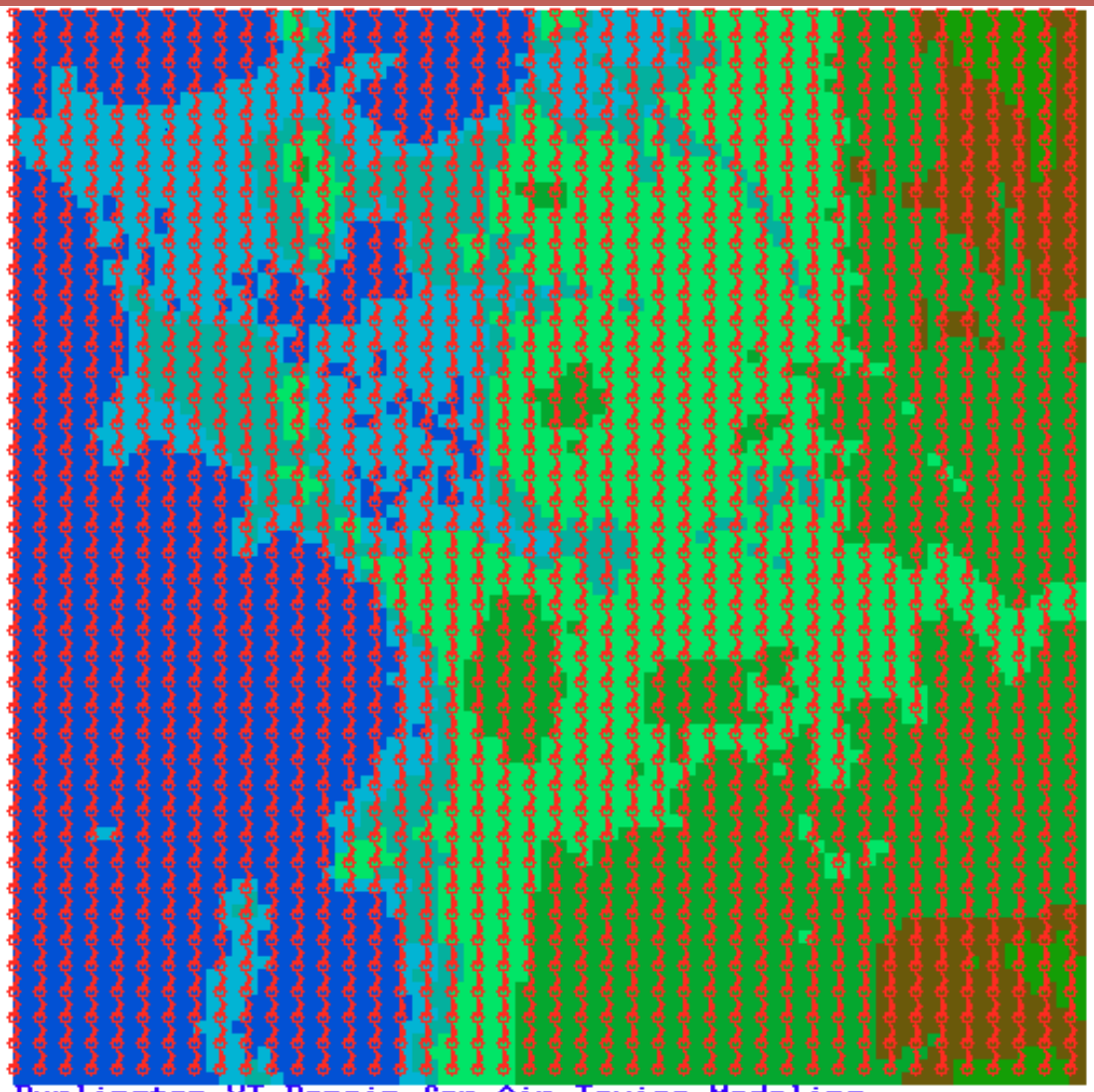


Burlington Toxics
0.2 KM. Resolution Domain
PLOT OF MIXING HEIGHTS
With ETA Upper Air,
Colchester Reef Over Lake,
Burlington Surface Data.

LEGEND
Mixing Height (Meters)

- < Than 100 m.
- 100 to 300 m.
- 300 to 600 m
- 600 to 1000 m
- 1000 to 1500 m
- 1500 to 2200 m
- 2200 to 2800 m
- 2800 to 3600 m
- 3600 to 5000 m
- 5000 to 6200 m

Isopleths Plotted For : Month : 7 Day : 1 Hour : 15



Burlington VT Domain for Air Toxics Modeling. At 200 meter horiz resolutior
Windfield Plotted For : Month : 7 Day : 12 Hour : 3 Speed Legend
Windfield Produced with ETA Data Length of This Wind Barb = 3 M/S
With R1,R2 = 0.2 km, FR NO. = 0.7

Conclusions for Burlington, VT Domain

- The findings in this study allow us to conclude that utilization of the ETA windfields is acceptable for this application of CALMET. Initially, there was some concern regarding the combination of the upper air ETA – derived meteorological fields with measured surface data. Reasonable values for mixing height and stability classification by CALMET, however, allay these concerns.
- Examination of the CALMET wind field predictions for this high resolution domain, by comparing modeled to measured values in Essex Junction, indicate generally good model performance and allow us to choose the option settings for the final runs that will be used by CALPUFF.

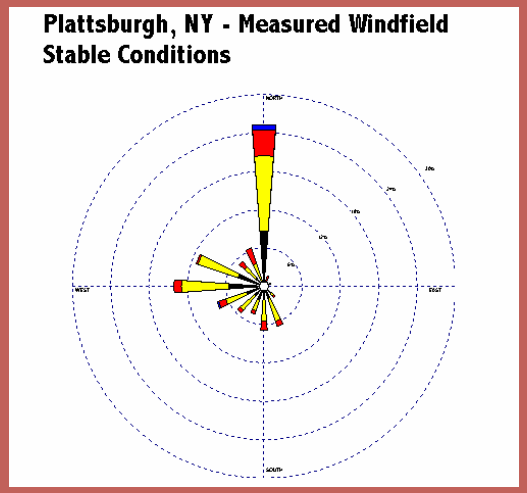
Calpuff - Complex Terrain Modeling :

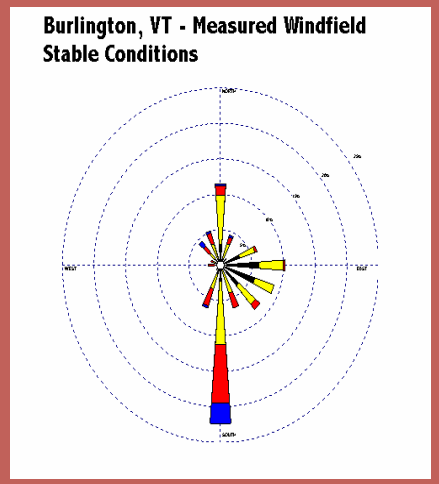
- For Domains in:
- Central Vermont
- Rutland, Vermont

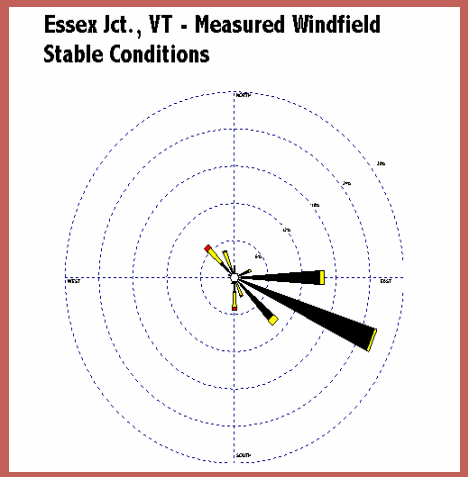
Vermont – Highly Affected by Complex Terrain

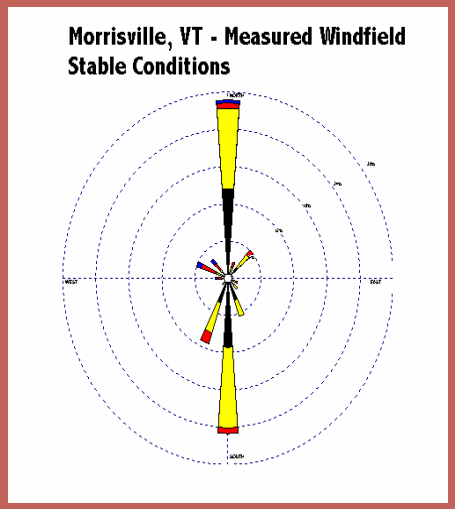
- In Vermont, it is essential to apply the model physics to attempt to capture smaller scale wind field variation (Mountain – valley circulations, lifting/wrapping around terrain features).
- E.G., linearly interpolating observations Between Morrisville and Montpelier is an erroneous representation of an averaged wind direction over the Worcester mountains, (at least, during stable conditions, when flow is actually ‘wrapping around’ the mountains.

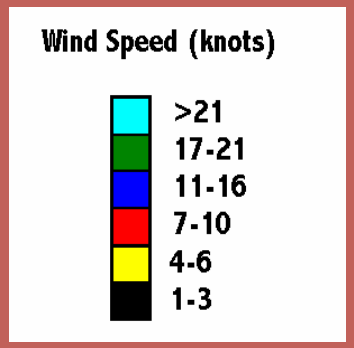
Variation in Measured Wind roses Throughout Complex Terrain is great



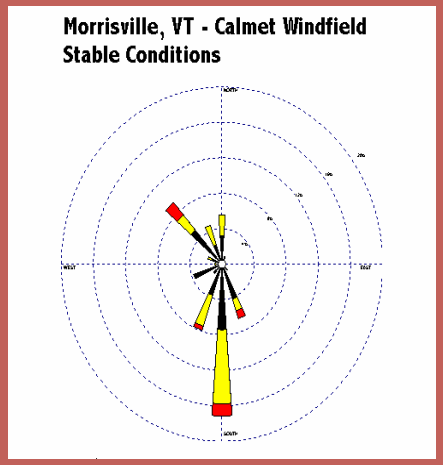


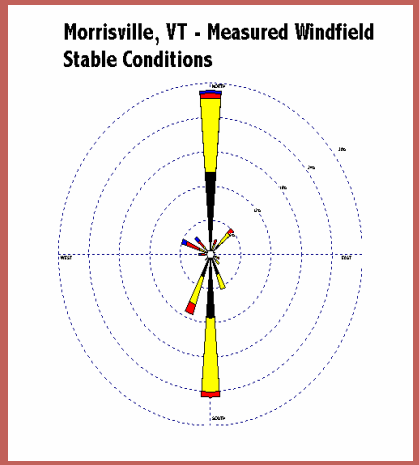


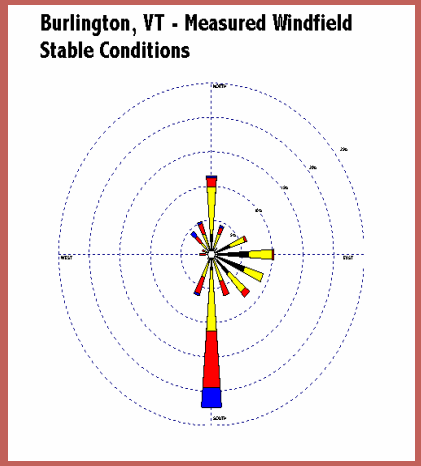


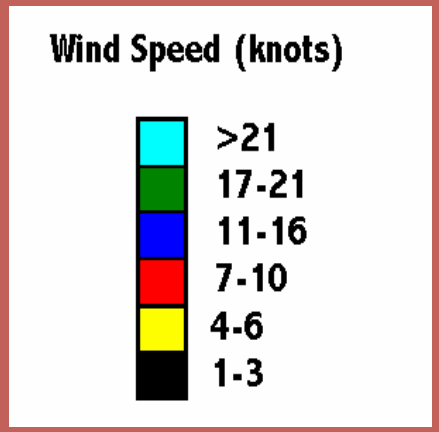


Applying Model Derived Wind field from a Location in Complex Terrain In Comparison to Burlington Data

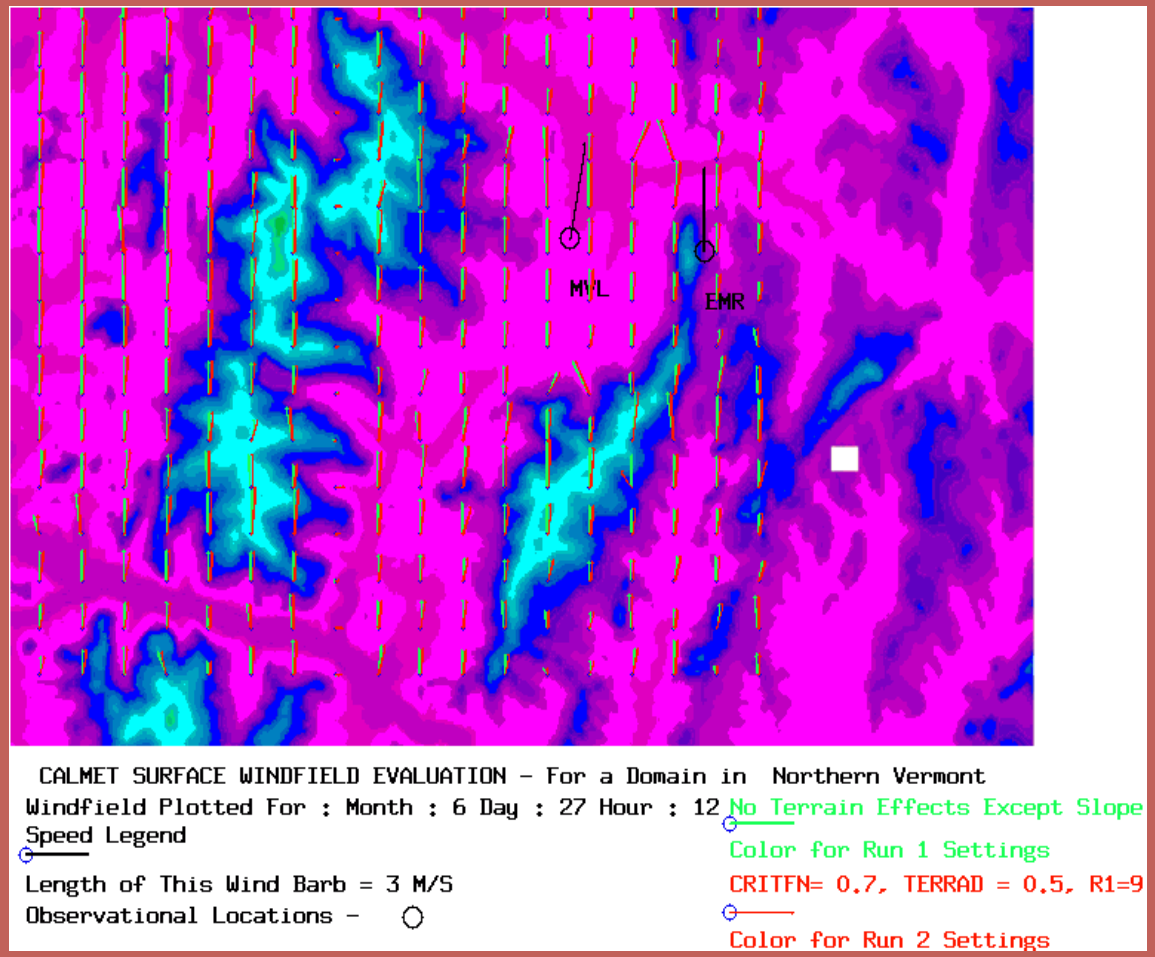




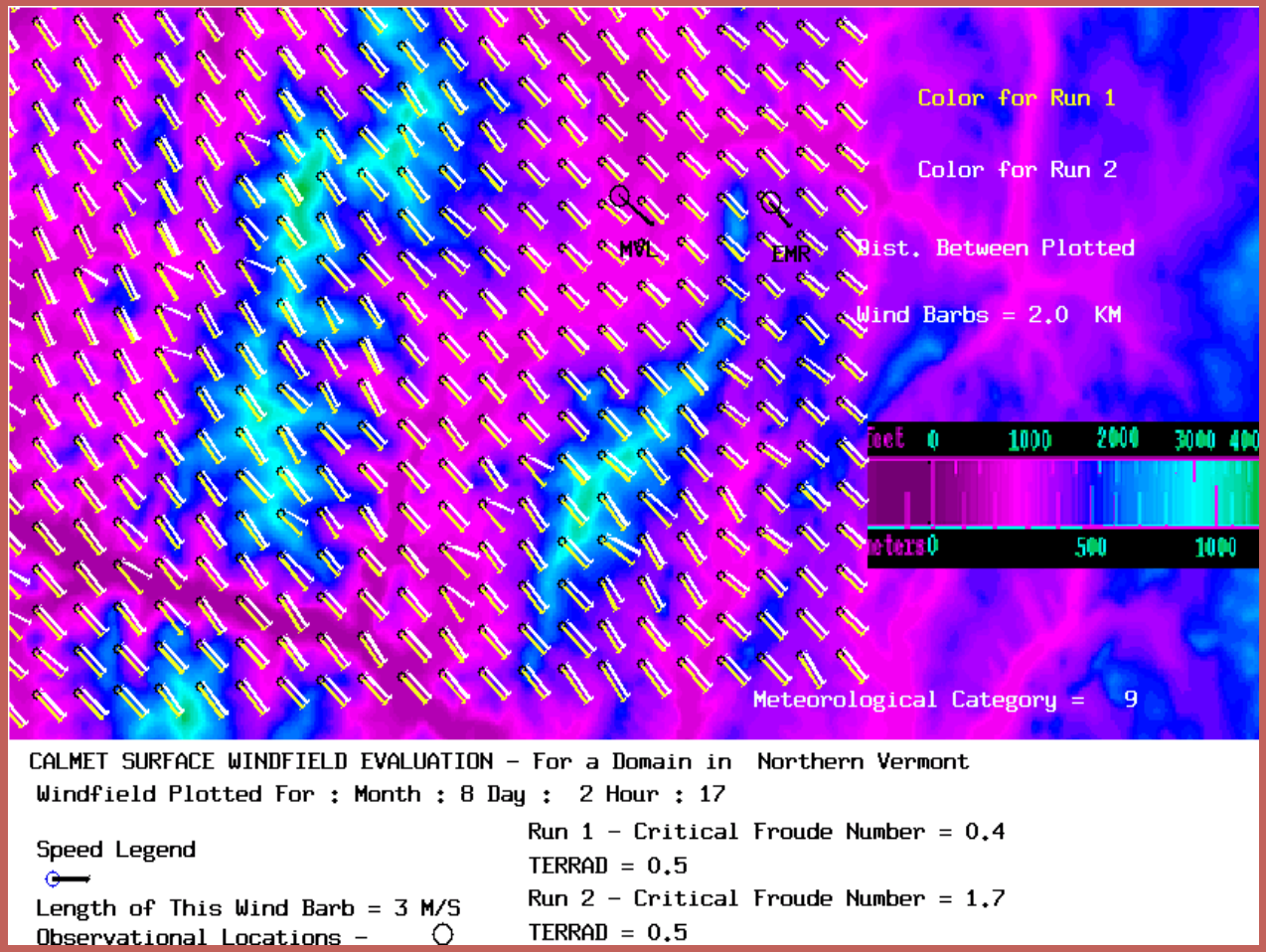


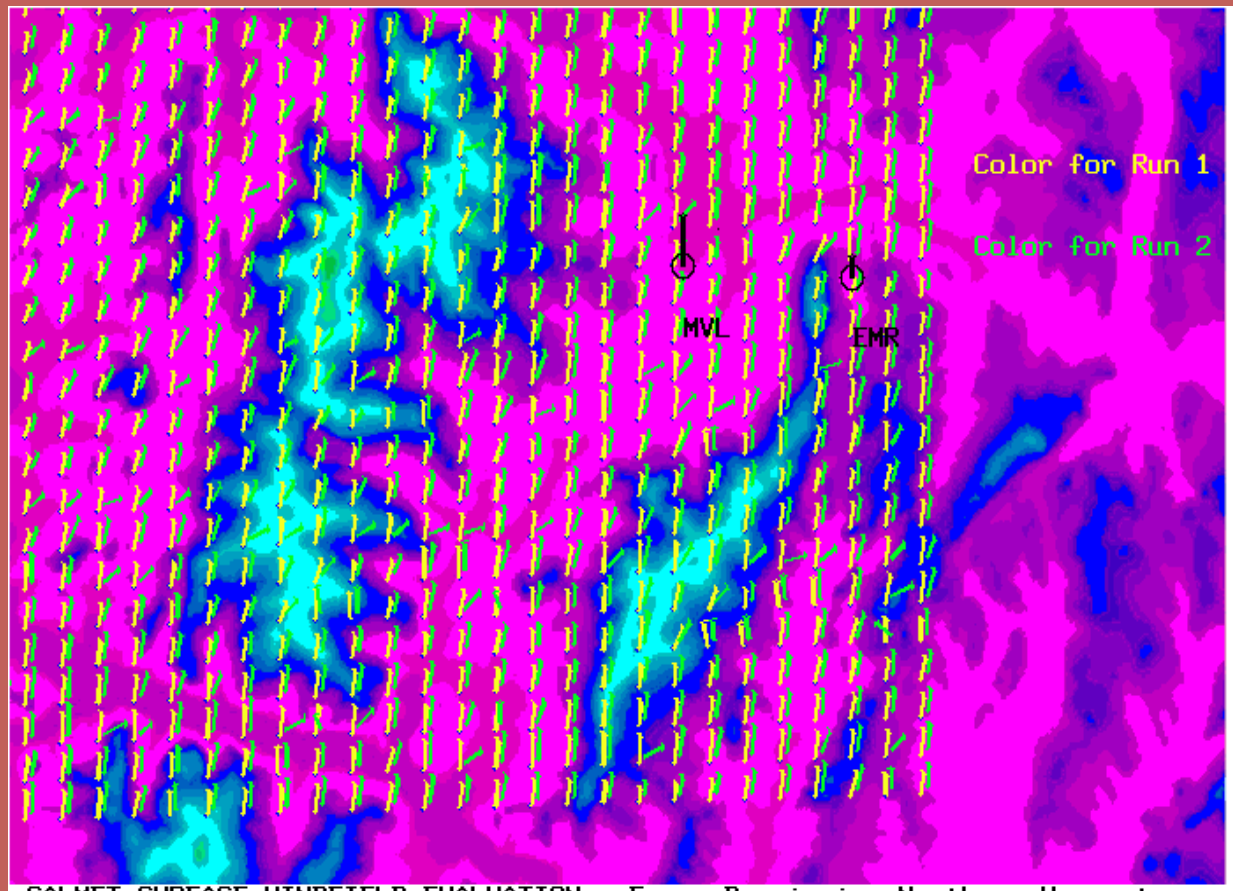


Terrain Effects for Slope Flow Only versus All Terrain Physics



NW wind – Well Mixed, Daytime Conditions





CALMET SURFACE WINDFIELD EVALUATION - For a Domain in Northern Vermont

Windfield Plotted For : Month : 6 Day : 10 Hour : 18

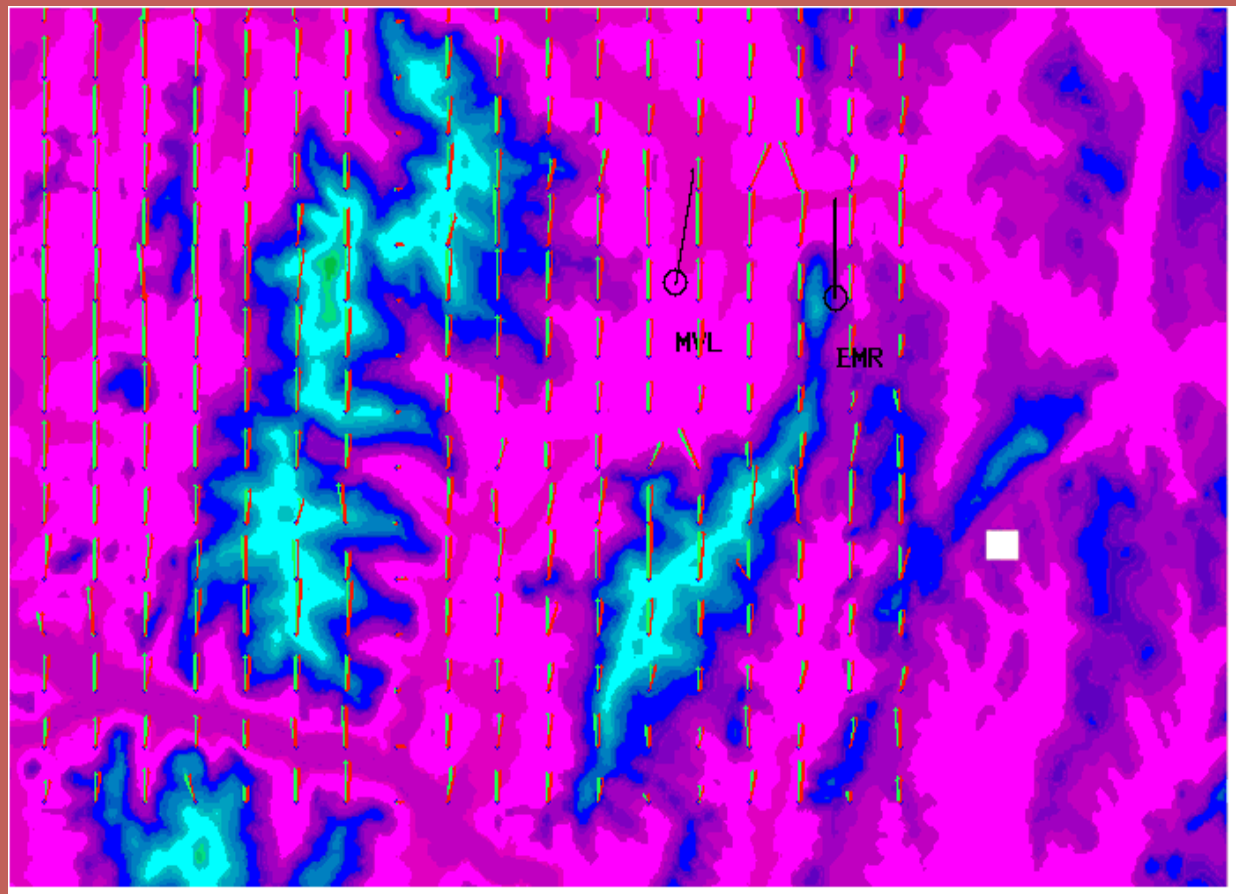
Speed Legend

Length of This Wind Barb = 3 M/S

Observational Locations -

Run 1 - Critical Froude Number = 0.4
TERRAD = 0.5

Run 2 - Critical Froude Number = 1.7
TERRAD = 0.5



CALMET SURFACE WINDFIELD EVALUATION - For a Domain in Northern Vermont

Windfield Plotted For : Month : 6 Day : 27 Hour : 12

Speed Legend

Length of This Wind Barb = 3 M/S

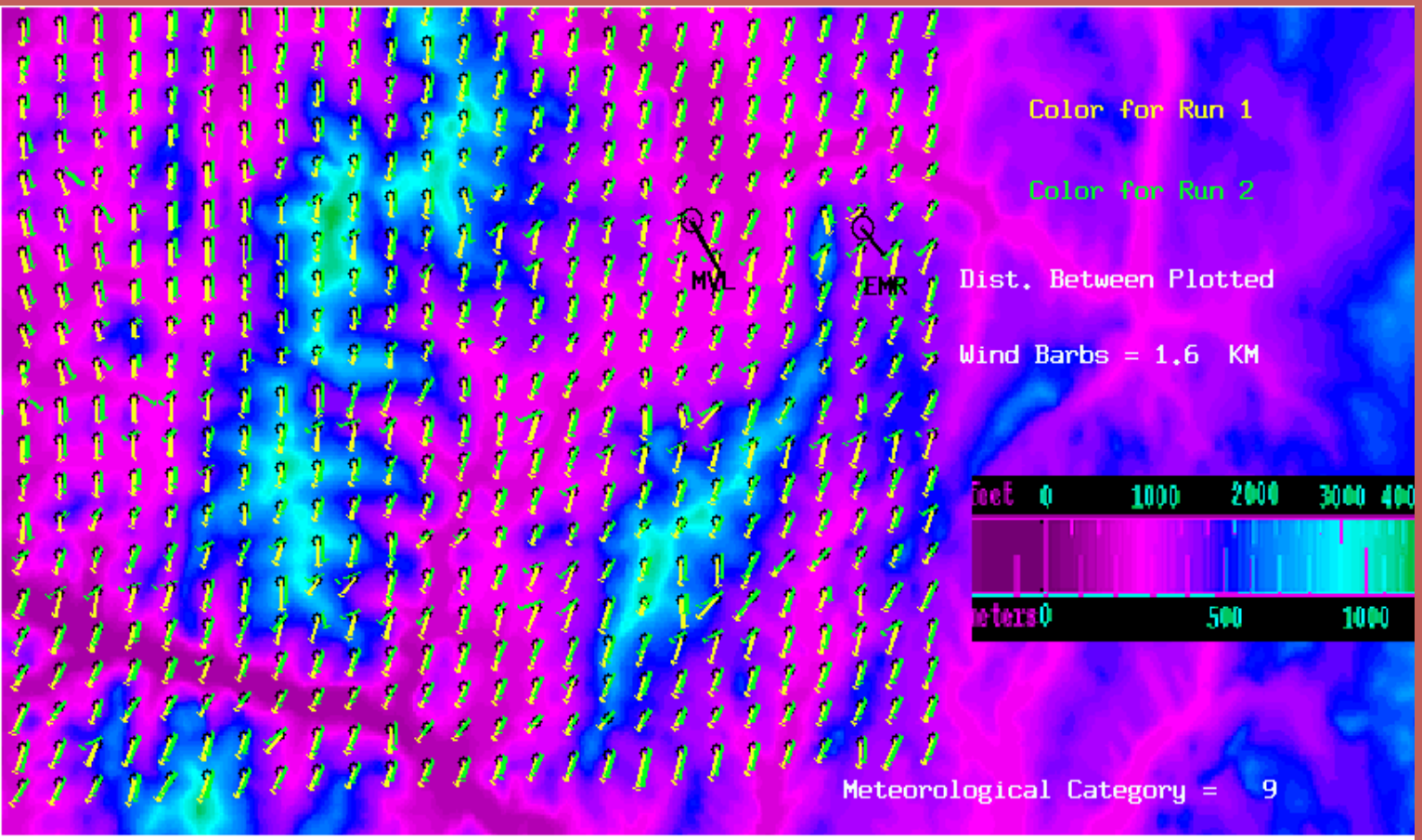
Observational Locations -

No Terrain Effects Except Slope

Color for Run 1 Settings

CRITFN= 0.7, TERRAD = 0.5, R1=9

Color for Run 2 Settings



CALMET SURFACE WINDFIELD EVALUATION - For a Domain in Northern Vermont

Windfield Plotted For : Month : 8 Day : 2 Hour : 13

Speed Legend

Length of This Wind Barb = 3 M/S

Observational Locations -

Run 1 - Critical Froude Number = 0.4

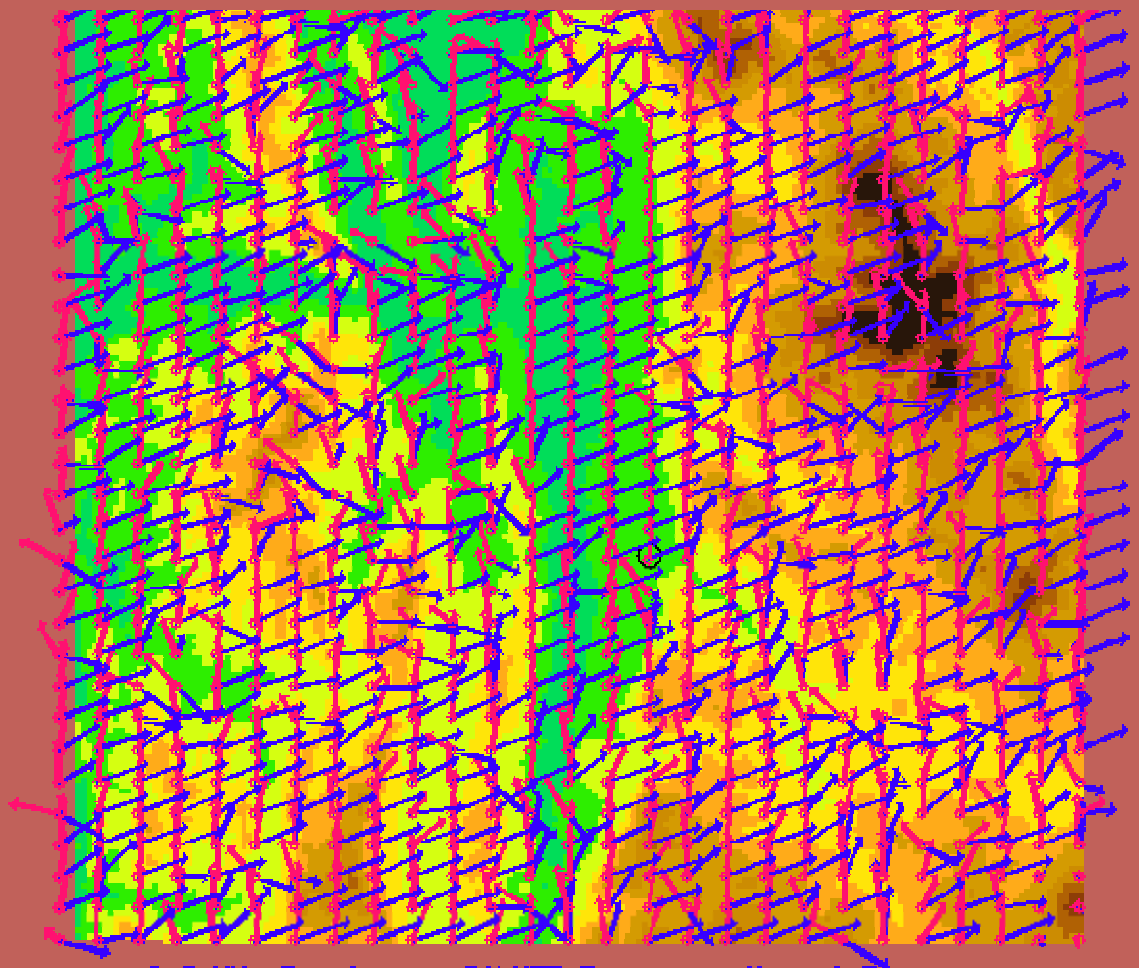
TERRAD = 0.5

Run 2 - Critical Froude Number = 1.7

TERRAD = 0.5

Calpuff Modeling – Complex Terrain Applications

- Meteorological field representation Use one surface station as a ‘driver’ to produce a spatially varying wind field over a local scale domain accounting for geographical effects



0.2 KM. Resolution CALMET Domain in Normal Projection

Winds for Rutland, Vermont Domain Froude # = 1.5

For Stable, Overnight Conditions

Speed Legend

Length of This Wind Barb - 5 M/S

Color for Concord Wind Driver

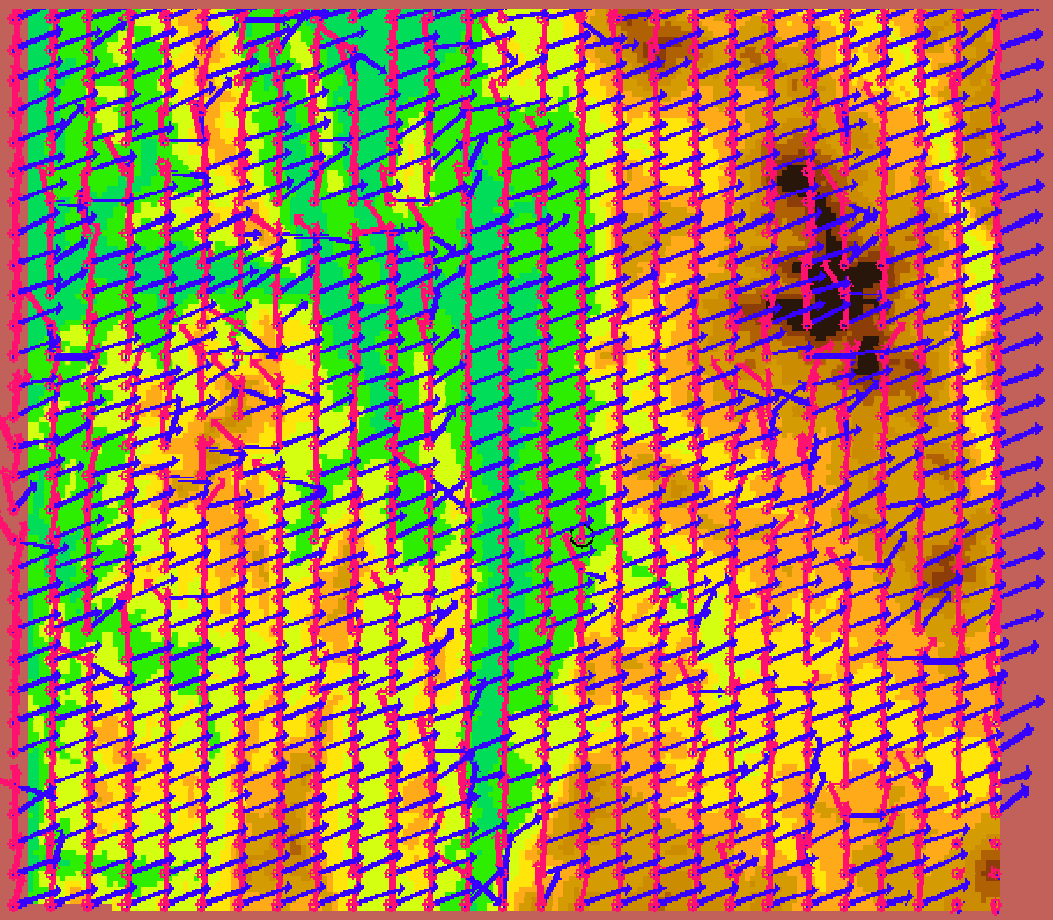
Color for Rutland Wind Driver

LEGEND

Terrain Height

(Meters)

- 100 to 200 m
- 200 to 300 m
- 300 to 400 m
- 400 to 500 m
- 500 to 600 m
- 600 to 700 m
- 700 to 800 m
- 800 to 900 m
- 900 to 1000 m



0.2 KM. Resolution CALMET Domain in Normal Projection

Winds for Rutland, Vermont Domain Froude # = 0.5

For Stable, Overnight Conditions

Speed Legend

Length of This Wind Barb = 5 M/S

Color for Concord Wind Driver

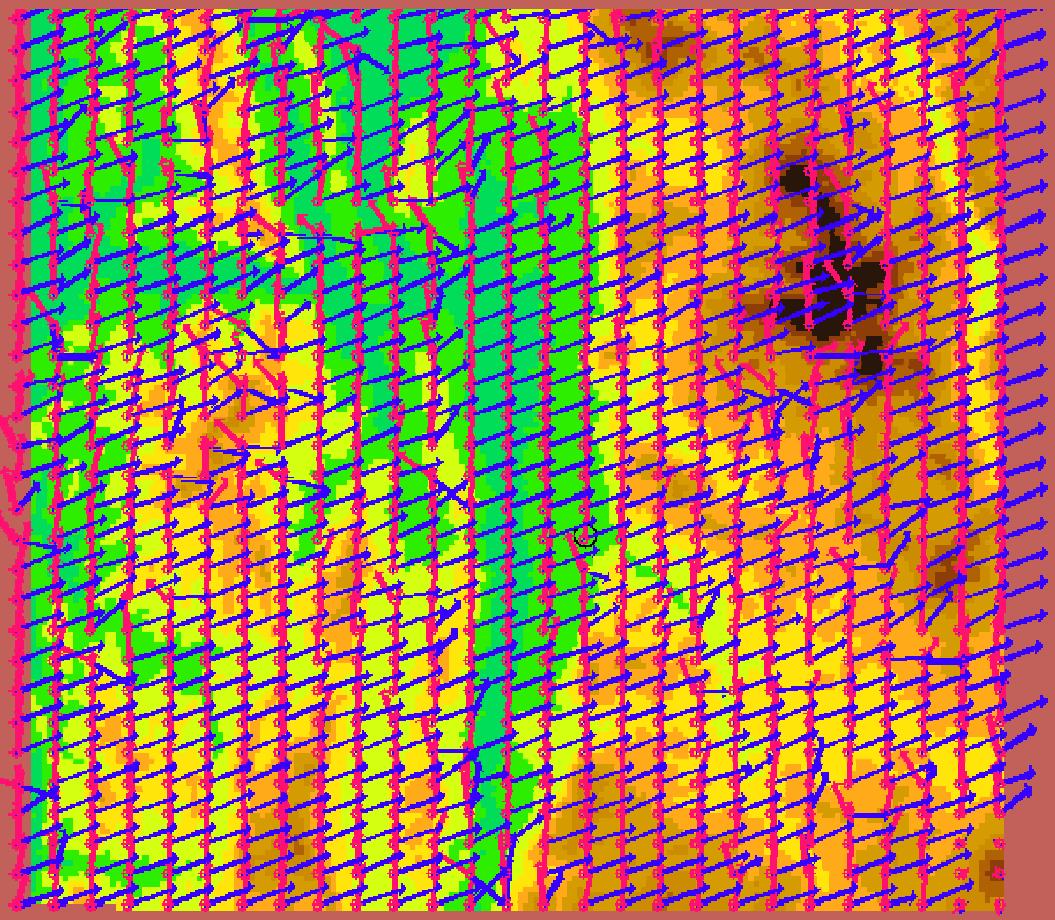
Color for Rutland Wind Driver

LEGEND

Terrain Height

(Meters)

- 100 to 200 m
- 200 to 300 m
- 300 to 400 m
- 400 to 500 m
- 500 to 600 m
- 600 to 700 m
- 700 to 800 m
- 800 to 900 m
- 900 to 1000 m



0.2 KM. Resolution CALMET Domain in Normal Projection

Winds for Rutland, Vermont Domain Froude # = 0.5

For Stable, Overnight Conditions

Speed Legend

Length of This Wind Barb = 5 M/S

Color for Concord Wind Driver

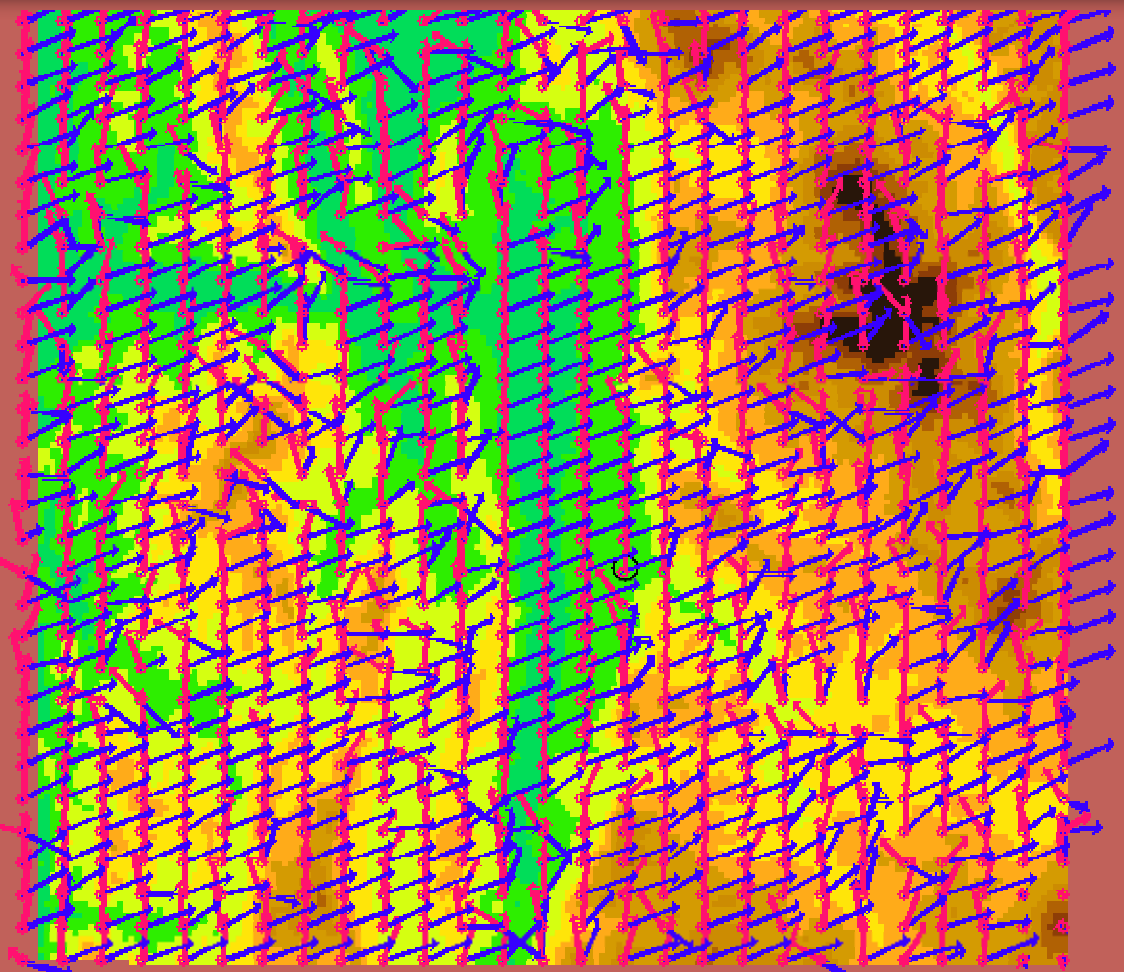
Color for Rutland Wind Driver

LEGEND

Terrain Height

(Meters)

- 100 to 200 m
- 200 to 300 m
- 300 to 400 m
- 400 to 500 m
- 500 to 600 m
- 600 to 700 m
- 700 to 800 m
- 800 to 900 m
- 900 to 1000 m



0.2 KM. Resolution CALMET Domain in Normal Projection

Winds for Rutland, Vermont Domain

For Stable, Overnight Conditions

Speed Legend

Length of This Wind Barb = 5 M/S

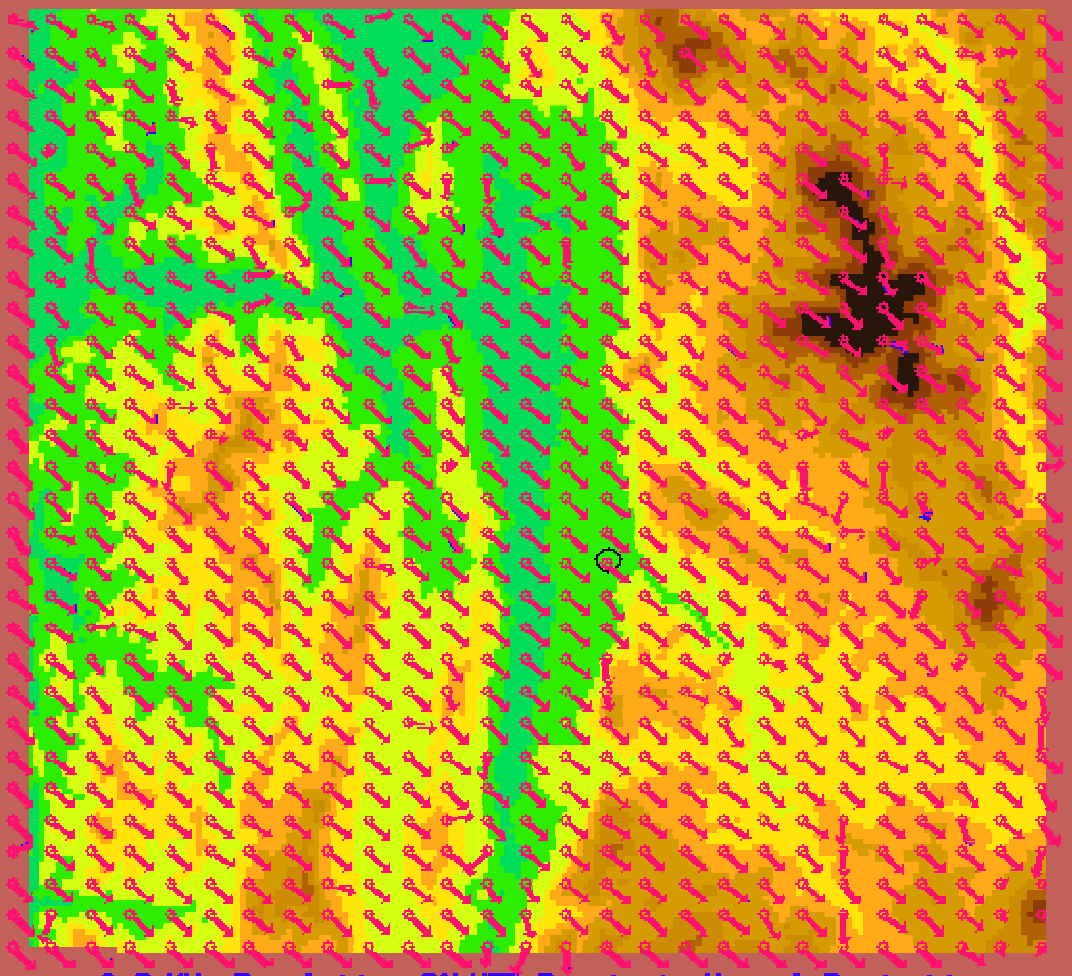
Color for Concord Wind Driver

Color for Rutland Wind Driver

LEGEND

Terrain Height (Meters)

- 100 to 200 m
- 200 to 300 m
- 300 to 400 m
- 400 to 500 m
- 500 to 600 m
- 600 to 700 m
- 700 to 800 m
- 800 to 900 m
- 900 to 1000 m



0.2 KM. Resolution CALMET Domain in Normal Projection

Winds for Rutland, Vermont Domain

For Neutral Conditions Overnight

Speed Legend

Length of This Wind Barb = 5 M/S

Color for Concord Wind Driver

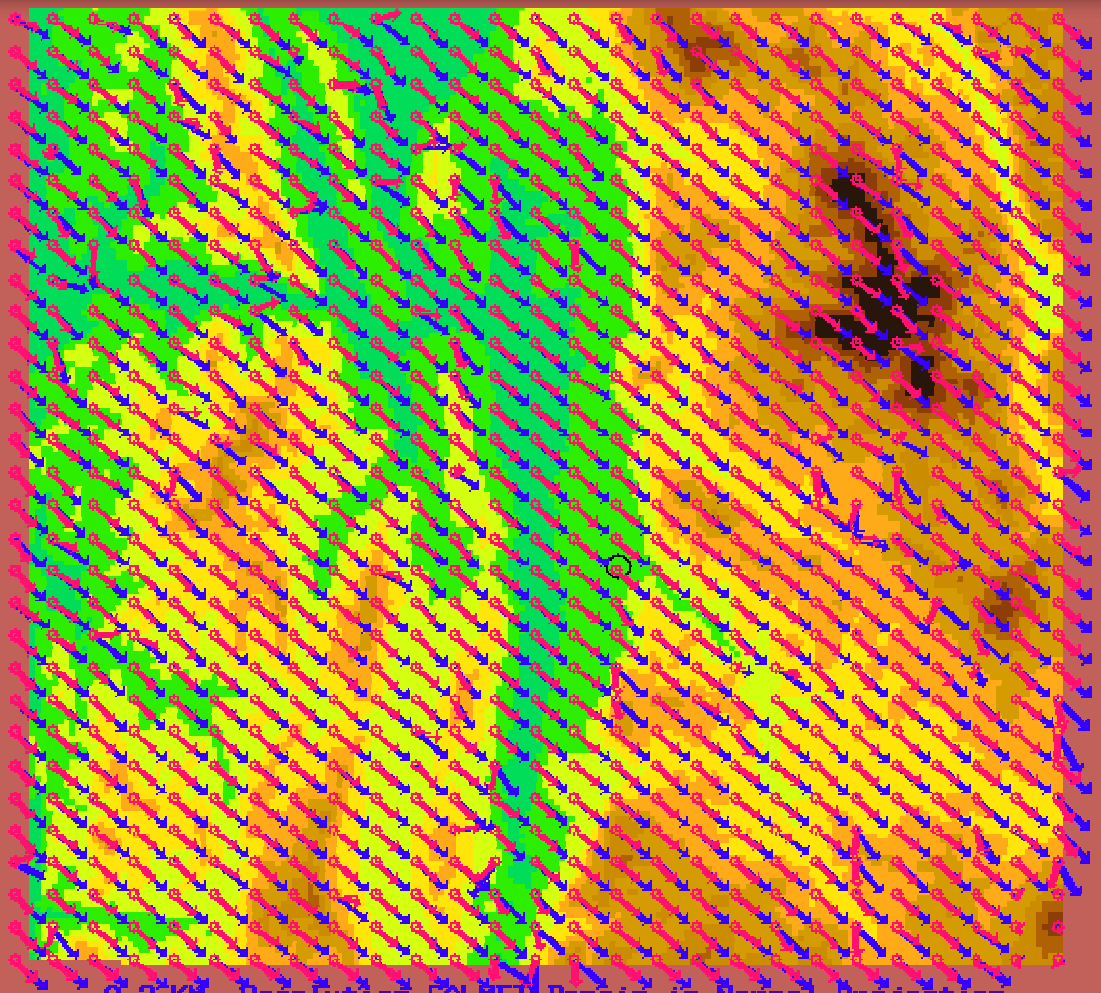
Color for Rutland Wind Driver

LEGEND

Terrain Height

(Meters)

- 100 to 200 m
- 200 to 300 m
- 300 to 400 m
- 400 to 500 m
- 500 to 600 m
- 600 to 700 m
- 700 to 800 m
- 800 to 900 m
- 900 to 1000 m



0.2 KM. Resolution CALMET Domain in Normal Projection

Winds for Rutland, Vermont Domain

For Neutral Conditions Overnight

Speed Legend

Length of This Wind Barb = 5 M/S

Color for Burlington Wind Driver

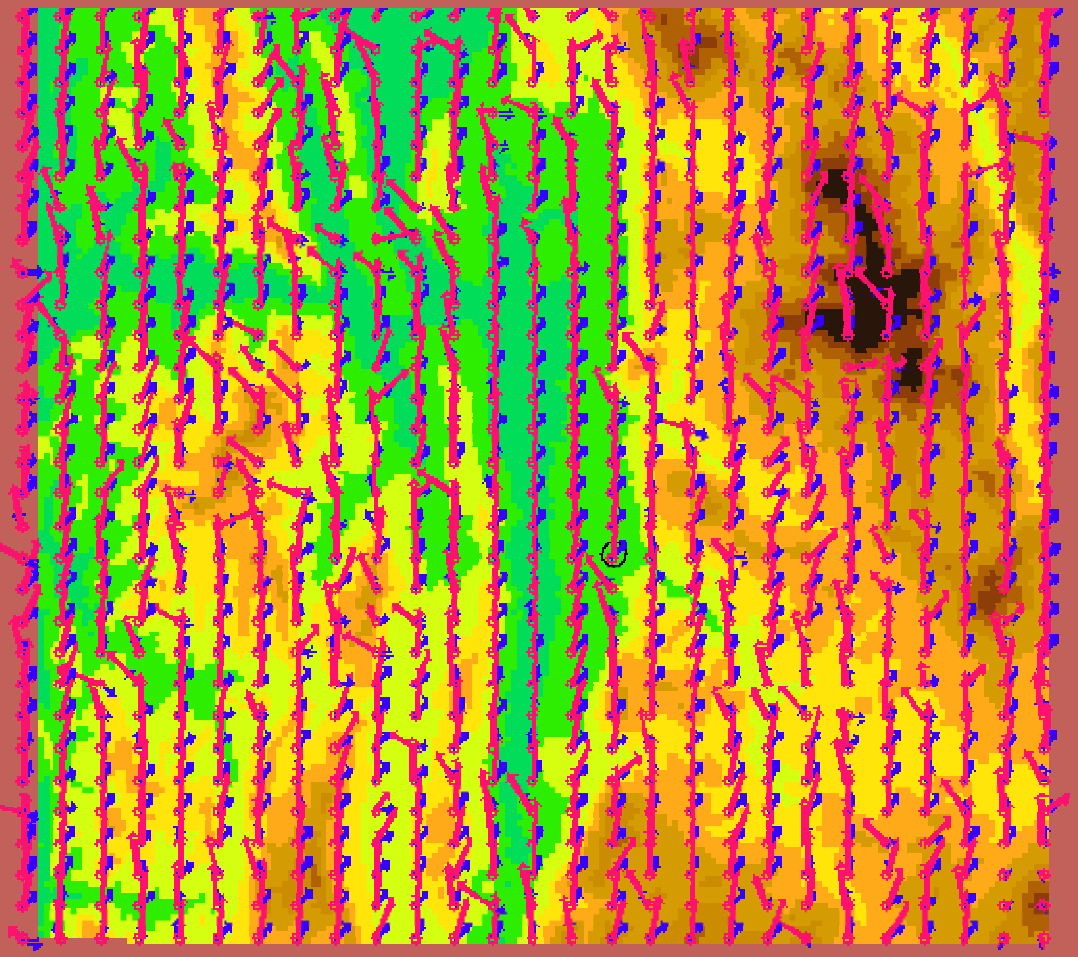
Color for Rutland Wind Driver

LEGEND

Terrain Height

(Meters)

- 100 to 200 m
- 200 to 300 m
- 300 to 400 m
- 400 to 500 m
- 500 to 600 m
- 600 to 700 m
- 700 to 800 m
- 800 to 900 m
- 900 to 1000 m



0.2 KM. Resolution CALMET Domain in Normal Projection

Winds for Rutland, Vermont Domain

For Stable, Overnight Conditions

Speed Legend

Length of This Wind Barb = 5 M/S

Color for Burlington Wind Driver

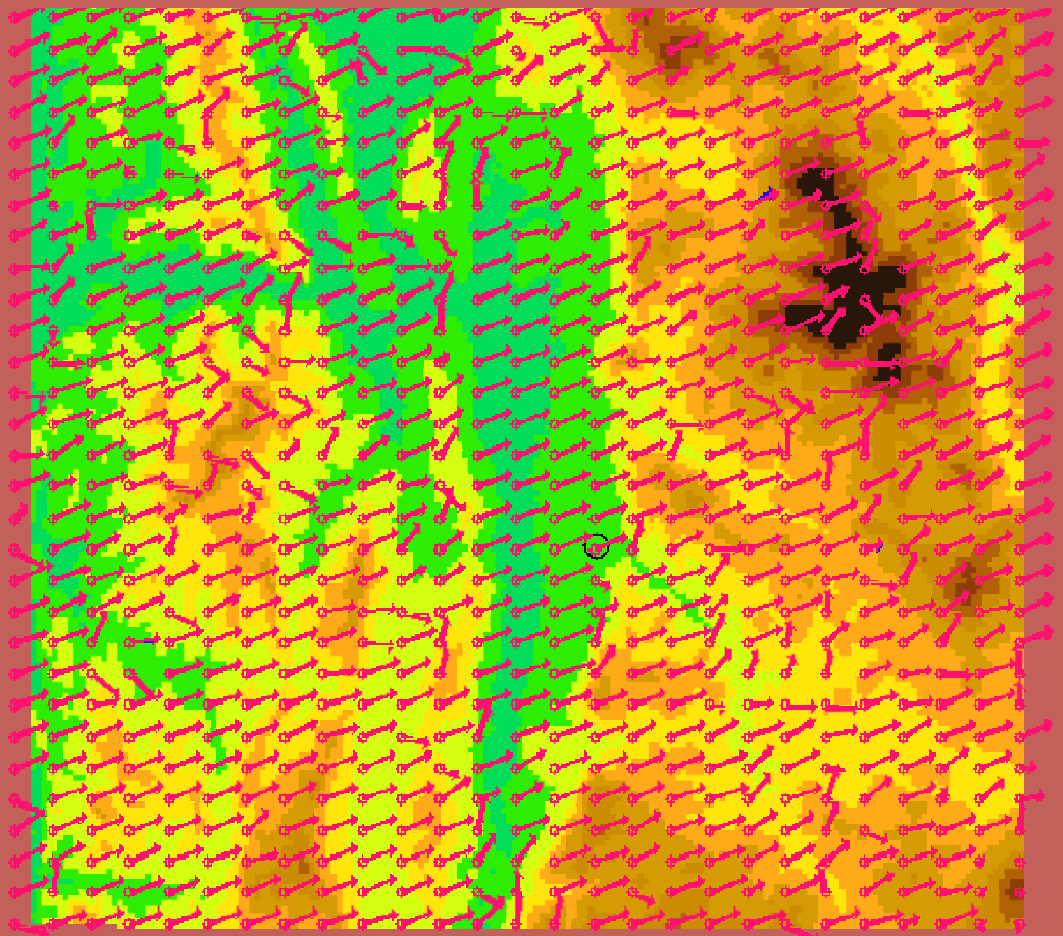
Color for Rutland Wind Driver

LEGEND

Terrain Height

(Meters)

- 100 to 200 m
- 200 to 300 m
- 300 to 400 m
- 400 to 500 m
- 500 to 600 m
- 600 to 700 m
- 700 to 800 m
- 800 to 900 m
- 900 to 1000 m



0.2 KM. Resolution CALMET Domain in Normal Projection

Winds for Rutland, Vermont Domain

For Stable, Overnight Conditions

Speed Legend

Length of This Wind Barb = 5 M/S

Color for Concord Wind Driver

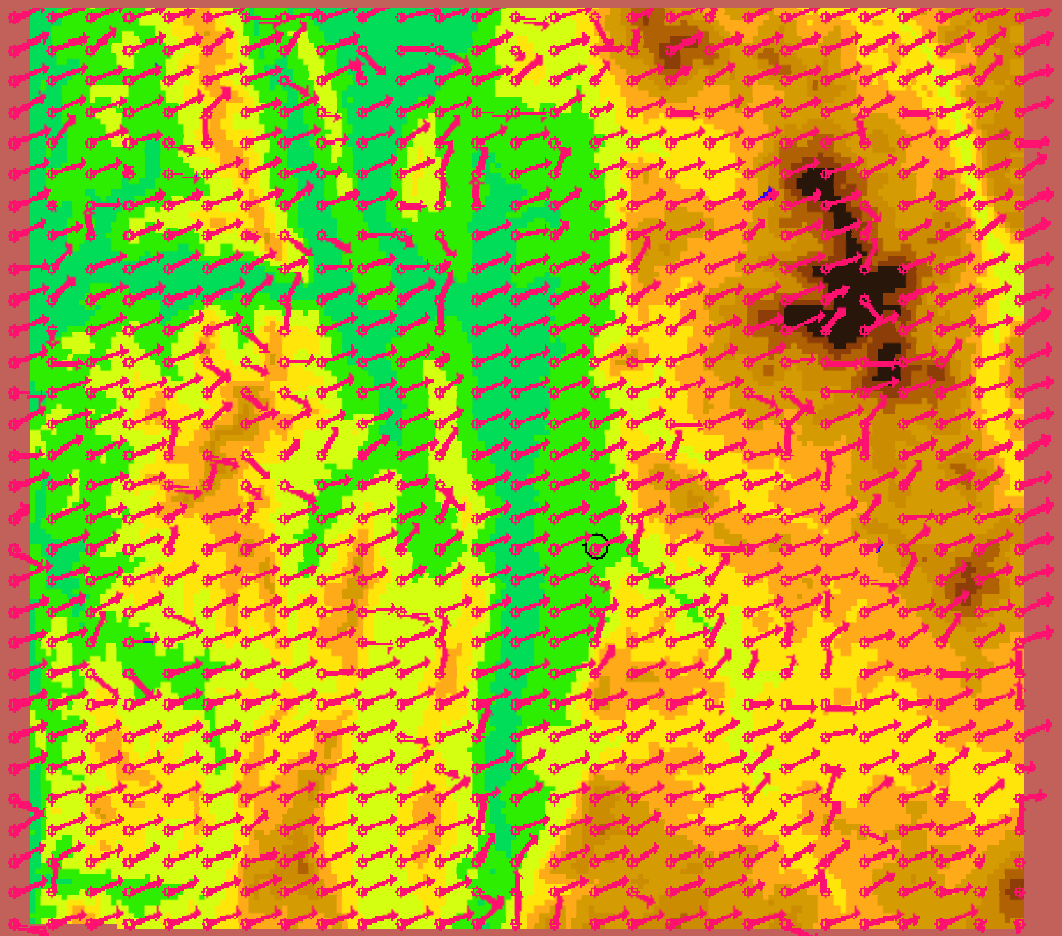
Color for Rutland Wind Driver

LEGEND

Terrain Height

(Meters)

- 100 to 200 m
- 200 to 300 m
- 300 to 400 m
- 400 to 500 m
- 500 to 600 m
- 600 to 700 m
- 700 to 800 m
- 800 to 900 m
- 900 to 1000 m



0.2 KM. Resolution CALMET Domain in Normal Projection

Winds for Rutland, Vermont Domain

For Stable, Overnight Conditions

Speed Legend

Length of This Wind Barb = 5 M/S

Color for Concord Wind Driver

Color for Rutland Wind Driver

LEGEND

Terrain Height

(Meters)

- 100 to 200 m
- 200 to 300 m
- 300 to 400 m
- 400 to 500 m
- 500 to 600 m
- 600 to 700 m
- 700 to 800 m
- 800 to 900 m
- 900 to 1000 m

Regional Scale Modeling

Example of Model Policy Validation Similar to a Validation For Regional Scale Application

- *To Determine Fundamental Variation in Model Predicted Impacts for Model Evaluations based on Prognostic Field Inputs versus Observations and in Comparison to Multiple Year Variation in Impacts*

The Annual Variation Indicator (AVI)

represents the ratio of highest / lowest values over the 5 years of meteorology

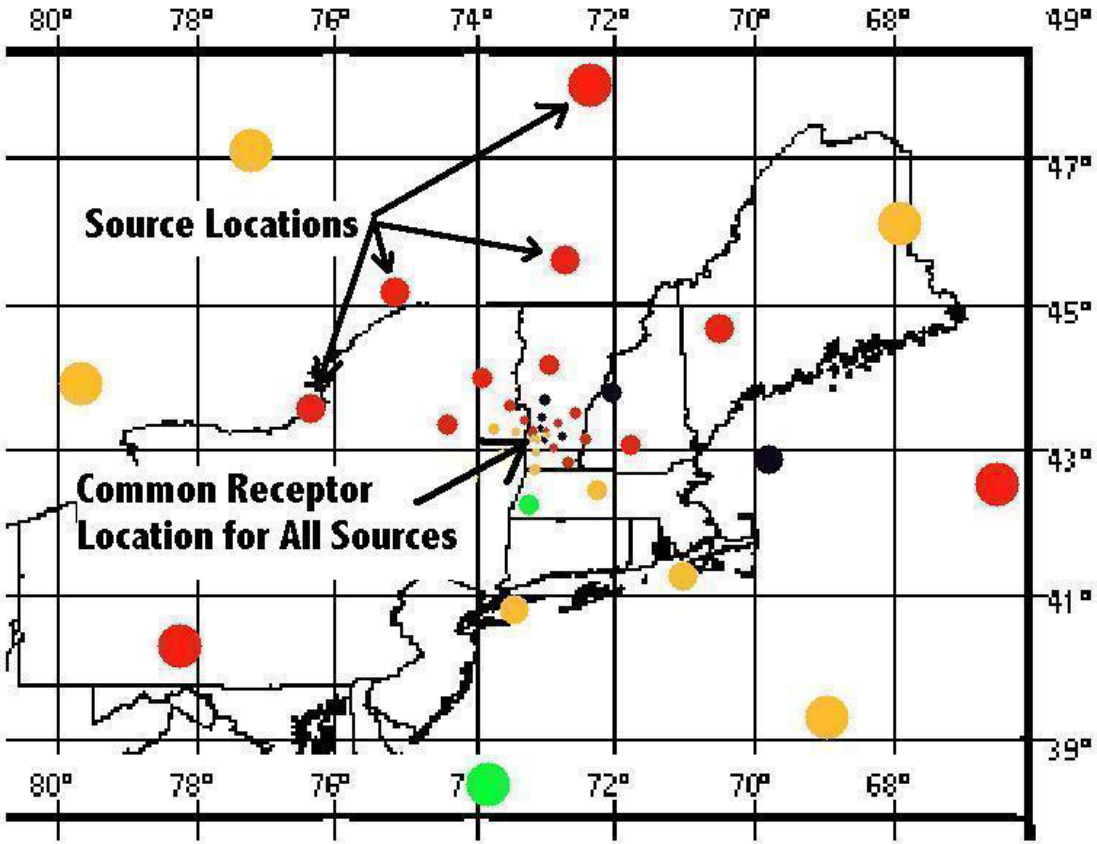
(A value of 1 for the AVI would indicate that there is no annual variation)

In the plots and tables, the AVI value is depicted for plotted source locations where the impacts have been computed at Lye Brook, Vermont, located at the confluence of all the source locations.

Overall Average AVI Values and MM5-Radiosonde Indicator Values for distances less than or greater than 50 km

Pollutant / Standard	Less than 50 km Annual Var. Indicator	Less than 50 km MM5-Rad. Indicator	Greater than 50 km Annual Var. Indicator	Greater than 50 km MM5-Rad Indicator
3 hr SO4 Conc.	2.6	1.6	2.1	1.6
Annual SO4 Conc.	2.5	1.7	1.9	1.3
3 hr SO4 Dry Dep.	4.5	3.6	3.4	3.1
Annual SO4 Dry Dep.	2.9	2.6	2.3	1.7
24 Hr. Visibility	4.0	2.8	2.8	1.9
Annual Visibility	2.5	2.1	2.1	1.4

Annual Variation Indicator Plot.
- Colored Circles Represent Source Locations.
- One Common Receptor Located in Southern Vermont



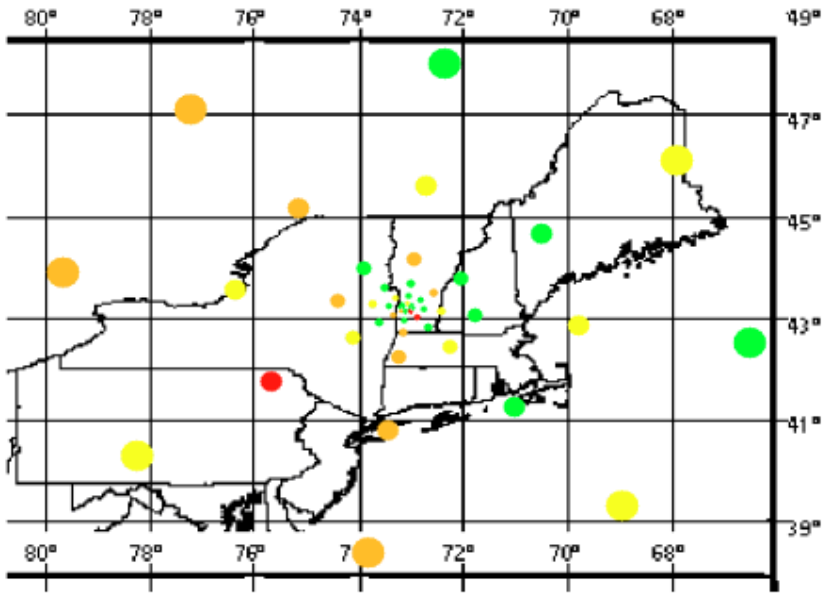
Potential sources of VARIATION of Impacts at Lye Brook for 3-hr SO4 Modeling (from source locations around LYBR)

MM5 versus Radiosonde
CALPUFF impacts

Compared TO

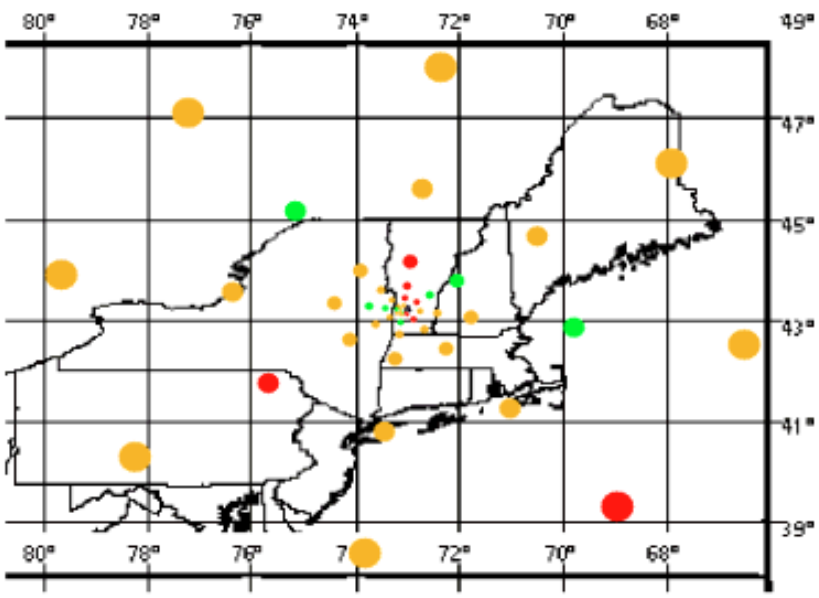
Multiple Year Variation
CALPUFF impacts

Figure 8. MM5 - Radiosonde Comparison of SO4 Concentrations. Maximum 3 HR Concentration Variation for 1992.



Color Legend
Color for Ratio Less Than 1.1 :
Color for Ratio From 1.1 to 1.5 :
Color for Ratio From 1.5 to 2.5 :
Color for Ratio From 2.5 to 5.0 :
Color for Ratio Greater than 5.0 :

Figure 2. Annual Variation Indicator for SO4 Concentrations. Maximum 3 Hr. Concentration Variation for each year.



Potential sources of VARIATION of Impacts at Lye Brook for Annual Average SO4 Modeling (from source locations around LYBR)

MM5 versus Radiosonde
CALPUFF impacts

Compared TO

Multiple Year Variation
CALPUFF impacts

Figure 9. MM5 - Radiosonde Comparison of SO4 Concentrations. Annual Average Concentration Variation for 1992.

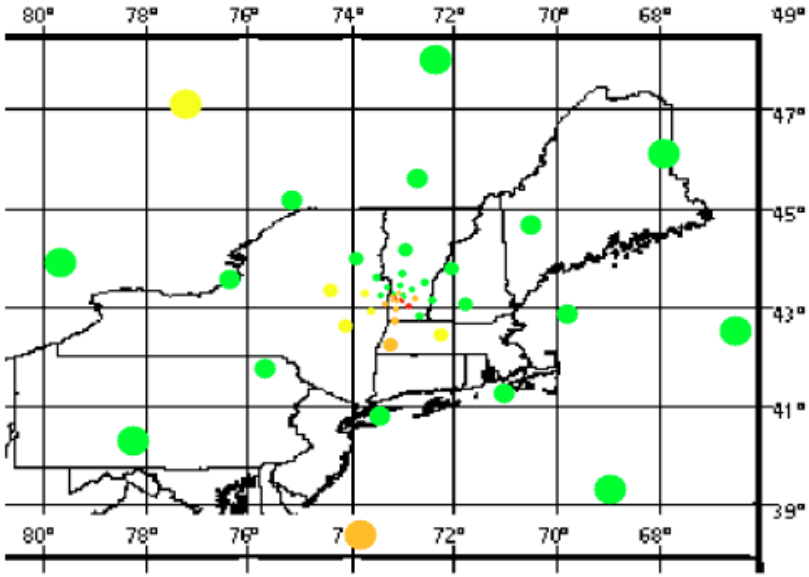
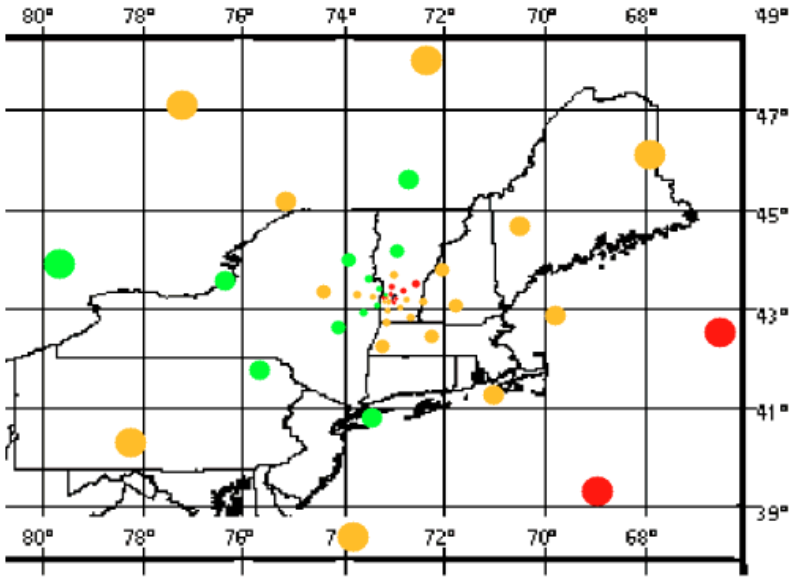


Figure 3. Annual Variation Indicator for SO4 Concentrations. Annual Average Concentration Variation for Each Year.



Color Legend
Color for Ratio Less Than 1.1 :
Color for Ratio From 1.1 to 1.5 :
Color for Ratio From 1.5 to 2.5 :
Color for Ratio From 2.5 to 5.0 :
Color for Ratio Greater than 5.0 :

- **REGIONAL DOMAIN**
- 70 x 64 grid at 36 km. which allows inclusion of source regions affecting all Class I areas in the NESCAUM region.
- Southwest corner of grid is at 33.5 North Latitude and 98.2 West Longitude. Grid projection is Lambert Conformal.
- Domain is consistent with RPO projection specifications.
-
- **MEASURED METEOROLOGY UTILIZED FOR REGIONAL DOMAIN**
- The year 2002 has been processed utilizing the NWS data sets. For 2002, meteorological inputs consist of 700 surface stations, 30 radiosonde stations, and 1100 precipitation sites.
- **Upper Air Radiosonde Data** – Decisions made regarding data substitution routines :
- When possible correct an existing sounding in order that CALMET will run.
- This approach allows one to retain valuable windfield data at the levels which are sufficient for a calmet run.
- - If an entire sounding is missing substitute in the nearest existing sounding for the same time.
- **Surface Weather Data** - The Integrated Surface Hourly Observations Dataset from NCDC was utilized. No Canadian Data Available.
- **Precipitation Data -** Data from the NCDC CD US Hourly Precipitation Data (TD3240 format), was utilized.
- - A laborious process because of the number of stations involved.

- **MANE-VU RPO Study**
- **Preliminary Examination of CALMET Fields Prior to Validation Effort**
- Based on Visual Inspection of Fields
- For *Winter* and *Summer*
- On a *Diurnal Basis*
- - Windfields
- - Temperature fields
- - Precipitation fields
- - Mixing Heights
- **Conclusion**
- (For Default Mode where observations are relied on exclusively)
- CALMET fields produced for measured variables were reasonable
- except *precipitation rates* increased exponentially from measurement points near the domain edges to domain edge itself.
- Secondary fields, such as mixing heights, appeared to be reasonable.

- **MANE-VU RPO Study**
- **CALPUFF Model Validation**
- Using a Comprehensive Emissions Inventory to try to Reproduce Monitored Impacts as Accurately as possible in a series of CALPUFF runs where CALMET and CALPUFF parameter settings affecting model predictions are varied.
- Because :
- 1) the myriad of options available suggests enhanced accuracy beyond default settings is possible for an application – for our effort better accuracy must hold domain wide for improvement.
- 2) When you choose something other than a default setting you must back your decision.
- **Intent is to improve model performance domain wide.**

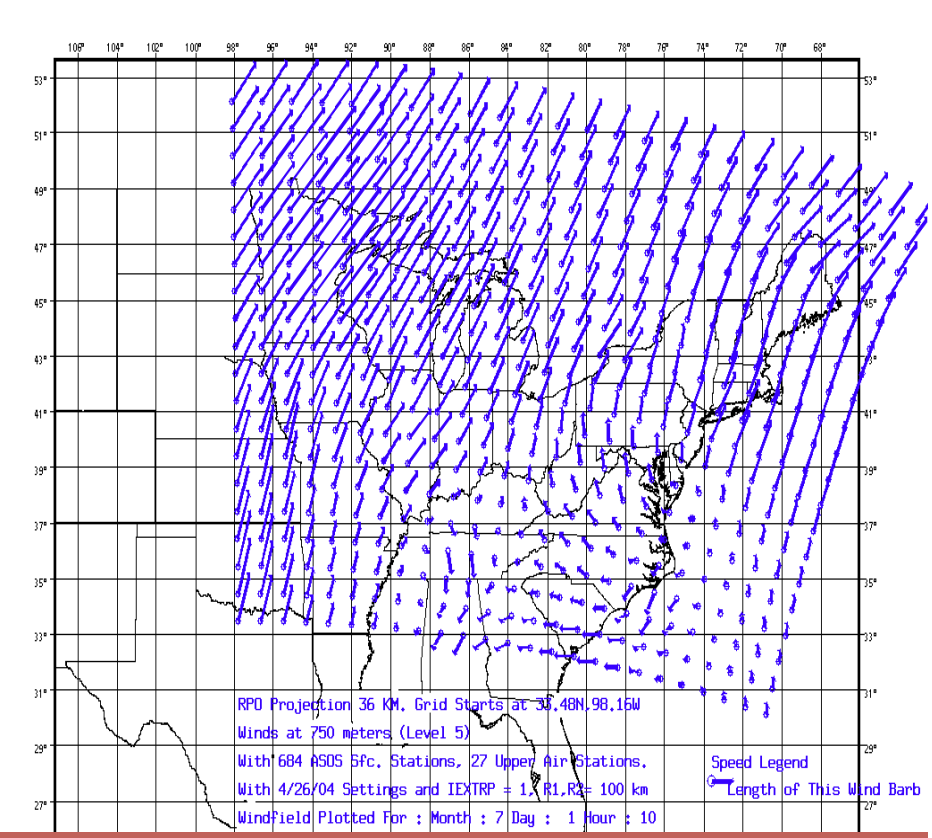
- **CALPUFF Model Validation**
- **This is a long range transport application**
- **(Lambert Conformal Projection - 70 x 64 grid at 36 km. Horizontal Resolution which allows inclusion of source regions affecting all Class I areas in the NESCAUM region).**
- **Initial Assumptions :**
- **Transport at levels above surface; surface level geographical effects less important. Therefore minimize CALMET physics producing STEP 1 WIND FIELD, and produce windfield by interpolating measured data.**

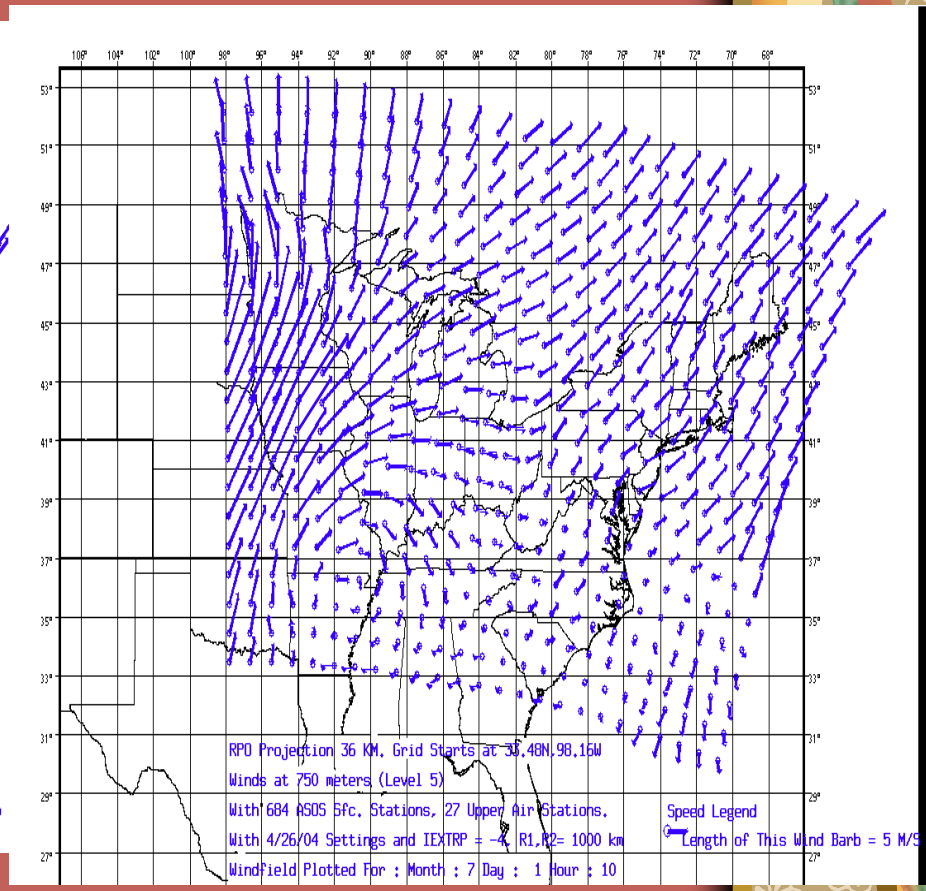
- **<u>CALPUFF Model Validation</u>**
- **Fundamental Processes Effecting Long Range Transported Air Pollutant Concentration Estimates**
- **Transport**
- **Dispersion**
- **Chemistry – not evaluated**
- **Transport**
- attempt to minimize geographical effects and rely on interpolation of measured data
- Where measured data insufficient e.g. Canada, extend interpolation horizontally
- **Dispersion**
- Horizontal Dispersion – rerun CALPUFF producing horizontal dispersion parameters with
- pasquill Gifford tables
- mesopuff equations
- internally derived.
- For internally derived, rerun CALMET with different resolution of vertical levels, to see whether du/dz estimate fundamental to friction velocity varies.
- **Vertical Dispersion** – vary maximum cap on mixing heights.

- **<u>CALPUFF Model Validation</u>**
- **Parameter Settings altered Initially to affect windfield production :**
- **IEXTRP - Extrapolate surface wind observations**
- **to upper layers**
- **LVARY - Use varying radius of influence**
- **R1,R2 - Relative weighting of the first**
- **guess field and observations in the**
- **SURFACE layer and ALOFT**
- **Side by Side examination of windfields produced revealed greatest effect on windfield above surface domain wide occurs when <u>IEXTRP</u> is varied**
- **Therefore proceeded to CALPUFF validation examining variation in IEXTRP (Transport)**
- **Maximum mixing height limitation, and lateral dispersion calculations (Dispersion)**
- **(see table of comparative results).**
- **And winter vs. summer,**
- **And complex terrain vs. discrete receptor**

- **In CALPUFF :**
- For sulfur chemistry.
- Comparing modeled to measured impacts.
- where measured impacts are the IMPROVE 24 HR average SO4 measurements.
- Where modeled impacts result from runs with a comprehensive SO4 inventory in an effort to model absolute SO4 impacts.
- **COMPREHENSIVE EMISSIONS INVENTORY – First Effort**
- **Has been accomplished utilizing CEMS Data and Canadian Point Sources.**
- **All sources modeled at the CALMET terrain elevation**
- **A Final Effort Will Occur in the Future Where Non-CEMS sources are represented through the NEI Inventory.**

Comparison of Upper Air Windfields Produced with Iextrp varied





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