Exploring the relationships between precipitation and surface temperature using satellite-based observations

II. Interannual variability in tropical and global mean time series: Assessing ENSO and volcanic effects

**Method to estimate ENSO and volcanic effects:**
- Divide the entire data record into two periods, i.e., the volcanic period (\( \tau \geq 0.16 \)) and non-volcanic period (\( \tau < 0.16 \)).
- Estimate the ENSO signals during the non-volcanic period using linear lag-correlation/regression with Nino 3.4.
- Apply the ENSO signals to the entire record and remove the estimated them in time series.
- Estimate the volcanic effect during the volcanic period by applying linear lag-correlation/regression with \( \tau \) in the residual (ENSO effect removed) time series.

**Observed relationships:**
- Tropical and global mean surface temperature (over both land and ocean) and tropospheric atmospheric temperatures (TLT and TMT) strongly respond to ENSO with same sign.
- Mean (tropical and global) precipitations over either land or ocean are also modulated by ENSO. However, the responses are always opposite between over land and ocean, resulting in weak ENSO responses in tropical and global land/ocean mean precipitation.
- No discernible ENSO signals are found in lower stratospheric layered temperature (TLS).

**Summary of volcanic signals:**
- Tropospheric water vapor strongly responds to both ENSO and volcanic eruptions through closely following surface temperature responses.
- Systematic volcanic signals are seen in tropical and global mean (land+ocean) tropospheric water vapor just like in surface temperature responses, in contrasting to weak ENSO responses in tropical and global mean (land+ocean) precipitation.
- Without large-scale forcings, tropical and global mean precipitation has no correlation with mean surface temperature, even over ocean.
- Tropical and global mean (land+ocean) tropospheric water vapor strongly correlates to surface temperature no matter whether large-scale forcings exist or not.

**El Chichon and Pinatubo:**

**El Chichon:**
- Intense ENSO response exist in precipitation, surface temperature, and tropospheric columnar water vapor, specifically in the tropics. However spatial features of responding are different especially between precipitation and surface temperature.
- Tropical and global mean mid-lower tropospheric (dry) instability represented by TLT-TMT is not responding to ENSO. This may partly account for the weak ENSO signals in tropical and global (land+ocean) mean precipitation.
- No discernible ENSO signals are found in lower stratospheric layered temperature (TLS).

**Pinatubo:**
- Tropical and global mean mid-lower tropospheric (dry) instability represented by TLT-TMT is strongly responding to volcanic eruptions. This may partly account for the intense warming in the lower stratosphere (TLS) during the volcanic period.
- Different from strong cooling in the tropospheric atmosphere and surface, intense warming is seen in the lower stratosphere (TLS) during the volcanic period.

**Tropospheric water vapor (vap) vs. surface temperature (Ts):**
- With the cooling effect of ENSO, tropospheric water vapor strongly correlates to surface temperature responses, in contrasting to weak ENSO responses in both tropical and global mean (land+ocean) precipitation.

**Nino 3.4:**
- ENSO and volcanic effects:
  - Tropical and global mean surface temperature (over both land and ocean) and tropospheric atmospheric temperatures (TLT and TMT) strongly respond to ENSO with same sign.
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**Summary of observations:**
- Global precipitation variations are examined by focusing on the impact of ENSO and volcanic eruptions during the GPCP record. This examination is further extended to exploring the dependency of precipitation variability averaged over large domains on surface temperature variations with and without large-scale forcings such as ENSO and volcanic eruptions.

1. **ENSO and volcanic effects:**
   - Tropical and global mean surface and tropospheric temperatures show strong same-sign responses to ENSO over both land and ocean. In contrast, ENSO has very weak influences on tropical and global mean (land/ocean) precipitation due to opposite precipitation anomalies over land and ocean.
   - However, two volcanic eruptions decreased not only global surface and tropospheric temperatures, but also global precipitations over both land and ocean. Different timings in the response of tropospheric water vapor to ENSO and volcanic eruptions are explained by the ENSO effect.
   - A similar mid-lower tropospheric (dry) instability associated with low-level tropospheric temperature and surface temperature responses, in contrasting to weak ENSO response in tropical and global mean (land/ocean) precipitation.

2. **Correlation between precipitation and surface temperature:**
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