A sonde monitoring and display facility for DYNAMO

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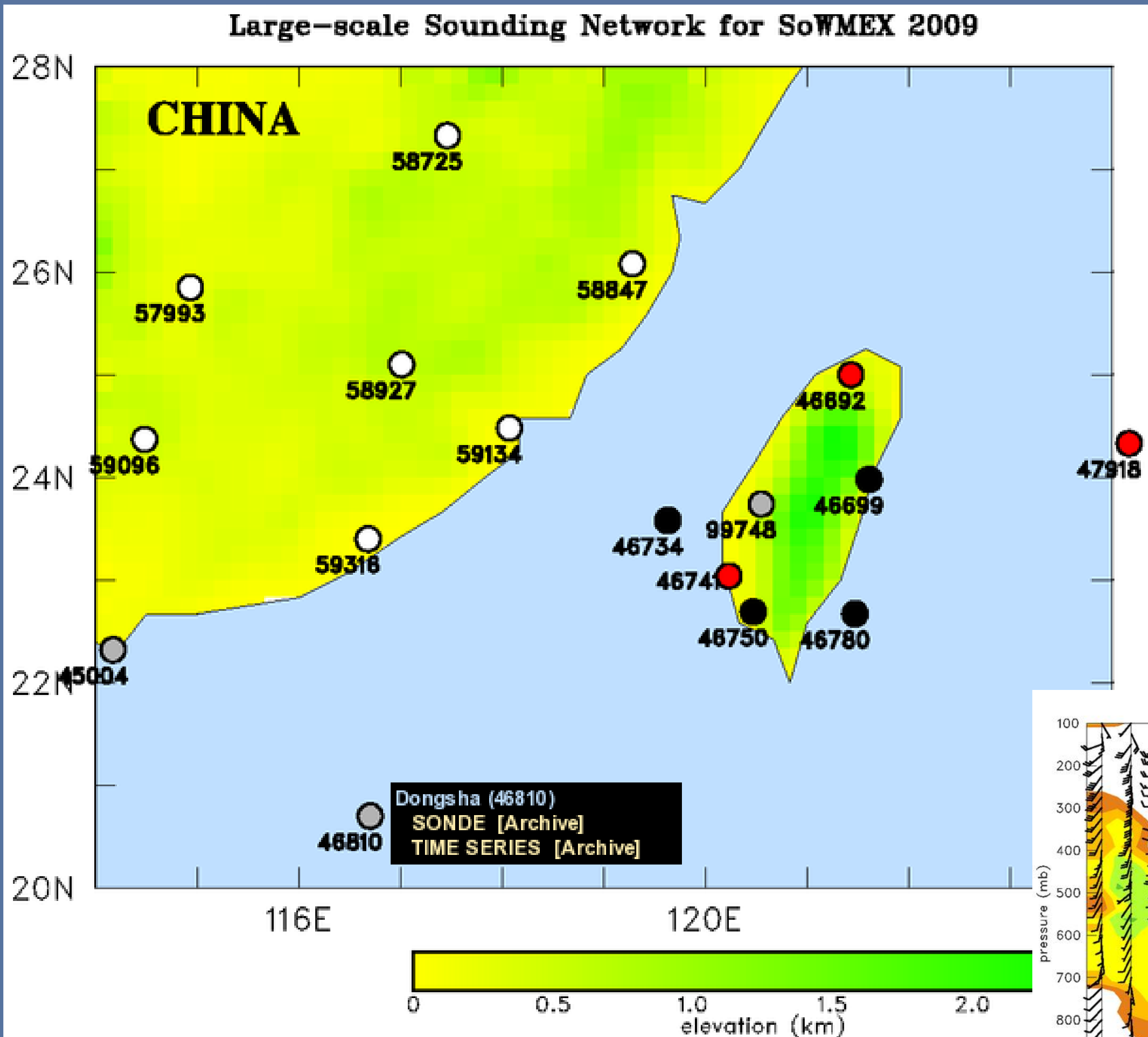
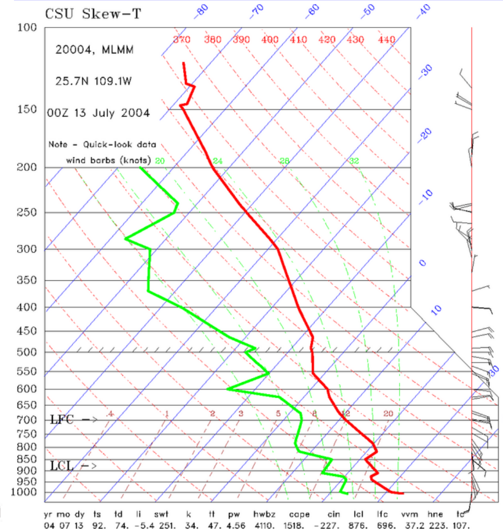
In support of sounding and forecast operations for several past field programs (TOGA COARE, SCSMEX, NAME, TiMREX, SoWMEX09), our group at CSU has designed a procedure to monitor sonde quality and then display the sondes and several analyzed products on a dedicated web site.

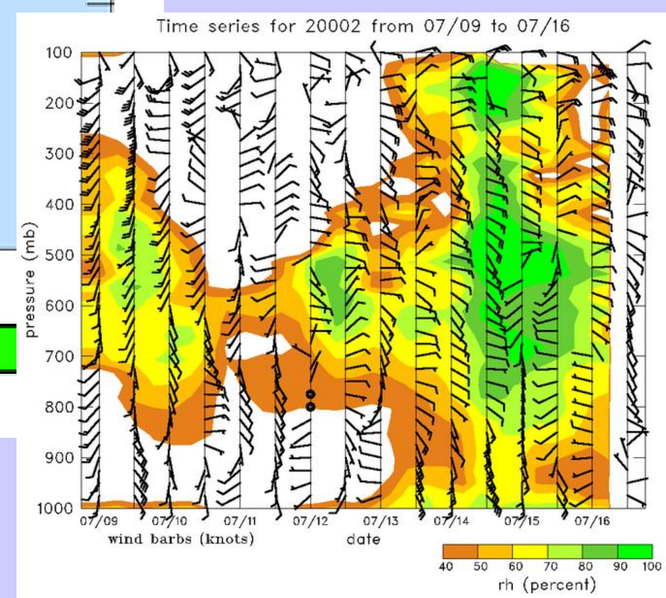
In this manner, problems (e.g., bad sonde batches, improper launch procedures, bad surface ground checks) can be quickly identified and fixed in a timely fashion.

- Sonde data are ingested from GTS or some other data feed.
- Some limited QC is performed (objective tests and visual)
- SkewT plots and analyzed products (such as station time-series, objectively analyzed fields of divergence, vertical motion and vorticity) can be quickly produced (within a few hours of when sondes were launched) to aide forecast operations.

Example from SoWMEX09 conducted in May/June 2009


Large-scale Sounding Network for SoWMEX 2009
CHINA
28N
26N
24N
22N
20N
116E
120E
58725
57993
58847
58927
59096
59134
59316
45004
46692
46699
99748
46734
46741
46750
46780
47918
46810
Dongsha (46810)
SONDE [Archive]
TIME SERIES [Archive]
0
0.5
1.0
1.5
2.0
elevation (km)


CSU Skew-T
20004, MLMM
25.7N 109.1W
00Z 13 July 2004
Note - Quick-look data
wind barbs (knots)
LFC
LCL


Time series for 20002 from 07/09 to 07/16
pressure (mb)
wind barbs (knots)
date
rh (percent)
07/09
07/10
07/11
07/12
07/13
07/14
07/15
07/16

SoWMEX 2009

Southwest Monsoon Experiment '09
CSU Mesoscale Dynamics Group

Colorado State University

Taiwan Date/Time
06/30/2010
03:30

UTC Date/Time
06/29/2010
19:30

QUALITY CONTROL PRODUCTS

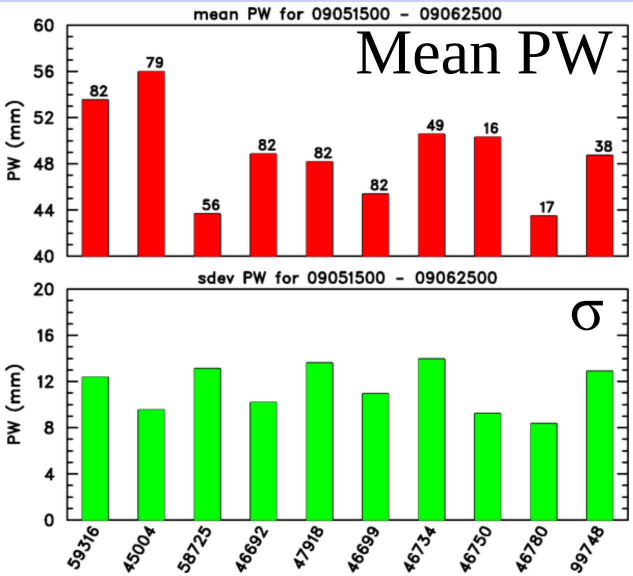
Convective Parameters:

	pw	cape	cin	lcl	fsl	dq	
mean							mean
time series 1							time series 1
time series 2							time series 2

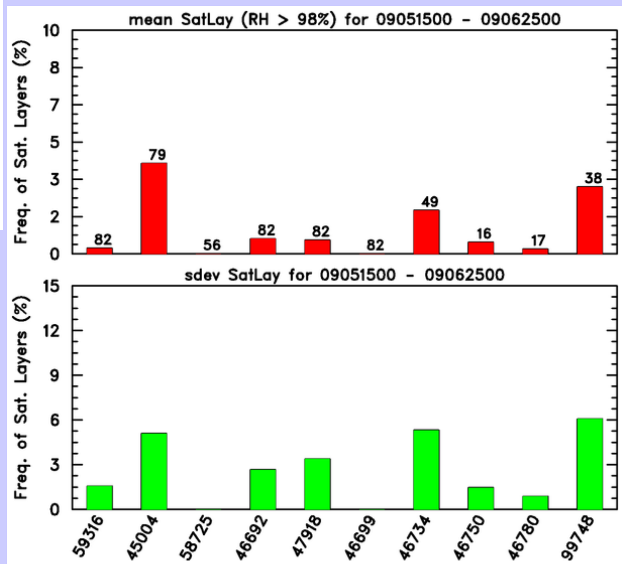
Basic Fields:

	z			t			q			u			
	mean	ts1	ts2	mean	ts1	ts2	mean	ts1	ts2	mean	ts1	ts2	
1025													1025
1000													1000
925													925
850													850
700													700
500													500
400													400
250													250
150													150

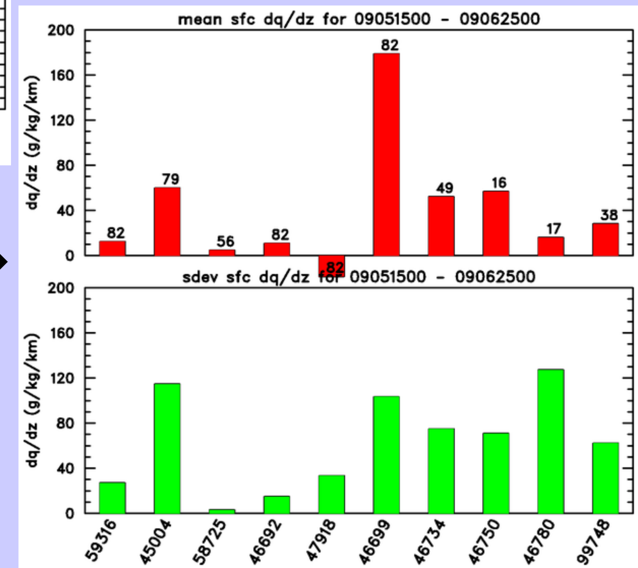
Quality Control of Sonde Moisture (an example from SoWMEX09)



🡐Mean PW suggest moisture biases might be present at a few sites.



🡐 Frequency of saturated layers is also a useful metric for identifying moisture biases



Near-surface q-gradient 🡒
(where q_{sfc} is independent from sonde) confirms that station 46699 (Hualien) has low-level dry bias in their sondes.

Examples of problems indentified with sonde monitoring system in recent experiments:

•incorrect starting elevation for Pingdong in SoWMEX09 (site elevation was checked and corrected)

• humidity bias in Vaisala RS80-A sondes in TiMREX (intercomparison study was initiated to correct bias)

• improper height computation at *RV* Altair in NAME (corrected using T_V instead T in hypsometric eqn.)

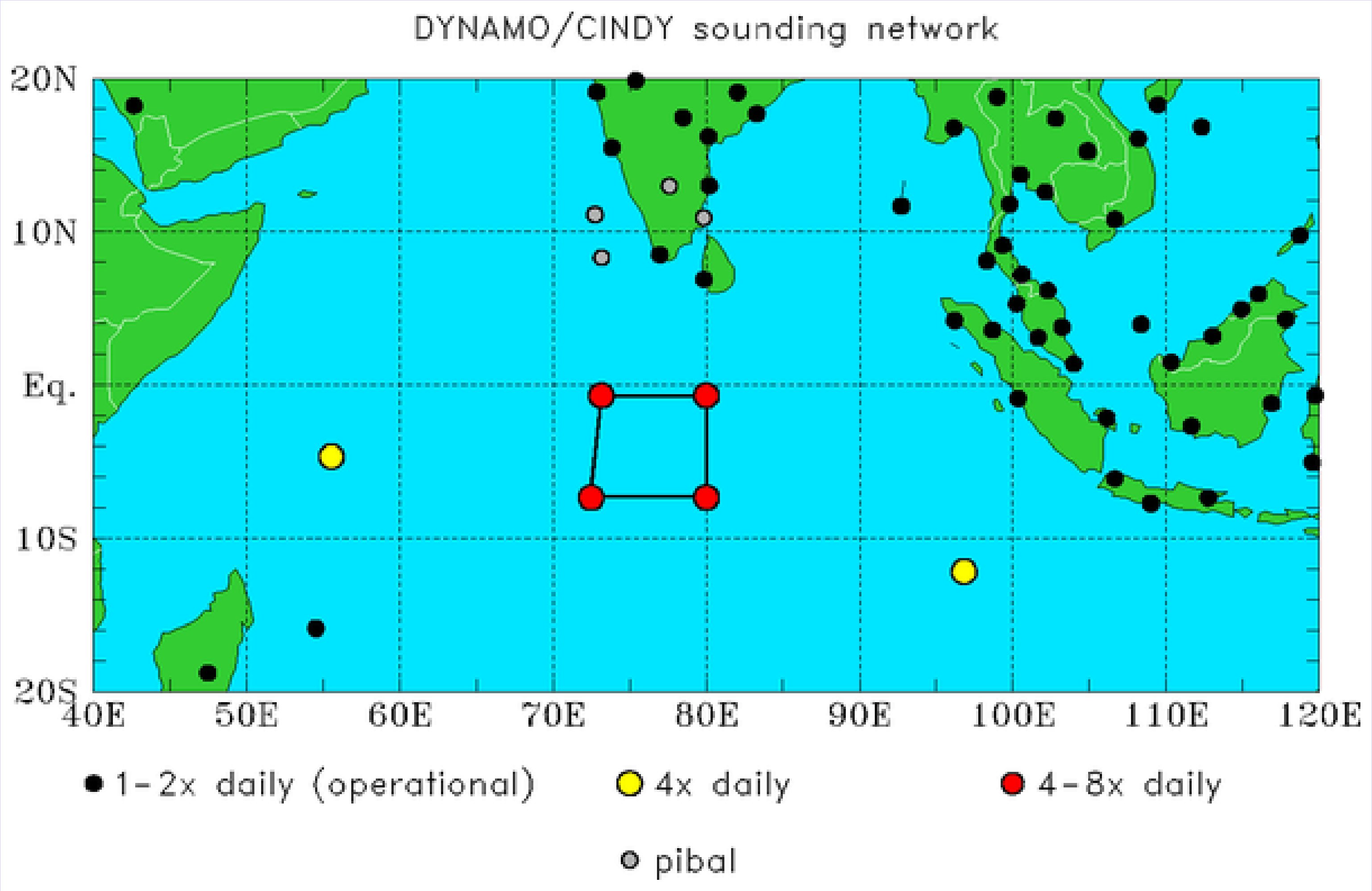
•humidity bias indentified in Mexican raobs in NAME (led to the development of a correction algorithm)

Sonde monitoring Web site can be designed as a one stop shopping center for various sonde and other operational products with links to:

- ISS profiler and RASS displays, as well as, surface met data
- EOL field catalog
- time series of GPS PW at land sites
- satellite products: TRMM rainfall, SSMI SSTs and winds
- Wheeler/Hendon MJO index
- radar products
- COSMIC sondes

Web site can be tailored to meet the operational and forecasting needs of experiment (e.g., horizontal maps may not be useful, time series of diagnosed fields could be).

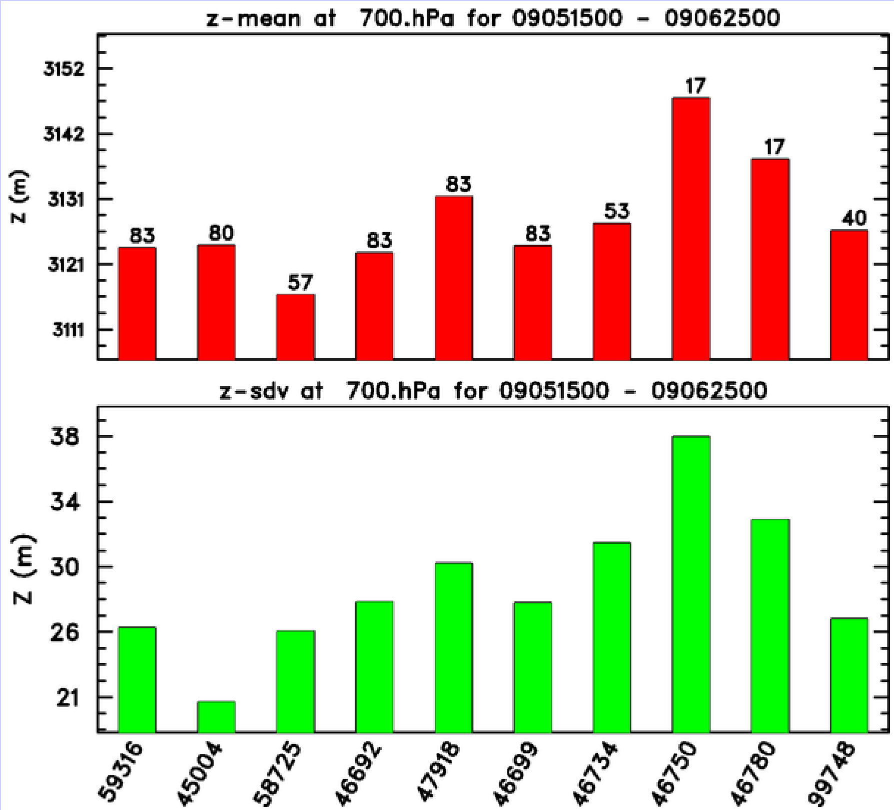
For is to happen, sonde data **MUST** be available in near real time.



- Would such a facility be useful to the DYNAMO experiment?

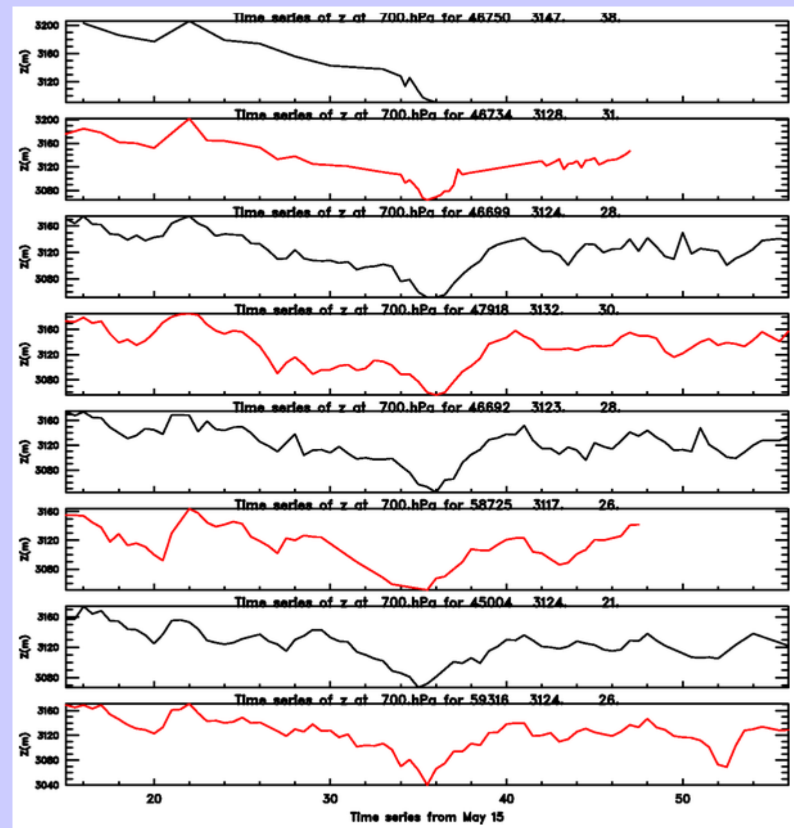
- What additional products would be useful to aide operations?

Supplemental material

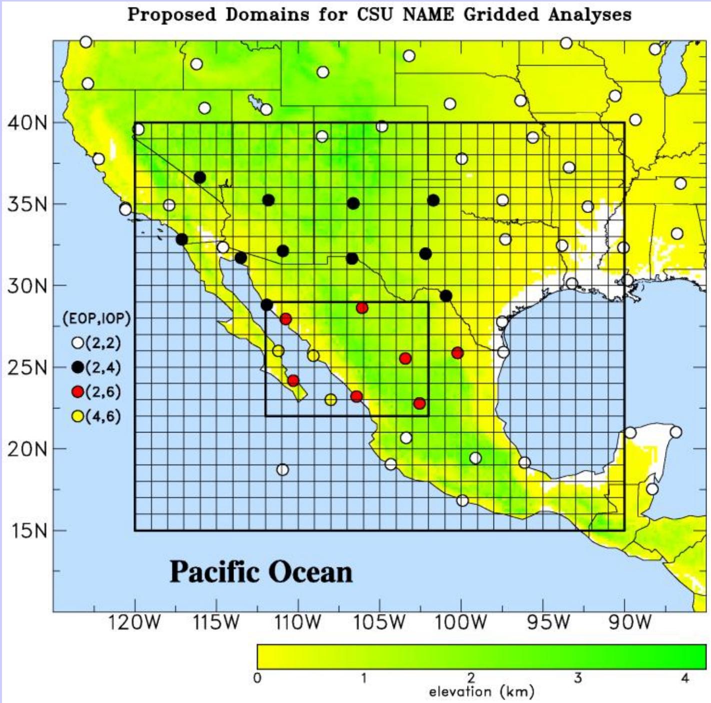


←Mean 700 hPa heights show a +10 m positive height anomaly at 46750. Also seen at other pressure levels.

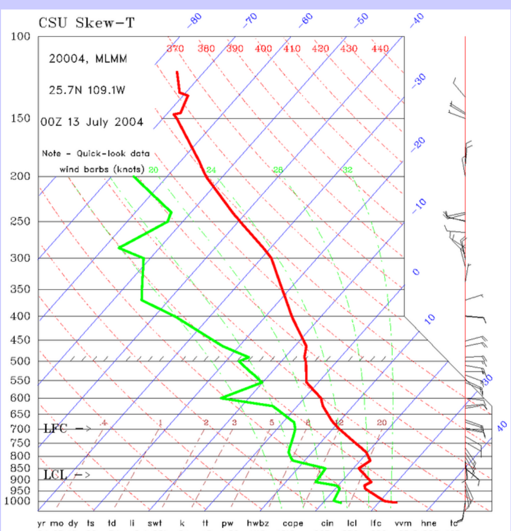
Time series of Z_{700} confirm that → height bias is not a result of a few bad obs but rather that wrong starting elevation was used for height computation at this station.



Example of sonde monitoring and analyses during NAME

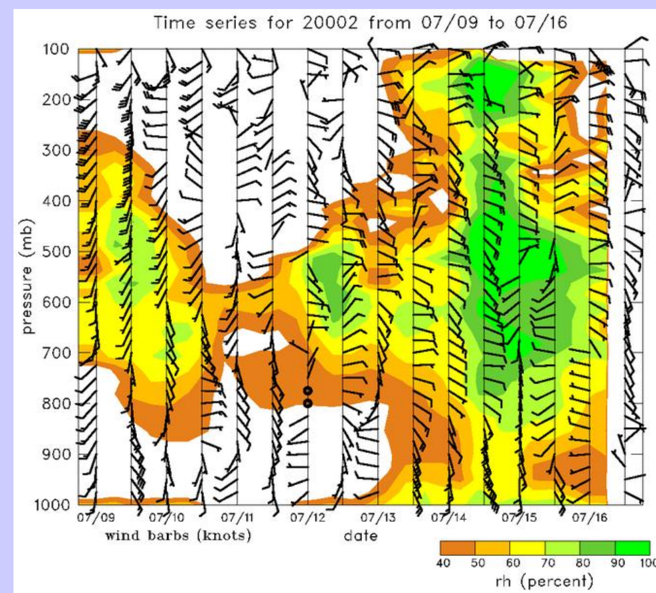


Sondes are QC'ed over region of interest, then objectively analyzed onto a regular grid at 25 hPa vertical resolution. From analyses of basic fields (*u*, *v*, *T*, *q*), we diagnose divergence, vertical motion, apparent heating (Q_1) and apparent moistening (Q_2).

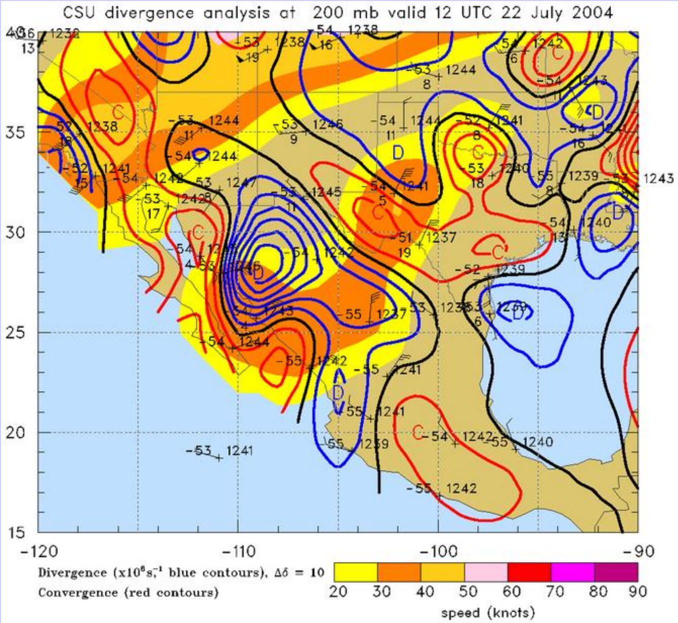


Sample Skew-T plot

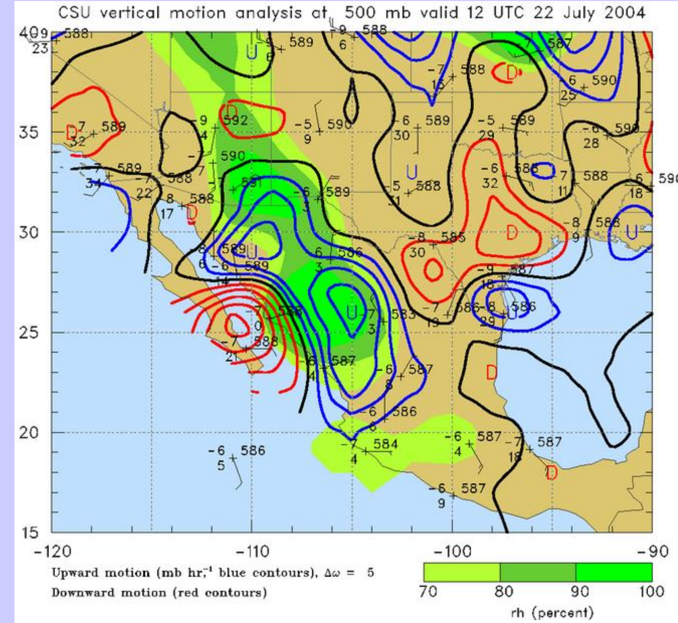
Station time series of winds and RH.

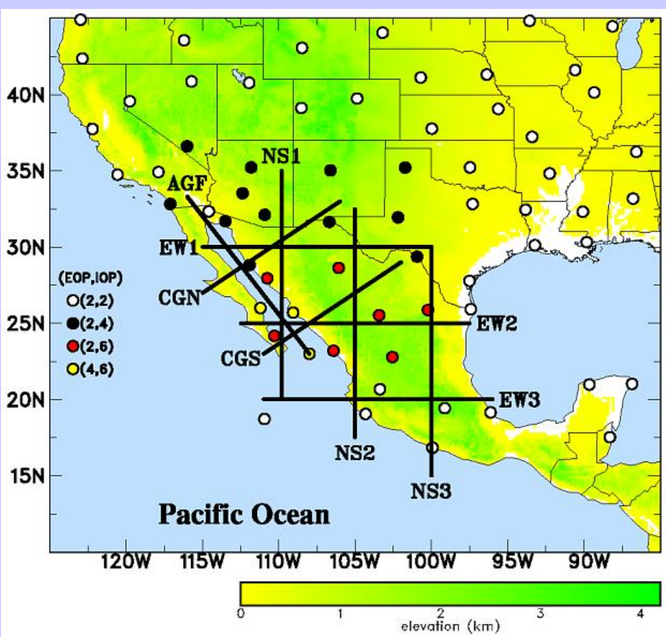


Example of analyses produced operationally during NAME

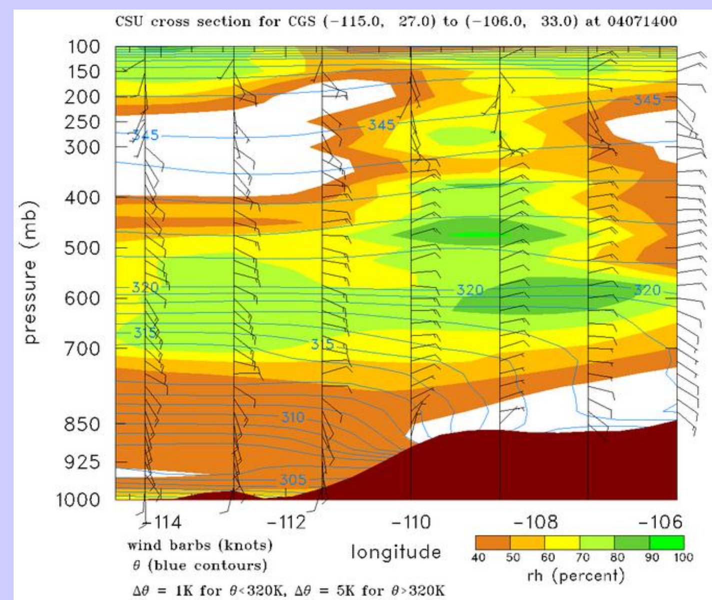


- 200 hPa divergence associated with upper-level TUTT
- 500 hPa vertical motion





- Cross sections were produced for several vertical slices.
- Cross-section along CGS of winds, T and RH.



sounding operation issues and recommendations

- concerns with surrounding operational network (e.g., Indian sondes)
- How high is sonde data needed? (only 15% of 200 gr balloon attain 25 km, whereas 85% of 800 gr balloons attain this level)
- Request surrounding countries to save high-resolution operational sondes
- Collocating ground based GPS and surface observations with sondes will help identify sonde moisture biases and validate their corrections.
- To capture large-scale forcing of convective systems, sondes impacted with convective scale motions should be avoided. Establish a no-launch window when sonde release occurs near strong convection (e.g., ±15 min of squall line).
- Balloon icing issues could potentially impact ~3-5% of sondes. (possible solutions: use larger balloons or more helium)
- Digicora software should be run in research mode so soundings don’t terminate when they encounter downdrafts.

There are two main sources for errors in large-scale atmosphere budgets: instrumental error and sampling error.

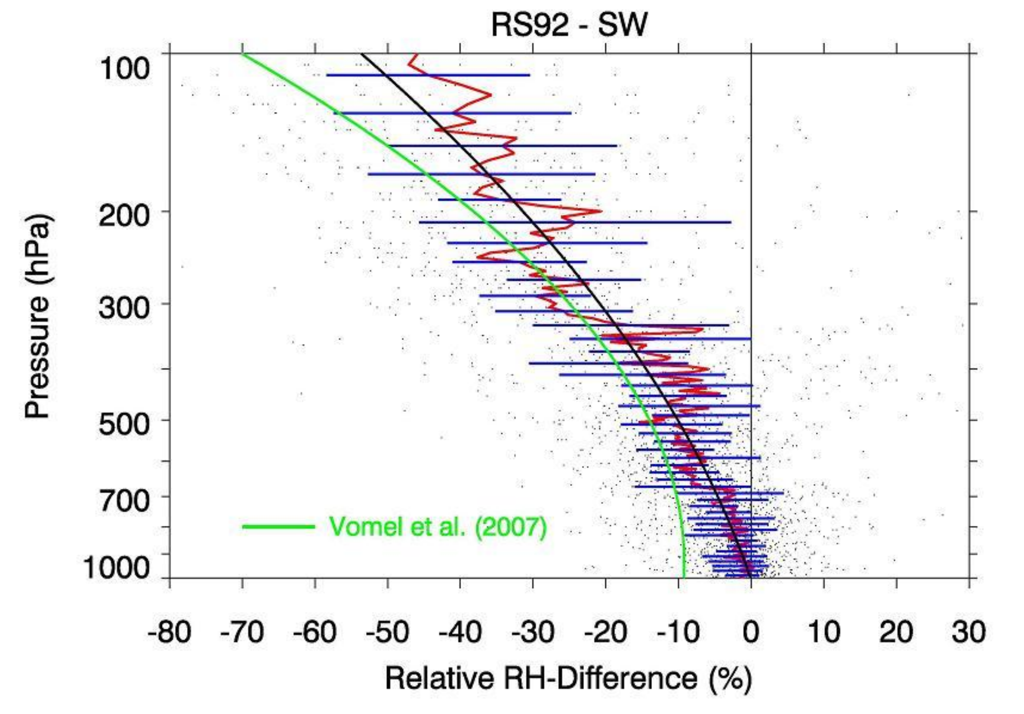
Instrumental errors in atmospheric soundings, typically humidity biases, can usually be dealt with in post processing the data, especially if independent data sources (e.g., colocated GPS PW) are available to identify errors and validate corrections.

Sampling errors, result from having an incomplete description of atmospheric fields. Random sampling errors are minimized by increasing the frequency of observations in both space and time. Random errors decrease rapidly with time averaging as $1/N^{1/2}$ where N is the # of samples. **(**Errors are roughly halved as samples increase by a factor of 4**).**

How these error can be minimized?

Instrument biases

• these reference sondes will be useful in calibrating other sondes
•Vaisala RS 92 sondes used at ARM sites have a daytime dry bias (Vomel et al. 2007, Yoneyama et al. 2008, Cady-Pereira et al. 2008)



Relative difference between humidity data from RS92 and Snow White (chilled mirror hygrometer) for 14 daytime (near noon) soundings taken during MISMO in 2006 shows significant dry bias in RS92 sondes, especially at upper levels.

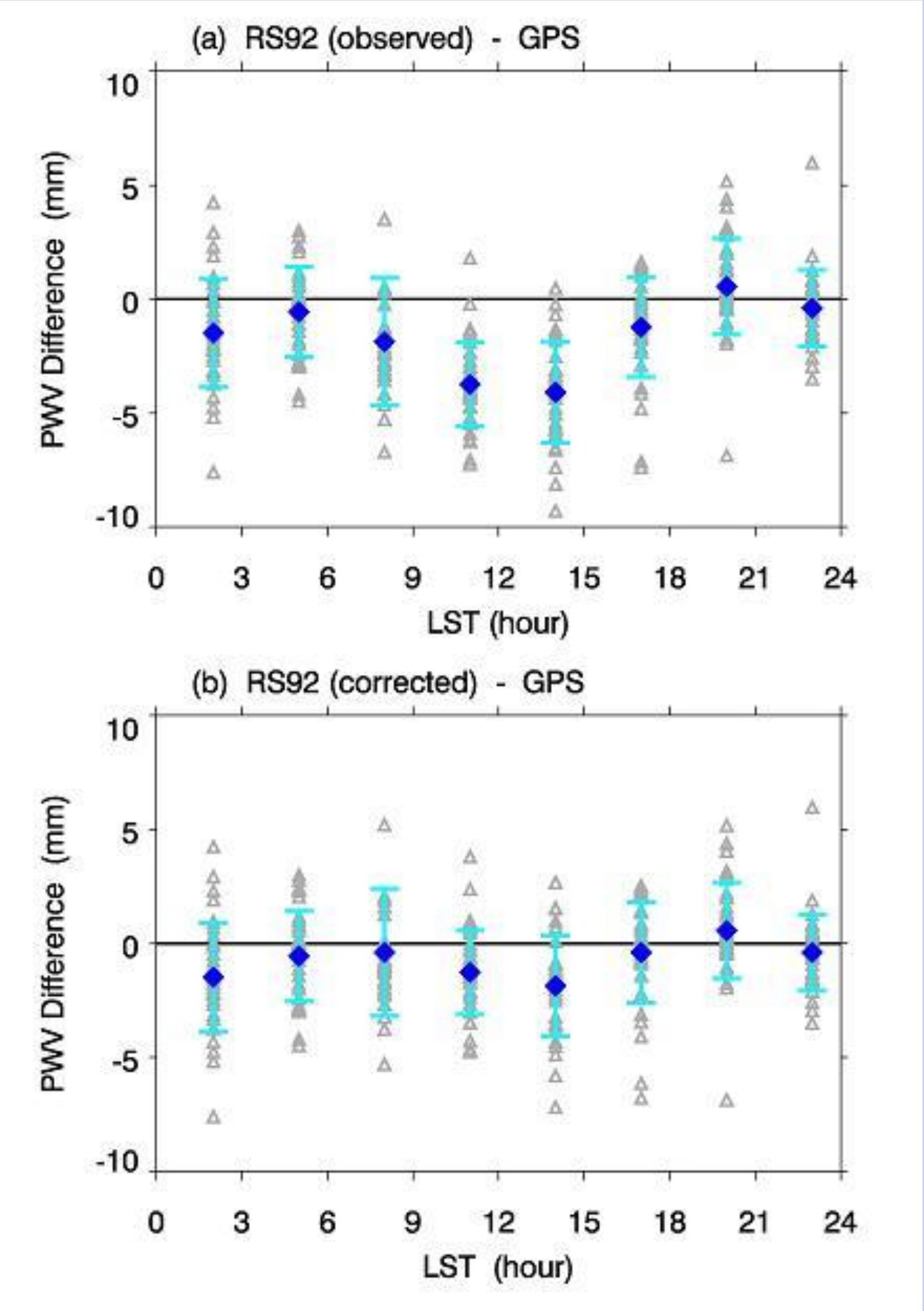
Green curve, which is Vomel’s correction, is considerably larger at lower levels. However Vomel’s study was over land, whereas MISMO was conducted over the Indian Ocean.

Instrument biases (continued)

- **Collocating ground-based GPS receivers, which measure total column PW, with sonde sites is strongly recommended.** Wang and Zhang (2008) recommend that sonde and GPS sites be within 50 km of each other.

- Using GPS PW data will allow us to better identify and correct the daytime Vaisala RS92 dry bias

- PW difference (sonde - GPS) → before and after correction in MISMO. Large daytime dry bias is significantly reduced with correction.



Sampling Issues

Launching sondes in the vicinity of deep convection will be a challenge yet is important if we hope to capture the large-scale forcing associated with convective lines and large mesoscale anvils.

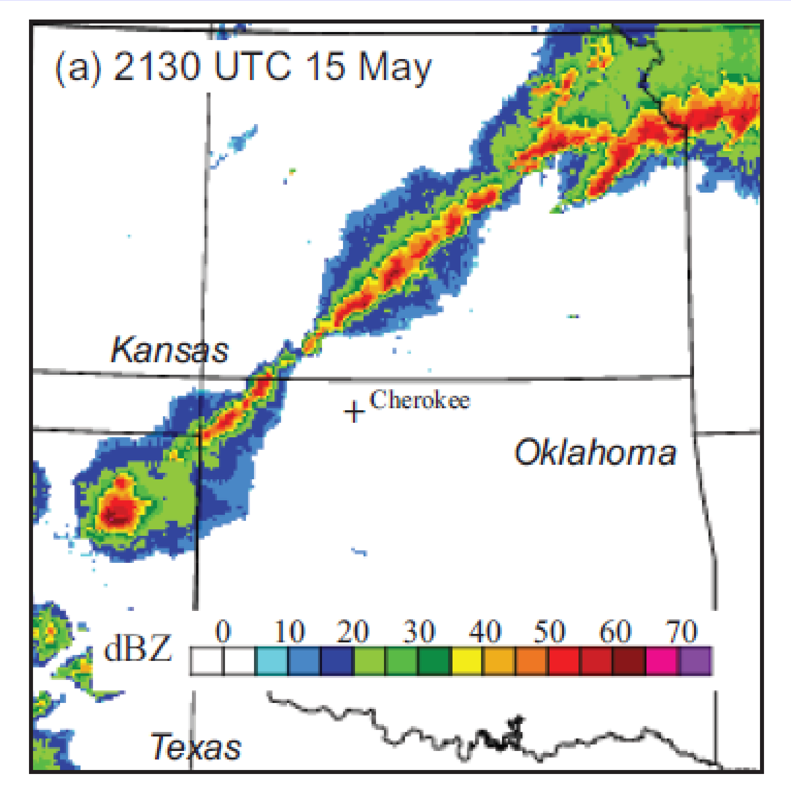
Main issues include:

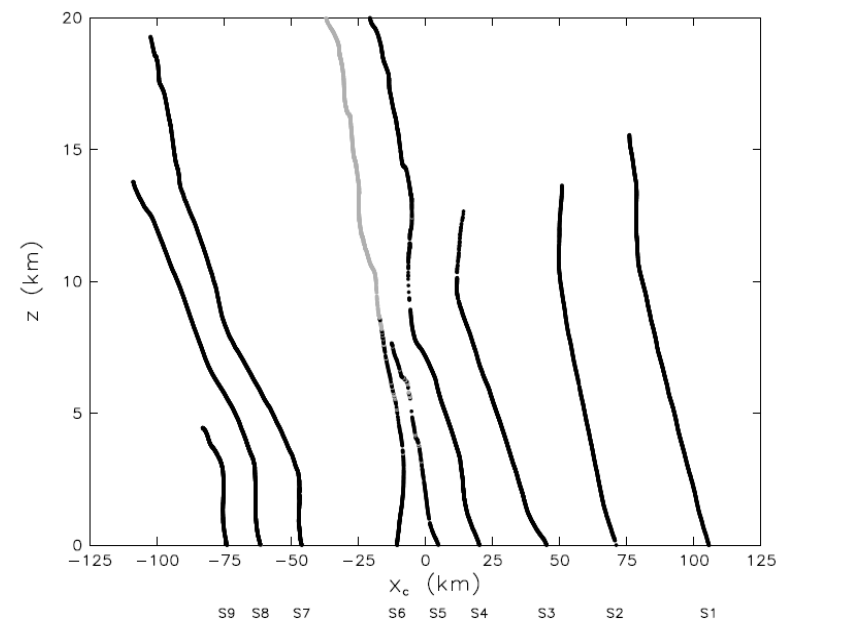
- Heavy icing on the balloon results in insufficient buoyancy to lift balloon above freezing level.

- Noisy soundings due to rapid changes in vertical motion in vicinity of convective cells and transmission fallout from electrical inference. Such soundings are not representative of large-scale environment.

- Safety issues associated with launching balloons in a highly electrified environment.

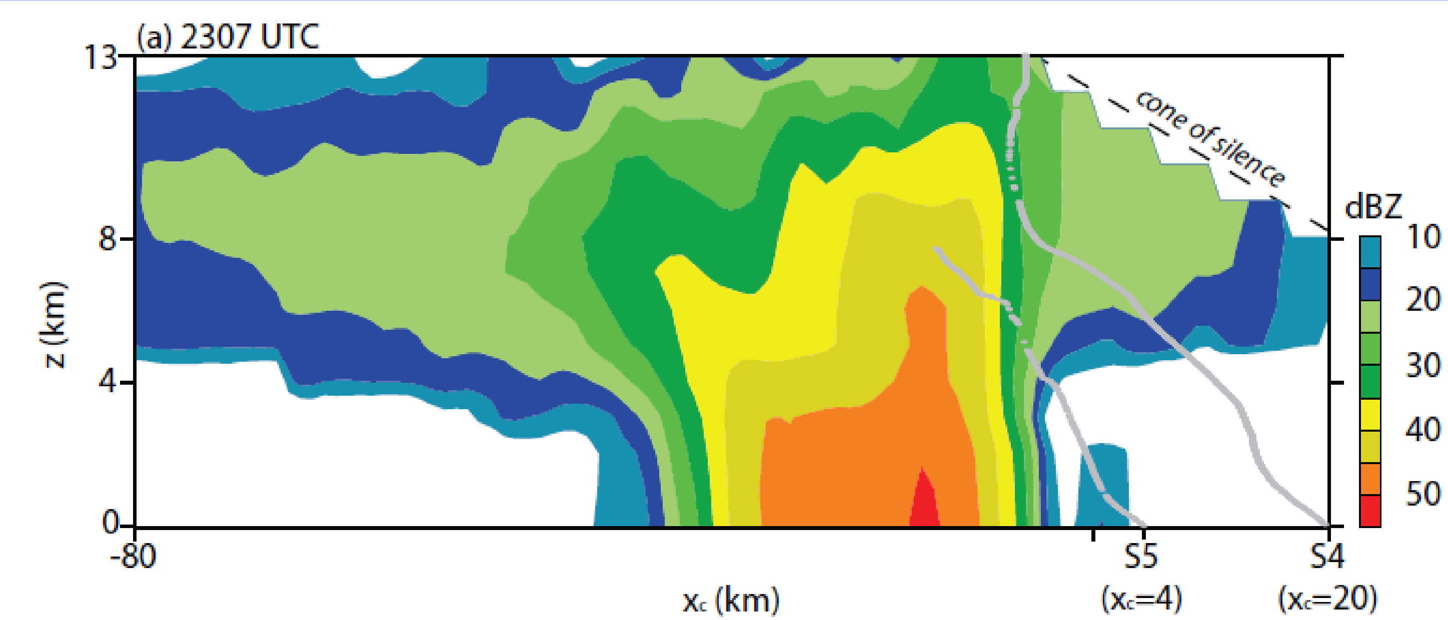
Soundings released during passage of squall line during VORTEX 2 (Bryan and Parker 2010)



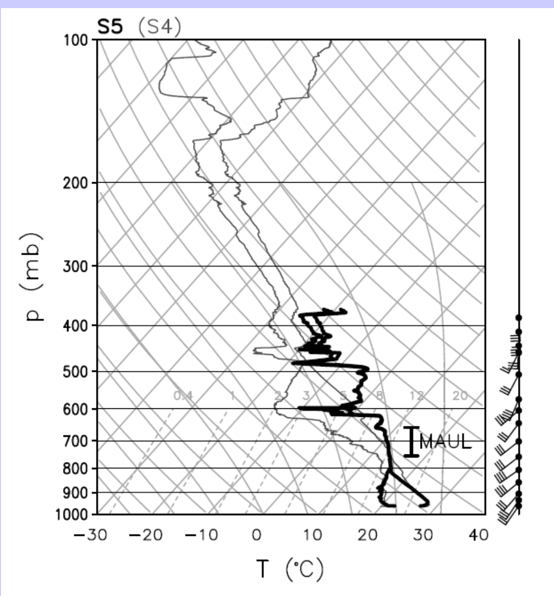


Radar composite showing near continuous 40 dBZ squall line – early in life cycle

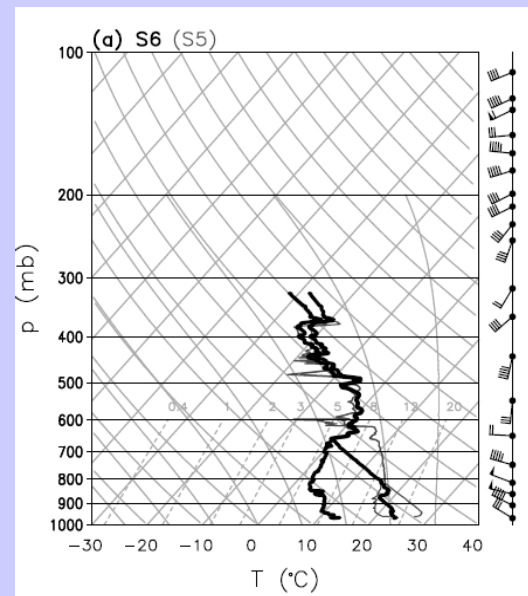
9 sounding released within 3 hrs of line passage from near Cherokee, OK.



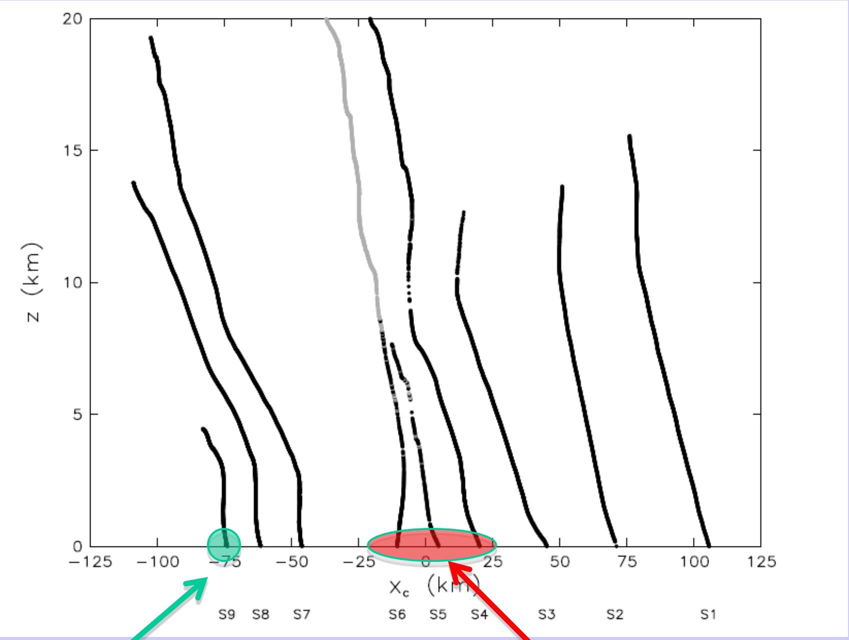
Cross-line radar analysis showing position of S4 and S5.



- S4 launched 20 km (+20 min) prior to gust front passage,
- S5 launched 4 km (+4 min) prior,
- S6 launched 11km (-11 min) after



Issues with sondes released in a strong convective environment



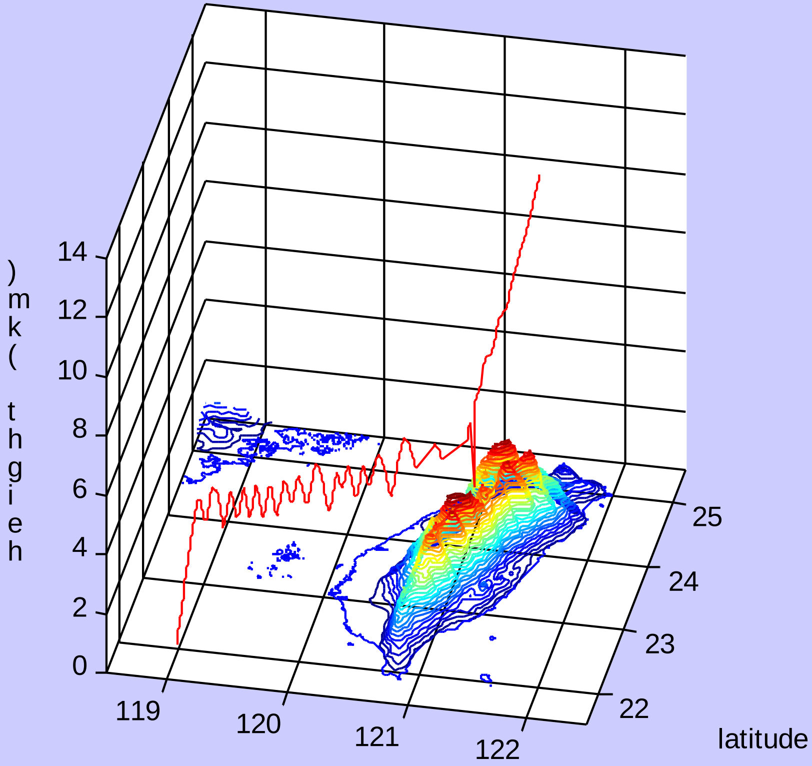
Sonde experienced icing and had insufficient buoyancy to rise above freezing level

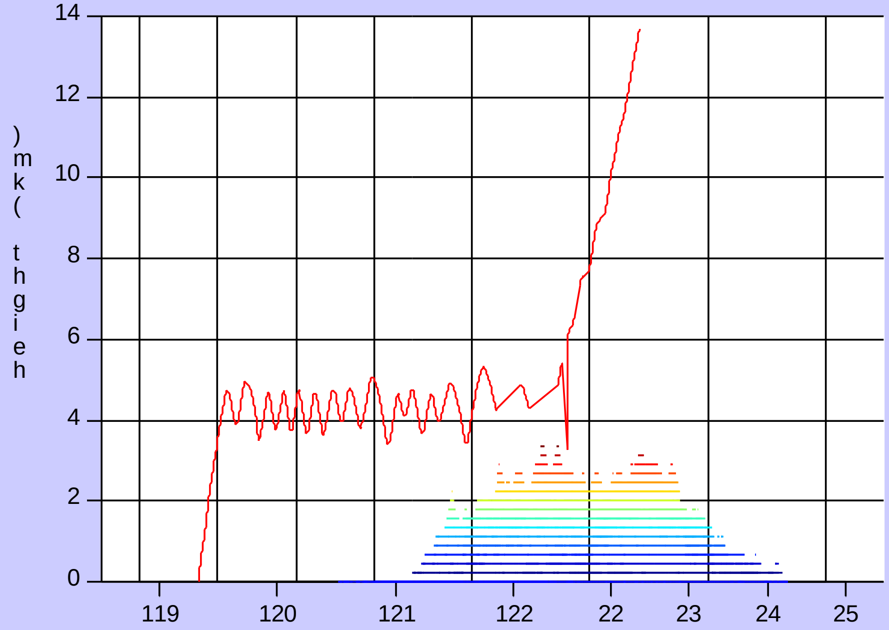
Signal loss in electrically active part of storm, noisy soundings due to strong convective scale vertical motions, hail damage to temp./humidity sensor.

- Does this suggest a no-launch window for periods with strong convective activity be established (e.g., ±15 min from squall line passage)?

Balloon icing in a convective environment

Trajectory of sonde launched on 14 June 2008 from ship upstream of Taiwan. 200 gr balloon did not have sufficient buoyancy to continue rising when iced up in a convective environment

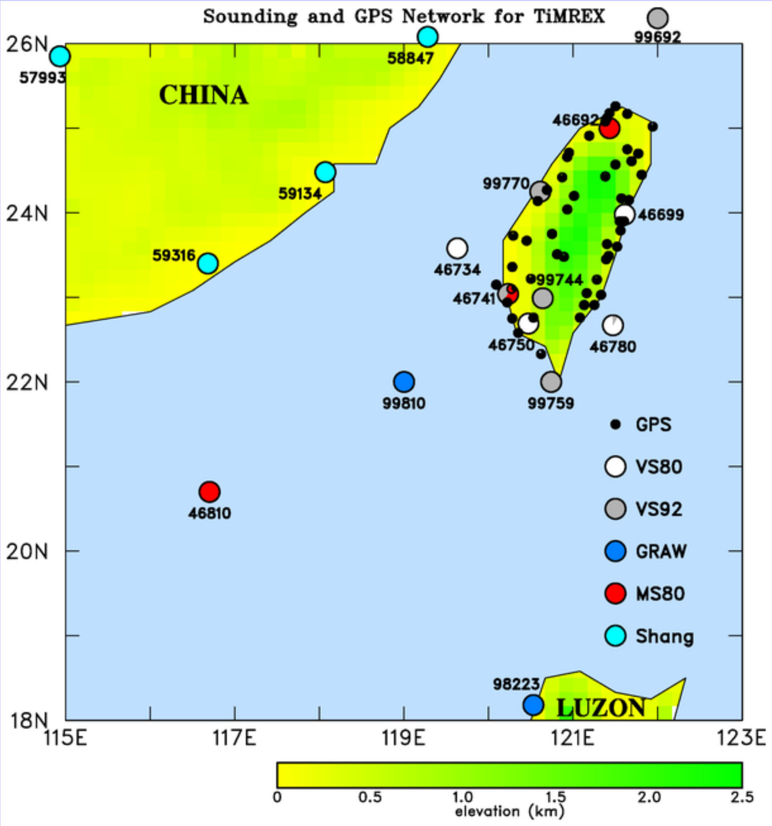




6% of sondes at this site recorded data only to freezing level due to balloon icing effects

Courtesy of Dr. J.-L. Wang

Sound issues in TiMREX conducted in May and June 2008



For sites using 200 gr balloon, 3.2% of all sondes recorded data only to freezing level.

Two sites used 800 gr balloons – at these sites only 1/361 sondes (or 0.3%) showed icing effects.

- Should larger balloons be used in environments where icing effects are likely, **or** should a second sonde be launched if the first fails to record data above the freezing level?

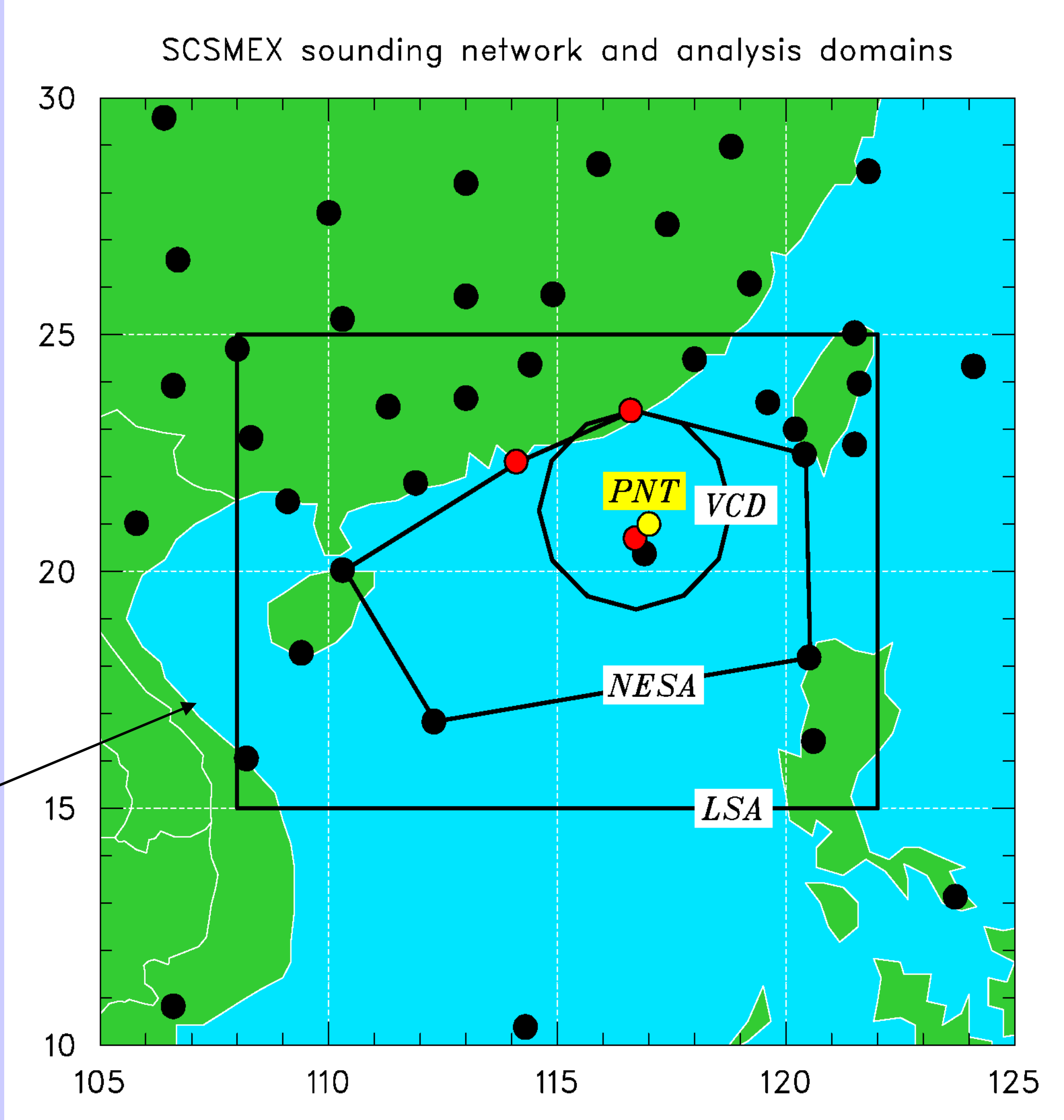
(option 1 cost: extra $70-$80, option 2 cost: extra $220)

Impacts of random sampling errors on budgets (Mapes et al. 2003)

Budget error come from two primary sources:

1. Non-random errors (e.g., instrumental biases)
2. Random errors caused by turbulence and convection.

Objective: obtain quantitative estimate of the effect of random errors in atmospheric bugdets

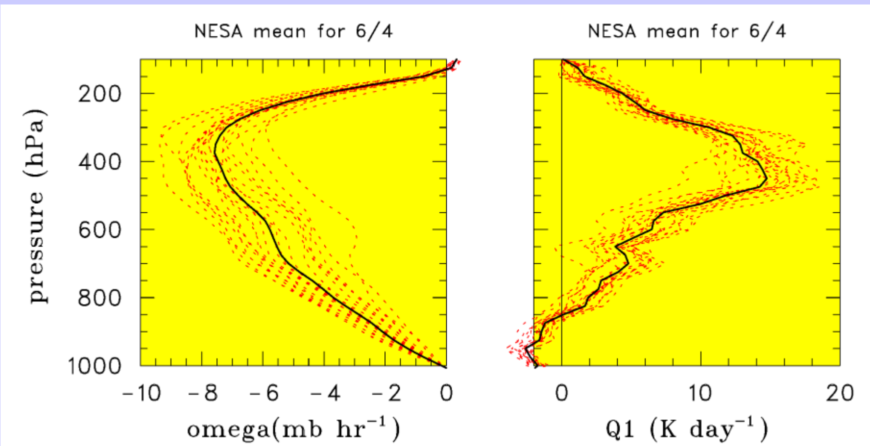


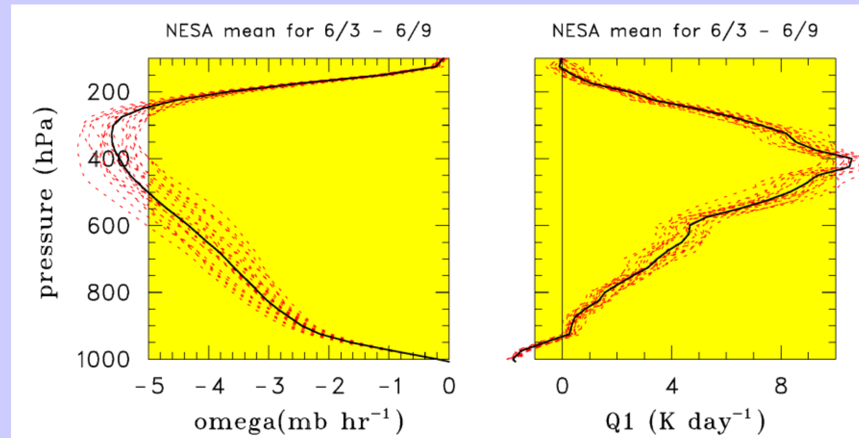
Averaging Areas:

PNT (111^2 km^2)
VCD (400^2 km^2)
NESA (770^2 km^2)
LSA ($1{,}425^2$ km^2)

Procedure: noise profile estimates were used to randomly perturb sonde profiles at all sounding sites to create a 20 member ensemble of the analyses. This ensemble was averaged at various time and space scales to provide error estimates for the analysis.

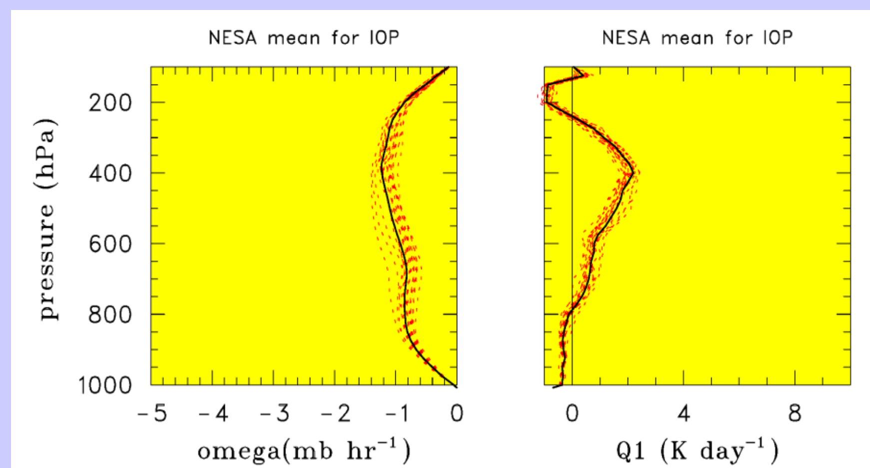
Q_1 profiles at different averaging period





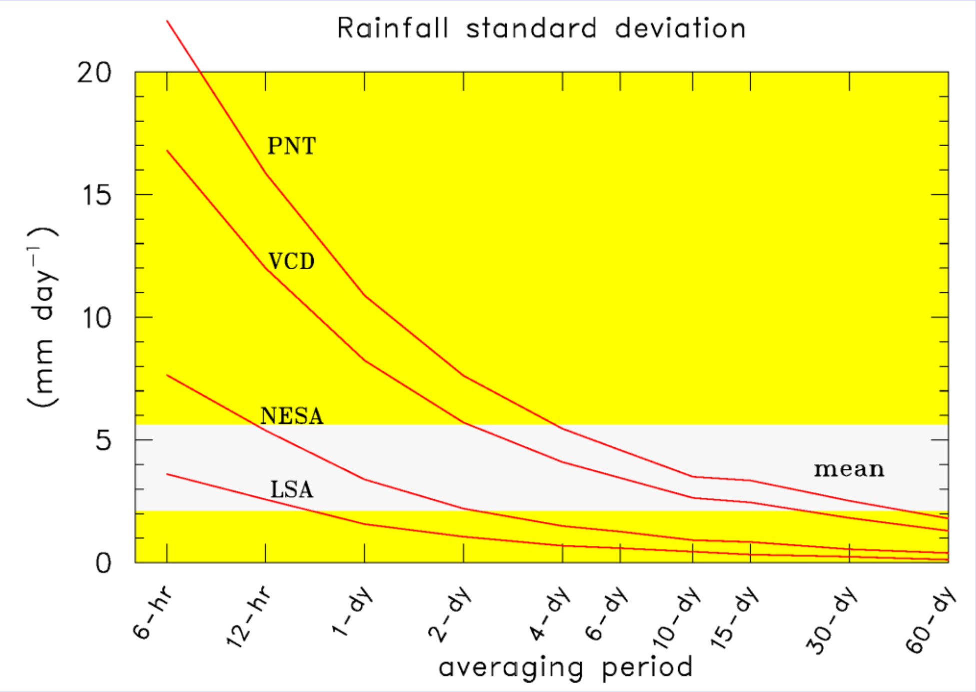
σ of Q_1 (K day^{-1}) at 400 hPa

1 day	2.3
1 week	.84
IOP (46 days)	.25



Averaging over longer period reduces ensemble spread

Rainfall uncertainty due to random sampling errors

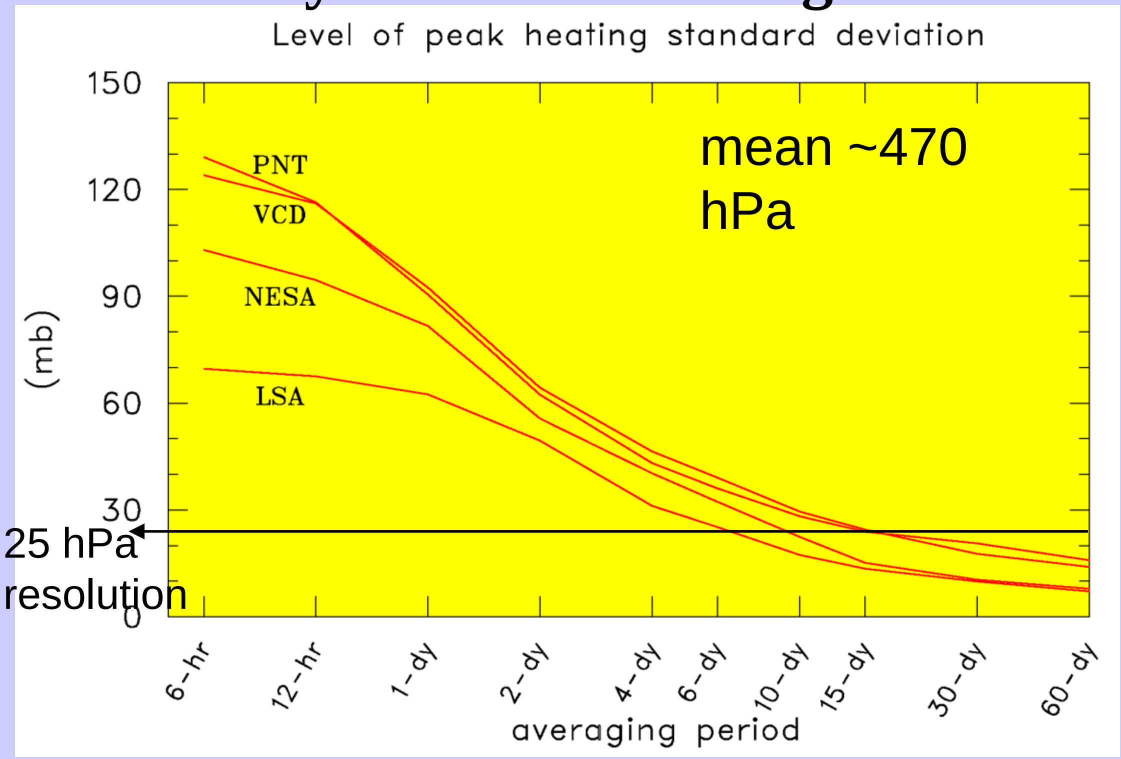


- **Random sampling errors decrease rapidly as spatial and temporal averaging increases roughly consistent with $N^{-1/2}$ sampling statistics, where N is the # of samples.**
- **Errors are roughly halved as samples increase by a factor of 4.**

Area (km^2)	**PNT** **111**	**VCD** **400**	**NESA** **770**	**LSA** **1425**
6 hr	22.1	16.8	7.6	3.6
1 days	10.9	8.2	3.4	1.6
6 days	4.6	3.5	1.3	0.6
30 days	2.5	1.8	0.5	0.2

- Uncertainty in units of mm/day,
- results are appropriate for a network with ~200 km spacing and 6 hrly sondes

Uncertainty in level of heating maximum due to sampling errors



As budget area get smaller, uncertainly due to random sampling increases.

Area (km^2)	PNT 111	VCD 400	NESA 770	LSA 1425
6 hr	129	123	103	70
1 day	91	92	82	62
6 days	36	39	32	25
30 days	21	18	10	10

← uncertainty in units of hPa

Heat and Moisture Budgets

Apparent heat source/moisture sink:

(Yanai et al. 1973)

$$Q_1 \equiv c_p[(\partial \bar{T}/\partial t + \bar{\mathbf{v}} \cdot \nabla \bar{T} + (p/p_0)^{\kappa} \bar{\omega} \partial \bar{\theta}/\partial p)]$$

$$Q_2 \equiv -L(\partial \bar{q}/\partial t + \bar{\mathbf{v}} \cdot \nabla \bar{q} + \bar{\omega} \partial \bar{q}/\partial p)$$

Integrated budgets:

[Definition: $< \quad > \; \equiv 1/g \int_{p_T}^{p_s} (\;)\, dp$]

$$\text{Heat}: \quad < Q_1 > \; = \; < Q_R > + LP + S \qquad (1)$$

$$\text{Moisture}: \; < Q_2 > \; = \; L(P - E) \qquad (2)$$

(1) − (2) yields

$$< Q_1 > - < Q_2 > \; = \; < Q_R > + S + LE \; , \qquad (3)$$

where P = Precipitation rate, E = Evaporation rate, S = Sensible heat flux

A powerful technique, but there are limitations…

Objective analysis errors

- Choice of analysis scheme (reviewed by Zhang et al. 2001)
  - line integral
  - least squares fitting
  - successive correction (Cressman 1959)
  - weighted-averaging interpolation (Barnes 1964)
  - statistical interpolation (Ooyama 1987)
  - multiquadric interpolation (Nuss and Titley 1994)
- Techniques yield different results for non-regular, data-sparse fields, networks with different observing systems
- More advanced approaches – constrained variational analysis (Zhang and Lin 1997)

Mass balancing

Upper boundary condition (locate tropopause)

$\omega = 0$ at tropopause

$d\theta/dt = 0$ at tropopause

$d\theta/dt = Q_R$ at tropopause (best, but Q_R and its diurnal cycle uncertain)

} High vertical resolution needed for $\partial\theta/\partial p$

Divergence correction (δ^c)

Variable (e.g., O'Brien 1970; for radar tracking)

Constant (for omegasonde or GPS)

Adjusting v in advective terms

Line integral (Molinari and Skubis 1998)

Gridded analyses (solve $\nabla^2\chi^c = \delta^c$)