Importance of Winds and Soil Moistures to the U.S. Summertime Drought of 1988: A GCM Simulation Study

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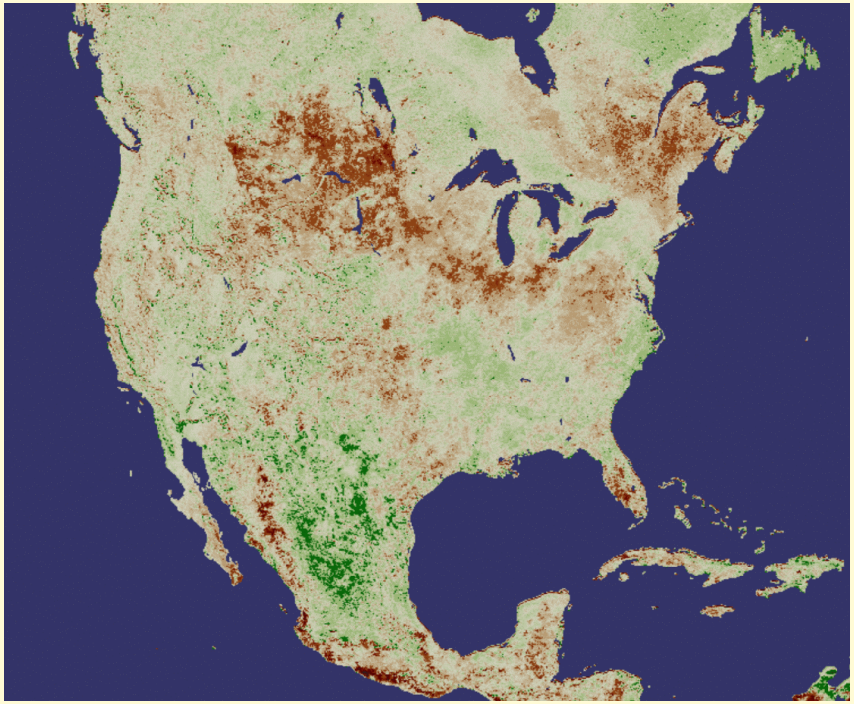
Agenda

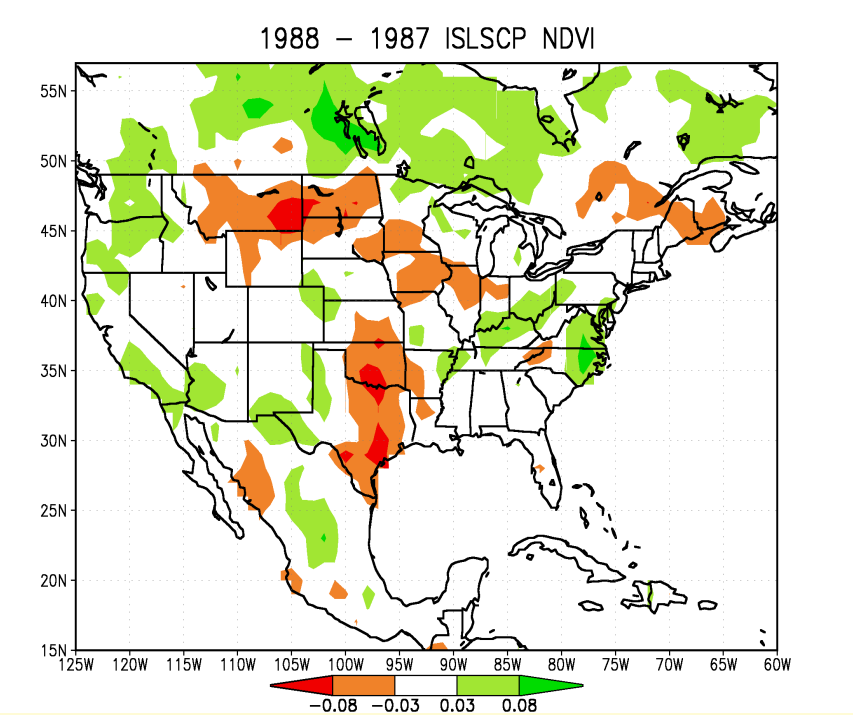
- Recent major North American Droughts
- Genesis of Drought of 1988
- Experiment Design
  - Effect of Winds & Soil Moisture Assimilation
  - Effect of Large-scale circulation on the region
  - Effect of ISLSCP Vegetation Local Feedback
- Conclusions

1988 NDVI Anomaly



August 1988 NDVI Anomaly

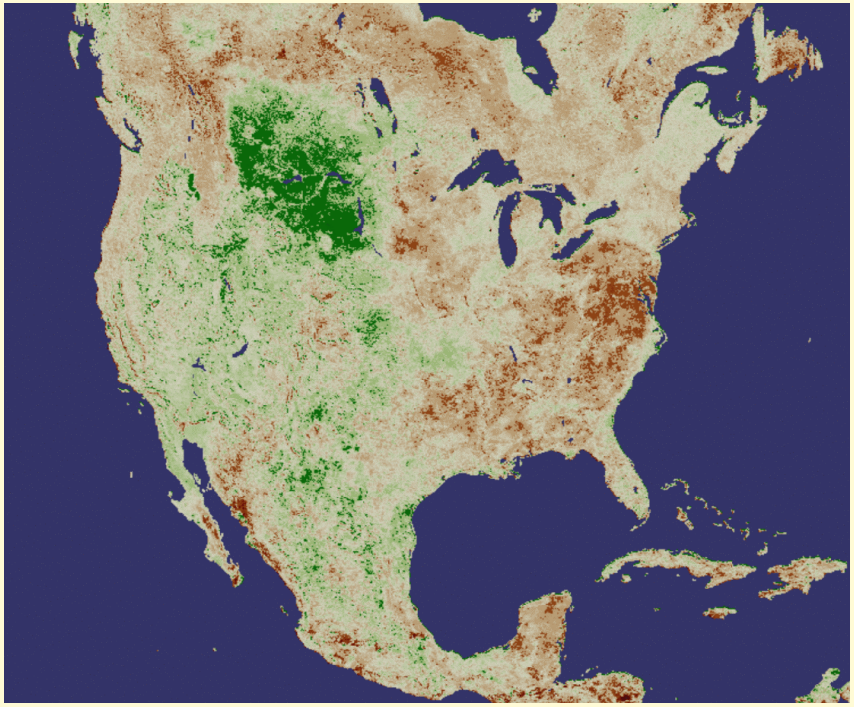
Source: NASA/GSFC Scientific Visualization Studio



August 1988 - 1987 NDVI at 1x1

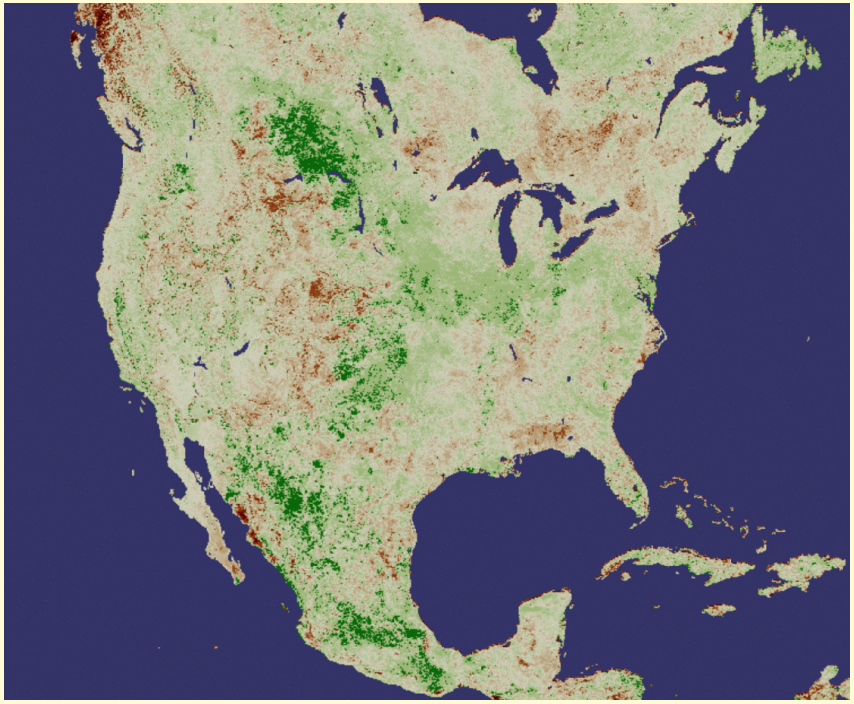
Source: ISLSCP Initiative I CD-ROM Dataset

Other recent U.S. Droughts



August 1993 NDVI Anomaly

Source: NASA/GSFC Scientific Visualization Studio

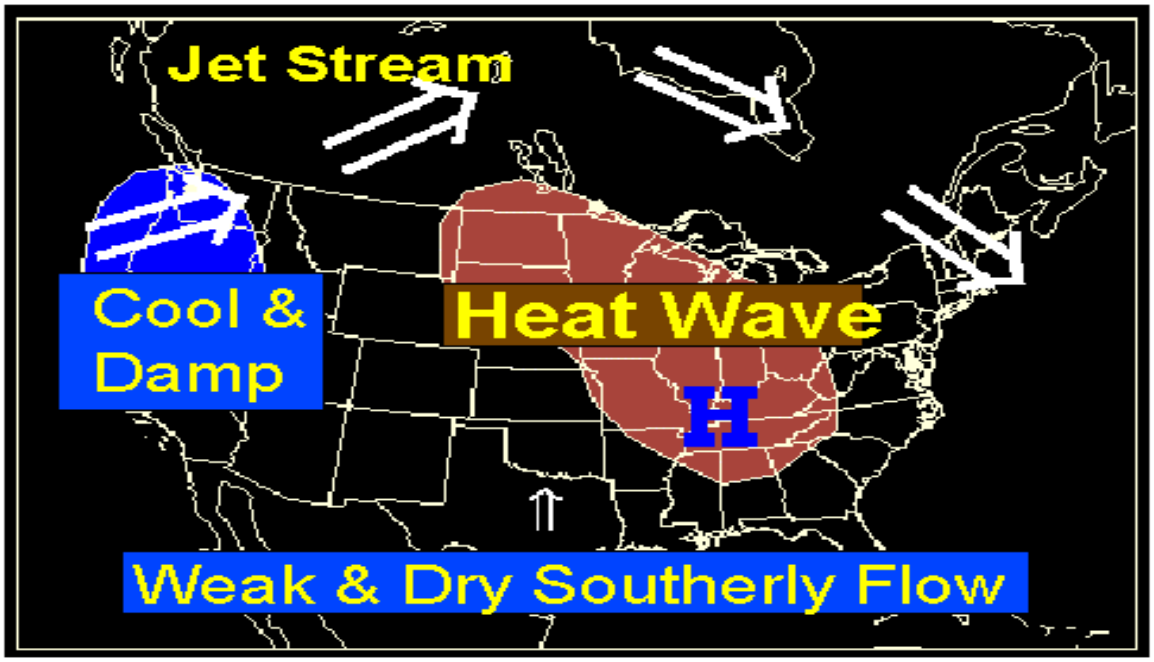


July 2000 NDVI Anomaly

Source: NASA/GSFC Scientific Visualization Studio

1988 U.S. Drought

Experiment 1a - 1988 Drought



Adapted from CAC, NWS, NOAA

Features of 1988 U.S. Drought

- Record-low precipitation in central Plains
  - 50-85% below normal in Midwest, Northern Plains, and Rockies
- Record-high surface temperatures
- Very dry soils & widespread forest fires
  - 4,100,000 acres burned by mid-autumn
- Record-low Mississippi River streamflow
  - Vicksburg MS had ~40% of normal flow in June 1988
- Massive crop and vegetation losses
- Total estimated damages: $40 billion

Factors of 1988 U.S. Drought

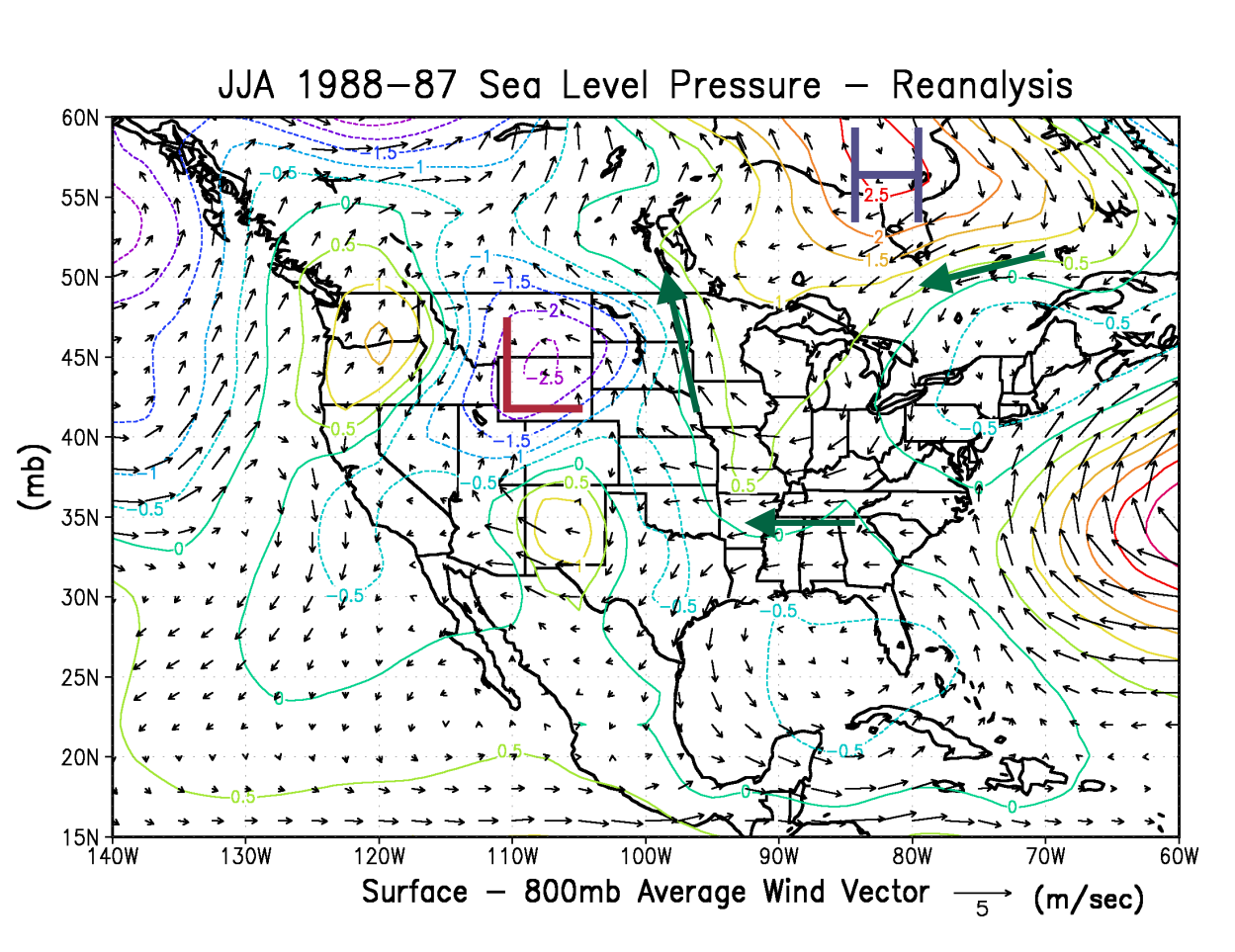
- Low-level jet as source for Gulf moisture greatly reduced
- Persistent high pressure in Canada and upper-ridge over central U.S.
- Winter 1988 had strong La Niña SSTs
- Below normal snowfalls in Northern Plains, Northwest, and Rockies
- Reduced spring rain also led to dry soils

JJA 1988-87 SLP & Winds

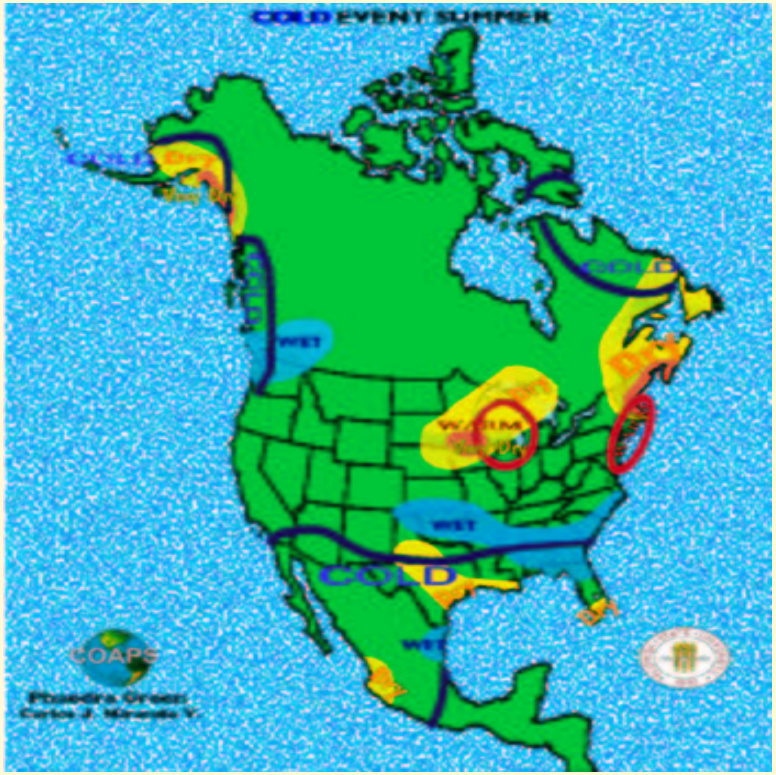
Higher pressure in 1988 over Canada/Lakes

Lower pressure over Northern Rockies

Moisture from Gulf of Mexico reduced via low-level jet

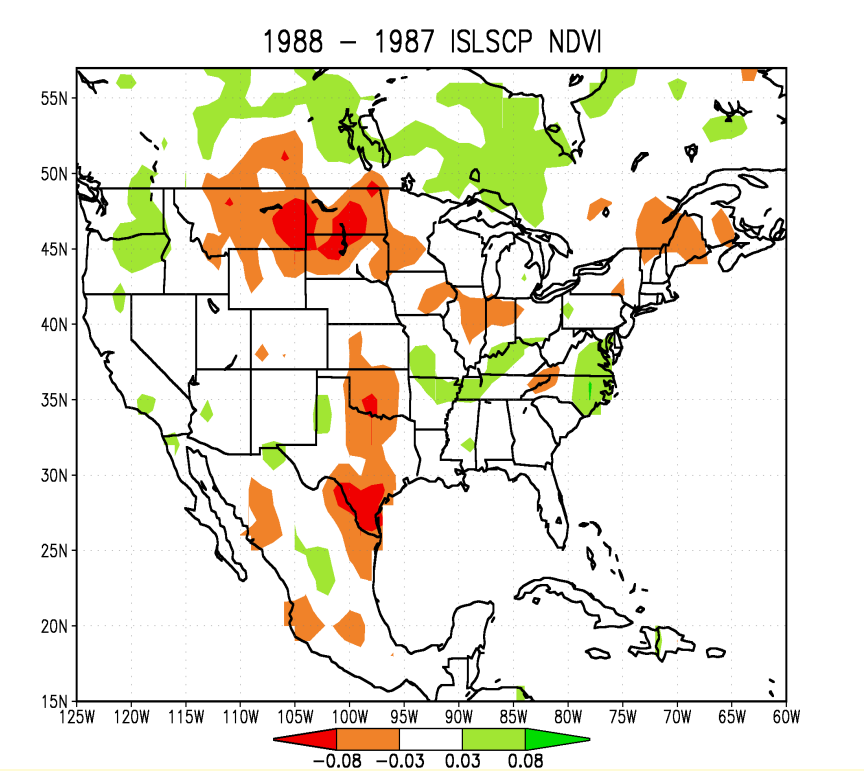


1988 Drought and La Niña



Cold Event Summer Pattern

Source: COAPS/Florida State Univ.



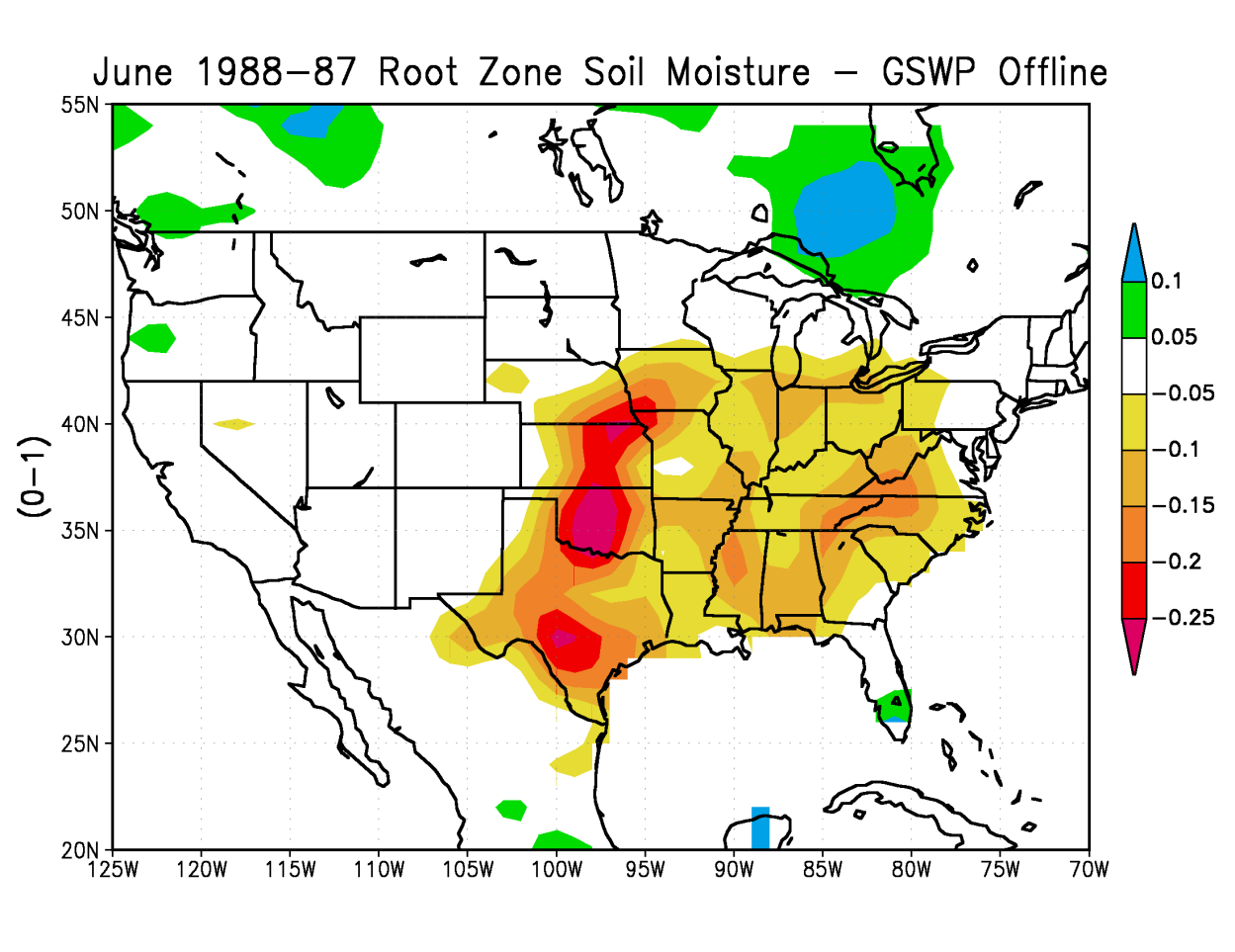
JJA 1988 - 1987 NDVI at 1x1

Source: ISLSCP Initiative I

June 1988-87 Soil Moisture

Reduced Soil Moisture in central to southern Plains

Soil Moisture anomaly moved northward into July & August



Previous Modeling Studies

a) GEOS-2 Climate GCM

- Mocko and Sud (1999) did not realistically simulate the 1988 drought despite upgrades to the land-surface model & its snow-physics scheme.

b) Other Goddard GCMs

- Atlas et al. (1993) showed importance of SST and soil moisture data in GLA simulations.

Previous Modeling Studies

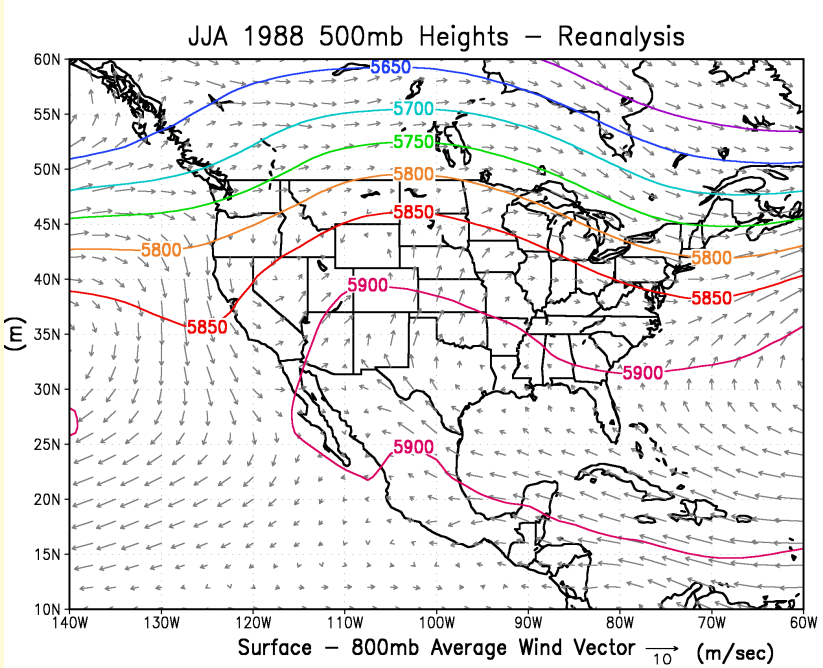
c) Other GCMs

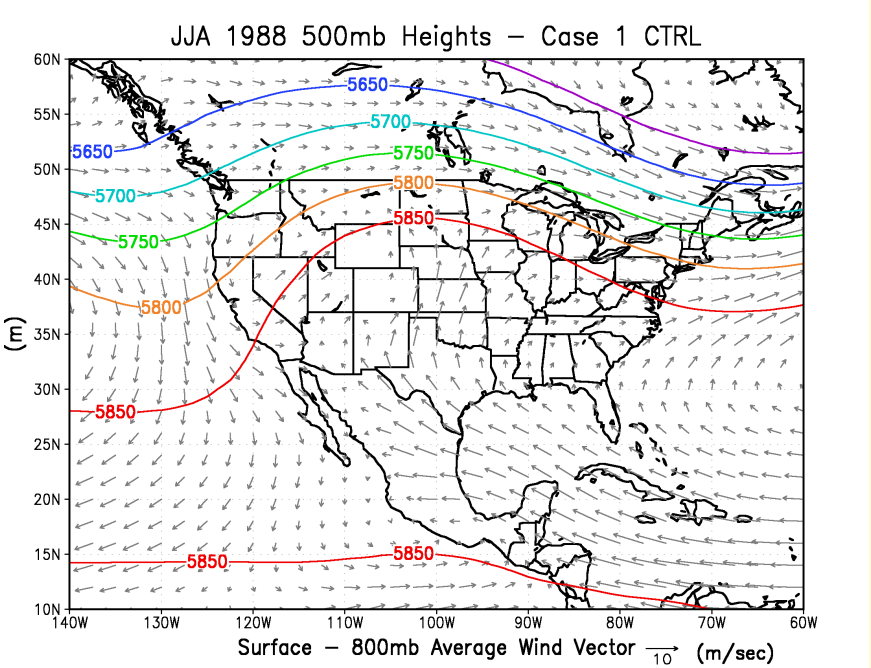
i. Dirmeyer (2000) showed in the COLA GCM that assimilating soil moisture improved the 1987/88 precipitation/temperature simulation.

ii. Pal and Eltahir (2001) found the sensitivity of precipitation to ISM was dependent on the convective parameterization.

iii. Giorgi et al. (1996) showed in the GENESIS model that the misplaced ridge led to a failure to capture the drought event of 1988.

JJA 1988 500mb Pattern

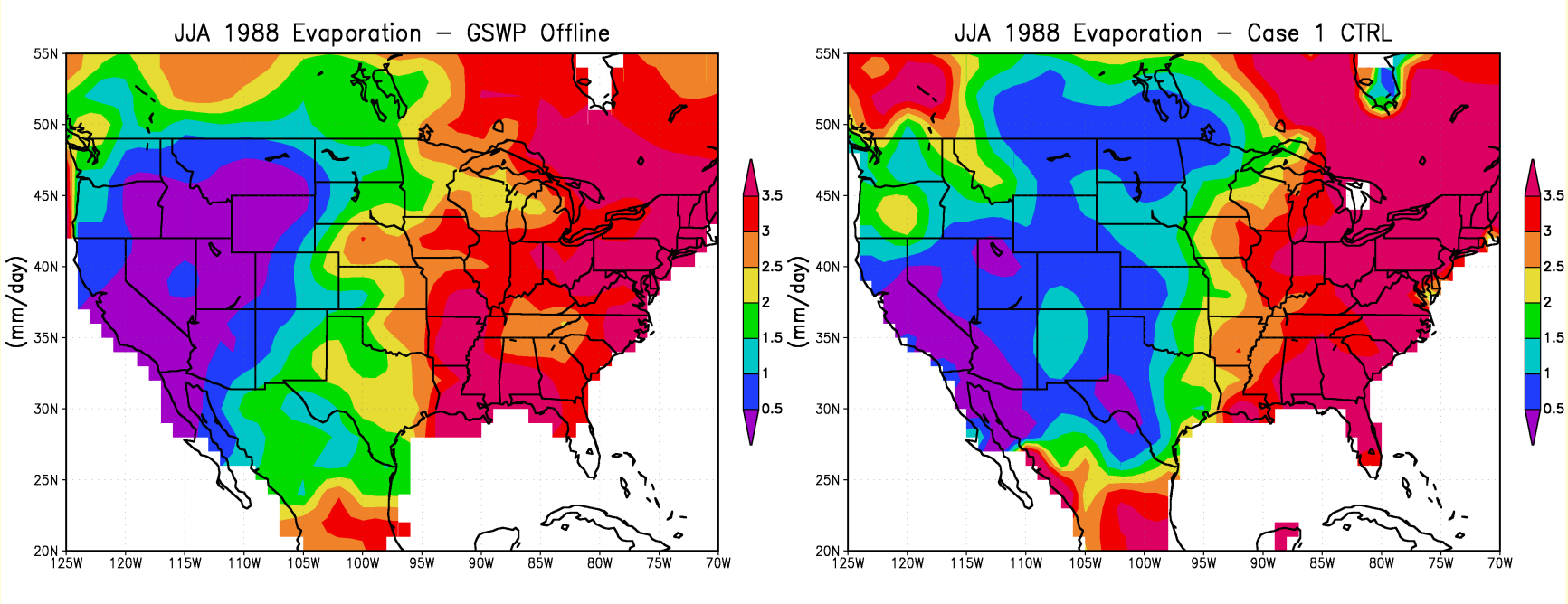




DAO Reanalysis

GEOS-2 GCM

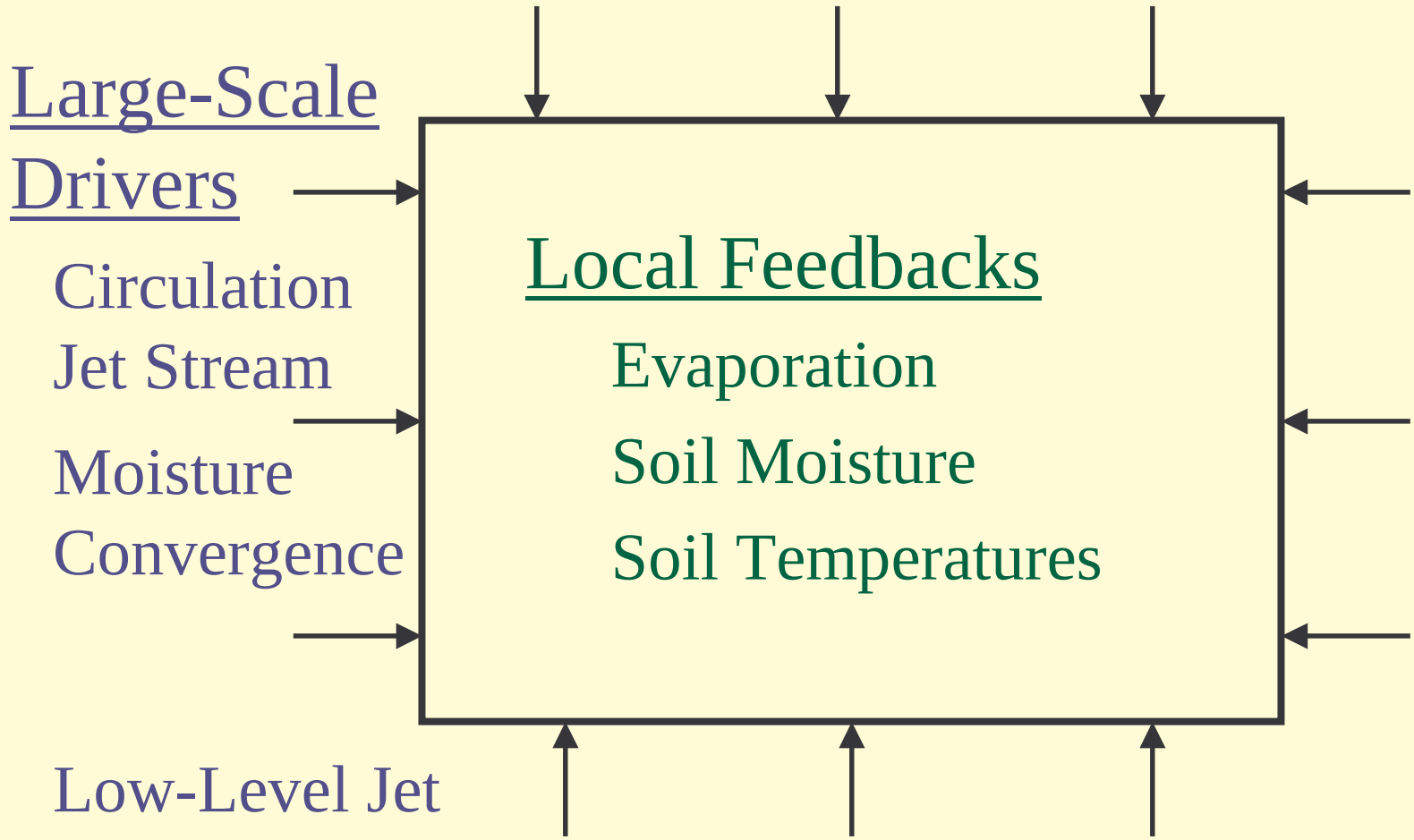
JJA 1988 Evaporation



GSWP Offline

GEOS-2 GCM

Large-Scale Drivers vs. Local Feedbacks

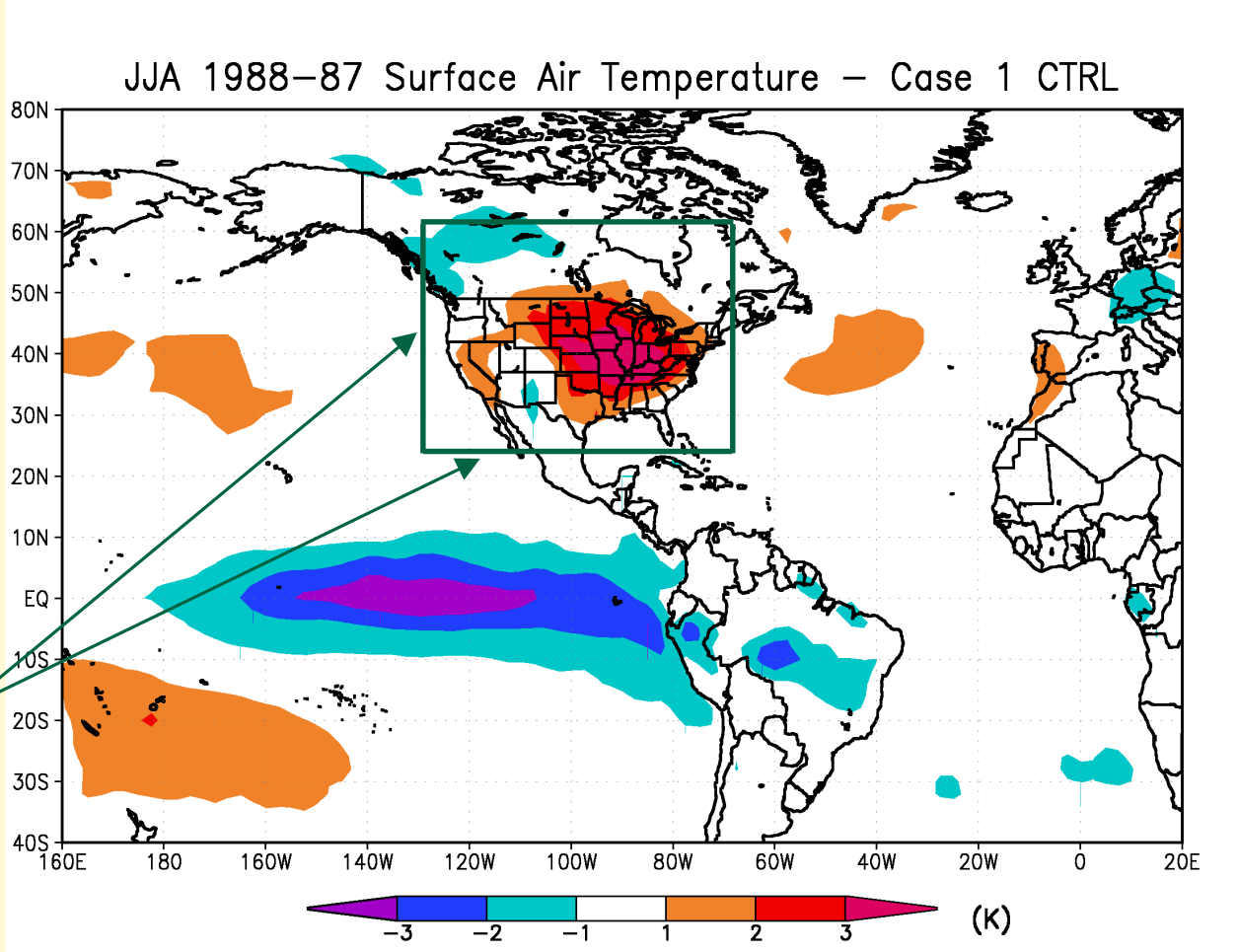


Large-Scale vs. Local Region

1988-87 Surface air temperature for JJA

Winds & Soil moisture within this “box” are free-running

Extent of “box”:
23 - 61 North
129- 66 West



Back to Basics

- Assimilate the circulation
  - Simulate correct jet stream
  - Simulate correct low-level jet
- Assimilate the soil moisture
  - Simulate correct evaporation
  - Simulate correct surface temperatures
- Assimilate circulation and soil moisture
- Assimilate large-scale only (outside “box”)
- Assimilate large-scale with improved vegetation

Summary

1. Several features must be simulated correctly to get a useful drought simulation:
   - Location of high/low pressures
   - Jet stream and low-level jet
   - Soil moisture and evaporation
2. Small modeling errors often combine to produce biases in the circulation:
   - Past history of rainfall
   - Vegetation & soil characteristics
   - Large-Scale circulation

Experiment Design

Case Number	Description
Case 1 CTRL	Control – Free-running GCM
Case 2 WIND	Winds replaced every 6 hours
Case 3 SOIL	Soil Moisture replaced daily
Case 4 BOTH	Both winds & soil moisture replaced
Case 5 LBOX	W/SM on large-scale only replaced
Case 6 VEGI	As Case 5, w/ ISLSCP vegetation

Experiment Design - CTRL

- GEOS-2 GCM 2x2.5 with 20 sigma layers
- Land-surface Model: HY-SSiB
- Moist Convection: McRAS
- Simulations from 1 Jan to 31 Aug
- 1987 and 1988 run separately
- Four members in each ensemble
- Ensemble members vary by initial atmospheric fields

Experiment Design – WIND/SOIL/BOTH

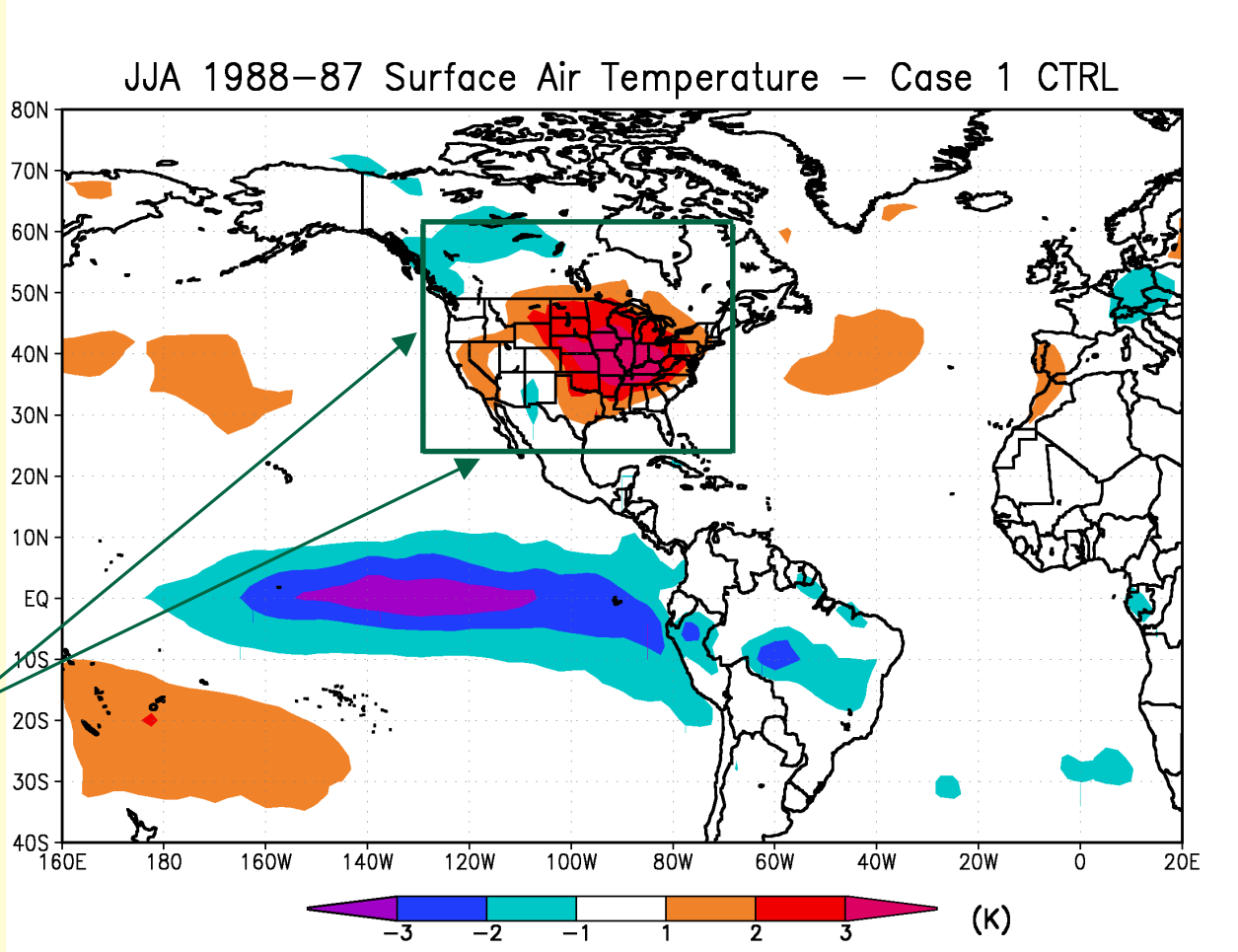
- WIND:
  - Wind values (U & V) replaced globally from DAO reanalysis with GEOS-2 GCM
  - Values replaced every 6 hours
  - Values replaced at all points and 20 sigma levels
- SOIL:
  - Soil Moisture (wetness at 3 layers) replaced globally from GSWP-style reanalysis with offline HY-SSiB integration for 1987/88 using ISLSCP Initiative I near-surface forcing
  - Values replaced daily

Experiment Design – LBOX

Winds inside the box are free-running

Soil moistures over land points also free-running

Extent of "box":
23 - 61 North
129- 66 West



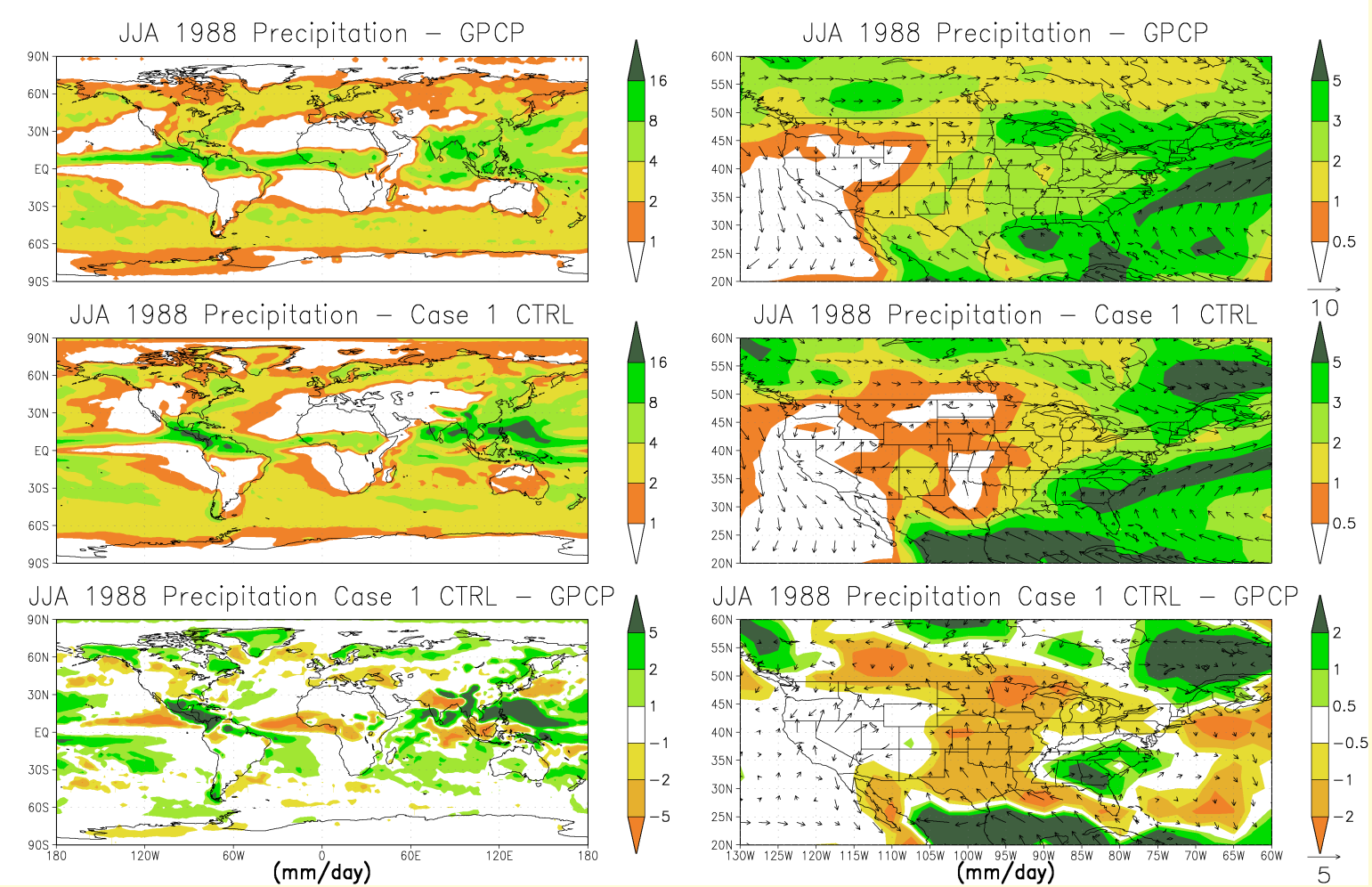
Experiment Design – VEGI

Same as LBOX, **EXCEPT**:

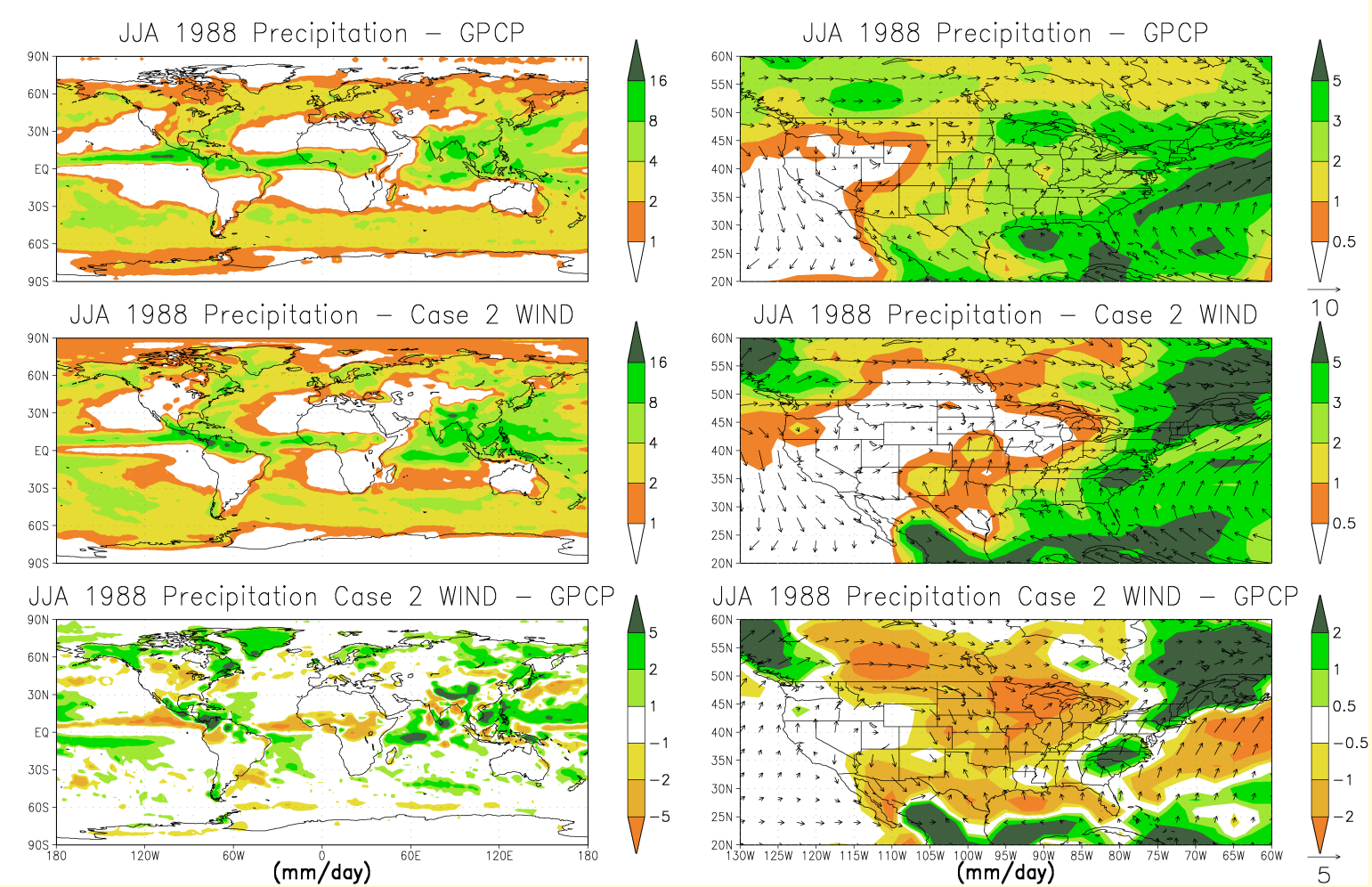
- VEGI – GCM climatological values of:
  - Vegetation Cover Fraction
  - Greenness
  - Leaf Area Index
  - Surface Albedo

  replaced using correct year's ISLSCP data

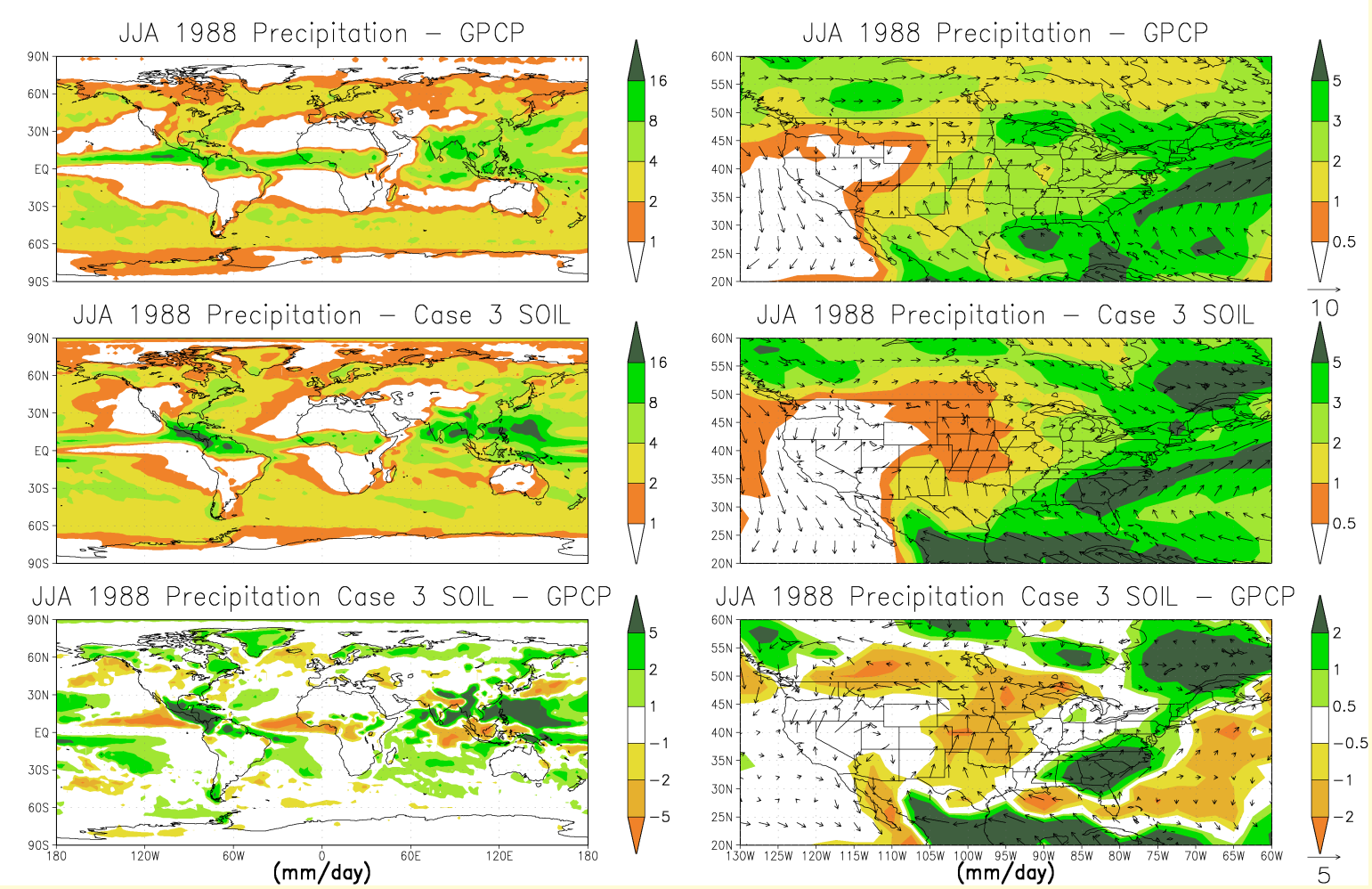
JJA 1988 Precipitation - CTRL



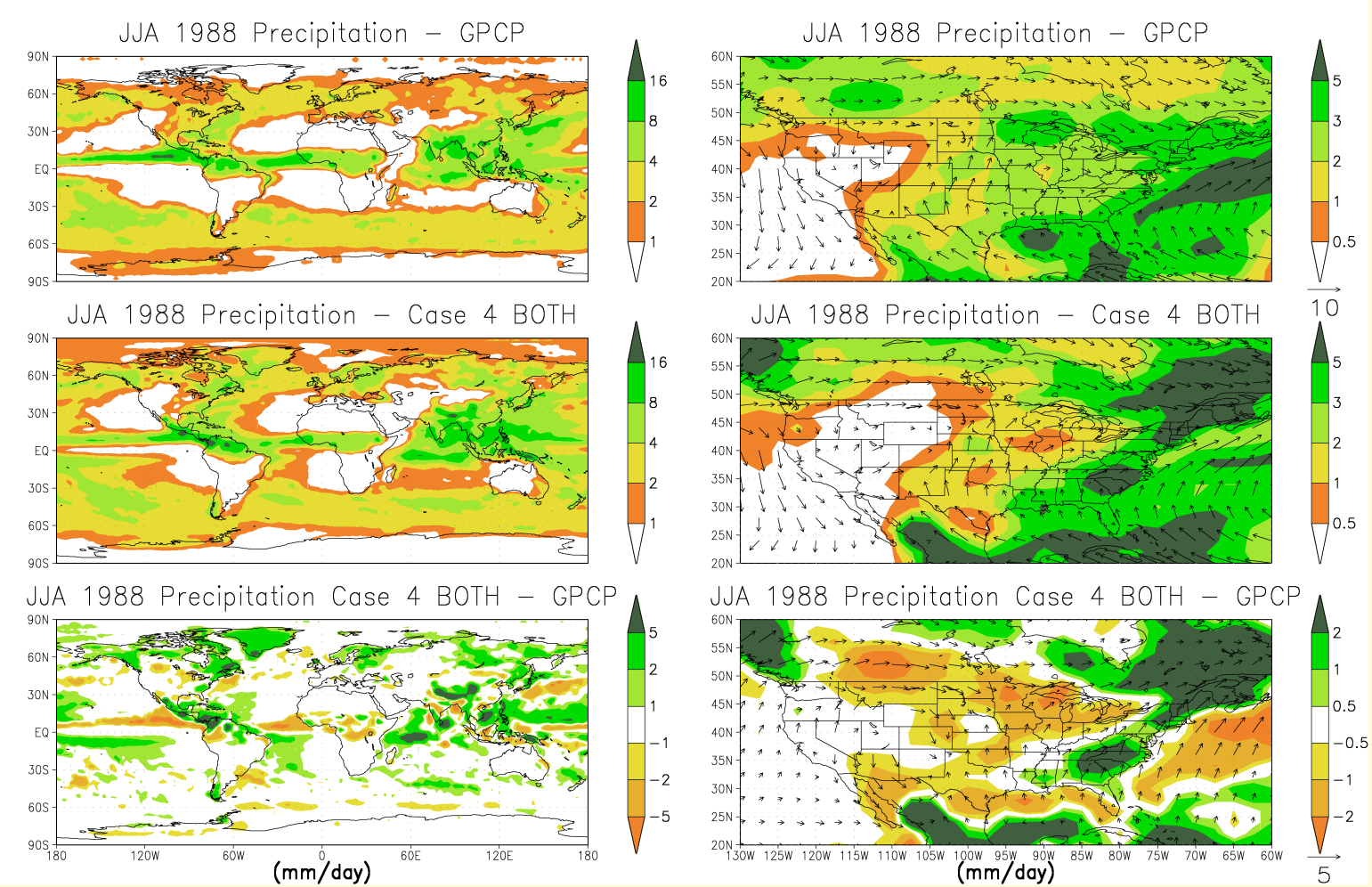
JJA 1988 Precipitation - WIND



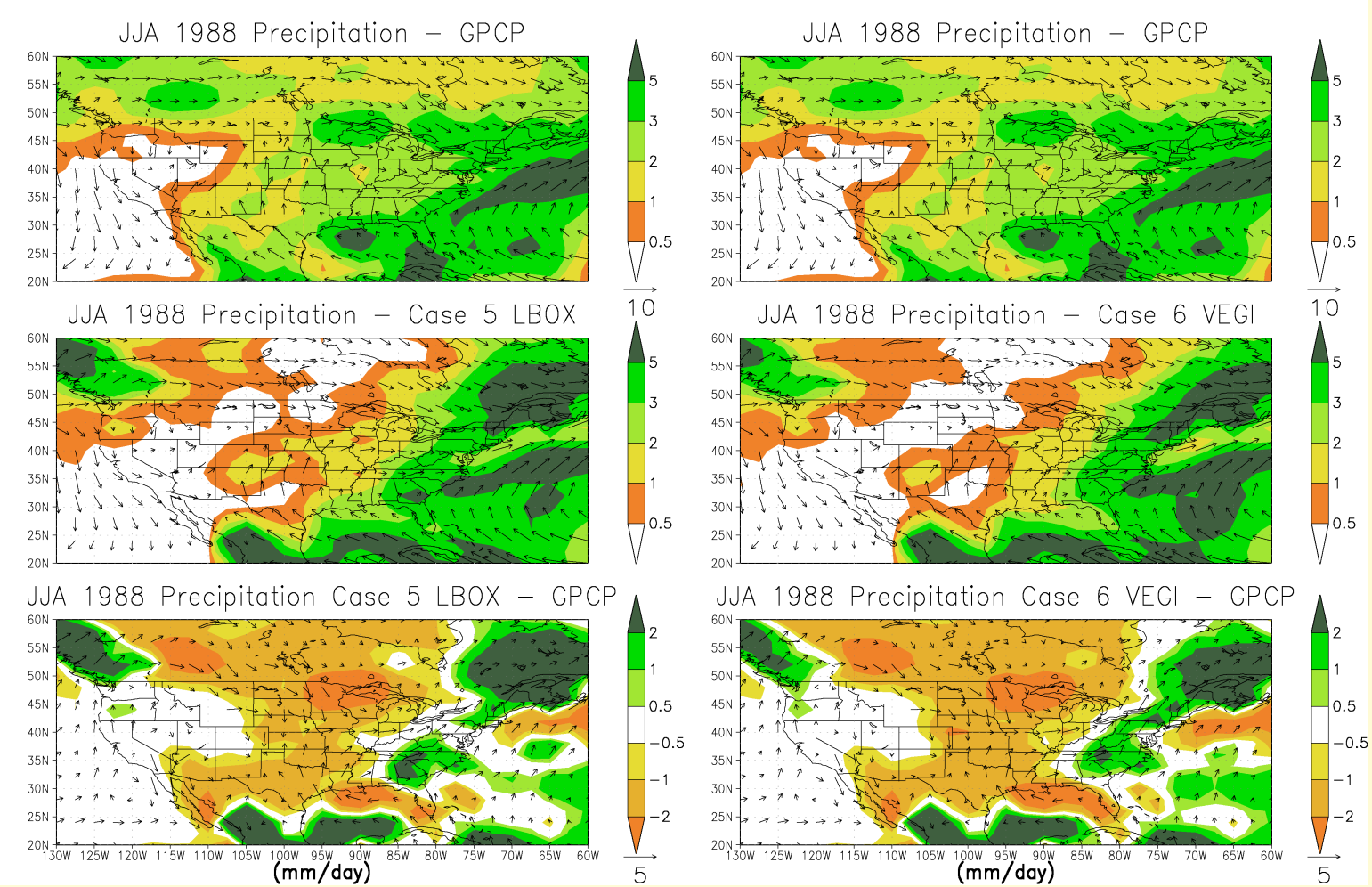
JJA 1988 Precipitation - SOIL



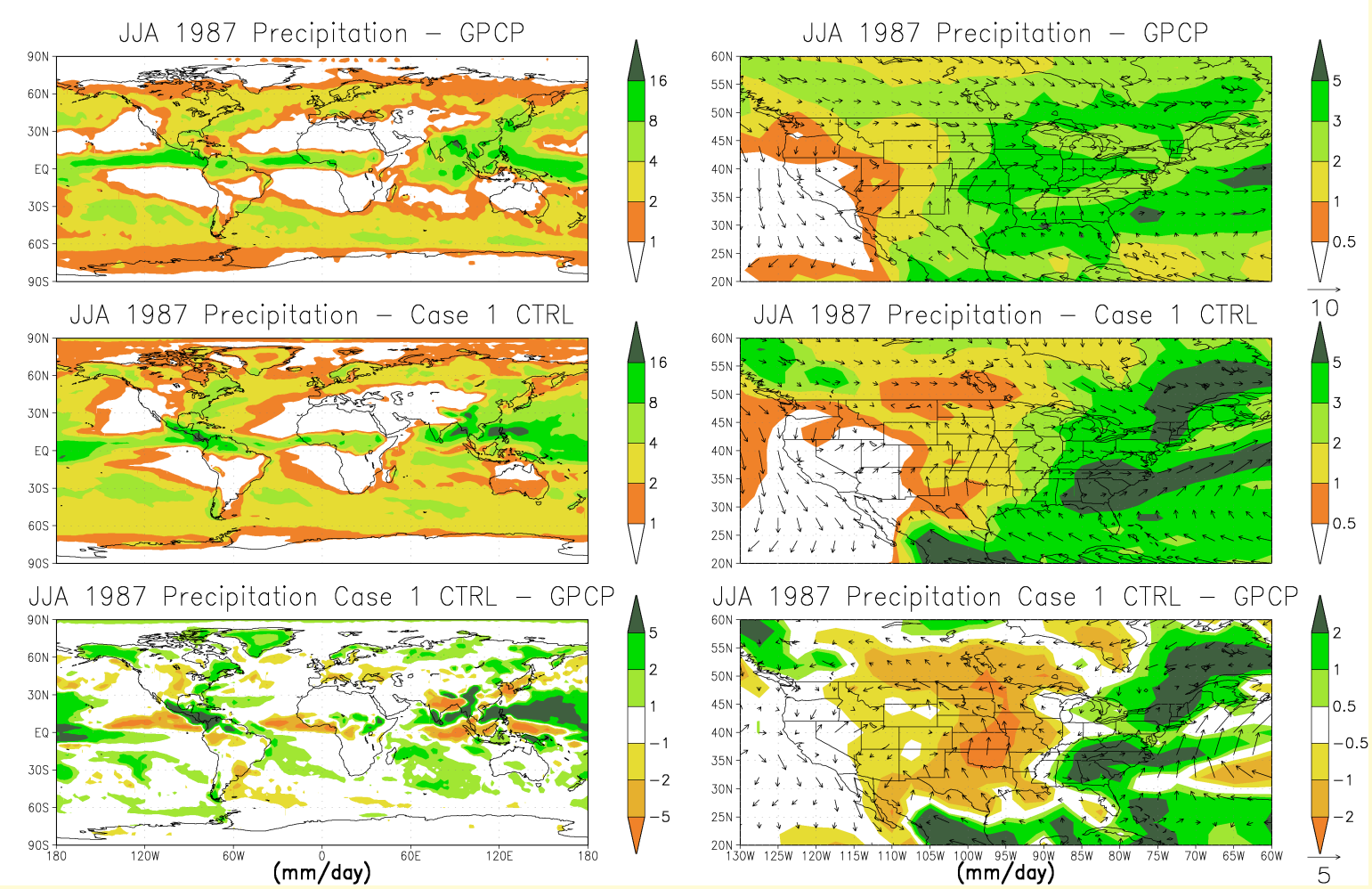
JJA 1988 Precipitation - BOTH



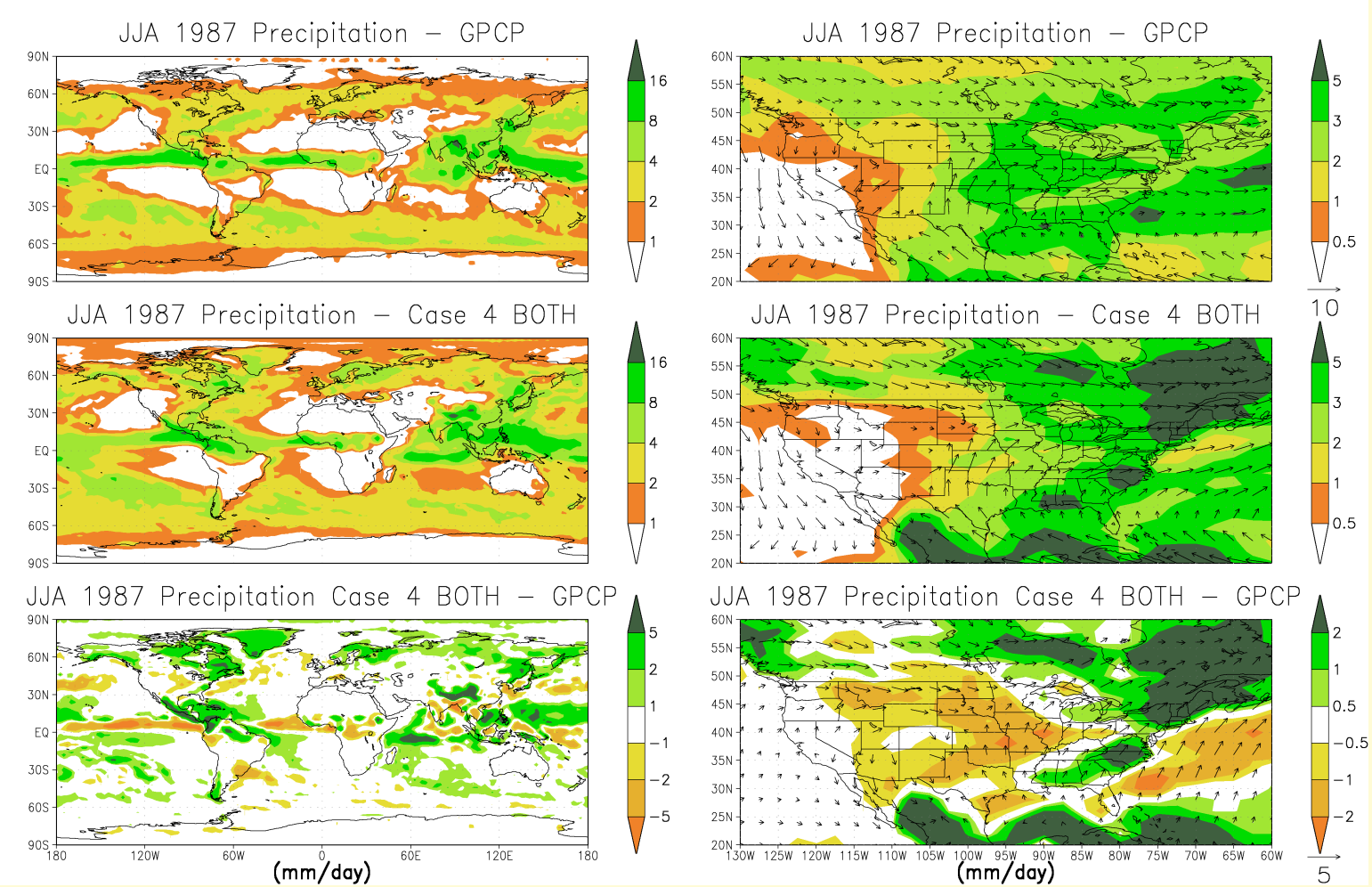
JJA 1988 Precipitation - LBOX/VEGI



JJA 1987 Precipitation - CTRL



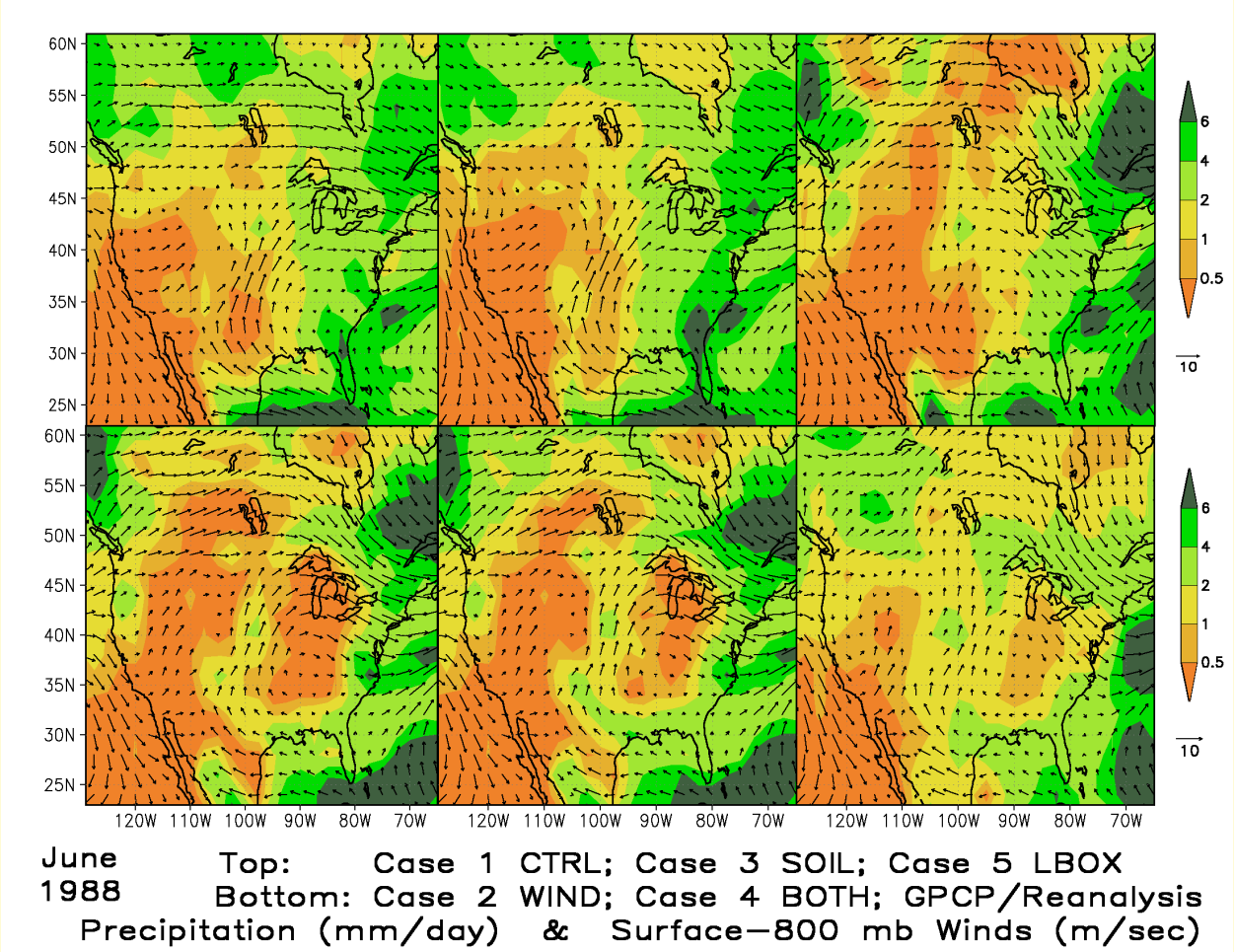
JJA 1987 Precipitation - BOTH



June 1988 Precipitation

Left to Right:
- Case 1 CTRL
- Case 3 SOIL
- Case 5 LBOX

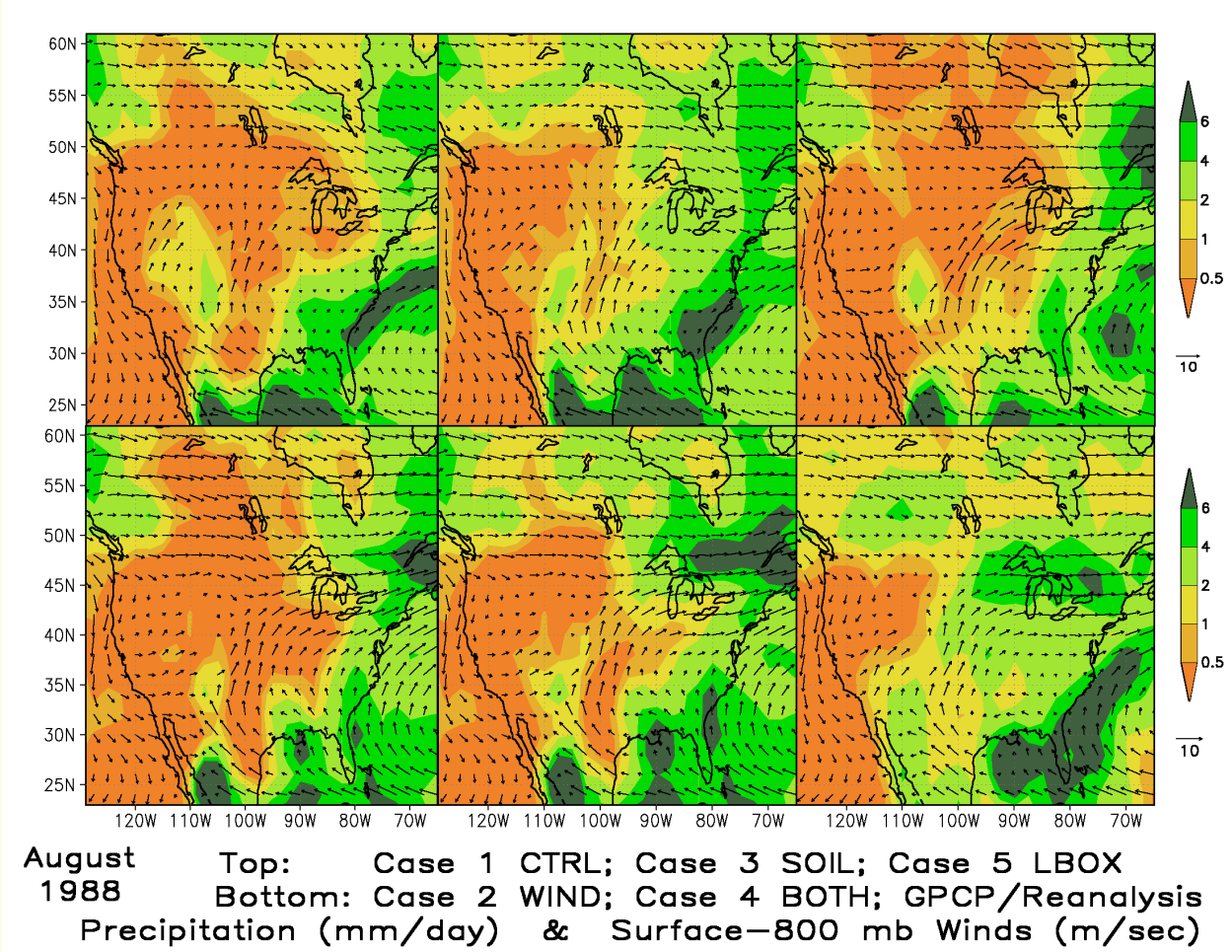
Left to Right:
- Case 2 WIND
- Case 4 BOTH
- GPCP Precip/ Reanalysis Winds



August 1988 Precipitation

Left to Right:
- Case 1 CTRL
- Case 3 SOIL
- Case 5 LBOX

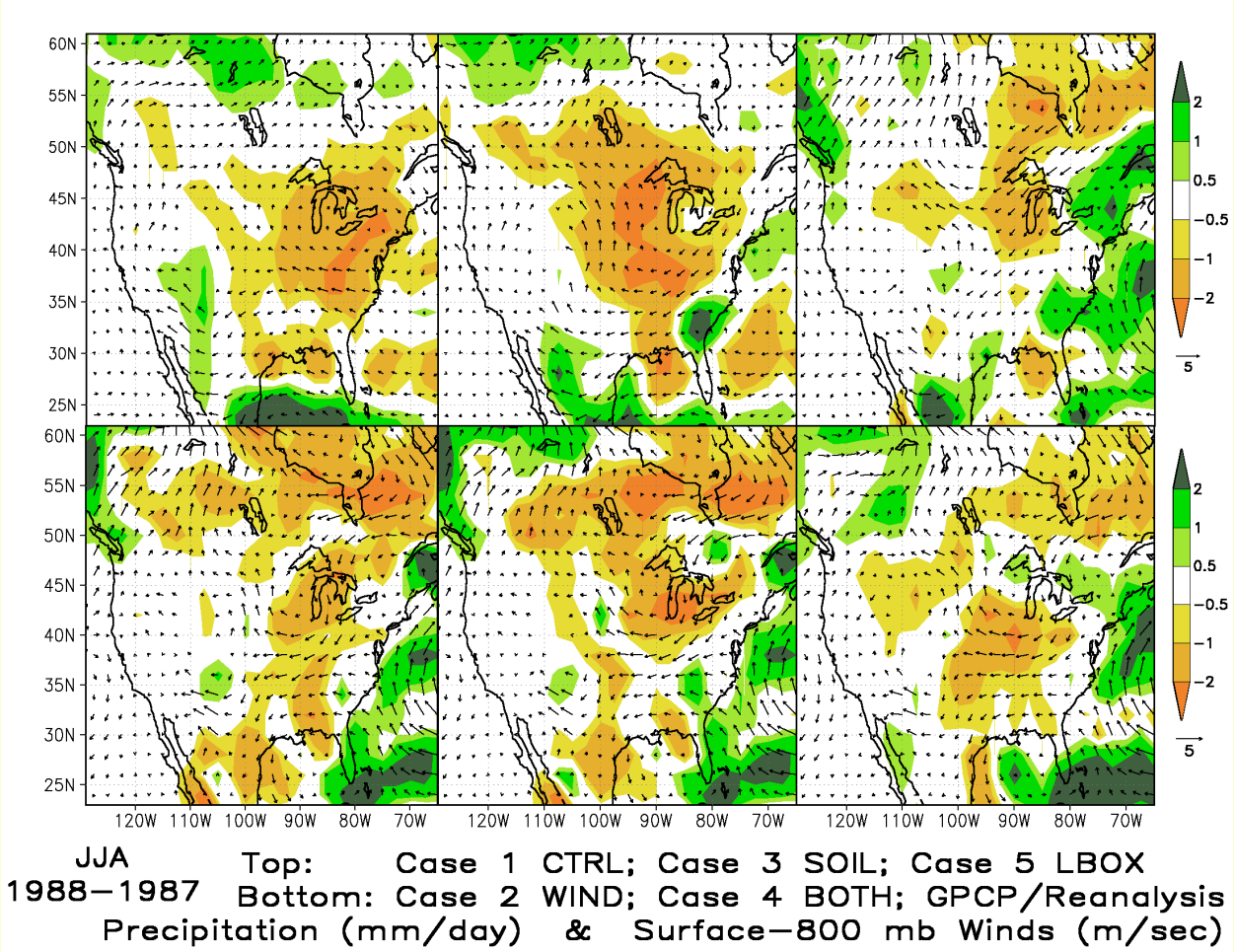
Left to Right:
- Case 2 WIND
- Case 4 BOTH
- GPCP Precip/ Reanalysis Winds



JJA 1988-87 Precipitation

Left to Right:
- Case 1 CTRL
- Case 3 SOIL
- Case 5 LBOX

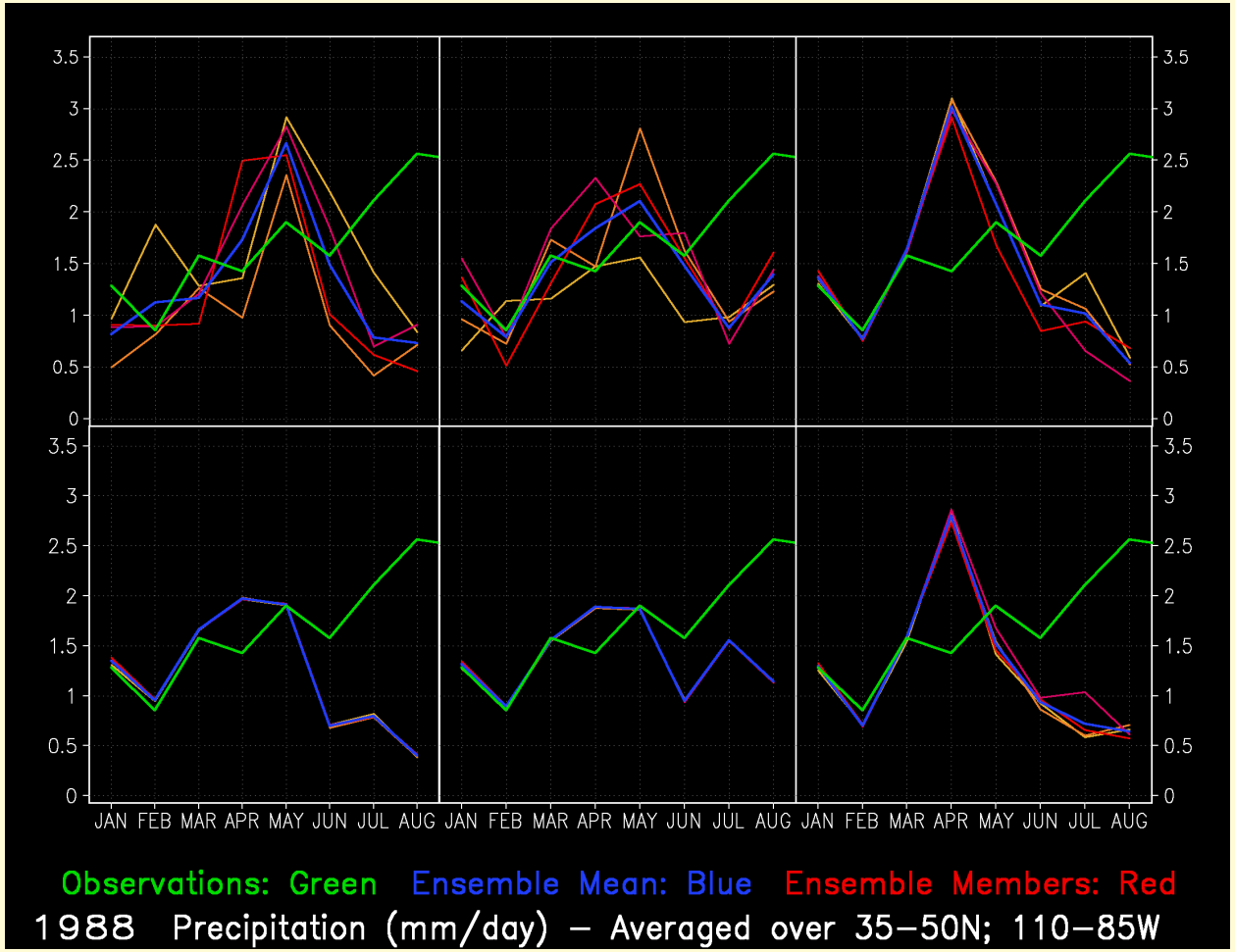
Left to Right:
- Case 2 WIND
- Case 4 BOTH
- GPCP Precip/ Reanalysis Winds



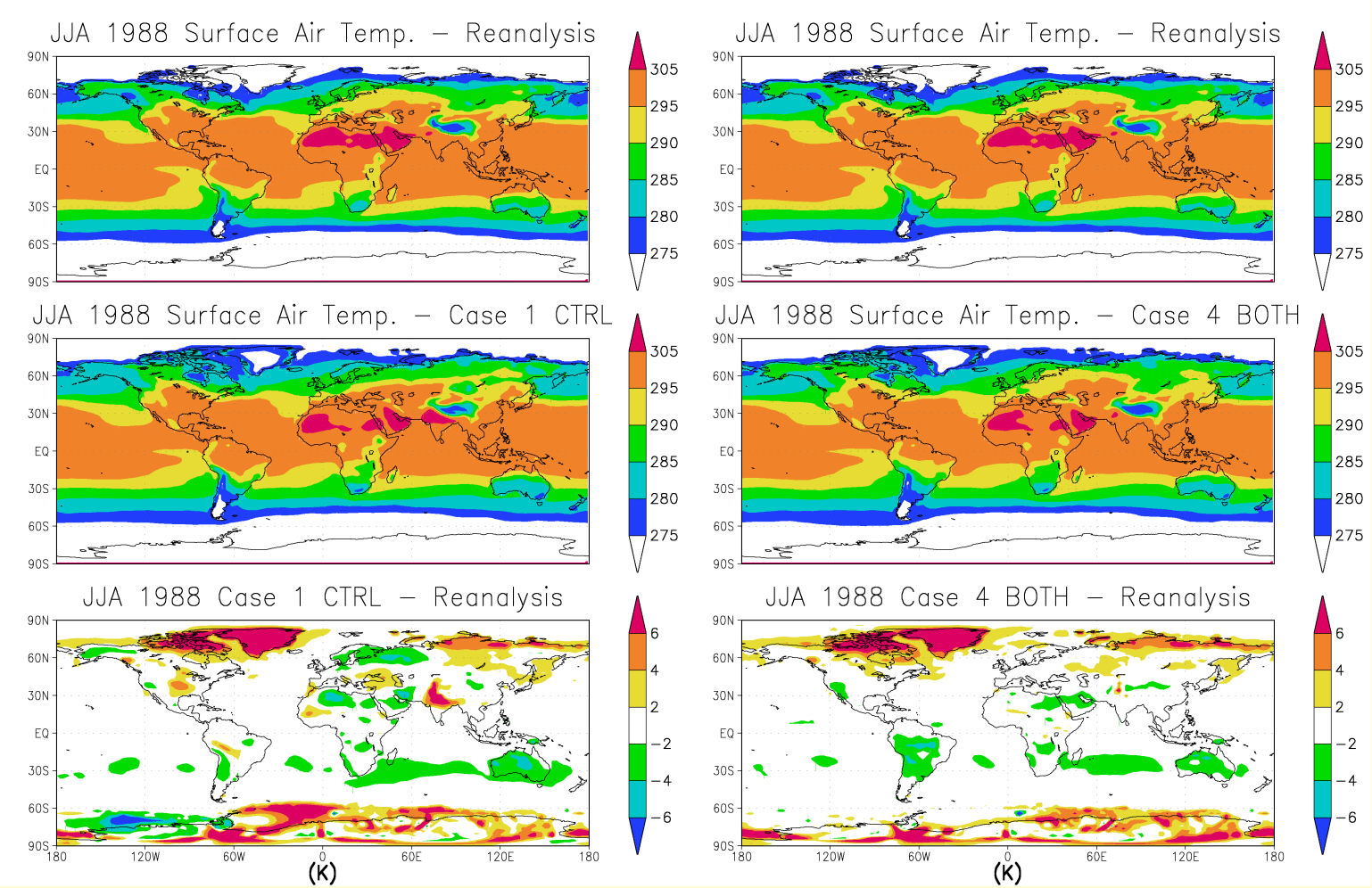
1988 Area-Averaged Precipitation

Left to Right:
- Case 1 CTRL
- Case 3 SOIL
- Case 5 LBOX

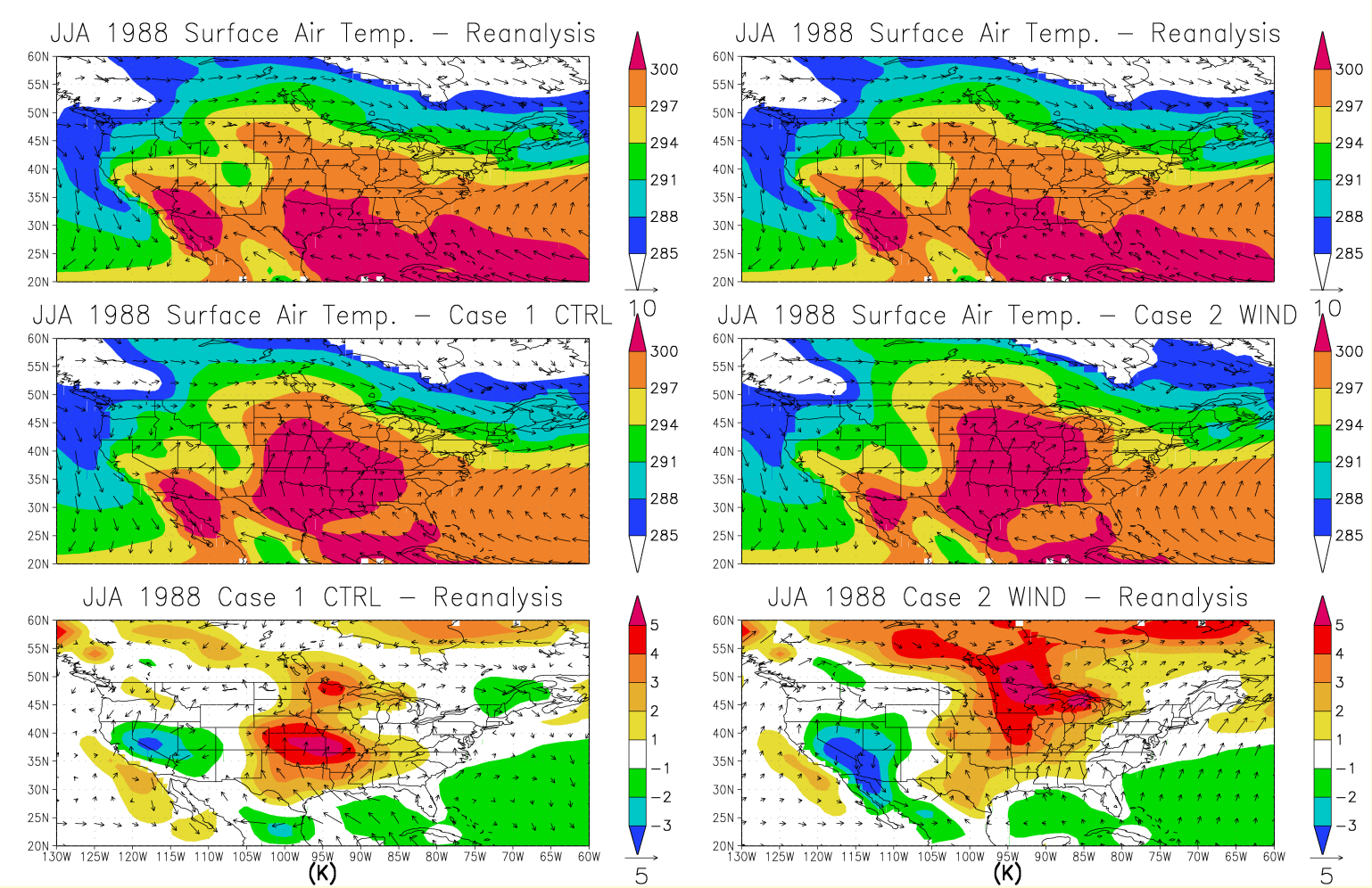
Left to Right:
- Case 2 WIND
- Case 4 BOTH
- Case 6 VEGI



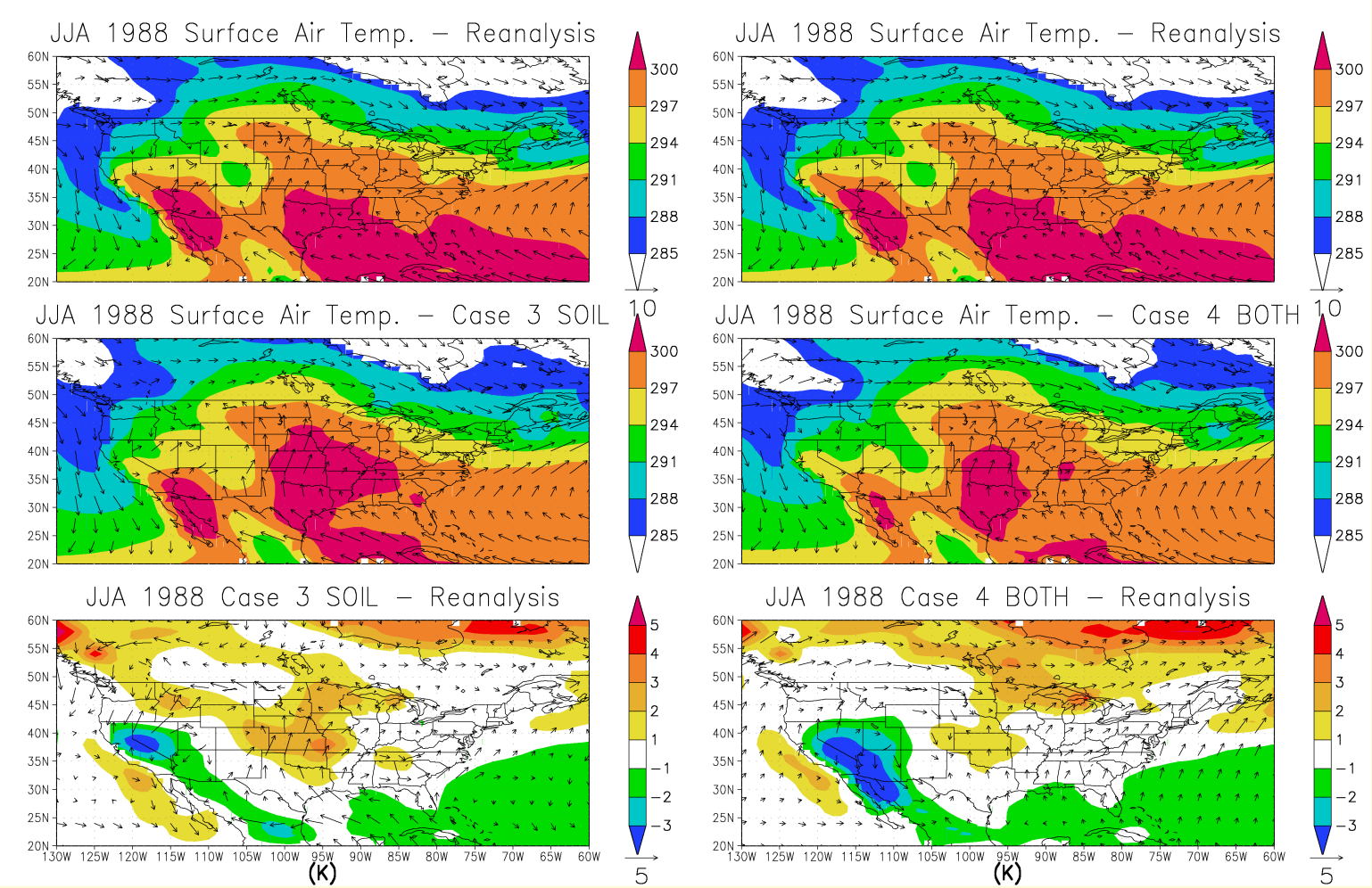
JJA 1988 Temperature – CTRL/BOTH



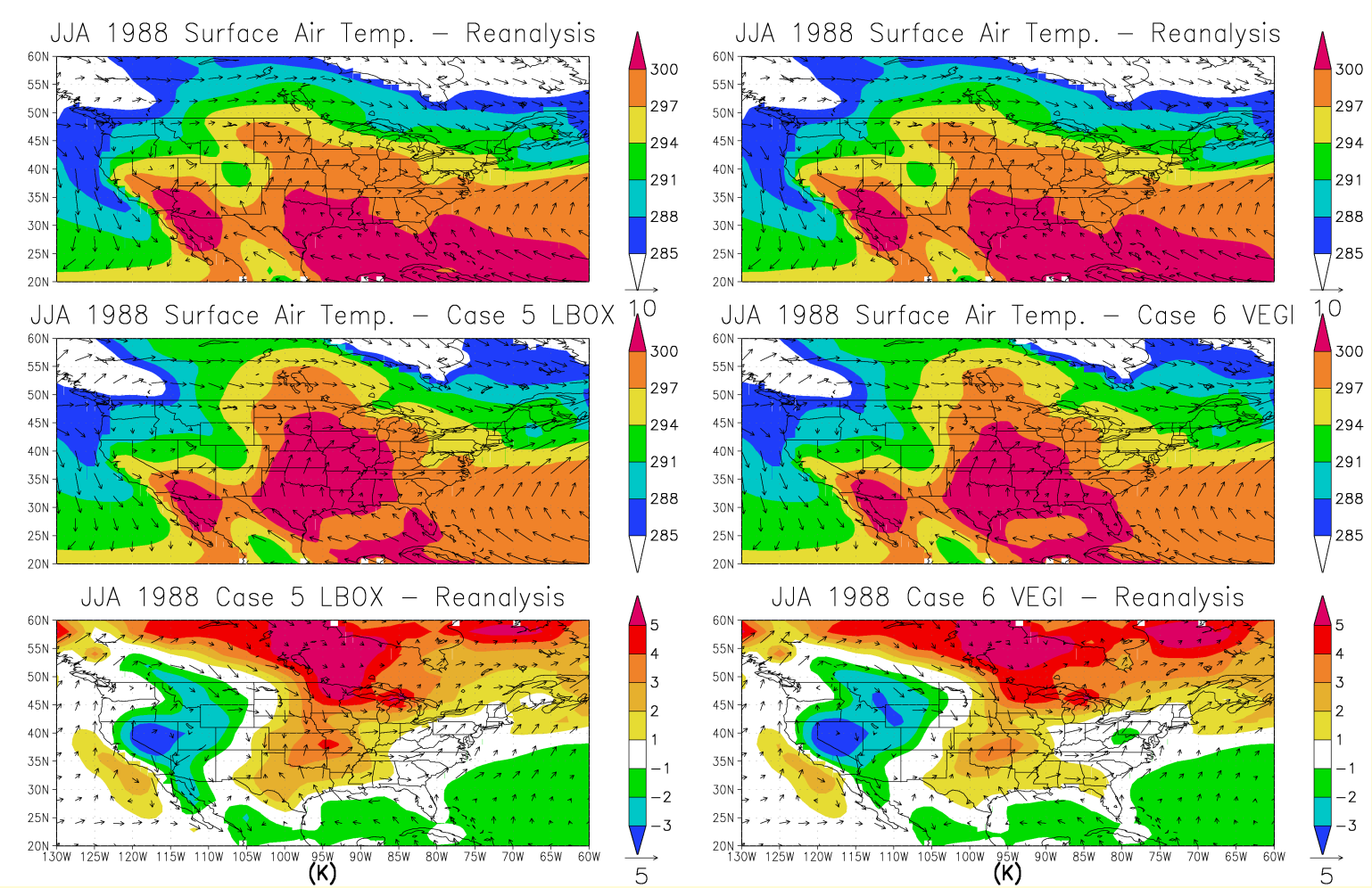
JJA 1988 Temperature – CTRL/WIND



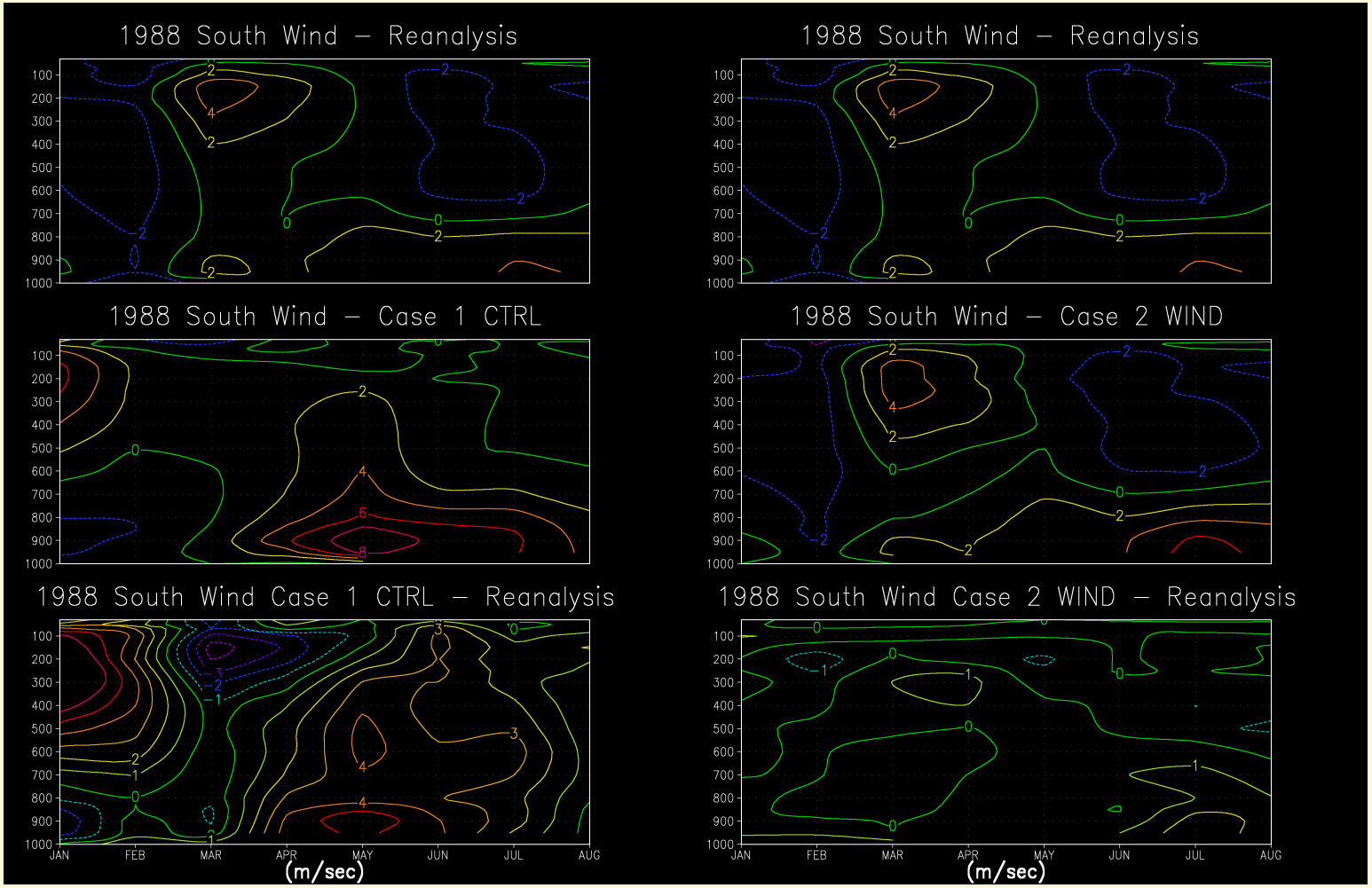
JJA 1988 Temperature – SOIL/BOTH



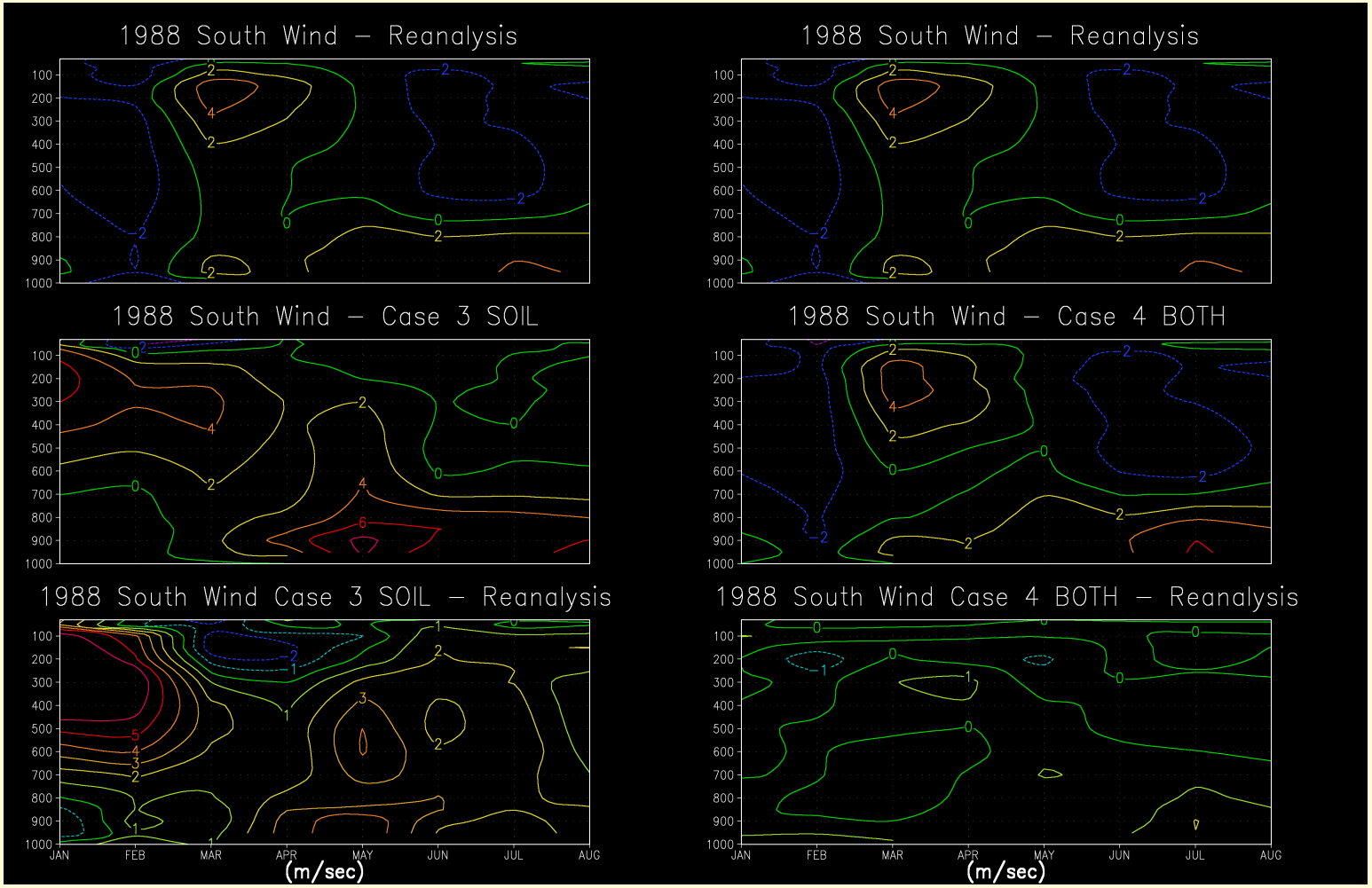
JJA 1988 Temperature – LBOX/VEGI



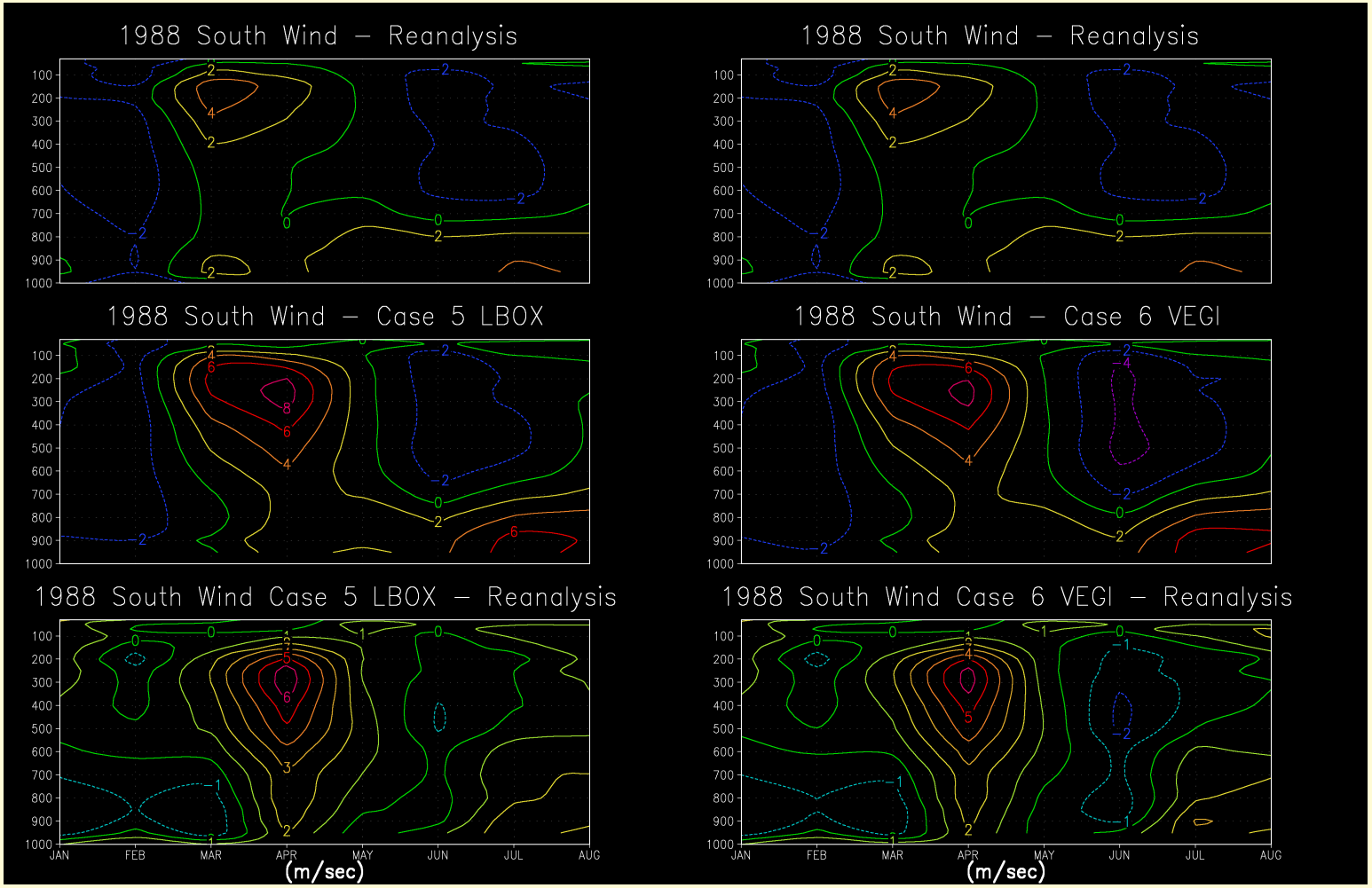
1988 Low-Level Jet – CTRL/WIND



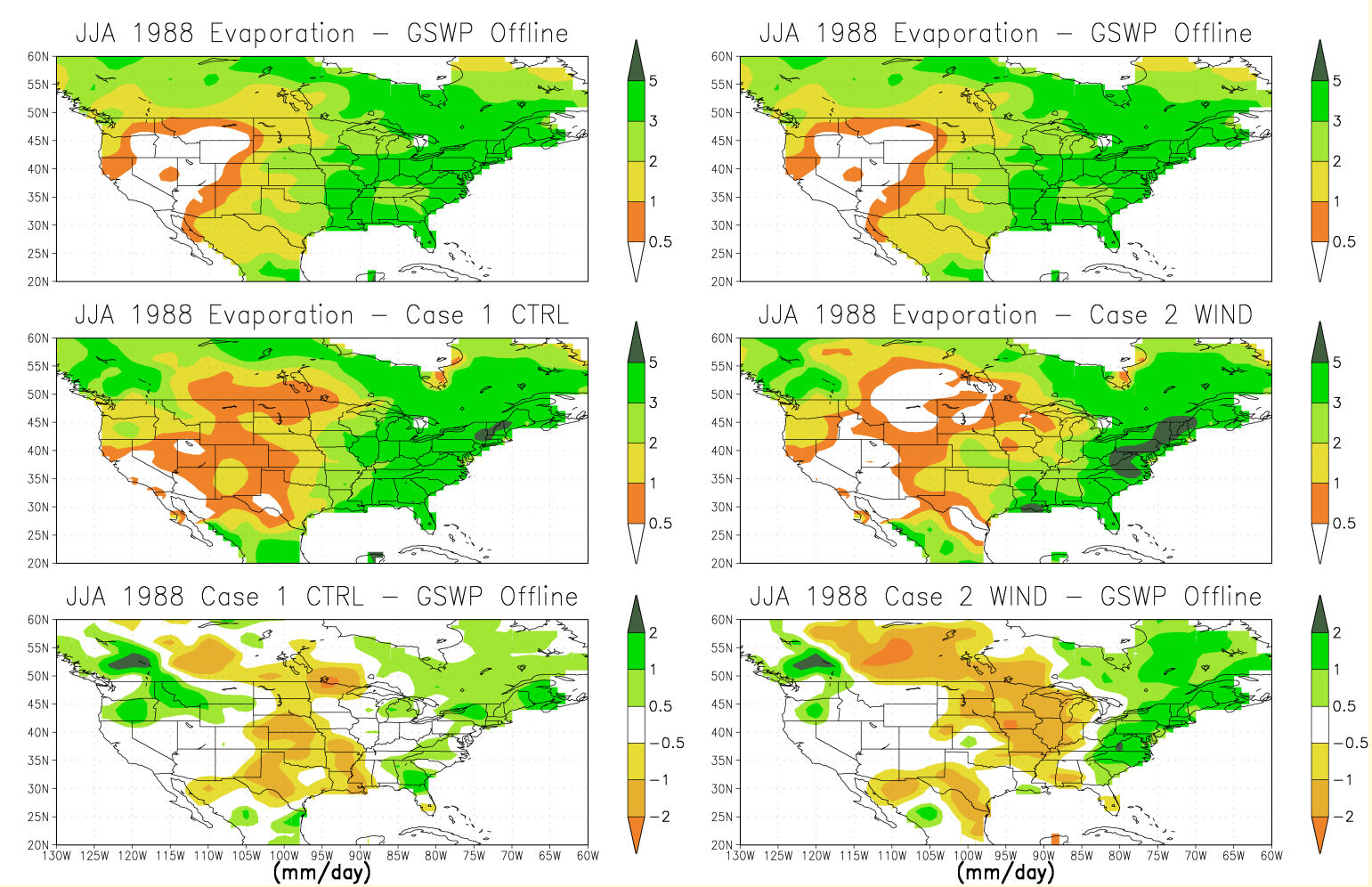
1988 Low-Level Jet – SOIL/BOTH



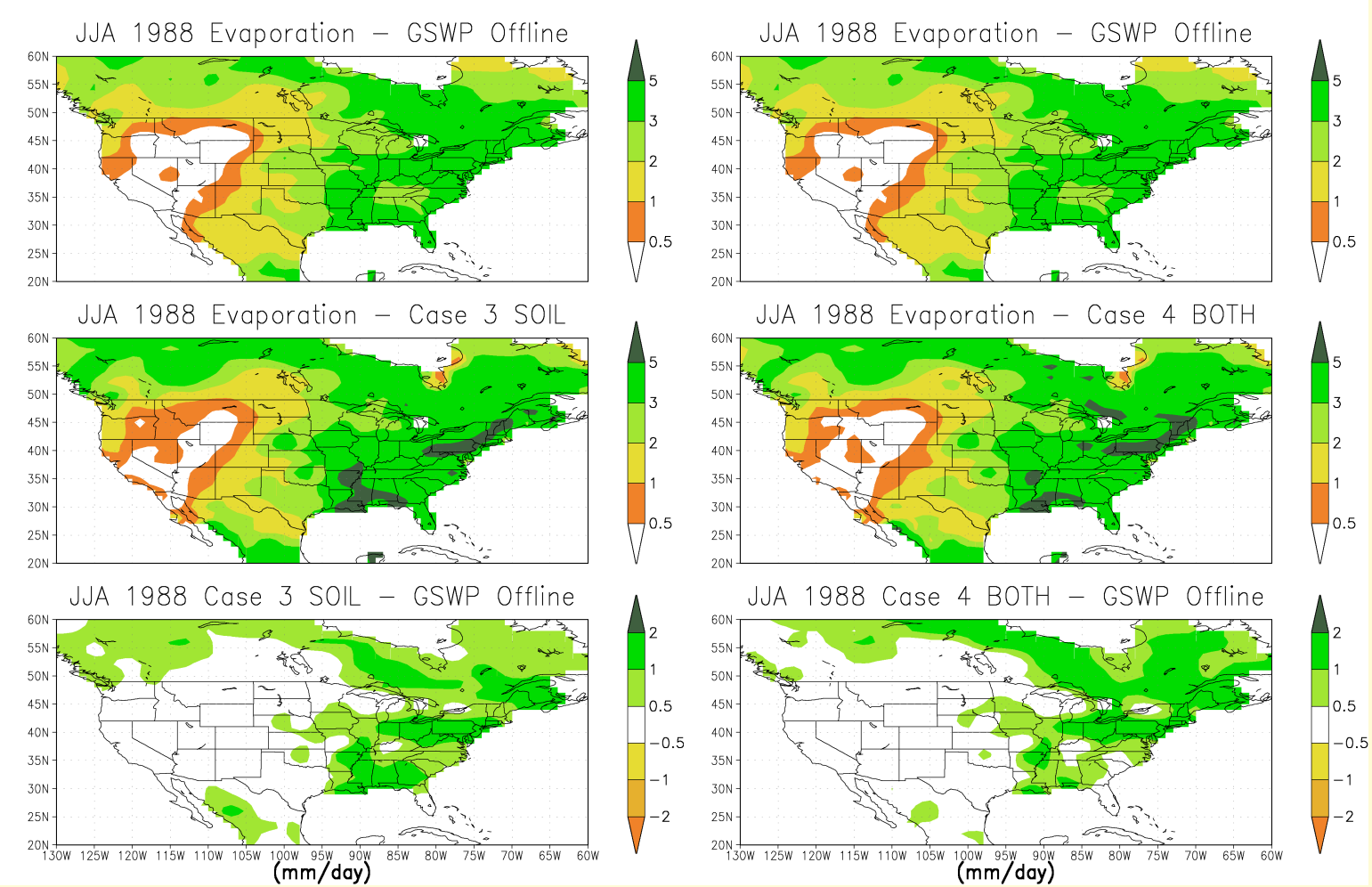
1988 Low-Level Jet – LBOX/VEGI



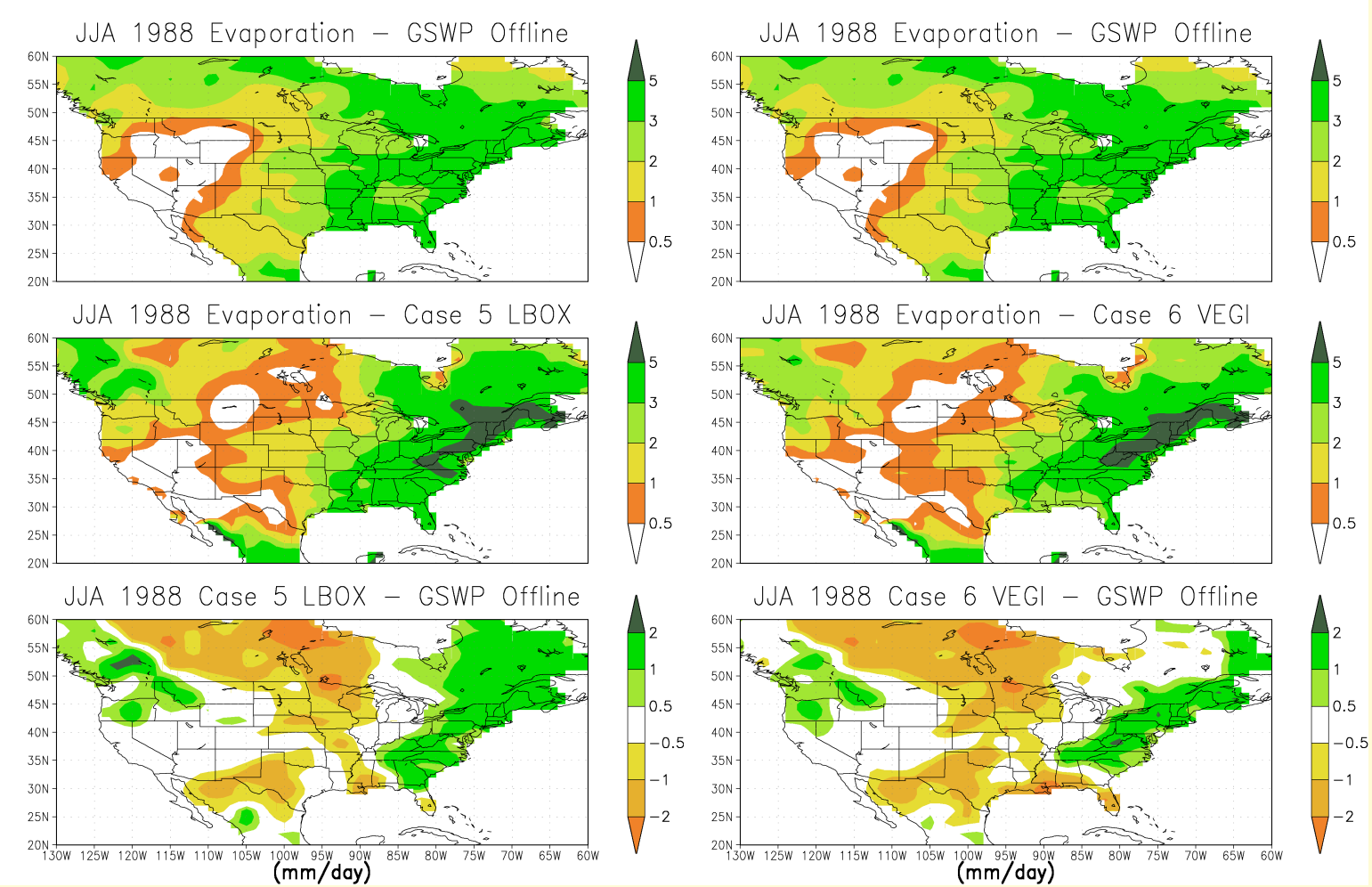
JJA 1988 Evaporation – CTRL/WIND



JJA 1988 Evaporation – SOIL/BOTH



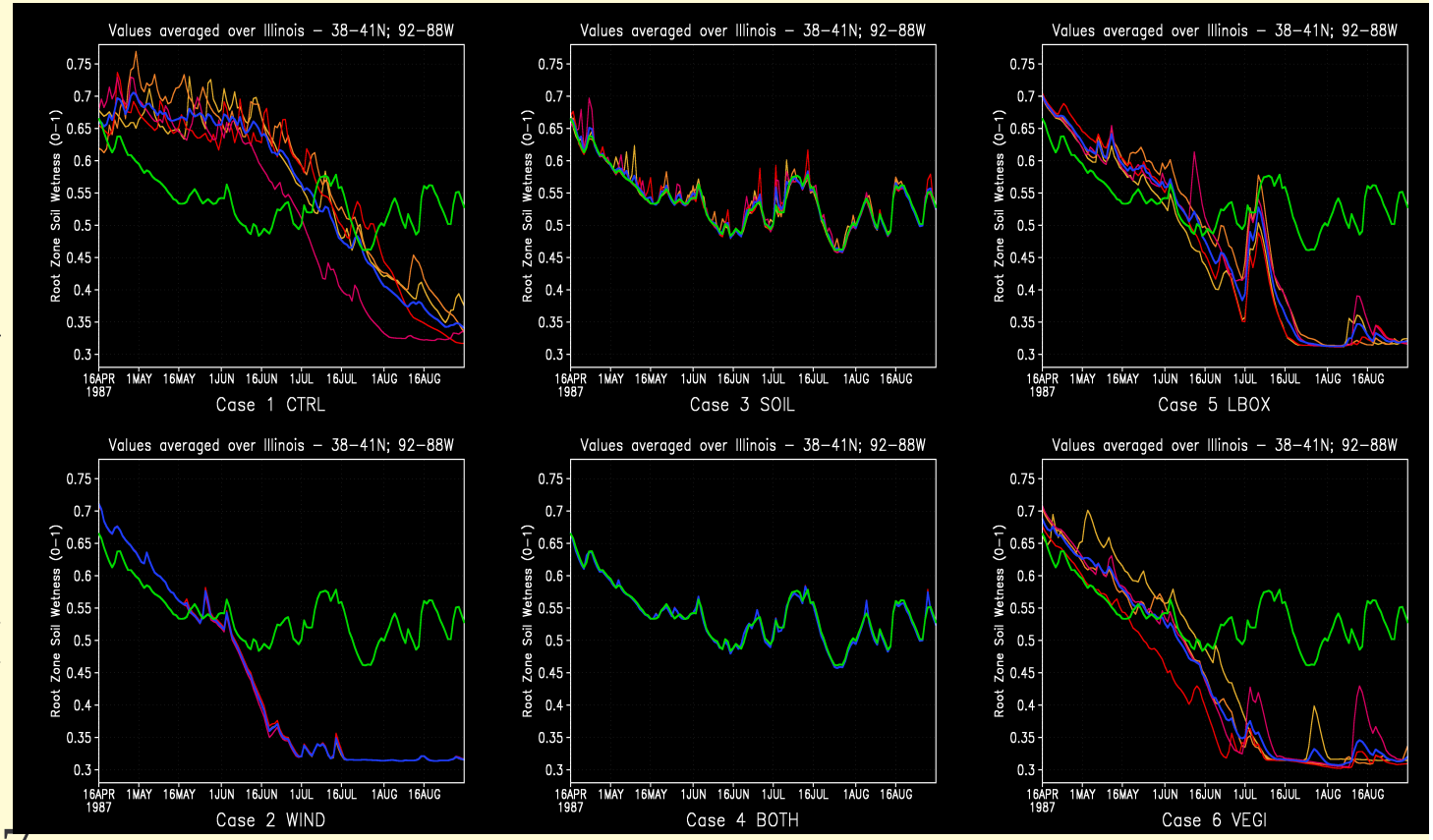
JJA 1988 Evaporation – LBOX/VEGI



1987 Soil Moisture

Left to Right:
- Case 1 CTRL
- Case 3 SOIL
- Case 5 LBOX

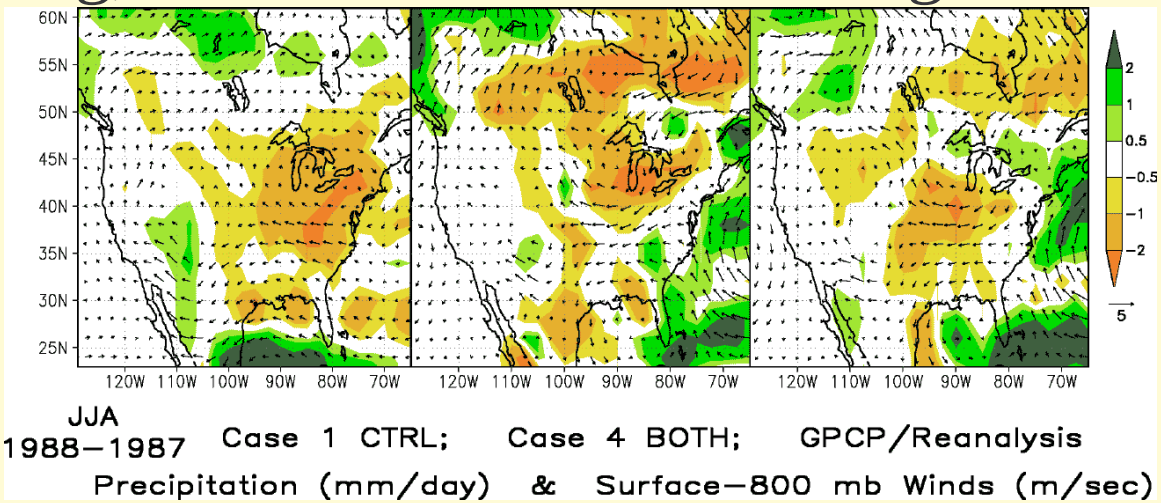
Left to Right:
- Case 2 WIND
- Case 4 BOTH
- Case 6 VEGI



16Apr-1Sep1987
38-41N; 92-88W

Conclusions

1. Improved moisture transport and soil moisture helps the model to simulate a more realistic drought. This suggests that **observational data** can help the model.
2. Soil moisture and evapotranspiration are critical to simulating the drought in the GEOS model with McRAS, which is not the case in every model.

Conclusions

3. Better knowledge of the biosphere had less of an effect on the ability of GEOS to simulate the drought as compared to soil moisture change.
4. Given the current state of GCMs and the complexity of evolving external and local forcing, simulation success is not guaranteed.