One-Dimensional Models

GCC Summer School, 2005
Banff, Alberta

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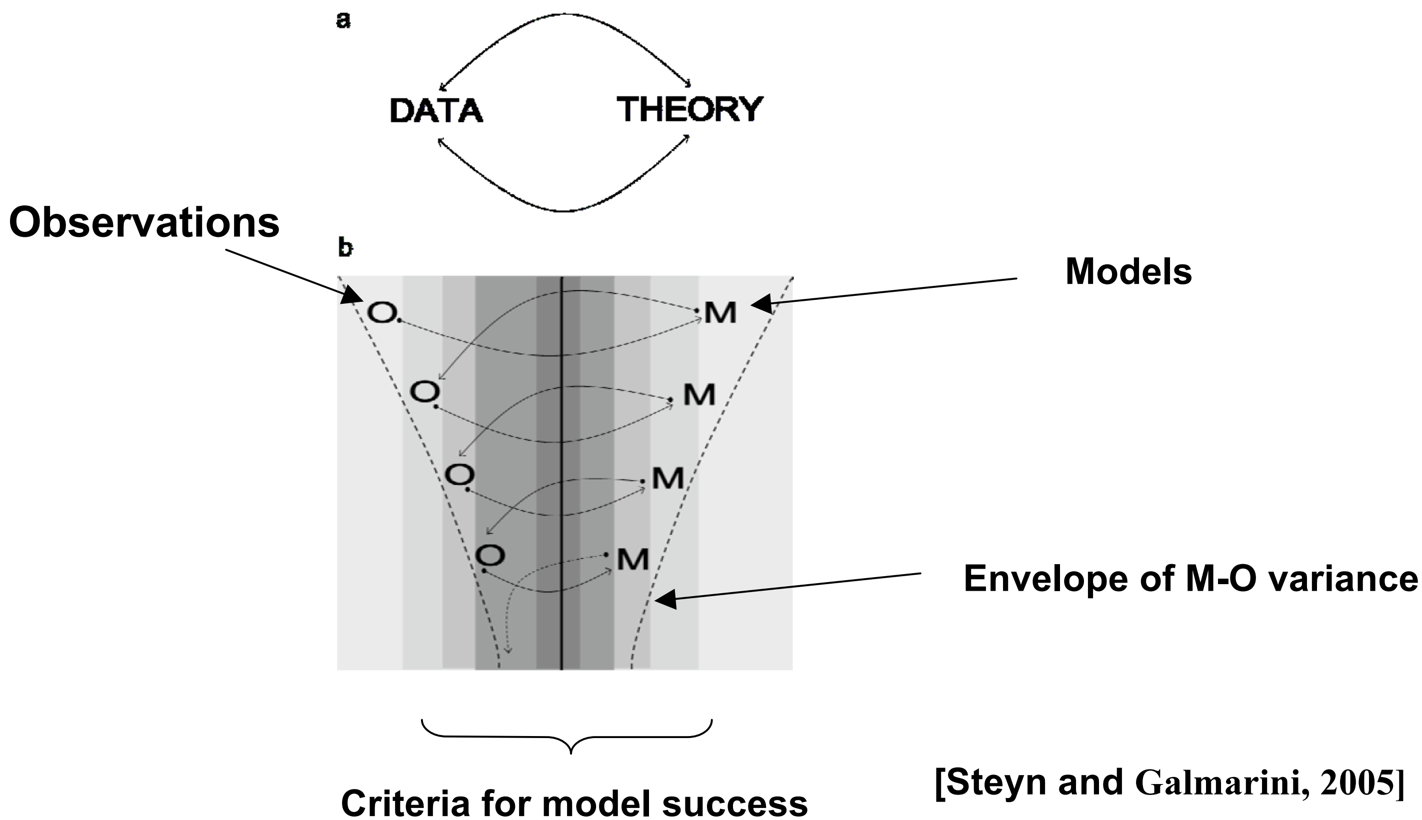
Observations and Models



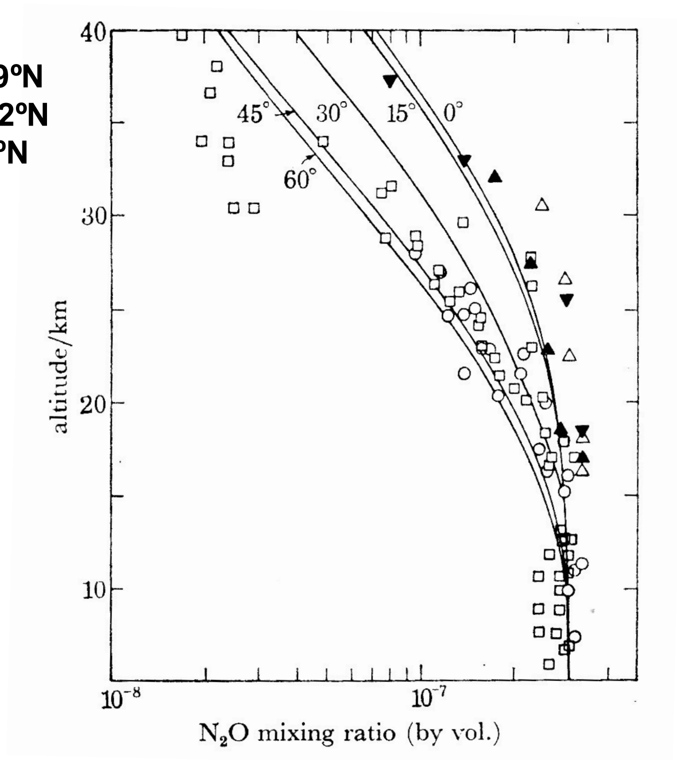
[Steyn and Galmarini, 2005]

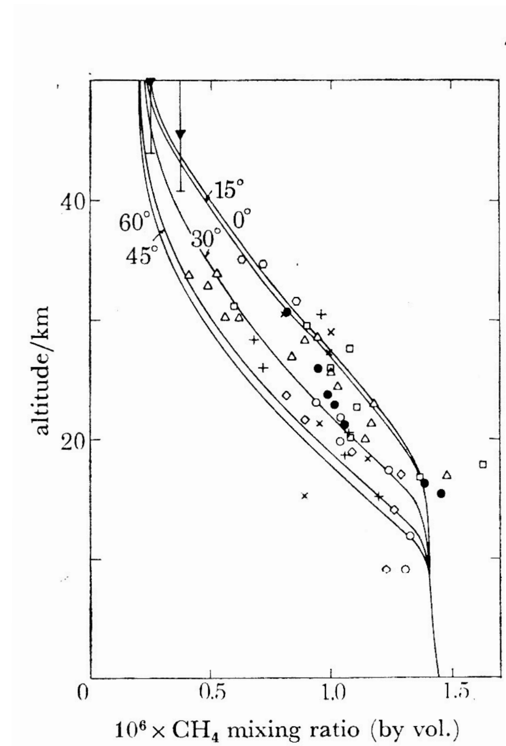
Choice of model should be guided by quality of observations and desired level of accuracy and precision of understanding or prediction of atmospheric phenomenon

One-dimensional Modelling

- Due to computational limitations, 1-D models were used extensively for assessments throughout the 1970s and 1980s

Triangles: 9ºN
Squares: 32ºN
Circles: 41ºN



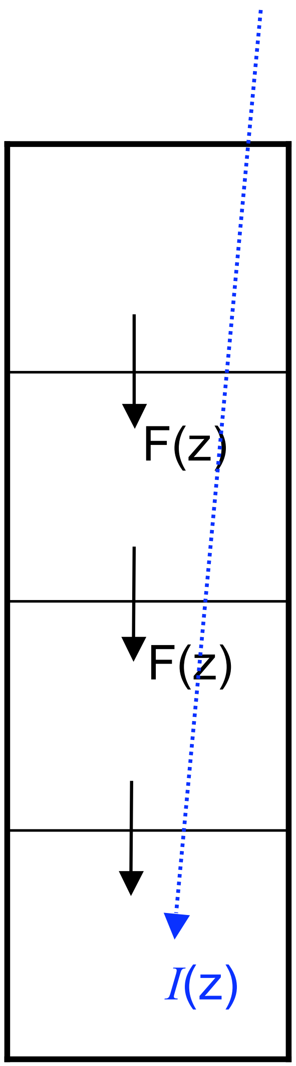


Obs: 32ºN
Filled circles: 32ºS

[Logan et al., 1978]

- Despite their limitations, 1-D models adquately provided much of our early understanding of the trace constituents in the atmosphere - reflects limited spatio-temporal distribution of data in the pre-satellite era

One-Dimensional Framework



1-D models provide a latitude-longitude averaged (global or hemispheric) representation of the atmosphere

Continuity equation

$$\frac{\partial n(z)}{\partial t} = P - L - \frac{\partial}{\partial z}\left(K(z)M(z)\frac{\partial f(z)}{\partial z}\right)$$

***M*(*z*) = atmospheric number density**
***n*(*z*) = tracer number density**
***f(z)* = tracer mixing ratio**
***K*(*z*)= vertical**

Radiation

$$I(z) = I_o \exp\left(-\frac{1}{\mu}\int_z^{\infty} \sigma n(z)dz\right)$$

Vertical Diffusion Coefficients

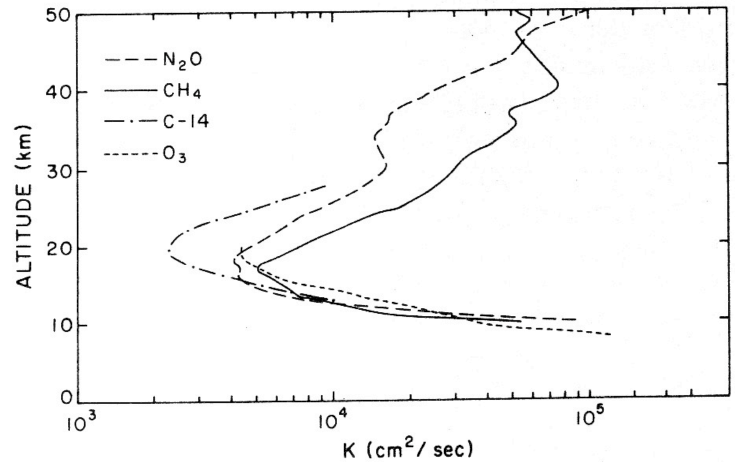
Use observed profiles of trace gases to empirically derive diffusion coefficient

$$vertical\ flux = -K(z)M(z)\,df(z)/dz$$

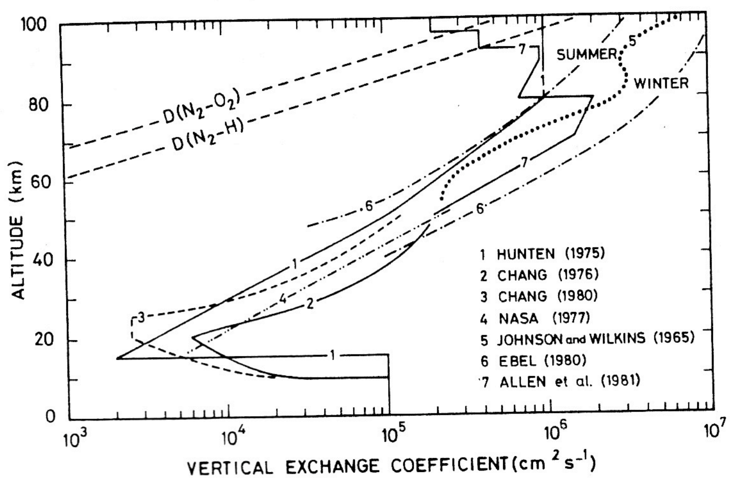
In steady state

$$K(z) = \left(M(z)\frac{df(z)}{dz} \right)^{-1} \left(\int_z^\infty (P(z) - L(z))dz \right)$$

Estimated Diffusion Coeff. Profiles



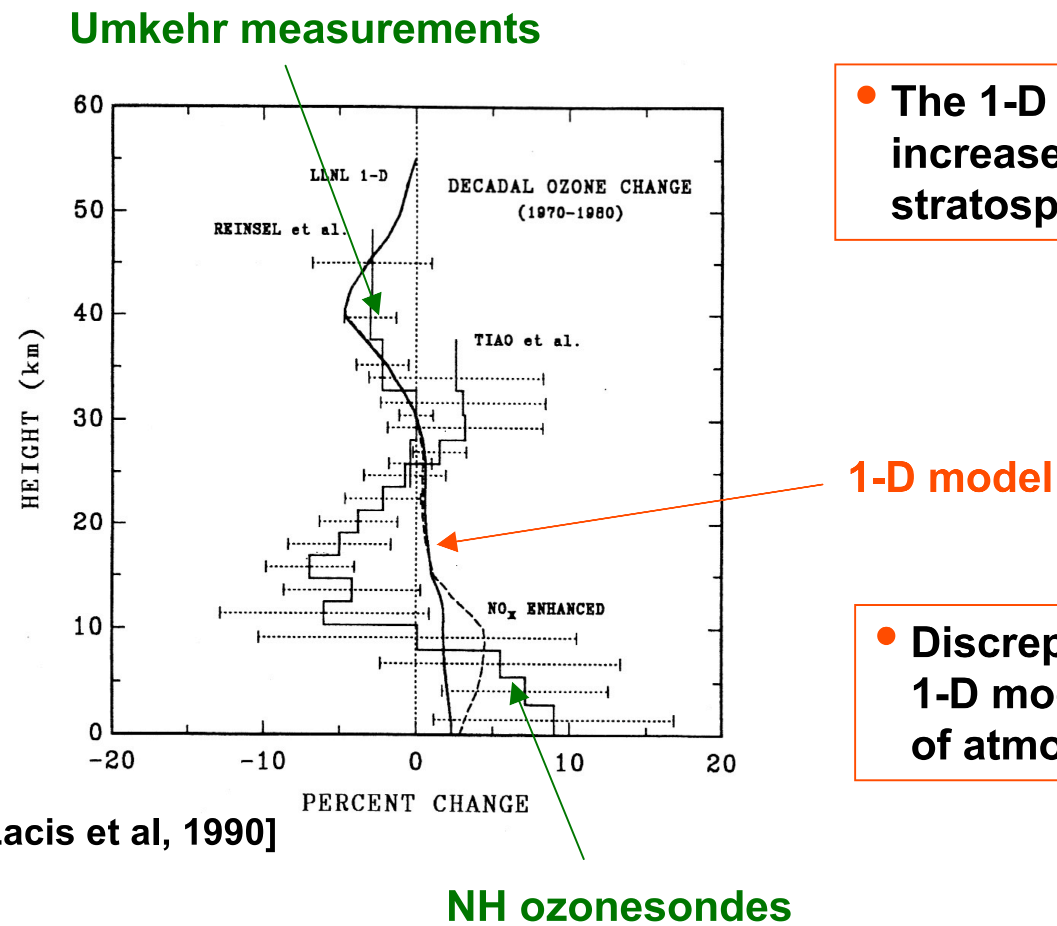
[Massie and Hunten, 1981]



[Brasseur and Solomon, 1986]

K **profiles used in a range of 1-D models in 1960s, 1970s and 1980s**

Stratospheric Ozone Trends



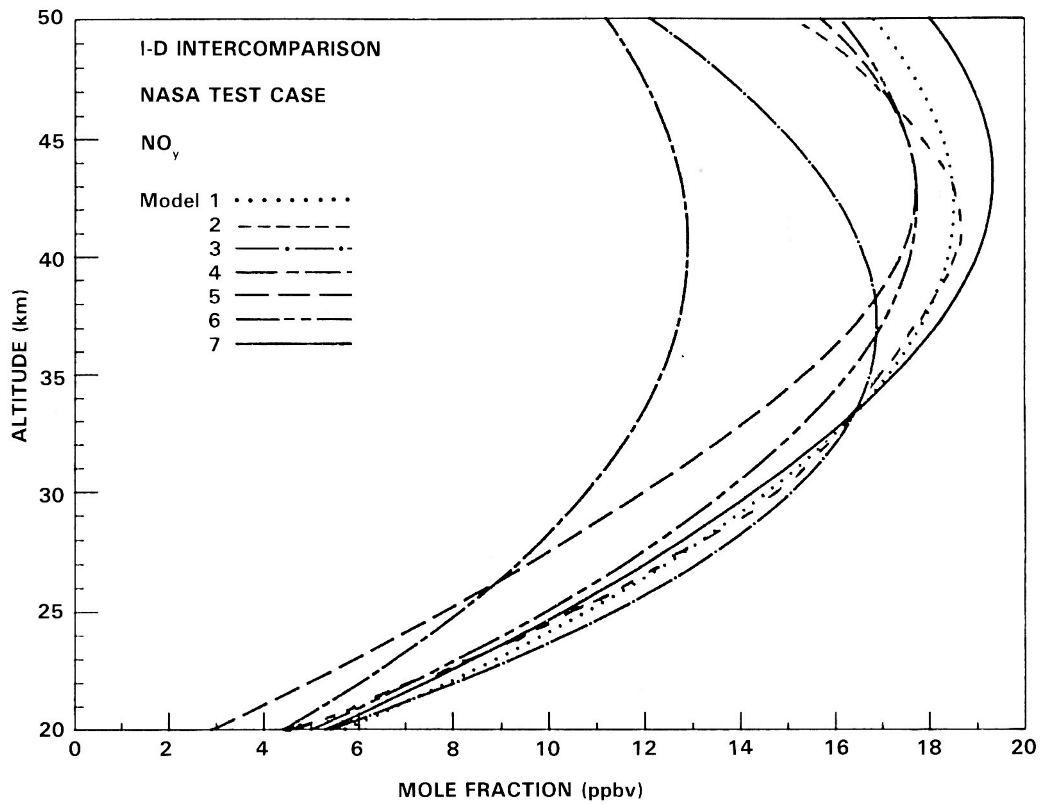
[Lacis et al, 1990]

- The 1-D model suggested a slight increase in O3 in the lower stratosphere due to CFC increases

- Discrepancy reflects the inability of the 1-D model the account for the effects of atmospheric transport

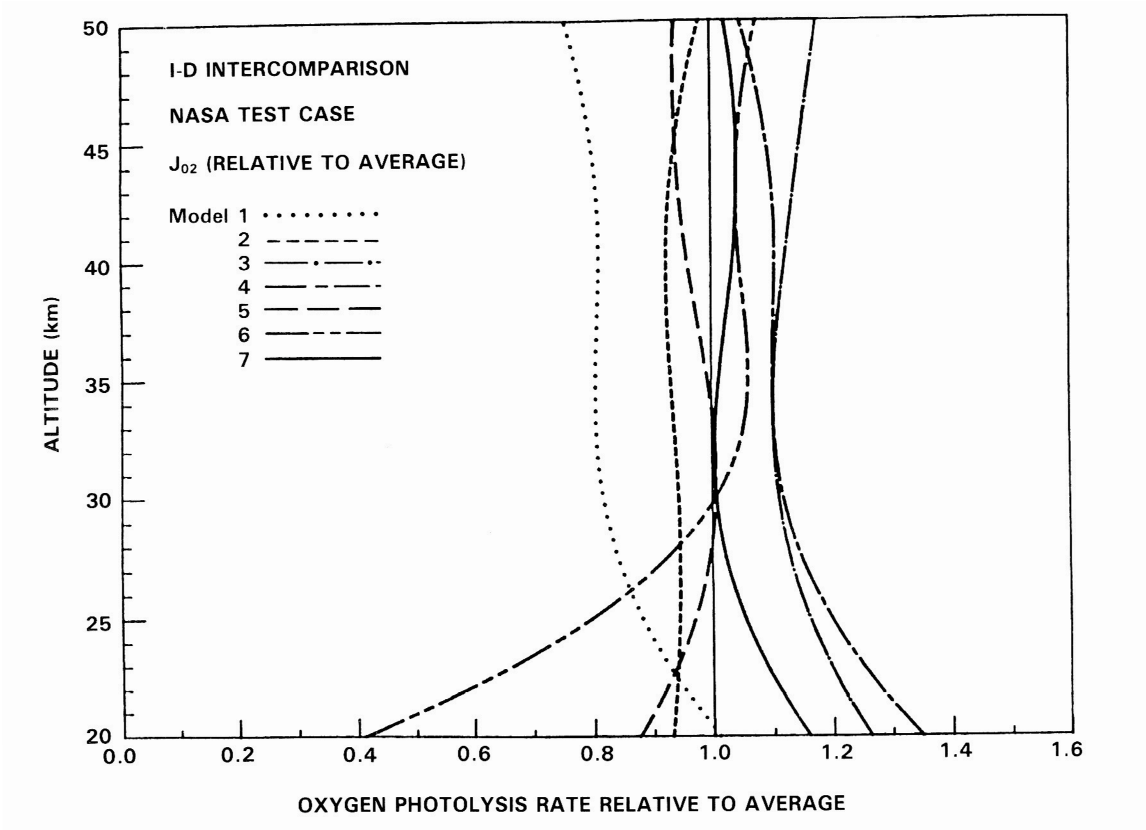
Comparison of NO_y in 1-D Models

[WMO, 1985]



NO_y VERTICAL PROFILES

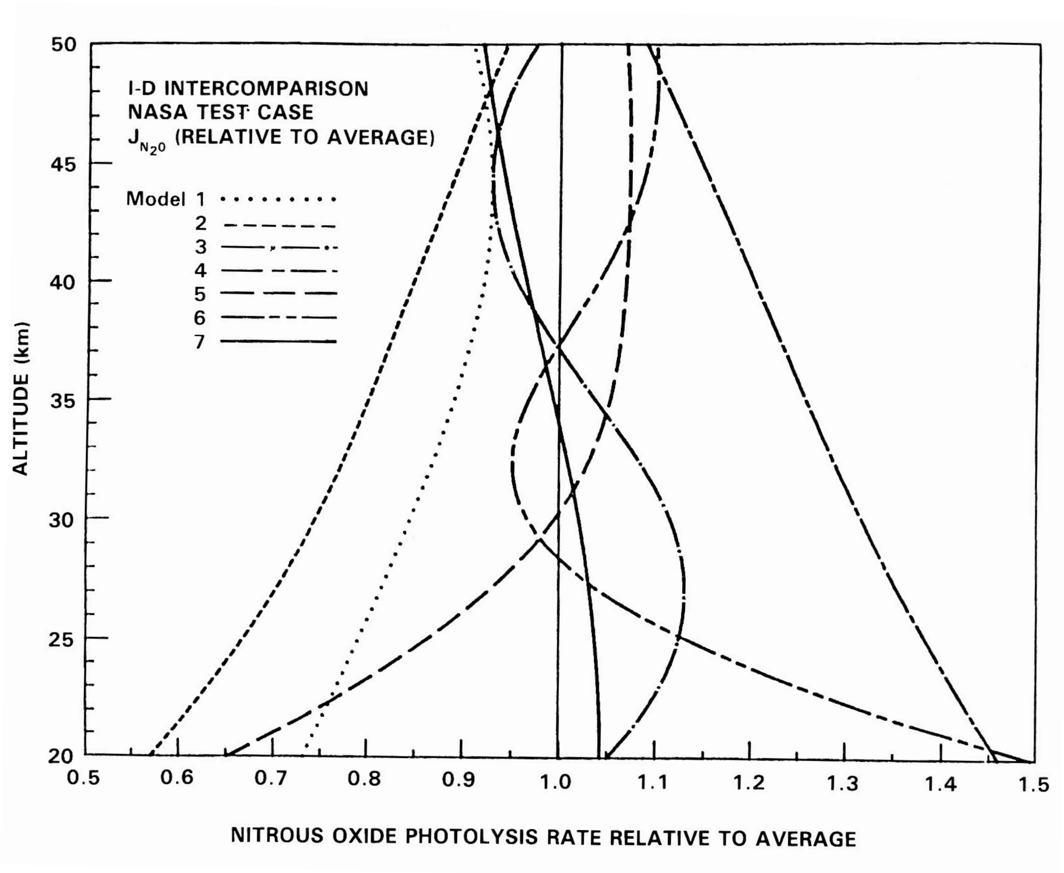
Comparison of O_2 Photolysis in 1-D Models



[WMO, 1985]

Photolysis of N_2O occurs in the region 173-240 nm ⇒ sensitive to Schumann-Runge bands (and Herzberg continuum) of O_2

Comparison of N_2O Photolysis in 1-D Models

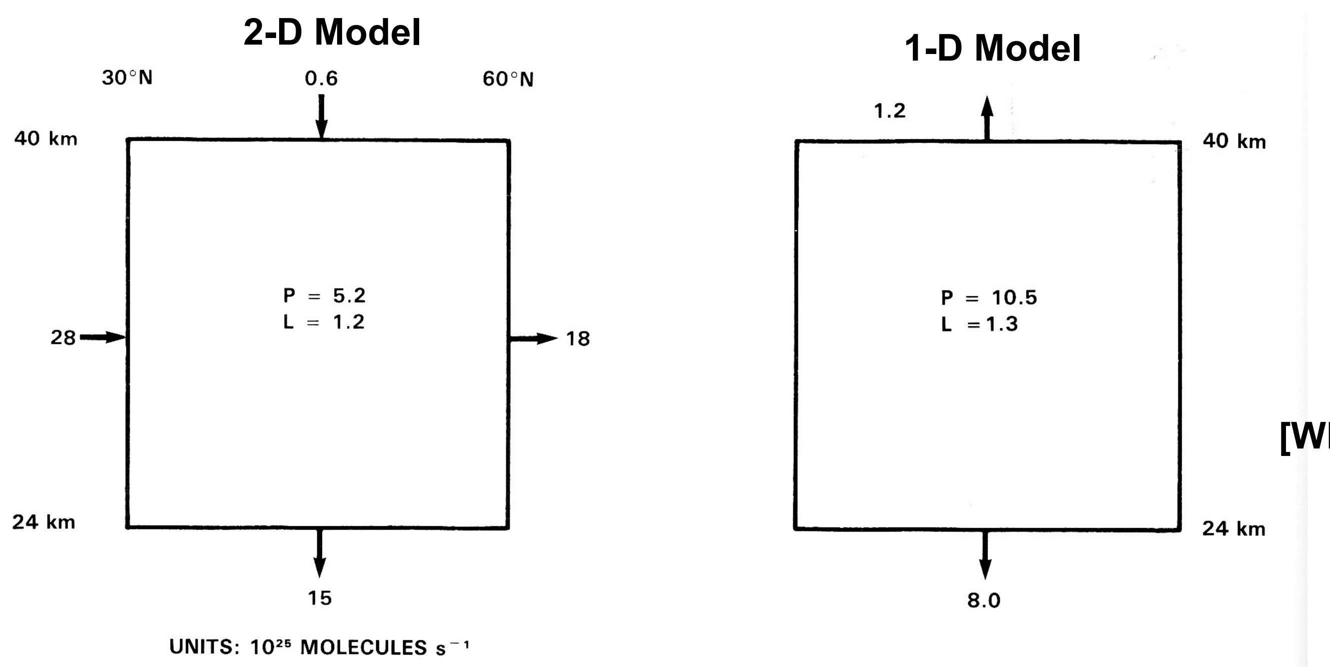


[WMO, 1985]

$N_2O + h\nu \Rightarrow N_2 + O$ **(90% of loss)**

$N_2O + O(^1D) \Rightarrow NO + NO$ **(source of NO_y)**

Comparison of NO_y budget in 1-D and 2-D Models

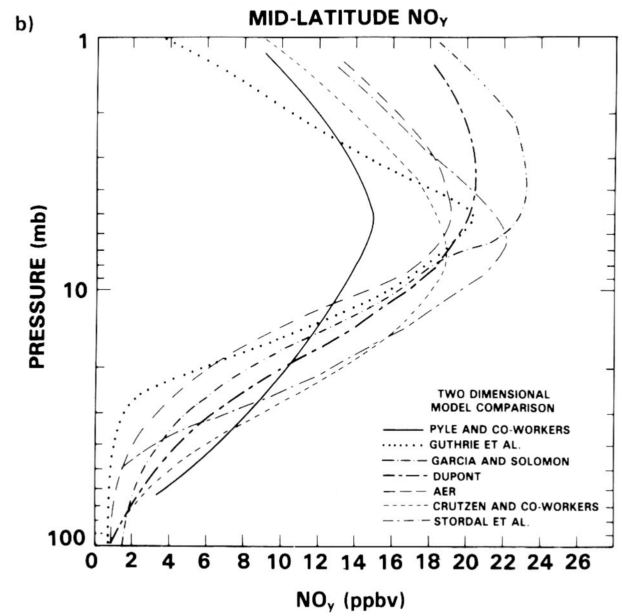


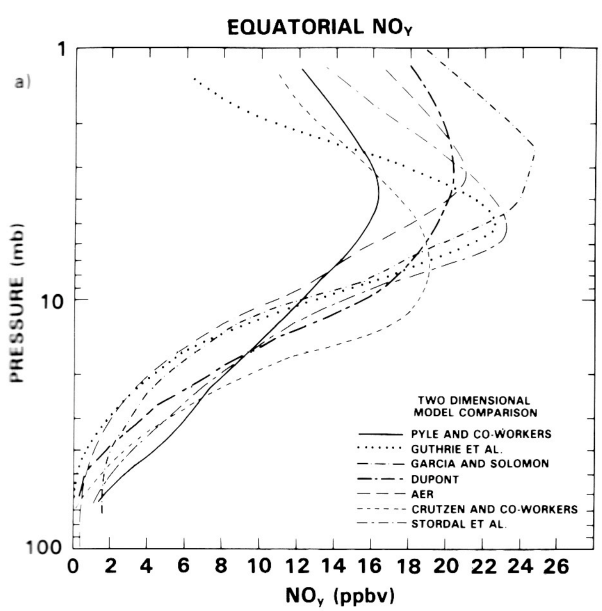
[WMO, 1985]

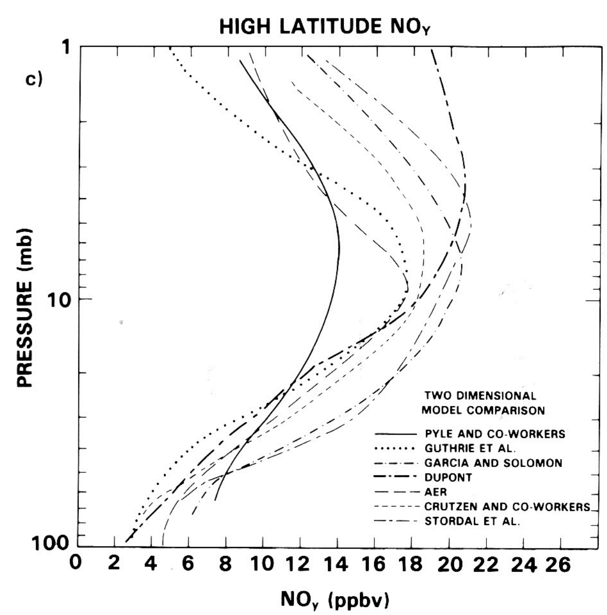
- In 2-D framework, meridional transport from source region in tropics important
- in 1-D model, balance is between in situ production (P) and vertical diffusive transport

Comparison of NO_y in 2-D Models

- In 1985 there were large differences in NO_y also in the 2-D models
- At present, the discrepancies in NO_y between models (2-D and 3-D) is not much better



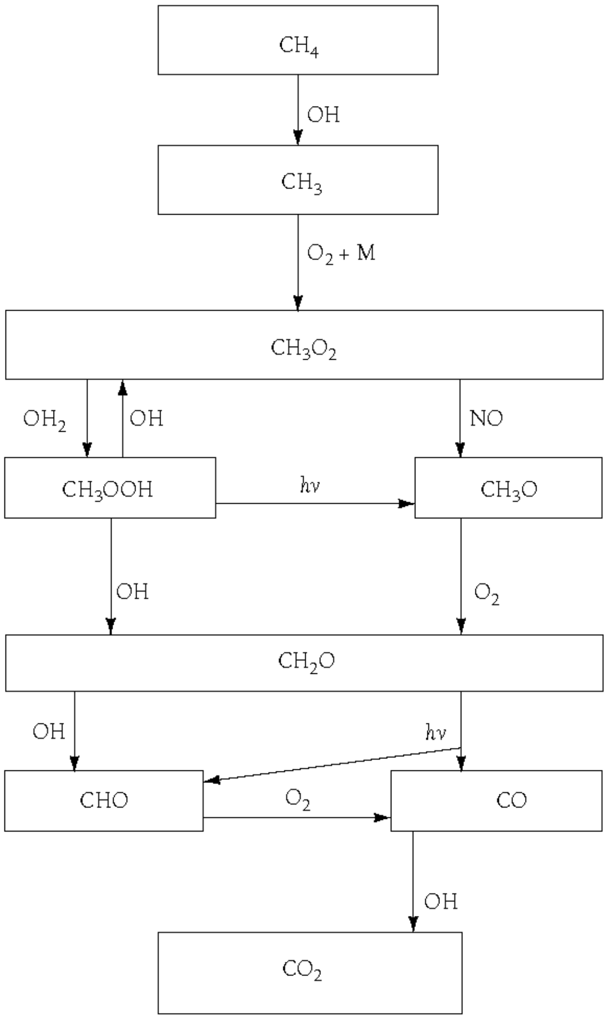




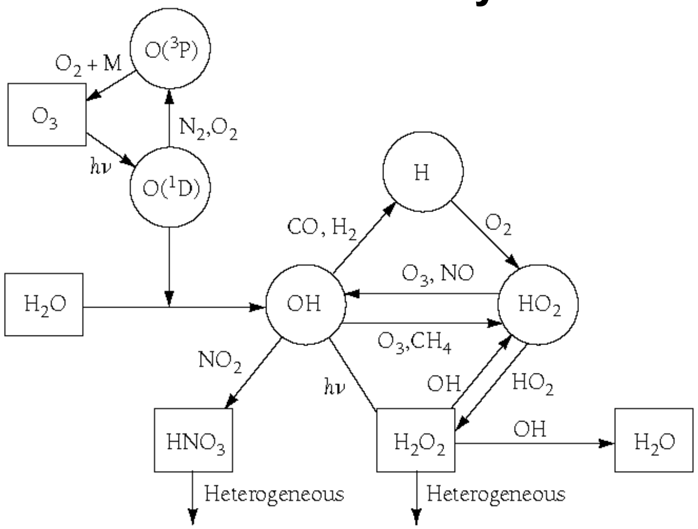
[WMO, 1985]

Tropospheric chemistry

Methane Oxidation

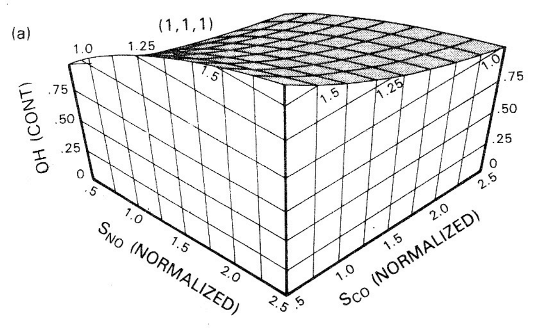


HOx Cycle



[M. B. McElroy, 2002]

Sensitivity of tropospheric OH to changes in emissions of NO and CO

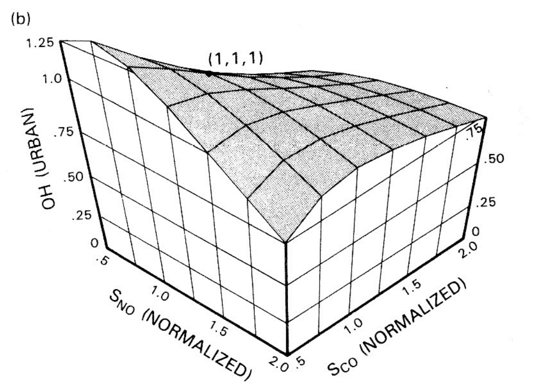


Continental

$S_{NO} = 8x10^9$ $cm^{-2}s^{-1}$ $[NO_x]$=0.2 ppb

$S_{CO} = 2.0x10^{11}$ [CO] = 130 ppb

$S_{CH4} = 6.5x10^{10}$ $[CH_4]$ = 1.7 ppm

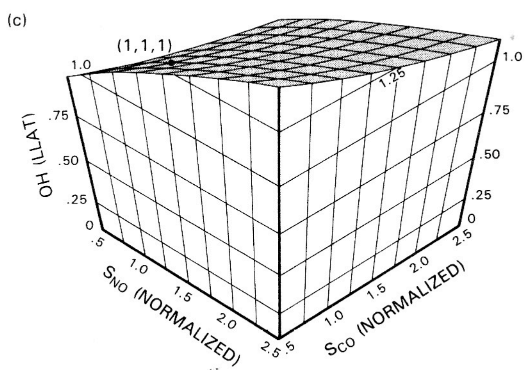


Urban

$S_{NO} = 7x10^{10}$ $cm^{-2}s^{-1}$ $[NO_x]$=1.4 ppb

$S_{CO} = 8.0x10^{11}$ [CO] = 380 ppb

$S_{CH4} = 7.8x10^{10}$ $[CH_4]$ = 1.7 ppm



Low Latitude

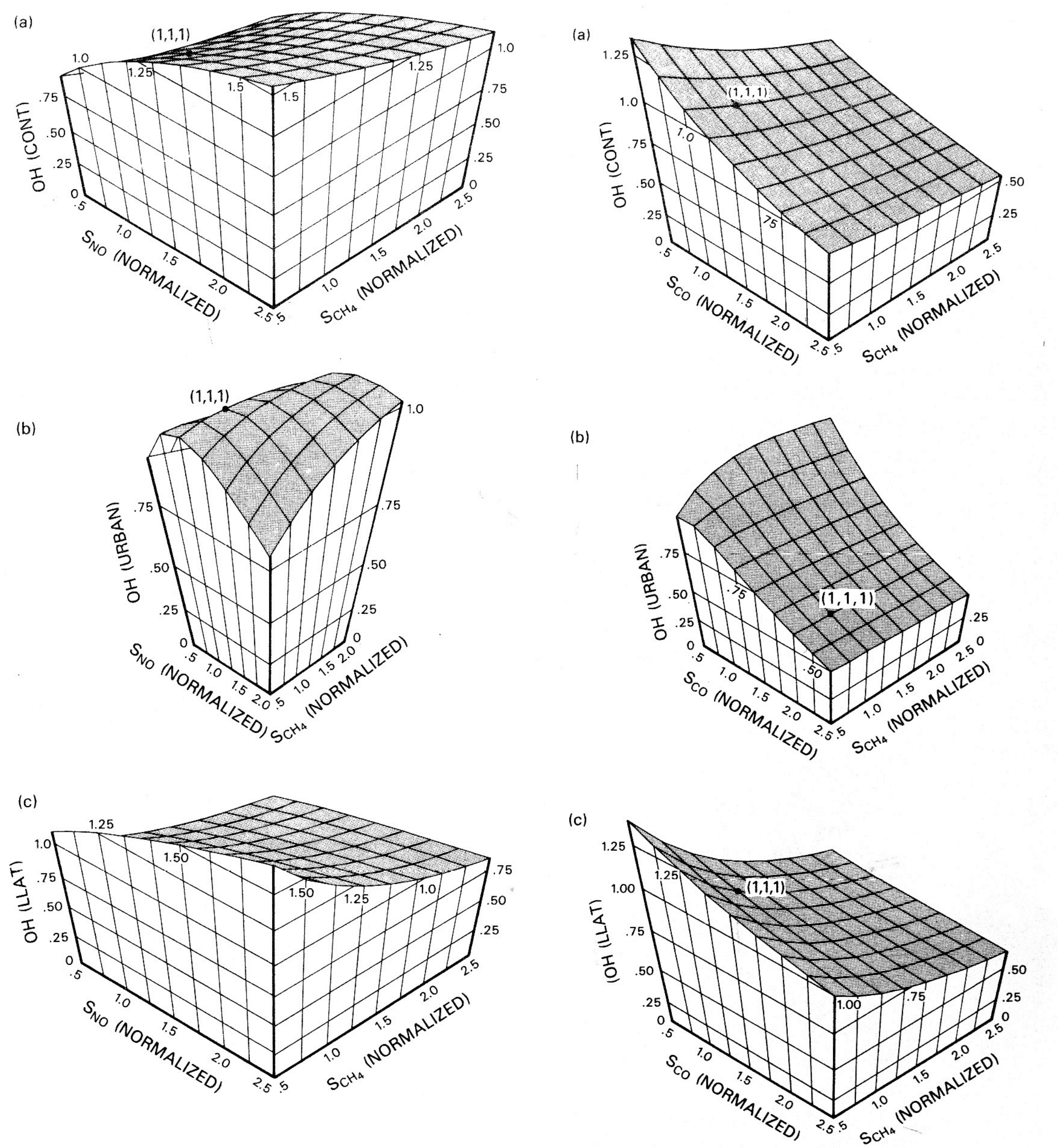
$S_{NO} = 6.7x10^8$ $cm^{-2}s^{-1}$ $[NO_x]$=0.024 ppb

$S_{CO} = 1.2x10^{11}$ [CO] = 89 ppb

$S_{CH4} = 1.0x10^{11}$ $[CH_4]$ = 1.7 ppm

[Thompson et al., 1989]

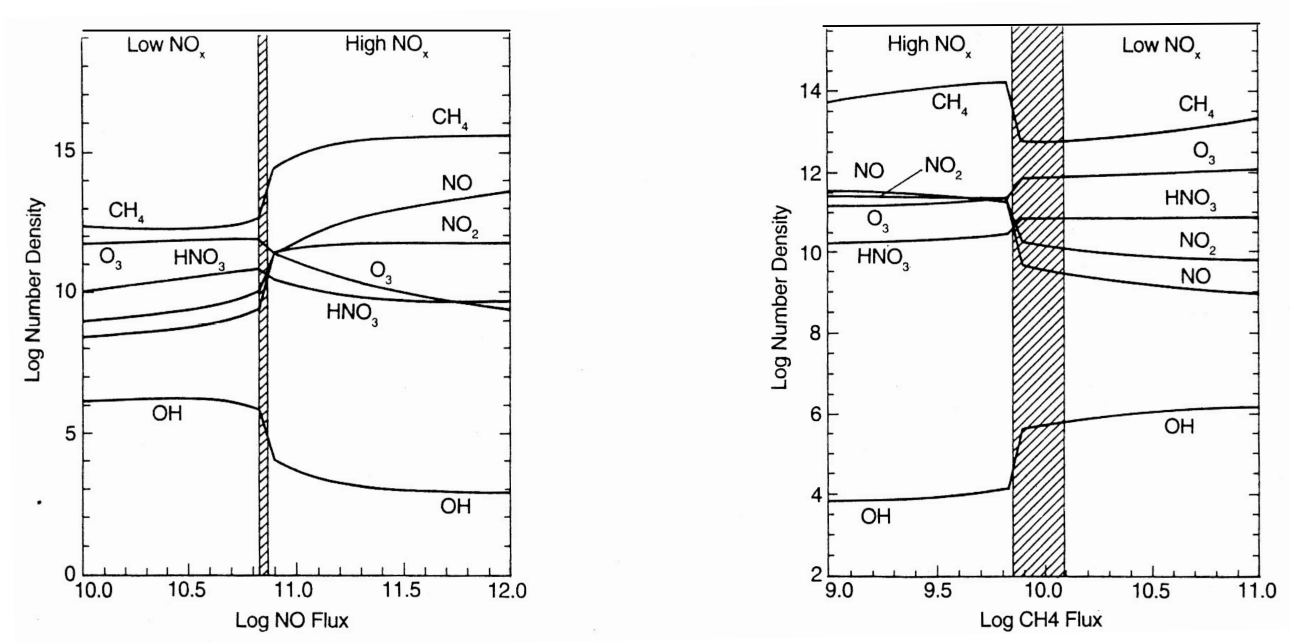
Sensitivity of tropospheric OH to changes in emissions of NO and CH_4



CH_4-HO_x-NO_x-CO chemistry nonlinear

[Thompson et al., 1989]

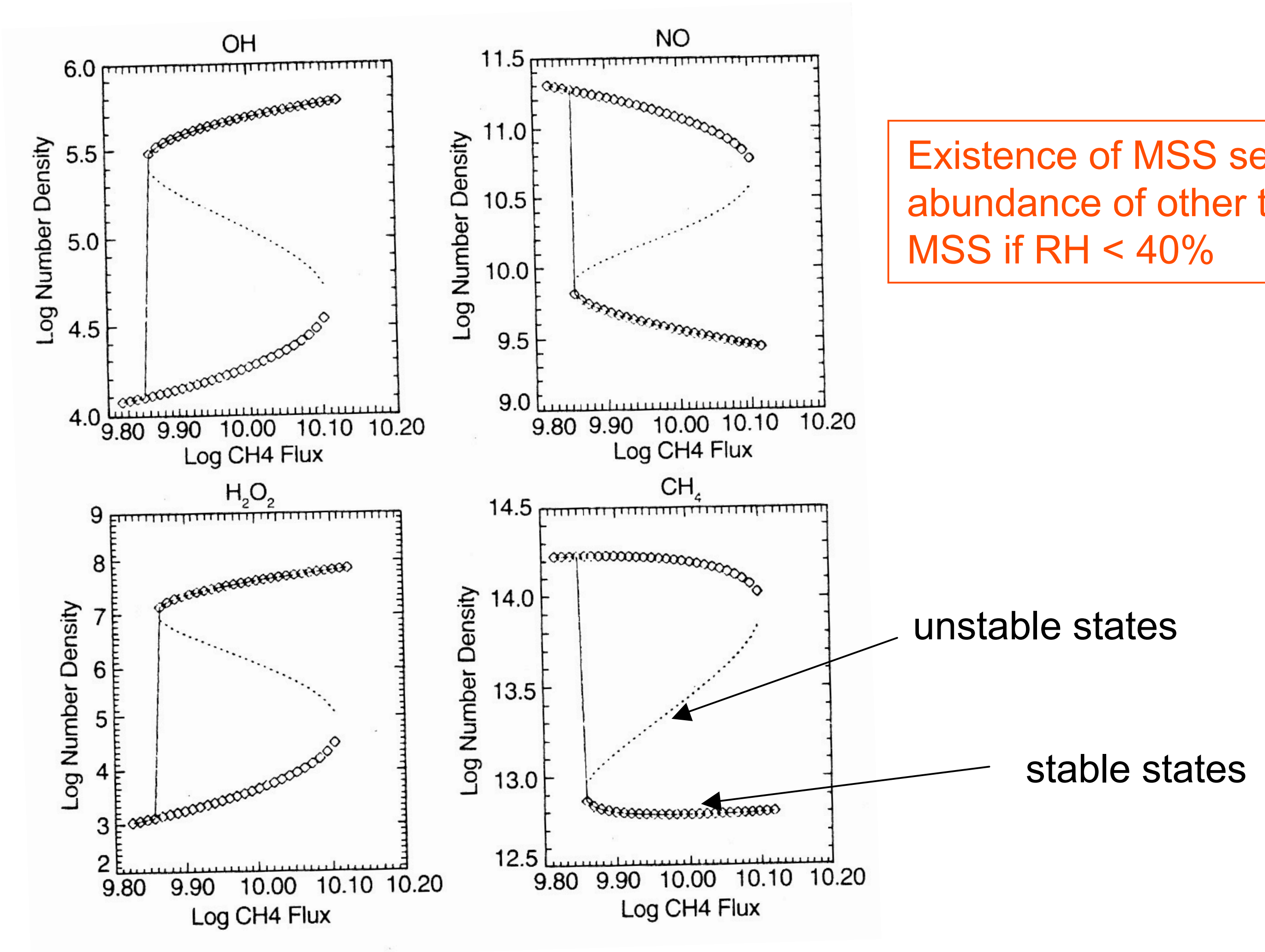
Instability in the CH_4-NO_x-O_x-HO_x Chemical System (in a Box Model)



[Stewart, 1993]

Abrupt transition between states characterized by low and high abundances of NO_X

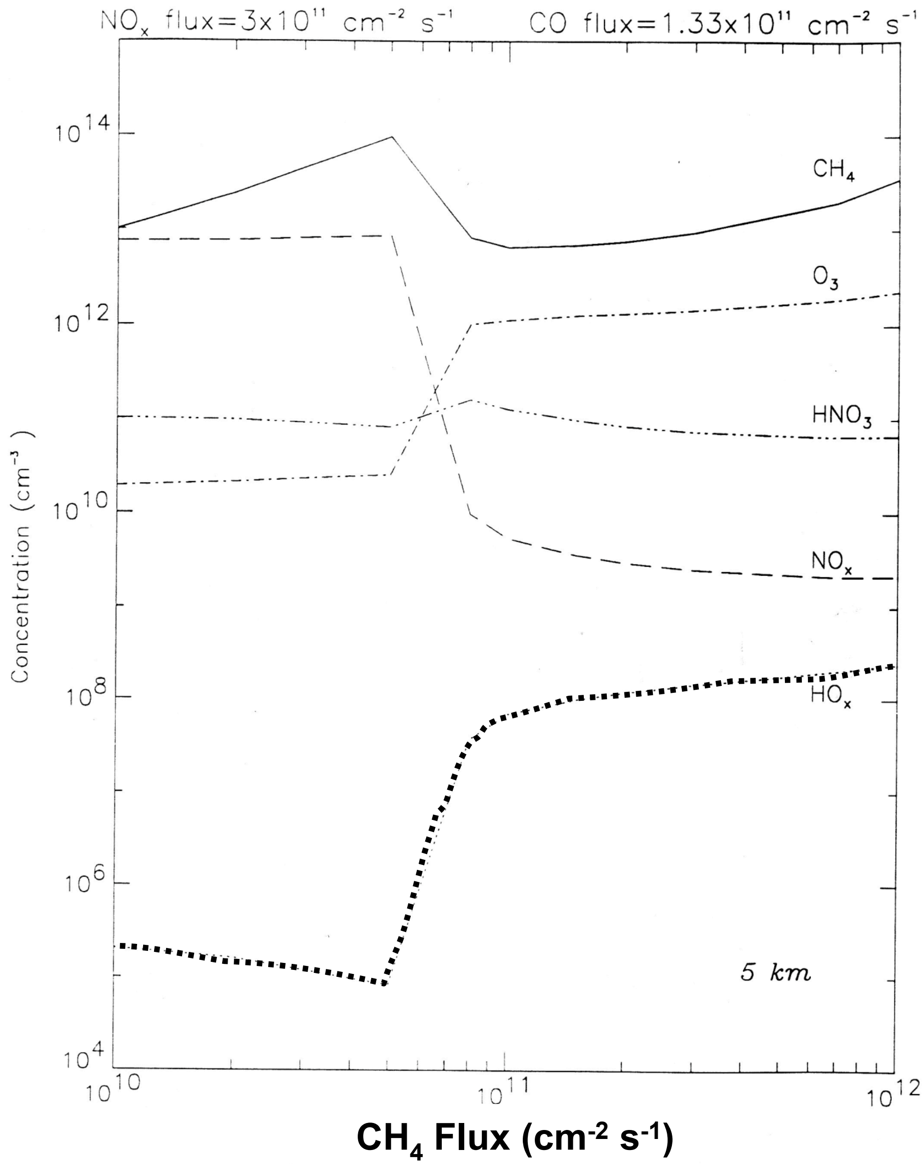
Multiple Steady States



Existence of MSS sensitive to abundance of other tracers e.g. no MSS if RH < 40%

[Stewart, 1993]

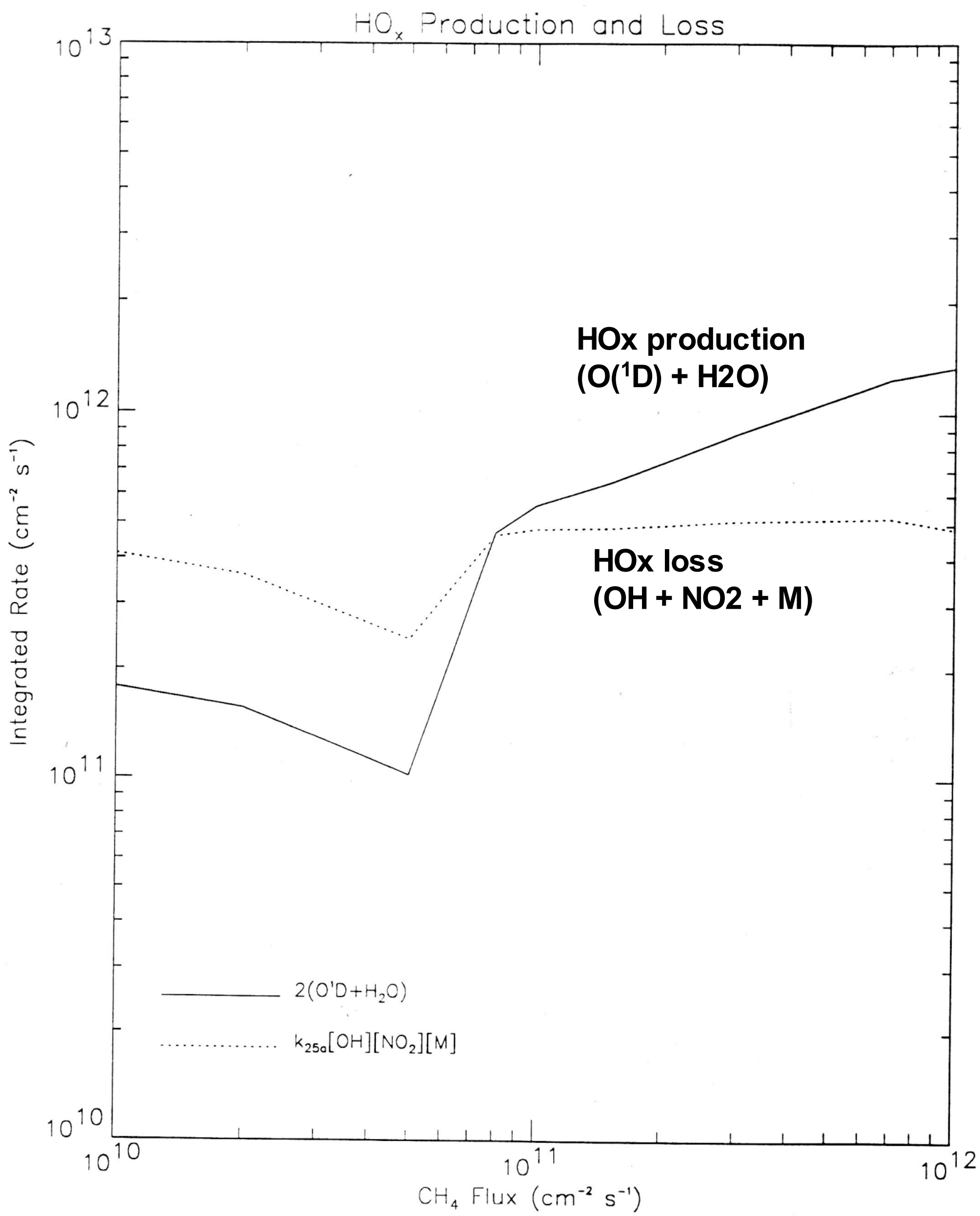
1-D Simulation of Stewart's Results



- **Decreasing CH_4 emissions results in a transition to a high NO_x regime**
- **Total O_3 column decreases by a factor of 3 from the low to high NO_x regime (NO_x in lower strat ≈ 0.5 ppm)**

- **Results <u>suggest</u> the possibility of MSS in the 1-D model**
- **These abrupt transitions were not found in the 2-D model**
- **A more detailed search of state space is needed for the 1-D and 2-D models**

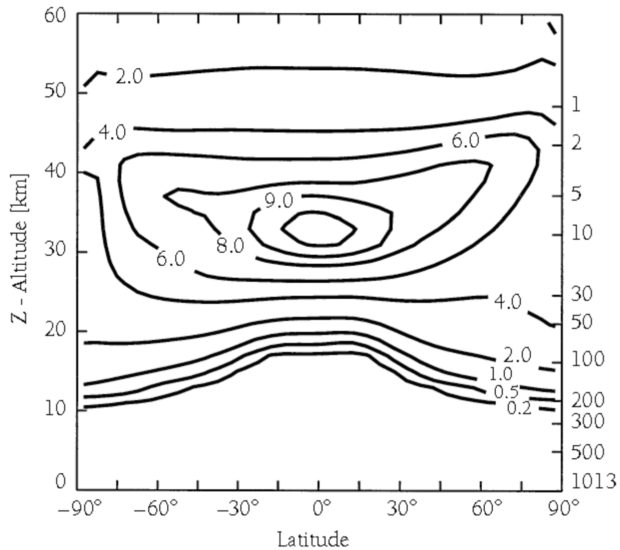
HO_x Production and Loss



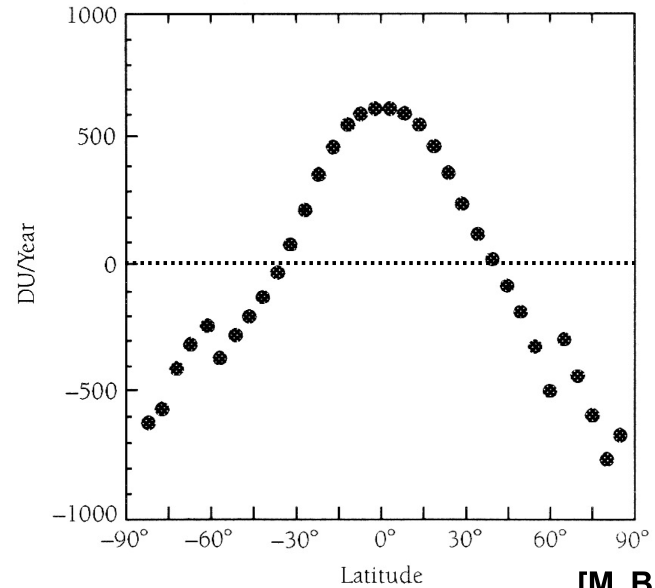
At low levels of CH_4, OH production is insufficient to support HNO_3 formation
$\Rightarrow NO_x$ concentrations increase dramatically

Influence of Transport on Stratospheric O_3

O_3 from Harvard 2-D model



Net Column O_3 P-L for equinox)



[M. B. McElroy, 2002]

- **Net O_3 production in tropical stratosphere reflects large flux of UV photons**
- **At high levels of CH4, oxidation shifts to tropical stratosphere which helps stabilize the system**

A More Dynamically Consistent Approach

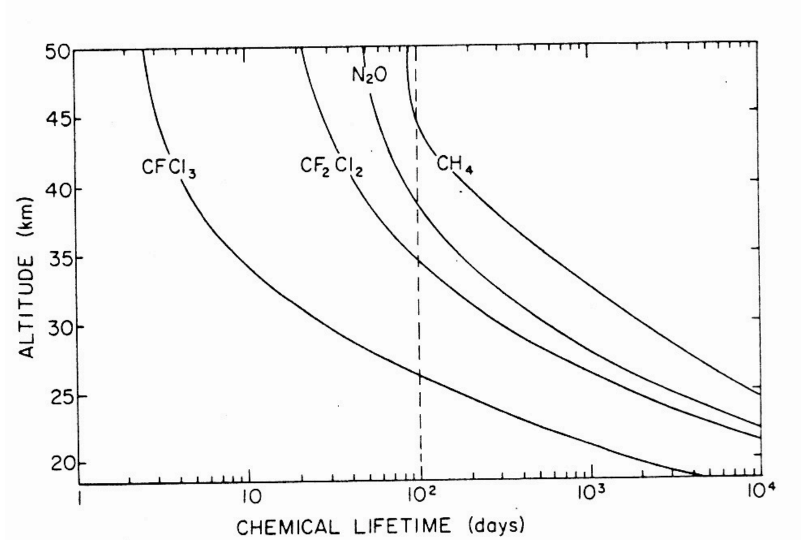
Approximate the transport with a vertical "eddy transport" coefficient

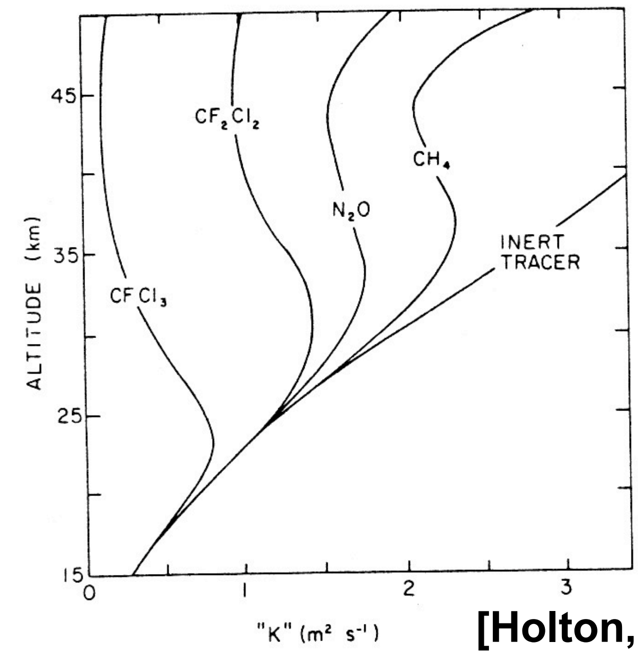
$$K = \frac{W_2^{\,2}}{5(\tau_{\mathbf{c}}^{-1} + \tau_{\mathbf{d}}^{-1})}$$

$$W_2 = RQ_2/(N^2 H)$$

- W_2 = **vertical mass circulation**
- Q_2 **is annual mean diabatic heating rate projected on** $P_2(\mu)$
- τ_c **= timescale for the chemistry**
- τ_d **= timescale for horizontal eddy mixing**

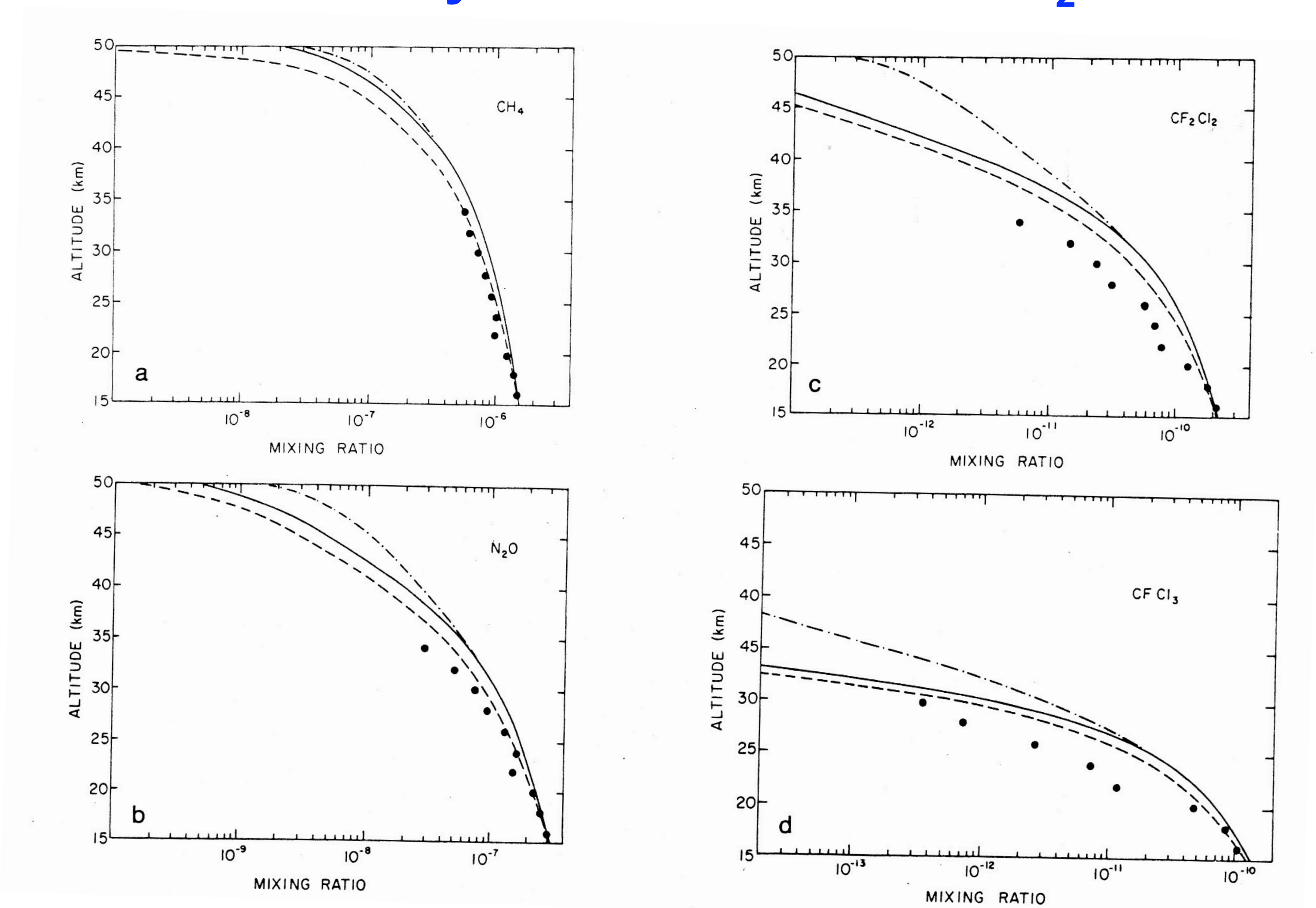
Vertical transport coefficient species-specific





[Holton, 1986]

Sensitivity of Tracer Profile to K_z



[Holton, 1986]

- Filled circles: Observations at 44ºN
- Dashed-dotted line: global mean with K_z for inert tracer
- Solid line: global mean for species specific K_z
- Dashed line: simulated profiles for 45ºN

Main Points of Lecture

- 1-D chemical-radiative-diffusive models were used extensively in 1970s and 1980s
- Modelling the vertical advective transport as a diffusive process provides a fundamentally flawed simulation of the distribution of the trace gases ⇒one *K* does not fit all
- More dynamically consistent approaches (e.g. Holton [1985]) were proposed but never adopted widely
- Despite these limitations, 1-D models provided much of our understanding of the trace constituents in the atmosphere during the pre-satellite era
- 1-D chemical-radiative models are currently used in 3-D model - e.g., domain decomposition for parallel numerical simulations
- The limitations of 1-D models reflects importance of the meridional transport of tracers in the atmosphere ⇒ Brewer-Dobson circulation