Hydrological Models and GRACE Satellite Observations in Cold Regions

by

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Workshop Presentation
IP3 in Cold Regions

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Overview

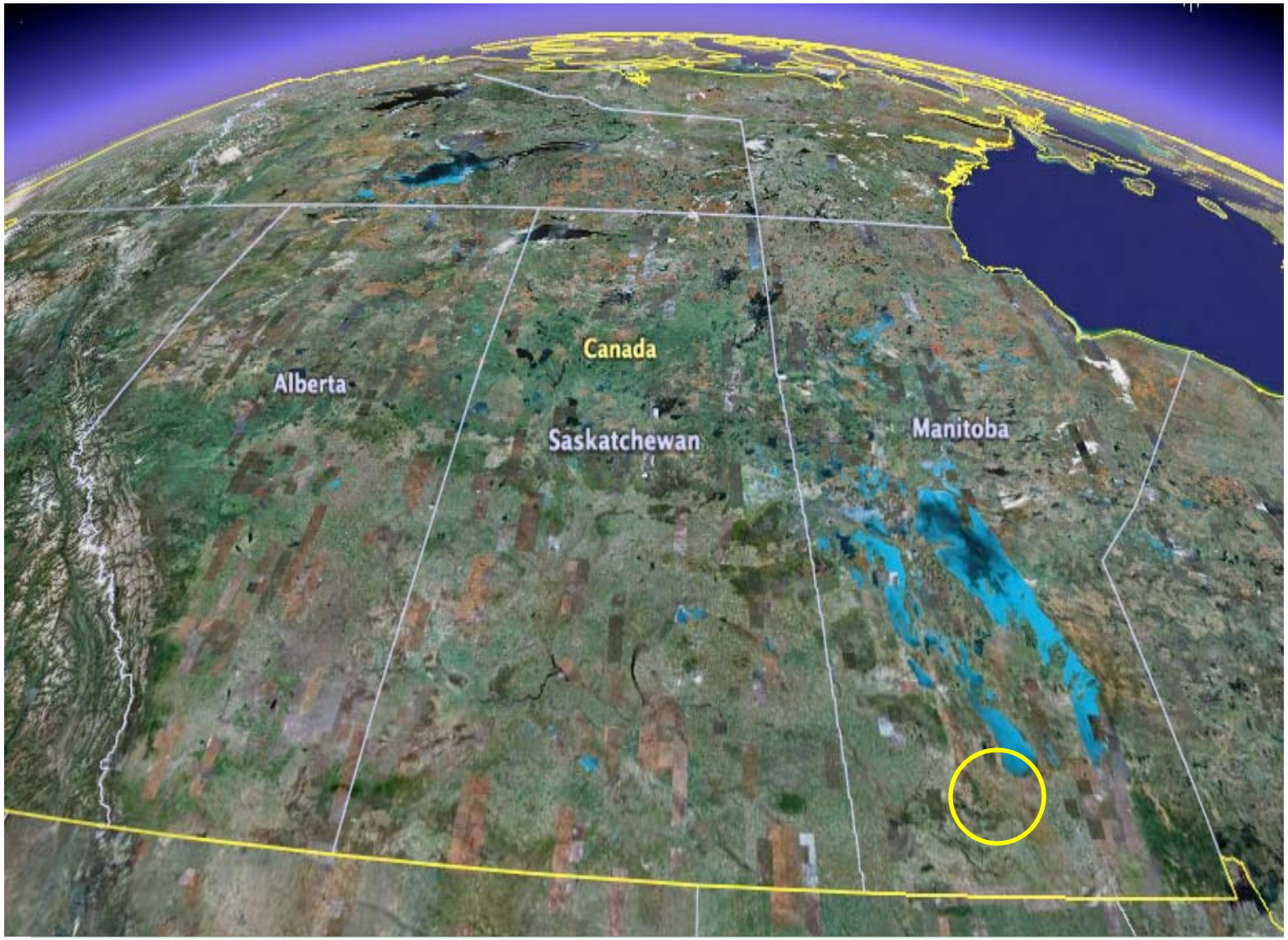
WatFLOW Development

- Adding groundwater for Atmospheric Models (CLASS)
- Coupling improved CLASS Model with Groundwater Model

GRACE Gravity Variation

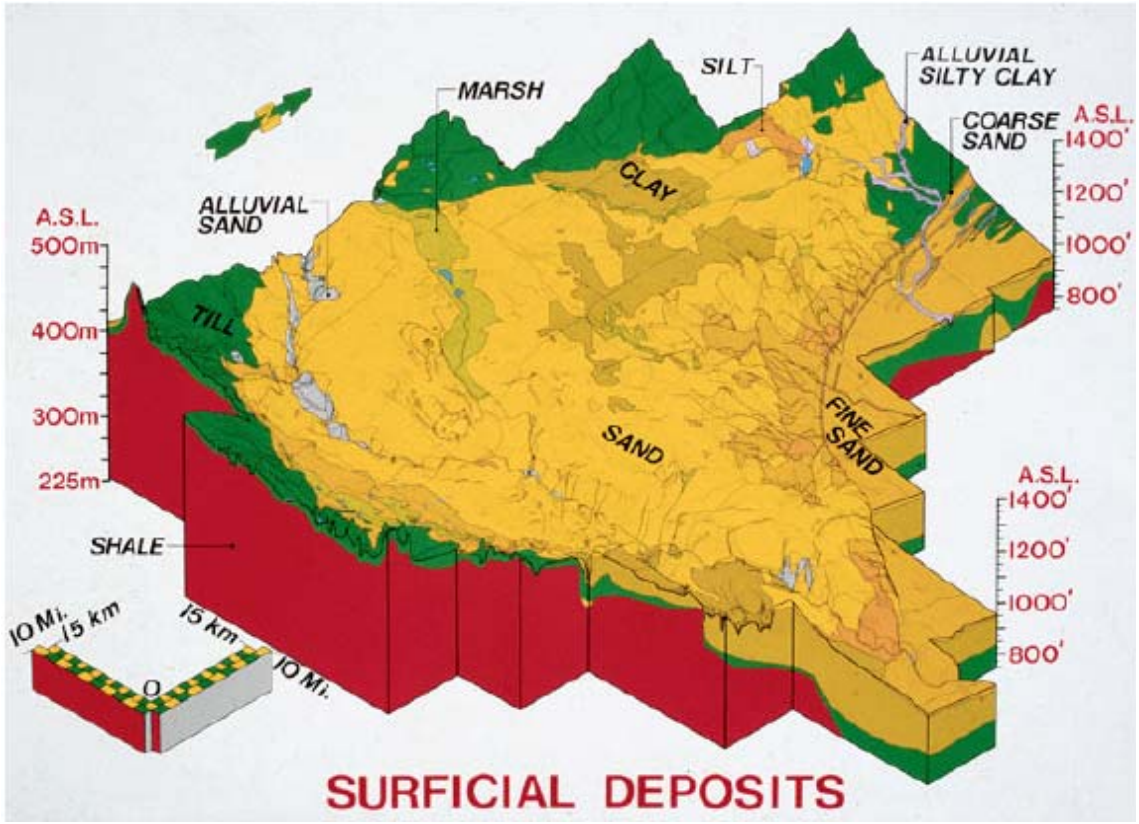
- Assess changes in moisture storage over Western Canada for Drought study
- Hydrological Model Calibration and Validation

Prairie Hydrology



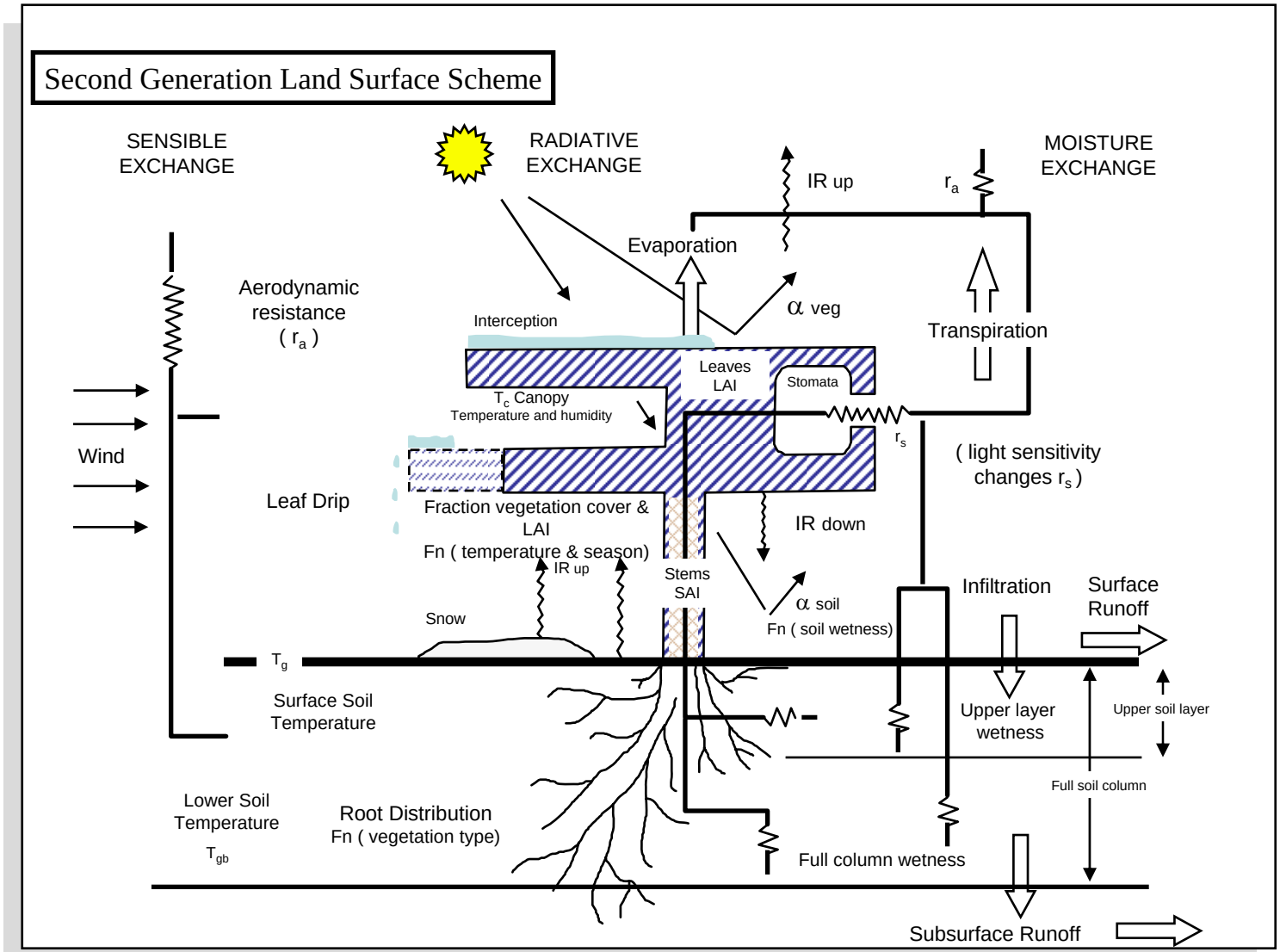
Assiniboine Delta Aquifer

Distribution of Surficial Deposits of the Assiniboine Delta Aquifer

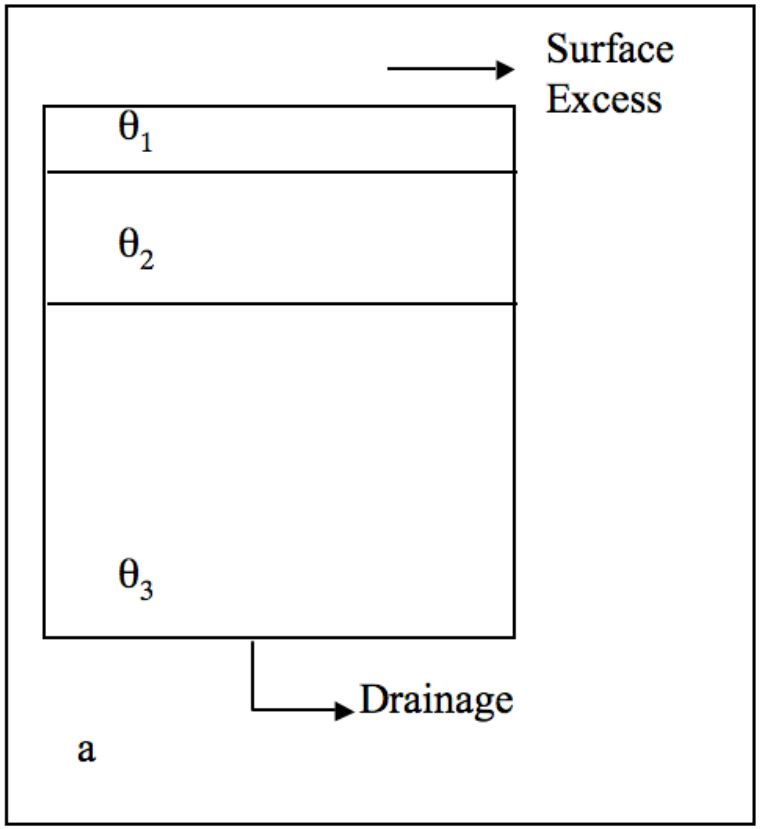


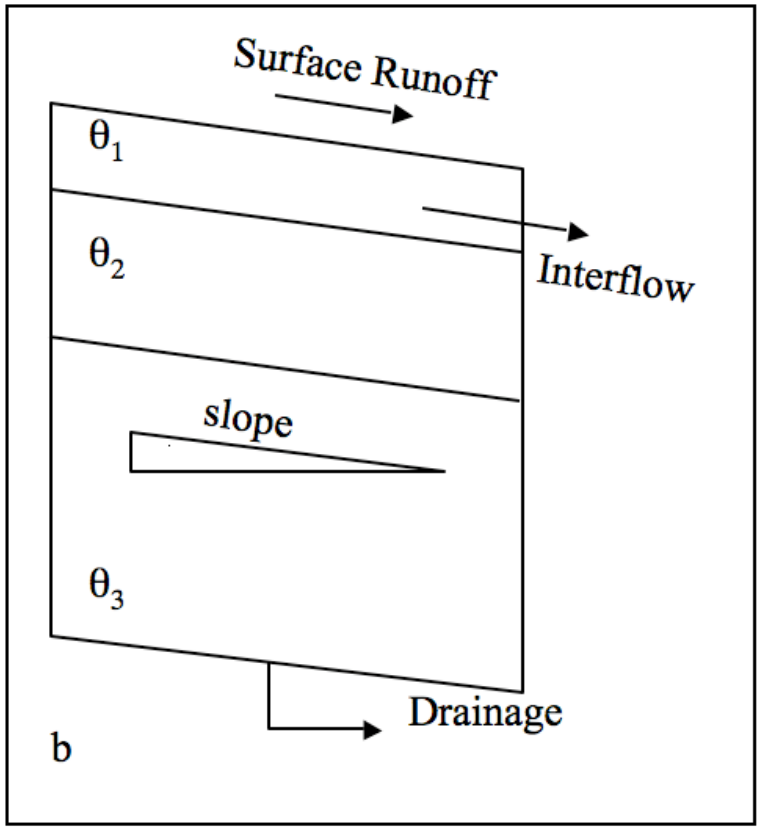
L.H. Frost and F.W. Render, 2002

CLASS

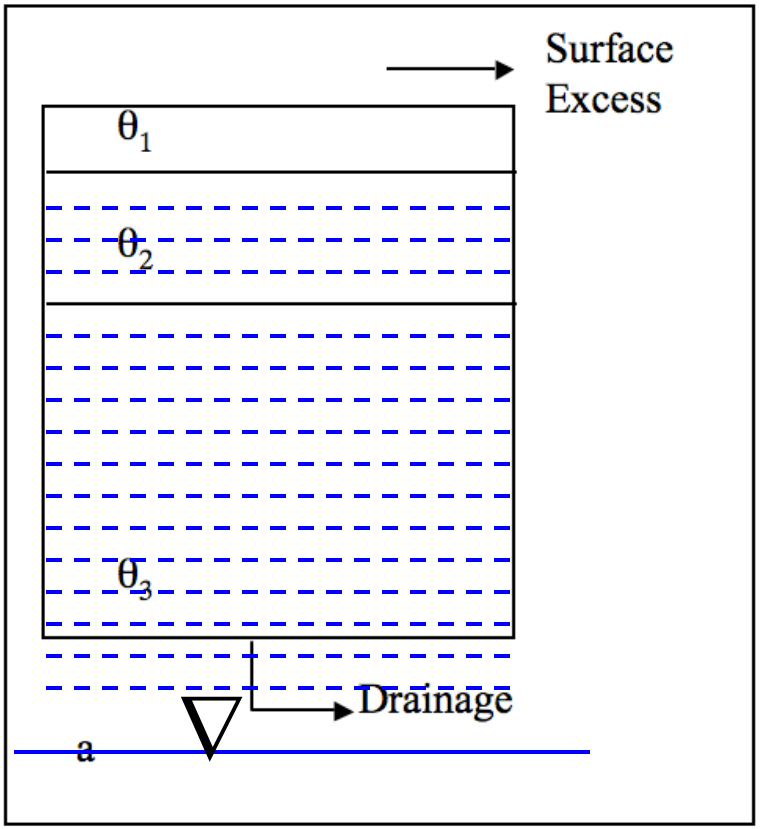

Second Generation Land Surface Scheme
SENSIBLE EXCHANGE
RADIATIVE EXCHANGE
MOISTURE EXCHANGE
IR up
r_a
Evaporation
Aerodynamic resistance (r_a)
α veg
Interception
Transpiration
Leaves LAI
Stomata
T_c Canopy Temperature and humidity
r_s
(light sensitivity changes r_s)
Wind
Leaf Drip
Fraction vegetation cover & LAI
Fn (temperature & season)
IR down
IR up
Stems SAI
α soil
Fn (soil wetness)
Infiltration
Surface Runoff
Snow
T_g
Surface Soil Temperature
Upper layer wetness
Upper soil layer
Full soil column
Lower Soil Temperature
T_{gb}
Root Distribution
Fn (vegetation type)
Full column wetness
Subsurface Runoff

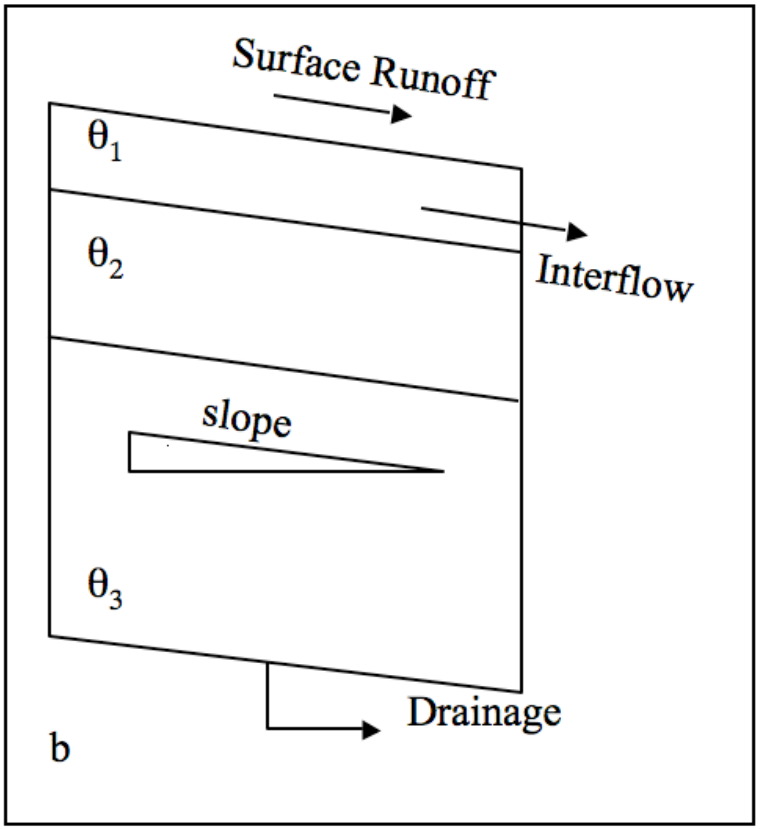
CLASS/WatCLASS



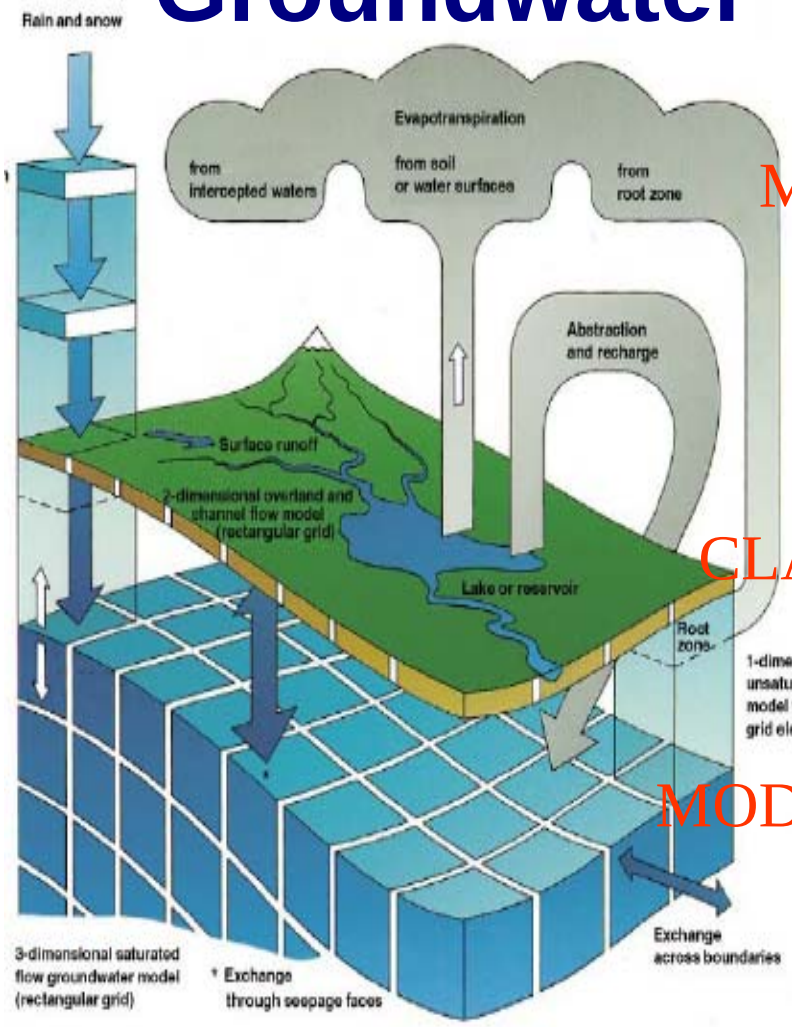


Coupling CLASS to Groundwater





Coupling CLASS to Groundwater

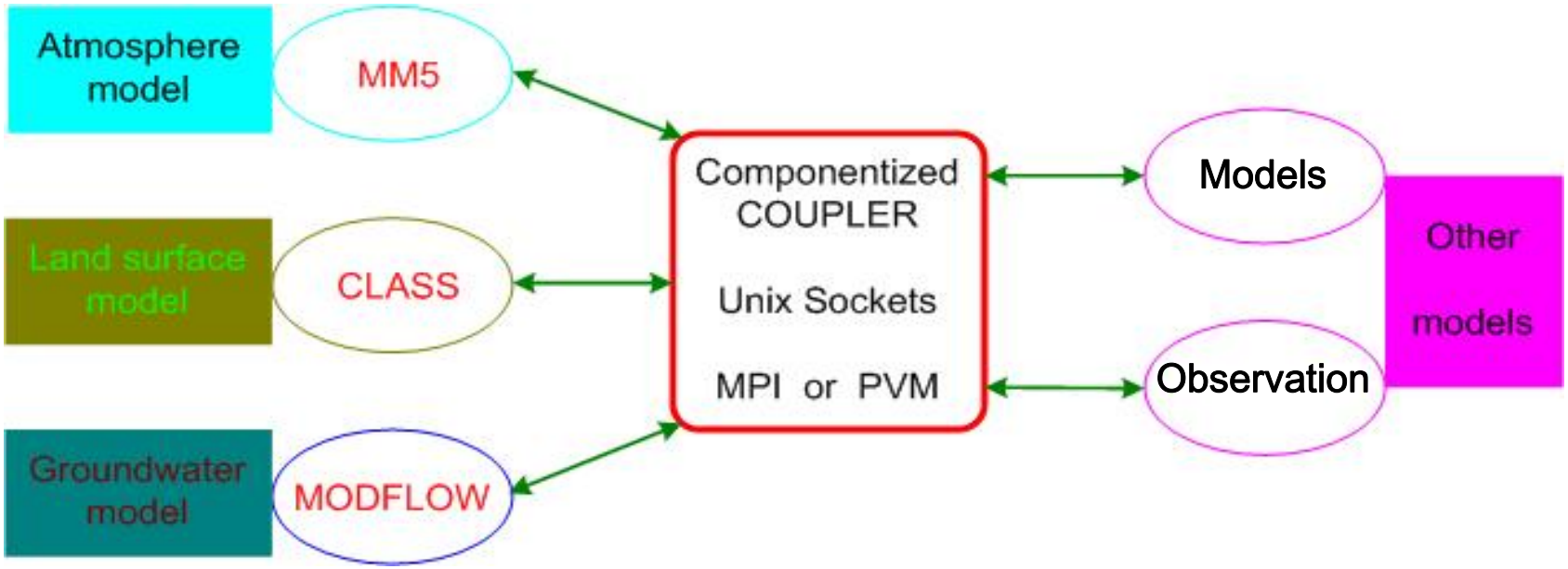


MM5

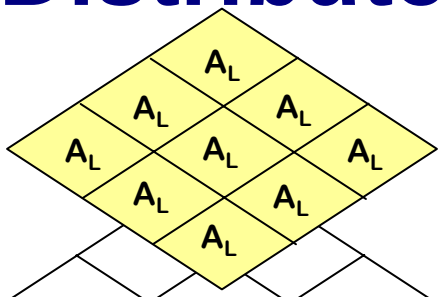
CLASS

MODFLOW

Coupling CLASS to Groundwater



Distributed Water Balance

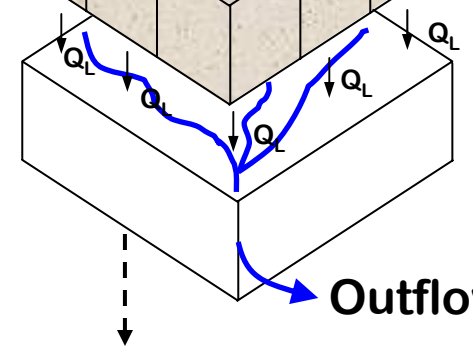


$=A_B$

Atmosphere (A)

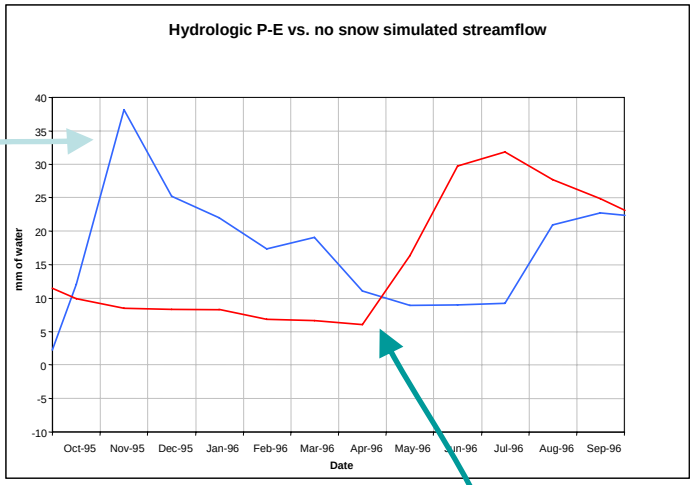
Land Surface (L)

Channel Network (C)



Groundwater flow (G)

P-E



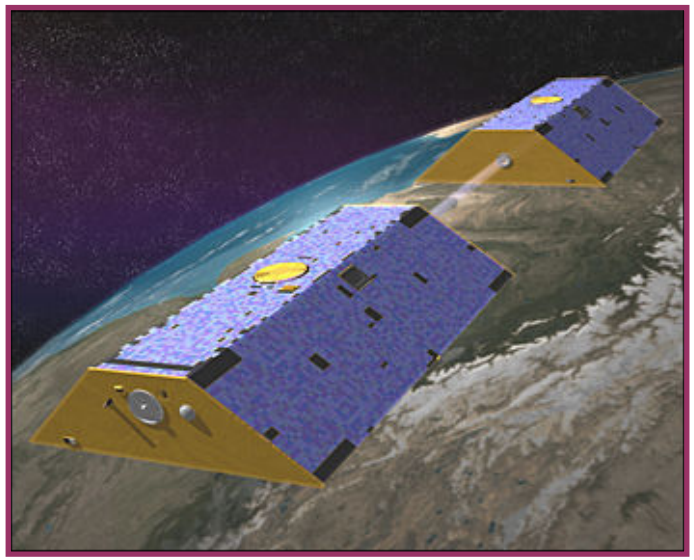
Outflow = Q_L, Runoff = R_L

Outflow Q_B,Runoff $R_B=Q_B/A_B$

GRACE Terrestrial Moisture Changes

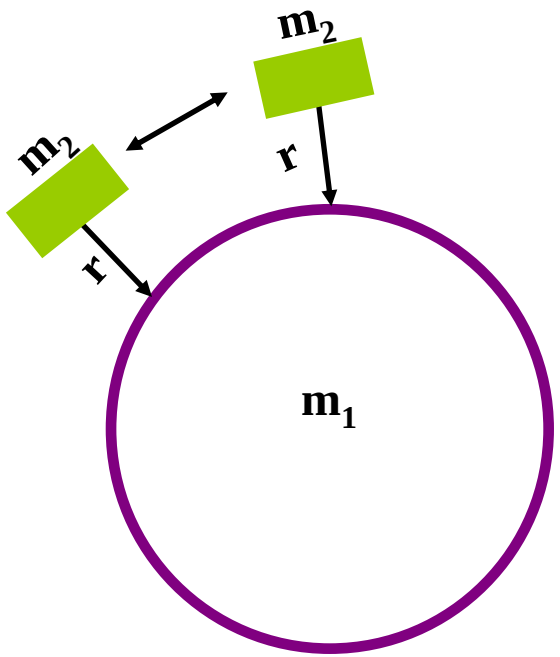
Introduction

- Twin GRACE Satellites
- Launch on 2002 March 17
- Flying approximately 220 km apart
- Altitude of 400-500 km

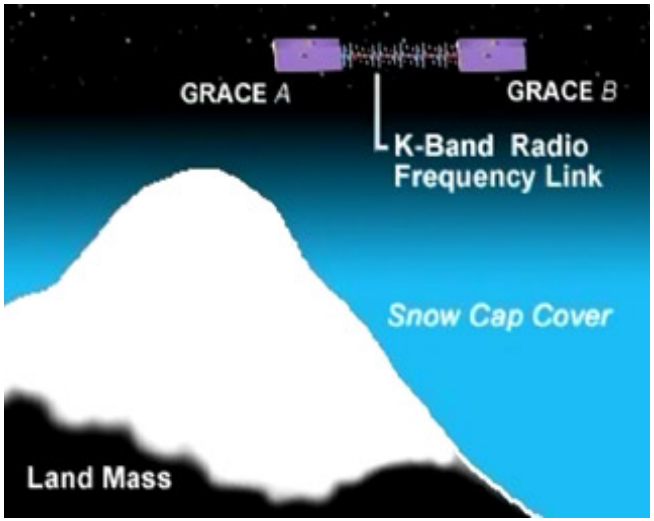


Newton's Law of Gravitation

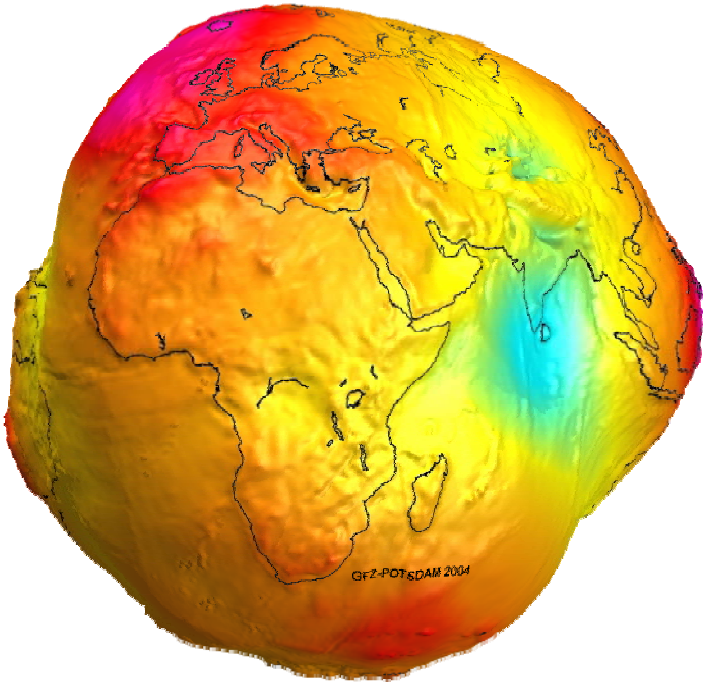
$$F = k\frac{m_1 m_2}{r^2}$$



GRACE Primary Mission



Gravity Model



- Develop geoid from averages over 5 year life
- Monthly variations related to surface moisture changes

Creation of Earth Geopotential Map

Time-variable geopotential δG(*t*) solution of Laplace Equation

$$\delta G(t) = \sum_{n=1}^{N} \sum_{m=0}^{n} (\delta C_{nm}(t) \cos m\lambda + \delta S_{nm}(t) \sin m\lambda) P_{nm}(\cos\theta)$$

where:
l is the latitude
q is the longitude
m & n are harmonic degree and order
P is Legendre's polynomial

```
FIRST GAA-2_0020_2002306-2002334_EIGEN_G---_0001 SHM     GFZ POTSDAM  20040202
CMMNT non-tidal atmosphere geopotential coefficients averaged over certain time period
EARTH 0.3986005000E+15 0.6378137000E+07
SHM     100  100 0.000 fully normalized not applicable
GRCOF2    0    0 -.3188251250478-10 0.0000000000000E+00 0.0000E+00 0.0000E+00 021102.080000
GRCOF2    1    0 -.7438583237668-10 0.0000000000000E+00 0.0000E+00 0.0000E+00 021102.080000
GRCOF2    1    1 0.4678361110968-10 0.2014604919978-09 0.0000E+00 0.0000E+00 021102.080000
GRCOF2    2    0 -.1411794499758-10 0.0000000000000E+00 0.0000E+00 0.0000E+00 021102.080000
GRCOF2    2    1 0.4356184590638-10 0.1462905366788-09 0.0000E+00 0.0000E+00 021102.080000
GRCOF2    2    2 -.6330756103318-10 0.4060580753988-11 0.0000E+00 0.0000E+00 021102.080000
GRCOF2    3    0 -.7360904506598-10 0.0000000000000E+00 0.0000E+00 0.0000E+00 021102.080000
GRCOF2    3    1 -.1990737612938-10 0.2328690765848-10 0.0000E+00 0.0000E+00 021102.080000
GRCOF2    3    2 -.4906018784608-10 -.1809146693528-10 0.0000E+00 0.0000E+00 021102.080000
GRCOF2    3    3 0.2337280512978-10 0.2524744711298-10 0.0000E+00 0.0000E+00 021102.080000
GRCOF2    4    0 0.7723251111568-10 0.0000000000000E+00 0.0000E+00 0.0000E+00 021102.080000
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GRCOF2    5    2 -.2979403861138-10 -.1466665501228-10 0.0000E+00 0.0000E+00 021102.080000
```
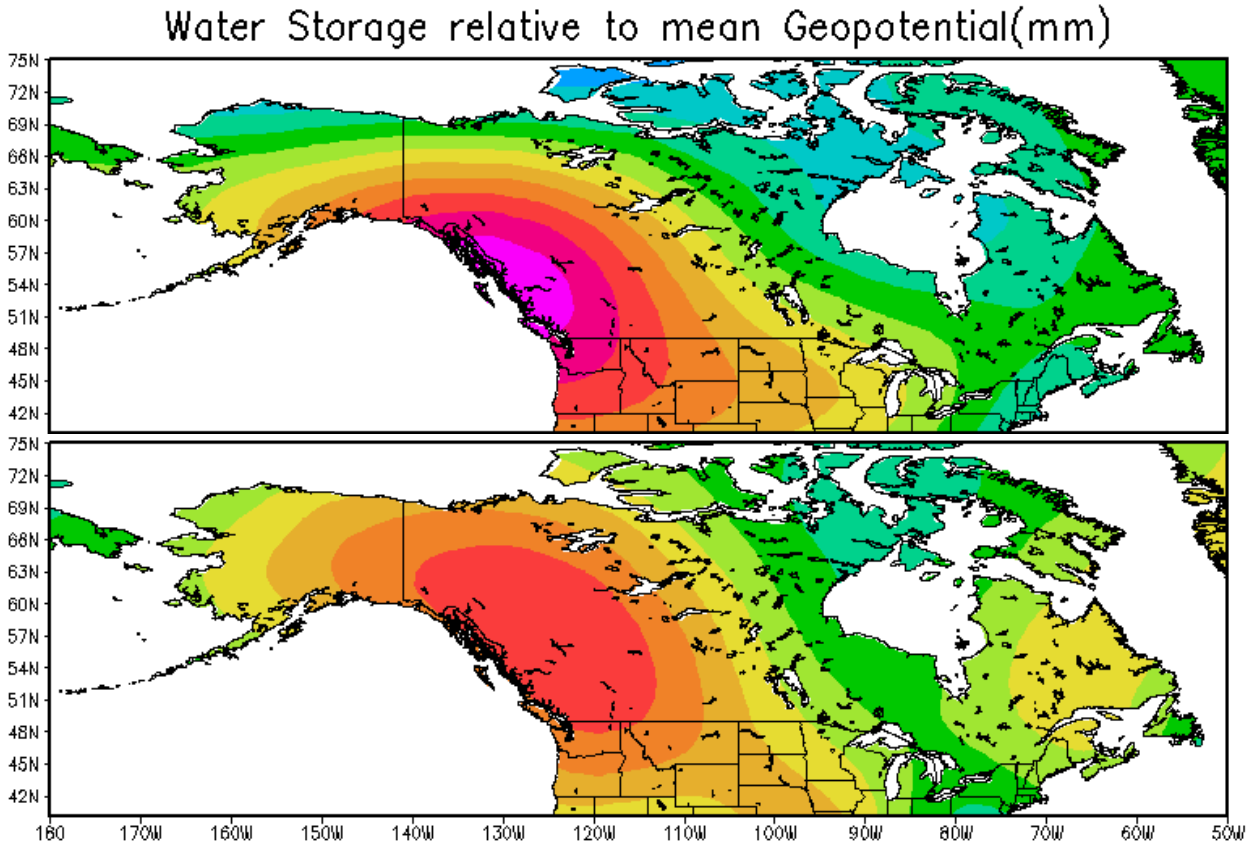
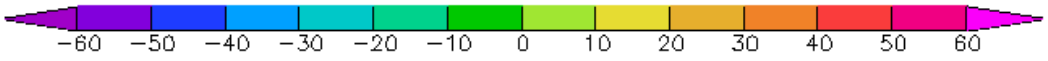

Monthly Difference Result



April 2002

April 2003



mm of Equivalent water thickness

Water Balance Methods

Atmospheric Moisture Budget:

$$\langle P - E \rangle_a = - \langle \partial q/\partial t \rangle - \langle \nabla \bullet \mathbf{Q} \rangle$$

Where: (P-E) = difference between precipitation and evapotranspiration,
q = the vertically-integrated vapour mass or precipitable water,
$\nabla \bullet$Q = the moisture flux divergence,
Q = qV ; V is wind speed

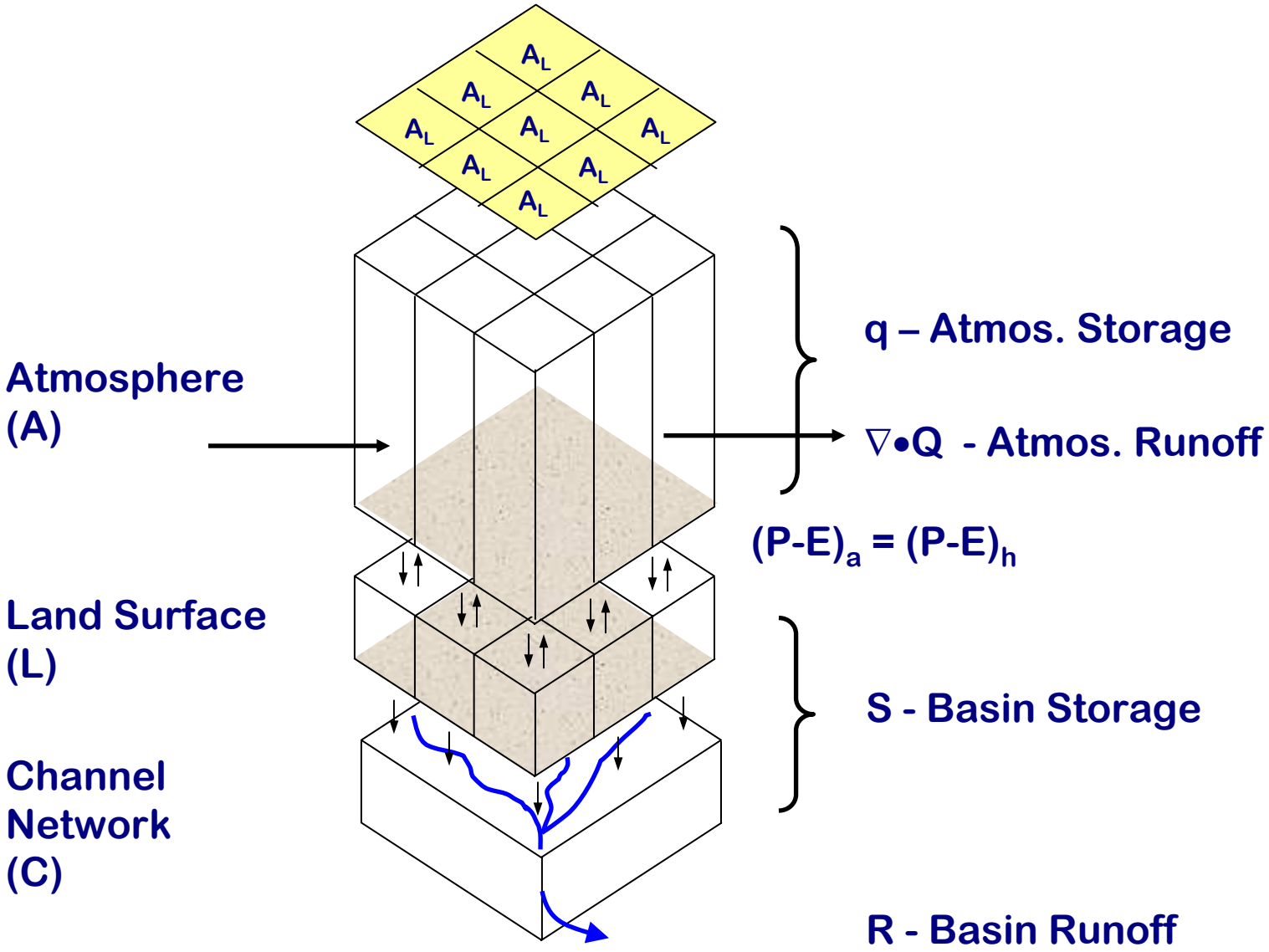
Hydrologic Water Budget:

$$\langle P - E \rangle_h = \langle R \rangle + \langle \partial S/\partial t \rangle$$

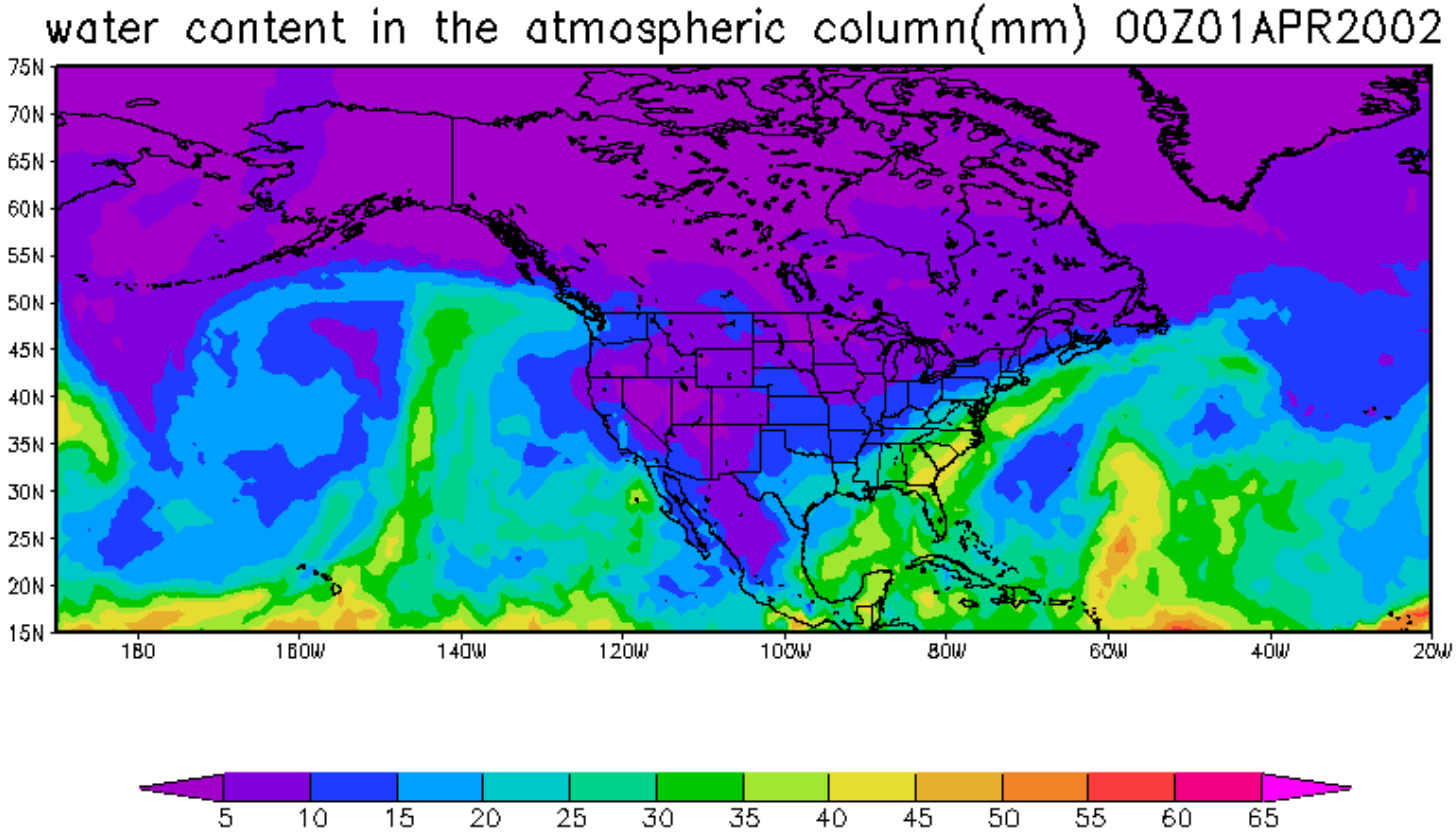
where: S = surface water storage
R = basin runoff

Grace Result := $\langle \partial S/\partial t \rangle + \langle \partial q/\partial t \rangle$

Water Balance Methods

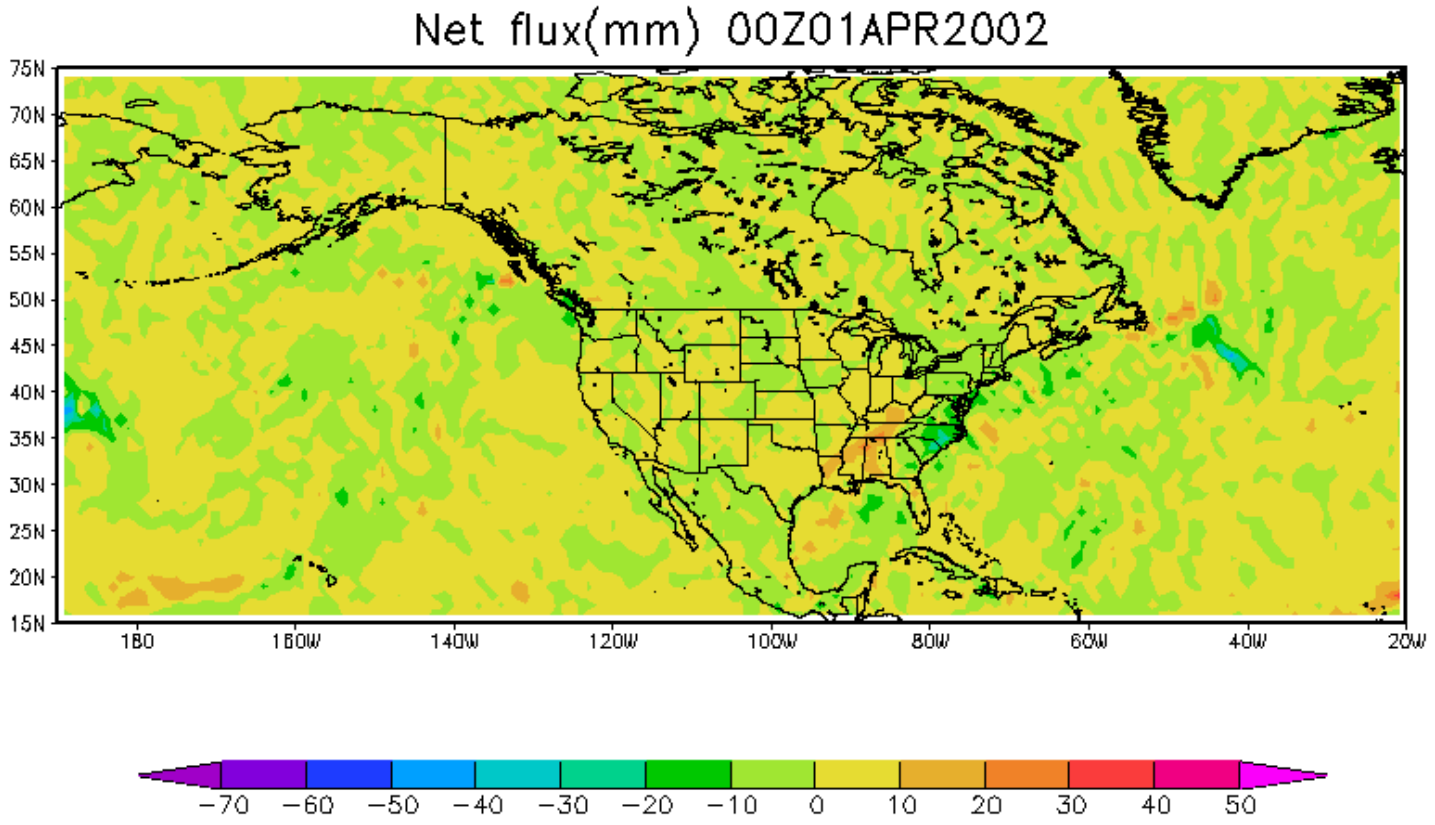


q - Atmospheric Storage



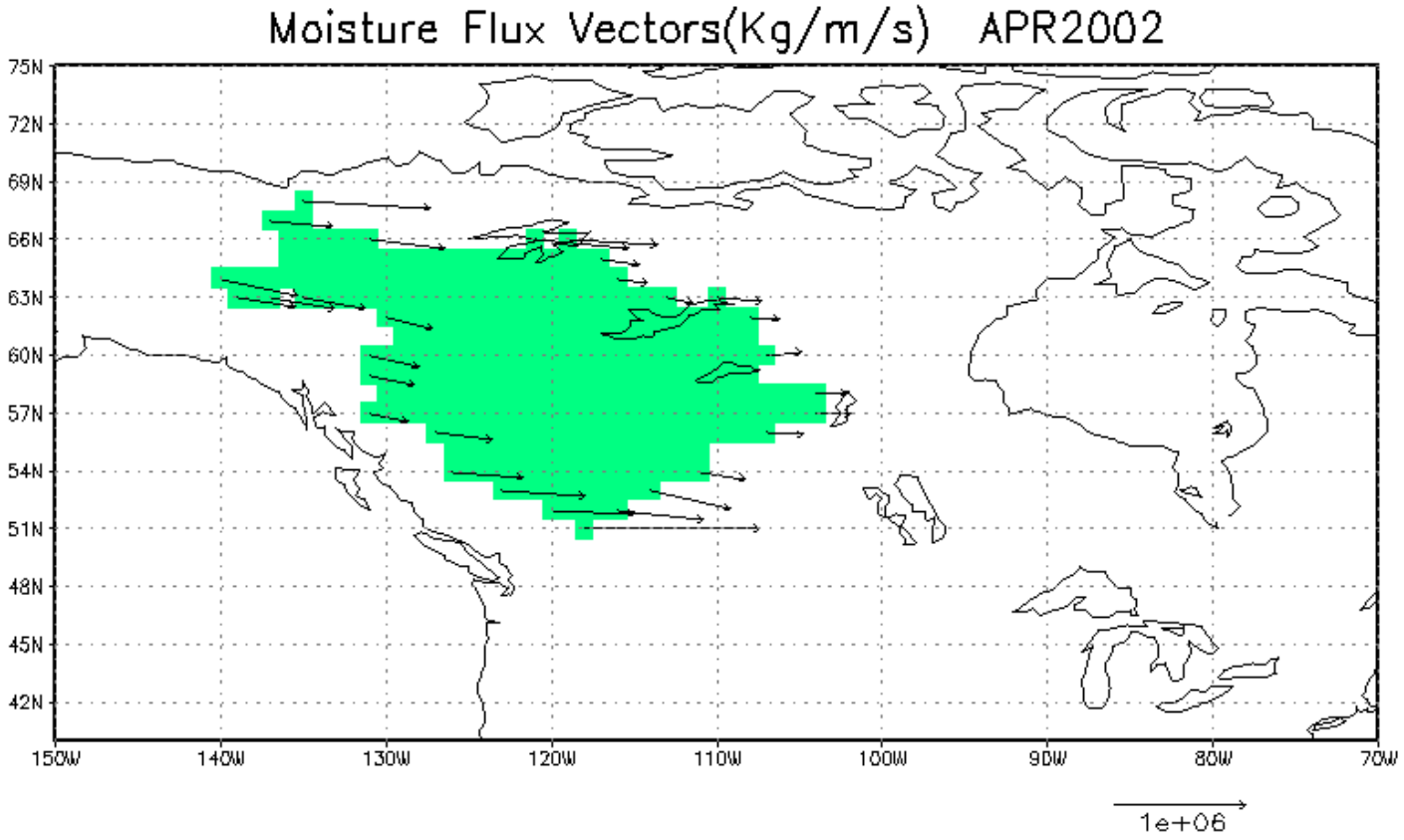
Data Source: CMC 4x Daily Analysis

∇·Q - Atmospheric Runoff



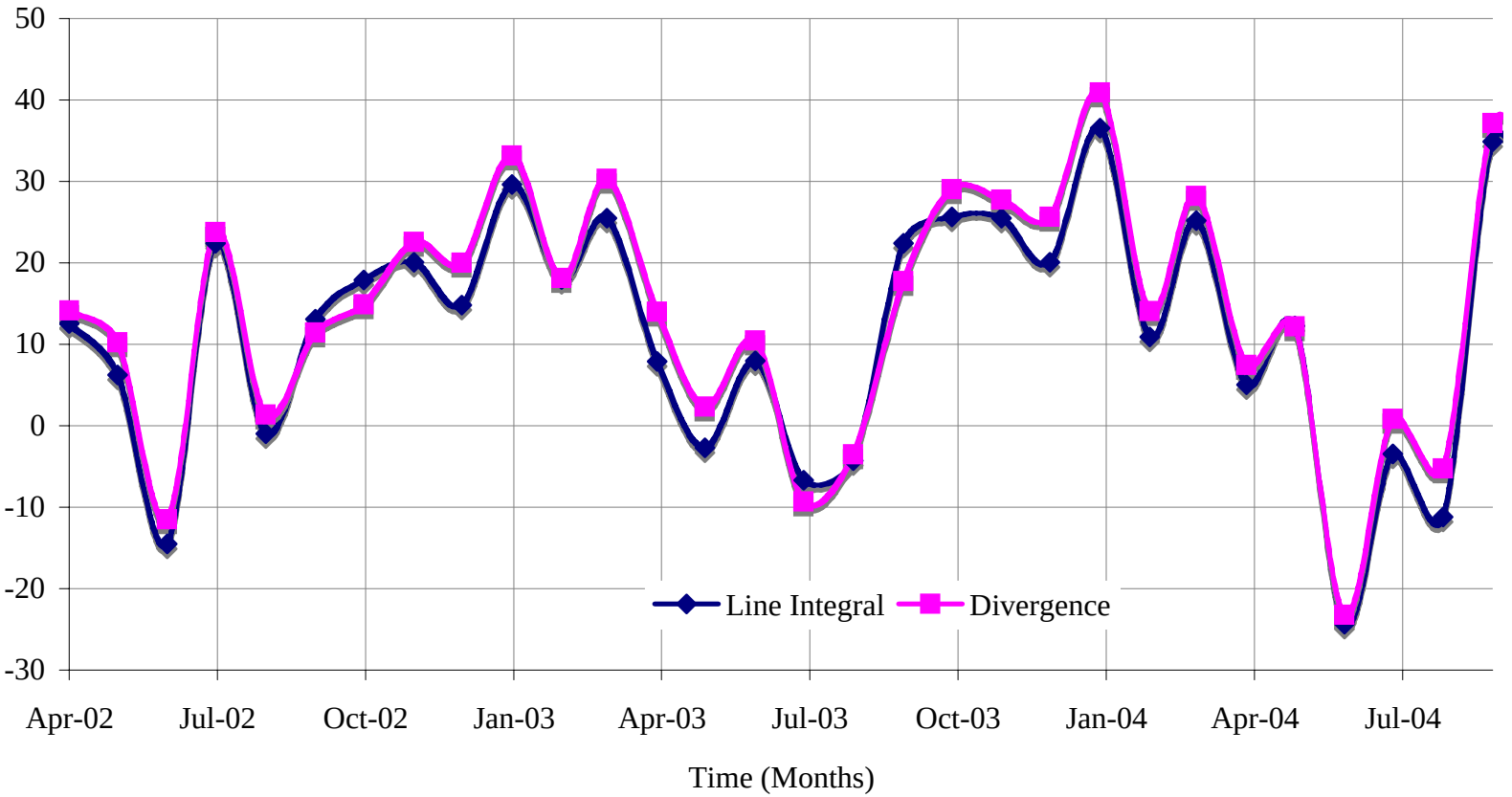
Data Source: CMC 4x Daily Analysis

Alternate ∇•Q - Calculation

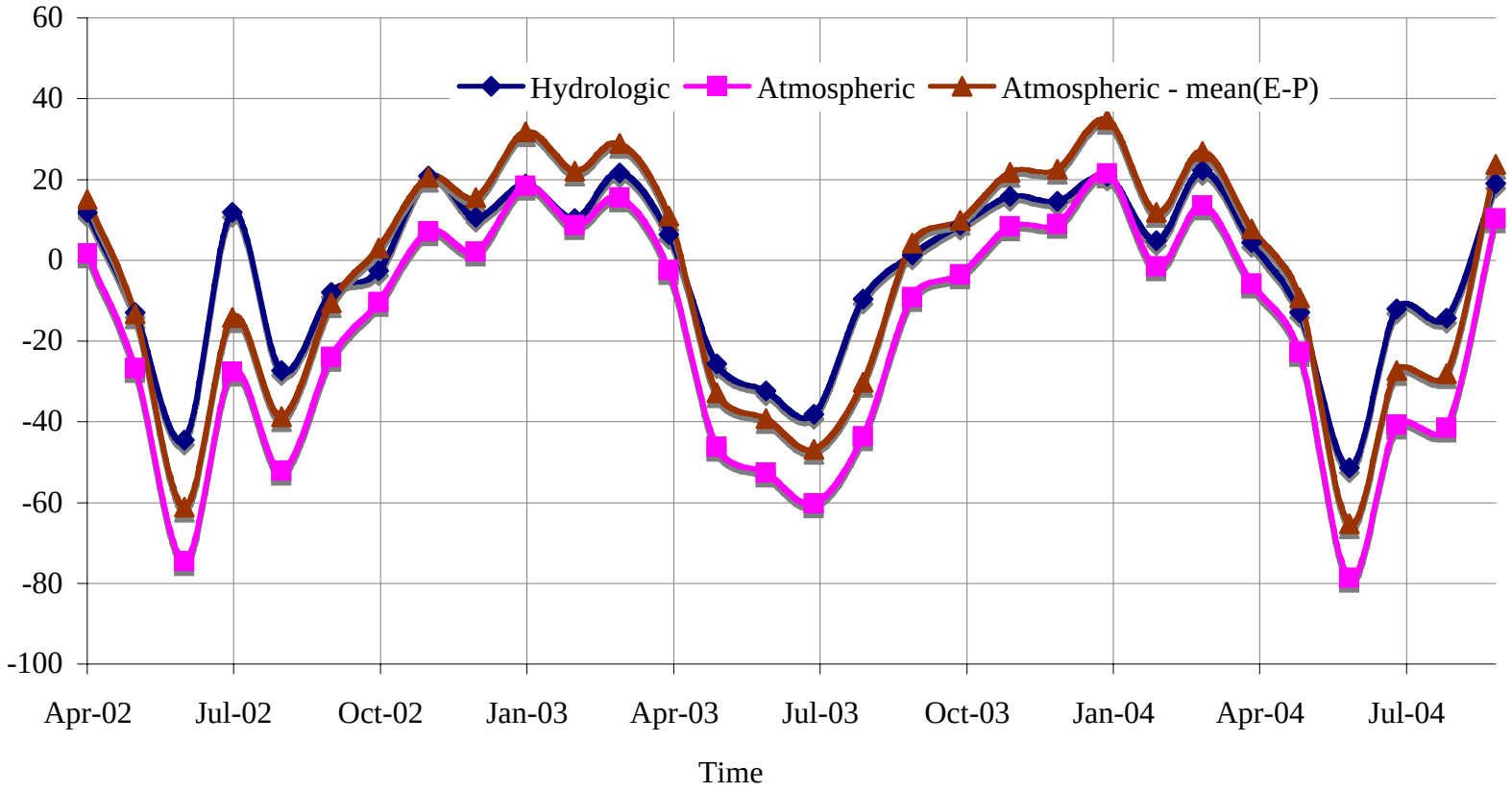


via Green's Theorem

Atmospheric (P-E) For Water Years 2002-2004 (Mackenzie River Basin)



Atmospheric and Hydrologic Basin Change in Storage For Water Years 2002-2004 (Mackenzie River Basin)



Atmospheric, Hydrologic and GRACE based Change in Storage relative to mean Geopotential For Water Years 2002-2004 (Mackenzie River Basin)