NATURAL HAZE LEVELS SENSITIVITY ASSESSMENT

2. Critical Evaluation of Current Approach for Estimating Natural Conditions

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Default Approach to Estimating Natural Haze Levels

- Use default annual natural concentrations of PM components, as estimated by Trijonis[1] and adjusted by the EPA,[2] in the IMPROVE equation
- Apply annual-average climatologically-representative f(RH) for each Class I area to account for sulfate and nitrate particle growth due to humidity.

[1] Characterization of Natural Background Aerosol Concentrations, by John C. Trijonis. In *Acidic Deposition: State of Science and Technology*, Report 24, Visibility:Existing and Historical Conditions -- Causes and Effects. National Acid Precipitation Assessment Program, Washington, DC, 1990.
[2] *Guidance for Estimating Natural Visibility Conditions Under the Regional Haze Rule. EPA-454/B-03-005. September 2003.*

Default Estimates of Concentrations Under Natural Conditions

Component	**Average Concentration E/W (µg/m^3)**	**Trijonis' Error Factor**	**Dry Extinct. Efficiency (m^2/g)**	**Dry PM Extinction (Mm^{-1})**
Ammonium sulfate	0.23/0.12	2	3	0.69/0.36
Ammonium nitrate	0.1	2	3	0.3
Organics (POM)	1.4/0.47	2	4	5.6/1.88
Elemental carbon	0.02	2 - 3	10	0.2
Fine soil	0.5	1.5 - 2	1	0.5
Coarse matter	3.0	1.5 - 2	0.6	1.8
Sum	**Fine 2.25/1.21** **Coarse 3.0**			**9.09/5.04**

Default Approach (cont'd)

- Add 10 Mm^{-1} for Rayleigh scattering to get annual b_{ext}
- Calculate annual haze index in deciviews
- Deduce haze indices for averages of the 20% worst/best days by the statistical procedure of Ames and Malm[3]
- Results for every Class I area are in EPA's natural conditions guidance

[3] Recommendations for Natural Condition Deciview Variability: An Examination of IMPROVE Data Frequency Distributions, by Rodger B. Ames and William C. Malm. In Proceedings (CD-ROM) of the A&WMA specialty conference on Regional Haze and Global Radiation Balance, Bend, Oregon, 2-5 October 2001.

How Did Trijonis Get His Default Concentrations?

- **Limited base of data interpreted with a healthy dose of intuition!**
- (Ammonium) sulfate --
  - East -- 0.23 μg/m^3 *: NAPAP emissions inventory estimated that 3% of sulfur emissions in E are from natural sources -- 3% of measured concentrations in E of 5 to 10 μg/m^3 is 0.15 to 0.30 μg/m^3.
  - West -- 0.12 μg/m^3 : In addition to above, considered rural measurements in southern hemisphere and background estimates from central Alaska.

* Numbers on these slides are values in current EPA guidance, some of which were adjusted from Trijonis' values to make them consistent with IMPROVE conventions.

Trijonis' Default Concentrations (2)

- Ammonium nitrate
  - East &West -- 0.10 µg/m^3: NAPAP emissions inventory indicated that natural NO_x emissions are about 4.5 times as great (on a molar basis) as those of sulfur -- but had to factor in that nitrate production should be relatively less than that of sulfate. Nitrate levels in tropical forests are about 0.1 µg/m^3.

Trijonis' Default Concentrations (3)

- Organics (POM)
  - East -- 1.4 $\mu g/m^3$: Assumed "arbitrarily" that 1/3 of the average measured concentration of 4 $\mu g/m^3$ is natural. Assumption supported (?) by measurements of organic aerosol in remote areas, which suggest background concentrations of 1.5 to 2.25 $\mu g/m^3$
  - West -- 0.47: Several speciation and carbon dating studies suggested organic background ranging from 0.1-0.2 $\mu g/m^3$ to 1-1.5 $\mu g/m^3$

Trijonis' Default Concentrations (4)

- Elemental carbon (LAC)
  - East & West -- 0.02 $\mu g/m^3$: NAPAP emissions inventory combined with estimate of fraction that is EC gives result that 2.8% of emissions are due to wildfires and prescribed burning; ambient EC concentrations average 0.2 to 1.0 $\mu g/m^3$. EC concentrations at extremely remote locations are very minute -- 0.003 to 0.04 $\mu g/m^3$

Trijonis' Default Concentrations (5)

- Fine soil
  - East & West -- 0.50 μg/m^3: "Arbitrarily" assumed that half of measured concentrations, of 1 μg/m^3 in both the E and W, are natural
- Coarse mass
  - East & West -- 3 μg/m^3: Lower end of range of coarse mass measurements at "remote" sites in the U.S.

Trijonis' Default Concentrations (6)

- Now we see why his error factors are so large (although possibly some should have been even larger when averaged over such large areas of the country)
- "Error Factor" is not defined, and is used interchangeably with "Uncertainty". Does it represent bounds for all possible values (save a few special outliers) or does it represent some statistical measure of uncertainty? [More later]

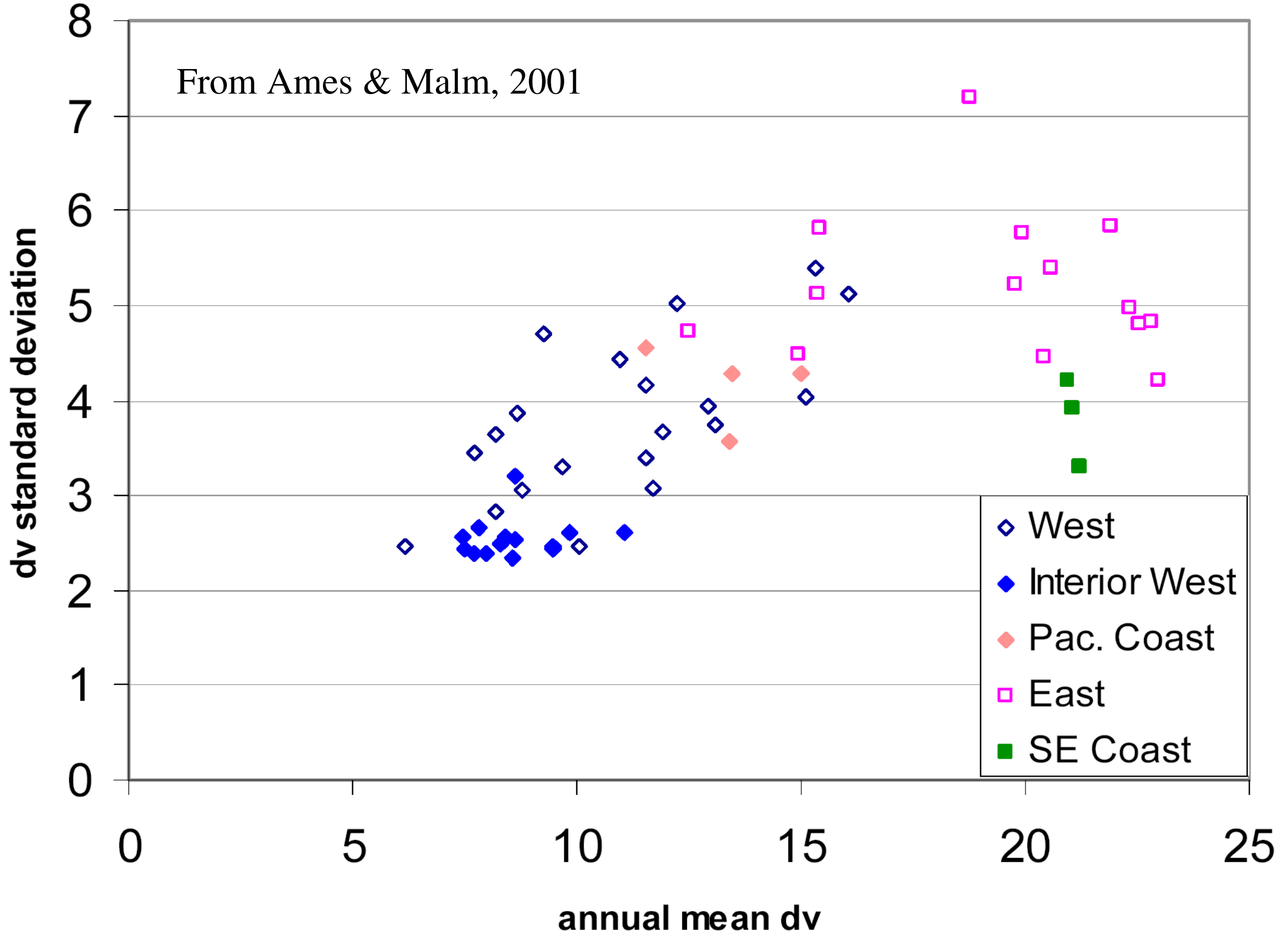
Note!

- Trijonis defined "West" as the "mountain/desert regions of the western United States."
- EPA's default approach takes "West" to include all states west of the first tier of states west of the Mississippi River, including Alaska and Hawaii.

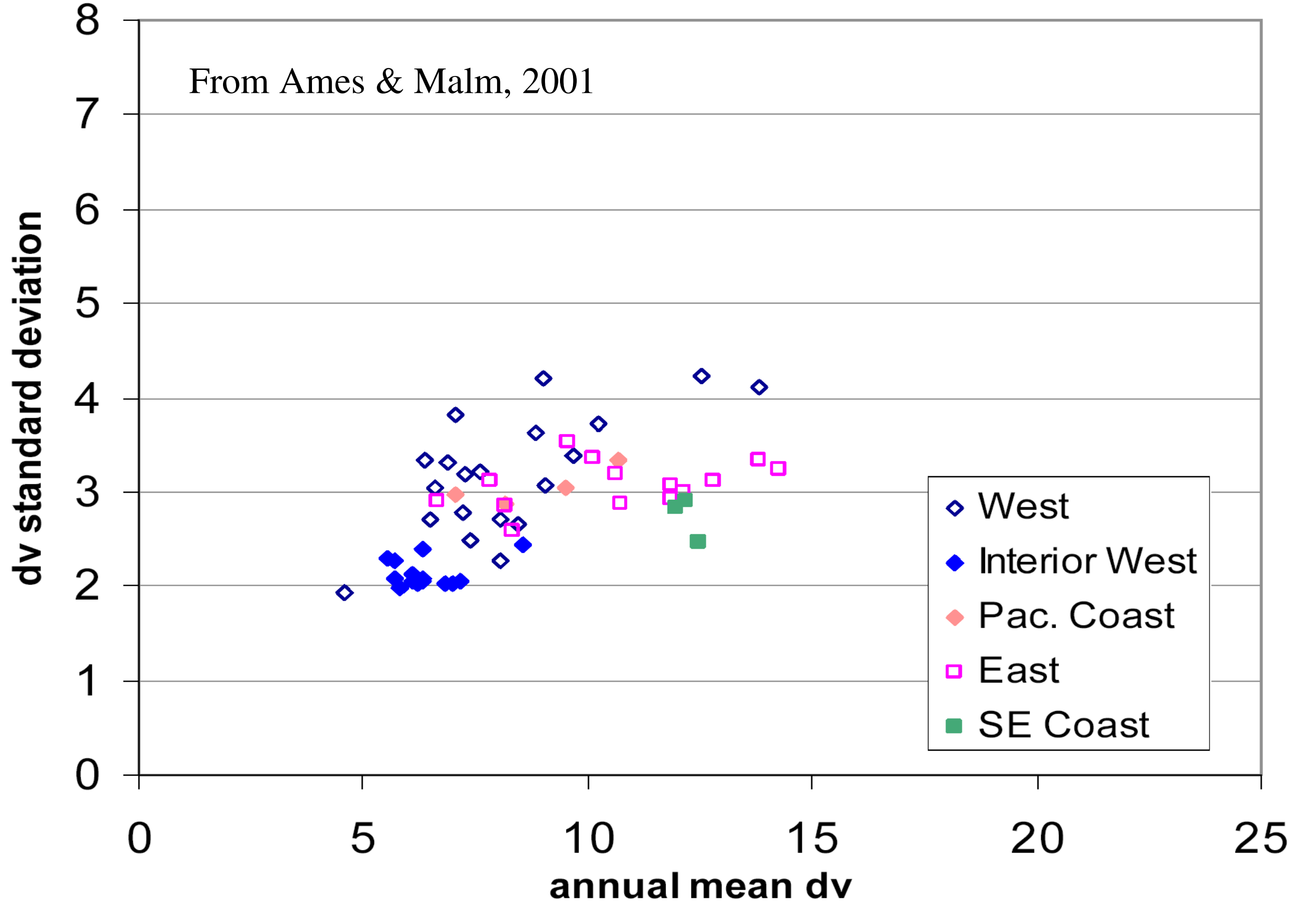
Estimating Average 20% Worst/Best Conditions

- Ames and Malm calculated standard deviations of haze indices using IMPROVE data for 1995-1999
- They then scaled sulfate and nitrate concentrations at each site to achieve default annual averages and recalculated standard deviations of haze indices
  - Concentrations of organics, LAC, soil, and coarse matter were not rolled back because of probable large natural components
- Plots on next two slides show that standard deviations differ between climatological/geographic subregions

Current Standard Deviations vs. Means of Haze Indices



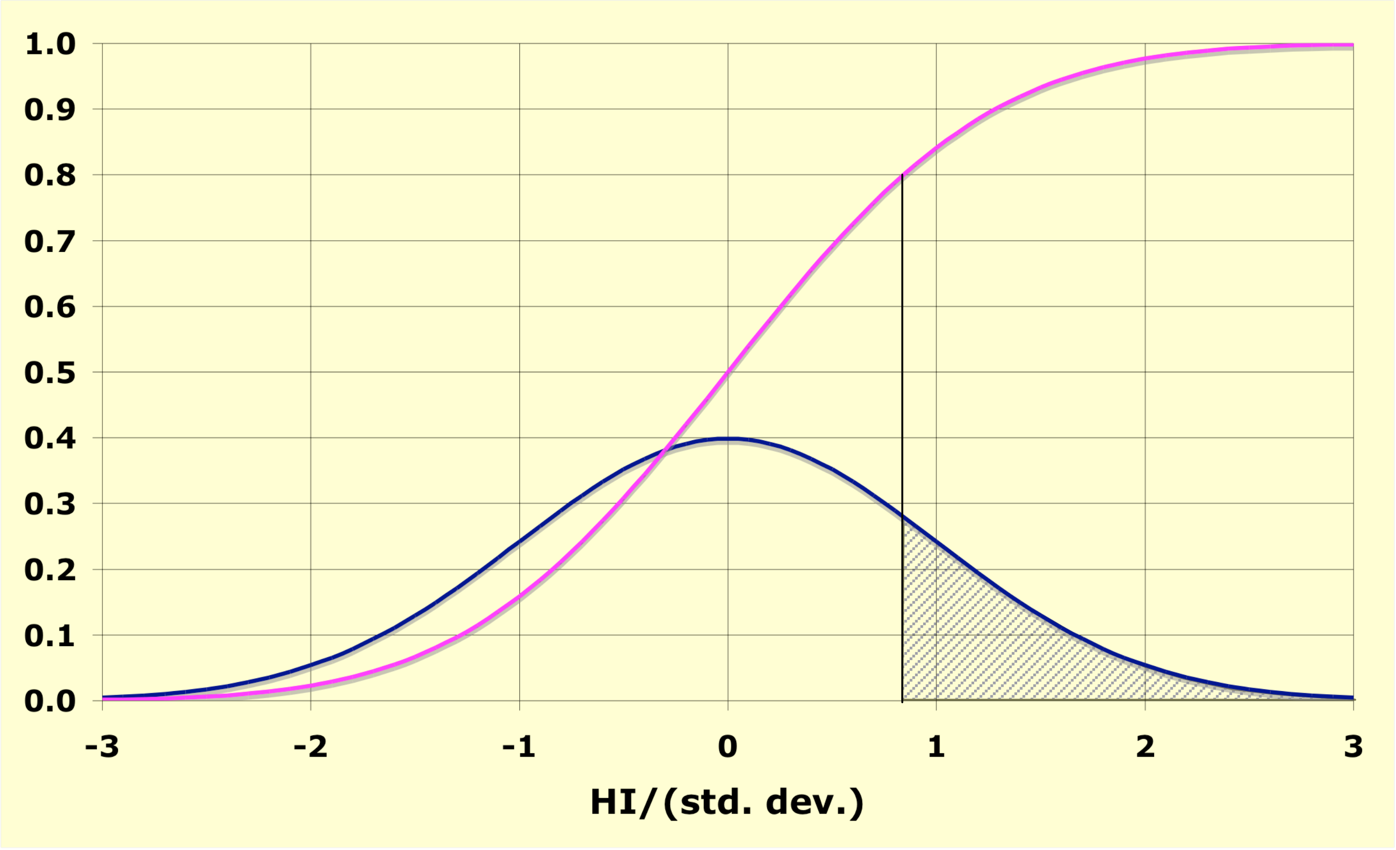
“Natural” Standard Deviations vs. Means of Haze Indices



Estimates of Standard Deviations (σ) Under Natural Conditions

- East
  - SE Coast σ ranges from 2.5 to 3.0 dv
  - σ for rest of E ranges from 2.6 to 3.6 dv
- West
  - σ for Interior West mostly around 2.0 to 2.1 dv, with some values up to 2.4
  - σ for Pacific Coast ranges from 3.0 to 3.4 dv
  - σ for rest of W ranges from 1.9 to 4.3 dv
- Ames and Malm chose 3 dv for East and 2 dv for **interior** West. However, EPA's default approach uses 2 dv for **all** of West including Alaska & Hawaii.

Assume Normal Distribution and Use σ To Estimate Worst/Best 20% Natural Concentrations



Determine HI for Worst 20% of Days

- Ames & Malm assumed 90th %ile represented average of worst 20% of days
- For normal distribution, 90th %ile is at 1.28 σ, so they said average haze on worst 20% of days is
  $HI(W20) = HI(Ann.\ Avg.) + 1.28\ \sigma$
- For best 20% of days, used ($-$ 1.28 σ)

Determine HI for Worst 20% of Days (cont'd)

- So, assuming σ = 3 dv in East and 2 dv in West, the default estimates for the 20% worst and best natural days are
  - East:
    HI(W20%/B20%) = HI(Ann. Avg.) ± 3.84 dv
  - West:
    HI(W20%/B20%) = HI(Ann. Avg.) ± 2.56 dv

How Certain are the Default Natural Condition Estimates?

- Trijonis' "error factor" (EF) can be viewed as a power of the geometric standard deviation σ_g in an assumed log-normal distribution of concentrations whose geometric mean is the default concentration value C_d
- If we assume $EF = \sigma_g^2$, then 95.5% of all values lie between C_d/EF and $C_d \bullet EF$
- If we assume $EF = \sigma_g^3$, then 99.7% of all values lie between C_d/EF and $C_d \bullet EF$

Uncertainty in Trijonis' Default Mass Estimates

	EAST Nominal = 5.25 μg/m^3	**WEST** Nominal = 4.21μg/m^3
Larger EF & σ_g= (EF)$^{1/2}$	4.27-6.64 μg/m^3 (nominal +26%/-19%)	3.31-5.49 μg/m^3 (nominal +30%/-21%)
Smaller EF & σ_g= (EF)$^{1/3}$	4.77-5.82μg/m^3 (nominal +11%/-9%)	3.81-4.67 μg/m^3 (nominal +11%/-9%)

Uncertainty in Default Dry Particle Non-Rayleigh b_{ext} Estimates

	EAST Nominal = 9.09 Mm^{-1}	**WEST** Nominal = 5.04 Mm^{-1}
Larger EF & $\sigma_g = (UF)^{1/2}$	7.34-11.56 Mm^{-1} (nominal +27%/-19%)	4.25-6.16 Mm-1 (nominal +22%/-16%)
Smaller EF & $\sigma_g = (UF)^{1/3}$	7.90-10.58 Mm^{-1} (nominal +16%/-13%)	4.57-5.61 Mm^{-1} (nominal +11%/-9%)

Summary Concerning Default Errors

- Error in total dry mass could be as much as +26%/-21%, or as little as +11%/-9%
  - Higher error % is a bit more in W, but difference between E and W is not great
- Error in dry non-Rayleigh extinction could be as much as +27%/-19%, or as little as +11%/-9%
  - Higher error % is a bit more in E this time, but difference between E and W is not great
  - Adding in effects of increased humidity would not greatly change these bounds

Other Sources of Error

- Assumption that 90%ile represents average of top 20% is wrong. For a normal distribution the 92%ile is the correct one
  - Changes 1.28 factor to 1.42 and thus increases the worst 20% days haze by 0.42 (i.e., 3 x 0.14) in the East and 0.28 in the West
  - Best 20% days haze is reduced by the same amounts

Other Sources of Error (2)

- It seems reasonable to assume that non-Rayleigh b_{ext} is log-normally distributed, because pollutant concentrations typically are approximately log-normally distributed. This might suggest that its logarithm, the HI, would be normally distributed.
- But, because a constant 10 Mm^{-1} is added to non-Rayleigh b_{ext}, the distribution of HI is **not** normally distributed. The distribution is particularly skewed under natural conditions, when particle b_{ext} is close to the 10 Mm^{-1} add-on.

Other Sources of Error (2a)

- ==> The assumptions used to derive the worst and best 20% HI are not correct. Also, the best and worst 20% are at different distances from the mean.

Other Sources of Error (3)

- Assigning σ = 3 dv to the East and 2 dv to the entire West results in some biases
  - Average σ for the West outside the interior should be around 3 dv, rather than 2 dv
  - There is large variation (σ ranges from 1.9 to 4.3 in the non-interior West), so additional geographic/climatological grouping would be desirable.
  - SE Coast might deserve its own value of σ

Recap

- Default concentrations values are inspired guesses by John Trijonis.
- If Trijonis' error factors were intended to encompass virtually all possible annual average values, then the impact of that uncertainty on PM mass and non-Rayleigh extinction is typically between 10 and 30% (roughly 0.5 to 2 dv after Rayleigh is added)

Recap (cont'd)

- Errors and simplifications in the Ames & Malm process for estimating best and worst 20% natural conditions from default annual means have as-yet undetermined, but potentially large, impacts on estimates of best and worst conditions. Because the actual distribution is skewed, the current estimates of best and worst 20% conditions are likely to be low.

Recap (Cont'd)

- All of these uncertainties could have a larger impact on estimates of glide path than might result from "refining" of individual component concentrations. (This is not to discourage such refining, but to increase awareness of where the important uncertainties lie.)

Recommendations

- Refine the default concentrations
  - Divide up country into more regions, particularly the West, to reflect different geography and climate
  - The results of this project, taking advantage of the enhanced IMPROVE network, will give guidance for choosing subregions and will suggest default concentrations for those subregions
- Revisit the Ames and Malm approach
  - Review statistical assumptions
  - For purposes of choosing σ, consider breaking up the country into more regions than just East and West

Bottom Line

- Break up the country into more regions!