Canadian Foundation for Climate and Atmospheric Sciences (CFCAS)
Fondation canadienne pour les sciences du climat et de l'atmosphère (FCSCA)

DROUGHT RESEARCH INITIATIVE
RÉSEAU DE RECHERCHE SUR LA SÉCHERESSE

# Gravity Measurement and Hydrology

by:
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(based on the PhD thesis of Sitotaw Yirdaw)

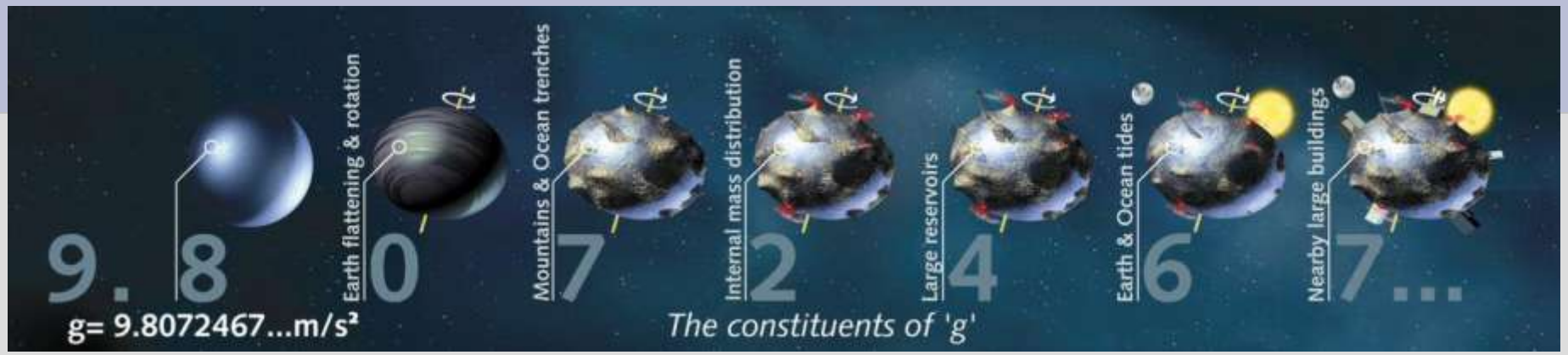
for:
GEO-DRI Presentation
May 11, 2010

**Memorial University of Newfoundland**
**Faculty of Engineering and Applied Science**

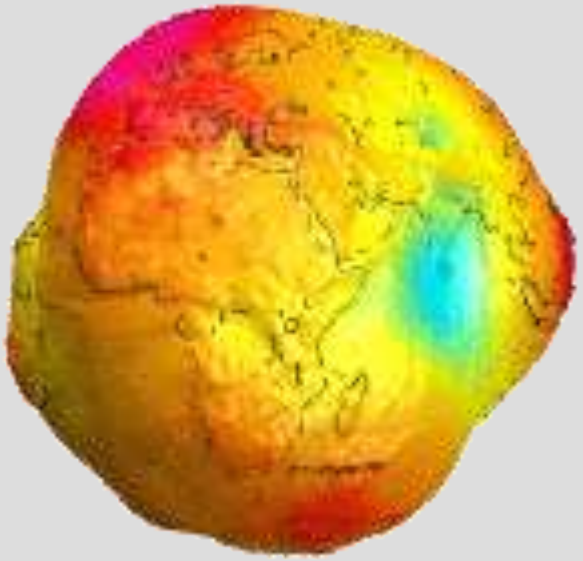
MEMORIAL UNIVERSITY

# Gravity Variability

Milligal = $10^{-5}$ m/s$^2$




source: ESA web site



source: MM Watkin, The GRACE Mission: Status and Latest Results

Gravity varies from 9.83 (poles) to 9.76 (equ)

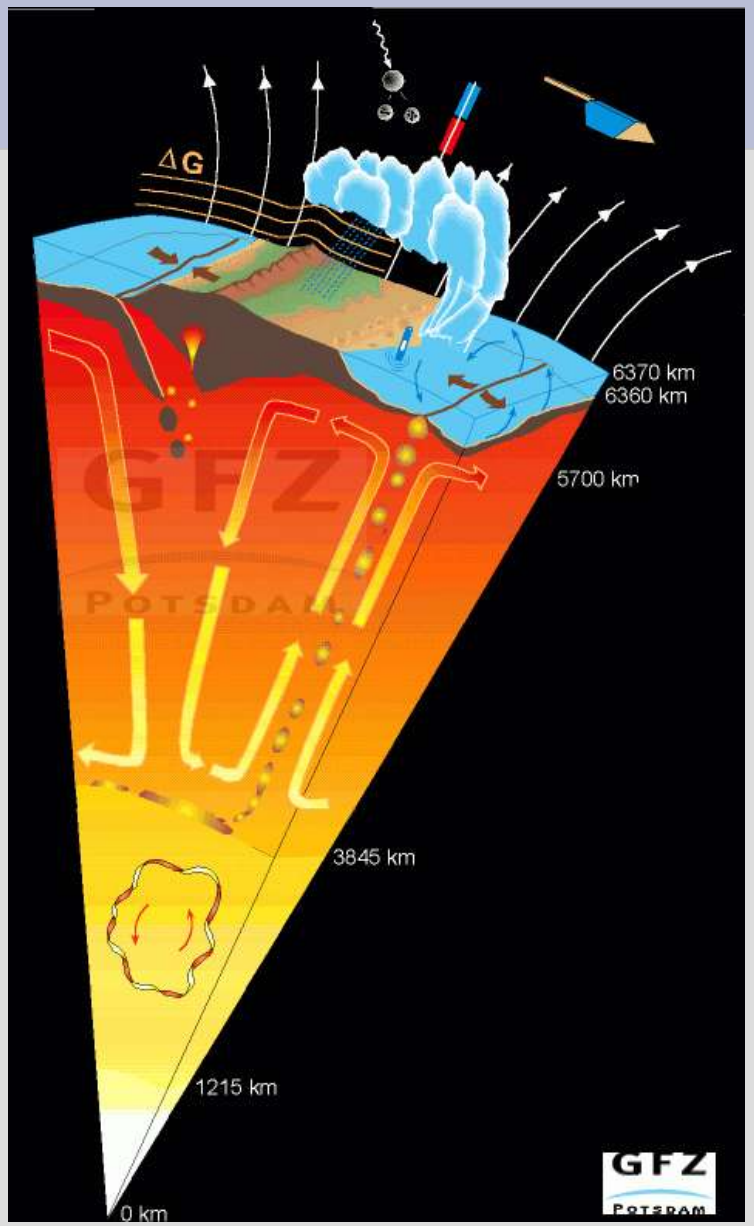
Gravitation Potential (N) given by Laplace Equation in Spherical Coordinate System

$$\nabla^2 N = \frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2\frac{\partial N}{\partial r}\right) + \frac{1}{r^2\sin\theta}\frac{\partial}{\partial\theta}\left(\sin\theta\frac{\partial N}{\partial\theta}\right) + \frac{1}{r^2\sin^2\theta}\frac{\partial^2 N}{\partial\phi^2} = 0$$

Solution is an orthogonal series summation for a given: lat($\phi$), lon($\theta$), and radius(r)

$$N(t) = a\sum_{l=0}^{l_{max}}\sum_{m=0}^{l} P_{lm}(\cos(\theta))\left[C_{lm}(t)\cos(m\phi) + S_{lm}(t)\sin(m\phi)\right]$$

# Why Gravity Measurement?




Oceanography - combining gravity based sea-level geopotential with altimeter data to map ocean currents.

Sea-Level Rise - measure glacier mass lost from polar ice caps and non-mass related sea level rise based on ocean warming.

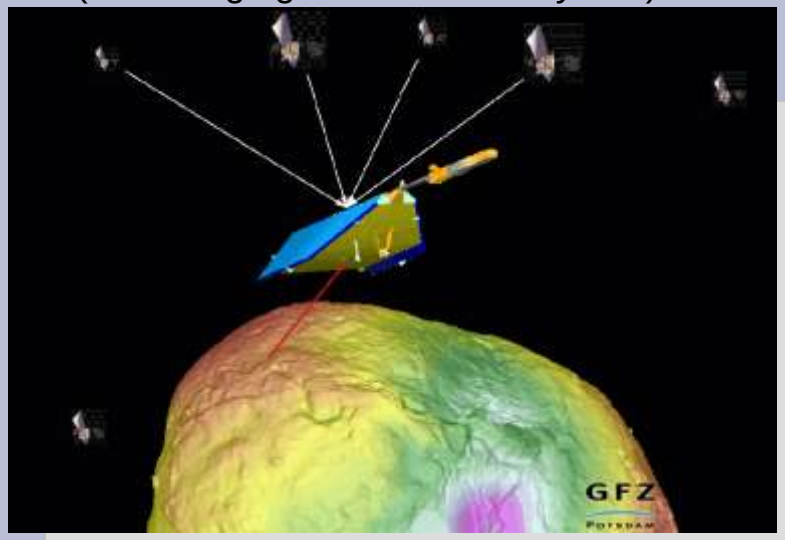
Geodesy - establishment of a vertical measurement datum.

Solid Earth Physics - combined with topography to understand internal earth processes.

Surface Fluid Motion - the short term fluctuations of gravity are related to the redistribution of near surface fluids (water & air)

# Three Gravity Measuring Systems

## CHAMP
(CHAllenging Minisatellite Payload)

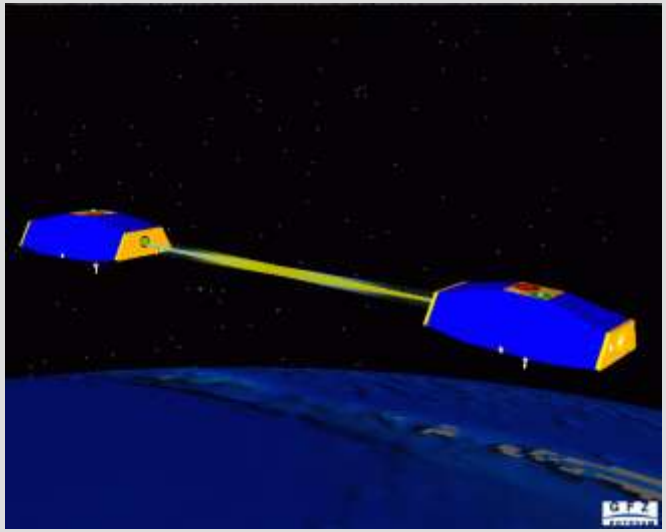



Alt: 450 km
Tech: GPS
Life: 5-years (2000)

## GOCE
(Gravity and Ocean Circulation Explorer )


Alt: 250 km
Tech: SGG
Life: 2-years (2009)

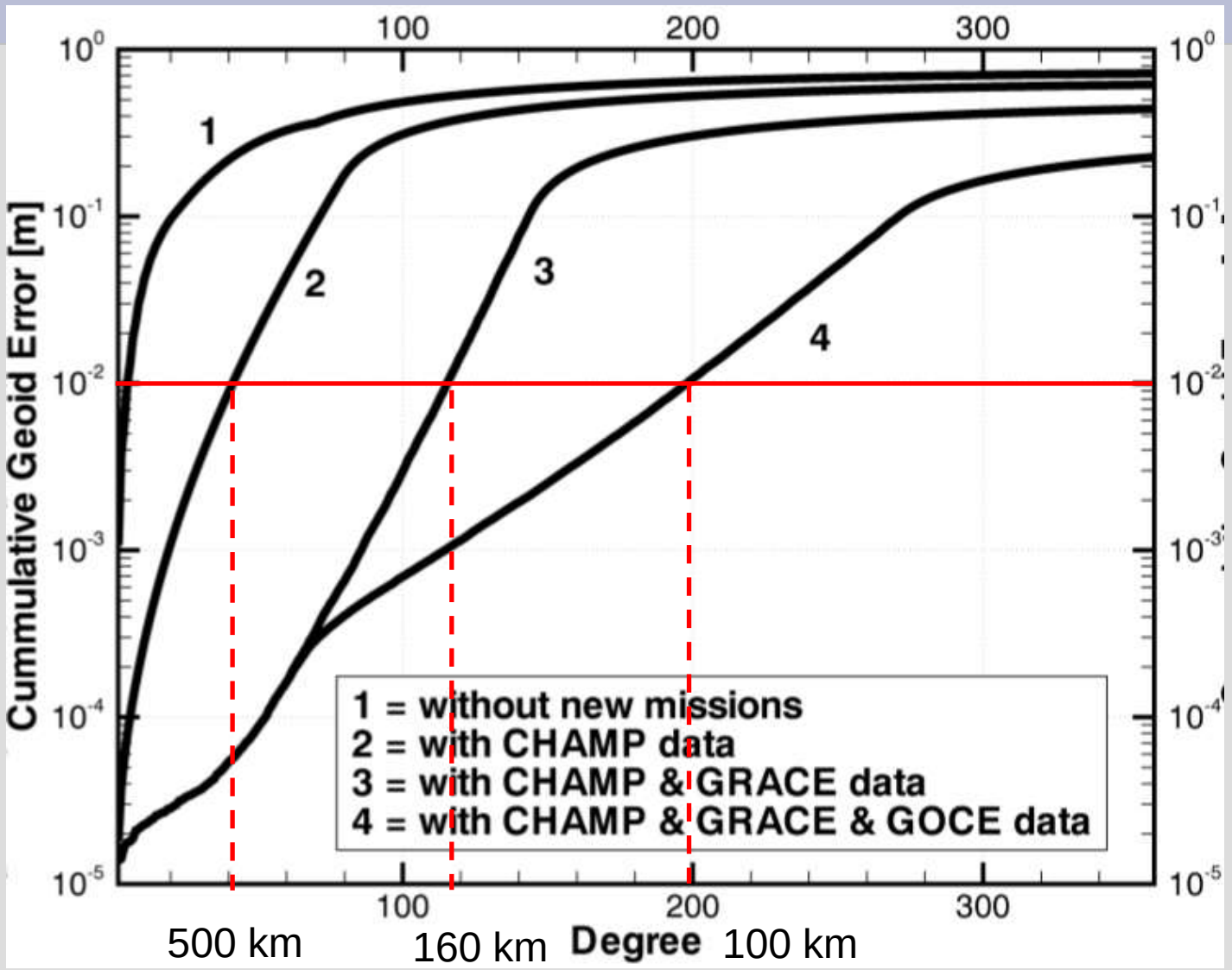
## GRACE
(GRavity And Climate Experiment)



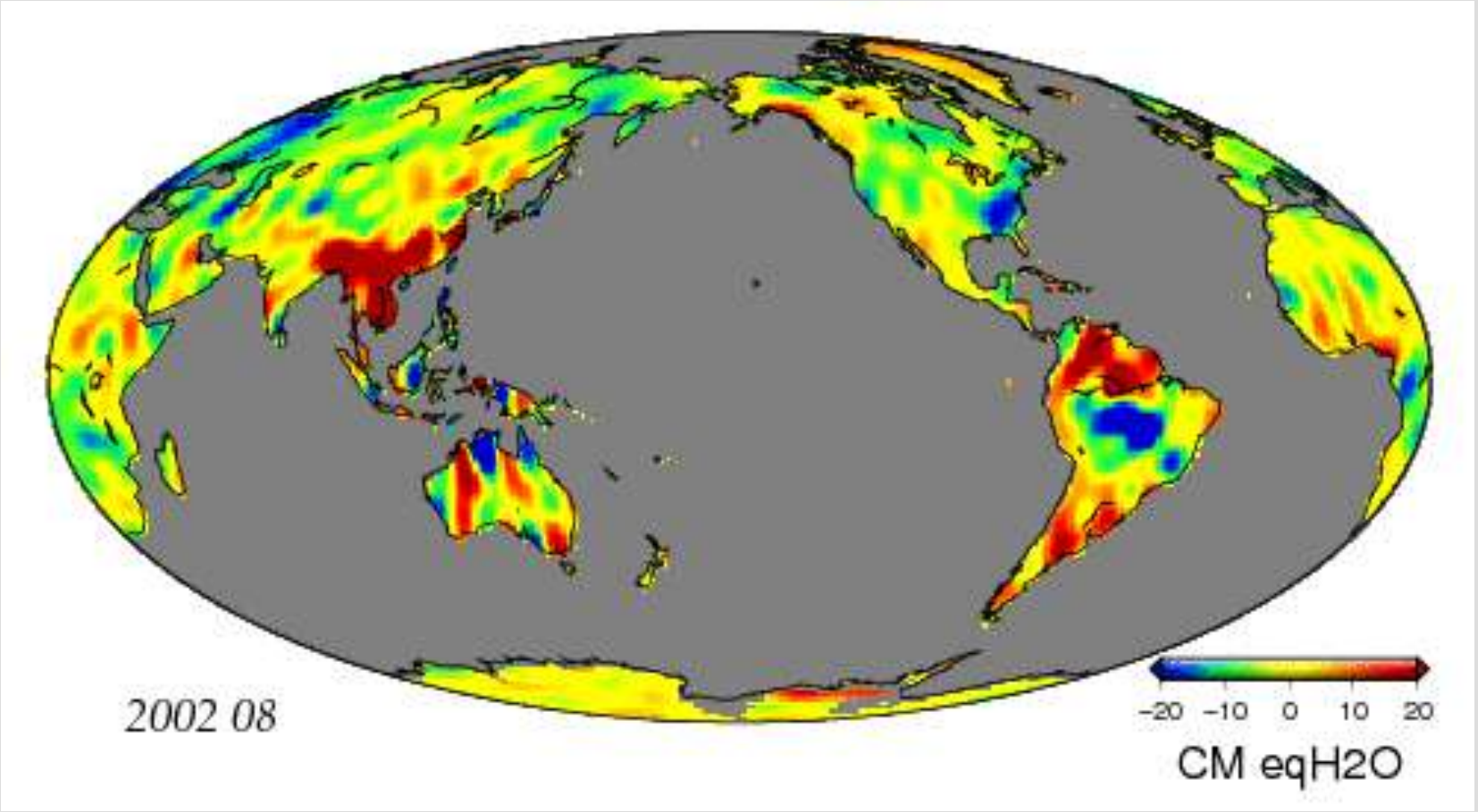
Alt: 500 km
Tech: SST
Life: 5-years (2002)

?Future?: SSI

# Satellite Error Inter-comparison

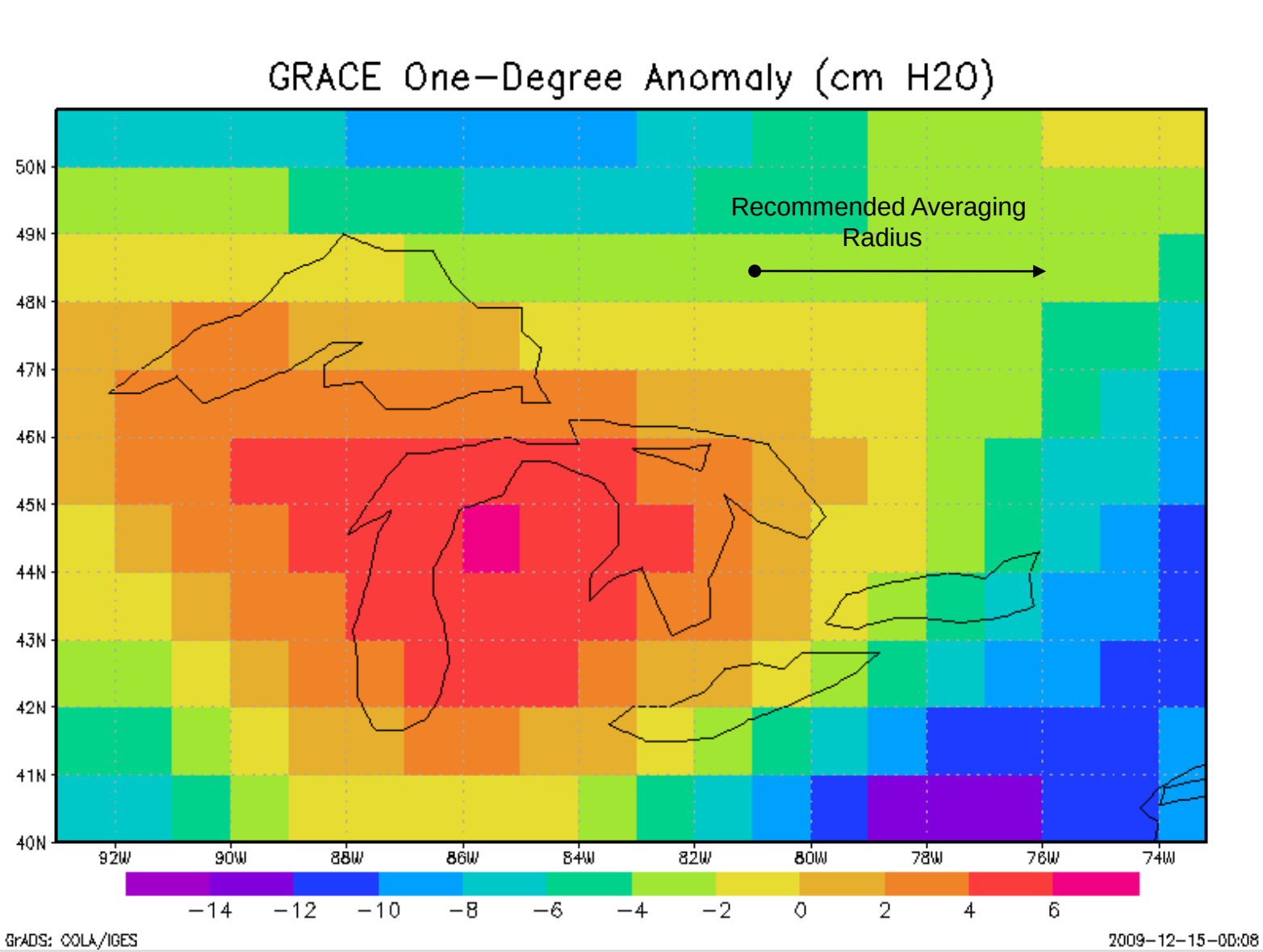


# Global Coverage of GRACE Satellite on Monthly Time Scale

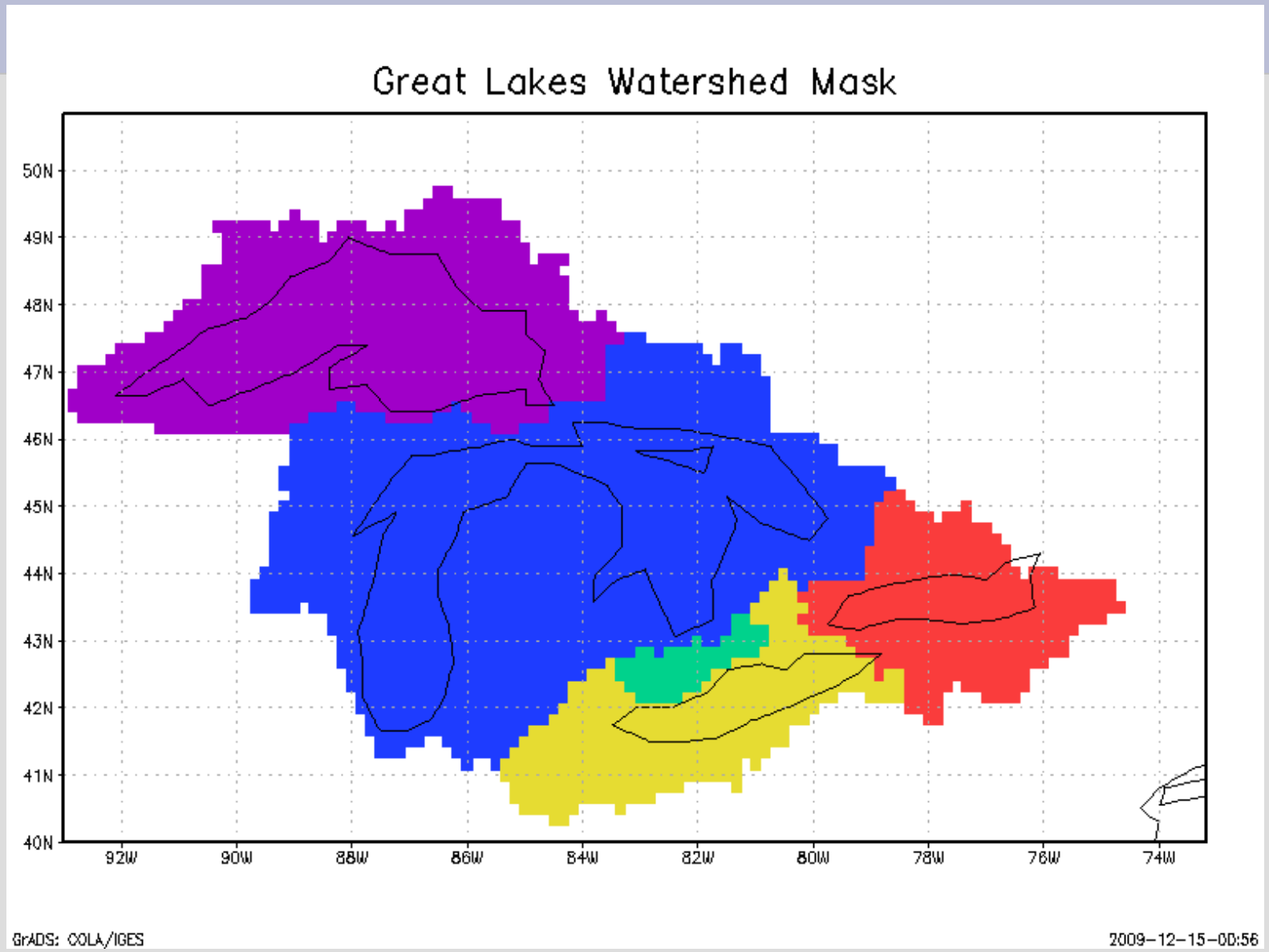



source: http://grace.jpl.nasa.gov/data/mass/

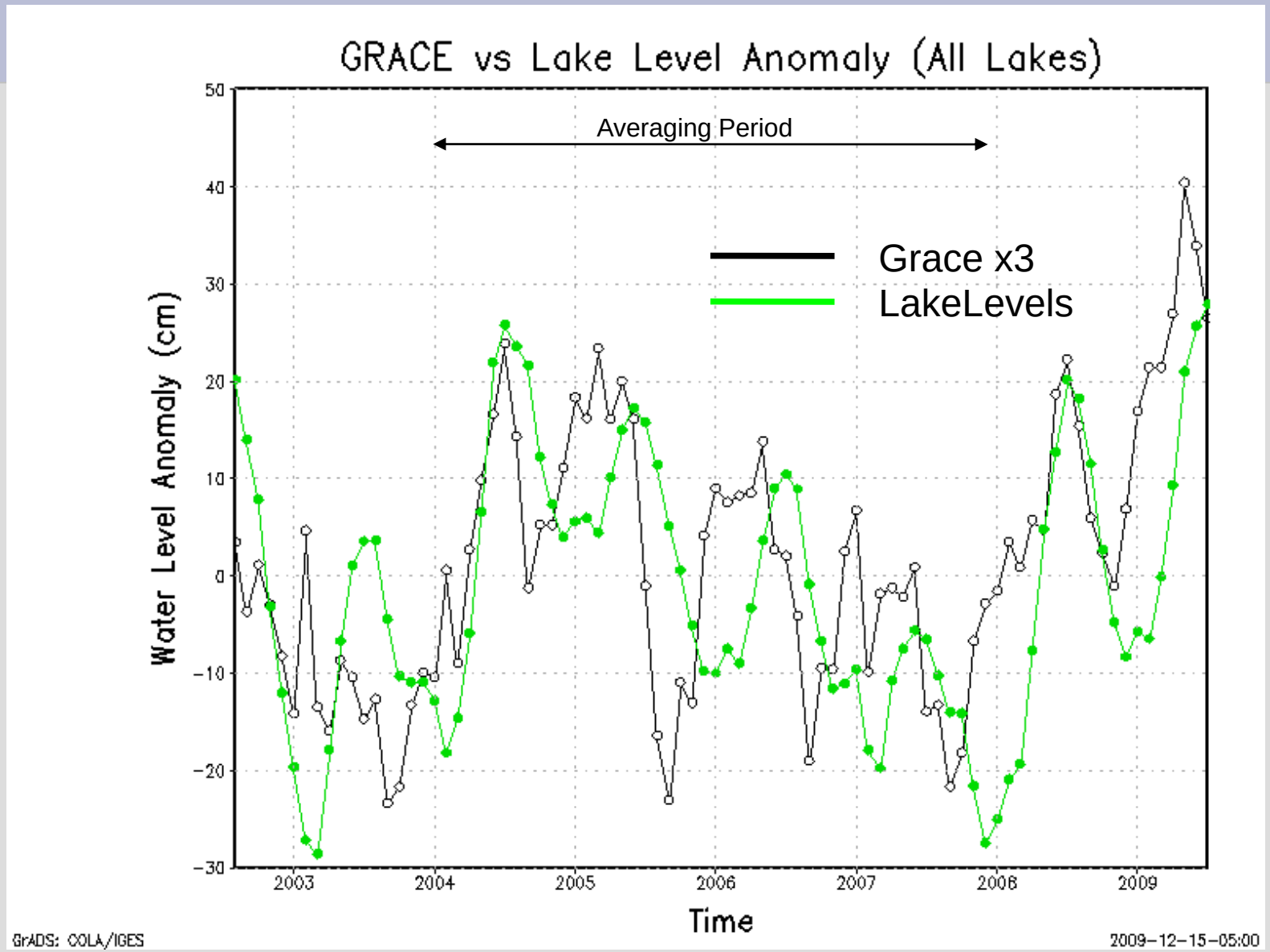
# GRACE Evaluation of Great Lakes Storage



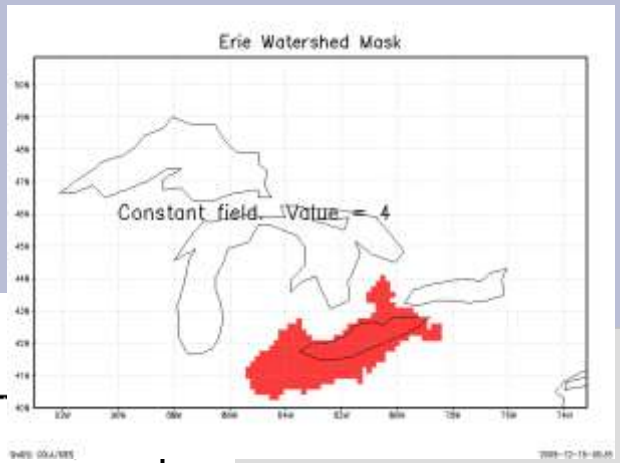
# Averaging Mask for Great Lakes

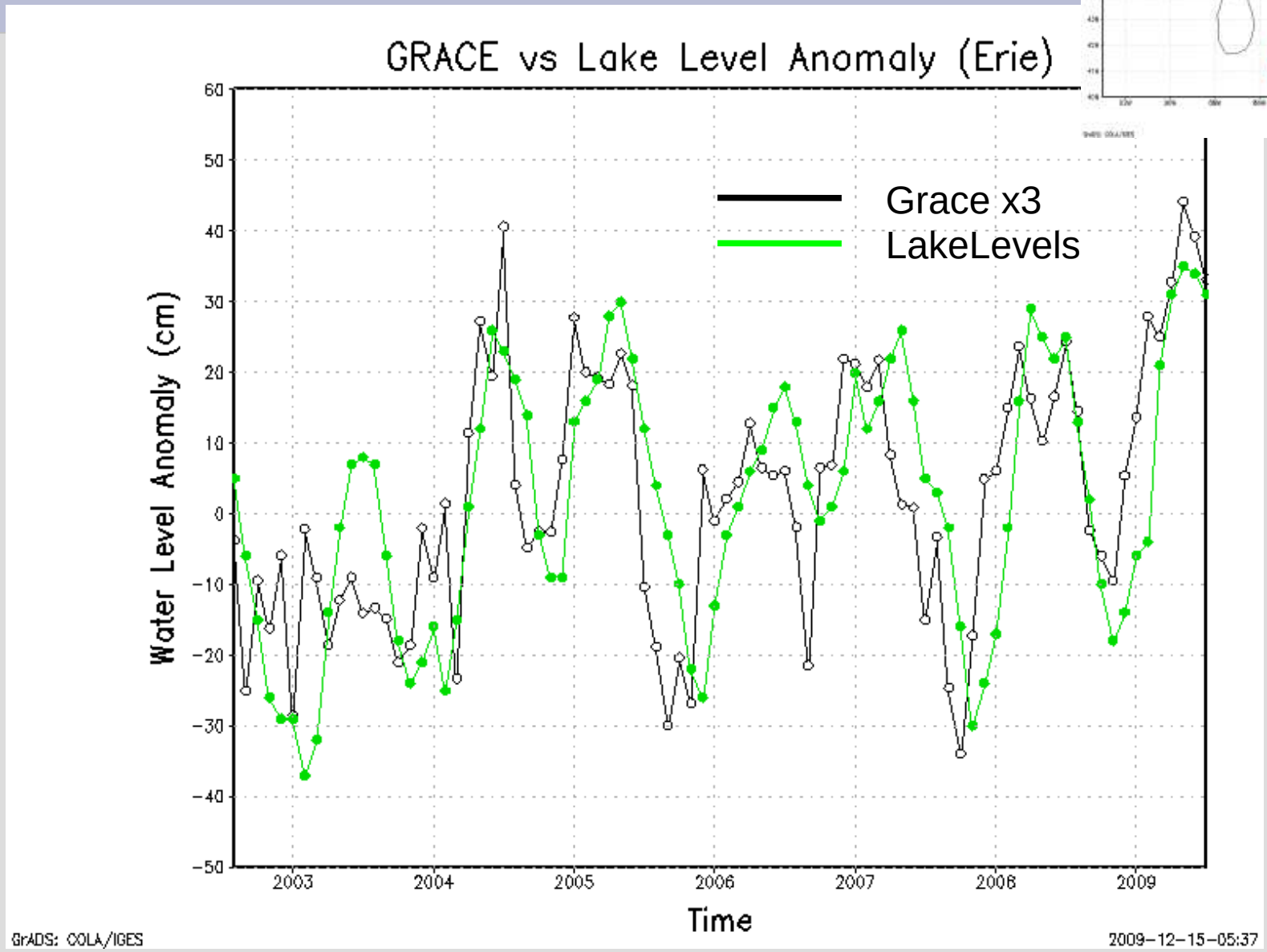


# GRACE Comparison to Great Lake Levels

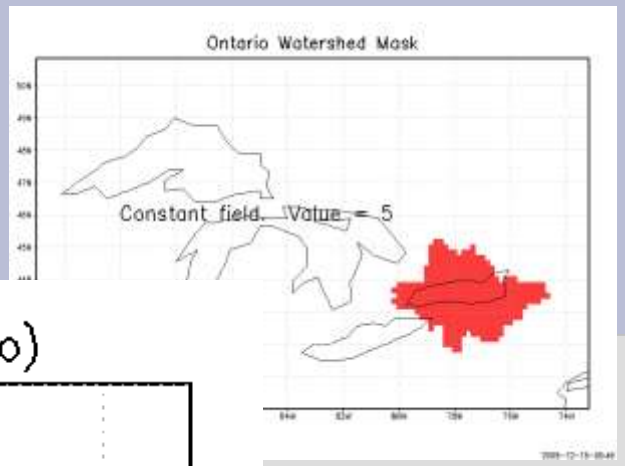


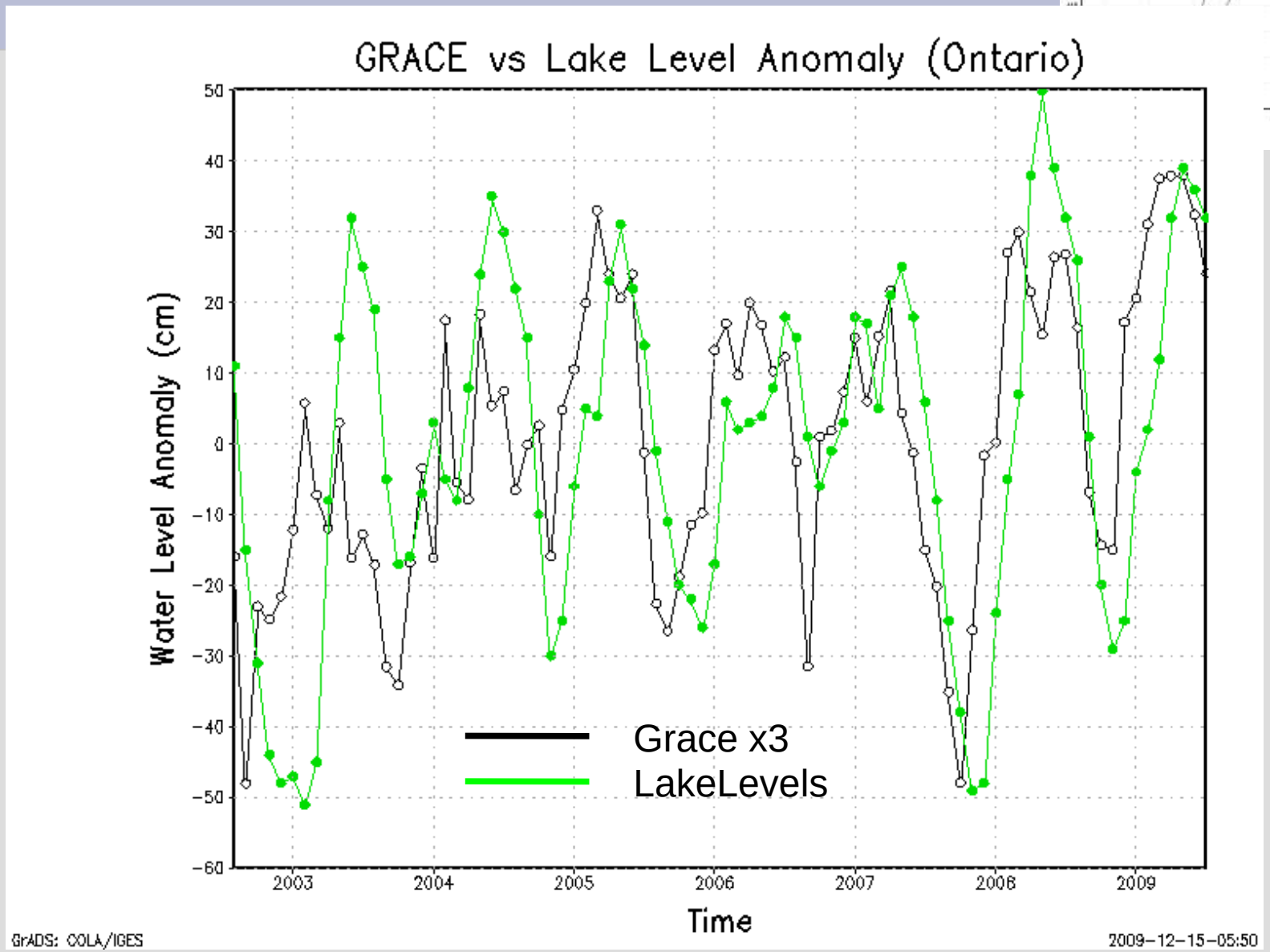
# GRACE Comparison to Lake Erie Levels



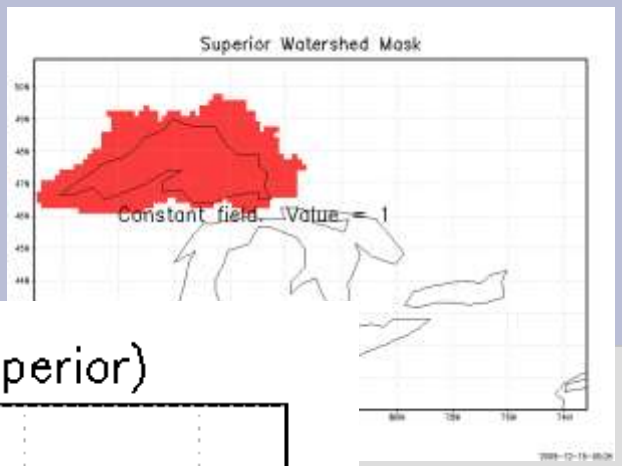



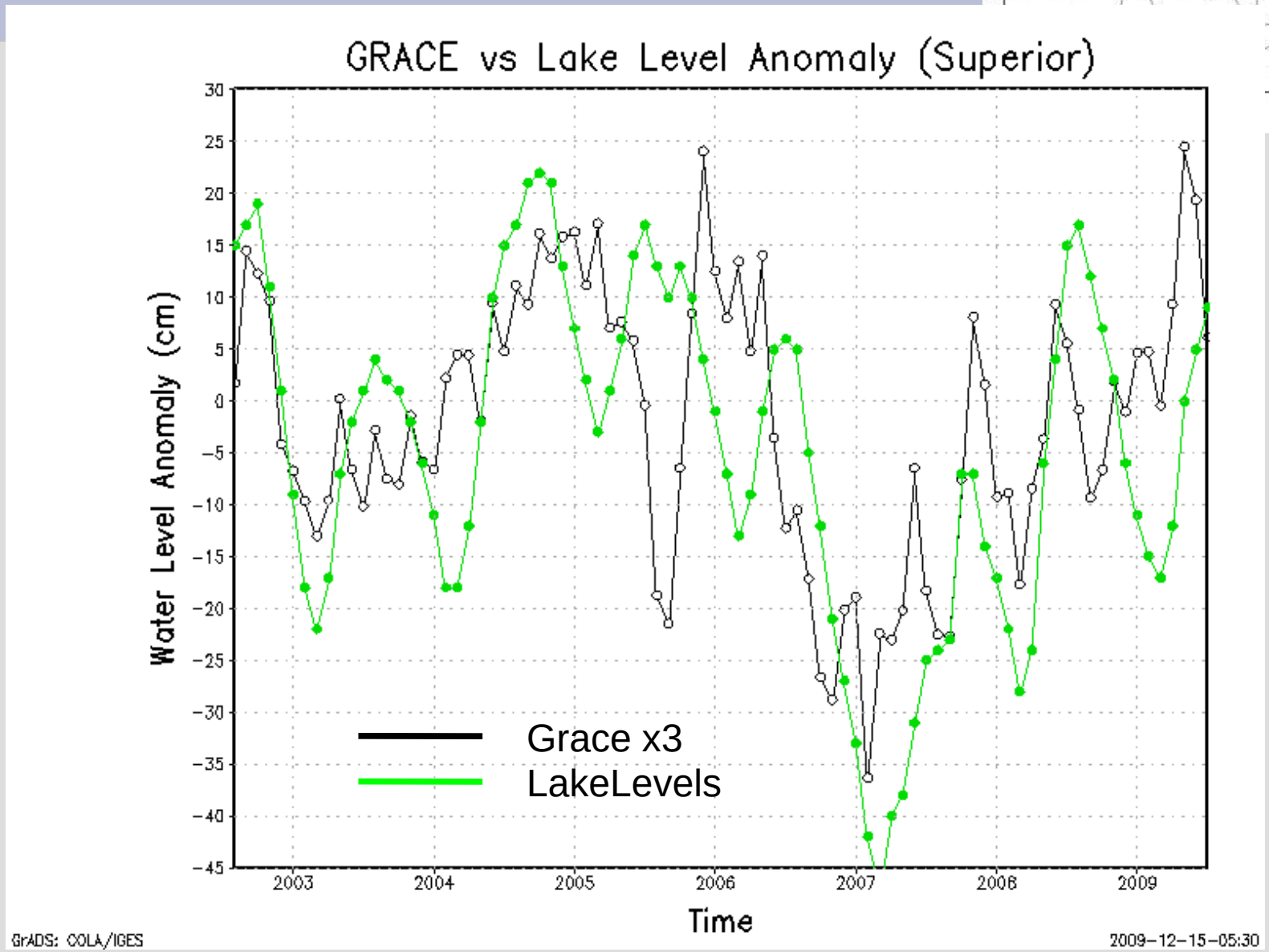
# GRACE Comparison to Lake Ontario



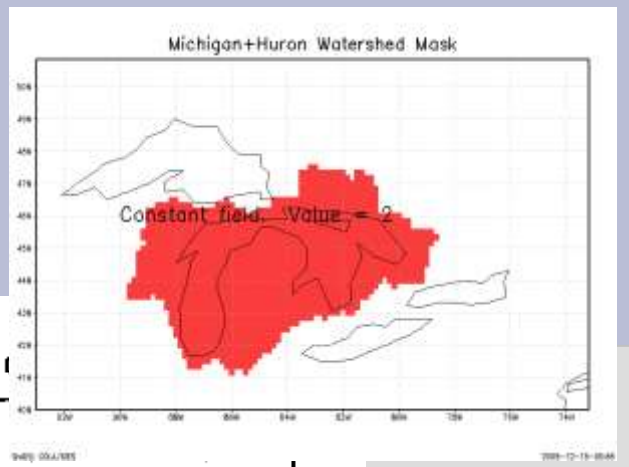



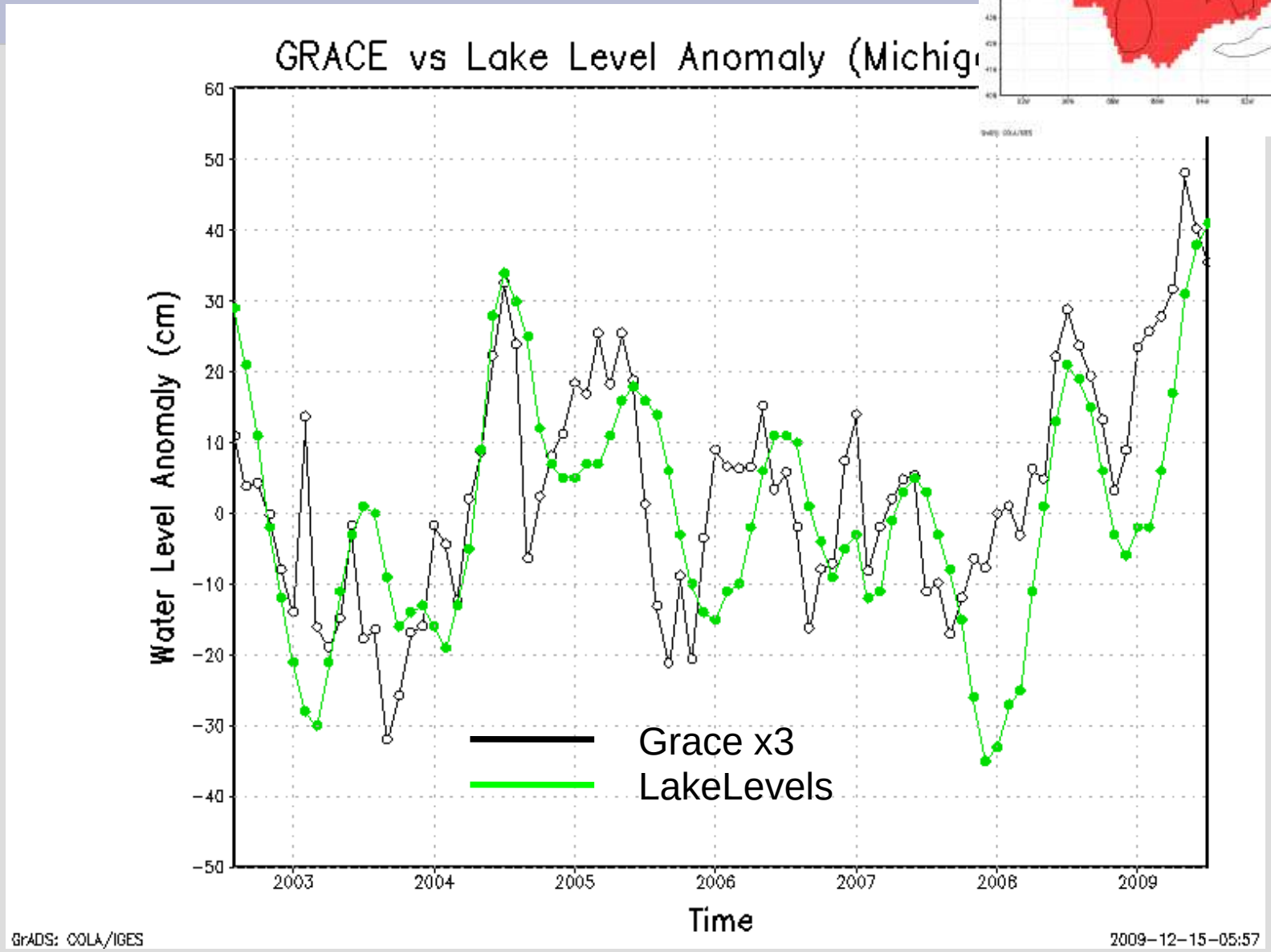
# GRACE Comparison to Lake Superior



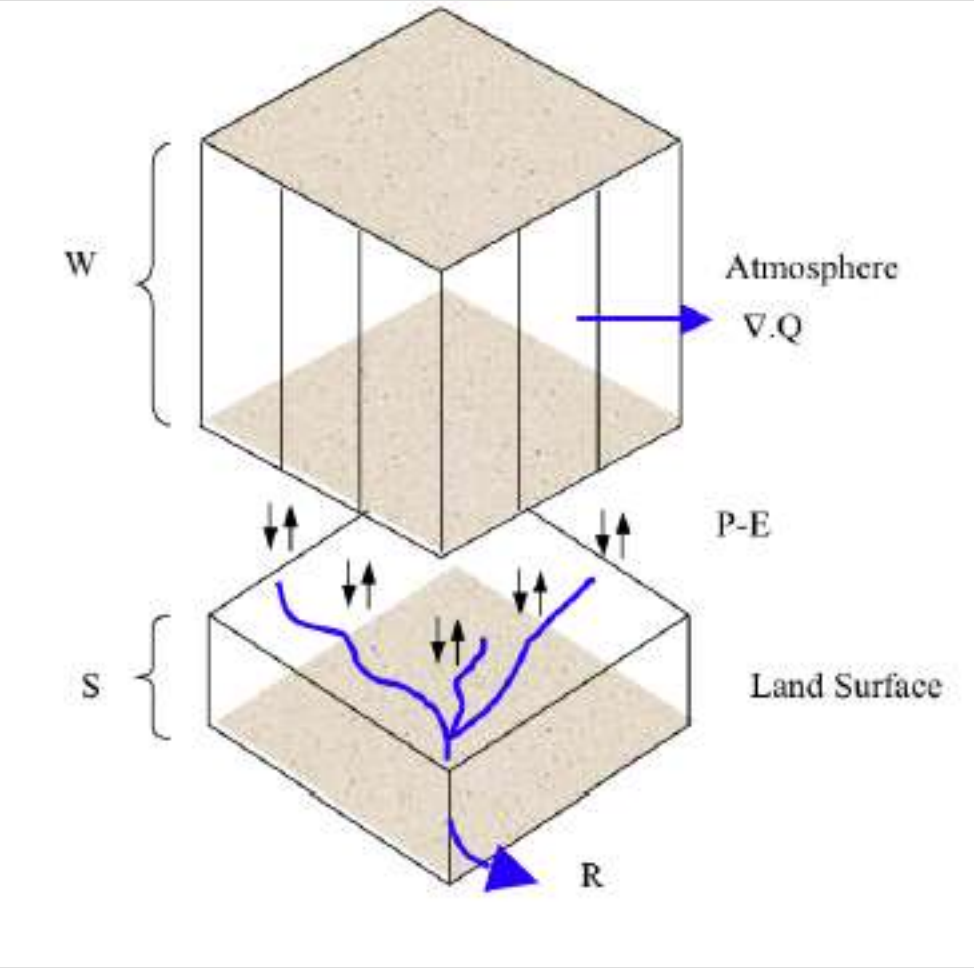
# GRACE Comparison to Michigan-Huron



# EXTRA SLIDES

# GRACE Water Balance Comparison



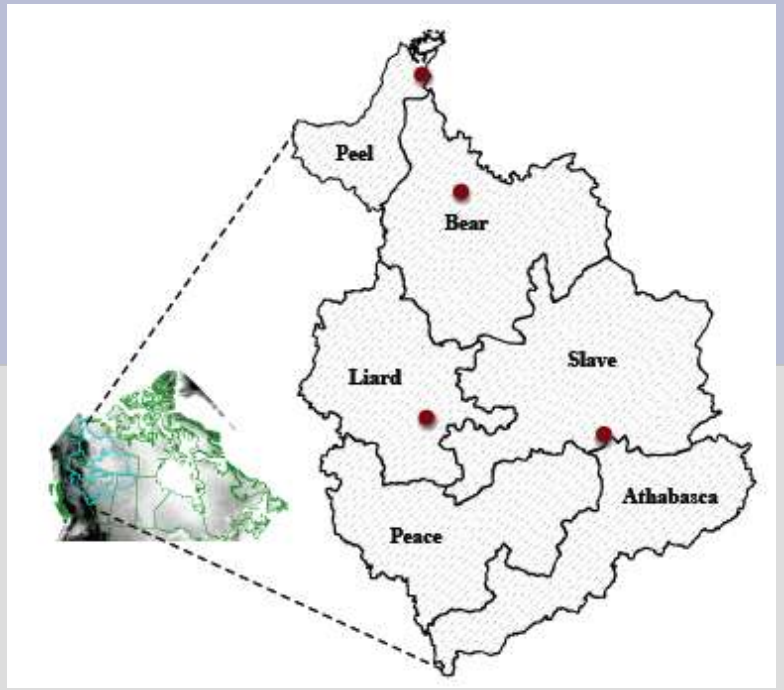

Atmospheric-Land Surface Water Balance

$$-\left(\frac{\partial W}{\partial t}+\nabla\cdot Q\right)=\left(\frac{\partial S}{\partial t}+R\right)=(P-E)$$

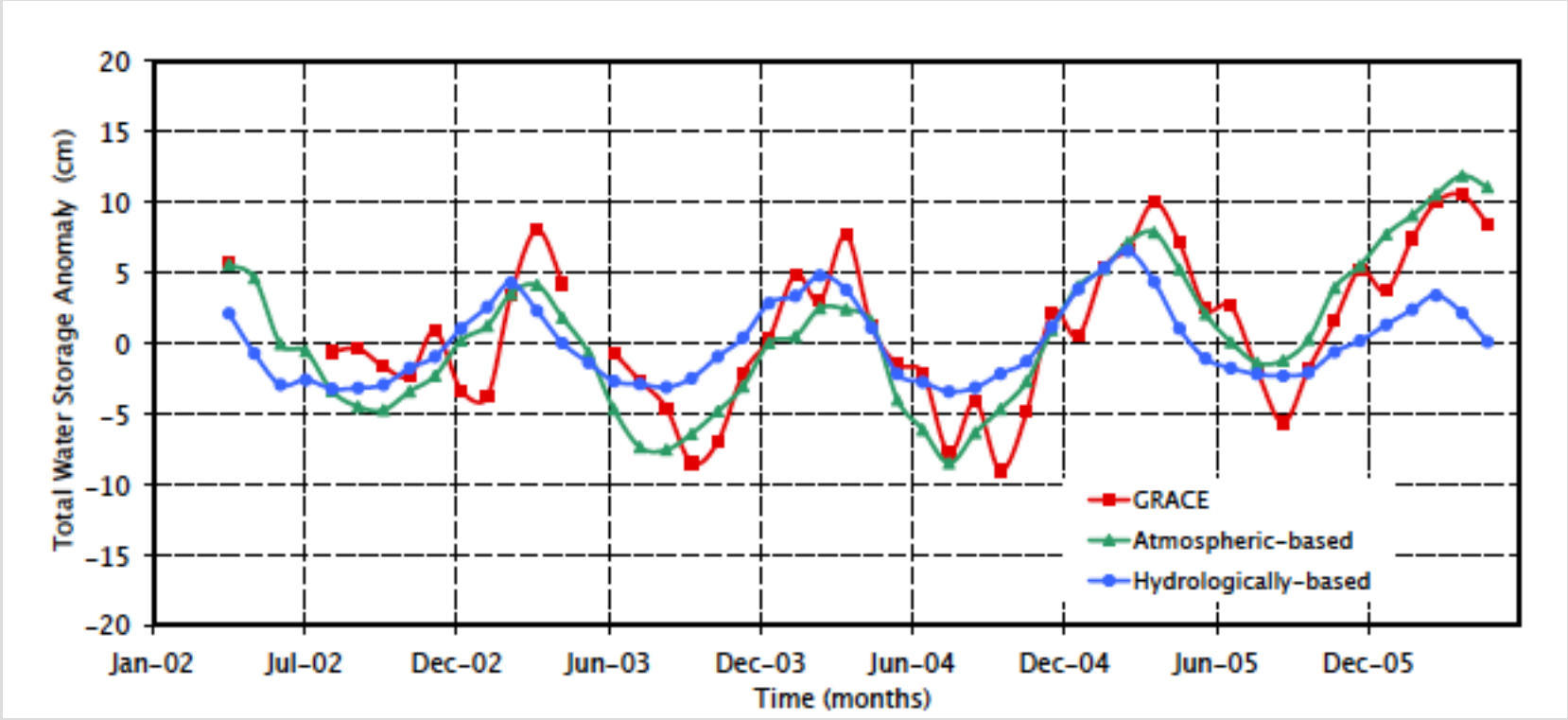
Given a starting storage ($S_{n-1}$) as the mean storage, we can determine GRACE equivalent measurement

$$S_n = S_{n-1} + \left(\frac{\Delta S}{\Delta t}\right)_n$$

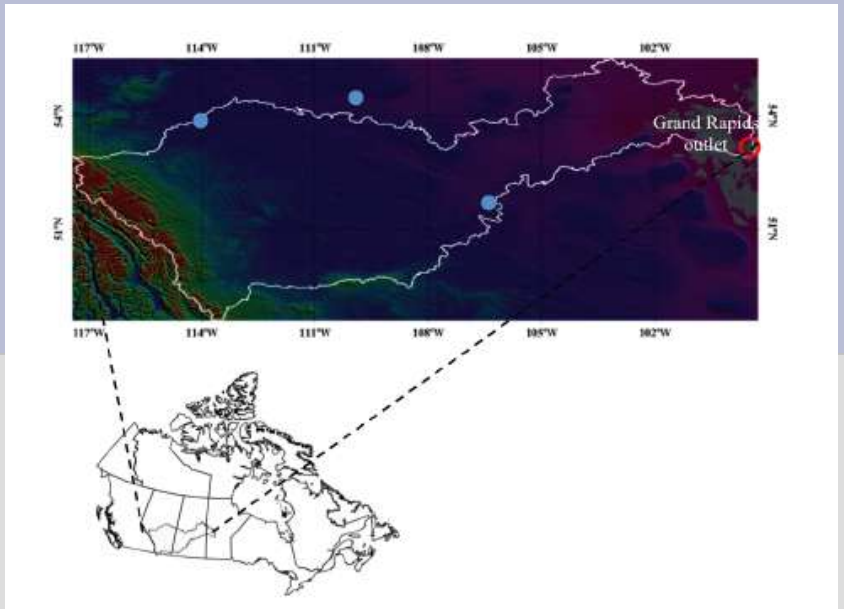
# GRACE Water Balance Comparison
# Mackenzie River Basin

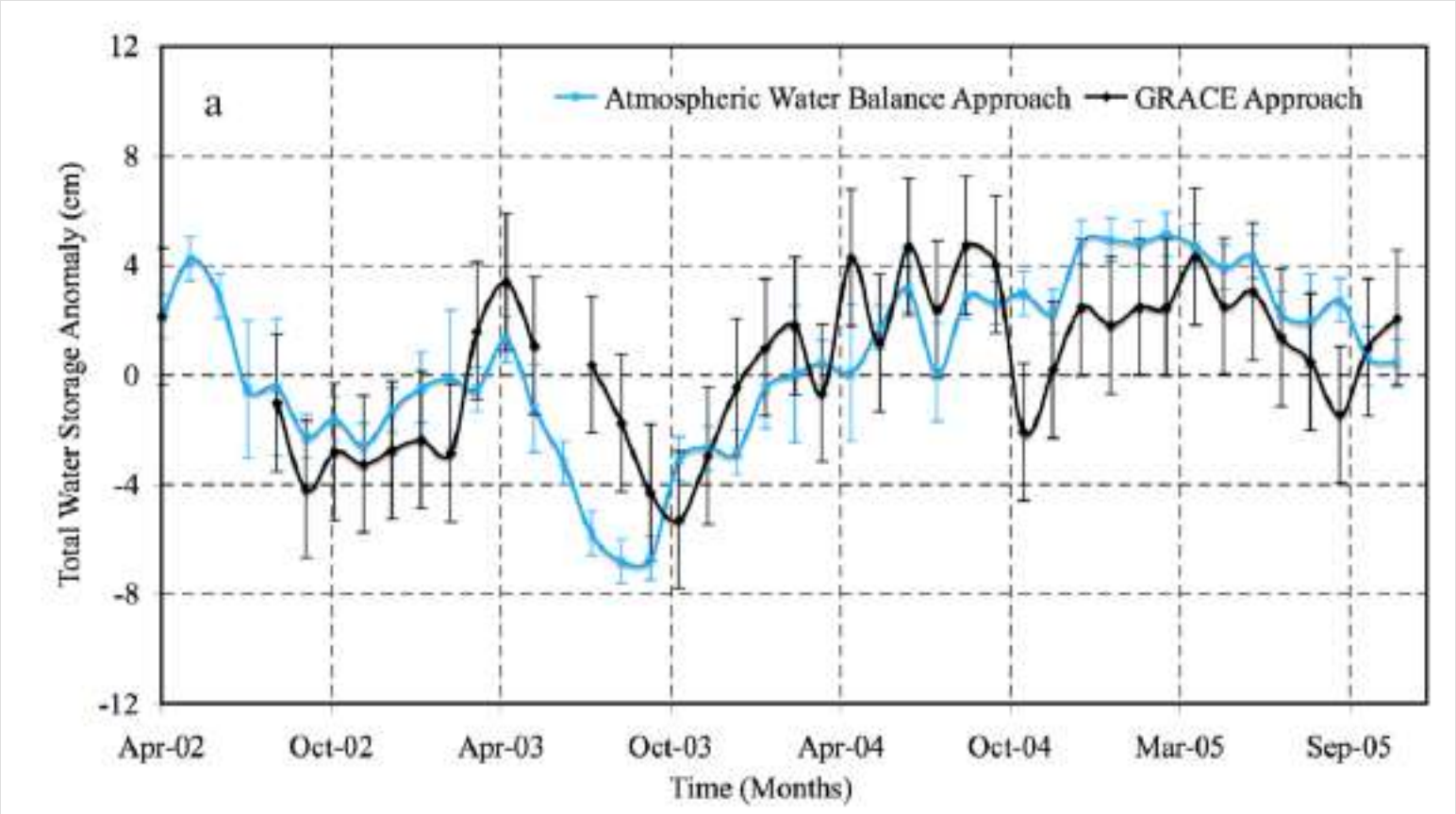



Correlation for G vs. A = 0.86

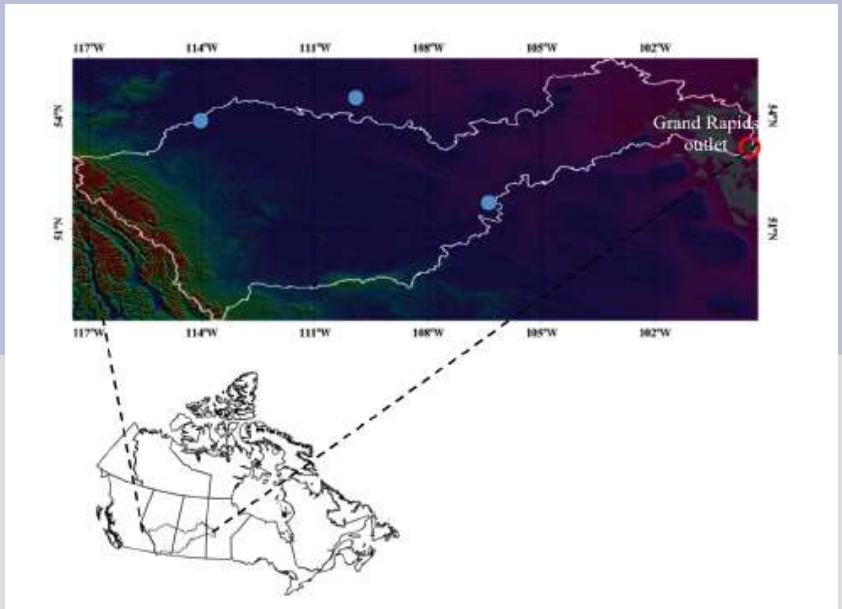


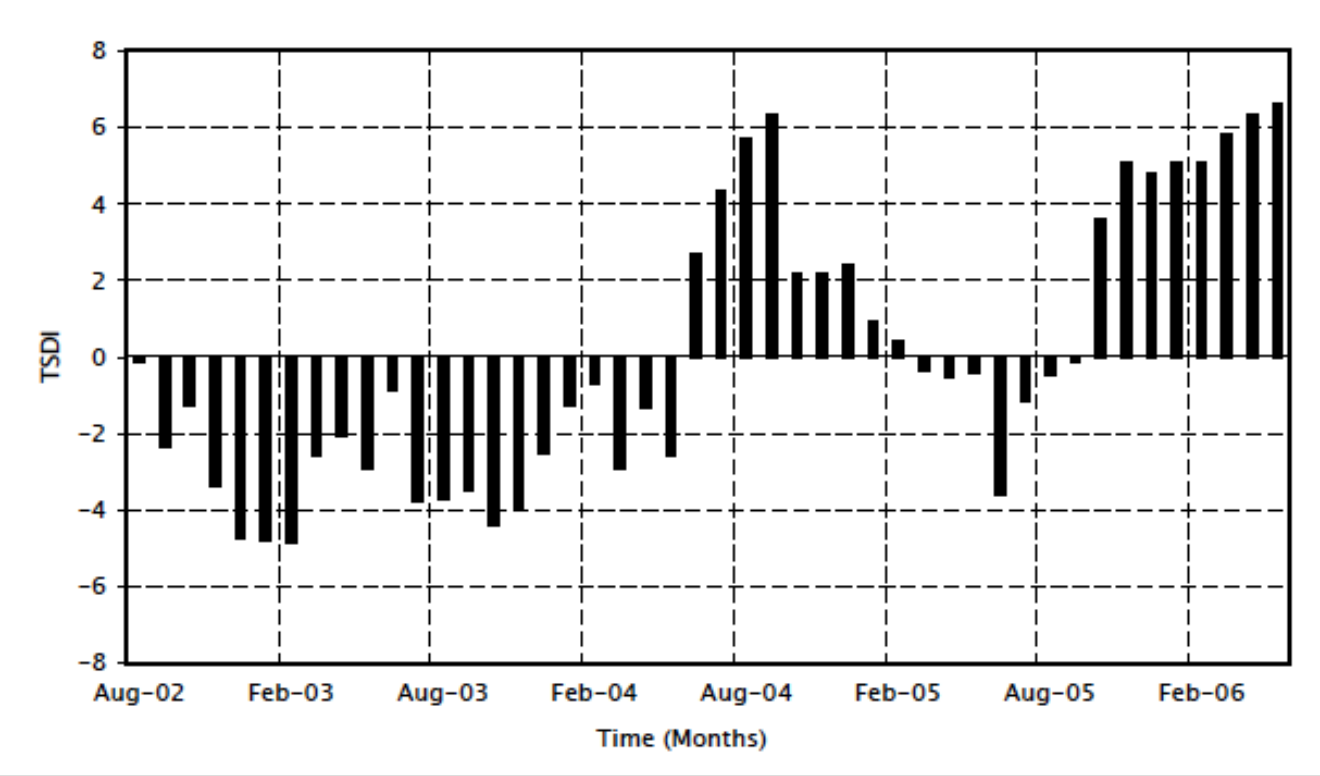
# GRACE Water Balance Comparison
# Saskatchewan River Basin



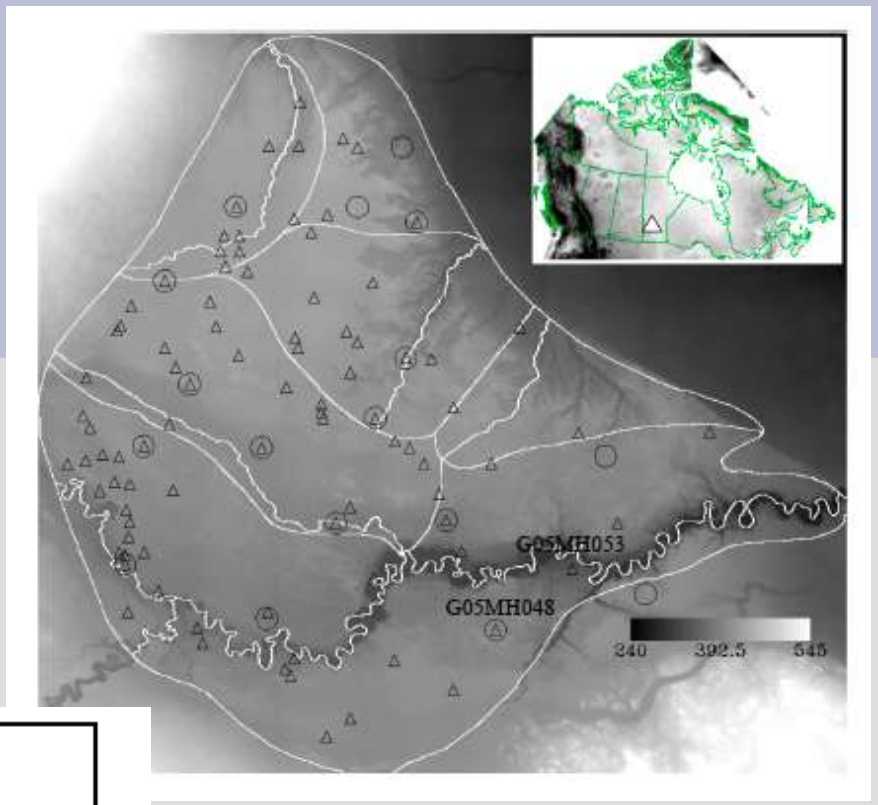
# GRACE Application
# Drought Monitoring

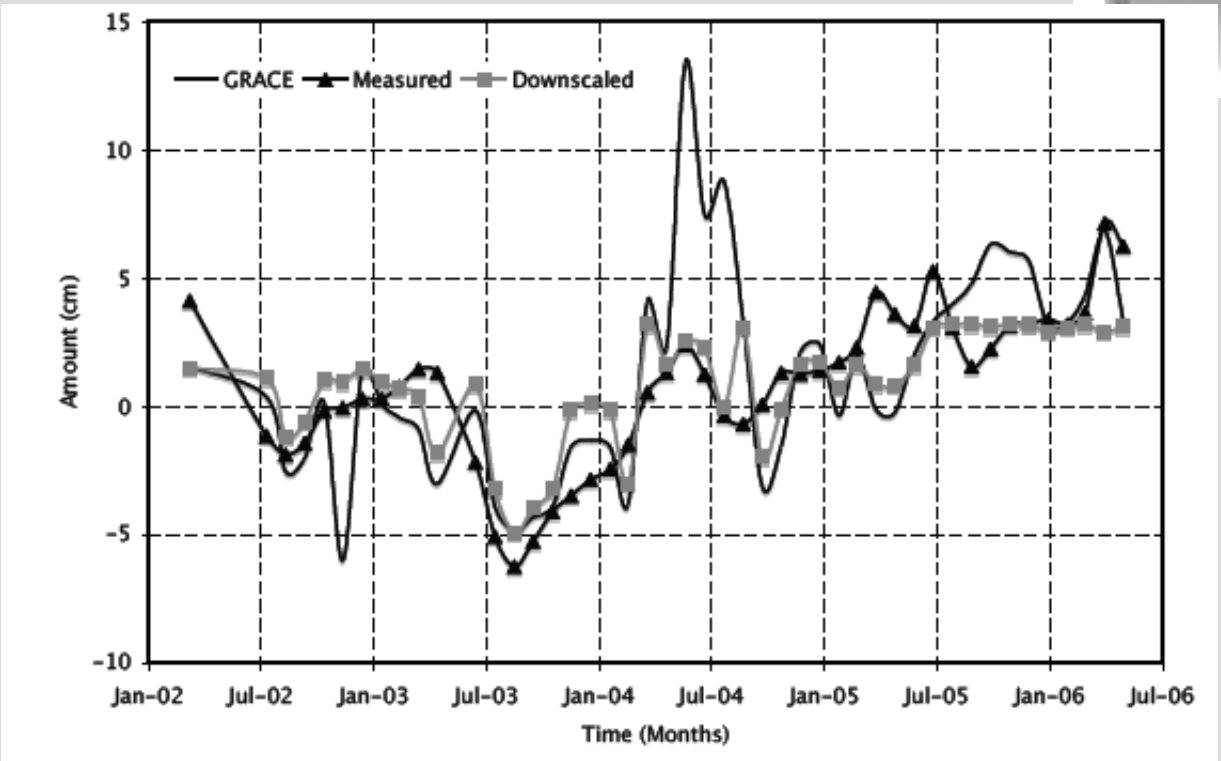



TSDI - total storage deficit index

# GRACE Application
# Assiniboine Delta Aquifer
# Well Comparison

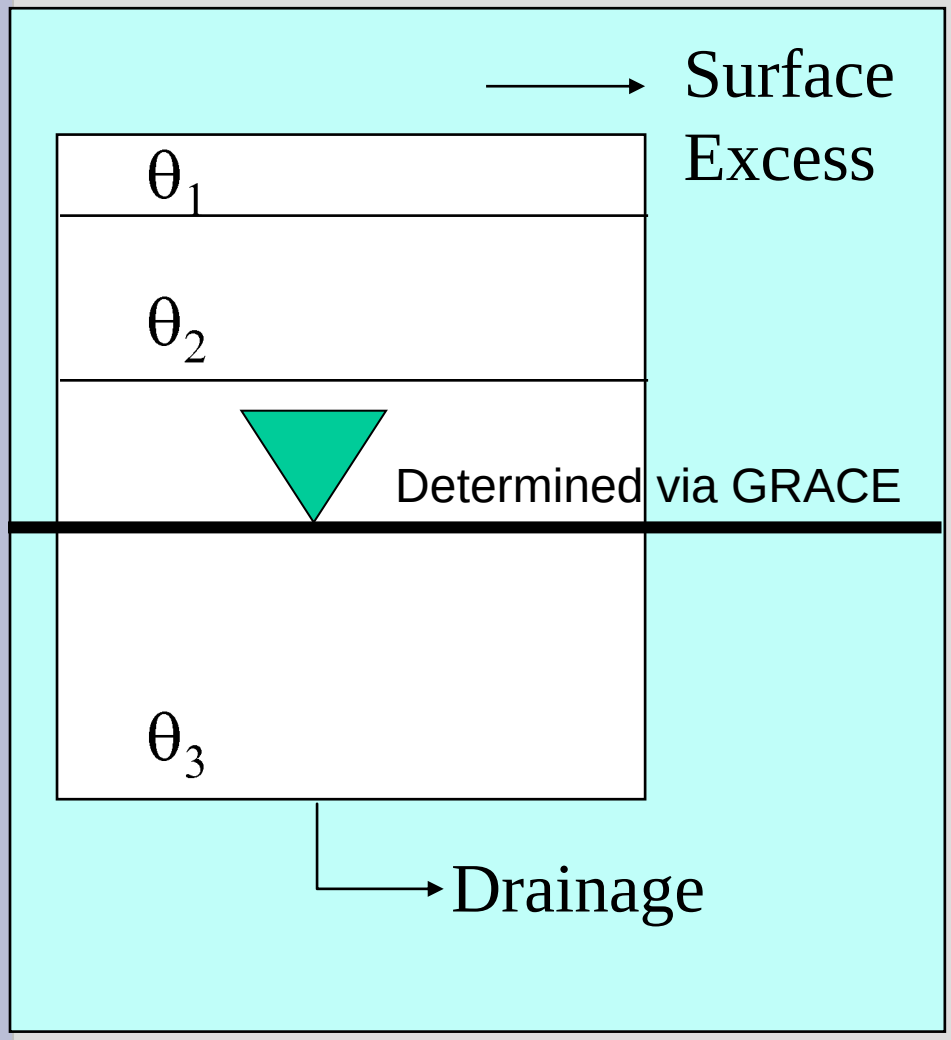


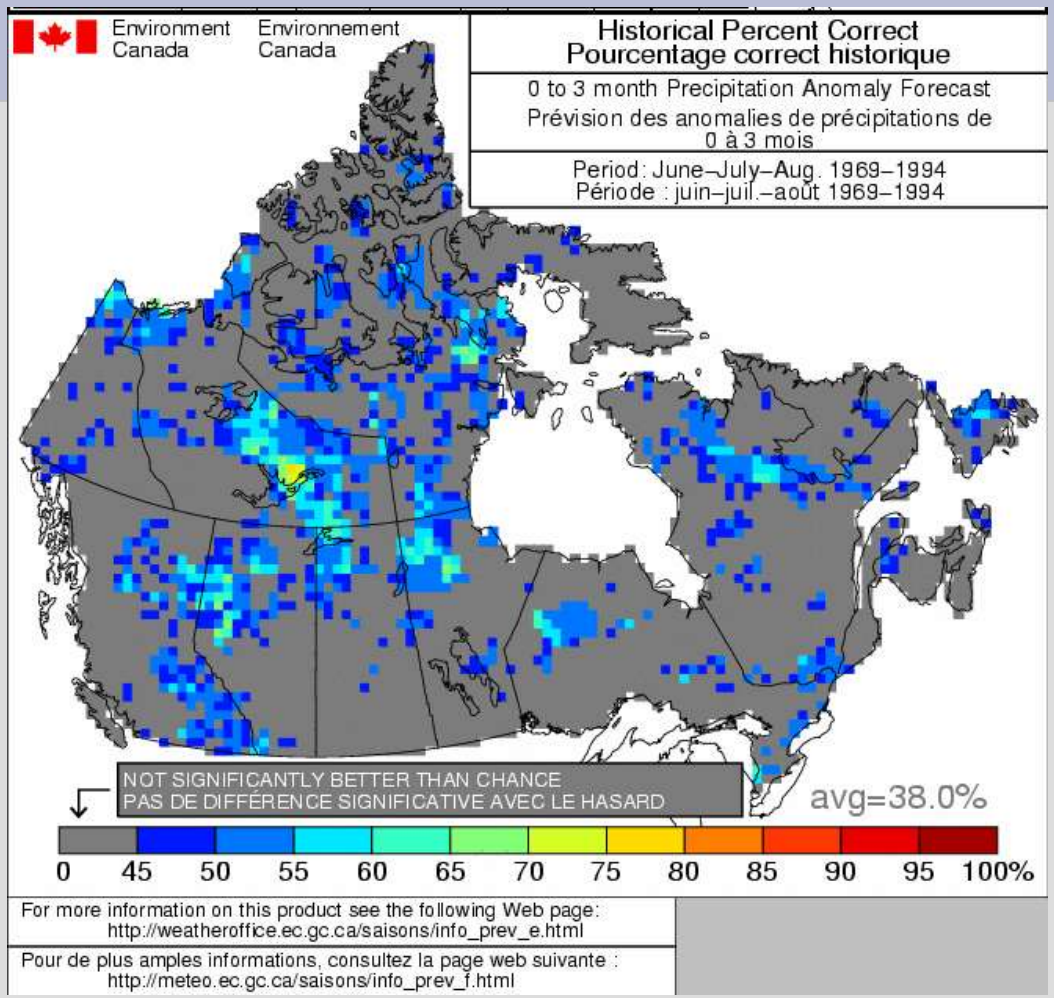




Downscaling GRACE data to fit well observations.

Useful for aquifer model studies.

# GRACE Application (Future Work)
# Seasonal Forecasting

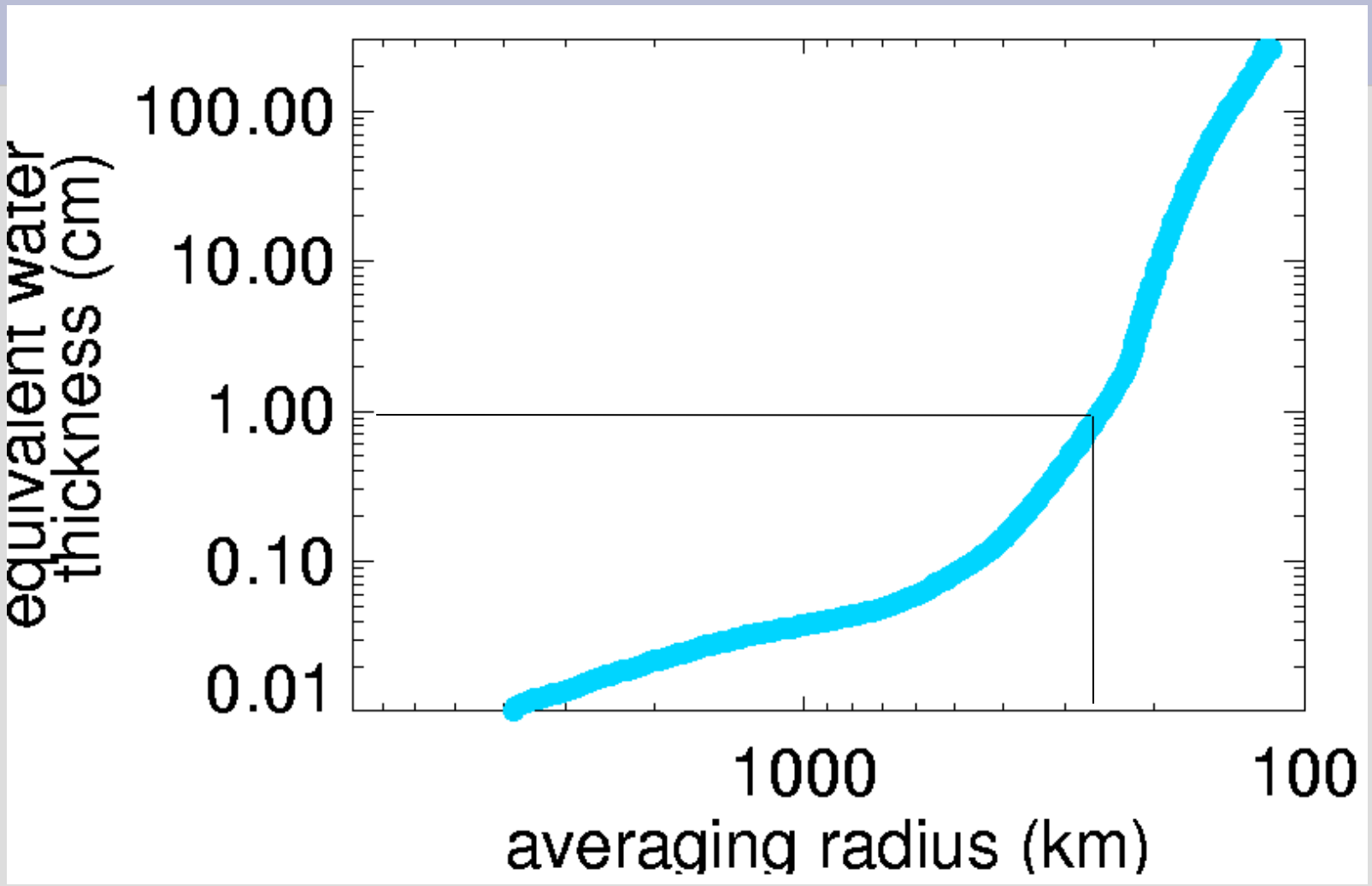



Does storage initialization improve seasonal forecasts?

Test with 7 years of GRACE data

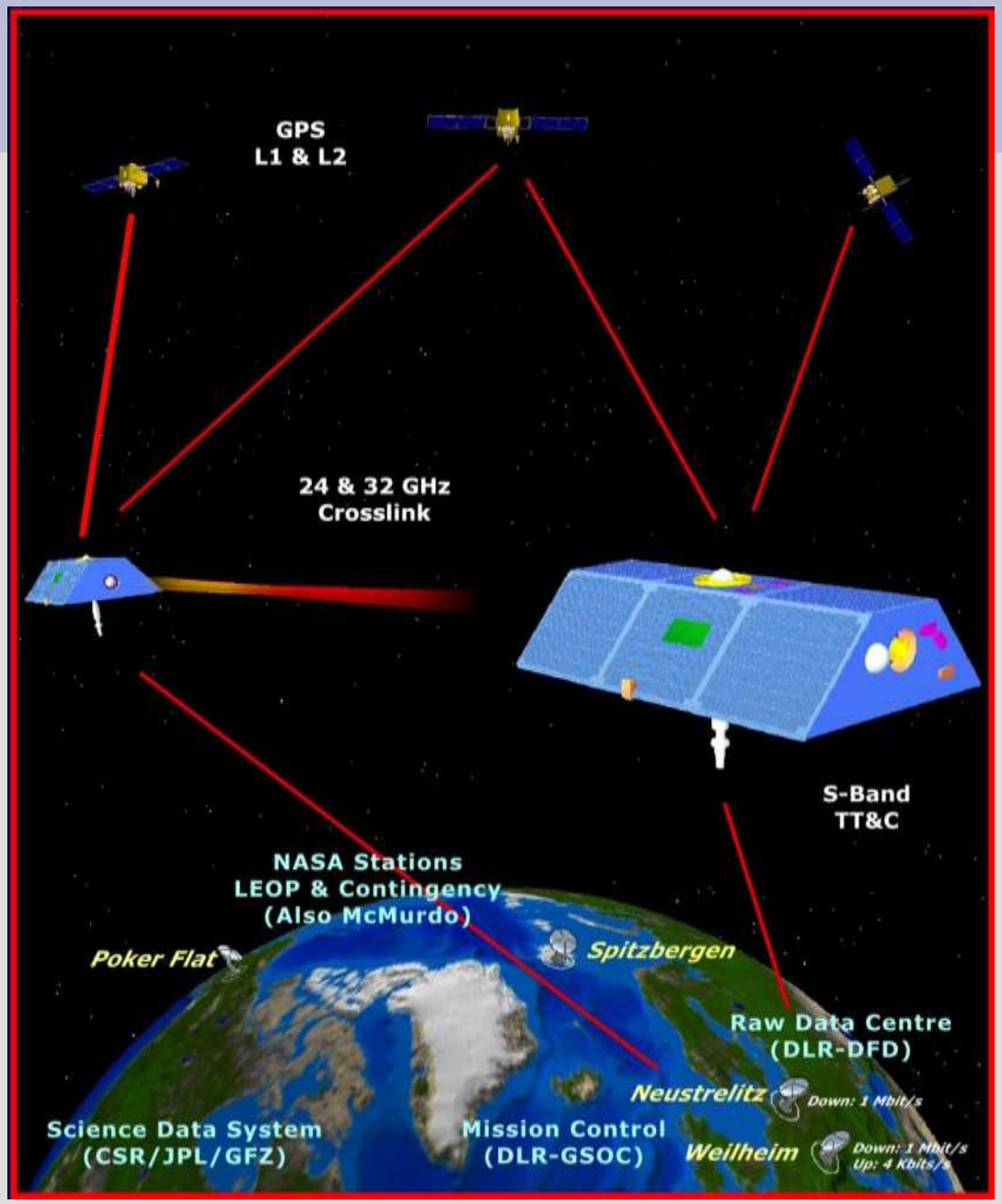
# GRACE Satellite Errors




source: MM Watkin, The GRACE Mission: Status and Latest Results

Corrections required: i) Earth Tides, ii) Ocean Tides, iii) atmospheric mass, iv) isostatic rebound, v) wind driven ocean waves.

# GRACE Satellite System

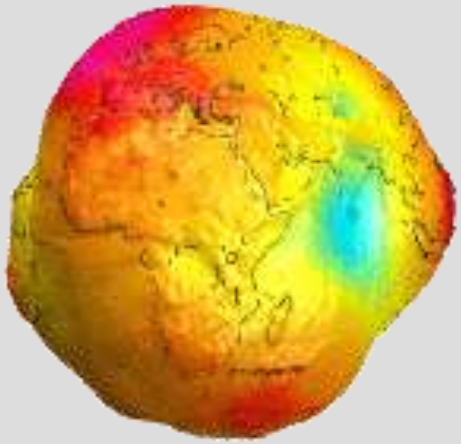



***Orbit***

**Launched: March 17, 2002**
**Initial Altitude: 500 km**
**Current Altitude: 476 km (30 m/d)**
**Inclination: 89 deg**
**Eccentricity: ~0.001**
**Separation Distance: ~220 km**

***Mission Time Frame***

**Original Length : 5 years**
**Current End of Life: 2011-2015**
**(Depends on solar activity, etc)**



source: MM Watkin, The GRACE Mission: Status and Latest Results