

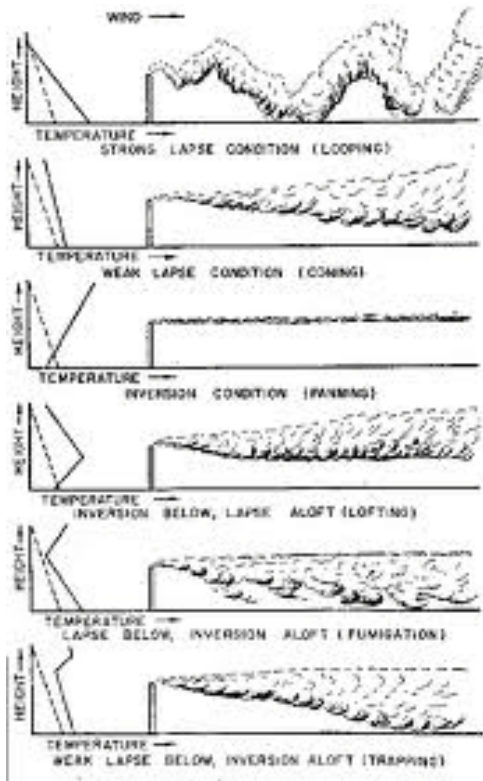
Dispersión de contaminantes en la atmosfera: Transporte medio + difusión

Factores que la controlan:

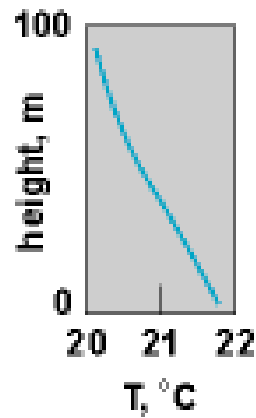
- **Magnitud y dirección del viento**
 - **Estabilidad atmosférica**
 - **Turbulencia atmosférica**
 - **Alzamiento de la pluma**



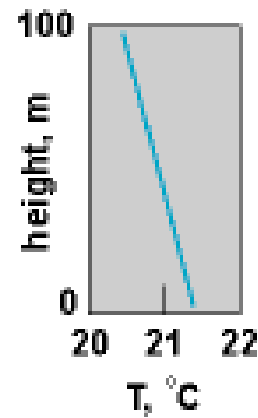
Dependencia en estabilidad atmosférica



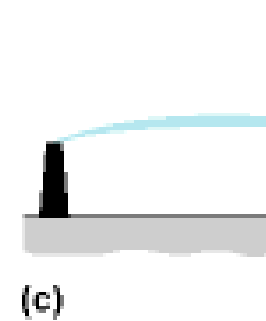
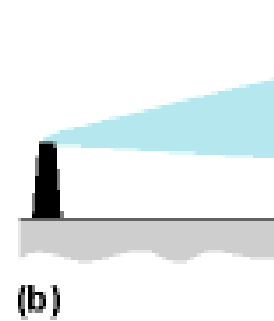
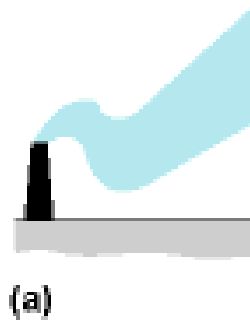
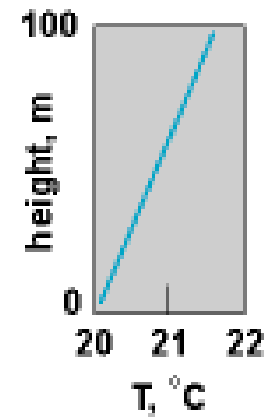
Inestable



Neutro



Estable



Gradiente adiabático (seco)

Empleando la **ley de gases ideales** ($pV=nRT$) y el **segundo principio de la termodinámica** ($dQ = dU + dW$) se puede demostrar que en un ascenso o descenso adiabático el **gradiente (cambio) de temperatura** con la altura es:

$$dT / dz = -\Gamma_{\text{adiabatico}}$$

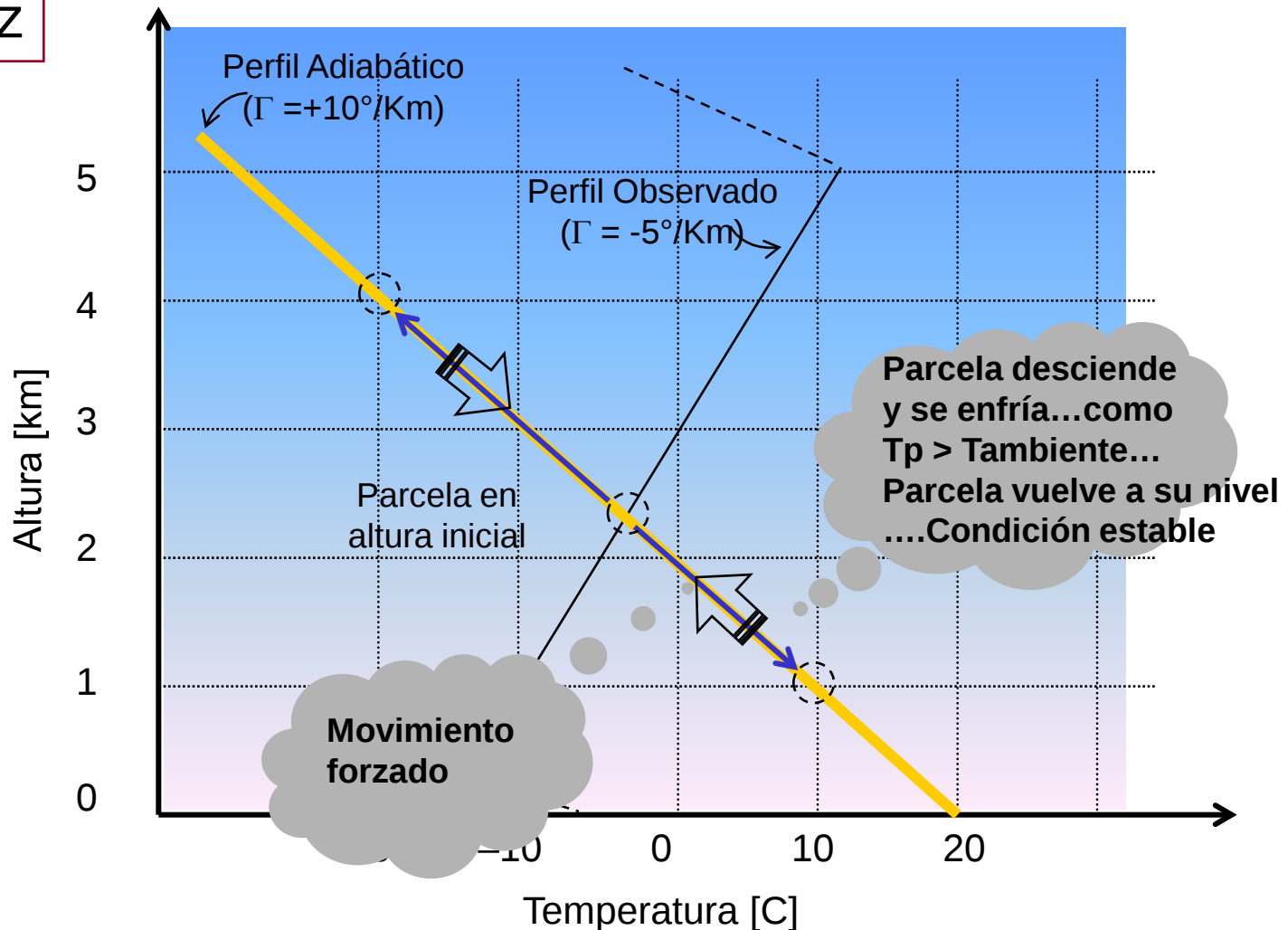
$$\Gamma_{\text{adiabatico}} = g/C_p = +10 \text{ }^{\circ}\text{C/km}$$

Esto es, por cada kilómetro de ascenso (descenso) la temperatura de la parcela disminuye (aumenta) 10°C , si el proceso es adiabático.

Nota: Si el ascenso/descenso toma menos de un día la aproximación adiabática es muy buena (intercambio de calor con el medio es pequeña).

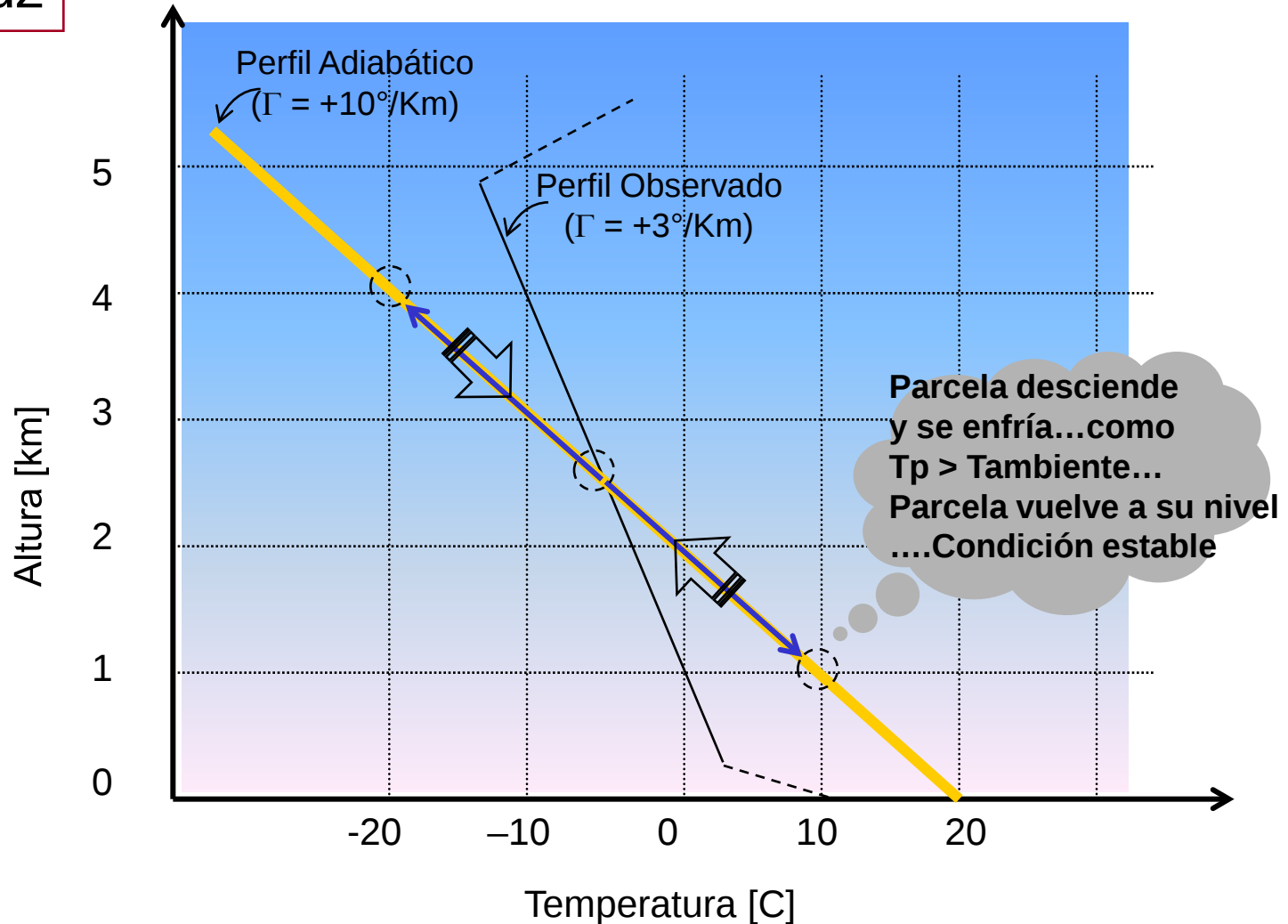
Análisis de estabilidad I (Inv. Térmica)

$$\Gamma = -dT/dz$$



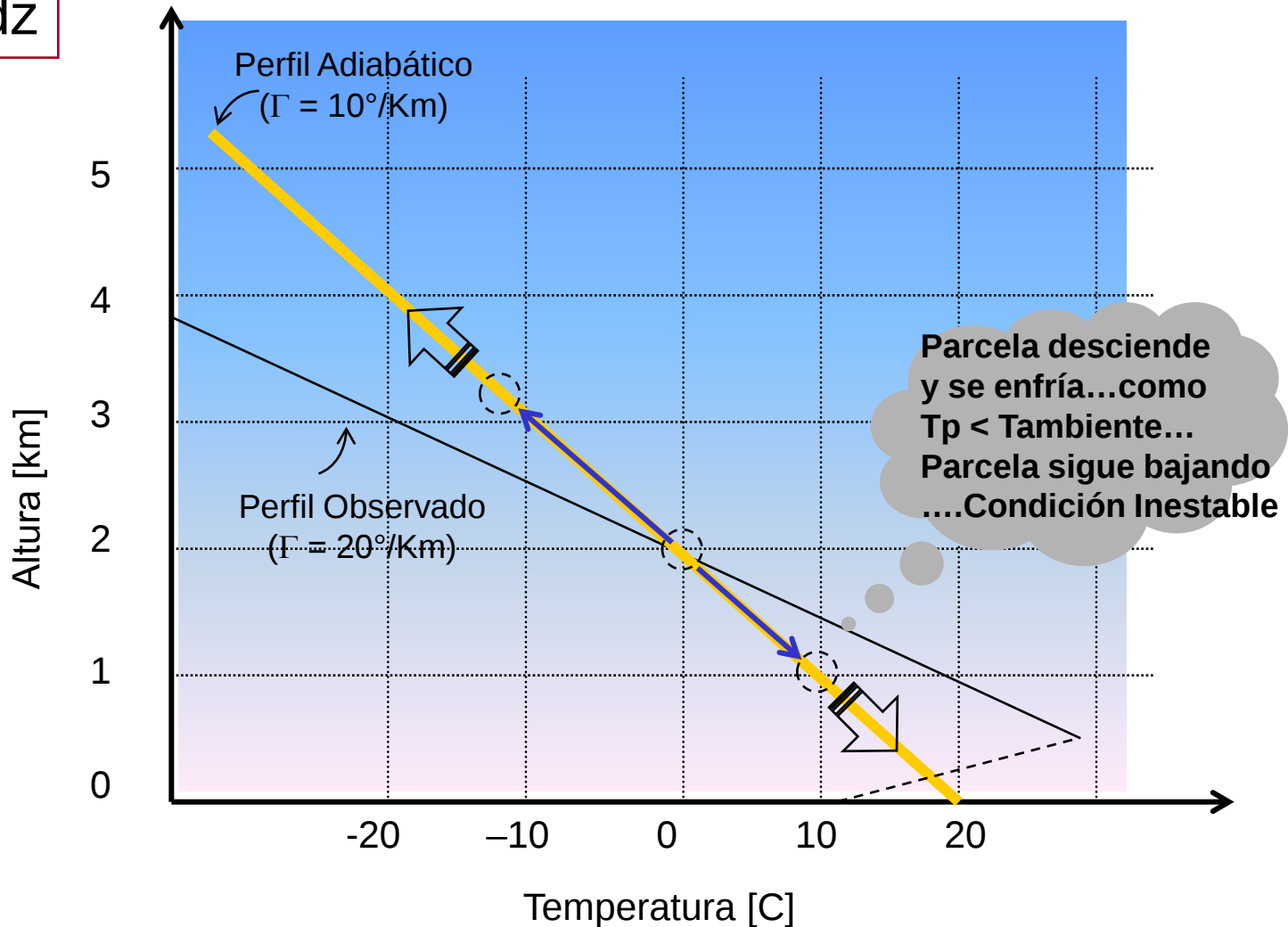
Análisis de estabilidad II

$$\Gamma = -dT/dz$$



Análisis de estabilidad III

$$\Gamma = -dT/dz$$



Introducción a la Meteorología – Estabilidad Atmosférica

UCH/FCFM/DGF – R. Garreaud

Resumen de estabilidad

Estabilidad absoluta

$$\Gamma_{\text{obs}} < \Gamma_{\text{adiab sat}} < \Gamma_{\text{adiab}}$$

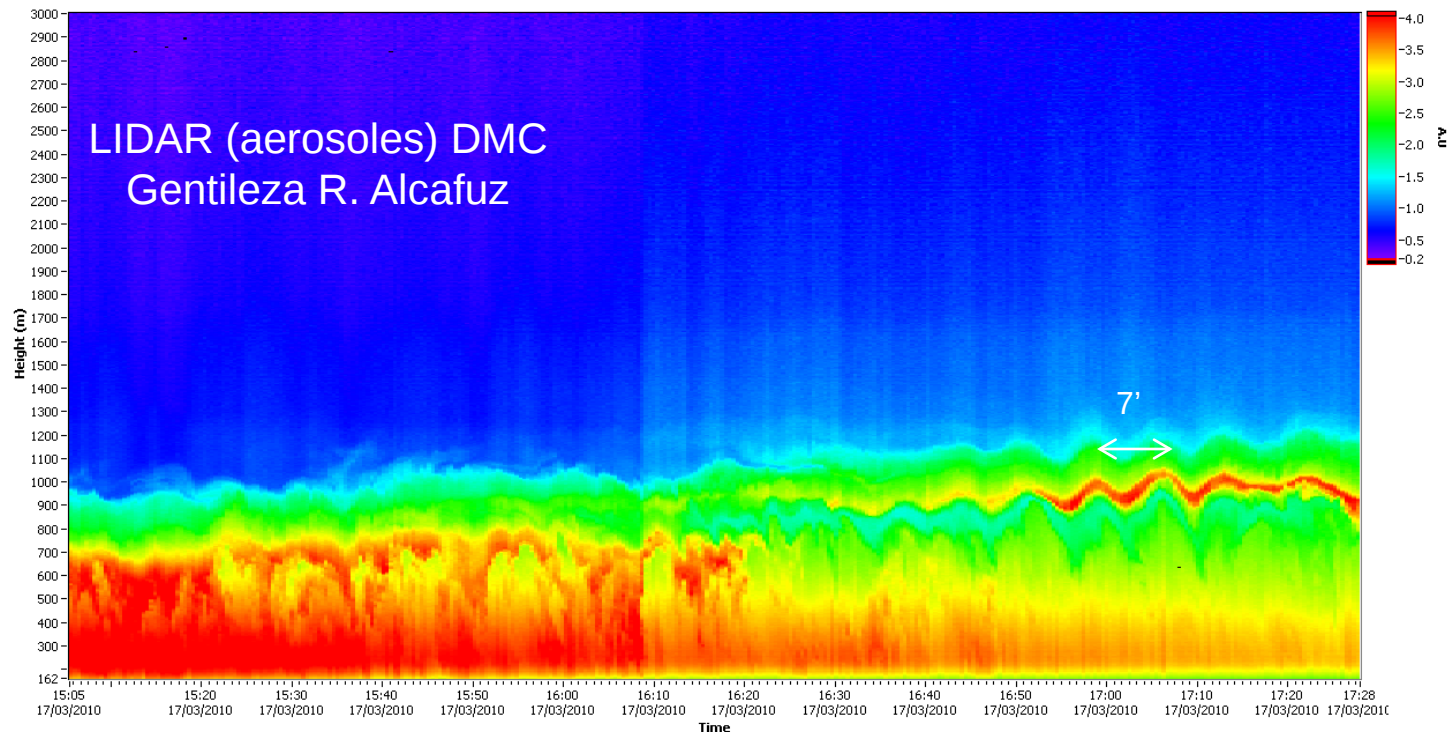
Estabilidad condicional

$$\Gamma_{\text{adiab sat}} < \Gamma_{\text{obs}} < \Gamma_{\text{adiab}}$$

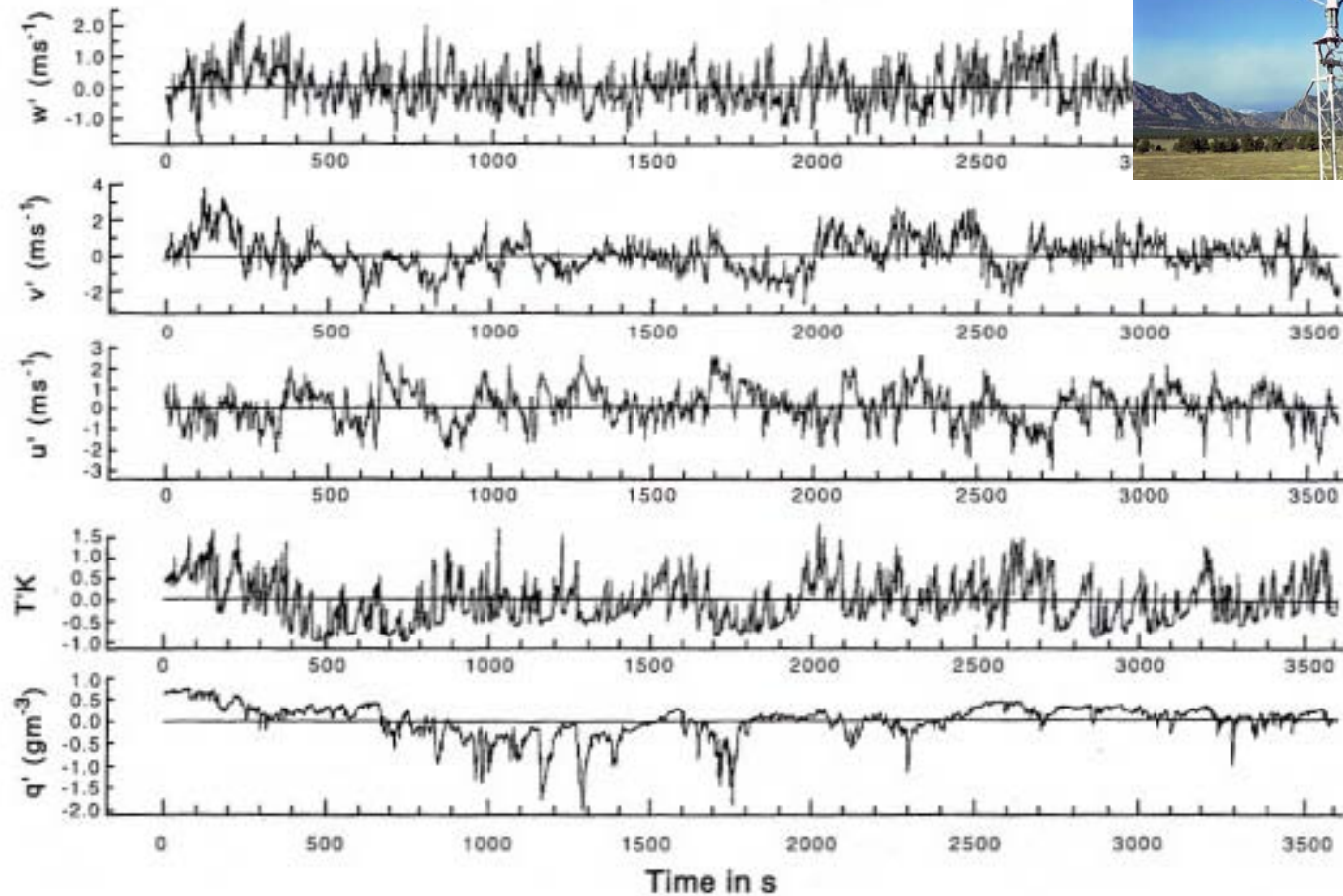
Inestabilidad absoluta

$$\Gamma_{\text{adiab sat}} < \Gamma_{\text{adiab}} < \Gamma_{\text{obs}}$$

En casos estables, se puede demostrar existencia de oscilaciones verticales con periodo cercano a los 10 minutos.



Turbulencia: variaciones irregulares y aleatorias (v,T,etc)



Introducción a la Meteorología – Turbulencia

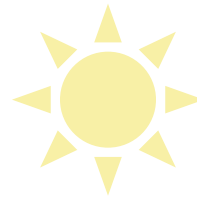
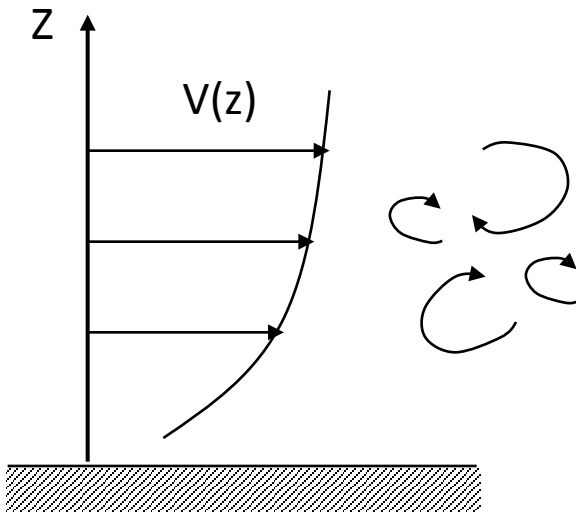
UCh/FCFM/DGF – R. Garreaud

Factores de la Turbulencia atmosférica

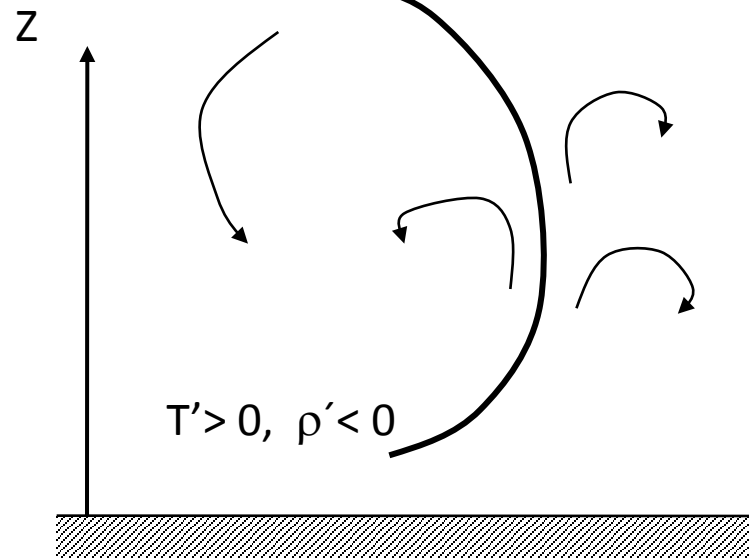
$$\partial \text{TKE} / \partial t = \text{Adv} + \text{Shear} + \text{Boyancia} + \text{Tte} + \text{Disipación}$$

$$\text{TKE} : \text{Energía Cinética Turbulenta} = \frac{1}{2}[\sigma_u^2 + \sigma_v^2 + \sigma_w^2]$$

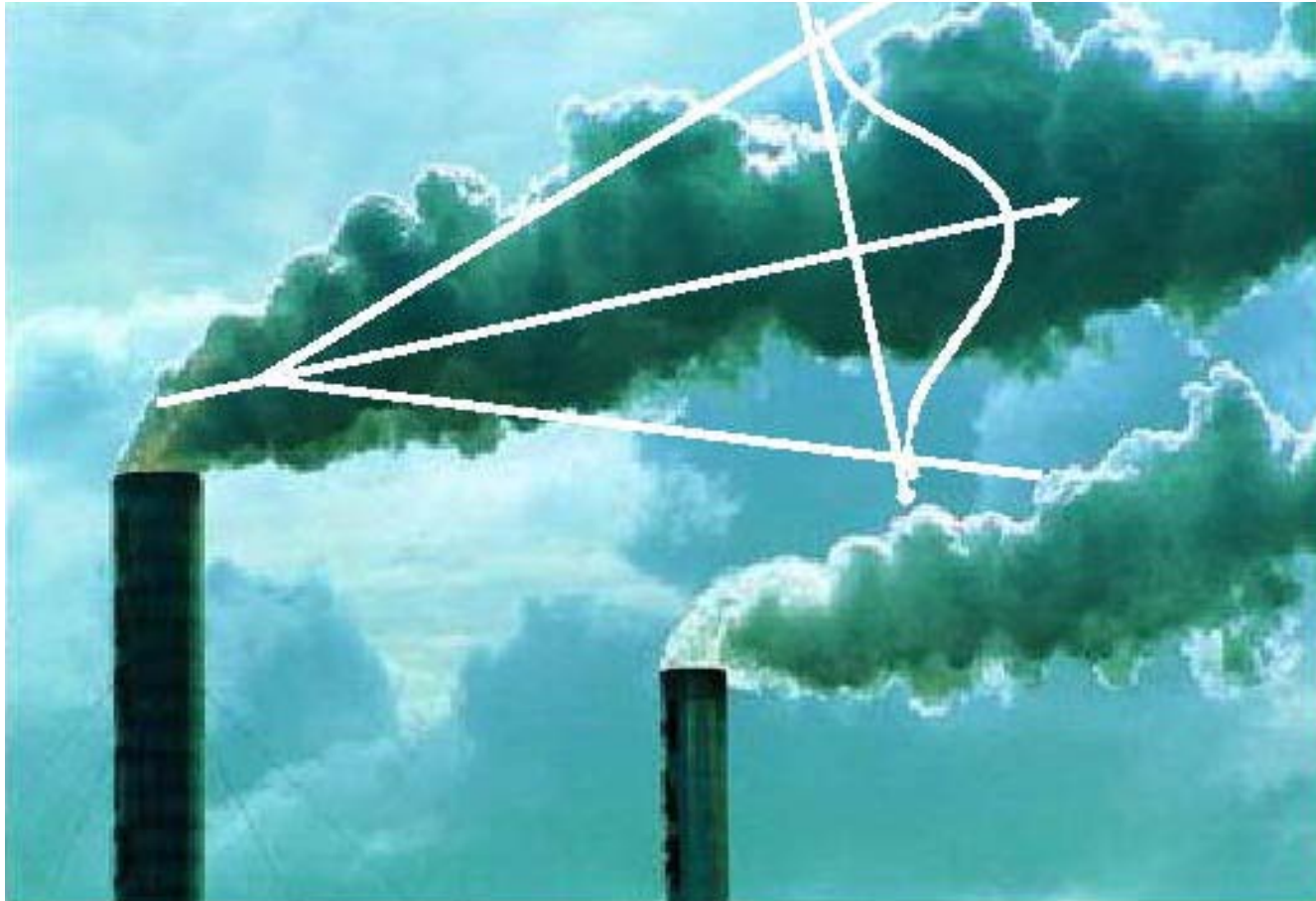
Turbulencia mecánica:
se produce cuando la
velocidad del viento cambia
en el espacio
(cizalle del viento)

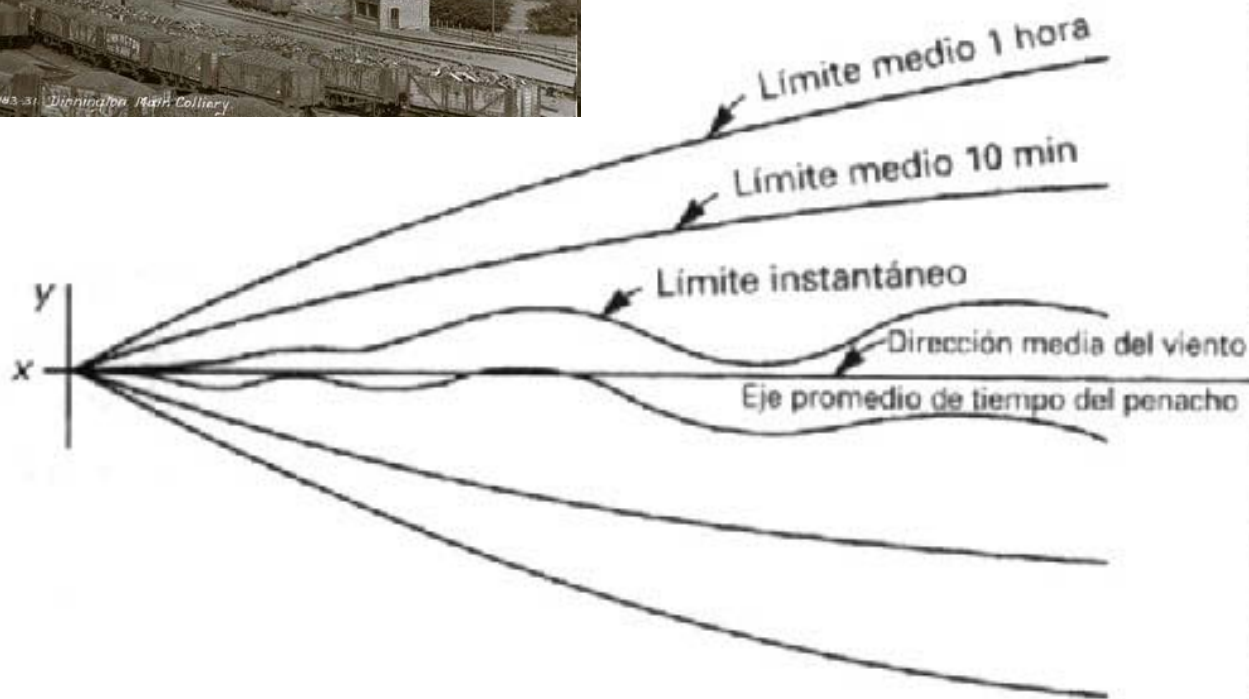


Turbulencia convectiva:
Muchas veces generada por
calentamiento superficial

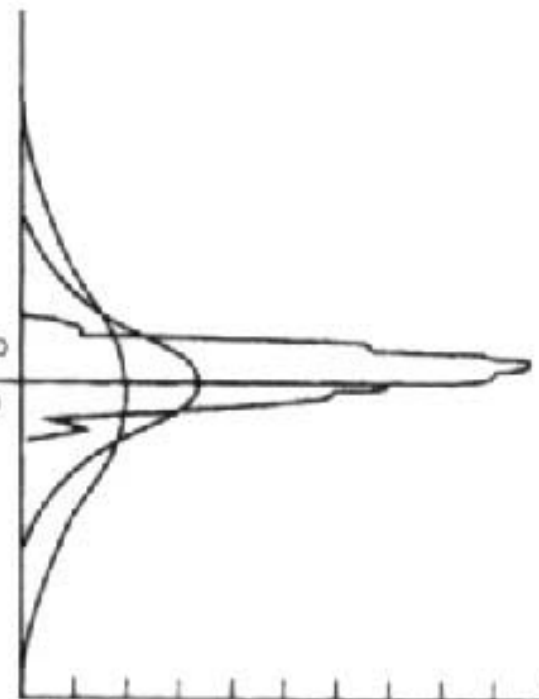


Modelos Gaussianos Estacionarios

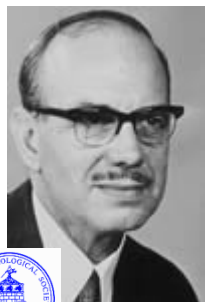




(a) Vista en planta



(b) Concentración relativa



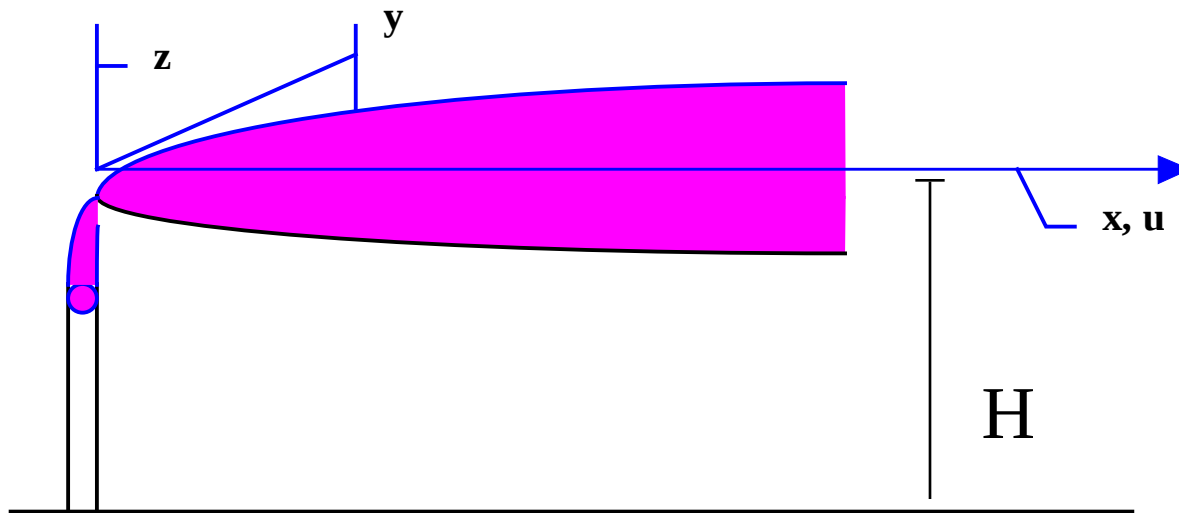
Frank Pasquill
1914 – 1994

GF3022



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

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



Desafío: ¡¡Estimar los sigmas!!

Los sigmas se determinan empíricamente....

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

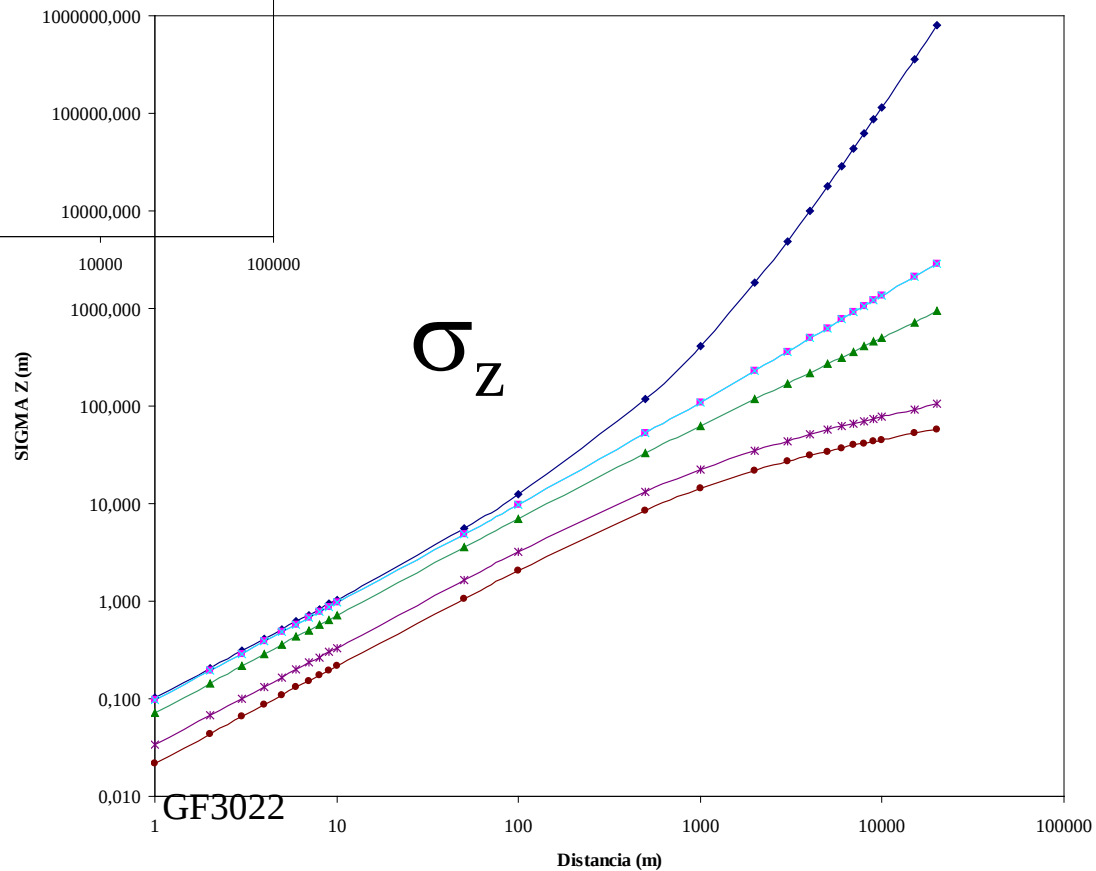
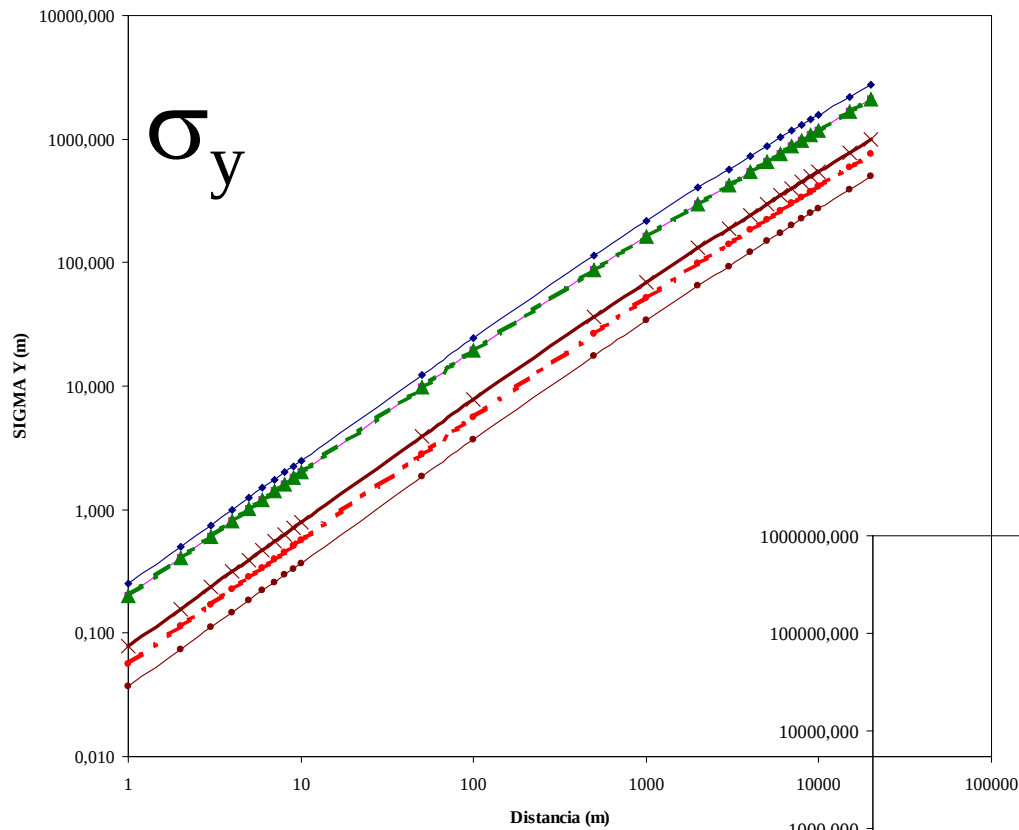
Clase de estabilidad	k ₁	k ₂	k ₃	k ₄	k ₅
A	0.250	927	0.189	0.1020	-1.918
B	0.202	370	0.162	0.0962	-0.101
C	0.134	283	0.134	0.0722	0.102
D	0.0787	707	0.135	0.0475	0.465
E	0.0566	1070	0.137	0.0335	0.624
F	0.0370	1170	0.134	0.0220	0.700

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

GF3022

Key Assumptions and Approximations in Gaussian Plume Model

1. **Continuous emission from the source at a constant rate**, at least for a time equal to or greater than the time of travel to the location (receptor) of interest. The plume diffusion formulae assume that release and sampling times are long compared with the travel time to receptor, so that the material is spread out in the form of a steady plume between the source and the farthest receptor.
2. **Steady-state flow and constant meteorological conditions**, at least over the time of transport (travel) from the source to the farthest receptor. This assumption may not be valid during rapidly changing meteorological conditions, such as during the passage of a front or a storm and also during the morning and evening transition periods.
3. **A constant mean transport wind in the horizontal (x-y) plane**. This implies horizontal homogeneity of flow and the underlying surface and becomes invalid over a complex terrain.
6. **No wind shear in the vertical**. This assumption is implicit in the constant mean transport velocity in the Gaussian plume formulae. In practice, is often taken as the wind speed at 10 m height for near-surface sources ($H \ll 10$ m) and the wind speed at the effective release height for elevated sources. The variation of wind speed with height can also be considered in more accurately estimating the effective transport velocity, but this requires the knowledge of vertical concentration distribution in the plume at each receptor location. The variation of wind direction with height is ignored, although its effect on the lateral plume spread and concentration field can be considered superficially through an appropriate parameterization of .
7. **Strong enough winds to make turbulent diffusion in the direction of flow negligible in comparison with mean transport**. This assumption, also known as the slender-plume approximation, which is implicit in the Gaussian plume model, generally becomes invalid very close to the source where material diffuses up-wind of the source due to longitudinal velocity fluctuations. The assumption becomes invalid farther and farther away from the source as mean wind becomes weaker and vanishes entirely (e.g., under extremely stable and free convection conditions).

Gaussian Plume Calculator - Google Chrome

www.shodor.org/os411/courses/_master/tools/models/gplume/gplume.html

Gaussian Plume Java Applet

Using this Applet

This applet provides a number of slider bars to change parameters:

1. wind speed
2. stack height
3. stack diameter
4. emission rate
5. gas temperature
6. gas velocity
7. atmospheric temperature
8. atmospheric conditions
9. 3D coordinates and graphics resolution

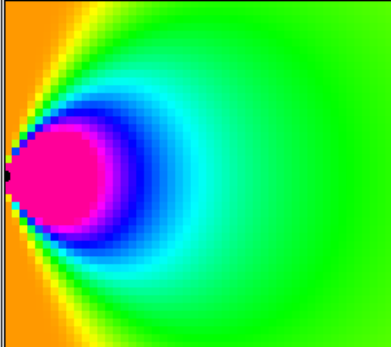
To change the values, simply slide the slider bar. Alternatively, you can type in a value and hit the Enter/Return key.

Output is provided in several formats: x-y graph, top and side view visualizations, and text-based output. In the side-view format, the black bar on the left of the graphics window shows the stack, changing in height as the stack height slider bar is modified. In the top-view format, the stack is seen as a black dot, half-way up the y-axis.

The x-y-z contour plot range sliders help to zoom in and out of the plume. The z-contour plot only modifies the side-view, while the y-contour slider only modifies the top view. The x-contour modifies both top and side views.

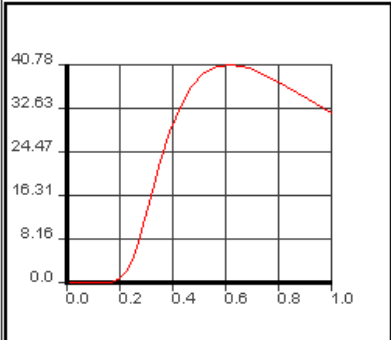
☒ Use Color

Top View



Max Ground Conc.

Graph Settings



Wind Speed

20.0 m/s

Stack Height

30.0 m

Stack Diameter

2.0 m

Emission Rate

10.0 g/s

Gas Temperature

210.0 deg C

Gas Velocity

5.0 m/s

Temperature

20.0 deg C

Atmospheric Condition

Neutral

Resolution

5.0 pixels

X contour plot range

1.0 km

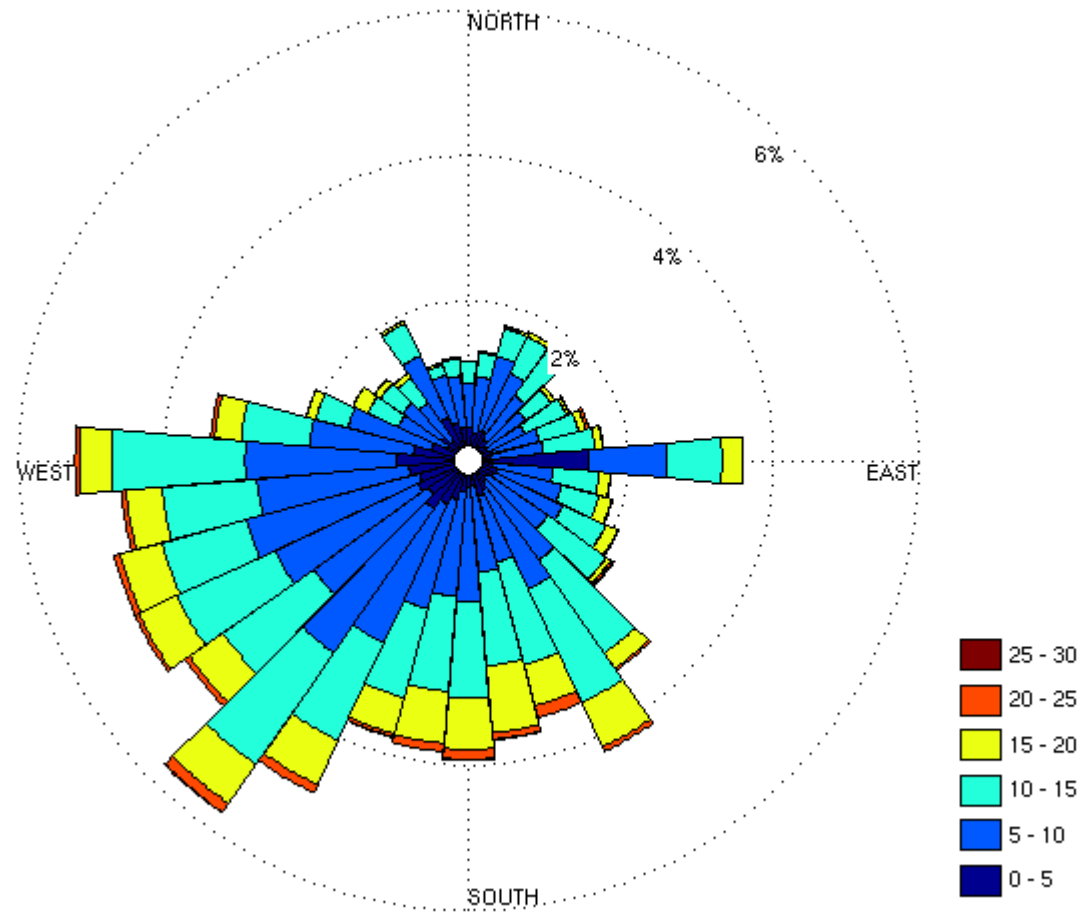
Y contour plot range

100.0 m

Z contour plot range

100.0 m

Para caracterizar el viento en un sitio se emplea rosa de vientos



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

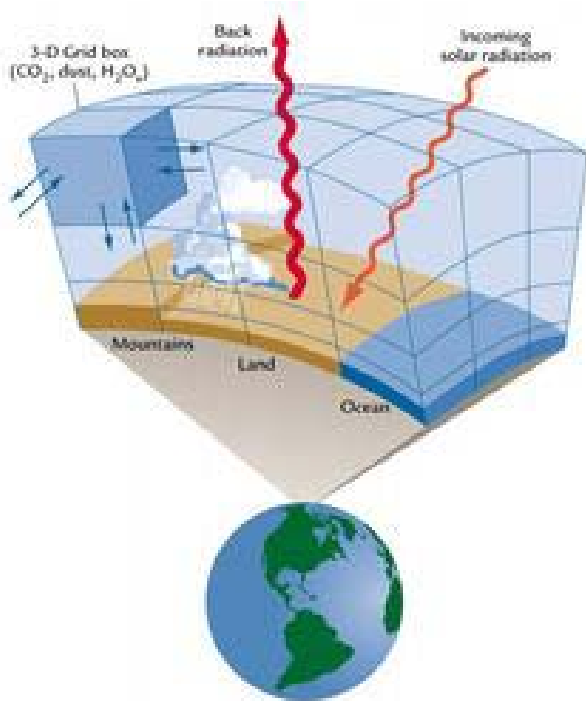
Típicamente, para modelos gaussianos...

- 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**
-
- **Modelo on-line:** <http://www.shodor.org/os411/index.html>

Que hacer cuando modelos Gaussianos son insuficientes?

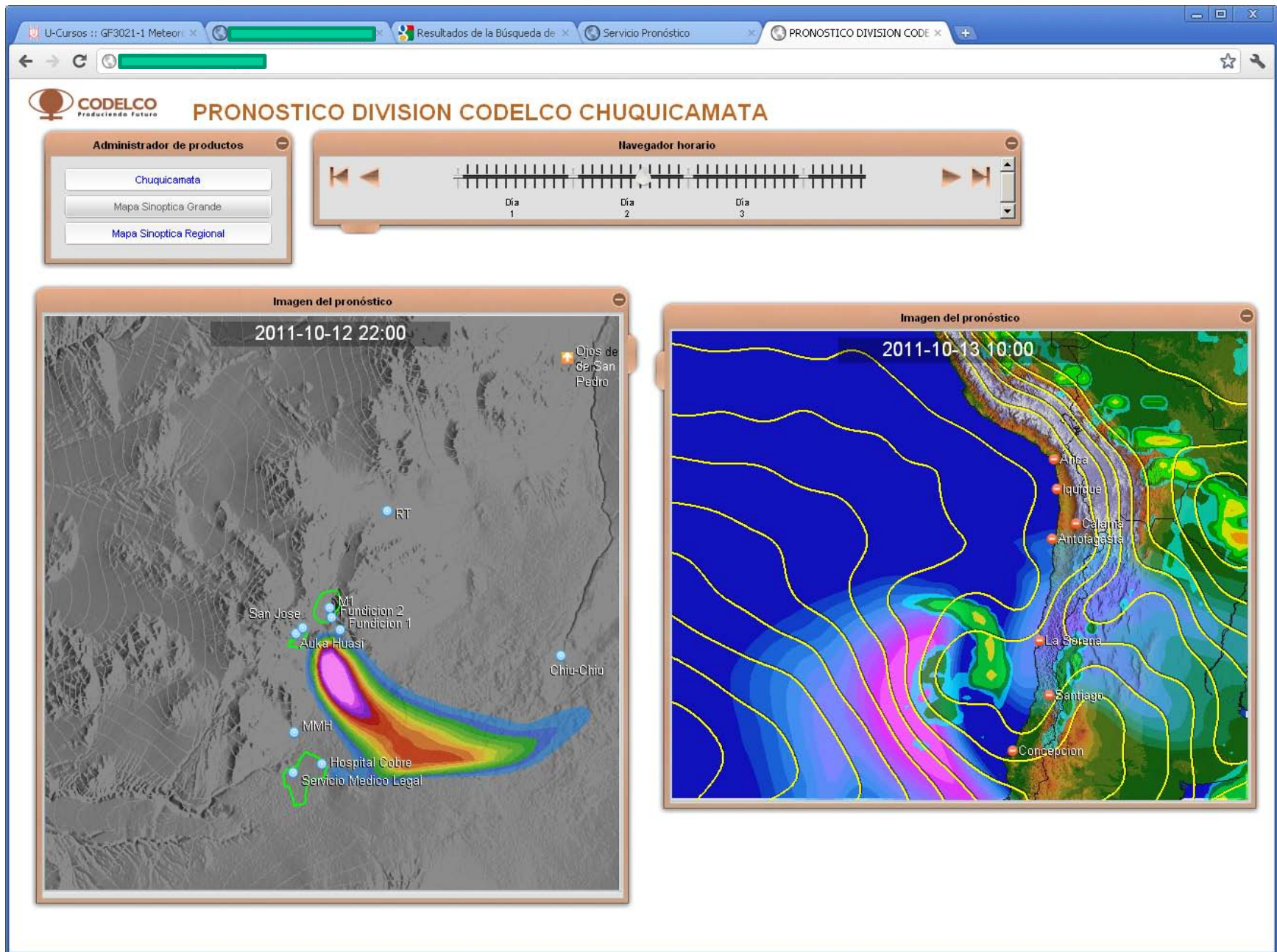
$$\frac{\partial c}{\partial t} = -\vec{v} \cdot \nabla c - c \nabla \cdot \vec{v} - \nabla \cdot (\langle c' \vec{v}' \rangle) + Q - S \quad \text{+CI \& CB}$$

Necesitamos conocer campo de viento (v) y turbulencia mediante un modelo meteorológico 3D.



(1) Modelos completos: MM5, WRF, etc.
Resuelven dinámica atmosférica
Pueden ser on-line o off-line, en este último caso se puede incluir química atmosférica

(2) Modelos cinemáticos (CALPUFF, AIRMODE, etc): interpolan el campo de viento desde observaciones



Ciclo diario de la contaminación atmosférica en cuenca de Santiago

Iso-superficie de concentración de CO = $25 \mu\text{mg}/\text{m}^3$

Simulación empleando modelo MM5 (gentileza de Rainer Schmitz)

