



## Introduction to Visual Plumes

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### Contents and Schedule

- 1) Purpose and intended audience (Ben Cope and others)
- 2) Visual Plumes (VP) software and systems notes and caveats
- 3) Theoretical basis, emphasis: the Lagrangian UM3 model
- 4) Visual Plumes—familiarization by basic example, the single port plume
- 5) Break
- 6) Multi-port diffuser example
- 7) Special capabilities
  - a) transition to far-field dispersion
  - b) the shallow water approximation technique
  - c) preparing and linking time-series files
  - d) background buildup
- 8) Ramifications
- 9) Questions

Notes (in the “Click to add notes” ppt space) give more detail



= animation

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>

The screenshot shows the EPA website's 'Exposure Assessment Models' page. The browser address bar is 'www.epa.gov/ceampubl/'. The page header includes the EPA logo and navigation links: 'LEARN THE ISSUES', 'SCIENCE & TECHNOLOGY', 'LAWS & REGULATIONS', and 'ABOUT EPA'. The main content area is titled 'Exposure Assessment Models' and includes a breadcrumb trail: 'You are here: EPA Home » Exposure Assessment Models'. A sidebar on the left lists various modeling products and information sources. The main text describes the EPA Center for Exposure Assessment Modeling (CEAM) and lists three types of models: Groundwater Models, Surface Water Models, and Multimedia Models. Each model type is accompanied by a small 3D diagram illustrating the environment it models. A red circle highlights the text 'chemicals and metals' in the 'Surface Water Models' section.

**Exposure Assessment Models**

You are here: EPA Home » Exposure Assessment Models

The EPA Center for Exposure Assessment Modeling (CEAM) was established in 1987 to meet the scientific and technical exposure assessment needs of the United States Environmental Protection Agency (U.S. EPA) as well as state environmental and resource management agencies. CEAM provides proven predictive exposure assessment techniques for aquatic, terrestrial, and multimedia pathways for organic chemicals and metals.

**Groundwater Models**  
Groundwater models quantify the movement of subsurface water and provide inputs to subsurface contaminant transport models. Simulation provides insight into groundwater and contaminant behavior and quantitative assessments for environmental decision making.

**Surface Water Models**  
By modeling contaminant movement and concentration in lakes, streams, estuaries, and marine environments, researchers can better understand how exposure to contaminants affects aquatic environments.

**Multimedia Models**  
Contaminants may travel through the atmosphere, soil, surface water, and the organisms that inhabit these media. The multimedia approach to exposure modeling

## Software and systems: CEAM website



Software and update: <http://www.epa.gov/ceampub/swater/vplume/index.html>

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, mercury, hg, surface water, pond, stream, river	CEAM
SWMM	Win 98, NT, ME, 2000, XP	aquatic biology, 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

# Software and systems: install and setup



Sof

Name	Date modified	Type	Size
attachments_2012_12_04	12/4/2012 12:13 PM	File folder	
project files	12/18/2012 1:18 PM	File folder	
rkiv	10/7/2011 7:14 AM	File folder	
3plumes.exe	8/7/1995 1:57 PM	Application	
PDSWIN.exe	12/24/2003 7:34 AM	Application	
Plumes.exe	10/8/2012 9:17 AM	Application	1,
Plumes60.exe	10/8/2012 9:17 AM	Application	1,
rsbfor.exe	10/31/2000 10:24 AM	Application	
xDkhw.exe	10/31/2000 10:24 AM	Application	
xUDKH-DEN.EXE	8/9/1989 8:13 AM	Application	
Arecibo41a57adii4.bmp	9/6/2011 8:34 AM	Bitmap image	2,
Arecibo41a57apath.bmp	9/6/2011 8:34 AM	Bitmap image	2,
Arecibo41a57aprof.bmp	9/6/2011 8:34 AM	Bitmap image	2,
Arecibo41a57atraj.bmp	9/6/2011 8:34 AM	Bitmap image	2,
4rossettes.001.db	10/7/2011 7:13 AM	Data Base File	
Aquadilla.001.db	10/11/2012 10:42 AM	Data Base File	
Aquadilla.vpp.db	10/11/2012 10:42 AM	Data Base File	
arec57a.001.db	9/6/2011 10:51 PM	Data Base File	
arec57a.vpp.db	9/6/2011 10:51 PM	Data Base File	
Arecibo0.001.db	10/11/2012 10:43 AM	Data Base File	
Arecibo0.vpp.db	10/11/2012 10:43 AM	Data Base File	
Arecibo41a.001 (2).db	9/8/2011 10:03 PM	Data Base File	
Arecibo41a.001.db	9/8/2011 10:03 PM	Data Base File	
Arecibo41a.vpp.db	9/5/2011 9:49 AM	Data Base File	

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## After setup:

### Software and systems: OS and use issues

**Most of VP: Windows XP and earlier**  
**Coding: Delphi 7 (no relation to Windows 7) and earlier**  
**90% interface**  
**Dependence on DLLs**  
**Borland Database Engine (e.g. BDEinfosetup.exe)**

**Vista, Windows 7, Windows 8**  
**Users Operating System experience**  
**User as novice: most issues can be resolved, not always easily**

**VP Upgrade example: install the BDE somehow;**  
**then, open Plumes.exe as Administrator; if vptempstorage**  
**error, retry; choose No, start a new project; UM3; if the error**  
**recurs, try again**

Notes

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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.

Terms and Definitions

# Terms and definitions

**Aspiration entrainment:** tends to be the dominant entrainment mechanism in low currents, including stagnant ambient; in UM3 it is proportional to the area the plume shares with the ambient fluid; where plumes are merged and are demarcated by vertical reflection planes it is assumed that the plume and its neighbor gain and lose equivalent amounts of mass so that no net entrainment occurs across those vertical surfaces, only over the surfaces still exposed to ambient fluid admittedly

**Background buildup technique:** an alternative approach to simulating the effects of merging; plumes are not restricted to the reflection technique but rather act in isolation with the effects of merging accounted for through changes to the plume's background conditions, particularly the background pollutant concentration; the approach more closely mimics actual mixing mechanisms but, to be rigorous, would involve not only adjusting the background concentration due to the presence of upstream plumes but the physical environment the plume in question occupies, including all variables and velocities

**Co-flowing plumes:** the condition where the effluent discharge and the ambient current flow in the same direction

**Control volume:** the modeling analogue of the plume element in the Eulerian plume model formulation, integral flux equations; unlike the plume element, the model accounts for flux changes as a function of  $s$ , the distance along the plume trajectory, the integration step being  $ds$ ; the stiffness of the model equations requires management of  $ds$  that can lead to discontinuous changes in the endpoint dilution as input conditions are changed only incrementally; also sometimes referred to as the plume element, the analogous Lagrangian control volume

**Counter-flowing plumes:** the condition where the effluent discharge flows in the opposite direction of the ambient current

**Critical Initial Dilution:** the flow weighted average of a diffuser plumes' endpoint dilutions; this review recommends that for the purposes of calculating the CID that merged plumes be treated as grouped entities each with their combined CID

**Cross-current:** ambient current not either co-flowing or counter-flowing will possess a component of velocity that is perpendicular to the plume at the port; cross-currents add another term to the entrainment equations, for example, as in UM3, and will tend to increase overall entrainment in the absence of merging; it is important in reducing the spacing between plumes to values less than the physical spacing

**Deep-water assumption:** integral plume models such as UD and UM3 were developed with the assumption that water depth would not constrain the motion of the plume; the reason for adopting the assumption was to simplify the theory; the models do not plume-water surface interaction; other steps or models must be taken to model the plume beyond the point where any part of it hits the surface (although some relaxation for slightly grazing the surface might be tolerable)

**Densimetric Froude number:** this is a similarity parameter that expresses the relative importance (ratio) of kinetic and potential energy inherent in the plume element at the source; small values represent pure plumes that possess little or no initial velocity (like a heated plate), large values are momentum dominated jets with little or no buoyancy perhaps requiring pump pressure to attain the high velocities; in vertical plumes (like natural draft cooling towers) values less than unity are plumes that possess excess buoyancy to briefly accelerate the plume element at the source causing it to stretch out and dynamically contract its diameter, the analogous mechanism experienced in seawater intrusion; finally, the similarity property allows plumes to be compared across spatial scales, plumes with the same similarity parameters exhibiting the same morphology (plume shape) when plotted in dimensionless terms (for example, in terms of diameters downstream and vertically)

**Notes**

UDKHDEN: a version of UDKHDEN that was developed explicitly for use with Visual Plumes (Frick et al. 2004); replaced in this review by an updated version of

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This slide is intended as a reference for future study

## Dilution Models for Effluent Discharges

4<sup>th</sup> Edition  
(Visual Plumes)

**Recommended  
Tutorial**



by

**W.E. Frick<sup>1</sup>, P.J.W. Roberts<sup>2</sup>, L.R. Davis<sup>3</sup>,  
J. Keyes<sup>4</sup>, D.J. Baumgartner<sup>5</sup>, K.P. George<sup>6</sup>**

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4 March 2003

**Ecosystems Research Division, NERL, ORD  
U.S. Environmental Protection Agency**

**960 College Station Road  
Athens, Georgia 30605-2700**

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

Visual Plumes, Ver. 1.0; U.S. Environmental Protection Agency, ERD-Athens, ORD, 22 July 2001

File Edit Models Stop Run Help

# Visual Plumes Manager/ Model Platform

Diffuser: Fan-Run-16.vpp.db | Ambient: C:\Plumes\Fan-Run-16.001.db | Special Settings | Text Output | Graphical Output

**Project: C:\Plumes\Fan-Run-16**

Ref: Fan, L.N.1967. Turbulent buoyant jets into stratified or flowing ambient fluids. KH-R-15, Keck Lab, Cal Tech, CA)  
 Input data on p. 61, elevation view on p. 69 (digitized in file Fan16.txt; use Verify button to bring into Visual Plumes).  
 Notes: Plume plotted from Fan's O' origin with depth arbitrarily assigned at approximately 1m. Initial and ambient temp. and salinities (and densities) are slightly off due to source not set exactly at 1.00m. The density column is set to

Ambient file list

Filename	Cases
C:\Plumes\Fan-Run-16.001.db	1

After run go to tab:  
 Diffuser  
 Ambient  
 Special  
 Text  
 Graphics

Units Conversion:  
 Convert data  
 Label only

UM3

**Model Configuration**

- Brooks far-field solution
- Graph effective dilution
- Average plume boundary
- Amb. current vector averaging
- Tidal pollution buildup
- Same-levels time-series input

Case selection:  
 Base or selected case  
 Sequential, all ambient list  
 Sequential, parse ambient  
 All combinations

**VP's main tab: Diffuser, Flow, Mixing Zone Inputs**  
**the Diffuser tab**

Port diameter	n/i	n/i	n/i	Acute mix zone	Chronic mix zone	Port depth	Effluent flow	Effluent density(*)	Effluent temp	Effluent conc
m	m	m	deg	deg	m	s	s	s	m	ppm
0.0025		0.1	0	0	1	5				

Parameters for selected row

Froude number	25.29
Eff density (kg/m3)	1000.001
Port vel (m/s)	0.63
P.dia (m)	0.0025
P.dia (in)	2.5000E-3
Case No.	1.0

Time Series-Files (optional)

Time-series filename	Port depth	Effluent flow	Effluent density(*)	Effluent temp	Effluent conc
	click for file	click for file	click for file	click for file	click for file
Time increment (hrs)					
Time cycling period					
Measurement unit					

Borrow time-series from project: C:\Plumes\Fan-Run-16

Visual Plumes, Ver. 1.0; U.S. Environmental Protection Agency, ERD-Athens, ORD, 22 July 2001

File Edit Models Stop Run Help

# The Ambient tab

Diffuser: Fan-Run-16.vpp.db Ambient: C:\Plumes\Fan-Run-16.001.db Special Settings | Text Output | Graphical Output

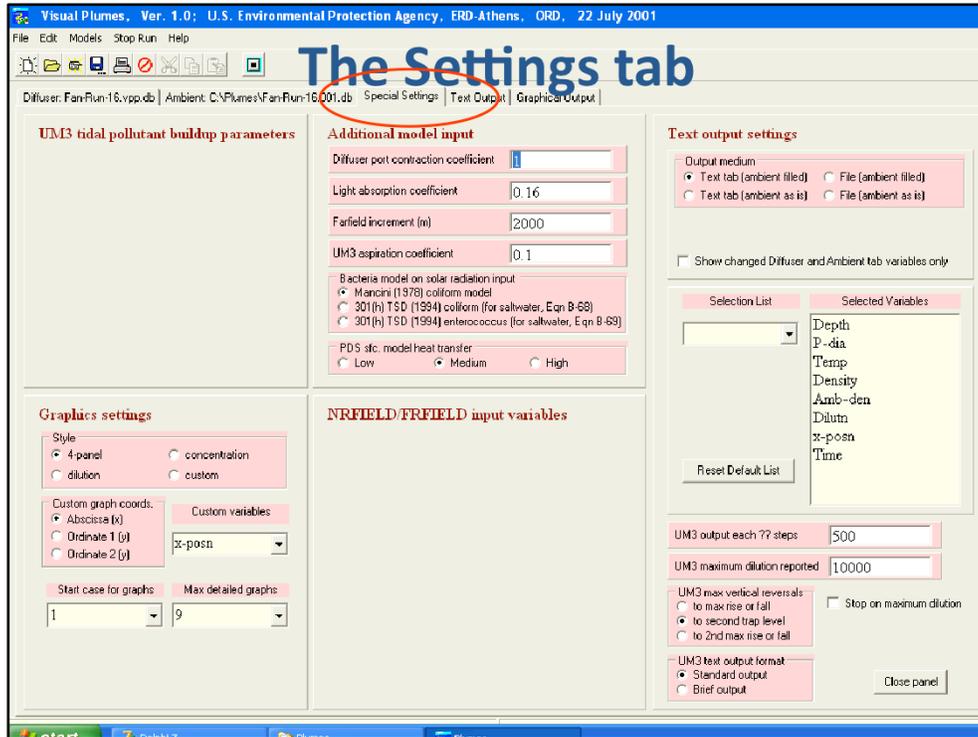
### Ambient Inputs

	Measurement depth or height	Current speed	Current direction	Ambient salinity	Ambient temperature	Background concentration	Pollutant decay rate(*)	n/z	n/h	Far-field diffusion coeff.
Depth or Height	depth	depth	depth	depth	depth	depth	depth	depth	depth	depth
Extrapolation (sf)	constant	constant	constant	constant	constant	constant	constant	constant	constant	constant
Extrapolation (btm)	constant	constant	constant	extrapolated	constant	constant	constant	constant	constant	constant
Measurement unit	m	m/s	deg	sigma-t	C	ppm	s-1	m/s	deg	m0.67/s2
	0	0	0	17.3	20	0	0			0.0003
	1			25.2	20					
	2									

Ambient file list  
Filename  
Fan-Run-16.001.db 1 1

Time-Series Files (optional) Borrow time-series files from project: C:\Plumes\Fan-Run-16

Time-series filename	click for file								
Time increment (hrs)									
Cycling period									
File measurement unit									



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

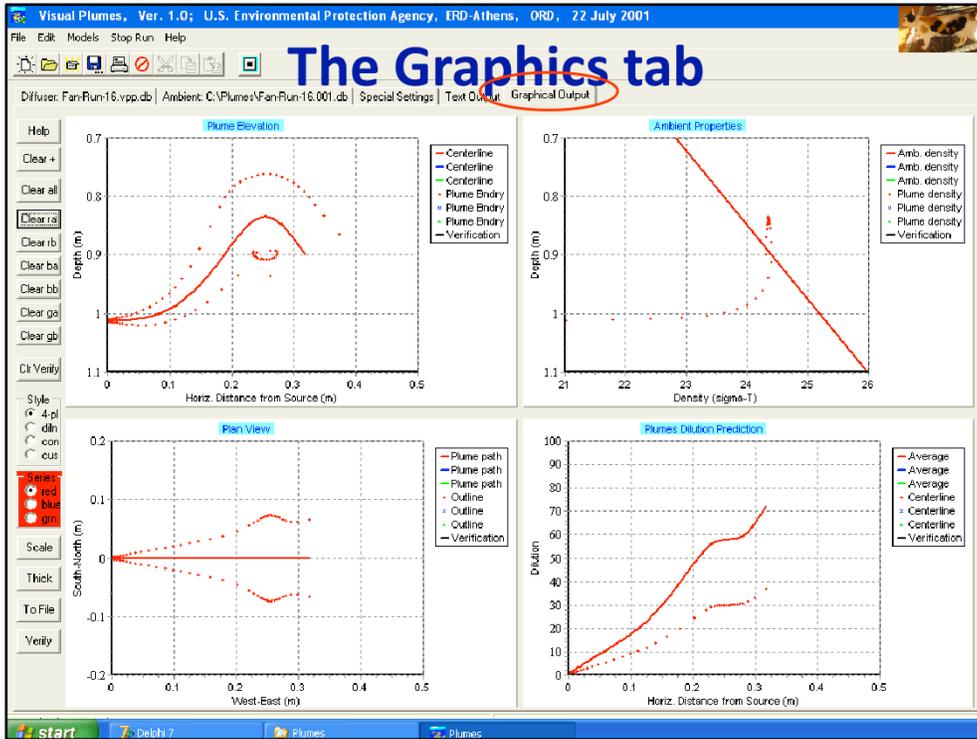
```

/ 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  AcuteHZ  ChrnHZ  P-depth  Ttl-ilo  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:
Frowde number: 25.28; effluent density (sigma-T) 0.001; effluent velocity 0.63(m/s);
Step  Depth  P-dia  Teap  Density  Amb-den  Dilutn  x-posn  Time
(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

```



Diffuser Peculiarity.vpp.db | Ambient: C:\PlumesXIV\Peculiarity.001.db | Special Settings | Text Output | Graphical Output

**Project:** C:\PlumesXIV\Peculiarity.vpp.db

Project "C:\PlumesXIV\Peculiarity" memo  
 The basis of this project was that a user identified an instance of the degenerative effluent ambient velocity matching problem. When the velocities are identical and co-flowing there is no forced entrainment or aspiration and the predictions are anomalous

Files: C:\PlumesXIV\Peculiarity.001.db 1 1  
 C:\PlumesXIV\Peculiarity.002.db 1 1

Model:  
 Diffuser  
 Ambient  
 Special  
 Text  
 Graphics

Units Conversion:  
 Convert data  
 Label only

Case selection:  
 Base or  
 Sequen  
 Sequen  
 All comb

**Diffuser, Flow, Mixing Zone Inputs**

Port diameter	Vertical angle	Horizontal angle	Source x-coord	Source y-coord	Num of ports	Port spacing	n/t	n/t	n/t	Mix zone distance	Isopleth value	Port depth	Effluent flow	Effluent salinity(‰)	Effluent temp	
m	deg	deg	m	m		m	s	s	s	m	concent	m	m <sup>3</sup> /s	psu	F	
0.057	0	0	0	0	1	999				1	0	3.7	0.00053		0	70
0.058	0															

Parameters for selected row

Froude number	
Eff density (kg/m <sup>3</sup> )	
Port vel (m/s)	
Spacing (m)	999.0
Spacing (m)	999.0
Case No.	1

Time Series-File

Time-series filename	click for file	click for file	click for file	click for file	click for file
Time increment (hrs)					
Time cycling period	ebinar 22-24 Jan 2013				
Measurement unit					

Time series from project: C:\PlumesXIV\Peculiarity

Effluent salinity(‰) Effluent temp Effluent conc

UM3

## Visual Plumes Model Suite

**DKHW:** Physics-based **exe**, Eulerian numerical formulation, integral flux model. One or multi-port diffusers.

**NRFIELD:** Empirical, dimensional analysis and curves fit to data; **exe**. Based on T-risers, for 4 or more ports.

**UM3:** Physics-based **native**, Lagrangian numerical formulation, material element model. One or multi-port diffusers. el

**PDS:** Eulerian integral flux surface plume model; **exe**. Buoyant discharges

**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.**

**All but PDS link to the Brooks far-field algorithm, far-field dispersion model.**

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**Notes**

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

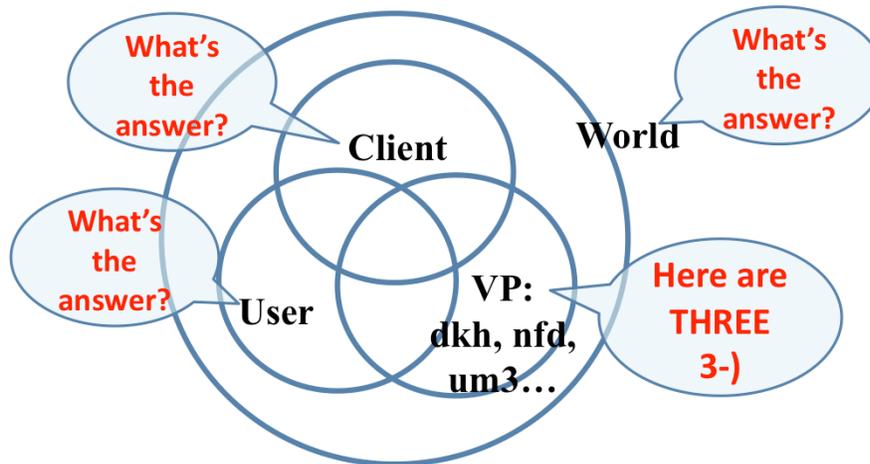
UM3 examples (built into Visual Plumes--not an external application)

examples chosen for simplicity, generality, and teaching potential

**VP is public domain software**

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## Mixing Zone analysis

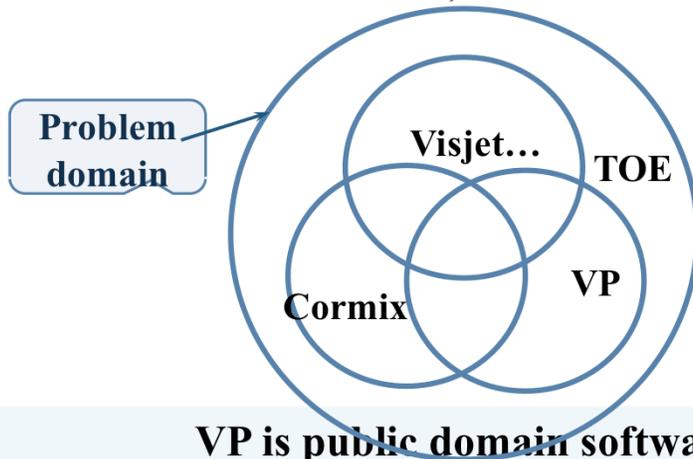


**Answers, yes, but no one knows it all (otherwise there'd one). MZ analysis is a partnership**

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## 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

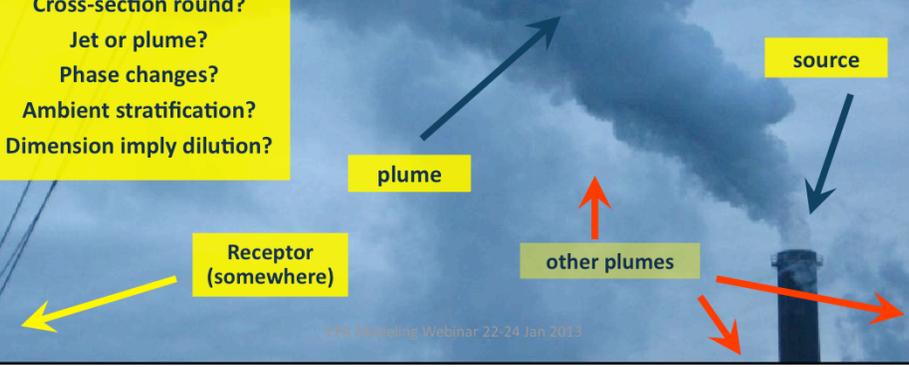
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**Even at its simplest, plume modeling guidance can appear mysterious and ambiguous. Understanding the capabilities and limitations of available models can help avoid pitfalls and confusion and promote confidence in model outputs. This section seeks 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?



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## 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.”

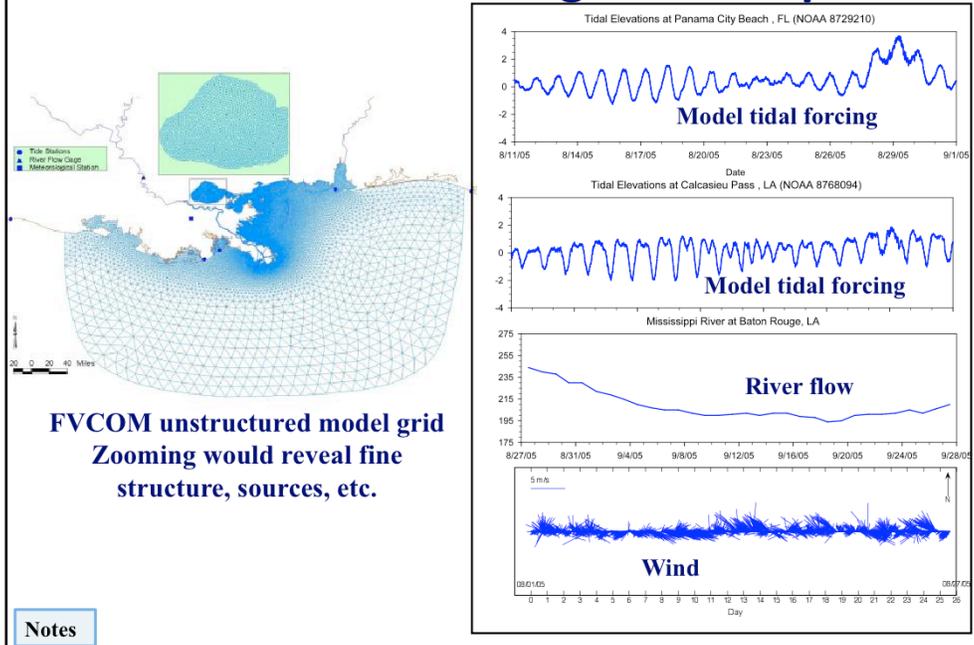
[http://en.wikipedia.org/wiki/Theory\\_of\\_everything](http://en.wikipedia.org/wiki/Theory_of_everything)

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....**

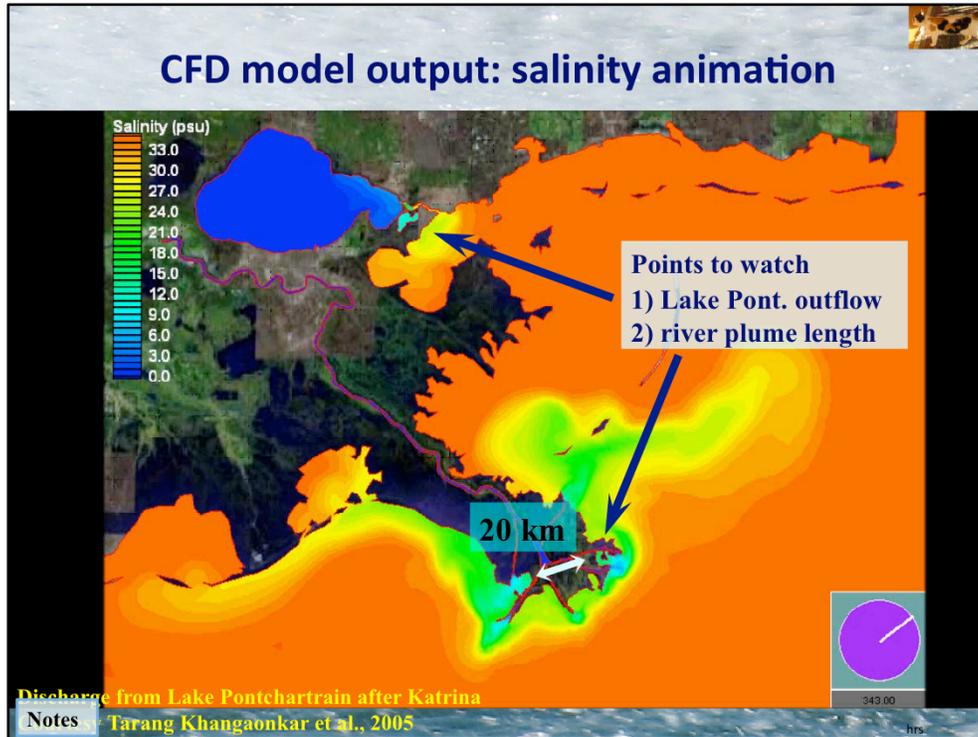
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## Meet a CFD model: grid and input

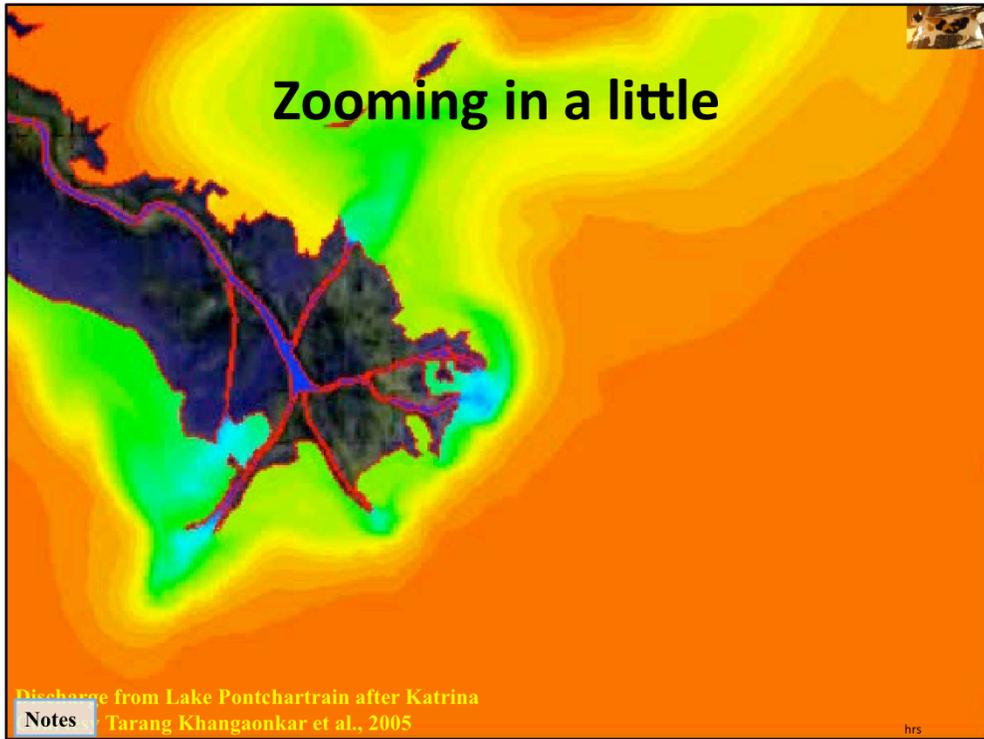


This work concerned events surrounding Hurricane Katrina, 2005.

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....**

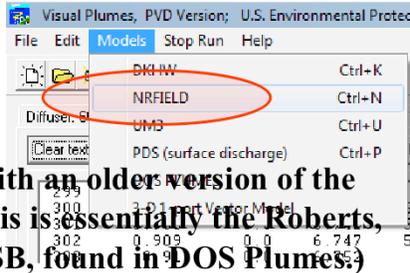
**We (modelers, users...) must formulate dispersion coefficients everywhere (eddies and turbulence) (models in themselves)**

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

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## 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

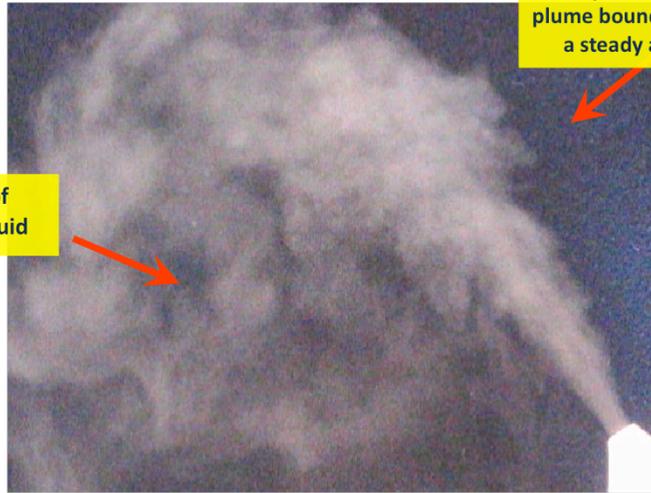
It is an endpoint model...

Notes

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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



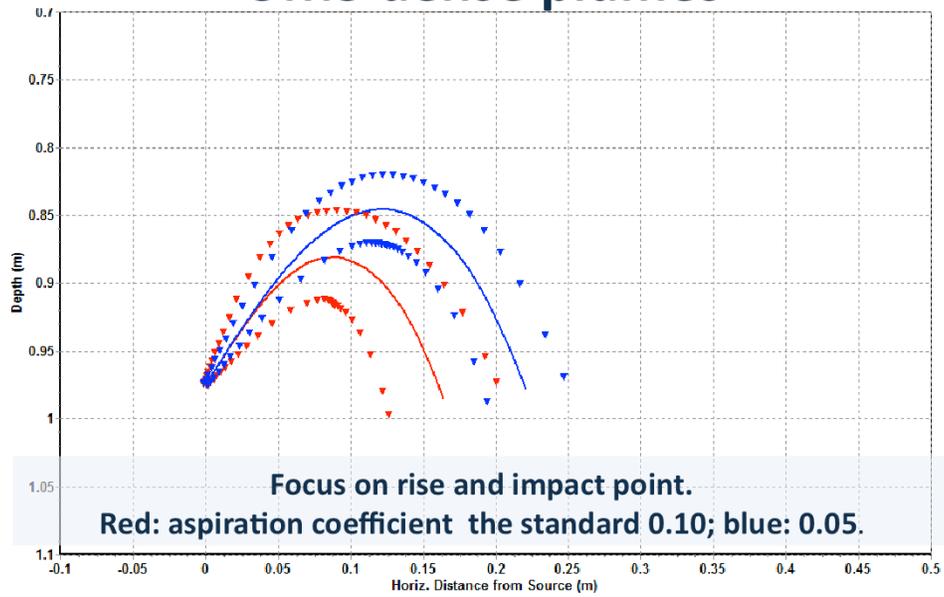
Evidence of  
detraining fluid

The "plume envelope" or  
plume boundary maintains  
a steady appearance

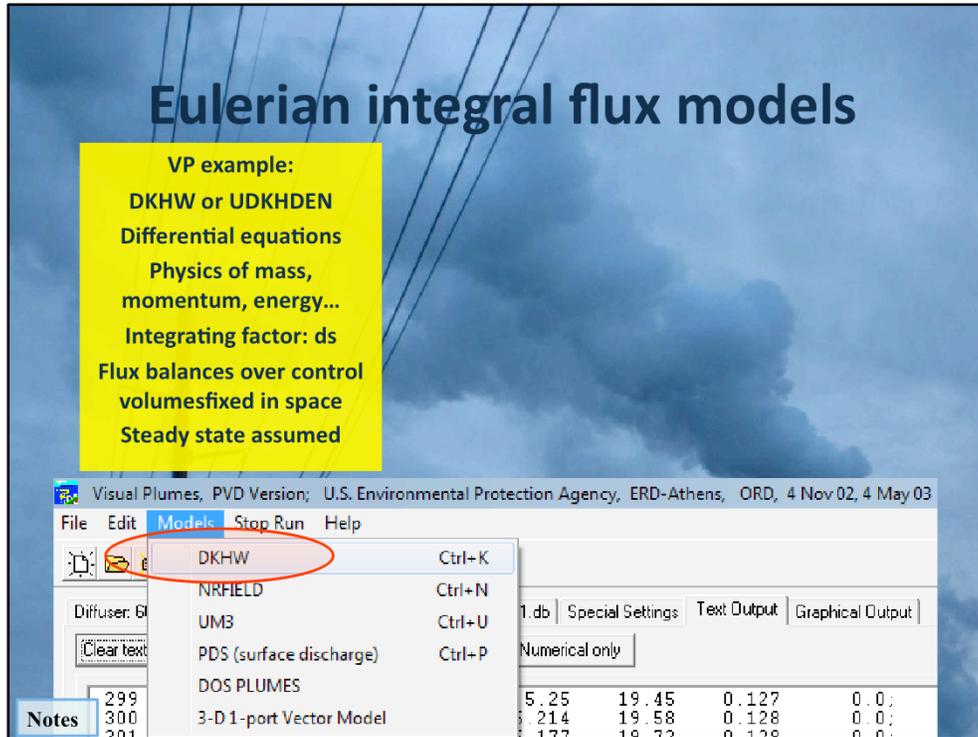
A household dehumidifier plume showing evidence of unexpected behavior. Mimicking the laboratory, will NRFIELD be the first model modified to explain observations?

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# UM3 dense plumes



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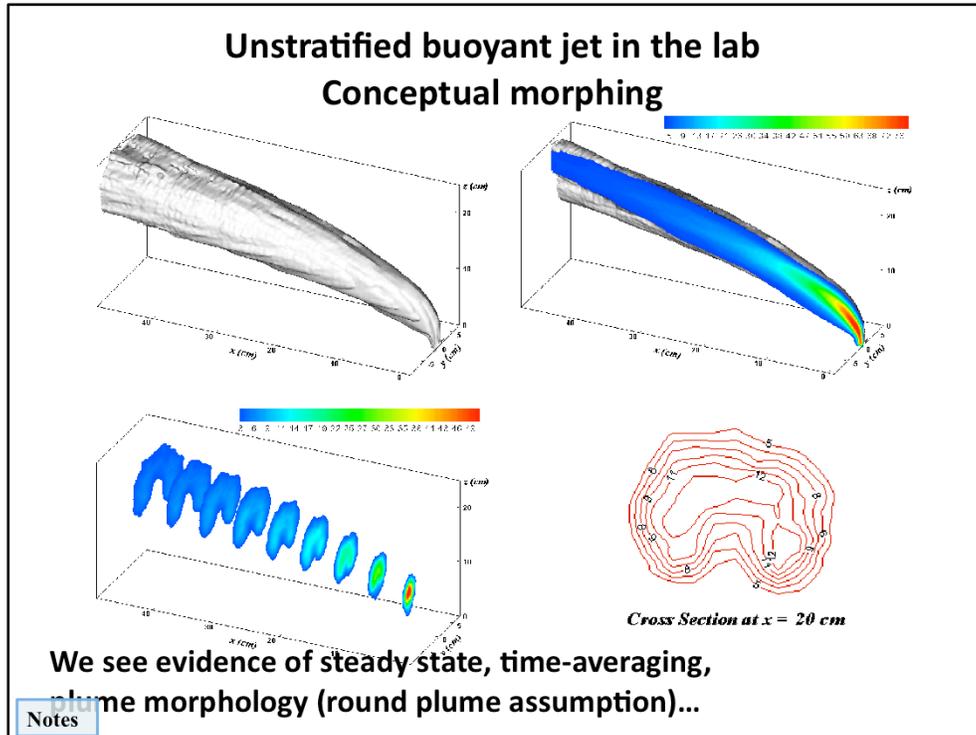


Corjet, one of the models in Cormix, is also an Eulerian integral flux model.

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?



Define the source:  
 IC, BC..  
 velocity vector ↑  
 radius  
 temperature ●  
 salinity ●  
 concentration ●  
 current ←  
 orientation...

Conservation of mass (4.1)

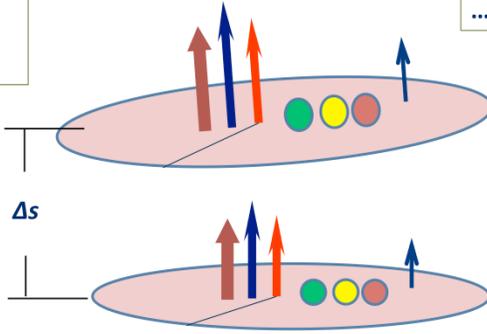
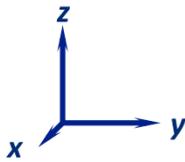
$$\frac{d}{ds} \int_0^\infty \bar{u} r dr = E$$

$$\left( \int_0^\infty \bar{u} r dr \right)_{s+\Delta s} = \left( \int_0^\infty \bar{u} r dr \right)_s + E \Delta s$$

Derive (compute)...

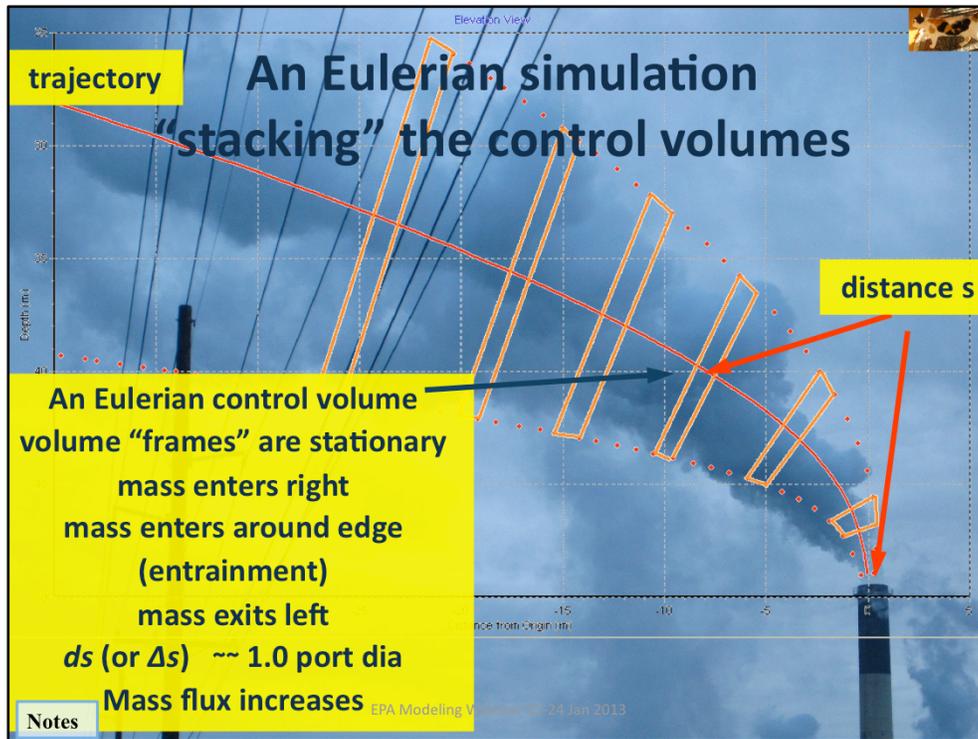
density  
 buoyancy  
 area...  
 mass flux ↑  
 momentum flux ↑  
 energy flux ↑  
 ...

Define coordinate system and location



By the way, the integral  $\int_0^\infty \bar{u} r dr$  is the mass flux





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

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## Finite difference plume model comparison

We just saw the Eulerian integral flux formulation

The infinitesimal distance  $ds$  is the integrating factor

Differential equations express fluid dynamics (physics)

e.g. conservation of mass:  $\frac{d}{ds} \int_0^\infty \bar{u} r dr = \text{entrainment}$

where the integral is consistent with the choice of control volume

In finite difference models  $ds$  is expressed by  $\Delta s = s_2 - s_1$ , which is small

Other equations, e.g. eqn. of state, bookkeeping, ... round out the model

With the Lagrangian integral flux formulation we will find

The infinitesimal time  $dt$  is the integrating factor

The control volume is called the plume element

It is a material (coherent) element

Again, differential equations express fluid dynamics (physics)

e.g. conservation of mass:  $\frac{dm}{dt} = \text{entrainment}$

where  $m = \rho_{\text{plume element}} \text{vol}_{\text{plume element}}$

In finite difference models  $dt$  is expressed by  $\Delta t = t_2 - t_1$ , which is small

Again, other equations, e.g. eqn. of state, bookkeeping, ... round out the model

Notes

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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.

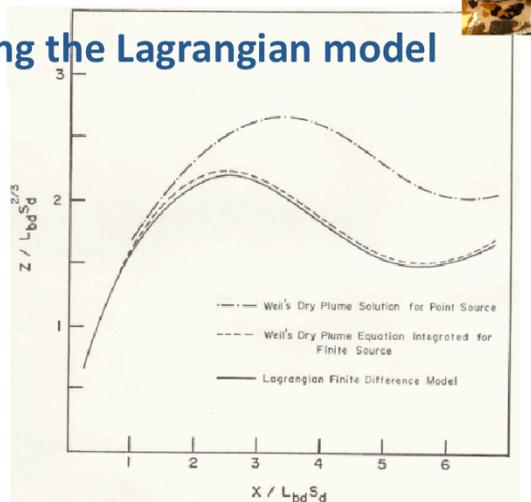
## Replication: proving the Lagrangian model

Eulerian plume models came first  
(Fan 1967, Weil 1974....)

Late to the party, when Winiarski  
& Frick developed the Lagrangian  
plume model formulation they set  
out to prove its equivalence to the  
Eulerian formulation

This was successful given the same  
assumptions: a round plume,  
steady state, equations of state,....

The proof was published and  
clarified the initial conditions of  
Weil's Eulerian plume model  
integration (upper and middle  
traces).



### Comments on "The Rise of Moist, Buoyant Plumes"

WALTER FRICK AND LARRY WINIARSKI

Thermal Pollution Branch, Environmental Protection Agency, Corvallis, Ore. 97330  
27 December 1974

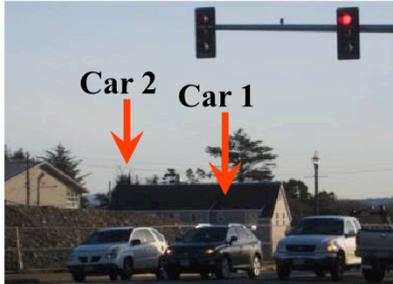
Notes

EPA Moc

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

## steady state leads to bonus ? answer

Two cars stopped, after they start how far apart are they when they reach the open road traveling, say, 60mph (88fps)?



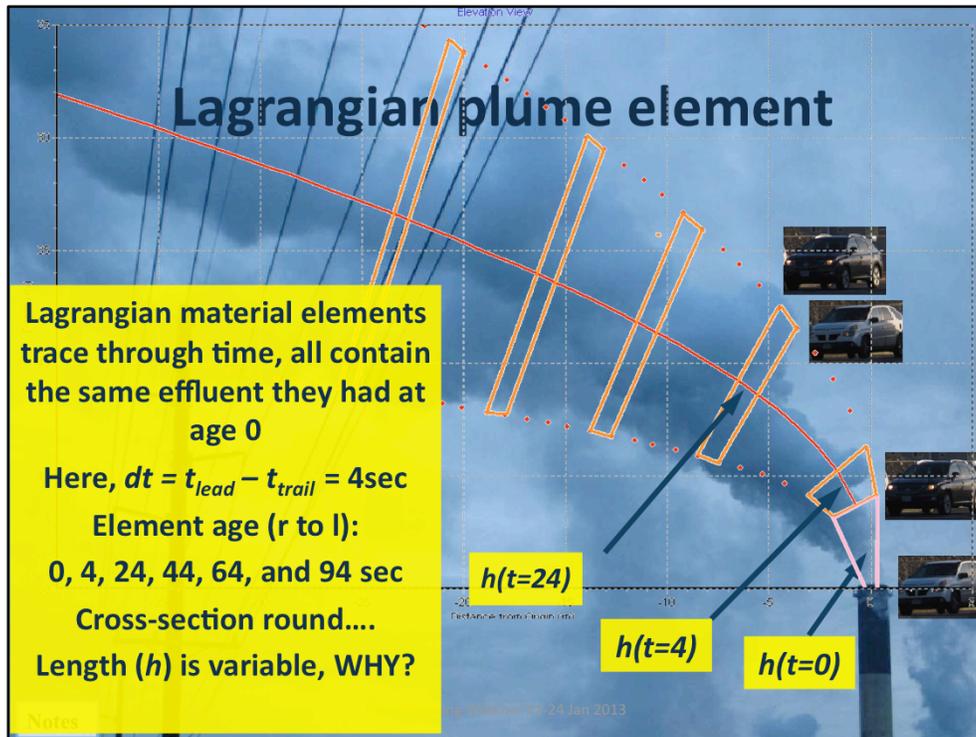
Trick question, we don't know the answer. However, we would if  
(1) we knew the time between Car 1 and Car 2 starting, and,  
(2) both drivers drove identically (same time history, steady state).

E.g., if they started 1.00sec apart, they would always be 1.00sec apart, which translates to 88ft at 60mph, 44ft at 30mph, etc.

Notes

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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.

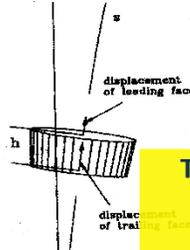
As the leading and trailing faces occupy position a given amount of time different in age,  $h = (\text{instantaneous speed})(t_2 - t_1)$ . Given steady state, the height  $h$  is a only a function of the instantaneous speed because  $t_2 - t_1$  is constant while steady state is maintained. Actual plume 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.

## Steady state and plume element length, $h$ ; the “free” equation gives the answer



Referring to Figure 65,  $\Delta|Z|$  is seen to be the difference in velocity at two opposing faces of the semi-infinitesimal element. (The velocity vectors are proportional to the displacement shown. Also, in both formulations the element is infinitesimal only along trajectory, thus it is a hybrid in volume which is treated differently from truly infinitesimal volume elements.) Since the Lagrangian formulation with material elements and it is assumed the velocity is uniform, the faces separate or converge, proportional to  $\Delta|Z|$ , i.e.,

$$\Delta h = \Delta|Z| \delta t \quad (29)$$



$$\frac{h}{h_0} = \frac{u_s}{u_{s0}}$$

The mass of the plume element

$$m = \rho \pi h r^2$$

or

$$r = \sqrt{\frac{m}{\rho \pi h}} \quad (30)$$

Thus  $r$  is not only a function of the mass of the plume element but also its height (or length)  $h$

**The answer to the poll question is NO**

where  $\Delta t$  is an arbitrary, but constant, time increment. Integrating Equation 29 and noting that the corresponding speed differentials and lengths are  $\Delta|Z|$  and  $h_0$ , and  $\Delta|Z|$  and  $h$  yields

$$\int_{h_0}^h dh = \delta t \int_{u_{s0}}^{u_s} du_s$$

where  $u_s = |Z|$  and  $u_{s0} = |Z_0|$ . Equation 30 can be integrated to yield

$$h - h_0 = (u_s - u_{s0}) \delta t$$

Finally, since  $\Delta t$  can be chosen to be  $h_0/u_{s0}$ ,

$$\frac{h}{h_0} = \frac{u_s}{u_{s0}}$$

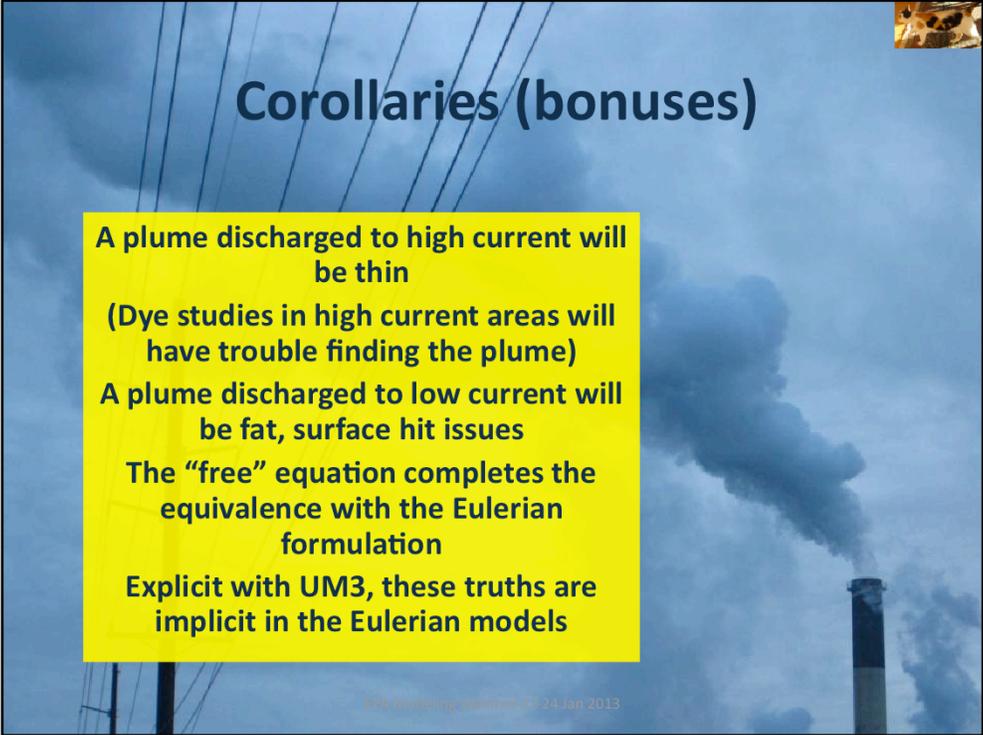
and  $|Z|$ , i.e.  $u_s$  and  $h$  change proportionally.

Figure 65. Convergence of element faces due to differences in face velocities.

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Notes

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**

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## 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  $h_0$ ) and  $\Delta t$

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  $\Delta m$ , the mass entrained into the plume element in the time step  $\Delta t$ .  
Requires an **entrainment function**

Calculate new element properties by mixing  $m$  and  $\Delta m$ . E.g., new salinity:

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

Apply equation of state ( $\rho, S, T$ ); 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

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## The name of the game: entrainment



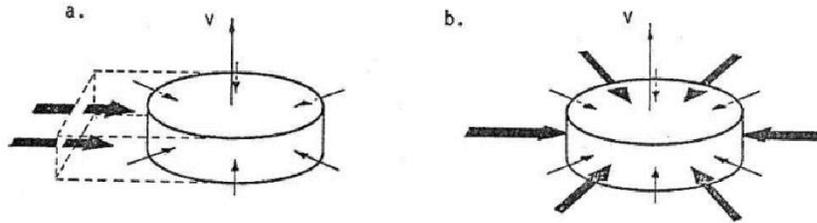
Considering that **identical** assumptions result in Eulerian integral flux and Lagrangian model **equivalence**, what sets integral models apart are the assumptions (if the underlying assumptions are different)

- (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.

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## Early entrainment conception

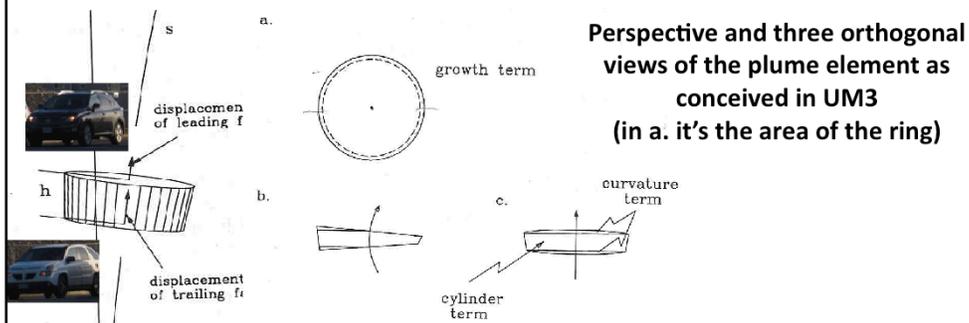


### historical context

- 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**

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# 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 =

$$(\text{ambient density}) * (\text{current}) * (\text{total area projected to the current})$$

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

$$(a) \text{ growth} + (b) \text{ cross-flow} + (c) \text{ cylinder and curvature}$$

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

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## 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  $\theta$ ?**

**1, 2, 5, 10?**

Notes

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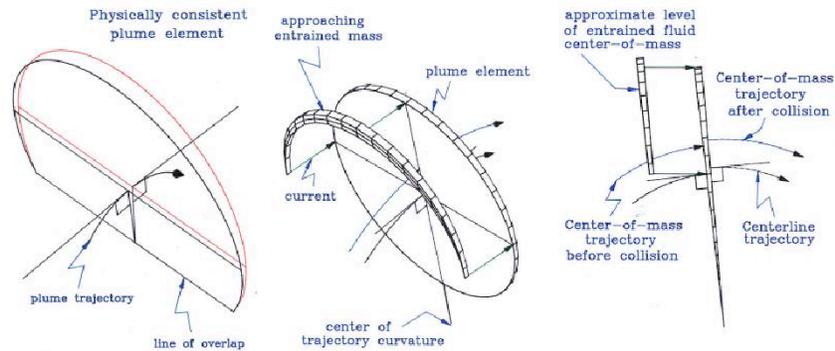
Understanding the significance of the steady state assumption ultimately led to a completely new conception of the plume element. The right-cylinder tuna can was replaced by a section from a bent cone. The trick became to accurately derive the projected area of the plume element’s surface as a function of  $r$ ,  $h$ , and  $\theta$ , 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

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.

## Model convergence scheme discontinuity



Differential equations (DE) express changes with time or distance that **cannot be solved exactly** (analytically).

Solving stiff equations means, in UM3, a new  $\Delta t = t_2 - t_1$  each step

UM3:  $\Delta t$  changes gradually & smoothly

DKH:  $\Delta s$  changes relatively larger

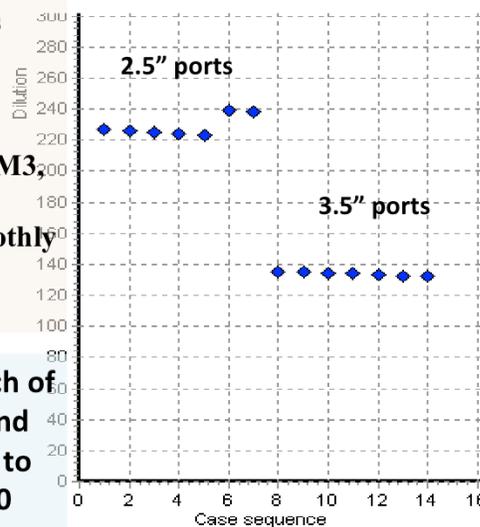


Figure: Two diffuser sections. Each of the 6 dilution estimates correspond to port spacing varying from 3.66 to 3.565m, very little. Between 3.570 and 3.565m the predicted DKH dilution increases over 8%.

Which side of the discontinuity has the more accurate solution?

Notes

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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  $\Delta t: t_2 - t_1$

For the Eulerian integral flux the infinitesimal integrating factor  $ds$  is replaced by  $\Delta s: s_2 - s_1$

The numeric integration is stepwise

If  $\Delta t$  or  $\Delta s$  are too large the solution diverges from the true solution

because the  $\Delta t$  or  $\Delta s$  too crude to capture rapid changes

If  $\Delta t$  or  $\Delta s$  are too small the solution diverges from truncation errors

The plume equations are sometimes called stiff:

at first  $\Delta t$  or  $\Delta s$  must be tiny but if constant truncation errors build up

Convergence schemes are needed, for example,  $dt$  must increase as the plume solution develops

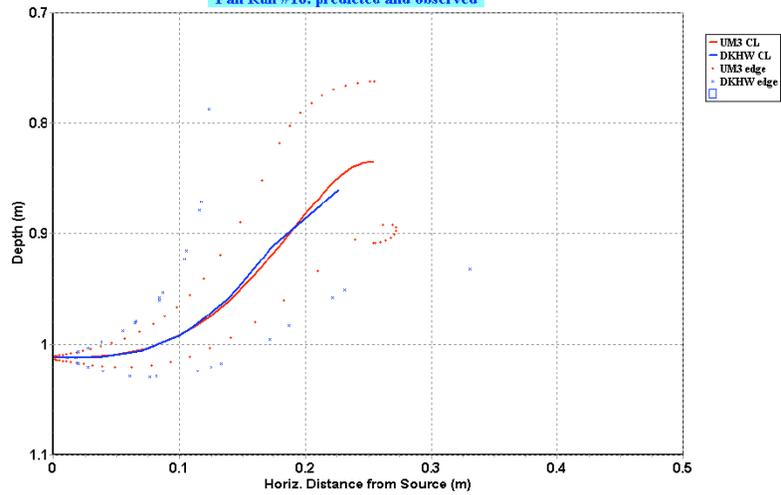
Good increase schemes for  $\Delta t$  or  $\Delta s$  yield solutions that converge

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

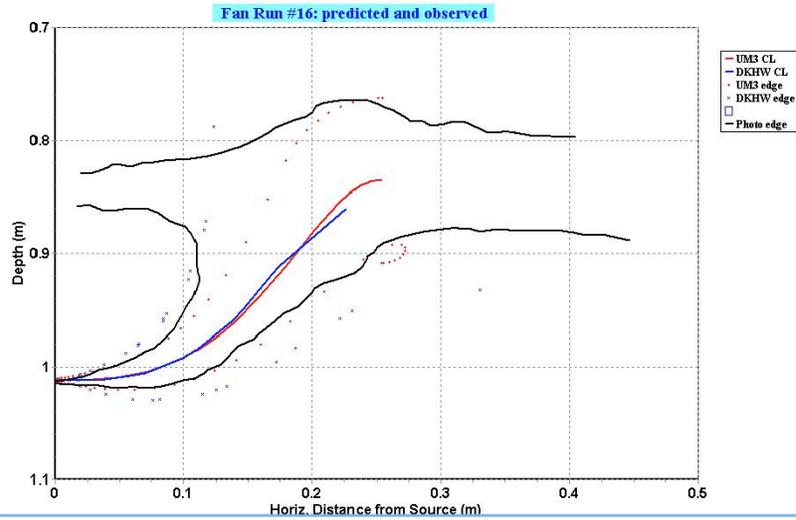
## Model comparison example: 1-port

Fan Run #16: predicted and observed



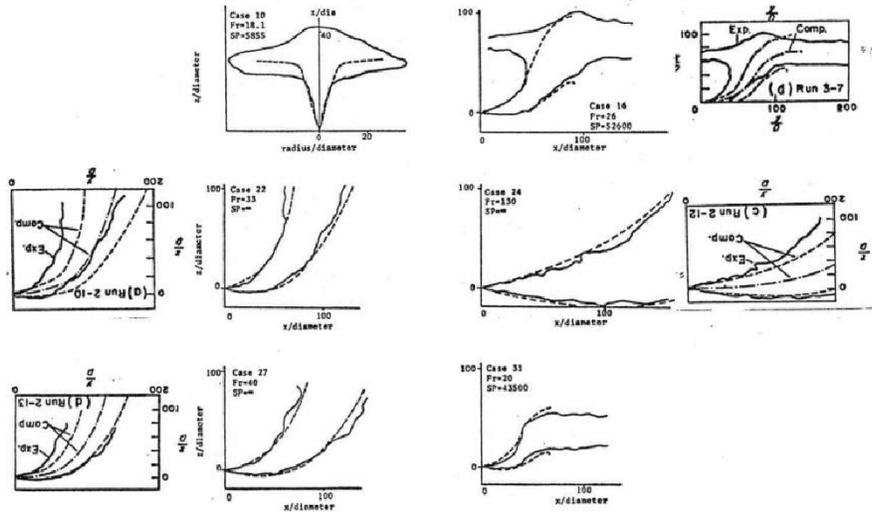
Fan Run 16 input; DKHW (blue) and UM3 (red) simulations.  
Stagnant, density stratified environment.

## 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



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Visual Plumes Ver 1.0 - U.S. Environmental Protection Agency, ERD-Athens, ORD, 22 July 2001

Diffuser: Fan-Run-15.vpp.db Ambient: C:\Plumes\Fan-Run-15.vpp.db

menus, buttons

# Fan 16 diffuser tab

Active tabs

Ambient Inputs

Measurement	Current	Current	Ambient	Ambient	Background	Pollutant	n/r	n/r	Far-field
depth or height	speed	direction	salinity	temperature	concentration	decay rate(1)			diffusion coeff.
Depth or Height	depth	depth	depth	depth	depth	depth	depth	depth	depth
Extrapolation (sf)	constant	constant	constant	constant	constant	constant	constant	constant	constant
Extrapolation (ftn)	constant	constant	constant	constant	constant	constant	constant	constant	constant
Measurement unit	m/s	deg	sigmaT	C	ppm	s-1			m <sup>2</sup> /s <sup>2</sup>

extrapolation modes

select units

run active model

Ambient file list

Ambient file list

ambient table

Time-Series Files (optional)

Borrow time-series files from project: file redirection

click in time-series files

Time-series filename	click for file								
Time increment (hrs)									
Cycling period									
File measurement unit									

Visual Plumes, Ver. 1.0: U.S. Environmental Protection Agency, ERD-Athens, ORD, 22 July 2001

File Edit Models Stop Run Help

# Fan 16 settings tab

Diffuser: FanRun-16.vpp.db | Ambient: C:\Plumes\FanRun-16.001.db | Special Settings | Text Output | Graphical Output

**UM3 tidal pollutant buildup parameters**

**context sensitive cells**

**Additional model input**

Diffuser port contraction coefficient: [input field]

Light absorption coefficient: 0.16

**parameter settings Sub-model selection**

Mancini (1976) coliform model  
 301(h) TSD (1994) coliform (for saltwater, Eqn B-68)  
 301(h) TSD (1994) enterococcus (for saltwater, Eqn B-69)

PDS stc model heat transfer:
   
 Low  Medium  High

**Text output settings**

Output to screen  
 Text tab (ambient file)  File (ambient file)  
 Text tab (ambient file)  File (ambient file)

**text output appearance**

Show changed Diffuser and Ambient tab variables only

**Graphics settings**

Style:
   
 4-panel  concentration  custom
   
 dilution  custom

Custom graphics variables:
   
 Abscissa
   
 Ordinate 1 (ft)
   
 Ordinate 2 (ft)

Start case for [input field]
   
 Contour
   
 Contour

**graphics control contour concentration**

**NRFIELD/FRFIELD input variables**

**reserved**

Selection List: [dropdown]

Selected Variables:

- Depth
- P-dil
- Temp
- Dist
- Amb-den
- P-posn
- Time

**output variable selection active output variable list**

**UM3 settings**

UM3 output scale: 500

UM3 maximum dilution: 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

# Fan 16 text output tab, UM3

data post process options

model ID, case #, project ID

ambient table

Depth	Amb-cur	Amb-dir	Amb-den	Amb-C	Decay	Far-spd	Far-dir	Disprsn	Density
m	m/s	deg	psu	kg/m <sup>3</sup>	s <sup>-1</sup>	m/s	deg	m <sup>2</sup> /s <sup>2</sup>	sigma-T
0.0	0.0	0.0	25.13	20.0	0.0	-	-	0.0003	17.3
1.0	0.0	0.0	35.55	20.0	0.0	-	-	0.0003	25.2
2.0	0.0	0.0	45.86	20.0	0.0	-	-	0.0003	33.1

diffuser and effluent table

Y-dia	P-elev	V-angle	H-angle	Ports	AcuteWZ	ChnWZ	P-depth	Ttl-flt	Eff-den	Temp	Polutnt
(m)	(m)	(deg)	(deg)	(m)	(m)	(m)	(m)	(m)	(sigmaT)	(C)	(ppm)
2.50E-3	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.00E-3	20.0	100.0

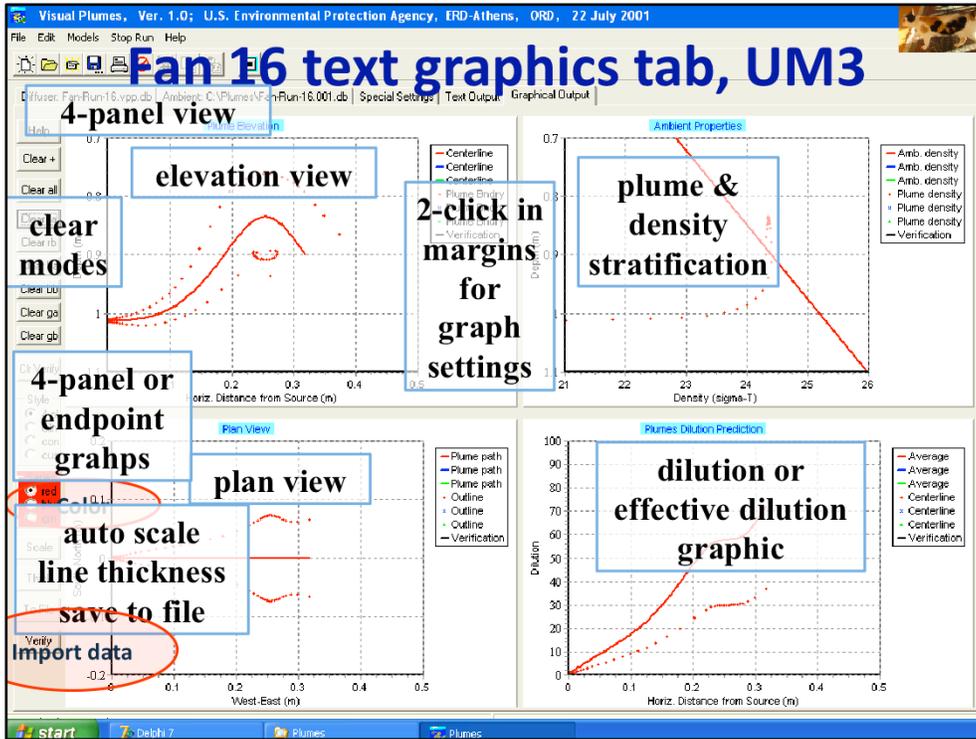
initial dilution simulation

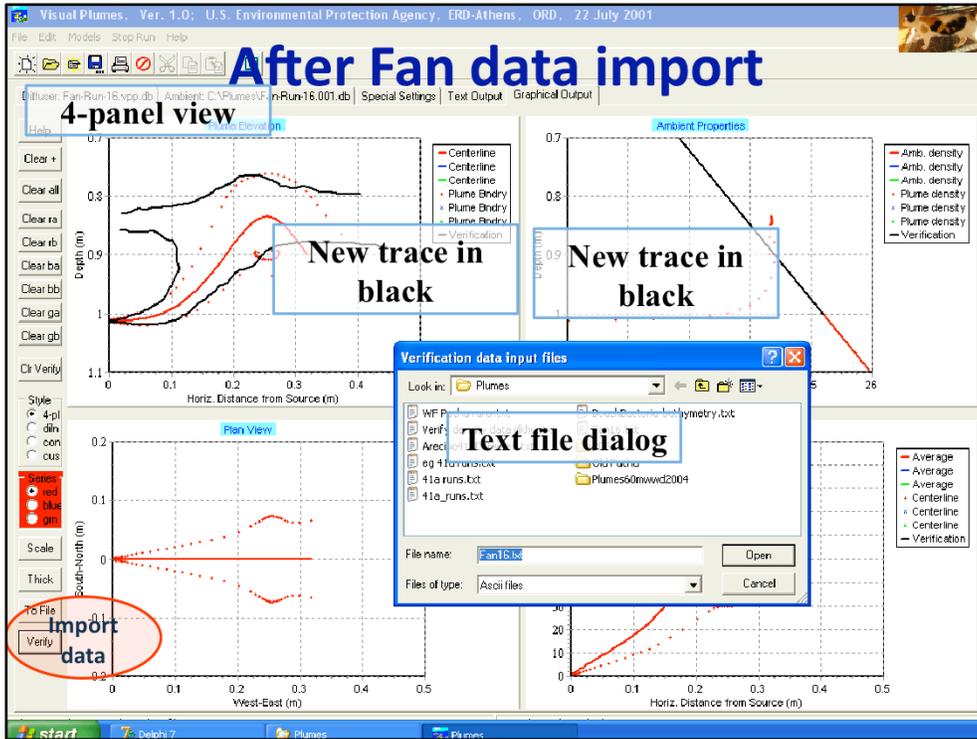
Step	Time (s)	Trap Density (sigmaT)	Amb-den (sigmaT)	Dilutn (C)	x-posn (m)	Time (s)
0	0.00	0.00E+00	0.00E+00	1.00	0.00	0.00
206	5.96	24.4092	24.3743	44.28	0.192	5.962: trap level;
225	8.67	24.3701	24.0186	55.34	0.225	8.673: begin overlap;
303	11.35	24.3528	23.8028	57.73	0.254	11.35: local
392	14.69	24.3305	24.0639	61.58	0.289	14.69: end overlap;
408	17.83	24.3114	24.3639	63.91	0.318	17.83: trap level;

Dilution factor

endpoint notes

far-field simulation if Brooks far-field algorithm linkage is set







# Flat data text file

side view

Key words to indicate elevation view

plume outline x-y coordinates

blank line to lift pen

Key words to indicate density panel

density panel

plume density coordinates

VP manual has detail

Notes

...omitted data (notes)

```

side view
0.0001 1.0145
0.0068 1.0157
0.0149 1.0158
0.0237 1.0153
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
0.4463 0.8879
0.4079 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 0.7836

```

```

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 1.0111
0.0042 1.0126
0.0001 1.0124
density panel
17.3 0.0
25.2 1.0

```

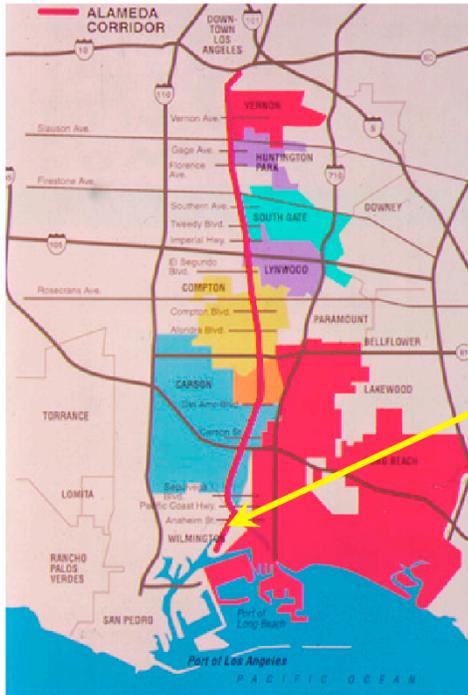
```

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

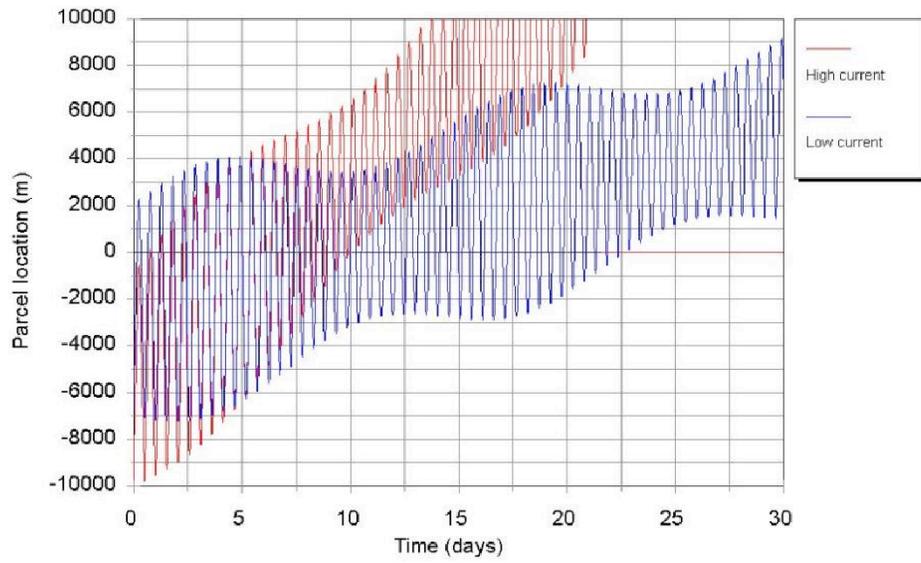
```

## Multi-run example Dominguez Channel

- Project map
- Channel

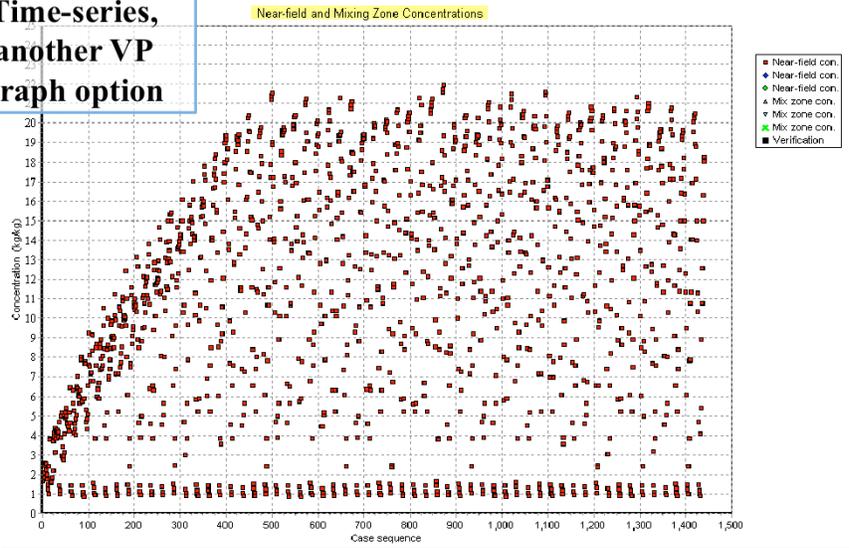


# Tidal Channel Excursion



# Time-Series Approach output

Time-series,  
another VP  
graph option



## Maximum Impact

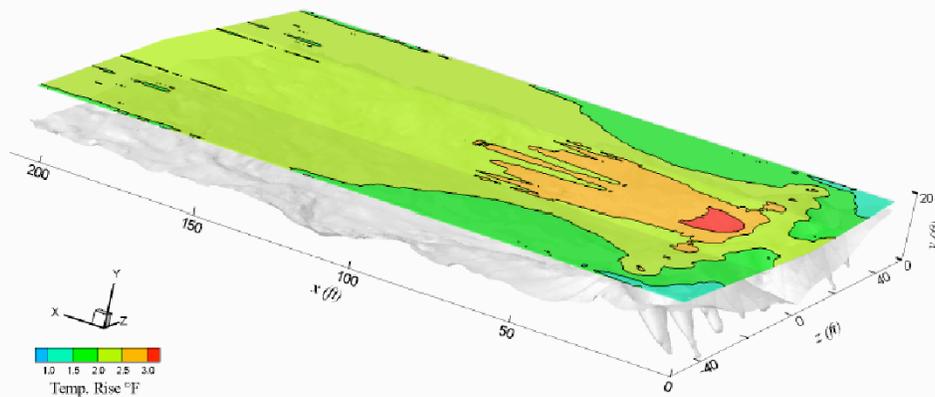


Figure 5. Perspective view of surface temperature rise.

- Surface temperature elevation hot spot

## Summary

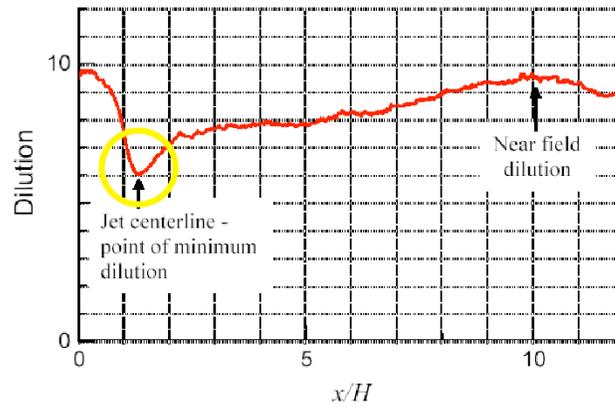
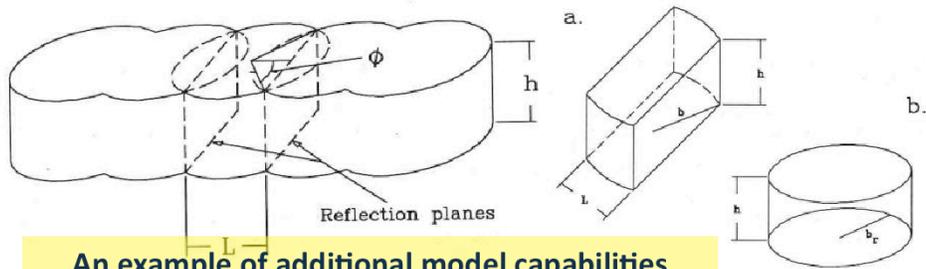


Figure 6. Variation of surface dilution with distance from the diffuser on the diffuser centerline.

- Verification? Verifying the verifier.

## Simulating merging with UM3

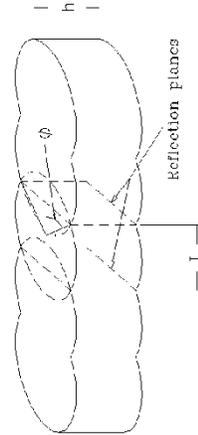


- When neighboring plumes merge, the mass is shifted in a direction perpendicular to the axis of the wastefield
- This is known as the reflection technique
- UM's algorithm is patterned after DKHw (UDKH DEN)
- In a and b, mass is conserved by this technique

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## 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.



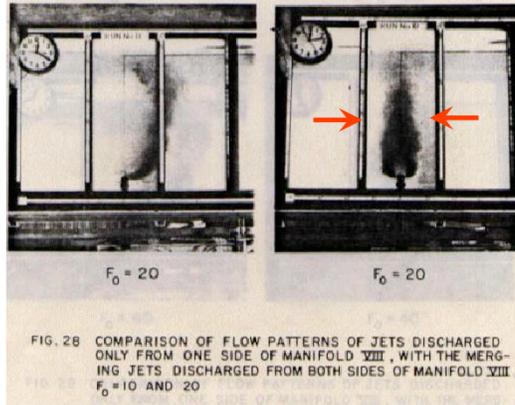
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## Model limitations

### Liseth experiments in zero current

### Zero current worst case: viable?

Single plume trajectory:  
ambient current = zero



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

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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...

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## 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

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## **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**

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# L.N. Fan Run 16

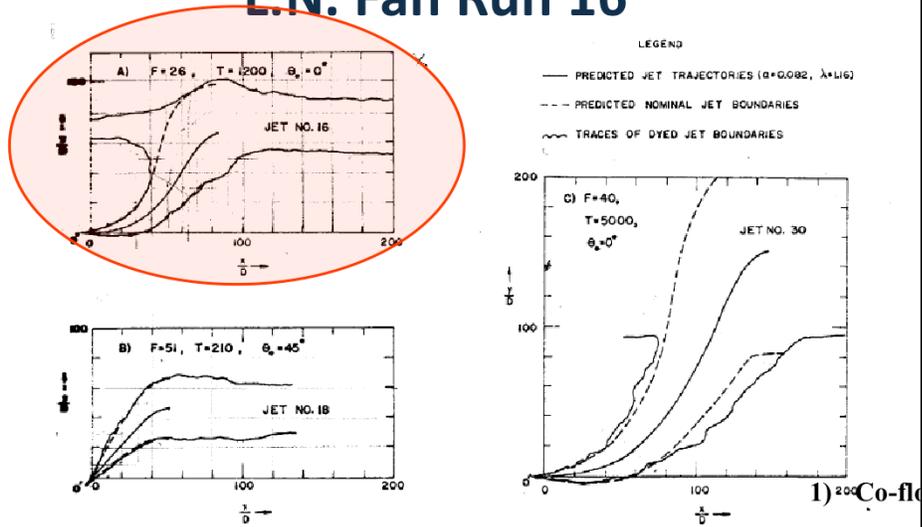


Fig. 26. Predicted and observed trajectories and nominal boundaries of buoyant jets in linearly stratified environments (note: traces inverted in the vertical direction except for Jet No. 16)

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

Jet Number	Initial Jet Values				Ambient Reference Density (1)	Density Gradient	Jet Reynolds Number	Jet Froude Number	Stratification Parameter	Reference for Detailed Results
	Angle	Diameter	Discharge	Velocity						
	$\theta$ deg.	D cm	$Q_0$ cc/sec	$U_0$ cm/sec	$\rho_1$ gr/ml	$\rho_0$ gr/ml	$R = \frac{U_0 D}{\nu}$	F Eq. (51)	T Eq. (52)	Figure Numbers
1	45	0.69	7.9	21	1.0087	1.0004	16.25	9.1	48	23, 24a
2	45	0.69	23	62	1.0087	1.0004	16.25	26	48	24b
3	0	0.69	17	46	1.0087	1.0005	25	20	48	--
4	90	0.69	29	79	1.0087	1.00125	25	35	44	--
5	0	0.22	4.3	110	1.0230	1.0048	50	55	160	--
6	26.7	0.22	4.3	109	1.0230	1.0036	50	53	170	--
7	90	0.22	8.2	105	1.0230	1.0046	50	53	160	--
8	54.5	0.22	8.7	111	1.0230	1.0038	50	54	170	--
9	-25	0.22	8.9	114	1.0230	1.0046	50	57	160	--
10	90	0.46	8.4	50	1.0240	1.0070	36.5	18	100	22
11	43.6	0.46	10.2	61	1.0240	1.0059	36.5	21	107	25a
12	2.8	0.46	6.4	38	1.0240	1.0052	36.5	13	110	25b
13	-28.2	0.46	6.4	38	1.0240	1.0082	36.5	14	93	--
14	-28.2	0.46	10.2	61	1.0240	1.0082	36.5	23	93	--
15	39.1	0.46	9.7	58	1.0240	1.0062	36.5	20	106	25c
16	0	0.25	3.1	64	1.0010	1.0249	7.6	26	1,200	26a
17	0	0.25	4.8	99	1.0021	1.0021	29.5	51	230	--
18	45	0.25	4.8	99	1.0175	1.0021	29.5	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)	--
22	0	0.25	2.5	51	1.0101	1.0000	0	33	infinite (3)	29a
23	0	0.25	5.0	101	1.0101	1.0000	0	66	infinite (3)	30a
24	0	0.25	10.5	205	1.0101	1.0000	0	130	infinite (3)	30b
25	0	0.25	2.6	53	1.118	1.000	0	10	infinite (3)	29b
26	0	0.25	3.5	73	1.118	1.000	0	13.6	infinite (3)	29c
27	0	0.25	10.6	214	1.118	1.000	0	40	infinite	28, 30c
28	0	0.25	2.6	53	1.118	1.001	9.5	10	5,000	--
29	0	0.25	3.5	73	1.118	1.001	9.5	13.6	5,000	--
30	0	0.25	10.6	214	1.118	1.001	9.5	40	5,000	26c
31	0	0.25	1.8	36	1.0134	1.0013	9.5	20	510	27a
32	0	0.25	3.5	72	1.0134	1.0013	9.5	40	510	27b
33	0	0.25	5.4	104	1.0134	1.0013	9.5	60	510	27c

Note:

- $\rho_0$  is taken to be the ambient density at the level of the nozzle
- F = infinity refers to a simple jet
- T = infinity refers to a buoyant jet in a uniform environment

## Fan Run 16 data

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Diffuser: Fan-Run-16.vpp.db | Ambient: C:\Plumes\Fan-Run-16.001.db | Special Settings | Text Output | Graphical Output

**Project:** C:\Plumes\Fan-Run-16

**Advanced File:** Filename: Case

After run go to tab:  
 Diffuser  
 Ambient  
 Special  
 Test  
 Graphics

**Model Configuration**  
 Enroll fanfile solution  
 Graph effective dilution  
 Average plume boundary  
 Amb. current vector averaging  
 Tidal solution buildup  
 Same-levels time-series input

**Units Conversion**  
 Convert data  
 Label only

**Case selection**  
 Ease o selectec case  
 Sequence, all ambient list  
 Sequence, paste ambient  
 All combinations

**Additional model input**  
 Diffuser pool correction coefficient: 1  
 Light absorption coefficient: 0.15  
 Farfield inverse-9 (fr): 2000  
 UMS excitation coefficient: 0.1  
 Bacteria model on solar radiation input:  
 Mancini (1978) sulfam model  
 301(h) TSC (1934) coliform for saltwater, Eqn B-68  
 301(h) TSC (1934) enterococcus for saltwater, Eqn B-69

**Diffuser, Flow, Mixing Zone Inputs**

Pct diameter	r <sup>2</sup>	Pct elevation	Hor. range	Num of ports	r <sup>2</sup>	r <sup>2</sup>	n <sup>2</sup>	n <sup>2</sup>	Acute mix zone	Chronic mix zone	Port depth	Effluent flow	Effluent density(1)	Effluent temp	Effluent concn
m	m	deg	deg		m	s	s	s	m	m	m	bb/d	g/m <sup>3</sup>	C	ppm
0.0025		0.1	0	1	5				1	2	1.012	1.6794	0.001	20	100
												3.2			

**Fan Run 16 VP input**

Measurement depth or height	Current speed	Current direction	Ambient salinity	Ambient temperature	Background concentration	Pollutant decoupled(1)	n1	n1	Faded dilution coeff
depth	depth	depth	depth	depth	depth	depth	depth	depth	depth
0	0	0	17.3	20	0	0			0.0003
1			25.2	20					
2									

**Measurement units**

Measurement unit	Current speed	Current direction	Ambient salinity	Ambient temperature	Background concentration	Pollutant decoupled(1)	n1	n1	Faded dilution coeff
m	m/s	deg	psu	C	ppm	s <sup>-1</sup>	m/s	deg	mD <sup>2</sup> /s <sup>2</sup>
0									
1									
2									

**Selection List**  
 Selected Variables: Depth, P-tie, Temp, Density, Amb-den, Dirm, x-posn, Time

**UMS output each ?? steps:** 500  
**UMS maximum dilution reported:** 10000

**UMS max vertical reversal:**  
 x max rise or fall  
 x second lag level  
 x 2nd max rise or fall

**UMS text output format:**  
 Standard output  
 Brief output

Close panel

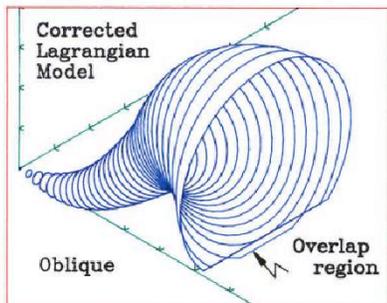
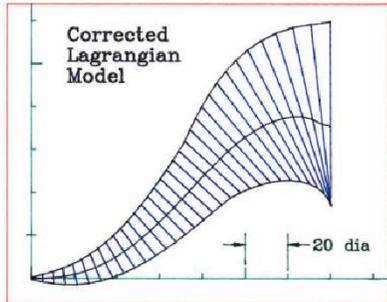
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## Worst Case

- 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

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## 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)

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Bonus  
slide