A multi-model hydrologic ensemble for seasonal streamflow forecasting in the western U.S.

*Ted Bohn, **Andy Wood**, Ali Akanda*
and Dennis P. Lettenmaier

Department of Civil and Environmental Engineering

UNIVERSITY OF WASHINGTON

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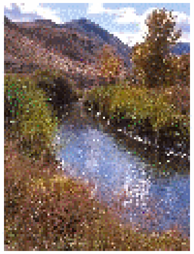
OUTLINE

- experimental western U.S. forecasting system
- expansion to multiple hydrologic model framework
- research issues

Experimental W. US Hydrologic Forecast System

http://www.hydro.washington.edu/Lettenmaier/Projects/fcst/



HOME
RESEARCH
PEOPLE
DISCLAIMER
LINKS

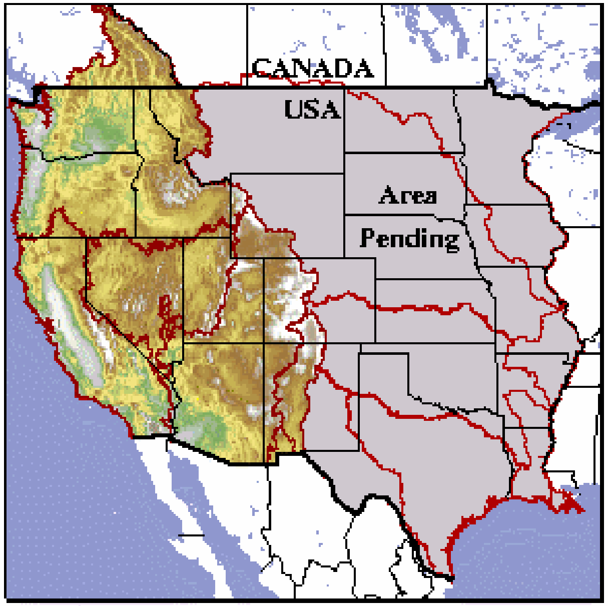
WEST-WIDE SEASONAL STREAMFLOW FORECASTING PROJECT

FORECASTS 12/25/03: Choose a basin . . .

Current Forecast Status:
- Initial conditions (SWE/SM) done
- ESP runs done
- GSM/NSIPP-1 runs done

FCST SUMMARY

Western US Forecasting Domain



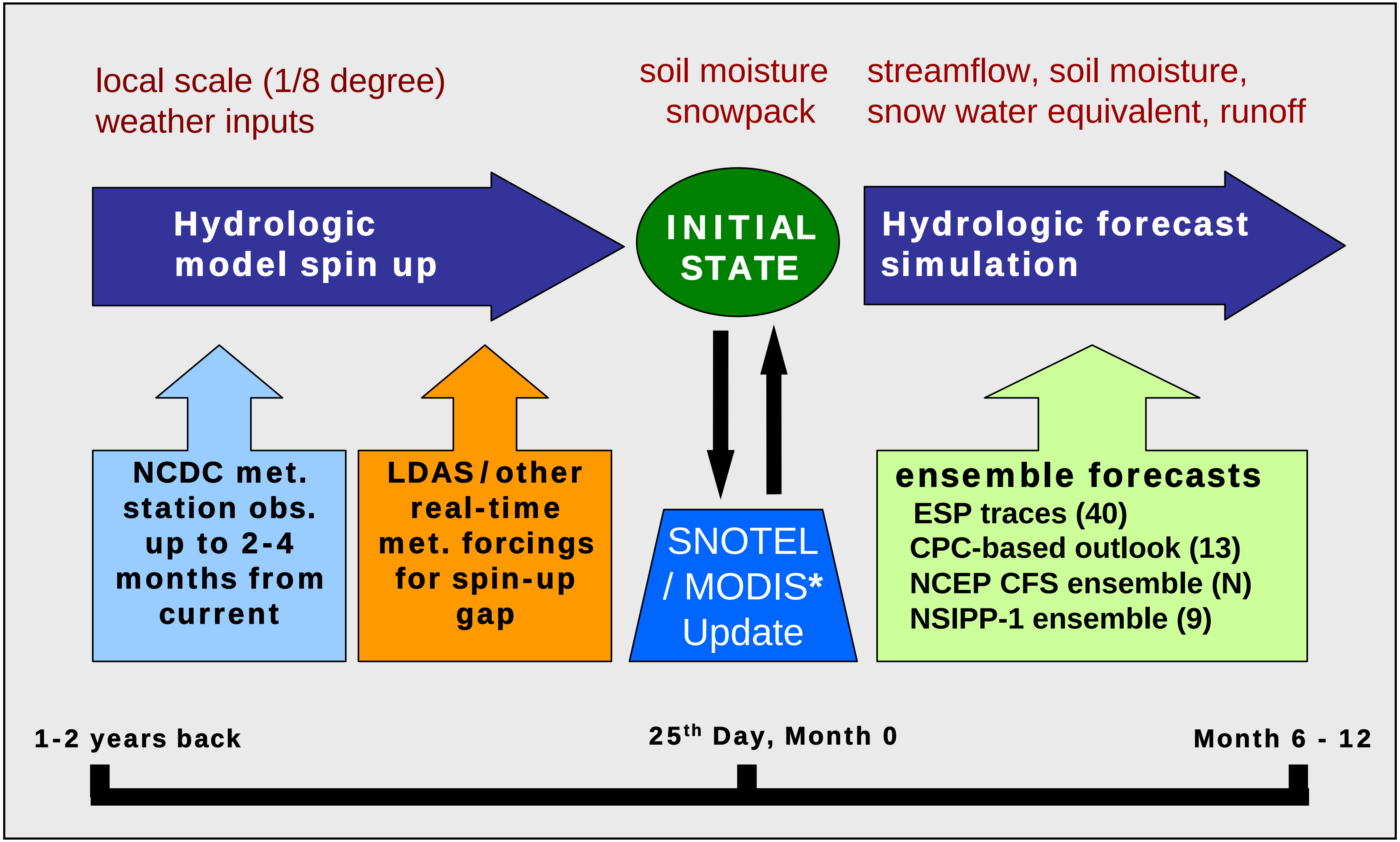
This website presents current monthly-to-seasonal hydrologic, streamflow and reservoir system forecasts for the western U.S. The experimental effort is funded by primarily by NOAA/OGP, the IRI/ARCS Regional Applications Project, and the NASA Seasonal-to-Interannual Prediction Project (NSIPP).

Currently, two forecast approaches are used, both centering on the use of macroscale hydrologic simulation with the VIC model:

- the Ensemble Streamflow Prediction (ESP, formerly Extended Streamflow Prediction) method; and the ESP method conditioned on ENSO and PDO states
- ensemble forecasts downscaled from several climate models (NCEP GSM and NASA NSIPP-1)

Forecast outputs include monthly streamflow ensembles, spatial distributions of snow water equivalent (SWE), soil moisture and runoff, and (*not yet active*) reservoir system storage and flow forecasts. In addition, the analyses of the initial hydrologic state at the forecast date constitute a nowcast of SWE and soil moisture conditions throughout the domain, based on observed meteorology.

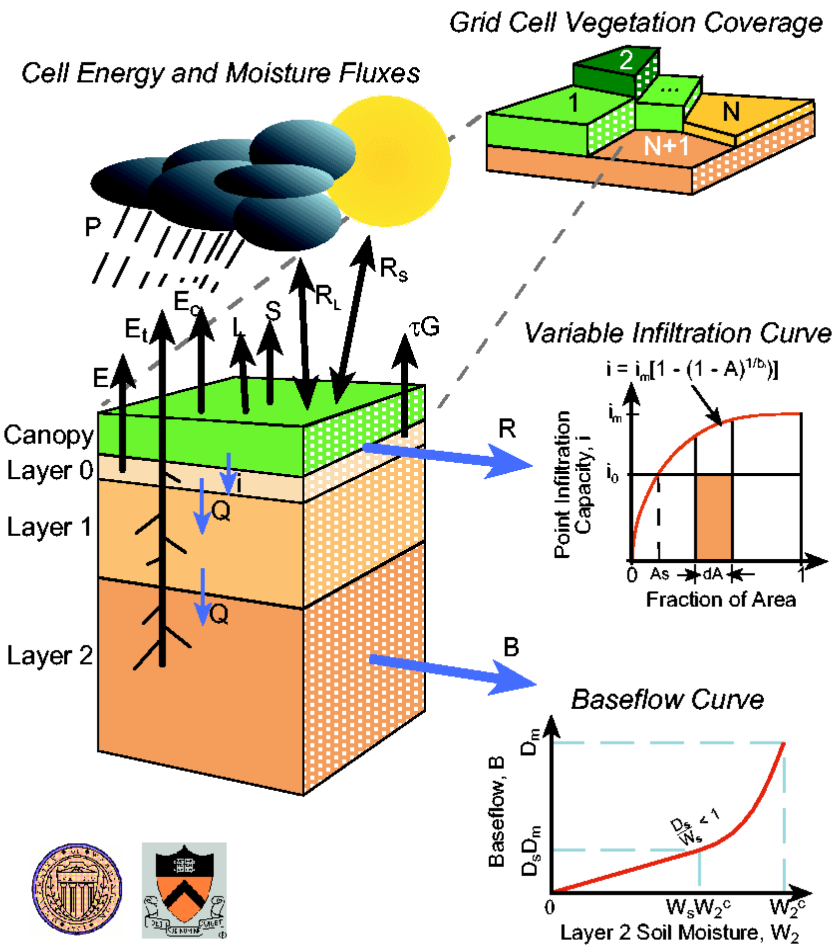
Experimental W. US Hydrologic Forecast System

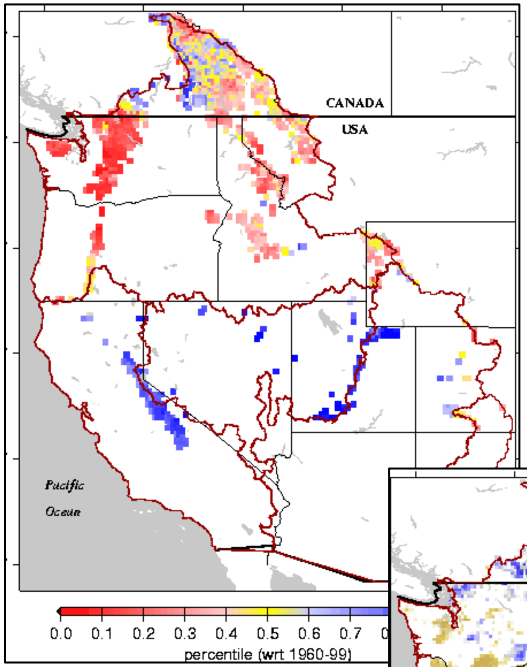


* experimental, not yet in real-time product

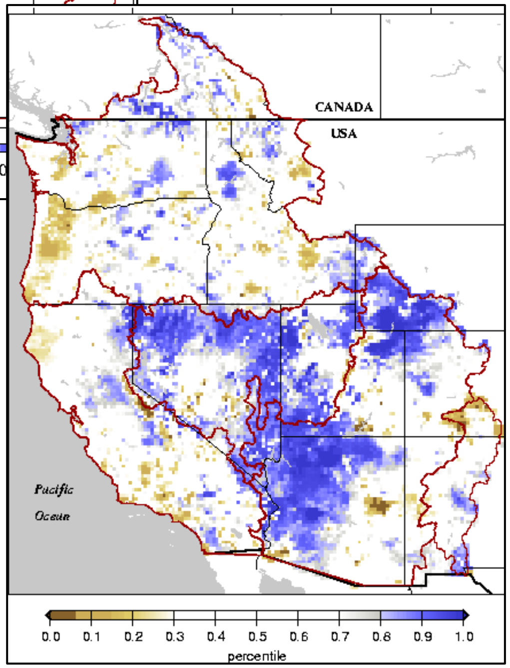
Experimental W. US Hydrologic Forecast System

Variable Infiltration Capacity (VIC) Macroscale Hydrologic Model

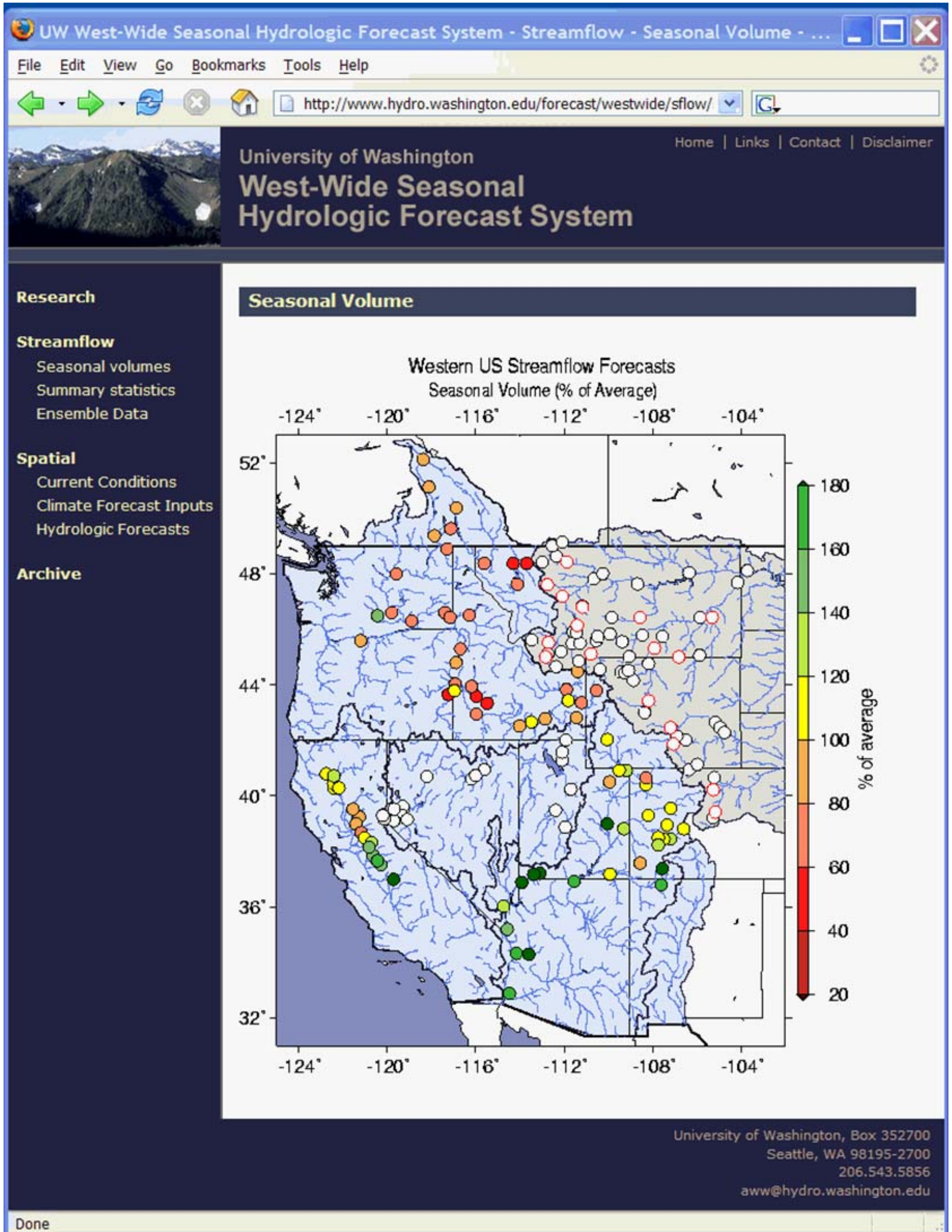




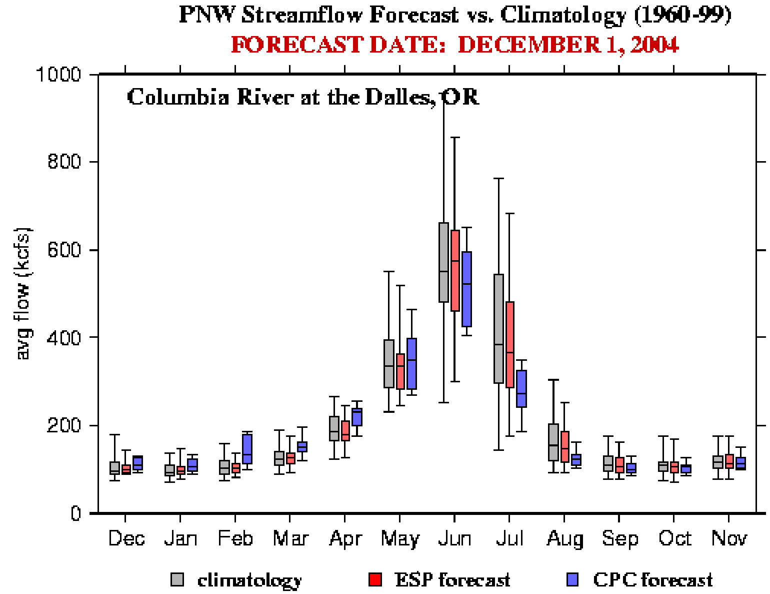
***Snowpack* Initial Condition**



***Soil Moisture* Initial Condition**



monthly hydrographs



targeted statistics

e.g., runoff volumes

```
Forecast flow percent of average for 2004
   at low, median and high percentiles

                    ----- unconditional -----
 #  NAME            0.1         0.5         0.9
------------------------------------------------
 1 MICAA            73          85          97
 2 REVEL            73          85          98
 3 ARROW            72          83          97
```

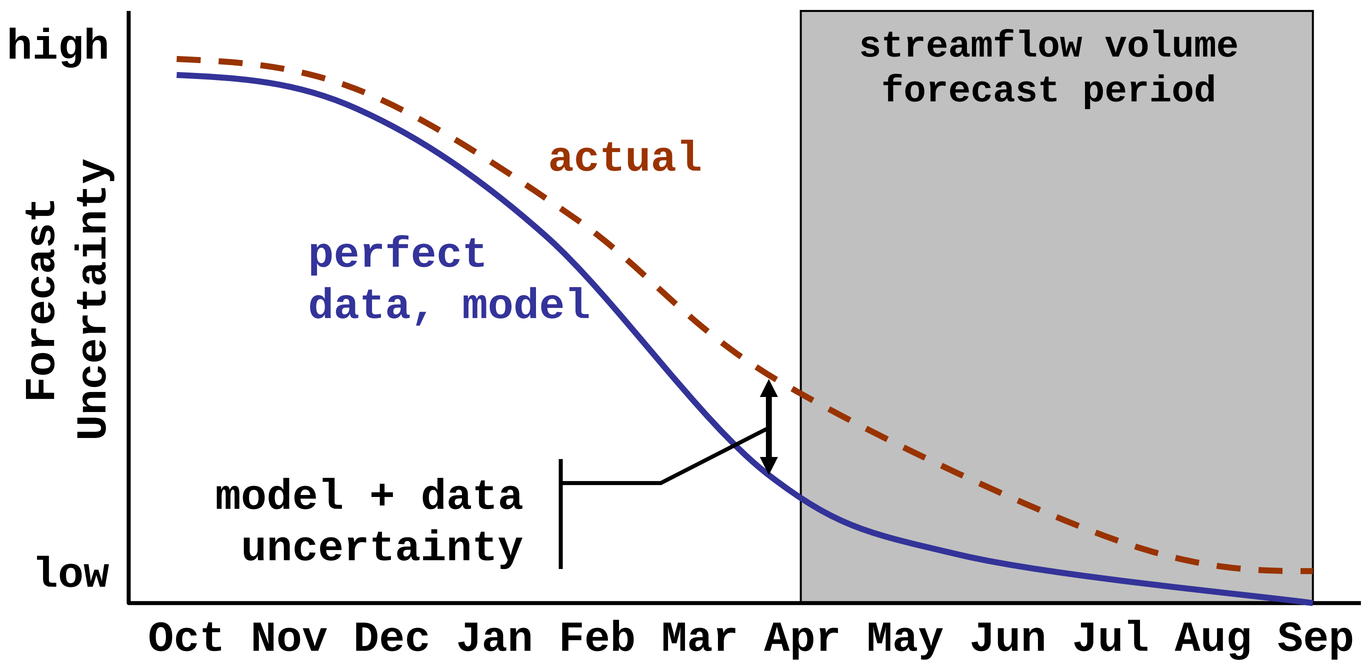
spatial forecast maps

Seasonal Hydrologic Forecast Uncertainty in Western US

Importance of uncertainty in ICs vs. climate vary with lead time …

IC error low
climate fcst error high

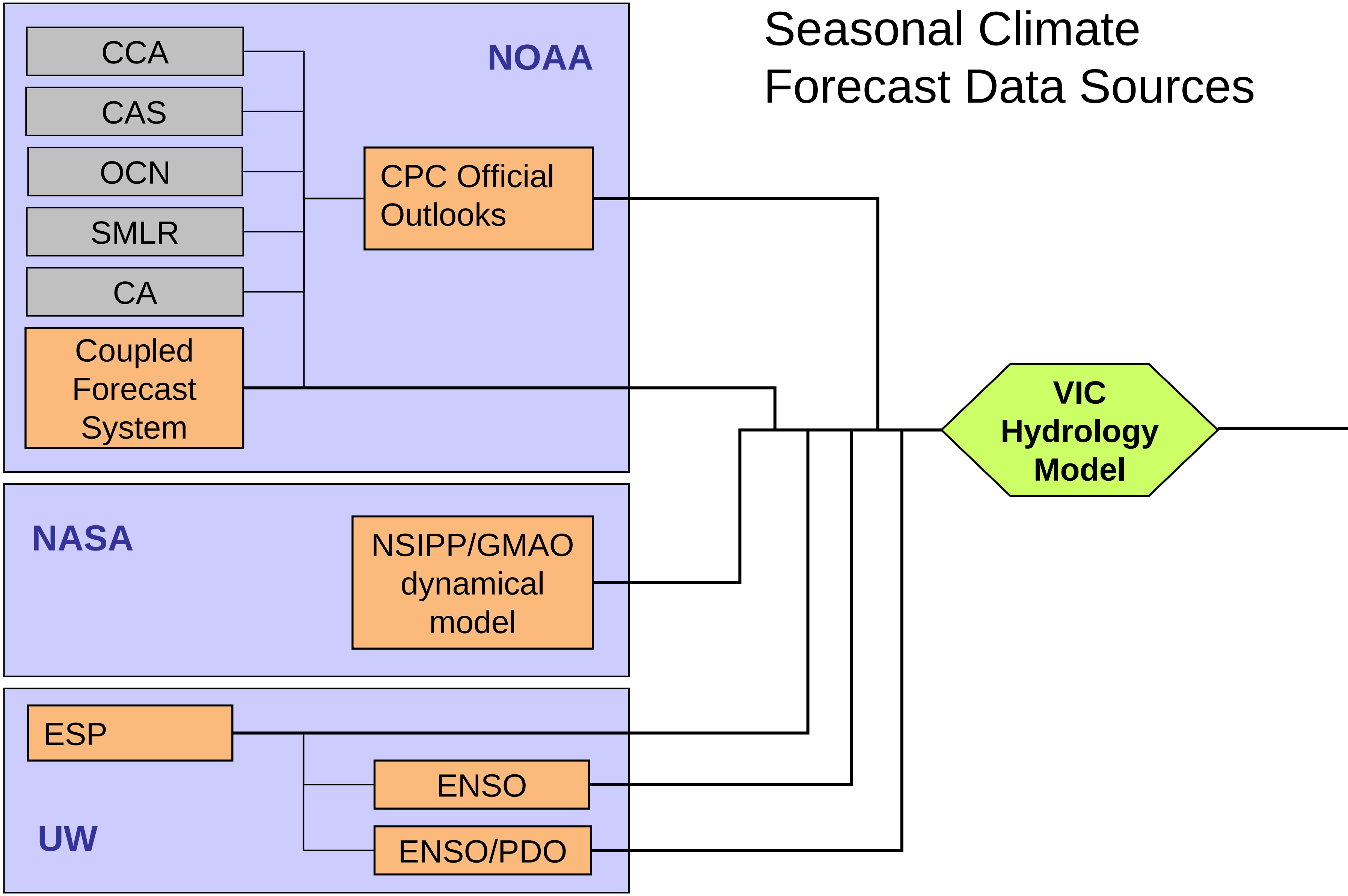
IC error high
climate fcst error low



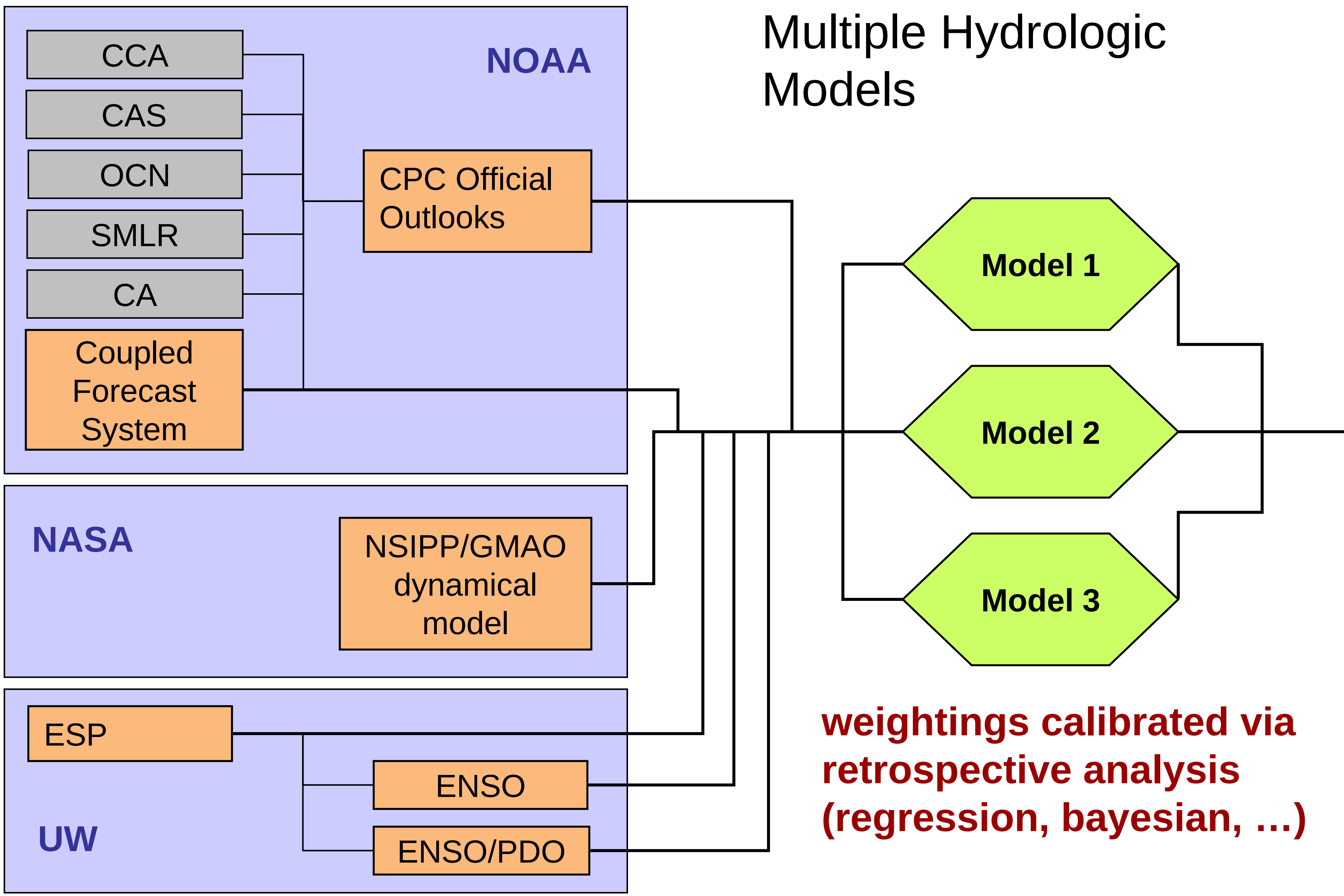
… hence importance of model & data errors also vary with lead time.

Expansion to multiple-model framework

Seasonal Climate
Forecast Data Sources

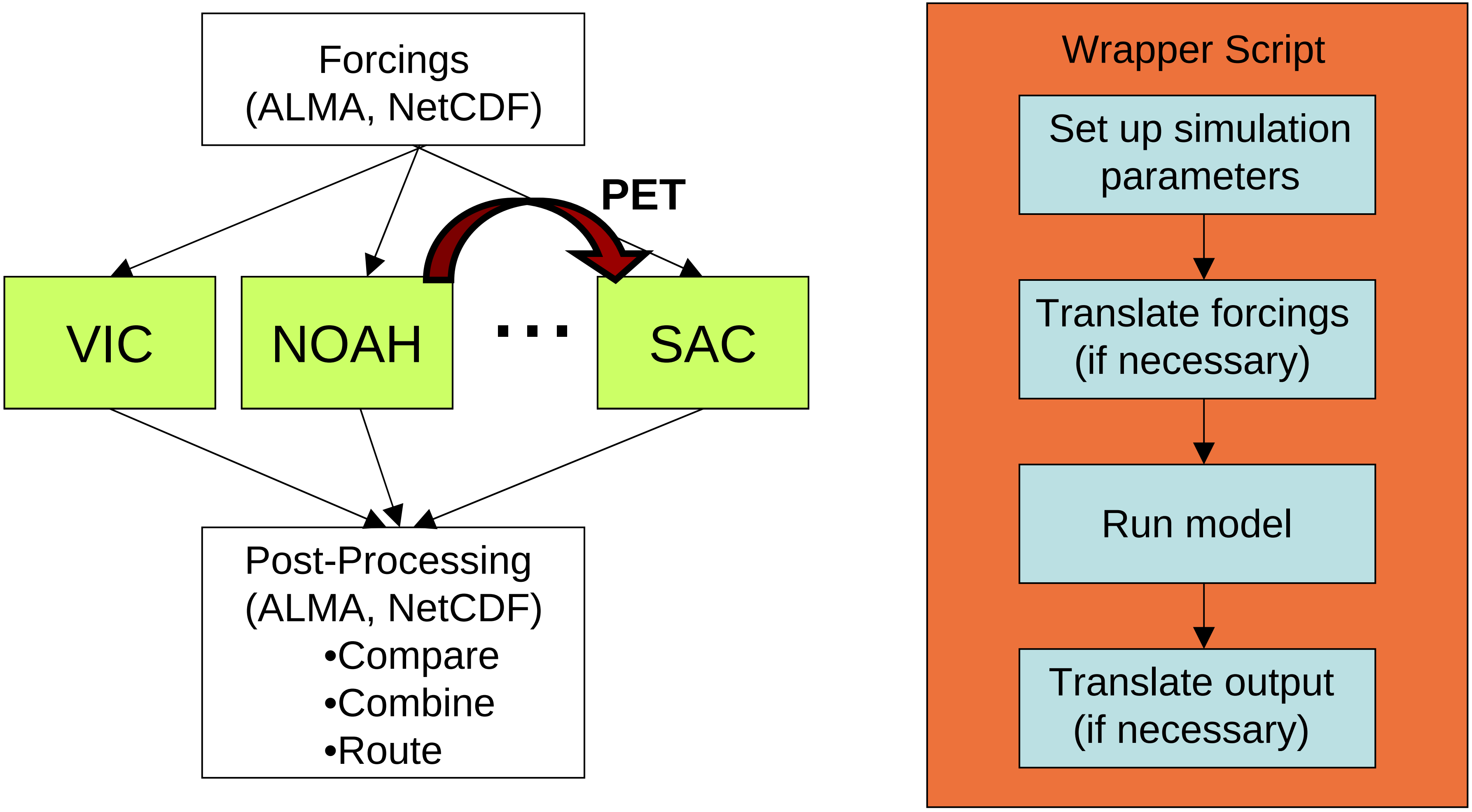


Expansion to multiple-model framework



SIMMA: "Standard Interface Multi-Model Array"

(the intended design)



SIMMA Features

- Common forcings (ALMA, NetCDF)
- Common output format (ALMA, NetCDF)
  - Easy to compare results
- Wrapper Scripts
  - Handle translation
  - Handle model-specific processing
- Minimal changes to model code
  - Easy to update a model
- Modular
  - Easy to add a new model
  - Re-use code

ALMA Standards - Forcings

Name	Units	Description
SWdown	W/m^2	Surface incident shortwave radiation
LWdown	W/m^2	Surface incident longwave radiation
Tair	K	Near surface air temperature
Qair	kg/kg	Near surface specific humidity
PSurf	Pa	Surface air pressure
Rainf	kg/m^2	Rainfall rate
Snowf	kg/m^2	Snowfall rate
Wind	m/s	Near surface wind speed

ALMA Standards - Outputs

Energy Balance Terms

SWnet	W/m^2	Net shortwave radiation
LWnet	W/m^2	Net longwave radiation
Qle	W/m^2	Latent heat flux
Qh	W/m^2	Sensible heat flux
Qg	W/m^2	Ground heat flux
Qf	W/m^2	Energy of fusion
Qv	W/m^2	Energy of sublimation
Qa	W/m^2	Advective energy
DelSurfheat	J/m^2	Change in surface heat storage
DelColdCont	J/m^2	Change in snow cold content

Water Balance Terms

Snowf	kg/m^2s	Snowfall rate
Rainf	kg/m^2s	Rainfall rate
Evap	kg/m^2s	Total Evapotranspiration
Qs	kg/m^2s	Surface runoff
Qsb	kg/m^2s	Subsurface runoff
Qsm	kg/m^2s	Snowmelt
DelSoilMoist	kg/m^2	Change in soil moisture
DelSWE	kg/m^2	Change in snow water equivalent
DelSurfStor	kg/m^2	Change in Surface Water Storage
DelIntercept	kg/m^2	Change in interception storage

Surface State Variables

SnowT	K	Snow Surface Temperature
VegT	K	Vegetation Canopy Temperature
BaresoilT	K	Temperature of bare soil
AvgSurfT	K	Average surface temperature
RadT	K	Surface Radiative Temperature
Albedo	unitless	Surface Albedo
SWE	kg/m^2	Snow Water Equivalent
SWEVeg	kg/m^2	SWE intercepted by vegetation
SurfStor	kg/m^2	Surface Water Storage

Subsurface State Variables

HLayerDepth	m	Hydrological Soil Layer Depth
SoilMoist	kg/m^2	Average layer soil moisture
SoilTemp	K	Average layer soil temperature
SMLiqFrac	unitless	Average layer fraction of liquid moisture
SMFrozFrac	unitless	Average layer fraction of frozen moisture
SoilWet	unitless	Total soil wetness

Evaporation Variables

PotEvap	kg/m^2s	Potential Evapotranspiration
ECanop	kg/m^2s	Interception evaporation
TVeg	kg/m^2s	Vegetation transpiration
ESoil	kg/m^2s	Bare soil evaporation
EWater	kg/m^2s	Open water evaporation
RootMoist	kg/m^2	Root zone soil moisture
CanopInt	kg/m^2	Total canopy water storage
SubSnow	kg/m^2s	Snow sublimation
SubSurf	kg/m^2s	Sublimation of the snow free area
ACond	m/s	Aerodynamic conductance

Cold Season Process Variables

SnowFrac	unitless	Snow covered fraction
IceFrac	unitless	Ice-covered fraction
IceT	m	Sea-ice thickness
Fdepth	m	Frozen soil depth
Tdepth	m	Depth to soil thaw
SAlbedo	unitless	Snow albedo
SnowTProf	K	Temperature profile in the snow
SnowDepth	m	Depth of snow layer

UW Multi-model Results

Arctic Basin application

- linearly combined CHASM, ECMWF, NOAH, and VIC based on snow cover simulation performance
- combination reduced annual runoff error

West-wide forecast application

our
forecast-related
multi-model
results to date

+

gets you

SIMMA implementation "hardships"

Model Versions and Parameters:

major experiment (PILPS, NLDAS) versions are a specialized branch off the main development tree.

Reconciling desired combination of parameters, I/O, and model physics to… substantial effort.

- PILPS-2e version of NOAH used NetCDF I/O, which we…
- NLDAS NOAH had desired CONUS domain, but…

No standard format for parameters:

- Different versions of the p… …fferent formats (sequential binary, a…

- Different ve… …rids, or even different individual param… …erent grids.

Dif… …same model) use different parameters:

- So… …d different soil/veg classification schemes than others, requi… …pping them to the desired scheme.

e.g. NLDAS parameters for an older version of NOAH than the desired one (2.7.1).

We want parameters from NWS OHD for CONUS domain, not sure what version

Some models (e.g. SAC) use conceptual parameters that lack an obvious relation to standard soil/veg types that are easily available.

Efforts to **standardize** formats & datasets (forcing/output/parameter), and/or provide **conversion tools** to/from standards, will be useful.

UW forecast/nowcast application of SIMMA

Test Case

Salmon R. at Whitebird, ID

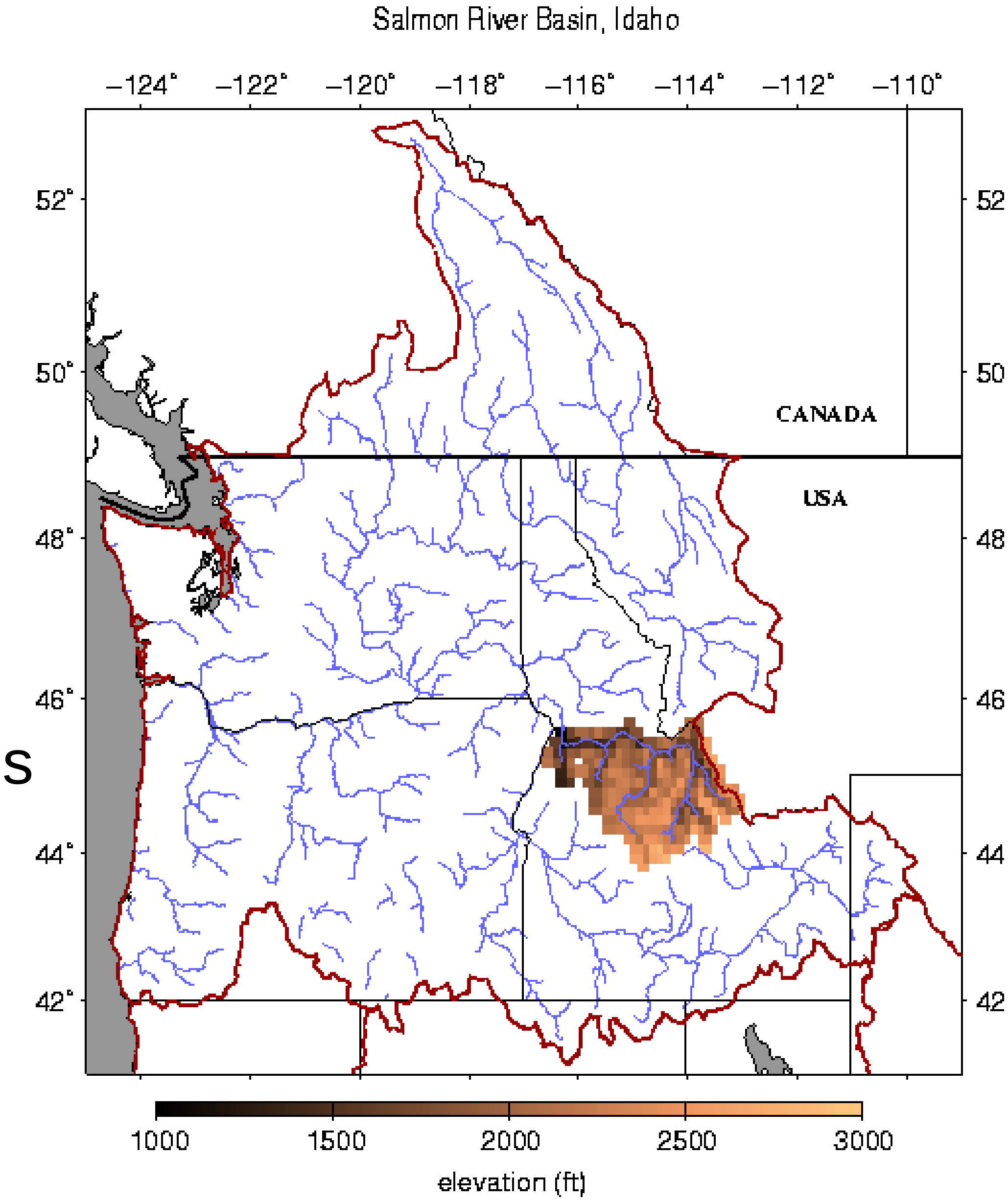
Future Applications

Westwide forecast domain

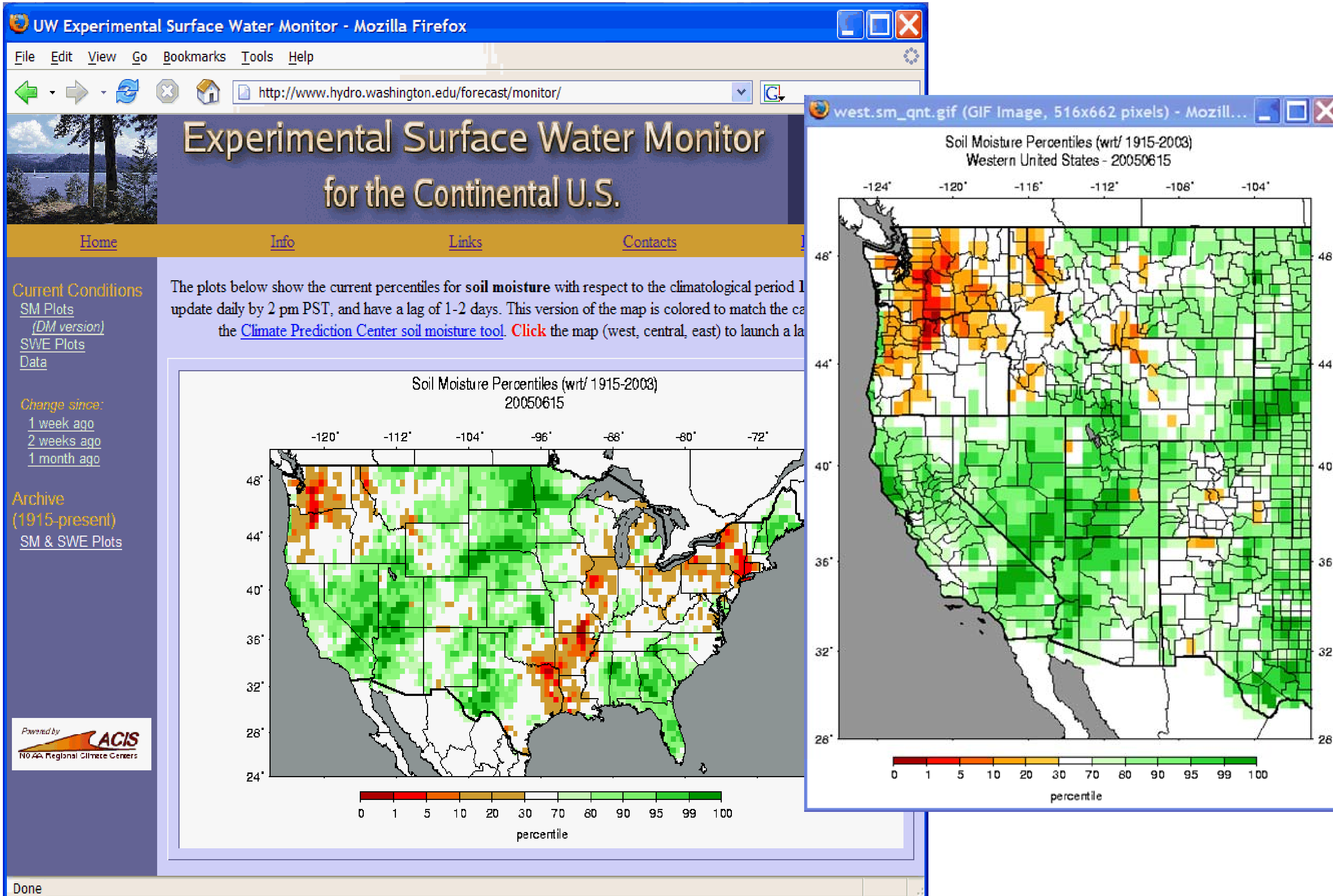
CONUS nowcast

Starting Point

NLDAS-grid implementations of VIC/NOAH/SAC



UW Real-time Daily Nowcast



Research Issues

- **Implementation Hurdles: grid specs, parameter inputs, model physics, I/O formats, etc.**

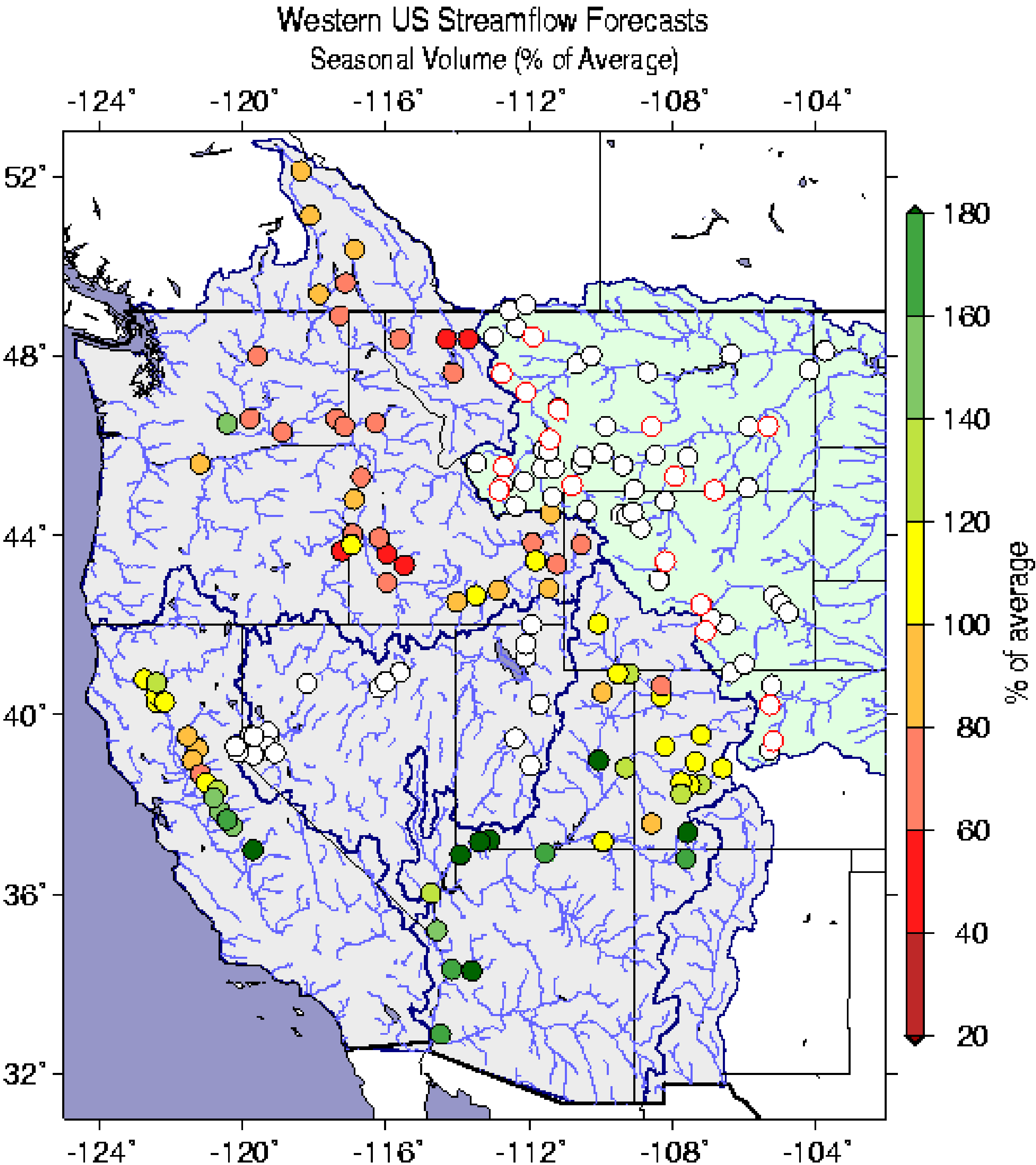
- **Combination methods in ungaged areas? (e.g., US nowcast)**
  What are OBS?

- **What if combinations that produce best streamflow do not also produce best SWE or soil moisture?**
  Is use as diagnostic physical tool compromised?

For more information:
Ted Bohn, tbohn@hydro.washington.edu

END

NEW



Western US Streamflow Forecasts
Seasonal Volume (% of Average)
-124°
-120°
-116°
-112°
-108°
-104°
52°
48°
44°
40°
36°
32°
180
160
140
120
100
80
60
40
20
% of average

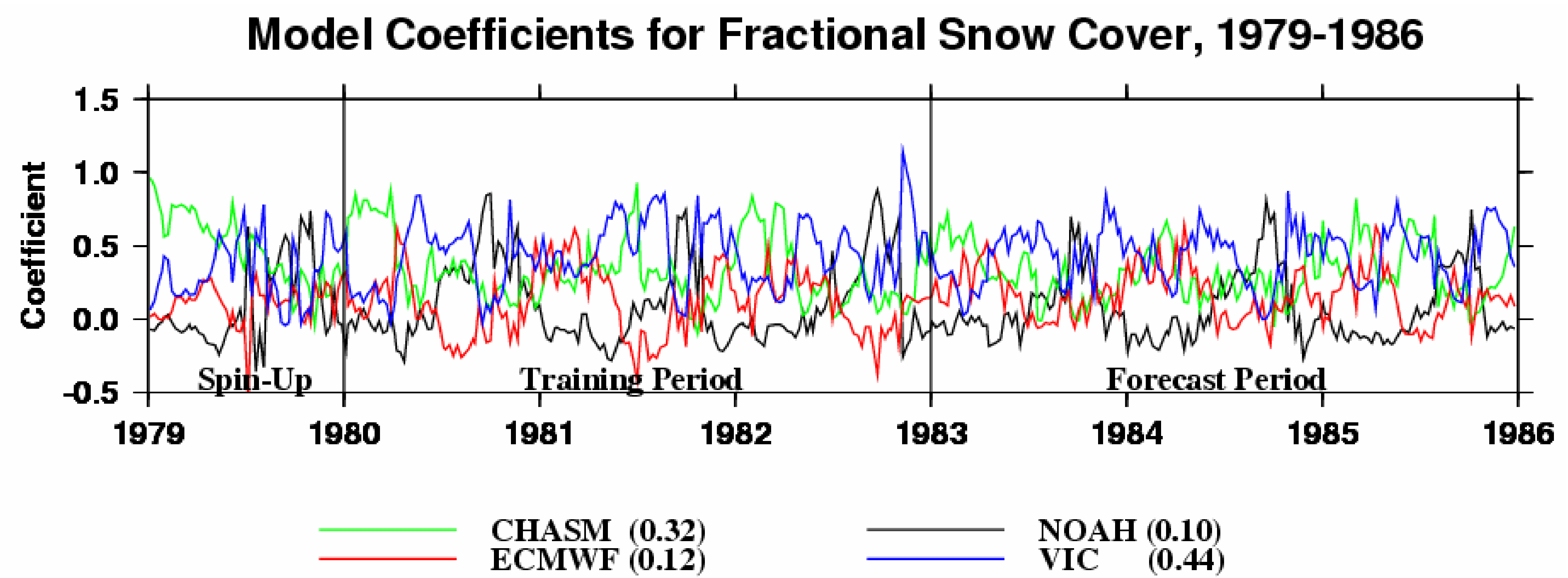
Expansion to multiple-model framework

Our current research with multi-model simulations is promising:

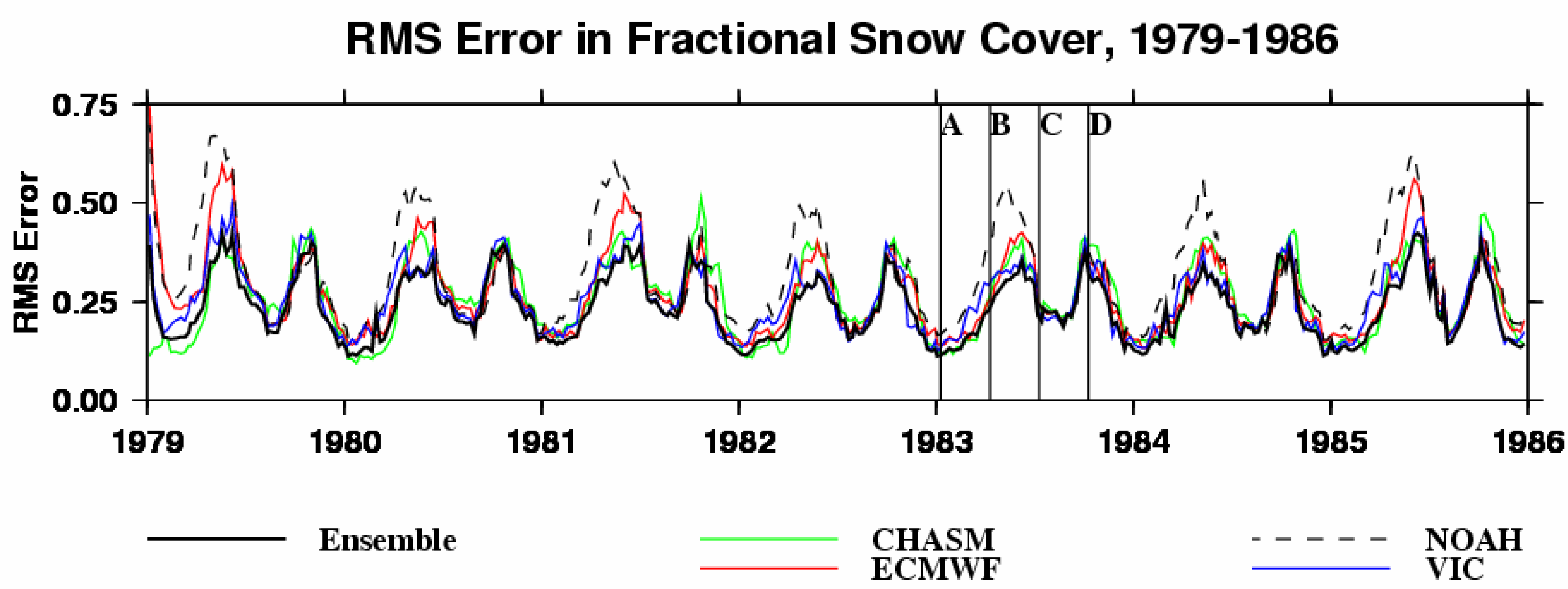
- 4 land surface models used to simulate arctic basin hydrology, 100 km resolution
- following linear combination approach of Krishnamurti et al., (2000)
  - weighting calibration based on simulation of snow-covered area
  - results for streamflow and other hydrologic variables evaluated

- multi-model errors are lower than single model errors, in most cases

(work by Ted Bohn at U. of Washington)



Expansion to multiple-model framework



annual discharge predictions