



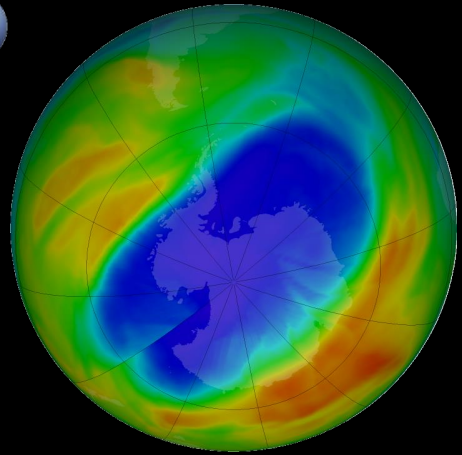
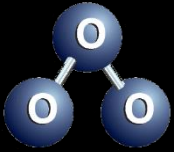
Rijksinstituut voor Volksgezondheid
en Milieu
*Ministerie van Volksgezondheid,
Welzijn en Sport*

Montreal Protocol: Successful international policies for ozone layer and climate

Guus Velders

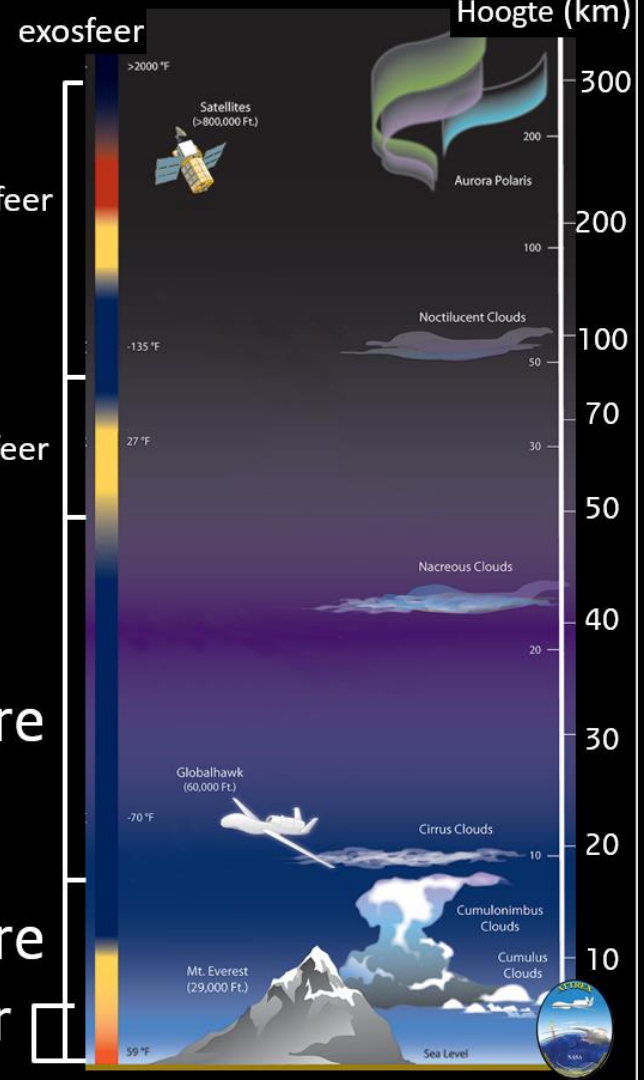
RIVM and Utrecht University

Utrecht, April 6, 2023

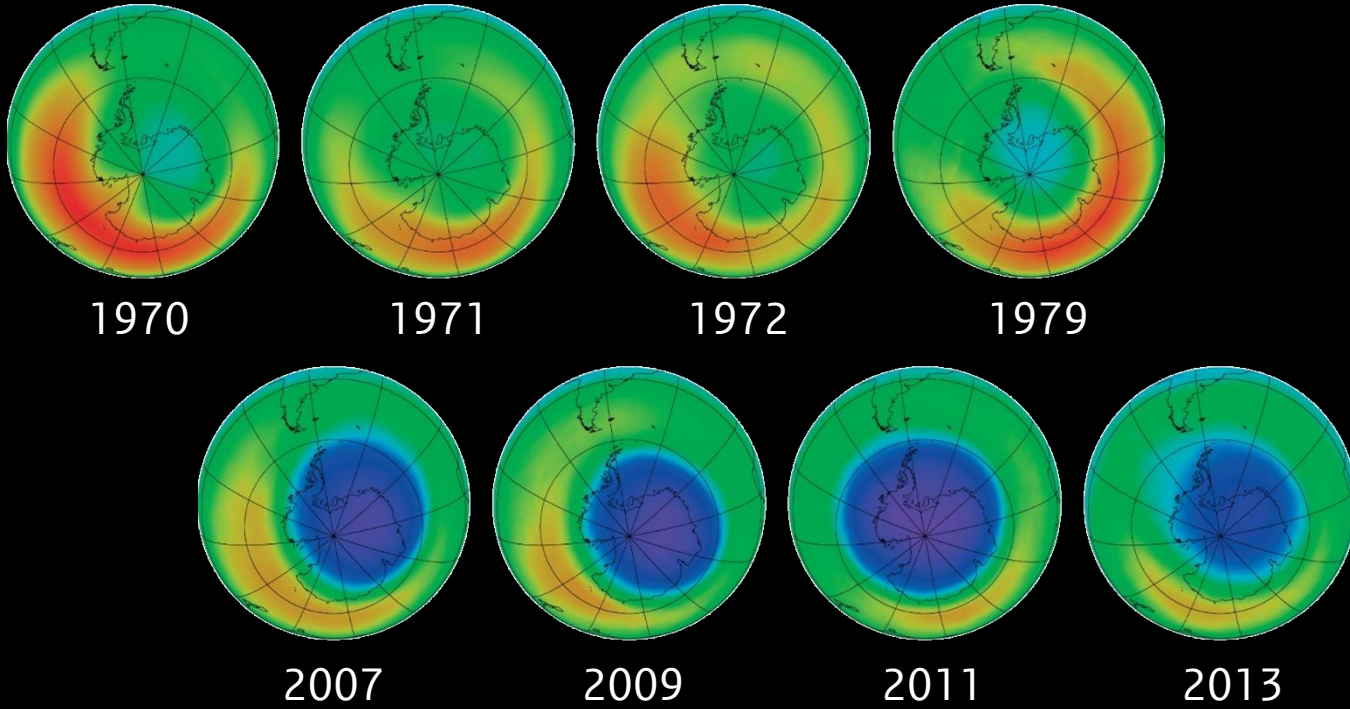


Ozone layer
15-50 km

→ stratosphere
troposphere
boundary layer



Ozone layer evolution

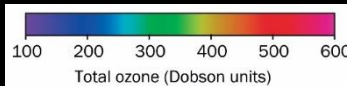


October

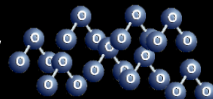
Source: NASA, KNMI

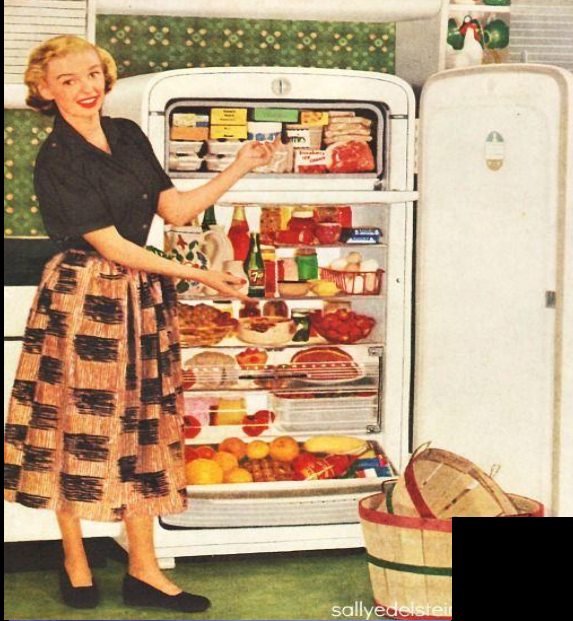


Few



Many





sallyedelstein



CFCs



1974: Mario Molina & Sherwood Rowland

Measurement show: CFCs can release chlorine and react with ozone



CFC-11: CFCl_3

CFC-12: CF_2Cl_2

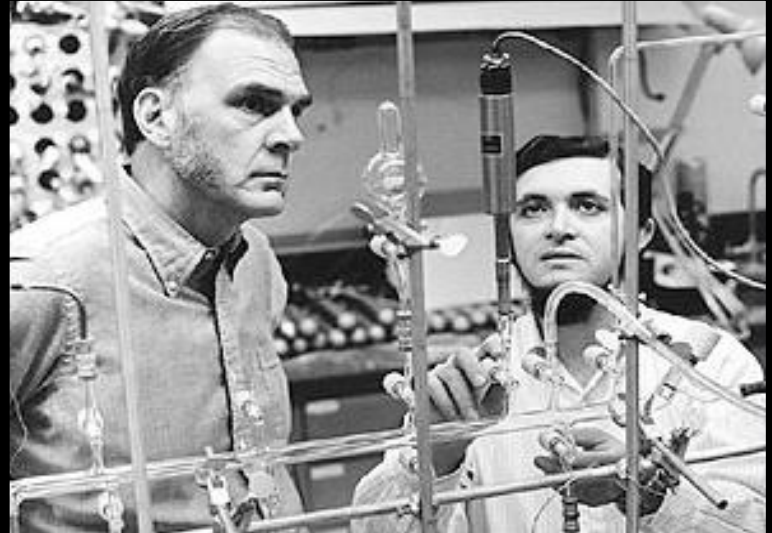
CFC-113: $\text{CF}_2\text{Cl}-\text{CF}_2\text{Cl}$

CCl_4

CH_3CCl_3

halons

CH_3Br



1985: Joe Farman, Brian Gardiner & Jon Shanklin

Measurements show strong ozone depletion over Antarctic



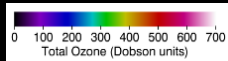
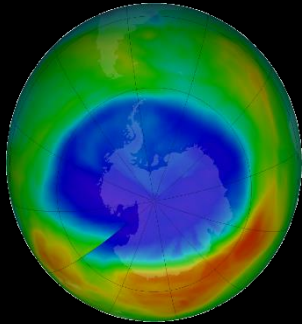
Large spring time ozone decreases

LETTERS TO NATURE

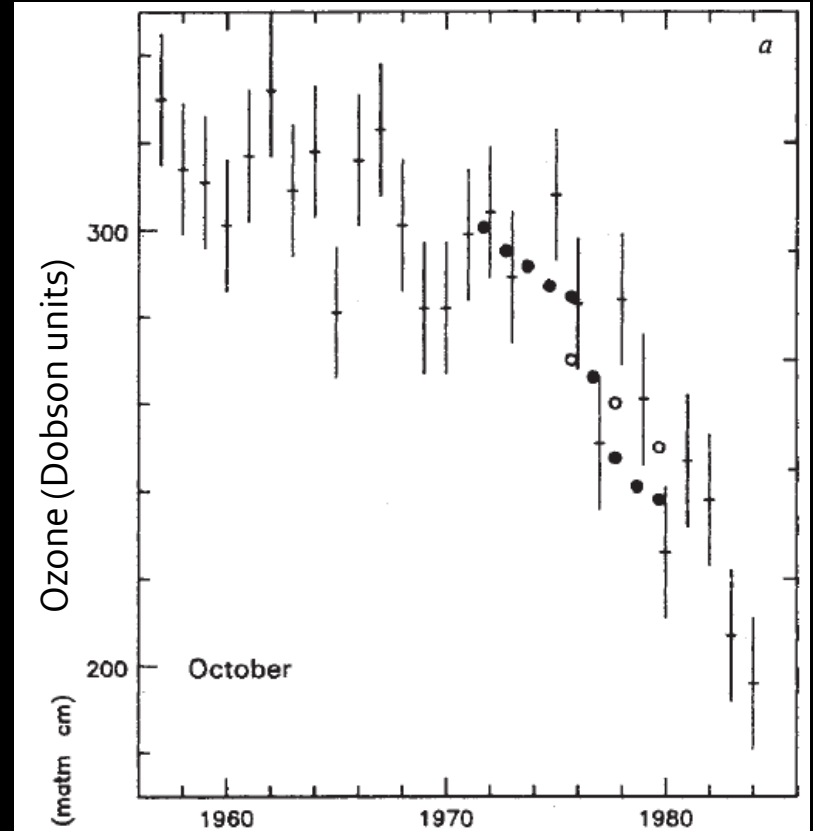
**Large losses of total ozone in Antarctica
reveal seasonal ClO_x/NO_x interaction**

J. C. Farman, B. G. Gardiner & J. D. Shanklin

British Antarctic Survey, Natural Environment Research Council,
High Cross, Madingley Road, Cambridge CB3 0ET, UK



Linked to
elevated
chlorine levels

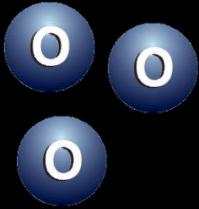
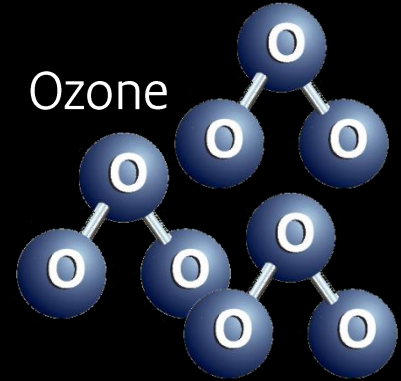


CFCs release chlorine atoms

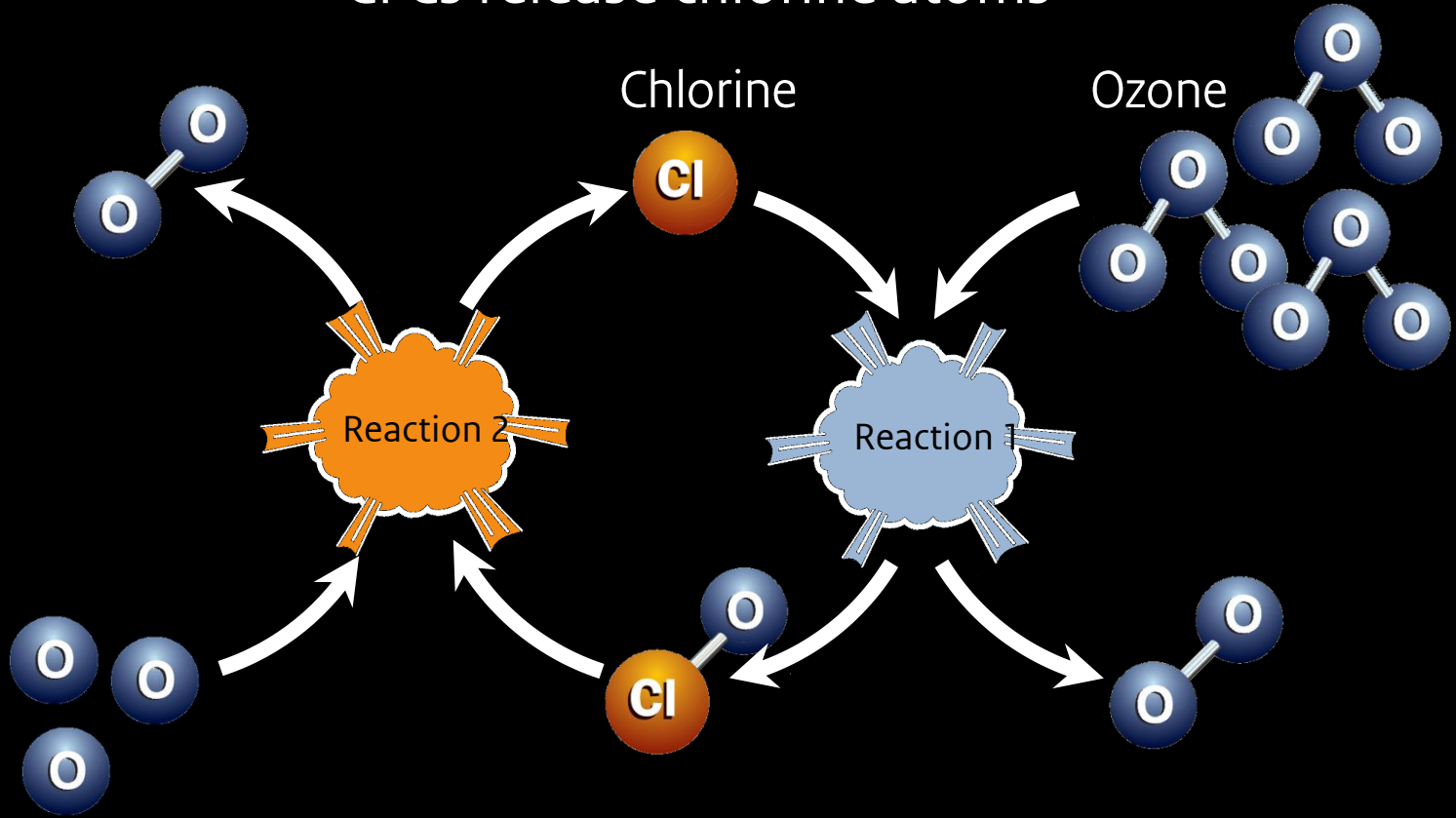
Chlorine



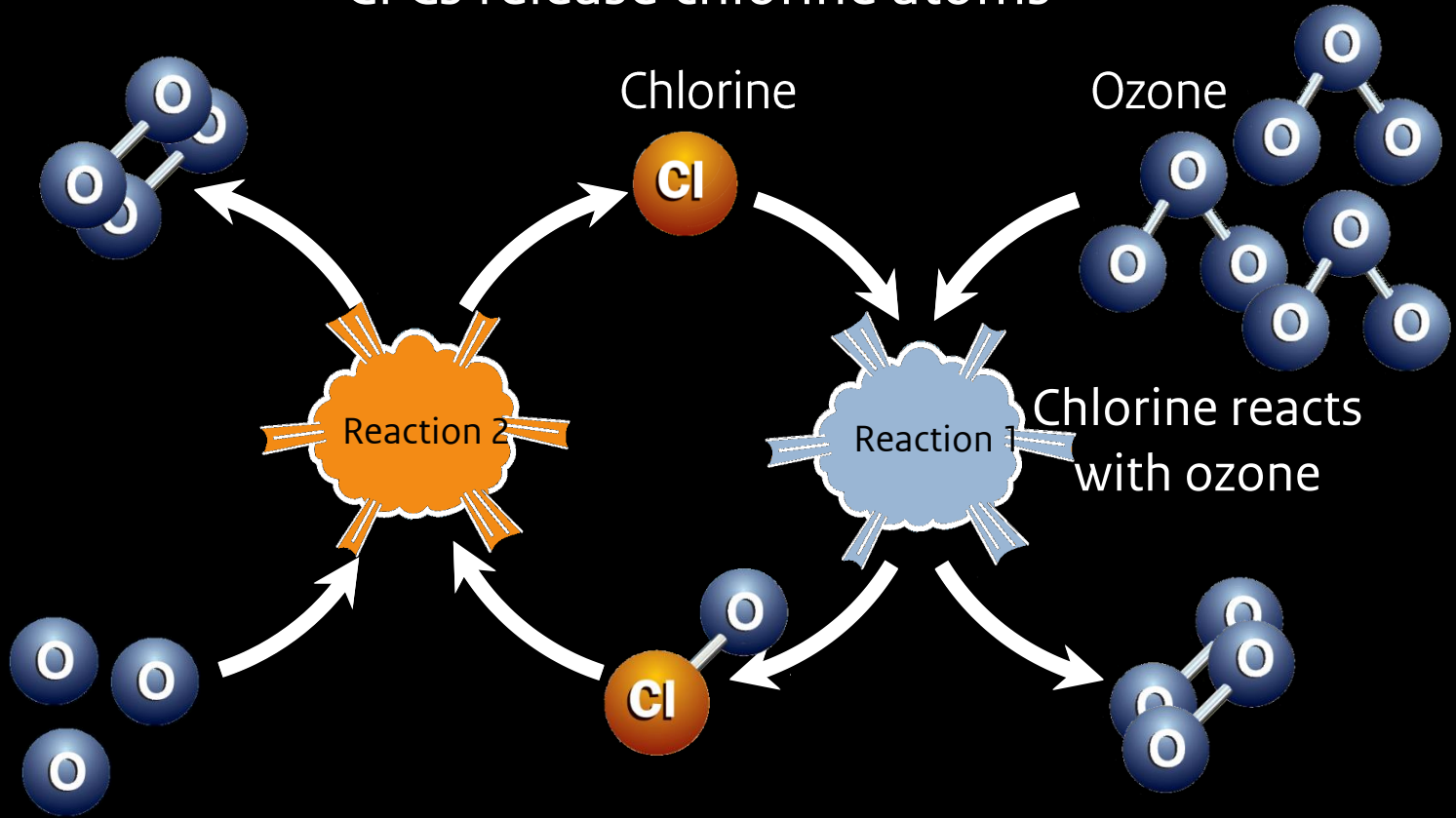
Ozone



CFCs release chlorine atoms

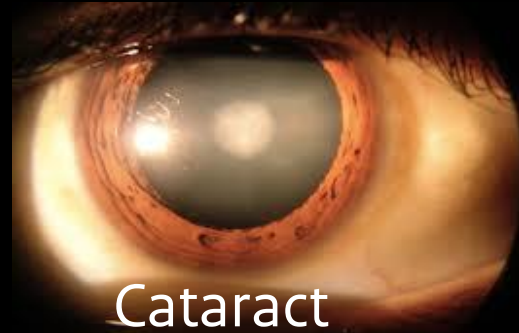
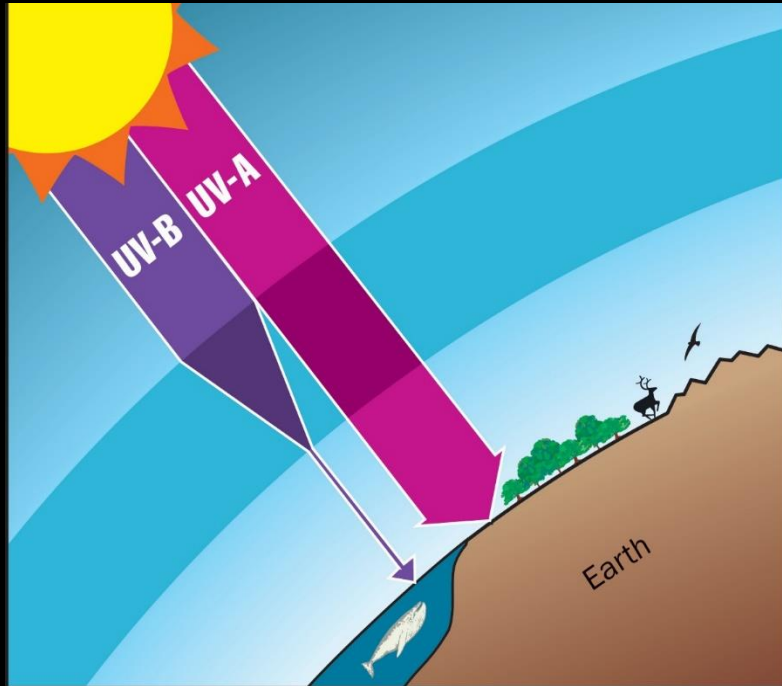


CFCs release chlorine atoms



1 chlorine atom breaks down 1000s ozone molecules

More UV radiation through thinner ozone layer



Montreal Protocol

1985: Vienna convention

1987: Montreal Protocol

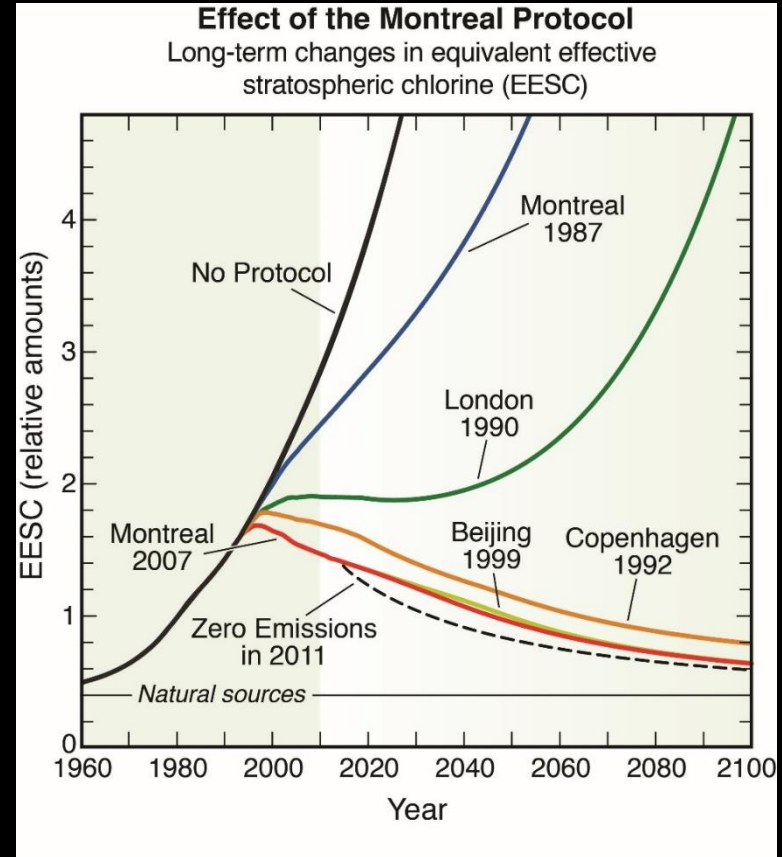
1990ff: Amended several times

1996: Phase-out CFCs/halons developed countries

2010: Phase-out globally

2020: Phase-out HCFC developed countries

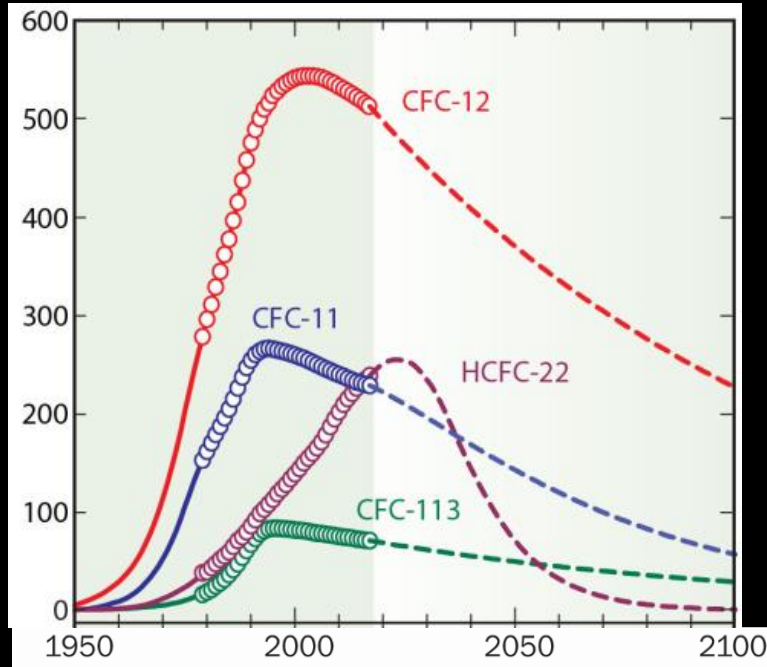
2030: Phase-out HCFC globally





1987: Countries agree to ban CFCs

CFC concentrations

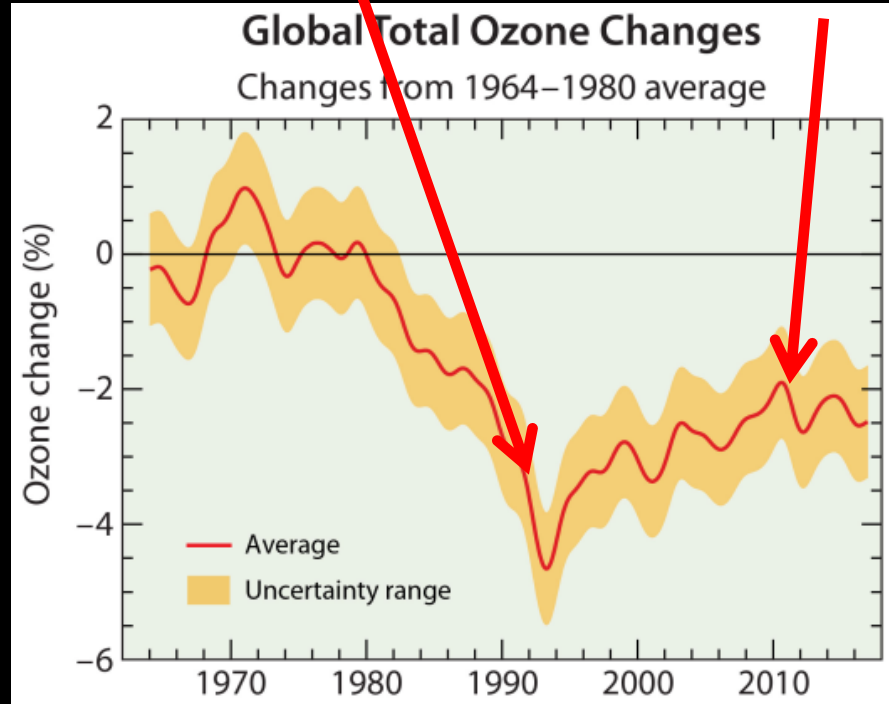


Source: WMO

Ozone layer has become thinner,

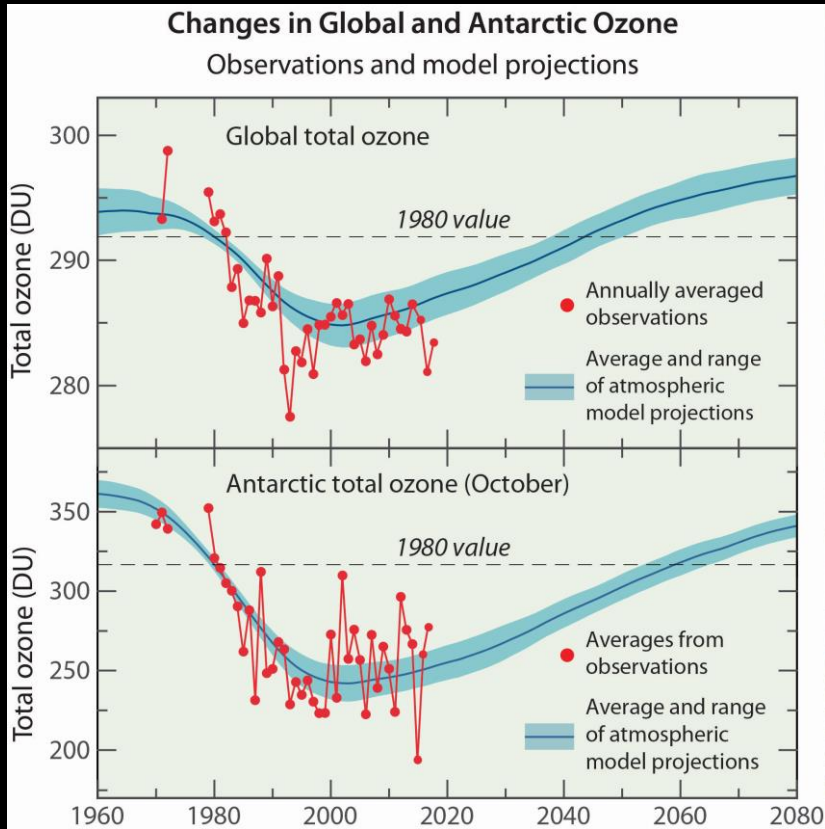
Percent change in ozone layer


but is it not getting worse



Source: WMO

Ozone layer start to recover



without 
increase in skin cancer

Projected recovery
~2040 mid latitude
~2065 Antarctic

CFCs are also potent greenhouse gases

Radiative forcing of climate

Global Warming Potential (GWP)

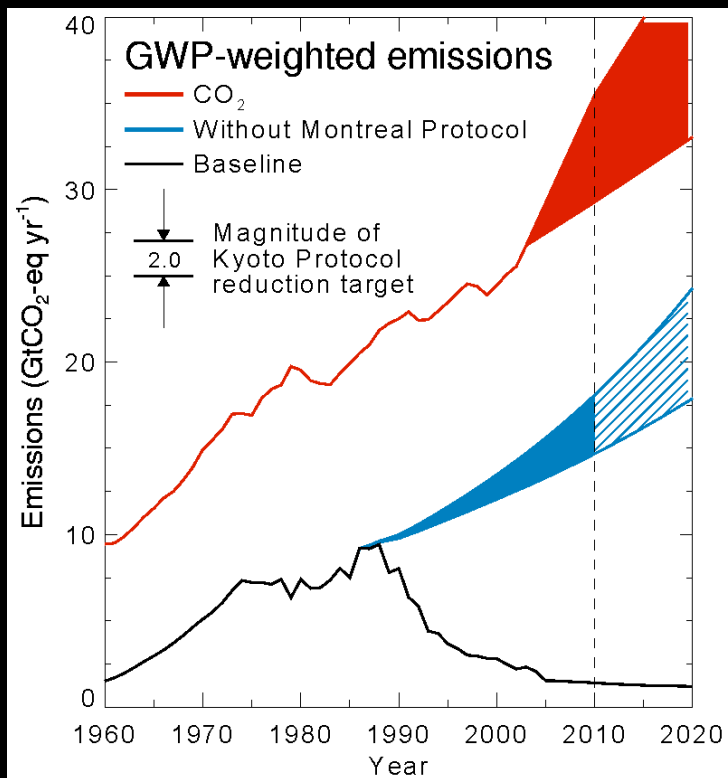
CO₂ = 1

CFCs: 4,700- 11,000

HCFC: 100-2,200

Decrease in CFCs → reduce radiative forcing of climate system

Large climate benefits Montreal Protocol



CO₂ emissions

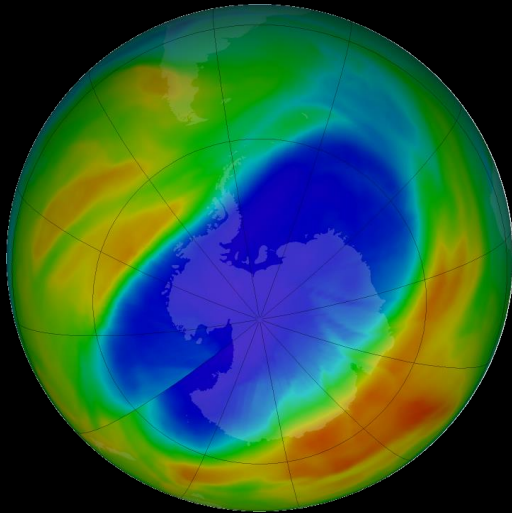
World avoided by Montreal Protocol

Reduction Montreal Protocol of
~11 GtCO₂-eq/yr

→ 5-6 times Kyoto target

(incl offsets HFCs, ozone depl.)

Ozone layer ↔ Climate change



CFCs, ...

Montreal Protocol



CO₂, methane, ...

Paris accord

Montreal Protocol changed chemicals used

It caused a change in chemicals used for refrigeration, AC, foam blowing, cleaning, fire extinguishing, etc.:

CFCs → HCFCs + other techn. → HFCs + other techn.

Range of different chemicals

CFCs: CFCl_3 (CFC-11), CF_2Cl_2 (CFC-12), etc.

Others: CF_3Br , CF_2ClBr (Halons), methyl bromide/chloride, methyl chloroform, CCl_4

Alternatives:

1. **HCFCs:** partially halogenated

CHF_2Cl (HCFC-22), CH_3CFCl_2 , $\text{CH}_3\text{CF}_2\text{Cl}$

2. **HFCs:** no chlorine

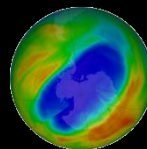
CH_2FCF_3 (HFC-134a), CHF_2CF_3 (HFC-125), CH_3CF_3 (HFC-143a)

3. **HFOs:** short lifetime

$\text{CF}_3\text{CF}=\text{CH}_2$ (HFO-1234yf), $\text{CF}_3\text{CH}=\text{CHF}$ (HFO-1234ze)



Good for
ozone layer



CFCs



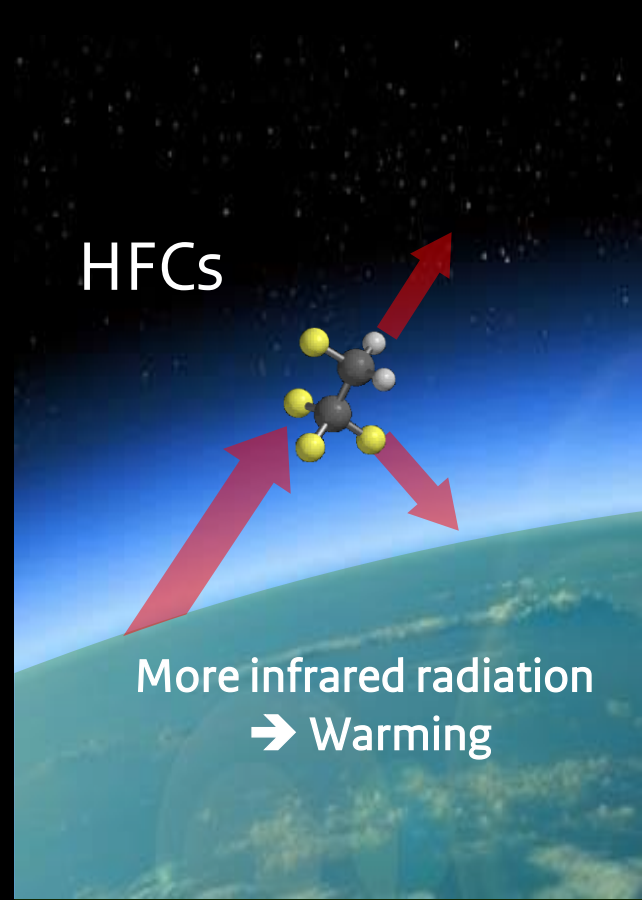
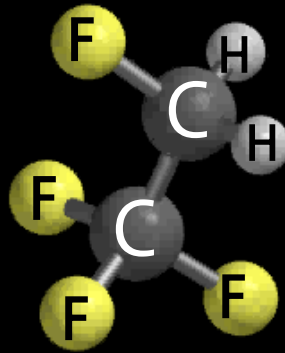
HFCs



Not for
climate



HFC: Hydrogen-Fluor-Carbon



Applications HFCs (1)

Refrigeration and air conditioning

- Domestic, commercial and industrial:
 - Originally: CFC-11, CFC-12
 - Now: HCFC-22, HFCs, NH₃, CO₂, hydrocarbons
- Mobile air conditioning
 - Initially: CFC-12
 - Now (since ~1995): HFC-134a (all cars)



Foam blowing: insulation, packaging

- Originally: CFCs
- Now: HFCs, hydrocarbons, others



Applications HFCs (2)

Solvent: Dry cleaning, electronics industry

- Originally: CFCs, CCl_4 , CH_2Cl_2
- Now: - mostly not-in-kind technologies, water, other chemicals
- HFCs for some specialized uses



Aerosols: Metered dose inhalers, spray cans (deodorant, hair)

- Originally: CFC-11
- Now: hydrocarbons, not-in-kind, HFCs (limited uses)

Fire fighting agent in aircraft and high-tech facilities

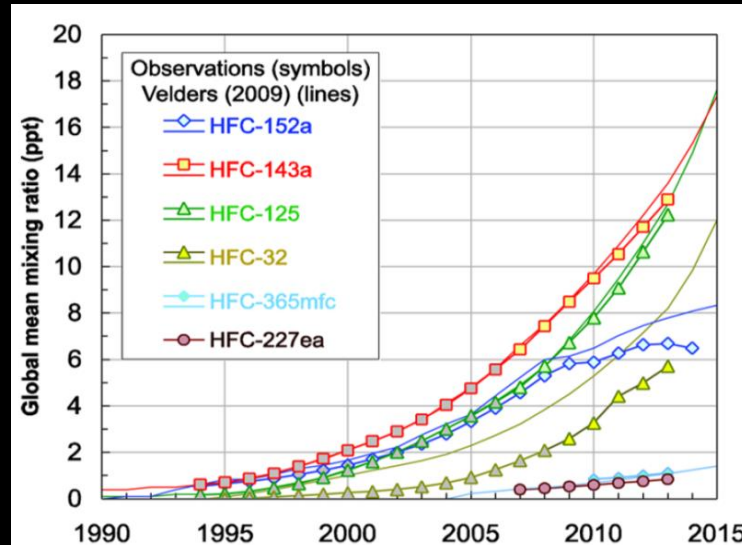
- Originally: halons and CCl_4
- Now: Inert gas (e.g. CO_2), water, HFCs



Large growth in HFC use

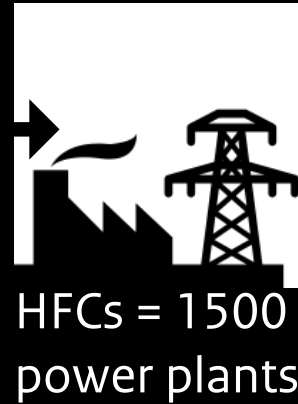
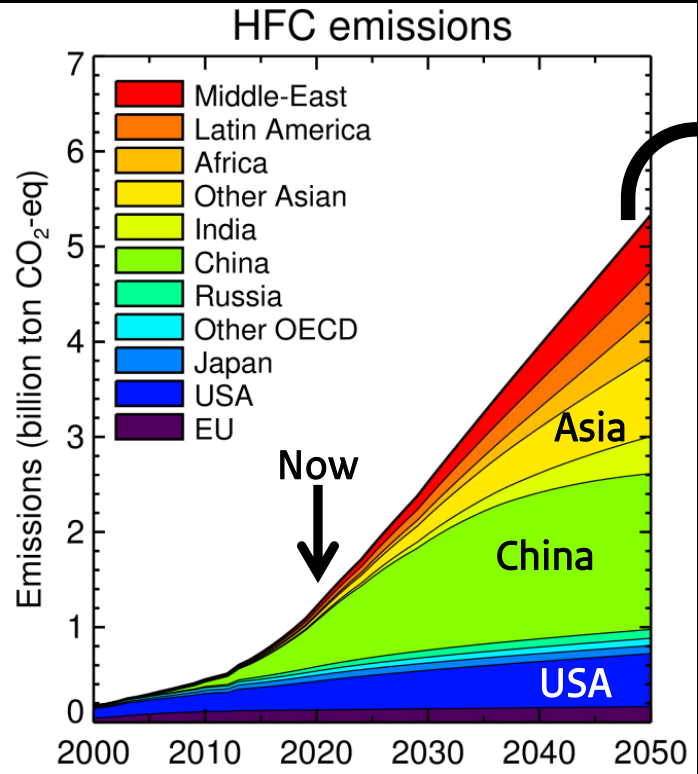
Continued large growth expected

- Refrigeration
- AC
- Heat pumps
- ...



Montzka et al. (2015)

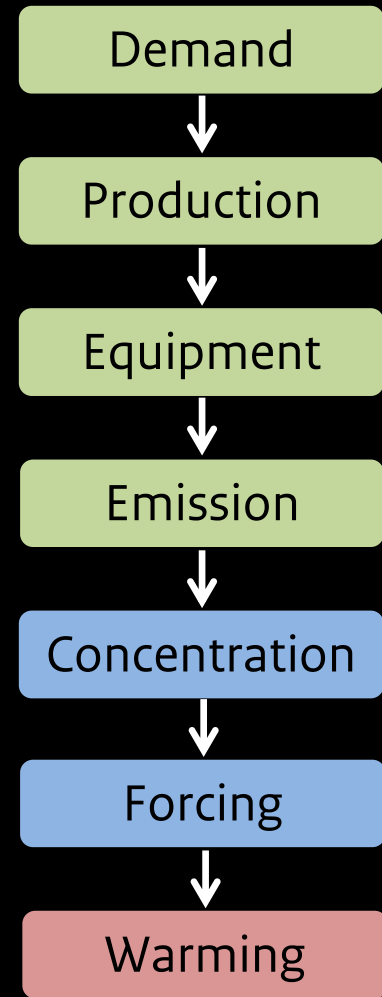
HFCs: Threat for climate



10 HFCs
X
11 regions
X
13 sectors

Extra 0.5 °C
warming 2100

Velders et al., 2015





Kigali Amendment 2016

Use HFCs reduced by 80-85% around 2045

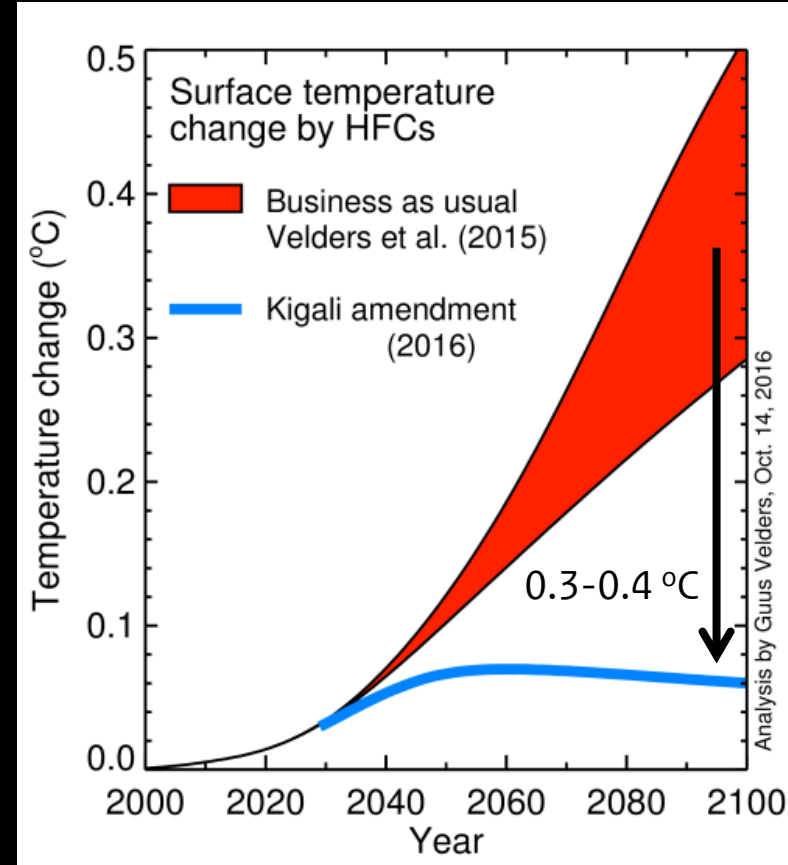
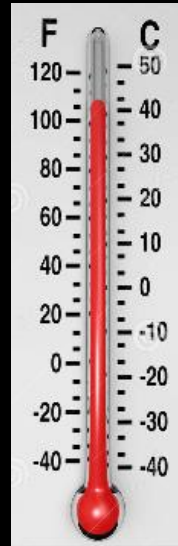


Avoided warming

Kigali climate accord (Oct. 2016)



1.5-2 °C



Accomplishment Montreal Protocol

Ozone layer protection

CFCs phased out

- Large decrease in emissions
- Decreases in concentration

Ozone layer slowly recovering

- ~2040 mid latitudes
- ~2065 Antarctic

Climate protection

- Phase-out of CFCs

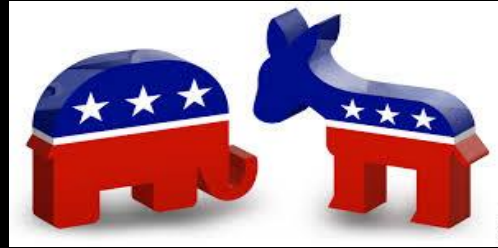
Kigali amendment of 2016

- Phase down of HFCs
- Avoided warming of 0.2-0.4 °C

Success: Now, Together, Coordinated



Science



Politics



Industry

Questions?

Dank u wel

Gracias

Danke

Merci

Diolch yn fawr

Спасибо

شكرا

谢谢

धन्यवाद

σας ευχαριστώ

תודה

terima kasih

teşekkür ederim

köszönöm

நன்றி

