Developing a new long-term and real-time land surface monitoring product

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Land surface monitoring is the key drought effort at NOAA CPC, which provides estimates of observed land surface states, consisting of soil moisture, runoff, evapotranspiration and snow conditions etc., providing process-based land state evolution for the drought development, persistence and relief. This paper summarizes CPC's recent progress on developing a new objective real-time and long-term land surface monitoring product for the U.S, by leveraging recent developments of observations and reanalysis at CPC and UFS land surface models at NOAA/NCEP EMC. The new land surface monitoring product is produced by driving EMC's newly released Noah-MP model (HR1 version) with CPC's newly developed hourly atmospheric forcings for the period 1950-present. The spatial resolution is designed to match the NLDAS ⅛ degree lon-lat grid, and the data history extends back to 1950. The hourly P and T2m forcings for 1950-present (with 1-day latency) are ingested from CPC's latest version of gauge-based observations, whereas the other five atmospheric forcings are obtained from the Conventional Observations Reanalysis (CORe). Since the gauge-based observations and CORe have 1-2 day latency at real-time, the forcings for the last 48 hours are produced by integrating available hourly observations and GFS forecasts for precipitation, and using GDAS for the other six atmospheric forcings. We found the new NoahMP land model considerably outperforms CPC leaky bucket model in the simulation of soil moisture. This effort represents an important step in advancing land surface monitoring and contributing to the development of an objective drought monitor at CPC.

Motivations

NLDAS2: Land Models

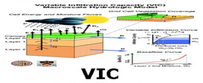
Atmospheric Community

Noah
NCEP operational land model

Mosaic
NASA GSFC

Hydrology Community

SAC
NWS operational hydrological model



VIC
Princeton & U. Washington

Current major issues

- Short retrospective analysis record for drought
  - Only 1979 to current
  - "empirical cumulative distribution function (ECDF)" (5-day centered window) to estimate D4 drought
- SAC and VIC have different layers configuration with Noah and Mosaic model
- 4.5 days latency in real-time (NLDAS v2.5 operational plan canceled)
- Old models (NLDAS v3 plan since 2017, recent survey at 2023Dec)
- Only CONUS, missing AK, HI, PR, VI

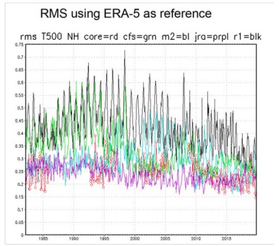
Target

- Develop a new **long-term** and **real-time** soil moisture analysis for drought monitor and prediction
  - More than 70 years historical records (1950-current)
  - Cover the severe droughts happened in 1950s (unfortunate, dust bowl in 1930s)
  - Minimum Real-time Latency
- Based on the recent NCEP/EMC **NoahMP land model** (P6->P8-> HR1 version)
- **Updated land model geographic information** (soil textile, vegetation types. Etc. from UFS 2022 later version)
- **New** CPC hourly P/T and atmospheric forcings (CORe reanalysis)
- match current operational NLDAS2 grid, **seamless** operational transition
- **Keystone** for the Objective drought monitor (blending/integration)

Methods and Data

- Atmospheric Forcing:
  - CPC **Conventional Observation Reanalysis (CORe)** (Ebisuzaki et al 2020)
    - The Newest NCEP reanalysis project, replacement for NCEP/NCAR reanalysis for climate monitoring
    - For data consistency, only use conventional observations, avoid the spurious jumps caused by satellite retrievals
    - Trades some spatial accuracy for better trends for climate monitoring
    - Based on the FV3-GFS with C128 grid, DA is ensemble Kalman filter with 80 ensemble members
    - 6-hr update from 1950-present with a 0.7 degree grid (512x256 Gaussian)

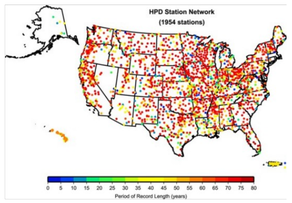
RMS using ERA-5 as reference



RMS of 500mb monthly mean TMP (30N-60N), CORe (red) is comparable toe JRA-55(purple), Merra2 (blue) and better than R1 (black) and CFSR (green), From Ebisuzaki et al 2020

Precipitation Forcing

- CPC unified P analysis (backbone)
  - Gauge (station report) based analysis
  - Long-term consistency (trends)
- Temporal disaggregation
  - **New CPC hourly P/T analysis** (Pingping Xie group, 1950-2014 based on the NCEI Hourly Precipitation Data (HPD) digital data set DSI-3240)
  - **Multi-Radar/Multi-Sensor (MRMS)** analysis (2015- current)
  - **CMORPH2** analysis (real-time gap)
  - **GFS PRCP 6hr forecast** (near real-time)



The location of each F&P station operating in 2019 and the period of record length (years) as indicated by the color. From Lawrimore et al 2020 JHM

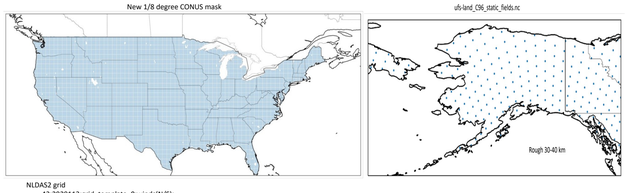
UFS Meteorological Forcing Engine (MFE)

- Based on the Python scientific computation ecosystem
  1. Data Ingestion (Pywgrib2_s for grib2 decoding)
  2. Conversion (RH->Q, ACPC-> Prate, U+V -> wind speed)
  3. Bias correction (optional for forecast)
  4. Formatting (Linux timestamp) and concatenate (xarray)
  5. Temporal disaggregation (daily– > hourly)
     - Reference rainfall data
     - Linear interpolation
     - Solar zenith angle (WRFhydro forcing Engine)

$$SWDOWN_{bias} = \left(c_1 + c_2 * \frac{fhr-1}{n\_fhr-1}\right) * \cos(\varphi_{solar}) * SWDOWN_{model}$$

From NWM forcing engine (https://github.com/NCAR/WrfHydroForcing)

  6. Downscaling/regrid to lon-lat or Cube-sphere grid (pyESMF library)
  7. Output to NetCDF (python NetCDF library)



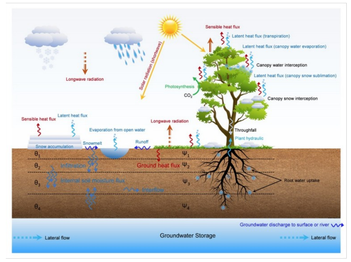
NLDAS2 grid
43:2929113:grid_template=0:winds(N/S):
lat-lon grid:(464 x 224) units 1e-06 input WE:SN output WE:SN res 48
lat 25.063000 to 52.938000 by 0.125000
lon 235.062000 to 292.937000 by 0.125000 #points=103936

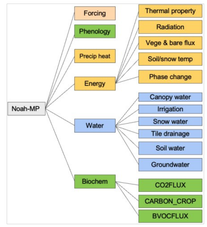
Model parameterization configurations

Noah-MP options	The option used in ULDAS
Dynamic vegetation	Dynamically off, use table LAI; use maximum vegetation fraction (GVF)
Canopy stomatal resistance	Ball-Berry
Water stress for stomatal conductance	Noah
Runoff and groundwater	TOPMODEL with groundwater
Surface layer exchange coefficient	Monin-Obukhov similarity theory
Supercooled liquid water	No iteration (niu and yang, 2006 jhm)
Frozen soil permeability	Linear effect, more permeable (niu and yang, 2006, jhm)
Radiation transfer	Modified two-stream
Ground snow surface albedo	CLASS
Snow-rain partitioning	Jordan91
Snow/soil temperature time scheme	Semi-implicit

LDAS System Design

Key physics in the UFS Noah-MP model (HRI version)

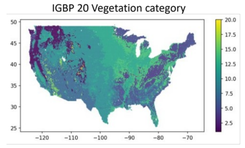




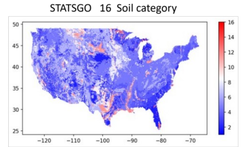
From https://github.com/NCAR/noahmp

CONUS 1/8 degree (12km) UFS geographic static fields
From UFS C768 grid (2022 later version)

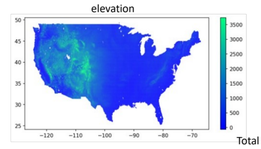
IGBP 20 Vegetation category



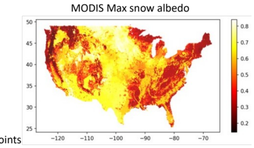
STATSGO 16 Soil category



elevation



MODIS Max snow albedo



Total 51458 points

1	Urban	7	Grassland	14	Evergreen Needleleaf	1	Sand	6	Loam	11	Silty Clay
2	Dryland Cropland	8	Shrubland	15	Mixed Forest	2	Loamy Sand	7	Sandy Clay Loam	12	Clay
3	Irrigated Cropland	9	Mixed Shrub/Grass	18	Wooded Wetland	3	Sandy Loam	8	Silty Clay Loam	13	Organic Soil
5	Cropland/Grassland	10	Savanna	19	Barren	4	Silt Loam	9	Clay Loam	14	Water
6	Cropland/Woodland	11	Deciduous Broadleaf	21	Wooded Tundra	5	Silt	10	Sandy Clay	15	Bedrock

Spatial Downscaling

- 2m temperature:
  - constant lapse rate 6.5k/km
  - dynamics lapse rate

$$T_{NLDAS} = T_{BDAS} + \gamma \Delta Z,$$

- 2m specific humidity: hold same relative humidity, adjusted by delta_T2m with Wexler's saturated water vapor pressure equation

$$q_{NLDAS} = \left(\frac{RH_{BDAS} * q_{sat_{NLDAS}}}{100}\right)$$

- Surface pressure: hydrostatic equation, similar NLDAS2 scheme (Cosgrove et al JGR 2003)

$$p_{NLDAS} = \frac{p_{BDAS}}{\exp\left(\frac{g\Delta Z}{RT_{mean}}\right)}.$$

- 10m wind speed: MicroMet high-res Terrestrial modeling (Listeon 2006 JHM): adjusted by topographic slope, azimuth and curvature

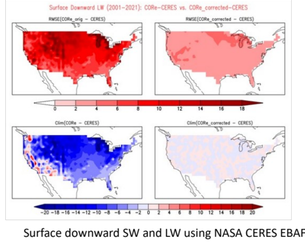
$$W_w = 1 + \gamma_s \Omega_s + \gamma_c \Omega_c,$$

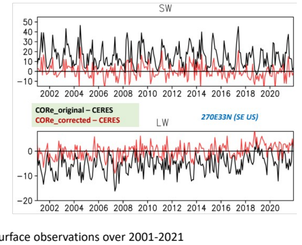
$$\xi = \frac{3\pi}{2} - \tan^{-1}\left(\frac{\partial z/\partial y}{\partial z/\partial x}\right), \qquad \beta = \tan^{-1}\left[\left(\frac{\partial z}{\partial x}\right)^2 + \left(\frac{\partial z}{\partial y}\right)^2\right]^{(1/2)},$$

$$\Omega_c = \frac{1}{4}\left[\frac{z - 1/2(z_{2\eta} + z_\xi)}{2\eta} + \frac{z - 1/2(z_\xi + z_\eta)}{2\eta} + \frac{z - 1/2(z_{2\eta} + z_{2\eta})}{2\sqrt{2}\eta} + \frac{z - 1/2(z_{2\eta} + z_{2\eta})}{2\sqrt{2}\eta}\right]$$

Surface Radiation (SW & LW) bias correction

CORe_corrected = CORe_monAnom*(CERES_monSTD/CORe_monSTD) + CERES_monClim

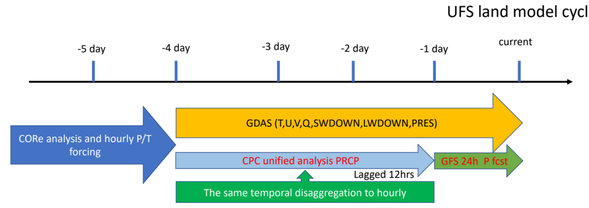




Surface downward SW and LW using NASA CERES EBAF-surface observations over 2001-2021

Realtime Scheme

Scheme for real-time meteorological forcing



Near real-time GDAS forcing will be overwritten by incoming CORe forcing with analysis cycle move forward

Results

UFS land Forcing streams

- Forcing-a:
  - Based on the CORe reanalysis
  - 1950-01-01-> 2023-12-31
  - Update when incoming CORe reanalysis available
  - Consistent in historical record to avoid any jump from data /system change
- Forcing-b:
  - Based on the real-time GFSv16 GDAS analysis
  - 2023-01-25-> current
  - Fill real-time gap , not guarantee consistent when GFS system update
- Forcing-c:
  - Merge forcing-a/b to near real-time
  - P/T from observation based analysis
  - Bias correction for SW/LW
    - CORe monthly surface downward SW and LW using NASA CERES EBAF-surface observations over 2001-2021

Planed hourly/daily output

vegetation_fraction	emissivity_total	albedo_total	snow_water_equiv
snow_depth	soil_moisture_vol	temperature_soil	soil_liquid_vol
canopy_water	transpiration_heat	snow_cover_fraction	ground_heat_total
runoff_baseflow	latent_heat_total	sensible_heat_total	evaporation_potential
runoff_surface	latent_heat_ground	latent_heat_canopy	snow_sublimation
soil_moisture_total	temperature_leaf	temperature_ground	canopy_ice
canopy_liquid	canopy_wet_fraction	snowfall	lake_water
depth_water_table	aquifer_water	saturated_water	leaf_area_index
stem_area_index	snow_age	soil_moisture_wtd	deep_recharge
recharge	temperature_2m	spec_humidity_2m	precipitation rate
eq_soil_water_vol	interface_depth	snow_level_ice	snow_level_liquid
evaporation_soil	evaporation_canopy		

Conclusions

- **Land soil moisture is the critical for the drought monitor and prediction**
- **Summarizes CPC's recent progress on developing a new objective real-time and long-term land surface monitoring product for the U.S.**
- **Produced by driving EMC's newly released Noah-MP model (HR1 version) with CPC's newly developed hourly atmospheric forcings for the period 1950-present**
- **Match the NLDAS ⅛ degree lon-lat grid, seamless transition in operation**
- **The hourly P and T2m forcings for 1950-present (with 1-day latency) are ingested from CPC's latest version of gauge-based observations, whereas the other five atmospheric forcings are obtained from the Conventional Observations Reanalysis (CORe)**
- **From prototype of testing experiment, new UFS land model considerably outperforms CPC leaky bucket model in the simulation of soil moisture**
- **Keystone to the development of an objective drought monitor (blending) at CPC**

Acknowledgement

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