

GLOBAL WARMING



Keynote

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July 03, 2008

GLOBAL WARMING

Research Seminar Team

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Mathematical and Statistical Modeling of Global Warming



- Do we scientifically understand the concept of “Global Warming”?
- Recent Definition: “GLOBAL WARMING- an increase in Temperature at the surface of the earth supposedly caused by the greenhouse effects” (Greenhouse Effects- Carbon Dioxide CO₂ (greenhouse gas))
- Supposedly
 - assumed to be true without conclusive evidence
 - Hypothetical, conjectural, etc.

Wikipedia(on-line encyclopedia)

- Defines the phenomenon of
“GLOBAL WARMING”
as the increase in the average
temperature of the earth’s near-surface
air and oceans in recent decades and its
projected continuation.

MEDIA CHAOS: PRO AND CONCERNED (SKEPTICS)

■ **PRO - GLOBAL WARMING**

*Intergovernmental Panel on Climate Change (IPCC) “Climate Change 2007”


- Increase in Temperature → Increase Sea Level
- Unpredictable Pattern in Rainfall
- Increase in Extreme Weather Events
- Alterations in Agriculture Yields
- Increase in River Flows
- Etc.

PRO - GLOBAL WARMING

(Continued)

- **Award Winning Documentary–Vice President Gore**
 - Fiction VS. Reality / Awareness
 - ABC: 20/20 / Give Me A Break!
- **A Number of Professional Organizations**
 - American Meteorological Society
 - American Geographical Union
 - AAAS
- **National Academies**
 - Blame Human Activities

CONCERNED / SKEPTICS

- 
- **Great Britain's Channel 4 Documentary**
 - “The Great Global Warming Swindle”
 - **NASA Scientists**
 - Sun spots are hotter than previously thought
 - **Danish National Space Center**
 - Temperature changes are due to fluctuations in the sun's output (NASA)
 - (Stated: ...there is absolutely nothing we can do to correct the situation)
 - **ABC – 20/20: Broadcast – “Give Me a Break”**

CONCERNED / SKEPTICS

(Continued)

- **Times Washington Bureau Chief, Bill Adair**
 - “Global Warming has been called the most dire issue facing the planet and yet, if you are not a scientist, it can be difficult to sort out the truth”
- **Finally, St. Pete Times, Jan 23, 2007**
 - “Global Warming: Meet Your Adversary” By the numbers: 9 out of 10 statistical Info. **Not Correct**

Wall Street Journal

“Global Warming is 300-years-old news”

- **“The various kind of evidence examined by NRC – National Research Council, led it to conclude that the observed disparity between the surface and atmospheric temperature trends during the 20-year period is probably at least partially real”**
 - Uncertainties in all aspects exist – can not draw any conclusions concerning “GW”
 - NRC concludes that “Major Advances” in scientific methods will be necessary before these questions (GW) can be resolved.
- **... spread fear of “Global Warming” demonizing, hydrocarbon fuel.**

Do We Understand the Problem of Global Warming?



- **Zero Legal Legislative Policies: Why?**
- **Continental U.S**
 - Popular Claim to Global Warming: The Marriage of Temperature and Carbon Dioxide (CO₂)
- **Need to Understand**
 - Temperature Behavior (Type)
 - Carbon Dioxide (Type)
 - Their Relationship

Temperature



- **Atmospheric (2 or 3 Versions)**
- **Surface**
 - Land
 - Ocean (73%)
- **Historical Data: 1895-2007 / Daily, Weekly, Monthly, Yearly**

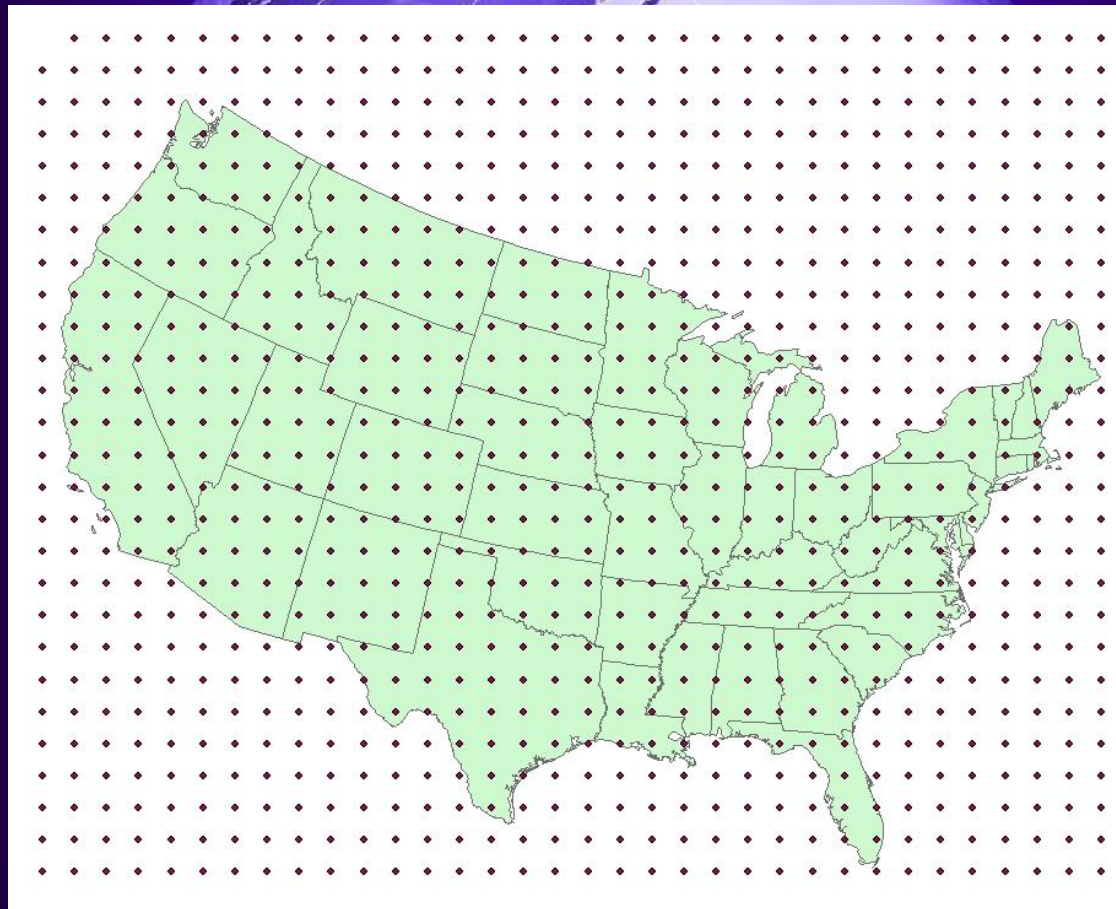
Atmospheric Temperature Data



- **Version 1: United States Climate Division, USCD, (1895-2007) 344 Climate Divisions**
- **Version 2: United States Historical Climatology Network, USHCN , (1895-2007) 1219 Stations**
- **Proposed Version: Stratified The Continental U. S. in Equal Segment**
 - Uniformly Weighted
 - Statistically Correct

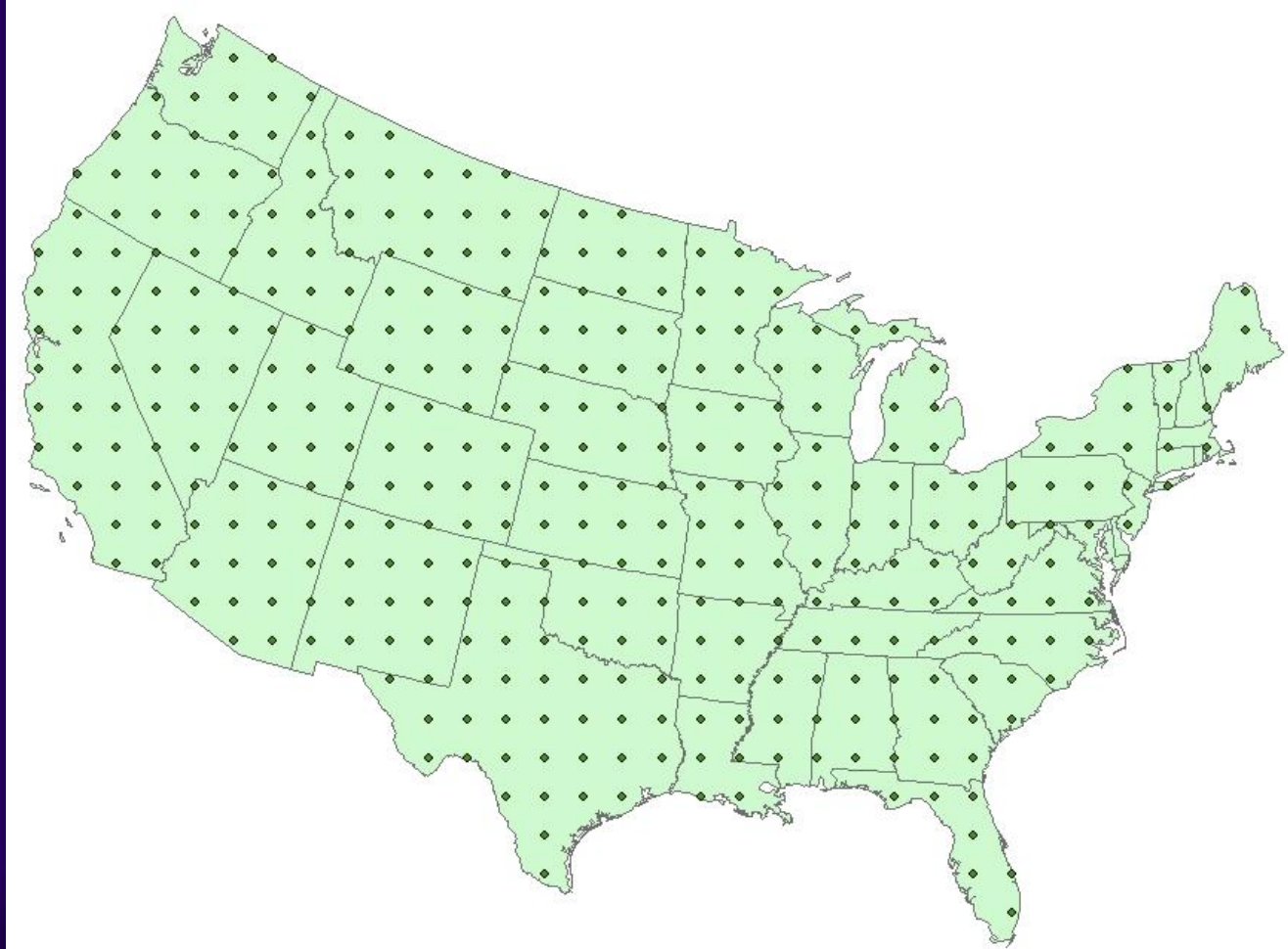
Creating Grid Point

- **Select a random point in bottom left corner of map, use do loops to create points every x meters**



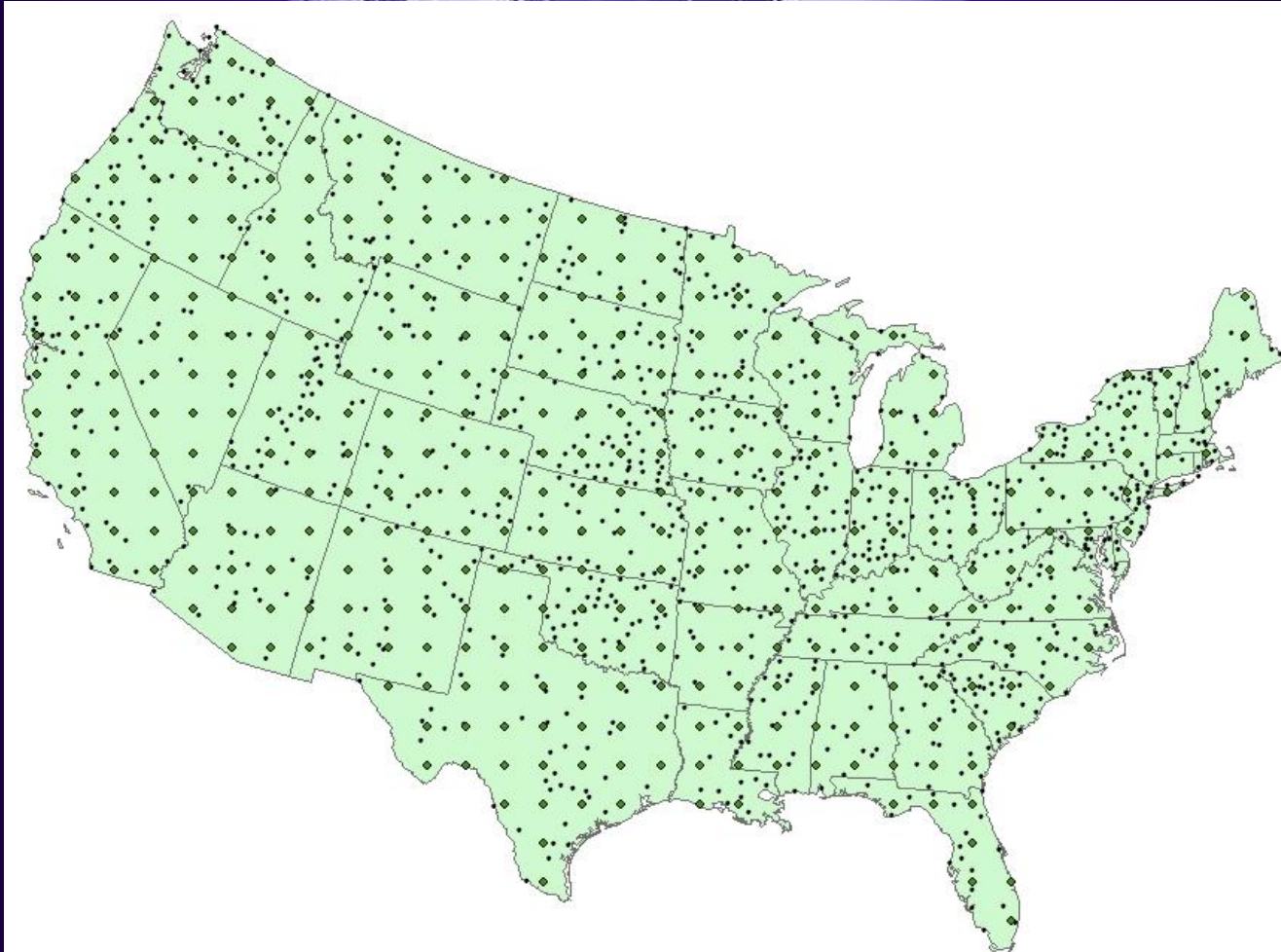
Clipping Grid Point

- **Clip the grids that fall within the boundary of the polygon**



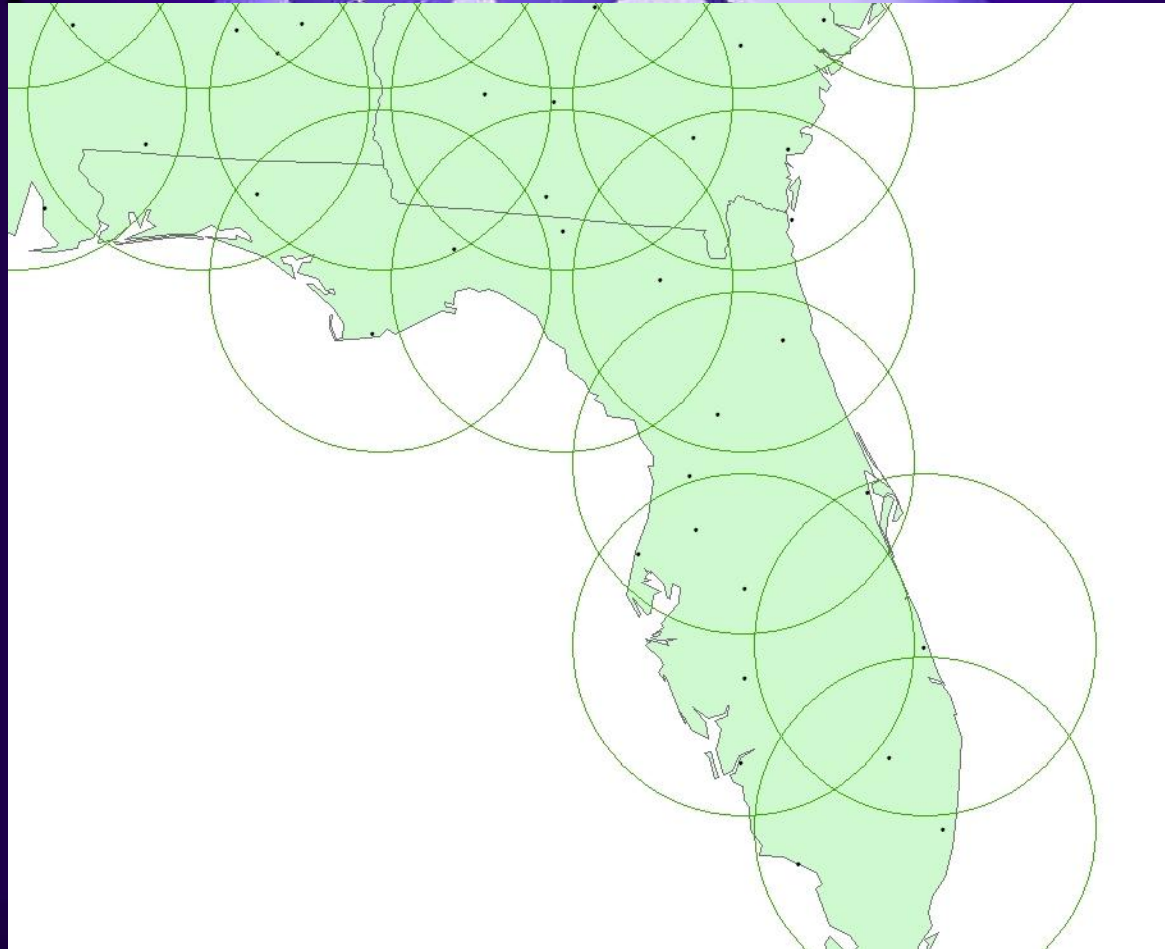
Sampling Stations and Grid Point

- **Output location of stations and grids in meters**



Sampling Stations and Grid Point

- **Select sampling locations within a certain radius of the grid points**



Comparison on Version 2 Temperature VS. Proposed Version

Version 2		* Proposed Version *	
Year	Temperature	Year	Temperature
1998	55.04	1934	56.0452266
2006	54.97	1921	55.32124871
1934	54.87	1931	55.1708375
1999	54.65	1998	55.16739946
1921	54.55	1939	55.07299072
2001	54.38	1953	54.96006998
1931	54.34	1938	54.92172591
2007	54.33	1954	54.90617377
2005	54.31	1999	54.83801259
1990	54.31	1946	54.77032593

Atmospheric Temperature

- **Descriptive Analysis**

- Tabular, Graphical – Not Very Useful

- **Parametric Analysis / Inferential**

- Temperature data follows 3-par. Lognormal pdf

$$f(x; \mu, \theta, \sigma) = \frac{\exp\left\{-\frac{1}{2}\left[\frac{\ln(x-\theta) - \mu}{\sigma}\right]^2\right\}}{(x-\theta)\sigma\sqrt{2\pi}}; x \geq \theta, \mu, \sigma > 0$$

- Scale $\mu: \hat{\mu} = 3.59$

- Shape $\sigma: \hat{\sigma} = 0.019$

-

- Location $\theta: \hat{\theta} = 0.195$

- X: Temperature

- **Thus, we can probabilistically characterize the behavior of temperature and obtain useful information.**

Temperature Forecasting Model

- **Version 2: ARIMA(2,1,1) × (1,1,1)₁₂**

$$\hat{x}_t = 1.0952x_{t-1} - 0.0556x_{t-2} - 0.0396x_{t-3} + 0.9964x_{t-12} - 0.9009x_{t-13} + 0.0554x_{t-14} + 0.0395x_{t-15} + 0.0036\Phi_1x_{t-24} + 0.0916x_{t-25} + 0.0002x_{t-26} + 0.00014x_{t-27} - 0.9855\varepsilon_{t-1} - 0.9741\varepsilon_{t-12} + 0.9599\varepsilon_{t-13}$$

$$\bar{r} = -0.0131$$

$$SE = 0.056$$

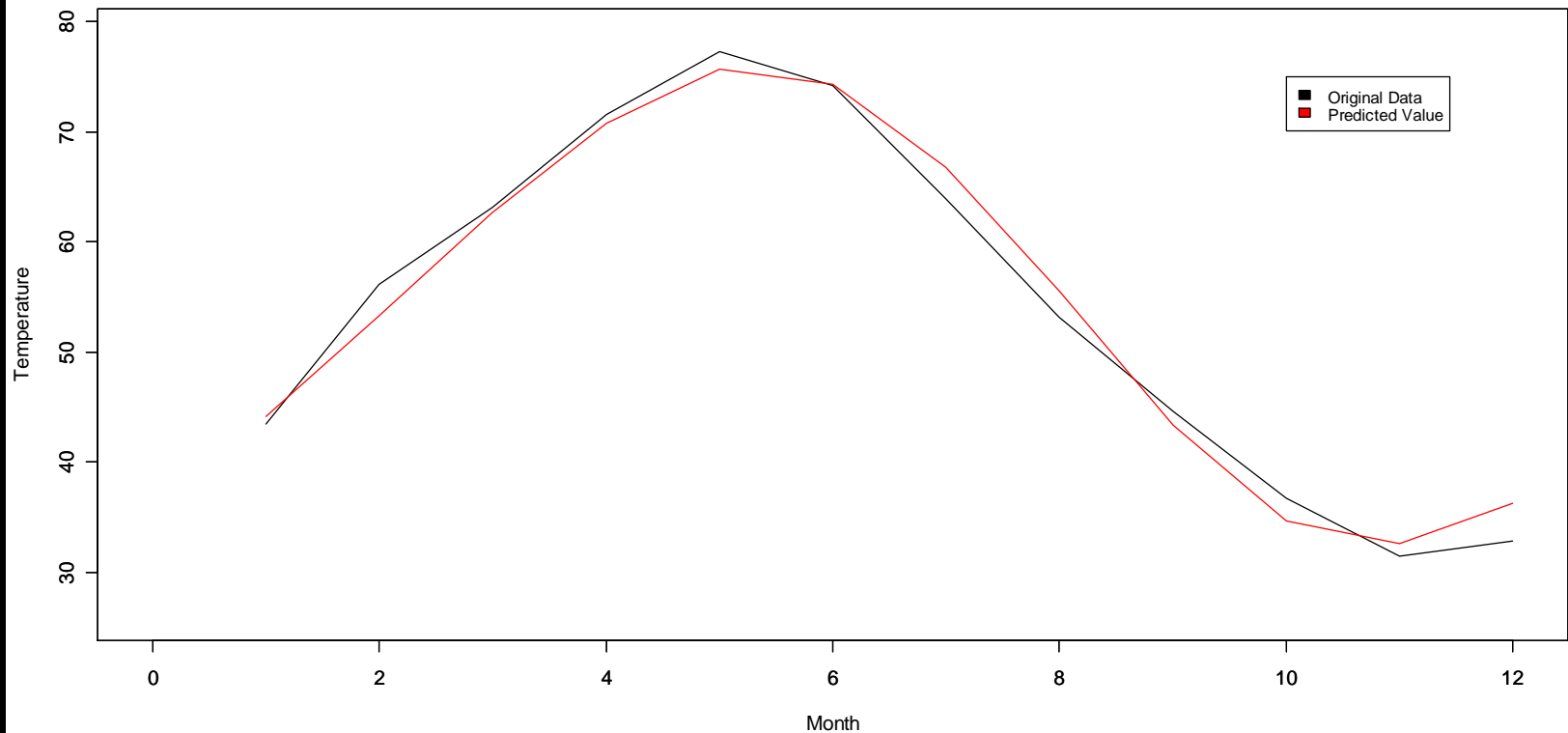
- **Ref. (Shih & Tsokos, Vol. 16, March 2008, NP&S Comp.)**

Estimated Values

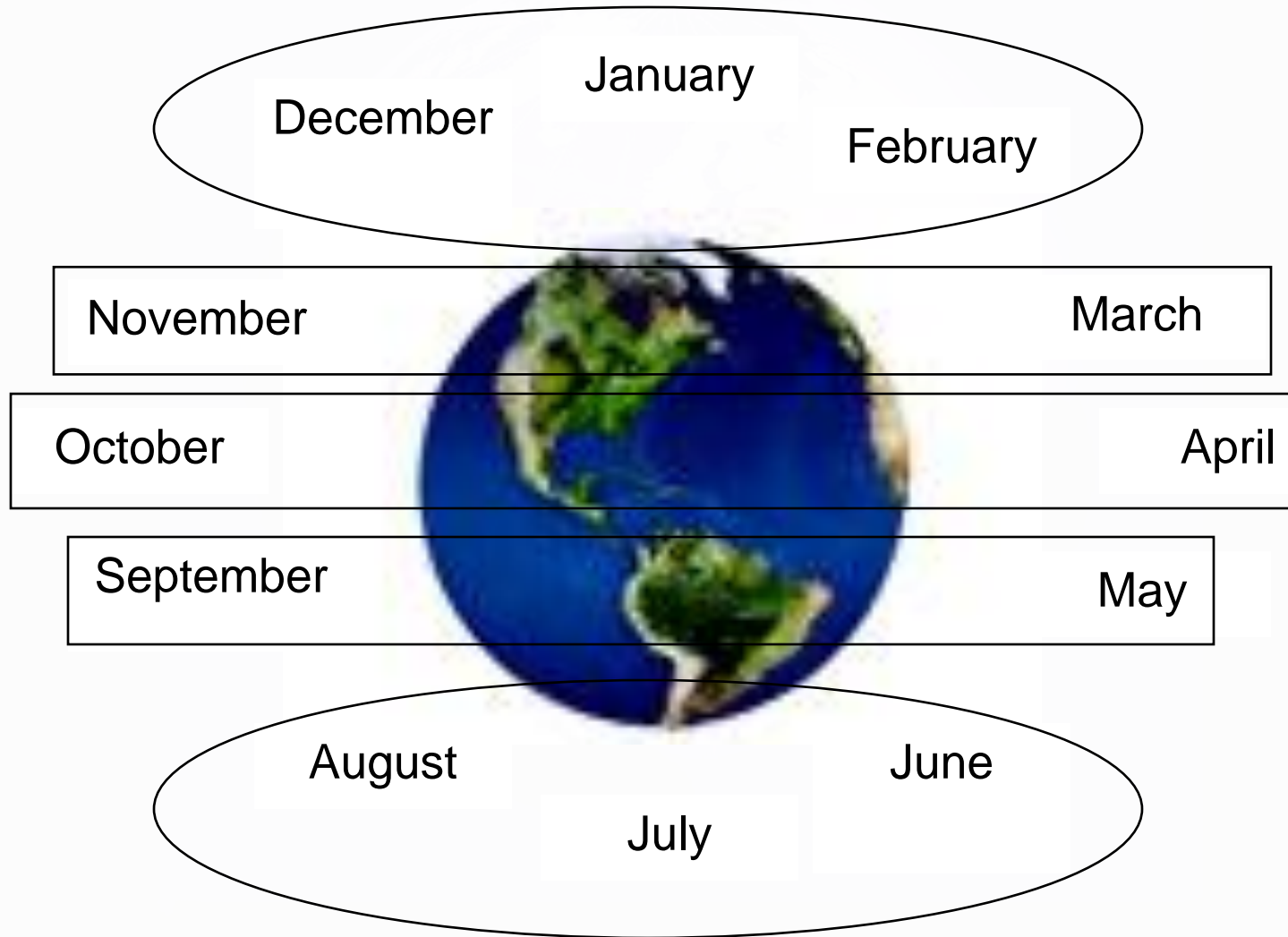


	Original Values	Forecast Values	Residuals
March 2006	43.45	44.1812	-0.7312
April 2006	56.12	53.2506	2.86942
May 2006	63.12	62.6351	0.48486
June 2006	71.55	70.7152	0.83478
July 2006	77.22	75.6947	1.52532
August 2006	74.19	74.3167	-0.1267
September 2006	63.86	66.8069	-2.9469
October 2006	53.13	55.6137	-2.4837
November 2006	44.58	43.3947	1.18529
December 2006	36.79	34.7224	2.06761
January 2007	31.46	32.6854	-1.2254
February 2007	32.86	36.3025	-3.4425

Monthly Temperature VS. Our Predicted Values



Yearly Temperature Patterns

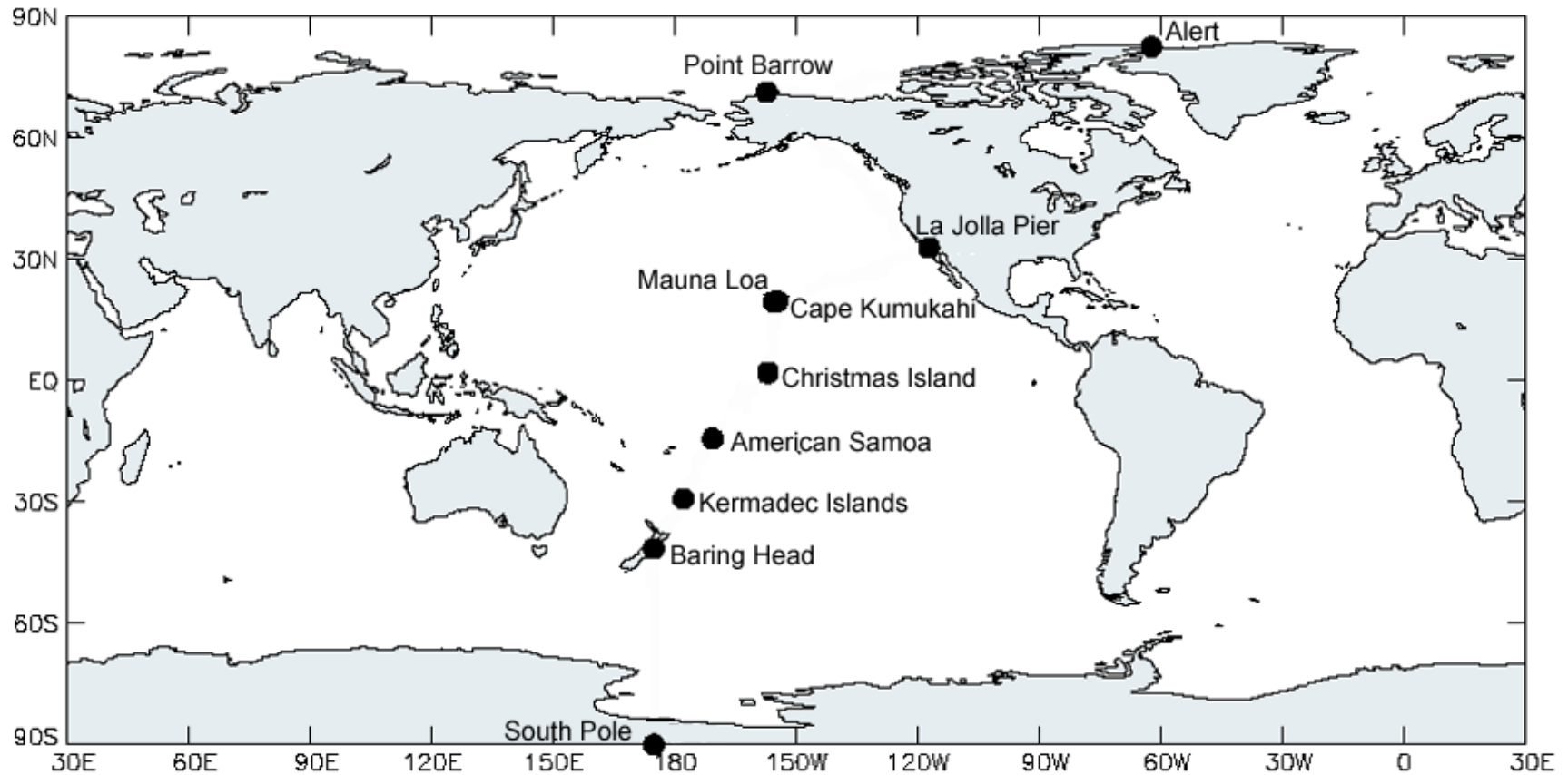


Carbon Dioxide, CO₂




- **CO₂ –**
 - No Color, No Odor, No Taste
 - Puts Out Fire, Puts Fizz in Seltzer
 - It is to plants what oxygen is to us
- **“It is hard to think of CO₂ as a poison”**
- **It is very important to understand its behavior**
- **Atmospheric CO₂: 5.91221 billion metric tons in U.S, Second to China**
- **CO₂ Emissions: Related to Gas, Liquid, Solid Fuels, Gas Flares, Cement Production**

Atmospheric Carbon Dioxide

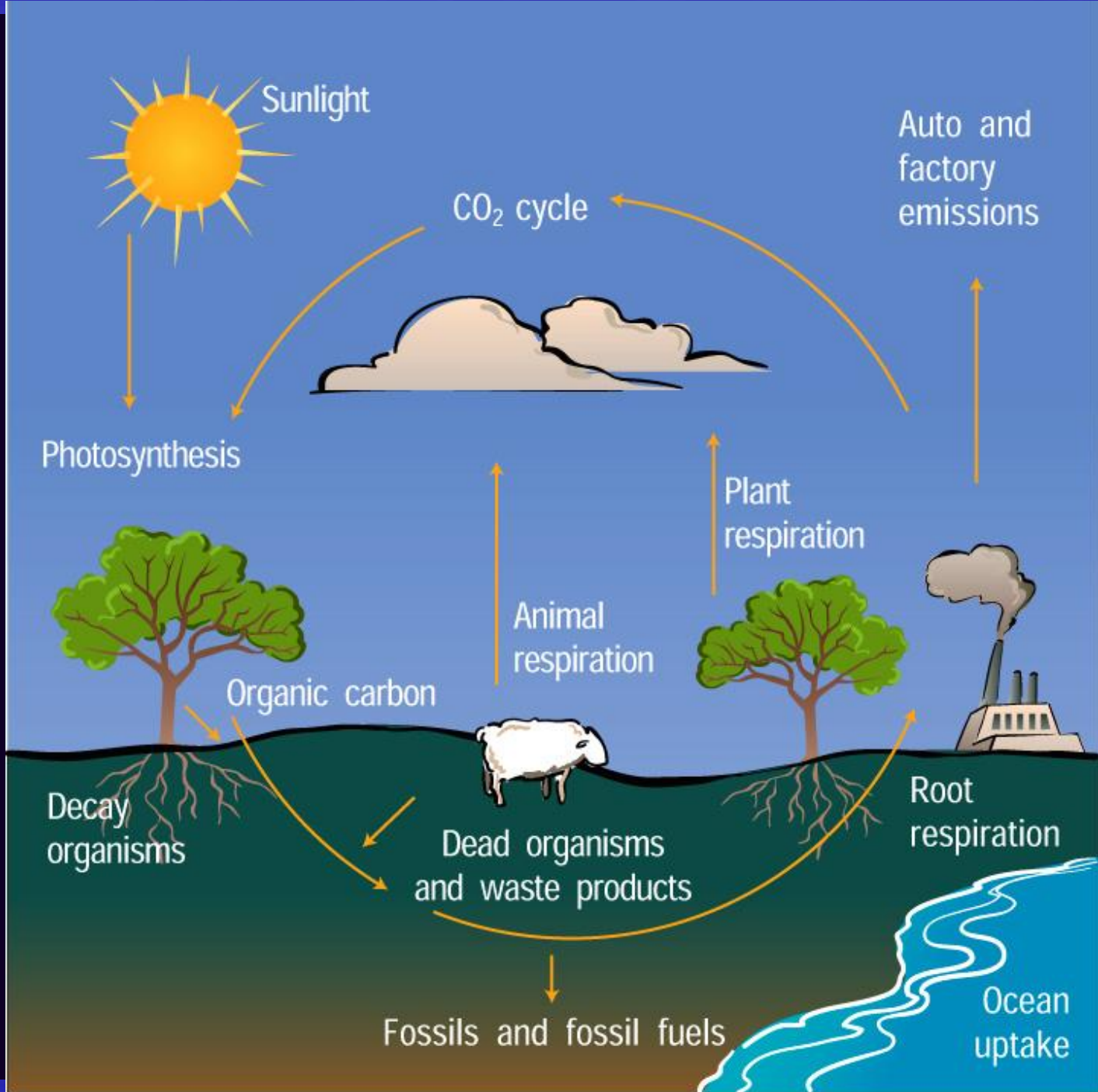


CO₂ in the Atmosphere

8 Contributable Variables



E	CO₂ emission (fossil fuel combustion)
D	Deforestation and destruction
R	Terrestrial plant respiration
S	Respiration
O	the flux from oceans to atmosphere
P	terrestrial photosynthesis
A	the flux from atmosphere to oceans
B	burial of organic carbon and limestone carbon



To Understand CO₂ - Atmosphere

- **We must analyze and model existing data**
 - To have a better understanding of the attributable variables (Rank)
 - To identify possible interactions of the attributable variables
 - Parametric / Inferential Analysis To probabilistically understand the behavior of CO₂
 - Develop forecasting models to accurately predict CO₂ in the future
 - Identify the relationship between Temperature and CO₂ i.e., knowing Temperature predict CO₂, etc.
- **Development of legal policies**
 - Development of Economic models of Global Warming for implementing legal policies

Atmospheric CO₂ (1958-2004)

Parametric Analysis / Inferential

- It is best characterized by the 3-par. Weibull, and its cumulative form is given by

$$F(x) = 1 - \exp \left\{ - \left(\frac{x - \gamma}{\beta} \right)^\alpha \right\}; x > 0$$

- Scale $\beta : \hat{\beta} = 23.029$

- Shape $\alpha : \hat{\alpha} = 2.779$

- Location $\gamma : \hat{\gamma} = 343.7$

- X: Atmospheric CO₂

$$F(x) = 1 - \exp \left\{ - \left(\frac{x - 343.7}{23.029} \right)^{2.779} \right\}$$

- Thus, we can obtain, E[X], Var[X], S.D[X], Confidence limits, etc.

Trend Analysis: Determine If Atmospheric CO₂ Depends on Time

■ The $E(X) = \beta \cdot \Gamma(1 - \frac{1}{\alpha}) = \mu$ where Γ : gamma function

■ Consider $\mu_t = f(t) + \varepsilon$

■ Best Fit

$$\hat{\mu}_t = 314.028 + .00225t + 8.7475 \times 10^{-8} t^2$$

$$\hat{\alpha} = 2.108; \hat{\beta}_t = \frac{\hat{\mu}_t}{0.8857}; \Gamma(1 + \frac{1}{2.108}) \approx 0.8857$$

■ Thus, F(x) as a function of time, is

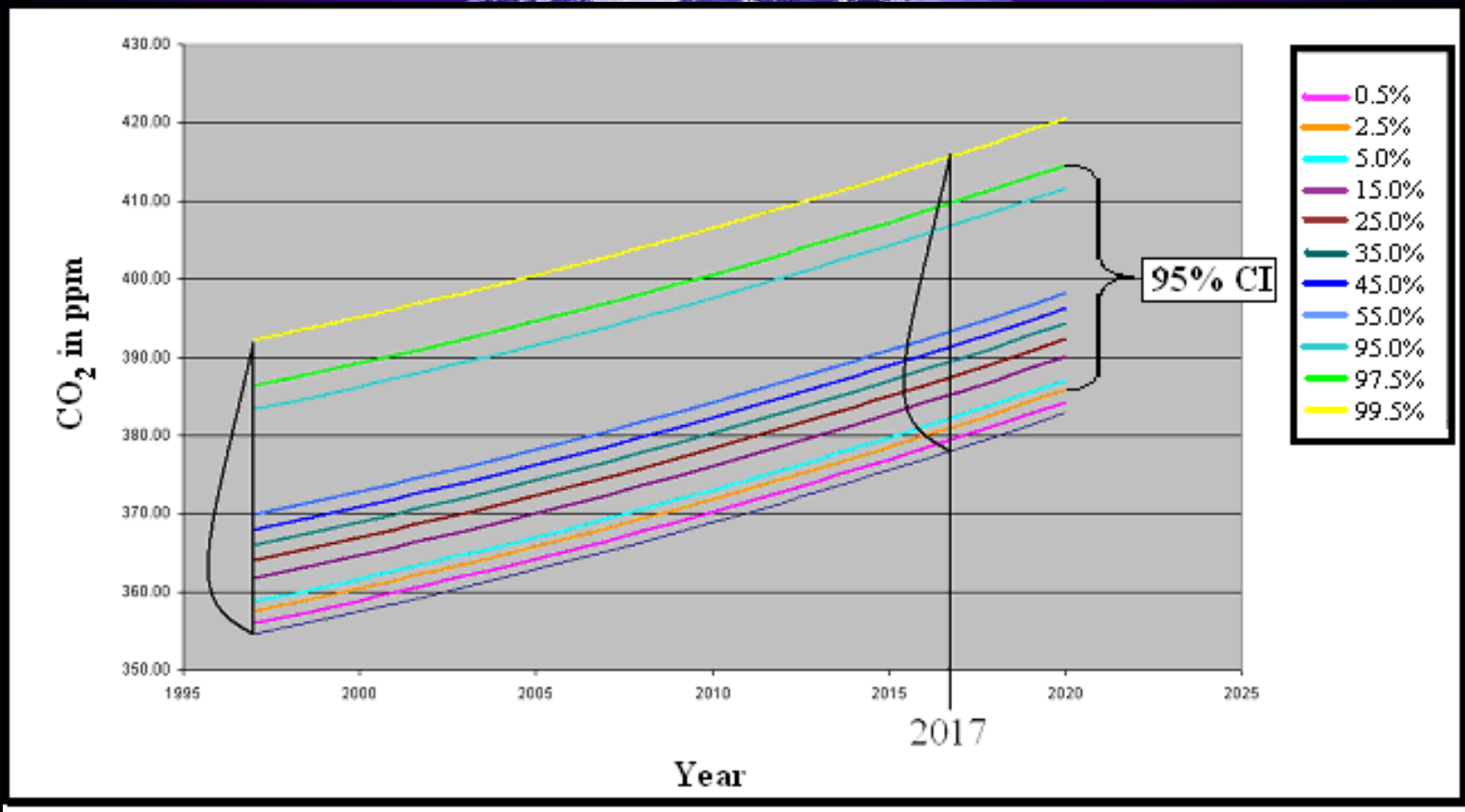
$$F(x) = 1 - \exp \left\{ - \left(\frac{x - (354.5534 + .00225t + 8.7475 \times 10^{-8} t^2)}{17.092} \right)^{2.108} \right\}$$

■ Using this result we can obtain projections with a desired degree of confidence, ten, twenty, fifty years from now.

Trend Analysis: Determine If Atmospheric CO₂ Depends on Time (Continued)

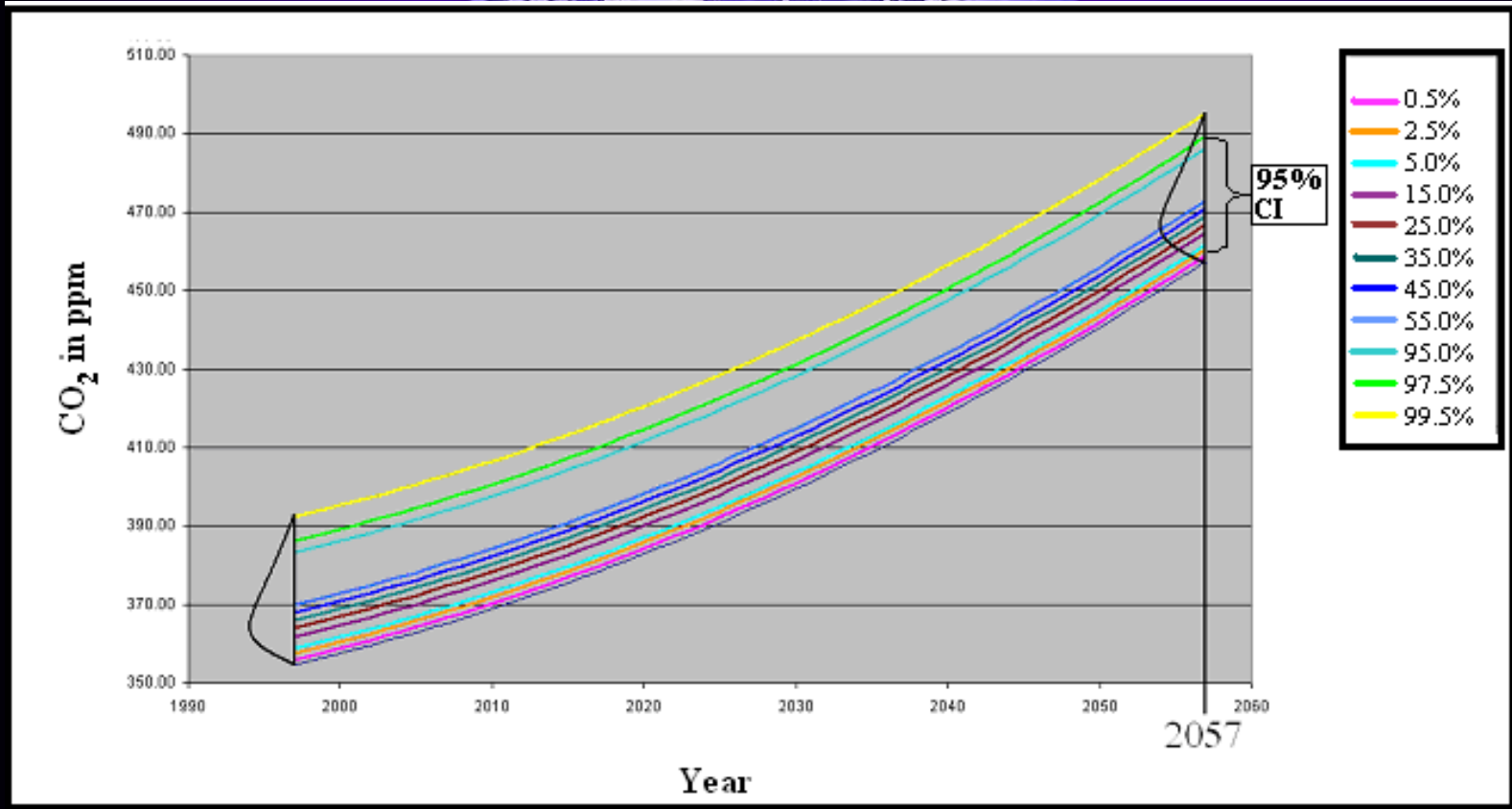
- That is, 10 years from now, 2018, at 95% level of confidence that the probable amount of carbon dioxide in the atmosphere will be between 381.35 and 410.11 ppm.
- 20 years, 2028, 95% CL, between 397.2 and 425.96 ppm, etc.

Profiling: Ten Year Projections




Projections through 2018

Profiling: Fifty Year Projections



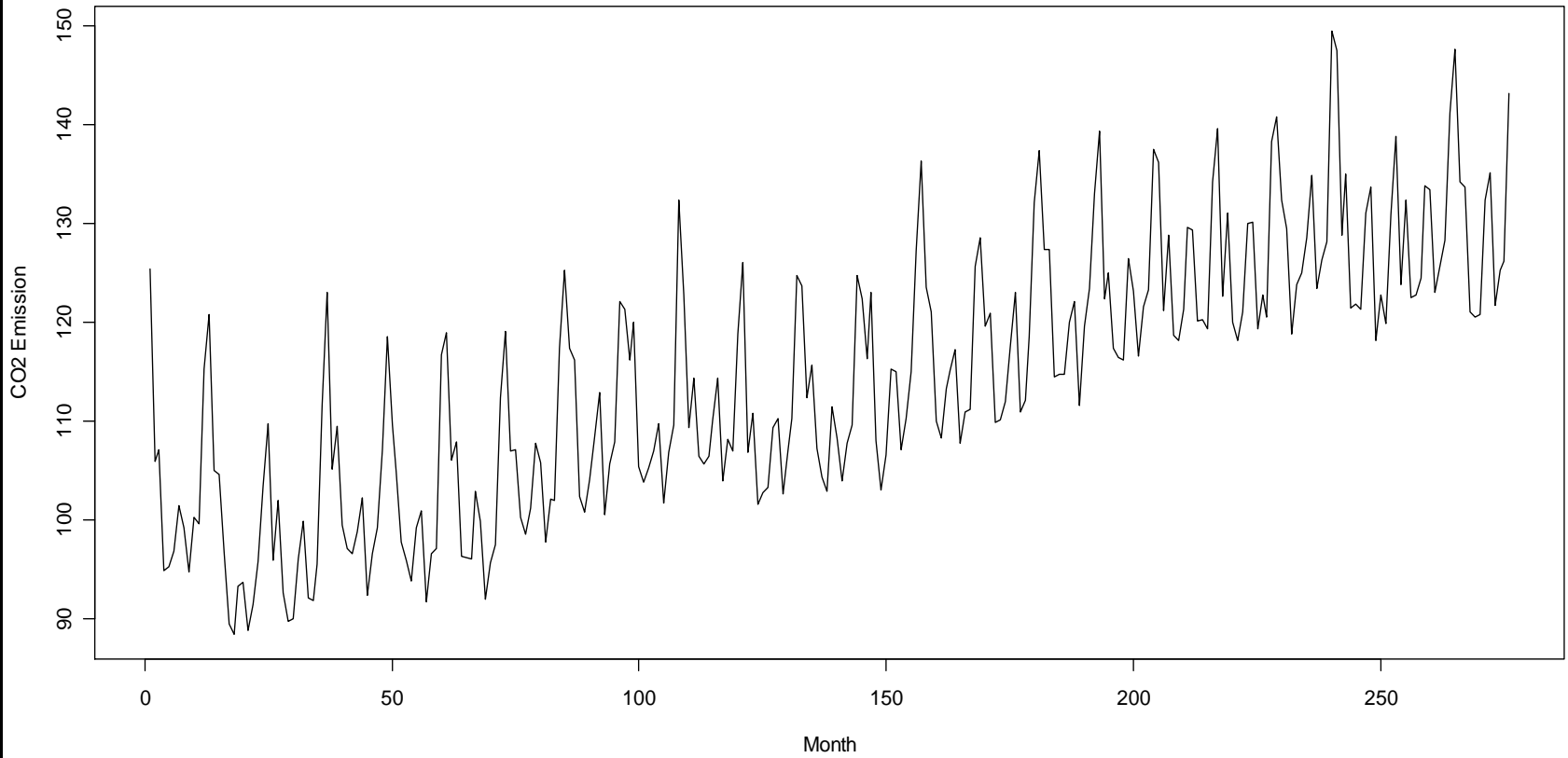
Projections through 2057

Confidence Intervals



Year	90% CI		95% CI		99% CI	
	Lower Limit	Upper Limit	Lower Limit	Upper Limit	Lower Limit	Upper Limit
2007	369.32	393.91	368.13	396.89	366.53	402.84
2008	370.52	395.11	369.33	398.09	367.73	404.04
2009	371.75	396.34	370.57	399.33	368.96	405.28
2010	373.01	397.60	371.82	400.58	370.22	406.53
2011	374.29	398.88	373.10	401.86	371.50	407.81
2012	375.60	400.18	374.41	403.17	372.81	409.12
2013	376.94	401.52	375.75	404.51	374.14	410.46
2014	378.30	402.88	377.11	405.87	375.50	411.82
2015	379.68	404.27	378.49	407.25	376.89	413.20
2016	381.09	405.68	379.91	408.67	378.30	414.62
2017	382.54	407.12	381.35	410.11	379.75	416.06
2018	384.00	408.59	382.81	411.57	381.21	417.52
2019	385.50	410.08	384.31	413.07	382.70	419.02
2020	387.01	411.60	385.82	414.58	384.22	420.53
2021	388.56	413.15	387.37	416.13	385.77	422.08
2022	390.13	414.72	388.94	417.70	387.34	423.65
2023	391.73	416.32	390.54	419.30	388.94	425.25
2024	393.35	417.94	392.16	420.92	390.56	426.87
2025	395.01	419.59	393.82	422.58	392.22	428.53
2026	396.68	421.27	395.49	424.25	393.89	430.20
2027	398.39	422.97	397.20	425.96	395.60	431.91

Time Series Plot on Monthly CO₂ Emissions 1981-2003



The CO₂ Emissions Model

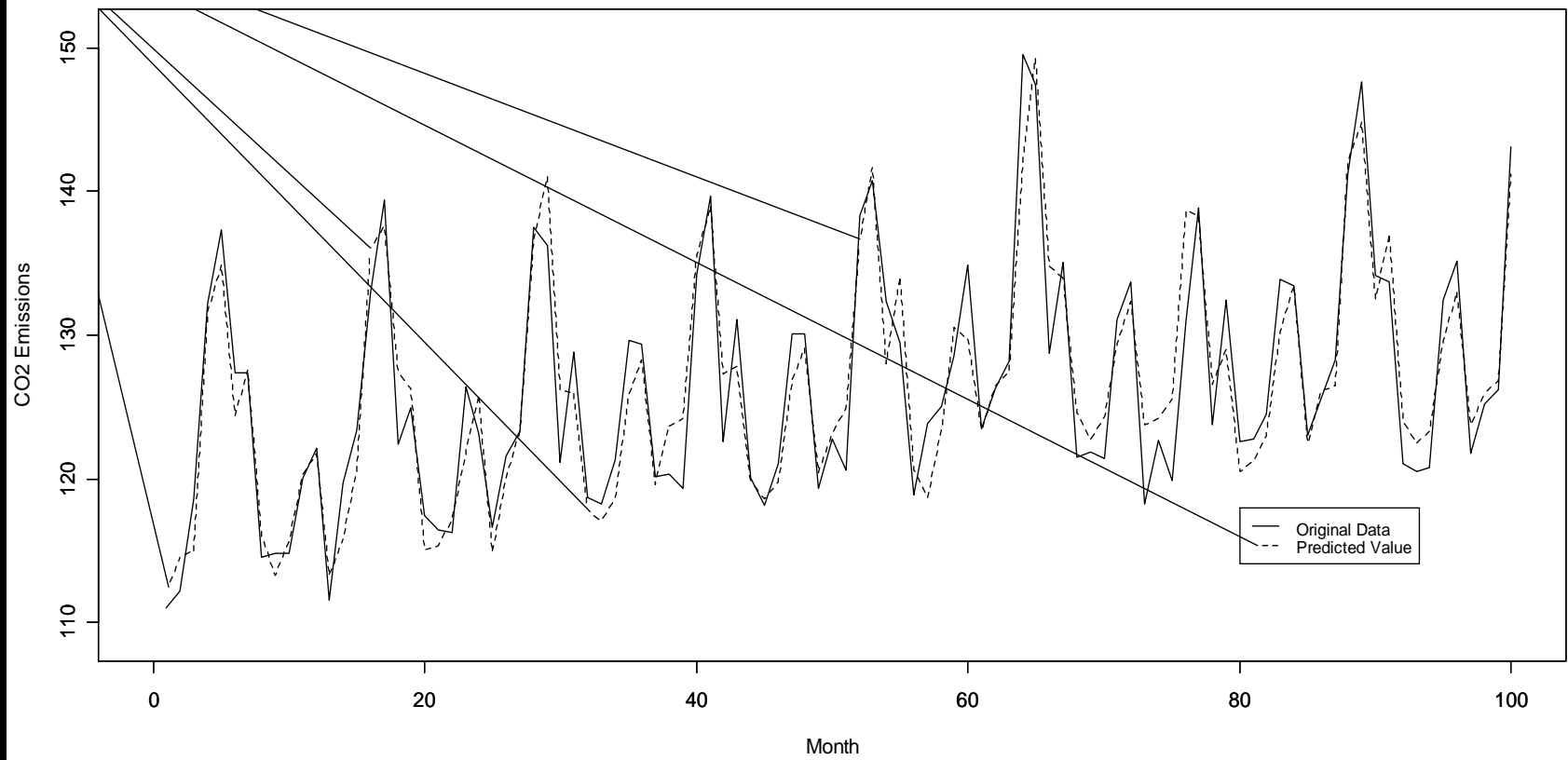
- ARIMA(1,1,2) × (1,1,1)₁₂

$$(1 - \Phi_1 B^{12})(1 - \phi_1 B)(1 - B)(1 - B^{12})x_t = (1 - \theta_1 B - \theta_2 B^2)(1 - \Gamma_1 B^{12})\varepsilon_t$$

- After expanding the model and inserting the coefficients, we have

$$\begin{aligned}\hat{CO}_{2E} &= 1.5203x_{t-1} - 0.5203x_{t-2} + 1.0049x_{t-12} - 1.527749x_{t-13} + 0.5228495x_{t-14} \\ &\quad - 0.0049x_{t-24} + 0.007449x_{t-25} - 0.002549x_{t-26} - 0.9988\varepsilon_{t-1} + 0.1234\varepsilon_{t-2} \\ &\quad - 0.8523\varepsilon_{t-12} + 0.8512772\varepsilon_{t-13} - 0.10517\varepsilon_{t-14}\end{aligned}$$

Monthly CO₂ Emissions VS. Forecast Values for the Last 100 Observations

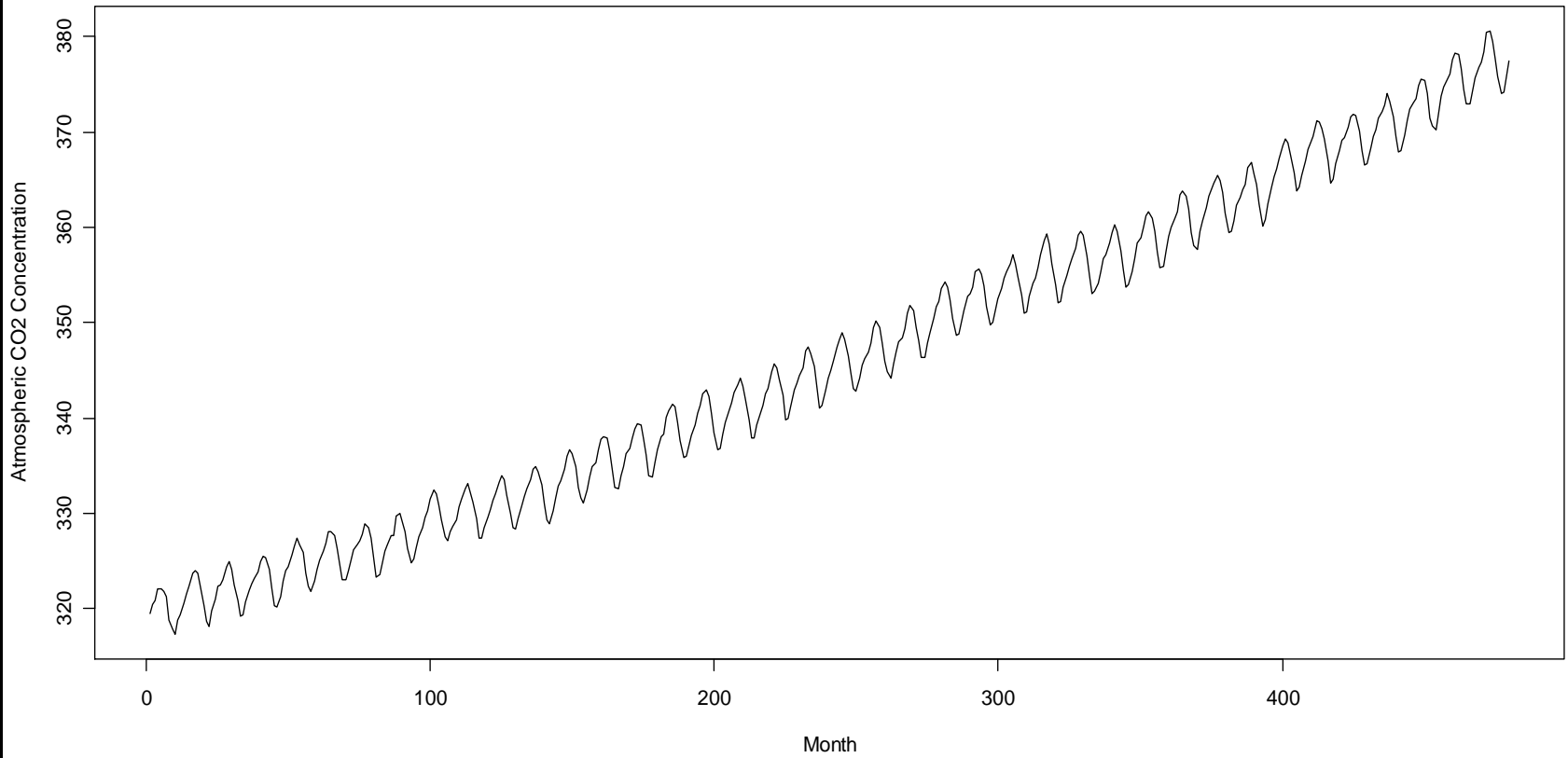


CO₂ Emissions Forecast



	Original Values	Forecast Values	Residuals
Jan-03	147.6298	145.2361	2.3937
Feb-03	134.1716	132.6554	1.5162
Mar-03	133.6979	137.3912	-3.6933
Apr-03	121.0047	124.5518	-3.5471
May-03	120.4789	122.4091	-1.9302
Jun-03	120.7394	123.101	-2.3616
Jul-03	132.4187	129.3481	3.0706
Aug-03	135.1314	132.787	2.3444
Sep-03	121.7753	123.8295	-2.0542
Oct-03	125.2487	125.9811	-0.7324
Nov-03	126.2127	126.812	-0.5993
Dec-03	143.1509	141.1834	1.9675

Time Series Plot for Monthly CO₂ in the Atmosphere 1965-2004



The Atmospheric CO₂ Model

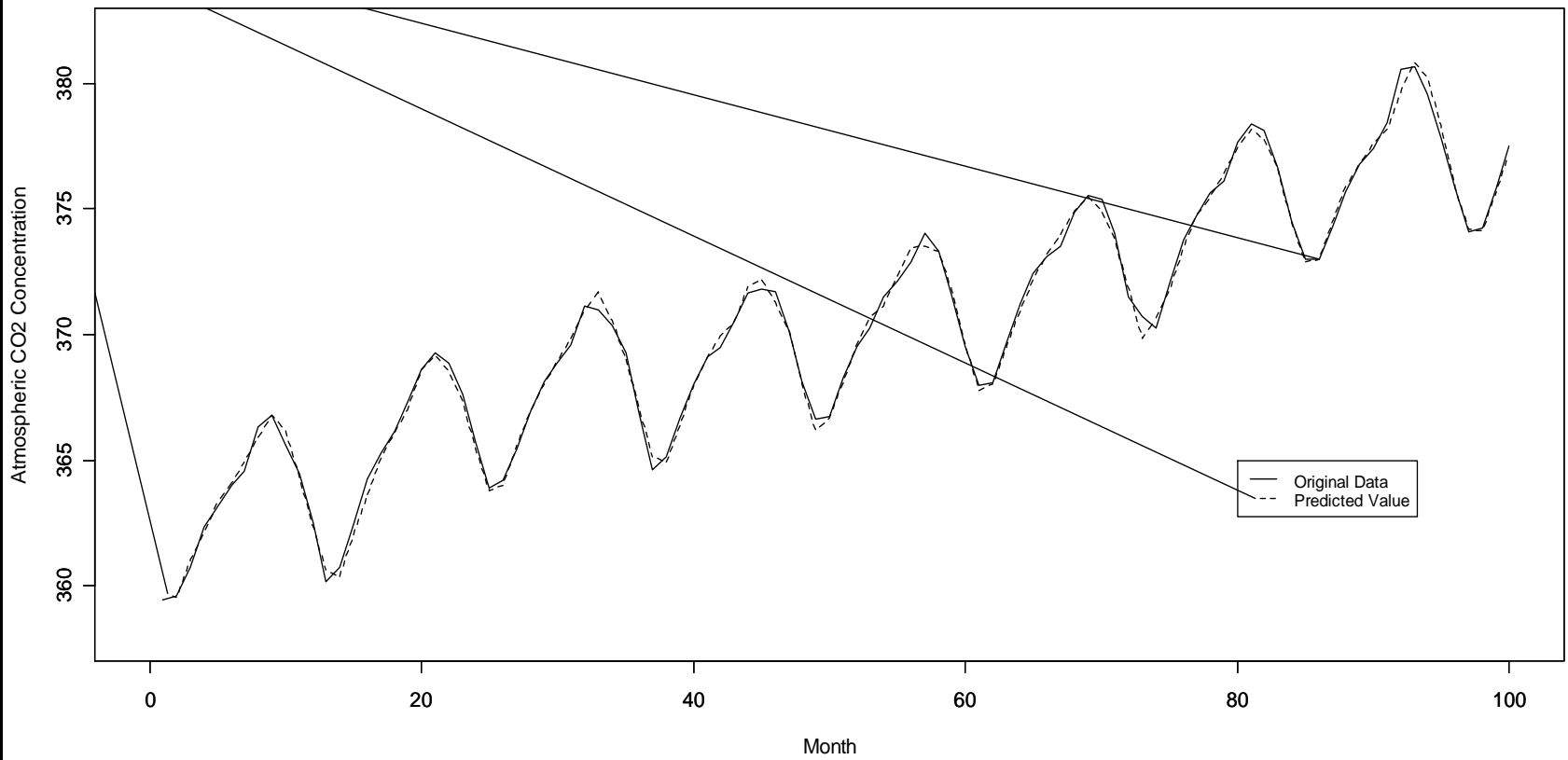
- ARIMA(2,1,0) × (2,1,1)₁₂

$$(1 - \Phi_1 B^{12} - \Phi_2 B^{24})(1 - \phi_1 B - \phi_2 B^2)(1 - B)(1 - B^{12})x_t = (1 - \Gamma_1 B^{12})\varepsilon_t$$


- After expanding the model and inserting the coefficients, we have

$$\begin{aligned} \hat{CO}_{2A} = & 0.6887x_{t-1} + 0.1989x_{t-2} + 0.1124x_{t-3} + 1.0759x_{t-12} - 0.74097x_{t-13} - \\ & 0.213997x_{t-14} - 0.12093x_{t-15} - 0.0683x_{t-24} + 0.047038x_{t-25} + \\ & 0.013585x_{t-26} + 0.00768x_{t-27} - 0.0076x_{t-36} + 0.005234x_{t-37} + \\ & 0.0015116x_{t-38} + 0.00085x_{t-39} - 0.8787\varepsilon_{t-12} \end{aligned}$$

Monthly CO₂ in the Atmosphere VS. Forecast Values for the Last 100 Observations




Atmospheric CO₂ Forecast



	Original Values	Forecast Values	Residuals
Jan-04	376.79	376.7963	-0.0063
Feb-04	377.37	377.609	-0.239
Mar-04	378.41	378.1837	0.2263
Apr-04	380.52	379.6653	0.8547
May-04	380.63	380.8268	-0.1968
Jun-04	379.57	380.2339	-0.6639
Jul-04	377.79	378.3489	-0.5589
Aug-04	375.86	375.837	0.023
Sep-04	374.06	374.1871	-0.1271
Oct-04	374.24	374.1482	0.0918
Nov-04	375.86	375.6897	0.1703
Dec-04	377.48	377.2186	0.2614

Total Atmospheric CO2



E	CO2 emission (fossil fuel combustion)	C1	Gas fuels
		C2	Liquid fuel
		C3	Solid fuel
		C4	Gas flares
		C5	Cement production
D	Deforestation and destruction	D1	deforestation
		D2	destruction of biomass
		D3	destruction of soil carbon
R	Terrestrial plant respiration		Only one variable
S	Respiration	S1	respiration from soils
		S2	respiration from decomposers
O	the flux from oceans to atmosphere		Only one variable
P	terrestrial photosynthesis		Only one variable
A	the flux from atmosphere to oceans		Only one variable
B	burial of organic carbon and limestone carbon	B1	the burial of organic carbon
		B2	burial of limestone carbon

Statistical Model for CO2 Emissions

$$\hat{CO}_{2E} = 807025.289 + 5.31 \times 10^{-6} C_1 C_3 - 57.529 C_4 + 5.228 \times 10^{-3} C_4 C_5 - 9.769 \times 10^{-5} C_1 C_5 + .255 C_2$$

- **C_2 & C_4 alone contributions**
- **C_1, C_3, C_5 Do not contribute alone, but their interactions contribute ($C_4 C_5, C_1 C_3, C_1 C_5$)**

Differential Equation of Atmospheric CO₂

$$\frac{d(\text{CO}_2)}{dt} = f(E, D, R, S, O, P, A, B)$$

8 Contributable Variables

E	CO₂ emission (fossil fuel combustion)
D	Deforestation and destruction
R	Terrestrial plant respiration
S	Respiration
O	the flux from oceans to atmosphere
P	terrestrial photosynthesis
A	the flux from atmosphere to oceans
B	burial of organic carbon and limestone carbon

Differential Equation of Atmospheric CO₂

$$CO_{2_A} = \int \{E + D + R + S + (O - A) - P - B\} dt$$

- **Note: B, P, R are constants, thus**

$$CO_{2_A} = \int \{k_E E + k_D D + k_R R + k_S S + k_{O-A} (O - A) - k_P P - k_B B\} dt$$

$$CO_2 = \left\{ \begin{array}{l} k_E \left\{ -593503t + 2.4755 \times 10^9 e^{\left(\frac{t}{1200}\right)} \right\} \\ + k_D (10730.5t + 0.01625t^2) \\ + k_S \left\{ -0.132(1995 + \frac{t}{12})^4 + 1054.4(1995 + \frac{t}{12})^3 \right\} \\ - 315462(1995 + \frac{t}{12})^2 + 3 \times 10^8 t \\ + k_{A-O} \{42.814t - 4.2665t^2 + 0.0967t^3\} \\ - k_P \int P dt - k_B \int B dt \end{array} \right.$$