Drought monitoring and environmental prediction with the Internet of Things

Adam Wolf & Kelly Caylor
Princeton University

http://tronic.princeton.edu/pulselab

Big Data in Kazakhstan

How much water is available for ecosystems?

Soil moisture is **0.001%** of all water on Earth. Provides basis for most agricultural food production and sustains all terrestrial ecosystems

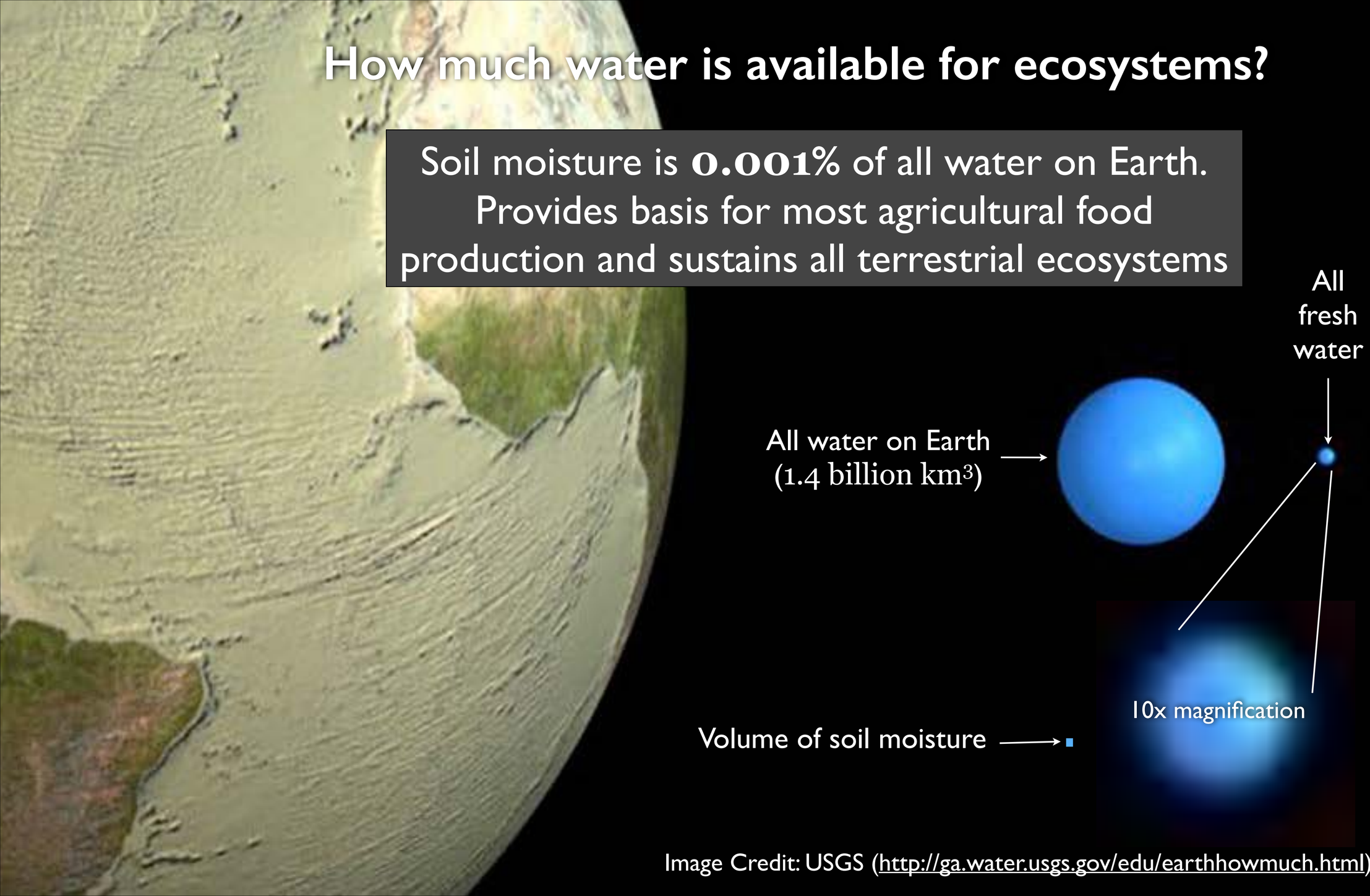
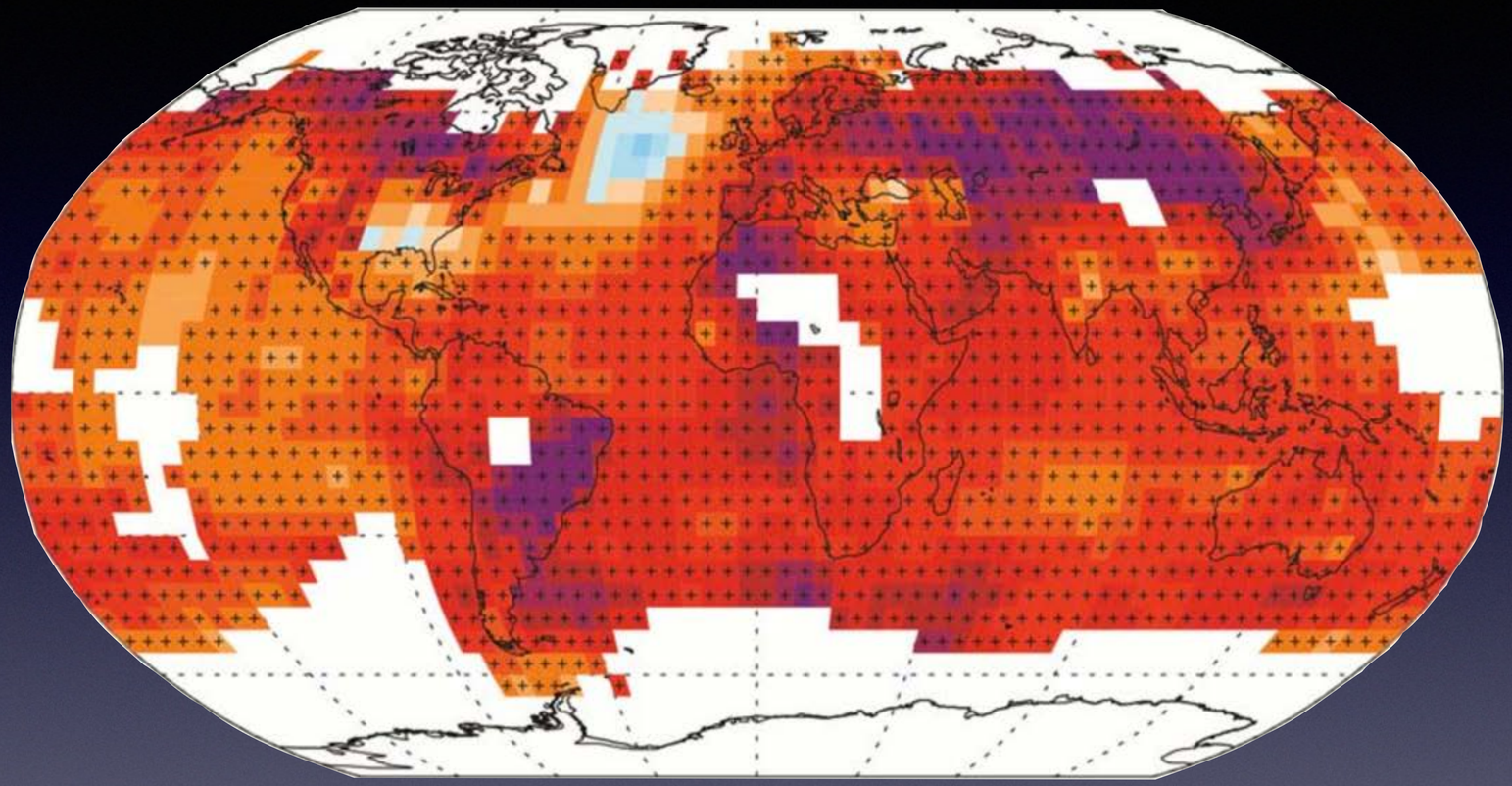


Image Credit: USGS (http://ga.water.usgs.gov/edu/earthhowmuch.html)

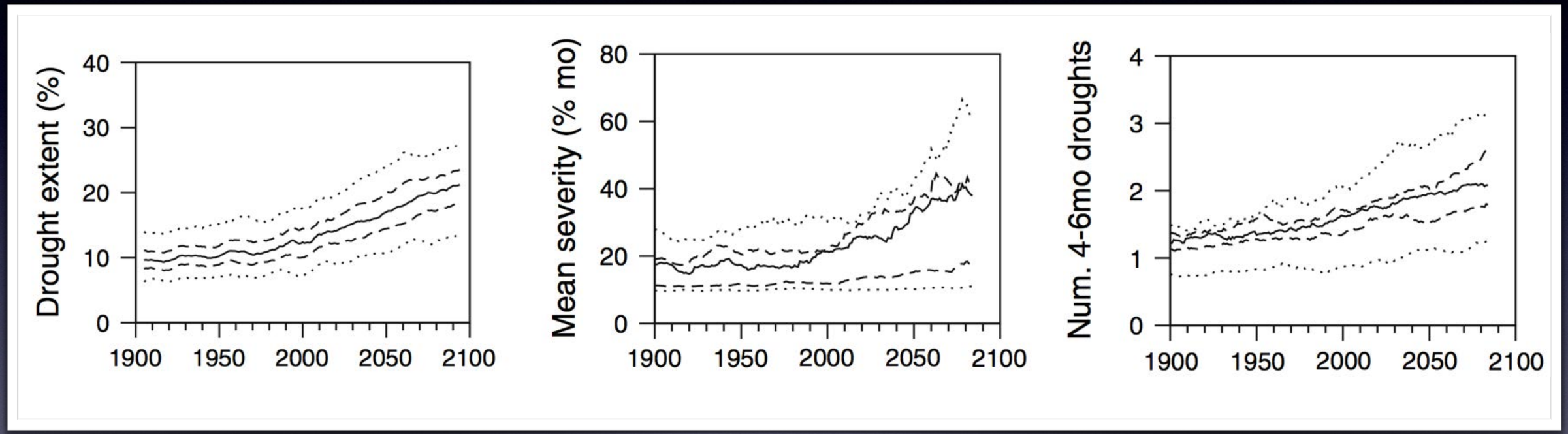
The World is Changing



Observed change in average surface temperature 1901-2012

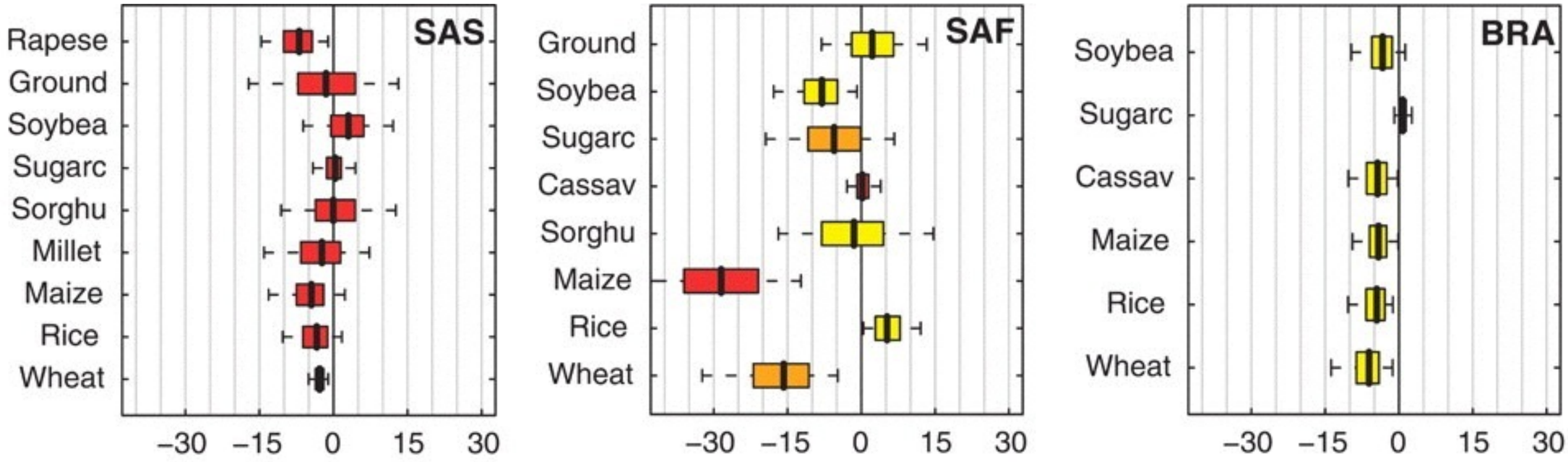
IPCC Working Group 1 - 5th Assessment Report
Summary for Policy Makers, 2013

Drought impacts to increase



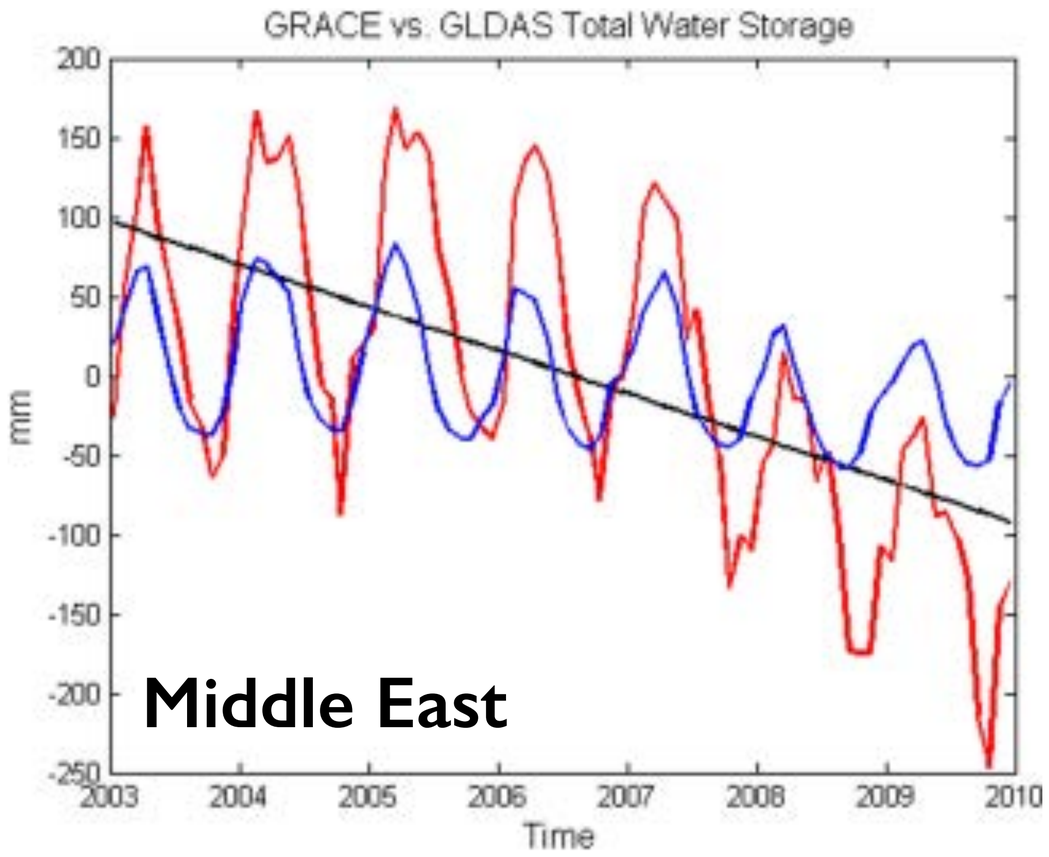
Sheffield and Wood, 2008

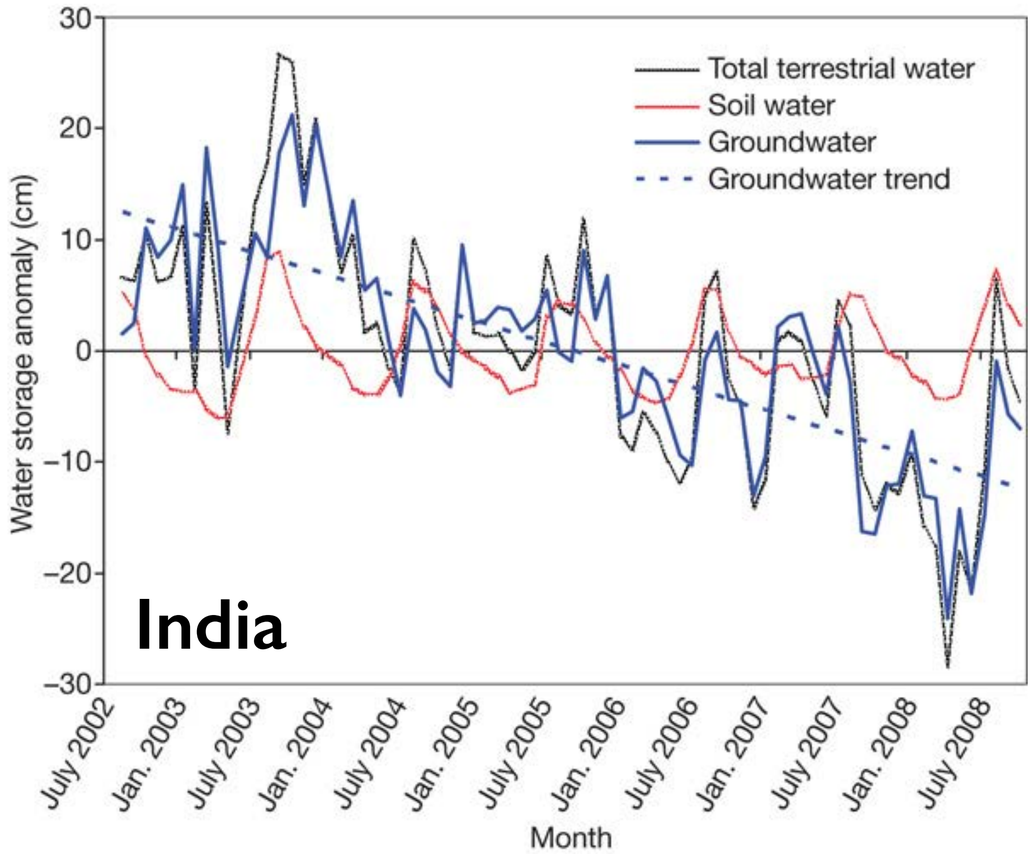
Crop yields to decline



Lobell et al 2010

Less water remains for irrigation

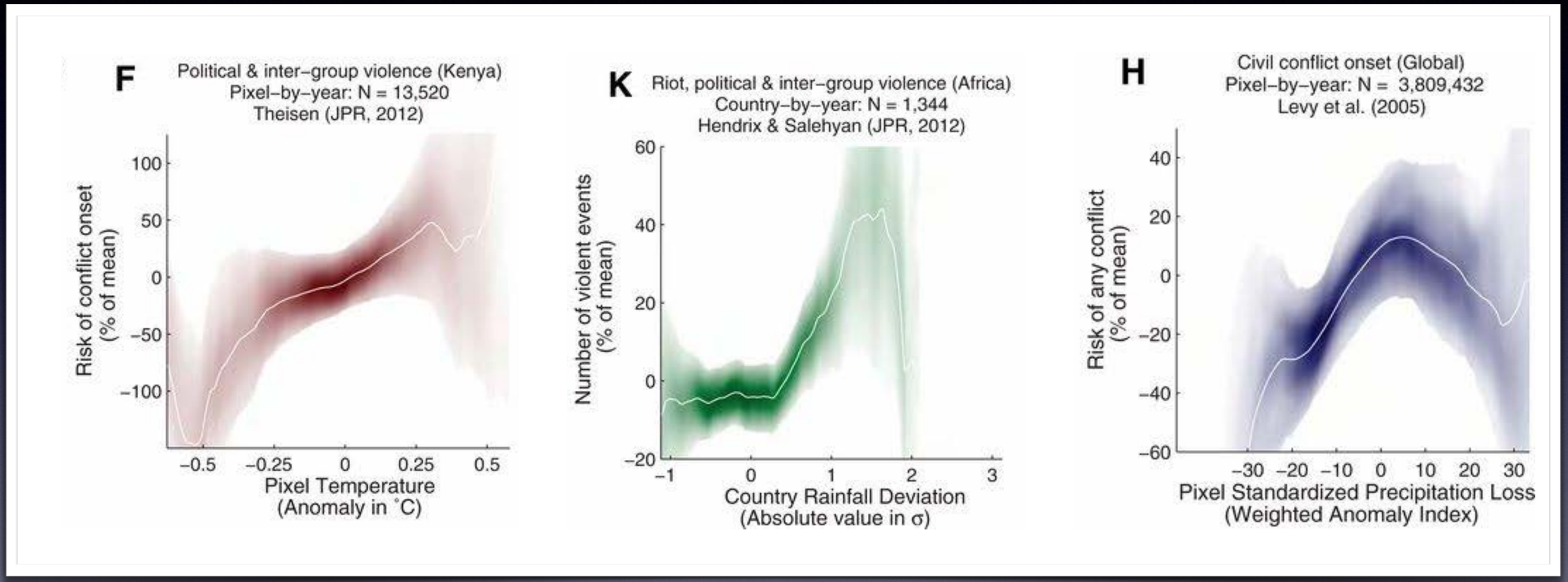




Voss et al 2013

Rodell et al 2009

Climate changes cause conflict



Heatwave

Rainstorm

Drought

Hsiang et al 2013

We seek to
improve forecasts
of droughts and floods,
crop productivity,
and food security

Climate change impacts the biosphere

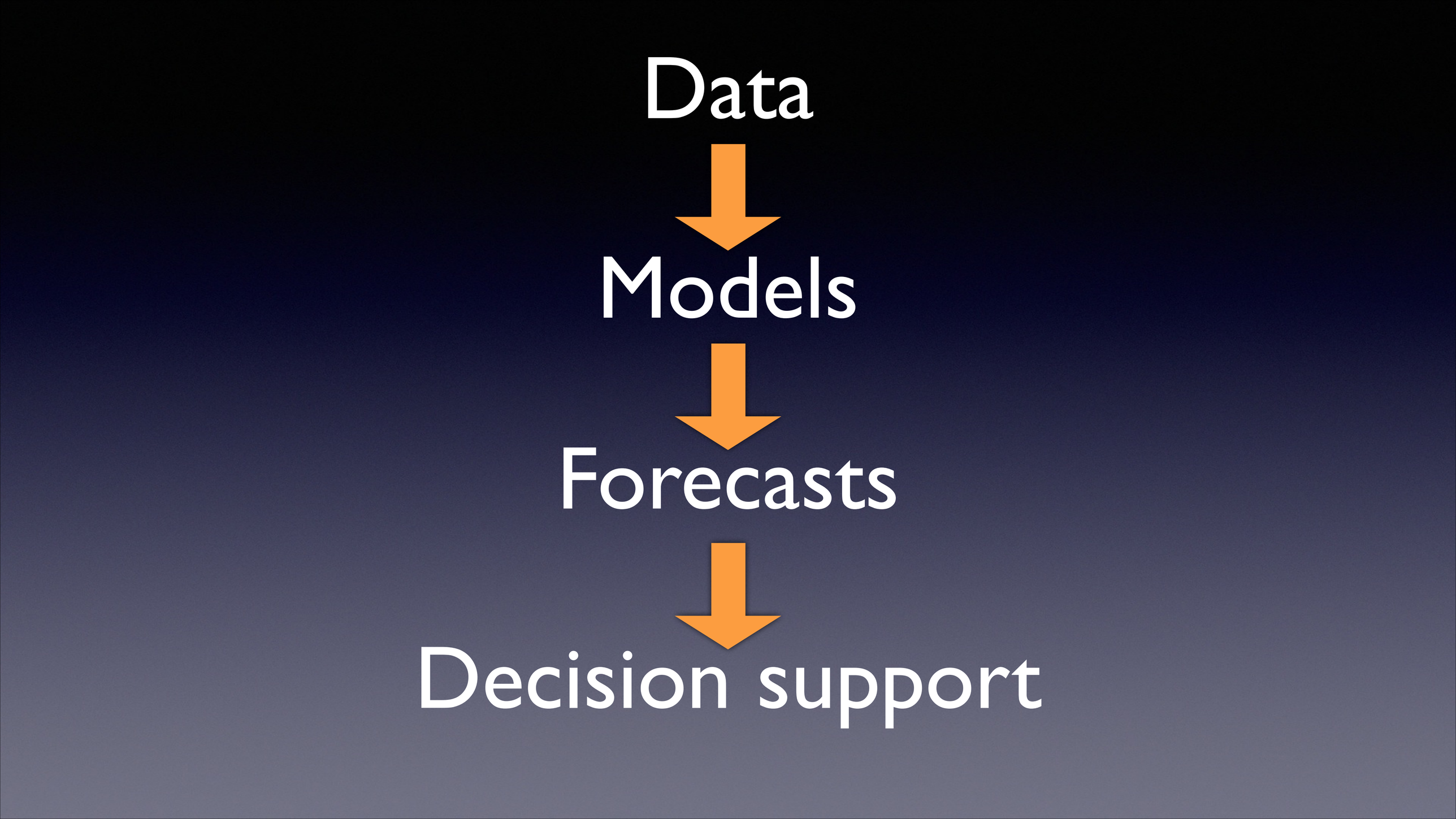
People depend on crops and forests

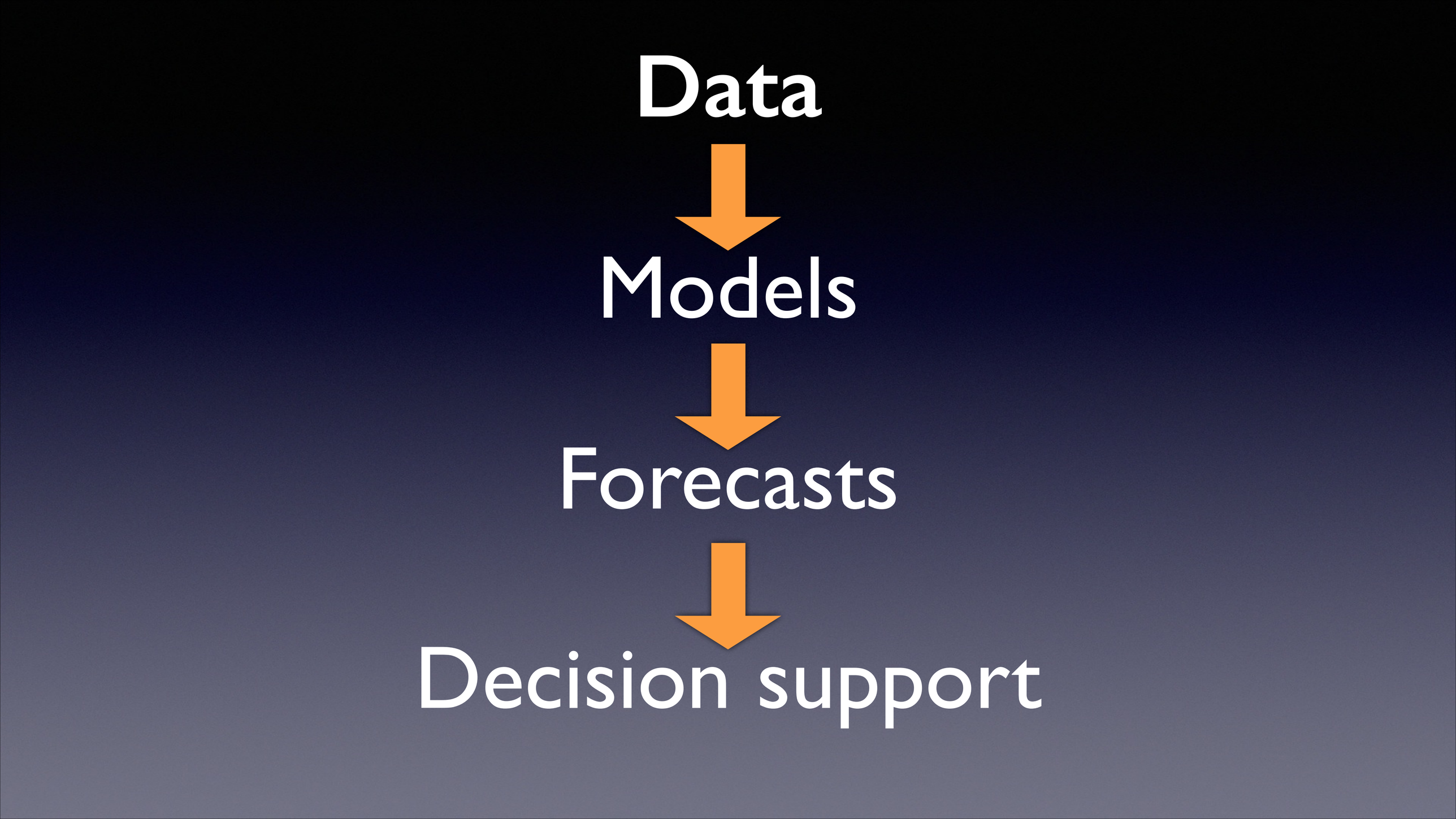
We don't really know how this is playing out

Models

+

Models


Data
Models
Forecasts
Decision support

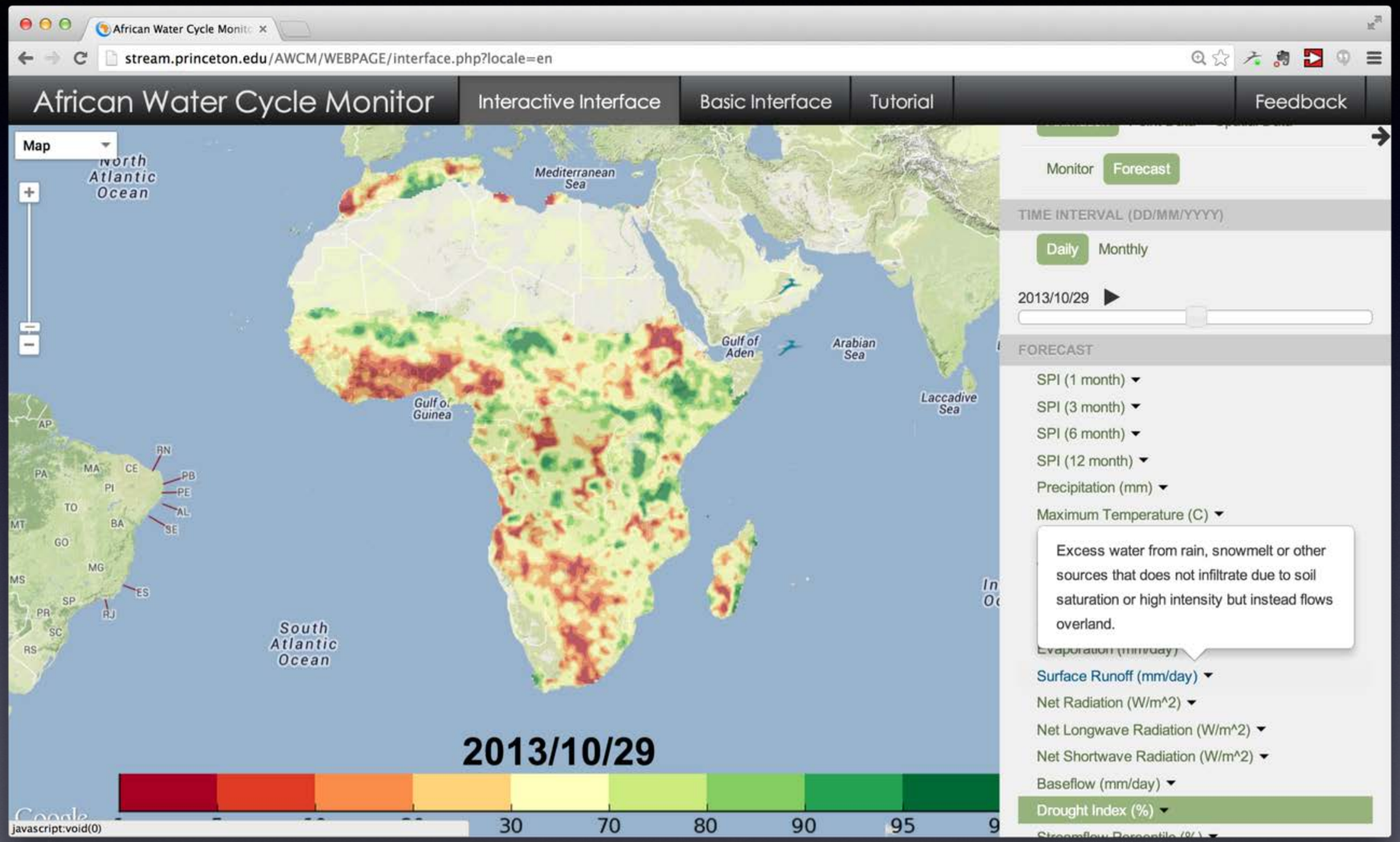

Data
Models
Forecasts
Decision support

Drought Monitor and Forecast: USA

Relies on
6000 stations
reporting < 1 hr

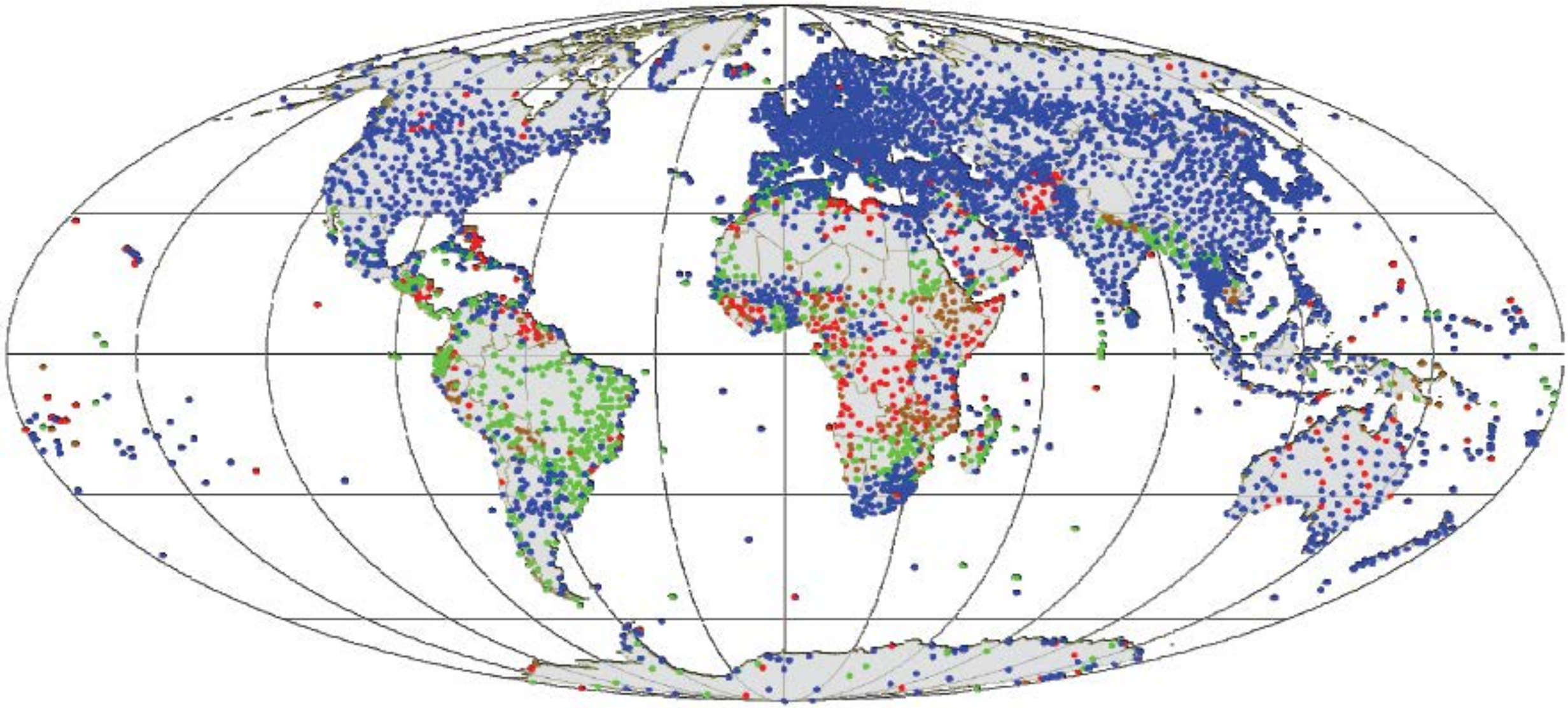
So dense:
No satellite

Drought Monitor and Forecast: Africa



Relies on
- zero -
station data

Entirely
satellite



Silent station crisis

Typical data collection

We need **data**

from **many locations**

that are delivered
in real-time

and are **easy to access**

We have **data**

from **increasingly fewer locations**

that are delivered **slowly**

and are **often hard to access**

Three related problems.

Data **density**

Data **latency**

Data **availability**

One integrated solution.

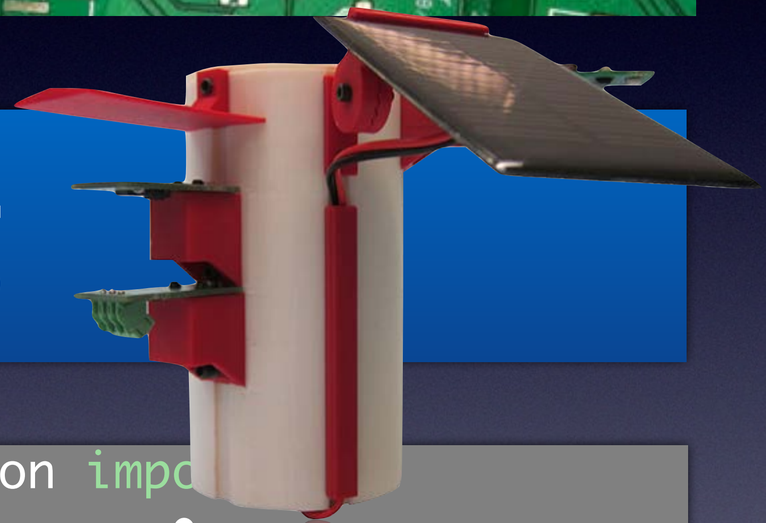
PULSE Lab

Princeton University Low-cost Sensors for the Environment

A **low cost** sensor network,
communicating in **real-time**,
storing data in an
open web-based API

A **low cost** sensor network,

Commodity electronics



3D Printing

```
import requests
from pdu2json impo
```

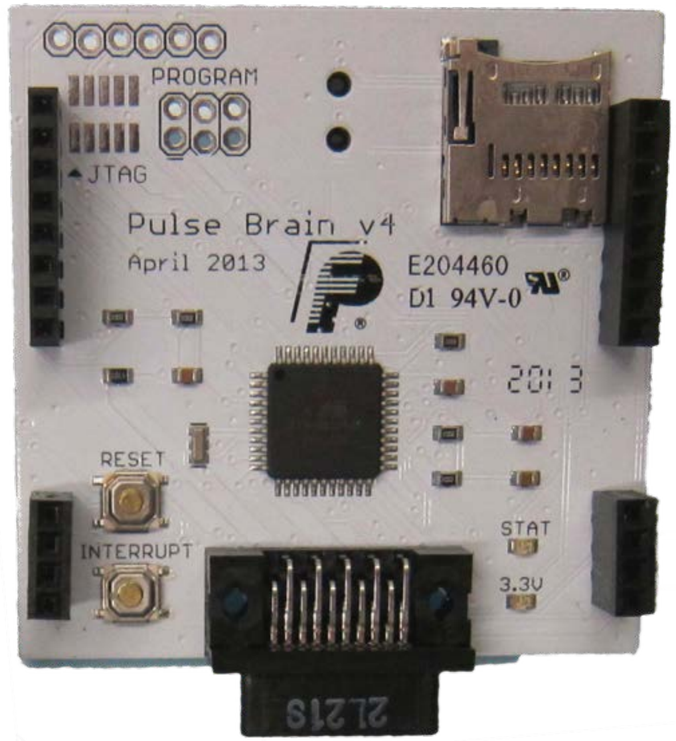
Open source libraries

```
from eve import Eve
import os
import json
```

A novel recipe from existing ingredients

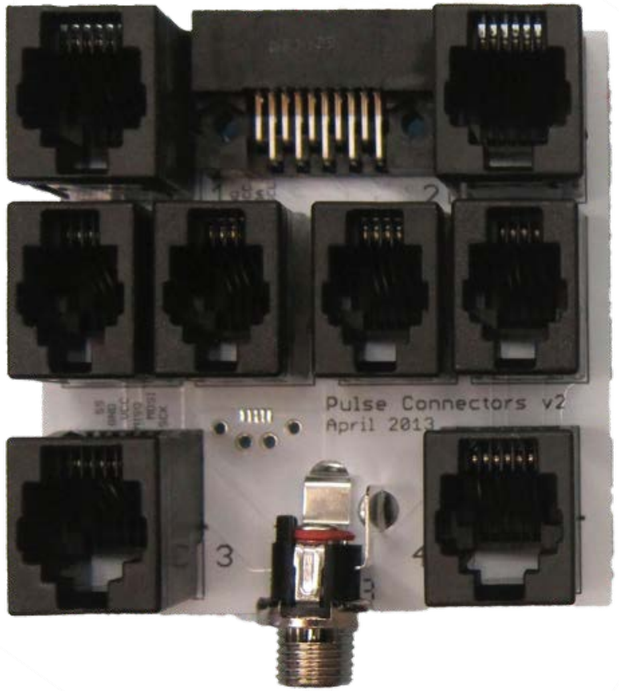
A low cost sensor network,

Brain
$25



uSD card logger
manages power,
sensors, comms

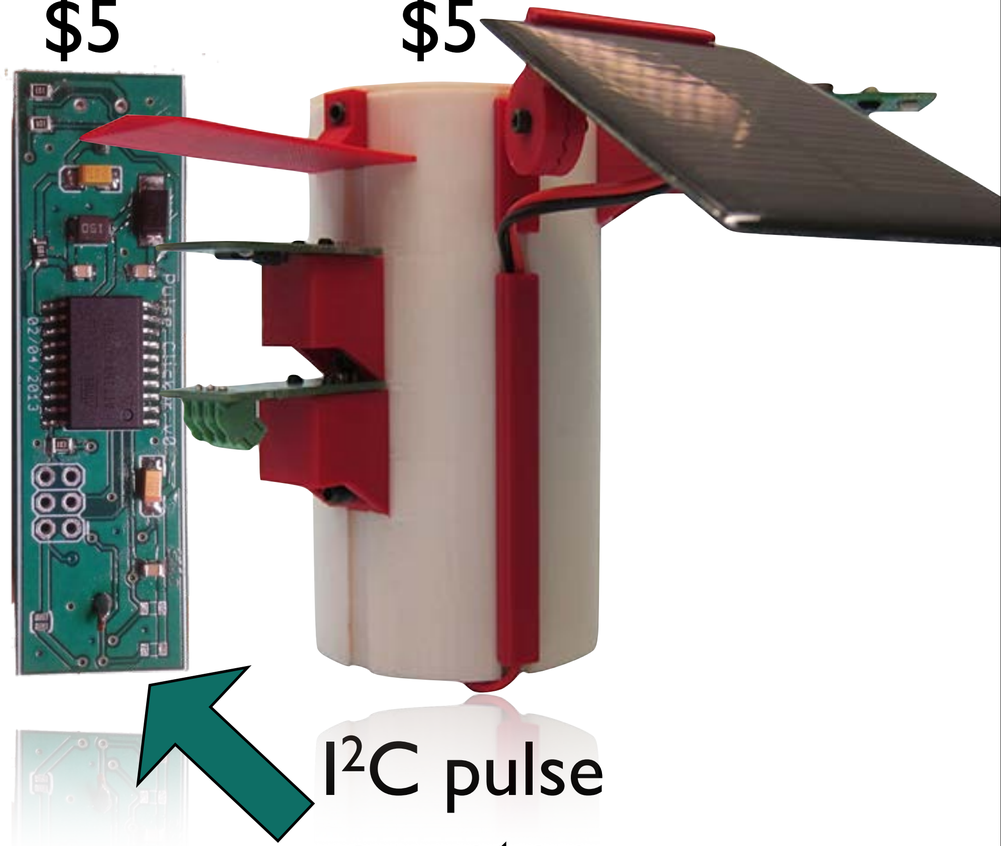
Connector
$10



Each pod can
accommodate up to 8
daughter boards

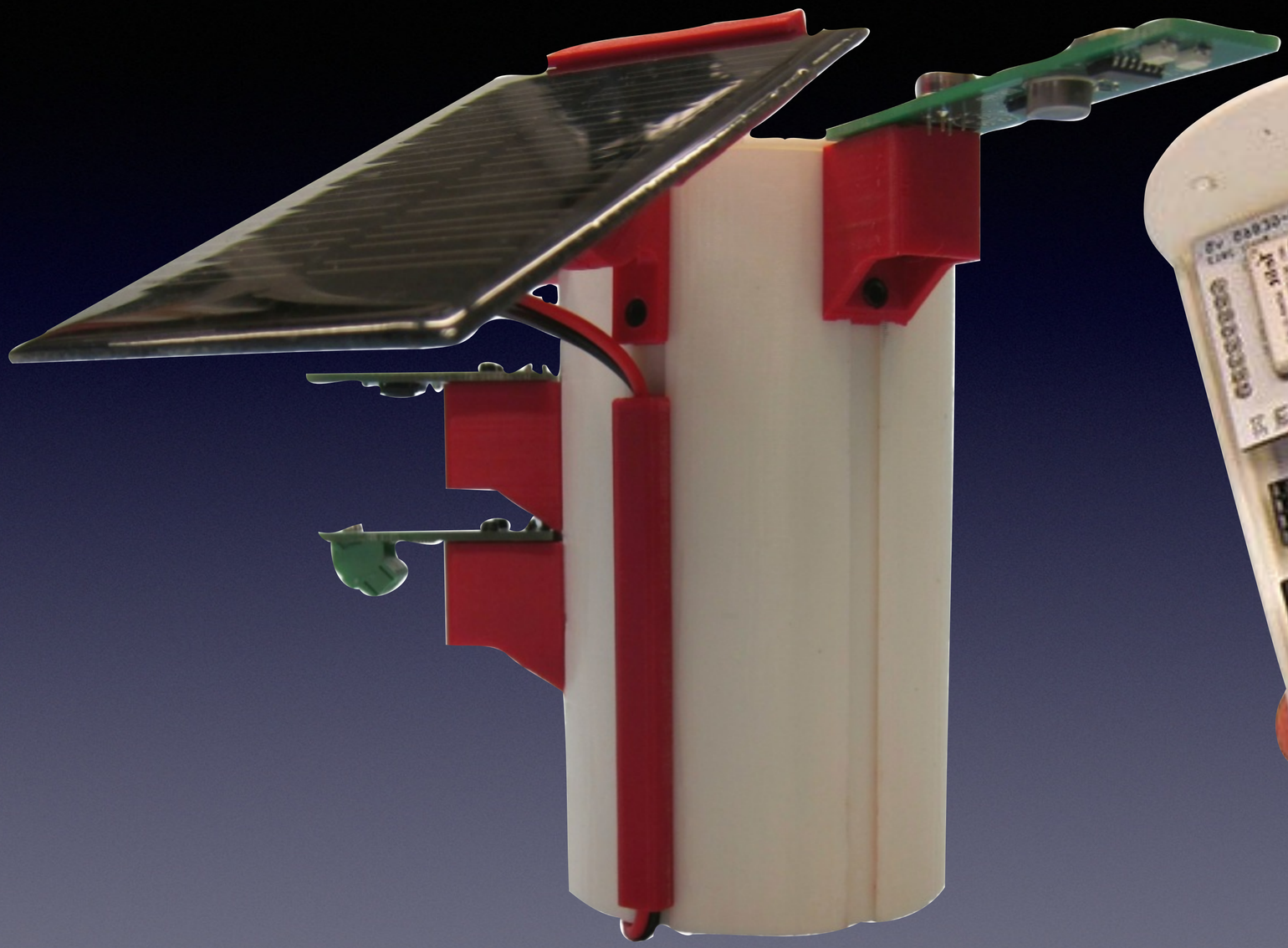
Sensor
$5

Enclosure
$5



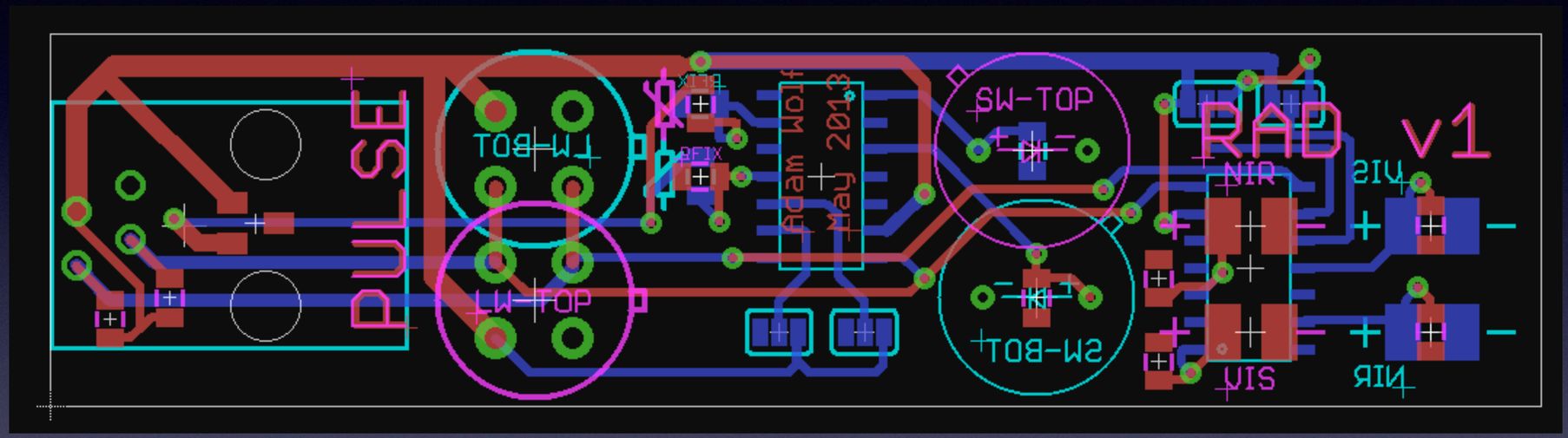
I²C pulse
counter
Rain gauge,
flow meter

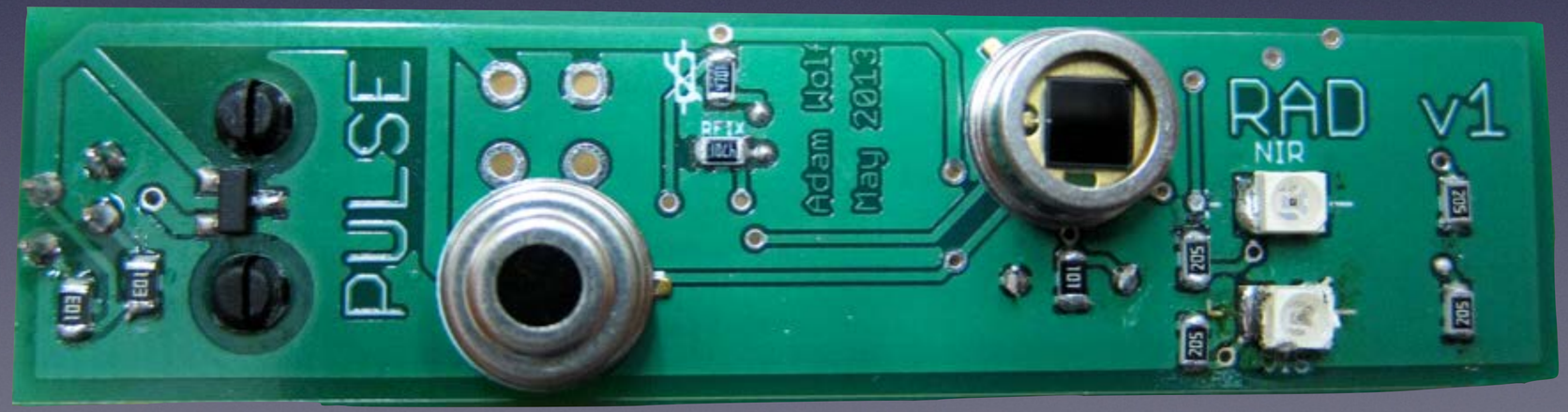
A low cost sensor network,



A low cost sensor network,

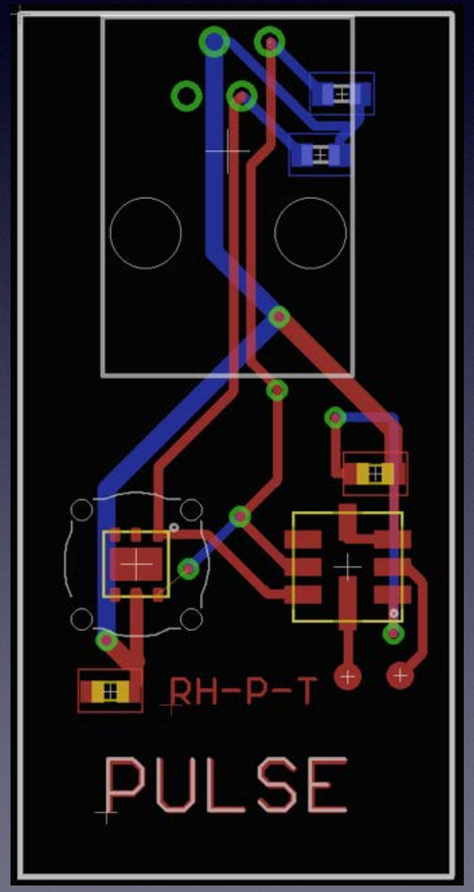
Longwave & Shortwave Radiation & Crop Greenness

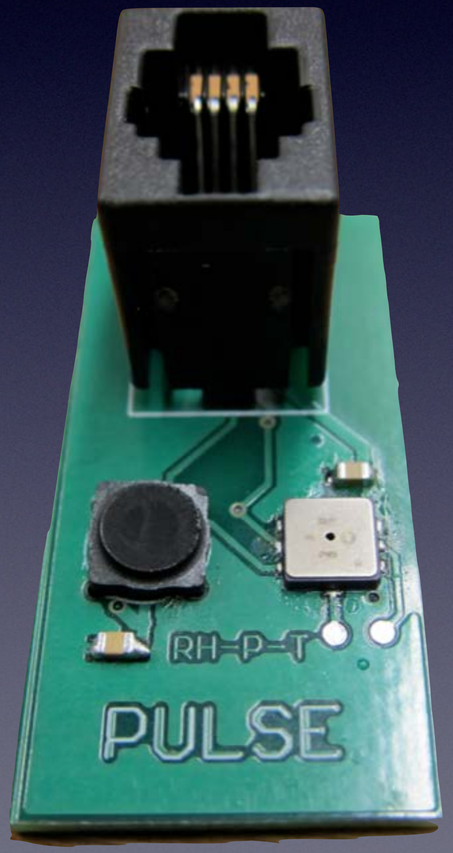




A low cost sensor network,

Daughter Sensor Boards
Pressure & RH





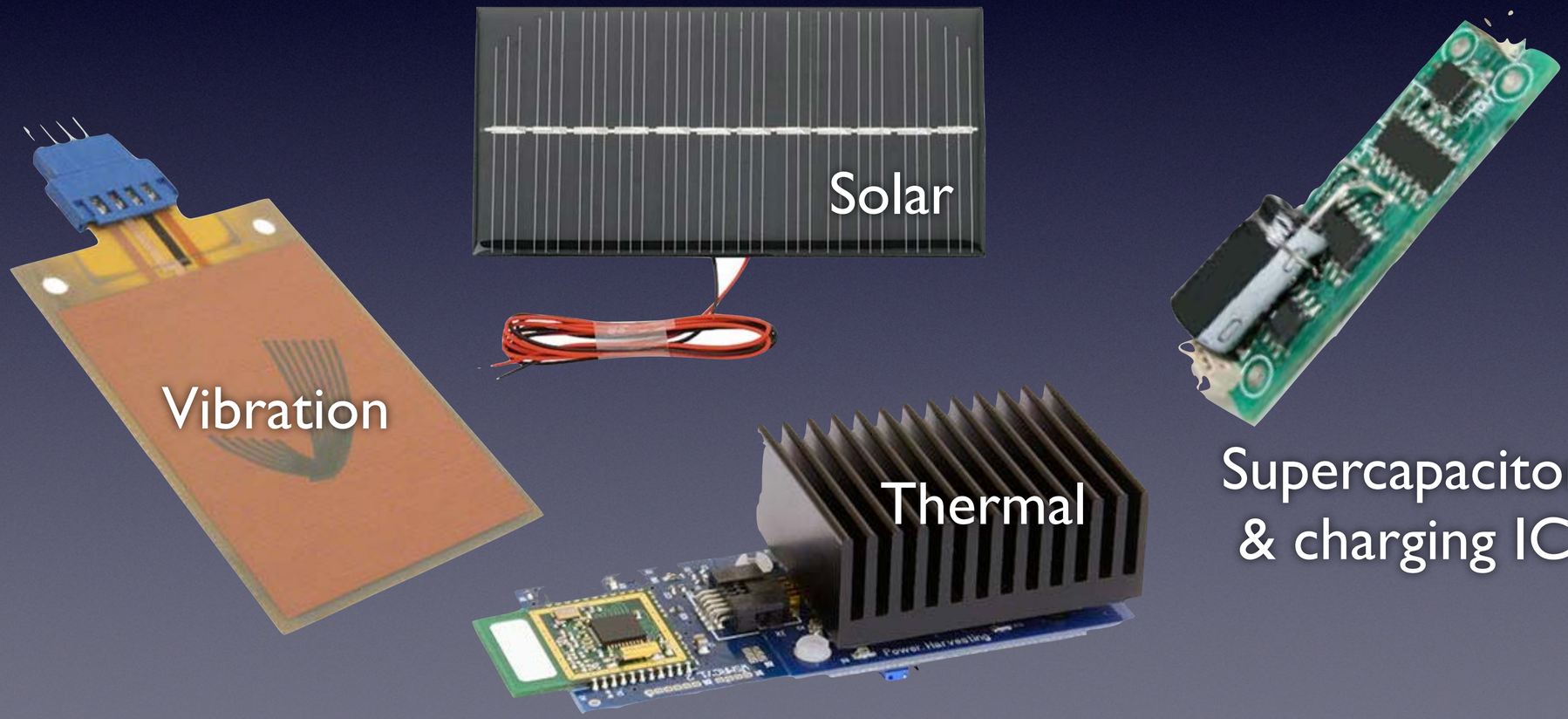
A low cost sensor network,

Burkina Faso – June 2013

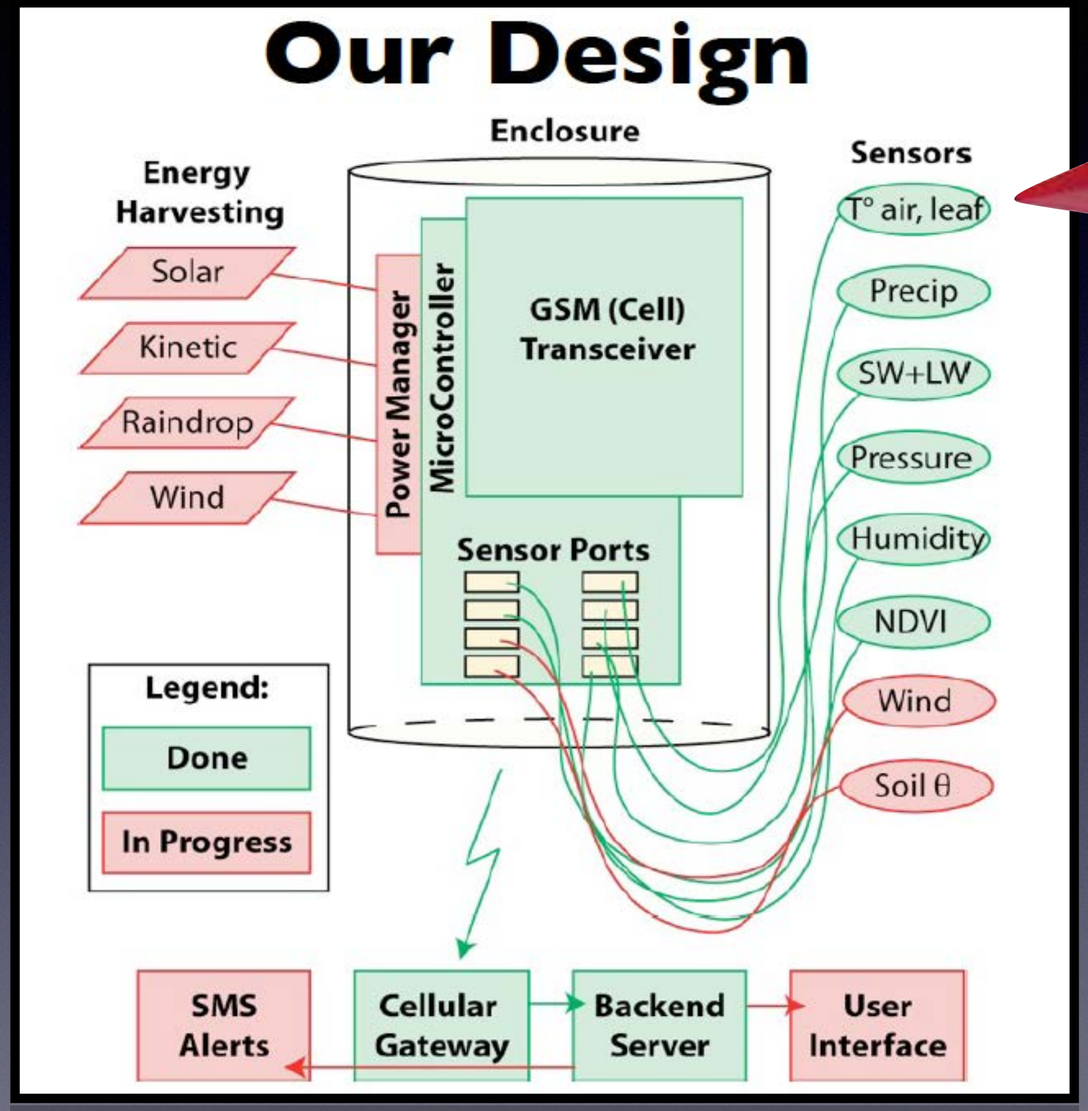
Easily integrates with existing recording gauges

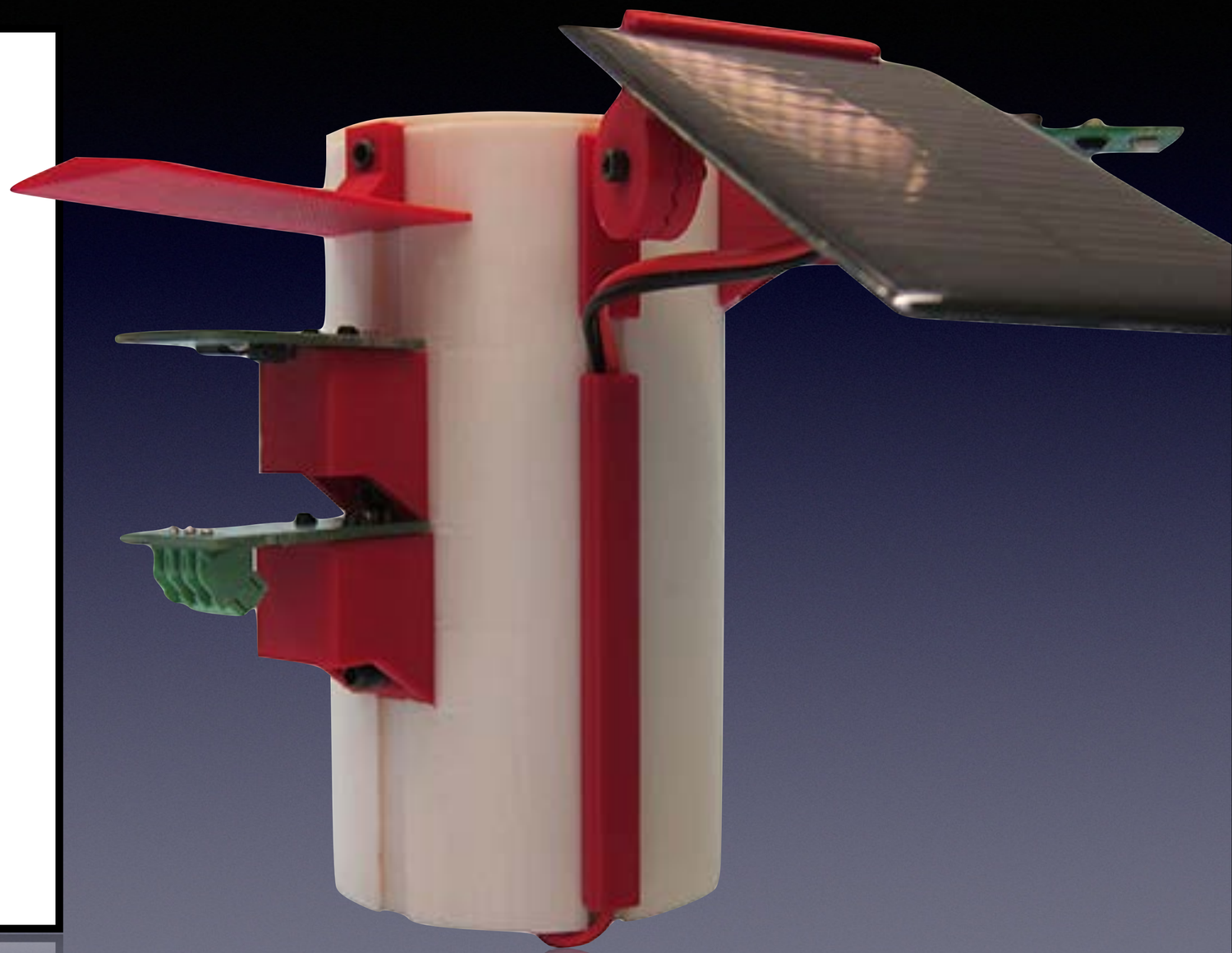
A low cost sensor network,

Many technologies are available to allow energy harvesting & battery management

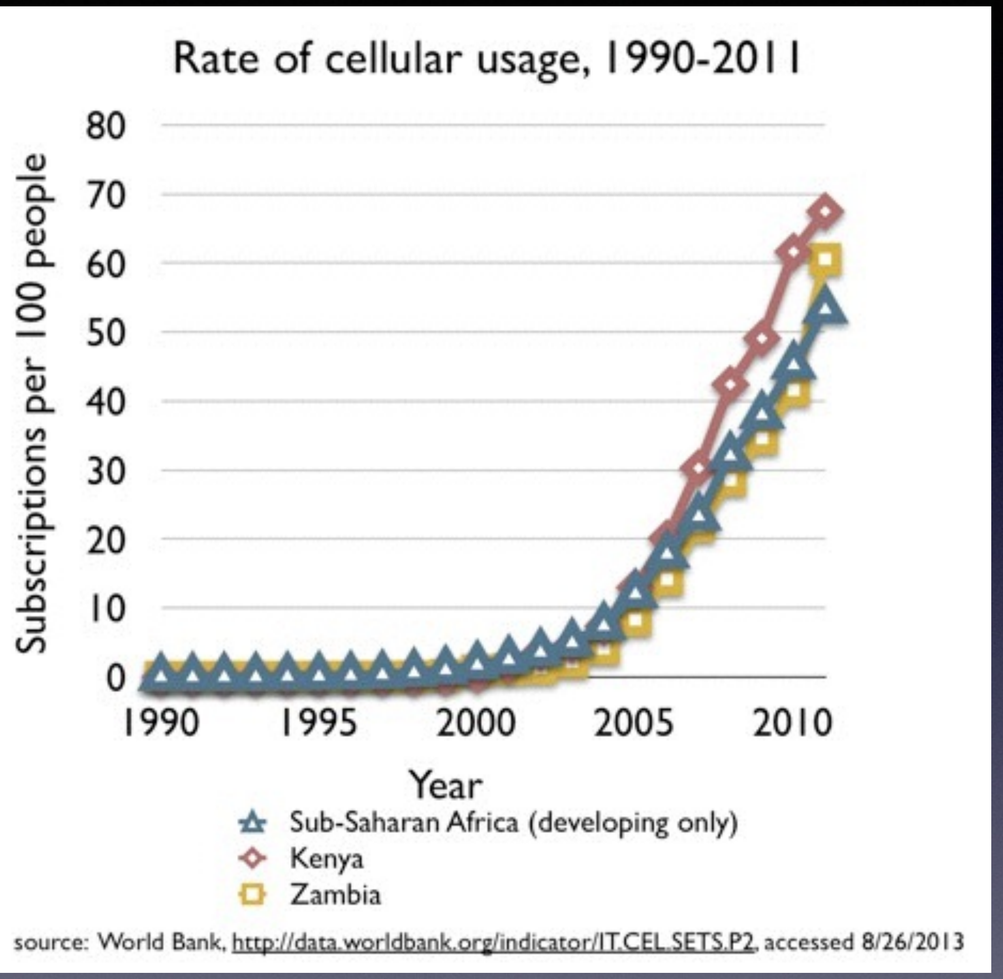


A low cost sensor network,



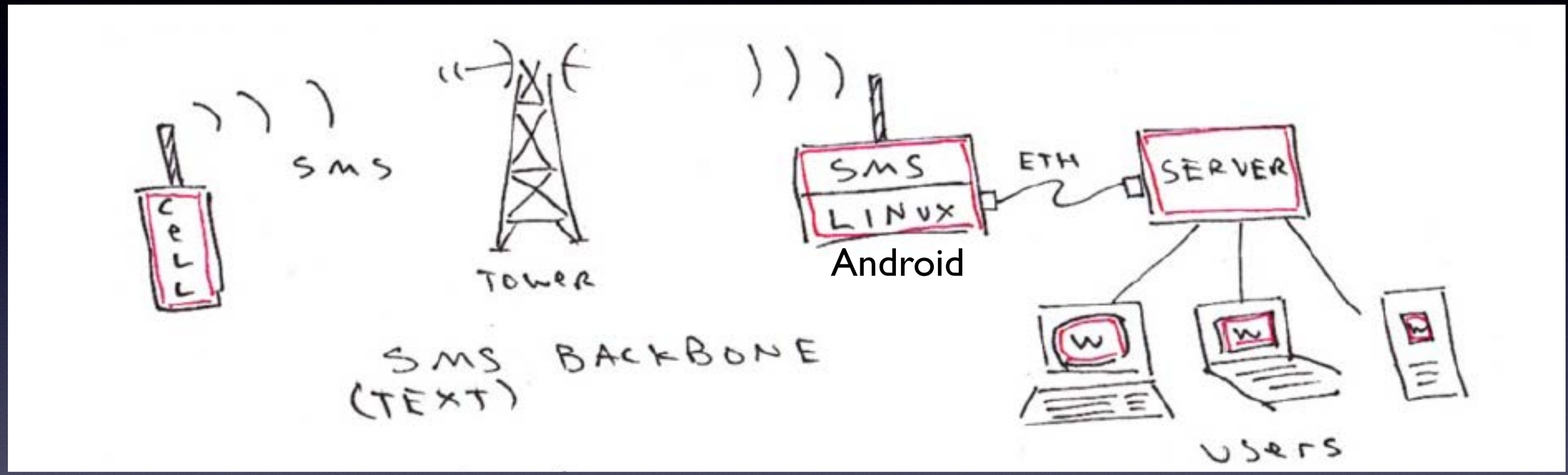


communicating in **real-time**,



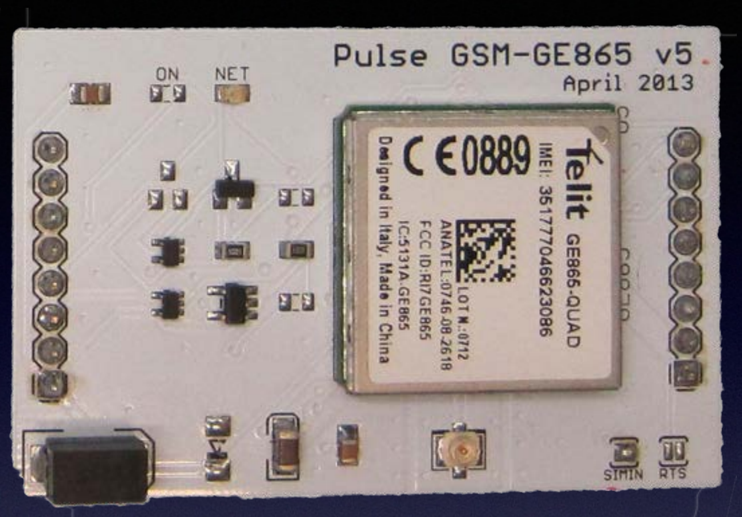
There's a large and rapidly growing cellphone network in sub-Saharan Africa

communicating in **real-time**,



Pods send SMS messages to a gateway that posts messages onto the internet

communicating in **real-time**,



GSM radio shield for SMS-based communication

Binary SMS, can pack at least 60 data points (including time stamps) per message

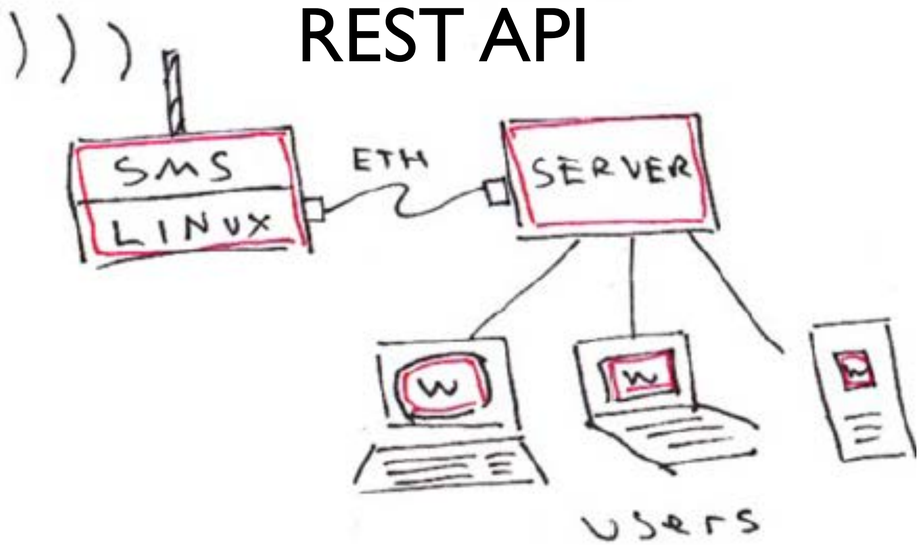
If $0.05 per SMS: $0.00083 per data point

35,000 data points per month:

$29.05 USD

storing data in an open web-based API

Adding data:
http POST



Adding data:
http GET

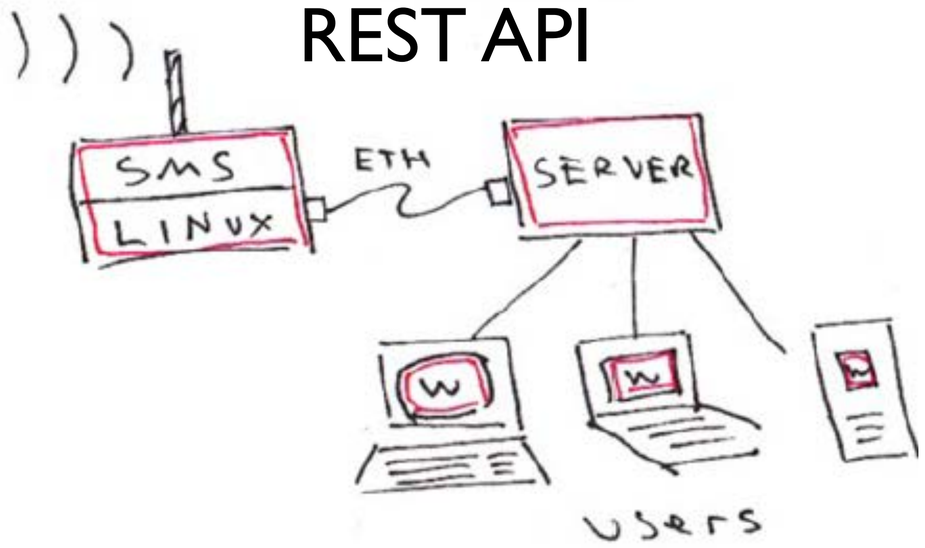
> curl -X POST http://app.ppd.io/data/ -d '{"<data document>"}'

Gateway posts messages onto the internet

storing data in an open web-based API

Adding data:
http POST

REST API



Adding data:
http GET

```
> curl -X GET http://app.ppd.io/data/
```

Posted data immediately available via http GET requests

storing data in an

open web-based API

University vs. Enterprise solution:
We want to be scaleable and open from the start

https://github.com/nicolaiarocci/eve

Heroku
PaaS

MongoHQ
DaaS

storing data in an open web-based API


```
{
  "_id": "5261da899e01040002a3ab30",
  "p" : "4152496520",
  "t":"Mon, 10/13/2013 12:04:00 GMT",
   "v":"10",
  "s":"rain",
  "u":"mm",
  "d":"24",
}
```


All data is stored as a JSON document for easy storage/retrieval, assimilation, and visualization

storing data in an open web-based API

```
{
  "_id": "5261da899e01040002a3ab30",
  "p" : "4152496520",
  "t":"Mon, 10/13/2013 12:04:00 GMT",
   "v":"10",
  "s":"rain",
  "u":"mm",
  "d":"24",
}
```

Unique ID

Each data record has a specific ID

IDs correspond to a specific URL:

`http://app.pulsepod.io/data/5261da899e01040002a3ab30`

storing data in an open web-based API

```
{
  "_id": "5261da899e01040002a3ab30",
  "p" : "4152496520",
  "t":"Mon, 10/13/2013 12:04:00 GMT",
   "v":"10",
  "s":"rain",
  "u":"mm",
  "d":"24",
}
```

Pod ID

Each data record is associated with a specific pod that collected the data

storing data in an open web-based API


```
{
  "_id": "5261da899e01040002a3ab30",
  "p" : "4152496520",
  "t":"Mon, 10/13/2013 12:04:00 GMT",
   "v":"10",
  "s":"rain",
  "u":"mm",
  "d":"24",
}
```


Data time stamp

Time stamps are recorded for all data.

It is possible to query on time intervals

storing data in an open web-based API

```
{
  "_id": "5261da899e01040002a3ab30",
  "p" : "4152496520",
  "t":"Mon, 10/13/2013 12:04:00 GMT",
   "v":"10",
  "s":"rain",
  "u":"mm",
  "d":"24",
}
```

Data value

Values are stored with sensor information necessary for data assimilation

storing data in an open web-based API


```
{
  "_id": "5261da899e01040002a3ab30",
  "p" : "4152496520",
  "t":"Mon, 10/13/2013 12:04:00 GMT",
   "v":"10",
  "s":"rain",
  "u":"mm",
  "d":"24",
}
```


Variable

Values are stored with sensor information necessary for data assimilation

storing data in an **open web-based API**

```
{
  "_id": "5261da899e01040002a3ab30",
  "p" : "4152496520",
  "t":"Mon, 10/13/2013 12:04:00 GMT",
   "v":"10",
  "s":"rain",
  "u":"mm",
  "d":"24",
}
```

Units

Values are stored with sensor information necessary for data assimilation

storing data in an **open web-based API**


```
{
  "_id": "5261da899e01040002a3ab30",
  "p" : "4152496520",
  "t":"Mon, 10/13/2013 12:04:00 GMT",
   "v":"10",
  "s":"rain",
  "u":"mm",
  "d":"24",
}
```


Duration (hours)

Values are stored with sensor information necessary for data assimilation

storing data in an open web-based API


```
{
  "_id": "5261da899e01040002a3ab30",
  "p" : "4152496520",
  "t":"Mon, 10/13/2013 12:04:00 GMT",
   "v":"10",
  "s":"rain",
  "u":"mm",
  "d":"24",
}
```


It is easy to extend data specification to include sensor error, measurement uncertainty, or any other attribute

storing data in an open web-based API

Retrieving all data for a specific pod:

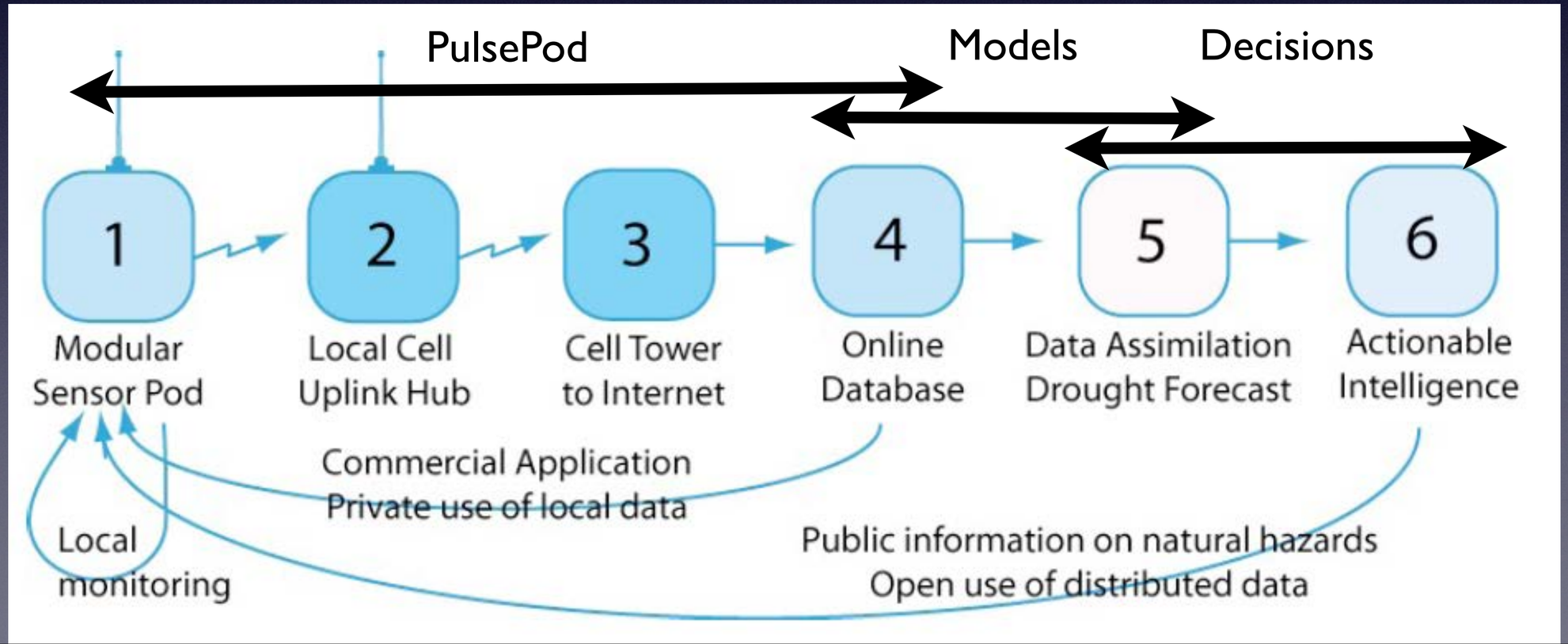
```
> curl http://app.ppd.io/data/?where={"p": "10023"}
```

Retrieving all data for a specific sensor:

```
> curl http://app.ppd.io/data/?where={"s":"rain"}
```

Queries can be combined
Spatial queries are possible

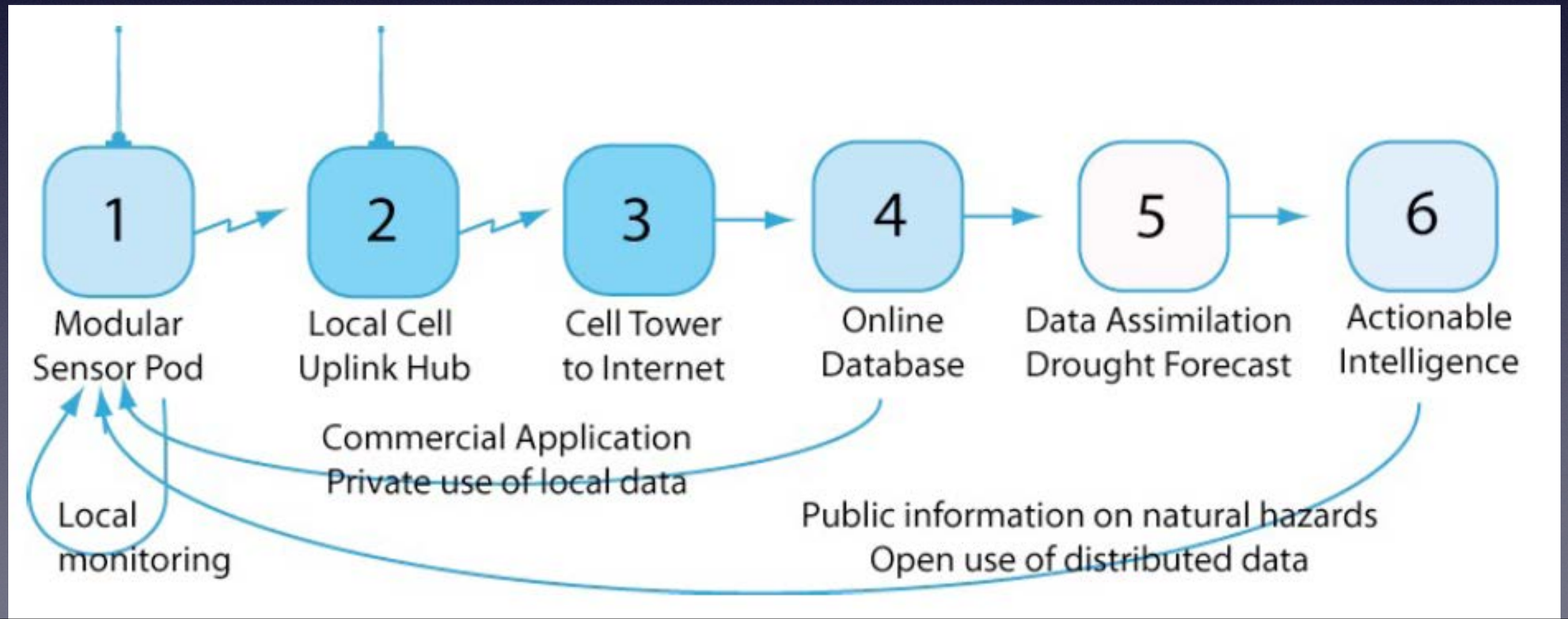
A **low cost** sensor network, communicating in **real-time**, storing data in an **open web-based API**



System is in beta, in the midst of multiple deployments

Summer, 2013: Ouagadougou, Burkina Faso
Nov, 2013: Zambia southern/eastern provinces
Spring, 2014: Kenya Laikipia/Mwea districts

We're eager to find more opportunities!



PULSE Lab

Princeton University Low-cost Sensors for the Environment

http://tronic.princeton.edu/pulselab

Thank You!

adamwolf@princeton.edu
kcaylor@princeton.edu

Thank You!

tronic.princeton.edu/pulselab

adamwolf@princeton.edu
kcaylor@princeton.edu