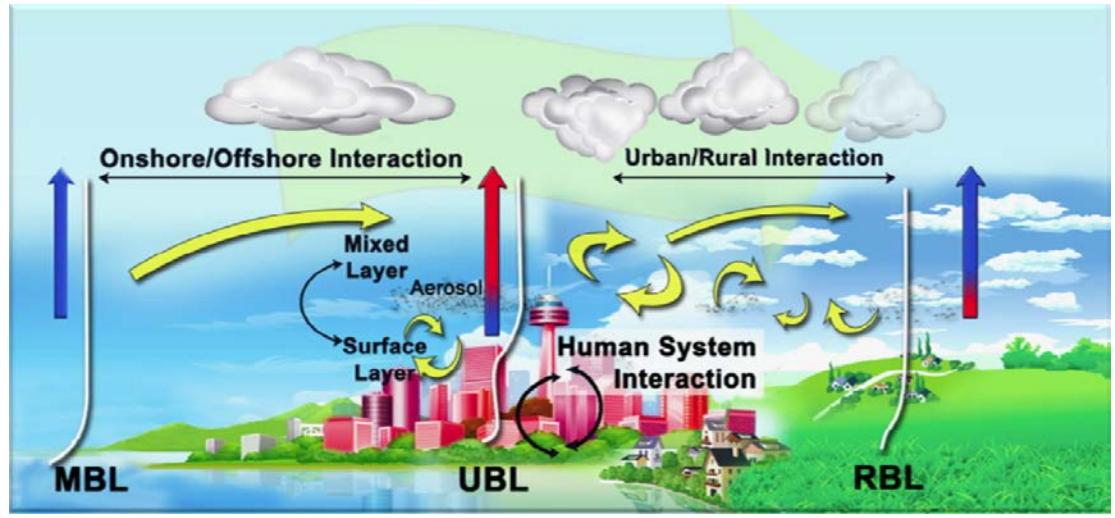
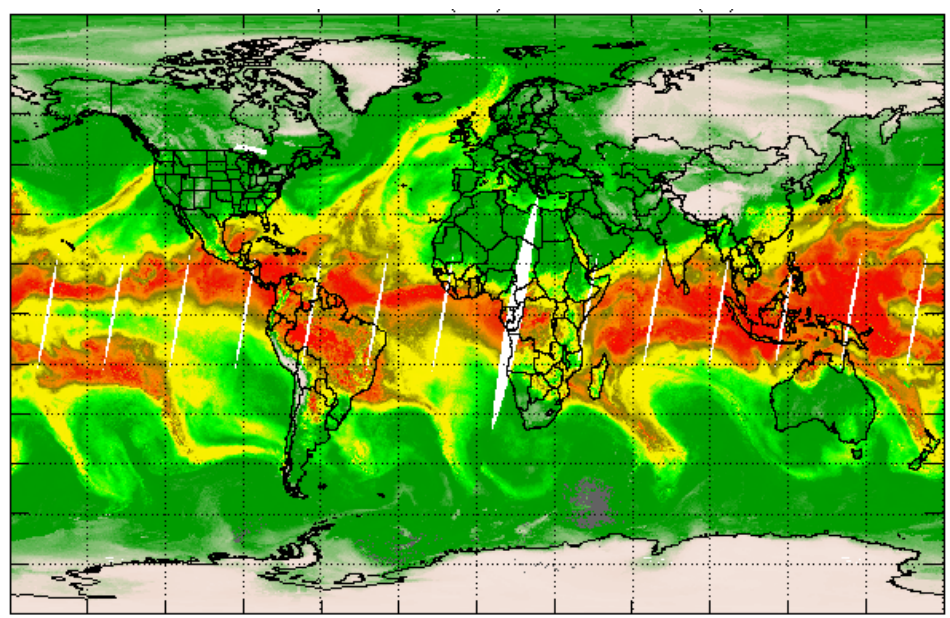
WATER, WATER EVERY WHERE, NOR ANY DROP TO DRINK: WATER VAPOR AS A RADIATIVE FORCING AGENT?

Stephen E. Schwartz, BNL
Jorge E. Gonzalez, CCNY



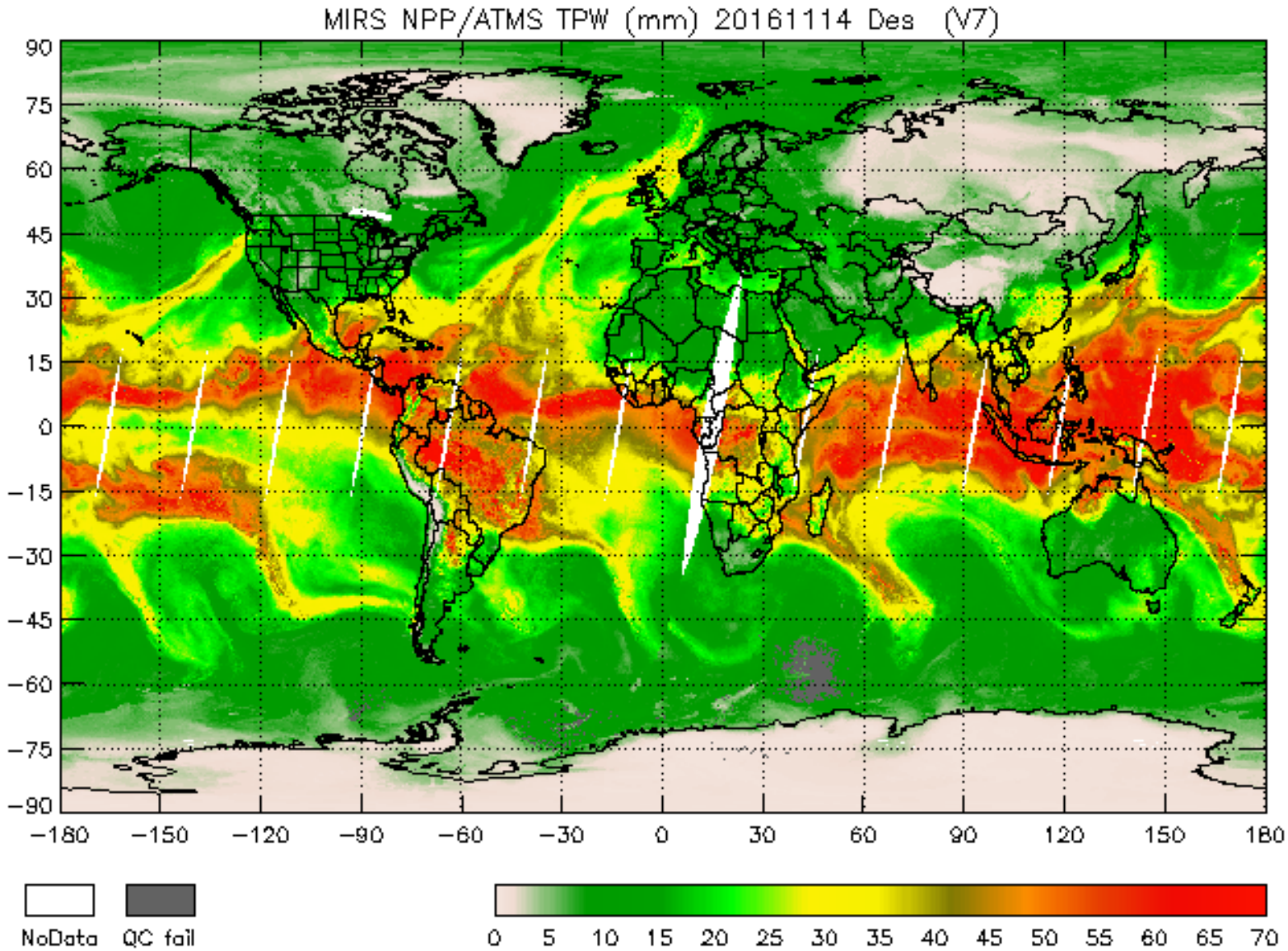
Planning Meeting
November 17-28, 2016
Brookhaven National Laboratory
Upton, NY

Energy & Water Cycles in Urban-Natural Landscapes: Challenges & Opportunities



PRECIPITABLE WATER

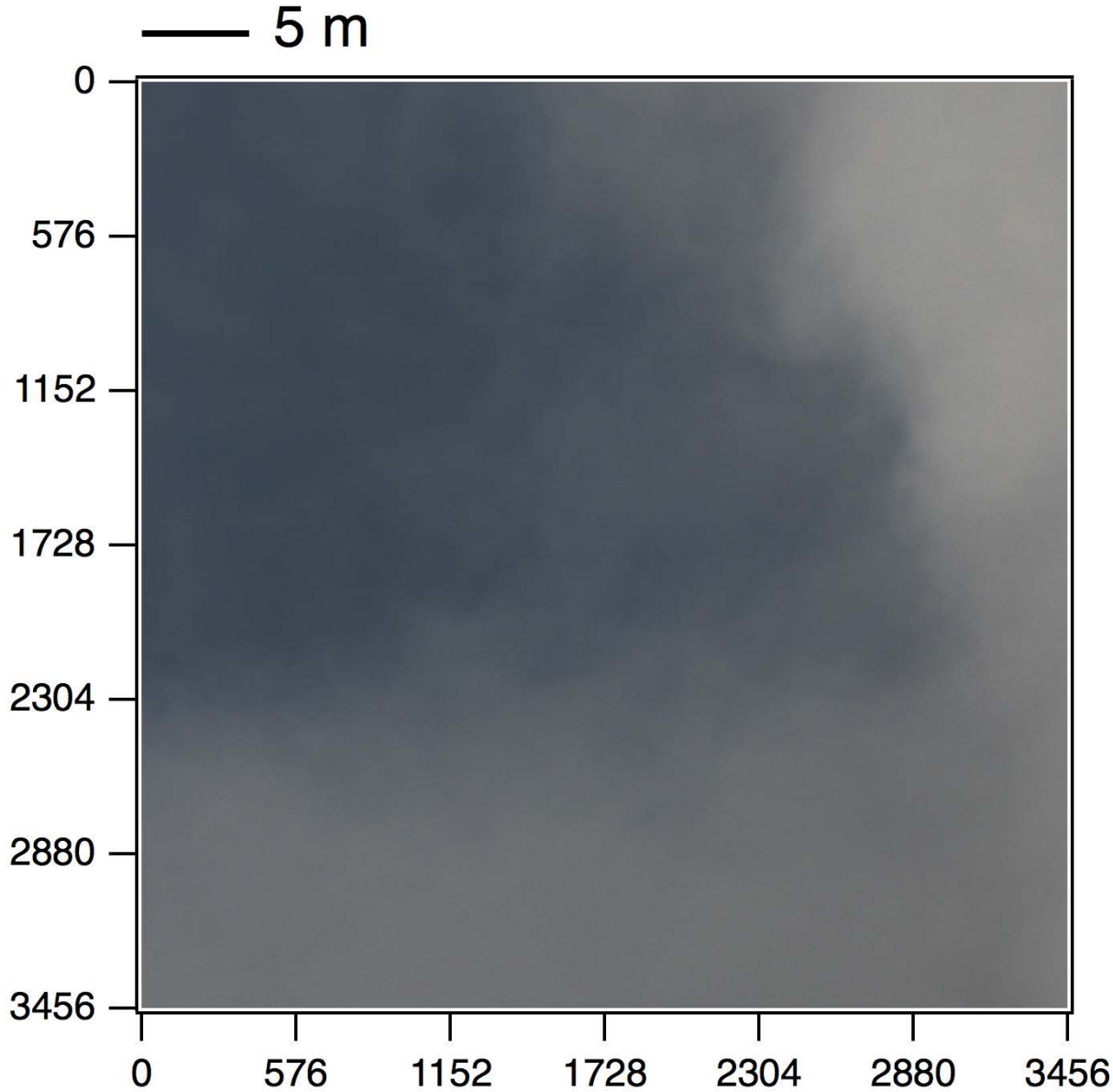
The height of a column of liquid water equal to the amount of water vapor in a column of air



Global mean 2.6 cm

Precipitable water, mm

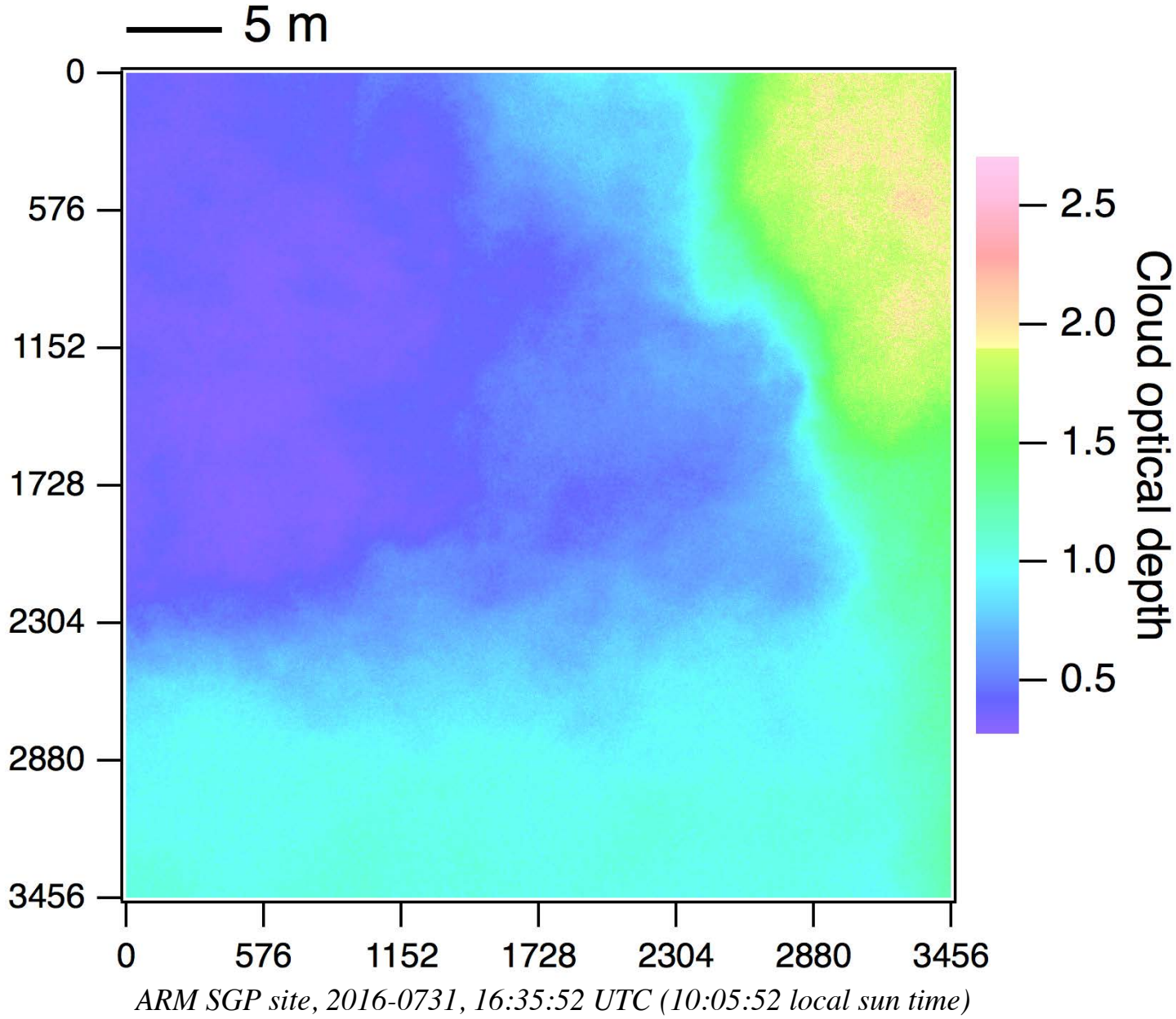
STEVE'S VIEW OF A CLOUD



ARM SGP site, 2016-0731, 16:35:52 UTC (10:05:52 local sun time)

RGB image obtained with zenith-pointing digital camera at surface.
12 M pixel, 16-bit. One pixel = 6 μrad = 12 mm at cloud height 2 km.

CLOUD OPTICAL DEPTH



Cloud optical depth determined from blue channel of RGB image.
12 million independent determinations of COD from single image.

SOME CONTEXT

These are thin clouds.

Liquid water path: $L = (2/3) r_e \tau$

τ = optical depth; r_e

For $\tau = 1$ and $r_e = 6$ μm, $L = 4$ μm $\Leftrightarrow$ 4 g m^{-2}.

Compare typical precipitable water, 2 cm $\Leftrightarrow$ 2×10^4 g m^{-2}.

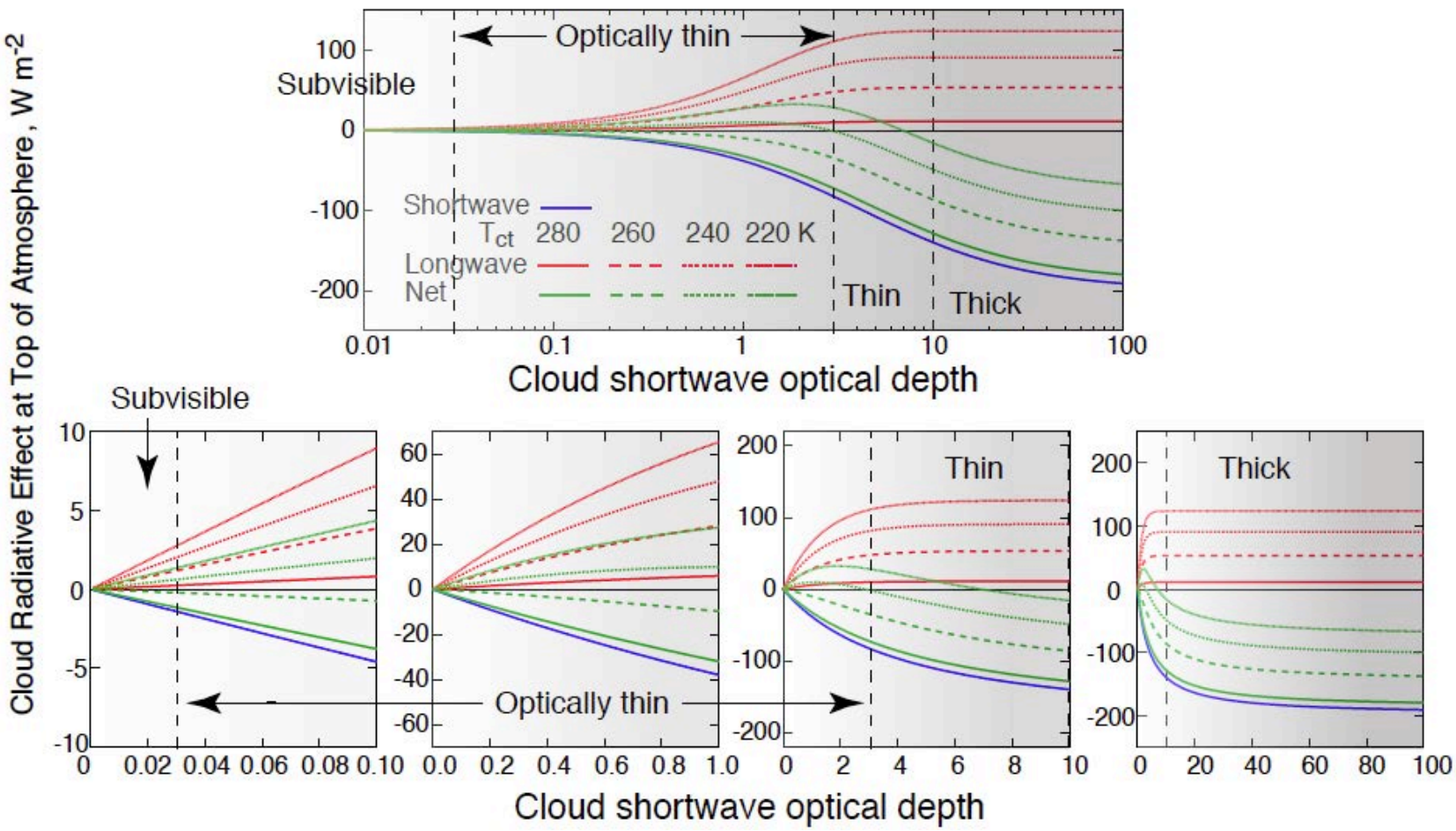
Compare Turner CLOWD (BAMS, 2007), 100 g m^{-2}.

Hard (impossible) to measure by radar, microwave.

These are thin clouds indeed!

FURTHER CONTEXT

24-Hour average cloud radiative effect at equinox
At midlatitude site



Optically thin clouds are radiatively very important!

SOME “OUTSIDE THE BOX” QUESTIONS

SOME “OUTSIDE THE BOX” QUESTIONS

Can human activities appreciably alter the amount of atmospheric water vapor?

- What processes?
- How much?
- On what scales?
- What would be the consequence?

- Urban scale – Water vapor island (Heat island)?
- Global scale – Anthropogenic water vapor as climate forcing agent?

CALCULATE THE PERTURBATION

Back of the envelope calculations

Volume of all beaches on Earth

length $\sim 10^5$ km
avg. width $\sim 10^2$ m
avg. depth ~ 10 m

"beaches" $\sim 10^{11}$ m^3

Volume of a grain of sand

$l \sim 0.5$ mm
$w \sim 0.5$ mm
$h \sim 0.5$ mm

"sand" $\sim 10^{-10}$ m^3

$\Rightarrow$ to fill all beaches requires about 10^{21} grains of sand

CALCULATE THE PERTURBATION

Back of the envelope calculations

$$\Delta M = \Delta Q \boxed{\tau}$$

Change in amount = Source × $\boxed{\text{Residence time}}$

Residence time of water vapor in atmosphere:

$$\tau = M / Q$$

$$Q = S$$

$$M = 2.6 \text{ cm}$$

$$S = 100 \text{ cm yr}^{-1}$$

$$\boxed{\tau = 0.026 \text{ yr} = 9.5 \text{ days}}$$

GLOBAL SOURCES OF WATER VAPOR FROM HUMAN ACTIVITIES

Water of combustion

Evaporation of water for cooling in electricity generation

Agricultural irrigation

COMPARE TO GLOBAL PRECIPITATION

Area of earth	5E+14	m2
Rain rate	1	m yr-1
	1.00E+03	kg m-2 yr-1
global precip rate	5E+17	kg yr-1

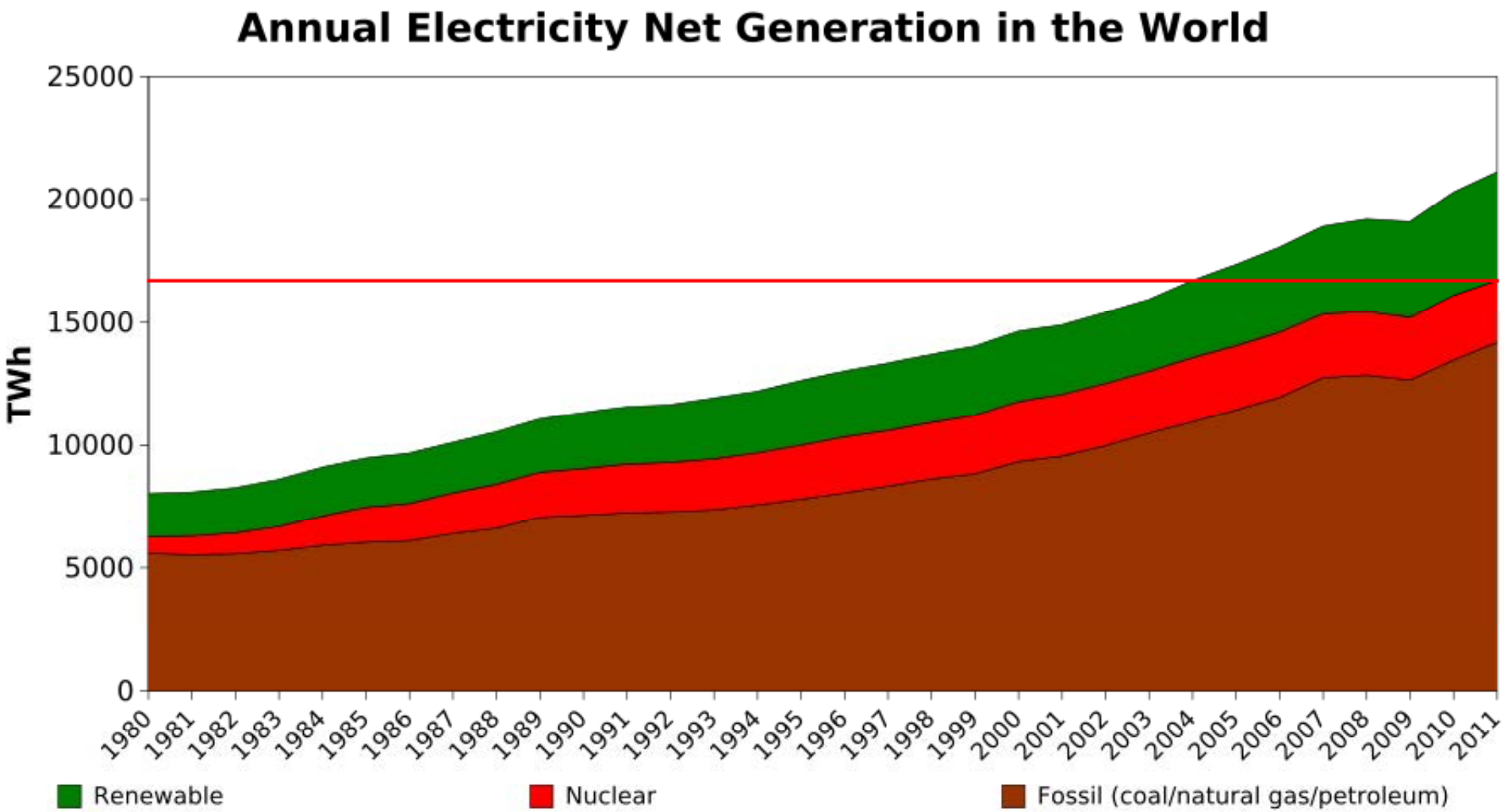
WATER OF COMBUSTION

Fossil fuel combustion rate	1E+13	kg C yr-1
Fraction hydrocarbons	0.5	
Hydrocarbon combustion rate	5E+12	kg C yr-1
MW water	18	
MW carbon	12	
Ratio	1.5	
Water of combustion rate	7.5E+12	kg H2O yr-1

Literature estimate: 1 E+13 kg yr-1

Fraction of natural: 1.5 – 2 E-5

EVAPORATIVE COOLING FROM ELECTRIC POWER GENERATION



Wikipedia

EVAPORATIVE COOLING FROM ELECTRIC POWER GENERATION

Global Elec Energy Prod	16000	TWh yr-1
Global Elec Energy Prod	1.60E+16	Wh yr-1
Fraction HVAC	0.5	
	8E+15	Wh yr-1
Fraction Evap Cooling	0.5	
Energy for HVAC	4E+15	Wh yr-1
	3.60E+03	s hr-1
Energy for HVAC	1.44E+19	W s yr-1 = J yr-1
Latent Heat Water Evap	2257	kJ kg-1
	1000	J kJ-1
Latent Heat Water Evap	2.26E+06	J kg-1
HVAC evap water source	6.38E+12	kg yr-1
Coefficient of Performance	3.8	
Including emissions at end use	2.42E+13	kg yr-1
Global pecip	5E+17	kg yr-1
Fraction	4.85E-05	

INCREASE IN PRECIPITABLE WATER FROM ELECTRIC POWER GENERATION

Evap water source	2.42E+13	kg yr-1
Residence time	0.026	yr
Δ Global water amt	6.30E+11	kg
Area of Earth	5.00E+14	m2
Δ column burden	1.26E-03	kg m-2
Density	1.00E+03	kg m-3
Column height	1.26E-06	m

Comparable to a thin cloud, but a vapor, so much less radiative effect

IRRIGATION (Boucher et al., 2004)

	lower	higher	
Irrigation evap	1000	2500	km3 yr-1
	1.00E+09	1.00E+09	m3/km3
	1.00E+03	1.00E+03	kg/m3
	1.00E+15	2.50E+15	kg yr-1
Global precip	5E+17	5E+17	kg yr-1
Fraction of natural	2.00E-03	5.00E-03	
Forcing	0.03	0.1	Wm-2
Anthro GHG Forcing	2.8		Wm-2

BOTTOM LINE

Water emissions from evaporative cooling associated with electric power production and HVAC end use have a negligible greenhouse gas effect.