Tropical Rainfall Extremes During the Warming Hiatus: A View from TRMM

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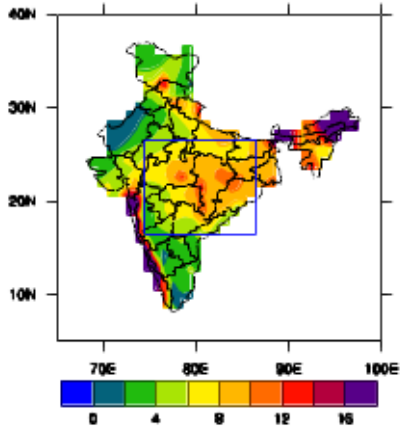
CAOS IISc

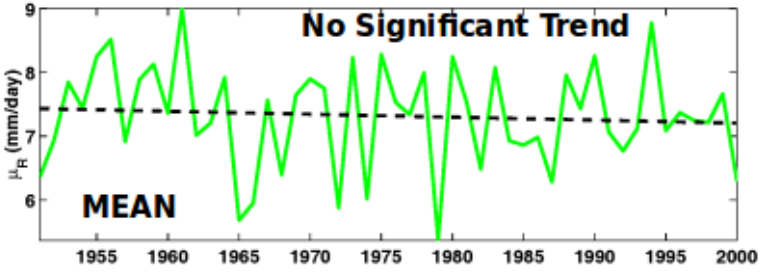
Influence of Warming

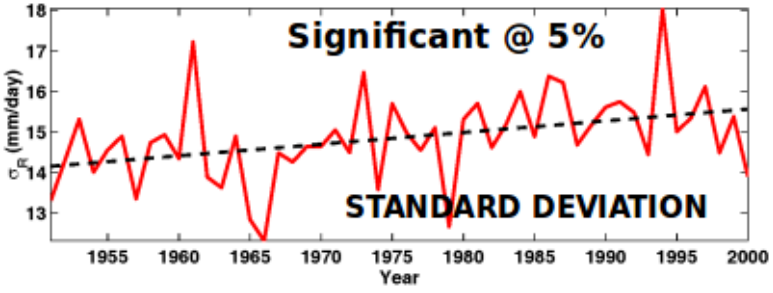
- Warming $\Longrightarrow$ increased moisture content in the atmosphere $\Longrightarrow$ expected amplification of short-duration extreme rainfall events (Trenberth, 1999; Allen and Ingram, 2002; O'Gorman and Schneider, 2009)
- Mostly validated by regional ground-based observations (Easterling et al., 2000; Groisman et al., 2005)
- Closer home...

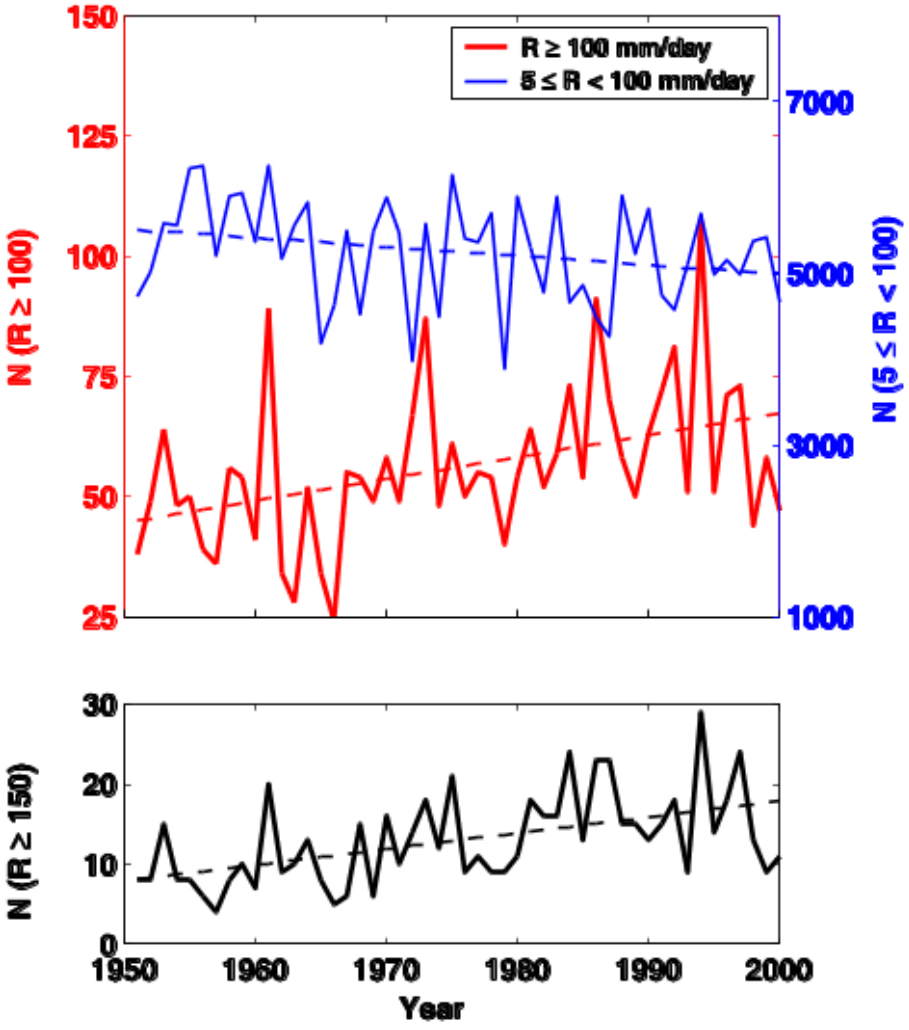
Trends in “Moderate” and “Extreme” Rain



JJAS

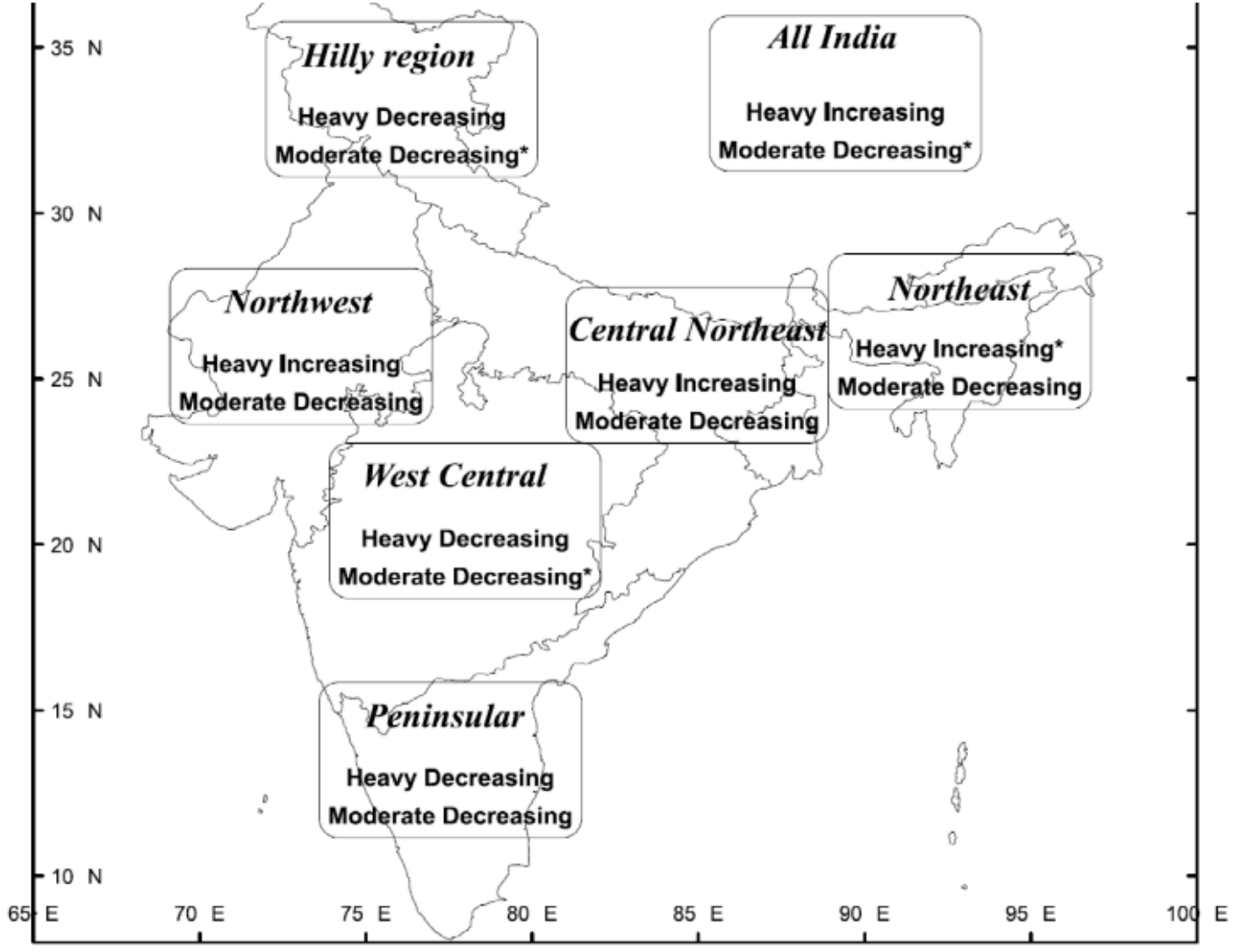






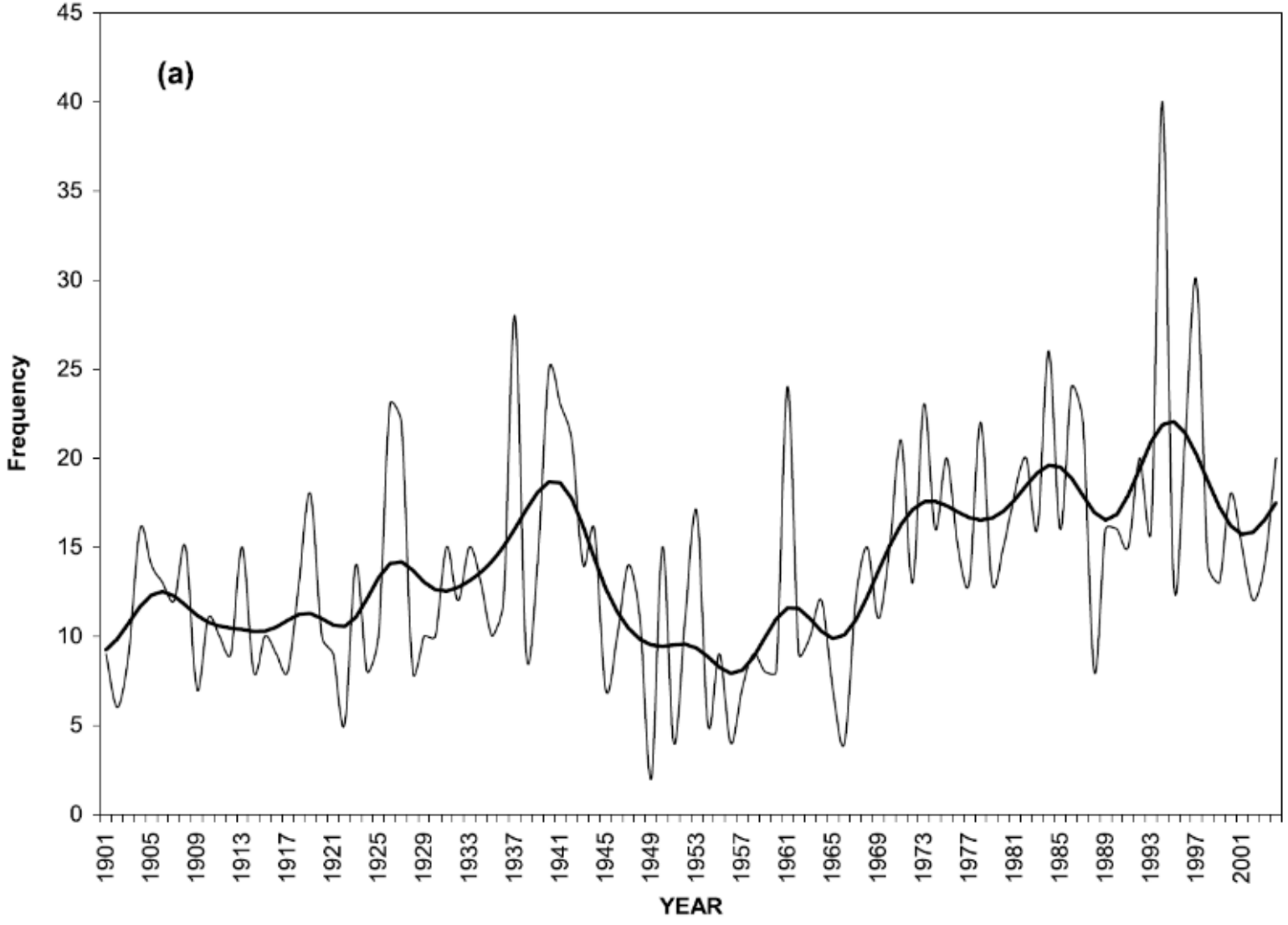
Goswami et al., Science, 2006

Trends in “Moderate” and “Extreme” Rain



Dash et al., JGR, 2009

Trends in “Very Heavy” Rain

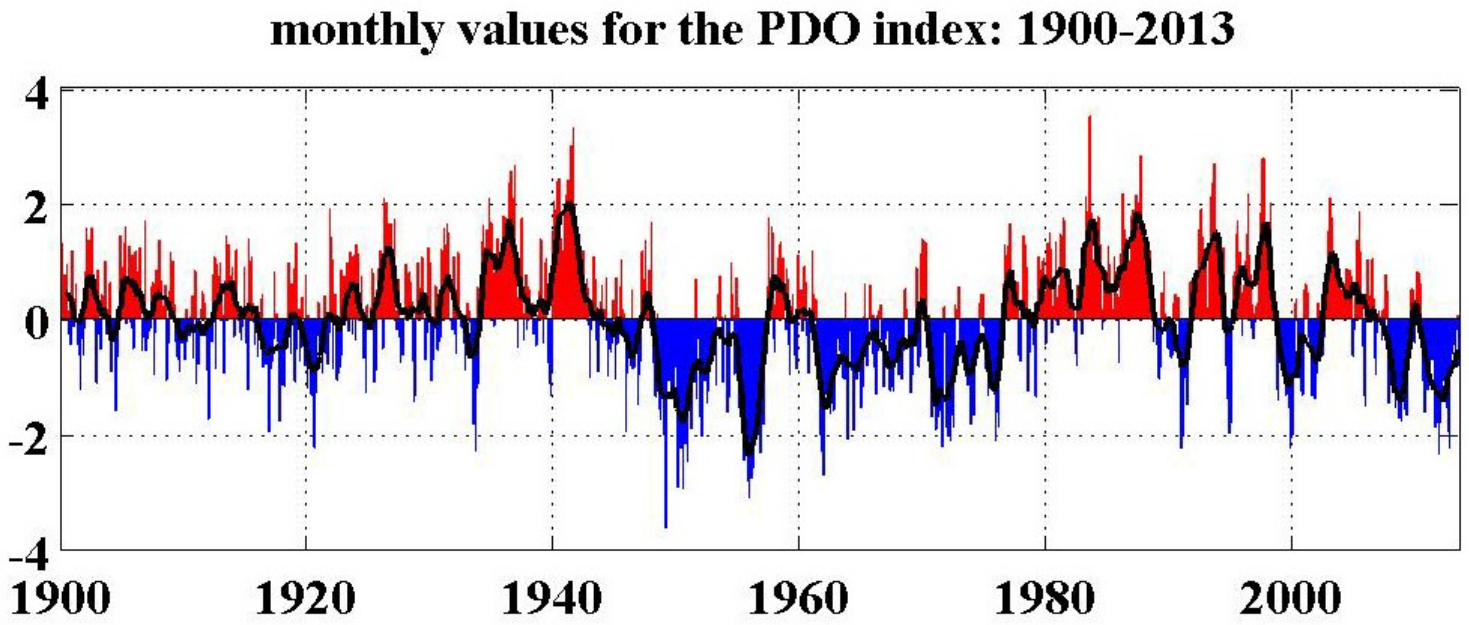


Rajeevan et al., GRL, 2008

Influence of Warming

- Warming World - Wet-wetter; Dry-drier (e.g., Held and Soden, 2006).
- Support for this warming world paradigm from observations (Allan et al., 2010; Chou et al., 2013) and long-term simulations (Giorgi et al., 2011; Lau et al., 2013).
- But, analysis of historical station-based rainfall data does not paint such a clear picture (Greve et al., 2014).
- Strong influence of ENSO on many tropical regions (e.g., Dai and Wigley, 2000)
- Waxing and waning of extreme annual tropical rainfall depending on the phase of ENSO (Sukhatme and Venugopal, 2015).

Pacific Decadal Oscillation/ENSO



The “hiatus” appears to be characterised by a “warm” period (1998-2005) transitioning into a “cold” period (2006-2013)

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- Ongoing “Pause” + phase change of PDO/ENSO - a natural laboratory (and unique opportunity) to understand the fate/state of tropical extreme rainfall.

- **Annual Accumulation** - arguably a robust measure for defining “wet” and “dry” regions.

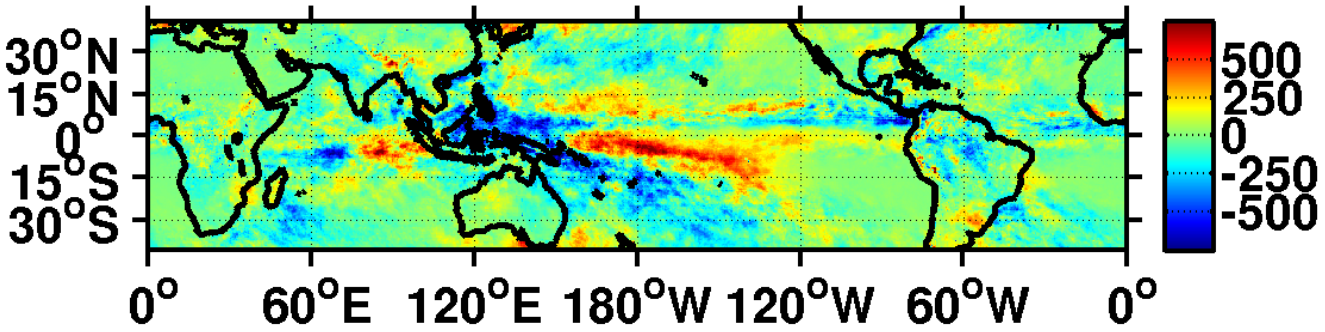
- Given the availablity high-resolution rainfall observations from TRMM during the hiatus, we focus on and try to isolate the effects of a change in phase of PDO/ENSO on tropical rainfall accumulation as well as its other attributes.

Datasets

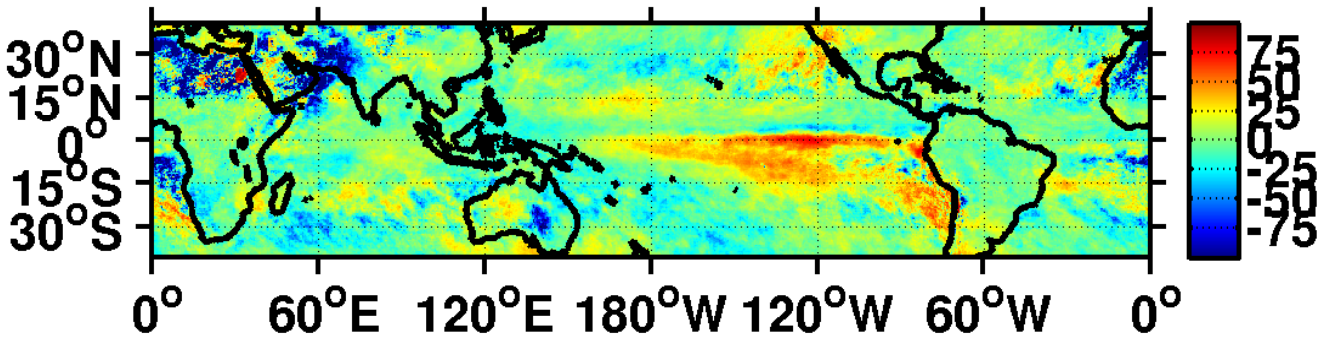
- TRMM 3B42 (V7)
  - 0.25-degree, daily gridded rainfall
  - 50S-50N (40S-40N)
  - 1998-2013
- GPCP
  - 2.5-degree, monthly gridded rainfall
  - 90S-90N (40S-40N)
  - 1979-2013 (1998-2013)
- GPCC (Land only)
  - 0.5-degree, monthly gridded rainfall
  - 90S-90N (40S-40N)
  - 1950-2010 (1998-2010)

Difference in Climatology of Annual Accumulation

(1998-to-2005) - (2006-to-2013) [in mm]

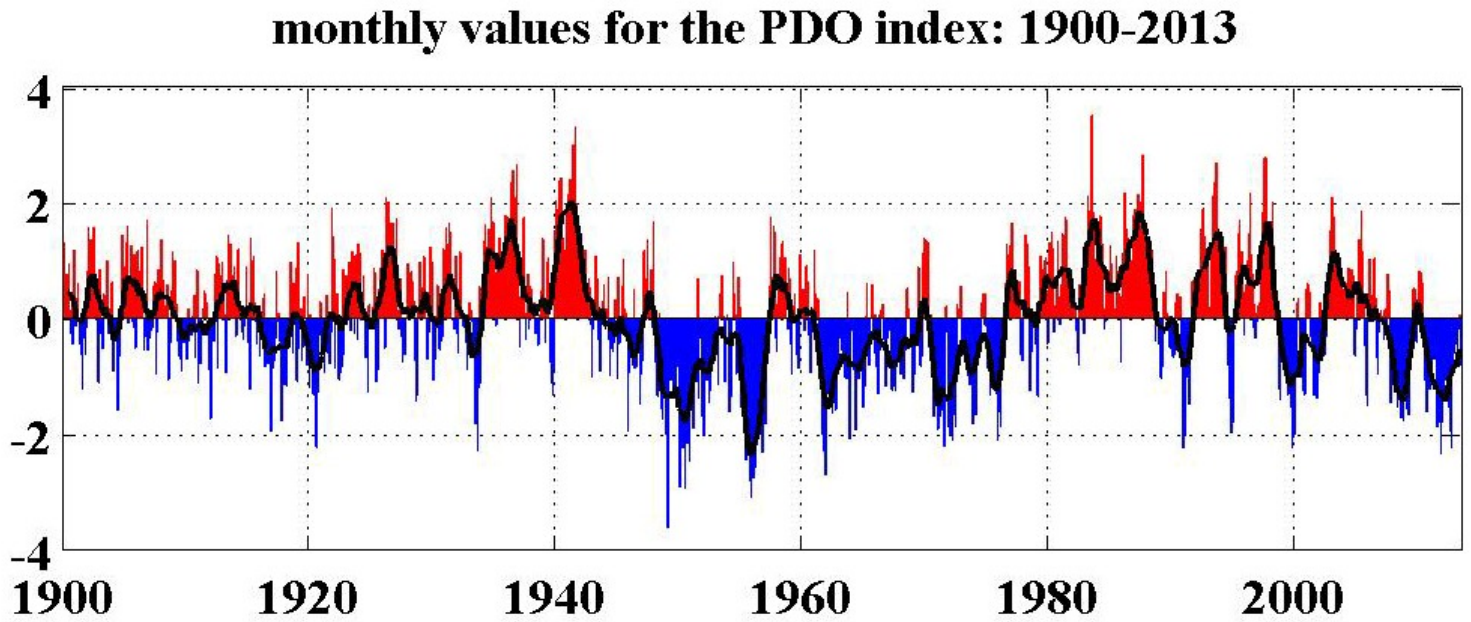


% Change w.r.t (1998-to-2005)



Westward shift - towards warm pool - of the “moist convection centre” during the latter half of the hiatus.

TRMM 3B42 (V7); 1998-2013; 0.25° , daily



The westward shift in the rain pattern is consistent with the more La Niña-ish state during the latter half of the hiatus.

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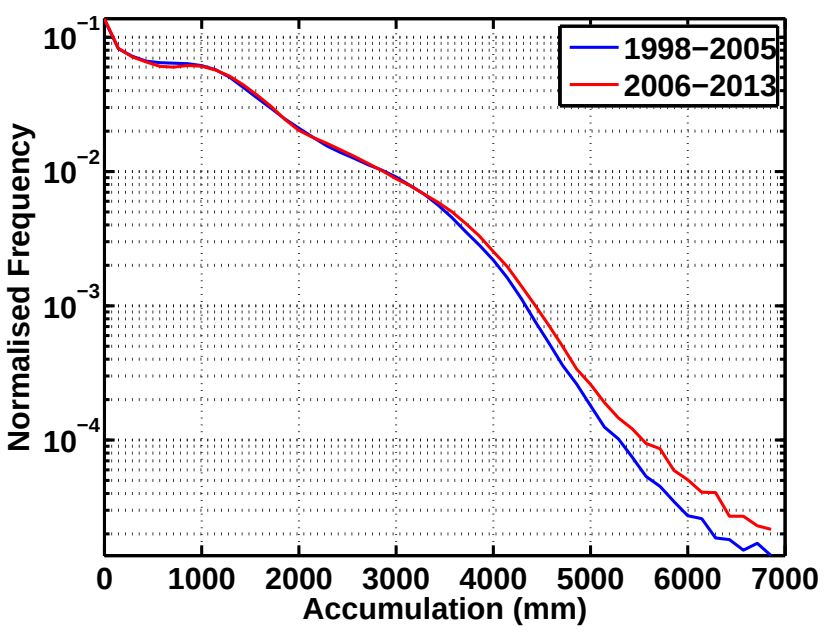
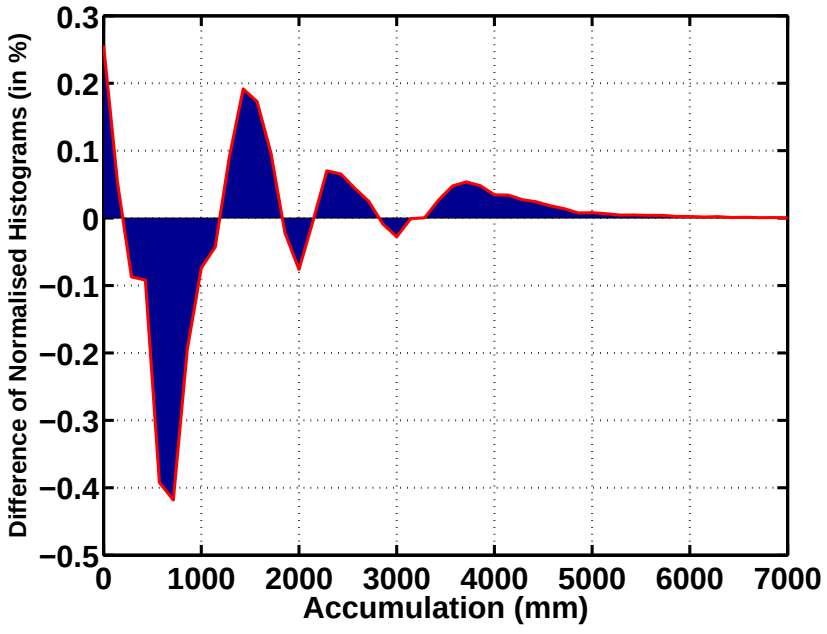
Difference in Frequency Distributions

1998-2005 vs 2006-2013



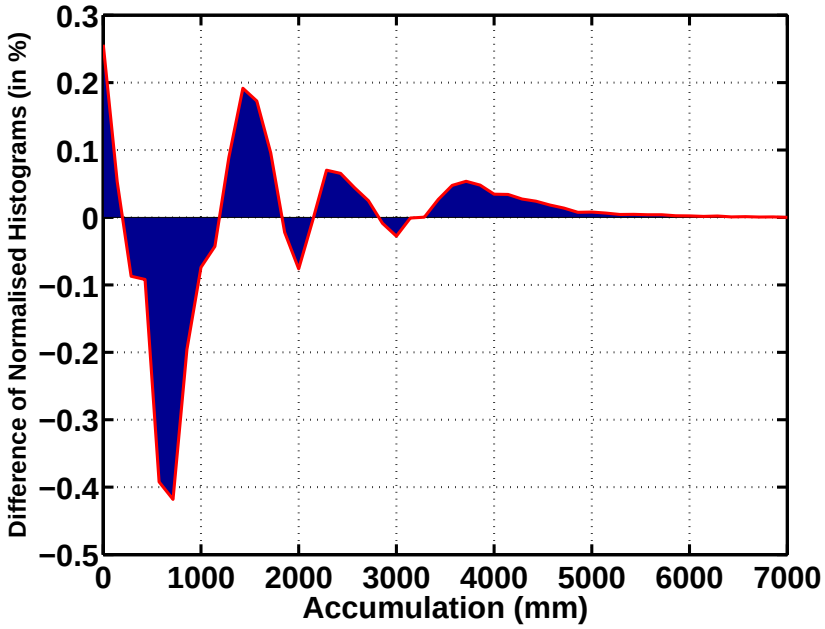


- The probability distributions of annual accumulation are significantly different (Kolmogorov-Smirnov test; p-value < 0.01) between the two eras.

- An increase in the regions with very high ($>$ 3000 mm) and very low ($<$ 200 mm) annual accumulation.

TRMM 3B42 (V7); 1998-2013; 0.25°, daily

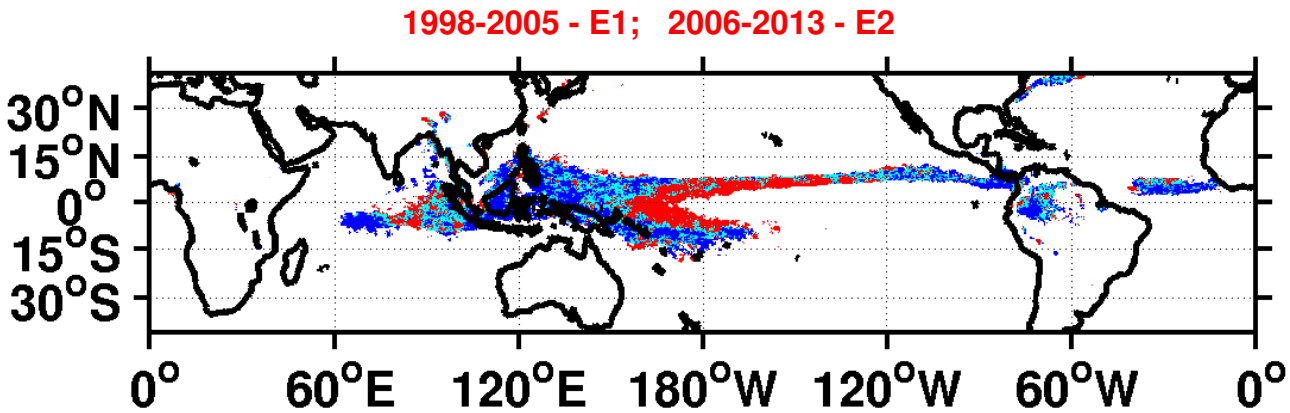
Geographical Changes: Index Maps



- "Natural" crossings at $\approx$ **200 mm** and **3000 mm** as thresholds for **"dry"** and **"wet"** tropical regions, respectively.
- **1998-2005 - Era1 (E1)**;
  2006-2013 - Era2 (E2)

- Index maps consisting of geographical locations that accumulated more (less) than 3000 mm (200 mm) of rain in
  - one or more of the years of E1 and E2 (**No Change**);
  - one or more of the years of E2 and *none of the years in E1* (**Appearance of Wet/Dry Locations**);
  - one or more of the years of E1 and *none of the years in E2* (**Disappearance of Wet/Dry Locations**).

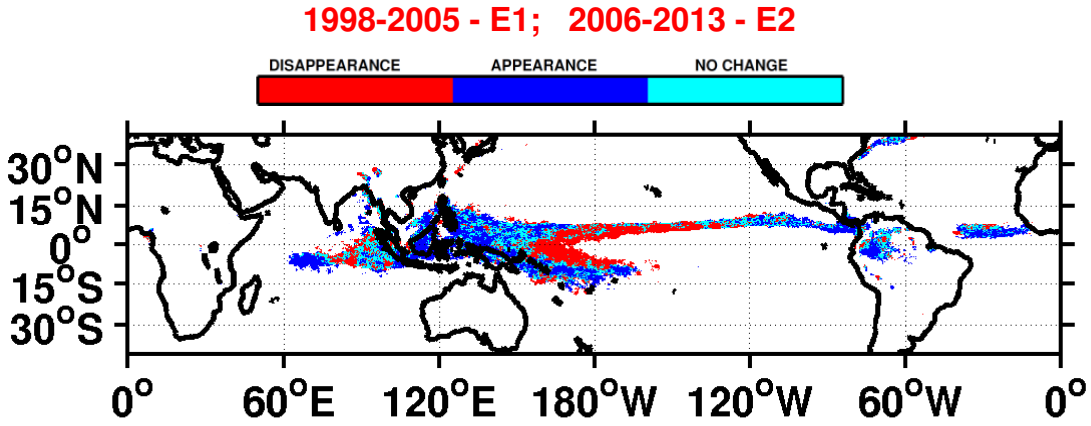
Geographical Changes: Very Wet Regions



Annual accumulation $>$ **3000 mm** in

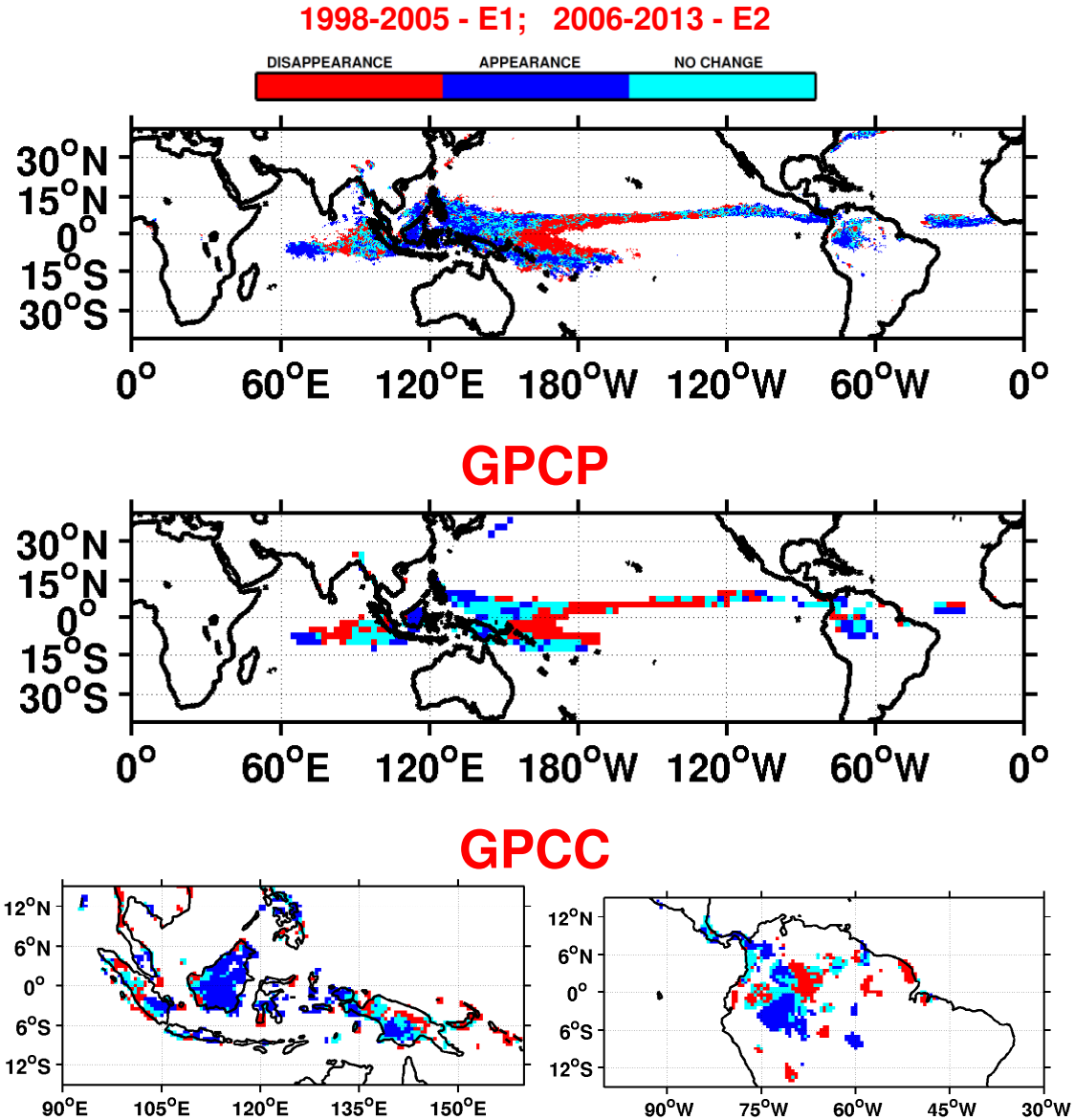
- one or more of the years of E1 and E2 (Cyan: No Change);
- one or more of the years of E2 and *none in E1* (Blue: Appearance of Wet Locations);
- one or more of the years of E1 and *none in E2* (Red: Disappearance of Wet Locations).

Geographical Changes: Very Wet Regions



- New high accumulation regions appear near the western maritime continent, over the Indian Ocean and the western part of equatorial South America.
- A depletion in the eastern core of the Pacific convergence zone.
- Overall, the “new” locations still lie within climatologically rainy zones, indicating a rearrangement of wet regions.

Geographical Changes: Very Wet Regions



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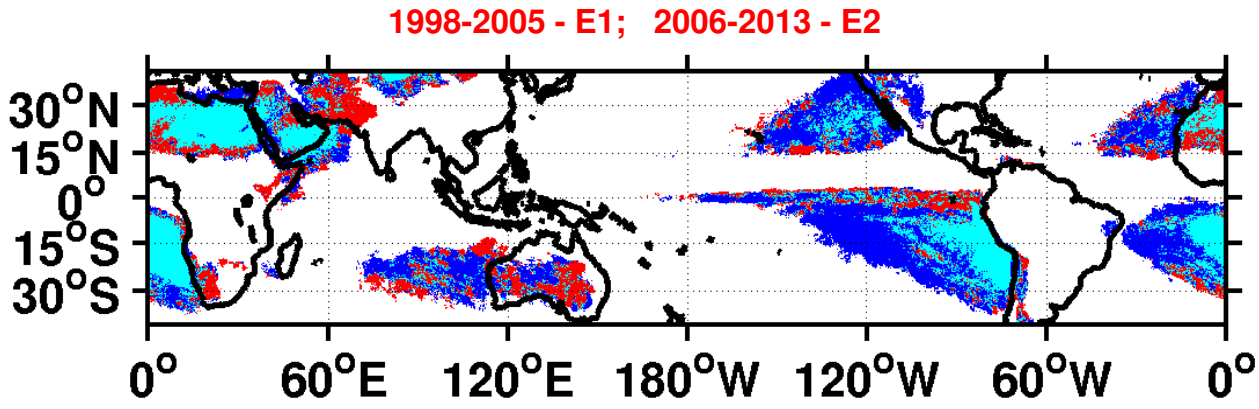
- A depletion in the eastern core of the Pacific convergence zone.
- Overall, the “new” locations still lie within climatologically rainy zones, indicating a rearrangement of wet regions.
- The robustness of these spatial changes are also seen in GPCP and GPCC (land only).

Geographical Changes: Very Dry Regions

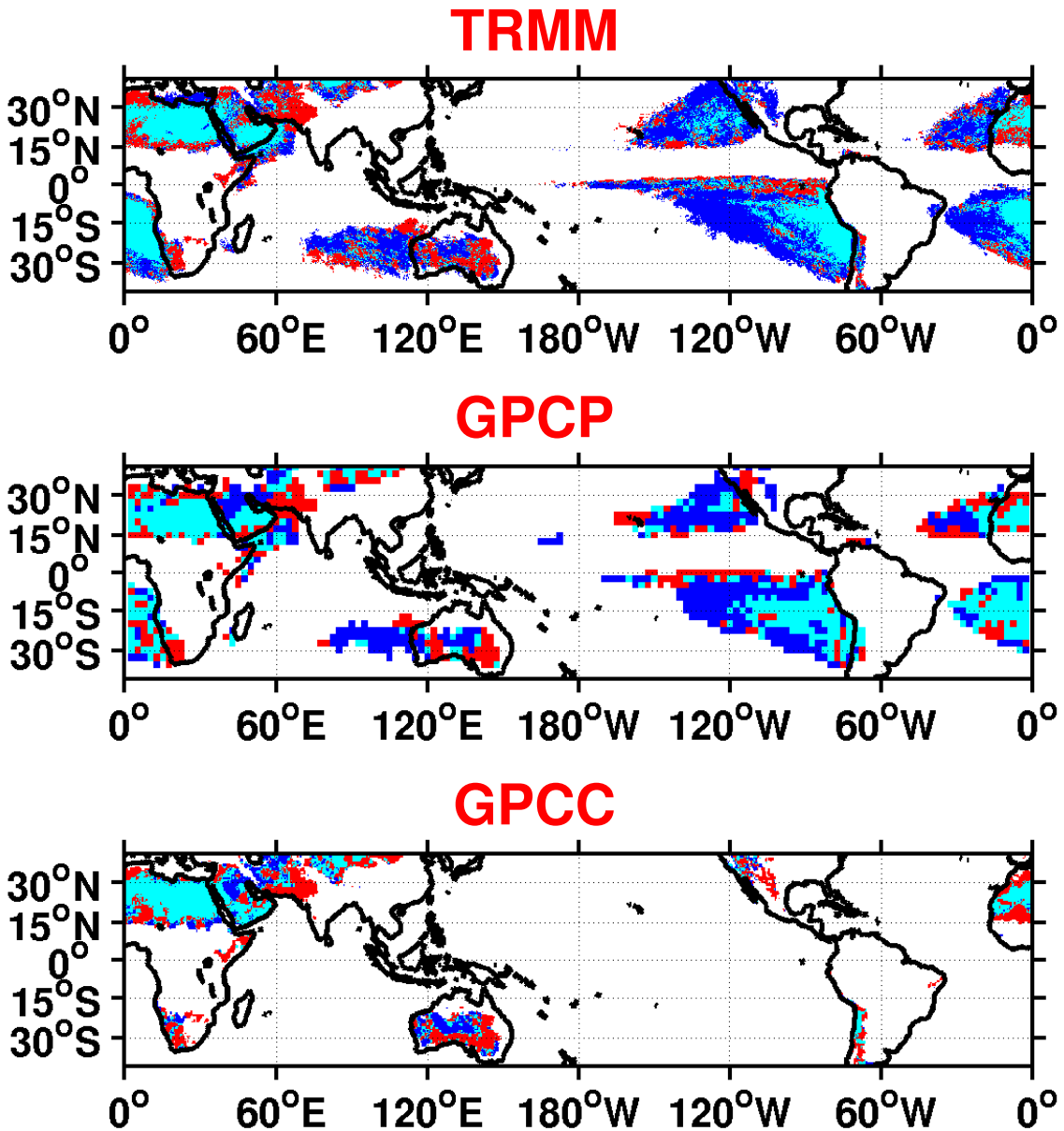


Annual accumulation $<$ **200 mm** in

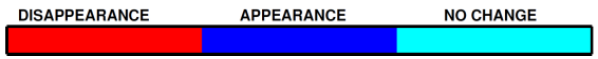
- one or more of the years of E1 and E2 (Cyan: No Change);
- one or more of the years of E2 and *none in E1* (Blue: Appearance of Dry Locations);
- one or more of the years of E1 and *none in E2* (Red: Disappearance of Dry Locations).

TRMM 3B42 (V7); 1998-2013; 0.25°, daily

Geographical Changes: Very Dry Regions



1998-2005 - E1; 2006-2013 - E2



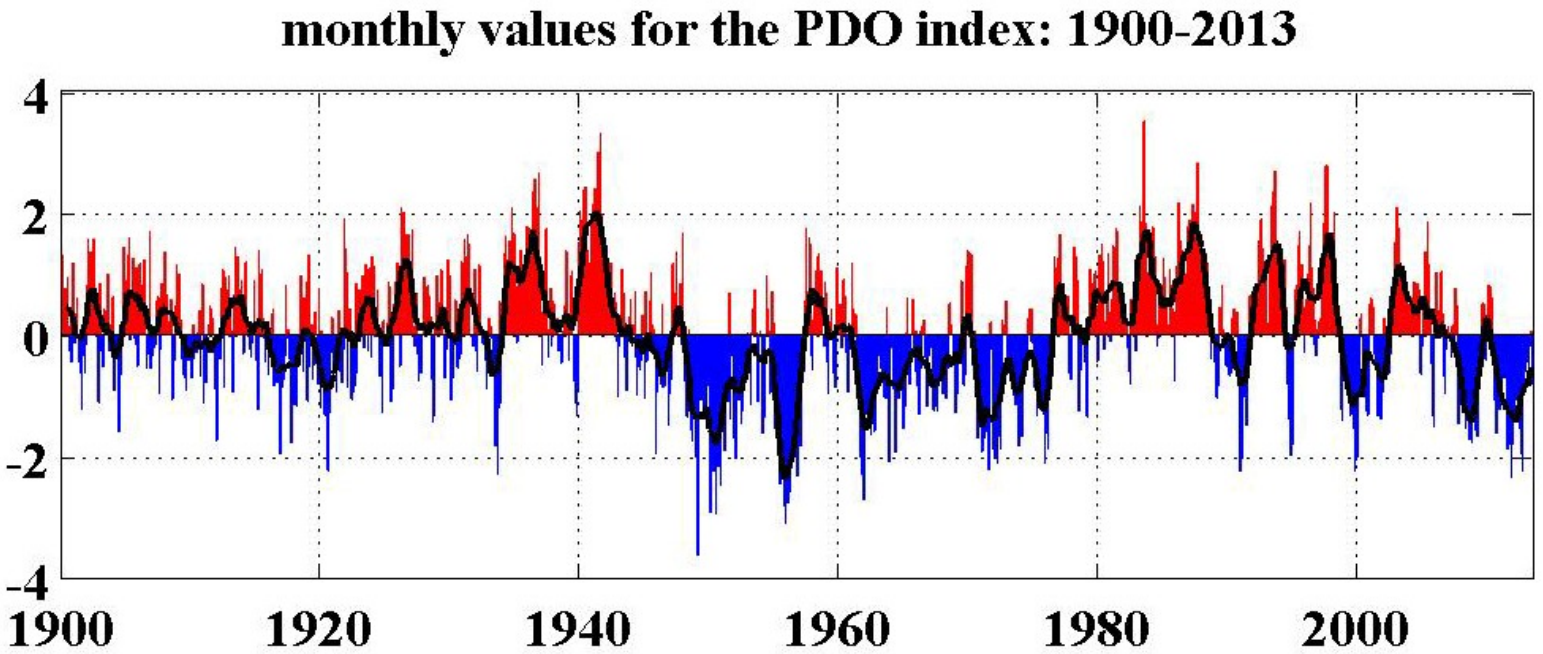
- Systematic expansion of the oceanic dry regions
- The “greening” of the Sahel?
- The drying of the south-western US
- Recovery from dryness in Pakistan and Australia

SUMMARY

- The changing character of tropical rainfall is examined during the ongoing global warming hiatus.
- At the outset, the difference in climatology in the two periods clearly indicates a shift towards a more La Niña-ish state in the latter part of the hiatus.
- Using annual accumulation as a measure, we show that the occurrence of very high and low rainfall has significantly increased in latter half of the hiatus.

SUMMARY

- An east-west rearrangement over the wet maritime continent, the Pacific convergence zones and equatorial South America.
- On the dry side:
  - Widespread areal expansion of oceanic dry zones;
  - Drying of the southwest United States,
  - Shrinking of the Sahel; and
  - Signs of recovery from extreme dryness in parts of Southern Australia, Western India and Pakistan.
- The spatial character of these changes is shown to be robust, evidenced by its consistency across TRMM, GPCP and GPCC (over land) data.



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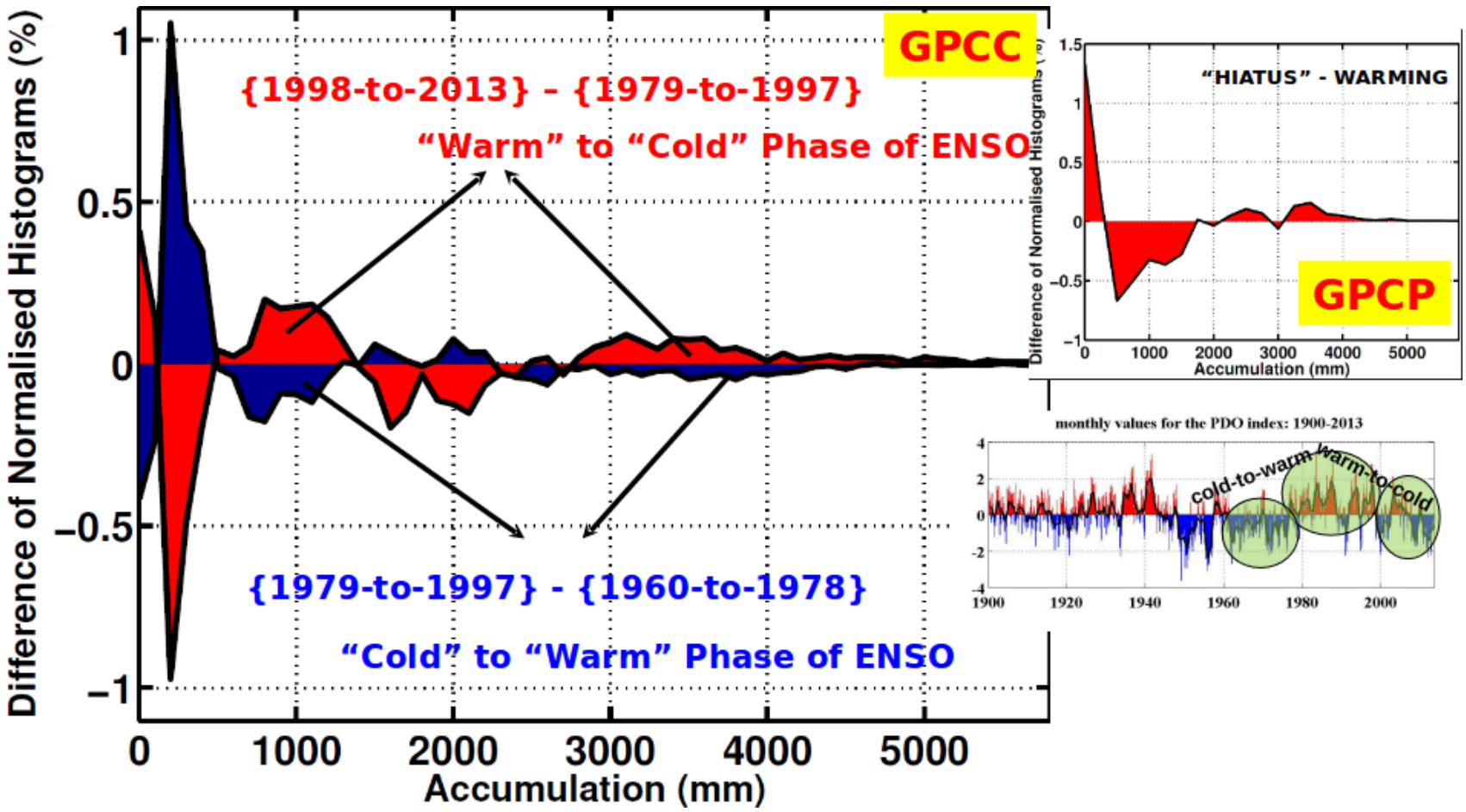
PDO/ENSO Influence?

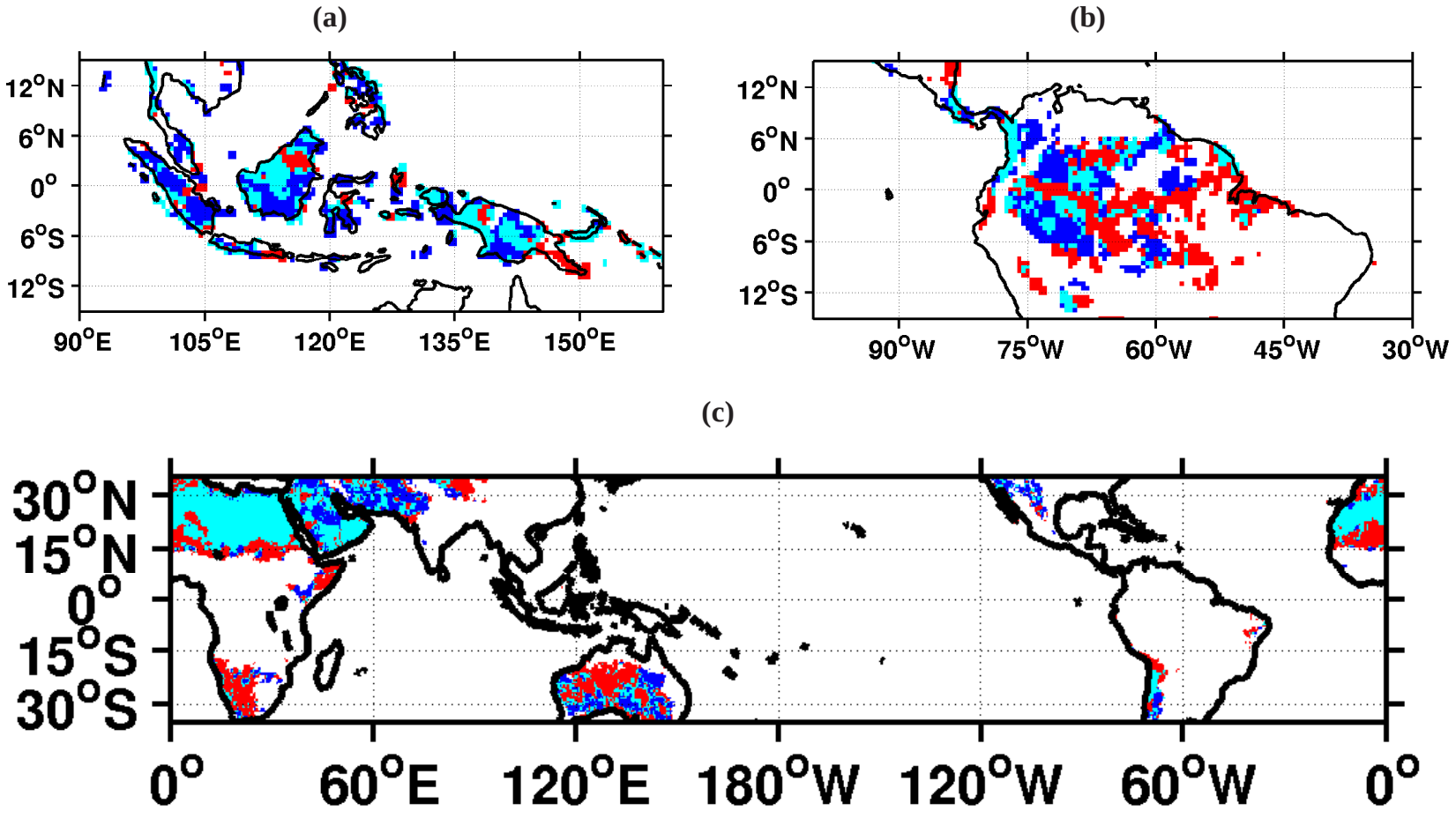


Near exact <u>reversal</u> of the very wet/dry between the two "phase transitions"

Sukhatme and Venugopal, Waxing and Waning of Observed Extreme Annual Tropical Rainfall, QJRMS, 2015

PDO/ENSO Influence?

Era1: 1979-1997; Era2: 1998-2013 **[WARM-to-COLD]**

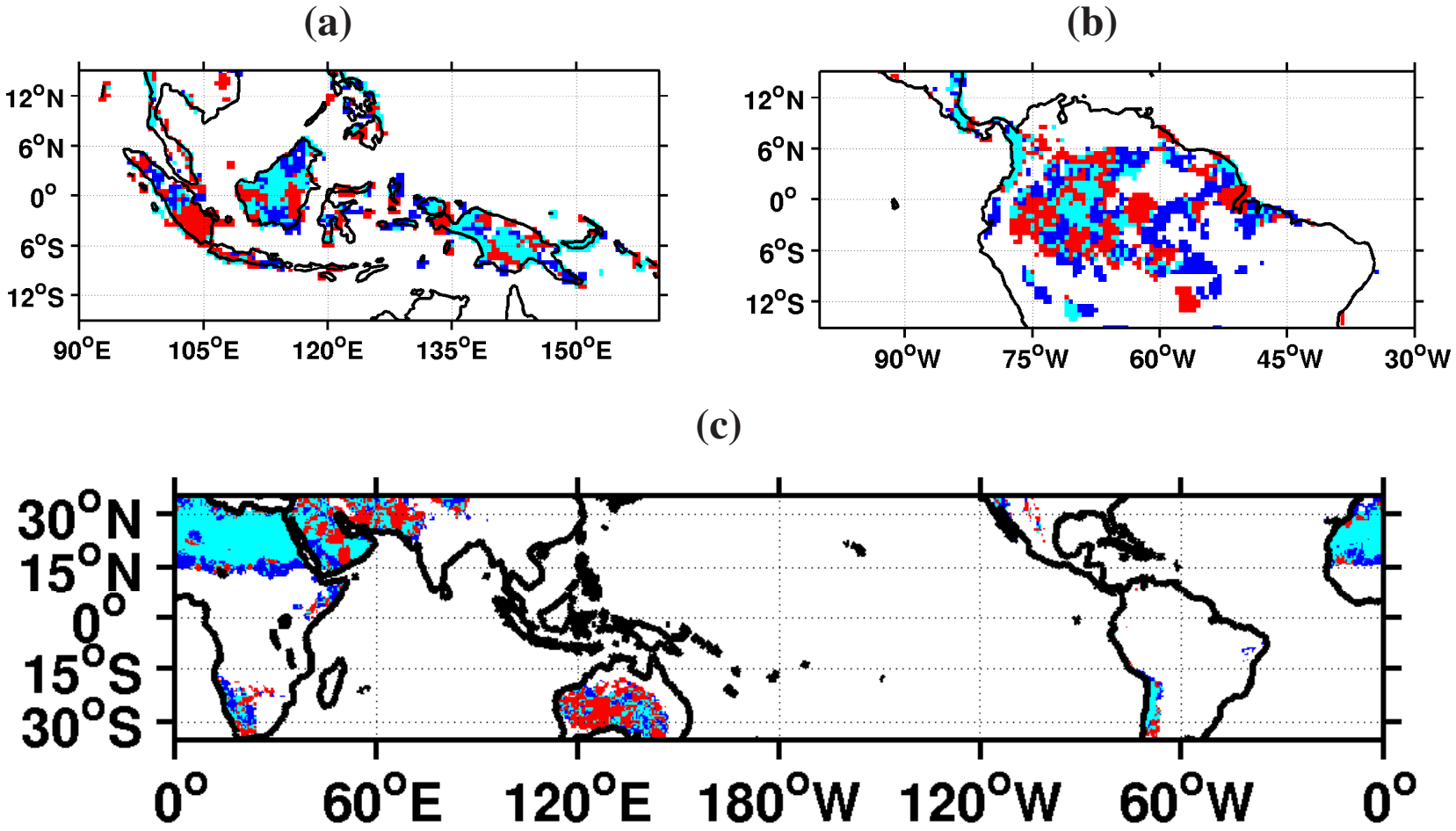


Top Panels: Very Wet Bottom Panel: Very Dry

GPCC land-only

PDO/ENSO Influence?

Era1: 1960-1978; Era2: 1979-1997 **[COLD-to-WARM]**

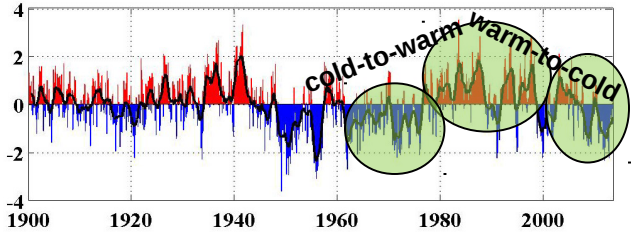


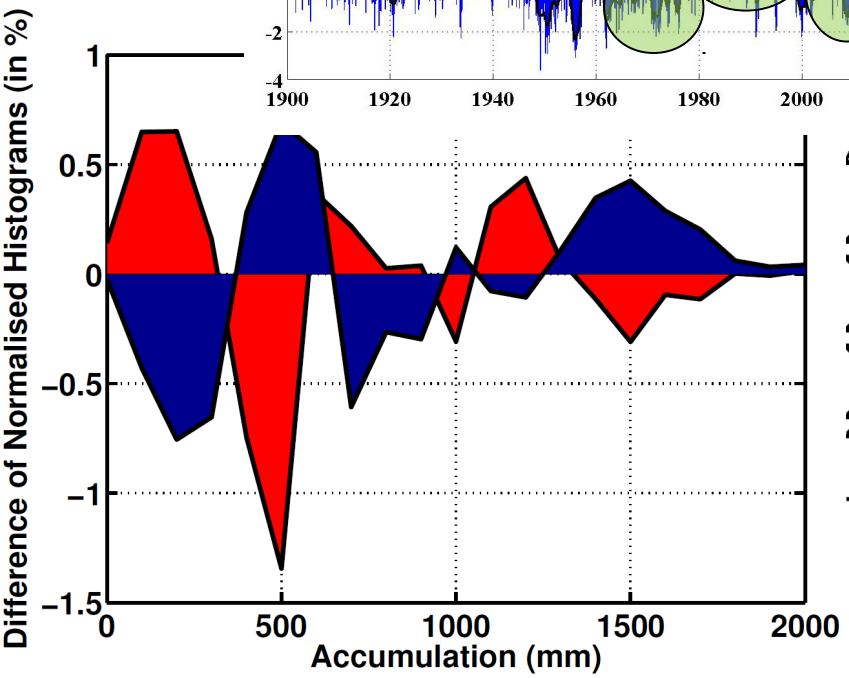
Top Panels: Very Wet **Bottom Panel: Very Dry**

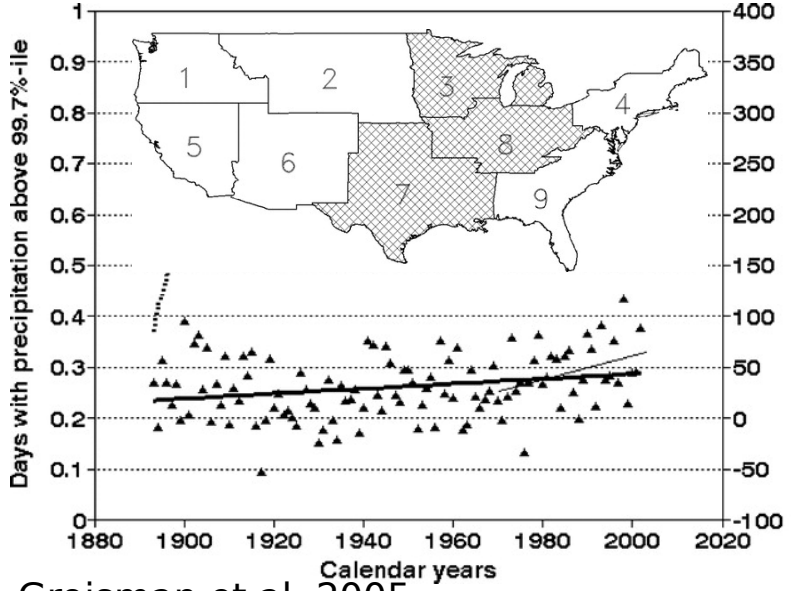
GPCC land-only

Is this consistent with regional changes?

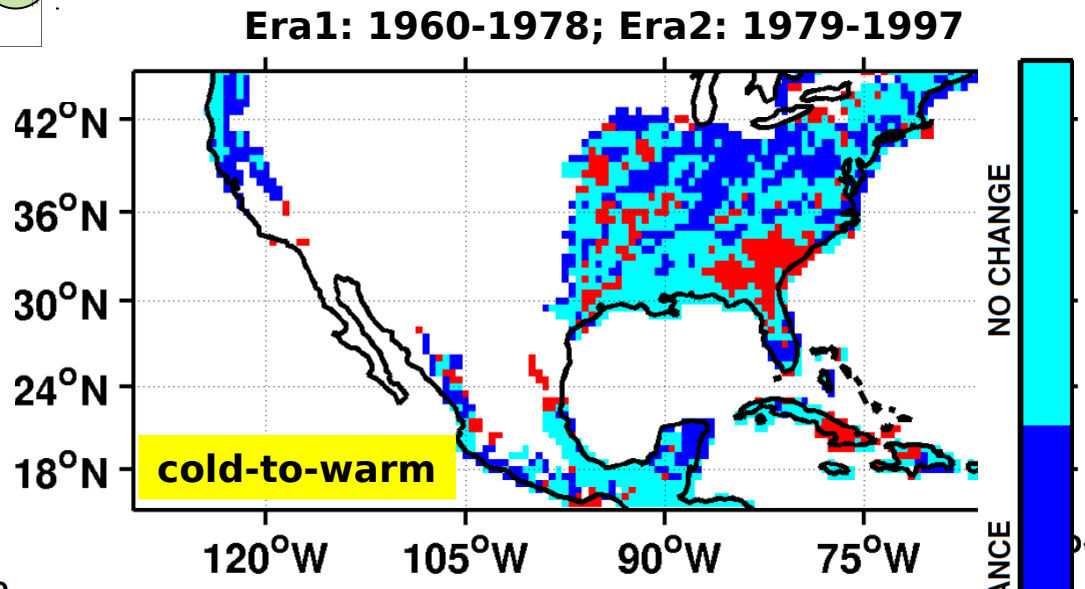
Case-study: Continental US

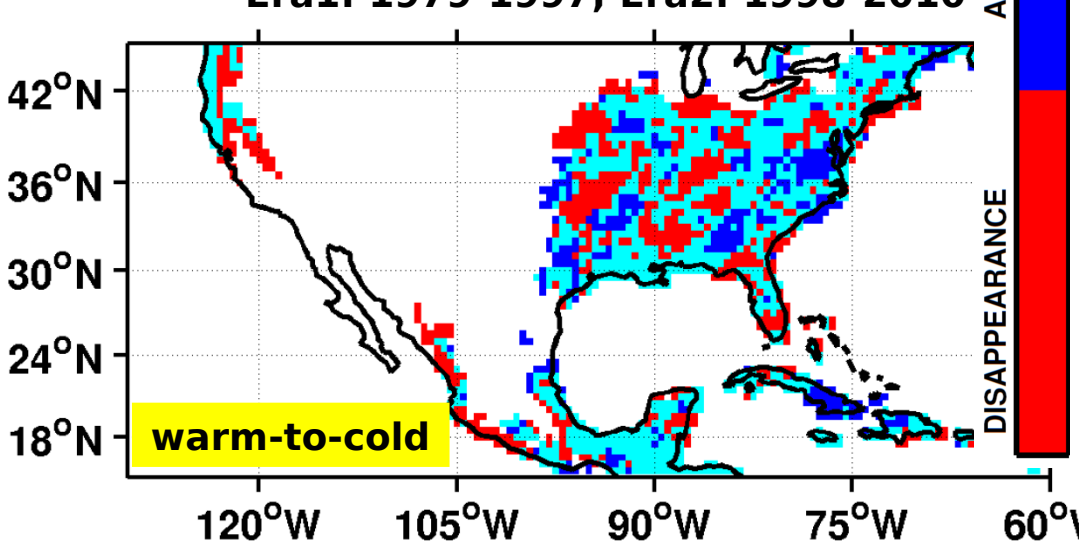


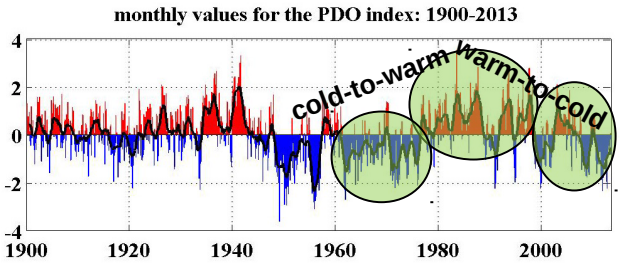




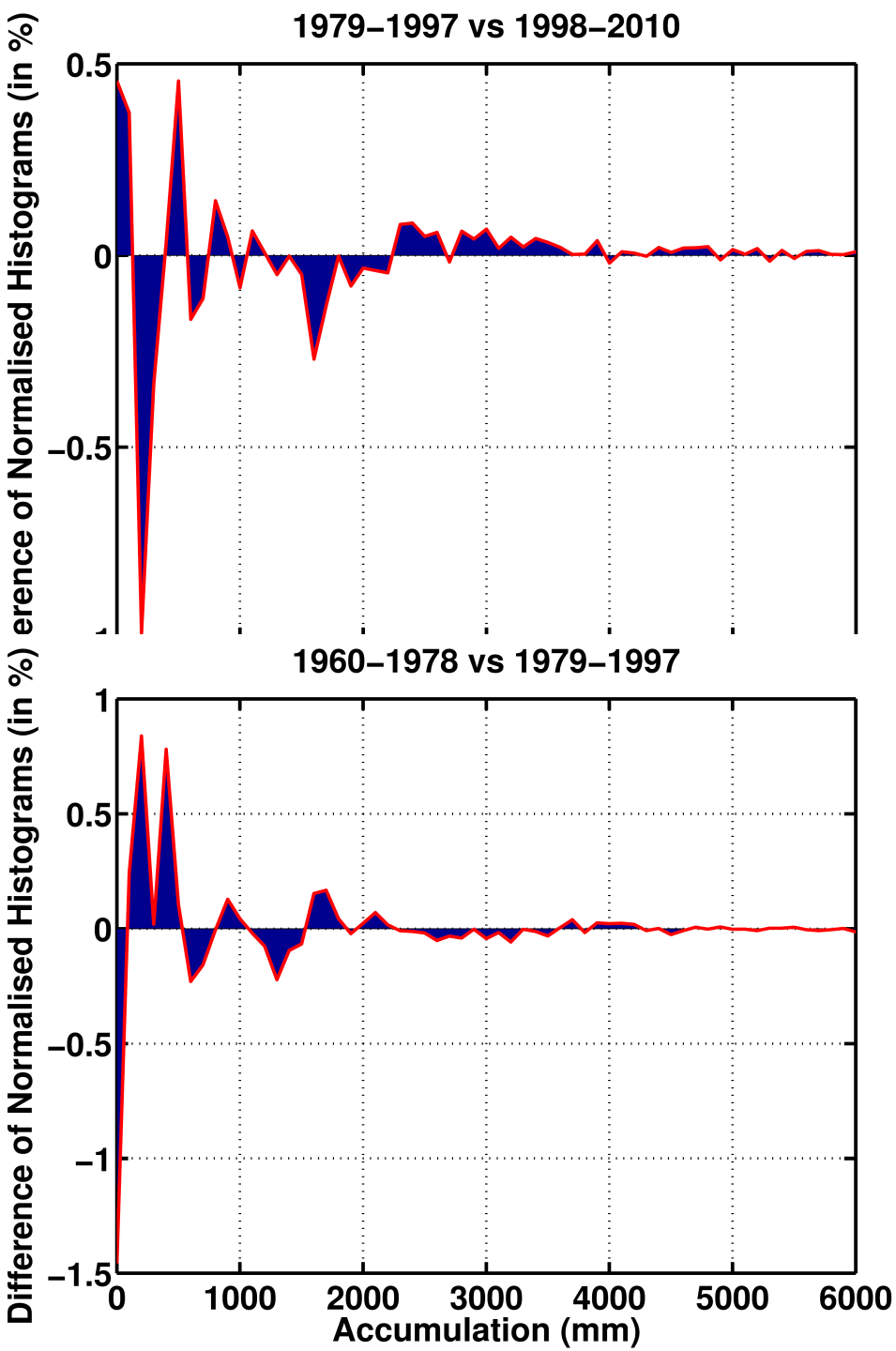
Groisman et al. 2005





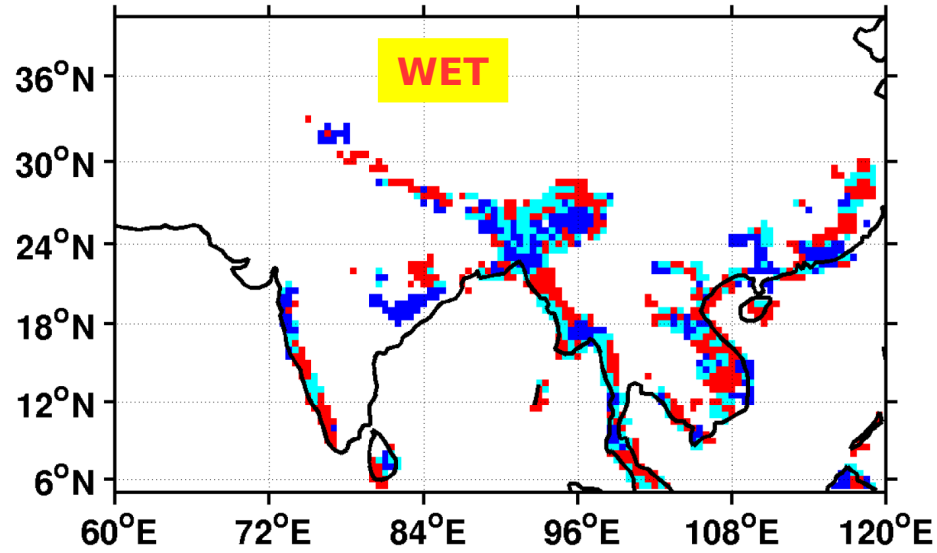


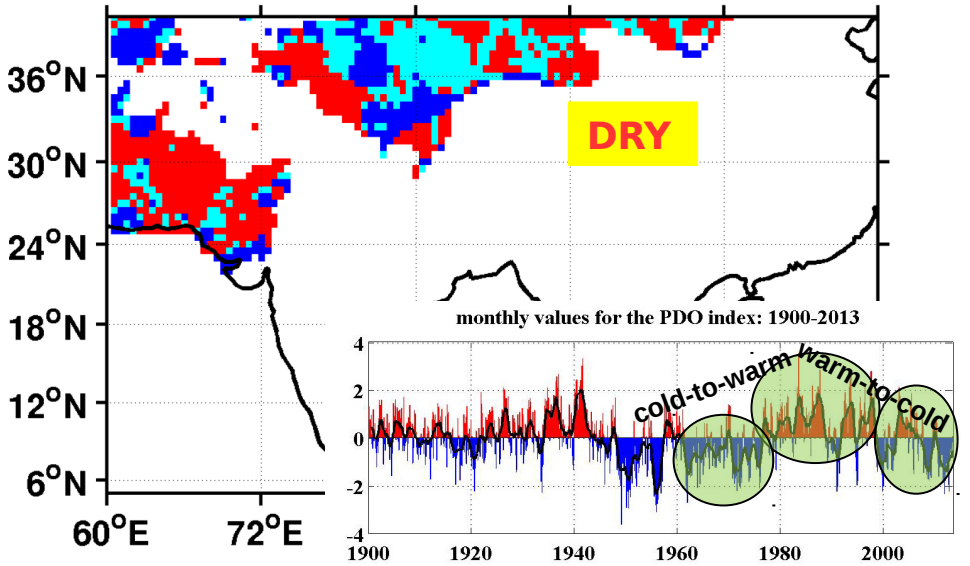
Case-study: South Asia



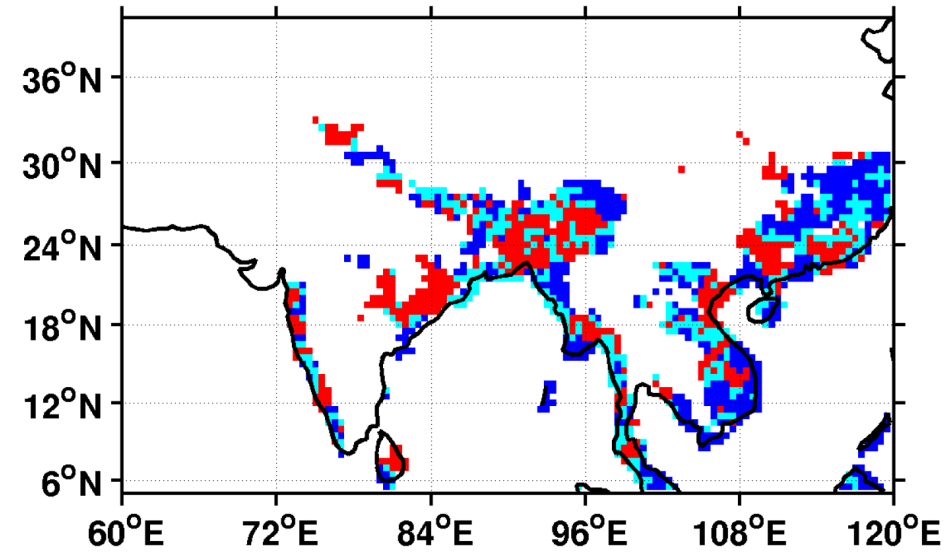
GPCC [Land-only]

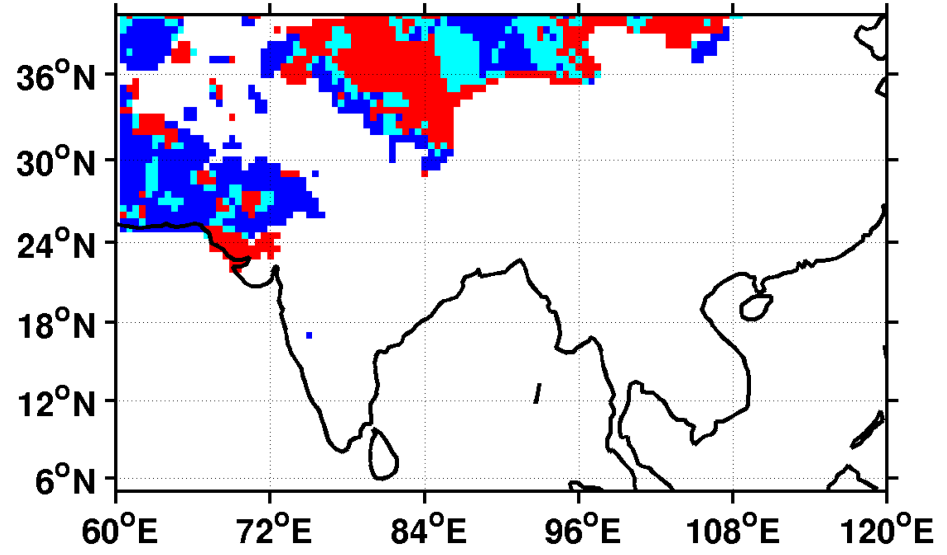
Era1: 1960-1978; Era2: 1979-1997 (cold-to-warm)

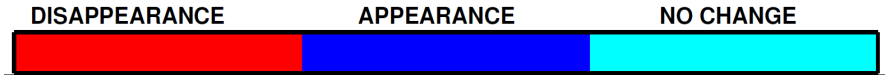




Era1: 1979-1997; Era2: 1998-2010 (warm-to-cold)



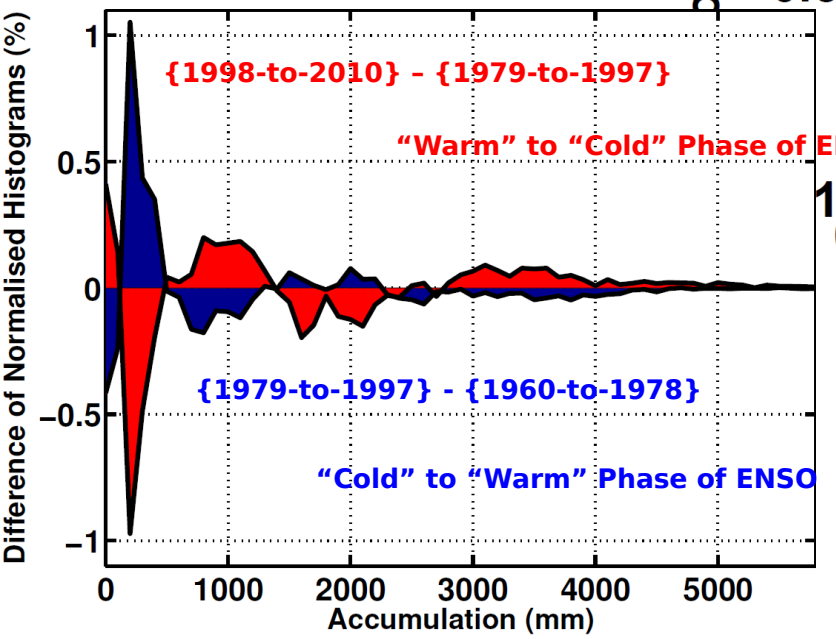


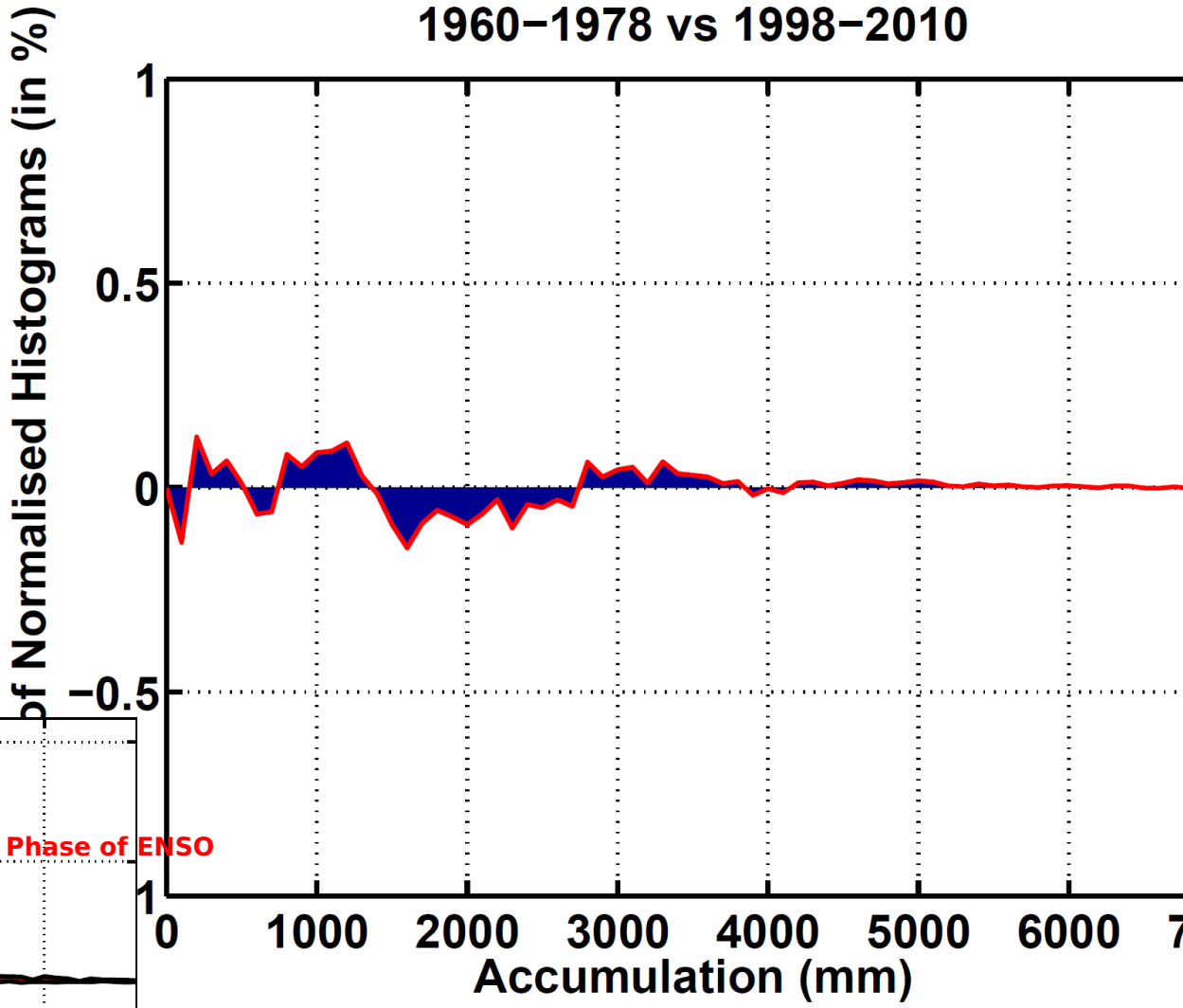


GPCC [Land-only]

What and where is the warming contribution?

Comparing two well-separated cold phases?





GPCC [Land-only]