Web-based Visualization of Ensemble Forecast Datasets

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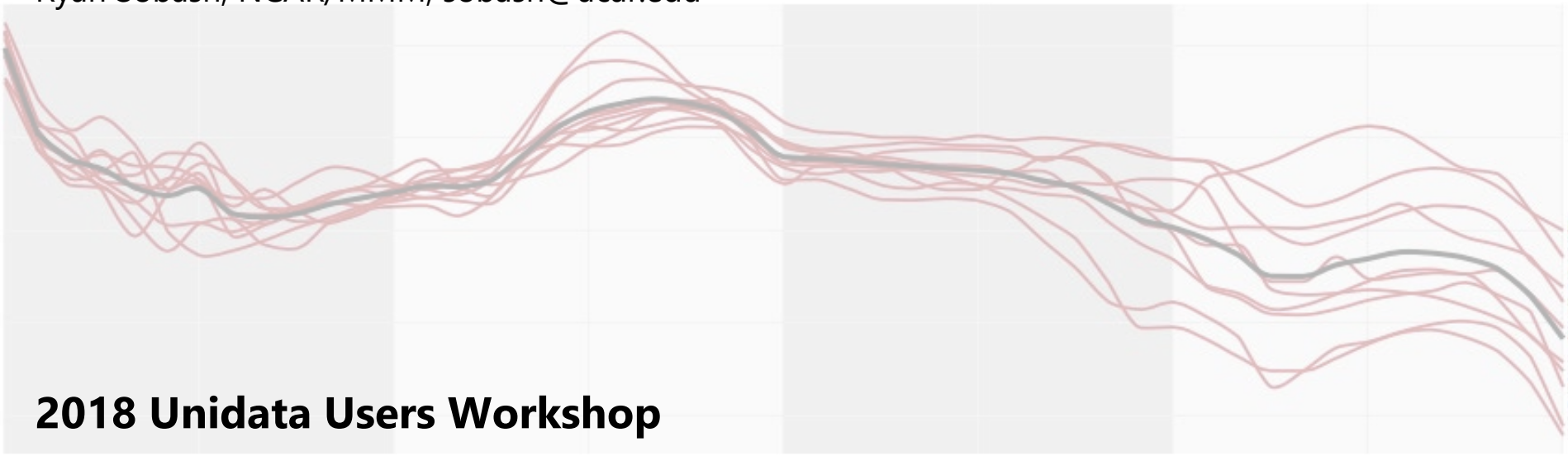


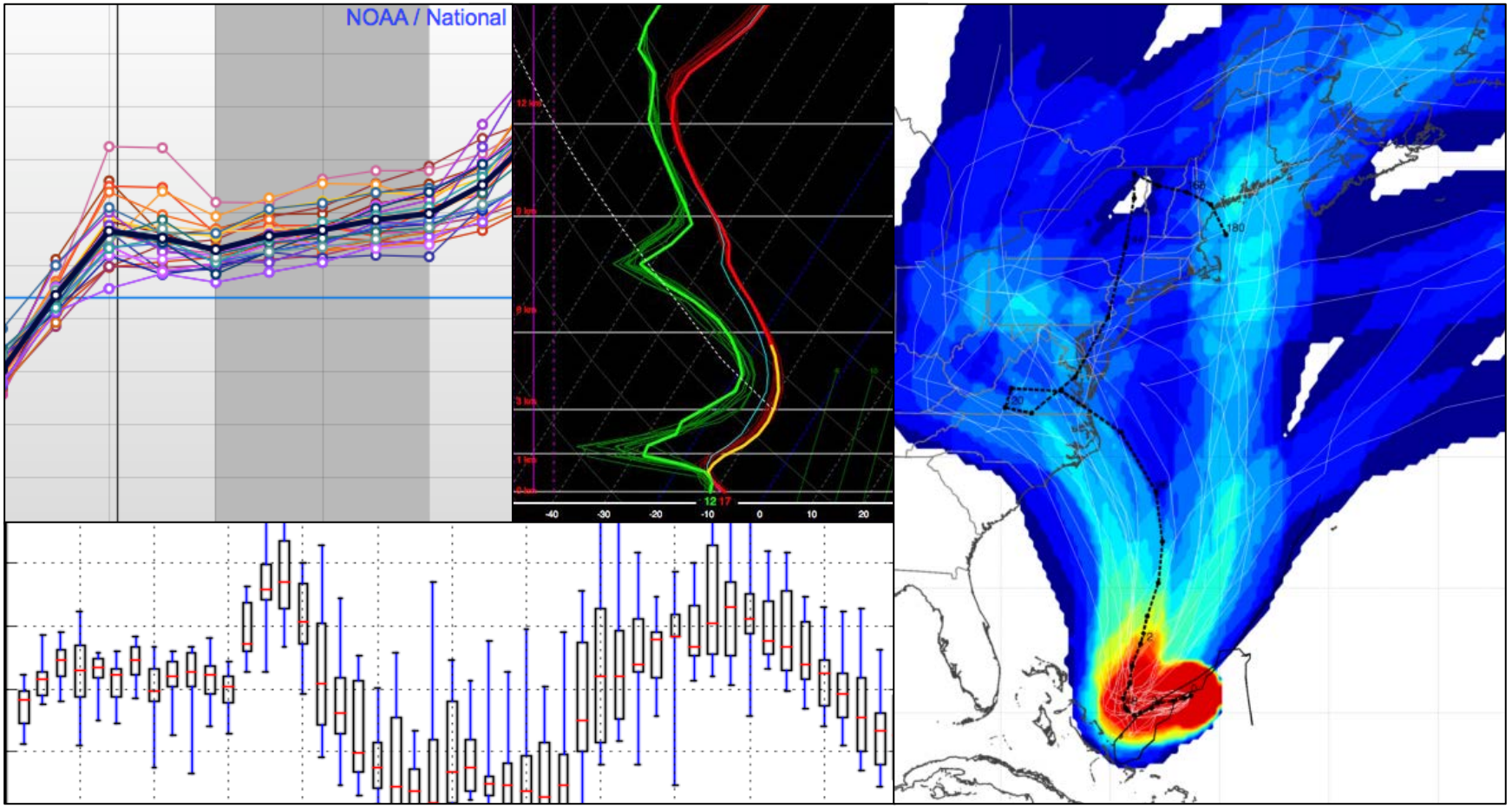
2018 Unidata Users Workshop

git clone https://github.com/rsobash/unidata.git

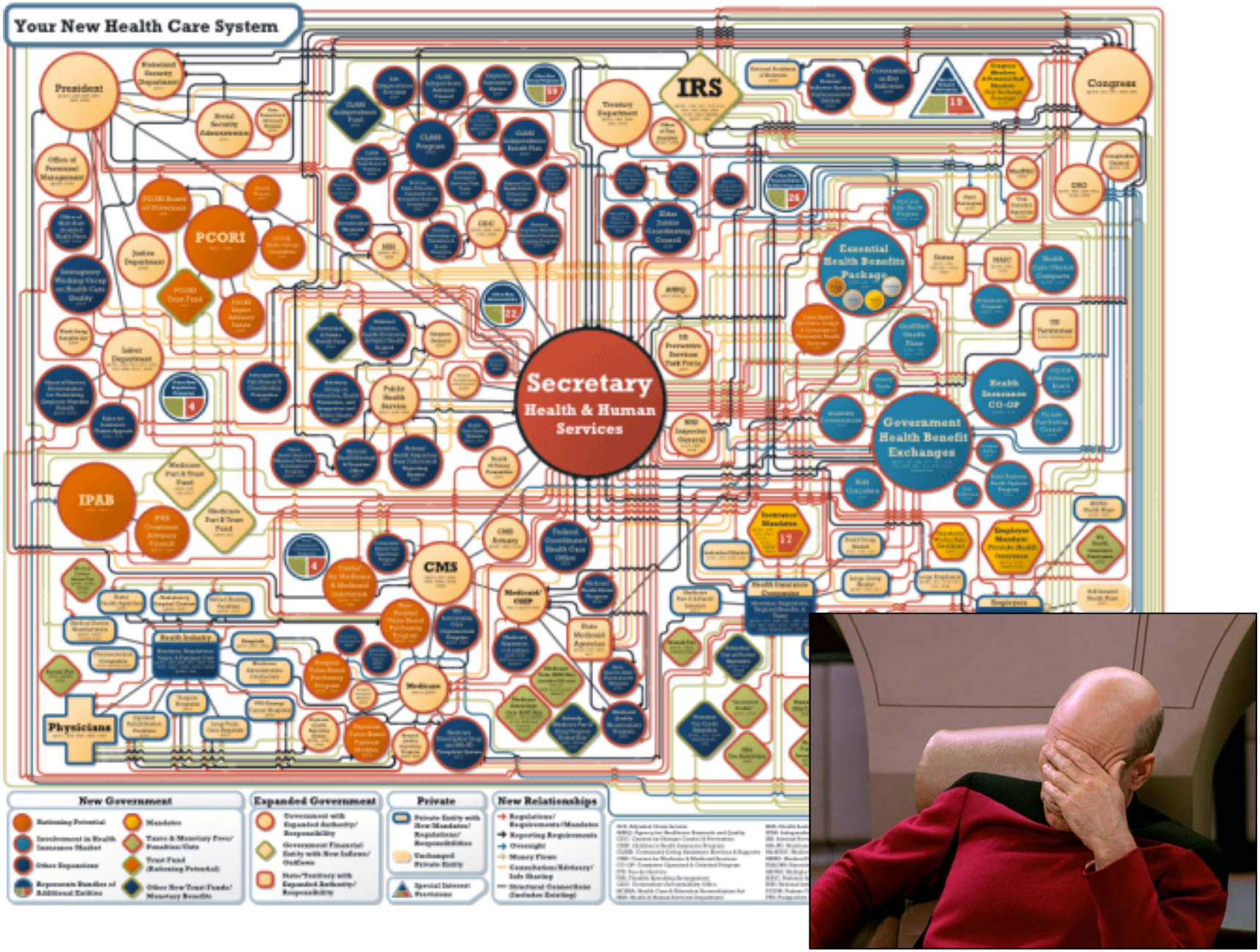
1. Open favorite browser

2. Open ”bar_chart.html” in repo (File > Open File in Safari).

What makes for effective web-based forecast visualization?



Design choices become even more important with ensembles


Your New Health Care System
President
IRS
Congress
PCORI
Secretary
Health & Human Services
Essential Health Benefits Package
Government Health Benefit Exchanges
IPAB
CMS
Medicare
Physicians
New Government
Expanded Government
Private
New Relationships

NOAA's Operational Numerical Guidance Suite

3D-Var DA
Climate Forecast System (CFS)
GFS, MOM4, GLDAS/Noah Land, Sea Ice

3D-En-Var DA
Regional Hurricane
GFDL
HWRF

Waves
WaveWatch III

Ocean (RTOFS)
HYCOM

Nearshore Waters
SURGE: SLOSH
ESTOFS: ADCIRC
NWPS: WWIII

Ecosystem
EwE

Regional Bays
- Great Lakes (POM)
- N Gulf of Mexico (FVCOM)
- Columbia R. (SELFE)
- Chesapeake (ROMS)
- Tampa (ROMS)
- Delaware (ROMS)

4D-En-Var DA
Global Forecast System (GFS)
Global Spectral
Noah Land model

3D-Hybrid VAR DA
NAM/NAM-nests
NMMB
Noah land model

Global Ensemble Forecast System (GEFS)
21 GFS Members

Short-Range Ensemble Forecast 26 members
WRF-ARW & NMMB
13 members each

Dispersion
HYSPLIT

Air Quality
CMAQ

North American Ensemble Forecast System
GEFS, Canadian Global Model

High Res Windows
WRF-ARW & NMMB

North American Land Surface Data Assimilation System
Noah Land Surface Model

Regional Climate Data Assimil. Syst.
Eta-32/NARR

National Water Model
Noah-MP

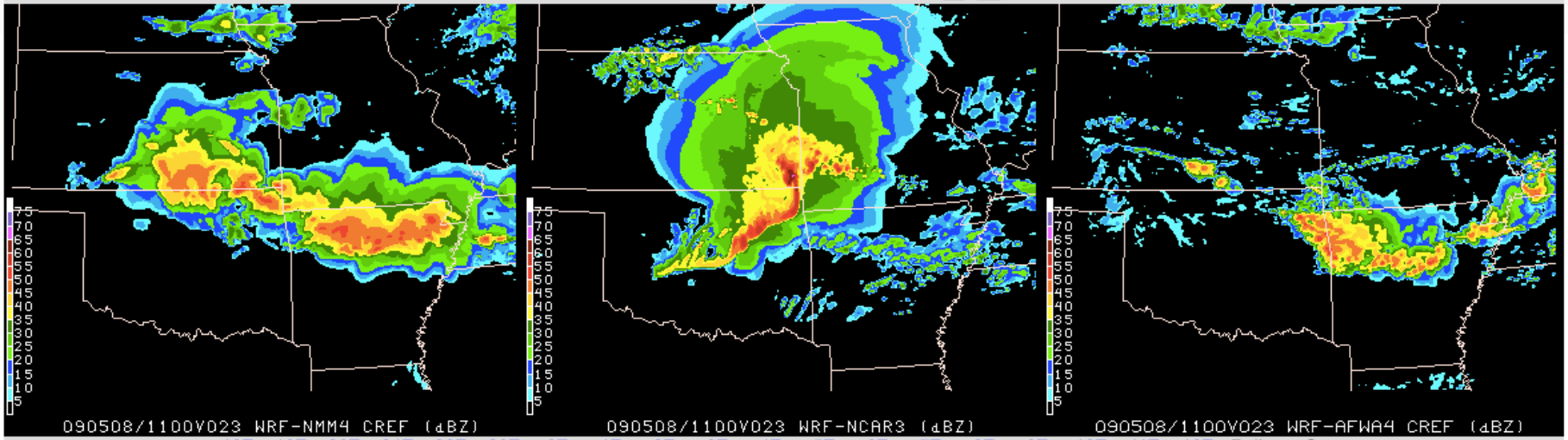
NEMS Aerosol Global Component (NGAC)
GFS & GOCART

2nd Annual Technical and Strategic Review of the
9-11 August 2016, NOAA Science Cente

NSSL/SPC Spring Experiment 2009

Model Comparison - 20090507 - Centerpoint: GMJ

Frame 18 of 19 20090508/11Z Start Stop < > - + 20 img/sec Dwell Rock



18Z 19Z 20Z 21Z 22Z 23Z 0Z 1Z 2Z 3Z 4Z 5Z 6Z 7Z 8Z 9Z 10Z 11Z 12Z Rollover On

keyboard: play **[p]** stop **[o]** step forward **[>]** step backward **[<]**

1km AGL Sim. Refl. Comparisons for 20090507

0Z NSSL	0Z NMM	BREF
0Z NSSL	0Z AFWA	BREF
0Z NMM	12Z NMM	BREF
0Z NCAR	12Z NCAR	BREF
0Z CAPSCNarw	0Z CAPS1	BREF
0Z CAPSCNarw	0Z CAPSC0arw	
0Z HRRR	BREF	(Yest. Centerpt)
12Z CAPSV2C0	12Z CAPSV2CN	
12Z HRRR	BREF	
0Z NMM	0Z NSSL	0Z CAPSCNarw
0Z NCAR	BREF	0Z CAPS1

Surrogate Severe Comparisons

0Z NSSL	0Z NMM	LSR
0Z NMM	12Z NMM	LSR

Temp/Dewpoint Comparisons

0Z NSSL T	0Z AFWA T	SfcOA T
0Z NSSL Td	0Z AFWA Td	SfcOA Td

4-panel Model Summaries (REFL/T/Td/CAPE)

00Z NSSL
00Z NMM
00Z AFWA

Case Studies

May 8th Derecho:
2009050712 Init: 1km REFL | CREF
2009050800 Init: 1km REFL | CREF

April - June 2009

S	M	T	W	R	F	S
26	27	28	29	30	1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30
31	1	2	3	4	5	6
7	8	9	10	11	12	13

Centerpoints

To see this comparison for another date, click the date above.

NCAR Ensemble Forecasts

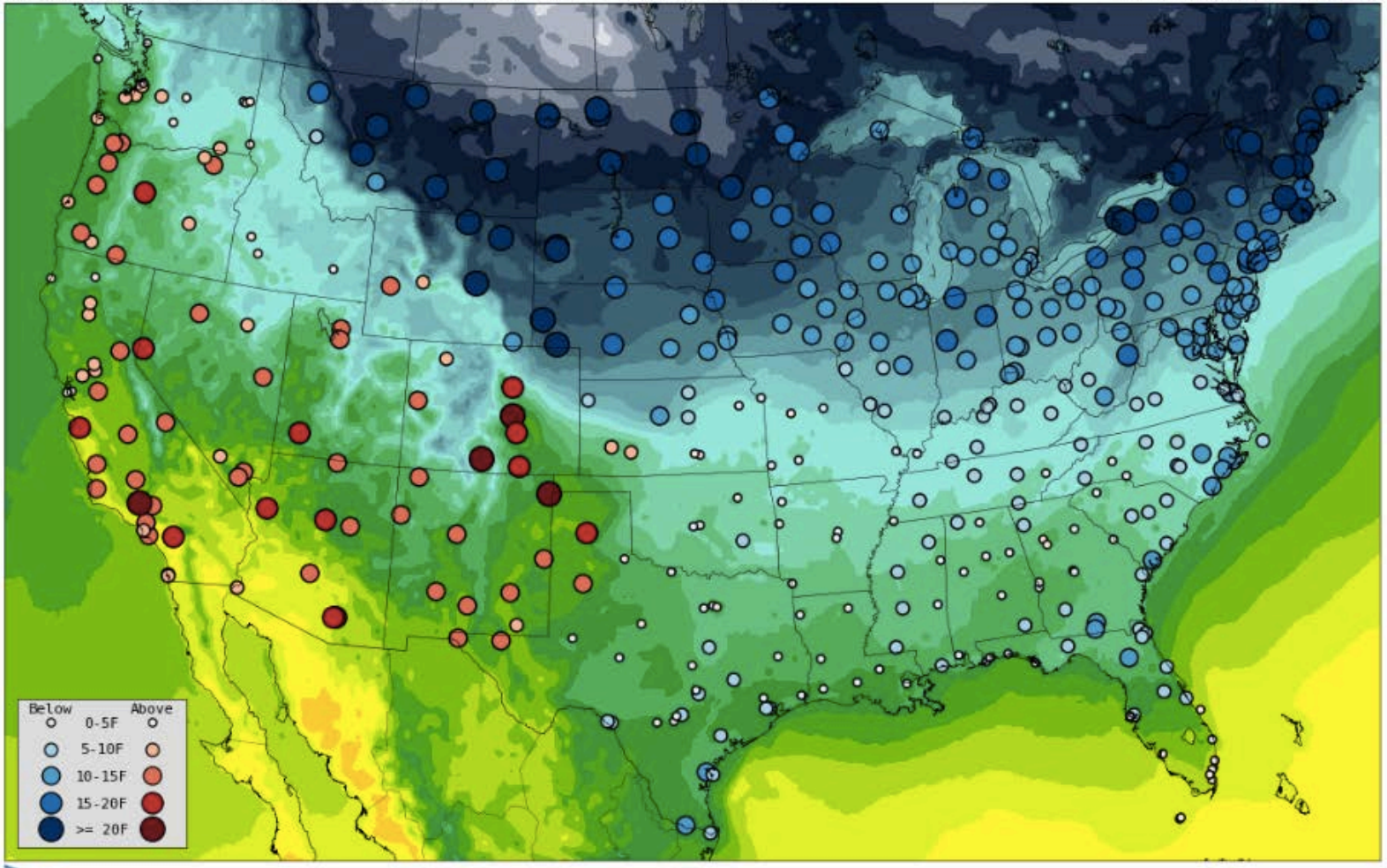
Initialized: 00 UTC Sat 30 Dec 2017

Surface / Precip | Upper-Air | Severe | Winter | Hourly-Max | Domains

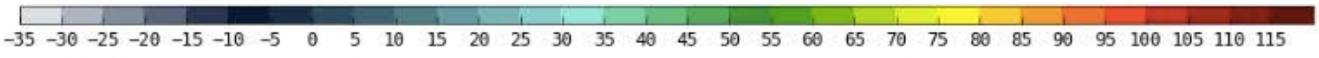
00 01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48

Ensemble mean 2-m temperature (F) and T departure from hrly climo

Init: Sat 2017-12-30 00 UTC
Valid: Sat 2017-12-30 00 UTC



NCAR
ensemble.ucar.edu



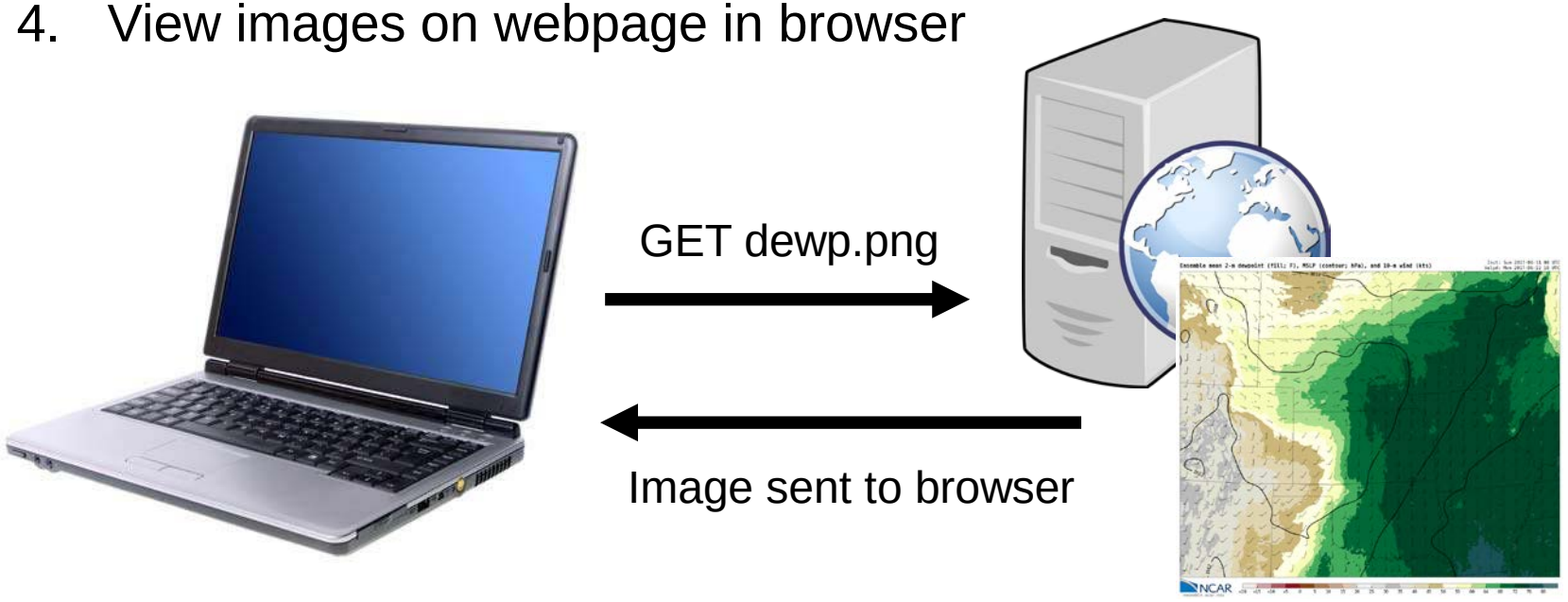
Keyboard commands: toggle county overlay (regions only) [o] --- previous image [<] --- next image [>] --- hide header [h]

Forecasts sponsored by the National Science Foundation, National Center for Atmospheric Research/Mesoscale and Microscale Meteorology Laboratory, and Computational Information Systems Laboratory

About these Forecasts || Analysis System Statistics || Verification || System Status || FAQ || Contact us: ensemble (at) ucar (dot) edu

Forecast visualization largely consists of static images…

1. Produce or retrieve model data (WRF, NAM, etc.)
2. Process using visualization software (NCL, python, GEMPAK)
3. Transfer to web server
4. View images on webpage in browser



Limited interaction, **synchronous** requests

Using web-based visualization packages

Many exist! Some higher, more abstracted than others (Google Charts, Tableau, Visual.ly).

Most libraries use **Javascript**. Browser processing of js has improved dramatically over previous decade.

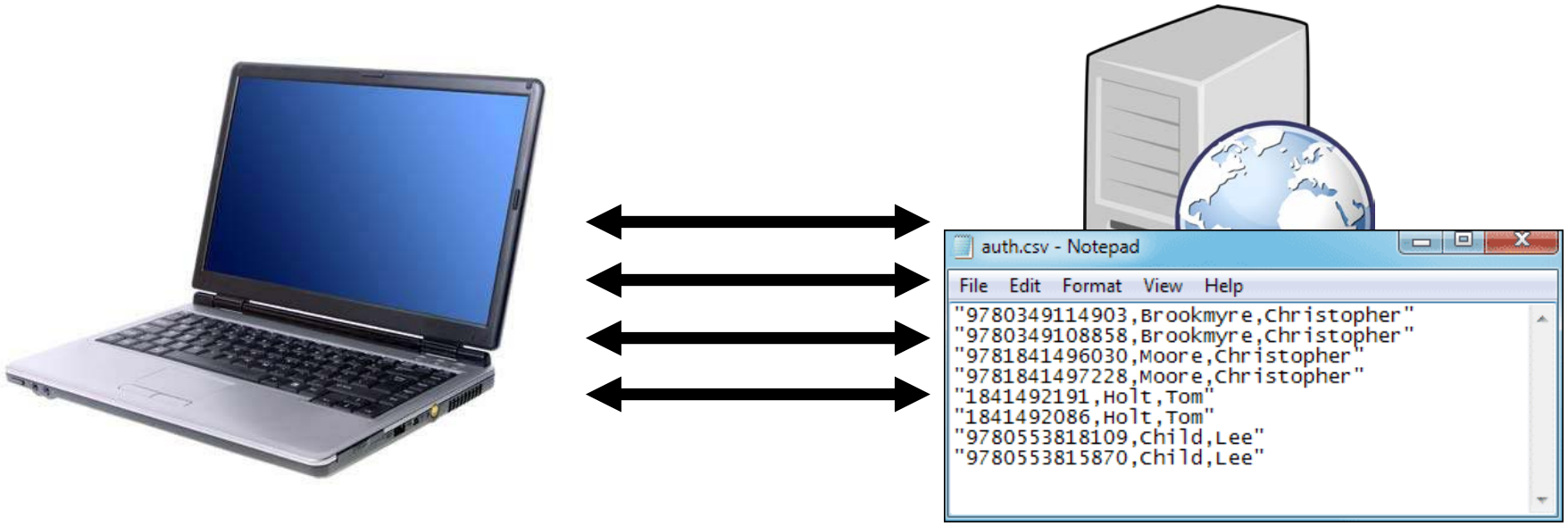
Today, js is used both on client and server sides to unify web application development.

Gmail and Google Maps (circa 2005) among the first single-page js apps that didn’t require a full page load after an interaction.

Uses XMLHttpRequest (XHR) to transfer data between browser and server using js.

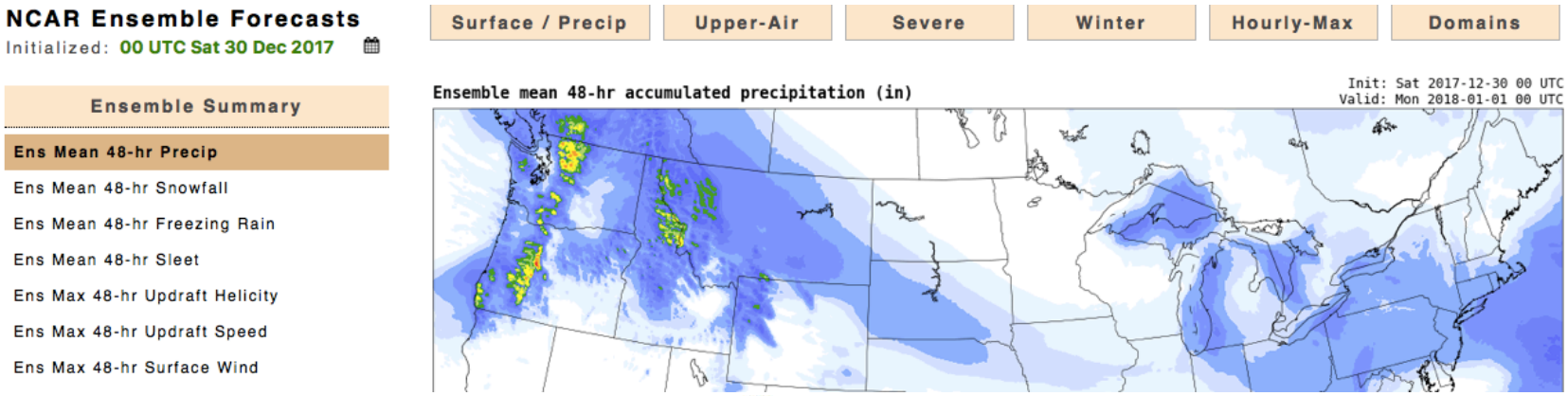
Backbone of “AJAX” (Asynchronous Javascript and XML) web development.

Data transferred as HTML, XML, JSON, CSV, etc.



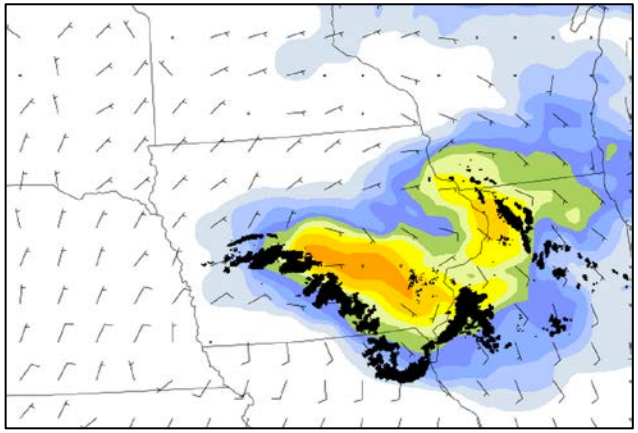
Extensive interaction possible, **asynchronous** requests

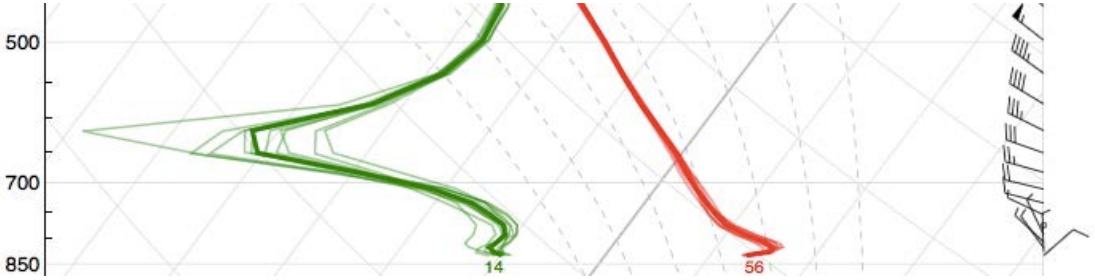
NCAR Ensemble Website



http://ensemble.ucar.edu

Last forecast: 30 December 2017

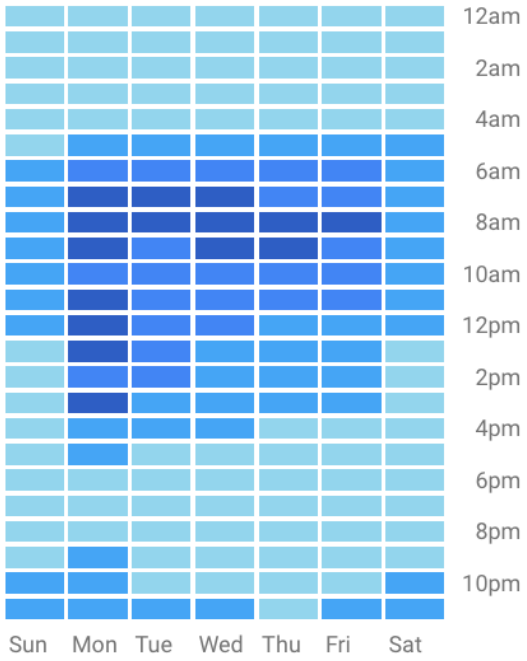




Each forecast generated 4 TB of data per day.

NCAR Ensemble Website

Usage by time of day

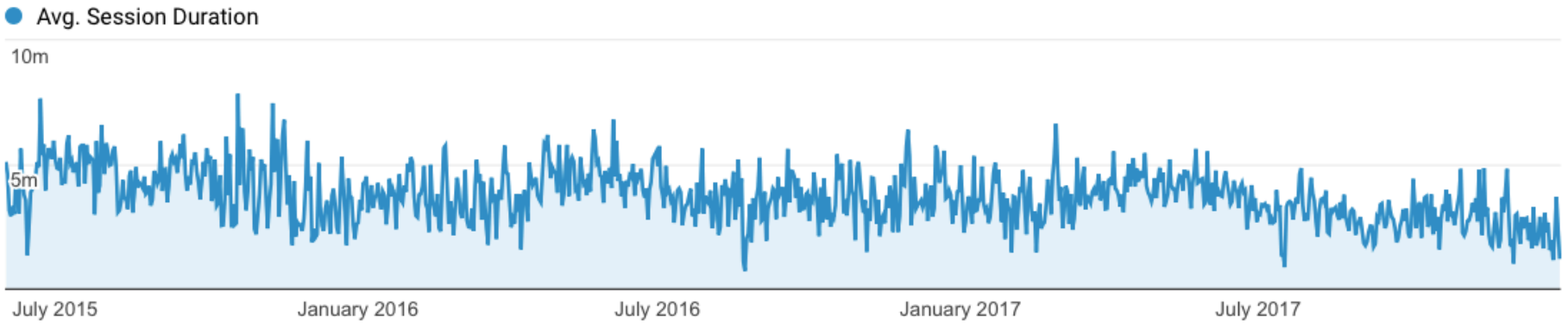


Top 5 network sources:

1.	national oceanic and atmospheric administration	18.22%
2.	national weather service eastern region headquarters	10.75%
3.	(not set)	8.21%
4.	national weather service southern region headquarters	5.22%
5.	national center for atmospheric research	2.74%

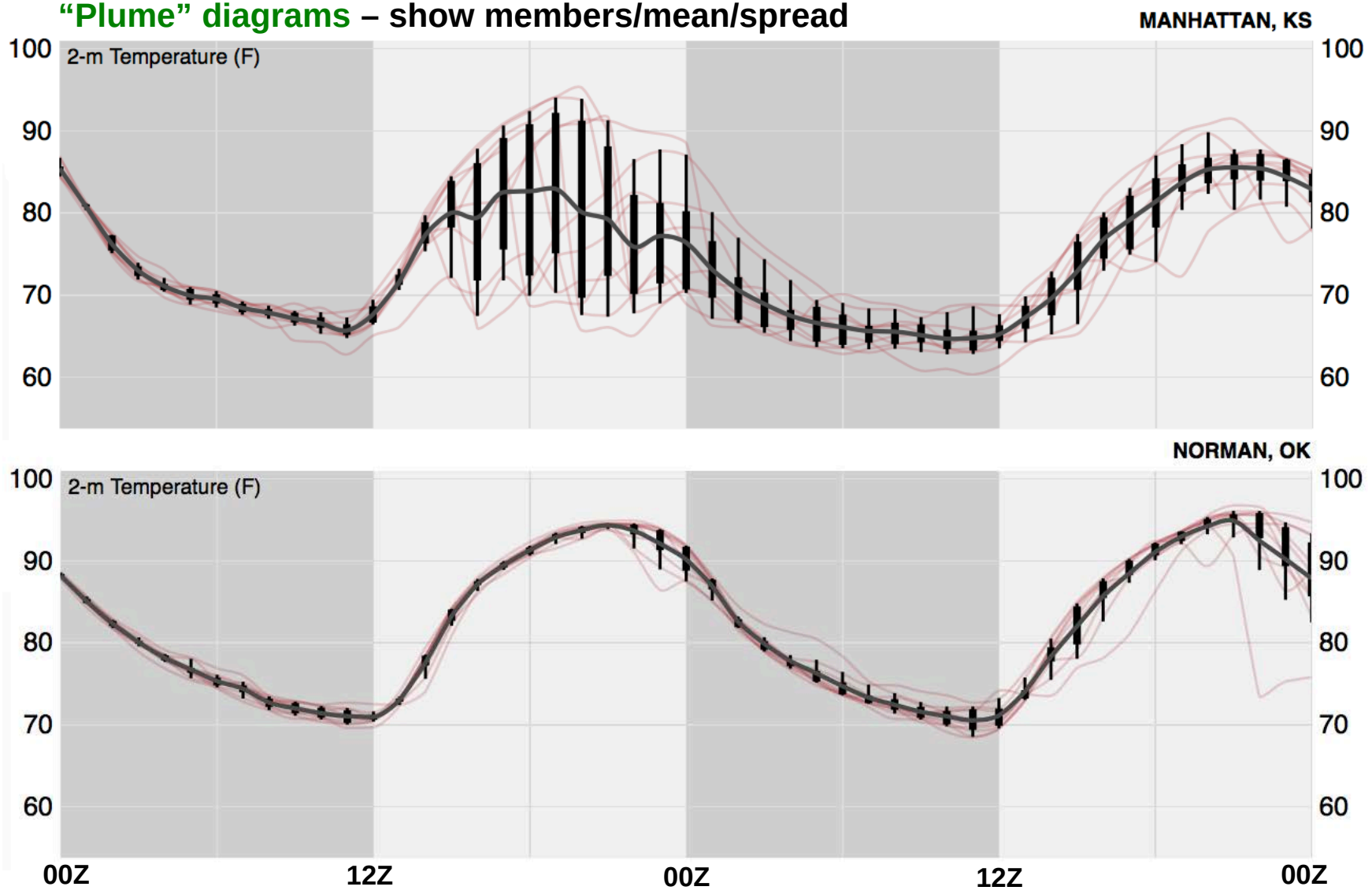
Top 5 Dates for website usage:

1.	20170313	1.26%	Winter Storm ”Stella”
2.	20160122	0.48%	Winter Storm “Snowzilla”
3.	20160425	0.39%	Central Plains Day 2 Mod Risk
4.	20170518	0.39%	Central Plains Day 1 High Risk
5.	20170404	0.38%	East Coast Day 2 High Risk

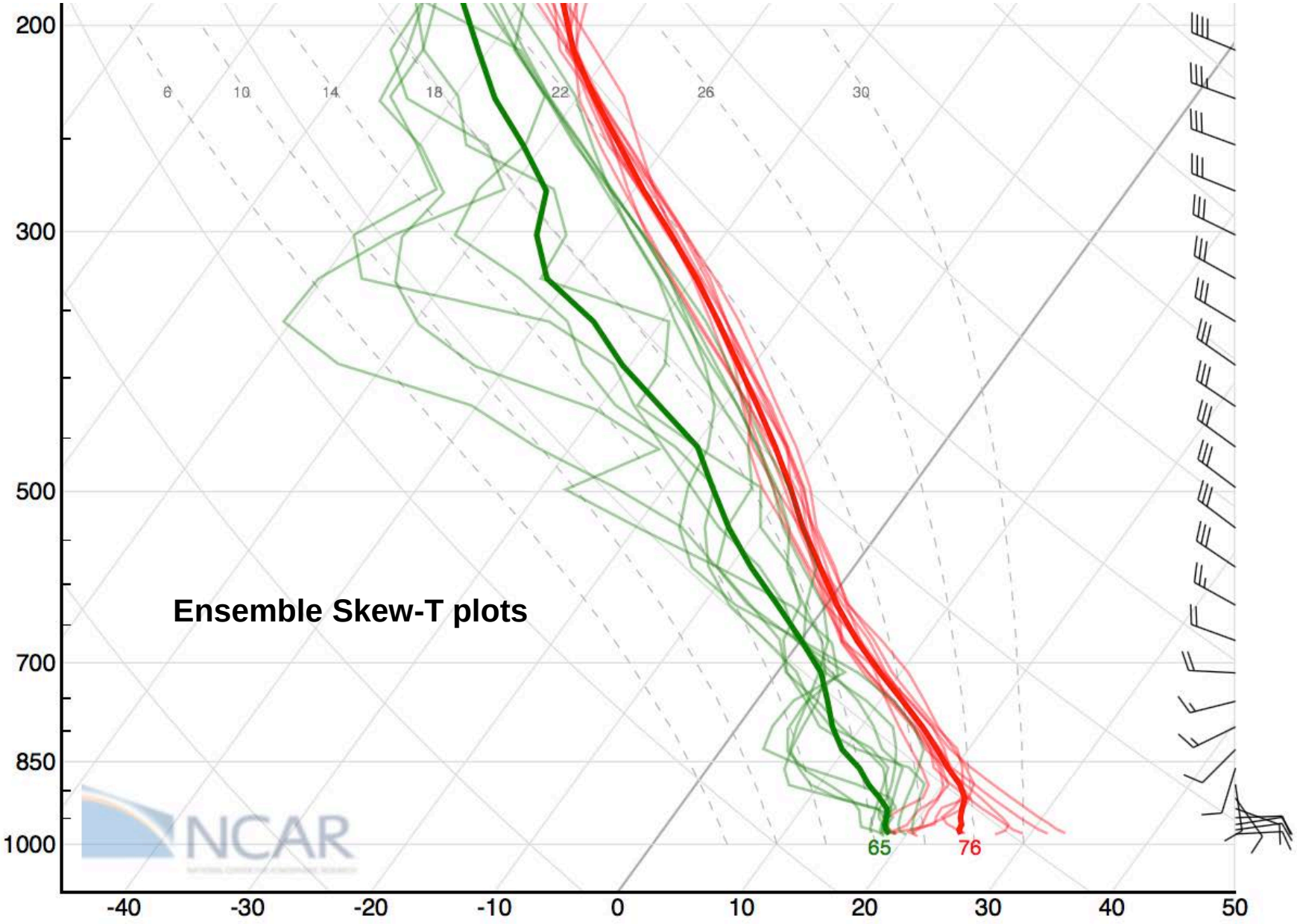


NCAR Ensemble Website

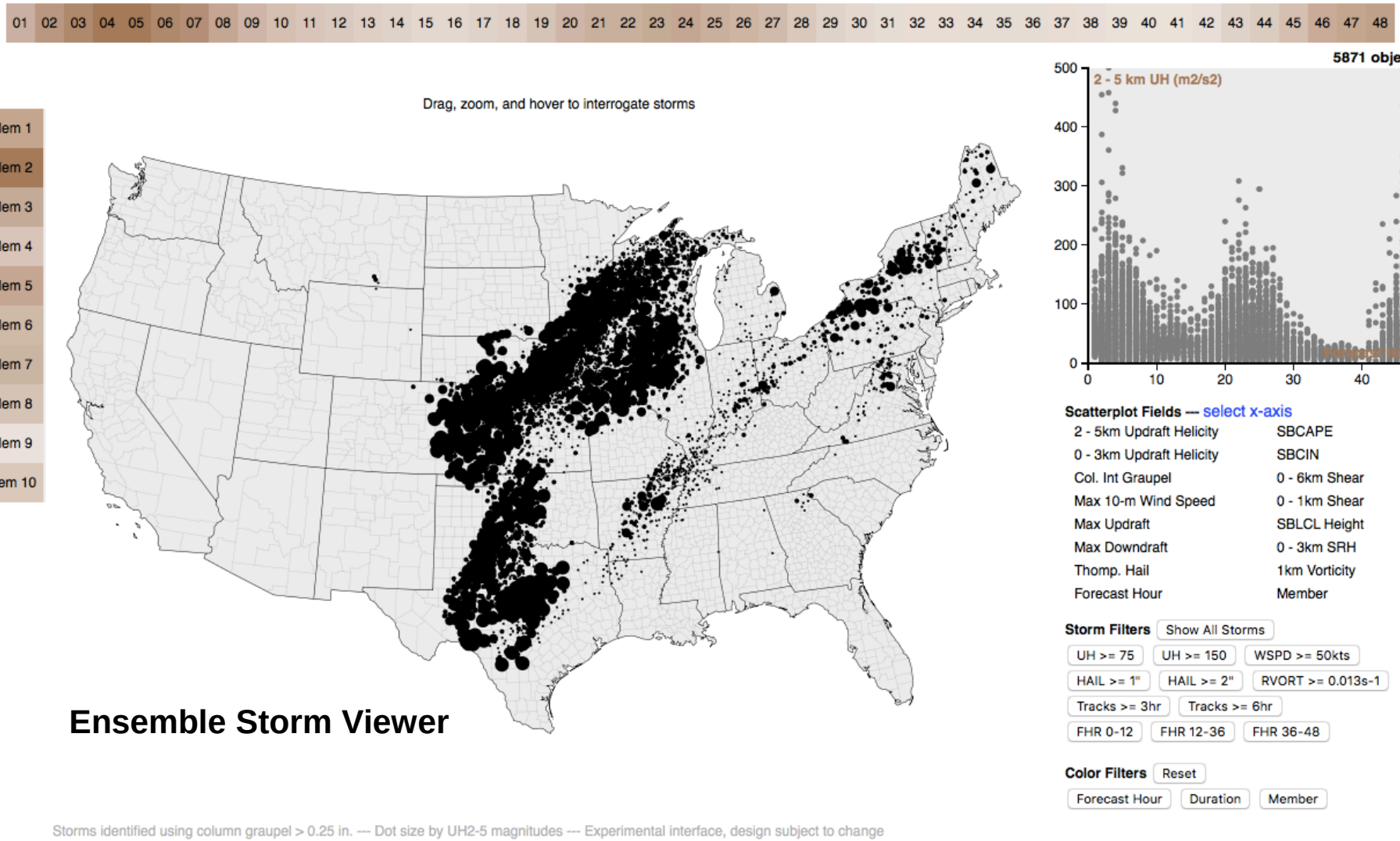
“Plume” diagrams – show members/mean/spread



NCAR Ensemble Website



NCAR Ensemble Website



Ensemble Storm Viewer

Who has used D3?

What is D3?

D3 – Data-Driven Documents

http://d3js.org

http://github.com/d3/d3

What is D3?

Javascript library for producing interactive data visualizations in web-browsers.

Makes use of web standards: Scalable Vector Graphics (**SVG**), **HTML5**, **CSS**. Browser needs to support SVG (all modern browsers do).

Fairly low level, allows for extensive control over visual elements. Interacts with DOM hierarchy (document object model).

Other packages exist on-top of D3 to make standard visualizations with less custom control.

Selections

How does D3 work?

D3 uses CSS-style **selections** to identify which DOM elements/nodes to create/manipulate/delete (similar to jQuery).

Let's select all <p> elements in an HTML document and change their text-color to **chartreuse:**

```
d3.selectAll("p").style("color", "chartreuse")
```

Now only get the *first* element with a class of "header" and align the div to be centered on the page:

```
d3.select("div.header").attr("align", "center")
```

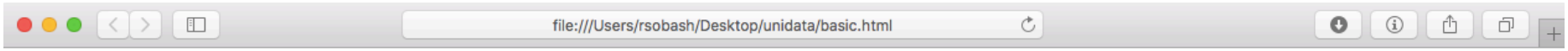
```
<!DOCTYPE html>
<html lang="en">
<head>
<meta charset="utf-8">
<title>Bar Chart Forecast Example</title>
<script src="http://d3js.org/d3.v3.min.js" charset="utf-8"></script>
</head>

<body>

<p>Block of text wrapped in paragraph tag</p>

<div>Block of text wrapped in div tag</div>

<div class=“header”>Block of text wrapped in div tag</div>

<div>Block of text wrapped in div tag</div>

</body>
</html>
```

Block of text wrapped in paragraph tag

Block of text wrapped in div tag
Block of text wrapped in div tag
Block of text wrapped in div tag

```
<!DOCTYPE html>
<html lang="en">
<head>
<meta charset="utf-8">
<title>Bar Chart Forecast Example</title>
<script src="http://d3js.org/d3.v3.min.js" charset="utf-8"></script>
</head>

<body>

<p>Block of text wrapped in paragraph tag</p>

<div>Block of text wrapped in div tag</div>

<div class="header">Block of text wrapped in div tag</div>

<div>Block of text wrapped in div tag</div>

<script type="text/javascript">
        d3.selectAll("p").style("color", "chartreuse")
        d3.select("div").attr("align", "center")
        d3.select("body").style("font-size", "36px")
</script>

</body>
</html>
```

Note:
method chaining



Block of text wrapped in paragraph tag

Block of text wrapped in div tag

Block of text wrapped in div tag

Block of text wrapped in div tag

The power of D3 is in its creation and manipulation of D3 SVG elements. Often the first step is to create a svg “container”:

```
var svg = d3.select("body")
            .append("svg")
            .attr("width", 300)
            .attr("height", 200);
```

The DOM now looks like this…

```
…
<body>

<svg width=“300” height=“200”></svg>

</body>
…
```

More on selections:

https://github.com/d3/d3-selection

Binding data to DOM elements

Creating SVG objects is controlled by the data, i.e., the data defines the look and feel of each object.

Let's say we have an array of arbitrary data…

```
<script type="text/javascript">

var data = [150, 230, 180, 90]; // arbitrary data

var svg = d3.select("body")
          .append("svg")
          .attr("width", 300)
          .attr("height", 200);

svg.selectAll(".bar")
    .data(data)
    .enter()
    .append("rect")
    .attr({
        class  : "bar",
        width  : function(d) { return d; },
        height : "40",
        y      : function(d, i) { return i*50 + 10; },
        x      : "10"
     });

</script>
```

Binding data to DOM elements

selection.data() binds array of data to selected elements.

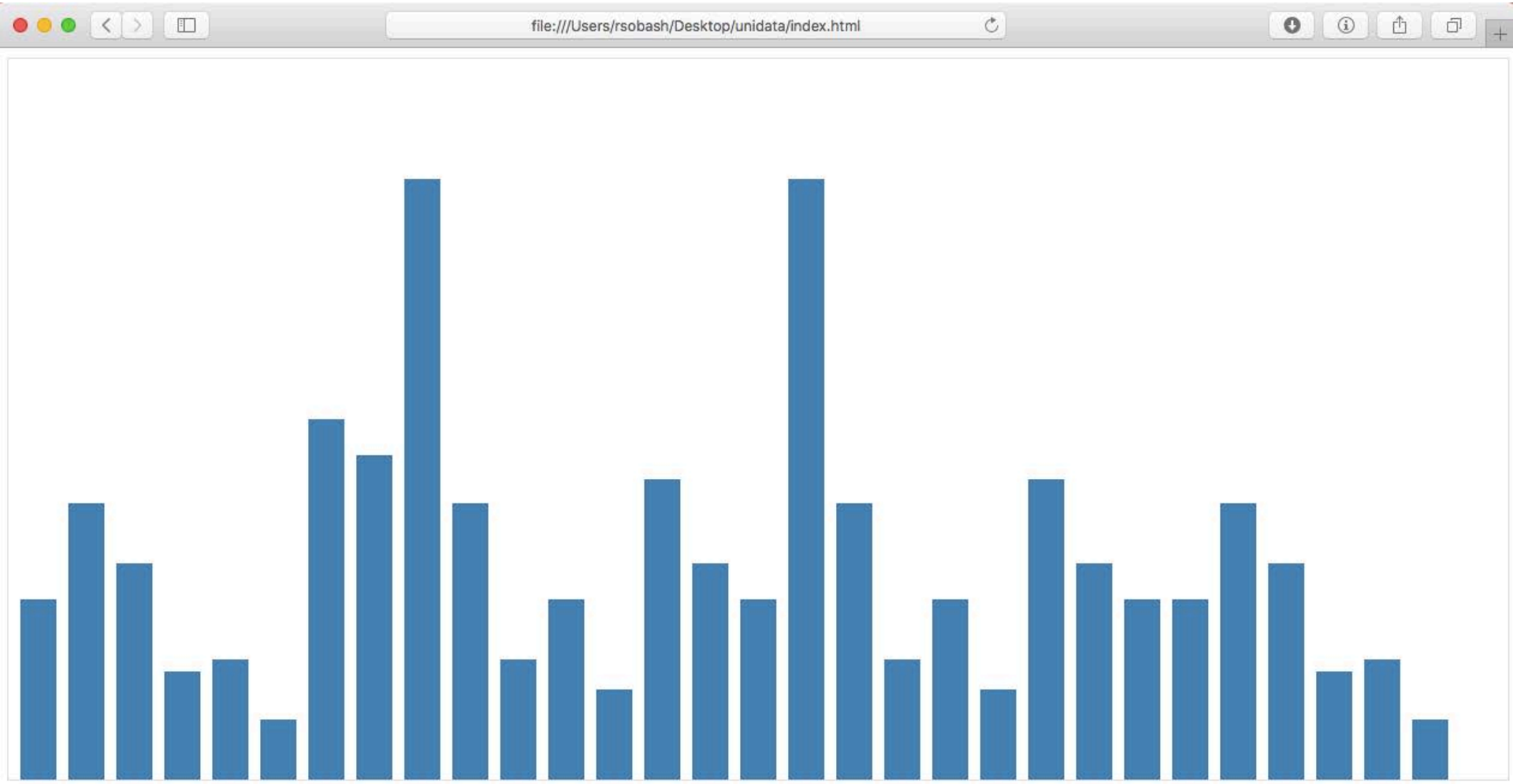
```
// creates SVG elements using data in above array
svg.selectAll(".bar")
   .data(data)
   .enter()
   .append("rect")
   .attr({
      class  : "bar",
      width  : function(d) { return d; },
      height : "30",
      x      : function(d, i) { return i*40 + 10; },
      y      : function(d) { return 600-d; },
    });
```

Accessor function

The first element in the selection is paired with the first array element, stored in __data__ property.

But what if there are more data than selected objects?

These data are stored in a special “enter” selection, accessed by .enter(), and bound to new elements through .append()


file:///Users/rsobash/Desktop/unidata/index.html

```
▼<svg width="1250" height="600">
   <rect class="bar" height="150" width="30" x="10" y="450"></rect>
   <rect class="bar" height="230" width="30" x="50" y="370"></rect>
   <rect class="bar" height="180" width="30" x="90" y="420"></rect>
   <rect class="bar" height="90" width="30" x="130" y="510"></rect>
   <rect class="bar" height="100" width="30" x="170" y="500"></rect>
   <rect class="bar" height="50" width="30" x="210" y="550"></rect>
   <rect class="bar" height="300" width="30" x="250" y="300"></rect>
   <rect class="bar" height="270" width="30" x="290" y="330"></rect>
   <rect class="bar" height="500" width="30" x="330" y="100"></rect>
   <rect class="bar" height="230" width="30" x="370" y="370"></rect>
   <rect class="bar" height="100" width="30" x="410" y="500"></rect>
   <rect class="bar" height="150" width="30" x="450" y="450"></rect>
   <rect class="bar" height="75" width="30" x="490" y="525"></rect>
   <rect class="bar" height="250" width="30" x="530" y="350"></rect>
   <rect class="bar" height="180" width="30" x="570" y="420"></rect>
   <rect class="bar" height="150" width="30" x="610" y="450"></rect>
   <rect class="bar" height="500" width="30" x="650" y="100"></rect>
   <rect class="bar" height="230" width="30" x="690" y="370"></rect>
   <rect class="bar" height="100" width="30" x="730" y="500"></rect>
   <rect class="bar" height="150" width="30" x="770" y="450"></rect>
   <rect class="bar" height="75" width="30" x="810" y="525"></rect>
   <rect class="bar" height="250" width="30" x="850" y="350"></rect>
   <rect class="bar" height="180" width="30" x="890" y="420"></rect>
   <rect class="bar" height="150" width="30" x="930" y="450"></rect>
   <rect class="bar" height="150" width="30" x="970" y="450"></rect>
   <rect class="bar" height="230" width="30" x="1010" y="370"></rect>
   <rect class="bar" height="180" width="30" x="1050" y="420"></rect>
   <rect class="bar" height="90" width="30" x="1090" y="510"></rect>
   <rect class="bar" height="100" width="30" x="1130" y="500"></rect>
   <rect class="bar" height="50" width="30" x="1170" y="550"></rect>
 </svg>
```

Updating data and transitioning between states

New data is bound to existing DOM elements to update/transition between states. Also, new elements created / old elements removed.

This is the general **D3 update pattern:**

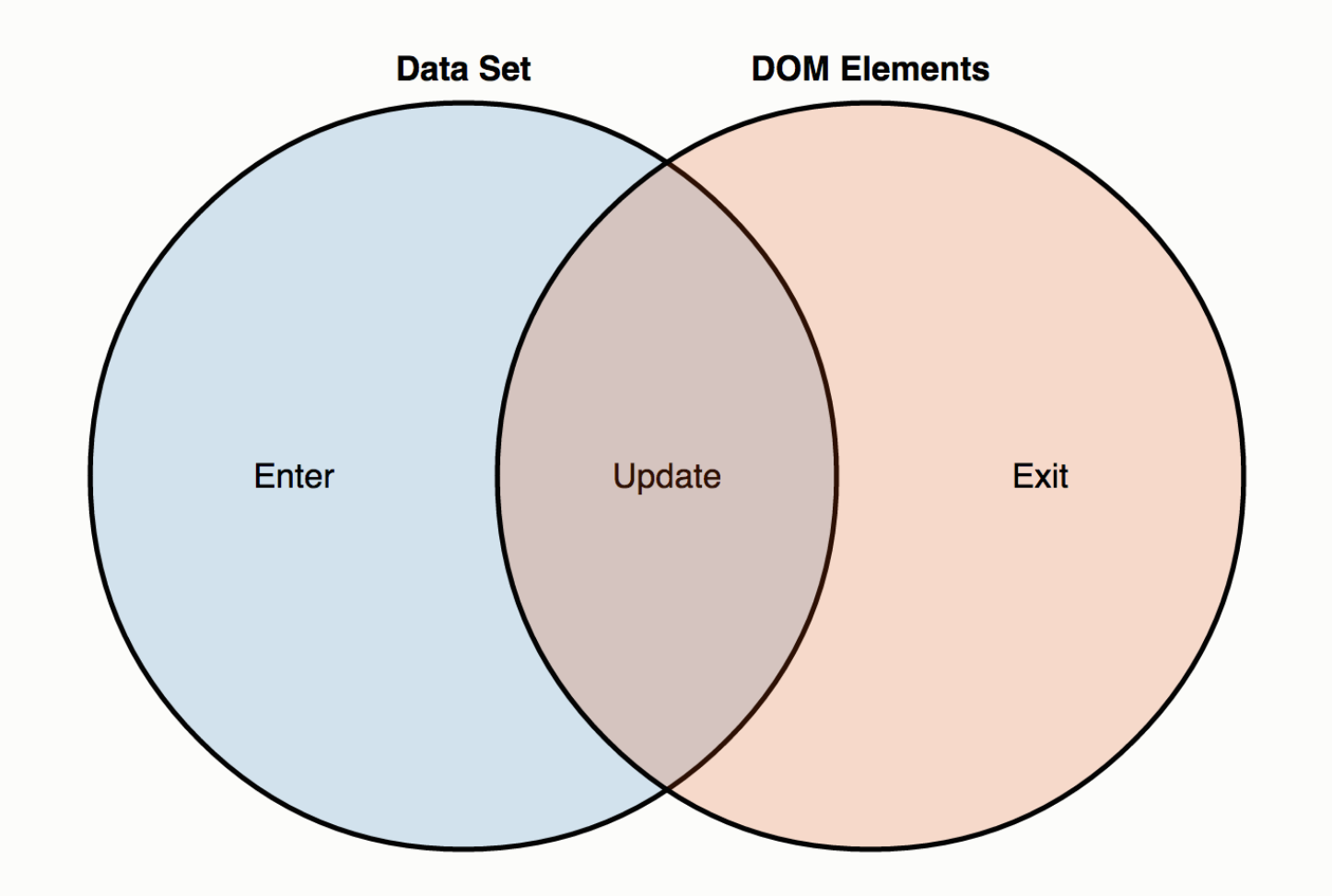
Bind data to SVG elements using **.data()**

Delete elements using **.exit().remove();**

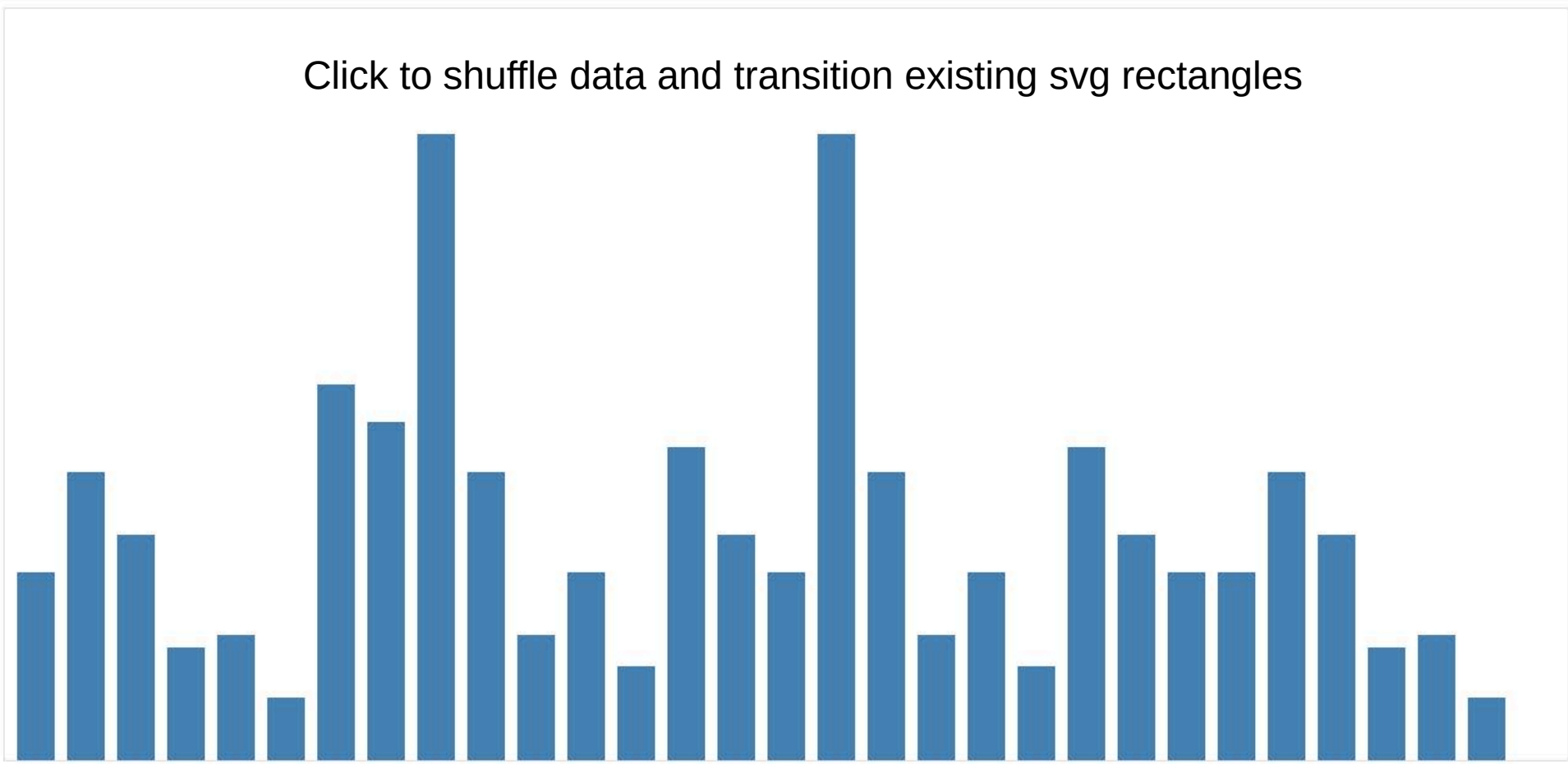
Add elements using **.enter().append();**

Update state of remaining elements / add transitions with **.transition()**

Updating data and transitioning between states



Look at code to drive data update and to trigger transition…



Take a few minutes to try to:

- Change number of elements in array
- Change mouse event that triggers transition (e.g., mousedown)
- Change rectangle color, size, transition time

Useful tools for plotting meteorological datasets with D3

Continuous scales:

https://github.com/d3/d3-scale

```
var x = d3.scaleLinear()
          .domain([10, 130])
          .range([0, 960]);
```

Given value from domain,
return result in range
E.g., temperature to pixel values

```
x(20); // 80
x(50); // 320
```

Also contains useful methods for plotting scales, e.g., ticks, tick labels, etc.

Useful tools for plotting meteorological datasets with D3

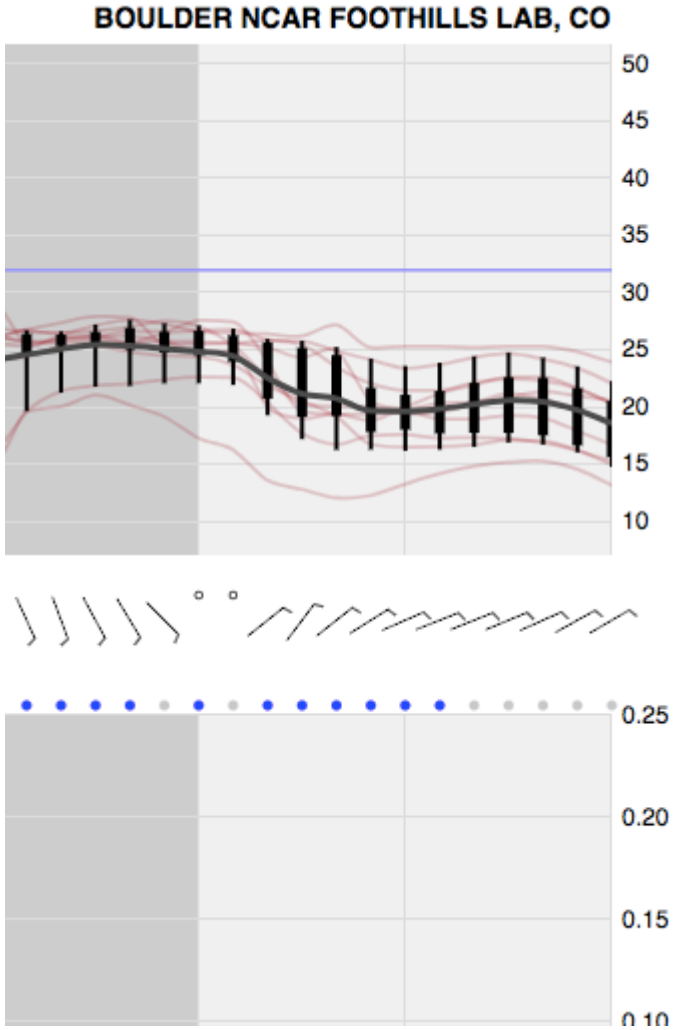
Accessing data:

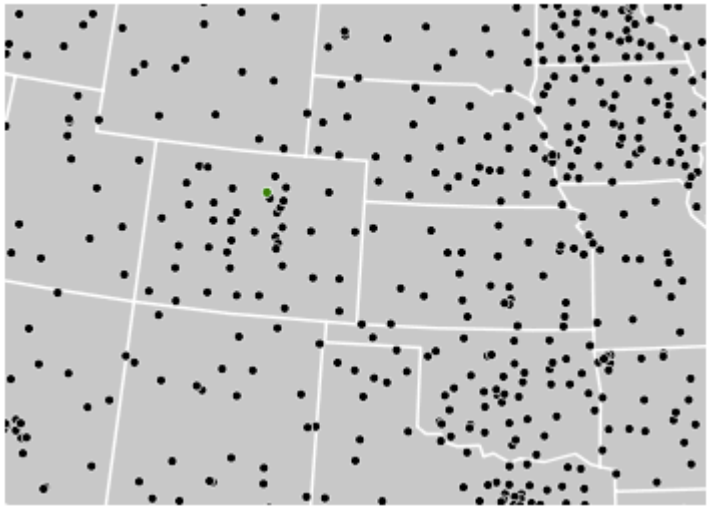
d3.csv()	request a comma-separated values file
d3.html()	request an HTML document
d3.json()	request a JSON blob
d3.text()	request a text file
d3.tsv()	request a tab-separated value file

```
d3.csv("ensemble.csv", function(data) {

        // manipulate data, plot here

});
```

Useful tools for plotting meteorological datasets with D3

Plotting on maps



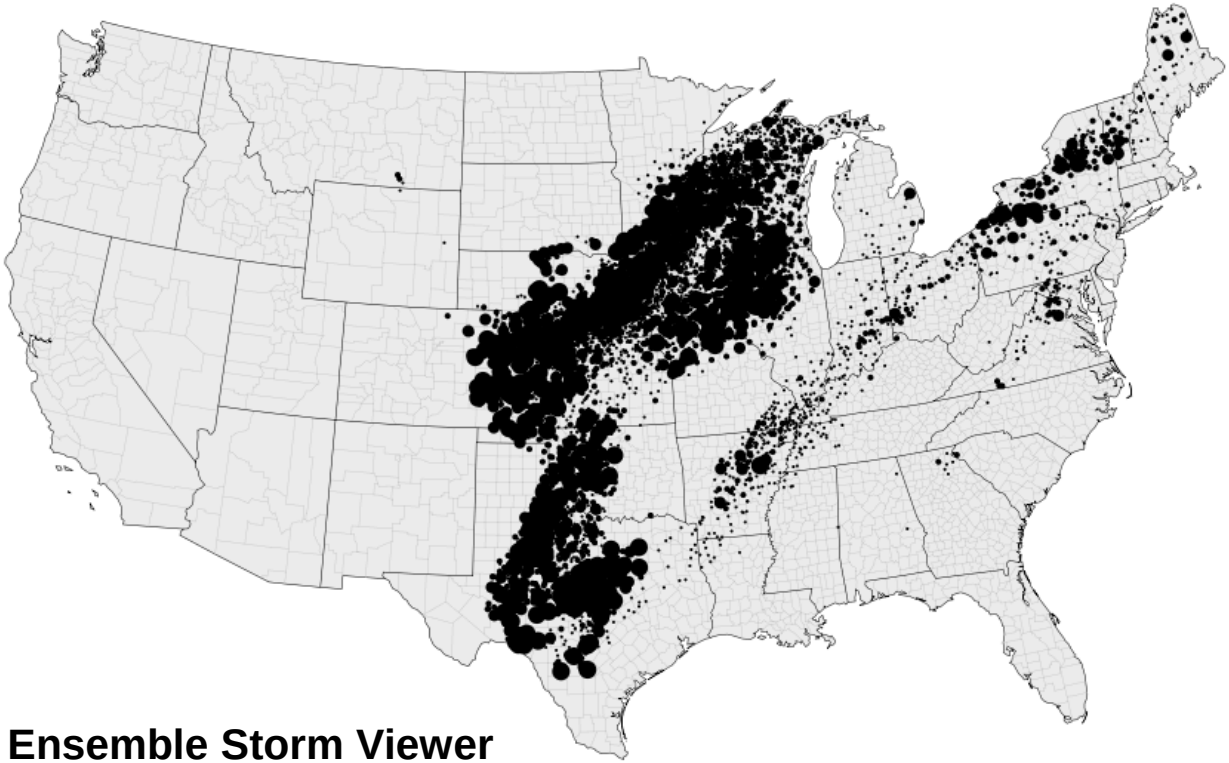


2-m Temperature	2-m Dewpoint
Hourly QPF	Accum QPF
Hourly Rain	Accum Rain
Hourly Snow	Accum Snow
Hourly Freezing Rain	Accum Freezing Rain
Hourly Sleet	Accum Sleet
SBCAPE	MLCAPE
MUCAPE	Max UH w/in 25 mi
NEW: Prob. of Precip	**NEW:** Ptype Cond. Prob

01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48

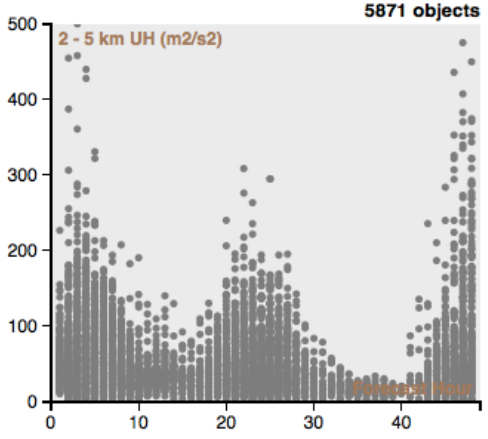
Mem 1
Mem 2
Mem 3
Mem 4
Mem 5
Mem 6
Mem 7
Mem 8
Mem 9
Mem 10

Drag, zoom, and hover to interrogate storms



Ensemble Storm Viewer

5871 objects



Scatterplot Fields — select x-axis

2 - 5km Updraft Helicity	SBCAPE
0 - 3km Updraft Helicity	SBCIN
Col. Int Graupel	0 - 6km Shear
Max 10-m Wind Speed	0 - 1km Shear
Max Updraft	SBLCL Height
Max Downdraft	0 - 3km SRH
Thomp. Hail	1km Vorticity
Forecast Hour	Member

Storm Filters Show All Storms

UH >= 75 | UH >= 150 | WSPD >= 50kts
HAIL >= 1" | HAIL >= 2" | RVORT >= 0.013s-1
Tracks >= 3hr | Tracks >= 6hr
FHR 0-12 | FHR 12-36 | FHR 36-48

Color Filters Reset

Forecast Hour | Duration | Member

Storms identified using column graupel > 0.25 in. --- Dot size by UH2-5 magnitudes --- Experimental interface, design subject to change

Additional D3 examples from bl.ocks.org

Final Thoughts

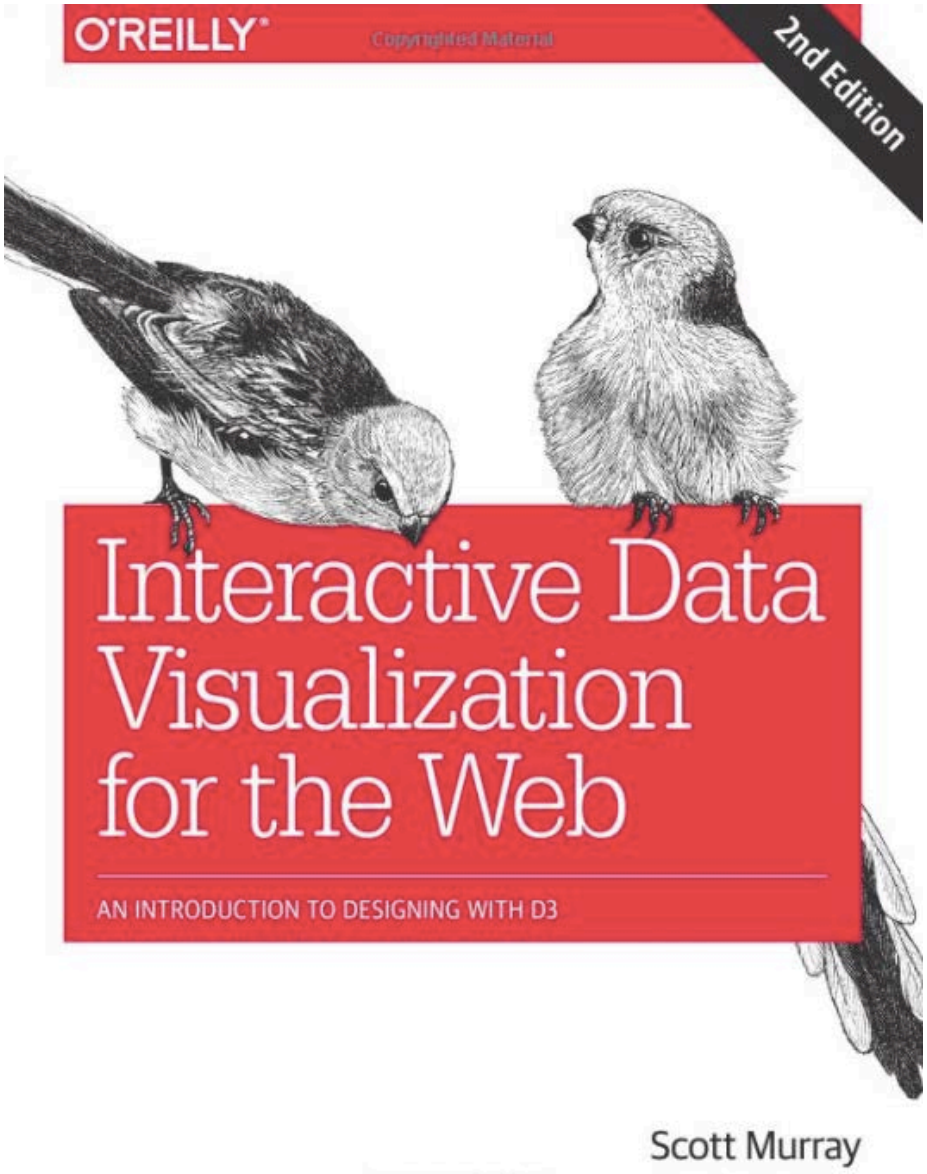
D3 is **not a charting library**. Barrier to entry is somewhat steep.

D3 is fairly low-level (more code than higher-level libraries). Takes time to develop web apps, but D3 is extremely powerful and fast.

Impossible to visualize all products, members, forecast hours from ensemble systems, especially with static images.

Will need **more interactive tools** to slice/dice ensemble data in the future.

Additional Reference



Thanks for your attention!

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