Hydrologic Modeling
~ VIC Model

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Introduction

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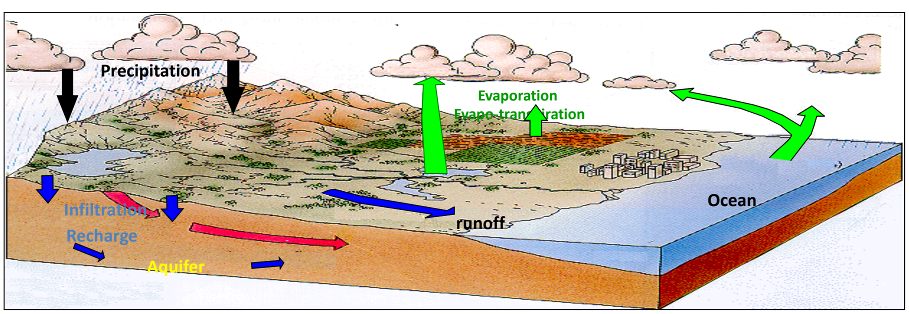
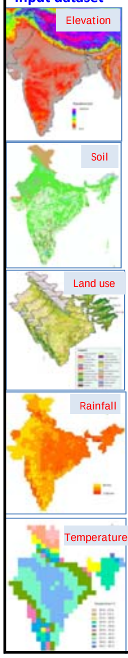
- Water resources availability and its controlling parameters are spatially distributed and show temporal change → which is a matter of concern.
- Quantification of hydrological components can be done in many ways, but Hydrological Modeling is one efficient way for consistent long term behavioral studies.
- Hydrological Models – AVSWAT, MIKE, VIC, HEC-HMS



Hydrological Modeling Framework

Input dataset

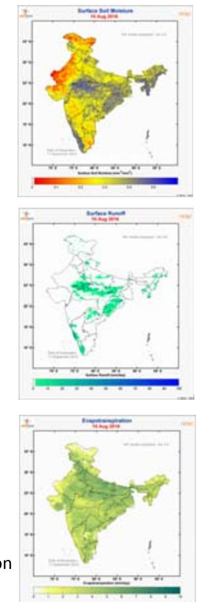


- **Variable Infiltration Capacity Hydrological Model**
  - *Open source; Grid-wise water and energy balance*
  - *Sub-grid heterogeneity of Land cover*
  - *Soil depth-wise hydrological response*
  - *Vegetation phenological changes*
  - *Daily / sub-daily time step*
- **9 min (~16.5km), 3 min (~ 5.5km) Grid-wise data base**
- **Geo-spatial data**
  - *Terrain - Topographic, Soil (NBSSLUP), LULC (NRC-250k), LAI, Albedo*
  - *Meteorological – Rainfall, Temperature, … (IMD & CPC)*
  - *Hydrological - River discharge, Reservoir Storage/Releases, GW levels, …*

Utility:

- ❑ Persistent Runoff Areas
- ❑ Forecasted Reservoir Inflow Estimation
- ❑ Hydrological Drought Assessment
- ❑ Irrigation Requirement Estimation

Output



Variable Infiltration Capacity (VIC) Model

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- Developed at University of Washington and Princeton University.
- Macro scale hydrological model.
- Spatial grid-wise water & energy balance modeling .
- Water & Energy balance computations carried out independently for each land cover
- Partitioning of Precipitation/Snowmelt and incoming Solar/long wave.
- Daily/Sub-daily time step.
- Sub-grid variations in land surface vegetation classes, soil moisture storage capacity.
- Multiple soil layers with variable infiltration.
- Each grid cell is modelled independently without horizontal water flow
- Version – 4.1 /4.2

VIC - Input Parameters

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- Soil parameters – No. of Layers, Layer depth, Texture, Porosity, Density, Hydraulic properties, Average elevation, Infiltration properties, …

- Vegetation parameters – No. of classes, Class fractional area, Monthly LAI, Albedo, Canopy resistance factors, root depths, root fractions, displacement length, …

- Meteorological Forcing parameters – Daily/Sub-daily, Maximum temperature, Minimum temperature, Rainfall, Wind speed, vapor pressure, incoming longwave and shortwave radiation, air pressure, …

- Lake parameters – Lake area, Minimum allowable lake depth, Outflow channel width, Initial lake depth, Maximum lake depth, …

VIC - Overview

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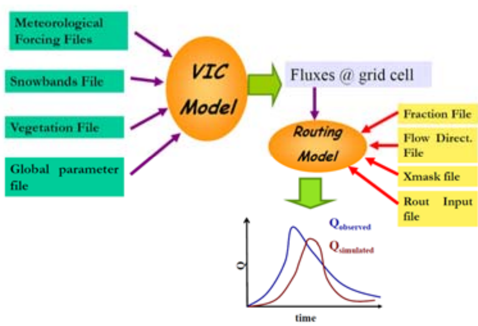
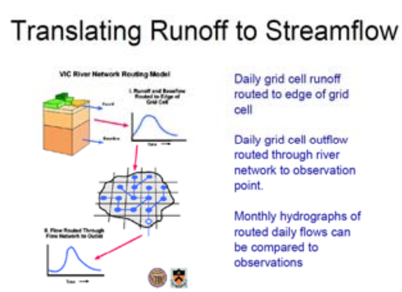
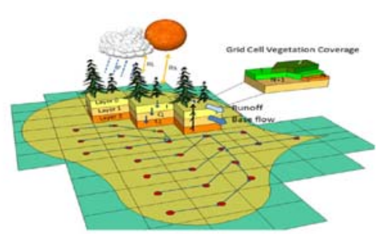






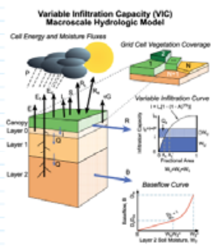
Source: Carrasco and Hamlet, Final Report for the Columbia Basin Climate Change Scenarios Project, Chapter 6, 2010.

Saksham's Notebook » Hydrological Modeling

VIC Model

Sunday, 29 November 2020 06:05

- Macroscale, Process based
- Semidistributed, Deterministic
- Hydrological model
- University of Washington & Princeton.
- large scale model
- Water balance computations.
- Energy balance computations.



→ Purpose → It was developed to simulate terrain processes and its integration with GCMs

Main features

1. Sub-grid heterogeneity (elevation, land cover)
2. Time-series meteorological data. (RF, Temp, Ws ---)
3. WB on EB computations
4. Water enters from atmosphere only.
5. No grid to grid interaction ⇒ { Surface & sub-surface RO that reaches the local channel network within the cell is assumed to be much larger than the water that crosses the grid cell boundaries into the neighbouring cell. }

land cover

1. m-number of land cover classes. (fraction)
2. geographic location is not considered.
3. 1 cell with 1 tile ⇒ lake/wetland
4. fluxes are averaged based on fractions

Soil

1. 3-Layer
2. Infiltration into top-layer (Infiltration curve)
3. layers with roots can lose moisture to ET.
4. Percolation → gravity driven (L1 to L2) – Brookes and Corey.
5. Baseflow (L3) → Arno model formulation.

Saksham's Notebook » Hydrological Modeling

Inputs

Soil parameter file

1. grid cell
2. lat/lon
3. b_{infilt}
4. D_s
5. D_{smax}
6. W_s
7. c
8. K_{sat}
9. Init_Moist
10. elevation
11. depth
12. d_p (soil thermal damping depth) 4m
13. BD
14. SD
15. FC
16. WP

vegetation library file

1. Architectural resistance (2 s/m)
2. stomatal resistance (100 s/m)
3. LAI
4. Albedo
5. roughness (0.123x H)
6. displacement (0.67x H)
7. Wind_h
8. RGL (– minimum incoming shortwave radiation)

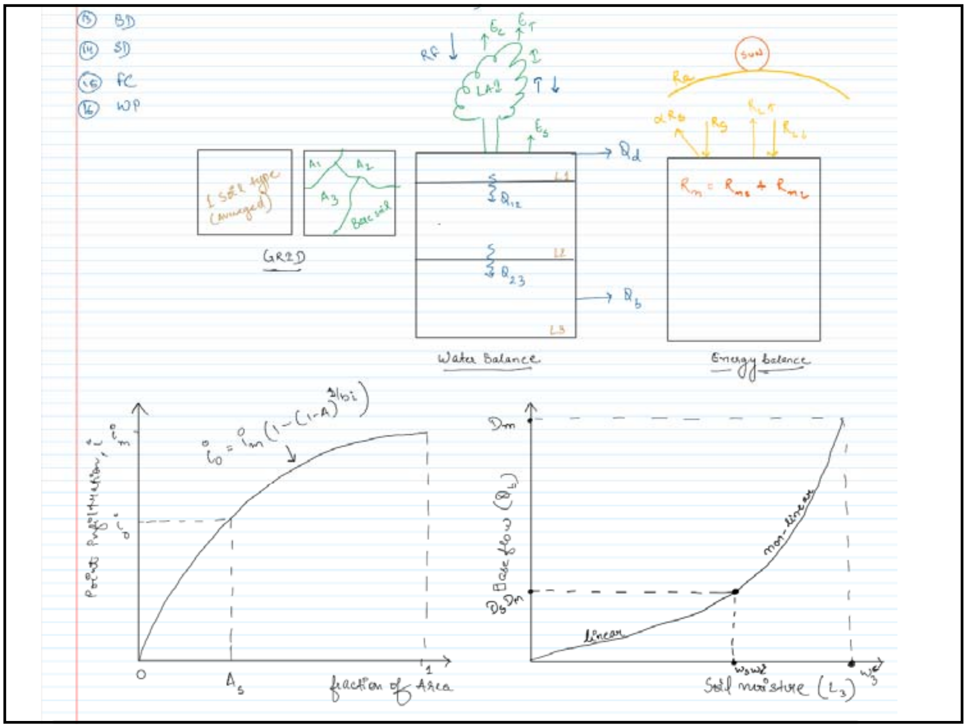
trees = 30 W/m²

crops = 100 W/m²

(at which transpiration occurs)

vegetation Parameter file.

1. veg class
2. Area fraction
3. root fraction (layer wise)



Saksham's Notebook » Hydrological Modeling

Steps

1. Porosity $(n) = 1 - \frac{BD}{SD}$
2. Saturation (w_1^c) (Max SM) $=$ Porosity $\times$ depth
3. $i_m = w_1^c \times (1 + b_i)$ max infiltration rate
4. Area under saturation $(A_s) = \frac{SM_{init}}{w_1^c}$
5. Point infiltration $(i_0) = i_m(1 - (1 - A_s))^{1/b_i}$

RD (direct + baseflow) and soil Moisture and Percolation

$$Q_d = P + w_1^- - w_1^c \; ; \; i_0 + P \geq i_m$$

$$Q_d = P + w_1^- - w_1^c + w_1^c\left[1 - \frac{i_0 + P}{i_m}\right]^{1+b_i} \; ; \; i_0 + P \leq i_m$$

$$w_1^+ = w_1^- + (P - Q_d - Q_{12} - E)$$

Q_{12} = percolat^n (brooks & corey) drainage under gravity.

$= f(K_s)$

$$Q_b = \frac{D_s D_m \times w_2^-}{W_s w_2^c} \quad \text{(Arno model)}$$

Evapotranspirat^n $= E_c + E_t + E_s$

1. PET $(E_p) = \frac{\Delta R_n + 6.43(1 + 0.54 U_2)\gamma(e_s - e_a)}{\lambda_v(\Delta + \gamma)}$

(Shuttleworth, 1993) modified PM eq^n (52)

*

$$E_c = \left(\frac{w_i(n)}{w_{im}}\right)^{2/3} E_p[n] \frac{r_w}{r_w + r_o}$$

r_o (architectural resistance) due to VPD

r_w (aerodynamic resistance) (due to transfer of vapor) $f(U_2)$

$$w_{im} = 0.2 \times LAI$$

$$r_w = \frac{1}{C_w \times U_n(z)} \; ; \; C_w = 1.3\, a^2 \times F_w$$

atmospheric stability (von karman co-eff) (Monin-Obukhov theory)

*

$$E_t = \left[1 - \left(\frac{w_i(n)}{w_{im}}\right)^{2/3}\right] \times E_p \times \frac{r_w}{r_w + r_o + r_c}$$

r_c → canopy resistance

$$r_c = \frac{r_{oc} \times g_{sm}}{LAI}$$ (g_{sm} → soil stress factor.)

*

$E_s = E_p[n+1]$ → for A_s

Area of Interest

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Present study made at 9min grid level

- To be extended to 3min grid level.
- Model setup prepared for Godavari, Mahanadi.

Column/Rows	9*9_Min_Grid
Grid Size (in Deg)	0.15°
Rows	197
Columns	203
Total Grids	13,709
Format	Shape File
Coordinate System	GCS
Datum	WGS_1984

Column/Rows	3*3_Min_Grid
Grid Size (in Deg)	0.05°
Rows	
Columns	
Total Grids	
Format	Shape File
Coordinate System	GCS
Datum	WGS_1984

Model Input Dataset Sources

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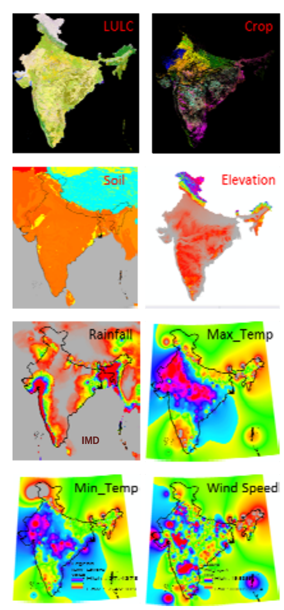
- Land use / land cover (NRC-250k)
- LAI, Albedo (MODIS)
- NBSS & LUP Soil Map of India (1:500,000 scale)
- Terrain (Carosat-1 DEM, Aster DEM, SRTM DEM, GTOPO)
- Meteorological Data sets(Rainfall, Temperature, Wind speed, Radiation,…)(IMD / ISRO AWS , Satellite meteorological products (TRMM, CPC, MOSDAC, Reanalysis Datasets)
- River discharge(CWC river discharge data)



VIC Parameters

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VIC Input Parameters

- Soil Parameter File
- Vegetation parameters
- Vegetation Library
- Meteorological Forcing parameters
- Lake parameters
- Elevation Band File

VIC output parameters

- Grid-wise water balance components (daily/sub-daily)
- Evapo-transpiration
- Runoff
- Base flow
- Soil Moisture Content (layer-wise)
- Evaporation
- Canopy Transpiration
- Energy fluxes

Meteorological Forcing Files

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Minimum forcing parameters

- Precipitation (PREC)
- Maximum Temperature (TMAX)
- Minimum Temperature (TMIN)

- Individual meteorological data file for each grid cell
- Obtained by:
  - Interpolating observed data onto VIC grid
  - Using existing gridded data sources
- CDAS – IMD Datasets
- CPC

Meteorological input is *flexible*

Variable Name	Definition	Default Units	ALMA units
AIR_TEMP	sub-daily air temperature	deg C	K
ALBEDO	surface albedo	fraction	fraction
CRAINF	convective rainfall	mm per step	mm/s == $kg/m^2/s$
CSNOWF	convective snowfall	mm per step	mm/s == $kg/m^2/s$
DENSITY	atmospheric density	kg/m^3	kg/m^2
LONGWAVE	incoming longwave (thermal infrared) radiation	W/m^2	W/m^2
LSRAINF	large-scale rainfall	mm per step	mm/s == $kg/m^2/s$
LSSNOWF	large-scale snowfall	mm per step	mm/s == $kg/m^2/s$
PREC	total precipitation	mm per step	mm/s == $kg/m^2/s$
PRESSURE	atmospheric pressure	kPa	Pa
QAIR	specific humidity	kg/kg	kg/kg
RAINF	total rainfall	mm per step	mm/s == $kg/m^2/s$
REL_HUMID	relative humidity	fraction	fraction
SHORTWAVE	incoming shortwave (solar) radiation	W/m^2	W/m^2
SNOWF	total snowfall	mm per step	mm/s == $kg/m^2/s$
TMAX	daily maximum temperature	deg C	K
TMIN	daily minimum temperature	deg C	K
TSKC	cloud cover	fraction	fraction
VP	atmospheric vapor pressure	kPa	Pa
WIND	wind speed	m/s	m/s
WIND_E	East component of wind speed	m/s	m/s
WIND_N	North component of wind speed	m/s	m/s
SKIP	indicates a data column which is ignored, e.g., year, month, and day columns if they are present		

- File name must be of format **<filename_prefix>_<lat>_<lon>**

data_7.025_93 - WordPad

```
24.90429   35.648033  0.978528   3.762715
24.618504  35.44883   20.903687  3.836245
24.773073  35.057144  3.6125793  3.8358796
24.019627  35.12825   41.20636   3.766975
24.987394  34.13047   24.423695  4.30013
24.799765  33.985302  14.10843   3.8986197
24.532738  34.30027   5.713522   3.6131568
25.07813   35.18372   3.9119248  3.8629284
25.088692  35.74071   1.4181559  3.7847397
25.450647  35.829826  15.189264  3.8377352
25.22545   35.35524   0.8099428  4.3482103
24.544003  34.093575  0.7171217  4.3915973
24.13607   33.88581   0.0   3.6833684
24.542202  34.42312   2.3788052  3.8243313
24.803791  34.172356  1.5492986  3.6026886
24.731653  34.57875   0.0   3.940285
24.830381  35.48356   0.0   3.7076983
24.950747  35.658062  0.81234    5.1178013
25.288774  35.522964  0.0   5.173404
25.360361  35.517376  0.0   4.3950267
25.585037  35.94408   0.227208   4.4504232
```

Soil Parameter File

Main purpose :-

- Defines cell ID no of each grid cell.
- Define grid cell soil parameters.
- Define Initial soil moisture conditions.

- *Main* Input File
- No of columns depends upon no of soil layers.

Column	Variable Name	Units	Number of Values	Description
1	run_cell	N/A	1	1 = Run Grid Cell, 0 = Do Not Run
2	gridcel	N/A	1	Grid cell number
3	lat	degrees	1	Latitude of grid cell
4	lon	degrees	1	Longitude of grid cell
5	infilt	N/A	1	Variable infiltration curve parameter (b_{infilt})
6	Ds	fraction	1	Fraction of Dsmax where non-linear baseflow begins
7	Dsmax	mm/day	1	Maximum velocity of baseflow
8	Ws	fraction	1	Fraction of maximum soil moisture where non-linear baseflow occurs
9	c	N/A	1	Exponent used in baseflow curve, normally set to 2
10 : (Nlayer+9)	expt	N/A	Nlayer	Values should be > 3.0.
(Nlayer+10) :(2*Nlayer+9)	Ksat	mm/day	Nlayer	Saturated hydrologic conductivity
(2*Nlayer+10):(3*Nlayer+9)	phi_s	mm/mm	Nlayer	Soil moisture diffusion parameter
(3*Nlayer+10):(4*Nlayer+9)	init_moist	mm	Nlayer	Initial layer moisture content
(4*Nlayer+10)	elev	m	1	Average elevation of grid cell
(4*Nlayer+11):(5*Nlayer+10)	depth	m	Nlayer	Thickness of each soil moisture layer
(5*Nlayer+11)	avg_T	C	1	Average soil temperature, used as the bottom boundary for soil heat flux solutions

Sample Soil Parameter file

- 1 column per parameter, 1 row per grid cell

Run Cell	Grid_No	LAT	LONG	infilt	Ds	Dsmax	Ws	c	expt-Layer1	expt-Layer2	expt-Layer3	Ksat-Layer1	Ksat-Layer2	Ksat-Layer3	phi_s	phi_s	phi_s	init_moist	init_moist	init_moist	Elevation	depth	depth	depth	avg_T	dp
1	1	73.6	37	0.4	0.04	0	0.6	2	0	0	0	0	0	0	-999	-999	-999	0	0	0	4680	0.15	0.35	1	25.33	4
1	2	73.9	37	0.4	0.04	0	0.6	2	0	0	0	0	0	0	-999	-999	-999	0	0	0	4515	0.15	0.35	1	25.33	4
1	3	74.2	37	0.25	0.02	867.789	0.8	2	11.2	13.6	13.6	9218	472.8	472.8	-999	-999	-999	0	0	0	4532	0.15	0.35	1	25.33	4
1	4	74.5	37	0.25	0.02	937.348	0.8	2	11.2	13.6	13.6	9218	472.8	472.8	-999	-999	-999	0	0	0	4602	0.15	0.35	1	25.33	4
1	5	74.8	37	0.25	0.02	1021.07	0.8	2	11.2	13.6	13.6	9218	472.8	472.8	-999	-999	-999	0	0	0	4674	0.15	0.35	1	25.33	4
1	6	75.1	37	0.25	0.02	989.333	0.8	2	11.2	13.6	13.6	9218	472.8	472.8	-999	-999	-999	0	0	0	4548	0.15	0.35	1	25.33	4
1	7	75.4	37	0.25	0.02	843.544	0.8	2	11.2	13.6	13.6	9218	472.8	472.8	-999	-999	-999	0	0	0	4974	0.15	0.35	1	25.33	4
1	8	73	36.7	0.4	0.04	0	0.6	2	0	0	0	0	0	0	-999	-999	-999	0	0	0	4637	0.15	0.35	1	25.33	4
1	9	73.3	36.7	0.25	0.02	1071.86	0.8	2	11.2	13.6	13.6	9218	472.8	472.8	-999	-999	-999	0	0	0	4318	0.15	0.35	1	25.33	4
1	10	73.6	36.7	0.25	0.02	969.148	0.8	2	11.2	13.6	13.6	9218	472.8	472.8	-999	-999	-999	0	0	0	4200	0.15	0.35	1	25.33	4
1	11	73.9	36.7	0.25	0.02	1009.57	0.8	2	11.2	13.6	13.6	9218	472.8	472.8	-999	-999	-999	0	0	0	4166	0.15	0.35	1	25.33	4
1	12	74.2	36.7	0.25	0.02	1083.1	0.8	2	11.2	13.6	13.6	9218	472.8	472.8	-999	-999	-999	0	0	0	4511	0.15	0.35	1	25.33	4
1	13	74.5	36.7	0.25	0.02	1074.34	0.8	2	11.2	13.6	13.6	9218	472.8	472.8	-999	-999	-999	0	0	0	4957	0.15	0.35	1	25.33	4
1	14	74.8	36.7	0.25	0.02	1103.36	0.8	2	11.2	13.6	13.6	9218	472.8	472.8	-999	-999	-999	0	0	0	3957	0.15	0.35	1	25.33	4
1	15	75.1	36.7	0.25	0.02	1176.14	0.8	2	11.2	13.6	13.6	9218	472.8	472.8	-999	-999	-999	0	0	0	4578	0.15	0.35	1	25.33	4
1	16	75.4	36.7	0.25	0.02	1028.8	0.8	2	11.2	13.6	13.6	9218	472.8	472.8	-999	-999	-999	0	0	0	5029	0.15	0.35	1	25.33	4
1	17	75.7	36.7	0.4	0.04	0	0.6	2	0	0	0	0	0	0	-999	-999	-999	0	0	0	5321	0.15	0.35	1	25.33	4
0	18	76	36.7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

bubble	bubble	bubble	quartz	quartz	quartz	bulk_density (kg/m3)	bulk_density (kg/m3)	bulk_density (kg/m3)	soil_density	soil_density	soil_density	off_gmt	Wcr_FRACT	Wcr_FRACT	Wcr_FRACT	Wpwp_FRACT	Wpwp_FRACT	Wpwp_FRACT	rough	snow_rough	annual_prec	resid_moist	resid_moist	resid_moist	fs_active	depth_full_snow_cover
0	0	0	0	0	0	0	0	0	2685	2685	2685	+5.5	0	0	0	0	0	0	0.001	0.0005	1500	0	0	0	1	1.5
0	0	0	0	0	0	0	0	0	2685	2685	2685	+5.5	0	0	0	0	0	0	0.001	0.0005	1500	0	0	0	1	1.5
7.26	11.15	11.2	0.95	0.41	0.41	1490	1490	1490	2685	2685	2685	+5.5	0.056	0.203	0.203	0.03	0.14	0.14	0.001	0.0005	1500	0	0	0	1	1.5
7.26	11.15	11.2	0.95	0.41	0.41	1490	1490	1490	2685	2685	2685	+5.5	0.056	0.203	0.203	0.03	0.14	0.14	0.001	0.0005	1500	0	0	0	1	1.5
7.26	11.15	11.2	0.95	0.41	0.41	1490	1490	1490	2685	2685	2685	+5.5	0.056	0.203	0.203	0.03	0.14	0.14	0.001	0.0005	1500	0	0	0	1	1.5
7.26	11.15	11.2	0.95	0.41	0.41	1490	1490	1490	2685	2685	2685	+5.5	0.056	0.203	0.203	0.03	0.14	0.14	0.001	0.0005	1500	0	0	0	1	1.5
7.26	11.15	11.2	0.95	0.41	0.41	1490	1490	1490	2685	2685	2685	+5.5	0.056	0.203	0.203	0.03	0.14	0.14	0.001	0.0005	1500	0	0	0	1	1.5
0	0	0	0	0	0	0	0	0	2685	2685	2685	+5.5	0	0	0	0	0	0	0.001	0.0005	1500	0	0	0	1	1.5
7.26	11.15	11.2	0.95	0.41	0.41	1490	1490	1490	2685	2685	2685	+5.5	0.056	0.203	0.203	0.03	0.14	0.14	0.001	0.0005	1500	0	0	0	1	1.5
7.26	11.15	11.2	0.95	0.41	0.41	1490	1490	1490	2685	2685	2685	+5.5	0.056	0.203	0.203	0.03	0.14	0.14	0.001	0.0005	1500	0	0	0	1	1.5
7.26	11.15	11.2	0.95	0.41	0.41	1490	1490	1490	2685	2685	2685	+5.5	0.056	0.203	0.203	0.03	0.14	0.14	0.001	0.0005	1500	0	0	0	1	1.5
7.26	11.15	11.2	0.95	0.41	0.41	1490	1490	1490	2685	2685	2685	+5.5	0.056	0.203	0.203	0.03	0.14	0.14	0.001	0.0005	1500	0	0	0	1	1.5
7.26	11.15	11.2	0.95	0.41	0.41	1490	1490	1490	2685	2685	2685	+5.5	0.056	0.203	0.203	0.03	0.14	0.14	0.001	0.0005	1500	0	0	0	1	1.5
7.26	11.15	11.2	0.95	0.41	0.41	1490	1490	1490	2685	2685	2685	+5.5	0.056	0.203	0.203	0.03	0.14	0.14	0.001	0.0005	1500	0	0	0	1	1.5
7.26	11.15	11.2	0.95	0.41	0.41	1490	1490	1490	2685	2685	2685	+5.5	0.056	0.203	0.203	0.03	0.14	0.14	0.001	0.0005	1500	0	0	0	1	1.5
7.26	11.15	11.2	0.95	0.41	0.41	1490	1490	1490	2685	2685	2685	+5.5	0.056	0.203	0.203	0.03	0.14	0.14	0.001	0.0005	1500	0	0	0	1	1.5
0	0	0	0	0	0	0	0	0	2685	2685	2685	+5.5	0	0	0	0	0	0	0.001	0.0005	1500	0	0	0	1	1.5
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Land Cover Classification

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Legend

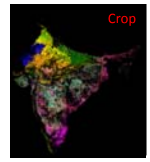
- (black)
- Build up
- Kharif only
- Rabi only
- Zaid only
- Double / tripple
- Current fallow
- Plantation/orchard
- Evergreen forest
- Deciduous forest
- Scrub/Deg. forest
- Littoral swamp
- Grassland
- Other wasteland
- Gullied
- Scrubland
- Water bodies
- Snow covered
- Shifting Cultivation
- Rann

Build up
Kharif only
Rabi only
Zaid only
Double / triple
Current fallow
Plantation/orchard
Evergreen forest
Deciduous forest
Scrub/Deg. forest
Littoral swamp
Grassland
Other wasteland
Gullied
Scrubland
Water bodies
Snow covered
Shifting Cultivation
Rann

13 Agriculture Classes

26 Vegetation Classes

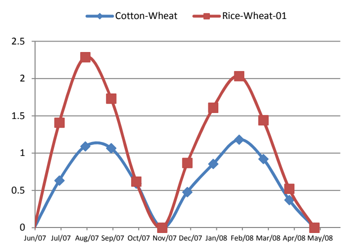
Cotton-Wheat
Rice-Wheat-01
Rice-Wheat-02
Rice-Rice
Rice-01
Maize-Bajra
Soybean
Rice-02
Bajra
Jowar
Coconut
Rice-03
Ragi
Plantation/Orchard
EG Forest
Deciduous Forest
Scrub/Deg. forest
Grassland
Scrubland
Gullied
Other Wasteland
Littoral Swamp
Build Up
Water Bodies
Snow covered
Rann



Legend

- Unclassified
- Cotton-Wheat
- Rice-Wheat(pnb)
- Rice-Wheat(UP)
- Rice-Rice
- Rice
- Maize/Bajra
- Soybean
- Sugarcane-Wheat
- Rice Aman Paddy
- Bajra
- Jowar
- Coconut
- Rice(TN)
- Ragi

LAI Profile



Vegetation Library File

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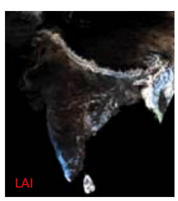
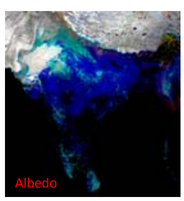
- One 58-column file used for all VIC model grid cells





- Modis Combined Aqua-Terra LAI & Albedo 8day product
- Monthly values of LAI, Albedo, Roughness, Displacement.

Relates land cover class to vegetation characteristics

Sample vegetation library file

```
#Class  OvrStry Rarc    Rmin    JUN-LAI JUL-LAI AUG-LAI SEP-LAI OCT-LAI NOV-LAI DEC-LAI JAN-LAI FEB-LAI MAR-LAI APR-LAI MAY-LAI JUN-ALB JUL-ALB AUG-ALB
SEP-ALB OCT-ALB NOV-ALB DEC-ALB JAN-ALB FEB_ALB MAR-ALB APR-ALB MAY-ALB JUN-ROU JUL-ROU AUG-ROU SEP-ROU OCT-ROU NOV-ROU DEC-ROU JAN-ROU FEB-ROU MAR-ROU
APR-ROU MAY-ROU JUN-DIS JUL-DIS AUG-DIS SEP-DIS OCT-DIS NOV-DIS DEC-DIS JAN-DIS FEB-DIS MAR-DIS APR-DIS MAY-DIS WIND_H  RGL     rad_atten       wind_atten
truck_ratio     COMMENT
1       0       25      80      0.37    1.80    2.45    2.90    1.70    0.60    0.20    1.20    2.50    3.20    2.40    0.40    0.135   0.125   0.120   0.120
0.120   0.140   0.135   0.130   0.125   0.120   0.125   0.135   0.022   0.036   0.107   0.172   0.172   0.101   0.000   0.037   0.092   0.135   0.123   0.000
0.120   0.194   0.582   0.938   0.938   0.550   0.000   0.201   0.503   0.737   0.670   0.000   3.25    100     0.5     0.5     0.2     Cotton-Wheat
2       0       25      80      0.61    1.50    3.50    3.10    1.40    0.40    0.75    1.20    2.50    3.20    2.40    0.40    0.130   0.105   0.100   0.100
```

Column	Variable Name	Units	Number of Values	Description
1	veg_class	N/A	1	Vegetation class identification number (reference index for library table)
2	overstory	N/A	1	Flag to indicate whether or not the current vegetation type has an overstory (TRUE for overstory present [e.g.trees], FALSE for overstory not present [e.g. grass])
3	rarc	s/m	1	Architectural resistance of vegetation type (~2 s/m)
4	rmin	s/m	1	Minimum stomatal resistance of vegetation type (~100 s/m)
5:16	LAI		12	Leaf-area index of vegetation type
17:28	albedo	fraction	12	Shortwave albedo for vegetation type
29:40:00	rough	m	12	Vegetation roughness length (typically 0.123 * vegetation height)
41:52:00	displacement	m	12	Vegetation displacement height (typically 0.67 * vegetation height)
53	wind_h	m	1	Height at which wind speed is measured. If using snow interception routines please read the information page
54	RGL	W/m^2	1	Minimum incoming shortwave radiation at which there will be transpiration. For trees this is about 30 W/m^2, for crops about 100 W/m^2.
55	rad_atten	fract	1	Radiation attenuation factor. Normally set to 0.5, though may need to be adjusted for high latitudes.
56	wind_atten	fract	1	Wind speed attenuation through the overstory. The default value has been 0.5.
57	trunk_ratio	fract	1	Ratio of total tree height that is trunk (no branches). The default value has been 0.2.
58	comment	N/A	1	Comment block for vegetation type. Model skips end of line so spaces are valid entrys.

Vegetation Parameter File

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- One large file describing land cover contents of each grid cell
- Can include "LAI" information, describing monthly LAI for each vegetation type at each grid cell.

Variable Name	Units	Description
gridcel	N/A	Grid cell number
Nveg	N/A	Number of vegetation tiles in the grid cell
veg_class	N/A	Vegetation class identification number
Cv	fraction	Fraction of grid cell covered by vegetation tile
For each vegetation tile, repeats for each defined root zone:		
root_depth	m	Root zone thickness (sum of depths is total depth of root penetration)
root_fract	fraction	Fraction of root in the current root zone.
LAI	N/A	Leaf Area Index, one per month

Sample vegetation Parameter file

Grid No → No of Land cover Class → Land cover class no's → Cv → Root Depth → Root Fraction

```
1  2
21  0.5065 0.150 0.400 0.350 0.600 1.000 0.000
25  0.4935 0.150 0.000 0.350 0.000 1.000 0.000
2  2
21  0.8451 0.150 0.400 0.350 0.600 1.000 0.000
25  0.1549 0.150 0.000 0.350 0.000 1.000 0.000
3  3
18  0.1270 0.150 0.300 0.350 0.600 1.000 0.100
21  0.7163 0.150 0.400 0.350 0.600 1.000 0.000
25  0.1567 0.150 0.000 0.350 0.000 1.000 0.000
4  3
18  0.1917 0.150 0.300 0.350 0.600 1.000 0.100
21  0.6105 0.150 0.400 0.350 0.600 1.000 0.000
25  0.1977 0.150 0.000 0.350 0.000 1.000 0.000
5  3
18  0.1924 0.150 0.300 0.350 0.600 1.000 0.100
21  0.7130 0.150 0.400 0.350 0.600 1.000 0.000
25  0.0946 0.150 0.000 0.350 0.000 1.000 0.000
6  3
18  0.4586 0.150 0.300 0.350 0.600 1.000 0.100
21  0.3928 0.150 0.400 0.350 0.600 1.000 0.000
25  0.1486 0.150 0.000 0.350 0.000 1.000 0.000
7  2
21  0.1235 0.150 0.400 0.350 0.600 1.000 0.000
25  0.8765 0.150 0.000 0.350 0.000 1.000 0.000
8  2
21  0.2532 0.150 0.400 0.350 0.600 1.000 0.000
25  0.7468 0.150 0.000 0.350 0.000 1.000 0.000
9  2
21  0.8182 0.150 0.400 0.350 0.600 1.000 0.000
25  0.1818 0.150 0.000 0.350 0.000 1.000 0.000
10  2
21  0.7681 0.150 0.400 0.350 0.600 1.000 0.000
25  0.2319 0.150 0.000 0.350 0.000 1.000 0.000
11  3
18  0.0743 0.150 0.300 0.350 0.600 1.000 0.100
21  0.6095 0.150 0.400 0.350 0.600 1.000 0.000
25  0.3162 0.150 0.000 0.350 0.000 1.000 0.000
12  3
18  0.0656 0.150 0.300 0.350 0.600 1.000 0.100
21  0.6543 0.150 0.400 0.350 0.600 1.000 0.000
25  0.2800 0.150 0.000 0.350 0.000 1.000 0.000
```

Flow Routing

nrsc

Routing Input Files:-

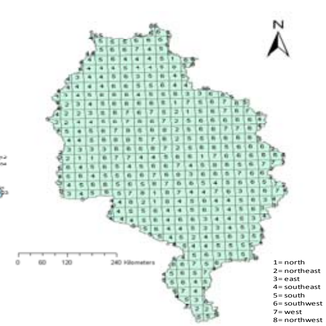
- Flow Direction File.
- Flow Fraction File.
- Station Location File.
- Unit Hydrograph File.
- Rout File.

↓

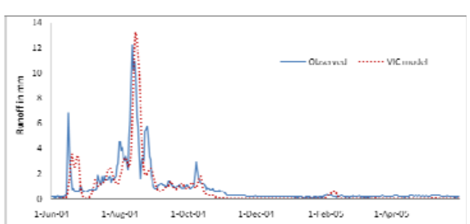
Routing Module

Fraction file

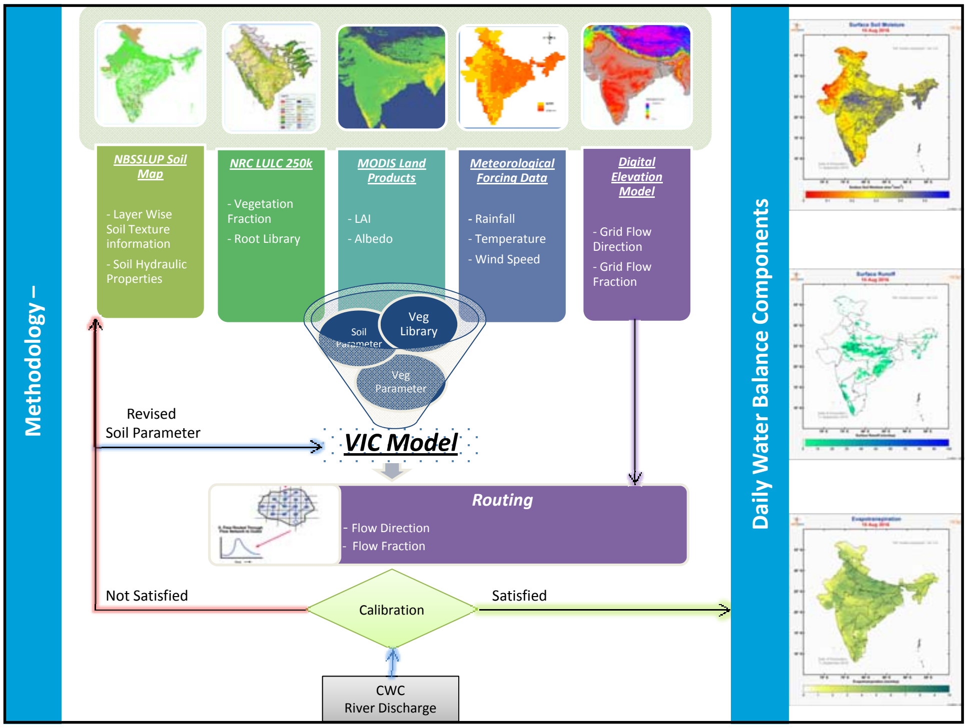
Flow direction



Bamnidhi sub basin



Model Runoff Calibration at Tikarapara.

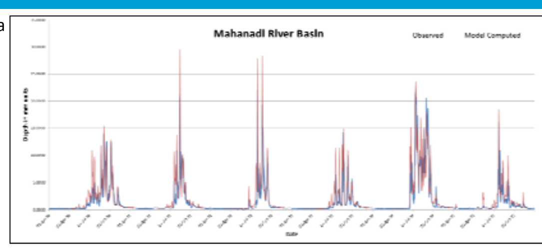


Model Calibration and Validation

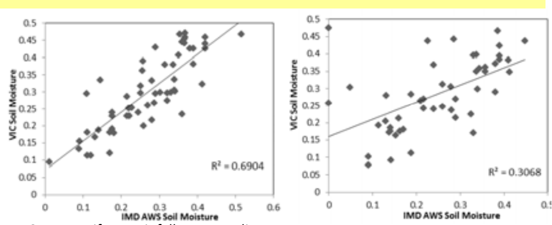
- Model is calibrated using CWC river discharge data at river basin scale for the period 1972-2006.
- Average Nash Sutcliff coefficient (NSE) of 0.71 is observed.

Fig. Mahanadi Basin

Mahanadi	NSE
1990	0.82
1991	0.85
1992	0.85
1993	0.62
1994	0.83
1995	0.54



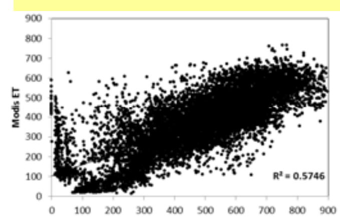
Soil Moisture Validation



Case1: Uniform rainfall across India
Case2: Region specific rainfall

- **Observed Data:** IMD Soil Moisture Data, 2013
- Pearson Correlation Coefficient (**R^2**) ~ 0.3 - 0.7
- **Number of Observation Stations:** 130

ET Validation



- **Observed Data:** MODIS 1km 8day Product, 2013
- Comparison of **VIC ET** Vs **MODIS ET** estimates
- Pearson Correlation Coefficient (**R^2**) ~ 0.5 - 0.6

Daily Operational Time Line, Processing Chain, Data Sources

Climate data Met Data Processing (Quality check and screening) (IMD, CPC, GEFS)	VIC Developed Specified Input Preparation	VIC Model Run In HPC environment	Output generation and conversion to Geo-Spatial format Using MATLAB	Product web - publishing
04:00	05:00	06:00	07:30	08:00

Data Sources and related info.

Meteorological Data Source	Parameter	Resolution	Latency
IMD Gridded data	Rainfall, Min, Max Temperature	0.5 degree	1 day
IMD AWS data	Rainfall, Min, Max Temperature	Point data (interpolated to 9min/3min)	1 day
IMD high density data (Godavari & Mahanadi)	Rainfall	Point data (interpolated to 3min)	1 day
CPC	Rainfall	0.1 degree	2 days
GEFS	Rainfall, Min, Max Temperature	0.5 degree (interpolated to 9min/3min)	Daily forecast data
APSDPS AWS data	Rainfall, Min, Max Temperature	Point data (interpolated to 3min)	1 day

Web Published VIC Model Derived Products

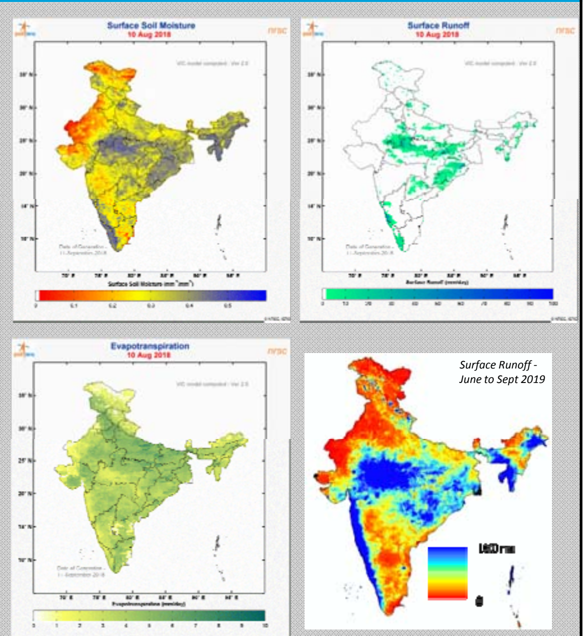
Product	Resolution	Frequency
Water Balance Components for entire India	3min (~5.5km), 9min (~16.5km)	Daily
Forecast Surface Runoff (d*+3)	9min (~16.5km)	Daily
Accumulated Surface Runoff	9min (~16.5km)	Daily
Climate Indices – SPI , SRI (1, 3, 6, 12 Months)	9min (~16.5km)	Daily
River Basin Wise Statistics	-	Weekly
WBC's for Godavari, Mahanadi River	3min (~5.5km)	Daily

VIC Model Derived Products

Product	Frequency
Water Balance Components for entire India (RO, SM, ET)	Daily
Forecast Surface Runoff (d*+3)	Daily
Accumulated Surface Runoff	Daily
Climate Indices – SPI , SRI, SMAI (1, 3, 6, 12 Months)	Daily
River Basin Wise Statistics	Weekly

Grid Details and Features

- 9min (~16.5km), 3min (~5.5km) grid level modelling frame work
- This product is downloadable at daily time step in NetCDF format.
- Utility: This product provides spatial representation of water balance components over entire India on a particular day.



Seasonal Water Balance Components Estimation
Jun-Oct, 2016

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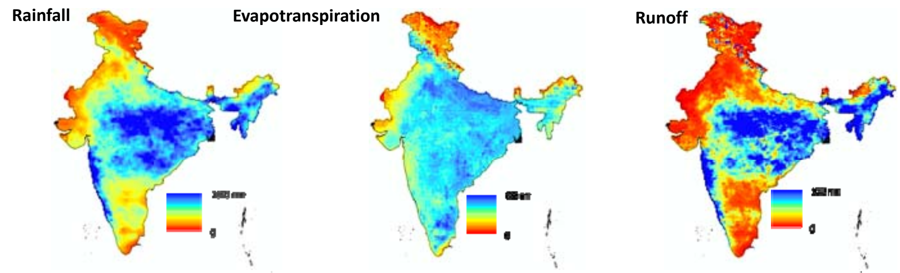
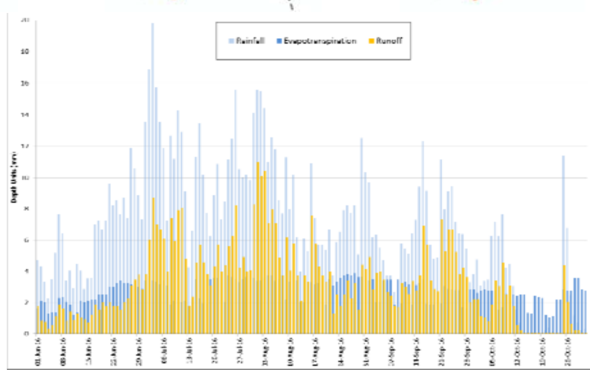


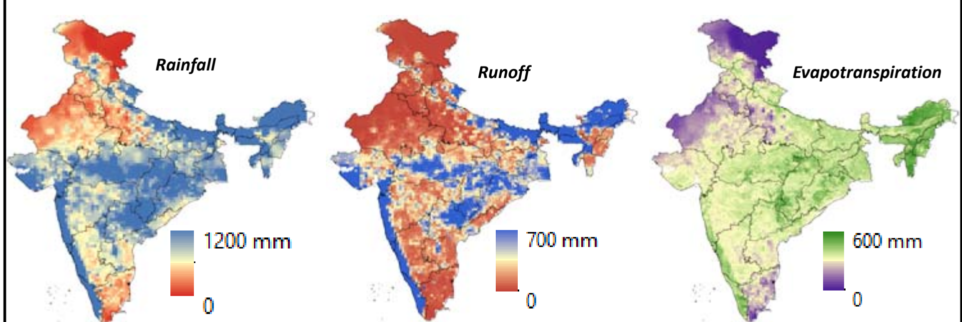
Daily Mean (India) Water Balance Components



Seasonal Water Balance Components Estimation
Jun-Sept, 2020

nrsc

Seasonal Water Balance Components (June to Sept) - 2020



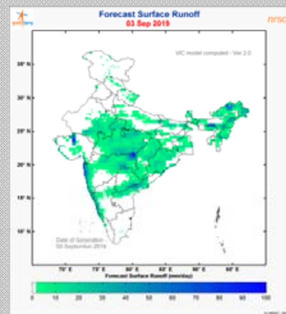
VIC Model Derived Products

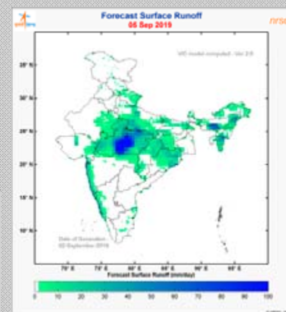
Product	Frequency
Water Balance Components for entire India (RO, SM, ET)	Daily
Forecast Surface Runoff (d*+3)	Daily
Accumulated Surface Runoff	Daily
Climate Indices – SPI , SRI, SMAI (1, 3, 6, 12 Months)	Daily
River Basin Wise Statistics	Weekly

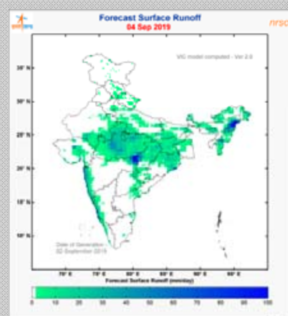
Details and Features

- Surface runoff forecast is presented for three successive days (d+1, d+2, d+3, where d = Current date) using weather forecast data (Rainfall and Temperature) from the Global Ensemble Forecast System
- Forecasted Surface Runoff products depict the likely runoff depth at each grid level in mm depth units.
- Utility: Forecasted Surface Runoff and its spatial distribution for 3 days lead time is useful for disaster management operations.

Forecasted as on 03rd Sept 2019





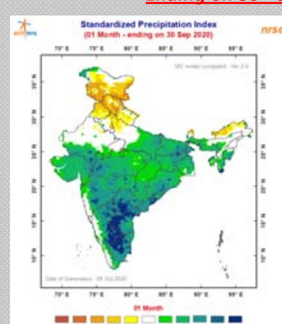


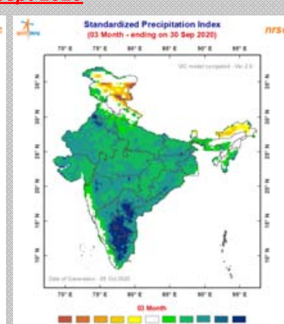
VIC Model Derived Products

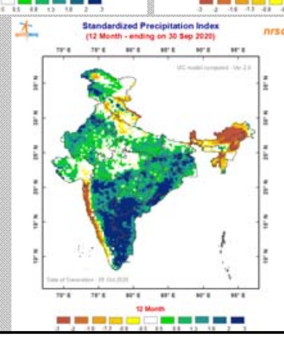
Product	Frequency
Water Balance Components for entire India (RO, SM, ET)	Daily
Forecast Surface Runoff (d*+3)	Daily
Accumulated Surface Runoff	Daily
Climate Indices – SPI , SRI, SMAI (1, 3, 6, 12 Months)	Daily
River Basin Wise Statistics	Weekly

Utility: SPI represents abnormal wetness and dryness, as it is probability based and takes into account the importance of timescales in the analysis of availability and managing water resources. The standardized index is derived for different time scales of 1, 3, 6 and 12 months.

Ending on 30th Sept 2020





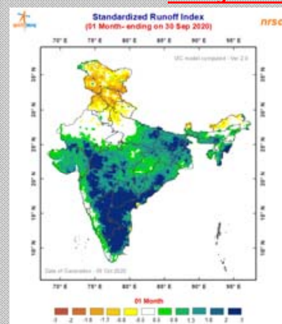


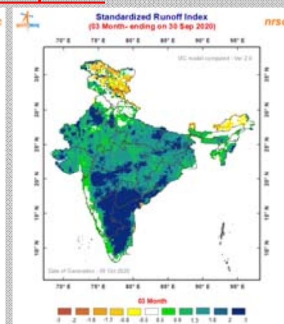
VIC Model Derived Products

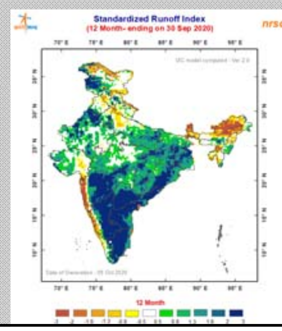
Product	Frequency
Water Balance Components for entire India (RO, SM, ET)	Daily
Forecast Surface Runoff (d*+3)	Daily
Accumulated Surface Runoff	Daily
Climate Indices – SPI , SRI, SMAI (1, 3, 6, 12 Months)	Daily
River Basin Wise Statistics	Weekly

Utility: SRI represents abnormal wetness and dryness, as it is probability based and takes into account the importance of timescales in the analysis of availability and managing water resources. The standardized index is derived for different time scales of 1, 3, 6 and 12 months.

Ending on 30th Sept 2020







Hydrological Science
Near Real Time Hydrological Modelling - Products & Services

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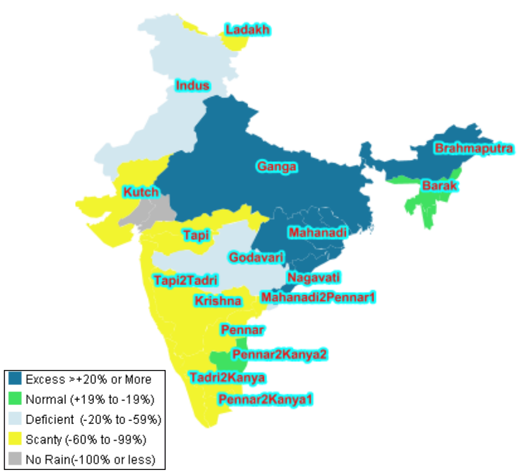
Basin Wise Statistics (week-37, September 10-16, 2016)



Rainfall

basin	Brahmaputra
Long Term Mean	86.1
2016	33.1

Runoff

basin	Brahmaputra
Long Term Mean	50.6
2016	21.4

Evapotranspiration

basin	Brahmaputra
Long Term Mean	26.0
2016	15.4

Soil Moisture

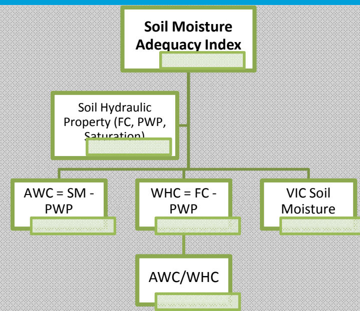
basin	Brahmaputra
Long Term Mean	2.5
2016	2.7

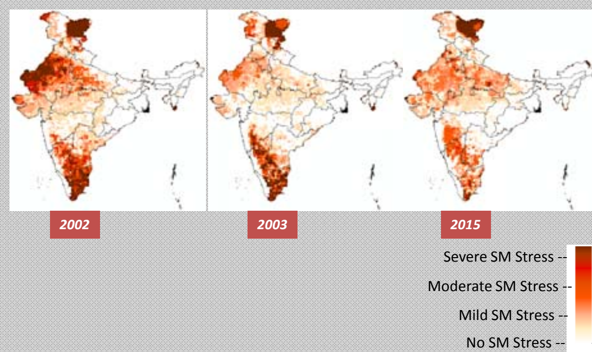
Details and Features

- Weekly (IMD standard weeks) departure maps of rainfall, runoff, evapotranspiration and soil moisture at basin scale
- A click on any basin will display current week Vs. Long term Mean.

VIC Model Derived Products

Product	Frequency
Water Balance Components for entire India (RO, SM, ET)	Daily
Forecast Surface Runoff (d*+3)	Daily
Accumulated Surface Runoff	Daily
Climate Indices – SPI , SRI, SMAI (1, 3, 6, 12 Months)	Daily
River Basin Wise Statistics	Weekly



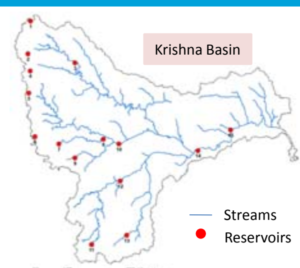


- *Higher the per cent fraction more is the available water*
- *Very relevant for agricultural impacts*
- *Soil Moisture is highly dynamics in space and time*

FC: Field Capacity
PWP: Permanent Wilting Point
AWC: Available Water Content
WHC: Water Holding Capacity

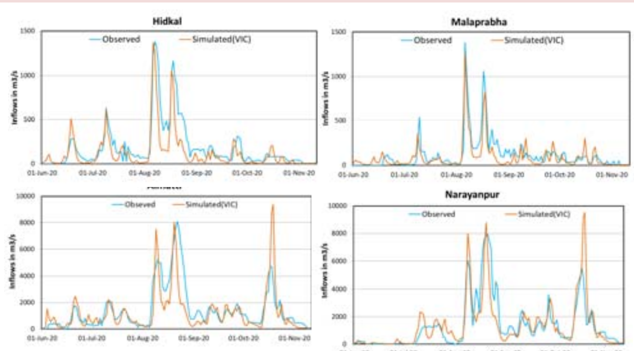
Inflow into Major Reservoirs of India

Basin Name	No. of Reservoir
Indus	3
Barak and Others	1
Ganga	14
WFR Kutch & Saurashtra	3
Sabarmati	1
Mahi	4
Narmada	6
WFR- Tapi & Tadri	4
Tapi	3
Bhramani & Baitrani	2
Mahanadi	3
Godavari	14
Krishna	15
Pennar	1
Cauvery	6
WFR Tadri & Kanyakumari	11
EFR Pennar & Kanyakumari	1
Total	91

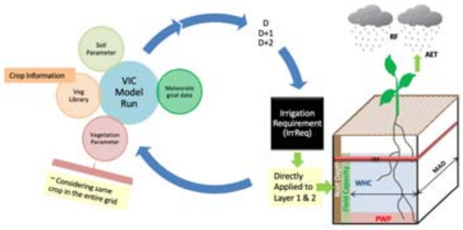


Res ID	NAME
1	MANIKDOH
2	KHADAKWASALA
3	UJJANI
4	DHOM
5	KOYNA
6	DUDHGANGA
7	HIDKAL
8	ALMATTI
9	MALAPRABHA
10	NARAYANPUR
11	BHADRA
12	TUNGABHADRA
13	VANIVILASA
14	SRISAILAM
15	NAGARJUNA SAGAR

Inflow into Reservoirs (01st June – 21st Nov 2020)



Irrigation Demand Estimation Module

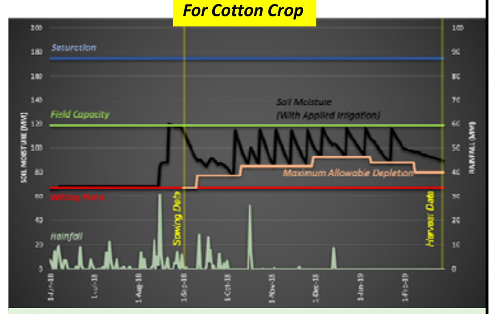


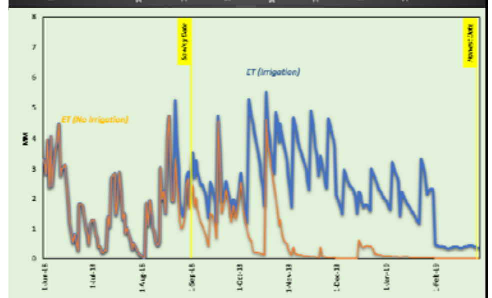
Dates	Irr Req (mm)
(Base Irrigation) 22-Aug	51.02
(Sowing Date) 1-Sep	0.00
7-Oct	54.8
24-Oct	44.3
4-Nov	48.03
15-Nov	48.15
26-Nov	46.42
6-Dec	37.28
23-Dec	36.75
5-Jan	37.09
23-Jan	44.34
(Harvest Date)28-Feb	0.00
Total Irrigation Estimated	448.18

Irrigation points

Crop Stages (Cotton Crop)	Est Irr Req (mm)
Base Irrigation	51.02
Germination	0
Vegetative Phase	54.8
Flower Bud	186.9
Flowering	111.1
Ball Development	44.3
Harvesting	0
Total	448.18

For Cotton Crop





Calibration and Validation of the satellite derived AET

Existing flux towers in country

Proposed sites for establishing flux network in the country in phase 1

Flux Tower

Ground based instrumentation will be established for calibration and validation of satellite derived AET product

4 Numbers of flux towers will be installed in phase 1 from proposed installation sites based on agro ecological region , climate zones , soil types and type of cropping system

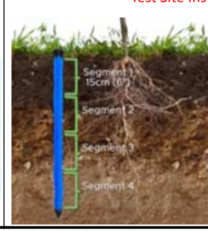
Scintillometer

Validation of Model Derived Soil Moisture Product

- Ground based instrumentation will be established for validation of hydrological model derived soil moisture
- Comprehensive soil moisture instrumentation is planned to establish across India over varying climatological and geographical conditions (Land Cover and Soil Type …)
- Network of Time Domain Reflectometer (TDR) and COSMIC ray probes will be installed

Permanent probes will measure soil moisture at 6 different depth along the soil column (1 m) at 10, 30, 50, 60, 80, 100 cm depths

Test Site Installed at NRSC, Hyderabad

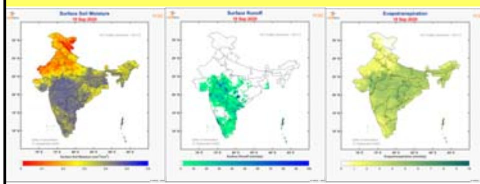


Information on description of instrument site conditions will be collected i.e.

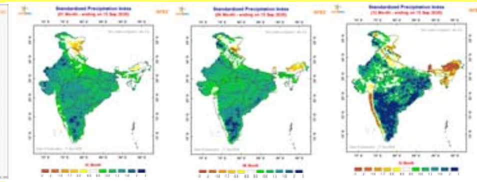
- land use/land cover,
- crop type,
- date of sowing,
- date of harvest,
- major growing stages of the crop,
- irrigation depths applied, etc.

Operational Web-based National Hydrological Modeling System

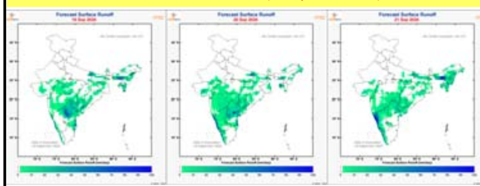
Daily Water Balance Components (19th Sept 2020)



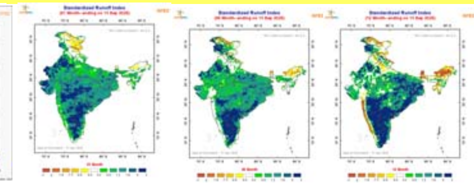
Climate Indices – SPI (19th Sept 2020)



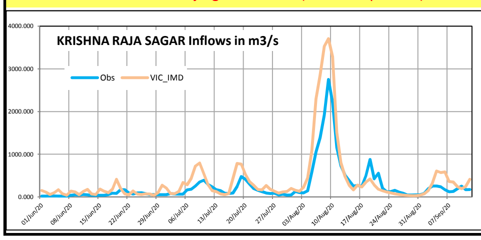
Forecast Surface Runoff (3 Day Lead Time)



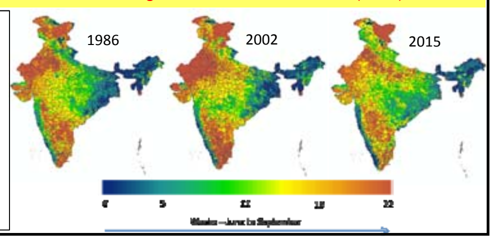
Climate Indices – SRI (19th Sept 2020)



Inflow into Krishnarajsagar Reservoir (till 19th Sept 2020)



Percentage Available Soil Moisture Index (PASM)



Thank You !!..