Health Applications of AIRS Data: Environmental Connection and Prediction of Influenza and Dengue Fever

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NASA Sounder Science Team Meeting, October, 2017

Influenza Background

- Seasonal influenza epidemics are a major public health concern
  - Millions of cases of severe illness worldwide each year
  - 250,000 to 500,000 deaths worldwide each year
  - Large economic toll

- In temperate regions influenza incidence generally has pronounced peaks in the winter.
  - But specific timing, magnitude and duration of individual local outbreaks in any given year are variable and not well explained

- If the timing and intensity of seasonal influenza outbreaks can be forecast, this would be of great value for public health response efforts.
  - Could guide both mitigation and response efforts
  - Planning and stockpiling of vaccines and drugs
  - Management of hospital resources
  - Focusing of efforts to areas with more urgent need

Humidity & Influenza

- Recent studies have highlighted a role of absolute (or specific) humidity conditions as a leading explanation for the seasonal behavior of influenza outbreaks
  - Decreasing absolute humidity associated with increased influenza activity

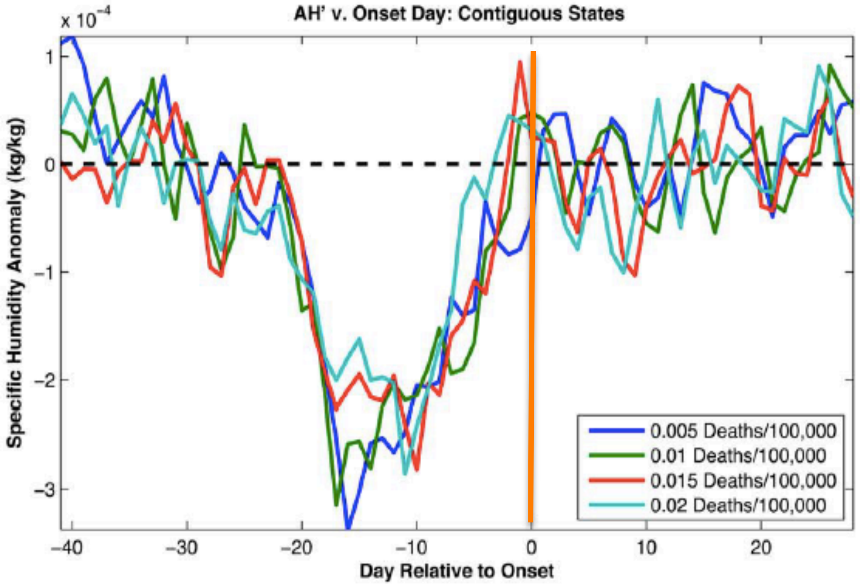
- Lab experiments:
  - Absolute humidity strongly modulates the airborne survival and transmission of the influenza virus.

- Climate & influenza data records:
  - Increased wintertime influenza-related mortality in the US associated with anomalously low absolute humidity levels

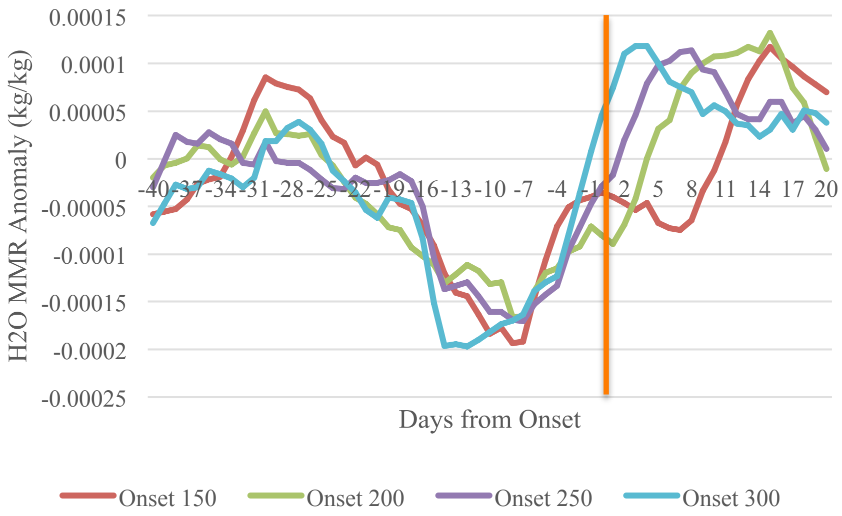
- Humidity-driven epidemiological models yielding promising results

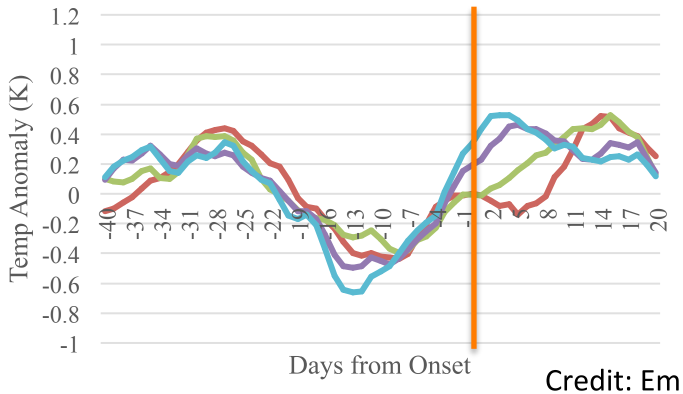
- The reason for the humidity–influenza relationship is not well established but a few mechanisms are proposed
  - Drying of mucous membranes
  - Humidity effects on droplet sizes and travel range
  - Increased survival times for the virus

Humidity & Influenza


AH' v. Onset Day: Contiguous States

- Shaman et al. (2010) used 30 years of flu-related mortality data and humidity data
- Anomalously low humidity preceding the onset of influenza seasons
- We have used AIRS and Google Flu Trends data at city, state and regional scales in the US to give further support for the role of humidity (and temperature) in driving influenza seasonality


GFT Plus State Level: Days from Onset vs Humidity Anomaly (Smoothed)


State Level: Onset vs Temperature Anomaly (Smoothed)

Credit: Emily Serman

Model of Influenza Outbreaks

- We have developed and implemented a numerical prediction system that is driven by specific humidity to predict influenza outbreaks.
- Standard compartmental epidemiological model, SIRS (Susceptible-Infectious-Recovered-Susceptible) type
- Two coupled first-order Ordinary Differential Equations numerically solved for the number of susceptible and infected/infectious people in a given population.
- Rate of infections and recoveries parameterized in terms of average length of immunity and mean infectious period and assumed to have a simple dependence on input specific humidity.

SIRS Model

$$\frac{dS}{dt} = \frac{N - I - S}{L} - \frac{\beta I S}{N} - \alpha$$

$$\frac{dI}{dt} = \frac{\beta I S}{N} - \frac{I}{D} + \alpha$$

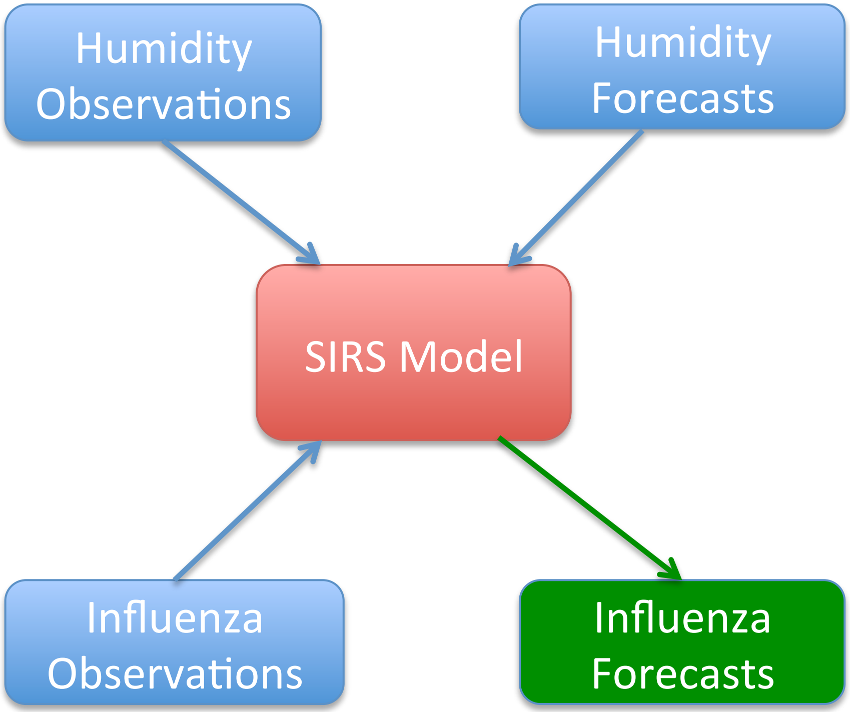
Specific humidity

$$\beta = \frac{R_0}{D} = \frac{1}{D}[R_{0min} + (R_{0max} - R_{0min})\mathrm{e}^{aq}]$$

N	Population size
S	Susceptible persons
I	Infectious (= infected) persons
L	Average immunity duration
D	Mean infectious period
α	Rate of (travel-related) import of virus into model domain
β	Contact rate
R_0	(Daily) basic reproductive number
a	(Negative) coefficient in contact rate exponential
q	Specific humidity

Quasi-Operational Forecasting System

- Daily updating most recent values for near-surface H_2O mixing ratio, AIRS level 3 data (v6)



Humidity Observations

Humidity Forecasts

SIRS Model

Influenza Observations

Influenza Forecasts

- NCEP forecasts for near-surface humidity

- Influenza data assimilated

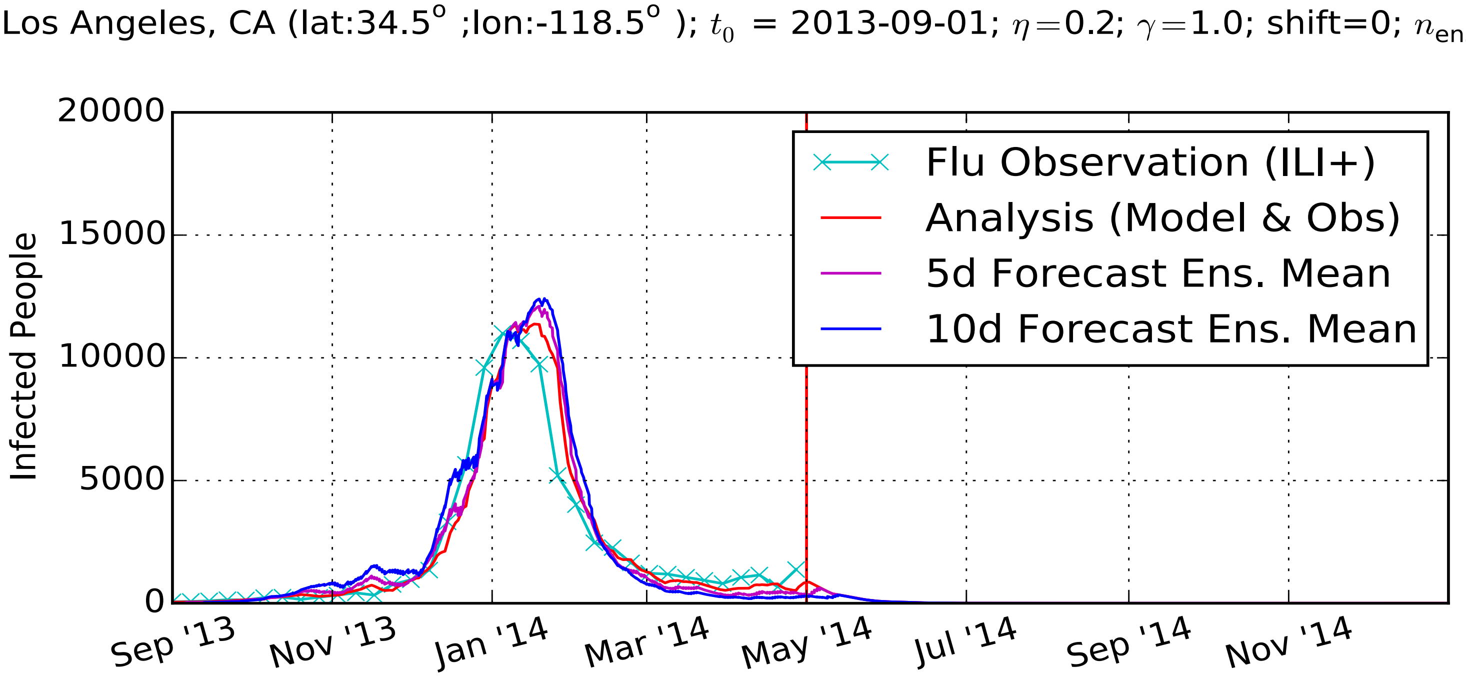
- Center for Disease Control (CDC):
  - Regional, weekly surveillance records for the proportion of doctor's visits for influenza-like illness (ILI)
  - Combined with lab virology results for the percentage of influenza positive samples

- Google Flu Trends:
  - Near real-time estimates of influenza infection rates based on online-search queries

- The output is the number of infected and susceptible people in a population (city/state/region)

Retrospective Simulations

- Pseudo-forecasts performed for 21 US cities (in hindsight with observed humidity) for 2005-2015 seasons
- 5-day and 10-day influenza forecasts (with AIRS humidity) are often quite accurate (example below for LA, 2013/14 winter)



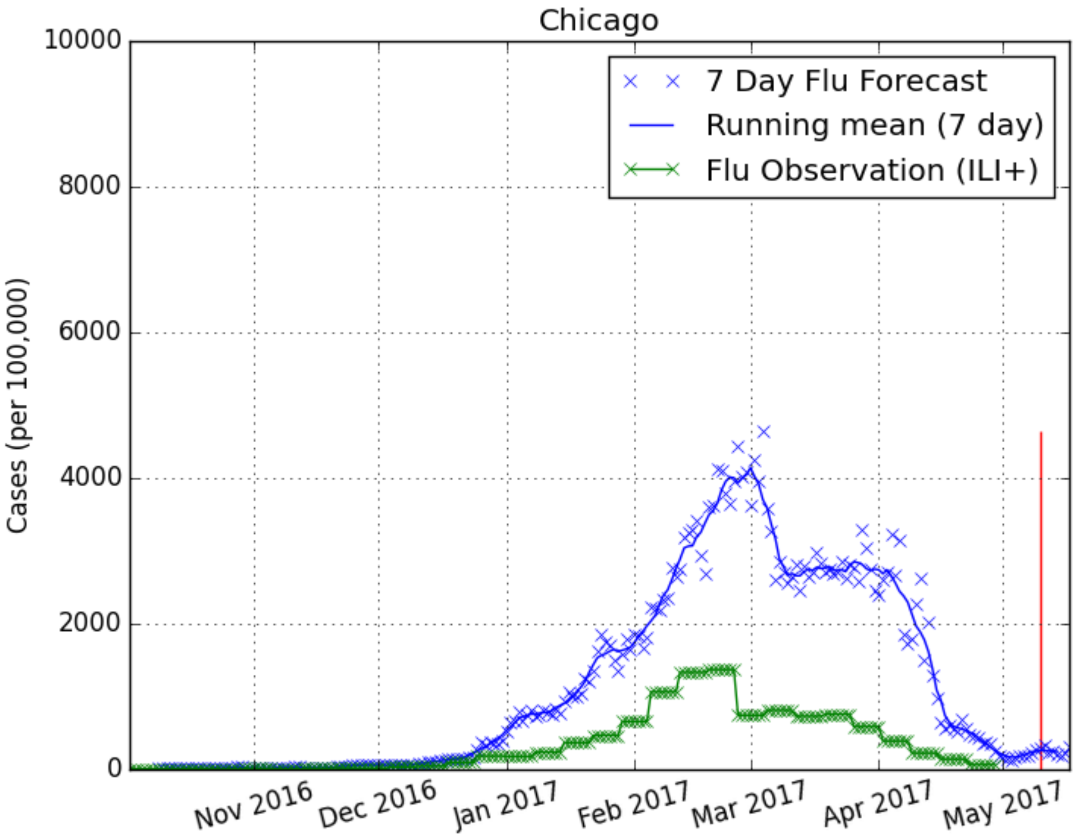
Los Angeles, CA (lat:34.5° ;lon:-118.5°); t_0 = 2013-09-01; $\eta=0.2$; $\gamma=1.0$; shift=0; $n_{\text{ens}}=100$

Thrastarson & Teixeira, 2017

Quasi-Operational Prediction System applied to US cities

- The system has been running quasi-operationally for several US cities
- AIRS near-surface humidity is key component of a quasi-operational (produced daily) influenza prediction system
- Most recent values of AIRS near-surface specific humidity as well as NCEP humidity predictions regularly incorporated into the model
- 'Observational' data for influenza incidence from CDC/Google assimilated to make analysis and re-initialize model
- Ensembles of forecasts run with different model parameter values drawn from distributions reflecting limited constraints

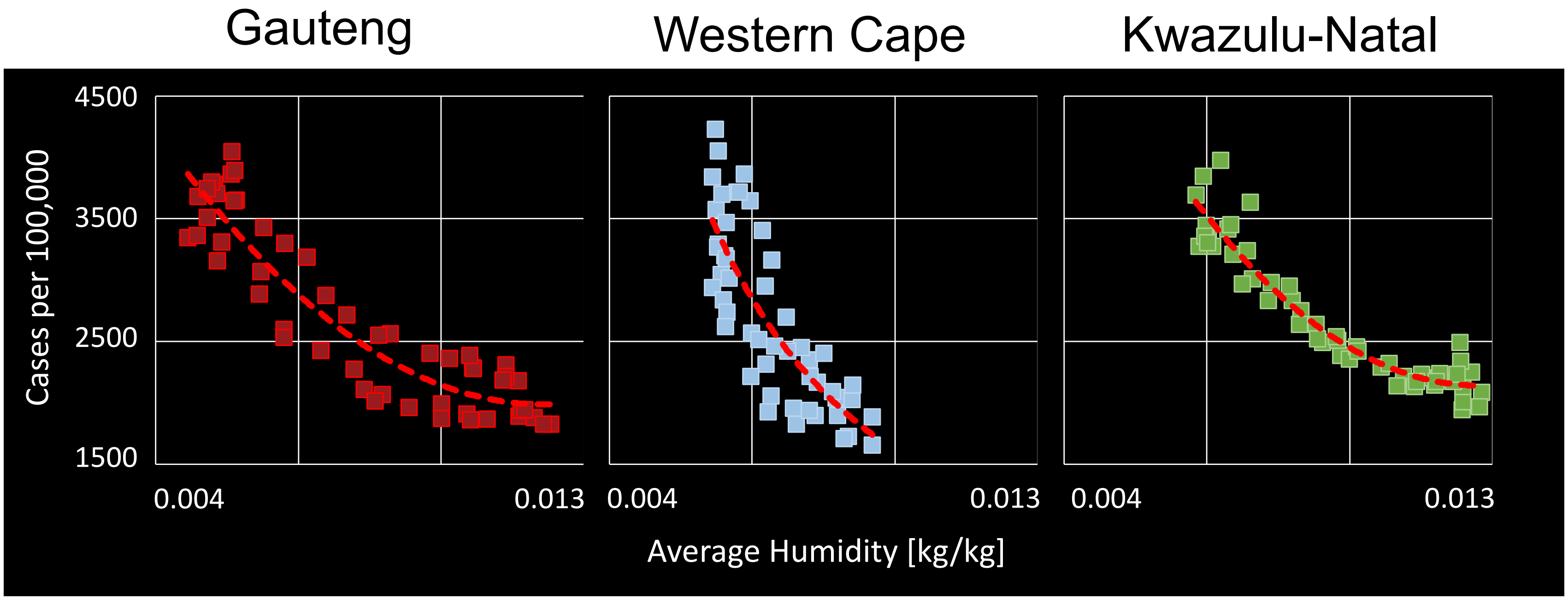
Example results for the 2016-2017 season



- Timing and relative behavior of influenza outbreaks generally captured fairly well, while getting absolute numbers of affected people is more challenging

AIRS and Influenza in South Africa

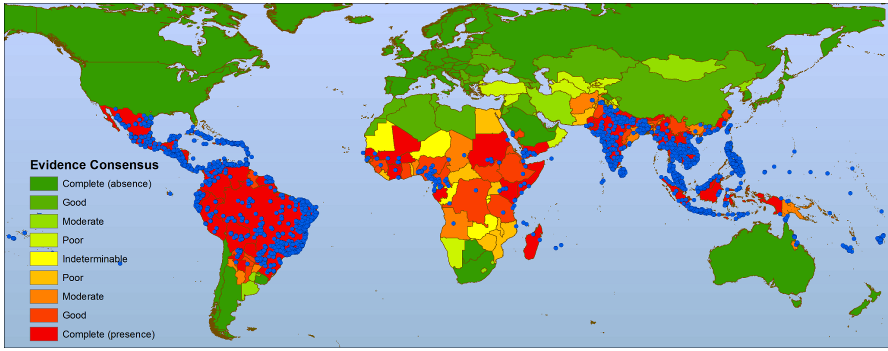
- Near-surface humidity plays critical role in influenza epidemics
- AIRS near-surface humidity correlates well with influenza cases
- Mathematical relations depend on regional climate (provinces)
- These relations can be used to monitor and predict influenza

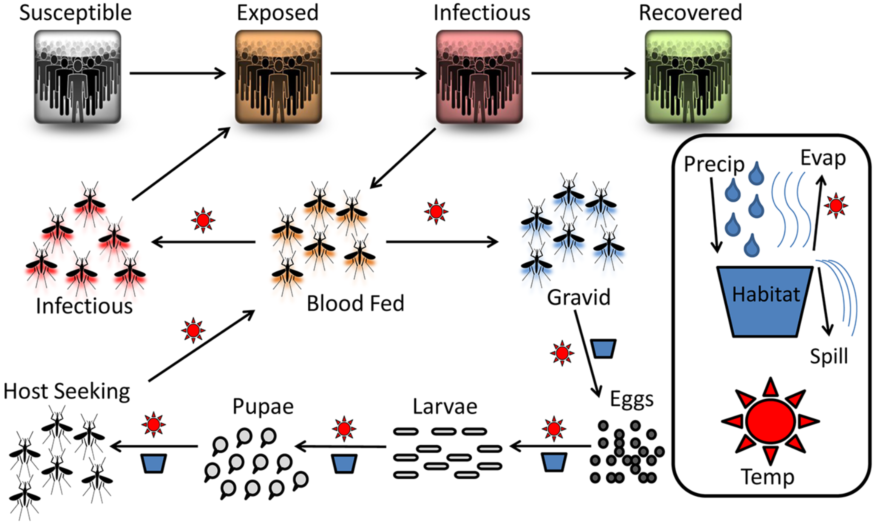


Credit: Anish Parekh

Dengue Fever and Environment Dependence

- Dengue Fever is the most common mosquito-borne virus in the world
- Carried by Aedes aegypti mosquitos (same as Zika, Chikungunya and Yellow Fever) – strongly affected by environmental conditions
- Temperature affects mosquito development and reproduction, frequency of feeding, virus incubation period and geographical range of the vector (tropics and sub-tropics)
- Precipitation provides breeding sites and stimulates egg hatching, but can also hurt habitats through flooding and humidity has also been identified as a substantial factor affecting favorable conditions for the vector
- Typically expect effects of temperature and humidity to take 6-8 weeks

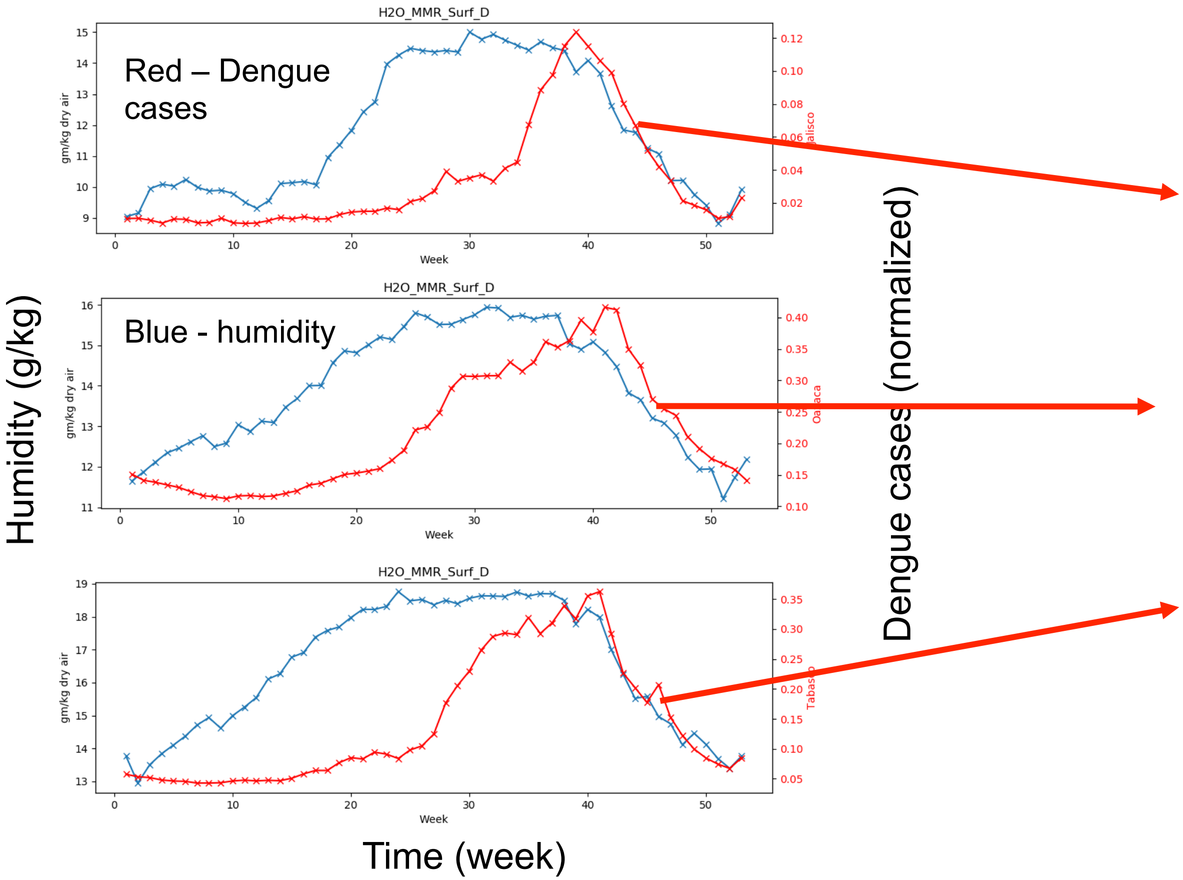




AIRS - Dengue

- We are exploring the application of AIRS climate data to the prediction of dengue fever incidence.
- An ultimate goal is to create and implement an improved prediction model for Dengue.
- We have done a focused study on Dengue fever in Mexico, from 2003-2015
- Mexico has significant Dengue incidence in varied climate conditions, with weekly Google Dengue Trends data available at state level as an estimate of disease activity
- AIRS variables: surface air temperature, specific humidity, relative humidity
- Examined trends, patterns and time lags, regression models of varying complexity

AIRS and Dengue Fever in Mexico



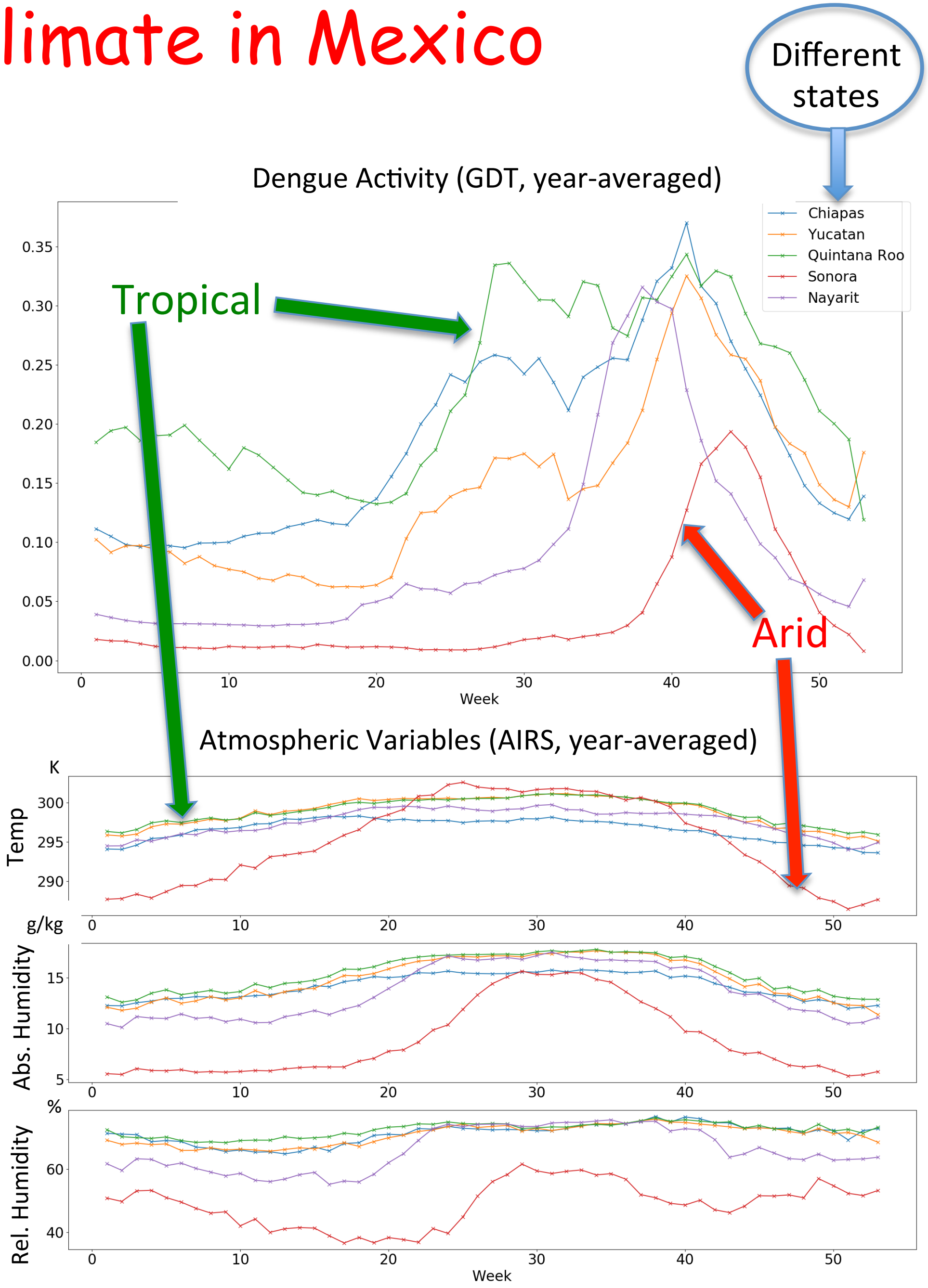
Dengue cases correlate particularly well with AIRS humidity during decay phase

These relations are being tested to monitor and predict Dengue incidence during its decay phase

Dengue and Climate in Mexico

Comparisons of year-averaged Dengue activity (Google Dengue Trends, top) and AIRS near-surface temperature and humidity (bottom) show climate-related regional differences

More tropical regions	**More arid regions**
More extended and elevated dengue seasons	Dengue peaks more sharply and only once
In correlation with extended and elevated temperatures and humidity	In correlation with steeper rises and falls in temperature and humidity
Shorter time lags in the climate-dengue relationship	Longer time lags in the climate-dengue relationship



Credit: Anna Zeng

Summary

- Results using AIRS and influenza data support role of humidity and temperature in driving the seasonality of influenza outbreaks
- We have developed a humidity driven influenza model operating on a city, state or regional scale
- AIRS near-surface humidity is key component of the quasi-operational (produced daily) influenza prediction system
- For Dengue Fever, we have done a focused study in Mexico, exploring trends, patterns and time lags for Dengue and environmental variables, using regression models of varying complexity.
- Promising correlations and climate-related regional differences have been identified.

Future Work

- Further validation of the prediction system
- Obtaining and incorporating more specific influenza incidence data from medical networks and authorities and internet sources.
- Developing confidence and uncertainty measures (including effects of AIRS humidity data uncertainty)
- Better constraining of parameters and methods that account for their variability and uncertainty
- Implementing and assessing longer term seasonal predictions (using climatology, maybe longer term humidity predictions in the future)
- Exploring different types of models, virus subtypes, population age structure, geographical spread
- More engagement with potential end users