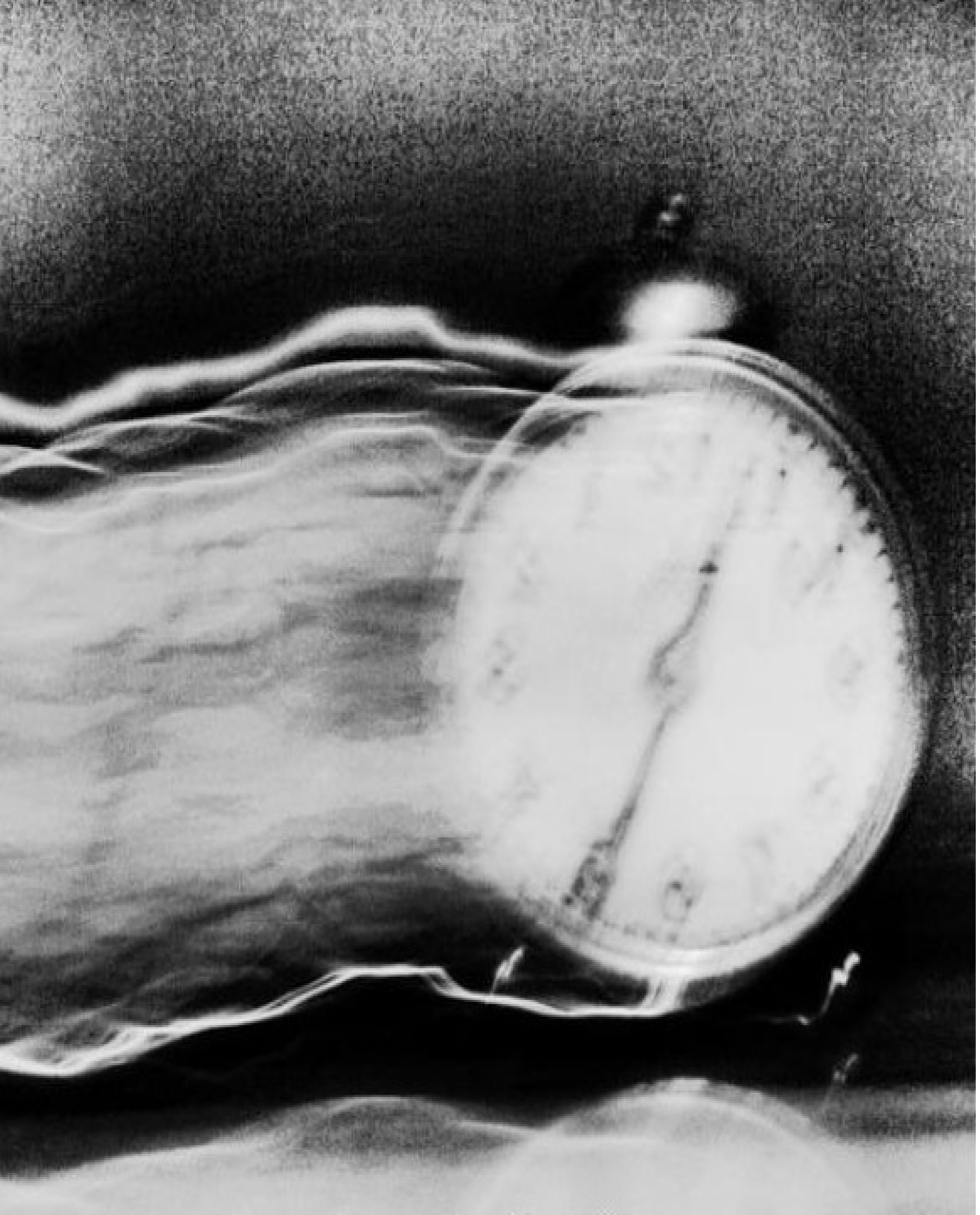


# Despacho óptimo con asimilación de pronósticos.

Ruben Chaer

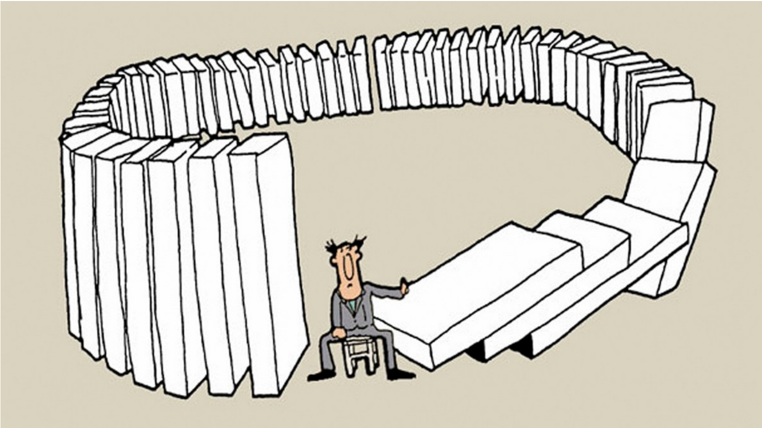
Curso SimSEE edición 2025 – Jueves 3 de abril.

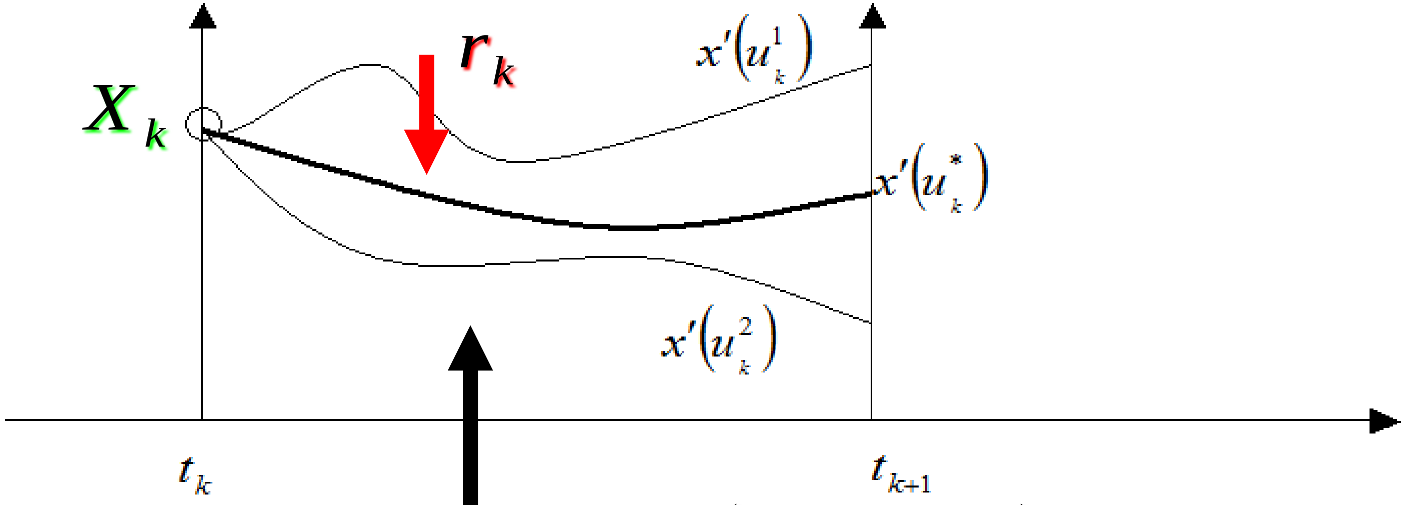
SimSEE

UNIVERSIDAD DE LA REPUBLICA URUGUAY

# PO_Optima = Minimizar el valor esperado del Costo Futuro

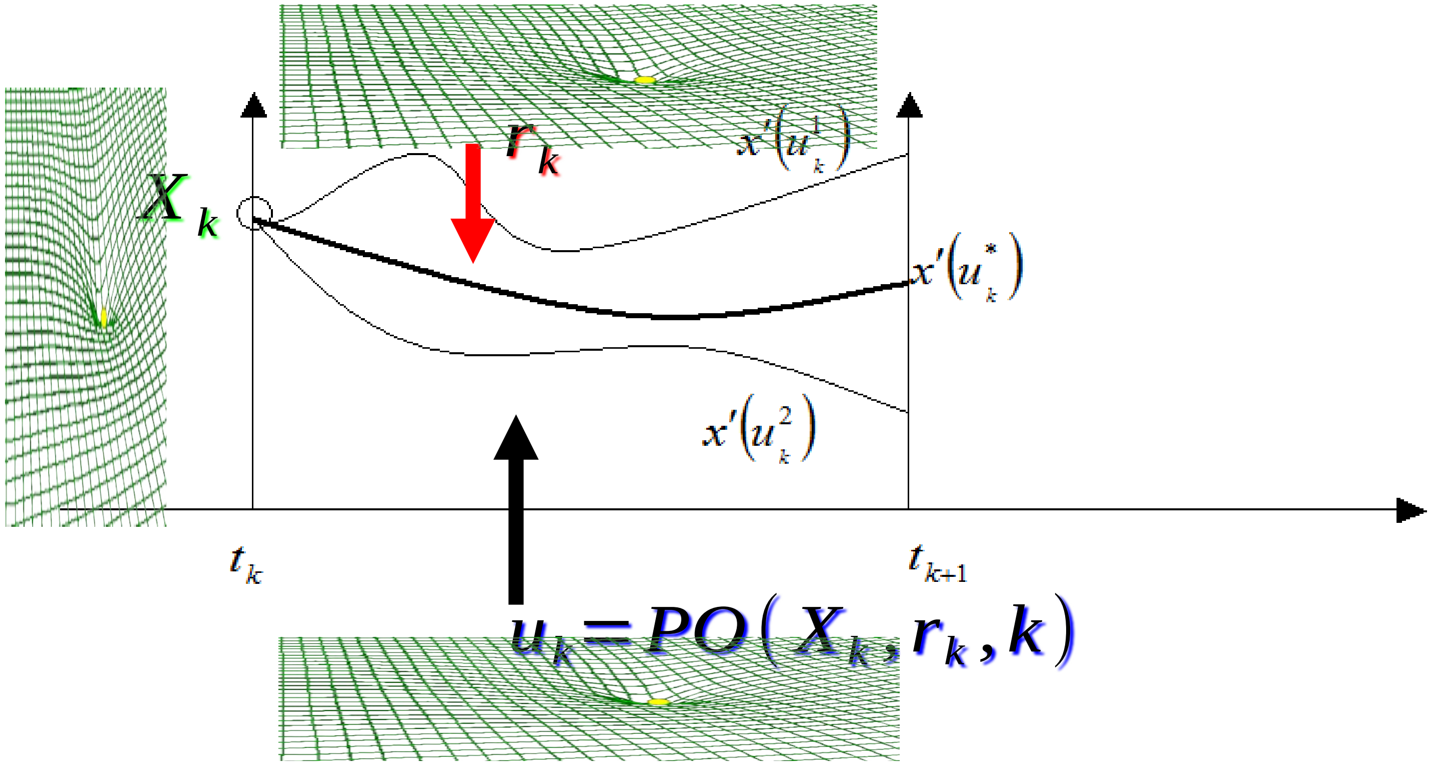
$$CF(x,k) = \left\langle \min_{u_k} \left\{ CE(x,u_k,r_k,k) + q \cdot CF(x',k+1) \right\} \right\rangle_{r_k}$$






$$u_k = PO(X_k, r_k, k)$$

# Bellman's curse of dimensionality.




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

# 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)

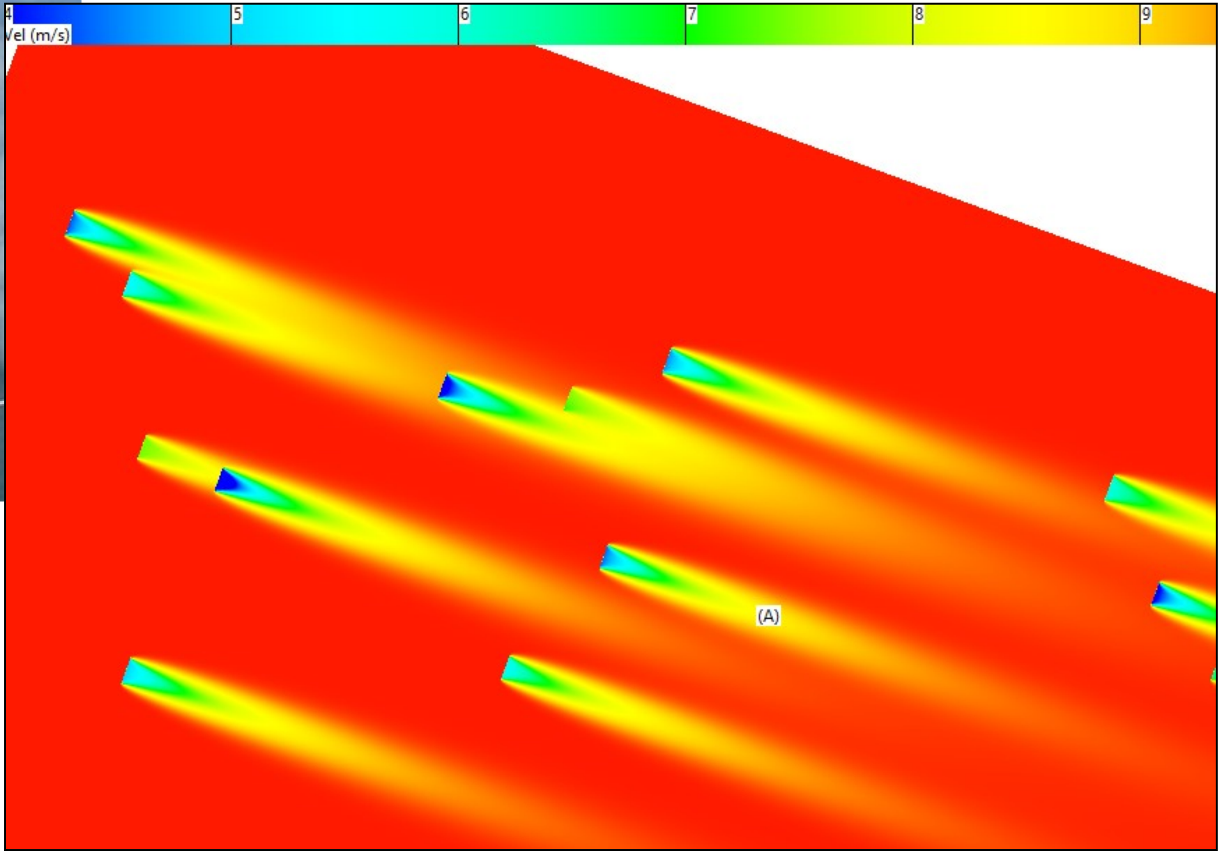
Equipment availability
(independent booleans)

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

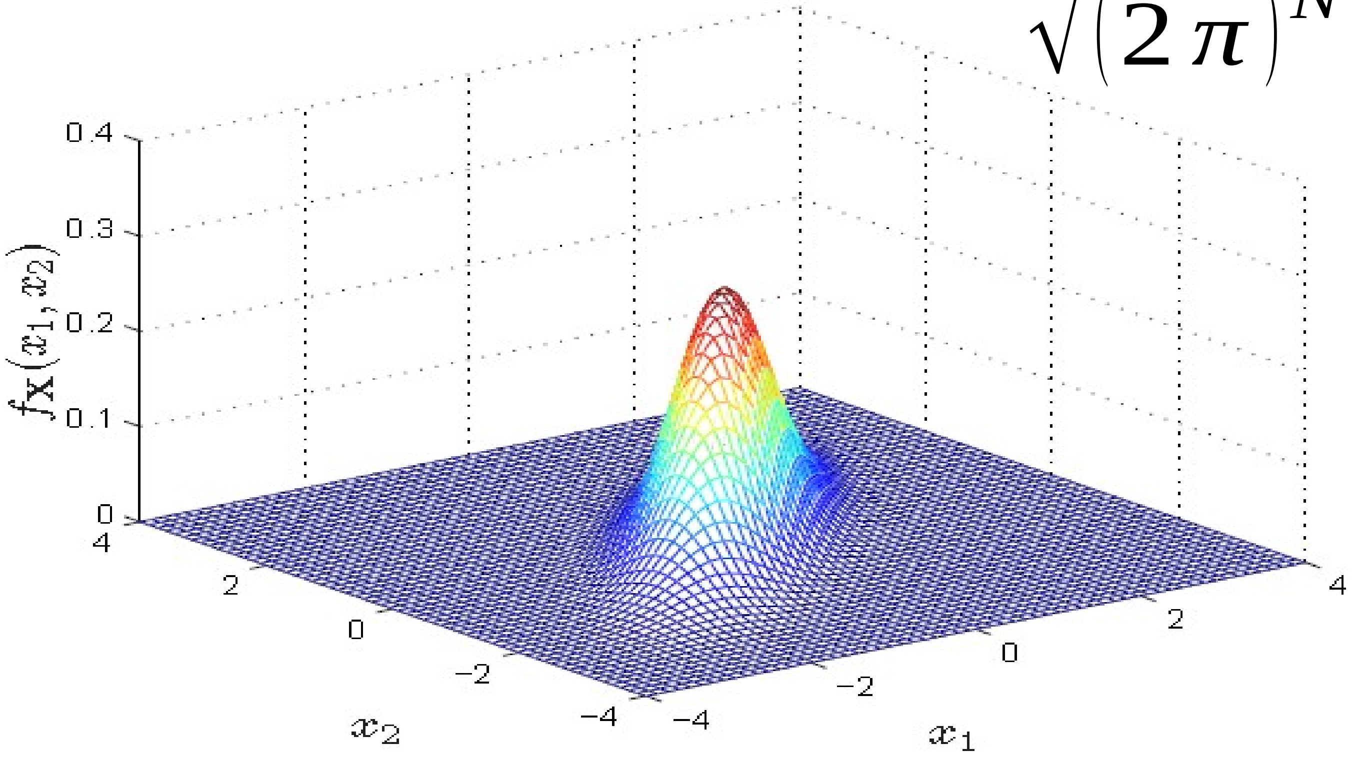
- Un modelo que capte los condicionamientos estadísticos de las series de datos entre si y con sus pasados.
- Un modelo que capte las probabilidades de ocurrencias de las diferentes amplitudes de las variables aleatorias.

# 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

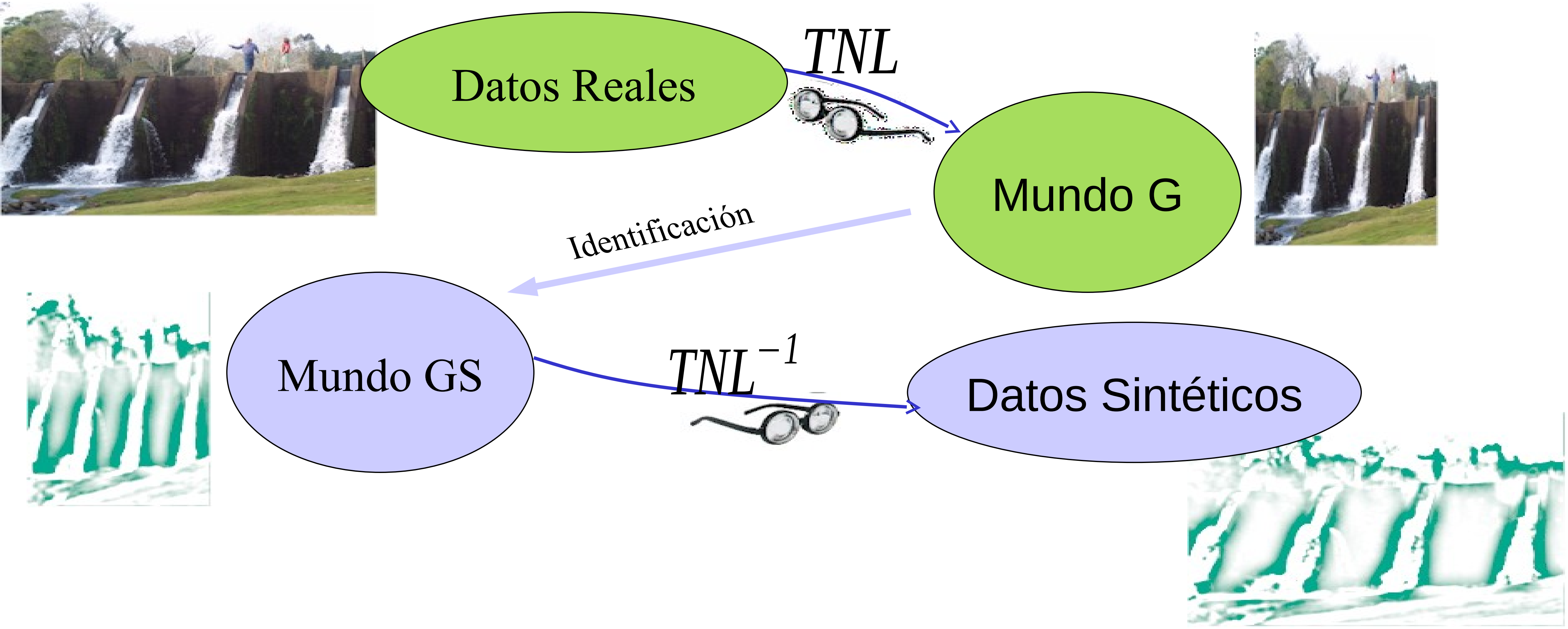
$$p_X(X) = \frac{1}{\sqrt{(2\pi)^N \cdot |\Sigma|}} \cdot e^{-\left(\frac{1}{2} X^T \Sigma^{-1} X\right)}$$




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

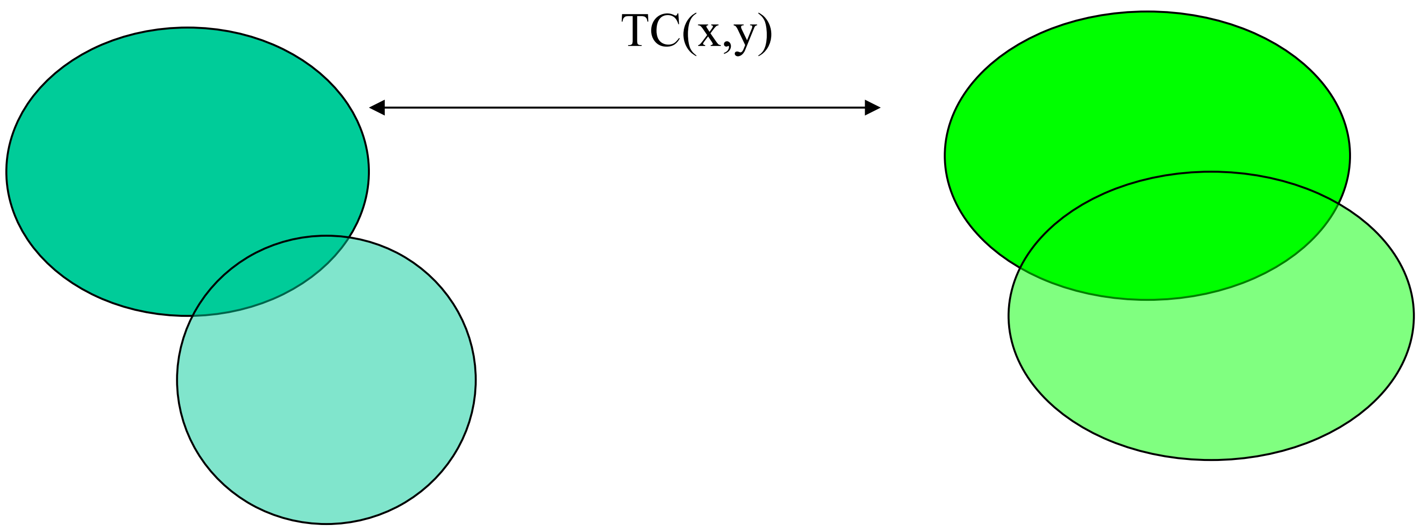
# Modelo CEGH

Correlaciones en Espacio Gaussiano con Histograma.

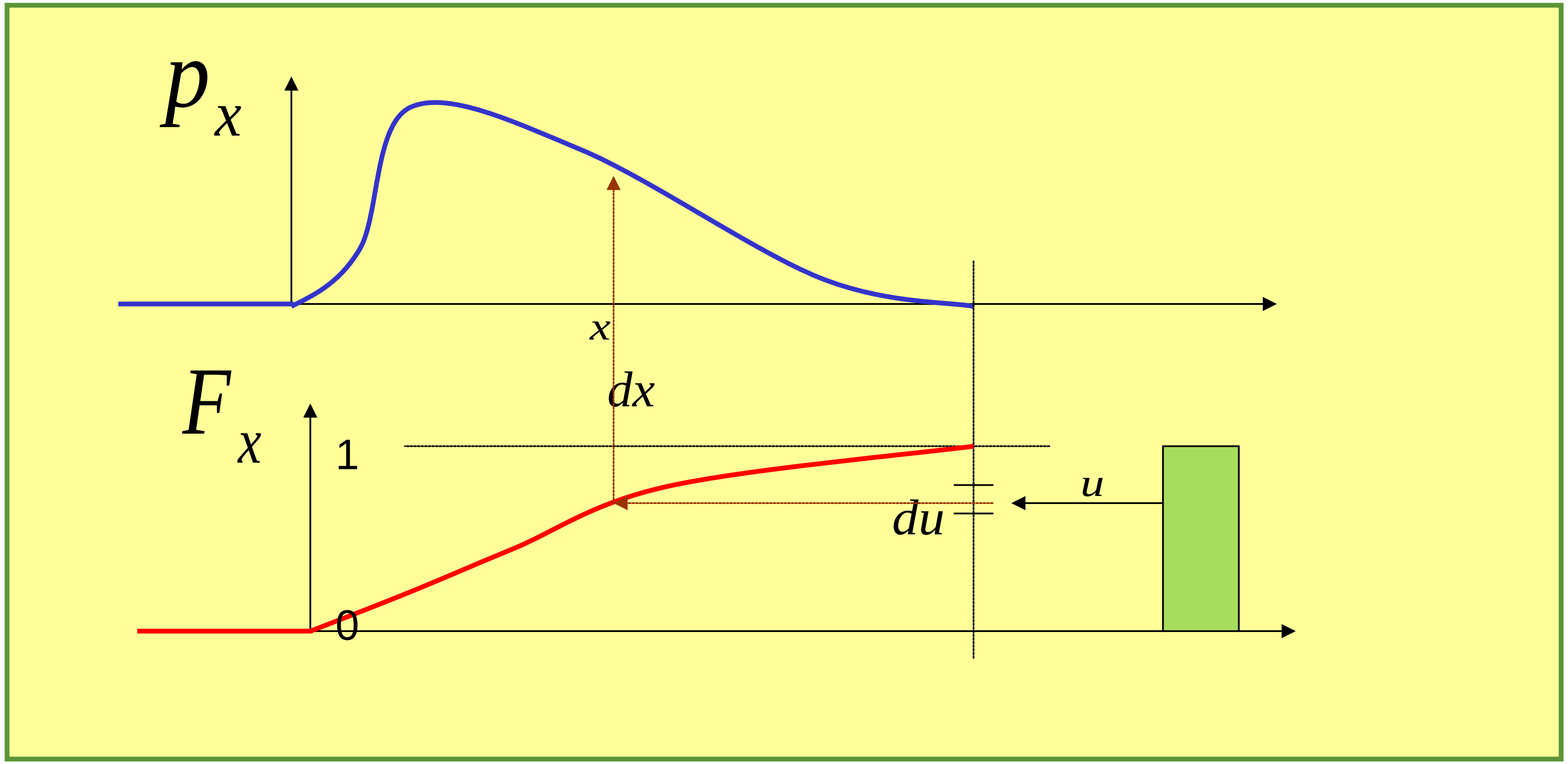


# Transformaciones Compactas.

- Biunívoca y que transforme todo compacto en un compacto.

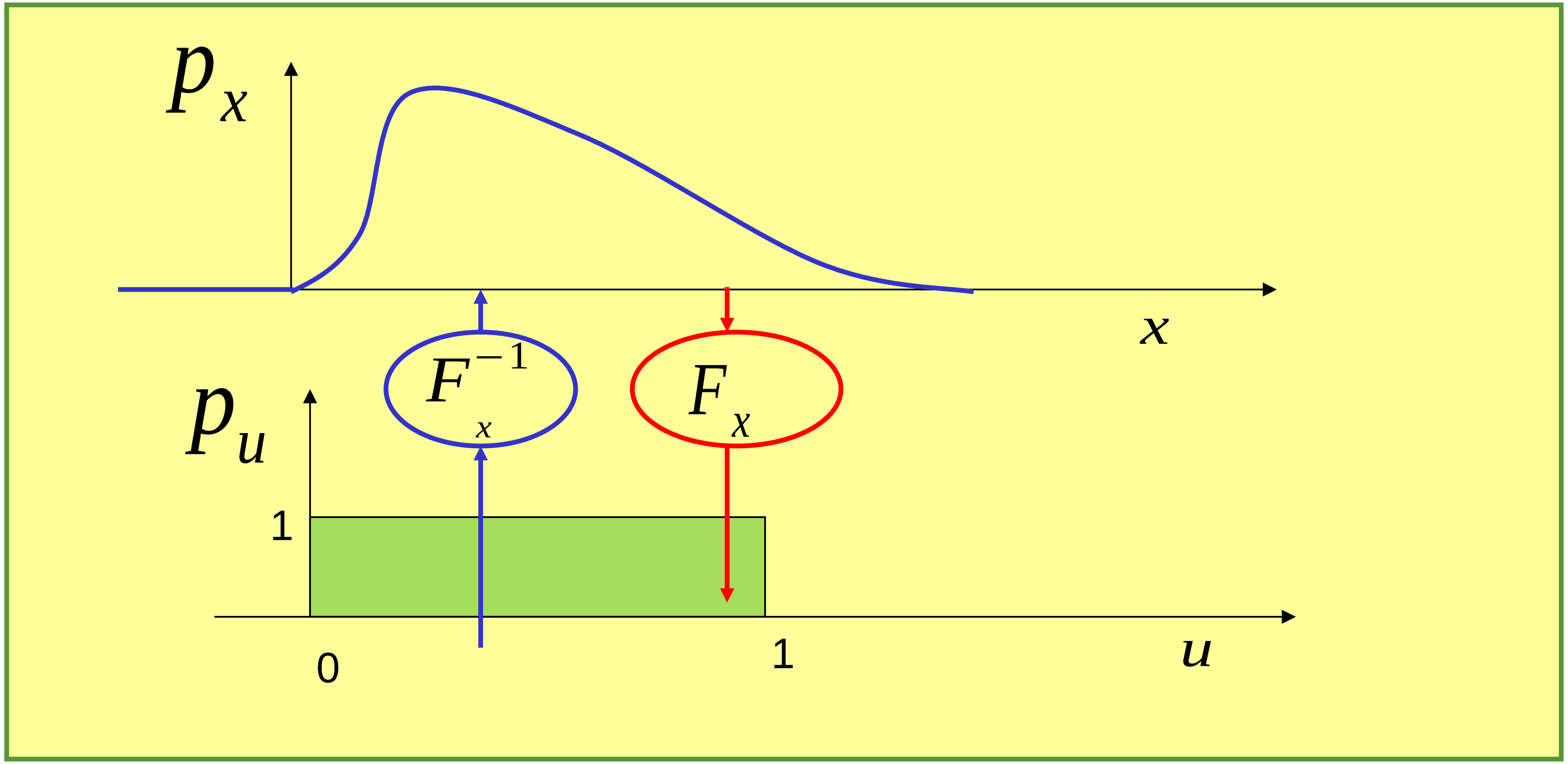


# Fuente aleatoria con histograma




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

# Fuente aleatoria con histograma



# Modelos lineales

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

$$Y_k = C X_k$$

- Potentes herramientas.
- No conservan los histogramas.

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

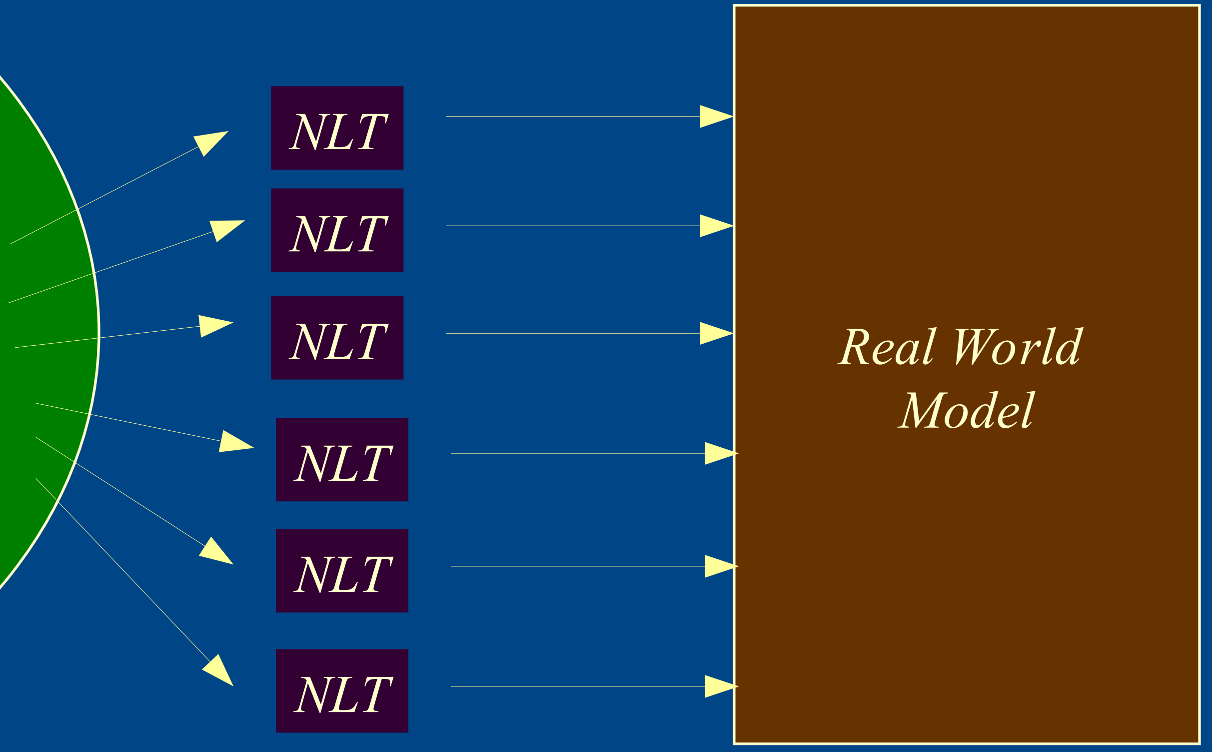
# CEGH modeling.

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

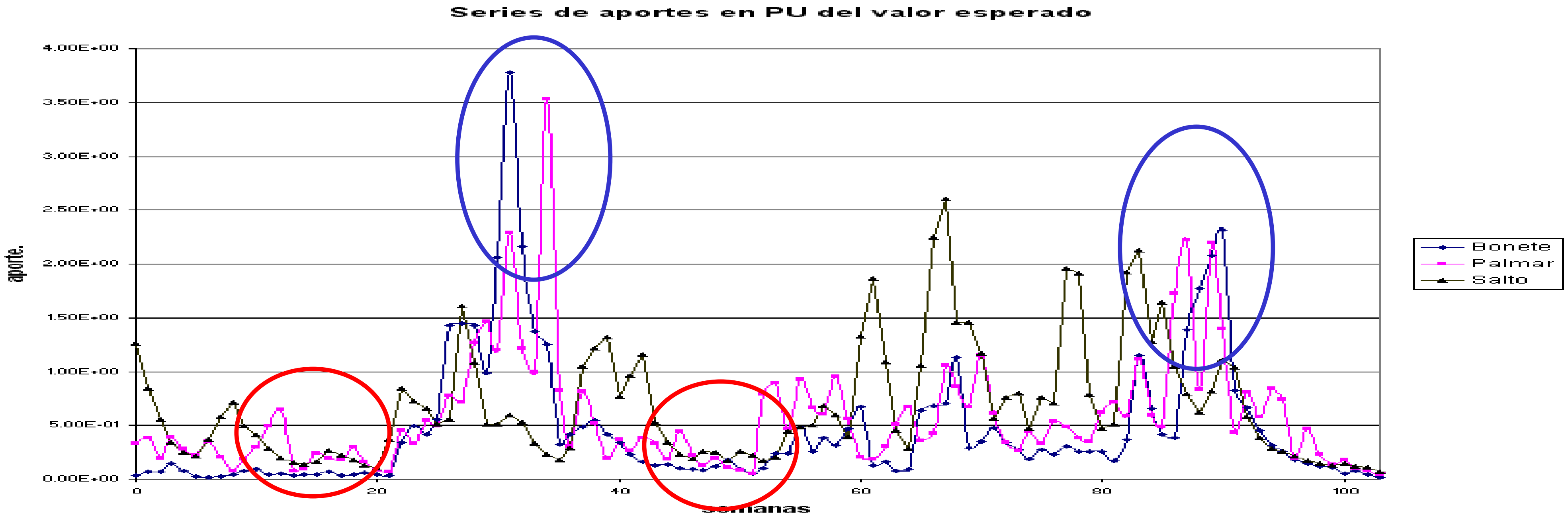
*Gaussian World:*
*Multi-variable linear system*
*fed with*
*Gaussian independent white noise*

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

Accept state space reductions.
Accept forecast information.

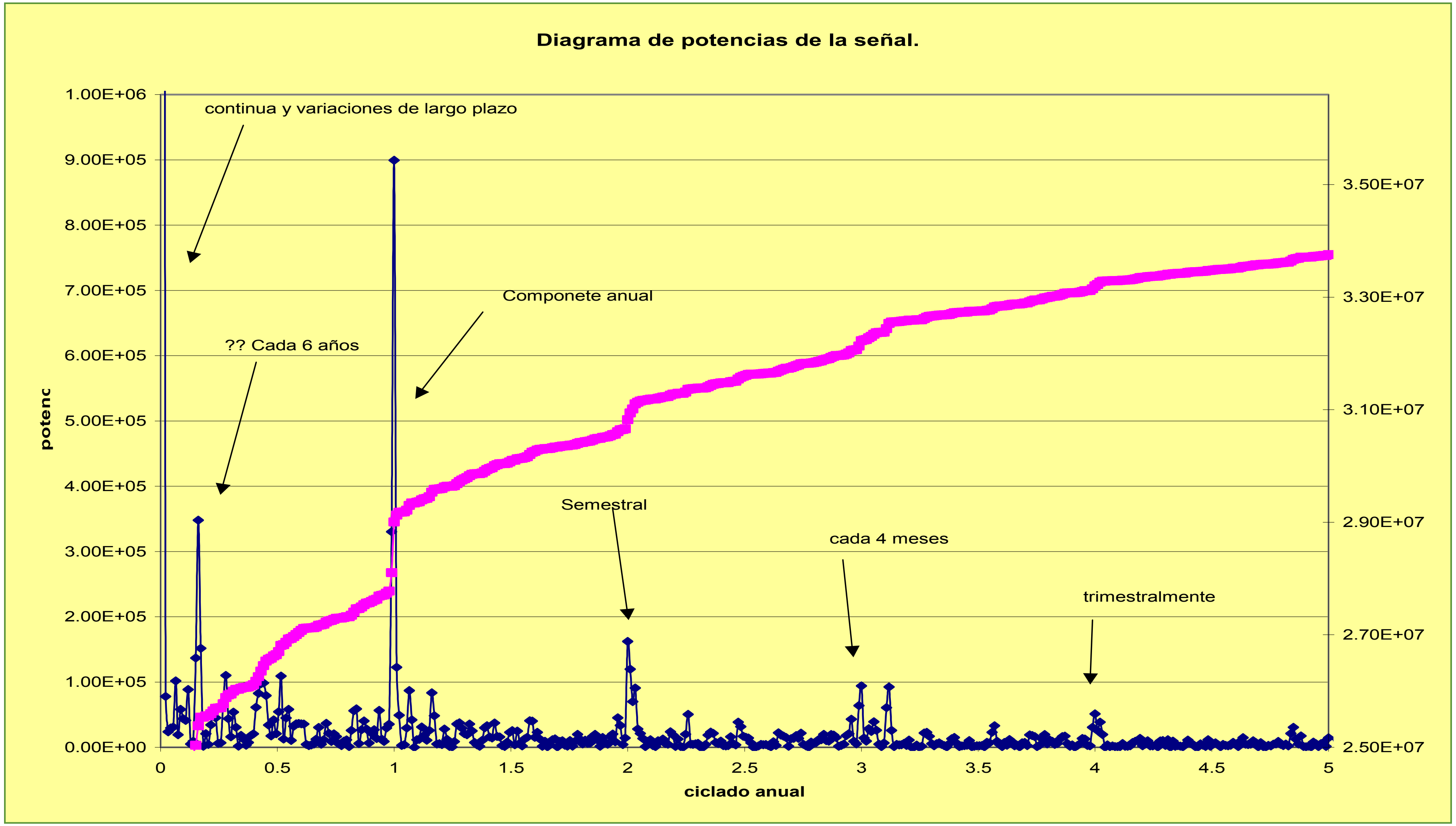


# Ejemplo de identificación del sistema hídrico de Uruguay.




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

# Espectro de Potencia SALTO GRANDE



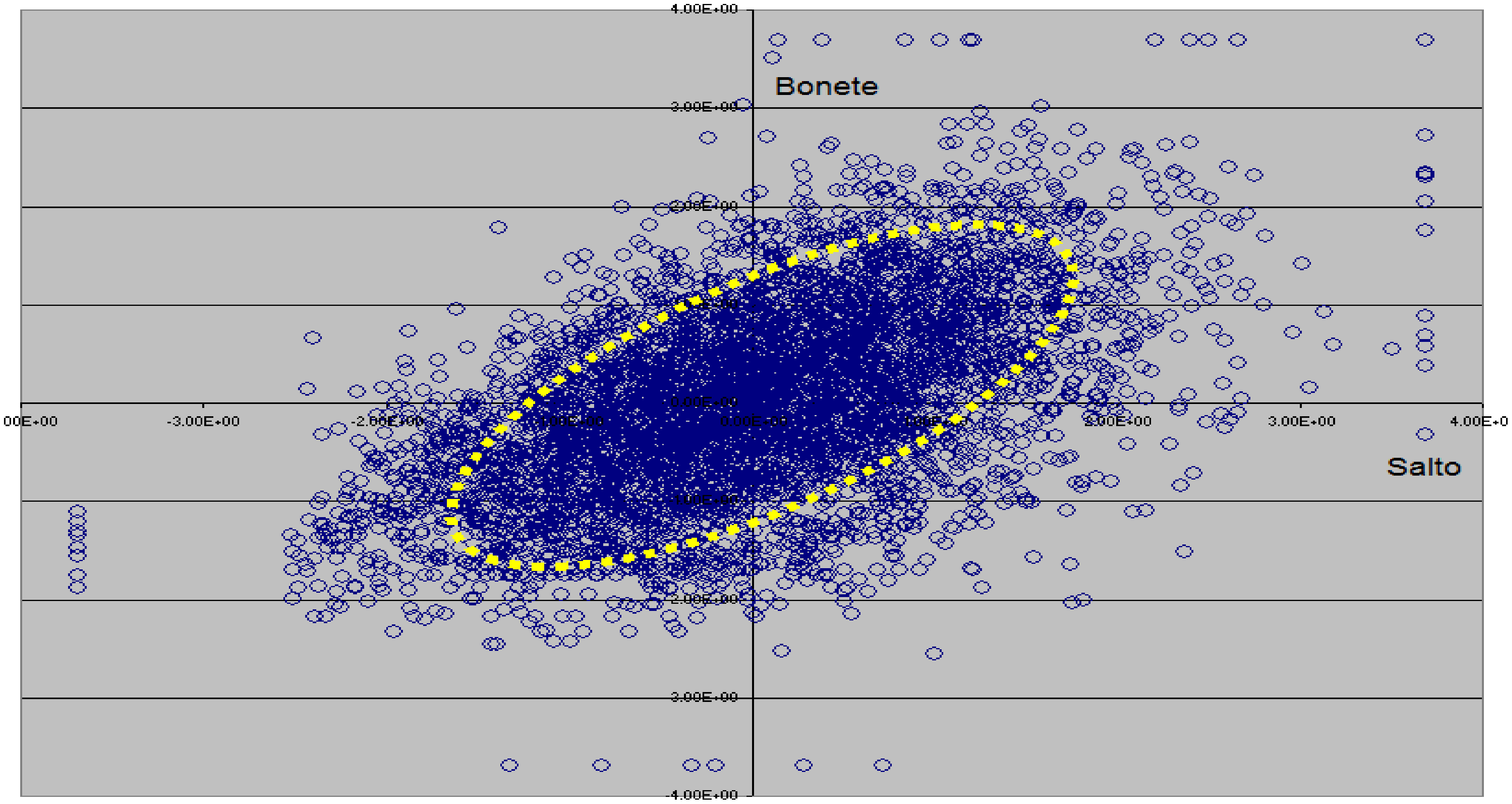
# Matríz de Covarianzas

| | B | P | S |
|---|---|---|---|
| B | 1.000 | 0.571 | 0.536 |
| P | 0.571 | 1.000 | 0.296 |
| S | 0.536 | 0.296 | 1.000 |

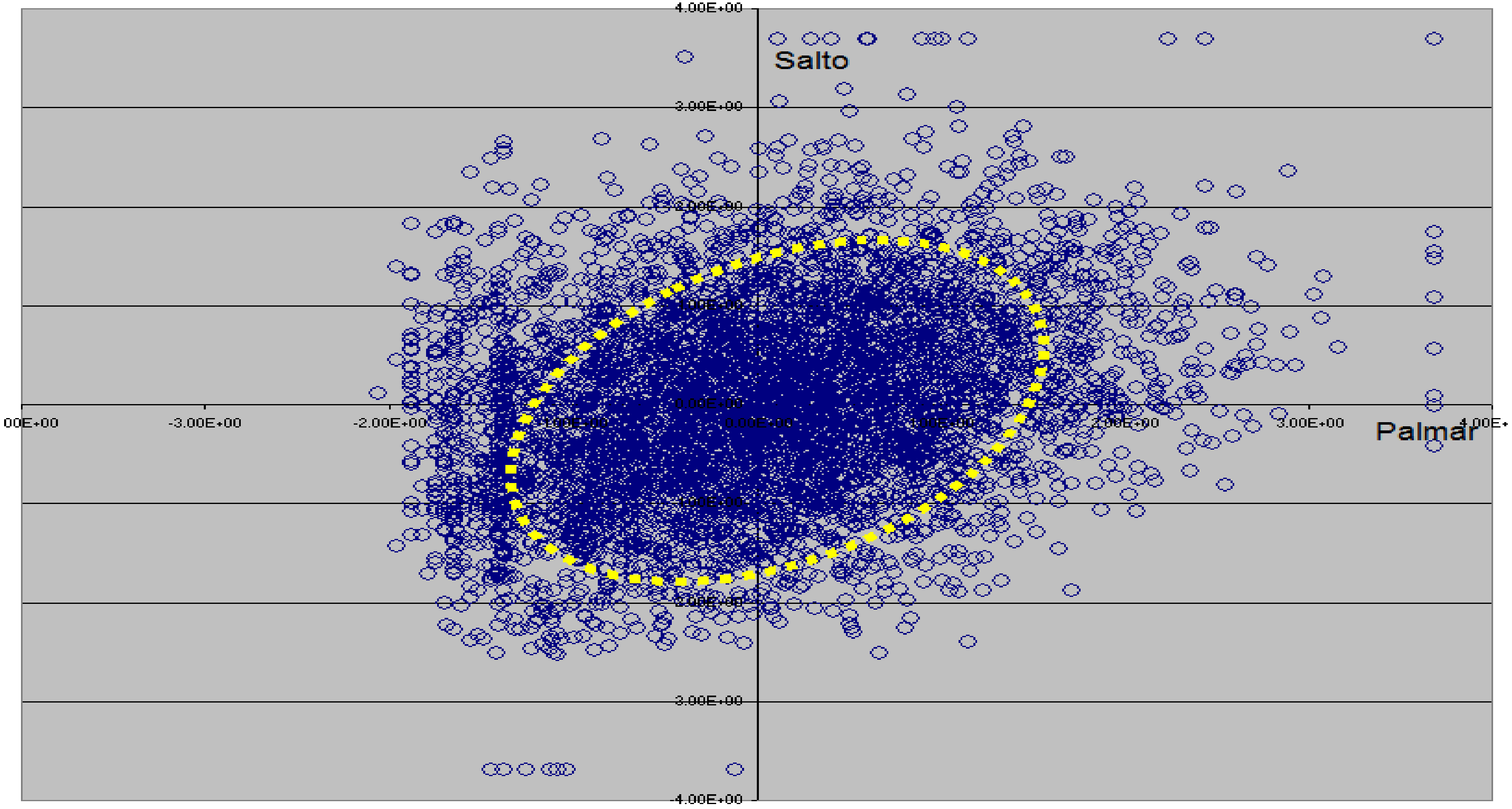
$$\Sigma = \langle X \cdot X^T \rangle$$

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

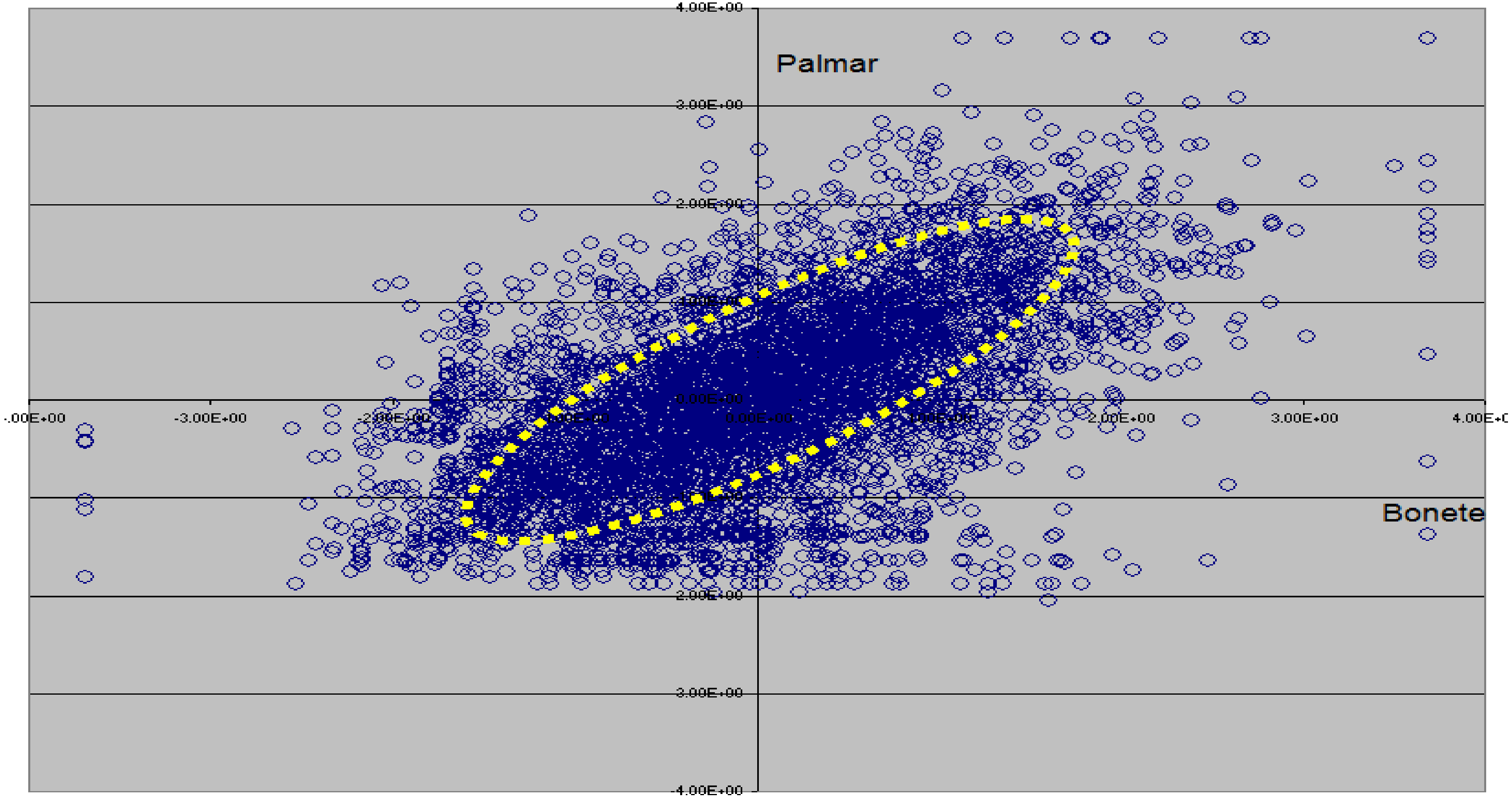
# Salto vs. Bonete - EG



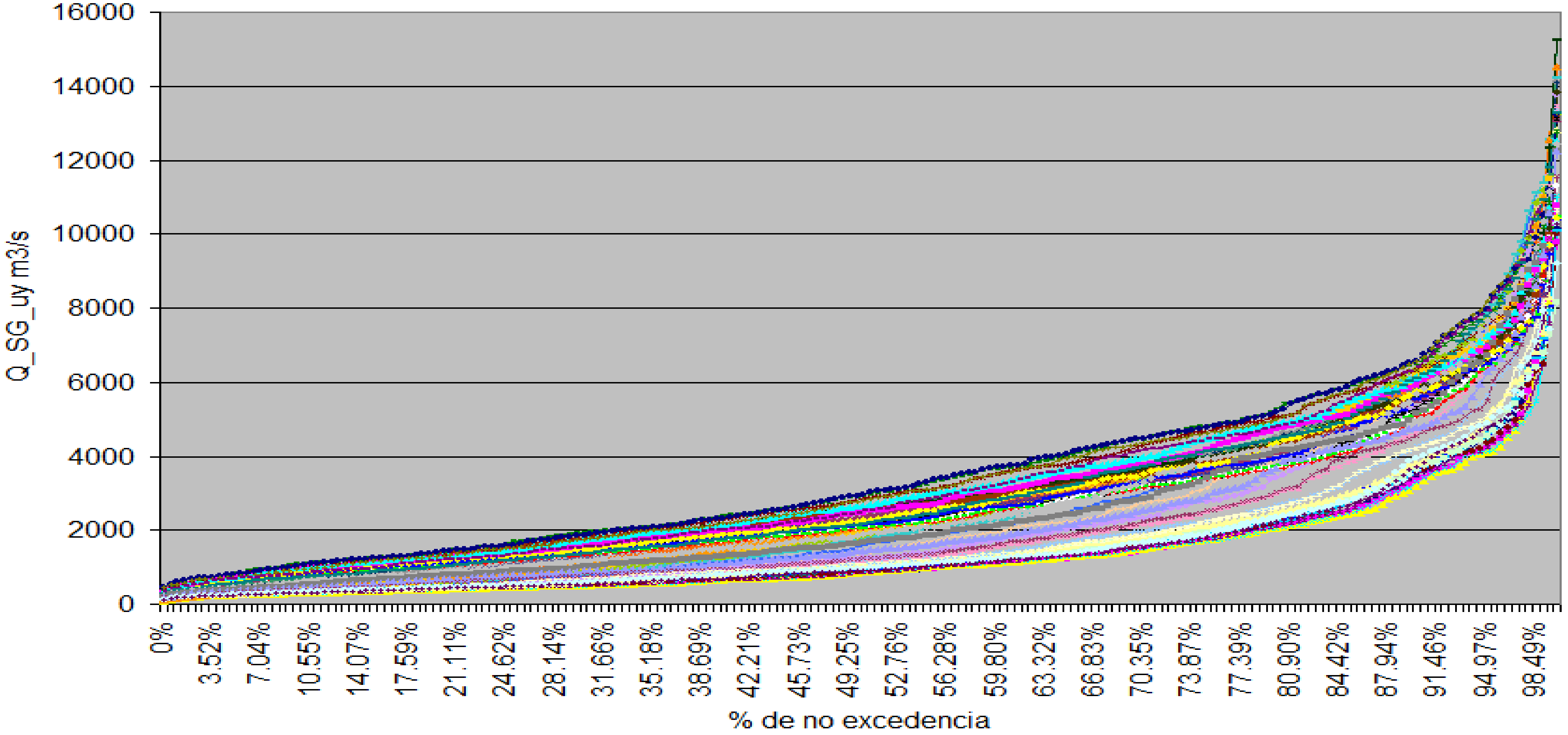
# Palmar vs. Salto - EG



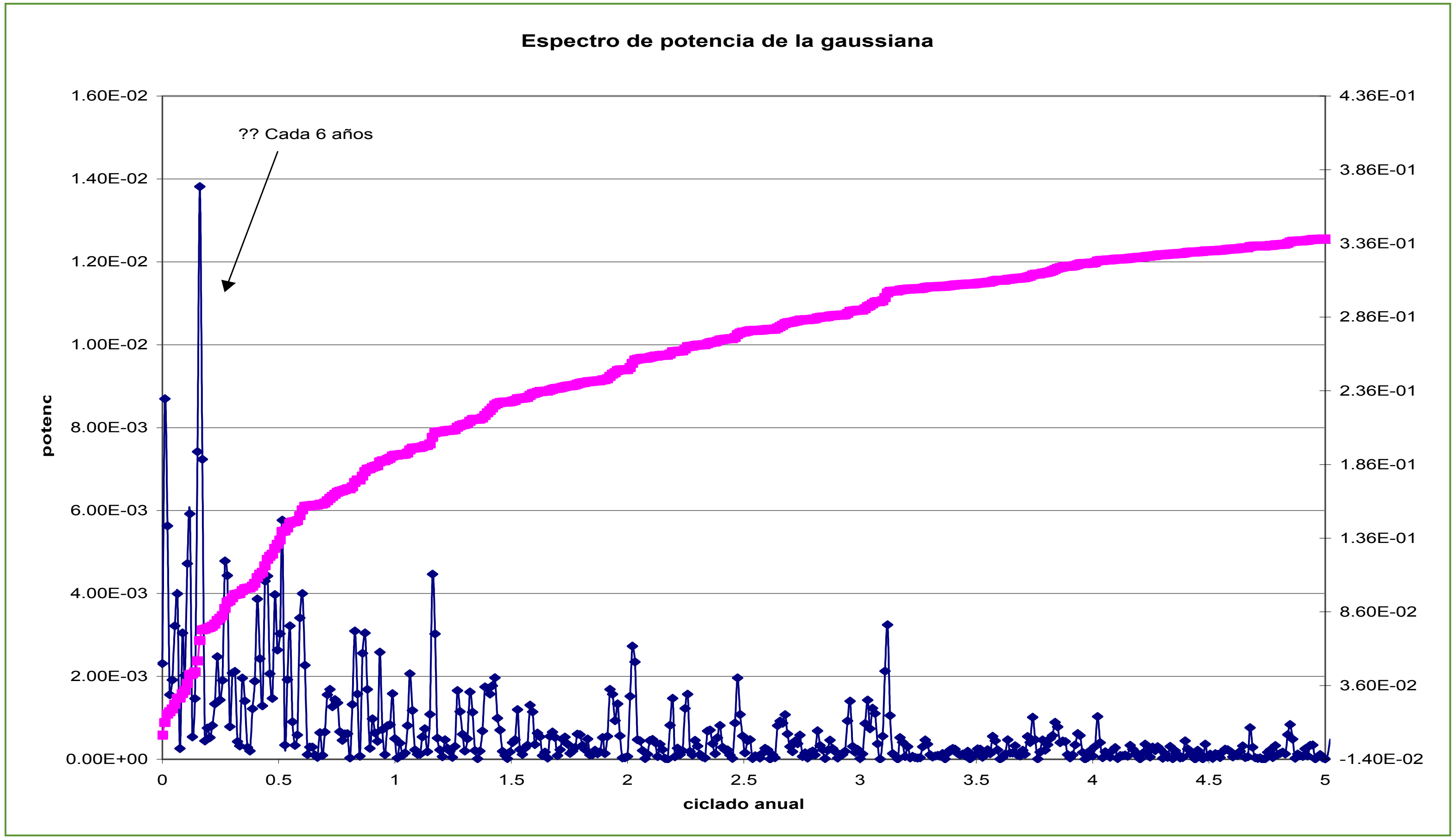
# Bonete vs. Palmar - EG



# 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] |

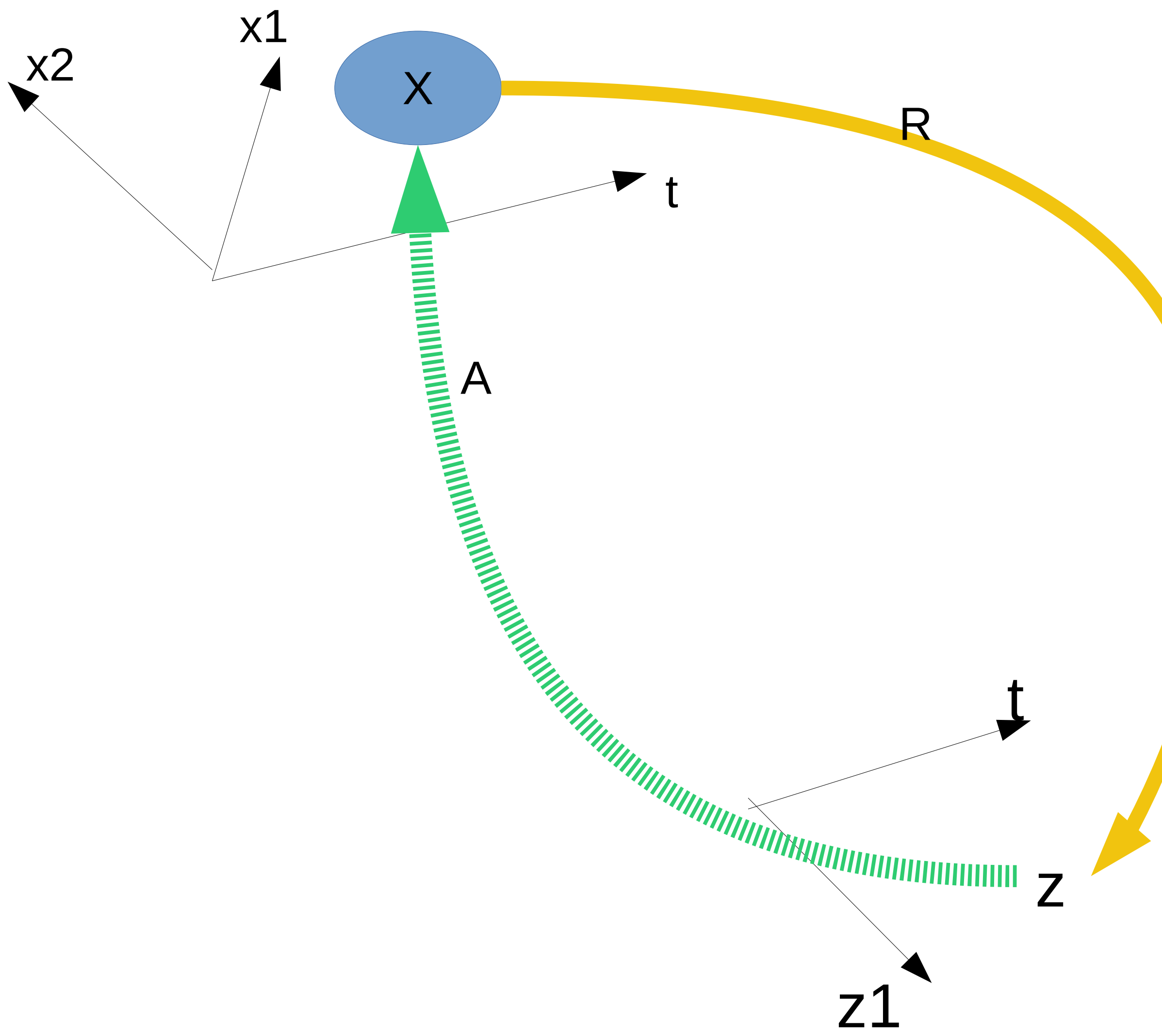
Estado = 3x1

# Maldición de Belman.

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

$$Dim(u) \times Dim(x) \times Dim(r) \times Dim(k)$$

# Reducción del Espacio de Estado en modelos CEGH



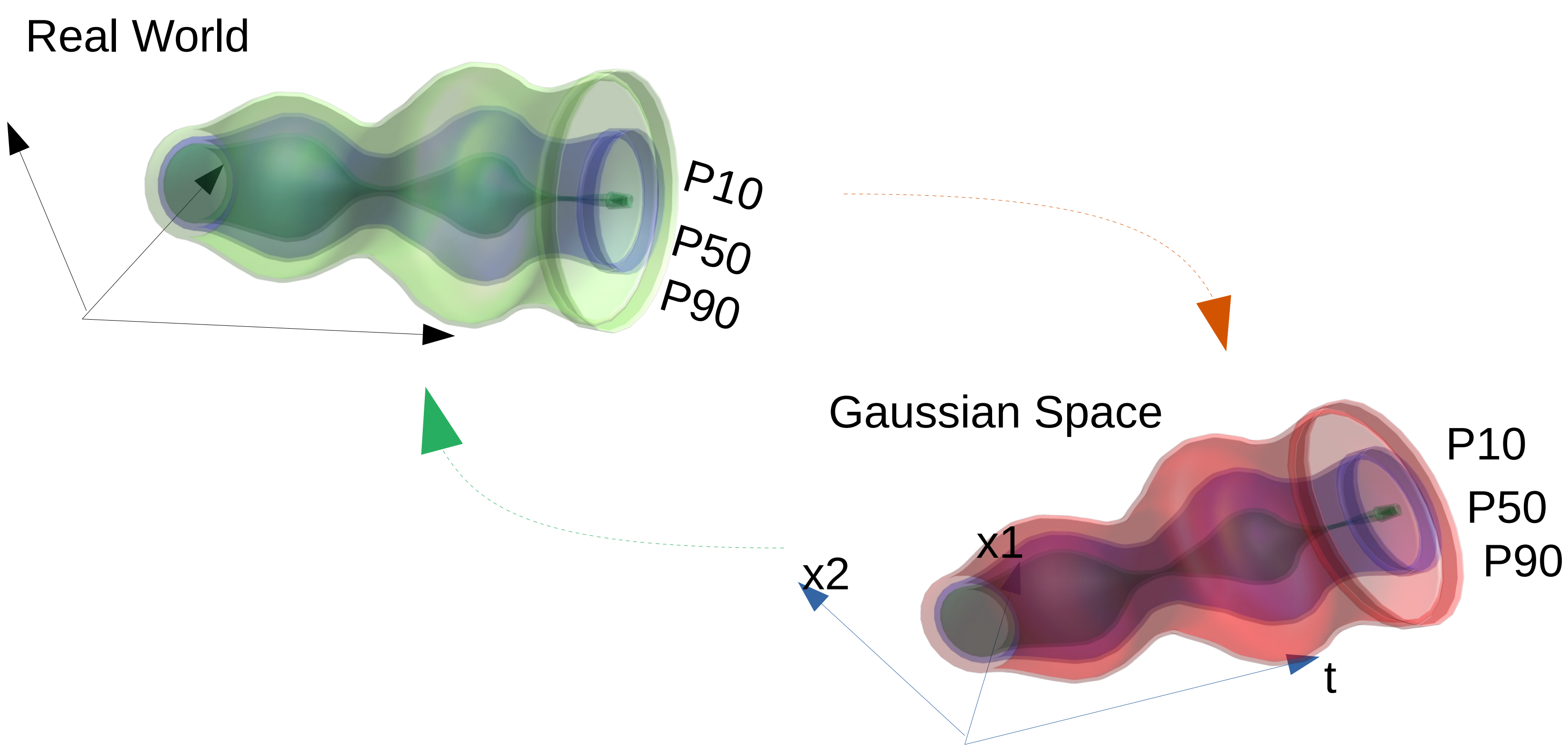

$$z = R(X)$$

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

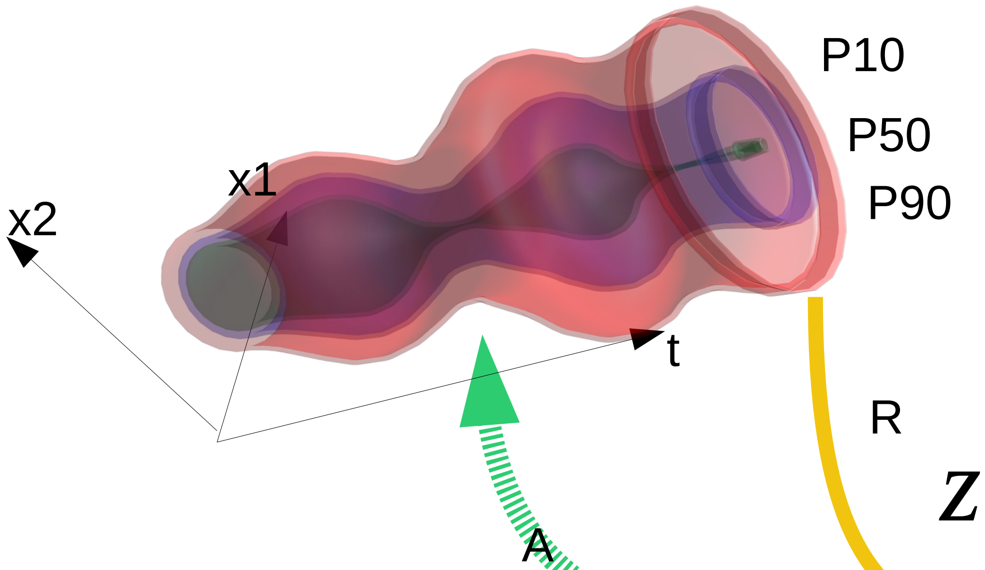
$$X = A(z, w)$$

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

# Treatment of forecasts in CEGH modeling.
# Gaussianization



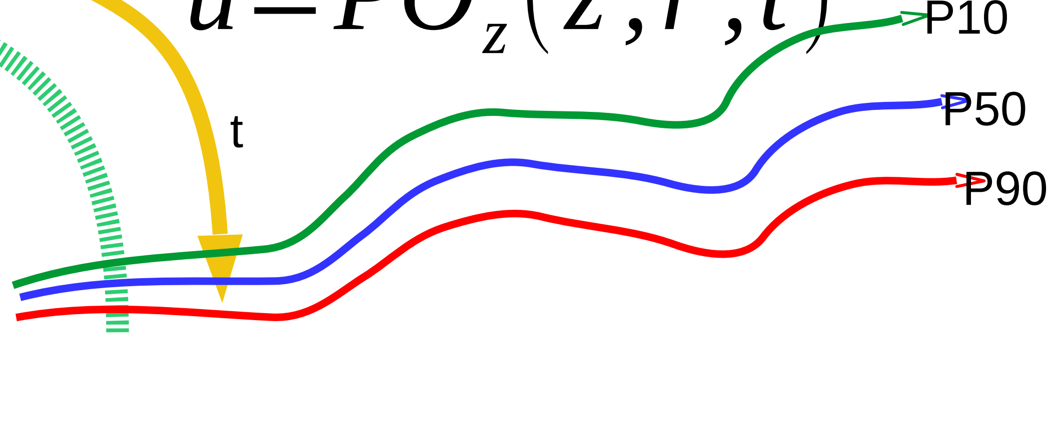
# Treatment of forecasts in Gaussian space with reduction in CEGH modeling.




$$z = M_R X$$

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

$$X = M_A(t) z + B_A(t) w$$




# 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:

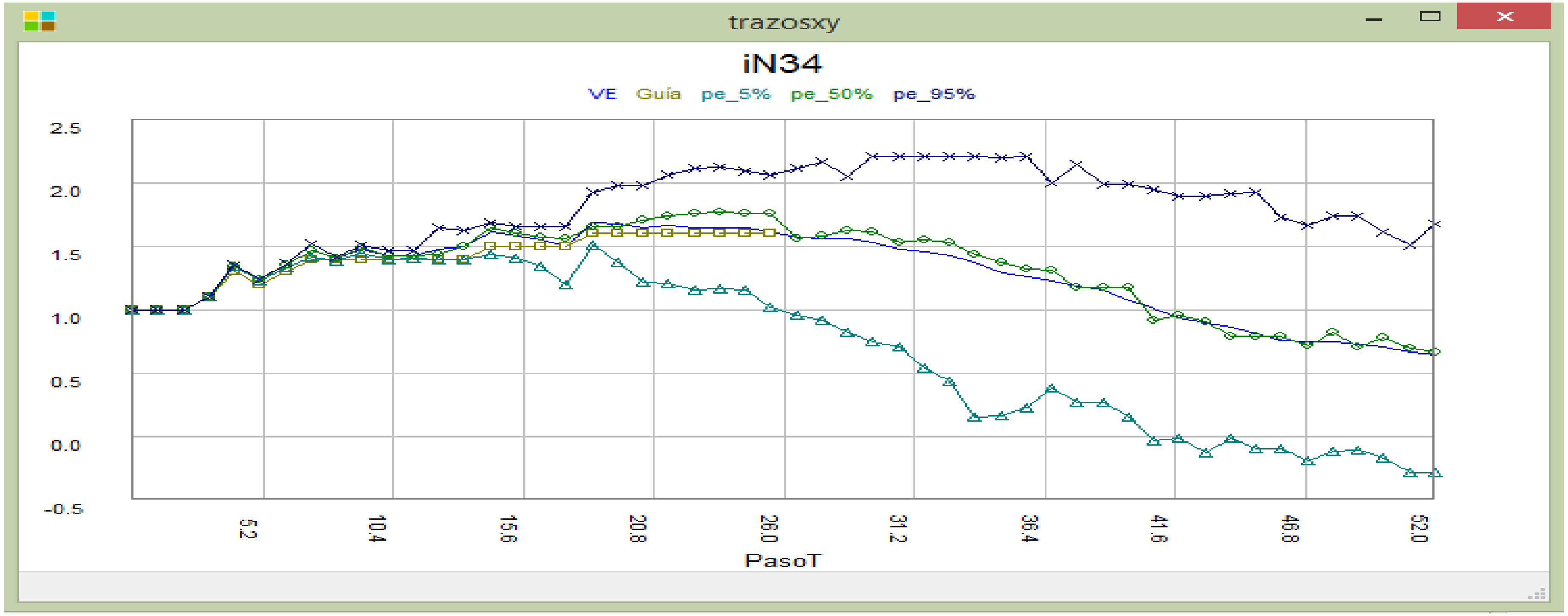
$$S_k = \begin{bmatrix} s_{1,k} \\ \dots \\ s_{n,k} \end{bmatrix}$$

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).

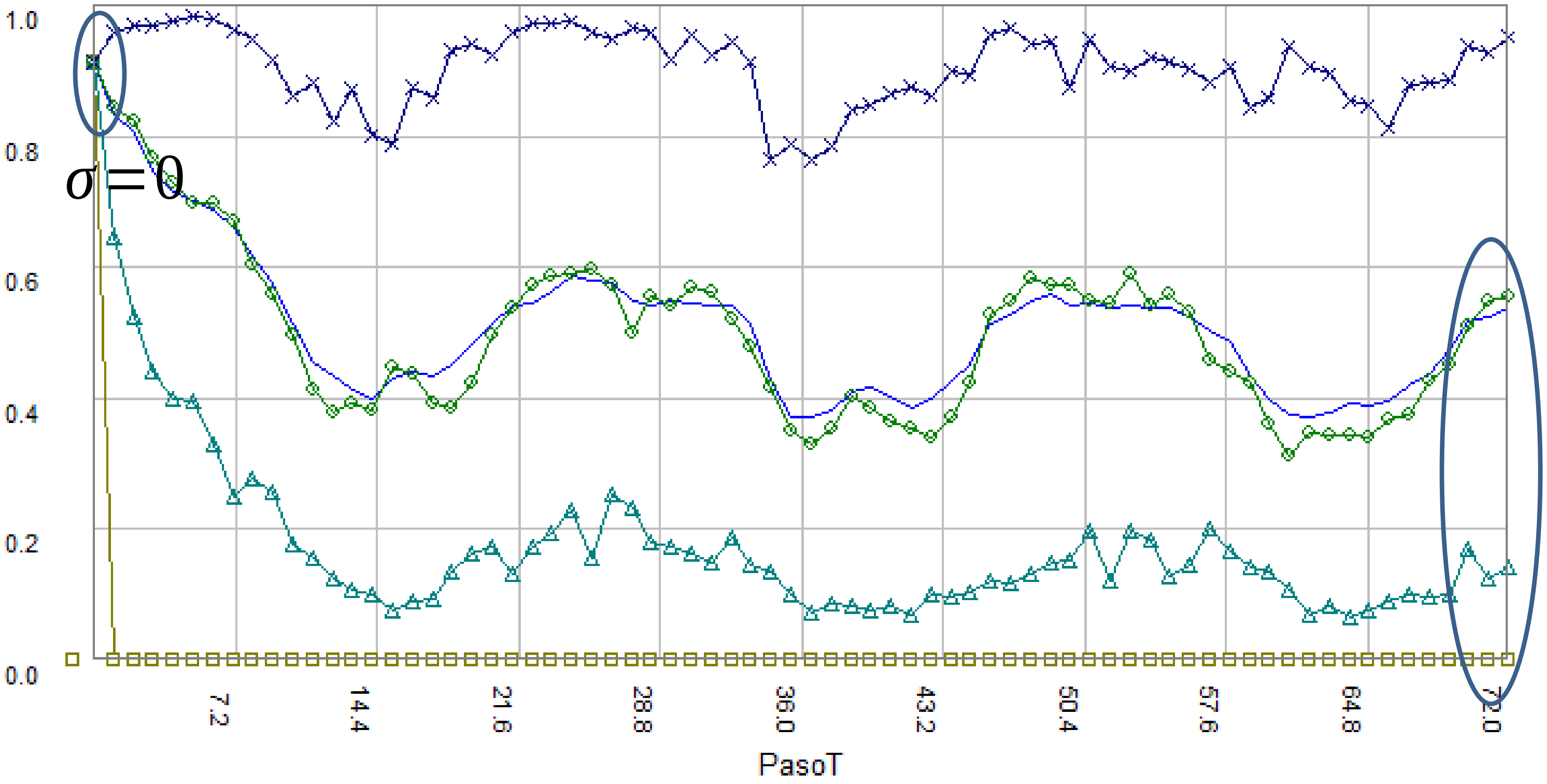
# Incorporación de iN34 a la Programación Estacional



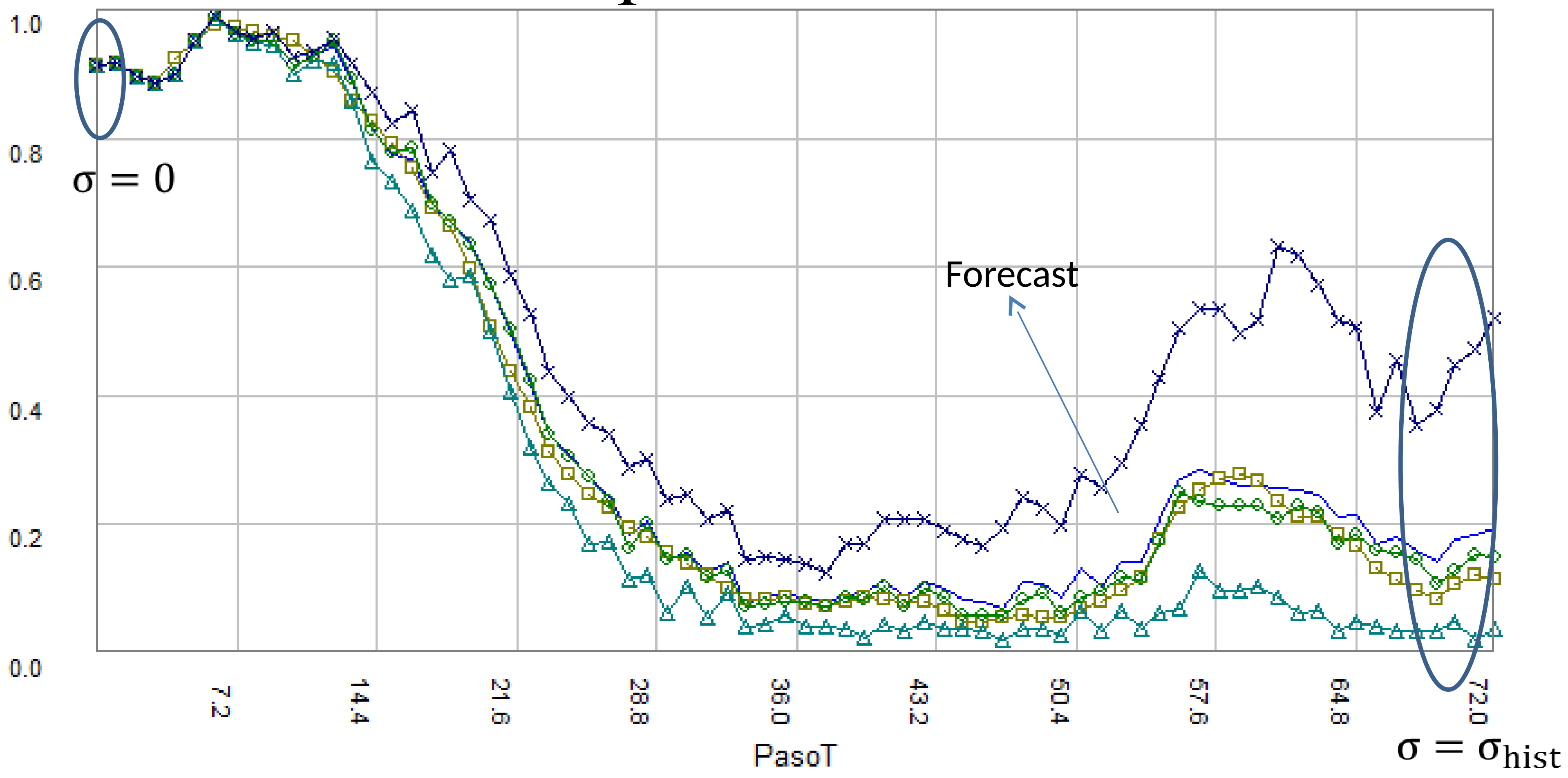
Reducción de CAD 5% apróx.

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

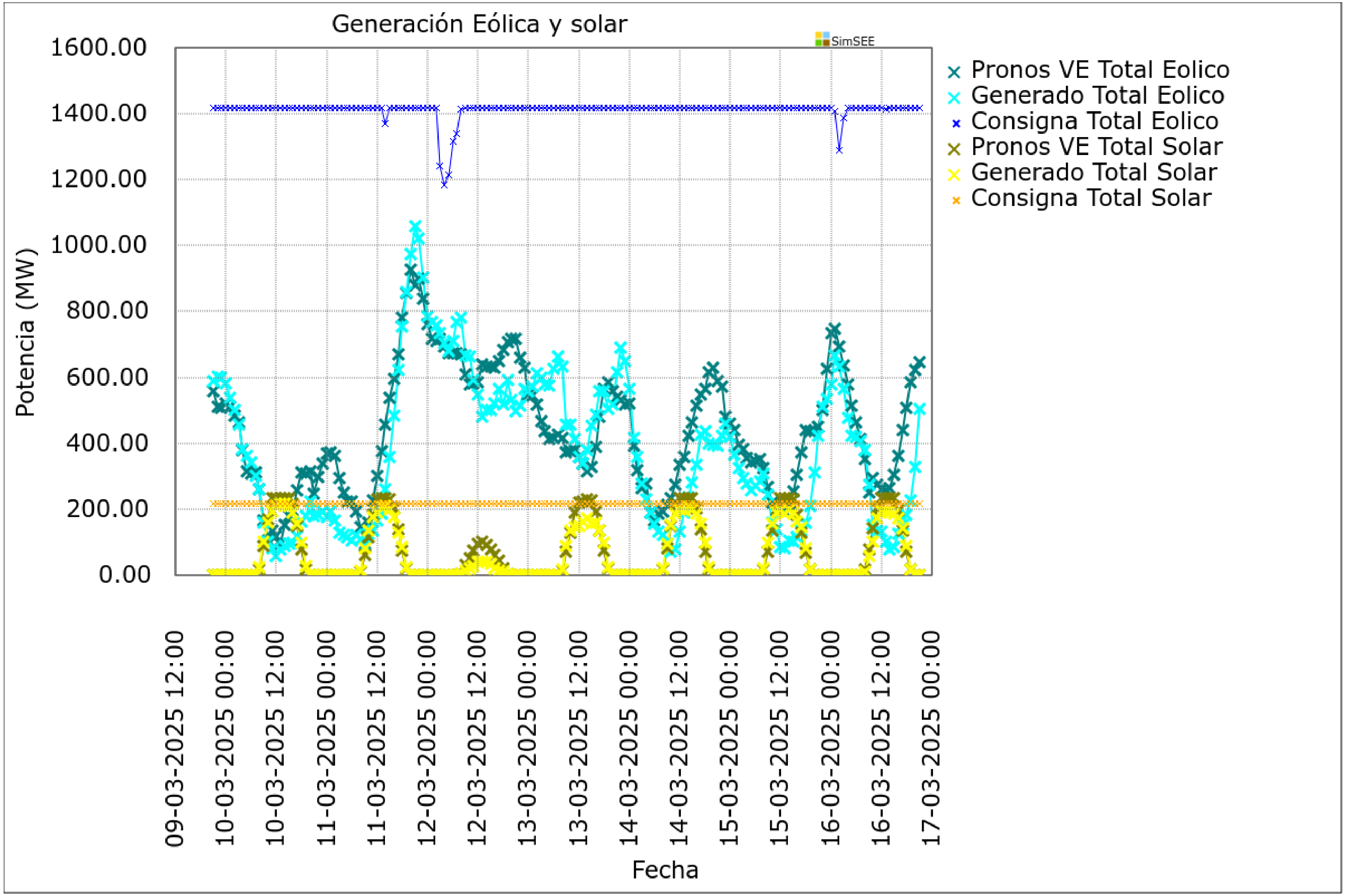
# Programming the enegy dispatch without windpower forecasts.



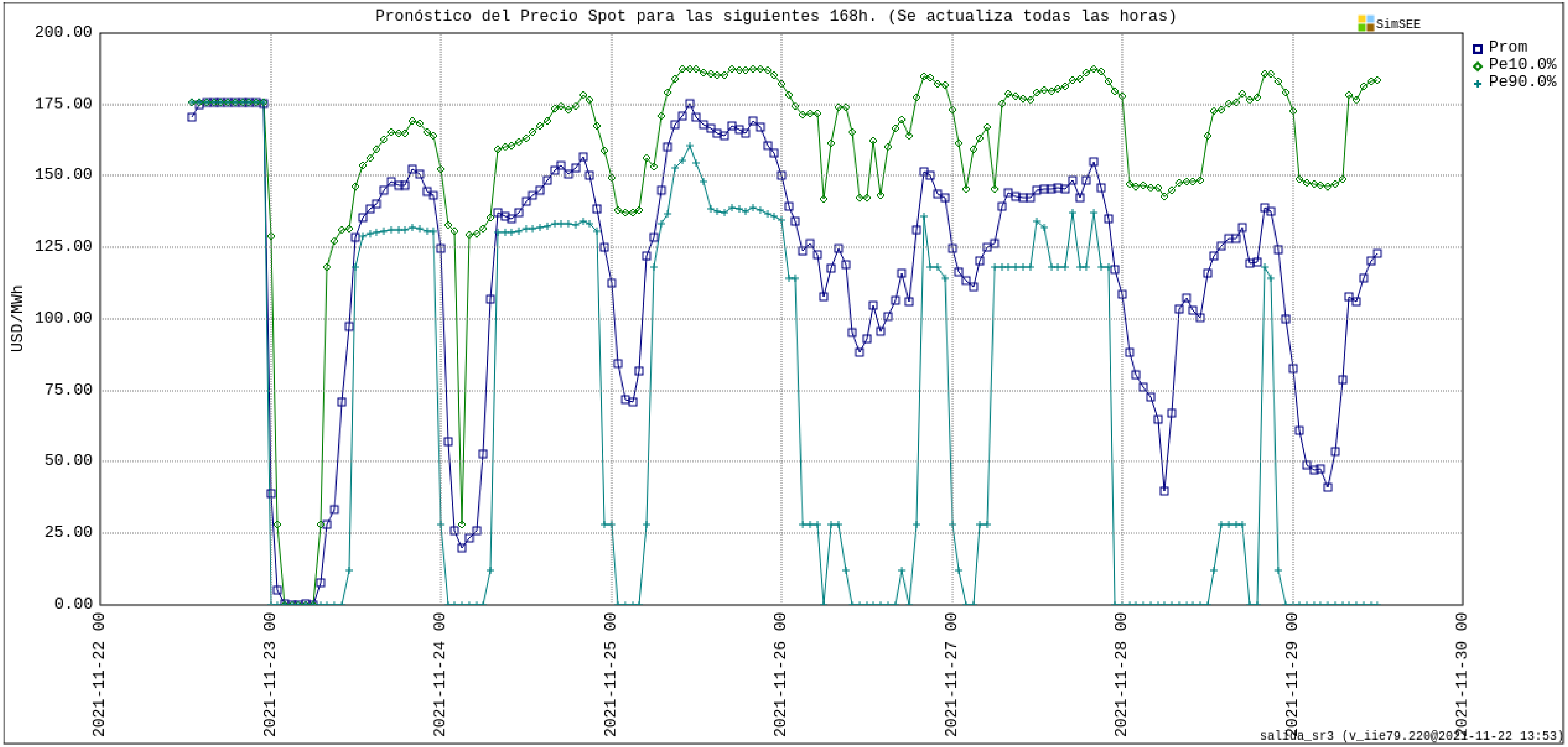
# Programming the enegy dispatch with 72h of windpower forecasts.



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



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

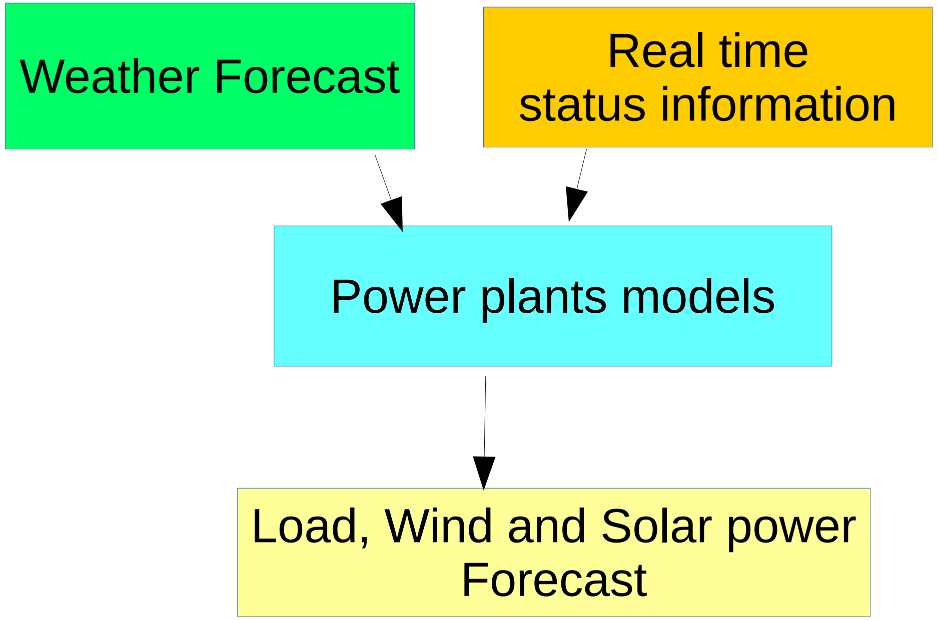


# PRONOS-1
# 2016-2017

ADME

Fundación Julio Ricaldoni
INGENIERIA EN EL URUGUAY

CAF BANCO DE DESARROLLO DE AMÉRICA LATINA



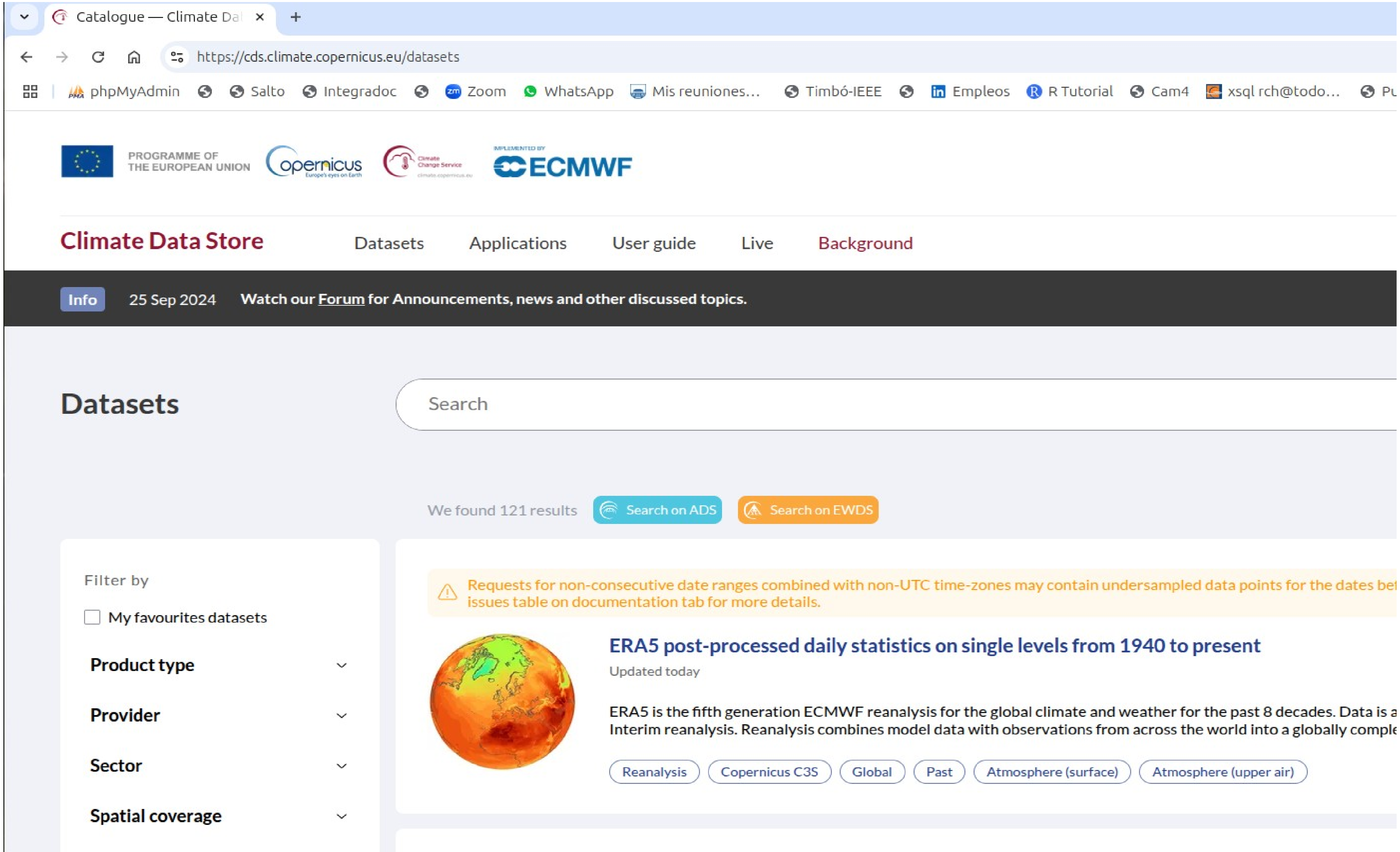

https://pronos.adme.com.uy
https://pronos.adme.com.uy/svg/

# VATES

Continuous forecast of the next 168 hours of optimal operation.

https://vates.adme.com.uy

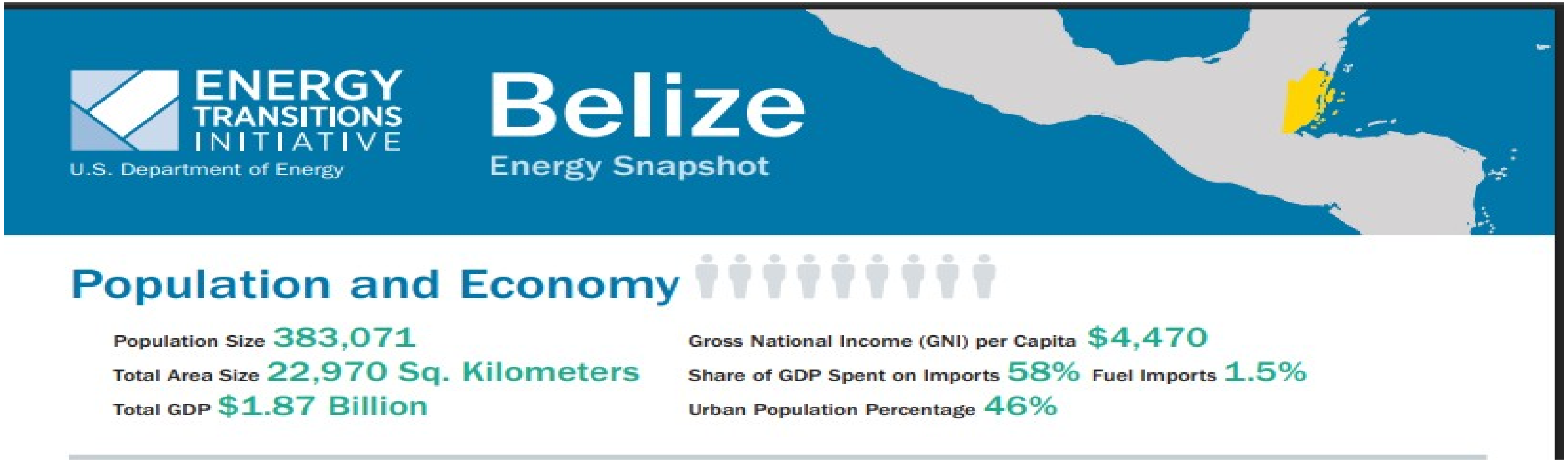
- https://cds.climate.copernicus.eu/datasets



SimSEE

2020

https://www.energy.gov/eere/articles/belize-island-energy-snapshot-2020?nrg_redirect=454723



ENERGY TRANSITIONS INITIATIVE

U.S. Department of Energy

# Belize

Energy Snapshot

## Population and Economy

Population Size 383,071

Total Area Size 22,970 Sq. Kilometers

Total GDP $1.87 Billion

Gross National Income (GNI) per Capita $4,470

Share of GDP Spent on Imports 58% Fuel Imports 1.5%

Urban Population Percentage 46%

2020
https://www.energy.gov/eere/articles/belize-island-energy-snapshot-2020?nrg_redirect=454723

## Electricity Sector Overview

**Installed Capacity** 119.98 MW

**RE Generation Capacity Share** 61%

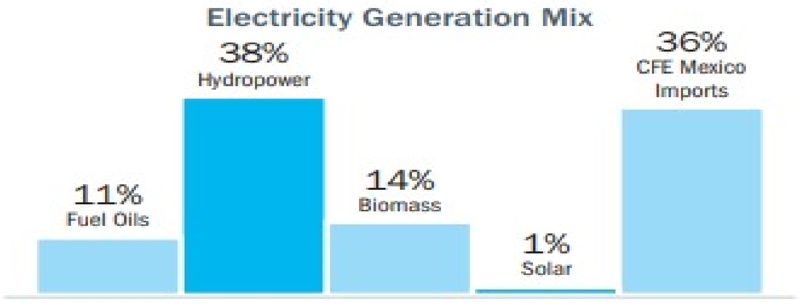
**Peak Demand (2018)** 104.2 MW

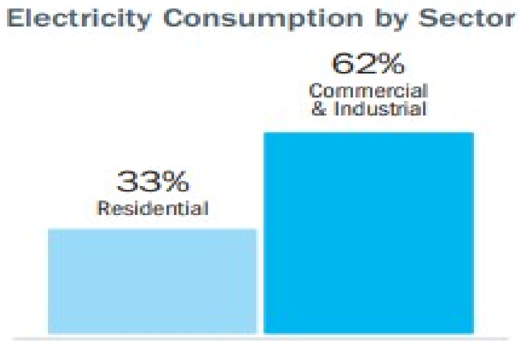
**Total Generation (2018)** 651.12 GWh
*Includes 235.16 GWh purchased/imported from Commission of Federal Electricity (CFE) in Mexico*

**Transmission and Distribution Losses** 11.9%

**Electricity Access** 92% (total population)
Electrification – Urban Areas 97.1% (2016)
Electrification – Rural Areas 88.4% (2016)

**Average Electricity Rates (USD/kWh)**
Social (60kWh or less per month) $0.11
*($2.50 minimum monthly charge)*
Residential and Small Commercial $0.20
*($5.00 minimum monthly charge)*
Large Commercial $0.20
*+ $75 monthly service charge*
Small Industrial $0.15
*+ $18.40 demand charge (kVA)*
*+ $124 monthly service charge*
Large Industrial $0.13
*+ $12.40 demand charge (kVA)*
*+ $124 monthly service charge*
Street Lights $0.23




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

## Renewable Energy Status

| Hydropower | Biomass | Solar |
|---|---|---|
| 51.3 MW | 21.5 MW | 0.48 MW |

## 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

SimSEE

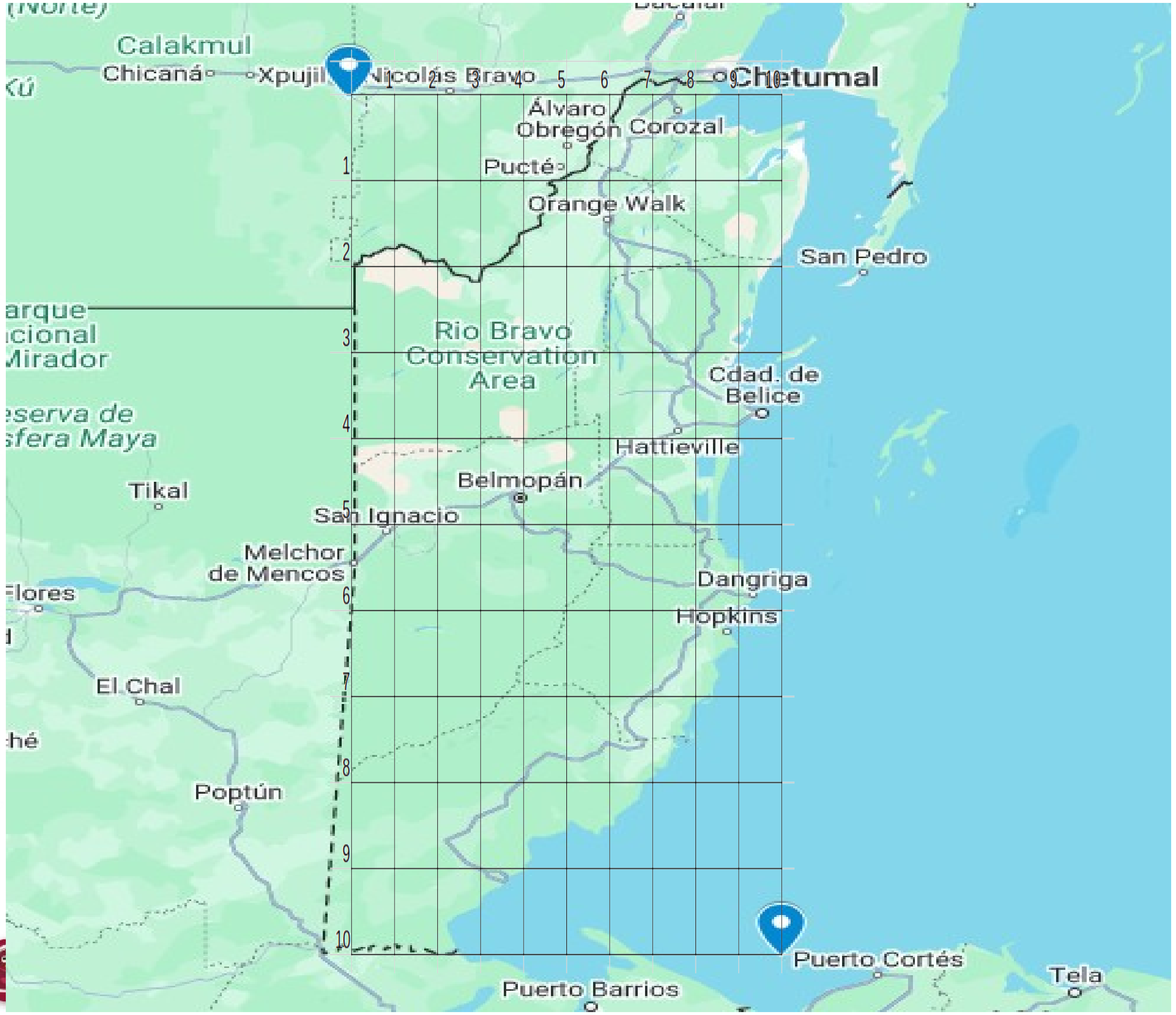
- https://cds.climate.copernicus.eu/datasets/reanalysis-era5-single-levels?tab=overview

SimSEE

# Belice

LAT , LON
18.4364, -89.1726
15.8805, -88.1618

| | |
|---|---|
| **Product type** | Reanalysis |
| **Variable** | 2m temperature, 100m u-component of wind, 100m v-component of wind, Surface solar radiation downwards |
| **Year** | 2023, 2024 |
| **Month** | January, February, March, April, May, June, July, August, September, October, November, December |
| **Day** | 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 |
| **Time** | 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 |
| **Geographical area** | North: 18.43640156987655°, West: -89.1725907716471°, South: 15.880548445295195°, East: -88.16184862757545° |
| **Data format** | GRIB |



| *Name* | *Units* | *Description* |
|---|---|---|
| 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. |

| *Name* | *Units* | *Description* |
|---|---|---|
| 100m u-component of wind | m s-1 | 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-1 | 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-2 | 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^-2 ). To convert to watts per square metre (W m^-2 ), the accumulated values should be divided by the accumulation period expressed in seconds. The ECMWF convention for vertical fluxes is positive downwards. |


Gracias por vuestra atención!!
... continuemos construyendo el camino!!