



# Modelado de la Calidad del Aire

## Introducción

FAUBA

11 de mayo de 2023

# Definiciones



- ▶ Modelo matemático
- ▶ Modelo regulatorio
- ▶ Dispersión de contaminantes atmosféricos
- ▶ Razones para modelar



# Episodio de Smog en Donora 1948

# Donora



Figura 1: Imagen aérea de Donora-Pensylvania

# Industria en Donora



(a) misma hora en 3 días  
de distinta estabilidad



(b) Emisión de industria metalúrgica

Figura 2: Efecto de las emisiones de la industria

# Terreno

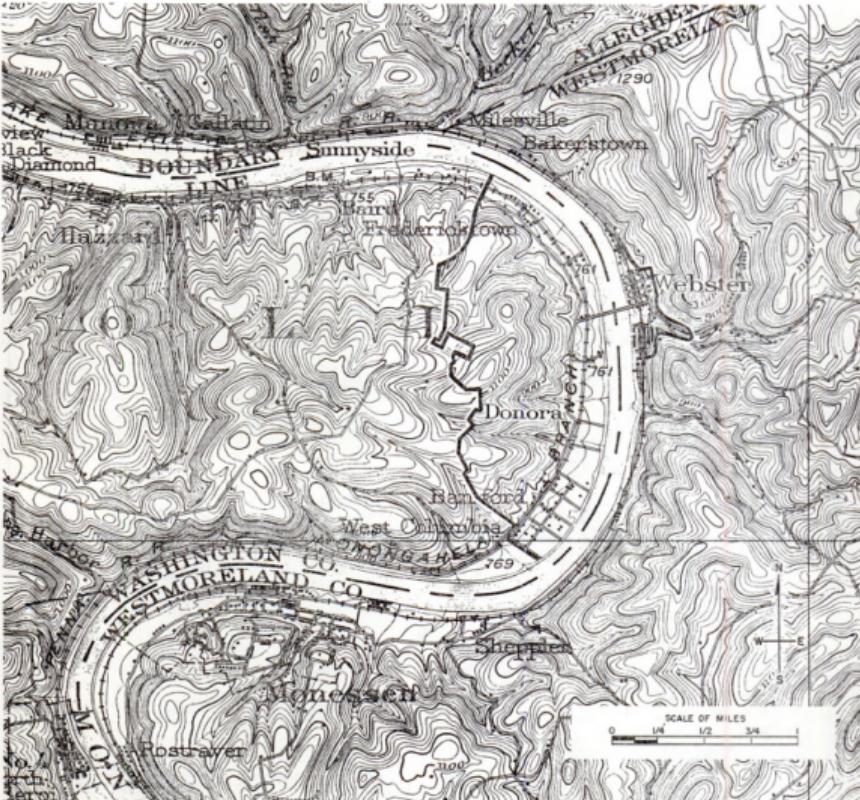
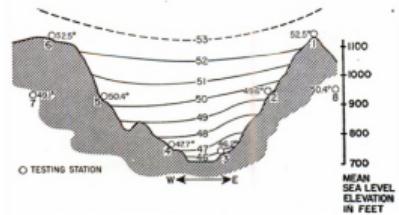


Figura 3: Carta topográfica (altura en pie 1/3 m )

# Meteorología



(a) isoterma en corte vertical del valle  
(46F=7C, 53F=11.5C)

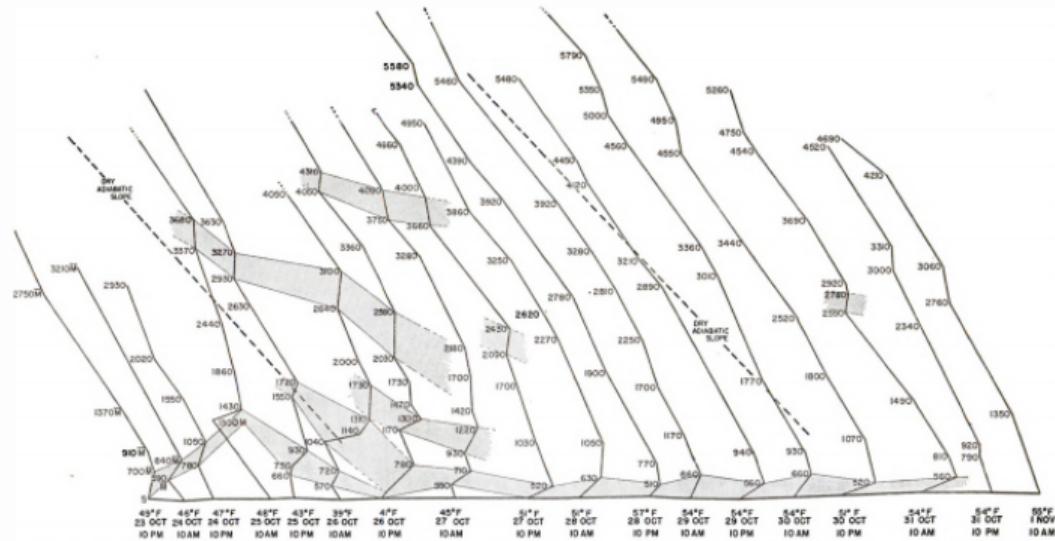


FIGURE 81.—Twice daily aerological soundings taken at Allegheny County (Pittsburgh) Airport Weather Station. Figures along lapse curves are mean sea level elevations in meters of significant levels. Temperature for each curve decreases to the left. Very stable layers (inversions) are shaded.

(b) Radiosondeos de aeropuerto de Pittsburgh durante el episodio

Figura 4: Meteorología de superficie y altura



# Contexto Regulatorio



**Estados Unidos** La principal guía de la EPA se encuentra en el código federal de regulación *CFR - Title 40 Chapter I Subchapter C Part 51 -Apéndice W* Requiere dos etapas de complejidad incremental. Sondeo y detallado.

**Unión Europea** Directiva "*2008/50/EC*", propone estándares y exige modelado. Crea un foro para fijar criterios.

**Reino Unido** Etapas de complejidad incremental. No explica modelos, sino contenido del informe.



Nación Ley 20.284 promulgada en 1973, como la "Ley nacional de Calidad de Aire".

**ENRE** Norma 13/97. Guía metodológica para la Evaluación del Impacto Ambiental Atmosférico.

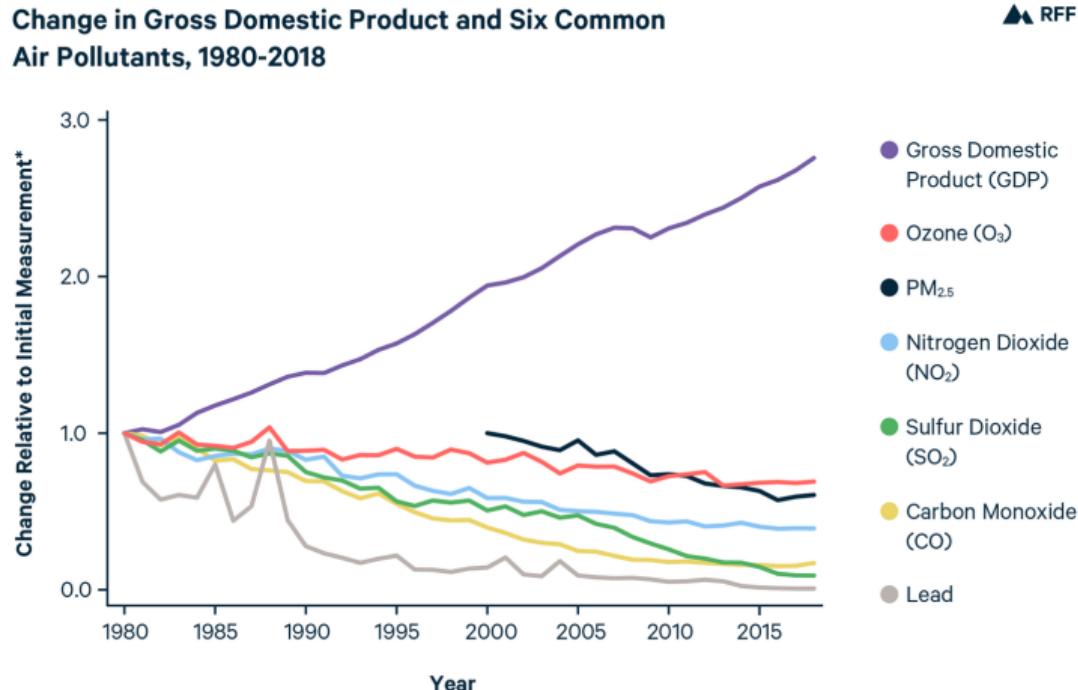


Ciudad de Buenos Aires Ley 1356 y decreto reglamentario N 198/2006.  
Autoridad realiza modelado de nuevas fuentes.

Provincia de Buenos Aires Ley 5965 y decreto N 1074/18 "licencia de emisiones a la atmósfera" en anexo III detalla guía de modelado. Tres etapas incrementales en complejidad.



# Efectividad de medidas de gestión (CAA)



\*The index begins at 1 in 1980, with the exception of PM2.5, which was measured beginning in 2000. The index for each year is the actual value divided by the initial value. Source: Federal Reserve Economic Data | Federal Reserve Bank of St. Louis

Figura 5



# Contexto histórico



Euler 1757

$$\frac{\partial \mathbf{v}}{\partial t} + (\mathbf{v} \cdot \nabla) \mathbf{v} = -\frac{1}{\rho} \nabla p + \mathbf{f}$$

Navier-Stokes 1850

$$\frac{\partial \mathbf{v}}{\partial t} + (\mathbf{v} \cdot \nabla) \mathbf{v} = -\frac{1}{\rho} \nabla p + \nu \nabla^2 \mathbf{v} + \mathbf{f}$$

# Armas químicas



(a) Flandes Bélgica - 1917



(b) Batalla de Somme Francia - 1916

Figura 6: Exposición gas tóxico en primera guerra mundial



# Experimentos de dispersión - Trazadores en cañerías

464

Sir Geoffrey Taylor

were very nearly Gaussian error curves. Some of these are here reproduced in figure 11. The time,  $2t_1$ , during which the concentration at various intermediate stations was greater than half the maximum concentration were measured and the value of  $K$  deduced from the expression

$$K = \frac{U^2 t_1^2}{4X \ln 2}. \quad (9-1)$$

Here  $X$  is the length of pipe from the point of injection to the point of observation. The mean speed of flow was 81.7 cm/s. The values of  $K$  found are given in table 4.

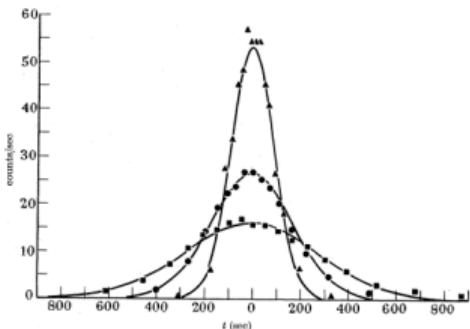


FIGURE 11. Hull & Kent's experiments. Observation stations: ▲ Bonanza (13.8 miles); ● Green River (45.1 miles); ■ Hasma (108.5 miles).

TABLE 4. DISPERSION OF A POINT SOURCE IN A 10 IN. PIPE 182 MILES LONG FROM RANGELY TO SALT LAKE

$X$ (miles)	1.9	13.8	43.1	108.5	125	130.2	182.5
$2t_1$ (s)	67	211	402	669	746	770	895
$K$ ( $\text{cm}^2 \text{s}^{-1}$ )	718	980	1140	1150	1350	1380	1330
$K/\alpha v_a$	12.3	16.9	19.3	20.0	22.8	23.4	22.5

The Reynolds numbers were between 21500 and 27000.

For  $R = 24000$ , figure 2 gives  $U/v_a = 17.9$ . The values of  $K/\alpha v_a$  are given in the last row of table 4.

It will be seen that only at  $X = 1.9$  miles was the dispersion at all close to the theoretical value represented by  $K/\alpha v_a = 10.1$ . This may well be due to the existence of bends which, as was shown in § 8, would necessarily increase the dispersion above what would occur in a straight unobstructed pipe. That this may well be the cause

Figura 7: Cuentas de trazadores radioactivos en cañerías. Tabla con coef. de dispersión. The dispersion of matter in turbulent flow through a pipe - Geoffrey Ingram Taylor - 1954

# Experimentos de dispersión - projectiles

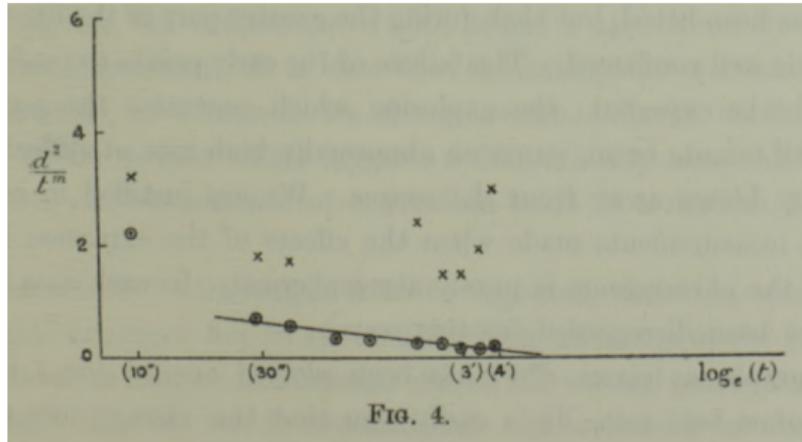
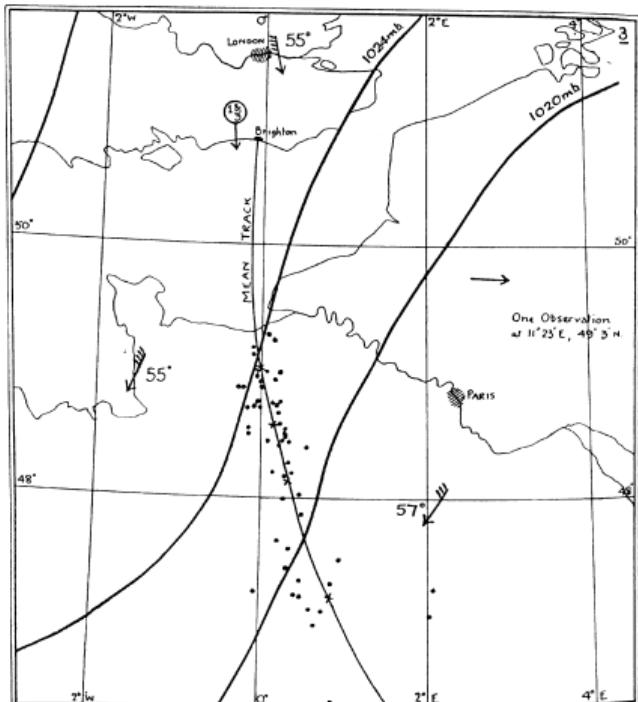
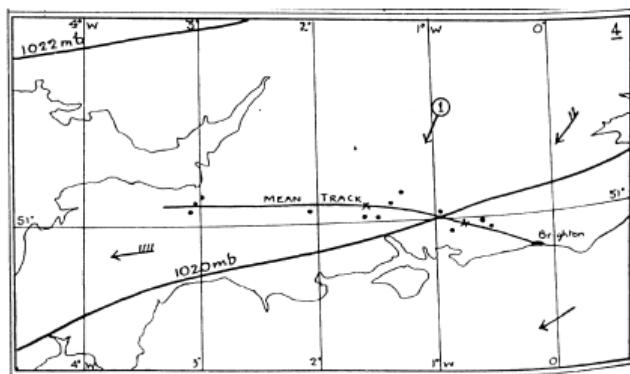


Figura 8: Crecimiento de límites de humo de explosivo, analizando valores de difusividad entre teoría de Taylor (x) y Sutton (\*) figura en: A theory of eddy diffusion in the atmosphere - O.G. Sutton 1932

# Experimentos de dispersión - globos



(a) 9/9/1922



(b) 1/6/1923

Figura 9: Richardson LF. 1926a. Atmospheric diffusion shown on a distance-neighbour graph.

# Experimentos de dispersión - plumas



*Richardson.*



Fig. 1.

*Phil. Trans., A, vol. 221, Plate 1.*

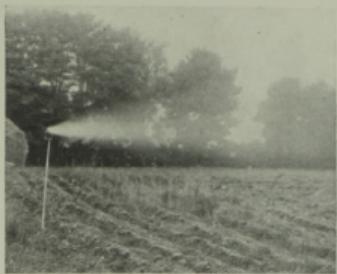


Fig. 2.

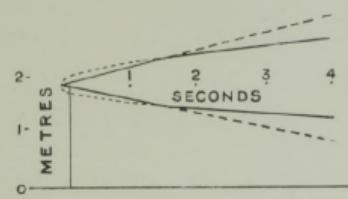
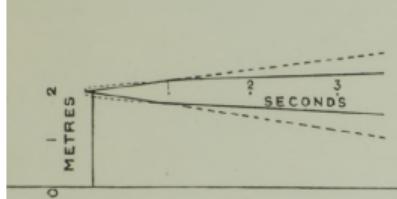


Figura 10: Some measurements of Atmospheric Turbulence - L.F.Richardson 1920

# Solución Gaussiana - Sutton

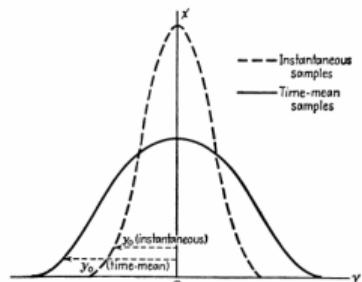


FIG. 30. Concentration in a point-source cloud (section across wind).

(a) Distribución normal  
instantánea y media

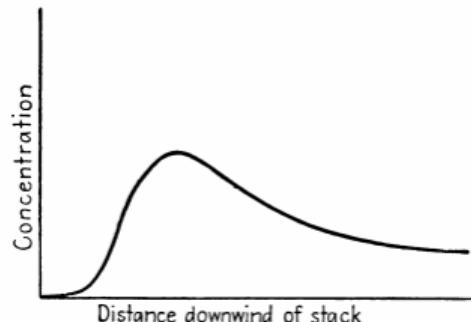


FIG. 16. Concentration at ground level from an isolated stack in a steady wind.

(b) Concentración en sentido  
del viento

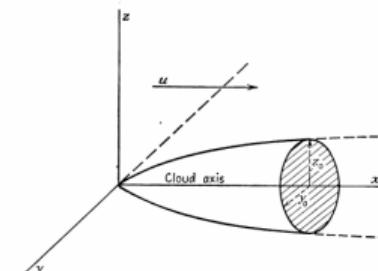
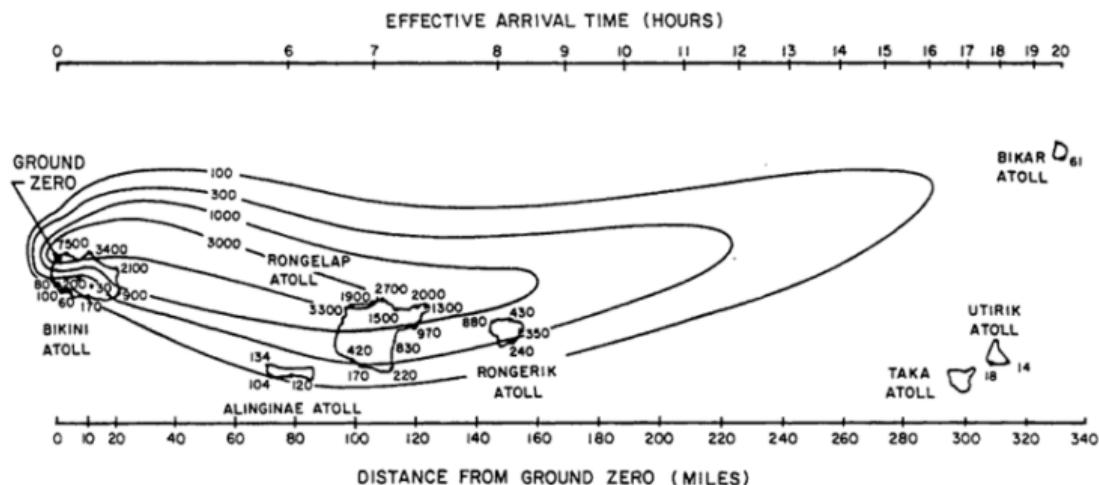


FIG. 15. Coordinate system for a continuous point source in a wind.

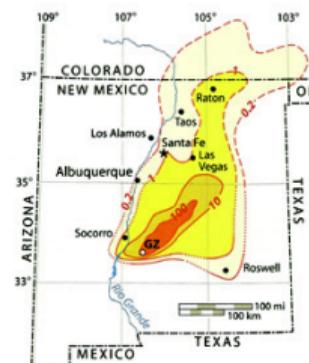
(c) Pluma simplificada de  
fuente continua

Figura 11: Figuras del libro: Micrometeorology - Sutton 1953

# Fallout



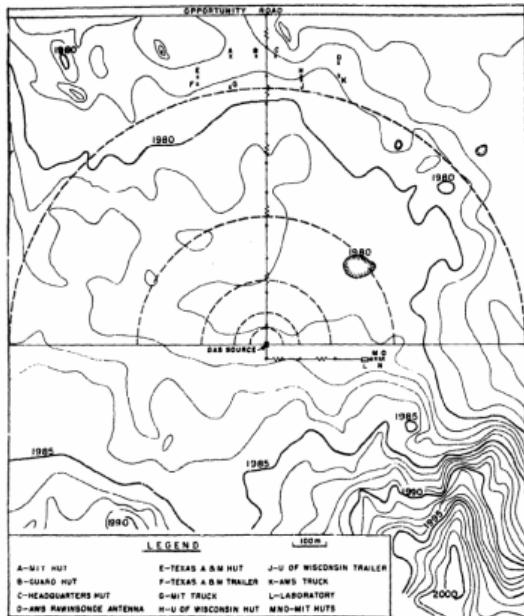
(a) Brabo-1954



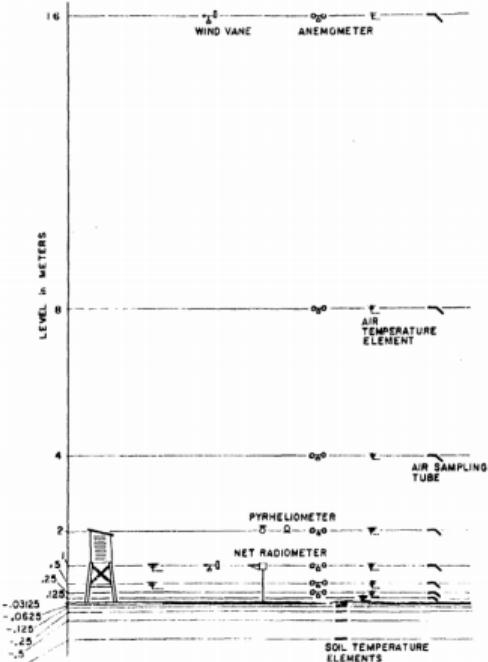
(b) trinity-1945

Figura 12: Exposición a radiación por "fallout" modelada

# Experimento de dispersión



(a) Layout de arcos de puntos de medición



(b) Esquema de instrumentos

Figura 13: Ensayo prarie grass 1956



# Experimento de dispersión

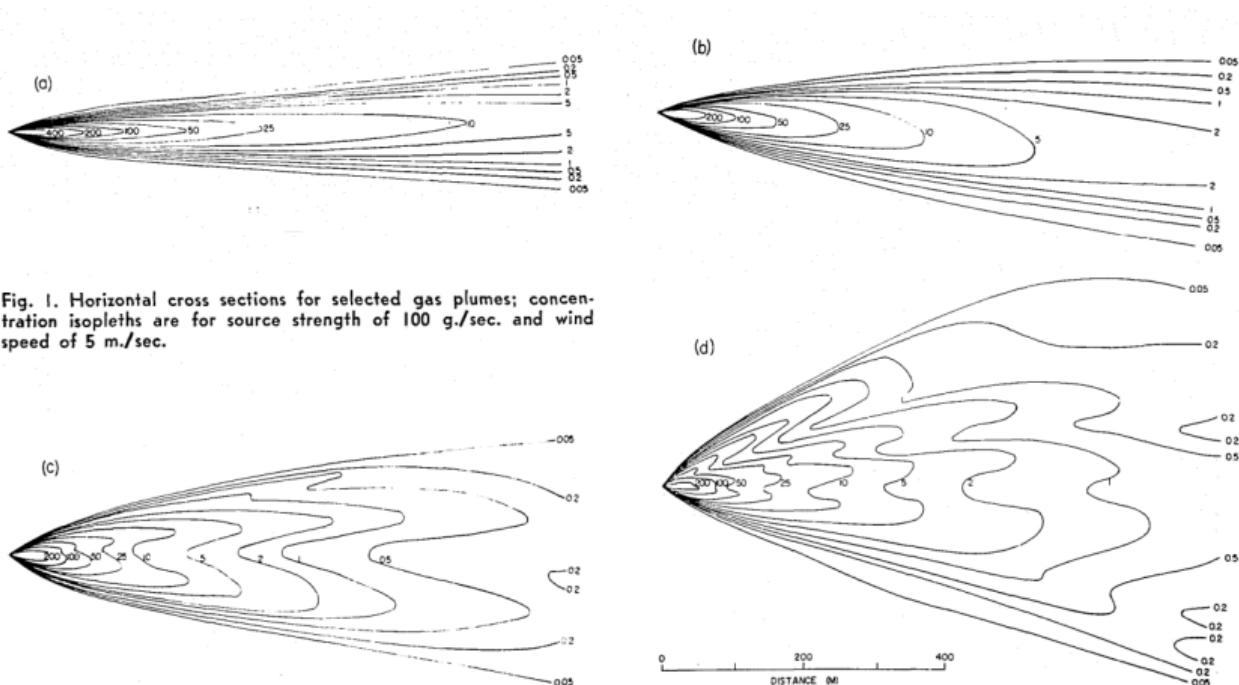
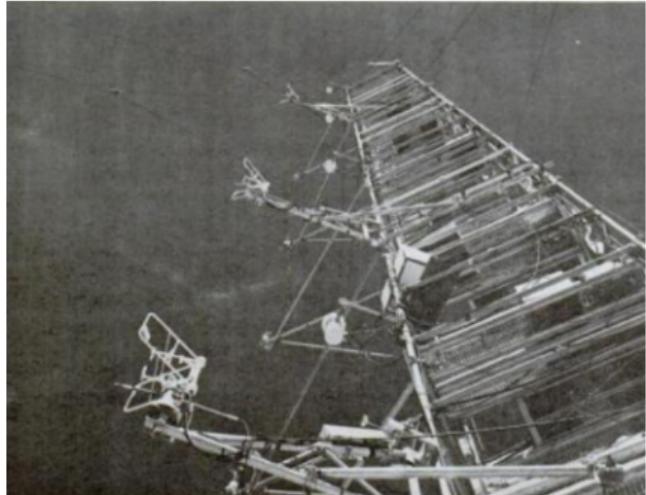


Fig. 1. Horizontal cross sections for selected gas plumes; concentration isopleths are for source strength of 100 g./sec. and wind speed of 5 m./sec.

Figura 14: Resultados de plumas - isopletas - Ensayo prarie grass 1956

# Experimento de difusión



(a) Torre de sensores



(b) Equipos de procesamiento  
de señales

Figura 15: Ensayo kansas 1968



# Elevación de la pluma

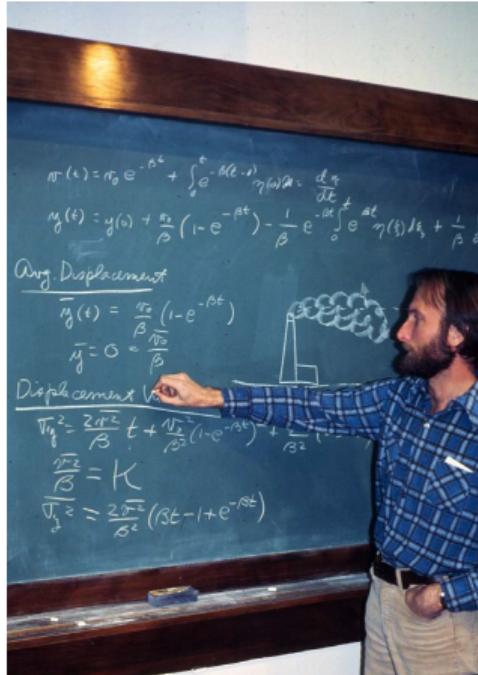


Figura 16: Gary Briggs derivando la ecuación de dispersión mediados de 1970

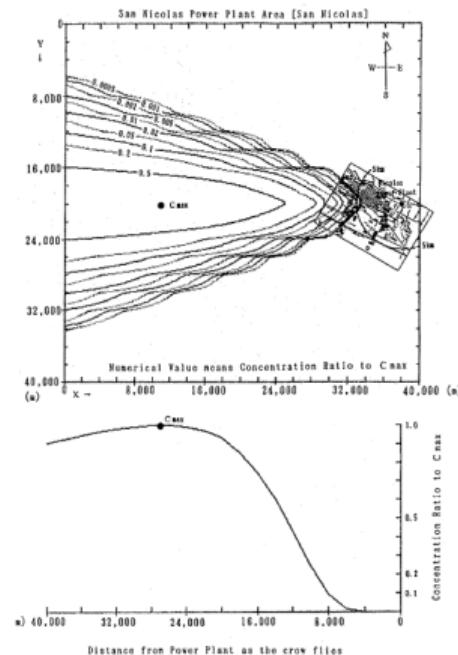
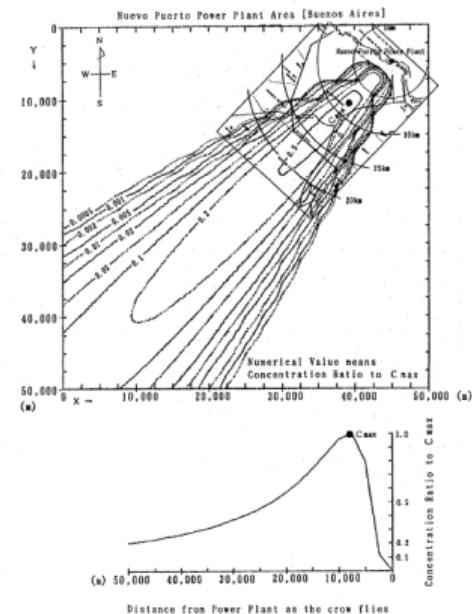
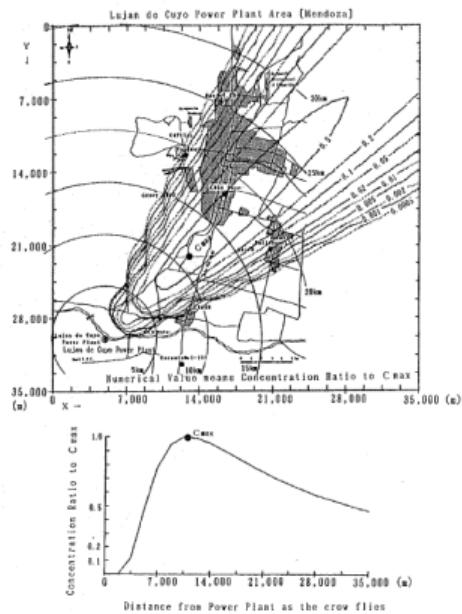


Figura 17: The Study on air pollution for thermal power plants (1994, JICA)