All-sky assimilation of IASI upper-tropospheric humidity channels

International TOVS working group, Darmstadt, 30th November 2017

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Spoiler: this talk is not really about cloud or water vapour…

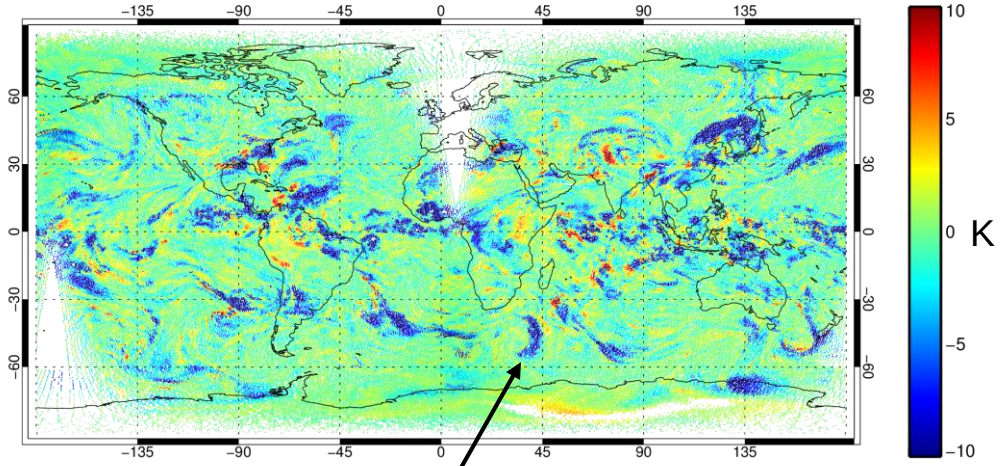
ECMWF

All-sky assimilation for IASI

Metop-A&B, channel 3002 (1395.25 cm^{-1})

21Z 1st May 2016 to 09Z 2nd May 2016

Clear-sky FG departure:
Observation – bias correction – clear-sky simulation

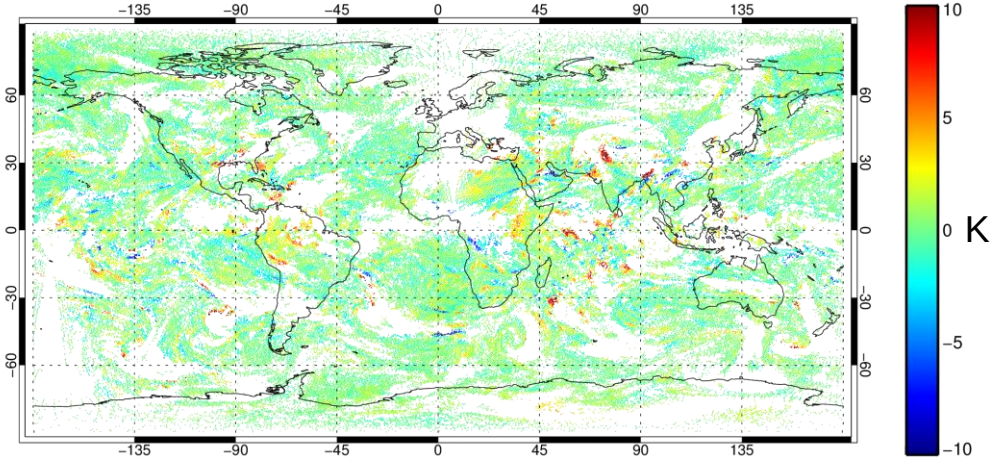


Cloud is missing from
the simulations

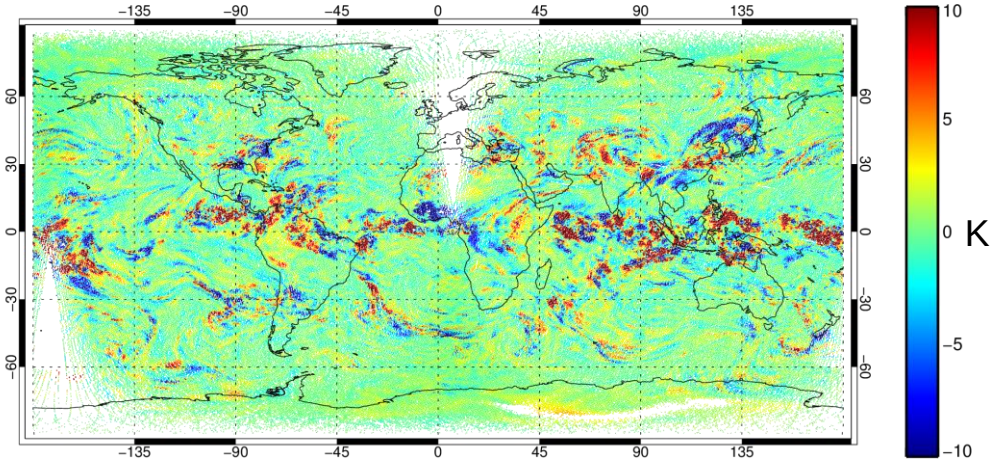
Traditional approach:
clear-sky assimilation

All-sky approach

Clear-sky FG departure after cloud screening

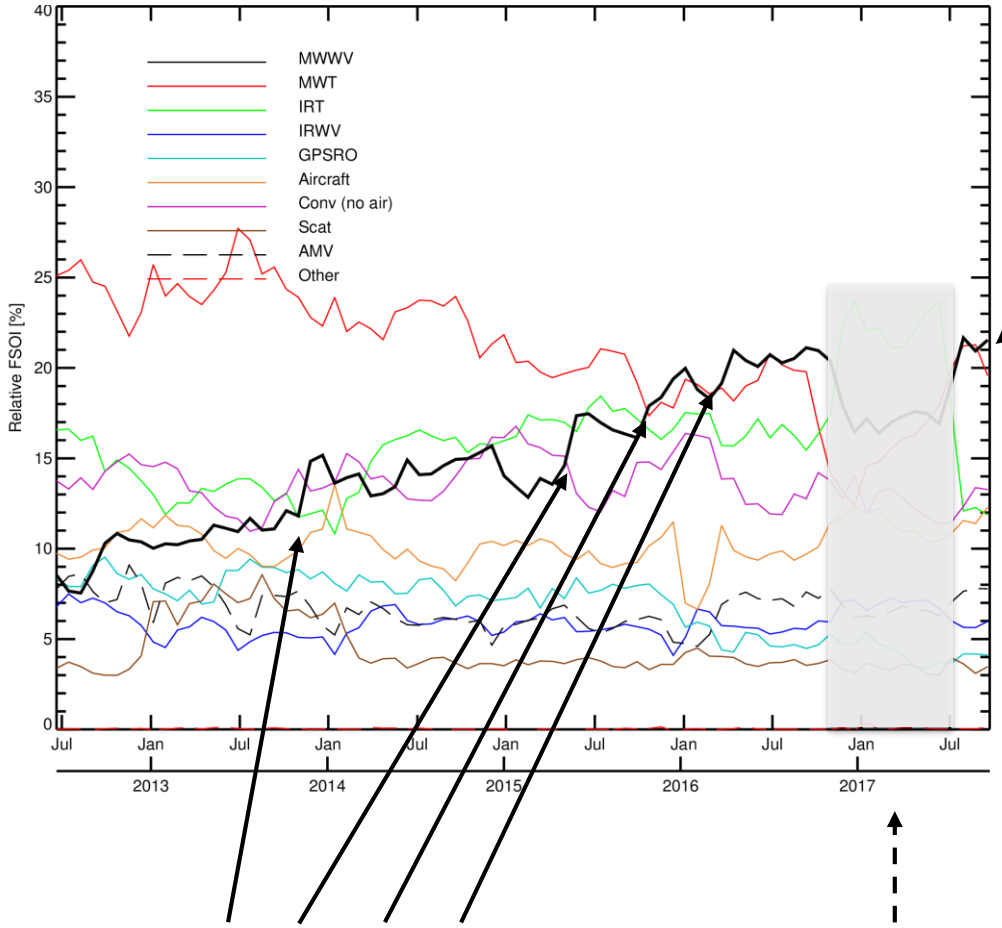


All-sky FG departure:
Observation – bias correction – **all-sky** simulation



All-sky **microwave** humidity assimilation benefits ECMWF forecasts

Relative FSOI from different observing system components
(FSOI = adjoint-based measure of short-range forecast impact)



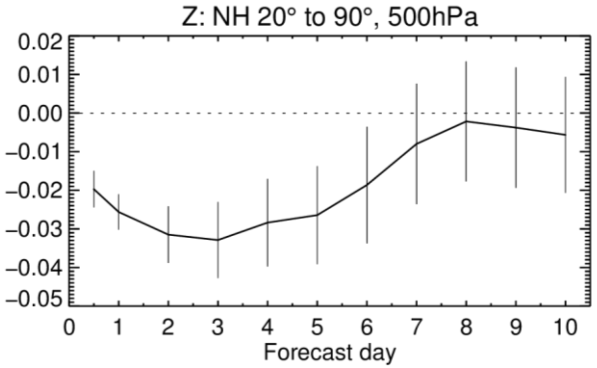
Microwave water vapour, cloud and precipitation radiances from **12 sensors** now provide as much information as microwave T radiances

Addition of more all-sky microwave data

(cycle 43r1 relative FSOI is incorrect due to correlated IR errors)

Real impact on dynamical medium-range forecasts:

Normalised change in RMSE when activating 7 all-sky microwave sensors in the otherwise full observing system



For more information see very recent 2017 papers:

- Review of ECMWF developments: DOI:10.1002/qj.3172
- Overview of all-sky assimilation at NWP centres: DOI:10.1002/qj.3202
- ECMWF strategy for all-sky assimilation: ECMWF TM 815

Reasons to do all-sky assimilation with IR WV (6.3μm) channels

- Demonstrated success with microwave 183 GHz channels that have similar radiative transfer (if we swap snow-scattering for cirrus)
  - Cirrus is partly transparent (somewhat like microwave cloud)
  - Mostly only the top layer of cloud is visible: cloud overlap less important
  - No sensitivity to the surface (in most conditions)

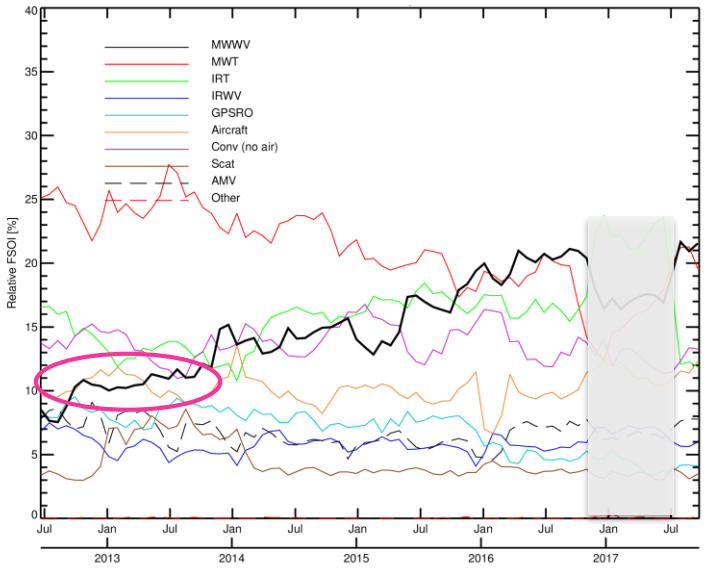
- Data assimilation is facilitated by:
  - Complementary sensitivities to ice cloud and water vapour
    - Similar to all-sky microwave 183 GHz assimilation, this avoids the zero-gradient problem and helps create cloud in the analysis where none existed in the first guess
  - Less chance of aliasing cloud increments into temperature (likely problem in CO_2 channels)

Initial tests of all-sky assimilation of HIRS ch. 11&12 (from 2013)

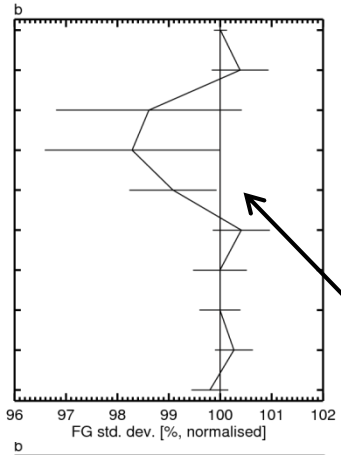
- Control = full observing system minus HIRS
- Experiment = control +
  - Assimilation of HIRS channels 11 and 12 in all-sky situations from Metop-A, NOAA-19
  - Constant observation error: 6K in channel 11, 4K in channel 12

Problem: back in 2013, we weren't yet using all-sky microwave WV channels →

FSOI timeseries 2012-2017

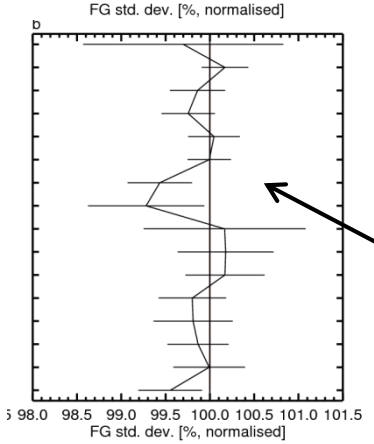


Sonde humidity



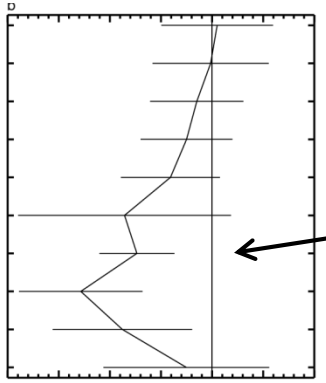
Upper tropospheric humidity improved by 1.5%

In-situ u-wind



UTLS wind improved by 0.5%

AMSU-A



UTLS temperature improved by 0.1%

2017: test all-sky IASI water vapour channels

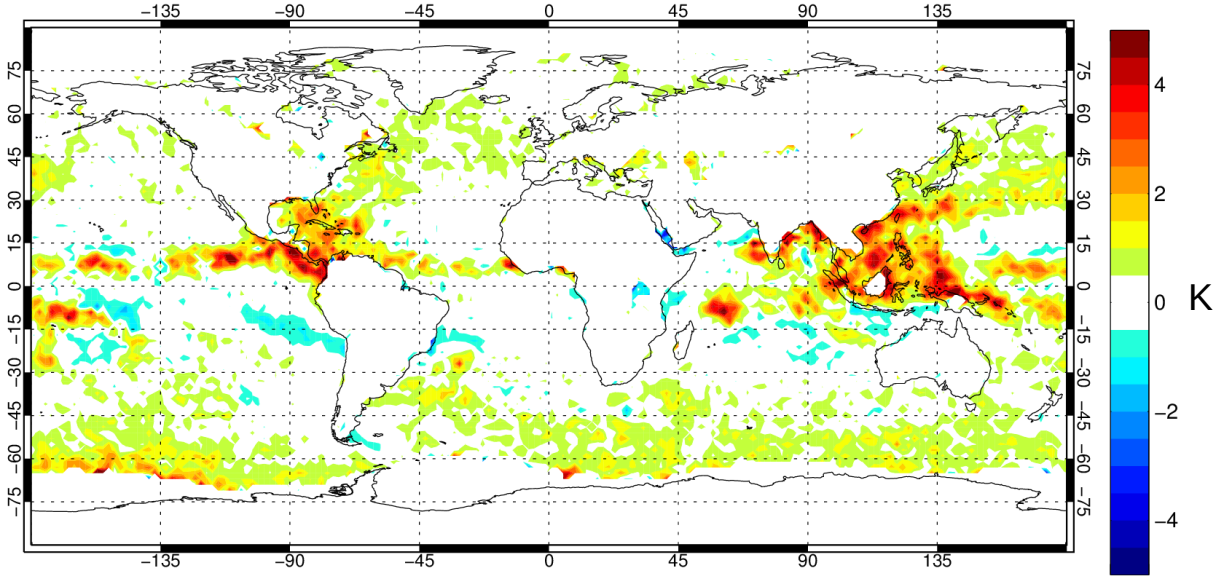
ECMWF

Method part 1: radiative transfer

- RTTOV with Chou scaling representation of cloud scattering (Matricardi, 2005, ECMWF TM 474)
  - "Cloud-fraction Max Simple Streams" (CMSS): One clear stream, one cloudy
    - (The multiple independent streams method is too slow and memory-intensive.)
  - Ice cloud scattering optical properties:
    - Baran scheme

- OK, but could be improved:
  - CMSS is incorrect for lower-peaking channels, so a new fast cloud overlap needs to be developed
  - Ice cloud optical properties

Ch. 3002 mean FG departures suggest cirrus cloud fraction or extinction is slightly overestimated (mean, 1-15 June 2016)



Method part 2: assimilation

- Assimilate other IASI channels as normal, but move the 7 water vapour channels to all-sky framework

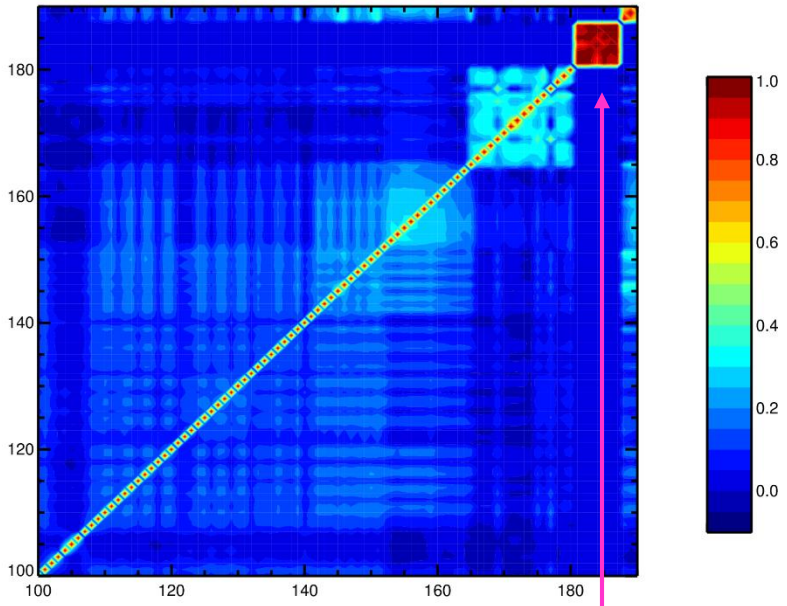
- Symmetric observation error model following Geer and Bauer (2010, QJ):
  - Clear-sky error ~1.5 K as Bormann et al. (2016, QJ)
  - Cloudy error inflated with Okamoto et al. (2014, QJ) predictor
  - All-sky error correlation (new)

- Screening does not remove cloudy situations, just:
  - Too-large normalised FG departures
  - Land and sea-ice
  - Aerosol contamination and excessive surface sensitivity

- Thinned along with other IASI channels to ~100km

- OK, but could be improved:
  - Assimilation of ice cloud ideally requires a cloud control variable

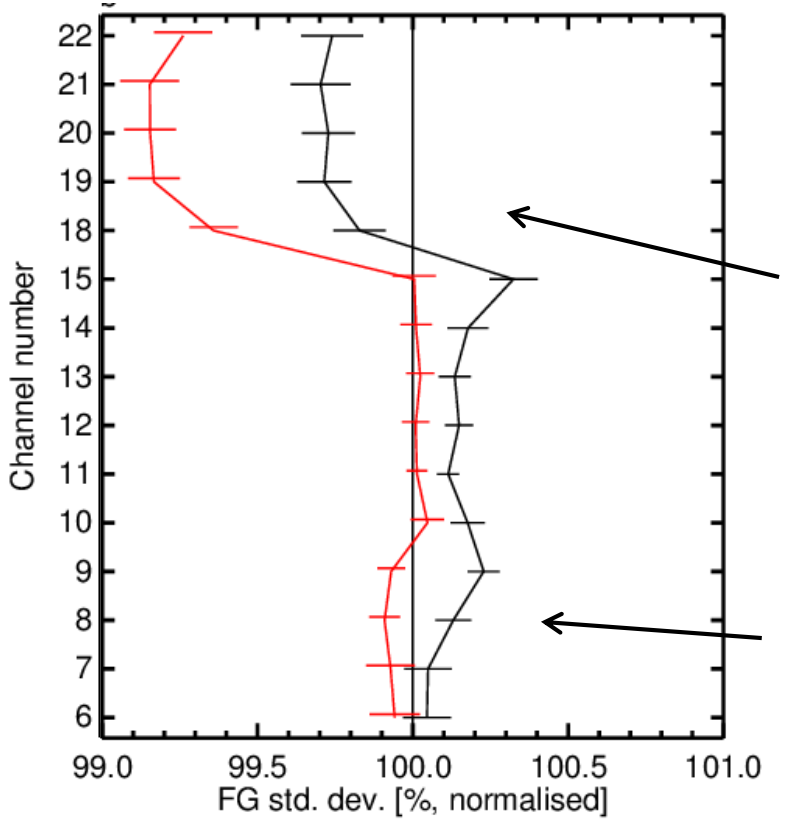
New IASI observation error correlation matrix



Other channels untouched (except that correlations with all-sky channels have been set to zero)

7 all-sky WV channels

2017 results: first guess fits to ATMS observations



FG humidity improved, but not as much as with a clear-sky approach

FG temperature “degraded” in upper-troposphere and stratosphere

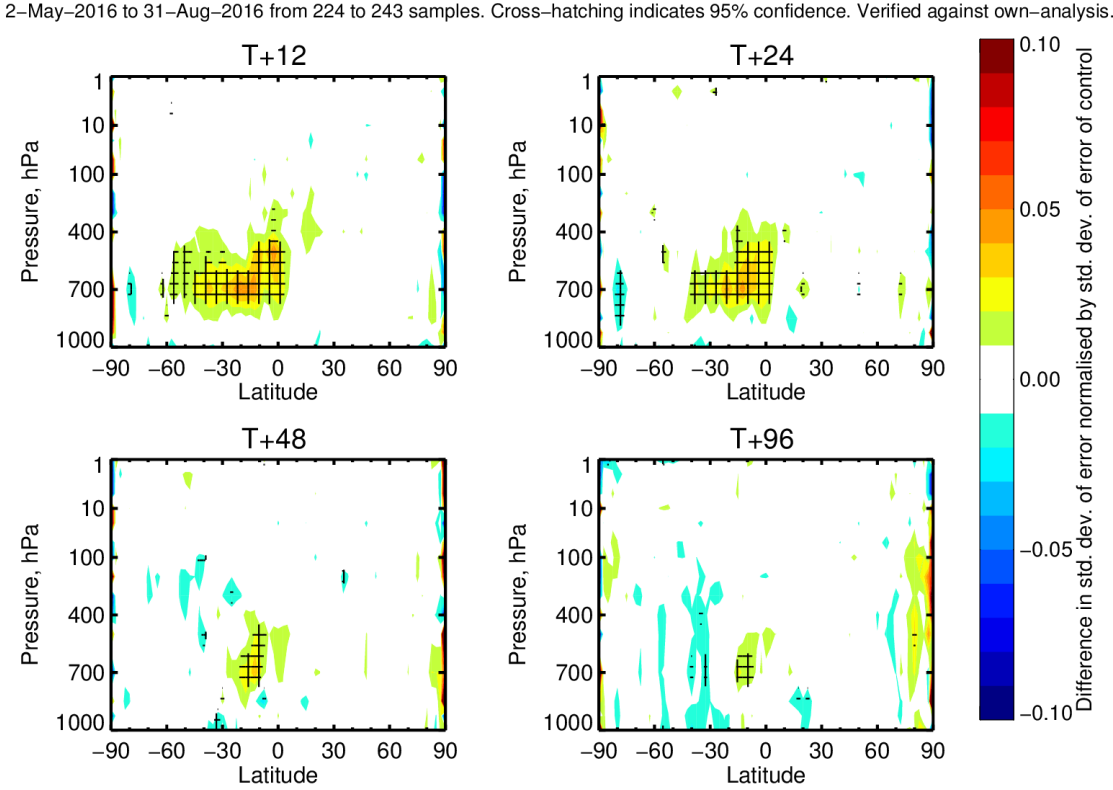
all–sky = add 7 IASI WV channels in all-sky framework

clear–sky = add 7 IASI WV channels in clear-sky framework

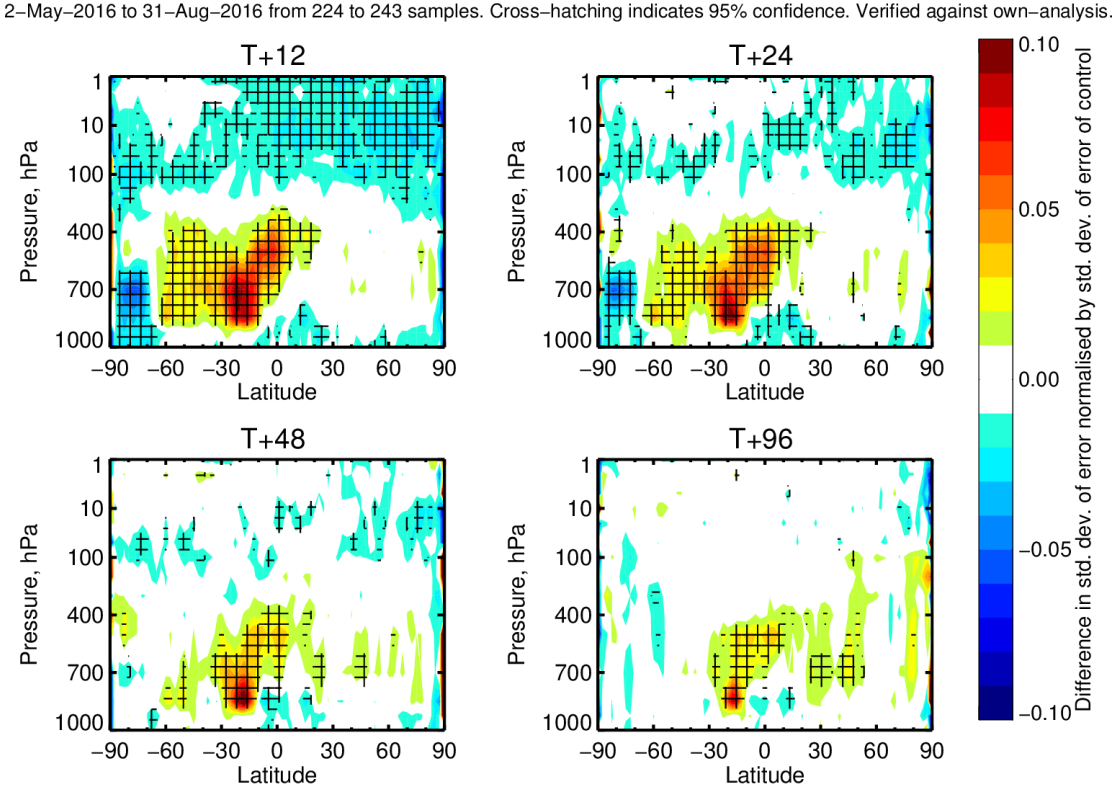
100% = control = Full observing system minus 7 IASI WV channels

2017 results: change in std. dev. of T errors

clear-sky minus control



all-sky minus control



All-sky IASI WV channel impact characteristics are similar to clear-sky, but bigger

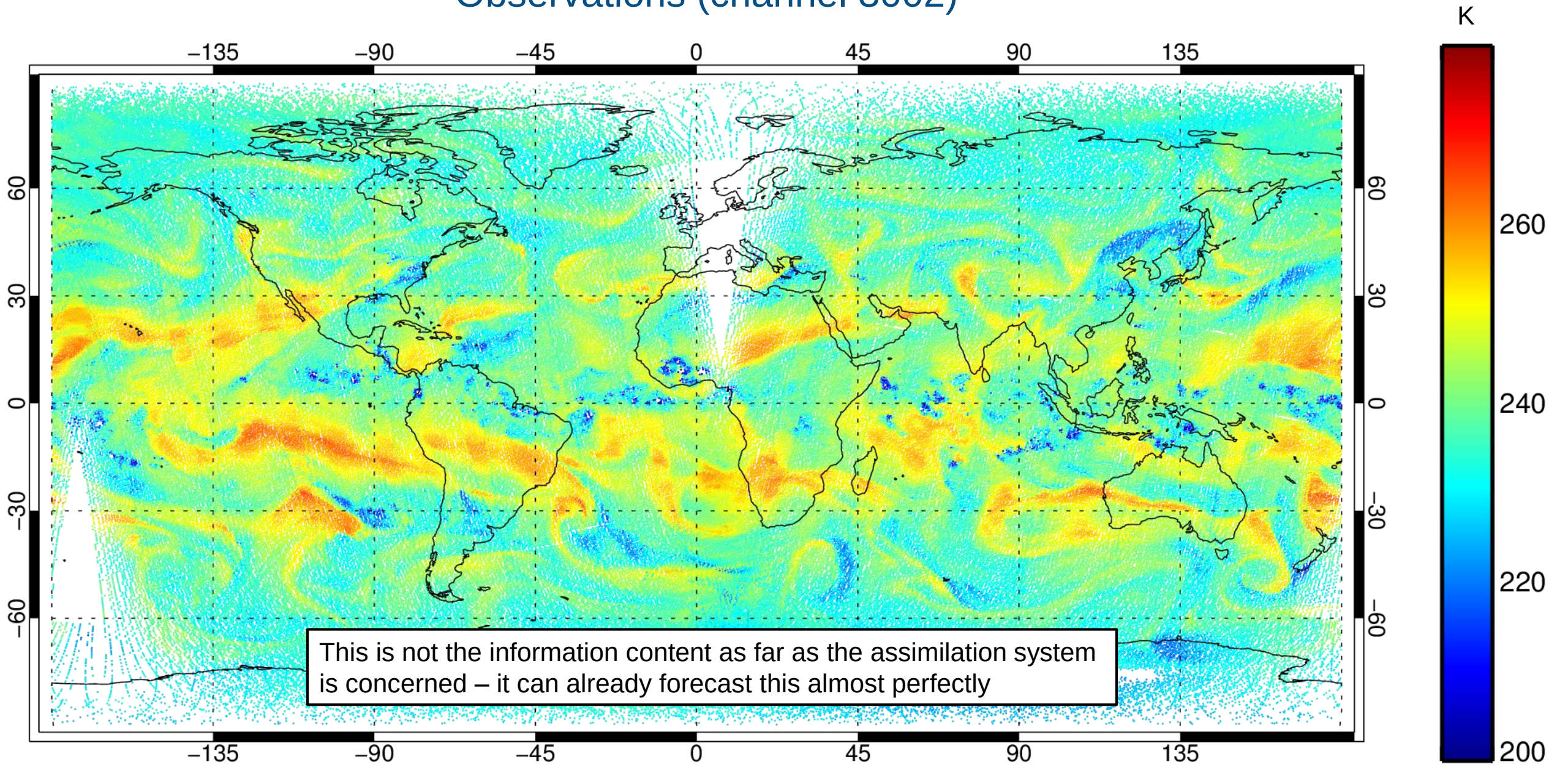
So…

Q: what really is the information content of all-sky infrared water-vapour channels in a sophisticated NWP system?

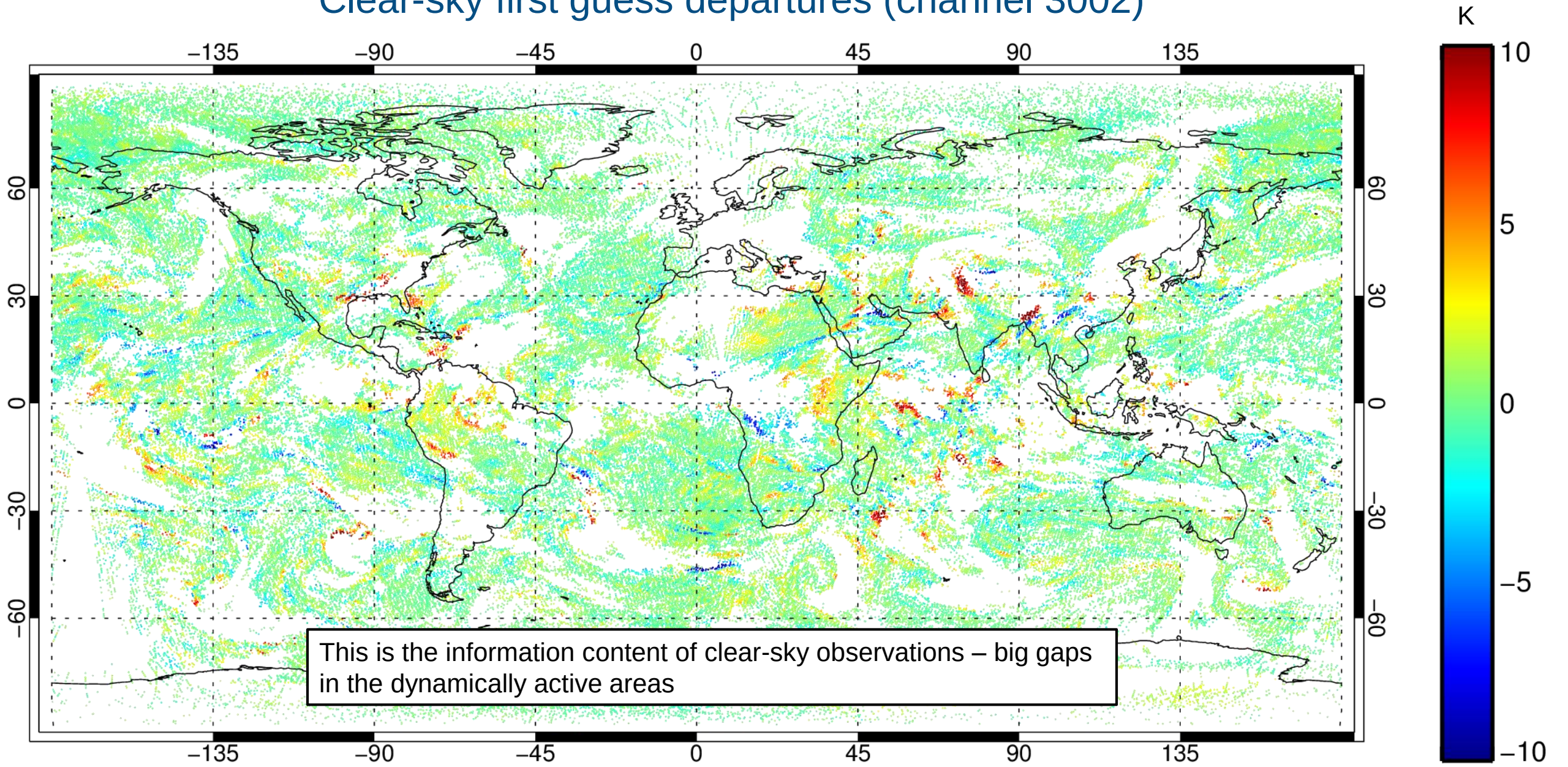
A: probably not what we thought.

ECMWF

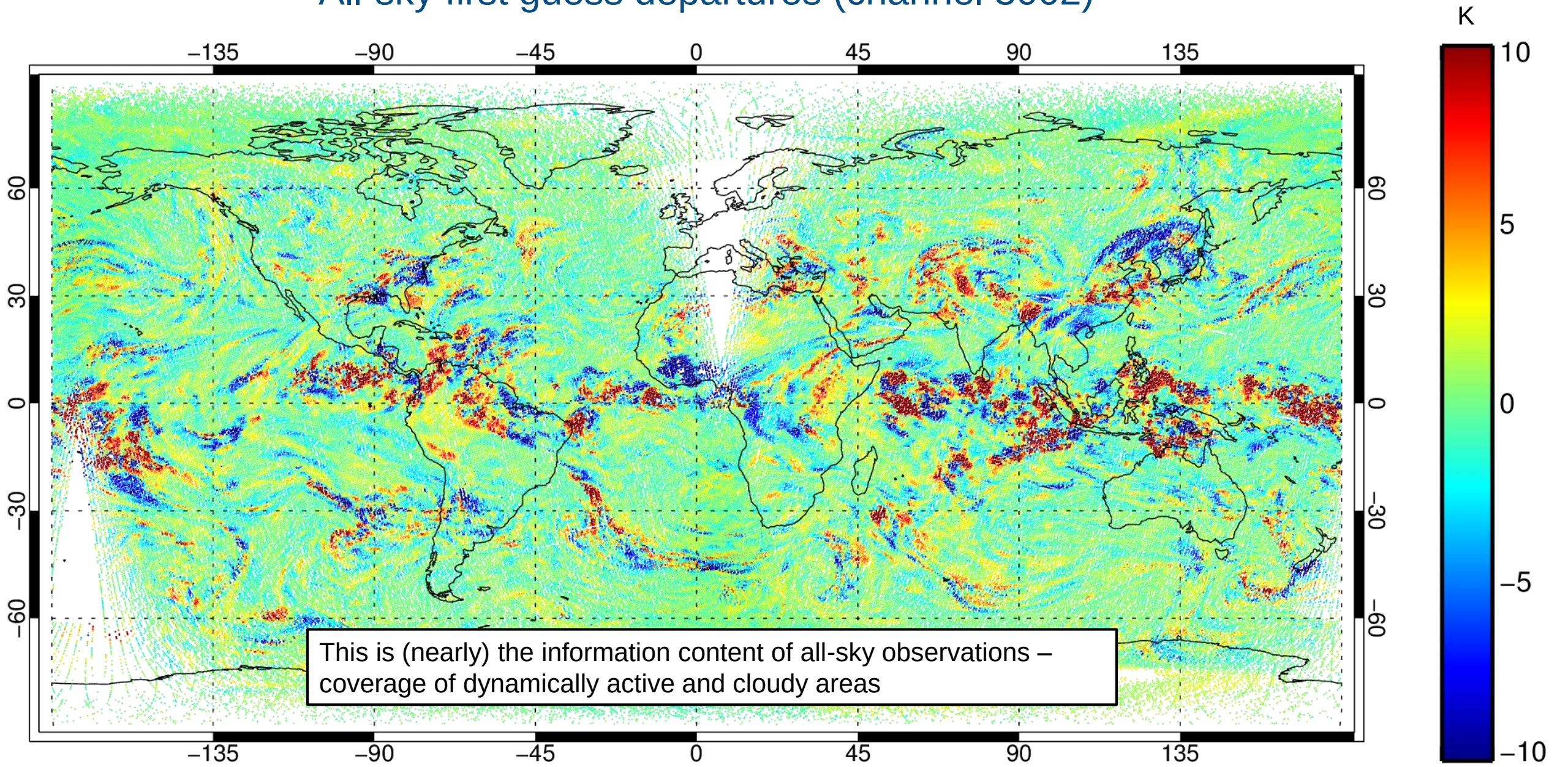
Observations (channel 3002)



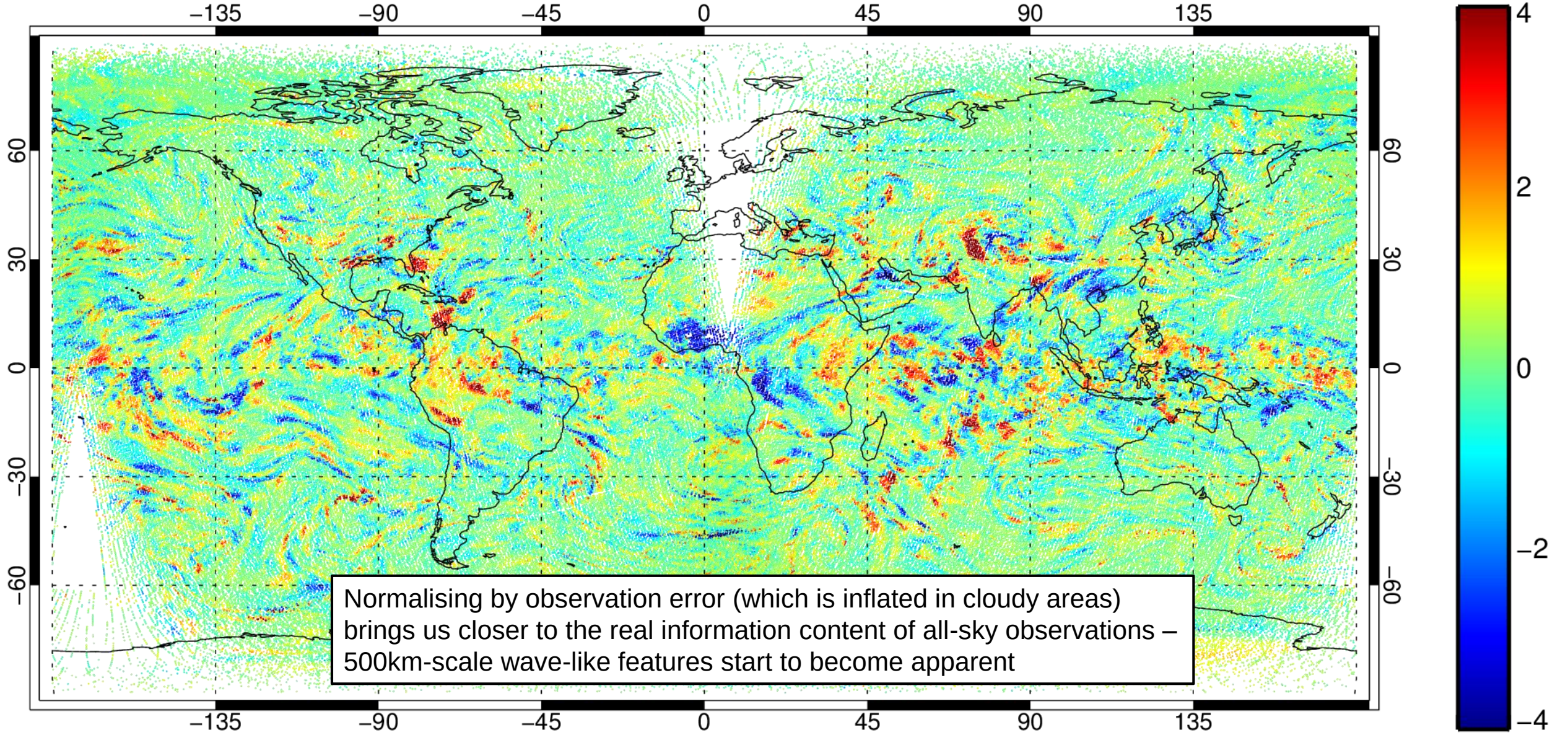
Clear-sky first guess departures (channel 3002)



All-sky first guess departures (channel 3002)

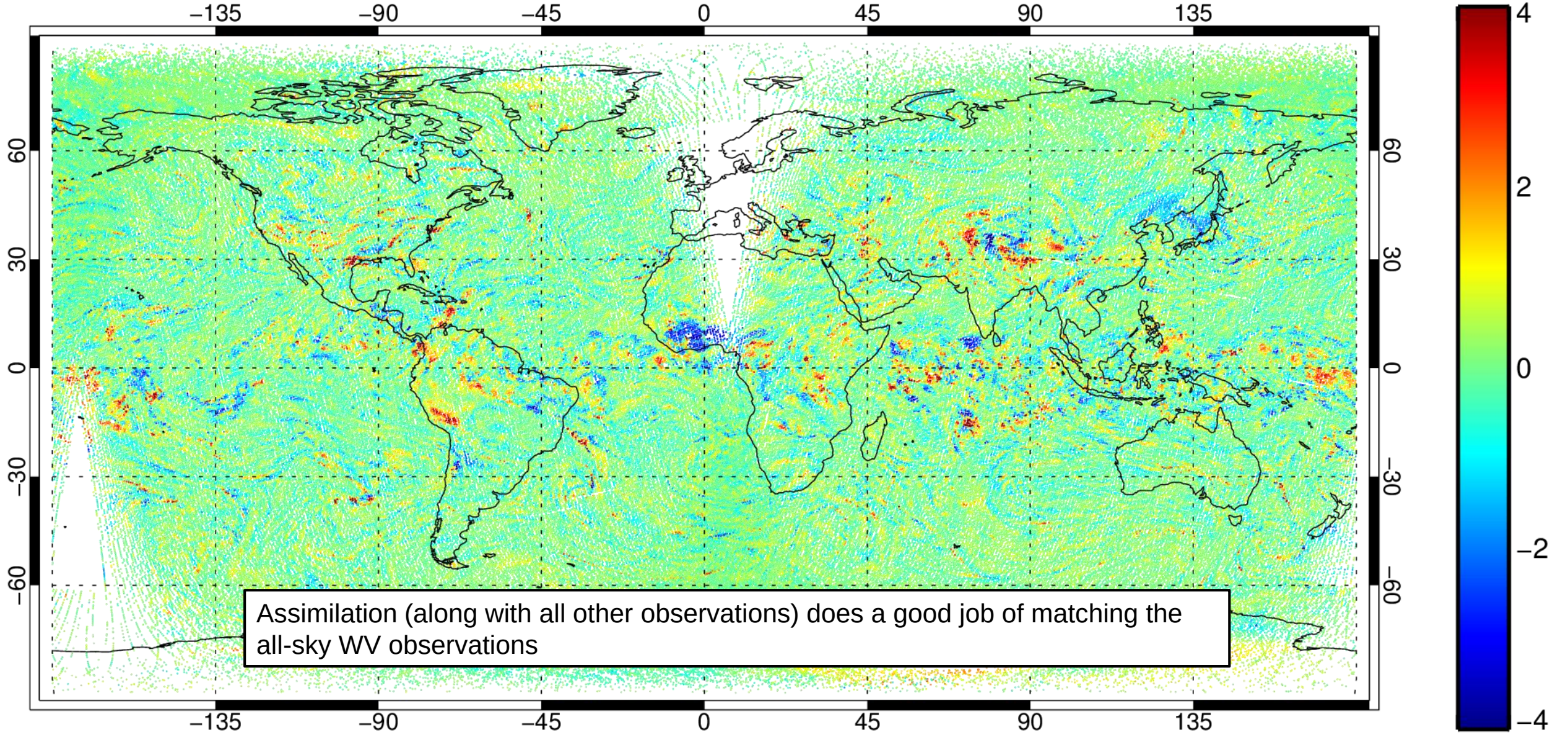


All-sky normalised first guess departures ((O-B)/obs error)



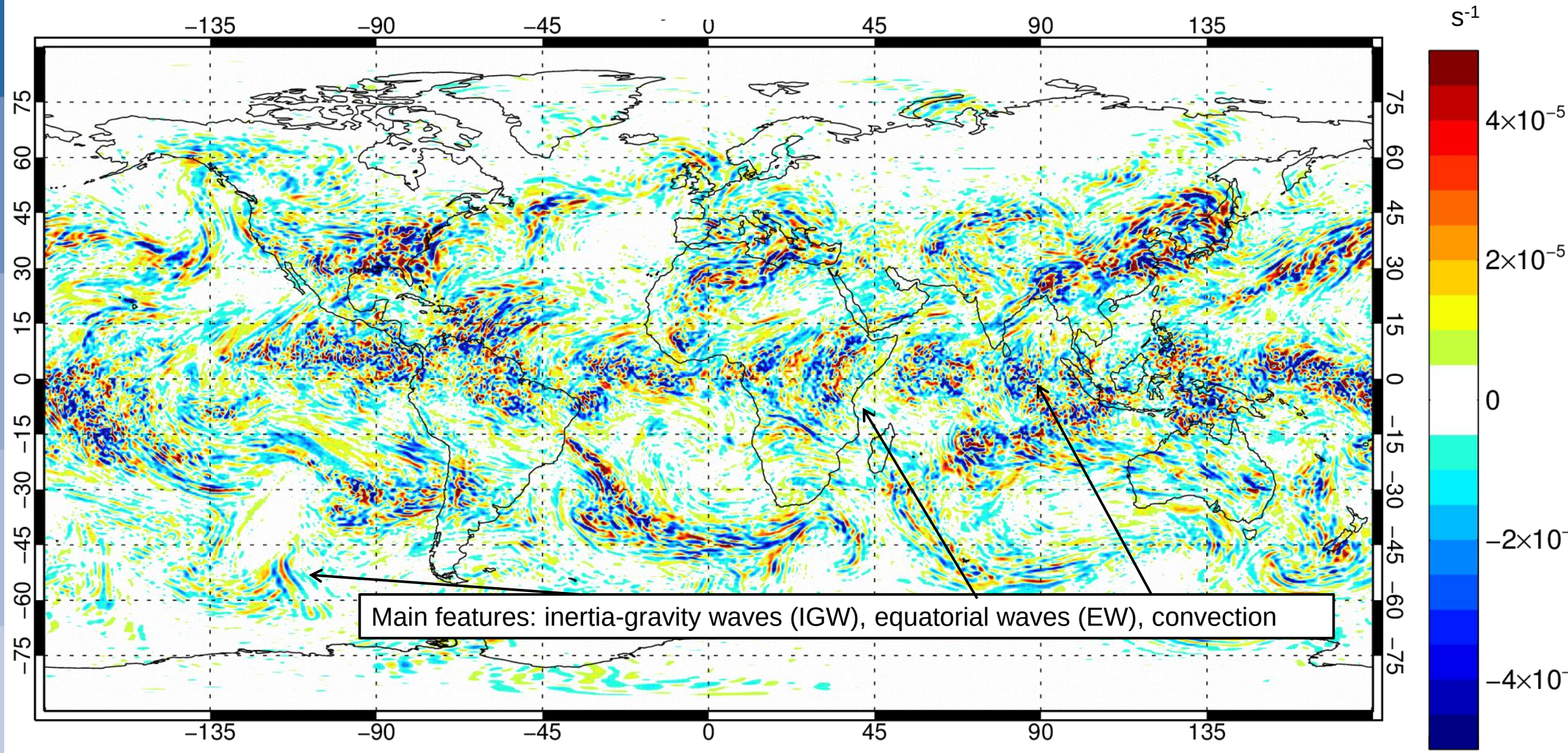
Normalising by observation error (which is inflated in cloudy areas) brings us closer to the real information content of all-sky observations – 500km-scale wave-like features start to become apparent

All-sky normalised analysis departures ((O-A)/obs error) - IASI WV active



Assimilation (along with all other observations) does a good job of matching the all-sky WV observations

Increments in wind divergence at 200hPa, 00Z, coming from all observations



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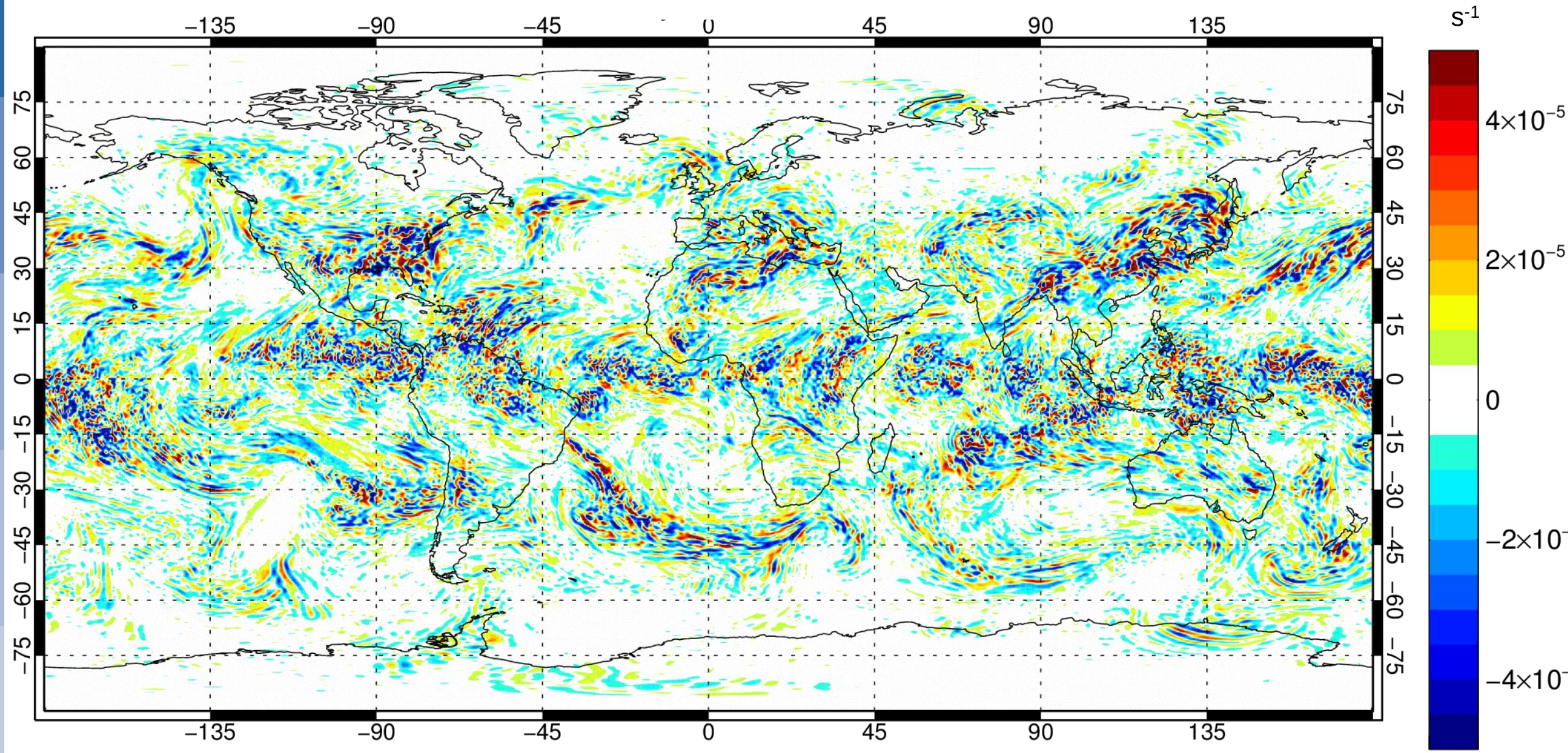

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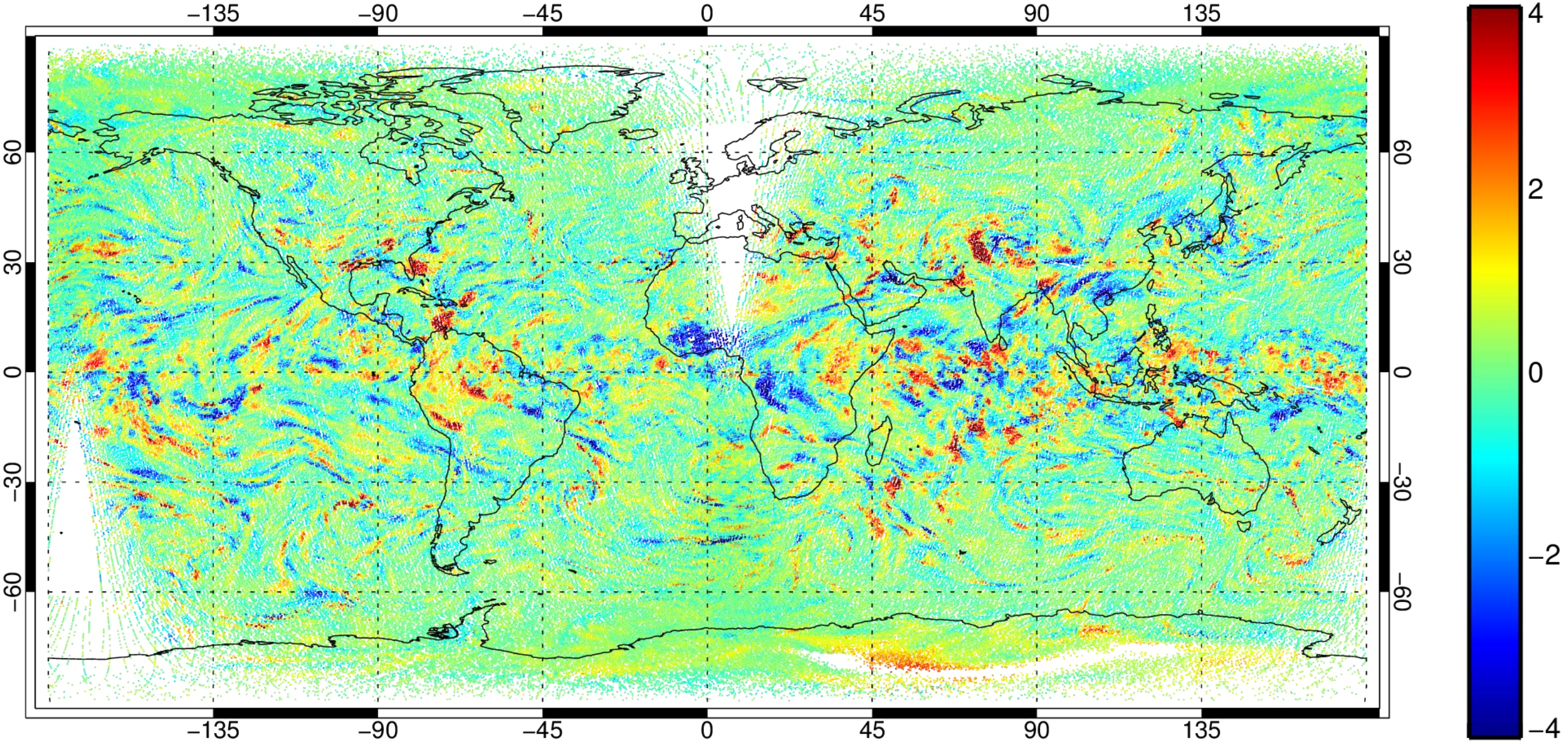

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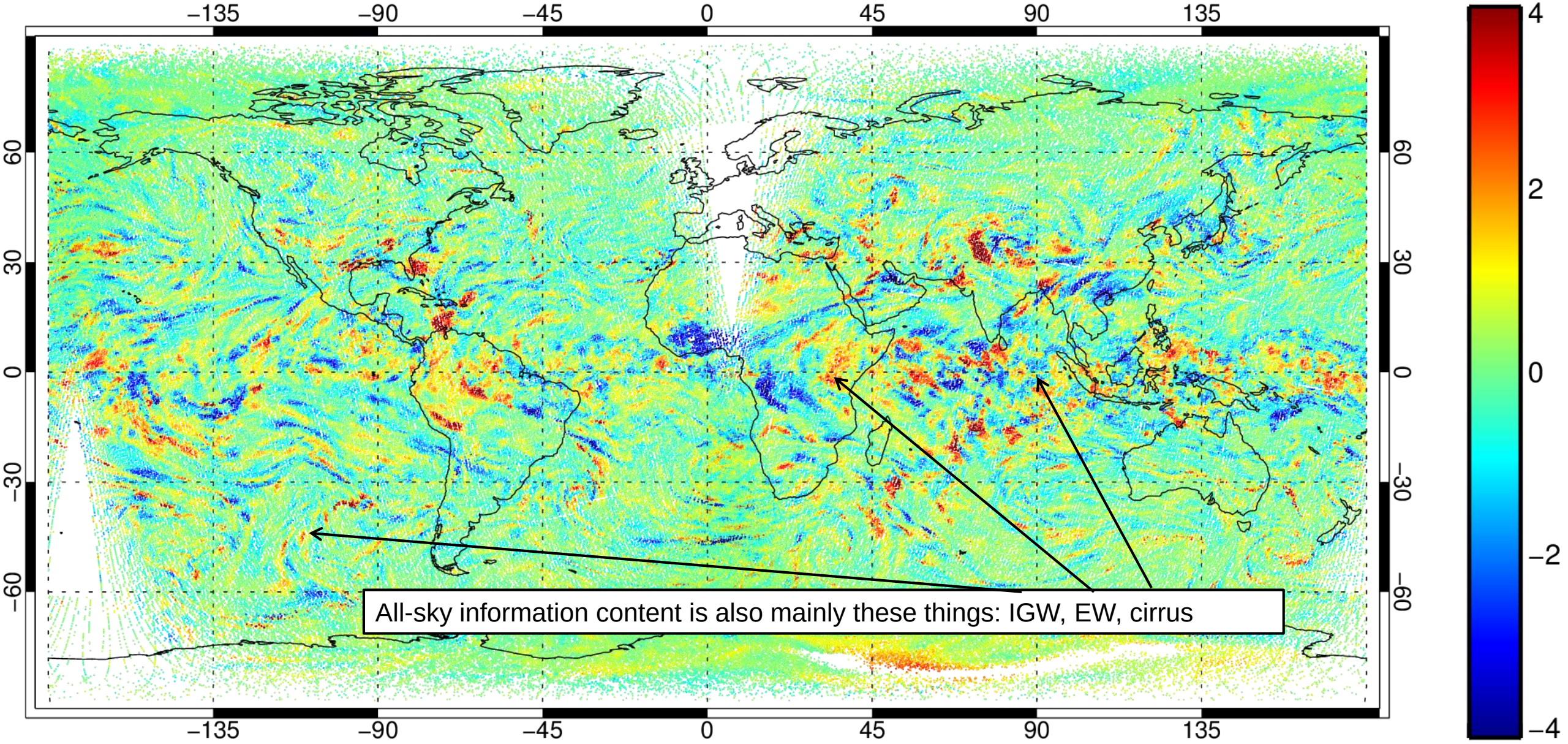

Conclusions

- There is no question that all-sky IR water vapour assimilation should work:
  - Excellent results from HIRS 11&12 back in 2013, prior to the big expansion of all-sky MW
- Methodology improvements could be made, but this will not transform the results:
  - Need better cirrus cloud optical properties and cloud overlap scheme (CMSS too simple)
  - Data assimilation of ice cloud would ideally require a cloud control variable
- **All-sky is just a better way of using the information in the observations.**
  - **For IR WV (6.3μm) channels, clouds are not the main story: by correctly accounting for clouds, we can see past them to the real remaining information content**
  - All-sky IR measures errors in the dynamically active regions of the upper-troposphere, at high spatial resolution
  - The errors in these regions come from features we might not even realise we are assimilating: inertia-gravity waves (IGW) and equatorial waves (EW).
- We may need to revise our approach to upper-tropospheric humidity channels
  - Assimilation systems can clearly fit IGWs, but does fitting IGWs benefit forecasts?
  - Hypothesis: IGWs may be imperfectly represented by ECMWF model (speed, wavelength)
  - Treat IGW as another source of representation error? Filter the analysis better?