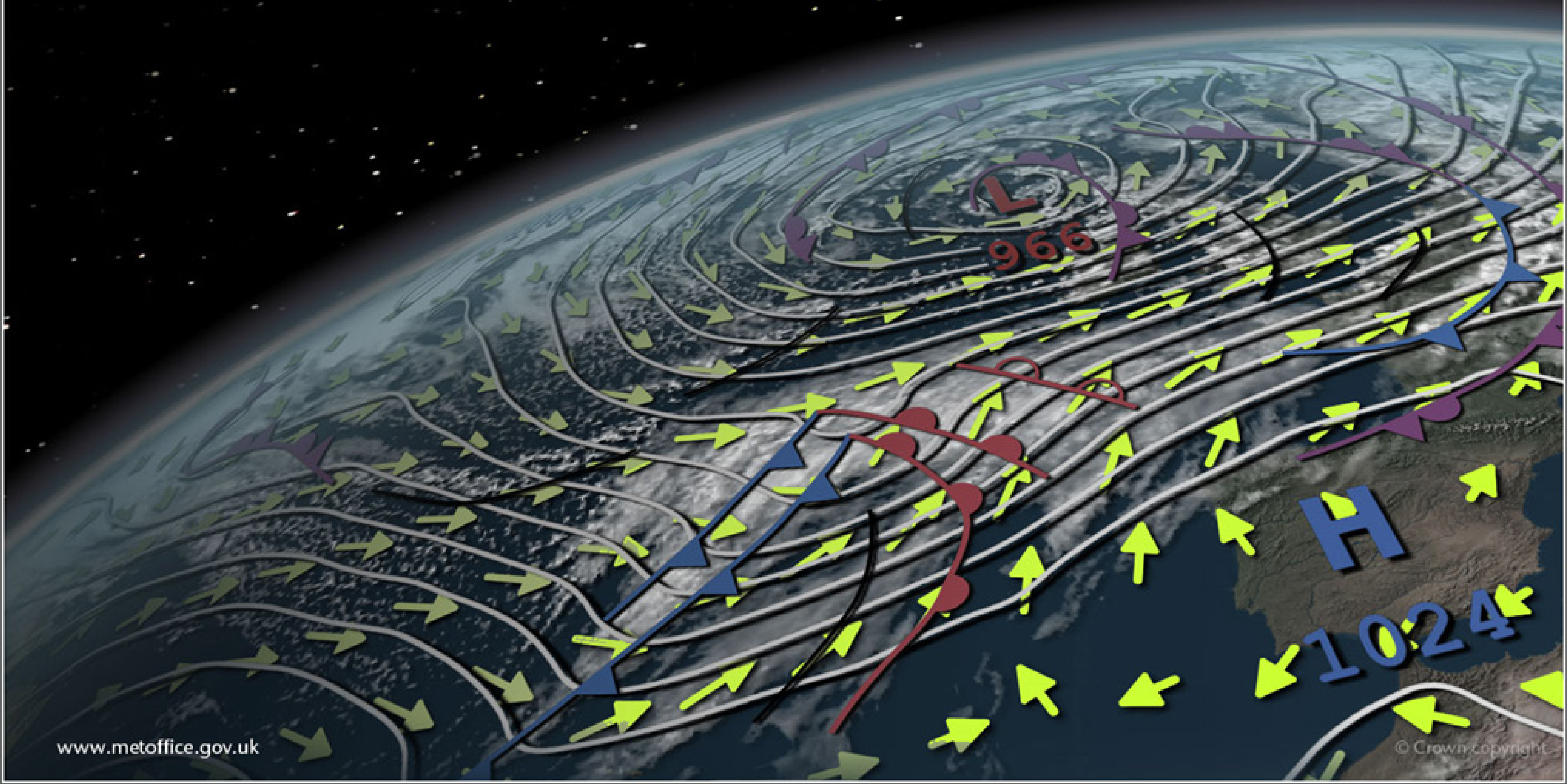
Progress in assimilating radio occultation data at the Met Office

Chris Burrows

16th April 2015



Met Office

Contents

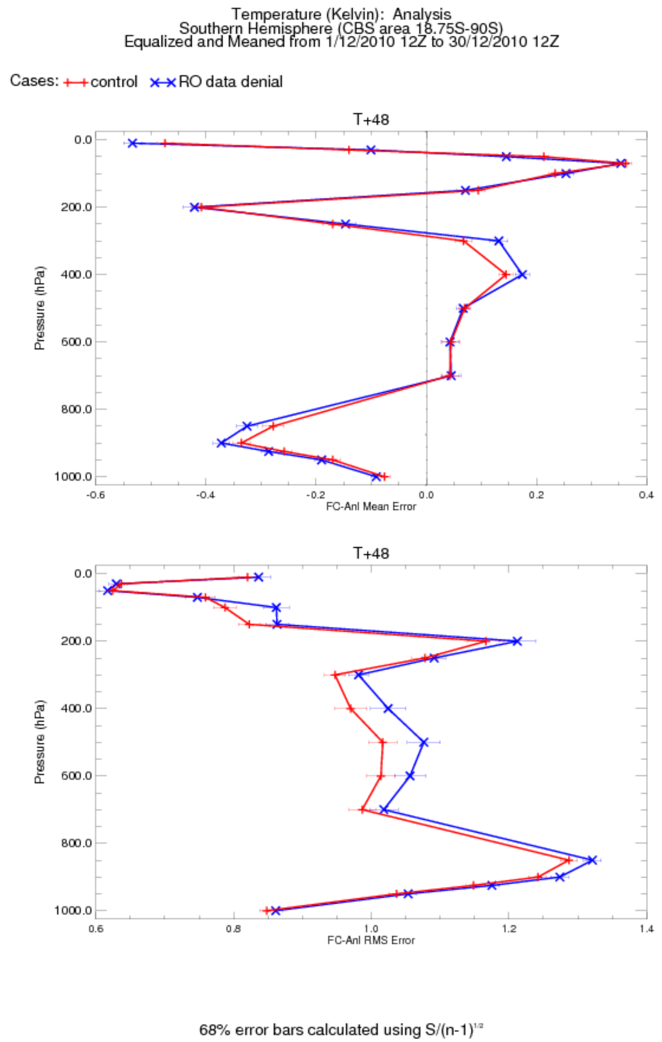
Met Office

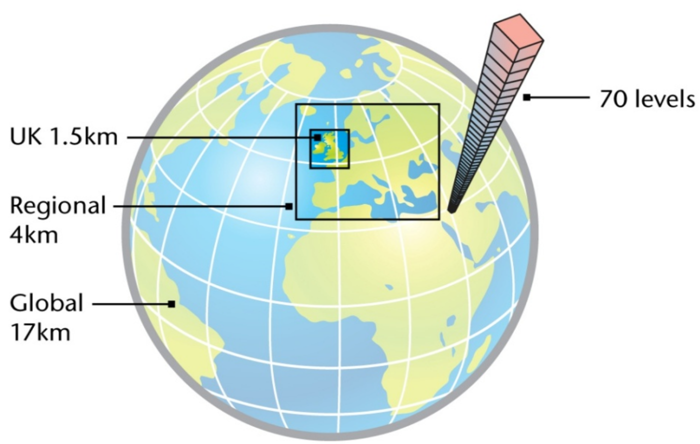
RO assimilation progress

RO assimilation at the Met Office

Met Office

- RO is assimilated in the Met Office global model (N768L70, ~17km). Forecast->7day.
- Window is 6h.
- Assimilation scheme is Hybrid 4D-Var.
- Bending angles are assimilated up to 60km (1D operator).
- Observation errors vary with height and latitude.

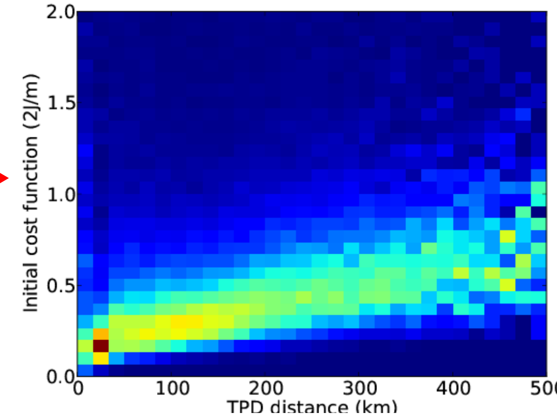




Tangent point drift

In July 2014 this was implemented in the Met Office global model, following other centres' implementation.

Normalised histogram of initial 1D-Var cost function binned by TPD distance.



Aim:

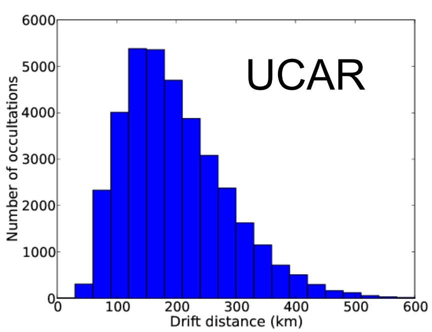
To assimilate bending angles at the most representative locations (drift is typically **100-250km**, see below). Model resolution is ~17km.

Motivation:

The fit of the observations to backgrounds is worse for larger drifts.

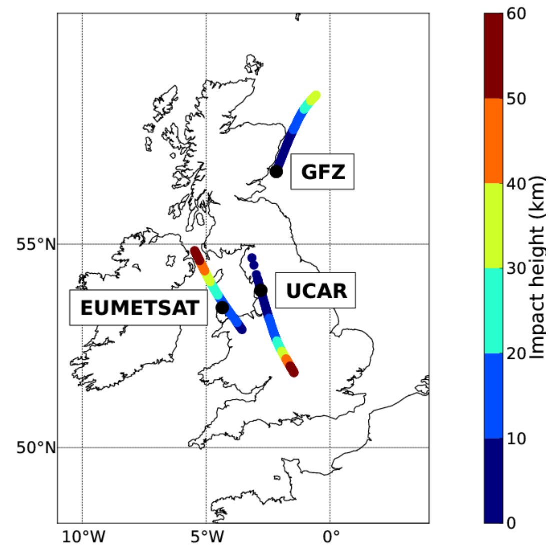
Method:

1) Split the profiles into their constituent observations to extract co-located backgrounds.
2) Reconstruct profiles to perform 1D-Var QC.
3) Broadcast QC information to the individual bending angles.
4) Assimilate the 'good' BAs at the tangent point locations in incremental 4D-Var.



Histogram of TPD distances

Some typical drifts showing 'occultation points' as provided by the three processing centres as black circles.



Tangent point drift – impact

Prior to implementation, the impact was assessed in forecast impact trials.

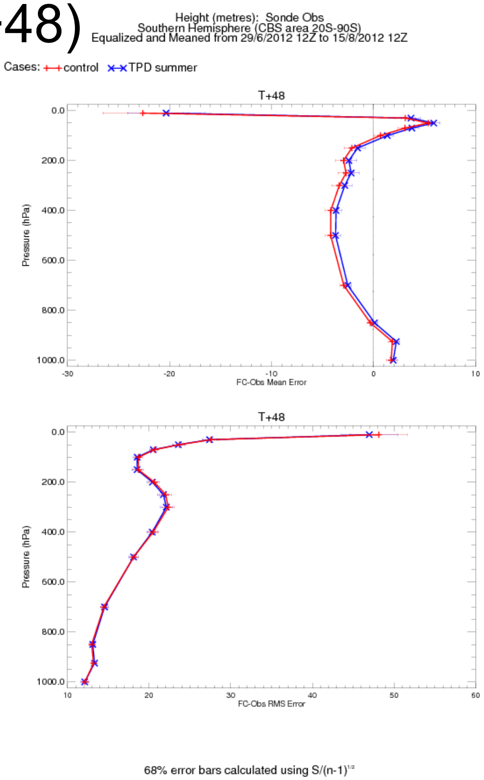
Verdict:

- Generally, the forecast impact was neutral.
- The model bias in geopotential height at all lead times was improved compared to radiosondes (SH in the July 2013 experiment). They increased compared to analyses though
- These experiments were performed with reduced horizontal resolution (N512, N216 in DA), so higher resolution may have provided a stronger improvement.

Sondes (T+48)

GPH bias
(expt. blue)

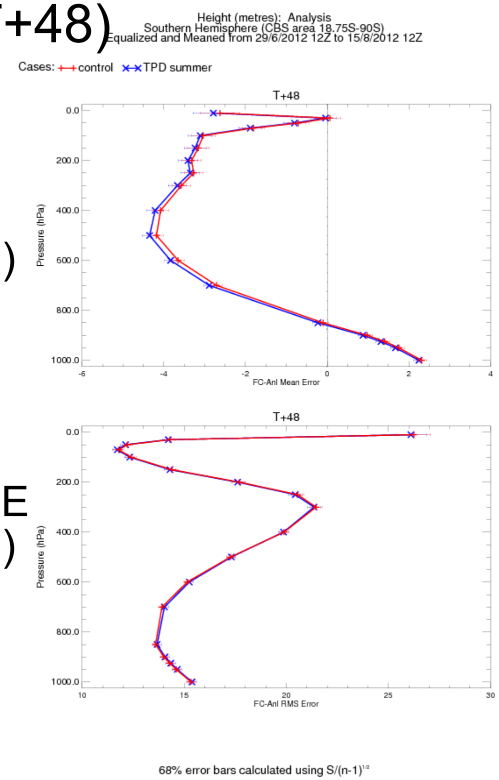
GPH RMSE
(expt. blue)



Analyses (T+48)

GPH bias
(expt. blue)

GPH RMSE
(expt. blue)



Improved bending angle operator

In February 2015 this was implemented in the Met Office global model. See AMT paper in special issue (Burrows, Healy, Culverwell).

Aim:

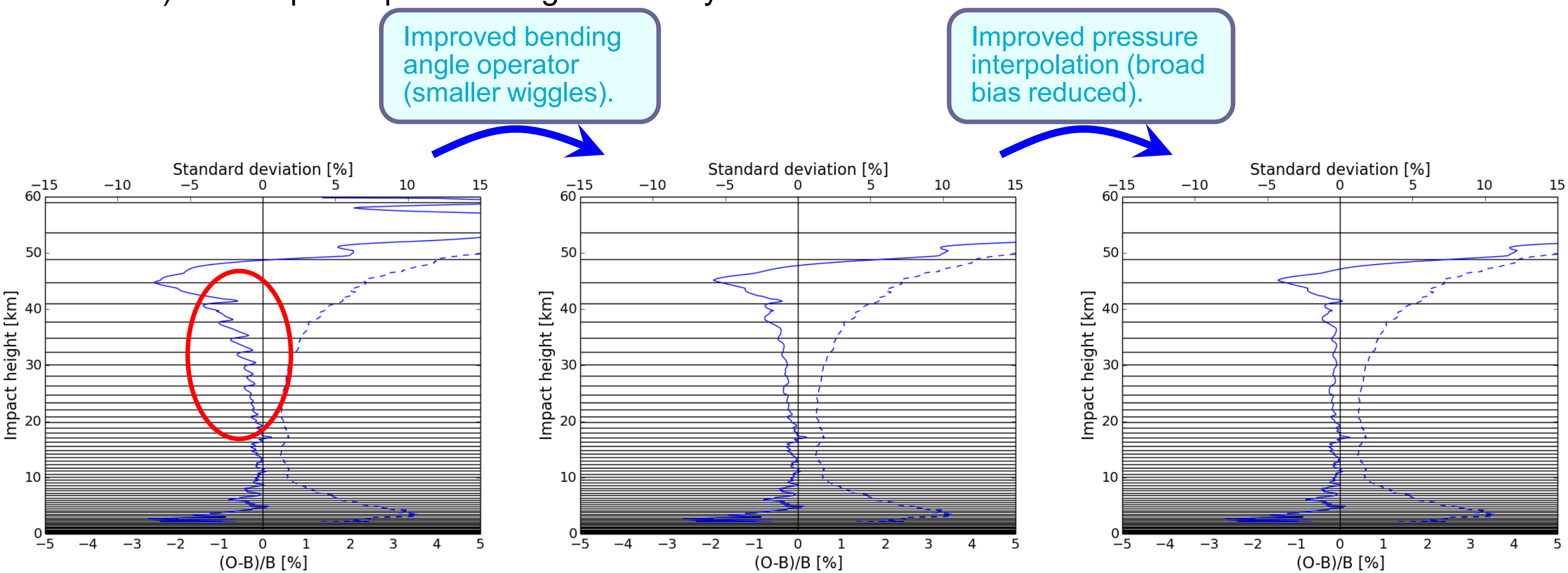
To reduce *systematic forward model biases* in existing operator (see O-B stats below).

Cause of biases:

1) Assumption of constant temperature in layer leads to large bending angle/refractivity biases **between model levels**.
2) Interpolating Exner pressure linearly (standard Met Office method) leads to a **broad bias** that grows with height.

Solutions:

1) Use improved form of N(x), equivalent to assuming linearly varying T within layer.
2) Interpolate pressure logarithmically.



Improved BA operator – impact

Forecast impact was fairly good compared to observations, but poor compared to analyses.

What is made worse?

Upper level quantities (esp. 100hPa and 50hPa winds) compared to analyses.

Why?:

Other observation operators (e.g. for passive sounders) use the old Exner interpolation and are assimilated with fixed bias corrections, so the analyses are dominated by these observations.

What is better:

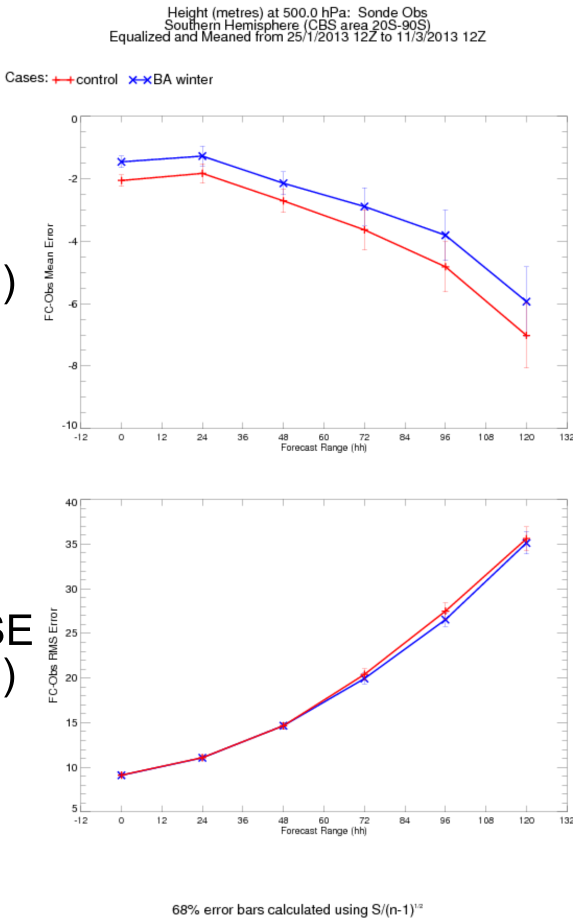
Geopotential height biases are reduced compared to radiosondes.

This should be an important change prior to the planned implementation of VarBC.

Sondes

Z500 bias (expt. blue)

Z500 RMSE (expt. blue)



Verifying VarBC experiment with RO

Currently, we assimilate radiances with fixed bias corrections.

Variational bias correction (VarBC) allows passive radiometers to be bias-corrected in a statistically optimal way as part of the assimilation scheme. RO is **not** corrected, but is an important **anchor measurement**. This scheme is being tested in the Met Office global model (James Cameron, Bill Bell, Stefano Migliorini).

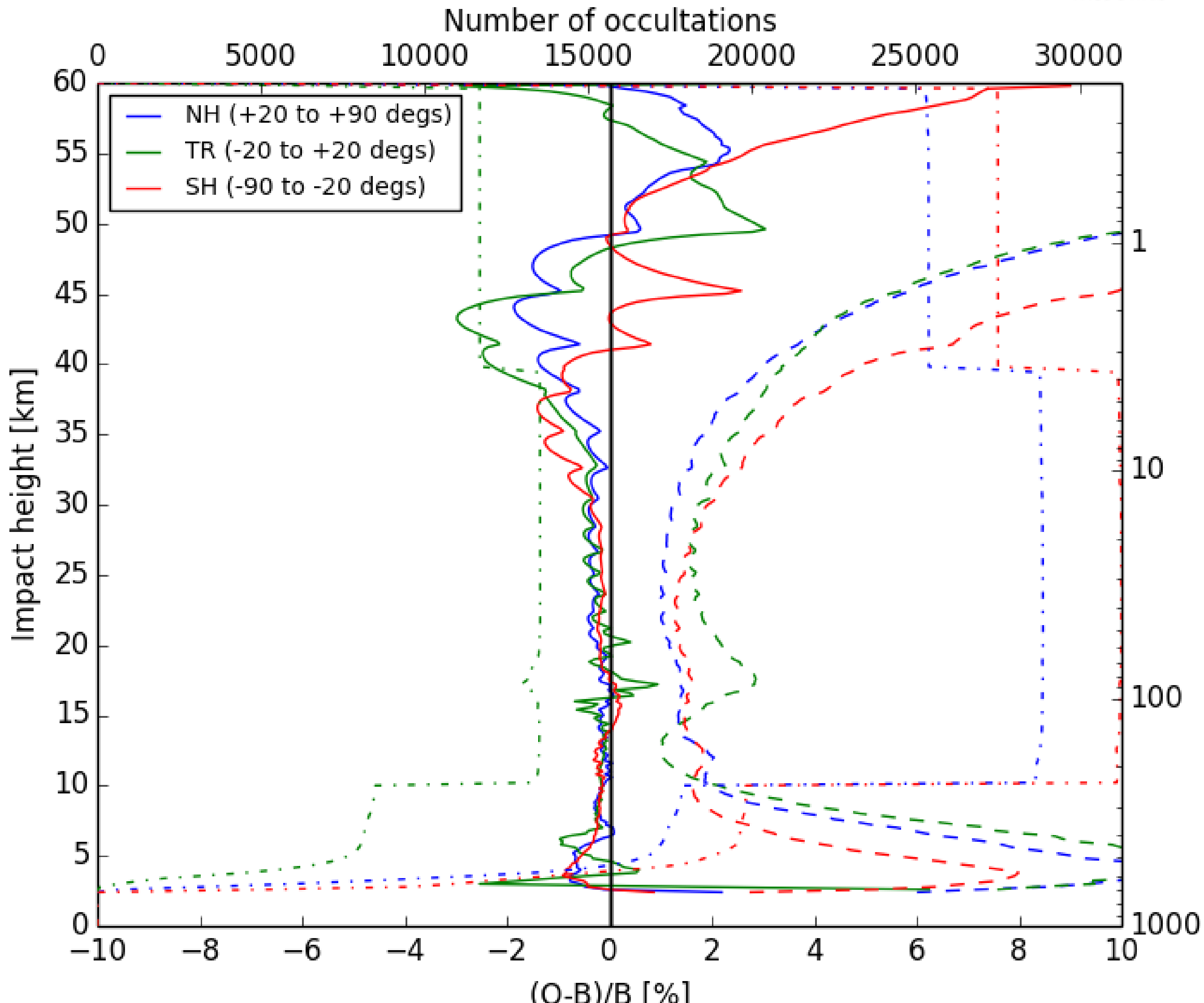
Motivation for using RO to assess the scheme:

Few other non-bias-corrected stratospheric observations.

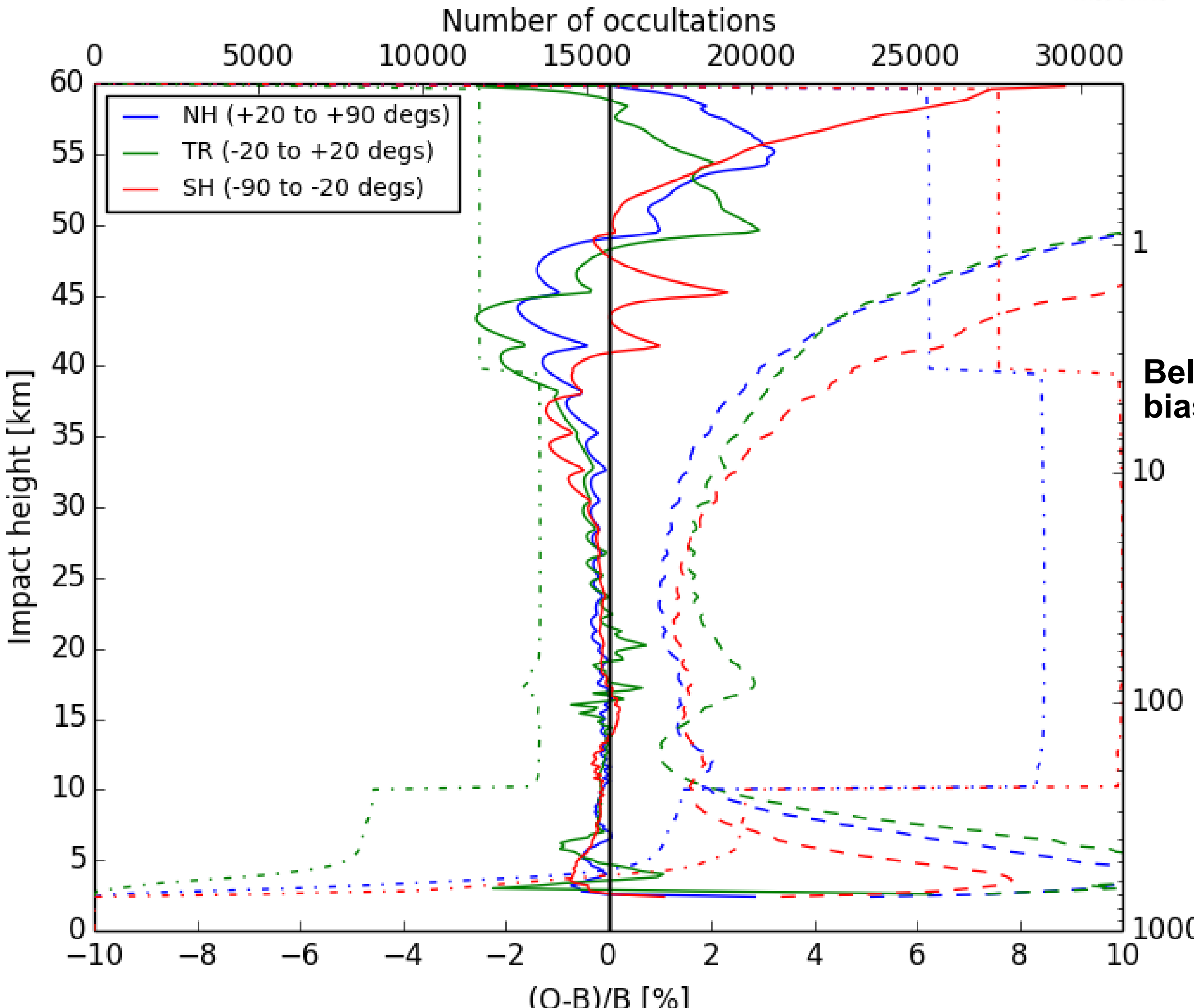
RO has global coverage, unlike radiosondes.

The following plots show O-B statistics for the control and experiment.

O-B stats by hemisphere: **Fixed bias corrections**



O-B stats by hemisphere: **VarBC experiment**



Below 50km the biases reduce.

ROM SAF

Verifying VarBC experiment with RO

In brief, VarBC is generally pulling more closely towards the RO.

VarBC experiments are underway with the **improved bending angle operator** to avoid bias-correcting against a ‘biased’ anchor.

Met Office

New forecast impact verification technique

(work in progress)

Motivation

It **is very hard** to show additional forecast impact from changes to RO assimilation, even when we know we're doing something better scientifically!

Why??

One reason **is the way we perform verification against analyses....**

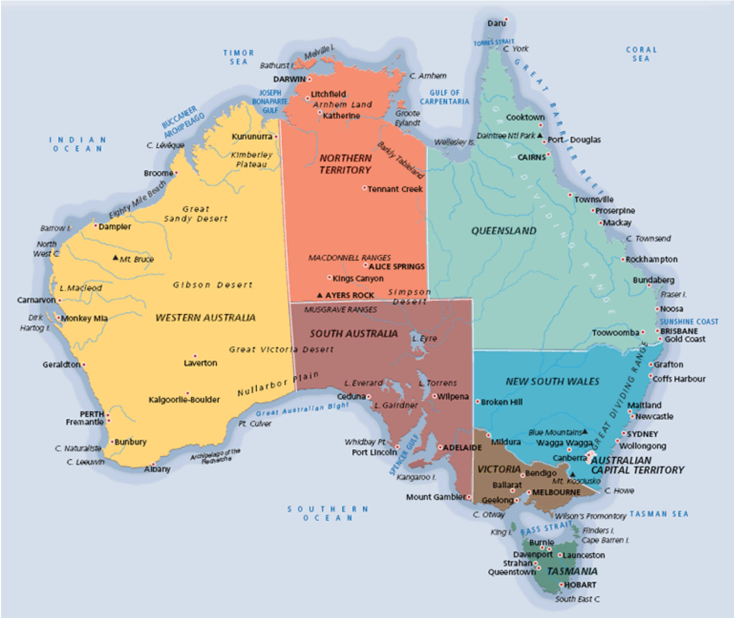
RO observations are localised, so the impact on the analyses/forecasts is also localised BUT, we verify using entire model fields, so the 'noise' easily dominates the signal!

A thought experiment....

Met Office

Thought experiment

Imagine a new observation type that produces **perfect forecasts** (compared to analyses), but *only* over Australia.



Australia covers 1.5% of the Earth's surface, so the RMS error in the global statistics is scaled by approximately

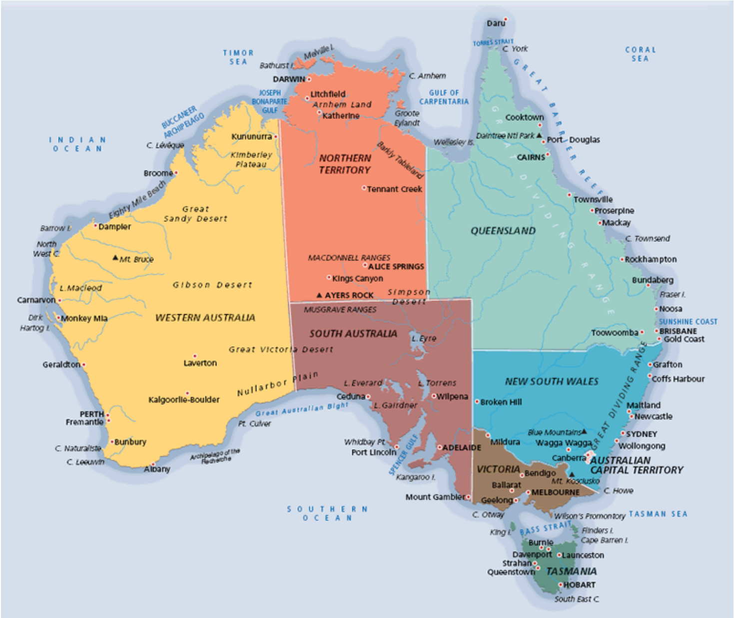
$$\sqrt{1-0.015} = 0.9925$$

So, the apparent RMSE, using standard methods is reduced by only 0.75%.

This is to be expected, but certainly doesn't reflect the impact where it occurs.

Met Office

Thought experiment



Imagine a new observation type that produces **perfect forecasts** (compared to analyses), but *only* over Australia.

Australia covers 1.5% of the Earth's surface, so the RMS error in the global statistics is scaled by approximately

$$\sqrt{1-0.015}=0.9925$$

So, the apparent RMSE, using standard methods is reduced by only 0.75%.

This is to be expected, but certainly doesn't reflect the impact where it occurs.

Solution is simple – only verify where the change affects the forecast.

What about for RO experiments?

Met Office

At T+24, the effect of RO will have drifted from the observation location.

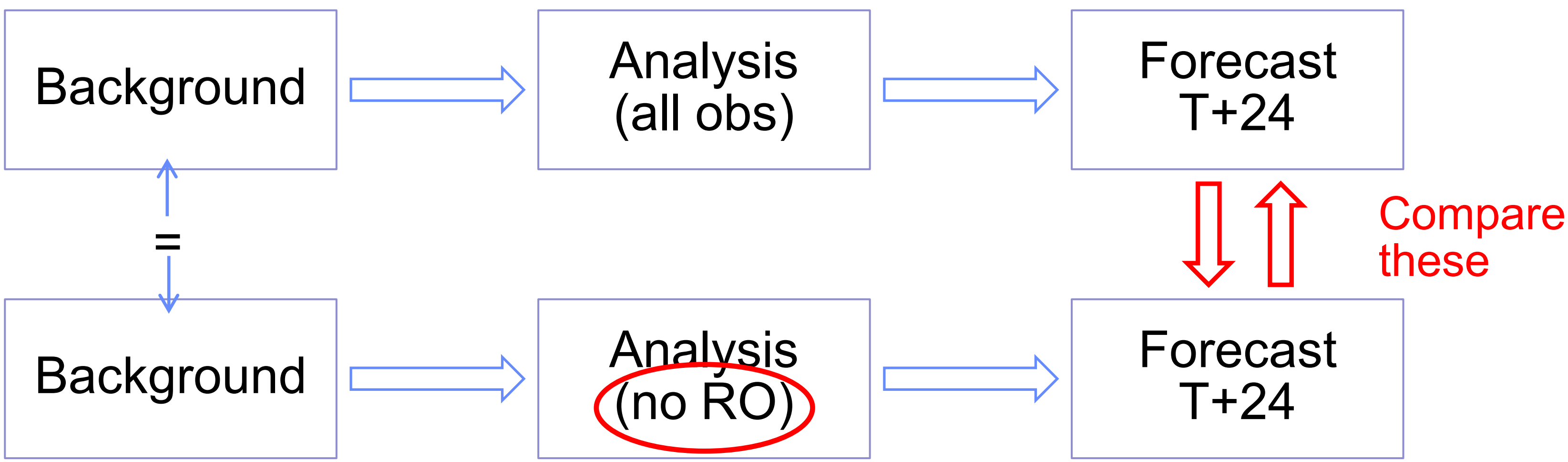
We can find where RO affects the forecast for a given cycle by comparing fields with and without RO being used in the analysis step:

Background → Analysis (all obs) → Forecast T+24

What about for RO experiments?

At T+24, the effect of RO will have drifted from the observation location.

We can find where RO affects the forecast for a given cycle by comparing fields with and without RO being used in the analysis step:



RO has the largest effect on the T+24 forecast at the locations where the two forecast fields differ the most.

Energy norm

The energy norm is a convenient **positive scalar** that uses wind, pressure, temperature etc. and sums the energy terms (kinetic, thermodynamic etc.)

$$\delta e = \delta \mathbf{w}^{\mathrm{T}} \mathbf{C} \, \delta \mathbf{w}$$

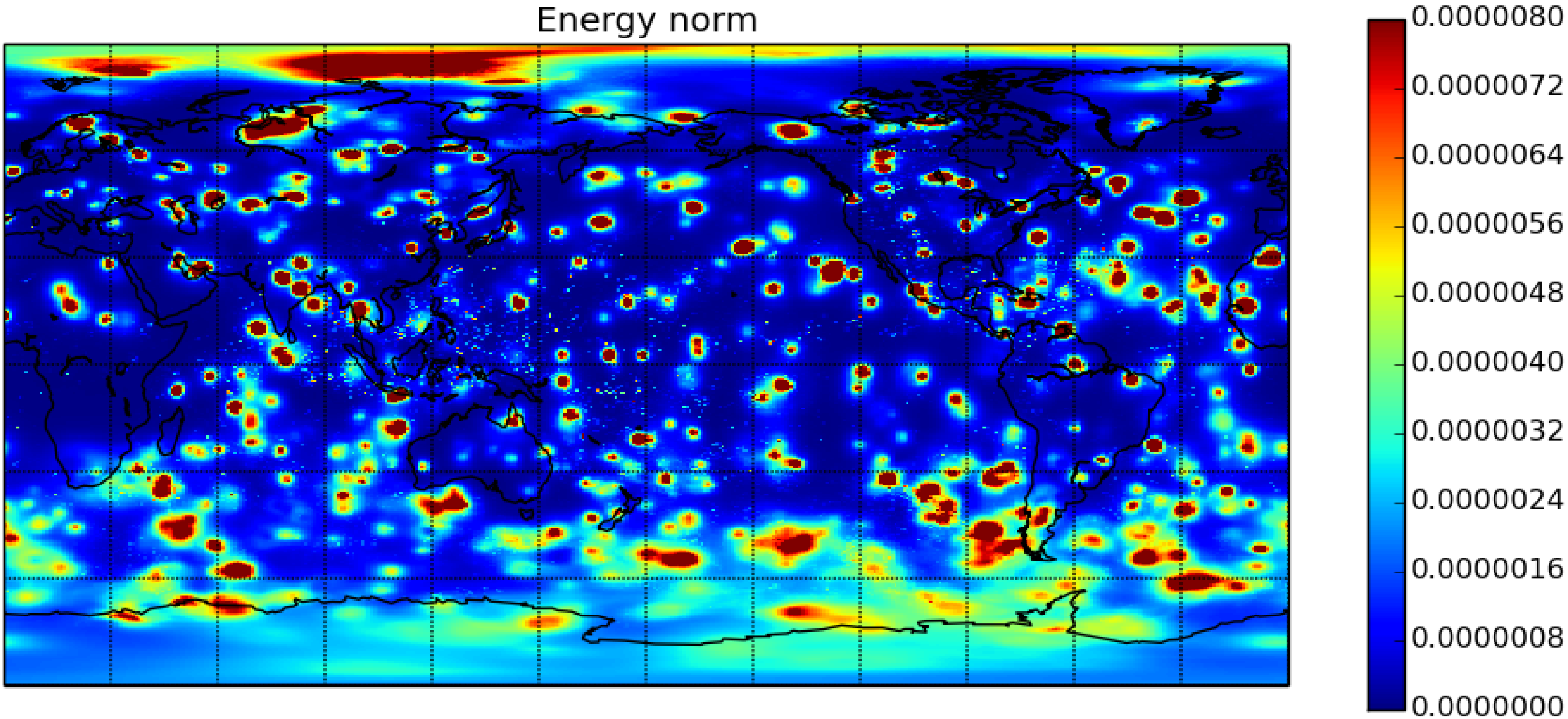
Energy norm

Conversion to energy

Difference between two forecast fields in previous slide

It varies relatively little with height so doesn't favour any particular height range.

This is commonly used for forecast sensitivity to observation (FSO) studies which are adjoint-based.



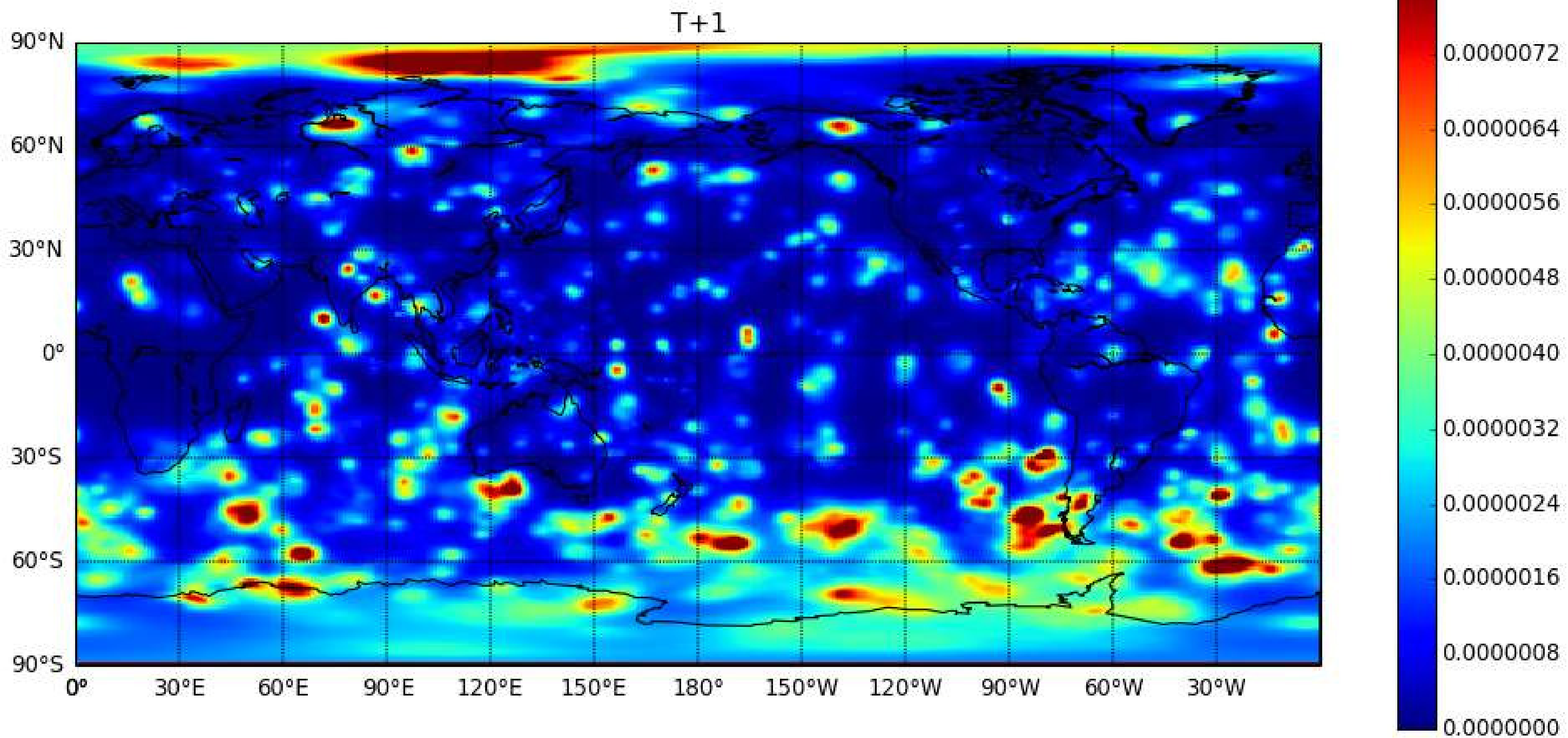
This is the **vertically-integrated** moist energy norm of the difference between a **1hr forecast** with all observations in the analysis and the 1hr forecast with no RO.

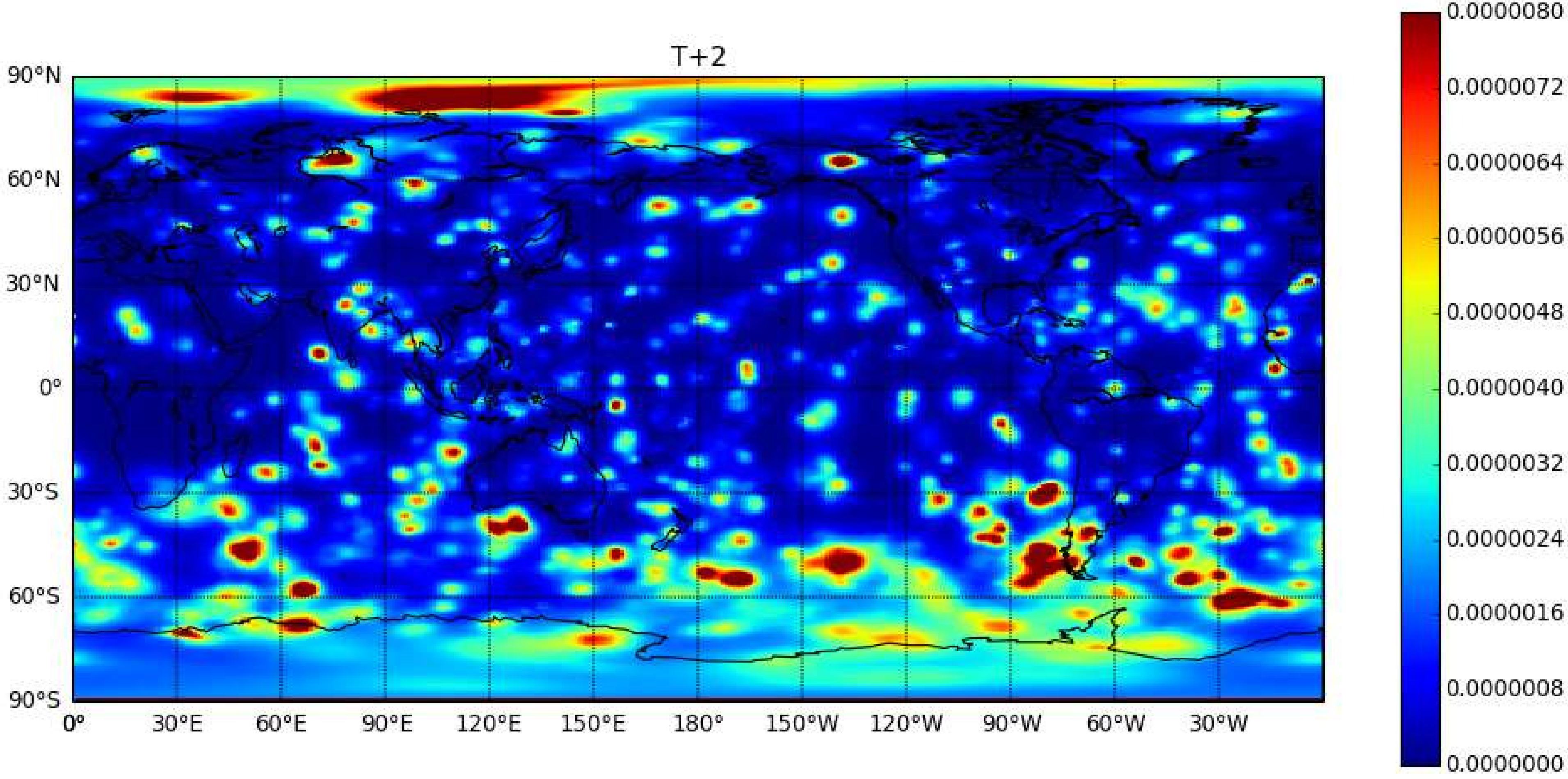
Each blob corresponds to a radio occultation observation.

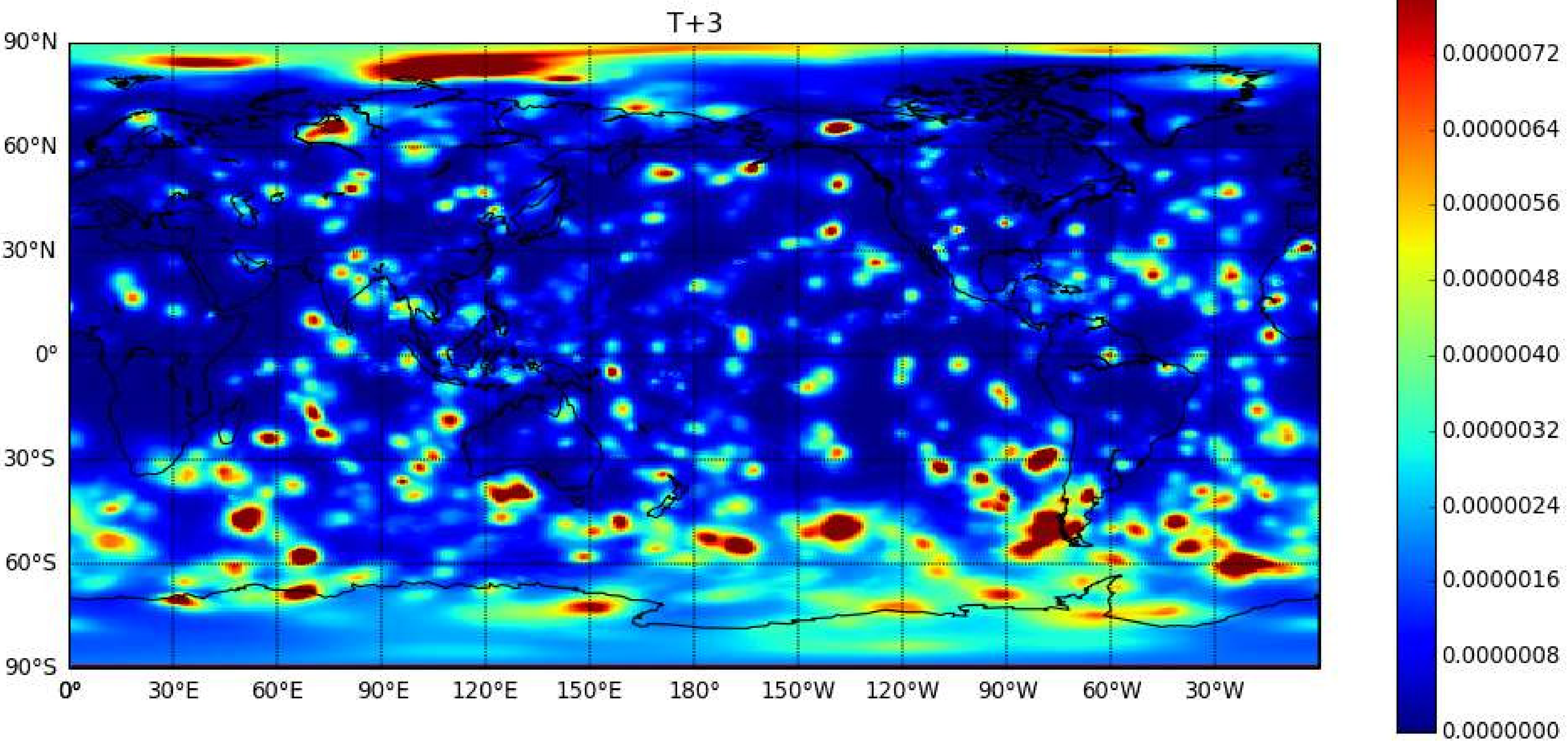
This is a **quadratic measure** – it gives magnitudes only, no indication of whether the impact is good or bad, i.e. it is impartial.

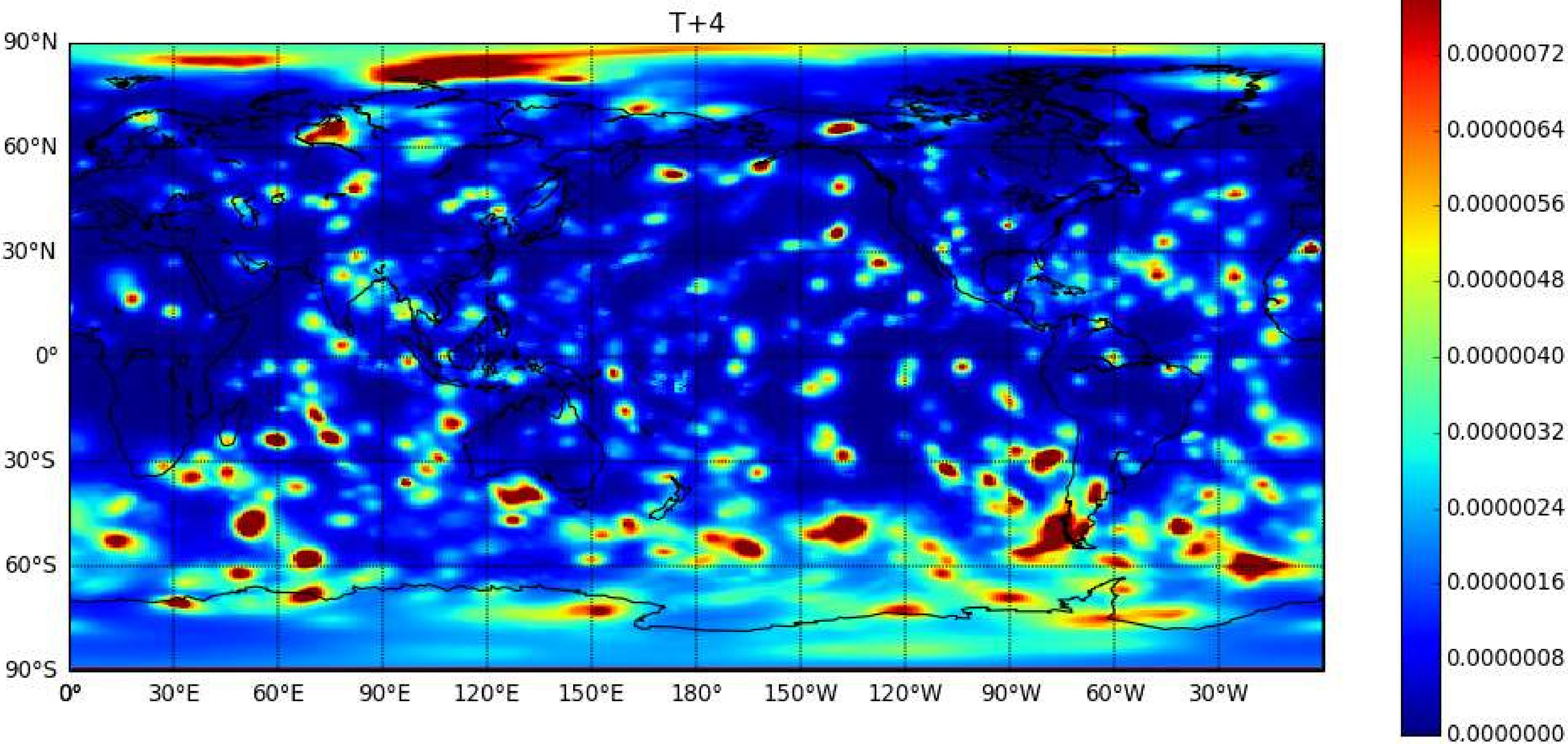
Note **speckles** – presumably parameterisation artifacts. Later figures are smoothed.

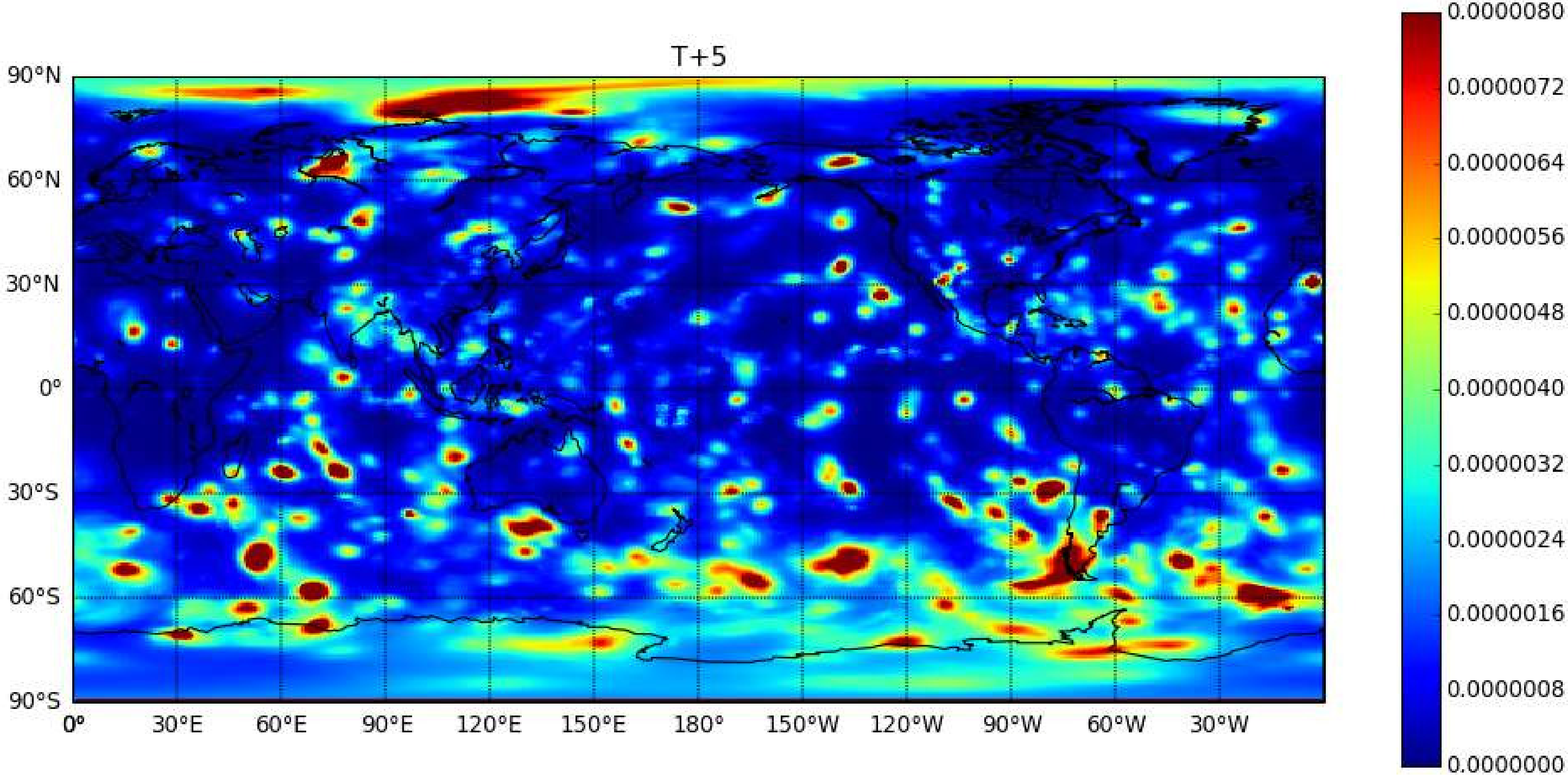
What about longer forecast times?

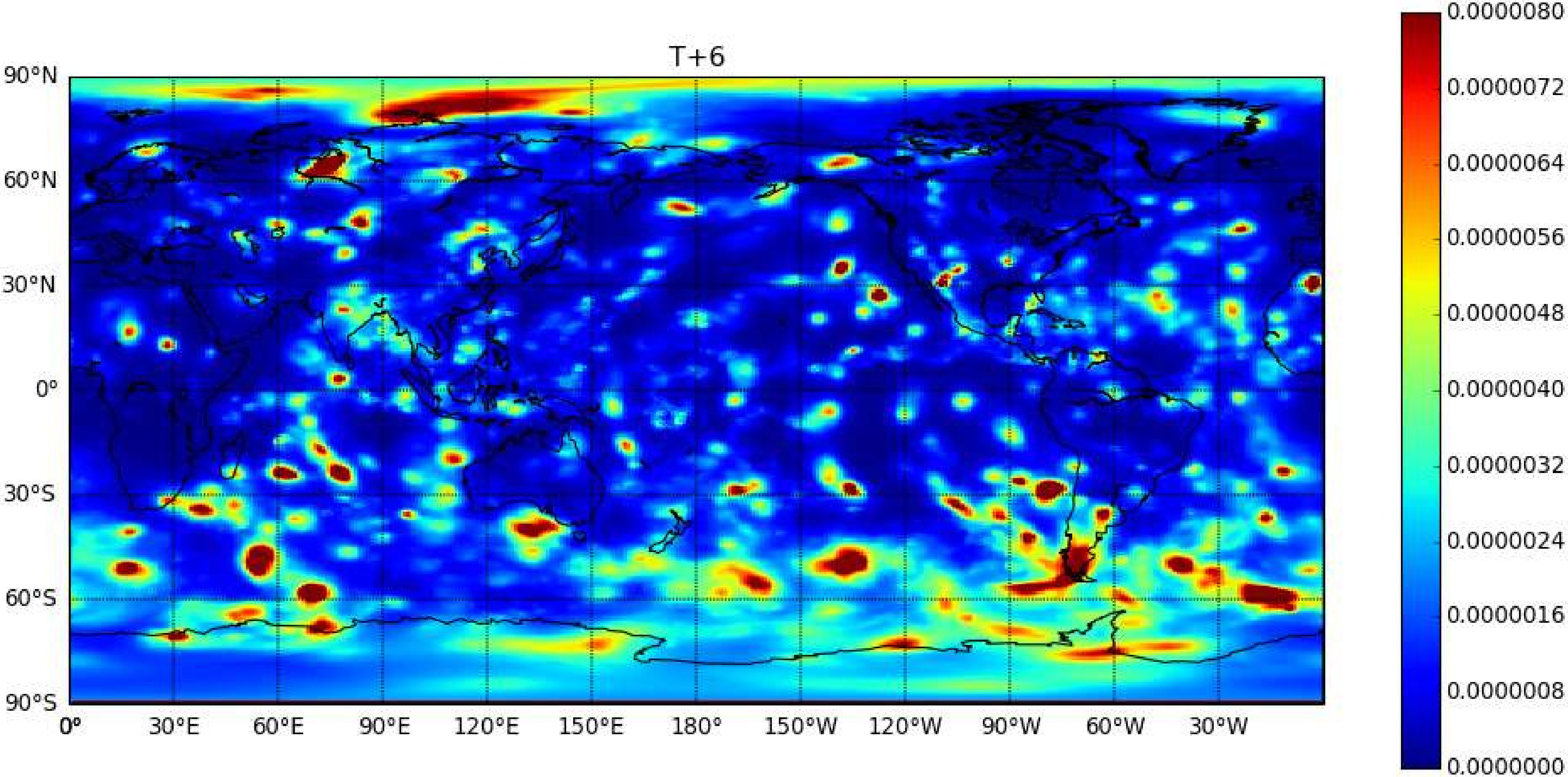

T+1
90°N
60°N
30°N
0°
30°S
60°S
90°S
0°
30°E
60°E
90°E
120°E
150°E
180°
150°W
120°W
90°W
60°W
30°W
0.0000080
0.0000072
0.0000064
0.0000056
0.0000048
0.0000040
0.0000032
0.0000024
0.0000016
0.0000008
0.0000000


T+2
90°N
60°N
30°N
0°
30°S
60°S
90°S
0°
30°E
60°E
90°E
120°E
150°E
180°
150°W
120°W
90°W
60°W
30°W
0.0000080
0.0000072
0.0000064
0.0000056
0.0000048
0.0000040
0.0000032
0.0000024
0.0000016
0.0000008
0.0000000

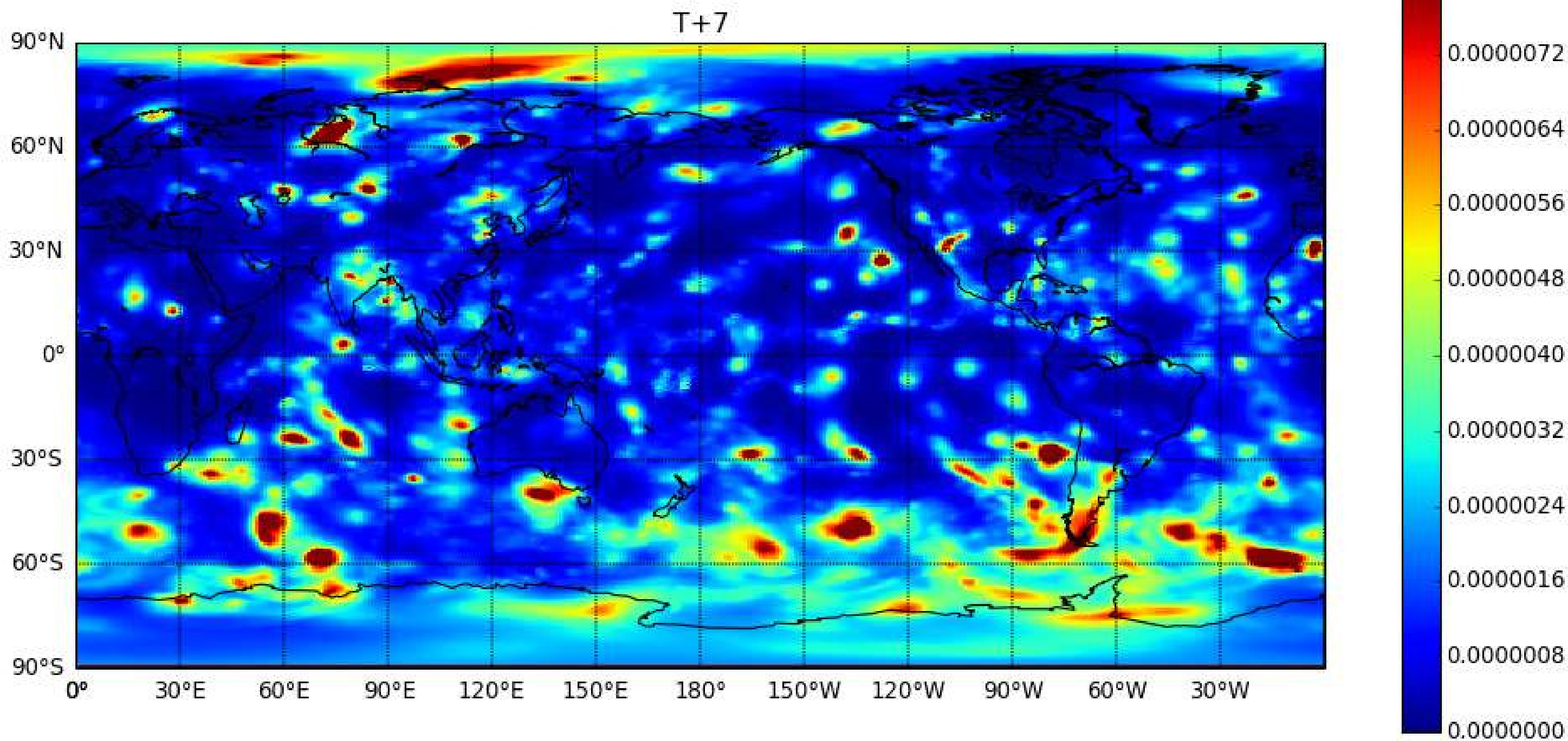

T+3
90°N
60°N
30°N
0°
30°S
60°S
90°S
0°
30°E
60°E
90°E
120°E
150°E
180°
150°W
120°W
90°W
60°W
30°W
0.0000080
0.0000072
0.0000064
0.0000056
0.0000048
0.0000040
0.0000032
0.0000024
0.0000016
0.0000008
0.0000000


T+4
90°N
60°N
30°N
0°
30°S
60°S
90°S
0°
30°E
60°E
90°E
120°E
150°E
180°
150°W
120°W
90°W
60°W
30°W
0.0000080
0.0000072
0.0000064
0.0000056
0.0000048
0.0000040
0.0000032
0.0000024
0.0000016
0.0000008
0.0000000

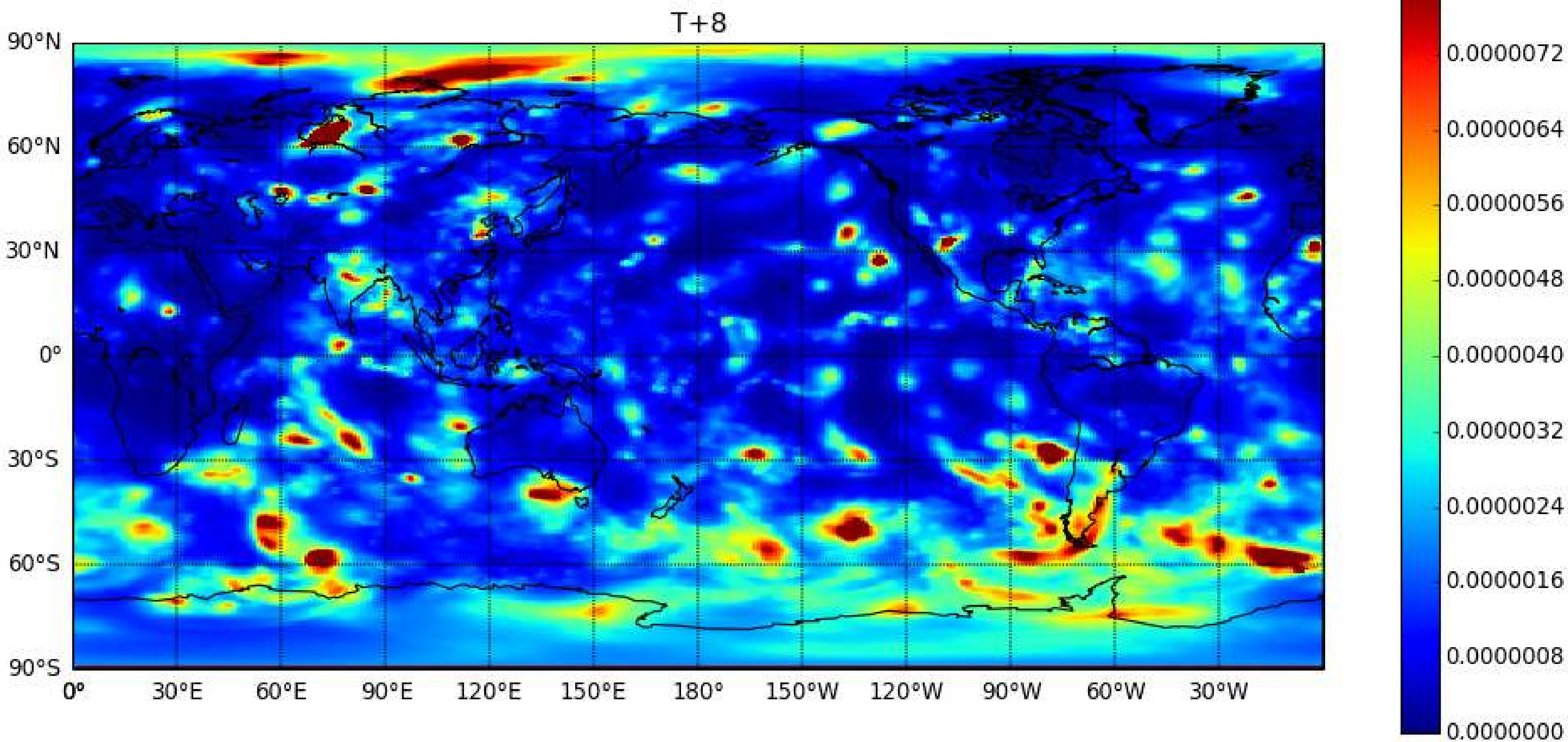

T+5
90°N
60°N
30°N
0°
30°S
60°S
90°S
0°
30°E
60°E
90°E
120°E
150°E
180°
150°W
120°W
90°W
60°W
30°W
0.0000080
0.0000072
0.0000064
0.0000056
0.0000048
0.0000040
0.0000032
0.0000024
0.0000016
0.0000008
0.0000000



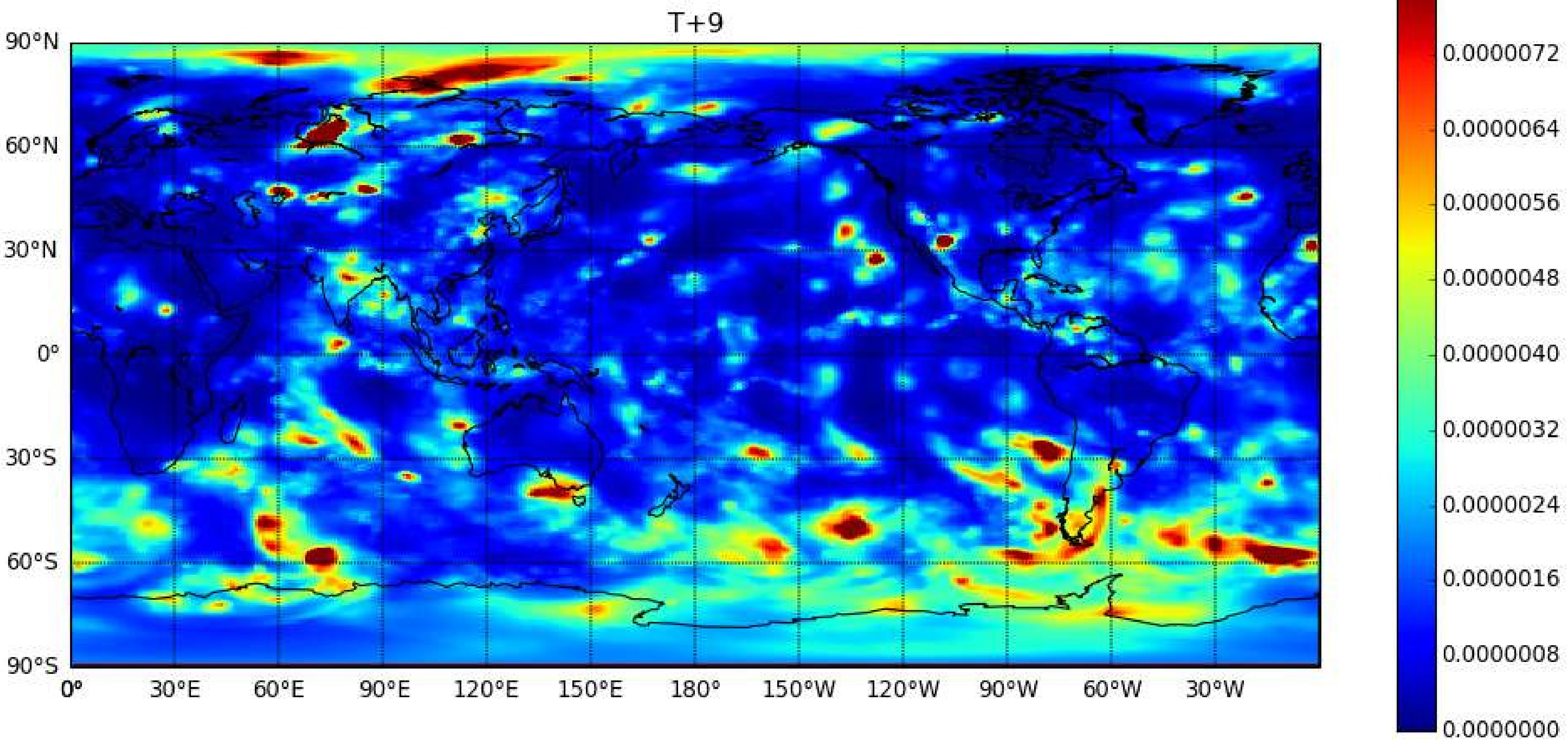
T+6
90°N
60°N
30°N
0°
30°S
60°S
90°S
0°
30°E
60°E
90°E
120°E
150°E
180°
150°W
120°W
90°W
60°W
30°W
0.0000080
0.0000072
0.0000064
0.0000056
0.0000048
0.0000040
0.0000032
0.0000024
0.0000016
0.0000008
0.0000000

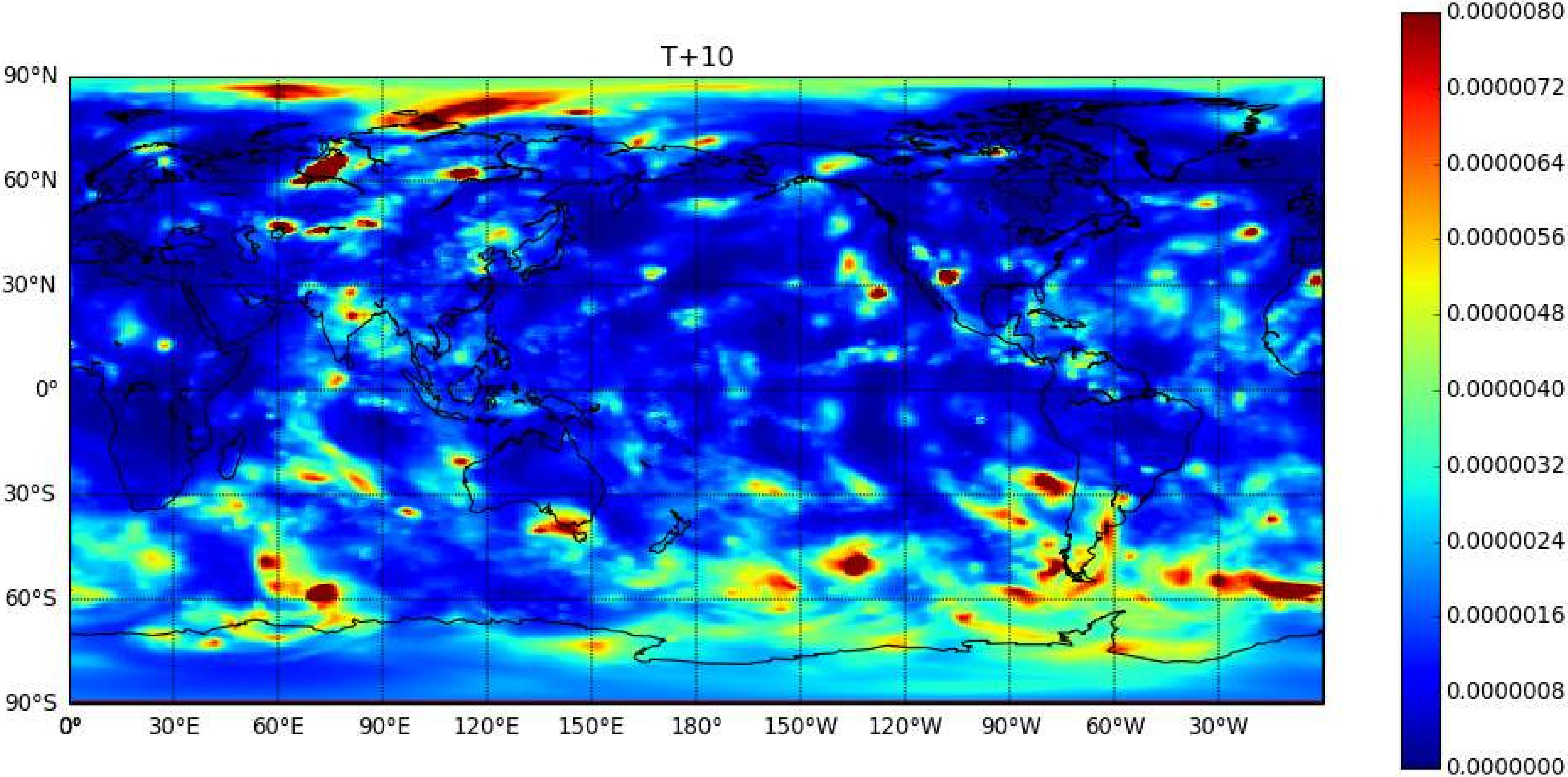


T+7
90°N
60°N
30°N
0°
30°S
60°S
90°S
0°
30°E
60°E
90°E
120°E
150°E
180°
150°W
120°W
90°W
60°W
30°W
0.0000080
0.0000072
0.0000064
0.0000056
0.0000048
0.0000040
0.0000032
0.0000024
0.0000016
0.0000008
0.0000000

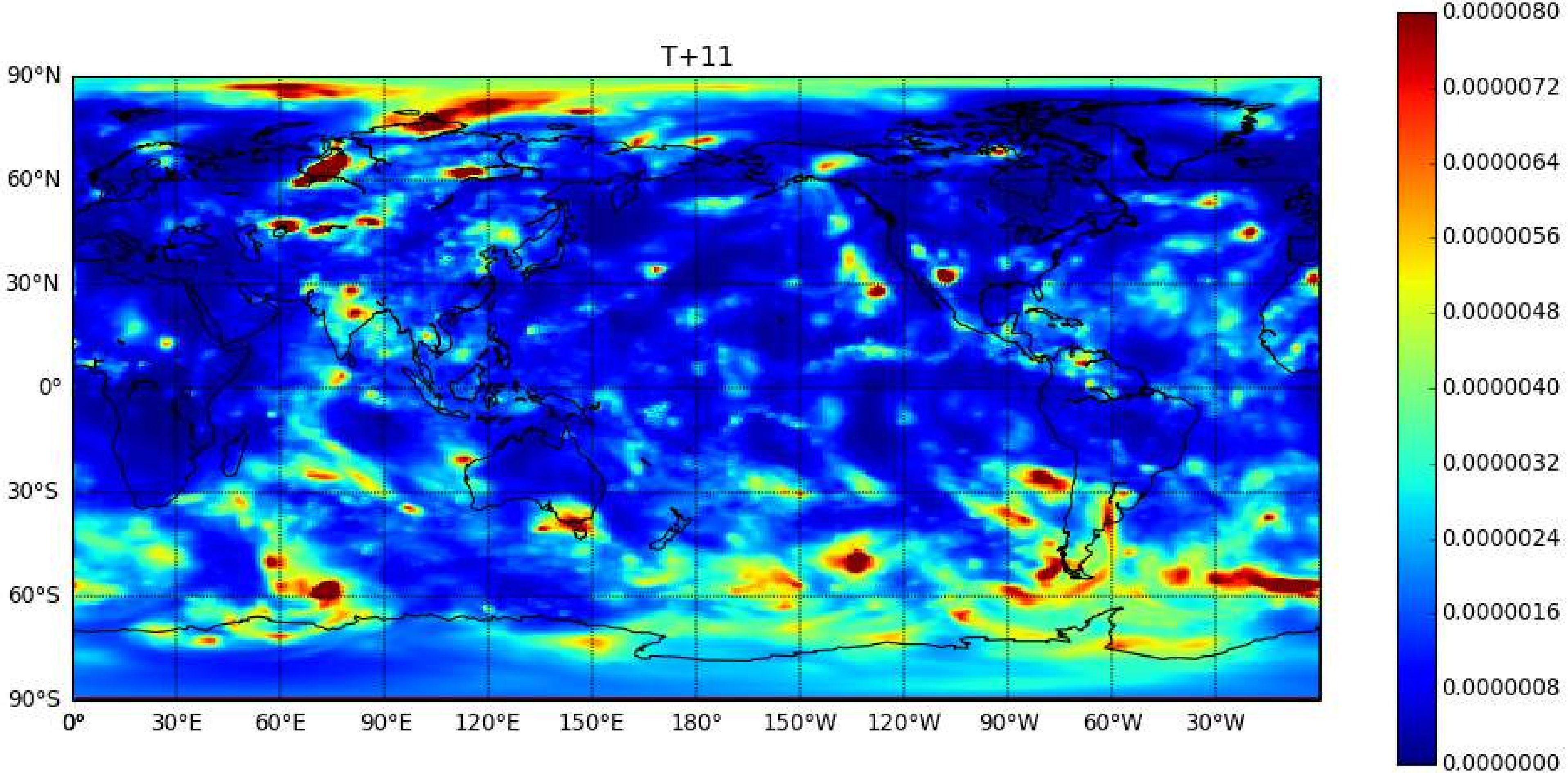


T+8
90°N
60°N
30°N
0°
30°S
60°S
90°S
0°
30°E
60°E
90°E
120°E
150°E
180°
150°W
120°W
90°W
60°W
30°W
0.0000080
0.0000072
0.0000064
0.0000056
0.0000048
0.0000040
0.0000032
0.0000024
0.0000016
0.0000008
0.0000000

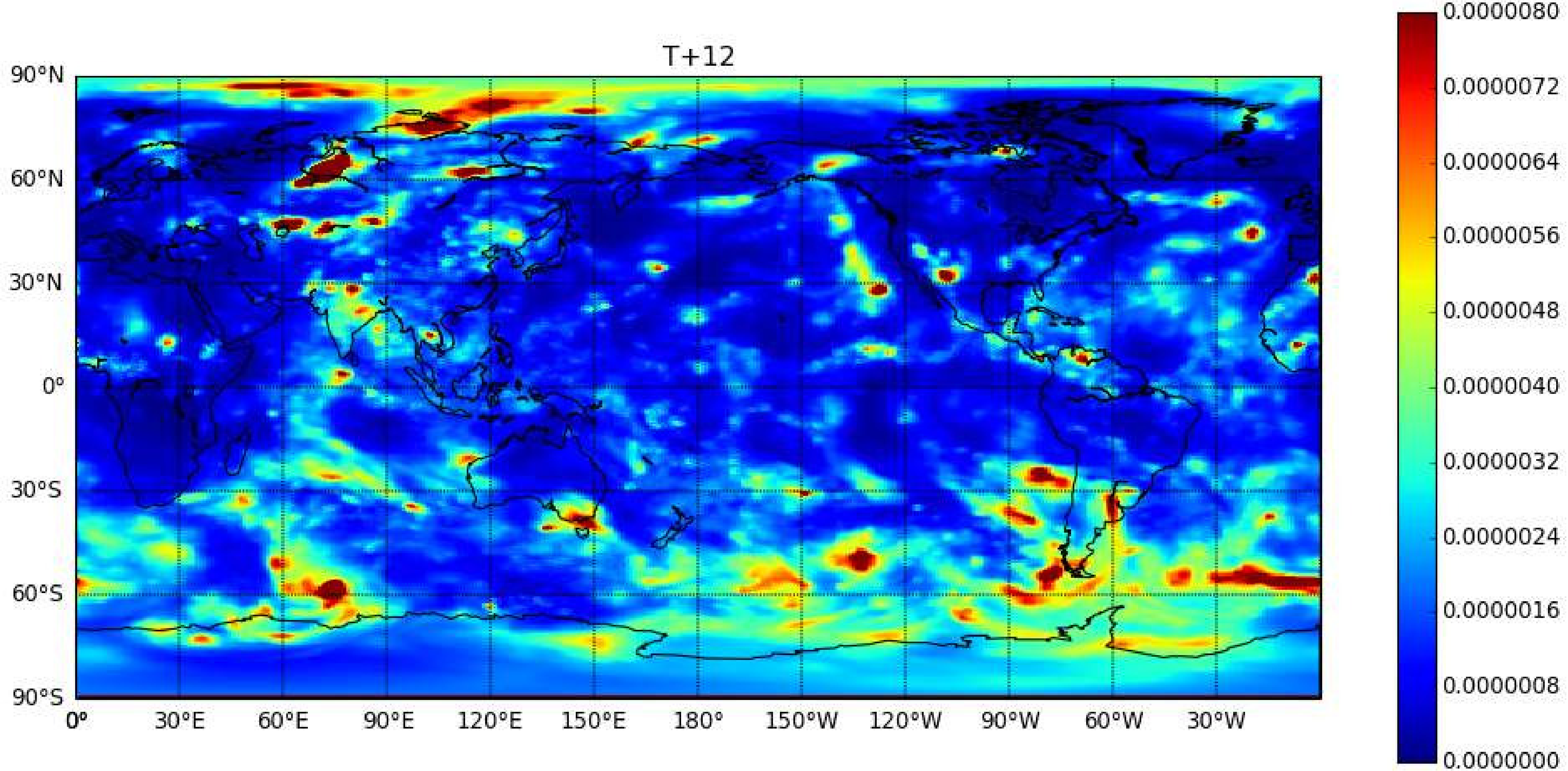

T+9
90°N
60°N
30°N
0°
30°S
60°S
90°S
0°
30°E
60°E
90°E
120°E
150°E
180°
150°W
120°W
90°W
60°W
30°W
0.0000080
0.0000072
0.0000064
0.0000056
0.0000048
0.0000040
0.0000032
0.0000024
0.0000016
0.0000008
0.0000000

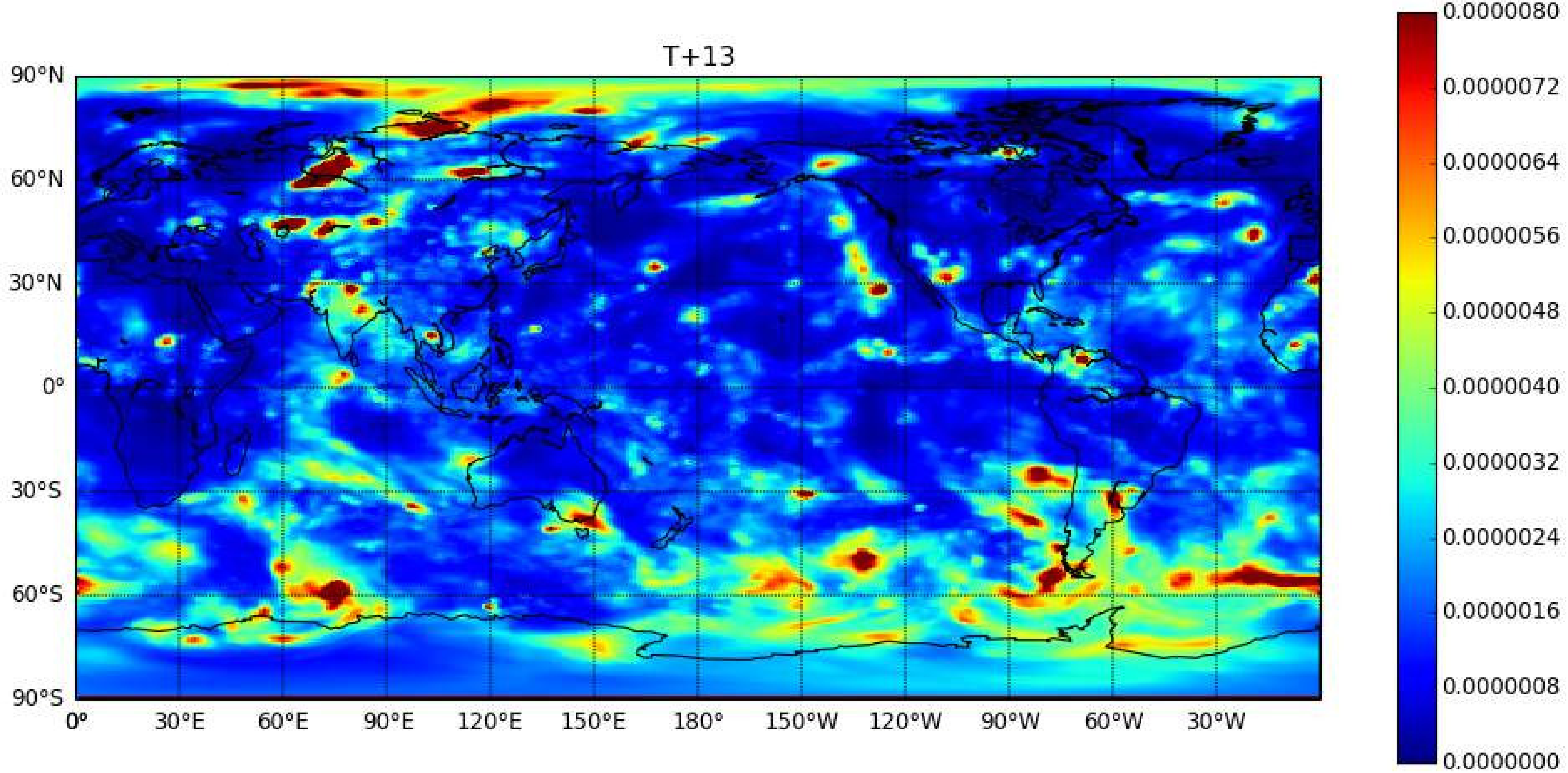


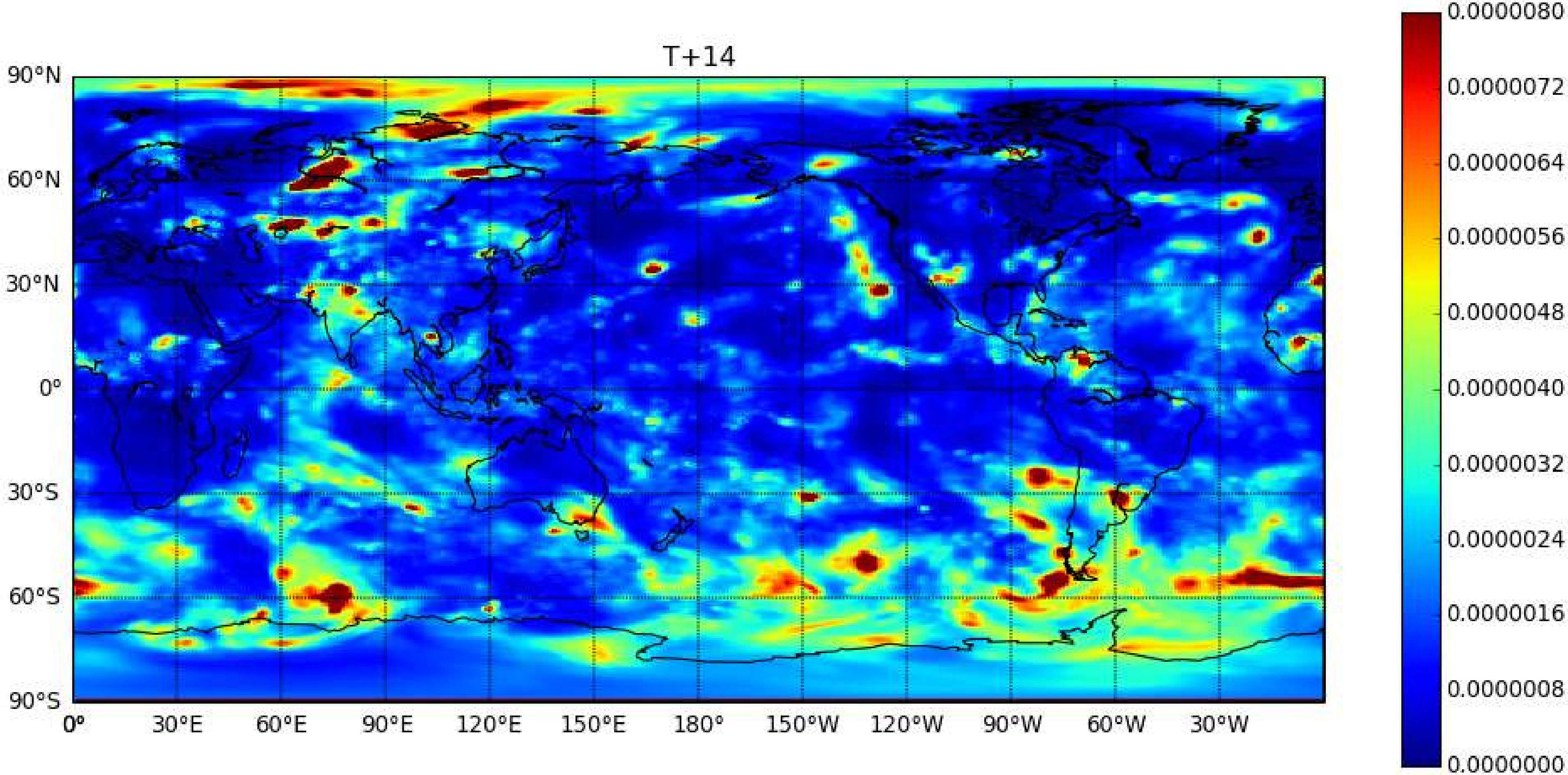
T+10
90°N
60°N
30°N
0°
30°S
60°S
90°S
0°
30°E
60°E
90°E
120°E
150°E
180°
150°W
120°W
90°W
60°W
30°W
0.0000080
0.0000072
0.0000064
0.0000056
0.0000048
0.0000040
0.0000032
0.0000024
0.0000016
0.0000008
0.0000000

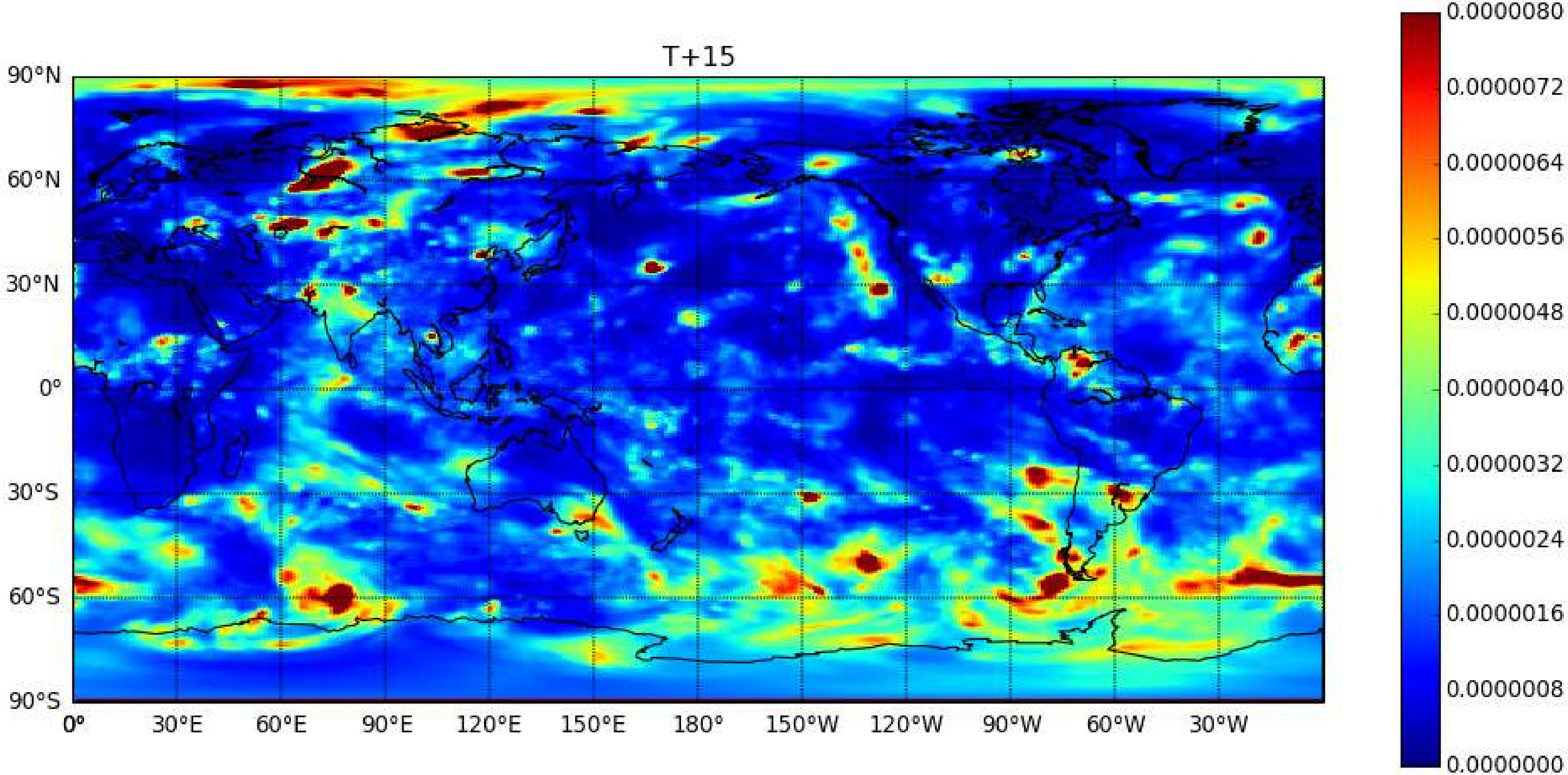


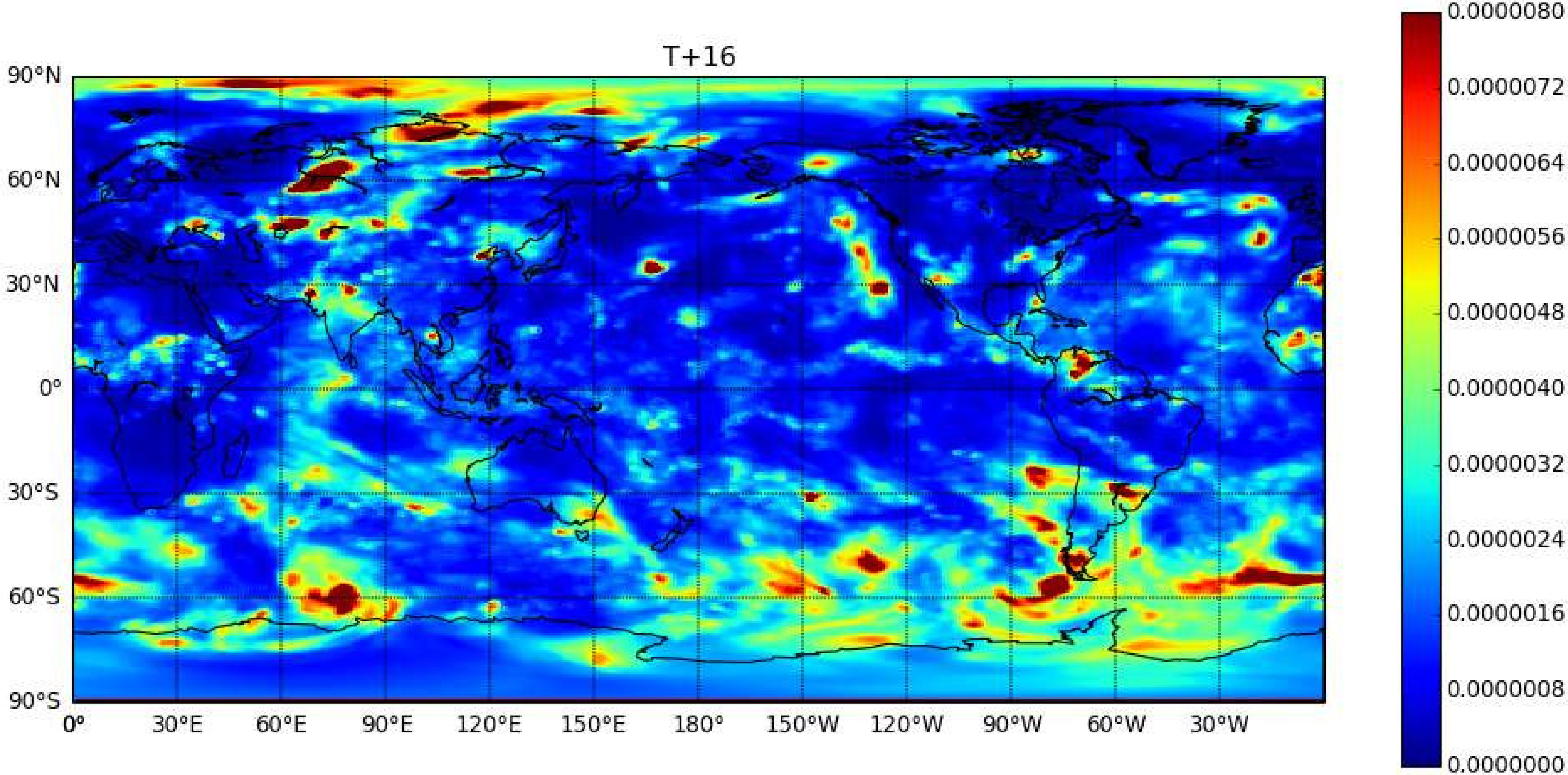
T+11
90°N
60°N
30°N
0°
30°S
60°S
90°S
0°
30°E
60°E
90°E
120°E
150°E
180°
150°W
120°W
90°W
60°W
30°W
0.0000080
0.0000072
0.0000064
0.0000056
0.0000048
0.0000040
0.0000032
0.0000024
0.0000016
0.0000008
0.0000000

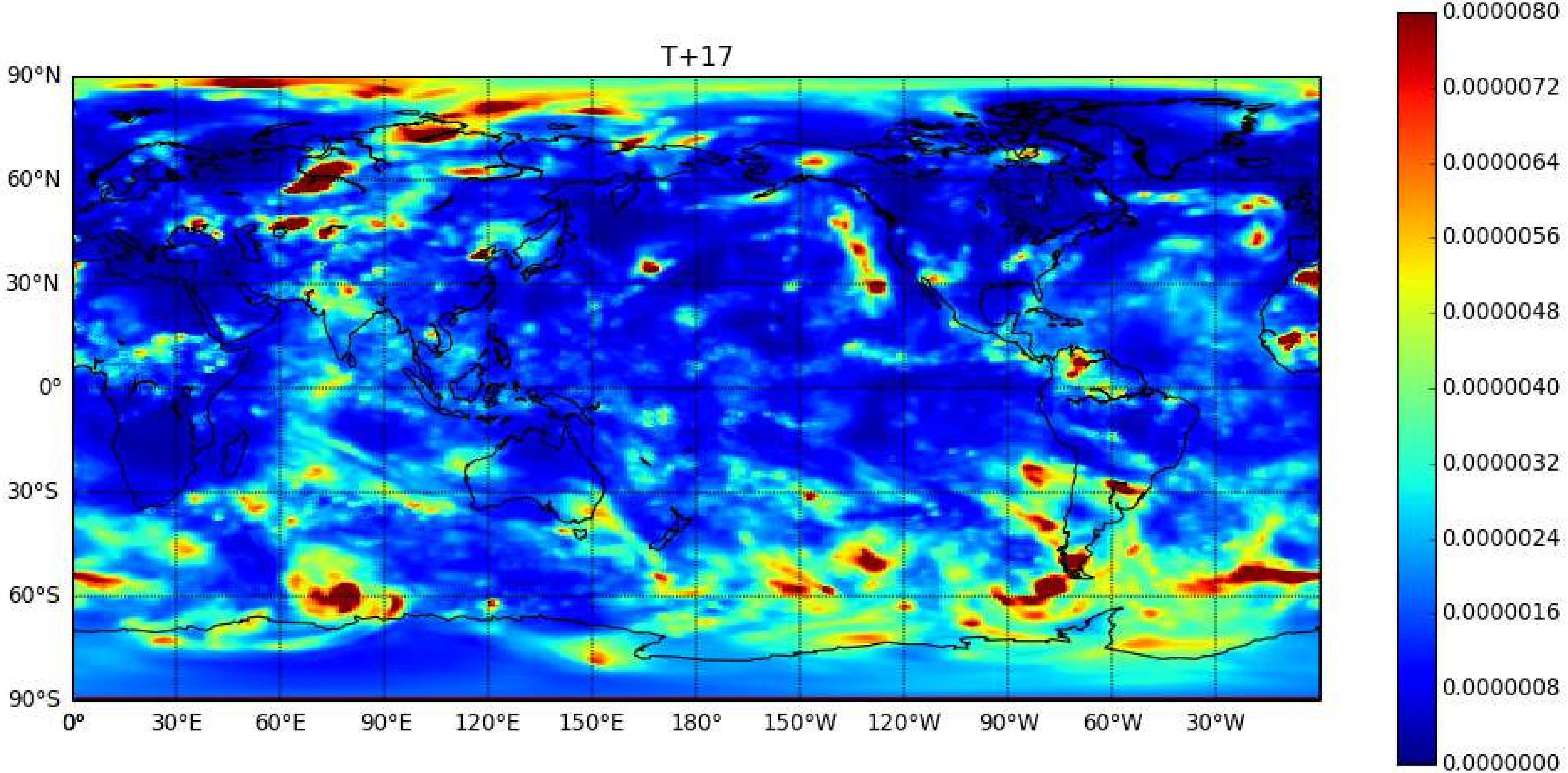

T+12
90°N
60°N
30°N
0°
30°S
60°S
90°S
0°
30°E
60°E
90°E
120°E
150°E
180°
150°W
120°W
90°W
60°W
30°W
0.0000080
0.0000072
0.0000064
0.0000056
0.0000048
0.0000040
0.0000032
0.0000024
0.0000016
0.0000008
0.0000000


T+13
90°N
60°N
30°N
0°
30°S
60°S
90°S
0°
30°E
60°E
90°E
120°E
150°E
180°
150°W
120°W
90°W
60°W
30°W
0.0000080
0.0000072
0.0000064
0.0000056
0.0000048
0.0000040
0.0000032
0.0000024
0.0000016
0.0000008
0.0000000

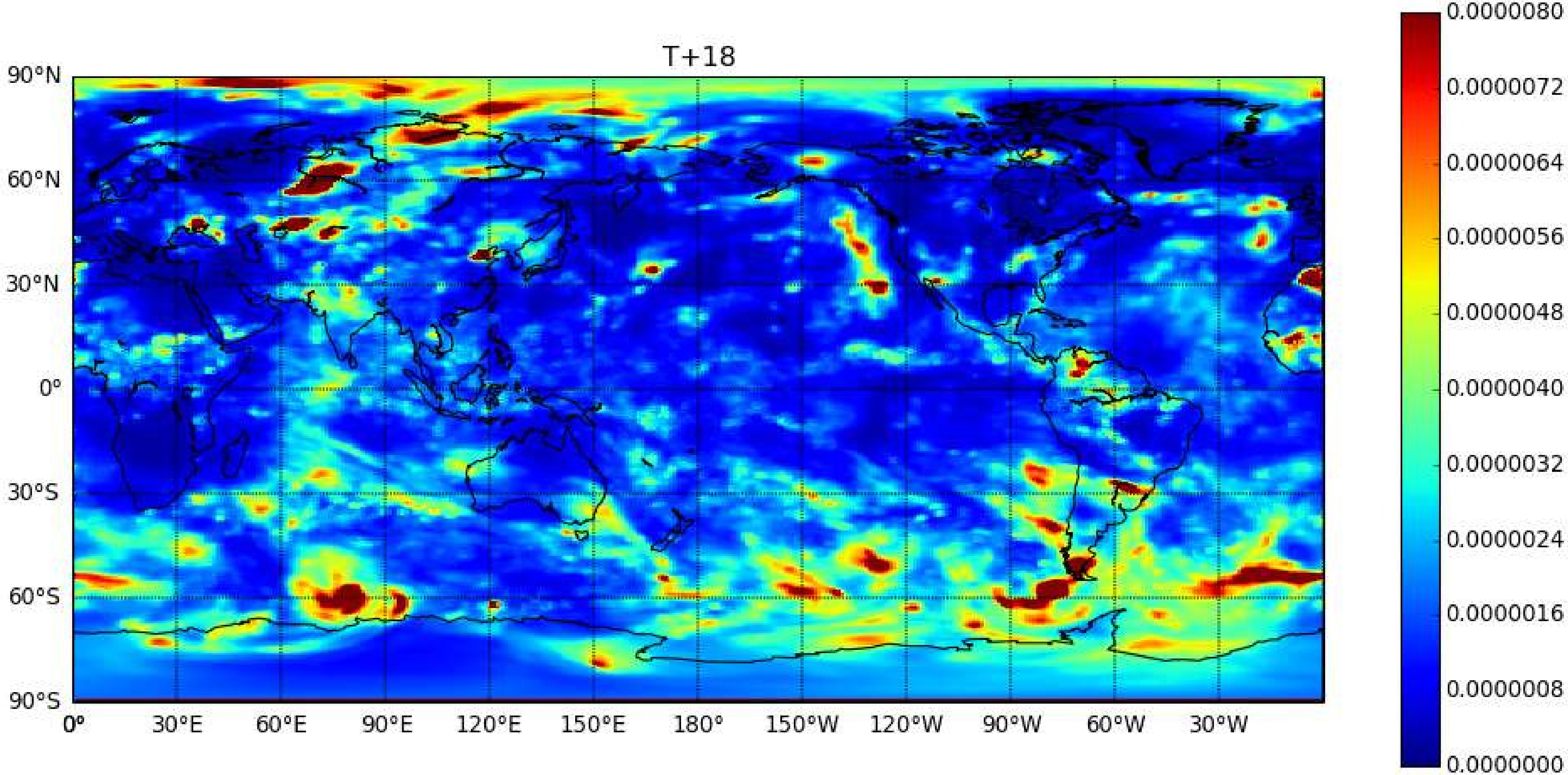

T+14
90°N
60°N
30°N
0°
30°S
60°S
90°S
0°
30°E
60°E
90°E
120°E
150°E
180°
150°W
120°W
90°W
60°W
30°W
0.0000080
0.0000072
0.0000064
0.0000056
0.0000048
0.0000040
0.0000032
0.0000024
0.0000016
0.0000008
0.0000000


T+15
90°N
60°N
30°N
0°
30°S
60°S
90°S
0°
30°E
60°E
90°E
120°E
150°E
180°
150°W
120°W
90°W
60°W
30°W
0.0000080
0.0000072
0.0000064
0.0000056
0.0000048
0.0000040
0.0000032
0.0000024
0.0000016
0.0000008
0.0000000

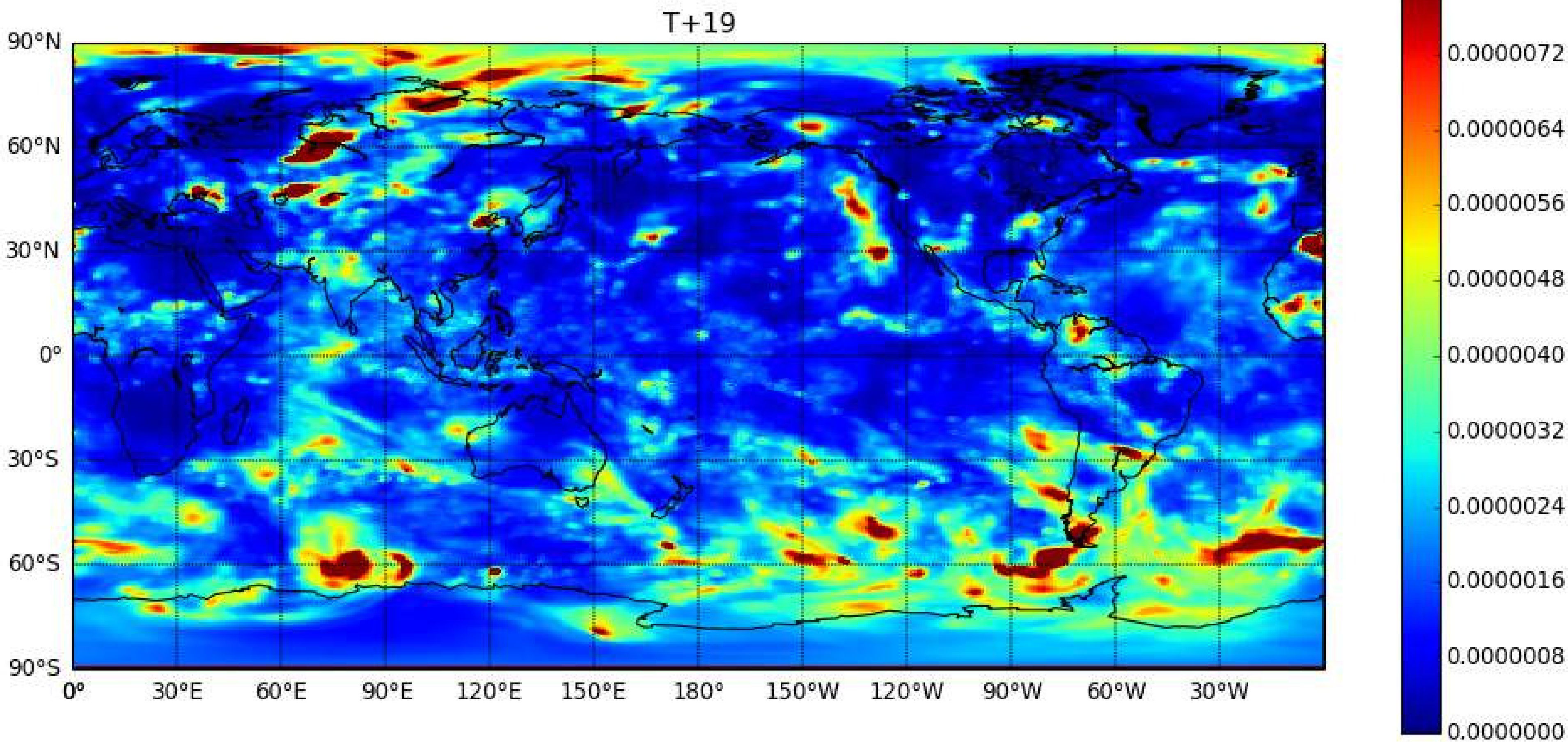

T+16
90°N
60°N
30°N
0°
30°S
60°S
90°S
0°
30°E
60°E
90°E
120°E
150°E
180°
150°W
120°W
90°W
60°W
30°W
0.0000080
0.0000072
0.0000064
0.0000056
0.0000048
0.0000040
0.0000032
0.0000024
0.0000016
0.0000008
0.0000000

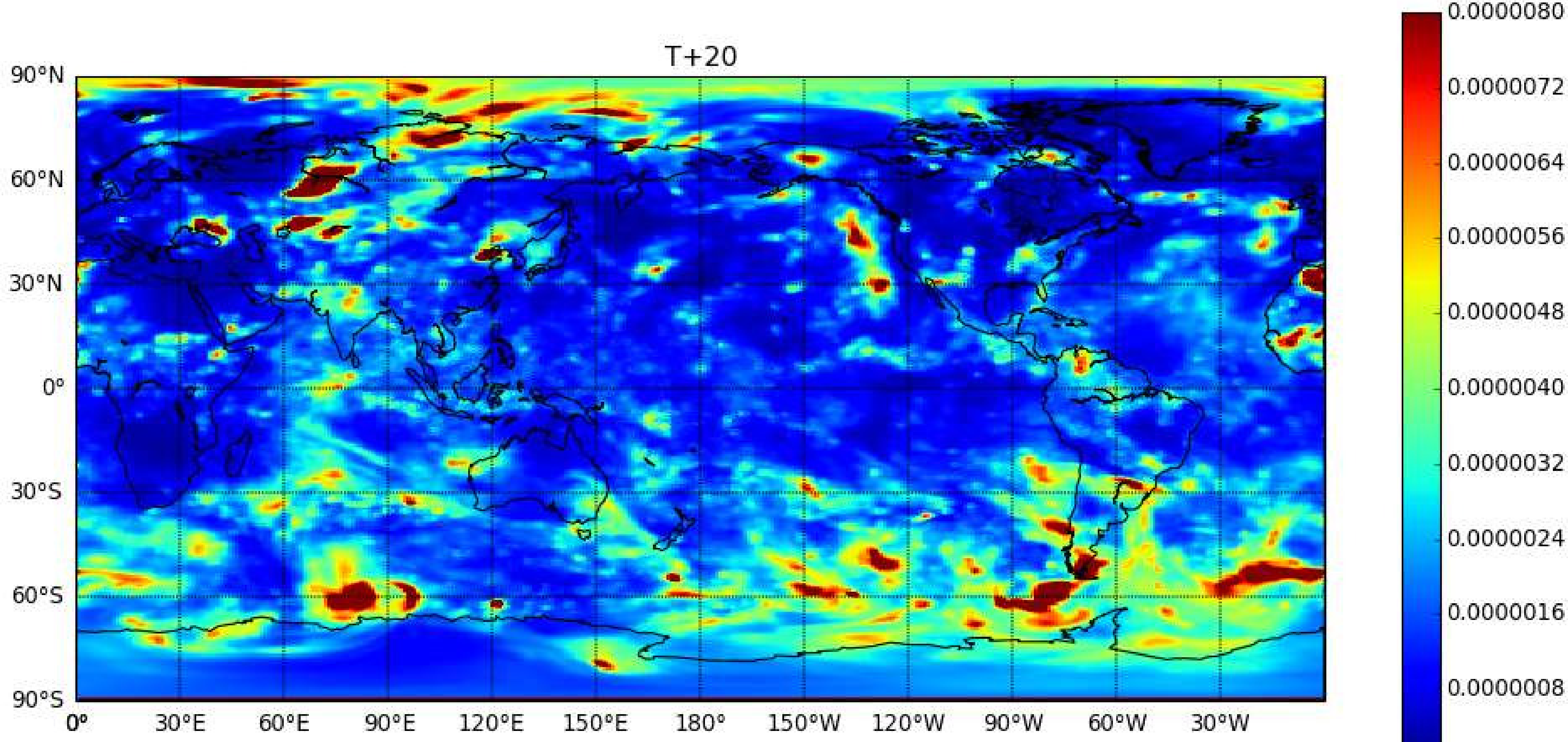


T+17
90°N
60°N
30°N
0°
30°S
60°S
90°S
0°
30°E
60°E
90°E
120°E
150°E
180°
150°W
120°W
90°W
60°W
30°W
0.0000080
0.0000072
0.0000064
0.0000056
0.0000048
0.0000040
0.0000032
0.0000024
0.0000016
0.0000008
0.0000000

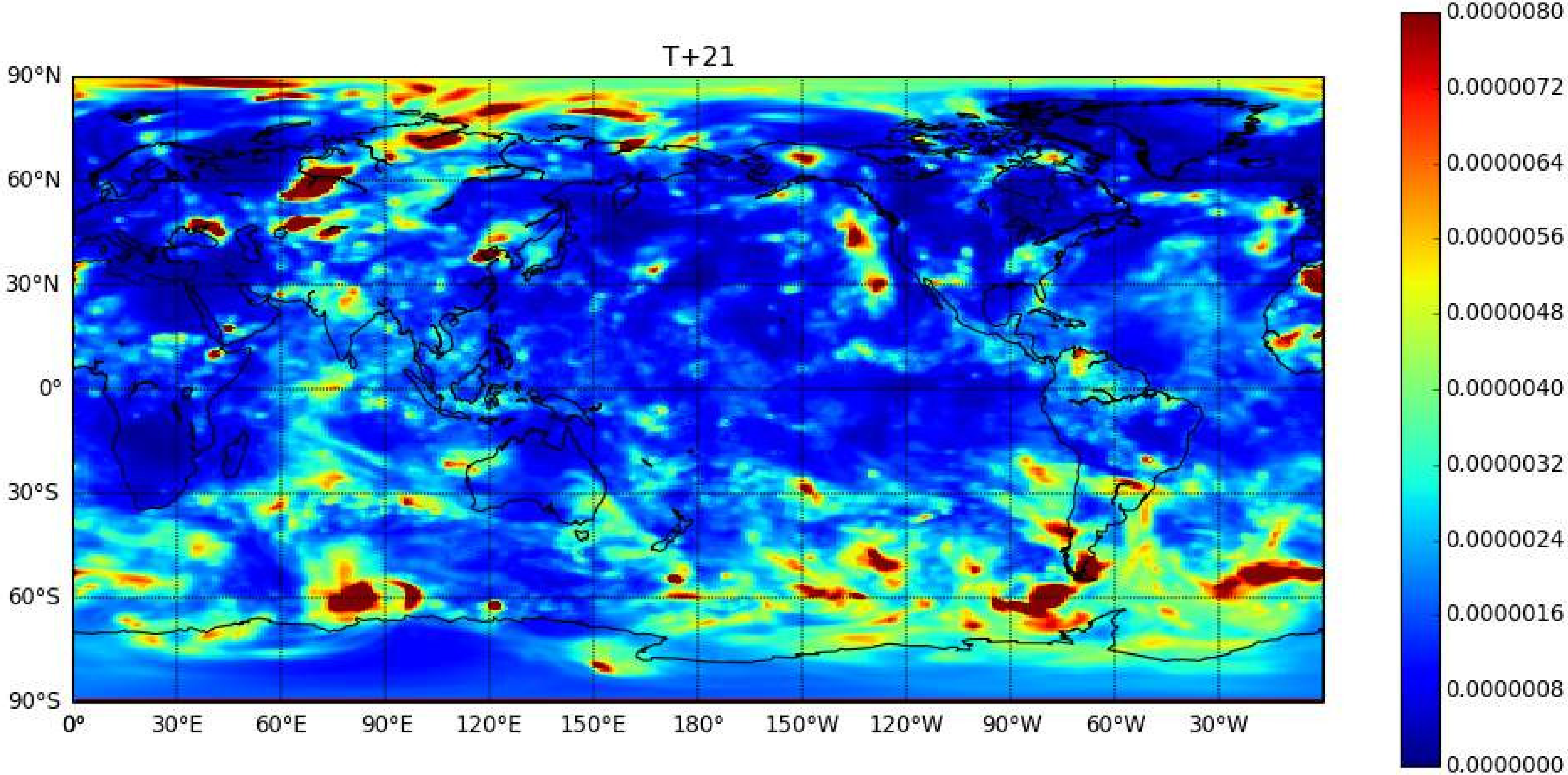


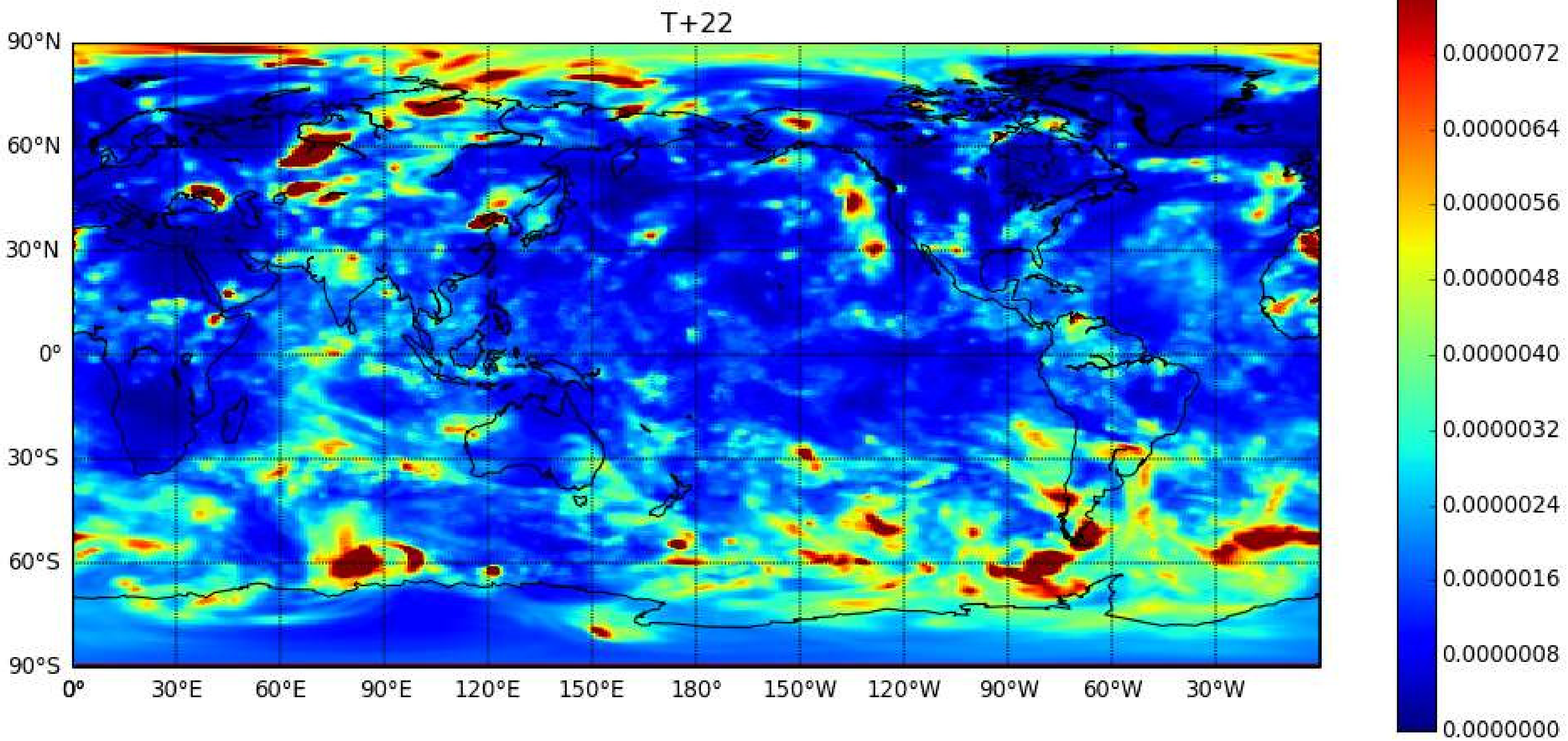
T+18
90°N
60°N
30°N
0°
30°S
60°S
90°S
0°
30°E
60°E
90°E
120°E
150°E
180°
150°W
120°W
90°W
60°W
30°W
0.0000080
0.0000072
0.0000064
0.0000056
0.0000048
0.0000040
0.0000032
0.0000024
0.0000016
0.0000008
0.0000000

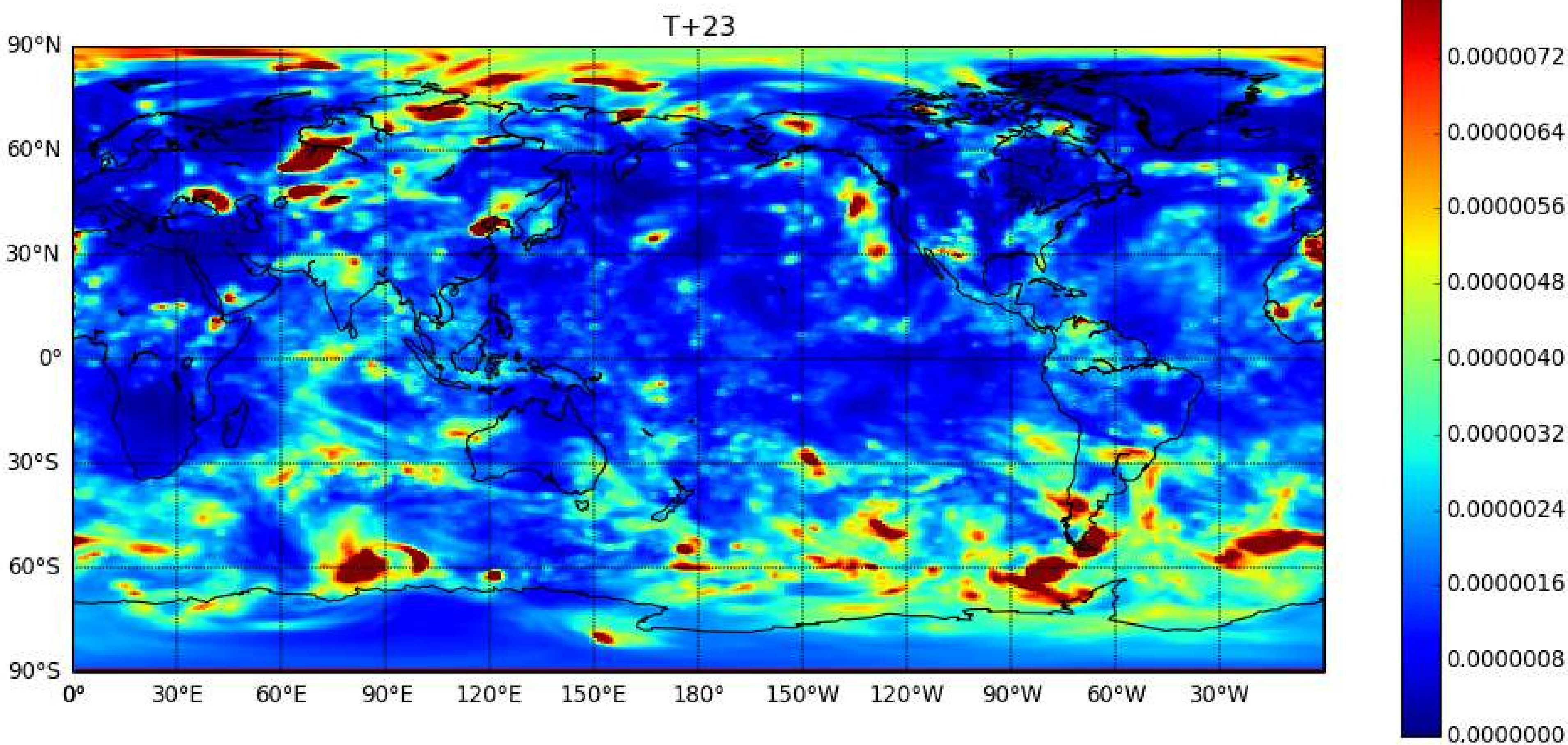

T+19
90°N
60°N
30°N
0°
30°S
60°S
90°S
0°
30°E
60°E
90°E
120°E
150°E
180°
150°W
120°W
90°W
60°W
30°W
0.0000080
0.0000072
0.0000064
0.0000056
0.0000048
0.0000040
0.0000032
0.0000024
0.0000016
0.0000008
0.0000000

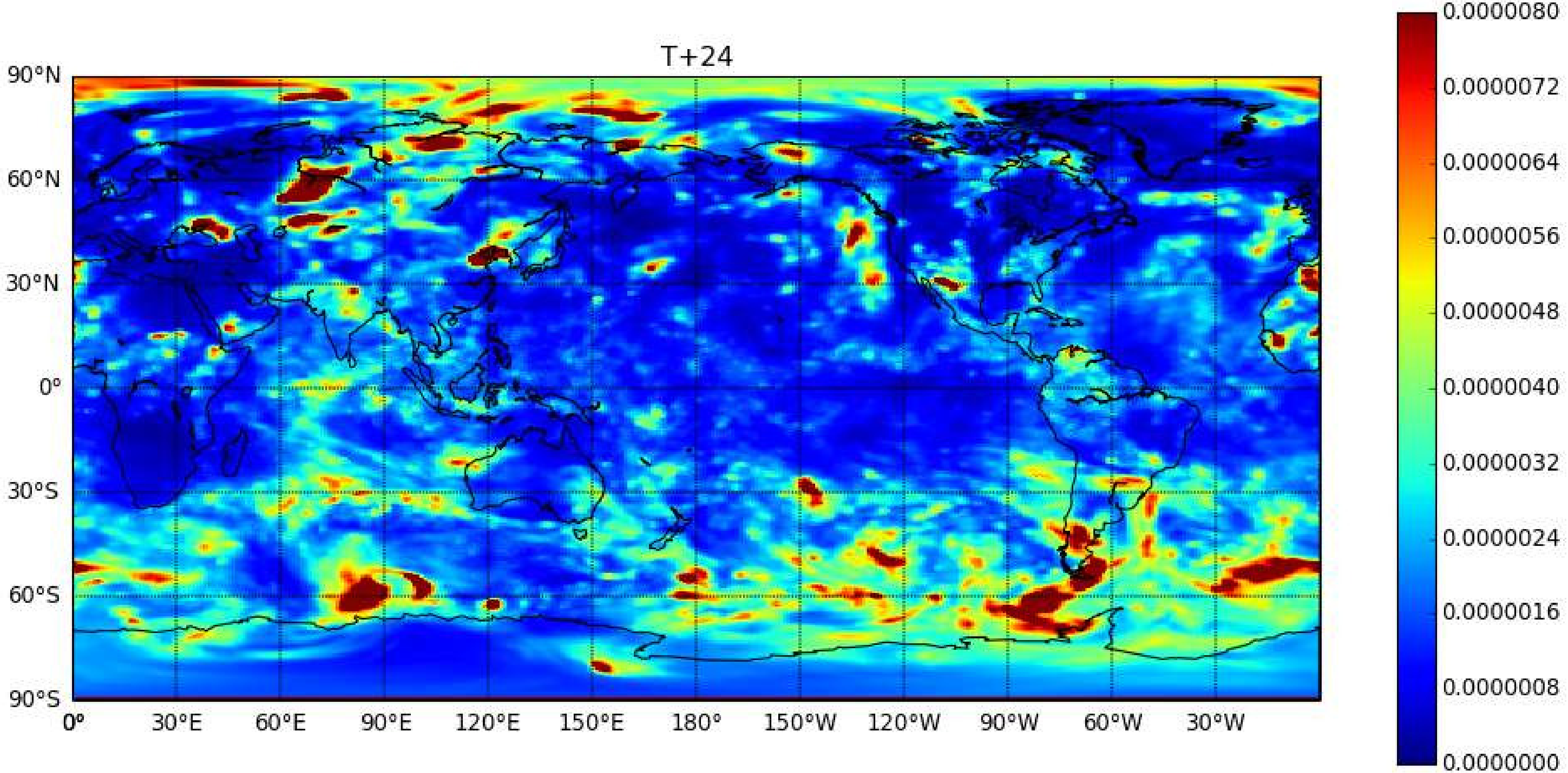


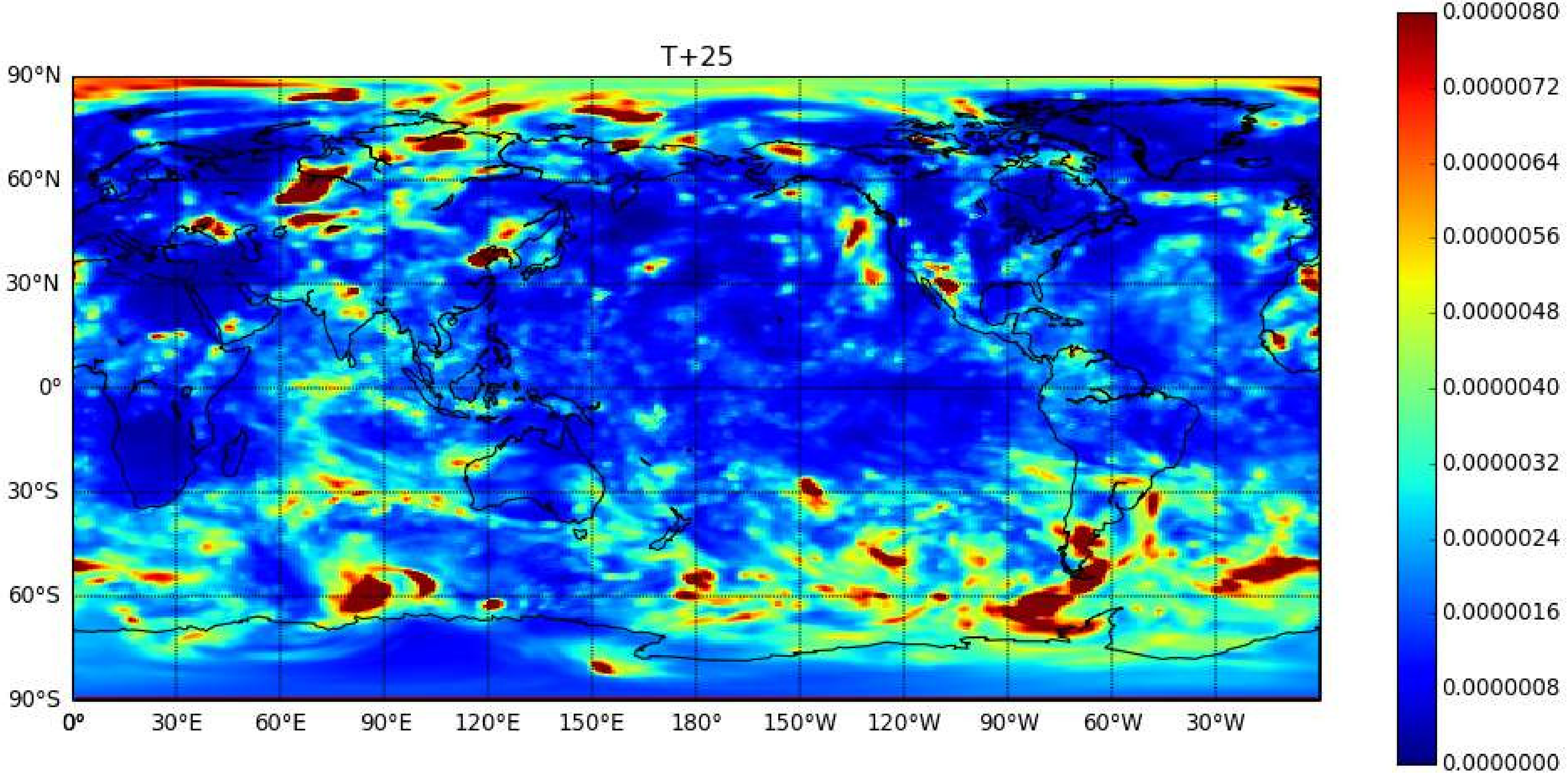
T+20
90°N
60°N
30°N
0°
30°S
60°S
90°S
0°
30°E
60°E
90°E
120°E
150°E
180°
150°W
120°W
90°W
60°W
30°W
0.0000080
0.0000072
0.0000064
0.0000056
0.0000048
0.0000040
0.0000032
0.0000024
0.0000016
0.0000008
0.0000000

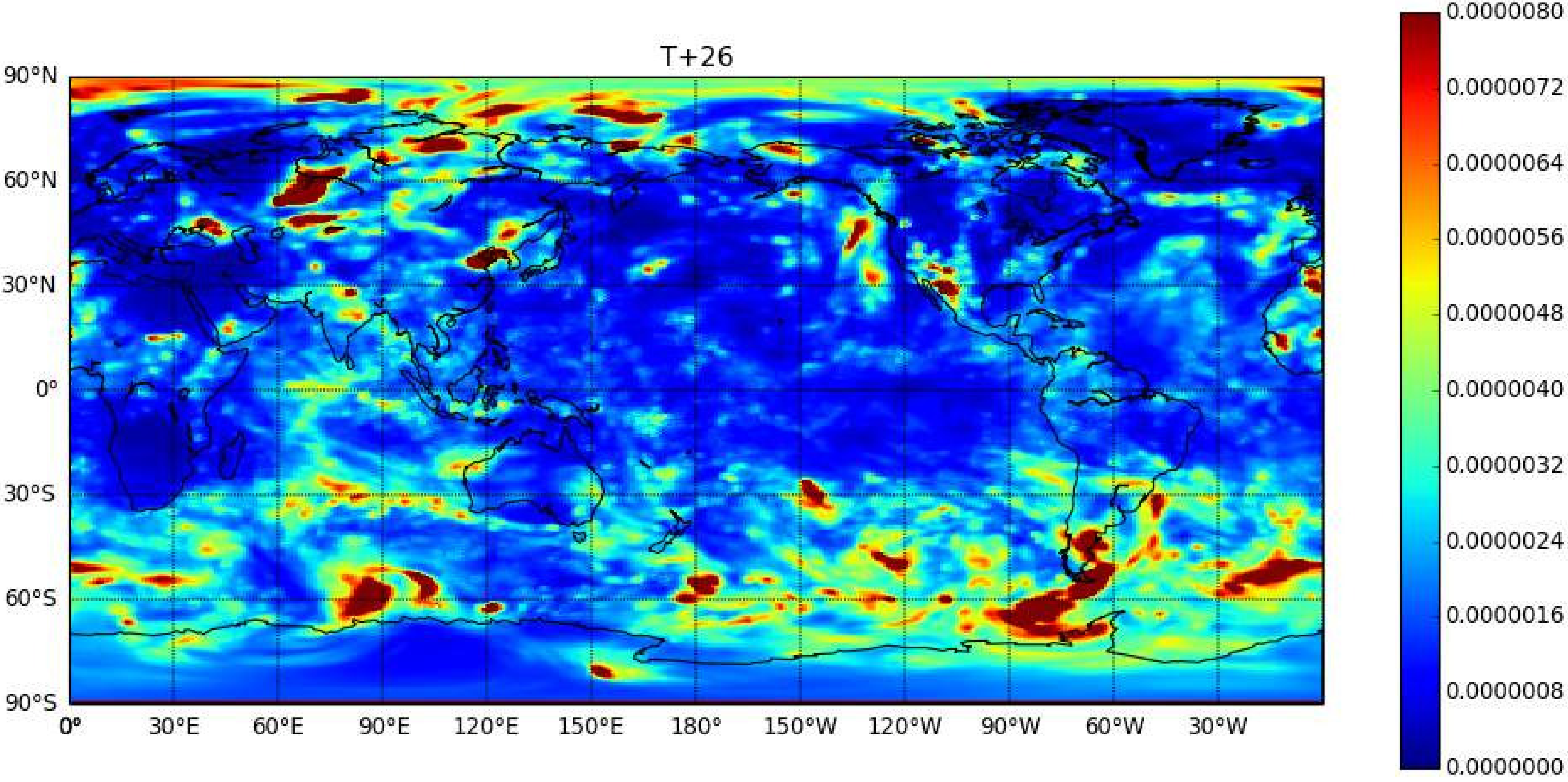

T+21
90°N
60°N
30°N
0°
30°S
60°S
90°S
0°
30°E
60°E
90°E
120°E
150°E
180°
150°W
120°W
90°W
60°W
30°W
0.0000080
0.0000072
0.0000064
0.0000056
0.0000048
0.0000040
0.0000032
0.0000024
0.0000016
0.0000008
0.0000000


T+22
90°N
60°N
30°N
0°
30°S
60°S
90°S
0°
30°E
60°E
90°E
120°E
150°E
180°
150°W
120°W
90°W
60°W
30°W
0.0000080
0.0000072
0.0000064
0.0000056
0.0000048
0.0000040
0.0000032
0.0000024
0.0000016
0.0000008
0.0000000

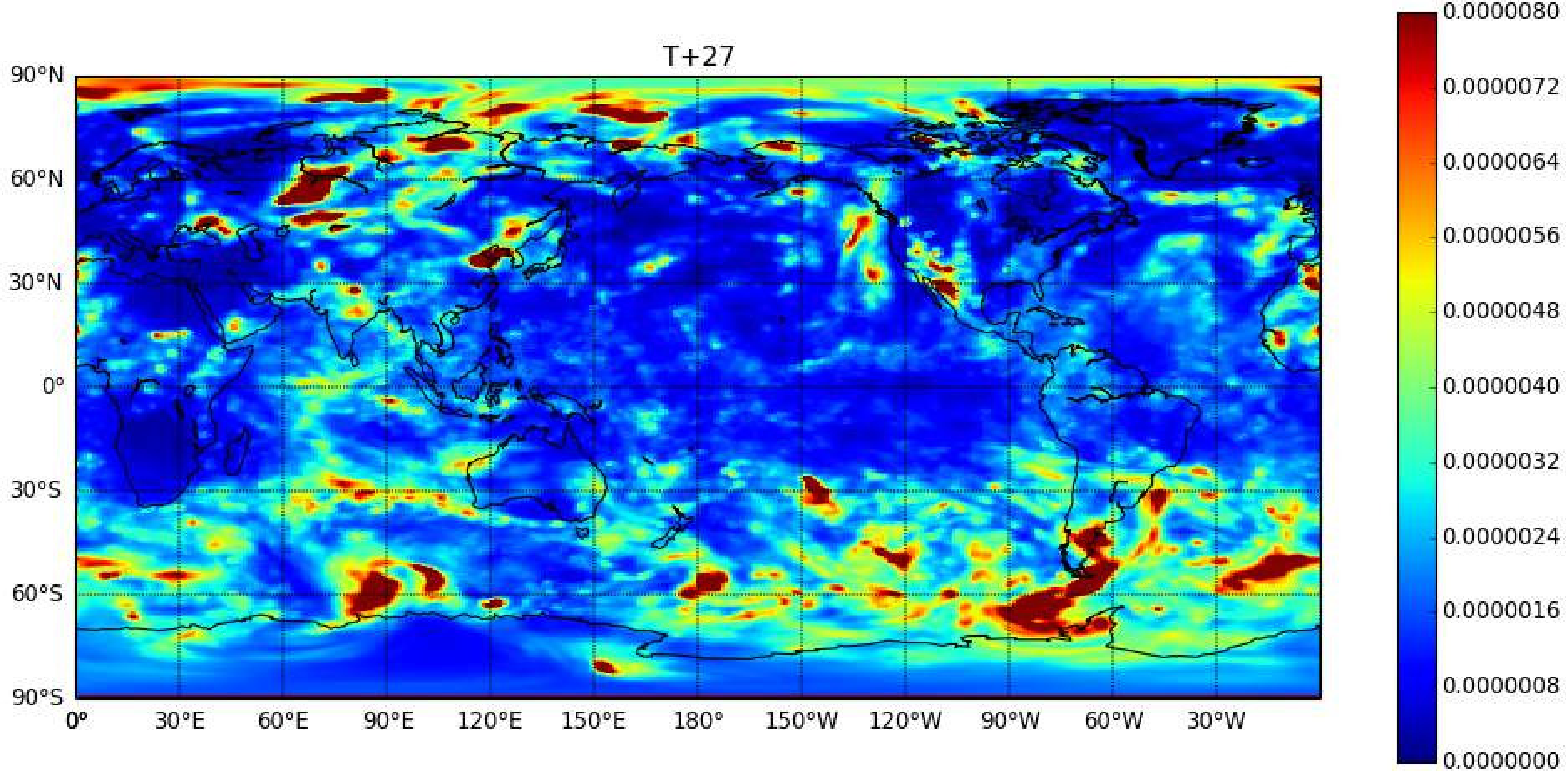

T+23
90°N
60°N
30°N
0°
30°S
60°S
90°S
0°
30°E
60°E
90°E
120°E
150°E
180°
150°W
120°W
90°W
60°W
30°W
0.0000080
0.0000072
0.0000064
0.0000056
0.0000048
0.0000040
0.0000032
0.0000024
0.0000016
0.0000008
0.0000000

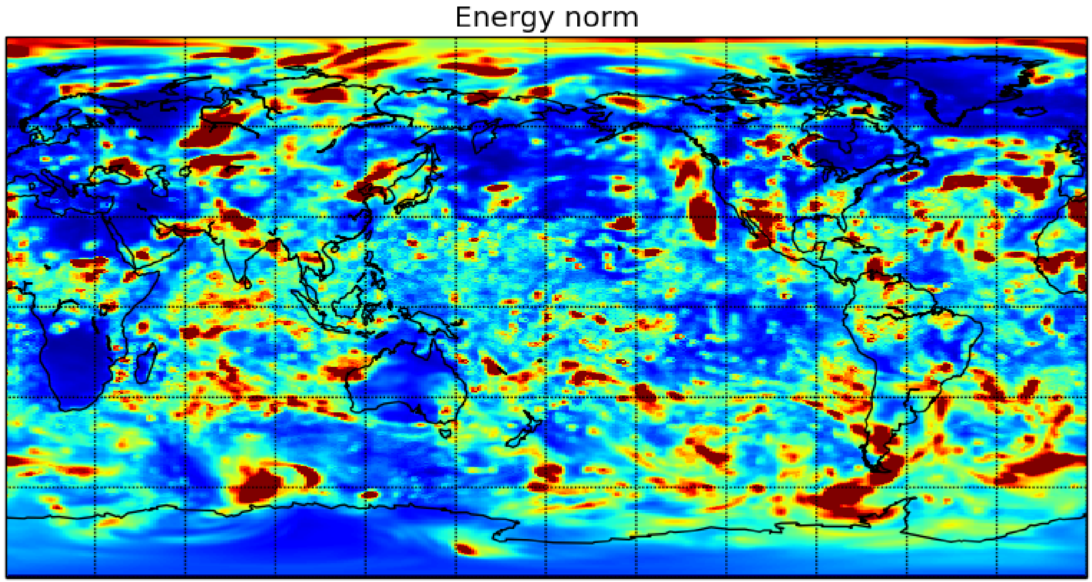

T+24
90°N
60°N
30°N
0°
30°S
60°S
90°S
0°
30°E
60°E
90°E
120°E
150°E
180°
150°W
120°W
90°W
60°W
30°W
0.0000080
0.0000072
0.0000064
0.0000056
0.0000048
0.0000040
0.0000032
0.0000024
0.0000016
0.0000008
0.0000000


T+25
90°N
60°N
30°N
0°
30°S
60°S
90°S
0°
30°E
60°E
90°E
120°E
150°E
180°
150°W
120°W
90°W
60°W
30°W
0.0000080
0.0000072
0.0000064
0.0000056
0.0000048
0.0000040
0.0000032
0.0000024
0.0000016
0.0000008
0.0000000



T+26
90°N
60°N
30°N
0°
30°S
60°S
90°S
0°
30°E
60°E
90°E
120°E
150°E
180°
150°W
120°W
90°W
60°W
30°W
0.0000080
0.0000072
0.0000064
0.0000056
0.0000048
0.0000040
0.0000032
0.0000024
0.0000016
0.0000008
0.0000000

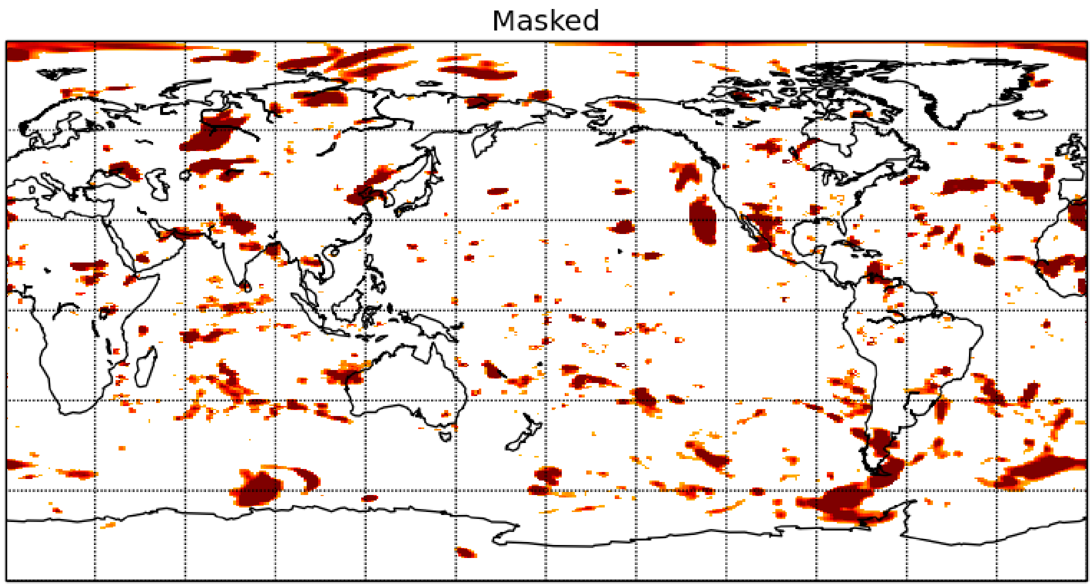

T+27
90°N
60°N
30°N
0°
30°S
60°S
90°S
0°
30°E
60°E
90°E
120°E
150°E
180°
150°W
120°W
90°W
60°W
30°W
0.0000080
0.0000072
0.0000064
0.0000056
0.0000048
0.0000040
0.0000032
0.0000024
0.0000016
0.0000008
0.0000000



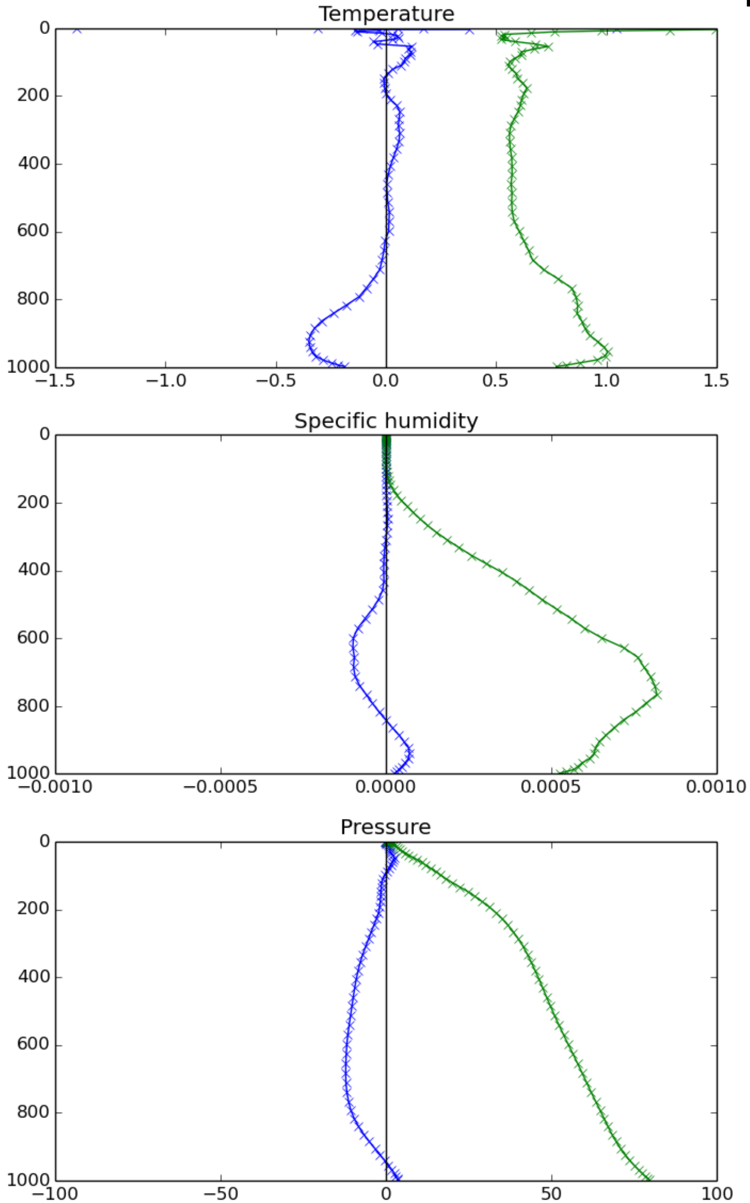
This is the mask for a **T+25h** forecast using the grid-points which have the largest energy norm values. In this case, the **top 10%**.

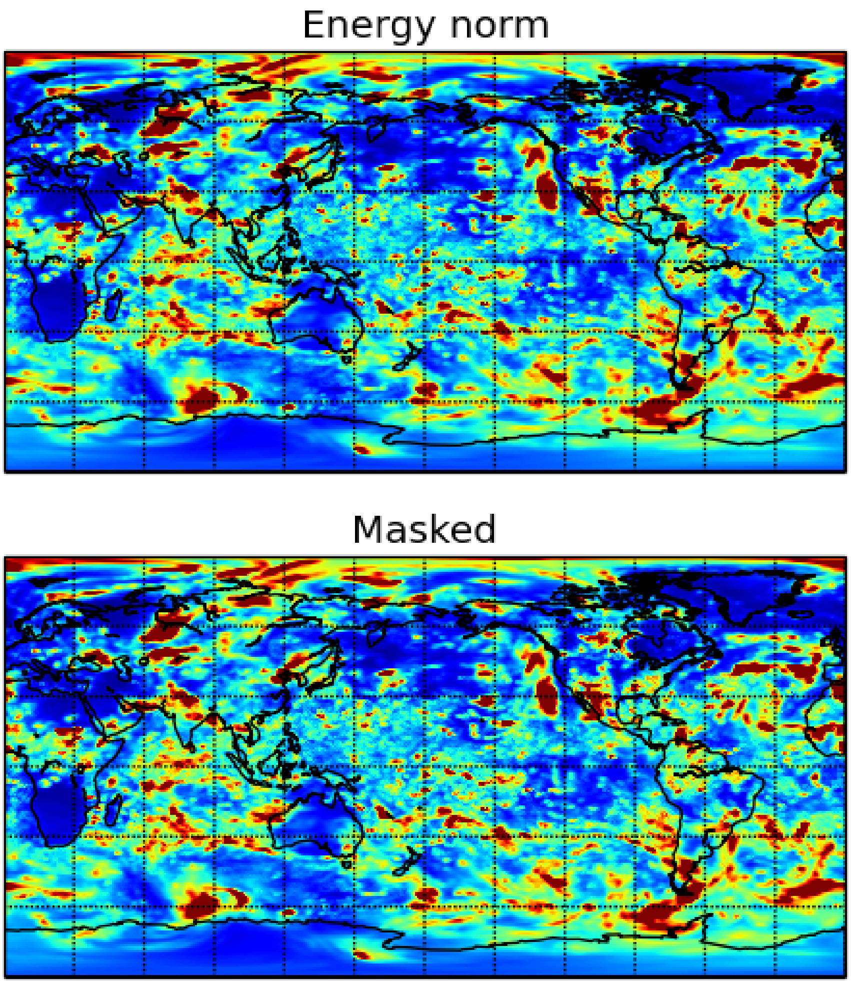
The verification plots that follow are **T+25h** mean and RMS error vs 'analysis' (T+1h forecast from next cycle).

Vertical coordinate is exponential pressure (just to avoid pressure->height conversion).

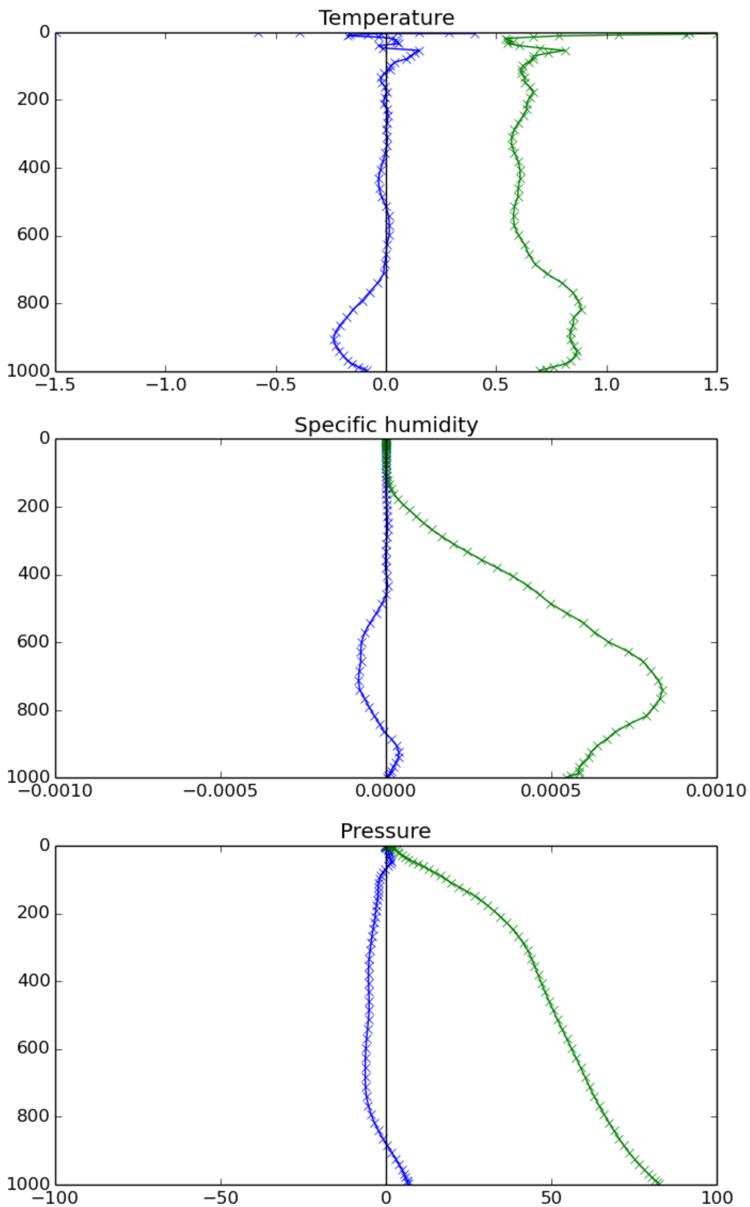


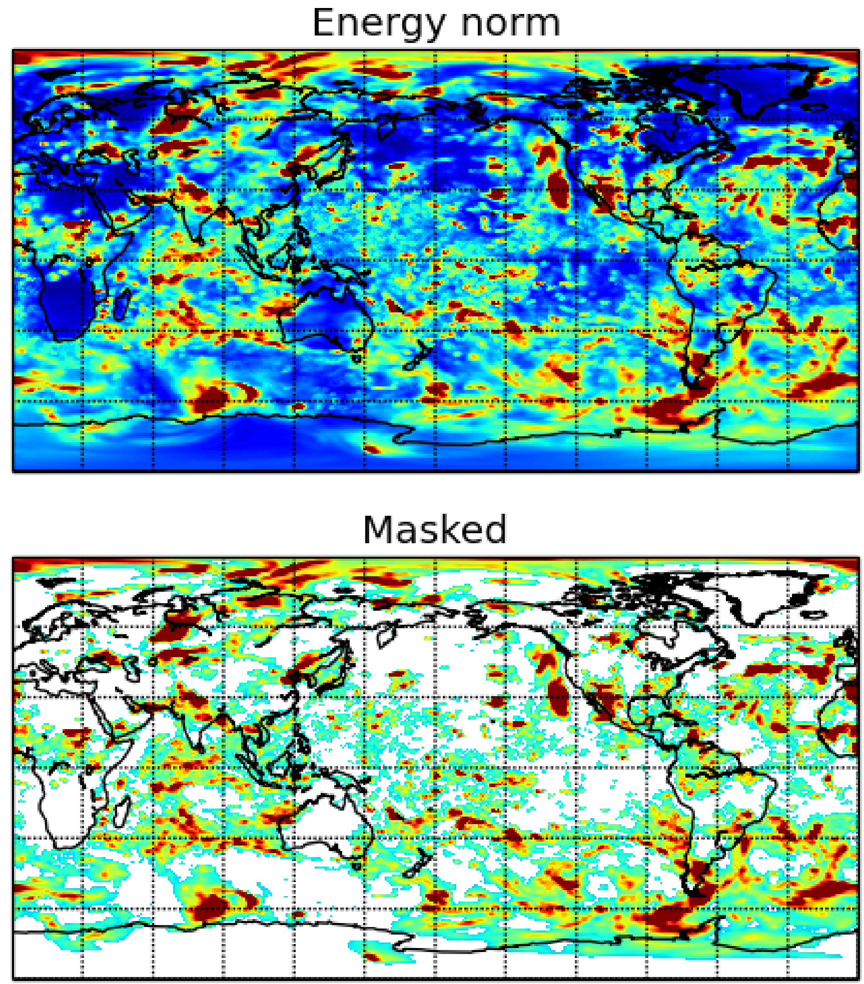
100%


Temperature
0
200
400
600
800
1000
−1.5
−1.0
−0.5
0.0
0.5
1.0
1.5
Specific humidity
0
200
400
600
800
1000
−0.0010
−0.0005
0.0000
0.0005
0.0010
Pressure
0
200
400
600
800
1000
−100
−50
0
50
100

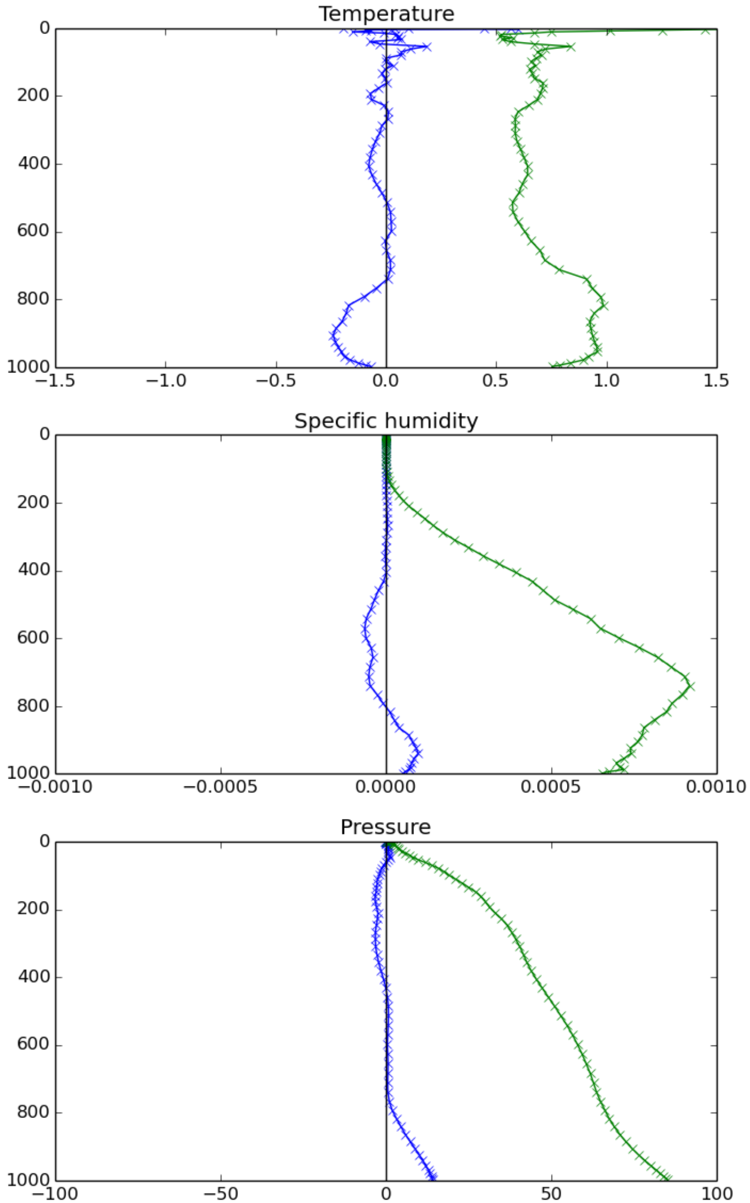

Energy norm
Masked

50%

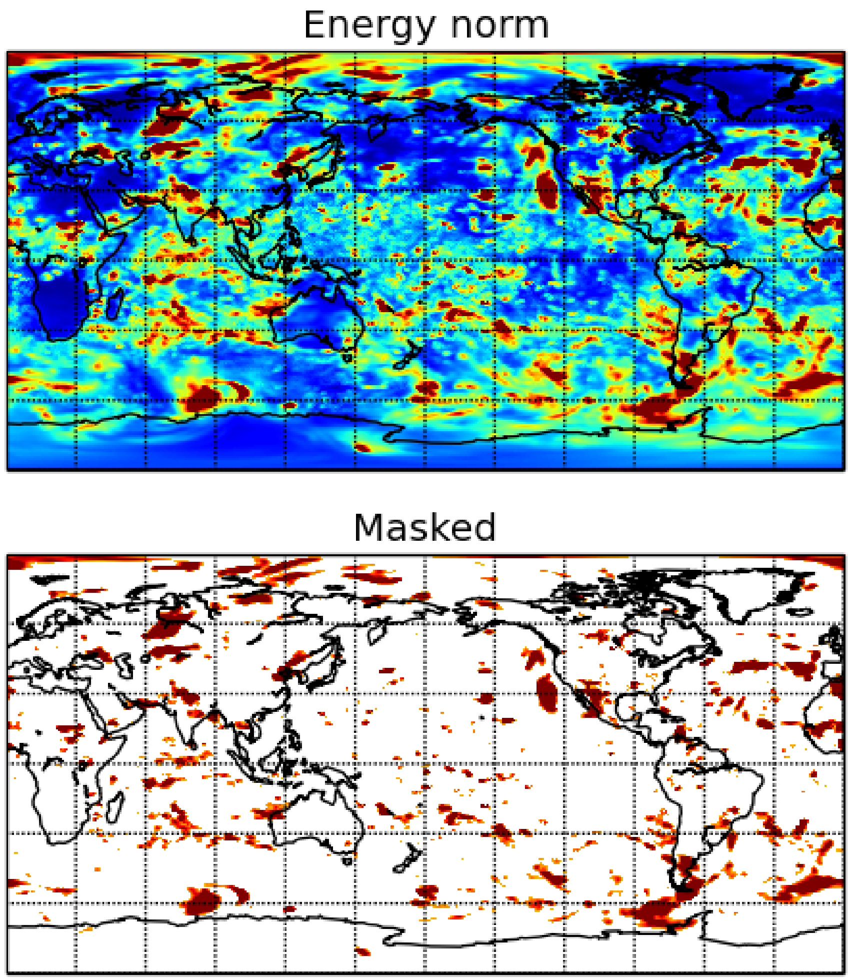

Temperature
0
200
400
600
800
1000
−1.5
−1.0
−0.5
0.0
0.5
1.0
1.5
Specific humidity
0
200
400
600
800
1000
−0.0010
−0.0005
0.0000
0.0005
0.0010
Pressure
0
200
400
600
800
1000
−100
−50
0
50
100


Energy norm
Masked

10%

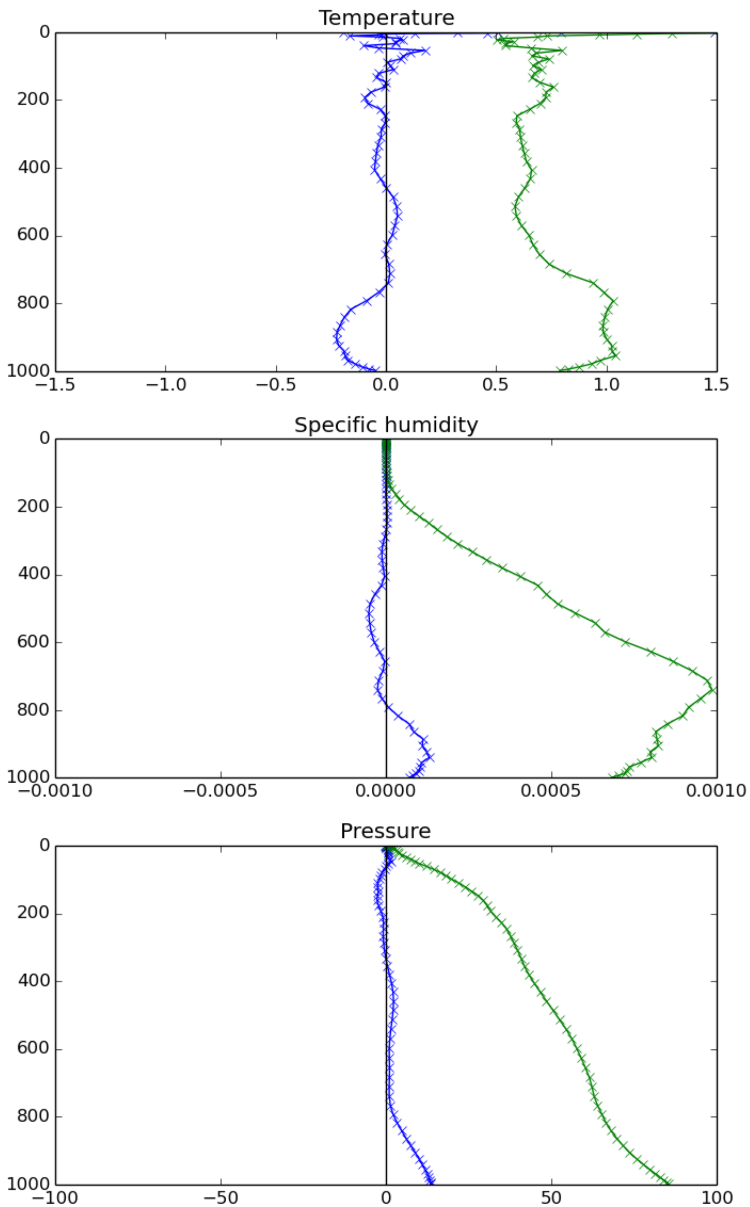


Temperature
0
200
400
600
800
1000
−1.5
−1.0
−0.5
0.0
0.5
1.0
1.5
Specific humidity
0
200
400
600
800
1000
−0.0010
−0.0005
0.0000
0.0005
0.0010
Pressure
0
200
400
600
800
1000
−100
−50
0
50
100

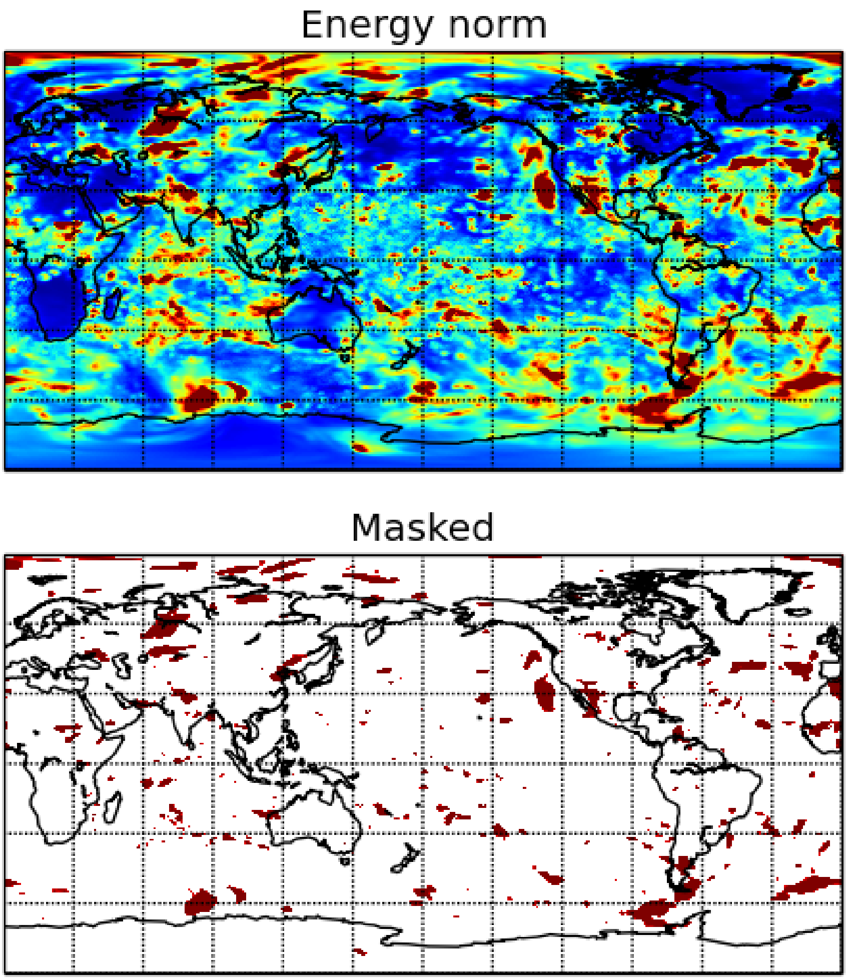


Energy norm
Masked

5%



Temperature
0
200
400
600
800
1000
−1.5
−1.0
−0.5
0.0
0.5
1.0
1.5
Specific humidity
0
200
400
600
800
1000
−0.0010
−0.0005
0.0000
0.0005
0.0010
Pressure
0
200
400
600
800
1000
−100
−50
0
50
100

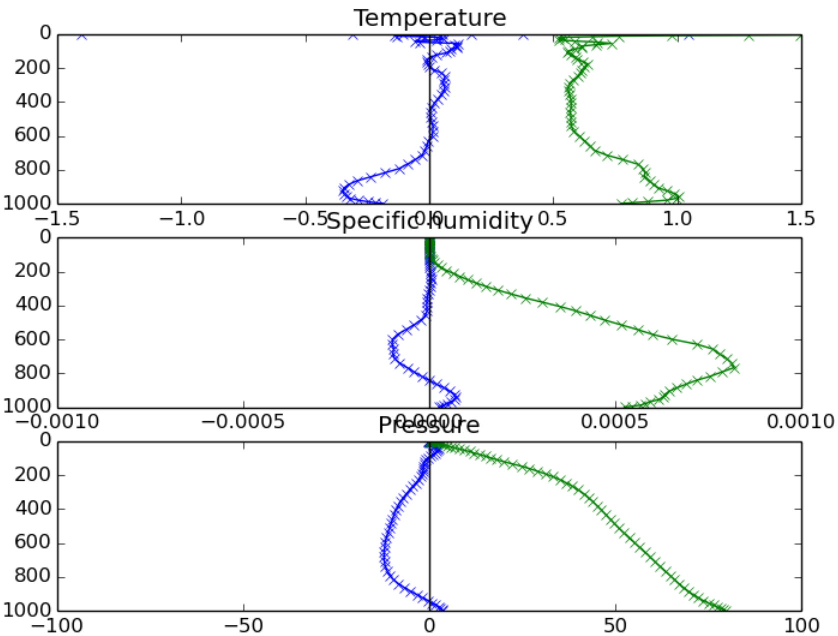


Energy norm
Masked

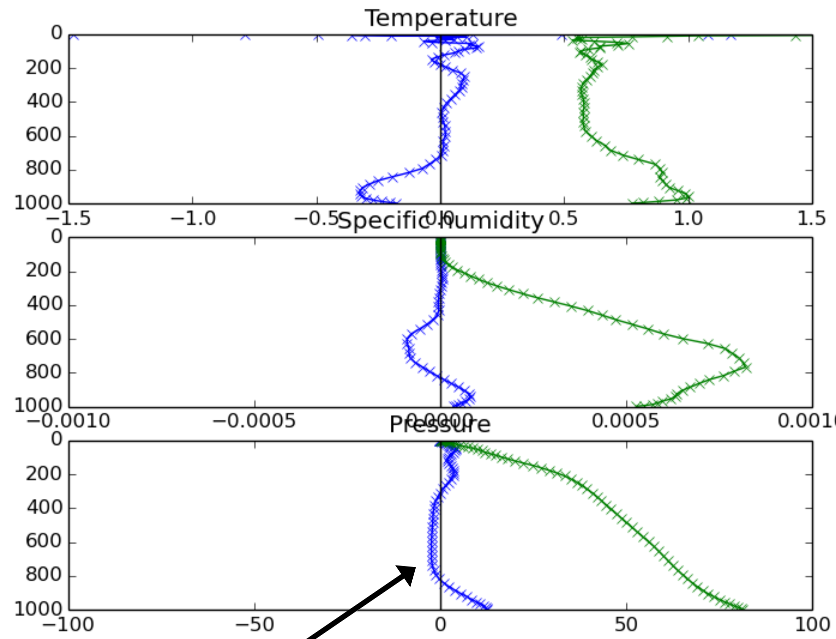
RO data denial experiment for one cycle...

100% of grid points

All obs



No RO

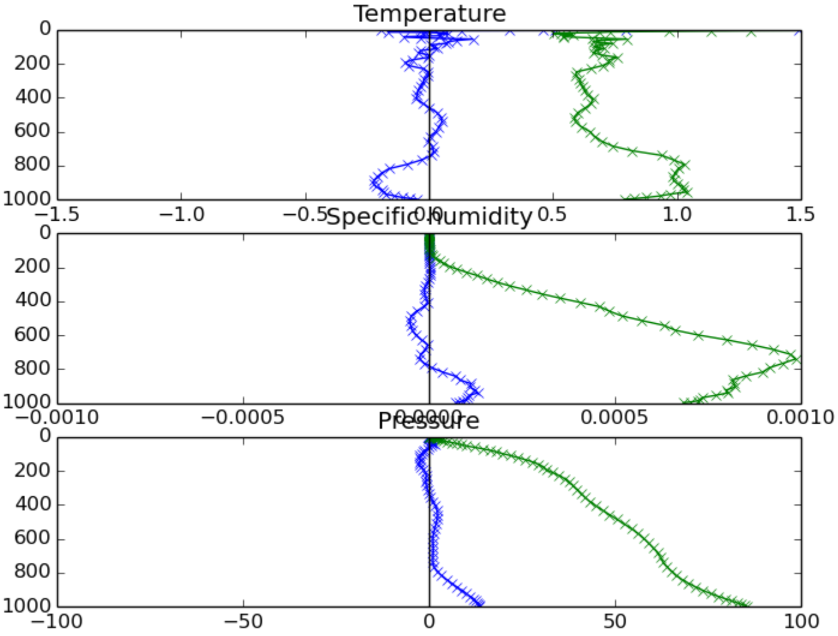


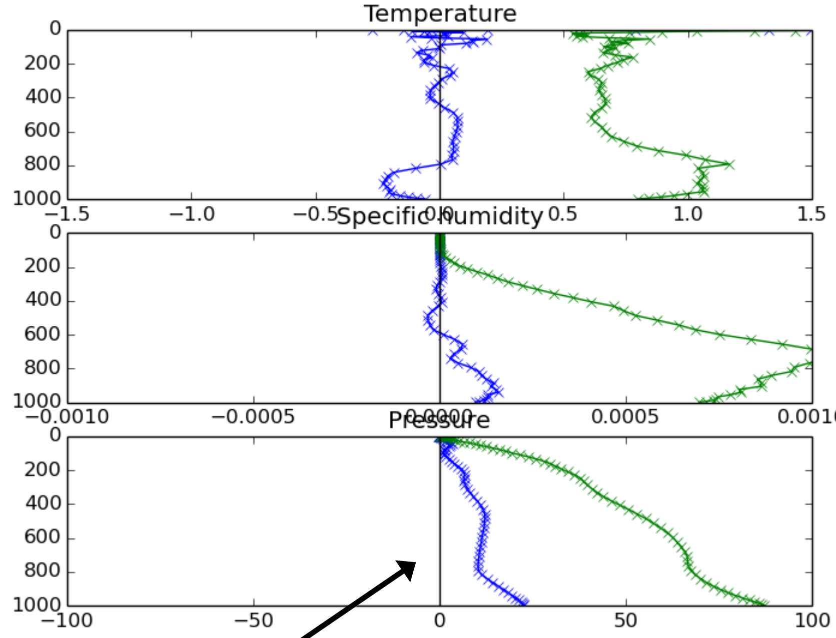
Rejecting RO reduces pressure bias???

5% of grid points

All obs

No RO





When RO is removed the bias is increased where FC difference is largest.

Future plans:

- Run this for more than one cycle.
- Use it to better assess changes such as TPD.
- Extend it to work for any model/DA change.
- If successful, recommend for routine use.

Met Office

Summary

Tangent point drift and the improved bending angle operator have been implemented in the Met Office global model.

RO has been used to assess the behaviour of VarBC in ongoing experiments.

A new verification technique has been proposed, aiming to amplify the signal in RO (and other) forecast impact experiments.

Thanks to Sean Healy, Ian Culverwell, James Cameron and several others at the Met Office and in the ROM SAF.

Possible topics for the NWP Subgroup

Met Office

Current/future missions:

1) Support for COSMIC-2 (polar).
2) Support for GNOS on FY-3{C,D,E,F,G}. This series runs from 2013-2027. Quality looks promising.
3) GRAS – provision of wave optics data.
4) Other missions, e.g. KOMPSAT-5.

Emphasis on:

1) Space weather.
2) Tropospheric humidity information.

Met Office

Data processing:

Vertically correlated bending angle errors:

These are increased in the recent UCAR dataset (priv. comm. Harald Anlauf), and the reprocessed GRAS data (priv. comm. Sean Healy), *despite reduced standard deviations* in both cases.

Bending angles are attractive for assimilation because the error correlations are significantly smaller than for refractivity, so we can treat the observations independently and implement, for example, tangent point drift.

Some caution is probably required here, even if initial assimilation experiments look promising.

Met Office

BUFR (thanks to Harald Anlauf and Dave Offiler for input):

The BUFR template for RO is generic, and this has led to different interpretations by the processing centres. Should the community agree on stricter guidelines (UW5-NWP16)? E.g.

- Standard set of vertical levels?
- Fixed definition of azimuth, occultation point, time of positions/velocities, etc.

Should we recommend the following to be a requirement?:

- L1/L2 bending angles

Also we should start looking ahead to possible direct use of:

- Ionospheric parameters
- Excess phase

Most of this can be covered by specifying requirements in the ROM SAF BUFR document or clarifying ‘notes’ in the WMO tables, but the last two will probably require an **additional** BUFR template for the new RO-specific element descriptors.

Met Office

Questions and answers