# CORPORATE RESEARCH PROGRAM IN CLIMATE/$CO_2$-GREENHOUSE

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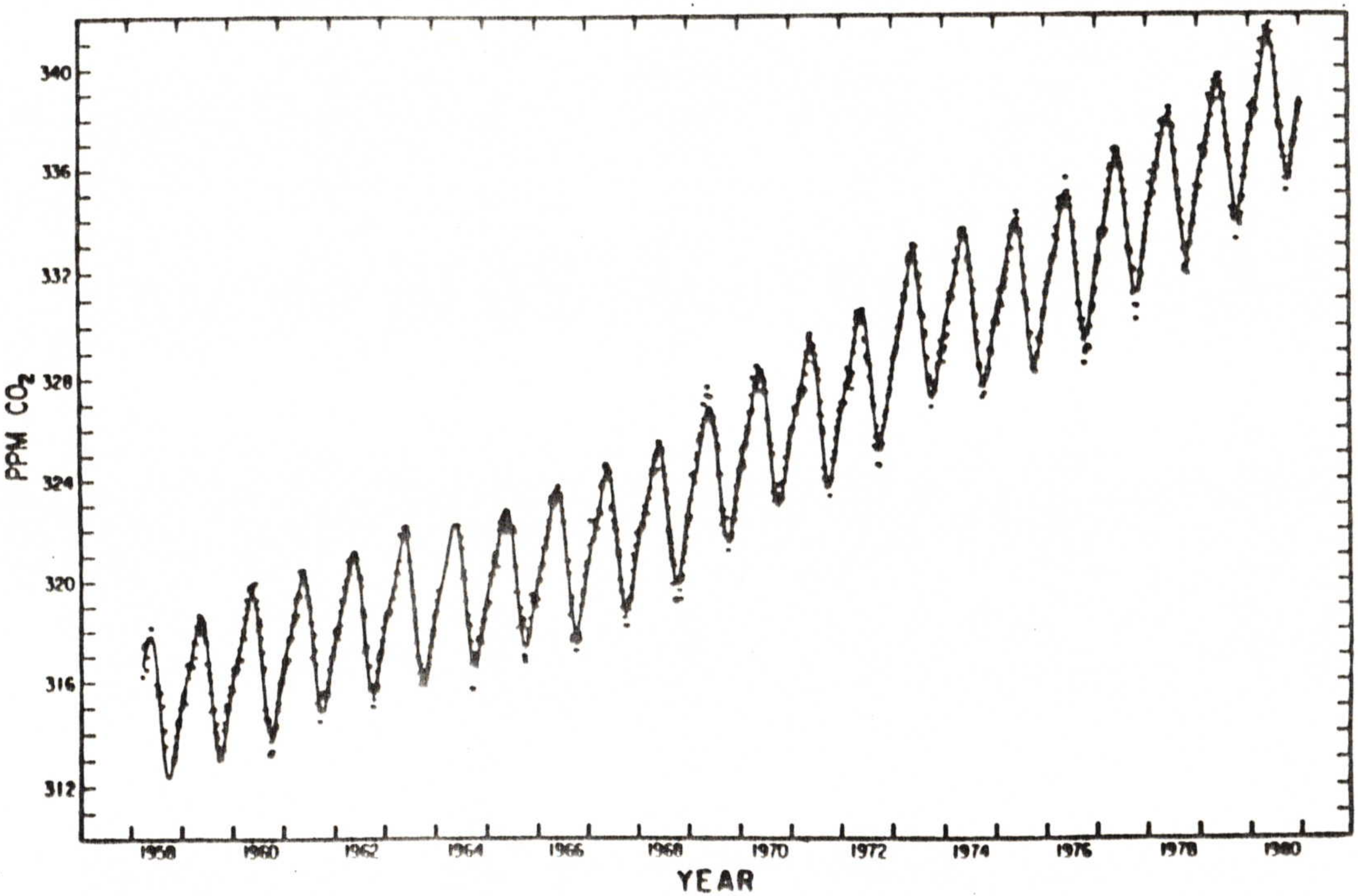
# CORPORATE RESEARCH PROGRAM

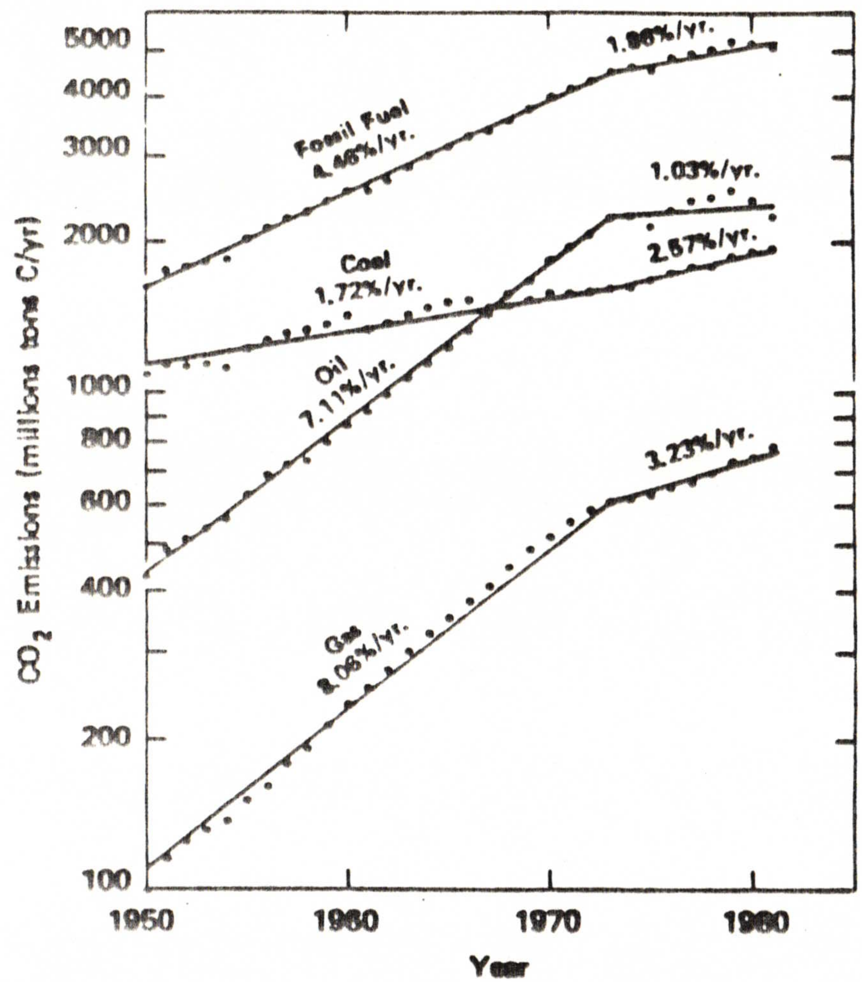
- OBJECTIVES
  - PROVIDE EXXON WITH A SOURCE OF EXPERTISE IN AN AREA WHICH COULD HAVE MAJOR IMPACT ON FUTURE BUSINESS ENVIRONMENT
  - HELP STIMULATE AND CONTRIBUTE TO A BROAD SCIENTIFIC INVESTIGATION OF $CO_2$ EFFECTS

- APPROACHES
  - ESTABLISH A SCIENTIFIC PRESENCE THROUGH RESEARCH PROGRAM IN CLIMATE MODELING
  - SELECTIVE SUPPORT OF OUTSIDE ACTIVITIES
  - MAINTAIN AWARENESS OF NEW SCIENTIFIC DEVELOPMENTS

# CONCENTRATION OF ATMOSPHERIC $CO_2$ AT MAUNA LOA OBSERVATORY, HAWAII

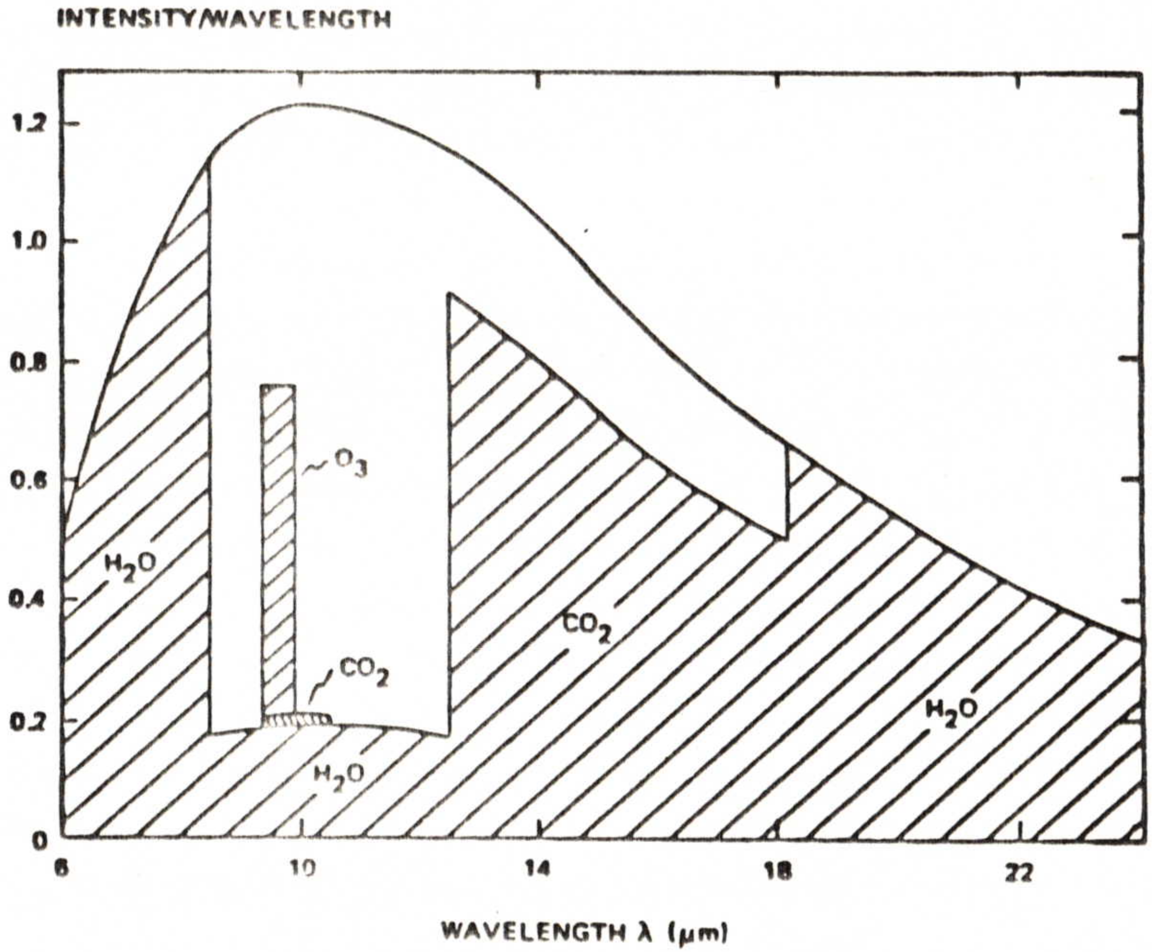


## INDUSTRIAL $CO_2$ PRODUCTION



## BASIS FOR $CO_2$-GREENHOUSE EFFECT

- ATMOSPHERIC ABSORPTION OF INFRARED RADIATION INCREASES EARTH's TEMPERATURE BY ~35°K
- INCREASING $CO_2$ AND OTHER TRACE GASES ABSORB IN THE REMAINING ATMOSPHERIC WINDOWS



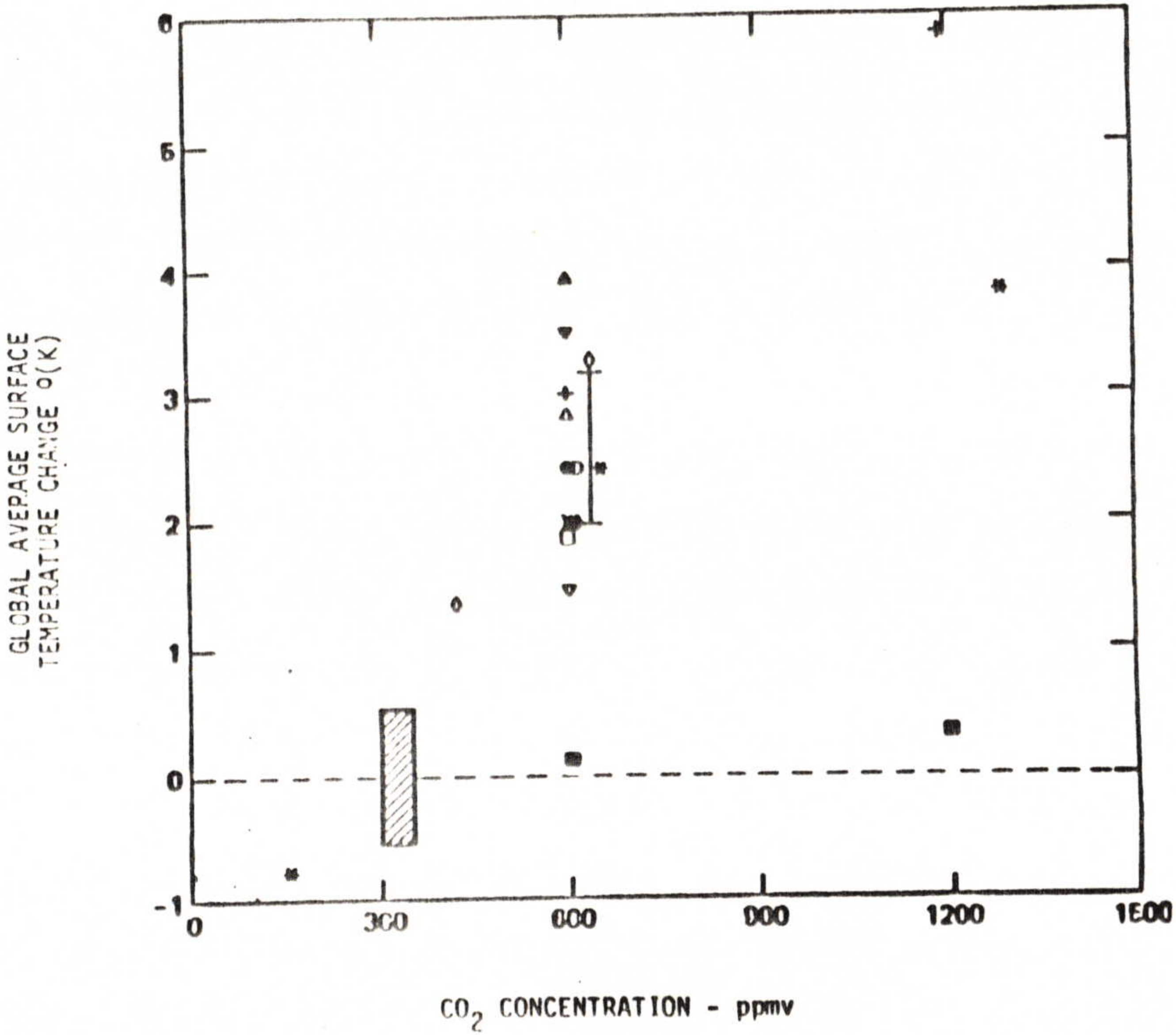
# ROLE OF MATHEMATICAL MODELING

- MODELS ARE BEING USED TO EXPLORE PHYSICAL EFFECTS (SCENARIOS) AND AS A PREDICTIVE TOOL
    - CARBON CYCLE MODELING TO DETERMINE FATE OF FOSSIL-FUEL $CO_2$ EMISSIONS
    - CLIMATE MODELING TO STUDY EFFECTS OF ATMOSPHERIC $CO_2$ INCREASES ON THE EARTH'S CLIMATE

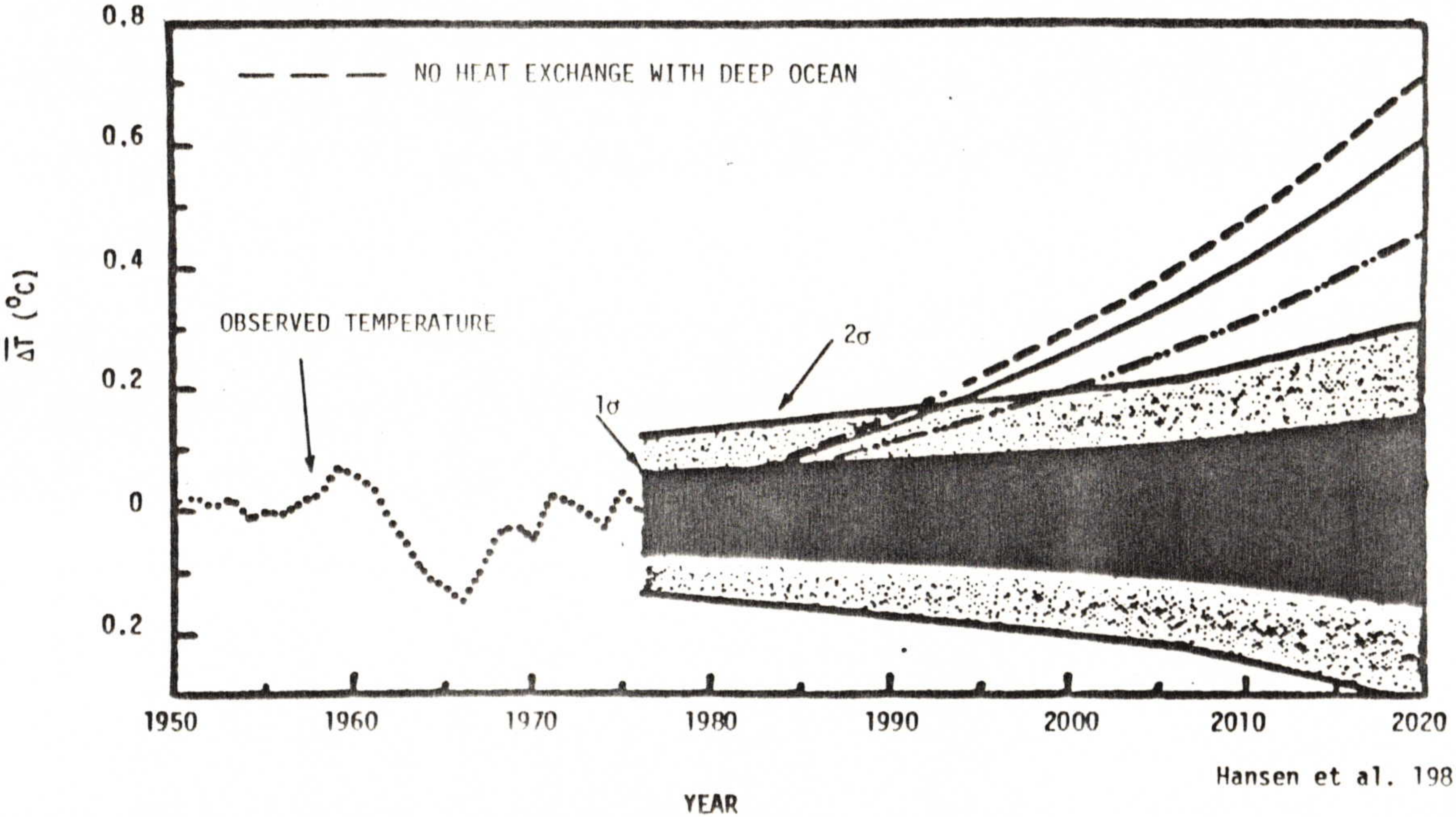
- VALIDITY OF MODELS NOT ESTABLISHED
    - COMPLEXITY OF CARBON CYCLE AND CLIMATE SYSTEM REQUIRE MANY APPROXIMATIONS AND PARAMETERIZATIONS
    - GEOLOGICAL AND HISTORICAL DATA ARE INADEQUATE FOR VALIDATION OF MODELS

# CLIMATE MODEL CONSENSUS

- ESTIMATES OF THE CHANGE IN GLOBAL AVERAGE SURFACE TEMPERATURE DUE TO VARIOUS CHANGES IN $CO_2$ CONCENTRATION
  - SHADING SHOWS PRESENT RANGE OF NATURAL FLUCTUATIONS



# FIRST EFFECTS PREDICTED BY YEAR 2000




Hansen et al. 1981

# POTENTIAL CLIMATIC EFFECTS

- CLIMATIC EFFECT OF $CO_2$ DOUBLING (NRC)
  - MEAN SURFACE TEMPERATURE RISE OF BETWEEN 1.5°C AND 4.5°C WITH "VALUES IN LOWER HALF OF RANGE MOST PROBABLE"
  - SIGNIFICANT LATITUDINAL TEMPERATURE VARIATIONS WITH INCREASES 2-3 TIMES MEAN IN POLAR REGIONS
  - COVERAGE AND THICKNESS OF SEA ICE DECREASES - SEA LEVEL RISE
  - HYDROLOGICAL CHANGES INDICATING SUMMER SOIL MOISTURE DECREASES IN MIDDLE AND HIGH LATITUDES OF NORTHERN HEMISPHERE

- ACTIVE AREAS OF SCIENTIFIC RESEARCH
  - MODEL VALIDATION TO STRENGTHEN CURRENT CONSENSUS
  - MONITORING AND EARLY DETECTION STRATEGIES

## CR ACTIVITIES

- CR RESEARCH IN CLIMATE MODELING AND $CO_2$-GREENHOUSE EFFECT (CALLEGARI, FLANNERY, HOFFERT (NYU))

  - EMPHASIZES ENERGY BALANCE MODELS

    (1) EXPLORE PHYSICAL EFFECTS (SCENARIOS)

    (2) TRANSIENT MODELING

- SERVE ON DOE-STATE-OF-THE-ART SUBCOMMITTEE THAT WILL PRODUCE REPORT ON TRANSIENT CLIMATE MODELING AND RESPONSE TO $CO_2$ INCREASES

  - PART OF GENERAL STATE-OF-THE-ART DOE REPORT

- SUPPORT RESEARCH AT COLUMBIA UNIVERSITY'S LAMONT GEOLOGICAL OBSERVATORY (BROECKER, TAKAHASHI)

  - OCEANIC $CO_2$-UPTAKE

  - OUTGROWTH OF EXXON TANKER PROGRAM

# EXXON SPONSORED LAMONT PROGRAM

- OCEANIC $CO_2$ MEASUREMENT PROGRAM: AIR-SEA EXCHANGE, TRANSPORT, CHEMISTRY IN WINTER NORTH ATLANTIC
  - CARBON CYCLE AIRBORNE FRACTION
  - PRE-INDUSTRIAL ATMOSPHERIC $CO_2$ CONTENT
  - SEASONAL $P(CO_2)$ VARIATION IN MIXED LAYER
- RESULTS THUS FAR INDICATE MUCH MORE VARIABILITY (SEASONAL) IN OCEAN CIRCULATION THAN PREVIOUSLY THOUGHT
  - WINTER $CO_2$-UPTAKE AND TRANSPORT TO DEEP WATER COMPLEX DUE TO LOCALLY LOWER AIR-SEA EXCHANGE BUT HIGHER DEEP WATER VENTILATION
  - DETERMINATION OF PRE-INDUSTRIAL ATMOSPHERIC $CO_2$-CONTENT BY CONSIDERING DEEP WATER $CO_2$ MORE COMPLEX DUE TO STRONG SEASONAL VARIABILITY
- THESE DATA UPSET CURRENT "UNDERSTANDING" OF $CO_2$ UPTAKE BY THE OCEAN.

# EXXON, 3 COMPONENT ENERGY BALANCE MODEL

COMPONENTS: AIR, SEA, LAND "SURFACE TEMPERATURE"

LOCAL PHYSICS: INSOLATION, ALBEDO, ICE ALBEDO FEEDBACK

SENSIBLE HEAT EXCHANGE $\propto \Delta T$

LATENT HEAT EXCHANGE $\propto \Delta\ (r_a q_{sat})$

IR FLUX LAND, SEA $\propto \sigma T^4$

ATMOSPHERIC IR: BOA, TOA FROM LOWTRAN5

TRANSPORT: SEA THERMAL DIFFUSION $\propto D \frac{\partial T}{\partial X}$

AIR DIFFUSION [LATENT + THERMAL ENERGY]

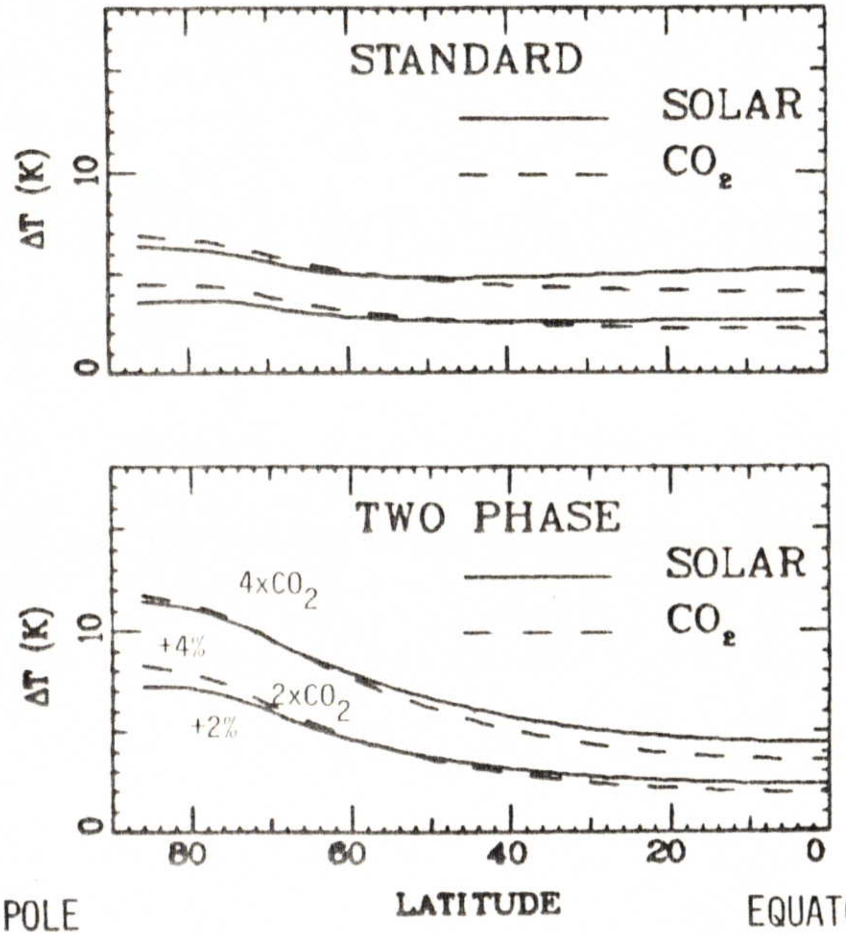
$$\propto D \frac{\partial}{\partial X} T\ (1 + \psi_L)$$

DEEP SEA TRANSPORT [UPWELLING AND EDDY DIFFUSIVITY]

$$\propto WT + K \frac{\partial T}{\partial z}$$

EBM POLAR AMPLIFICATION

EBM TEMPERATURE CHANGE VS LATITUDE

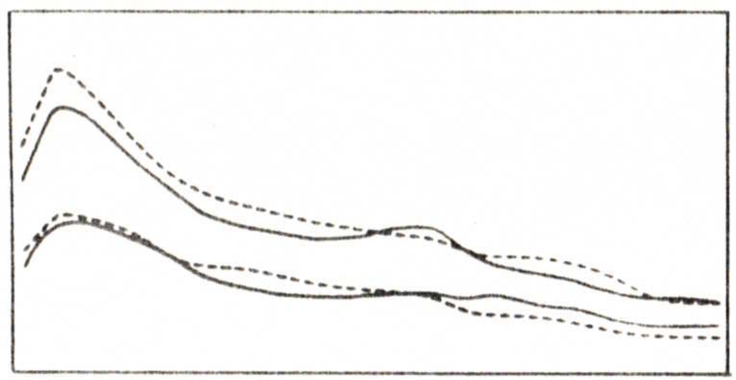



WITHOUT EVAPORATION

WITH EVAPORATION

POLE

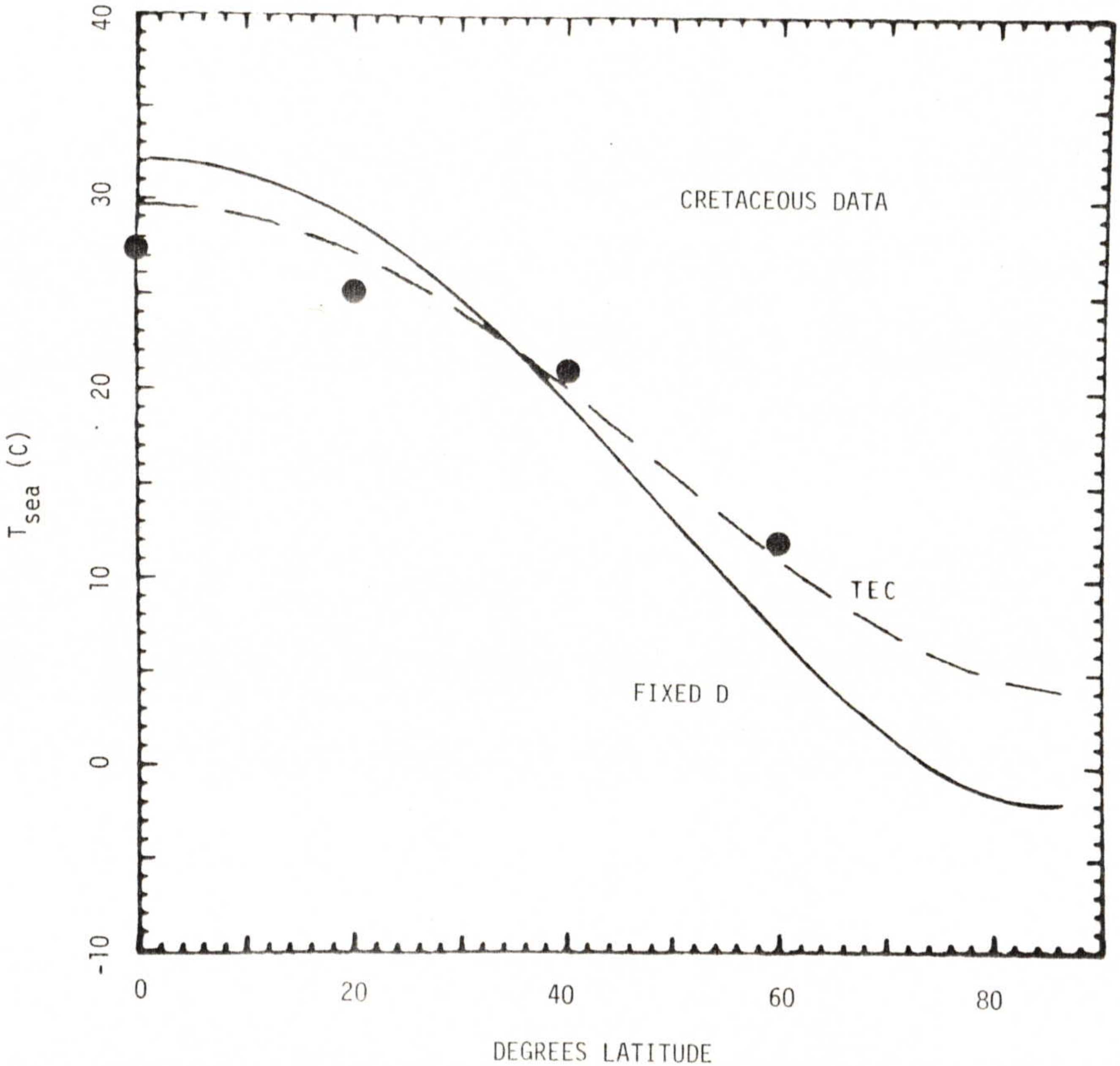
EQUATOR



MANABE & WETHERALD
1980 J. ATMOS. SCI.

20 x $CO_2$ COMPARISON TEMPERATURE DISTRIBUTION

3 COMPONENT EBM



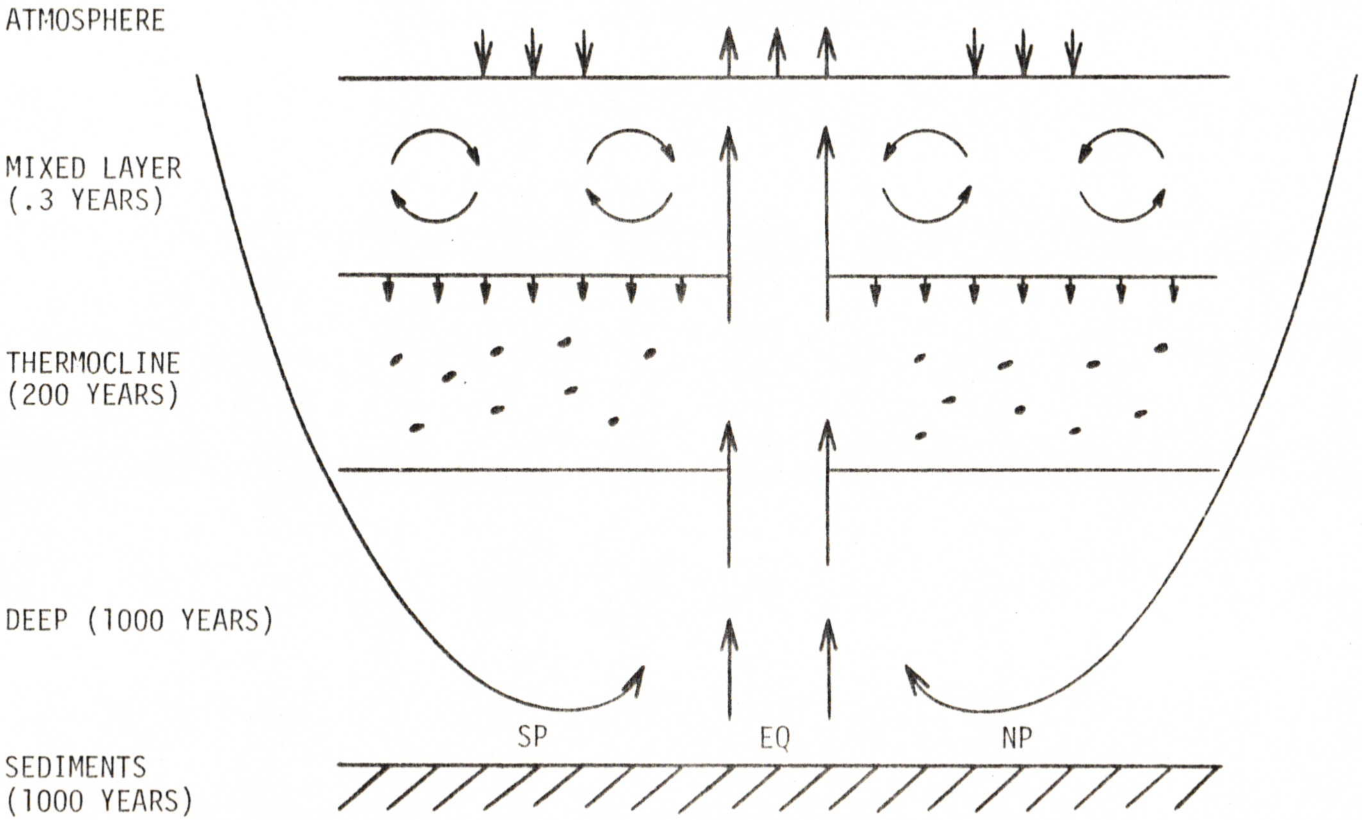
## STATUS AND NEW RESEARCH DIRECTIONS

- ADVANCED MULTI-PURPOSE MODEL FOR EXPLORING PHYSICAL EXPLANATIONS OF CLIMATE VARIATION
  - EVOLUTIONARY SCENARIOS FOR $CO_2$ AND TRACE GAS EFFECTS
- OCEANIC ROLE IN FUTURE $CO_2$ BUILD-UP
  - SEASONAL CYCLE IN SURFACE WATERS
  - LONG TERM MIXING DEEP OCEANS
  - CHANGES IN AIRBORNE FRACTION
- RELATE PLAUSIBLE PHYSICAL SCENARIOS TO PALEOCLIMATE RECORD
  - VALIDATION OF THE CLIMATE MODEL AND MECHANISMS
  - INCREASED INSIGHT INTO GEOHISTORY RELATIONS
  - E.G. ICE AGES

    MILANKOVITCH CYCLES

    OCEANIC DEGASSING OF $CO_2$

# OCEAN CARBON CYCLE




GAS EXCHANGE (7.9 YEARS)

CAPACITY: CHEMISTRY

RATE: SMALL SCALE FLUID DYNAMICS

CHEMISTRY (.1 YEAR)

BIOLOGY (.2 YEAR)

MIXED LAYER $CO_2$ SINK

REGENERATION WITH DEPTH

MIXING (.3-1000 YEARS)

- SIGNIFICANT $CO_2$ ENTERS OCEAN BECAUSE OF CARBONATE CHEMISTRY (8 FOLD INCREASE OVER PURE WATER)
- SMALL CHANGES IN OCEAN CARBON CONTENT CAN CAUSE LARGE CHANGES IN ATMOSPHERIC $CO_2$ CONCENTRATION
  - REVELL FACTOR: $$\left.\frac{\delta PCO_2}{PCO_2}\right|_{\text{ATMOS.}} \bigg/ \frac{\delta\ (\text{TOTAL INORGANIC CARBON})}{\text{TOTAL INORGANIC CARBON}} = 9 - 13$$
- BIOSPHERIC CARBON FLUX MAINTAINS MIXED LAYER UNDERSATURATION OF $CO_2$ AND SMALL CHANGES ARE MAGNIFIED BY REVELL FACTOR
  - BIOSPHERE NUTRIENT LIMITED