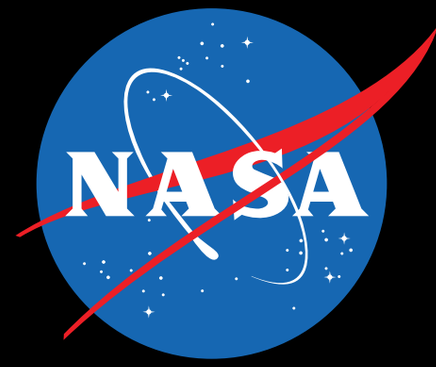
National Aeronautical and
Space Administration



A Multi-Sensor Perspective on the Interannual Variability of Tropical Humidity and Clouds

Calvin K. Liang

Annmarie Eldering, Andrew Gettelman,
Biajun Tian, Sun Wong, Eric Fetzer, Kuo-Nan Liou

Joint Institute for Regional Earth System Science and Engineering at UCLA
Jet Propulsion Laboratory, California Institute of Technology

NOAA CDR Workshop

Motivation

To better characterize the controls on the tropical upper tropospheric/lower stratospheric (UTLS) humidity and clouds.

Stratosphere

~50hPa

~100hPa

Tropopause

TTL

$Q_{clear}=0$

~200hPa

Cold

Warm

Troposphere

Warm
Moist
Upward Motion

Cool
Dry
Subsidence

~1000hPa

Warmer SST

Cooler SST

Tropical Western Pacific

Tropical Central Pacific

Stratosphere

~50hPa

~100hPa

~200hPa

~1000hPa

Quasi-Biennial Oscillation (QBO)
Baldwin, RG, 1999

Tropopause

Cold

Warm

TTL

$Q_{clear}=0$

Troposphere

Warm
Moist
Upward Motion

Cool
Dry
Subsidence

El Niño Southern Oscillation (ENSO)
Trenberth, AMS, 1997

Warmer SST

TWP

Cooler SST

TCP

Stratosphere

~50hPa

~100hPa

~200hPa

~1000hPa

Quasi-Biennial Oscillation (QBO)
Baldwin, RG, 1999

TTL *T*, H_2O, *and Clouds?*

Tropopause

TTL

Q_{clear}=0

Cold

Warm

Troposphere

Warm
Moist
Upward Motion

Cool
Dry
Subsidence

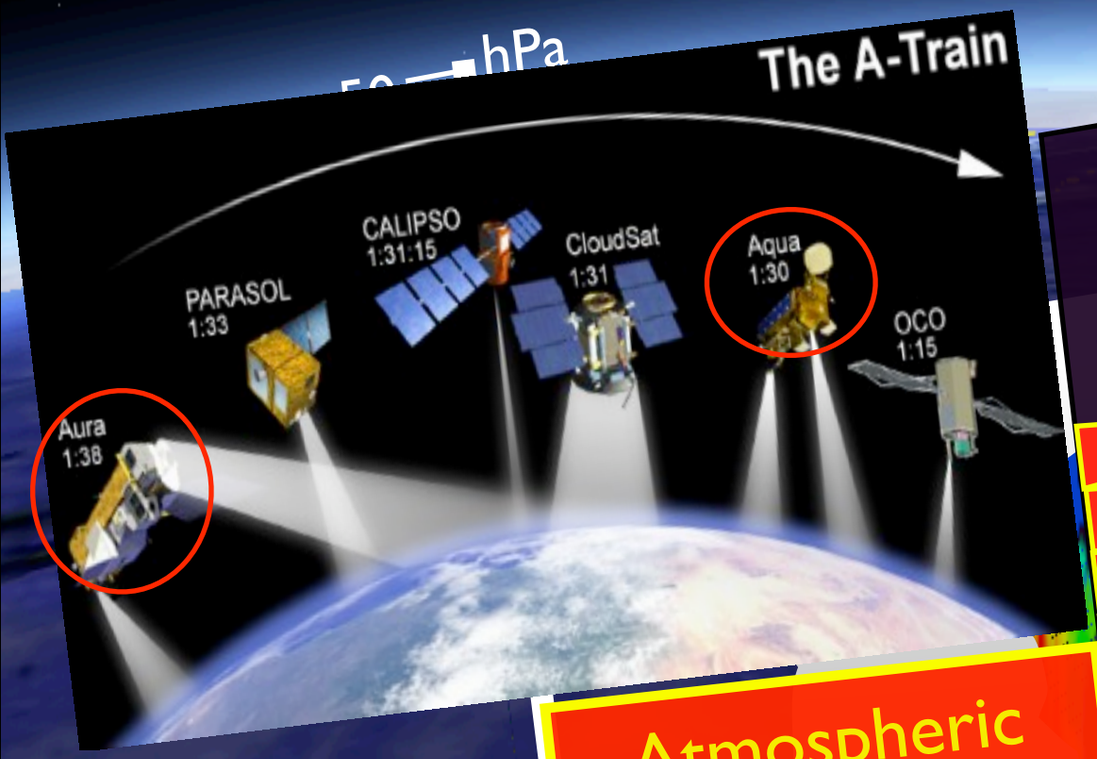
El Niño Southern Oscillation (ENSO)
Trenberth, AMS, 1997

Warmer SST

TWP

Cooler SST

TCP



hPa

500

1,000

Atmospheric Infrared Sounder (AIRS)

AIRS ~1-3 km

MLS ~2 km

Microwave Limb Sounder (MLS)

~45 km

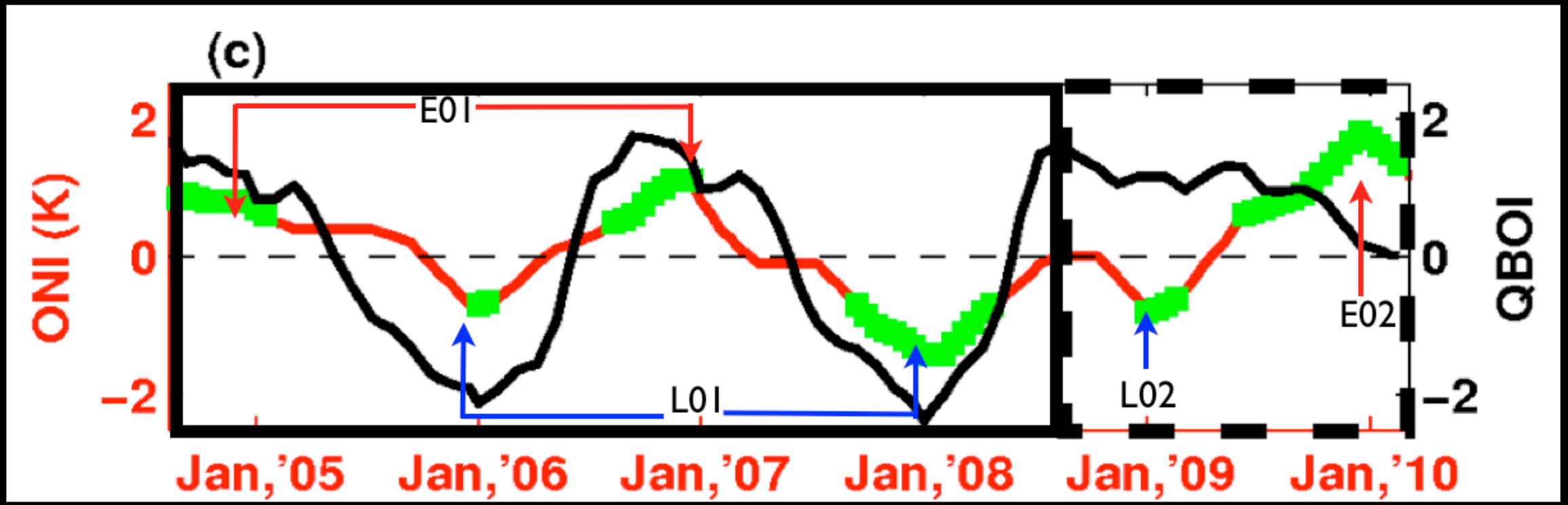
MLS (~200 km)

Datasets:

(1) Temperature (AIRS)
(Accuracy ≤ 1.0 K)

(2) Combined H_2O (AIRS,MLS)
(Liang, et.al, AMTD (2010))

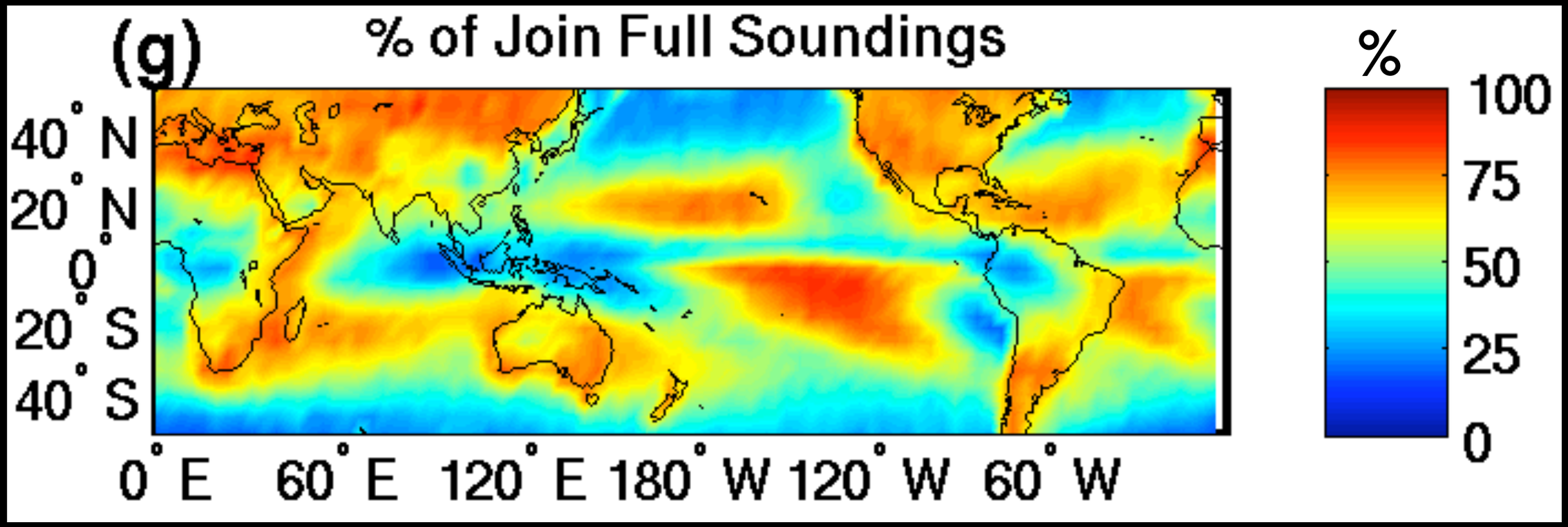
ENSO and QBO Indices



- Ocean Niño Index (ONI) in the Niño3.4 region (5S-5N, 120W-170W) *(Source: NOAA CPC, in-situ measurements)*

- QBOI represent zonal mean zonal wind anomalies at 50 hPa *(Source: NCAR/NCEP reanalysis)*. Anomalies in thermal wind balance with lower stratospheric temperatures *(Randel et.al, JGR, 2000)*

Data Sampling



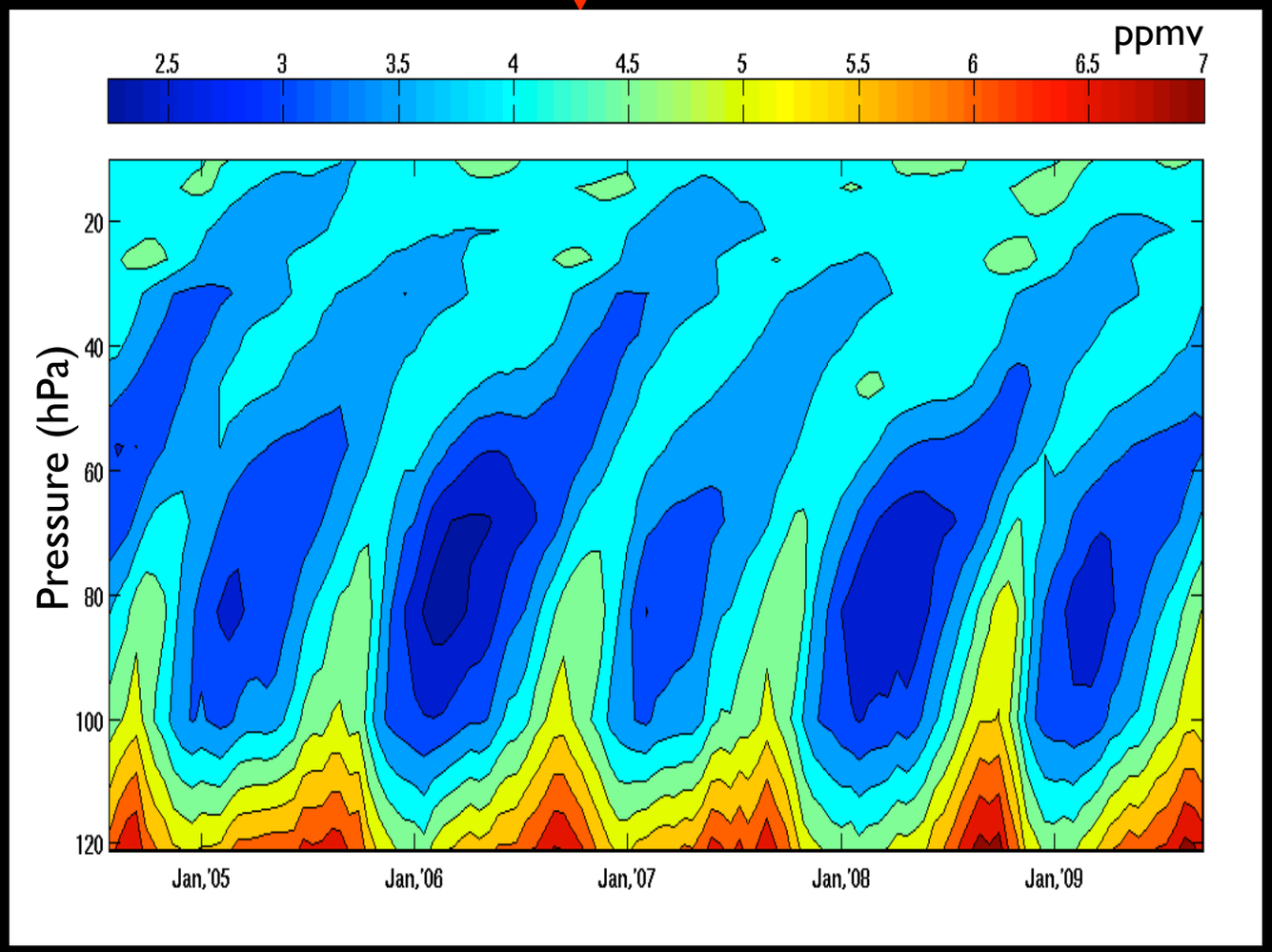
Our analysis will focus on the tropics between 8S-8N

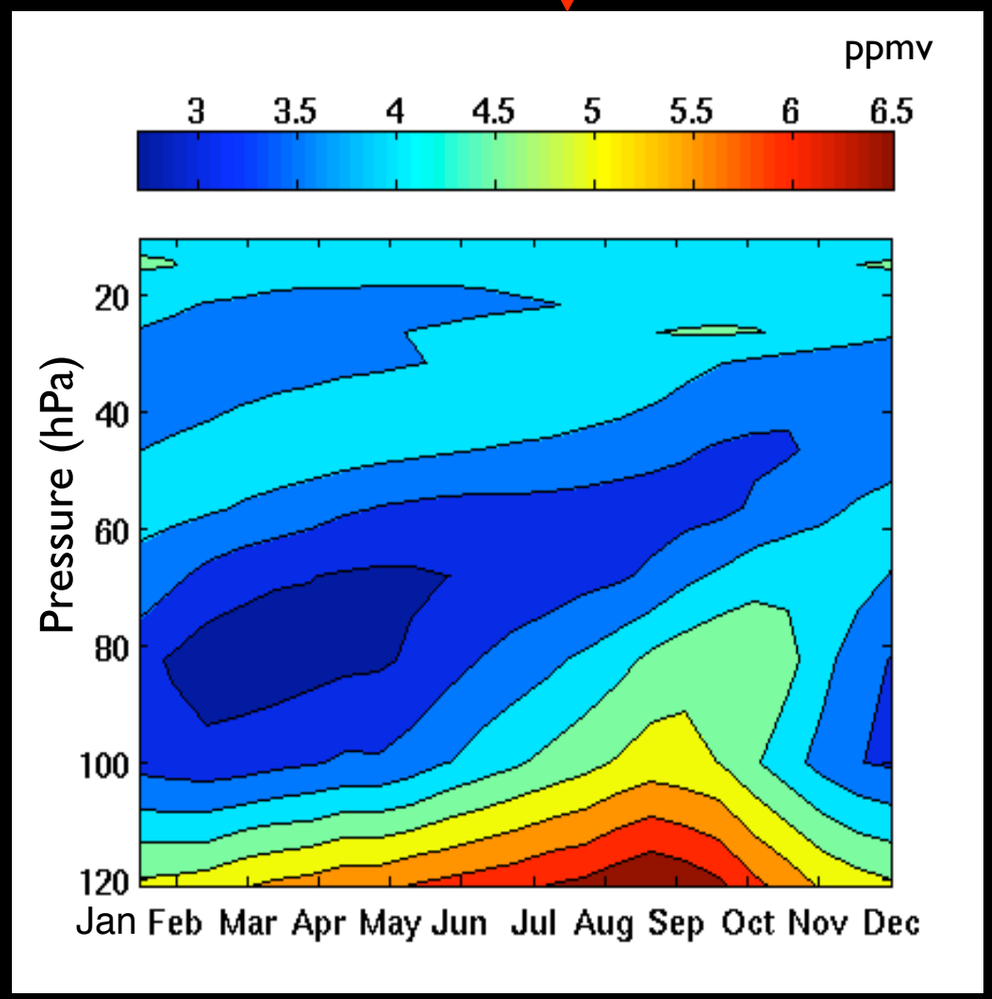
Seasonal and Annual Cycle of H_2O

AIRS/MLS Time Series

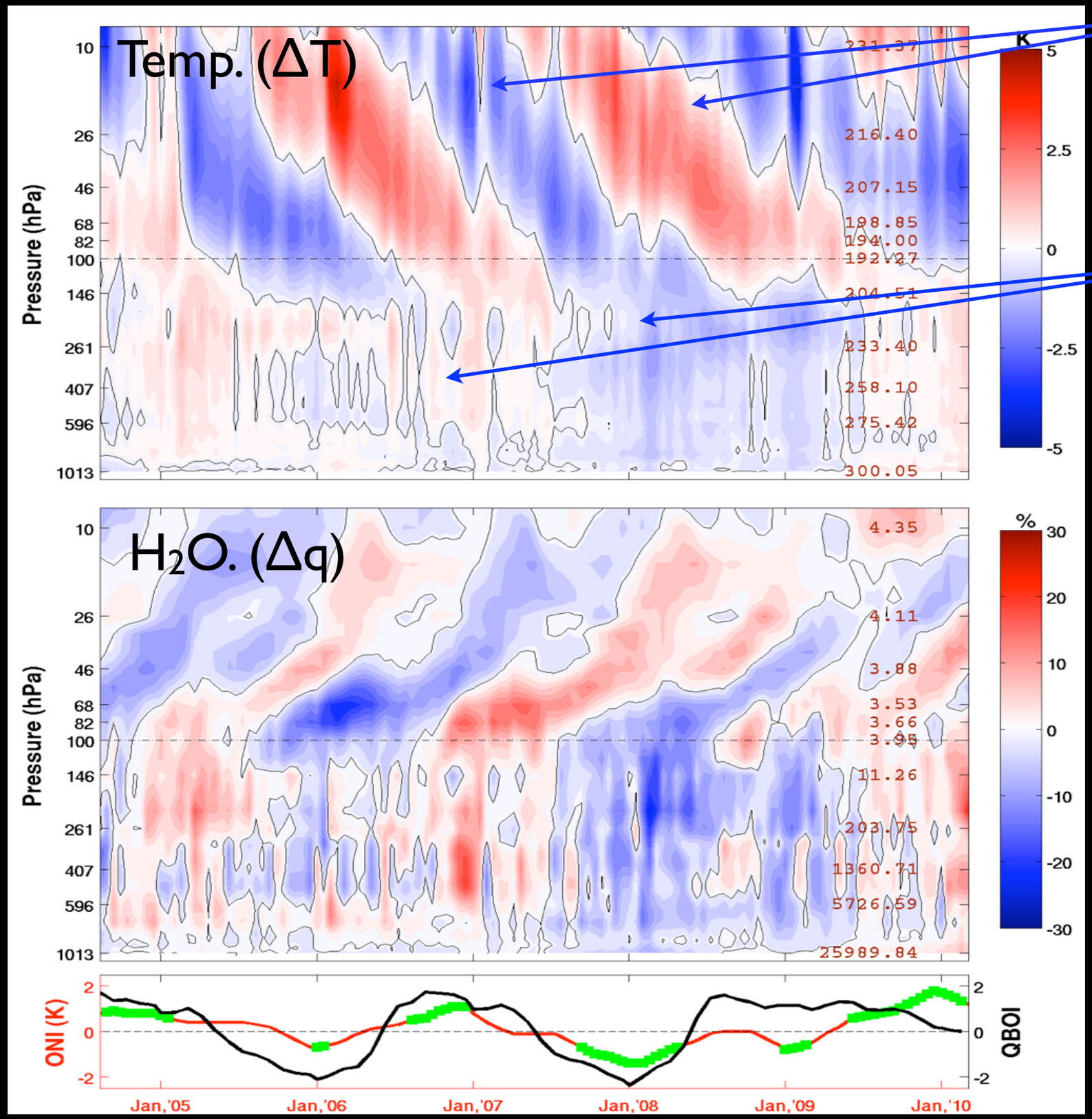
minus

Annual Cycle





Surface to Stratosphere Interannual Variability of T and H_2O

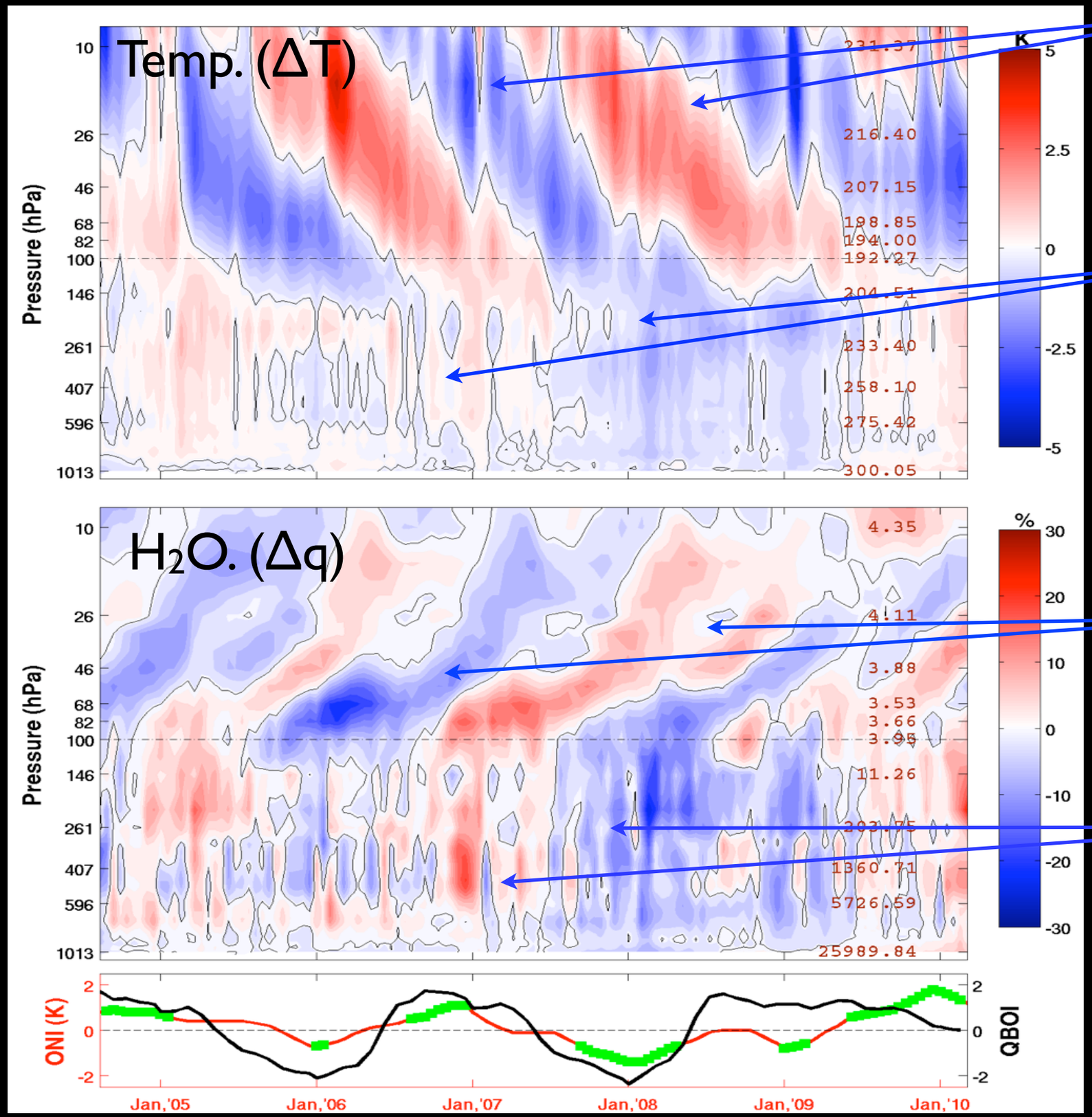


Quasi-biennial Oscillation (QBO) for T with period ~28 months

ENSO

Liang, et.al, JGR (2011), In Press

Surface to Stratosphere Interannual Variability of T and H_2O



Quasi-biennial Oscillation (QBO) for T with period ~28 months

ENSO

Interannual Variability of tape recorder

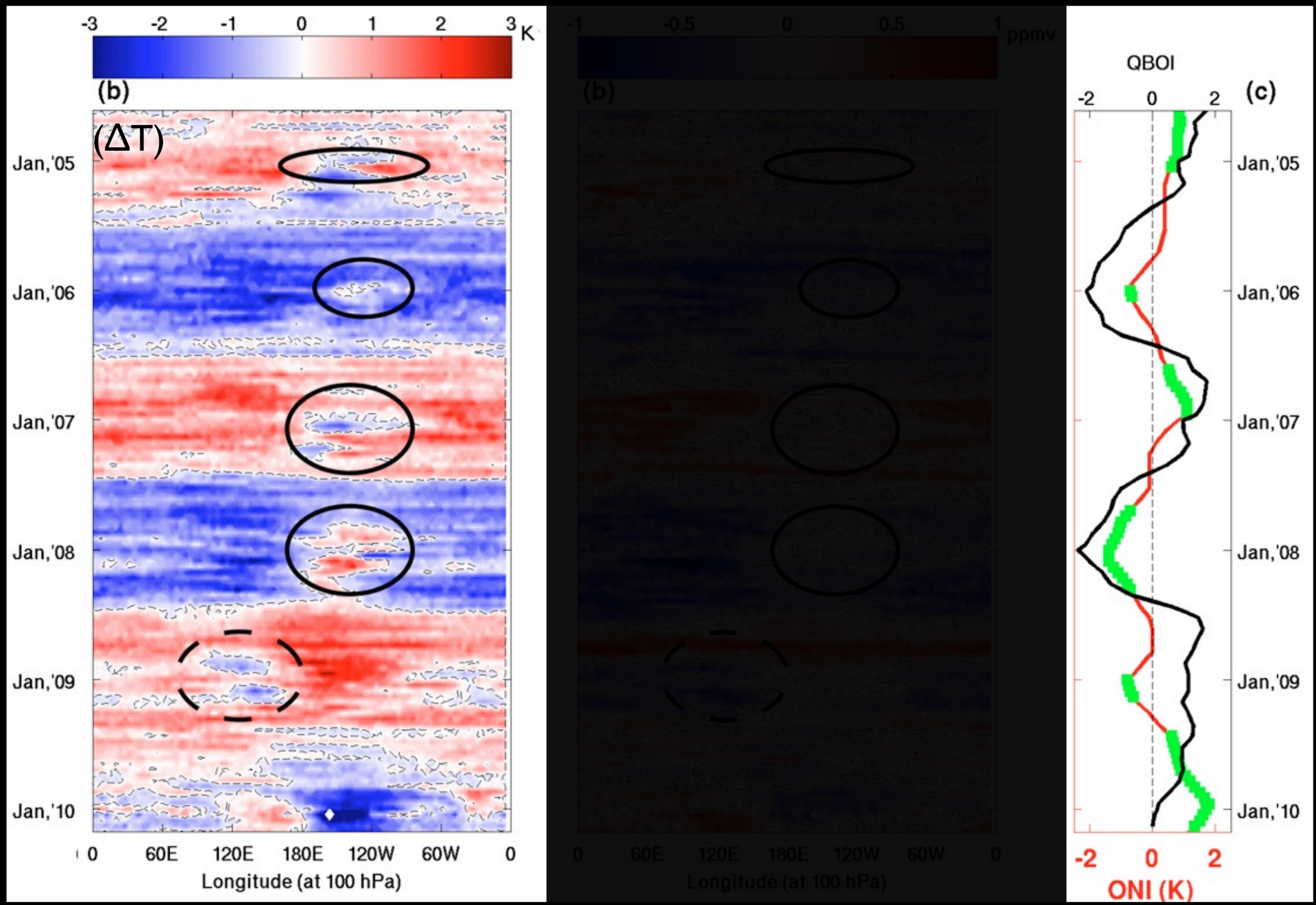
(Randel, et. al., JAS, 1998, Gellar, et. al., JAS, 2002)

ENSO

New vertical picture of H_2O

Liang, et.al, JGR (2011), In Press

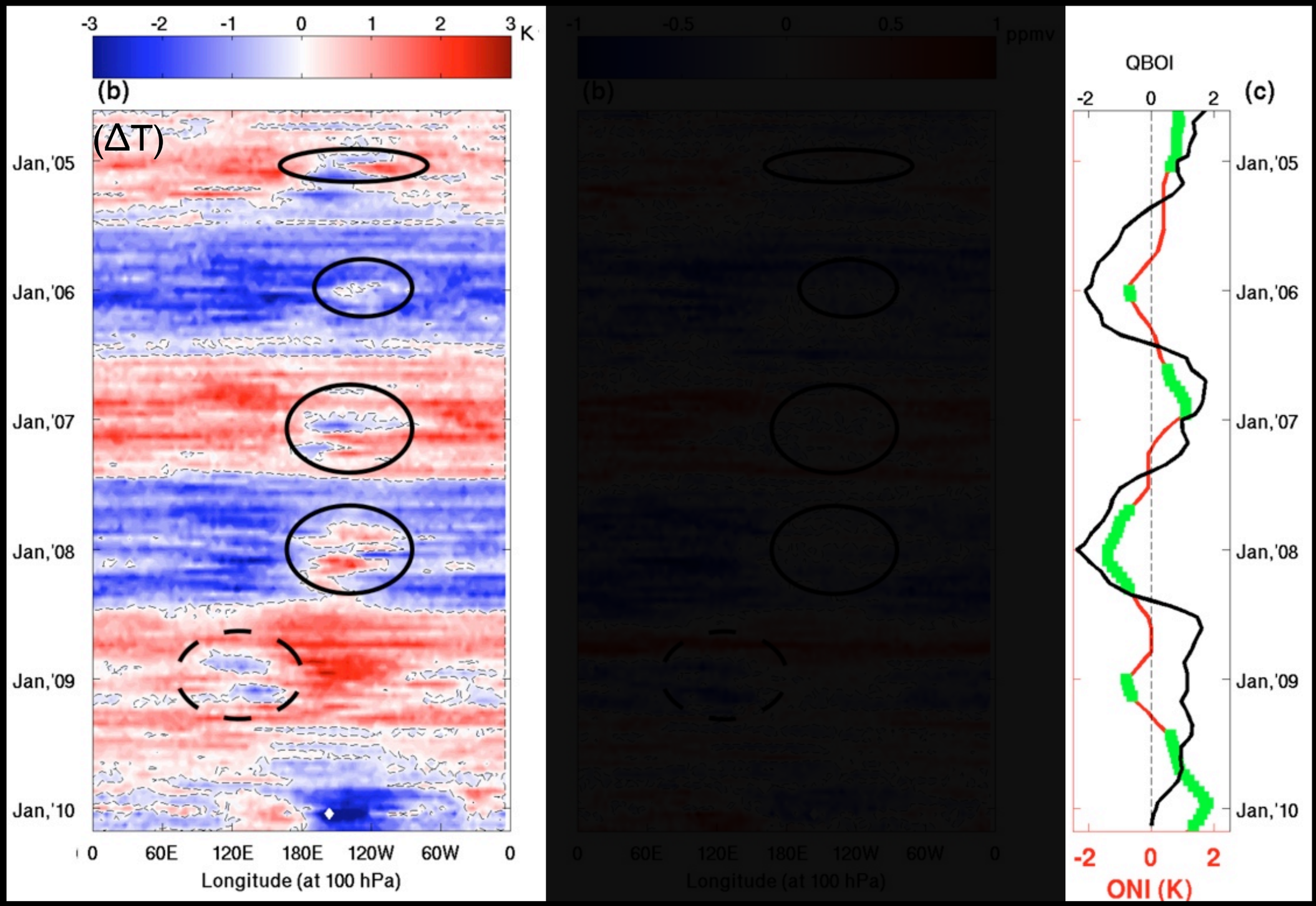
Zonal Structure of ΔT and Δq



Liang, et.al, JGR (2011), In Press

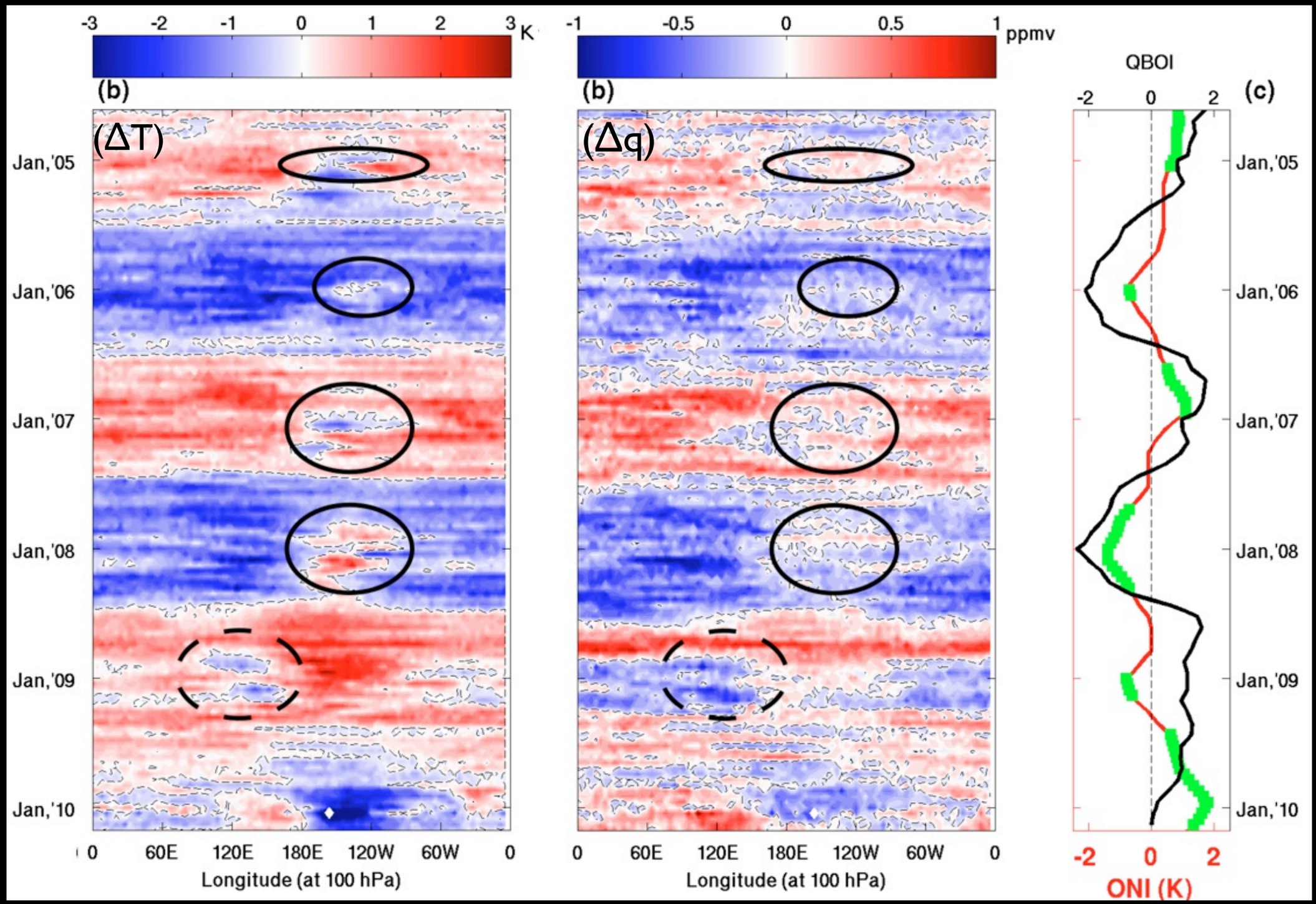
Zonal Structure of ΔT and Δq

Correlation between ΔT and QBO: R=0.86



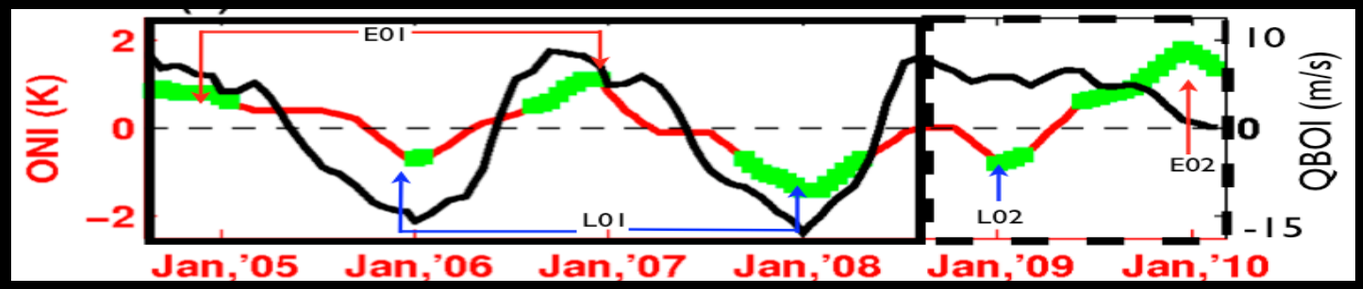
Liang, et.al, JGR (2011), In Press

ΔT and Δq mainly driven by QBO *(Randel, et.al, 1998)* but with some zonal asymmetries



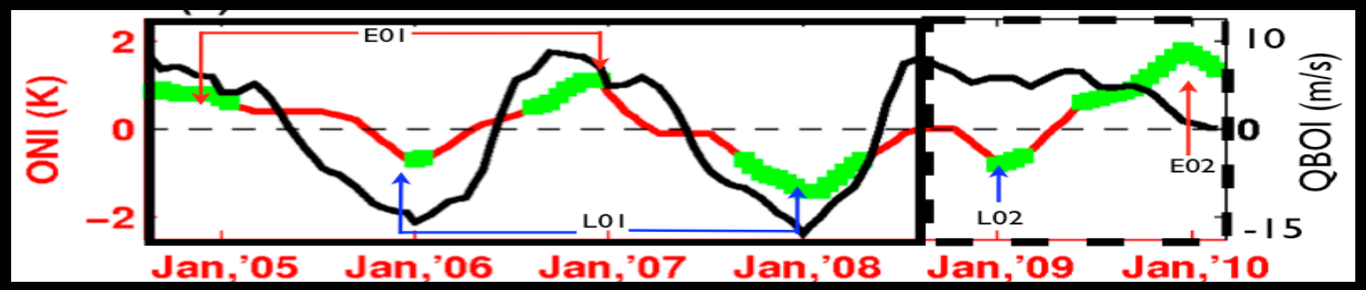
Liang, et.al, JGR (2011), In Press

ENSO Composites



ENSO Phase
E+ = El Niño
E- = La Niña

QBO Phase
Q+ = Westerly
Q- = Easterly



ENSO Phase
E+ = El Niño
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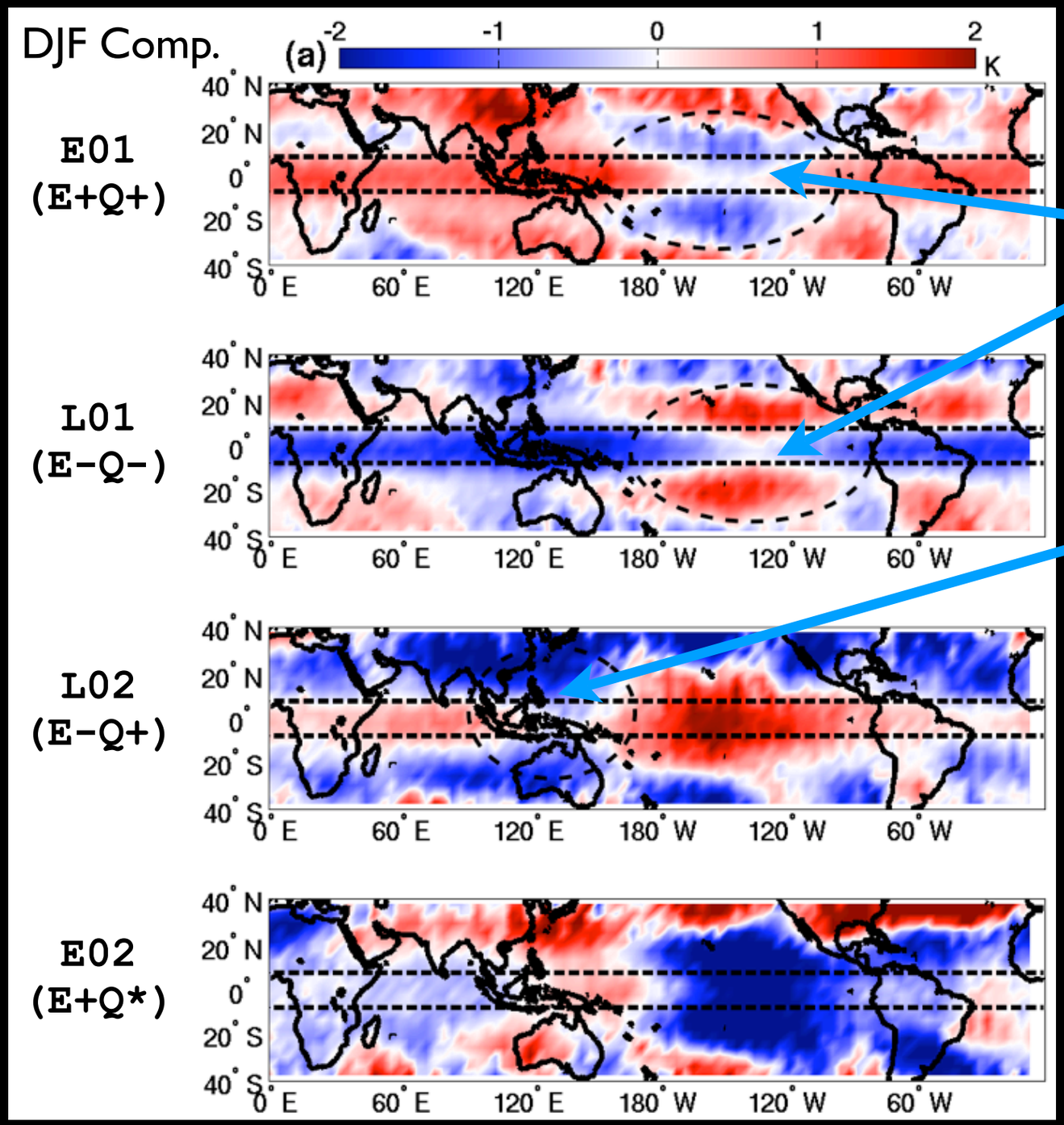
Q- = Easterly

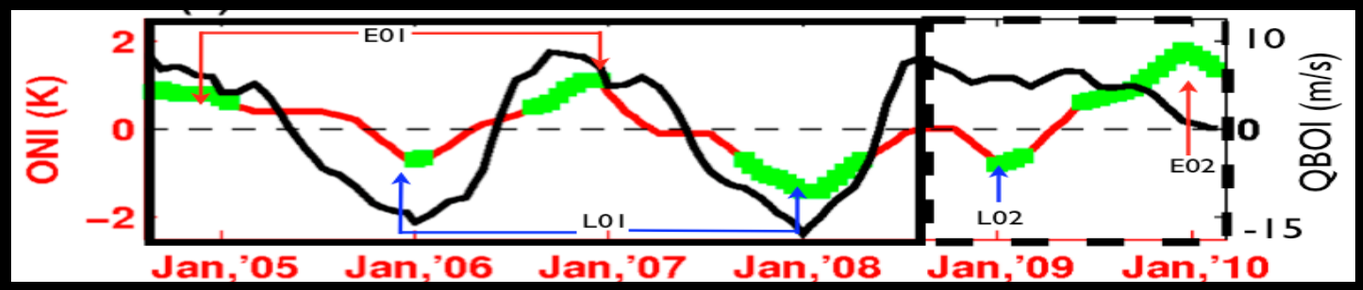
ΔT (100 hPa)

DJF Comp.



- Zonal break over TCP when QBO and ENSO in phase
- TWP experiences zonal break when ENSO and QBO out of phase

Liang, et.al, JGR (2011), In Press



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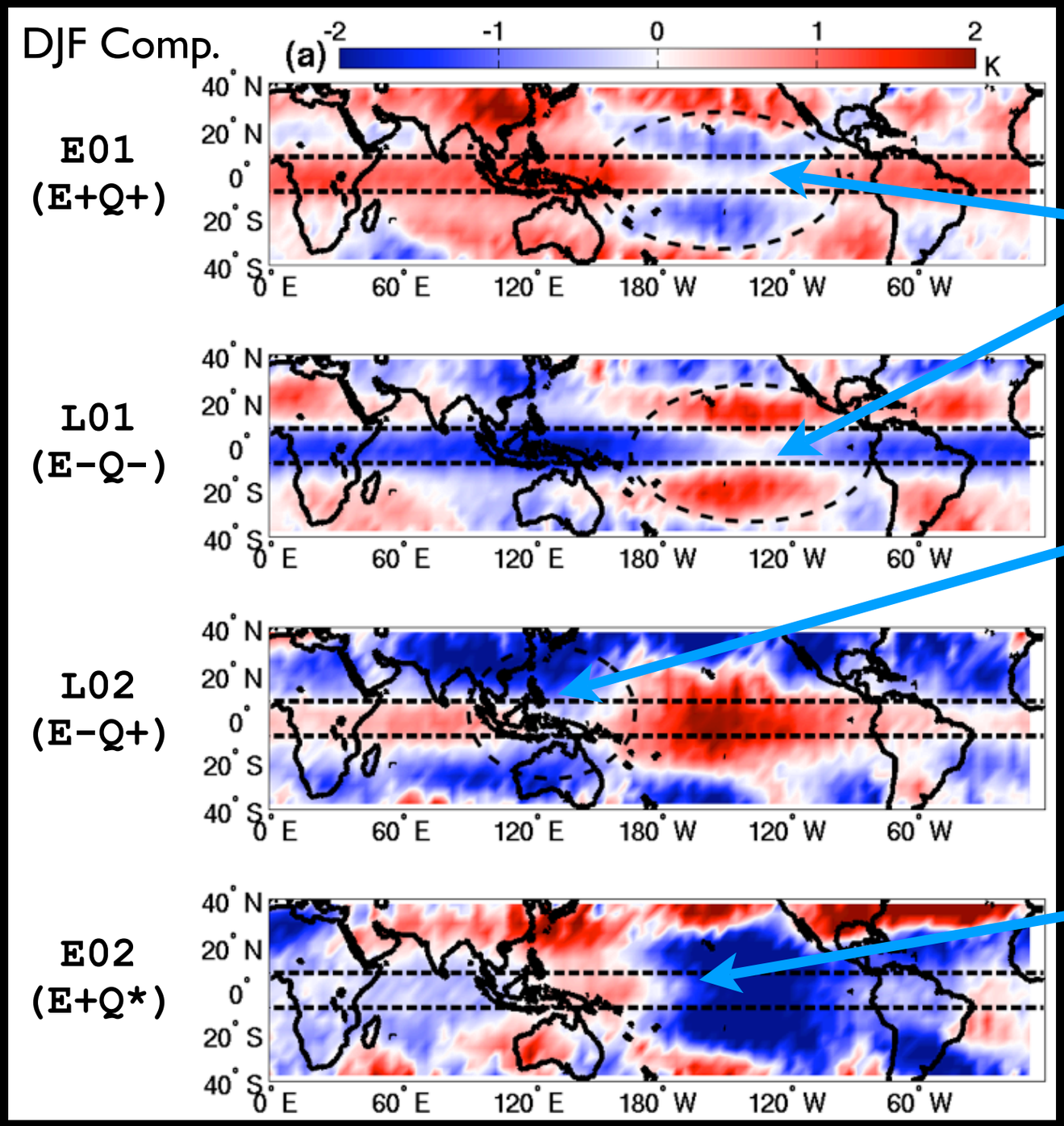
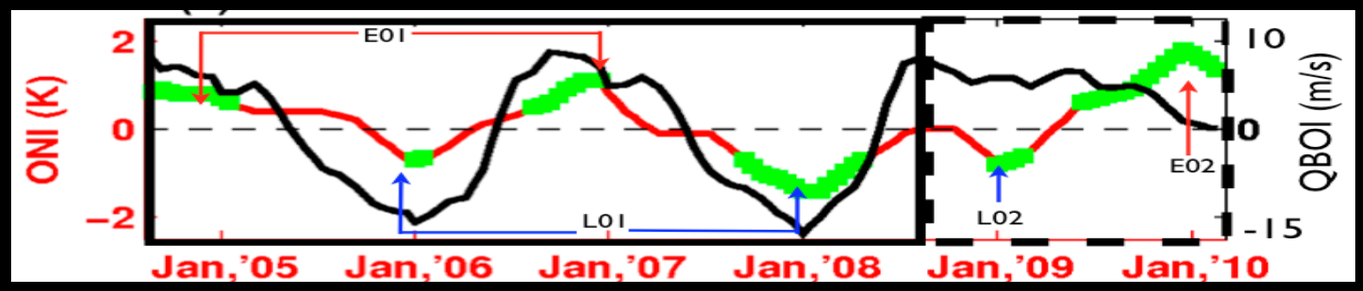
ΔT (100 hPa)



- Zonal break over TCP when QBO and ENSO in phase
- TWP experiences zonal break when ENSO and QBO out of phase
- E02 event primarily an ENSO signal; QBO in transition

Liang, et.al, JGR (2011), In Press



ENSO Phase
E+ = El Niño
E- = La Niña

QBO Phase
Q+ = Westerly
Q- = Easterly

ΔT (100 hPa)

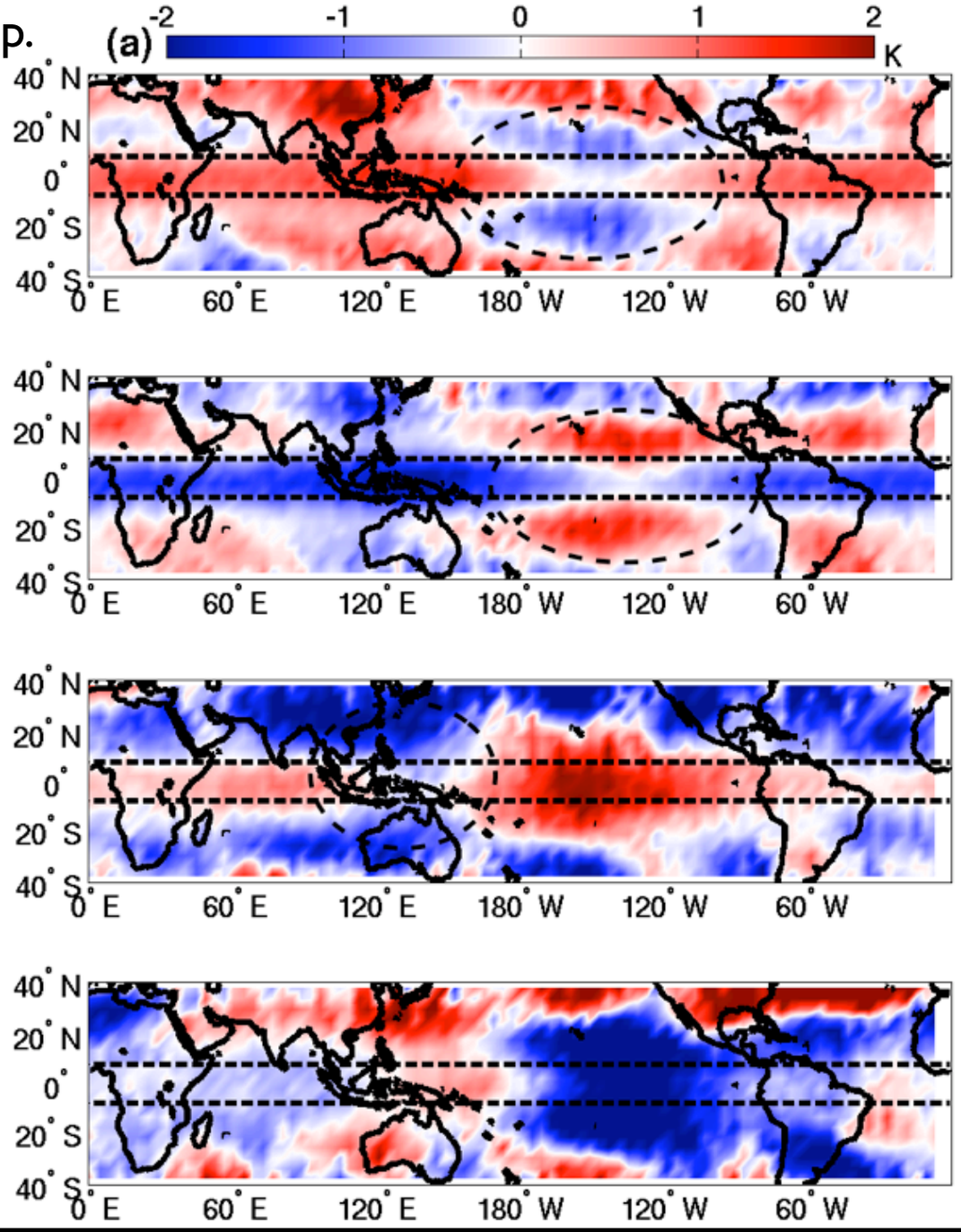
DJF Comp.

E01 (E+Q+)

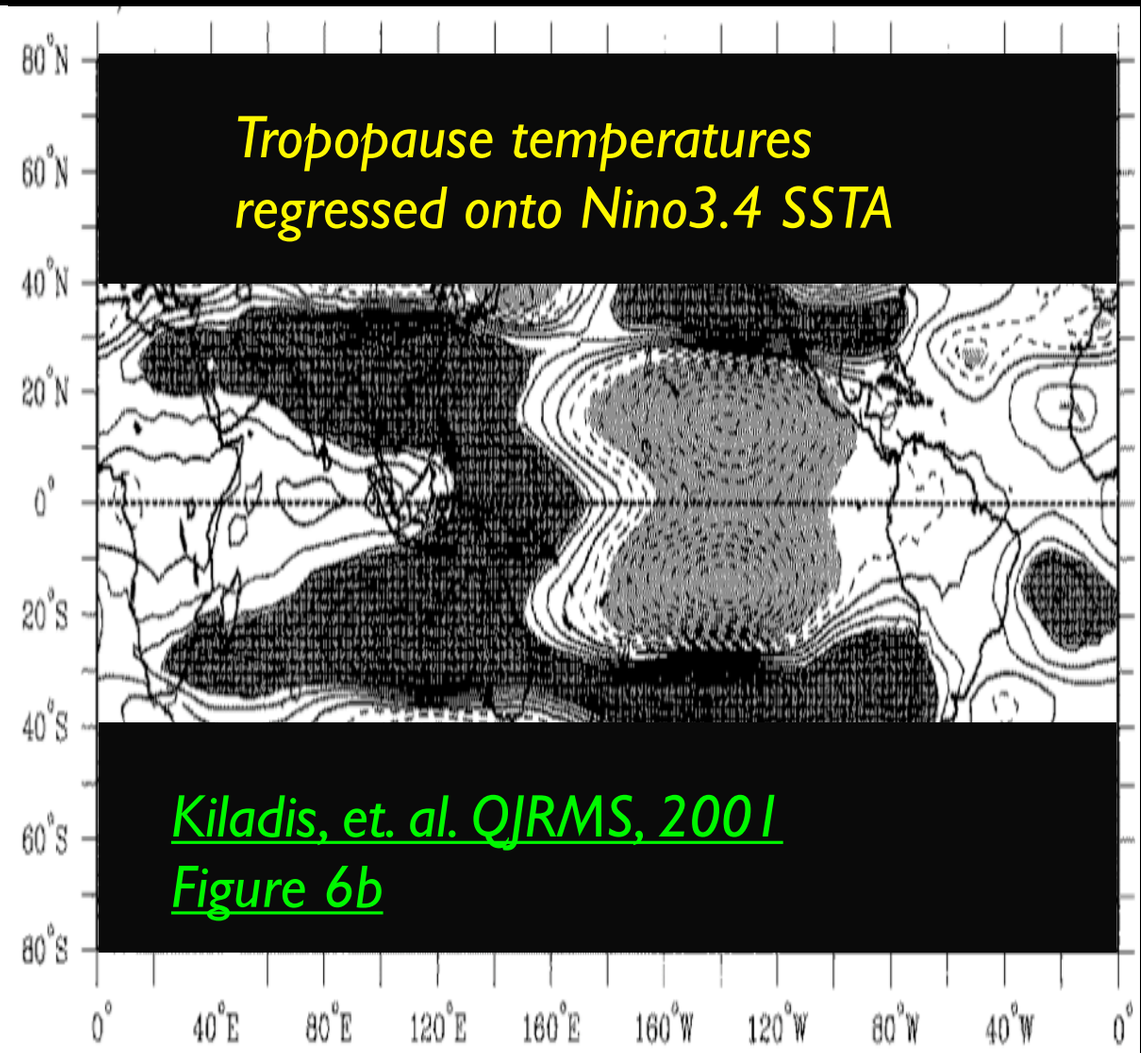
L01 (E-Q-)

L02 (E-Q+)

E02 (E+Q*)

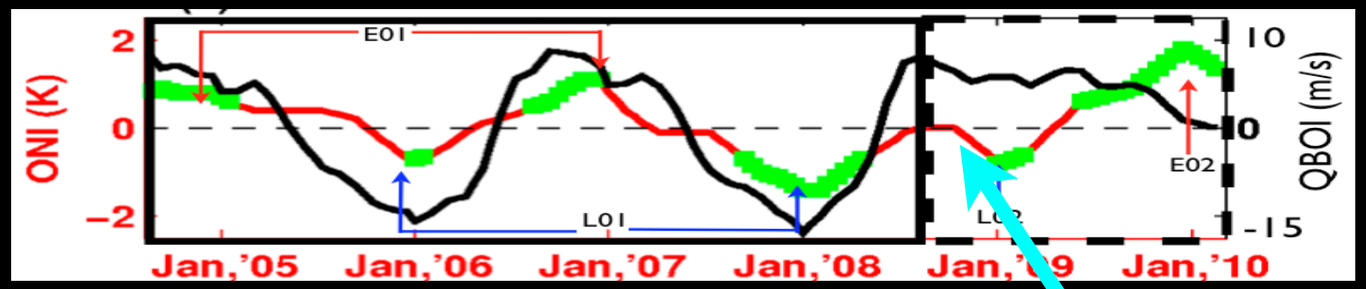


Tropopause temperatures regressed onto Nino3.4 SSTA



Kiladis, et. al. QJRMS, 2001
Figure 6b

Liang, et.al, JGR (2011), In Press



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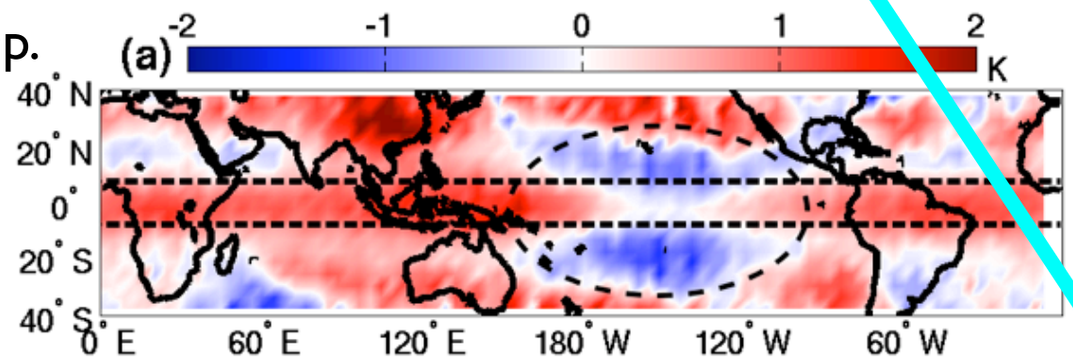
QBO Phase
Q+ = Westerly
Q- = Easterly

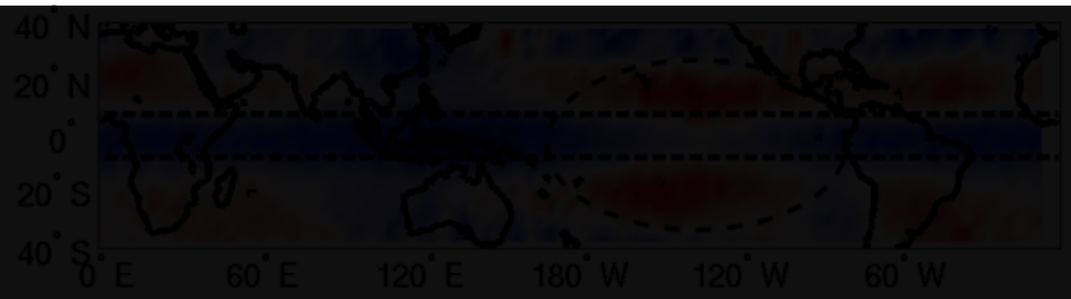
ΔT (100 hPa)

DJF Comp.

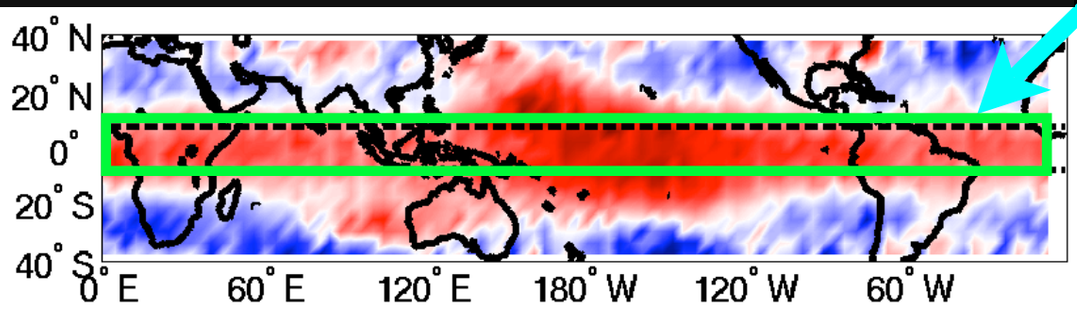
E01 (E+Q+)

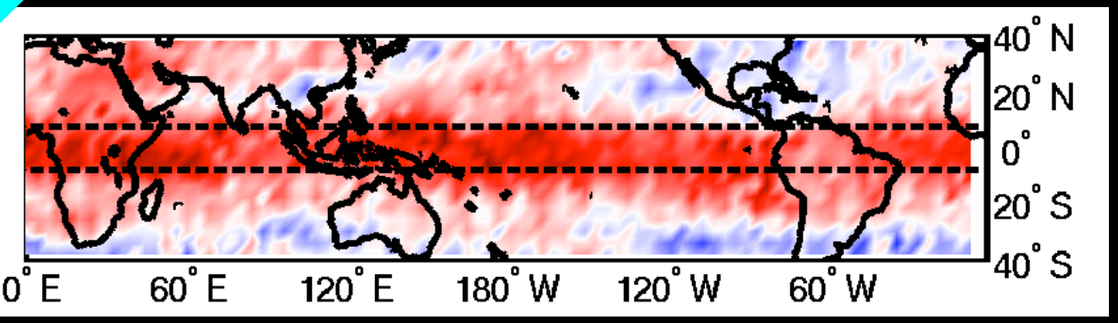


L01 (E-Q-)

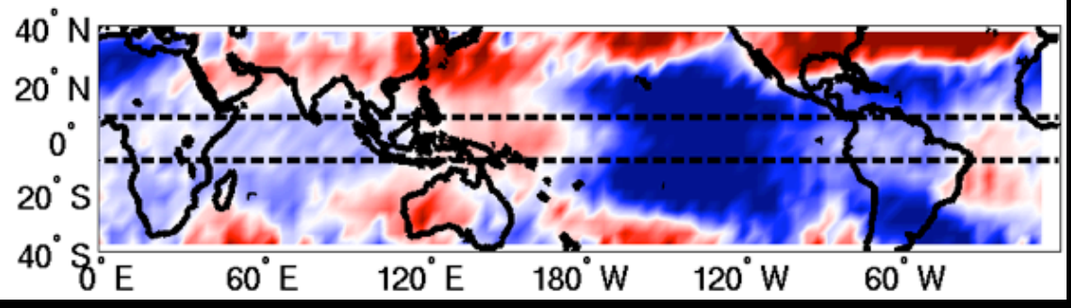


For ONI ~ 0 (~Fall of 2008), and +QBOI we see the zonal symmetry of the QBO

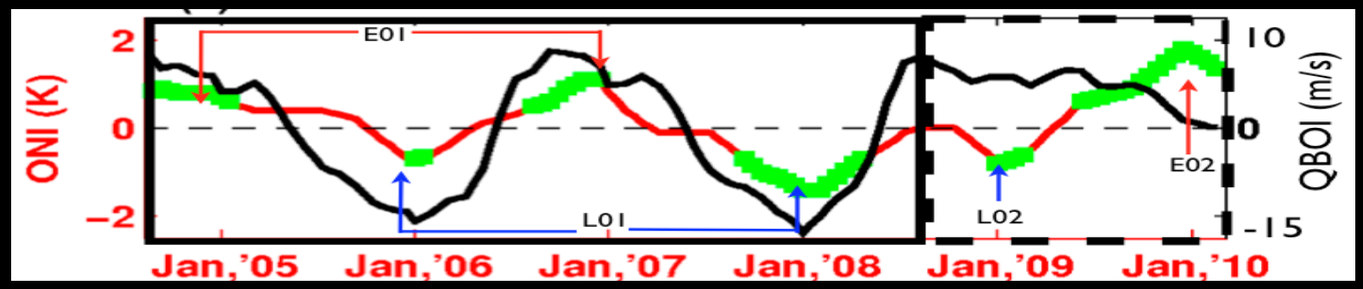




E02 (E+Q*)



Liang, et.al, JGR (2011), In Press



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QBO Phase
Q+ = Westerly
Q- = Easterly

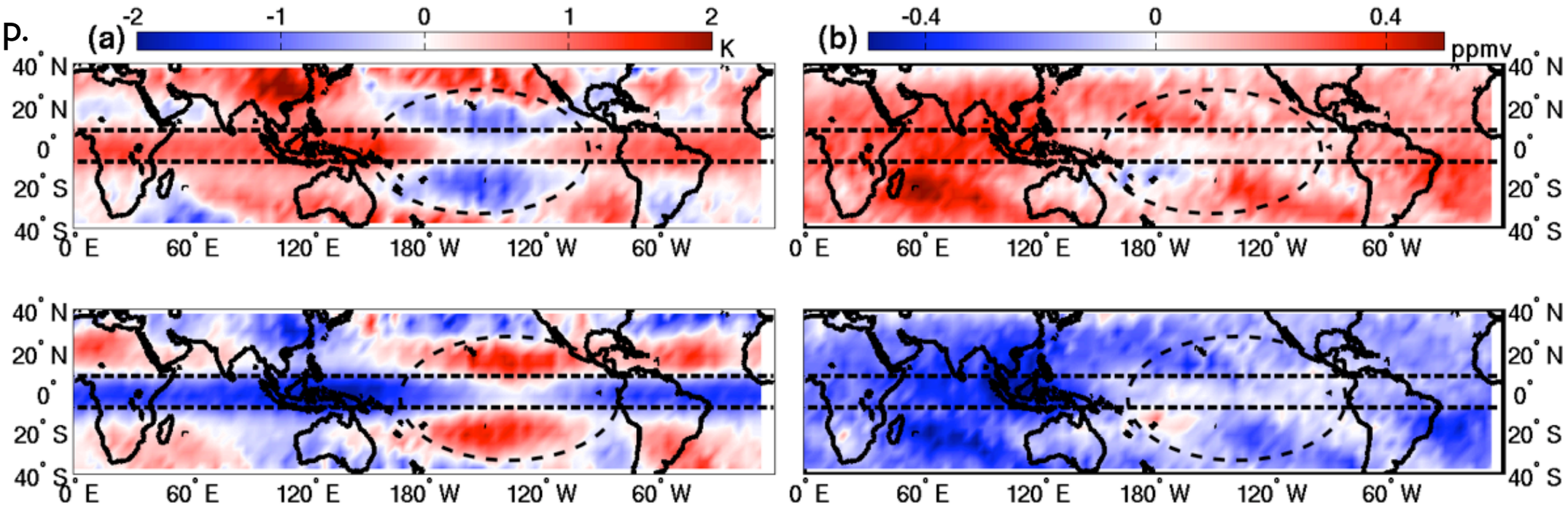
ΔT (100 hPa)

Δq (100 hPa)

DJF Comp.

E01 (E+Q+)

L01 (E-Q-)



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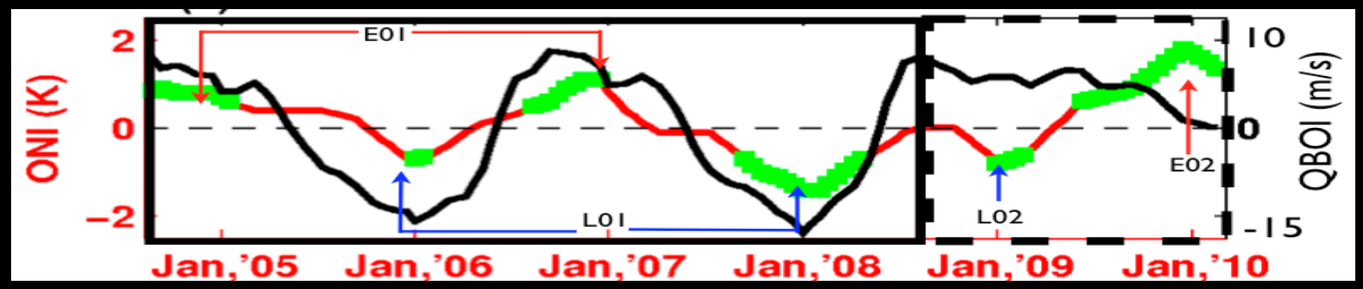

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Q- = Easterly

ΔT (100 hPa)

Δq (100 hPa)

DJF Comp.

E01 (E+Q+)

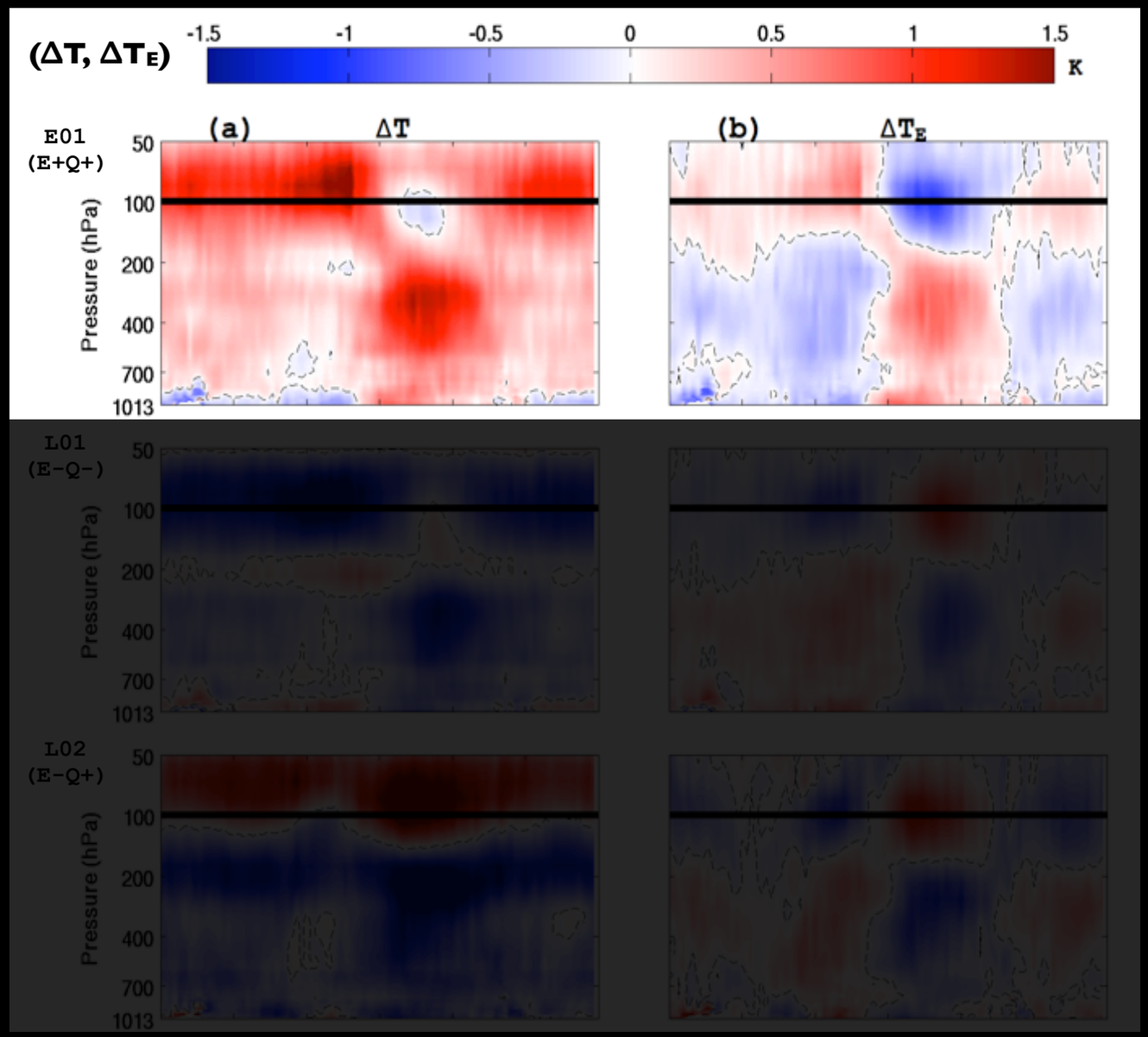
L01 (E-Q-)

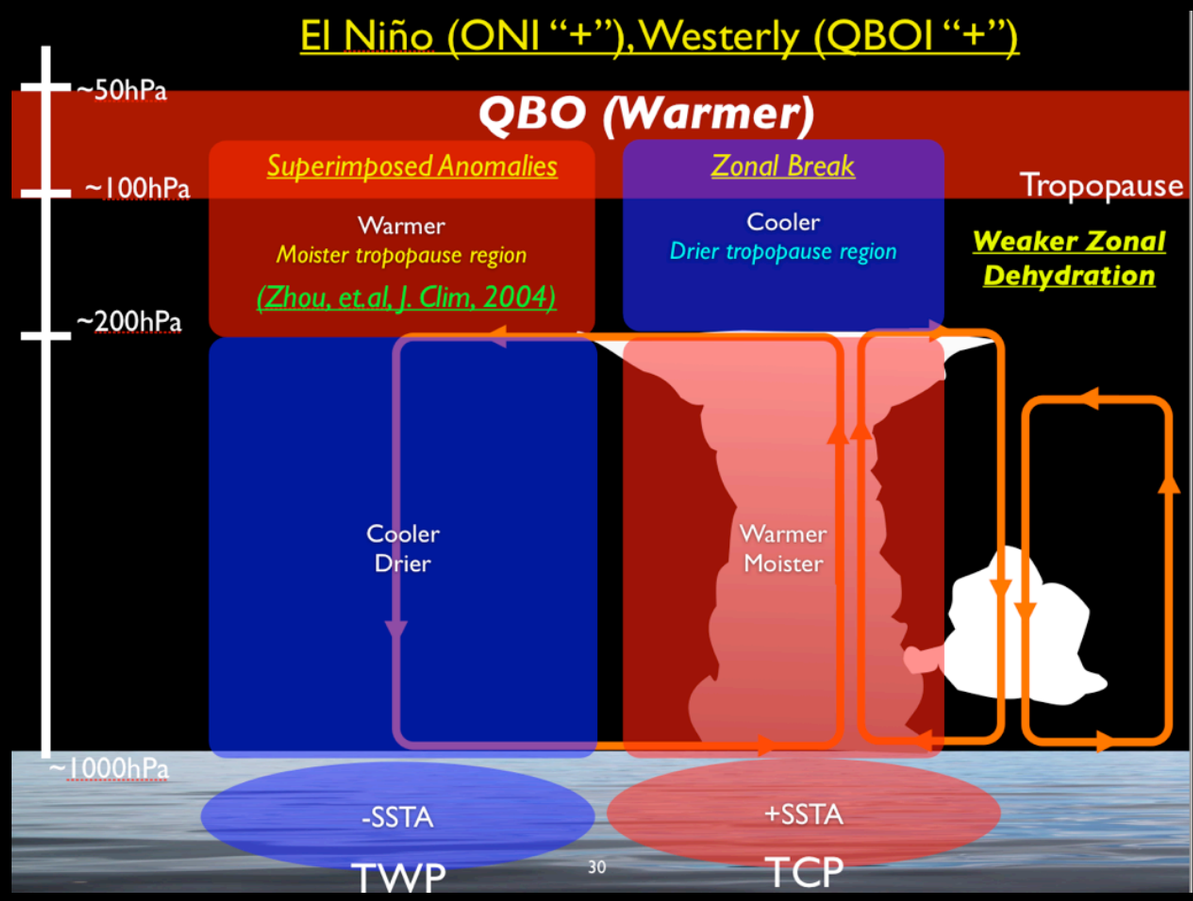
L02 (E-Q+)

E02 (E+Q*)

Liang, et.al, JGR (2011), In Press

Vertical and Zonal Structure of ΔT and Δq

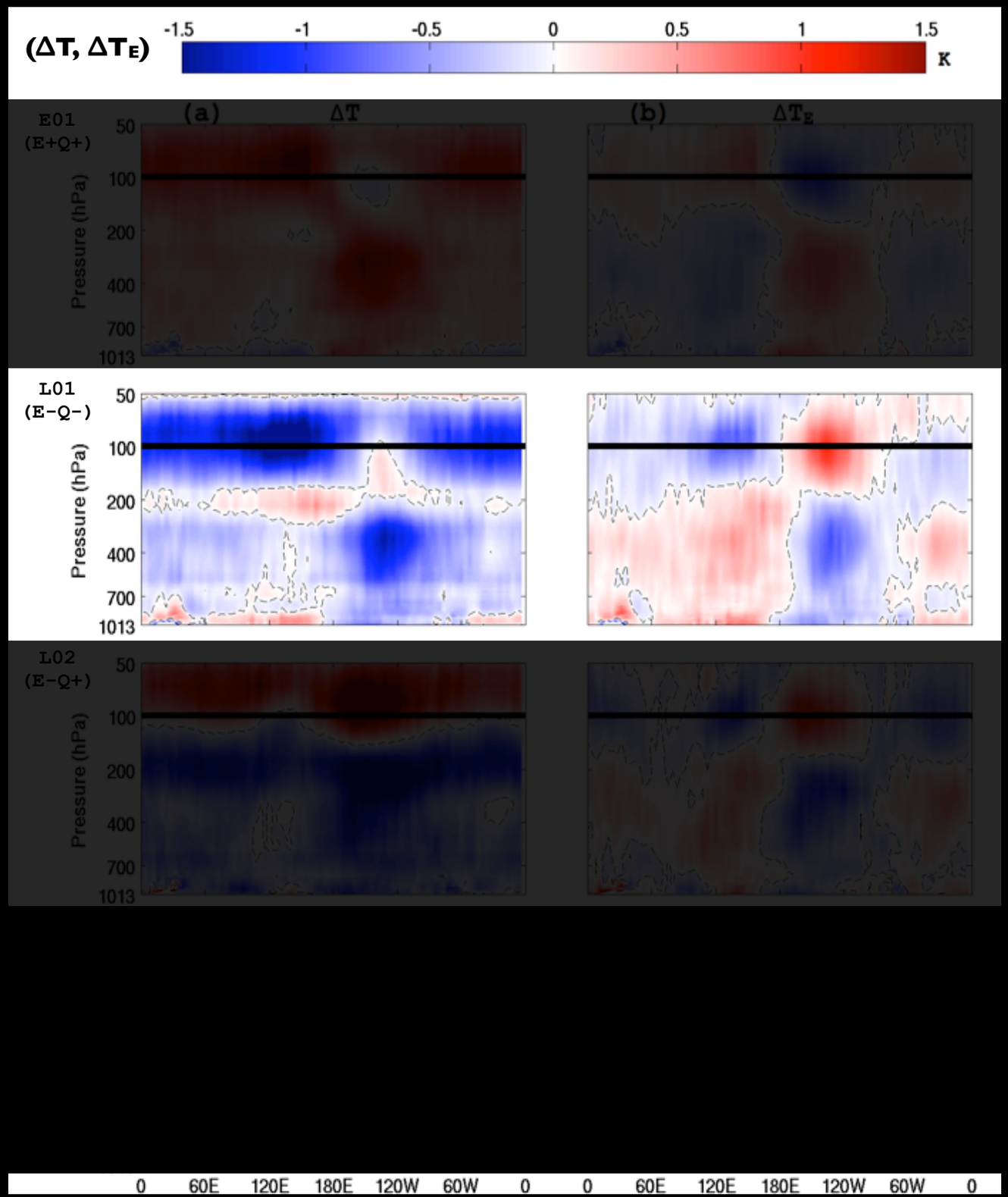


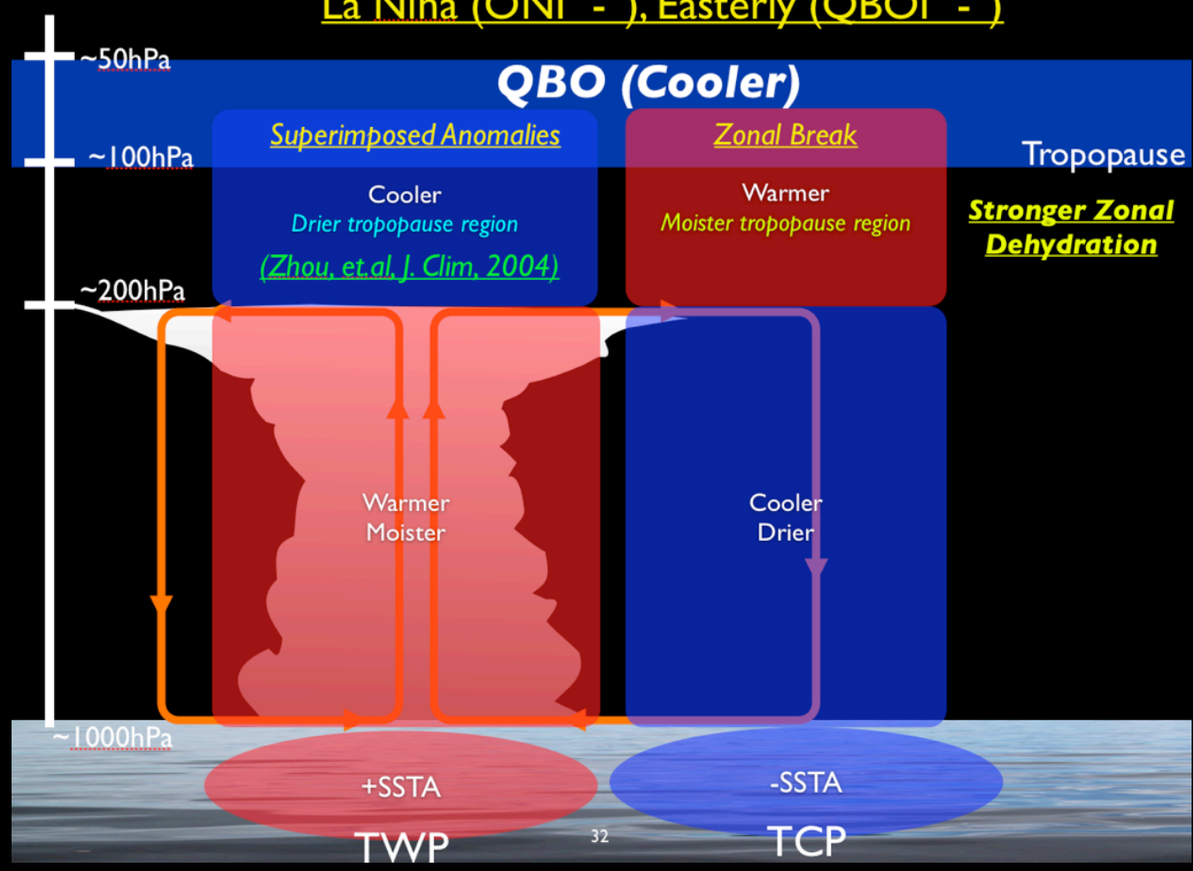


- Zonal break in QBO signal is due to ENSO induces changes in convection
- ΔT_E shows quadrupole structure between TCP and TWP.

Adapted from Liang, et.al, JGR (2011), In Press

Vertical and Zonal Structure of ΔT and Δq





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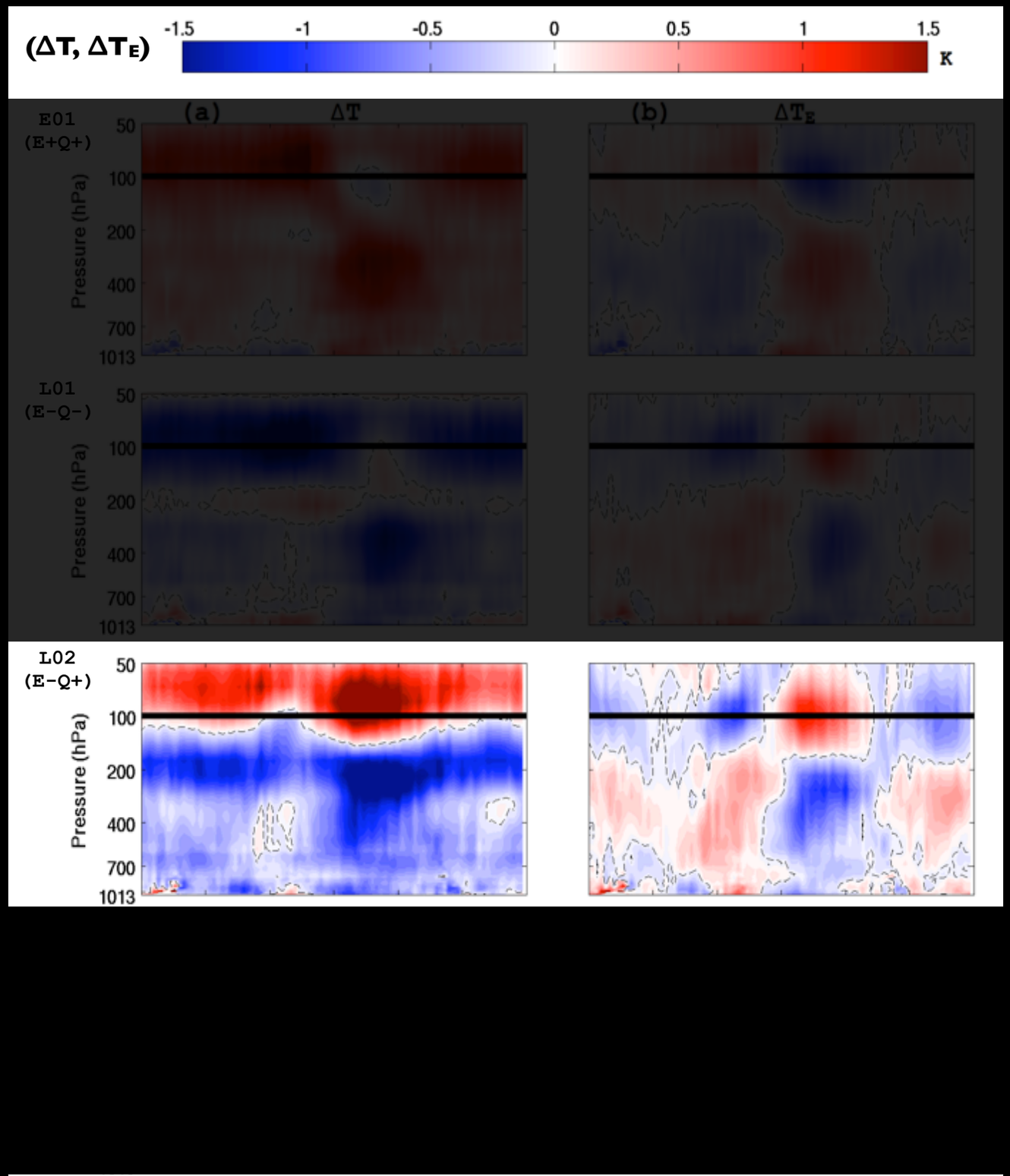

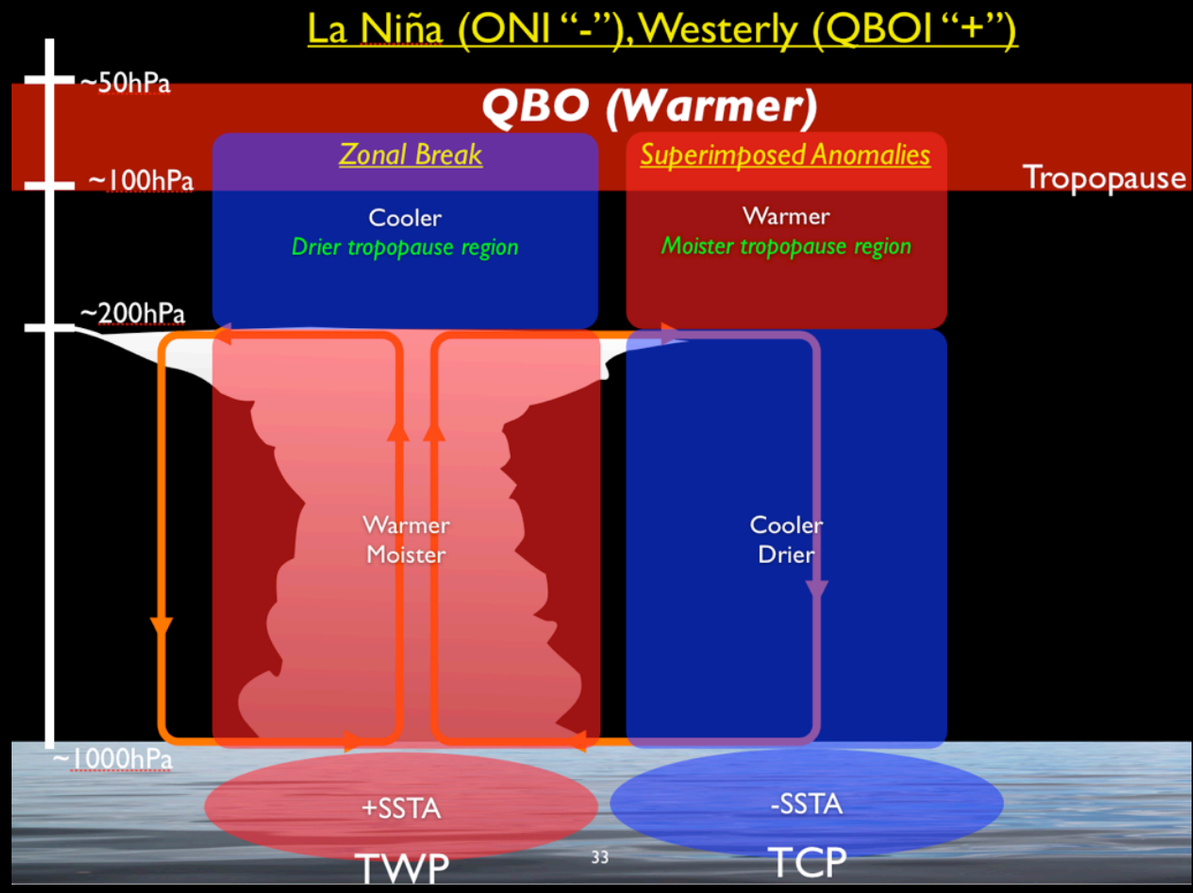

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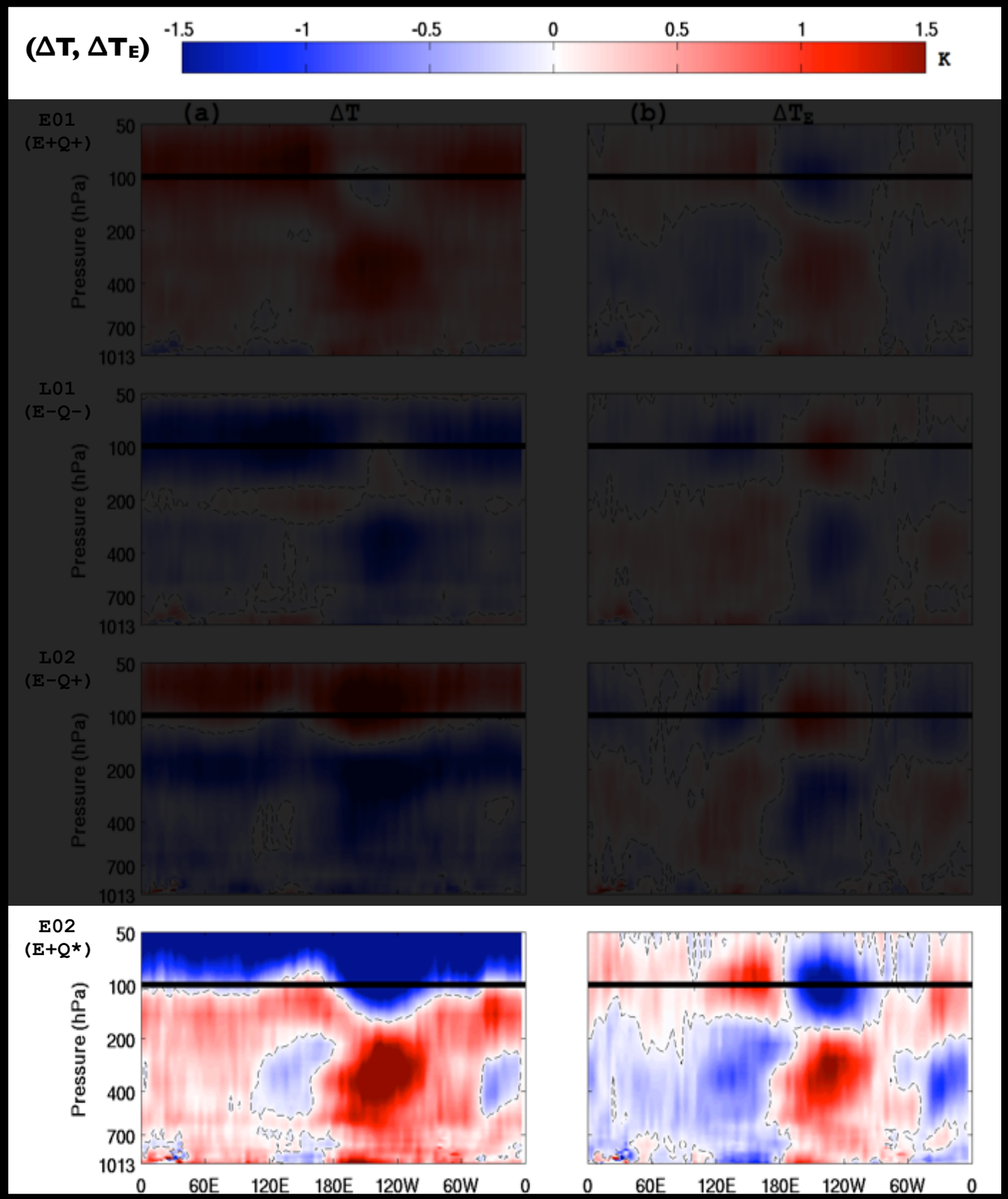

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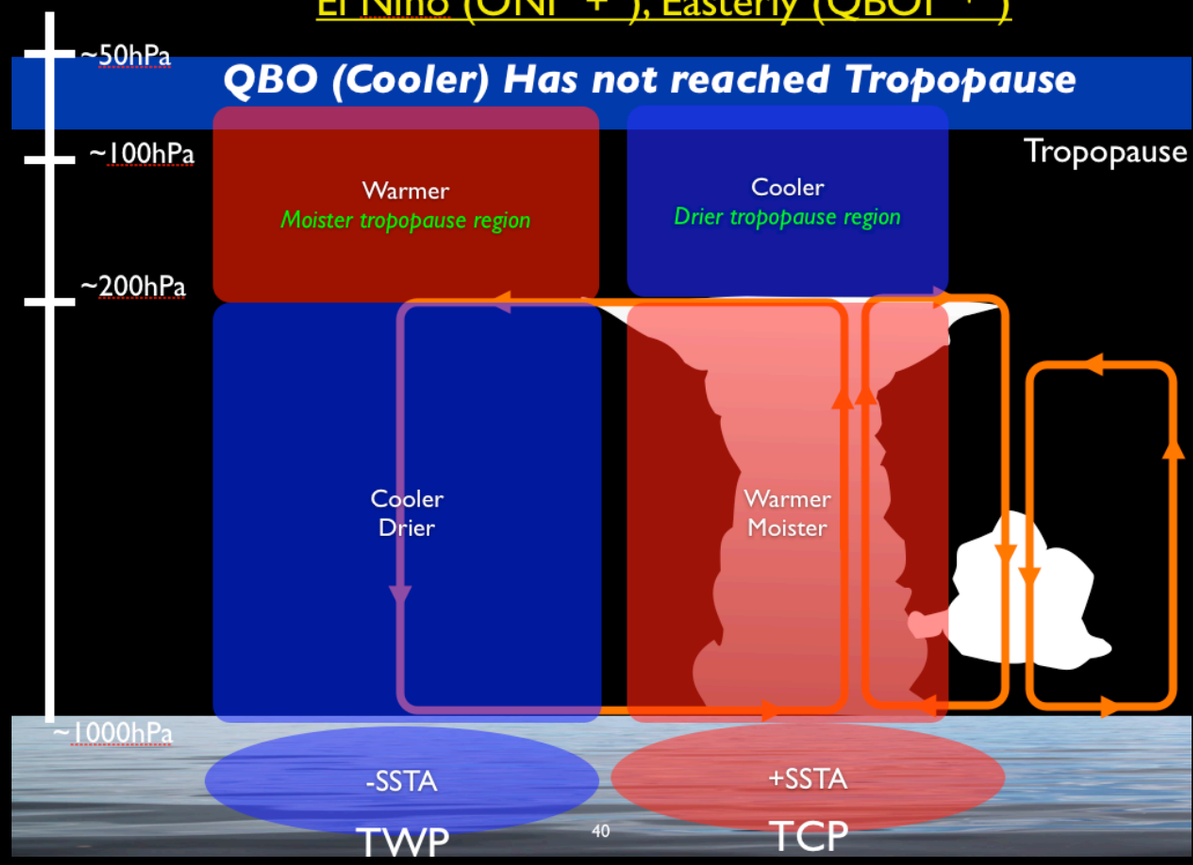

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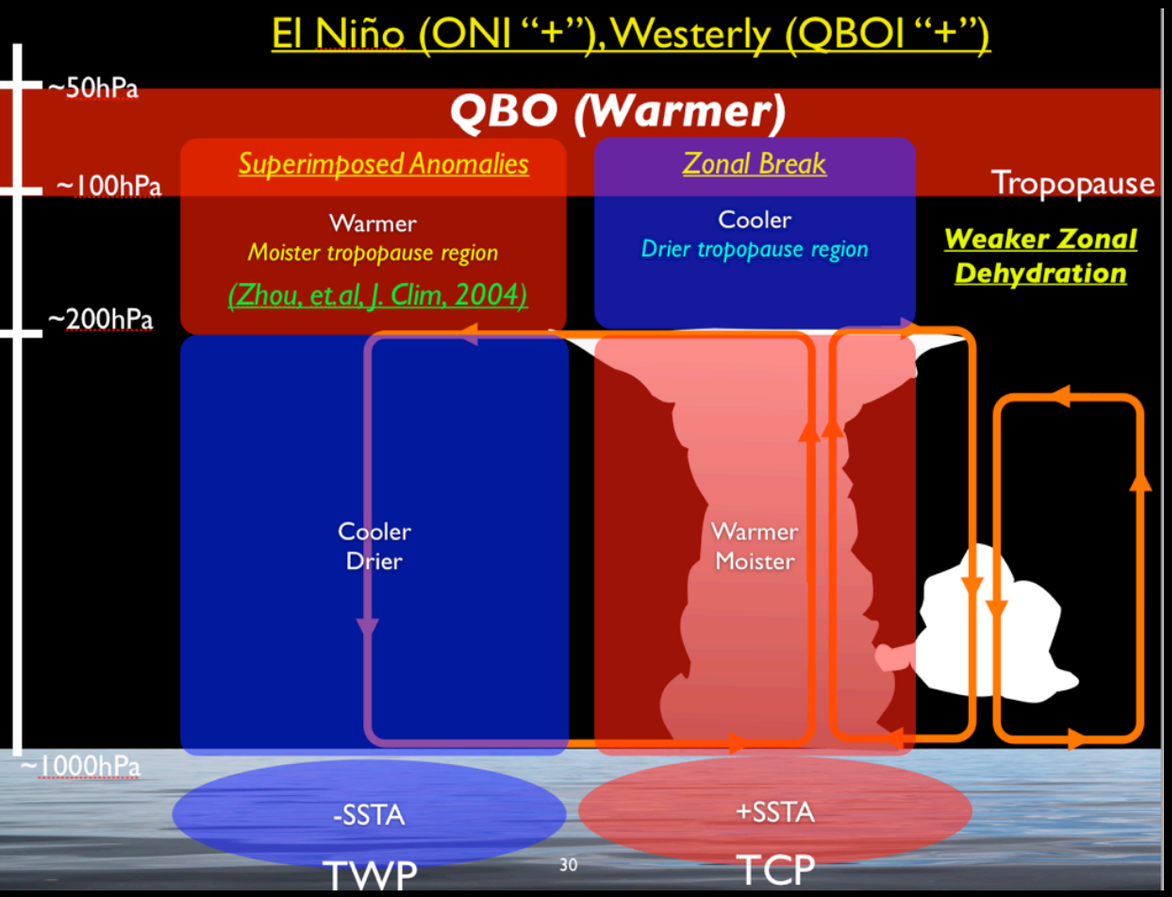
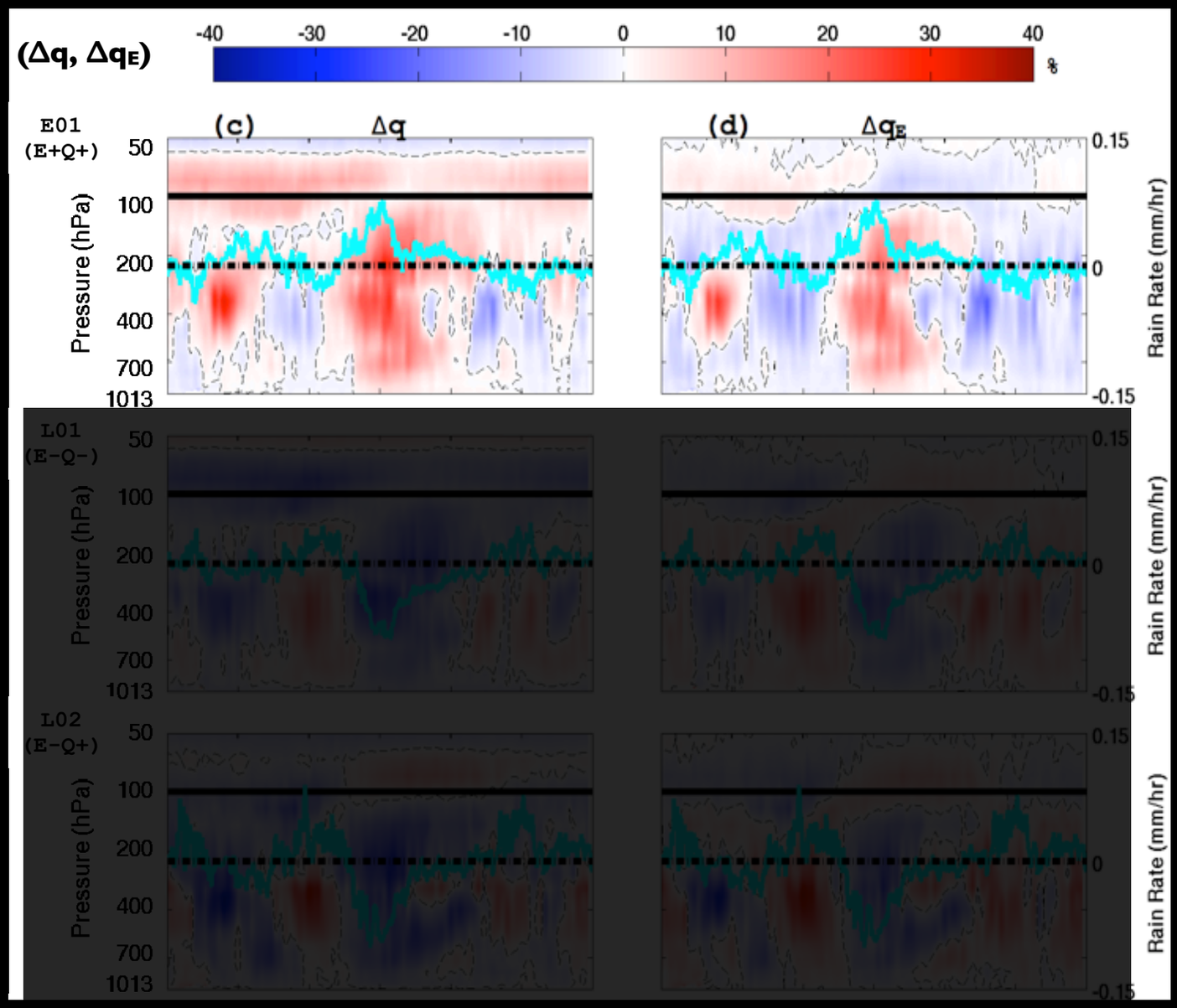
Vertical and Zonal Structure of ΔT and Δq

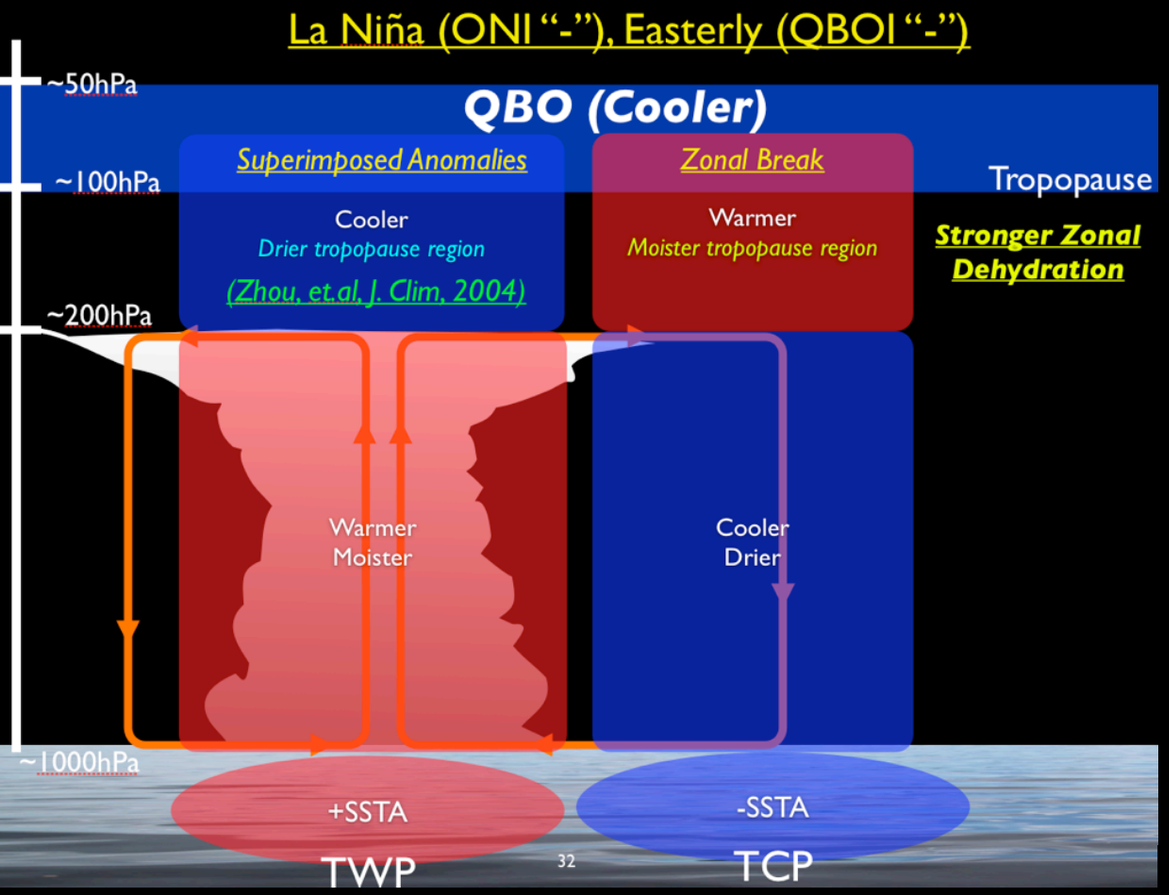




- Moisture and rain rate (TRMM) anomalies track each other
- Δq_E shows moisture also has quadrupole feature like ΔT_E but with different vertical extent

Adapted from Liang, et.al, JGR (2011), In Press

Vertical and Zonal Structure of ΔT and Δq



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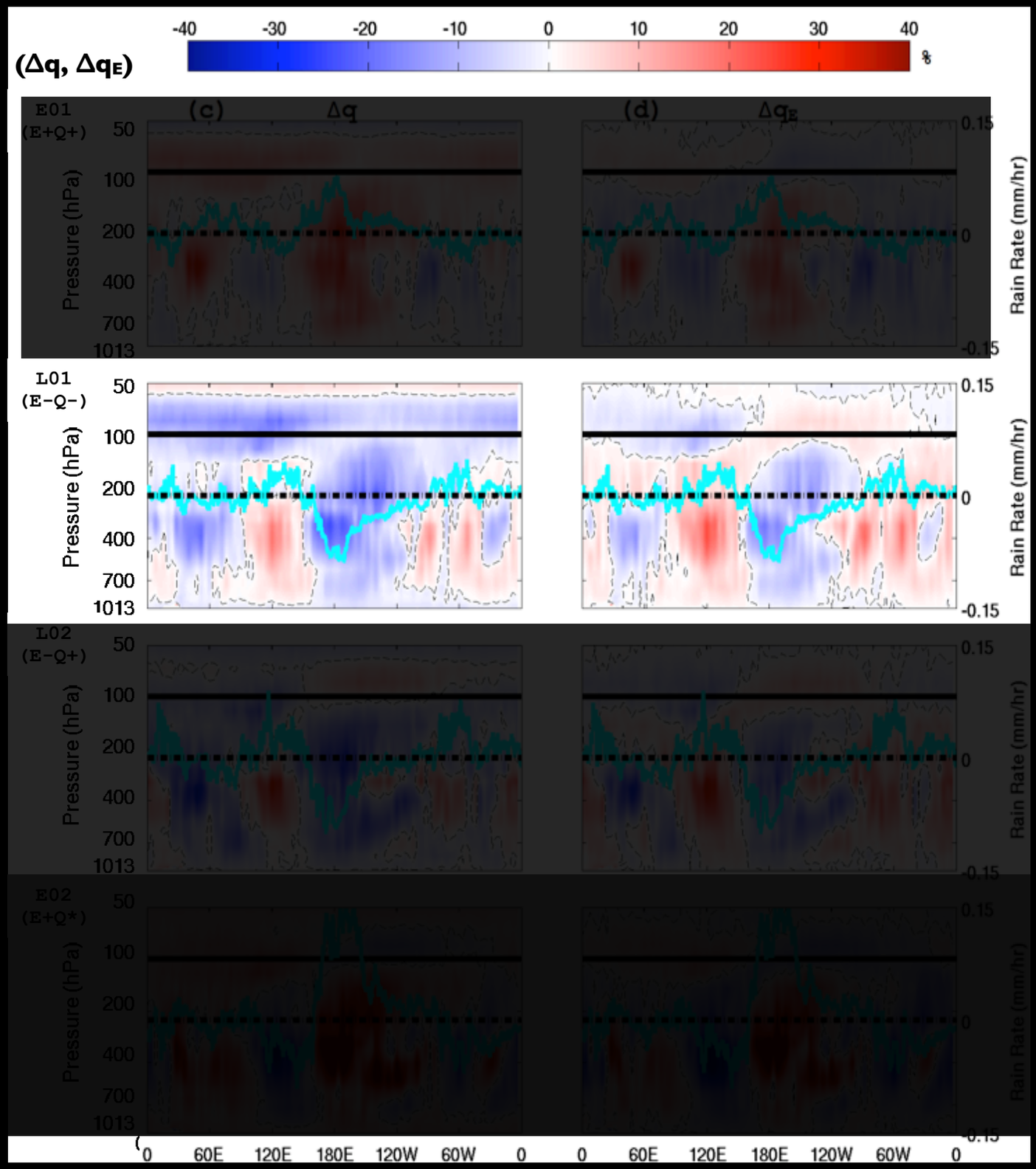
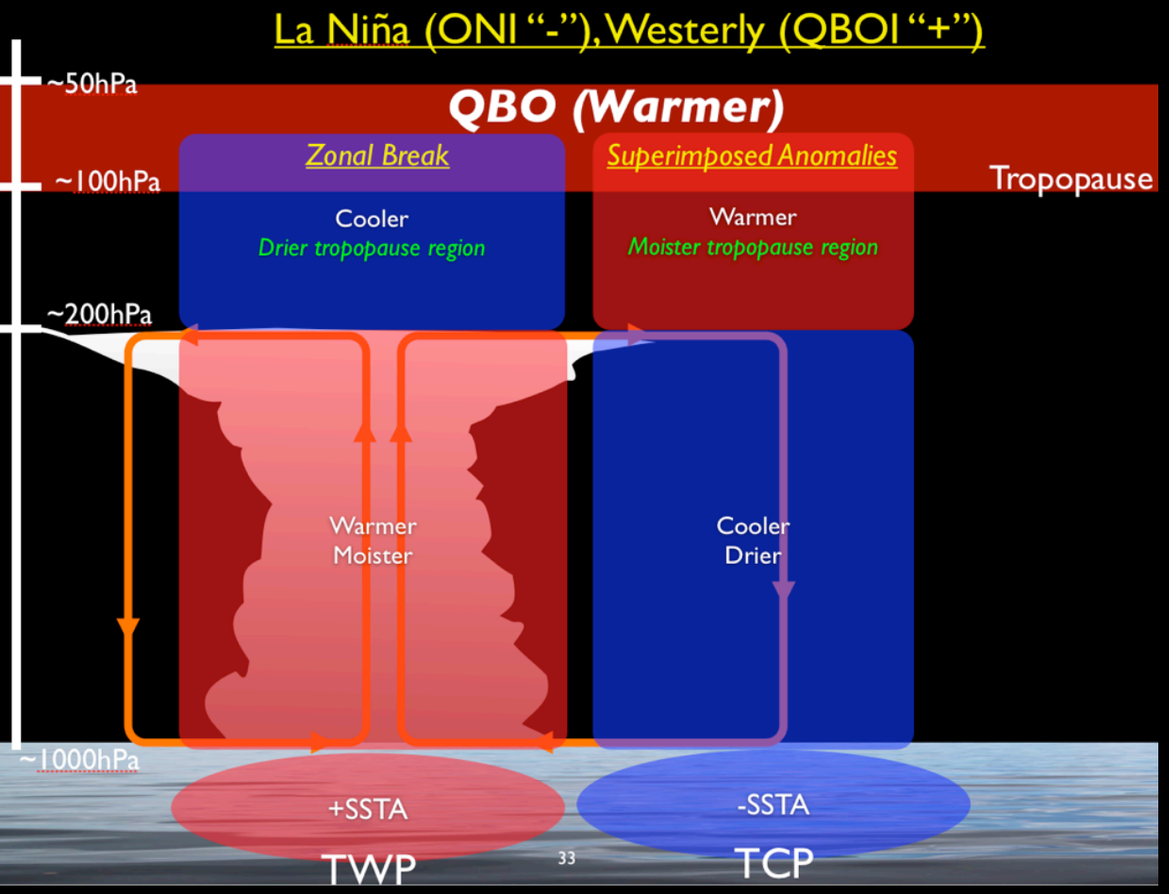
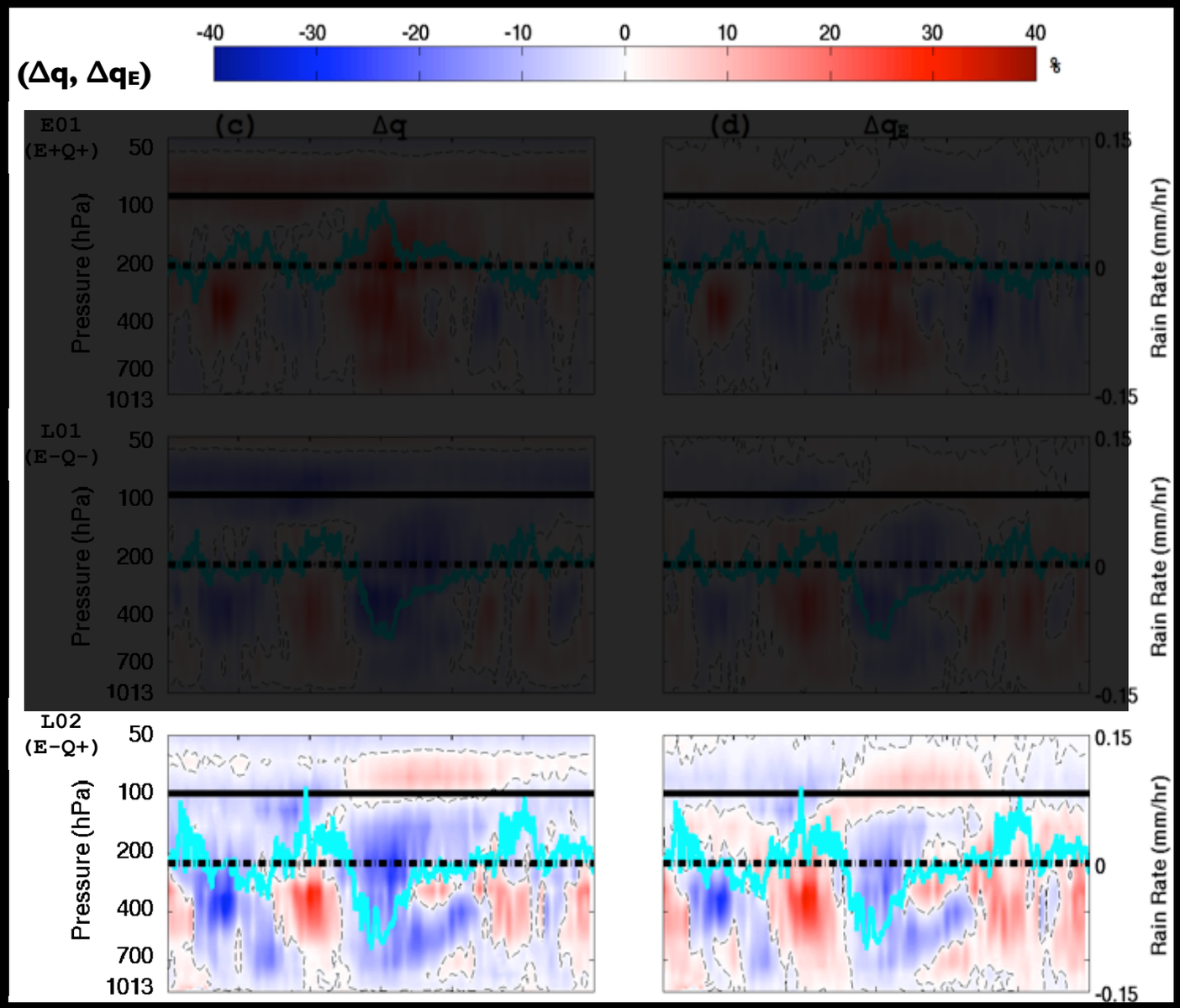


Adapted from Liang, et.al, JGR (2011), In Press

Vertical and Zonal Structure of ΔT and Δq





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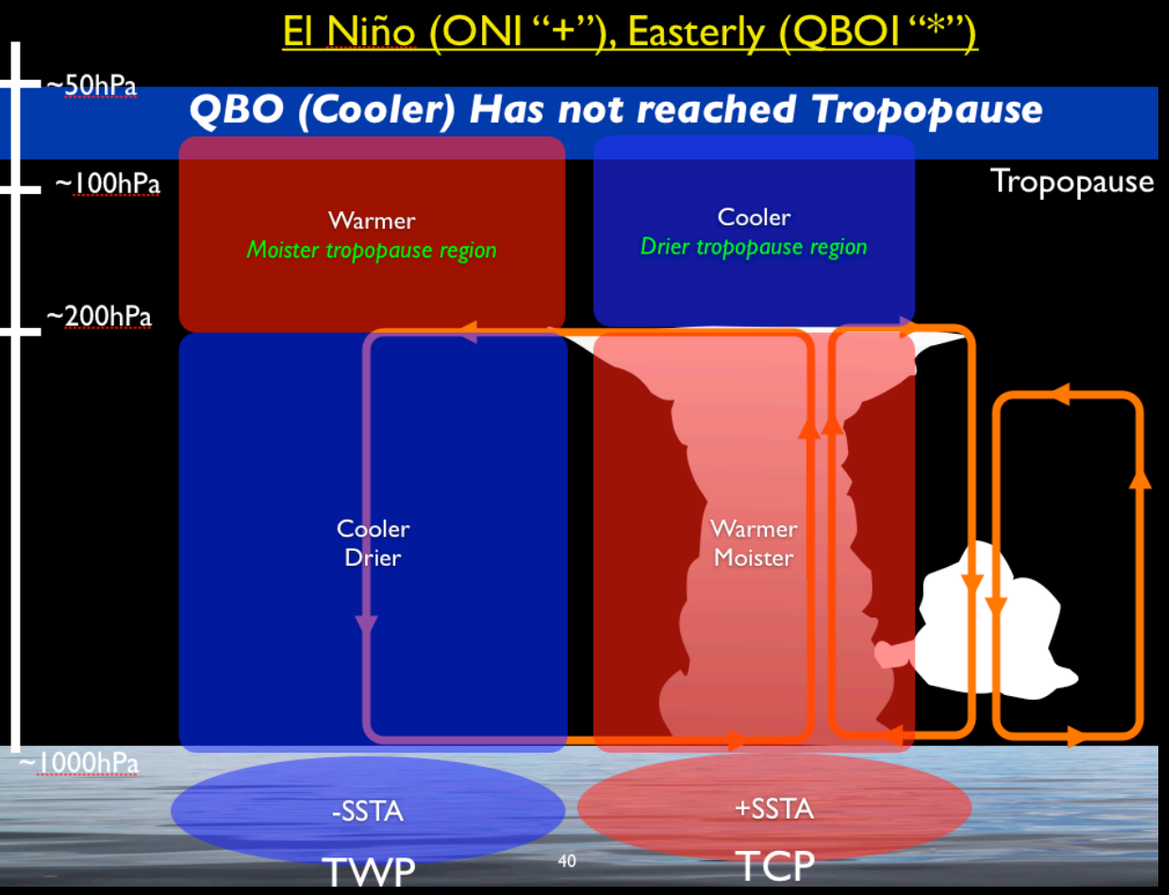
Vertical and Zonal Structure of ΔT and Δq



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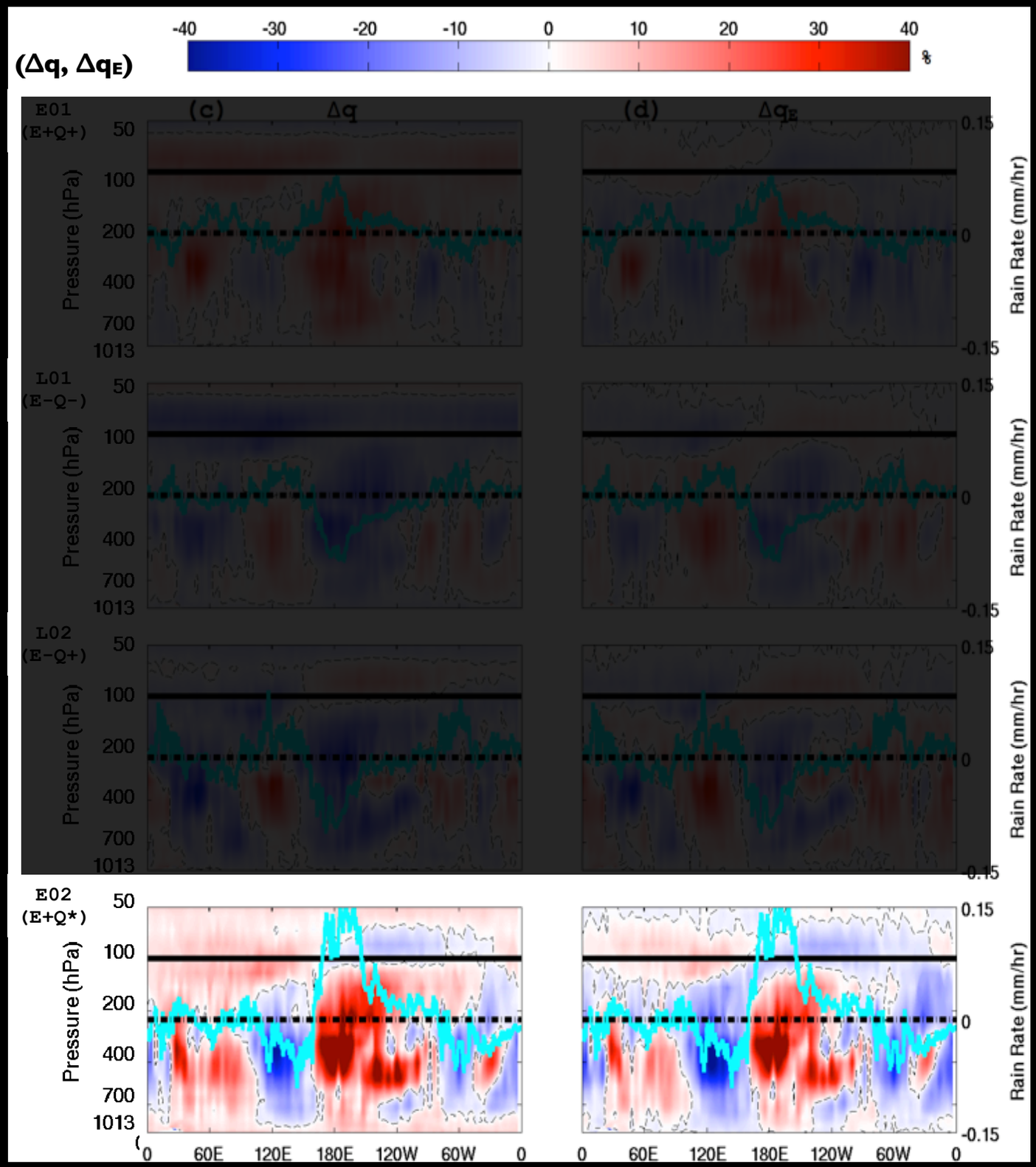


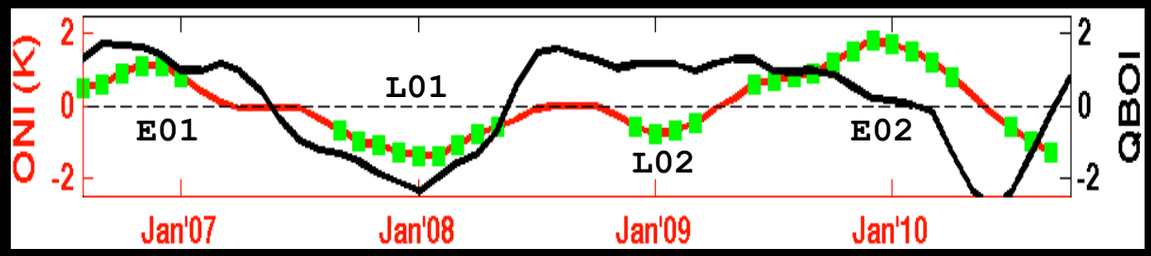
Adapted from Liang, et.al, JGR (2011), In Press

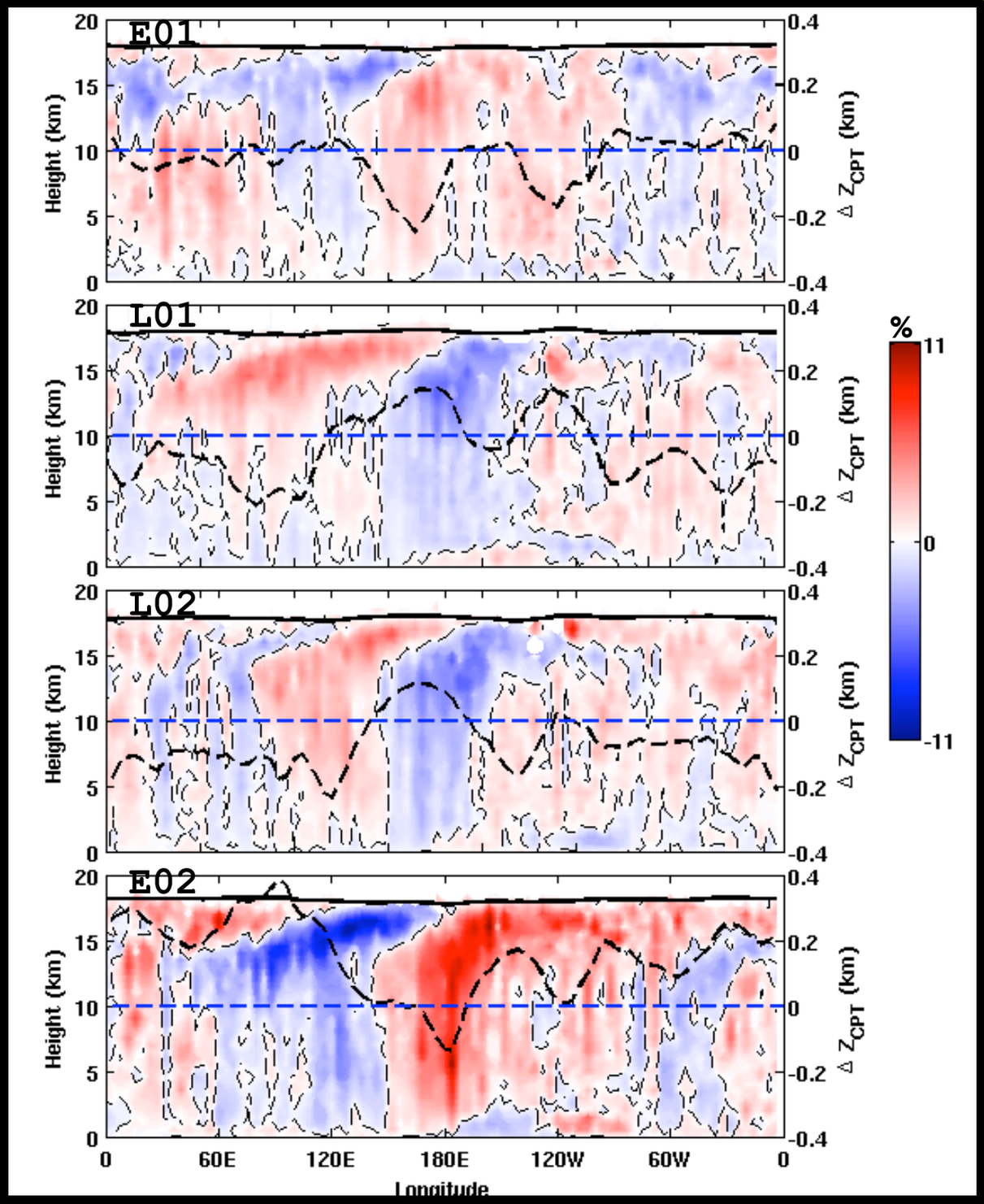
Cloud Fraction (8S-8N)

August 2006-July 2010

All Clouds (CloudSat + CALIPSO)

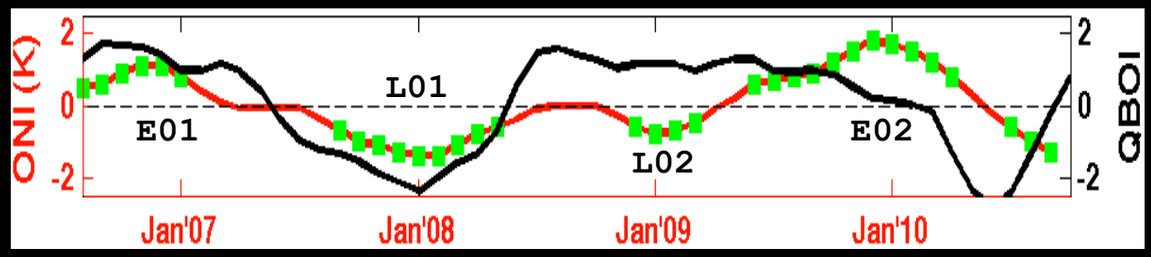
(1)

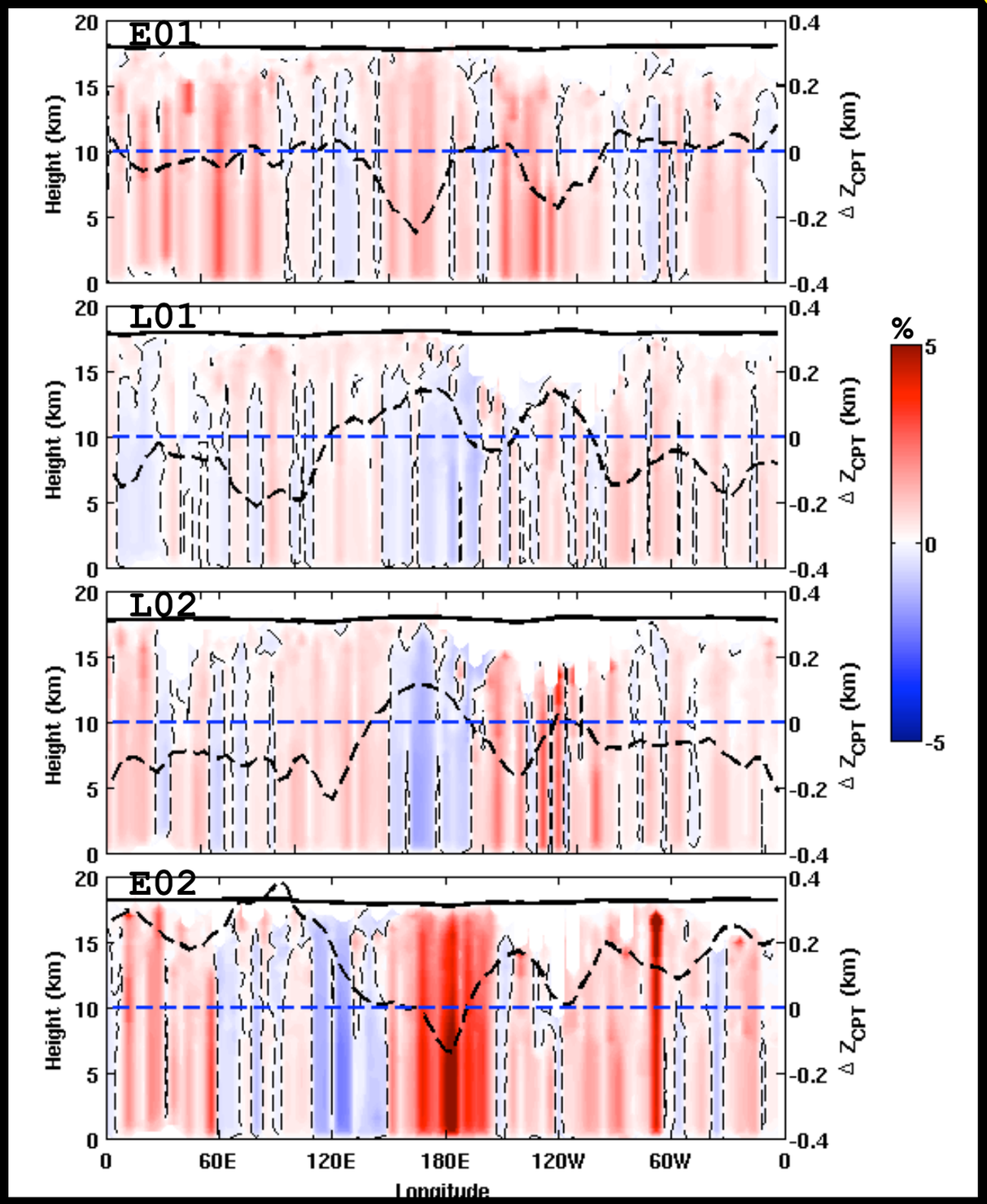


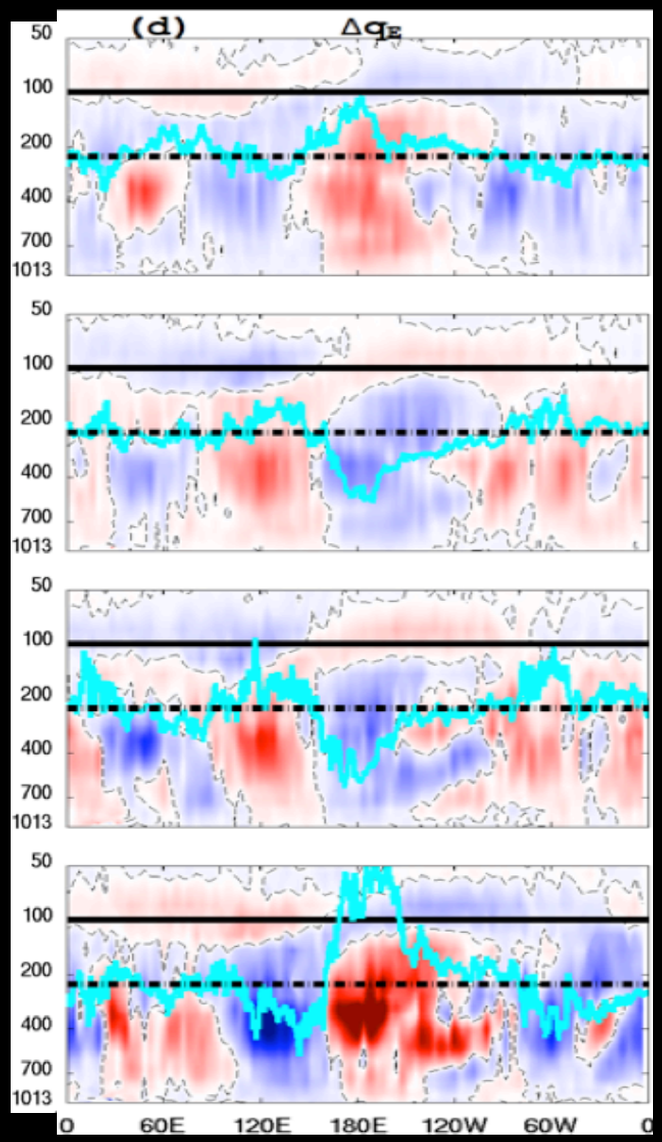


- Strong ENSO impact on total tropical cloud distribution.
- Vertical anomalies in free troposphere and upper troposphere. TTL shows eastward slanted anomalies

Cumulonimbus (CloudSat) (2)

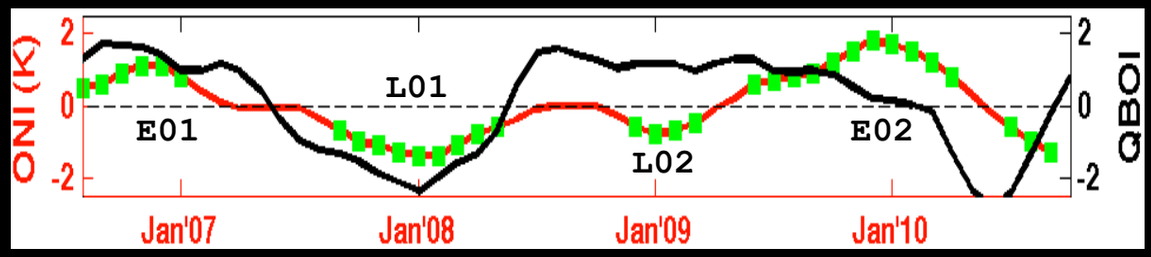


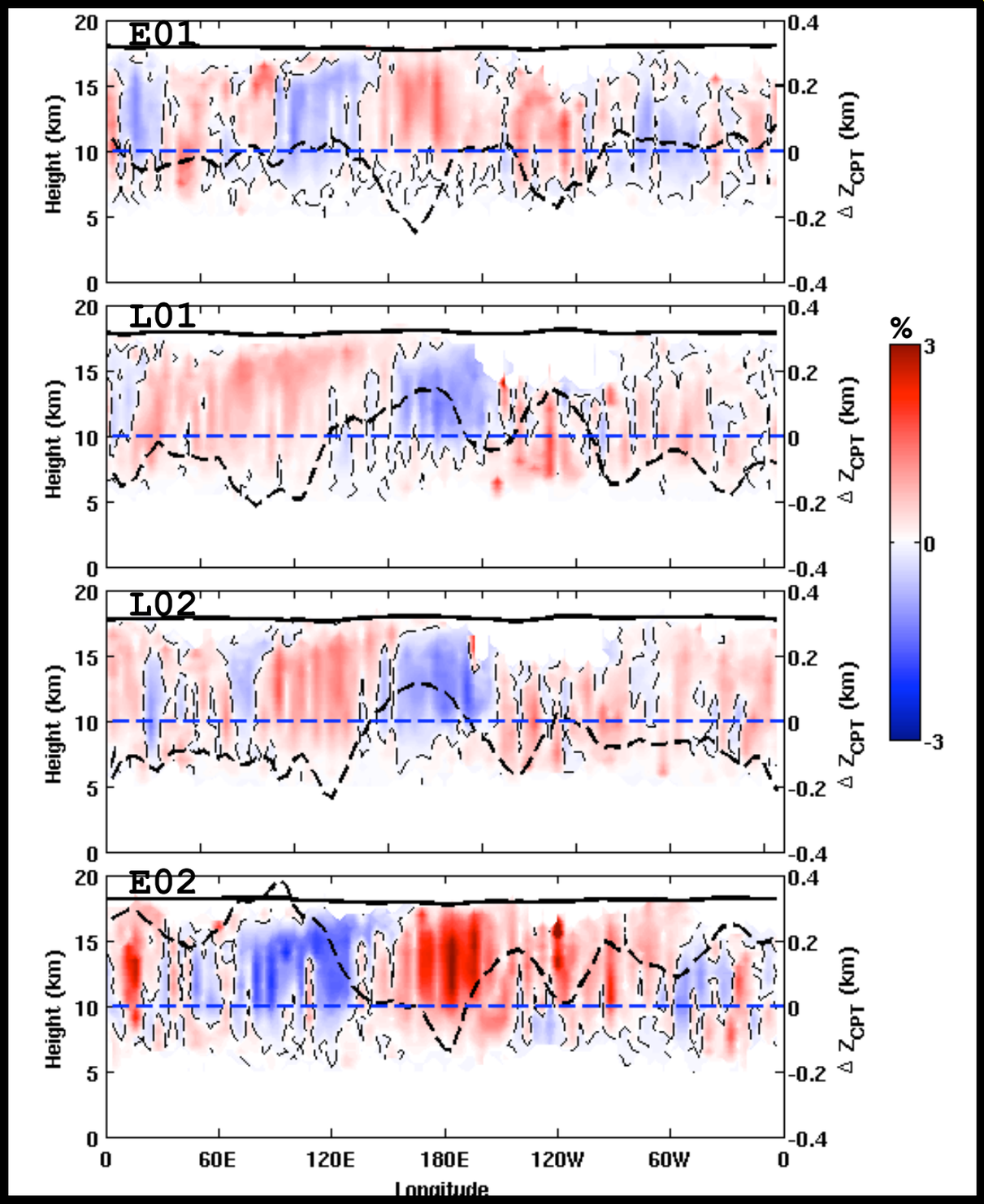




Deep clouds similar to vertical structure of Δq.

Cirrus (CloudSat) (3)

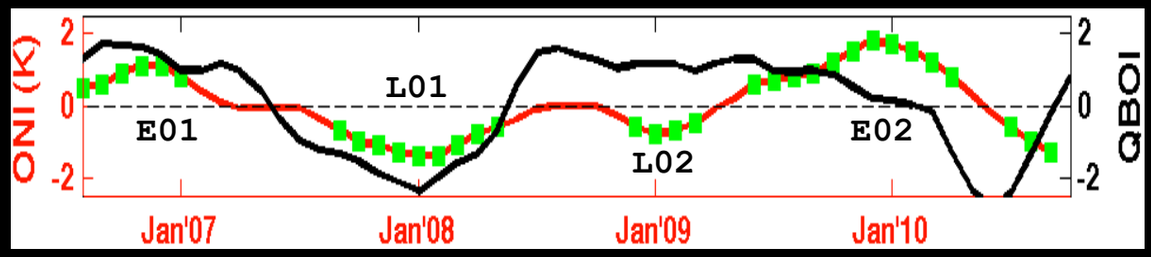


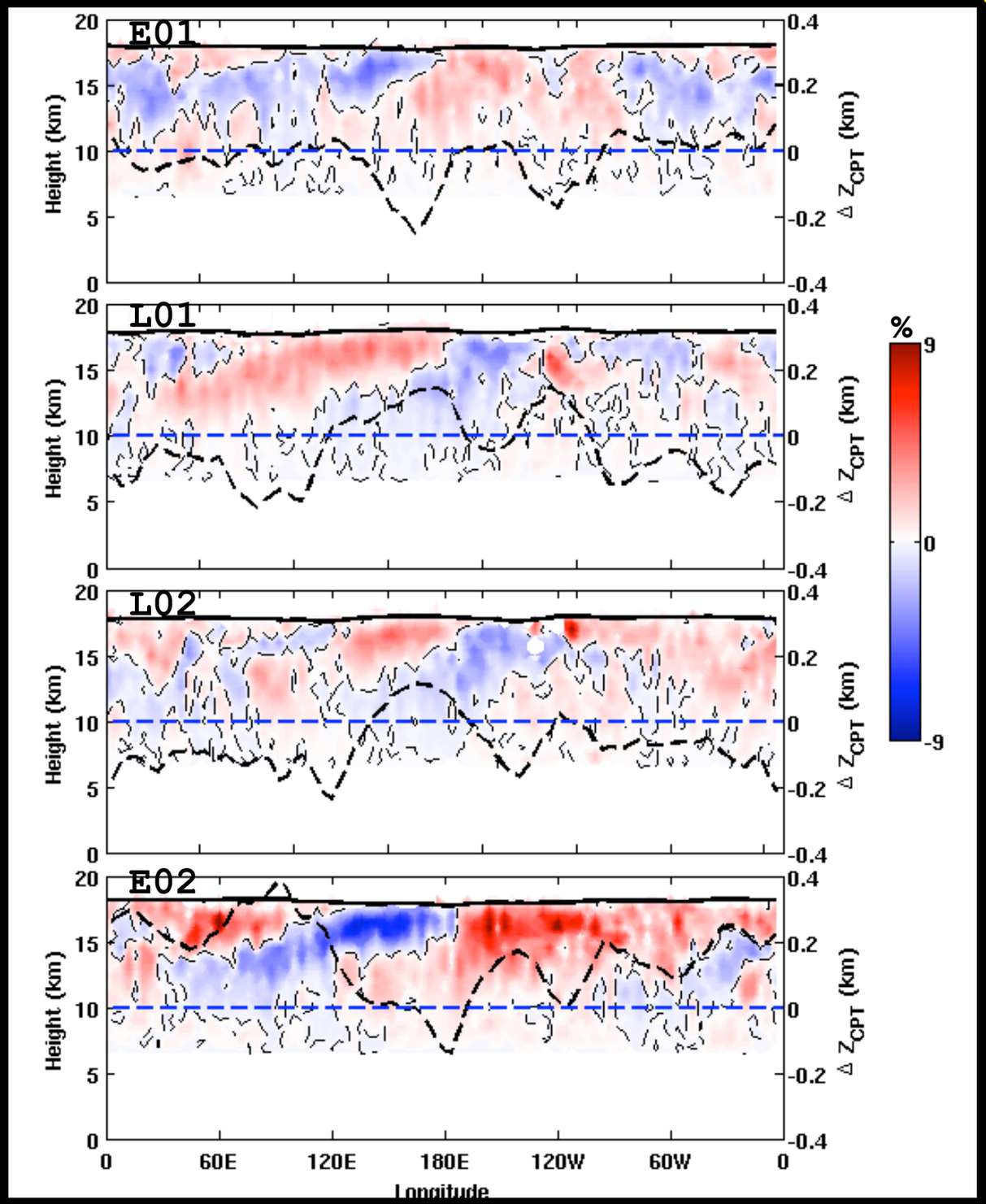


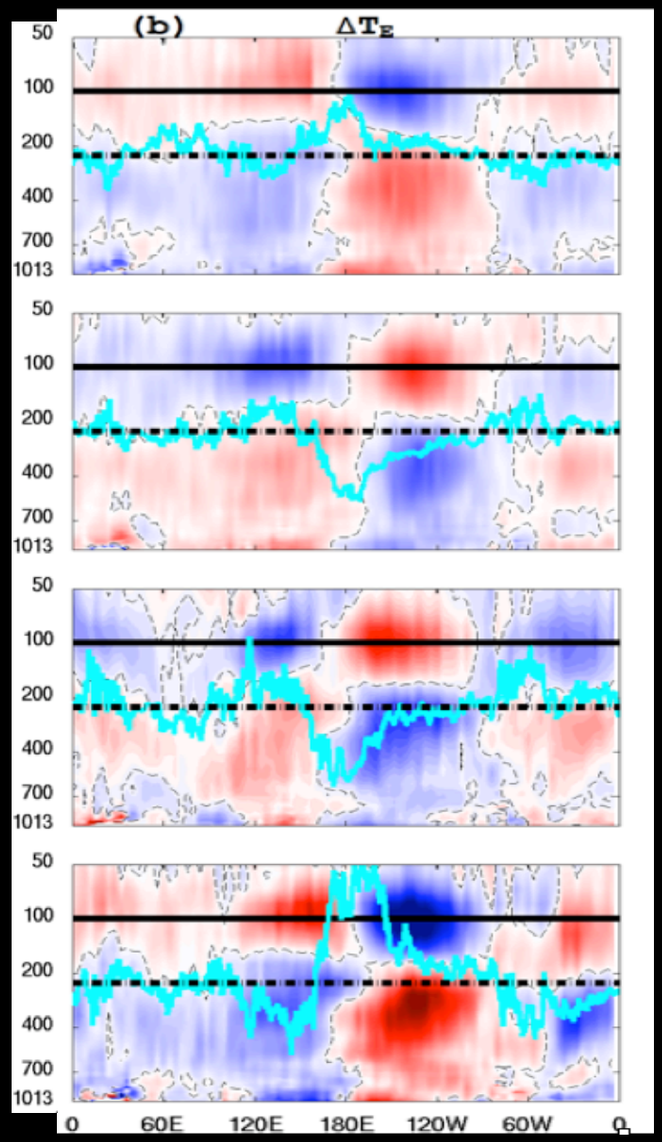
- Thick cirrus anomalies mimic the deep convective clouds, with evidence of eastward slant near tropopause.
- CF are about the same because these clouds are detrained from deep convection.

Cirrus (CALIPSO)

(4)







High thin cirrus have eastward slanting anomalies likely due to ΔT.

Conclusion

- TTL T and H_2O anomalies show a location dependent zonal break depending on the relative phase of the ENSO and QBO. Migration of convection is one mechanism responsible for this.
- Evidence of joint ENSO and QBO impact on zonal water vapor distribution; TCP might play a role.
- ENSO signature is strong on high clouds. Still need to investigate possible QBO signature on high clouds. Need longer time series!
- Thin cirrus (CALIPSO) clouds closely follow T anomalies (Eastward tilt). Deep cloud ENSO signature consistent with H_2O changes.
- ***Combined A-Train soundings can be used to assess climate models and process representation of humidity.***
- ***Cloud profiles enable us to better characterize possible cloud feedback mechanisms for different cloud types.***

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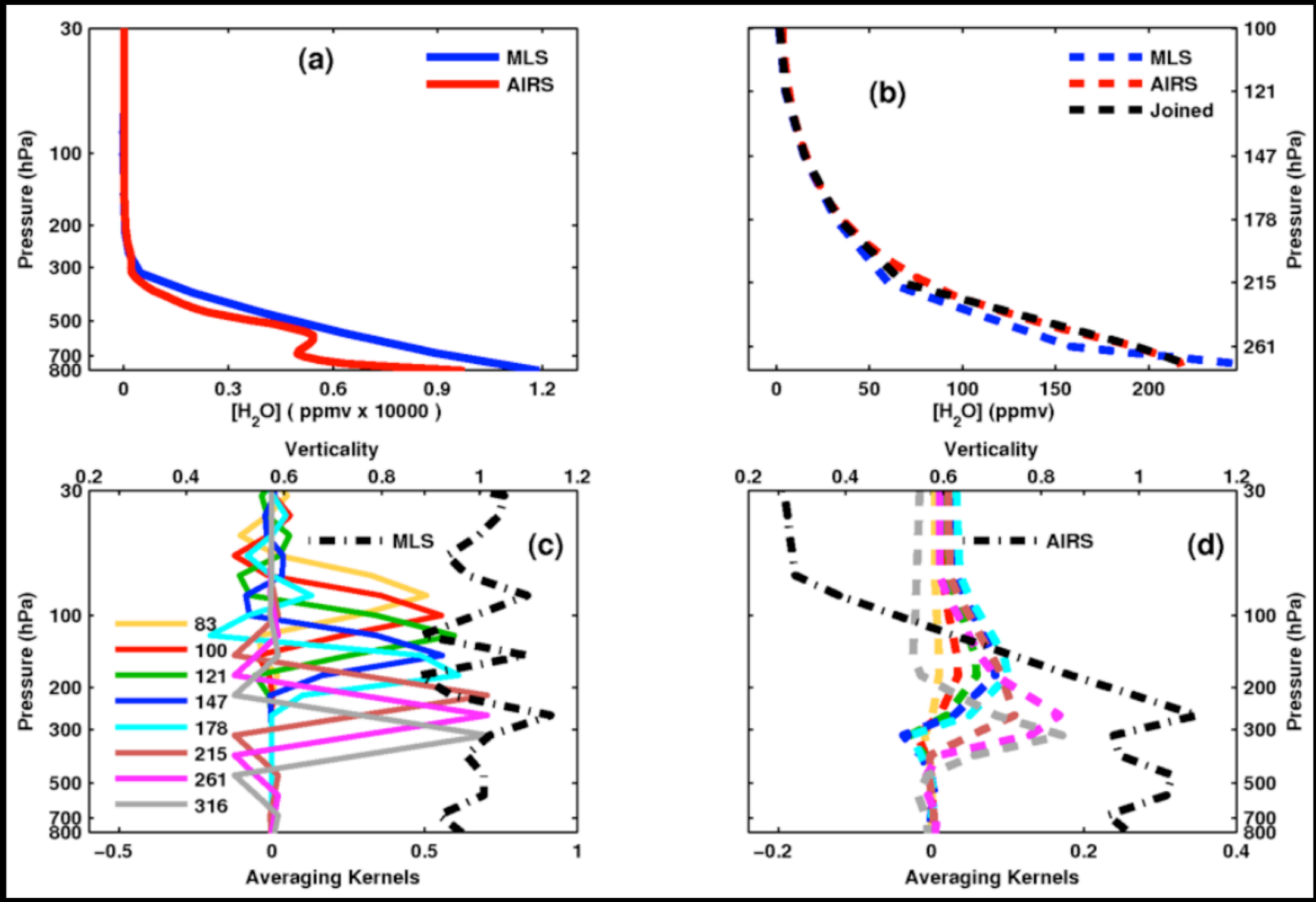
- ***Cloud profiles enable us to better characterize possible cloud feedback mechanisms for different cloud types.***

Thank You!!!

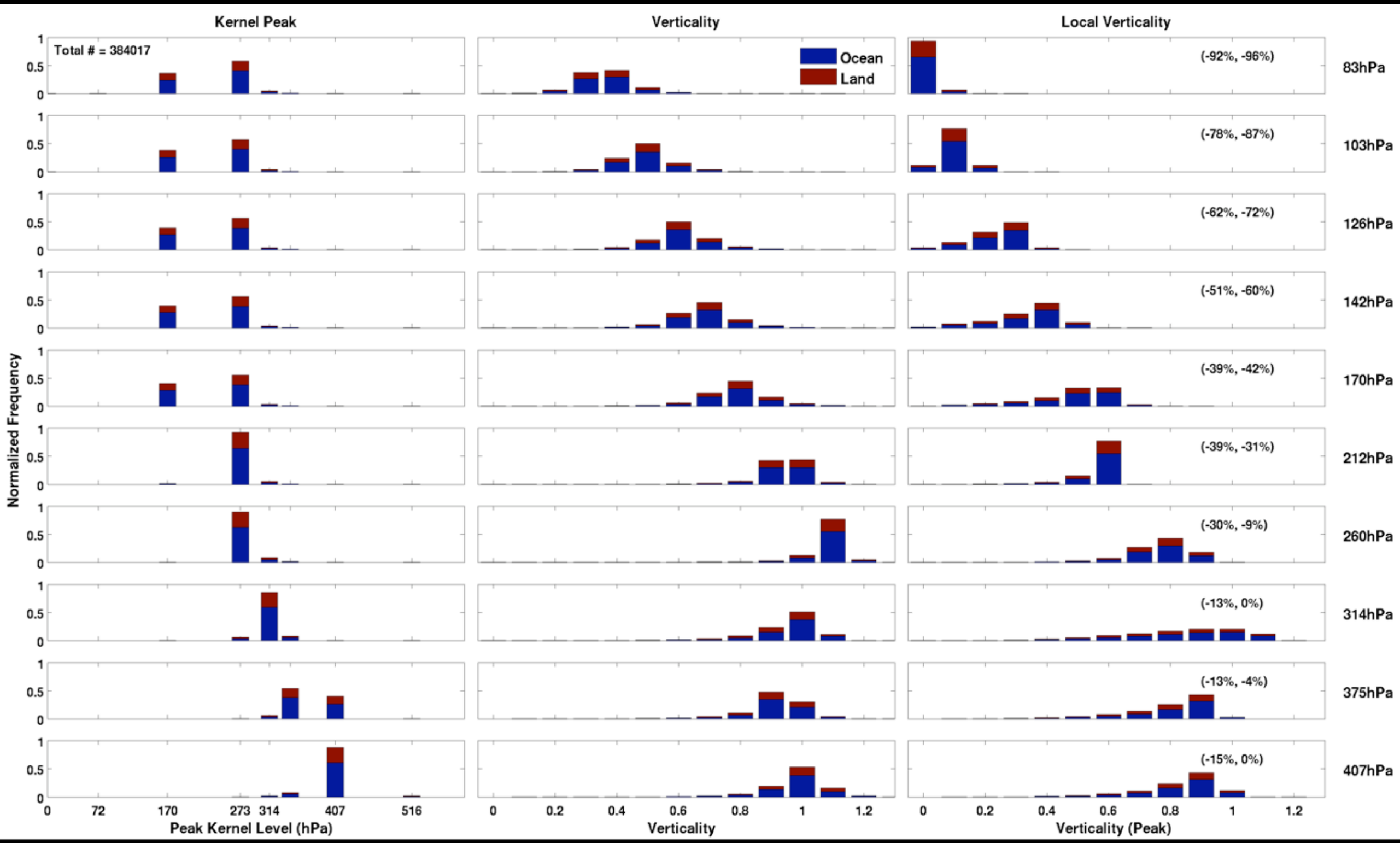
Constructing a Full Atmospheric H_2O Profile

Averaging Kernels



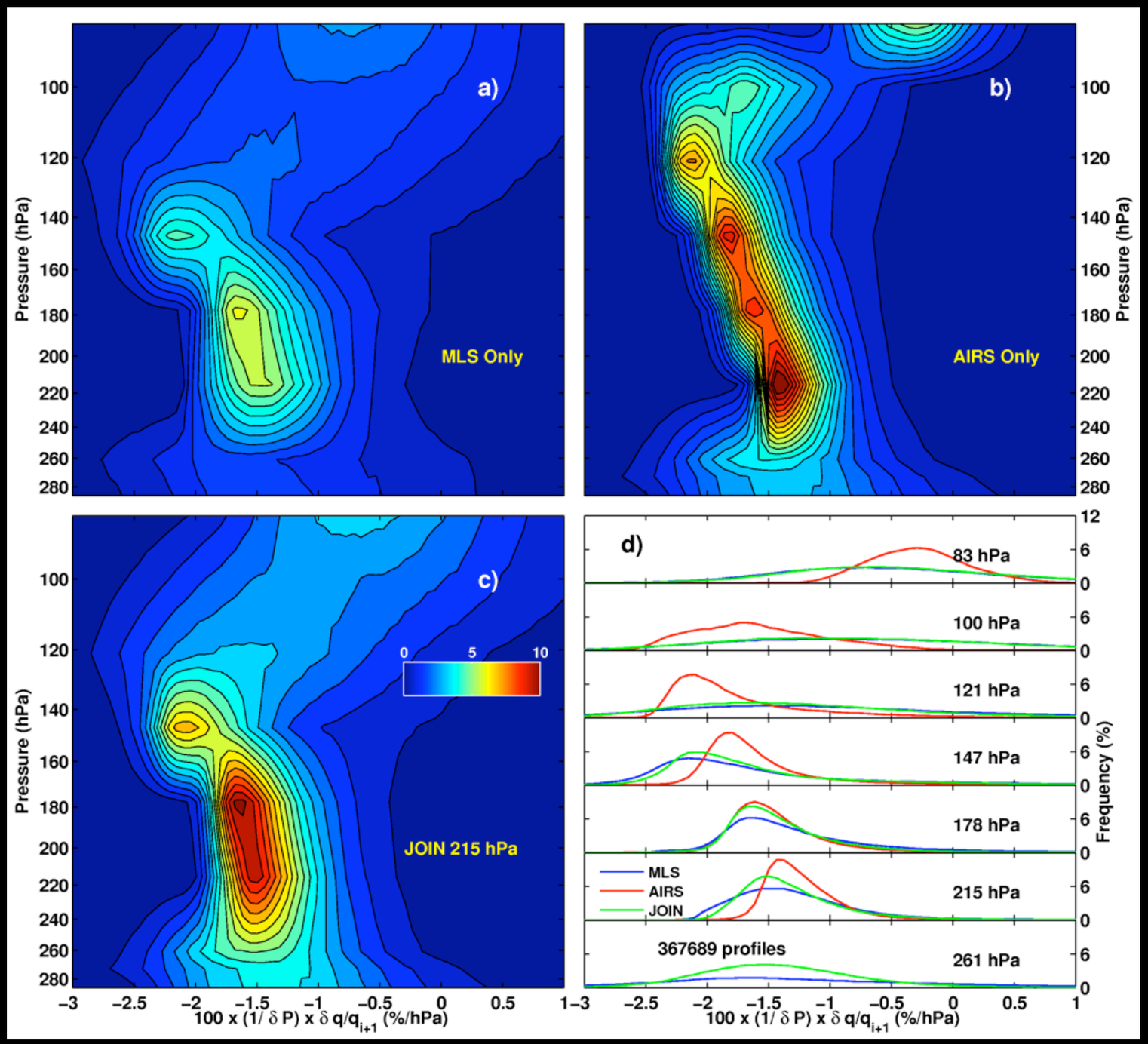
Liang, et.al, AMTD (2010)

Verticality



Liang, et.al, AMTD (2010)

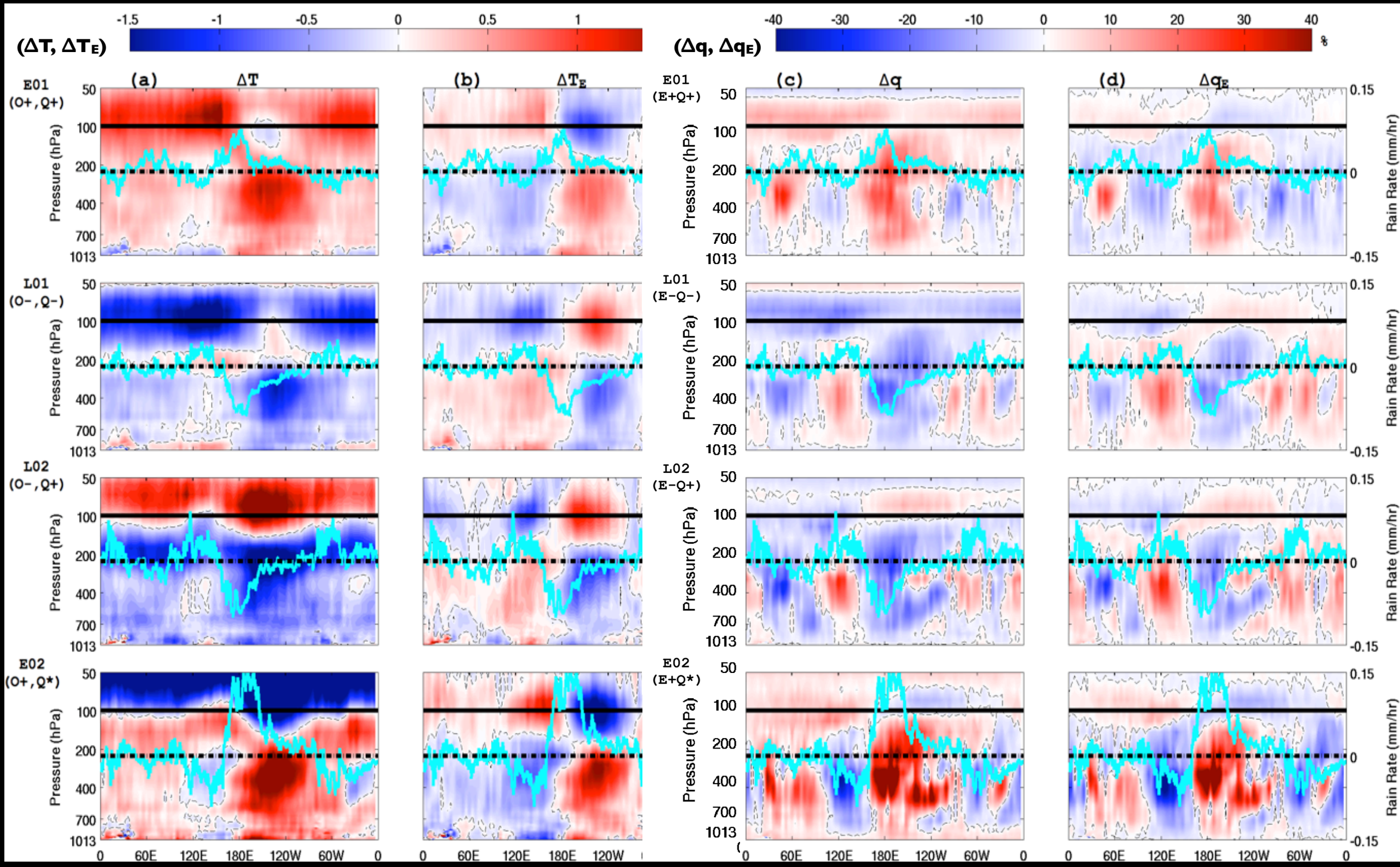
Profile Smoothness



- No unphysical "kinks" in profiles
- Spliced profile is constrained by AIRS and MLS
- New profile does not fall outside of the error estimates of either instrument

Liang, et.al, AMTD (2010)

Vertical and Zonal Structure of ΔT and Δq



Adapted from Liang, et.al, JGR (2011), In Press

Cloud Fraction Annual Cycle