Factors influencing life cycle environmental impact calculations of MACs

Armin Hafner & Petter Nekså
SINTEF Energy Research
Trondheim – Norway

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Definition

GWP

The GWP is a measure of the future radiative effect of an emission of a substance relative to the emission of the same amount of CO_2 integrated over a chosen time horizon.

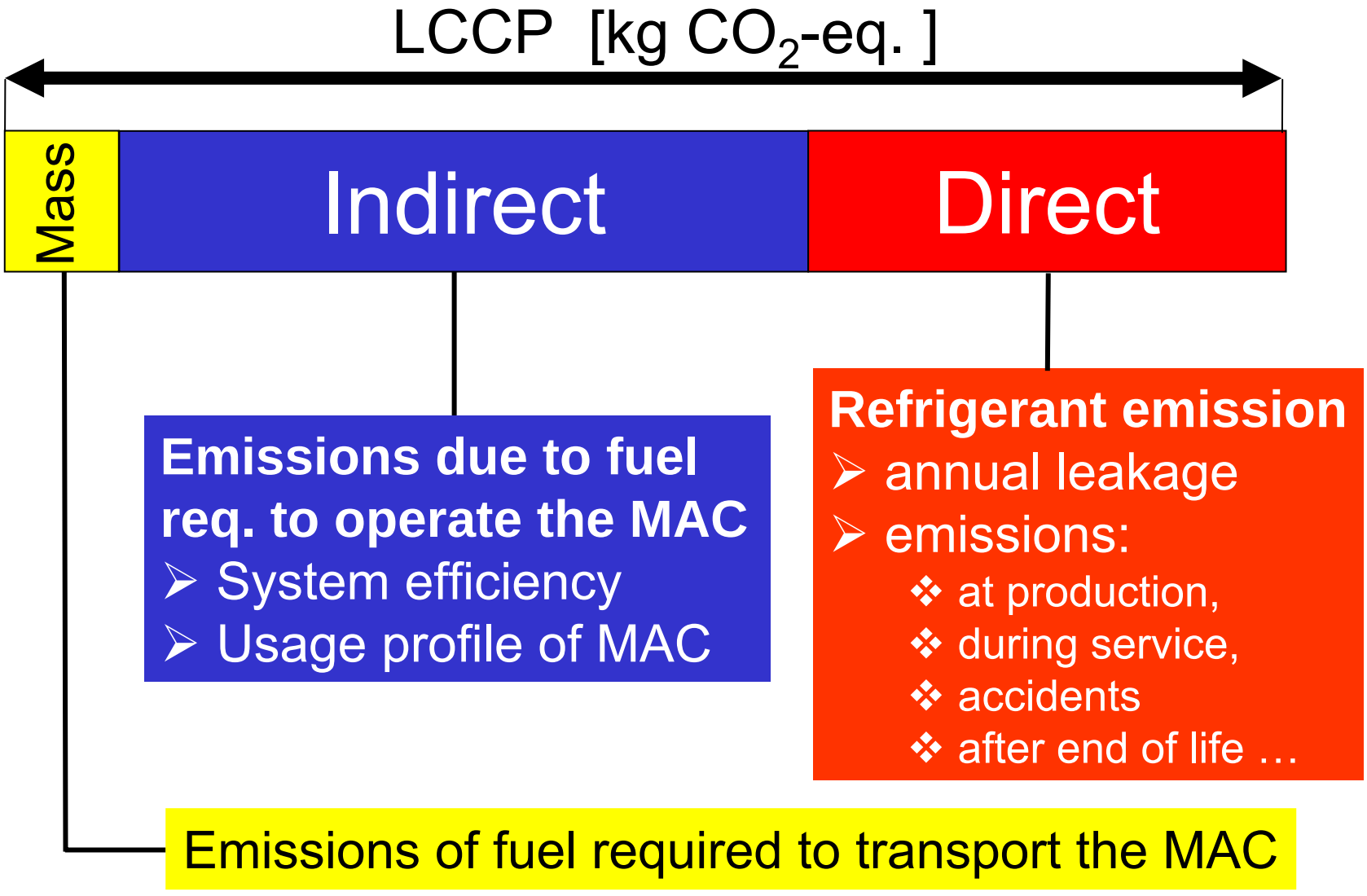
100-year time horizon is current practice.

Integration (100 year) means a compromise:
-> reduces the contribution of short living species
-> effect of long living gases (as PFC's) is not fully taken into account.

LCCP (Life Cycle Climate Performance)

A measure of the overall GW-impact of equipment over its entire life cycle (incl. ref. production & end of live).

Unit: kg CO_2-eq


LCCP [kg CO_2-eq.]
Mass
Indirect
Direct
Emissions due to fuel req. to operate the MAC
System efficiency
Usage profile of MAC
Refrigerant emission
annual leakage
emissions:
at production,
during service,
accidents
after end of life …
Emissions of fuel required to transport the MAC

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Major Input Factors to LCCP and their influence

a) End user / region specific

- Driving Cycles & Driving Distance
- **Climate Data**
- AC usage profile

- **Leakage:**
  - at refrigerant production
  - at service / uncontrolled losses
  - end of life recovery

b) MAC / Car specific

- System mass

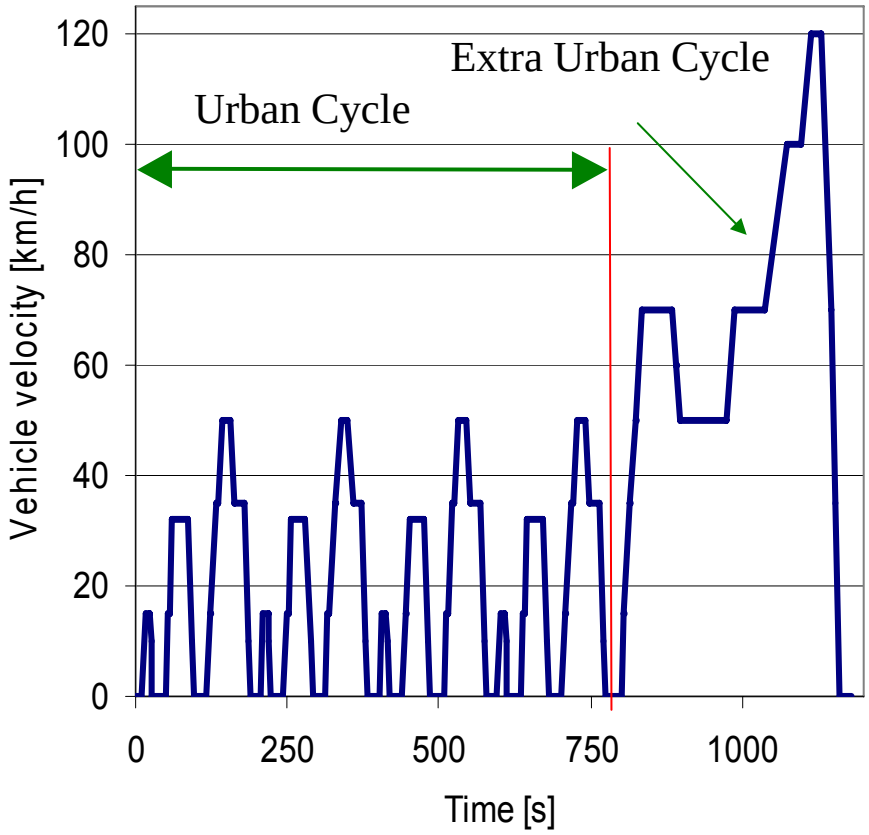
- **Cooling Demand**
- **System COP**
- Elevated air inlet temperatures / idle

- **Refrigerant**
- Leakage:
  -- during ordinary operation

End user / region specific

Driving Cycles & Driving Distance & Daily travel

New European Driving Cycle (NEDC)



Applied for European locations

Mean vehicle velocity: 34 km/h

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End user / region specific

Driving Cycles & Driving Distance & Daily travel

Driving distance(?):	Annual	Total
• USA:	22.000	209.000 km
• Europe:	12.500	150.000 km

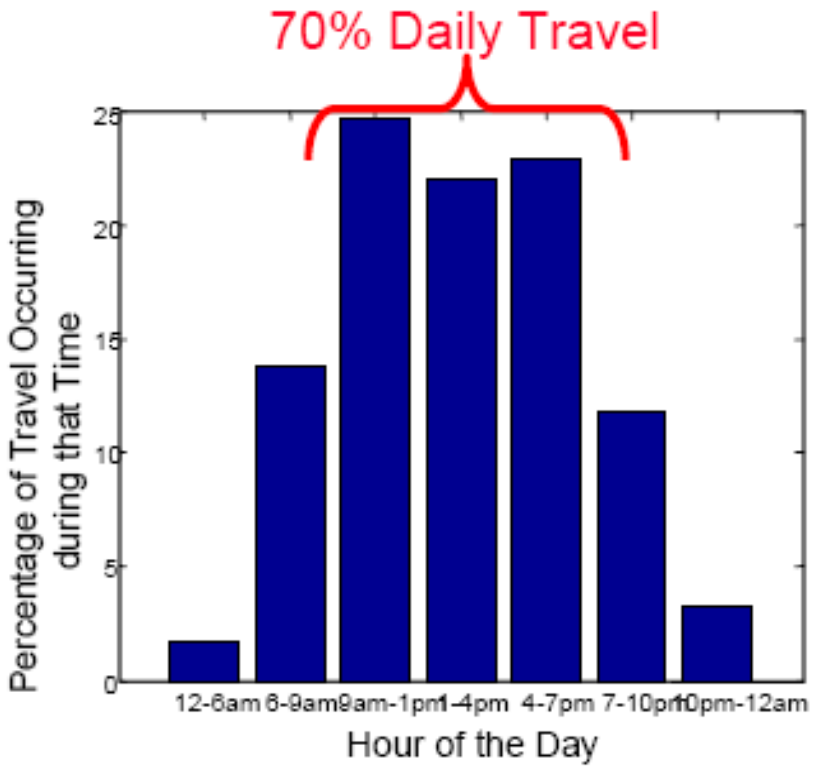
Influence on LCCP in a direct system comparison:

- **higher mileage reduces the share of direct emissions**

Absolute values cannot be compared across different locations

End user / region specific

Driving Cycles & Driving Distance & Daily travel



Example: USA

Ref. John Rugh, NREL
SAE 2002-01-1957

Strong influence on:
Climate data:

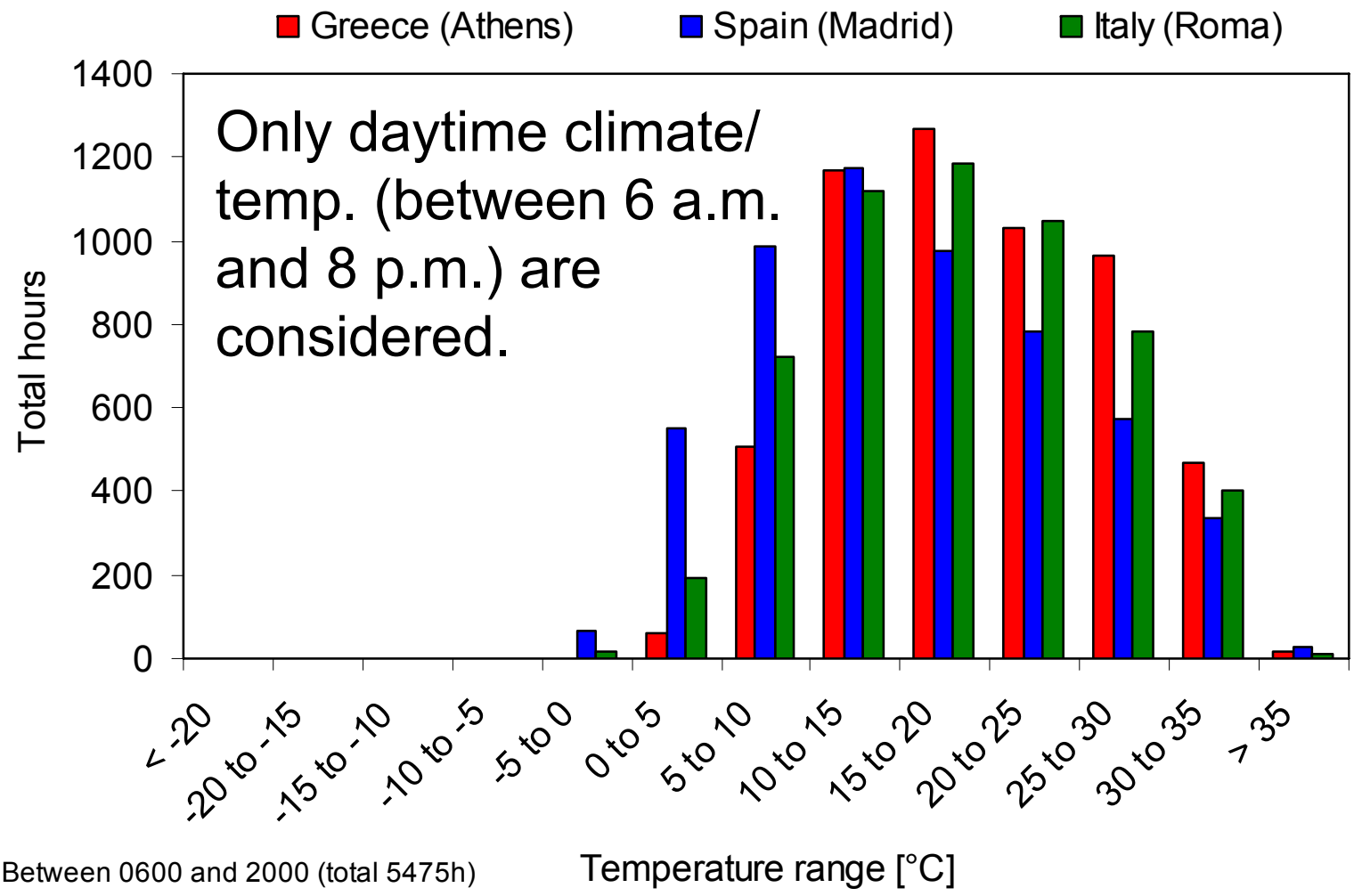
-> hourly climate data
have to be applied

Most driving between:
06.00 and 20.00

End user / region specific

Climate Data: Example (temperature-bin) Europe, *south*

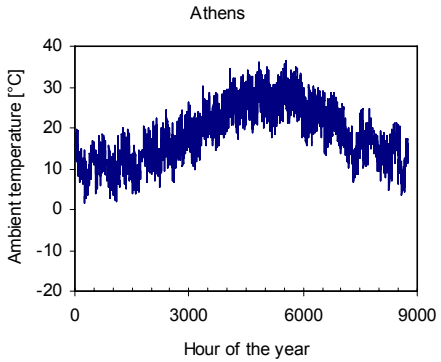
Temperature hour ratio, between 06:00 and 20:00

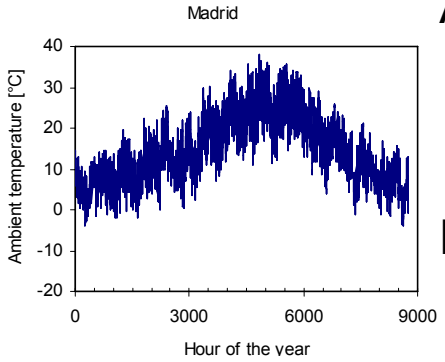


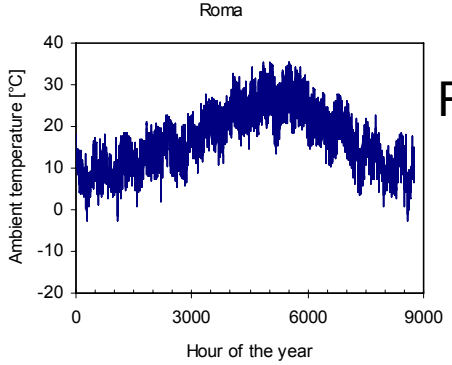
Between 0600 and 2000 (total 5475h)

Climate data ref: *Meteonorm*

Europe
south
Temperature & rel. humidity







Athens:

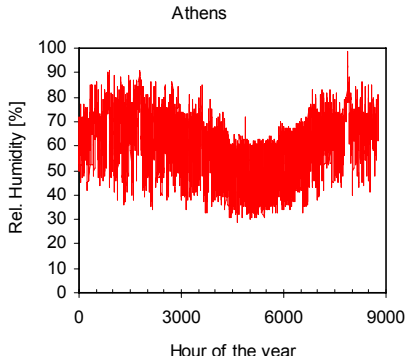
mean: 18.5 °C; 57 % RH
max: 36 °C @ 35 % RH

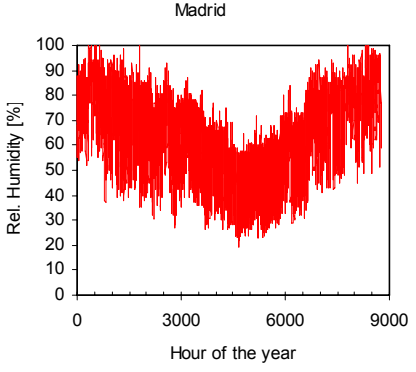
Madrid:

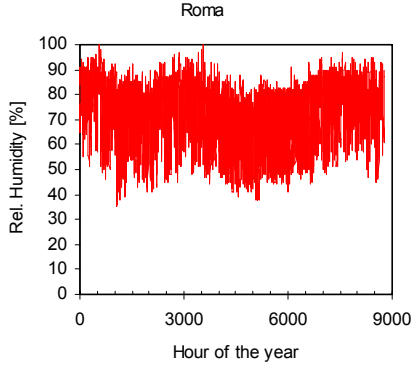
mean: 14.8 °C; 59 % RH
max: 27 °C @ 25 % RH

Roma:

mean: 17 °C; 68 % RH
max: 35 °C @ 40 % RH







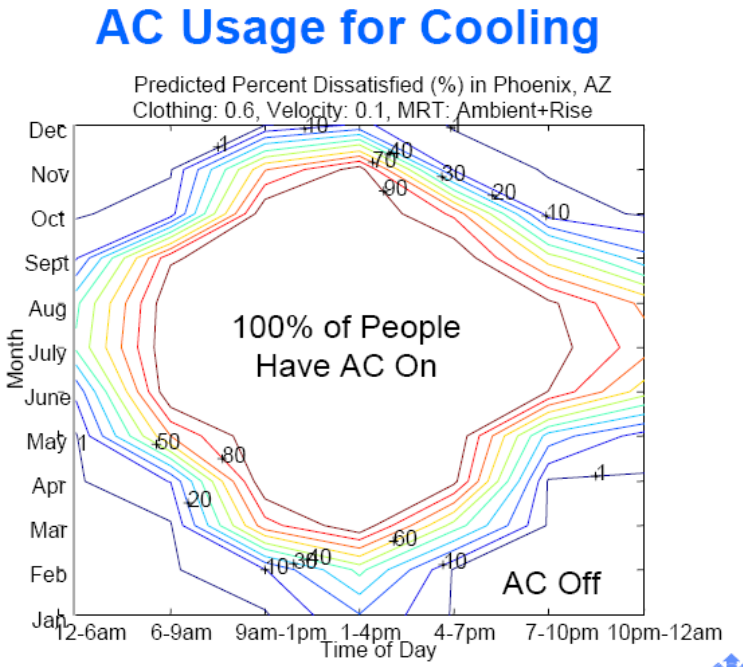
Ambient temperature

Rel. Humidity

End user / region specific

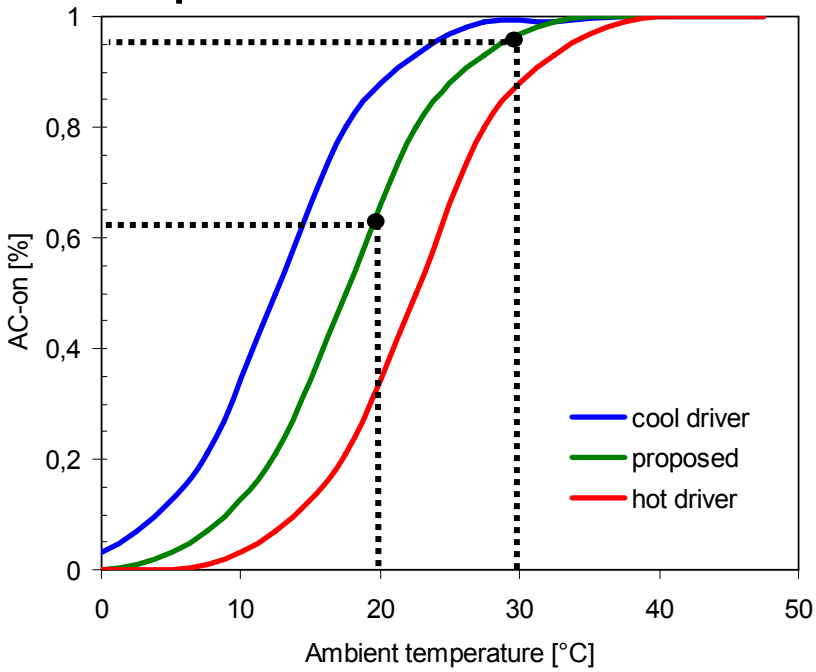
AC usage profiles

Example 1



Example 2

Share when AC is operated:



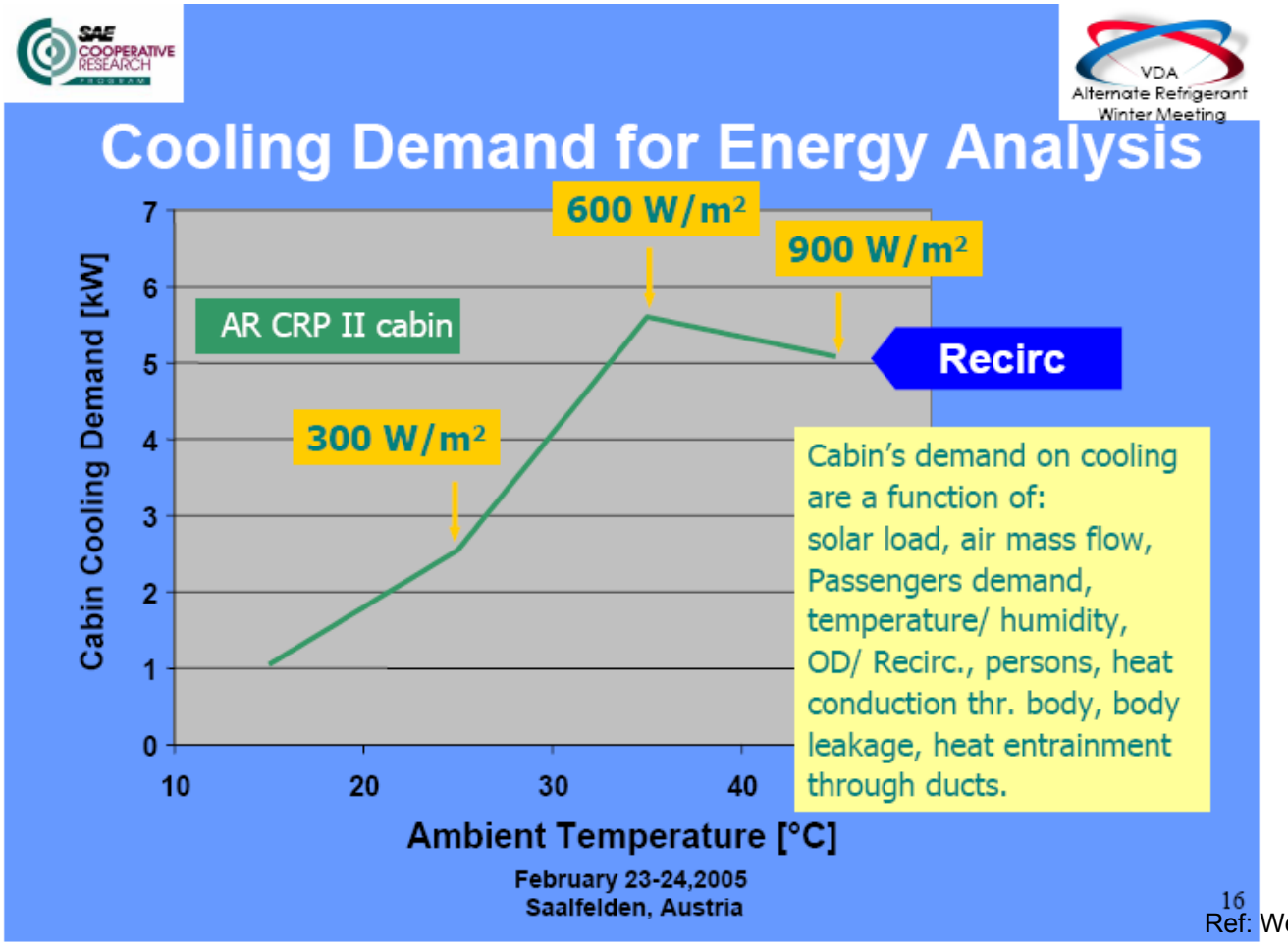
62% AC-on @ t_{amb} = 20°C

95% AC-on @ t_{amb} = 30°C

Includes: demisting of windshields

MAC/ car specific

Cooling load, car specific



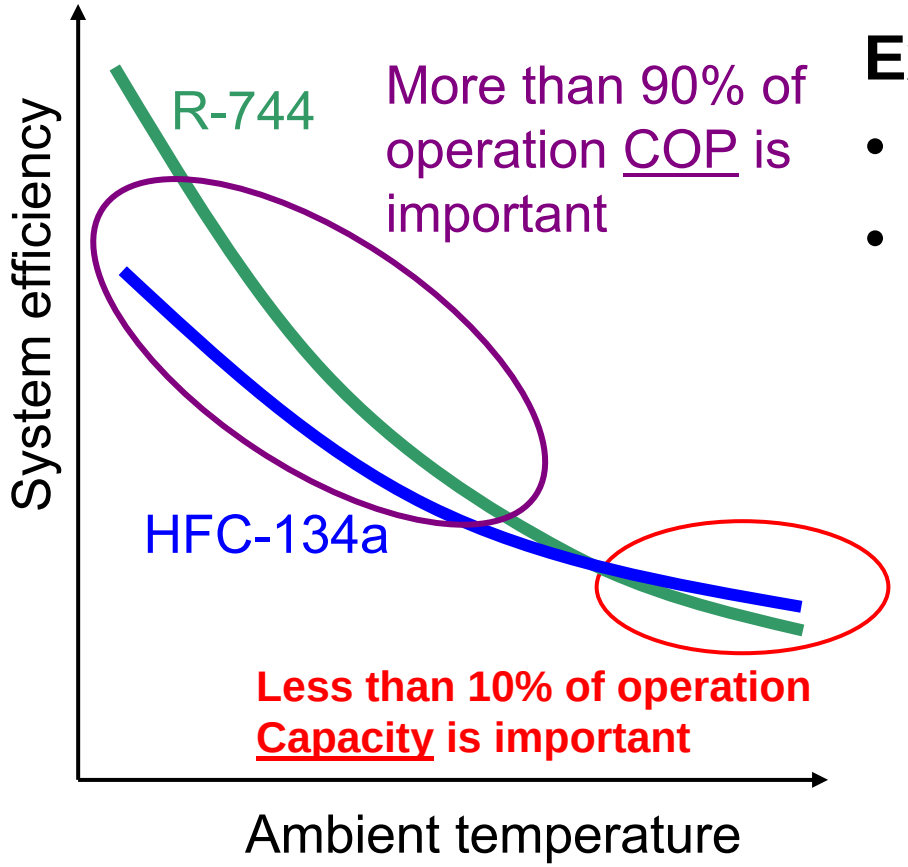
Issue:

- Should be applied when measuring system COP data

Ref: Wertenbach, DC

MAC/ car specific
Influence of **System COP** on LCCP

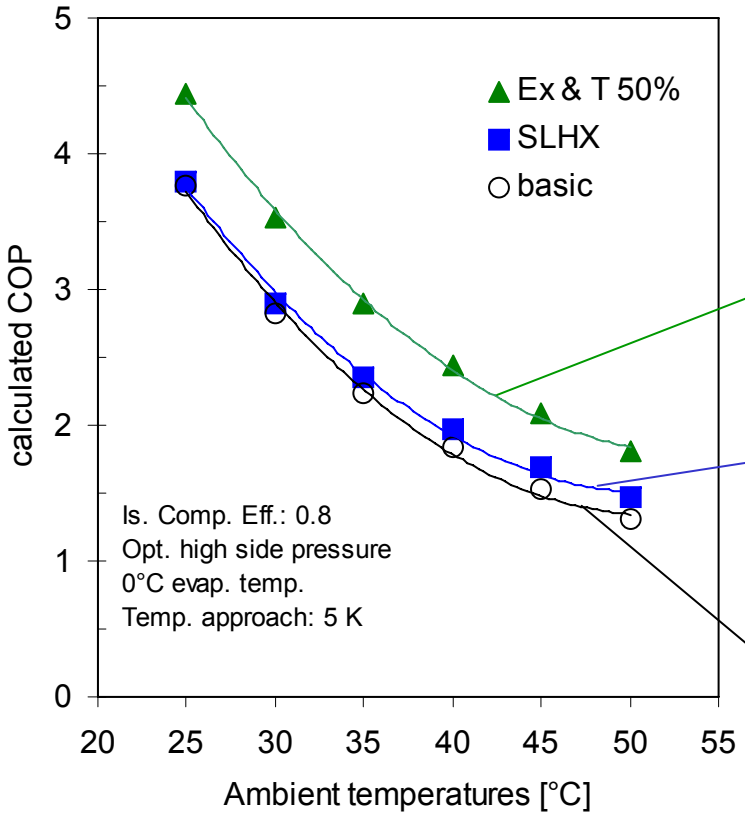
System efficiency at varying ambient temperatures



Experimentally verified by:

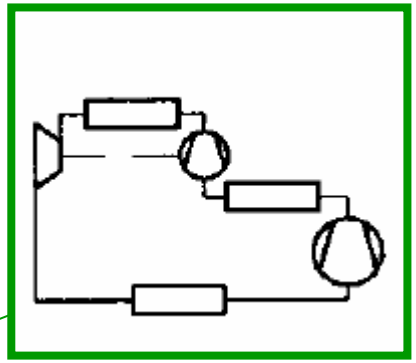
- SAE ARCRP
- Field and Bench tests performed by various OEM's

Example: System COP data: Basic -> Advanced R-744 for **high ambient temperature areas/conditions**

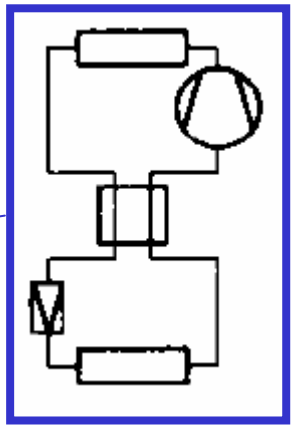


Advanced

+25 % COP improvement

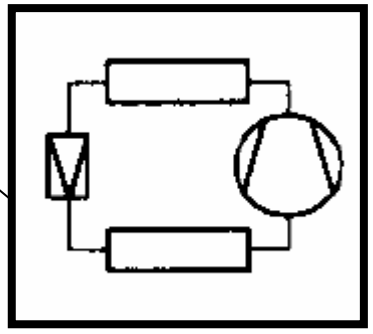


(Heyl 2000)



(Heyl 2000)

Base line



(Heyl 2000)

theoretical

Alternative: Ejector Technology -> Ref: *UoI or Denso*

MAC/ car specific
Refrigerants

HFC-134a ; CH_2FCF_3 ; 1,1,1,2-Tetrafluoroethane

GWP_{100}: **1410 [kg CO_2-eq kg^{-1}]**

short lifetime in atmosphere: 14 years

HFC-152a ; CHF_2CH_3 ; 1,1-Difluoroethane

GWP_{100}: **122 [kg CO_2-eq kg^{-1}]**

very short lifetime in atmosphere: 1.4 years

R-744 ; CO_2 ; Carbon Dioxide

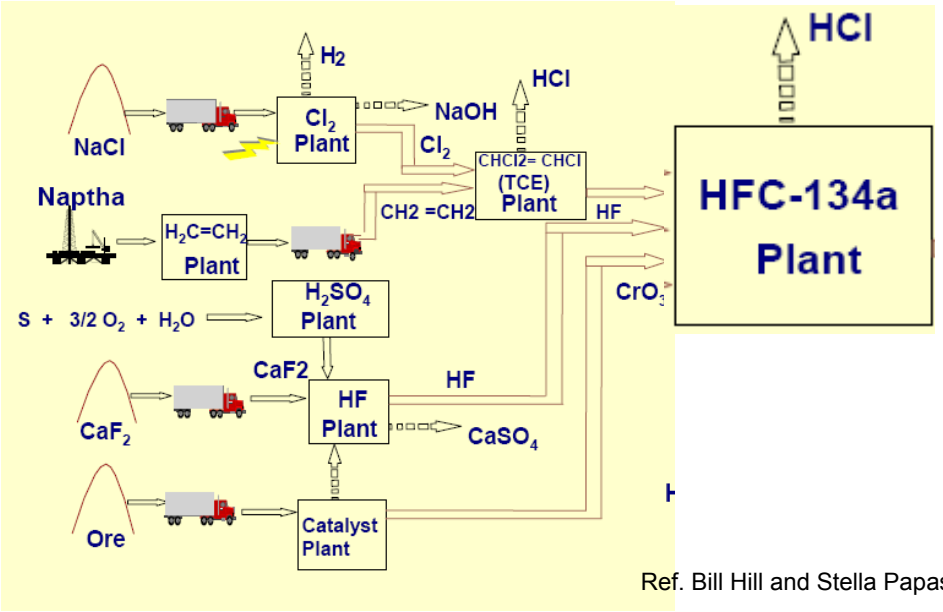
GWP_{100}: **1 [kg CO_2-eq kg^{-1}]**

long lifetime in atmosphere

End user / region specific,

Leakage: **at refrigerant production** ; at service ; uncontrolled losses ; end of life recovery

HFC-134a is made from different pre-products, emissions of by-products per kg of produced HFC-134a are up to **77 [kg CO_2-eq]** (McCulloch&Cambell, 1998)



Ref. Bill Hill and Stella Papasavva; GM

R-744

CO_2 emission from source to end user (can be extracted from well-, petrochemical waste gases [ammonia production] & combustion- sources):

0,129 to 1,167 kg CO_2 per kg R-744 (JOHNSON, 2004)

End user / region specific,

Leakage: at refrigerant production ; **at service** ; uncontrolled losses ; end of life recovery

Significant leakages during service

			Recoveries Per Year 20,000,000	Recoveries Per Year 25,000,000
	%	Ounces	Emissions	Emissions
Average System Charge	1.00	28.00	Lbs./Year	Lbs./Year
Refrigerant Not Recovered	0.30	8.40	10,500,000	13,125,000
	0.25	7.00	8,750,000	10,937,500
	0.20	5.60	7,000,000	8,750,000
	0.15	4.20	5,250,000	6,562,500
	0.10	2.80	3,500,000	4,375,000
	0.05	1.40	1,750,000	2,187,500

"…an estimated 20 to 25 million automotive A/C systems are serviced annually…"
Increasing Summer Profits with A/C Work, Larry Carley, Brake & Front End, 3/2005

IMAC Ref: Bill Hill

Best case: High skilled mechanics and workshops

….

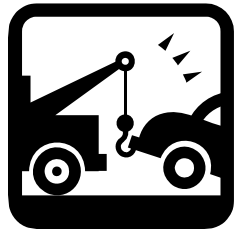
Worst case: *'Do it yourselfers'* (small cans)
Workshops with unskilled mechanics

End user / region specific,

Leakage: at refrigerant production ; at service ; **uncontrolled losses ; end of life recovery**

Accident:

-> 100% loss of HFC charge = 6 month no driving



(Emission Compensation Equation)

Average Remaining Charge	Average Charge Remaining Pounds	Vehicles Scrapped Annually	30% Have Charge Potential Emissions Lbs./Year	40% Have Charge Potential Emissions Lbs./Year
Vehicles Scrapped Annually	1.00	12,000,000	3,600,000	4,800,000

Studies done in New Jersey and California suggest that 30% to 40% of vehicles arriving at end of life have an average refrigerant charge of one pound in system.

Ref: Bill Hill

Significant HFC emissions of vehicles arriving at end of life, due to no or only partly recovery of HFC!

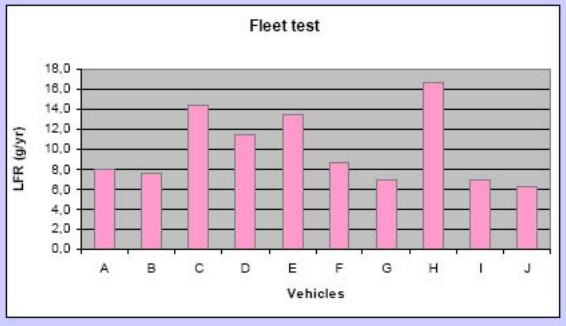
MAC/ car specific
Leakage during ordinary operation

Previous investigation of HFC-leakage in European vehicle fleet:

2.5 to 10% of original charge/year

The fleet test results

6.3 g/yr < annual emission < 16.6 g/yr
Average emission of the 37 vehicles : 10 g/yr



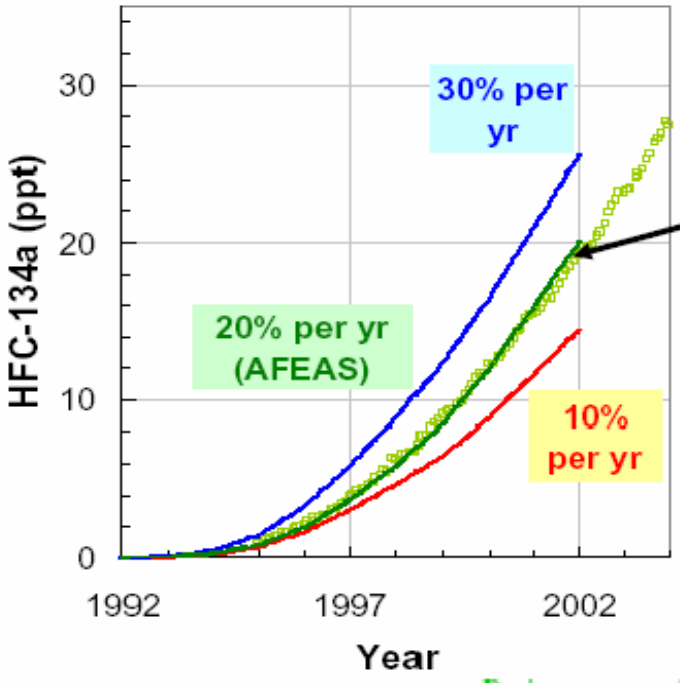
New vehicles: ≈10 g/a

Not including:
-Losses at service
-Losses due to accidents
-Losses at end of life

Denis CLODIC, Yingzong YU
Center for Energy and Processes
Ecole des Mines de Paris

End user / region specific, Leakage: total

HFC-134a Refrigerant Emissions



Points are global mean measurements

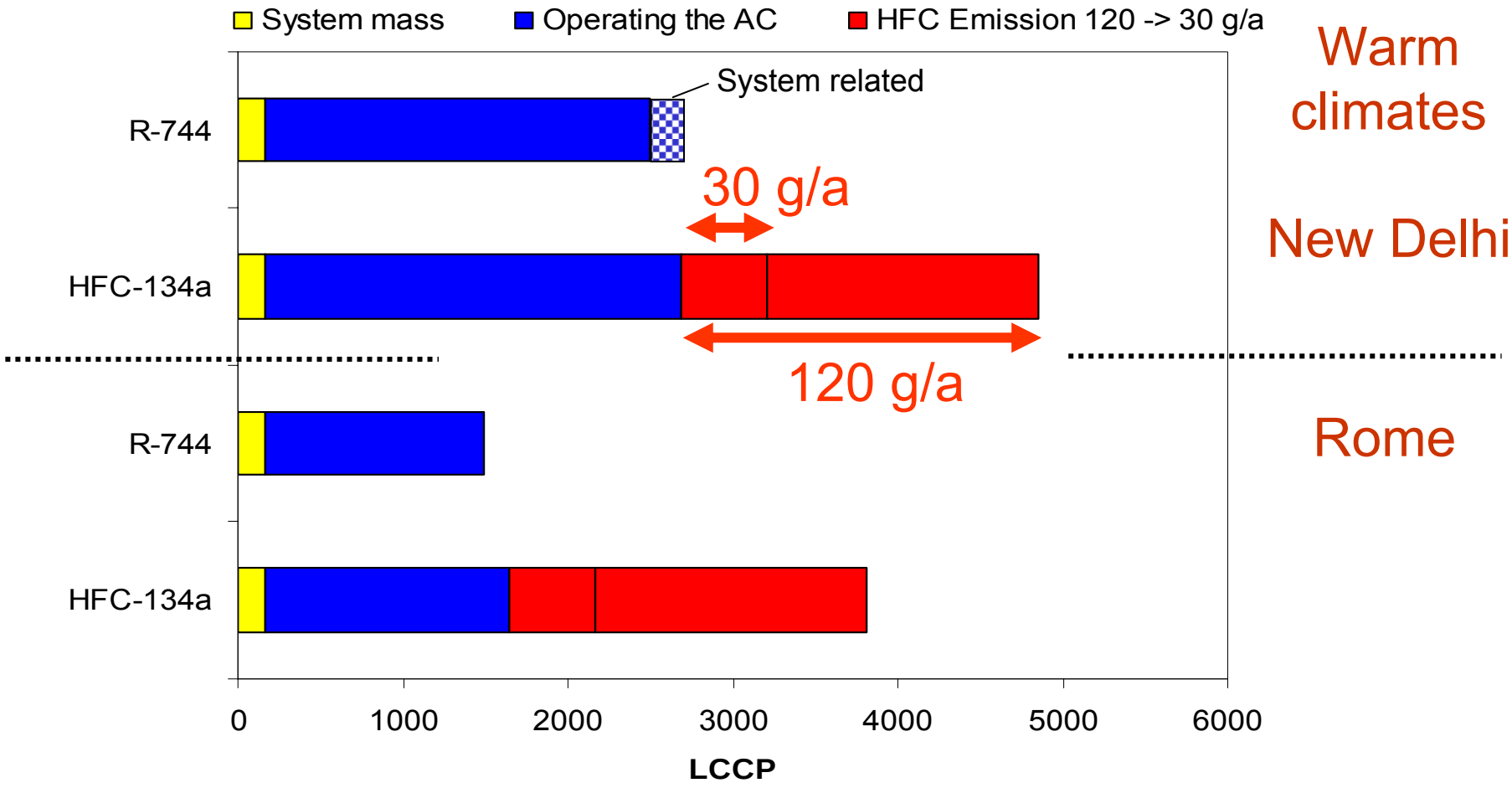
Comparison of calculated atmospheric concentrations to measured concentrations shows that about **20% of refrigerant in equipment is emitted to atmosphere each year**

Information from:

Stephen Montzka

NOAA – CMDL, Boulder, CO USA

Example: LCCP; Italy, *Rome* & India, *New Delhi*



120 g/a = 20% of 600g HFC, today's global emission rate

30 g/a = possible future emission scenario (best case)

Summary

- The major influence factors to Life Cycle Climate Performance have been presented
- Sustainable alternatives are available:
  - Highly improving LCCP
  - Lower overall energy consumption
  - Comparable energy consumption in high ambient temperature regions
- The overall picture is clear:
  - Direct emissions can be avoided

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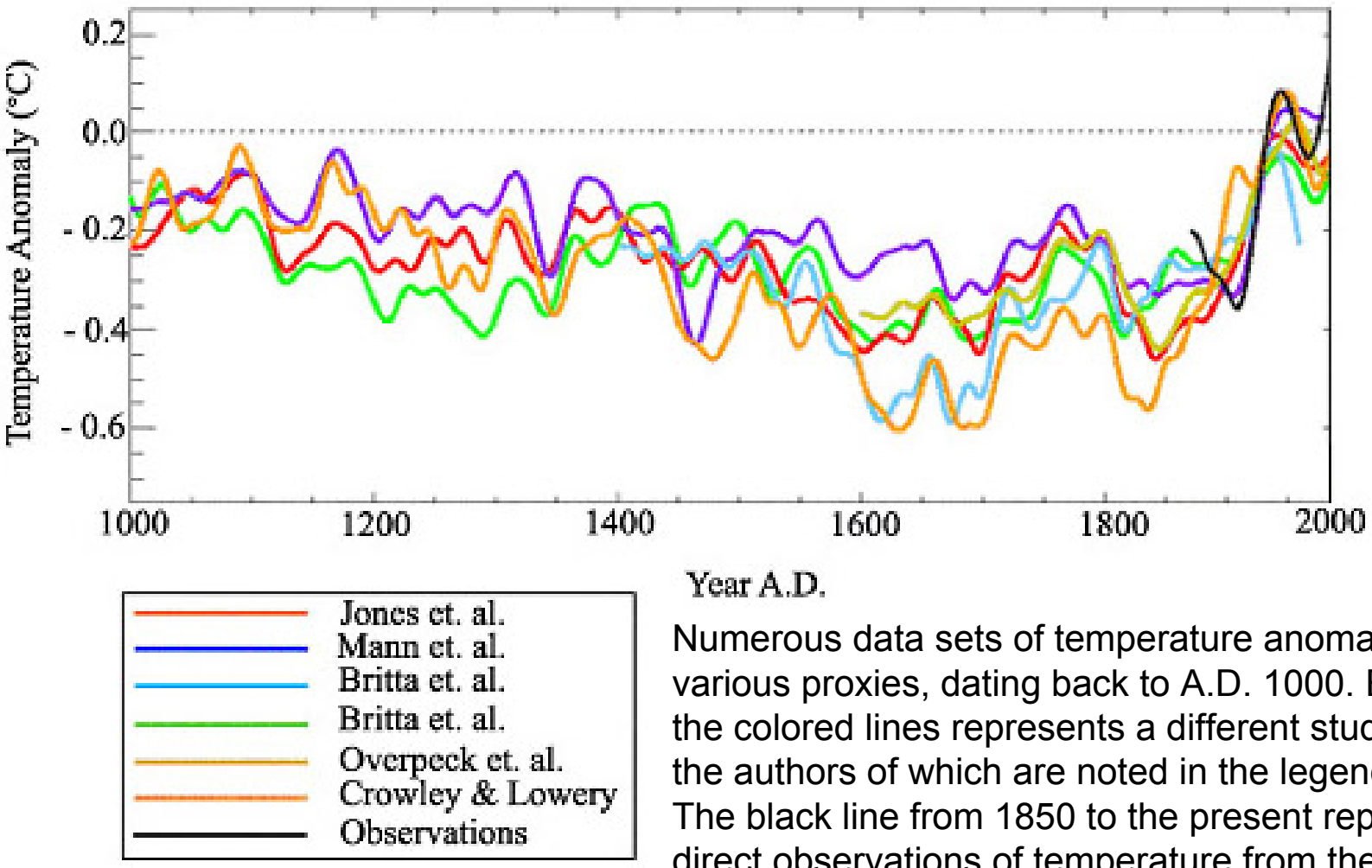
Thank you for your attention!!!

Questions are welcome

Armin.Hafner@sintef.no
www.sintef.org

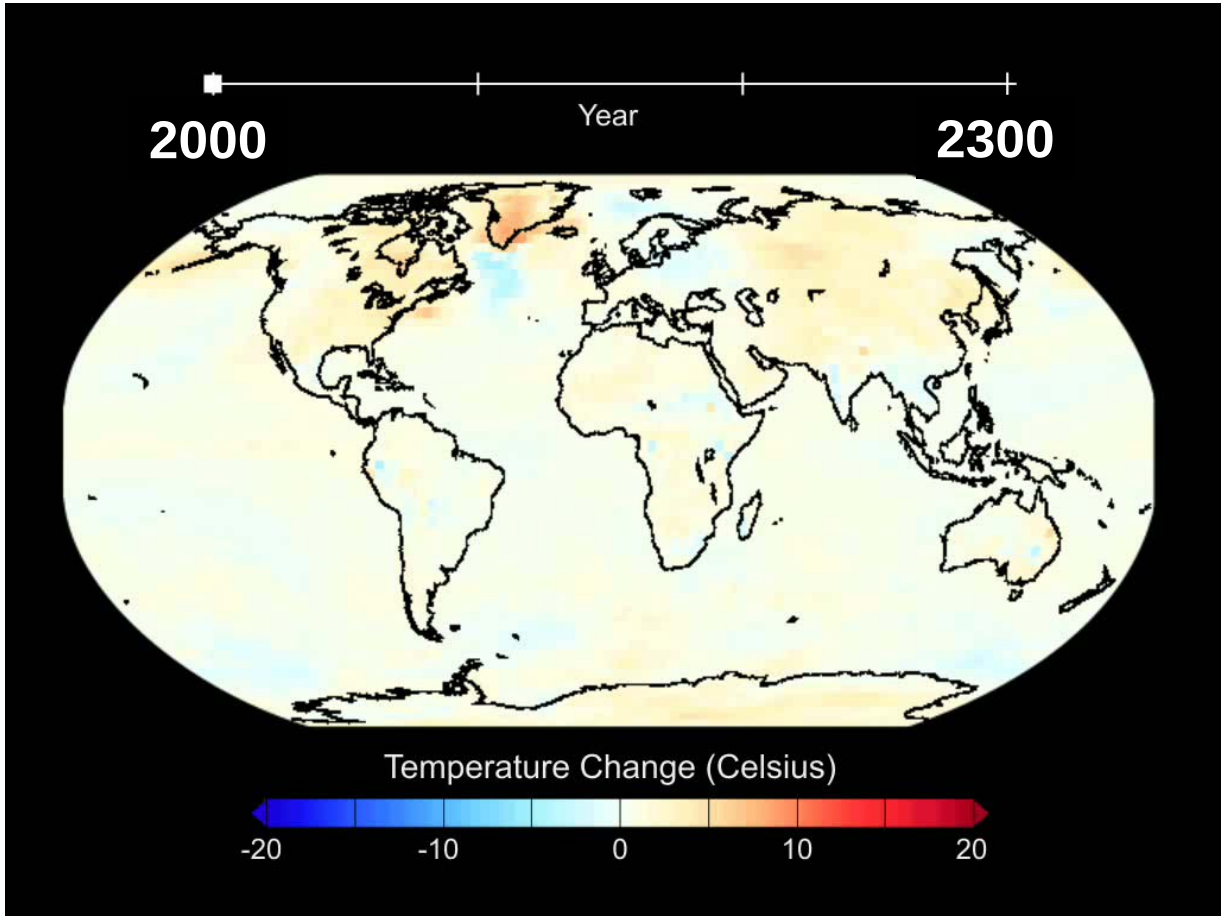
Welcome to:



Numerous data sets of temperature anomalies from various proxies, dating back to A.D. 1000. Each of the colored lines represents a different study, the authors of which are noted in the legend. The black line from 1850 to the present represents direct observations of temperature from thermometers

http://calspace.ucsd.edu/virtualmuseum/climatechange2/05_1.shtml

Climate change, calculated by Lawrence Livermore National Laboratory, California



http://www.llnl.gov/pao/news/news_releases/2005/NR-05-11-01.html

"The scientists found that the earth would warm by 8 °C (14.5 °F) if humans use the entire planet's available fossil fuels by the year 2300."

"The temperature estimate is actually conservative because the model didn't take into consideration changing land use such as deforestation and build-out of cities into outlying wilderness areas" .