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Water vapor variability in the Asian summer monsoon lower stratosphere from satellite observations and transport model simulations

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Key Points

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- CLaMS captures key features of MLS distribution in the ‘upward spiraling range’, but with a wet bias, sharper spatial gradients and larger variance in time
- Identify leading modes of deseasonalized variability in LSWV:
  1. Regional wet/dry anomalies (40%): temperature and circulation anomalies facilitate upward spiraling transport of detrainment from anomalously deep convection
  2. Vertical dipole (20%): reduced ascent limits moist air to southwestern anticyclone
  3. East–west dipole (10%): convection ‘fills up’ meridionally-displaced anticyclone core
- Mode 1 mainly interannual, mode 2 at ~1 month, and mode 3 at ~2 weeks
- All three modes highlight the influence of intense deep convection over the western Himalayan indentation on variations in LSWV in the ASM anticyclone
- CLaMS captures much of the variability in the first ($r \sim 0.7$) and third ($r \sim 0.5$) modes, but fails to capture second mode ($r \sim 0.2$)
- CLaMS-EI captures large LSWV in 2017 but CLaMS-M2 does not; this difference can be attributed to interannual variations in reanalysis radiative heating anomalies

Introduction

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The Details

- Period: 2005–2017
- Domain: 30°E–130°E, 15°N–45°N
- Layer: 68–100 hPa (‘upward spiraling range’)

The Benchmark

- Aura MLS v4

The Simulations

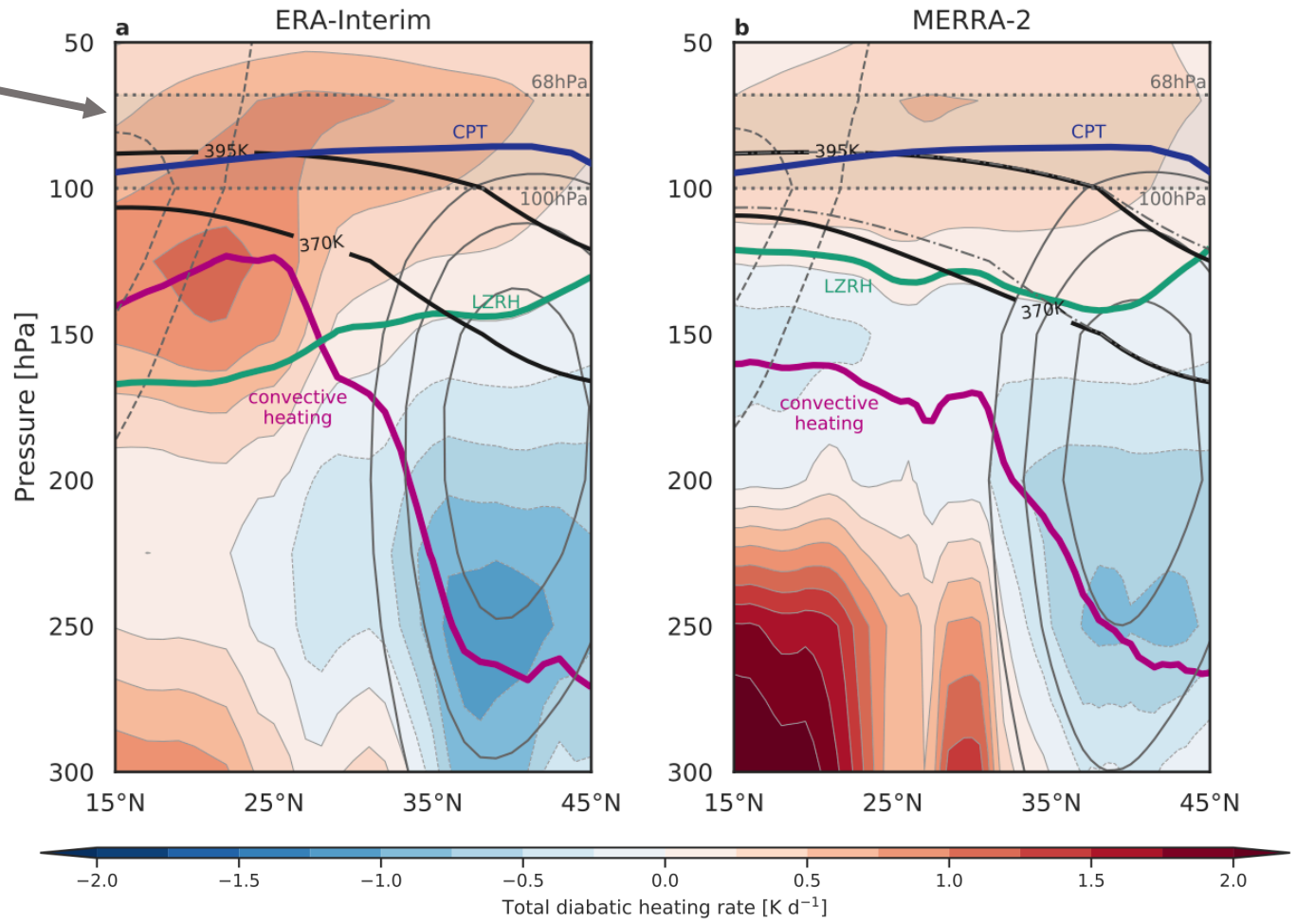
- CLaMS driven by ERA-Interim
- CLaMS driven by MERRA-2

two transport environments

Evaluation Criteria

- Climatology and seasonal cycle
- EOF analysis of vertical & horizontal variations (all regressed onto MLS PCs for consistency)
- Relationships with key variables (convection, anticyclone, cold point tropopause)
- Simulation of large LSWV anomalies in 2017

CPT: cold point tropopause
LZRH: level of zero net radiative heating
Convective heating: non-rad > 0.3 K/d



1 Lower stratospheric water vapor (LSWV)

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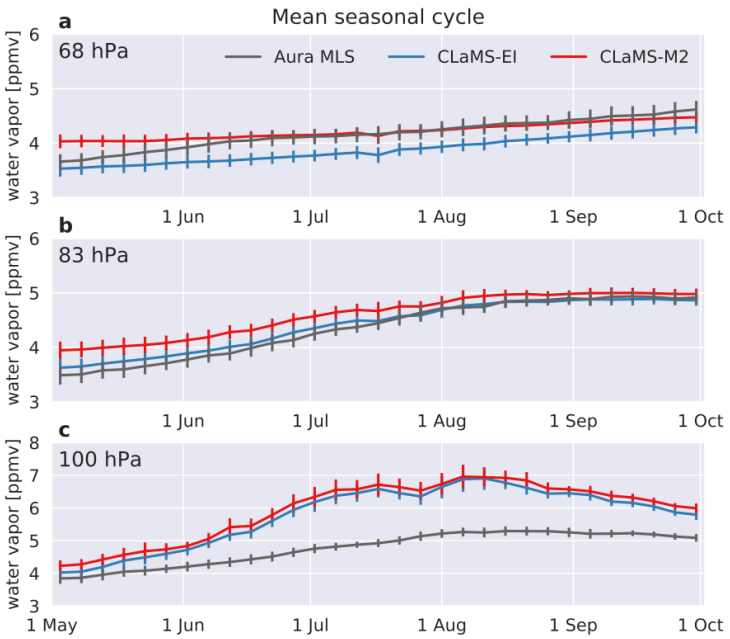
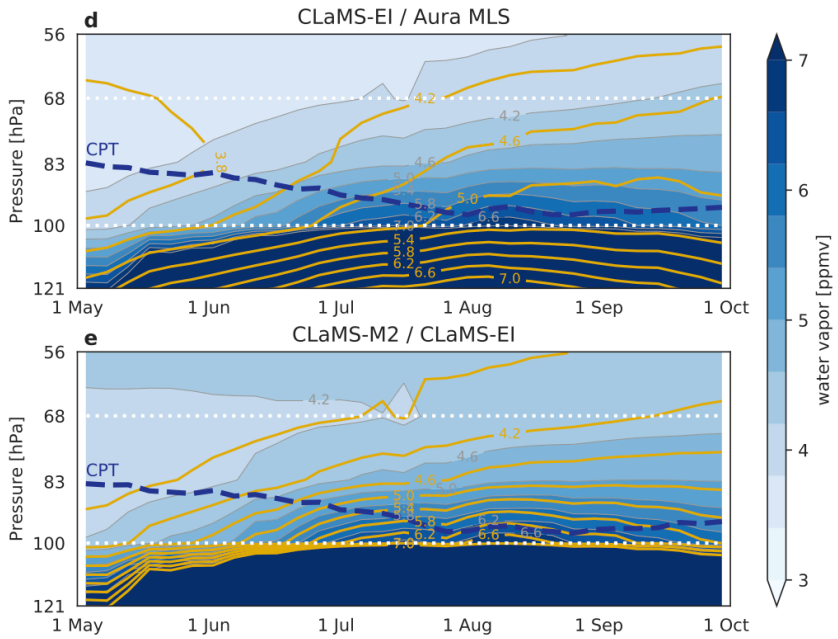


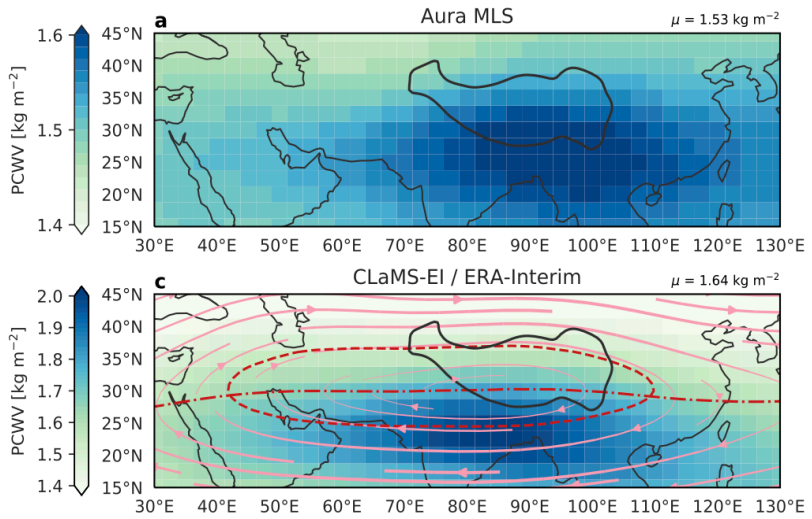


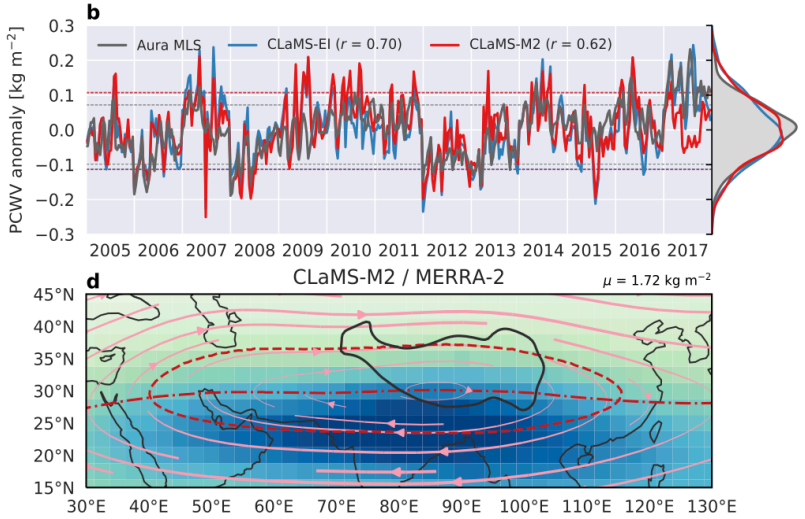
- Localized water vapor maximum over Bay of Bengal and Tibetan Plateau with variations at a range of time scales
- CLaMS simulations capture key features but with a systematic moist bias against Aura MLS, especially below the CPT
- Seasonal cycle ascends more slowly in CLaMS, especially CLaMS-M2 — ascent rates too slow or dilution too strong?

- CLaMS shows sharper spatial gradients and larger variance in time than MLS
- CLaMS-EI captures large LSWV in 2017 but CLaMS-M2 does not

$$\mathrm{PCWV} = \frac{1}{g}\int_{100\,\mathrm{hPa}}^{68\,\mathrm{hPa}} q\,dp$$

partial column water vapor





2 Mode 1: Regional Wet/Dry (36~42%)

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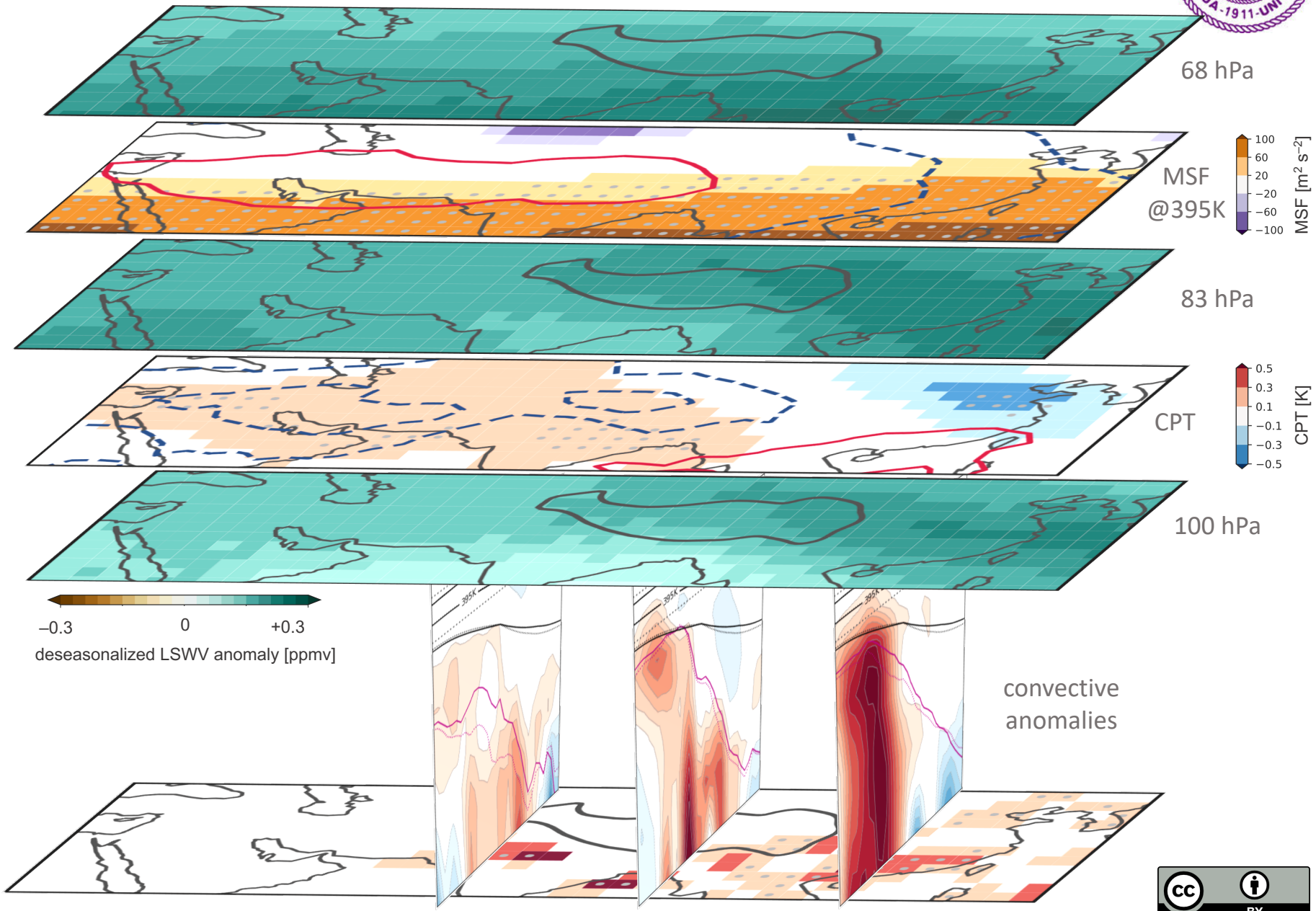
Positive Mode 1:

Temperature and circulation anomalies facilitate upward spiraling transport of air detrained from anomalously deep convection

1. Systematically deeper convection
2. Warm anomalies in western part of anticyclone
3. Isentropic tilt supports ascent along northern flank of anticyclone

Spectral Analysis:

Mainly associated with interannual variations



3 Mode 2: Vertical Dipole (17~18%)

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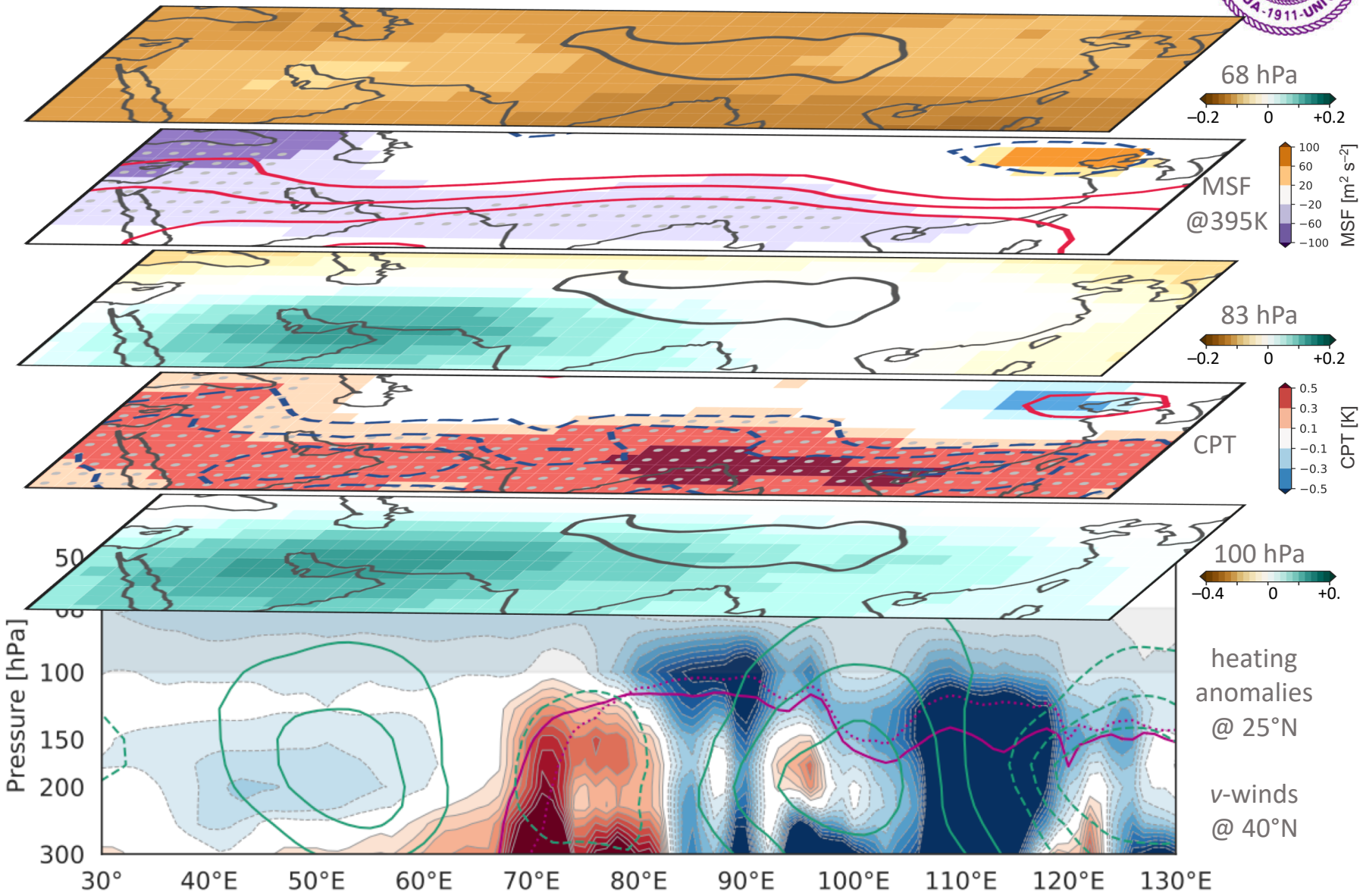
Positive Mode 2:

Reduced ascent traps moist air detrained from deep convection over the western Himalayas and Hindu Kush in the southwestern quadrant of the anticyclone

1. Convection shifted from east to west
2. Large warm anomalies along southern edge of anticyclone
3. Negative radiative heating anomalies in LS indicate suppressed ascent

Spectral Analysis:

Peaks at 30–40 days; coherent variations with CGT (subtr. jet)



4 Mode 3: East–West Dipole (7~8%)

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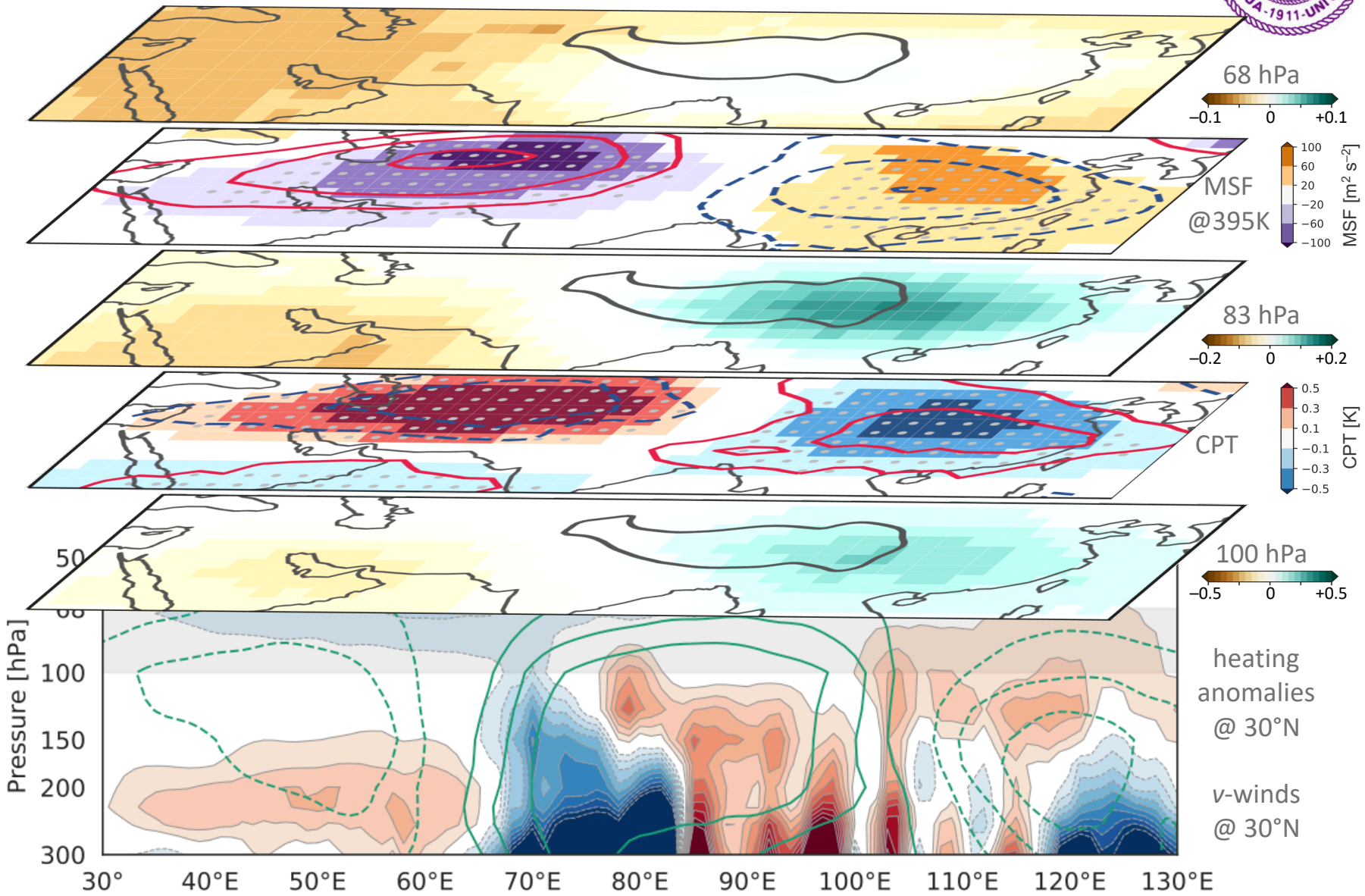
Positive Mode 3:

Coherent east–west shifts of anticyclone and convective activity ‘fill up’ anticyclone core

1. Enhanced convection over southeastern Tibetan Plateau and Sichuan Basin
2. Cold temperatures over strong convection; warm over weak
3. Anticyclone variations in phase with convective anomalies

Spectral Analysis:

Peaks at around 15 days



5 LSWV Anomalies in 2017

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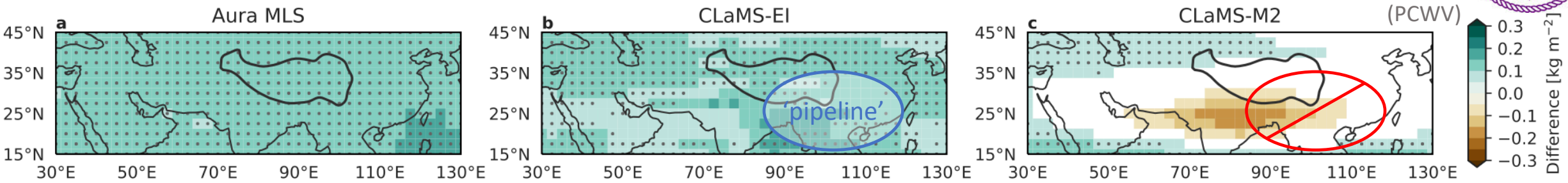

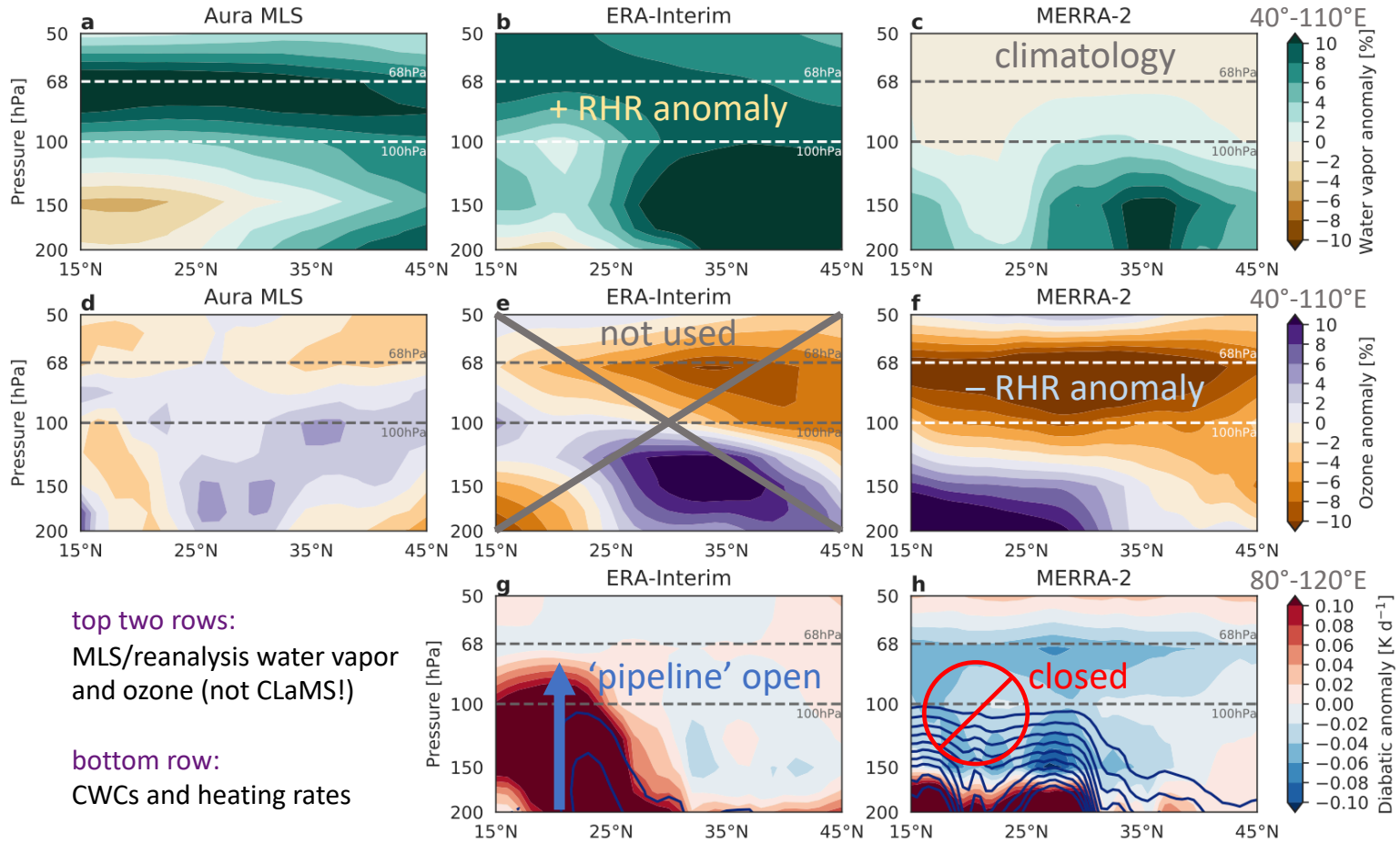

top two rows:
MLS/reanalysis water vapor and ozone (not CLaMS!)

bottom row:
CWCs and heating rates

- CLaMS-EI reproduces; CLaMS-M2 does not
- Explained by differences in radiatively active species in reanalysis models:
  1. ERA-I uses its own LSWV (b), MERRA-2 relaxes to climatology (c)
  2. MERRA-2 uses analyzed ozone for radiation (f); ERA-I uses climatology
  3. Similar convective anomalies but different cloud radiative effects
- Differences intensify LS radiative heating in ERA-I but weaken it in MERRA-2
- Convection enhanced in both but diabatic 'pipeline' only open in CLaMS-EI
- Does not explain initial anomaly, only simulated differences in persistence