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Constraining aerosol-cloud interactions for future scenarios

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Present-day Climate Constraints with Satellites

The magnitude of aerosol-cloud interactions remains unconstrained and subject to a large range of uncertainty: -0.3 to -4.0 W m^{-2}

We would like to make future predictions for different aerosol scenarios. How realistic would that be?

To constrain GISS GCM predictions of aerosol indirect effect for future scenarios we use satellite data to understand present-day simulations.

We examine 3 time intervals: 1980

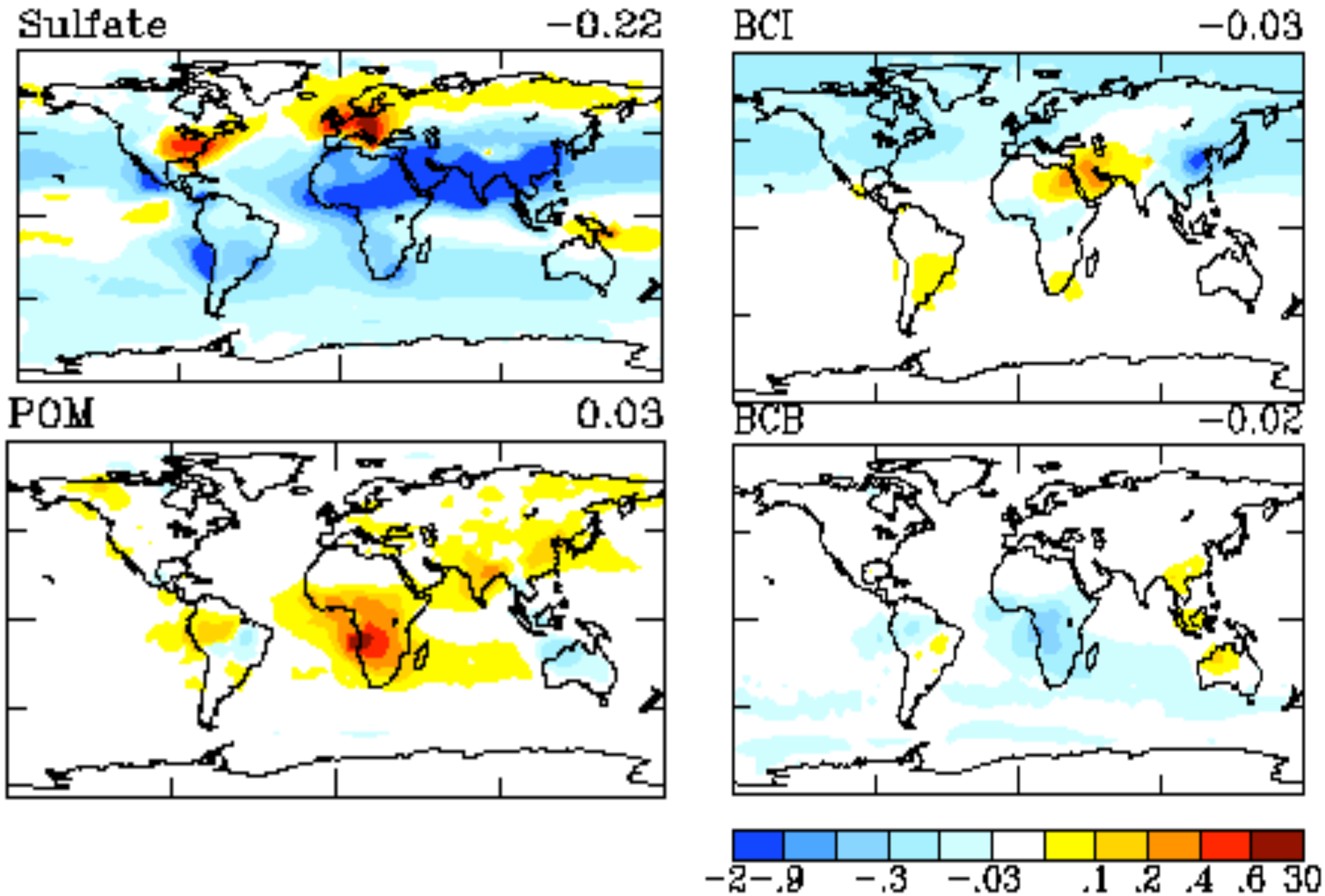
2000

2030A1B and
alternate 2030A1B scenarios

We focus on Year 2000 and use MODIS and AMSR to analyse signatures of aerosol-cloud interactions.

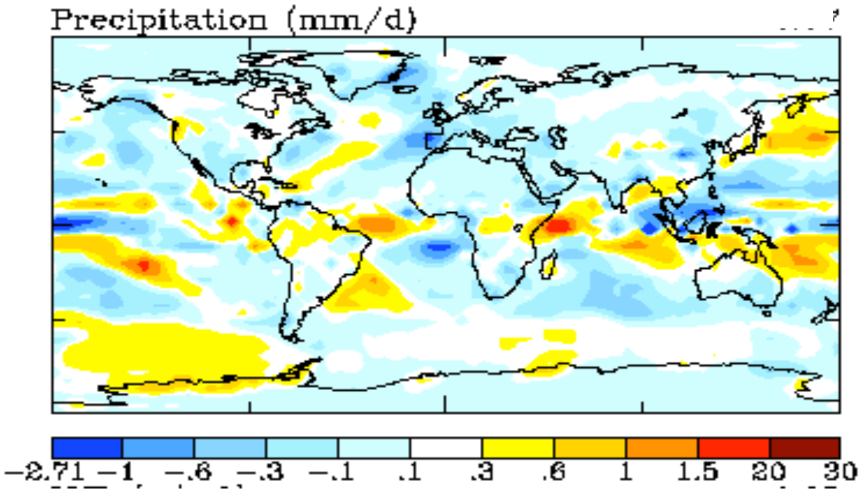
Future Climate : 2030 - PD

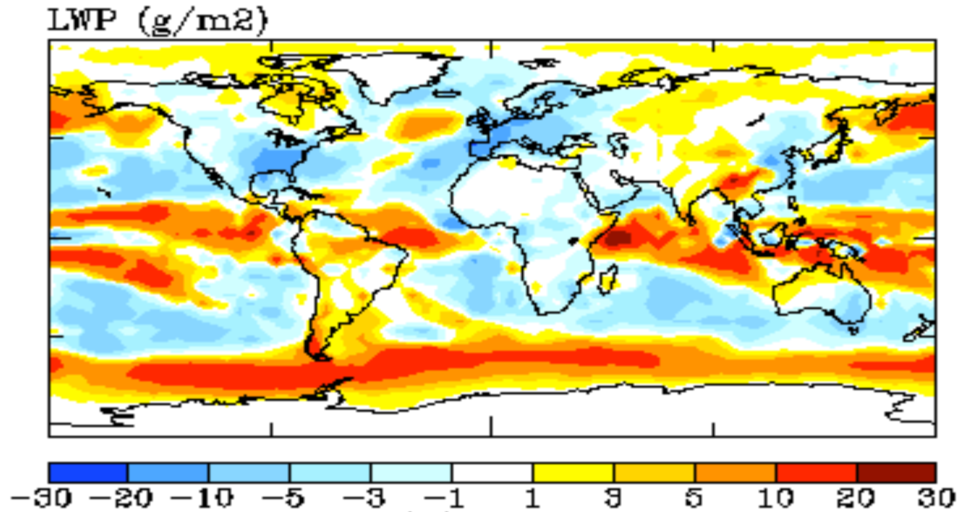
Direct effect = — 0.24 W m^{-2}

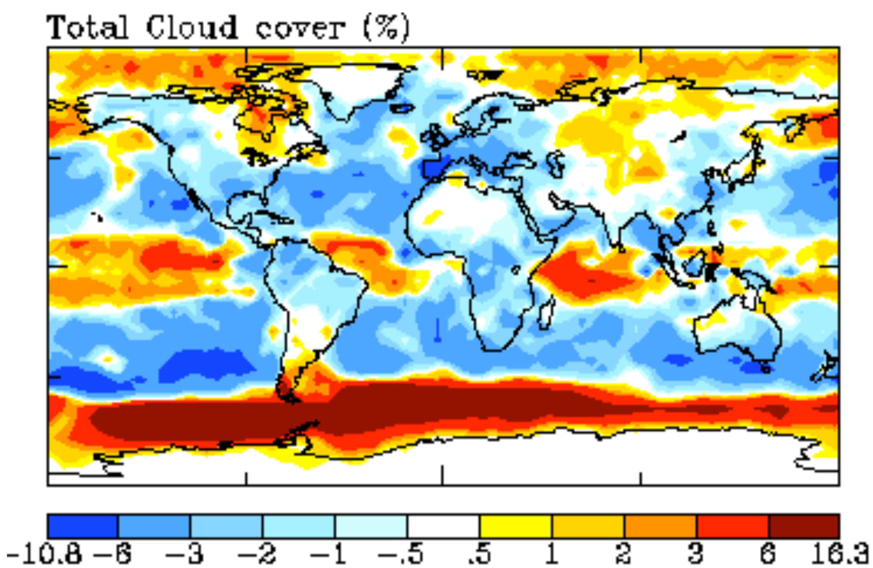


Future Climate : 2030 - PD

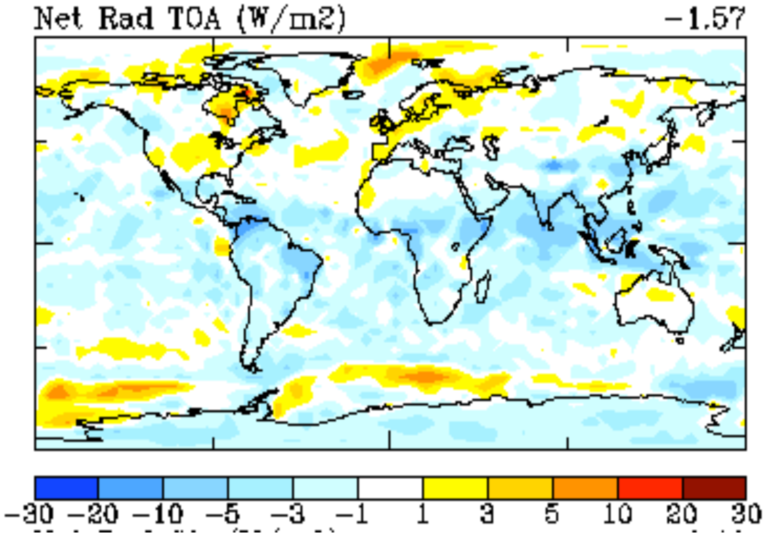
Indirect effect = — 0.64 W m^{-2}



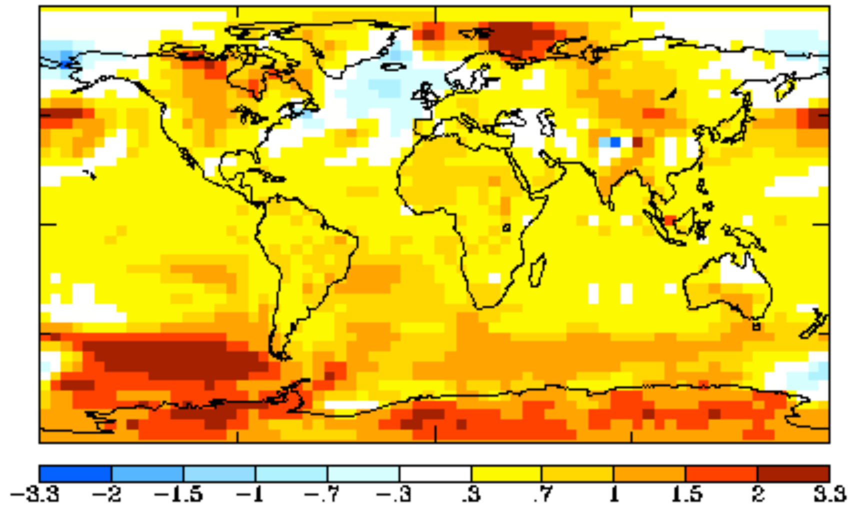


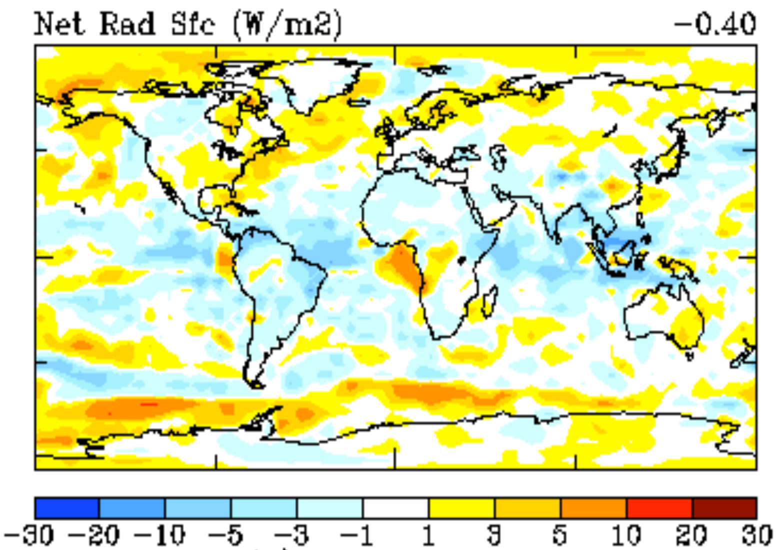


Future Climate : 2030 - PD

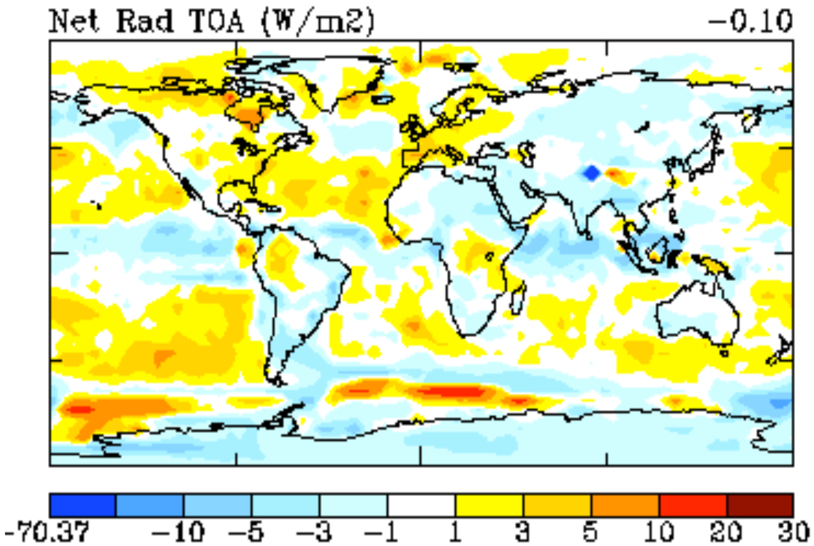


SAT change for 2030's=0.7C

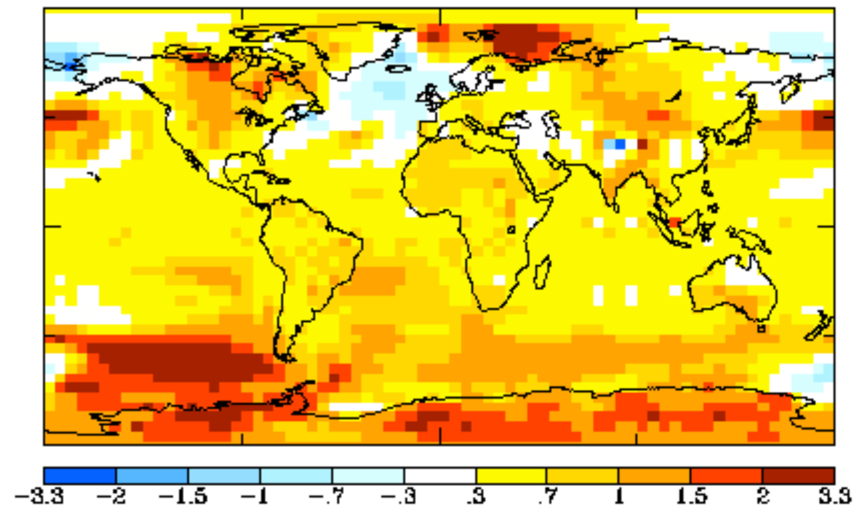


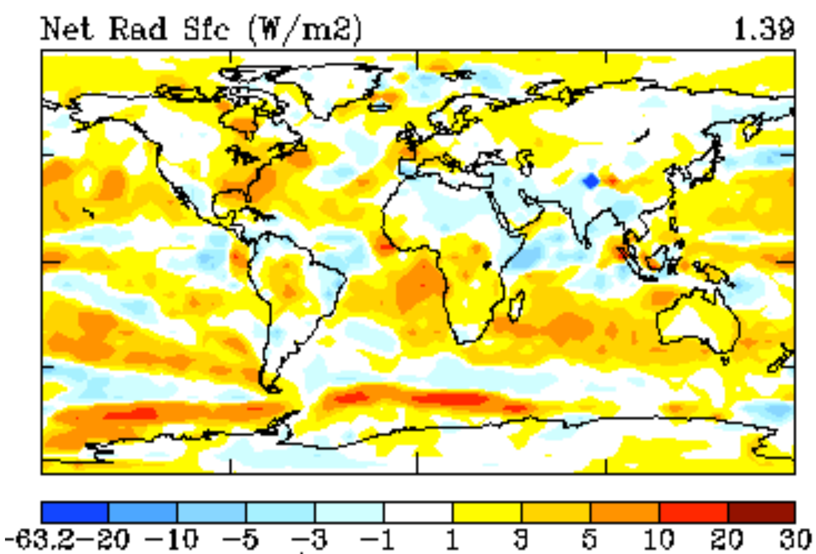


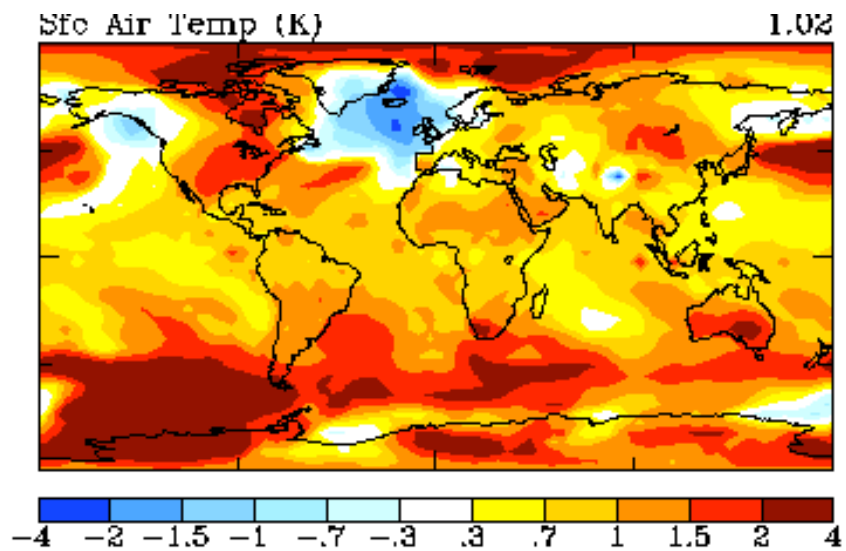
Future Climate -Slab Ocn: 2030 - PD



SAT change for 2030's=0.7C

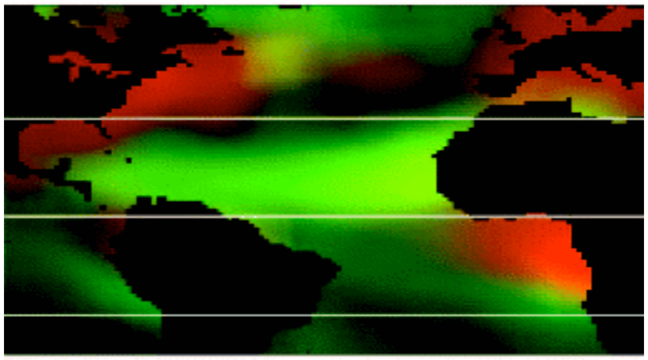




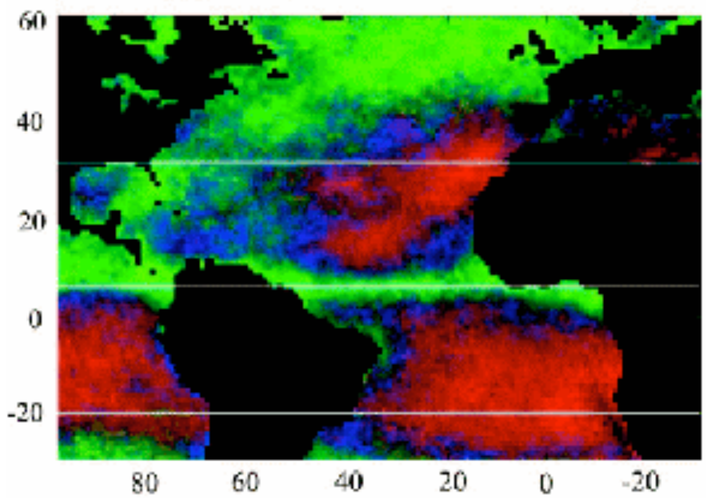


MODIS Detection of Aerosols and Clouds

Aerosol number and type



Cloud coverage



Based on Kaufman et al. 2005, PNAS

<u>SPECIFICS</u>:

Atlantic Ocean Region

Daily 1° June-July-August 2002

Shallow water clouds

(Cloud top pressure > 640hPa)

Partial cloud covered pixels

Both aerosols and cloud properties retrieved simultaneously

Aerosol optical depth < 0.6

Cloud optical depth > 3

Simulations

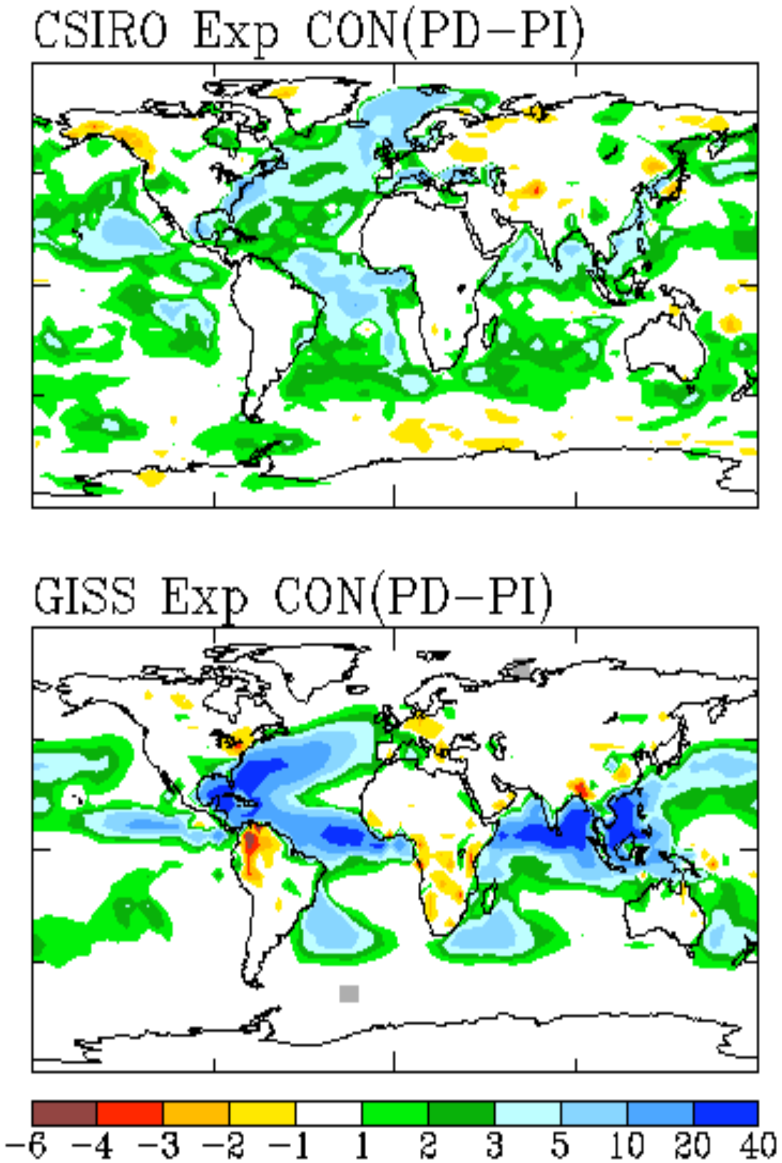
Process parameterizations and Dynamics

Exp N: **Std GISS simulation with aerosol direct effects only**

Exp C: **Like Exp N but includes aerosol effects on warm stratus and cumulus clouds**

Exp CN: **Like Exp C but GCM winds are nudged to reanalysis winds**

Aerosol-Cumulus Interactions



Convective systems linked to large-scale stratiform cloud systems via detrained water & moisture.

Detrained condensate (mg m^{-3}) for present day (PD) and pre-industrial (PI) aerosol emissions at 850 hPa (level of maximum detrainment) for CSIRO and GISS.

Results are for aerosol effects on cumulus clouds only.

(Menon and Rotstayn, 2006, Clim. Dyn.)

Simulation Specifics

Semi-prognostic CDNC : based on aerosol, cloud cover and turbulence
Includes dispersion effects on cld droplet radius (Liu et al. 2005).

CDNC for stratus clouds based from *Gultepe and Isaac* (*1999, I J Clim.*).

$$CDNC_{Land} = 298 \times \log_{10} Na_{Land} - 595$$

$$CDNC_{Ocean} = 162 \times \log_{10} Na_{Ocean} - 273$$

Nal and Nao : aerosol number for land or ocean, respectively.
Autoconversion scheme of Beheng (1994)

(Menon and Del Genio, 2006)

CDNC for convective clouds based from *Segal et al.* (*2004, QJRMS*).

$$CDNC_{Land} = 174.8 + 1.51 N_{al}^{0.886}$$

$$CDNC_{Ocean} = -29.6 + 4.92 N_{ao}^{0.694}$$

Autoconversion scheme converts condensate to precip. if liquid water > value for droplet size =14 µm. (Based on Rotstayn and Liu, 2005)

(Described in Menon and Rotstayn, 2006, Clim Dyn)

Methodology

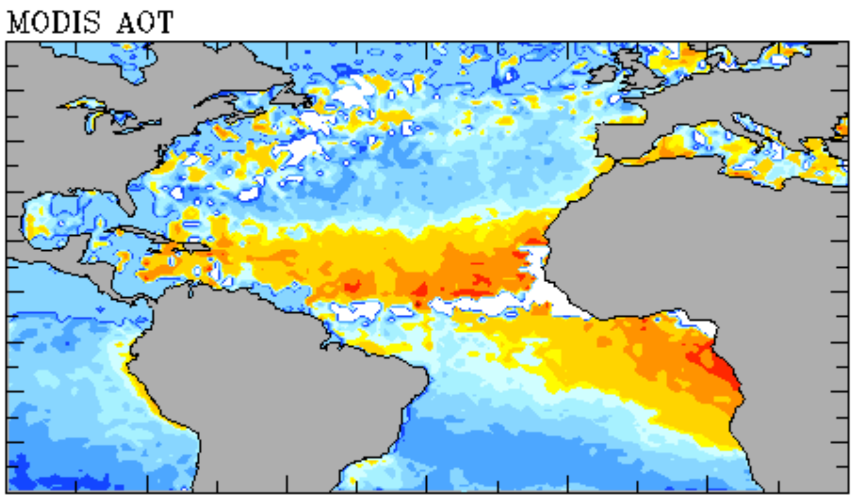
We examine 7 variables from MODIS and GCM to detect signatures of aerosol-cloud interactions.

- Aerosol Optical Thickness -AOT
- Cloud Top Temperature (K) -CTT
- Cloud Top Pressure (hPa) -CTP
- Cloud Fraction
- Cloud Effective Radius (μm) - Reff
- Cloud Optical Thickness - COT
- *Water Path* ($g\ m^{-2}$)

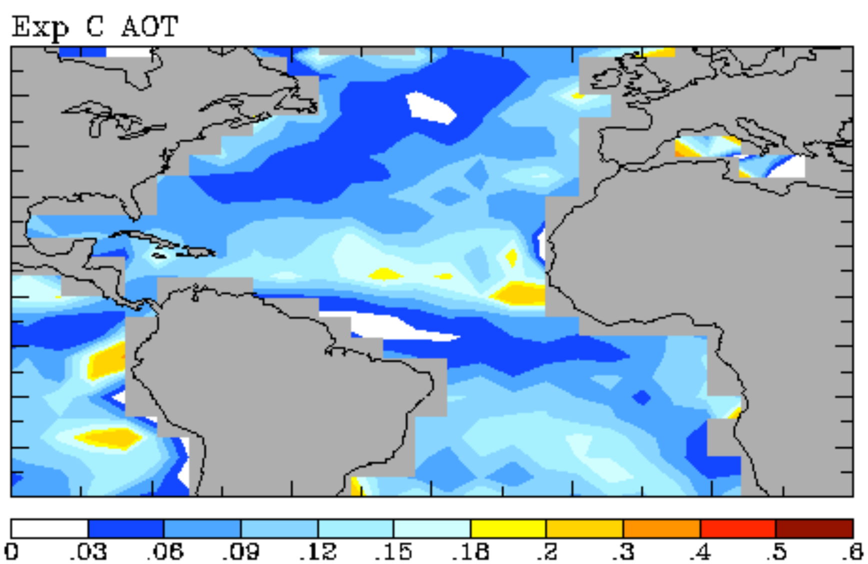
Additionally, we examine temperature, winds and vertical velocity fields from NCEP reanalysis and GCM.

GCM values are sampled at cloud top and are instantaneous daily values.

Aerosol optical thickness (AOT)



Satellite data (Total AOT at 0.55 μm) indicate presence of dust and biomass aerosols

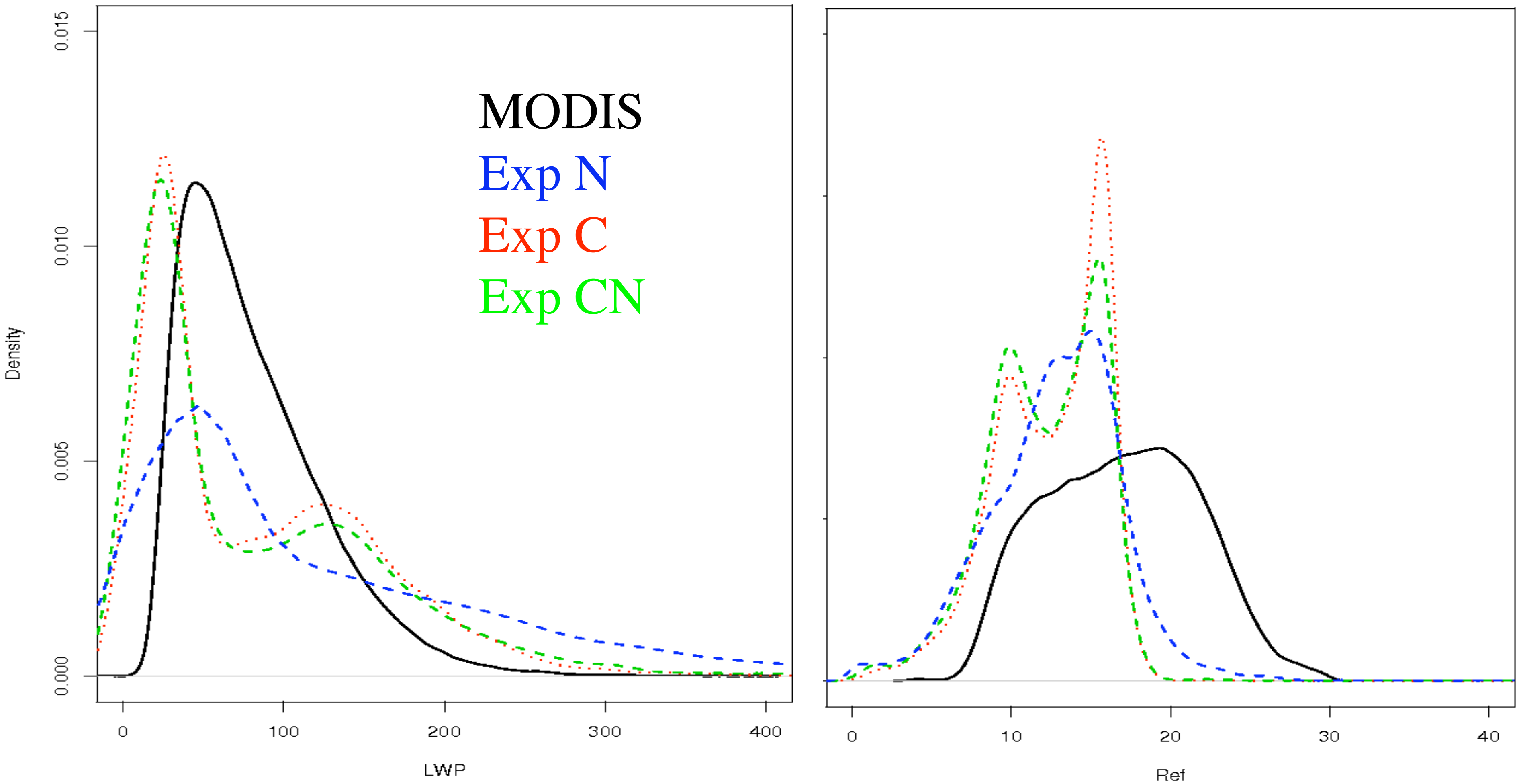


GCM AOT for clear-skies do not include dust aerosols that are in the 5-20N region.

Dust assumed to not affect cloud.

GCM low bias estimated to be a result of aerosol sizes assumed.
AOT is scaled by cloud fraction rather than values of 0 or 1.

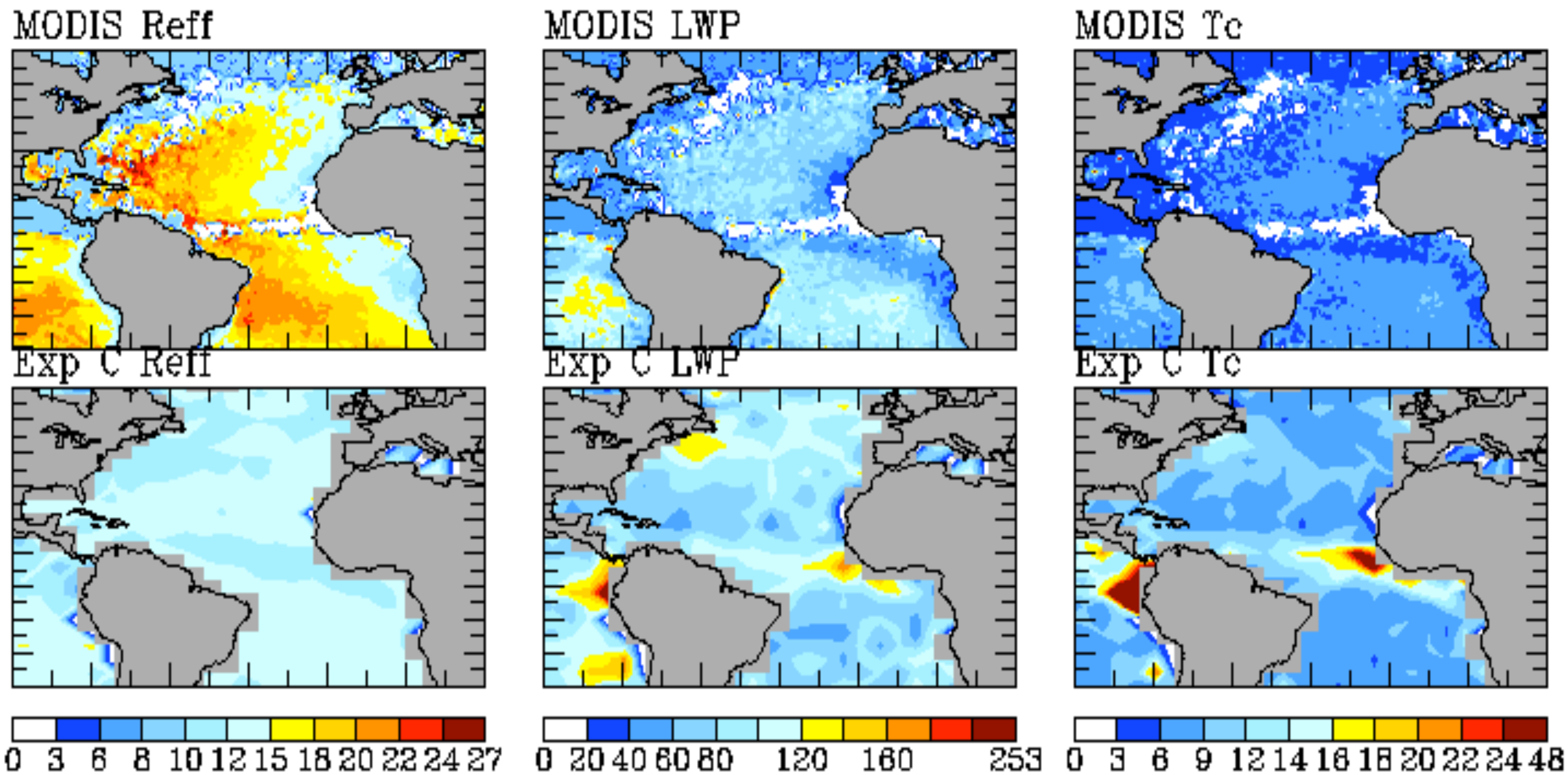
Density distribution of LWP and R_{eff}



LWP (gm^{-2})

Reff (μm)

Mean values for Reff, LWP and Cloud Optical Depth

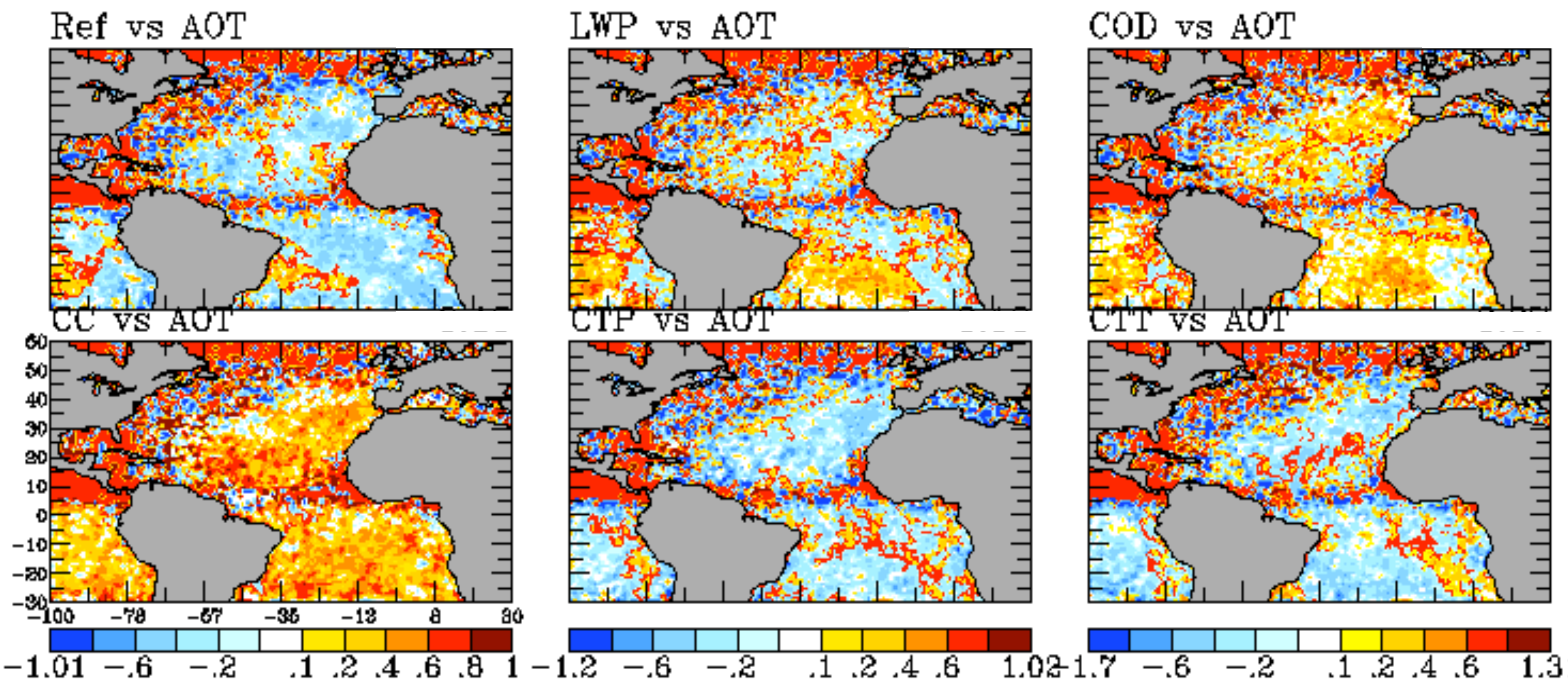


Mean values

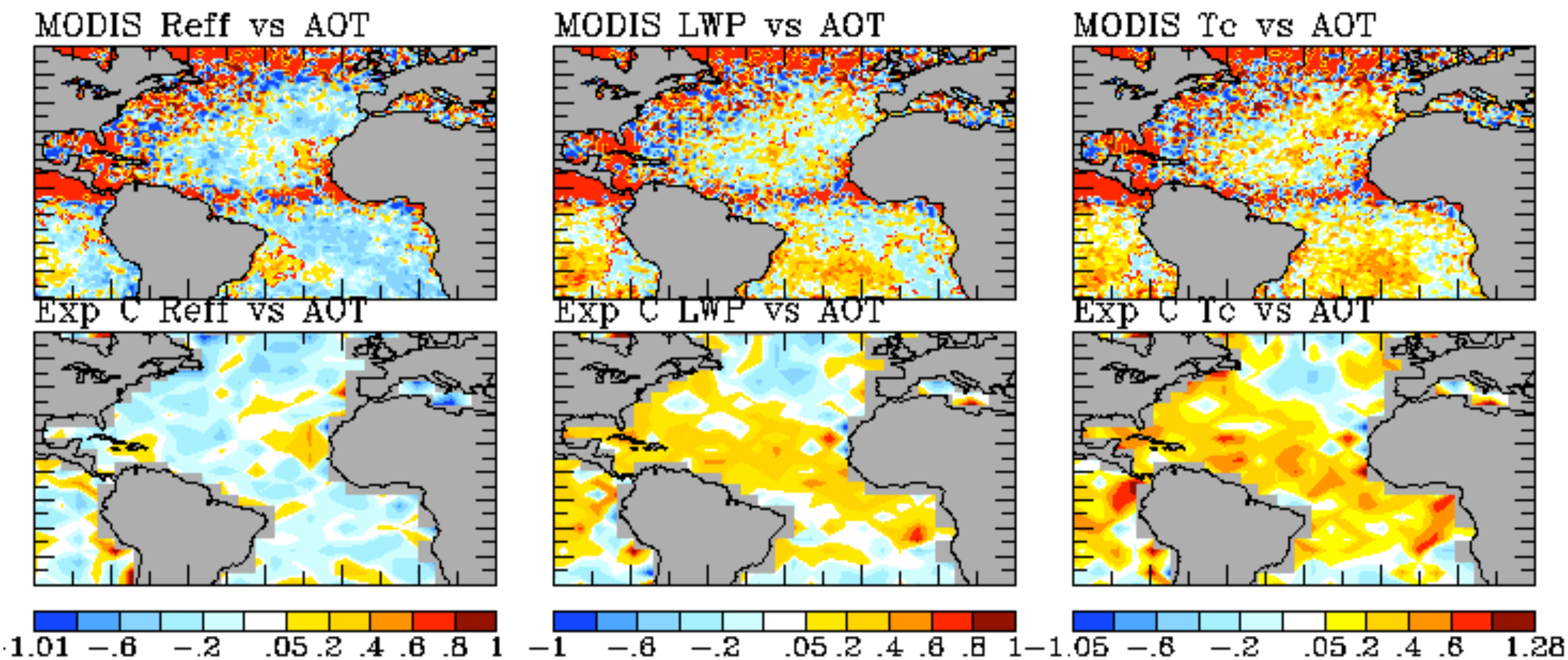
Mean	MODIS	Exp N	Exp C	Exp CN
AOT	**0.15**	**0.092**	**0.0924**	**0.10**
Reff	**16.9**	**12.8**	**12.5**	**12.4**
LWP	**81.0**	**136.0**	**83.2**	**82.4**
CC	**0.48**	**0.44**	**0.45**	**0.44**
τ_c	**8.54**	**12.7**	**9.50**	**9.84**
CTT	287	289	289	289
CTP	855	896	894	897

Correlation coefficients

MODIS



Correlation coefficients for variables



Slopes - Strength of the indirect effect

Slopes for log-linear relationships.

Slope	MODIS	Exp N	Exp C	Exp CN
R_{eff} -AOT	-2.2	0.15	-0.26	-0.31
LWP-AOT	-6.5*	1.42	-1.58	-3.15
CC-AOT	11.4	-5.33 1.10	-5.19 1.12	-6.41 0.61
τ_c -AOT	0.31	0.58	0.85	0.89
SWTOA-AOT	NA	-0.58	-0.91	-0.69
CDNC-AOT	NA	0.70	5.85	6.34

Clean and Polluted Conditions

AOT < 0.06

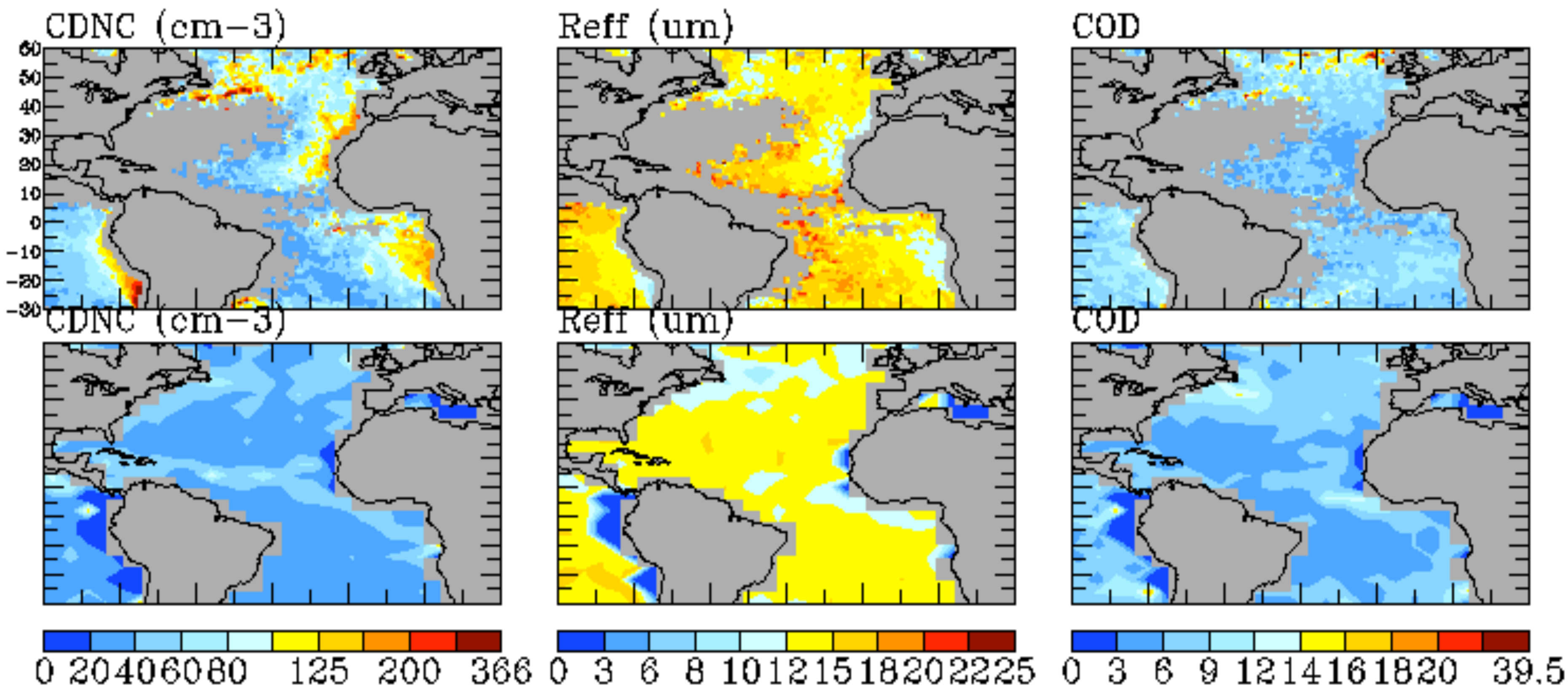
	AOT	Reff	LWP	COD	CC	SWT	CDNC
MOD	0.041	18.7	79.7	6.34	33.3	-	-
ExpN	0.027	12.6	133	12.3	47.0+7.78	-1.97	63
ExpC	0.026	12.7	82.8	8.72	48.2+7.83	-1.48	39
ExpCN	0.029	12.4	83.8	9.05	48.5+8.68	-2.42	43

AOT > 0.06

	AOT	Reff	LWP	COD	CC	SWT	CDNC
MOD	0.173	16.6	81.3	7.16	51.2	-	-
ExpN	0.186	13.0	140	13.4	38.8+6.26	-2.93	64
ExpC	0.179	12.4	83.6	10.6	39.9+6.22	-3.87	49
ExpCN	0.186	11.9	80.8	10.7	38.2+6.47	-3.59	56

Can AMSR be used to constrain LWP and CDNC?

Mean values for CDNC, Reff, and Cld Optical Depth

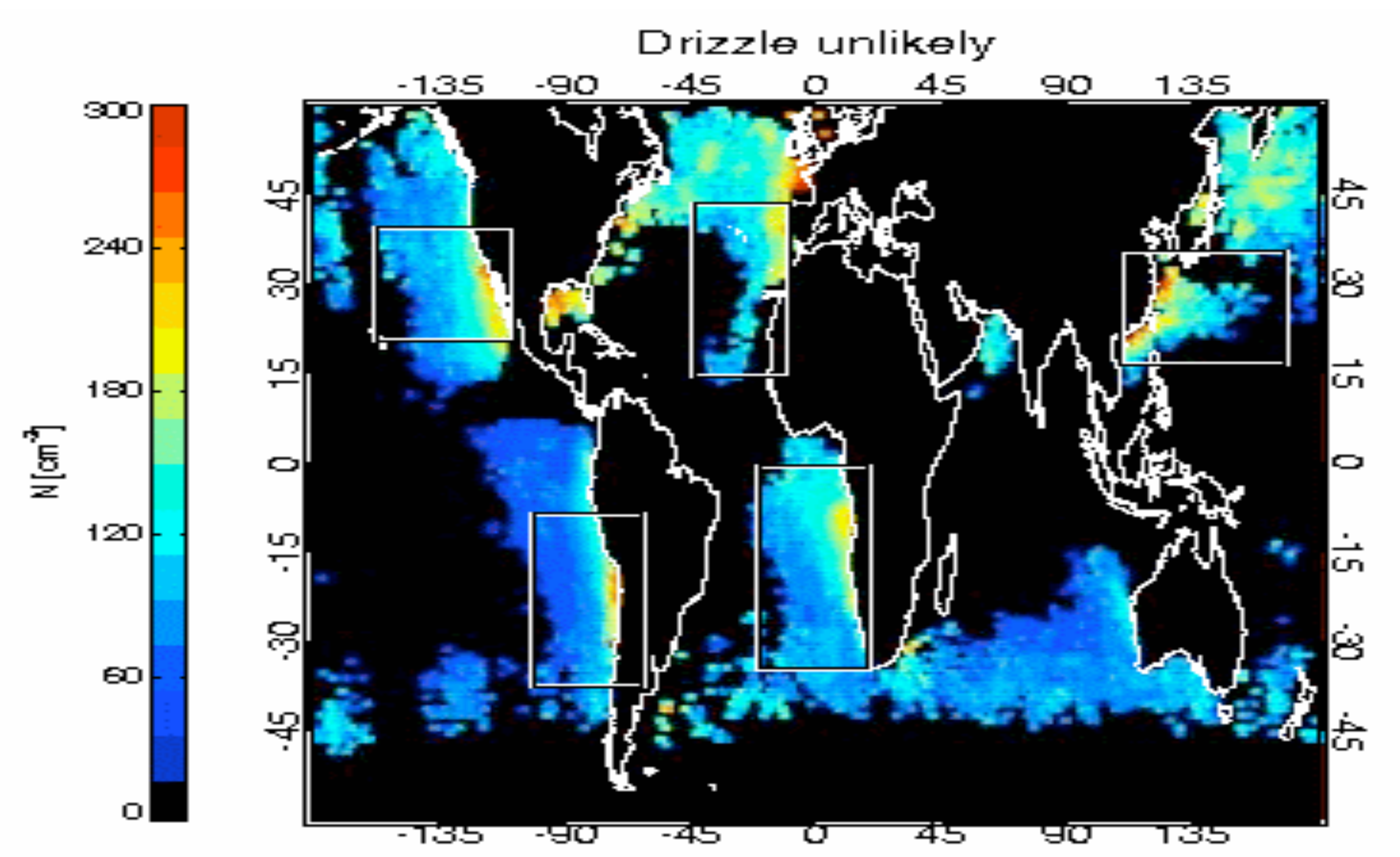


Top = MODIS-Aqua
Bottom = Exp C

CDNC and H = f(LWP, CC and COD)
H = f(LWP, condensation rate)
CDNC = f(COD, LWP, CC, condensation rate)
(Bennartz, 2006, JGR)

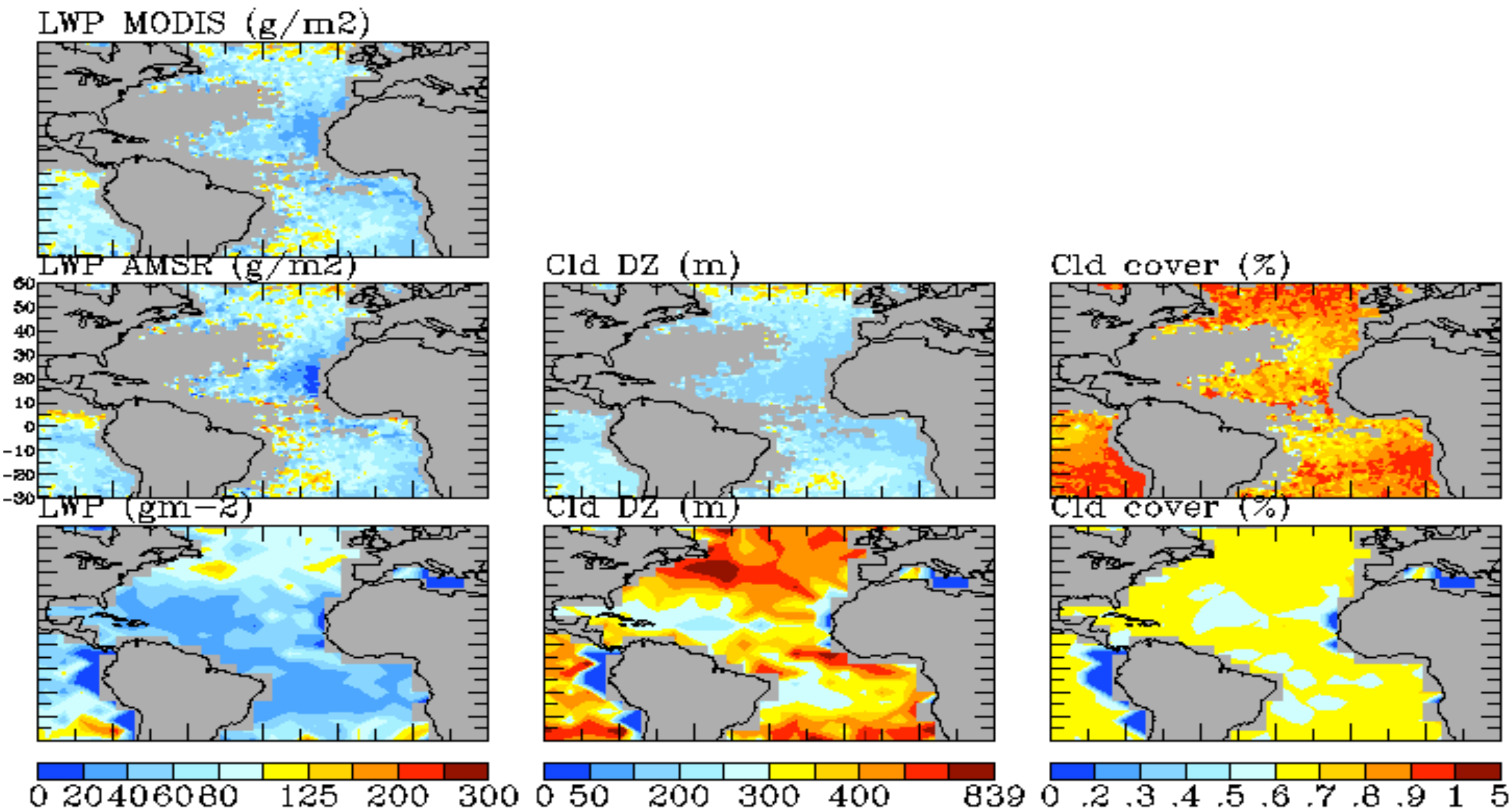
Can AMSR be used to constrain LWP and CDNC?

Mean CDNC for 2 1/2 yrs for all stratiform clouds



(Bennartz, 2006, JGR)

Mean values for LWP, Cloud depth and Cloud cover

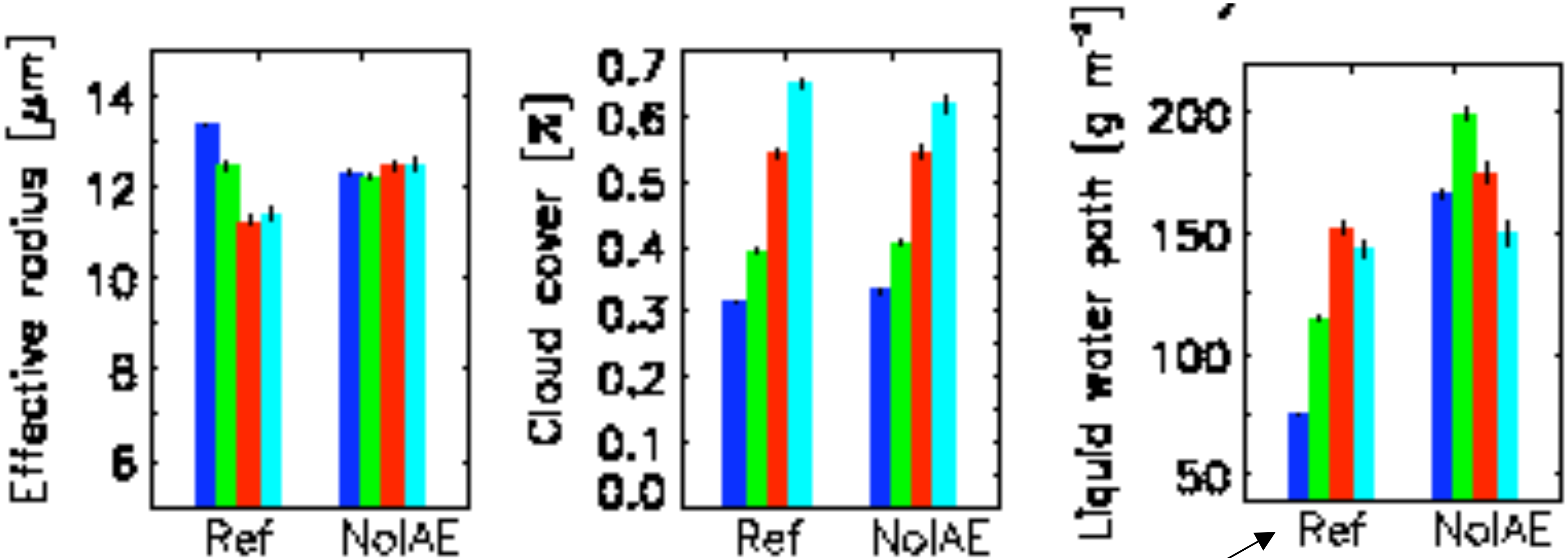


Top and middle = MODIS-Aqua and AMSR-E
Bottom = Exp C

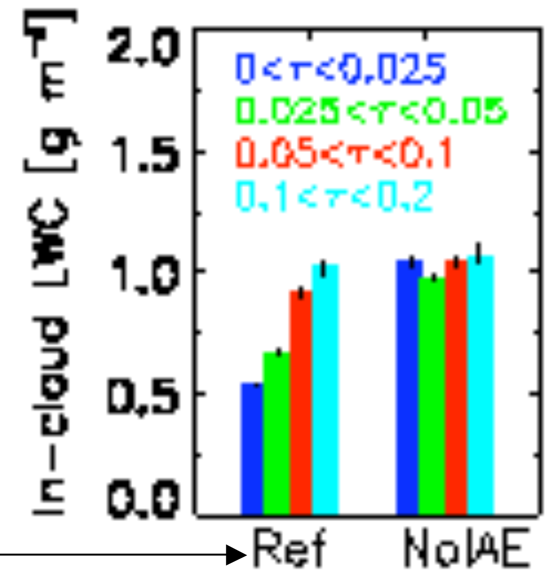
Mean values for AMSR and MODIS

Mean	MODIS	AMSR	Exp N	Exp C
CDNC	**79**		**63**	**43**
Reff	**14.3**		**12.6**	**12.2**
LWP	**69.8**	**69.5**	**125**	**75.9**
τ_c	**8.59**		**12.3**	**9.21**
Cld DZ	**219**		**564**	**560**

Strength of the indirect effect

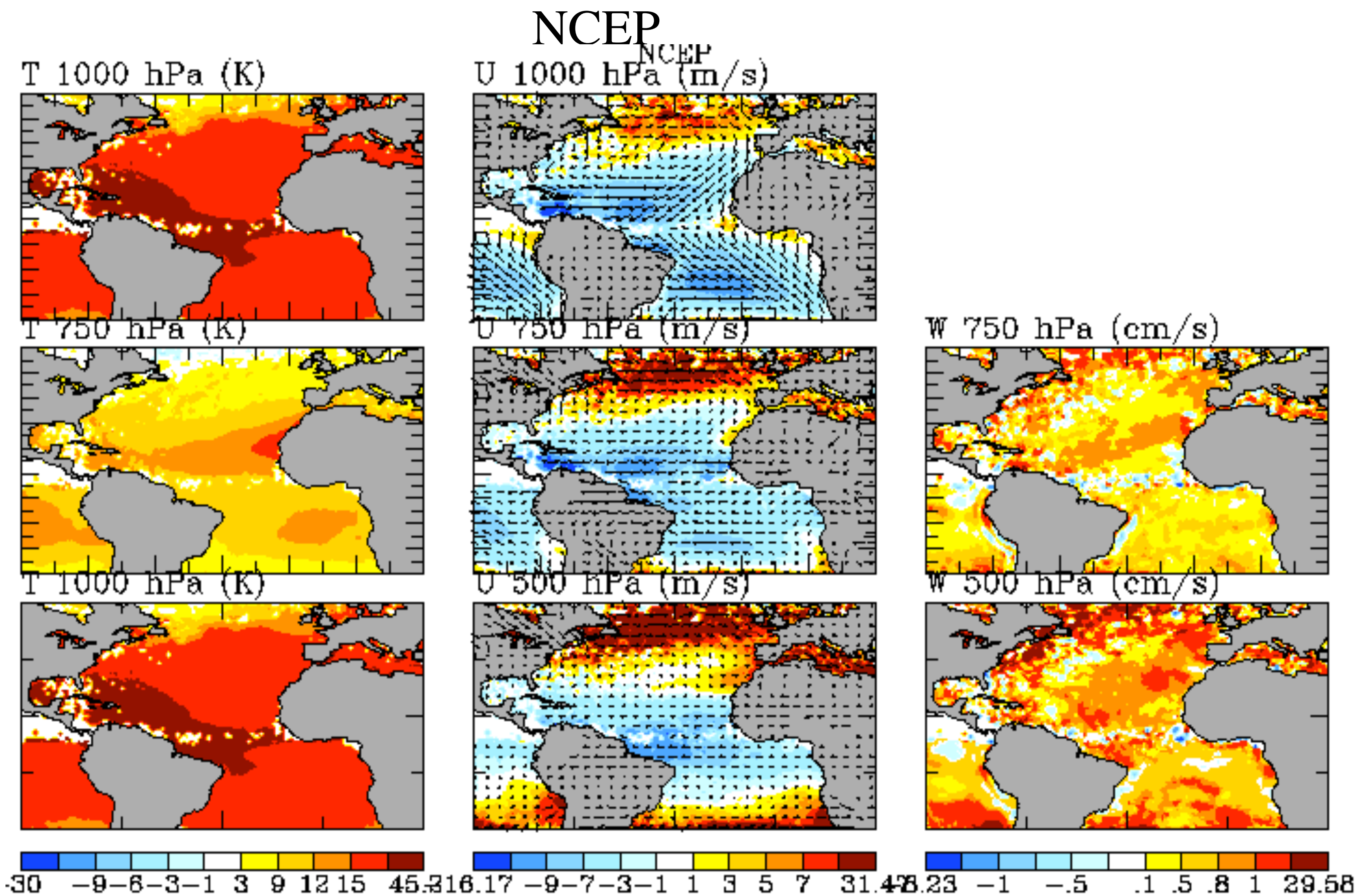


With aerosol-cloud effects

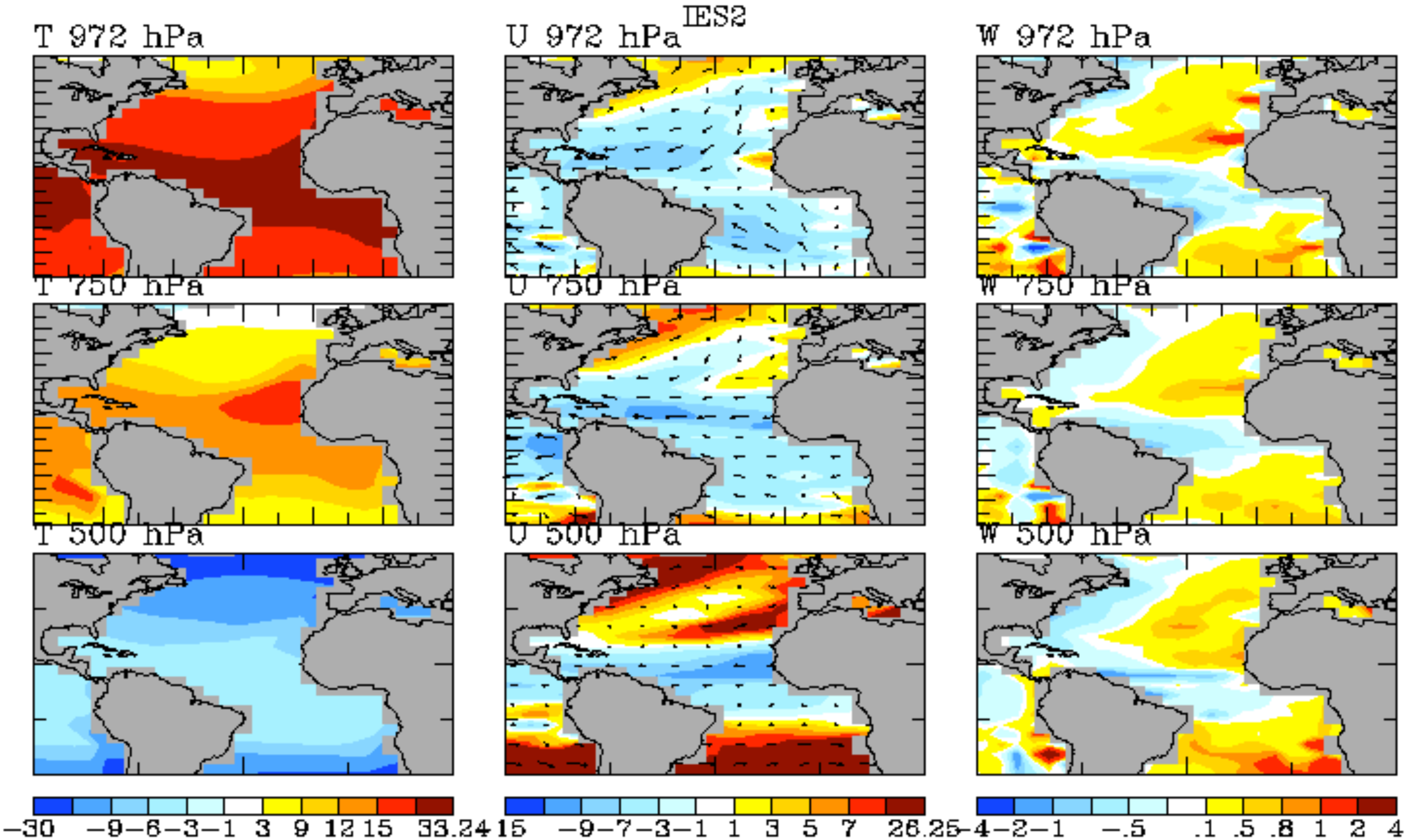


(Lohmann et al., 2006, GRL)

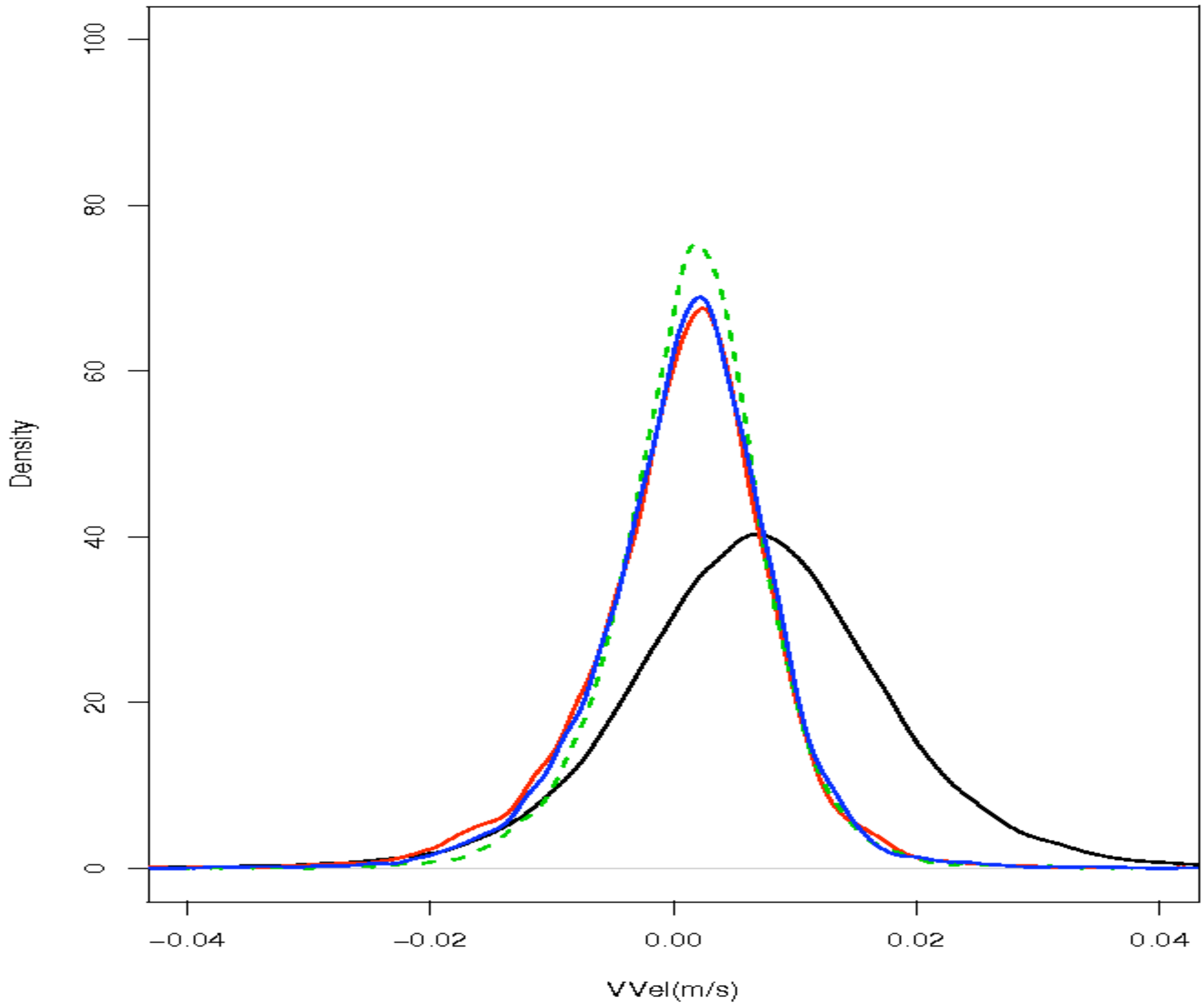
Meteorological fields



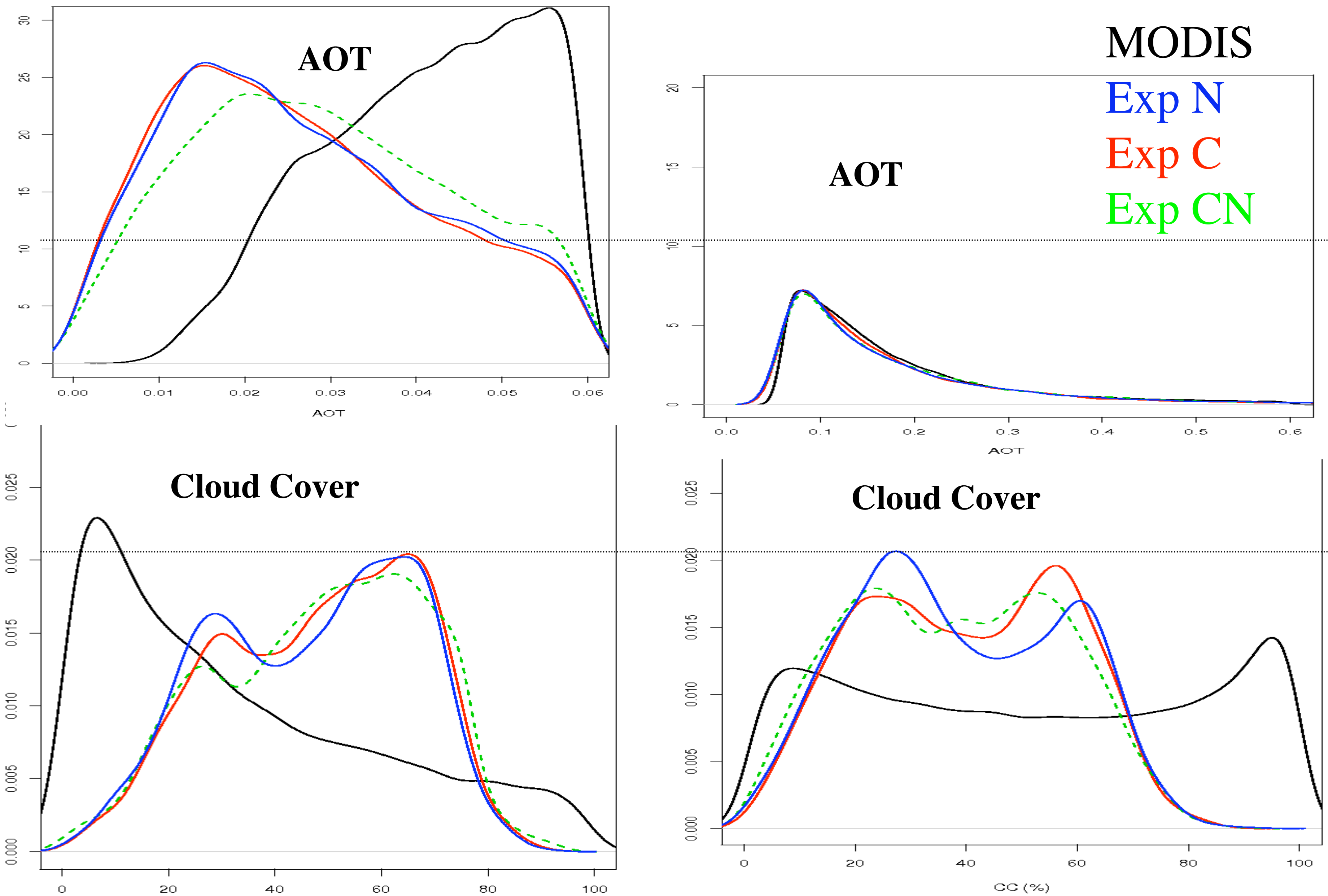
Meteorological fields for Exp C



Meteorological fields: Vertical velocity

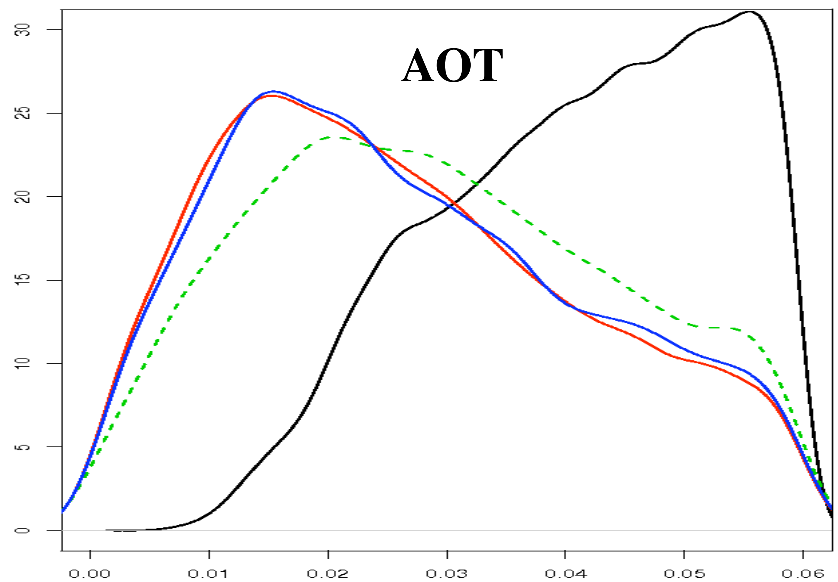


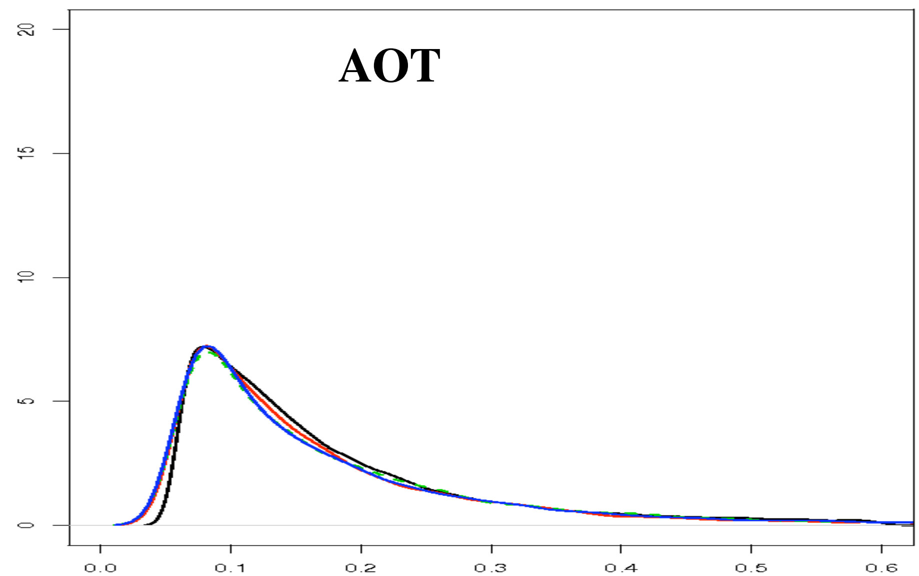
Low AOT / High AOT

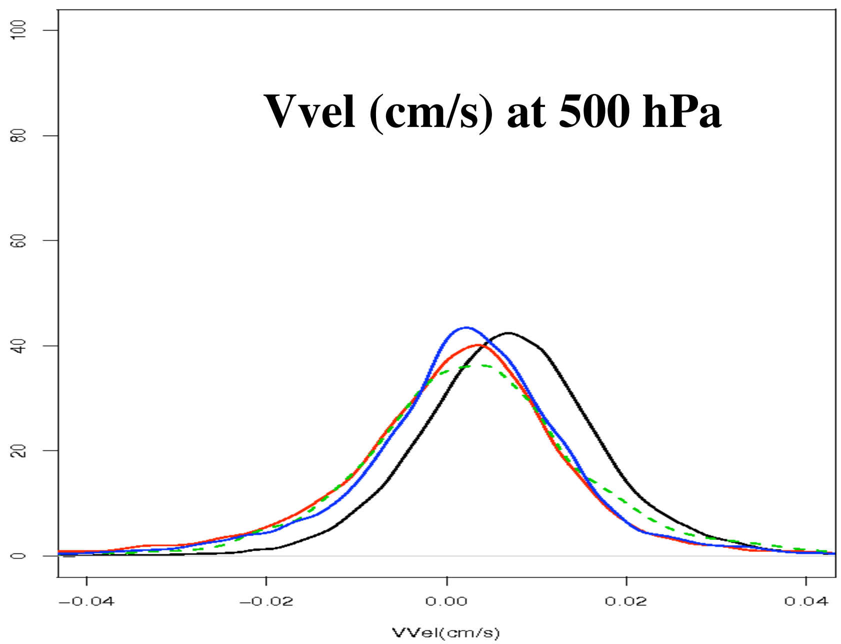


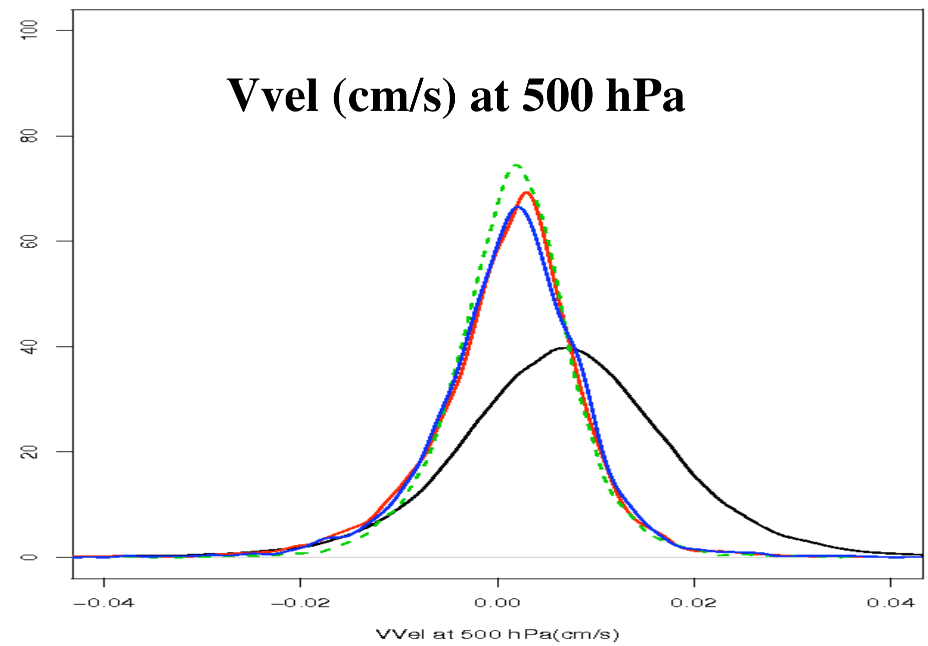
Low AOT

High AOT









Summary

MODIS data: **Negative/Positive corr. bet. Reff/CC and AOT.**
LWP-AOT variations indicate a decrease in LWP (weak) with increasing AOT.

For GCM:

- **Small decrease in Reff with increasing aerosols for aerosol indirect effect.**
- **Increase in cloud optical depth in GCM more pronounced than in MODIS;**
- **Some of the increase (including cloud cover) are from dynamical changes.**

Somewhat similar to results from Lohmann et al. (2006), Storelvmo et al. (2006).

From NCEP and MODIS, subsidence did not play an important role in affecting AOT.
In areas of subsidence, cloud cover increases with AOT.

50% of GCM changes are from aerosol-induced microphysical changes (τ_c-AOT slopes).

Indirect effect may not be overestimated.