Verification of the Convection-Allowing Ensemble System over the Hindu Kush Himalaya Region during the 2018 and 2019 Pre-monsoon Severe Thunderstorm Seasons

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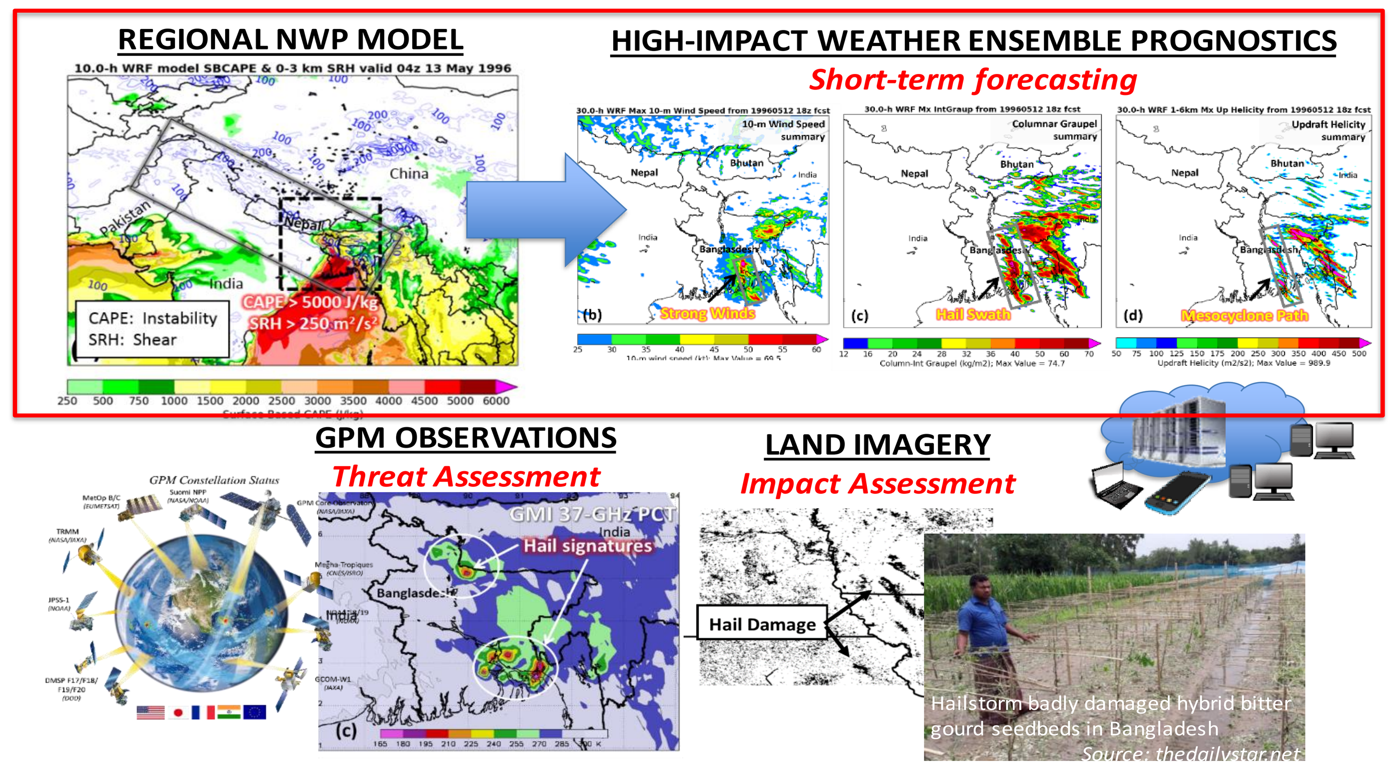
Introduction and Project Background

- Some of the most intense thunderstorms on the planet occur in the Hindu Kush Himalaya (HKH) region of South-Central Asia
- NASA/SERVIR Applied Sciences Team competitive project to develop capacity of severe thunderstorm monitoring and forecasting tool for HKH
- Project 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 HKH region
- Specific objectives:
  1. *Prototype and transition High-Impact Weather Assessment Toolkit (HIWAT)*
  2. *Jointly develop HIWAT capabilities & training with SERVIR's hub in Kathmandu, Nepal: International Centre for Integrated Mountain Development (ICIMOD)*
  3. *Demonstrate capacity in end-user environment*
  4. *Transition HIWAT system to ICIMOD for future maintenance*

What is HIWAT System?



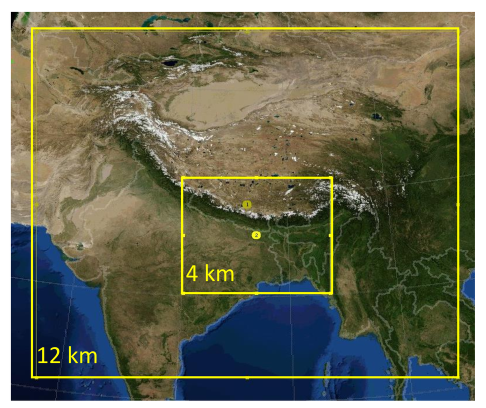
Hardware / Software Environment and Tools

- Computing development environment: SERVIR Operational Cluster Resource for Applications - Terabytes for Earth Science [SOCRATES]
  - *Series of network-connected Virtual Linux nodes, each with 32 processors and 128 GB RAM*
  - *"Shared" solid-state disk for fast I/O during model execution, and "storage" disk for post-processing / archiving*
- Modeling software system: NOAA/NWS SOO Science and Training Resource Center's Unified Environmental Modeling System (UEMS)
  - *Largely based on Weather Research and Forecasting (WRF) community NWP model*
  - *Simplifies and streamlines installation and model simulation without requirement of expensive licensed compilers, knowledge of compiler options, intimate understanding of parameterizations, etc*
  - *Manages data acquisition, model initialization/execution, and post-processing*
  - *Includes numerous utilities for process flow, graphics creation, and data manipulation*
- Largely python-based software development and scripting package for computing ensemble products
- Developmental Testbed Center's Model Evaluation Tools (MET) for computing verification statistics

Real-Time Ensemble Modeling System Configuration

Fixed nested grid domain over South Asia:

- 12-km outer grid: 351 x 321 / 4-km nested grid: 367 x 322
- 42 terrain-following vertical levels, sfc to 20 hPa
- Daily 48-hour forecasts with 1800 UTC initialization
- Strategy: Create sufficient spread in ensemble system by varying both initial/boundary conditions and physics parameterizations
- Settings common to ensemble members:
  - 60-second dynamic timestep
  - 8 acoustic steps per dynamic time step
  - Kain-Fritsch cumulus parameterization (12-km grid only)
  - RRTM-G shortwave radiation (topo shading with 25-km shade length)
  - RRTM-G longwave radiation
  - Noah land surface model
  - EPSSM = 0.5 (damp vertically-propagating acoustic waves)



Run 12 UEMS/WRF 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

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

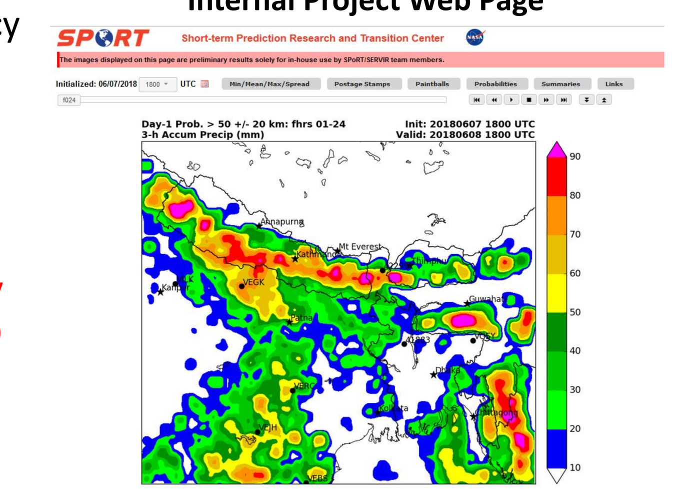
- Simple diagnostic algorithm that can be applied to any [WRF] model mixed-phased microphysics scheme with graupel
- Weighted combination of graupel flux at -15C (THR1) & vertically-integrated ice (THR2):
  - $THR1 = k_1(wq_g)|_{T=-15C}$; $THR2 = k_2 \int \rho(q_g + q_s + q_i)dz$
  - *LFA = 0.95*THR1 + 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 in-cloud **and** cloud-to-ground lightning; units total flashes km^{-2} $(5\ min)^{-1}$
- LFA set to zero below 0.07 flashes km^{-2} $(5\ min)^{-1}$ [~1 flash per hour]

Post-Processing and Product Generation

Run UEMS post-processor (emsupp)

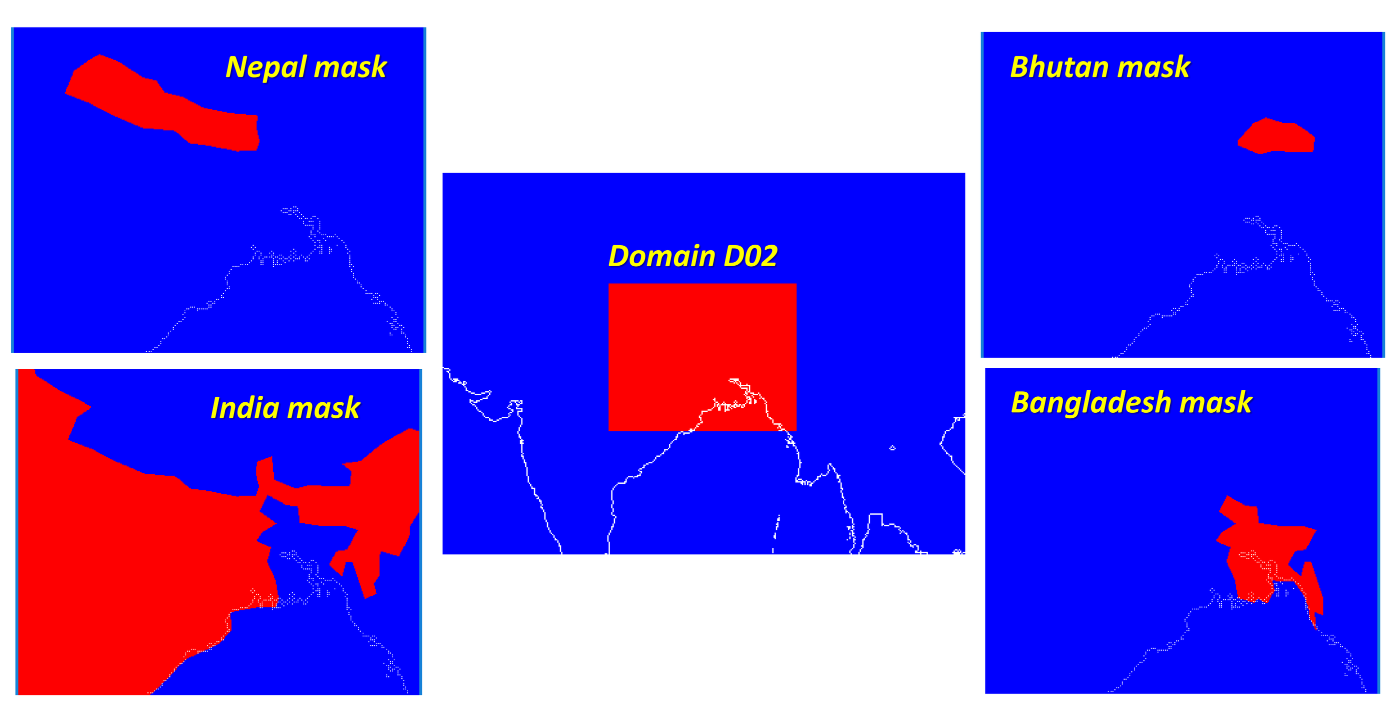
- Member#1: 12-km/4-km grids; HKH2 to HKH12: only process 4-km grid
- Auto-post process to expedite products; hourly output frequency
- Model fields for thunderstorm hazard proxies: (Kain et al. 2010)
  - Convective intensity: Composite reflectivity
  - Lightning: Lightning Forecast Algorithm (McCaul et al. 2009)
  - Straight-line winds: max output interval 10-m wind speed
  - Hail threat: maximum output interval total column graupel
  - Mesocyclone/tornado: maximum output interval updraft helicity
  - Flooding rainfall: Accumulated precipitation thresholds (esp. 3 h)
- Archive hourly wrfout netcdf and GRIB2 files
- Visualization products using GrADS/python for deterministic (HKH1) output, and Python scripts for ensemble products

Internal Project Web Page



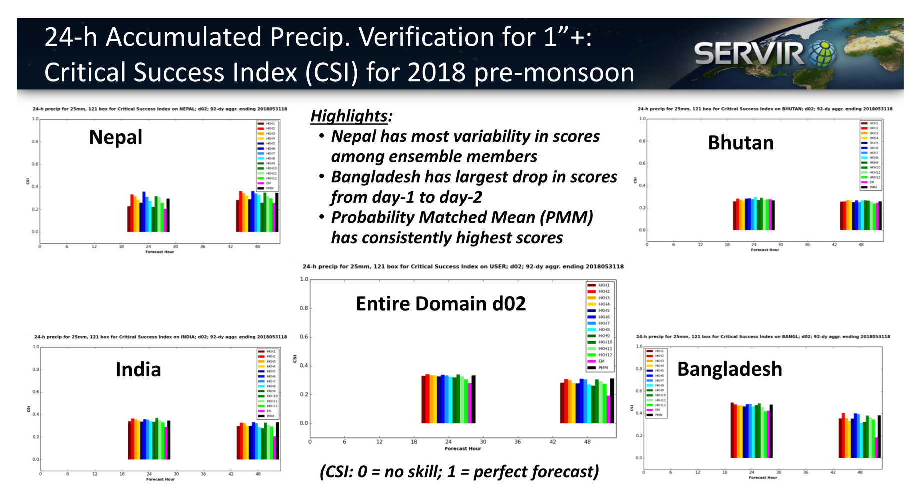
Precipitation and Lightning Verification Methodology

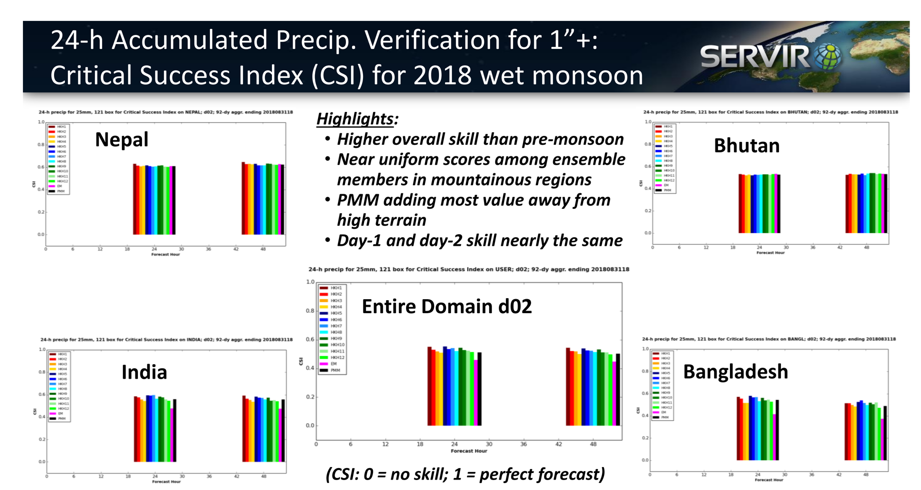
- Verify ensemble precipitation against GPM/IMERG-Final product and ensemble lightning against Earth Networks Total Lightning Network (ENTLN)
  - Hourly LFA snapshots from ensemble model output for each of the 12 members
  - ENTLN flashes collected at +/- 10 minutes at top of each hour and gridded
- Run through Model Evaluation Tools (MET) verification package
  - Group pcp/ltg into time bins (1, 3, 6, 12, and 24 hour "accumulations")
  - Compute verification skill scores (e.g., POD, FAR, FBIAS, CSI, HSS)
- Calculate verification scores for daily runs and collectively for seasons
  - Each ensemble member (+ens. mean and probability matched mean for rainfall)
  - Masked by country to examine regional variability in model skill
  - Seasonal summaries for Mar–May (pre-monsoon) and Jun–Aug (wet monsoon)

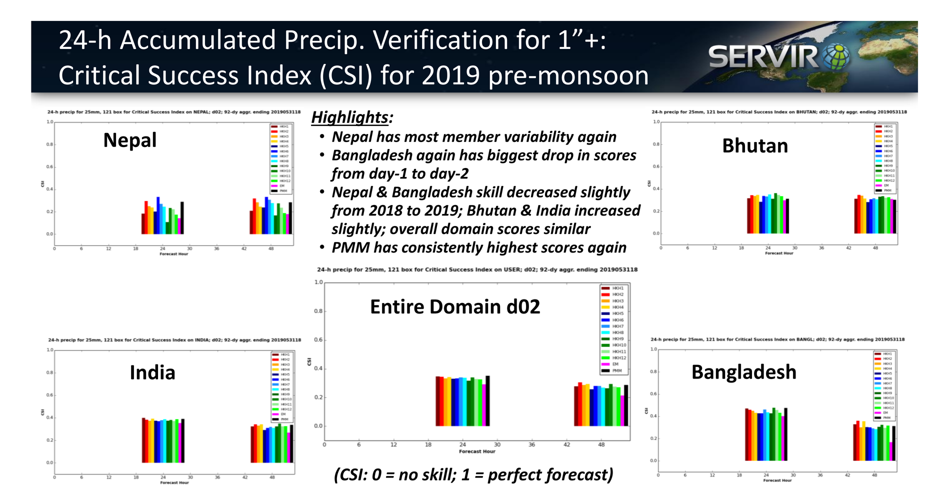


Verification Results: [24-h] Precipitation and Lightning during 2018 and 2019 Pre-Monsoon (MAM) and Wet Monsoon Months (JJA)

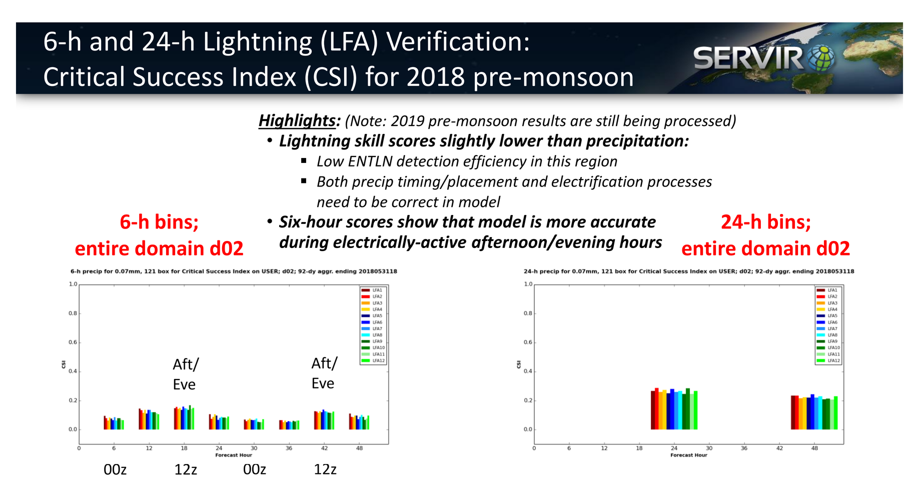
Precipitation

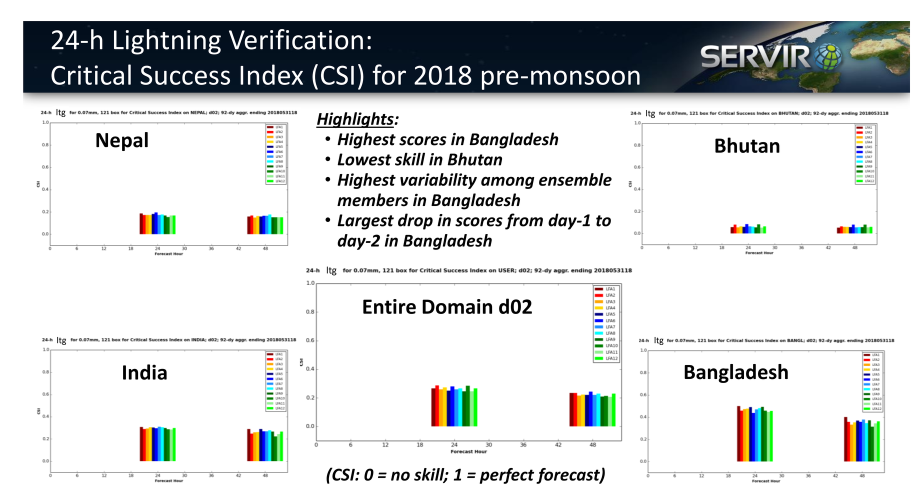


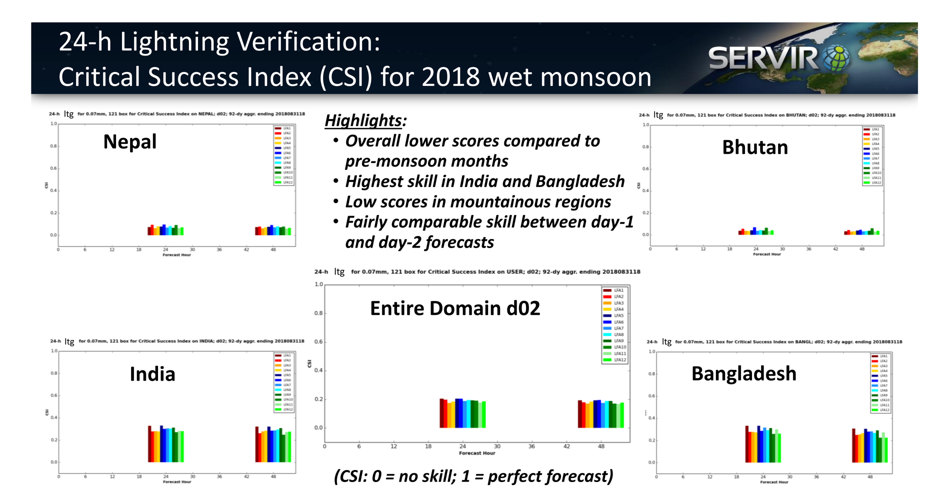




Lightning







Highlights of Precip and Ltg Verification Results

- Pre-monsoon months experienced the largest variability in precip forecast skill among the different physics members, mainly in Nepal.
- Highest skill in pre-monsoon precip and lightning forecasts was over Bangladesh and India, away from high terrain.
- Bangladesh had the largest drop in skill from day-1 to day-1 in the pre-monsoon.
- During the wet monsoon months, precip skill scores increased substantially, especially in Nepal and Bhutan.
- Very little skill variability is found among physics members in the higher-terrain countries of Nepal and Bhutan during the wet monsoon months.
- The Probability Match Mean field generally has the highest skill compared to any of the individual ensemble members, esp. during the pre-monsoon months.
- Lightning forecasts have the greatest skill during the most active time of day, generally during the local afternoon and evening hours.