Bringing the ARM Constrained Variational Analysis to 3D

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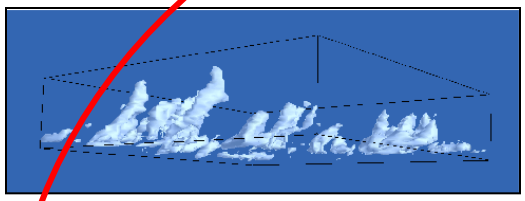
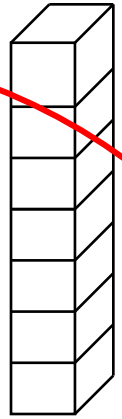
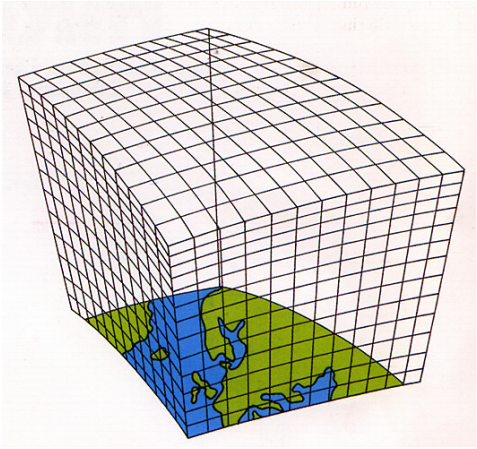
Working Strategy of GCSS (Pier Siebesma)







Large Eddy Simulation (LES) Models

Cloud Resolving Models (CRM)

Single Column Model

Versions of Climate Models

3d-Climate Models

NWP's

Observations from
Field Campaigns and/or
Observational sites (ARM)

Global observational
Data sets

Development

Testing

Evaluation

Minimum set of forcing data for LES, CRM, and SCM:

Horizontal advections of temperature and water vapor;
Vertical velocity.

To compare models with observations, forcing data are derived from objective analysis of sounding arrays or operational analyses.

ARM has been using a constrained variational algorithm to derive the large-scale forcing data for an atmospheric column from sounding arrays during IOPs.

ARM has used the same constrained variational algorithm to correct the operational analysis for an atmospheric column over fixed sites – the continuous variational analysis VAP.

Cost function minimized (3D VAR):

$$J(\mathbf{x}) = \frac{1}{2}(\mathbf{x}-\mathbf{x}_b)^T \mathbf{B}^{-1}(\mathbf{x}-\mathbf{x}_b) + \frac{1}{2}(\mathbf{y}_o - H(\mathbf{x}))^T \mathbf{R}^{-1}(\mathbf{y}_o - H(\mathbf{x}))$$

with analysis subject to constraints of column integrated conservations:

$$< \nabla \cdot \vec{V} >= -\frac{1}{g p_s}\frac{dp_s}{dt}$$

$$\frac{\partial < q >}{\partial t} + < \nabla \cdot \vec{V} q >= E_s - Prec - \frac{\partial < q_l >}{\partial t}$$

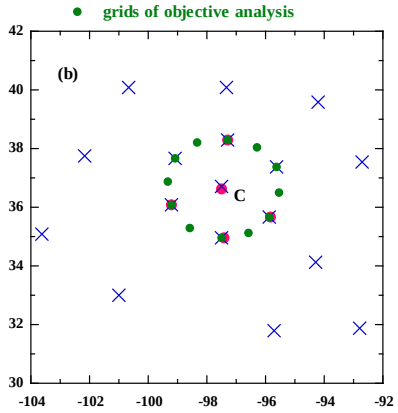
$$\frac{\partial < s >}{\partial t} + < \nabla \cdot \vec{V} s >= R_{TOA} - R_{SRF} + LPrec + SH + \frac{\partial < q_l >}{\partial t}$$

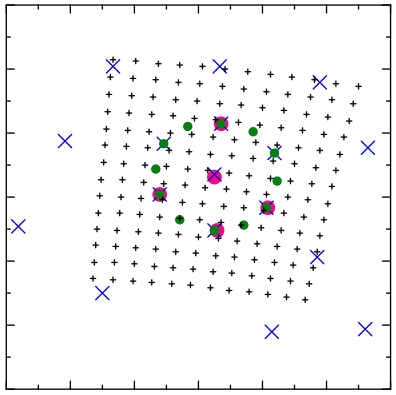
$$\frac{\partial < \vec{V} >}{\partial t} + < \nabla \cdot \vec{V}\vec{V} > - f\vec{k} \times < \vec{V} > -\nabla < \phi >= \vec{\tau}_s$$

Zhang et al (2001)

The algorithm integrates multiple datasets into consistent format

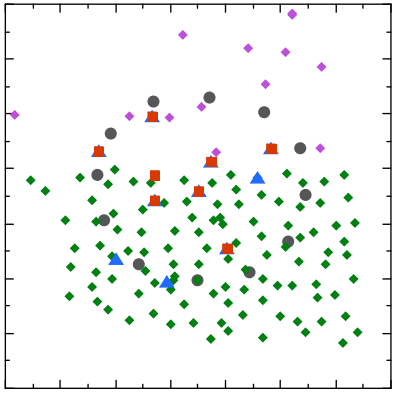
Soundings and wind profilers

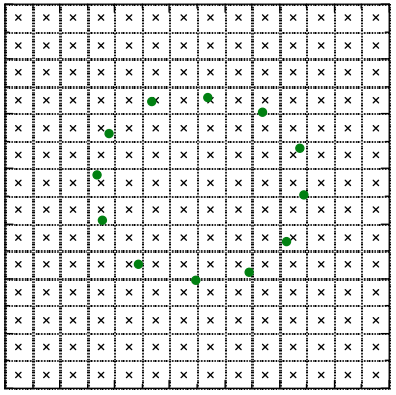




Operational analysis

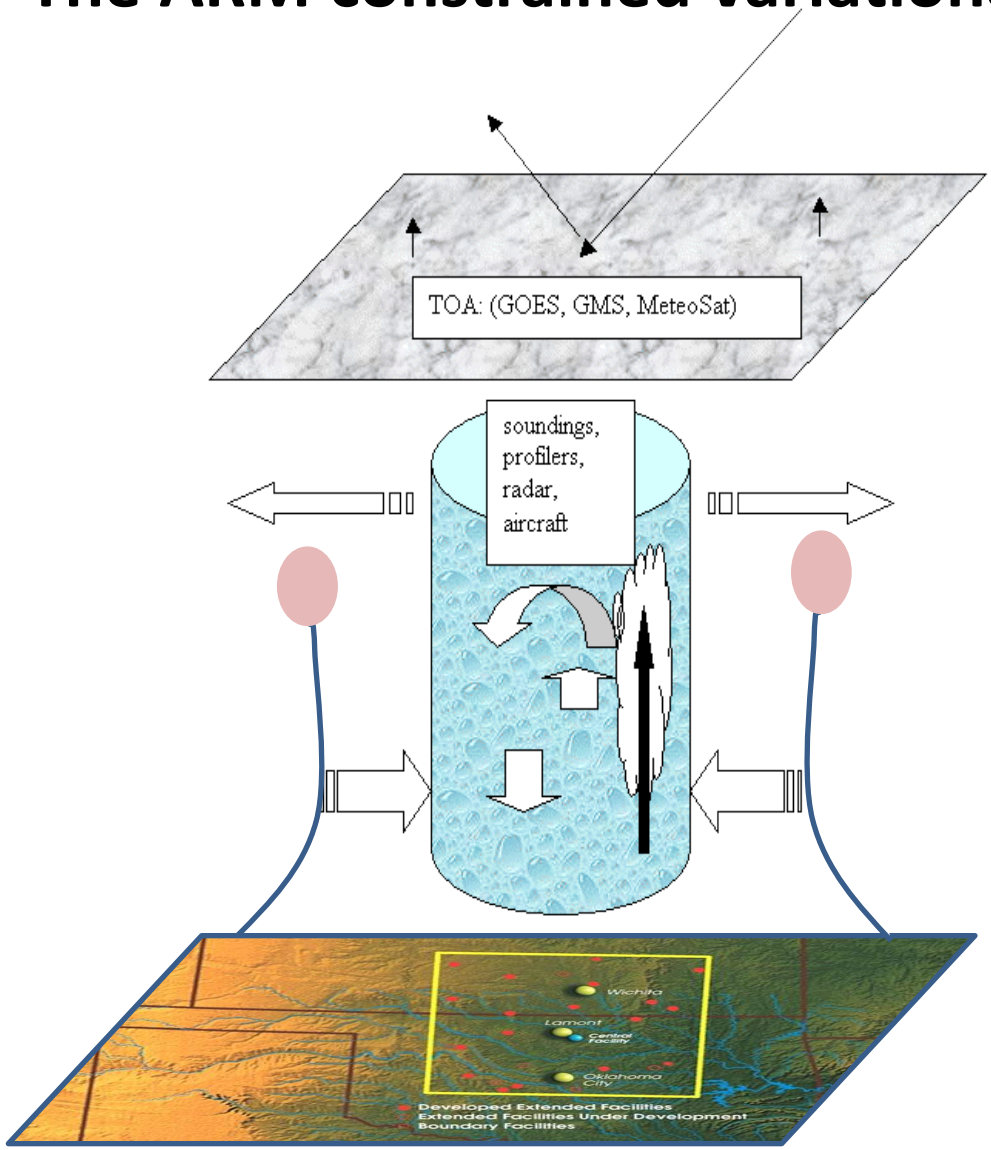
Surface Measurements





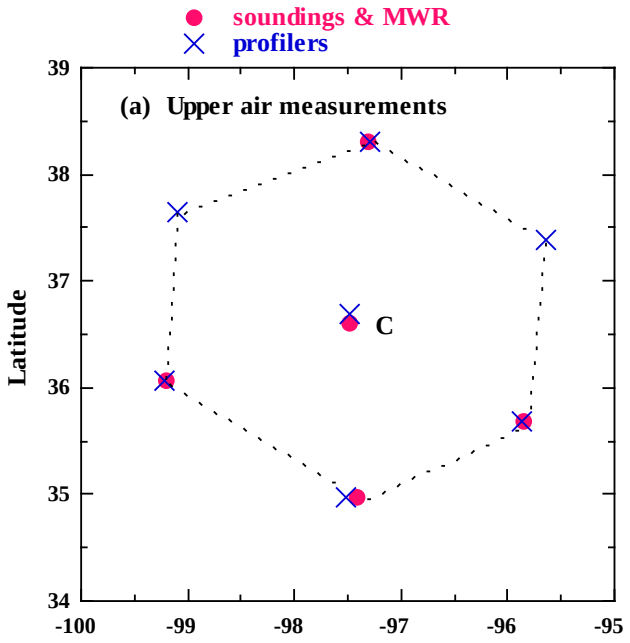
Satellite measurements at TOA

The ARM constrained variational analysis



New needs for model forcing data

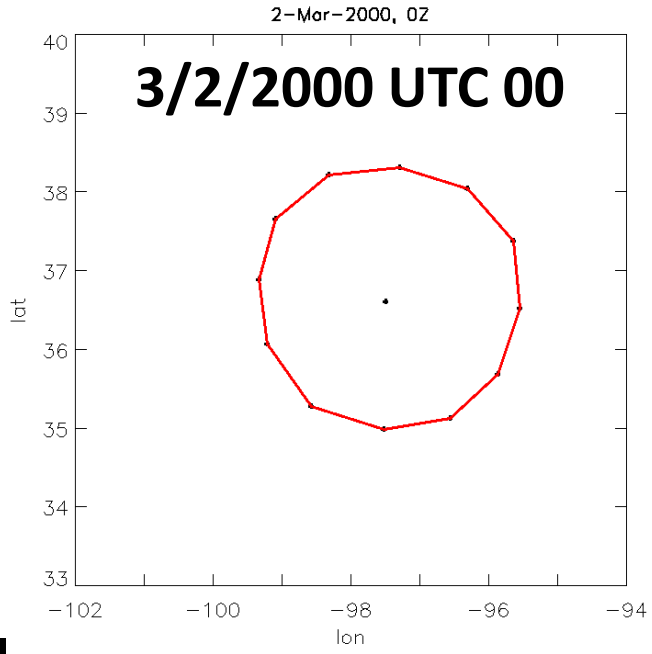
- **High resolution or resolution dependent parameterization**
- **Sub-synoptic dynamical structures**
- **Use of 3-D cloud data**



ARM-GCSS Case 4 Study

March 2000 ARM Cloud IOP

Frontal Clouds


2-Mar-2000, 0Z
3/2/2000 UTC 00
lat
lon
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−102
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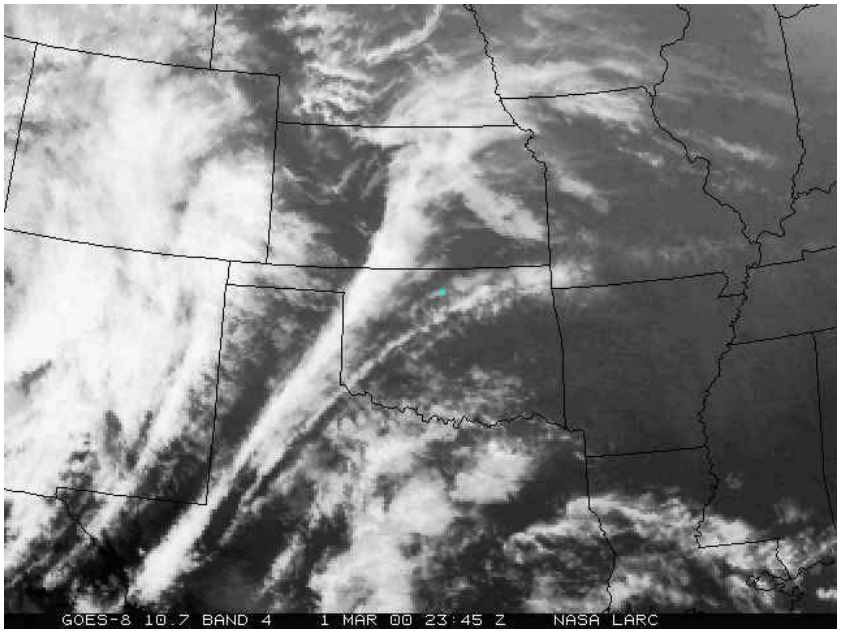
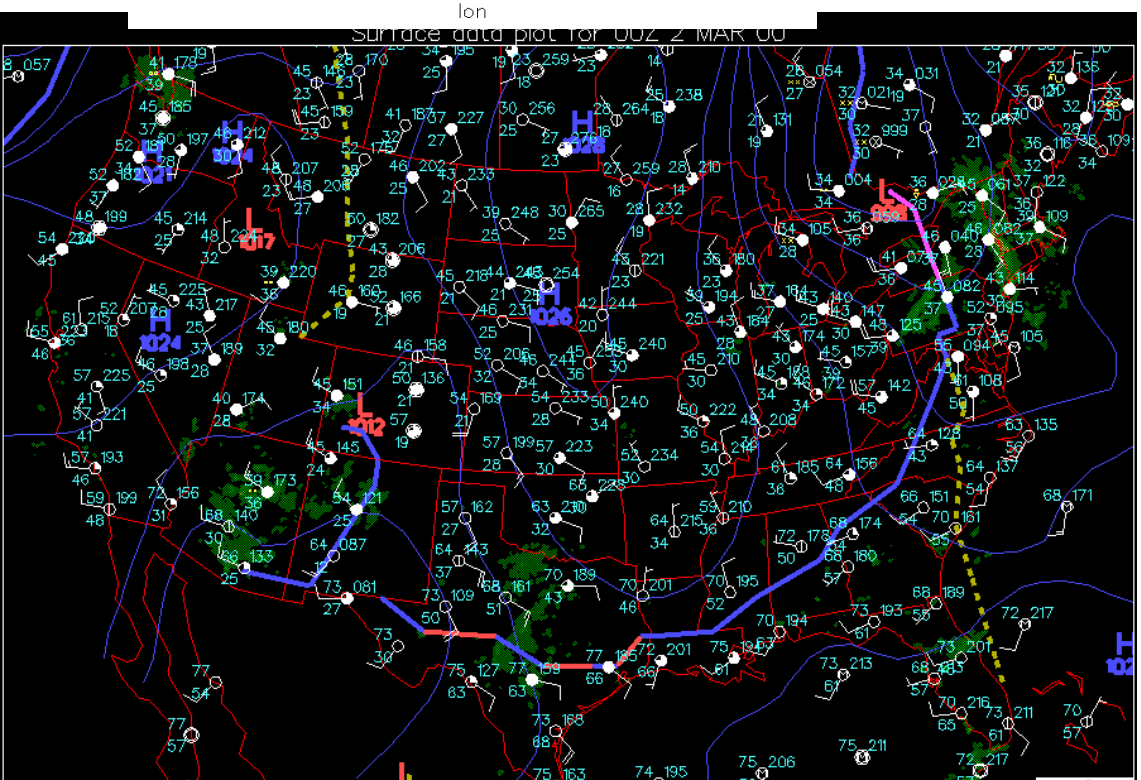
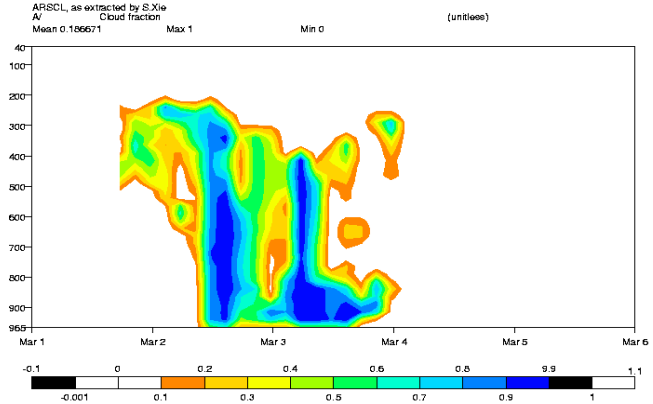
−96
−94

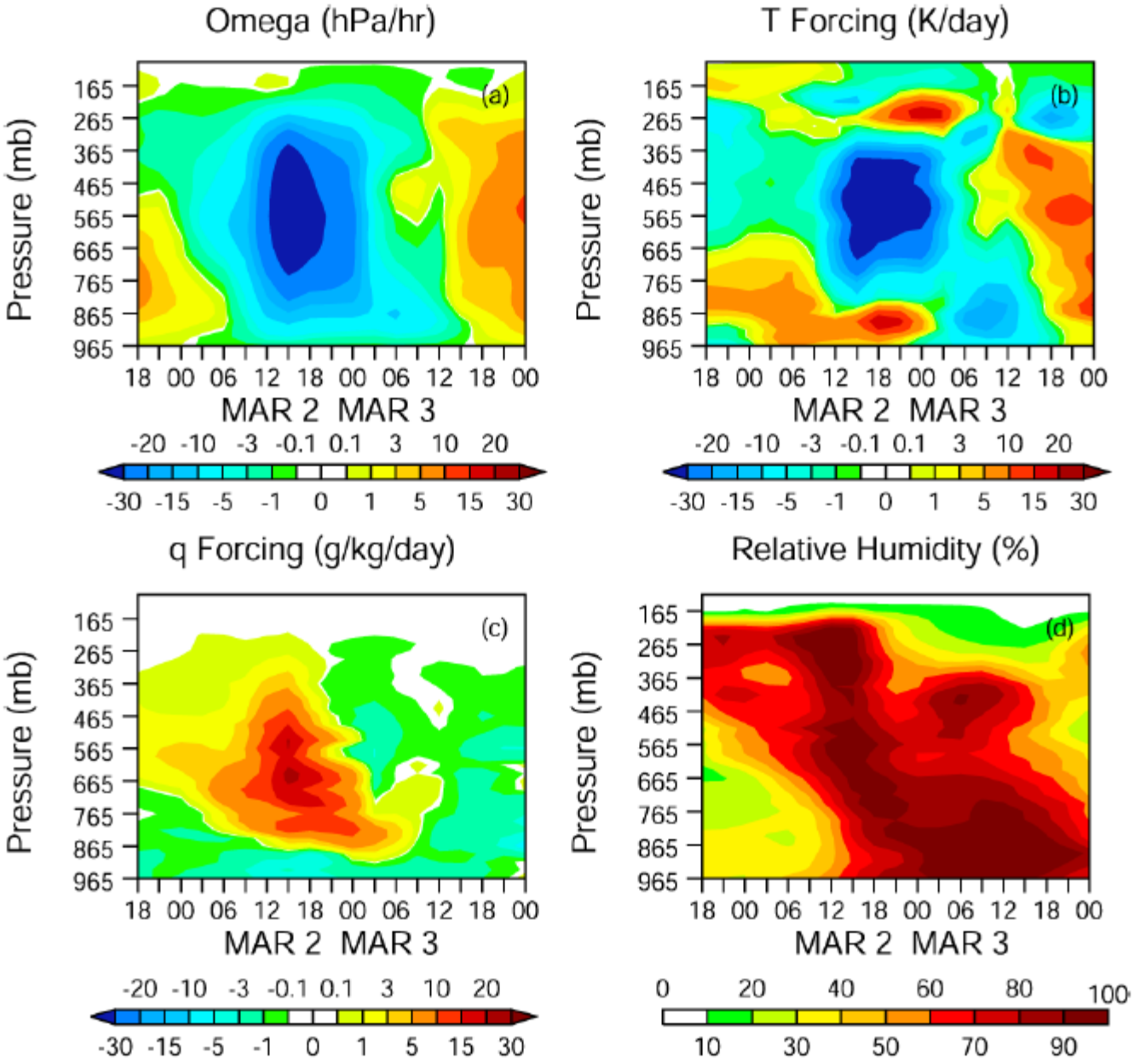

GOES-8 10.7 BAND 4 1 MAR 00 23:45 Z NASA LARC


Surface data plot for 00Z 2 MAR 00

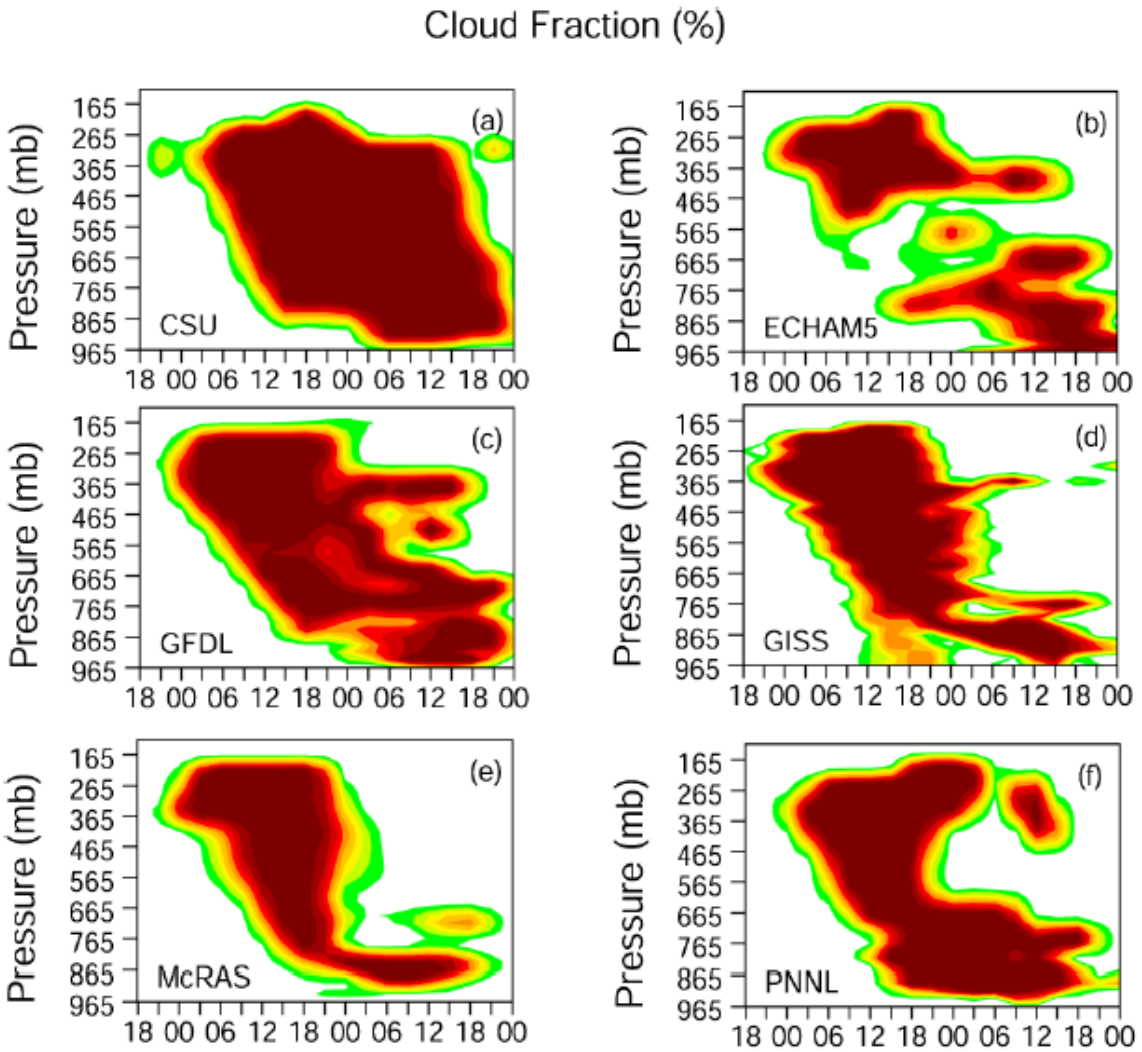

ARSCL, as extracted by S.Xie
A/ Cloud fraction (unitless)
Mean 0.186671 Max 1 Min 0
Mar 1
Mar 2
Mar 3
Mar 4
Mar 5
Mar 6

The variation analysis

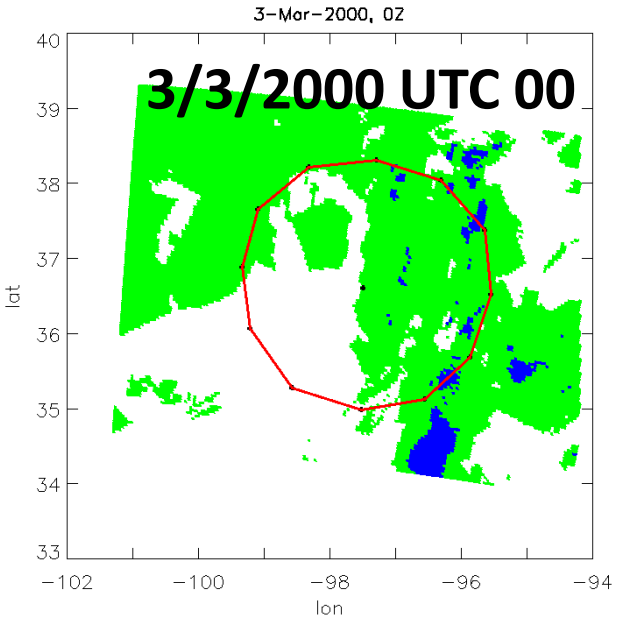
Xie et al. (2005)



SCM Clouds



Xie et al. (2005)


3-Mar-2000, 0Z
3/3/2000 UTC 00
lat
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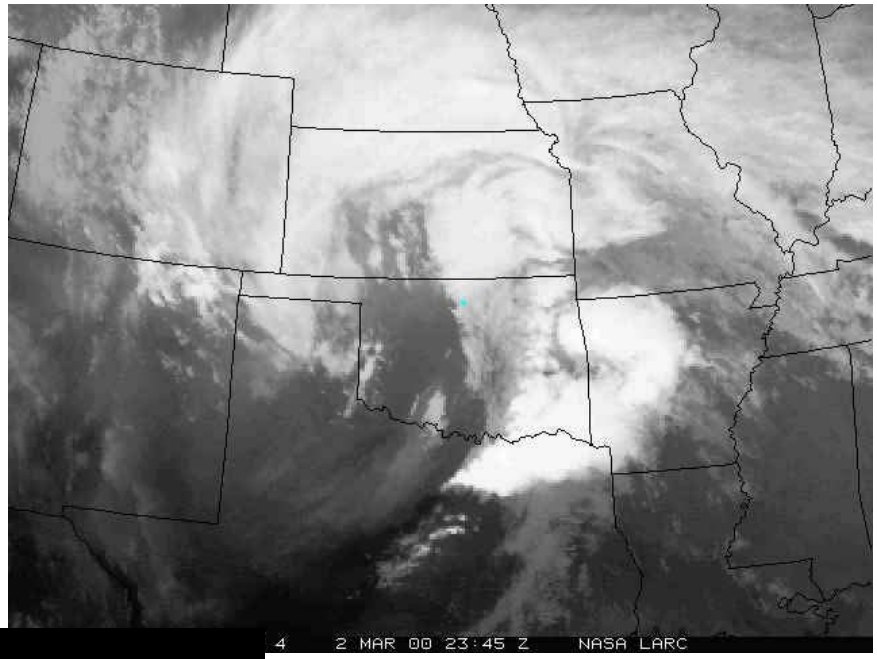
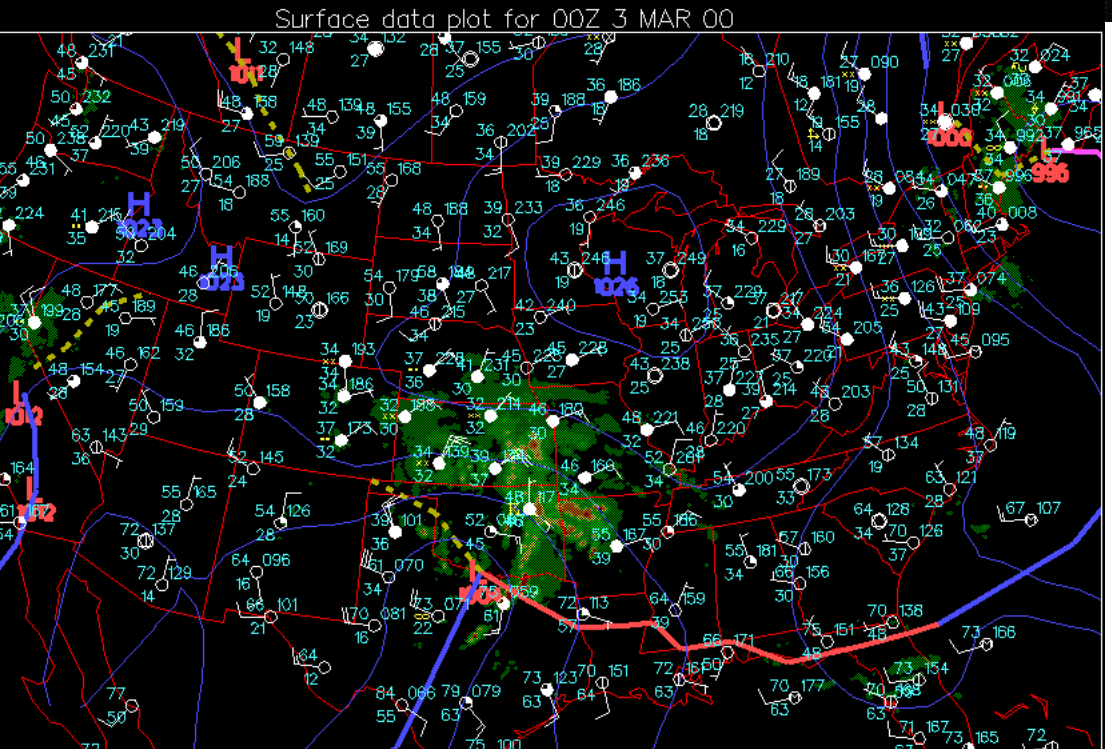
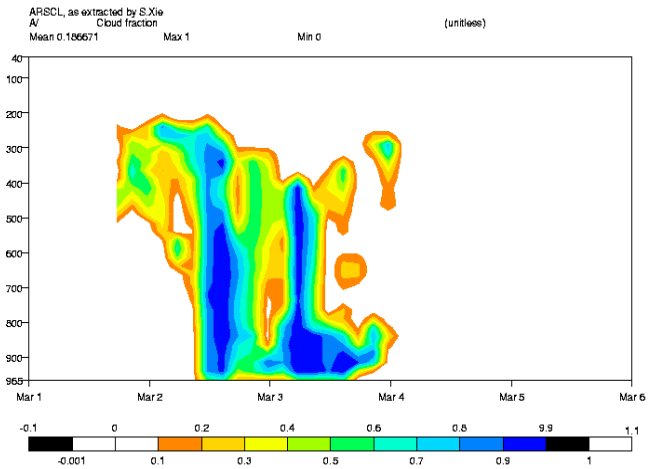
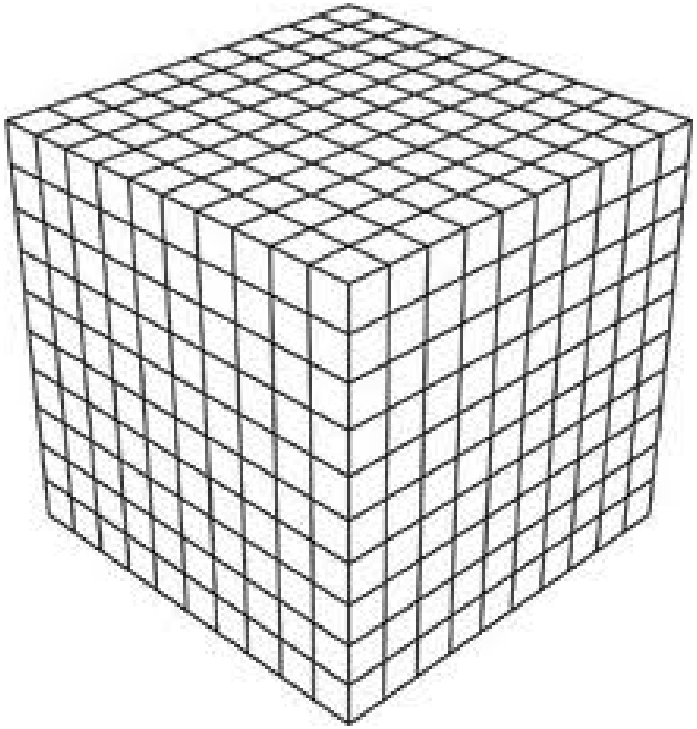
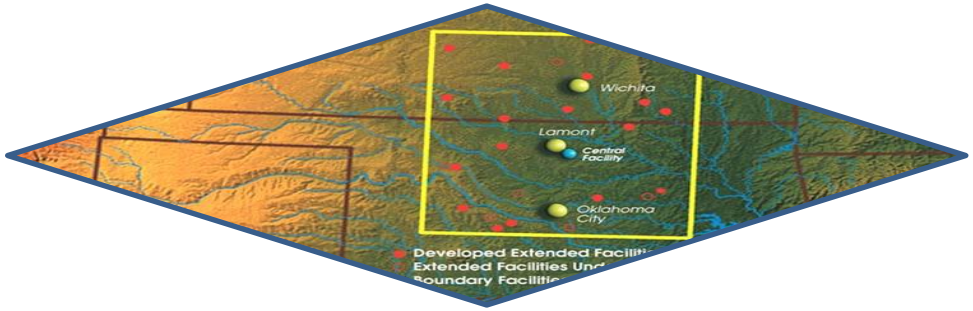

4 2 MAR 00 23:45 Z NASA LARC


Surface data plot for 00Z 3 MAR 00


ARSCL, as extracted by S.Xie
A/ Cloud fraction
(unitless)
Mean 0.186671
Max 1
Min 0
Mar 1
Mar 2
Mar 3
Mar 4
Mar 5
Mar 6

Constrained variational analysis in 3D





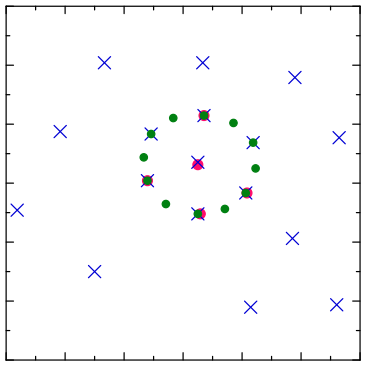
To enforce internal consistency with global constraints

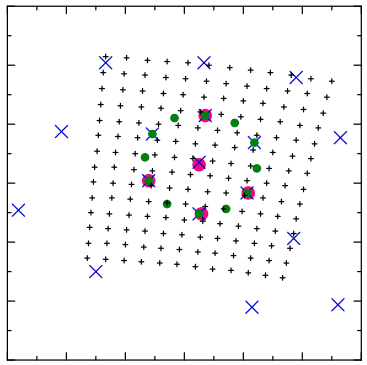
March 2000 ARM Cloud IOP

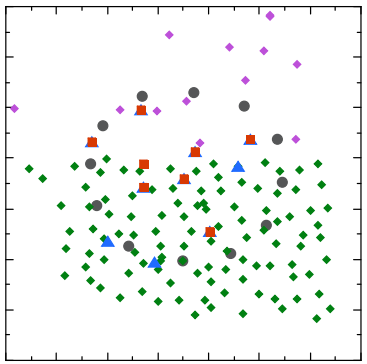
Input data:

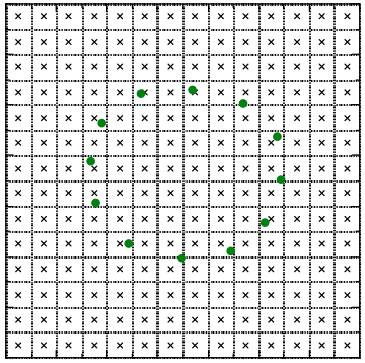
- **Soundings**
- **Profilers**
- **Operational analysis**

- **Radar precipitation**
- **GOES satellite data (Pat Minnis)**
- **Surface measurement from a suite of stations**









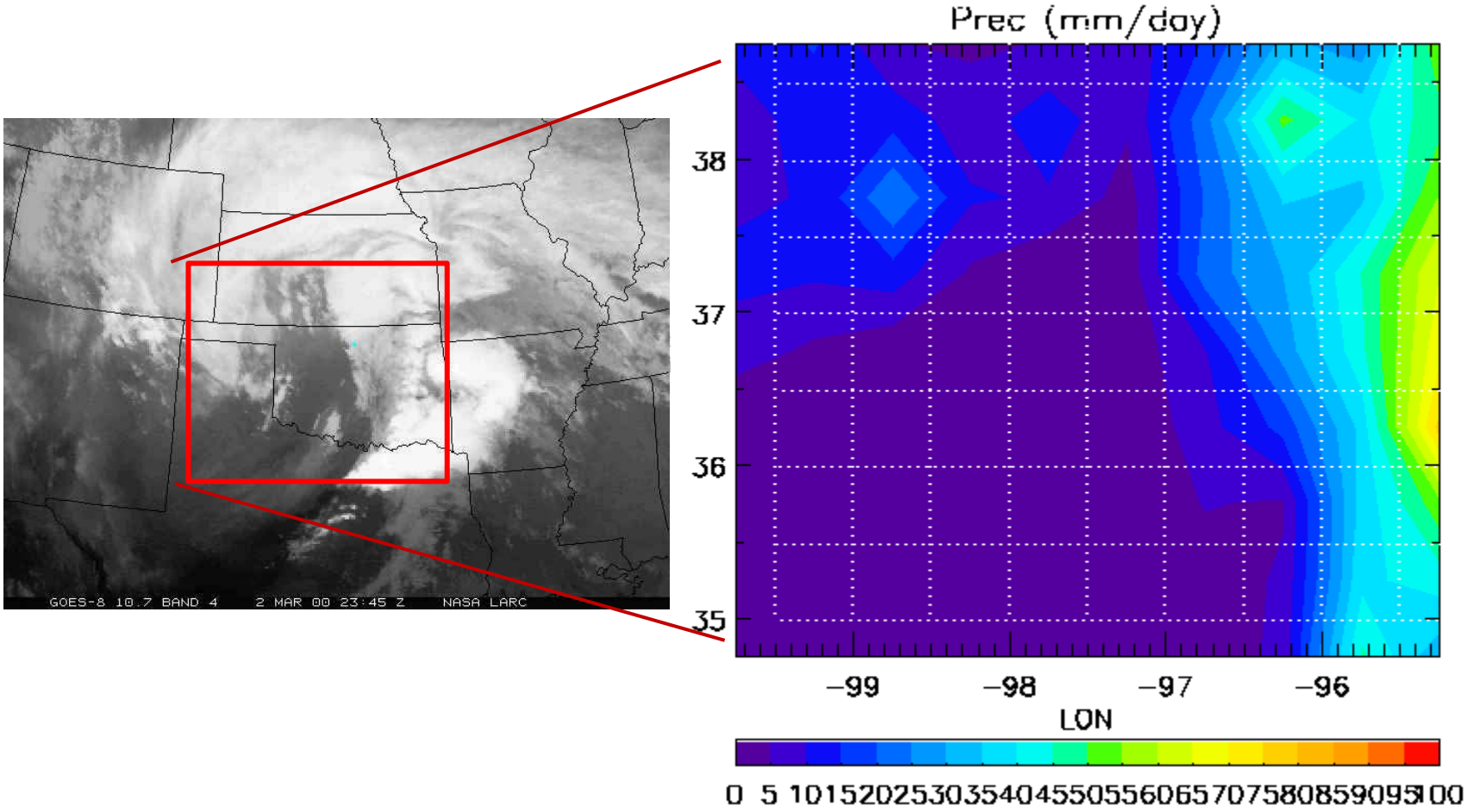
Analysis:

0.5°X0.5° resolution

100°W – 95°W, 34°N-39°N

3/3/2000 UTC 00

Clouds and Surface Precipitation



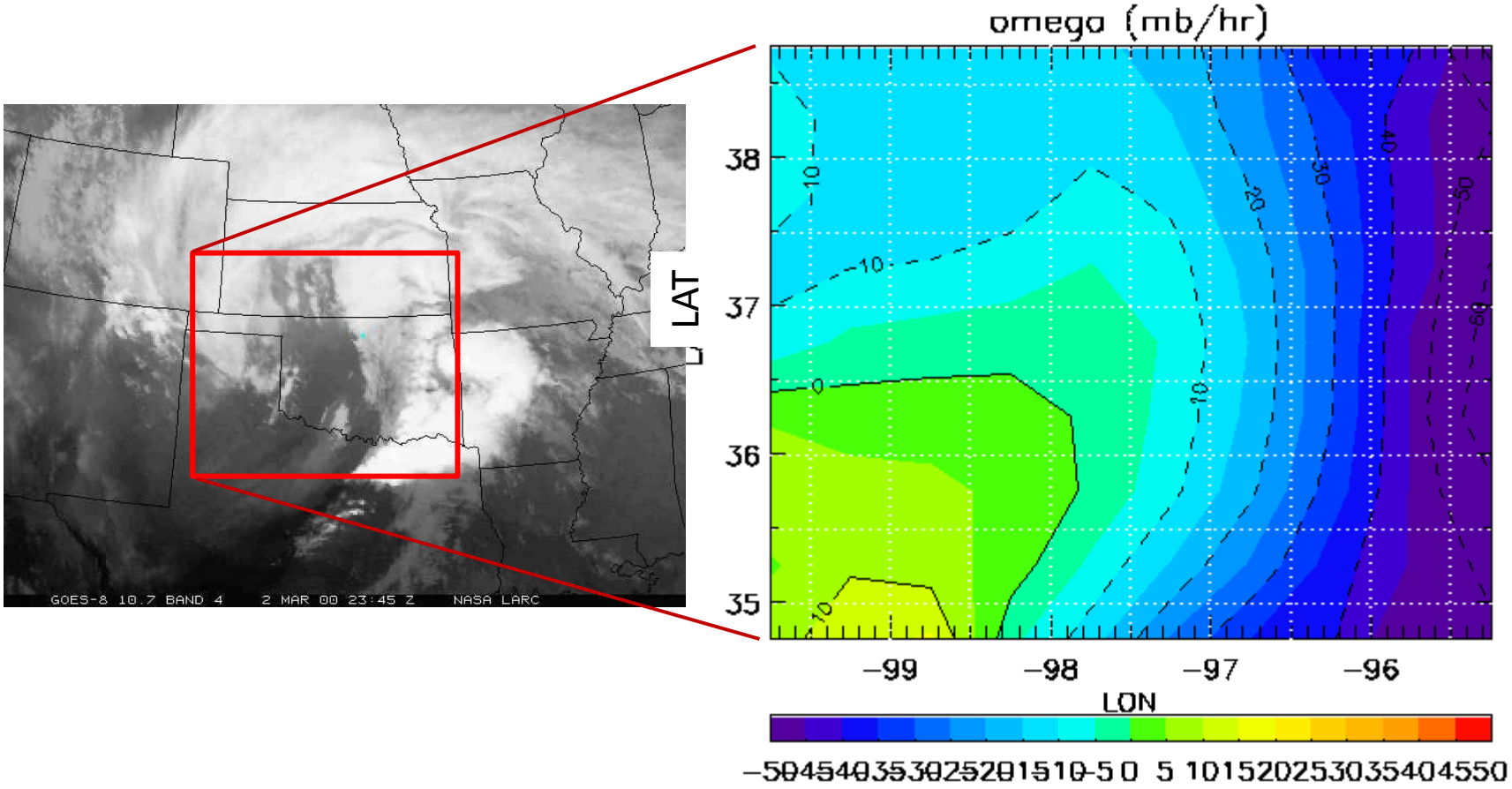
$$\frac{\partial \overline{s}}{\partial t}+\overline{V}\bullet\nabla\overline{s}+\overline{\omega}\frac{\partial \overline{s}}{\partial p}=Q_{rad}+L_v(c-e)-\frac{\partial\overline{\omega's'}}{\partial p}$$

$$\frac{\partial \overline{q}}{\partial t}+\overline{V}\bullet\nabla\overline{q}+\overline{\omega}\frac{\partial \overline{q}}{\partial p}=-(c-e)-\frac{\partial\overline{\omega'q'}}{\partial p}$$

$$Q_1=Q_{rad}+L_v(c-e)-\frac{\partial\overline{\omega's'}}{\partial p}$$

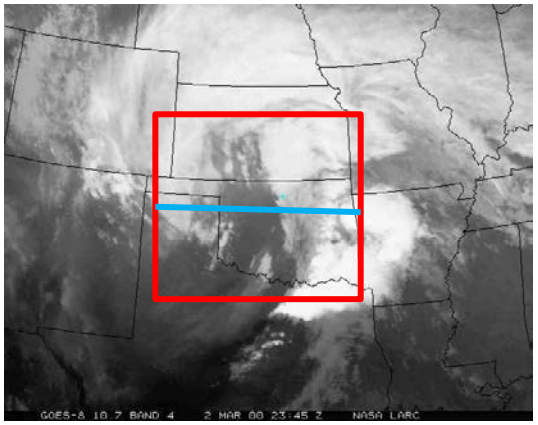
$$-Q_2/L_v=-(c-e)-\frac{\partial\overline{\omega'q'}}{\partial p}$$

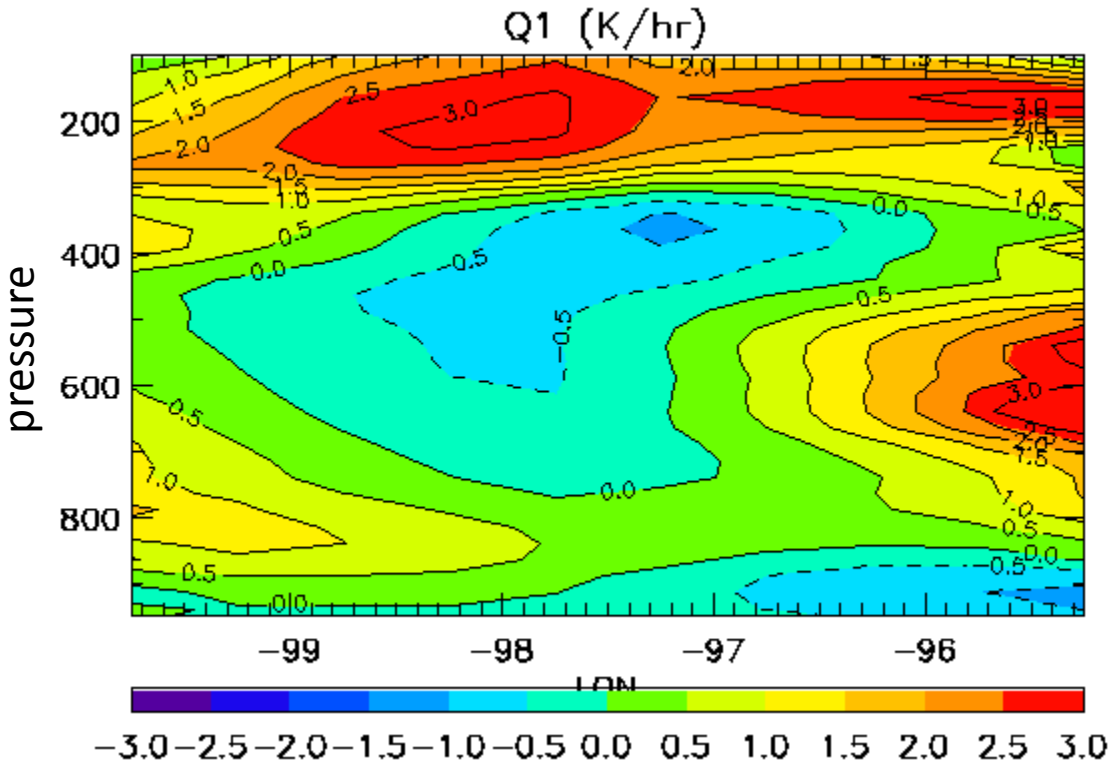
Omega at 500 hPa, 3/3/2000 UTC 00



3/3/2000 UTC 00

Longitude-pressure cross section of Q1 at 36.5°N





Summary

We have developed a 3D constrained variational algorithm to derive dynamical forcing data.

The forcing data allow modelers to carry out LES/CRM/SCM simulations and parameterization development under more realistic dynamical conditions. The data also enable the use of more ARM data to evaluate and constrain models.

We are doing further tests of the algorithm. The next plan is to add more constraints, and to combine it with the WRF data assimilation system so that hydrometer advections can be estimated.