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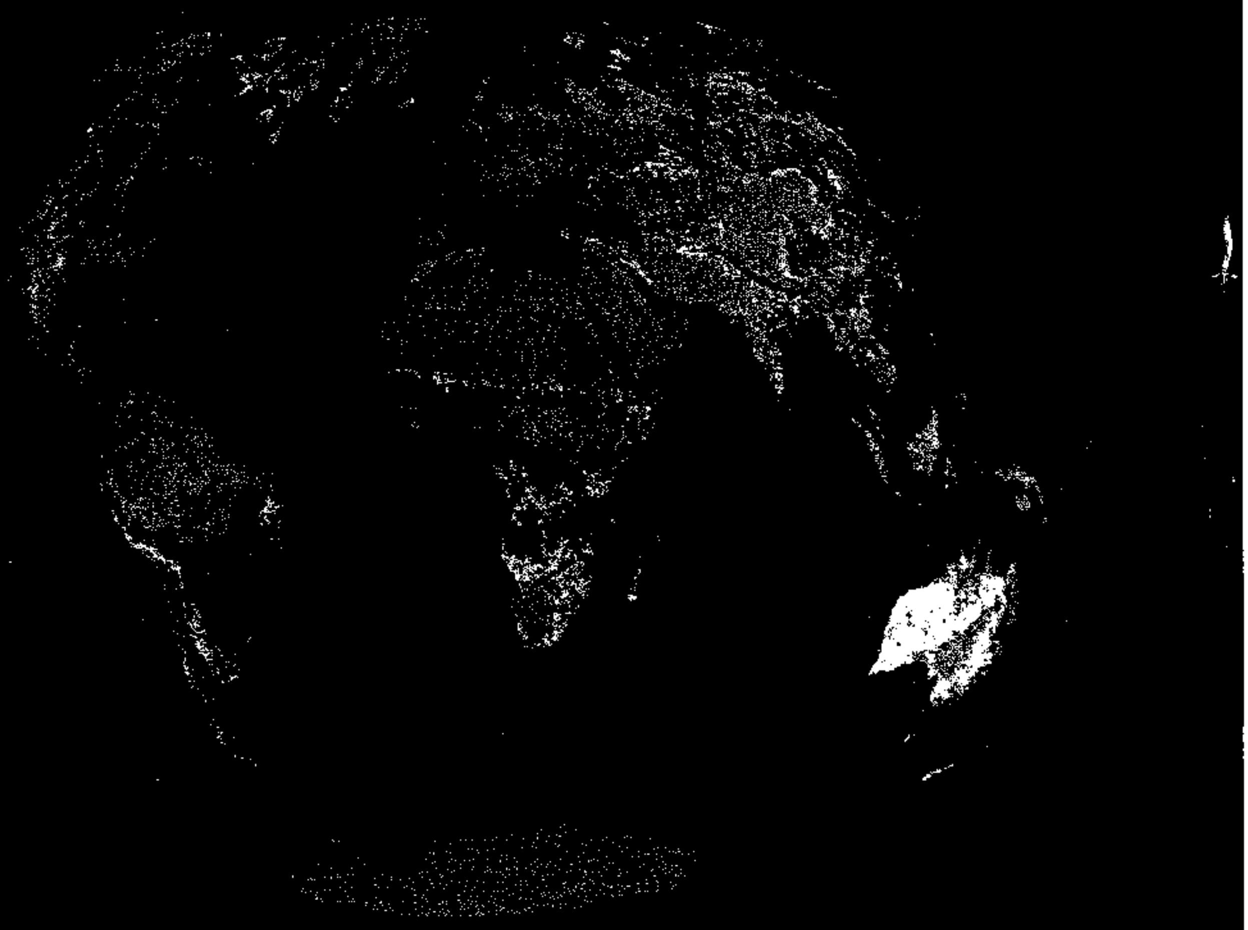
Coupling of Ecological Studies with Remote Sensing



U.S. MAN AND THE BIOSPHERE PROGRAM

CHAPTER 3. COWEETA HYDROLOGIC LABORATORY BACKGROUND AND SYNTHESIS

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Abstract. This paper gives a historical sketch, site characteristics, and a general description of the Biosphere Reserve at Coweeta Hydrologic Laboratory, North Carolina. Up-to-date assessment of production values, water chemistry, and physical characteristics of the numerous experimental and control watersheds are provided.

INTRODUCTION

In October 1984, Coweeta celebrated 50 years of long-term hydrologic and ecological research through several events including a three-day symposium. Thirty-five papers covering physical, chemical, and biological process research and watershed-scale experiments with applications to management were presented. This synthesis (Swank and Crossley 1986) will be published in book form and provides an extensive ecosystem data base for a variety of alternative analyses including the development of ground-truth values for high altitude remote sensing systems. In this paper, our objective is to summarize a few components of this extensive data base.

SITE DESCRIPTION

The 2185-ha Coweeta Hydrologic Laboratory is located in the Nantahala Mountain Range of western North Carolina, within the Blue Ridge Physiographic Province (35°N latitude, 83° 30'W longitude). The topography of Coweeta is steep; elevations range from 686 to 1600 m with average side slopes of 50%. The climate of the region is characterized by cool summers, mild winters, and abundant rainfall in all seasons. Average annual precipitation varies from 1700 mm at lower elevations to 2500 mm on the upper slopes. Less than 5% of annual precipitation is comprised of snow. Precipitation has been gauged at over 135 sites during the past 50 years. In general, precipitation increases with elevation at a rate of about 5% per 100 m along the east-west axis of the Coweeta valley but changes little with elevation between opposite facing slopes. Over the past 50 years, 30 climatic stations have been operated at Coweeta. The climatic monitoring network now consists of five fully instrumented stations distributed over the basin. Long-term monthly averages and ranges for several important climatic variables measured in the laboratory administrative area are given in Table 1.

Table 1. Averages and ranges of monthly means for climatic variables at Coweeta CS01

Climatic variable	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Precipitation (mm/month)												
Average	174	181	203	156	140	130	144	139	125	112	139	178
Minimum	50	28	72	13	32	32	9	41	6	1	24	23
Maximum	371	423	433	287	477	318	300	340	333	291	478	388
Evaporation (mm/month)												
Average	34	43	77	97	104	107	108	98	81	67	46	30
Minimum	16	11	50	57	83	79	88	77	60	48	34	14
Maximum	60	76	132	137	133	157	135	120	100	83	57	57
Air temperature (°C/day)												
Average	3.3	4.4	8.0	12.6	16.4	20.0	21.6	21.3	18.4	13.0	7.8	4.1
Minimum	-4.0	-0.4	1.7	10.0	13.4	17.4	19.6	19.5	16.5	10.8	4.8	-0.6
Maximum	10.9	8.8	12.8	15.0	18.8	22.9	23.1	22.8	20.4	16.0	10.9	8.5
Solar radiation (MJ/m2/day)												
Average	8.0	11.1	14.1	17.8	18.2	19.2	17.9	16.2	14.0	12.5	9.0	7.0
Low	6.0	9.0	10.3	12.9	15.4	14.5	13.9	12.5	12.3	9.2	7.2	5.2
High	10.8	13.6	17.6	21.3	21.4	22.5	24.3	19.8	16.9	17.7	11.1	8.7

There are 69 km of first-, second-, and third-order perennial streams within the basin. The drainage pattern is dendritic, stream channels are generally V-shaped, and drainage density is uniform at 3.15 $km \cdot km^{-2}$. Permanent weirs were constructed on 32 Coweeta streams, and records were initiated on some streams in 1934. Presently, 16 streams are being continuously gauged. The range of monthly streamflow is rather narrow, but discharge is highest and most variable during February and March and lowest and most stable during late summer and early fall. Large differences in runoff occur between watersheds in the Coweeta Basin in response to differences in rainfall amount, soil depth, evapotranspiration, and topography. The range of physiographic and mean hydrologic characteristics of Coweeta control watersheds are shown in Table 2.

The regolith within the Coweeta Basin is deeply weathered and averages about 7 m in depth. Soils generally occur within two orders--fully developed Ultisols and immature Inceptisols. The underlying bedrock is termed the Coweeta Group and has been mapped and described in detail. The group consists of a series of metasedimentary and possibly metaigneous rocks which overlie the older rocks of the Tallulah Falls Formation of Precambrian origin. This formation is predominantly biotite, muscovite, and garnet. The biotite schist is coarse grained and medium to dark gray, containing biotite, orthoclase, quartz, garnet, and sillimanite. Within the formations are interlayers of pelitic schist, metasandstone to metagraywacke, and minor calc-silicate quartzite.

In 1968, the measurement of annual and seasonal fluxes of select nutrients were initiated for several forested watershed ecosystems in the Coweeta Basin. In subsequent years, the baseline network for precipitation and stream chemistry measurements was expanded and was fully implemented by 1972. Characterization of precipitation and stream chemistry is available for seven control and nine treated watersheds. The chemical composition of bulk precipitation is dominated by H and SO_4 ions (Table 3). Bulk precipitation at Coweeta is characterized as a weak solution of sulfuric and nitric acids that is somewhat buffered by base cations to produce a mean pH of 4.6. Stream water chemistry of low elevation watersheds is dominated by Na, Ca, and Mg cations, while HCO_3 is the dominant anion (Table 3). Thus, stream water is characterized as a cation-bicarbonate solution with a mean pH of 6.7. At high elevations, ionic strength of stream water is reduced by about 50% and SO_4 replaces HCO_3 as the dominant anion.

The long-term mean annual inputs, outputs, and net budgets for control catchments are summarized in Table 4. There is more NO_3, NH_4, and PO_4 added annually in precipitation than is lost in streamflow for all control ecosystems. Net losses occur for Ca, Na, K, Mg, and SiO_2 in all watersheds, a reflection of the dominance of these net budgets by geochemical weathering processes. Chloride is in close balance for most catchments, which supports the reliability of the budget approach at Coweeta to characterize the biogeochemistry of forest ecosystems. The budget for HCO_3 shows a large net loss which reflects the biological production and dissolution of CO_2 within the soil. All controls show large apparent accumulations of sulfate due to soil SO_4 to organic S forms in litter and soil layers.

Table 2. Some physiographic and mean hydrologic characteristics of Coweeta control watersheds

Characteristic		Watershed 2	14	18	34	27	36
(1) Area	ha	12.26	61,03	12.46	32.70	39.05	48.60
(2) Maximum elevation	m	1004	992	993	1184	1455	1542
(3) Minimum elevation	m	709	707	726	852	1061	1021
(4) Land slope	X	60	49	52	52	55	65
(5) Record length	yr	37	44	45	18	35	39
(6) Mean annual precipitation	cm	177.17	187.55	193.90	200.94	245.08	222.25
(7) Mean annual runoff	cm	85.39	98.81	103.42	117.47	173.74	167.51
(8) Precipitation - runoff	cm	91.78	88.74	90.48	83.47	71.34	54.74
(9) Hursh's runoff coefficient = $\frac{(7)}{(6)}$		.482	.527	.536	.585	.709	.754
(10) Initial flow rate	l/s/km2	24.52	29.46	29.54	36.57	36.30	40.81
(11) Quickflow before peak	cm	2.22	3.30	2.73	1.83	17.65	11.33
(12) Quickflow after peak	cm	5.93	6.62	7.00	3.74	34.15	25.86
(13) Delayed flow	cm	77.20	88.90	93.69	111.91	121.94	130.33
(14) Storm duration	hr	13.78	13.45	13.50	11.10	29.93	26.75
(15) Time to peak	hr	4.20	4.65	4.11	3.95	9.31	8.02
(16) Absolute peak	l/s/km2	68.78	81.12	79.97	75.65	242.60	154.05
(17) Recession time	hr	9.57	8.81	9.39	7.15	20.62	18.73
(18) Mean runoff events/year		66	80	79	80	68	68
(19) Response factor - $\frac{(11)+(12)}{(6)}$		.046	.053	.050	.028	.211	.167
(20) Hursh's storm runoff ratio = $\frac{(11)+(12)}{(7)}$		.095	.100	.094	.047	.298	.222

Table 3. Volume-weighted mean annual concentrations of dissolved inorganic constituents in bulk precipitation and stream water for Coweeta WS 2[a]

Constituent	Precipitation		Stream water	
	mg/1	µeq/l	mg/l	µeq/l
H^+	0.027	26.64	<0.000	0.2
Ca^{2+}	0.194	9.70	0.583	29.1
Na^+	0.170	7.38	1.22	53.2
NH_4^+	0.095	6.80	.002	0.2
Mg^{2+}	0.041	3.35	0.326	26.9
K^+	0.094	2.41	0.499	12.8
SO_4^{2-}	1.59	33.1	0.450	9.4
NO_3^-	0.143	10.2	.003	0.2
Cl^-	0.271	7.65	0.662	18.7
HCO_3^-	0.074	1.21	4.97	81.5
PO_4^{3-}	0.013	0.42	.006	0.2
Dissolved silica	0.030	—	8.80	—
	Σ+	56.3	E+	122.3
	Σ-	52.6	Σ-	109.9

[a]Data span the period 1973-1983 (June-May water year) for all ions except SO_4^{2-} (1974-1983), dissolved silica (1975-1983), and HCO_3^- (1977-1982).

Table 4. Average annual nutrient (kg ha^{-1}) and water (cm) budgets for control watersheds at Coweeta Hydrologic Laboratory

Watershed number	Input	Output	Net difference	Input	Output	Net difference	Input	Output	Net difference	Input	Output	Net difference
	Water			NO_3-N			NH_4-N			PO_4		
2	187	93	+94	2.67	0.02	+2.65	1.78	0.02	+1.76	0.25	0.05	+0.20
14	214	119	+95	3.15	0.05	+3.10	2.14	0.04	+2.10	0.29	0.05	+0.24
18	206	119	+87	2.97	0.04	+2.93	1.97	0.03	+1.94	0.28	0.05	+0.23
27	265	187	+78	4.38	0.34	+4.04	2.54	0.07	+2.47	0.38	0.08	+0.30
32	240	171	+69	3.77	0.04	+3.73	2.52	0.06	+2.46	0.35	0.07	+0.28
34	215	128	+87	3.22	0.04	+3.18	2.24	0.04	+2.20	0.29	0.06	+0.23
36	225	183	+42	3.25	0.14	+3.11	2.15	0.06	+2.09	0.31	0.07	+0.24
	SO_4			Cl			K			Na		
2	29.03	4.10	+24.93	5.07	6.18	-1.11	1.76	4.66	-2.90	3.17	11.43	-8.26
14	33.97	5.67	+28.30	6.98	6.44	+0.54	1.80	4.08	-2.28	4.51	8.73	-4.22
18	32.12	4.90	+27.22	5.72	6.30	-0.58	1.98	4.93	-2.95	3.56	10.31	-6.75
27	39.47	21.14	+18.33	9.44	9.21	+0.23	1.86	4.31	-2.45	5.16	9.07	-3.91
32	40.62	7.74	+32.88	8.35	8.48	-0.13	2.20	5.08	-2.88	5.24	11.18	-5.94
34	34.61	5.46	+29.15	6.60	7.37	-0.77	1.91	4.99	-3.08	4.14	11.58	-7.44
36	35.26	16.57	+18.69	6.21	9.94	-3.73	2.18	5.49	-3.31	3.89	13.79	-9.90
	Ca			Mg			SiO_2			HCO_3		
2	3.63	5.45	-1.82	0.76	3.05	-2.29	0.55	77.25	-76.70	1.27	40.44	-39.16
14	3.83	5.28	-1.45	0.88	3.25	-2.37	0.48	59.09	-58.61	—	—	—
18	4.00	7.03	-3.03	0.85	3.49	-2.64	0.62	83.69	-83.07	—	—	—
27	3.31	6.80	-3.49	1.17	3.87	-2.70	0.46	65.50	-65.04	—	—	—
32	4.25	8.25	-4.00	1.04	4.82	-3.78	—	81.43	—	—	—	—
34	3.90	8.82	-4.92	0.88	4.40	-3.52	0.44	79.81	-79.37	—	—	—
36	4.40	10.80	-6.40	0.93	4.73	-3.80	0.68	106.46	105.78	—	—	—

VEGETATION DESCRIPTION

Vegetation of the Coweeta Basin was traditionally included in the oak-chestnut association, but due to the loss of chestnut to blight, the area is now classified as belonging to the oak-hickory association. Plant communities in the basin are typically diverse for the Southern Appalachians and are distributed over the highly varied topography in relation to temperature and moisture gradients. The composition and structure of the plant communities are still changing in response to past land use history and the loss of chestnut.

A network of about 400 permanent 0.08-ha (0.2-acre) plots distributed over the basin provide the basis for a gradient analysis of vegetation composition (Fig. 1). Four major community types occupy topograpic positions which traverse from mesic coves to slopes to dry ridges and include northern hardwoods, cove hardwoods, oak, and oak-pine. Within the oak type, chestnut oak is the most widespread species and is abundant at middle elevations on slopes with mesic aspects. Scarlet oak is primarily found on drier slopes and ridges. Northern red oak increases in importance at higher elevations (3500 feet) while white oak and black oak are important species at lower elevations. Red maple and hickories are also important components in the oak type.

A variety of watershed experiments, such as cutting and species conversions, have produced a wide range of forest communities with diverse structures. These communities include 30-year-old white pine plantations, even-aged hardwood stands ranging in age from 5 to 40 years, and succession from old field to forest. These communities occupy areas from 6 to 60 ha in size.

BIOMASS, NET PRIMARY PRODUCTION, AND LEAF AREA INDEX

Detailed studies have been conducted on vegetation structure, productivity, nutrient pools, and nutrient fluxes in a variety of forest ecosystems at Coweeta. The standing crop biomass, net primary production, and leaf area index for some of these ecosystems are summarized in Table 5. The aboveground biomass of lower elevation mixed hardwood forests is about 140 t ha^{-1} with an LAI of 6.0, while at high elevations LAI is typically about 3.5; all estimates are for watershed-scale ($\geq$20 ha) populations. These same parameters have been estimated for young successional forests revealing a recovery of net production and LAI following clearcutting. Black locust dominated stands show complete recovery of standing biomass after only 17 years of regrowth, and by age 38 biomass is more than double the uneven-aged hardwood forests. Net primary production of these stands is high and ranges from 11 to 15 t ha^{-1} $year^{-1}$. At low elevations, leaf-out is usually complete about mid-May, and leaf-fall is largely complete by the end of October. Mountain laurel and rhododendron are the dominant evergreen understory species. They provide an LAI of 0.5 or less in the dormant season, although values can be much higher on some sites occupied by dense stands of these species. There is a phenological gradient in the basin in response to temperature and moisture gradients, with later leaf-out and somewhat earlier leaf-fall at higher elevations.

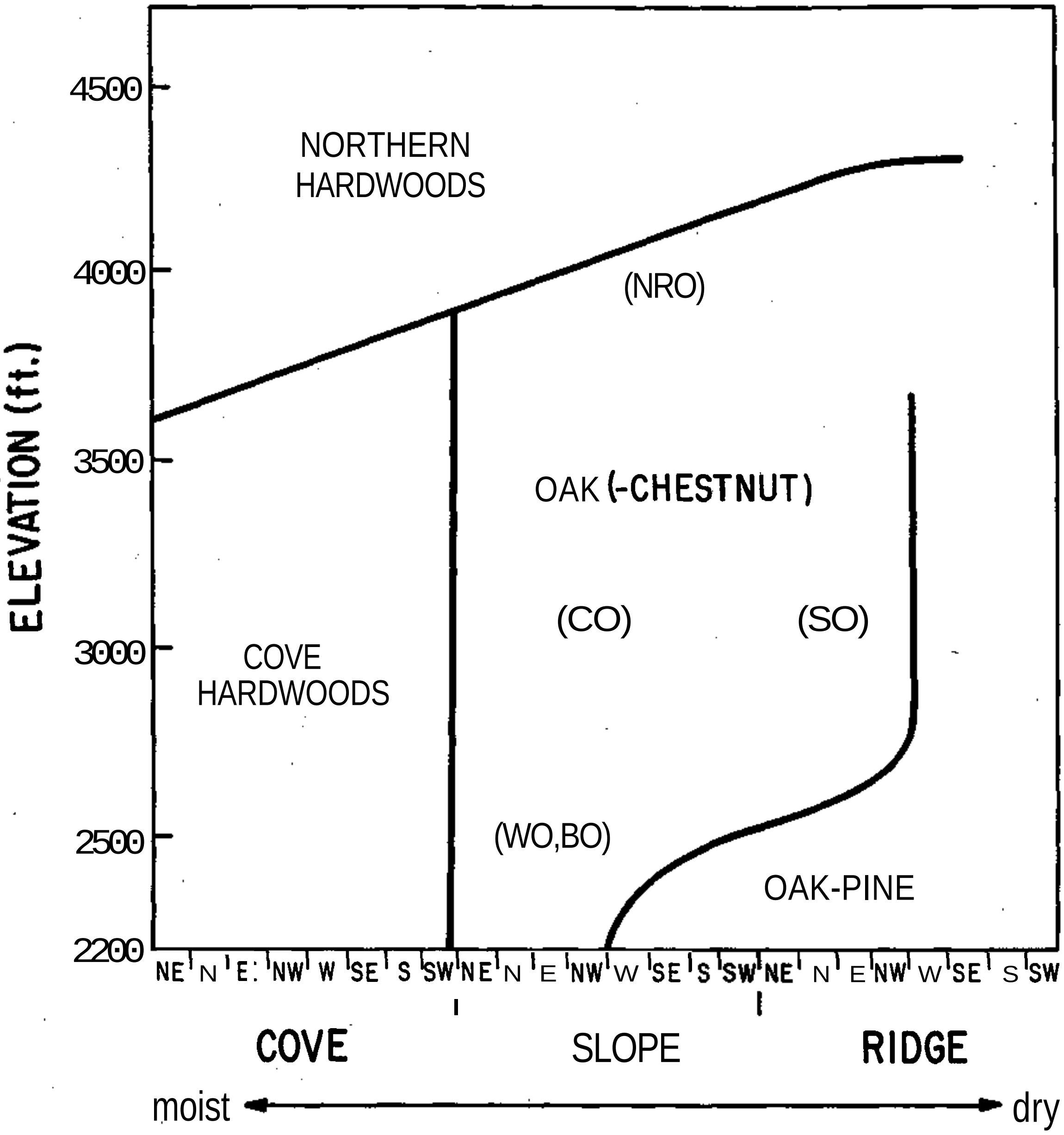

Fig. 1. Major forest types at Coweeta in relation to elevation and aspect. BO = Black Oak, CO = Chestnut Oak, NRO = Northern Red Oak, SO = Scarlet Oak, WO = White Oak.

Table 5. Summary of biomass, net primary production (NPP), and leaf area index (LAI) for selected Coweeta forest ecosystems

Ecosystem	Biomass $t\ ha^{-1}$	NPP $t\ ha^{-1}\ yr^{-1}$	LAI $m^2\ m^{-2}$
Oak hickory forest (low elevation)	140.0	8.4	6.0
Oak-hickory forest (high elevation)	—	—	3.5
Even-aged hardwoods (3 years)	9.1	4.2	4.2
Even-aged black locust dominated stands			
4 years	22.	11.5	--
17 years	142.0	14.9	--
38 years	328.0	15.0	--
White pine plantation (15 years)	69.6	13.5	9.9-17.8

The two white pine plantations (now 30 years old) provide a sharp contrast in LAI to hardwood forests. At age 15 the dormant season LAI (all sides of needles) was nearly 10 and increased to 18 in the growing season. Additional estimates of biomass, NPP, and LAI are available from age 10 through age 30 for one of the plantations in addition to the spatial distribution of these parameters over time.

Detailed analyses of nutrient pools and fluxes for most of these ecosystems are also available, and an equally intensive data base is available on stream ecosystem structure and function at Coweeta. Taken together, forest ecosystem characterizations at Coweeta are among the most extensive available and provide an excellent opportunity to develop, test, and modify remote sensing capabilities.

LITERATURE CITED

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