# The TIMES Climate Module

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## Basic features (1)

- **Approach adopted from Nordhaus and Boyer (1999)**
- **Well documented, good approximation of equations in more complex climate models**
- **Linear recursive equations for concentrations and temperature changes**
- **Three-reservoir model for carbon cycle balances:**
  - Atmosphere (*ATM*)
  - Biosphere and upper ocean (*UP*)
  - Deep ocean layers (*LO*)

$$M_{atm}(y) = E(y-1) + (1-\varphi_{atm\text{-}up})\, M_{atm}(y-1) + \varphi_{up\text{-}atm}\, M_{up}(y-1)$$

$$M_{up}(y) = (1-\varphi_{up\text{-}atm}\ \ \varphi_{up\text{-}lo})\, M_{up}(y-1) + \varphi_{atm\text{-}up}\, M_{atm}(y-1) + \varphi_{lo\text{-}up}\, M_{lo}(y-1)$$

$$M_{lo}(y) = (1-\varphi_{lo\text{-}up})\, M_{lo}(y-1) + \varphi_{up\text{-}lo}\, M_{up}(y-1)$$

# Basic features (2)

- **Commonly accepted formula for radiative forcing from $CO_2$ concentration (IPCC TAR):**

$$\Delta F(t) = \gamma \frac{\ln(M_{atm}(t)/M_0)}{\ln 2} + O(t)$$

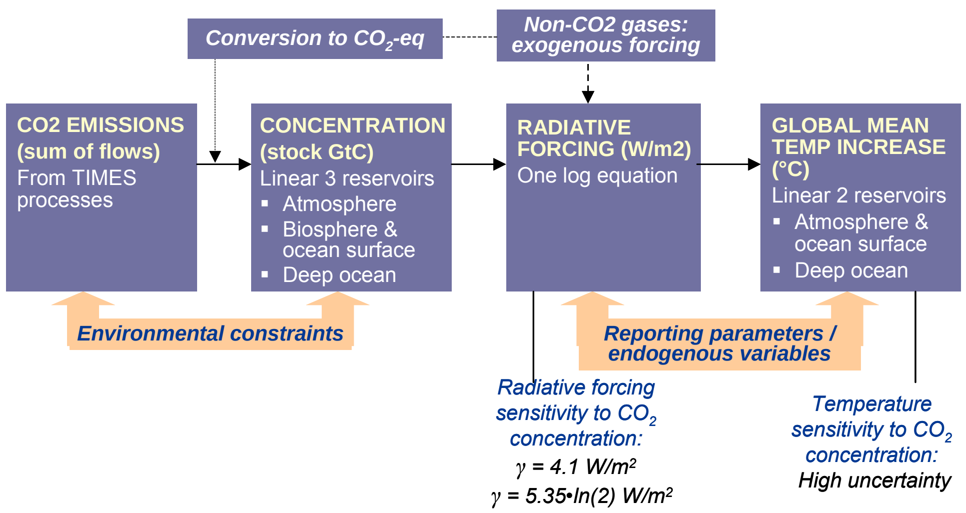
- **Two-reservoir model for temperature balance**
  - Atmospheric / surface temperature (*UP*)
  - Deep ocean temperature (*LO*)

$$\Delta T_{up}(y) = \Delta T_{up}(y-1) + \sigma_1\{F(y) - \lambda\, \Delta T_{up}(y-1) - \sigma_2\, [\Delta T_{up}(y-1) - \Delta T_{low}(y-1)]\}$$

$$\Delta T_{low}(y) = \Delta T_{low}(y-1) + \sigma_3\, [\Delta T_{up}(y-1) - \Delta T_{low}(y-1)]$$



# Climate Module – Main features



# Modeling of non-$CO_2$ emissions: Approach 1

- **Use GWP potentials to express non-$CO_2$ emissions as equivalent $CO_2$ emissions**
- **Feed all GHG emissions into the carbon cycle model**
- **Advantages:**
  - Ease of use
  - Commonly accepted values for GWP-100 available
  - Provides a reasonably good approximation
- **Disadvantages:**
  - Carbon circulation model used for non-$CO_2$ emissions
  - Prevailing non-$CO_2$ gas concentrations not fully accounted for
  - May cause systematic errors in the total radiative forcing

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# Modeling of non-$CO_2$ emissions: Approach 2

- **Use separate models for non-$CO_2$ concentrations**
- **Convert non-$CO_2$ concentrations into $CO_2$ equivalent concentrations; or**
- **Use separate functions also for radiative forcing from non-$CO_2$ concentrations (e.g. IPCC TAR)**
- **Advantages:**
  - More detailed and justified model for non-$CO_2$ gases
  - Less systematic errors in radiative forcing
- **Disadvantages:**
  - More complicated climate model
  - No commonly agreed concentration models for non-$CO_2$ gases

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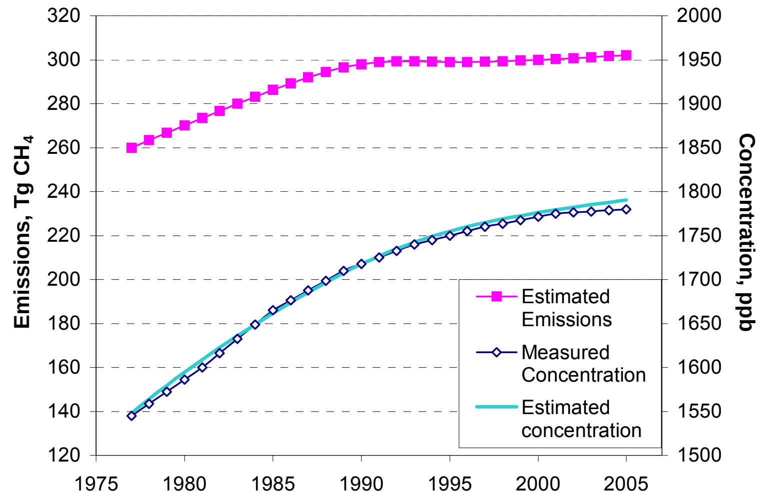
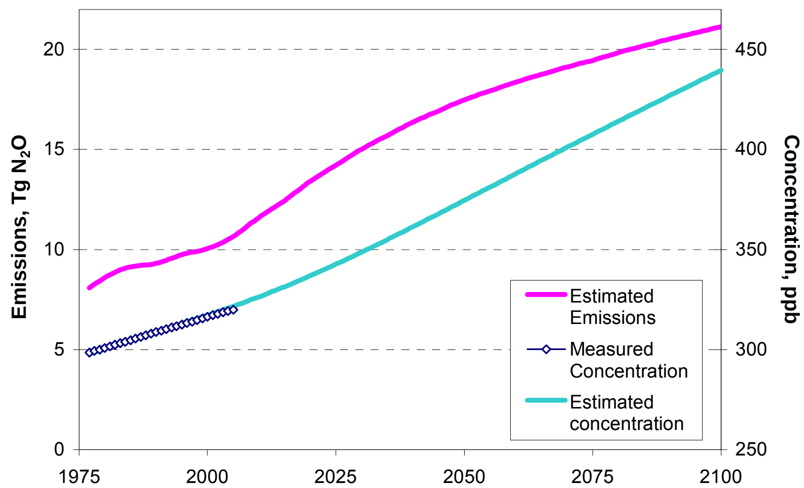
# Example: $CH_4$ concentrations






# Example: $N_2O$ concentrations

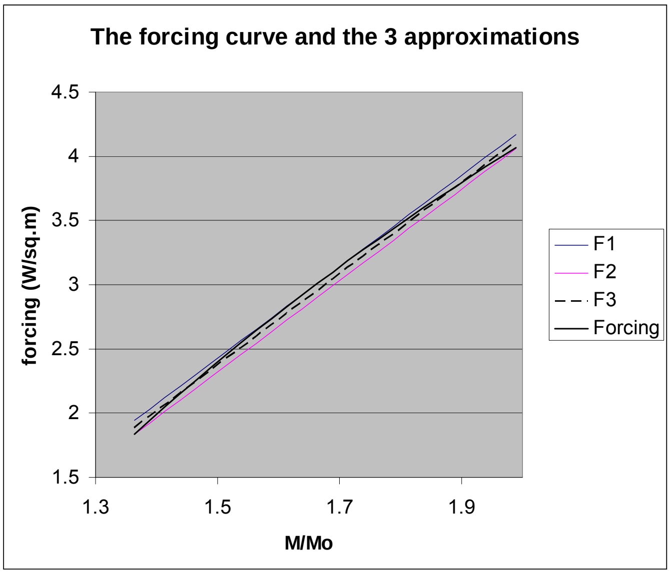


# Endogenous equations for forcing and temperature change

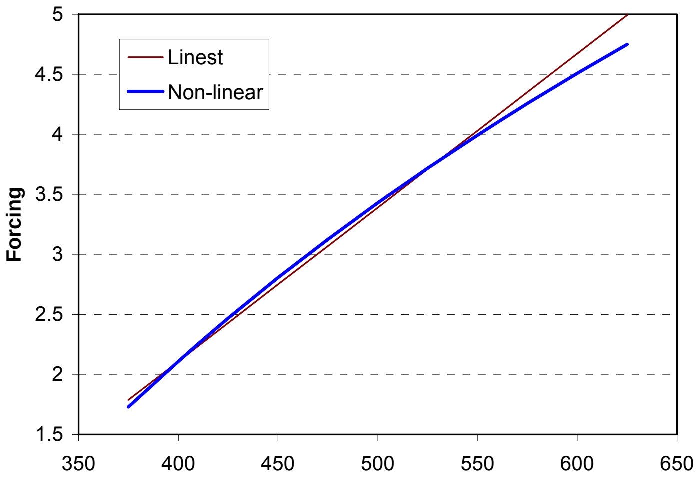
- **Linearized forcing functions on range of key interest:**
  - CM_LINFOR(*YEAR, ITEM, LIM*)
  - Can be used for both $CO_2$ and non-$CO_2$ concentrations
- **Linear forcing functions can be time dependent**
  - Improved accuracy at early periods
  - Concentration results could be used for iterative functions
- **Linear two reservoir model for temperature change**
  - Atmospheric/surface temperature
  - Ocean temperature
- **Reporting of climate results according to both non-linear and linear formulations**



# Linearized forcing



# Linearized forcing: 375–560 ppm

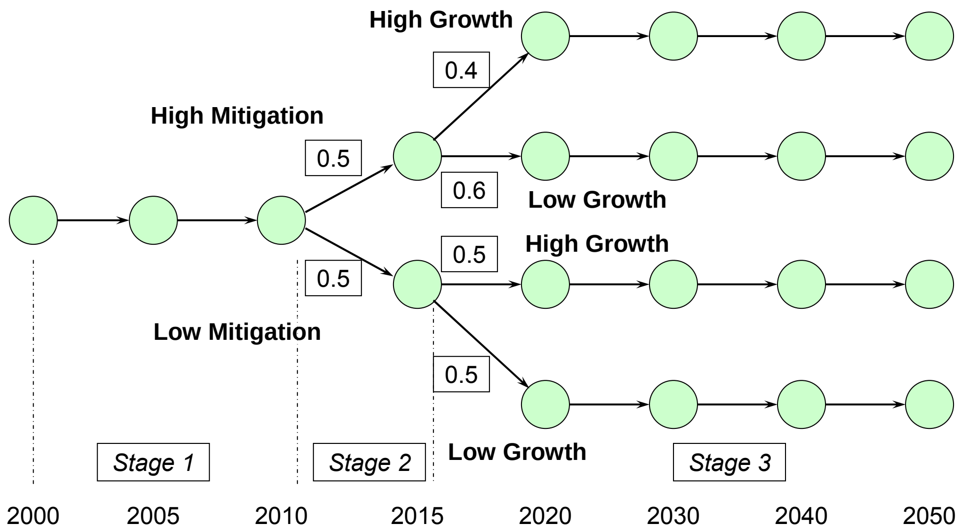





# Uncertain attributes in stochastic mode

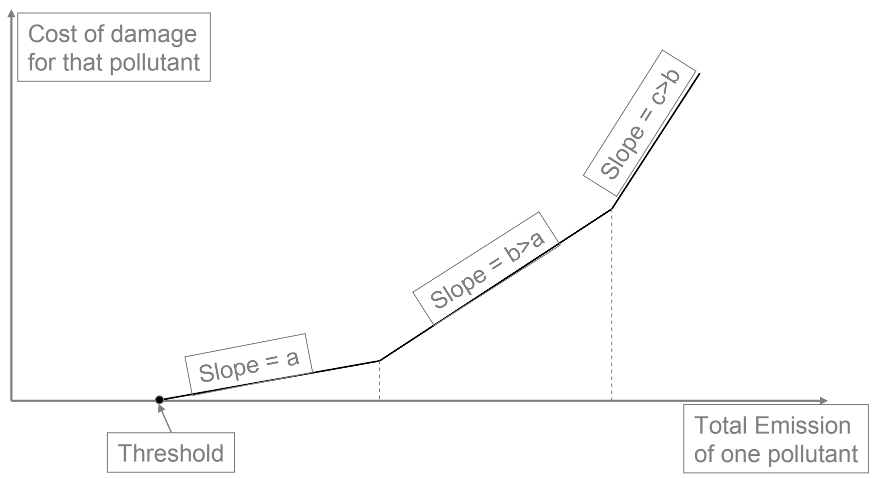
- **Maximum levels of climate variables (S_CM_MAXC):**
  - Concentrations, forcing, temperature, global emissions
- **Climate sensitivity parameters (S_CM_CONST):**
  - Sensitivity to doubling of $CO_2$ concentration (Cs)
  - Related speed of adjustment parameter (Sigma1)
- **Special handling of uncertainty related to climate sensitivity in TIMES**
  - Temperature changes are not accurately observable
  - Uncertainty concerning the global temperature remains until given date, after which it is retroactively resolved
  - Handling of stochastic variables different from other uncertainties

# Stochastic TIMES – Example






# Damage functions



15

## Damage functions for climate variables

- **Damage functions can be defined for all Climate variables:**
  - Concentrations
  - Radiative forcing
  - Temperature
  - Global emissions
- **Damage functions can be defined for each region or globally:**
  - Different climate impacts in different regions – allocate damage costs accordingly; or
  - Use a single damage function for global damages

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16

## Future improvements

- **Introduce climate-to-climate feedbacks: links between climate equation parameters (Cs, Lag, etc.):**
  - THC instability (may provoke extra temperature change)
  - Rapid melting of ice cap and glaciers (increases heat exchange)
- **Introduce climate-to-emissions feedbacks**:
  - Increased $CH_4$ emissions from melting pergelisol
  - Increased methane hydrates emissions from ocean floors
- **Introduce climate-to-energy feedbacks**:
  - Altered potentials for hydroelectricity and wind power
  - Altered tree growth due to $CO_2$ concentration
  - Increased forest fires (more $CO_2$, less wood)
  - Decreased space heating, increased space cooling demands

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17

# Summary

- All the features described are available in TIMES v2.2 (excl. future improvements)
- Update of Climate Module documentation is in progress
- Future enhancements dependent on demand and resources

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