

Electric Power Load Forecasting under Changing Climate :

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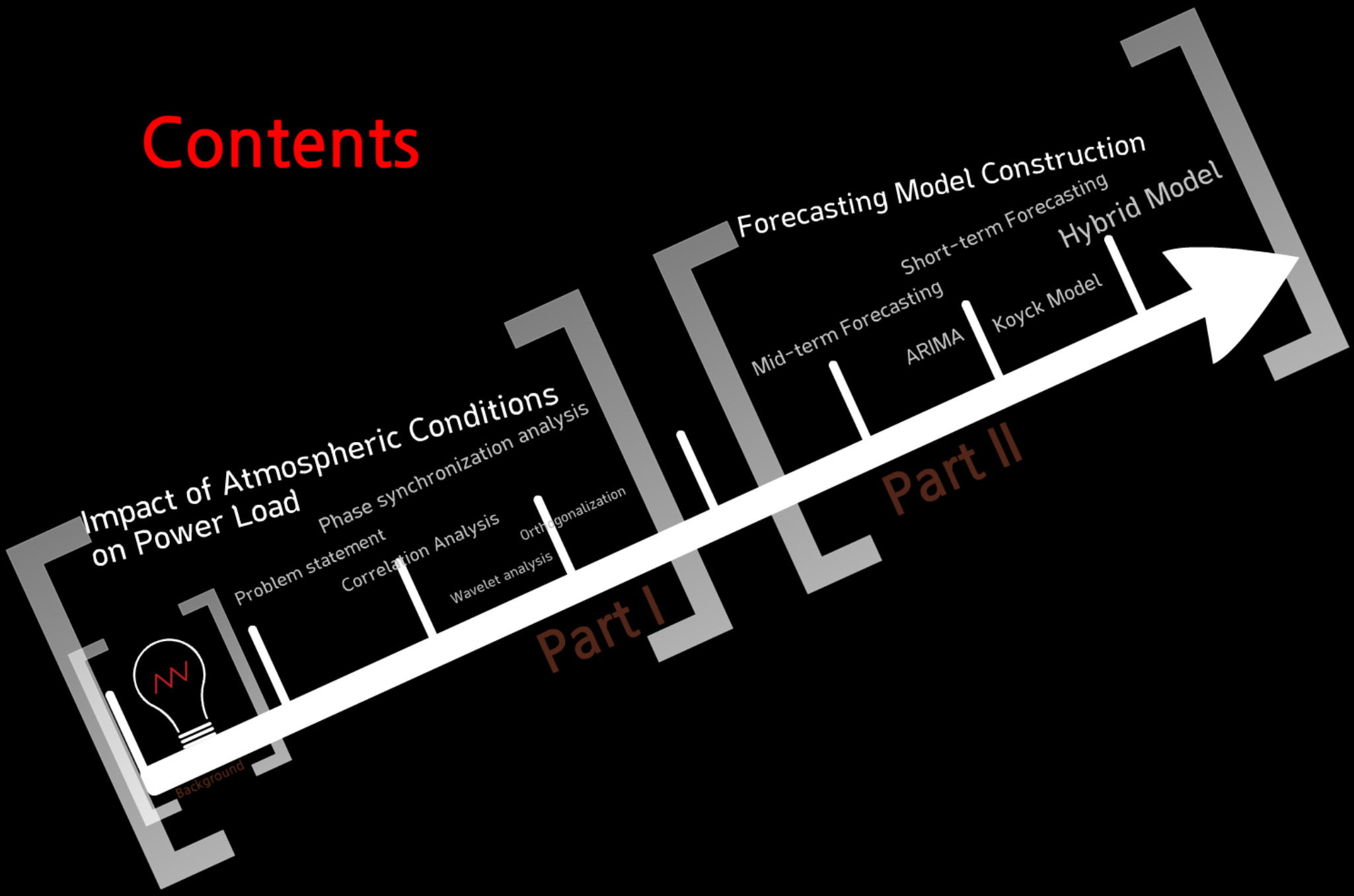
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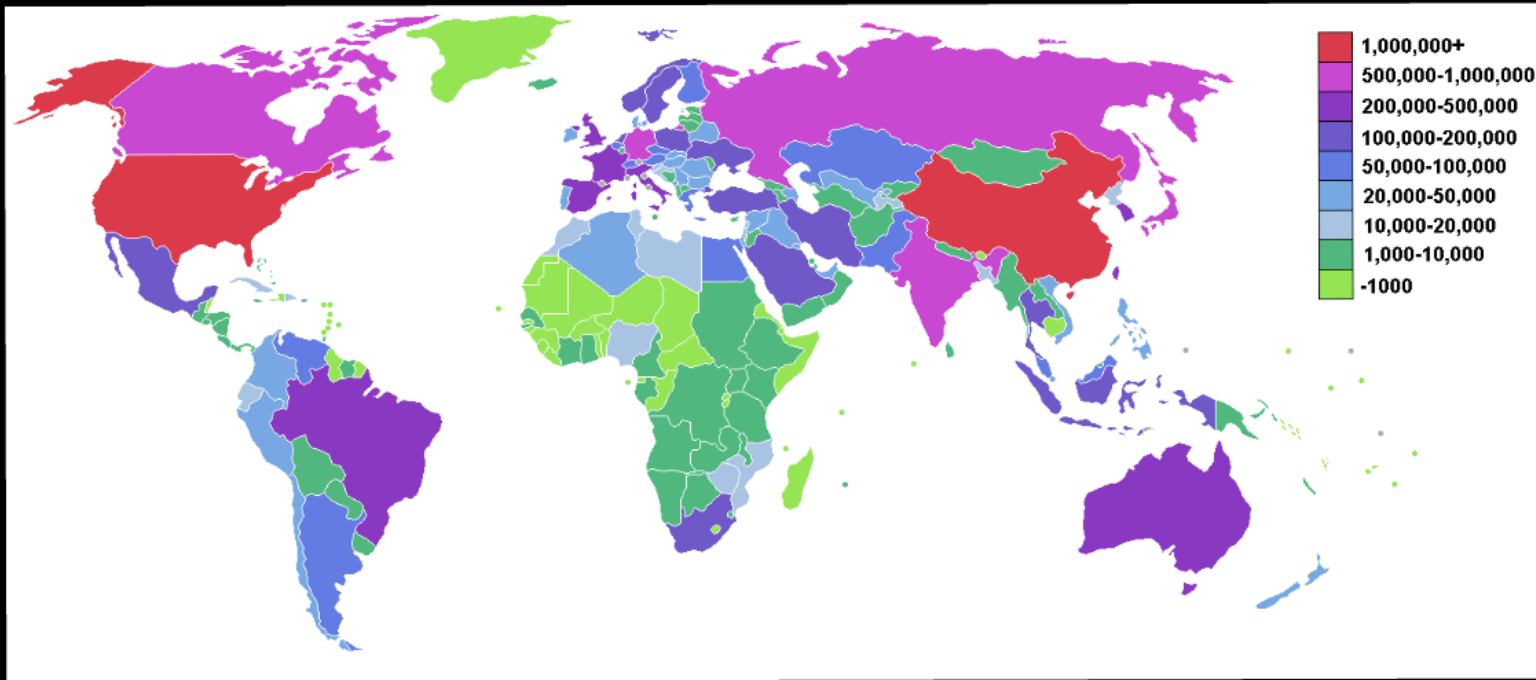
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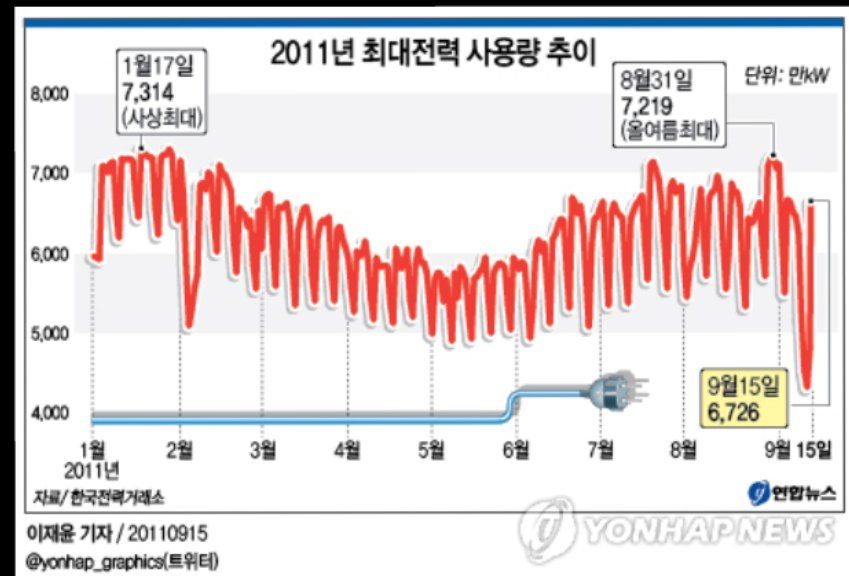




power shortages
blackouts
well planned and managed energy efficiency
conservation programs
Accurate electric power load forecasting

Blackout in Korea

365-1=0



전력수급 대란과 기후변화??

전력수요 급증

- 최근 10년 동안 전력사용량 67% 증가 (OECD국가 중 최대 증가율)
- 유가 급등 및 시스템 에어컨 설치에 따라 난방에 사용되는 전력소비량 증가 (2009년부터 겨울에 최대 전력사용량 기록)
- 전력공급의 불안정과 예비전력률의 급감

보다 정확한 전력수요예측의 필요성

- 2011년 9월 15일 뚝더위로 인한 정전 대란 사태
- 2012년 2월 2일 기록적인 한파로 인한 최대 전력수요 기록 경신
- 수요오차의 경제적 손실

전력수요와 기상상황(meteorological status)의 상관관계

- 전력사용량의 온도 민감도: 115만KW / °C
- 지구온난화 효과에 따른 전력-기온 상관관계 변화

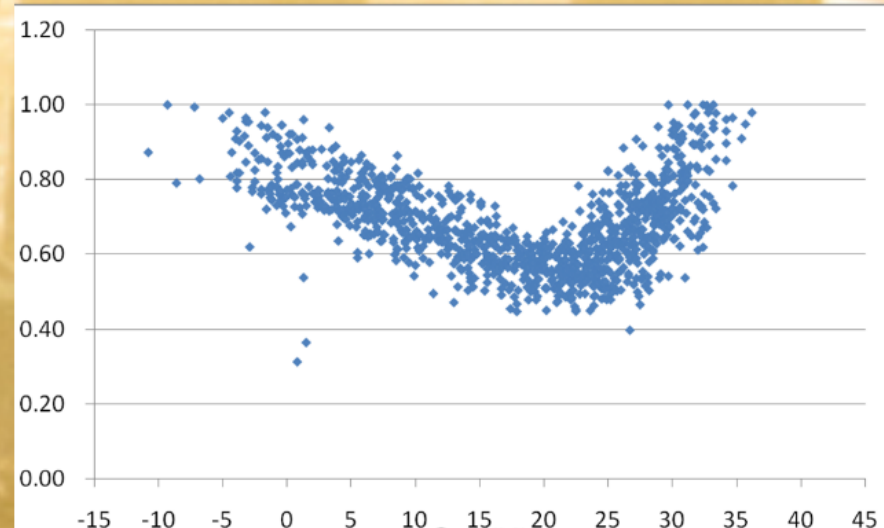
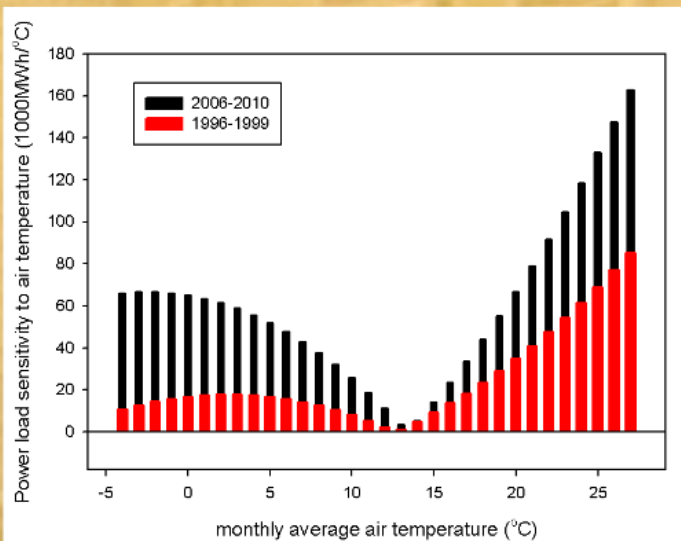
질문들.....

1. 기상 인자가 전력사용량에 어느 정도 영향을 미칩니까?
2. 보다 나은 전력수요 예측을 위하여 어떤 기상 인자를 고려해야합니까?
3. 일기예보의 오차가 전력수요예측에 어떤 영향을 줍니까?



A few things we know...

- 1) Electric power load is sensitive to air temperature.
- 2) Sensitivity of power load to air temperature shows temporal variation.
- 3) There is no forecasting model to consider several atmospheric variables explicitly.



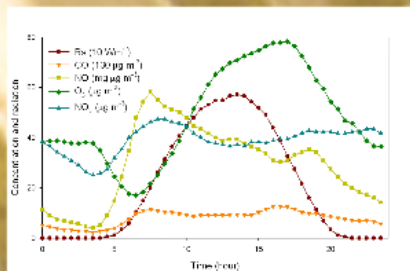
Scientific Issues

- Atmospheric conditions are correlated (diurnal & seasonal).
 - 1) Traditional statistics requires iid and Gaussian distribution
 - 2) Nonlinearity must be handled properly.
- Correlation sometimes is not all for load forecasting.
 - 1) Uncertainties in measurements and forecasting of weather
 - 2) Human-induced variations of power load

Pitfall of a correlation coefficient



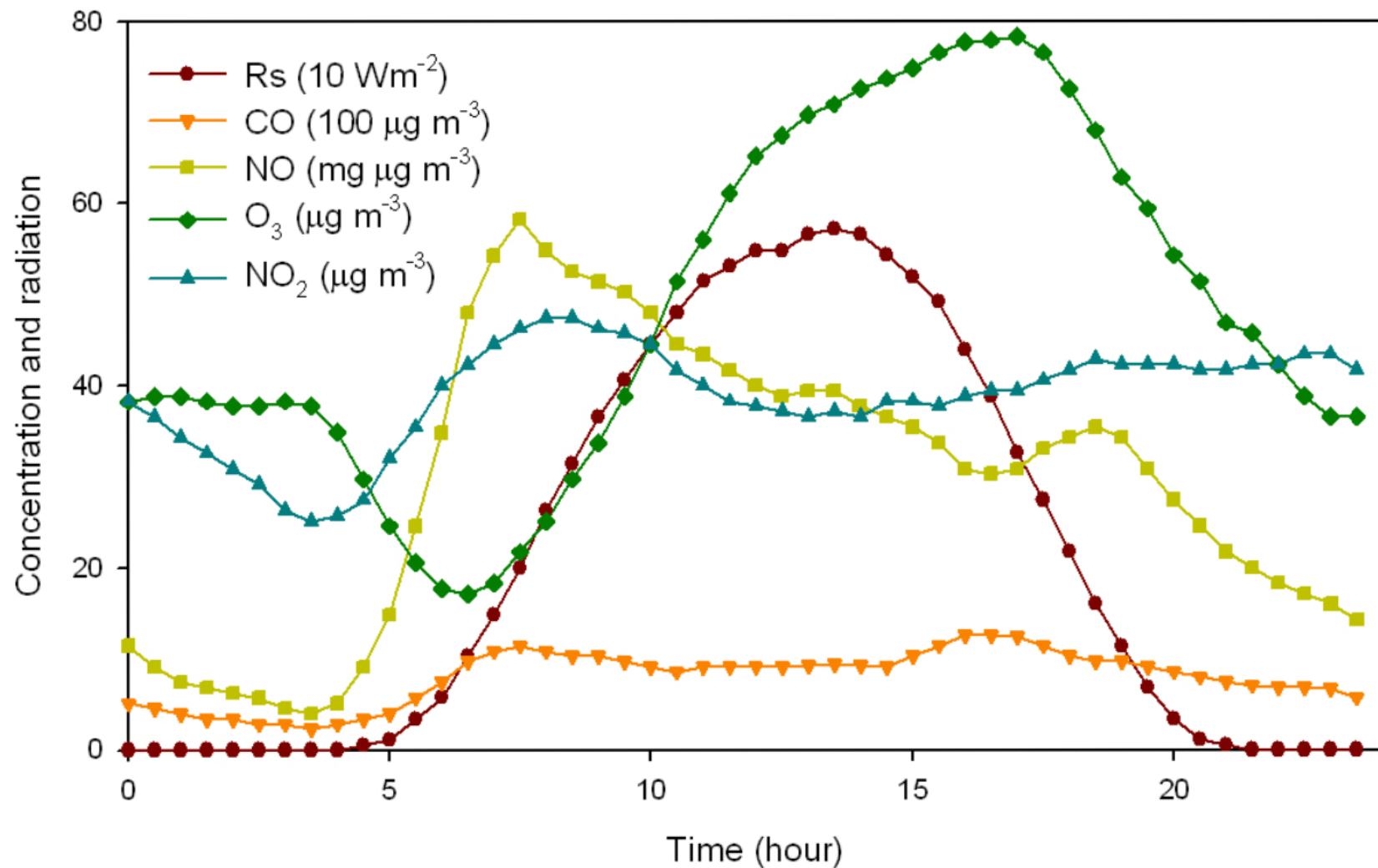
One example: air pollution data



reproduced from Barbaresco et al. (2006)



One example: air pollution data



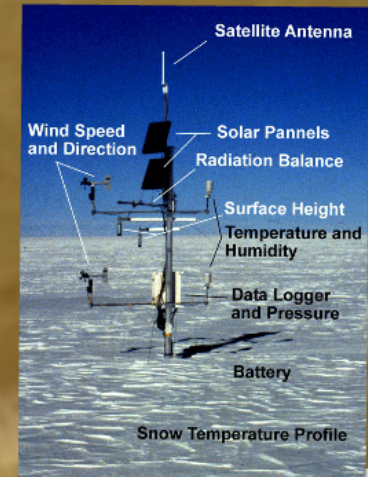


Economic
condition

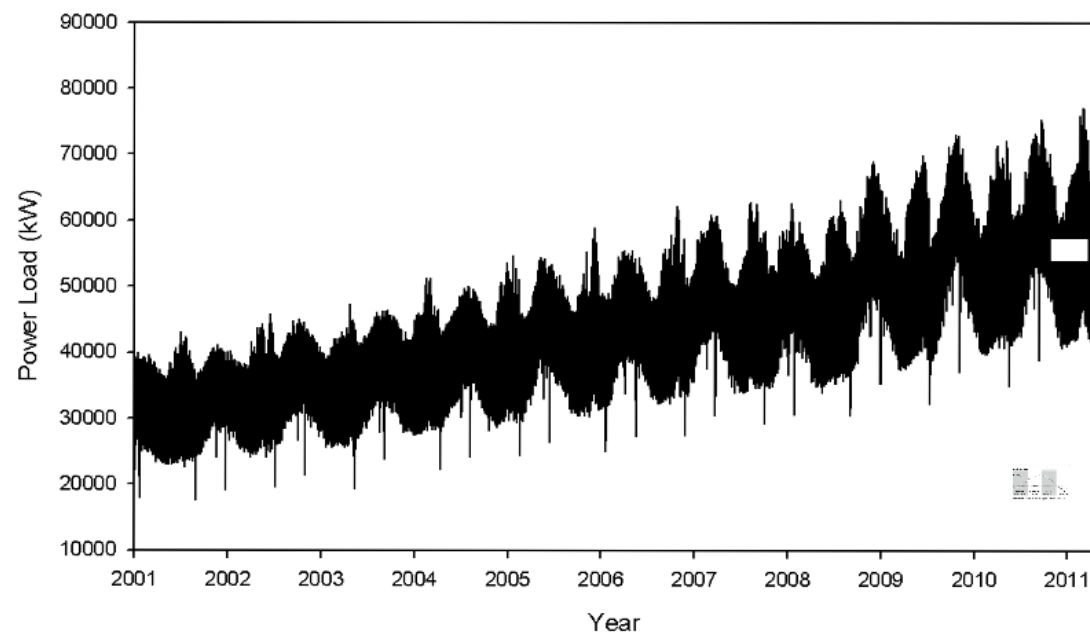
Supply&Demand
control

Power
load

Meteorology

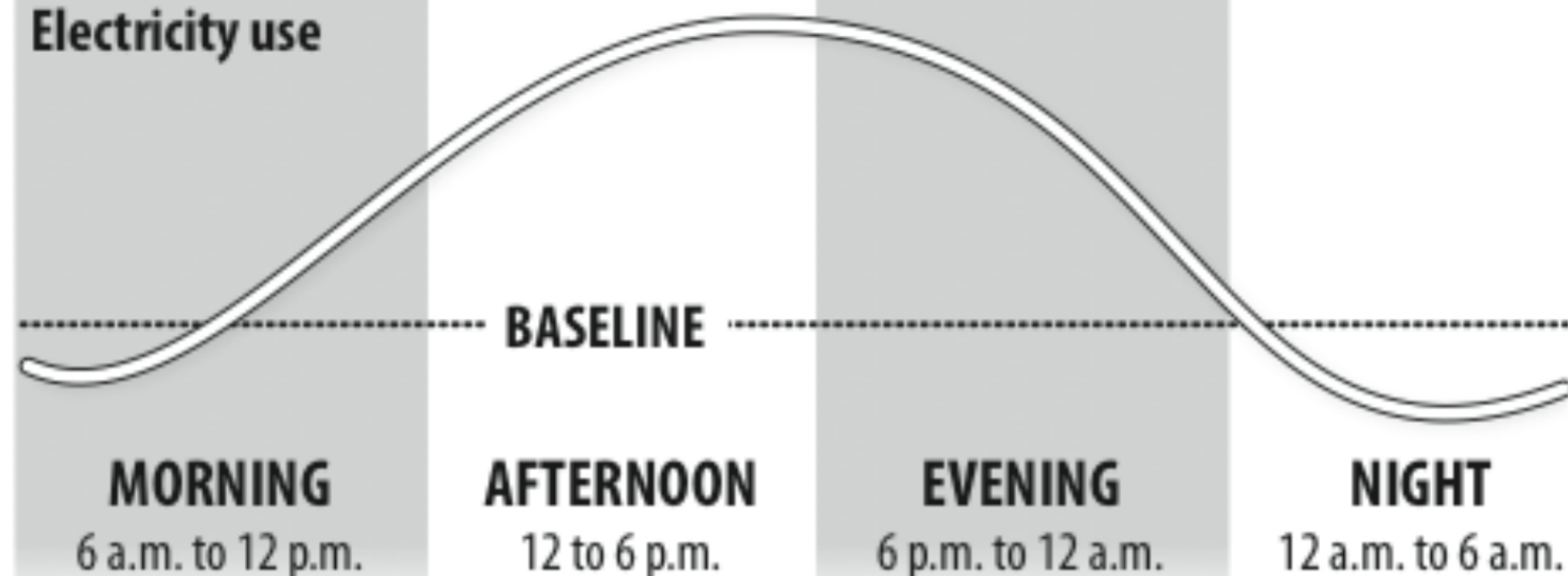


Time series of domestic power load (2001~2012)

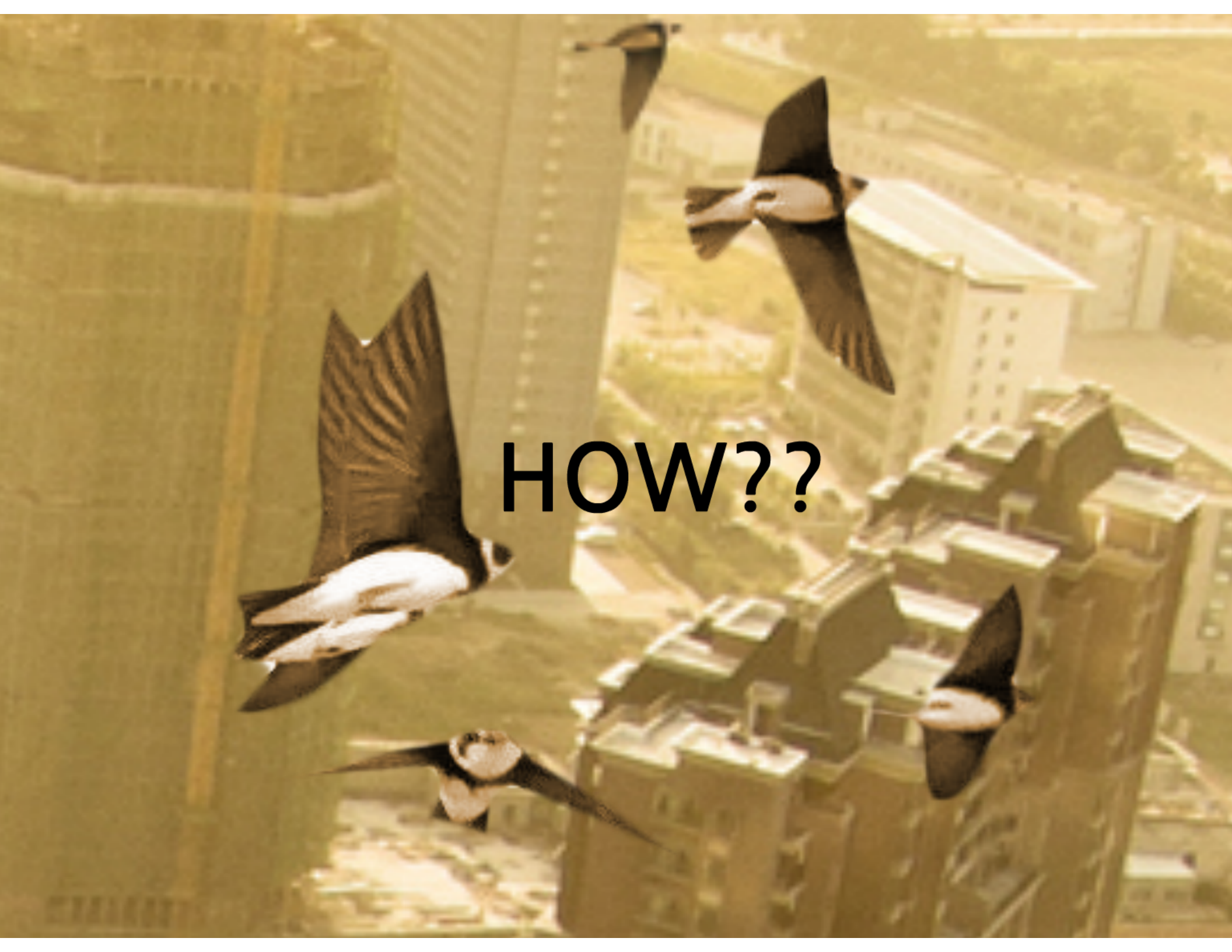


Peak Demand

Electricity use



Peak load is the maximum load during a specified period of time.

A photograph of four birds, likely swallows, flying over a dense urban landscape. The birds are in various stages of flight, with their wings spread wide. The background shows a city with many buildings, including a prominent tall skyscraper on the left. The overall color palette is warm and yellowish, suggesting a sunset or sunrise. The text "HOW??" is overlaid in the center of the image.

HOW??

1. Partial Correlation Analysis

Combined with a Graphical Model

Conditional Probability based on linear correlation coefficient

N-dimensional dynamic process

$$X_1, X_2, \dots, X_N$$

$$X_z \{X_z | Z = 1, \dots, N, Z \neq k, l\}$$

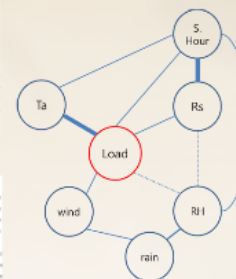
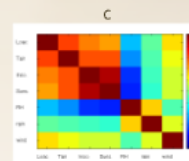
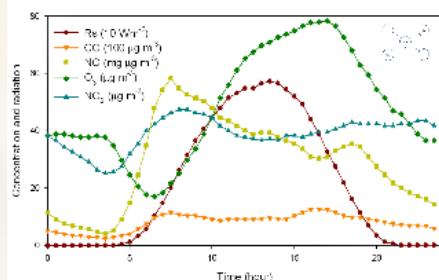
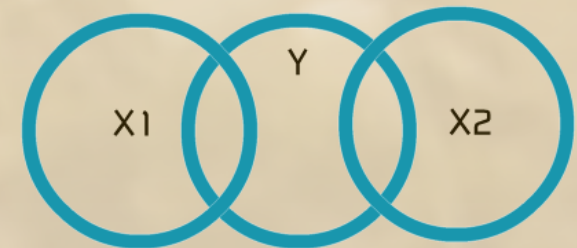
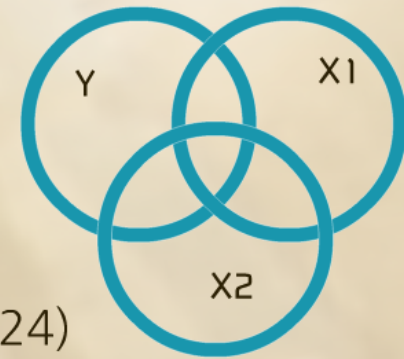
$$G(V, E) (V = \{1, \dots, k\}, E \subset \{(a, b) \in V \times V\})$$

$$C_{X_i X_j \cdot V \setminus X_i, X_j} = -\frac{\Omega_{ij}^{-1}}{\sqrt{\Omega_{ii}^{-1} \Omega_{jj}^{-1}}}$$

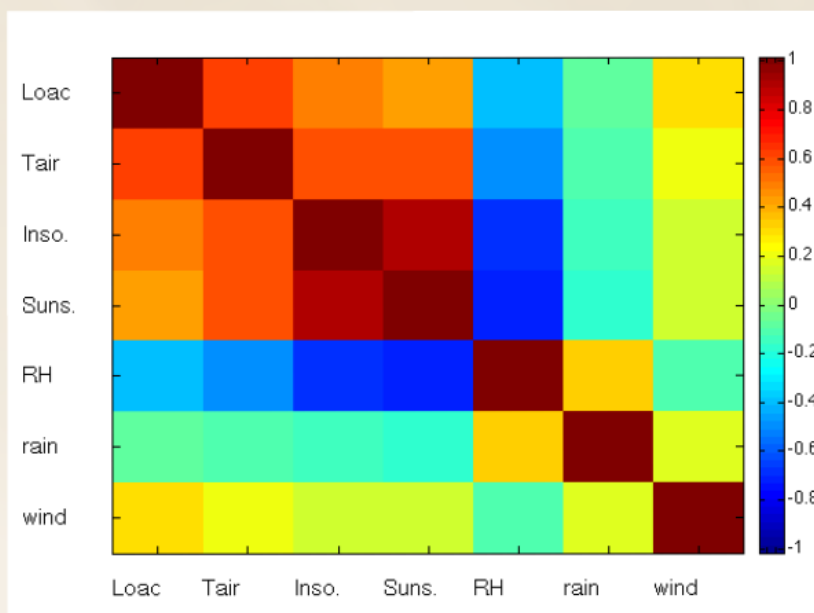
$$\Omega_{ij} = \rho_{X_i X_j}$$

$$C_{X_k X_l | X_z}$$

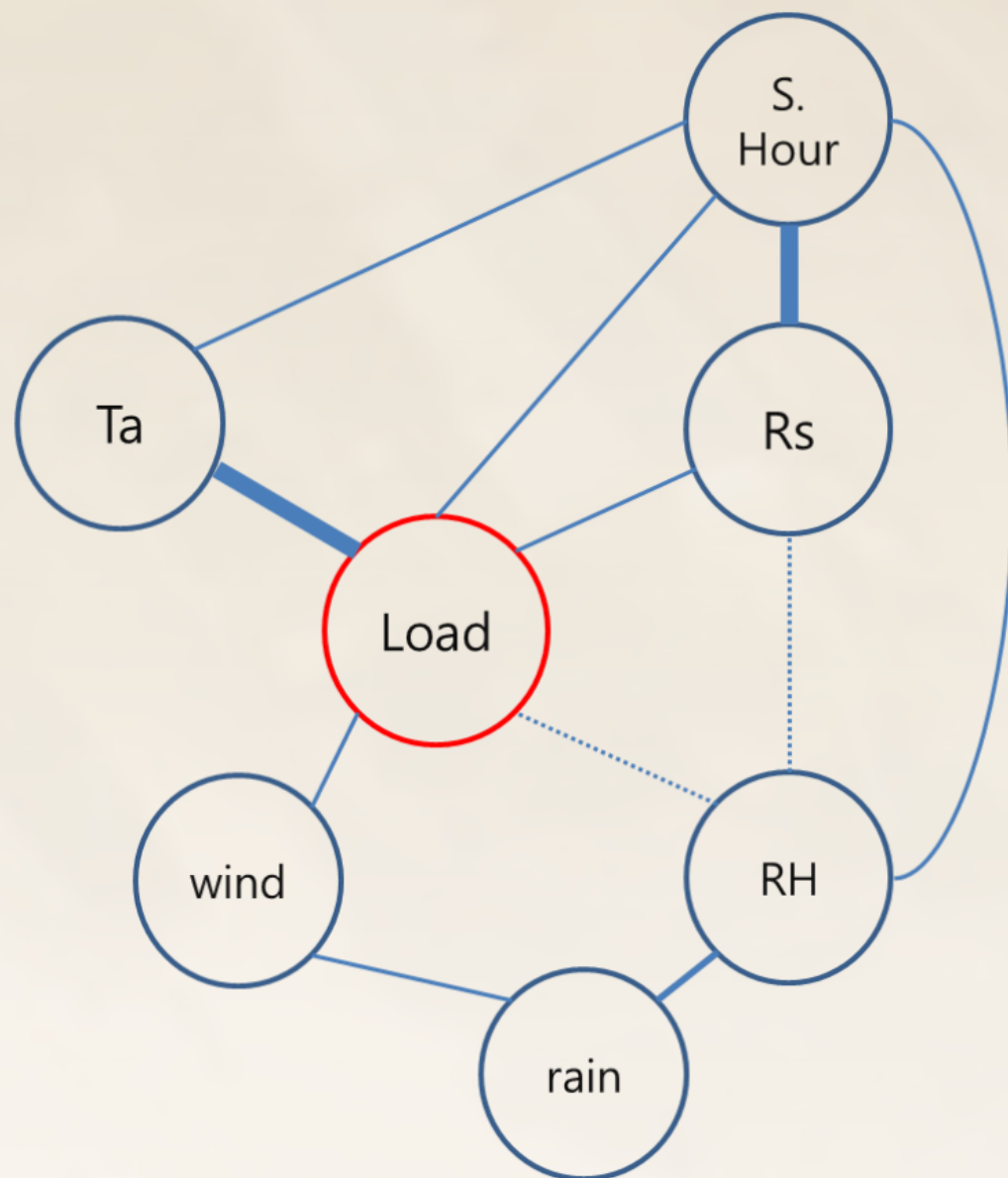
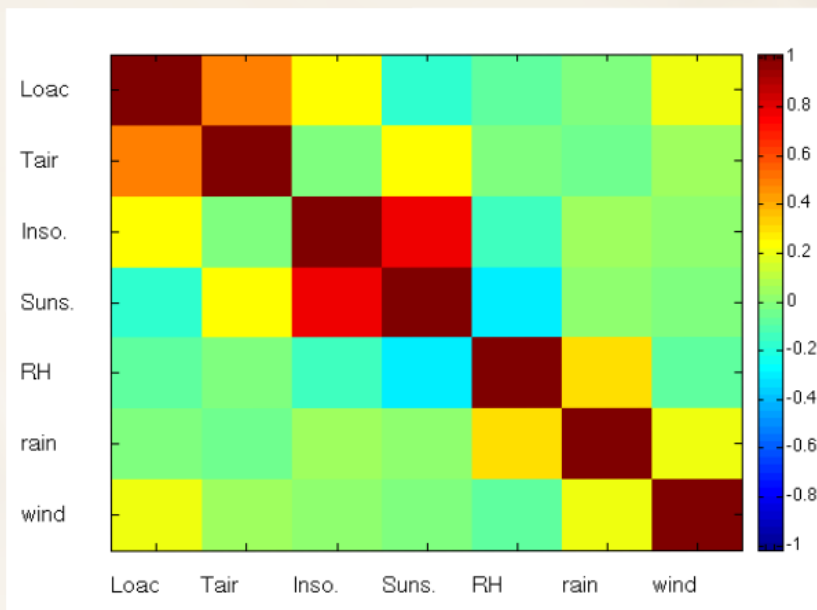
Fisher (1924)



C



PC



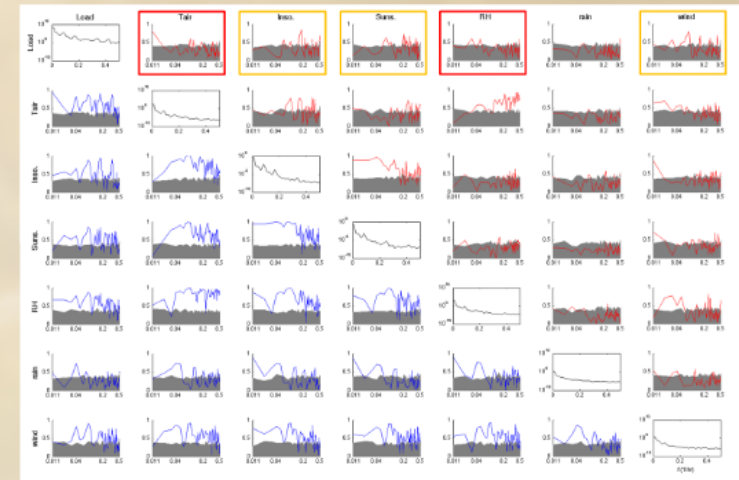
2. Partial Coherence Analysis Combined with a Graphical Model

Conditional Probability based on linear systems

$$S_{X_k X_l | X_z} = S_{X_k X_l} - S_{X_k X_z} S_{X_z X_z}^{-1} S_{X_z X_l}$$

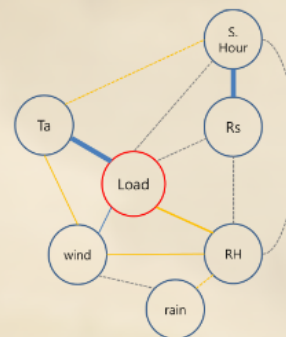
$$S_{X_k X_l}(\omega) \propto \sum_t X_k(t) e^{-i\omega t} X_l(t) e^{i\omega t}$$

$$\vec{S}(\omega) = \begin{pmatrix} S_{X_1 X_1}(\omega) & S_{X_1 X_2}(\omega) & \dots & S_{X_1 X_N}(\omega) \\ S_{X_2 X_1}(\omega) & S_{X_2 X_2}(\omega) & \dots & \vdots \\ \vdots & \vdots & \ddots & \vdots \\ S_{X_N X_1}(\omega) & \dots & \dots & S_{X_N X_N}(\omega) \end{pmatrix}$$

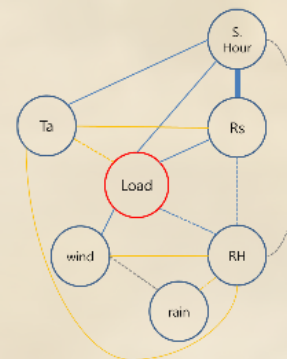


Statistical significance test based on Theiler et al. (1992)

> 1 day period



< 1 day period



Partial correlation and Partial coherence spectrum

They are still global analysis and for the linear system.

It does not provide the characteristics of temporal variations.



3. Partial Phase Synchronization Analysis

Combined with Wavelet transform/Graphical model

$$V(t) = A(t)e^{i\Phi(t)} \equiv A(t)Q(t)$$

$$Per_{Q_k Q_l}(\omega) \propto \sum_t Q_k(t) e^{i\omega t} \sum_t Q_l(t)^* e^{i\omega t}$$

$$R_{kl} \propto \sum_{\omega} Per_{Q_k Q_l}(\omega)$$

$$\vec{R} = \begin{pmatrix} 1 & R_{12} & \dots & R_{1,N} \\ R_{1,2}^* & 1 & \dots & R_{2,N} \\ \vdots & \vdots & \ddots & \vdots \\ R_{1,N}^* & R_{2,N}^* & \dots & 1 \end{pmatrix}$$

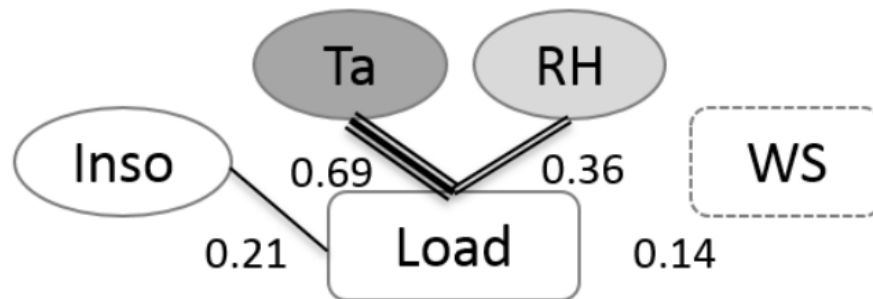
$$R_{kl|z} = \frac{|R_{kl}^{-1}|}{\sqrt{R_{kk}^{-1} R_{ll}^{-1}}}$$

Phase locking problem

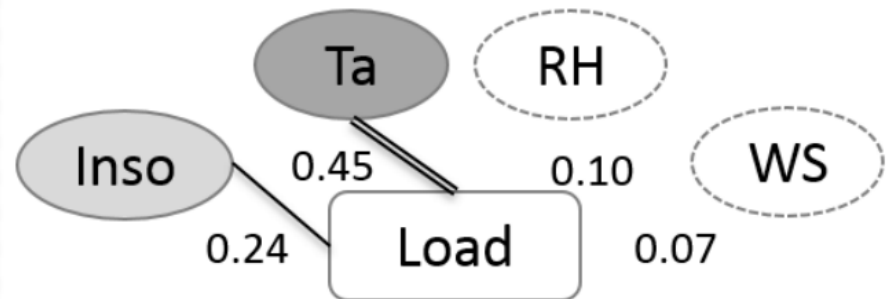


Schelter et al. (2006)

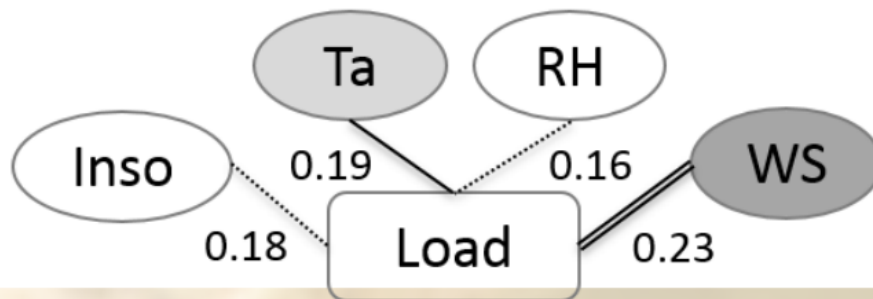
(a) summer/ 1-day period



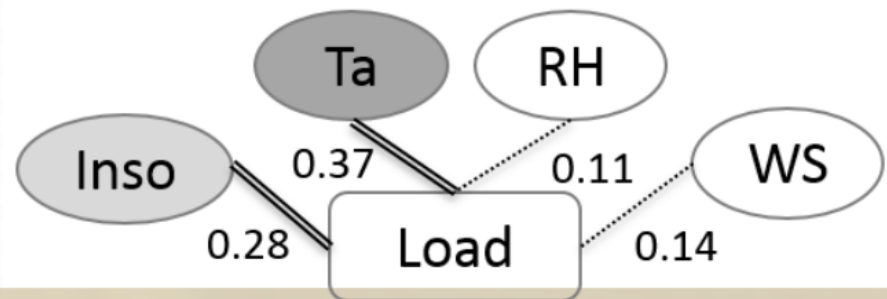
(c) summer / 6-hourly period



(b) winter / 1-day period



(d) winter / 6-hourly period





liberty

Thank you all much.



김동환을 아십니까?

Load Forecasting vs Connectivity

1) Load Forecasting: Estimate the load of a system in advance.
2) Connectivity: Establish a connection between different systems.
3) Load Forecasting: Predict the future load of a system.
4) Connectivity: Connect different systems to a common network.
5) Load Forecasting: Analyze the historical load data to predict future trends.
6) Connectivity: Ensure that different systems can communicate with each other.
7) Load Forecasting: Use machine learning algorithms to improve forecast accuracy.
8) Connectivity: Implement security measures to protect the network.
9) Load Forecasting: Monitor the system load in real-time to detect anomalies.
10) Connectivity: Regularly update the network to maintain optimal performance.

1) Short-term Forecasting: Economic operation of power plants

- Peak daily load
- Diurnal variation
- Several days ahead

2) Mid-term Forecasting: power plant maintenance/hydrothermal regulation

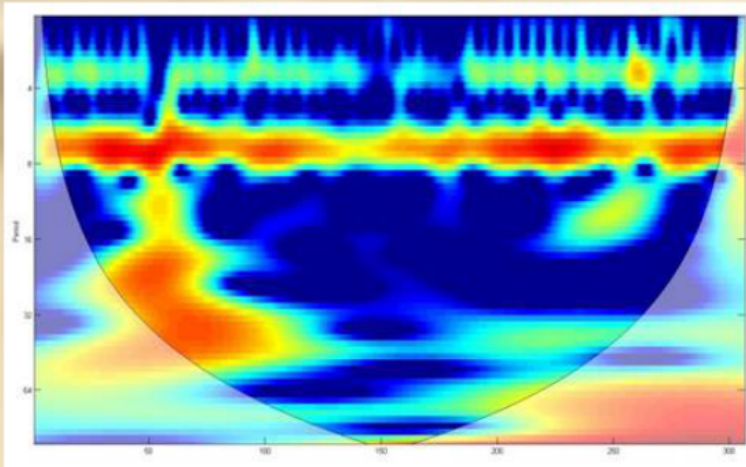
- A few month ahead
- Peak monthly load

3) Long-term Forecasting: plan for construction of power plants

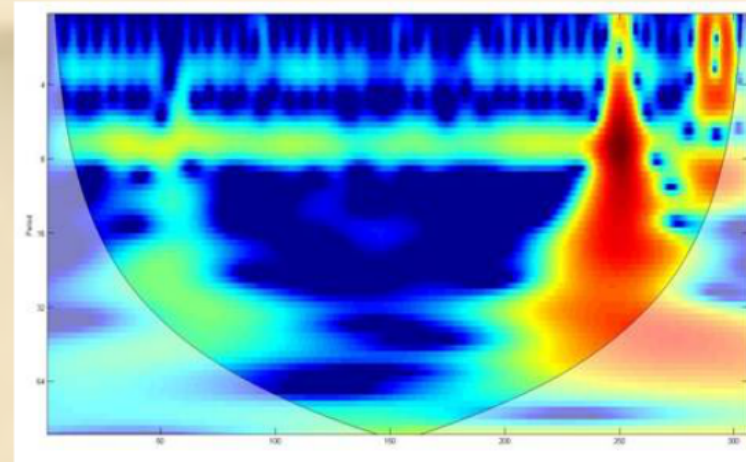
- Several years ahead

Maximum power load forecasting: KSLF@KPX

Observed Ta

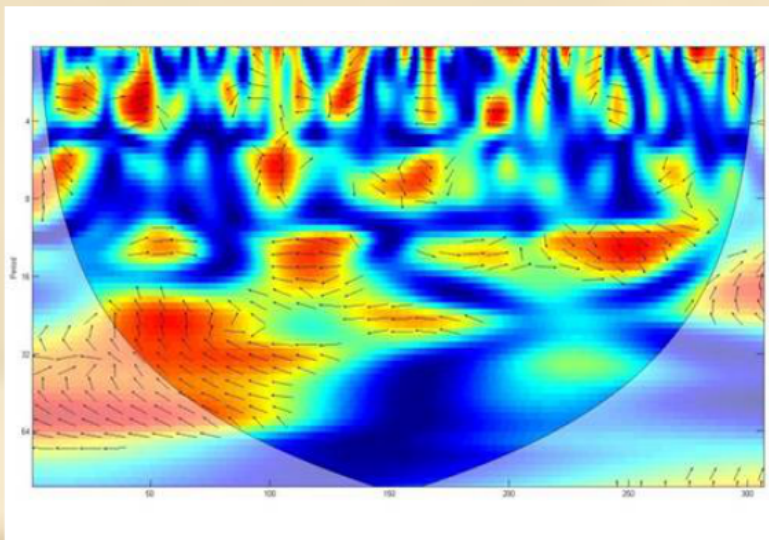


Predicted Ta

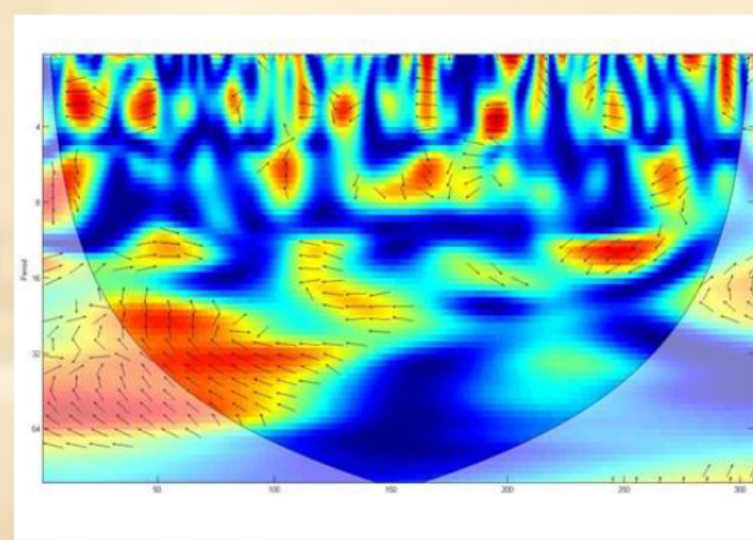


Load sensitivity to air temperature

Observed Ta / Actual load



Observed Ta/ Forecasted load



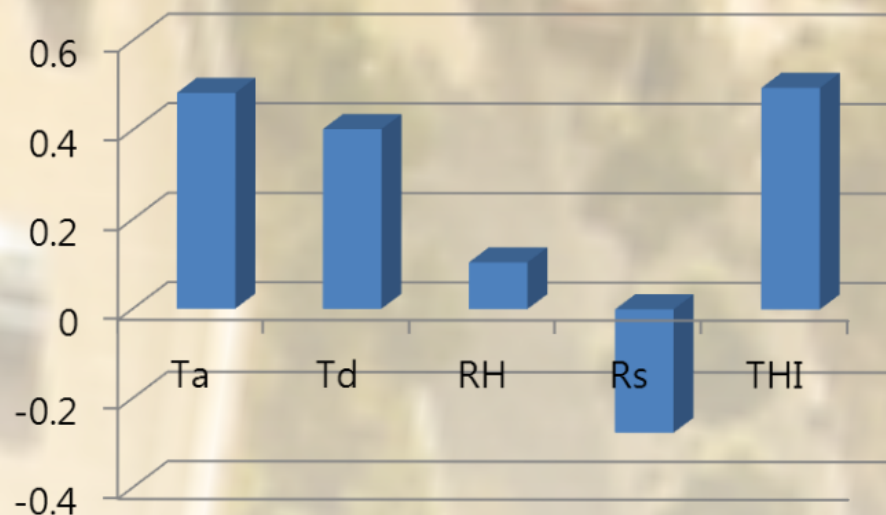
Multiple Regression based on Orthonormalization

Gram-Schmid Orthonormalization

Let $z_{1i} = x_{1i}$ and for $m > 1$

$$z_{mi} = x_{mi} - \sum_{k=1}^{m-1} r_{mk} z_{ki} \quad \text{where} \quad r_{mk} = \left(\sum_i x_{mi} z_{ki} \right) / \left(\sum_i z_{ki}^2 \right)$$

Statistical testing: adj R2, AIC, BIC, HQC



Ta+Rs

Ta+RH

THI

0.26

0.25

0.24

explanation ability





Hybrid Dynamic and Fuzzy Time Series Model

Load Forecasting: Hybrid

$$Y_t = \alpha + \beta Y_{t-s} + \gamma T_{t-1} + \delta T_{t-1}^2 + \epsilon_t$$

$$t = 1, 2, \dots, n$$

$$e_t = Y_t - \hat{Y}_t$$

$$A_i = f_{A_i}(u_1)/u_1 + f_{A_i}(u_2)/u_2 + \dots + f_{A_i}(u_n)/u_n$$

$$A_1 = \frac{1}{u_1} + \frac{0.5}{u_2}$$

$$A_i = \frac{0.5}{u_{i-1}} + \frac{1}{u_i} + \frac{0.5}{u_{i+1}} \quad i = 1, \dots, n-1$$

$$A_n = \frac{0.5}{u_{n-1}} + \frac{1}{u_n}$$

non-parameteric / nonlinear sysem

Load Forecasting: Koyck Model

$$Y_t = \alpha + \beta_0 X_t + \beta_{0,1} X_t^2 + \beta_{1,1} X_{t-1} + \beta_2 X_{t-2} + \cdots + u_t \quad (1)$$

$$\beta_i = \beta_0 \lambda^i, \quad \forall i, \text{ with } 0 < \lambda < 1.$$

$$\begin{aligned} \lambda Y_{t-1} = \lambda \alpha &+ \beta_{0,1} \lambda X_{t-1} + \beta_{0,2} \lambda X_{t-1}^2 + \dots \\ &+ \beta_{0,1} \lambda^2 X_{t-2} + \beta_{0,2} \lambda X_{t-2}^2 + \dots \\ &+ \beta_{0,1} \lambda^3 X_{t-3} + \cdots + \lambda u_{t-1} \end{aligned} \quad (2)$$

$$Y_t = c_1 + c_2 X_t + c_3 X_t^2 + \lambda Y_{t-1} + \epsilon_t. \quad (3)$$

Load Forecasting: ARIMA

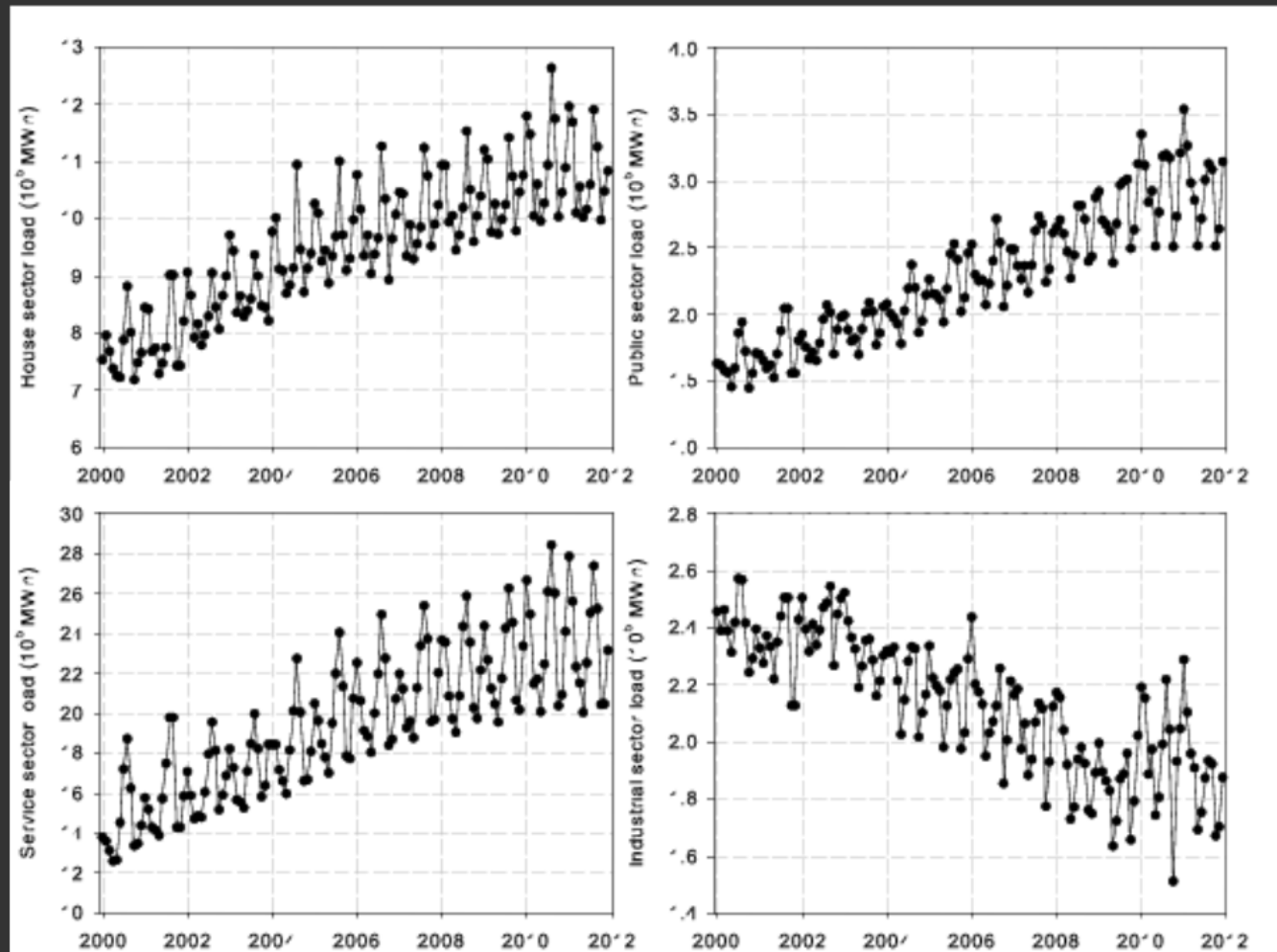
ARIMA(Auto-Regressive Integrated Moving Average)

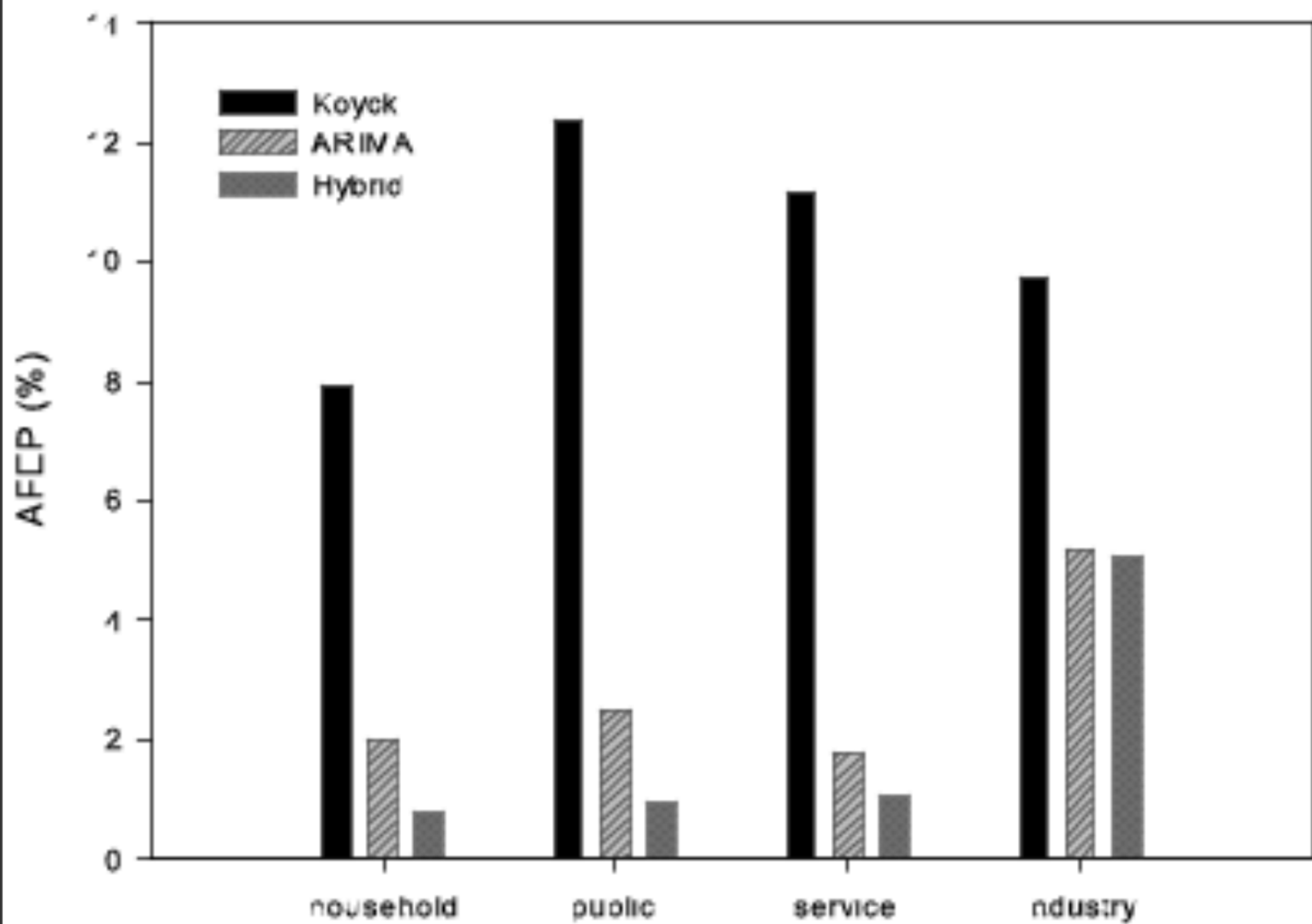
$$\Phi(B)\Delta^d Y_t = \theta(B)\epsilon_t$$

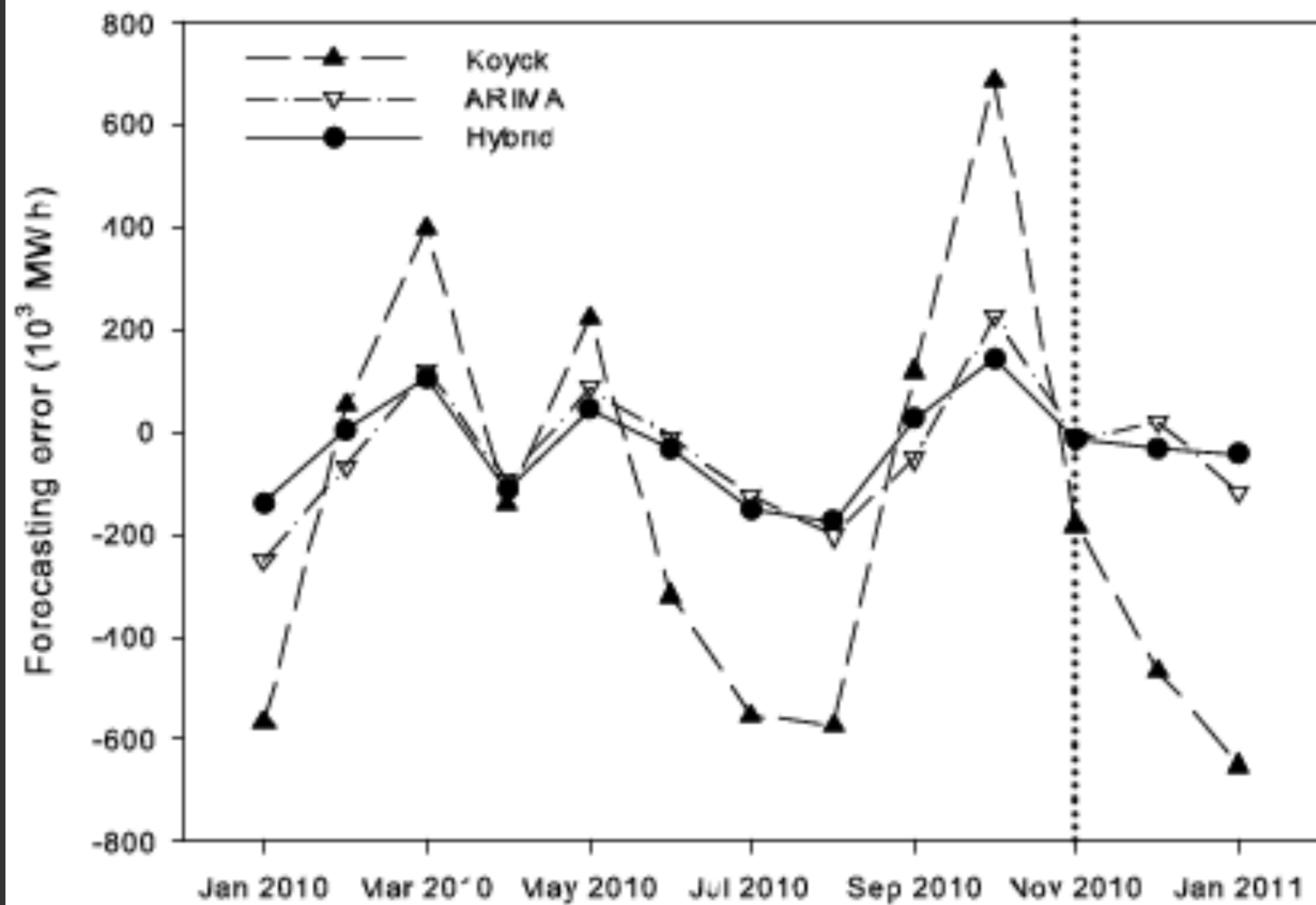
B : the backshift operator / ϵ_t : a white noise $(0, \sigma_\epsilon^2)$.

Mid-Term Forecasting

Seoul: monthly power load (2000 ~ 2012)





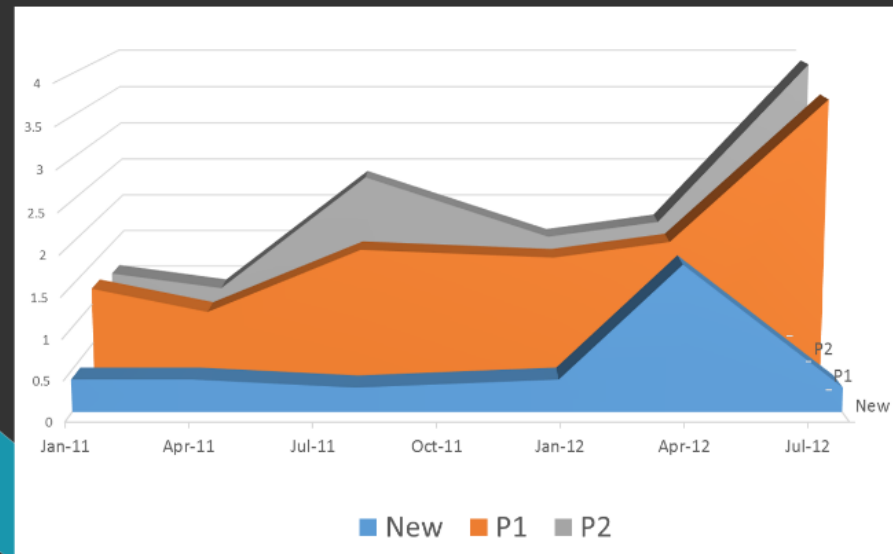


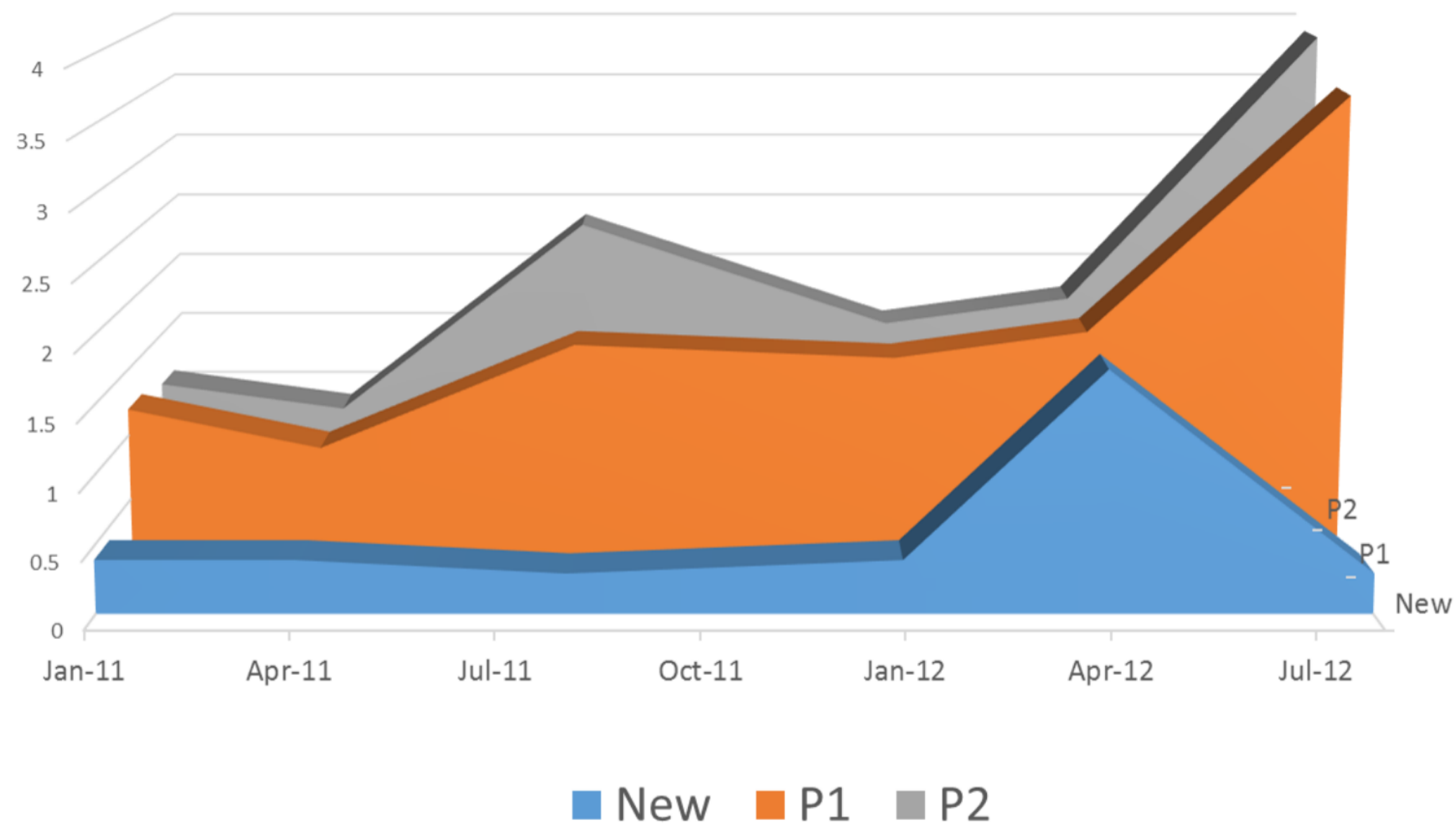
Short-Term forecasting

Peak daily power load
(2008.11.1-2012.12.31)

Forecasting load at t

- air temperature at $(t-1)$
- past peak daily load





Summary

1. Direct/Indirect impact of atmospheric conditions on power load has been analyzed based on several partialization methods.
2. Power load shows different sensitivities to atmospheric conditions with different temporal scales.
3. Traditional statistical methods may be inappropriate in analyzing electric power load and its relationships with climate conditions.
4. Hybrid model has been proposed to overcome uncertainties of weather forecasting and human-electricity interactions.
5. Issues on database and diversification in KMA and KPX

Thank you so much.

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