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# Climate impacts of Montreal protocol and Kigali amendment

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IO3C 30<sup>th</sup> anniversary MP Symp. Paris, Sep. 2017

# Climate already mentioned early

## 1985 Vienna Convention for the Protection of the Ozone Layer

### Article 1: Definitions

“Adverse effects” means changes in the physical environment or biota, including **changes in climate**, ...

## 1987 Montreal Protocol on Substances that Deplete the Ozone Layer

**Preamble:** Recognizing that world-wide emissions of certain substances can significantly deplete and otherwise modify the ozone layer ...,  
Conscious of the **potential climatic effects** of emissions,

## 2007 Adjustment: Accelerated HCFC phase out



# Greenhouse effect of CFCs

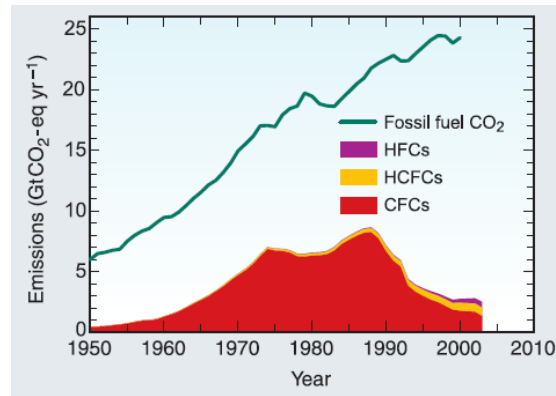
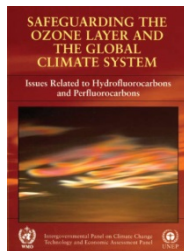
Ramanathan, Science (1975)

## Greenhouse Effect Due to Chlorofluorocarbons: Climatic Implications

*Abstract. The infrared bands of chlorofluorocarbons and chlorocarbons enhance the atmospheric greenhouse effect. This enhancement may lead to an appreciable increase in the global surface temperature if the atmospheric concentrations of these compounds reach values of the order of 2 parts per billion.*

## IPCC-TEAP special report (2005) on safeguarding the ozone layer and the global climate system

Andersen, Kuijpers, Pons,  
Solomon, Davidson, Metz



# Dual protection of the Montreal Protocol

Important  
Message

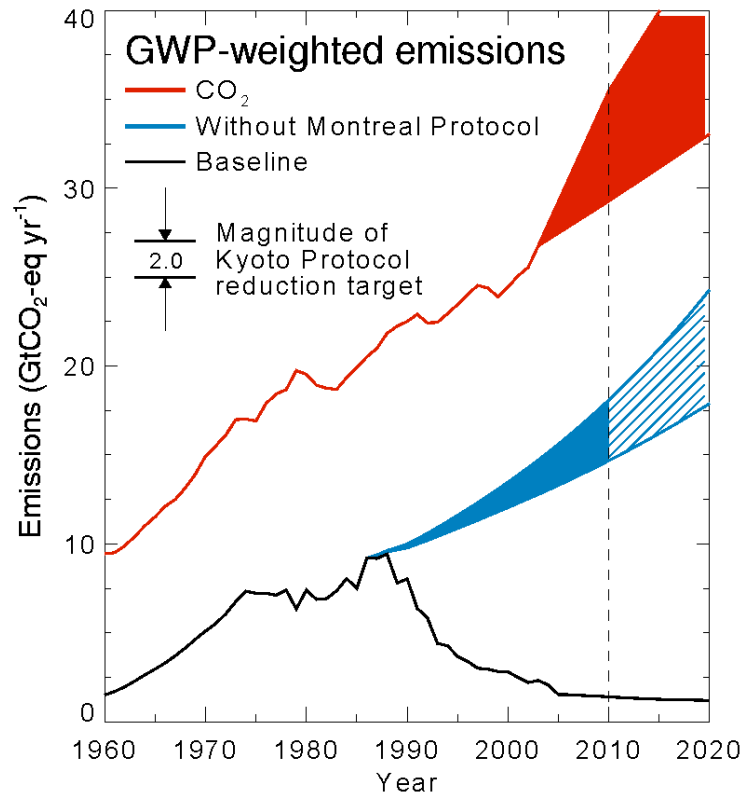
## To Ozone layer and Climate change

- Already achieved climate benefits 5-6 times larger than Kyoto Protocol targets for 2008-2012

## Montreal Protocol amendment in 2016 for climate protection

↙  
**'Kigali amendment' reduces surface temperature warming of HFCs from 0.3-0.5 °C to less than 0.1 °C by 2100**

# Climate benefits Montreal Protocol: ODSs



} CO<sub>2</sub> emissions

} **World avoided** by Montreal Protocol

} Reduction Montreal Protocol of ~11 GtCO<sub>2</sub>-eq/yr

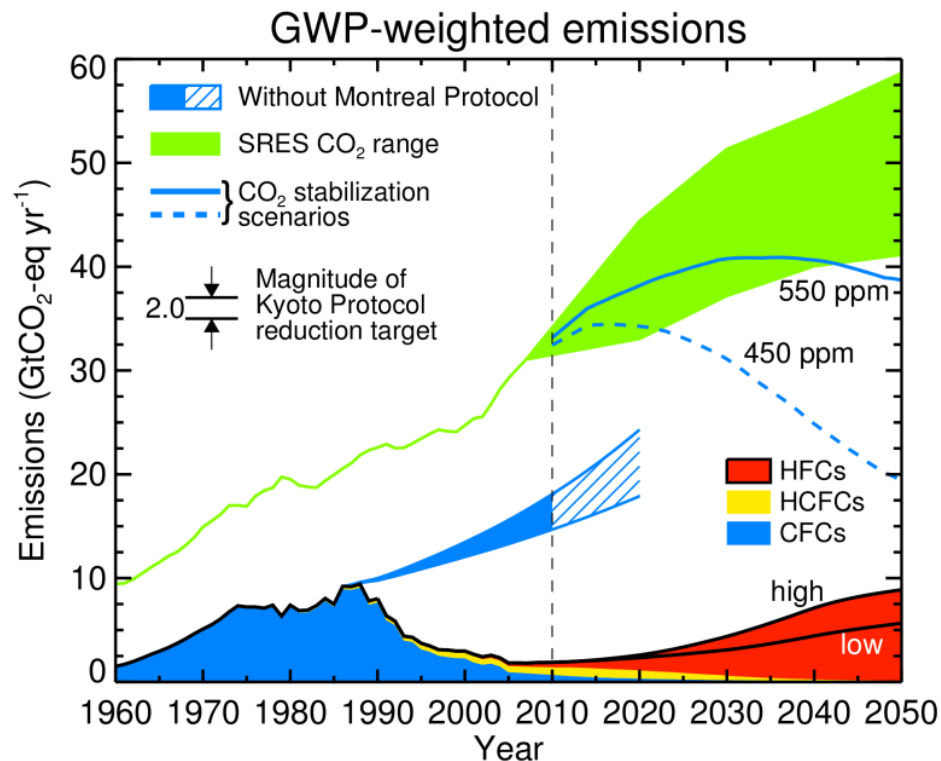
→ 5-6 times Kyoto target

(incl. offsets: HFCs, ozone depl.)

Velders et al. (PNAS, 2007)

# HFCs could offset climate benefits

- In 2010, CFCs could have reached 15–18 GtCO<sub>2</sub>-eq yr<sup>-1</sup> (in absence of Montreal Protocol)
- In 2050, HFC emissions: 5.5–8.8 GtCO<sub>2</sub>-eq yr<sup>-1</sup> = 9–19% of global CO<sub>2</sub> emissions
- Larger in comparison with CO<sub>2</sub> stabilization scenarios from IPCC/AR4



Velders et al. (PNAS, 2009)



# HFC scenarios

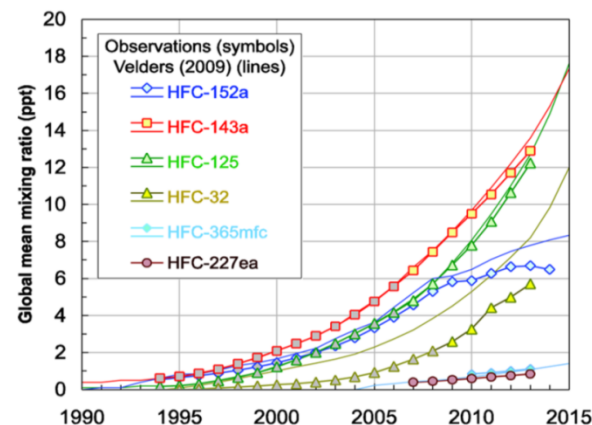
## Starting point:

- Large growth rates in observed concentrations of most HFCs
- Growth in HCFC consumption (UNEP)
- HCFC phase-out in Montreal Protocol
- Expected growth in demand for HFCs for refrigeration, AC



## Scenarios for 1990 to 2050

- Business-as-usual scenarios
- Growth proportional to GDP and population
- Market saturation
- Emissions constrained by observations
- Effects of national regulations. Effects of Kigali amendments
- **CO<sub>2</sub>-eq consumption and emissions, Radiative forcing**



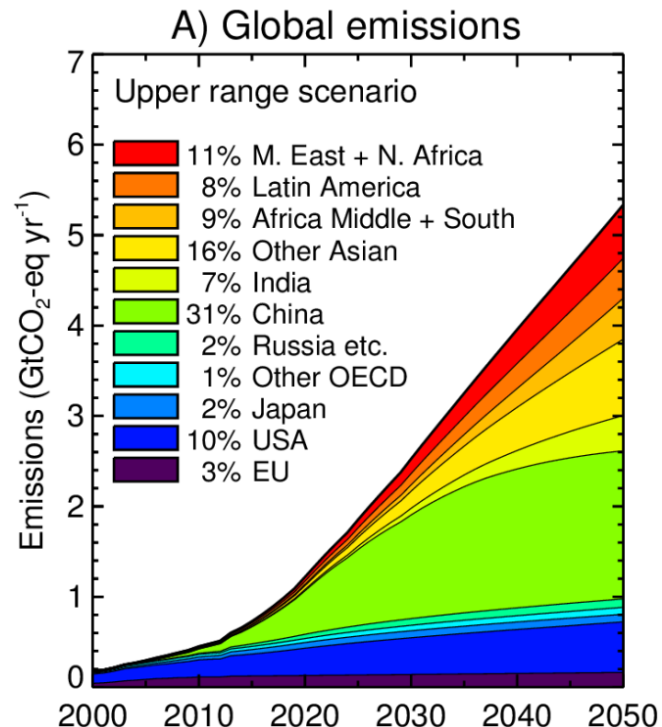
Montzka et al. (2015)

# Business-as-usual emissions for each region

## Major 2050 emissions from developing countries

- Historical emissions mainly from USA and EU
- China is projected to be largest emitter in 2020
- Major regions in 2050
  - China (31%)
  - India and other Asian countries (23%)
  - USA (10%), Middle East - N. Africa (11%)

Velders et al. (Atmos. Env., 2015)



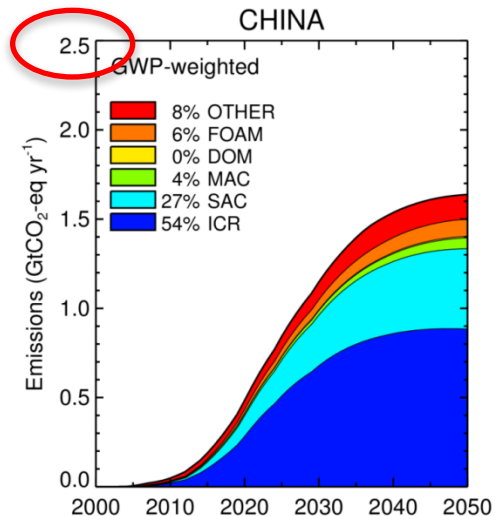
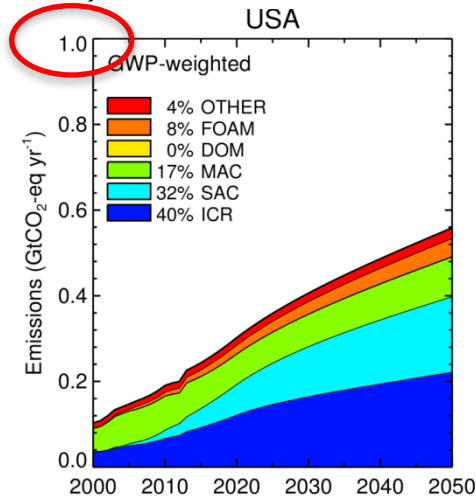
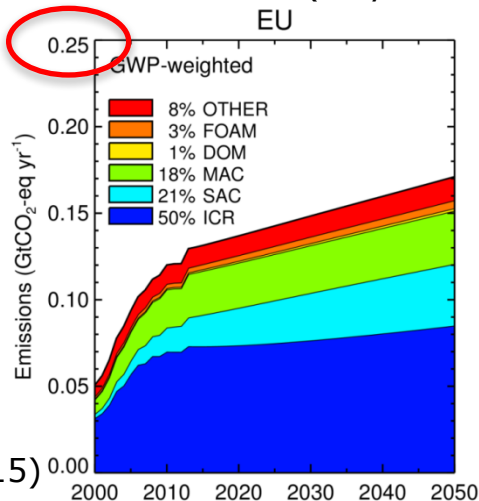
Guus Velders et al.



# Business-as-usual emissions per region

## CO<sub>2</sub>-eq emissions

- Main non-A5 regions: USA, EU
- Main A5 regions: China, other Asian countries
- Main sectors: - ICR: Industrial and commercial refrigeration  
- SAC: Stationary AC  
- MAC: Mobile AC (only for non-A5)



Note vertical scales

Velders et al. (AE, 2015)

Guus Velders et al.

# Kigali amendment (Oct. 15, 2016)

## Agreed baselines and phasedown schedules



	<i>A5 (China etc)</i>	<i>A5 (India, Saudi Arabia, etc)</i>	<i>A2 (USA, EU, etc.)</i>
Baseline	2020-2022	2024-2026	2011-2013
Formula	Average HFC consumption	Average HFC consumption	Average HFC consumption
HCFC	65% baseline	65% baseline	15% baseline*
Freeze	2024	2028	-
1 <sup>st</sup> step	2029 – 10%	2032 – 10%	2019 – 10%
2 <sup>nd</sup> step	2035 – 30%	2037 – 20%	2024 – 40%
3 <sup>rd</sup> step	2040 – 50%	2042 – 30%	2029 – 70%
4 <sup>th</sup> step			2034 – 80%
Plateau	2045 – 80%	2047 – 85%	2036 – 85%

\* For Belarus, Russian Federation, Kazakhstan, Tajikistan, Uzbekistan: small difference

# Agreement legal text: Oct. 15 6:55 am

## *Article 2J*

The following Article shall be inserted after Article 2I of the Protocol:

### “Article 2J: Hydrofluorocarbons

1. Each Party shall ensure that for the twelve-month period commencing on 1 January 2019, and in each twelve-month period thereafter, its calculated level of consumption of the controlled substances in Annex F, expressed in CO<sub>2</sub> equivalents, does not exceed the percentage, set out for the respective range of years specified in subparagraphs (a) to (e) below, of the annual average of its calculated levels of consumption of Annex F controlled substances for the years 2011, 2012 and 2013, plus fifteen per cent of its calculated level of consumption of Annex C, Group I, controlled substances as set out in paragraph 1 of Article 2F, expressed in CO<sub>2</sub> equivalents:
  - (a) 2019 to 2023: 90 per cent
  - (b) 2024 to 2028: 60 per cent
  - (c) 2029 to 2033: 30 per cent
  - (d) 2034 to 2035: 20 per cent
  - (e) 2036 and thereafter: 15 per cent
2. Notwithstanding paragraph 1 of this Article, the Parties may decide that a Party shall



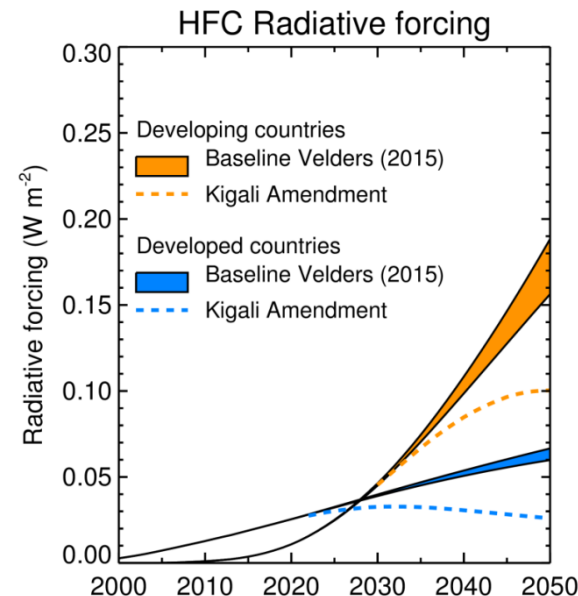
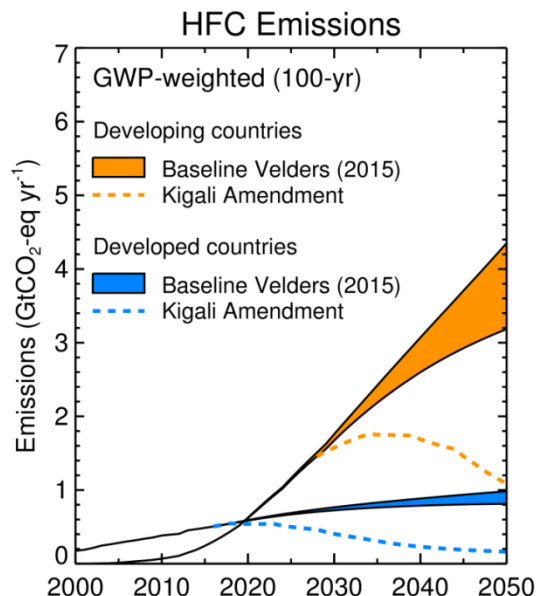
# Kigali amendment on emissions and forcing

## CO<sub>2</sub>-eq emissions

- Developed countries: from 1 to 0.2 GtCO<sub>2</sub>-eq/yr by 2050
- Developing countries: from 3-4 to 1 GtCO<sub>2</sub>-eq/yr

## Radiative forcing

- Slower/delayed reductions



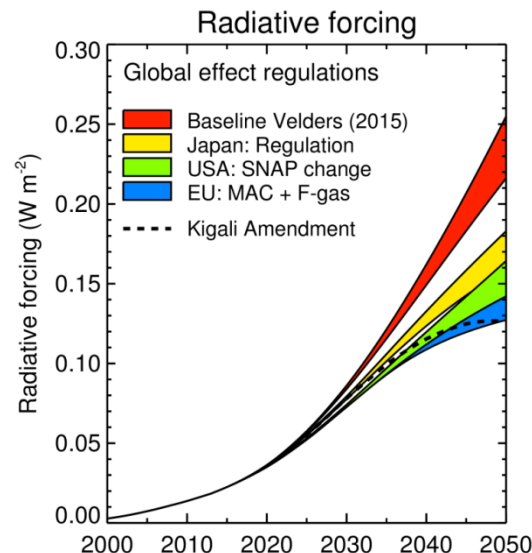
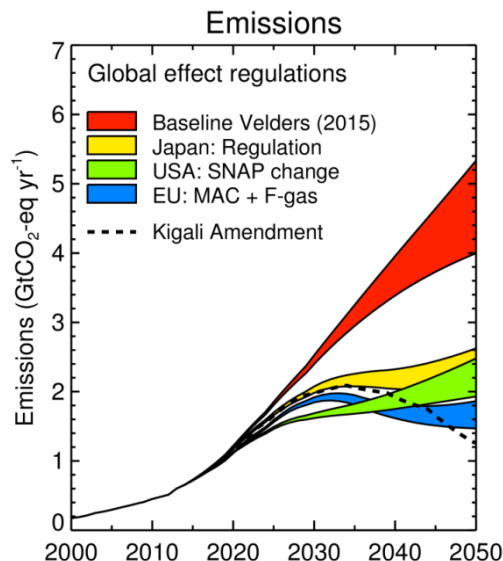
# National/regional regulations

## Regulations in force or proposed

- EU: Revised F-gas regulation + MAC directive
- USA: Changes to SNAP list
- Japan: F-gas controls
- Also discussion in Canada, Australia

## National regulation will drive global technological changes

- Estimate effects of applying national regulations on emissions in developed and developing countries



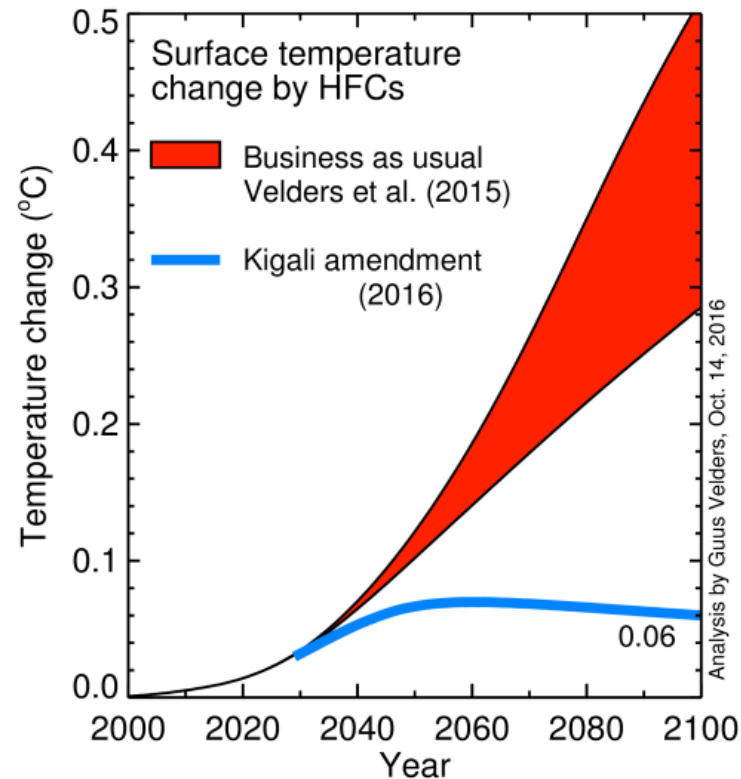
# Surface temperature projections

## Climate effects calculated

- MAGICC6 model

**BAU: range from 0.3 – 0.5 °C in 2100**

**Kigali amendment: reduced to about 0.06 °C**



# Novel aspects of the agreement

## **Montreal Protocol used to protect climate**

- Governance: crossing boundaries on environmental topics

## **Split in developing countries**

- China, majority of Asia, Latin America, Africa: faster track
- India, Saudi Arabia, gulf states: slower track

## **Exemptions possible for high ambient temperatures**

- Alternatives for AC in high ambient temperatures ( $>40\text{ }^{\circ}\text{C}$ ) partly under development

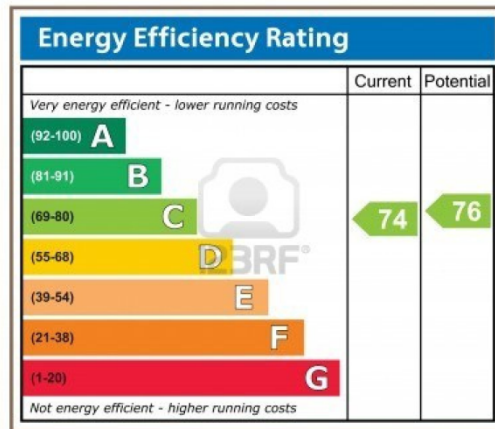
## **Small exemption for Russia, Belarus**

- Year later to comply (implement national regulations)



# Total climate impact important

- Also climate impact through energy used/saved
- Direct climate forcings
  - GWP-weighted emissions, Radiative forcing
- Indirect climate forcings
  - Energy used or saved during the application lifespan
  - Energy used to during manufacturing
- Total effect on climate → Life cycle climate performance
- Also important: costs, availability, flammability, toxicity, humidity, etc.





# Conclusions

## Montreal Protocol amended for climate protection

- HFCs included and phasedown of their global use

**Surface temperature contribution of HFCs reduced from 0.3-0.5 °C to about 0.06 °C**

With global adoption of technologies **required to meet national regulations the** Kigali amendment is within reach for many countries by 2050



***Remember!!!***

# Thanks to a lot of people

David Fahey  
Steve Andersen  
John Daniel  
Mack McFarland  
Susan Solomon  
Marco Gonzalez  
Durwood Zaelke

...

## Meeting of the Parties



## Assessment co-chair at work

