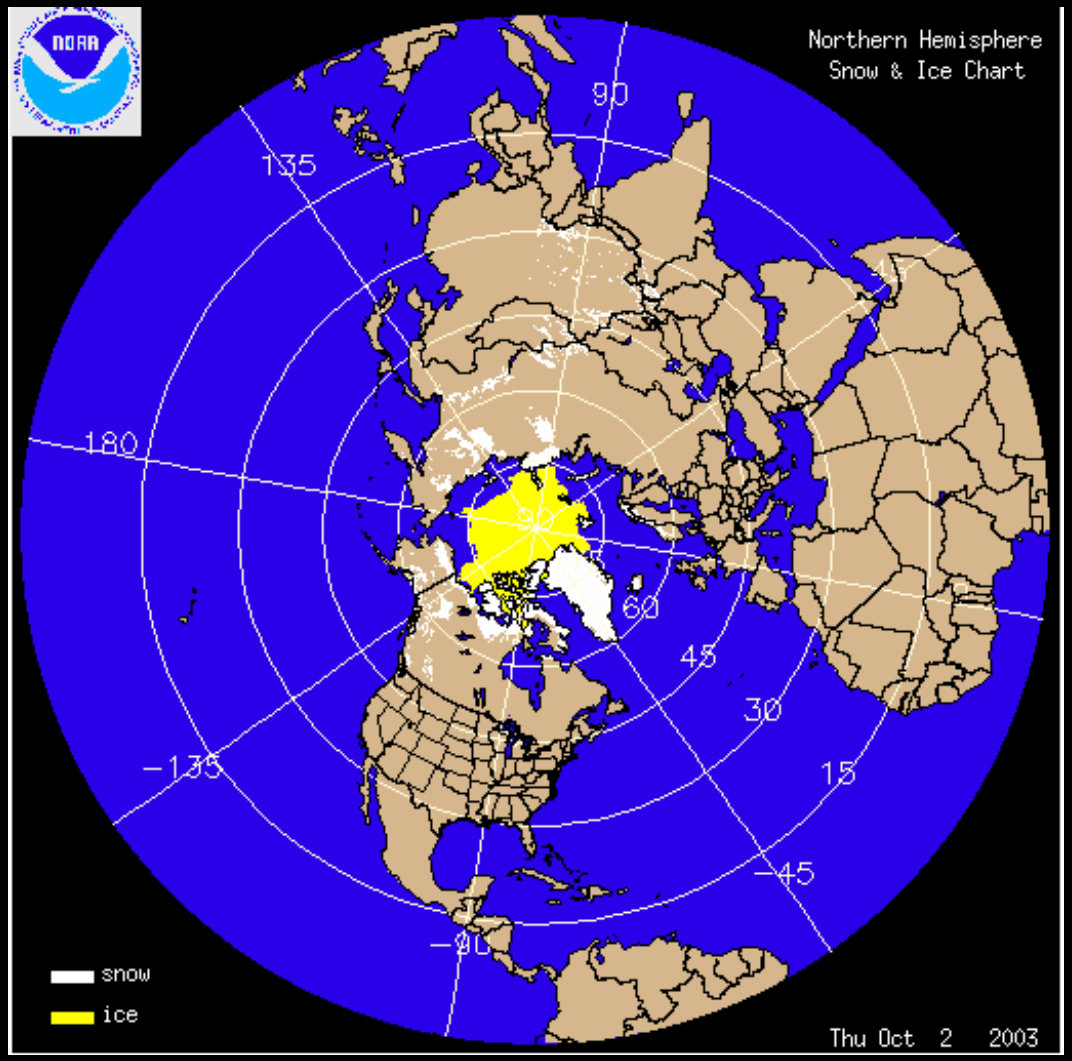
ARCTIC CLIMATE INDICATORS - Snow, Ice and Agriculture

9th Bi-Annual Circumpolar Remote Sensing Symposium

May 17, 2006 Seward, AK



Michael R. Ferrari Rutgers University
aeroculus@gmail.com

Is Northern Hemisphere Snow/Ice Cover an Early Indicator of Summer Temperatures?

Polar Remote Sensing and the Applications for US Agriculture

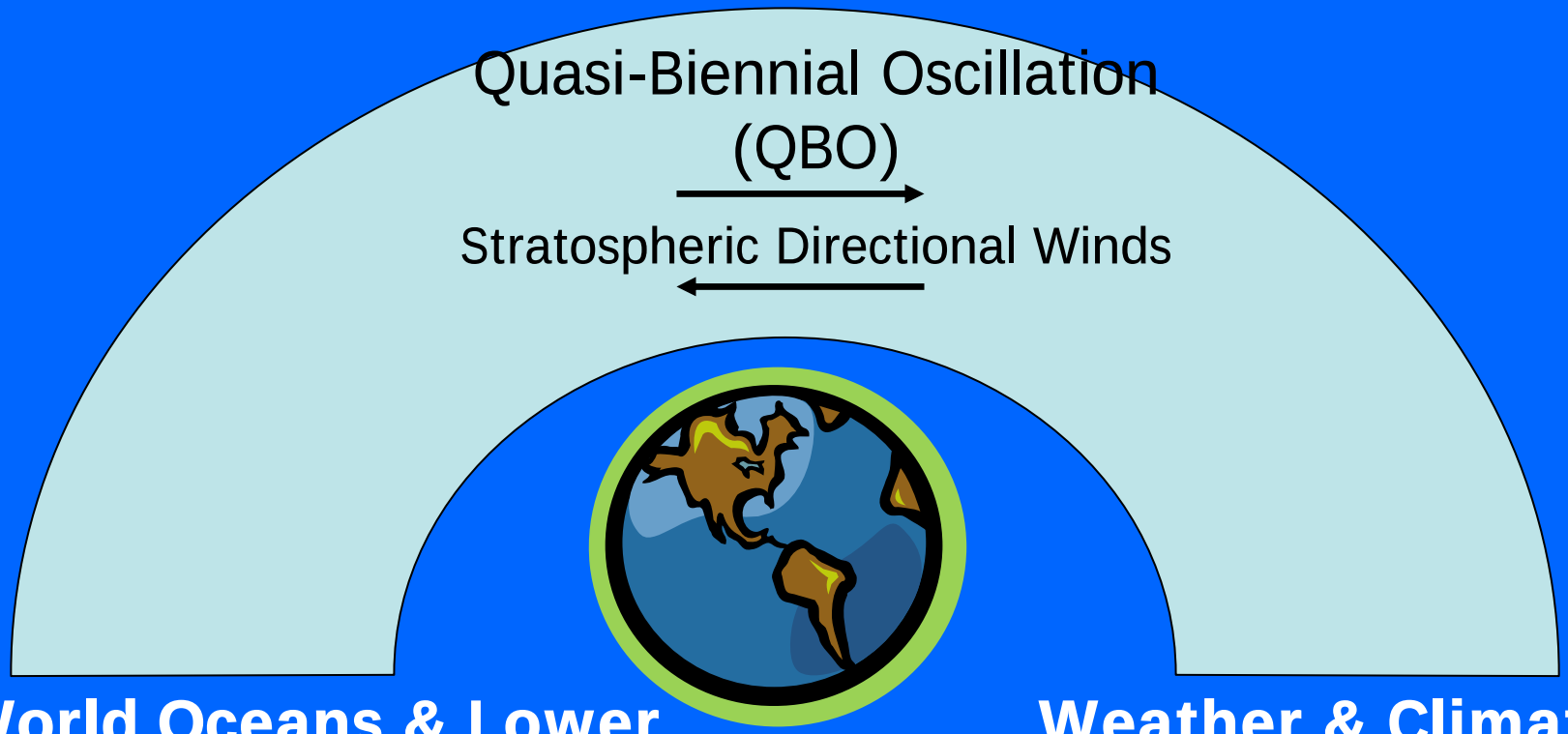
Objectives:

- Background
- Applications of Seasonal Forecasting to Agriculture
- Integration of Polar Remote Sensing as a seasonal forecast precursor
- Summary/Questions

m&m's
BRAND

Weather Station - Dimbokro, Cote-d’Ivoire

Start With Global Geophysical Drivers - narrow down to particular area of interest

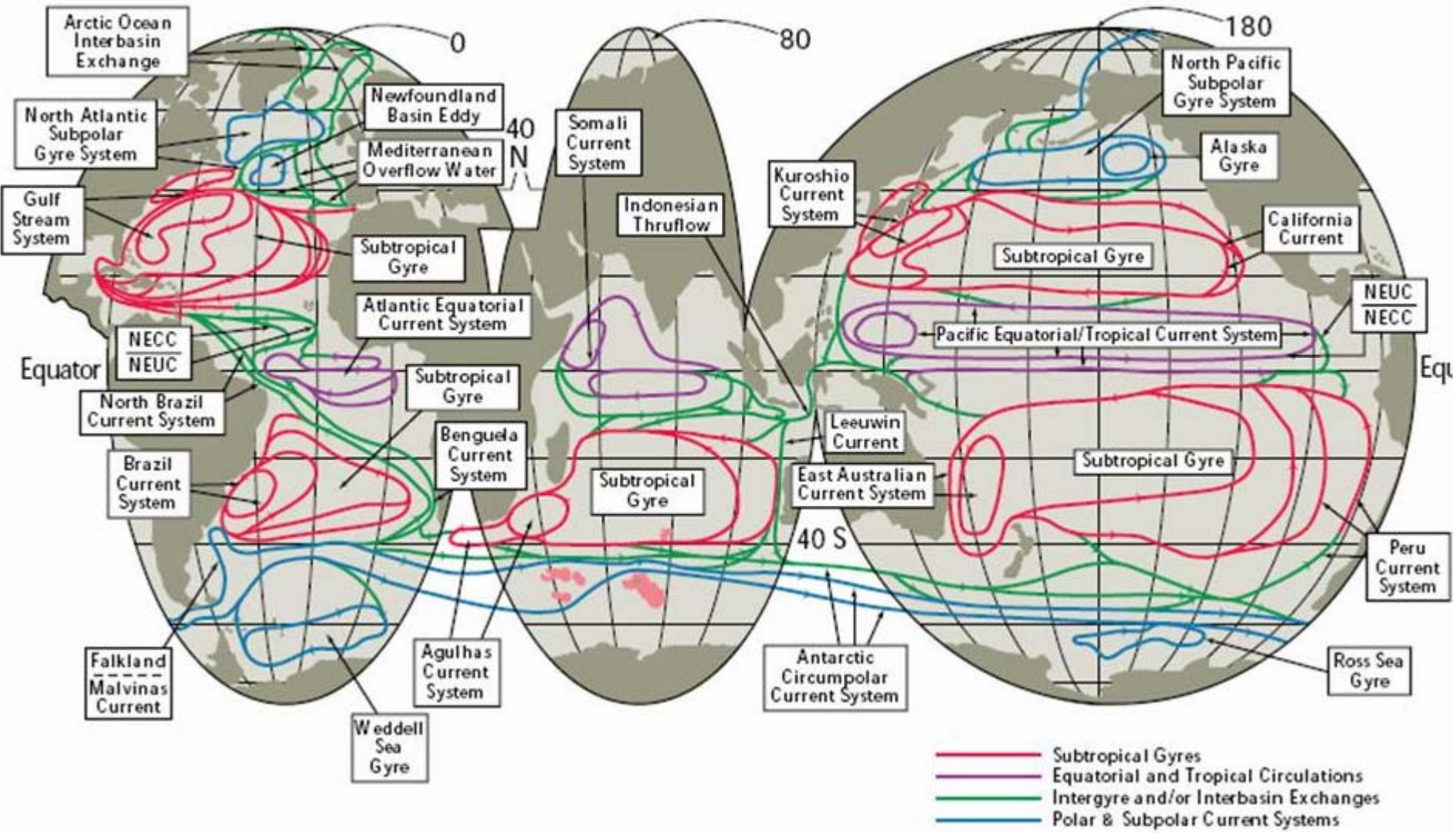


World Oceans & Lower Level Atmosphere

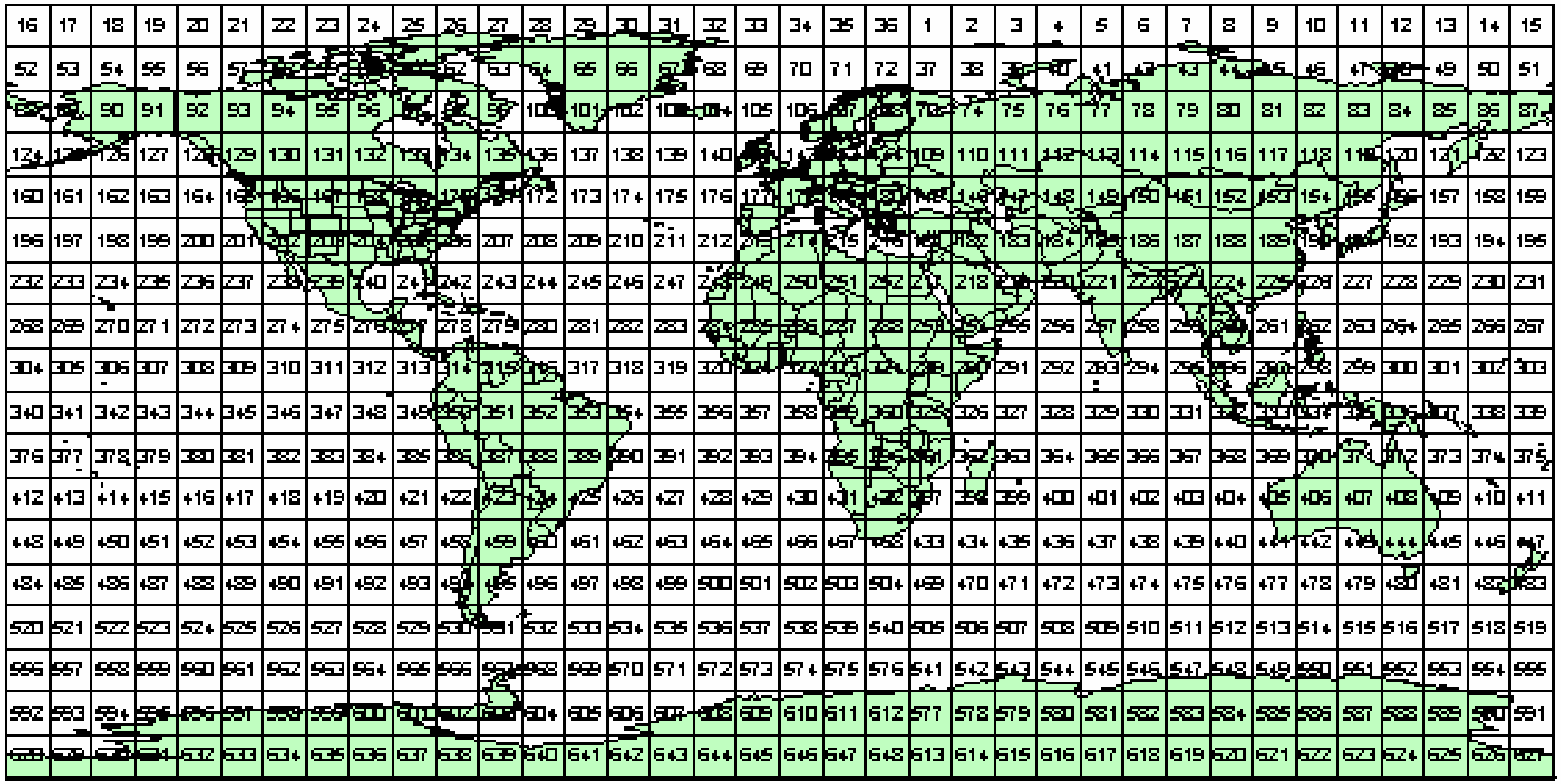
- Atmospheric Pressure from surface (1000 mb) to 500 mb
- Sea Surface Temperatures
- Atlantic Thermohaline Circulation

Weather & Climate

- ENSO
- QBO phase
- Zonal and Meridional Winds
- Solar Activity


Arctic Ocean Interbasin Exchange
0
80
180
North Atlantic Subpolar Gyre System
Newfoundland Basin Eddy
Mediterranean Overflow Water
40 N
Somali Current System
Indonesian Thruflow
Kuroshio Current System
North Pacific Subpolar Gyre System
Alaska Gyre
California Current
Gulf Stream System
Subtropical Gyre
Atlantic Equatorial Current System
Subtropical Gyre
NEUC
NECC
Pacific Equatorial/Tropical Current System
NECC
NEUC
Equator
Equ
North Brazil Current System
Subtropical Gyre
Leeuwin Current
Benguela Current System
Brazil Current System
Subtropical Gyre
East Australian Current System
Subtropical Gyre
40 S
Peru Current System
Falkland Malvinas Current
Agulhas Current System
Antarctic Circumpolar Current System
Ross Sea Gyre
Weddell Sea Gyre
Subtropical Gyres
Equatorial and Tropical Circulations
Intergyre and/or Interbasin Exchanges
Polar & Subpolar Current Systems

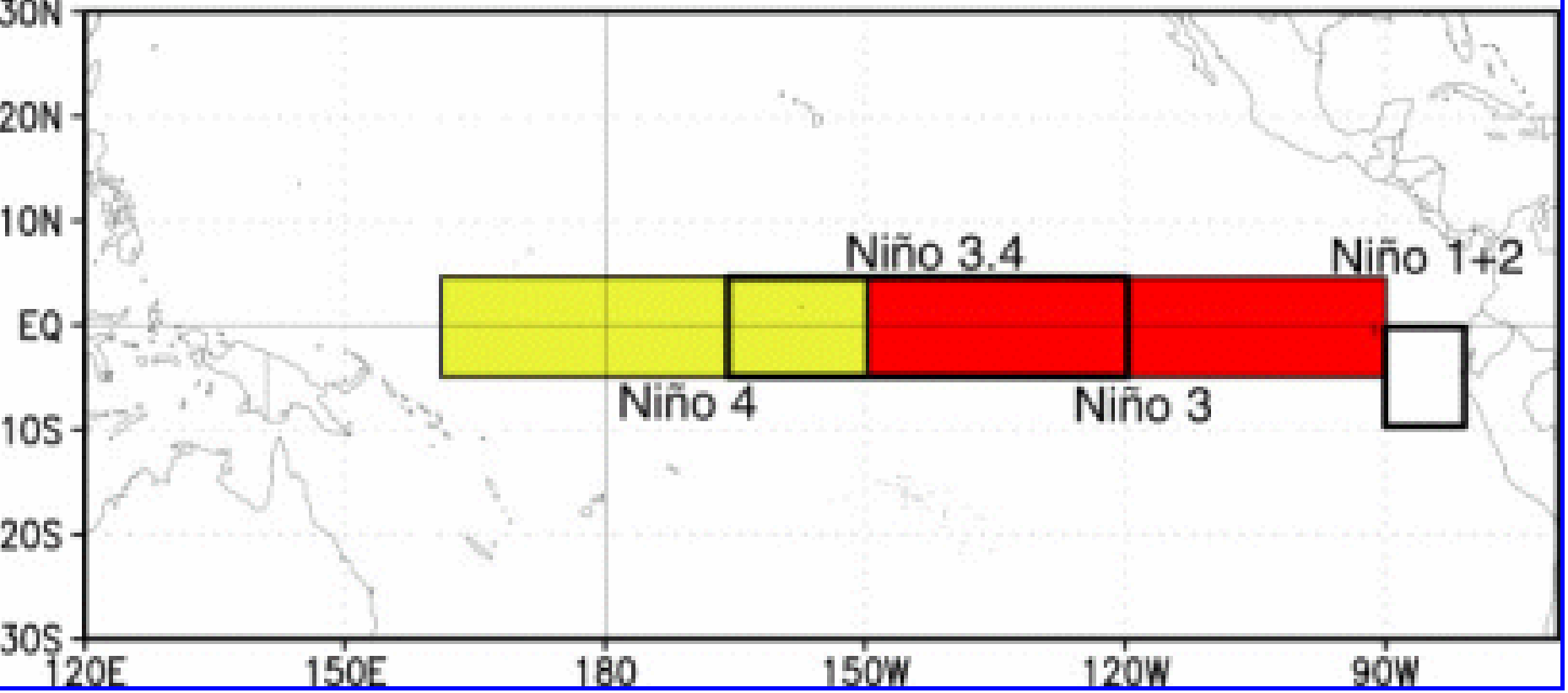
1 degree scaled up to 10 degree global grid



For many forecast parameters, complete records exist back to 1900 (some ship records from fisheries & trans-Atlantic voyages extend pre-1850).

Approximately 250 Global Weather Indices (regional to global scale processes) 1900-present

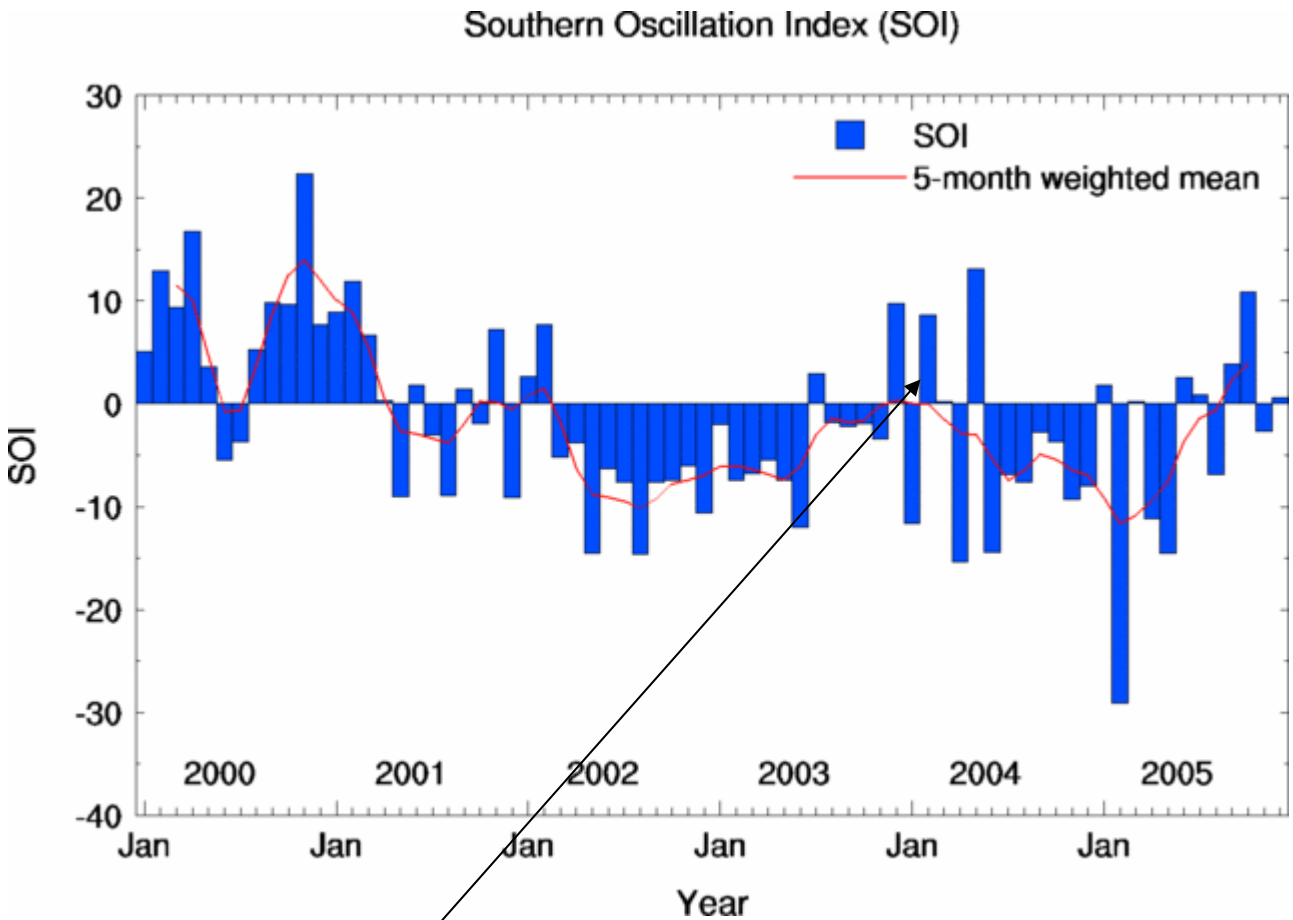
	A	B	C	D	E	F	G	H	I	J
1	B0102_102	B0102_123	B0102_138	B0102_142	B0102_164	B0102_190	B0102_195	B0102_197	B0102_278	B0102_298
2	B0102_329	B0102_356	B0102_363	B0102_367	B0102_394	B0102_401	B0102_410	B0102_422	B0102_482	B0405_123
3	B0405_142	B0405_164	B0405_190	B0405_195	B0405_197	B0405_200	B0405_207	B0405_210	B0405_320	B0405_356
4	B0405_367	B0405_394	B0405_401	B0405_410	B0405_422	B0405_427	B0405_435	B0405_438	B0708_138	B0708_164
5	B0708_195	B0708_197	B0708_200	B0708_207	B0708_210	B0708_219	B0708_226	B0708_236	B0708_363	B0708_394
6	B0708_410	B0708_422	B0708_427	B0708_435	B0708_438	B0708_441	B0708_449	B0708_453	B1011_190	B1011_197
7	B1011_207	B1011_210	B1011_219	B1011_226	B1011_236	B1011_240	B1011_271	B1011_278	B1011_401	B1011_422
8	B1011_435	B1011_438	B1011_441	B1011_449	B1011_453	B1011_463	B1011_480	B1011_482	P0102_N4	P0102_NP
9	P0102_QBO50	P0102_QBOPh	P0102_Sng100	P0102_SSP	P0102_TAH	P0102_TGL	P0102_TNH	P0102_TSH	P0405_N12	P0405_N34
10	P0405_NAO	P0405_NP	P0405_PDO	P0405_QBO50	P0405_QBOPh	P0405_Sng100	P0405_SSP	P0405_TAH	P0708_DAR	P0708_HuBay
11	P0708_N3	P0708_N34	P0708_N4	P0708_NAO	P0708_NP	P0708_PDO	P0708_QBO50	P0708_QBOPh	P0708_VSH	P1011_AO
12	P1011_EAJS	P1011_HuBay	P1011_N12	P1011_N3	P1011_N34	P1011_N4	P1011_NAO	P1011_NP	P1011_TSH	P1011_VNH
13	P13_AtlHur	P13_CO2	P13_EOF3	P13_IndiaMon	P13_LOD	P13_TripAtl	B0102_240	B0102_271	B0102_282	B0102_320
14	B0102_200	B0102_207	B0102_210	B0102_219	B0102_226	B0102_236	B0102_463	B0102_480	B0405_102	B0405_138
15	B0102_427	B0102_435	B0102_438	B0102_441	B0102_449	B0102_453	B0405_282	B0405_298	B0405_329	B0405_363
16	B0405_219	B0405_226	B0405_236	B0405_240	B0405_271	B0405_278	B0708_102	B0708_123	B0708_142	B0708_190
17	B0405_441	B0405_449	B0405_453	B0405_463	B0405_480	B0405_482	B0708_329	B0708_356	B0708_367	B0708_401
18	B0708_240	B0708_271	B0708_278	B0708_282	B0708_298	B0708_320	B1011_142	B1011_164	B1011_195	B1011_200
19	B0708_463	B0708_480	B0708_482	B1011_102	B1011_123	B1011_138	B1011_367	B1011_394	B1011_410	B1011_427
20	B1011_282	B1011_298	B1011_320	B1011_329	B1011_356	B1011_363	P0102_N3	P0102_N34	P0102_NAO	P0102_PDO
21	P0102_AMO	P0102_AO	P0102_DAR	P0102_EAJS	P0102_HuBay	P0102_N12	P0405_EAJS	P0405_HuBay	P0405_N3	P0405_N4
22	P0102_VGL	P0102_VNH	P0102_VSH	P0405_AMO	P0405_AO	P0405_DAR	P0708_AMO	P0708_AO	P0708_EAJS	P0708_N12
23	P0405_TGL	P0405_TNH	P0405_TSH	P0405_VGL	P0405_VNH	P0405_VSH	P0708_VGL	P0708_VNH	P1011_AMO	P1011_DAR
24	P0708_Sng10(	P0708_SSP	P0708_TAH	P0708_TGL	P0708_TNH	P0708_TSH	P1011_TGL	P1011_TNH	P1011_VGL	P1011_VSH
25	P1011_PDO	P1011_QBO50	P1011_QBOPh	P1011_Sng100	P1011_SSP	P1011_TAH				



- **Nino1+2:** 0°-10°S, 80°W-90°W
- **Nino3:** 5°S-5°N, 90°W-150°W
- **Nino3.4:** 5°S-5°N, 120°W-170°W
- **Nino4:** 5°S-5°N, 160°E-150°W

El Niño:Onset and Ending Dates

Date of Onset	Date Ending	Date of Onset	Date Ending
1864-Aug	1869-Feb	1951-Aug	1951-Dec
1877-Apr	1878-Jul	1957-Jul	1958-May
1888-Aug	1889-May	1963-Aug	1963-Dec
1896-Aug	1897-Mar	1965-Jun	1966-Feb
1899-Aug	1900-Jun	1969-Aug	1970-Feb
1902-Jun	1903-Feb	1972-May	1973-Mar
1905-Jan	1906-Mar	1976-Aug	1977-Feb
1911-Oct	1912-Mar	1982-May	1983-Sep
1914-Jul	1915-Aug	1986-Oct	1988-Jan
1918-Jul	1920-Jun	1991-Aug	1992-Jun
1925-Sep	1926-May	1997-May	1998-Oct
1930-Jul	1931-May	2001-Sept	2002-Aug
1940-Jan	1942-Feb	2004-Aug	2005-Apr

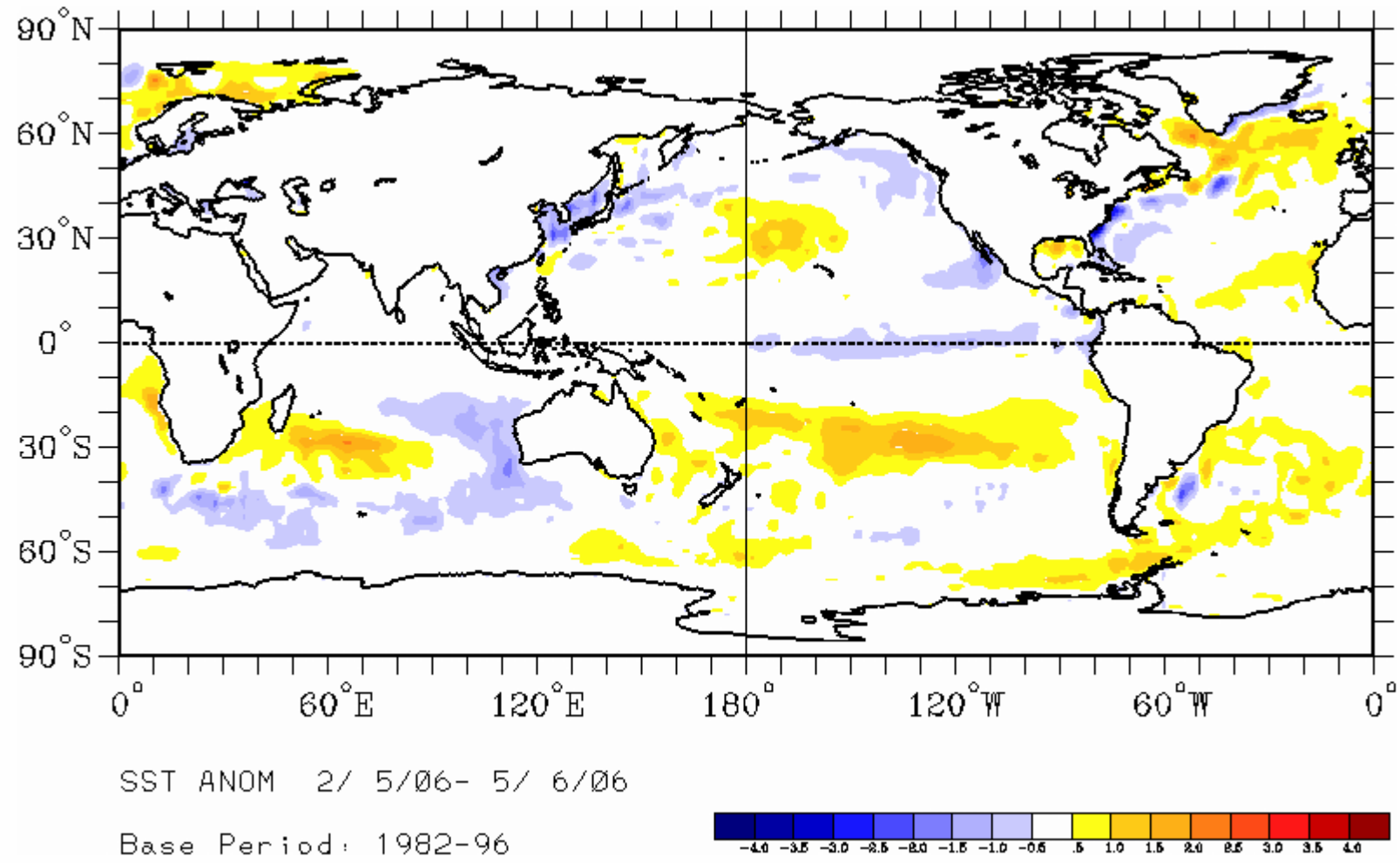


SOUTHERN OSCILLATION INDEX

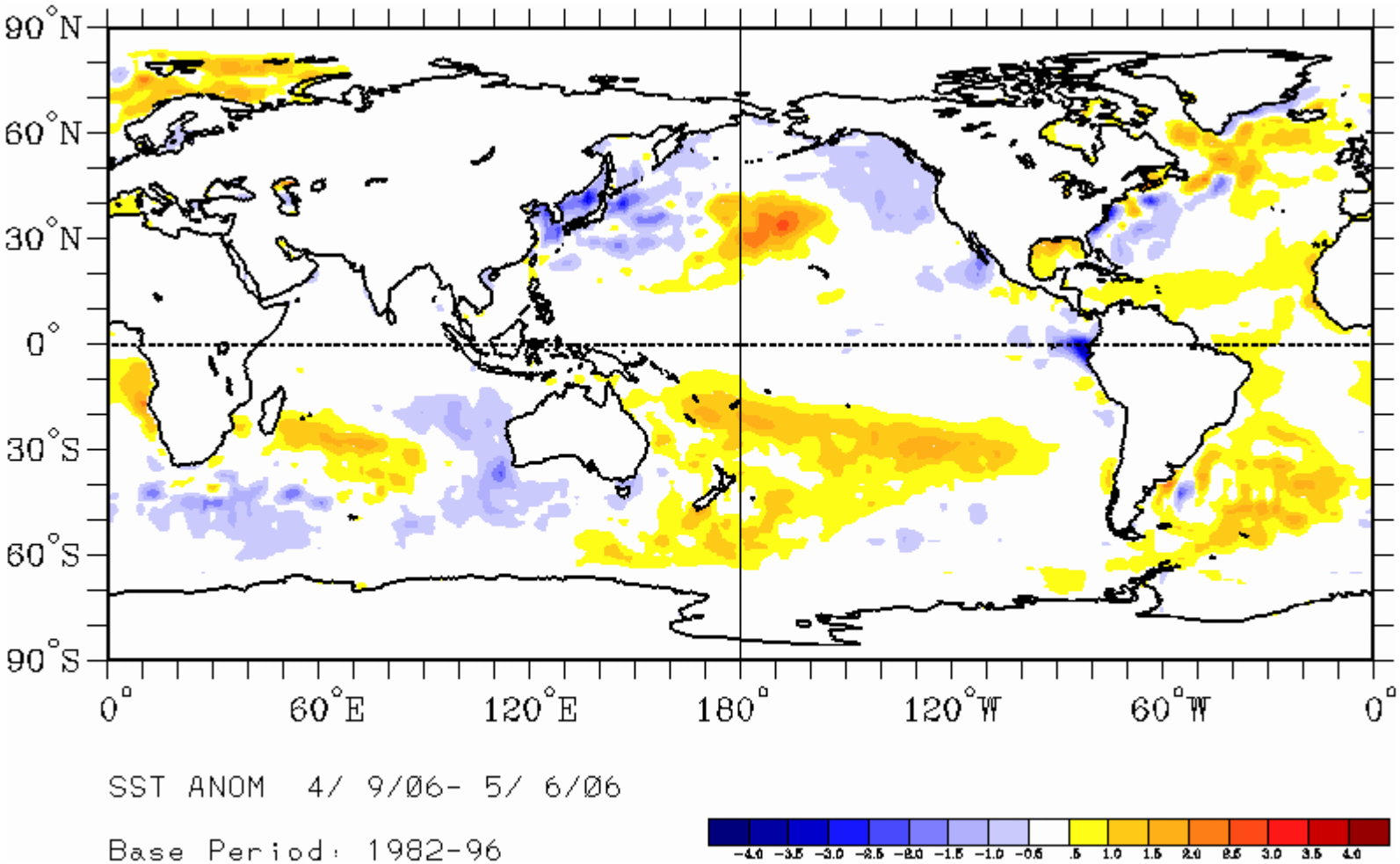
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2000	5.1	12.9	9.4	16.8	3.6	-5.5	-3.7	5.3	9.9	9.7	22.4	7.7
2001	8.9	11.9	6.7	0.3	-9	1.8	-3	-8.9	1.4	-1.9	7.2	-9.1
2002	2.7	7.7	-5.2	-3.8	-14.5	-6.3	-7.6	-14.6	-7.6	-7.4	-6	-10.6
2003	-2	-7.4	-6.8	-5.5	-7.4	-12	2.9	-1.8	-2.2	-1.9	-3.4	9.8
2004	-11.6	8.6	0.2	-15.4	13.1	-14.4	-6.9	-7.6	-2.8	-3.7	-9.3	-8
2005	1.8	-29.1	0.2	-11.2	-14.5	2.6	0.9	-6.9	3.9	10.9	-2.7	0.6

Source: Australia Bureau of Meteorology

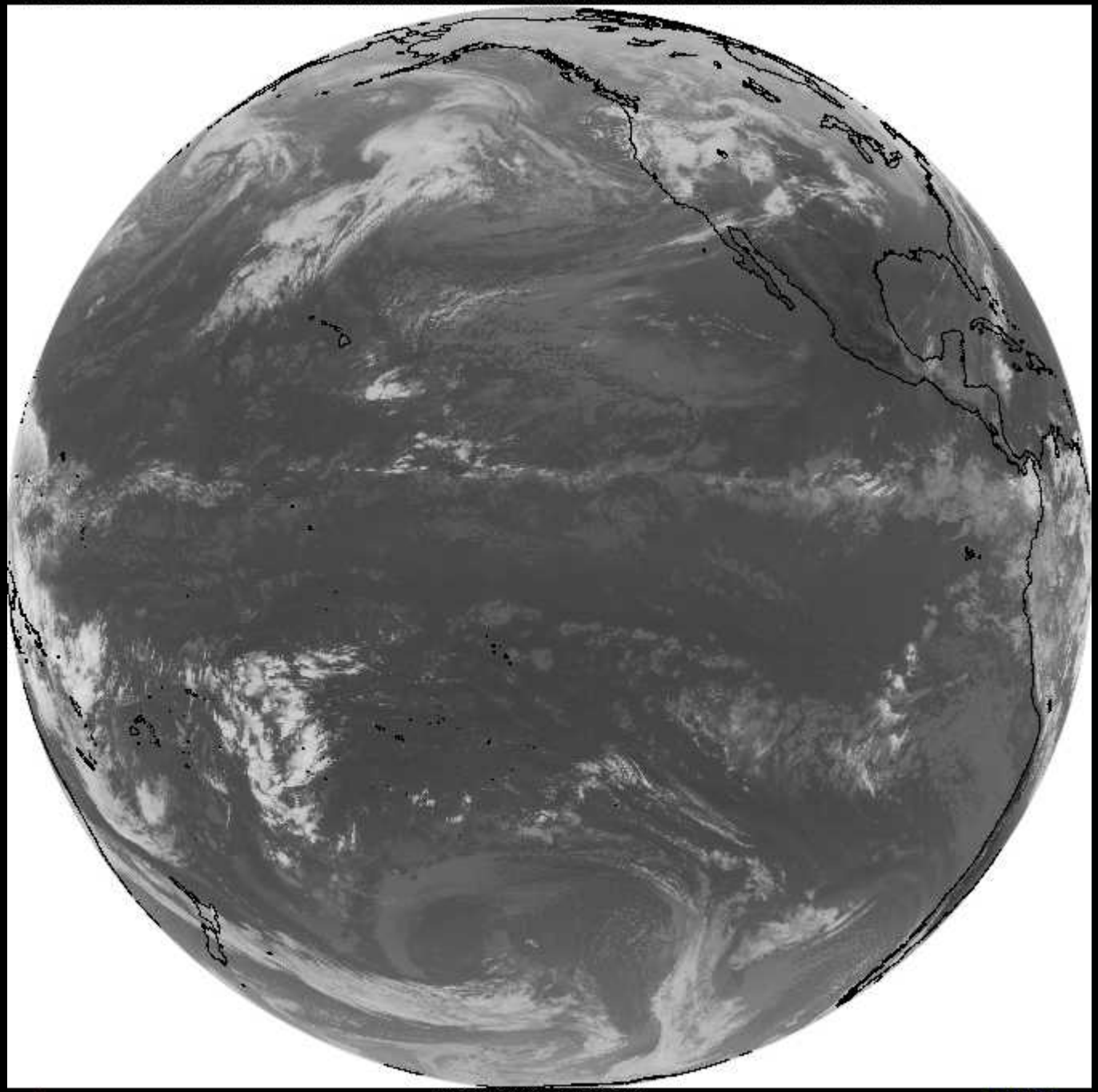
Seasonal SST anomalies



Monthly SST anomalies

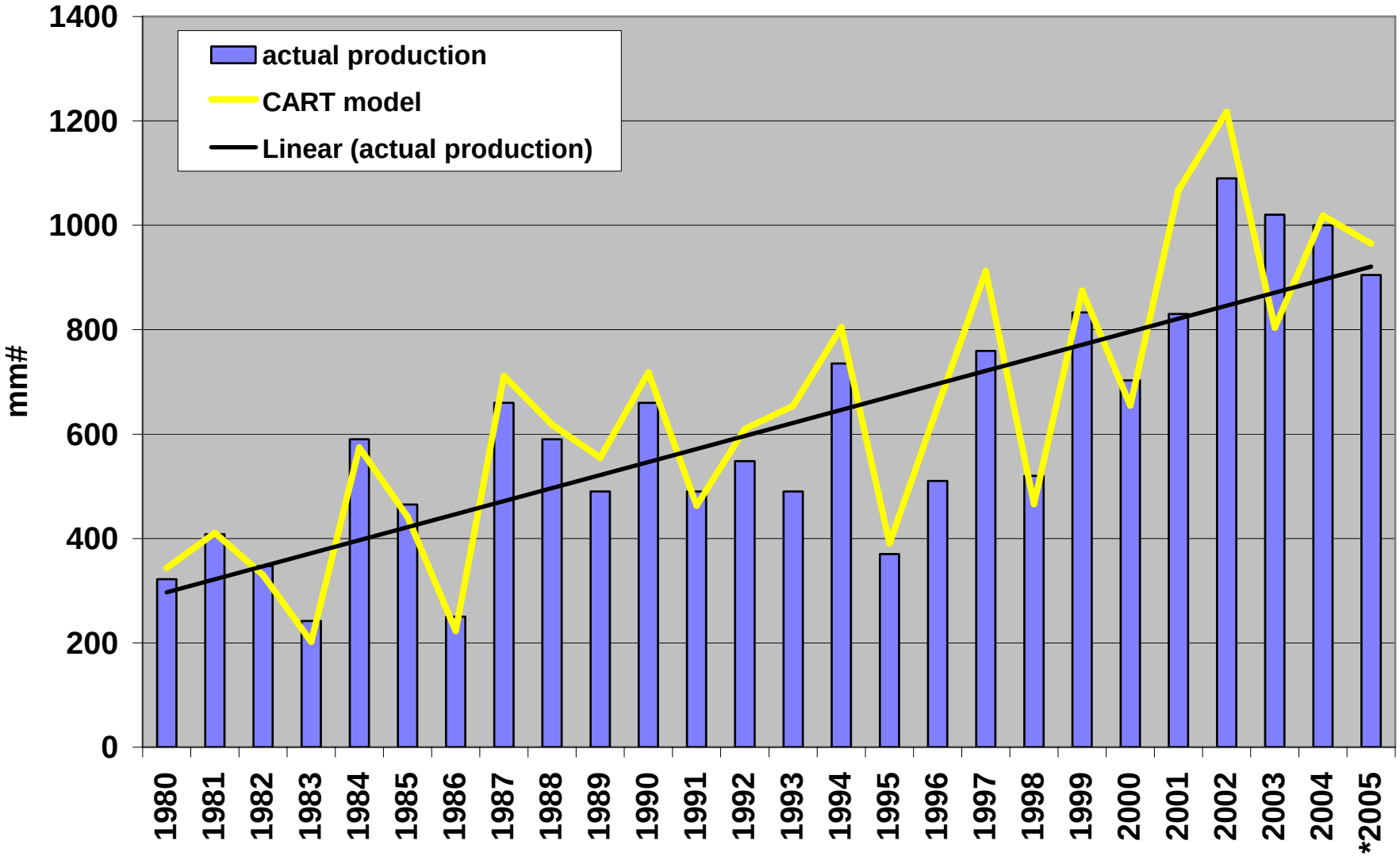


GOES WEST FULL DISK LONGWAVE IR 18 JAN 06 18:00 SSEC: UW-MADISON



1 2006018 180000 McIDAS

Calififorнia Almond Production
Modeled vs. Observed



SSEC: GOES West Satellite Images - Microsoft Internet Explorer provided by SDS

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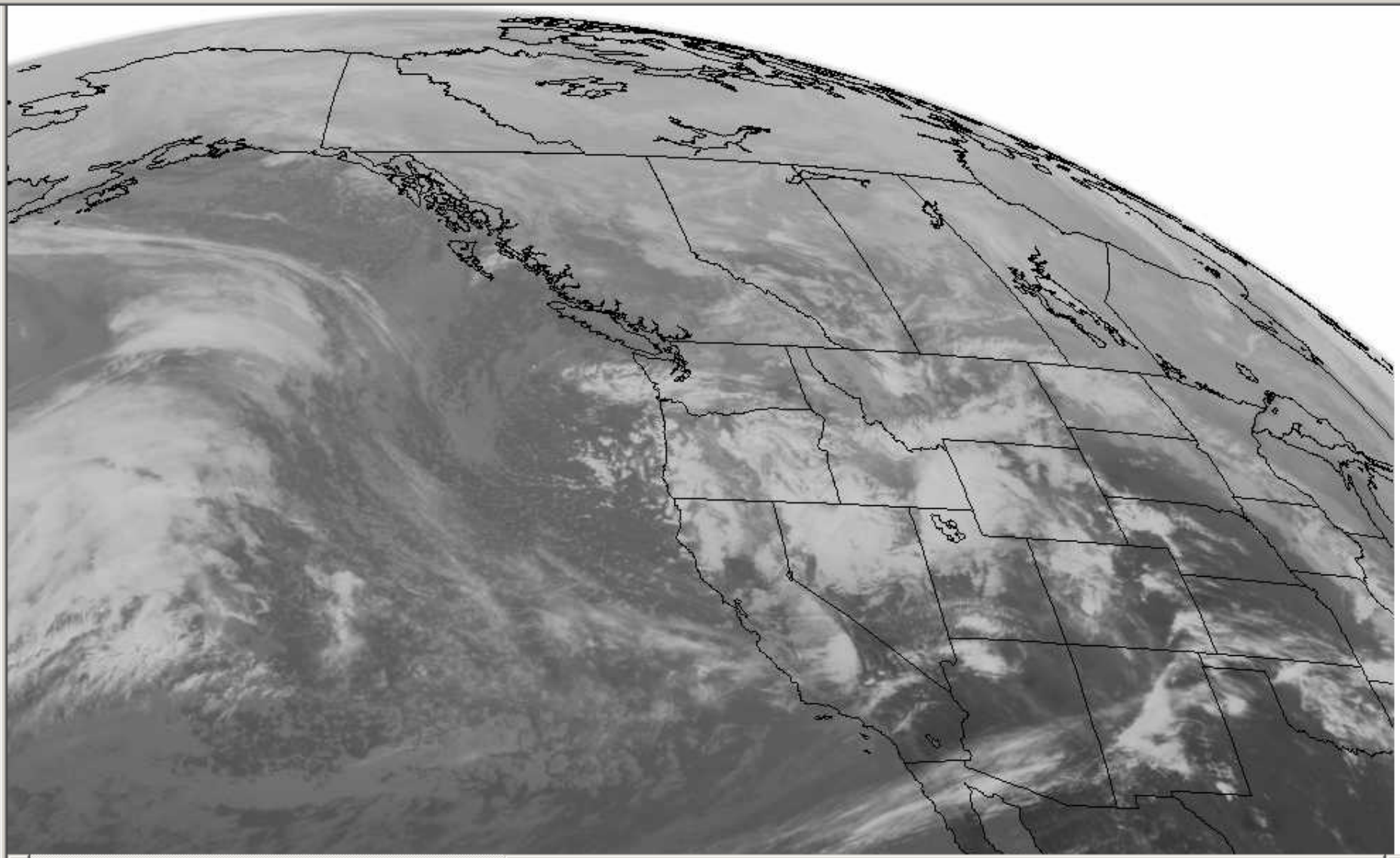

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Start R... A... sli... E... G... M... A... Vi... S... 3:36 PM

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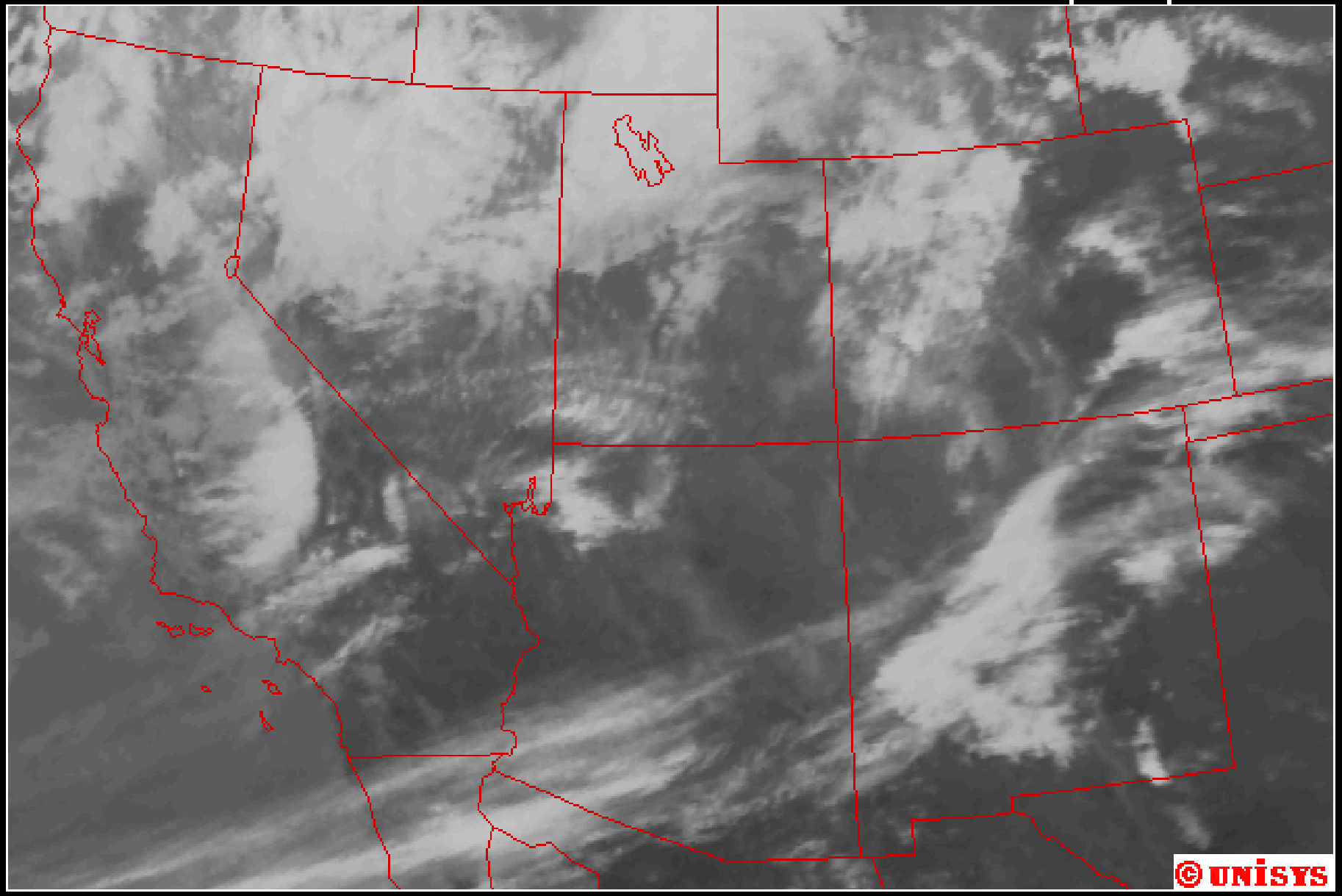

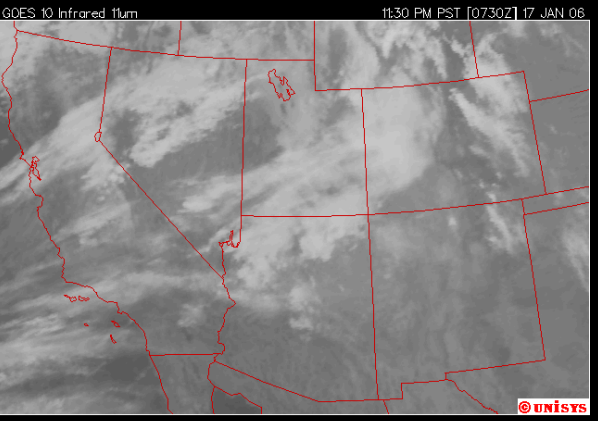
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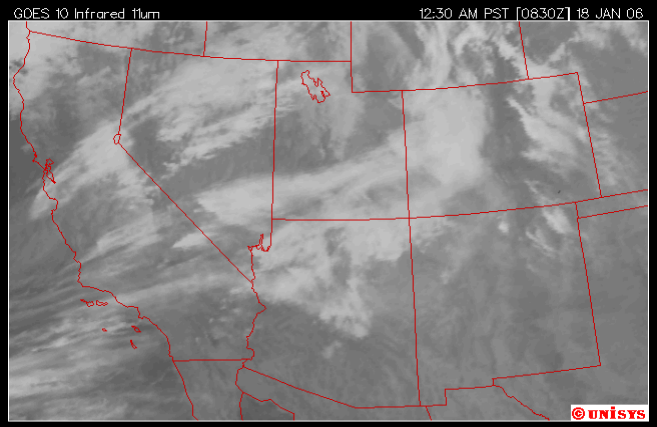
UNISYS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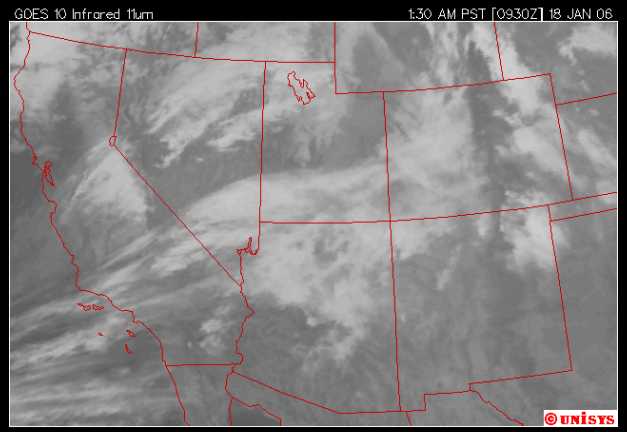
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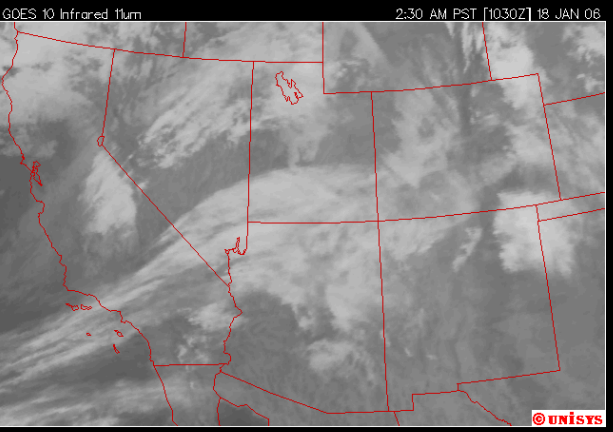
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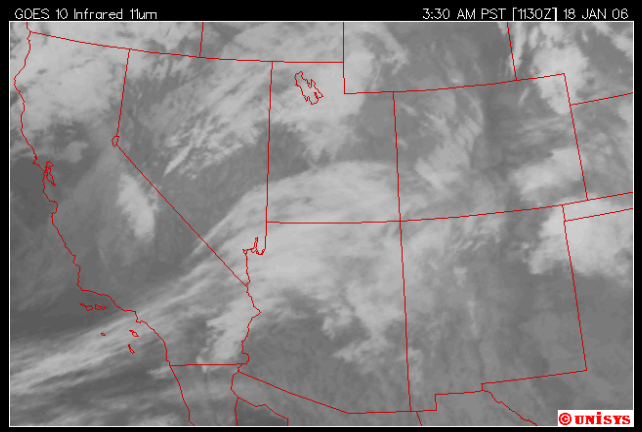
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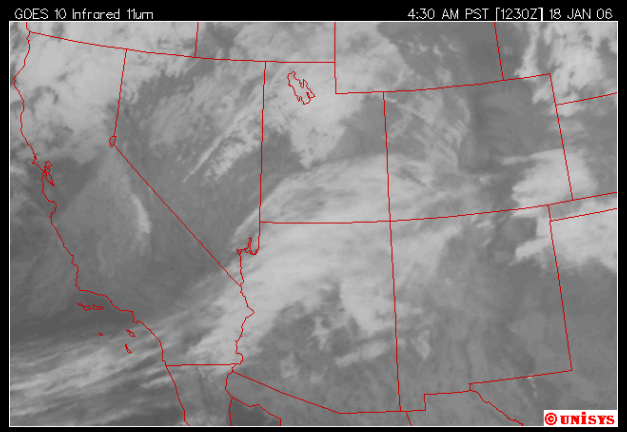
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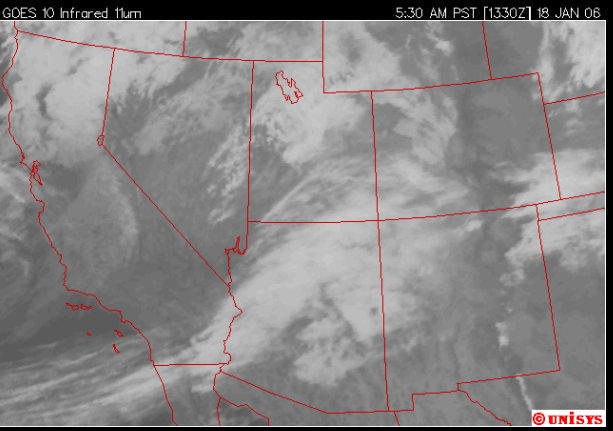
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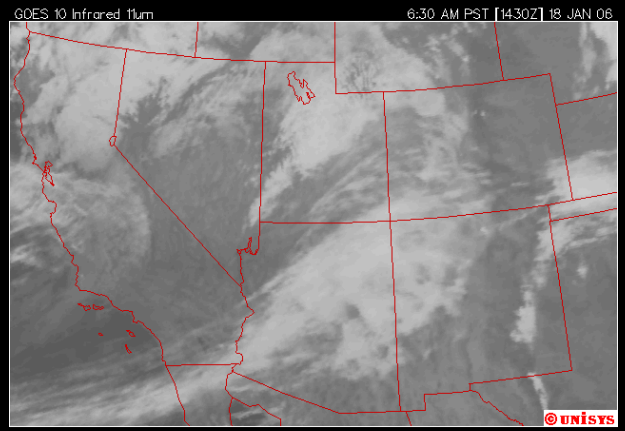
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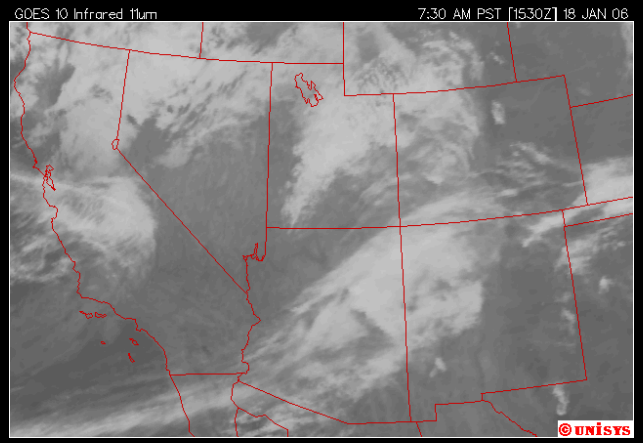
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UNISYS

CALIFORNIA DAIRY HERD IMPROVEMENT ASSOCIATION

Serving the Western United States

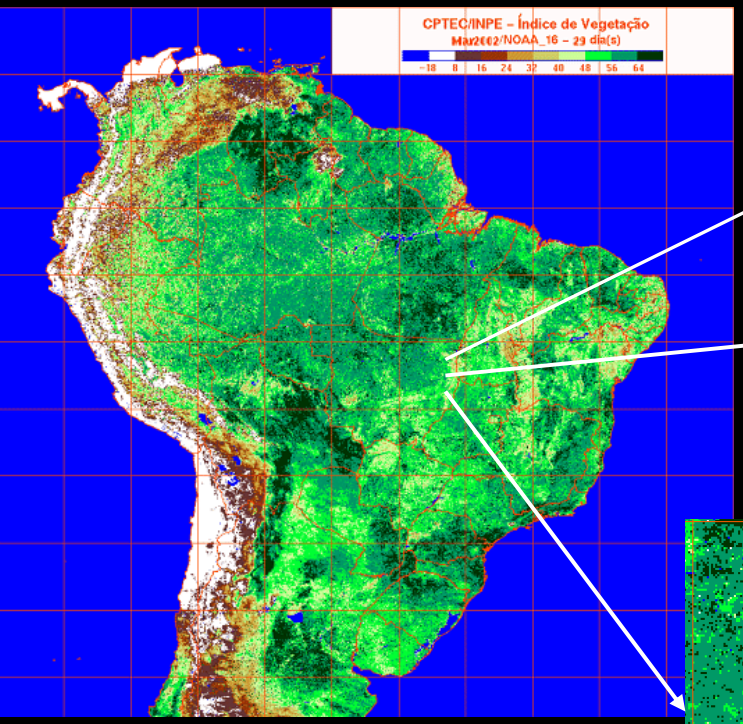
CALIFORNIA ALMONDS

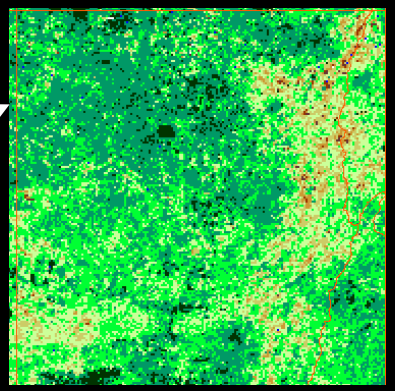
Current Remote Sensing Applications

- Assessing crop health
- Near real time information
- Crop management
- Acreage estimates

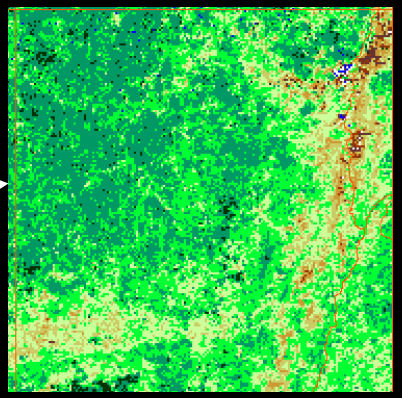
- Real time access/ESN
- ID specific bandwiths in EMS for clues to plant physiology by field
- Calibrate with specific weather events
- Predictive model development (production, yield, stress, disease)

Change Detection

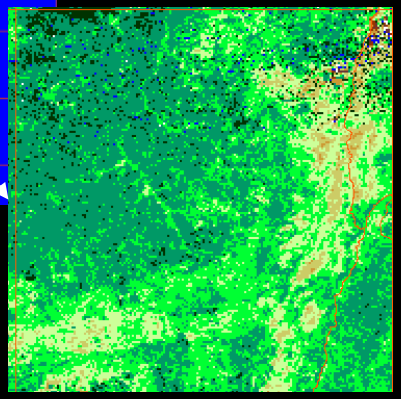




JAN2002



FEB2002



MAR2002

<u>Target Parameters:</u>

-Vegetation Health

-Soil & Tissue Moisture

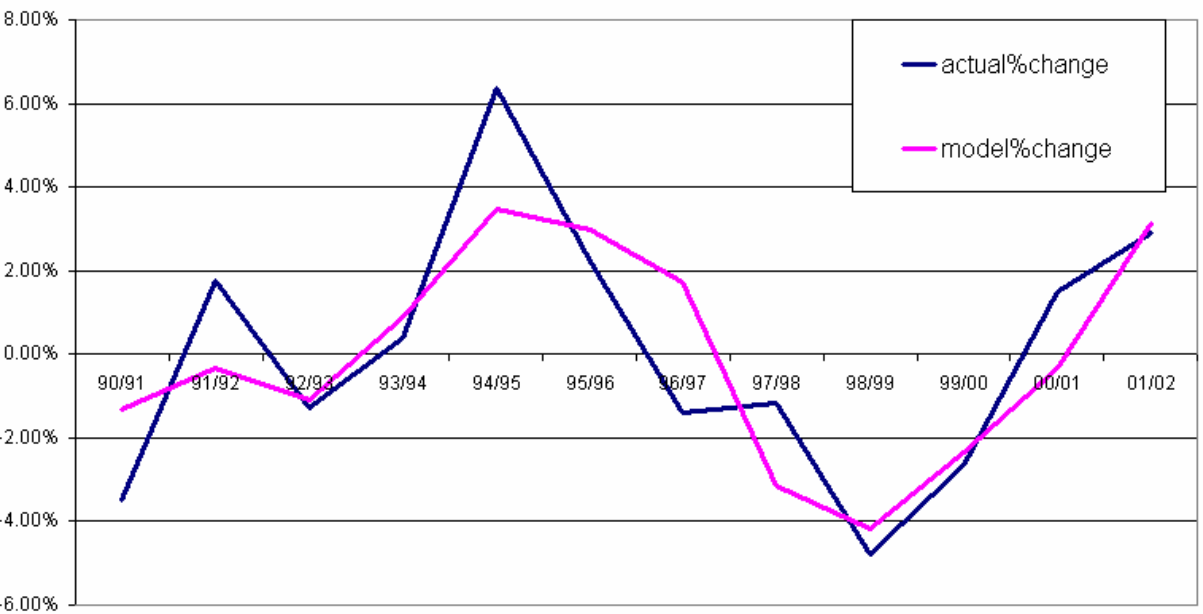
-Chlorophyll Production

NOAA/NCEP reanalysis data (currently back to 1948) combined with remotely sensed imagery allows us to build predictive models well before harvest

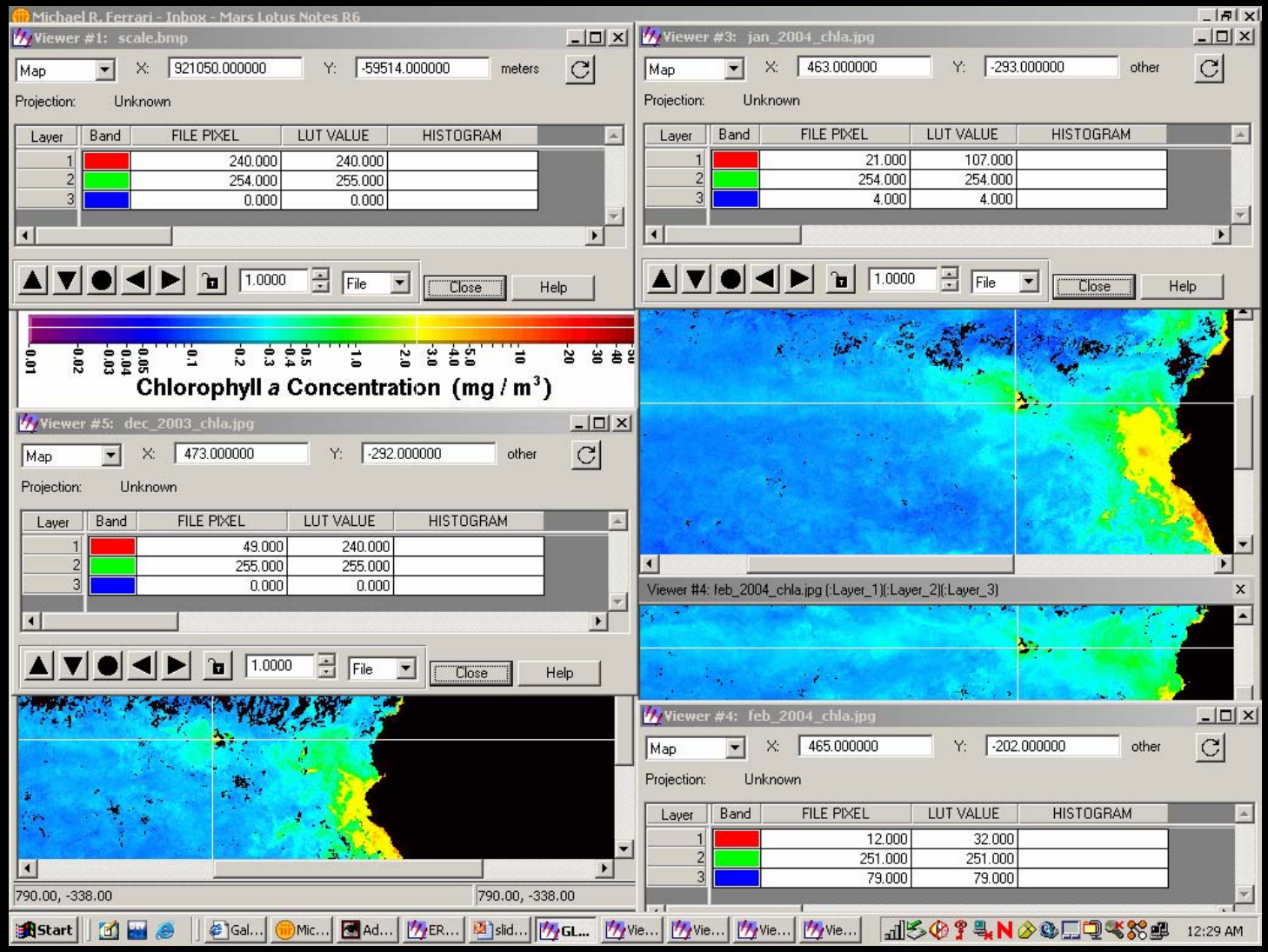
correlation matrix

700mbRelHum	*yield%diff*	SurfaceTemp	*yield%diff*	Precipitation	*yield%diff*	700mbGPH	*yield%diff*
yield%diff	1	yield%diff	1	yield%diff	1	yield%diff	1
700rh_jan1	0.09196191	SAT_jan1	0.183064784	Prec_jan1	0.019228334	700gph_jan1	-0.444470491
700rh_feb1	0.028966032	SAT_feb1	0.132132422	Prec_feb1	0.012445646	700gph_feb1	-0.228478849
700rh_mar1	0.405486387	SAT_mar1	0.014456995	Prec_mar1	-0.071581864	700gph_mar1	0.07288614
700rh_apr1	0.115446149	SAT_apr1	-0.136034798	Prec_apr1	0.627166995	700gph_apr1	-0.43677238
700rh_may1	0.605168668	SAT_may1	0.092430838	Prec_may1	0.594323651	700gph_may1	-0.177797832
700rh_jun1	0.102308732	SAT_jun1	-0.367872731	Prec_jun1	0.523415924	700gph_jun1	-0.128561849
700rh_jul1	0.24557623	SAT_jul1	0.267950753	Prec_jul1	0.126273006	700gph_jul1	0.255457888
700rh_aug1	-0.556526905	SAT_aug1	-0.126031932	Prec_aug1	0.080894835	700gph_aug1	-0.250041922
700rh_sep1	-0.229582081	SAT_sep1	0.052314717	Prec_sep1	-0.249824862	700gph_sep1	0.178562105
700rh_oct1	-0.23228421	SAT_oct1	0.034224994	Prec_oct1	0.16037813	700gph_oct1	0.147092878
700rh_nov1	-0.145472298	SAT_nov1	0.09519409	Prec_nov1	-0.018844849	700gph_nov1	-0.335396737
700rh_dec1	0.118189721	SAT_dec1	-0.37031473	Prec_dec1	0.246929801	700gph_dec1	-0.132786611
700rh_jan2	0.697565105	SAT_jan2	-0.455405408	Prec_jan2	0.735049784	700gph_jan2	0.047222808
700rh_feb2	0.154477406	SAT_feb2	-0.232438948	Prec_feb2	0.078381949	700gph_feb2	-0.254009616
700rh_mar2	0.370762867	SAT_mar2	-0.049761325	Prec_mar2	0.21904722	700gph_mar2	0.084259817
700rh_apr2	0.317617278	SAT_apr2	-0.345146132	Prec_apr2	0.580640998	700gph_apr2	-0.389159772
700rh_may2	0.217947475	SAT_may2	-0.498314857	Prec_may2	0.331338688	700gph_may2	0.384174022
700rh_jun2	-0.036646804	SAT_jun2	0.542980817	Prec_jun2	0.202804257	700gph_jun2	0.088844915
700rh_jul2	-0.080928111	SAT_jul2	0.428438293	Prec_jul2	-0.328388623	700gph_jul2	0.210145244
700rh_aug2	-0.282942998	SAT_aug2	0.516205892	Prec_aug2	0.325798538	700gph_aug2	0.443430209
700rh_sep2	0.201109002	SAT_sep2	0.025519981	Prec_sep2	0.471629867	700gph_sep2	-0.171396065
700rh_oct2	0.211982776	SAT_oct2	-0.109080124	Prec_oct2	0.285118222	700gph_oct2	0.17328439
700rh_nov2	-0.364913727	SAT_nov2	0.591309183	Prec_nov2	-0.308211748	700gph_nov2	0.453241019
700rh_dec2	-0.018121136	SAT_dec2	0.067923639	Prec_dec2	0.255295669	700gph_dec2	0.418543635

Modeled vs. Actual % change in Sugarcane Yields
Sao Paulo, Brazil

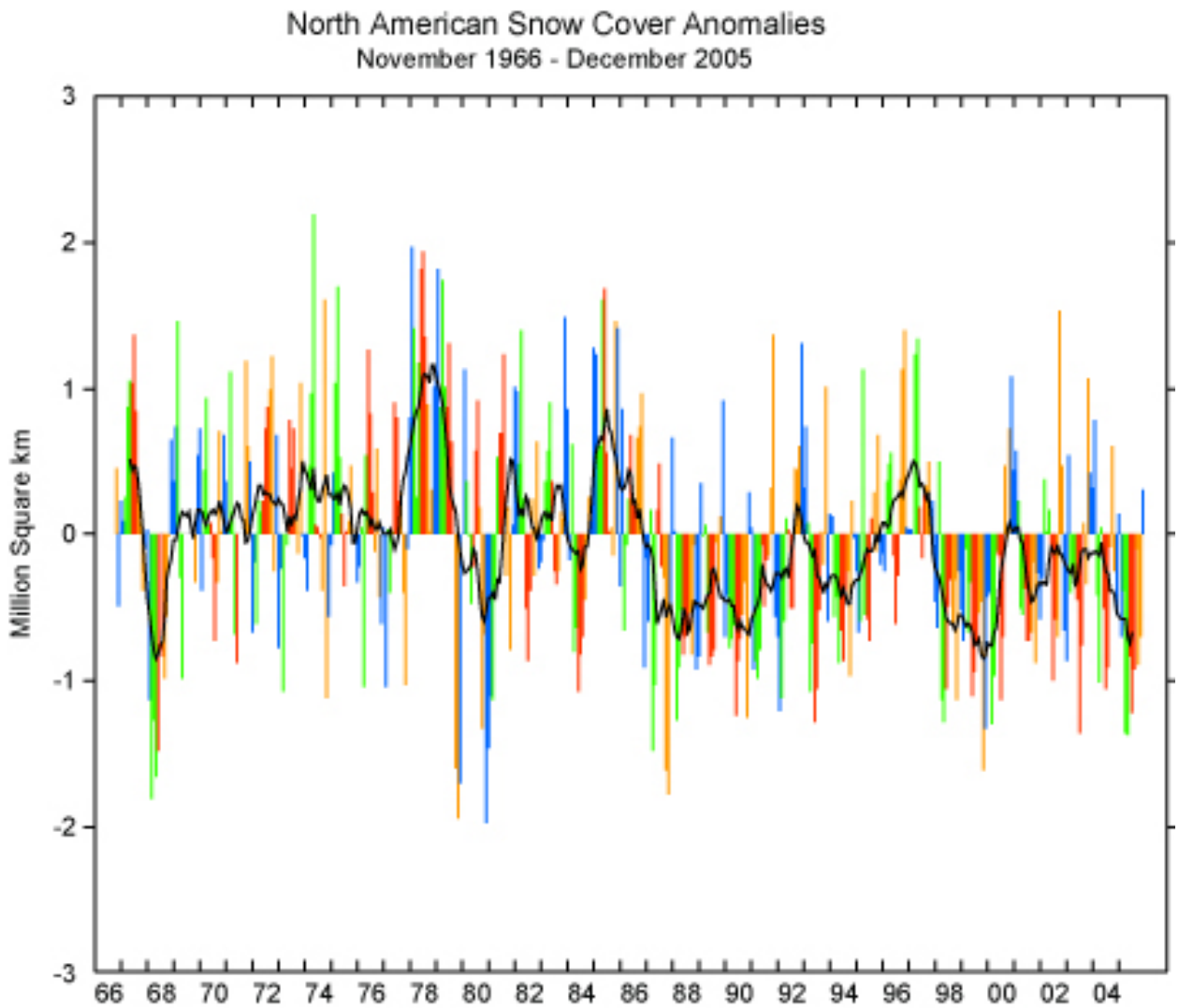


- Combining Atmospheric Indices and Remotely sensed data has also been useful in reconstructing past environmental conditions.
- Looking at events that can influence upwelling events and biological productivity.



Next step is to use arctic data for forecasting:

	A	B	C	D	E	F	G	H	I	J
1	B0102_102	B0102_123	B0102_138	B0102_142	B0102_164	B0102_190	B0102_195	B0102_197	B0102_278	B0102_298
2	B0102_329	B0102_356	B0102_363	B0102_367	B0102_394	B0102_401	B0102_410	B0102_422	B0102_482	B0405_123
3	B0405_142	B0405_164	B0405_190	B0405_195	B0405_197	B0405_200	B0405_207	B0405_210	B0405_320	B0405_356
4	B0405_367	B0405_394	B0405_401	B0405_410	B0405_422	B0405_427	B0405_435	B0405_438	B0708_138	B0708_164
5	B0708_195	B0708_197	B0708_200	B0708_207	B0708_210	B0708_219	B0708_226	B0708_236	B0708_363	B0708_394
6	B0708_410	B0708_422	B0708_427	B0708_435	B0708_438	B0708_441	B0708_449	B0708_453	B1011_190	B1011_197
7	B1011_207	B1011_210	B1011_219	B1011_226	B1011_236	B1011_240	B1011_271	B1011_278	B1011_401	B1011_422
8	B1011_435	B1011_438	B1011_441	B1011_449	B1011_453	B1011_463	B1011_480	B1011_482	P0102_N4	P0102_NP
9	P0102_QBO50	P0102_QBOPh	P0102_Sng100	P0102_SSP	P0102_TAH	P0102_TGL	P0102_TNH	P0102_TSH	P0405_N12	P0405_N34
10	P0405_NAO	P0405_NP	P0405_PDO	P0405_QBO50	P0405_QBOPh	P0405_Sng100	P0405_SSP	P0405_TAH	P0708_DAR	P0708_HuBay
11	P0708_N3	P0708_N34	P0708_N4	P0708_NAO	P0708_NP	P0708_PDO	P0708_QBO50	P0708_QBOPh	P0708_VSH	P1011_AO
12	P1011_EAJS	P1011_HuBay	P1011_N12	P1011_N3	P1011_N34	P1011_N4	P1011_NAO	P1011_NP	P1011_TSH	P1011_VNH
13	P13_AtlHur	P13_CO2	P13_EOF3	P13_IndiaMon	P13_LOD	P13_TripAtl	B0102_240	B0102_271	B0102_282	B0102_320
14	B0102_200	B0102_207	B0102_210	B0102_219	B0102_226	B0102_236	B0102_463	B0102_480	B0405_102	B0405_138
15	B0102_427	B0102_435	B0102_438	B0102_441	B0102_449	B0102_453	B0405_282	B0405_298	B0405_329	B0405_363
16	B0405_219	B0405_226	B0405_236	B0405_240	B0405_271	B0405_278	B0708_102	B0708_123	B0708_142	B0708_190
17	B0405_441	B0405_449	B0405_453	B0405_463	B0405_480	B0405_482	B0708_329	B0708_356	B0708_367	B0708_401
18	B0708_240	B0708_271	B0708_278	B0708_282	B0708_298	B0708_320	B1011_142	B1011_164	B1011_195	B1011_200
19	B0708_463	B0708_480	B0708_482	B1011_102	B1011_123	B1011_138	B1011_367	B1011_394	B1011_410	B1011_427
20	B1011_282	B1011_298	B1011_320	B1011_329	B1011_356	B1011_363	P0102_N3	P0102_N34	P0102_NAO	P0102_PDO
21	P0102_AMO	P0102_AO	P0102_DAR	P0102_EAJS	P0102_HuBay	P0102_N12	P0405_EAJS	P0405_HuBay	P0405_N3	P0405_N4
22	P0102_VGL	P0102_VNH	P0102_VSH	P0405_AMO	P0405_AO	P0405_DAR	P0708_AMO	P0708_AO	P0708_EAJS	P0708_N12
23	P0405_TGL	P0405_TNH	P0405_TSH	P0405_VGL	P0405_VNH	P0405_VSH	P0708_VGL	P0708_VNH	P1011_AMO	P1011_DAR
24	P0708_Sng10(	P0708_SSP	P0708_TAH	P0708_TGL	P0708_TNH	P0708_TSH	P1011_TGL	P1011_TNH	P1011_VGL	P1011_VSH
25	P1011_PDO	P1011_QBO50	P1011_QBOPh	P1011_Sng100	P1011_SSP	P1011_TAH				

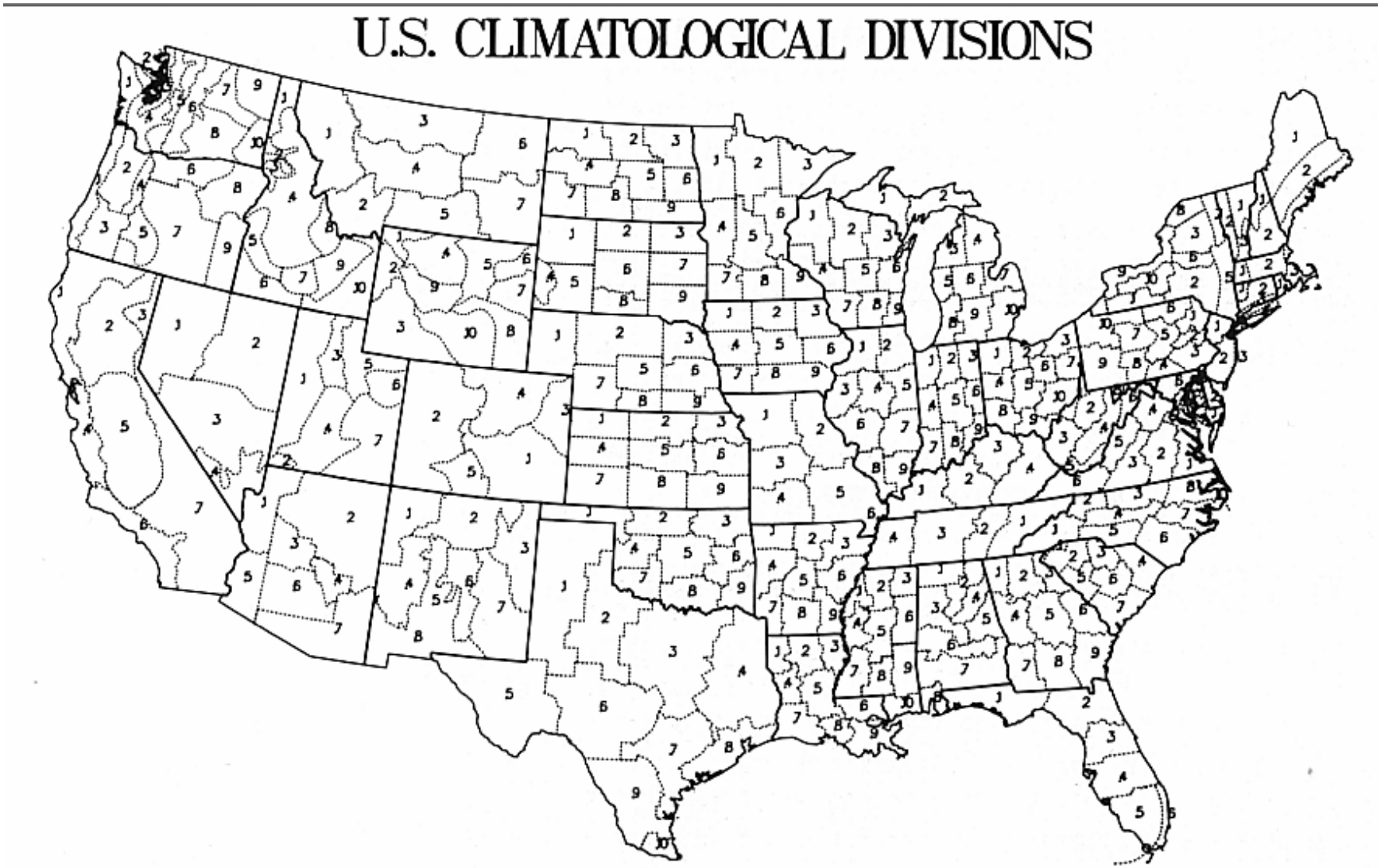


ENSO yr1: 76, 82, 86, 91, 97, 01, 04

Year	Month	Sea of Okhotsk	Bering Sea	Hudson Bay	Baffin Bay	Greenland Sea	Kara-Barents Seas	Arctic Ocean	Canadian Archipelago	Gulf of St. Lawrence	Total Arctic
1978	11	29286	27294	629880	605104	479065	1150872	6512461	692784	14374	10141121
1978	12	298019	132810	1119918	700244	650129	1543612	6774152	703136	21871	11943892
1979	1	1027555	169750	1156229	833113	803291	1767840	6794172	695364	70035	13317348
1979	2	1200843	339693	1177906	913949	817179	1882337	6840788	692975	129493	13995162
1979	3	1234545	401480	1141838	1022060	703605	1930684	6848256	695560	106650	14084679
1979	4	891127	263745	1101356	896202	669582	1986296	6919053	709357	33913	13470632
1979	5	243657	108517	1044710	782414	600983	1791648	6846466	712293	30857	12161545
1979	6	48091	20056	798670	579525	489661	1314242	6500616	690547	5878	10447285
1979	7	0	2300	223222	266103	293283	702796	5783796	533980	0	7805479
1979	8	0	0	62201	71335	163068	213001	5177533	501692	0	6188831
1979	9	0	4828	29234	46504	147985	78793	4966359	470239	0	5743942
1979	10	21893	9696	58601	113380	263764	471291	5766495	614141	1020	7320282
1979	11	50518	33632	329382	479210	368369	1025872	6492356	681595	12617	9473552
1979	12	298500	230103	958791	737668	463612	1410205	6865790	702596	24576	11691841
1980	1	702308	467973	1122486	863495	564101	1578879	6875732	701424	43033	12919433
1980	2	1054458	558230	1166224	950144	672234	1676858	6873780	702220	118322	13772470
1980	3	1079412	552823	1167835	1027346	663328	1666983	6892450	704292	108467	13862935
1980	4	940207	459540	1127613	975197	621080	1625438	6964097	710005	33534	13456711
1980	5	389609	194791	1018827	806228	531051	1457629	6896524	702786	25708	12023153
1980	6	83912	28368	756102	577254	457318	1211361	6366618	622544	7436	10110914
1980	7	0	2556	199467	297407	329489	759849	5561605	498908	0	7649283
1980	8	0	0	53187	60084	225839	379836	5037433	315434	0	6071812
1980	9	0	3278	18887	34358	235452	282293	5099290	351041	0	6024599
1980	10	16852	9417	38284	126908	362144	578739	5929496	562174	1251	7625266
1980	11	36477	45141	299140	410930	520380	1248120	6577222	680818	13020	9831247
1980	12	128204	260479	1025461	683057	651884	1554675	6795974	698451	28173	11826358
1981	1	447031	464664	1148118	920665	716375	1562961	6845183	694813	90159	12889968
1981	2	863378	511111	1144273	1014678	698312	1581966	6853546	693692	100531	13461486
1981	3	945485	503022	1110569	942756	692574	1779764	6897159	704948	32159	13608434
1981	4	585939	338402	1151026	958339	644162	1870627	6932921	704629	23832	13209876

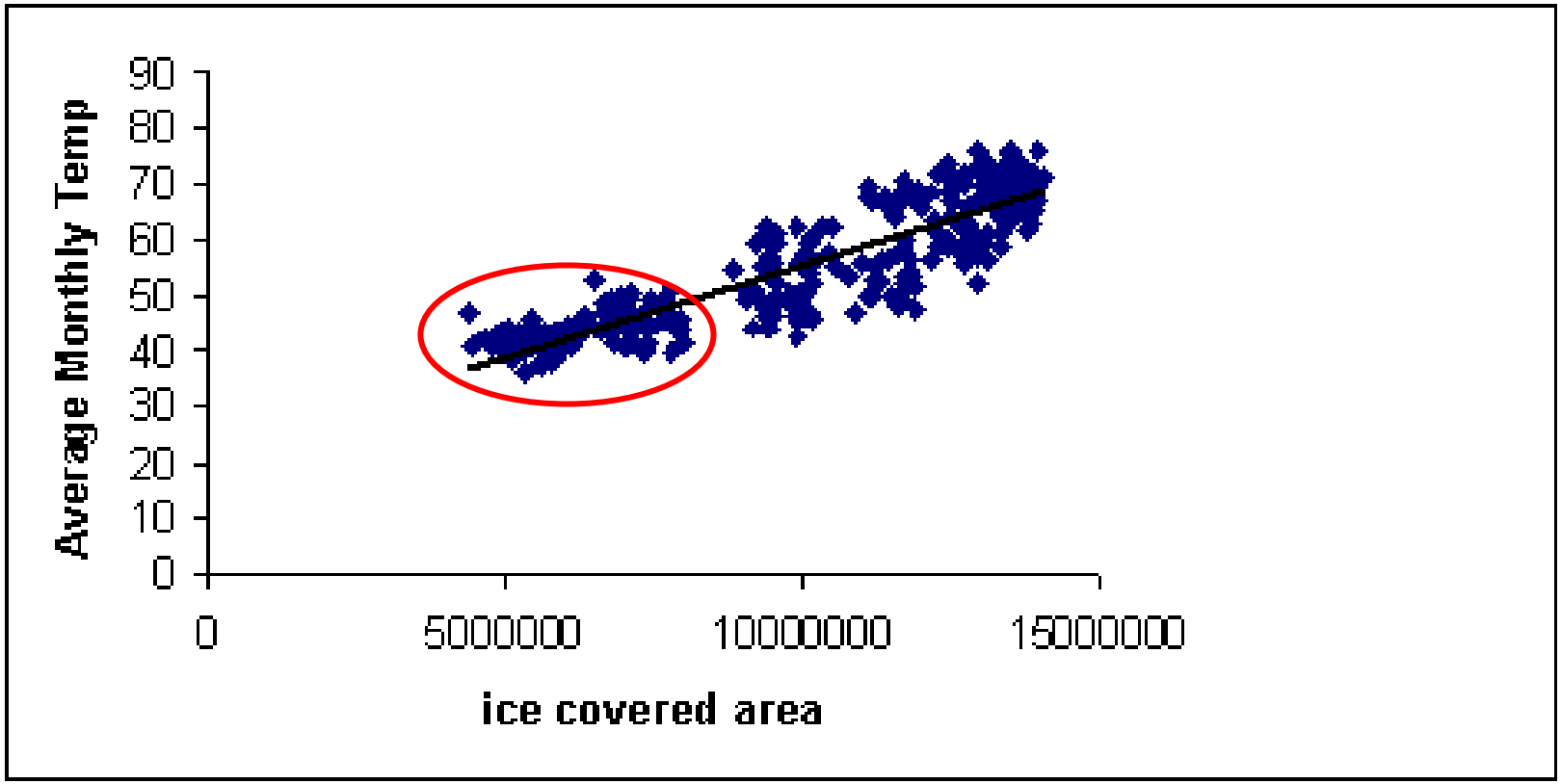
all_daily / Chart2 / Sheet1 / **all_monthly** / HB_daily / Chart1 / HB_monthly

source: NSIDC



Using California as an example, the focus in on the Sacramento and SJ Valleys through Climate Divisional data (CA_div2&5)

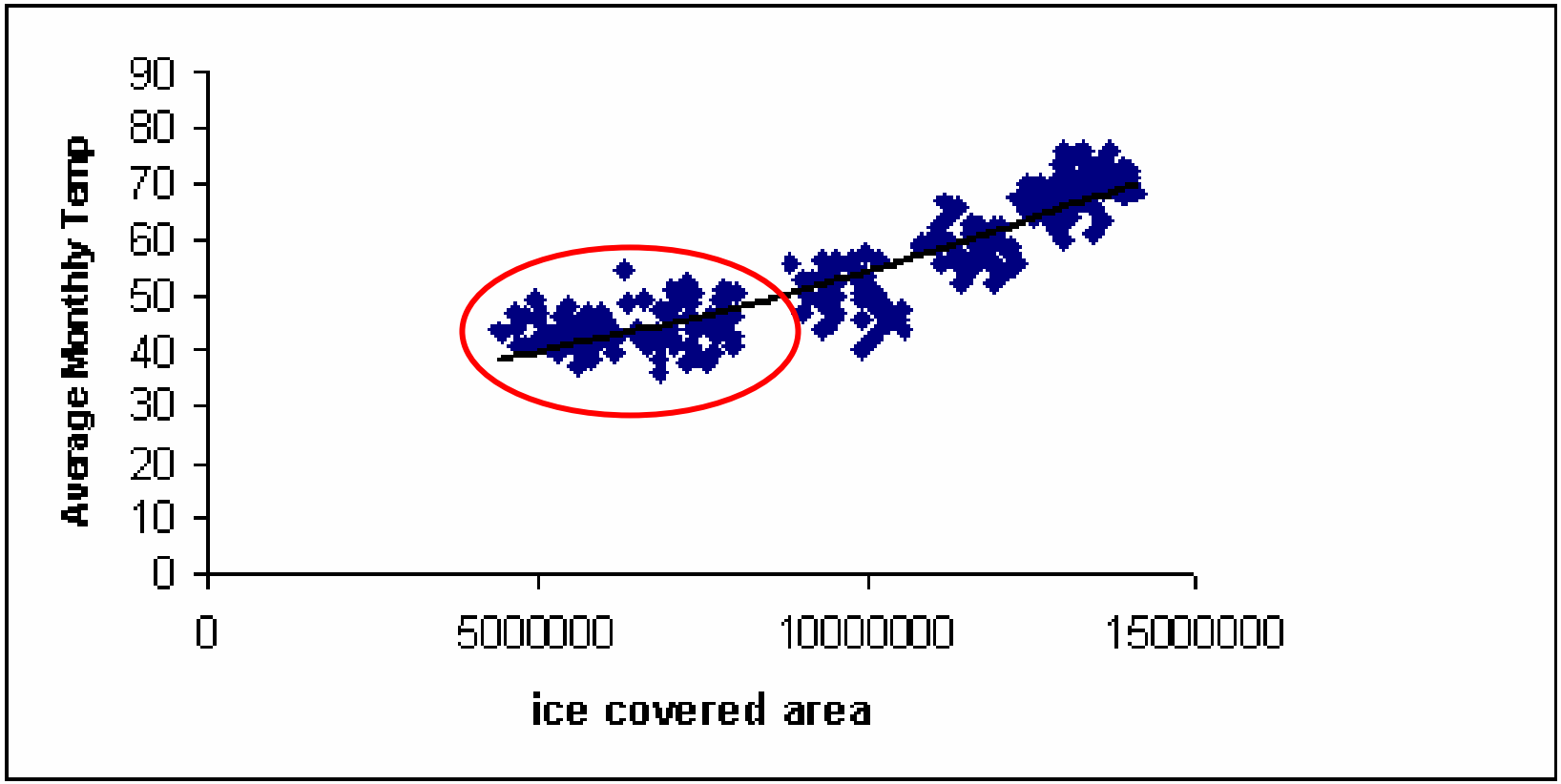
Total Arctic Ice - CA Monthly Temperature (4 month lag)



R^2: 0.79

This relationship would be expected in northeastern US (Hudson Bay/AO dipole with NE temps), but the relationship in CA is surprising.

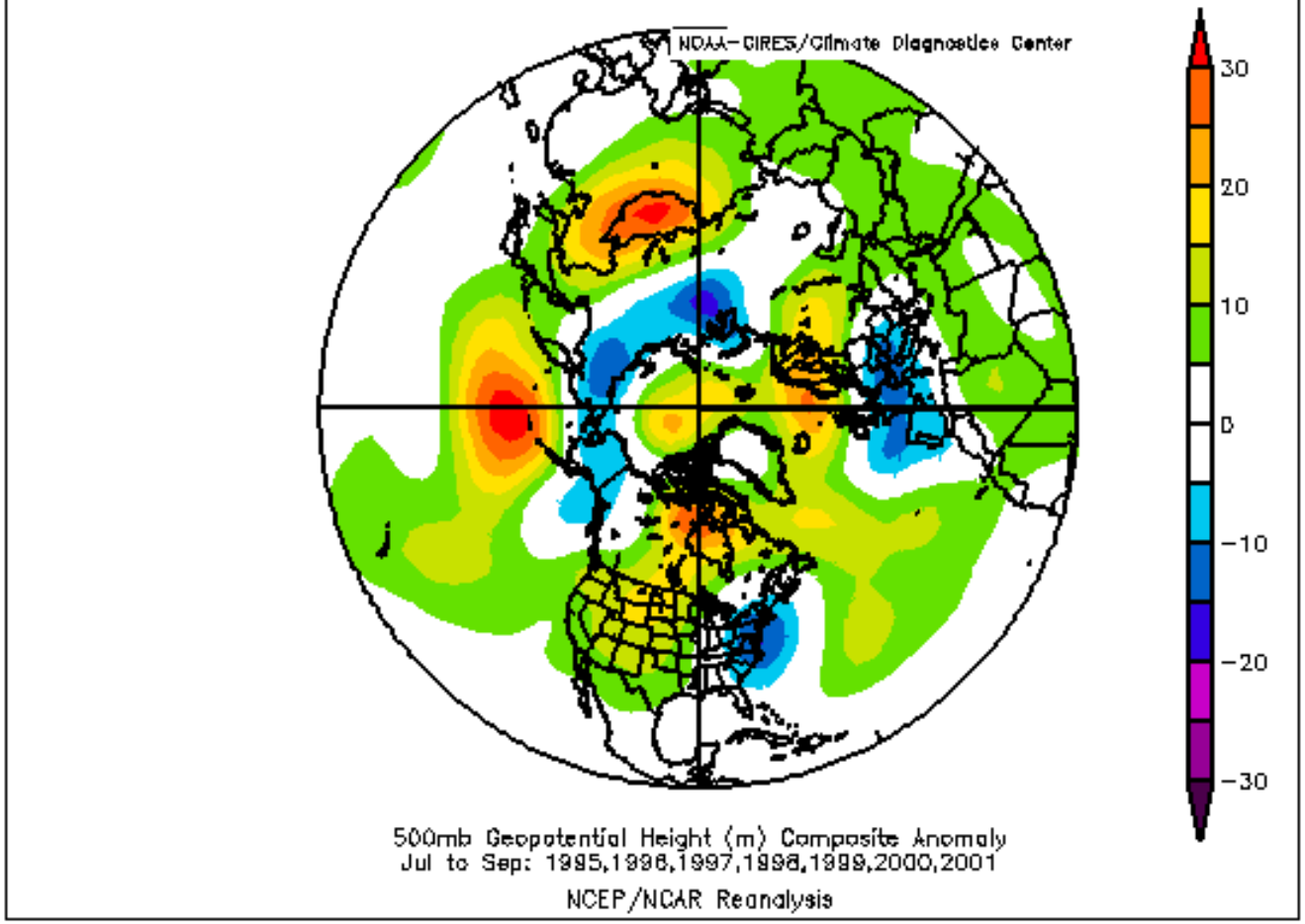
Total Arctic Ice - CA Monthly Temperature (5 month lag)



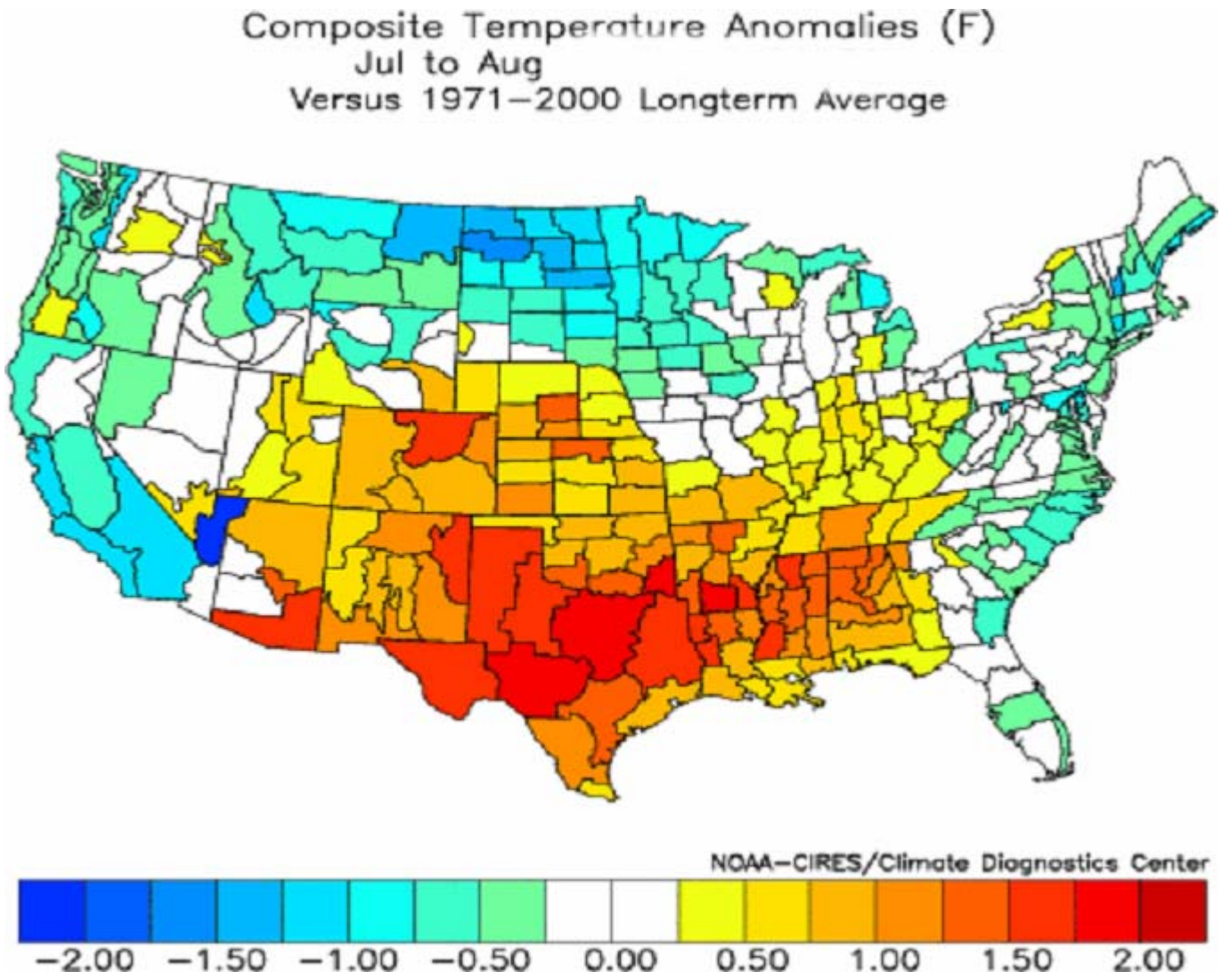
R^2: 0.89

This relationship would be expected in northeastern US (Hudson Bay/AO dipole with NE temps), but the relationship in CA is surprising.

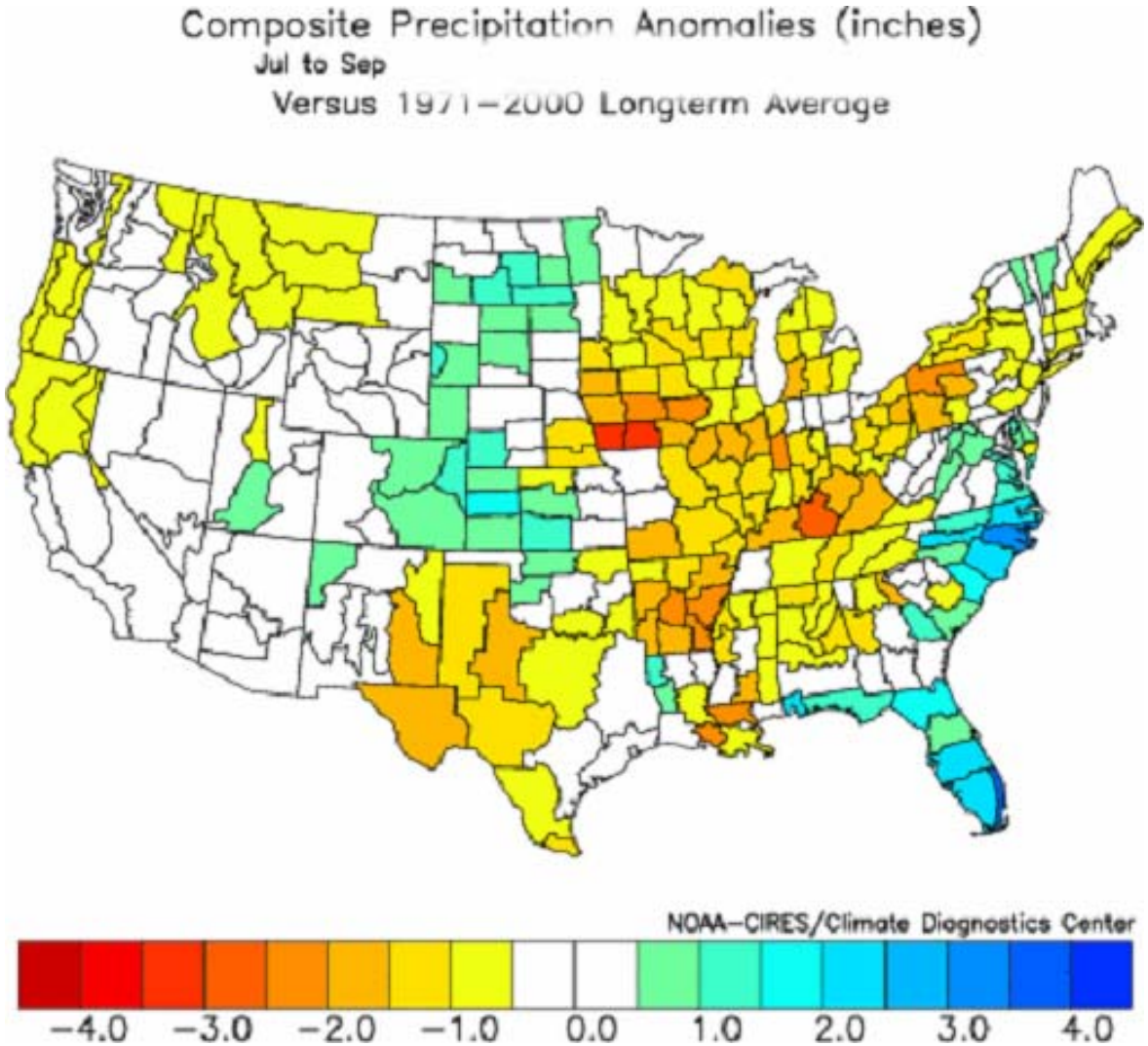
Upper air pattern 1995-2001



Summer Temperatures 1996-2003



Summer Rainfall 1996-2003



Summary/Future Research

- Winter Ice Cover does demonstrate a relationship with summer temperatures in CA. Lower Ice cover tends to correlate with stronger gph - A dipole exists between strong high pressure over the arctic and very strong high pressure in summer over TX.
- Monthly comparisons do not provide a great deal of information when trying to forecast seasonal conditions
- However, when we look at current arctic conditions, they appear to be a useful precursor for early identification of extreme conditions in CA.
- Same types of analyses need to be done with all data sources (beyond Arctic Ice & HB ice)
- Use specific station level data in stead of Climate Divisional data.
- Other applications beyond agriculture - property risk, energy demand, food security.

gsl
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- National Environmental Satellite Data and Information Service
- NASA/NOAA/USGS