Using Climate Forecasts for Drought Management

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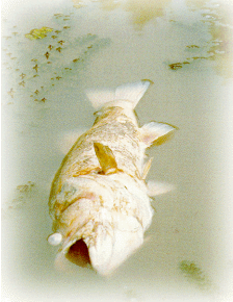
Overview of Talk

- Motivation
  - Costs of drought
  - Potential benefits of climate forecasts
- Integrating Forecasts with Drought Planning
  - Drought plans
  - Forecasts as indicators
- Application: Drought Management in Georgia
  - Surveys and interviews with decision makers
  - Adapting forecasts for user needs
  - Adapting decision-making for using forecasts
- Results and Lessons

Costs of Droughts

- Average annual loss in U.S.:
  $6-$8 billion/year
- Georgia drought losses (2002):
  over $2 billion
- Major impacts: agriculture, hydropower,
  environmental, municipal and industrial



Losses that Climate Forecasts Could Reduce

Advance Warning Can Reduce Drought Impacts

Examples: crop losses, fish kills, energy shortages, groundwater contamination, job losses, landscaping losses, reduced tourism and recreation, wildfires, habitat fragmentation

Economic Value of What Climate Forecasts Could Mitigate (in Georgia):

$400 million – $600 million per year

Questions This Work Addresses

- What types of forecast information have potential skill and value for decisions concerning drought?
- How can forecast information be communicated and used effectively?
- What is the value of that information?

Georgia Drought Planning

- Developed First State Drought Plan (2000-2003) (funded by NSF, GaDNR)
- Led process with more than 150 stakeholders, 30 federal and local agencies
- Main sectors involved: municipal, industrial, agriculture, fish and wildlife, health, environmental, hydropower, recreation, tourism
- Analyzed indicators, impacts, and responses

Drought Characterization in Georgia: Percentile-Based Indicators

CD 3	Jan-97	Feb-97	Mar-97	Apr-97	May-97	Jun-97	Jul-97	Aug-97	Sep-97	Oct-97	Nov-97	Dec-97	Jan-98	Feb-98	Mar-98
SPI-3								1	1						
SPI-6								0							
SPI-9	0	0	0					0							
SPI-12			0	0	0										
Lake Hartwell							0		0	0					
Clark Hill									1	0					
Broad R. near Bell - PCT				0			0	1							
Broad R. near Bell - AAD					0	0	1	2	1	0	0				
Chattahoochee R. near Cornelia - PCT		0		0				1	1			0			
Chattahoochee R. near Cornelia - AAD						0	0	1	1	0	0	0			

CD 3	Apr-98	May-98	Jun-98	Jul-98	Aug-98	Sep-98	Oct-98	Nov-98	Dec-98	Jan-99	Feb-99	Mar-99	Apr-99	May-99	Jun-99
SPI-3				2	3	3	1	0	1	0	1	2	2	2	
SPI-6					0	0	2	3	3	1	1	2	2	2	1
SPI-9								1	1	2	3	4	3	2	1
SPI-12											1	2	3	4	3
Lake Hartwell				0	0	0	0	1	0	0	0	1	2	2	1
Clark Hill									1	1	1	1	1	2	2
Broad R. near Bell - PCT						0		0	1	1		3	1	2	1
Broad R. near Bell - AAD			0	0	0	1	1	1	1	1		1	0	2	1
Chattahoochee R. near Cornelia - PCT				1	1	2	2	2	2	1	0	2	2	2	2
Chattahoochee R. near Cornelia - AAD			0	0	2	3	2	2	1	1		0	0	0	1

CD 3	Jul-99	Aug-99	Sep-99	Oct-99	Nov-99	Dec-99	Jan-00	Feb-00	Mar-00	Apr-00	May-00	Jun-00	Jul-00	Aug-00	Sep-00
SPI-3	0	0	3				0	2	1	2	2	3	4	1	0
SPI-6	2	2	1			1	0	0	0	2	3	3	4	3	2
SPI-9	2	2	2	1	1	1	0	1	2	1	1	2	4	4	3
SPI-12	2	2	2	1	1	1	1	2	1	1	2	3	3	2	2
Lake Hartwell	1	2	1	1	1	1	1	2	2	2	2	2	2	2	2
Clark Hill	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2
Broad R. near Bell - PCT	1	3	3	0	1	2	1	2	2	3	3	4	4	3	1
Broad R. near Bell - AAD	1	3	3	2	2	2	0	0	0	2	4	4	4	3	2
Chattahoochee R. near Cornelia - PCT	1	4	4		0	1	1	3	2	0	2	3	4	2	3
Chattahoochee R. near Cornelia - AAD	0	4	4	0	0	0	1	2	0		4	4	4	4	3

CD 3	Oct-00	Nov-00	Dec-00	Jan-01	Feb-01	Mar-01	Apr-01	May-01	Jun-01	Jul-01	Aug-01	Sep-01	Oct-01	Nov-01	Dec-01
SPI-3	1	0	2	1	3	0	1	0	1		0	3	4	4	4
SPI-6	4	1	2	1	2	2	2	2	1	0	1	2	2	3	4
SPI-9	4	3	3	3	3	2	2	2	2	1	2	2	2	2	4
SPI-12	4	4	4	4	4	3	4	3	2	1	2	3	2	4	4
Lake Hartwell	2	2	2	2	3	3	3	3	2	2	2	2	2	2	2
Clark Hill	1	2	1	2	2	2	2	2	2	2	2	2	2	2	2
Broad R. near Bell - PCT	4	2	2	3	3		3	4	0	1	2	4	4	4	4
Broad R. near Bell - AAD	4	3	2	3	2		2	4	1	1	3	3	4	4	4
Chattahoochee R. near Cornelia - PCT	4	2	3	3	4	2	3	4	3	3	2	4	2	4	2
Chattahoochee R. near Cornelia - AAD	4	1	3	2	4	0	4	4	4	4	4	3	4	4	2

Category		Percentile
	Normal/Wet	0.50-1.00
0	Near-normal/dry	0.35-0.50
1	Level 1	0.20-0.35
2	Level 2	0.10-0.20
3	Level 3	0.05-0.10
4	Level 4	0.00-0.05

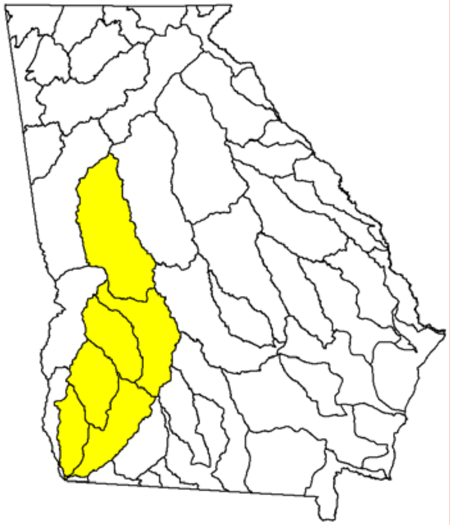
Climate Forecast Applications: Drought Management in Georgia

- Linked with State Drought Management Plan
- Forecasts transformed into indicators
- Applications:
    - Utilities’ decisions to implement water use restrictions
    - State’s decision to implement program to buy out farmers
    - Interstate decisions to modify water allocation formulas

Statewide Drought Responses: Agricultural Users

Flint River Drought Protection Act (FRDPA)

- Pays farmers to not irrigate their land (~$125/acre)
- Decision made by March 1st of each year for coming year
- Based on climate forecasts and drought indicators
- Costs: $5 - $30 million (if implemented)
- Potential Cost Savings:
  $50 - $200 million (if drought)



Climate Forecasts as a Drought Indicator

- Indicators typically retrospective; this one would be prospective
- Used together with existing indicators and drought levels based on percentiles
- What types of climate forecast information would be useful as indicators?

Forecast Usability, Needs, Potential Net Benefits

- Surveyed and interviewed 25 water managers
- Assessed climate forecast uses, barriers to use, science needs, and potential benefits/costs

Then…

- Implemented forecasts with decision-makers

Results: Survey and Interviews

- Water managers say they “really need” climate forecasts, but do not currently use them

- Out of 25 water managers
  - 21 had seen the CPC seasonal forecasts
  - 2 had tried to use them but didn’t
  - None had actually used them

- **Why is this the case?**

"If you have seen the CPC climate forecasts, but have not used them, why not?"

Difficulties in understanding and assessing:

- Forecast information; specifically the forecast maps, probability anomaly, tercile probabilities, POE curves, skill assessments
- How the CPC generated the forecasts
- How to find needed forecasts on CPC webpage
- The CPC's explanations about forecasts
- The improvement over climatology
- The uncertainty associated with forecasts
- The CPC's calculations of skill, and what skill means
- How to apply a forecast to a smaller area

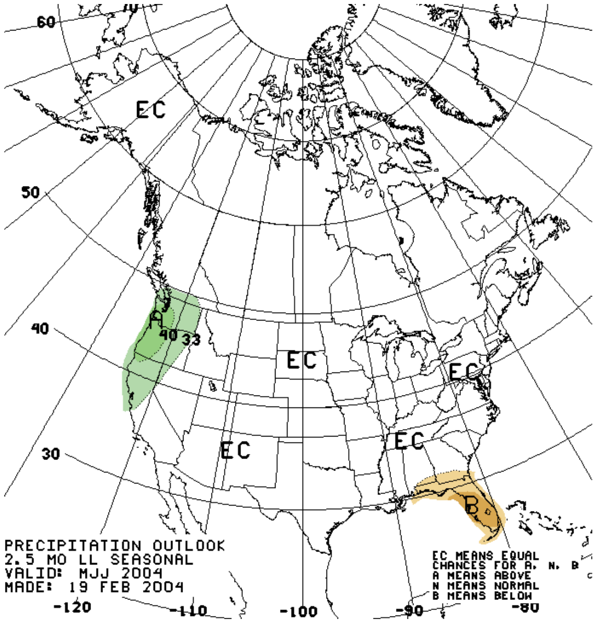
CPC Seasonal Outlooks

Climate Outlook

The key below is used to interpret each of the color versions of the ***Climate Outlook*** products. In areas where confidence in predictive skill has been established, the probabilities of the above normal, near normal or below normal categories are increased accordingly above the Climatology level of 1/3 (33.3%) for each category. These probabilities are contoured using colors as depicted in the key below.

In those areas where the skill of our present prediction tools is not sufficient, the default is equal chances (white color). The probabilities of experiencing each of the three categories (above normal, near normal or below normal) remain equally likely (1/3) in the white areas on attached maps.

Precip	Temp	Probability anomaly as shown on map	Probability of occurrence for each Equal: A	N	B	Most likely category
		40%-50%	73.3%-83.3%	23.3%-13.3%	3.3%	"Above"
		30%-40%	63.3%-73.3%	33.3%-23.3%	3.3%	"Above"
		20%-30%	53.3-63.3%	33.3%	13.3%-3.3%	"Above"
		10%-20%	43.3-53.3%	33.3%	23.3%-13.3%	"Above"
		5%-10%	38.3-43.3%	33.3%	23.3%-28.3%	"Above"
		0%-5%	33.3-38.3%	33.3%	33.3%-28.3%	"Above"
		0%-5%	30.8%-33.3%	33.3%-38.3%	30.8%-33.3%	"Near Normal"
		5%-10%	28.3%-30.8%	38.3%-43.3%	28%.3-30.8%	"Near Normal"
		0%-5%	33.3%-28.3%	33.3%	33.3%-38.3%	"Below"
		5%-10%	28.3%-23.3%	33.3%	38.3%-43.3%	"Below"
		10%-20%	23.3%-13.3%	33.3%	43.3%-53.3%	"Below"
		20%-30%	13.3%-3.3%	33.3%	53.3%-63.3%	"Below"
		30%-40%	3.3%	33.3%-23.3%	63.3%-73.3%	"Below"
		40%-50%	3.3%	23.3%-13.3%	73.3%-83.3%	"Below"
		0%	33.3%	33.3%	33.3%	"Equal Chances"



CPC Explanation

THE CMP IS AN ENSEMBLE MEAN FORECAST OF A SUITE OF 20 GCM RUNS FORCED WITH TROPICAL PACIFIC SSTS PRODUCED BY A COUPLED OCEAN-ATMOSPHERE DYNAMICAL MODEL. THE CMP SKILL HAS BEEN ESTIMATED THROUGH THE USE OF 45 YEARS OF SIMULATIONS USING THE NCEP CLIMATE GCM FORCED BY SPECIFIED OBSERVED SSTS. THE SKILL OF THE CMP FORECASTS DEPENDS HEAVILY ON ENSO - BEING ALMOST ENTIRELY ASSOCIATED WITH EITHER COLD OR WARM EPISODES. THE CMP FORECASTS ARE AVAILABLE ONLY FOR LEADS 1 THROUGH 4 FOR THE LOWER 48 STATES AND ALASKA. BEGINNING IN MARCH 2000 - A NEW VERSION OF THE COUPLED MODEL - DESIGNATED AS CMS - THAT INCORPORATES INTER-ACTION WITH LAND SURFACES VIA SOIL MOISTURE BECAME AVAILABLE.

CANONICAL CORRELATION ANALYSIS (CCA) LINEARLY PREDICTS THE EVOLUTION OF PATTERNS OF TEMPERATURE AND PRECIPITATION BASED UPON PATTERNS OF GLOBAL SST - 700MB HEIGHT - AND U.S. SURFACE TEMPERATURE AND PRECIPITATION FROM THE PAST YEAR FOR THE MOST RECENT FOUR NON-OVERLAPPING SEASONS. CCA EMPHASIZES ENSO EFFECTS - BUT ONLY IN A LINEAR WAY - AND CAN ALSO ACCOUNT FOR TRENDS - LOW FREQUENCY ATMOSPHERIC MODES SUCH AS THE NORTH ATLANTIC OSCILLATION (NAO) AND OTHER LAGGED TELECONNECTIONS IN THE OCEAN-ATMOSPHERE SYSTEM. CCA FORECASTS ARE AVAILABLE FOR ALL 13 FORECAST PERIODS FOR THE LOWER 48 STATES - HAWAII - AND ALASKA.

COMPOSITE ANALYSIS PROVIDES GUIDANCE FOR U.S. ENSO EFFECTS BY SUPPLYING HISTORICAL FREQUENCIES OF THE THREE FORECAST CLASSES IN PAST YEARS WHEN (FOR THE PARTICULAR FORECAST SEASON) THE CENTRAL EQUATORIAL PACIFIC WAS CHARACTERIZED BY MODERATE OR STRONG LA NINA OR EL NINO CONDITIONS OR NEAR NEUTRAL CONDITIONS INCLUDING WEAK EL NINO OR LA NINA STATES. REGIONS INFLUENCED BY ENSO ARE DEFINED BY HISTORICAL FREQUENCIES THAT DIFFER SIGNIFICANTLY FROM CLIMATOLOGY. PROBABILITY ANOMALIES ARE ESTIMATED BY THE USE OF HISTORICAL FREQUENCIES TEMPERED BY THE DEGREE OF CONFIDENCE THAT WARM - COLD - OR NEUTRAL ENSO CONDITIONS WILL BE IN PLACE IN A GIVEN TARGET SEASON. VERSIONS OF THE MAPS OF THE HISTORICAL FREQUENCIES USED TO MAKE THE FORECASTS CAN BE VIEWED UNDER "U.S. EL NINO IMPACTS" AND U.S. LA NINA IMPACTS" ON THE CPC WEBSITE LOCATED AT HTTP://WWW.CPC.NCEP.NOAA.GOV. A COMPOSITE ANALYSIS OF ALASKAN TEMPERATURES IS ALSO AVAILABLE BUT NOT YET PLACED ON THE WEB….

“How would forecast information need to be communicated in order for you to use it for drought management?”

- Provide in terms relative to historic conditions
- Make consistent with other drought triggers
- Make applicable to regional and local scales
- Provide improvement over climatology
- Give "best guess" — most likely amount
- Provide easy-to-understand measures of accuracy and uncertainty
- Assess forecast performance in the context of drought events

Using These Results…

translating forecasts to meet user needs

Forecast Precipitation Index (FPI)

CPC seasonal outlooks ➔ index representing shift of forecast relative to climatology, expressed as percentile on the climatological cumulative distribution function

Example: PrA = 0.274, PrB = 0.393, PrN = 0.333

PrAB = **–5.97** probability anomaly of the most favored tercile.

FPI = $\Phi_c(Z_{FPI})$ = **43.54%** (–6.46% from climatology)

Φ_c = cumulative probability on the normalized climatological distribution

Z_{FPI} = FPI standardized anomaly = $\{(y^*)^p - (\mu_X)^p\} / \sigma_X$

y^* = forecast value (un-powered) reported by CPC = $\mu_{X|Y}$ = conditional forecast mean

μ_X = climatological mean (un-powered)

p = de-skewing power

σ_X = climatological (unconditional) standard deviation (of powered values) = $\sigma_{X|Y}(1-\rho^2)^{-1/2}$

$\sigma_{X|Y}$ = forecast (conditional) standard deviation (of powered values)

ρ = Pearson product-moment correlation between observations and forecasts

Skill Assessment:
CPC Forecasts for Georgia

Target month	Forecasts Issued	SMAE	SRMSE	SLEPS
1	22	11.52	6.85	15.80
2	23	8.50	7.25	10.14
3	8	0.63	1.14	0.91
4	7	-4.48	-3.83	-6.30
5	3	11.00	11.27	17.33
6	6	7.42	10.62	12.45
7	5	-7.58	-0.33	-8.78
8	9	-7.59	-6.00	-8.48
9	1	-25.45	-25.45	-26.14
10	6	0.26	1.99	0.32
11	6	5.76	5.87	6.60
12	16	25.44	20.31	27.97

“Target month” is the middle month of the season.
“Lead time” is in terms of months.
Skill scores are in terms of percentages.

Lead Time	Forecasts Issued	SMAE	SRMSE	SLEPS
0.5	22	9.49	8.14	11.77
1.5	19	10.32	6.47	13.50
2.5	17	8.79	6.72	10.60
3.5	13	10.49	7.38	12.02
4.5	9	15.11	9.35	18.13
5.5	11	7.67	3.99	9.76
6.5	10	4.00	3.64	5.04
7.5	4	1.15	1.15	1.50
8.5	2	1.39	0.99	1.74
9.5	2	-0.90	0.11	-0.99
10.5	1	-1.26	-1.26	-1.80
11.5	1	0.72	0.72	0.78
12.5	1	0.78	0.78	0.84

“Would the forecast have helped us prepare for a drought?”

	Total forecasts	Total seasons forecasted	Seasons with observed level3 or 4	Seasons without forecast for observed level 3 or 4	Seasons with forecast for observed level3 or 4	Total forecasts for observed level 3 or 4	Total forecasts for observed level 3 or 4	
							Same direction	Different direction
1995	7	4	1	0	1 (100%)	2	0	2 (100%)
1996	0	0	-	-	-	-	-	-
1997	20	5	3	3 (100%)	0	-	-	-
1998	26	8	5	2 (40%)	3 (60%)	5	5 (100%)	0
1999	45	11	7	6 (86%)	1 (14%)	10	9 (90%)	1 (10%)
2000	13	8	5	1 (20%)	4 (80%)	7	7 (100%)	0
Total	**111**	**36 (50%)**	**21**	**12 (57%)**	**9 (43%)**	**24**	**21 (88%)**	**3 (12%)**

Context Matters, Not Only Accuracy

Explanations from State Water Officials:

"If the forecast said dry, and it is wet, I do not see us being blamed for anything. If we call wet, and it turns very dry, they [the public] could be very upset with us."

"At early stages of drought, the consequences are not that severe, in either case. But at later drought stages, it is important to be conservative. If we were going to have a drought, it would be OK for a dry forecast to turn out to be wet, but the other way around would cause severe impacts."

Application:
Forecasts for FRDPA Decision

Climate Forecasts:

CPC seasonal outlooks, #56 and #69
Target months of April, May, June

Retrospective Drought Indicators:

Climate Divisions #4 and #7
Streamflows, Groundwater, Precipitation
Months of January and February

If FPI Level 0 or more severe for MAM, AMJ, or MJJ, then implement FRDPA.
If above-normal or climatological forecast for all months, then check other indicators.
If indicators Level 2 or less severe, and if above-normal or climatological forecasts for all months, then do not implement FRDPA.

Forecasts for FRDPA Decision: Results

- FRPDA implemented in 2001, 2002, and not implemented in 2003, 2004, 2005, 2006
- Officials “called it right” each year
- Drought damages avoided: estimated $100-$350 million (during drought year)
- Implementation costs avoided: estimated $5-$30 million (during non-drought year)

Findings and Lessons on Forecast Use

- Decision-makers often view forecasts, accuracy, and value differently than forecasters (e.g., "right/wrong" forecasts)
- Decision-makers need more explicit criteria for when forecasts waffle or contradict other indicators
- Forecast use (and proper forecast use) directly related to user interaction, education, and organizational support
- Talking with users is more effective than surveys or emails
- Benefits of forecasts often difficult to place in monetary terms, especially for public agency
- This takes time

The End

A General Process…

for working with users and getting forecasts used

1. Explore Potential
2. Define Applications
3. Understand Context
4. Assess Potential Benefits/Costs
5. Check Feasibility
6. Specify Products
7. Deliver, Obtain Feedback On, and Revise Products
8. Get Forecasts Used
9. Evaluate Forecasts
10. Iterate

1. Explore Potential

- What is the decision problem?
- How might forecast information help?
- What forecasts have potential skill and usefulness?
- What can forecasters provide that decision-makers need, but don't currently have or use?
- Would those forecasts have skill?
- Are decision-makers interested and willing to work with us?
- Will their organization support this?

2. Define Applications

- Identify specific problem(s)
- Identify decision(s) that could benefit from forecast information
- Identify decision-makers(s) that would use that information
- Identify how and what forecast information (or other information) is currently being used — benchmarking
- Identify how decisions can incorporate uncertainty
- Identify forecasts that would have potential skill and usefulness for those decisions

3. Understand Context

- Goals of agency, managers, operators, or other individuals that will be using forecasts
- Degree of flexibility
- Institutional inertia
- Operating procedures, terminology, and objectives
- Key people within and outside organization (champions, decision-makers, opinion leaders, consultants)
- Incentives and Barriers, Benefits and Costs (and to whom)

4. Assess Potential Benefits and Costs

- What are the benefits and costs of using forecast information — relative to existing information?
- Would these forecasts have skill? Which ones?
- What are the incentives and barriers to actually using forecast information?
- What benefits and costs are important but difficult to place in monetary terms? (security, environmental quality, public perceptions, reliability, liability, …)

5. Check Feasibility

Feasibility (scientific, political, economic, social, etc.)

- Managerial commitment of personnel and resources
- Buy-in from users
- Access to information
- Scientific requirements
- Potential net benefits
- Specific people willing and able to try out forecasts

6. Specify Products

- Forecast variable(s)
- Lead time(s)
- Target month(s)
- Temporal scale
- Spatial scale
- Expression of uncertainty
- Accuracy desired or needed (meaning of accuracy)
- Format (contingency tables, maps, charts)
- Time frame for delivery

7. Deliver, Obtain Feedback on, and Revise Products

- Work between forecasters and users; wear two hats
- Give users something early; important for maintaining enthusiasm, commitment, and credibility
- Give users what they ask for, and give them something more (without discounting their ideas)
- Listen to feedback, revise forecast products, re-deliver
- Be enthusiastic, believe in and demonstrate potential, but be careful to not oversell
- Education is part of this (and it's two-way)

8. Get Forecasts Used

- More of an art than a science
- Work directly with people in using the forecasts
- Keep focused on specific uses and needs
- Instill sense of “ownership” among users
- Present forecasts as a way to help users
- Note organizational side-effects

9. Evaluate Forecasts

- Retrospectively:
  "If we had had this forecast information last year, how much could we have saved?" Assumes decisions would have been made on the basis of forecasts.

- Operationally:
  "Use this information, track decisions, benefits and costs, and other effects." Assumes forecasts being used and decisions being made from them.

- Prospectively:
  "If you had this information next year, how could this help you make decisions?" Assumes decision-maker could predict actions based on forecasts and other information.

➡ **Need to compare benefits/costs of using forecasts relative to existing information. Also, who benefits and who bears the costs?**