Integrated Physical Modelling of the Lake George, NY Watershed

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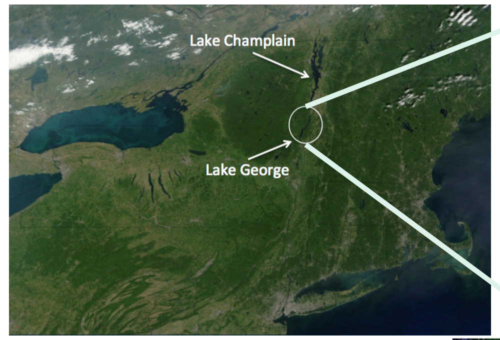
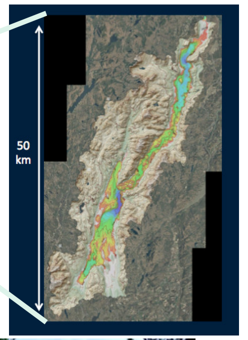
264

Background

- One of the world's most pristine natural ecosystems with $1B annual tourism industry
- Understand and manage the impact from road salt, storm water runoff and invasive species
- Make the lake smarter with a coupled observational and modeling platform

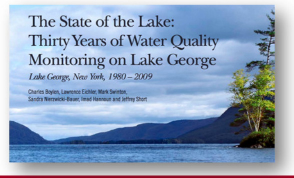


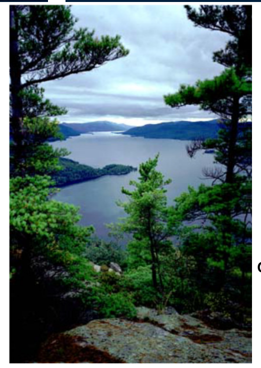


Lake George

- Oligotrophic
- Dimictic
- Spring and tributary-fed with only one outlet at northern end
- Two basins connected by The Narrows
- Maximum depth of 57 m
- 395 islands

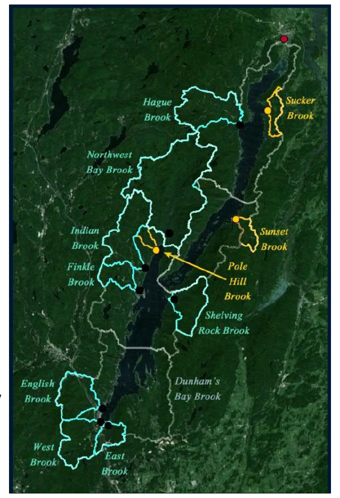
- Recent 30 year longitudinal study highlighted three environmental stressors
  - Road salt (NaCl)
  - Nutrient loading via storm water runoff
  - Invasive species





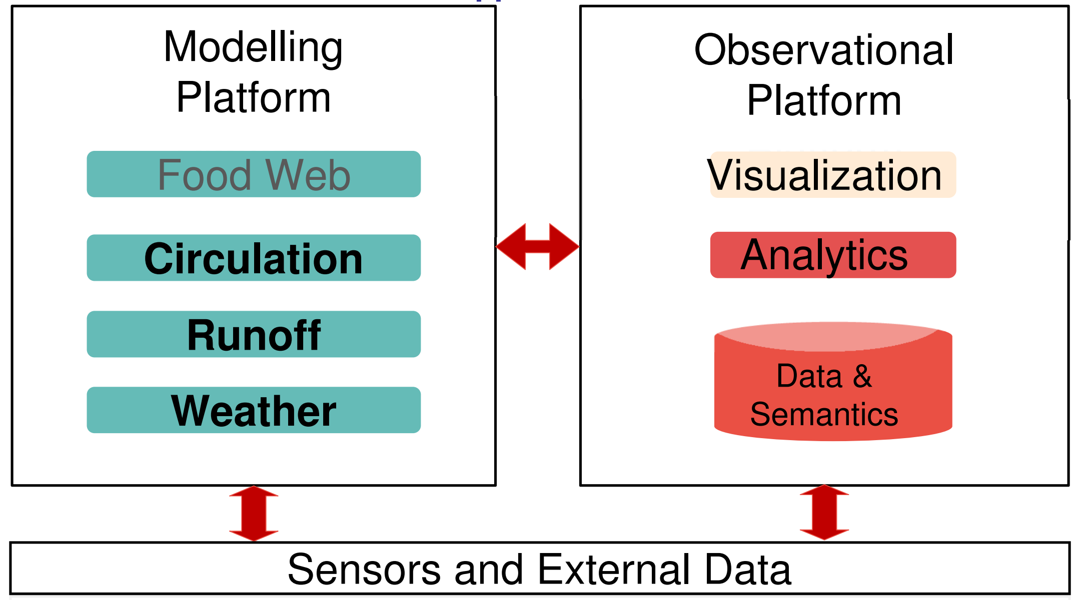
Lake George Watershed

- Location: New York State Adirondack Park
- Area: 238.4 square miles
- Highest elevation: 2646 feet
- Average drainage divide elevation: 1350 feet
- Limited agriculture usage
- Population centers: Lake George Village - south, Ticonderoga - north
- Over 90 in-flowing tributaries with eight accounting for about 45% of total inflow



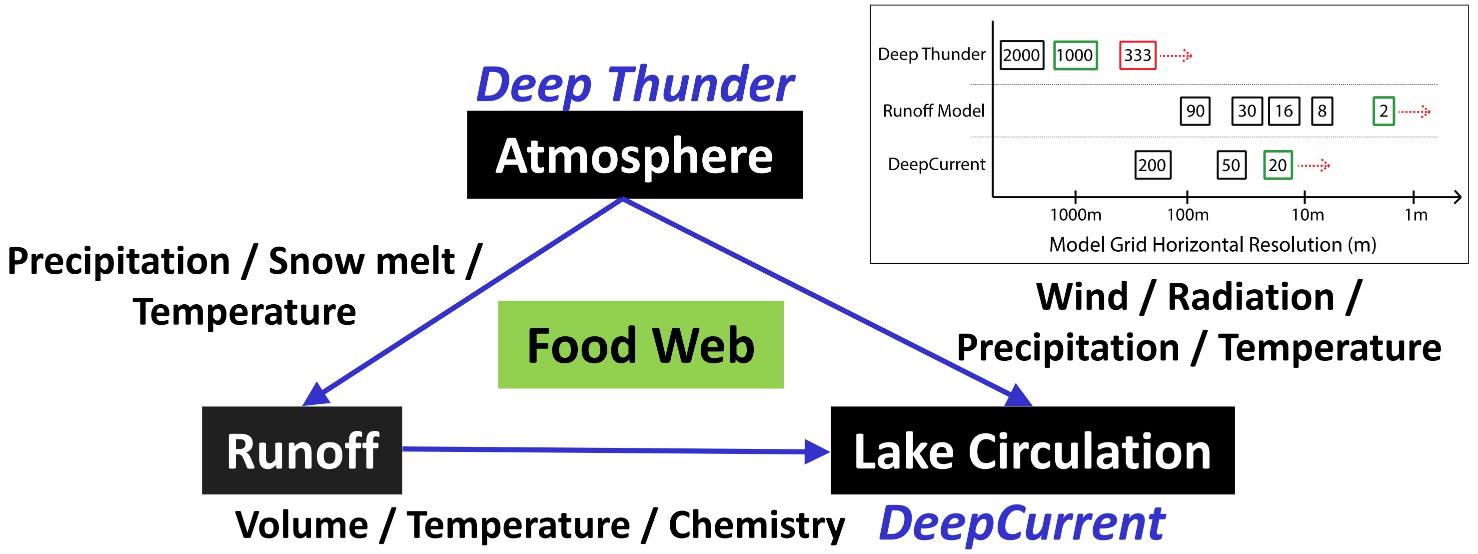
Courtesy USGS and Google Earth

Approach



Realtime, event-driven, distributed, intelligent…

Coupled Models



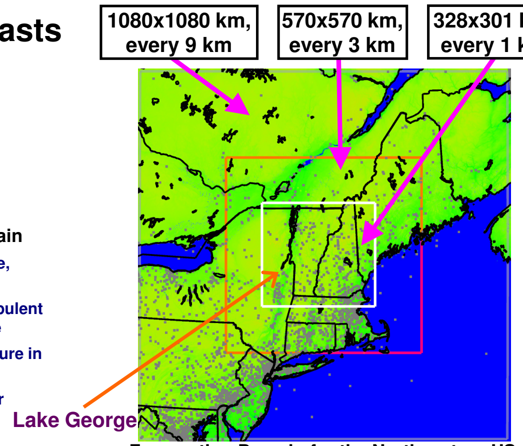
- Weather model (*Deep Thunder*) enables atmospheric forcing for other models, predictions for operations and field work, and public outreach: scaling to O(100m)
- Lake circulation (*DeepCurrent*) to understand transport, hydrodynamics and water quality: scaling to O(10m)
- Runoff model to understand salt transport (precipitation, snowmelt) into the lake: scaling to O(1m)

Weather Model

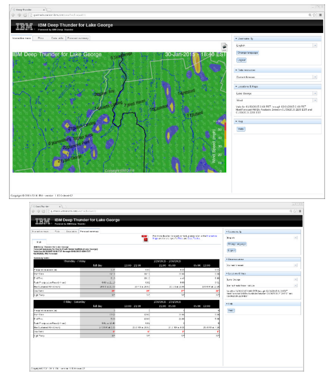
Operational Deep Thunder Forecasts

Model Description

- WRF-ARW 3.5.1
- 9/3/1 km nested for 72 hours (51 vertical levels, with increased resolution in the PBL: 10s of meters near the surface)
- Run twice daily (initialized at 00 and 12 UTC)
- Physics configuration for highly urbanized to rural domain
  - Thompson double-moment microphysics (includes explicit ice, snow and graupel)
  - Mellor-Yamada-Nakanishi-Niino (MYNN) PBL scheme with turbulent kinetic energy (TKE)-based local mixing and 2.5-order closure
  - NOAH land-surface modeling with soil temperature and moisture in four layers, fractional snow cover and frozen soil physics
  - Explicit cumulus physics for innermost nests, Grell Freitas for outer nest
  - 3-category urban canopy model with surface effects for roofs, walls, and streets
  - RRTMG long- and short-wave radiation
- Data assimilation (3dVAR) of near-real-time surface and upper-air observations from Earth Networks WeatherBug, MADIS and private mesonets
  - Surface stations, radiosondes, aircraft, ship, profiles, satellite, …
  - ~3000 stations (gray markers on map): 9km nest (~3000), 3km nest (~1200), 1km nest (~450) – varies for each forecast
  - Additional quality control
- NASA high-resolution (2km) sea surface temperatures (SST), which include Lake Surface Temperature (LST) analysis over the Great Lakes
- NASA high-resolution (90m) Shuttle Radar Topography Mission (SRTM) terrain elevation
- MODIS 1km 20-category land-use data
- NASA 4km dynamic (daily) VIIRS Green Vegetation Fraction (GVF) data
- NASA 3km land surface fields for initialization
- NOAA Rapid Refresh (RAP) 13km analysis for background fields
- NOAA North American Model (NAM) 12km lateral boundary conditions



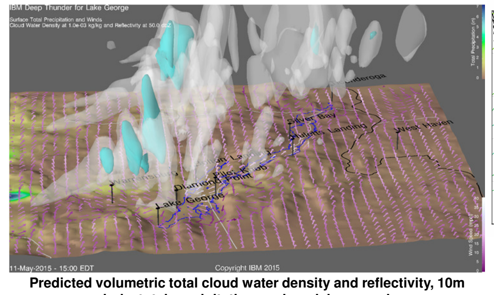
Forecasting Domain for the Northeastern US (Gray Dots Mark Sites for Data Assimilation)



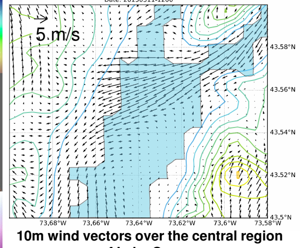
Snapshots from Web-based Dissemination

The weather model is the foundational capability, which couples to and drives the physical modeling suite, providing:

- Precipitation forecasts for runoff and hydrological modelling
- Wind, temperature, precipitation and radiation forecasts for lake circulation modelling
- Weather predictions for operations and field work
- Predictive analytics for adaptive sensor data sampling strategy
- Weather predictions to enable community and educational outreach
- Forcing of a VLES-scale domain to further resolve watershed scale processes



Predicted volumetric total cloud water density and reflectivity, 10m winds, total precipitation, and model orography



10m wind vectors over the central region of Lake George

Example Deep Thunder 333m VLES results from a 48-hour run initialized at 11 May 2015 12 UTC

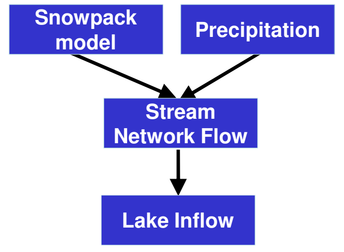
Runoff Model

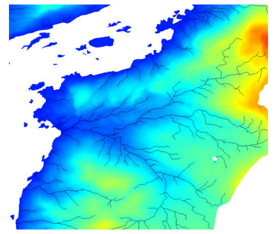
Model Description

- Unsteady routing of runoff generated by Deep Thunder's subsurface flow (from snow pack) and precipitation estimates
- Transport of temperature and solute density (chloride and sodium) along the stream network segments

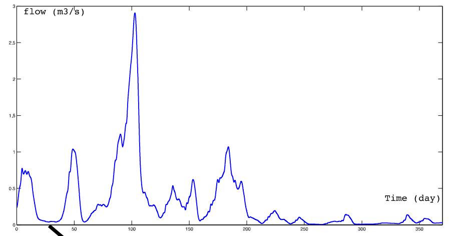
Input Data

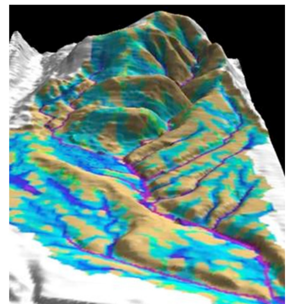
- Deep Thunder hourly run-off estimates
- Stream networks derived from red laser LiDAR data at a resolution of 5m
  - 407 stream networks with a length of 1154 km
  - Modeled by 13,794 segments

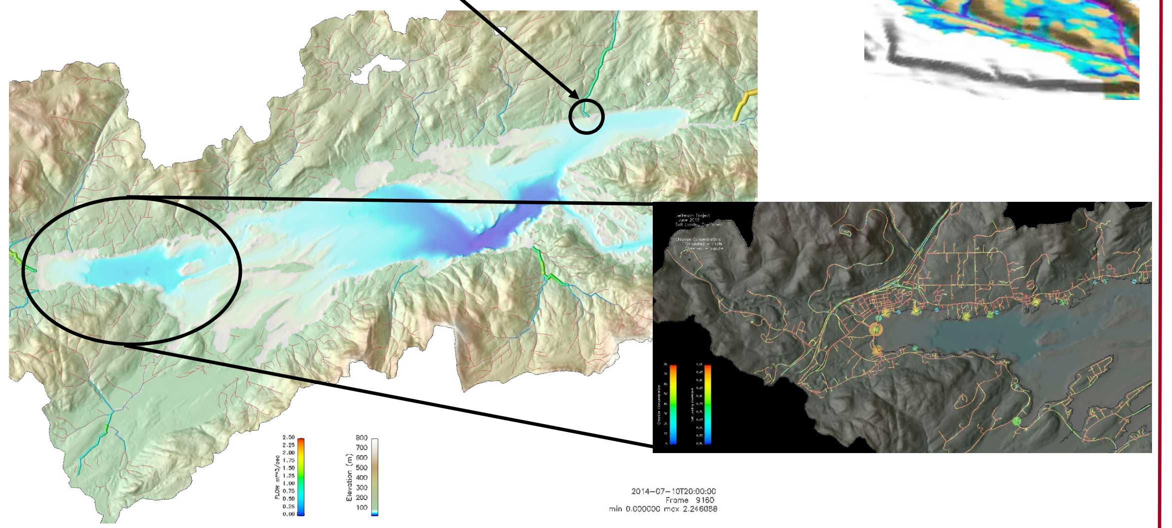




Stream network delineated from LiDAR data







Unsteady routing simulation frame (colored dots on top of red streams)

Circulation Model

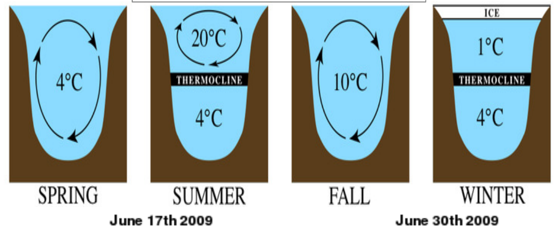
Model Description (*DeepCurrent*)

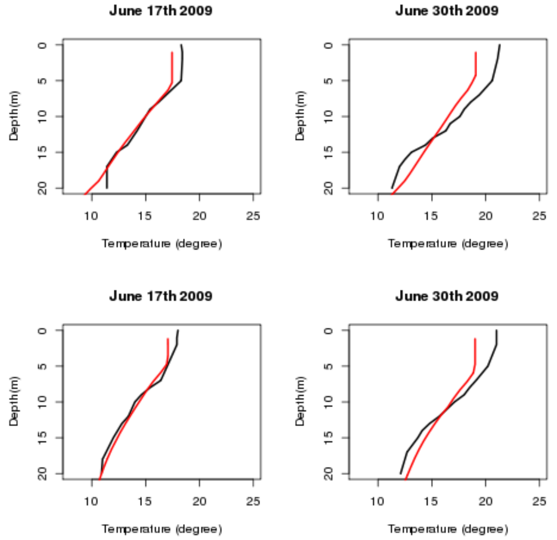
- Based upon Environmental Fluid Dynamics Code (EFDC)
- A general-purpose modelling package for simulating three-dimensional flow, transport and bio-geochemical processes in surface water systems

Validation Philosophy - Thermocline Path

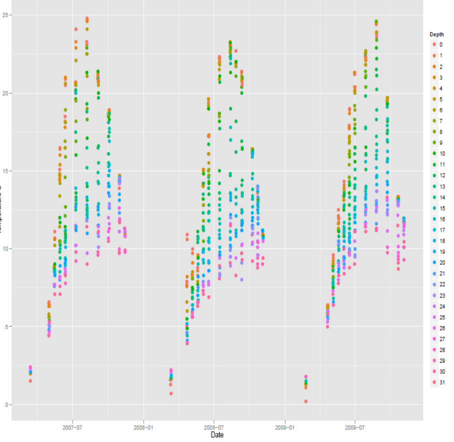
- Limited flow data – impossible to validate directly
- Sparse temperature data – detailed statistical validation detailed
- Thermocline path – detect the turnover events

Seasonal Vertical Mixing

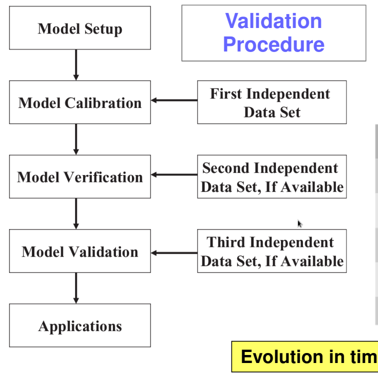




- Comparison of measured and modelled water temperatures at different points within the lake
- Black lines are measurements and red lines indicate model



Measurement Data for 3-year period



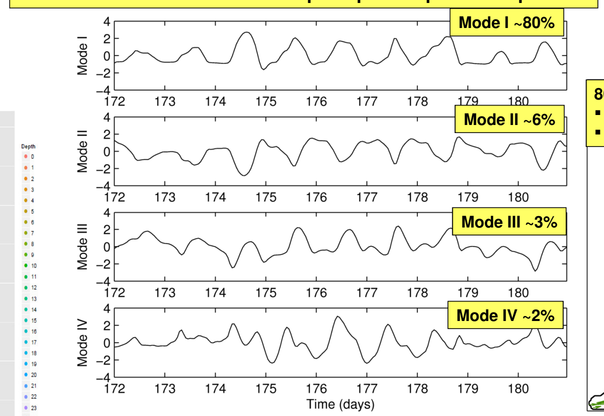
Analysis of dominant flow processes – Principal Component Analysis (PCA)

- Identification of statistically independent patterns of flow that can be associated with different physical processes via PCA
- A mathematical procedures that transforms a number of (possibly) correlated variables into a (smaller) number of uncorrelated variables

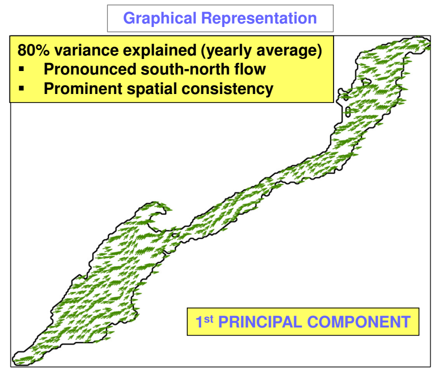
PC	May	June	July	August	Sept	Oct
Mode I	0.82	0.79	0.80	0.83	0.72	0.86
Mode II	0.89	0.87	0.86	0.87	0.80	0.90
Mode III	0.92	0.90	0.89	0.90	0.84	0.92
Mode IV	0.94	0.93	0.91	0.92	0.87	0.93
Mode V	0.95	0.94	0.93	0.94	0.89	0.95

- Allows the temporal and spatial variations of the data to be examined separately
- Informs on relationship between flow processes and lake inflows (streams), wind forcing and solar heating

Evolution in time of the first four principal component amplitudes



Graphical Representation



Related Presentations

14th History Symposium:
- 4.2 The History, Development and Application of the Business of Weather at IBM

23rd Conference on Probability and Statistics in the Atmospheric Sciences:
- 14.5 Verification od High-resolution WRF-ARW Forecasts for Vermont Utility Applications

7th Conference Weather, Climate, Water and the New Energy Economy
- 2.4 Enhanced Statistical Post-Processing of Solar Irradiance Predictions Using Optimized WRF Forecasts of Cloud Cover Categories
- 2.5 Coupling Numerical Weather Predictions to Demand and Solar Energy Forecasting Models in an Operational Setting
- 5.5 Analysis of Short-term Wind Power Forecasting in the Northeastern United States
- 7.4 Deployment of Coupled Models to Enable Renewable Integration in Vermont
- 8.2 Toward Integration of Seasonal Climate Forecasts into Energy Decision Support Systems
- 8.5 The Characteristics and Formation Mechanisms of Low Level Jets in China and their Relationship with Wind Energy
- 427 Application of Ensemble Forecast and Linear Regression Methods in Improving PM10 Forecast over Bejing Areas

30th Conference on Hydrology
- 538 Modulation of Urban Heat Island and Heat Waves under Current and Future Climate
- 5B.3 Surface Runoff Simulation and Application using WRF-Hydro for city Flood in ChinaEverything in Between

Related Presentations (Continued)

18th Conference on Atmospheric Chemistry
- 698 Impacts of an Unknown Daytime HON Source on the Mixing Ratio and Budget of HONO and Hydroxyl, Hydroperoxyl and Organic Peroxy Radicals in the Coastal Regions of China

20th Conference on Integrate Observing and Assimilation Systems for the Atmosphere, Oceans and Land Surface (IOAS-AOLS)
- 255 The Use of Breeding Method for Nested WRF-ARW Simulations
- 676 An Integrated Modeling, Observing and Visualization System for the Study of the Ecology of Lake George in the Jefferson Project

31st Conference on Environmental Information Processing Technologies
- 14A.3 WISE: A weather Visualization Tool for Operational Environments

6th Conference on Transition of Research to Operations
- 6.1 Fine Scale Hail Hazard Prediction using the WRF Model

Town Hall Meeting: The Weather Value Chain of the Future From Commercial Satellites to Crowdsourcing, and Everything in Between

Major Weather Impacts in 2015
- 492 The January 26-27, 2015 Winter Storm in the Northeastern United States and the Challenges for Mesoscale Weather Forecasting