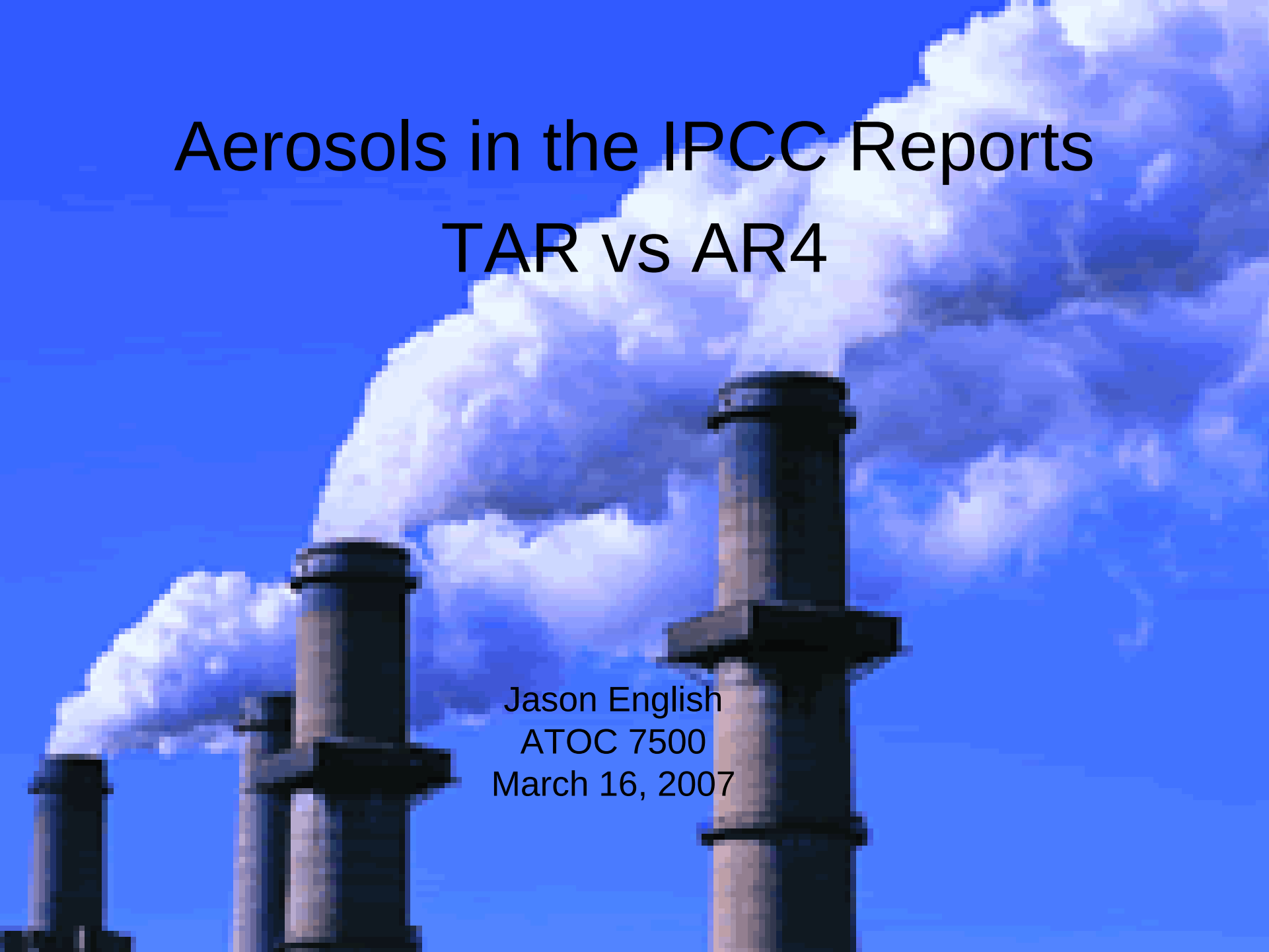


Aerosols in the IPCC Reports
TAR vs AR4

Jason English
ATOC 7500
March 16, 2007

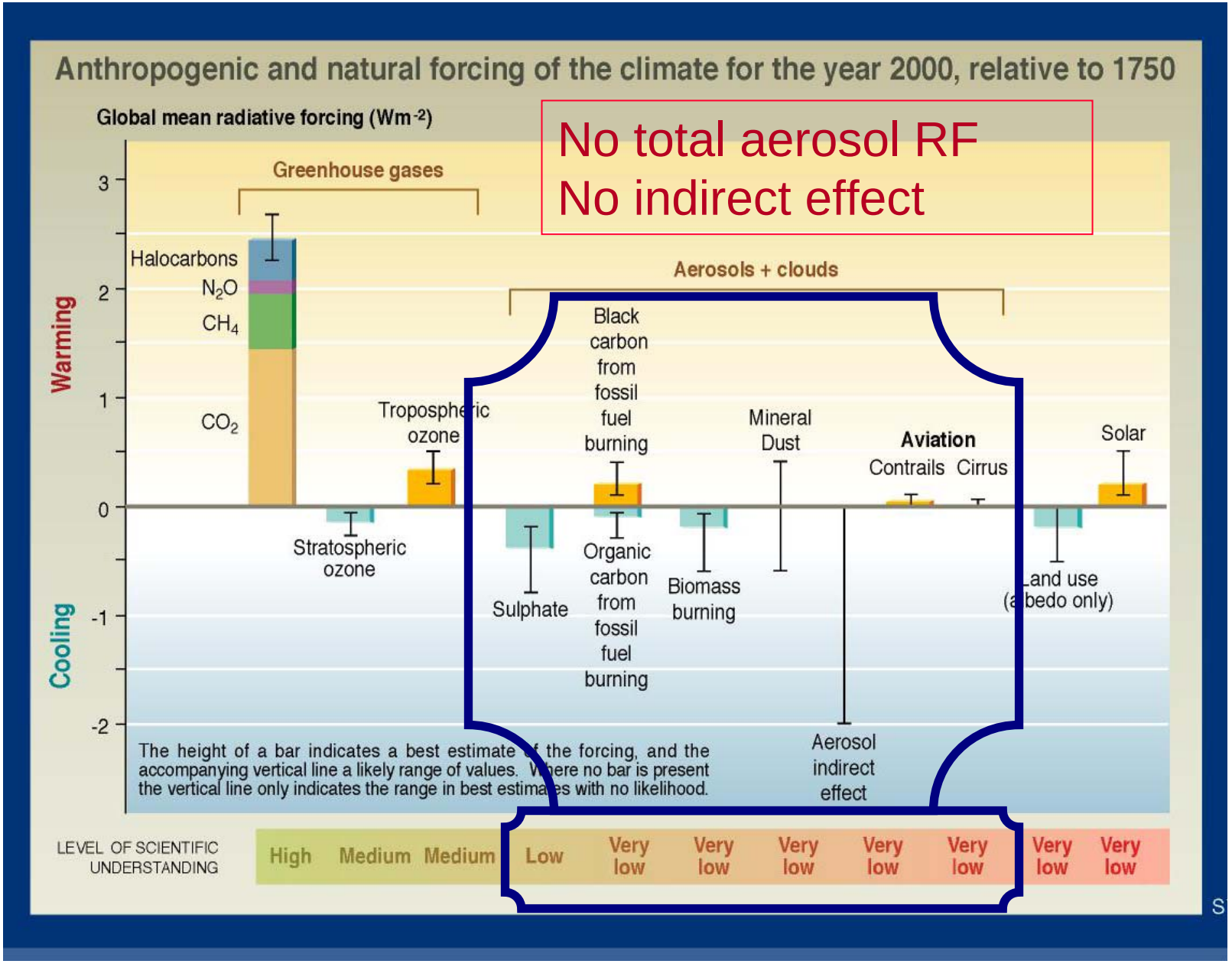
The big picture

- We've come a long way with understanding the RF of aerosols,

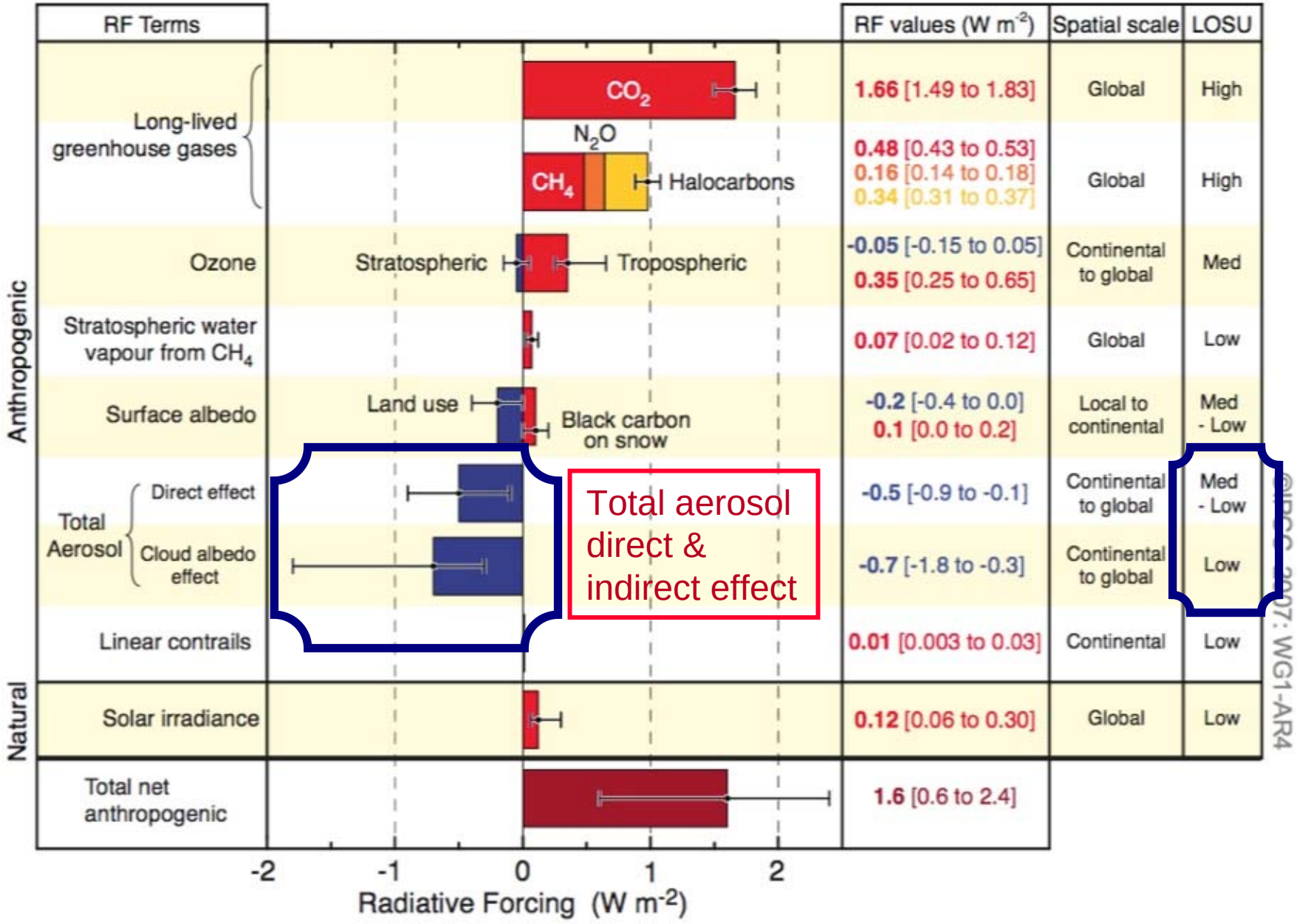
  AND

- We have a long way to go!

IPCC TAR (2001)



IPCC AR4 (2007)

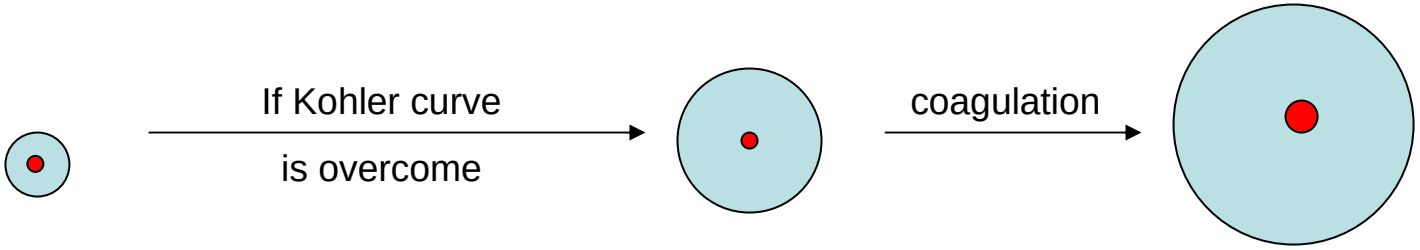


What are aerosols?

Tiny solid particles (usually a mixture of the types below, plus water)

Type	Min. Size	% Anthrop.	Key Sources
Sulfate	0.01 um	75%	fossil fuel combustion
Organic Carbon	0.01 um	75% ?	industry
Black Carbon	0.01 um	90%	fossil fuel combustion
Nitrate	0.01 um	75% ?	fossil fuel combustion
Dust	1 um	40%	deserts
Sea Salt	1 um	0%	oceans

Human-influenced



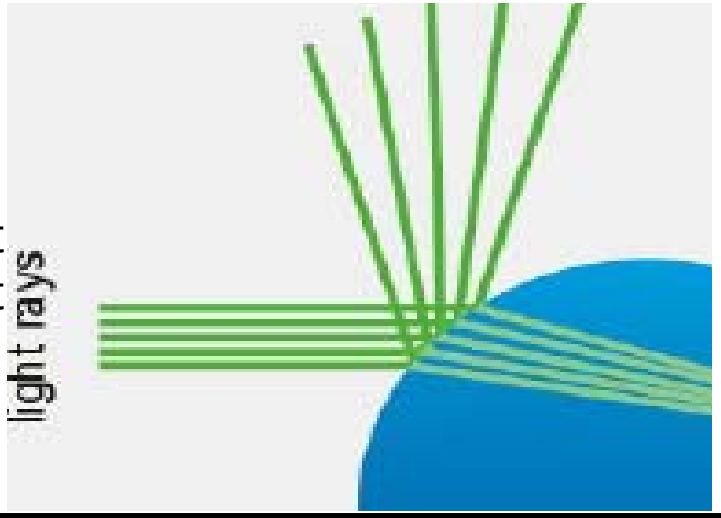
Nucleation mode	Accumulation mode	Drizzle mode
typical size: ~1 um unactivated haze	typical size: ~10 um cloud drops	typical size: ~100 um drizzle

Why are aerosols important?

Aerosols & Climate:

Global cooling effect, but spatially variable forcings may affect global circulation (e.g. regional warming or cooling)

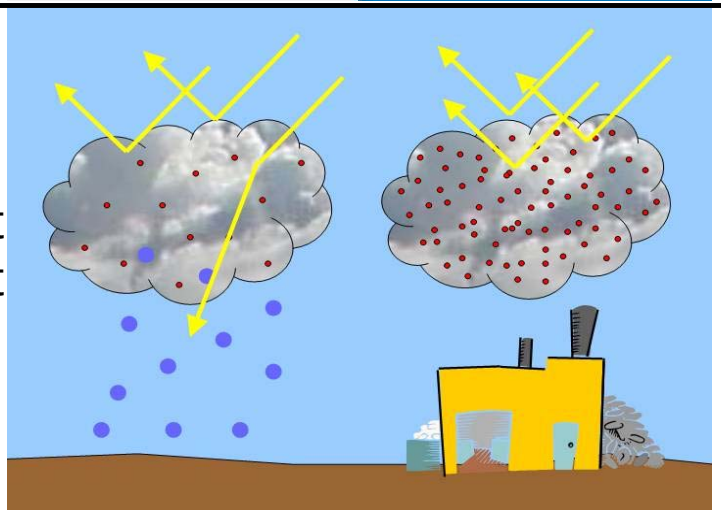
Direct effect



Direct effect:
albedo ↑
albedo ↓

Addressed in AR4

Indirect effect



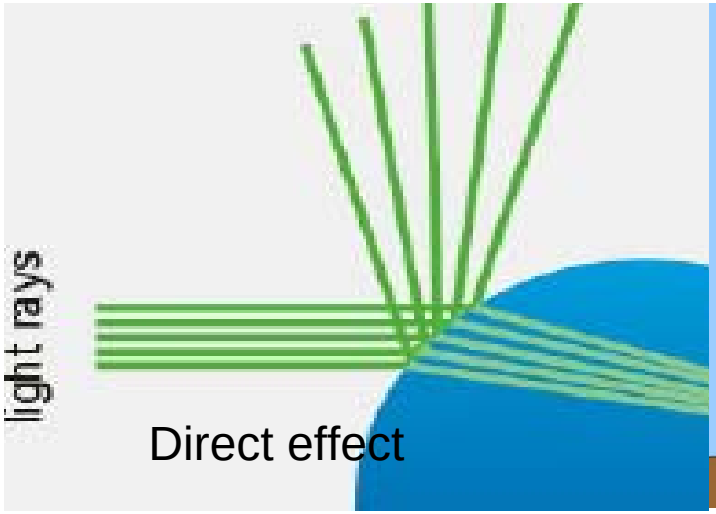
1st indirect effect:
albedo ↑

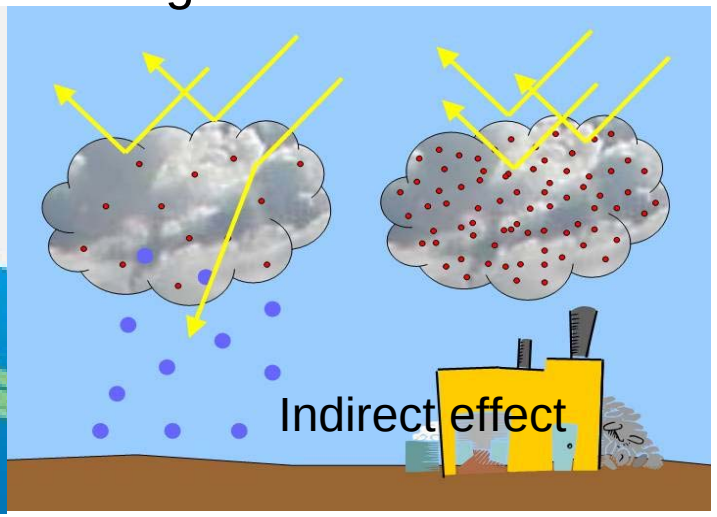
2nd indirect effect:
cloud lifetime ↑

Semidirect effect:
stability ↑
stability ↓

Why are aerosols important?

Climate Cooling

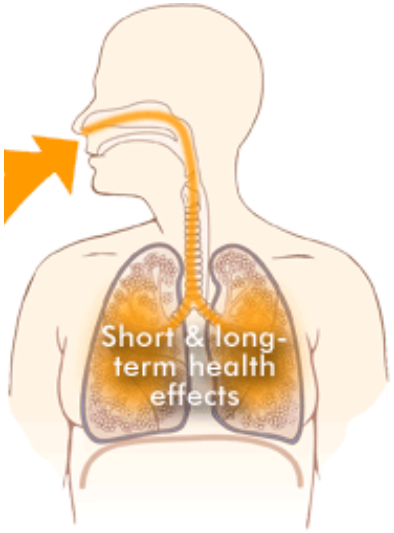




Acid Rain (sulfates)

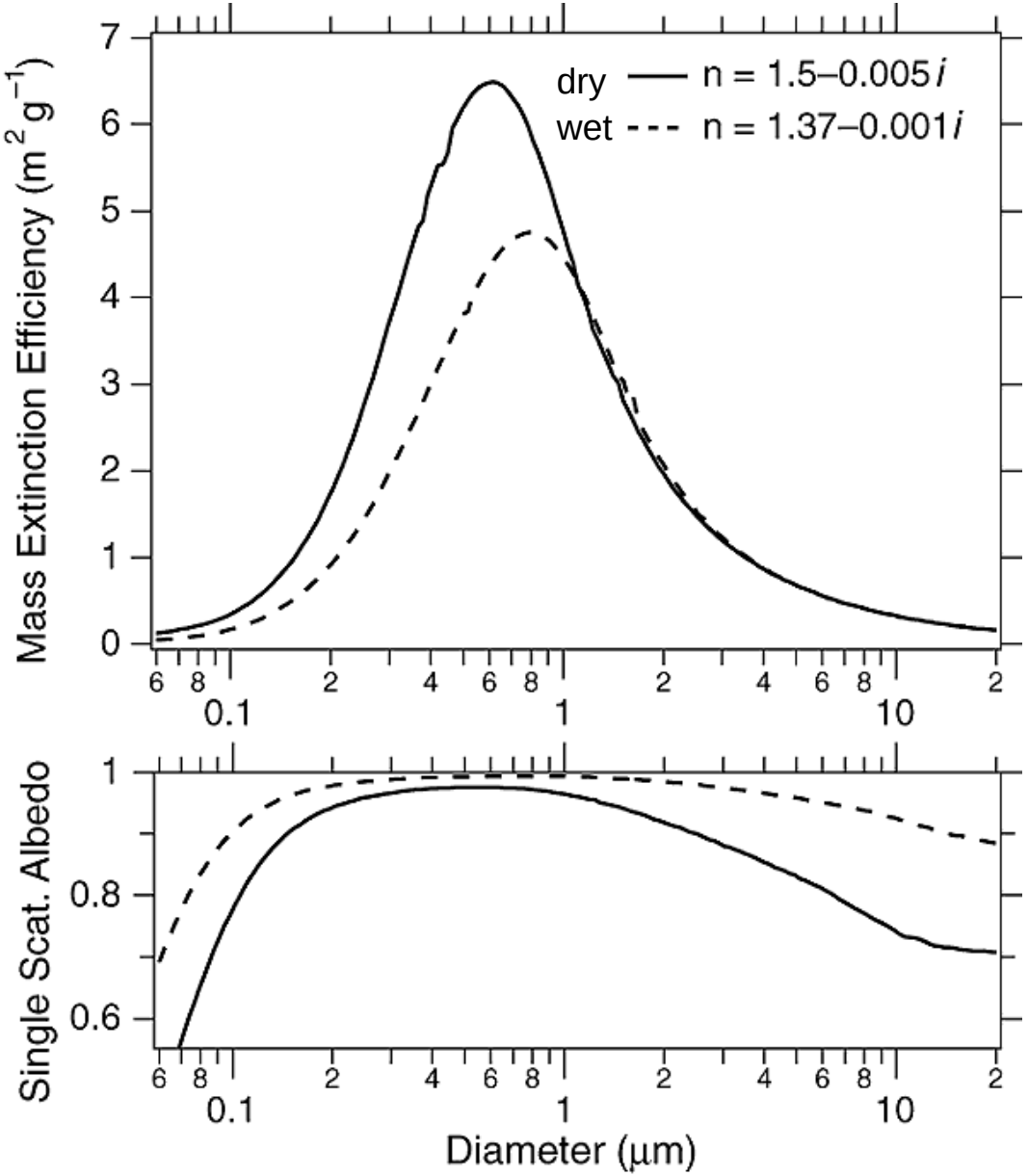
$$SO_{2(g)} \xrightarrow{O_2} SO_{3(g)} \xrightarrow{H_2O} H_2SO_4$$

Health Effects



Reduced Visibility

Aerosol Growth



0.2 to 2 um diameters scatter the most light per unit mass

Hydration (dotted line) has higher SSA but less per unit aerosol mass

IPCC, 2001

Improvements TAR→ AR4

"We've come a long way…."

- Satellites
  - New generation sensors
  - Adv. retrieval - fine mode fraction, effective particle radius
  - Better algorithms
  - Measuring size dist, composition, scattering, absorption
  - Longer continuous running satellite obs to compare models to
  - Plus, new dedicated aerosol instruments
    - POLDER
      - 0.44-0.91 um spectral channels
      - Several viewing angles
      - Measures polarization of rad., τ_{aer}, A, over oceans
      - Measures τ_{aer} over land
    - MISR
      - New aerosol type distinction algorithms
      - Mutiple viewing capability for brighter surfaces
      - Radiance signature measured using 9 viewing geometries; 2 radiances

Improvements TAR→ AR4

"We've come a long way…."

- Surface observations
  - More of them - near global retrieval now
    - 150 AERONET sites (surface sunphotometer)
    - 11 MPLNET sites (LIDAR network)
    - 15 EARLINET sites (European LIDAR network)
    - 12 ADNET sites (Asian LIDAR network)

Compared to satellite obs with improved consistency since TAR

Improvements TAR→ AR4

"We've come a long way…."

- Modeling
  - Higher resolution (better than 2º x 2º; 20 vertical levels)
  - Incorporation of more chemical species
  - Increased number of runs
    - 16 groups in AEROCOM initiative
  - Better (but still variable) consistency in τ_{aer} across models
    - Global τ_{aer} ranges from 0.11 to 0.14
    - But regional temporal distributions have larger variation
  - More comparisons to (and agreement with) obs

Direct effect uncertainty reduced by a factor of 2

Remaining Issues

"…and we have a long way to go"

- Satellite + surface obs
  - Significant discrepancies still exist - RF variability reflects this
  - Challenges distinguishing Anthropogenic/Natural aerosols
- Modeling compared to obs
  - Modelled τ_{aer} 2-4 times lower than observations
  - Aerosol distributions, compositions, size uncertainty
- All models share some misleading limitations
  - Parameterizations
  - Similar emissions databases
- Clouds!
  - Algorithms for obs
  - Indirect effects for models

RF Calculations

- Mean values
  - TOA
  - Global-mean quantity integrated over 24 hours
  - Includes the effects of clouds
  - AEROCOM & other studies included

- Standard deviations
  - Model results statistics included
  - For AEROCOM results, emissions uncertainty is added to the error

Sulfate Direct RF

Study	Direct RF (Wm^{-2})	
	Avg	Std Dev
TAR	**-0.40**	**UF = 2**
Non-AEROCOM	-0.46	± 0.20
AEROCOM	-0.35	± 0.15
AR4	**-0.40**	**± 0.20**

"We've come a long way…."

- High confidence in optical parameters
  - ω_o=1 (but minor absorption in near-IR)
  - f_{RH} well understood
  - Sig. contribution to accum. mode mass, τ_{aer} and RF
  - Average hasn't changed; error reduced

"…and we have a long way to go"

- Internal/External mixtures are common, not well understood, and cause changes in optical properties

Black Carbon Direct RF

Study	Direct RF (Wm^{-2})	
	Avg	Std Dev
TAR	**+0.20**	**UF = 2**
Non-AEROCOM	+0.13	± 0.03
AEROCOM	+0.22	± 0.11
AR4	**+0.20**	**± 0.10**

"We've come a long way…."

- BC has complex chain structure; collapses as it ages; modifies optical properties
- Absorbs strongly across most wavelengths
- Average hasn't changed; error reduced

"…and we have a long way to go"

- Uncertainty in split between anthrop/natural
- Internal/External mixtures…

Organic Carbon Direct RF

Study	Direct RF (Wm^{-2})	
	Avg	Std Dev
TAR	**-0.10**	**UF = 3**
Non-AEROCOM - total	-0.24	± 0.08
Non-AEROCOM - FF only	-0.06	± 0.03
AEROCOM - total	-0.18	± 0.10
AEROCOM - FF only	-0.04	± 0.02
AR4	**-0.10**	**± 0.10**

"We've come a long way…."

- TAR had virtually a "wild guess"
- Improvements in understanding composition; internal/external mixing

"…and we have a long way to go"

- Internal/External mixtures; optical properties…lots of room for improvement

Nitrate Direct RF

Study	Direct RF (Wm^{-2})	
	Avg	**Std Dev**
Van Dorland (1997)	-0.03	N/A
Jacobson (2001)	-0.16	N/A
Adams et al (2001)	-0.22	N/A
TAR	**N/A**	**N/A**
Martin et. Al (2004)	-0.06	N/A
Liao and Seinfeld (2005)	-0.16	N/A
AR4	**-0.10**	**± 0.10**

"We've come a long way…."

- TAR had no confidence in an estimate
- Additional studies conducted; slightly better agreement

"…and we have a long way to go"

- Limited studies!
- Internal/External mixtures; optical properties…lots of room for improvement

Mineral Direct RF

Study	Direct RF (Wm^{-2})	
	Avg	Std Dev
TAR	**+0.4 to -0.6**	**N/A**
Liao et al (2004)	+0.1	N/A
Reddy et. al (2005a)	-0.14	N/A
Jacobsen (2001)	-0.13	N/A
Myhre and Stordal (2001a)	-0.70	± 0.60
AEROCOM LSCE	-0.30	N/A
AR4	**-0.10**	**± 0.10**

"We've come a long way…."

- TAR had very little confidence - just a range
- Additional studies conducted; enough confidence to estimate an RF

"…and we have a long way to go"

- Limited studies! Large disagreement!
- Anthropogenic component; optical properties…lots of room for improvement

Combined Species RF

Study	Direct RF (Wm^{-2})	
	Avg	Std Dev
TAR	**N/A**	**N/A**
Simulation (minus nit,dust)	-0.20	± 0.20
Estimated with nit,dust	-0.40	± 0.30
Bellouin et al (2005)	-0.80	± 0.10
Chung et al (2005)	-0.35	± 0.25
Yu et al (2006)	-0.50	± 0.33
AR4	**-0.50**	**± 0.40**

Models

Observations

"We've come a long way…."

- TAR had no confidence in an overall estimate
- Extensive validation/constraint conducted between models and observations since then
- Nonlinear interactions between species makes an educated overall effect more reliable than adding each species individually

"…and we have a long way to go"

- Still a lot of disagreement/uncertainty

Aerosol Anthropogenic Direct RFs

Type	TAR (Wm^{-2})		AR4 (Wm^{-2})	
	Avg	U.F.**	Avg	Range
Sulfate	-0.40	2	-0.40	± 0.20
Black Carbon	+0.20	2	+0.20	± 0.10
Organic Carbon	-0.10	3	-0.10	± 0.10
Nitrate	N/A	N/A	-0.10	± 0.10
Mineral Dust	+0.4 to -0.6	N/A	-0.10	± 0.20
Biomass Burning*	-0.2	3	+0.00	± 0.10
Combined	N/A	N/A	-0.50	± 0.40

AR4 RFs remain similar to TAR…with a narrower range
(except biomass burning)

*Produces OC, BC, nitrate, sulfate….separate category due to unlikelihood of regulating components from this emissions source

**Uncertainty Factor – too many unknowns for a std dev; range is approximately x times the average

Aerosol Anthropogenic Indirect RFs

Study	Indirect RF (Wm^{-2})		
	Avg	Std Dev	
TAR	N/A	0 to -2	
AR4 – All 16 models	-1.09	± 0.47	Models
AR4 – 8 most confident models*	-0.90	± 0.43	Models
POLDER	-0.85	N/A	Observ.
AVHRR	-0.64	± 0.16	Observ.
AR4	**-0.90**	**± 0.43**	

*Models w/ higher resolution and incorporating numerous chemical species

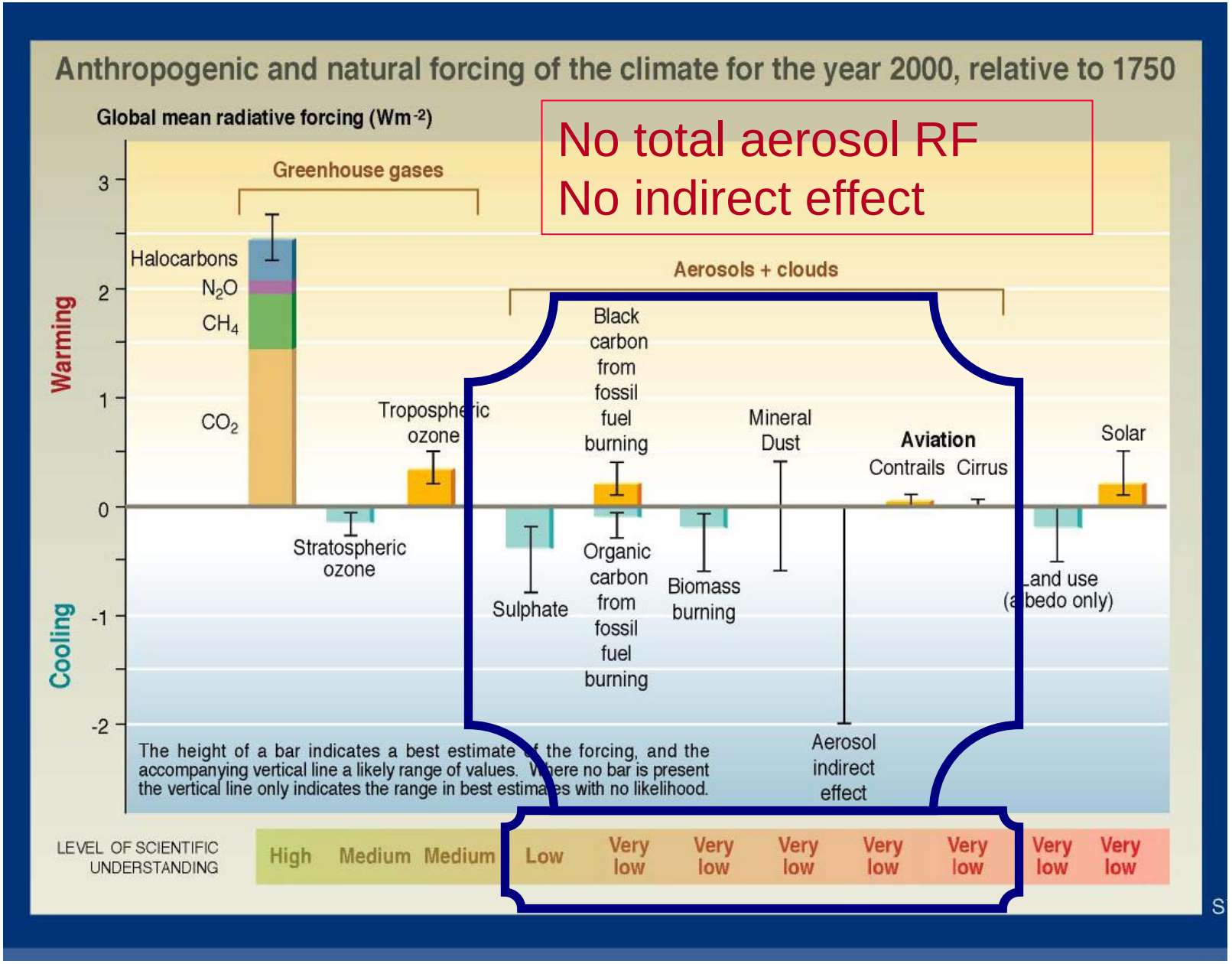
"We've come a long way…."

- TAR had no confidence in an overall estimate; just a wide range
- Extensive validation/constraint conducted between models and observations since then

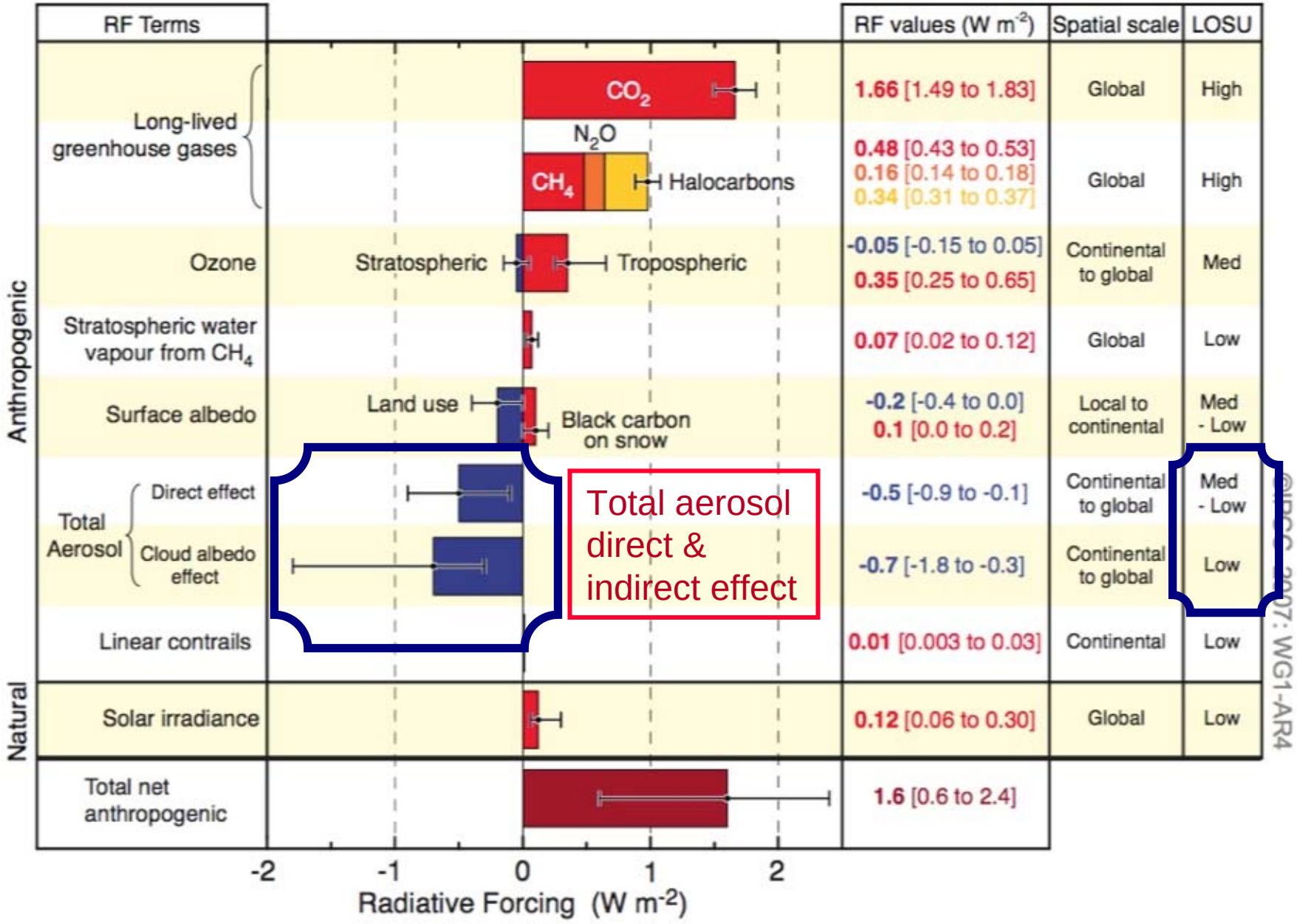
"…and we have a long way to go"

- Still a lot of disagreement/uncertainty
- *ONLY 1st indirect effect taken into account (cloud albedo effect)

IPCC TAR (2001)



IPCC AR4 (2007)



Aerosol Summary - AR4 vs TAR

"We've come a long way…."

- Aerosol total direct RF and indirect effect calculated
- "LOSU" increased from low/very low to medium/low
- Good news – averages haven't changed much
- Increased aerosol confidence level contributed to confidence in anthropogenic cause of earth's increasing surface T
  - TAR - "Likely" (66%)
  - AR4 - "Very Likely" (90%)

"…and we have a long way to go"

- Clouds!
  - Algorithms for obs
  - Indirect effects for models
- Aerosol spatial distributions, compositions, size distributions
- Better understand model parameterizations
- Improve observations