Ensemble Lightning Forecasts and Validation over the Hindu Kush Himalayan Region

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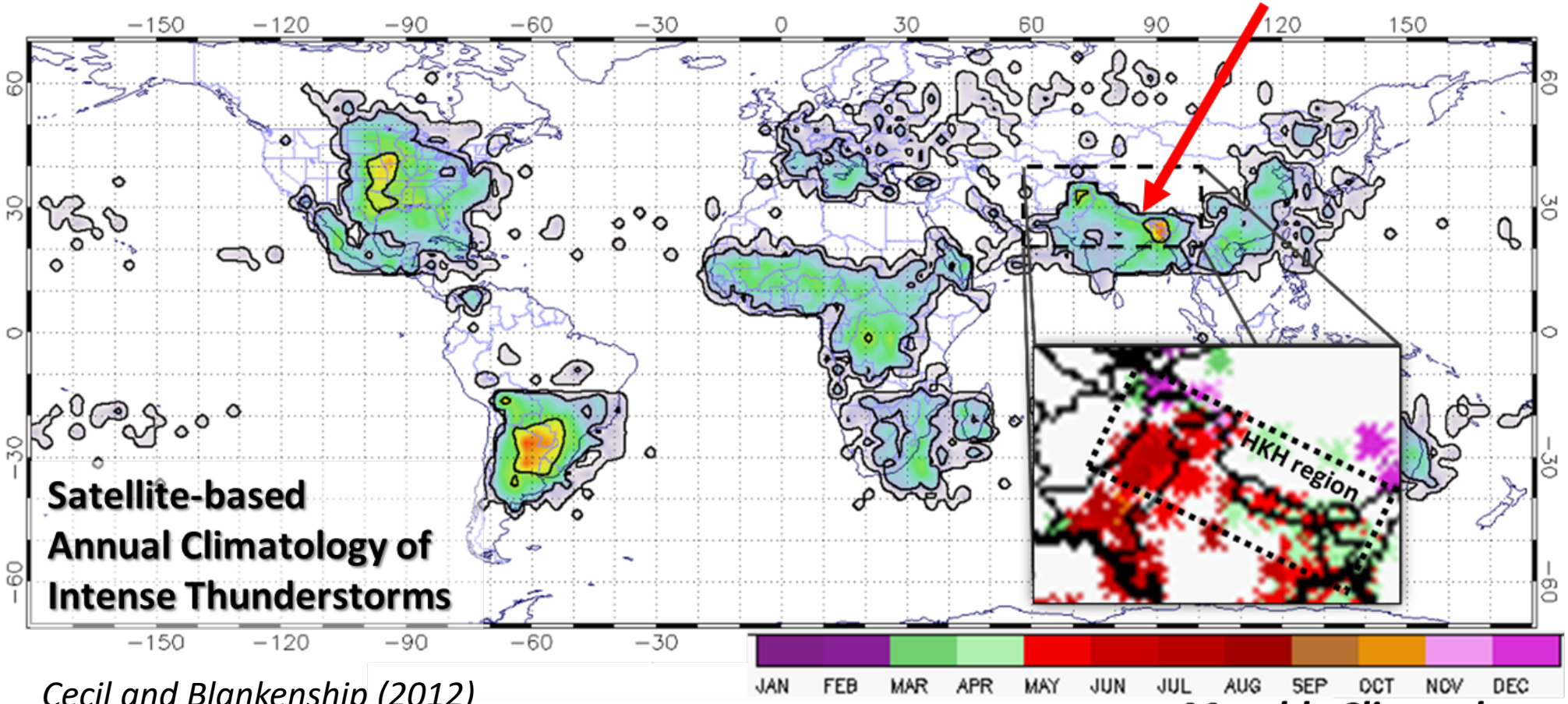
Ninth Conf. on Meteorological Application of Lightning Data; Phoenix, AZ

9 January 2019

Talk 4.2

Why Thunderstorms and Why the Hindu Kush Himalayan (HKH) Region?

Some of the most intense thunderstorms on Earth plague the HKH region:



Cecil and Blankenship (2012)

Monthly Climatology

Premonsoon (April-May): Bangladesh to eastern Nepal

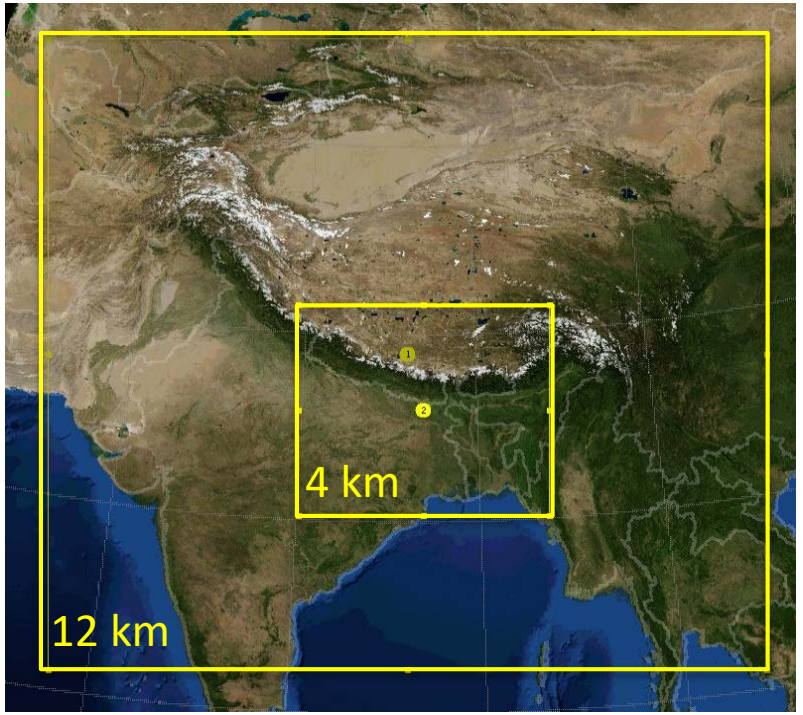
Monsoon (June-August): Nepal to northern Pakistan

****Numerous Lightning Casualties**

2018 Spring Demonstration (Mar to May): Ensemble Model Configuration

Nested mode grid domain over South Asia

- WRF community model
- 12-km outer grid 4-km nested grid (picture at right)
- Daily 48-hour forecasts with 1800 UTC initialization
- Strategy: Create sufficient spread in ensemble system by varying both initial/boundary conditions and physics parameterizations



**Chose different GEFS members to initialize each ensemble member

Run 12-member ensemble of model runs with varying initial conditions & physics

MP → / PBL ↓	Godd	Lin	WSM6	Morr
YSU	HKH1: GFS	HKH2: GEFS 03	HKH3: GEFS 05	HKH4: GEFS 07
MYJ	HKH5: GEFS 09	HKH6: GEFS 11	HKH7: GEFS 13	HKH8: GEFS 15
MYNN2	HKH9: GEFS 17	HKH10: GEFS 19	HKH11: GEFS 02	HKH12: GEFS 04

**Varied Planetary Boundary Layer (PBL) and Microphysics (MP) schemes, as these are important related to convection and lightning

Table at left shows initial condition and physics variations for the 12 ensemble runs.

Post-Processing and Product Generation

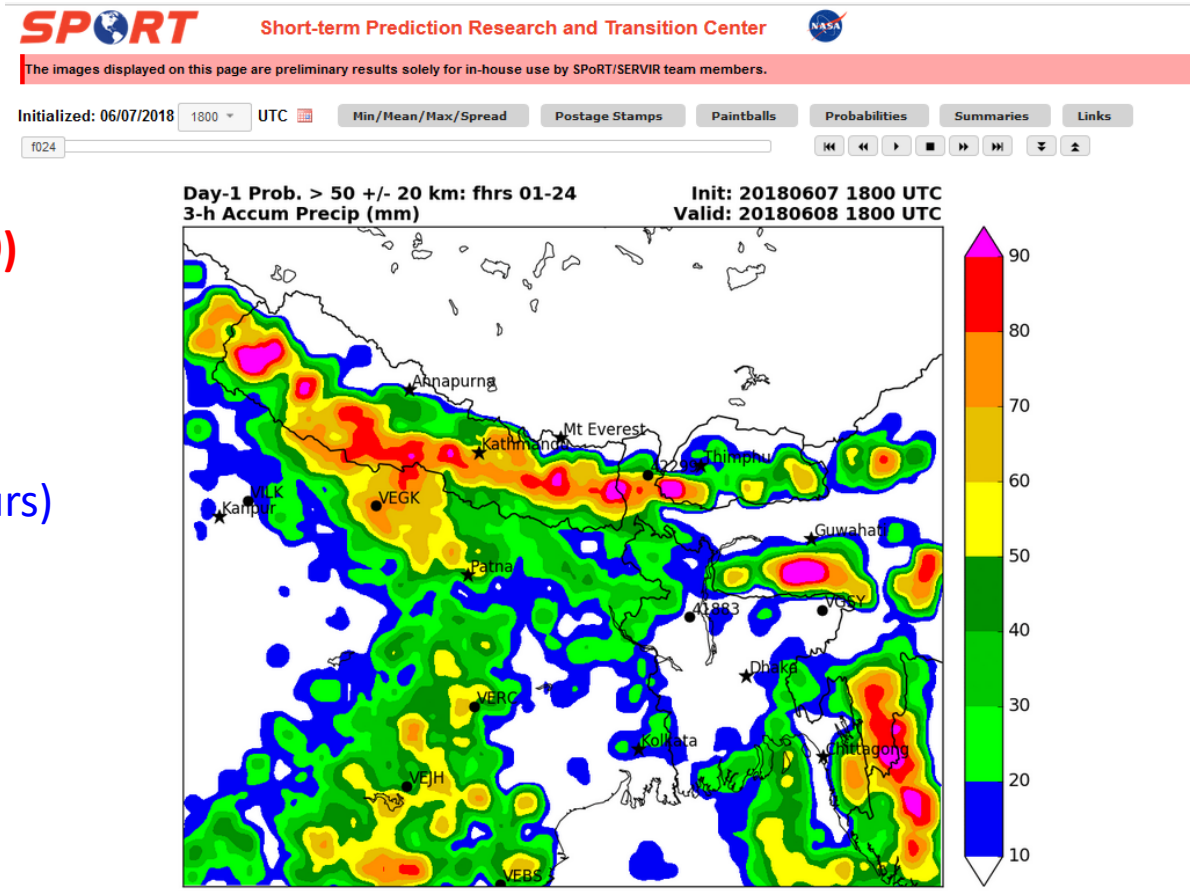
Post-processing to generate model products

- Hourly output frequency
- Following NOAA SPC/NSSL/WPC (Kain et al. 2010), use model fields for thunderstorm hazard proxies:
  - Convective intensity: Composite reflectivity
  - **Lightning: Lightning Forecast Algorithm (McCaul et al. 2009)**
  - Straight-line winds: Max output interval 10m wind speed
  - Hail threat: Max output interval total column graupel
  - Mesocyclone/tornado: Max output interval updraft helicity
  - Flooding rainfall: Accumulated precip thresholds (esp. 3 hours)

Generate visualization products

- GrADS/python for deterministic (HKH1) output
- Python scripts for ensemble web products (right)
- Netcdf/GDAL for NASA/SERVIR Web Mapping Service

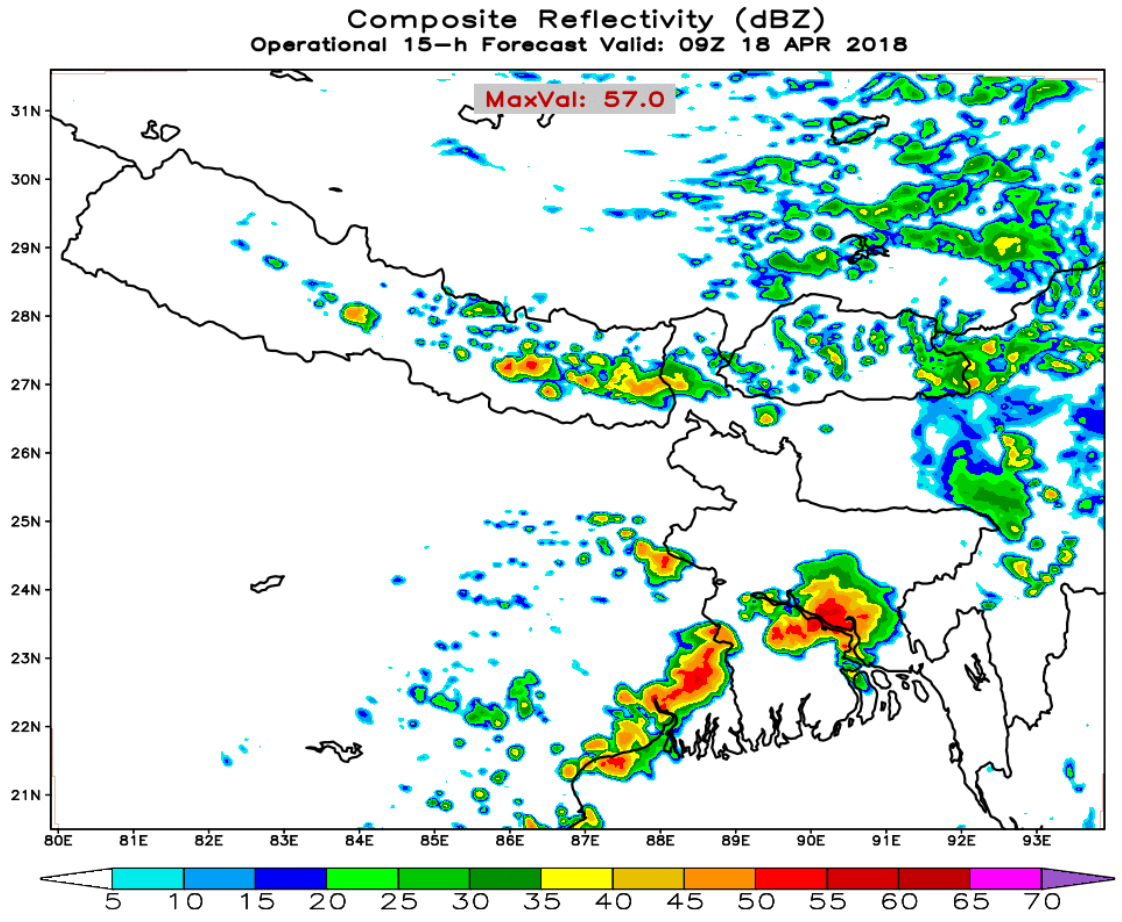
Internal Project Web Page



WRF Lightning Forecast Algorithm

Lightning Forecast Algorithm (LFA; McCaul et al. 2009]

- Weighted combination of graupel flux at -15deg C (threat 1) and vertically-integrated ice (threat 2):
  - $THR1 = k_1(wq_g)|_{T=-15C}$; $THR2 = k_2 \int \rho(q_g + q_s + q_i)dz$
  - *LFA = 0.95*THR1 + 0.05*THR2*
  - Coefficients k_1, k_2 empirically determined through calibration against northern Alabama total lightning flash rate observations
  - Requirement: WRF model must run in convection-permitting mode; *i.e., sufficiently fine horizontal grid spacing (~5km or less), with convective parameterization scheme de-activated, and microphysics scheme with graupel.*
- LFA represents both in-cloud and cloud-to-ground lightning activity
- Units are total flashes km^{-2} $(5\ min)^{-1}$
- LFA set to zero below 0.07 flashes km^{-2} $(5\ min)^{-1}$ (~1 flash per hour)



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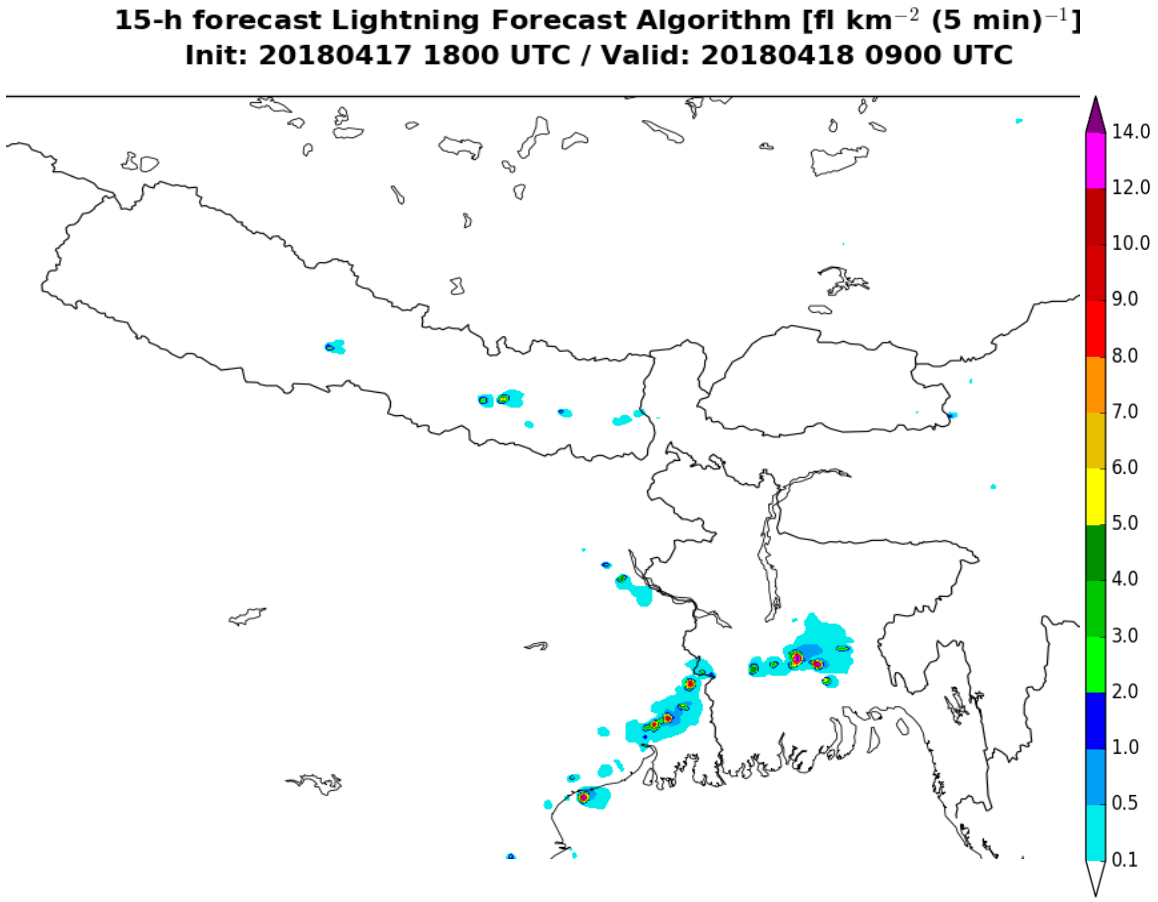
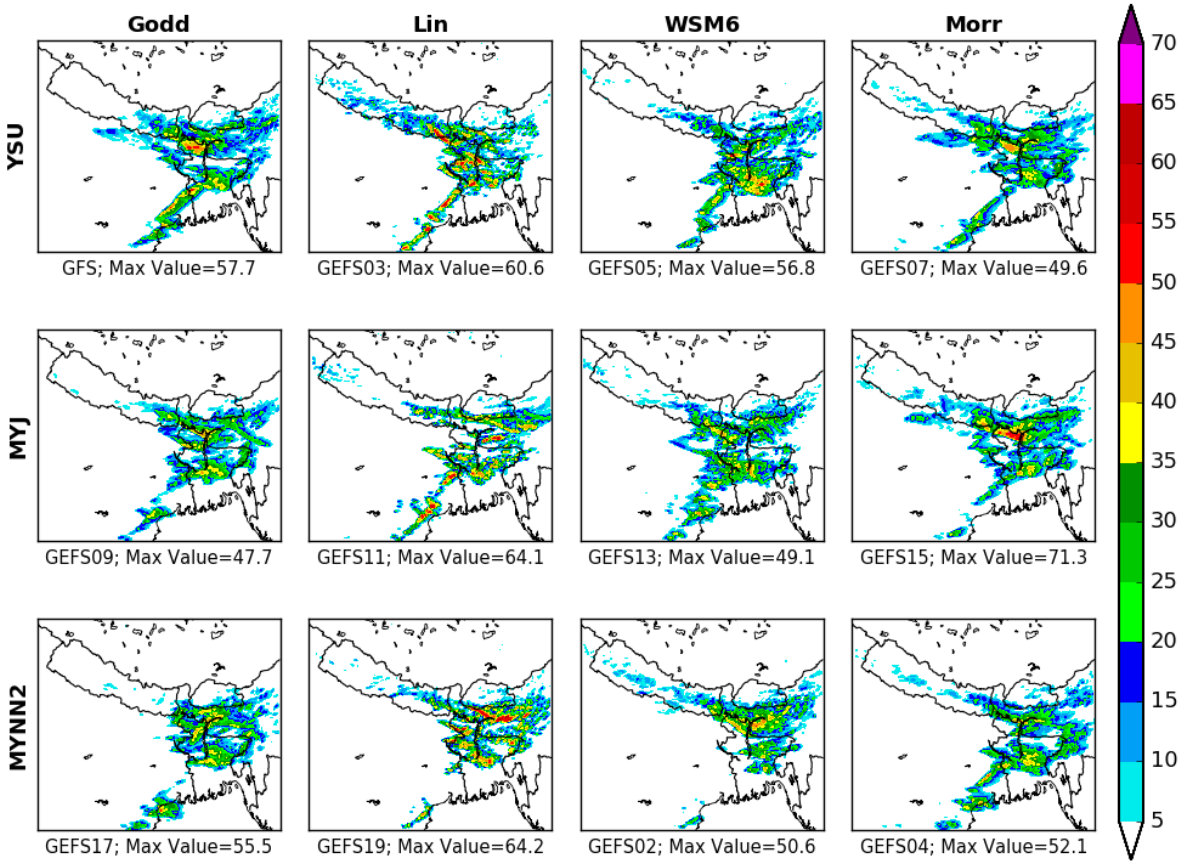


Ensemble Products for Spring 2018 Experiment

Summarize 12-member ensemble into meaningful fields for severe thunderstorm forecast guidance (Schwartz et al. 2015; Ebert 2001; Clark 2017)



- Postage Stamps
- Ensemble Statistics
  - *Mean*
  - *Minimum / Maximum*
  - *Spread*
- "Paintball" plots
- Probability products
  - *Grid point probability*
  - *Neighborhood probability*
  - *Probability Matched Mean (PMM)*
- Daily Summaries for Day-1 / Day-2
  - *Maximum hazard maps and probabilities for 1-24h and 25-48h*

Pre-monsoon 2018 Storm Reports

Event	Location	Lightning	Wind	Hail
29-Mar-18	Bhutan			X
	NE India	X	X	
30-Mar-18	***Bangladesh***	***X***	***X***	***X***
	Nepal			***X***
	N India			***X***
	NE India	***X***	***X***	
11-Apr-18	NW India	X	X	
17-Apr-18	N. India	X	X	
21-Apr-18	NE India		X	
22-Apr-18	Bangladesh	X	X	
29-Apr-18	Bangladesh	X		
	N. India	X		
30-Apr-18	Bangladesh	X	X	
2-May-18	N. India	X	X	
6-May-18	Bangladesh	X		
	NE India	X	X	
7-May-18	NE India		X	
9-May-18	Bangladesh	X		
	NE India	X	X	
10-May-18	Bangladesh		X	X
	NE India		X	
11-May-18	Bangladesh	X	X	X
	NE India		X	X
13-May-18	N. India	X	X	
15-May-18	Bangladesh	X		

***Totals:**

- 17 lightning events with fatalities
  - Over 100 total lightning fatalities during Spring Campaign
- 16 damaging wind events
- 7 damaging hail events
- 30 March 2018 event highlighted (in forthcoming slides)

**Not an exhaustive list; sourced from local news media outlets available online*

30 March 2018 Event:

Southeast Nepal/northern & central Bangladesh/NE India

Deadly Lightning, Damaging Winds and Large Hail

SERVIR

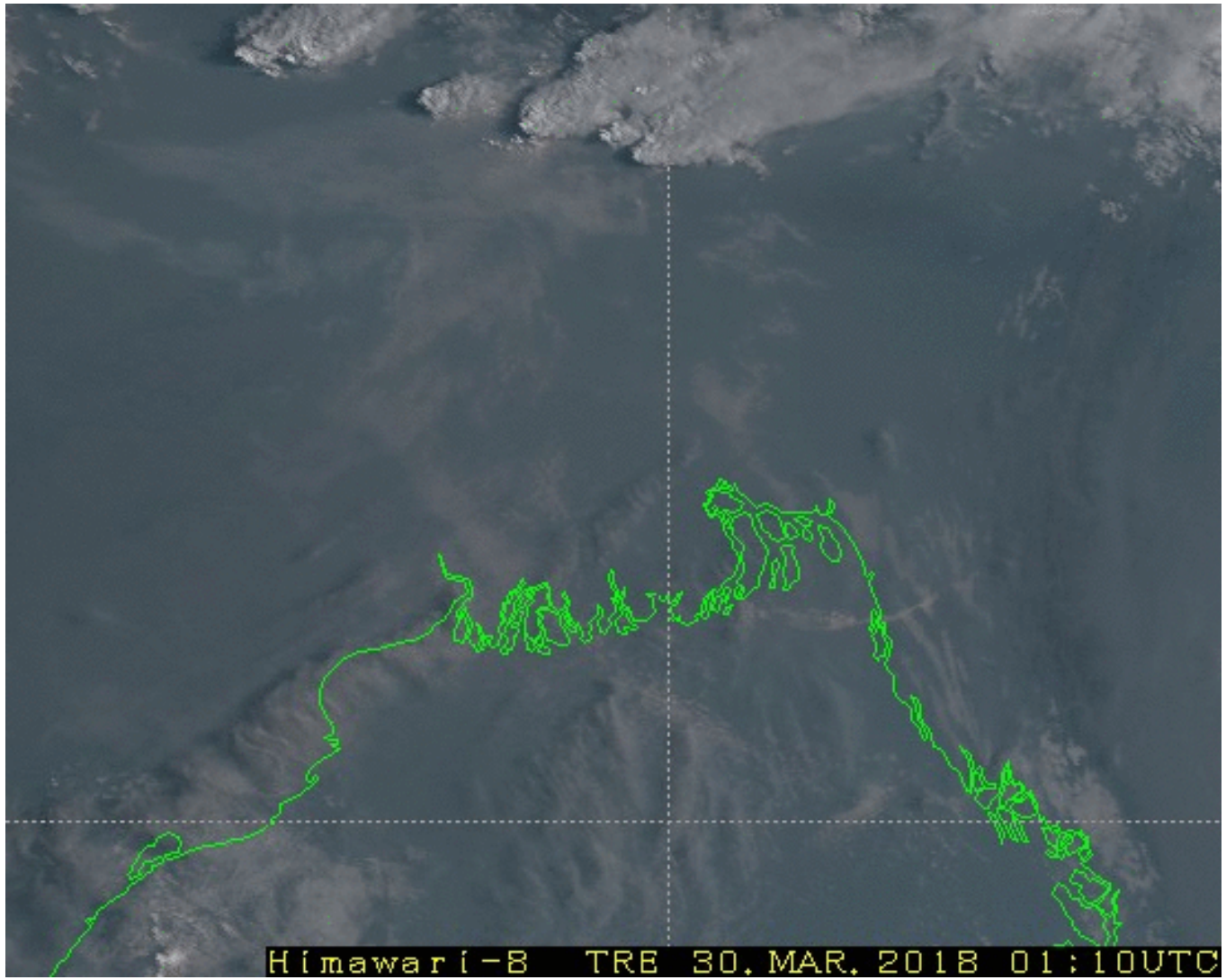
USAID FROM THE AMERICAN PEOPLE

NASA

30 Mar 2018 Severe Event

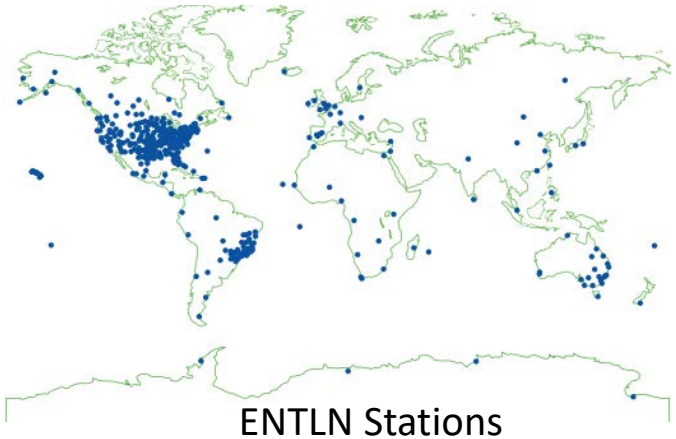
Japan Meteorological Agency Himawari-8

True Color RGB



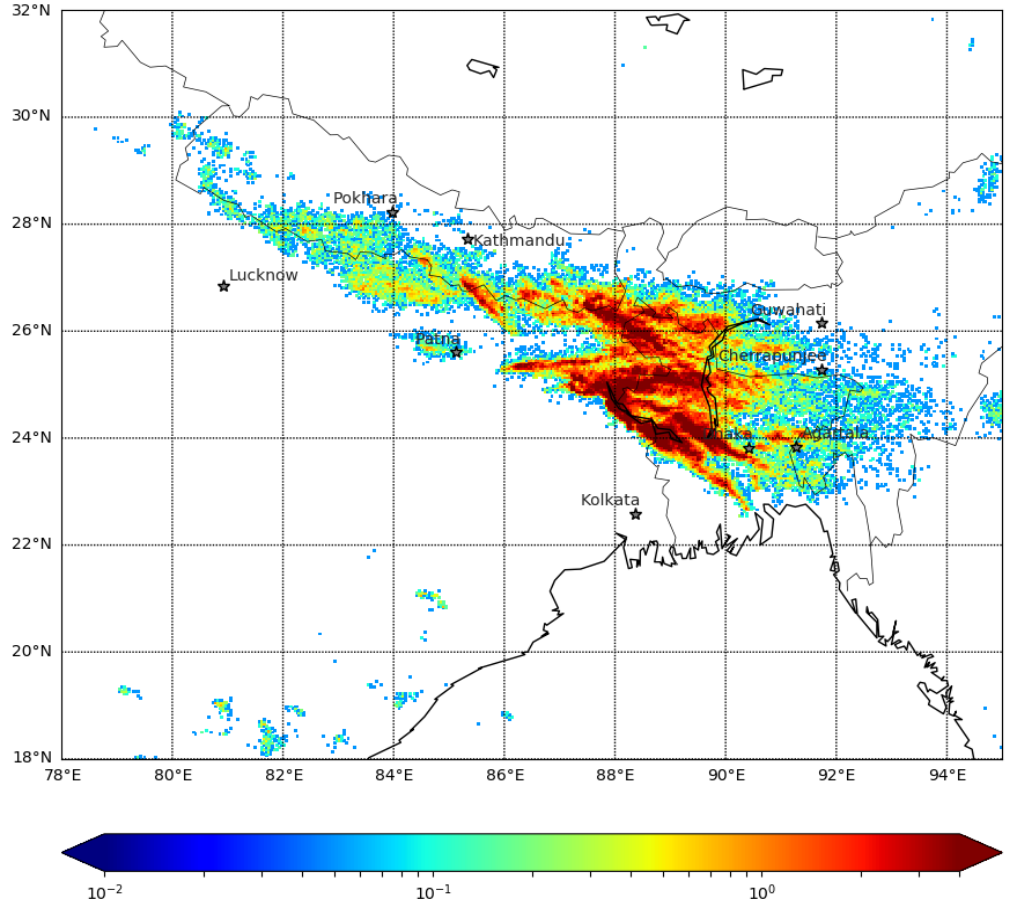
ENTLN Total Lightning Observations

- Earth Networks Total Lightning Network
  - Can detect both cloud-to-ground strokes and intra-cloud pulses at long range
  - Technology: Wideband E-field at 1Hz to 12 MHz; TOA
  - Detection efficiency: 28% in W. Hemisphere (Rudlosky et al. 2014)...likely less in S. Asia



ENTLN Stations

Daily Summary of ENTLN Observations: 30 March 2018



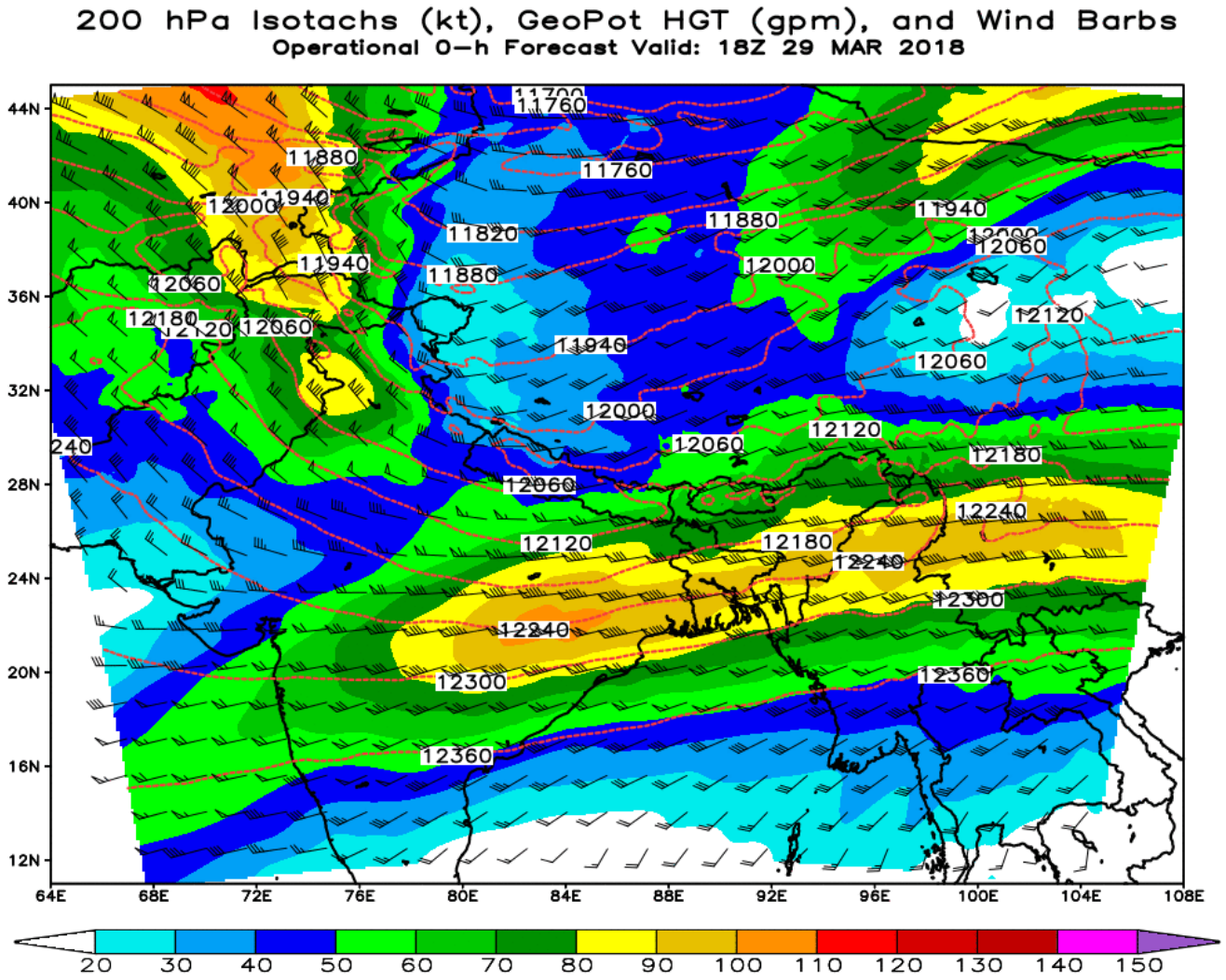
Stroke Density (Strokes/km^2)

30 Mar 2018 Severe Event

Deterministic Forecast Fields from ensemble member#1
Initialized at 1800 UTC 29 March 2018

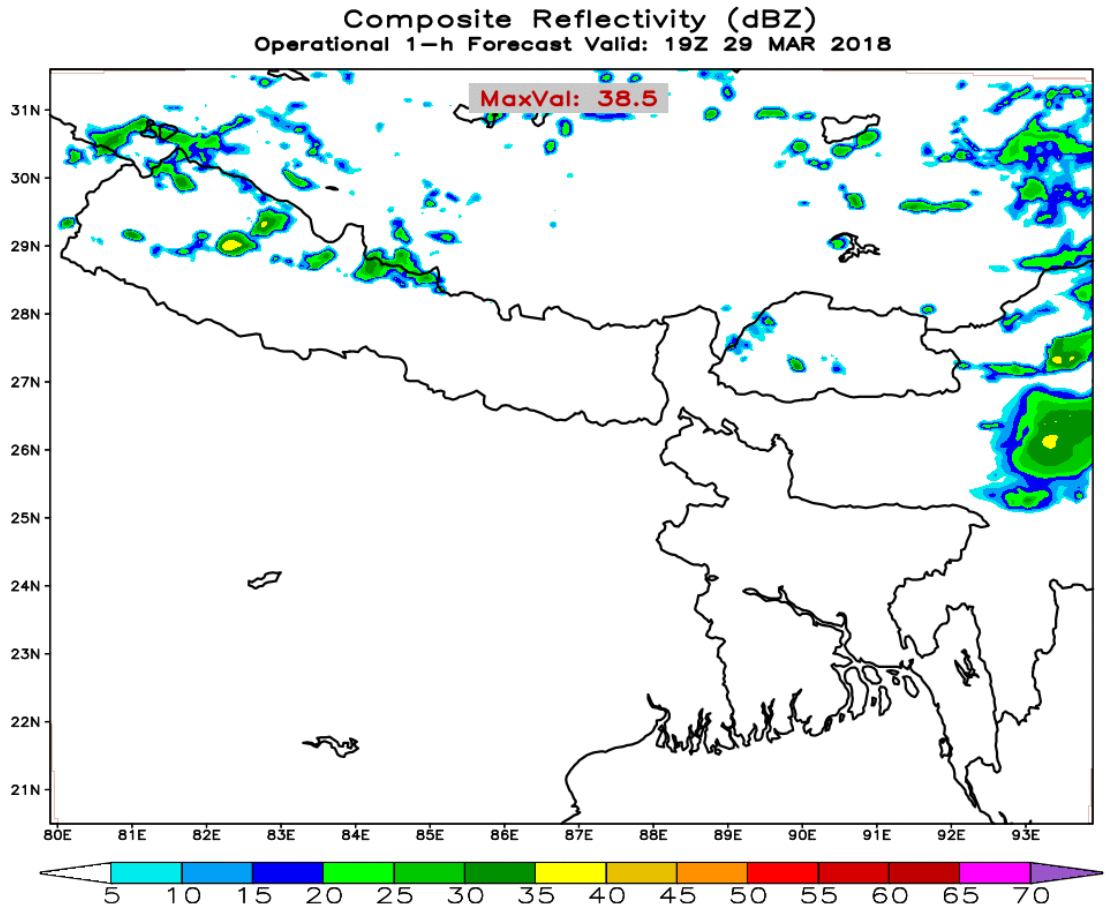
30 Mar 2018 Severe Event

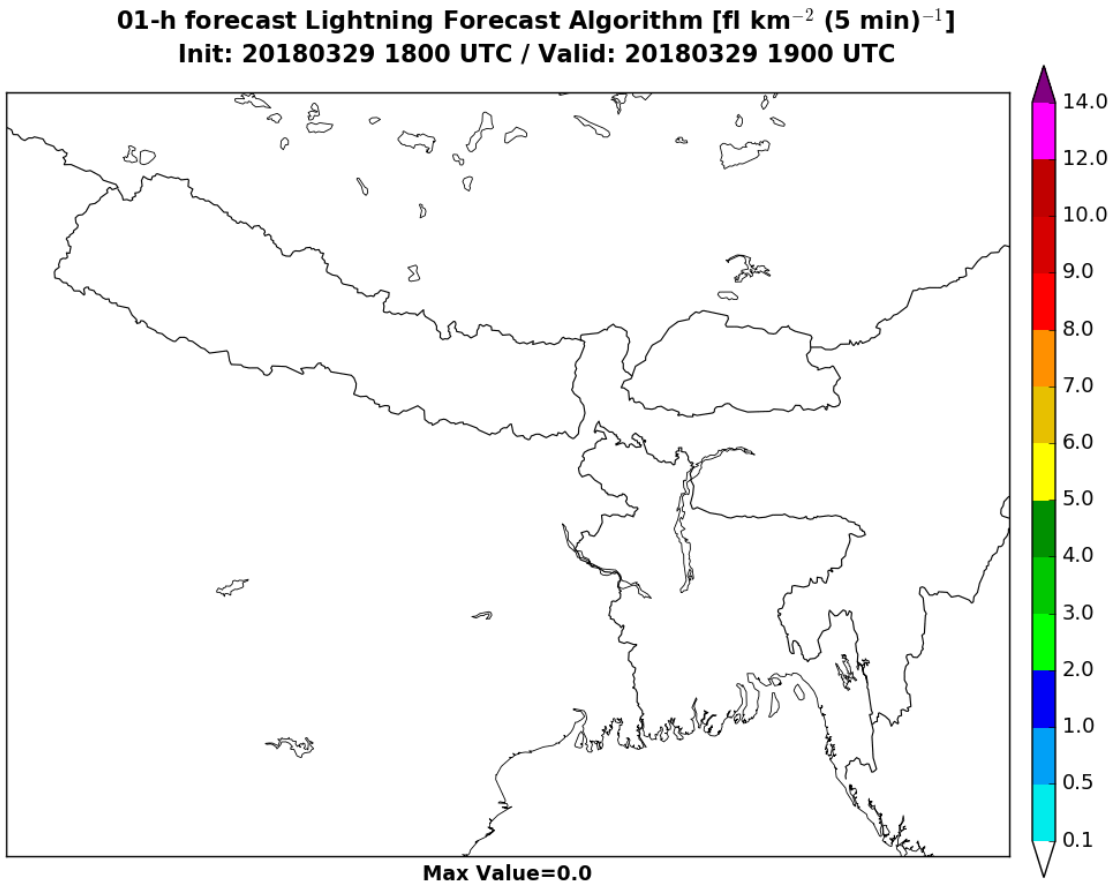
WRF Model 200 hPa Wind Speeds



30 Mar 2018 Severe Event

Deterministic 4-km WRF model radar reflectivity & LFA Lightning Flash Rates: First 24 hours



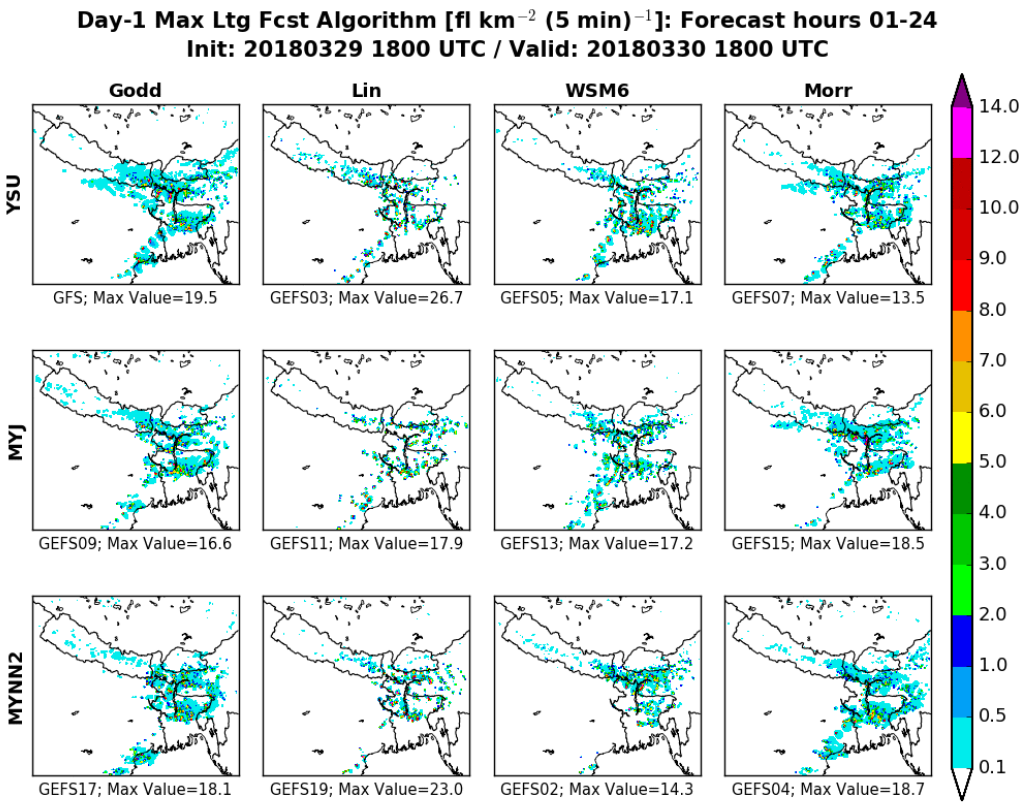


30 Mar 2018 Severe Event

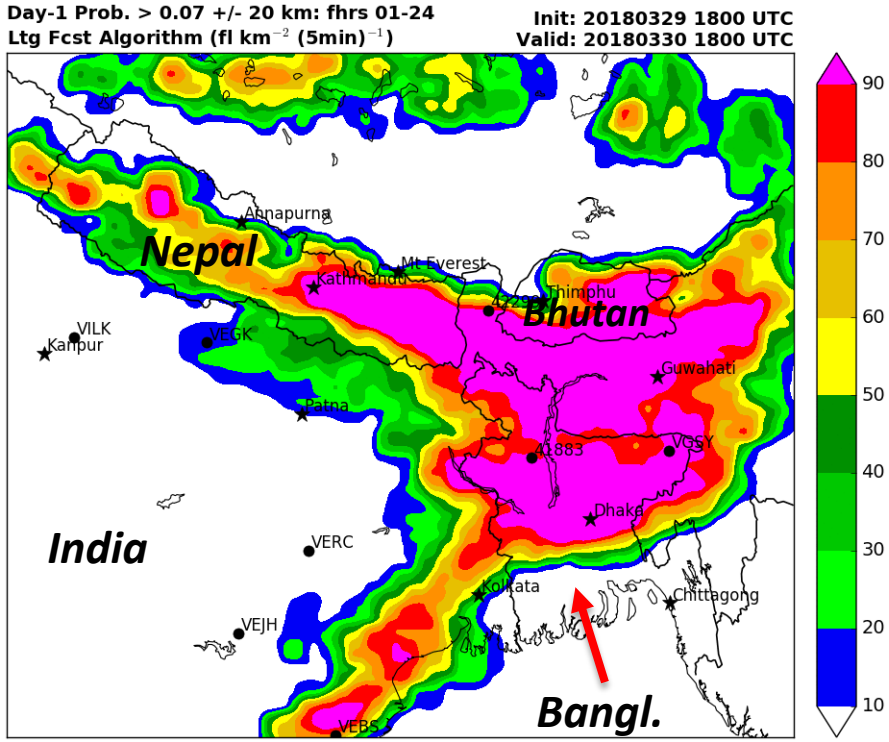
Ensemble Lightning Forecast Products
Initialized at 1800 UTC 29 March 2018

Day-1 Ensemble Summary Fields (18z 29 March to 18z 30 March)

Postage Stamp: Max lightning flash rates in first 24h



Probability of any lightning flashes within 20 km of a point during first 24 hours

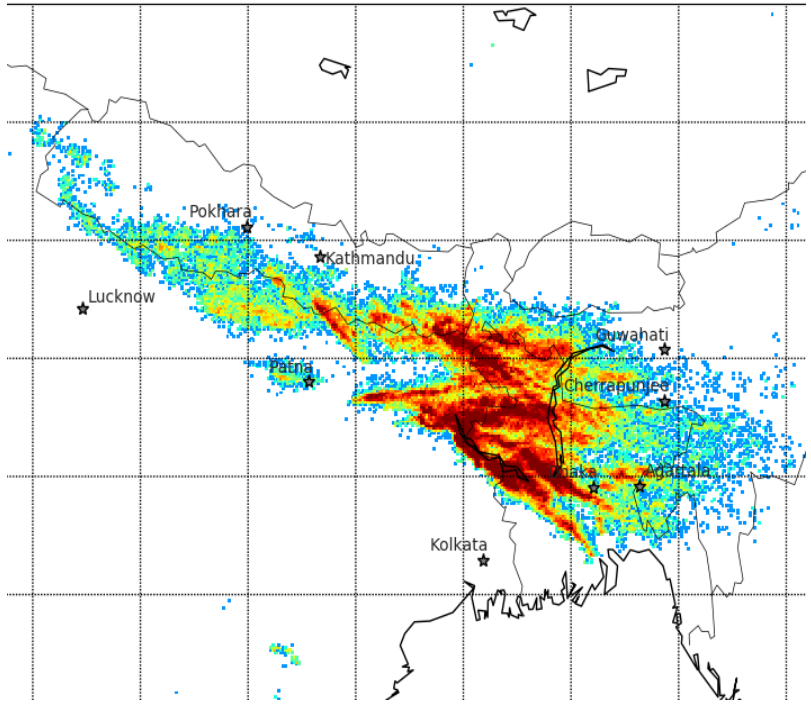


- Highest lightning probabilities over central Bangladesh and SE Nepal into northeastern India
- Higher threshold probability (> 1 flash/min) focused over central and northern Bangladesh

ENTLN Total Lightning Observations

(Observed ENTLN daily lightning summary shown again at right for comparison to ensemble model probability patterns on previous and next slides)

Daily Summary of ENTLN Observations: 30 March 2018



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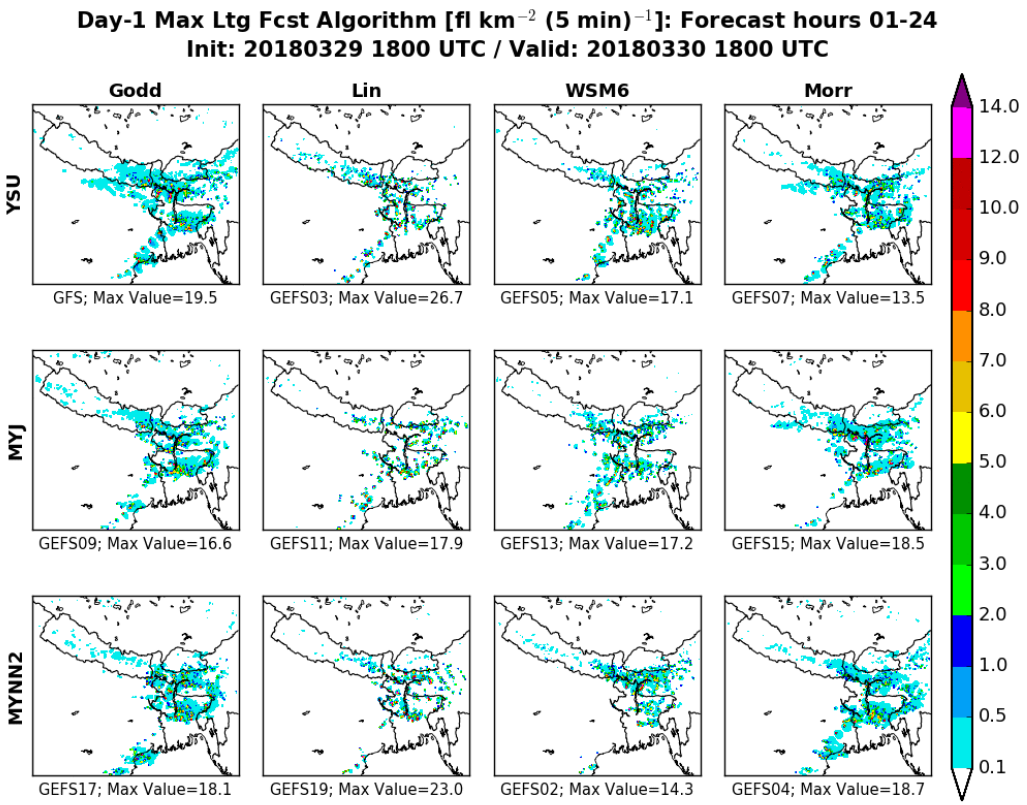
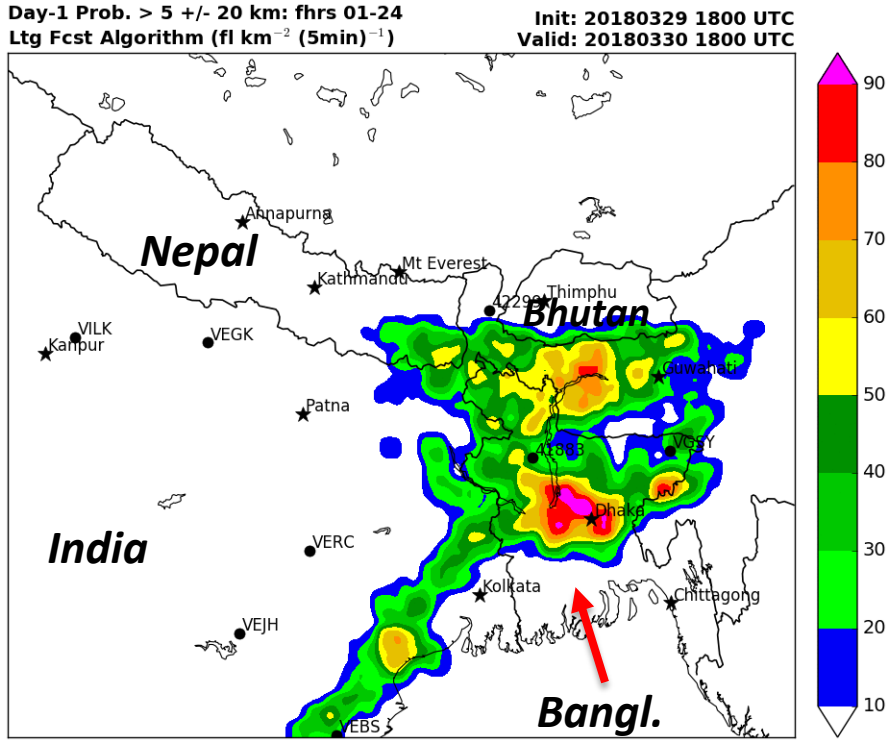


Probability of lightning > 1 fl/min within 20 km of a point during first 24 hours



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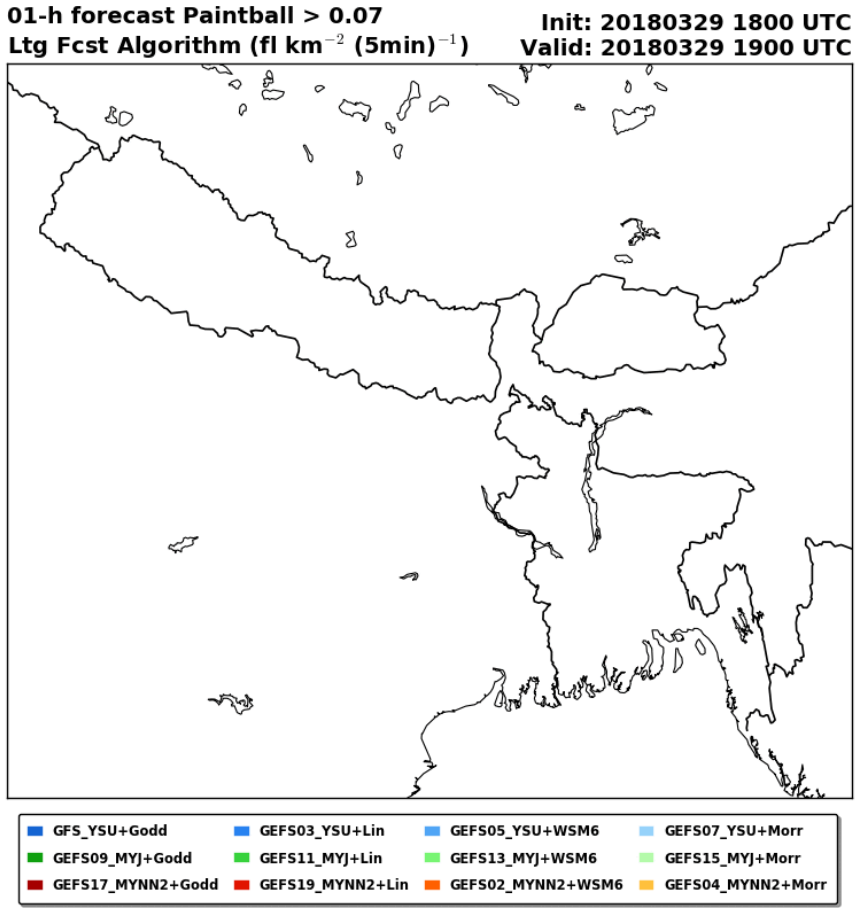
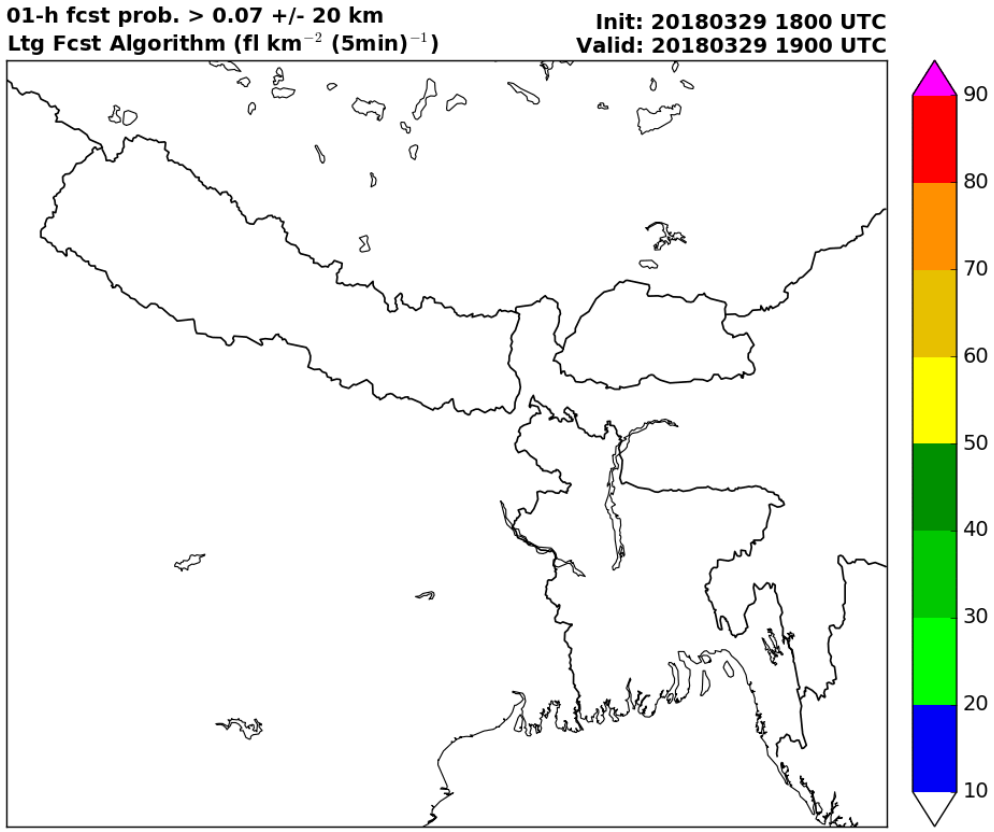
- Higher threshold probability (> 1 flash/min) focused over central and northern Bangladesh

30 Mar 2018 Wind and Hail Event

Hourly Paintball of any lightning (LFA; left)



Hourly probability of lightning (right)



Lightning Validation Workplan

- Verify ensemble model lightning against ENTLN network
  - Hourly LFA snapshots from ensemble model output
  - ENTLN flashes collected at +/- 10 minutes at top of each hour and gridded
- Run through Model Evaluation Tools (MET) verification package
  - Group lightning into various time bins (1, 3, 6, 12, and 24 hour “accumulations”)
  - Compute verification skill scores much like precipitation (e.g., FBIAS, CSI, HSS)
- Summarize results for individual cases and collectively for Spring Campaign
- Also verify lightning during summer monsoon months (Jun – Aug)
  - Ensemble LFA and ENTLN already collected for these months
  - Compare behavior and accuracy of LFA during pre-monsoon and summer monsoon

Future Efforts

- Finish validating severe events against available observational assets
  - Human casualties / storm reports from news sites and regional collaborators
  - Lightning [ENTLN] / GPM hail algorithm / IMERG precipitation estimates
  - In situ and other regional datasets (e.g., India radars)
- Optimize diagnostic output for HKH: (e.g., graupel/hail relationship in Nepal)
- Satellite / SAR signals for damage and flood inundation for the HKH region
- Automate product generation into SERVIR visualization App called “Tethys”
- Transition ownership of modeling tools to NASA SERVIR in Nepal

Thank you!! (Questions and Comments?)

NASA/SERVIR web: https://www.servirglobal.net/
Twitter: @SERVIRGlobal / Facebook: servirglobal

NASA/SPoRT web: https://weather.msfc.nasa.gov/sport/
Twitter: @NASA_SPoRT / Facebook: NASA.SPoRT

***ICIMOD/SERVIR-Himalaya Collaborator: Bhupesh Adhikary*

Funding acknowledgement: Project funded by NASA's Applied Science Capacity Building Program Manager (Nancy Searby)

Backup Slides

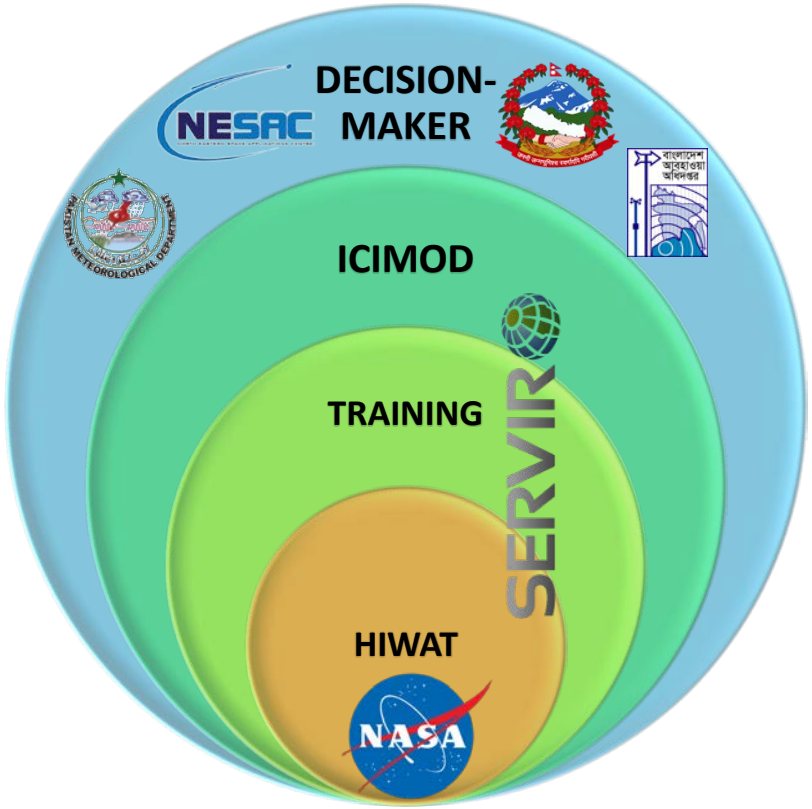
Project Overview

Goal: *Use [NASA] modeling and remote-sensing assets to build early warning capabilities and facilitate timely disaster response for high-impact weather events in the Hindu Kush Himalayan (HKH) region*

Objectives:

1. High-Impact Weather Assessment Toolkit (HIWAT) for the HKH region
2. Jointly develop HIWAT capabilities/training with the International Centre for Integrated Mountain Development (ICIMOD)
3. Demonstrate capability in end-user environment
4. Transition HIWAT to ICIMOD

ICIMOD is the NASA/SERVIR hub in Nepal

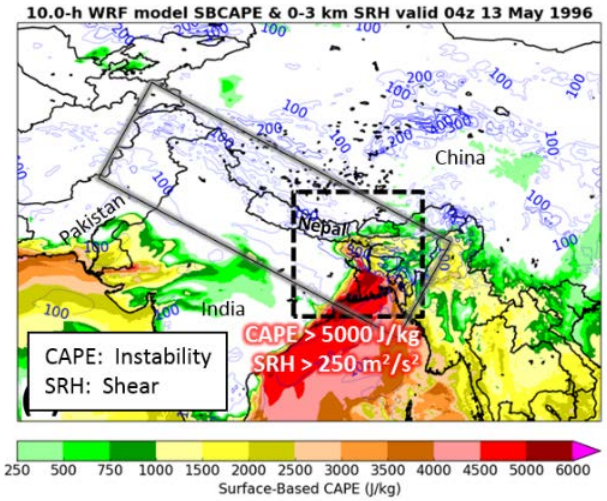



HQ of Bangl. Met. Dept.


HIWAT overview at Tribhuvan Univ. (Nepal)

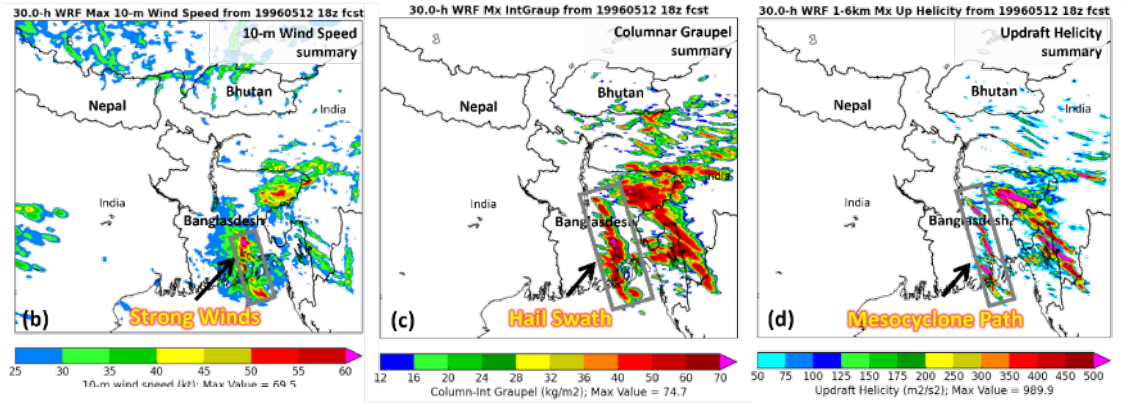
What is HIWAT?

REGIONAL NWP MODEL



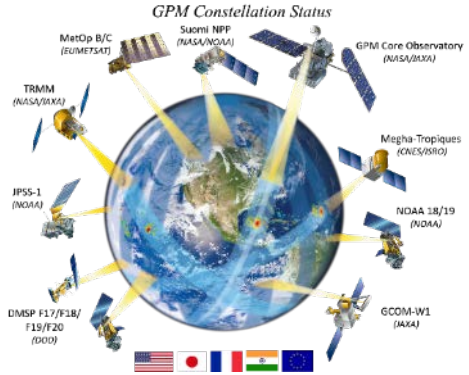
HIGH-IMPACT WEATHER ENSEMBLE PROGNOSTICS

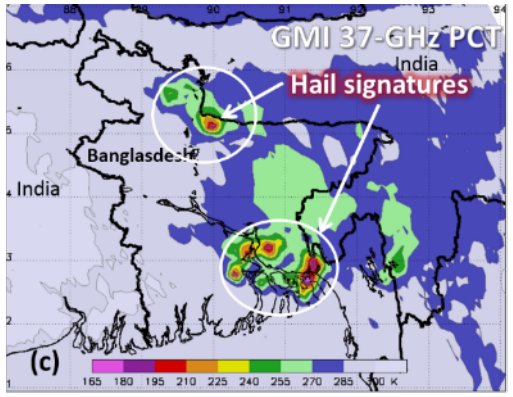
Short-term forecasting / situational awareness



GPM SATELLITE OBSERVATIONS

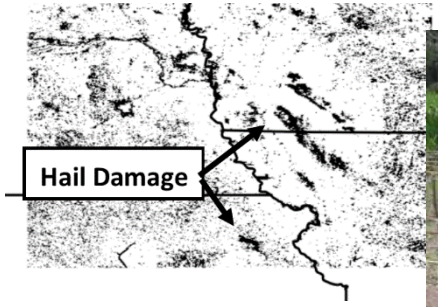
Threat Assessment





SATELLITE LAND IMAGERY

Impact Assessment



Hailstorm badly damaged hybrid bitter gourd seedbeds in Bangladesh

Source: thedailystar.net

2018 Spring Demonstration: Computing Platform and Software

Computing environment: “SOCRATES” system

- SERVIR Operational Cluster Resource for Applications - Terabytes for Earth Science [SOCRATES]
- Series of network-connected Virtual Linux nodes running Ubuntu OS
- Each node has 32 processors (16 dual cores), 128 GB RAM
- Two network-mounted disks
  - “shared” disk: model software installation and run-time environment; 1.2 TB disk space
  - “storage” disk: archive location for model run output; post-processed GRIB2 files; 96 TB

Numerical Weather Prediction (NWP) and supporting software

- Unified Environmental Modeling System (UEMS), version 15
  - NOAA/NWS SOO Science and Training Resource Center
  - Based on Weather Research and Forecasting (WRF) v3.7.1 community NWP model
  - Manages data acquisition, model initialization/execution, and post-processing
  - Includes numerous utilities for system execution, creating graphics, and manipulating data
  - Freely available to international community
- Software for generating products (python, ImageMagick, etc.)

2018 Spring Demonstration: Ensemble Model Simulation Strategy

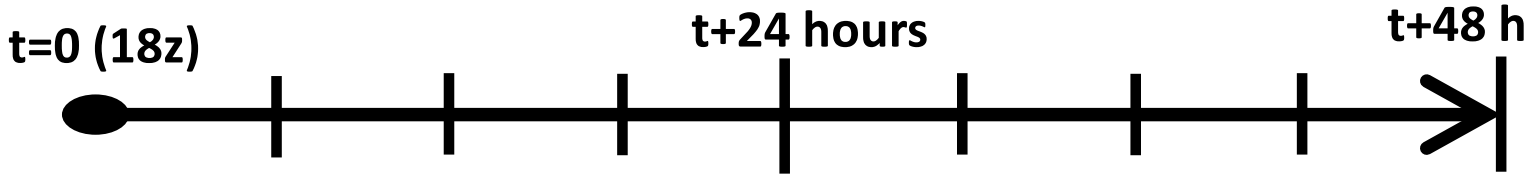
Deliver daily, real-time 2-day ensemble guidance for severe thunderstorm hazard forecasting in HKH region

- Generate sufficient spread in ensemble members to capture uncertainty
- Cover two full diurnal heating cycles for day-1 and day-2 outlooks
- Minimize latency for product relevancy and usefulness

Based on these criteria, we chose:

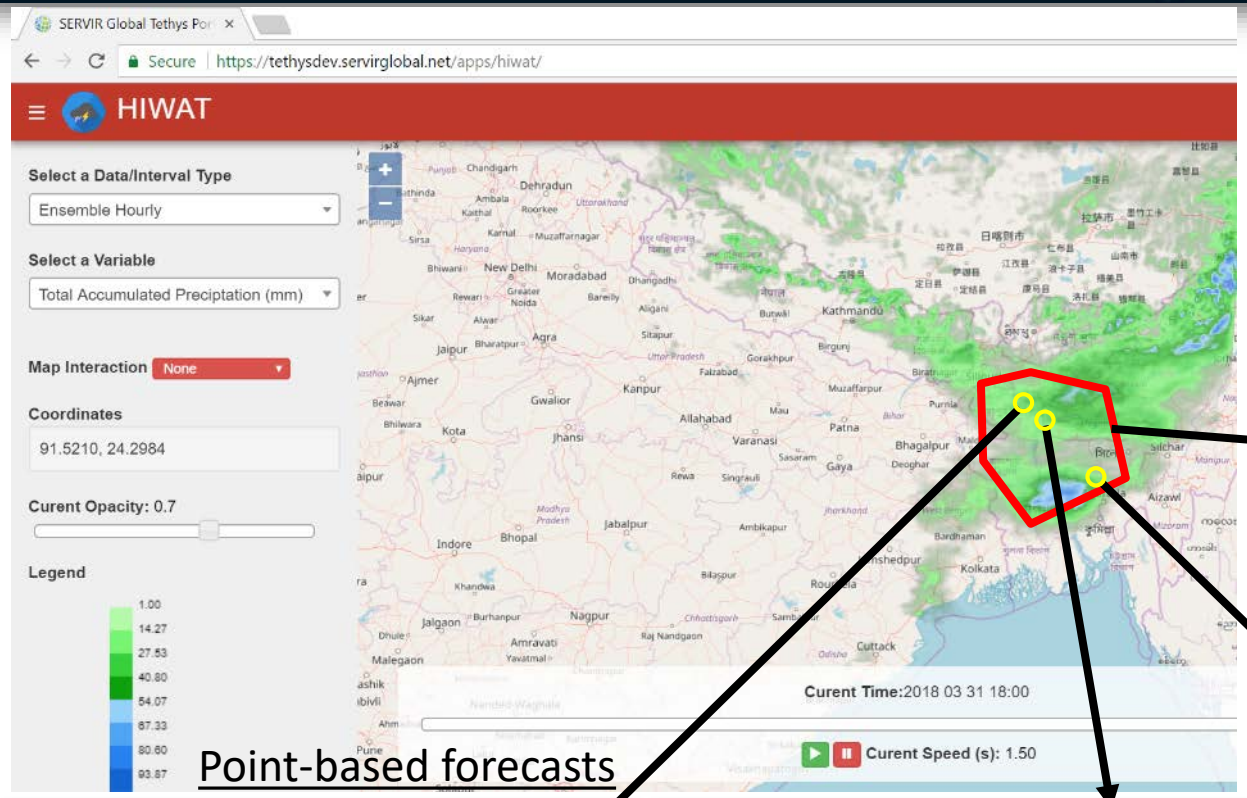
- Ensemble system of 12 individual model runs with combination of initial condition and physics variability to generate spread
- 18z initialization; initial conditions from 12z UTC GFS/GEFS 6-hour forecasts
  - Local midnight initialization provides several hours model spin-up prior to day-1 sunrise
  - Enables earlier start to ensemble; no need to wait for 18z cycle to become available
- 48-hour model forecasts to cover 2 diurnal cycles; hourly output frequency
- Concurrent post-processing; products become available as ensemble system runs, rather than waiting until after all model simulations complete

Initial Conditions:
Ensemble#1: 12z GFS 6-h fcst
Ensemble#2-12: GFS 6-h fcst

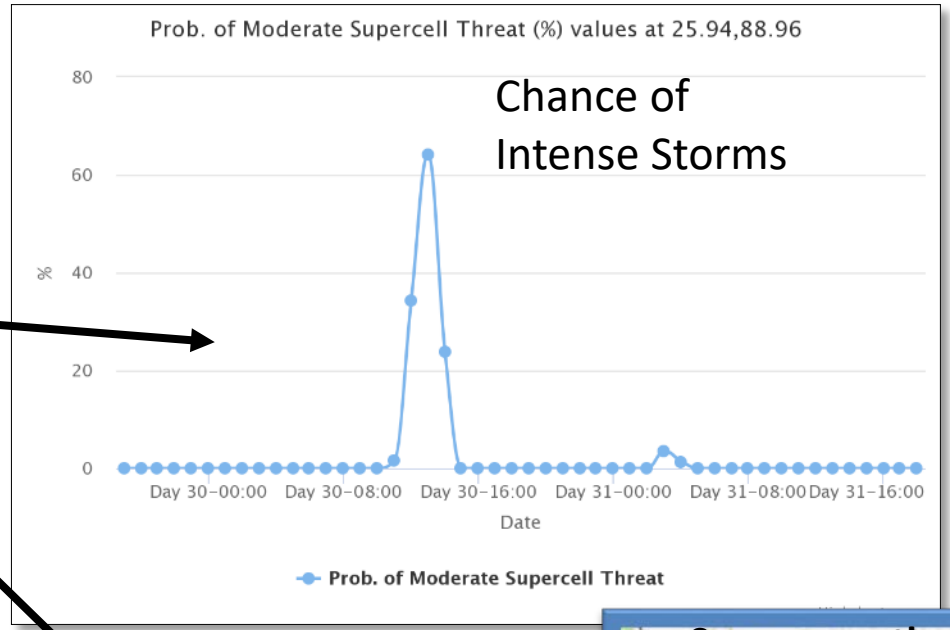


Boundary Conditions:
Ens#1: 12z GFS every 3 hours; Ens#2-12: GEFS every 6 hours

NASA/SERVIR Web Mapping Service App “Tethys” to convey information for end-user/decision-makers



HIWAT Thunderstorm Hazards Forecasts



Point-based forecasts