Examining Global Precipitation Change and Variability during 1901-2010 using Observations and CMIP5 Outputs

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Global surface temperature has been increasing during the past over 100 years, but interrupted by evident interannual-to-interdecadal time scale variations;

How may the global hydrological cycle specifically precipitation have varied/changed during the time period?
Objectives:

1) Explore long-term (centennial-time scale) precipitation changes/trends including spatial patterns during the past over one hundred years; (*Whether are these changes/trends dominated by the effects of anthropogenic greenhouse gases (GHG)?)

2) Examine the effects of ocean-based (internal) interannual-decadal/interdecadal oscillations/modes on precipitation, such as Pacific Decadal Oscillation (PDO) and Atlantic Multidecadal Oscillation (AMO).
Data sets:

Precipitation:

1) **GPCC full data reanalysis version 6 of monthly land precipitation [1901-2010; on global grid with resolutions of 0.5°, 1.0°, and 2.5° (Schneider et al. 2013; Becker et al. 2013)]**
2) **NOAA/CICS-Smith reconstructed (RECONS) monthly land+ocean precipitation primarily used over global ocean [1900-2008; on global grid with resolution of 5°; reconstructed from modes derived from historical SST and sea level pressure data, constrained by rain-gauges over land, and further trained by the satellite-based global precipitation product (GPCP) for the post-1979 period (Smith et al. 2009, 2012)]**

Surface temperature:

1) NASA/GISS-surface temperature anomaly analysis (1880-present)
2) NOAA/NCEP extended reconstructed sea surface temperature (ERSST) v3b (1854-present)

CMIP5 simulations (**temperature and precipitation**):

1) Coupled historical experiments from multiple CMIP5 models (1880-2005), forced by (i) historical (total) natural and external radiative forcings (Hist), (ii) anthropogenic greenhouse-gas (GHG) forcing only (HistGHG), and (iii) historical natural radiative forcing only (HistNat); [-------- multi-model ensemble means limit internal variations]
2) Atmosphere-only (AMIP) experiments from NASA/GISS Model E (1880-2010), forced by surface (observed SST & sea ice extent) and historical radiative forcings. [-------- include both (natural and anthropogenic) radiative forcings and oceanic-based variations]
Outline:

Part I. Long-term (centennial-time scale) precipitation changes/trends

Part II. Precipitation changes/variations associated with various decadal/interdecadal-scale factors/mechanisms in global SST
Part I. **Long-term (centennial-time scale) precipitation changes/trends**

- Observed and simulated (CMIP and AMIP) spatial patterns of global precipitation trends;
- Estimating/discriminating contributions from various physical mechanisms: natural, anthropogenic GHG and aerosols?
- Likely components of precipitation change/trend patterns related to anthropogenic GHG forcing

**Precipitation products:**

- Over land: GPCC (& RECONS), NASA GISS/AMIP, CMIP5 (Hist, HistGHG, HistNat)
- Over ocean: RECONS, NASA GISS/AMIP, CMIP5 (Hist, HistGHG, HistNat)

**Estimating anthropogenic aerosol effect in temperature and precipitation using (multi-model) CMIP5 historical simulations:**

\[
\text{HistResidual} = \text{Hist (total)} - \text{HistGHG} - \text{HistNat}
\]
Surface temperature keeps increasing during the past century especially over land and in the NH mid-high latitudes;

CMIP5 historical (Hist) runs can catch general spatial features of temperature changes, but with differences in detail over several regions in the NH mid-higher latitudes; Also, HistGHG shows much intense warming globally compared to observations and Hist, because of the opposite (cooling) effect from aerosols (HistResidual);

Aerosol effect is primarily in NH, forming an interhemispheric surface temperature gradient.
Long-term changes/trends in precipitation

Over land:
- Precipitation increase in mid-higher latitudes; decrease in tropical/subtropical regions;
- Consistencies in spatial features in GPCC, RECONS, AMIP, and Hist: for instance, **NH mid-high latitudes, part of West Africa, Australia, etc.**

Over ocean:
- Large discrepancy in the tropical Pacific and Atlantic, in particular for AMIP.

HistGHG shows more intense precipitation increase globally than Hist, while aerosols (HistResidual) tend to shift precipitation southward.
Long-term precipitation changes/trends related to anthropogenic GHG

Estimate GHG-related changes in (a) observations and (b) AMIP:

(a) \([\text{GPCC (over land) + RECONS (over ocean)}] - [\text{HistResidual (aerosols) + HistNAT}]\);
(b) \(\text{AMIP (5-member-mean)} - [\text{HistResidual (aerosols) + HistNAT}]\)
Long-term precipitation changes/trends related to anthropogenic GHG

Observed (total) changes/trends & estimated HistNat and HistResidual

GHG-related changes/trends in observations & HistGHG

(a) Precipitation trend over ocean
- GPCC(I)+RECONS(o)
- GISS/AMIP
- HistNot
- HistResidual

(b) Precipitation trend over land
- Obs (total)
- AMIP (total)

(c) Precipitation trend over land+ocean

(d) Precipitation trend over ocean
- Composite
- Obs (GHG)
- AMIP (GHG)
- HistGHG

(e) Precipitation trend over land

(f) Precipitation trend over land+ocean

Latitudes: -90 to 90°
Longitudes: -180 to 180°
Summary I:

- Precipitation (long-term) increases are observed in the NH mid-higher latitudes during 1901-2010, with reductions primarily appearing in the tropical/subtropical lands including tropical Africa, part of South America, and northern India-Tibetan region. These features are in general confirmed by the NOAA/CICS Smith-reconstruction and CMIP5 historical simulations.

- Further comparisons between GPCC, the reconstruction and CMIP5 simulations suggest that these observed long-term changes/trends specifically spatial structures could be related to the effects of both anthropogenic GHG and aerosols.

- Composite patterns *(best estimate?)* of GHG-related precipitation changes/trends could not only improve our understanding of the past climate change, but also provide certain guidance for climate projections in the coming decades.
Part II. Precipitation changes/variations associated with various decadal/interdecadal-scale factors/mechanisms in global SST

- Identify long-term change signal and interannual-interdecadal/multidecadal oscillations in global SST through an EOF analysis of SST anomalies between 65°N-65°S;
- Compare regressed precipitation anomalies to identified SST indices in both observations and NASA GISS/AMIP

Precipitation products:

- Over land: GPCC (& RECONS), NASA GISS/AMIP
- Over Ocean: RECONS, NASA GISS/AMIP
SST-based physical modes/mechanisms:
An EOF analysis of ERSST anomalies between 65°N-65°S (1900-2012)

Three leading SST EOFs

Leading SST PCs

Further decomposition of EOF2/PC2

SST indices:

PC1: long-term change/trend;
PC2: ENSO & PDV;
  PC2-high: ENSO;
  PC2-low: PDV;
PC3: AMO
(1) Long-term precipitation change/trend: SST PC1

- Spatial structures of regressed precipitation anomalies are generally in agreement with those for respective linear trends;
- AMIP precipitation anomalies in tropical Pacific tend to be more similar to RECONS than AMIP precipitation trends.
Consistency can be found over land, though with differences in intensity; Over ocean, differences in spatial structures of anomalies appear in the tropical oceans.
Over land, consistency is seen among GPCC, RECONS, and AMIP. RECONS and AMIP tend to be weaker especially in northern mid-high latitudes;

Over ocean, similarities appear, though with detailed discrepancies.
Consistency over land, including West Africa, North and part of South America, Australia, etc.; large discrepancy over ocean, not only in the Indian Ocean and Pacific, but also in the Atlantic.
Summary II:

- Decadal/interdecadal (ocean-based) variations/modes, including PDV and AMO, in addition to interannual variability (ENSO), can effectively influence/modulate global precipitation changes/variations, in particular their spatial patterns;

- RECONS and AMIP can catch relatively well these variations over land. Over ocean, general consistency between RECONS and AMIP can be found for ENSO and PDV, but not for AMO;

- Thus, on the decadal/interdecadal time scales, precipitation variations specifically spatial features result from a combined impact from these (internal) mechanisms and anthropogenic effects including GHG-related global warming and aerosols-related (mostly in the NH) cooling;

- This indicates that accurately estimating regional (and even global mean) precipitation changes is difficult when the length of time period considered is relatively short.