Assimilating microwave satellite observations over the vortex – from TMI to microwave sounders and radar scatterometry

Z.S. Haddad, J. Steward, S. Kacimi, S. Hristova-Veleva, T. Vukicevic

1) developed an observation operator for TRMM-**TMI** (~ AMSR) into AOML/HRD's HEDAS system – main issues: TMI (now GMI) does not observe very frequently in time (see 3 below) … so why TMI?

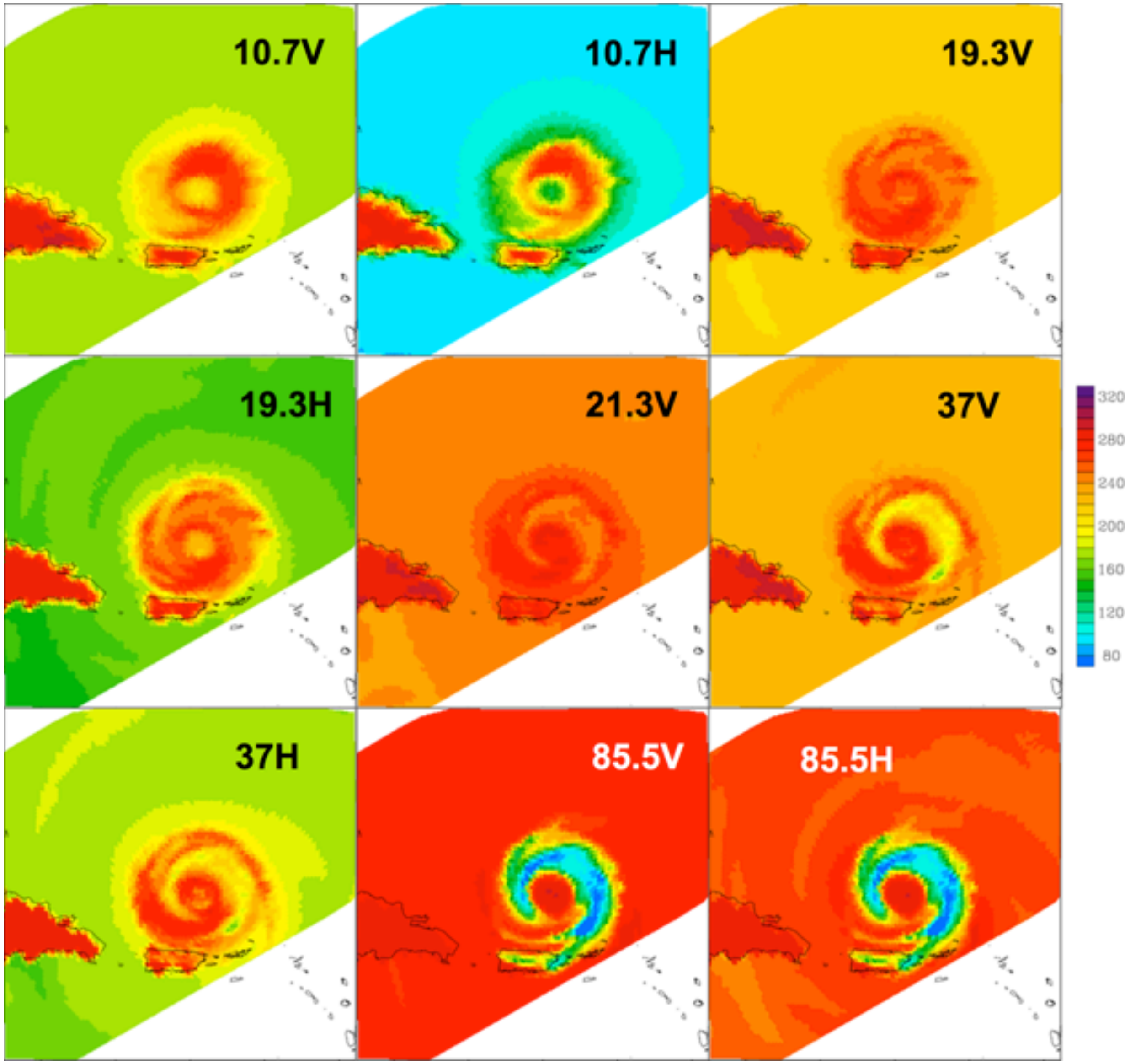
2) developing a representation of Megha-Tropiques **SAPHIR** obs, **AMSU-B** – main challenge: representing the scattering from hydrometeors at these high frequencies

3) use of hyperspectral IR (**AIRS**)

4) developing an approach for more systematic assimilation of scatterometer (**RAPIDSCAT**) observations – main challenge: covariance localization

Why TMI?

Mainly because it is sensitive to convection (with better spatial resolution than other similar radiometers)



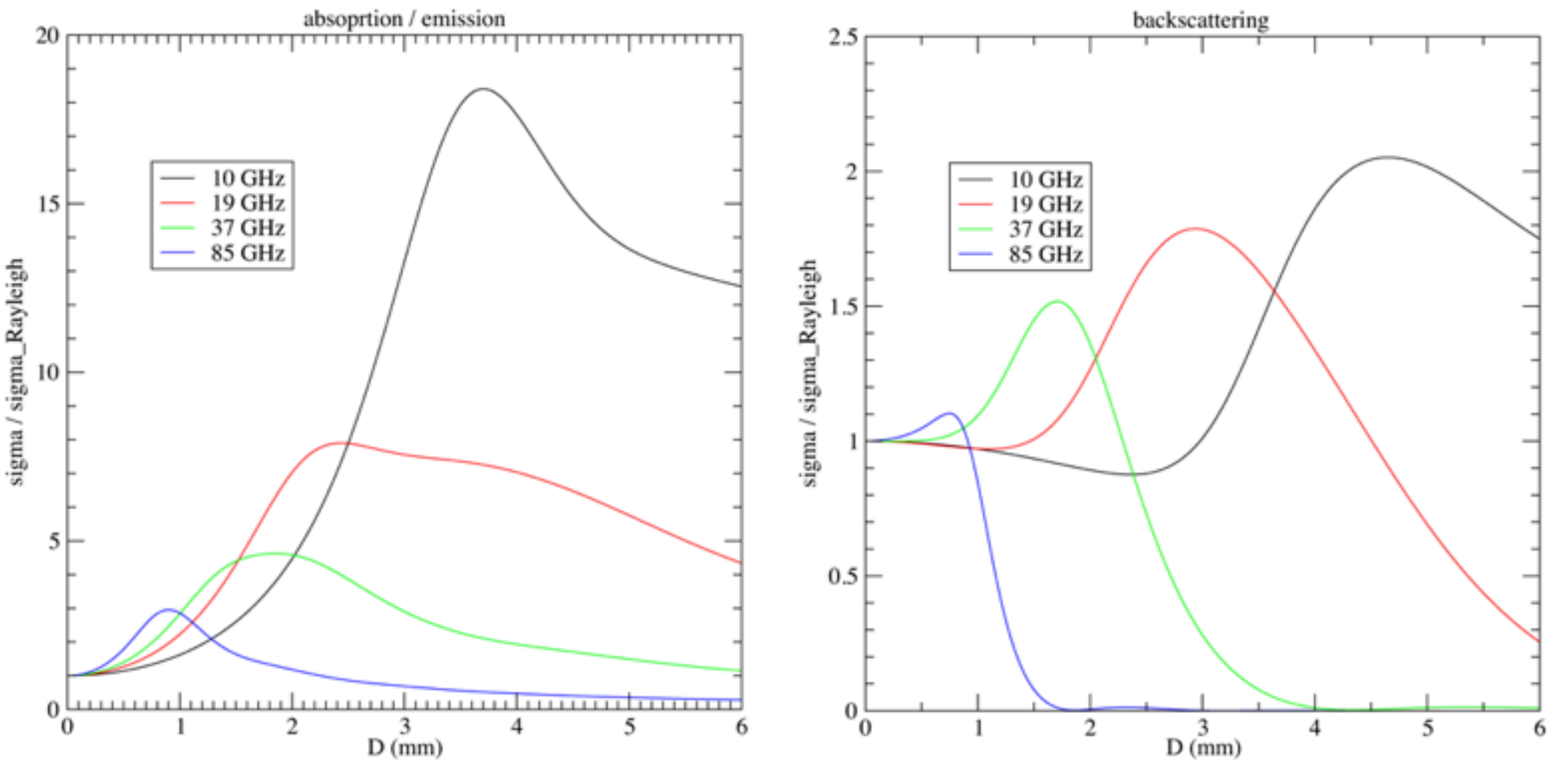
Hurricane Earl on 31 August 2010 at 0600Z
HWRF sim

Why is it necessary to do something different to obtain an observation operator in the case of microwave obs?

Because variational DA tries to minimize

$$(\vec{x} - \vec{x_b})^t B^{-1} (\vec{x} - \vec{x_b}) + \left(\vec{\mathcal{O}} - F(\vec{x};\lambda)\right)^t R^{-1} \left(\vec{\mathcal{O}} - F(\vec{x};\lambda)\right)$$

where $F(x, \lambda)$ is meant to be the mean value of the obs associated with (x, λ)



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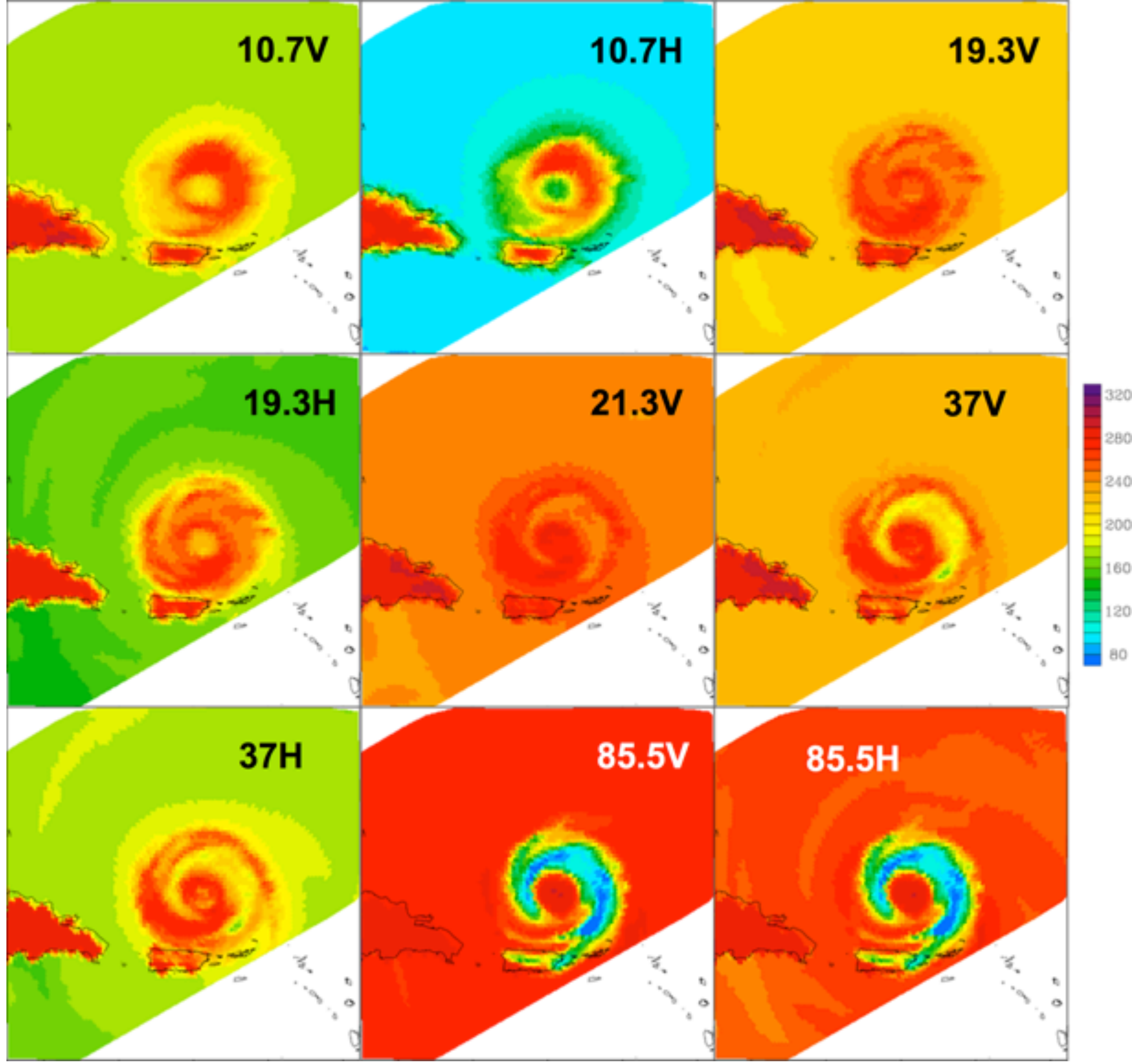
$$(\vec{x} - \vec{x_b})^t \, B^{-1} \, (\vec{x} - \vec{x_b}) \; + \; \left(\vec{O} - F(\vec{x};\lambda)\right)^t R^{-1} \left(\vec{O} - F(\vec{x};\lambda)\right)$$

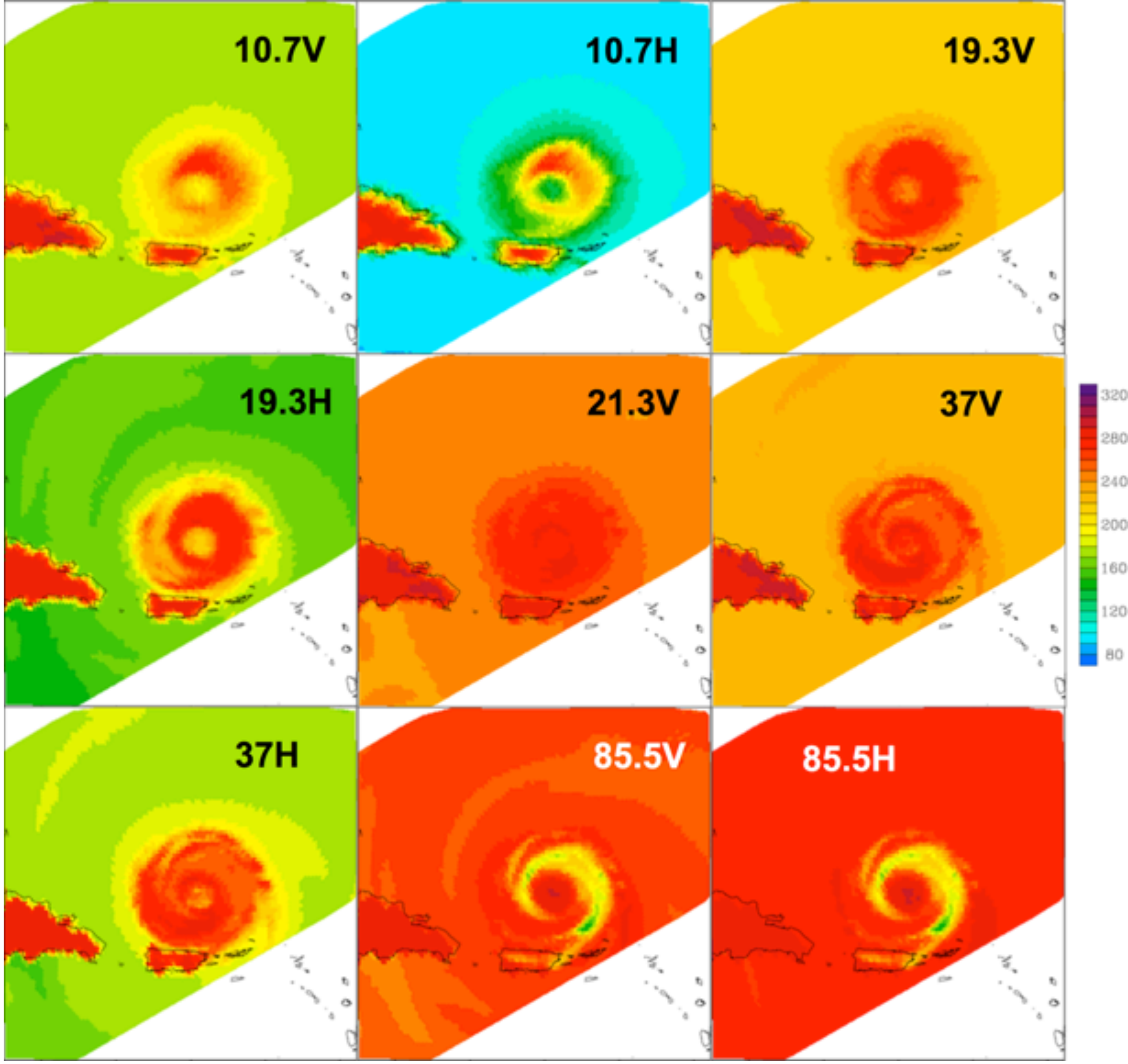
$F(x, \lambda)$ is quite different for clear-sky radiances:

$$F \;\simeq\; \epsilon T_S e^{-\int_0^\infty k_{ext}(\vec{x})} \; + \; \int_0^\infty k_{ext}(\vec{x}) T(h) \, e^{-\int_h^\infty k_{ext}(\vec{x})} dh$$

is essentially an increasing function of x
(more water vapor = warmer brightness temperature)



Brightness temperatures for HWRF simulation of Hurricane Earl on 31 August 2010 at 0600Z, calculated using CRTM with the default microphysical parameter values.



Brightness temperatures for HWRF simulation of Hurricane Earl on 31 August 2010 at 0600Z, calculated using CRTM with adjusted microphysical parameter values:
rain drops smaller by 44%, smaller graupel that is half as dense

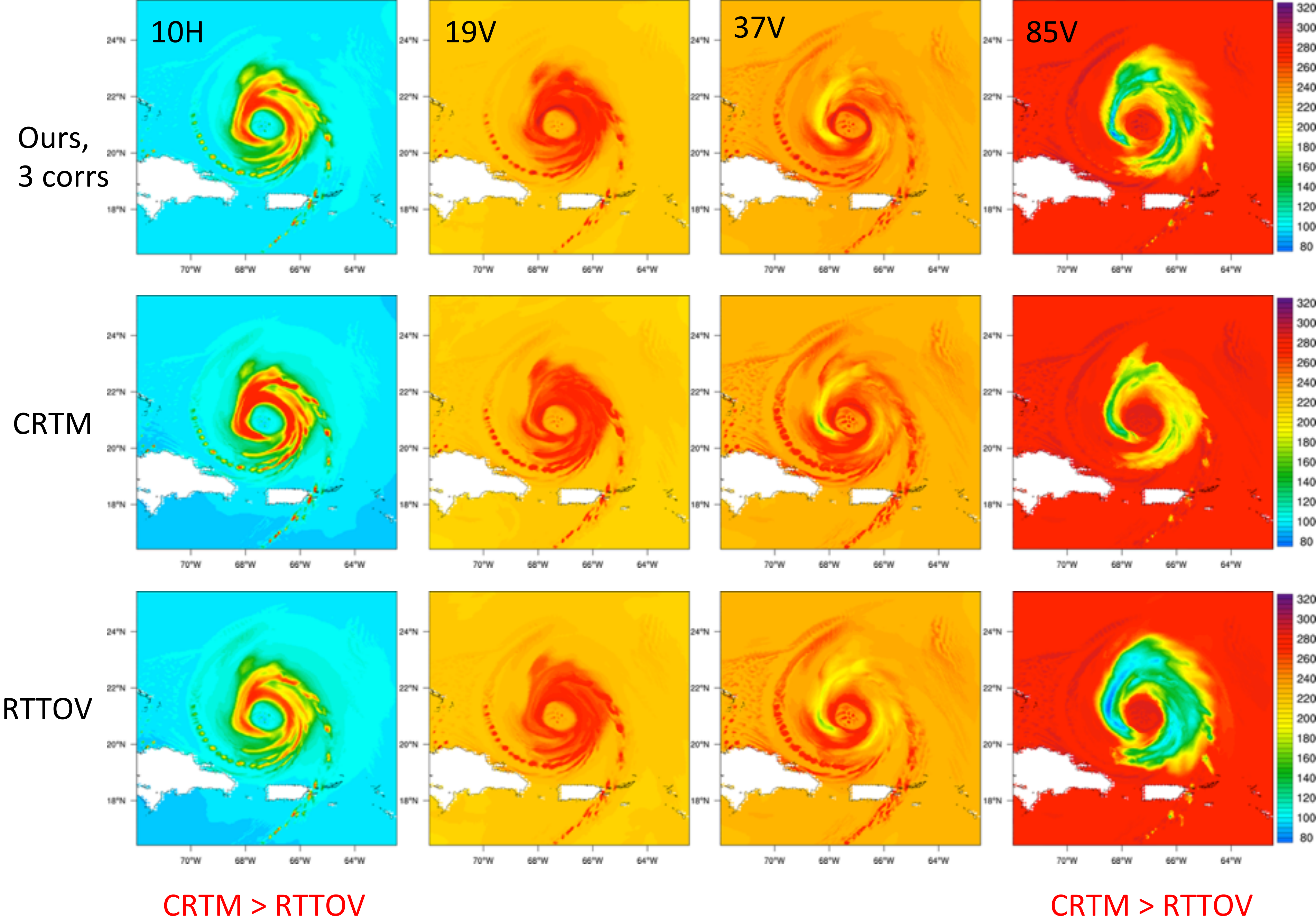
We developed a method to quickly calculate the mean brightness temperatures associated to a given atmospheric state vector, without having to perturb around the nominal value of every variable in x and every parameter in λ:

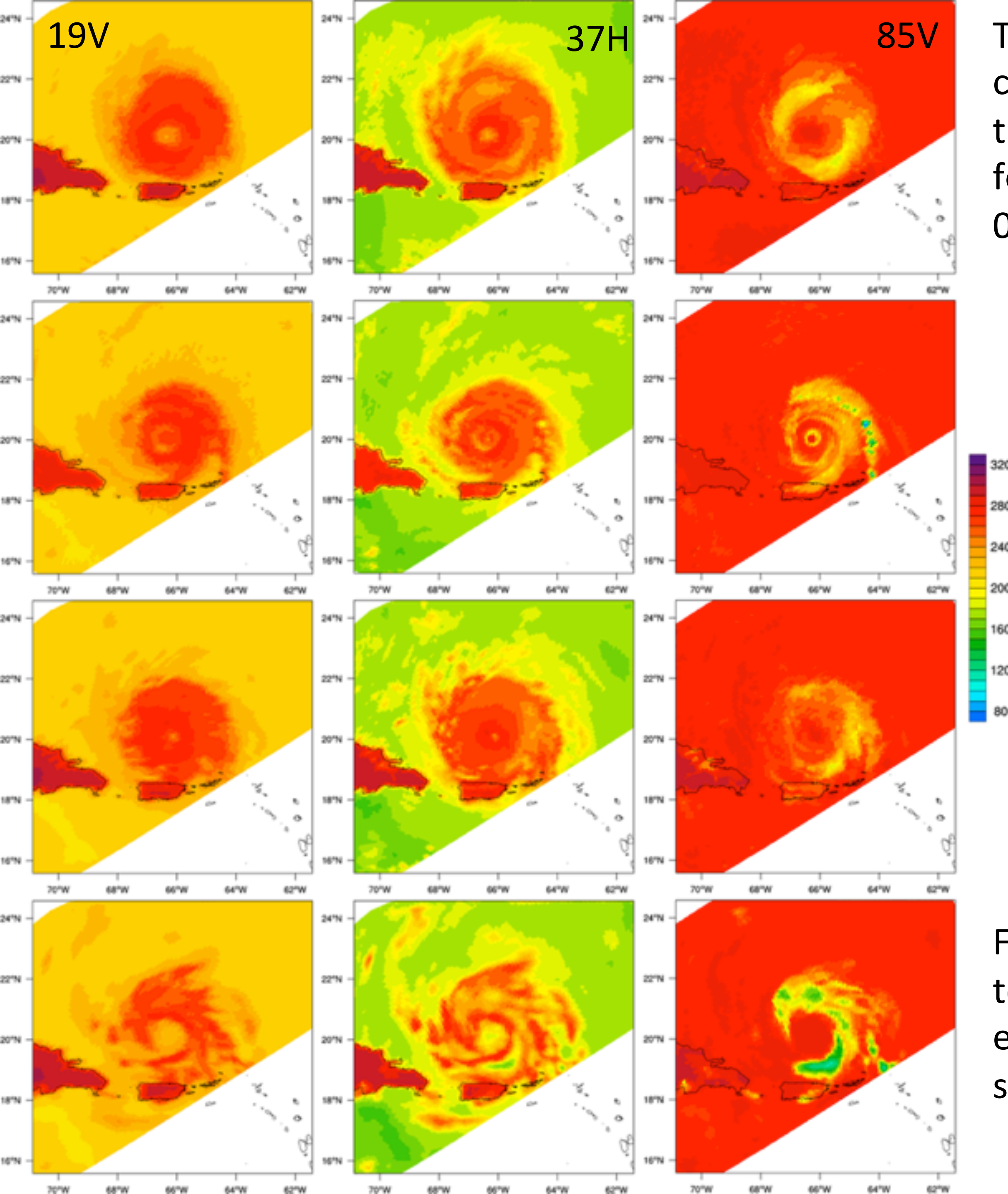
- Start with HWRF simulations (say HEDAS Earl 2010 h3vk, 2010-08-29-12Z to 2010-09-03-18Z), using stream ψ, potential χ, P, T, RH, W, q_{cliq}, q_r, q_{cli}, q_s, q_g, q_h at 12 vertical levels for a total of 504 variables $x_1, \ldots, x_{504}$
- for each of these 12million columns, forward-calculate $T_{b1}, \ldots, T_{b9}$

- Step 1: find the principal components $x_1', \ldots, x_{504}'$
  Step 2: find the principal components $T_1', \ldots, T_9'$

- Step 3: find the top 3 combos of $x_1',\ldots, x_{504}'$ that correlate best with the corresponding 3 combos of $T_1',\ldots, T_9'$ (requires diagonalization)

  and express T_1'', T_2'', T_3'' in terms of x_1'', x_2'', x_3''
  (with differentiable expression, in order to compute derivatives)


10H
19V
37V
85V
Ours,
3 corrs
CRTM
RTTOV
CRTM > RTTOV
CRTM > RTTOV

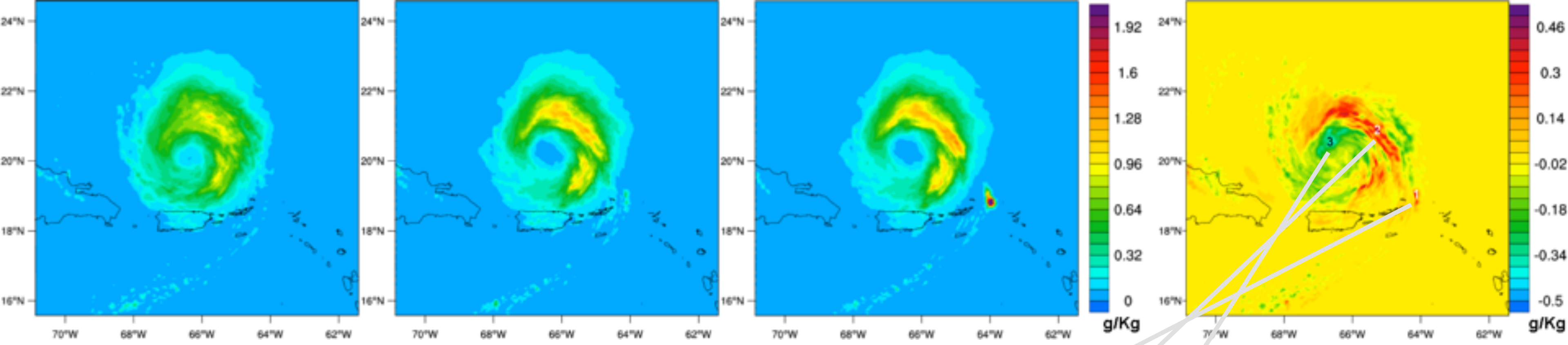


Top row: Brightness temperatures calculated using our operator for the ensemble mean of our HEDAS forecast of Hurricane Earl for 0430Z on 31 August 2010.

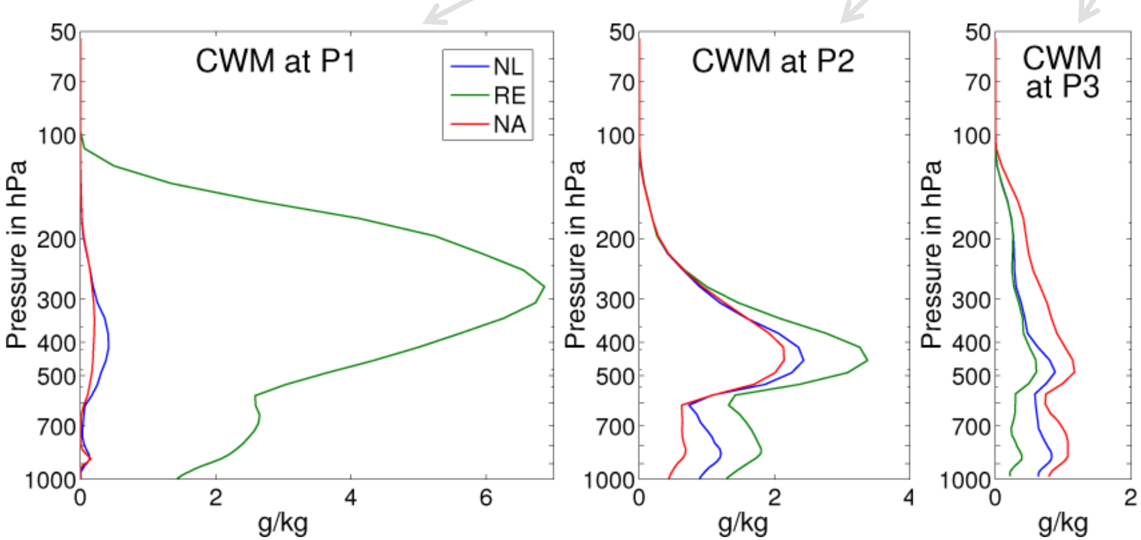
Second row: Actual TMI observations at 0439Z.

Third row: Brightness temperatures calculated using our operator for the analyzed variables at 0430Z (post-assimilation).

Fourth row: Brightness temperatures calculated for the ensemble forecast at 0530Z starting with the analysis at 0430Z.

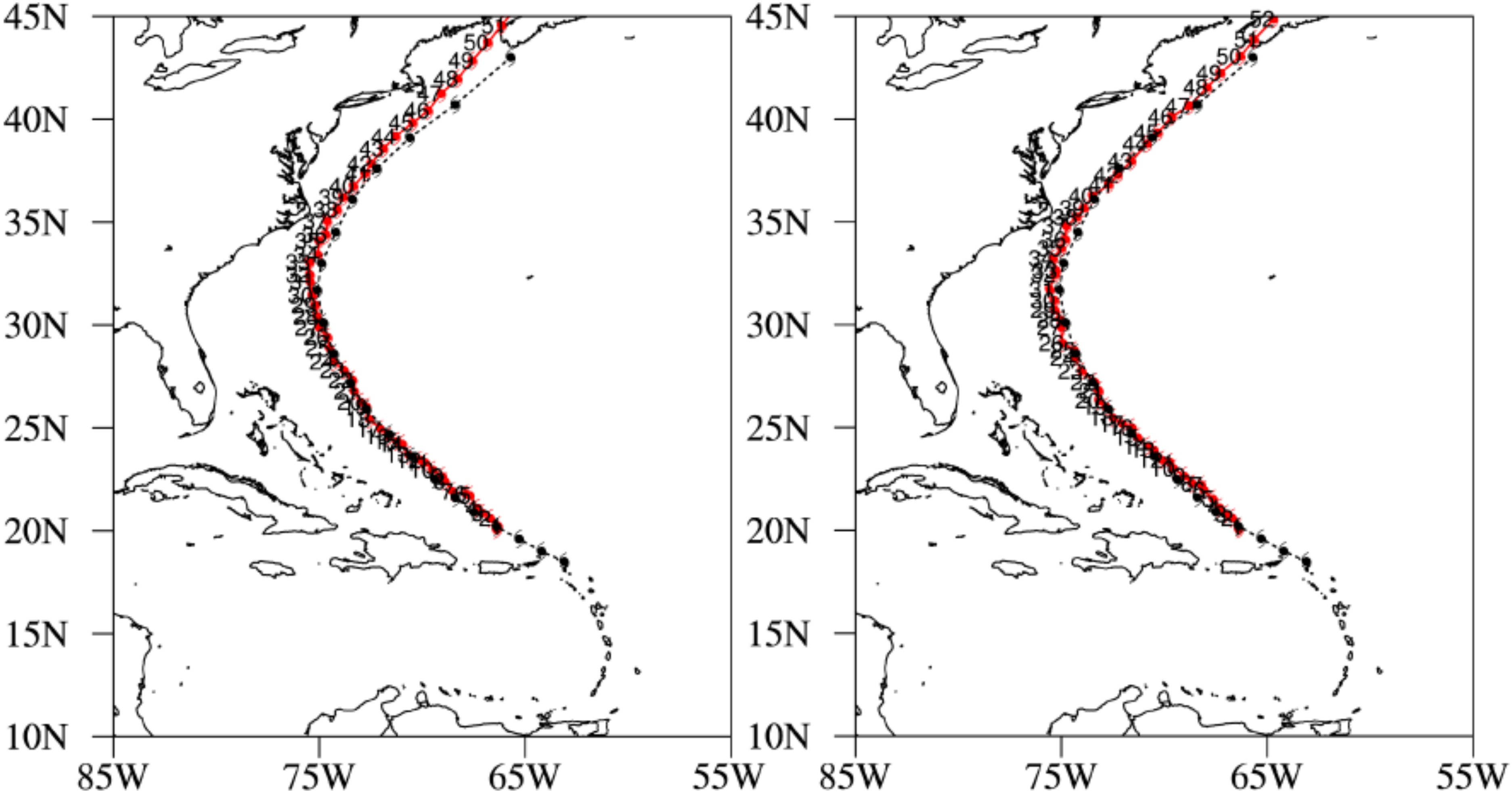


Vertically-averaged condensed-water-mass mixing ratios, from the ensemble mean before the assimilation (left panel) and after the assimilation (center left panel), as well as after a different assimilation where we divided the observation covariance matrix by 4 to increase the impact of the TMI observations (center right panel). The rightmost panel shows the adjustment to the vertically-averaged condensed water mass, with the three grid points selected for vertical examination highlighted.

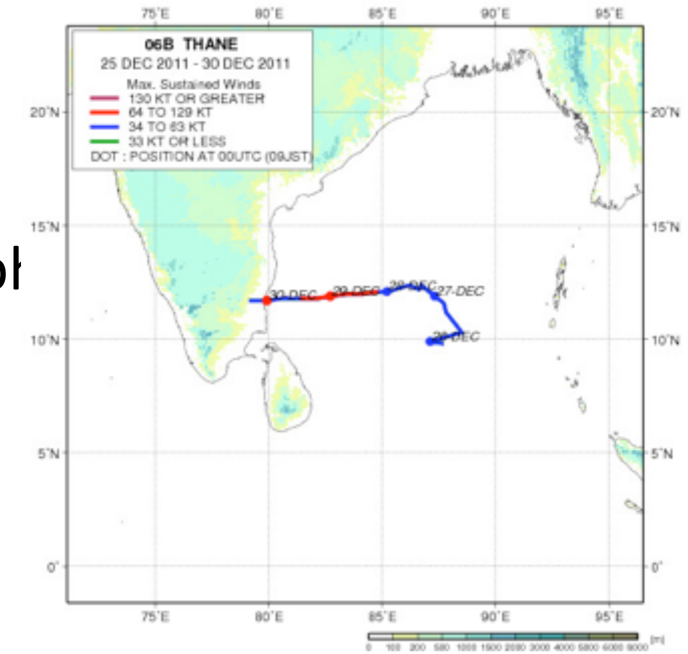


Vertical profiles of the condensed water mass at the three grid points in the right panel above, with the background values (NA) in red, the analyzed values (NL) in blue, and the results of the assimilation with a 4-fold reduction in the observation covariance (RE) in green.

Track without TMI assimilation (left) and with (right)

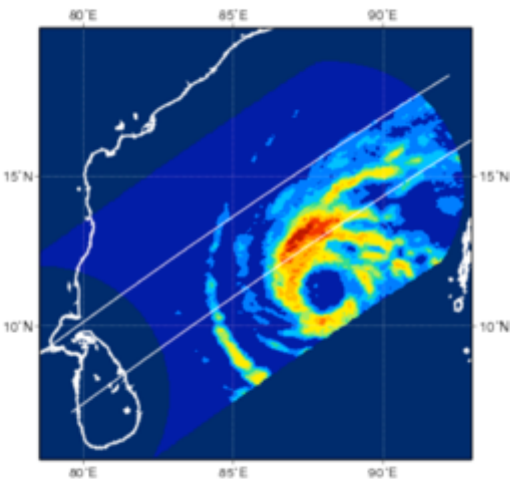


How bad is GMI temporal sampling?

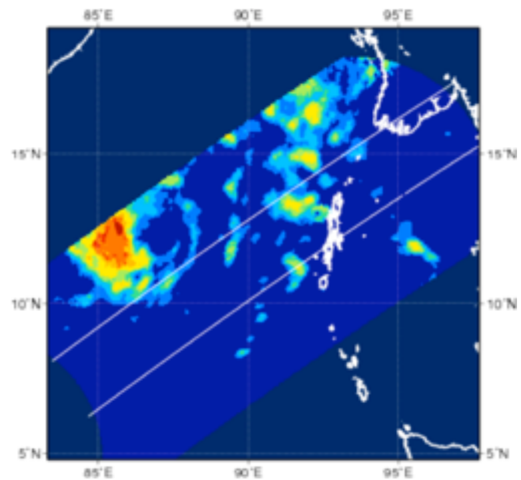


November+December 2011 (because of Sapl

TC Thane (BoB, 25-30 Dec), seen 4 times:

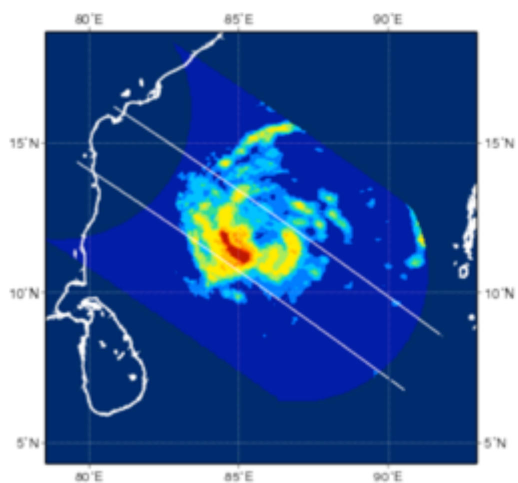


26@13:04,

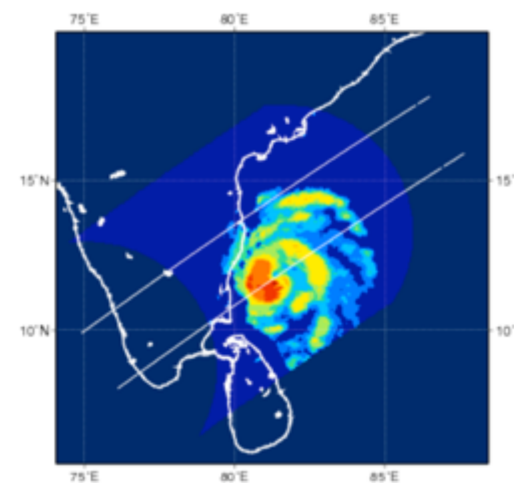


27@12:09,

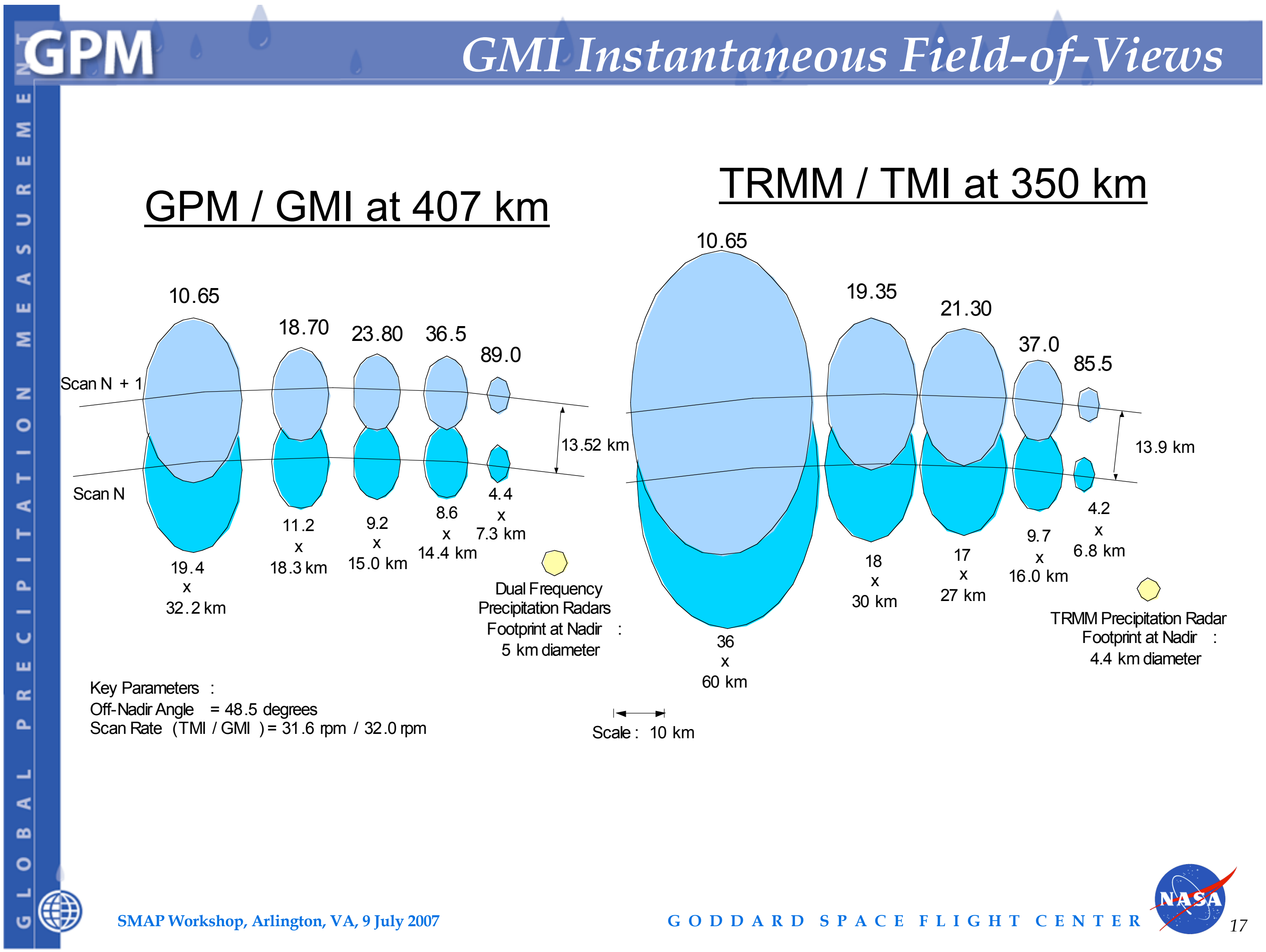
27@21:59



, and 29@11:53



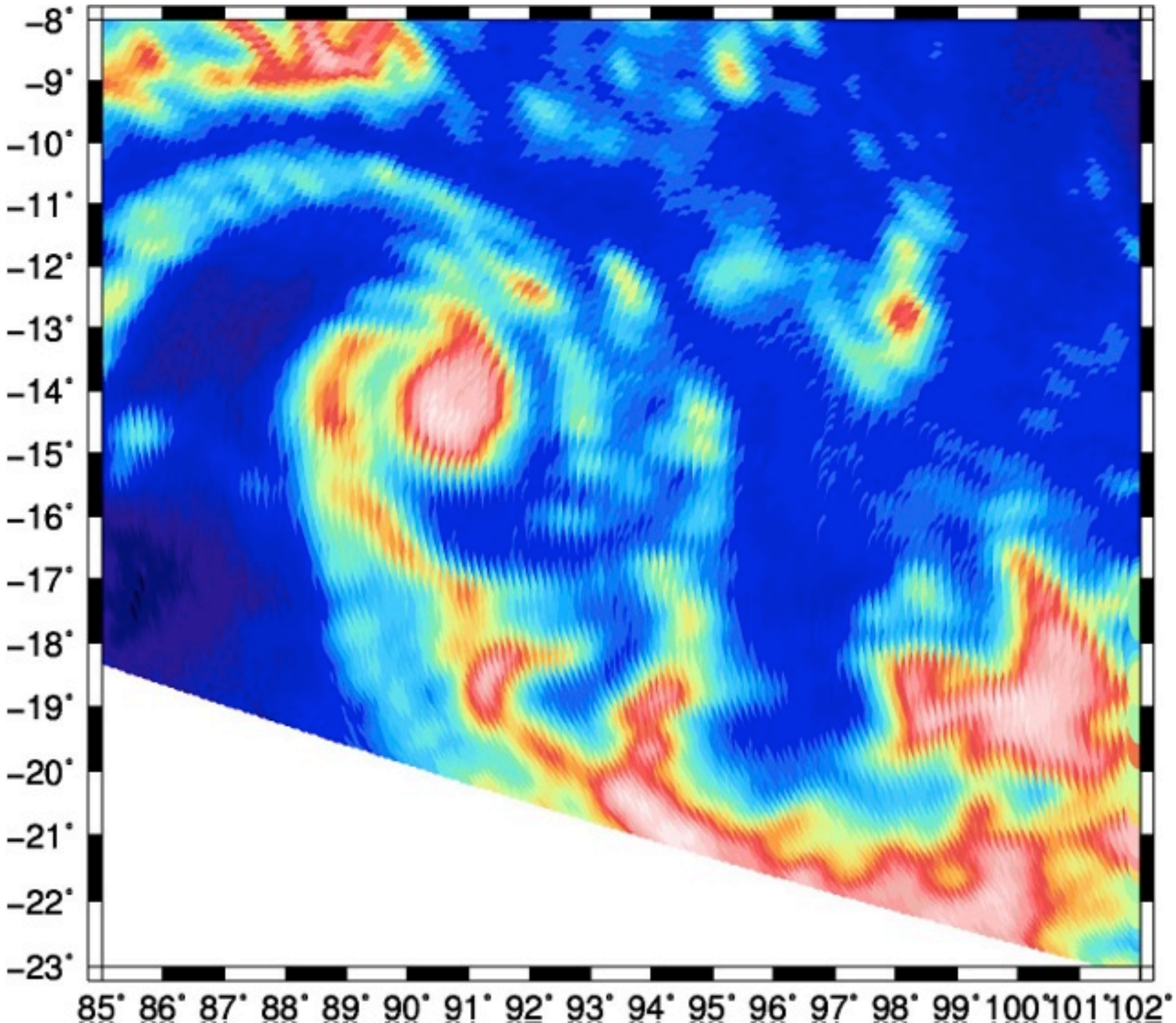
How bad is GMI resolution?



How to remedy poor MADRAS resolution?

hi-frequency+hi-resolution-guided deconvolution:

$$(T_b - A \cdot \vec{x})^t E^{-1}(T_b - A \cdot \vec{x}) + (\vec{x} - \tau(T_{hiF+hiR}))^t C^{-1}(\vec{x} - \tau(T_{hiF+hiR}))$$



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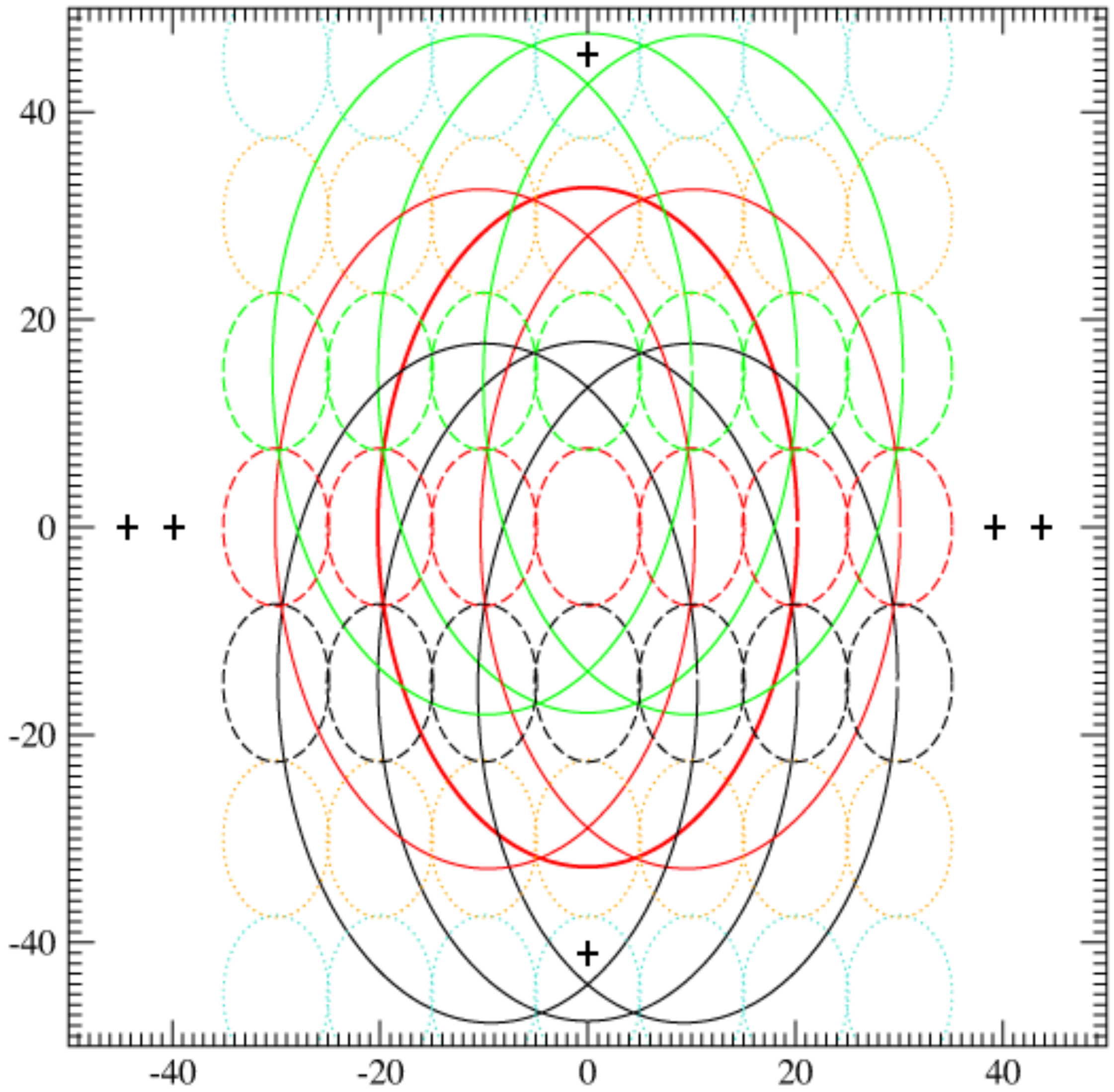

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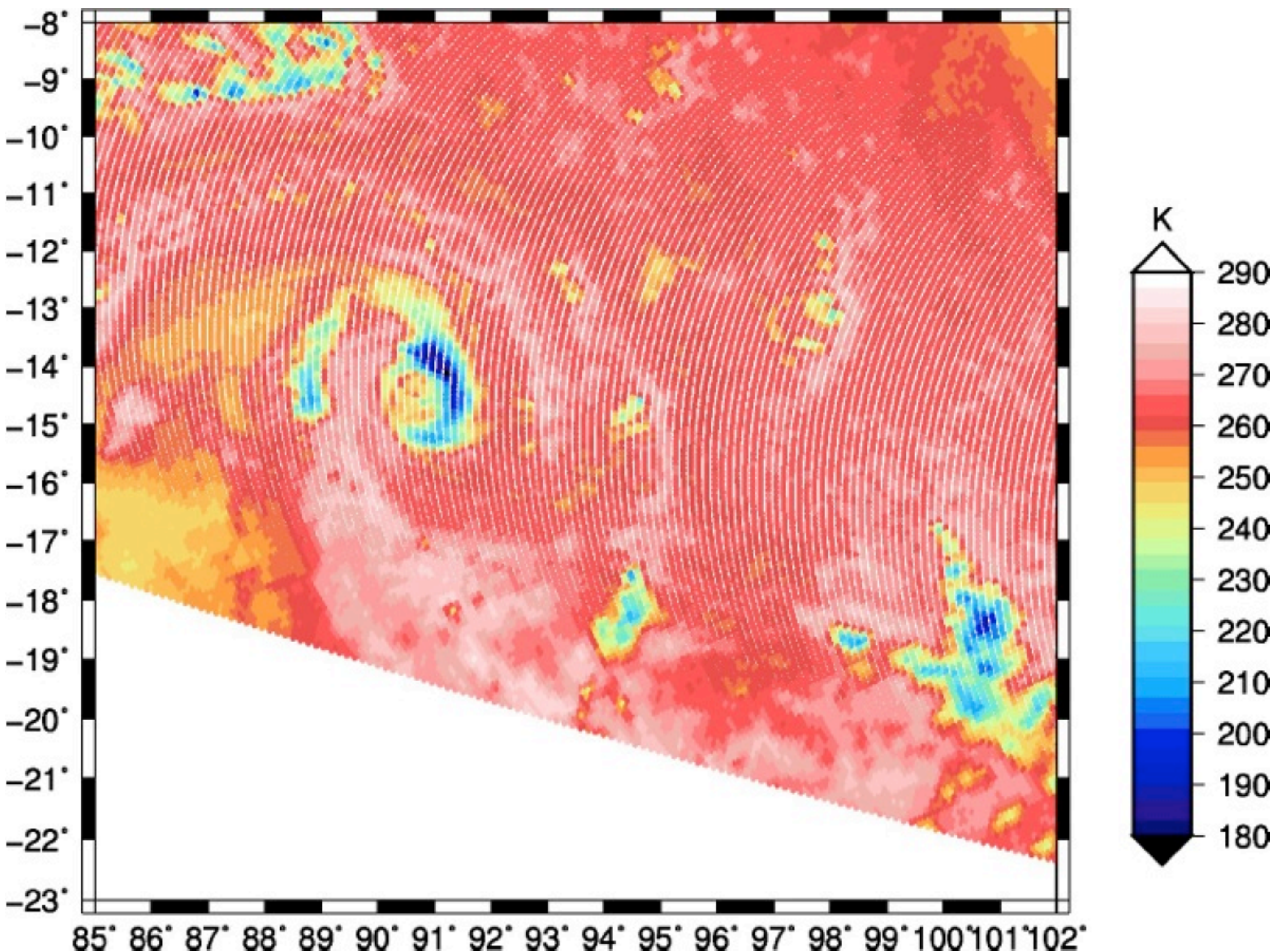
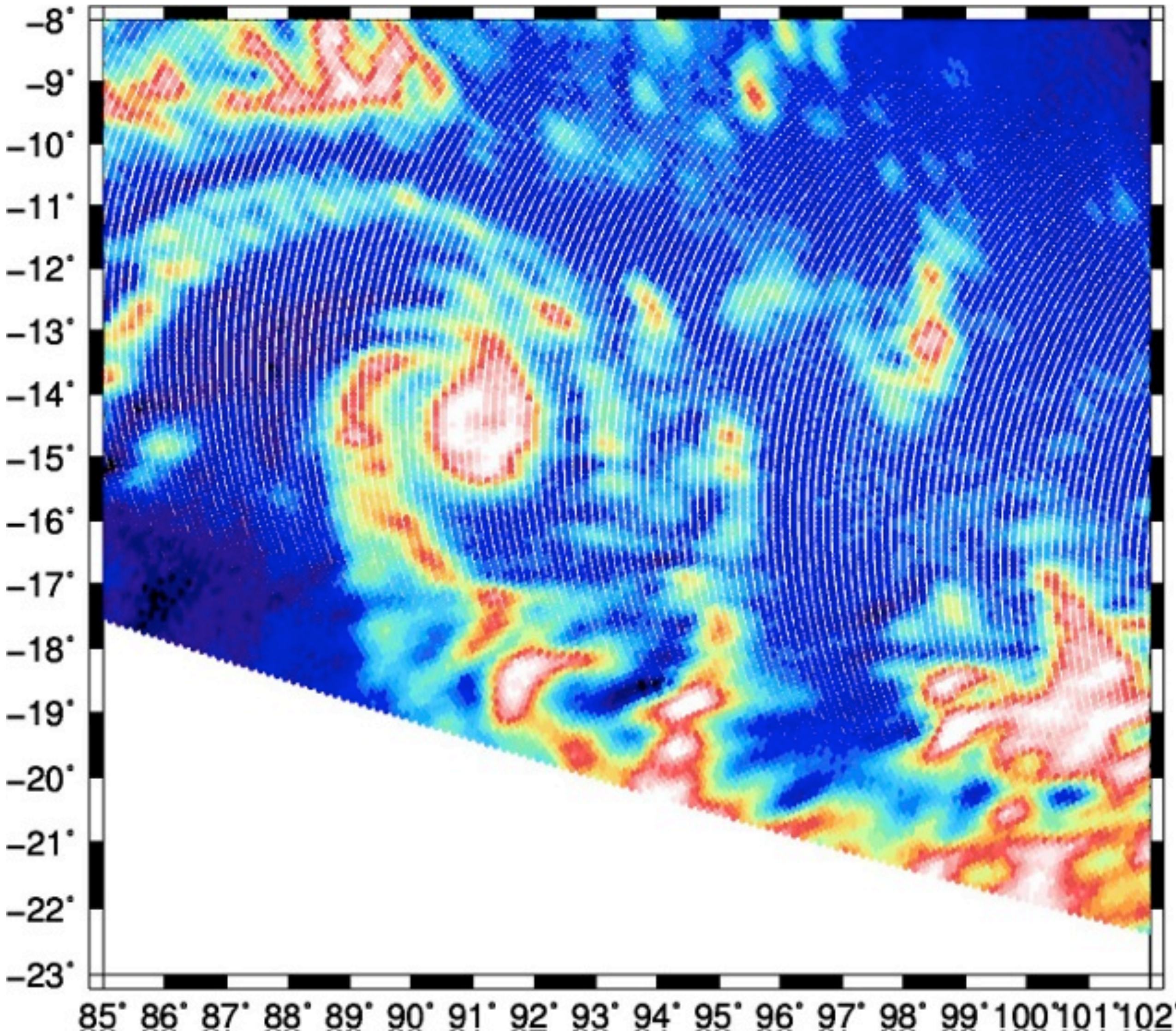


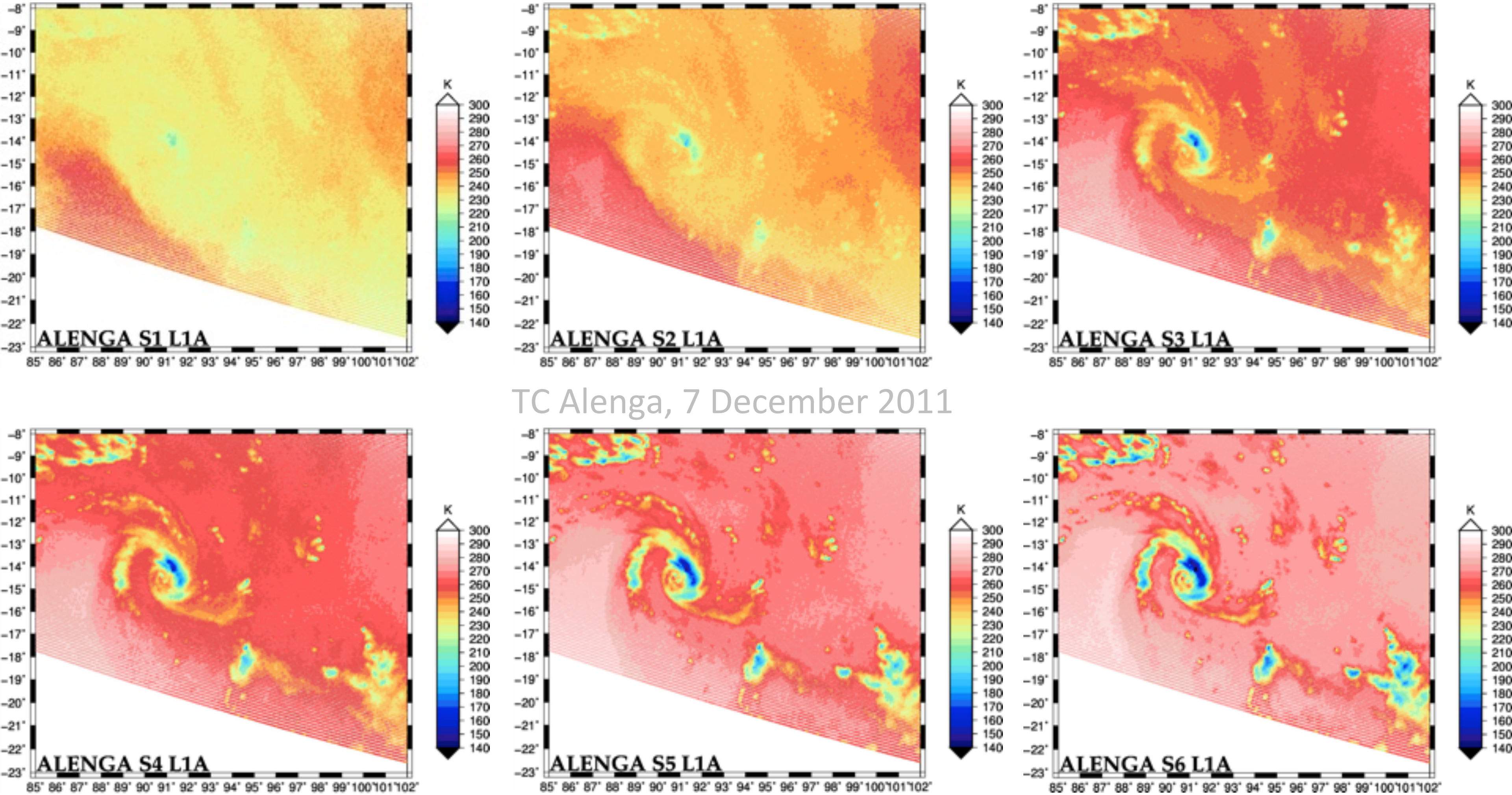
How to remedy poor MADRAS resolution?

hi-frequency+hi-resolution-guided deconvolution:

$$\vec{x} = \tau(T_{hiF+hiR}) + (1 + C\,A^t\,E^{-1}\,A)^{-1}\,C\,A^t\,E^{-1}\,(T_b - A\tau(T_{hiF+hiR}))$$



Alternative: Sounders -- yes, sounders have better resolution, but difficult to interpret over condensation:



TC Alenga, 7 December 2011

SAPHIR (183.3 ± 0.2 , ± 1.1 , ± 2.8 , ± 4.2 , ± 6.8 , ± 11),
resolution ~ 10km at nadir, swath=1700km

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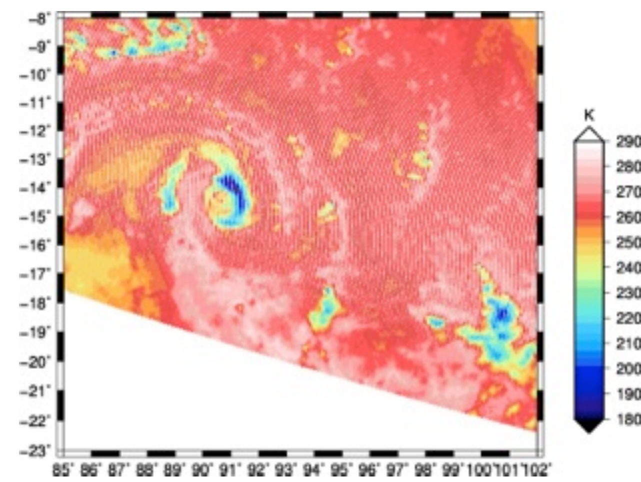
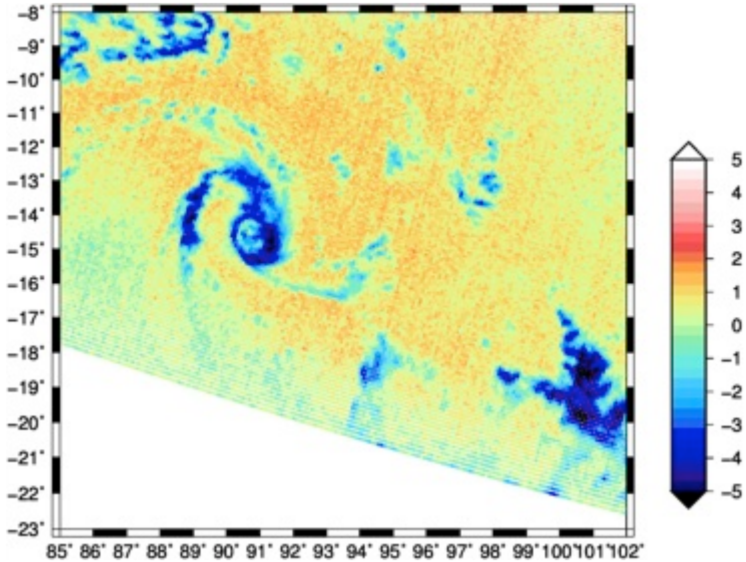


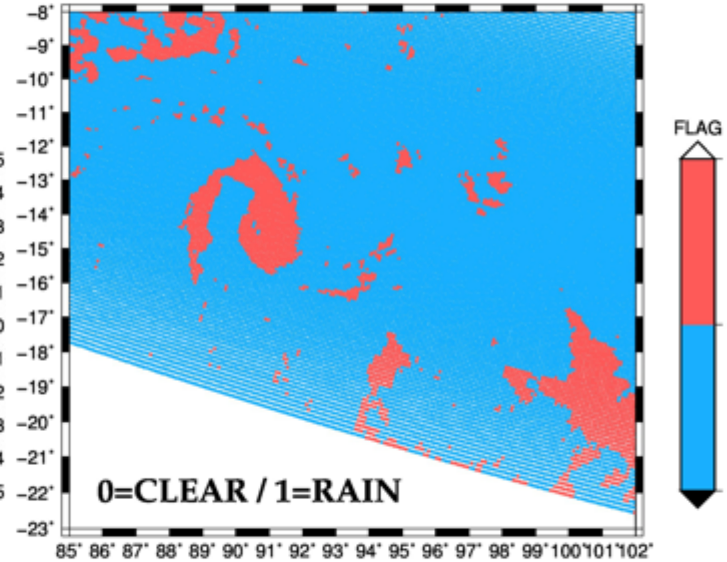
Madras 89GHz channel

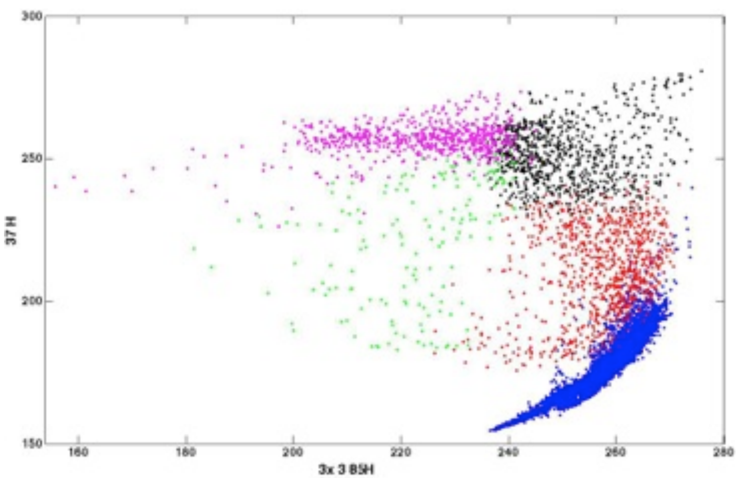
First, detect (i.e. classify precip vs non-precip)

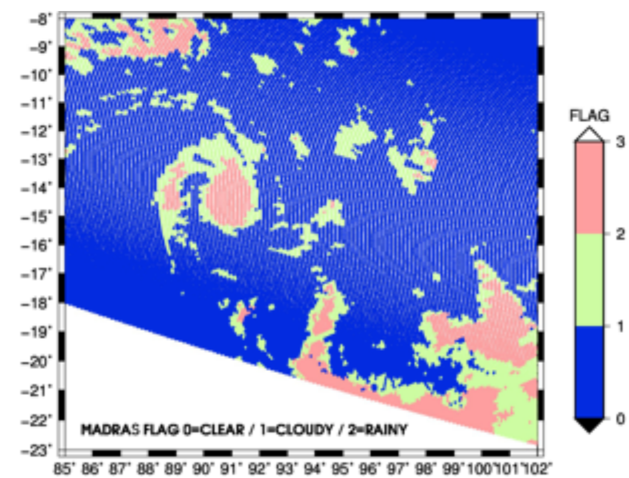
detector = lin_discr(T_1 , … , T_6)



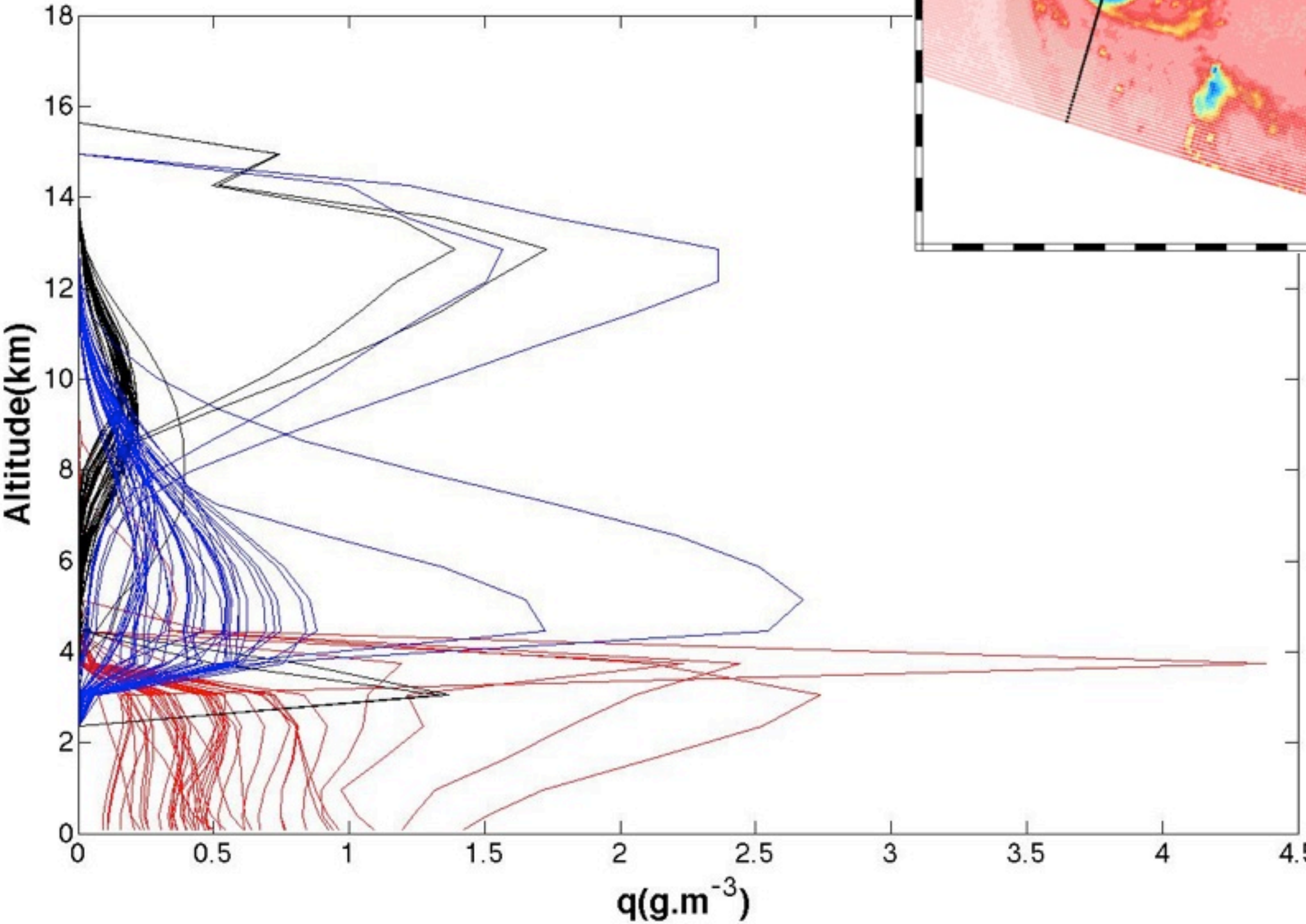
detector > or < -0.47

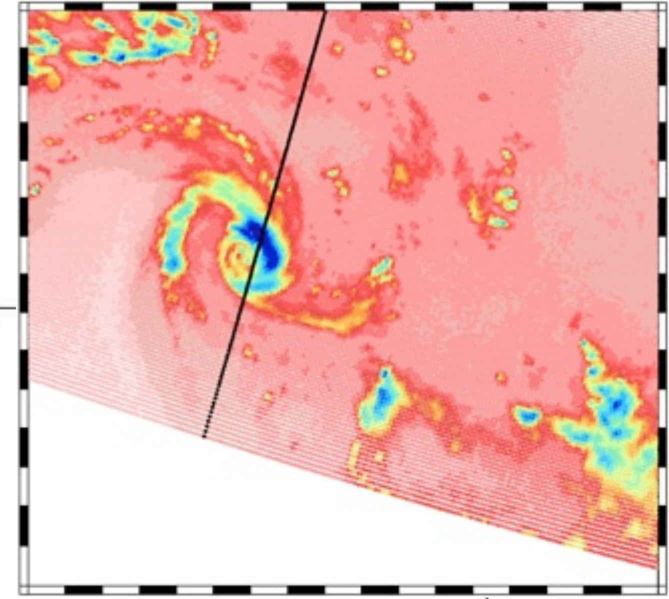




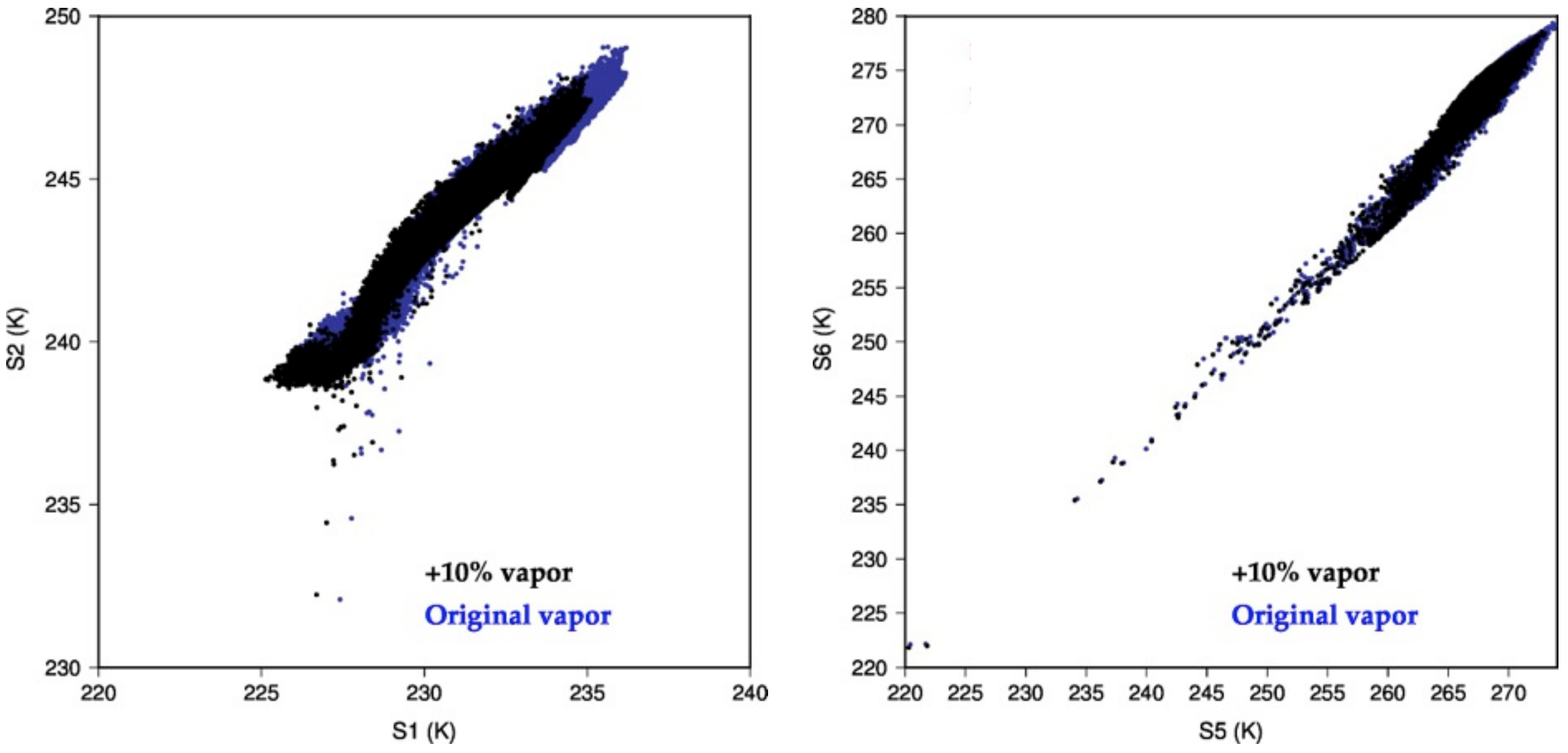


SAPHIR 1Dvar (retrieval) of condensed water mass:





Sounders sensitive to water vapor, of course:

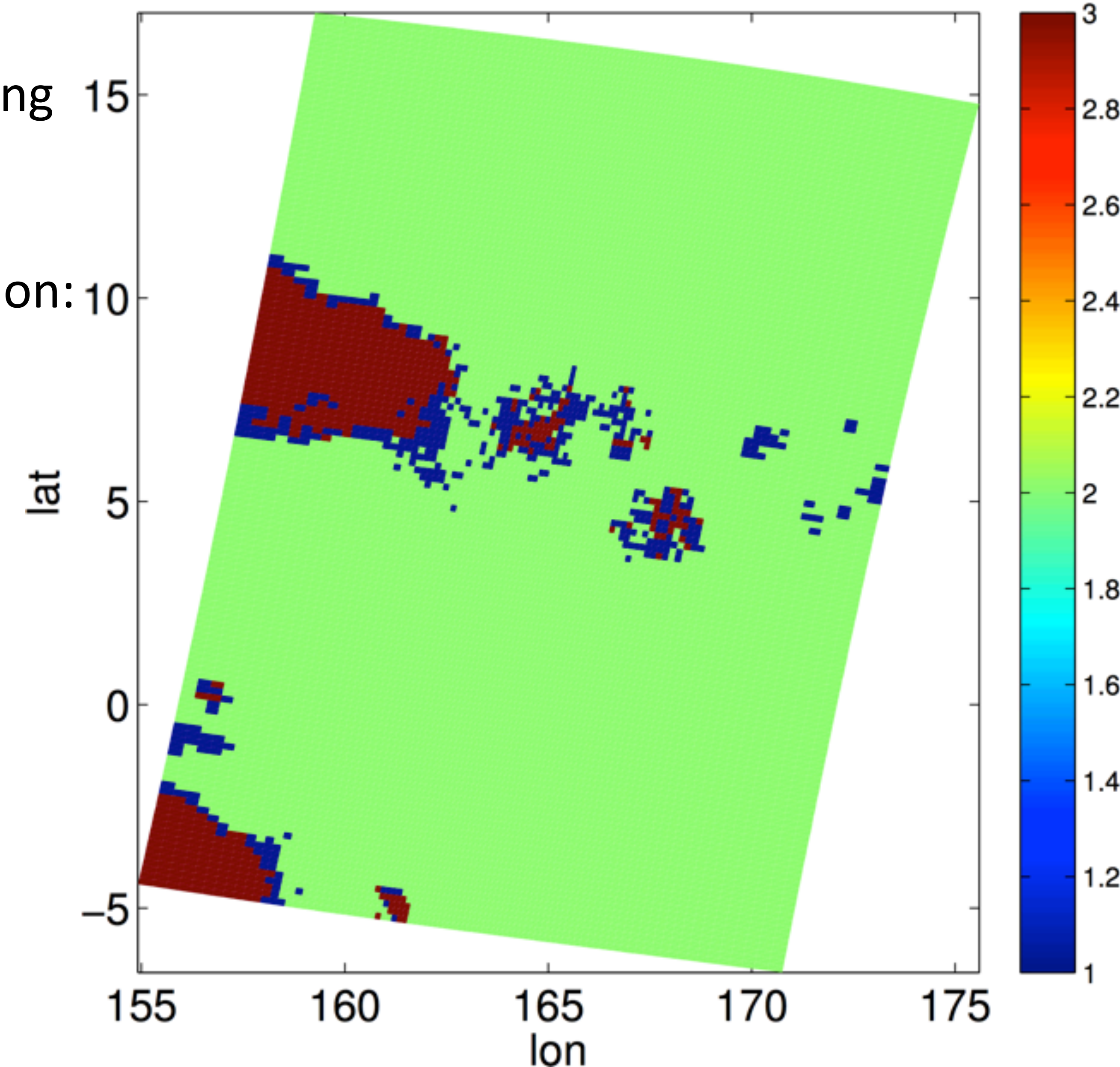


beware the bias!

Can AIRS help with water vapor?

we are studying the sensitivity of AIRS, using 2 days' worth of forward calculations from ECMWF simulation:

First, a detector



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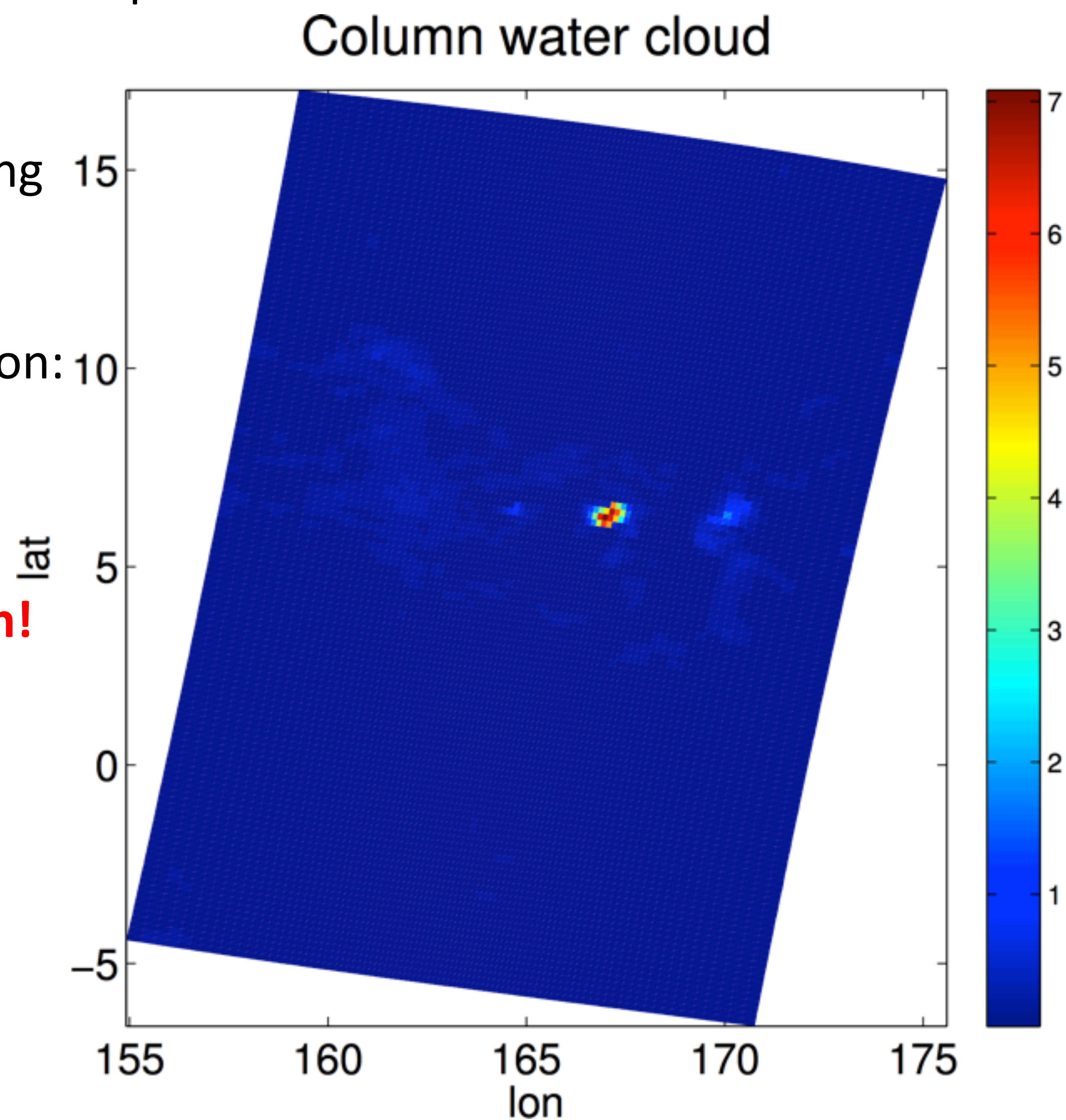
Not a detector of liquid condensation!



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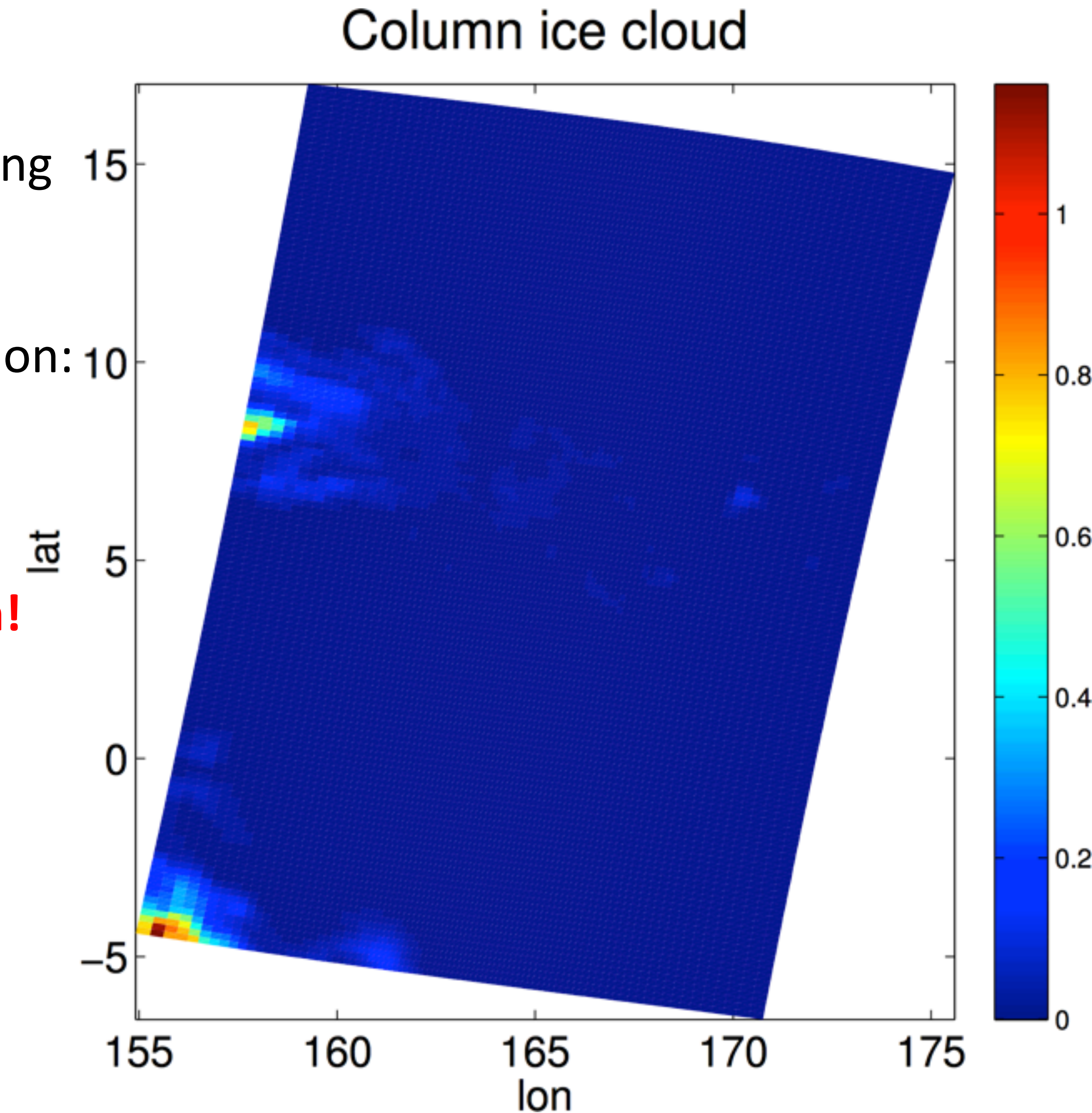

Not a detector of solid condensation!

Can AIRS help with water vapor?

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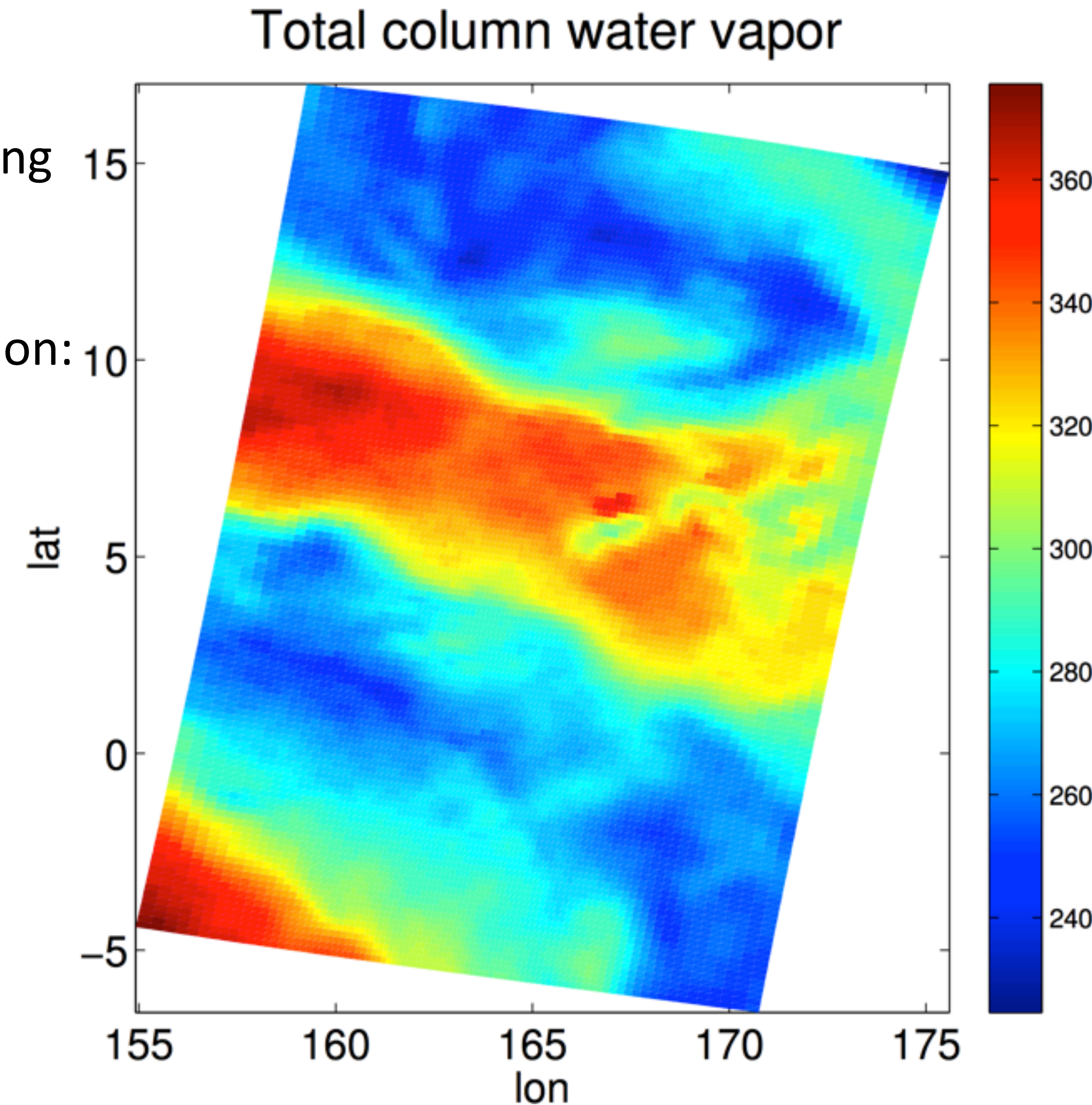


a detector of … water vapor!

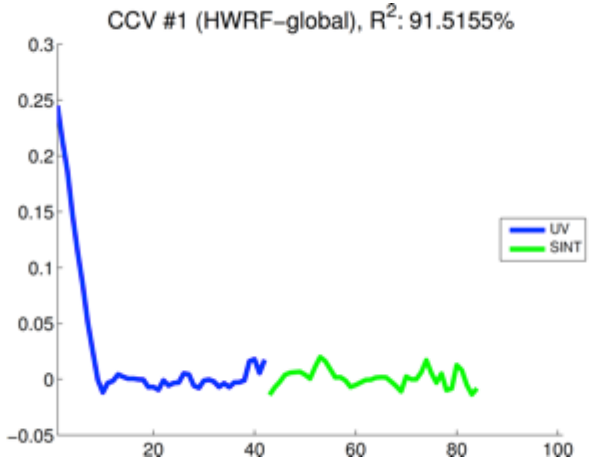
New, different use of “data assimilation”:

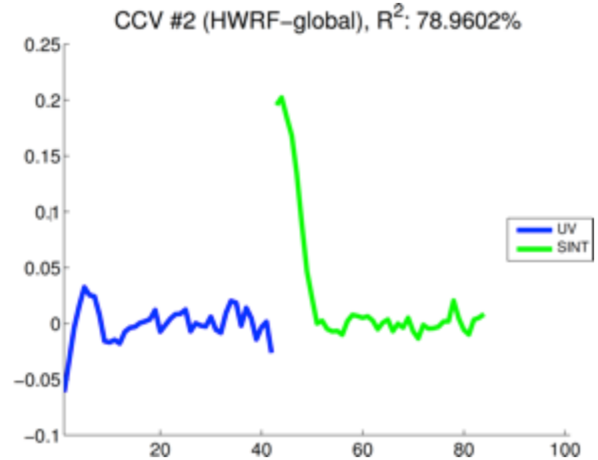
let’s not leave info on the table:
precip measurements can be used to analyze instantaneous state
(final in 3Dvar / EnKF, or initial/intermediate in 4Dvar)

but they also tell about the process,
so we should try to use them to improve model,
improve model parametrizations,
improve parameters or parameter correlations in parametrizations

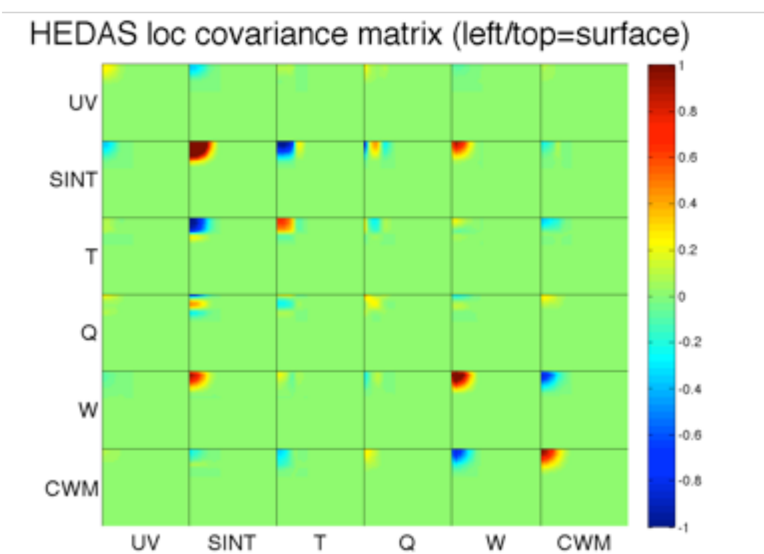
… still just a rough idea, but Kalnay has been thinking the same …

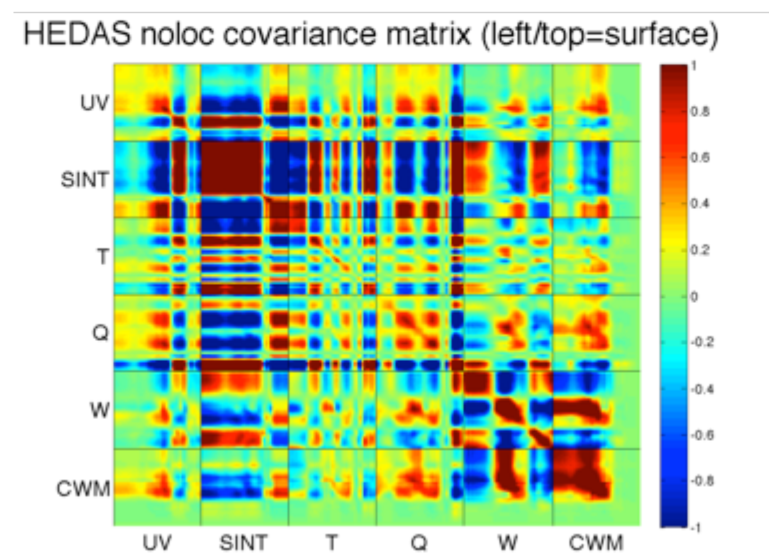
Applied the same approach to represent scatterometer observations as functions of wind (speed and inflow angle) at every vertical level:





Unfortunately, background covariance representation problematic:

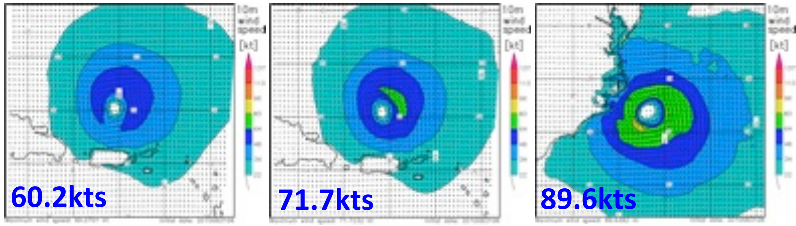




Applied the same approach to represent scatterometer observations and tested on Earl:

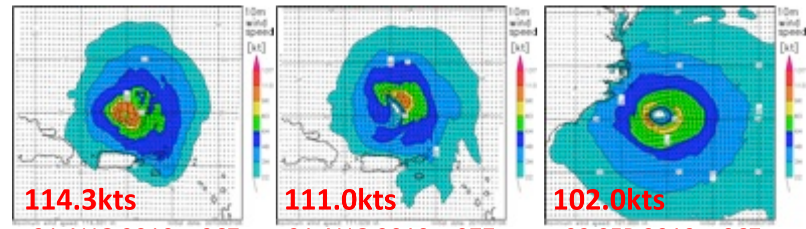
HEDAS Earl **forecasts without (left) / without (right) assimilation of OSCAT with our Robust-NL observation operator** (best track estimate at 31 AUG 06Z: 115kts; at 02 SEP 06Z: 125kts)

No assimilation:



31 AUG 2010 – 06Z *31 AUG 2010 – 07Z* *03 SEP 2010 – 06Z*

OSCAT assimilated:



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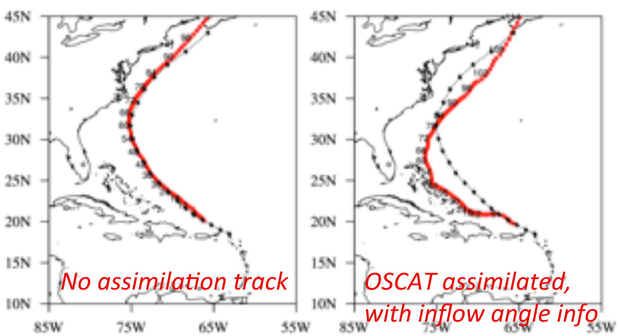

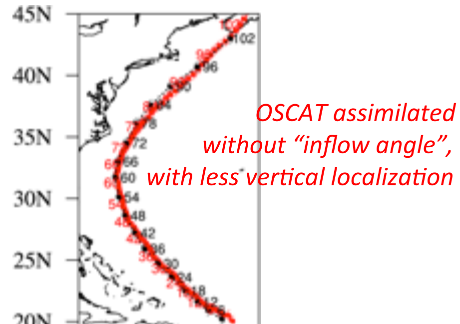

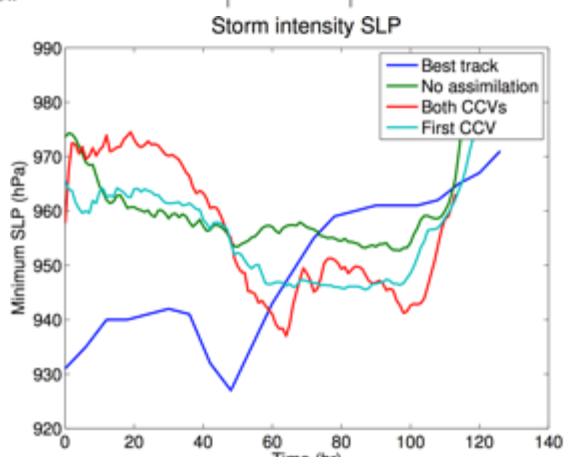

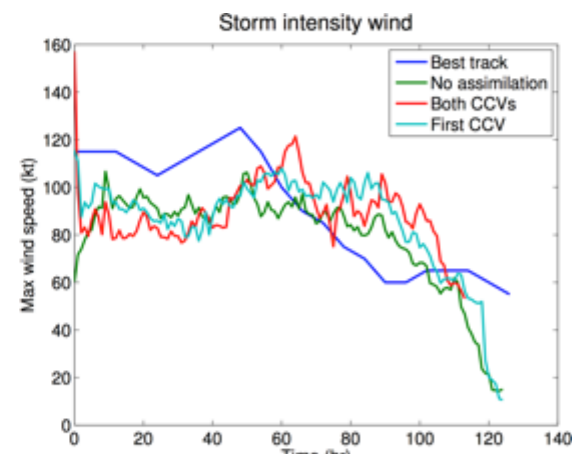

Plan:

1) test observation operator for SAPHIR, develop version for AMSU-B

2) test for dependence on ice signatures

3) test for bias by specific humidity, and ability to reduce (eliminate?) bias using AIRS

4) implement systematic assimilation of RAPIDSCAT for the upcoming season using our operator, then evaluate …