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The stratospheric ozone rich cold intrusion during El-Niño over the Indian region: Implications during Indian summer monsoon

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Introduction

Ozone:

- Rising trend in tropospheric ozone and surface ozone has been observed
- Tropospheric ozone is hazardous to
  - human health, vegetation & climate
- Surface ozone contributes to
  - air pollution & smog events
- Upper tropospheric ozone
  - crucial in maintaining the Earth's radiative budget

Stratospheric intrusion (SI) of ozone:

- ~30 – 40 % of the total budget of tropospheric ozone
- amplifies the global warming signature, ozone being a greenhouse gas

An increased frequency in stratospheric intrusions in a warming climate has been observed.

SI of ozone and Indian summer monsoon (ISM):

- linked to Rossby Wave Breaking (RWB)
  - which causes invasion of high potential vorticity (PV), ozone-rich, dry air mass from extra-tropical lower stratosphere (LS) into tropical upper troposphere (UT)
- alters atmospheric radiative forcing (RF), temperature distribution & circulation patterns.
- SI of ozone in the tropics can increase during an event of El Niño Southern Oscillation (ENSO),
  - warming in the east Pacific
  - impact the ISM convective processes via teleconnection
- ENSO induces strong anomalous subsidence over India and thereby causing rainfall deficiency

Gap area:

Linkages of SI on circulation and RF during ISM, co-occurring with El Niño

Science questions to be addressed

- How does stratospheric intrusions during break days influence temperature distribution and circulation pattern over India during El Niño?

- What is the impact of ozone variability in the upper troposphere on radiative forcing over Indian during summer monsoon, accompanied by El Niño?

Methodology

Reanalysis data used: **ERA-Interim**

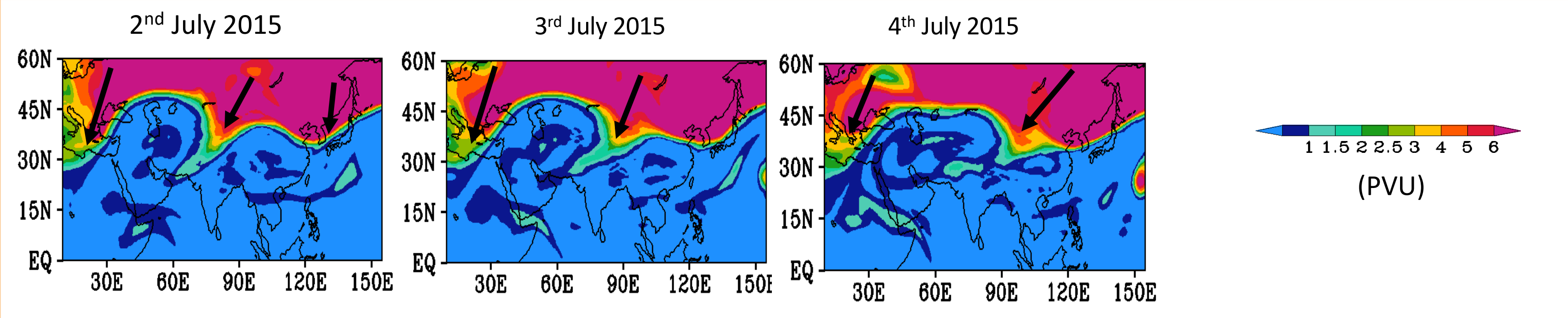
- Period of study: 1979 – 2015
- Year marked as El Niño: if the amplitude of SST anomalies exceeded one standard deviation, over Niño-3.4
- Parameters used:
  - Potential vorticity (PV)
  - Ozone mixing ratios
  - Winds
  - Temperature

Model used: **ECHAM5-HAMMOZ** (T42L31)

- Expt. 1: El-Niño (EL)
  - model is forced with SSTs typical of an El Niño over the tropical Pacific domain
- Expt. 2: CTRL (CL)
  - model is forced with a monthly varying climatological SST)

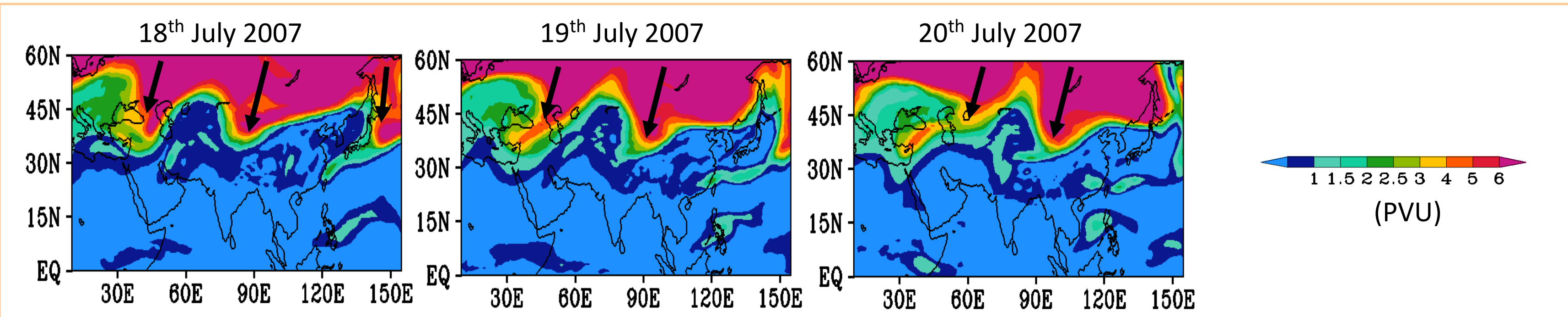
- Days marked as breaks days: if standardized rainfall anomaly is less than −1.0, consecutively for three days or more over the core Indian monsoon region
- Following this, from ERA-Interim and ECHAM5-HAMMOZ simulations, we segregated:
  - **El-Niño-break days/ELBR** (break days during all El Niño years)
  - **non-El-Niño-break days/non-ELBR** (break days during all normal years)
- Anomaly = (composite of ELBR – composite of non-ELBR)

PV distribution on 350 K isentropic surface from ERA-Interim



A case of ELBR, 2nd – 4th July 2015

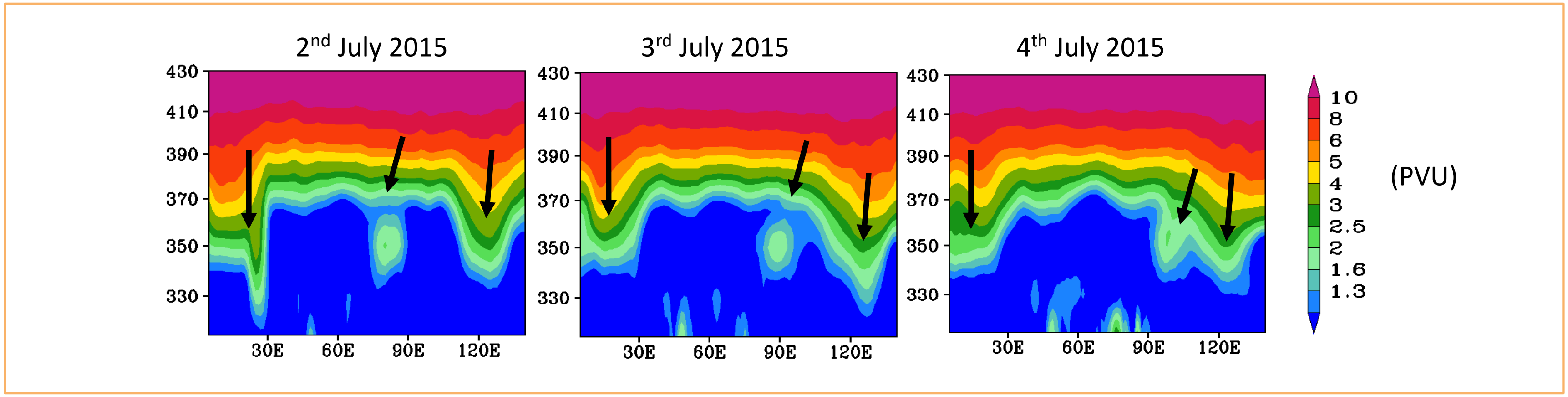
- A tongue of air with high values of PV traverses from extra-tropics towards the Indian region, extending into the tropics up to 20 °N
- 3 RWB events - RWB-1: 20 °E, RWB-2: 75 °E (over North India-Tibetan Plateau (NI-TP)), RWB-3: 120 °E



A case of non-ELBR, 18 – 20th July 2007

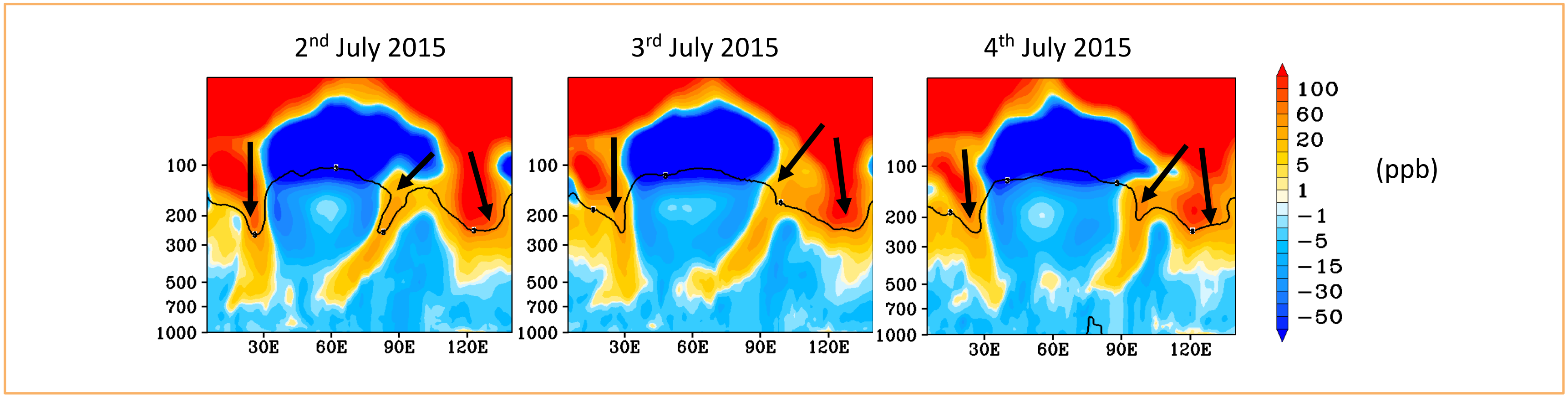
- The extension of high PV does not traverse beyond 30 °N
- 3 RWB events - RWB-1: 35 °E, RWB-2: 75 °E, RWB-3: 120 °E
- RWB-1, RWB-2, RWB-3 remain north of 30 °N; influence may be minimal over Indian region

Zonal cross-section of PV & ozone from ERA-Interim during ELBR



In the vertical, Rossby waves may take a form of tropopause fold

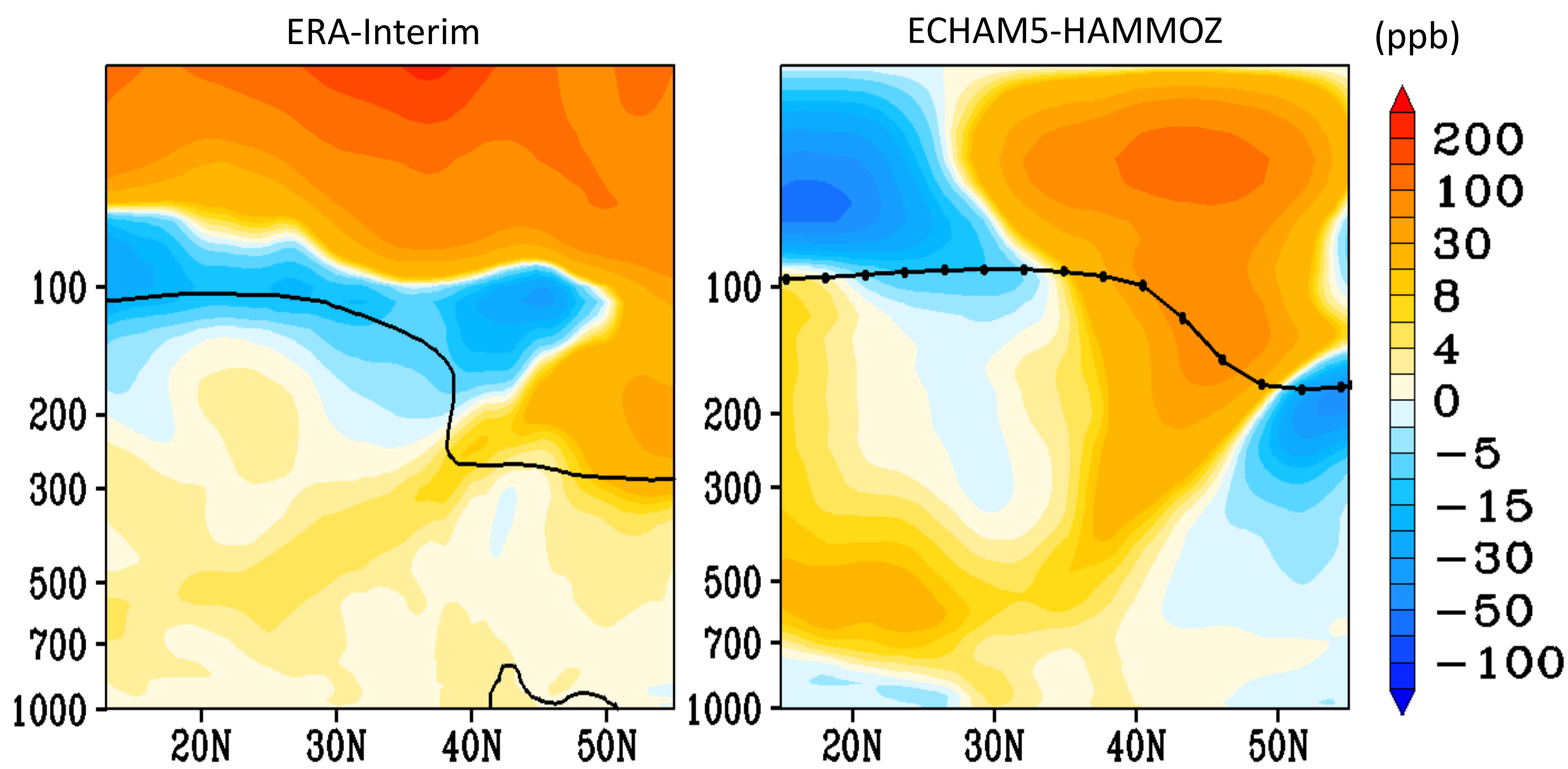
- Stratospheric intrusions occurs along: RWB-1 at western edge of anticyclone, RWB-3 at the eastern edge of anticyclone, RWB-2 over the NI-TP region



Ozone intrusions are mostly collocated with the region of RWB

- RWB-2 (40 – 100 ppb; 20 - 80 %) and RWB-3 (~40 – 80 ppb; 20 – 60 %) spreads enormous ozone amounts in the upper troposphere over India during ELBR

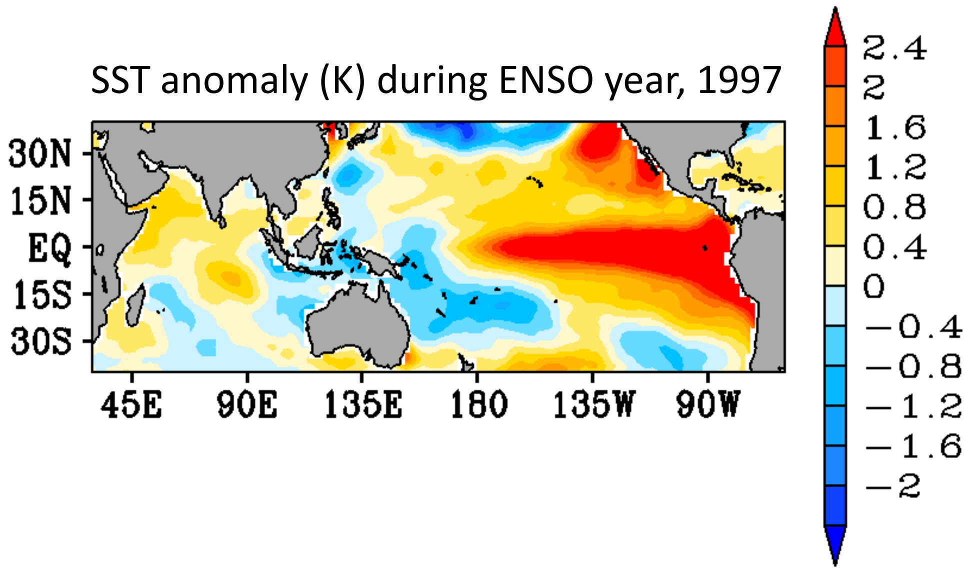
Anomalous ozone intrusion over NI-TP



Ozone intrusions during ELBR is higher than that during non-ELBR over NI-TP

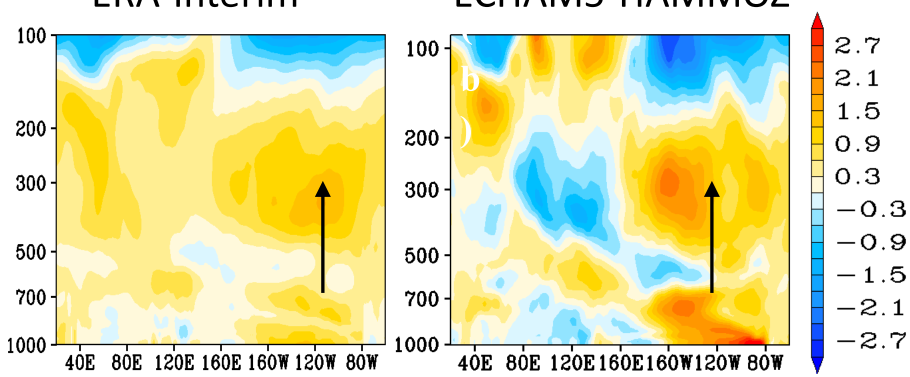
- Intrusions during ELBR enhance ozone by ~30 - 100 ppb in the UT over NI-TP
- Downward transport enhances boundary layer ozone by ~10 - 20 ppb
- El Niño facilitate the transport of stratospheric ozone rich air downwards into UT

SST anomaly (K) during ENSO year, 1997



Vertical distribution of temperature (K)

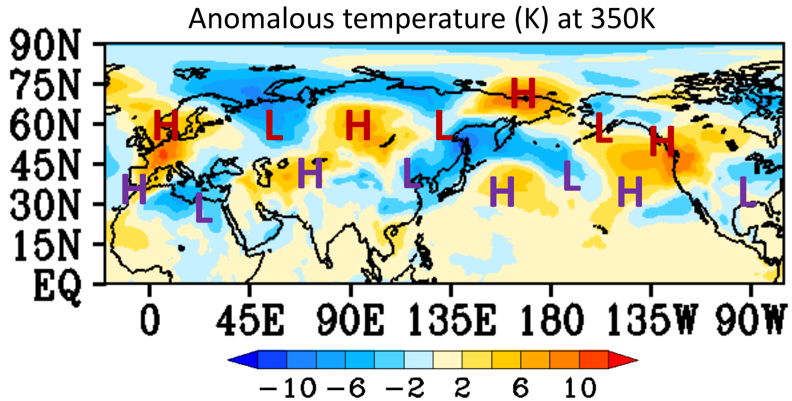
ERA-Interim ECHAM5-HAMMOZ

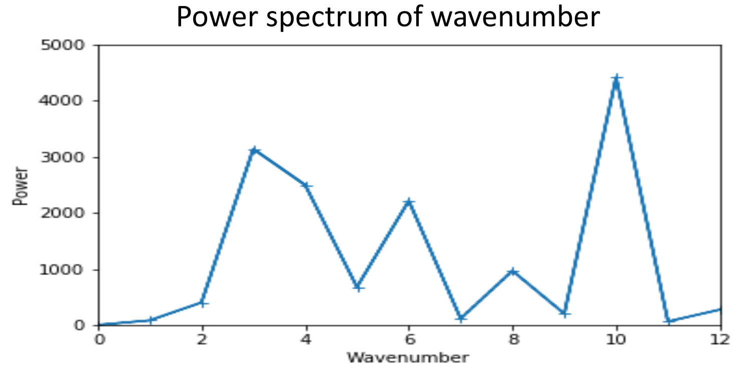


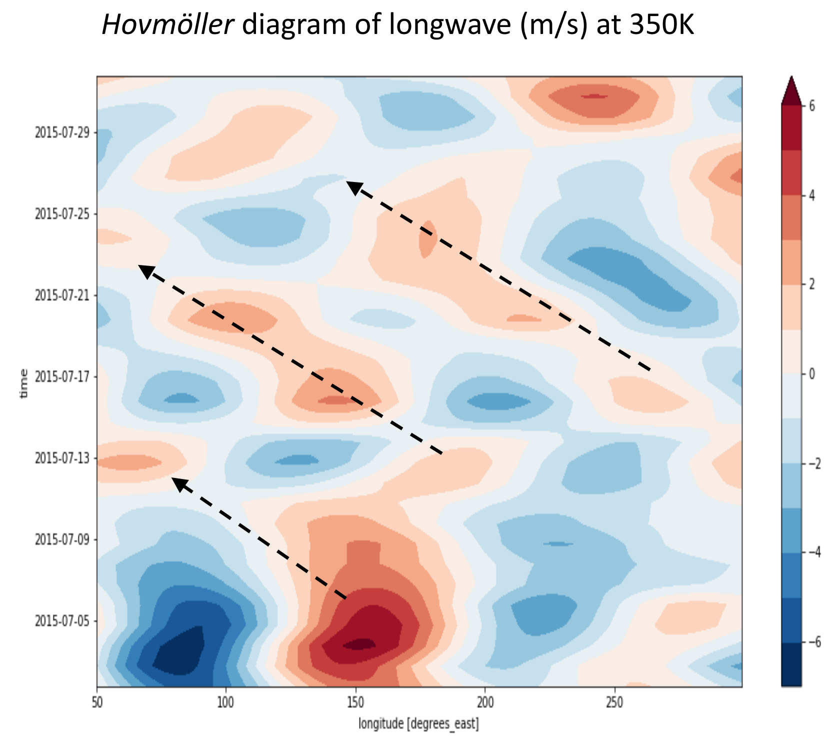
Warming in SST (ERSST) over east Pacific propagates upward via planetary Rossby waves

- Vertical distribution of anomalous temperature (representative of diabatic heating) extends from surface of east Pacific up to the UT (~200 hPa)
- Convection over the eastern Pacific associated with El Niño give rise to convectively coupled Rossby wave trains (periodicities of ~5-8 days)

Wave-trains in the UT & Fourier scale separation







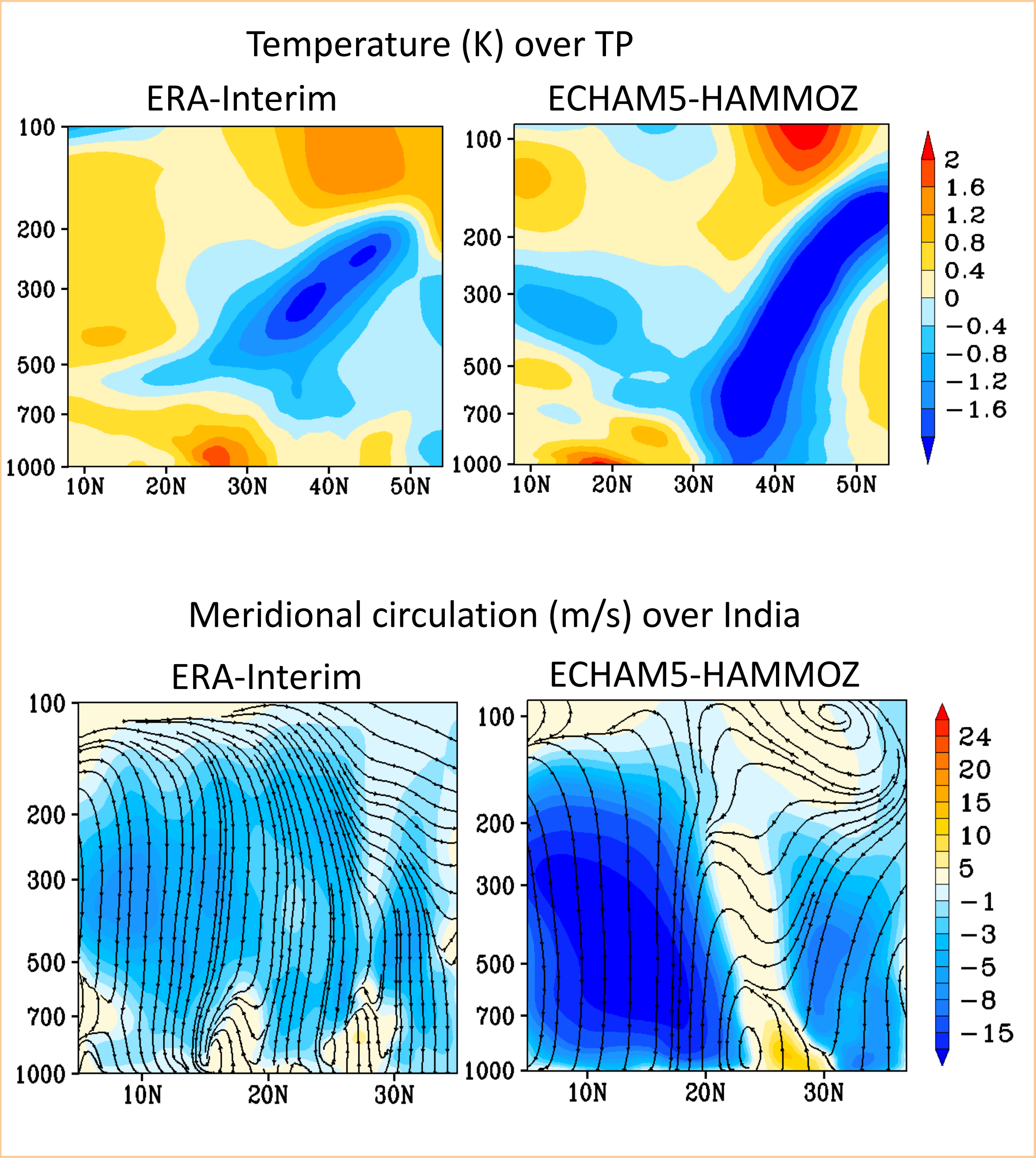
Wave trains (WTs) originate from El Niño region (marked by high/H & low/L)

- WT1: traversing over extra-tropics (H/L)
- WT2: traversing over mid to high latitude (H/L)
- WT-1 carries cold and dry stratospheric air-mass towards India; WT-2: warm wave

Fourier scale separation adopted during ELBR to filter out long waves & short waves

- Prominent peaks of both
  - shortwave, wavenumber 5 – 10
  - longwave, wavenumber 2 - 4
- Short waves poleward &eastward along with the two WTs
- *Hovmöller* diagram shows westward propagation of longwave, speed of 16 m/s

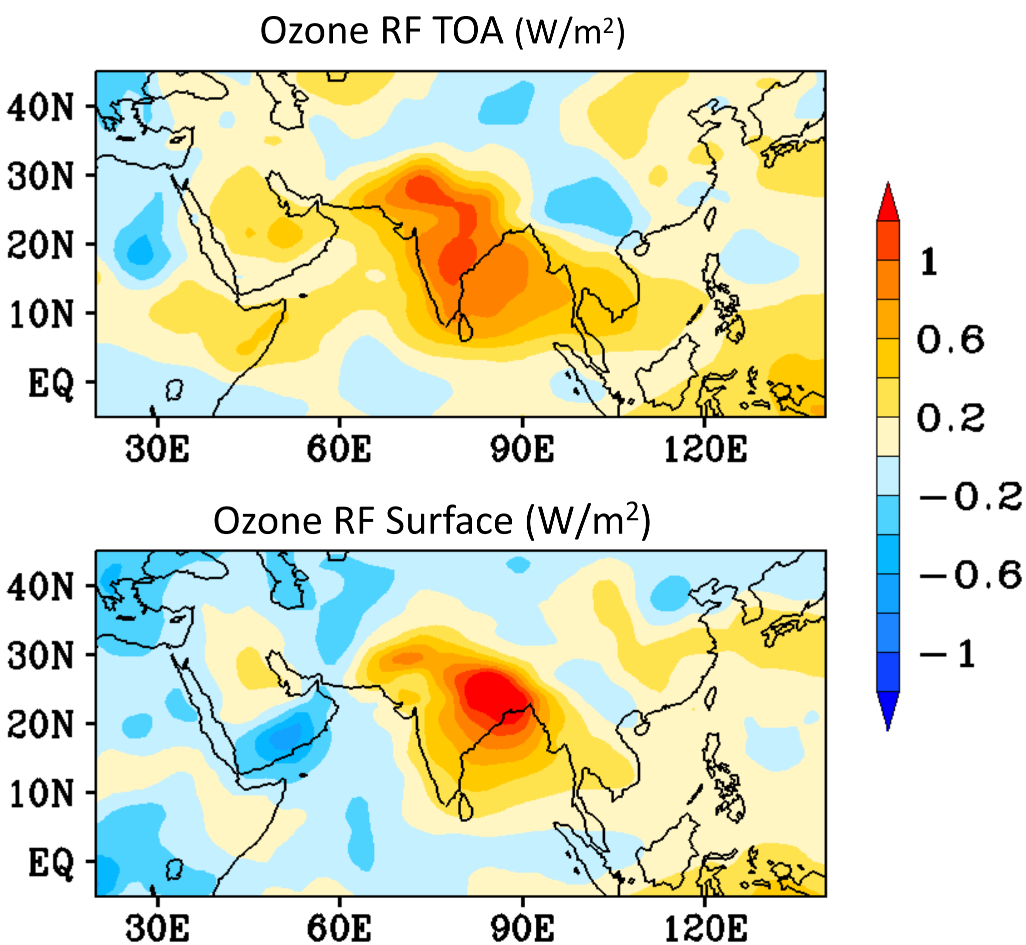
Impact on temperature & meridional circulation



Upper tropospheric temperature over the TP affect the ASM circulation

- Cold WT-1 traveling from east Pacific & arriving at NI-TP may affect the tropospheric temperature
- Anomalous cooling of ~1.6 – 2 K observed in UT over NI-TP during ELBR
- This cooling enhances subsidence over NI-TP region during ELBR
- Meridional circulation over India show strong subsidence over India, leading to rainfall deficit

Impact on radiative forcing from ECHAM5-HAMMOZ



Anomalous tropospheric ozone due to SI produces significant radiative impacts

- RF due to ozone
  - surface: +0.3112 Wm^{-2}
  - TOA: +0.333 Wm^{-2}
- Changes in RF over NI-TP during El Niño may have implications on atmospheric heating
- However, net temperature changes show significant cooling over NI-TP region, indicating the dominant influence of
  - RWB
  - cold WT-1

Summary

- During ELBR, SI occurs via RWB at
  - NI-TP region (~85 ^{o}E)
  - eastern edge of monsoon anticyclone (100 – 120 °E)
- Enhancement of ozone by ~30 – 100 ppb in the troposphere over India
- ELBR reveals the presence of WT1 & WT2 in the UT which:
  - travels from East Pacific to NI-TP
  - increases upper tropospheric ozone, via RWB
- ELBR are consequently experience cooling of ~1.6 – 2 K over NI-TP, due to transport of cold air-mass by WT-1
- Cold stratospheric subsidence may further weaken meridional circulation over India
- SI of ozone during El Niño enhances ozone RF over NI-TP by 0.3112 Wm^{-2} at surface and 0.333 Wm^{-2} at TOA, which can enhance the atmospheric temperature
- However, cold subsidence seems to be counteracting the warming due to positive ozone RF
- Overall, ELBR lead to exacerbation of deficit rainfall by,
  - RWB
  - transport of cold air via WT-1
  - subsidence by El Niño circulation
- Frequent cold SI over India can have a seminal role in worsening the deficit rainfall during El Niño years, which will have societal impacts

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Thank you

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