Water Cycle Variability, Change and Prediction in the Eastern United States

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Outline:
- Importance of Water Cycle
- Global Water Cycling
- Eastern U.S.
  - Climate
  - Forecasts
  - Climate Change

Acknowledging:
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Eric Wood (Princeton)

Water Cycle Research Making a Difference

http://mason.gmu.edu/~phouser
http://crew.iges.org
The Water and Energy Cycle

Why study the water & Energy cycle?

1. Water exists in **all three phases** in the climate system and the **phase transitions** are a significant factor in the regulation of the global and regional energy balances.

2. Water vapor in the atmosphere is the **principal greenhouse gas** and clouds at various levels and composition in the atmosphere represent both positive and negative feedback in climate system response.

3. Water is the **ultimate solvent** and global biogeochemical and element cycles are mediated by the dynamics of the water cycle.

4. Water is the element of the Earth system that most **directly impacts and constraint** human society and its well-being.
Seamless Suite of Forecasts to meet W&E cycle needs

Outlook

Guidance

Threats Assessments

Forecast

Uncertainty

Seasons

Years

Forecast Lead Time

2 Week

1 Week

Days

Hours

Minutes

Initial Conditions

Forecast Uncertainty

Boundary Conditions

Protection of Life & Property

Flood Mitigation & Navigation

Space Operation

Transportation

Fire Weather

Hydropower

Agriculture

Reservoir Control

Recreation

Ecosystem

Energy

Health

Commerce

State/Local Planning

Environment

Benefits

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Model variability ~0.005 mm/d
Model 100yr trend: ~0.1 mm/d

Observed yearly variability: ~0.05 mm/d
A generally accepted hypothesis regarding global water cycle changes:

“According to model predictions, the most significant manifestation of climate change would be an acceleration of the global water cycle, leading to … a general exacerbation of extreme hydrologic regimes, floods and droughts” (NASA-GWEC, 2000).
The availability of new observations strongly motivates advances in understanding, prediction, and application.
Current Observation Capabilities

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TRMM Precipitation Observations

MODIS Snow Observations
**OBJECTIVE:** Understand the horizontal and vertical structure of rainfall and its microphysical element. Provide training for constellation radiometers.

**OBJECTIVE:** Provide enough sampling to reduce uncertainty in short-term rainfall accumulations. Extend scientific and societal applications.

### Core Satellite
- Dual Frequency Radar
- Multi-frequency Radiometer
- H2-A Launch
- TRMM-like Spacecraft
- Non-Sun Synchronous Orbit
- ~65° Inclination
- ~400 - 500 km Altitude
- ~4 km Horizontal Resolution (Maximum)
- 250 m Vertical Resolution

### Constellation Satellites
- Multiple Satellites with Microwave Radiometers
- Aggregate Revisit Time, 3 Hour goal
- Sun-Synchronous Polar Orbits
- ~600 km Altitude

### Precipitation Validation Sites
- Global Ground Based Rain Measurement

### Global Precipitation Processing Center
- Capable of Producing Global Precip Data Products as Defined by GPM Partners

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Soil Moisture from Space

Soil Moisture and Ocean Salinity (SMOS) mission (ESA)

- 2-dimensional interferometric radiometer
- 50-km resolution, 3-day repeat
- Multiple-incidence-angle
- Target launch 2008
GRACE Mission

Science Goals
High resolution, mean & time variable gravity field mapping for Earth System Science applications.

Mission Systems
Instruments
- KBR (JPL/SSL)
- ACC (ONERA)
- SCA (DTU)
- GPS (JPL)

Satellite (JPL/DSS)
Launcher (DLR/Eurockot)
Operations (DLR/GSOC)
State of the Water & Energy Cycle

Evaluate our ability to detect, analyze, and understand global water cycle change, variability, prediction and predictability.

**Water and Energy Cycle Data Integration**

**Atmosphere**
- **Storages:**
  - Water Vapor
  - Cloud Liquid/Frozen Water Content

- **States:**
  - Cloud Cover
  - Cloud Physical/Radiative Properties

- **Intra-system Fluxes:**
  - Water Vapor Transport (Vertical and Horizontal)
  - Convective Heating
  - Radiative Heating

**Land**
- **Storage:**
  - Lakes/Reservoirs
  - Soil/Ground Water
  - Snow/Glaciers/Ice
  - Vegetation/Interception

- **States:**
  - Albedo
  - Land Cover
  - Vegetation Properties
  - Soil Properties

- **Intra-system Fluxes:**
  - Streamflow
  - Groundwater Flow
  - Ground Heat Flux

**Ocean**
- **States:**
  - Salinity
  - Heat Content
  - Sea-ice (extent/storage)
  - Albedo/Sea-color

- **Intra-System Fluxes:**
  - Thermohaline Flow
  - Ocean Currents

**Precipitation (1979-1999):**
- CPC Merged Analysis of Precipitation (CMAP): Xie and Arkin (1997)

**Ocean Evaporation (1987-1999):**

**Land Evaporation:**
- Global Soil Wetness Project Phase 2 (GSWP2): 1986-1995

**Precipitable Water:** NASA Global Water Vapor Project (NVAP)

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**Figure 1:** Major global water and energy cycle storages and fluxes to be included in the integration center.
- Evaporation excess nearly ubiquitous over sub-tropical oceans, with a sharp contrast at coastal regions.
- Equatorial ocean evaporation minimum consistent with other findings (e.g. Seager et al., 2003).
- Tropical land areas show richest excess in precipitation.
- Major desert regions, tundra, and mountainous regions all indicate deficit to marginally-balanced conditions.
- Mid-latitude and boreal coastal/maritime environments exhibit adequate precipitation supply over evaporation.
### Annual Mean Statistics

| Units in kg/yr | Precipitation       | Evaporation          | | P-E | |
|----------------|----------------------|-----------------------|-----------------|-----------------|
| Land           | 1.05E+17 ± 0.02E+17  | GOLD1: 0.64E+17      | ~4.0E+16        |
|                | 1.02E+17 ± 0.02E+17  | GOLD2: 0.62E+17      | ~4.2E+16        |
| Ocean          | 3.80E+17 ± 0.06E+17  | 4.41E+17              | 6.5E+16         |
|                | 3.72E+17 ± 0.04E+17  | 3.93E+17              | 1.7E+16         |
| Global         | GPCP 4.85E+17 ± 0.06E+17 | GSSTF2+GOLD 5.03E+17 | ~ 2.4E+16       |
|                | CMAP 4.74E+17 ± 0.04E+17 | HOAPS+GOLD 4.56E+17  |                  |

Note: Total atmospheric water storage ~ 10^{16} kg

Adapted from Schlosser and Houser (2007)

On average annual basis, \( P \) and \( E \) differ by 5\% (24,000 Gton of water), which exceeds precipitation uncertainty (1\%). For any given year, the annual flux imbalance is ~10\% (48,000 Gton of water). Observed global TPW interannual variations suggest an imbalance on the order of 0.01\% (48 Gton of water).
Global fluxes of precipitation and evaporation are comparable to previous century of estimates.

No discernable trend is seen in both compilations of the flux estimates.

The notable disparity with this study is the lower values of both precipitation (not shown) and evaporation flux estimates over land.
Model-based (offline and coupled) scatter of estimates marginally higher than compilation of “modern” observationally-based estimates.
Change in (P-E) for 2100 minus 2000

"Dry regions get drier, wet regions get wetter"

Held and Soden (2006)

"Thermodynamic" component

Δ(P-E) mm/day

Vecchi and Soden (2007)
Basic Climatology:
Surface Air Temperature

- Appropriate scales for both seasons
- Winter is very zonal except for orographic interruptions
- Summer shows influence of Gulf of Mexico
Basic Climatology: Relative Humidity

- Largest annual cycle in RH in northwestern US and upper midwest.
Basic Climatology:
Wind Speed

- **Winter**: windiest on mountain tops where surface pierces the free atmosphere (above PBL)
- **Summer**: marked low level jet from Gulf of Mexico into center of US
**Precipitation**

**Winter mean**
- Pacific NW rainy season;
eastern US max in Gulf states

**Summer mean**
- **Winter:** Gulf Coast and upper midwest maxima from very different sources - tropical systems vs. mesoscale convective complexes
**Basic Climatology:**

**Precipitation Variability**

**Winter mean**

- Winter max along Appalachians in eastern US and west of Cascades

**Summer mean**

- Summer: three maxima in desert SW (monsoon), Gulf coast (tropical systems) and upper midwest (summer thunderstorms)
Basic Climatology: Soil Moisture

Summer mean

- Eastern US and Pacific NW are well saturated everywhere in winter
- Summer drying is proportional to winter wetness in west but occurs less rapidly in Ohio Valley
Interannual Standard Deviation

- Summer variability tends to be up and downstream of the Appalachians

- Soil wetness modulated by vegetation type more than other variables
- Range of precipitation in eastern US on monthly time scales is relatively narrow.
- West and east tend to vary independently.
Decadal change in Precipitation:
1949-73 to 1979-2003

Summer

Spring

(normalized by mean of 1949–1973)
ENSO Predictability

Warm ENSO Composite

Cold ENSO Composite
Project objectives:

(i) develop a seasonal hydrologic forecasting system that utilizes NCEP dynamical Climate Forecast System (CFS),

(ii) evaluate the hydrologic forecast uncertainty and skill over a range of basins and

(iii) develop verification approaches for the generated hydrologic ensembles.
Hindcast over Ohio River Basin

Precipitation (mm/day) Mean Anomaly (Init: 199105)


OBS  

ESP

CFS

CFS + DEEMETER
A Look at Future Trends

- In general, an overall increase of precipitation is likely in the next century, especially in mid-to-upper latitudes.
- The predicted increase in temperature, though, will cause heightened evaporation rates but estimating the long term trend is difficult.
- Seasonal severity of fire hazard to increase by around 10% in the next century.
- Hadley Model – small decrease in fire hazard in Great Plains.
- Canadian Model – 30% increase in fire hazard in southeastern US and Alaska.
Climate Change Models Disagree over Eastern U.S.

Percent Change Veg. Carbon 2090-2099

Hadley

a) HADCM2SUL

Canadian

b) CGCM1
These maps show current and projected forest types for the eastern US. The current distribution of forest types reflects temperature and moisture gradients in this part of the nation. The simulated changes in forest types by the end of the 21st century are in response to the Hadley and Canadian climate scenarios using the DISTRIB model, a tree species distribution model. Pine-dominated types decline in the Southeast under both climate scenarios. Oak-pine and oak-hickory forest types are projected to expand northward.

- **Southeast pine decrease**
- **Oaks replace maples**
Precipitation Change

Observed 20th Century

Significant increases in precipitation have occurred across much of the US in the 20th century. Some localized areas have experienced decreased precipitation. The Hadley and Canadian model scenarios for the 21st century project substantial increases in precipitation in California and Nevada, accelerating the observed 20th century trend (some other models do not simulate these increases). For the eastern two-thirds of the nation, the Hadley model projects continued increases in precipitation in most areas. In contrast, the Canadian model projects decreases in precipitation in these areas, except for the Great Lakes and Northern Plains, with decreases exceeding 20% in a region centered on the Oklahoma panhandle. Trends are calculated relative to the 1961-90 average.
Soil moisture has tended to increase in the central US with decreases in some localized areas. In the Northeast and in the western third of the country, there has been less change in soil moisture, despite the increase in precipitation, due to compensating temperature increases.

The Hadley and Canadian models project strong increases in soil moisture in the Southwest. For the rest of the nation, the Hadley model projects mostly increases while the Canadian model projects mostly decreases, with large decreases in the Central Plains. The contrasts between the two models result from the combination of greater precipitation in the Hadley model and higher air temperatures in the Canadian model.
Droughts have, for the most part, become shorter, less frequent, and cover a smaller portion of the country over the last century. (2)

Decreasing trends ... are mostly found in the Northeast, Great Lakes, Lower Mississippi, and the Pacific Northwest. Upward trends are fewer ... and are located mostly in Texas, the Southwest and intermountain West. The results were similar for model soil moisture.

There is a predominant reduction in drought frequency for the eastern U.S. and Midwest, with a few significant upward trends in parts of the Southwest. (2)

Drought Forecasts

- Probable drought frequency decrease
- Duration of droughts may increase in east
- Eastern drought severity uncertain
- Models disagree greatly

http://www.usgcrp.gov/usgcrp/nacc/default.htm
- Seasonal severity of fire hazard to increase by around 10% in the next century

- Hadley Model – increases in precipitation and soil moisture in east and southeast, small decrease in fire hazard in Great Plains

- Canadian Model – no significant change in average precipitation; slight decrease in soil moisture in east and southeast, 30% increase in fire hazard in southeastern US and Alaska

Decreased drought and fire potential?