Response of tropical convection to the presence of Saharan dust over the Atlantic Ocean during summer 2013

Lars Klüser, Thomas Popp

German Aerospace Center (DLR)

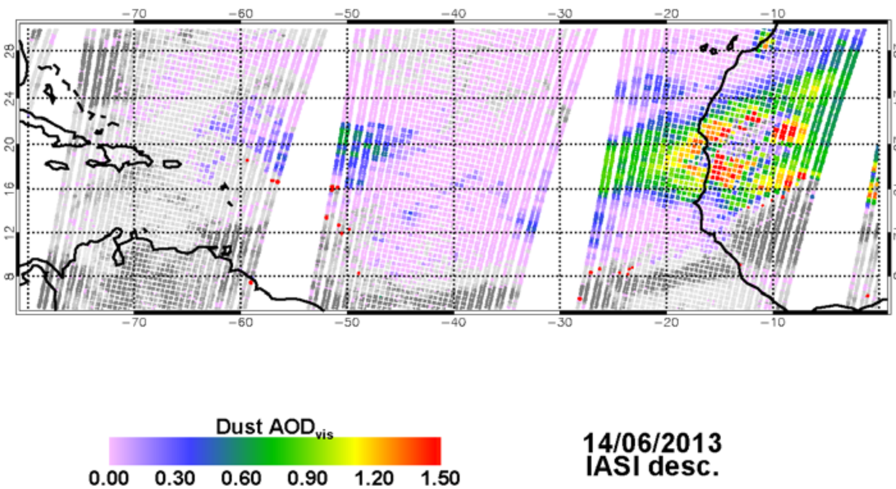
Earth Observation Center (EOC)

German Remote Sensing Datacenter (DFD)

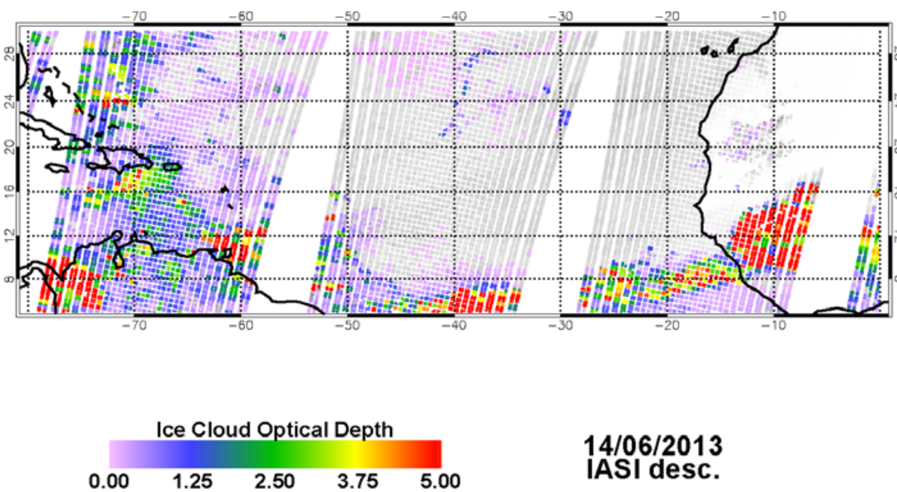
Data

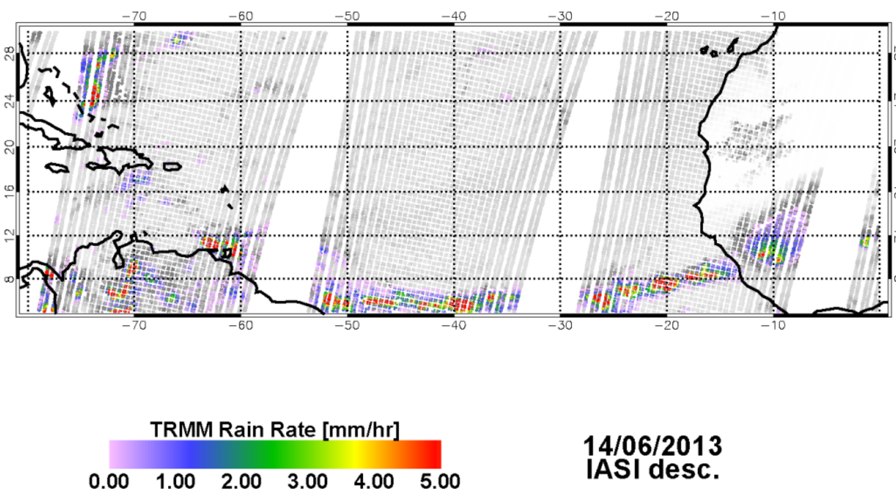
- Dust and cloud observations from IASI (hyperspectral infrared sounder on Metop) with the *Infrared Mineral Aerosol Retrieval Scheme* IMARS v5.0 (*Klüser et al.*, 2015)
- Terrestrial Infrared (TIR) observations: independent from solar illumination and thus two overpasses / day from Metop-A.
- IMARS ice clouds: COD signal in the TIR saturates at approximately 5-10 and thus causes an upper limit for COD and IWP in IMARS retrievals.
- Co-registrated precipitation assessment from TRMM (3B42: 0.25 degree, 3hourly, based on microwave and TIR).
- No simultaneous dust and cloud observation in the same pixel: Cloud-impacting dust levels are assumed from averaging dust observations inside the dust correlation length (varying over the domain).
- Analysis example for the Tropical Atlantic Ocean domain (10^{o}-80^{o} W / 5^{o}-30^{o} N) for Summer 2013 (June, July, August).

IMARS + TRMM data example: 14/06/2013 daytime

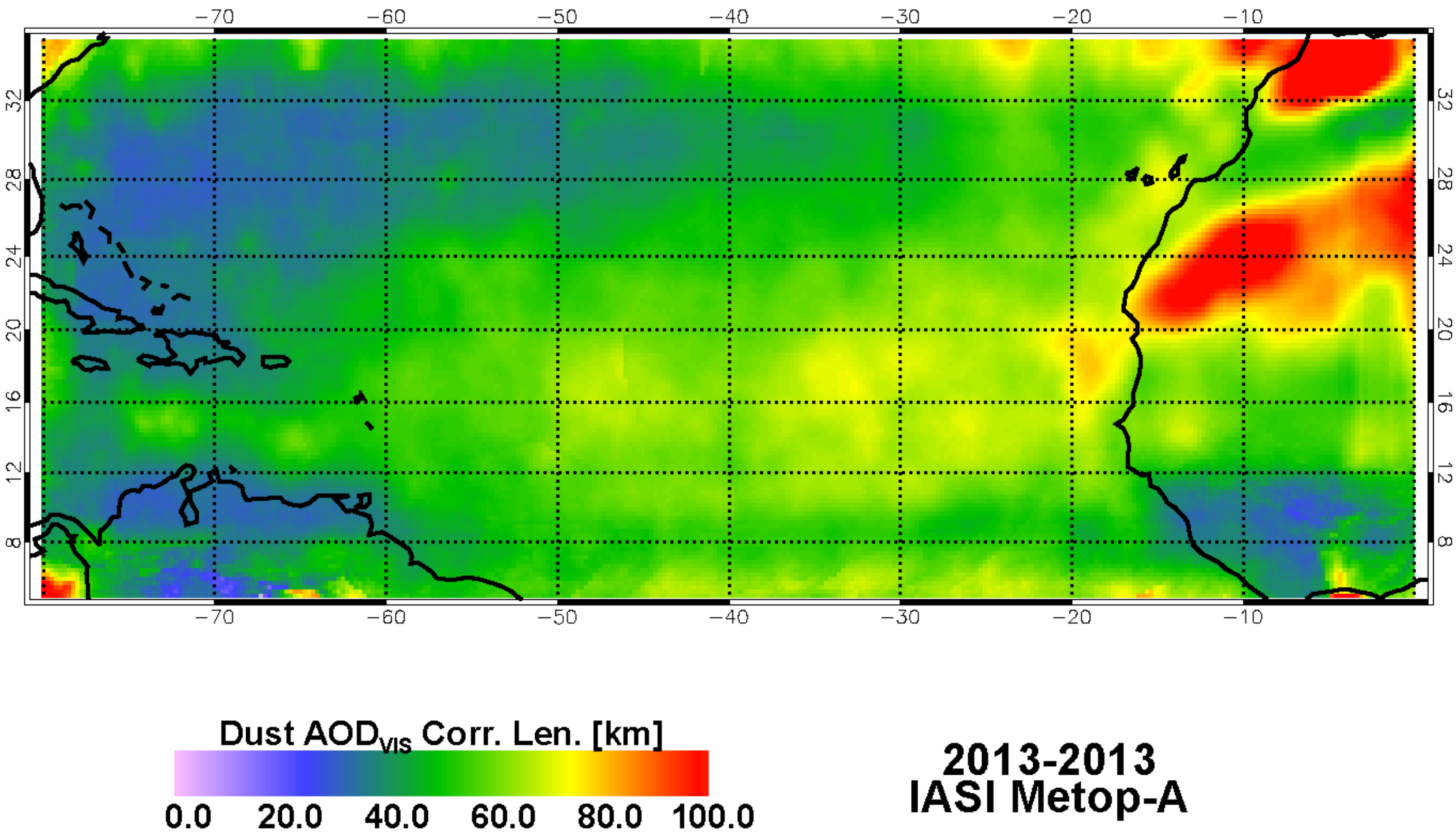


- IMARS dust AOD and cloud properties in sensor projection (twice daily).
- TRMM rain rates mapped to IASI projection and accounted for only if COD_{IASI}>0.
- 3-hourly Rain Rates around individual IASI observations.



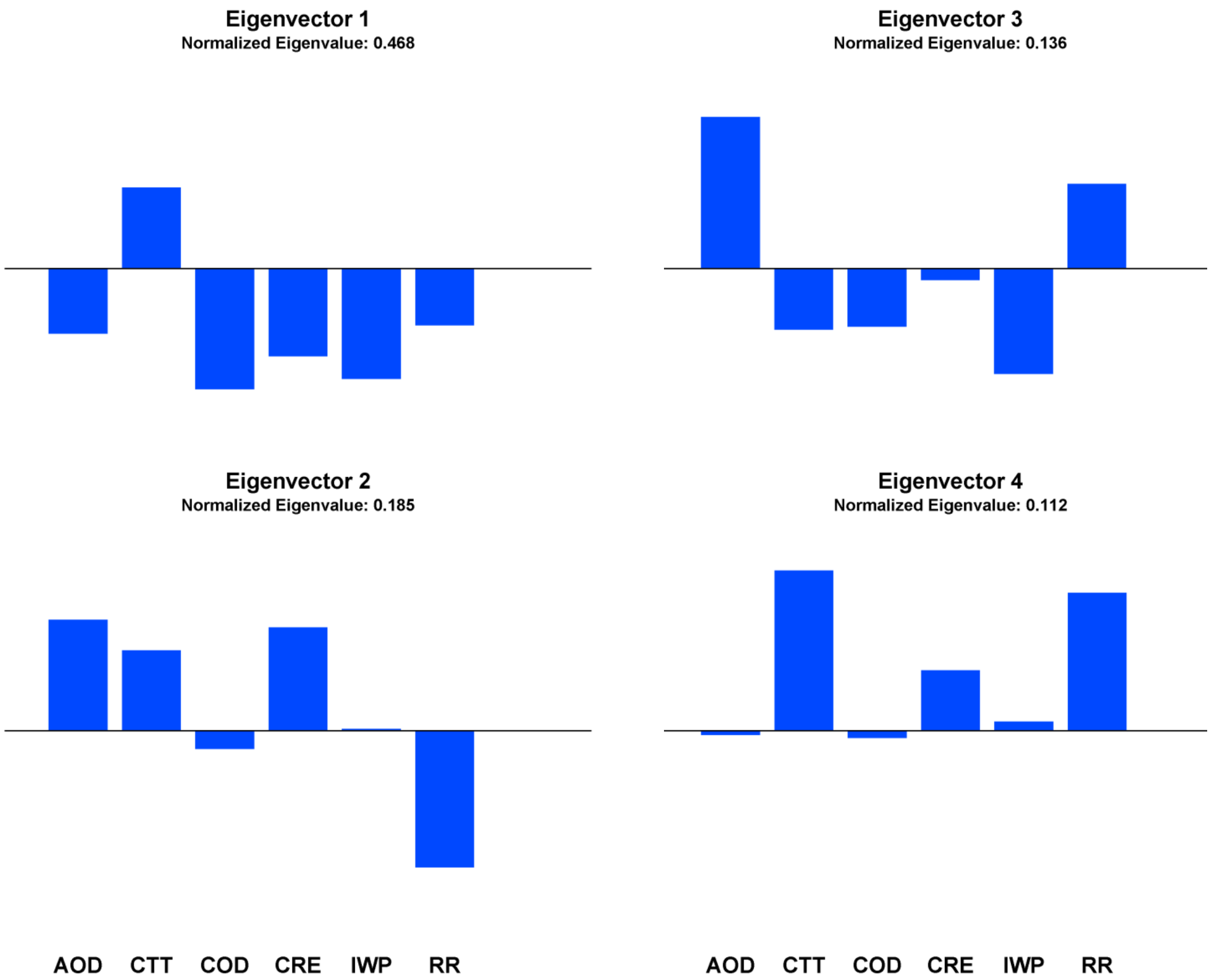


Dust AOD spatial correlation length in the tropical Atlantic Ocean



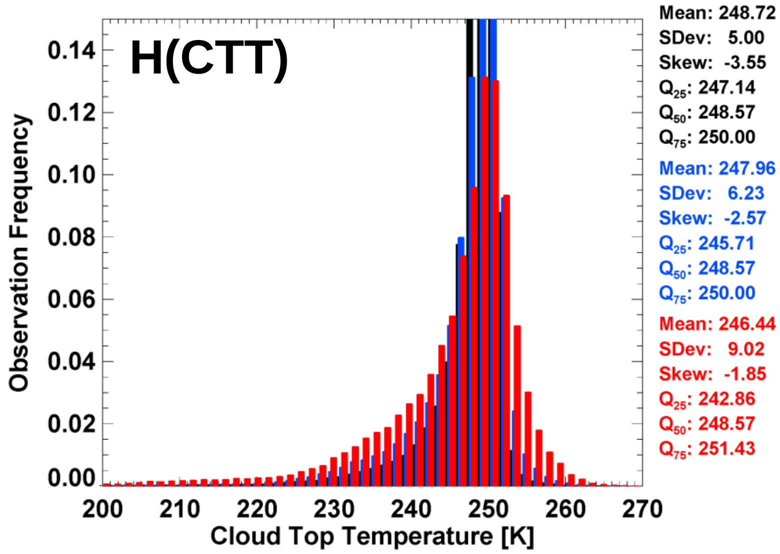
- Spatial correlation length describes statistical representativity of an observation.
- Calculated as in *Schepanski et al.* (2015) from IASI for JJA 2013.

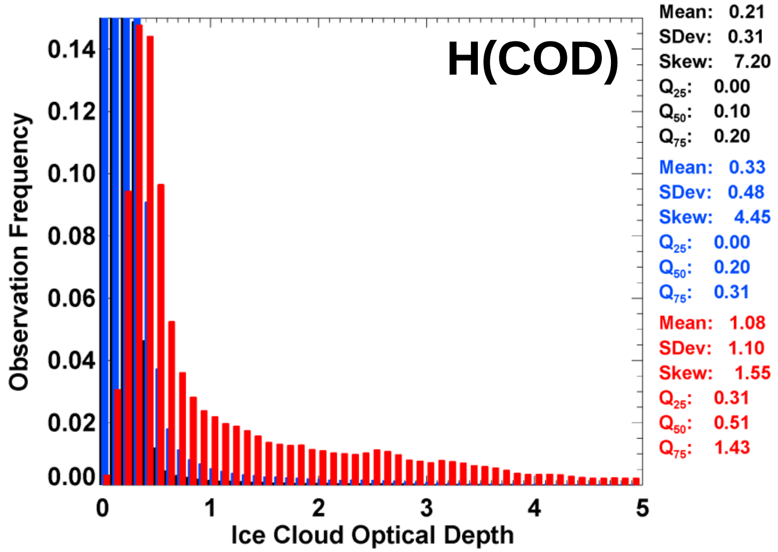
Principal Component Analysis of the Dust-Cloud-Precipitation system



- Leading two Eigenvectors account for more than 65% of the variability, the leading four for about 90%.
- Variability of dust AOD, cloud variables and precipitation highly connected.
- All cloud properties have as well strong co-variability with CTT.
- CTT, CRE and RR have mode almost independent from AOD (EV 4).

Data preparation for statistical assessment





- Histogram analysis for 3 dust classes (background, moderate and high) from IMARS:

  Background: $AOD_{0.55}<0.2$

  Moderate: $0.2<AOD_{0.55}<0.8$

  High: $0.8<AOD_{0.55}$

- AOD: avg. over dust correlation length
- Statistical correction for different meteorological conditions based on Bayes theorem and the CTT distribution of the observations.
- It is assumed that CTT sufficiently reflects differences in the meteorological state; other variables such as CWP or PWC can also be used.

Statistical assessment

Starting from Bayes theorem $P(x \mid y) = \dfrac{P(y \mid x) \cdot P(x)}{P(y)}$

x represents cloud observables (e.g. COD) and y the meteorological state.

Assumptions:

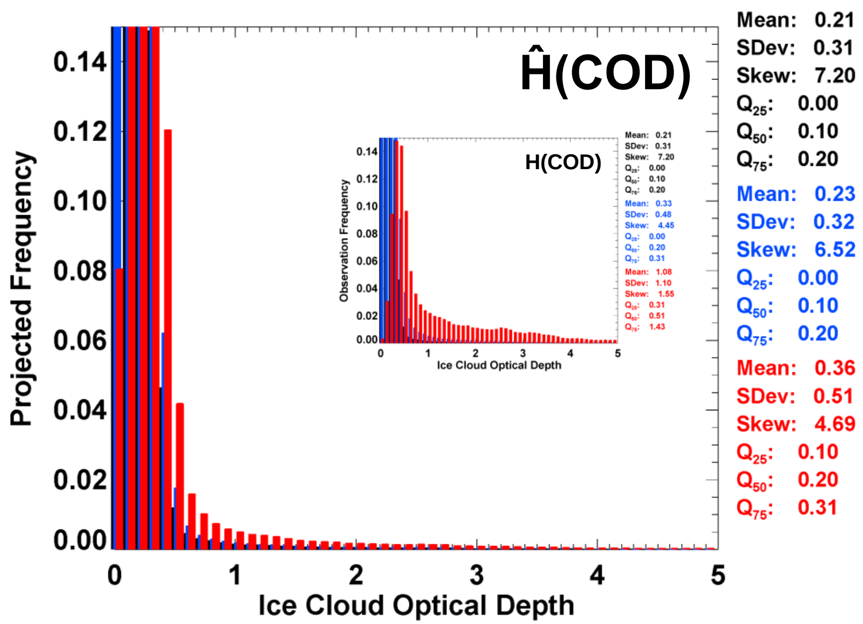
- probability interpretation of histogram densities H.
- CTT is a valid estimator for the meteorological state.
- The physical relationship between x and CTT depends on the meteorological state only (i.e. $P(y|x)$ is unique).

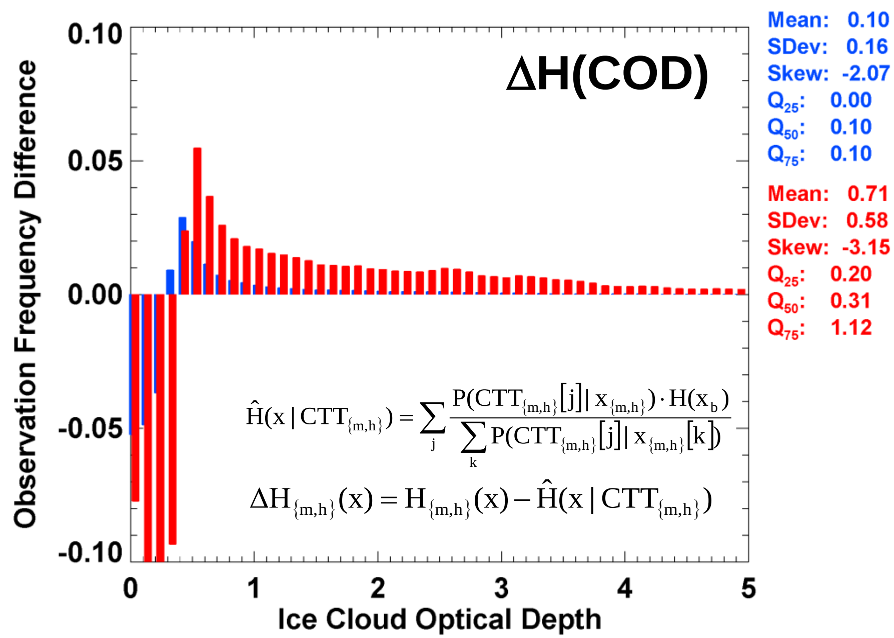
Consequently the probability $\hat{H}$ of a given value of x under meteorological state $y_{\{m,h\}}$ can be estimated from the background conditions $P(x_b)$, the meteorological state $P(y)=\Sigma_x P(y|x)$ and the CTT-x relationship $P(y|x)$.

The deviation of the true state from the estimator is assumed to represent the aerosol effect:

$$\hat{H}(x \mid CTT_{\{m,h\}}) = \sum_j \frac{P(CTT_{\{m,h\}}[j] \mid x_{\{m,h\}}) \cdot H(x_b)}{\sum_k P(CTT_{\{m,h\}}[j] \mid x_{\{m,h\}}[k])} \quad ; \quad \Delta H_{\{m,h\}}(x) = H_{\{m,h\}}(x) - \hat{H}(x \mid CTT_{\{m,h\}})$$

Assessment for Summer 2013 over the Tropical Atlantic Ocean





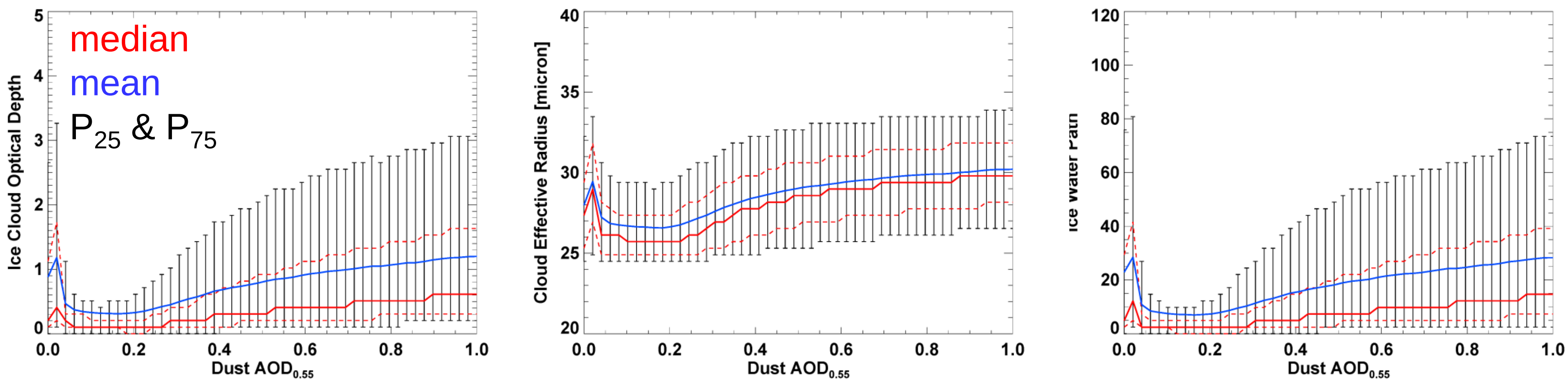
Projected pristine background Ĥ reflects sampling and meteorology (in terms of CTT distribution).

It is clearly evident that not all differences in the COD distribution are explained by CTT and sampling.

Integration of ΔH yields average dust effect.

Alongside calculated differences of Skewness and 25th, 50th, 75th percentiles moreover indicate an asymmetry of the dust impact in all variables.

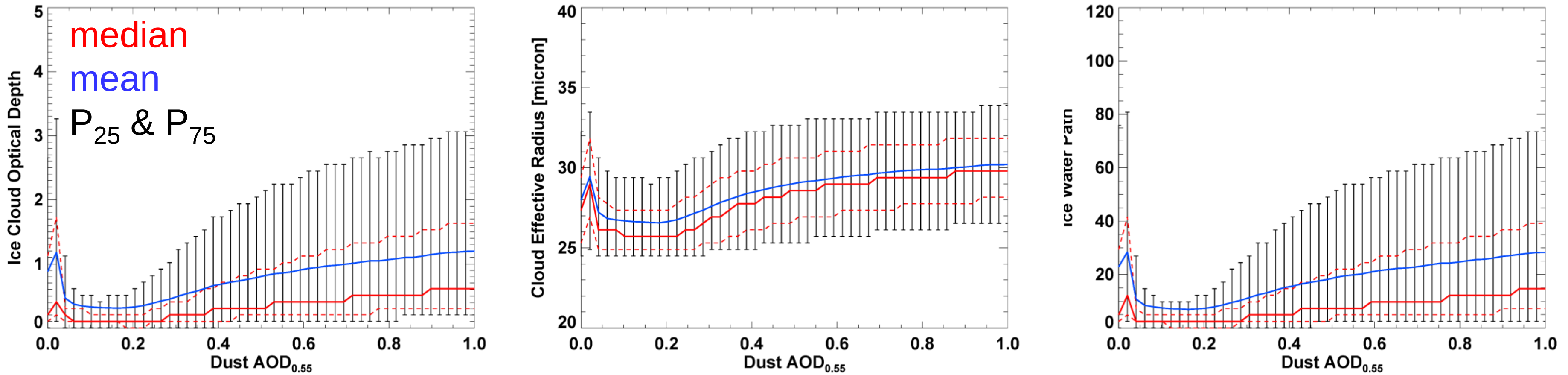
Results from IMARS Analysis



	ΔCOD	ΔR_{eff} [μm]	ΔIWP [g/m²]	ΔRR [mm/hr]
absolute deviation	+0.1±0.1 +0.7±0.1	+1.2±0.2 +2.7±0.2	+2.1±2.4 +17.5±2.4	+0.02±0.10 +0.03±0.10
relative deviation	+30.3±30.3 % +65.7±9.3 %	+4.3±0.7 % +8.7±0.6 %	+29.9±34.2 % +69.4±9.5 %	+22.2±111.1% +30.0±100.0%

- Numbers are similar for precipitating and non-precipitating clouds.
- The majority of changes happens at CTT between 240K and 260K.
- (Slight) Increase in TRMM rain rates appears to be related to increasing ice water amount as well as ice crystal size.

Results from IMARS Analysis constrained by IWP



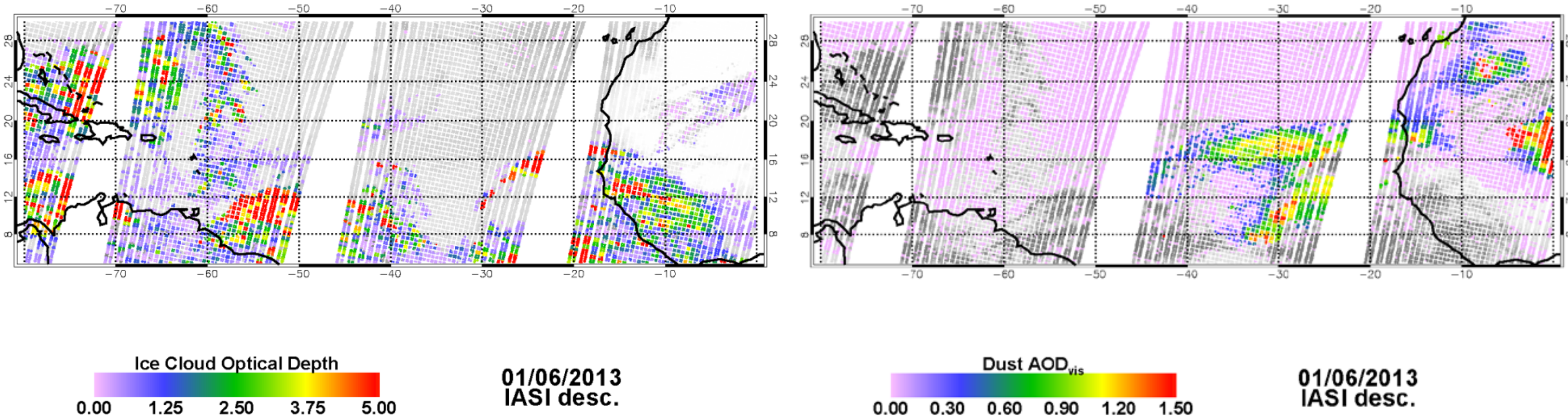
	ΔCOD	ΔR_{eff} [µm]	ΔCTT [K]	ΔRR [mm/hr]
absolute deviation	+0.07±0.1 +0.39±0.1	+1.2±0.2 +2.8±0.2	-0.3±1.4 -0.9±1.4	+0.02±0.10 +0.03±0.10
relative deviation	+35.0±50.0 % +73.6±18.9 %	+4.1±0.7 % +9.1±0.6 %	-0.1±0.6 % -0.4±0.6 %	+22.2±111.1% +30.0±100.0%

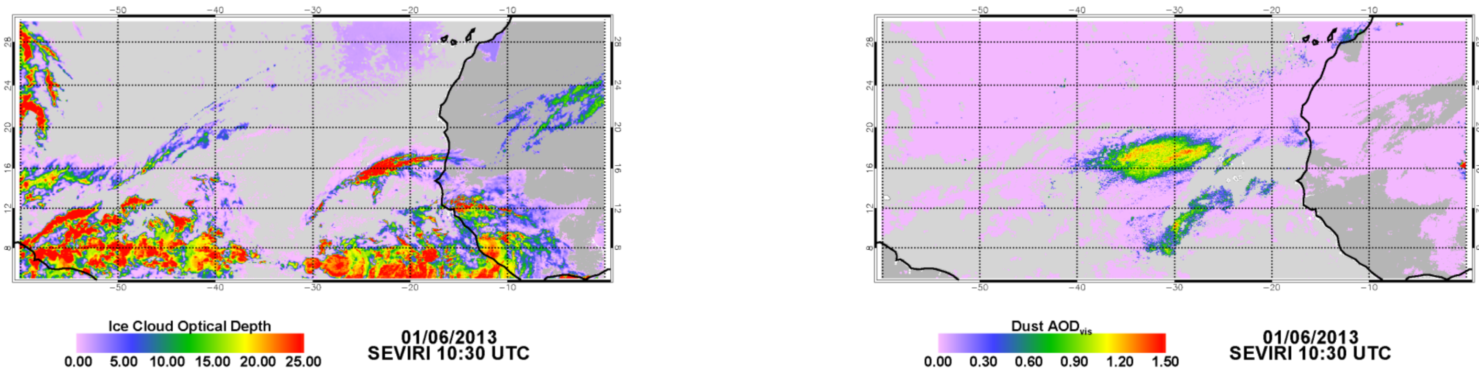
- If IWP is used as meteorological constraint, ΔCOD, ΔR_{eff} and ΔRR are similar to the CTT constraint, the response of CTT to dust presence is rather insignificant.

Outlook: One day analysis with SEVIRI

SEVIRI dust and cloud retrieval based on 3 TIR channels using Brightness Temperature Difference Distributions from WRF-RTTOV simulations.

Much better temporal and spatial resolution, less information on dust properties, limited field-of-view. Dust and cloud sensitivities are somewhat different for SEVIRI.





Summary and Outlook

- Statistical analysis of the response of ice cloud properties and precipitation to dust presence analyzed from combined satellite observations (IASI/SEVIRI and TRMM).
- Principal component analysis suggests widespread co-variability between dust AOD and cloud variables.
- Subdivision into three classes by IMARS dust AOD together with Bayesian statistics accounting for different meteorological states in the observations.
- Increase in R_{eff}, and IWP and to a lesser degree in COD and RR found for ice clouds from IASI under the influence of Saharan dust during summer.
- It is planned to use SEVIRI observations (similar retrieval scheme based on three TIR channels) for tracking individual tropical cloud systems / storms: temporal evolution of the ice cloud response to the encounter with Saharan dust during the lifetime of the system.