Recent Updates on land model physics in WRF Version 4.3

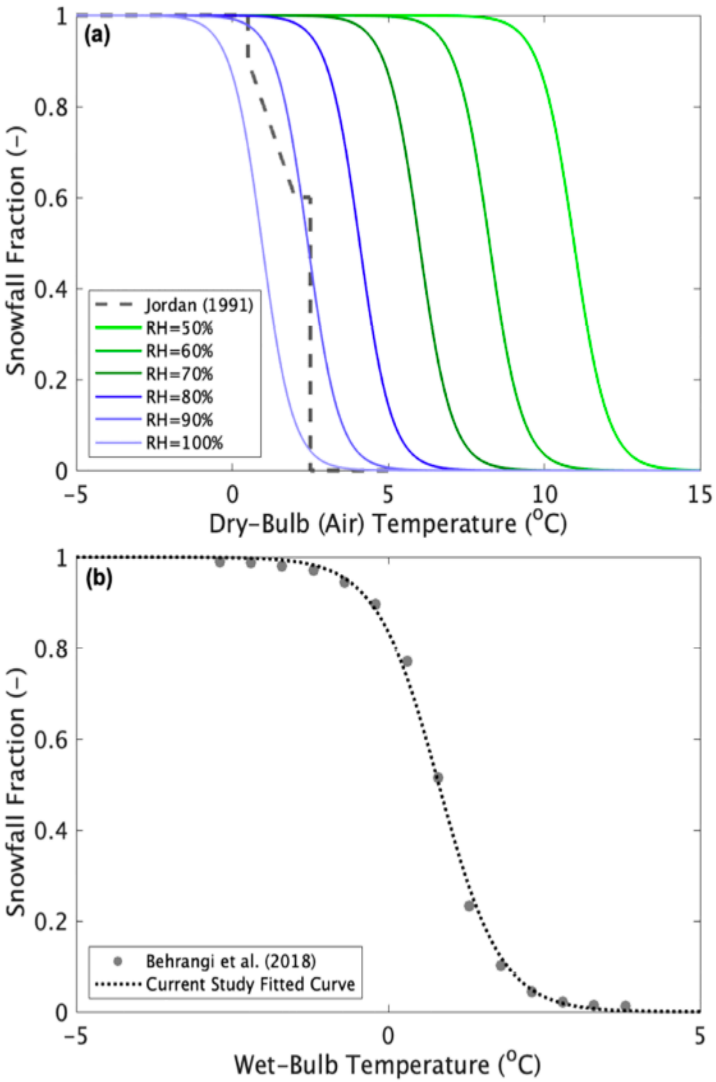
- **Snow process and parameter updates in Noah-MP**
- **New irrigation scheme in Noah-MP**
- **Crop model parameter update in Noah-MP**
- **WRF-urban update (LCZ, solar panel, green roof, building drag)**
- **Updates related to Pleim-Xiu LSM and WRF-CTSM**
- **Unified Noah-MP GitHub repository and refactor/modularization**

Cenlin He, NCAR/Research Application Laboratory

Main contributors: Fei Chen, Michael Barlage, Prasanth Valayamkunnath, Dave Gochis, Zhe Zhang, Andrea Zonato, Guo-Yue Niu, Negin Sobhani, Dave Lawrence, Bill Sacks, and other WRF-LSM developers

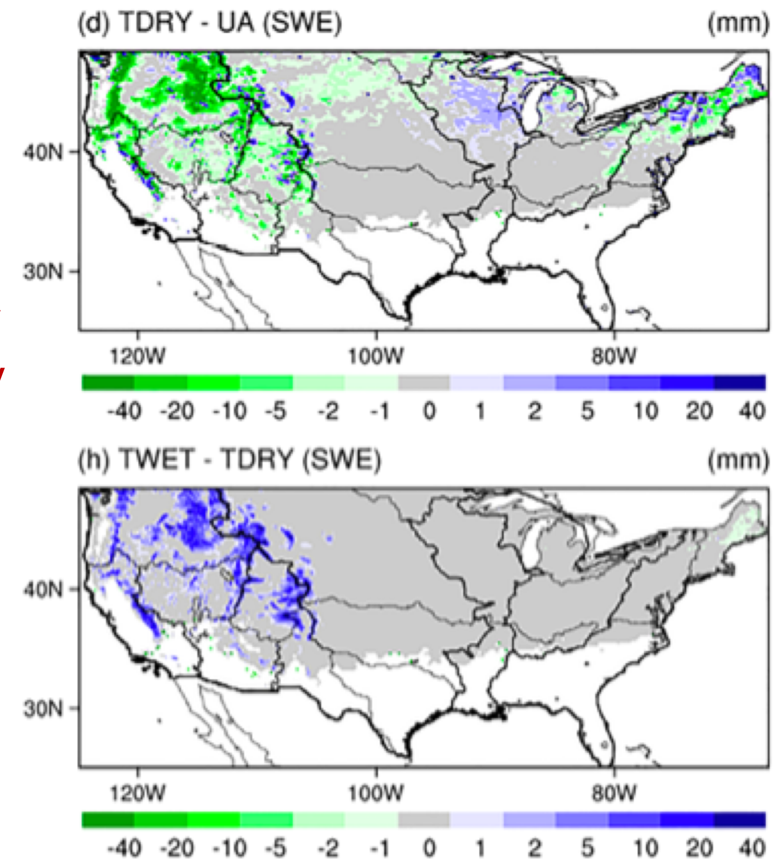
Noah-MP snow update I: New rain-snow partitioning option

- Add wet-bulb temperature snow-rain partitioning scheme (OPT_SNF=5 in Noah-MP) based on Wang et al. 2019 (also included in the National Water Model)



- *Wet-bulb temperature represents better the "cooling effects" of a falling hydrometeor*
- *Fit a curve against data at 547 weather stations (Behrangi et al., 2018)*

Improve snow simulation over the western dry mountains

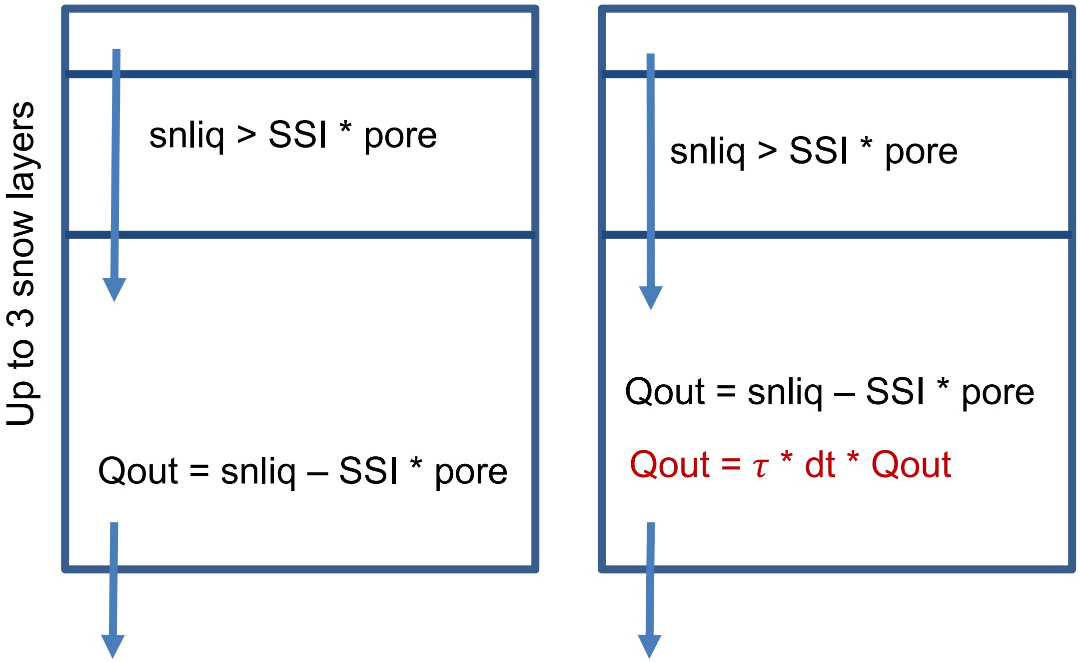


Figures from Guo-Yue Niu (U of Arizona)

Noah-MP snow update II: New snowmelt water retention process

- Add snow retention process at the snowpack bottom to slow down drainage water out of snowpack and hence improve the modeling of streamflow diurnal variation (also included in the National Water Model)

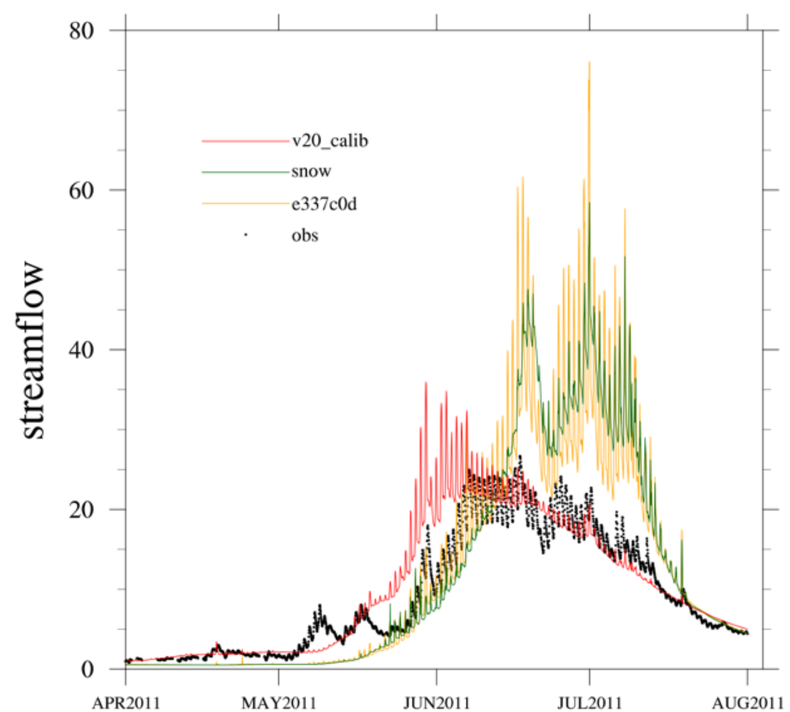
Original Noah-MP snow | **New snow water retention**



SSI: snow liquid water holding capacity (0.03 m3/m3)
τ: snowpack water release timescale factor (1/s)

Parameters are tunable and set in MPTABLE.TBL

New snowmelt water retention process improves the streamflow diurnal variation



Figures from Mike Barlage (NCAR, now at NOAA/EMC)

Noah-MP snow update III:

- Bring hard-coded snow emissivity and snow cover parameter (2.5*z0) to tunable MPTABLE parameters

Snow emissivity

EMG = parameters%EG(IST)*(1.-FSNO) + 1.0 * FSNO

EMG = parameters%EG(IST)*(1.-FSNO) + parameters%SNOW_EMIS * FSNO

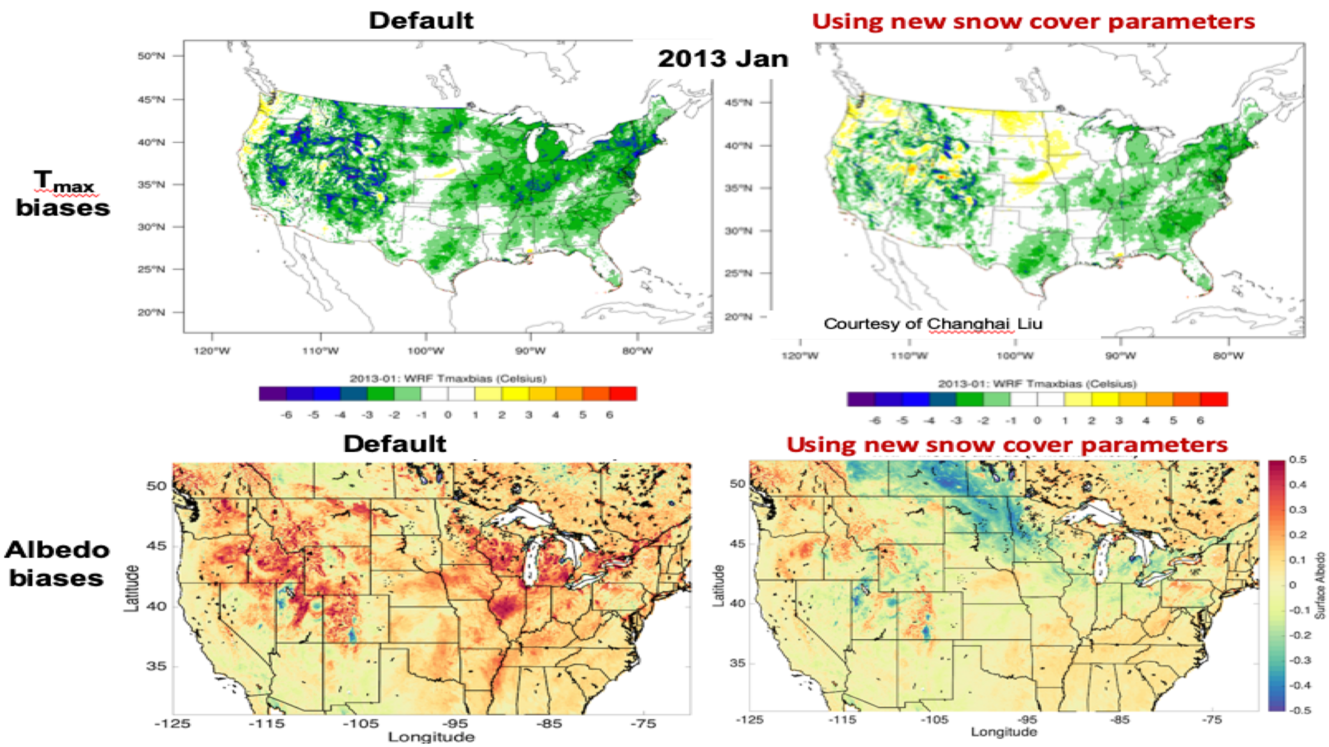
Snow cover parameter

FSNO = TANH(SNOWH /(2.5* Z0 * FMELT))

FSNO = TANH(SNOWH /(parameters%SCFFAC * FMELT))

FMELT = (BDSNO/100.)**parameters%MFSNO

- Optimize snow cover parameters (SCFFAC & MFSNO in MPTABLE.TBL) to be land type dependent and to improve surface albedo & temperature simulations



Noah-MP turbulence parameter updates:

- Update wind-canopy absorption coefficient (CWPVT) parameter values in MPTABLE to be vegetation dependent based on Goudriaan1977
  original CWPVT value: 0.18 (constant)

Aerodynamic resistance for sensible heat (ra_{hg}) below the canopy

$$ra_{hg} = \frac{H_{CAN} \times e^{a}}{K_c(H_{CAN}) \times a} \times \left(e^{-a\left(\frac{Z_{0HG}}{H_{CAN}}\right)} - e^{-a\left(\frac{Z_{0H}+\mathrm{ZPD}}{H_{CAN}}\right)} \right)$$

$$a = (\alpha \times \mathrm{VAI} \times H_{CAN} \times \Phi_m)^{0.5}$$

α: canopy wind absorption parameter (CWPVT)

- Limit the bulk leaf boundary layer resistance (RB) to a more realistic range (5~50)
  Original: RB >= 100 (unrealistic);
  Update: RB = 5~50 (based on tests for various vegetation/canopy types)

New dynamic irrigation scheme in Noah-MP

- Different from the irrigation options under the WRF &physics list that is released in version 4.2 (added to Noah; parameterize irrigation as a function of three evaporative processes: channel, drip, sprinkler; Arianna Valmassoi (University College Dublin))

- New Noah-MP option (under &noahmp list): opt_irr, opt_irrm

```
opt_irr
0 -> No irrigation
1 -> Irrigation ON
2 -> irrigation trigger based on crop season Planting and harvesting dates
3 -> irrigation trigger based on LAI threshold
```

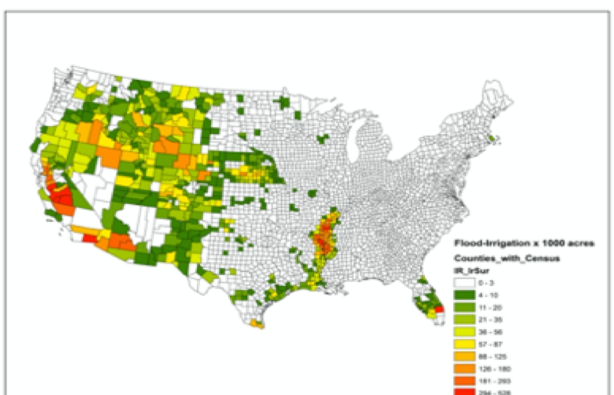
```
opt_irrm
0 -> method based on geo_em fractions (all three methods are ON)
1 -> sprinkler method
2 -> micro/drip irrigation
3 -> surface flooding
```

- Explicit representations of three irrigation methods: sprinkler, micro, and surface flooding with new irrigation input maps for CONUS (Prasanth Valayamkunnath, NCAR/RAL)

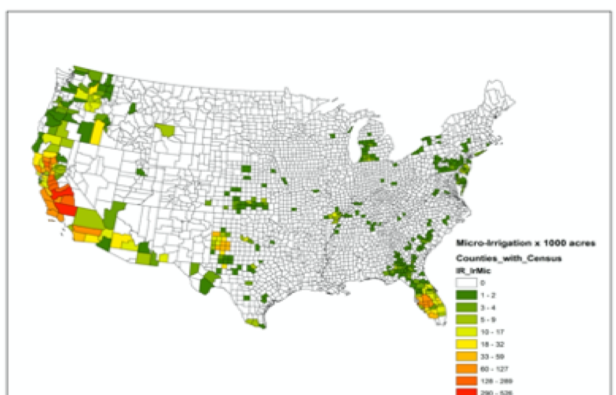
IRRIGATION METHOD

USDA WATER CENSUS-2015

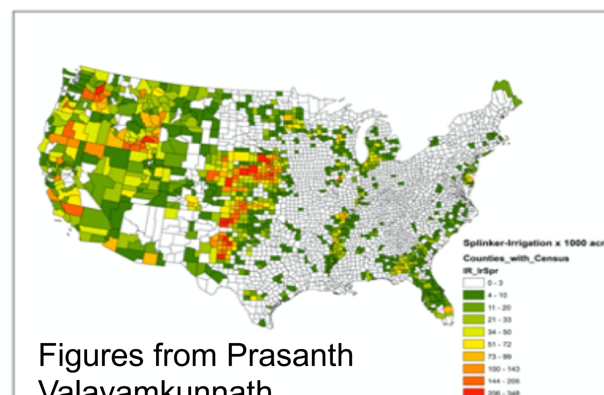
Flood



Micro (Drip+Micro Sprinkler)



Sprinkler



Figures from Prasanth Valayamkunnath

New dynamic irrigation scheme in Noah-MP

- **Sprinkler**
  - Applying water from certain height (~2m) above ground.
  - Treat as precipitation to allow canopy water and heat processes
  - Evaporation of irrigation water before reaching the ground

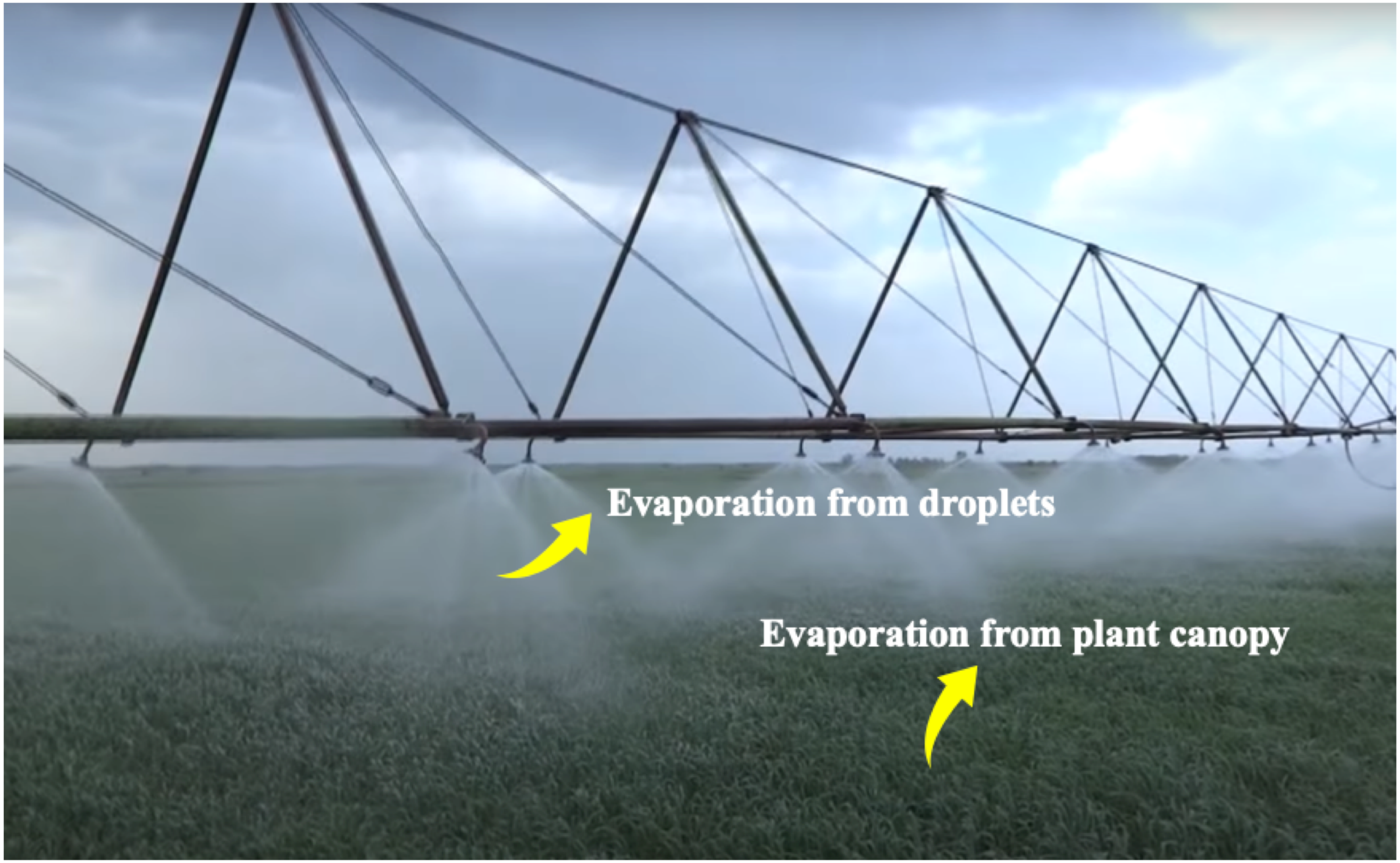
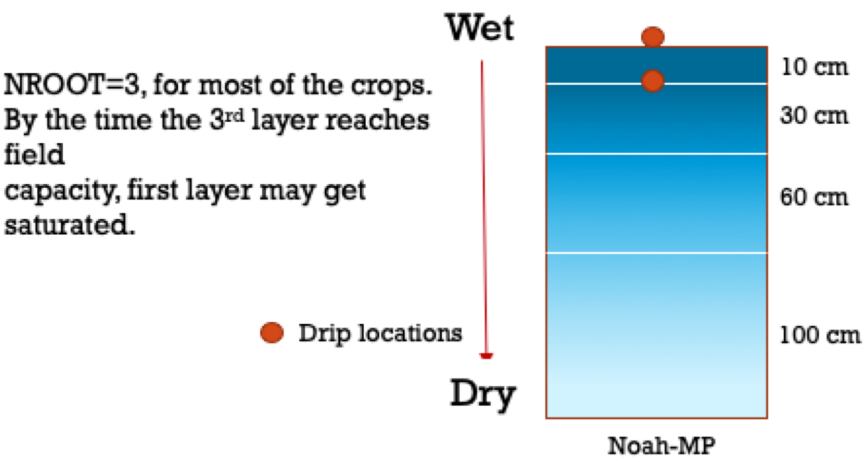


Figure from Prasanth Valayamkunnath

New dynamic irrigation scheme in Noah-MP

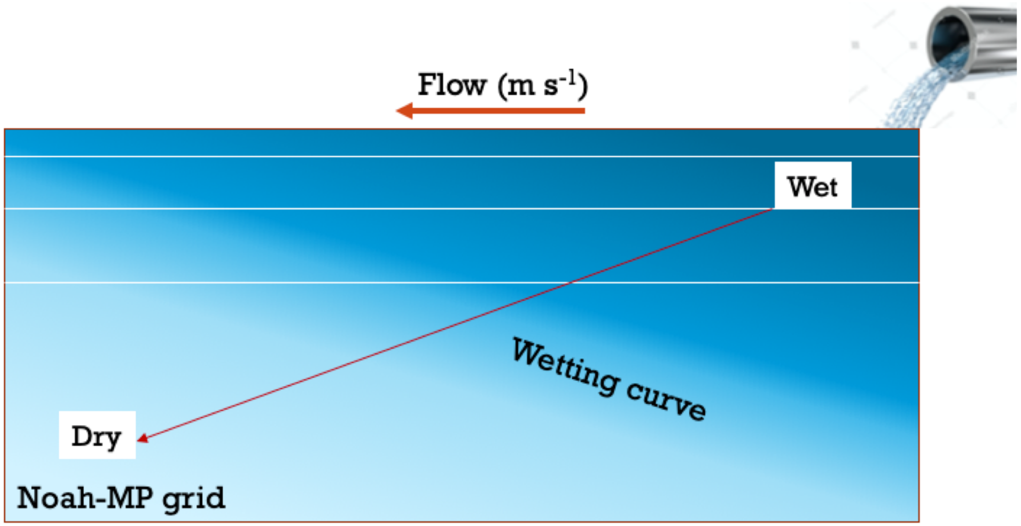
- **Micro Irrigation**
- ➢ Applying water on the surface or subsurface
- ➢ Probably saturate the root zone
- ➢ Implementation: (1) bring the rootzone soil moisture to field capacity (FC) without any losses; (2) apply water on to the first layer till rootzone becomes FC, low application rate (drips)



Figures from Prasanth Valayamkunnath

New dynamic irrigation scheme in Noah-MP

- **Flood irrigation**
- Applying water on the surface and saturate it.
- Unlike other methods, water applied from one edge and advances the flow to other edge.
- Application rate will be higher than maximum infiltration rate
- Implementation: (1) apply water on to the first layer till rootzone becomes FC; (2) higher application rate > infiltration capacity; (3) ponding water on the surface.



Figures from Prasanth Valayamkunnath

Crop model parameter updates in Noah-MP

- Previously, only generic C3 photosynthetic parameters are included in the &noahmp_modis_parameters section (column 12 for croplands), where 11 parameters are related, such as maximum rubisco capacity (VCMX25), minimum stomatal resistance (BP), initial slope of photosynthetic light response (QE25).
- This was fine for single-point simulation, as user can manually switch these parameters values in this column (Liu et al., 2016)
- Now, these parameters are separated into two columns to distinguish photosynthetic characteristics for C3 (soybean) and C4 (corn) crops. This modification is necessary for regional simulation where two crop types co-exist (Zhang et al., 2020).. Some parameters are adjusted based on a synthesis from a wide range of literature and LSMs.

MPTABLE.TBL (updated)

```
&noahmp_crop_parameters

 ! NCROP = 5
 !   1: Corn
 !   2: Soybean
 !   3: Sorghum
 !   4: Rice
 !   5: Winter wheat

DEFAULT_CROP = 0
```

```
 !------------------------------
 !                 1       2
 !------------------------------
C3PSN     =    0.0,    1.0,
KC25      =   30.0,   30.0,
AKC       =    2.1,    2.1,
KO25      =   3.E4,   3.E4,
AKO       =    1.2,    1.2,
AVCMX     =    2.4,    2.4,
VCMX25    =   60.0,   80.0,
BP        =   4.E4,   1.E4,
MP        =     4.,     9.,
FOLNMX    =    1.5,    1.5,
QE25      =   0.05,   0.06,
```

Slide from Zhe Zhang (U of Saskatchewan)

WRF-urban model update I: Local climate zone (LCZ)

- **Original urban classifications: 3 types** (Low-dens Res, Hi-dens Res, Commercial)
- **New urban classifications: 11 LCZ types based on WUDAPT types (31-41)**

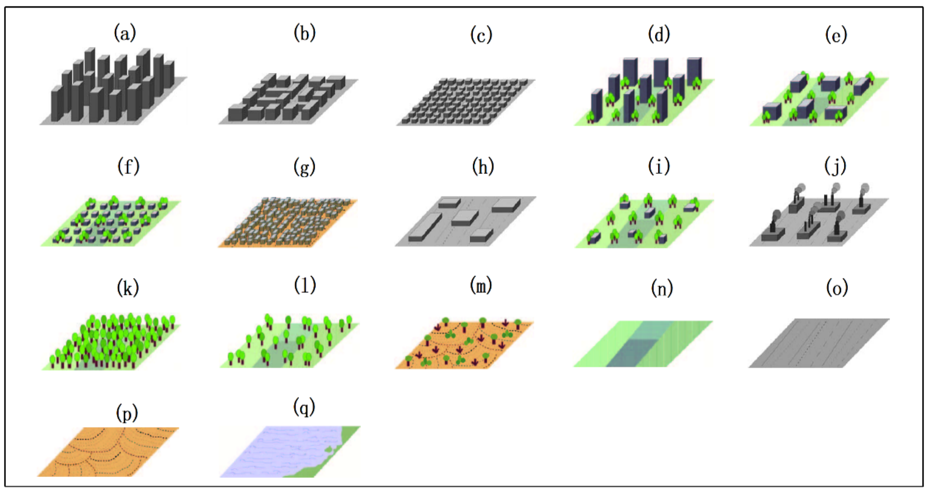
  (1) New physics option (under &physics):

  use_wudapt_lcz (=0, use traditional 3 types; =1, use 11 LCZ types)

  (2) LCZ works for all urban physics options

  (3) If using LCZ, model will read a new urban parameter table (URBPARM_LCZ.TBL)

  (4) If the urban type data in input file is inconsistent with the use_wudapt_lcz option, error message will occur and model will crash.



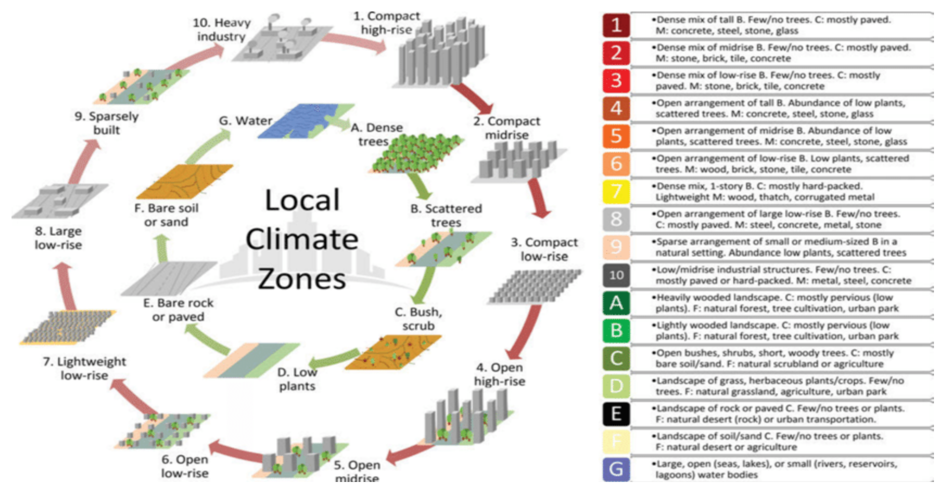


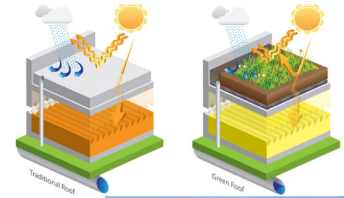
Fig 1 LCZ classes. (a) LCZ1 compact high rise; (b) LCZ 2: Compact mid-rise; (c) LCZ 3: Compact low-rise; (d) LCZ 4: Open high-rise; (e) LCZ 5: Open mid-rise; (f) LCZ 6: Open low-rise; (g) LCZ 7: Light weight low-rise; (h) LCZ 8: Large low-rise; (i) LCZ 9: Sparsely built; (j) LCZ 10: Heavy industry; (k) LCZ A: Dense trees; (l) LCZ B: Scattered trees; (m) LCZ C: Bush, scrub; (n) LCZ D: Low plants; (o) LCZ E: Bare rock or paved; (p) LCZ F: Bare soil or sand; (q) LCZ G: Water

How to make LCZ land use types: http://www.wudapt.org/

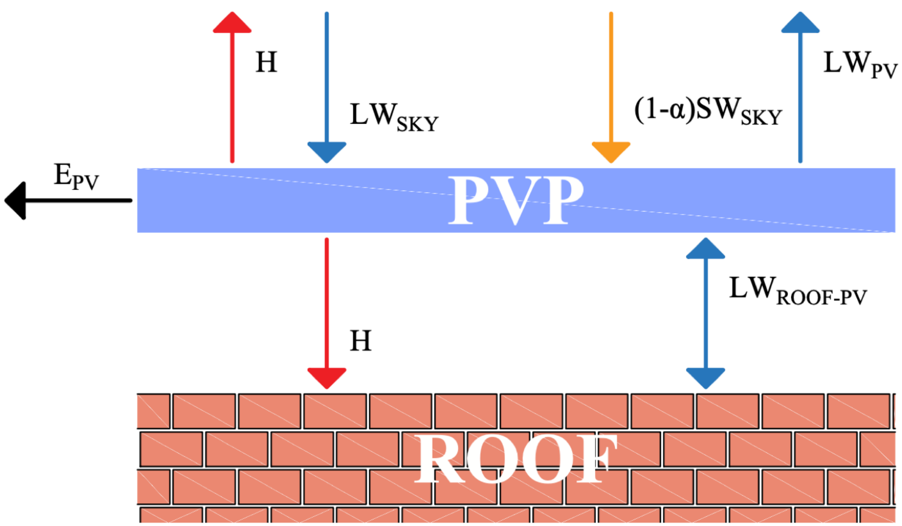
Figures from Mike Barlage

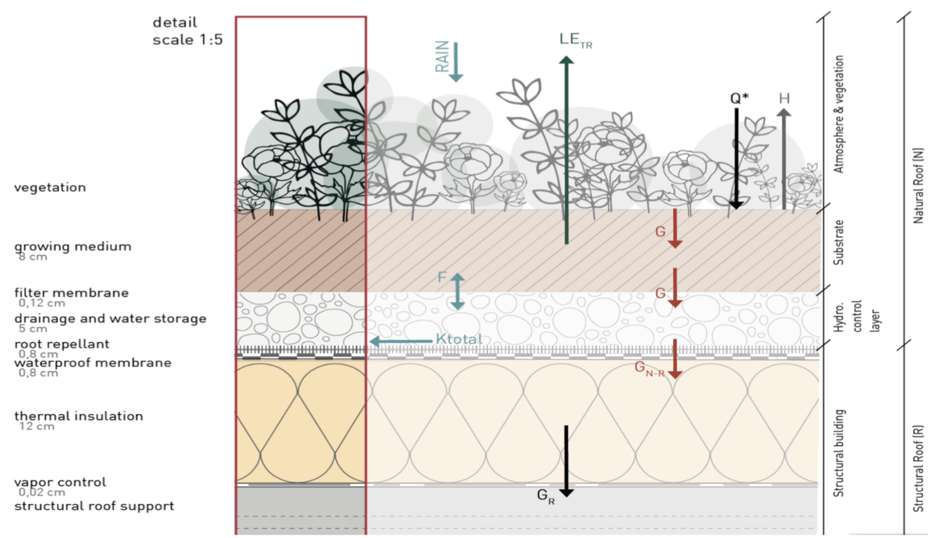
WRF-urban model update II: Green roof & solar panel (PVP) roof

- Only works with urban physics = 3 (**BEP+BEM**)
- New variables related to green roof and solar panel are included in **URBPARM.TBL**
  - GR_TYPE (1 or 2): 1 is grass vegetation, 2 sedum vegetation;
  - GR_FLAG (0 or 1): setting it to 1 turn on the green roof parameterization;
  - GR_FRAC_ROOF (from 0 to 1): fraction of roof covered by green roof;
  - PV_FRAC_ROOF (from 0 to 1): fraction of roof covered by photovoltaic panels;
  - IRHO (from 0 to 1 for each hour of the day): it allows to turn on drip irrigation over the roof.



- Green roof and solar panel roof modules are coupled and can be activated at the same time (e.g., a case where green roof is shielded by solar panels)





Reference: Andrea Zonato, et al., 2021: Exploring the effects of rooftop mitigation strategies on urban temperatures and energy consumption, *JGR-Atmos.*, in review.

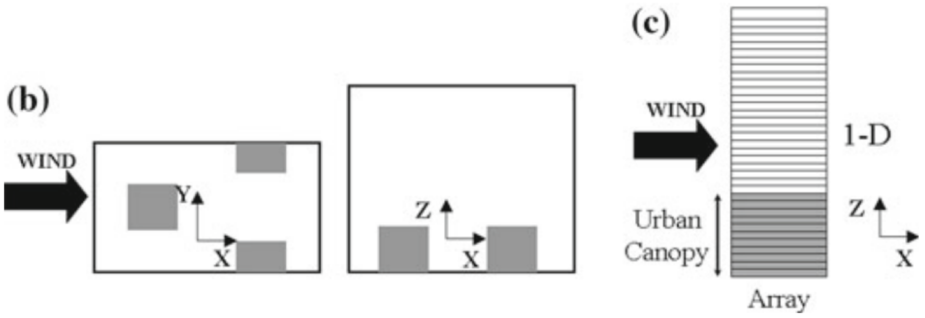
WRF-urban model update III: New building drag coefficient

- **Original BEP+BEM scheme**: the drag coefficient induced by buildings for mean wind speed and turbulent kinetic energy is ***C_D* = 0.4, constant** for all buildings packing density (or building plan area fraction).

- **Update in version 4.3**:

$$C_D(\lambda_p) = \begin{cases} 3.32\,\lambda_p^{0.47} & \text{for } \lambda_p \leq 0.29 \\ 1.85 & \text{for } \lambda_p > 0.29 \end{cases}$$

where λ_p is the buildings plan area fraction.



More information about WRF-urban modeling:

https://ral.ucar.edu/solutions/products/urban-canopy-model

References:

Santiago, J. L. and Martilli, A. (2010). A Dynamic Urban Canopy Parameterization for Mesoscale Models Based on Computational Fluid Dynamics Reynolds-Averaged Navier- Stokes Microscale Simulations. Boundary-Layer Meteorology, 137(3):417–439.

Gutierrez, E., Martilli, A., Santiago, J. L., and Gonzalez, J. E. (2015). A Mechanical Drag Coefficient Formulation and Urban Canopy Parameter Assimilation Technique for Complex Urban Environments. Boundary- Layer Meteorology, 157(2):333–341.

WRF-urban model update IV: Coupling with PBL

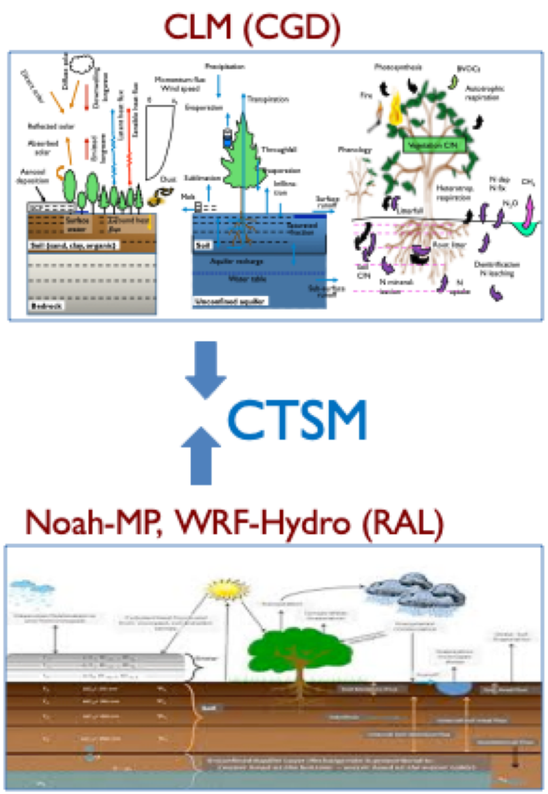
- Originally, the BEP and BEP+BEM urban canopy models only works with MYJ and BouLac PBL schemes
- Update: **BEP** and **BEP+BEM** are coupled with the **YSU** PBL scheme.
- **Reference:** Hendricks, E. A., J. C. Knievel, and Y. Wang, 2020: Addition of multilayer urban canopy models to a nonlocal planetary boundary layer parameterization and evaluation using ideal and real cases, J. Appl. Met. Clim., 59, 1369-1392.

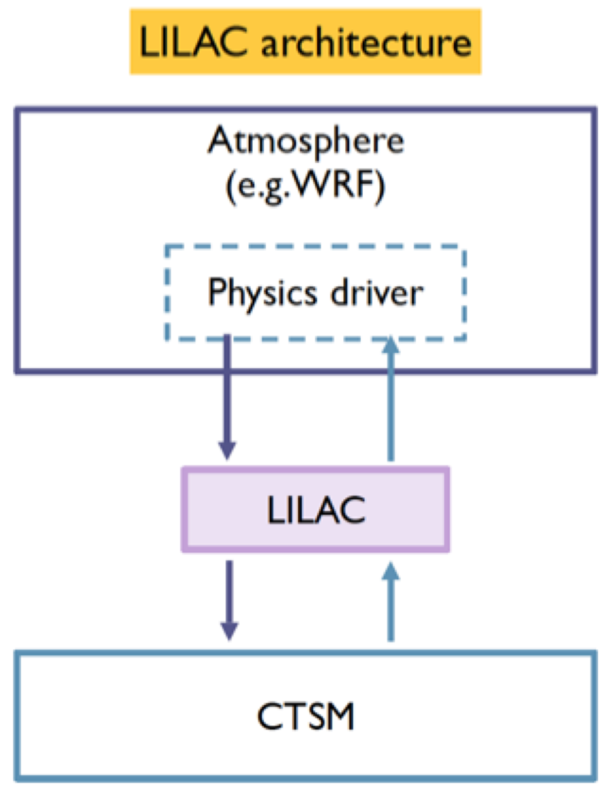
Other LSM update in WRF: Pleim-Xiu LSM

- Pleim-Xu LSM update: The biggest effect on surface statistics is the added evaporation from the ground in vegetative fraction of the grid cell. This increases near surface water vapor mixing ratio.

WRF-CTSM updates

- Community Terrestrial Systems Model (CTSM) coupling with WRF:
   - A unified model for research and prediction in climate, weather, water, and ecosystems
   - Coupling via the **LIghtweight Land Atmosphere Coupler (LILAC)** is added and activated by setting namelist option sf_surface_physics to 6.
   - This is the initial beta release of WRF-CTSM coupling capability.
   - For instructions on how to run WRF with CTSM please check instructions on the WRF-CTSM User's Guide (https://escomp.github.io/ctsm-docs/versions/master/html/lilac/specific-atm-models/wrf.html).





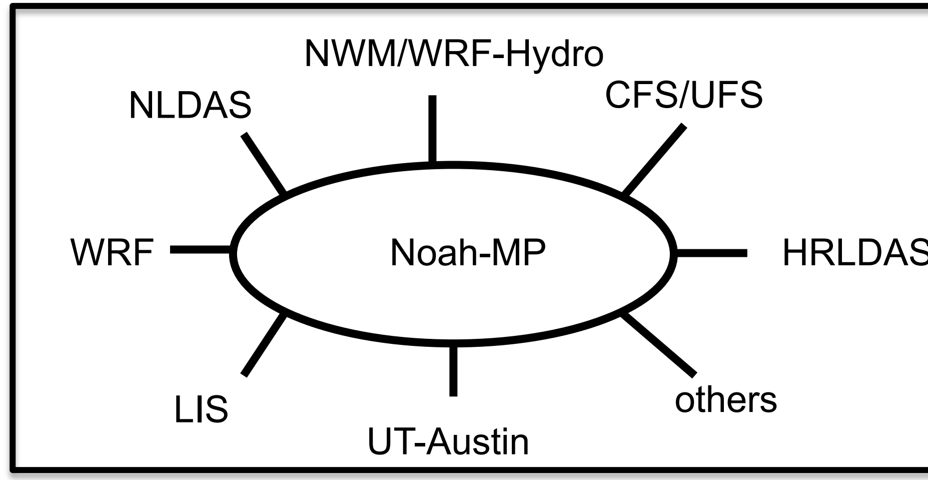
Main developers: Negin Sobhani, Dave Lawrence, Fei Chen, Bill Sacks, Mike Barlage

Figures from Fei Chen (NCAR)

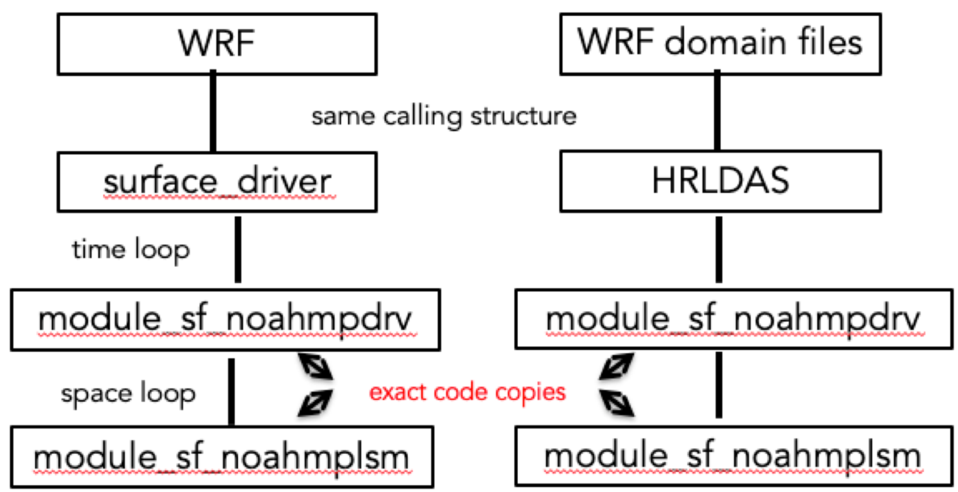
Noah-MP Unified code and Github repository

- Noah-MP LSM exists in multiple systems:
  - NWM/WRF-Hydro
  - WRF
  - NOAA CFS/UFS
  - NLDAS
  - HRLDAS
  - LIS
  - UT-Austin
  - others?

Need for a unified Noah-MP source code for use in various host models



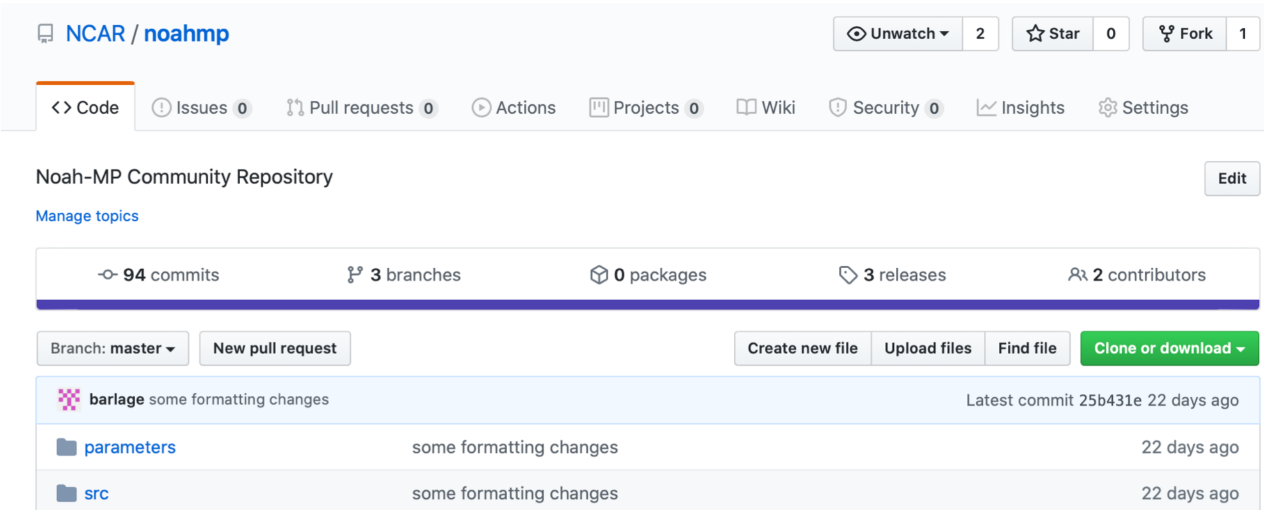
- HRLDAS (High Resolution Land Data Assimilation System): a host model to execute the standard-alone version of Noah-MP in an offline/uncoupled mode for a 2-D gridded domain or a single point
- HRLDAS became the core of WRF-Hydro and eventually the National Water Model

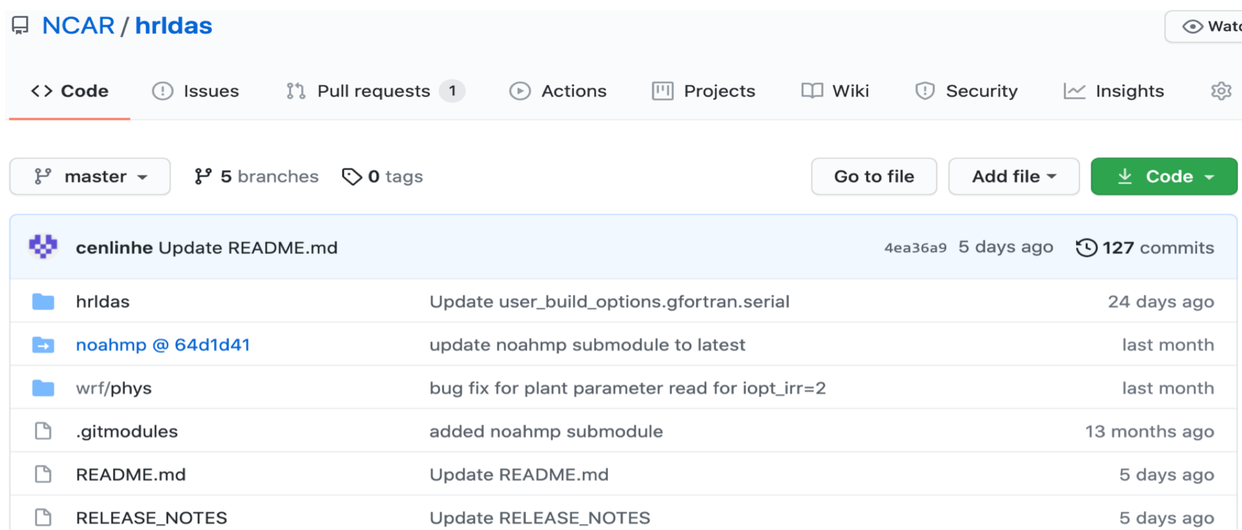


Figures from Fei Chen

New Unified Noah-MP & HRLDAS Repositories

- Noah-MP: https://github.com/NCAR/noahmp
- HRLDAS: https://github.com/NCAR/hrldas
- HRLDAS repo automatically linked to Noah-MP repo via git submodules





On-going Noah-MP model development efforts

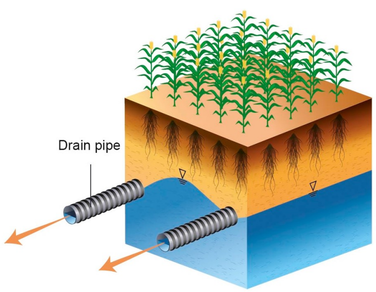
(expected to be released in WRF version 4.4)

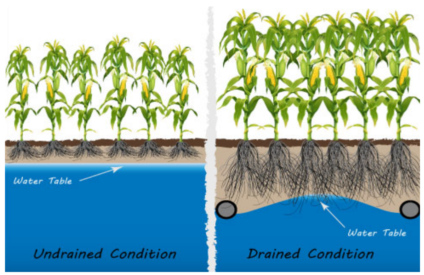
1. **Noah-MP code refactor** (modularization using modern code structures):

- Started & hope to complete within a year (NCAR team: Cenlin He, Prasanth Valayamkunnath, Fei Chen, David Gochis) with collaboration with Mike Barlage (now at NOAA/EMC)

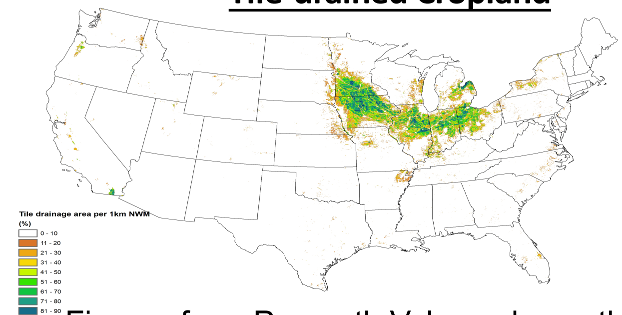
2. **Additional runoff options** (VIC, Xiananjiang, and dynamic VIC schemes)

3. **New tile drainage scheme**





Tile-drained Cropland



Figures from Prasanth Valayamkunnath

4. **New turbulence scheme by accounting for roughness sublayer**

5. **Plant hydraulics**

7. **Others**

8. **New updates will be synced via the unified Noah-MP & HRLDAS Github repositories.**

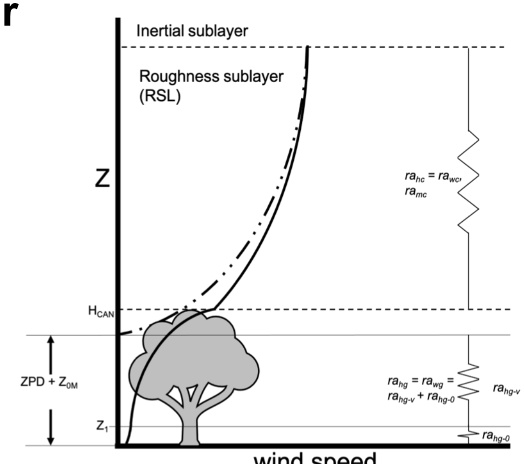


Figure from Ronnie Abolafia-Rosenzweig

Questions?

We thank all the code contributors to the WRF LSM updates!