Uncertainties in aerosol cloud-mediated radiative forcing: Two large and highly uncertain opposite effects from shallow and deep clouds

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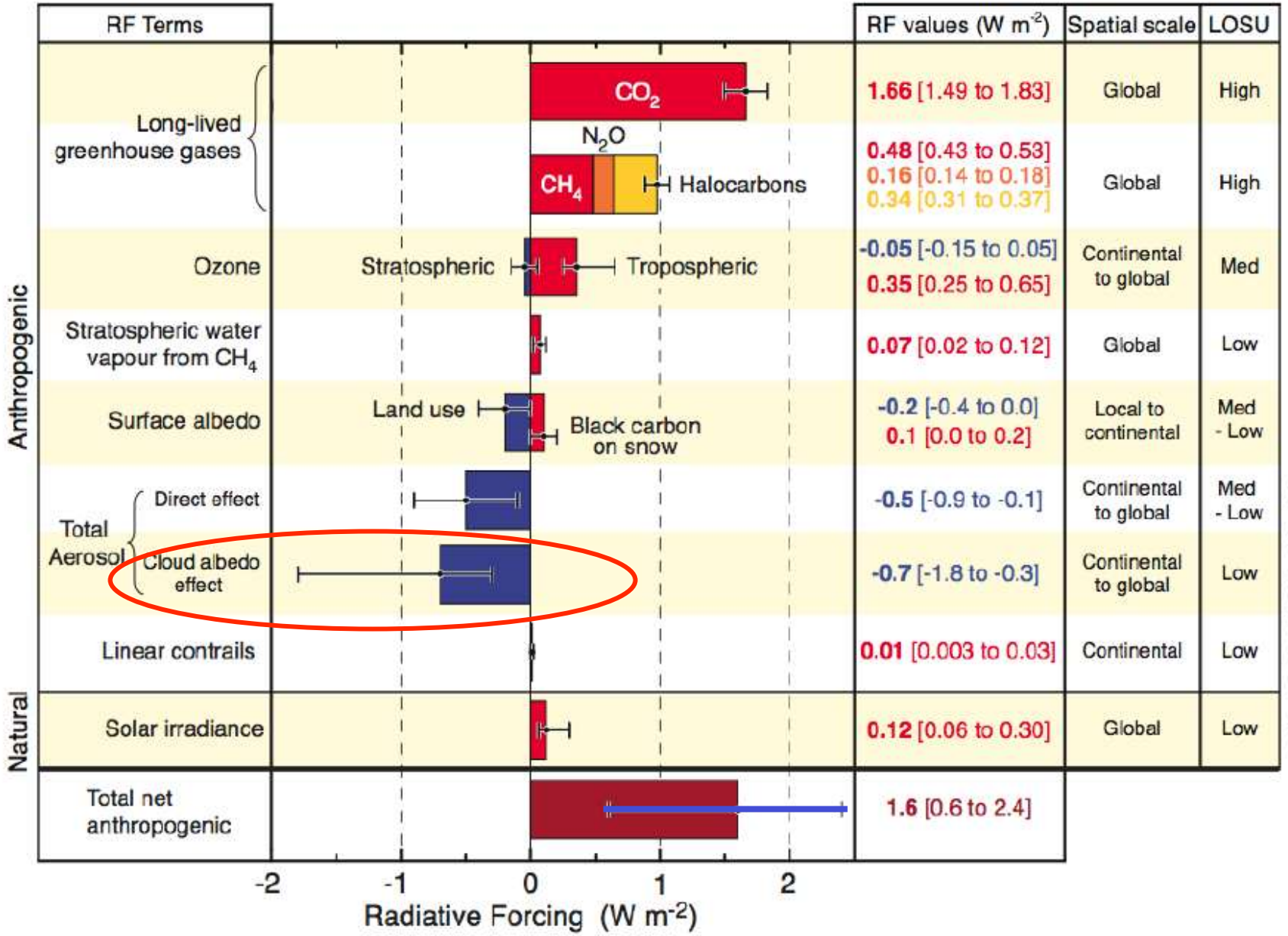
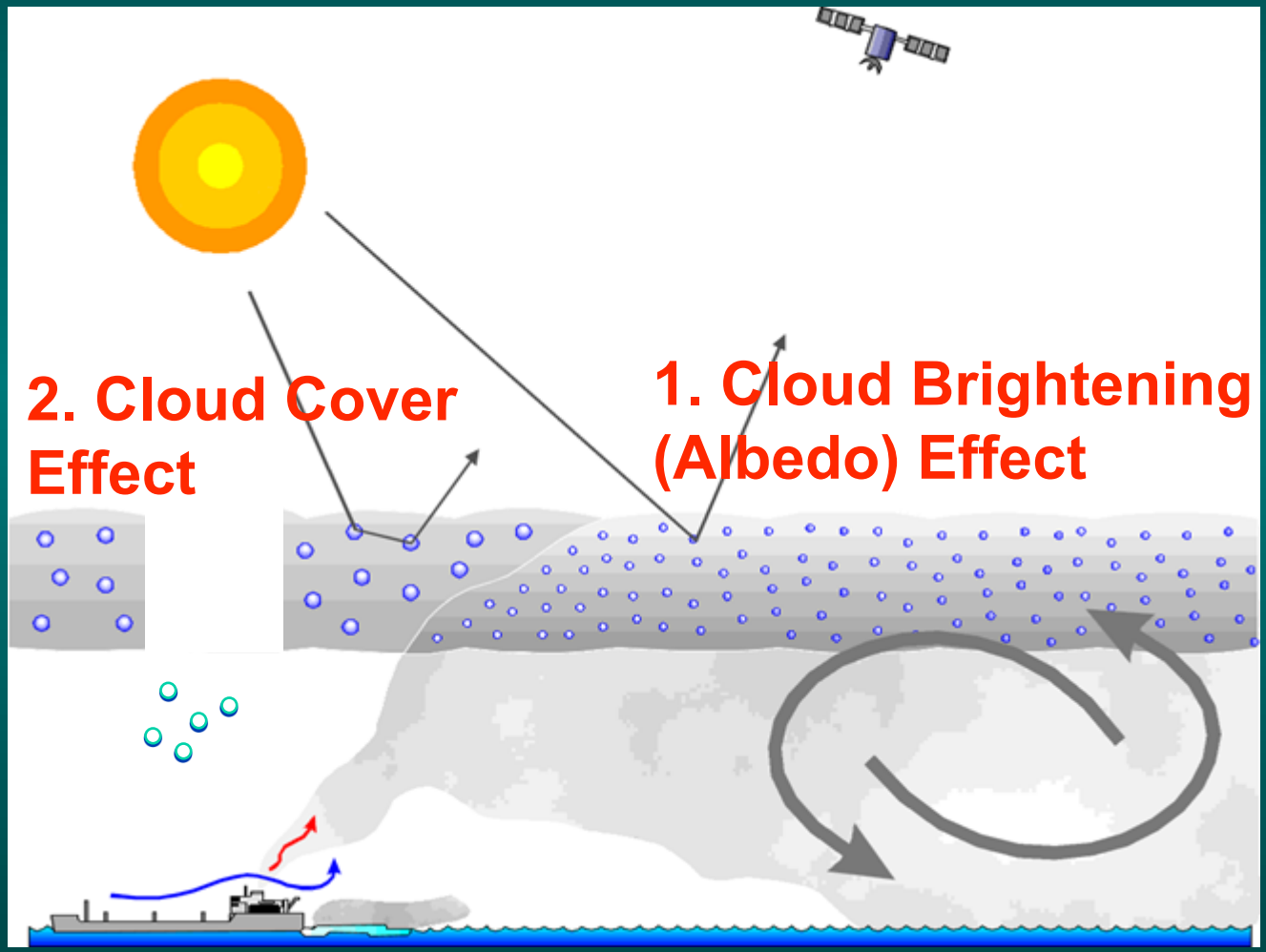
Radiative Forcing Components



Ship Track Formation



$N \sim 40\ cm^{-3}$
$W \sim 0.30\ g\ m^{-3}$
$r_e \sim 11.2\ \mu m$

$N \sim 100\ cm^{-3}$
$W \sim 0.75\ g\ m^{-3}$
$r_e \sim 10.5\ \mu m$


Clouds rain themselves out in super-clean air
Photo:
Joseph Prospero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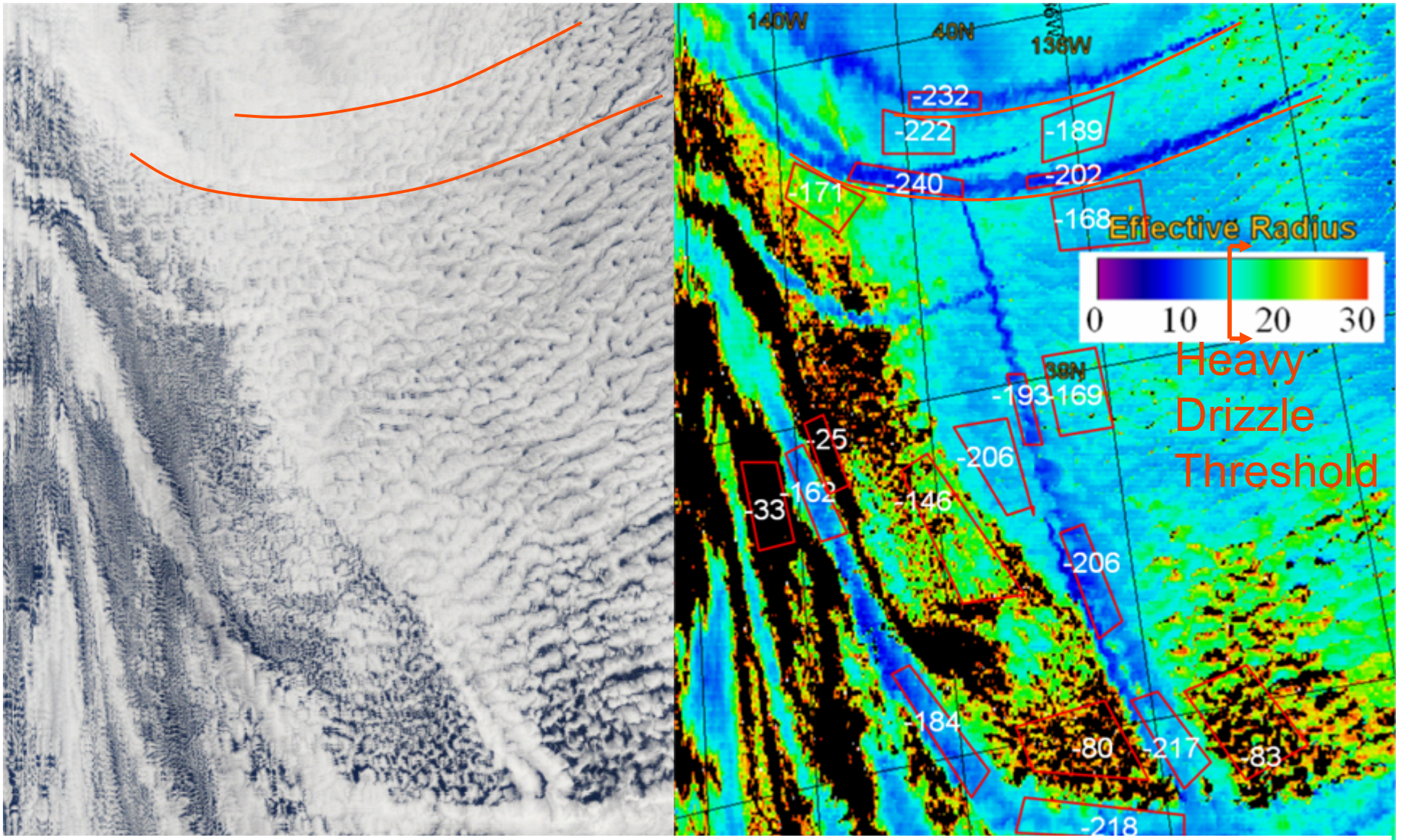
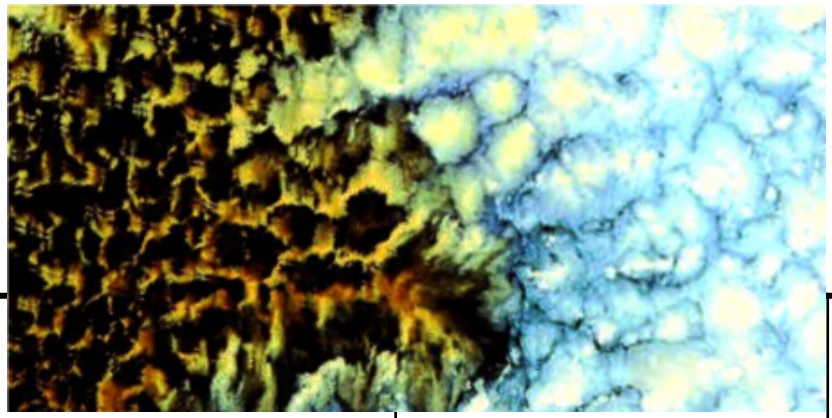


R. Wood and G. Feingold contributed major insights to the relations between aerosols and the regime changes. Please see Session B6 on Tuesday Afternoon.

Analysis of 48 pairs of open vs. adjacent closed cells shows:

Goren and Rosenfeld, in preparation, 2011



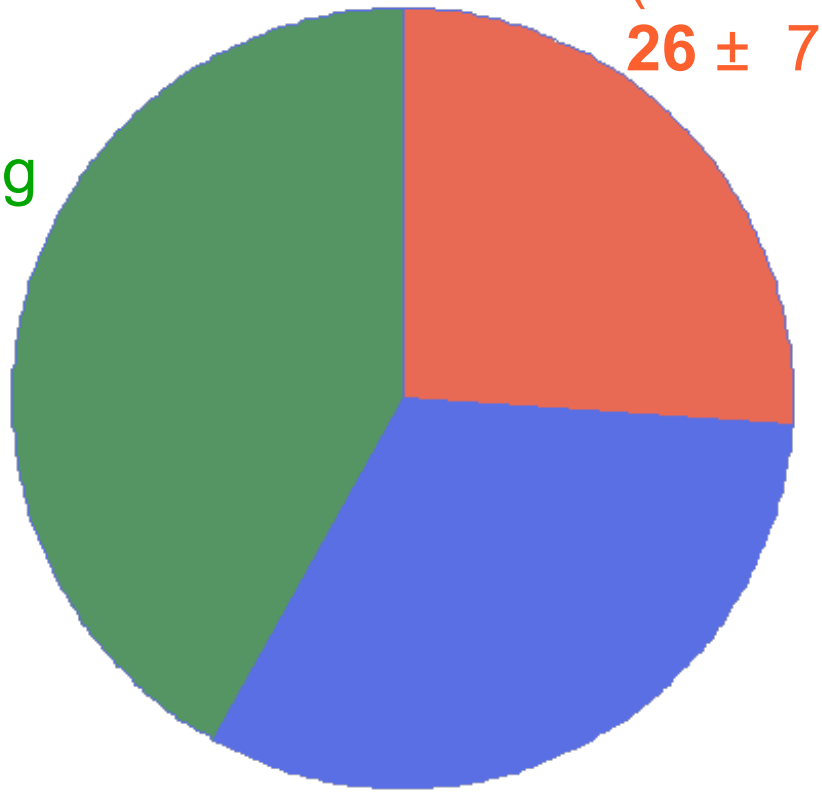
	Open	Closed	Difference Closed-Open
N of cloud drops cm^{-3}	13 ±3	53 ±18	40
Drop eff. radius mm	26 ±1	15 ±2	11
R. Forcing wm^{-2}	-28 ±5	-138 ±19	-109 ±18

The components of the radiative forcing due to closing open MSC

Goren and Rosenfeld, in preparation, 2011

Cloud brightening for a given cloud water path (**Twomey**)
26 ± 7 %

Scene brightening due to increased **Cloud Cover**
42 ± 9 %



Cloud brightening due to increased **Cloud Water Path**
32 ± 11 %

Previous estimates of forcing components

Sekiguchi et al., JGR 2003, AVHRR:

Cloud cover = 4 X albedo effect over global oceans. Total = -0.6 – -1.2 wm^{-2}.

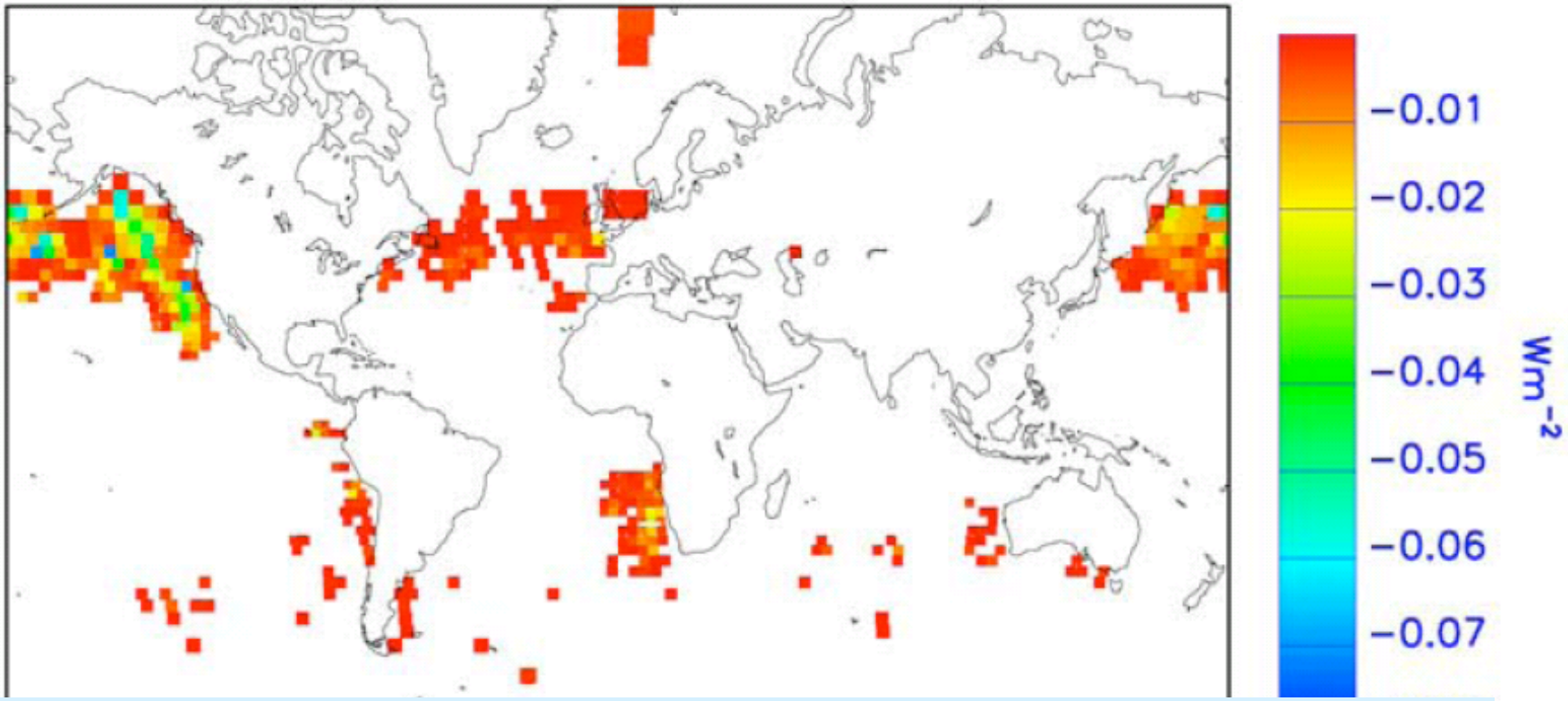
Kaufman et al., PNAS 2005, MODIS:

Cloud cover > 4 X albedo effect over the Atlantic, total RF = -4.5 – -9.5 wm^{-2}.

Lebsock et al., JGR, 2008, CloudSat+MODIS:

Cloud water path >> albedo effect over global oceans (no quantification).

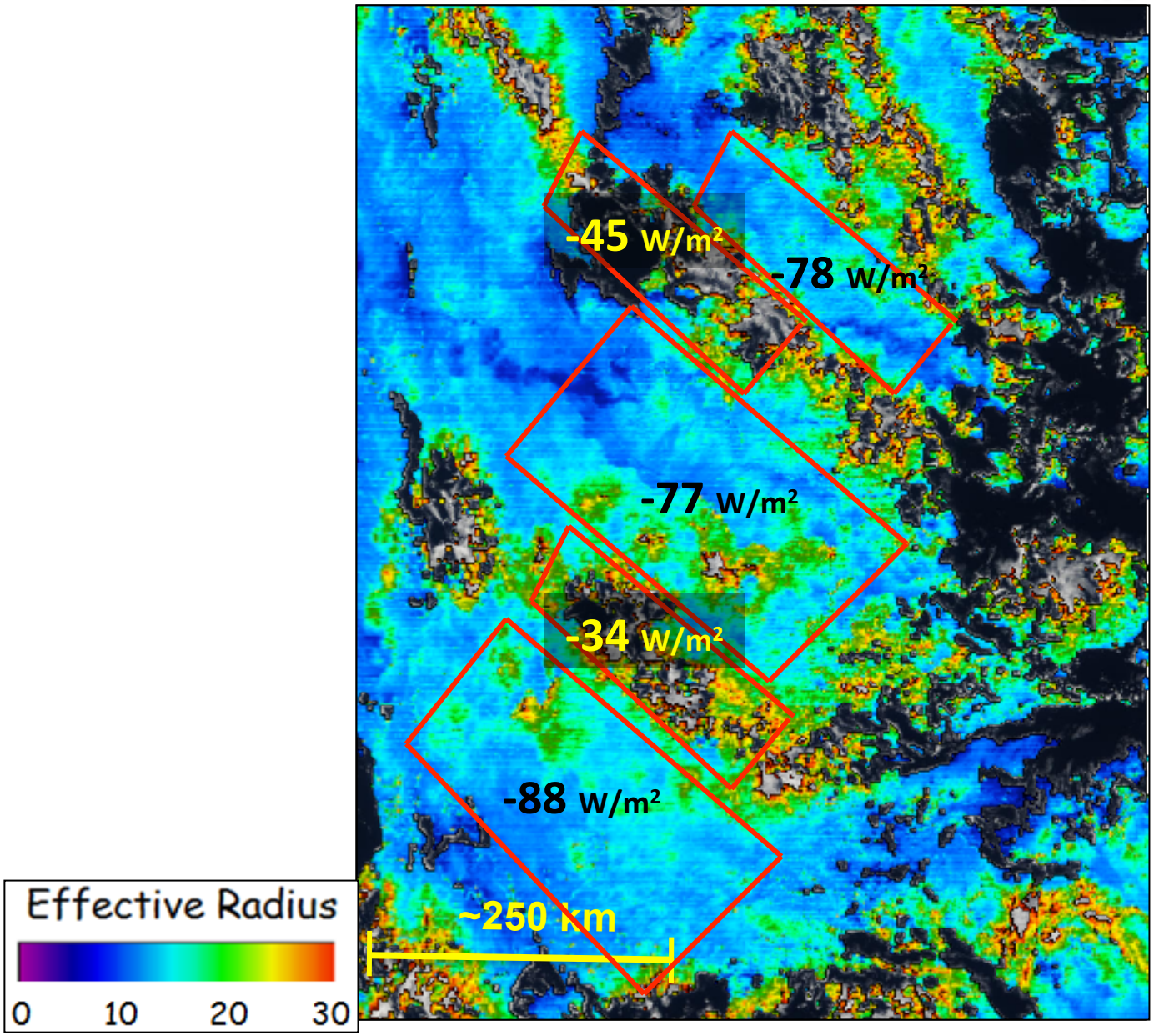
Albedo forcing = -0.42 wm^{-2}.



The global radiative forcing due to visible ship tracks is ~ 0.005 wm^{-2}. So do ship emissions matter at all?

Annual mean radiative forcing of ship tracks During 2004. *Schreier et al., GRL 2007.*

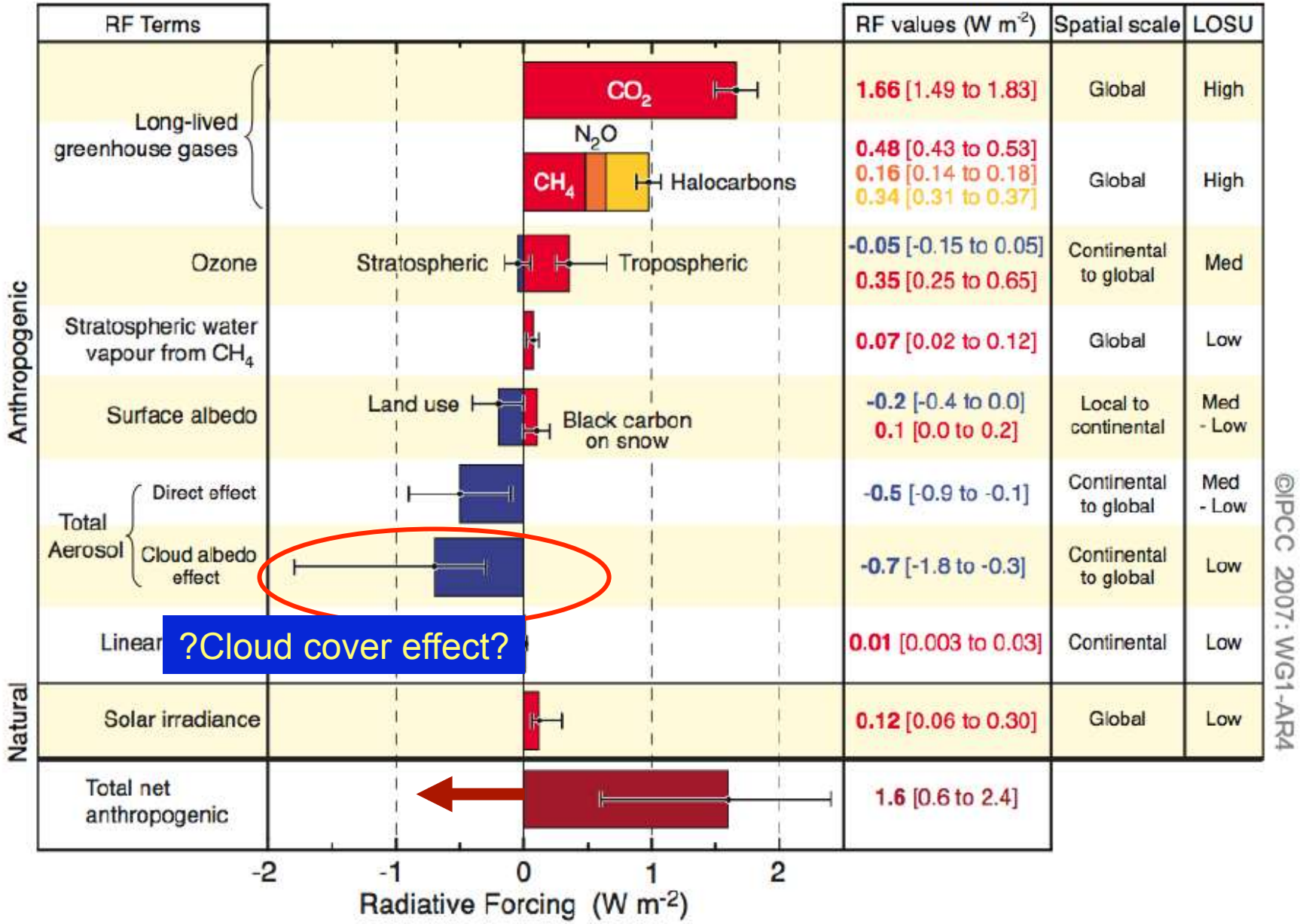
Air pollution from 42 hours old ship tracks "Clouds" the Oceans

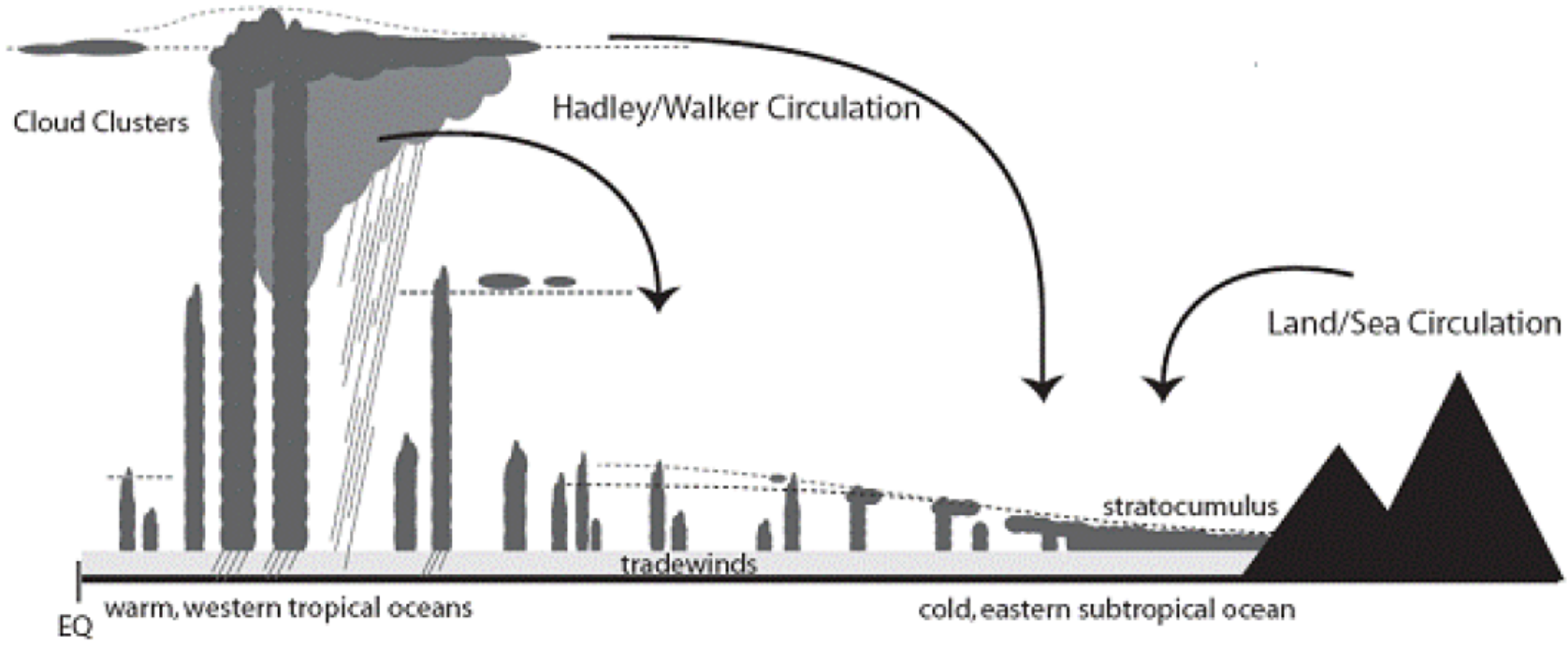


19/1/06 12:00 UTC
MODIS Re TERRA

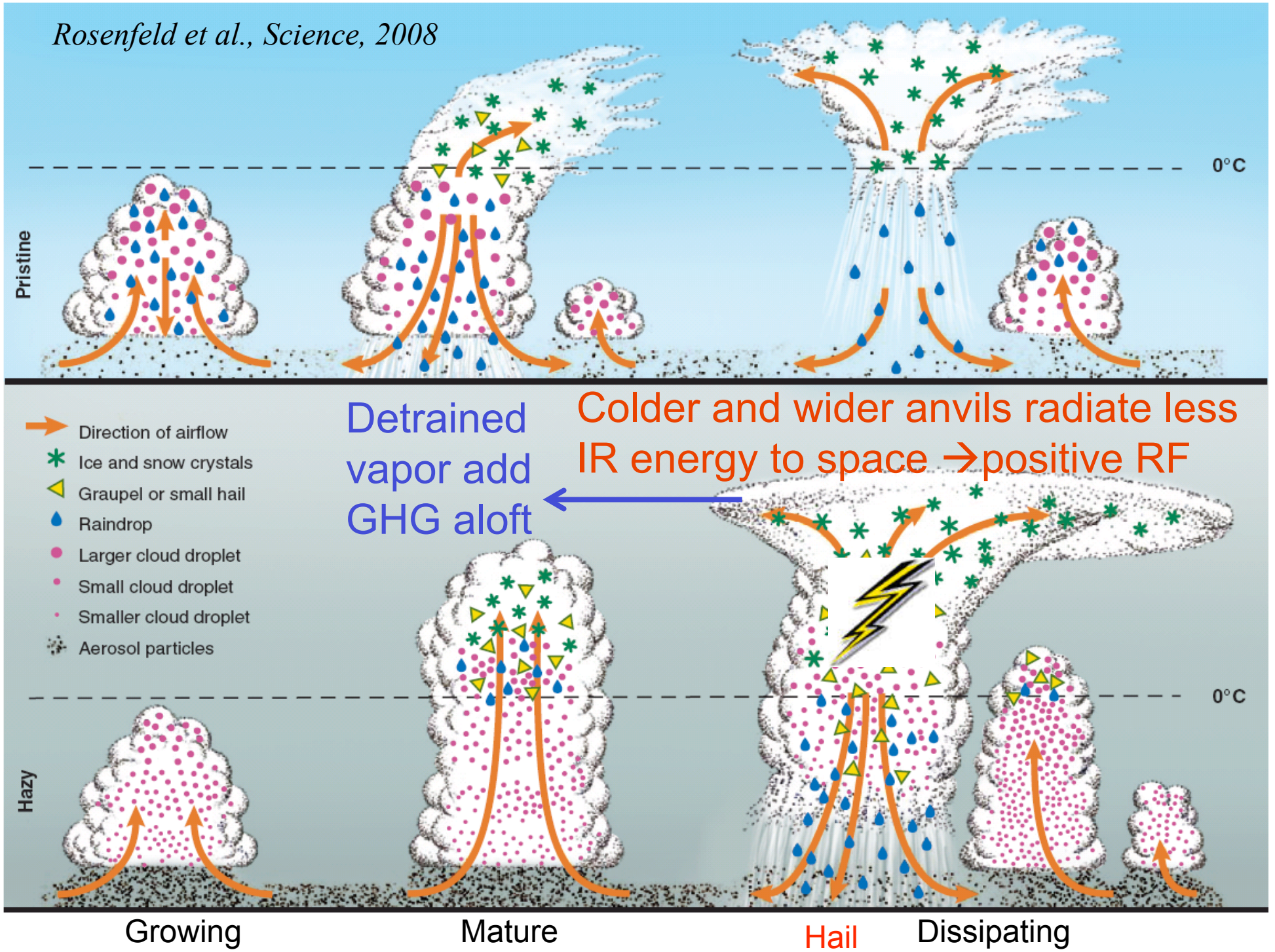
Goren and Rosenfeld, in preparation, 2011

Radiative Forcing Components

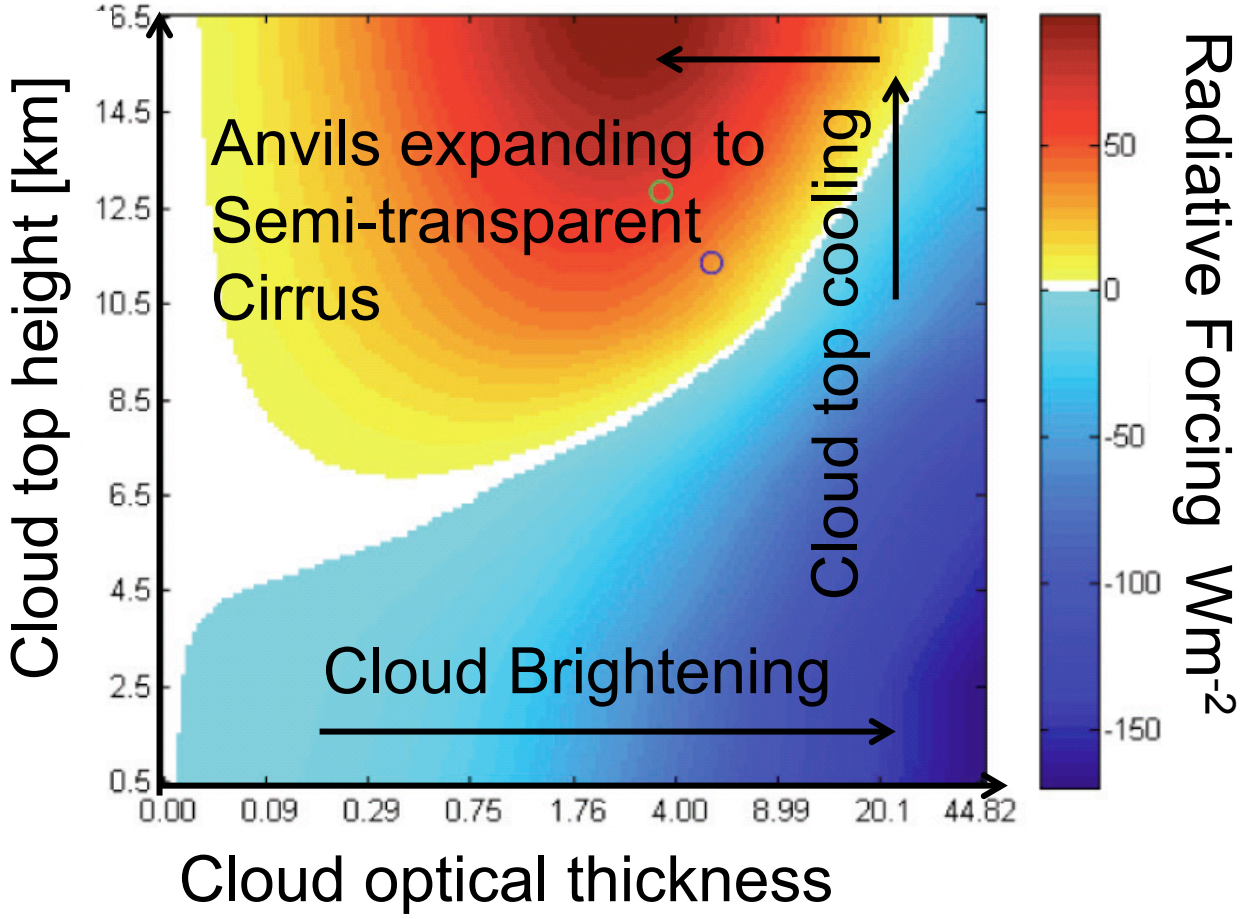


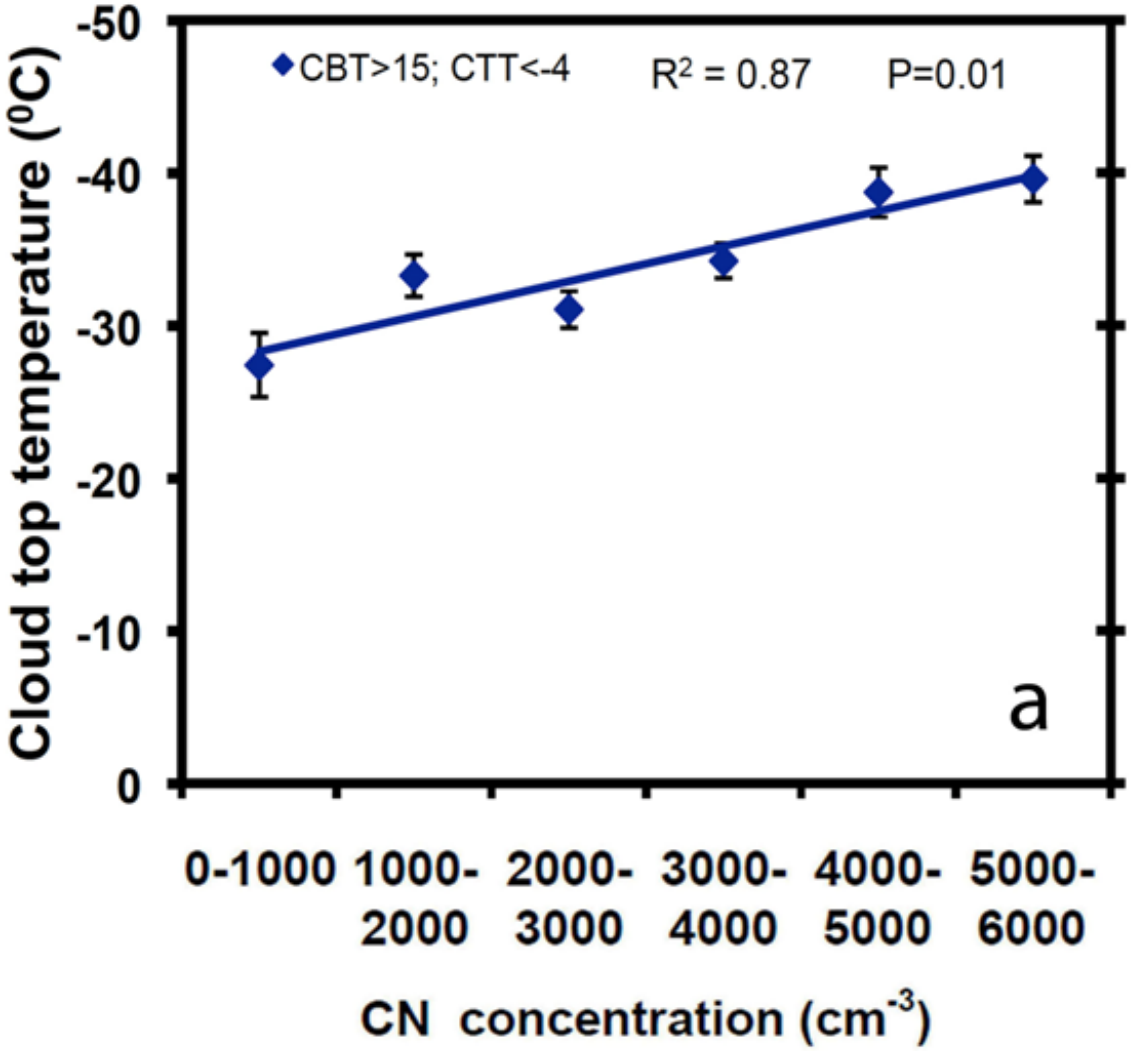


Schematic of the transition from marine stratocumulus under the subtropical high to the trade-wind cumulus regime that in turn transitions to deep convection in the ITCZ. Aerosol-precipitation interactions may affect the transition from solid to broken clouds. (Stevens, *Annu. Rev. Earth Planet. Sci.*, 2005)

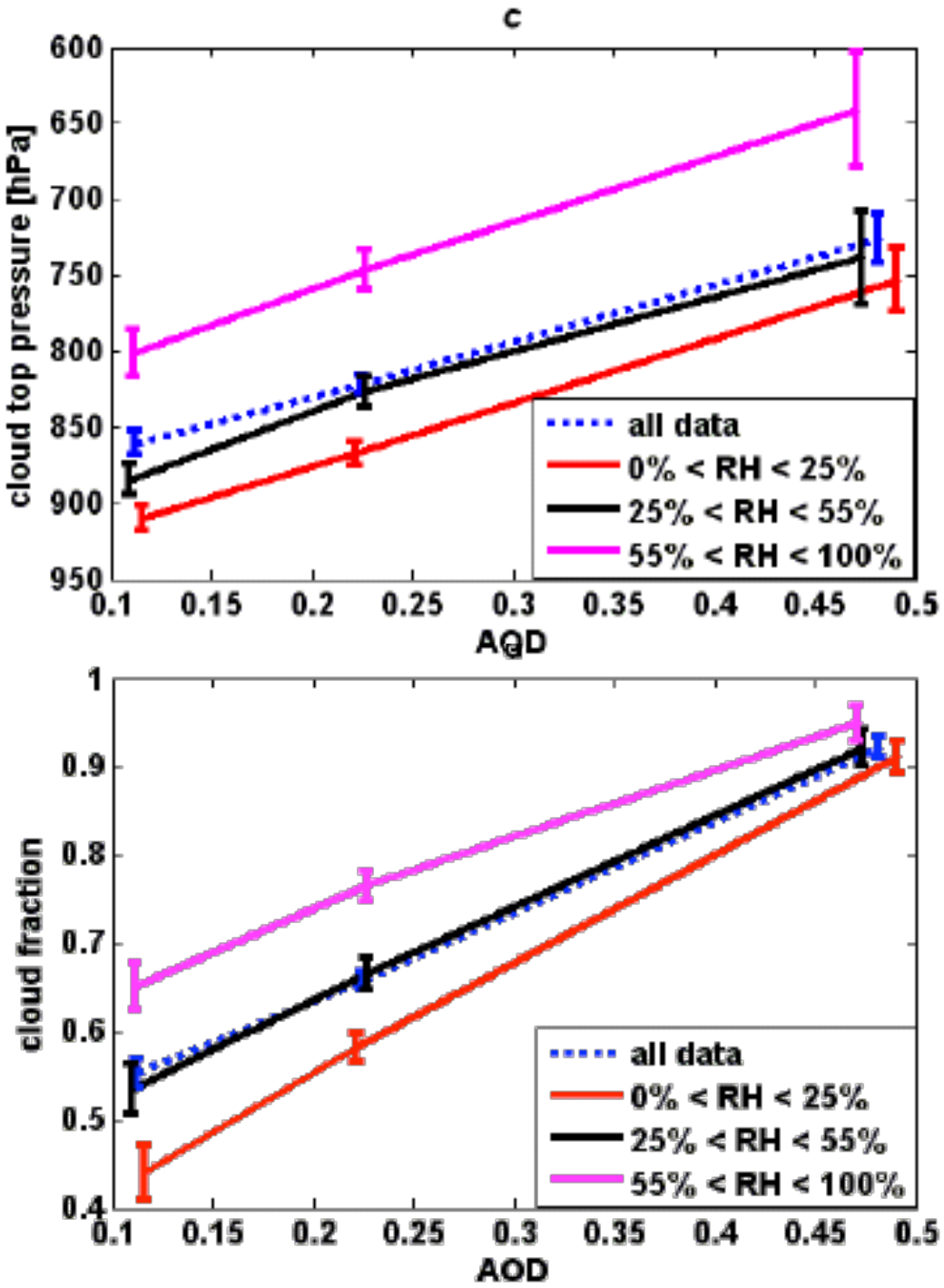

Rosenfeld et al., Science, 2008
0°C
Pristine
Direction of airflow
Ice and snow crystals
Graupel or small hail
Raindrop
Larger cloud droplet
Small cloud droplet
Smaller cloud droplet
Aerosol particles
Detrained vapor add GHG aloft
Colder and wider anvils radiate less IR energy to space →positive RF
0°C
Hazy
Growing
Mature
Hail
Dissipating

How common is this aerosol-induced invigoration of deep clouds, and the respective positive radiative forcing?





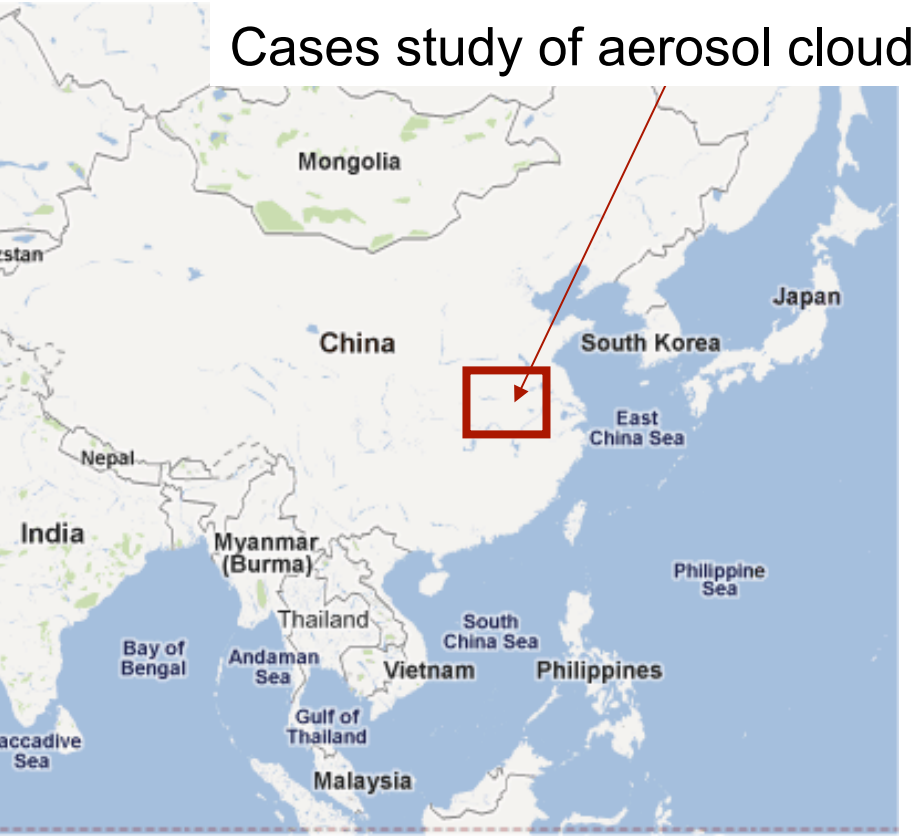
Aerosols heighten the tops of deep clouds with warm base. Based on 10 years of data from the Atmospheric Radiation Measurements (ARM) collected in the U. S. Southern Great Plains. *Li et al., accepted, 2011.*



MODIS measured cloud top heights and fraction increases observed aerosol optical depth over the Equatorial Atlantic Ocean (From Koren et al., ACP 2010), in agreement with the invigoration hypothesis (Rosenfeld et al., Science 2008)

Koren et al.,: ACP, 2010

Cases study of aerosol cloud-mediate forcing of moist deep convection, wm^{-2}



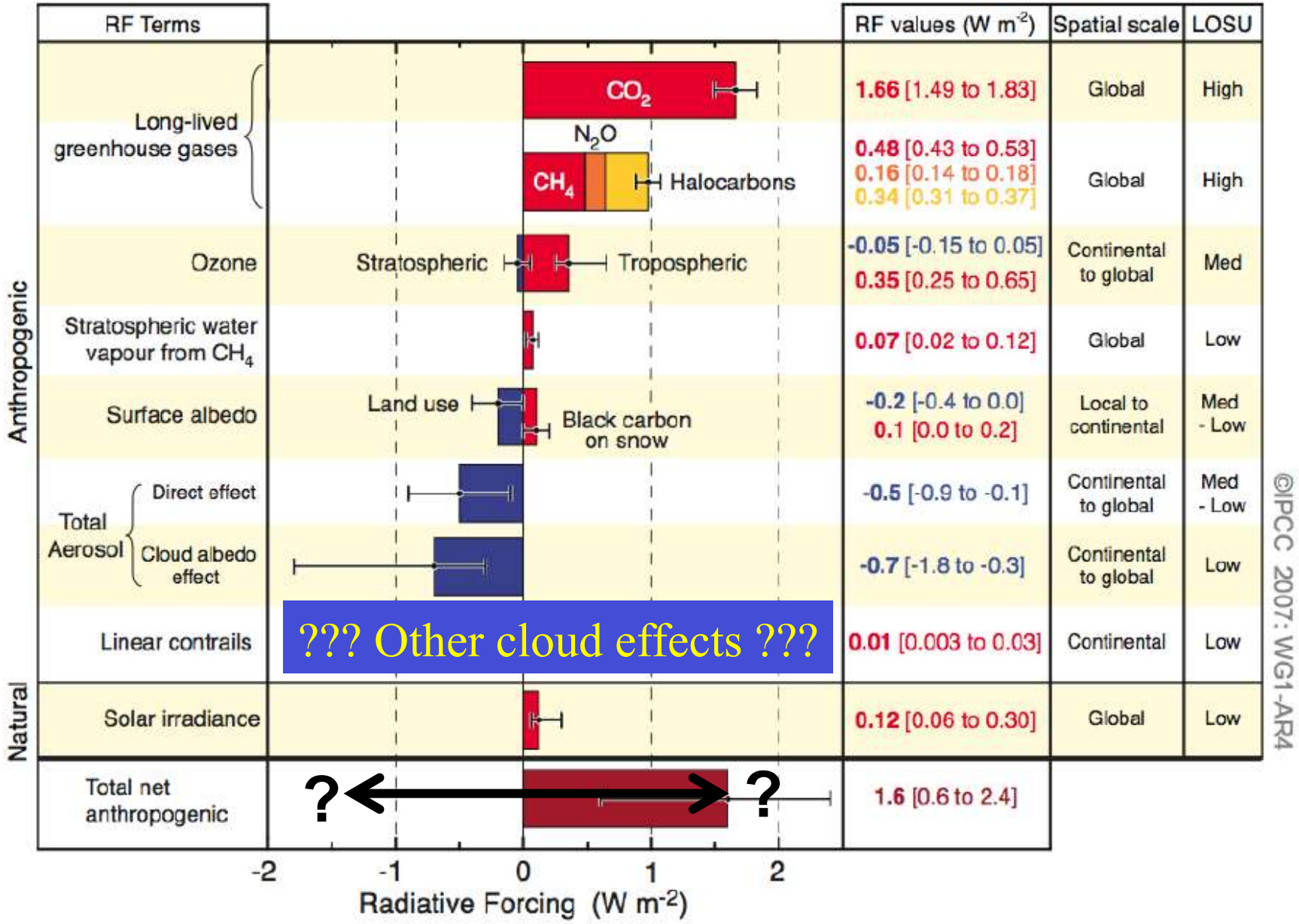
	Solar	+	LW	=	NET
Top of Atmosphere	-3.0		+6.6	=	+3.6 wm^{-2}
Atmosphere	-0.6		+6.3		+5.7
Surface	-2.4		+0.3		-2.1

Full spectral bin microphysics
2 km resolution
Domain of ~450 X 600 km
Summer subtropical conditions
Cloud base temperature ~ 25°C
Clean: CCN = 280 cm^{-3}
Polluted: CCNX6 =1680 cm^{-3}

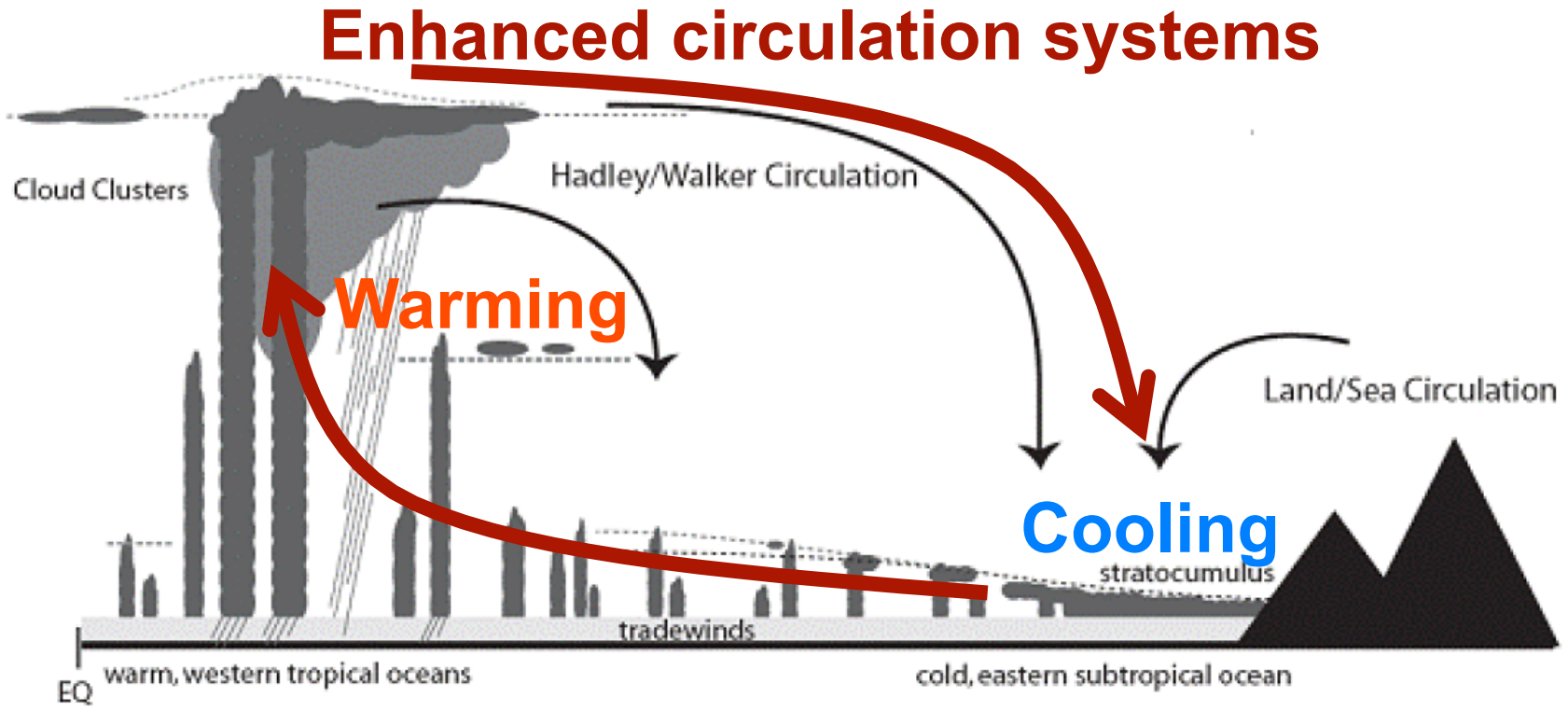
By J. Fan et al., in preparation, 2011

Almost all the LW positive radiative forcing heats the atmosphere, in addition to the thermodynamic heating of 2°K day^{-1}.

Radiative Forcing Components



Even if globally cooling is balanced by warming,



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Conclusions

- The main anthropogenic aerosol cloud-mediated radiative forcing considered so far, at least in the IPCC, is the albedo effect on shallow clouds.
- Cloud cover effect appears to be even much larger, to the extent that the world should have been cooling...
- Aerosols slowing precipitation in deep clouds induce strong positive radiative forcing of unknown global magnitude.
- The net effect is a difference between two comparably large and highly uncertain numbers.
- Therefore, the net aerosol cloud-mediated radiative forcing is highly uncertain, beyond the recognized uncertainty.
- It carries the same uncertainty to the climate sensitivity and respectively to predictions of warming scenarios.
- Resolving this uncertainty requires much improved combined simulations and global satellite observations. This is doable, but we are not there yet…