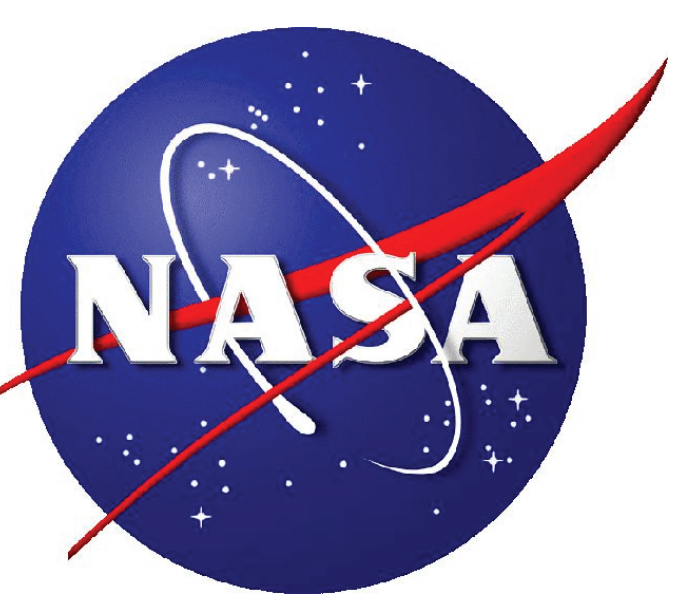


Tropical Three-dimensional Cloud Climatology during El Niño Events with CALIPSO Level-3 Cloud Products



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Abstract

A previous case study showed opposite cloud anomalies at high, middle and low altitude regions during a weak 2006/2007 El Niño and a moderate 2009/2010 El Niño. In this work, we use CALIPSO Level 3 (L3) Cloud Products to provide a comprehensive picture of cloud anomalies during all recent five El Niño events since 2006, with a particular focus on thin cirrus clouds at high altitudes, which are challenging for passive sensor detection algorithms. Specifically, the vertical cloud anomalies are calculated with the L3 Cloud Occurrence Product, the horizontal cloud anomalies are from the L3 GEWEX product, and the ice cloud extinction profiles and ice water content are obtained from the L3 Ice Cloud product. The cloud anomalies are further analyzed with the magnitude and pattern of sea surface temperature (SST) anomalies. These findings will improve current knowledge of ENSO from a new perspective.

Motivation

CALIPSO L3 cloud products are designed for cloud climatology analysis. How do they contribute to understand El Niño events?

Overview of three L3 Cloud Products

Cloud Occurrence and CALIPSO-ST GEWEX products

- **Input data:** V4.10 L2 5-km merged layer (05kmMLay) product;
- **Output data:** day, night, day + night;
- **Quality filters** applied to L2 data: confident cloud feature; high confidence cloud phase; exclude low altitude water clouds identified from coarse horizontal averaging (cloud top ≤ 8.2 km, HA = 5/20/80 km);
- **Cloud Occurrence Product** reports vertically resolved cloud occurrence at 60-m vertical resolution from -0.5 km to 20.2 km, and horizontal grid 2.5° lon by 2.0° lat. Cloud observations are represented as sample counts;
- **CALIPSO-ST GEWEX product** provides column cloud amount, low-level, mid-level, and high-level cloud amounts at horizontal 1.0° lat by 1.0° lon grid.

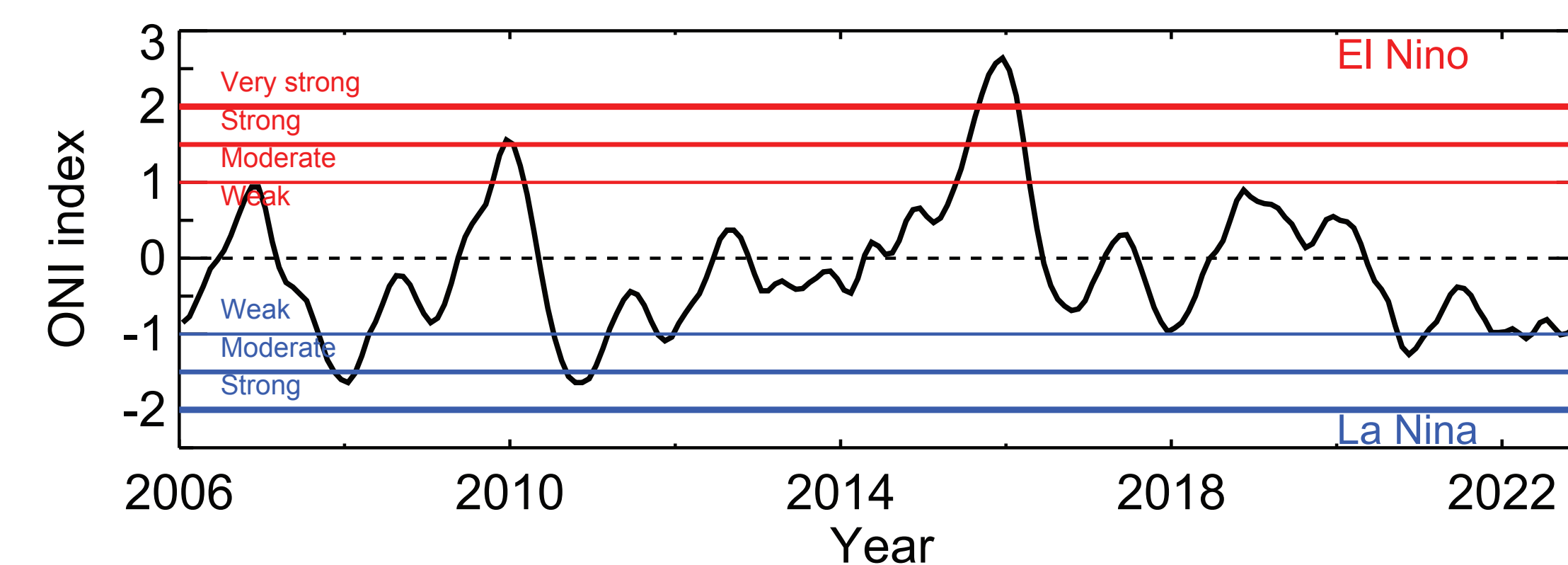
Ice Cloud Product

- **Input data:** V4.10 L2 5-km profile (05kmCPro) product;
- **Output data:** day, night, day + night;
- **Quality filters** applied to L2 data: confident cloud feature; high confidence ROI; extinction QC and uncertainty test; range filter; overlying optical depth threshold filter (OverlyingOD ≤ 2.0);
- **Ice Cloud Product** reports histograms of ice cloud extinction coefficients and ice water content at 120-m vertical resolution from -0.5 km to 20.2 km, and horizontal grid 2.5° lon by 2.0°.

Acknowledgements

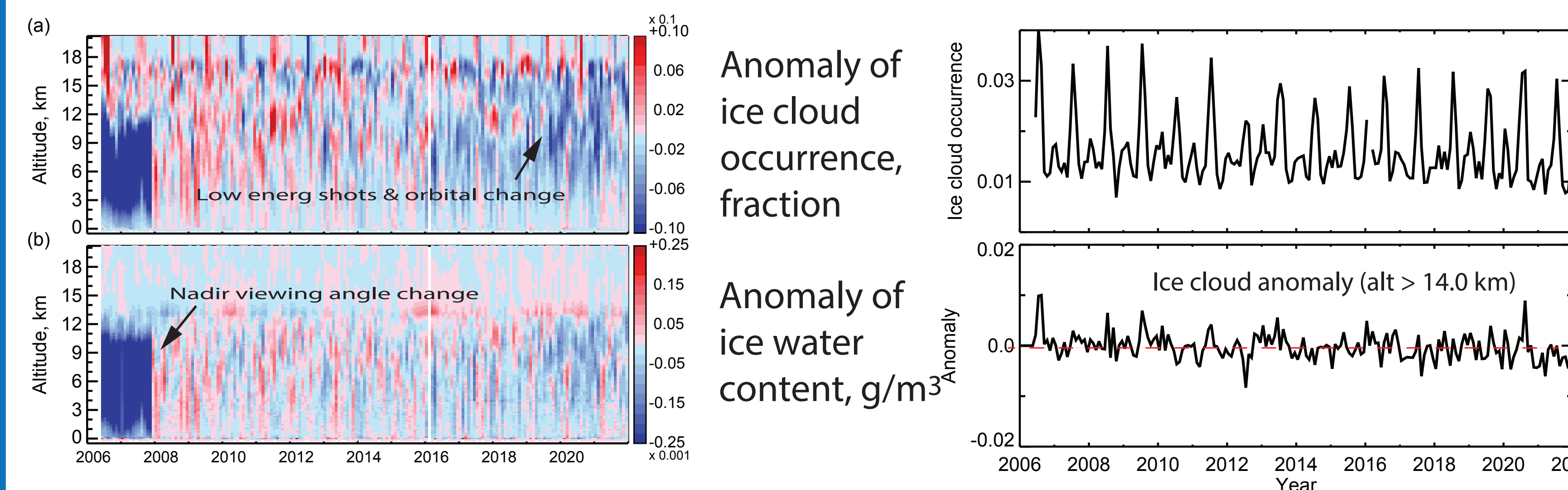
This work is supported by NASA SMD. The DARDAR data is provided by ICARE Data and Service center at the University of Lille, France. The 2C-ICE data is downloaded from the CloudSat Data Processing Center at Colorado State University. The monthly mean SST data is provided by the NOAA PSL, Boulder, Colorado, USA. The ocean mask is obtained from IMERG land-sea mask NetCDF.

Recent El Niño events



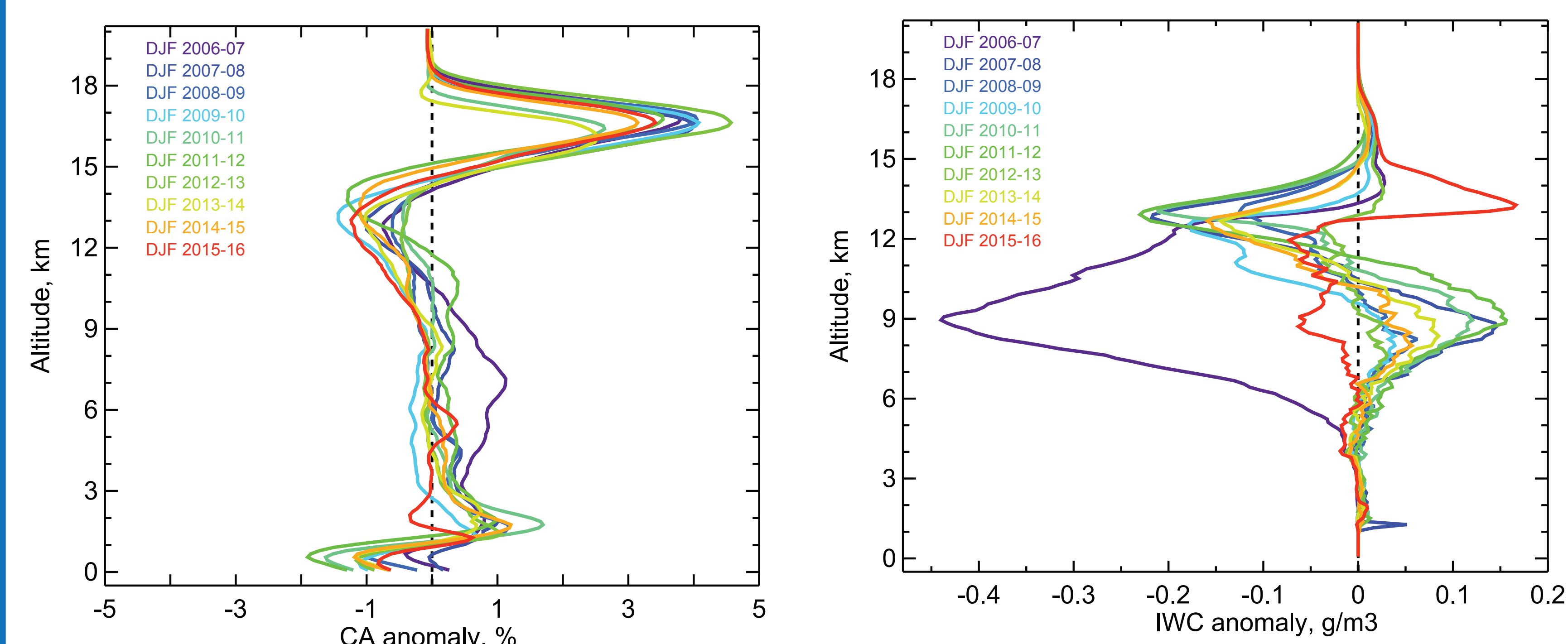
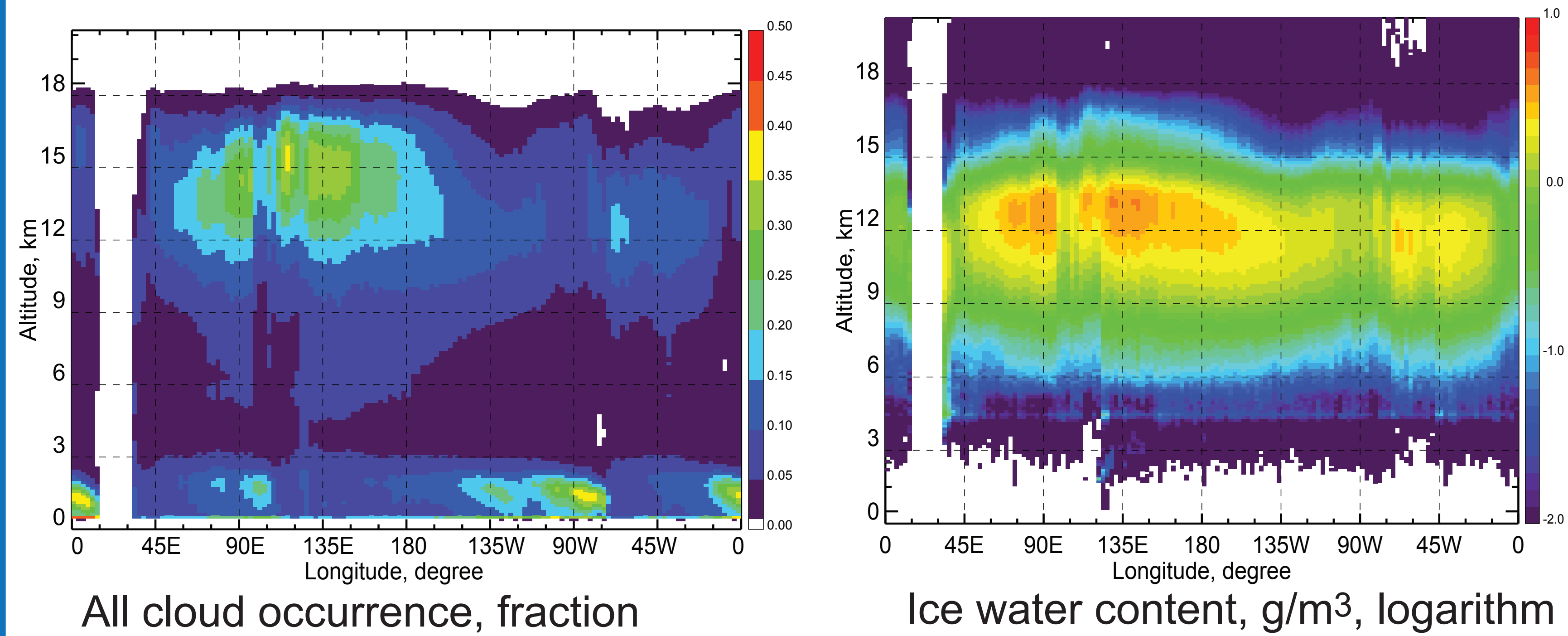
El Niño	Category
2006-2007	Weak
2009-2010	Moderate
2014-2015	Weak
2015-2016	Very strong
2018-2019	Weak

Long-term trend of L3 cloud products



Vertical ice cloud occurrence and IWC anomaly

- **L3 ice cloud product**, all granules, 2006-2016
- **Altitude region:** -0.5 ~ 20.2 km, tropical ocean (100% water, 30° S - 30° N), deseasonalized anomaly

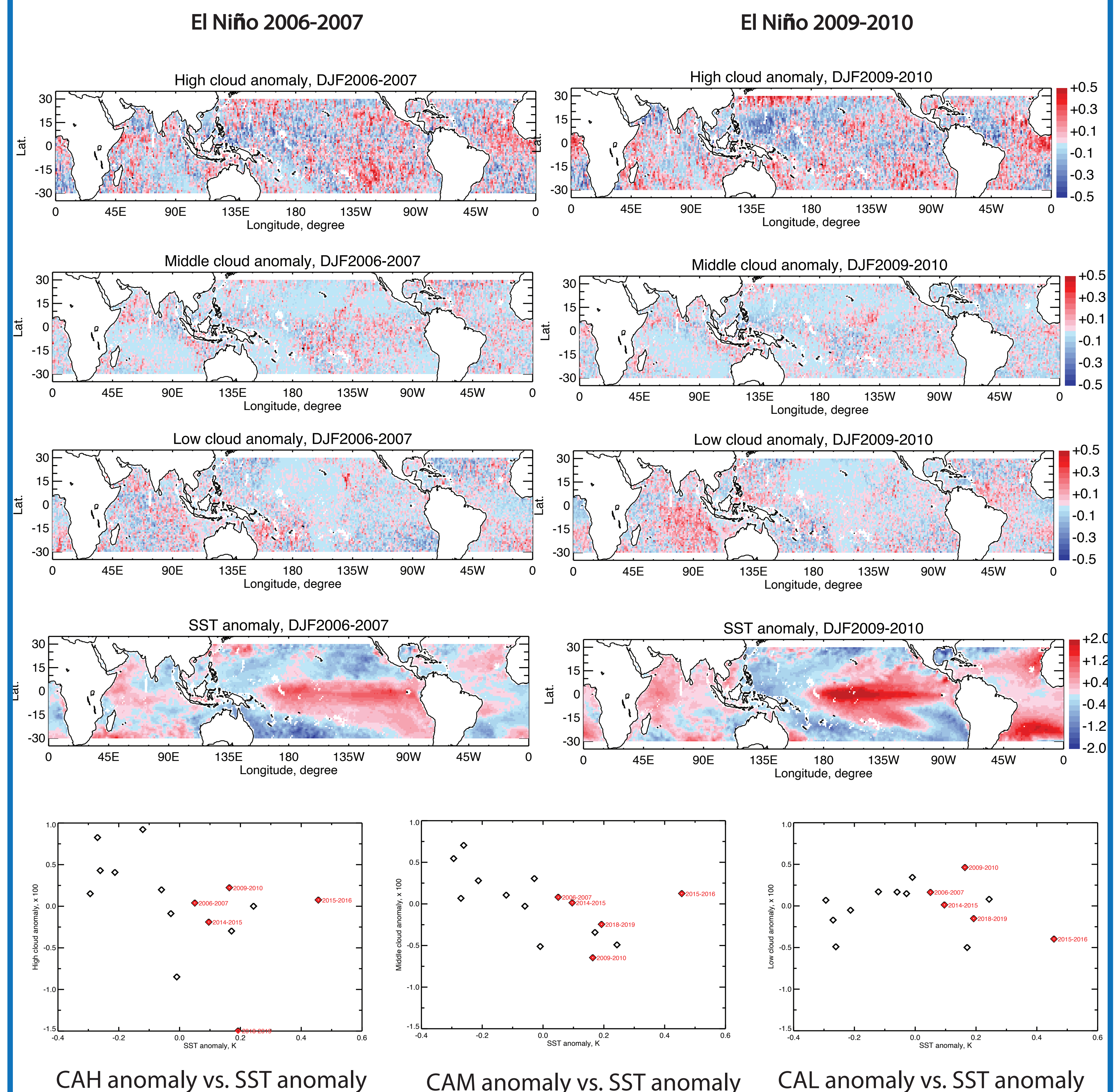


Reference

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Horizontal cloud occurrence and SST Anomaly

- **L3 GEWEX cloud product**, all granules, 2006-2021
- **High-level clouds:** cloud top pressure < 440 hPa; **middle-level clouds:** 440 \leq cloud top pressure < 680 hPa; **low-level clouds:** cloud top pressure \geq 680 hPa
- **Tropical ocean, deseasonalized anomaly**



Discussion and summary

- **CALIPSO L3 cloud products may be impacted by LIDAR nadir viewing angle change, low energy sorts, and satellite orbital change.** For example, detection sensitivity of ROI is lower with nadir viewing angle 0.3° than 3.0°. It impacts considerably the retrieved IWC.
- This work confirmed opposite middle cloud anomaly in 2006-2007 and 2009-10. Similarly opposite IWC anomalies at high and middle altitude are also seen in 2015-2016 and other El Niño events.
- The strength of El Niño events is related to not only the magnitude of SST anomaly, but also the pattern of SST anomaly. And the relationship is nonlinear.
- **CALIPSO L3 cloud products provide valuable information on thin cirrus clouds > 14 km at tropical region**, which is challenging for passive sensors and radar due to detection sensitivity.
- **CALIPSO L3 cloud products are specially designed for cloud climatology analysis.** They allow convenient seasonal, annual and interannual aggregation. They also provide valuable information on thin cirrus clouds at high altitude.