Simulating Lake Water Surface Temperature for USCONUS

Yihua Wu, Michael Ek
Geoff DiMego, George Gayno & Robert Grumbine

NOAA / NWS / NCEP / EMC
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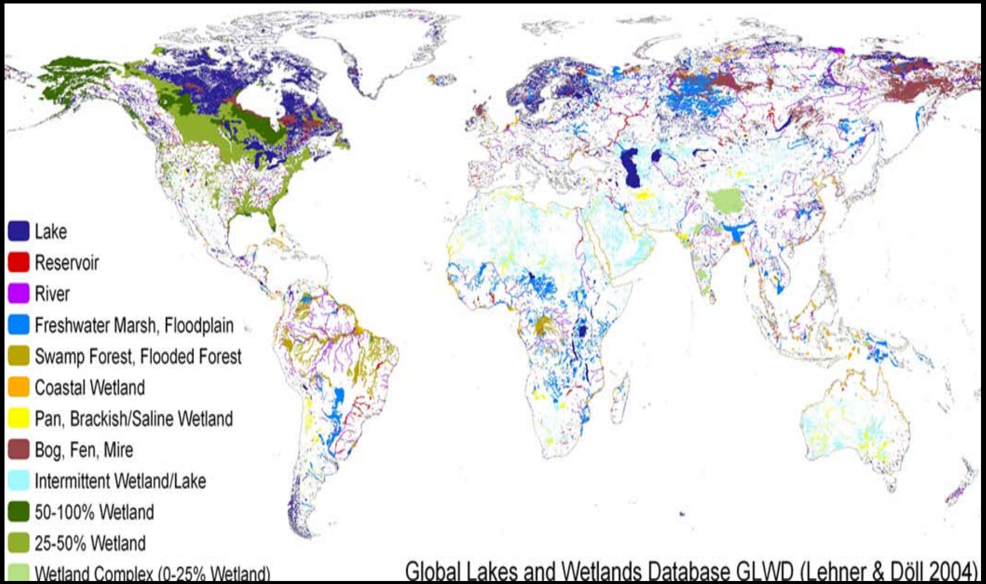
Many Lakes On The Earth

- About 304 million lakes (4.2 million km^2 in area) on the earth (J. A. Downing et al., 2006).
- The majority are fresh water, & most lie in the NH at higher latitudes (R. P. Schwarzenbach et al., 2003).
- More lakes & Fresh bodies in NA continent.
  1. Minnesota--The Land of Ten Thousand Lakes.
  2. Manitoba claims more than 100 thousand lakes.
  3. The Great Lakes form the largest group of freshwater lakes on Earth by total surface and volume.



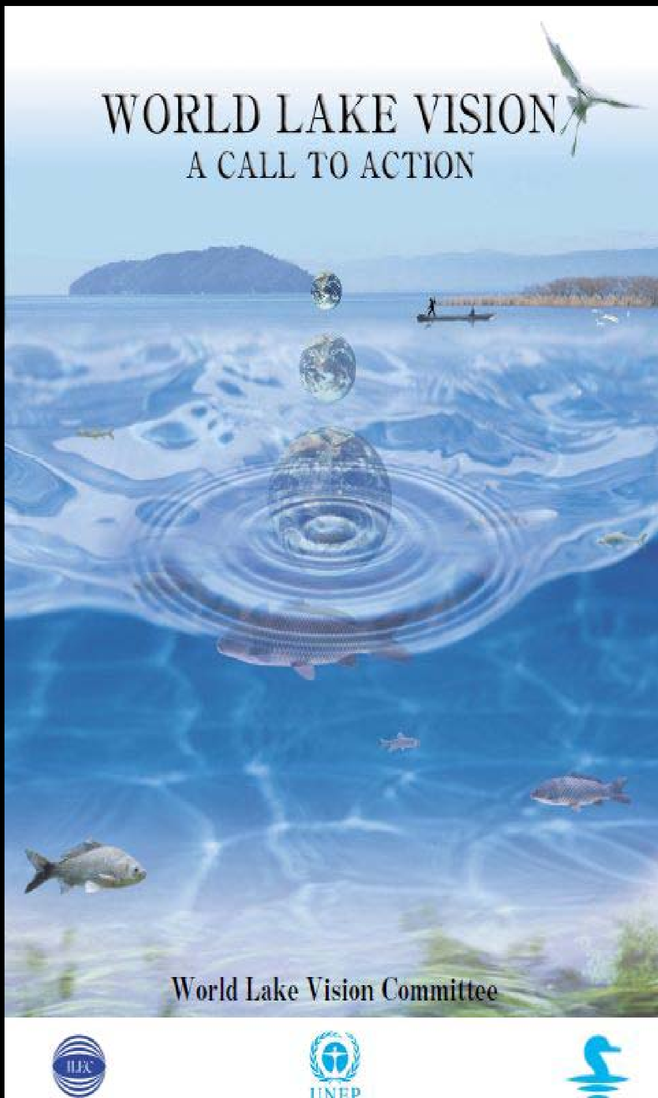
Global Lakes and Wetlands Database GLWD (Lehner & Döll 2004)

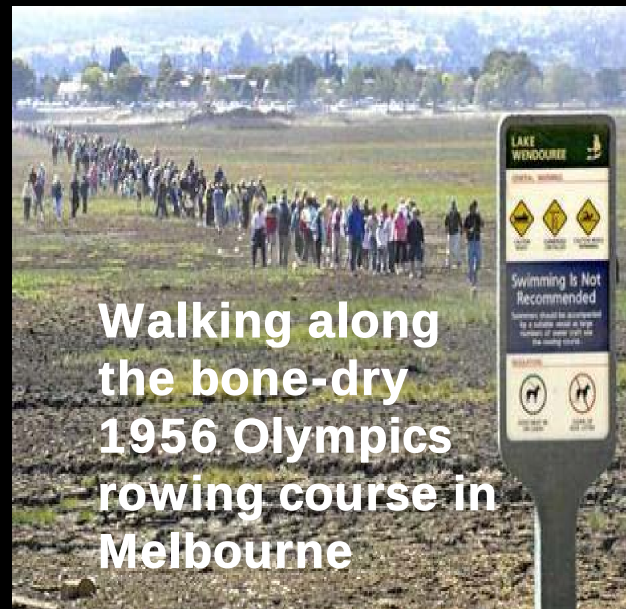
Importance of Lakes

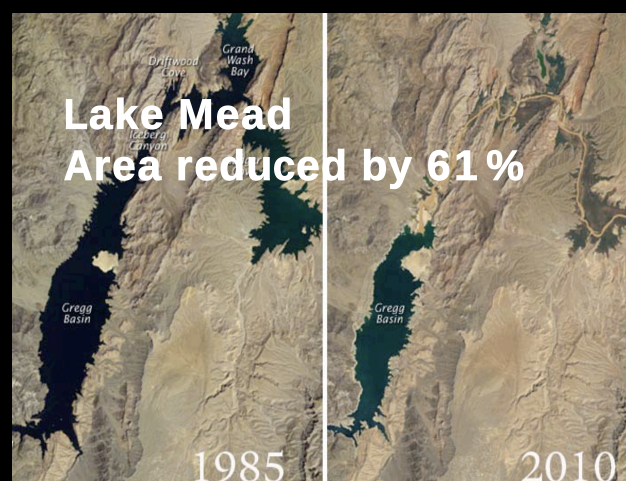
- **Lakes are important in human society**
  1. **Vital water resources, contributing 90 % of the liquid freshwater on the surface of our planet**
  2. **Engines for economic growth in millions of communities,**
  3. **An important role in maintaining the ecological health of the planet.**
- **Lakes are important in Hydrological Cycle**
  1. **Lake storage of runoff regulates stream outflow by sustaining low flows and suppressing peak discharges**
  2. **Lake-effect precipitation**
  3. **Evaporation from the lakes are larger than from the land**
- **Lakes are important in Carbon Cycle**
  1. **Lakes are aquatic habitat; the chemical and ecological cycles are strongly influenced by physical limnological processes (*e.g.*, upwelling & downwelling, spring & fall turnover, currents)**
  2. **Important component of ecosystem carbon cycle through both organic carbon sequestration and carbon dioxide and methane emissions.**
  3. **Lake sediments are considered to be one of the rather permanent sinks of carbon in boreal regions.**
  4. **Freshwater ecosystems process large amounts of carbon originating from terrestrial sources**

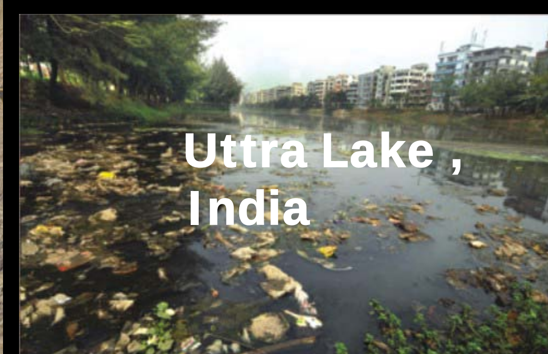
Many World's Lakes in Jeopardy

Two causes: Climate Change & Man activities.









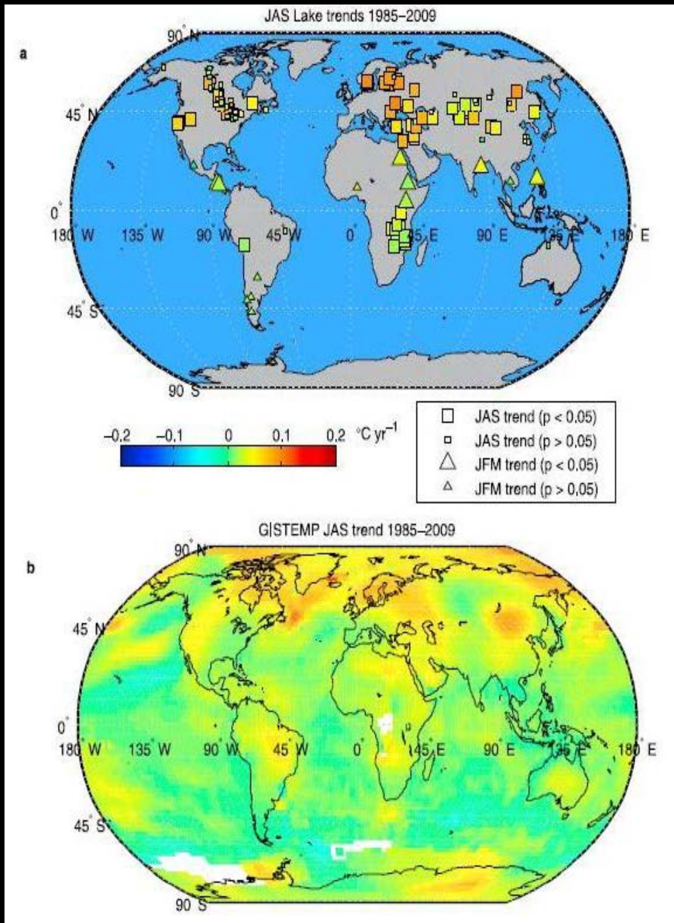
Sentinels of climate change

- **Lakes are sensitive to climate, respond rapidly to change, and integrate information about changes in the catchment**
- **Indicators:**
  1. **Temperature**
  2. **Ice phenology**
  3. **Chemical variables**
  4. **Dissolved organic carbon**
  5. **Oxygen concentration**
  6. **Changes in spring and early summer phenology**
  7. **Growth rates, abundance, and species composition**
  8. **Other climate-related responses of lake biota**
     a) **Primary productivity**
     b) **zooplankton body size**
     c) **increased bacterial cell densities**
     d) **benthic net photosynthesis a& dark respiration**
     e) **species diversity & composition**

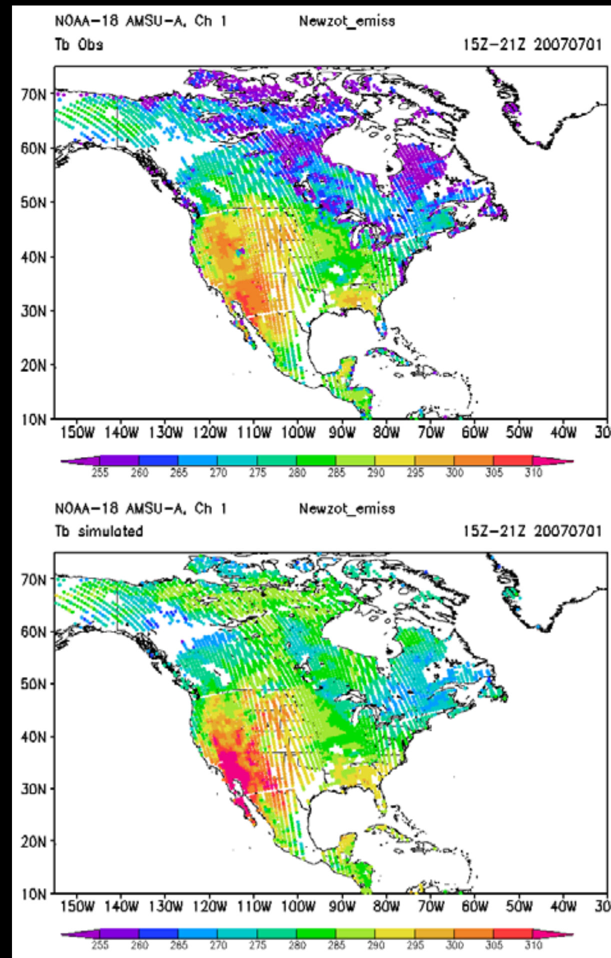
Water Volume?

Rita Adrian et al., 2009, Lakes as sentinels of climate change, Limnol Oceanogr. 2009 November ; 54(6): 2283–2297

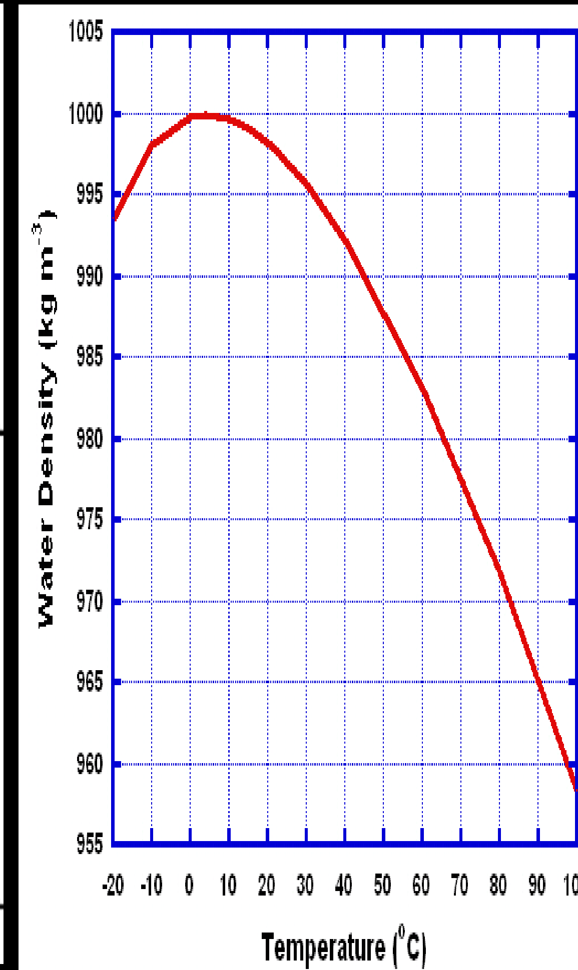
Lake Water Surface Temperature - A Key Factor



Schneider & Hook, 2010: Space Observations of inland water bodies show rapid surface warming since 1985



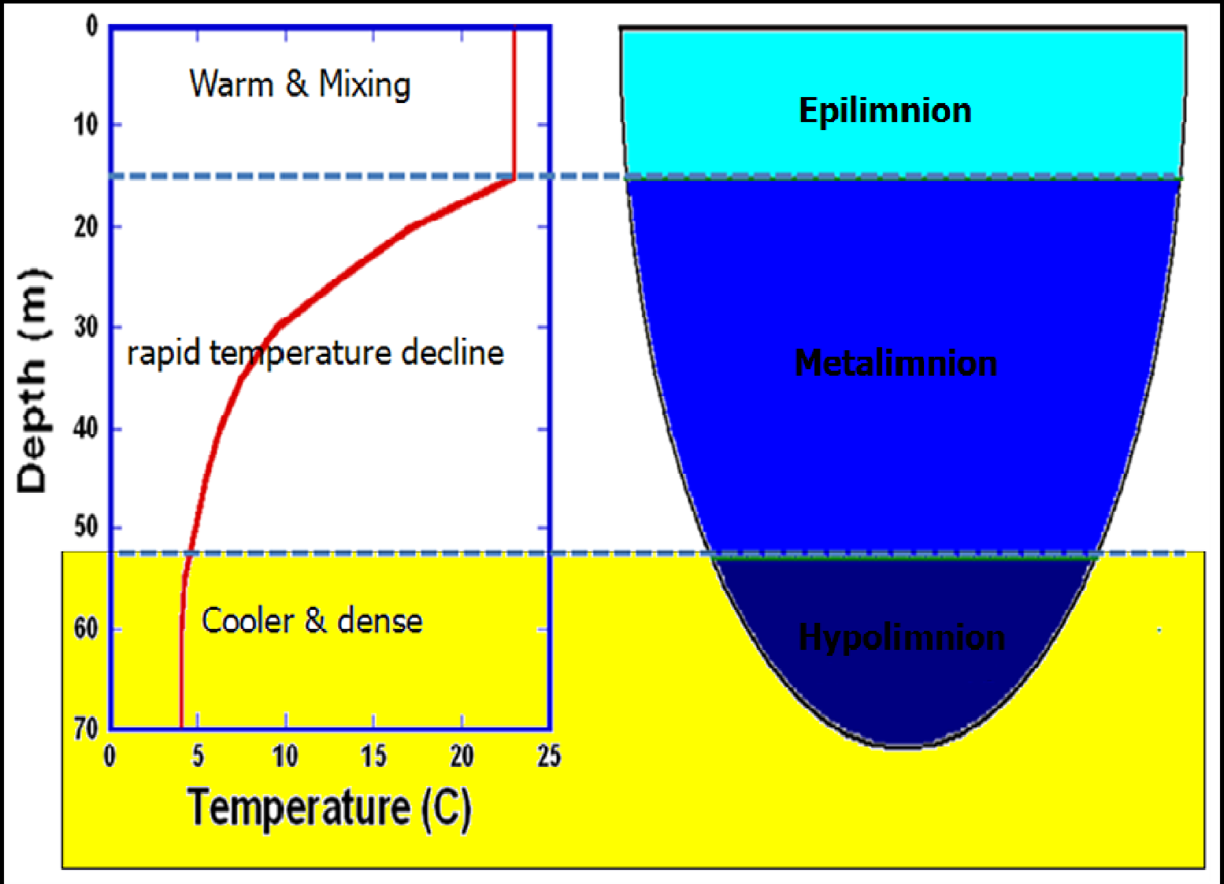
Zheng & Ek, *2010: Many lakes are missing from GFS model*



Water density varies with temperature

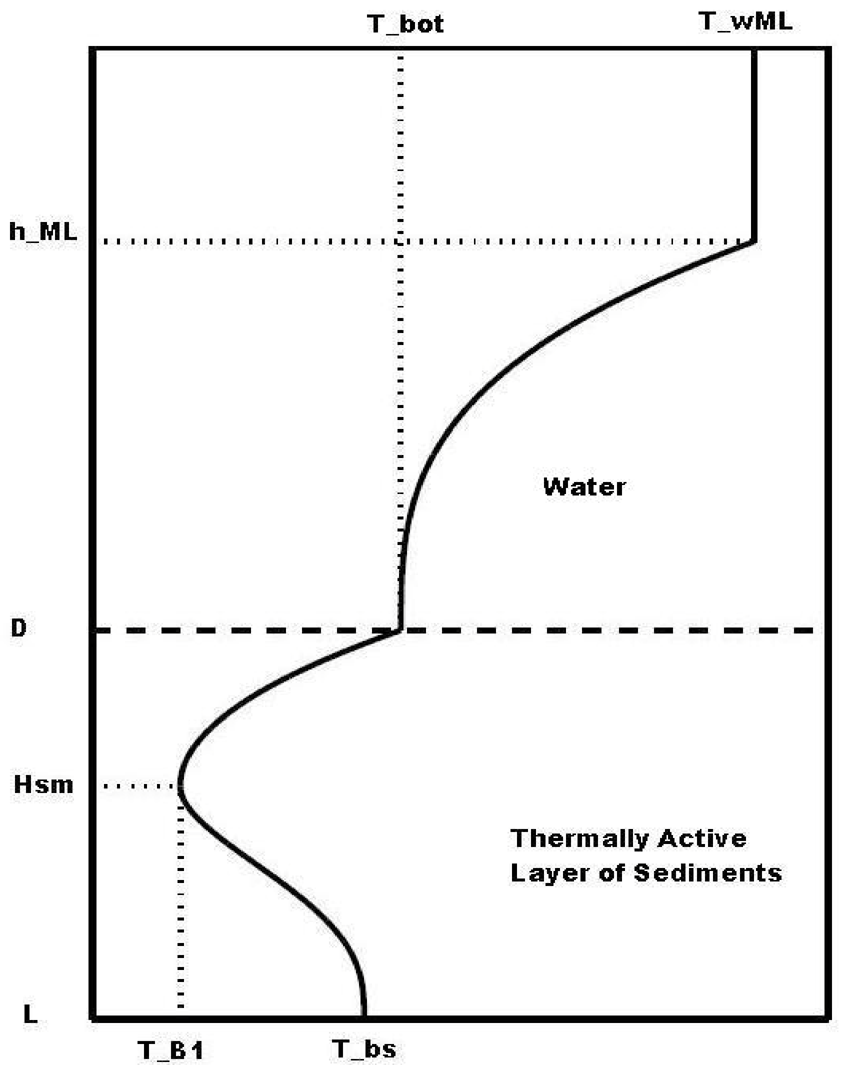
The Flake Model

- One-dimension, two-layer: mixed-layer & thermocline
- temperature & energy budget
- Sediment module
- snow-ice module
- specified depth & turbidity
- atmospheric forcing inputs

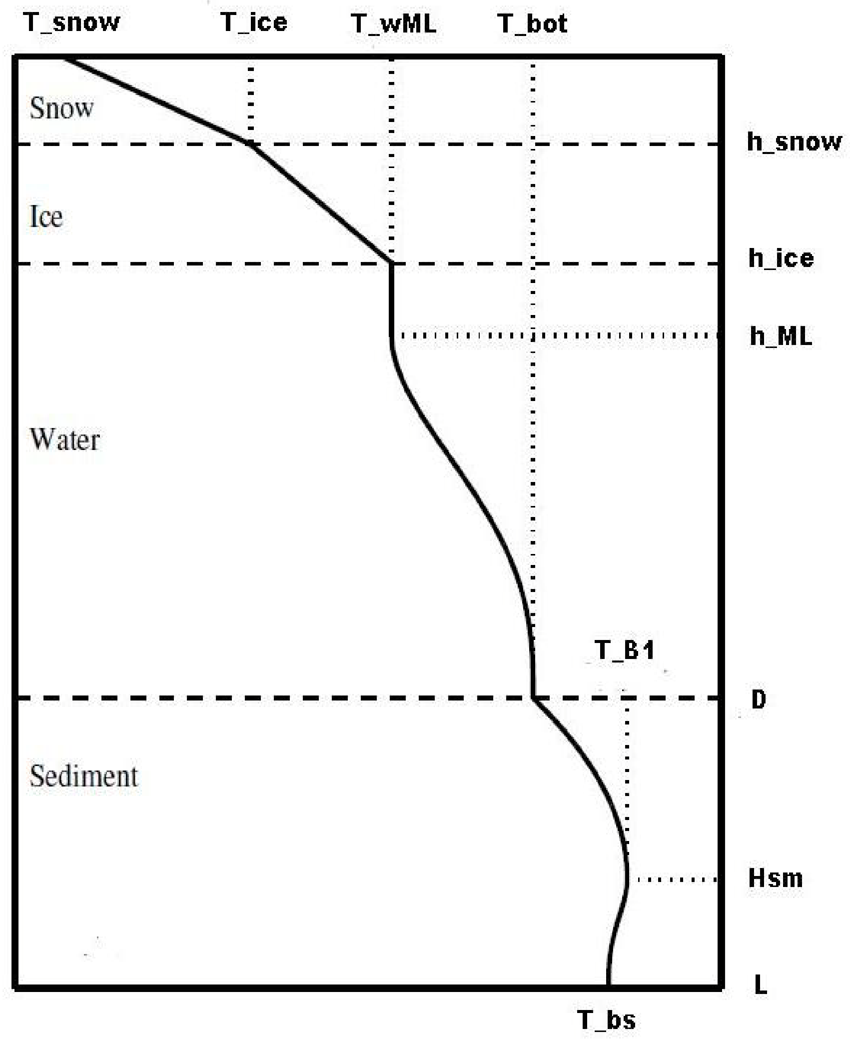


Schematic representation of lake stratification and the corresponding temperature profile in the Flake

Typical Temperature Profiles in FLAKE



Typical Temperature Profile for Summer Stratified Lakes



Typical Temperature Profile for Winter Stratified Lakes

The Concept of Self-similarity

$$T(z,t) = \begin{cases} T_s(t) & 0 \le z \le h \\ T_s(t) - \left(T_s(t) - T_b(t)\right)\Phi_T(\zeta) & h < z \le D \end{cases} \quad (1)$$

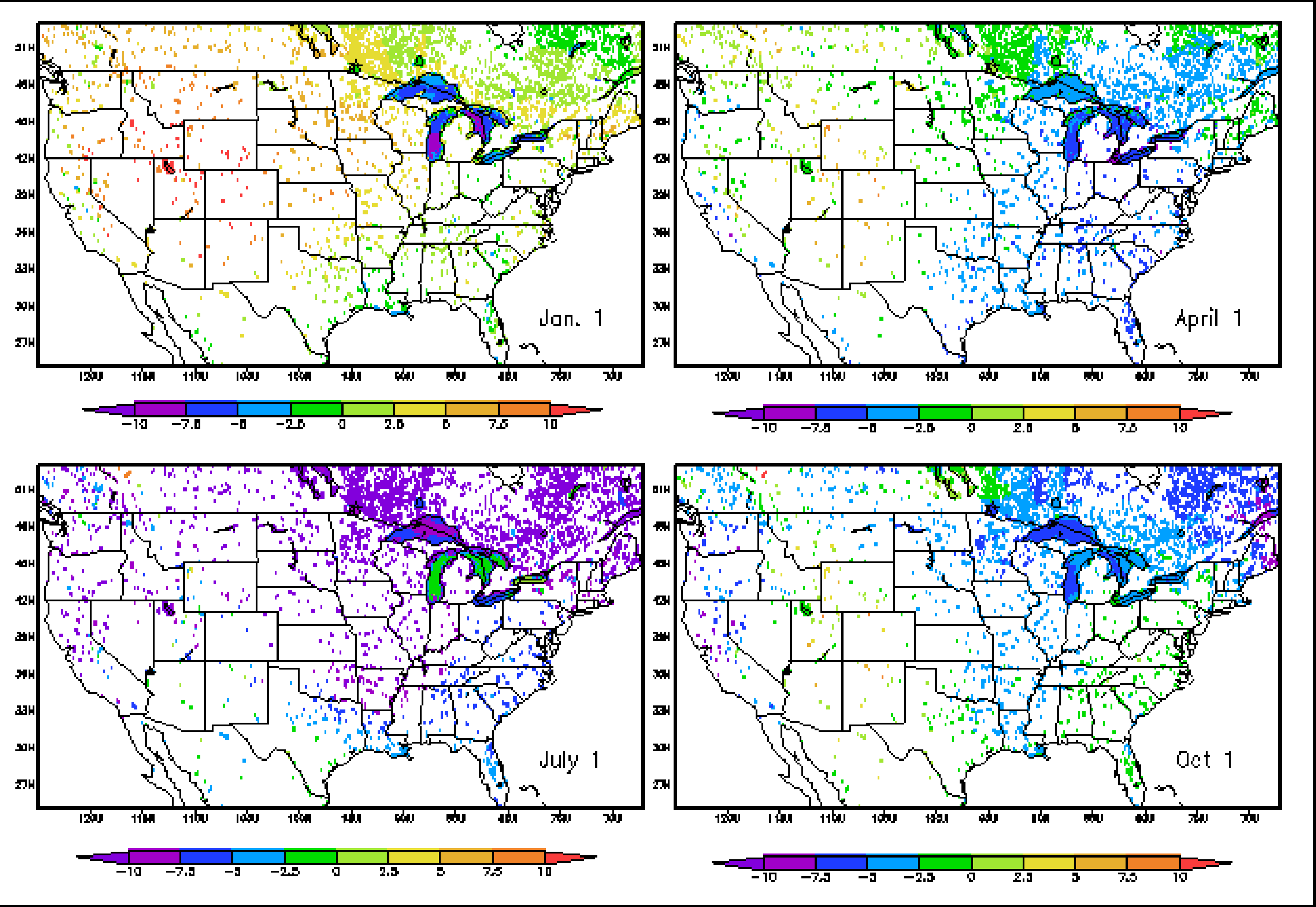
$$\Phi_T = \left(\frac{40}{3}C_T - \frac{20}{3}\right)\zeta + (18 - 30C_T)\zeta^2 + (20C_T - 12)\zeta^3 + \left(\frac{5}{3} - \frac{10}{3}C_T\right)\zeta^4 \quad (2)$$

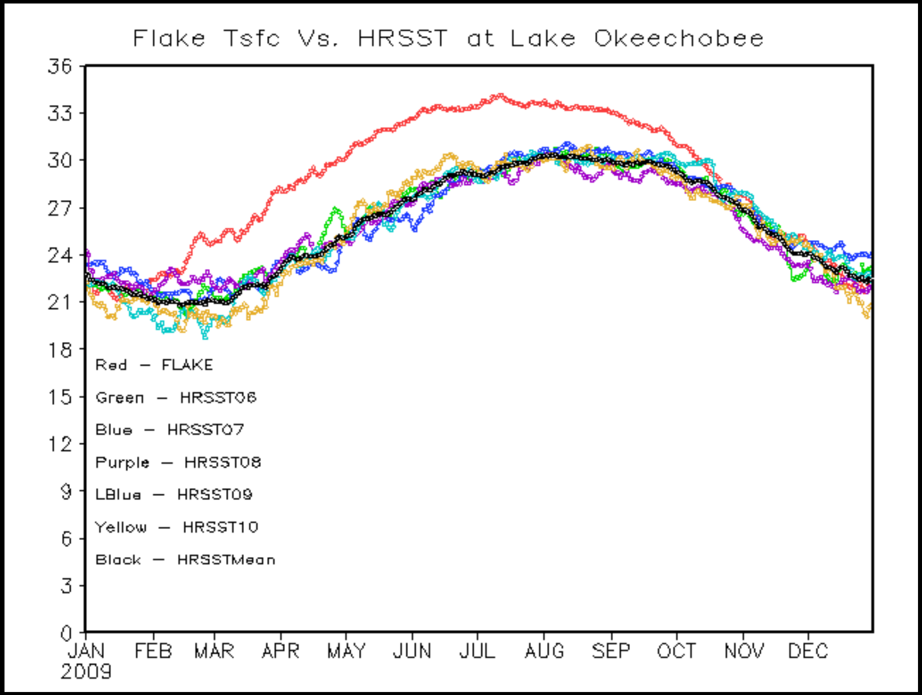
$$\zeta \equiv (z-h)/(D-h) \quad (3)$$

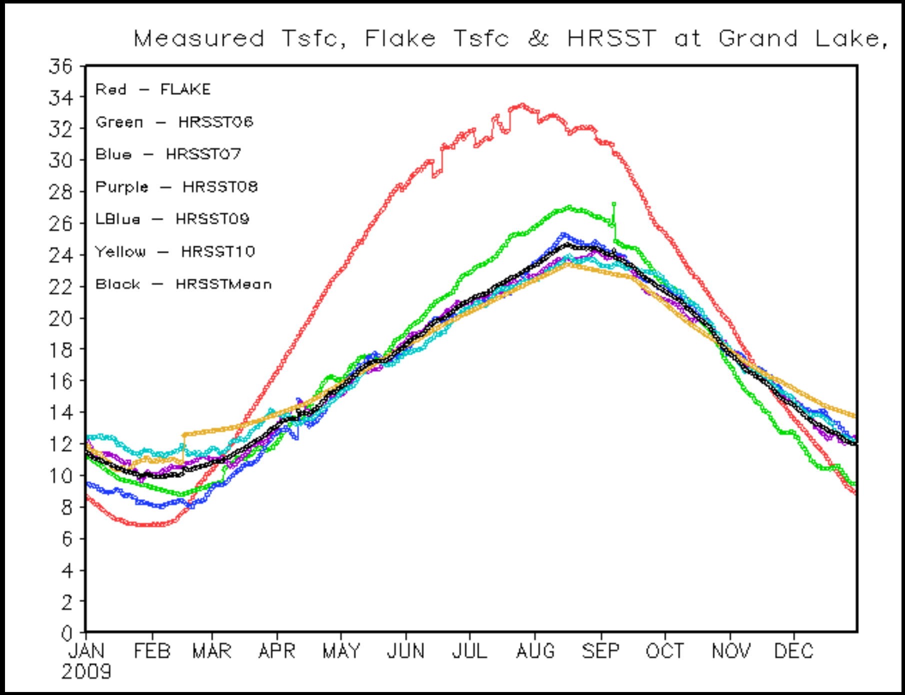
Flake Tsfc Vs. HR_RTG_SST

- A 2-D driver was developed, the Flake is called for each lake grid point
- The Flake was run at 4km for the lakes in USCONUS with NARR data as the driving force.
- The HR_RTG_SST of 2006 to 2010 year and the average of the 5 year were interpolated into the Flake domain at 4km resolution, the values for land is flagged out.
- The differences between Flake Tsfc and the average HR_RTG_SST on 4 different days
- Annual variations of HR_RTG_SST and Flake of lakes.

Differences between HR_RTG_SST and Flake Tsfc




Flake Tsfc Vs. HRSST at Lake Okeechobee
Red – FLAKE
Green – HRSST06
Blue – HRSST07
Purple – HRSST08
LBlue – HRSST09
Yellow – HRSST10
Black – HRSSTMean
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
2009


Measured Tsfc, Flake Tsfc & HRSST at Grand Lake,
Red – FLAKE
Green – HRSST06
Blue – HRSST07
Purple – HRSST08
LBlue – HRSST09
Yellow – HRSST10
Black – HRSSTMean
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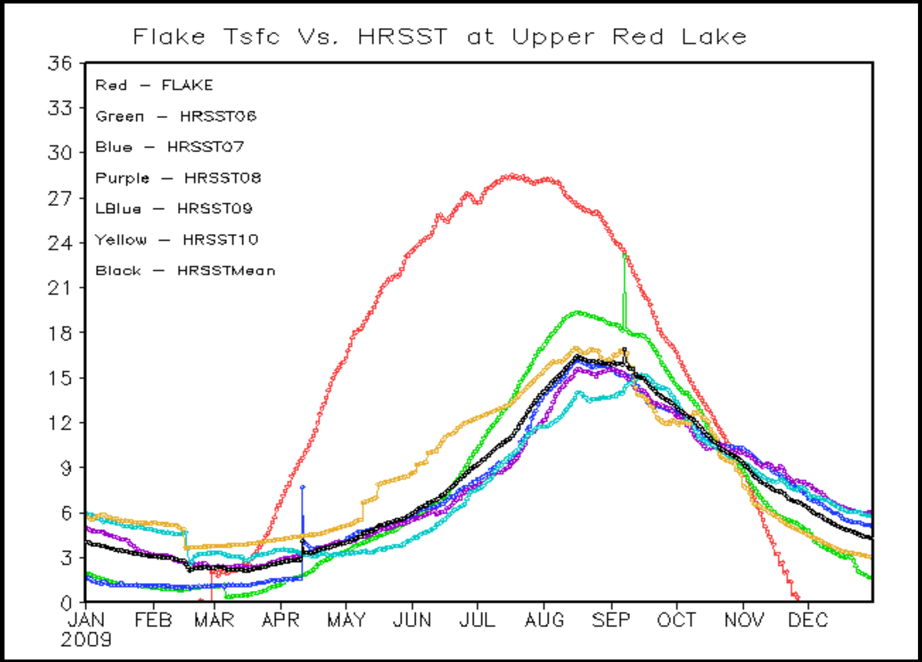
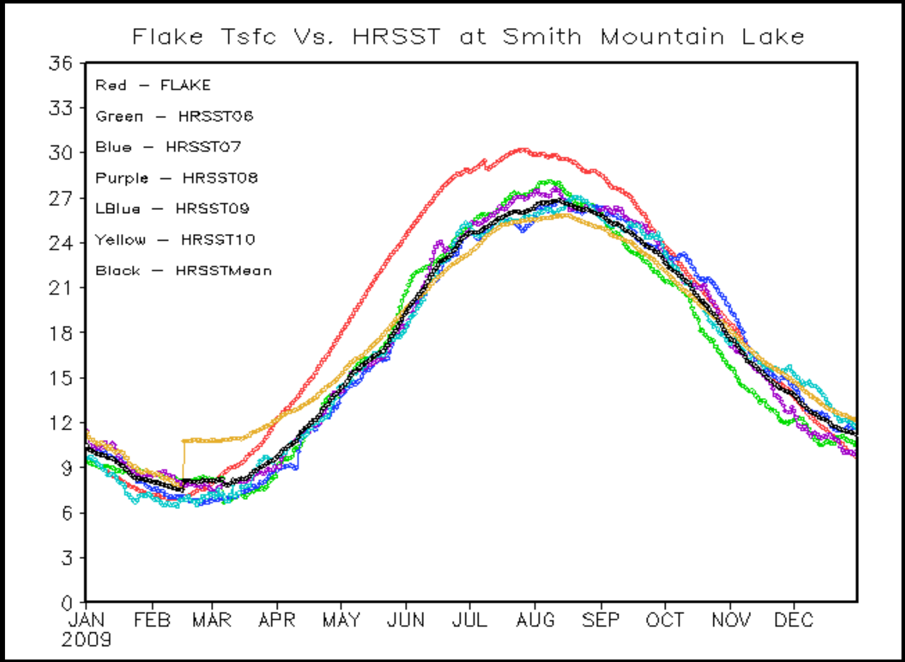
2009


Flake Tsfc Vs. HRSST at Upper Red Lake
Red – FLAKE
Green – HRSST06
Blue – HRSST07
Purple – HRSST08
LBlue – HRSST09
Yellow – HRSST10
Black – HRSSTMean
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
2009


Flake Tsfc Vs. HRSST at Smith Mountain Lake
Red – FLAKE
Green – HRSST06
Blue – HRSST07
Purple – HRSST08
LBlue – HRSST09
Yellow – HRSST10
Black – HRSSTMean
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
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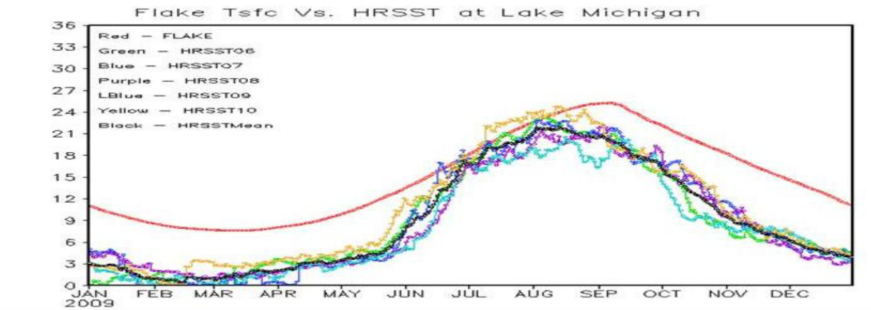

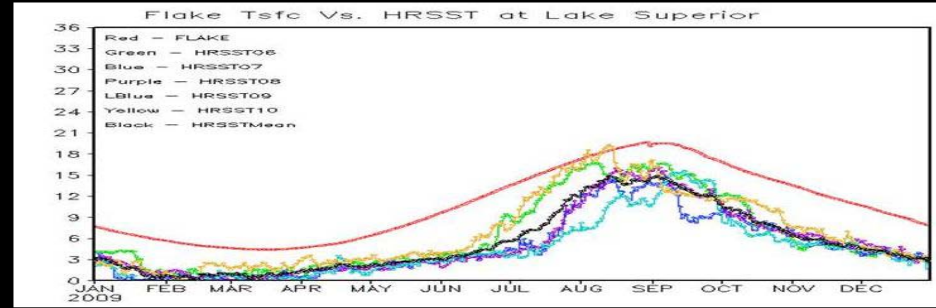

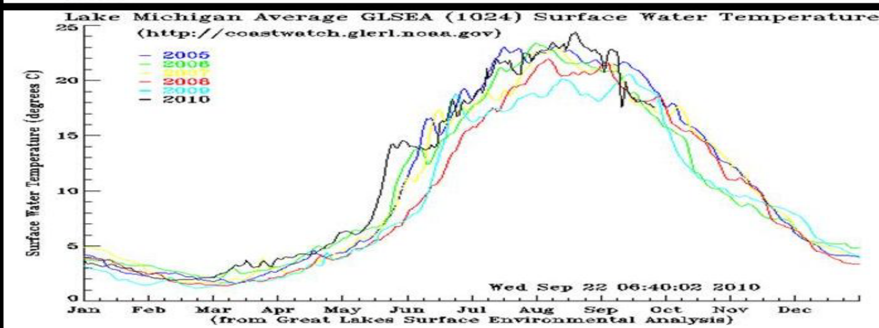

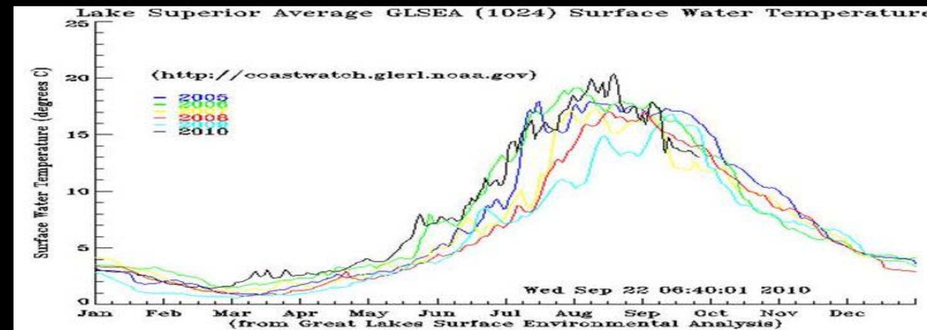

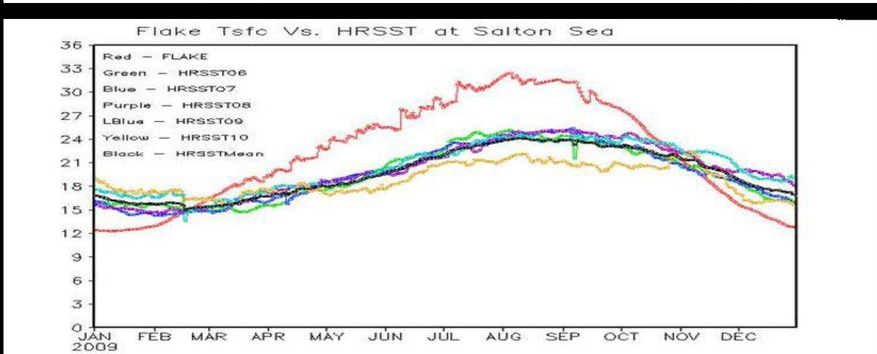

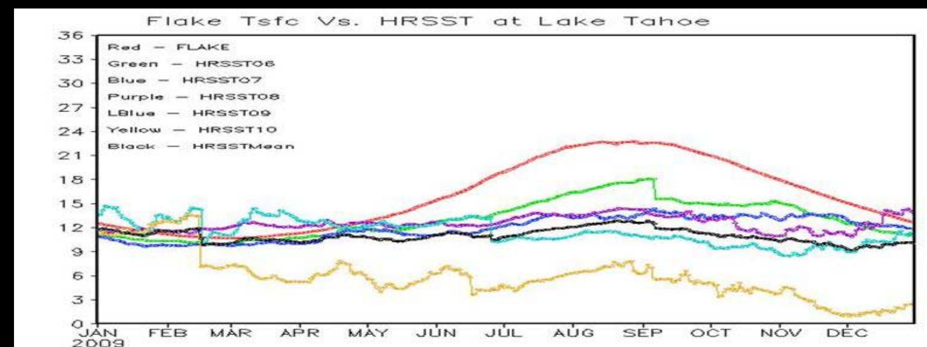

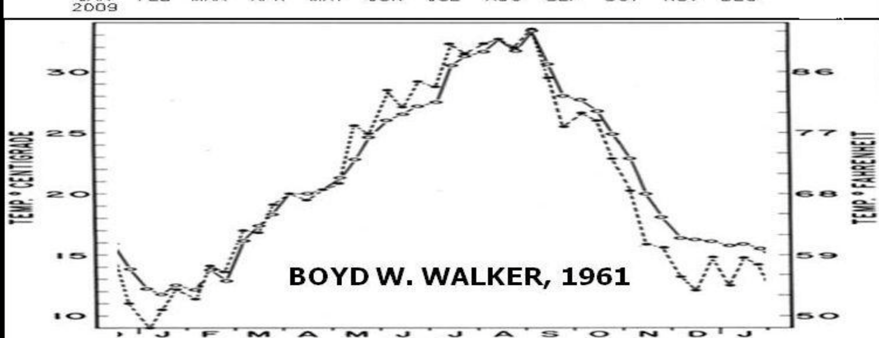

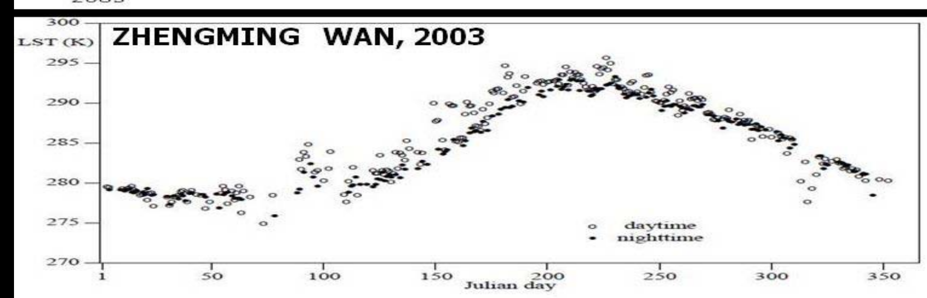

Figure 1. The daytime and nighttime LSTs near the center of Lake Tahoe in the V3 and V4 MOD11A1 products in 2002 before (top) and after (bottom) applying the cloud-screen scheme.

Summary

- Lake water surface temperature for USCONUS was simulated using Flake driven by NARR data forcing
- Flake Tsfc was compared with HR_RTG_SST
- In general, Flake has larger annual variation, and is warmer in warm seasons, colder in cold seasons
- In Winter and Summer, the difference between flake and HR_SST can be larger than 10 degree. In Spring and Fall, the difference is less than 10 degree
- Flake can be used in lake climotologies for high res grids (e.g. fire weather) where lakes are not resolved by the HR_RTG_SST
- Flake can a part of the model physics in NAM as well as NLDAS and GFS/CFS
- Flake is a useful tool for lake management

Thank You