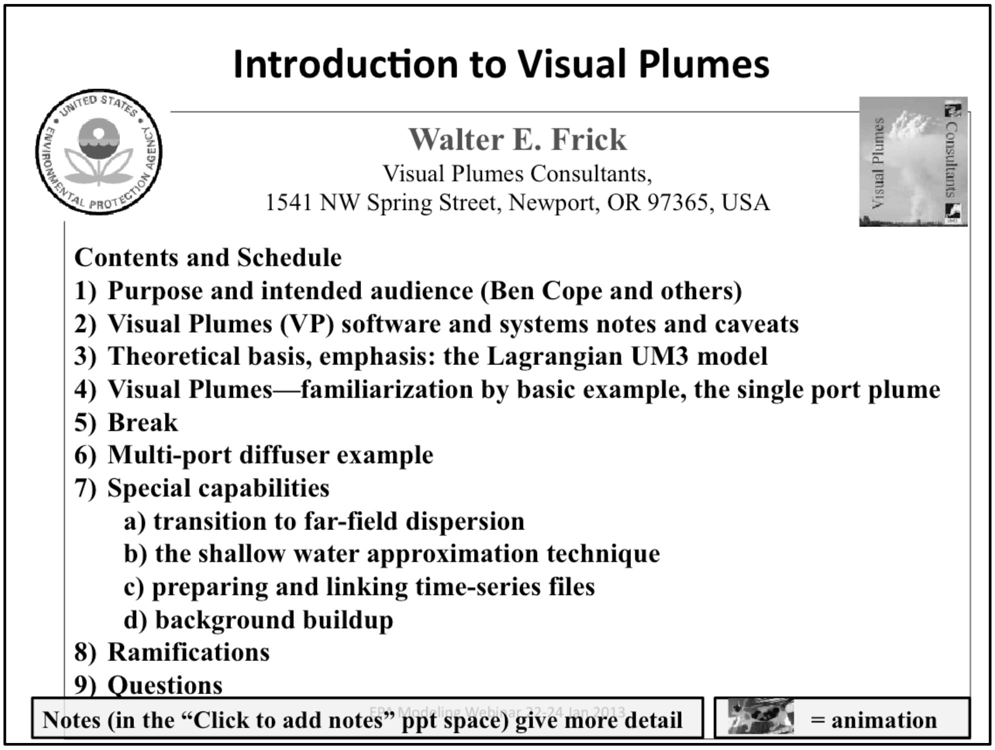


To help re-establish context for anyone involved subsequent future study of this presentation:

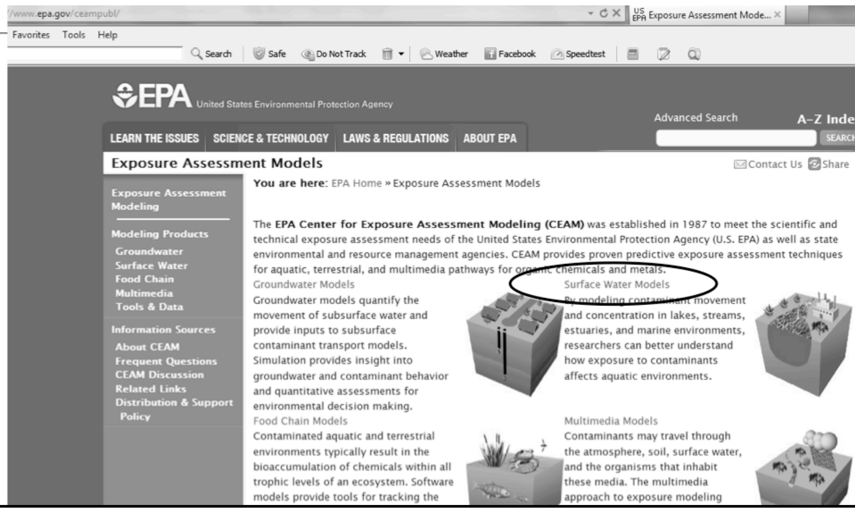
Purpose and intended audience

The purpose of these workshops is to help EPA's ORD, Regions, and headquarters, as well as tribes, states, and other federal agencies build capacity in mixing zone modeling. The workshops will "demystify" mixing zone studies and provide participants context to understand them. The overarching goals of the workshops are to help participants develop and maintain basic capacity in mixing zone assessment and modeling, train staff on what to look for when reviewing a mixing zone study, discuss current trends in mixing zone assessment and modeling, and encourage collaboration and consistency between EPA regions and state partners with regards to mixing zone assessment and modeling. Specifically, the workshop will train participants on:

1. **The basic science behind the mixing of effluent in the environment.**
2. **What to look for when reviewing mixing zone studies.**
3. **How various assumptions affect dilution results.**
4. **How to interpret mixing zone modeling results.**

Software and systems notes and caveats

Visual Plumes, a model platform available through EPA:
CEAM at Athens, Georgia: http://www.epa.gov/ceampubl/
Manual: http://www.epa.gov/ceampubl/swater/vplume/VP-Manual.pdf
Software and update: http://www.epa.gov/ceampubl/swater/vplume/index.html



Software and systems: CEAM website

ter/index.html | Surface Water | Exposure As...

Search | Safe | Do Not Track | Weather | Facebook | Speedtest

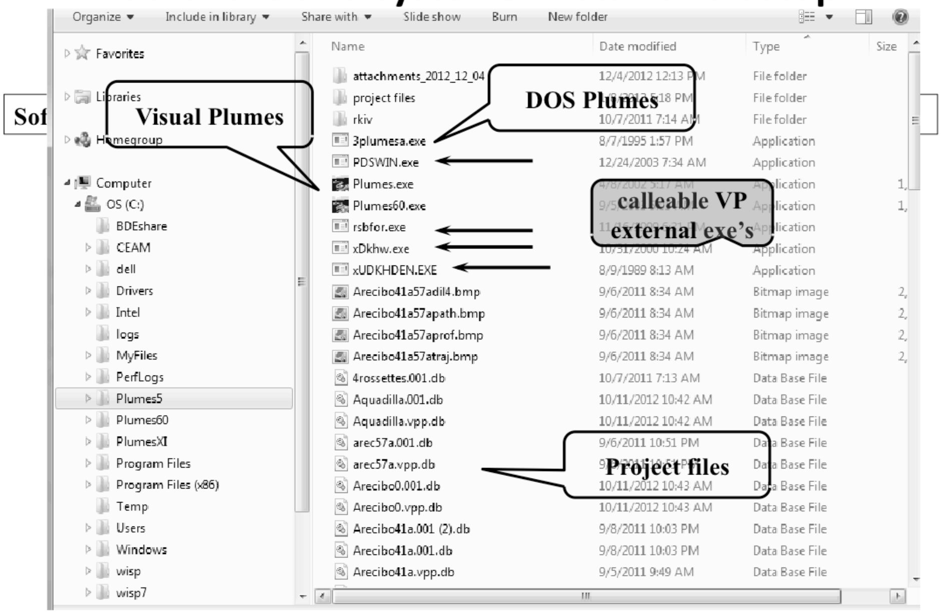
Software and update: http://www.epa.gov/ceampubl/swater/vplume/index.html

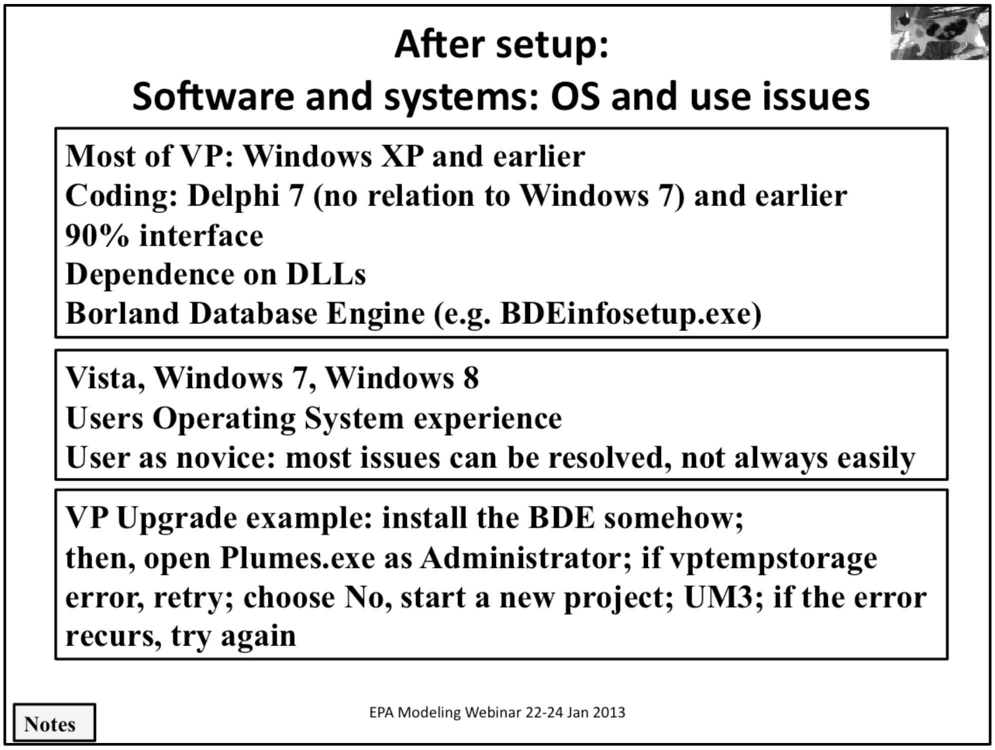
		source(s), surface water, test/analysis, TMDL related	Support Center ... on 4)
RUSLE2	Win 98, NT, 2000, XP	rill, interrill, erosion, sediment, overland flow, climate, soil, topography, land use	USDA Agricultural Research Service
SERAFM	MS-Excel 2003	serafm, exposure, assessment, mecury, hg, surface water, pond, stream, river	CEAM
SWMM	Win 98, NT, ME, 2000, XP	aquatic biol... assessment, combined sewer, community, discharge, environmental effects, metals, NPS related, NPDES, ... streams, surface water, test/analysis, TMDL related	Water Supply & Water Resources Division (NRMRL)
Virtual Beach	MS Windows	surface water, water bodies, beach, pathogen predictor, multiple linear regression, MLR, best-fit model	CEAM
Visual Plumes	Win 98, NT, 2000, XP	surface, water, jet, plume, model, quality, contaminant, TMDL	CEAM
WASP	Win 95, 98, ME, 2000, XP	aquatic biology, assessment, compliance, discharge, environmental effects, hydrology, metals, NPS related, NPDES, point source(s), surface water, test/analysis, TMDL related	Watershed & Water Quality Modeling Tech Support Center (ERD/EPA Region 4)
WHATIF	Win XP(SP2)	watershed, health, fish, habitat, macro-invertebrate, biodiversity, BASS, biomass, biota, aquatic ecosystem, MAHA, CVI, hydraulic, bankfull, flow, restoration, foodweb, mercury, PCB, dioxin	CEAM

Virtual Beach
Authors of Ver. 1 (Research)
Frick and Ge

CEAM: Home | Products | Information | Archived Models

Software and systems: install and setup



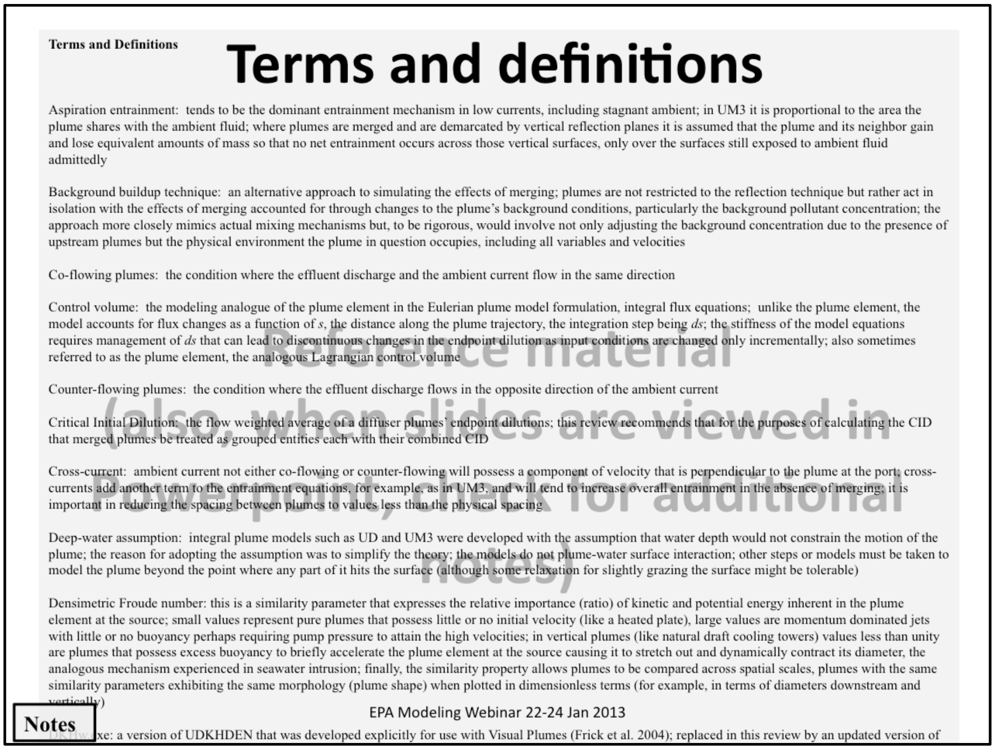


Visual Plumes was developed in Windows XP and earlier versions of Microsoft Windows Operating System (OS). Beginning with Windows Vista it became difficult to compile VP (convert the computer code into executable language) VP. At this time VP is compiled on a Windows 7 machine through a Windows XP emulator. The computer language is Delphi 7 (a superset of Pascal) .

VP uses the Borland Database Engine (BDE), software that supports the handling of the diffuser and ambient tables used in VP. Various other software applications also use the BDE engine. If the BDE engine is installed on any given computer (due to other prior application installations) then VP works directly after installing VP. If not, it is necessary to find a application which will install the BDE components. One such application is called BDEinfosetup.exe. While VPC owns the file, it is not clear that VPC can legally distribute it. Therefore, VPC depends on the user to acquire the necessary software. It may be possible that EPA could bundled the application with VP on the CEAM website.

Users should also be aware that there are a few known bugs in VP that have not been fully identified and corrected. In some instances these are initialization problems that can be overcome by repeating the action again. In any case, the user is invited to report bugs so that future versions of VP may be corrected.

VPC seeks to maintain VP in the public domain and offers to update older versions of VP for inclusion as updates on the EPA CEAM website.



This slide is intended as a reference for future study

United States Environmental Protection Agency | National Exposure Research Laboratory Research Triangle Park NC 27709 | EPA/600/R-03/025 March 2003

Dilution Models for Effluent Discharges

4th Edition
(Visual Plumes)

Recommended Tutorial

Get the VP manual!! Tutorial starts on page 4.7 to 4.20

by

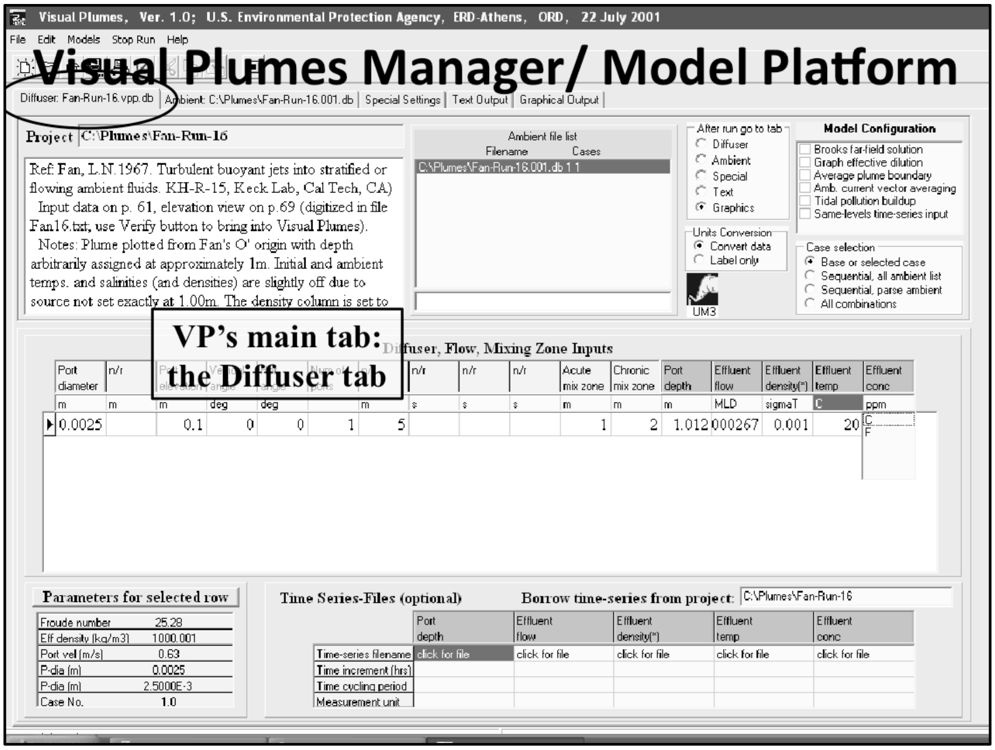
W.E. Frick[1], P.J.W. Roberts[2], L.R. Davis[3], J. Keyes[4], D.J. Baumgartner[5], K.P. George[6]

[1] Ecosystems Research Div., NERL, USEPA, Athens, Georgia 30605-2700
[2] Georgia Institute of Technology, Atlanta, Georgia 30332
[3] CH2M HILL, Corvallis, Oregon 97330
[4] Brown and Caldwell, Atlanta, Georgia 30346
[5] University of Arizona, Tucson, Arizona 98706
[6] Alaska Department of Environmental Conservation, Juneau, Alaska 99801

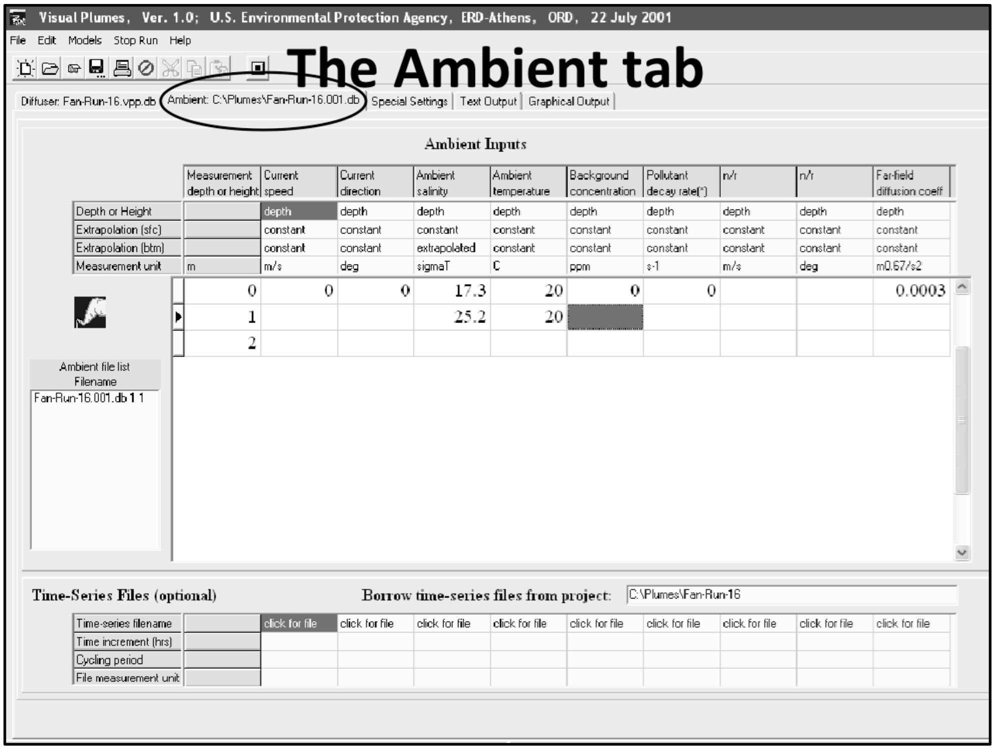
4 March 2003

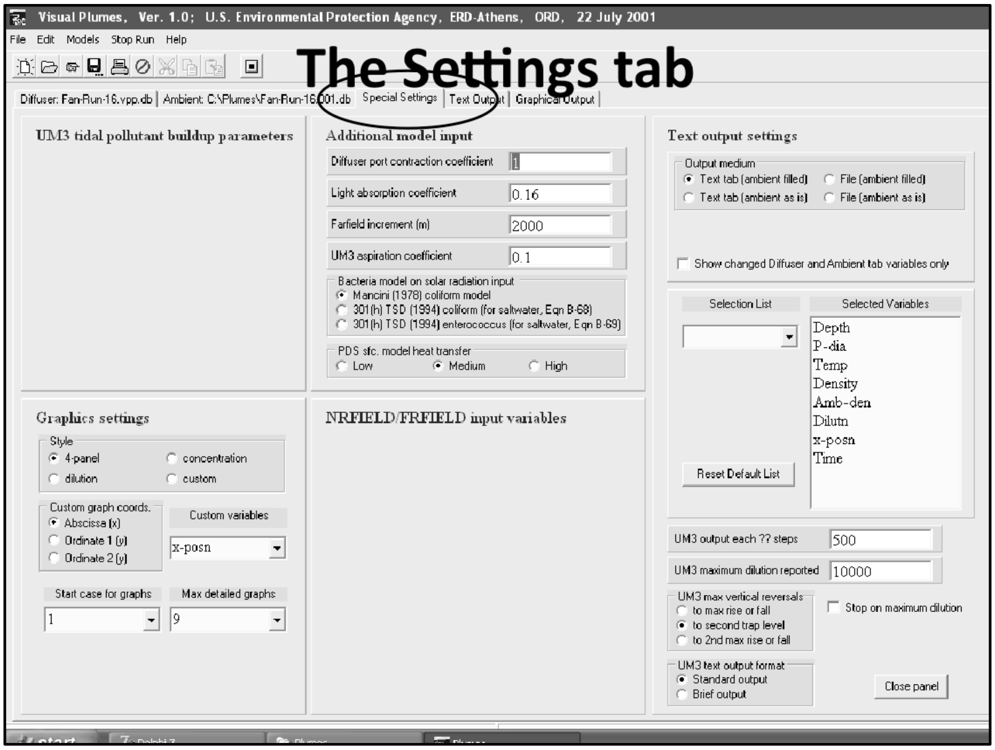
Ecosystems Research Division, NERL, ORD
U.S. Environmental Protection Agency
960 College Station Road
Athens, Georgia 30605-2700

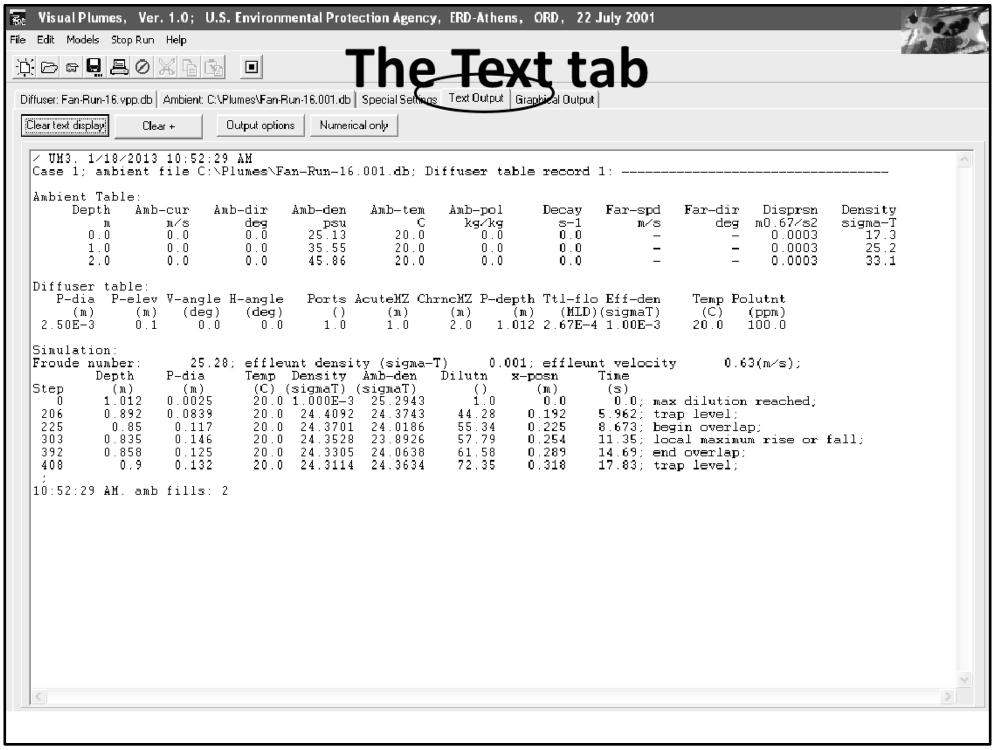
Visual Plumes Manager/ Model Platform



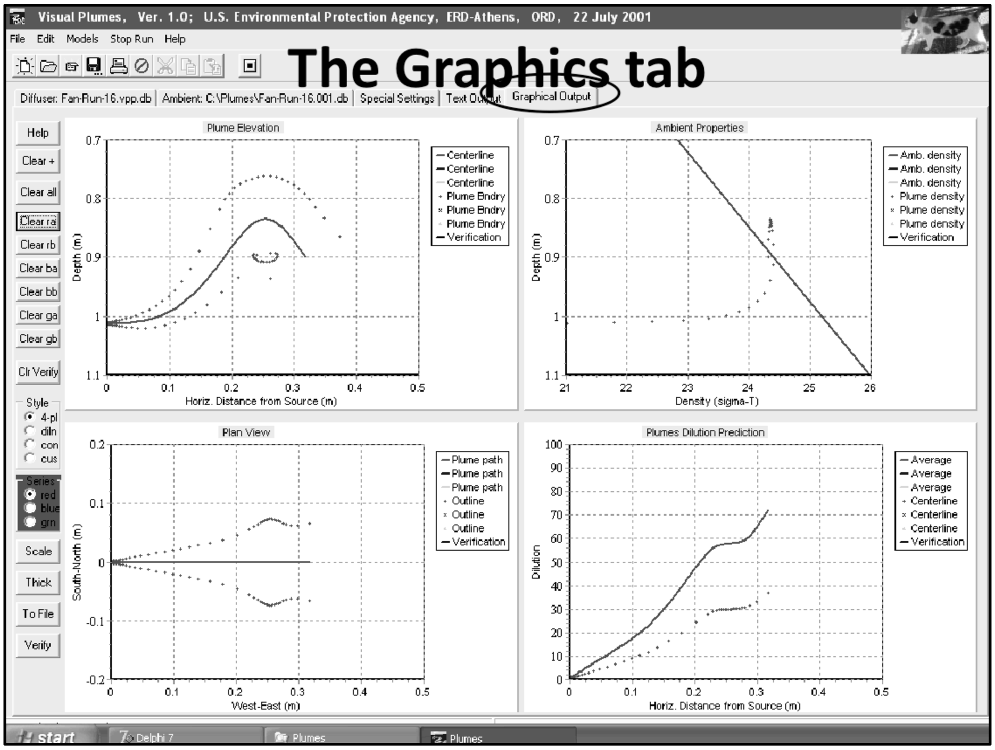
The Ambient tab



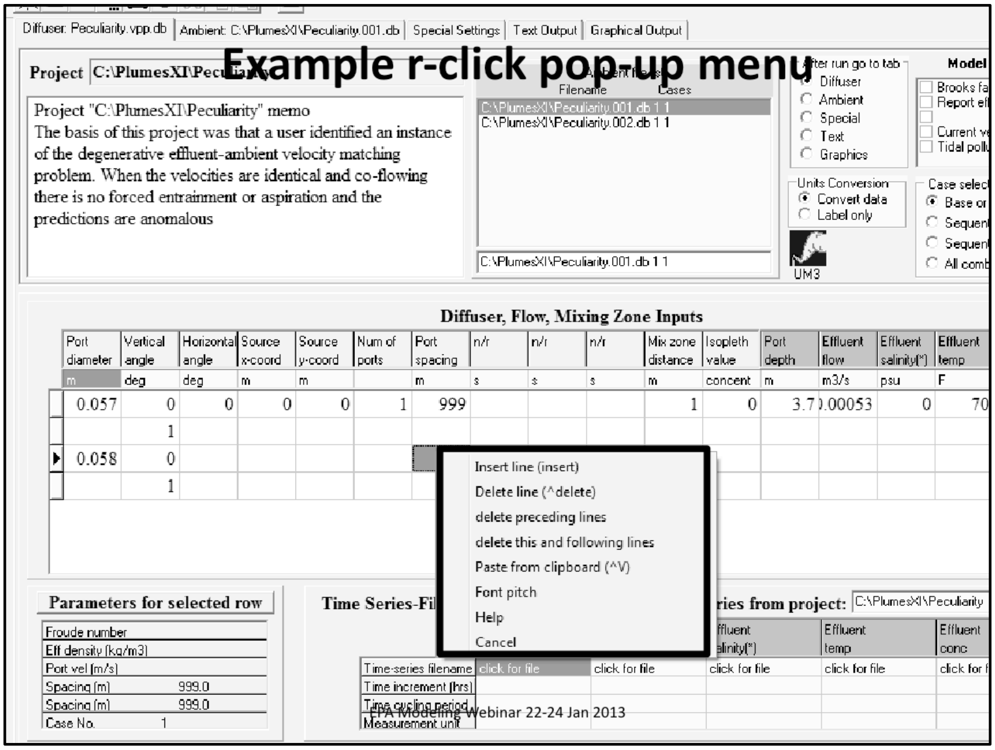

The Settings tab
Visual Plumes, Ver. 1.0; U.S. Environmental Protection Agency, ERD-Athens, ORD, 22 July 2001
File Edit Models Stop Run Help
Diffuser: Fan-Run-16.vpp.db
Ambient: C:\Plumes\Fan-Run-16.001.db
Special Settings
Text Output
Graphical Output
UM3 tidal pollutant buildup parameters
Additional model input
Diffuser port contraction coefficient
1
Light absorption coefficient
0.16
Farfield increment (m)
2000
UM3 aspiration coefficient
0.1
Bacteria model on solar radiation input
Mancini (1978) coliform model
301(h) TSD (1994) coliform (for saltwater, Eqn B-68)
301(h) TSD (1994) enterococcus (for saltwater, Eqn B-69)
PDS sfc. model heat transfer
Low
Medium
High
Text output settings
Output medium
Text tab (ambient filled)
File (ambient filled)
Text tab (ambient as is)
File (ambient as is)
Show changed Diffuser and Ambient tab variables only
Selection List
Selected Variables
Depth
P-dia
Temp
Density
Amb-den
Dilutn
x-posn
Time
Reset Default List
Graphics settings
Style
4-panel
concentration
dilution
custom
Custom graph coords.
Abscissa (x)
Ordinate 1 (y)
Ordinate 2 (y)
Custom variables
x-posn
Start case for graphs
1
Max detailed graphs
9
NRFIELD/FRFIELD input variables
UM3 output each ?? steps
500
UM3 maximum dilution reported
10000
UM3 max vertical reversals
to max rise or fall
to second trap level
to 2nd max rise or fall
Stop on maximum dilution
UM3 text output format
Standard output
Brief output
Close panel

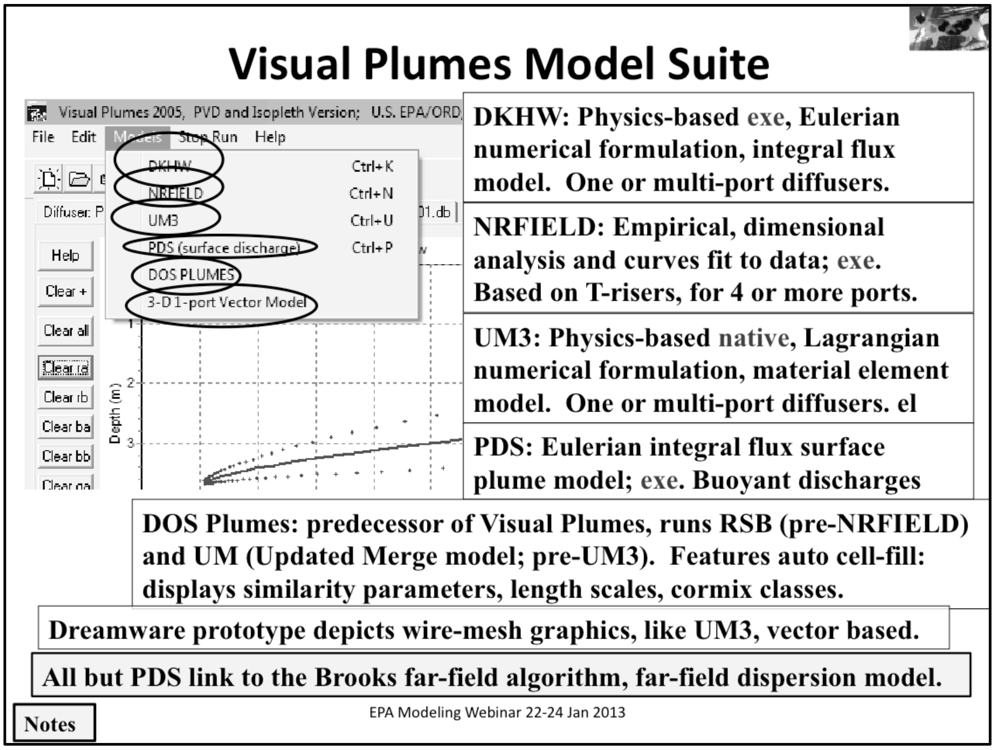


Visual Plumes, Ver. 1.0; U.S. Environmental Protection Agency, ERD-Athens, ORD, 22 July 2001
File Edit Models Stop Run Help
The Text tab
Diffuser: Fan-Run-16.vpp.db
Ambient: C:\Plumes\Fan-Run-16.001.db
Special Settings
Text Output
Graphical Output
Clear text display
Clear +
Output options
Numerical only
/ UM3. 1/18/2013 10:52:29 AM
Case 1; ambient file C:\Plumes\Fan-Run-16.001.db; Diffuser table record 1: ------------------------------------
Ambient Table:
Depth Amb-cur Amb-dir Amb-den Amb-tem Amb-pol Decay Far-spd Far-dir Disprsn Density
m m/s deg psu C kg/kg s-1 m/s deg m0.67/s2 sigma-T
0.0 0.0 0.0 25.13 20.0 0.0 0.0 - - 0.0003 17.3
1.0 0.0 0.0 35.55 20.0 0.0 0.0 - - 0.0003 25.2
2.0 0.0 0.0 45.86 20.0 0.0 0.0 - - 0.0003 33.1
Diffuser table:
P-dia P-elev V-angle H-angle Ports AcuteMZ ChrncMZ P-depth Ttl-flo Eff-den Temp Polutnt
(m) (m) (deg) (deg) () (m) (m) (m) (MLD)(sigmaT) (C) (ppm)
2.50E-3 0.1 0.0 0.0 1.0 1.0 2.0 1.012 2.67E-4 1.00E-3 20.0 100.0
Simulation:
Froude number: 25.28; effleunt density (sigma-T) 0.001; effleunt velocity 0.63(m/s);
Depth P-dia Temp Density Amb-den Dilutn x-posn Time
Step (m) (m) (C) (sigmaT) (sigmaT) () (m) (s)
0 1.012 0.0025 20.0 1.000E-3 25.2943 1.0 0.0 0.0; max dilution reached;
206 0.892 0.0839 20.0 24.4092 24.3743 44.28 0.192 5.962; trap level;
225 0.85 0.117 20.0 24.3701 24.0186 55.34 0.225 8.673; begin overlap;
303 0.835 0.146 20.0 24.3528 23.8926 57.79 0.254 11.35; local maximum rise or fall;
392 0.858 0.125 20.0 24.3305 24.0638 61.58 0.289 14.69; end overlap;
408 0.9 0.132 20.0 24.3114 24.3634 72.35 0.318 17.83; trap level;
;
10:52:29 AM. amb fills: 2


Visual Plumes, Ver. 1.0; U.S. Environmental Protection Agency, ERD-Athens, ORD, 22 July 2001
File Edit Models Stop Run Help
The Graphics tab
Diffuser: Fan-Run-16.vpp.db | Ambient: C:\Plumes\Fan-Run-16.001.db | Special Settings | Text Output | Graphical Output
Help
Clear +
Clear all
Clear ra
Clear rb
Clear ba
Clear bb
Clear ga
Clear gb
Clr Verify
Style
Scale
Thick
To File
Verify
Plume Elevation
Depth (m)
Horiz. Distance from Source (m)
Centerline
Plume Bndry
Verification
Ambient Properties
Density (sigma-T)
Amb. density
Plume density
Plan View
South-North (m)
West-East (m)
Plume path
Outline
Plumes Dilution Prediction
Dilution
Average
Centerline
start
Delphi 7
Plumes

Example r-click pop-up menu





Models such as DKHw are external executable files (exe). VP sets up their input files, calls the exe, waits for the exe to finish, then looks for the output file, reads it, and interprets the information on the text and graphics tabs. Problems can arise when the exe terminates abnormally. A file handling problem can arise when VP then reads an older output file, which is not always apparent when several consecutive cases are involved.
UM3 is a native model so called because it is coded into the VP code. This makes for easier control for the developer as model and interface are compiled together.

DKHw, NRFIELD, and UM3 are initial dilution models that can be linked with the Brooks far-field model.

What is in the names:
DKHW: Physics-based exe, Eulerian numerical formulation, integral flux model. One or multi-port diffusers.
Acronyms: Davis, Kannberg, Hirst model (w = Windows; Windows VP package). Previous versions DKHDEN, UDKHDEN (1985)…. Later compilations up to 2011….

NRFIELD: Empirical, dimensional analysis and curves fit to data; exe.
Based on T-risers, for 4 or more ports. RSB in DOS Plumes, native, Roberts, Snyder, Baumgartner model. Roberts continues work on NRFIELD currently conducting experiments with dense discharges.

UM3: Physics-based native, Lagrangian numerical formulation, material element model. One or multi-port diffusers. Merge (pre 1985), UMERGE (1985), UM (1993), UM3, Updated Merge 3-D model.

PDS: Eulerian integral flux surface plume model; exe. Buoyant discharges. Acronym: Prych, Davis, Shirazi model.

DOS Plumes: predecessor of Visual Plumes, runs RSB (pre-NRFIELD) and UM (Updated Merge model; pre-UM3). Features auto cell-fill: displays similarity parameters, length scales, cormix classes.

Dreamware prototype depicts wire-mesh graphics, like UM3, vector based.

Brooks far-field algorithm is a set of equations for estimating dispersion (dilution) in the far-field, beyond the initial dilution phase of plume development.

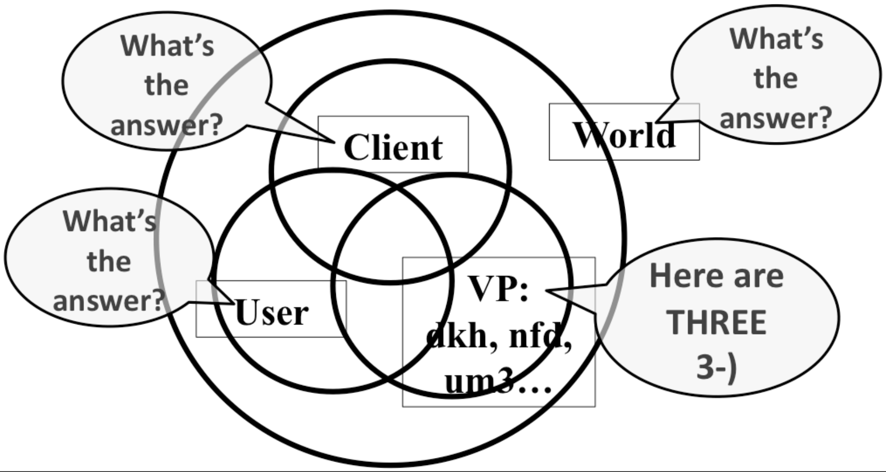
More to come

There is more to follow on empirical, hydrodynamic fluid dynamic codes, empirical, Eulerian integral flux and Lagrangian plume models.

explain
illustrate
“demystify“
touch on basic principles of physics
mathematical formulations
modeling assumptions
UM3 examples (built into Visual Plumes--not an external application)
examples chosen for simplicity, generality, and teaching potential

VP is public domain software

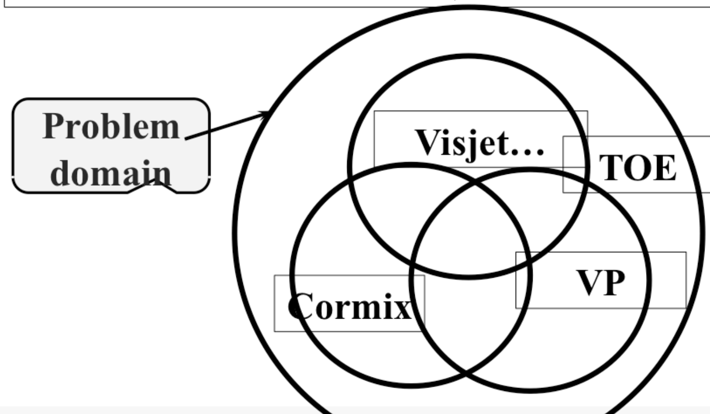
Mixing Zone analysis



Answers, yes, but no one knows it all (otherwise there'd one). MZ analysis is a partnership

The problem/model universe

Whom to believe, *best*? How feasible?



VP is public domain software
Everyone can be on the same page
Facilitates inter-model comparison & competition

Mixing effluent in environment—basic science

Before illustrating by example:

Let us take a brief tour of plume problem, physics, and prediction

Touch on:

capabilities
limitations
pitfalls
mystery and ambiguity

And end with promise:

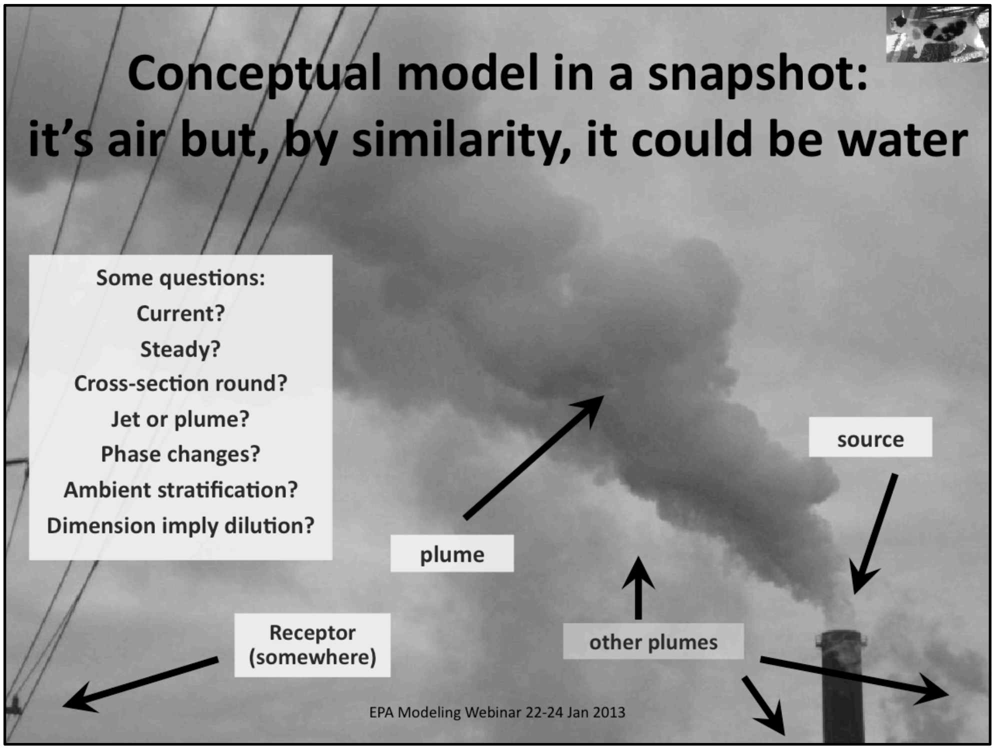
A bonus rule
Reason for optimism and confidence

Notes

EPA Modeling Webinar 22-24 Jan 2013

Visual Plumes Consultants

Even at its simplest, plume modeling guidance can appear mysterious and ambiguous. Understanding the capabilities and limitations of available models can help avoid pitfalls and confusion and promote confidence in model outputs. This section seeks to help the user demystify the art and science of plume modeling for themselves.



Conceptual model in a snapshot:
it's air but, by similarity, it could be water
Some questions:
Current?
Steady?
Cross-section round?
Jet or plume?
Phase changes?
Ambient stratification?
Dimension imply dilution?
source
plume
Receptor
(somewhere)
other plumes
EPA Modeling Webinar 22-24 Jan 2013

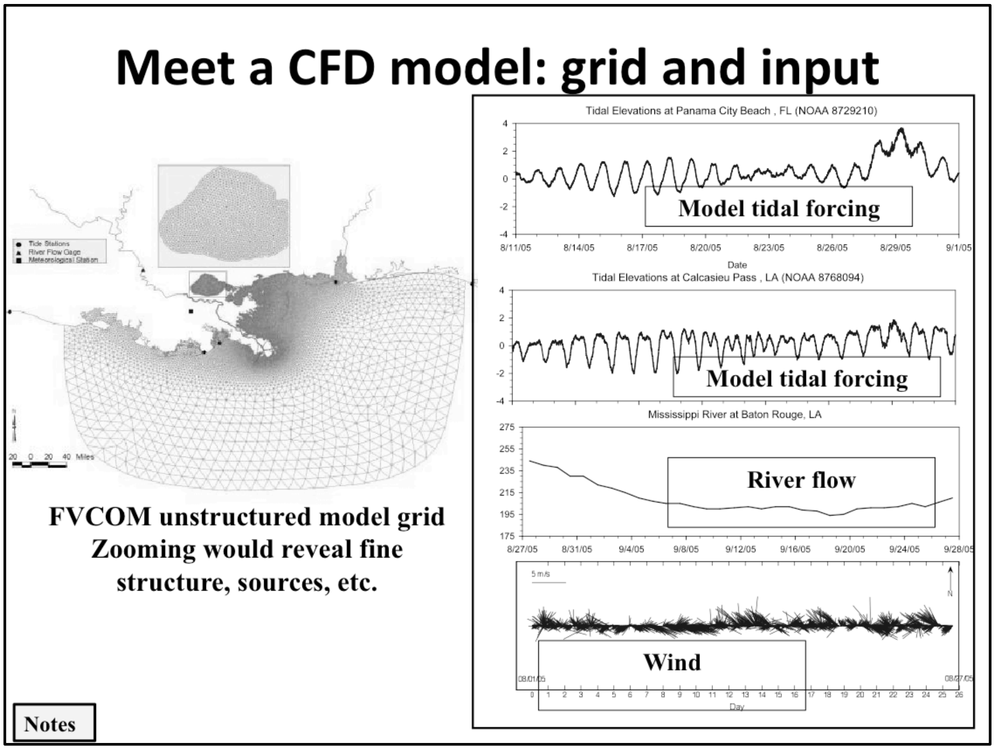
Why not the TOE for Visual Plumes?

Theory of Everything

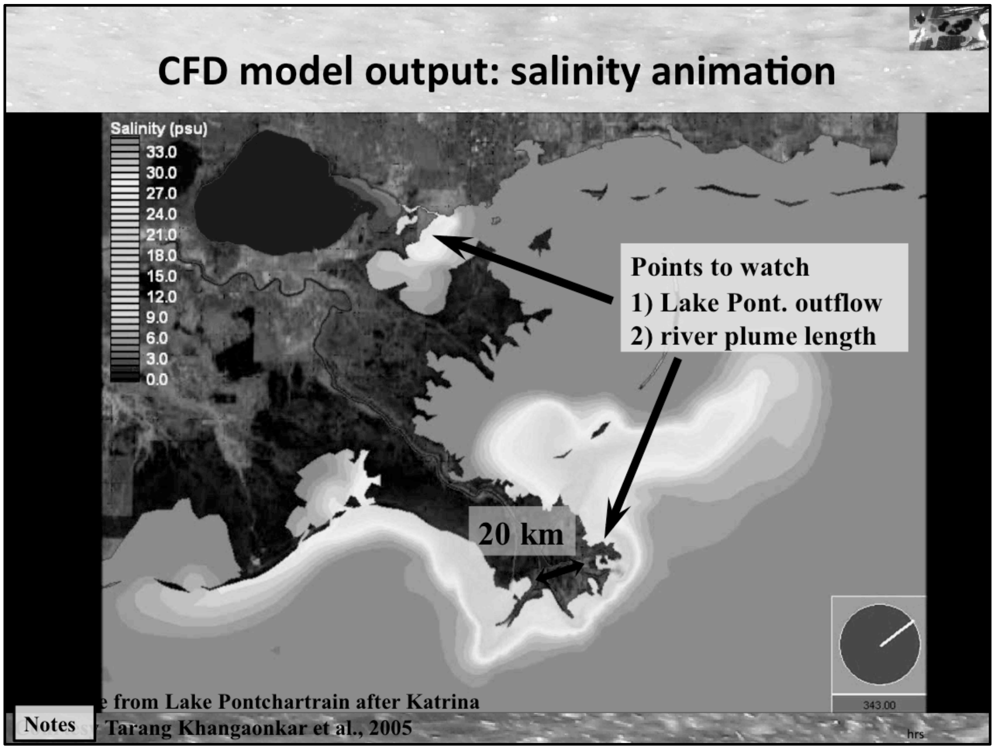
"A theory of everything (ToE) or final theory is a putative theory of theoretical physics that fully explains and links together all known physical phenomena, and predicts the outcome of any experiment that could be carried out in principle."
http://en.wikipedia.org/wiki/Theory_of_everything

In plume modeling this dream is called Computational Fluid Dynamics (CFD). In principle a comprehensive CFD model could model any plume in relationship to other plumes and their bathymetric, chemical, and physical environments. All that is required is precise and accurate knowledge of

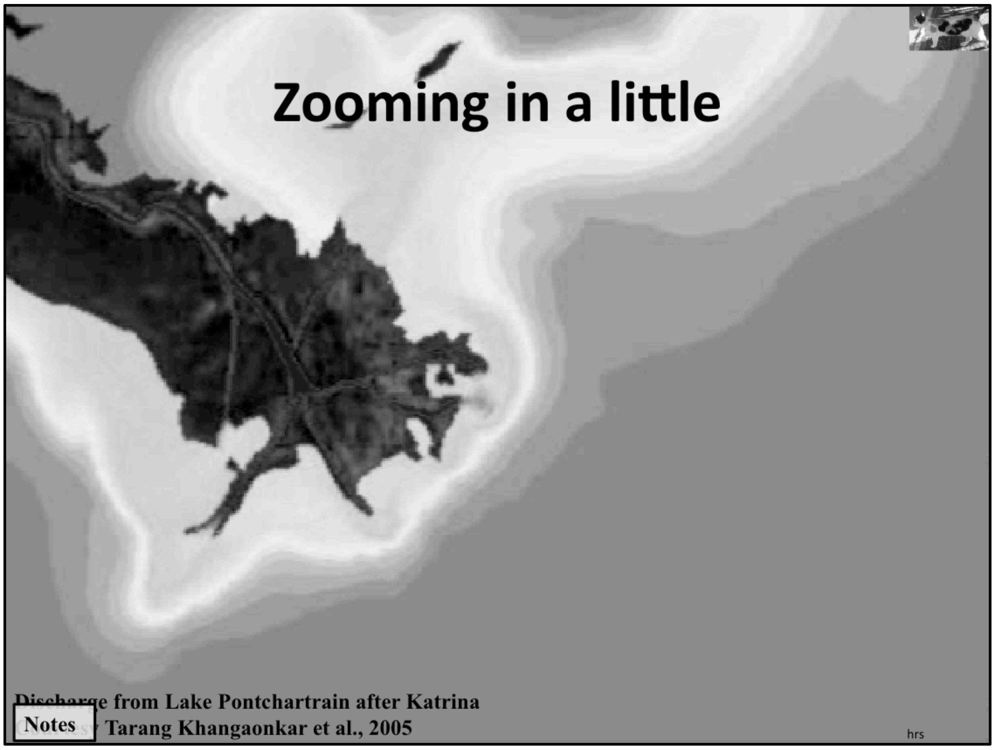
Initial conditions (IC)
Boundary conditions (BC)
Forcing functions
Chemistry
Physics
Thermodynamics….



This work concerned events surrounding Hurricane Katrina, 2005.
Note the Mississippi River flow at Baton Rouge, 6000 cubic meters per second equals about 212,000cfs. This is about 3 times larger than the tidal Yaquina River, Oregon, however, the Mississippi has multiple mouths, including the Atchafalaya River that discharges near Morgan City, west of New Orleans (not shown here). (This note refers to another comparisons including use of the Visual Plumes PDS river discharge model.)



Another output of the modeling. Note the intense parts of the plumes penetrate about 5km into the Gulf.



The intense parts of the plumes penetrate about 5km into the Gulf.

Done! Except….

In theory, we can accurately model plumes using accurate CFD models.

However, consider the

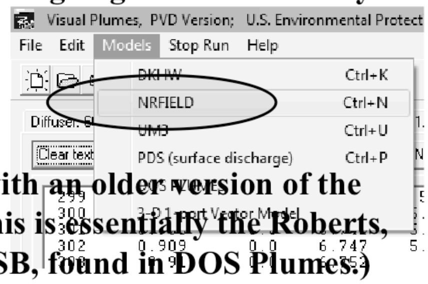
Resources
Setup
Data collection (IC, BC….)
Expense….

We (modelers, users…) must formulate dispersion coefficients everywhere (eddies and turbulence) (models in themselves)

A dream for most of us. On to Visual Plumes' imperfect answers.

One alternative: empirical modeling

While we wait for CFD, how about going to the laboratory for solutions? Empirical models.



Visual Plumes comes bundled with an older version of the NRFIELD empirical model. (This is essentially the Roberts, Snyder, Baumgartner model, RSB, found in DOS Plumes.)
NRFIELD is a stand-alone executable that can be called by VP:

- **VP creates the input file**
- **VP initiates NRFIELD execution**
- **VP reads the output file and displays output**

Considerations:

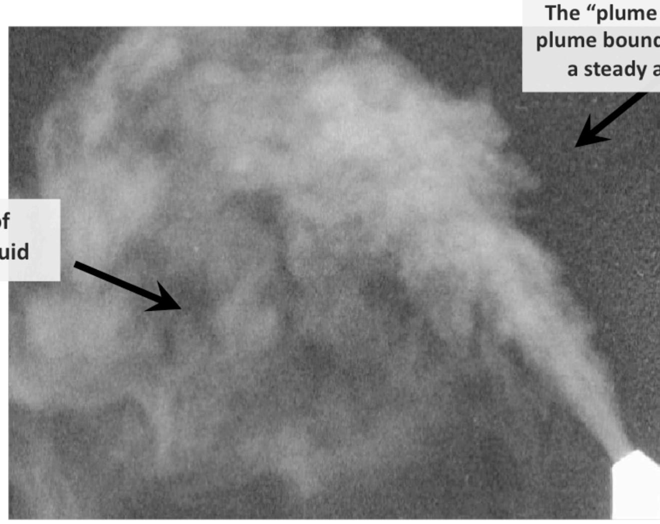
- **NRFIELD addresses multiple merging plume problems**
- **It is an endpoint model…**

Notes

EPA Modeling Webinar 22-24 Jan 2013

Empirical models are based on laboratory measurements. Lab results may be fitted to model parameters that are derived through dimensional analysis or other techniques. Coefficients are established that produce the best fits and similarity theory may be used to generalize the results, making it possible to adapt results to larger or smaller length scales. Similarity may be achieved by matching Froude number, stratification number, Reynolds number and other similarity parameters or length scales. Non-linear effects like the density of water near freezing temperature can complicate similarity theory, sometimes with unexpected and significant consequences.

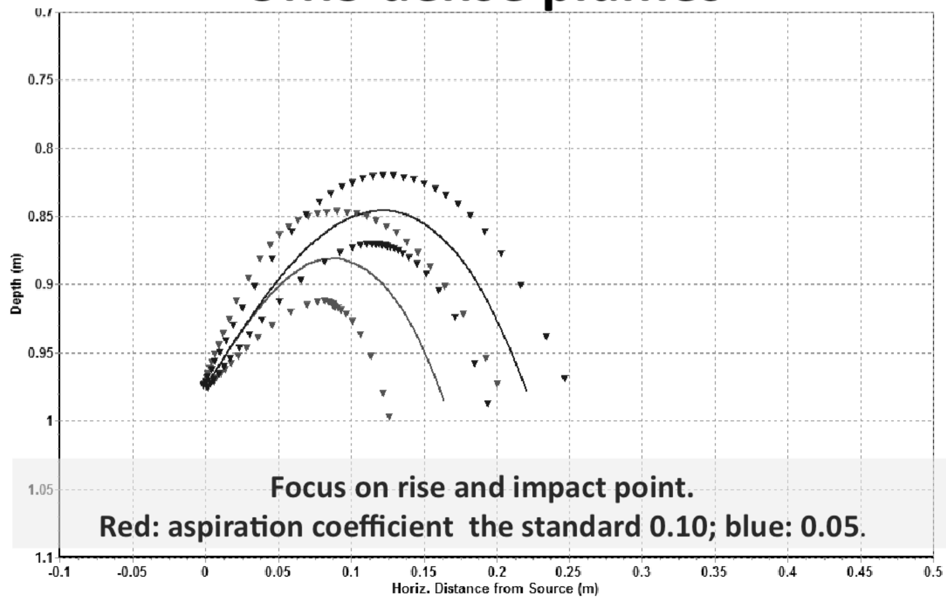
A dense plume



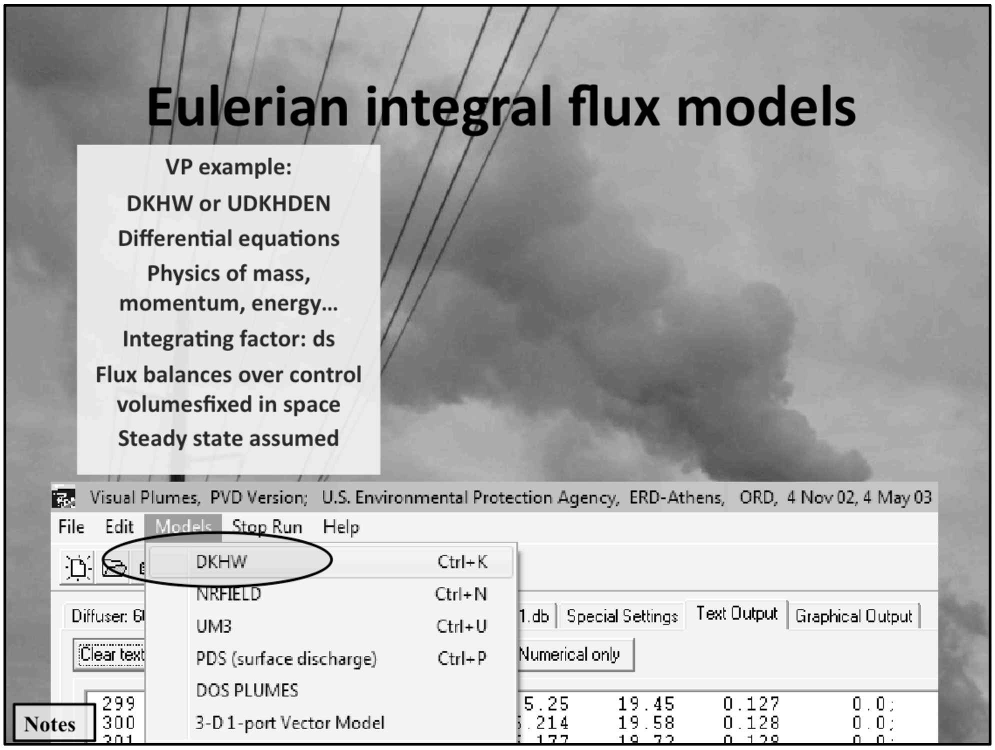
A household dehumidifier plume showing evidence of unexpected behavior. Mimicking the laboratory, will NRFIELD be the first model modified to explain observations?

EPA Modeling Webinar 22-24 Jan 2013

UM3 dense plumes



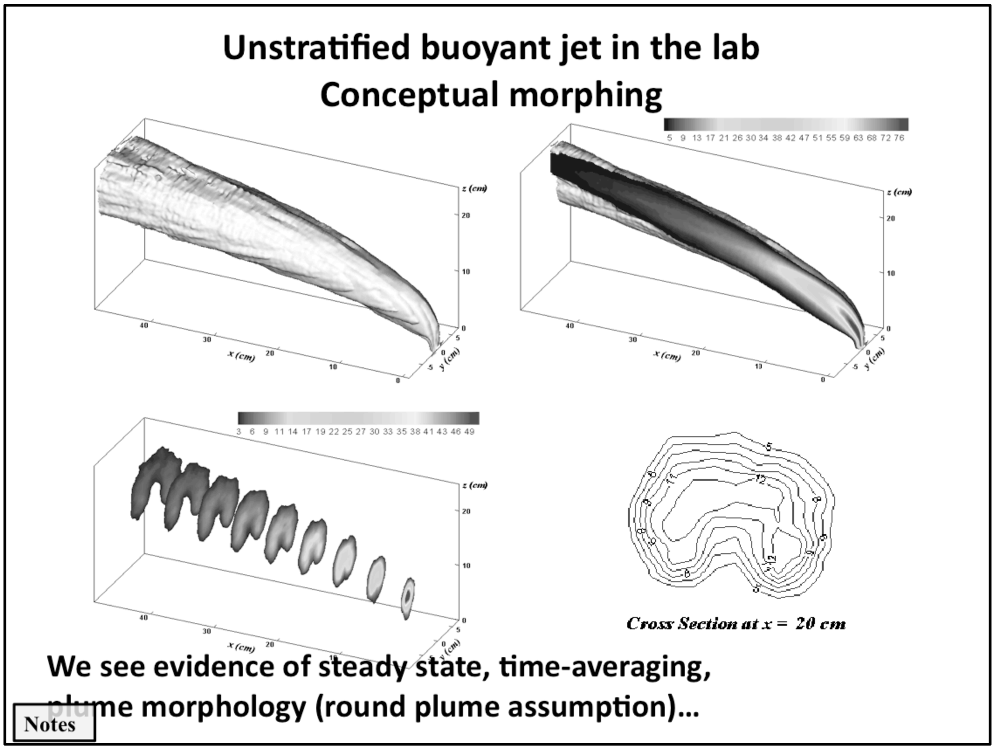
Focus on rise and impact point.
Red: aspiration coefficient the standard 0.10; blue: 0.05.



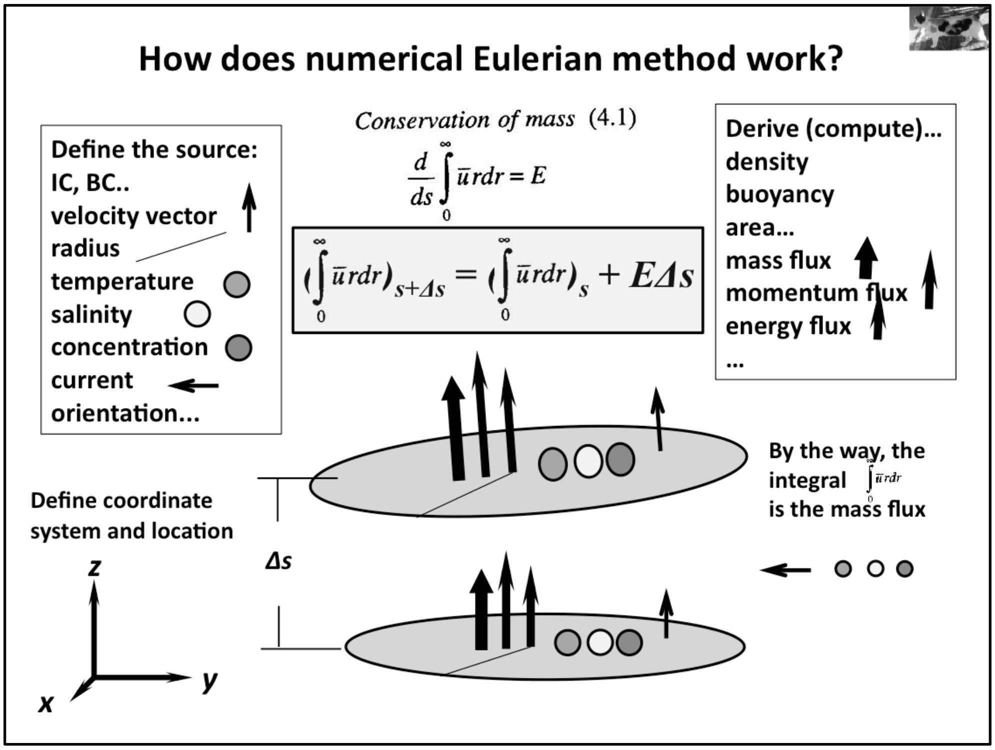
Corjet, one of the models in Cormix, is also an Eulerian integral flux model.

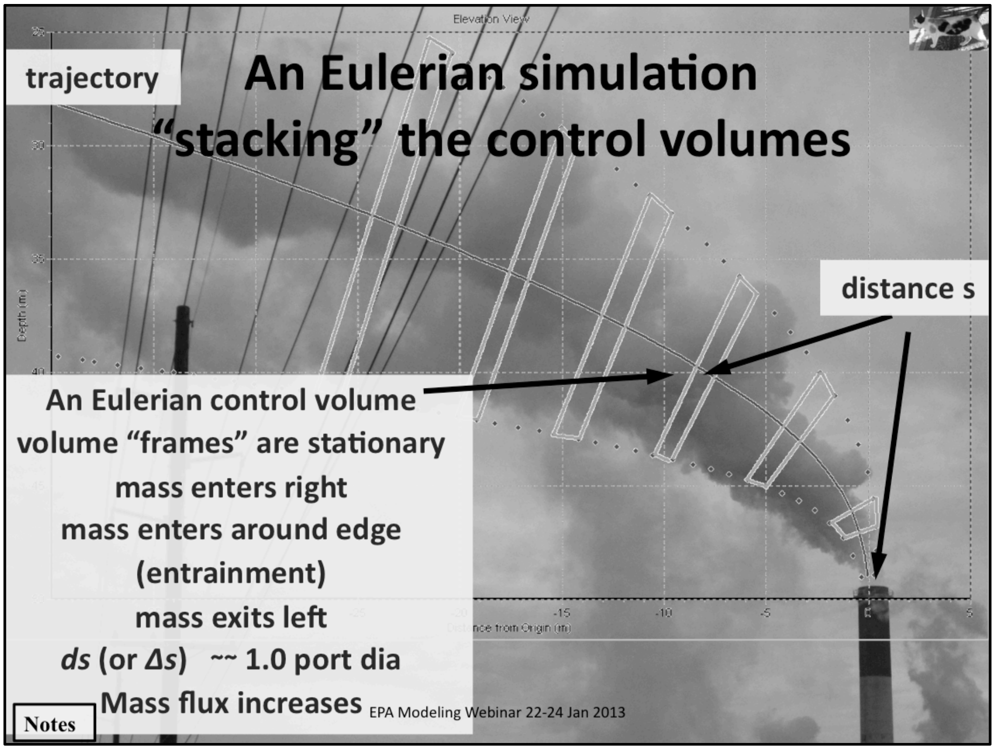
DKH refers to Davis, Kannberg, and Hirst, the original authors of DKHden even before the UDKHDEN and UMERGE (now UM3) models were published in the EPA publication of EPA/600/3-85/073a and b: "Initial mixing characteristics of municipal ocean discharges" in 1985. (Muellenhoff, Soldate, Baumgartner, Schuldt, Davis, and Frick.) The U stood for Universal because each included model used the same input format called Universal Data Files (UDF) files. UM3 now might suggest the "Updated Merge 3-dimensional" model. UMERGE was a quasi 3-D model whereas UM3 is fully three-dimensional when modeling individual plumes, making full use of vector algebra to represent three-dimensional physics.

Cautionary DKHw and UDKHDEN notes for the record:
1) they do not report when the plumes intersect the receiving water surface
2) they hold plume spacing constant even when the current is not perpendicular to the diffuser axis (to be conservative the user should input the reduced spacing, the spacing distance projected to the current)



This presentation covers a lot of ground. For the sake of time some aspects of modeling are emphasized at the expense of other aspects. The previous Eulerian model simulations are based on the concept of steady state. This means that the predictions represent time-averaged behavior. We may think of averaging together many snapshots of the instantaneous plumes that are quite turbulent and heterogeneous. The result of this averaging is to produce smooth surfaces and concentration patterns as shown in the upper right panel. It is such patterns and concentrations we attempt to simulate. To make the problem tractable we assume the cross-section is round but already recognize that this is a simplification which can have significant consequences. In current the plumes are often kidney shaped as shown in the lower right panel. If stratification is strong the cross-section can become even more flattened in shape. This can affect our interpretation of when the plume's upper surface intersects the water surface.


How does numerical Eulerian method work?
Conservation of mass (4.1)
$\frac{d}{ds}\int_0^\infty \bar{u} r dr = E$
$(\int_0^\infty \bar{u} r dr)_{s+\Delta s} = (\int_0^\infty \bar{u} r dr)_s + E\Delta s$
Define the source:
IC, BC..
velocity vector
radius
temperature
salinity
concentration
current
orientation...
Derive (compute)…
density
buoyancy
area…
mass flux
momentum flux
energy flux
…
By the way, the integral $\int_0^\infty \bar{u} r dr$ is the mass flux
Define coordinate system and location
Δs
z
y
x



This simulation is not based on actual input conditions, which are unknown. This is a crude example of similarity. The actual medium is air, the model medium is water. Input conditions were varied until a fit, relative to a common diameter, was obtained. Output was set up to plot diameters (denoted by red dots) and at constant intervals to help represent the concept of control volumes.

Shown is a UM3 simulation. UM3 was modified to output plume diameters (diameter endpoints) whenever the travel distance increased by more than the criterion distance after the previous diameter output. The apparent lengths*ds* of the control volumes, which should be equal, differ slightly from one control volume to the next because the integration step is variable and finite (though small). As several steps of variable size are involved between outputs, the accumulated distance varies from one cross-section to the next.

The control volume length could be varied as part of a model convergence scheme but the main idea is that the volumes are stationary with mass flux in (from the source, from the upstream control volume, or from the surroundings) or out (to enter the downstream control volume).

Any handy laws/rules on dilution?

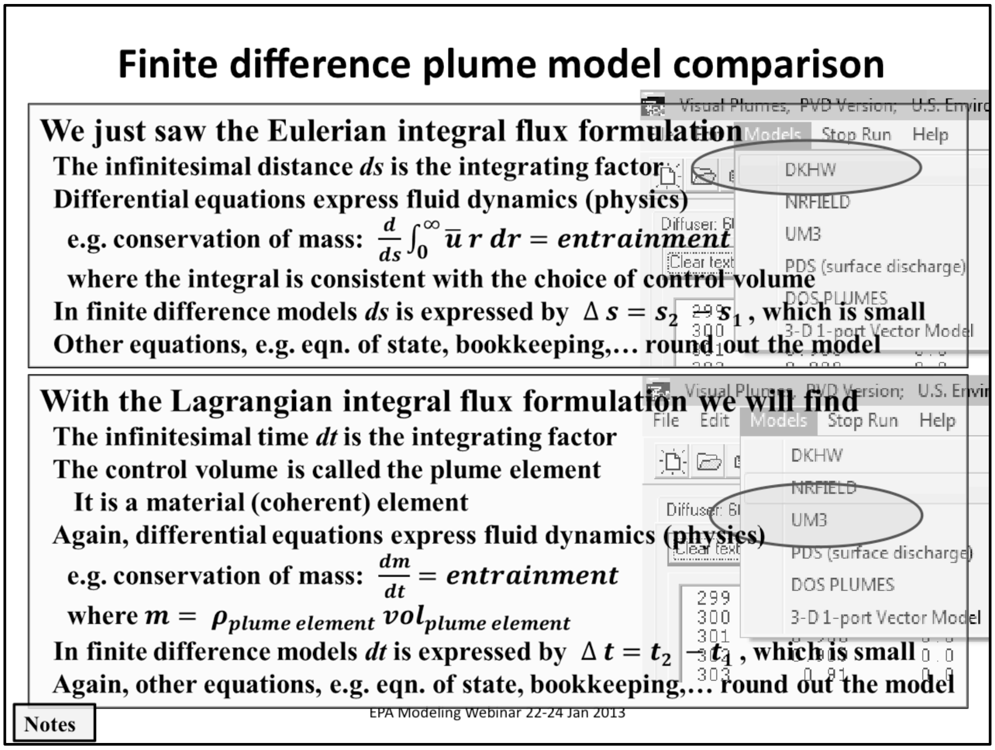
As the fluid entering the bottom of the control volume, augmented by the entrained fluid coming in from the ambient, all exits the top of the control volume we may ask:

At some travel distance *s*, is dilution approximately directly proportional to the area of the cross-section of the plume?

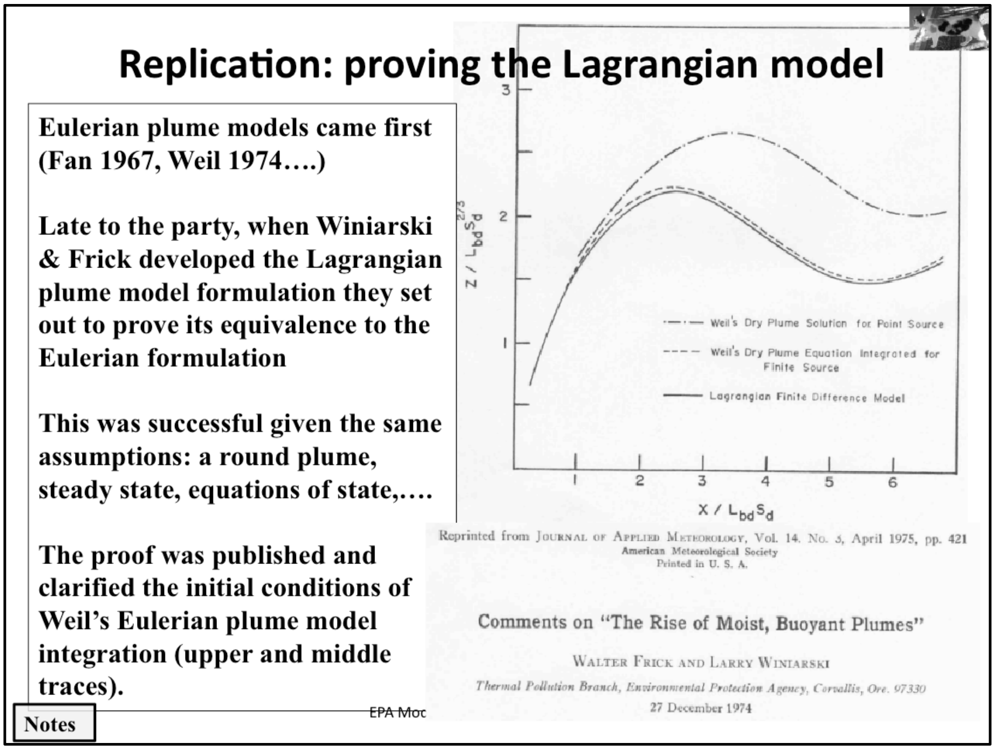
Yes or no?

Other than holding the plume shape constant, the significance of steady state is a little obscure (implicit?) with Eulerian models. Does it help answer the question? More to follow.

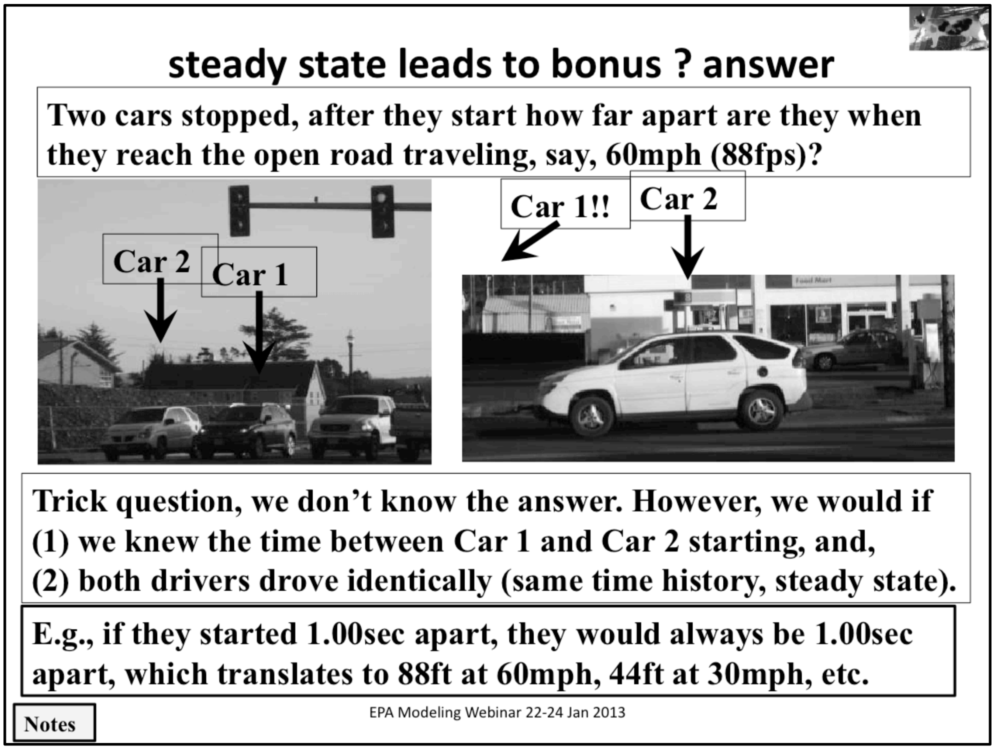
Notes



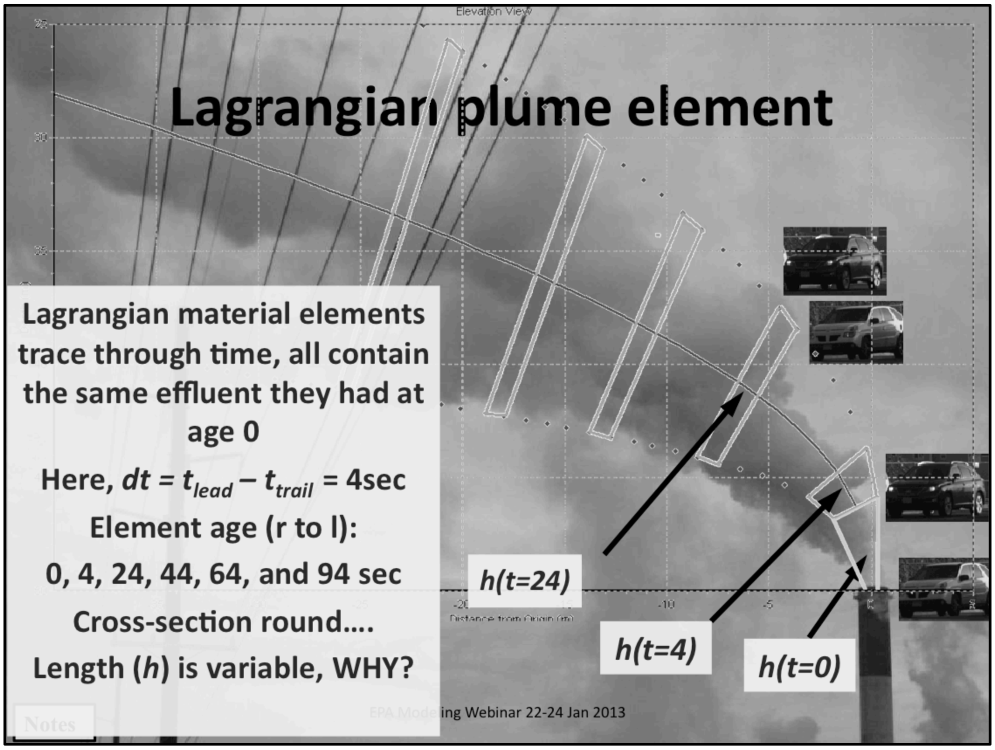
The DOS Plumes manual covers the Lagrangian theory in some detail. The first journal article to outline the complete plume theory (excluding merging and other out of scope complications) was published in 1984. The finite-difference model, which is very useful for understanding the practicalities of numerical modeling of this type, is found in EPA-600/3-76-100 (Cooling tower plume model), 1976.



Presumably no Eulerian modeler has to prove equivalence with the Lagrangian formulation ☺

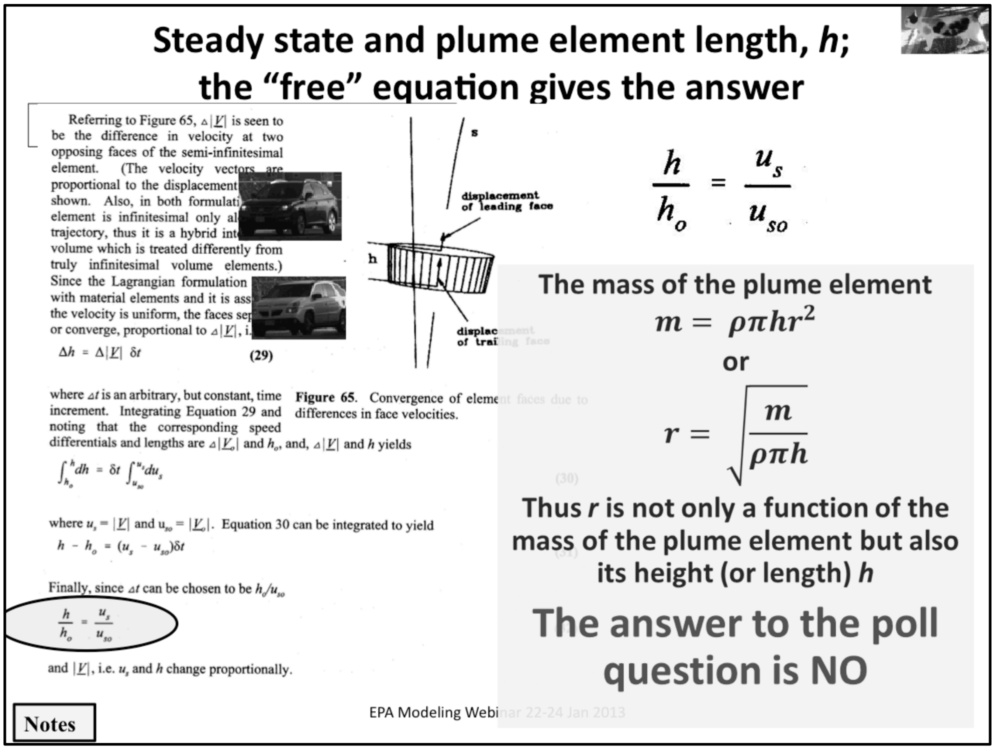


Actually, a more useful analogy to plumes would be two cars possessing the same speed as they pass through the light but car 2 passing that point one second behind car 1. If they practice the same driving pattern (steady state) their distance apart will either increase or decrease depending on whether they speed up or slow down down the road. Now you know why trucks are usually closer together on steep grades. They may be spacing themselves, say, 2 seconds apart.

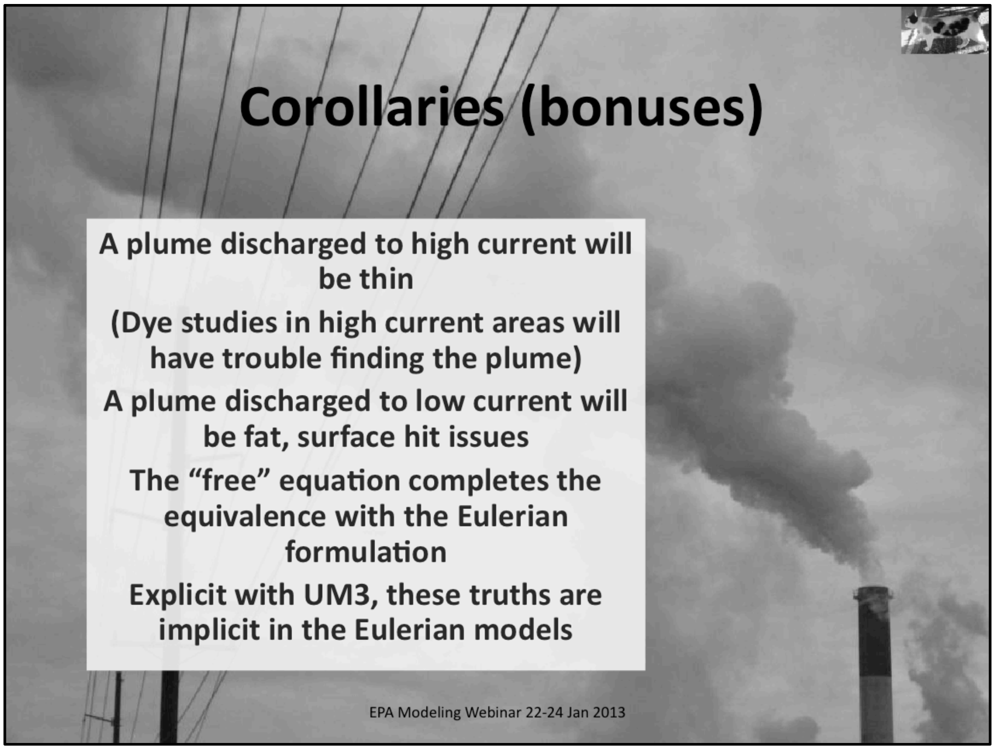


In Lagrangian theory all the material in the plume element at its inception remain in the plume element. In this sense it is a material element. Its increase in volume is due to entrainment plus changes in density that come about from water's density non-linear response to salinity and temperature.

As the leading and trailing faces occupy position a given amount of time different in age, $h = (instantaneous\ speed)(t_2\text{-}t_1)$. Given steady state, the height *h* is a only a function of the instantaneous speed because $t_2\text{-}t_1)$ is constant while steady state is maintained. Actual plume elements are shorter, exaggerated here for instructional purposes. In initializing conditions UM3 sets h(0) to one-tenth of the initial diameter. The initial time step $(\Delta t)_o$ is correspondingly small.



This effect is sometimes referred to as the "jelly sandwich" equation. Squeeze both ends and the diameter increases. Pull both ends outward, like bellows, and the diameter decreases. This is in the absence of entrainment, which may mask some of the jelly-sandwich effect.


Corollaries (bonuses)
A plume discharged to high current will be thin
(Dye studies in high current areas will have trouble finding the plume)
A plume discharged to low current will be fat, surface hit issues
The “free” equation completes the equivalence with the Eulerian formulation
Explicit with UM3, these truths are implicit in the Eulerian models
EPA Modeling Webinar 22-24 Jan 2013

UM3 skeleton or flow chart

Define initial conditions (IC): element mass *m*, properties (temperature *T*, salinity, time, position…), radius *r*, and, of course, *h* (or h_o) and Δt

Define boundary conditions (BC): ambient properties (temperature T, salinity, current, concentration, decay), stratification of properties

Begin model loop
Bookkeeping: interpret and interpolate the ambient array of properties

Calculate Δm, the mass entrained into the plume element in the time step Δt. Requires an entrainment function

Calculate new element properties by mixing *m* and Δm. E.g., new salinity:

$$S_{t+\Delta t} = \frac{S_t m + S_{amb} \Delta m}{m + \Delta m}$$

Apply equation of state (ρ, *S*, *T*); calculate dynamics: momentum, energy, buoyancy; calculate displacement (new position)

Use the "free" eqn. (*h*) (steady state) to solve for radius: $r = \sqrt{\frac{m}{\rho \pi h}}$

More bookkeeping, like output. Finally, return to the beginning of the model loop

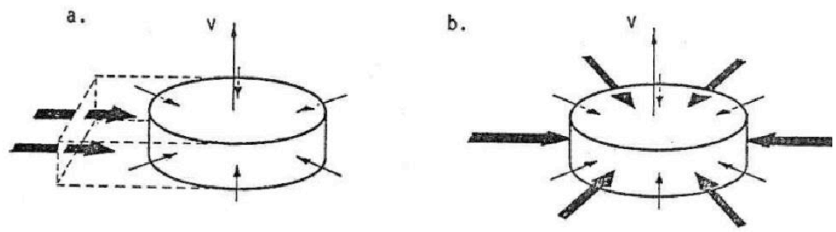
The name of the game: entrainment

Considering that identical assumptions result in Eulerian integral flux and Lagrangian model equivalence, what sets integral models apart are the assumptions (if the underlying assumptions are different)

(1) entrainment hypotheses (functions)
(2) numerical convergence scheme
(3) ancillary capabilities like plume merging and treatment of surfaces
(4) Facilities: unit conversion, time-series input, and other capabilities or constraints

Given the assessment satisfies the underlying assumptions used in model development (viz. deep water and steady state) the entrainment functions deserve the greatest attention.

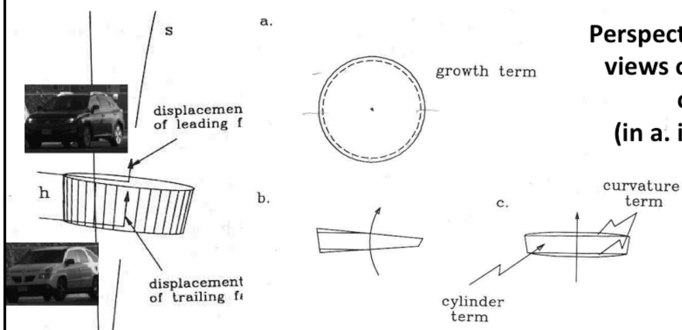
Early entrainment conception



historical context

a) forced entrainment due to current (more next 3 slides)
b) aspiration entrainment due to suction: this mechanism is due to the Bernoulli effect; the inflow velocity is proportional to the surface area of the element and the velocity shear between the average plume element velocity and the ambient velocity; it is governed by an adjustable aspiration entrainment coefficient

Projected Area Entrainment (PAE)



Perspective and three orthogonal views of the plume element as conceived in UM3 (in a. it's the area of the ring)

The PAE hypothesis postulates forced entrainment =

(ambient density)*(current)*(total area projected to the current)

Total projected area of the plume element (3D conception) =

(a) growth + (b) cross-flow + (c) cylinder and curvature

The PAE hypothesis appears to require no adjustment; the coefficient is 1.0.

Follow science for the answer--yes, but…

Before recognizing the significance of steady state (aka jse)

Developing the Lagrangian "pre-UM3" from scratch took about a year.

?About how many entrainment assumptions/hypotheses did W&F try in the effort to obtain good fit to Fan's data?
1, 2, 5, 10, 20, 50?

?After adding the "free" equation for plume element length, how many revisions before formulating the forced entrainment equation as a function of *r, h,* and *θ*?
1, 2, 5, 10?

Notes

EPA Modeling Webinar 22-24 Jan 2013

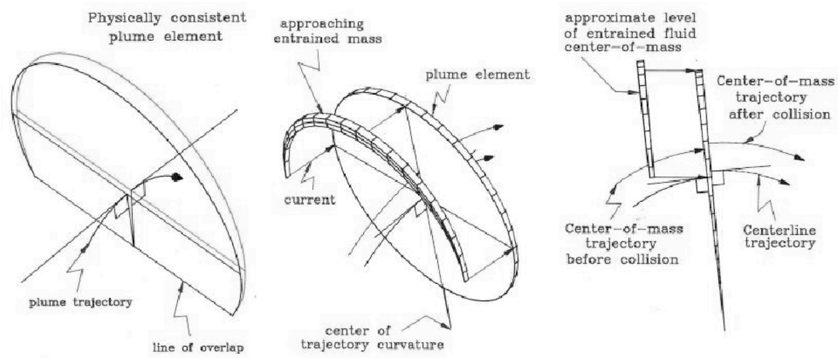
Understanding the significance of the steady state assumption ultimately lead to a completely new conception of the plume element. The right-cylinder tuna can was replaced by a section from a bent cone. The trick became to accurately derive the projected area of the plume element's surface as a function of r, h, and ***θ***, the trajectory inclination angle to the horizontal axis.

First assuming that the plume element height (*h*) was constant (the "tuna can," right cylinder conception of the Lagrangian plume element) Winiarski and Frick formulated about 20 different entrainment functions, some leading to fabulous, but wrong, solutions, like blowing up.

After suspecting that perhaps *h* could not be assumed constant, W&F rather quickly formulated the current expression for forced entrainment, probably less than 5. First, an examination of Fan's dilution and radii data confirmed that they were not directly proportional or linearly related. Something like the car analogy, followed by the rigorous integration found in the DOS Plumes manual, was then used to develop the "free" equation for *h*.

UM3 equations are based on the "top hat" assumption, that plume properties are average values when it comes to expressing the equations of motion. This is an idealization, obviously plume centerline properties are different from edge properties. In omitting a pressure force on the plume, they reasoned that plume properties "feathered" into ambient properties at the plume's edge, hence no pressure force as would be experienced by a solid object.

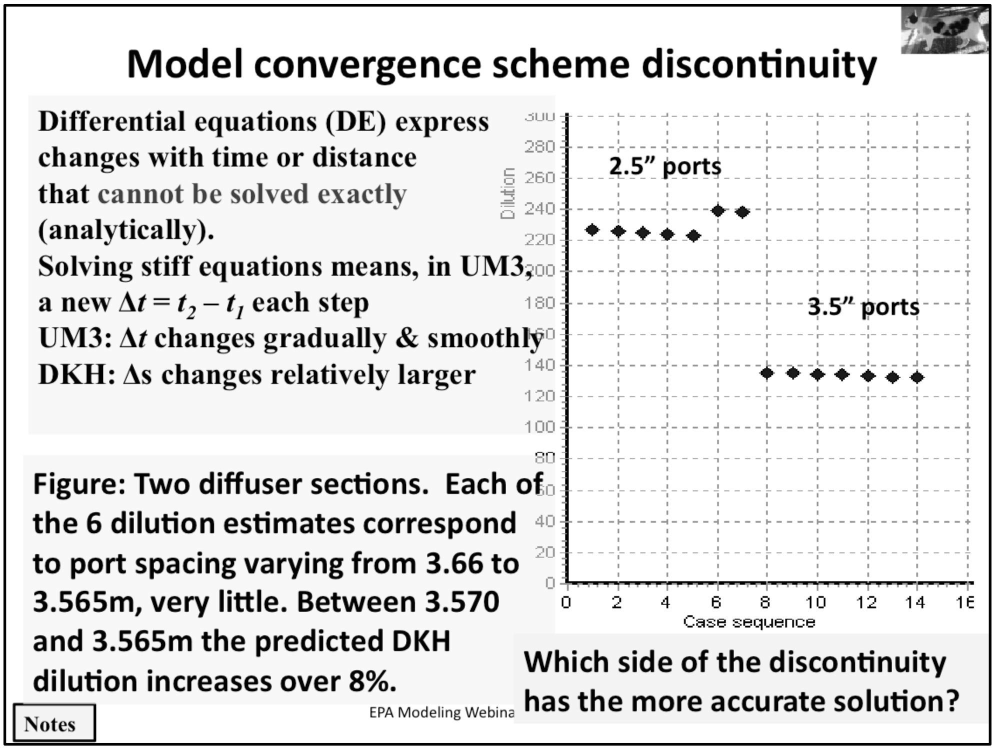
Dream model element & entrainment



- Wedge shape and overlap (left)
- The concept of all approaching ambient fluid being captured by the plume element (middle and right)

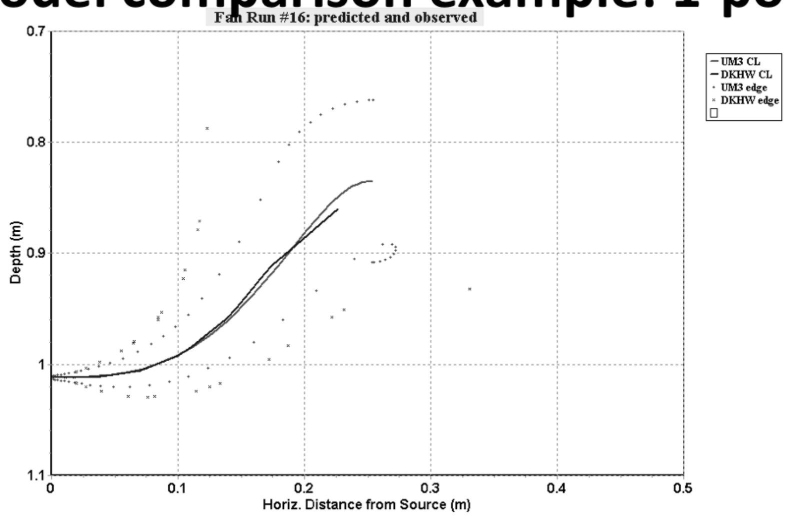
Notes 9 Oct 07 44

Dream model consider mass distribution about the center of mass (not the center of the cross section). Overlap is dealt with explicitly.
Schematic diagrams illustrating details of plume merging theory; the plume element as a wedge-shaped, overlapped entity; mass about to collide with the plume to become entrained mass—part of the plume.



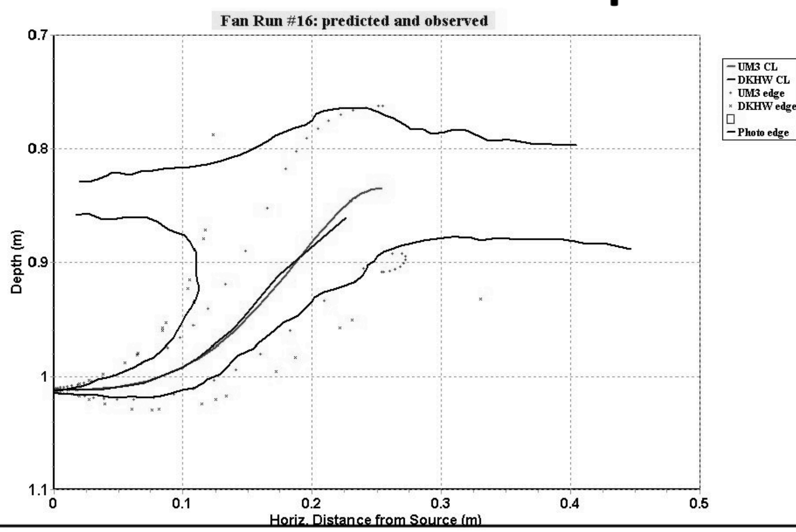
Differential equations (DE) express changes with time or distance
Usually the changes are smooth and continuous
The plume DE can not be solved analytically
The DE must be solved numerically: a finite difference approach
For the Lagrangian model the infinitesimal integrating factor like *dt* is replaced by Δt: $t_2 - t_1$
For the Eulerian integral flux the infinitesimal integrating factor *ds* is replaced by Δs: $s_2 - s_1$
The numeric integration is stepwise
If Δt or Δs are too large the solution diverges from the true solution
because the Δt or Δs too crude to capture rapid changes
If Δt or Δs are too small the solution diverges from truncation errors
The plume equations are sometimes called stiff:
at first Δt or Δs must be tiny but if constant truncation errors build up
Convergence schemes are needed, for example, *dt* must increase as the plume solution develops
Good increase schemes for Δt or Δs yield solutions that converge
Crude schemes cause divergence or quantum jumps, i.e., a tiny change in current angle will cause a not insignificant change in dilution prediction simply because the integrating factor adjustment was too coarse.
UM3 is very continuous

Model comparison example: 1-port



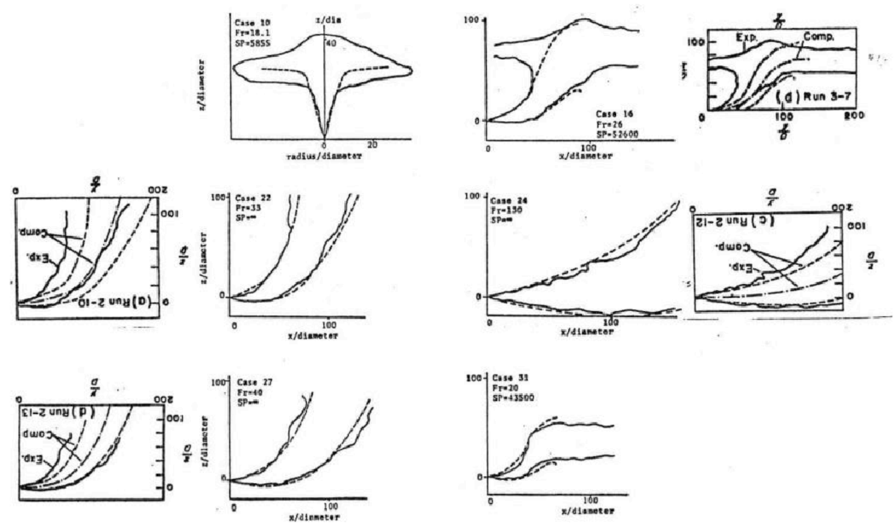
Fan Run 16 input; DKHW (blue) and UM3 (red) simulations. Stagnant, density stratified environment.

VP verification example



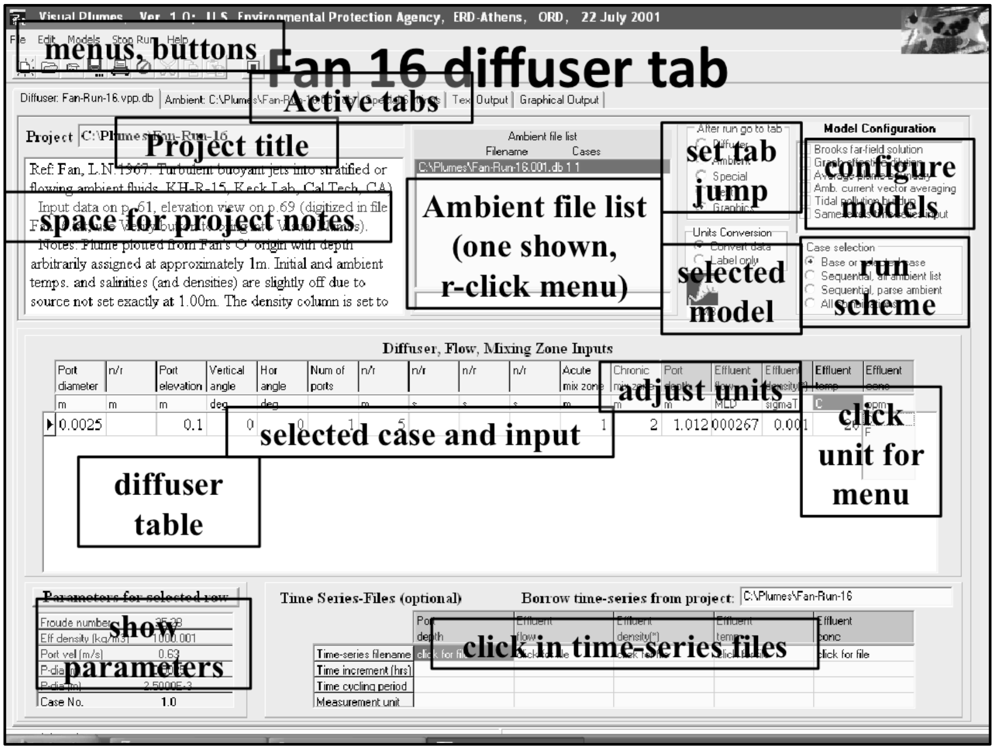
Same input as previous slide. VP allows input from text files, a capability used to show the experimental plume trace.

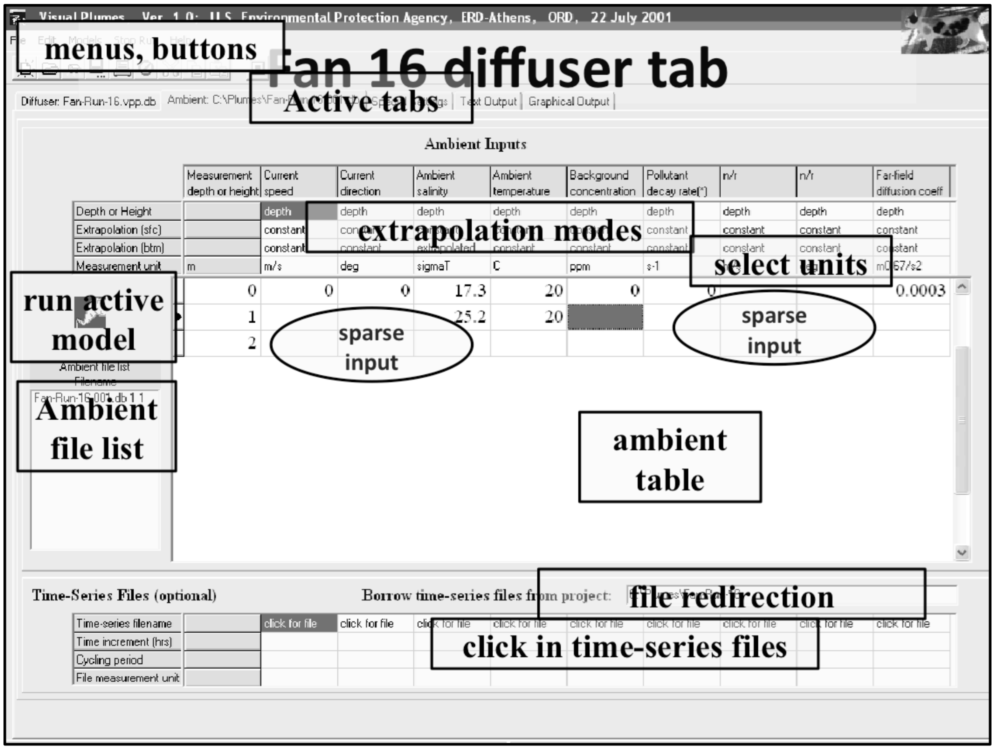
Example UM3 verification



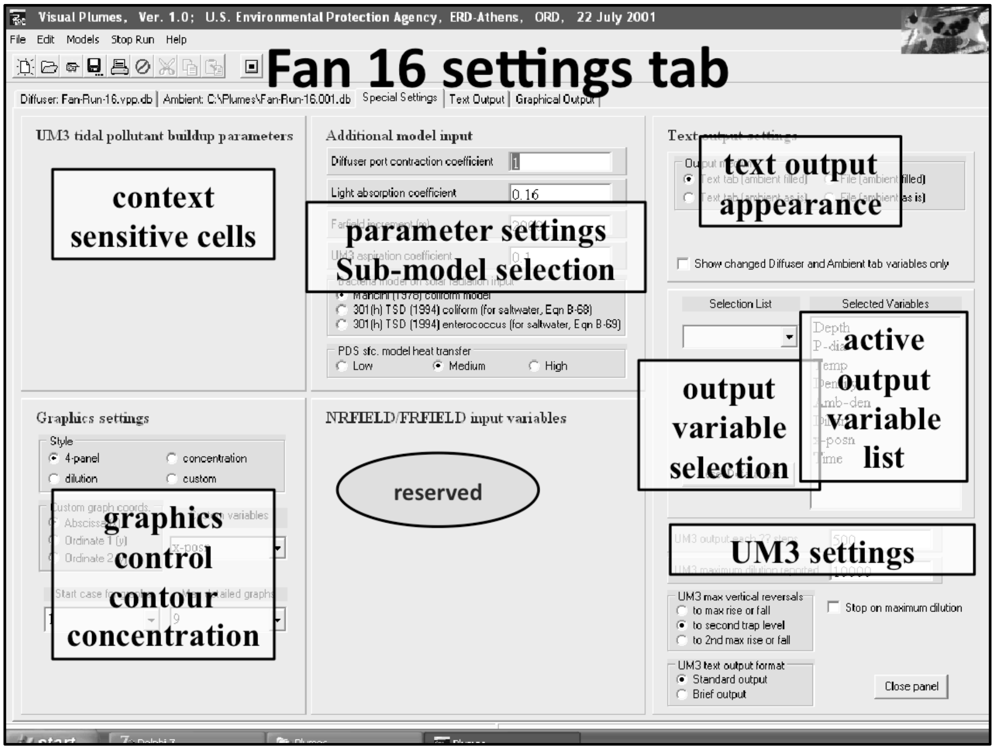
Six center panels, UMERGE (UM3 predecessor) model predictions. Schatzmann's multi-parameter model predictions in margins. Data from Fan, 1967.

Preface to the live demonstration

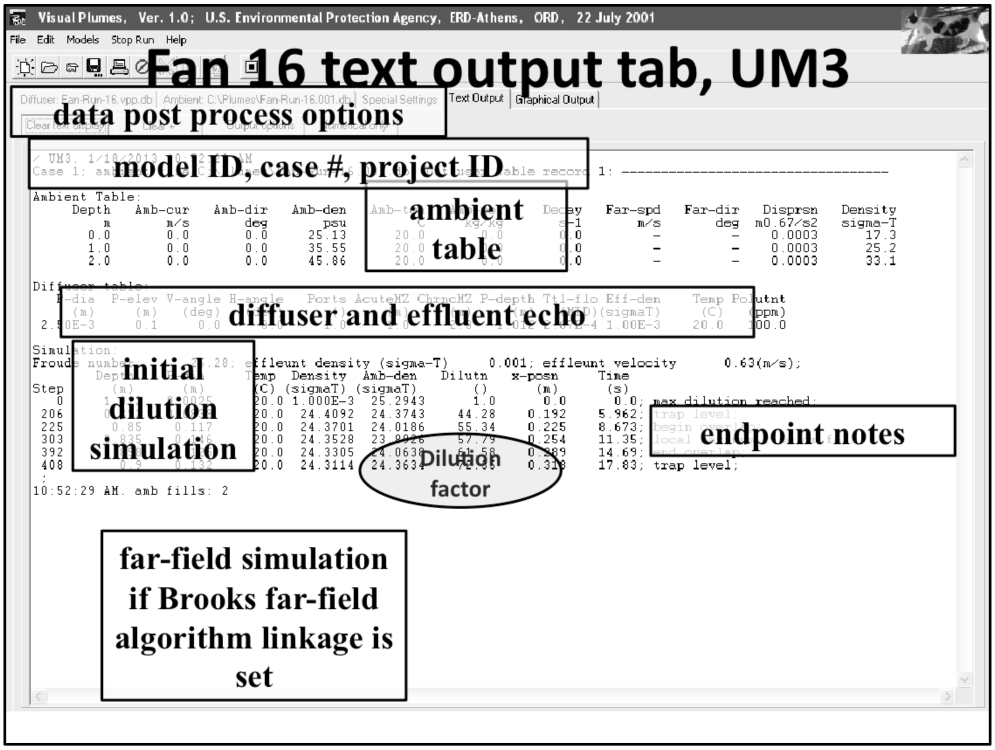

Fan 16 diffuser tab
menus, buttons
Active tabs
Project title
space for project notes
Ambient file list (one shown, r-click menu)
set tab jump
configure models
selected model
run scheme
adjust units
selected case and input
click unit for menu
diffuser table
show parameters
click in time-series files

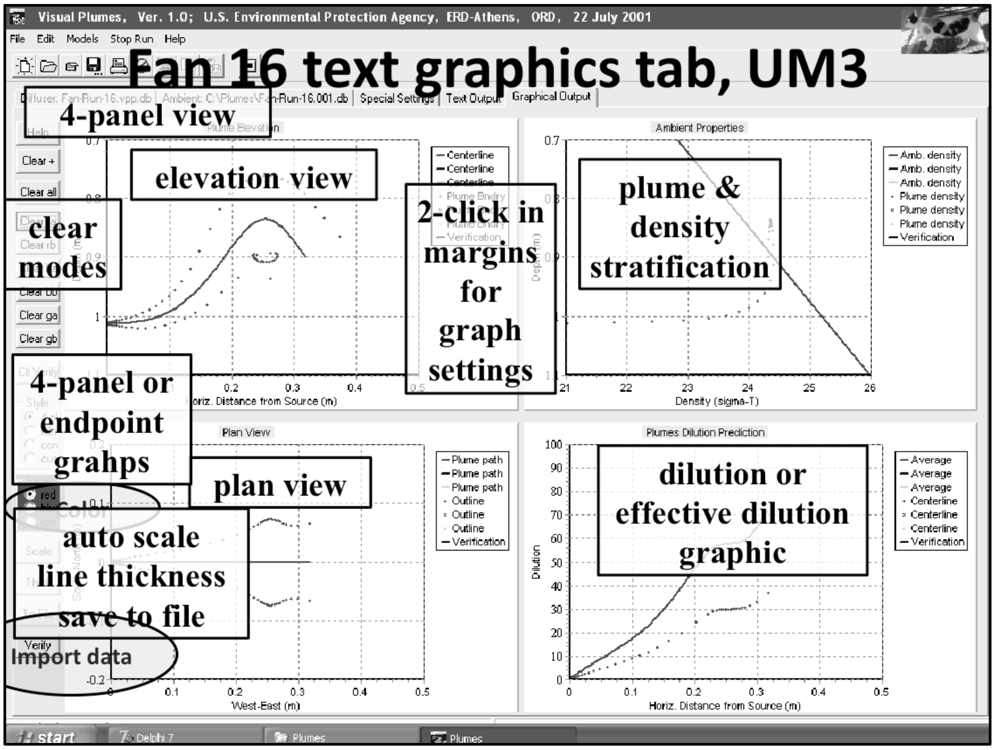

Fan 16 diffuser tab
menus, buttons
Active tabs
Ambient Inputs
extrapolation modes
select units
run active model
sparse input
sparse input
Ambient file list
ambient table
Time-Series Files (optional)
file redirection
click in time-series files

Fan 16 settings tab

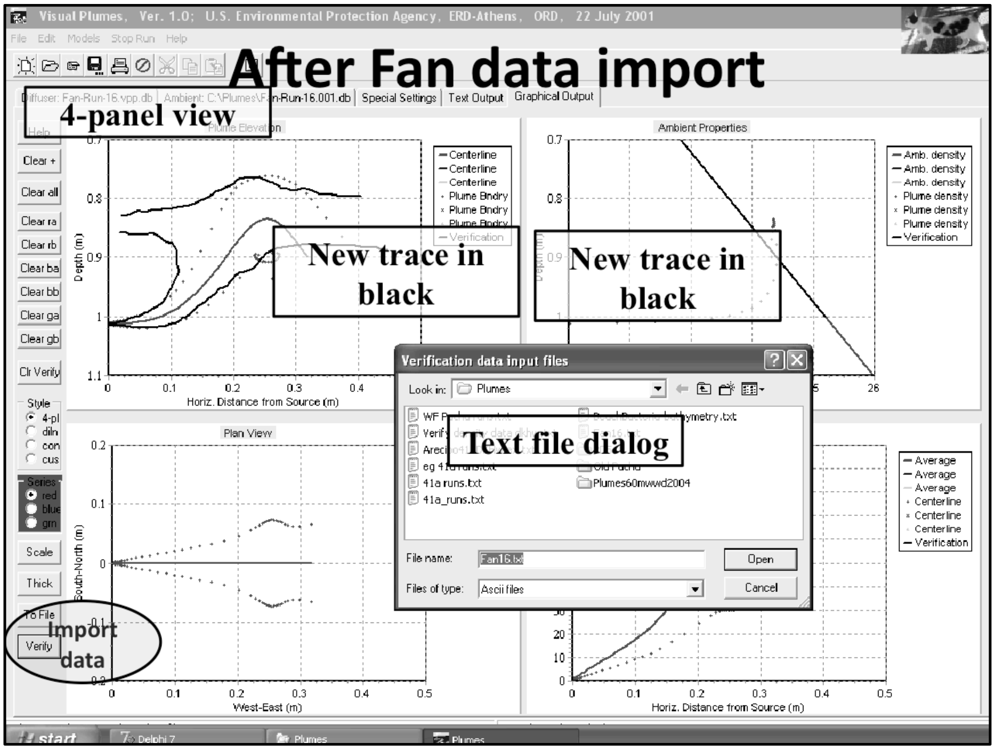


Fan 16 text output tab, UM3




Visual Plumes, Ver. 1.0; U.S. Environmental Protection Agency, ERD-Athens, ORD, 22 July 2001
File Edit Models Stop Run Help
Fan 16 text graphics tab, UM3
Special Settings
Text Output
Graphical Output
4-panel view
elevation view
2-click in margins for graph settings
plume & density stratification
clear modes
Clear +
Clear all
Clear ga
Clear gb
4-panel or endpoint grahps
plan view
auto scale line thickness save to file
Import data
dilution or effective dilution graphic
Ambient Properties
Plan View
Plumes Dilution Prediction
Horiz. Distance from Source (m)
Density (sigma-T)
West-East (m)
Dilution
Centerline
Amb. density
Plume density
Verification
Plume path
Outline
Average
start
Delphi 7
Plumes

After Fan data import



Flat data text file

```
side view
0.0001   1.0145
0.0068   1.0157
0.0149   1.0158
0.0197   1.0161
0.0264   1.0159
0.0339   1.0164
0.0423   1.0182
0.0491   1.0191
0.0565   1.0180
0.0638   1.0180
0.0676   1.0186
0.0776   1.0177
0.0830   1.0169
0.0912   1.0146
0.1000   1.0118
0.1084   1.0100
0.1155   1.0053
0.1181   1.0024
0.1236   1.0003
0.1285   0.9976….
```

```
0.4373   0.8854
0.4468   0.8878

0.4047   0.7966
0.3985   0.7965
0.3920   0.7966
0.3855   0.7961
0.3800   0.7961
0.3723   0.7958
0.3651   0.7943
0.3581   0.7932
0.3536   0.7918
0.3477   0.7923
0.3420   0.7927
0.3353   0.7920
0.3286   0.7884
0.3254   0.7864
0.3211   0.7843
0.3169   0.7831
0.3116   0.7834
0.3077   0.7838….
```

```
0.0485   0.9988
0.0411   1.0011
0.0343   1.0028
0.0273   1.0065
0.0212   1.0084
0.0168   1.0095
0.0099   1.0114
0.0042   1.0126
-0.0001  1.0124
density profile
17.3 0.0
25.2 1.0
```

Key words to indicate elevation view

plume outline x-y coordinates

blank line to lift pen

Key words to indicate density panel

plume density coordinates

VP manual has detail

….omitted data (notes)

Notes

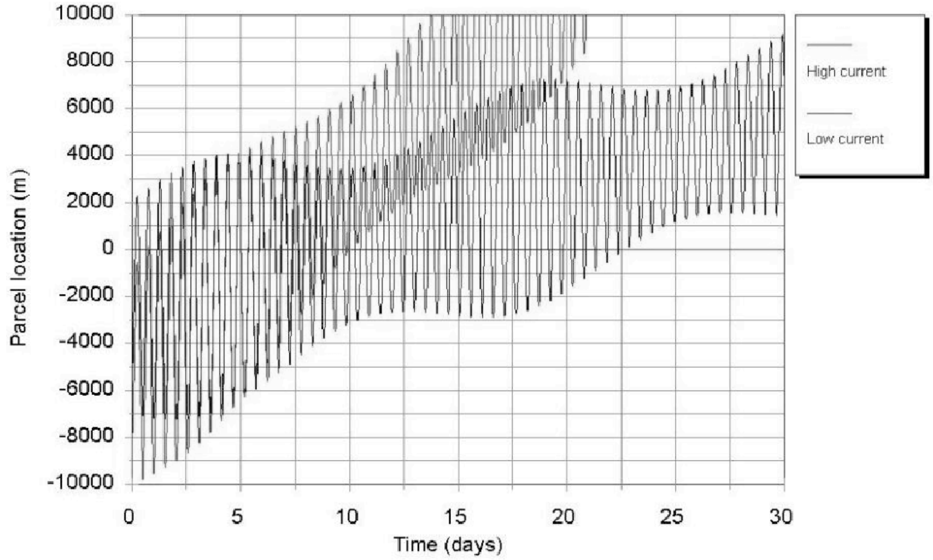
```
side view
0.0001  1.0145
0.0068  1.0157
0.0149  1.0158
0.0197  1.0161
0.0264  1.0159
0.0339  1.0164
0.0423  1.0182
0.0491  1.0191
0.0565  1.0180
0.0638  1.0180
0.0676  1.0186
0.0776  1.0177
0.0830  1.0169
0.0912  1.0146
0.1000  1.0118
0.1084  1.0100
0.1155  1.0053
0.1181  1.0024
0.1236  1.0003
0.1285  0.9976
0.1336  0.9924
0.1391  0.9854
0.1420  0.9819
0.1482  0.9789
0.1543  0.9758
0.1585  0.9709
0.1642  0.9662
0.1709  0.9600
0.1773  0.9530
0.1835  0.9500
0.1889  0.9468
0.1950  0.9400
0.1999  0.9343
0.2023  0.9303
0.2092  0.9261
0.2168  0.9239
0.2253  0.9205
0.2327  0.9173
0.2385  0.9114
0.2422  0.9049
0.2431  0.9019
0.2478  0.8989
0.2504  0.8942
0.2550  0.8907
0.2615  0.8878
0.2684  0.8849
0.2777  0.8826
0.2865  0.8804
0.2968  0.8786
0.3072  0.8770
0.3134  0.8768
0.3239  0.8781
0.3308  0.8799
0.3395  0.8789
0.3428  0.8777
0.3528  0.8789
0.3616  0.8796
0.3701  0.8795
0.3777  0.8792
0.3876  0.8796
0.3947  0.8796
0.4032  0.8812
0.4095  0.8827
0.4193  0.8832
0.4288  0.8831
0.4373  0.8854
0.4468  0.8878

0.4047  0.7966
0.3985  0.7965
0.3920  0.7966
0.3855  0.7961
0.3800  0.7961
0.3723  0.7958
0.3651  0.7943
0.3581  0.7932
0.3536  0.7918
0.3477  0.7923
0.3420  0.7927
0.3353  0.7920
0.3286  0.7884
0.3254  0.7864
0.3211  0.7843
0.3169  0.7831
0.3116  0.7834
0.3077  0.7838
0.3027  0.7849
0.2977  0.7858
0.2934  0.7868
0.2899  0.7850
0.2864  0.7830
0.2838  0.7826
0.2791  0.7826
0.2762  0.7826
0.2739  0.7804
0.2674  0.7762
0.2626  0.7728
0.2568  0.7707
0.2507  0.7673
0.2435  0.7646
0.2351  0.7643
0.2262  0.7635
0.2165  0.7647
0.2086  0.7668
0.2035  0.7691
0.1999  0.7749
0.1945  0.7786
0.1870  0.7816
0.1800  0.7843
0.1714  0.7882
0.1659  0.7926
0.1586  0.7973
0.1519  0.8016
0.1441  0.8049
0.1376  0.8078
0.1293  0.8107
0.1184  0.8134
0.1097  0.8153
0.1020  0.8166
0.0942  0.8172
0.0847  0.8176
0.0769  0.8193
0.0672  0.8201
0.0595  0.8228
0.0514  0.8216
0.0457  0.8208
0.0408  0.8236
0.0338  0.8266
0.0291  0.8284
0.0199  0.8291
0.0170  0.8577
0.0212  0.8574
0.0278  0.8569
0.0358  0.8608
0.0459  0.8615
0.0530  0.8605
0.0630  0.8591
0.0726  0.8601
0.0808  0.8641
0.0884  0.8705
0.0953  0.8736
0.1012  0.8759
0.1061  0.8820
0.1100  0.8908
0.1105  0.8977
0.1100  0.9073
0.1101  0.9118
0.1111  0.9166
0.1123  0.9216
0.1124  0.9236
0.1100  0.9304
0.1073  0.9380
0.1026  0.9464
0.0997  0.9524
0.0962  0.9597
0.0924  0.9673
0.0839  0.9769
0.0777  0.9828
0.0693  0.9870
0.0624  0.9920
0.0541  0.9959
0.0485  0.9988
0.0411  1.0011
0.0343  1.0028
0.0273  1.0065
0.0212  1.0084
0.0168  1.0095
0.0099  1.0114
0.0042  1.0126
-0.0001  1.0124
density profile
17.3 0.0
25.2 1.0
```

Multi-run example Dominguez Channel

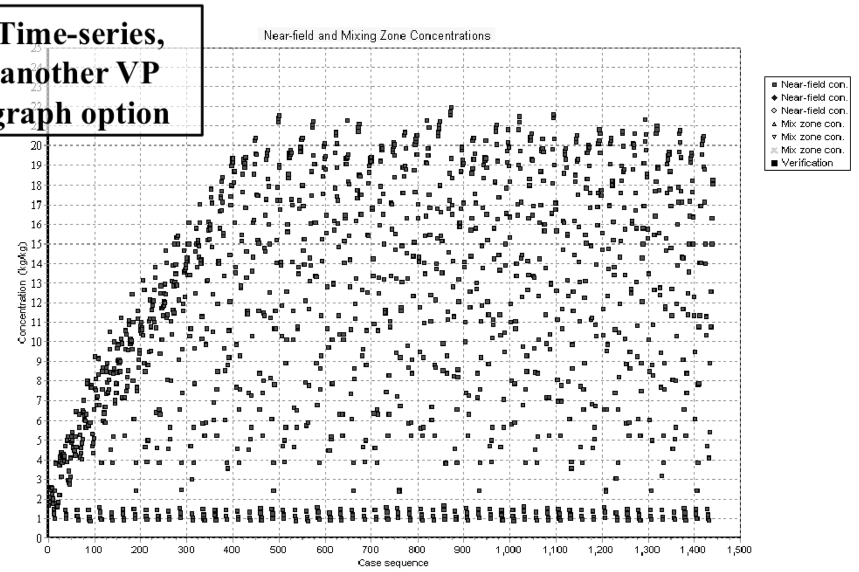
- Project map
- Channel

Tidal Channel Excursion



Time-Series Approach output

Time-series, another VP graph option



Maximum Impact

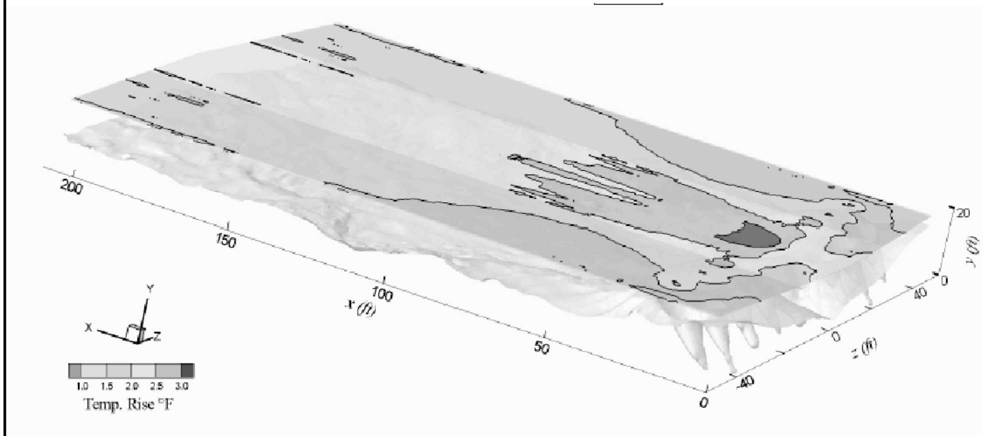


Figure 5. Perspective view of surface temperature rise.

- Surface temperature elevation hot spot

Summary

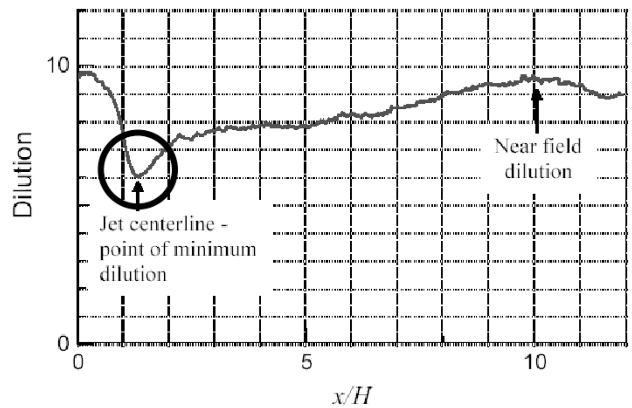
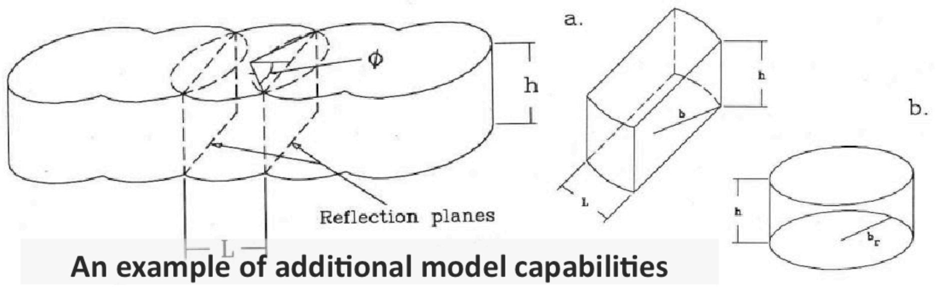


Figure 6. Variation of surface dilution with distance from the diffuser on the diffuser centerline.

- Verification? Verifying the verifier.

Simulating merging with UM3



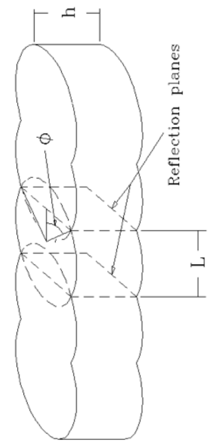
An example of additional model capabilities

- When neighboring plumes merge, the mass is shifted in a direction perpendicular to the axis of the wastefield
- This is known as the reflection technique
- UM's algorithm is patterned after DKHw (UDKHDEN)
- In a and b, mass is conserved by this technique

EPA Modeling Webinar 22-24 Jan 2013

UM3 Very Shallow Water capability

- **If the merging diagram is rotated 90 degrees then it is a representation for shallow water, where the bottom and surface are represented by the two planes of reflection.**
- **The true depth becomes associated with spacing (L in the diagram), thus spacing will represent depth.**
- **The width of the water body (river, channel) becomes associated with the depth.**



Model limitations
Liseth experiments in zero current
Zero current worst case: viable?

Single plume trajectory: ambient current = zero

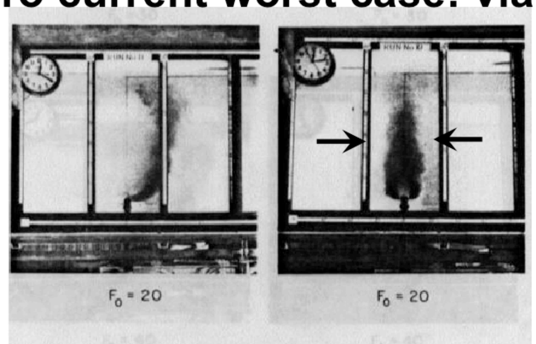


FIG. 28 COMPARISON OF FLOW PATTERNS OF JETS DISCHARGED ONLY FROM ONE SIDE OF MANIFOLD VIII, WITH THE MERGING JETS DISCHARGED FROM BOTH SIDES OF MANIFOLD VIII, F_0 = 10 AND 20

Same plume in the presence of its opposite twin: “ambient” current (red arrows) is no longer zero

When plumes aspirate they generate inflowing current nearby. Self-induced current is not addressed by VP models.

Notes

EPA Modeling Webinar 22-24 Jan 2013

Work done by Liseth (reference not immediately available) shows plumes generate current around themselves. Here identical single and double plumes of equal densimetric Froude are shown in two sets of experiments. It is striking how in pairs the plumes “attract” each other.

References and acknowledgements

1) To be completed…

Conclusions and Recommendations

1) Visual Plumes, model manager, native and callable (exe) models
2) Ease of use: sparse input, units conversion, time-series files…
3) Public domain, inter-model comparison
4) Plume morphology, steady state and the "free" equation (jse)
5) Strong basic physics, finite difference models, Lagrangian (UM3, native) and Eulerian (DKH, exe)
6) Dimensional model empirical NRFIELD, multi-port T-riser diffusers; ongoing research on dense plumes
7) Linkage to Brooks far-field equations
8) DOS Plumes: legacy UM and RSB, similarity parameters, Very Shallow Water (VSW) technique and Cormix classes
9) Extensive guidance, DOS and Visual Plumes
10) Mixing zone course documentation (Frick et al. 2005) illustrates the use of the PDS as well as the other models

Conclusions and Recommendations continued

1) Visual Plumes has capabilities and flaws
2) Can operating system problems be solved?
3) Resources
4) Can progress be propagated?
5) Diversity is honesty
6) Answers meaningful in conflicting contexts
7) Progress more certain
8) Replacing VP? Inevitable
9) User facilities, physics, multi-model, partnership….
   A concept worth improving and refining

Thank you

EPA Modeling Webinar 22-24 Jan 2013

L.N. Fan Run 16

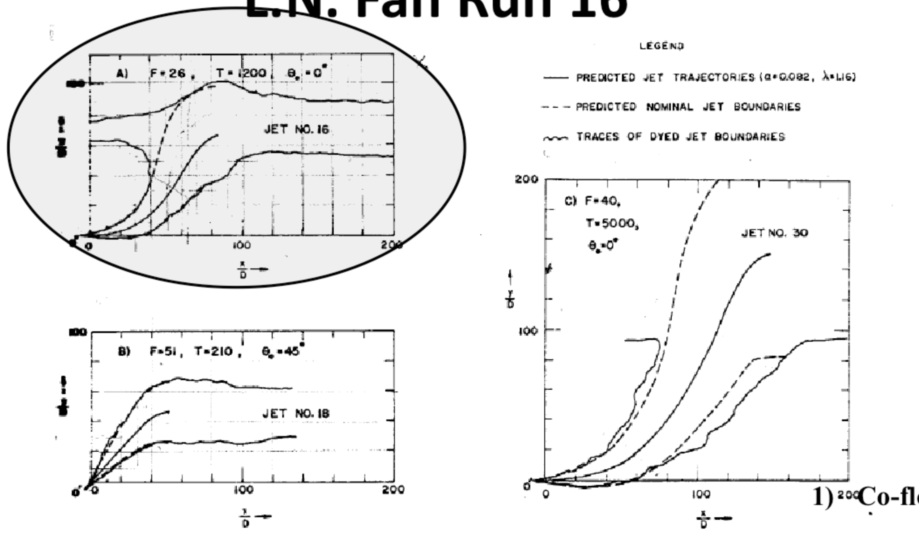


Fig. 26. Predicted and observed trajectories and nominal boundaries of buoyant jets in linearly stratified environments (note: traces inverted in the vertical direction except for Jet No. 16)

Table 1. Summary of Experiments on Round Jets in Stagnant Environments

Jet Number	Initial Jet Values: Angle	Diameter	Discharge	Velocity	Density	Ambient Reference Density (1)	Density Gradient	Jet Reynolds Number	Jet Froude Number	Stratification Parameter	Reference for Detailed Results
	θ_o deg.	D cm	Q_o cc/sec	U_o cm/sec	ρ_1 gr/ml	ρ_o gr/ml	$-\frac{1}{\rho_o}\frac{d\rho_a}{dy}$, 10^{-5}/cm	$R = \frac{U_o D}{\nu}$	F Eq. (51)	T Eq. (52)	Figure Numbers
1	45	0.69	7.9	21	1.0087	1.0004	25	1,500	9.1	48	23, 24a
2	45	0.69	23	62	1.0087	1.0004	25	4,300	26	48	24b
3	0	0.69	17	46	1.0087	1.0005	25	3,200	20	48	--
4	90	0.69	29	79	1.0087	1.0012	25	5,400	35	44	--
5	0	0.22	4.3	110	1.0230	1.0048	50	2,500	55	160	--
6	26.7	0.22	4.3	109	1.0230	1.0036	50	2,400	53	170	--
7	90	0.22	8.2	105	1.0230	1.0046	50	2,300	53	160	--
8	54.5	0.22	8.7	111	1.0230	1.0038	50	2,500	54	170	--
9	-25	0.22	8.9	114	1.0230	1.0046	50	2,500	57	160	--
10	90	0.46	8.4	50	1.0240	1.0070	36.5	2,300	18	100	22
11	43.6	0.46	10.2	61	1.0240	1.0059	36.5	2,800	21	107	25a
12	2.8	0.46	6.4	38	1.0240	1.0052	36.5	1,800	13	110	25b
13	-28.2	0.46	6.4	38	1.0240	1.0082	36.5	1,800	14	93	--
14	-28.2	0.46	10.2	61	1.0240	1.0082	36.5	2,800	23	93	--
15	39.1	0.46	9.7	58	1.0240	1.0062	36.5	2,700	20	106	25c
16	0	0.25	3.1	64	1.0010	1.0249	7.6	1,600	26	1,200	26a
17	0	0.25	4.8	99	1.0175	1.0021	29.5	1,900	51	210	--
18	45	0.25	4.8	99	1.0175	1.0021	29.5	1,900	51	210	21, 26b
19	0	0.25	--	--	1.0030	1.0030	0	--	infinite (2)	--	--
20	0	0.25	~12	~240	1.0015	1.0015	0	~6,000	infinite (2)	--	31
21	0	0.25	~12	~240	1.0015	1.0015	0	~6,000	infinite (2)	-- (3)	31
22	0	0.25	2.5	51	1.0101	1.0000	0	1,300	33	infinite (3)	29a
23	0	0.25	5.0	101	1.0101	1.0000	0	2,600	66	infinite (3)	30a
24	0	0.25	10.5	205	1.0101	1.0000	0	5,200	130	infinite (3)	30b
25	0	0.25	2.6	53	1.118	1.000	0	1,300	10	infinite (3)	29b
26	0	0.25	3.5	73	1.118	1.000	0	1,800	13.6	infinite (3)	29c
27	0	0.25	10.6	214	1.118	1.000	0	5,300	40	infinite (3)	28, 30c
28	0	0.25	2.6	53	1.118	1.001	9.5	1,300	10	5,000	--
29	0	0.25	3.5	73	1.118	1.001	9.5	1,800	13.6	5,000	--
30	0	0.25	10.6	214	1.118	1.001	9.5	5,300	40	5,000	26c
31	0	0.25	1.8	36	1.0134	1.0013	9.5	900	20	510	27a
32	0	0.25	3.5	72	1.0134	1.0013	9.5	1,800	40	510	20, 27b
33	0	0.25	5.4	104	1.0134	1.0013	9.5	2,700	60	510	27c

Note:

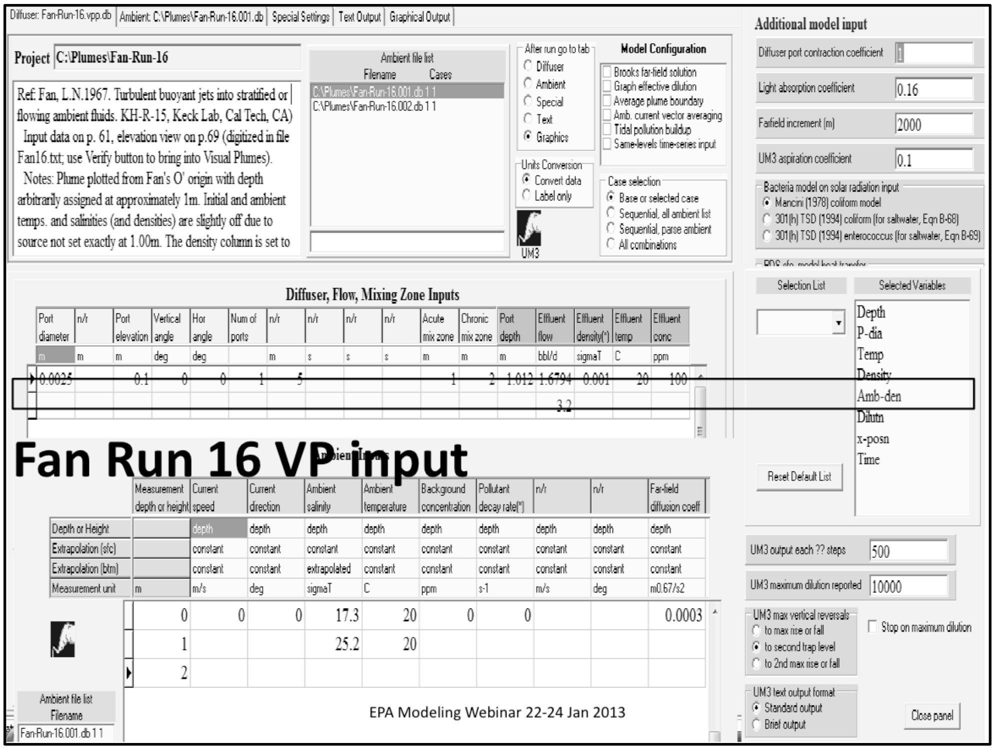
1) ρ_o is taken to be the ambient density at the level of the nozzle

2) F = infinity refers to a simple jet

3) T = infinity refers to a buoyant jet in a uniform environment

Fan Run 16 data

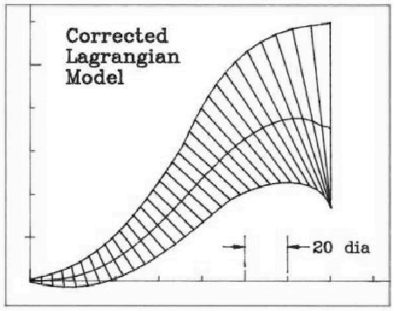
Fan Run 16 VP input

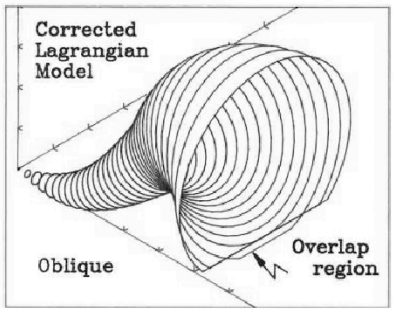


Worst Case

1) Co-flow conditions are not generally worst case for multi-port diffusers
    1) Current direction is important
2) Integral models should account for variable plume spacing
3) Existing models sometimes can be used in a way to compensate for these deficiencies where they exist:
    1) As in DOS Plumes, input reduced spacing instead of port spacing
    2) Post-process output to determine dilution at the point of plume impact
4) And, not explicitly addressed here, the plume centerline should not be used to determine when plumes surface (rather the plume edge)
5) Also, if using weighted average dilution as a measure of overall diffuser performance, merged plumes should be considered in aggregate
6) VP provides a time-series capability useful for better identifying worst-case conditions

Bonus slide





Vector Lagrangian model: Mathematical and Physical necessities

1) UM3 simulates the overall "average behavior" of the plume along the plume trajectory
2) Wire frame depiction conforms roughly to the idea or the shape of the plume element
3) However, the equal spacing between cross-sections does not conform to maintaining only effluent particles in the plume element defined at the source
4) Typically plume effluent velocities exceed current velocities and hence the plume element tends to decrease with distance from the source
    1) This implies the leading edge of the element has a lesser velocity than the trailing edge
    2) By mass continuity, the plume element radius grows from this velocity convergence (the jelly-sandwich equation)

Bonus slide