

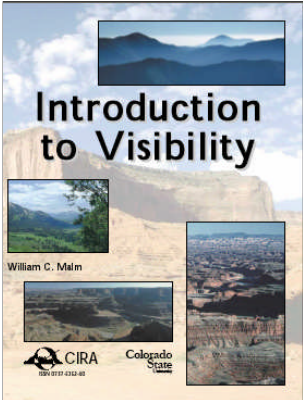
# CALPUFF & Regional Haze Modeling

Are We Doing it Right  
or  
Just Doing it?

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Comments to docket for the  
8<sup>th</sup> Conference on Air Quality Modeling  
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My name is Steve Lund and I work for URS-North Carolina in the Morrisville, North Carolina Office. I was hoping to make this presentation at the conference but technical difficulties prevented this from happening. The actual presentation contains several video animations that are not included in this PowerPoint slideshow. Only the first frame is displayed here. However, the animations have been transferred to the conference computer during the meeting. I welcome the opportunity to make this slide presentation and present these comments with respect to using the CALPUFF modeling system when modeling regional haze. Since many industrial clients may soon be affected by BART modeling requirements, I was given the opportunity to review how we currently conduct single point source regional haze reviews and supply comments to our clients if any changes maybe available to improve the modeling procedures.

I have been doing individual facility regional haze modeling for many years thinking IWAQM/FLAG was the only way the analysis could be conducted. But given the opportunity to review the history of these procedures I now believe there might be a better and technically more refined way to do the analysis.



## Definitions

**extinction:** the attenuation of light due to scattering and absorption as it passes through a medium.

**visual range:** the distance at which a large black object just disappears from view.

**deciview:** a unit of visibility proportional to the logarithm of the atmospheric extinction. Under many circumstances a change in one deciview will be perceived to be the same on clear and hazy days.

**haze:** an atmospheric aerosol of sufficient concentration to be visible. The particles are so small that they cannot be seen individually, but are still effective in visual range restriction. See visual range.

**plume blight:** visual impairment of air quality that manifests itself as a coherent plume.

I started my review by first reviewing definitions. These are just a few. I again realized that many of the key definitions either directly or indirectly talk about a distance component (function). Also to my surprise, one definition for deciview even supplied a time period for the metric I have been using over the years. This time period was days. This made sense to me since haze takes time to form for combustion sources and several days may be needed to evenly distribute this material over a region.

The distant function can be seen in the definition of extinction, “through a medium”, visual range, “the distance”, deciview, the word extinction used again, haze, is directly tied to “visual range” and plume blight, “plume” or dispersion of a substance. From this simple review I know one very important thing about haze and the deciview metric. Visual range is a key component in the definition.

I’m also told that visibility is a “short range” issue and is measured in terms of hours while haze is a “long range” issue measured in terms of days.

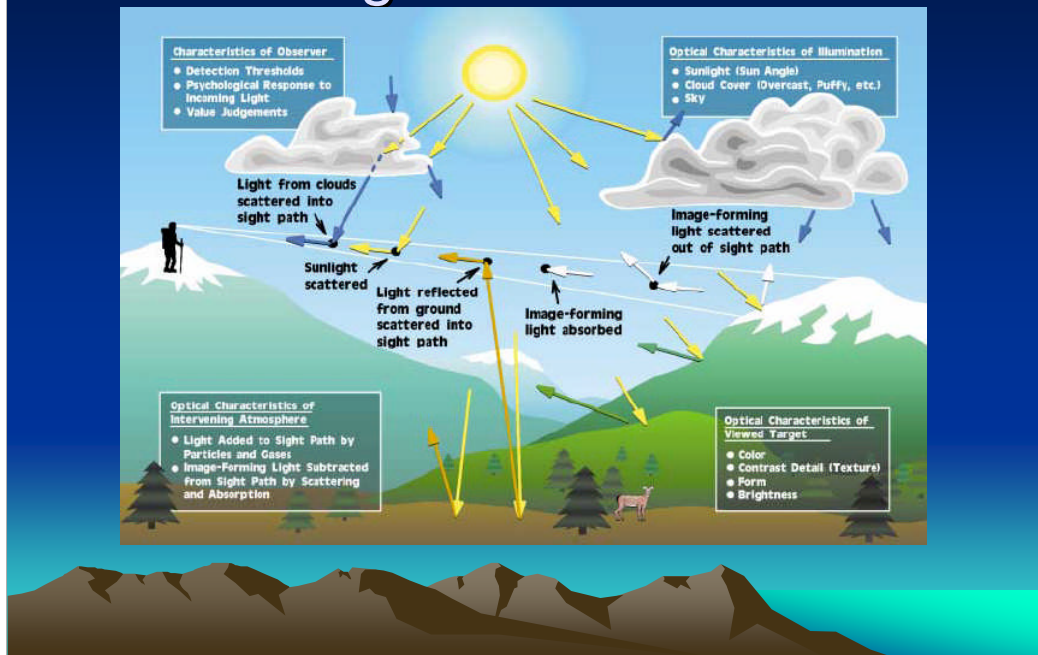
## COMPONENTS OF EXTINCTION

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- $B_{\text{ext}}$  - light scattering and absorption components
- Scattering
  - particle scattering from natural or anthropogenic aerosols
  - Rayleigh scattering from air molecules
- Absorption
  - absorption by particles (e.g., elemental carbon or soot)
  - absorption by gases ( $\text{NO}_2$ ) only major component, but not important for evaluation hazes

Before there was a deciview, extinction was most commonly used by researchers. Again I'm told that extinction is made up of two components scattering and absorption.

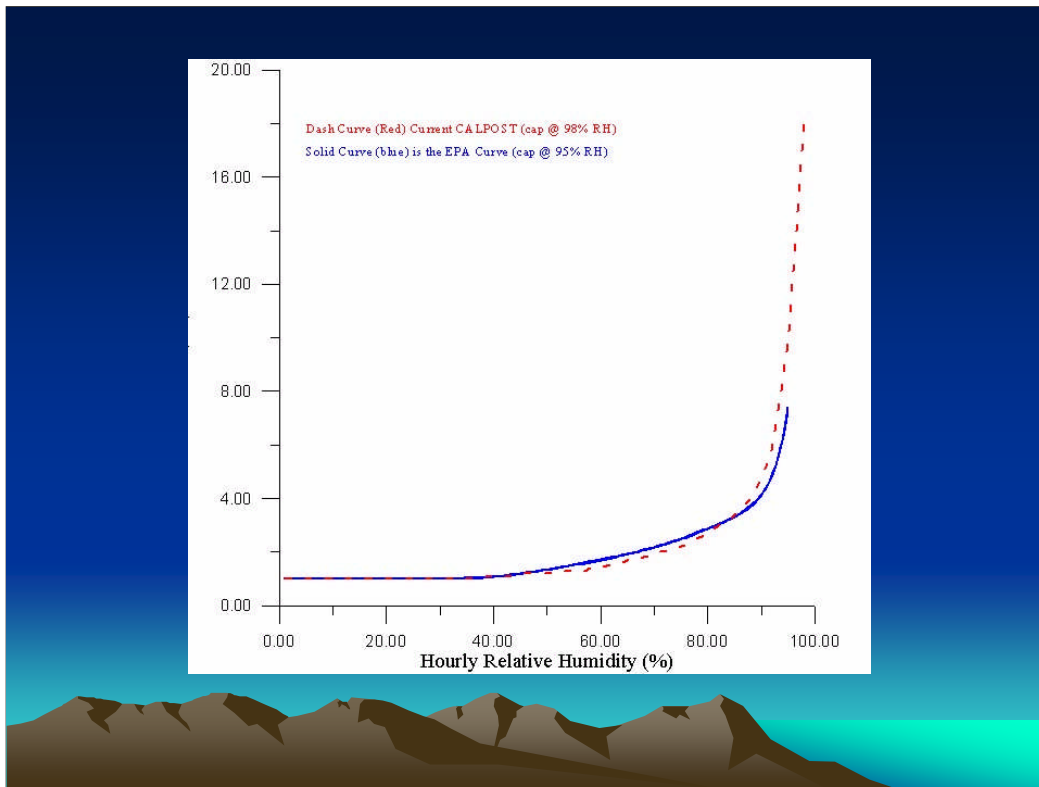
# Light Extinction



This frequently used slide tells me a little more about the key components to visibility which are again light scattering and light absorption. It also shows the interaction of sun light and clouds and an observer that somehow reacts to this information over a period of time. I assume for an hour or less. It also includes the important parameter of distance from the definitions.

However a funny thing happens at 50 kilometers (according to government modeling guidance). From a CALPUFF modeling standpoint, the sun and clouds are no longer important, only particle scattering is modeled but not for an hour but now for a day.

Relative to long range transport and BART modeling, this issue isn't important when an analysis is conducted for a distance greater than 50 km from a Class I area. However, it is a problem area for sources located less than 50 km from a Class I area. More on this subject will be presented later in the presentation.




The CALPUFF model does not directly make final deciview/extinction estimates. The CALPOST model uses concentration and humidity information from CALPUFF output files to make the calculations. One extremely important component to the calculation is the famous  $f(RH)$  curves. The most important issue here is where to cap the highest RH and what curve to use.

### CALCULATION OF EXTINCTION

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$b_{ext} = b_{SO_4} + b_{NO_3} + b_{OC} + b_{soil} + b_{coarse} + b_{ap} + b_{Ray}$

- Hygroscopic components:
  - $b_{SO_4} = 3 [(NH_4)_2SO_4] f(RH)$   
(ammonium sulfate)
  - $b_{NO_3} = 3 [NH_4NO_3] f(RH)$   
(ammonium nitrate)
  - $f(RH)$  is relative humidity adjustment factor
- Non-hygroscopic components
  - $b_{OC} = 4 [OC]$   
(organic aerosols)
  - $b_{soil} = 1 [Soil]$   
(soil, fine particulate matter)
  - $b_{coarse} = 0.6 [Coarse\ Mass]$
  - $b_{ap} = 10 [EC]$   
(elemental carbon (soot))
  - $b_{Ray} = 10 Mm^{-1}$



This is the current equation that CALPOST uses to reconstruct extinction. It's been around for years but BART modeling is forcing everyone to look at it again since the IMPROVE ambient monitoring program wants to revise/update it. It is my belief that this measurement of extinction is grounded in the monitoring world where a real world atmosphere is being measured which includes a homogeneous mixture of contaminants from many sources extending to the visual range. The use of this equation for single plume modeling where strong concentration gradients over a 24-hour period are expected needs to be modified to include a distance component which shows the change in extinction over a sight path (light path) extending to the visual range for natural conditions.

I personally would like to see CALPOST code revisions that allow for the integration of extinction along a string of receptors instead of using a single receptor to make final deciview estimates. This kind of change to the modeling procedures is a true refinement and provides an answer in keeping with the definition of the deciview metric.

I am told we are using a single receptor because this is a conservative assumption. I agree, but it is an assumption that can be removed by doing slightly more refined modeling.

**VISIBILITY - OTHER MEASURES**

- Visual Range (VR)
  - defined as the greatest distance that a large dark object can be seen
$$\text{VR (km)} = 3.912 / b_{\text{ext}} (\text{km}^{-1})$$

$$= 3912 / b_{\text{ext}} (\text{Mm}^{-1})$$
  
- Deciview (Pitchford and Malm, 1994)
  - visual index (dv) which is linear relative to fractional changes in extinction coefficients
$$dv = 10 \ln (b_{\text{ext}} / 0.01 \text{ km}^{-1})$$

$$dv = 10 \ln (391.2 \text{ (km)} / \text{VR(km)})$$
  - dv scale is near zero for a pristine atmosphere, and increases with increasing extinction
  - 0.5 dv ~ 5% change in extinction

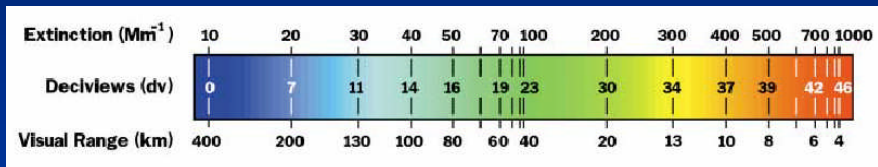
This slide just reinforces the importance of visual range in the development of the deciview and why a distance function is needed if not mandated for refined CALPUFF modeling. When I brought up the need for a distance function in verbal comments at the conference, a representative from the National Park Service (NPS), immediately responded that this could not be done since sight paths are applicable to instantaneous time periods. I disagree with this statement since photons are scattered along a light path which can be measured in seconds, minutes, hours or days using the right equipment?

I agree a shorter time period maybe better but the federally mandated averaging period for BART modeling and I assume all haze modeling is for a day. These words have been taken from the Final BART Guidelines page 307: “you should calculate the daily visibility value at each receptor as a change in deciviews compared against natural visibility conditions”. This forces the analyst (me) to use a 24-hour time period and not the more instantaneous period the NPS would prefer. Until government develops a guidance document training a person to “perceive a one deciview change over a 24-hour period, how can any BART model predictions be verified anyway?

**In my mind, mandating a 24-hour time period cannot negate the need to include a sight path as required by the deciview metric and common sense.** CALPOST single facility haze modeling is done by summing a series of what could be considered instantaneous one hour values, dividing by 24 and comparing it to a 24-hour natural background conditions. I know the FLM would rather do the delta deciview on an hourly basis and then sum the delta deciviews but again an applicable one hour natural condition extinction value isn't publicly available for each hour of the day. I wonder if it was, whether light path haze modeling would be acceptable?

The need to include a light path is an extremely important component when doing plume modeling where large concentration gradients are still occurring, even at great distances for a 24-hour time period. I assume most modelers know this. The term haze from a single point source on a short term basis (24 hours) may only occur if plume material is widely distributed into the region and particles are more evenly distributed otherwise we maybe talking about plume blight.

# Visibility/Haze Metric Scale



I present this slide to show the easily understood relationships of the haze metrics.

## More on Deciview

- Pitchford and Malm, developers of the deciview indicator state that their deviation applies to a scenic element at the most sensitive distance, that is, an element at the greatest distance that is still visible at the lower extinction coefficient value but just disappears at the higher extinction coefficient. This distance relates to the visual range.



Regional haze/BART regulations have decided to hang it's hat on the deciview metric. **Read definition from slide.** A major problem develops because of this decision. The developers of the metric say that the metric is based on using a line of sight (LOS) equal to the visual range, however the regulatory language talks about a change in deciviews within the Class I area. Many within government want to restrict the LOS to the distance within the Class I areas. It is my view and many within the regulated community that the LOS can only be equal to the visual range unless some intervening terrain feature is present. If a terrain feature is present which limits the true line of sight then a new (higher) threshold limit ( $> 0.5 D_v$ ) would need to be determined based on an empirical relationship presented later in this presentation.

## More on Deciview

$$dv = 10 \ln (391.2 \text{ (km)} / \text{VR}(\text{km}))$$

This slide again shows the importance of the visual range to the deciview metric.

## Deciview & CALPUFF

- Current procedures use only one receptor location in Class I Area
- Metric and common sense requires a distance function (more than one receptor)
- Initial testing by URS using distance function has indicated predicted deciviews could be reduced by 50%
- Single receptor OK if haze is uniform

Current federal procedures for conducting a refined CALPUFF analysis for haze requires the applicant to place receptors in the Class I area only, run the model and compare the modeling results for the “worst-case” receptor location to a threshold.

If the haze (plume) has a uniform concentration extending to a distance equal to the visual range then a distance function would not be needed. This assumption maybe applicable for a monitoring program but is not appropriate for modeling plumes from a single BART facility where large concentration gradients would be expected. A distance function (component) represented by two string of receptors that extend back towards the emission source and through the Class I area and another string of receptors that extend forward in a downwind direction and through the Class I area is needed. Each of these strings of receptors would extend to the visual range. By integrating the change in deciviews along each string, a true light path value for what ever averaging period can be determined.

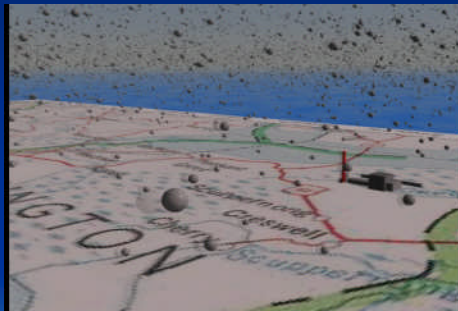
I conducted initial testing and found predicted deciviews could be reduced by 50 percent.

The current single receptor approach may be based on the FLM wanting to be able to directly compare a monitored value to a modeled value. This concept works for compounds such as SO<sub>2</sub>, NO<sub>2</sub> and PM<sub>10</sub> but not for reconstructed light extinction resulting from emissions from a single facility unless multiple monitors are placed along the light path.

# Haze or Plume Blight

**haze:** an atmospheric aerosol of sufficient concentration to be visible. The particles are so small that they cannot be seen individually, but are still effective in visual range restriction. See visual range.

**plume blight:** visual impairment of air quality that manifests itself as a coherent plume.



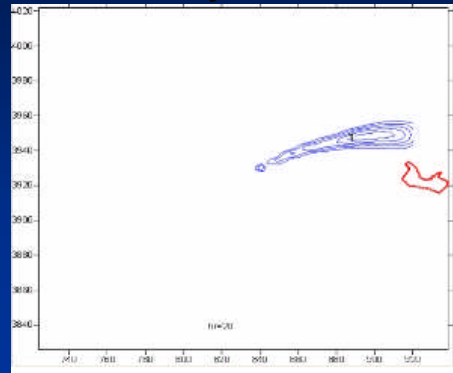
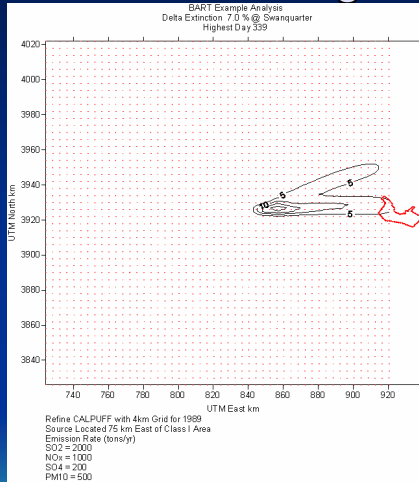
The following animations graphically displays the issue. In a true haze situation the animation on the left shows the haze to be somewhat uniform over a large area and a single point could be used to determine a relatively accurate reconstructed light extinction value assuming the haze is uniform to the visual range.

When modeling a single facility the animation on the right shows that a uniform haze situation is not occurring therefore concentrations along a light path are needed to accurately determine the “worst-case” reconstructed light extinction.

# Is this Plume Blight or Regional Haze?

## 24-Hour Average

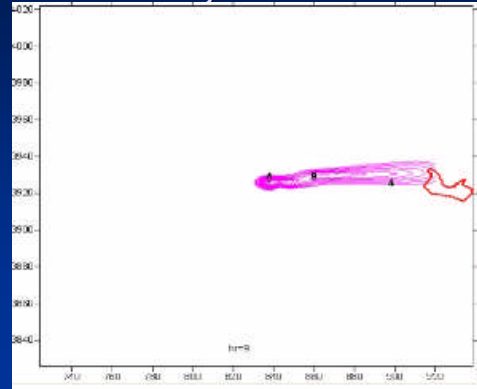
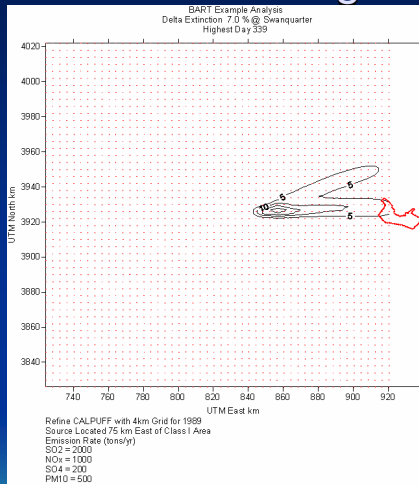
## Hourly



If the answer is haze then current modeling procedures assumes the maximum concentration in the Class I area extends, in all directions, to the visual range. (VR=155 km this day)

This animation shows the relationship between a 24-hour averaging period and a one-hour period. The 24-hour plot make it relatively simple to pick the correct light path or a line-of-sight (LOS) to model for the BART analysis. The EPA, FLM and the Regional Planning Groups will need to let the regulated community know the answer to the question so modeling can be performed correctly.

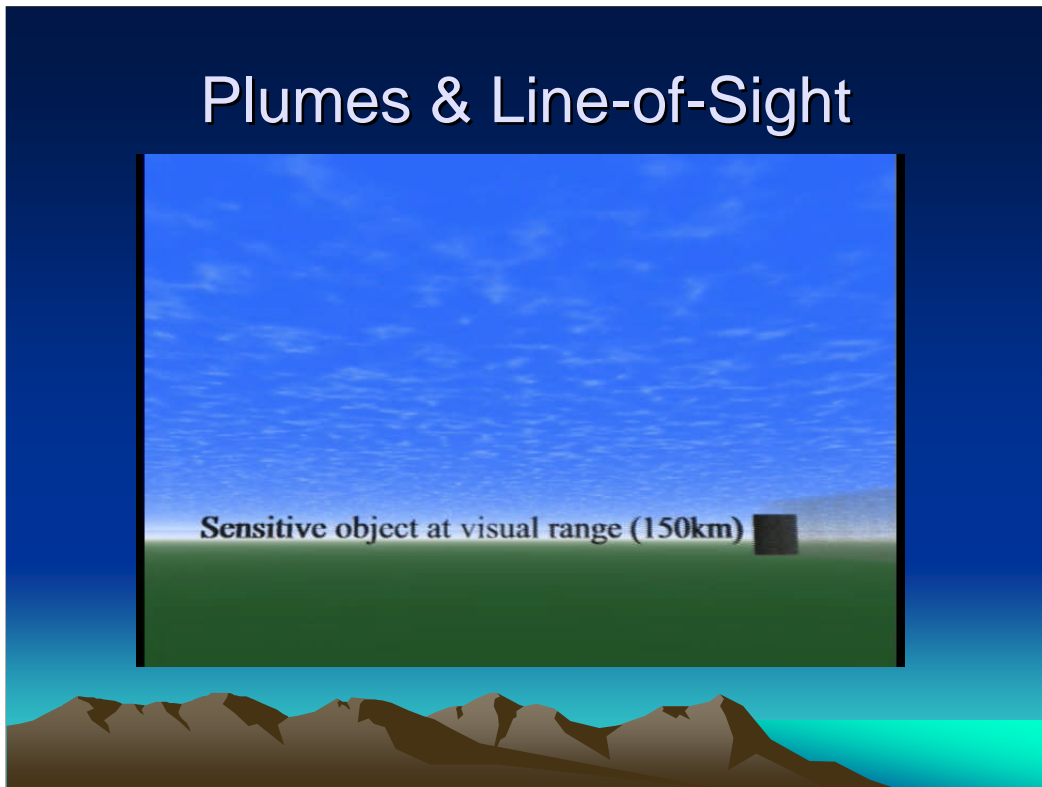
# Is this Plume Blight or Regional Haze? 24-Hour Average Hourly



If the answer is blight then a string of receptors along the line-of-sight is needed to determine the change in concentration extending to the visual range.

I believe that current single source CALPUFF modeling for a 24-hour period is not a true representation of large scale regional haze impacts where a single reconstructed light extinction value (or receptor) is acceptable. This type of CALPUFF modeling, whether for a 24 or 1-hr period, is more like a plume blight situation which requires a line-of-sight or distance function for modeling.

## Plumes & Line-of-Sight



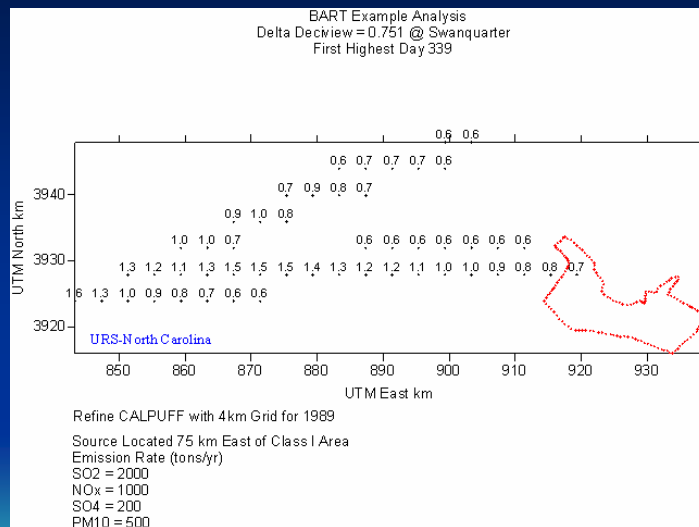
This slide provides some insights into why modeling particles at just one location when dealing with a plume can be misleading unless a light path component is added. It is also useful in showing how visual range is defined and how sight angles can increase and decrease light extinction.

## Observation

- For single source CALPUFF modeling a line-of-sight modeling approach should be considered a further refinement to current federal guidance since large concentration gradients are expected from plume modeling and a sight path is a key component to the metrics used for haze/visibility measurements.

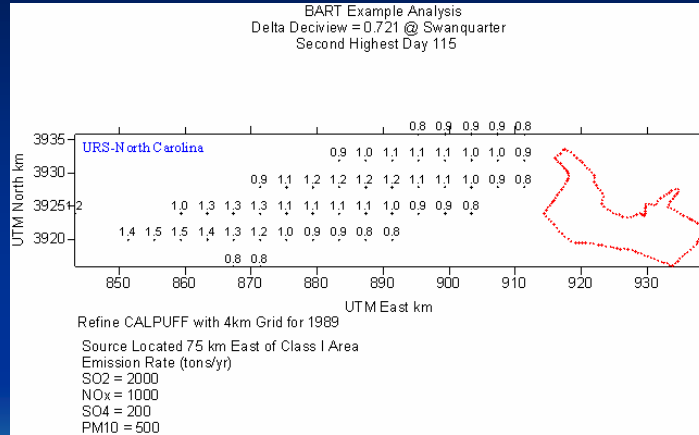
(Read the observation from slide).

# Plume Plots



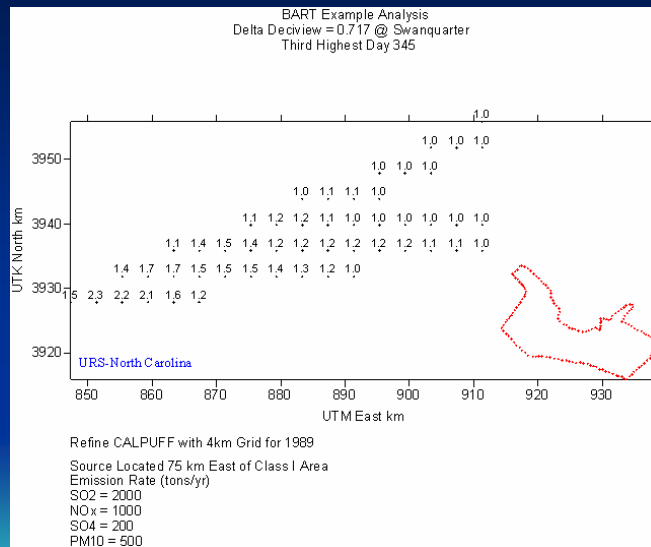
I will now display a series of slides that show typical plume plots for a facility located 75 km from a class I area and emits 2000 tons/year of SO<sub>2</sub>, 1000 tons/year of NO<sub>2</sub>, 200 tons/year of SO<sub>4</sub> and 500 tons/year of PM<sub>10</sub>. Note that only 50 delta deciview values are displayed. This results from CALPOST only being able to provide written output for the top 50 receptors. Therefore most plots do not display the true plume configuration. This plot shows the plume configuration for the highest day. Information on the modeling domain configuration will be presented later in this presentation.

# Plume Plots



This is a plot for the 2<sup>nd</sup> highest day.

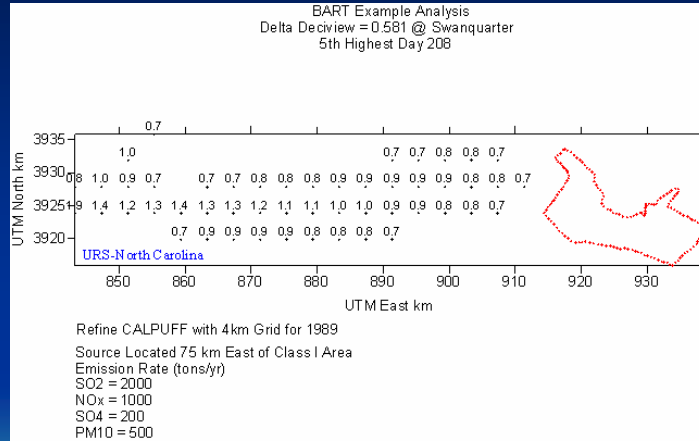
# Plume Plots



This is a plot showing the third highest values.

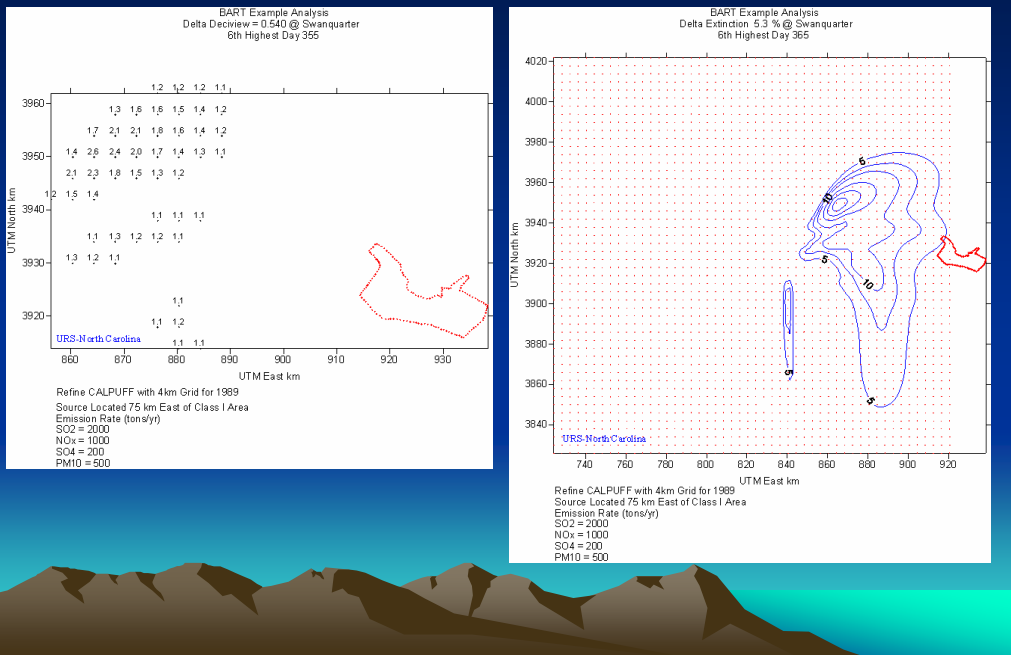


# Plume Plots



A plot for the 5<sup>th</sup> highest day.

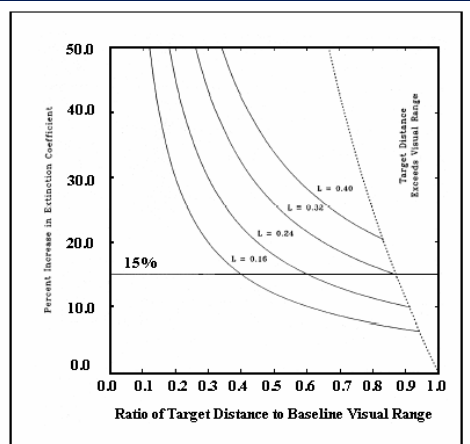
# Plume Plots



This plot is somewhat interesting since it is the first plot that widely distributed material over a fairly large area. It represents the distribution for the 6<sup>th</sup> highest day or a day near the 98<sup>th</sup> percentile which will be used for BART modeling. The value of doing these plots is to help determine where the largest concentration gradients occur and therefore help the analyst determine the worst-case light path for the 24-hr period.

CALPOST Method 6 was used for all the plots along with the FLAG recommended natural condition defaults for the Swanquarter Class I area.

# Limiting Line-of-Sight



**Figure 1.** Figure 1 from Pitchford et al.<sup>4</sup> The curves were calculated from eq 12 using a liminal contrast of 5% ( $-ln\epsilon = 3.0$ ). The line labeled  $L = 0.24$  best corresponds with the analyses in the NPR. This line indicates that a 10% increase in  $b_{ext}$  (i.e., a 1-dv change) corresponds to a JNC in haze when the length of the sight path is equal to the VR. For points below and to the left of this line, the change in  $b_{ext}$  is too small for a noticeable visibility change to occur.<sup>4</sup> Points to the right of the dotted line are beyond the VR. Points above the  $L = 0.24$  line and to the left of the dotted line correspond to noticeable changes in visibility. The horizontal line at a 15% increase was proposed by Pitchford et al.<sup>4</sup> as the basis for a regulatory strategy.

This is an important component when the line-of-sight is not related to the visual range. It shows that if line-of-sight is limited to 20% of the visual range then the deciview metric, which is base on the visual range, would need to be increased by a factor of 4 in order to cause a just noticeable change in extinction. This means that instead of using a 0.5 deciview as a threshold of concern, the concern threshold now could be 4 times higher or 2 deciviews. This concept is best demonstrated by viewing the Plumes & Line-of-sight animation and reading a 1999 AWMA paper on this subject prepared by L. Willard Richards.

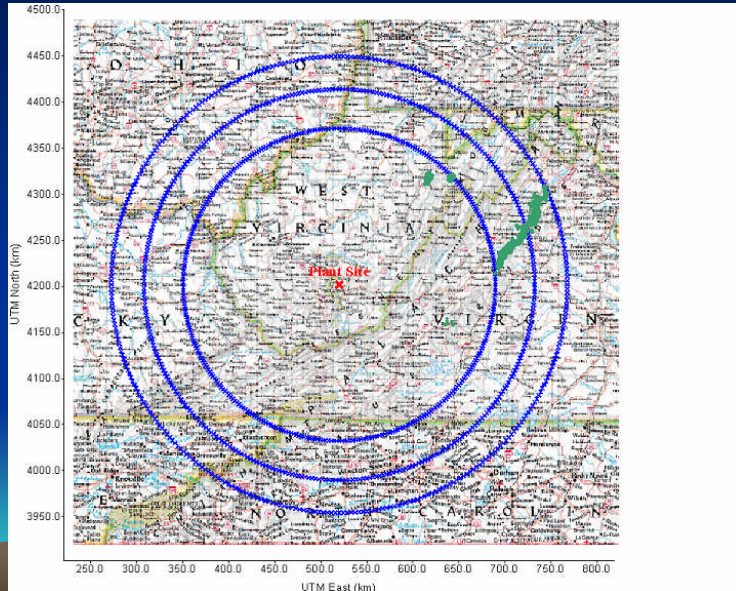
# Example from Line-of-Sight

FORWARD LOOKING LOS	
24-Hour Period	Delta
Distance (km)	Deciview
0	1.647
10	1.524
20	1.246
30	0.911
40	0.631
50	0.475
60	0.39
70	0.328
80	0.279
90	0.244
100	0.217
110	0.194
120	0.174
130	0.156
140	0.137
150	0.12
160	0.102
170	0.085
Average	0.492222

BACKWARD LOOKING LOS	
24-Hour Period	Delta
Distance (km)	Deciview
0	1.246
-10	1.524
-20	1.647
-30	2.003
-40	1.466
-50	0.872
-60	0.036
-70	0.007
-80	0.001
-90	0
-100	0
-110	0
-120	0
-130	0
-140	0
-150	0
-160	0
-170	0
Average	0.489

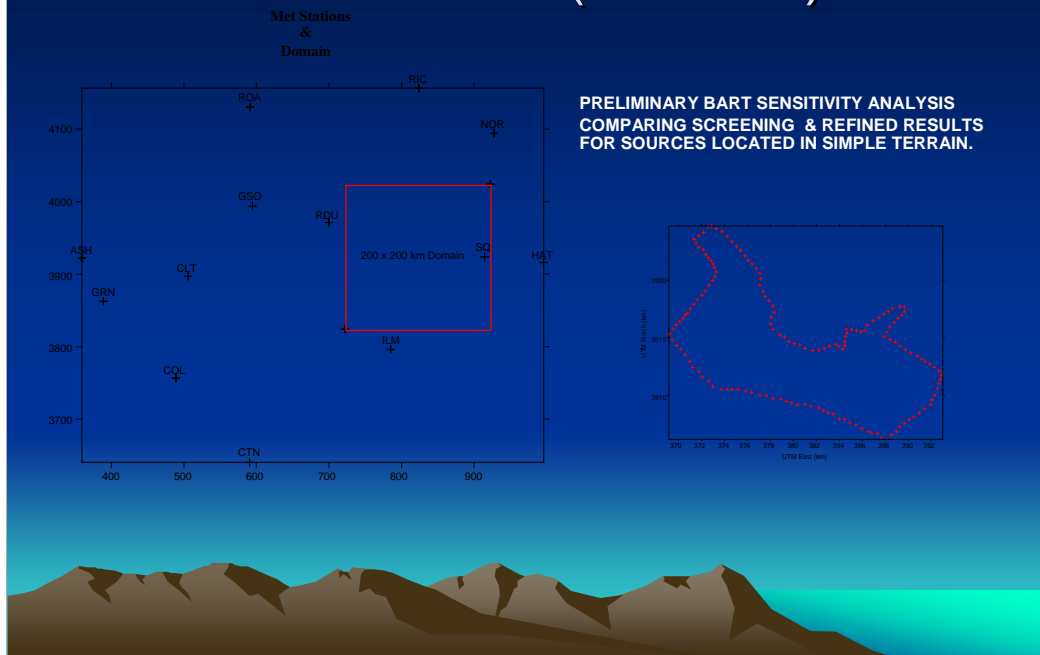
These are the results from an actual refined CALPUFF line-of-sight modeling analysis. Note that the backward looking LOS has the first receptor located along the back edge of the Class I area facing the emission source and ends at the visual range. Only 18 evenly spaced receptors were used in this simple line-of-sight analysis. A maximum of 50 receptors could be used with the CALPOST current configuration. The forward looking LOS has the first receptors located on the Class I boundary nearest the source and extends downwind to the visual range. This receptor was determined based on standard FLM CALPUFF modeling procedures and was the “worst-case” receptor location. The Class I area is 20 km wide. It is interesting to note that this example facility would be subject to BART using current modeling procedures but be exempted using the proposed more refined modeling approach. A 70 percent reduction in predicted values was calculated in this example.

# Haze Screening



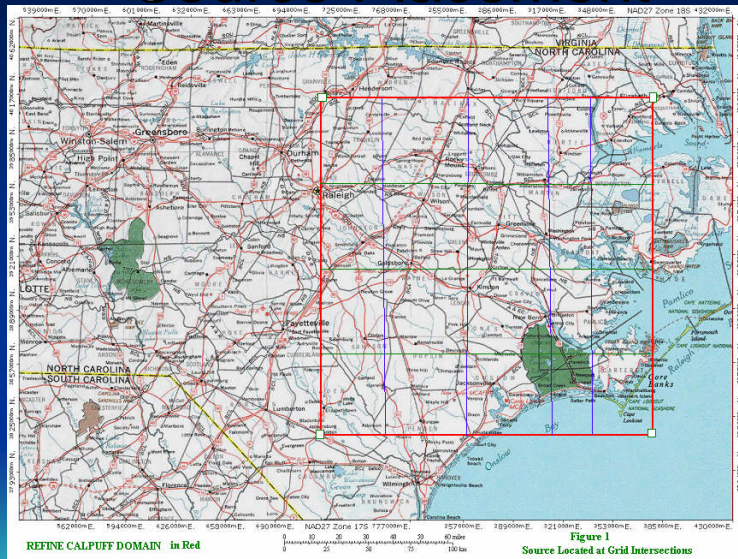
Another analysis was conducted with respect to using a screening approach for BART exemption modeling.

# Refine Grid (Domain)



This slide displays the location of the meteorological stations used for all refined modeling used in this presentation.

# Source Placement



As this slide states an example source was located at the intersections of the blue lines. The red line is the refined modeling domain. A one year period was modeled in a screening and refine mode.


# Screen/Refine Results

**EXAMPLE COMPARING SCREENING/REFINED CALPUFF MODELING FOR COASTAL CLASS I AREA**  
**Partial Demonstration that CALPUFF Screening is Conservative in Simple Wind and Terrain Situations**  
**Refined CALPUFF Used a 200x200 km Domain with 4 km Grid Spacing Near Swan Quarter**  
**Source Parameters: 550 Ton/Year Source (250 T/Yr SO<sub>2</sub> & 250 T/Yr NO<sub>x</sub> & 50 T/Yr PM) with 200 foot Stack**  
**Source Placed East of Class I Area @ 20 Different Locations in Domain**  
**Meteorological Input: 1989 Meteorological Data from 12 Surface & Precipitation Stations (GSO Used for Screening)**  
**Including 6 Upper Air Sites. No MM Data.**

Dv = Deciview

Dis. North (km)	25 km Slice Downwind				50 km Slice Downwind				100 km Slice Downwind				150 km Slice Downwind			
	Dis. (km)	Ring Dv	Refine Dv	Over-Prediction	Dis. (km)	Ring Dv	Refine Dv	Over-Prediction	Dis. (km)	Ring Dv	Refine Dv	Over-Prediction	Dis. (km)	Ring Dv	Refine Dv	Over-Prediction
100	103	0.371	0.1	3.71	111.8	0.351	0.099	3.55	141.4	0.301	0.06	5.02	180.3	0.262	0.052	5.04
50	55.9	0.528	0.159	3.32	70.7	0.482	0.101	4.77	111.8	0.351	0.045	7.80	158.1	0.299	0.05	5.98
0	25	0.625	0.178	3.51	50	0.538	0.18	2.99	100	0.379	0.112	3.38	150	0.276	0.051	5.41
-50	55.9	0.528	0.449	1.18	70.7	0.482	0.233	2.07	111.8	0.351	0.164	2.14	158.1	0.299	0.104	2.88
-100	103	0.371	0.179	2.07	111.8	0.351	0.162	2.17	141.4	0.301	0.095	3.17	180.3	0.262	0.085	3.08
Average		0.485	0.213	2.76		0.441	0.155	2.85		0.3366	0.0952	3.54		0.2796	0.068	4.09

Conclusion: For Relatively Flat Terrain Near Coastal Class I Areas CALPUFF Screen Provides an Adequate Margin of Safety. Safety Factor Increases with Increasing Distance from Class I Area.  
 May not be Applicable to Western North Carolina Class I Areas where Terrain is a Factor. Further Analysis Required.  
 CALPUFF Screen for Coastal Class I Areas Provides a High Degree of Certainty for Selecting BART Sources.



The results from the analysis are shown on the slide along with conclusions.

Thank you for your time.

Steve Lund