River basin budgets from ERA40

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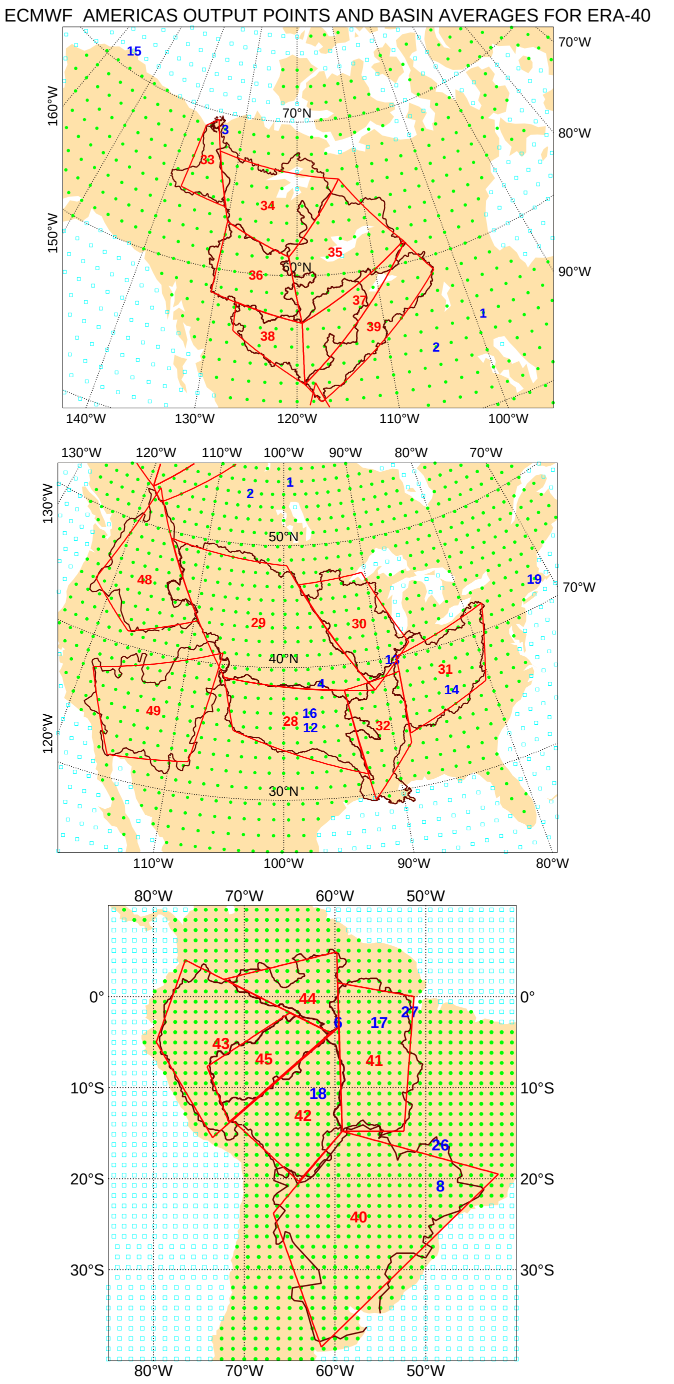

In this paper hourly river basin-scale budgets are analyzed from ERA40 for the Mississippi, Mackenzie and Amazon rivers for 1990-1992. For the Mississippi comparisons are made with ERA15 and basin averaged observations. For the Mackenzie, comparisons are made with MAGS data

ECMWF Workshop on Reanalysis
Nov. 5-9, 2001

Supported by:
NASA under Grant NAG5-11578
NSF under Grant ATM-9988618

ERA40 AMERICAS RIVER BASINS

Index #	MISSISSIPPI	LS Mask
28	Red-Arkansas	1
29	Missouri	1
30	Upper Mississippi	1
31	Ohio	1
32	Lower Mississippi/Tennessee	1
	MACKENZIE	1
33	Peel/Delta	1
34	Great Bear Lake sub-basin	0.964
35	Great Slave Lake sub-basin	0.968
36	Liard	1
37	Peace (East)	1
38	Peace (West)	1
39	Athabasca	1
40	RIO DE LA PLATA	1
	AMAZON	
41	Xingu/Tapajos/Trombetas/Uatuma	1
42	Madiera	1
43	Solimoes	1
44	Negro	1
45	Purus	1

[Also: Columbia and Colorado in NA]

Intercomparison of Water and Energy Budgets for Five Mississippi Sub-basins between ECMWF Reanalysis (ERA-40) and NASA-DAO fvGCM for 1990-1999.

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- Michael Bosilovich [NASA-GSFC]
- Pedro Viterbo [ECMWF]
- Yuanchong Zhang [Columbia University]
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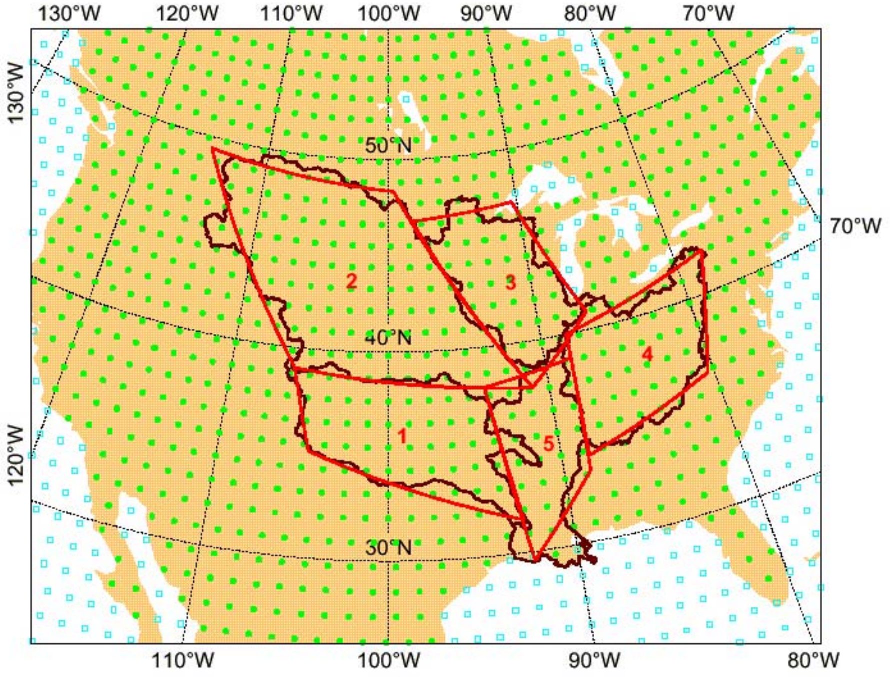
J. Geophys. Res., 108 (D16), 8618, doi:10.1029/2002JD003127, GCIP-3, July 2003

Basin Budgets

- 1990-1999: monthly
- Quadrilateral approx. of basins
- ERA-40 T-159 grid
- ERA-40: Σ 12-24h FX
- NASA DAO fvGCM 1x 1.25 deg. grid
- fvGCM: ex.1986-2000



Model physics

- **ERA-40**
- Analysis: 3D-VAR
- Land-surface:Van den Hurk et al. 2000
- Convection: Tiedtke, 1989
- Prognostic clouds: Tiedtke,1993

- **fvGCM**
- 15-year run [SST's]
- Land-surface: CCM3, Bonan, 1998
- Convection: Zhang/McPharlane, 1995, Hack,1994

Validation data

- Mississippi budgets: VIC model: Maurer et al. *J. Climate*, 2002 [basin means]

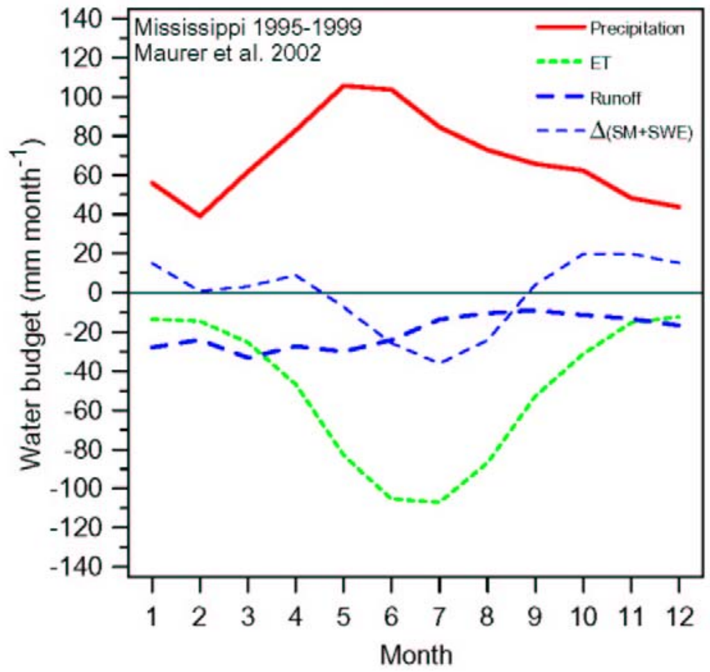
- ISCCP : Rossow and Zhang, 1995; Rossow and Schiffer, 1999 [from 2.5 deg. grid]

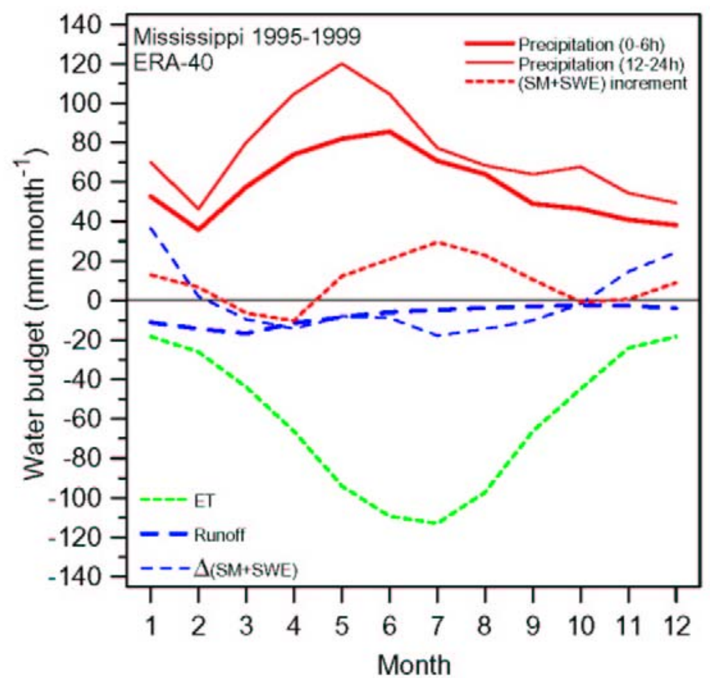
- NCDC: T_{2m} and Q_{2m} [gridded to 1x1.25^{o}]

Annual water budget

- Summer precip. and ET
- Winter and spring runoff
- Summer soil dry-down

- ERA-40 spinup
- Increment SWE/soil water
- Runoff low

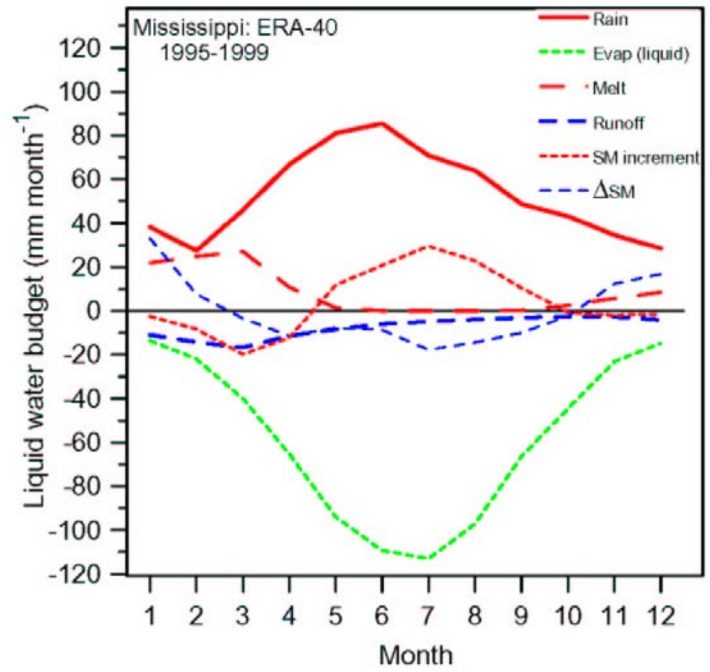


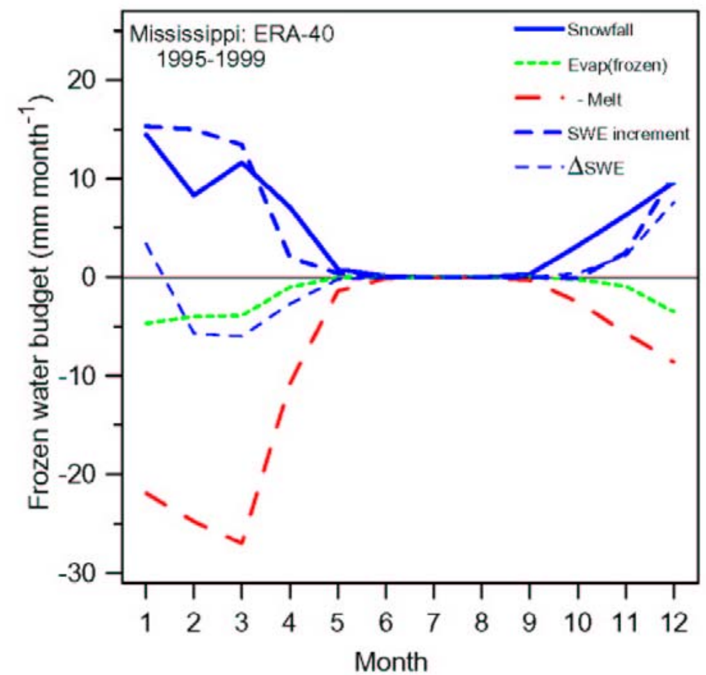


ERA-40

- **Liquid budget:**
- Rain, melt and analysis increment
- ET, runoff, Δ(SW)

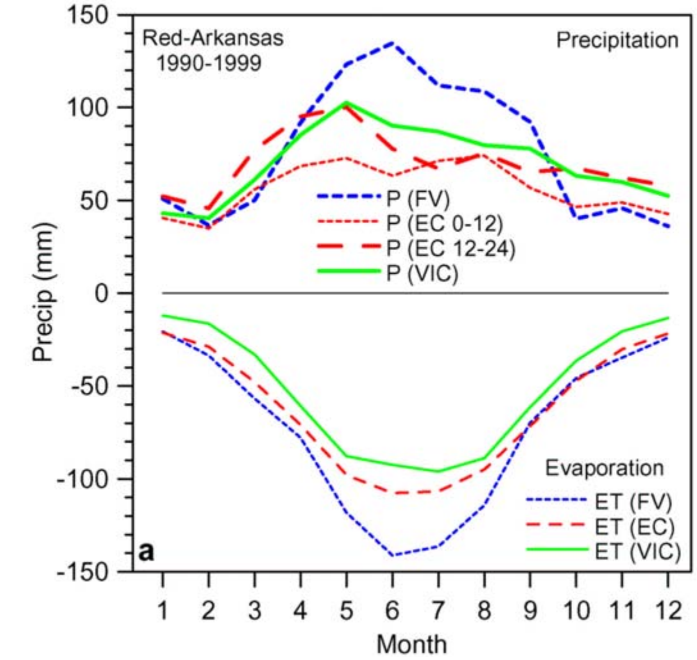
- **Frozen budget:**
- Snowfall = anal. increment
- Loss by melt

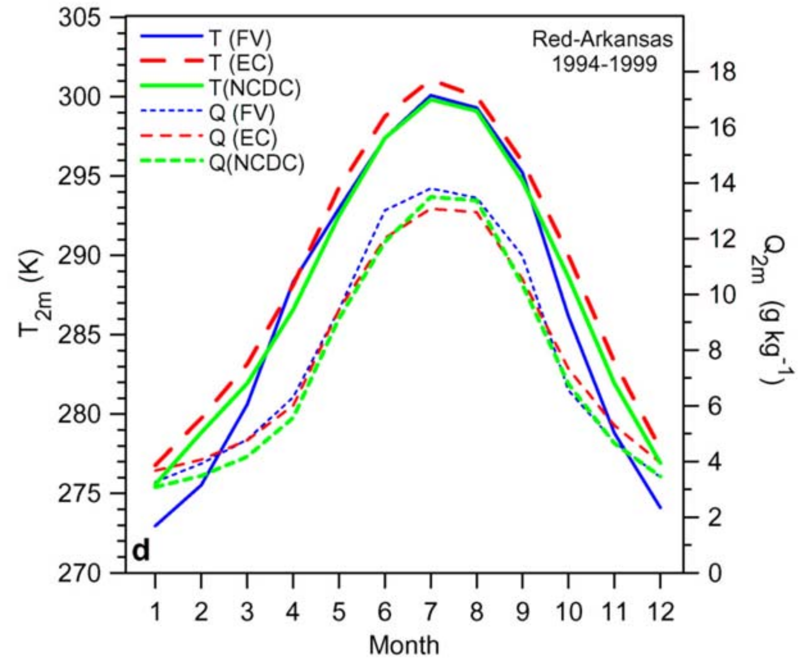




Red-Arkansas

- Precipitation
  - fvGCM>data >ERA
- ET
  - fvGCM>ERA>VIC
- Temperature and humidity
  - fvGCM: cold winter
  - ERA-40 warm [+1K]

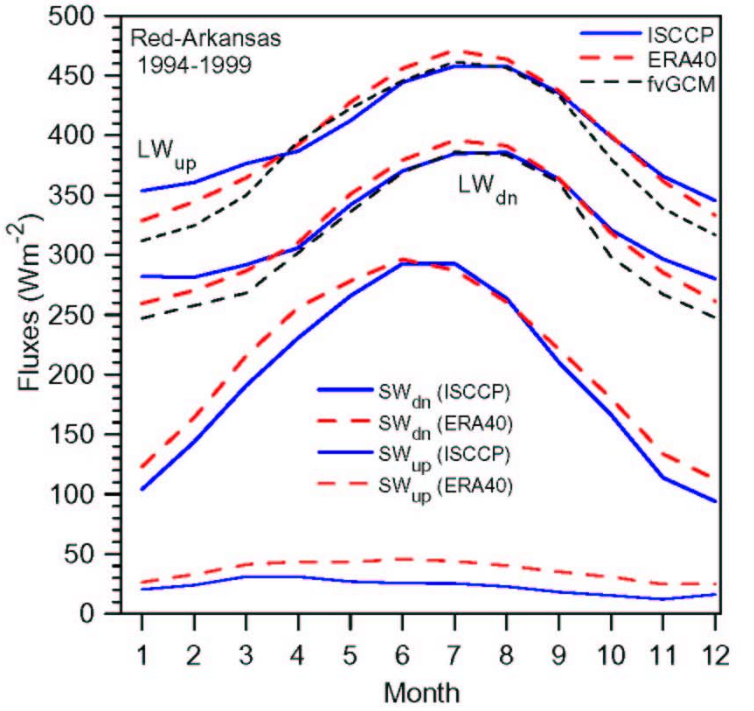


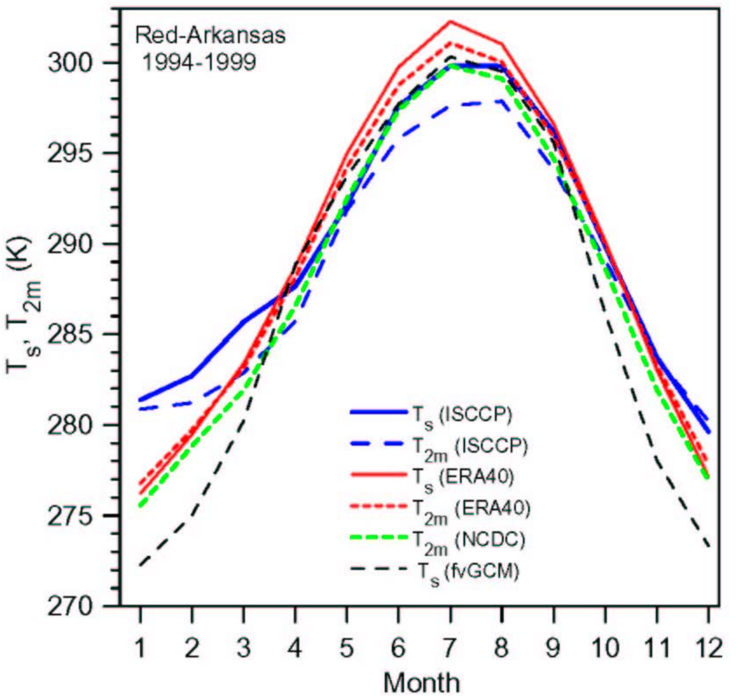


ISCCP comparison

- ERA-40 less reflective cloud in winter than ISCCP
- ISCCP albedo low
- LW fluxes reflect temperature

- ISCCP skin temperature warm in winter, little cool in summer





Evaluation of the ERA-40 surface water budget and surface temperature for the Mackenzie River basin.

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December, 2003

J. Hydrometeorology, 4, 1194-1211.
http://www.ecmwf.int/publications/library/ecpublications/_pdf/ERA40_PRS_6.pdf

ECMWF – ERA-40

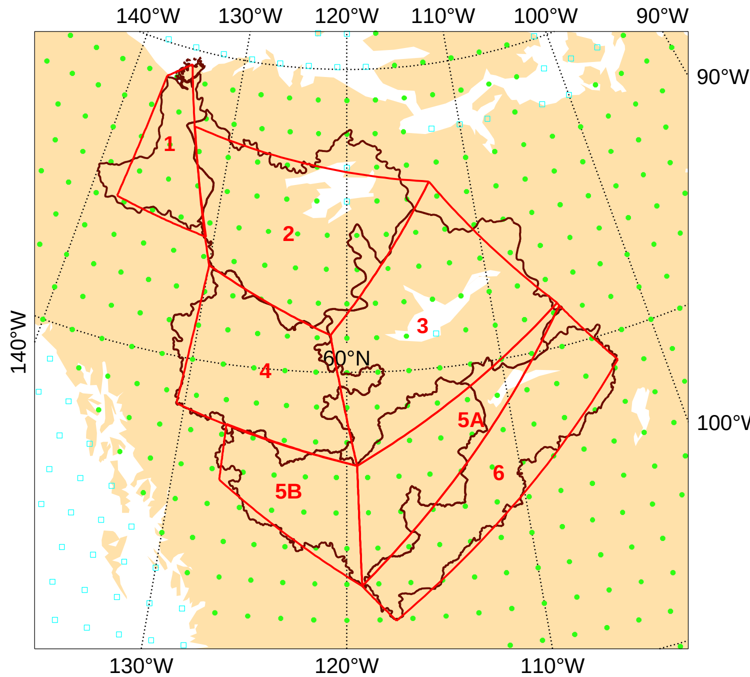
www.ecmwf.int/research/era

ECMWF 40-year reanalysis (ERA-40)

actually covers the 45 years,
9/1957-8/2002.

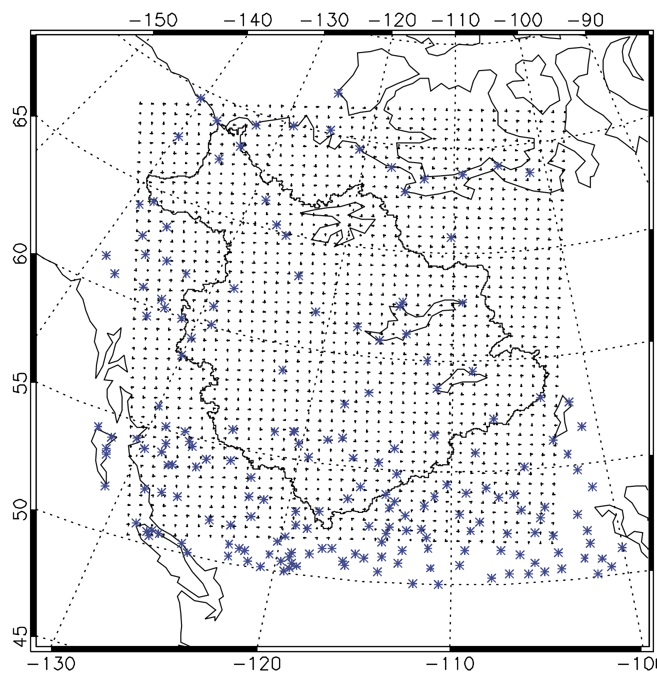
River basin averages

Mackenzie river [MAGS] flows northward into the Arctic



Data: *[Louie et al., 2002]*
interpolated and gridded

Precipitation
Temperature
Evaporation [model]



Stream gages on main rivers

Table 1. Mackenzie sub-basin drainage areas and their model representation.

Sub-Basin	Drainage Area (km^2)	ERA40 Area (km^2)	Model Elevation (m) Mean	SD	max	min
1 Peel	117127	108187	686	384	1284	121
2 Great Bear Lake	421191	367573	478	361	1506	187
3 Great Slave Lake	378245	418757	348	99	565	196
4 Liard	273395	283920	991	315	1515	412
5 Peace	319110	344659				
5A (E)		(206549)	573	198	1122	286
5B (W)		(138110)	1147	213	1482	782
6 Athabasca	285111	260982	651	333	1611	358
TOTAL	1791857	1784078				

Table 2. Distribution of vegetation across the Mackenzie in ERA-40 as % of basin.

Basin	1	2	3	4	5A	5B	6
HIGH VEG.	**44**	**56**	**64**	**77**	**90**	**92**	**91**
evergreen needleleaf [3]			26	13	25	49	69
deciduous broadleaf [5]	43	17	32	51	55	43	
interrupted forest [19]	1	39	5	12	10		21
LOW VEG.	**56**	**40**	**33**	**23**	**10**	**7**	**9**
tundra [9]	53	15	10	23		5	1
bogs/marsh [13]	3	25	6		2		1
deciduous shrubs [17]			17		1		4
crops/mixed farming [1]					7	2	3
Water		4	3				

44-year Overview

The idea of renanalysis is to use one recent 'frozen' model and data assimilation system to cover the entire period, in contrast to operational analyses in which the modeling system is revised on a frequent basis, as improved numerical or data assimilation schemes and physical parameterizations are introduced, along with increases in resolution. However, although the model is frozen, the data going into the reanalysis has changed markedly in the 44 years from 1958 to 2001, and this has a *major impact on the analyses*.

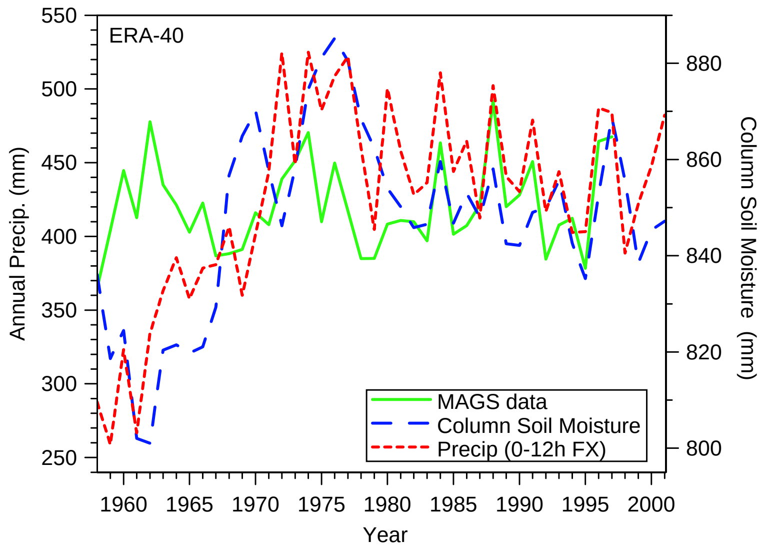
There are three important epochs in ERA-40:
1958-1972, before "satellite data", when the upper air analysis depends on the sounding data;
1973-1986, starting with the assimilation of the radiances from the first satellite infrared channels on the Vertical Temperature Profiler Radiometer (VTPR) and, from late 1978, infrared and microwave sounders from the Television and Infrared Observational Satellite Operational Vertical Sounder (TOVS) suite of instruments;
1987-2001, with the addition of information of radiances from the satellite microwave channels of the Special Sensor Microwave Imager (SSM/I) to the atmospheric water vapor assimilation over the ocean.

Change of spinup and bias with time

The model hydrological cycle is not in balance during the 6-hour analysis cycle.

Precipitation generally increases in ERA-40 in mid- and high latitudes during the first 36 hours of forecasts. This spin-up of precipitation varies considerably over the period of the reanalysis.

Model spinup and bias from data are correlated



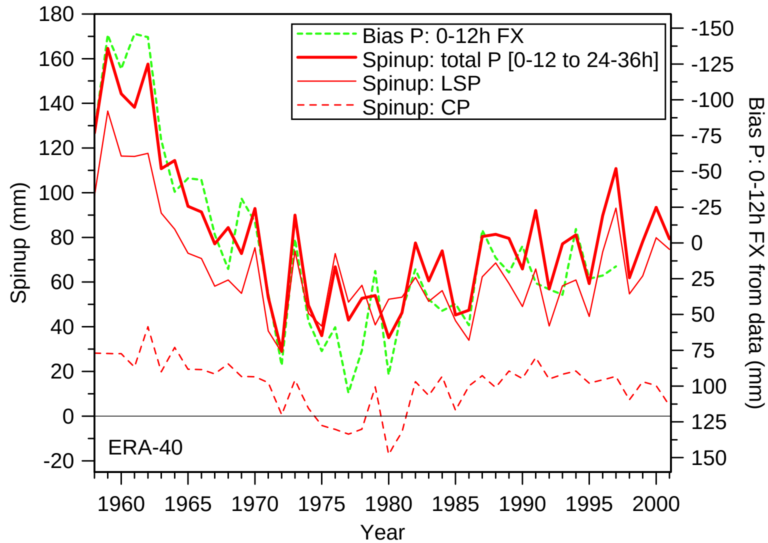


Figure 3. Annual mean precipitation in model and MAGS observations and column soil moisture (upper); model precipitation spinup and bias from observations (lower).

Change of bias and spinup with time linked to *changes in the analysis increment of atmospheric water vapor* during the 44 years.

Upper panel shows the annual mean atmospheric total column water vapor (TCWV) and the analysis increment of TCWV (blue). The increment, on the right-hand-scale, shows a drift with time.

The middle and lower panels show that both the *bias of the model 0-12h FX precipitation from the MAGS observations, and the spinup of model precipitation* are correlated with the TCWV analysis increment.

The analysis removes TCWV, which reduces precipitation in the analysis cycle, and the model then spins up to restore precipitation.

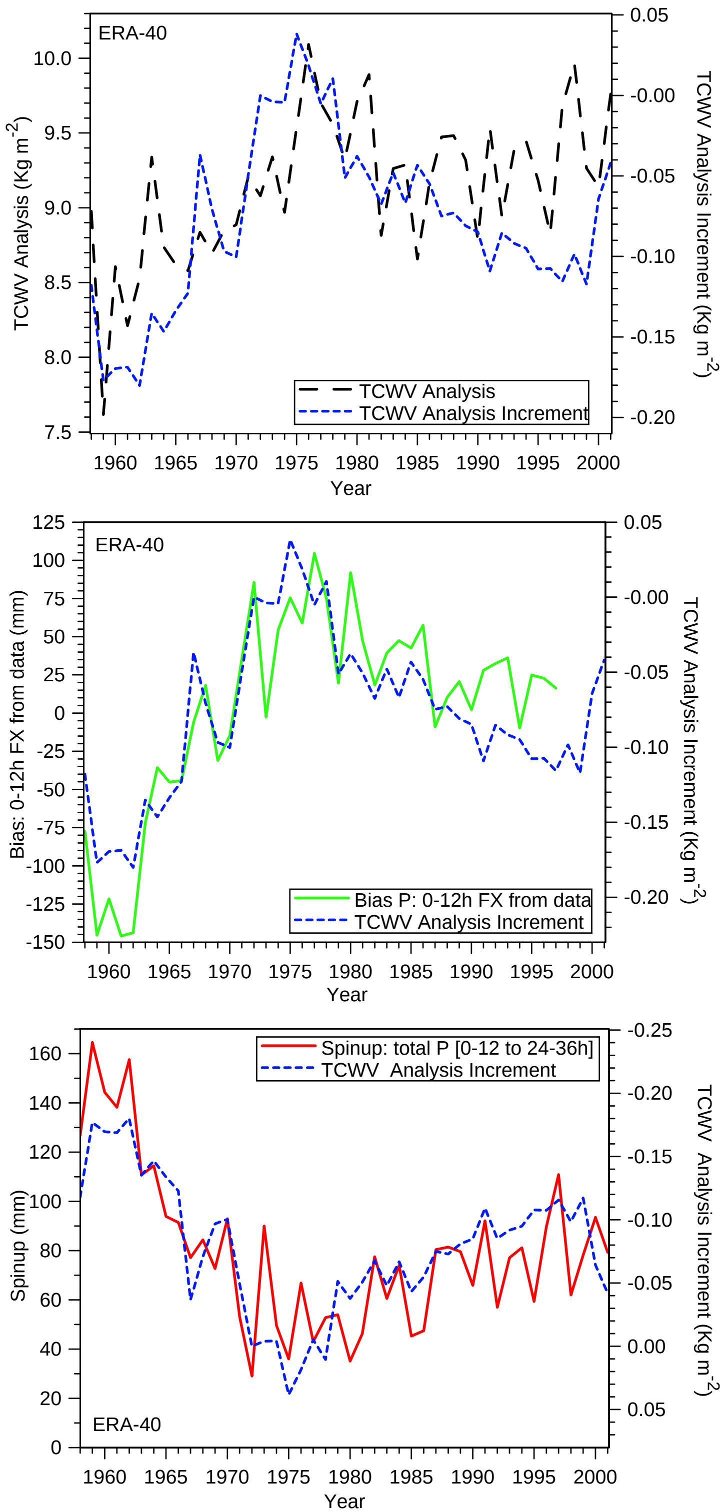
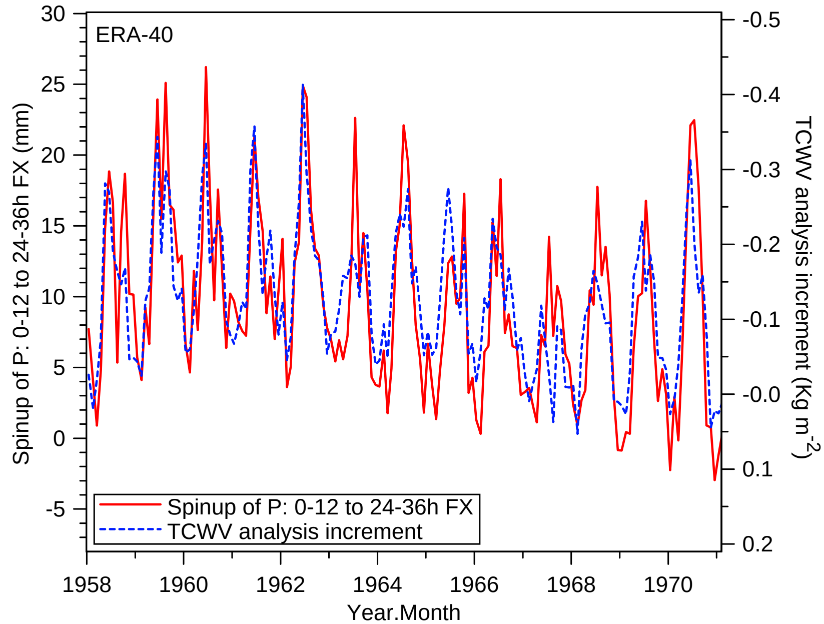


Figure 4. Annual variation of TCWV and its analysis increment (upper), model precipitation bias (middle) and model precipitation spinup (lower).

Upper panel shows the monthly variation of *spinup and the TCWV analysis increment* during the early part of the analysis.



The lower panel shows the correlation between monthly mean spinup and TCWV analysis increment for the whole of ERA-40.

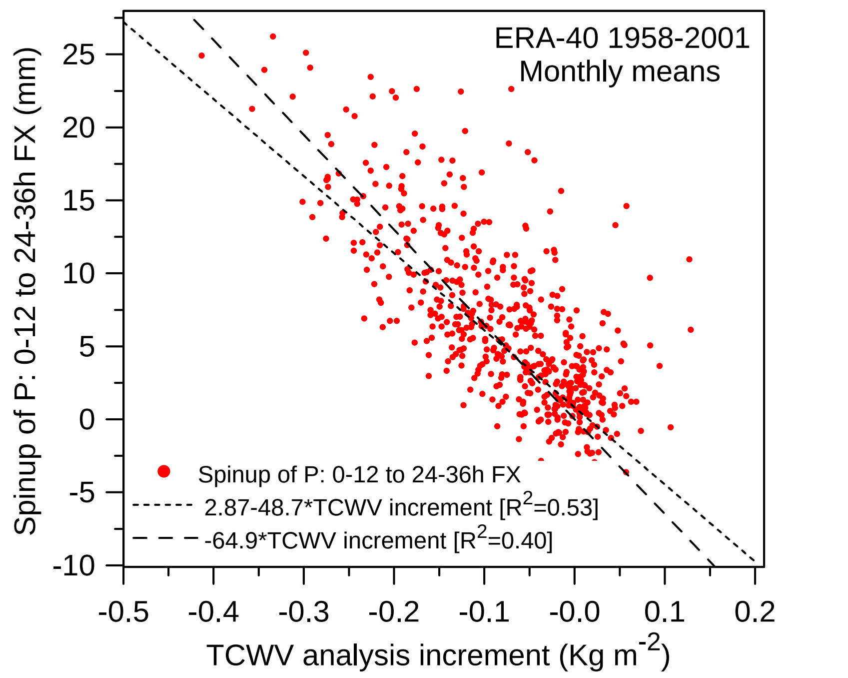


Figure 5. Monthly timeseries of model spinup and TCWV increment (upper) and (lower) scatterplot of spinup against TCWV increment.

Annual cycle of precipitation spinup and bias

Three periods, 1958-1970; 1974-1981 and 1987-1997, illustrate differences in the mean annual cycle.

Figure 6 shows the mean annual cycle for the three periods of the *observed Mackenzie precipitation* (upper panel), The Mackenzie precipitation remains low in Spring till May and peaks sharply in July.

Model precipitation spinup between the 0-12h and 24-36h FX (middle). Spinup is larger in winter in the 1960s. The first and last periods have a July spinup maximum, while in the middle period, the spinup is low and has a dip in summer, related to a spindown in convective precipitation

TCWV analysis increment (lower).

The annual cycle of the TCWV incement bears some resemblance to the spinup, but the peak is shifted to June

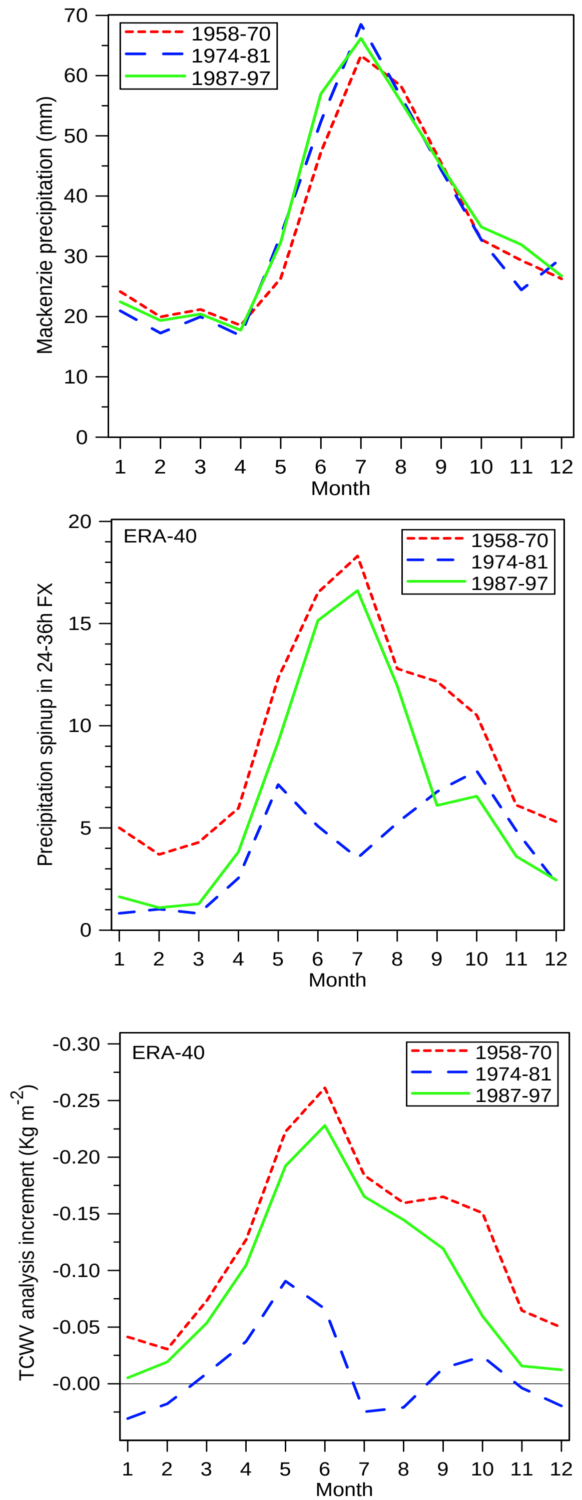
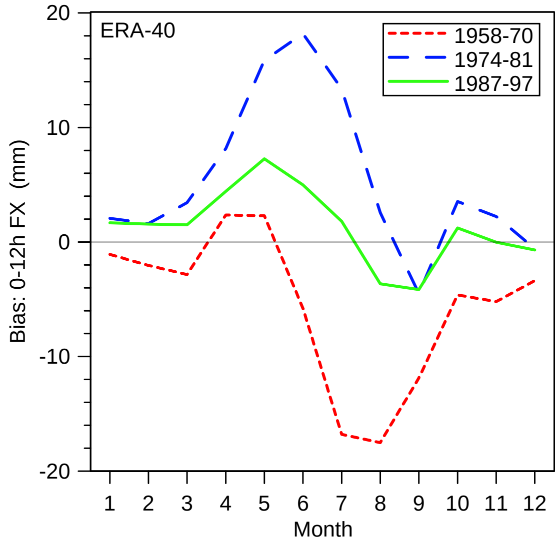


Figure 6. Mean annual cycle of observed Mackenzie precipitation, model precipitation spinup, and TCWV analysis increment for three periods.

Model has a *distinct seasonal bias in precipitation*

The upper panel shows the *bias of ERA-40* precipitation in the 0-12h FX. It shows not only the marked difference between the three periods (seen in Figures 3 and 4), but it also shows the bias has a spring peak and a fall minimum.



In the 24-36h FX (lower panel), the difference in bias between the periods has reduced, and it is clear that the model has a high precipitation bias in May-June, and a low bias in August-September.

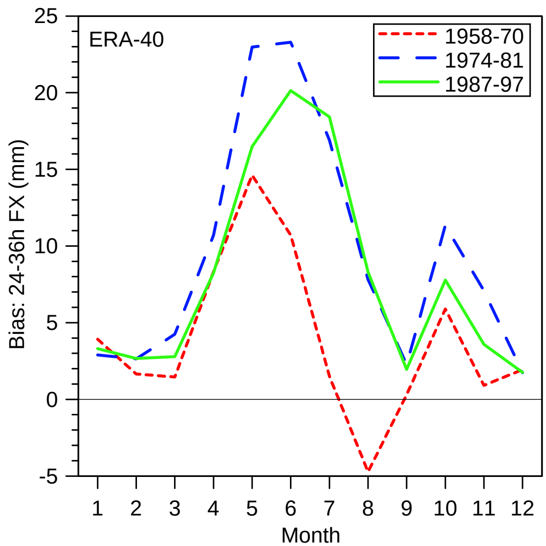


Figure 7. Mean annual cycle of 0-12h FX bias and 24-36h FX bias for thee periods.

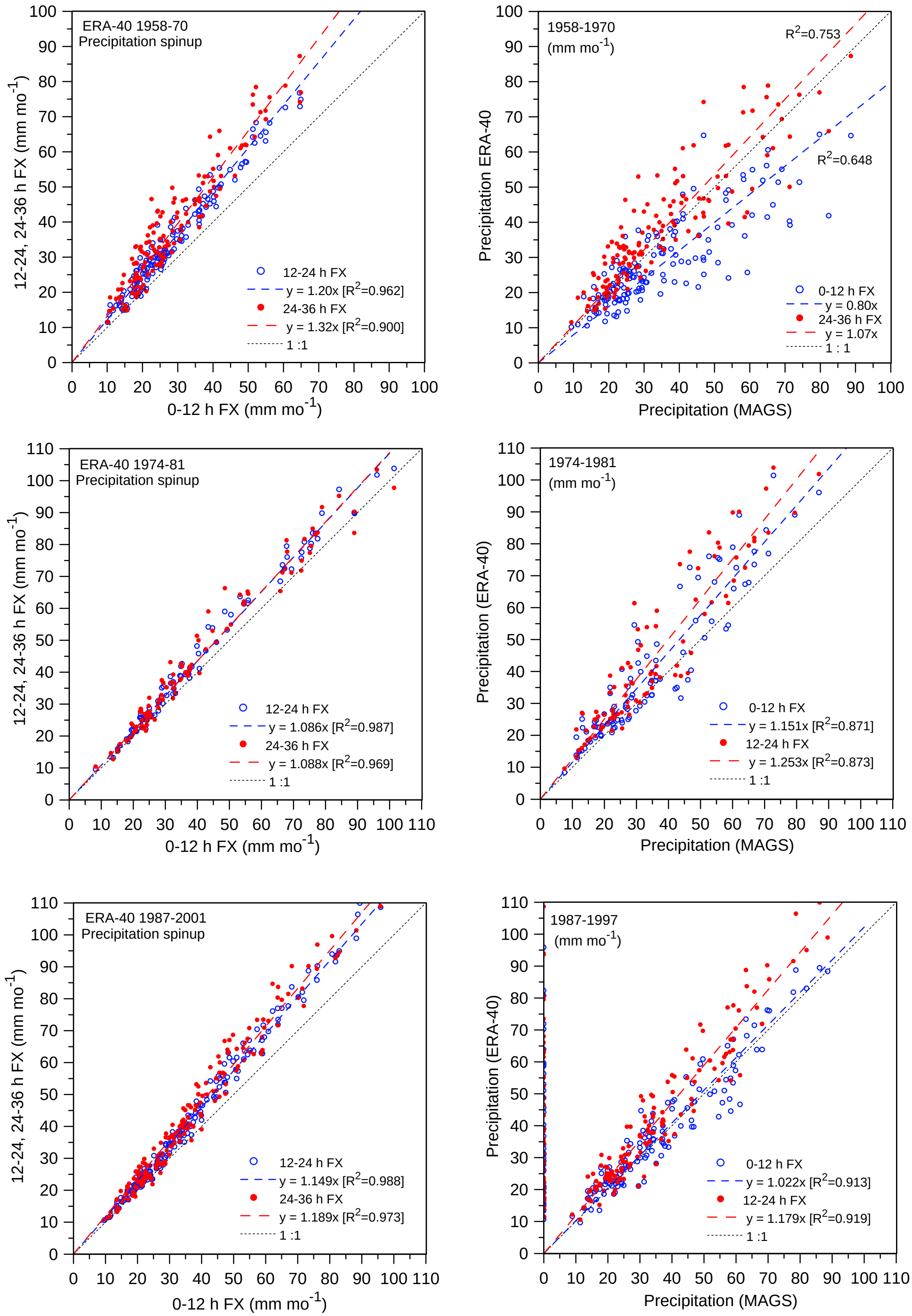
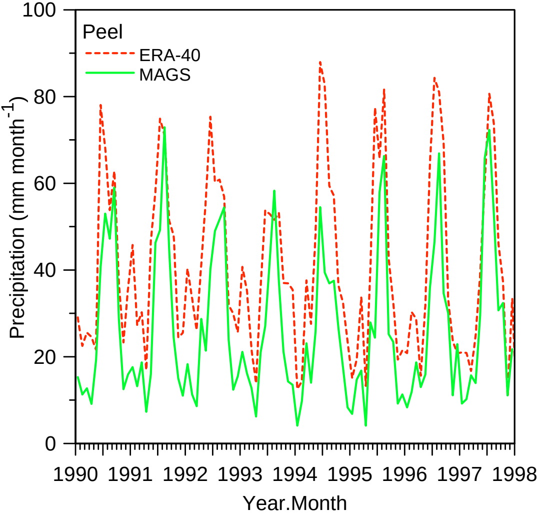
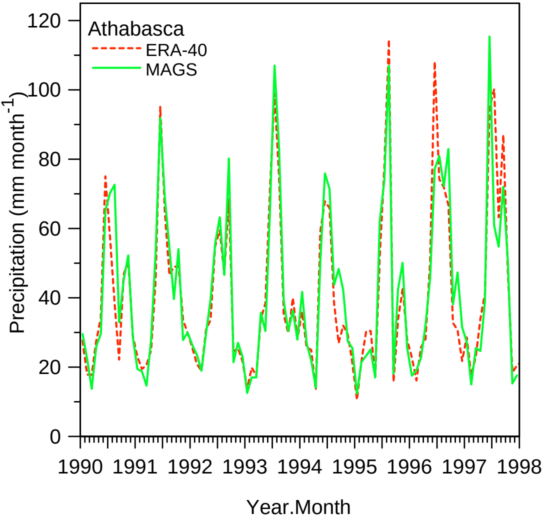


Figure 8. Spinup of ERA-40 precipitation for three epochs (left panels); comparison of ERA-40 with MAGS precipitation estimates (right panels)


Peel
ERA-40
MAGS
Precipitation (mm month^{-1})
0
20
40
60
80
100
1990
1991
1992
1993
1994
1995
1996
1997
1998
Year.Month


Athabasca
ERA-40
MAGS
Precipitation (mm month^{-1})
0
20
40
60
80
100
120
1990
1991
1992
1993
1994
1995
1996
1997
1998
Year.Month

Comparison of ERA-40 evaporation with MAGS estimate

Annual cycle of the MAGS estimate (Louie et al. 2002) of basin evapotranspiration (ET), and the bias of the ERA-40 0-12h FX total evaporation from the MAGS estimate.

ERA-40 is generally slightly positive with about 5 mm month^{-1} more evaporation than the MAGS estimate. This bias decreases to near zero in spring, before increasing to about 15 mm month^{-1} in summer, with a peak in August-September.

ERA-40 evaporation is probably biased high.

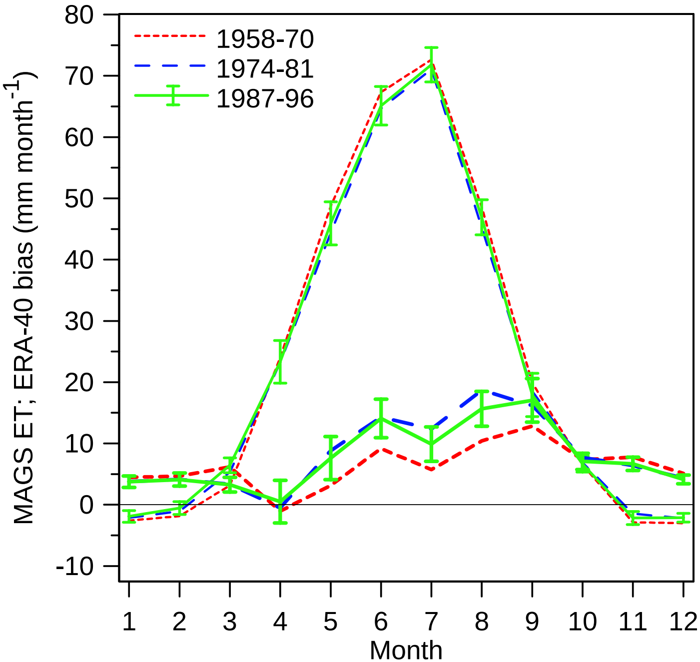


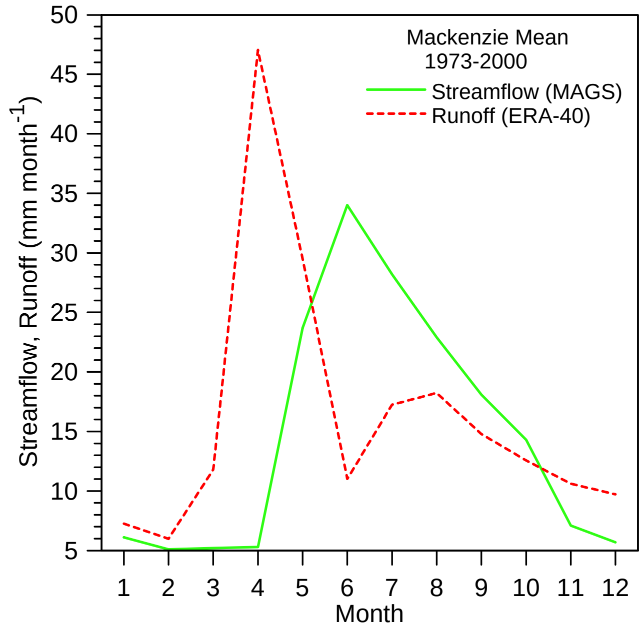
Figure 9. MAGS ET estimate and ERA-40 bias from MAGS estimate.

Comparison of Mackenzie streamflow and ERA-40 runoff

We have streamflow data for the Mackenzie River from 1973 to the present.

Mean annual cycle (1973-2000) of streamflow for the Mackenzie and the corresponding runoff in ERA-40.

ERA-40 has 2 peaks: snowmelt and deep drainage.
Mackenzie streamflow has a single peak



Total annual streamflow on the Mackenzie and model runoff.

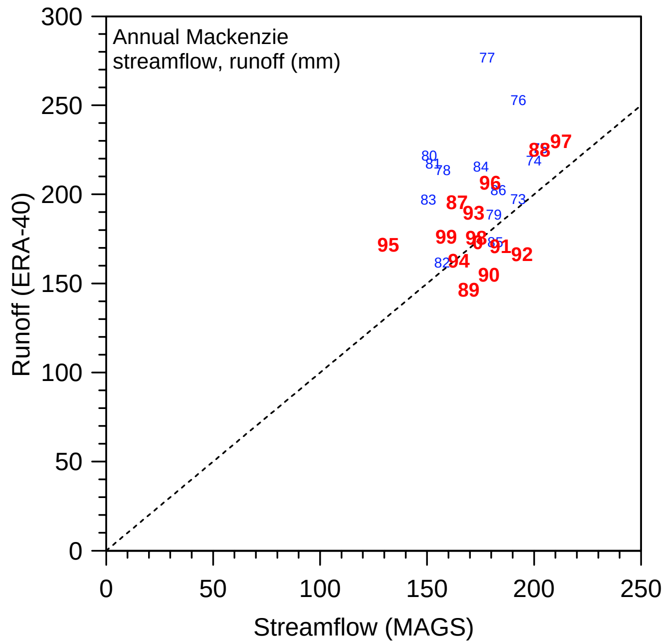


Figure 10. Comparison of Mackezie streamflow and ERA-40 runoff: annual cycle (upper panel) and annual total (lower panel)

Soilwater and snow water equivalent

ERA-40 soilwater analysis modifies soilwater in the first three soil layers (0-7, 7-28 and 28-100 cm), based on analysis increments of 2-m temperature and humidity (Douville et al., 2000).

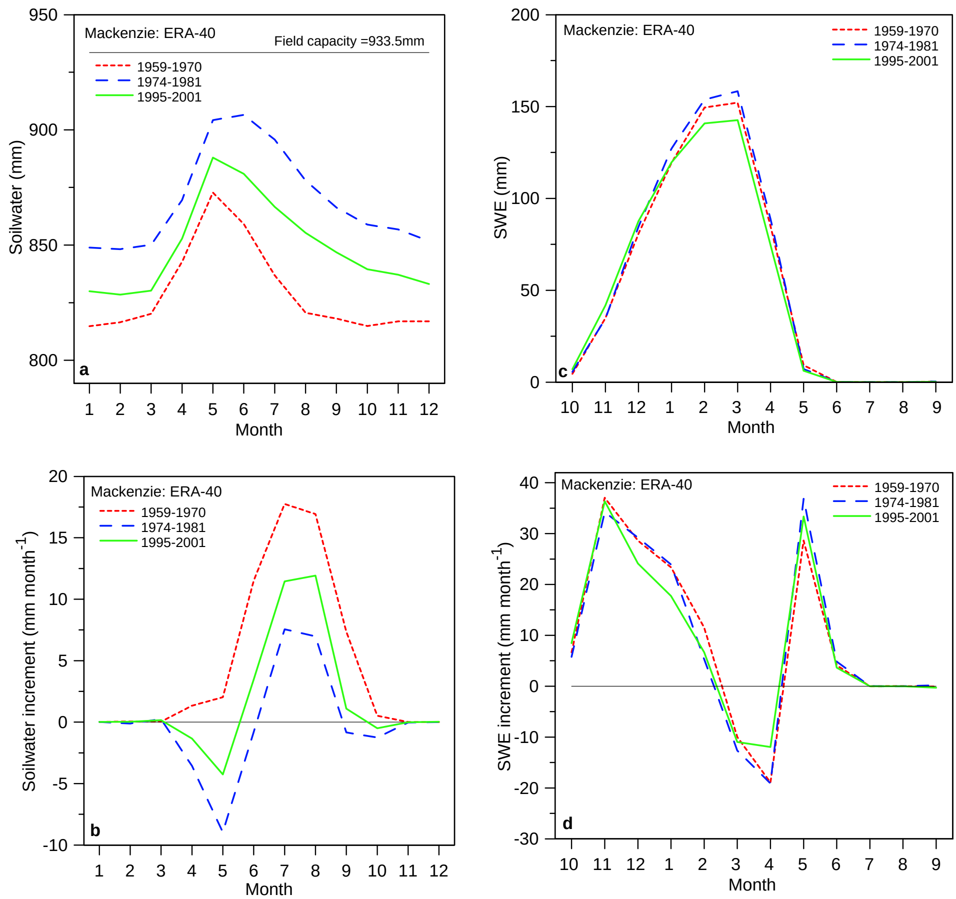


Figure 11. (a) Mean annual cycle of column soilwater, (b) soilwater analysis increment, (c) total snow water equivalent and (d) SWE analysis increment for three data periods.

ERA-40 has a single snow layer, with modeled snow water equivalent (SWE) and snow depth, linked by the model snow density.
Snow observations are inadequate: increments are large.

LIQUID AND FROZEN WATER BUDGET

36-year mean annual cycle of the *liquid water budget.*

ΔCSM
= Rain + Melt - E_{liquid} - Runoff

Frozen water budget:

ΔSWE = Snowfall - E_{frozen}
- Melt + $SWE_{increment}$

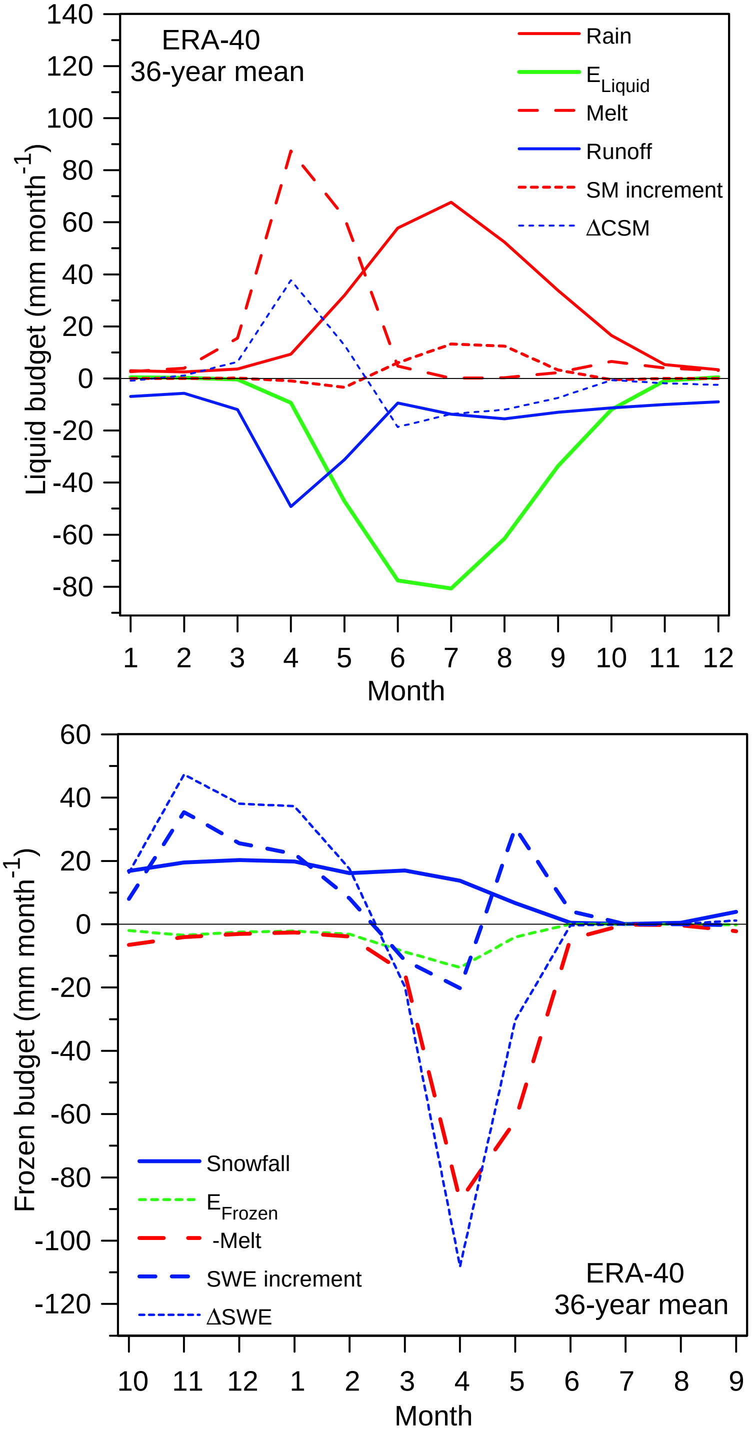


Figure 12. Terms in the liquid (upper panel) and frozen water budget.

Comparison of the ERA-40 water budget with the MAGS water budget climatology.

Mean annual totals (in mm)	ERA-40 Liquid	ERA-40 Frozen	ERA-40 Total	MAGS Climate
Precipitation	323	140	463	422
Evaporation	-327	-38	-366	-274
Melt	194	-194		
Runoff/Stream flow			-207	-176
Analysis increment	17	97	114	
Climate residual				-28
Storage change	0	-2	-2	

ERA-40 total water budget has 10% more precipitation and 18% more runoff than the MAGS ‘climate’, but 34% more evaporation.

‘Extra’ water comes from the analysis increments (mostly from the snow analysis).

The MAGS water budget itself has a -28mm residual (-7%), suggesting perhaps that “observed” precipitation is underestimated.

Temperature comparison

ERA-40 has a *realistic interannual variability*, but it is slightly cool in summer and warm in winter by 2-3K. The model temperature bias, shown as heavy dashes, has a distinct seasonal pattern, which is similar in all years.

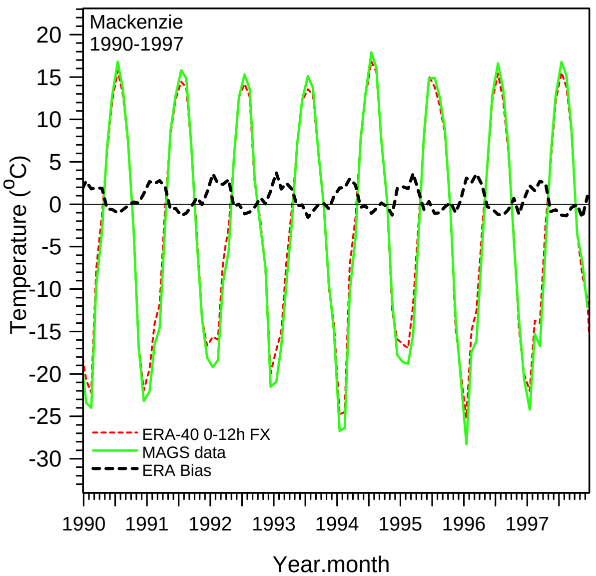


Figure 13. Comparison of temperature for the Mackenzie basin with ERA-40.

Mean annual cycle of the MAGS basin temperature, and the mean bias.

The variability in the bias is smaller than the variability in temperature, which is largest in winter.

ERA-40 has a distinct warm bias in winter from December to April, peaking in March at +3K. There is a sharp shift in May to a cold bias, which peaks in July at -1.5K.

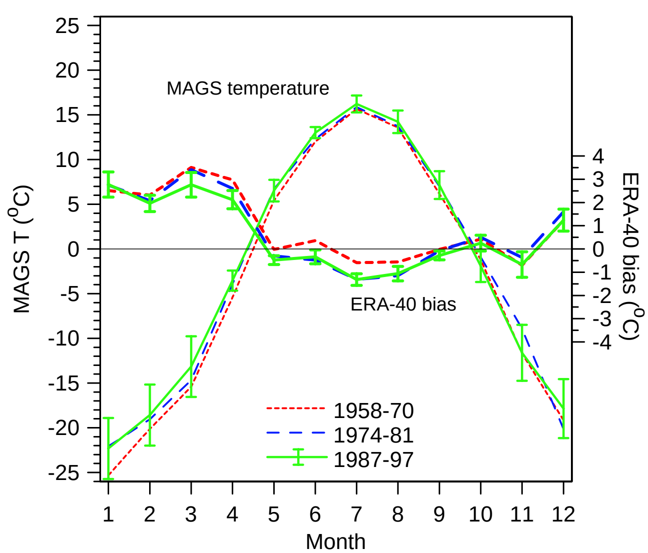


Figure 14. Annual cycle of temperature and ERA-40 bias for three periods.

Sub-basin comparison of precipitation

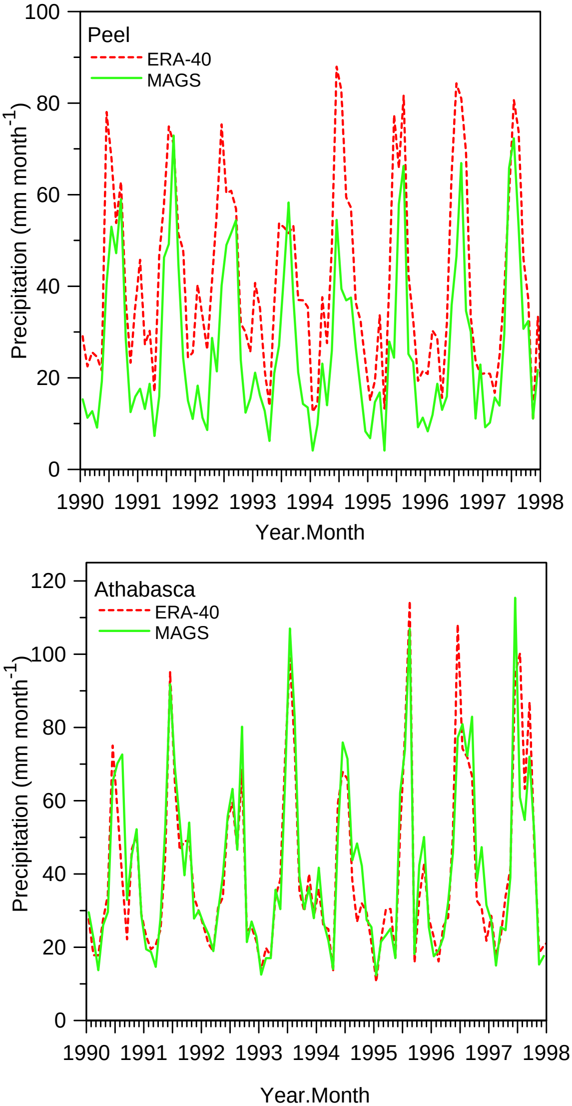


Figure 15. Time-series of precipitation for Peel and Athabasca sub-basins from ERA-40 0-12h FX and MAGS data.

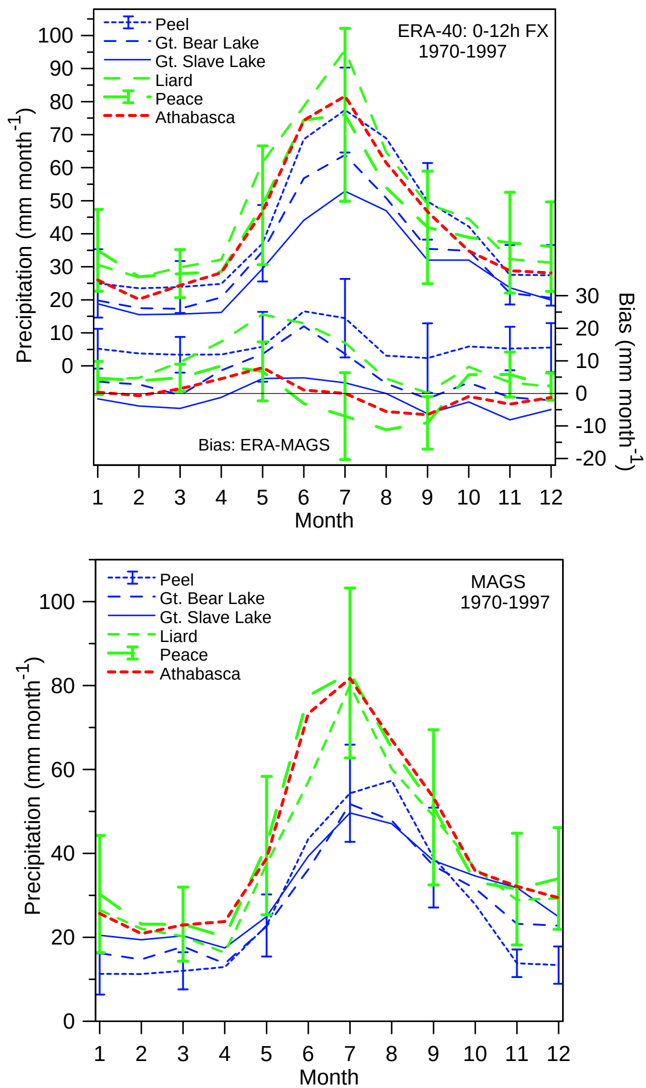


Figure 16. Mean annual cycle of precipitation for Mackenzie sub-basins from MAGS estimate (lower) and ERA-40 (upper), with model bias (right-hand-scale).

Temperature

Warm model bias from December to April and cool bias from May to November.

The basins with the warmest bias in winter (Athabasca and Peace) are those with over 90% cover of high vegetation (forests), which have the lowest albedo (0.15 for this vegetation class with snow underneath.

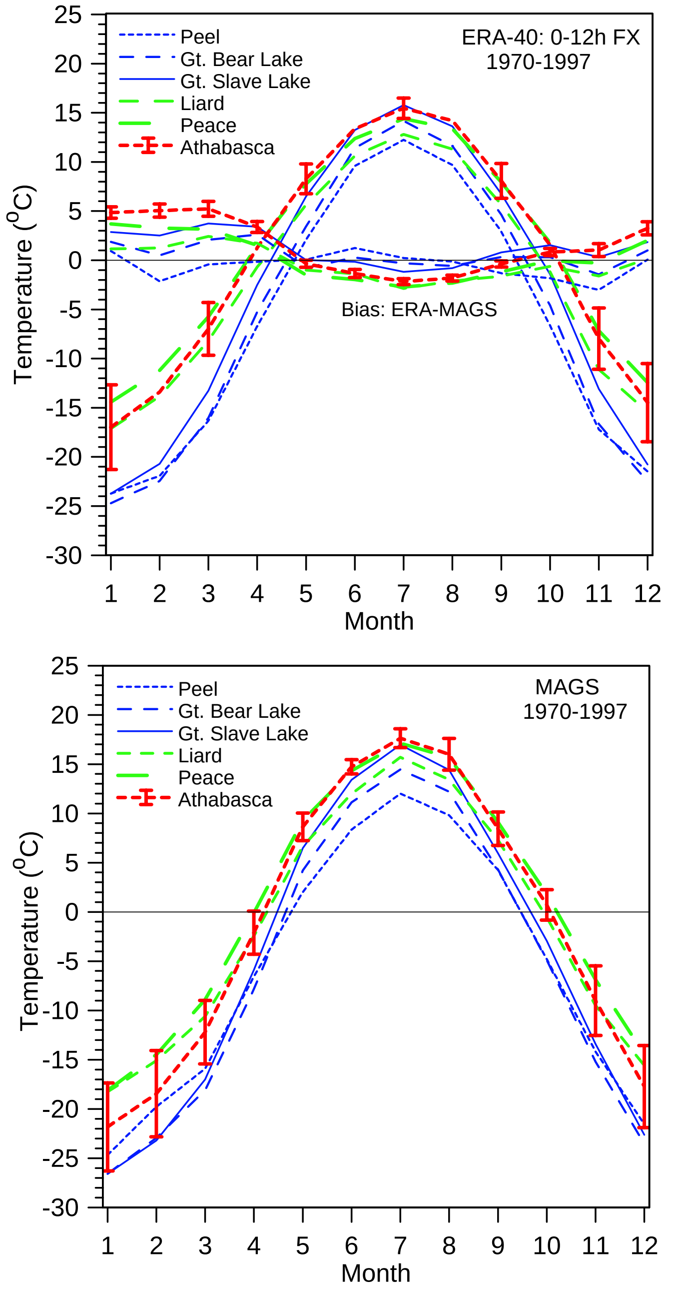


Figure 17. Mean annual cycle of temperature for Mackenzie sub-basins from MAGS observations (lower) and (upper) ERA-40, showing also model bias.

Soil temperature and Permafrost

Large difference in deep soil temperature across the sub-basins

The northern basins remain largely frozen at depth even in summer, while the western basin of the Peace, the warmest basin, only just freezes at this depth in winter.

The Liard has a very small annual cycle of deep soil temperature, because the freeze-thaw cycle introduces a large thermal inertia

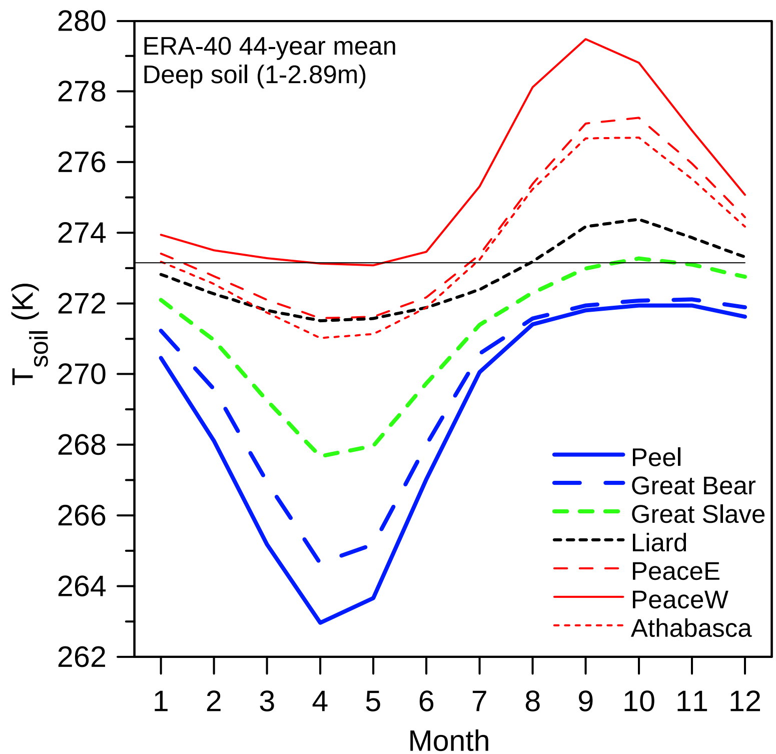


Figure 18. Seasonal cycle of deep soil temperature in ERA-40 for sub-basins.

Conclusions

Assessed systematic biases in temperature and precipitation, and the surface water budget of ERA-40 for the Mackenzie River basin by comparing monthly averages with basin averages of surface observations of temperature, precipitation, evaporation and streamflow from the Mackenzie GEWEX Study (MAGS).

– Bias and spinup of precipitation are correlated with the analysis increment of atmospheric total column water vapor (TCWV): large changes in early part of reanalysis
– The analysis removes TCWV, which reduces precipitation in the analysis cycle, and the model then spins up to restore precipitation.
– The monthly precipitation analysis is best for the most recent decade, when the bias of the 0-12h forecast precipitation is only a few percent higher than the MAGS observations.

– Annual evapotranspiration from ERA-40 is higher than a MAGS estimate by 30% : ERA-40 evaporation is probably biased high.

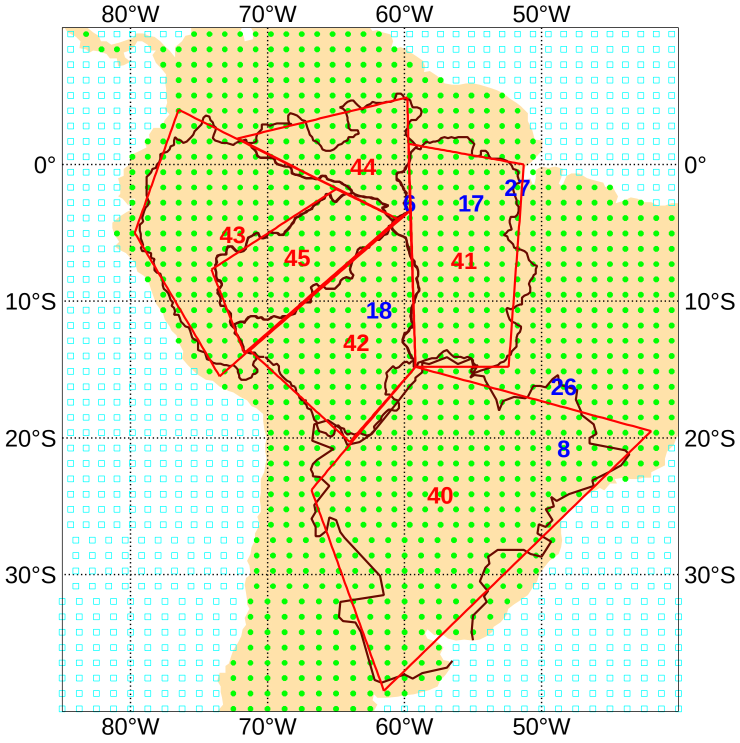
– For the Mackenzie, ERA-40 has a distinct seasonal temperature bias, with a +2 to 3K warm bias from December to April, and a cool bias in summer, reaching -1.5K in July. This signal is most pronounced for the heavily forested southern basins.

ERA40 basin averages for S. America. Alan Betts and Pedro Viterbo

Basins as implemented for S. America showing ERA40 grid, including 5 sub-basins for the Amazon and the Rio de la Plata

#	40	Rio de la Plata
#	41	Amazon: Xingu + Tapajoz+ Trombetas+Uatuma
#	42	Amazon: Madeira River
#	43	Amazon: Solimoes
#	44	Amazon: Negro
#	45	Amazon: Purus/Jurua+

[Amazon basin coordinates based on file from Brad Newton
Rio de la Plata basin definition from Hugo Berberry]

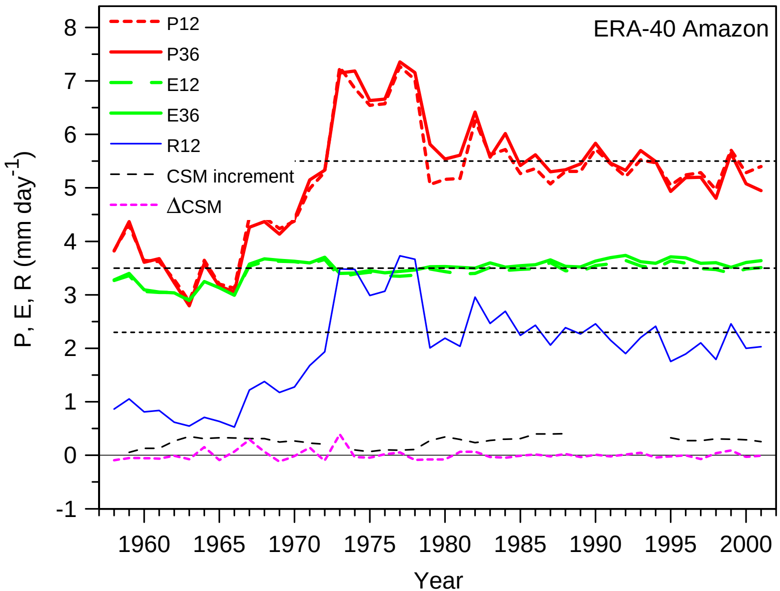


Amazon annual water balance in ERA40

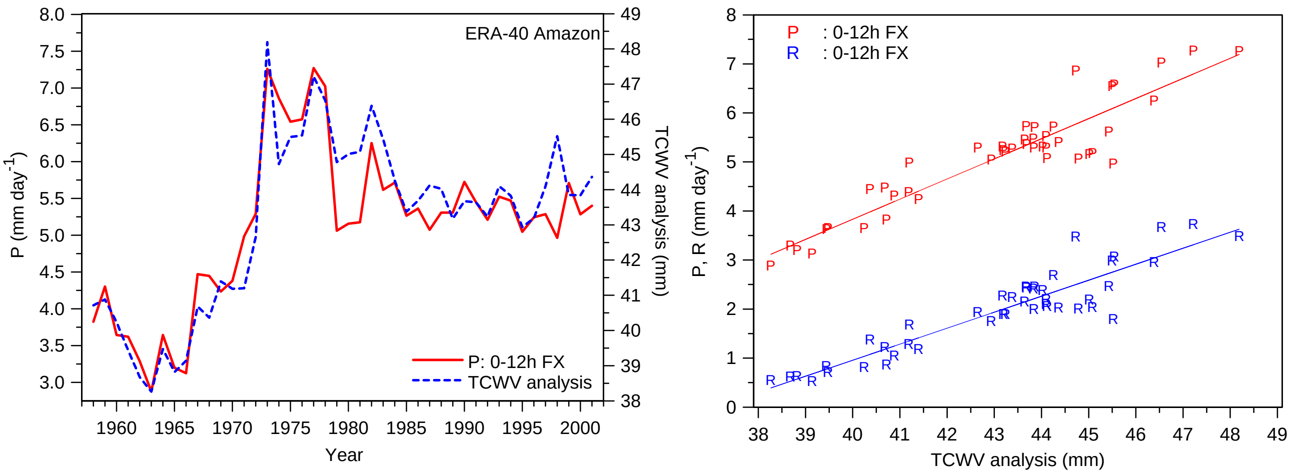
– Little spinup: 0-36h

– Large drifts with time

– ‘Nudging’ of SM small



Problem is atmospheric water vapor analysis



Precipitation, P, Runoff, R and total column water vapor, TCWV – are correlated

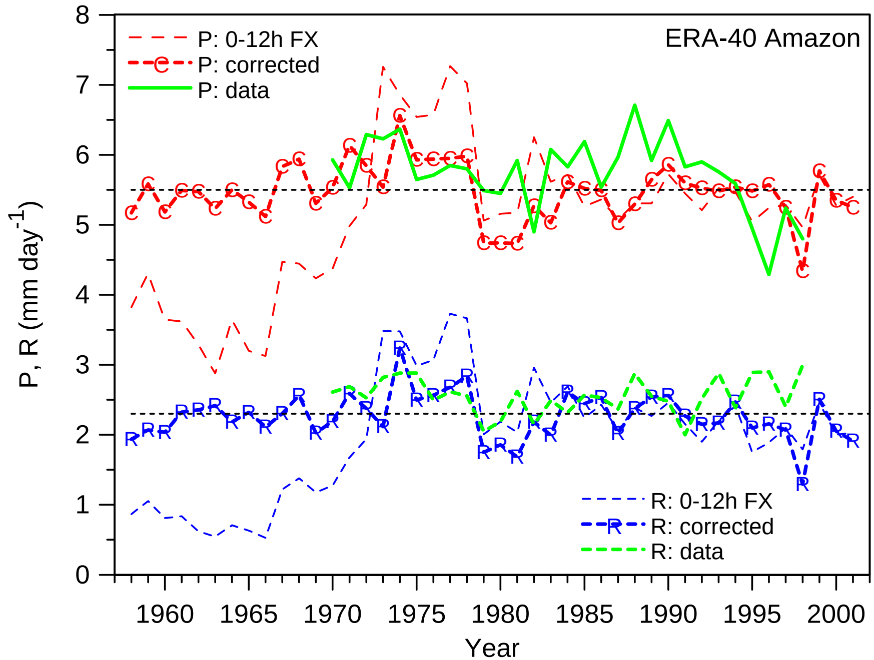
– TCWV varies by a lot over the 44 years, with different satellite data [and some data errors in the pre-satellite period]

Simple correction using regression lines

– ‘Correction’ removes long-term drifts

– mean P and R consistent with data

– interannual variability ’lost’



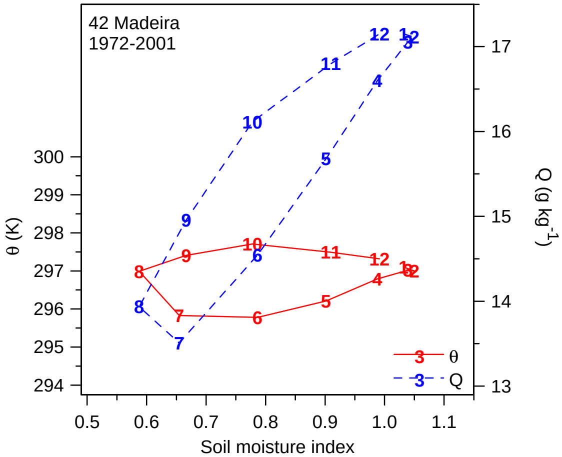
[Data: Marengo et al. 2004]

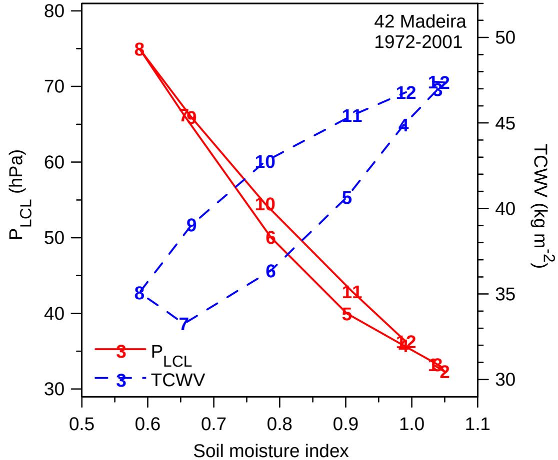
Madeira basin: 1971-2001: mean annual cycle

Coupling of physical processes

SMI to P_{LCL}

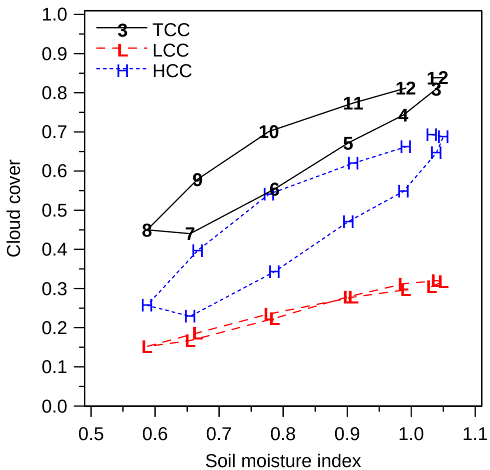
[TCWV to Q]

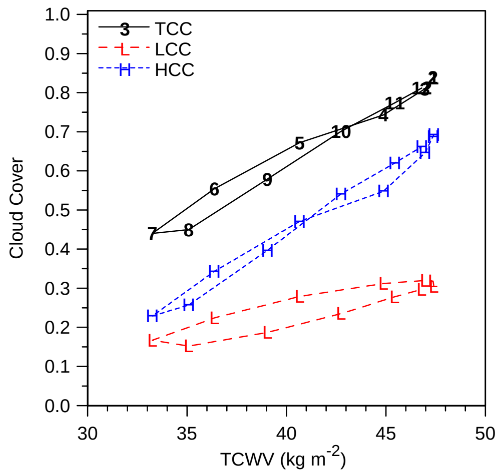




SMI to LCC

TCWV to TCC

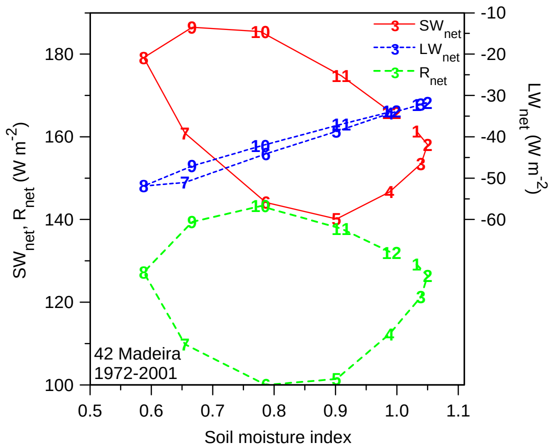


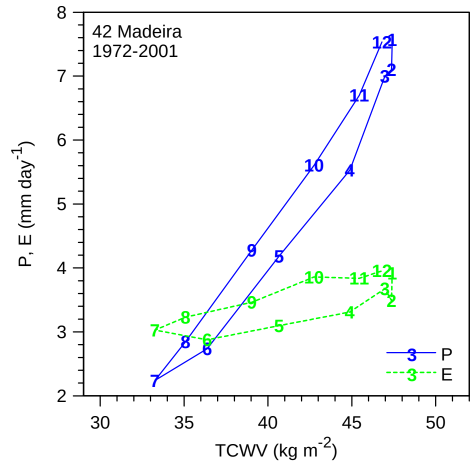


Surface radiation and water budget, SMI, TCWV, moisture convergence and cloud cover

SMI to LW_{net}

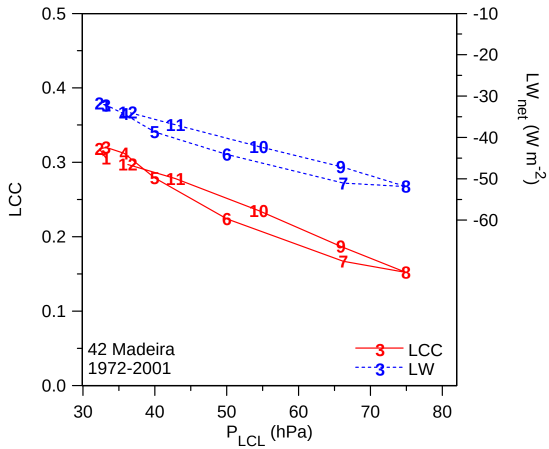
TCWV to P

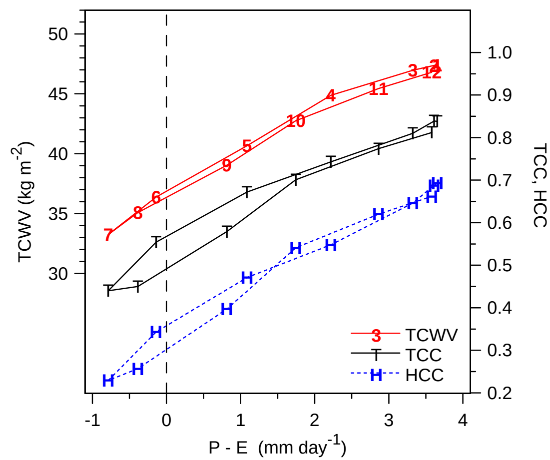




P_{LCL} to LW_{net} and LCC

(P-E) to TCWV HCC and TCC





Conclusions – Amazon in ERA-40

– 0-36h Spinup small

– Drift of water budget 1958-1972 very large

– Associated with TCWV analysis problems

– Retrospective ‘correction’ removes also interannual information

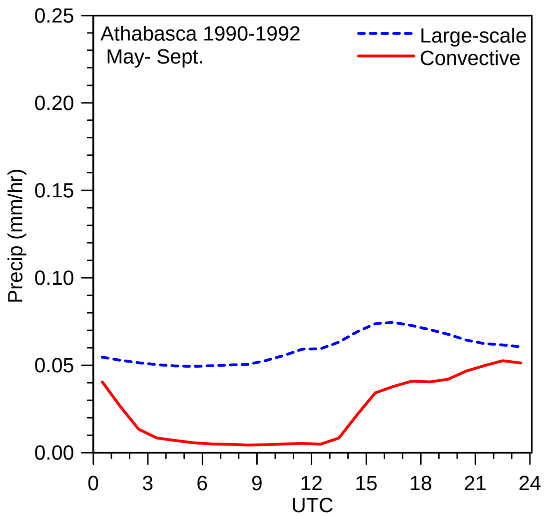
Monthly mean cycle shows coupling of

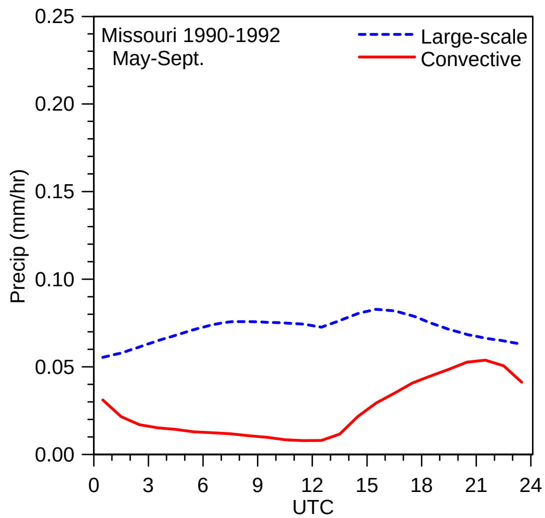
a) Surface processes to CBL and LW budget
[SMI to P_{LCL}, LW_{net}, LCC]

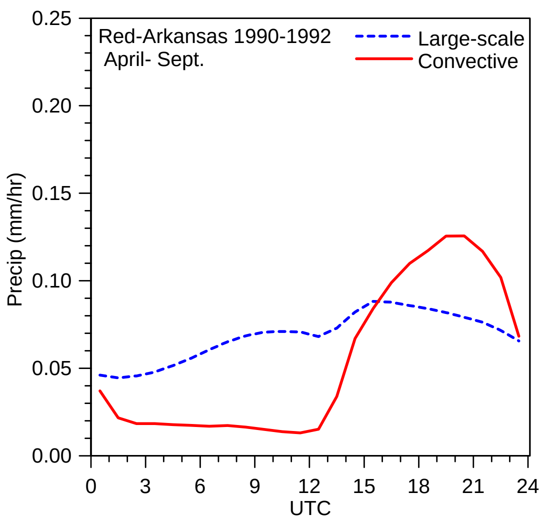
b) Atmospheric dynamic processes [TCWV to P and TCC]

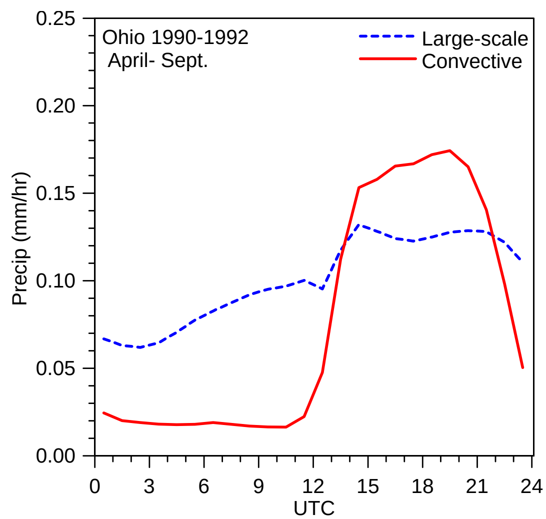
Diurnal cycle of convective and large-scale precipitation

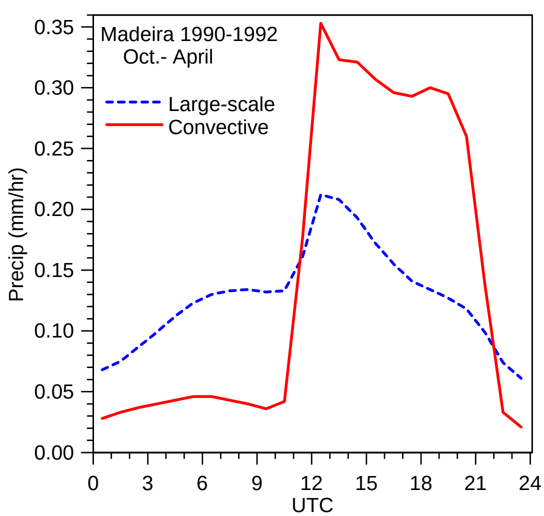
[12-24FX]

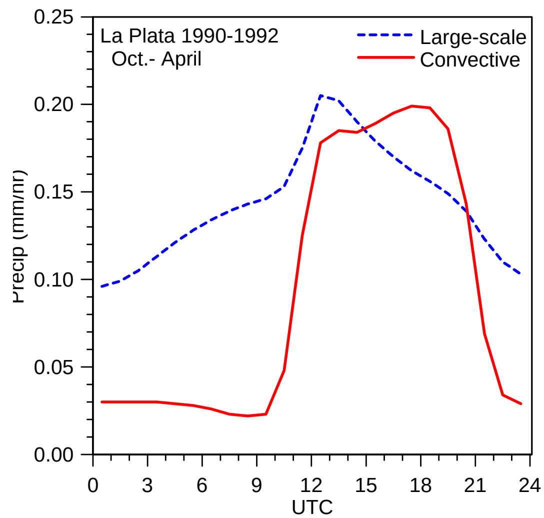












Tendency for precipitation peaks a few hours after sunrise

Conclusions: River basin budgets

– Integrate over regions, simple tractable time-series with no loss of model time or space resolution
[Hourly data is 1GB/basin/45years]

– Useful to assess model systematic biases against climate and satellite data: see ERA40 precipitation drifts with time
[water vapor analysis issues]

– Useful to see and understand water and energy cycle, and 'calibrate' against river basin hydrology data
[although ERA40 hydrology is poor]

– Useful in studying model diurnal and seasonal cycles
[ERA40 diurnal cycle of precipitation unrealistic]

– Useful on daily/monthly timescale for studying model physics
[yesterday's talk on cloud-BL-surface coupling]

– Recommend as standard model diagnostics