

33th CERES Science Team Meeting 2020, Apr 28–30, Hampton, VA, USA



Cloud Changes over the Pacific Using A-train Measurements

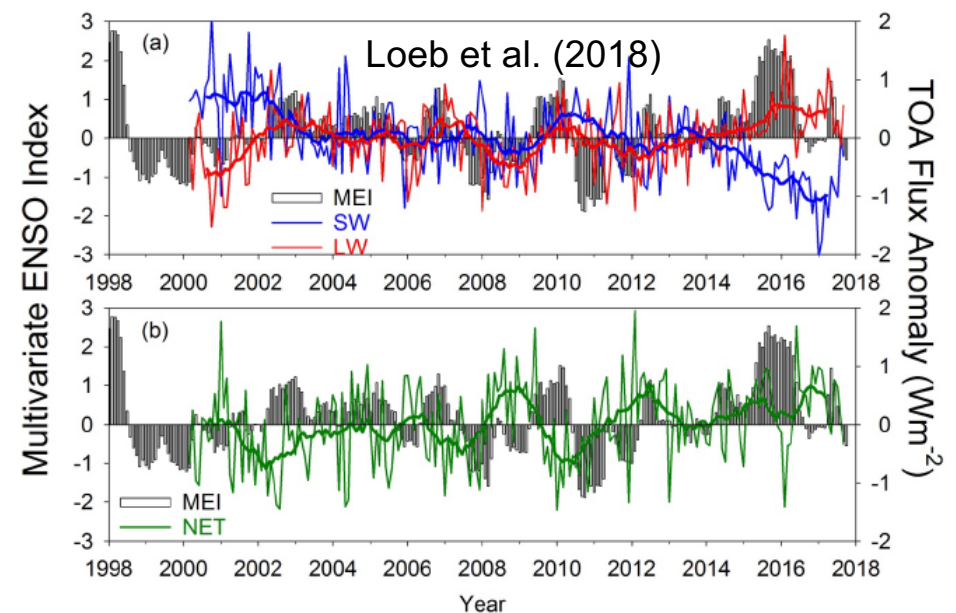
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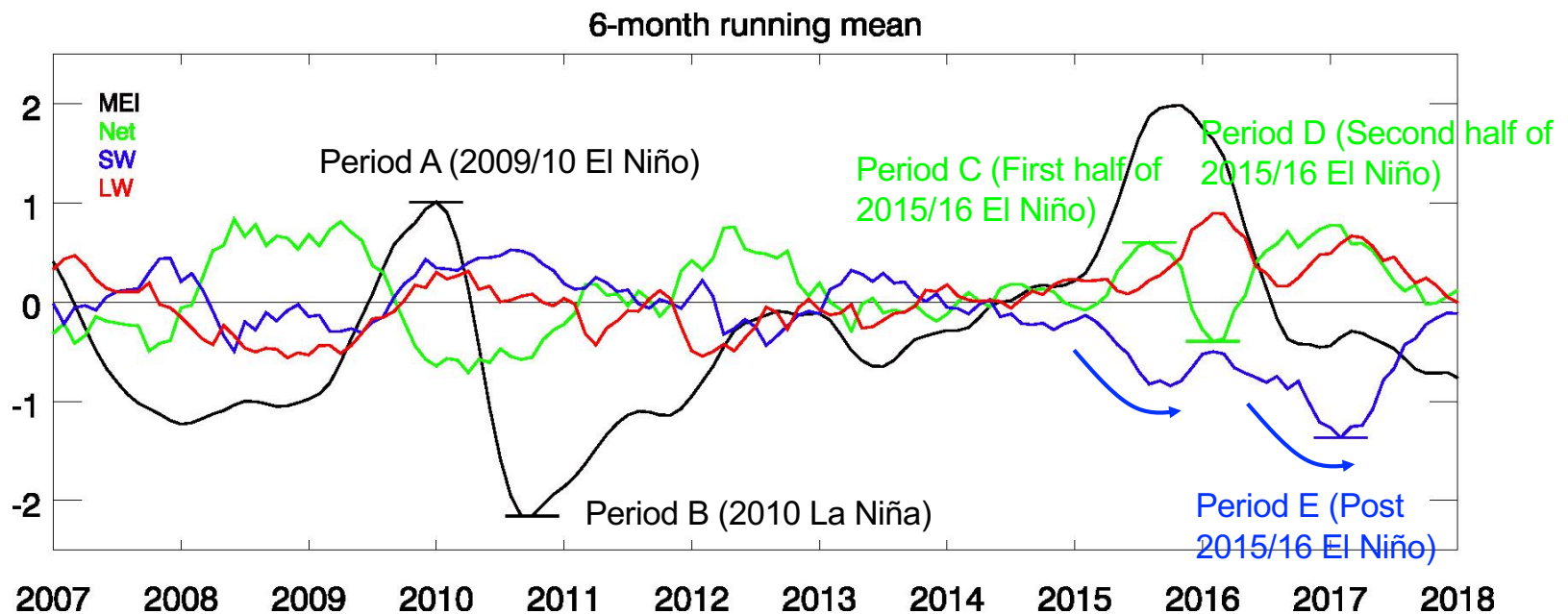
Background

- From A-train observations, more than 18 years of CERES and MODIS data are available, and more than 11 years of CALIPSO and CloudSat data are available. This enables us to examine clouds and cloud radiative effects for the period longer than a decade.
- According to Loeb et al. (2018), there has been significant SW anomaly trend since 2014, and it lasted until 2018, which were largely driven by low cloud anomalies.
- Therefore, it is interesting to examine long-term cloud changes using CERES, CALIPSO, CloudSat, and MODIS.



Five Periods of Interest

Period	Note	MEI mean	SW outgoing anomaly (Wm^{-2})	LW outgoing anomaly (Wm^{-2})	Net incoming anomaly (Wm^{-2})
A: Oct 2009–Mar 2010	2009/10 El Niño	+1.01	+0.34	+0.30	+0.64
B: July 2010–Dec 2010	2010 La Niña	-2.16	+0.48	+0.08	-0.56
C: May 2015–Oct 2015	2015/16 El Niño	+1.87	-0.83	+0.22	+0.60
D: Nov 2015–Apr 2016	2015/16 El Niño	+1.64	-0.50	+0.90	-0.40
E: Nov 2016–Apr 2017	Neutral	-0.35	-1.36	+0.59	+0.77



Datasets

- ❑ CERES **EBAF Ed4.1** flux dataset
- ❑ MODIS (Passive sensor) cloud properties: **CERES Ed4A SSF** Aqua hourly data
- ❑ CALIPSO (Lidar) cloud properties: **CALIPSO V4 VFM** product
- ❑ CloudSat (Radar) cloud properties:

CloudSat R05 2B-GEOPROF, 2B-CWC-RO, 2C-ICE

- ❑ CloudSat + CALIPSO (Radar+Lidar) cloud properties:

Combination of CloudSat R05 and CALIPSO V4 based on Kato et al. (2010)

- ❑ Meteorological properties: **MERRA-2**, ERA-5

Sea surface temperature (SST), temperature, humidity, and vertical velocity

- *CloudSat has been operating for daytime only since June 2012, and for the consistency, cloud properties for daytime are analyzed for all cloud datasets. Also we use MODIS SSF Aqua for consistent sampling with CloudSat and CALIPSO.*

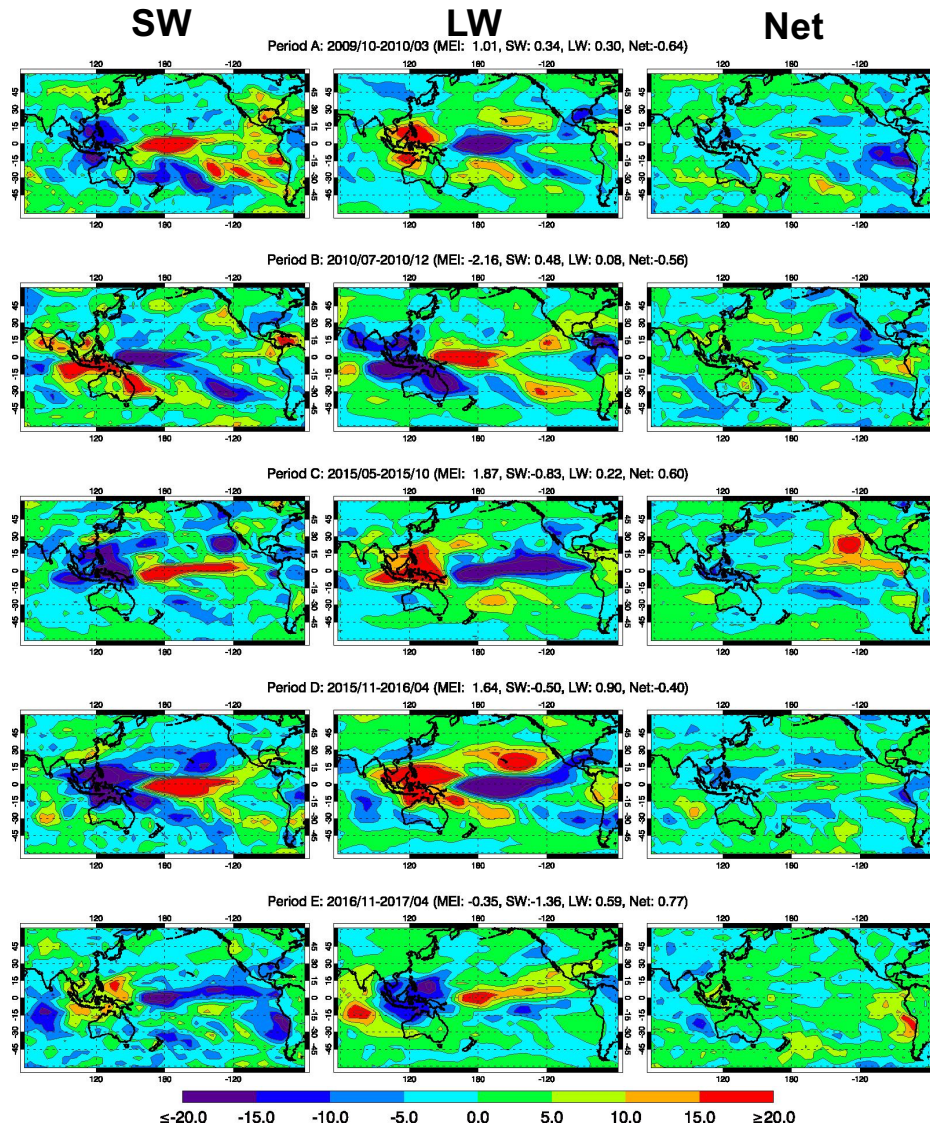
Period A
(2009/10 El Niño:
Oct 2009 – Mar 2010)

Period B
(2010 La Niña:
Jul 2010–Dec 2010)

Period C
(First Half of
2015/16 El Niño:
May 2015–Oct 2015)

Period D
(Second Half of
2015/16 El Niño:
Nov 2015–Apr 2016)

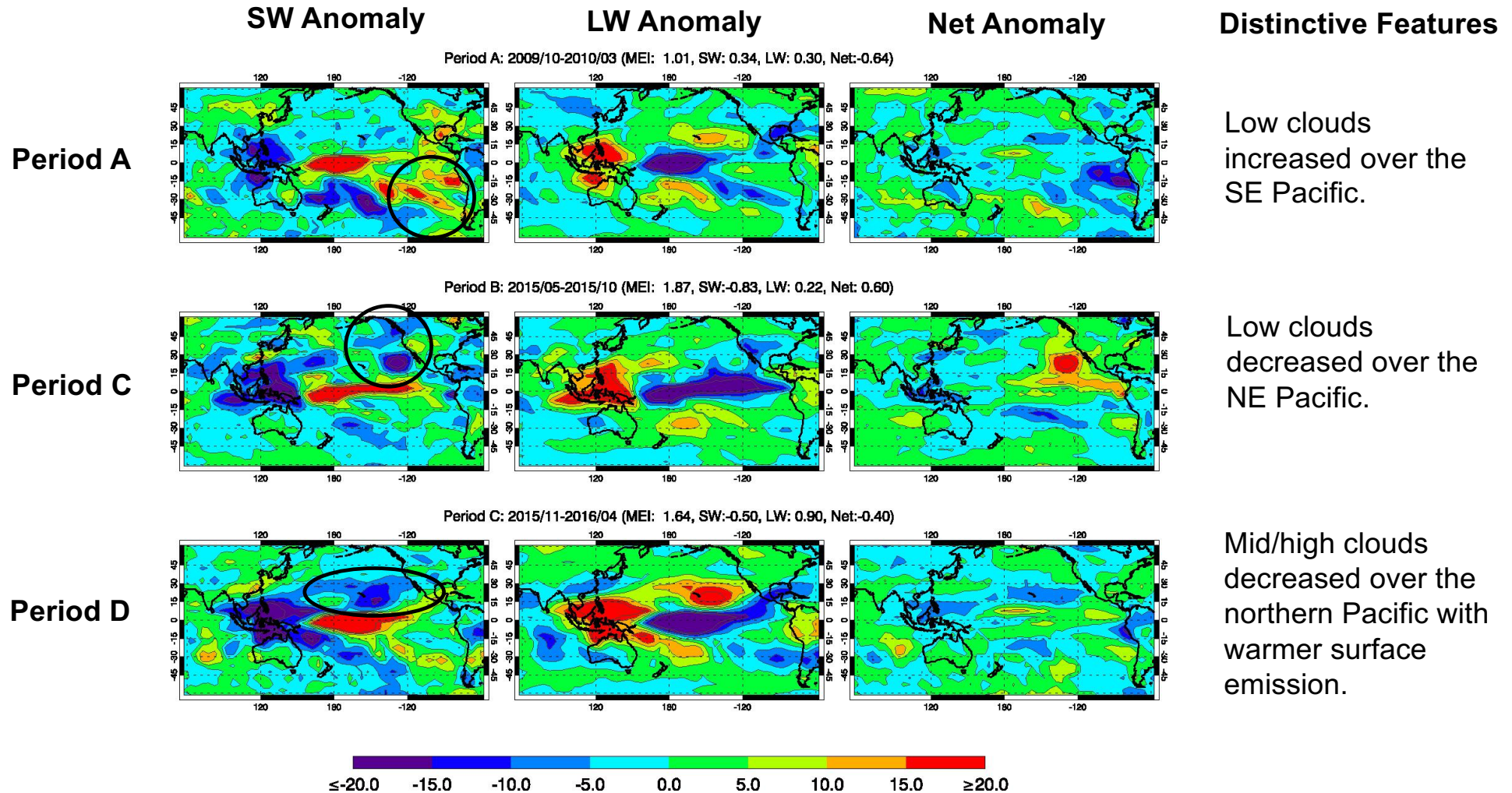
Period E
(Post 2015/16 El Niño:
Nov 2016–Apr 2017)



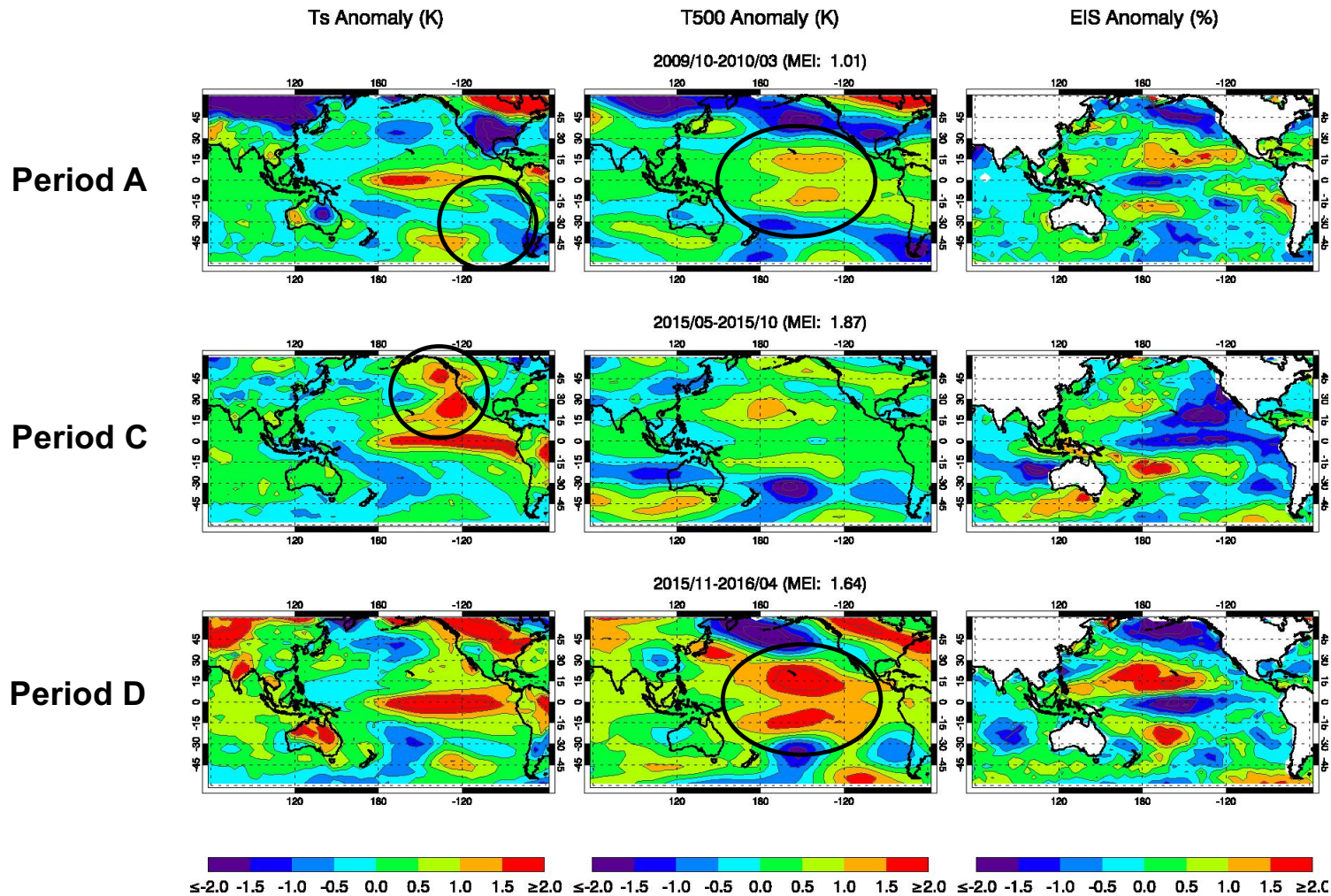
EBAF Flux Anomalies for the five periods

- ENSO events derive shifts of locations of maxima of SW and LW anomalies related to deep convective clouds.
- However, deep convections over the Warm Pool (during La Niña) or central Pacific (during El Niño) do not impact net anomalies much, since SW and LW anomalies cancel.
- In contrast, low-level clouds over the Eastern Pacific mainly drive net anomalies.

Why Do The Net Anomalies Are Different between 2009/10 El Niño (Period A) and 2015/16 El Niño (Periods B & C)?



MERRA-2 Temperature Anomalies in 2009/10 El Niño (Period A) vs 2015/16 El Niño (Periods C & D)



- During period A, SST anomalies remained positive in southeastern (SE) Pacific and it provided favorable condition of low-level cloud generation.
- During period B and C, SST anomalies were negative in the Eastern Pacific.
- Two different types (central Pacific type El Niño vs Eastern Pacific type El Niño) caused opposite signs of SST anomalies over the EP (Ashok et al., 2007; Kug et al., 2009; Yeh et al., 2009; Kao et al. 2009).

How Did the Satellite Measurements Capture Low Cloud Anomalies in 2009/10 El Niño (Period A) vs 2015/16 El Niño (Periods C & D)?

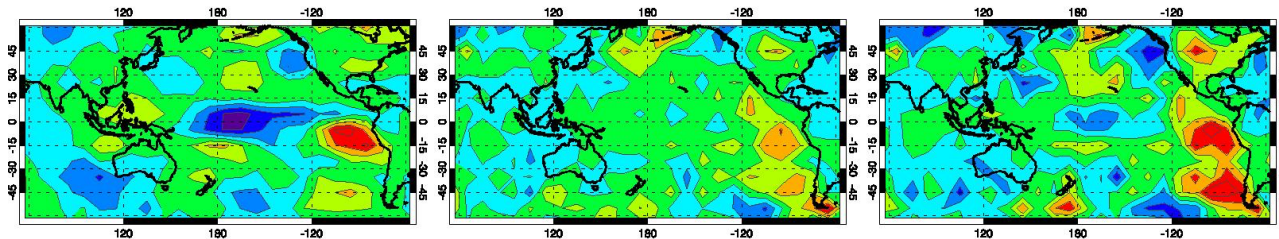
MODIS

CloudSat

CC

Period A

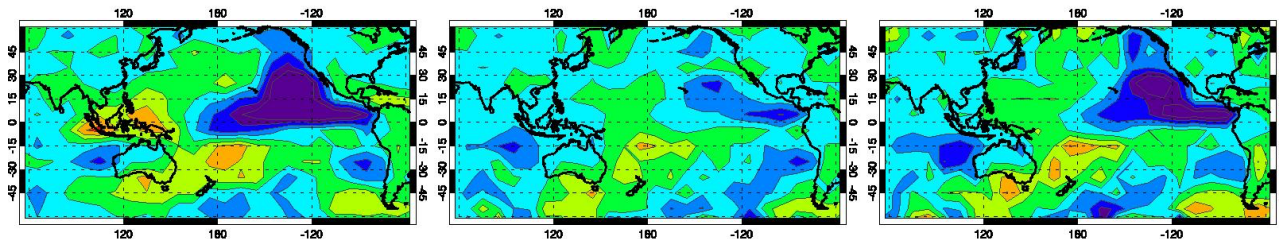
Period A: 2009/10-2010/03 (MEI: 1.01, MODIS: 0.32, CloudSat: 0.53, CC: 0.42)



- CloudSat misses/underestimates most of important low-level cloud anomalies.

Period C

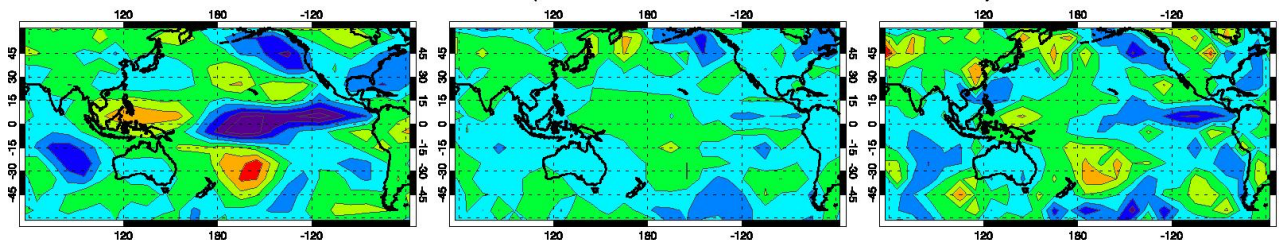
Period B: 2015/05-2015/10 (MEI: 1.87, MODIS: -0.47, CloudSat: -0.49, CC: -0.57)



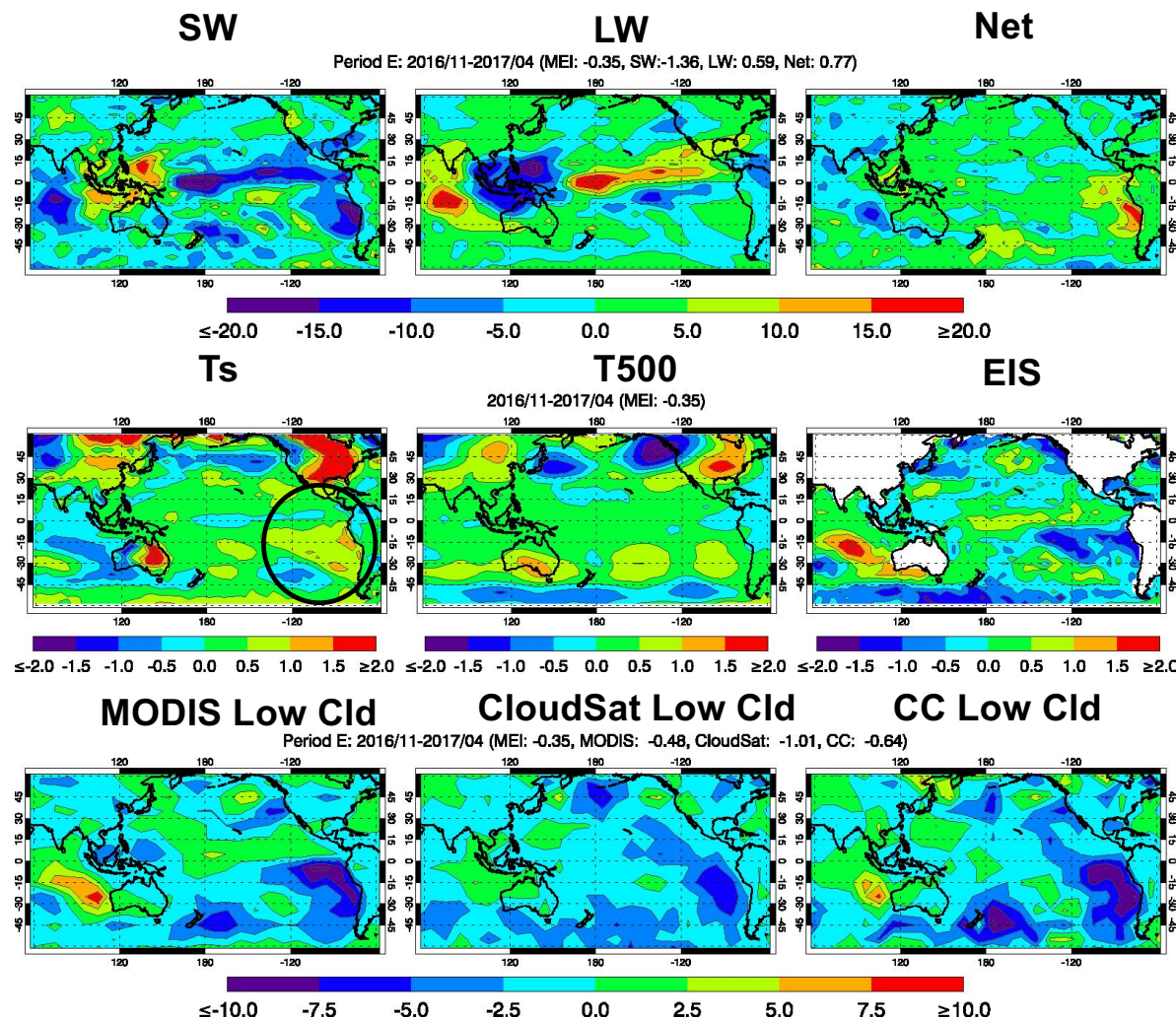
- CALIPSO-CloudSat (CC) and MODIS low cloud anomalies agree well. These are strongly correlated with EIS anomalies.

Period D

Period C: 2015/11-2016/04 (MEI: 1.64, MODIS: -0.11, CloudSat: -0.34, CC: -0.09)



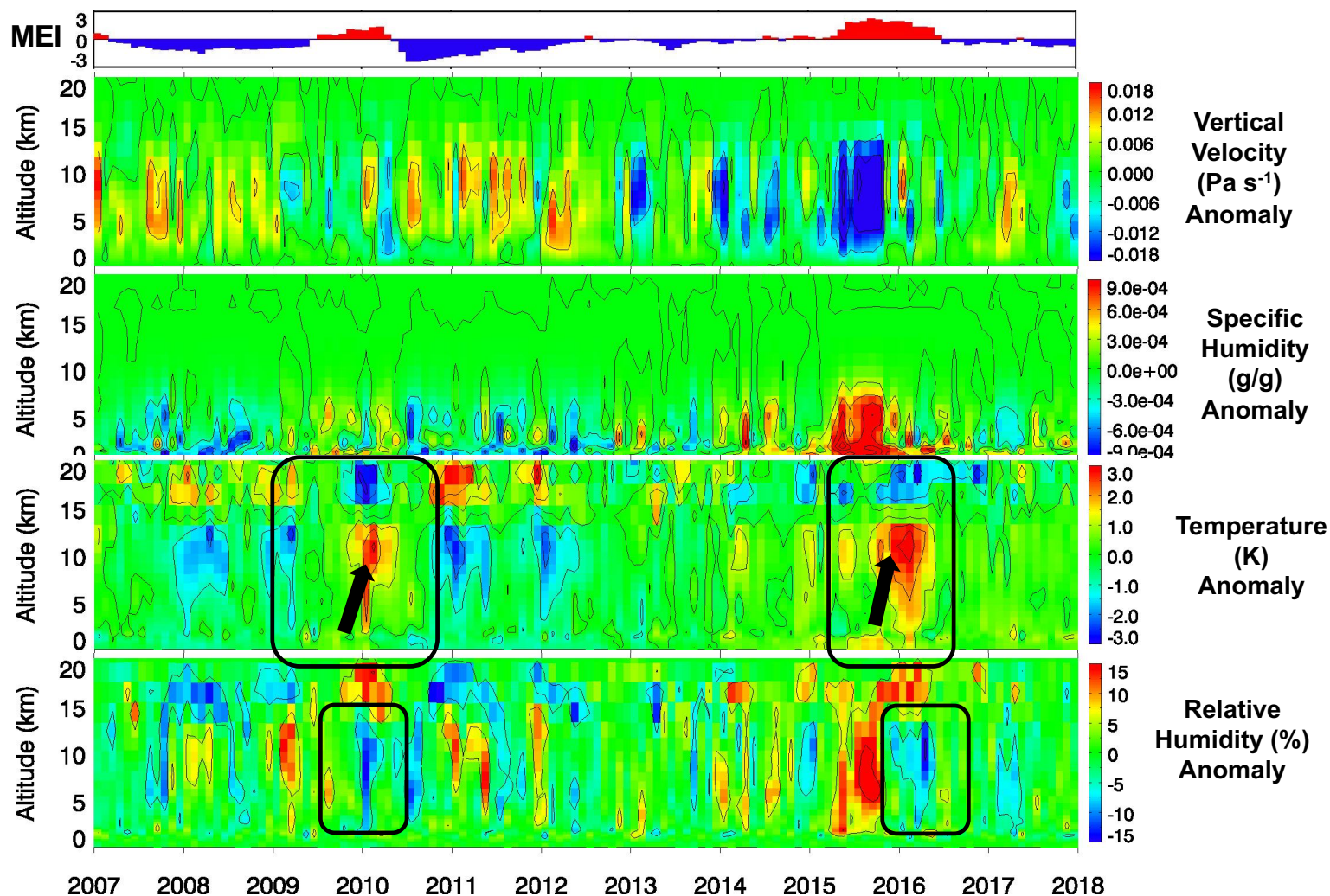
How About Period E (Post 2015/16 El Niño)?



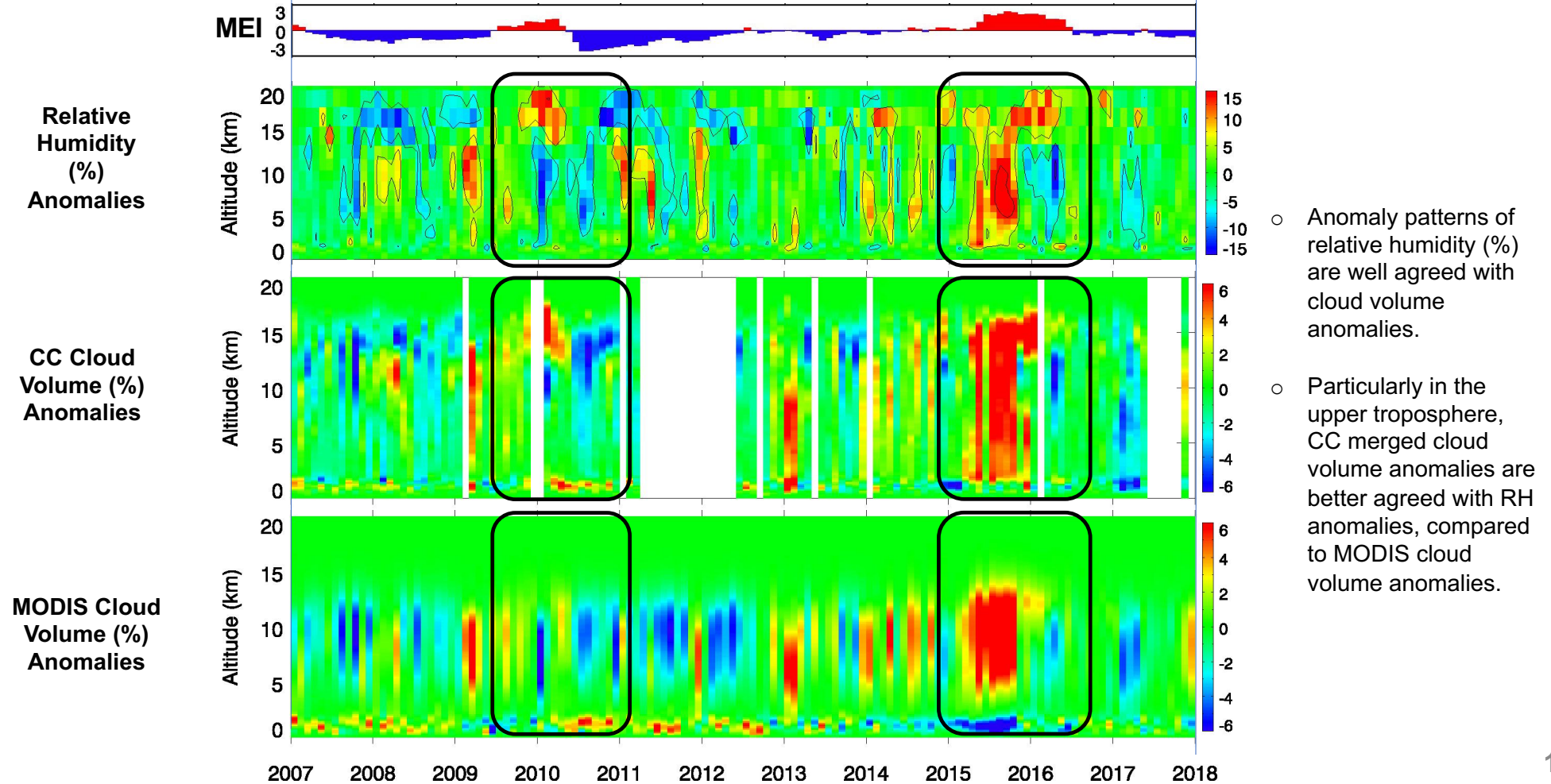
- The ENSO phase did not turn La Niña (MEI index = as -0.35), and the warm SST anomalies appeared over the southeastern (SE) Pacific.
- As a result, low-clouds decreased and net SW anomalies were negative.
- MODIS, CloudSat, and CALIPSO/CloudSat (CC) captured these feature, but CloudSat had a smaller magnitude than other datasets.

Meteorological conditions over the EP (150W-120W, EQ-30N)

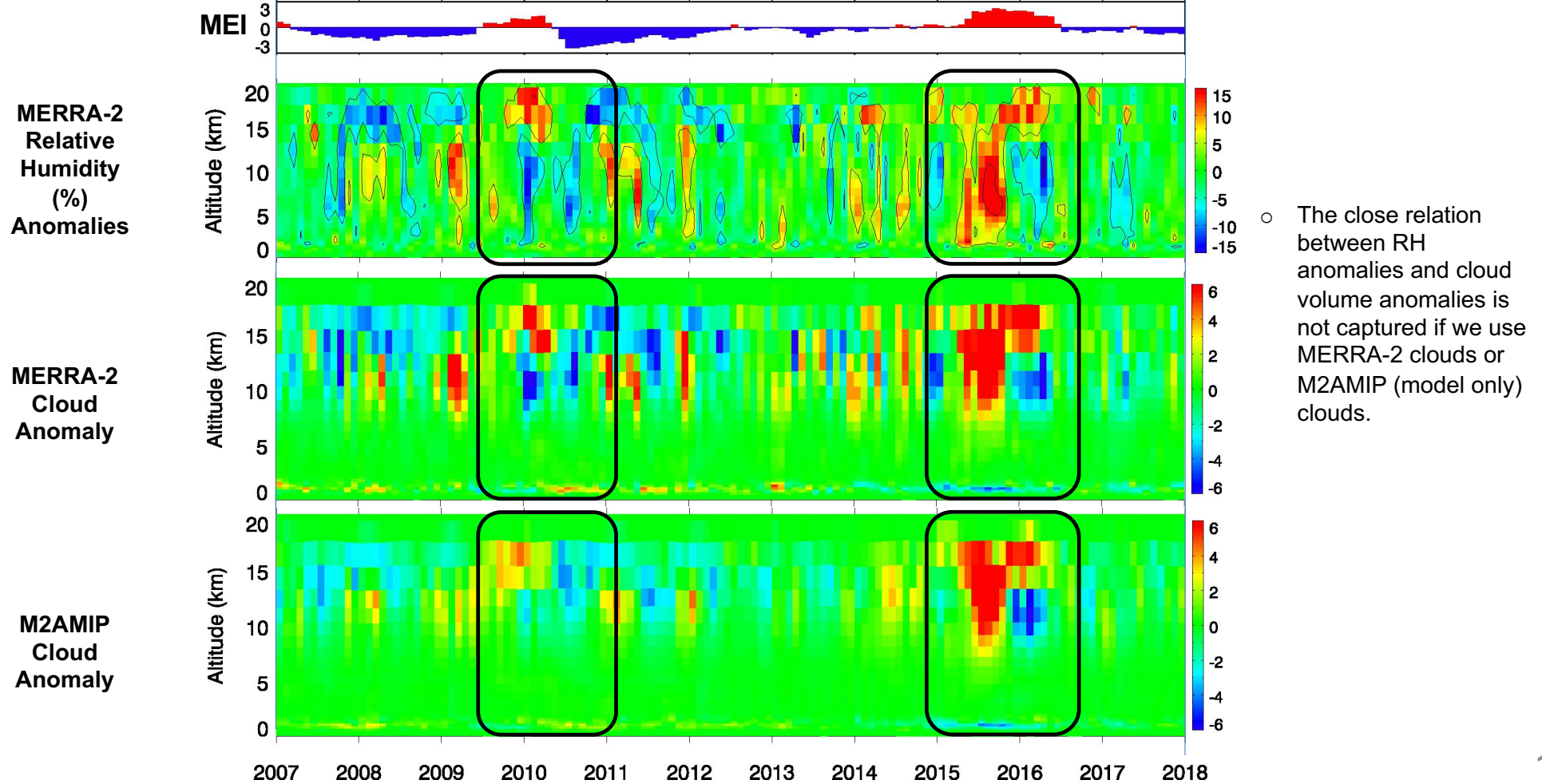
- During El Niño seasons (e.g., the end of 2009 and 2015), positive anomalies in SST, low-troposphere specific humidity, and upward vertical motion occur.
- After positive anomalies of SST, mid/upper troposphere (5-13 km) air temperature increased and tropopause temperature (13-18 km) decreased in the following spring.
- As a result, relative humidity decreased at 5-13 km, and increased at 13-18 km in the next spring of El Niño.



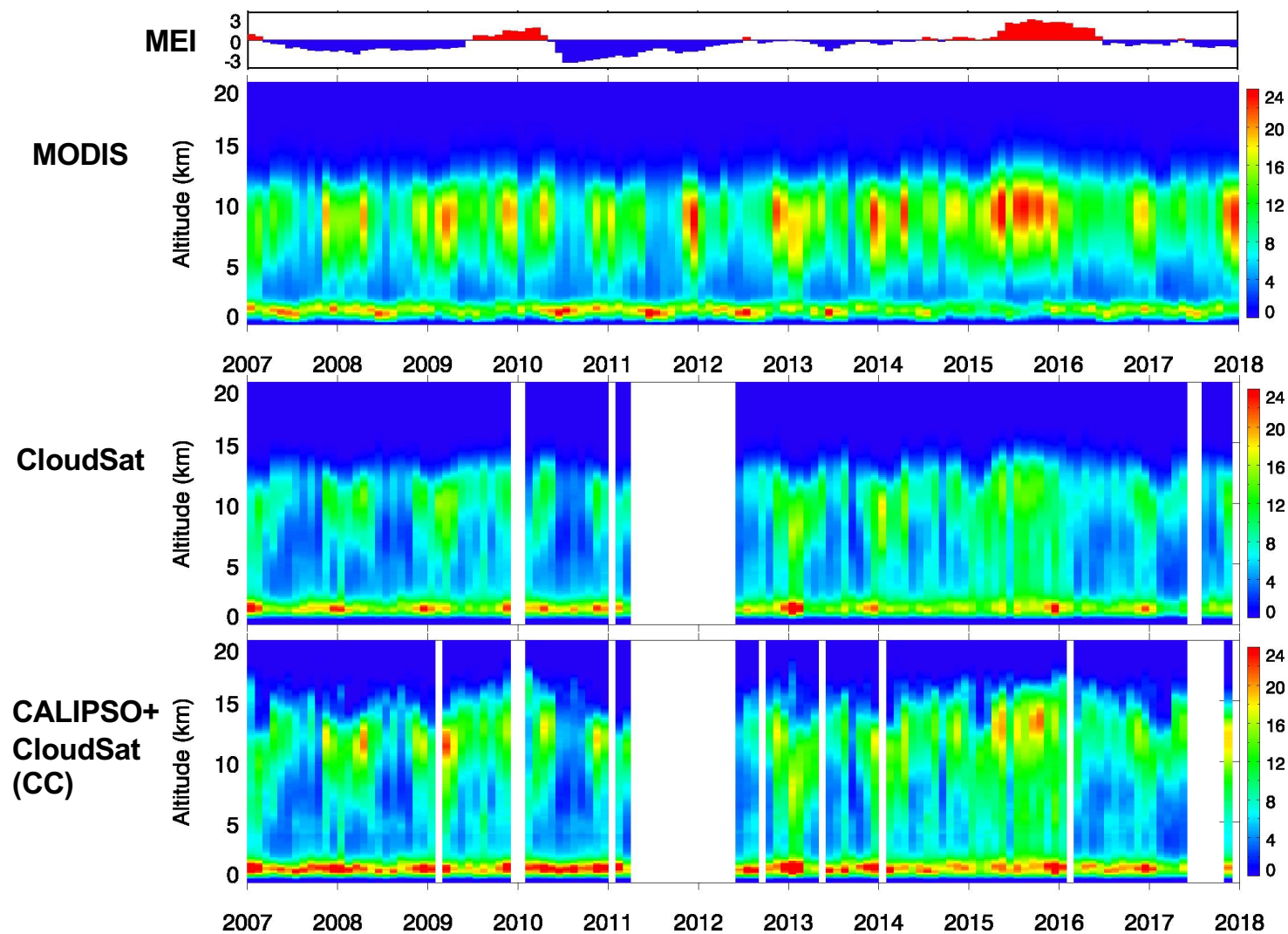
RH (%) versus Cloud Volume Fraction (%) Anomalies over the EP (150W-120W, EQ-30N)



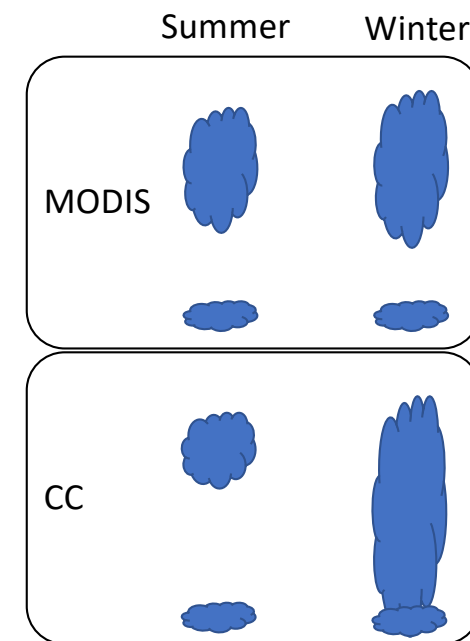
RH (%) versus Cloud Volume Fraction (%) Anomalies over the EP (150W-120W, EQ-30N)



Cloud Volume Fractions (%) over the Eastern Pacific (EP) (150W-120W, EQ-30N)



- The vertical gap between high/mid clouds and low clouds are different between CC and MODIS:



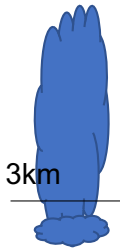
Smoothed with a
3-month moving
window

EIS (K)

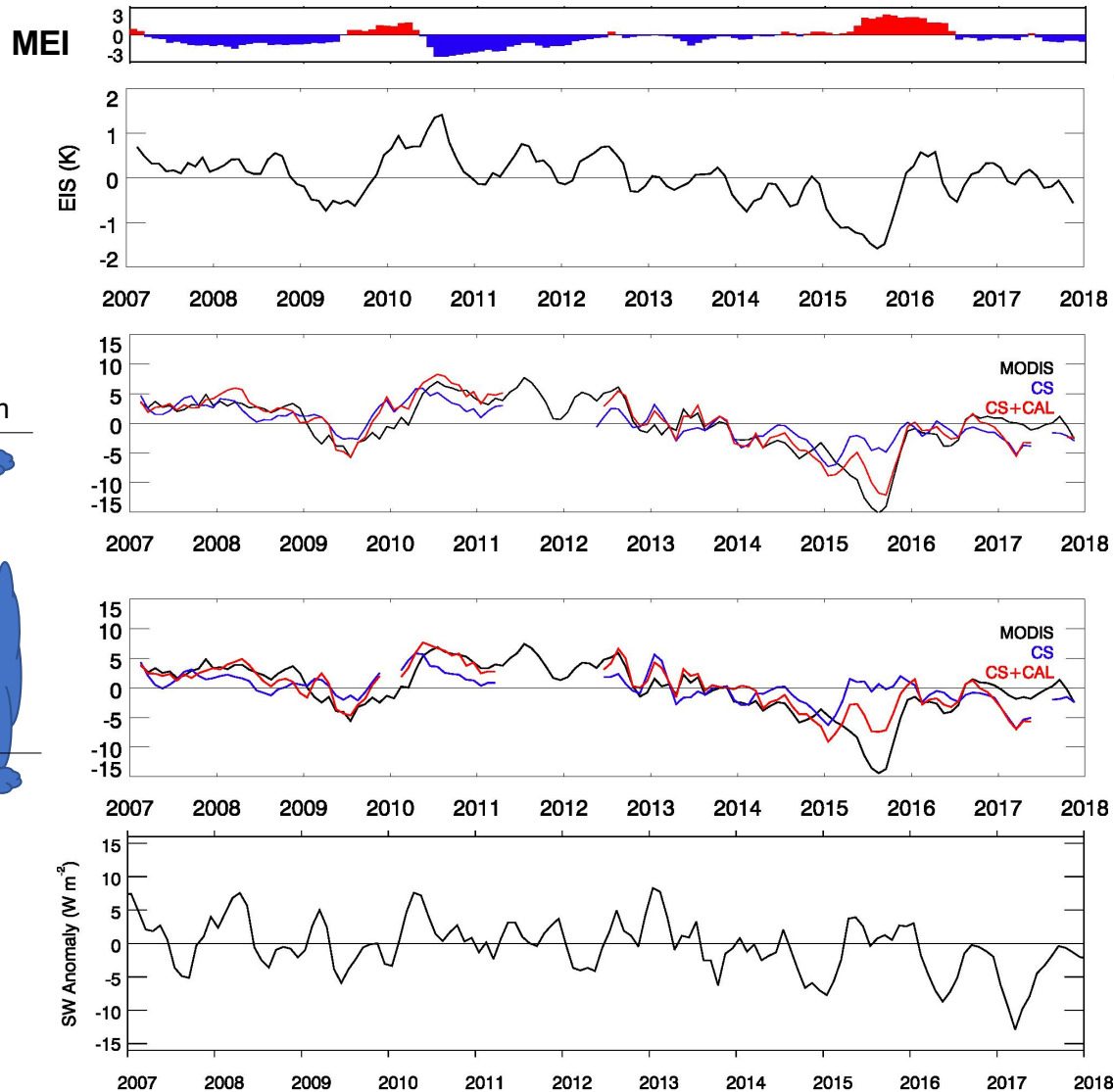
Low cloud
anomalies
(%) according
to cloud top
< 3 km



Low cloud
anomalies
(%) according
to cloud
occurrence 0-
3 km



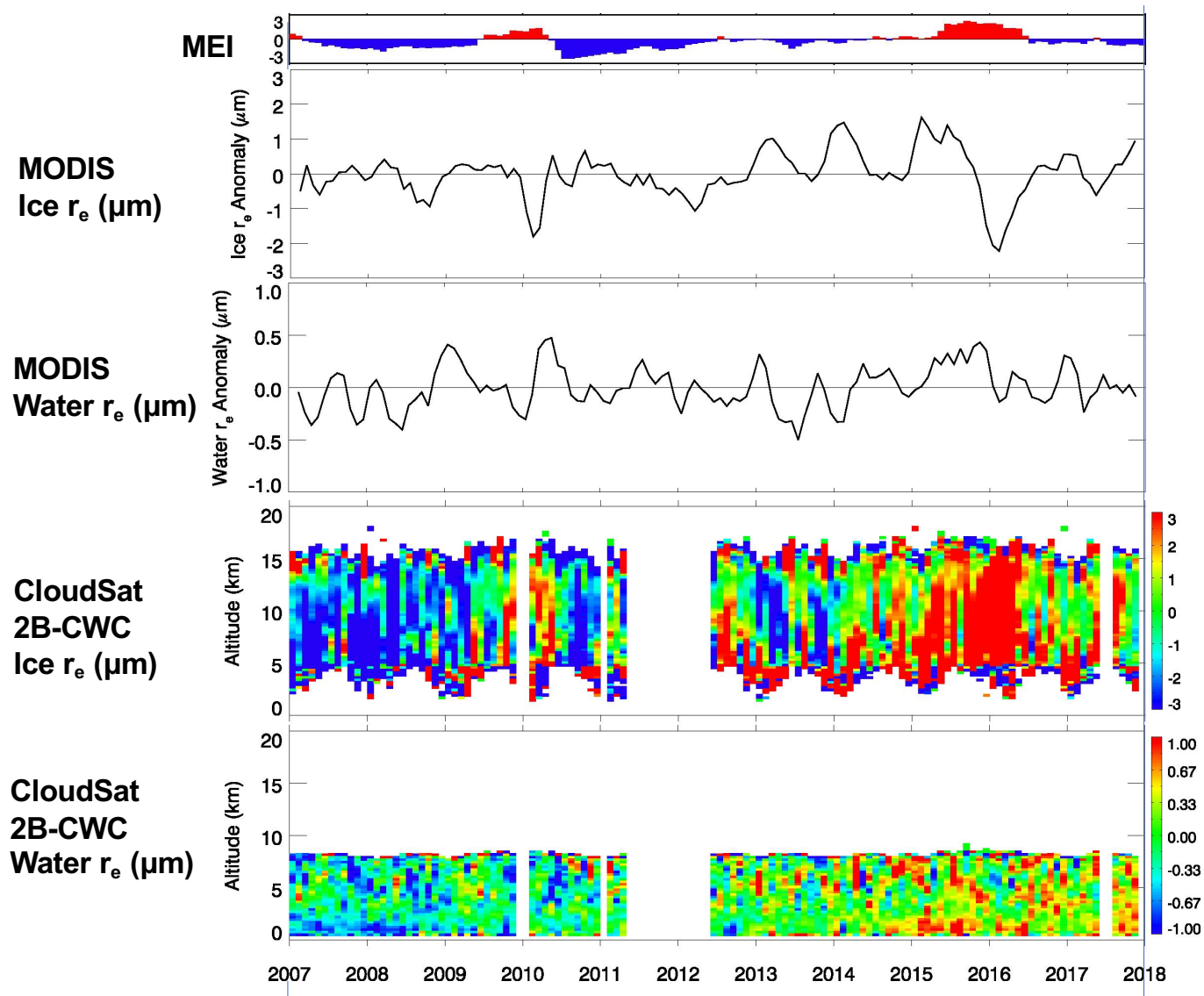
SW Anomaly



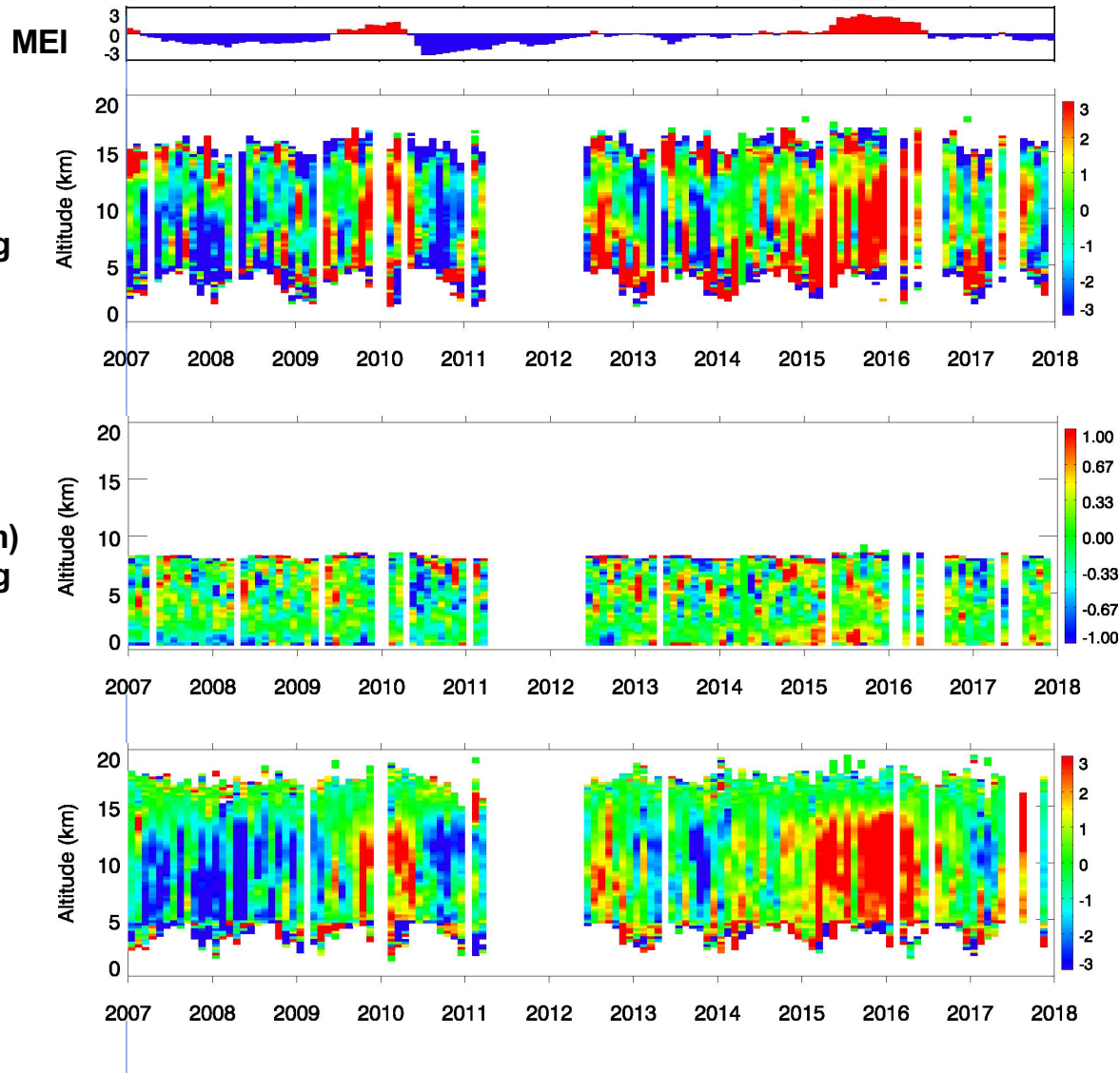
Cloud Anomalies (%) over the EP (150W-120W, EQ- 30N)

- Low-level cloud anomalies are consistent between MODIS and CC if we only count low-level clouds with top below 3 km. These low-level cloud anomalies are well correlated with EIS anomalies.
- CC indicates that the low-level cloud top generation is reduced during El Niño events due to negative EIS anomalies. However, mid- and high-level clouds are increased during El Niño events, the cloud amounts at 0-3 km altitude can be still be increased due to increased activity of mid and high clouds.

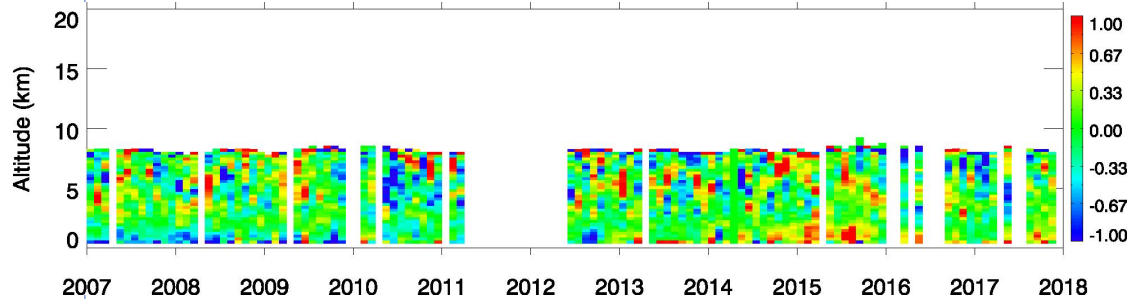
Cloud Particle Size over the EP (150W-120W, EQ-30N)



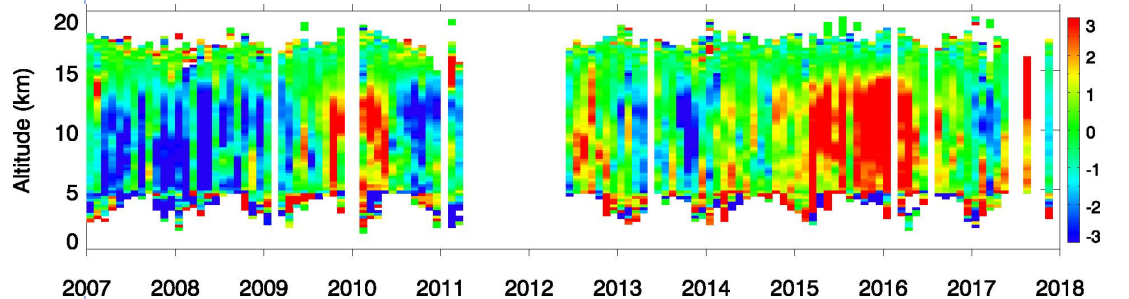
CloudSat
2B-CWC
Ice r_e (μm)
with filtering
 $Z < -25$ dBZ



CloudSat
2B-CWC
Water r_e (μm)
with filtering
 $Z < -25$ dBZ



CloudSat
2C-ICE
Ice r_e (μm)



Cloud parameters over the EP (150W-120W, EQ-30N)

- The positive trends in 2B-CWC particle size get removed if we filter out very thin cloud layers with weak signals ($Z < -25$ dBZ), meaning that over time, CloudSat CPR sensitivity has changed.
- 2C-ICE particle size is less sensitive to the CPR sensitivity change because it also uses CALIPSO for the retrievals.
- Overall ice particle size changes response to ENSO events are similar between 2C-ICE and 2B-CWC.

Conclusions

- The strong negative SW anomalies happened during 2015 are related to reduction of low-level clouds over the NE Pacific. This did not happen in 2009/10 El Nino because cold SST anomalies were prevalent over the EP.
- Combining CloudSat and CALIPSO has a large benefit in detecting low-level cloud anomalies and high-level cloud anomalies.
- MODIS total cloud anomalies are consistent with CALIPSO-CloudSat combined anomalies, but in terms of cloud height, there are disagreements if we separate clouds by height. In addition, there is a distinct vertical gap between low and mid-level clouds in MODIS, but CALIPSO-CloudSat does not show this feature.
- Mid- and high-level cloud anomalies are well correlated with relative humidity (RH) anomalies. This feature is not shown if we use reanalysis clouds.
- High and low-level clouds are often anti-correlated over the Pacific because positive SST anomalies are often accompanied by negative ω_{500} anomalies. The negative ω_{500} anomalies cause positive WV anomalies, which eventually increase mid and high-level clouds.
- Low cloud top occurrence below 3 km is well explained by inversion strength. However, CALIPSO CloudSat indicate that cloud base of mid/high level clouds stretched to low altitude and actual low-level cloud volume is smaller.