# The <u>C</u>oupled <u>R</u>outing and <u>E</u>xcess <u>ST</u>orage (CREST) distributed hydrological model Family: Development and Application 2011-2026

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The UNIVERSITY of OKLAHOMA

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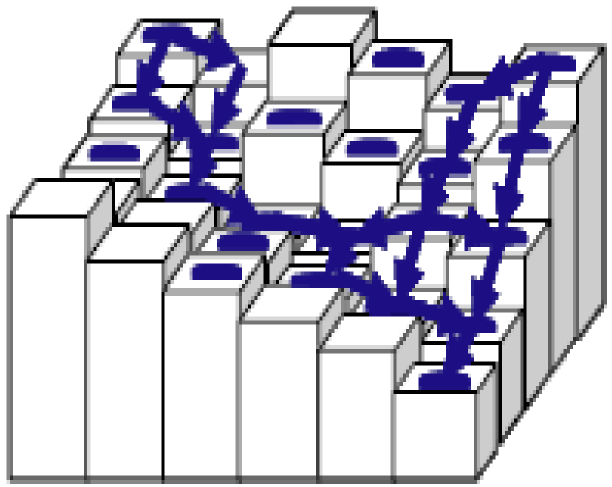
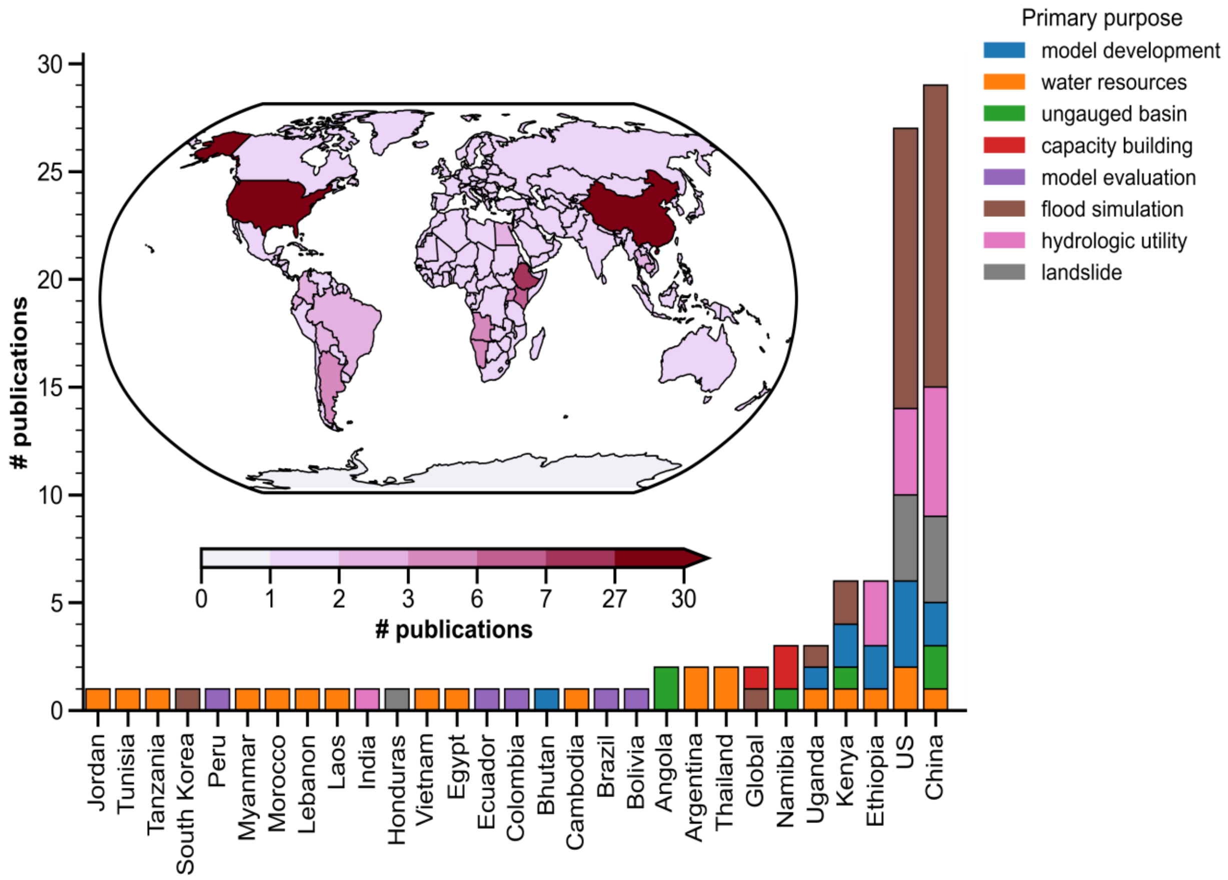
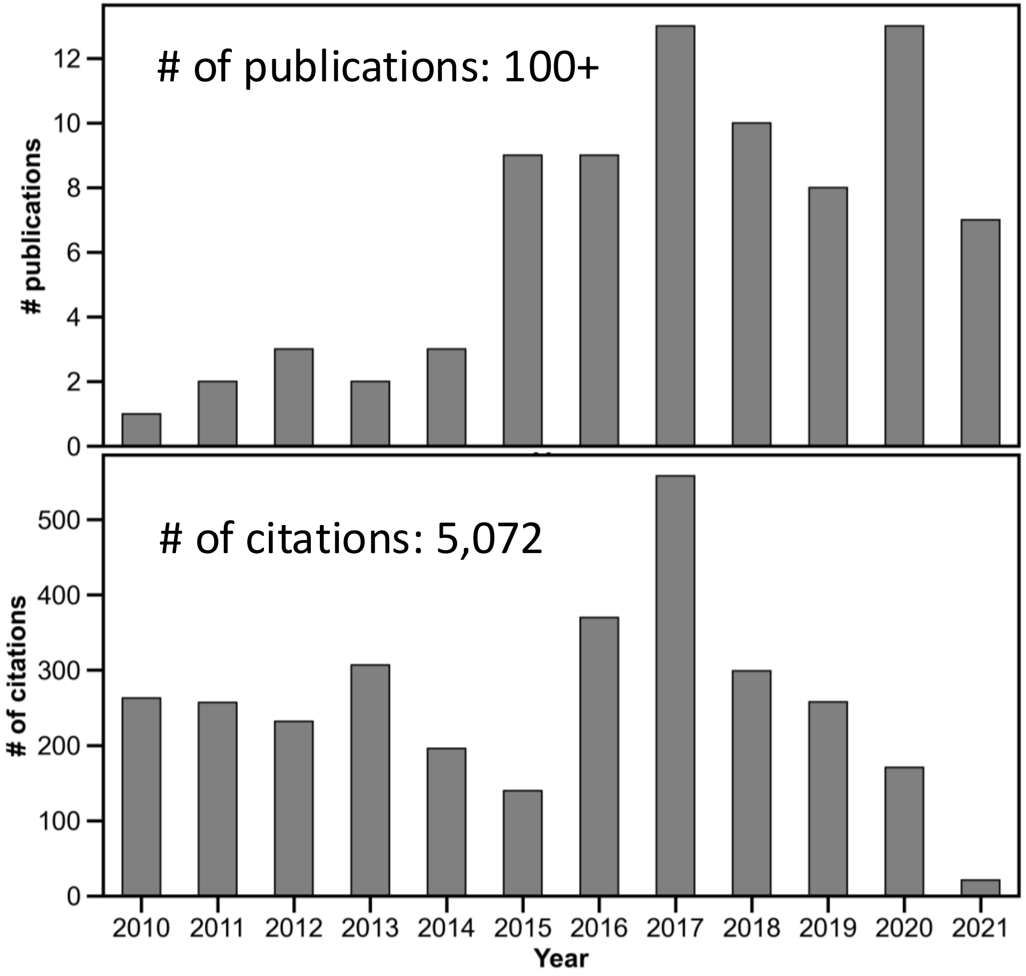
# The **C**oupled **R**outing and **E**xcess **ST**orage (CREST) distributed hydrological model

- A Distributed Hydrologic Model designed to take advantage of the 4-D remote sensing data, can be used at global, regional, or basin scales.
  - Three soil layers.
  - Distributed, fully coupled runoff generation and routing model
  - Simulates water and energy fluxes and storage on a regular grid
  - Cell-to-cell flow routing
- 2 Forcings
  - Precipitation, PET
- 17 Parameters
  - Water balance, Water routing
- 9 Outputs
  - Streamflow, soil moisture, unit streamflow, runoff, etc.

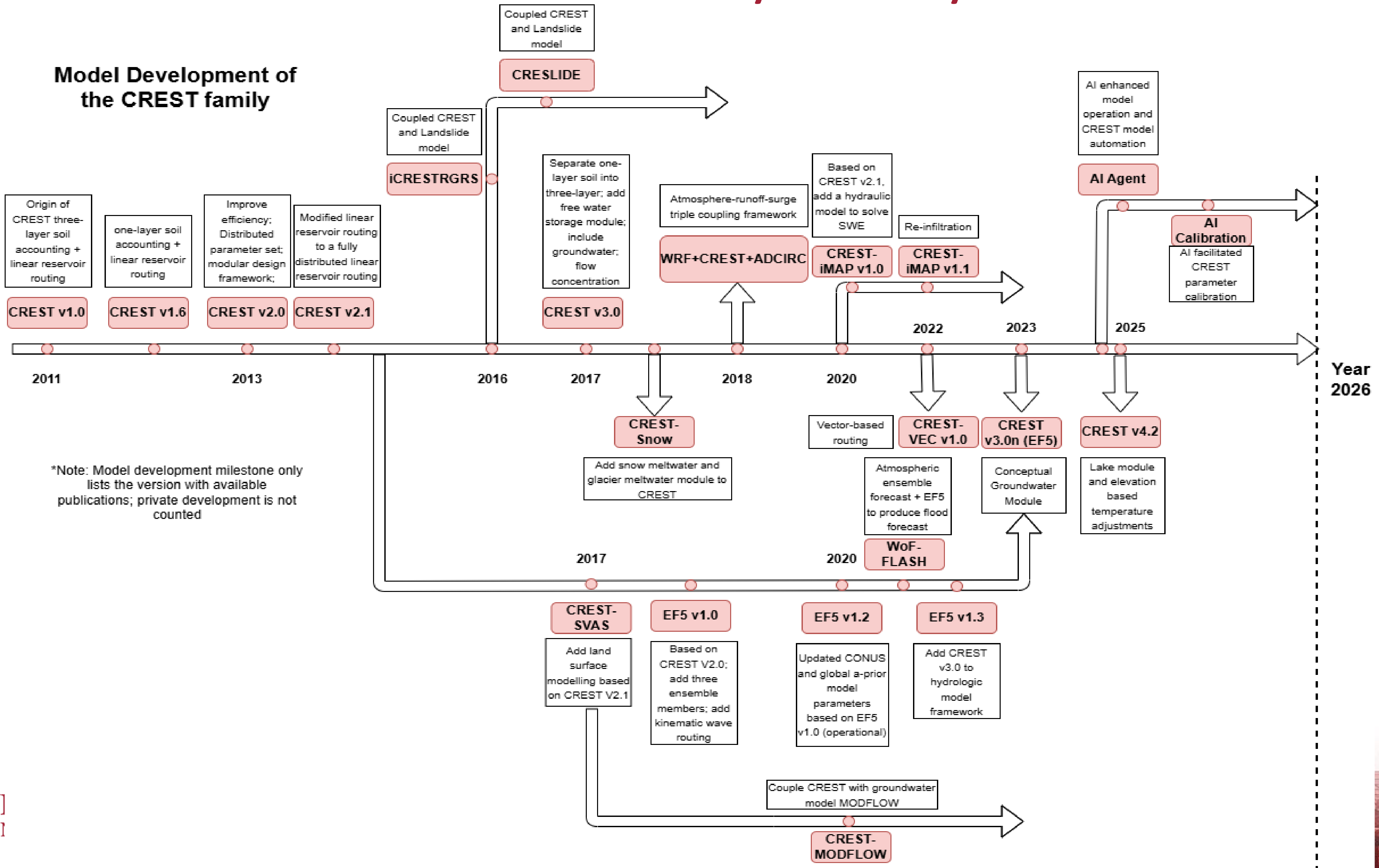


# CREST Family Model: Global users, publications and Citations over 2011-2021



# CREST Model family tree by 2026

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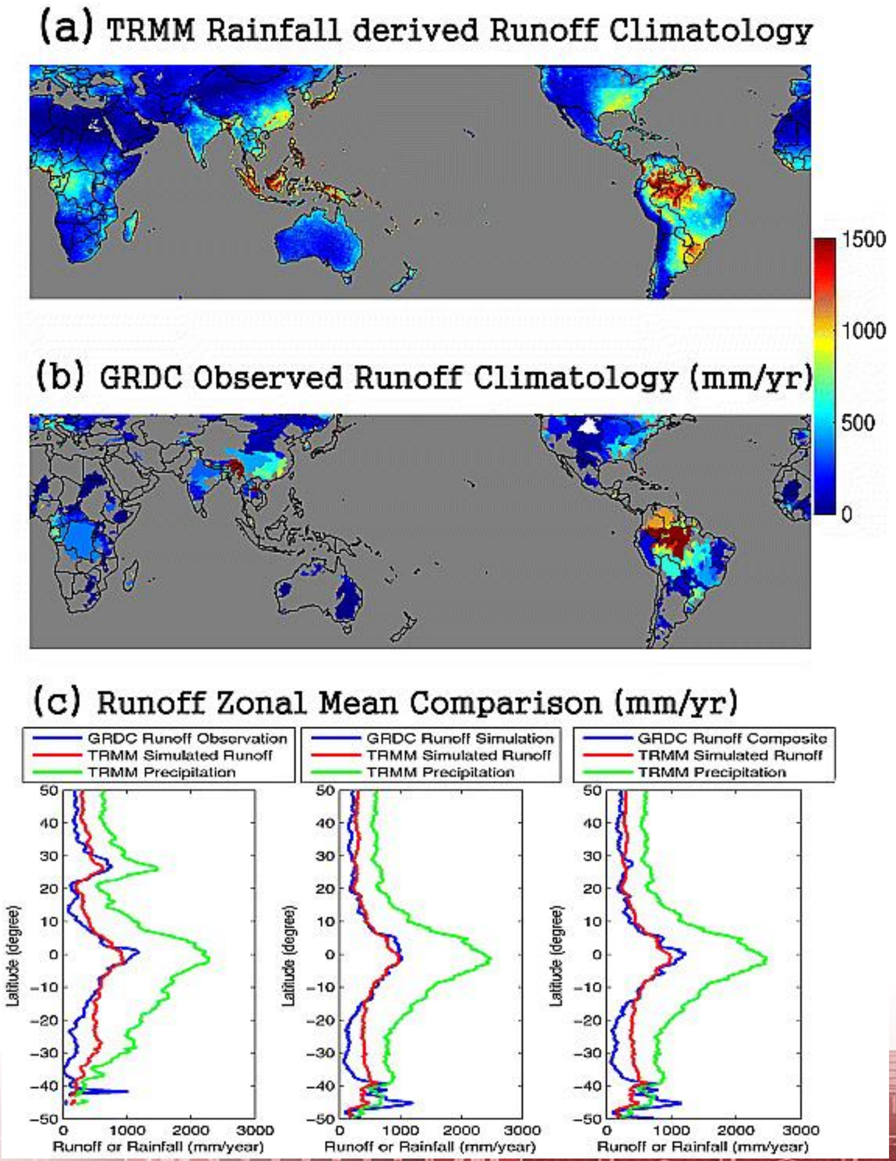
# The Original Concept: Satellite-driven Global Hydrological Model

- **Hong, Y.**, R. Adler, F. Hossain, S. Curtis, and G. Huffman, 2007: A first approach to global runoff simulation using satellite rainfall estimation, *Water Res. Research*, **43(8)**. {230} *The first satellite-driven global runoff real-time modeling system in supporting multi-continental hydrologic prediction*

- **Hong, Y.**, R.F. Adler, A. Negri, and G.J. Huffman, 2007: Flood and landslide applications of near real-time satellite rainfall estimation, *Natural Hazards*, **43(2)**, 510-521 {238}



# The Birth 2011

- Wang, J., **Hong, Y.**, Li, L., Gourley, J.J., Khan, S.I., Yilmaz, K.K., Adler, R.F., Policelli, F.S., Habib, S., Irwn, D., Limaye, A.S., Korme, T., Okello, L., 2011. The coupled routing and excess storage ([CREST]) distributed hydrological model. Hydrological Sciences Journal 56, 84–98. {299} *Introduced the remote-sensing–native, coupled routing-storage distributed model that became the foundation of the CREST model family (CREST/EF5/CRES-iMAP/CREST-VEC/iCRESLIDE/iCRESTRIGRS) used worldwide*.

- CREST v1.0 (2011)

1) distributed rainfall-runoff generation process and cell-to-cell routing,

2) coupled routing and runoff generation mechanisms,

3) sub-grid variability of soil moisture capacity

- Funding acknowledgment of NASA USAID and NOAA

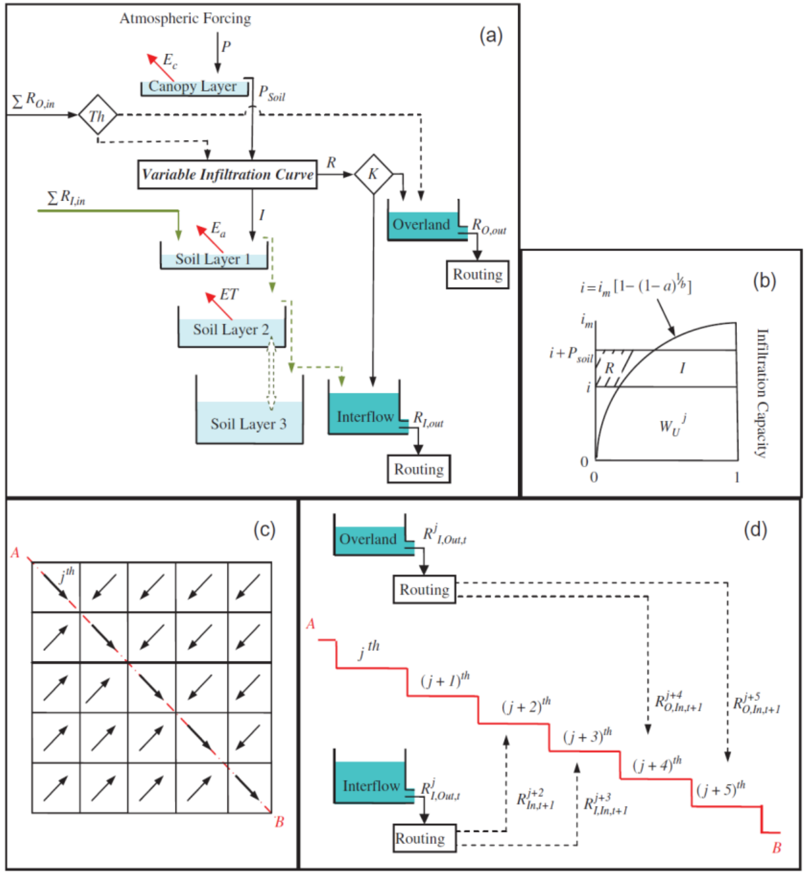
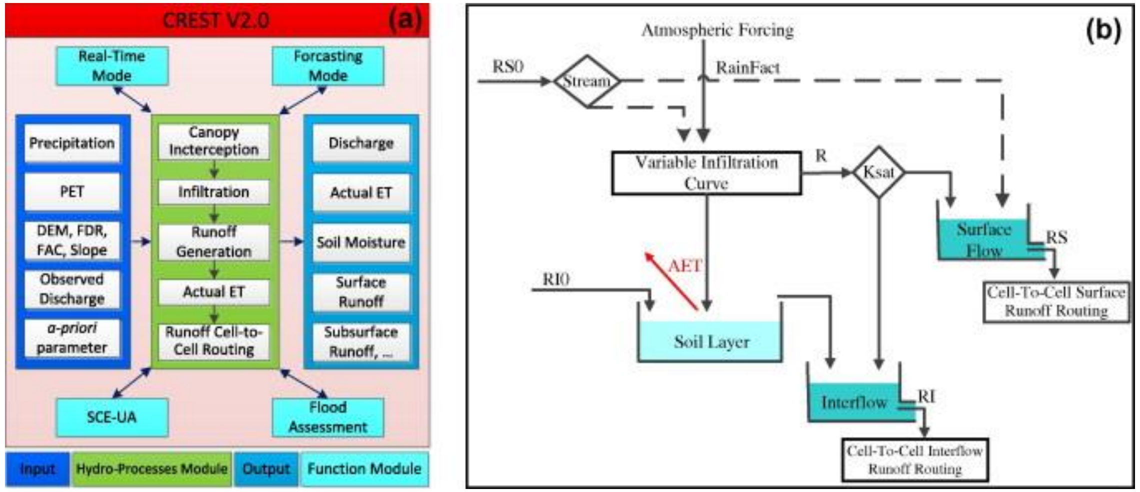



**Fig. 1** Core components of CREST: (a) vertical profile of a cell including rainfall–runoff generation, evapotranspiration, sub-grid cell routing and feedbacks from routing; (b) variable infiltration curve of a cell; (c) plan view of cells and flow directions; and (d) vertical profile along several cells including sub-grid cell routing, downstream routing, and subsurface runoff redistribution from a cell to its downstream cells.

# Widely used version CREST v2.0, 2013-2017

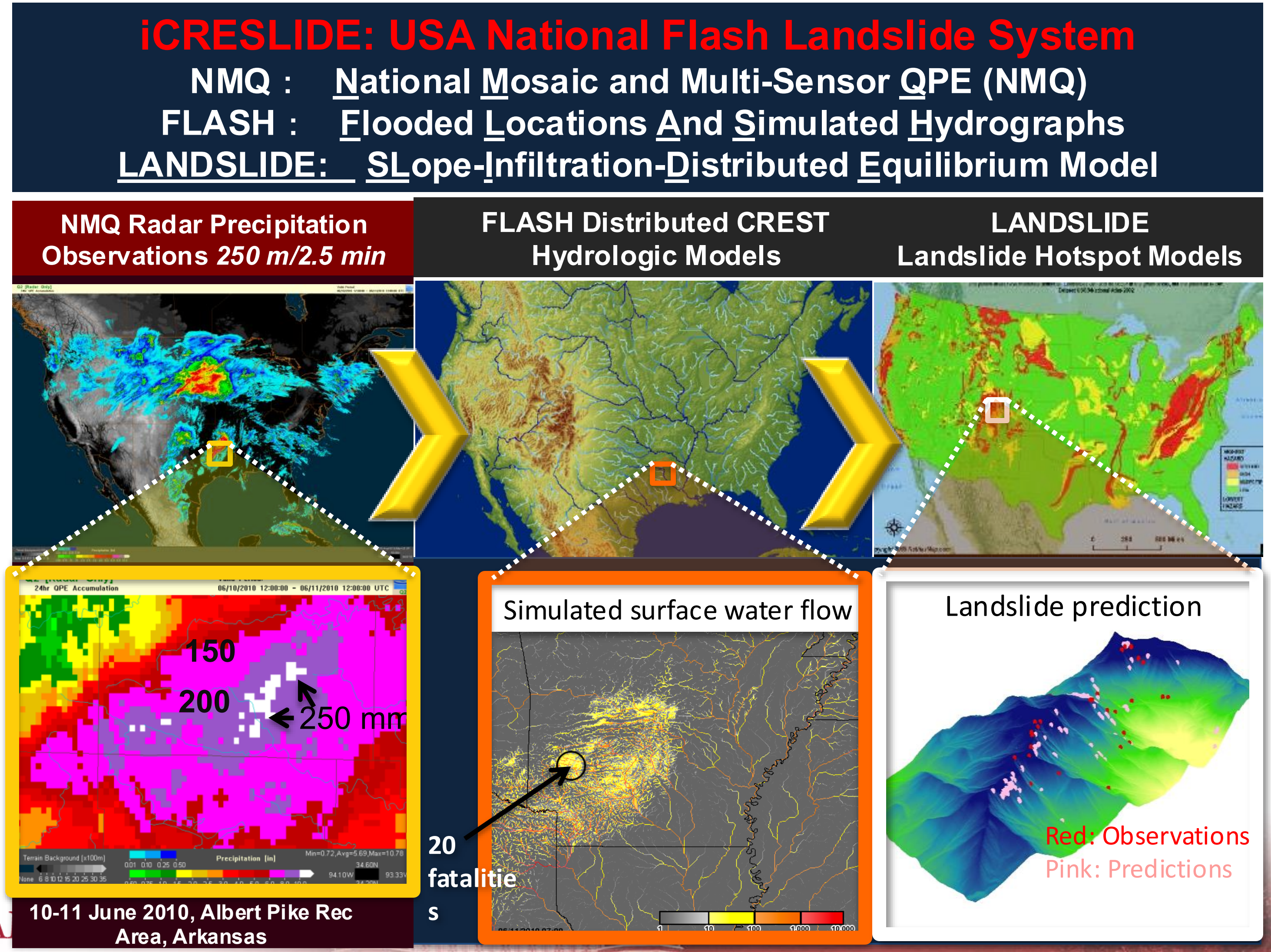



- (1) model implementation with options of either spatially uniform, semi-distributed, or distributed parameter values,
- (2) including impervious area ratio parameter to emulate fast runoff generation,
- (3) including a rainfall multiplier parameter to mitigate the impact of
- rainfall bias on hydrologic predictions,
- (4) automatic calibration using the SCE-UA algorithm
- (5) parallel computing
- (6)modular design framework and enhancement of the computation adpability using FORTRAN matrix operation to make the model more efficient
- Xue, X., Hong, Y., Limaye, A.S., Gourley, J.J., Huffman, G.J., Khan, S.I., Dorji, C., Chen, S., 2013. Statistical and hydrological evaluation of TRMM-based Multi-satellite Precipitation Analysis over the Wangchu Basin of Bhutan: Are the latest satellite precipitation products 3B42V7 ready for use in ungauged basins? Journal of Hydrology 499, 91–99. https://doi.org/10.1016/j.jhydrol.2013.06.042

# Coupled Flood and Landslide Hazard modeling:
# iCRESLIDE = CREST + SLIDE, 2016

- Coupled the CREST model with the SLIDE model, which computes slope stability as a factor of safety.
- The relatively more accurate subsurface hydrologic variables from CREST were fed to the SLIDE model in an integrated way.

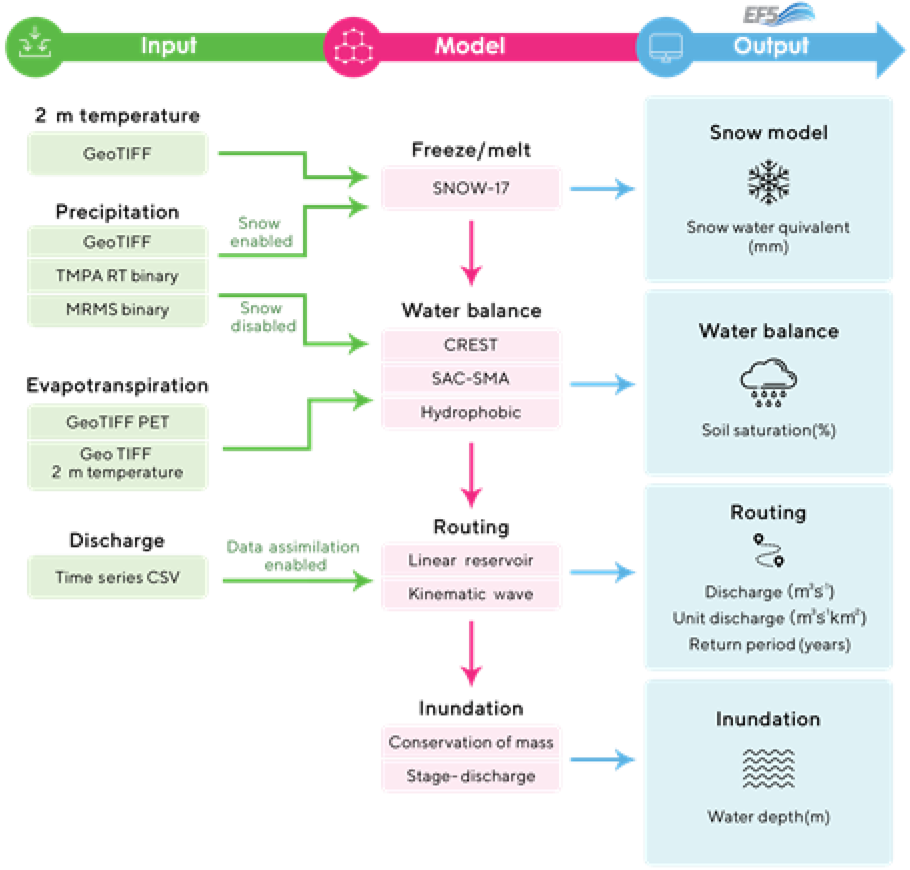

- He, X., Hong, Y., Vergara, H., Zhang, K., Kirstetter, P.-E., Gourley, J.J., Zhang, Y., Qiao, G., Liu, C., 2016. Development of a coupled hydrological-geotechnical framework for rainfall-induced landslides prediction. Journal of Hydrology 543, 395–405. https://doi.org/10.1016/j.jhydrol.2016.10.016
- Zhang, K., Xue, X., Hong, Y., Gourley, J.J., Lu, N., Wan, Z., Hong, Z., Wooten, R., 2016. iCRESTRIGRS: a coupled modeling system for cascading flood–landslide disaster forecasting. Hydrol. Earth Syst. Sci. 20, 5035–5048. https://doi.org/10.5194/hess-20-5035-2016

# NOAA/NSSL Operational Flash Flood model EF5, 2017-

- Ensemble framework for flash flood forecasting (EF5)
- Incorporate multiple models for water balance and runoff routing to provide ensemble results
- Operate in real-time to serve NWS for facilitating flood warning in the USA.


- Vergara, H., Kirstetter, P.-E., Gourley, J.J., Flamig, Z.L., Hong, Y., Arthur, A., Kolar, R., 2016. Estimating a-priori kinematic wave model parameters based on regionalization for flash flood forecasting in the Conterminous United States. Journal of Hydrology 541, 421–433. https://doi.org/10.1016/j.jhydrol.2016.06.011
- Clark, R.A., Flamig, Z.L., Vergara, H., Hong, Y., Gourley, J.J., Mandl, D.J., Frye, S., Handy, M., Patterson, M., 2017. Hydrological Modeling and Capacity Building in the Republic of Namibia. Bulletin of the American Meteorological Society 98, 1697–1715. https://doi.org/10.1175/BAMS-D-15-00130.1
- Gourley, J.J., Flamig, Z.L., Vergara, H., Kirstetter, P.-E., Clark, R.A., Argyle, E., Arthur, A., Martinaitis, S., Terti, G., Erlingis, J.M., Hong, Y., Howard, K.W., 2017. The FLASH Project: Improving the Tools for Flash Flood Monitoring and Prediction across the United States. Bulletin of the American Meteorological Society 98, 361–372. https://doi.org/10.1175/BAMS-D-15-00247.1
- Flamig, Z.L., Vergara, H., Gourley, J.J., 2020. The Ensemble Framework For Flash Flood Forecasting (EF5) v1.2: Description and Case Study (preprint). Hydrology. https://doi.org/10.5194/gmd-2020-46

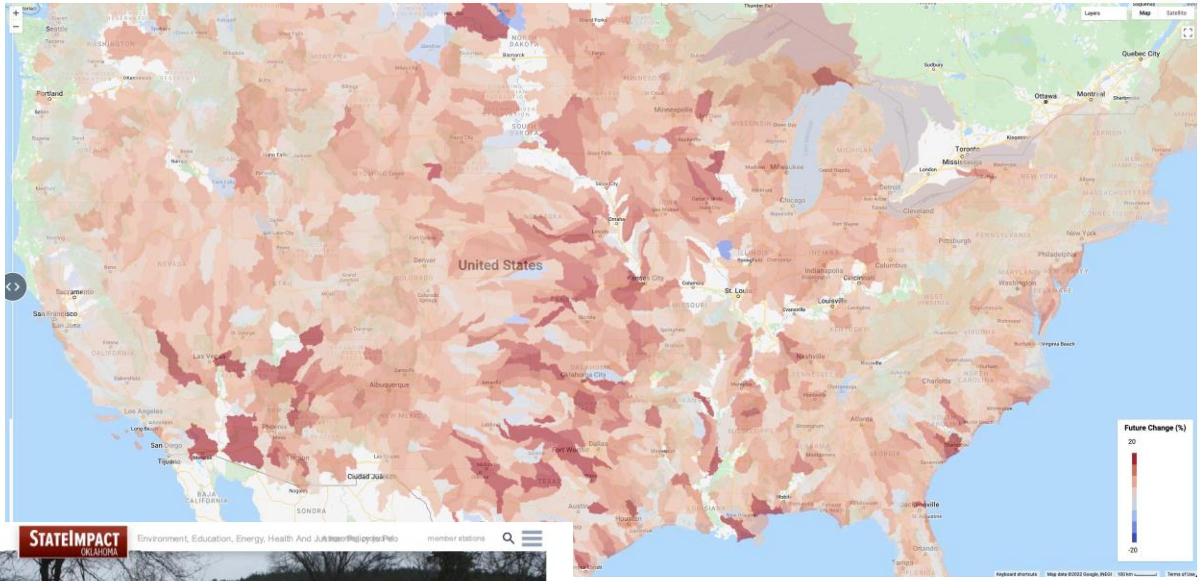

Operational web viewer: https://mrms.nssl.noaa.gov/qvs/product_viewer/

# 2D flood inundation modeling CREST-iMAP, 2021-

- CREST – inundation MApping and Prediction
- Coupled the CREST v2.1 with 2D Hydraulic Model using finite volume method to solve shallow water equation.
- The model produce comprehensive outputs for a flooding event: streamflow (1D), flood extent (2D), flood dept (2D), surface water speed and direction (2D), etc.
- Chen, M., Li, Z., Gao, S., Luo, X., Wing, O.E.J., Shen, X., Gourley, J.J., Kolar, R.L., Hong, Y., 2021. A comprehensive flood inundation mapping for Hurricane Harvey using an integrated hydrological and hydraulic model. Journal of Hydrometeorology. https://doi.org/10.1175/JHM-D-20-0218.1
- Li, Z., Chen, M., Gao, S., Luo, X., Gourley, J.J., Kirstetter, P., Yang, T., Kolar, R., McGovern, A., Wen, Y., Rao, B., Yami, T., Hong, Y., 2021. CREST-iMAP v1.0: A fully coupled hydrologic-hydraulic modeling framework dedicated to flood inundation mapping and prediction. Environmental Modelling & Software 141, 105051. https://doi.org/10.1016/j.envsoft.2021.105051
- Chen, M., Li, Z., Gao, S., Xue, M., Gourley, J.J., Kolar, R.L., Hong, Y., 2022. A flood predictability study for Hurricane Harvey with the CREST-iMAP model using high-resolution quantitative precipitation forecasts and U-Net deep learning precipitation nowcasts. Journal of Hydrology 612, 128168. https://doi.org/10.1016/j.jhydrol.2022.128168
- Li, Z., Chen, M., Gao, S., Wen, Y., Gourley, J.J., Yang, T., Kolar, R., Hong, Y., 2022. Can re-infiltration process be ignored for flood inundation mapping and prediction during extreme storms? A case study in Texas Gulf Coast region. Environmental Modelling & Software 155, 105450. https://doi.org/10.1016/j.envsoft.2022.105450

# Vector-based model and large-scale CREST-VEC simulation 2022-

- CREST model with a vector-based routing scheme: CREST-VEC
- Coupled the CREST v2.1 with MizuRoute water routing model
- Include a vector-based lake module, surface and subsurface runoff routings
- Highly computational efficient and suitable for large-scale simulations (CONUS, Li et al.,2023)
- Li, Z., Gao, S., Chen, M., Gourley, J., Mizukami, N., Hong, Y., 2022. CREST-VEC: a framework towards more accurate and realistic flood simulation across scales. Geosci. Model Dev. 15, 6181–6196. https://doi.org/10.5194/gmd-15-6181-2022
- Li, Z., Gao, S., Chen, M., Gourley, J.J., Hong, Y., 2022. Spatiotemporal Characteristics of US Floods: Current Status and Forecast Under a Future Warmer Climate. Earth's Future 10, e2022EF002700. https://doi.org/10.1029/2022EF002700
- Li, Z., Gao, S., Chen, M., Gourley, J.J., Liu, C., Prein, A.F., Hong, Y., 2022. The conterminous United States are projected to become more prone to flash floods in a high-end emissions scenario. Commun Earth Environ 3, 86. https://doi.org/10.1038/s43247-022-00409-6





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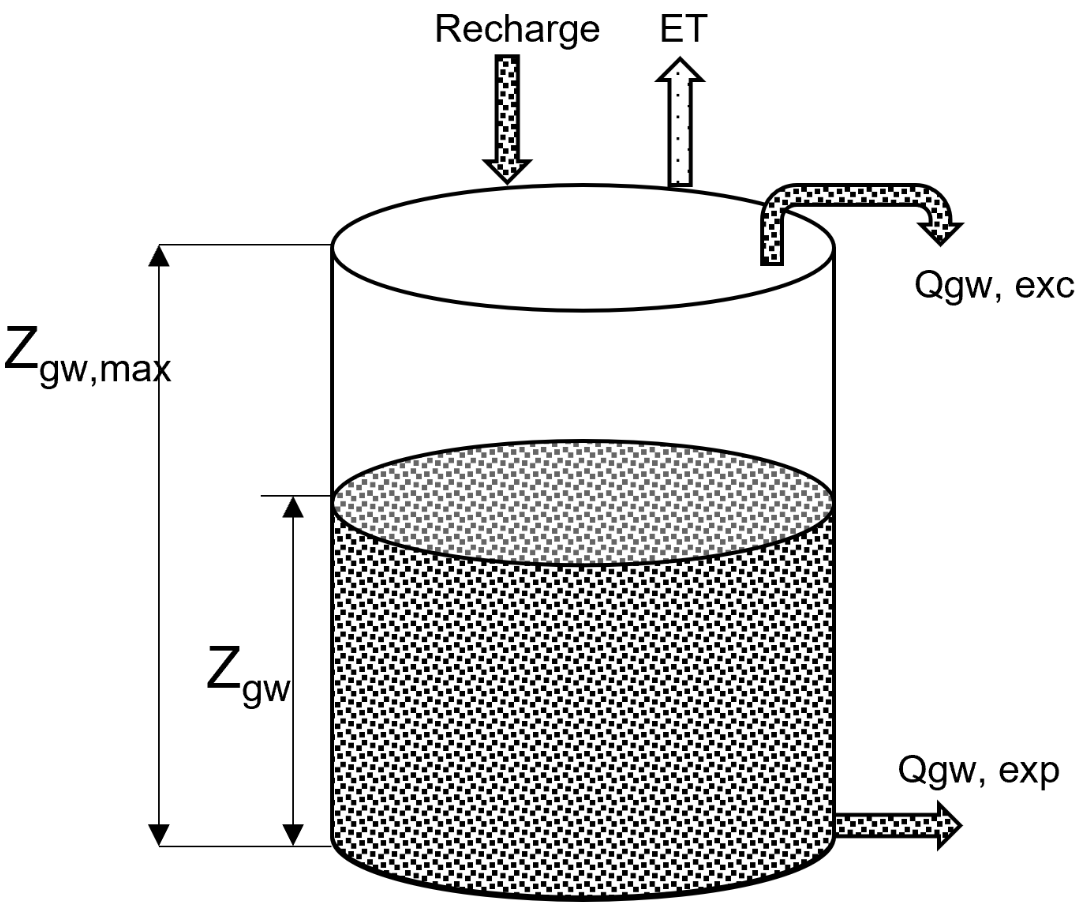
Central U.S. to emerge as flash flood hotspot, study finds

Beth Wallis

New research has found flash flooding events are likely to become more severe in the future if carbon dioxide emissions continue at their current rate.

Using climate simulations and modeling that examined the years 2070-2100, the research team from the University of Oklahoma, the National Oceanic and Atmospheric Administration and the National Center for Atmospheric Research predicts flash flooding could happen more rapidly and that the events would

# Recent developments, 2023, 2025

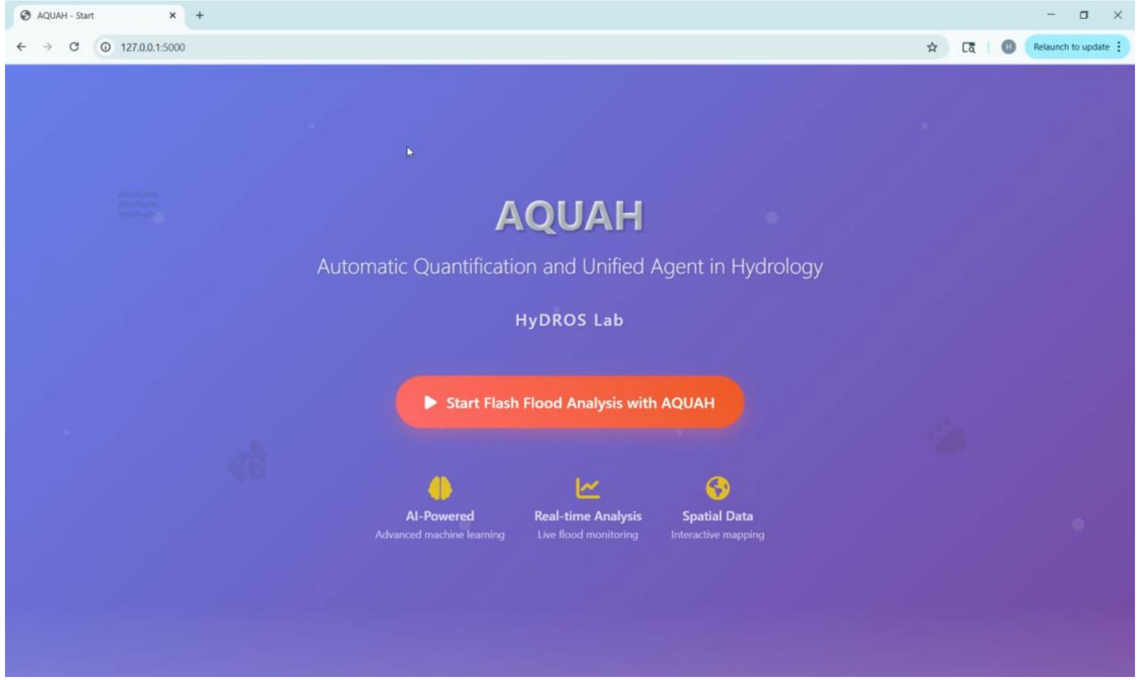



- CREST V3.0 added a groundwater module
- CREST V4.3 added a lake module and elevation-based temperature resampling

- Chen, M., Li, Z., Vergara, H.J., Gourley, J.J., Xue, M., Hong, Y., Hu, X.-M., Mayol Novoa, H., Martin, E.R., McPherson, R.A., Gao, S., Vitaliano Perez, A., Yanqui Morales, I., 2023. Conus-wide model calibration and validation for CRESTv3.0 – An improved Coupled Routing and Excess STorage distributed hydrological model. Journal of Hydrology 626, 130333. https://doi.org/10.1016/j.jhydrol.2023.130333

# CREST-AI: AI agent for hydrological model, 2025

- Leverage the advances of the LLMs, to automate the CREST model operations.
- Users can interact with multi-version CREST model using plain languages.
- AI calibration: has higher efficiency for users to achieve accurate CREST simulation, in-situ data is required.





- Yan, S., Li, Z., Zhu, S., Wen, Y., Zhang, M., Chen, M., Cao, J., Hong, Y., 2025. AQUAH: Automatic Quantification and Unified Agent in Hydrology. https://doi.org/10.48550/ARXIV.2508.02936
- Songkun Yan, Mengye Chen, Li, Z., Yixin Wen, Siyu Zhu, Mofan Zhang, et al. (2026). AI Agent for Hydrologic Modeling: Definition, Development and Application. https://doi.org/10.13140/RG.2.2.34824.48643

# Education and capacity buildings

- We transfer the technology and knowledge to build local capacity through workshops and training in Norman, Oklahoma, and anywhere in the world. Over the past 15 years, 30+ workshops have been held, with 1,000+ trainees participating in the training.

Africa: Kenya, Uganda
Asia: Pakistan, Nepal, China
Central and South America: Panama, Colombia, Peru

- CREST model was adapted by the Eastern African Hydrological service serving Ethiopia, Uganda, Kenya, Somalia, Rwanda, Tanzania, and Burundi








# Summary and future development

- Since 2011, the CREST model has been successfully applied in research, hazard warning, and emergency response sectors.
- The CREST model is efficient, powerful, and can produce comprehensive results for hydrological simulation and flood detection.
- Years of development of the CREST model family enable various applications and solve real-world hydrological problems.

- Future development
  - AI integration
    - CREST-AI: ML-powered hydrological model
    - CREST AI agent: LLM-supported hydrological model
  - Water resource management
    - For arid regions
  - Global flood detection
    - International collaboration
  - Future flood project
    - WRF + CREST coupling

# Key Publications


1. Xue X., Y. Hong, A. S. Limaye, et al. (2013), Statistical and hydrological evaluation of TRMM-based Multi-satellite Precipitation Analysis over the Wangchu Basin of Bhutan: Are the latest satellite precipitation products 3B42V7 ready for use in ungauged basins? Journal of Hydrology, 499(0): 91-99. doi: 10.1016/j.jhydrol.2013.06.042. (Introduction of CREST v2.0)
2. Wang. J., Y. Hong, L. Li, J.J. Gourley, K. Yilmaz, S. I. Khan, F.S. Policelli, R.F. Adler, S. Habib, D. Irwn, S.A. Limaye, T. Korme, and L. Okello, 2011: The Coupled Routing and Excess STorage (CREST) distributed hydrological model. Hydrol. Sciences Journal, 56, 84-98. (Detailed Description of CREST v1.x)
3. Zhang, Y., Y. Hong, et al., 2014: Hydrometeorological Analysis and Remote Sensing of Extremes: Was the July 2012 Beijing Flood Event Detectable and Predictable by Global Satellite Observing and Global Weather Modeling Systems?, Journal of Hydrometeorology, doi: 10.1175/JHM-D-14-0048.1
4. Khan, S. I., P. Adhikari, Y. Hong, H. Vergara, T. Grout, R. F. Adler, F. Policelli, D. Irwin, T. Korme, and L. Okello, 2011: Observed and simulated hydroclimatology using distributed hydrologic model from in-situ and multi-satellite remote sensing datasets in Lake Victoria region in East Africa, Hydrol. Earth Syst. Sci. Discuss., 7, 4785-4816, doi: 10.5194/hessd-7-4785.
5. Khan, S. I., Y. Hong, H. J. Vergara, et al. (2012), Microwave Satellite Data for Hydrologic Modeling in Ungauged Basins, Geoscience and Remote Sensing Letters, IEEE, 9(4), 663-667
6. Khan, S. I., Y. Hong, J. Wang, K.K. Yilmaz, J.J. Gourley, R.F. Adler, G.R. Brakenridge, F. Policelli, S. Habib, and D. Irwin, 2011: Satellite Remote Sensing and Hydrologic Modeling for Flood Inundation Mapping in Lake Victoria Basin: Implications for Hydrologic Prediction in Ungauged Basins, IEEE Transactions on Geosciences and Remote Sensing, 49(1), 85-95, Jan. 2011, doi: 10.1109/TGRS.2010.2057513.
7. Shen, X., Hong, Y., Zhang, K., Hao, Z., and Wang, D. (2014) "CREST v2. 1 Refined by a Distributed Linear Reservoir Routing Scheme." Proc., AGU Fall Meeting, H33G-0918.
8. Chen, M., Li, Z., Gao, S., Luo, X., Wing, O.E.J., Shen, X., Gourley, J.J., Kolar, R.L., Hong, Y., 2021. A comprehensive flood inundation mapping for Hurricane Harvey using an integrated hydrological and hydraulic model. Journal of Hydrometeorology. doi: 10.1175/JHM-D-20-0218.1
9. Chen, M., Li, Z., Gao, S., Xue, M., Gourley, J.J., Kolar, R.L., Hong, Y., 2022. A flood predictability study for Hurricane Harvey with the CREST-iMAP model using high-resolution quantitative precipitation forecasts and U-Net deep learning precipitation nowcasts. Journal of Hydrology 612, 128168. doi: 10.1016/j.jhydrol.2022.128168
10. Chen, M., Li, Z., Vergara, H.J., Gourley, J.J., Xue, M., Hong, Y., Hu, X.-M., Mayol Novoa, H., Martin, E.R., McPherson, R.A., Gao, S., Vitaliano Perez, A., Yanqui Morales, I., 2023. Conus-wide model calibration and validation for CRESTv3.0 – An improved Coupled Routing and Excess STorage distributed hydrological model. Journal of Hydrology 626, 130333. doi: 10.1016/j.jhydrol.2023.130333
11. Xue, X., Zhang, K., Hong, Y., Gourley, J.J., Kellogg, W., McPherson, R.A., Wan, Z., Austin, B.N., 2016. New multisite cascading calibration approach for hydrological models: case study in the Red River Basin using the VIC model. Journal of Hydrologic Engineering 21. https://doi.org/10.1061/(ASCE)HE.1943-5584.0001282.
12. Clark, R.A., Flamig, Z.L., Vergara, H., Hong, Y., Gourley, J.J., Mandl, D.J., Frye, S., Handy, M., Patterson, M., 2017. Hydrological Modeling and Capacity Building in the Republic of Namibia. Bulletin of the American Meteorological Society 98, 1697–1715. doi: 10.1175/BAMS-D-15-00130.1
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14. Gourley, J.J., Flamig, Z.L., Vergara, H., Kirstetter, P.-E., Clark, R.A., Argyle, E., Arthur, A., Martinaitis, S., Terti, G., Erlingis, J.M., Hong, Y., Howard, K.W., 2017. The FLASH Project: Improving the Tools for Flash Flood Monitoring and Prediction across the United States. Bulletin of the American Meteorological Society 98, 361–372. doi: 10.1175/BAMS-D-15-00247.1
15. Li, Z., Chen, M., Gao, S., Luo, X., Gourley, J.J., Kirstetter, P., Yang, T., Kolar, R., McGovern, A., Wen, Y., Rao, B., Yami, T., Hong, Y., 2021. CREST-iMAP v1.0: A fully coupled hydrologic-hydraulic modeling framework dedicated to flood inundation mapping and prediction. Environmental Modelling & Software 141, 105051. doi: 10.1016/j.envsoft.2021.105051
16. Li, Z., Gao, S., Chen, M., Gourley, J., Mizukami, N., Hong, Y., 2022a. CREST-VEC: a framework towards more accurate and realistic flood simulation across scales. Geosci. Model Dev. 15, 6181–6196. doi: 10.5194/gmd-15-6181-2022
17. Li, Z., Gao, S., Chen, M., Gourley, J.J., Hong, Y., 2022b. Spatiotemporal Characteristics of US Floods: Current Status and Forecast Under a Future Warmer Climate. Earth's Future 10, e2022EF002700. doi: 10.1029/2022EF002700
18. Li, Z., Gao, S., Chen, M., Gourley, J.J., Liu, C., Prein, A.F., Hong, Y., 2022c. The conterminous United States are projected to become more prone to flash floods in a high-end emissions scenario. Commun Earth Environ 3, 86. https://doi.org/10.1038/s43247-022-00409-6
19. Li, Z., Chen, M., Gao, S., Wen, Y., Gourley, J. J., Yang, T., Kolar, R., Hong, Y., 2022. Can re-infiltration process be ignored for flood inundation mapping and prediction during extreme storms? A case study in Texas Gulf Coast region. Environmental Modelling & Software, 155, 105450.
20. Shen, X., Hong, Y., Zhang, K., Hao, Z., 2017. Refining a Distributed Linear Reservoir Routing Method to Improve Performance of the CREST Model. J. Hydrol. Eng. 22, 04016061. https://doi.org/10.1061/(ASCE)HE.1943-5584.0001442 (Description of CREST v2.1)
21. Vergara, H., Kirstetter, P.-E., Gourley, J.J., Flamig, Z.L., Hong, Y., Arthur, A., Kolar, R., 2016. Estimating a-priori kinematic wave model parameters based on regionalization for flash flood forecasting in the Conterminous United States. Journal of Hydrology 541, 421–433. https://doi.org/10.1016/j.jhydrol.2016.06.011
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# Thank you!

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