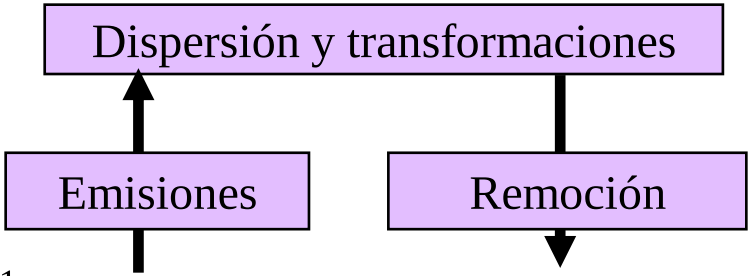
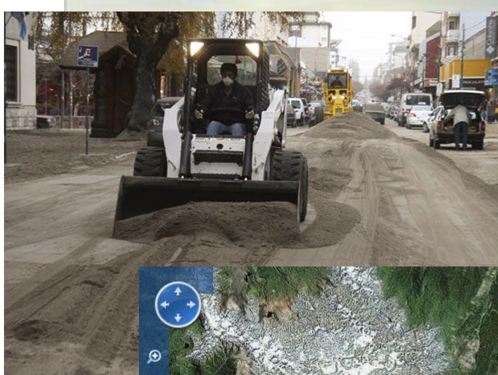
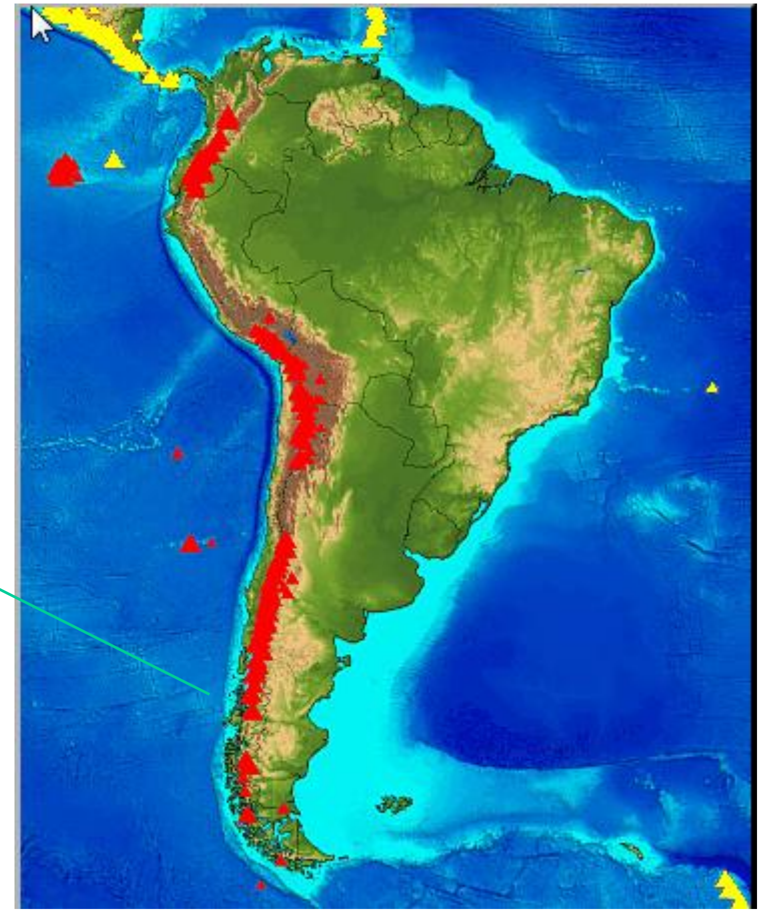
GF 3022
Contaminación Atmosférica

- ***(Dispersión del Puyehue)***
- ***La ecuación a resolver***
- **Modelos gaussianos**
- **Modelos 0, 1, 2, 3, 4 D**
- **Evaluación de modelos**



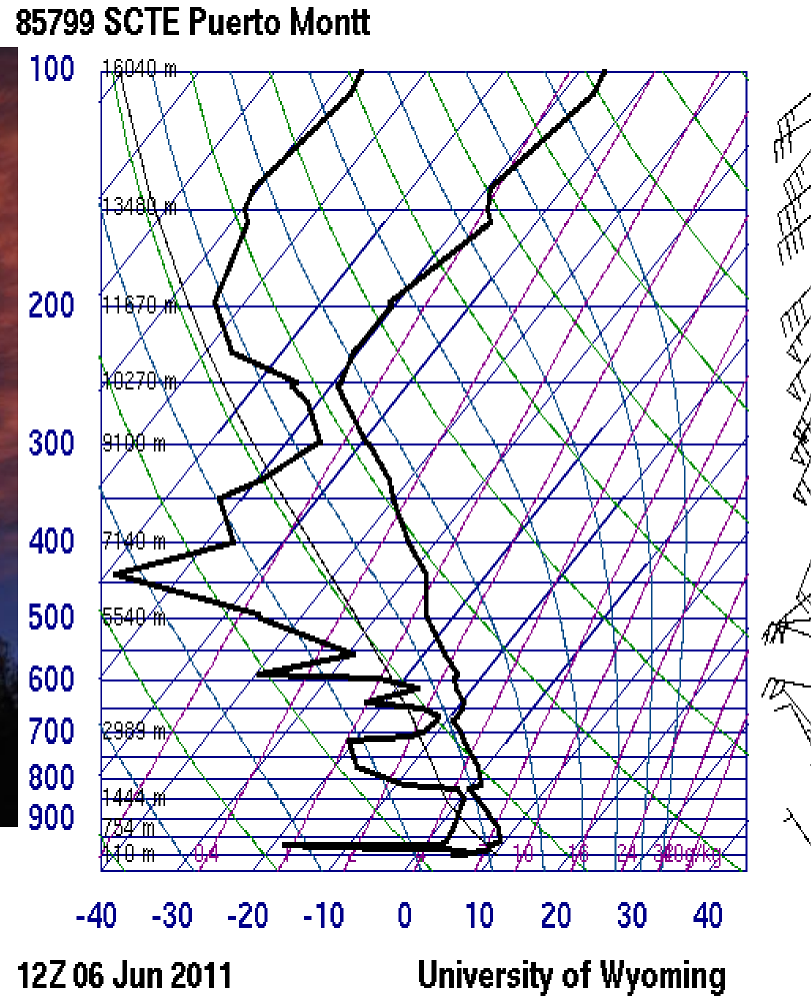
Circulación y erupción del Puyehue/Caulle
40.6S; 72.1W; 2236 msnm





LGK 2011

¿Hasta dónde alcanzó el penacho?

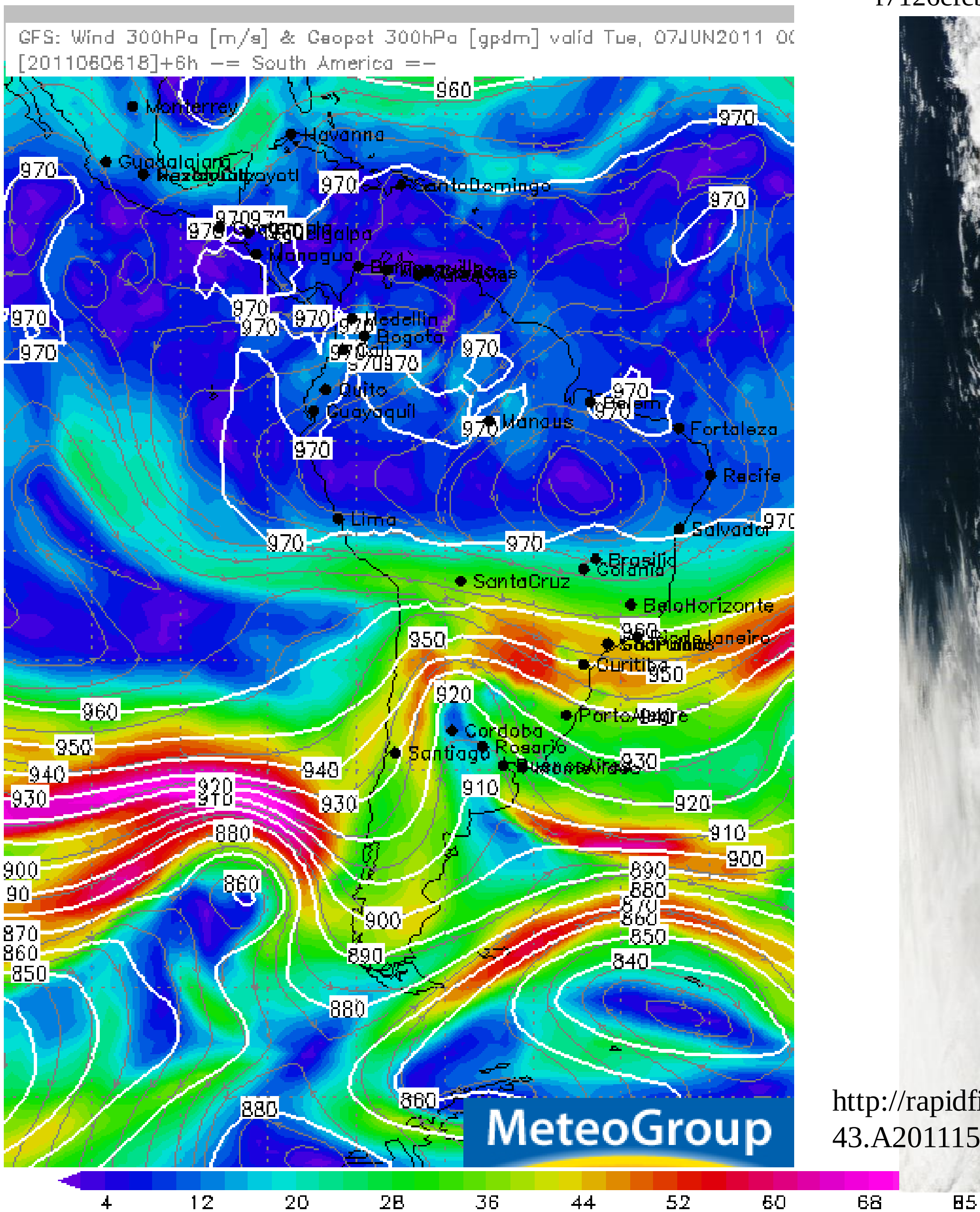


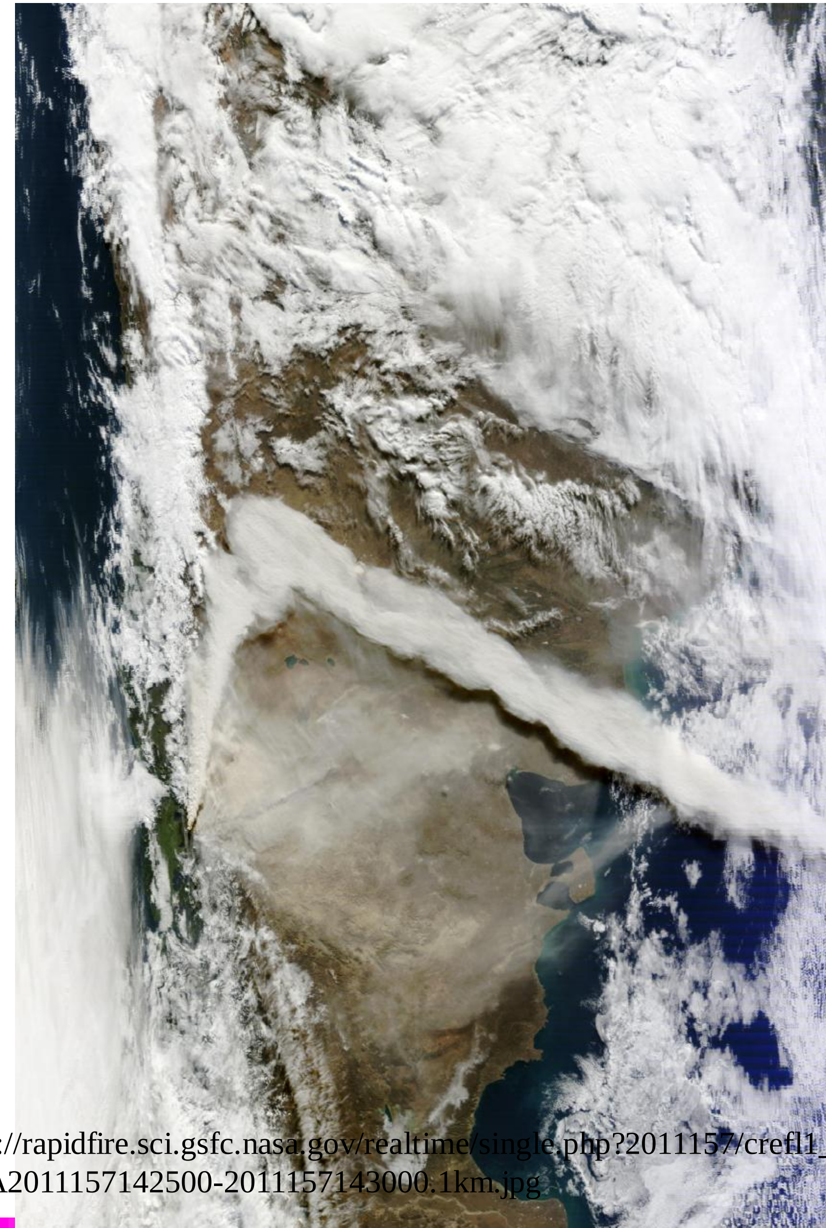
the evolution of the plume from 1:45 p.m. local time June 4, 2011, until 10:45 a.m. June 6, 2011.

http://earthobservatory.nasa.gov/NaturalHazards/view.php?id=50882

Geopotencial de 300 hPa e isotacas

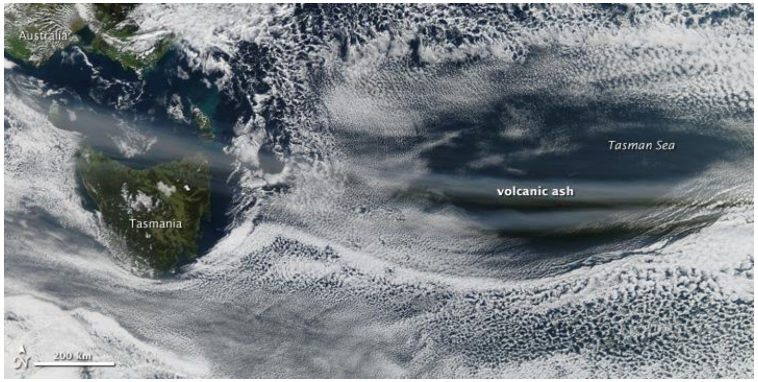
http://www.tiempohoy.es/es/home/tiempo/modelos-meteorologicos/gfs-popup/archiv/SAmerica/wind300/2011060700/nothumb/on/0/ch/e9a11b832baf7126cfcbdc3ffc206331.html

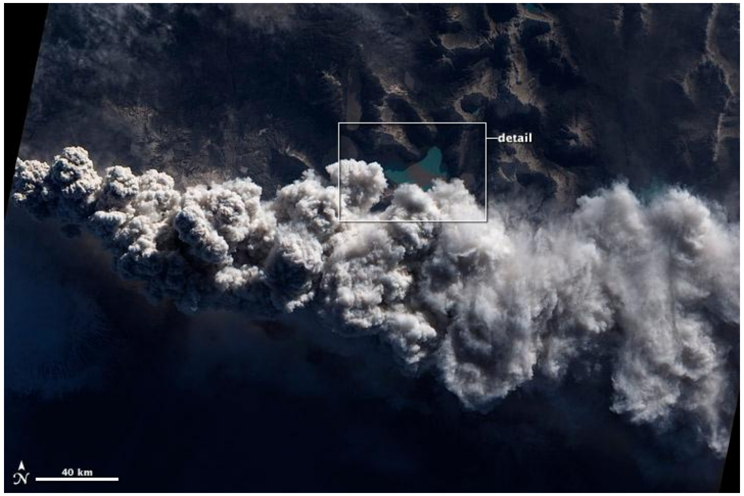




http://rapidfire.sci.gsfc.nasa.gov/realtime/single.php?2011157/crefl1_143.A2011157142500-2011157143000.1km.jpg

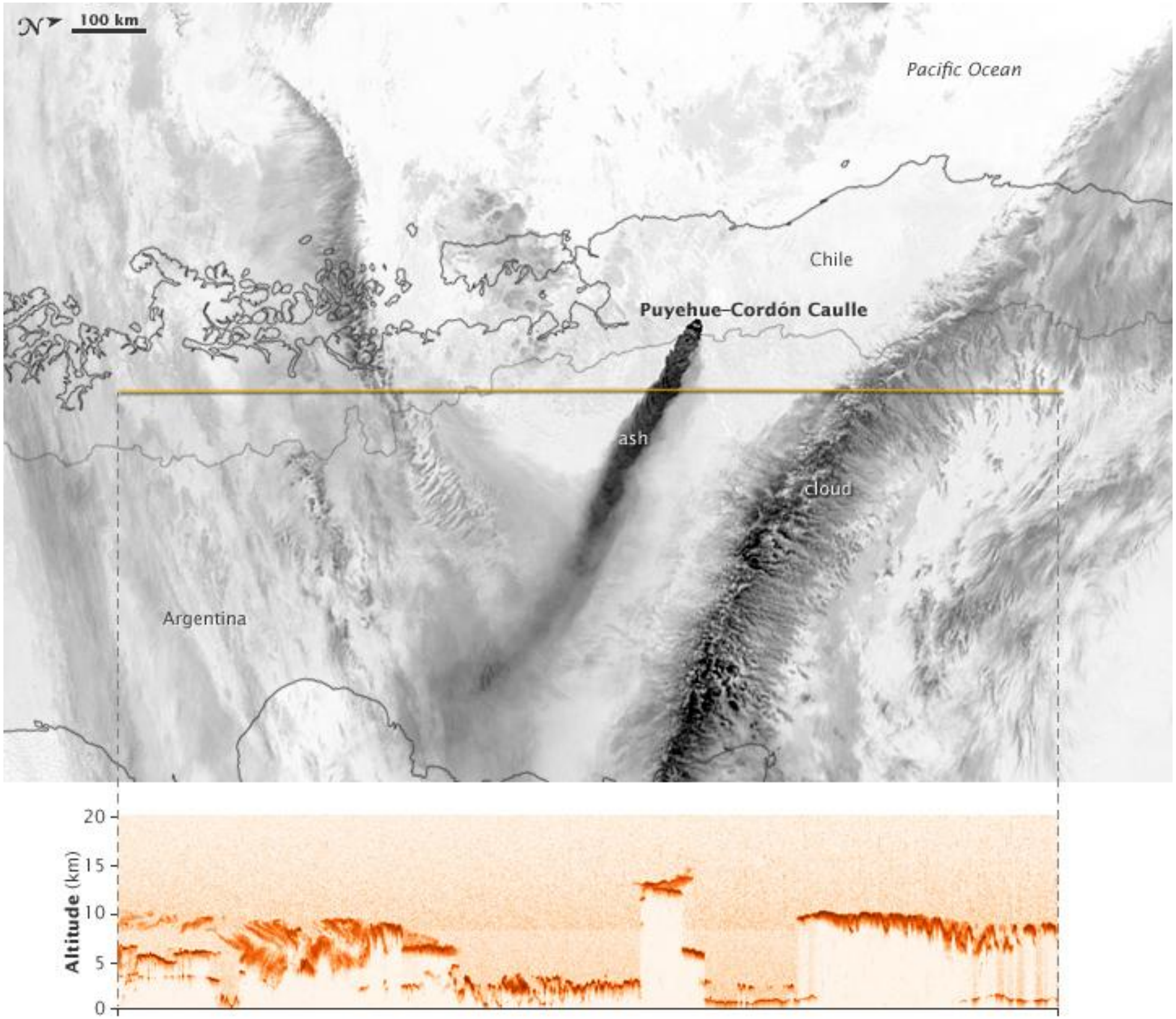
Aerosoles-Puyehue/Caulle: alrededor del amundo



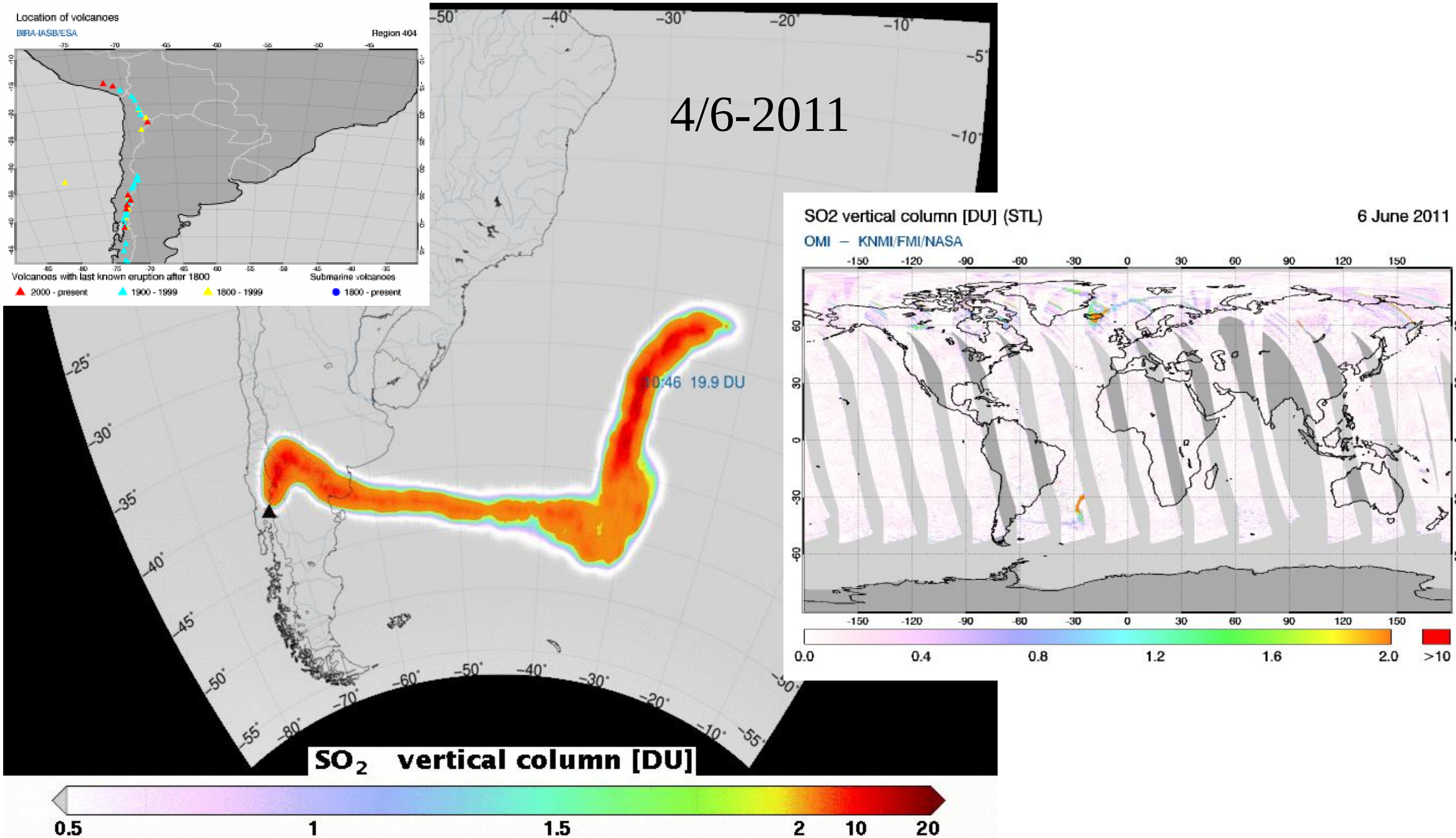


http://earthobservatory.nasa.gov/NaturalHazards/view.php?id=51060&src=nha

Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO, http://www-calipso.larc.nasa.gov/)



Dióxido de azufre desde satélites



http://sacs.aeronomie.be/

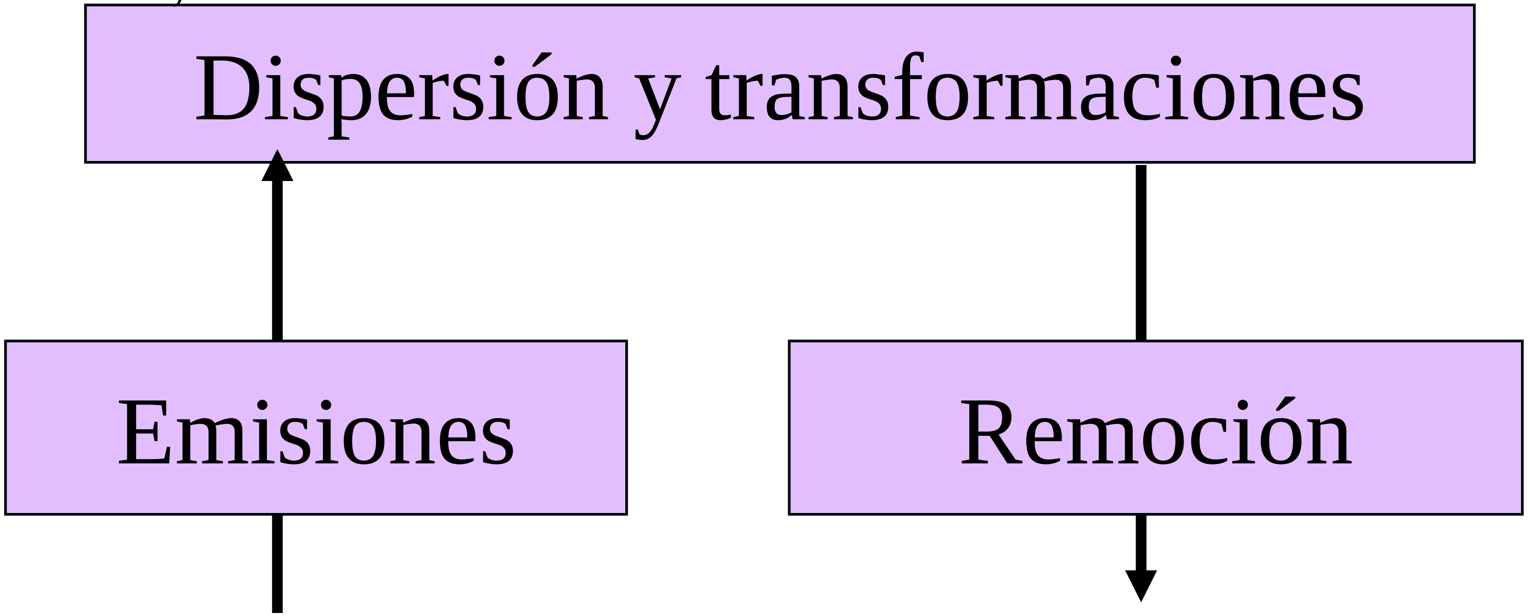
Pausa in situ

I help you, reach out! Stretch your tiny paw...!

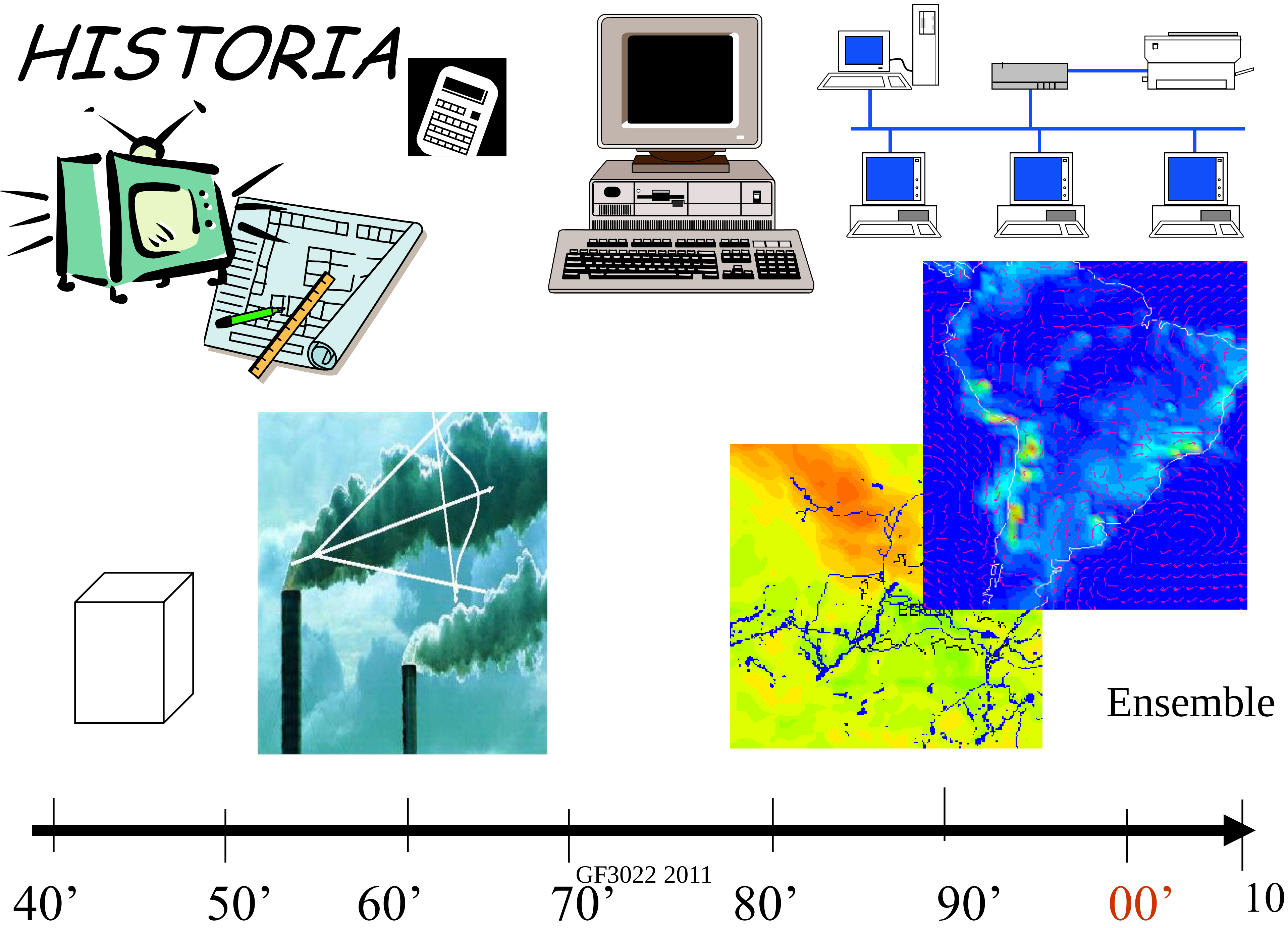
$$\frac{\partial c}{\partial t} = -\vec{v}.\nabla c - c\nabla.\vec{v} - \nabla.(<c'\vec{v}'>) + Q - S$$

Lavoisier, 1789

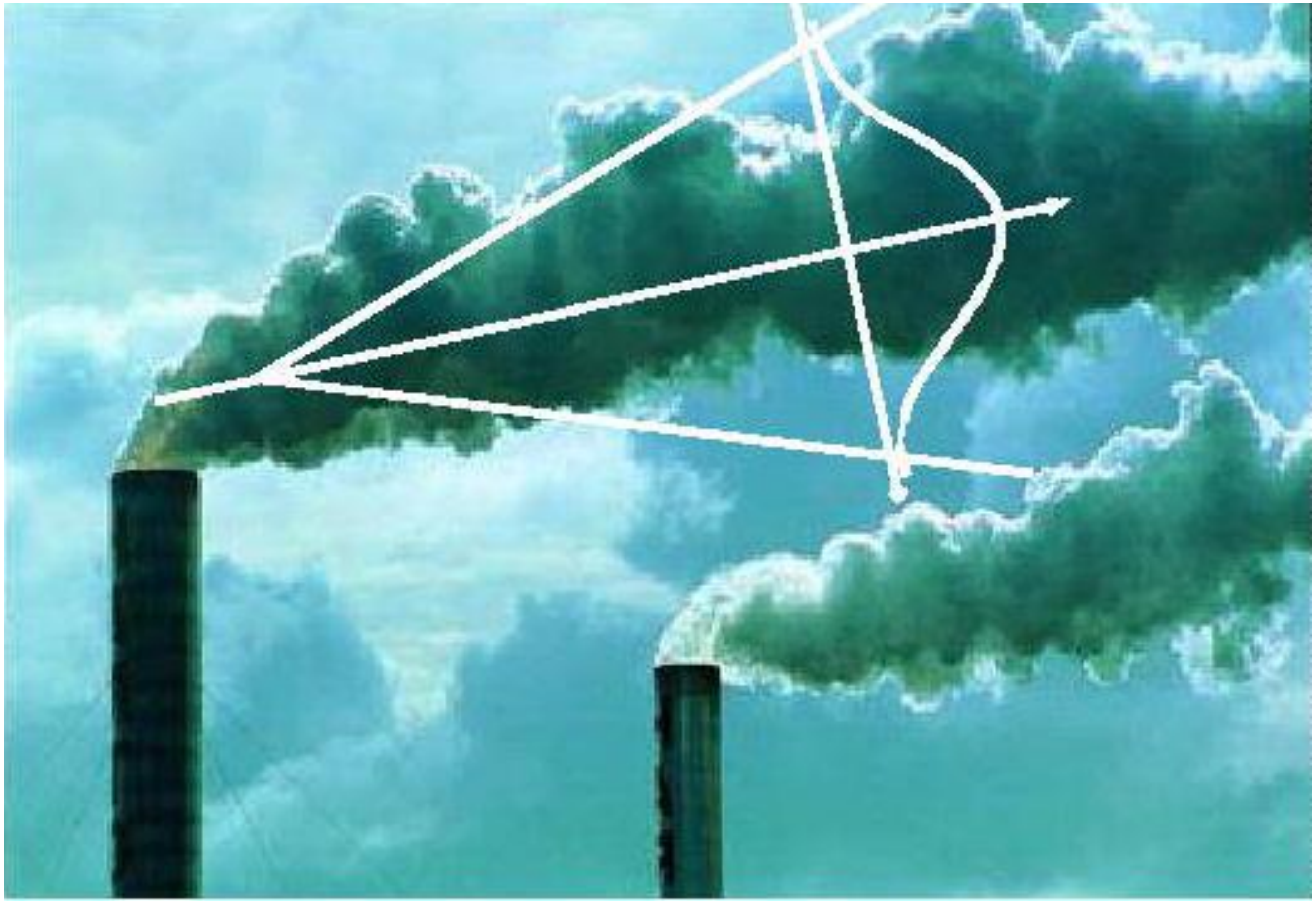
+CI & CB

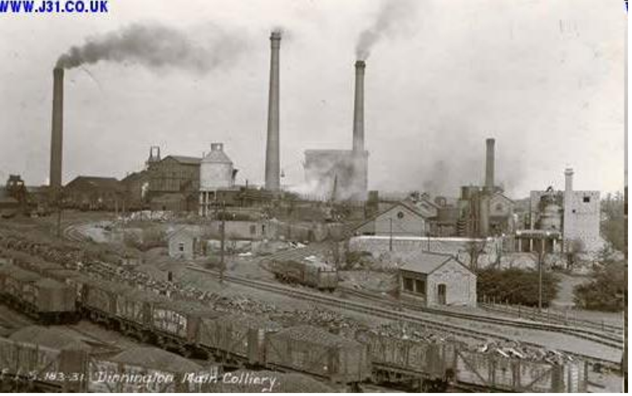


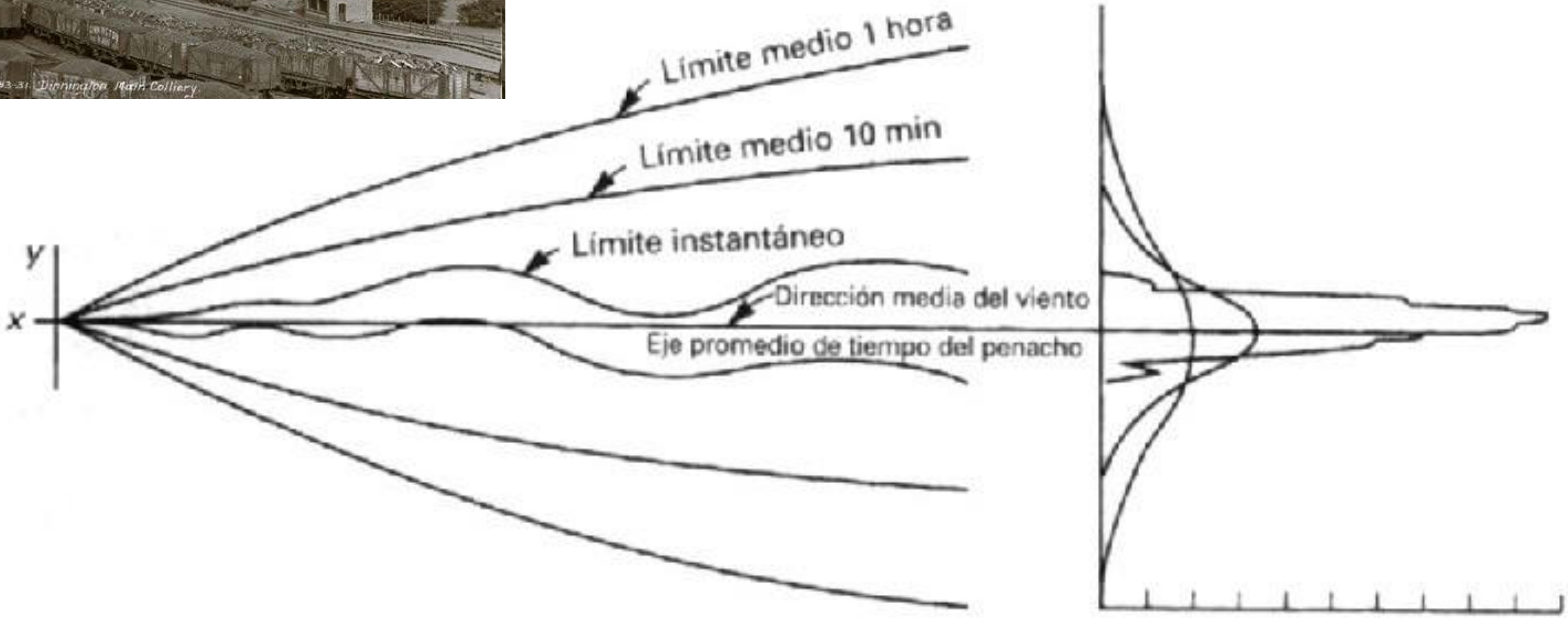
HISTORIA



Modelos Gaussianos Estacionarios





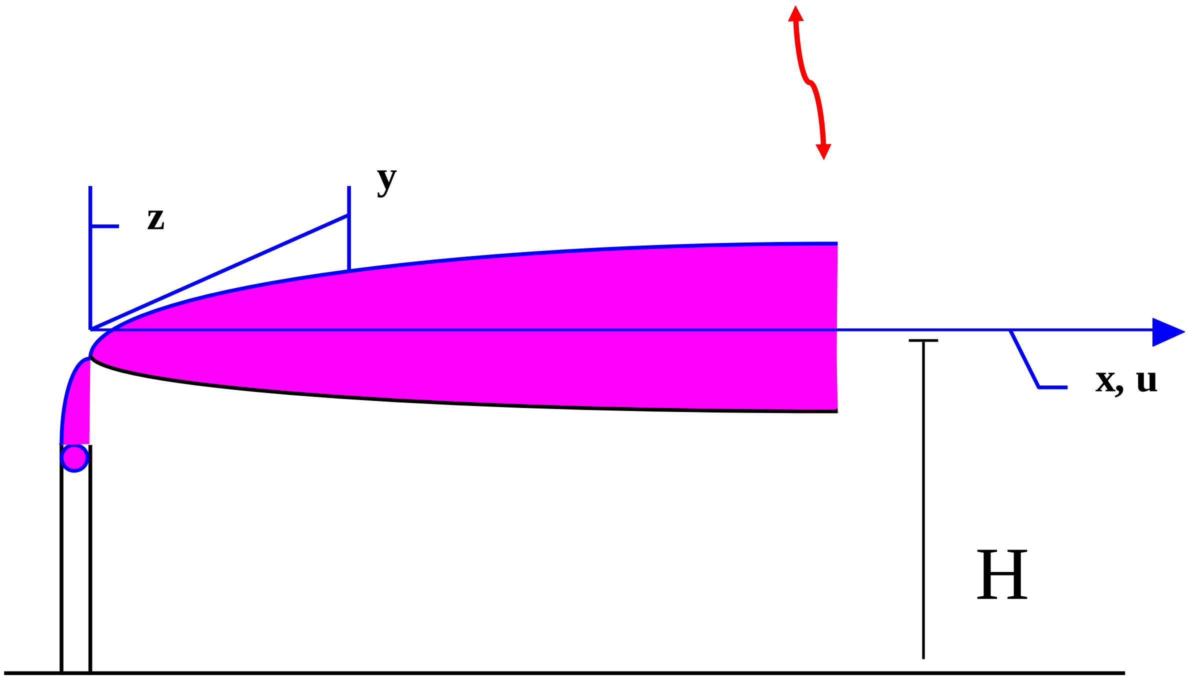


(a) Vista en planta

(b) Concentración relativa

Frank Pasquill
1914 – 1994

$$\bar{c}(x, y, z) = \frac{Q}{2\pi \bar{u} \sigma_y \sigma_z} \exp\left[-\frac{1}{2} \left(\frac{y^2}{\sigma_y^2} + \frac{(z-H)^2}{\sigma_z^2} \right) \right]$$



Desafío: ¡¡Estimar los sigmas!!

Los sigmas se determinan empíricamente....

$$\sigma_y(x) = \frac{k_1 x}{\left[1+\left(x/k_2\right)\right]^{k_3}} \qquad \sigma_z(x) = \frac{k_4 x}{\left[1+\left(x/k_2\right)\right]^{k_5}}$$

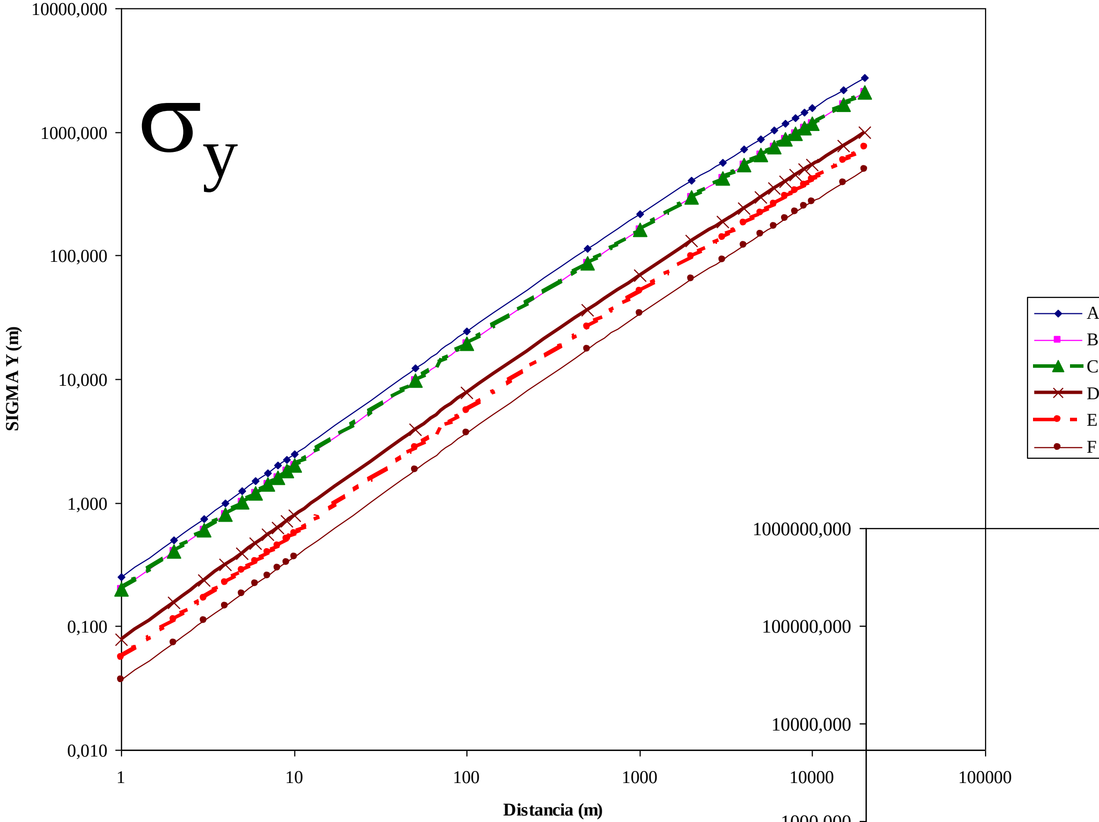
Clase de estabilidad	k_1	k_2	k_3	k_4	k_5
A	0.250	927	0.189	0.1020	-1.918
B	0.202	370	0.162	0.0962	-0.101
C	0.134	283	0.134	0.0722	0.102
D	0.0787	707	0.135	0.0475	0.465
E	0.0566	1070	0.137	0.0335	0.624
F	0.0370	1170	0.134	0.0220	0.700

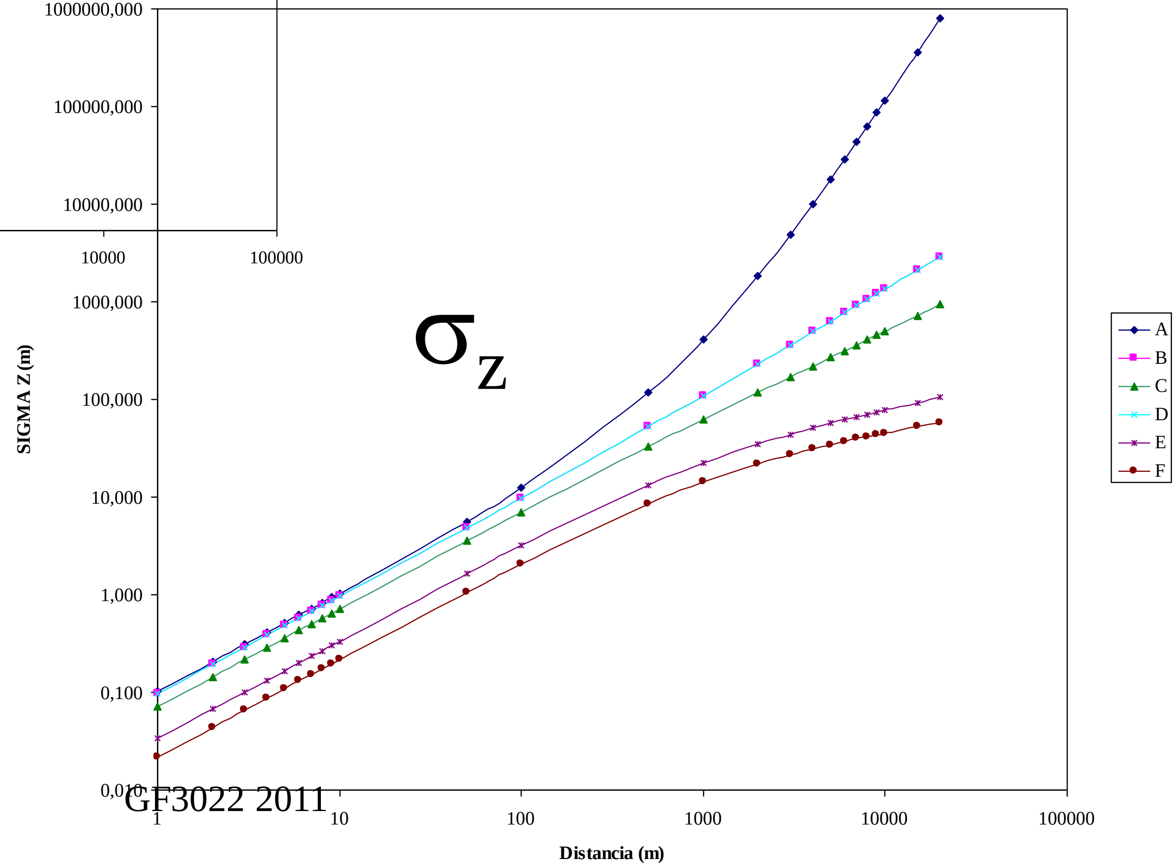
Pasquill, F. (1961). *The estimation of the dispersion of windborne material*, The Meteorological Magazine, vol 90, No. 1063, pp 33-49.

Clasificación de Pasquill

Viento (m/s)	Insolación fuerte	Insolación moderada	Insolación débil	Nubosidad nocturna inferior a 4/8	Nubosidad nocturna superior a 4/8
<2	A	A,B	B	-	-
2-3	A,B	B	C	E	F
3-5	B	B,C	C	D	E
5-6	C	C,D	D	D	D
>6	C	D	D	D	D

Pasquill, F. (1961). *The estimation of the dispersion of windborne material*, The Meteorological Magazine, vol 90, No. 1063, pp 33-49.



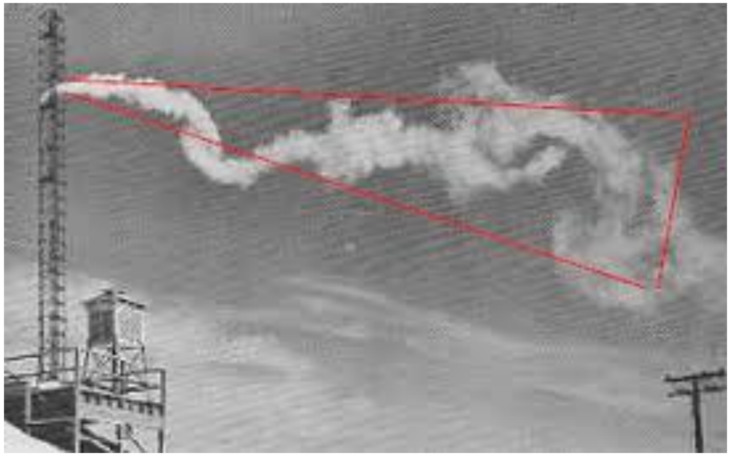


NB. La dispersión vertical es más sensible que la dispersión horizontal a las condiciones meteorológicas

Las cosas no siempre se pueden aproximar à la Gauss

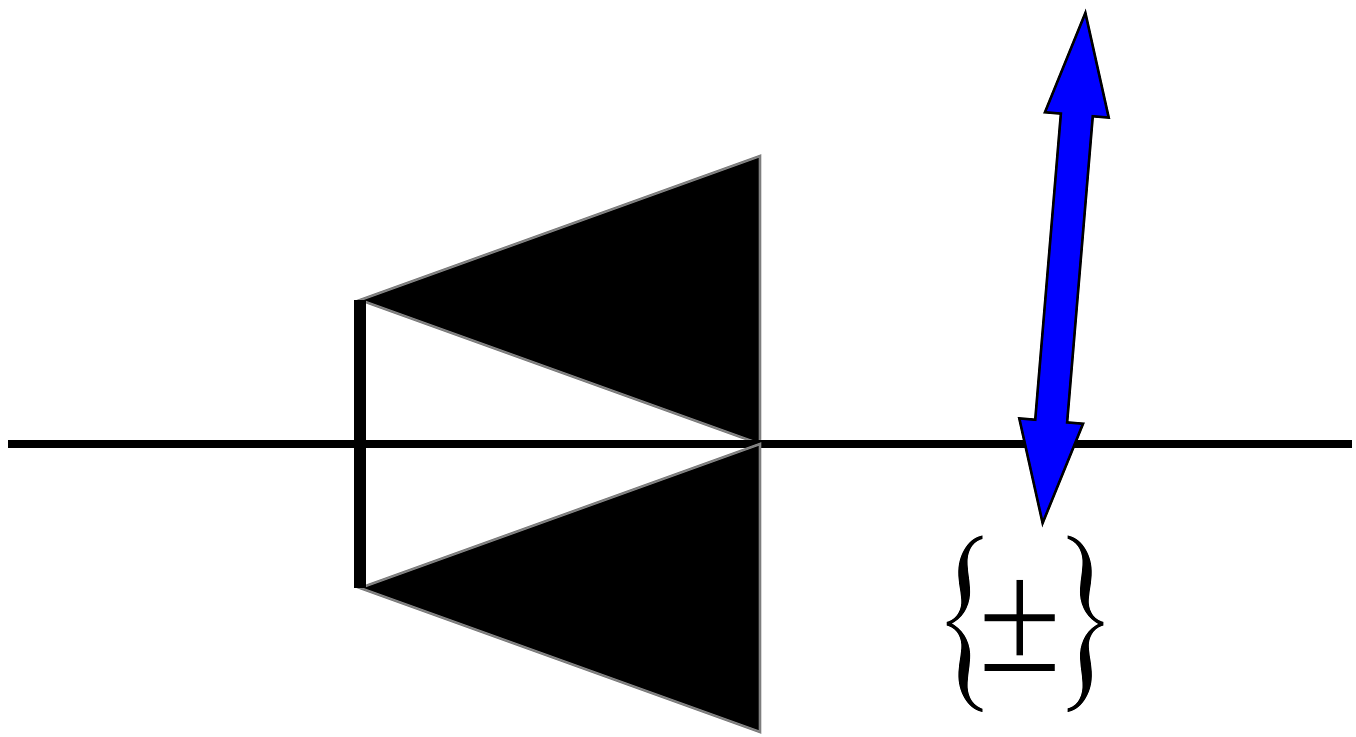
Reversal of Plume Direction due to Vertical Wind Shear

©The COMET Program



Reflexión/Absorción total en una superficie...

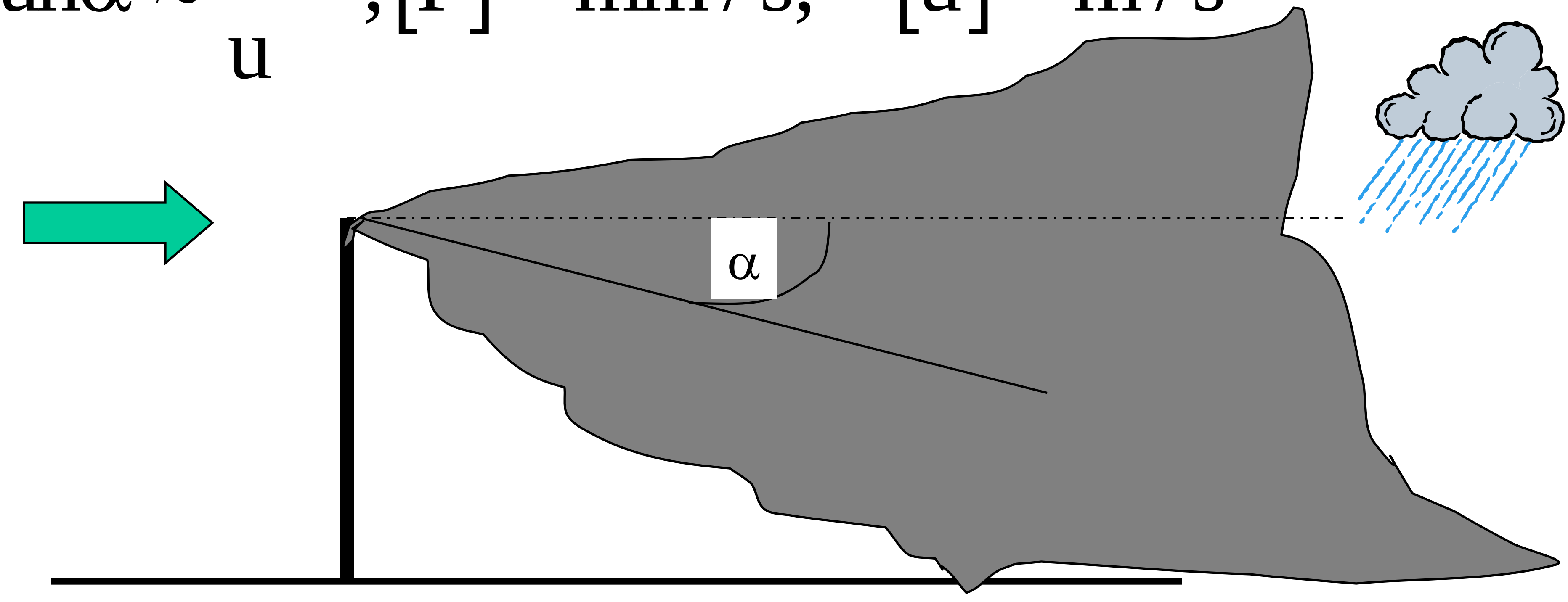
$$< c(x,y,z) > = \frac{Q}{2\pi\sigma_y\sigma_z\bar{u}}\exp\left[-\frac{1}{2}\frac{y^2}{\sigma_y^2}\right]\left\{\exp\left[-\frac{1}{2}\frac{(z-H)^2}{\sigma_z^2}\right]\pm\exp\left[-\frac{1}{2}\frac{(z+H)^2}{\sigma_z^2}\right]\right\}$$



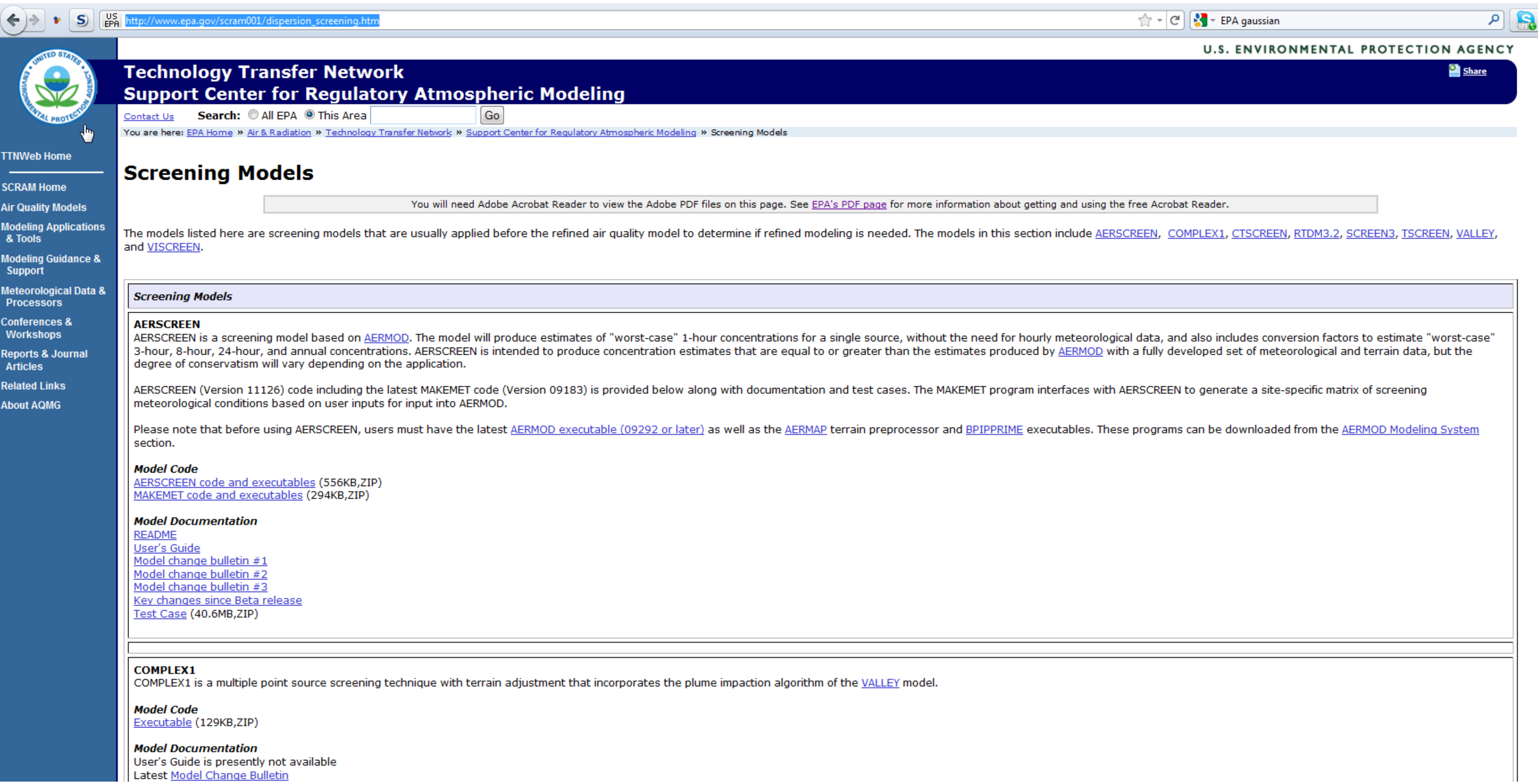
Deposición Seca/Húmeda

$$C(x,y,z) \approx [\text{idem}] * \exp\left[\frac{-x}{\bar{u}\tau}\right], \quad \tau = \frac{Z_{capa\_límite}}{v_{dep}}$$

$$\tan\alpha \approx \frac{P}{u} \quad , [P] = mm/s; \quad [u] = m/s$$



¡De muy fácil acceso!



http://www.epa.gov/scram001/dispersion_screening.htm

U.S. ENVIRONMENTAL PROTECTION AGENCY

Technology Transfer Network
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Screening Models

You will need Adobe Acrobat Reader to view the Adobe PDF files on this page. See EPA's PDF page for more information about getting and using the free Acrobat Reader.

The models listed here are screening models that are usually applied before the refined air quality model to determine if refined modeling is needed. The models in this section include AERSCREEN, COMPLEX1, CTSCREEN, RTDM3.2, SCREEN3, TSCREEN, VALLEY, and VISCREEN.

Screening Models

AERSCREEN
AERSCREEN is a screening model based on AERMOD. The model will produce estimates of "worst-case" 1-hour concentrations for a single source, without the need for hourly meteorological data, and also includes conversion factors to estimate "worst-case" 3-hour, 8-hour, 24-hour, and annual concentrations. AERSCREEN is intended to produce concentration estimates that are equal to or greater than the estimates produced by AERMOD with a fully developed set of meteorological and terrain data, but the degree of conservatism will vary depending on the application.

AERSCREEN (Version 11126) code including the latest MAKEMET code (Version 09183) is provided below along with documentation and test cases. The MAKEMET program interfaces with AERSCREEN to generate a site-specific matrix of screening meteorological conditions based on user inputs for input into AERMOD.

Please note that before using AERSCREEN, users must have the latest AERMOD executable (09292 or later) as well as the AERMAP terrain preprocessor and BPIPPRIME executables. These programs can be downloaded from the AERMOD Modeling System section.

Model Code
AERSCREEN code and executables (556KB,ZIP)
MAKEMET code and executables (294KB,ZIP)

Model Documentation
README
User's Guide
Model change bulletin #1
Model change bulletin #2
Model change bulletin #3
Key changes since Beta release
Test Case (40.6MB,ZIP)

COMPLEX1
COMPLEX1 is a multiple point source screening technique with terrain adjustment that incorporates the plume impaction algorithm of the VALLEY model.

Model Code
Executable (129KB,ZIP)

Model Documentation
User's Guide is presently not available
Latest Model Change Bulletin

http://www.epa.gov/scram001/dispersion_screening.htm

Modelos Gaussianos Estacionarios

Ventajas

- Fáciles de usar (y adquirir)
- Solución sencilla a problemas complejos
- Se alimentan con inf. meteorológica simple

Desventajas

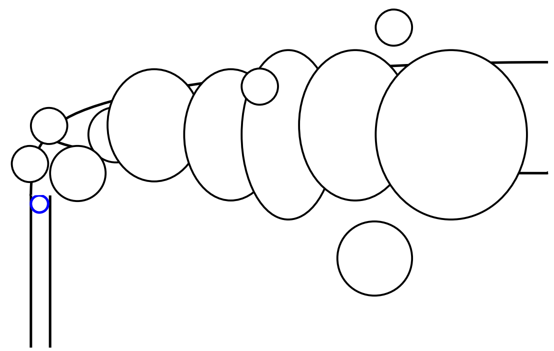
- Son empíricos
- No manejan bien:
  - calmas
  - transf. químicas
  - procesos de deposición
  - terrenos complejos

Típicamente, para modelos gaussianos...

- Condiciones ideales (gaussianas): cerca (10 km), tiempos cortos de promedio (min-hr), terreno plano, meteorología constante 10-20%
- Idem salvo fuentes en altura, 20-40%
- Condiciones no tan ideales pero no extremas....factor 2
- Condiciones extremas tipo bordes costeros...orden de magnitud

http://www.risoe.dk/vea-atu/atm_disp/rimpuff/rp_ind2.htm

Modelos Gaussianos No Estacionarios



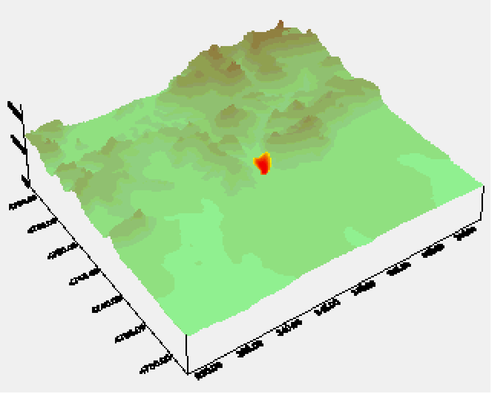
$$\Delta c = \frac{\Delta M}{(2\pi)^{3/2}\sigma_h\sigma_z} \exp\left[-\frac{1}{2}\left(\frac{x_P - x_R}{\sigma_h}\right)^2\right] \exp\left[-\frac{1}{2}\left(\frac{y_P - y_R}{\sigma_h}\right)^2\right] \exp\left[-\frac{1}{2}\left(\frac{z_P - z_R}{\sigma_z}\right)^2\right]$$

Desafío: ¡¡Estimar los sigmas y las trayectorias de los “puffs”!!

Modelos Gaussianos No Estacionarios

Ventajas

- Manejan situaciones no estacionarias
- Manejan situaciones de viento en calma



Desventajas

- Son empíricos
- Requieren inf. meteorológica detallada
- No manejan bien:
  – transf. químicas
  – procesos de deposición

Una aproximación más difícil: simular la turbulencia

Large Eddy Simulations (LES)

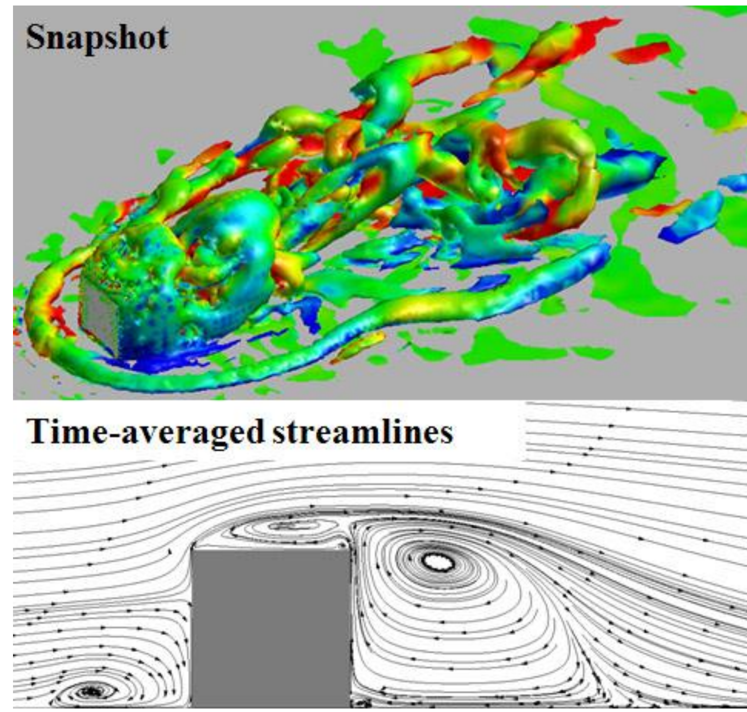
LES EQUATIONS

$$\frac{\partial u_i}{\partial t} + u_j \frac{\partial u_i}{\partial x_j} = \frac{g_i}{T_0}\theta - \frac{1}{\rho}\frac{\partial p}{\partial x_i} + \upsilon \frac{\partial^2 u_i}{\partial {x_j}^2}$$

Apply filter G

$$\tilde{u}_i = \iiint u_i G \, dxdydz$$

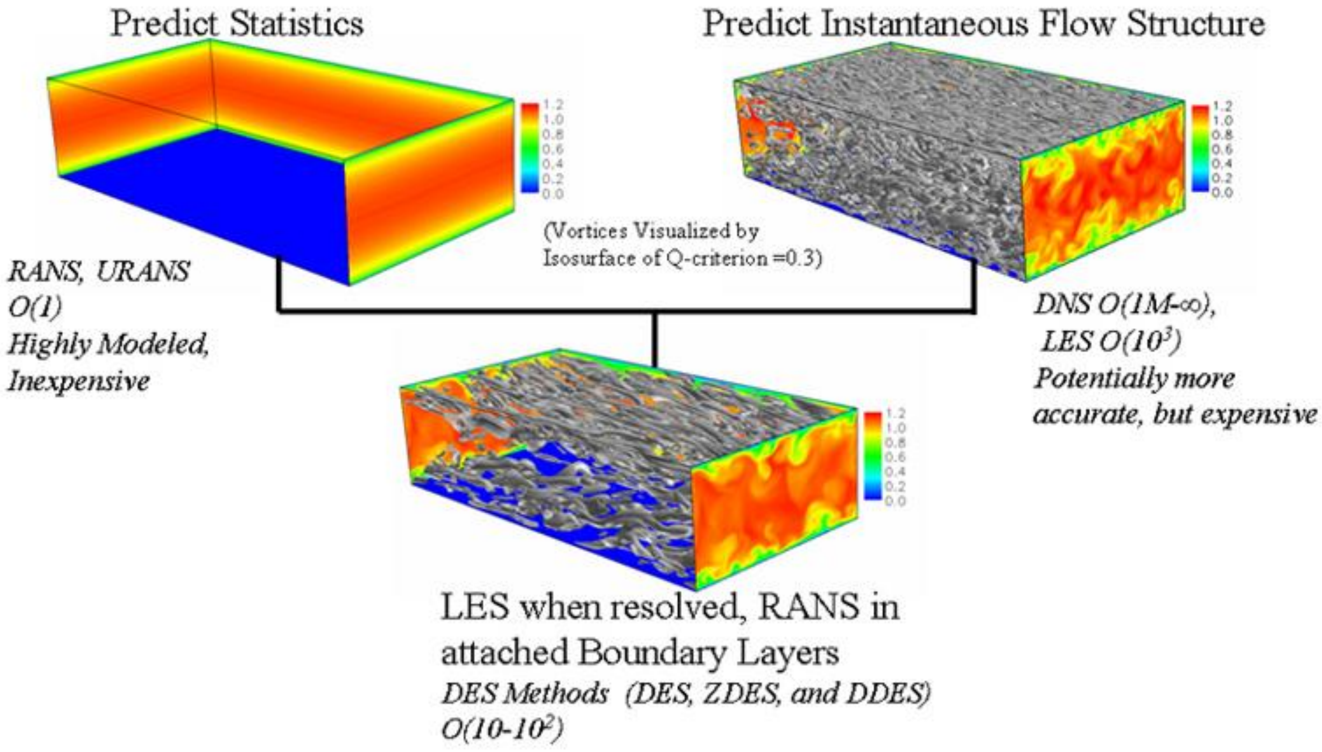
$$\frac{\partial \tilde{u}_i}{\partial t} + \tilde{u}_j \frac{\partial \tilde{u}_i}{\partial x_j} = \frac{g_i}{T_0}\tilde{\theta} - \frac{1}{\rho}\frac{\partial \tilde{p}}{\partial x_i} - \frac{\partial(\widetilde{u_i u_j} - \tilde{u}_i\tilde{u}_j)}{\partial x_j} + \upsilon \frac{\partial^2 \tilde{u}_i}{\partial {x_j}^2}$$



Joseph Smagorinsky
(1924-2005)

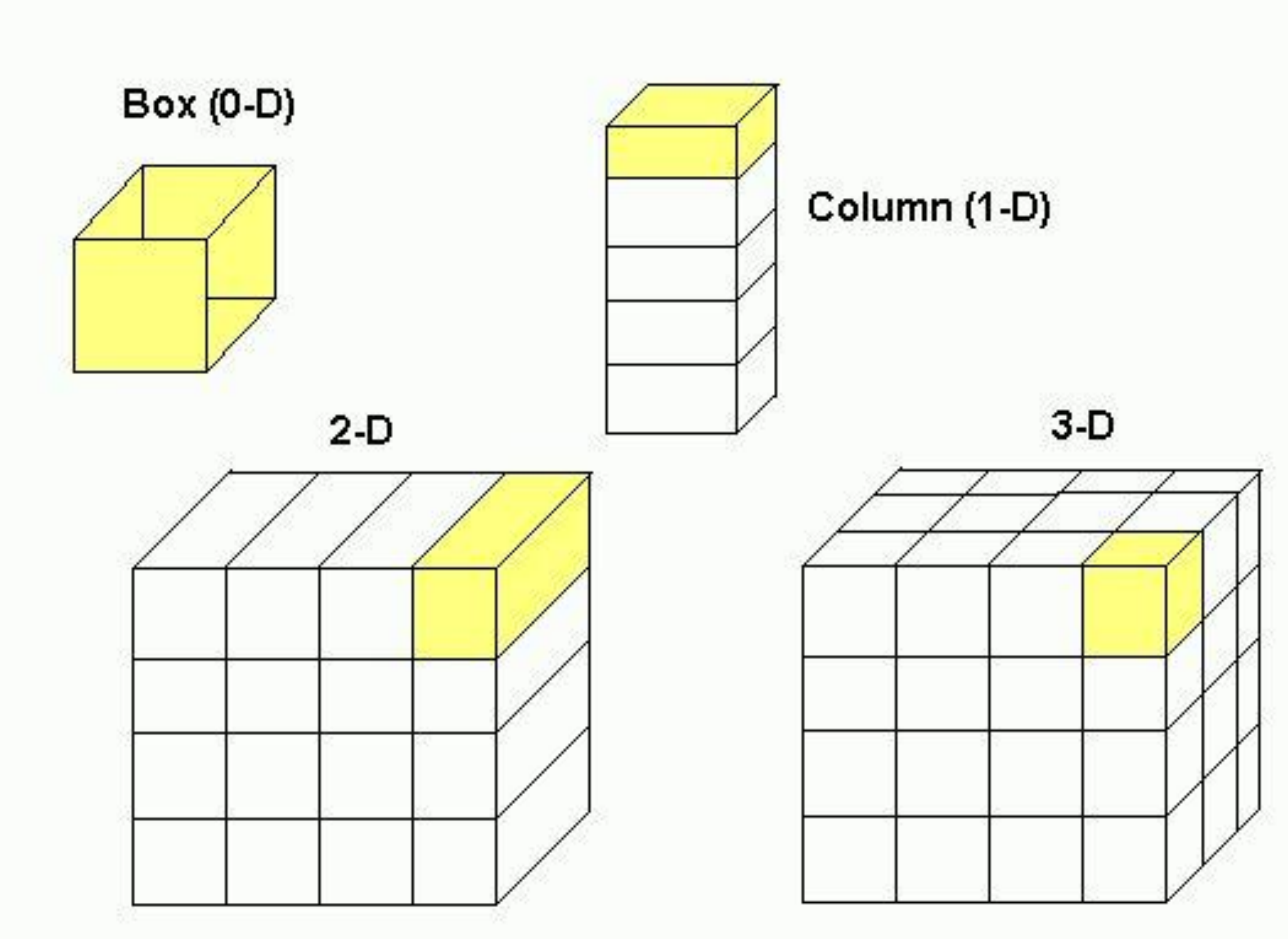
Se simulan, a partir de Navier-Stokes, los remolinos importantes (?) y se parametrizan los más pequeños.

Simulando turbulencia/micrometeorología

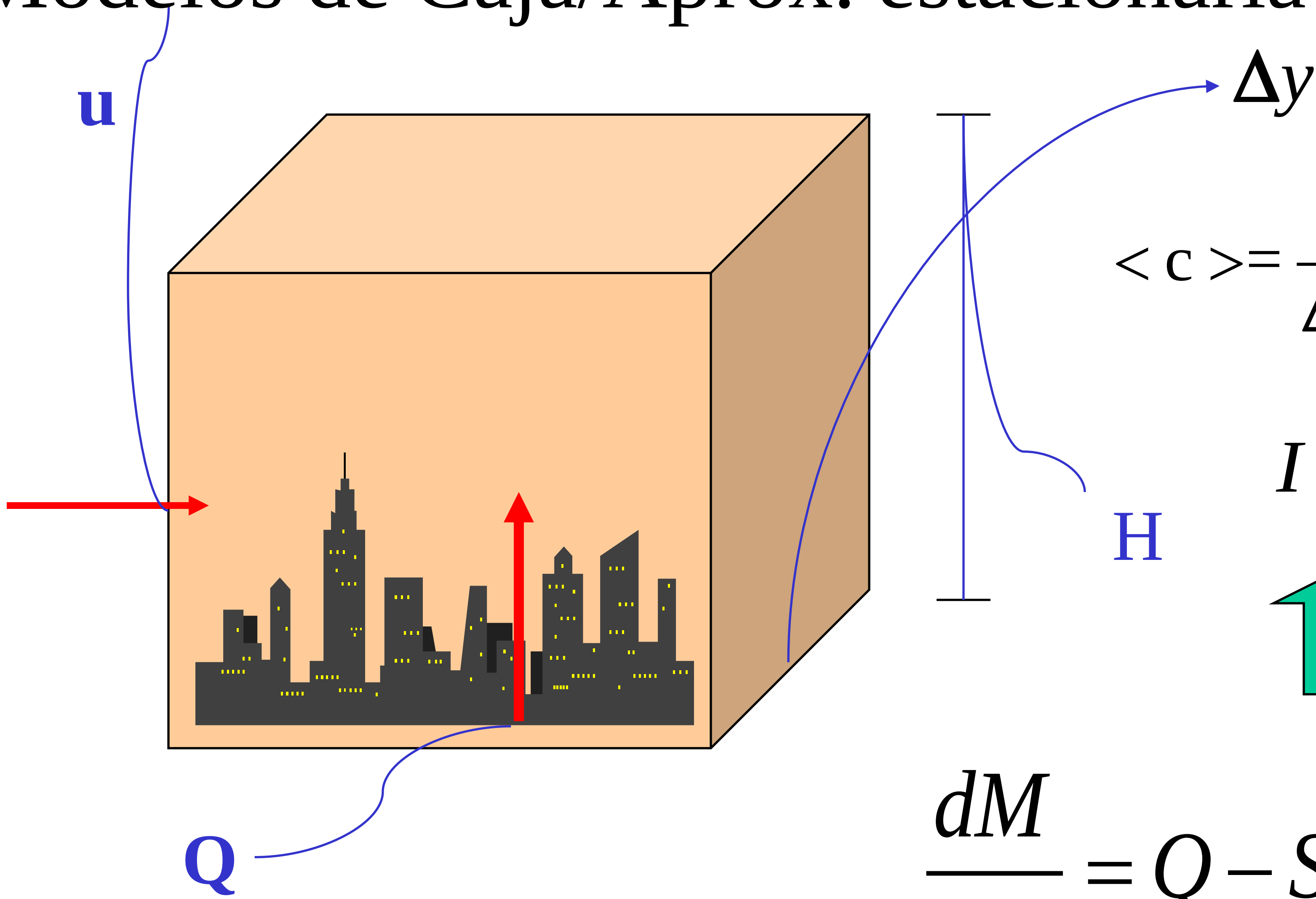


Reynolds-Averaged Navier-Stokes (RANS)
Direct Numerical Simulation (DNS).
Large Eddy Simulation (LES)

http://www.arl.psu.edu/capabilities/fsm_cm_eddysim.html


Box (0-D)
Column (1-D)
2-D
3-D

Modelos de Caja/Aprox. estacionaria



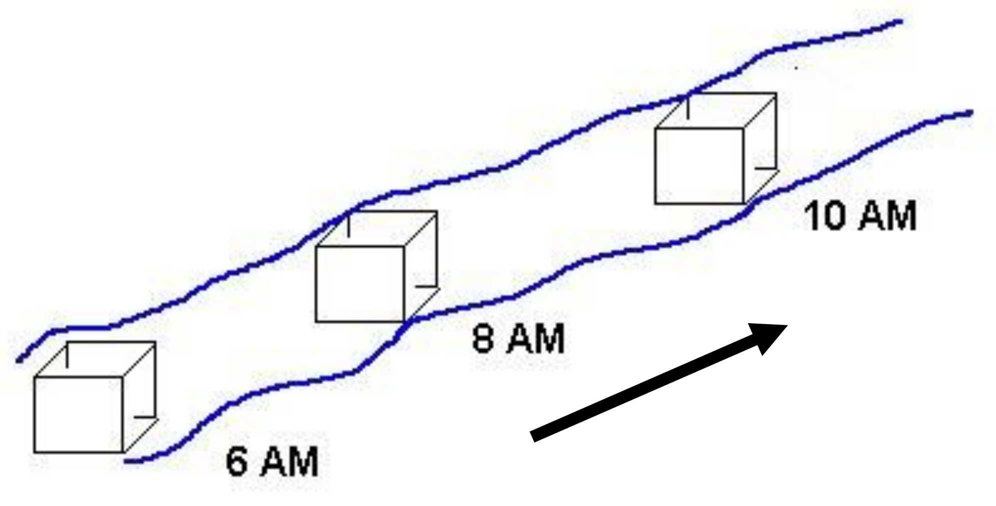
$$\langle c \rangle = \frac{Q}{\Delta y . u . H}$$

$$I = u\,H$$

$$\frac{dM}{dt} = Q - S \approx 0$$

Aproximación à la Lagrange...

$$\frac{dC}{dt} = -c\nabla.\vec{\mathrm{v}} - \nabla.(<\mathrm{c}'\vec{\mathrm{v}}'>) + Q - S$$



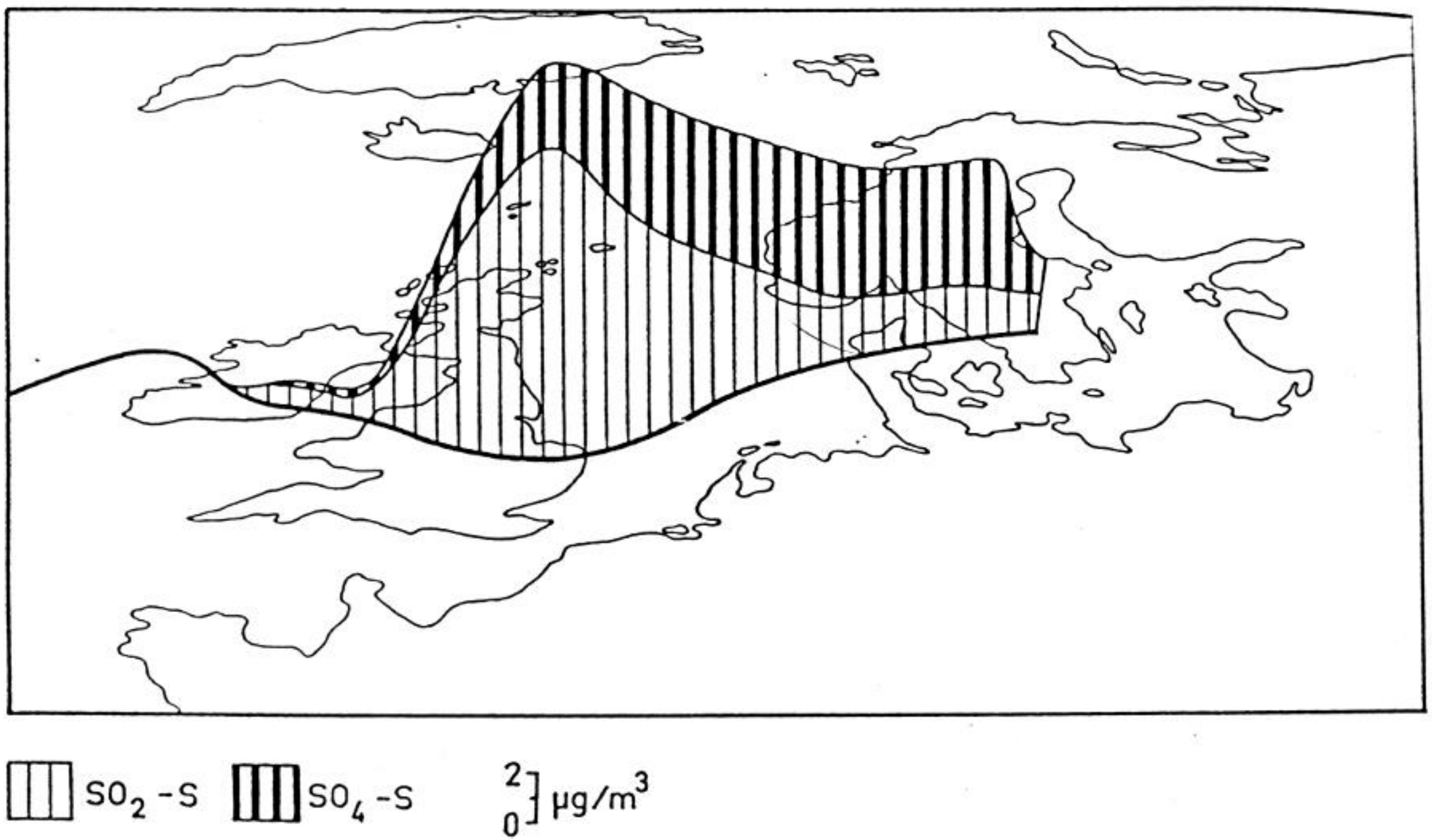
$$\frac{d(CH)}{dt} = \frac{E}{\Delta x \Delta y} + RH - \frac{S}{\Delta x \Delta y}$$

$$\frac{dC_1}{dt} = (1 - \boldsymbol{\alpha} - \boldsymbol{\beta})\frac{Q}{D} - \left(\frac{v_1}{D} + k_t + k_{w1}\right)C_1$$

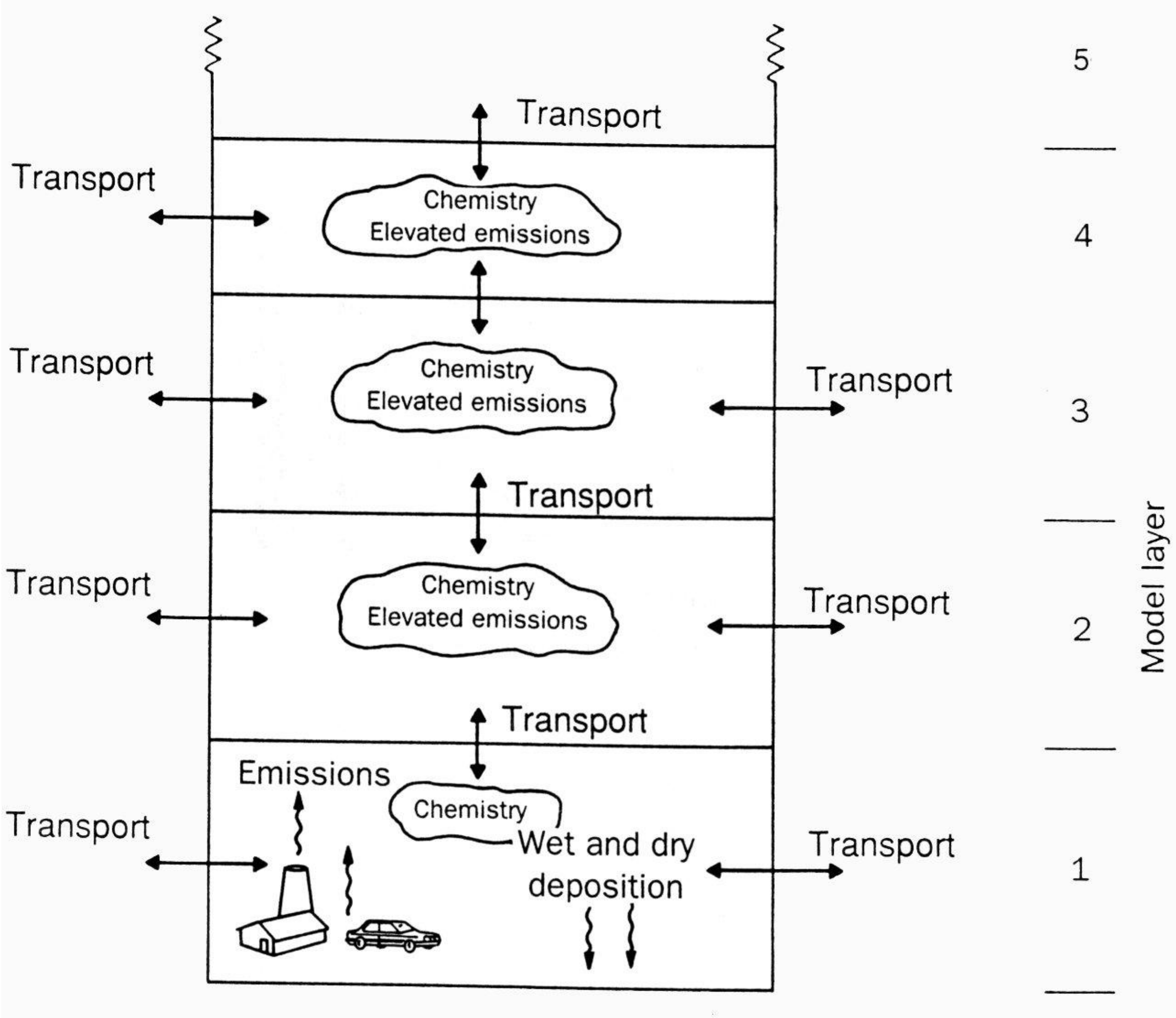
$$\frac{dC_2}{dt} = \boldsymbol{\beta}\frac{Q}{D} + k_t C_1 - \left(\frac{v_2}{D} + k_{w2}\right)C_2$$

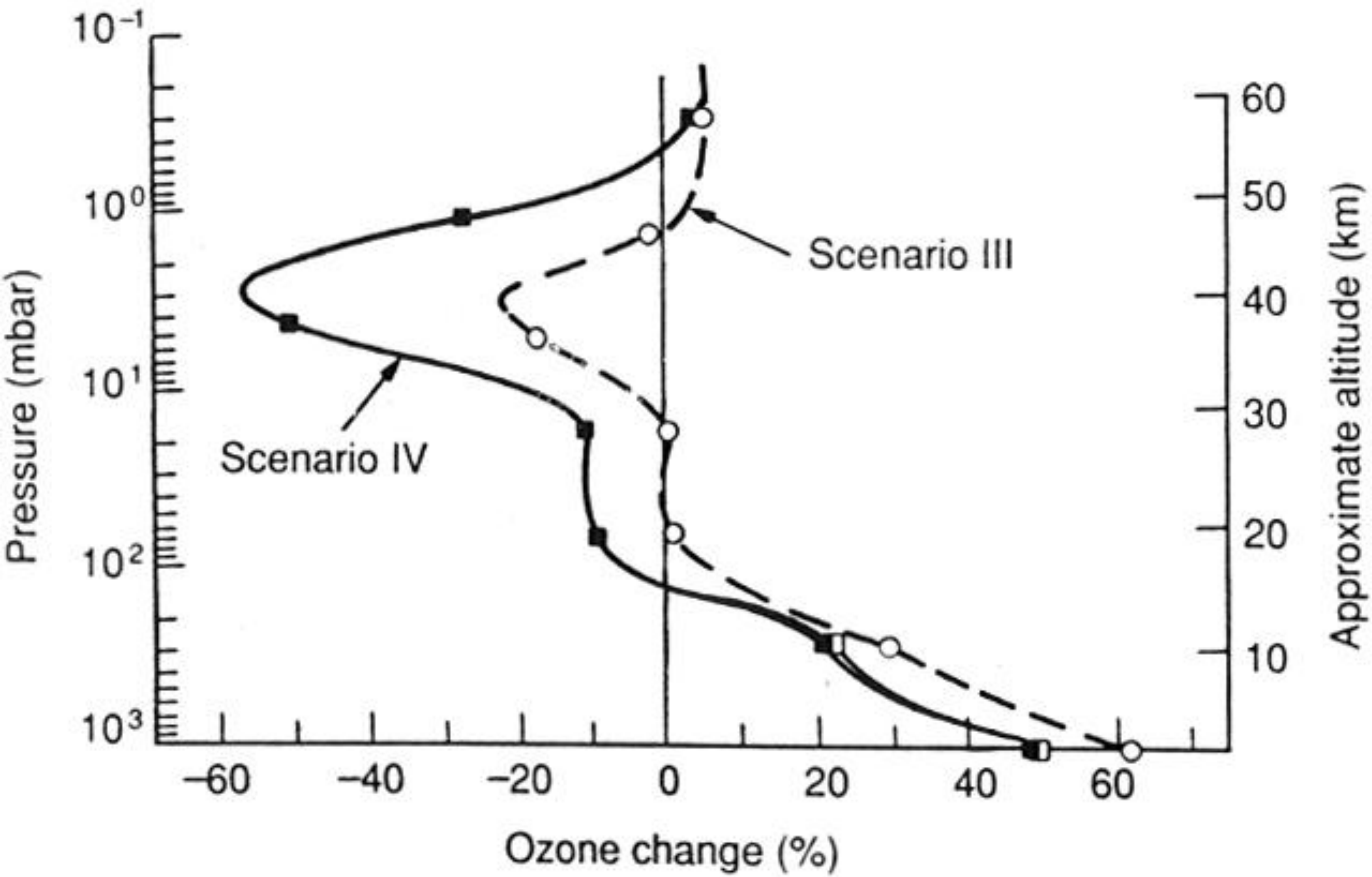
EMEP

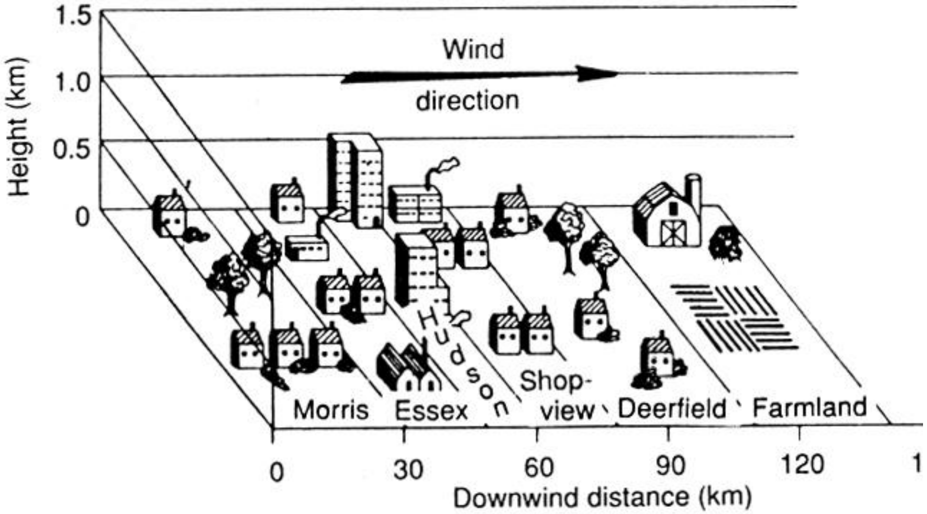
Eliassen et al, 1982. *J. appl. Met.*, 21, 1645-1661



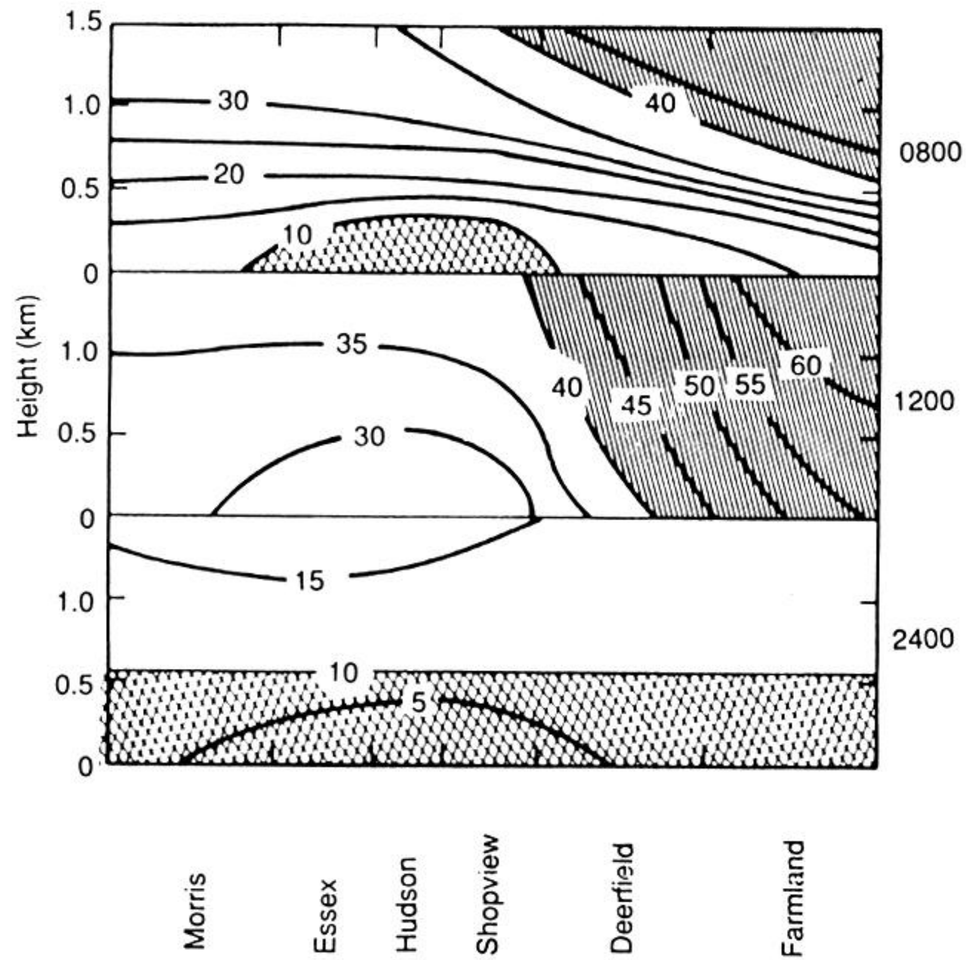
Modelos Unidimensionales (1-D)



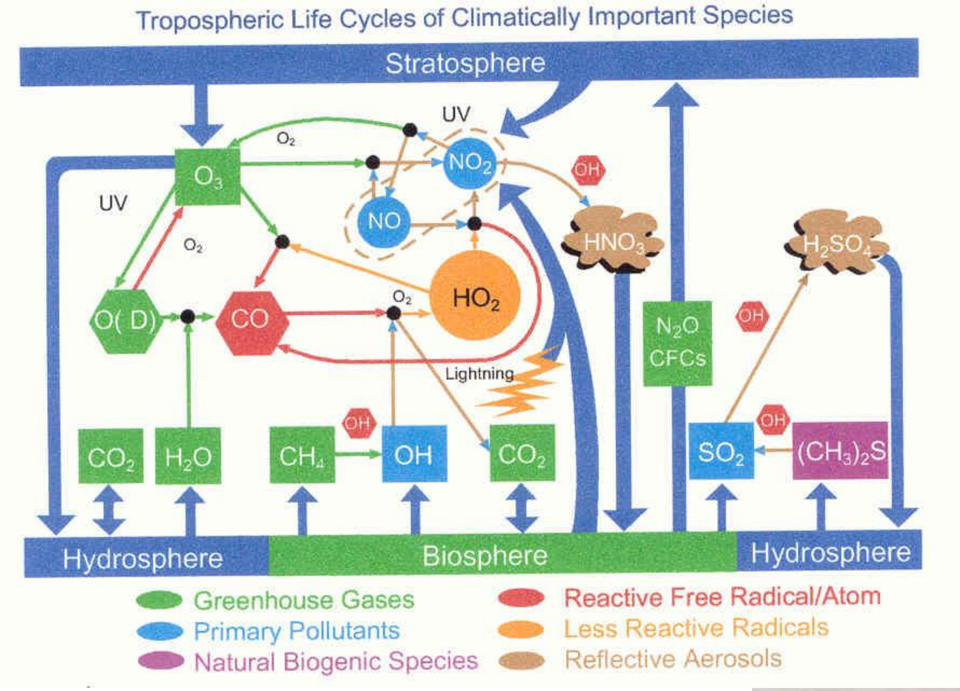

10⁻¹
10⁰
10¹
10²
10³
Pressure (mbar)
Scenario III
Scenario IV
−60
−40
−20
0
20
40
60
Ozone change (%)
60
50
40
30
20
10
Approximate altitude (km)



Height (km)
1.5
1.0
0.5
0
Wind
direction
Hudson
Morris
Essex
Shop-
view
Deerfield
Farmland
0
30
60
90
120
Downwind distance (km)

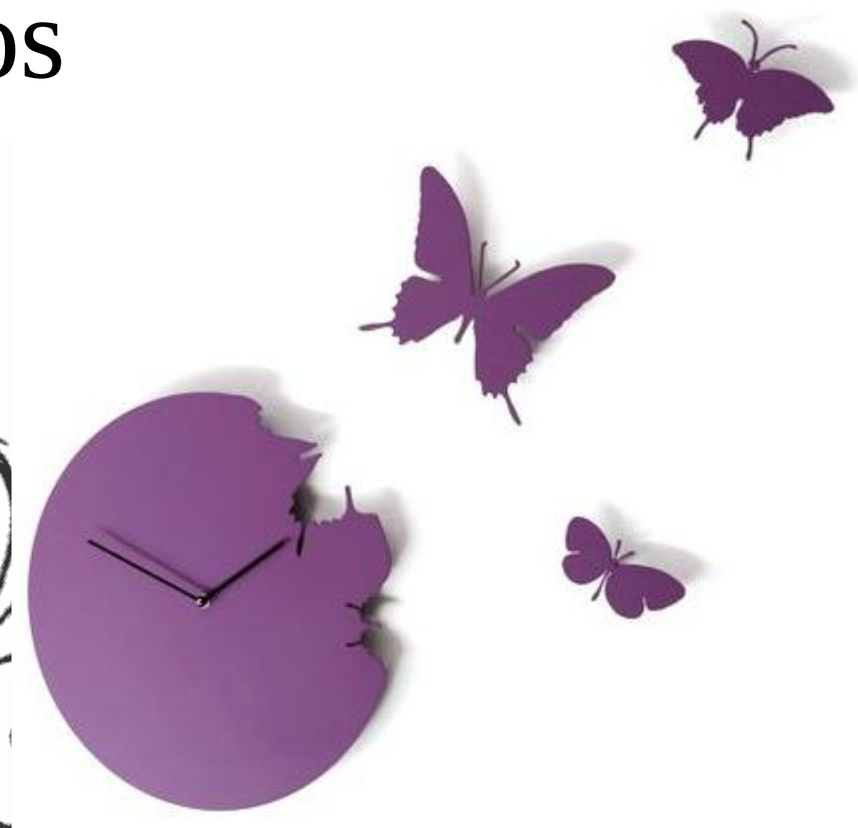


Height (km)
1.5
1.0
0.5
0
30
40
20
10
0800
35
40
45
50
55
60
30
1200
15
10
5
2400
Morris
Essex
Hudson
Shopview
Deerfield
Farmland


Tropospheric Life Cycles of Climatically Important Species
Stratosphere
UV
O₂
NO₂
NO
OH
HNO₃
H₂SO₄
O₃
HO₂
O(D)
CO
Lightning
N₂O
CFCs
CO₂
H₂O
CH₄
SO₂
(CH₃)₂S
Hydrosphere
Biosphere
Greenhouse Gases
Primary Pollutants
Natural Biogenic Species
Reactive Free Radical/Atom
Less Reactive Radicals
Reflective Aerosols

3-D

Pausa 5 minutos



Modelos de dispersión

$$\frac{\partial c}{\partial t} = -\vec{v}.\nabla c - c\nabla.\vec{v} - \nabla.(< c'\vec{v}' >) + Q - S$$

+CI & CB

REPRESENTACIÓN FÍSICO-COMPUTACIONAL

Abstracción...Simplificación...Síntesis...Diagnóstico...Pronóstico

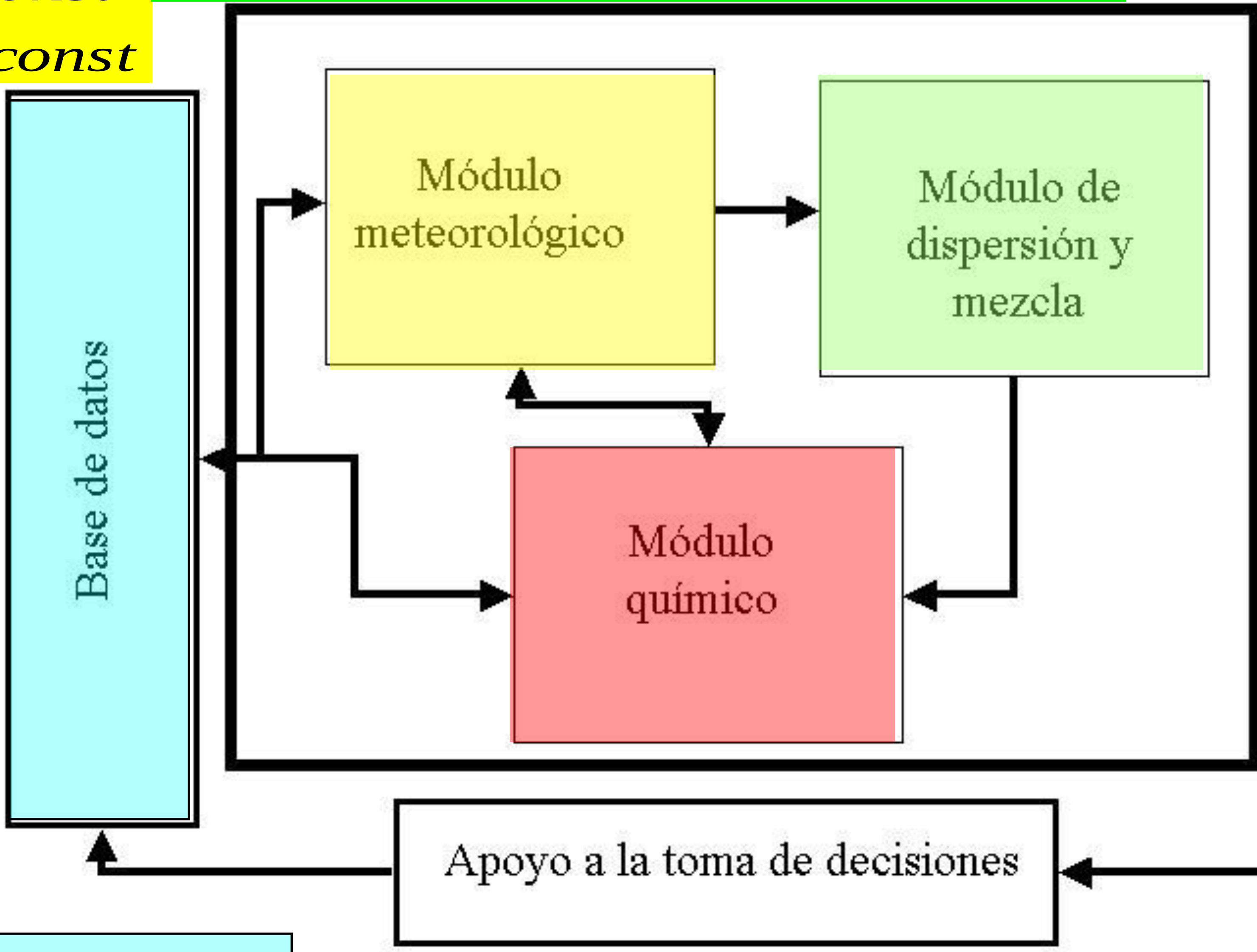
$$\vec{F} = m\,\vec{a}$$

$$E = const$$

$$M = const$$

$$T = -\vec{v}.\nabla c - c\nabla.\vec{v} - \nabla.(< c'\vec{v}' >)$$

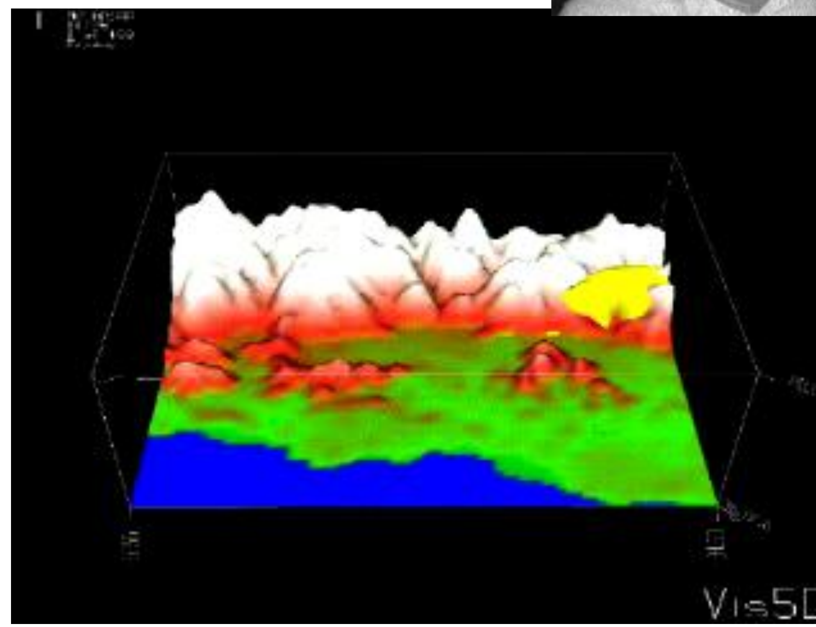
$$C = Q - S$$



Emission inventories
Observations

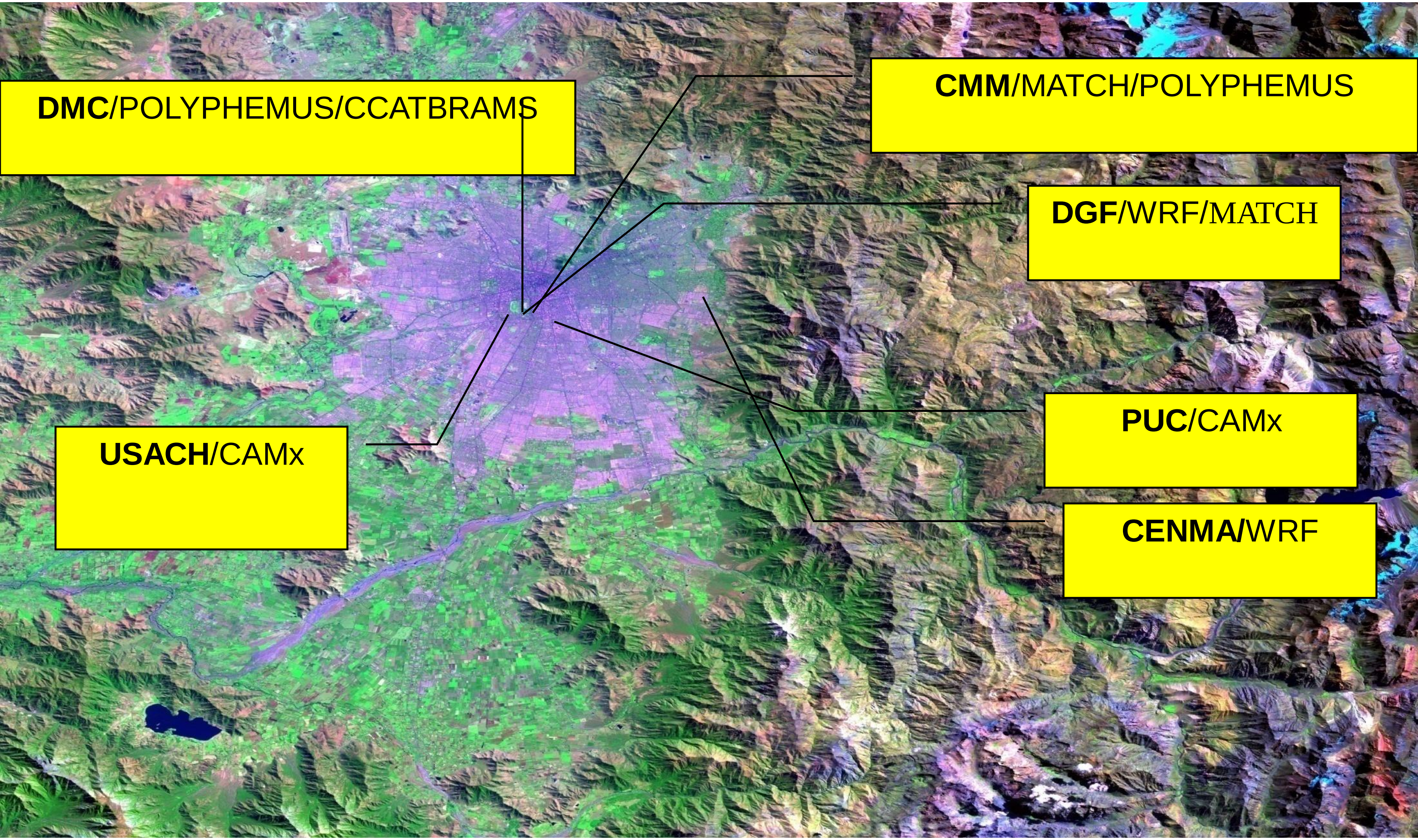
Modelación (de química) atmosférica en Chile

- 80’s Pablo Ulriksen (DGF)…Gaussianos/Caja
- 80…presente Consultoras…Gaussianos estacionarios y no estacionarios
- Tarde en los 90’s MATCH
- Temprano en los 2000’ WRF
- Hoy modelos similares se aplican en Santiago, Temuco, Concepción, La Serena…



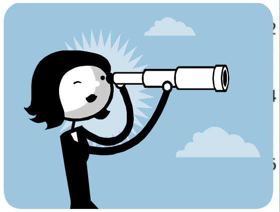
Dispersión de SO2 desde Caletones en conexión con una baja costera (Gallardo et al, 2002)

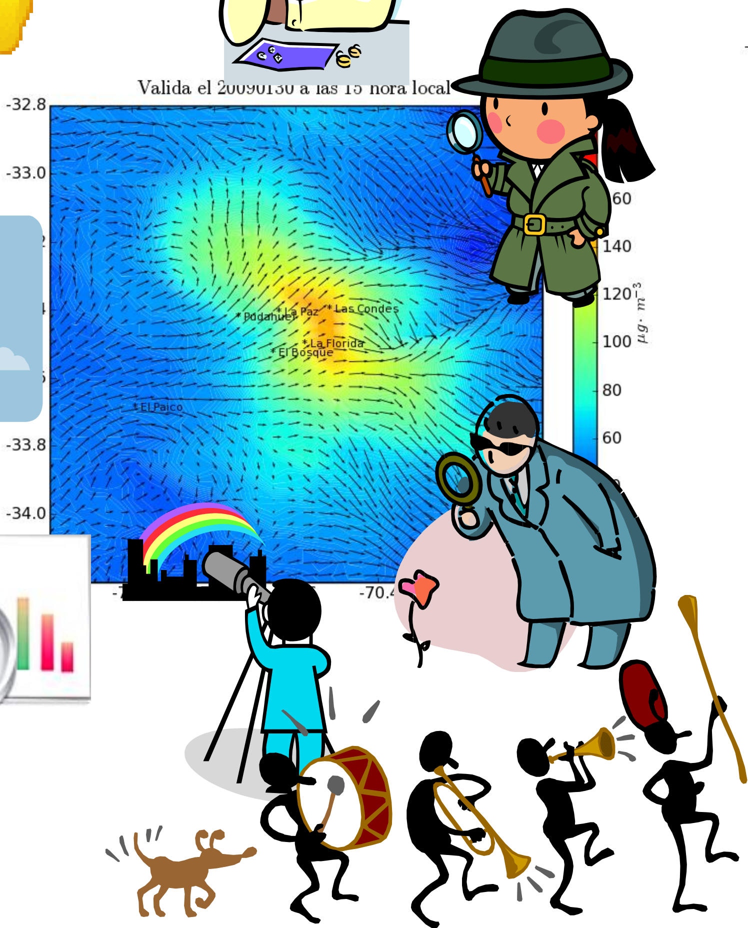
¿Modelos en Santiago?...

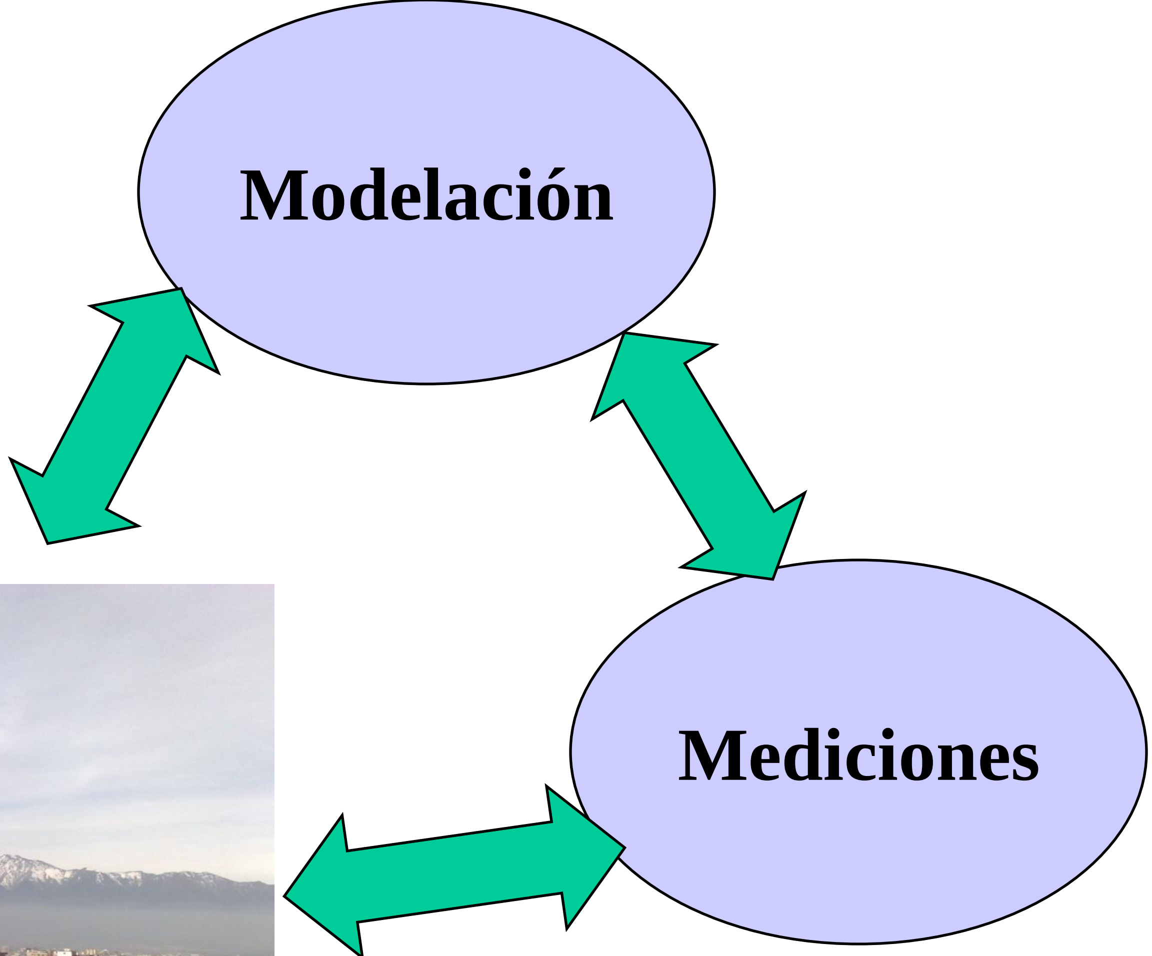


Contenidos: evaluación de modelos de calidad del aire

- Física en modelos vs. física observada
  - Precisión vs exactitud
- Indicadores estadísticos
- Intercomparación y *ensemble*
- Modelación inversa (sensibilidad)







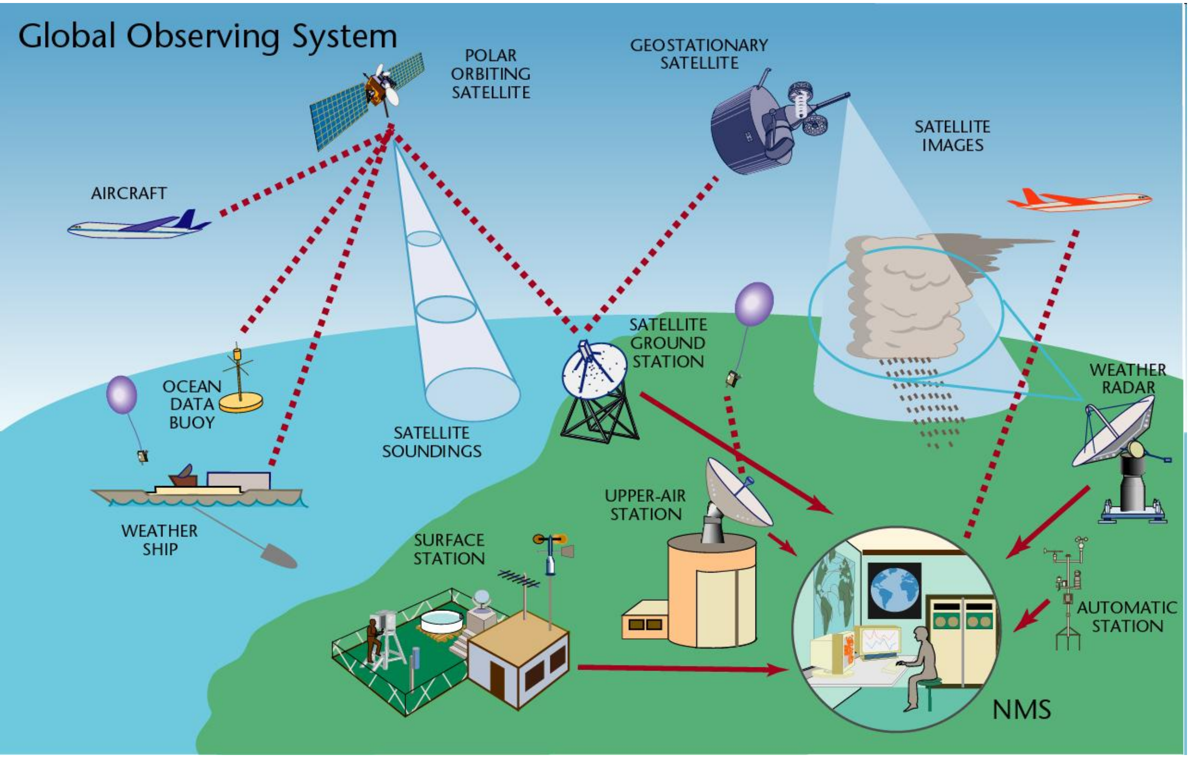
Modelos y observaciones/mediciones son instrumentos de entendiemiento: tienen errores asociados y son complementarios

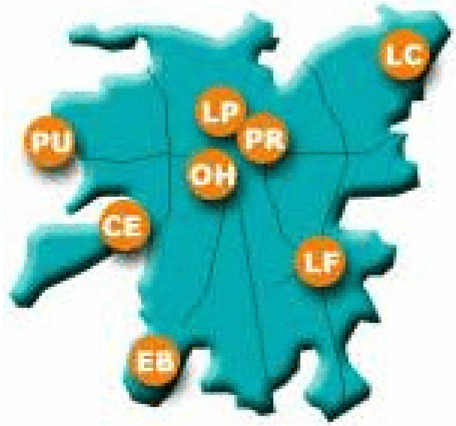
Tras un modelo SIEMPRE hay APROXIMACIONES y datos inciertos

- Datos de entrada con errores inciertos (e.g., inventarios de emisiones; tasas de reacción y fotólisis)
- Escalas no representables explícitamente (parametrizaciones)
- Errores numéricos y computacionales
- Comprensión incompleta o errónea de procesos

Las observaciones son siempre imperfectas e insuficientes

±

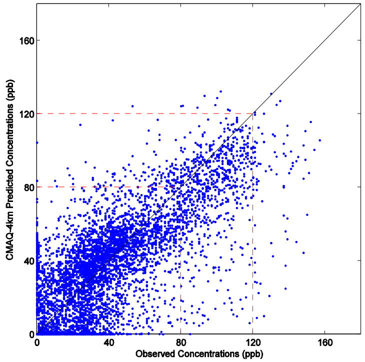




NB. Los modelos atmosféricos tienen hoy ~10^6-10^8 variables de entrada y ~ 10^8-10^{10} variables de salida.

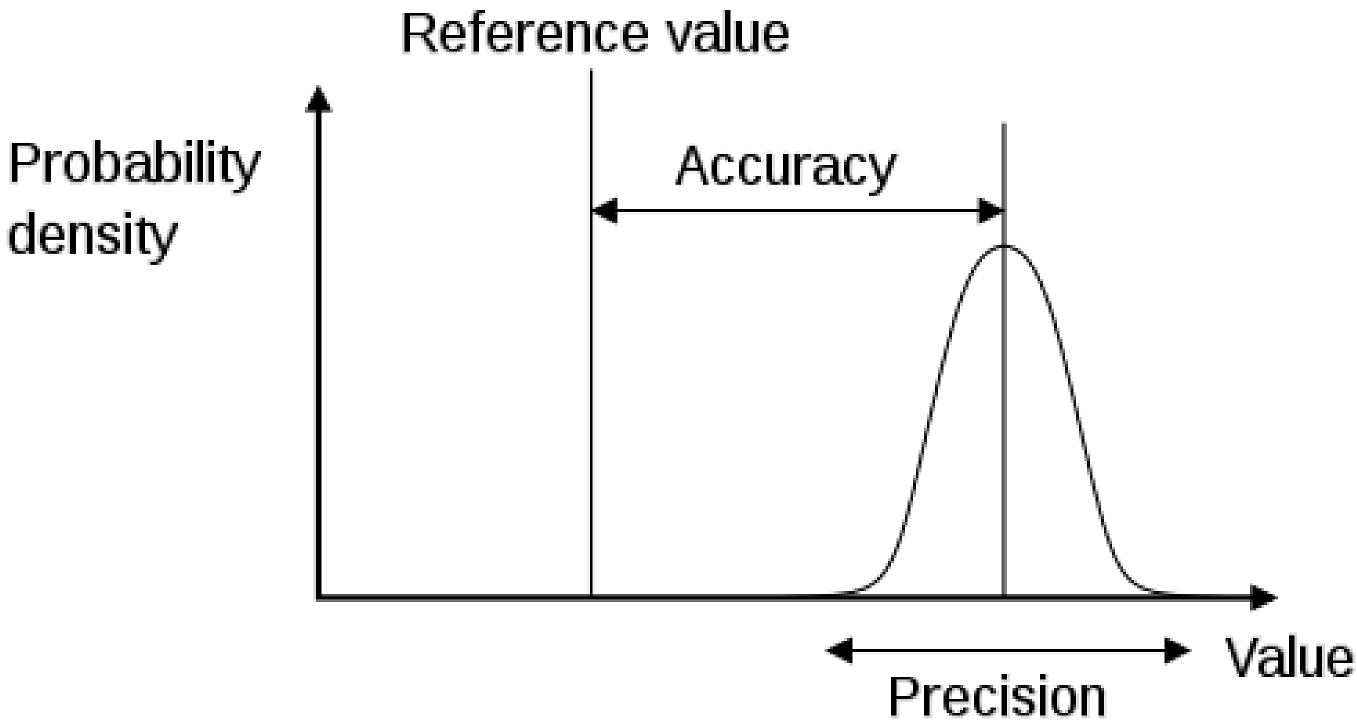
Errores

- Error: del Latín errare…vagar
- Definición: Diferencia entre el valor medido o calculado y el real



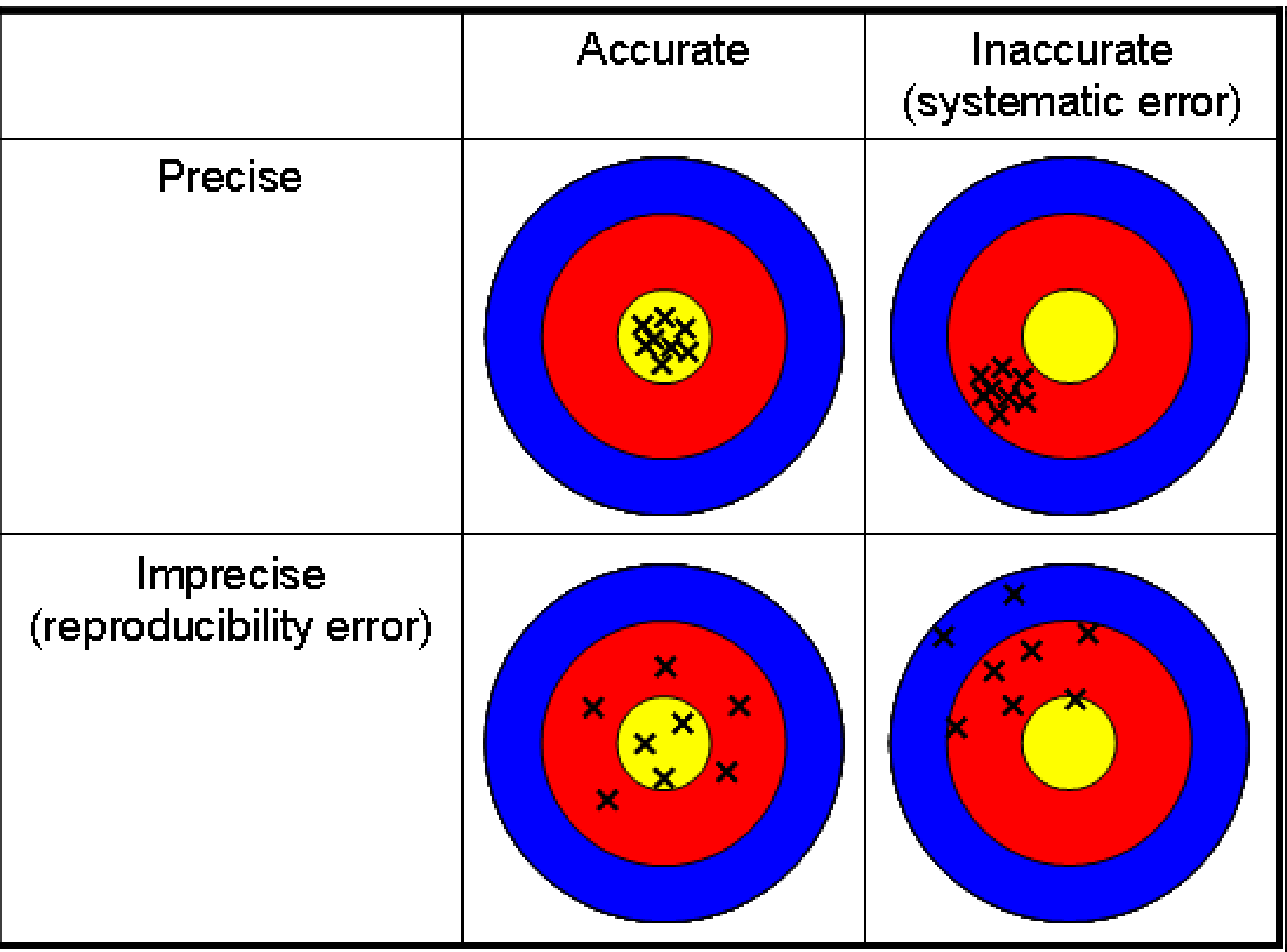
- Pueden ser: aleatorios o sistemáticos

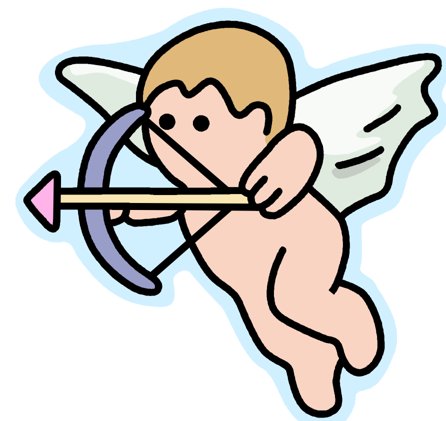
Exactitud vs precisión



¡¡Las ciencias naturales aspiran a la exactitud pero sólo pueden asegurar precisión!!

…exactitud vs precisión





Indicadores de error

"Sesgo medio (Mean Bias)"

$$MB = \frac{1}{mn}\sum_{i=1}^{n}\sum_{j=1}^{m} PRED_{i,j} - OBS_{i,j}$$

"Error medio (Mean Error)"

$$ME = \frac{1}{mn}\sum_{i=1}^{n}\sum_{j=1}^{m} \left| PRED_{i,j} - OBS_{i,j} \right|$$

"Sesgo medio normalizado (Mean Nomalized Bias)"

$$MNB = \frac{1}{mn}\sum_{i=1}^{n}\sum_{j=1}^{m} \frac{PRED_{i,j} - OBS_{i,j}}{OBS_{i,j}}$$

"Error bruto, medio, absoluto, normalizado (Mean Absolute Nomalized Gross Error)"

$$MANGE = \frac{1}{mn}\sum_{i=1}^{n}\sum_{j=1}^{m} \left| \frac{PRED_{i,j} - OBS_{i,j}}{OBS_{i,j}} \right|$$

Diagrama de Taylor

$$\overline{E} = \bar{f} - \bar{r}$$

Sesgo ("bias")

$$E' = \left\{ \frac{1}{N} \sum_{n=1}^{N} \left[\left(f_n - \bar{f} \right) - \left(r_n - \bar{r} \right) \right]^2 \right\}^{1/2}.$$

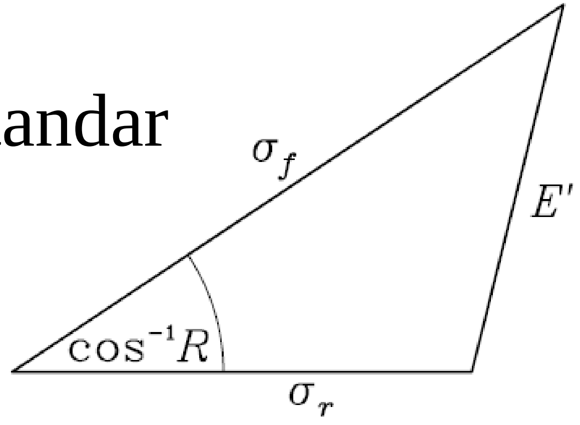
Error cuadrático medio centrado("RMSE")

$$R = \frac{\frac{1}{N} \sum_{n=1}^{N} \left(f_n - \bar{f} \right)\left(r_n - \bar{r} \right)}{\sigma_f \sigma_r},$$

Correlación

$$\sigma = \sqrt{\frac{1}{N} \sum_{i=1}^{N} (x_i - \overline{x})^2}$$

Desviación estandar



f: modelo; r:observación

Ref. Taylor, 2001

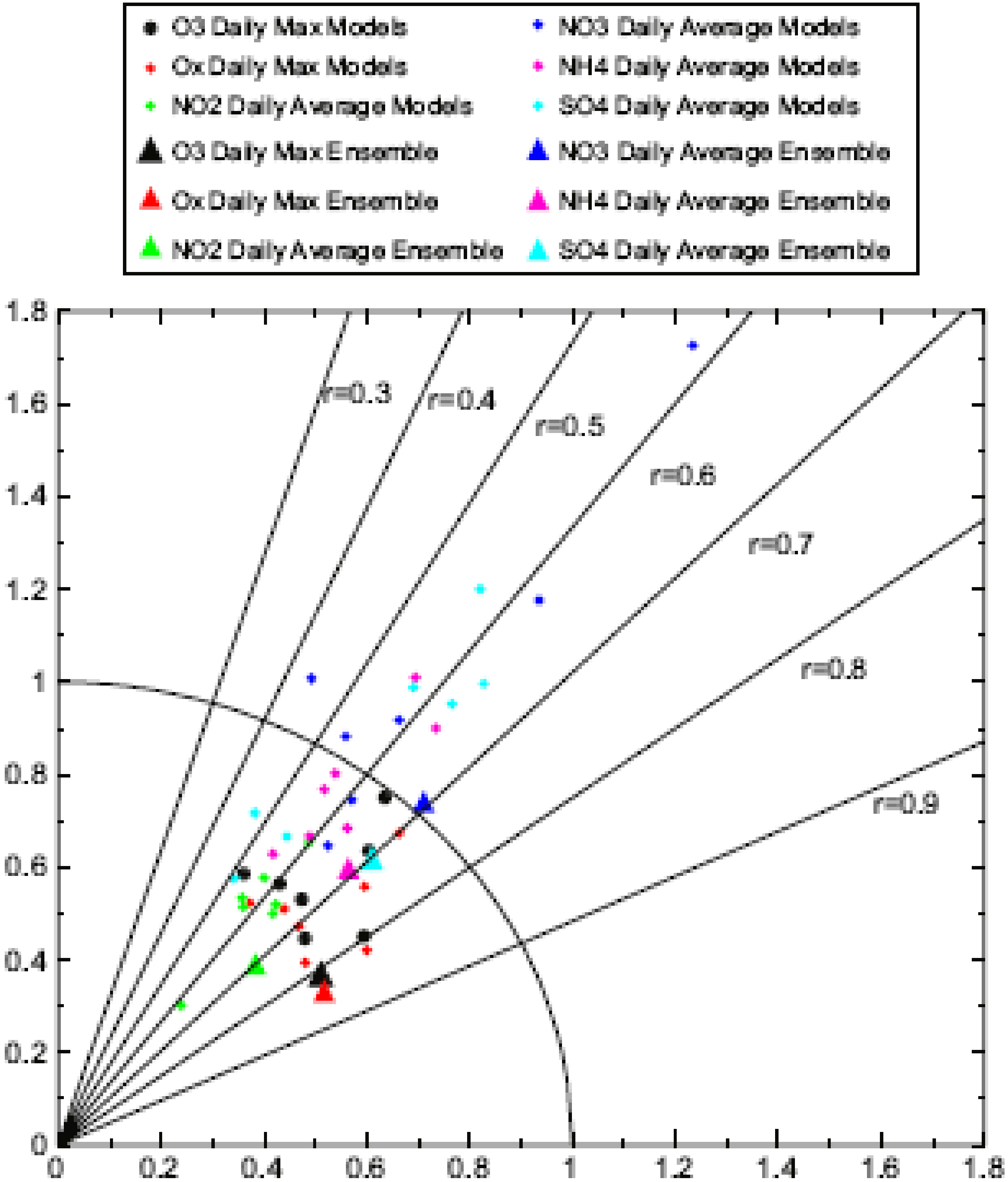


Diagrama de Taylor normalizado para la intercomparación de 7 modelos y su "ensemble"

Vautard et al, 2008 (AE)

¿Cuál(es) indicador(es) estadístico(s) conviene(n)?

Table 1

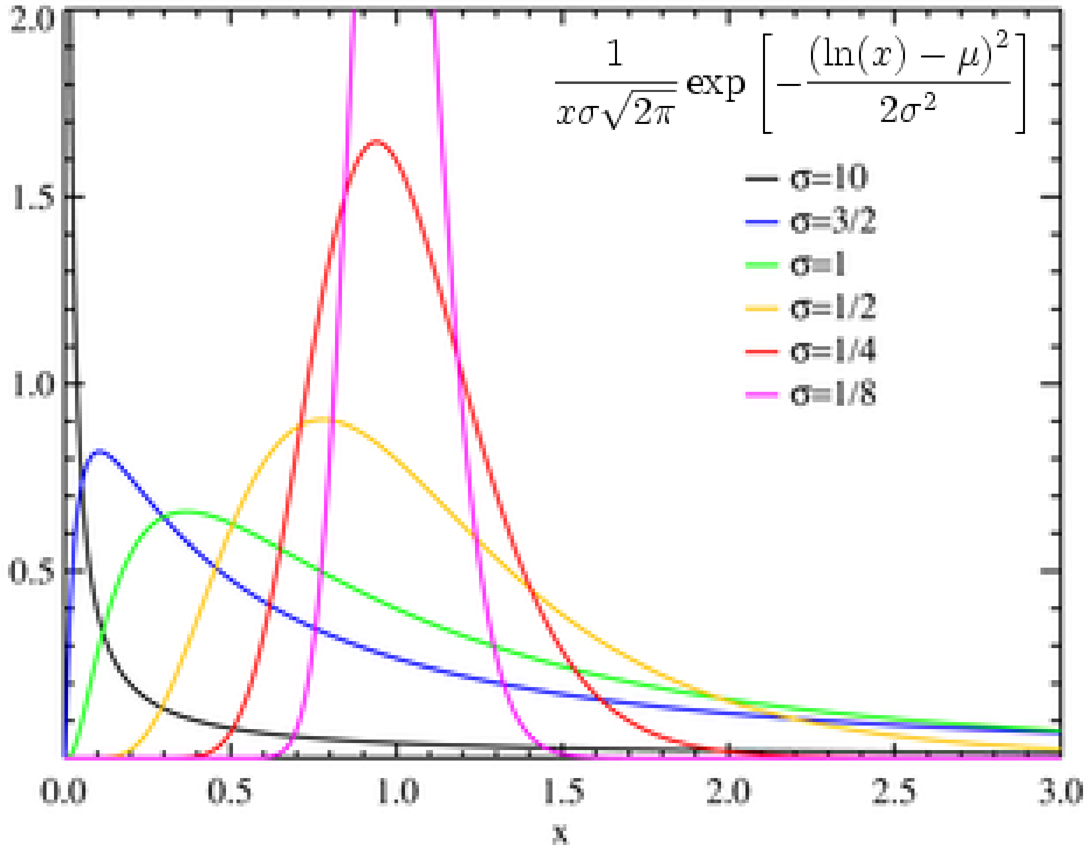
Statistical quality indicators for air quality model performance evaluation

Quality indicators	Formula	Range of acceptable values	Ideal value	Observations
Correlation coefficient	$r=\left[\frac{\sum_{i=1}^{n}\left(C_{oi}-\overline{C_o}\right)\left(C_{pi}-\overline{C_p}\right)}{\sqrt{\sigma_o\sigma_p}}\right]$	0–1	1.0	Co and Cp are the concentration observed and predicted
Fractional bias	$FB=\frac{\overline{Co}-\overline{Cp}}{0.5\left(\overline{Co}+\overline{Cp}\right)}$	(−2)–2	0.0	$\overline{Co}$ and $\overline{Cp}$ are the averaged concentration observed and predicted
Root mean squared error	$RMS=\sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(C_{oi}-C_{pi}\right)^2}$	n.a.	0.0	σ_O and σ_P are the standard deviations of observations and predictions
Normalized standard deviation	$NSD=\frac{\sigma_p}{\sigma_o}$	0–1	1.0	
Normalized mean square error	$NMSE=\frac{\overline{(Co-Cp)^2}}{\overline{Co}\,\overline{Cp}}$	n.a.	0.0	
Average normalized absolute bias	$ANB=\overline{\left(\frac{\lvert Co-Cp\rvert}{Co}\right)}$	n.a.	0.0	
Geometric mean bias	$MG=\exp\left(\overline{\ln Co}-\overline{\ln Cp}\right)$	>0.0	1.0	Co_i and Cp_i are the observed and predicted concentration in monitoring station "i"; n the total number of monitoring stations.
Geometric variance	$VG=\exp\left[\left(\overline{\ln Co}-\overline{\ln Cp}\right)^2\right]$	>0.0	1.0	
Fraction of predictions within a factor of 2 of observations	$\frac{Cp}{Co}$	0.5–2	1.0	
Index of agreement	$d=1-\frac{\sum_{i=1}^{n}\left(Cp_i-Co_i\right)^2}{\sum_{i=1}^{n}\left(\lvert Cp_i-\overline{Co}\rvert+\lvert Co_i-\overline{Co}\rvert\right)^2}$	0–1	1.0	

n.a. — not applicable.

Borrego et al, 2008 (A E)

Notar que las concentraciones de trazas atmosféricas suelen ser log-normales (no gaussianas)



RMS o sesgo pueden ser engañosos por los valores extremos

Sesgo y varianza geométrico son mejores pero no tratan bien el extremo inferior

Borrego et al, 2008 (A E)

No hay evaluaciones estadísticas "normalizadas" …pero hay a veces recomendaciones según el interés

EPA's quality indicators for air quality model performance evaluation

Quality indicators	EPA	Ideal values
Normalized accuracy of the maximum 1 h concentration unpaired in space and time	$A_u = 100\left(\frac{Co_{max} - Cp_{max}}{Cp_{max}}\right)$	±15–20%
Normalized bias test	$D = \frac{1}{N}\sum_{i=1}^{N} \frac{Co_i - Cp_i}{Co_i}$	±5–15%
Gross error of all pairs Co>60 ppb	$E = \frac{1}{N}\sum_{i=1}^{N} \frac{Co_i - Cp_i}{Co_i}$	±30–35%

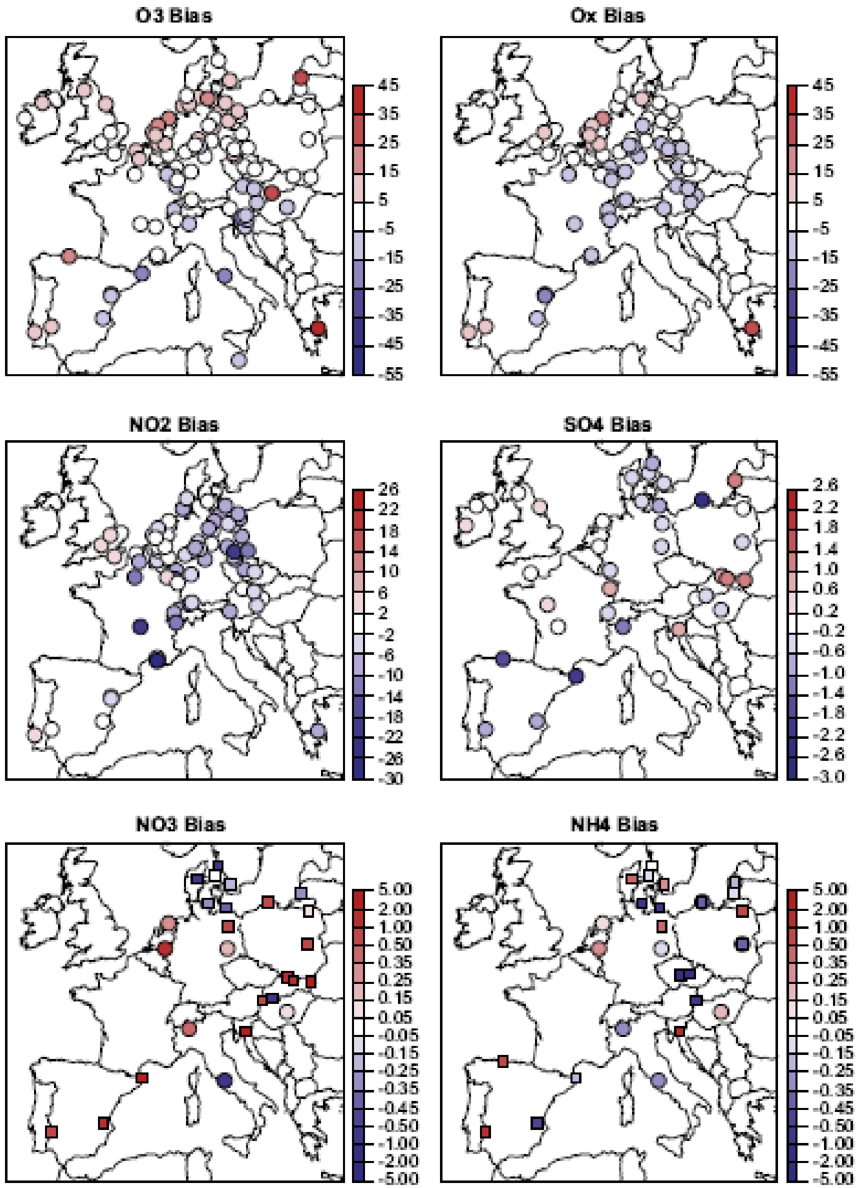
E.g., para fines regulatorios,¿cuán bien se describen los máximos horarios de ozono? (Salud)

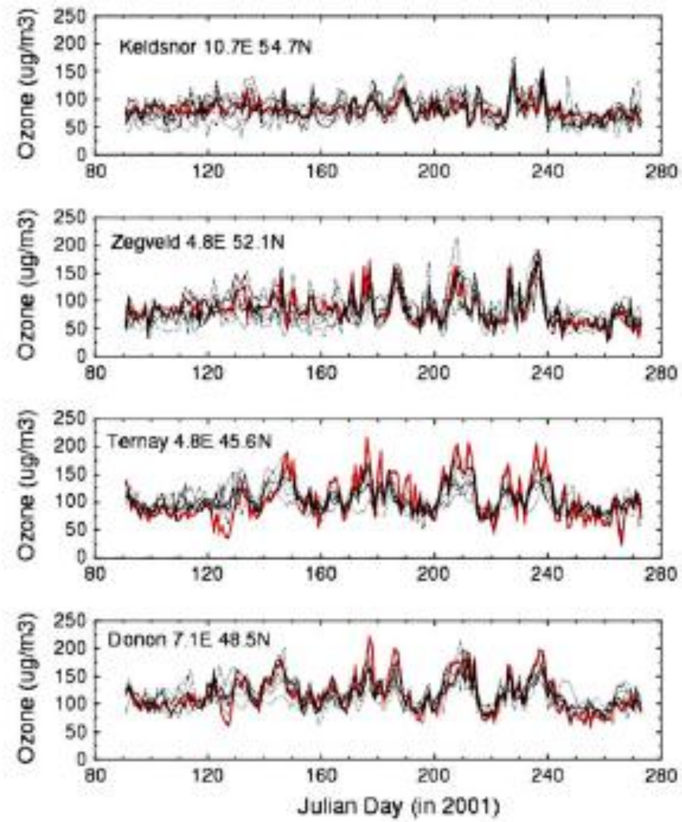
$$\mathrm{RME} = \frac{\max\left(\left|\mathrm{Co}_p - \mathrm{Cp}_p\right|\right)}{\mathrm{Co}_p}$$

Modelling quality objectives established by EU Directives

Pollutant	Quality indicator	Quality objective	Directive
SO_2, NO_2, NO_x	Hourly mean	50–60%	1999/30/EC
	Daily mean	50%	
	Annual mean	30%	
PM, Pb	Annual mean	50%	
CO	8-hour mean	50%	2000/69/EC
Benzene	Annual mean	50%	
Ozone	8-hour daily mean	50%	2002/03/EC
	1-hour average	50%	

NB. Los análisis se hacen temporal y espacialmente





Vautard et al, 2008 (AE)

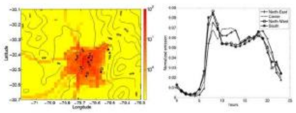
Estudios de sensibilidad

Análisis estocástico
(Monte Carlo)

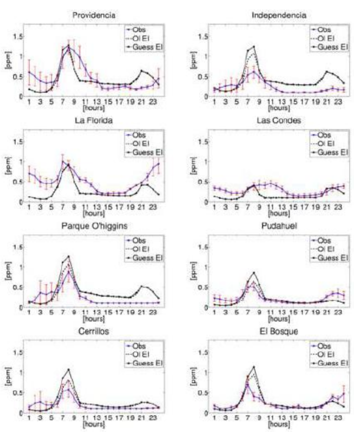
Modelación inversa
(Adjunto)

Modelación directa e inversa de CO

Inventario de Emisiones



Campos de viento, temperatura, etc.



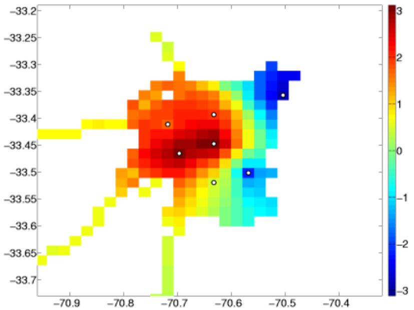
Modelo de dispersión

Datos de entrada → modelo → salida → evaluación de salidas (comparación con observaciones)

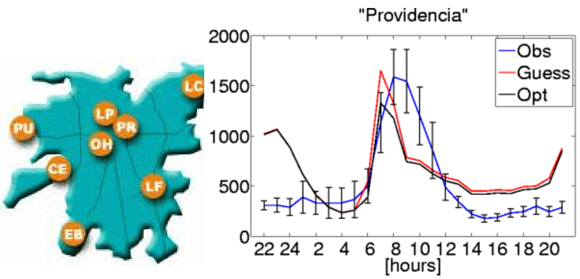
Modelación directa e inversa de CO

Campos de viento, temperatura, etc.

Inventario de Emisiones



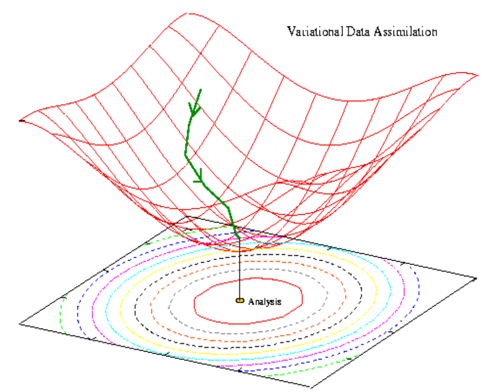
Modelo de dispersión



Observaciones → modelo → Selección de parámetros de entrada que optimizan el modelo (evaluación del modelo)

¿Cómo se resuelven los problemas inversos?

Camino 1: Buscar un conjunto óptimo de parámetros de entrada que maximice el acierto del modelo…



La búsqueda se hace por métodos variacionales o secuenciales

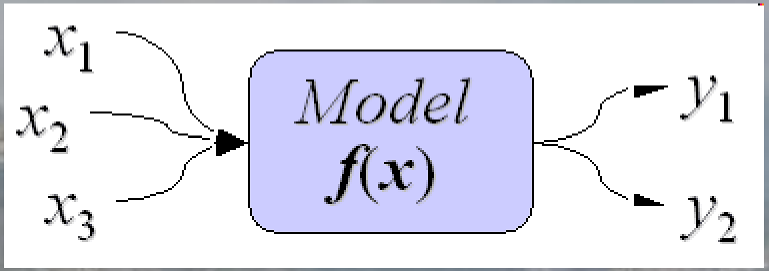
Se impone una “**condición de optimalidad**”, es decir, se define un funcional que minimice la distancia entre modelo y observaciones.

$$J(E_i) = \frac{1}{2}\sum_{k=1}^{k=K}\left\| S_k^{mod}(E_i, i=1,\ldots,n) - S_k^{obs}\right\|^2$$

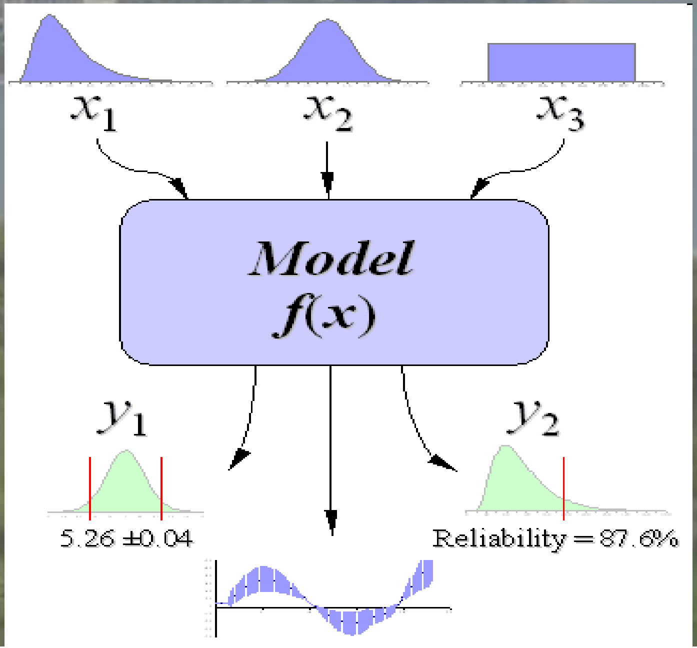
Técnica de Monte Carlo (*grosso modo*)

1. **Definir el conjunto de posibles entradas (pdf)**: emisiones, tasas de reacción, condiciones iniciales, etc.
2. **Generar entradas de modo aleatorio:** usar estadísticas de las entradas o "criterio experto"
3. **Computar en modo determinístico para cada distribución de entradas**
4. **Agregar el resultado de los cómputos**

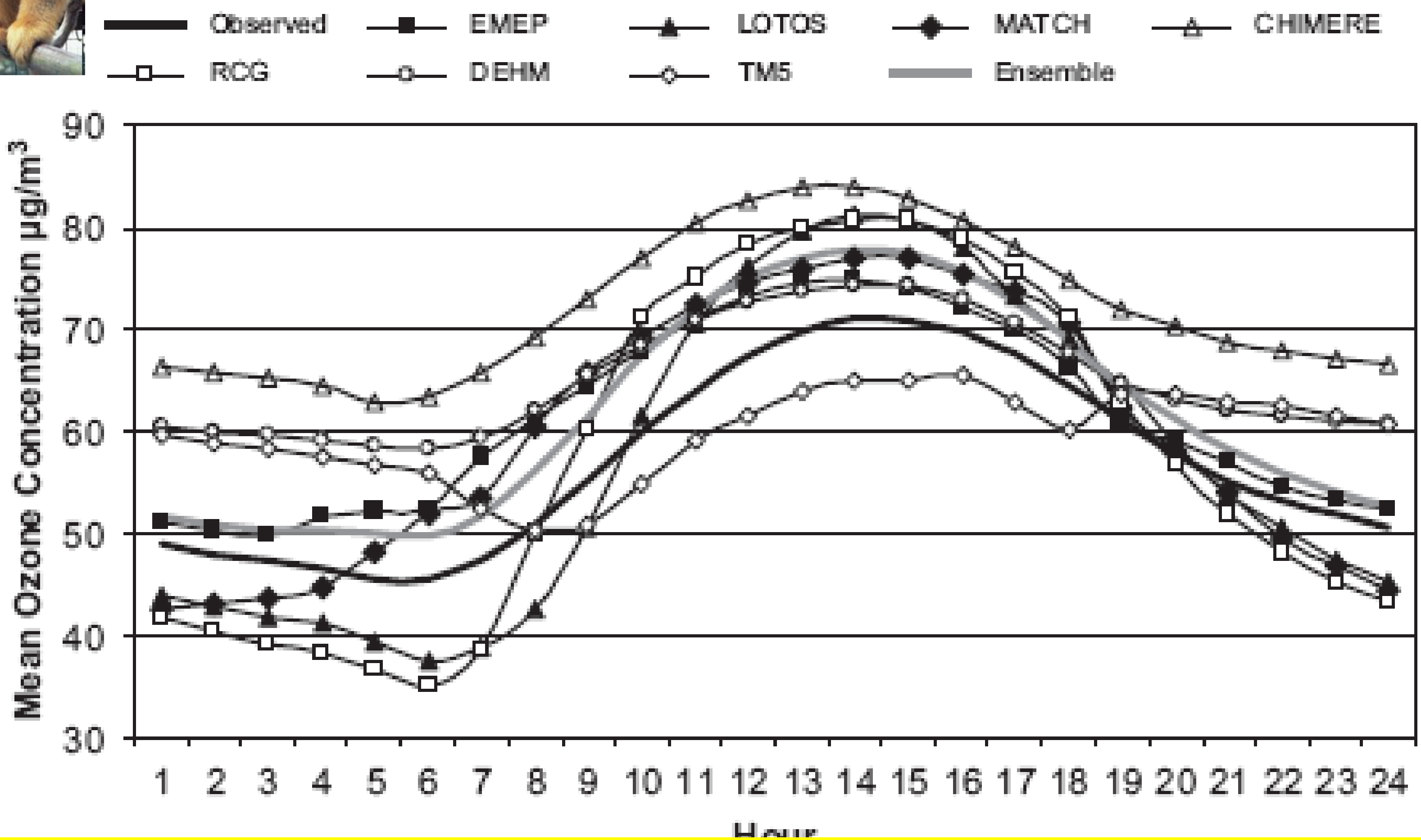
Modelo determinístico



Modelo probabilístico

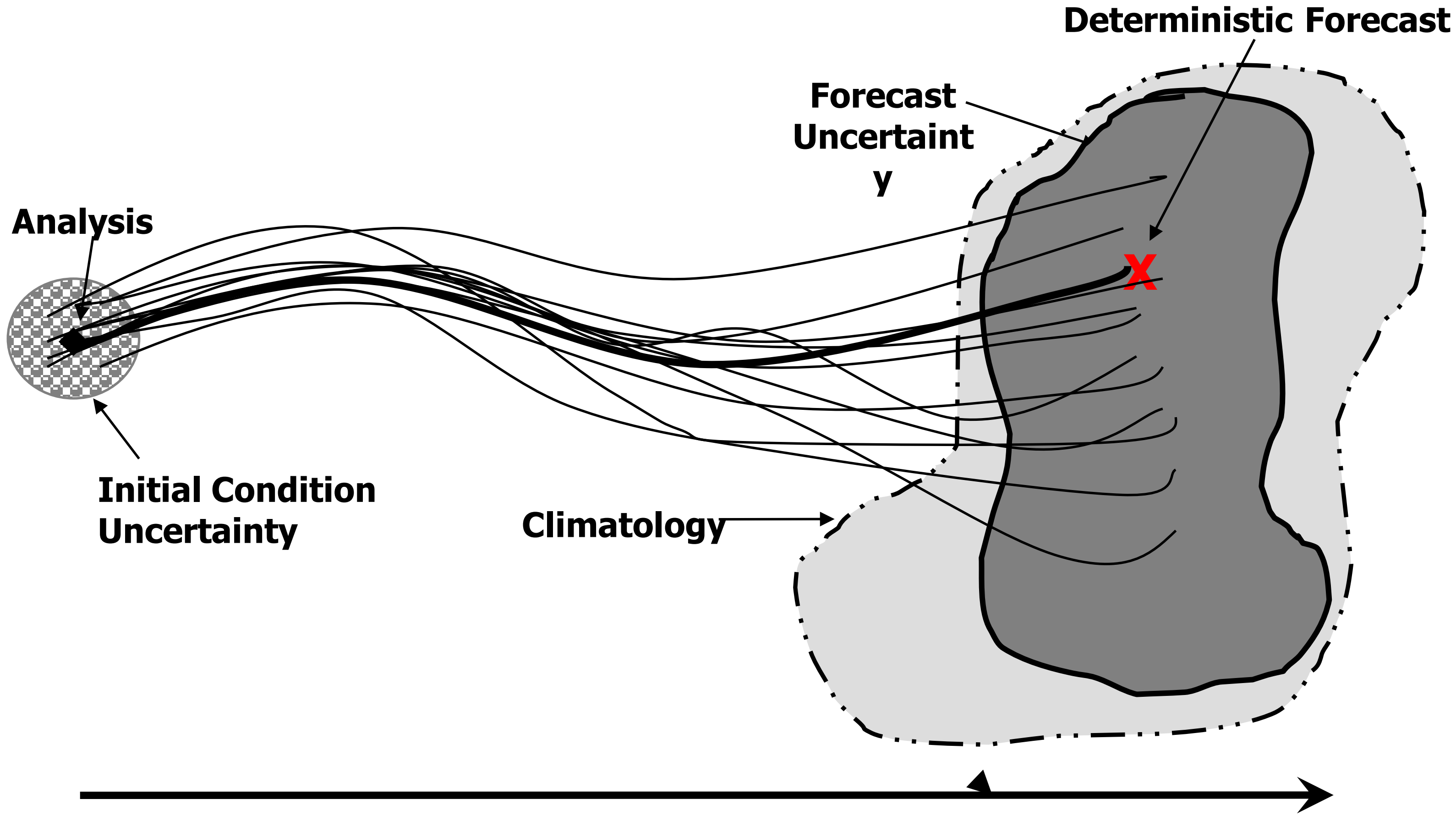


Intercomparación de modelos



- Sirve para determinar problemas con ciertos procesos o estudiar diferencias entre modelos
- ¿Qué, cómo, cuándo, dónde comparar?

“Ensemble Forecast” (Determinístico----Estocástico)



* Brian Golding/Ken Milne, UKMO

Se quiere dar cuenta de la varianza de las observaciones

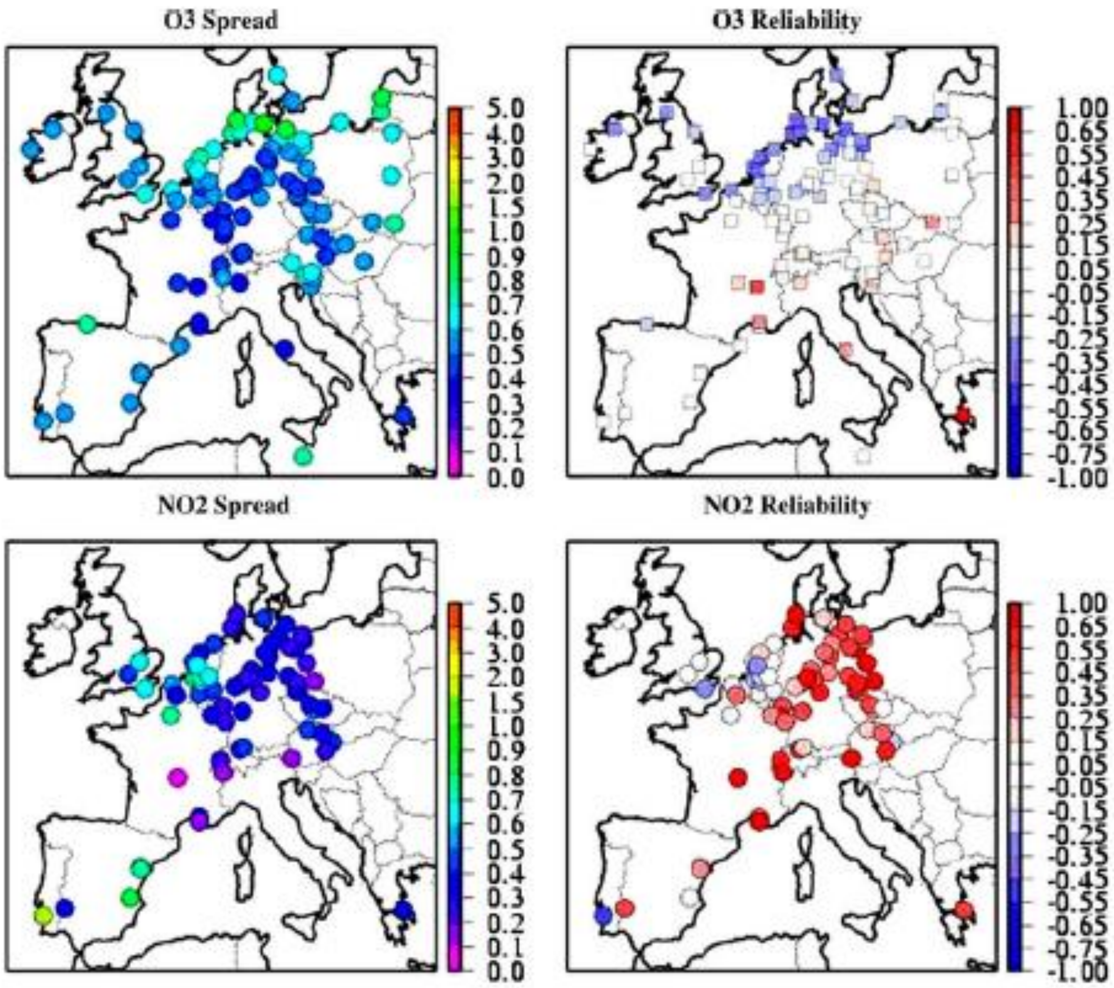
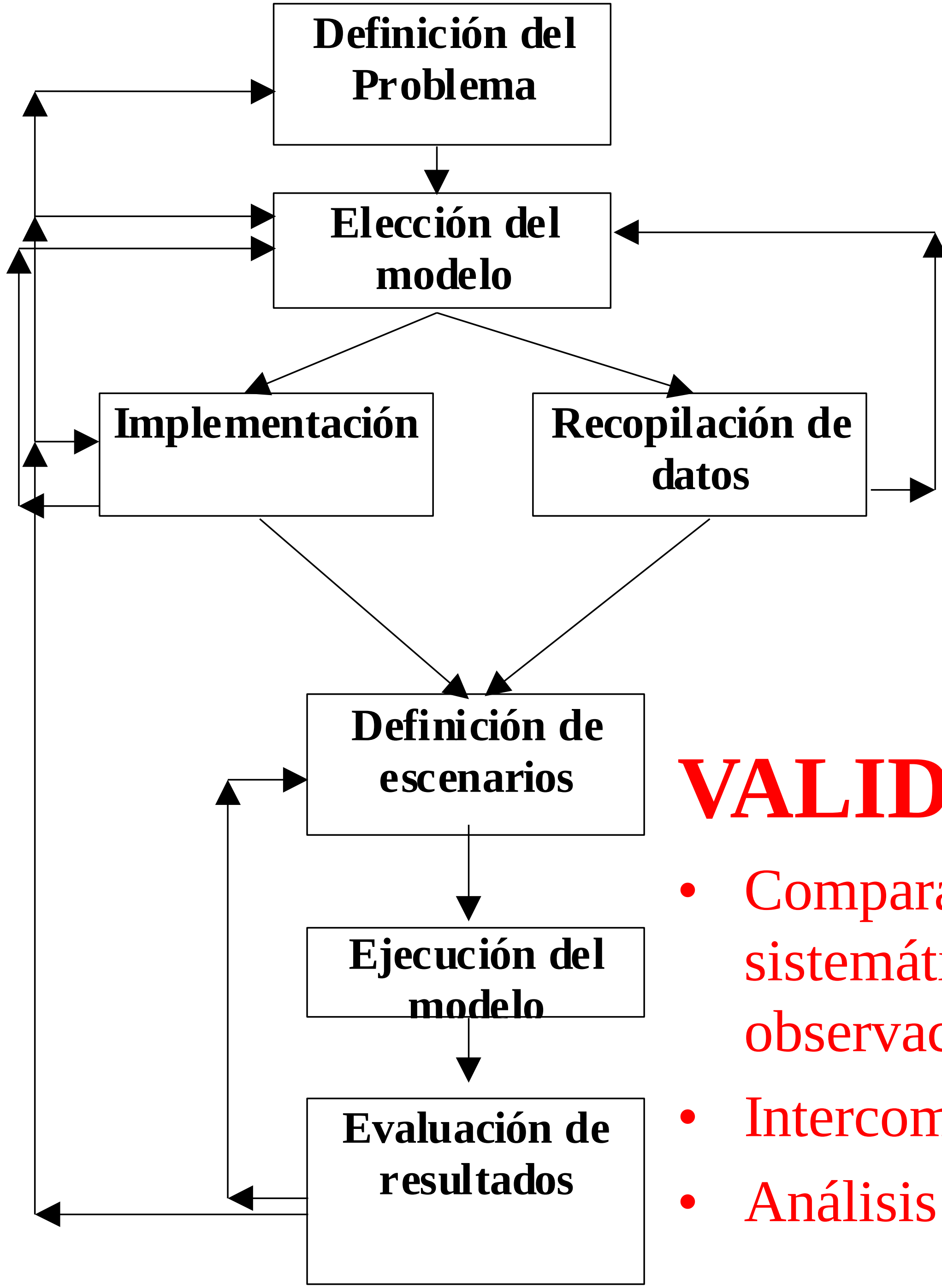


Fig. 6. Spatial distribution of the reliability index and normalized spread (see text), for ozone and NO_2.

Vautard et al, 2008



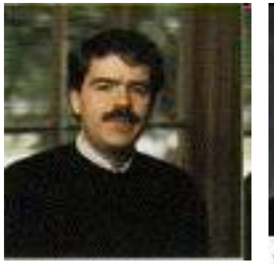
VALIDACIÓN:

- Comparación sistemática contra observaciones
- Intercomparación
- Análisis de sensibilidad

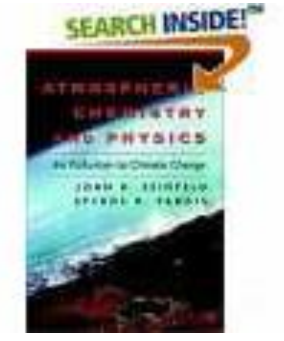
"...La física, como cualquier otra ciencia, no se rige sólo por la inteligencia sino también por la razón..."

Max Planck (1858-1947) en "Wege zur physikalischen Erkenntn is"

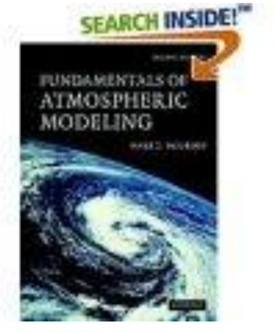
Lecturas



- Capítulo 23 en:Seinfeld, J. y Pandis, S., 1998. *Atmospheric Chemistry and Phyics From Air pollution to climate change*, J. Wiley and Sons, Inc.



- Capítulo 21 en: Jacobson, M. 1999: *Fundamentals of atmospheric modeling*, Cambridge University Press, Cambridge.



Towards an Integrated Observing System for South America: air quality assessment and forecasting in Mega cities

Enero 9-12/2012








Non South Americans

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