

# Despacho óptimo con asimilación de pronósticos.

Ruben Chaer

Curso SimSEE edición 2026 – Martes 9 de abril.

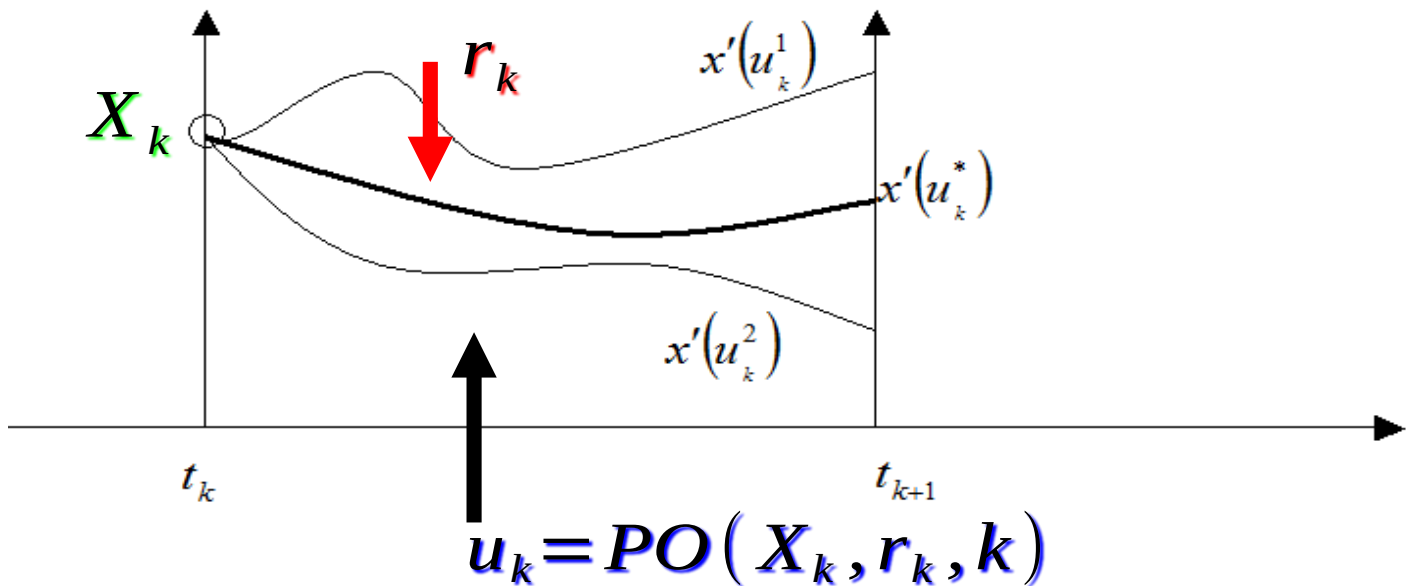
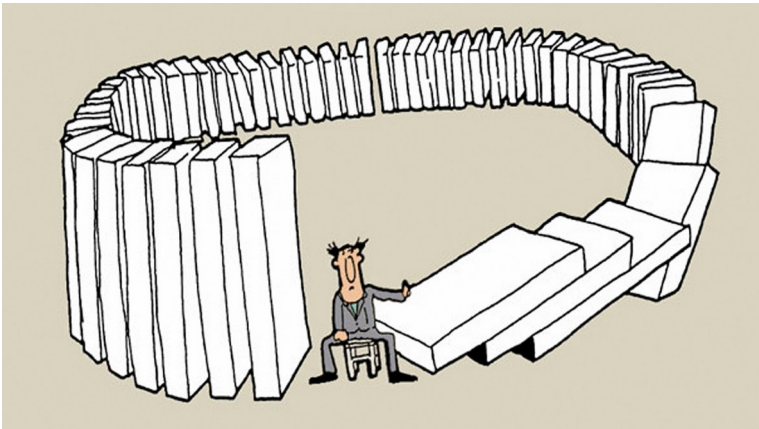


UNIVERSIDAD  
DE LA REPUBLICA  
URUGUAY

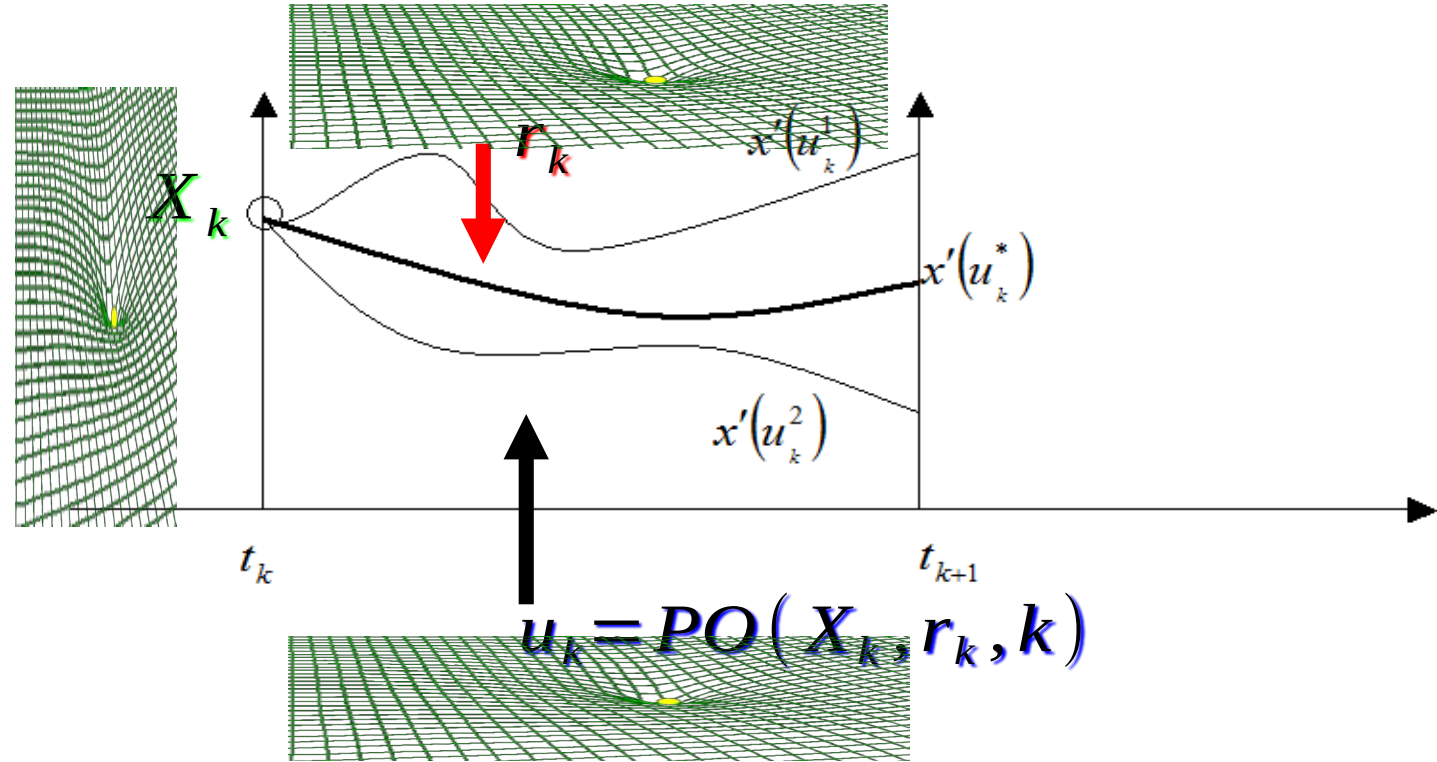


PO\_Optima = Minimizar el valor  
esperado del Costo Futuro

$$CF(x, k) = \langle \min_{u_k} \{ CE(x, u_k, r_k, k) + q \cdot CF(x', k+1) \} \rangle_{r_k}$$



# Bellman's curse of dimensionality.



$$Dim(u) \times N_{X_1} \times N_{X_2} \dots \times N_{X_{Dim(X)}} \times N_{r_1} \times N_{r_2} \dots \times N_{r_{Dim(r)}} \times N_k$$

# Operador Sin Pronósticos.



# Operador Con Pronósticos.



# Representation of uncertainty.

## Sources of randomness Stochastic processes

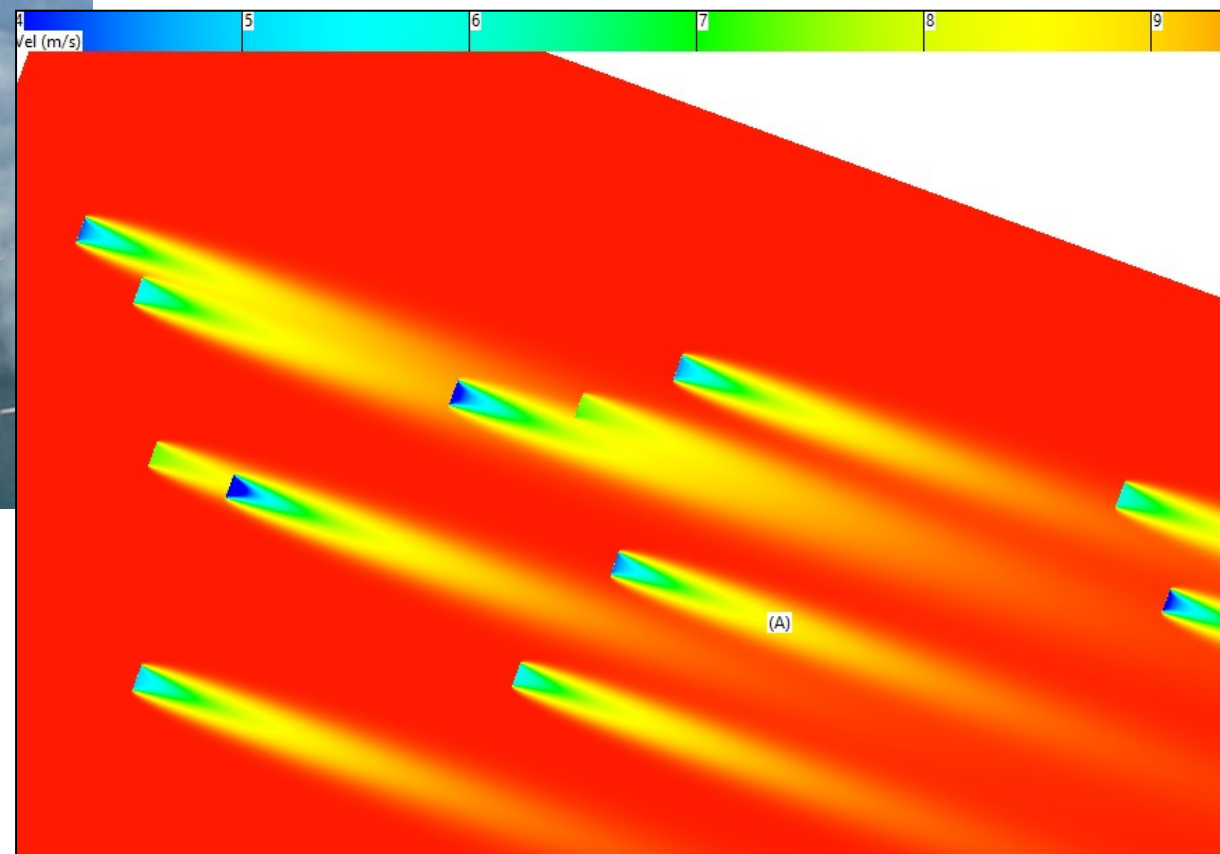
- Demand and temperature
- Flows of water contributions
- Wind speed
- Solar radiation
- Price of interconnected markets
- Fuel prices
- Availability of fuels
- Availability of generating plants
- Availability of transport lines

El Niño, Hydro, Wind, Solar, Demand,  
Temperature.  
(correlated processes)

Equipment availability  
(independent booleans)

We are managing faster dynamics, therefore, the correlation between the different resources has greater importance. We need models of variability that correctly represent the correlation between resources and the correlation with the past. That is, we have to represent the inertia behind the stochastic variables.

# ADME\_Data y ADME\_WindSim



Fundamentos del modelo CEGH de procesos  
naturales  
multi-variables.

# Fundamentos del CEGH.

- Dado un conjunto de series de datos, como ser caudales medios semanales a las represas.
- ¿Cómo introducir esa aleatoriedad en las simulaciones?.
- ¿Cómo generar series sintéticas con iguales características que las series de datos?

# Qué Modelar, Qué Conservar.

- Histograma de Amplitudes.
- Condicionamientos estadísticos.
- Los condicionamientos estadísticos con el pasado deben estar representados en la ecuación de evolución del sistema e implican la identificación de El Estado del proceso.

# Solución: “0 Estado”

## Serie determinística.

- Simplemente suponer que esas series históricas de medidas se repiten y ver cómo se comporta el sistema con esas entradas.
- Si durante el proceso de Optimización se utiliza una serie determinística el optimizador calculará la política óptima conociendo el Futuro. En la realidad no podrá operar así, porque seguramente no se repita el pasado Tal Cual.

# Solución: “0 Estado”

## Histogramas SIN MEMORIA

- Este es el caso por ejemplo en que el proceso estocástico realmente no tiene memoria. Y es aplicable para ciertos procesos. Por ejemplo, la rotura fortuita de máquinas generalmente se modela como un sorteo sin memoria que determina si una unidad está o no disponible para el paso de tiempo simulado.
- No es aplicable en casos donde el pasado realmente condiciona el futuro.

# Qué queremos

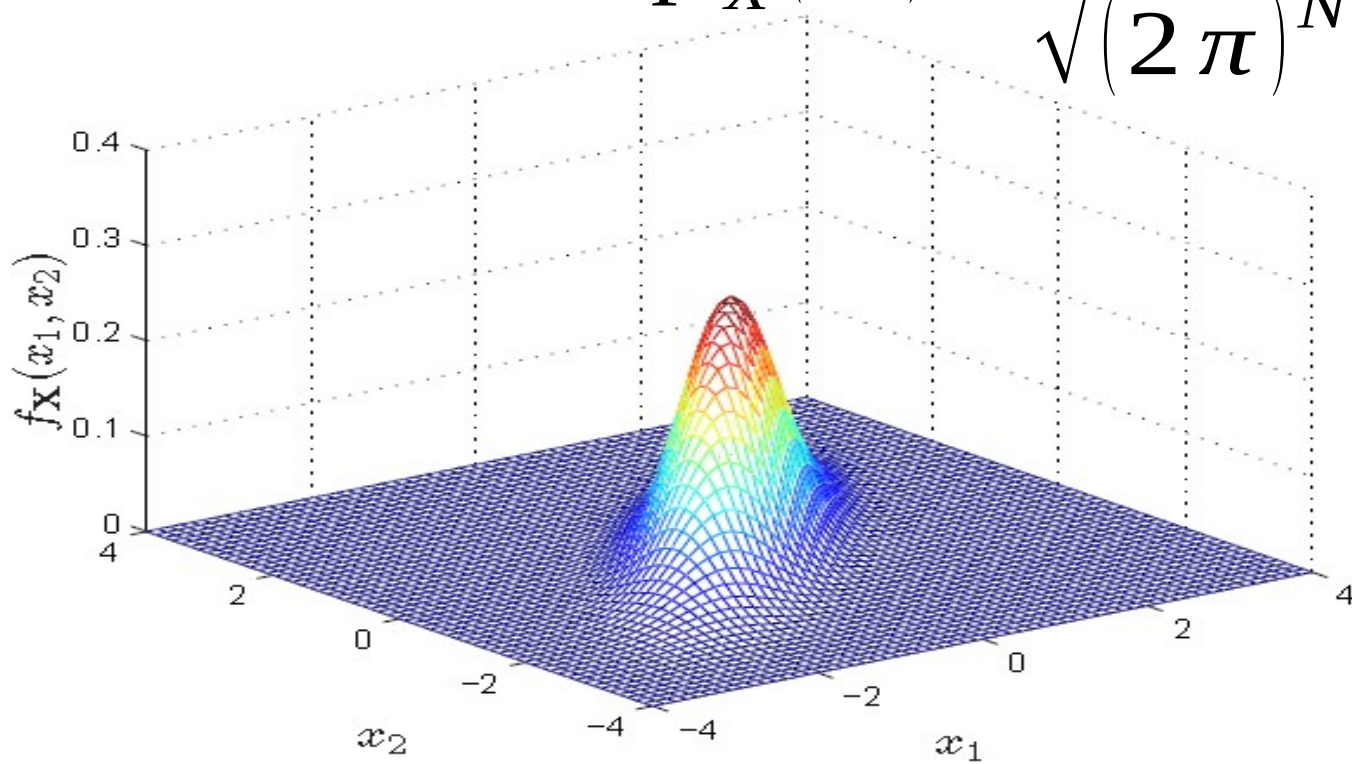
- Un modelo que capte los condicionamientos estadísticos de las series de datos entre si y con sus pasados.
- Un modelo que capte las probabilidades de ocurrencias de las diferentes amplitudes de las variables aleatorias.

# Herramientas disponibles

- Terrible arsenal para tratamiento de sistemas lineales invariantes en el tiempo.
- Algunos resultados aplicables a procesos ergódicos.
- Algunos resultados sobre procesos gaussianos.

# FDP Gaussiana

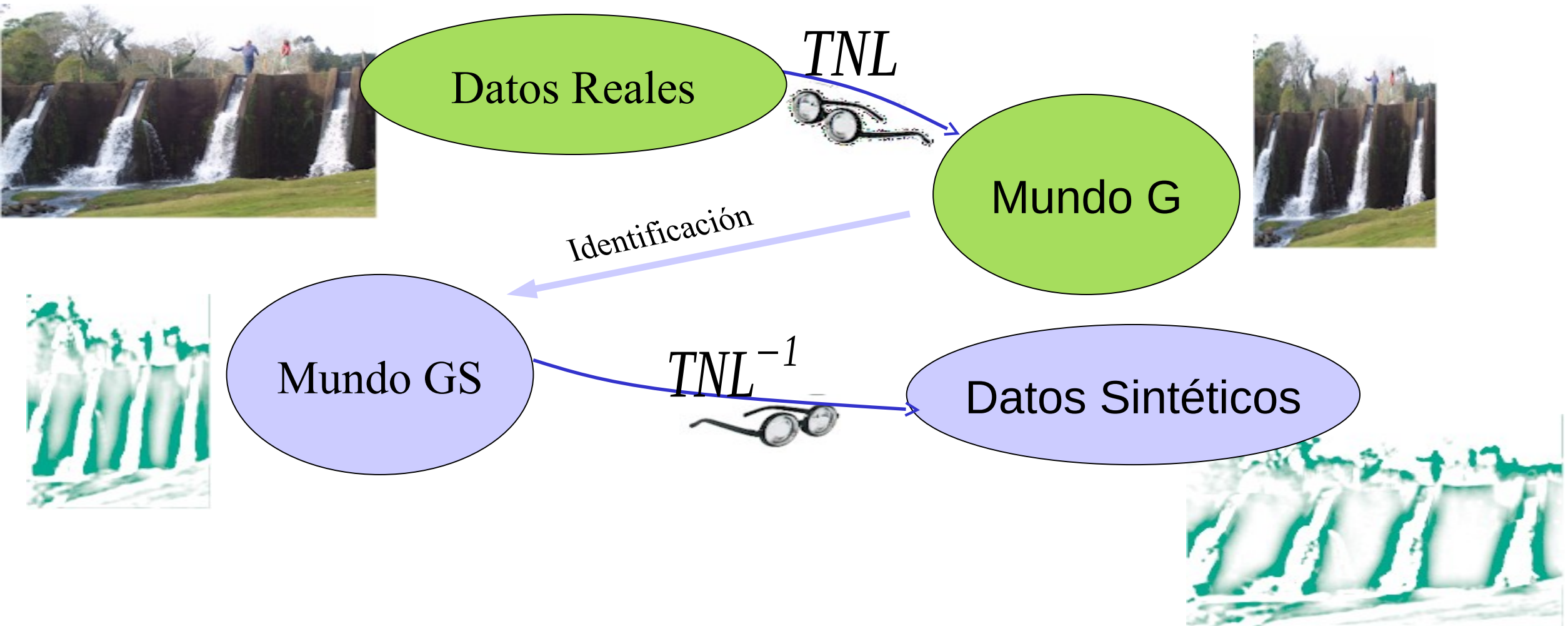
$$p_X(\mathbf{X}) = \frac{1}{\sqrt{(2\pi)^N \cdot |\Sigma|}} \cdot e^{-\left(\frac{1}{2} \mathbf{X}^T \Sigma^{-1} \mathbf{X}\right)}$$



$$\Sigma = \langle \mathbf{X} \cdot \mathbf{X}^T \rangle$$

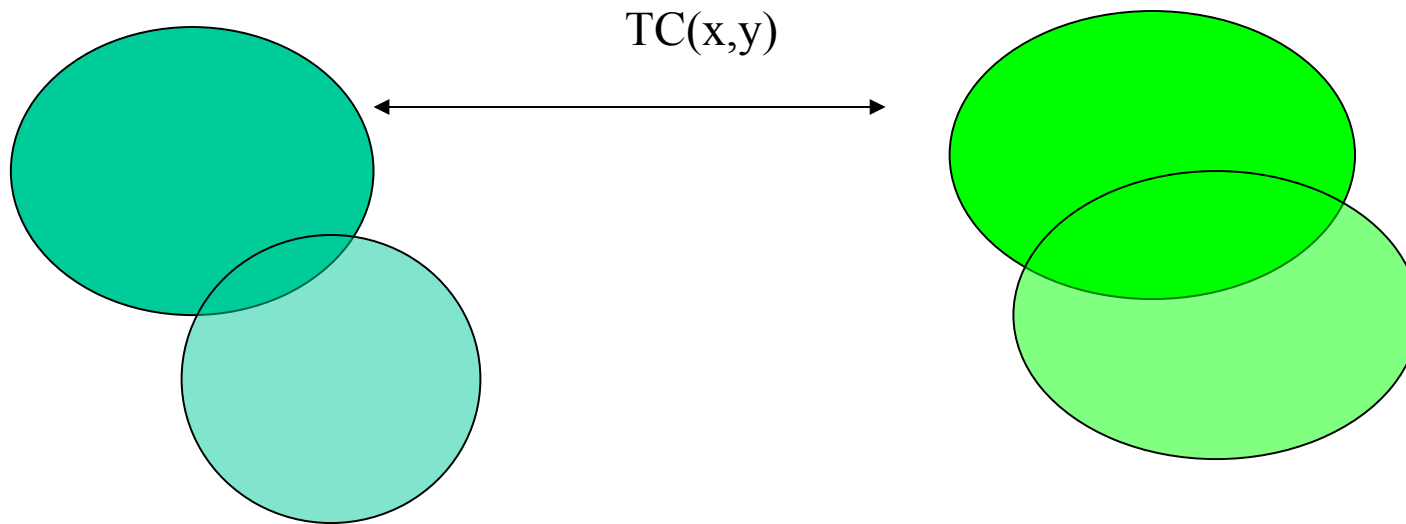
# Modelo CEGH

Correlaciones en Espacio Gaussiano con Histograma.

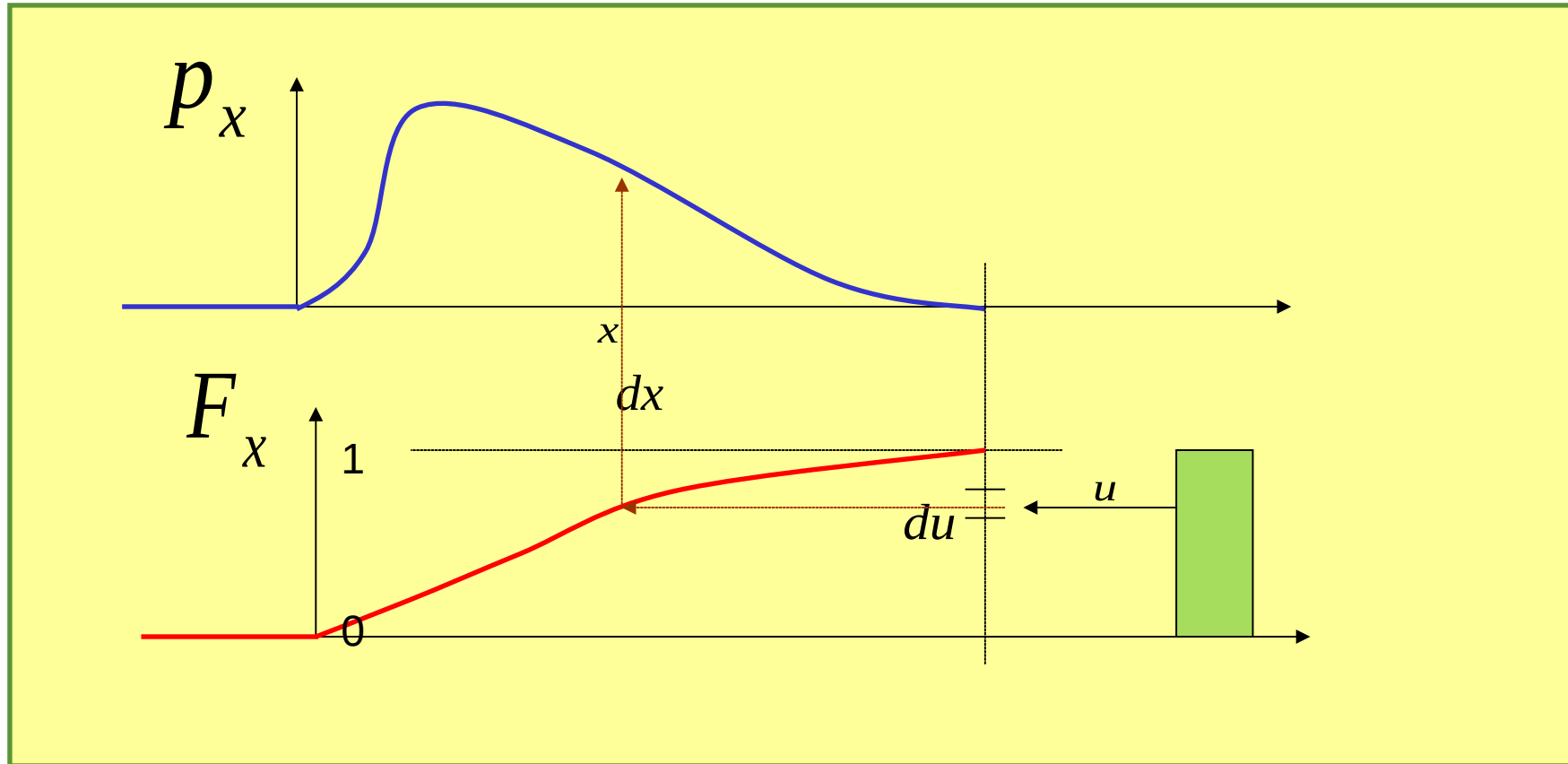


# Transformaciones Compactas.

- Biunívoca y que transforme todo compacto en un compacto.

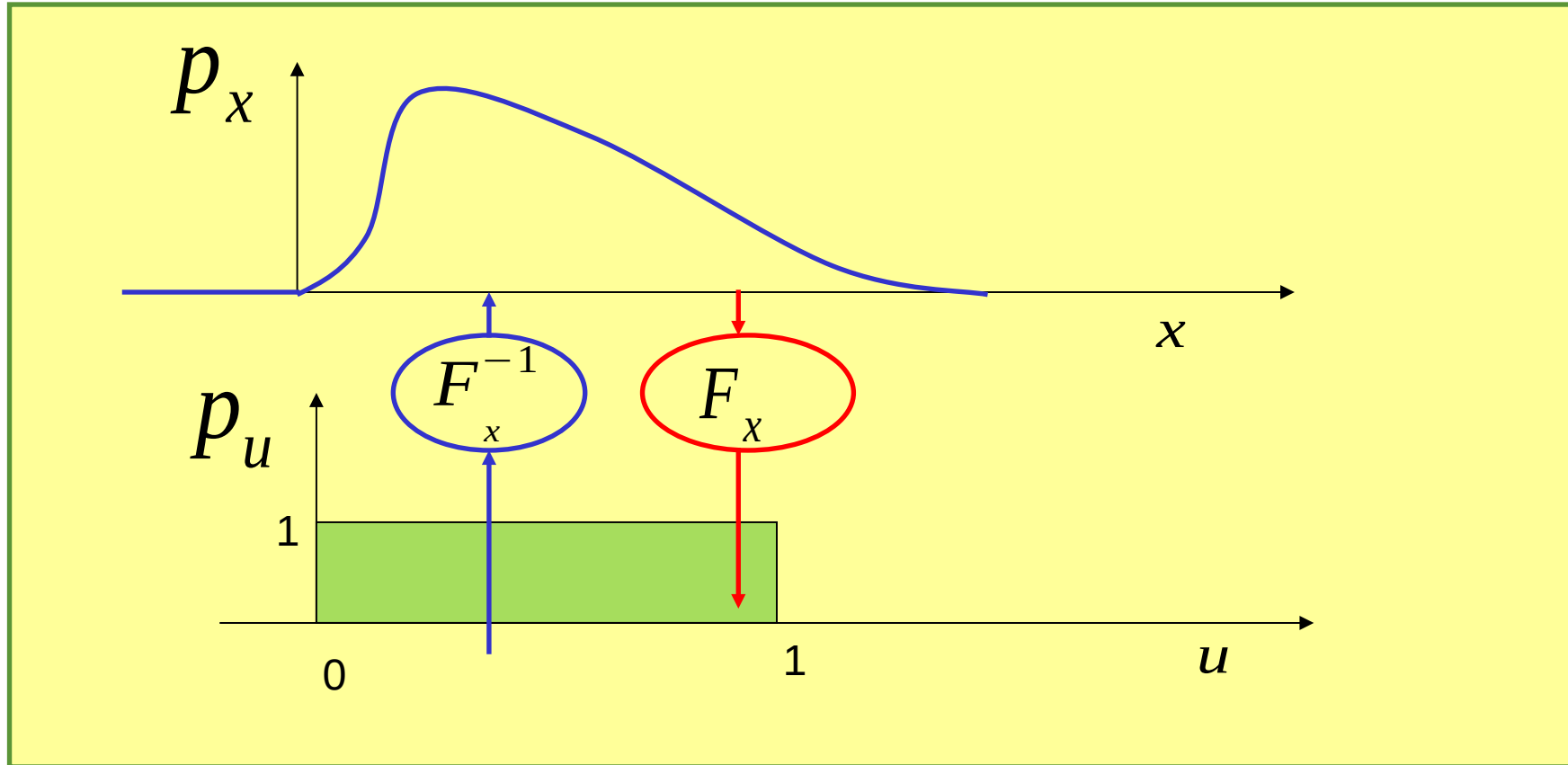


# Fuente aleatoria con histograma



$$F_x(z) = \text{prob}(x \leq z) = \int_{-\infty}^z p_x(x) \cdot dx$$

# Fuente aleatoria con histograma



## Modelos lineales

$$X_{k+1} = \sum_{h=0}^{h=n-1} A_h X_{k-h} + \sum_{h=0}^{h=m-1} B_h R_{k-h}$$
$$Y_k = CX_k$$

- Potentes herramientas.
- No conservan los histogramas.

Si las R son gaussianas indep. las X y las Y lo son.

# CEGH modeling.

- reproduces the amplitude histograms of the original processes.
- reproduces the spatial and temporal correlations in a gaussian space.

*Gaussian World:  
Multi-variable linear system  
fed with  
Gaussian independent white noise*

$$X_{k+1} = \sum_{h=0}^{h=n-1} A_h X_{k-h} + \sum_{h=0}^{h=m-1} B_h R_{k-h}$$

Accept state space reductions.  
Accept forecast information.

*NLT*

*NLT*

*NLT*

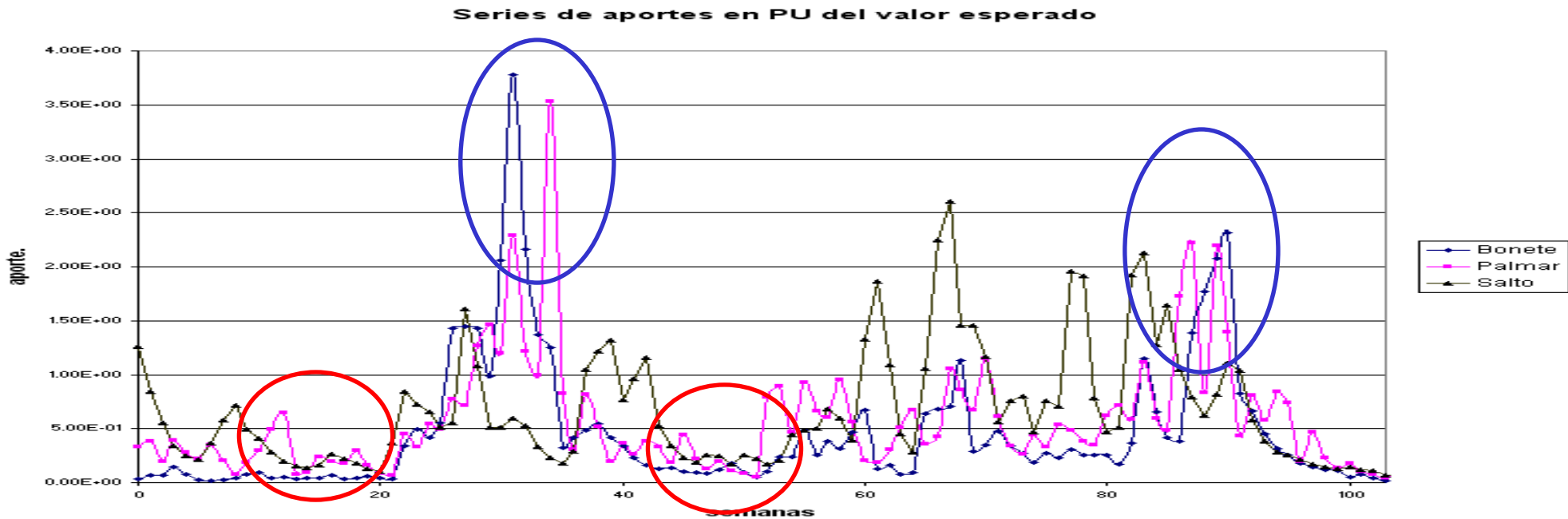
*NLT*

*NLT*

*NLT*

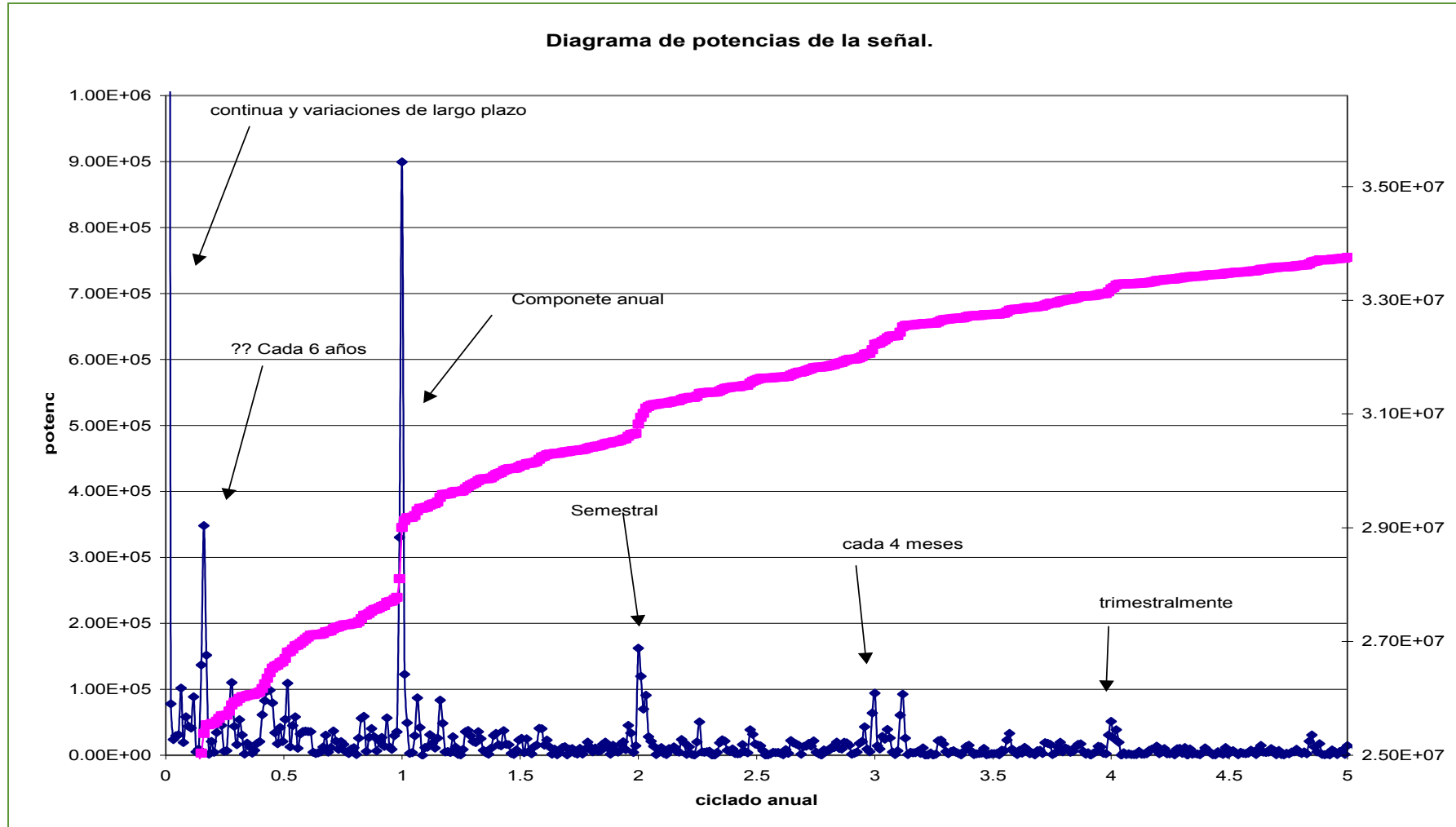
*Real World  
Model*

# Ejemplo de identificación del sistema hídrico de Uruguay.



Dos años de aportes semanales históricos en Bonete, Palmar y Salto

# Espectro de Potencia SALTO GRANDE



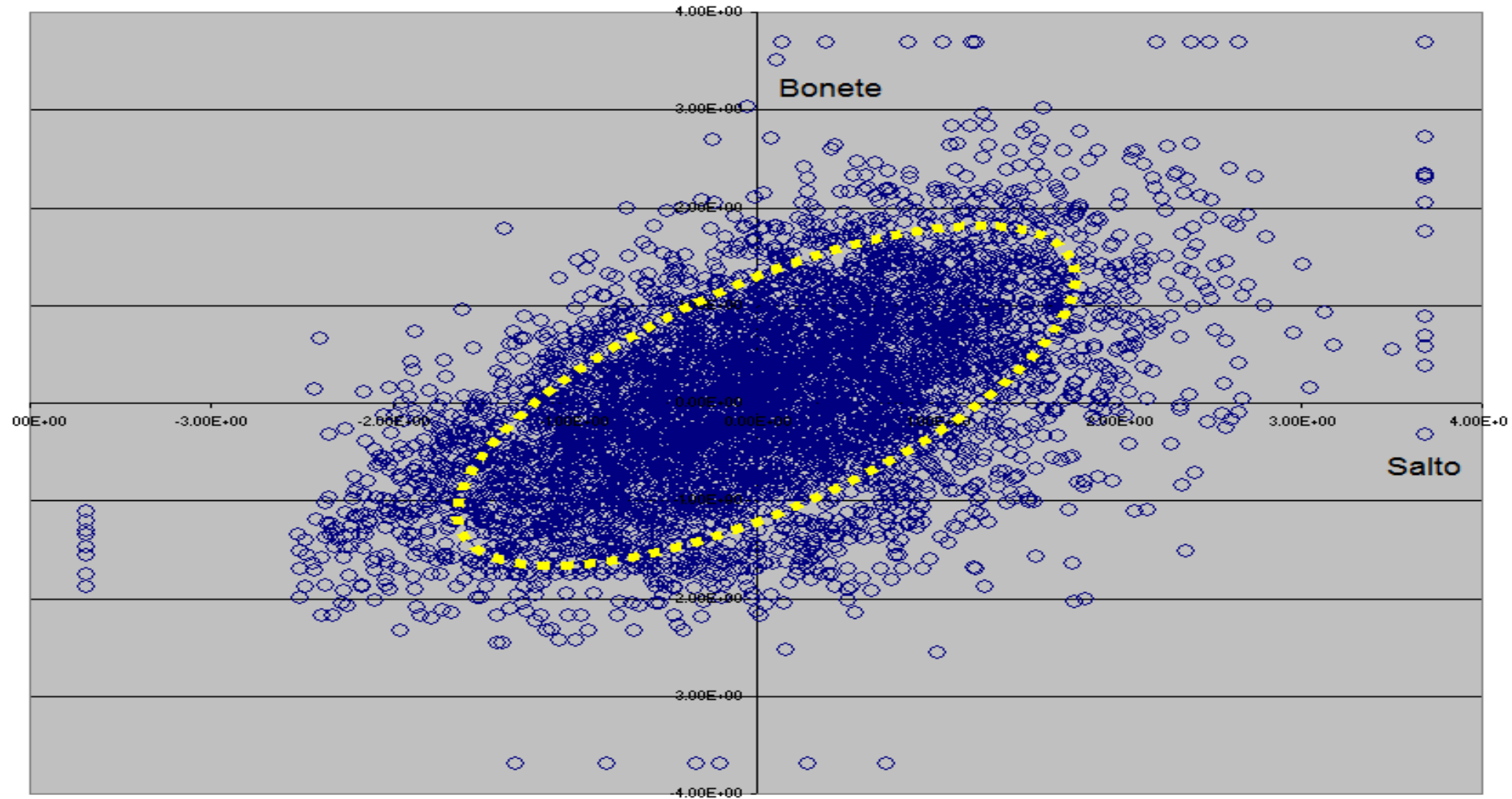
# Matríz de Covarianzas

	B	P	S
B	1.000	0.571	0.536
P	0.571	1.000	0.296
S	0.536	0.296	1.000

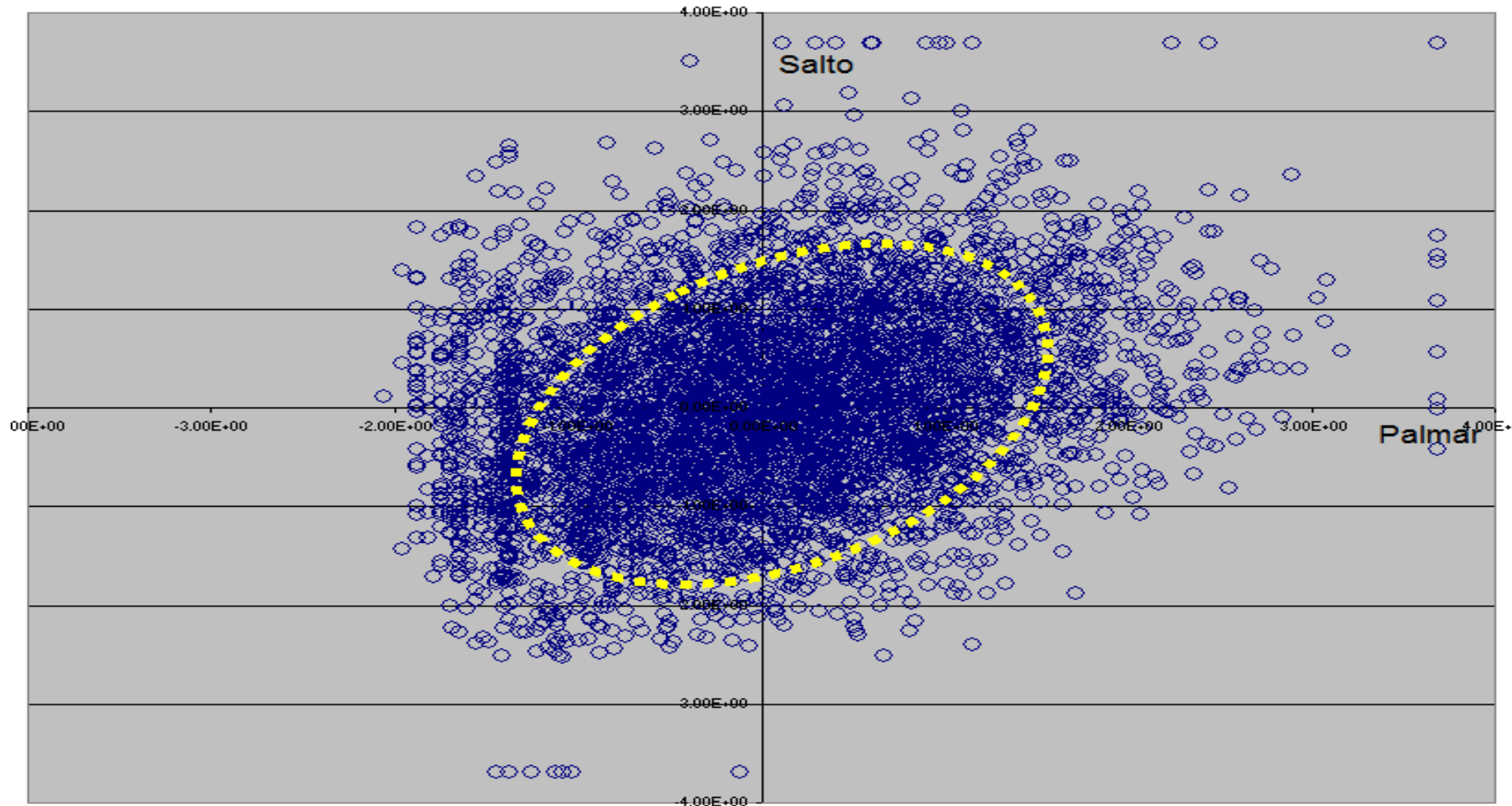
$$\Sigma = \langle X \cdot X^T \rangle$$

$$p_X(X) = \frac{1}{\sqrt{(2\pi)^N \cdot |\Sigma|}} \cdot e^{-\left(\frac{1}{2} X^T \Sigma^{-1} X\right)}$$

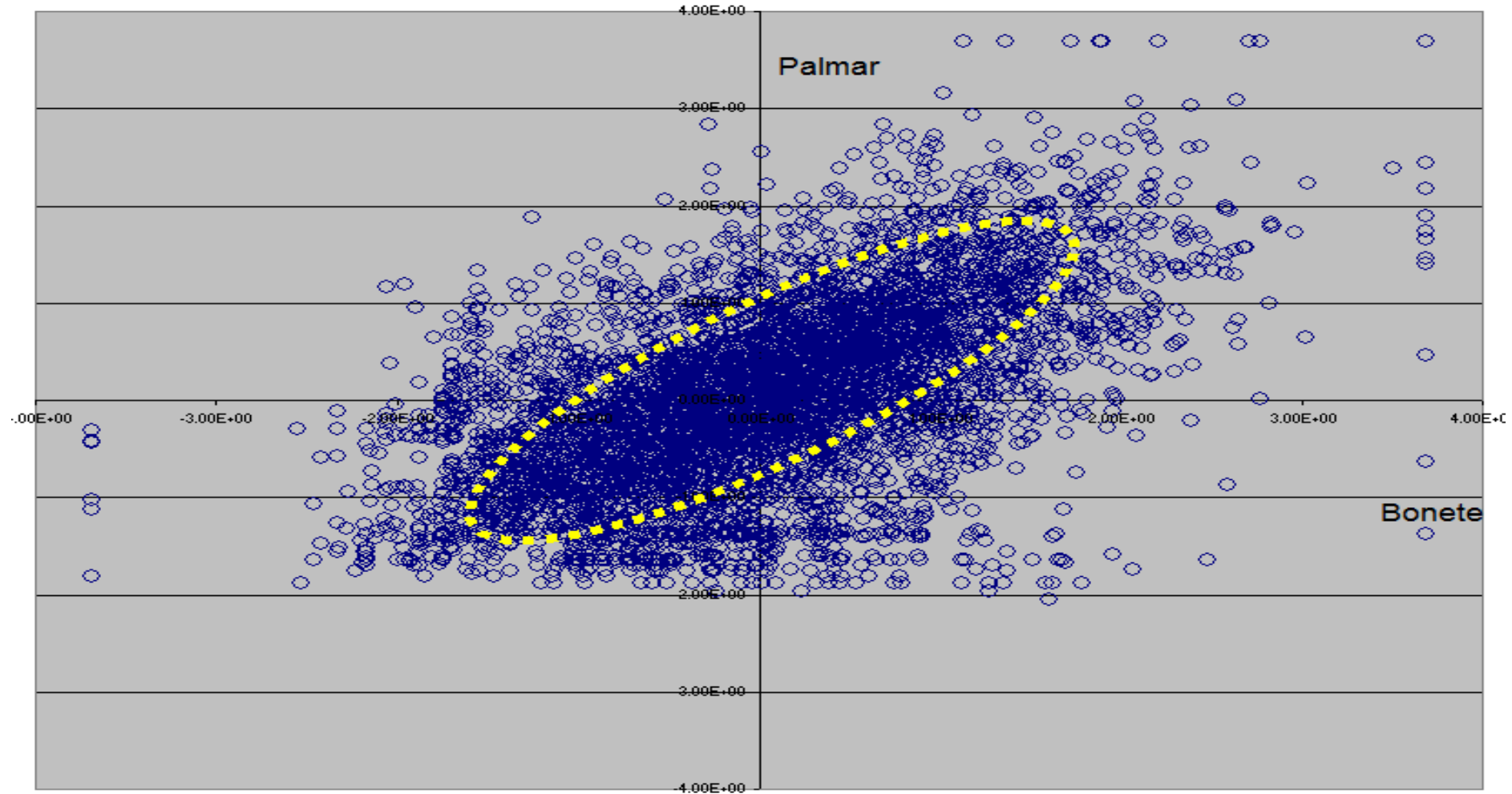
# Salto vs. Bonete - EG



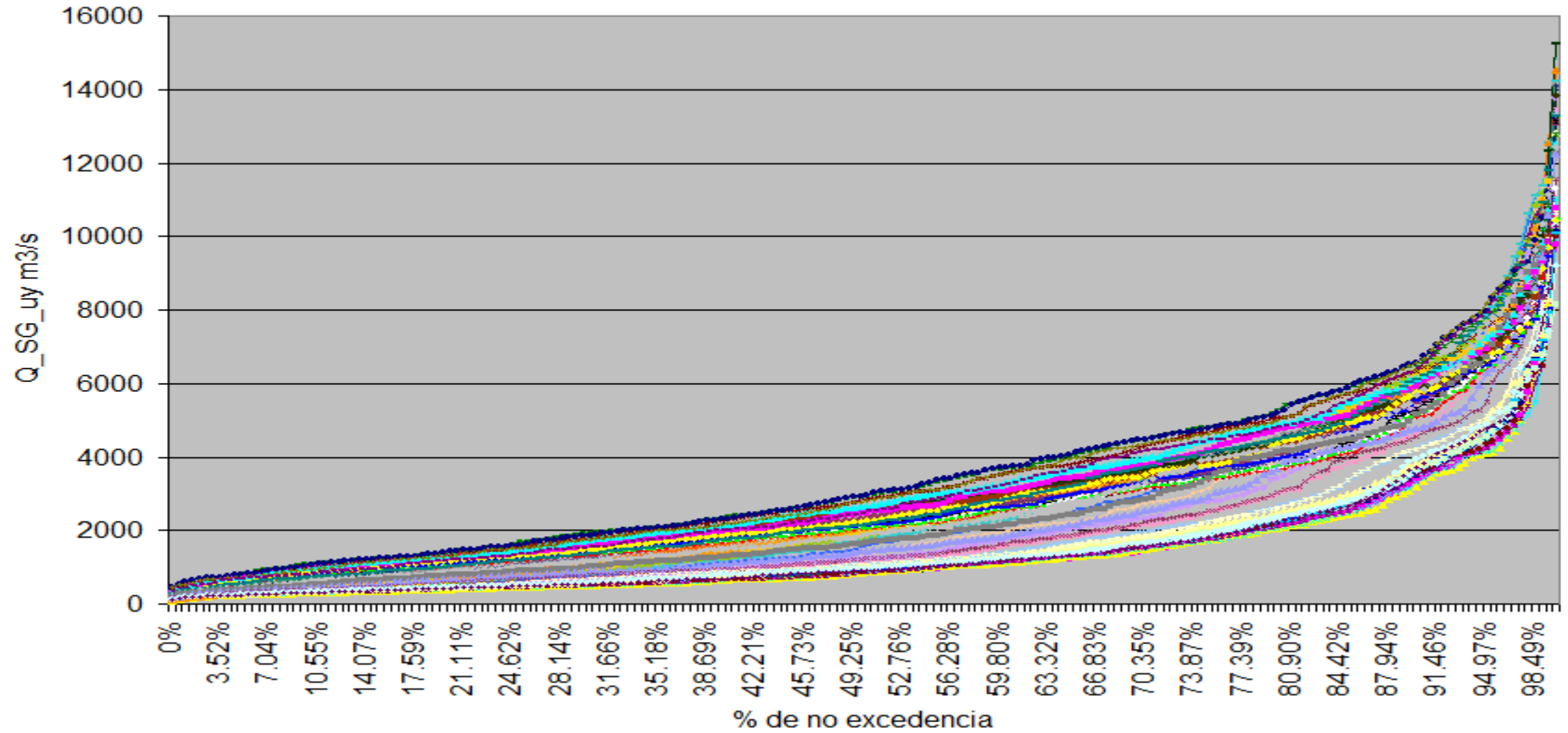
# Palmar vs. Salto - EG



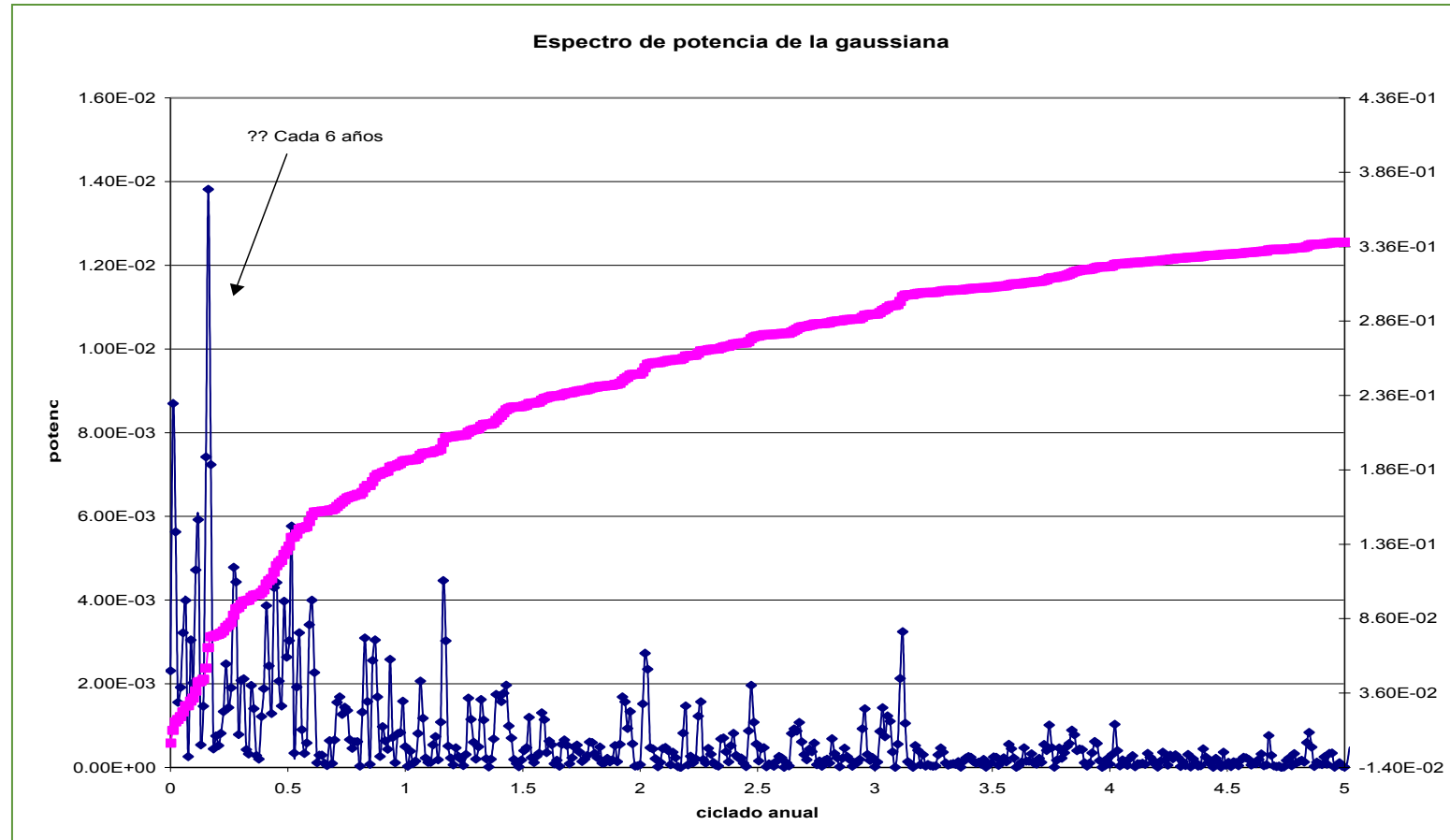
# Bonete vs. Palmar - EG



# Deformadores del caudal medio semanal de la mitad uruguaya de Salto Grande para cada semana del año.



# Espectro de potencia de la serie SG transformada.



# Matriz A y B del filtro (1 paso) Bonete, Palmar y Salto

B[k]		0.76	0.02	0.08	*	B[k]		0.38	-0.18	-0.40	*	R1[k]
P[k]	=	0.16	0.63	0.01		P[k]	+	0.61	0.25	0.17		R2[k]
S[k]		0.12	-0.03	0.78		S[k]		0.18	-0.48	0.24		R3[k]

Estado = 3x1

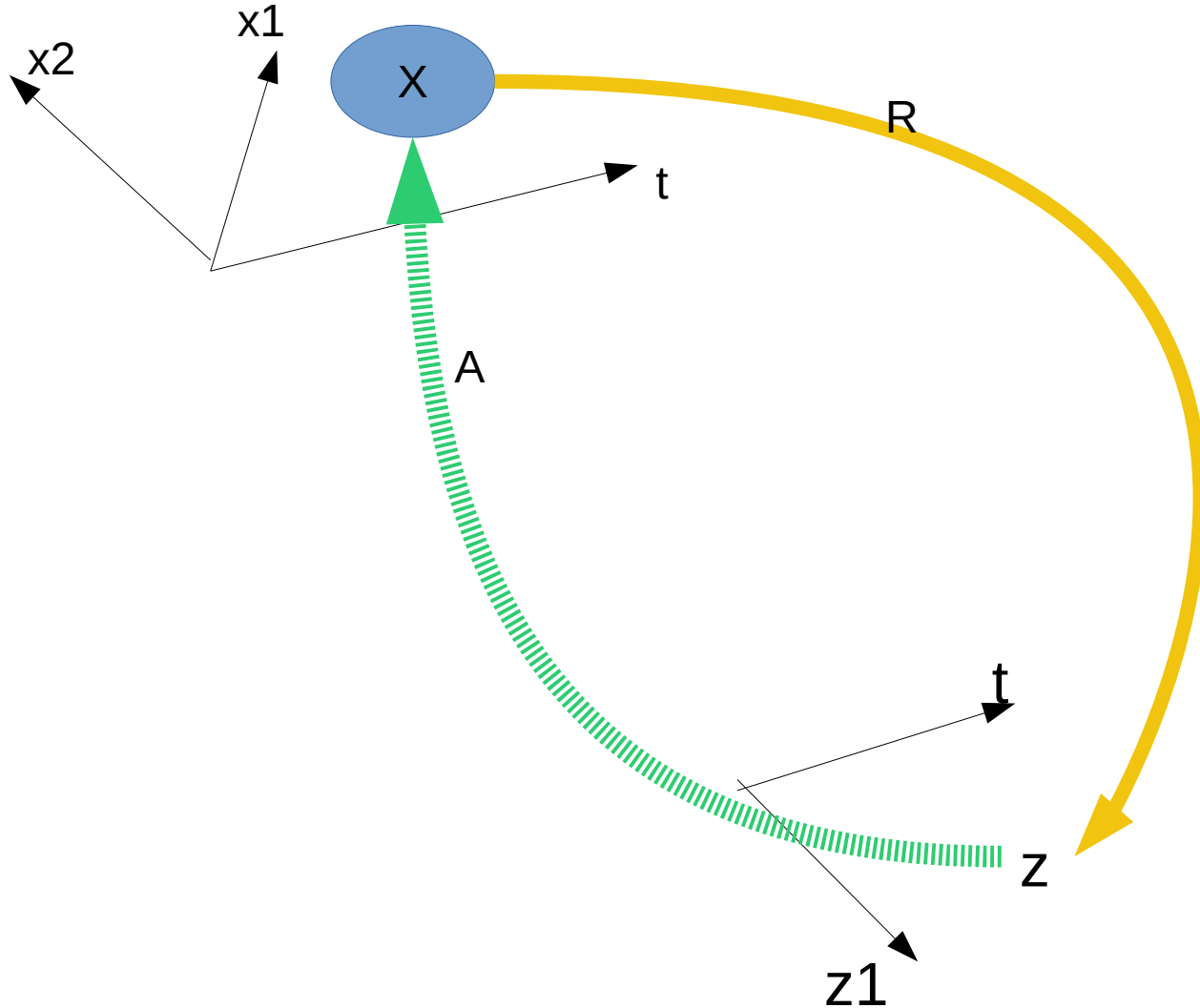
# Maldición de Belman.

$$u_k = p(x_k, r_k, k)$$



$$\text{Dim}(u) \times \text{Dim}(x) \times \text{Dim}(r) \times \text{Dim}(k)$$

# Reducción del Espacio de Estado en modelos CEGH



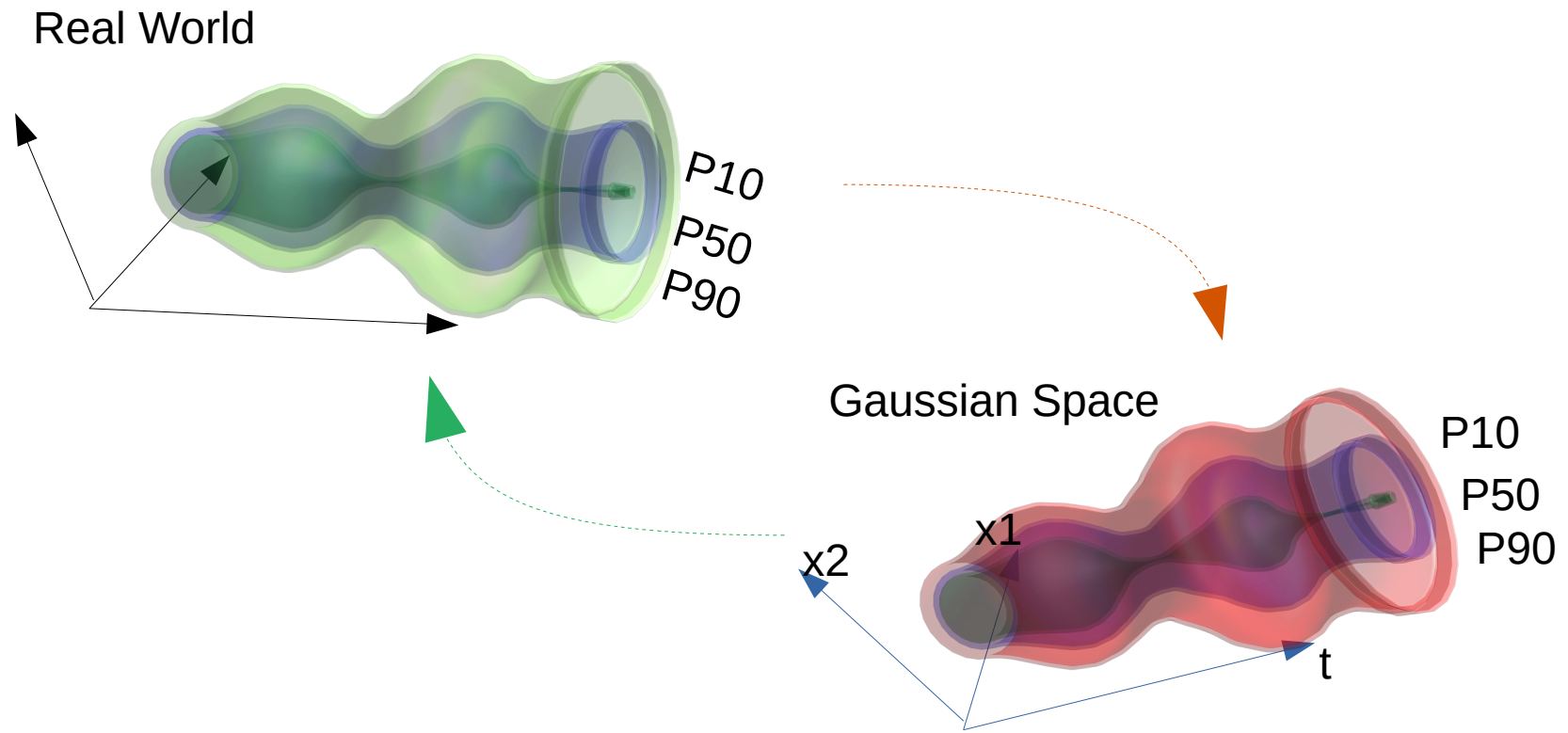
$$z = R(X)$$

$$u = PO_z(z, r, t)$$

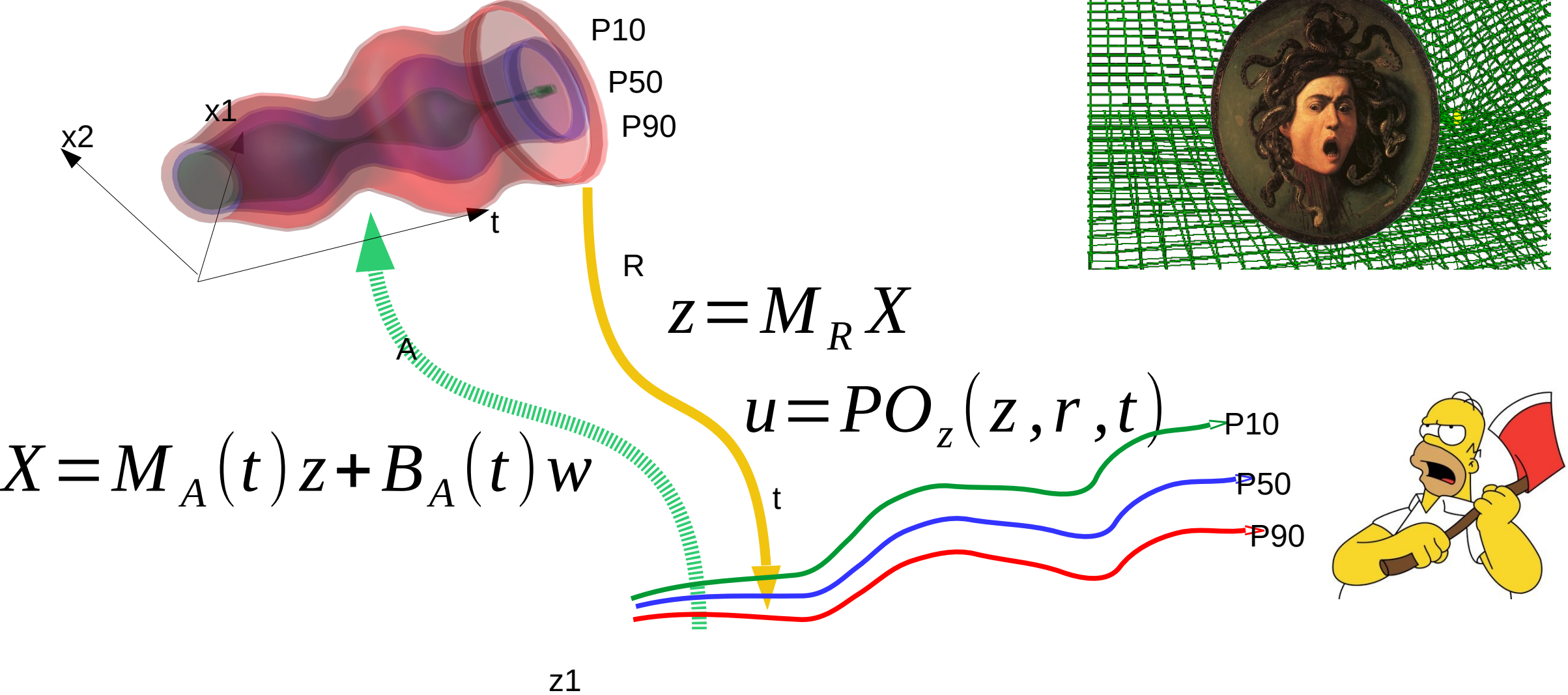
$$X = A(z, w)$$

$W$  es el ruido que permite poblar el volumen de  $X$  que mapea en el  $z$  dado.

# Treatment of forecasts in CEGH modeling. Gaussianization



# Treatment of forecasts in Gaussian space with reduction in CEGH modeling.



# Ease integration of FORECASTS in CEGH modeling.

$$X_{k+1} = \sum_{h=0}^{h=n_r-1} A_h X_{k-h} + S_k + F_k \sum_{h=0}^{h=m-1} B_h R_{k-h}$$

biases:

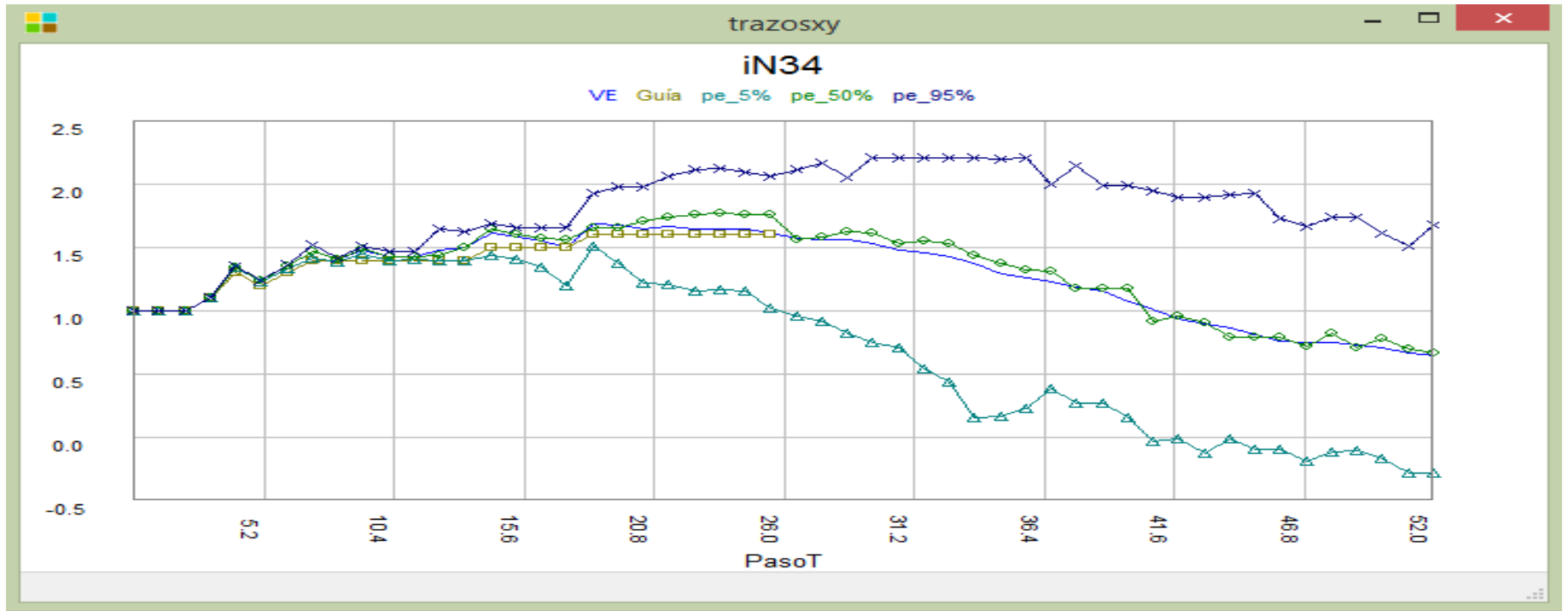
$$S_k = \begin{bmatrix} s_{1,k} \\ \dots \\ s_{n,k} \end{bmatrix}$$

attenuators:

$$F_k = \begin{bmatrix} f_{1,k} & 0 & \dots & 0 \\ 0 & f_{2,k} & \dots & 0 \\ 0 & \dots & 0 & f_{n,k} \end{bmatrix}$$

The biases (S) change the 50% probability guide and the attenuation factors (F) regulate the noise injection, allowing to go from a Deterministic Forecast ( $F = 0 =$  null noise) to the disappearance of the forecast ( $S = 0; F = 1 =$ historical noise).

# Incorporación de iN34 a la Programación Estacional

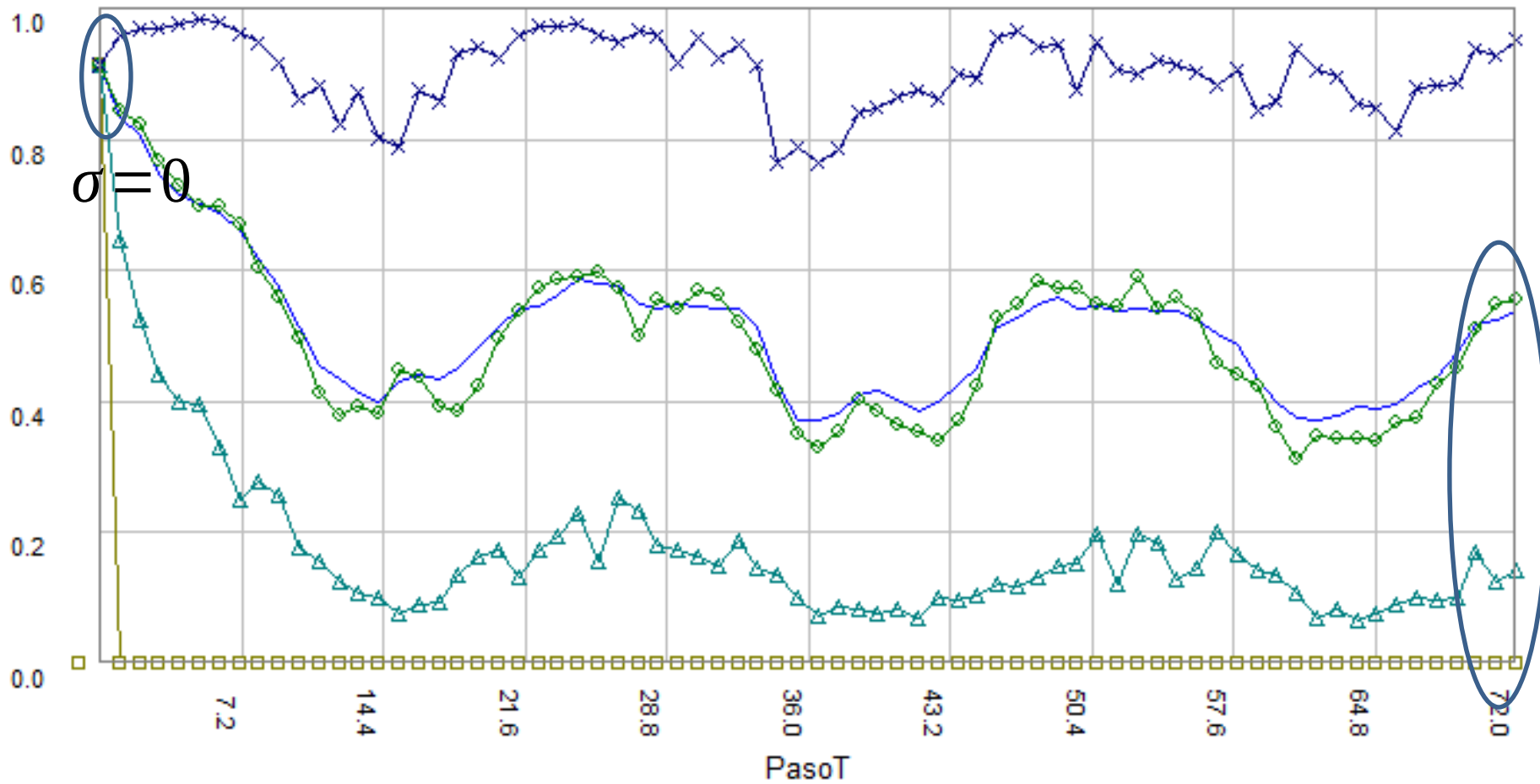


**Reducción de CAD 5%  
aprox.**

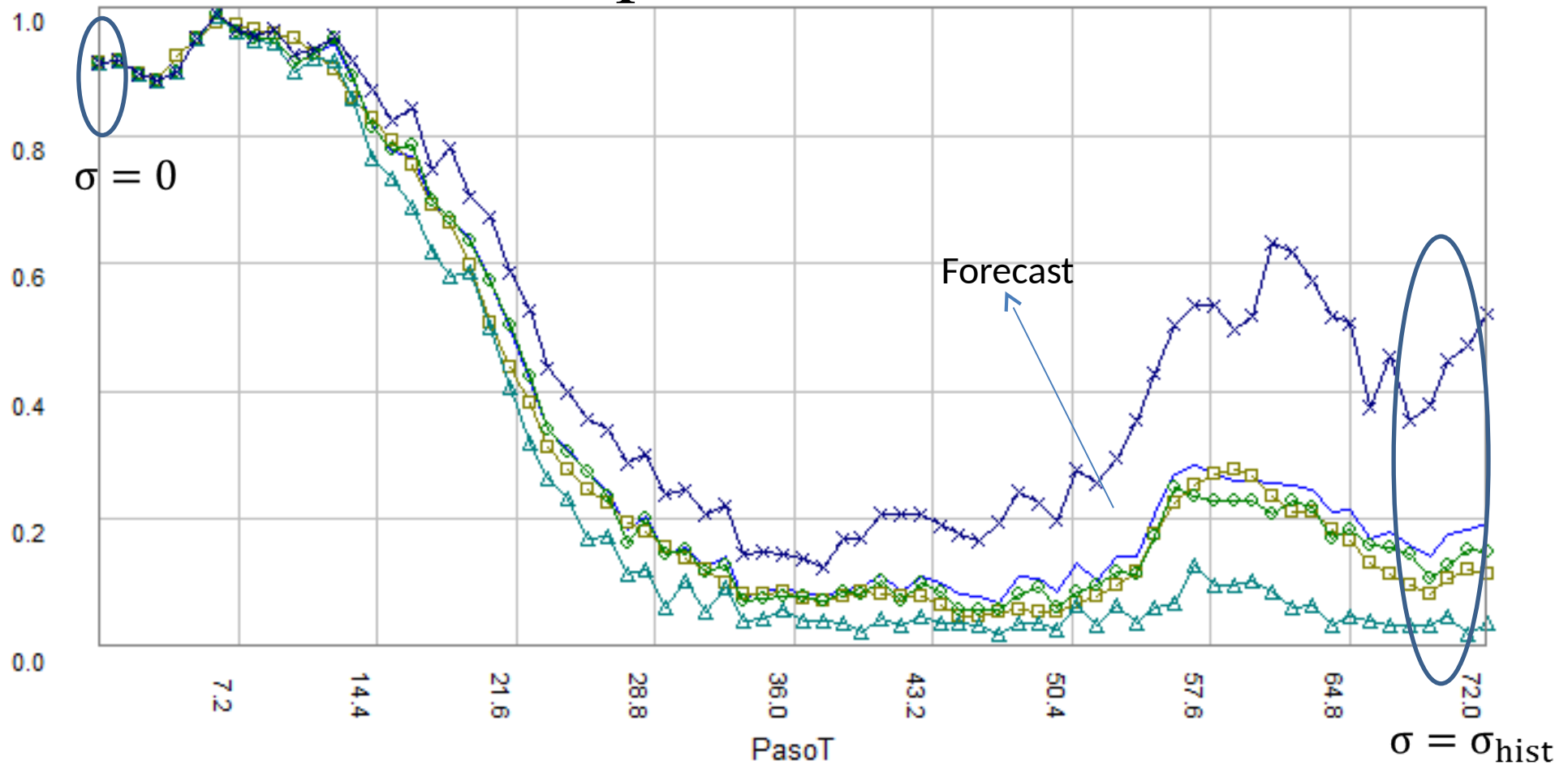
**Mejora en Previsión  
Presupuestal y compras de  
combustibles 30% del CAD**



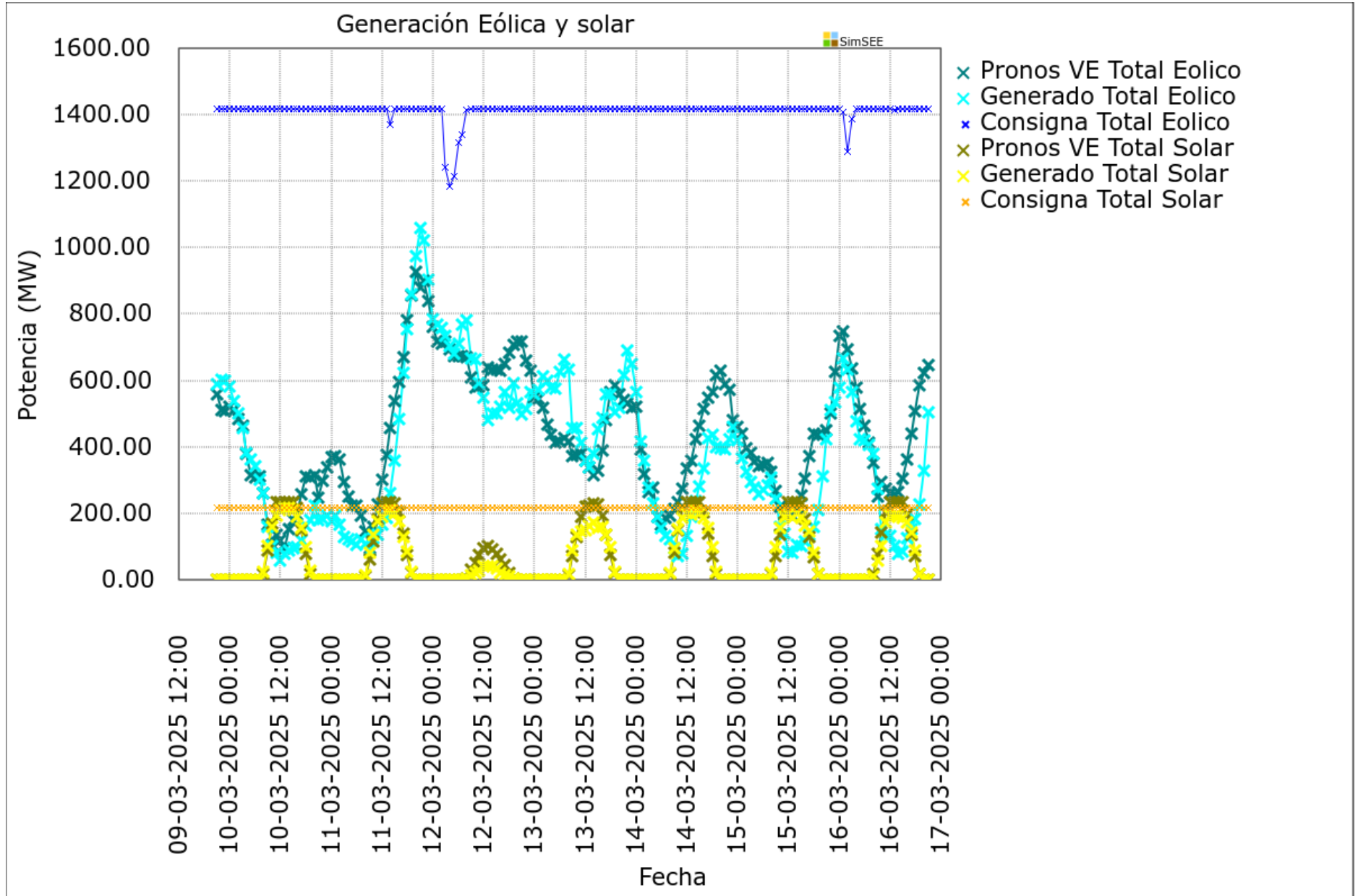
# Programming the energy dispatch without windpower forecasts.



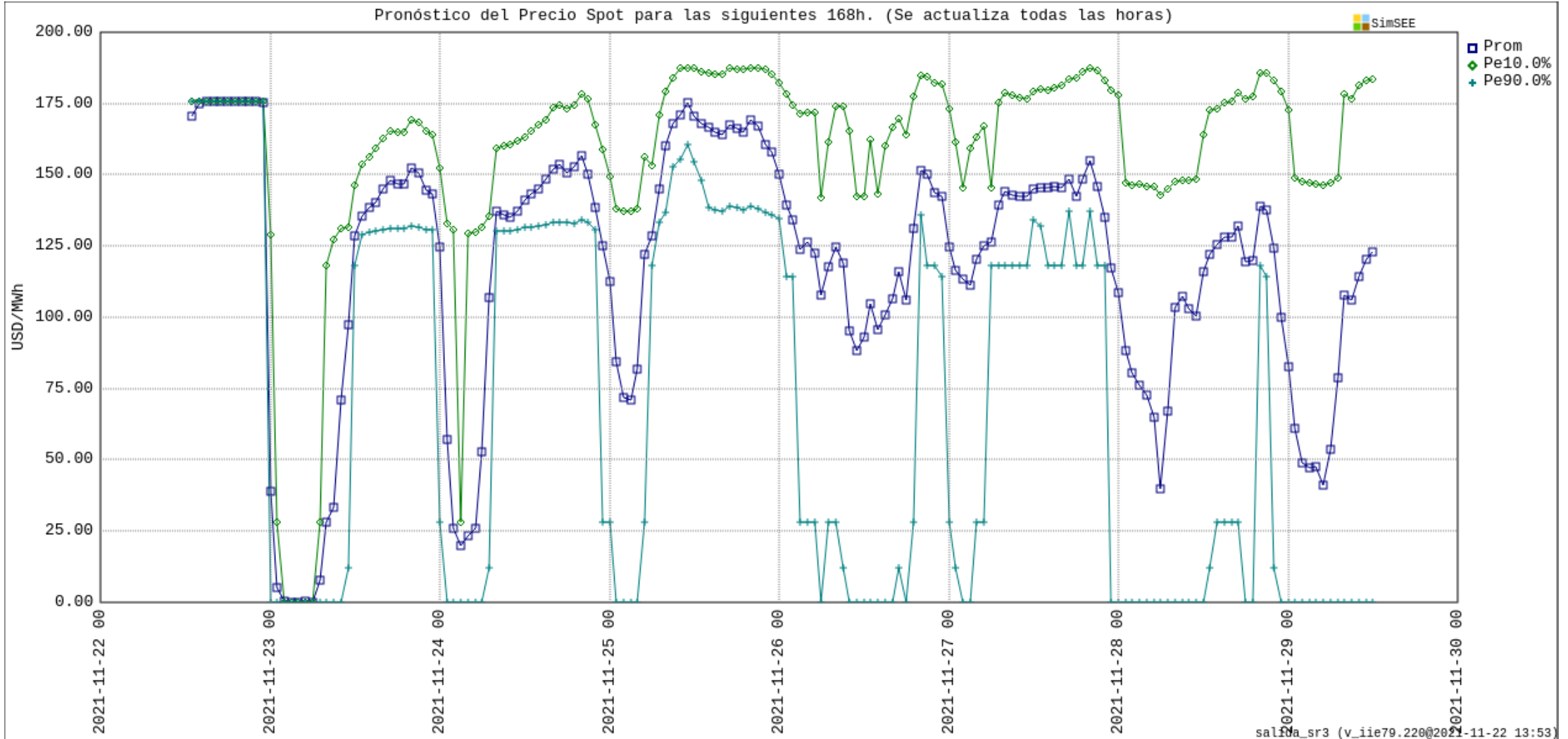
# Programming the energy dispatch with 72h of windpower forecasts.



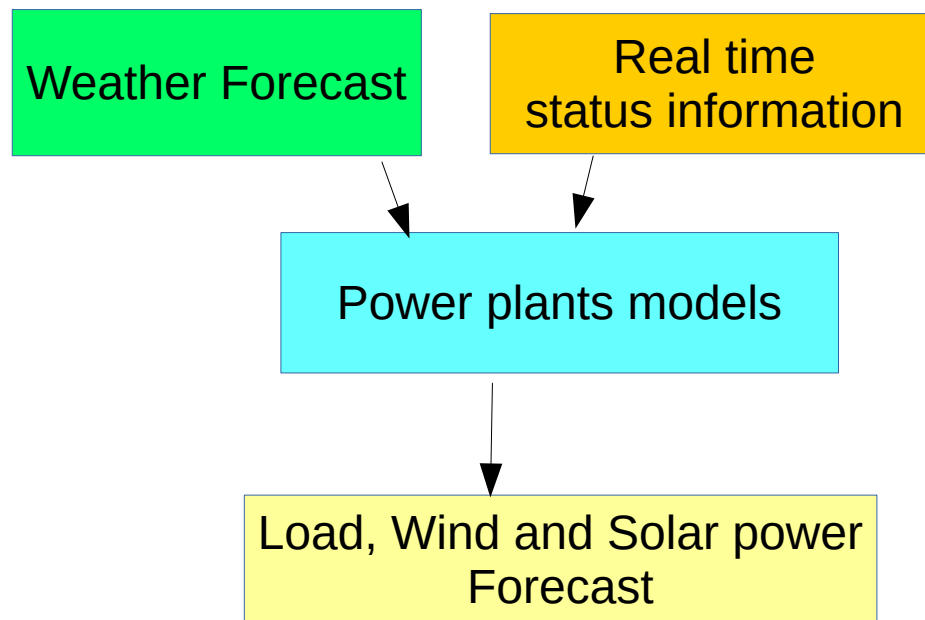
<https://pronos.adme.com.uy/svg/>



# Next 168 h, Spot Price forecast. (Example from ADME's WEB)



# PRONOS-1 2016-2017



<https://pronos.adme.com.uy>

<https://pronos.adme.com.uy/svg/>

**VATES**

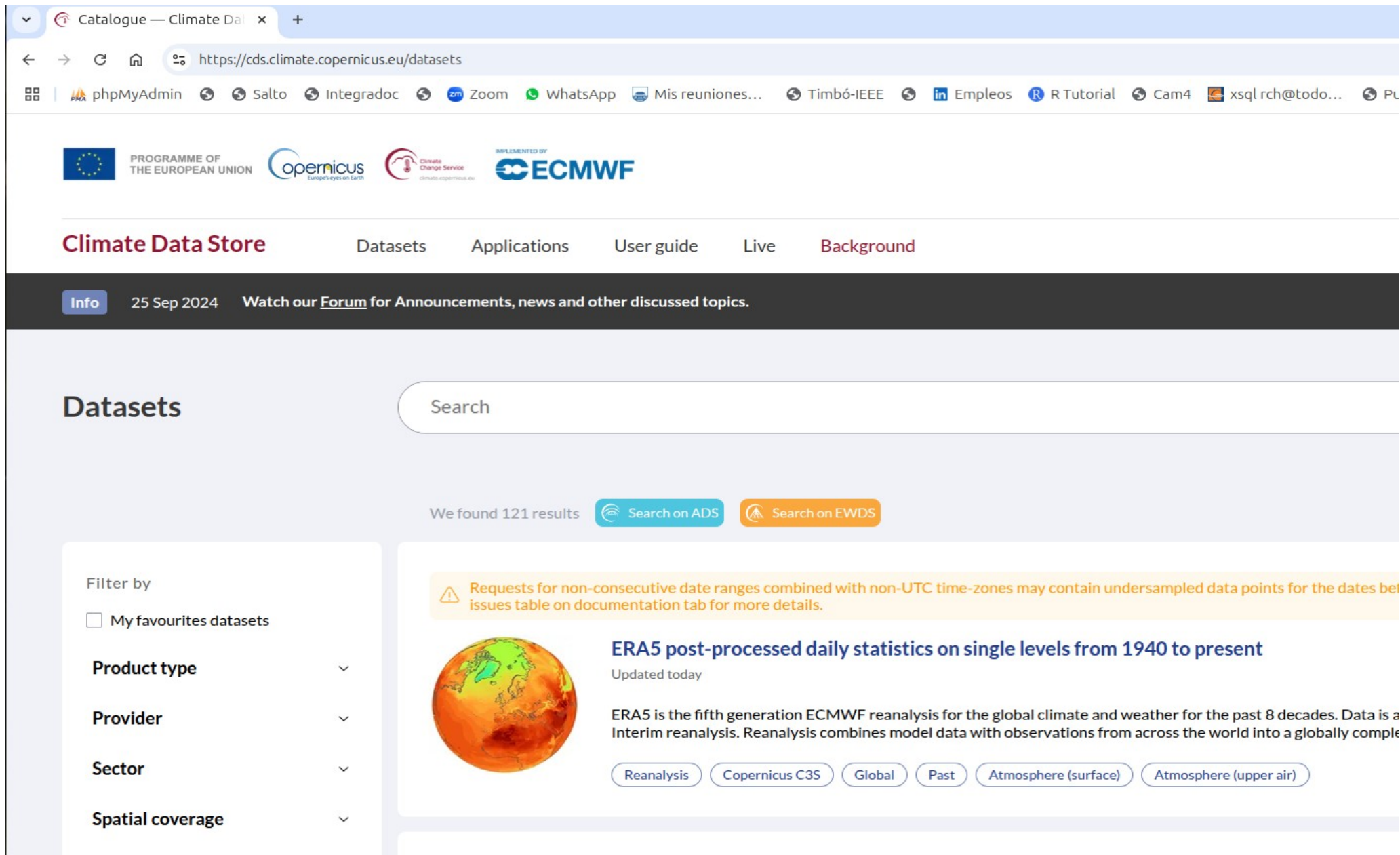
Continuous forecast of the next 168 hours  
of optimal operation.



<https://vates.adme.com.uy>

Slide: 39

- <https://cds.climate.copernicus.eu/datasets>



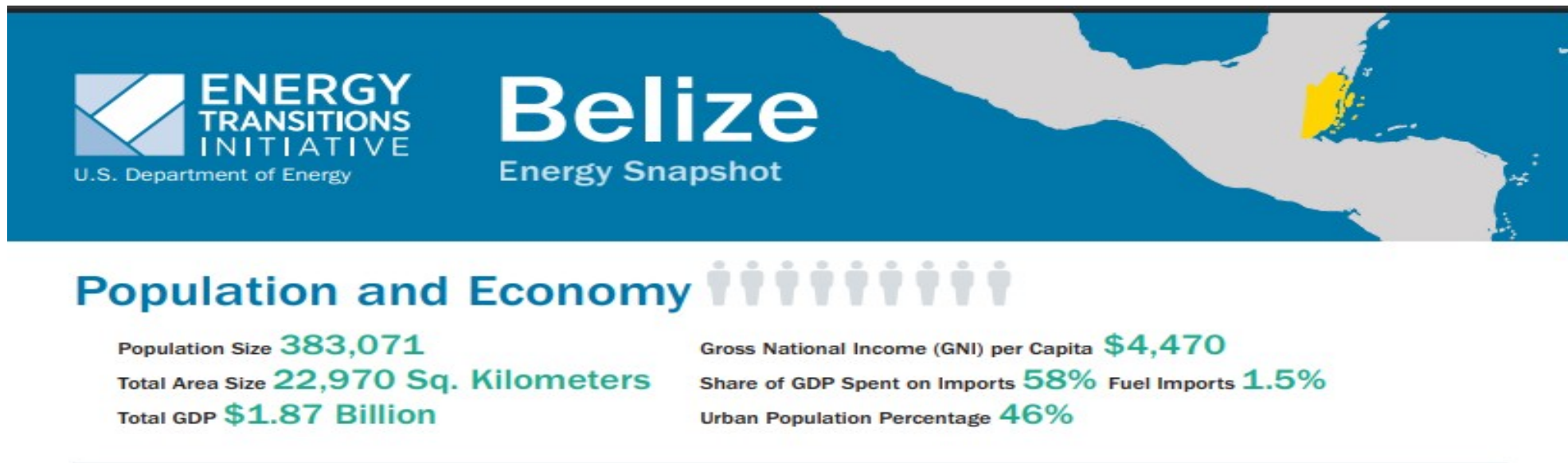
The screenshot shows the Copernicus Climate Data Store website. The browser address bar displays the URL <https://cds.climate.copernicus.eu/datasets>. The page header includes logos for the European Union, Copernicus, and ECMWF. The main navigation menu contains links for "Climate Data Store", "Datasets", "Applications", "User guide", "Live", and "Background". A dark banner below the navigation menu provides information: "Info 25 Sep 2024 Watch our [Forum](#) for Announcements, news and other discussed topics."

The "Datasets" section is active, featuring a search bar and a notification: "We found 121 results". Below this, there are two buttons: "Search on ADS" and "Search on EWDS". A warning message states: "Requests for non-consecutive date ranges combined with non-UTC time-zones may contain undersampled data points for the dates below. See the issues table on documentation tab for more details."

The first search result is for the "ERA5 post-processed daily statistics on single levels from 1940 to present" dataset, which was updated today. The description notes that ERA5 is the fifth generation ECMWF reanalysis for the global climate and weather for the past 8 decades. The dataset is categorized by "Reanalysis", "Copernicus C3S", "Global", "Past", "Atmosphere (surface)", and "Atmosphere (upper air)".

2020

[https://www.energy.gov/eere/articles/belize-island-energy-snapshot-2020?nrg\\_redirect=454723](https://www.energy.gov/eere/articles/belize-island-energy-snapshot-2020?nrg_redirect=454723)

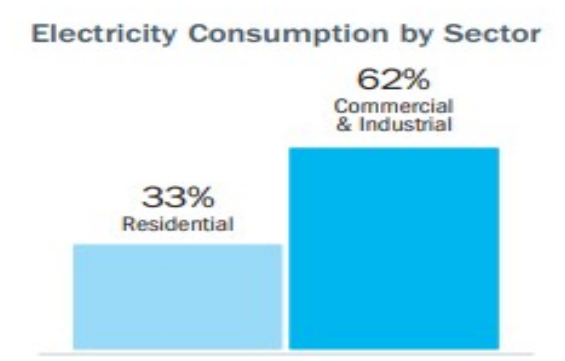
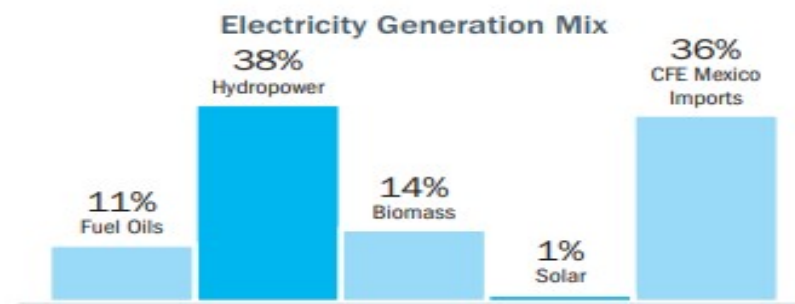


2020

[https://www.energy.gov/eere/articles/belize-island-energy-snapshot-2020?nrg\\_redirect=454723](https://www.energy.gov/eere/articles/belize-island-energy-snapshot-2020?nrg_redirect=454723)

## Electricity Sector Overview

<b>Installed Capacity</b> <b>119.98 MW</b>
<b>RE Generation Capacity Share</b> <b>61%</b>
<b>Peak Demand (2018)</b> <b>104.2 MW</b>
<b>Total Generation (2018)</b> <b>651.12 GWh</b> <i>Includes 235.16 GWh purchased/imported from Commission of Federal Electricity (CFE) in Mexico</i>
<b>Transmission and Distribution Losses</b> <b>11.9%</b>
<b>Electricity Access</b> <b>92%</b> (total population) Electrification – Urban Areas <b>97.1%</b> (2016) Electrification – Rural Areas <b>88.4%</b> (2016)
<b>Average Electricity Rates (USD/kWh)</b> Social (60kWh or less per month) <b>\$0.11</b> <i>(\$2.50 minimum monthly charge)</i> Residential and Small Commercial <b>\$0.20</b> <i>(\$5.00 minimum monthly charge)</i> Large Commercial <b>\$0.20</b> <i>+ \$75 monthly service charge</i> Small Industrial <b>\$0.15</b> <i>+ \$18.40 demand charge (kVA)</i> <i>+ \$124 monthly service charge</i> Large Industrial <b>\$0.13</b> <i>+ \$12.40 demand charge (kVA)</i> <i>+ \$124 monthly service charge</i> Street Lights <b>\$0.23</b>

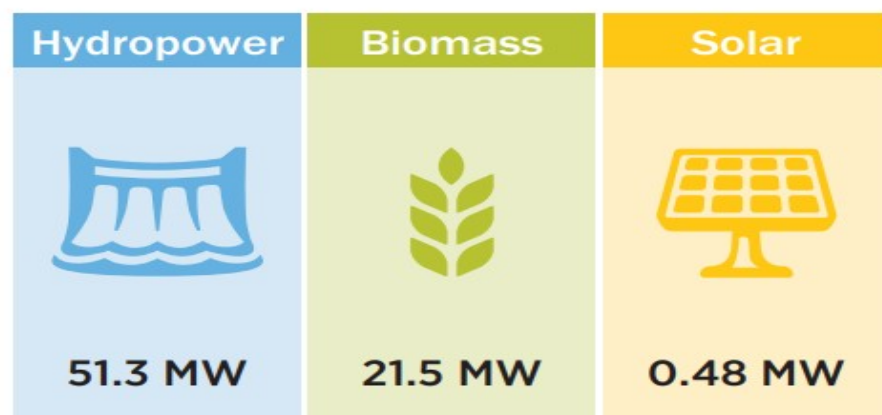


In 2022, a total of 619.1 GWh of electricity was consumed across various sectors.

2020

[https://www.energy.gov/eere/articles/belize-island-energy-snapshot-2020?nrg\\_redirect=454723](https://www.energy.gov/eere/articles/belize-island-energy-snapshot-2020?nrg_redirect=454723)

## Renewable Energy Status



## Targets

### Renewable Energy Generation

 **85%** by 2030\* **70 MW** Total installed Hydropower by 2033  
Supply **5MW** of electricity from municipal solid waste by 2033


\*Conditional NDC Goal <https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/Belize%20First/BELIZE%27s%20%20NDC.pdf>

### Energy Efficiency

 **30%** Increase in energy efficiency by 2033\*

\*Based on baseline year 2011 <https://climate-laws.org/cclow/geographies/18/policies/1081>

### Transportation

 **20%** reduction in conventional transportation fuel use by 2030

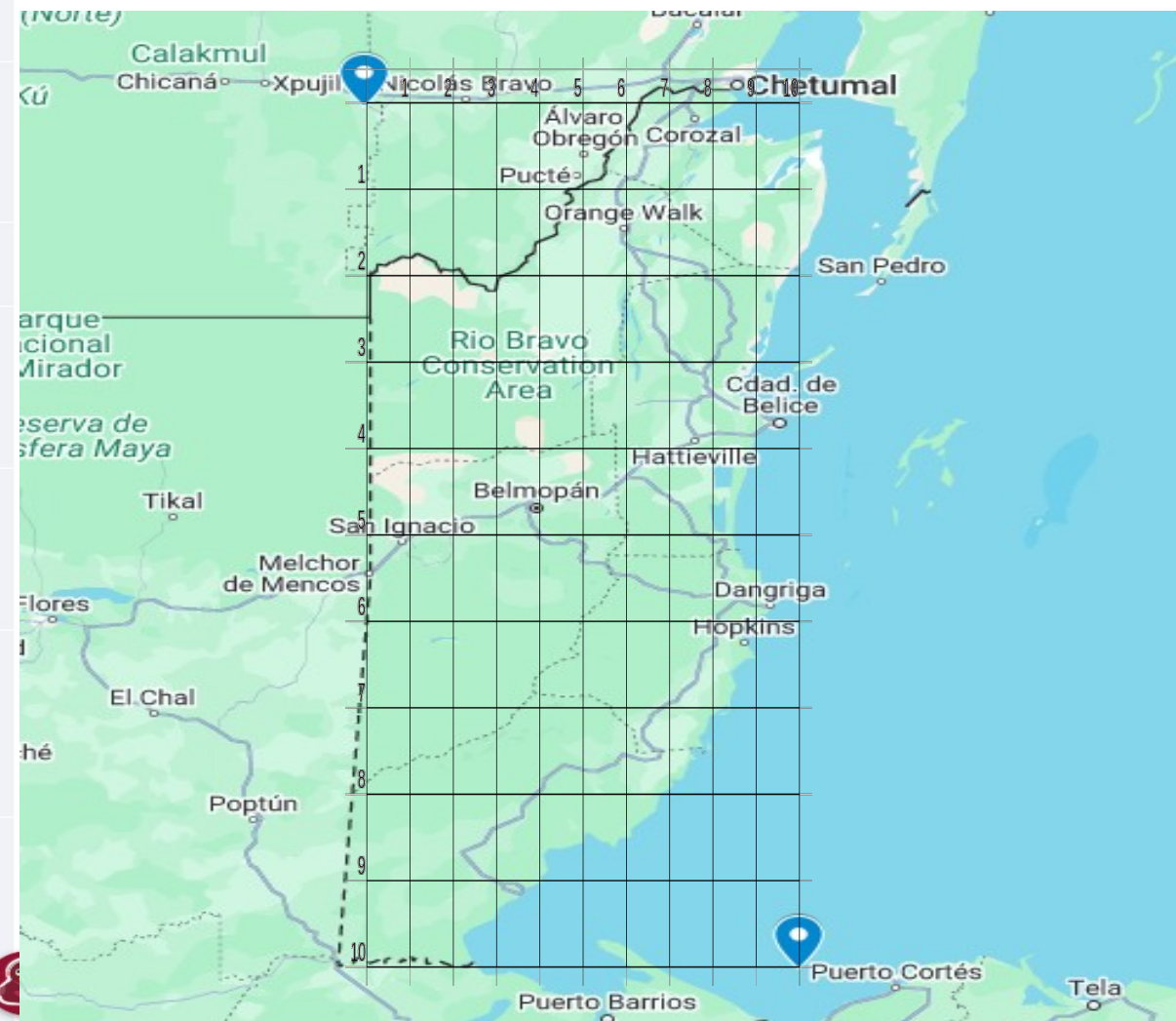
- <https://cds.climate.copernicus.eu/datasets/reanalysis-era5-single-levels?tab=overview>



# Belize

LAT , LON  
 18.4364, -89.1726  
 15.8805, -88.1618

<b>Product type</b>	Reanalysis
<b>Variable</b>	2m temperature, 100m u-component of wind, 100m v-component of wind, Surface solar radiation downwards
<b>Year</b>	2023, 2024
<b>Month</b>	January, February, March, April, May, June, July, August, September, October, November, December
<b>Day</b>	01, 02, 03, 04, 05, 06, 07, 08, 09, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31
<b>Time</b>	00:00, 01:00, 02:00, 03:00, 04:00, 05:00, 06:00, 07:00, 08:00, 09:00, 10:00, 11:00, 12:00, 13:00, 14:00, 15:00, 16:00, 17:00, 18:00, 19:00, 20:00, 21:00, 22:00, 23:00
<b>Geographical area</b>	North: 18.43640156987655°, West: -89.1725907716471°, South: 15.880548445295195°, East: -88.16184862757545°
<b>Data format</b>	GRIB



<i>Name</i>	<i>Units</i>	<i>Description</i>
2m temperature	K	This parameter is the temperature of air at 2m above the surface of land, sea or inland waters. 2m temperature is calculated by interpolating between the lowest model level and the Earth's surface, taking account of the atmospheric conditions. This parameter has units of kelvin (K). Temperature measured in kelvin can be converted to degrees Celsius (°C) by subtracting 273.15.

<i>Name</i>	<i>Units</i>	<i>Description</i>
100m u-component of wind	m s <sup>-1</sup>	This parameter is the eastward component of the 100 m wind. It is the horizontal speed of air moving towards the east, at a height of 100 metres above the surface of the Earth, in metres per second. Care should be taken when comparing model parameters with observations, because observations are often local to a particular point in space and time, rather than representing averages over a model grid box. This parameter can be combined with the northward component to give the speed and direction of the horizontal 100 m wind.
100m v-component of wind	m s <sup>-1</sup>	This parameter is the northward component of the 100 m wind. It is the horizontal speed of air moving towards the north, at a height of 100 metres above the surface of the Earth, in metres per second. Care should be taken when comparing model parameters with observations, because observations are often local to a particular point in space and time, rather than representing averages over a model grid box. This parameter can be combined with the eastward component to give the speed and direction of the horizontal 100 m wind.

Name	Units	Description
Surface solar radiation downwards	J m <sup>-2</sup>	<p>This parameter is the amount of solar radiation (also known as shortwave radiation) that reaches a horizontal plane at the surface of the Earth. This parameter comprises both direct and diffuse solar radiation. Radiation from the Sun (solar, or shortwave, radiation) is partly reflected back to space by clouds and particles in the atmosphere (aerosols) and some of it is absorbed. The rest is incident on the Earth's surface (represented by this parameter). To a reasonably good approximation, this parameter is the model equivalent of what would be measured by a pyranometer (an instrument used for measuring solar radiation) at the surface. However, care should be taken when comparing model parameters with observations, because observations are often local to a particular point in space and time, rather than representing averages over a model grid box. This parameter is accumulated over a particular time period which depends on the data extracted. For the reanalysis, the accumulation period is over the 1 hour ending at the validity date and time. For the ensemble members, ensemble mean and ensemble spread, the accumulation period is over the 3 hours ending at the validity date and time. The units are joules per square metre (J m<sup>-2</sup>). To convert to watts per square metre (W m<sup>-2</sup>), the accumulated values should be divided by the accumulation period expressed in seconds. The ECMWF convention for vertical fluxes is positive downwards.</p>

Gracias por vuestra atención!!



... continuemos construyendo el camino!!