

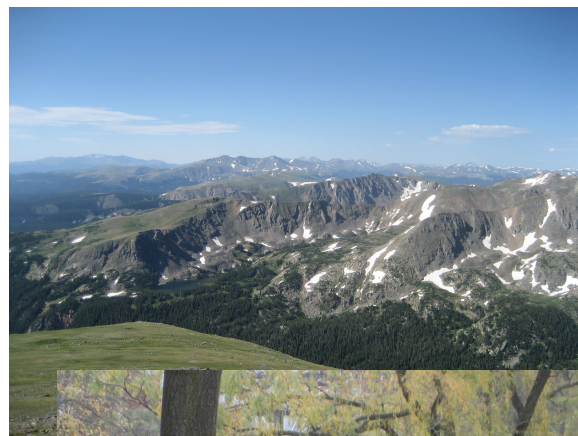
Spatial Forecast Verification: The Image Warp



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Background

Objective

Deform the forecast field, F , to better match the observed field, O .

Calculate measures of forecast performance based on:

- (i) the original field,
- (ii) the amount of displacement, and
- (iii) the improvement in performance of the deformed forecast over the original.

Background

Literature

Among the earliest spatial forecast verification methods:

Polynomial Image Warping

Dickinson and Brown (1996); Alexander et al. (1999)

Other

Nehrkorn et al. (2003)

More recently:

Optical Flow (or similar)

Marzban et al. (2009a,b); Keil and Craig (2007, 2009)

Field Deformation Methods result in a vector field describing an *optimal* deformation of the forecast that better compares with the observed field.

Image Warp Methodology

The image warp:

A likelihood function is used to find the optimal warp function (among a class of warp functions).

$$\tilde{F}(x, y) = F(\mathbf{W}(x, y)) = F(W_1(x, y), W_2(x, y)),$$

where $\mathbf{W}(x, y)$ maps coordinates from the undeformed image, F , to the deformed image, \tilde{F} .

Methodology

Many choices for \mathbf{W} . A few popular choices.

- polynomials
- thin-plate splines
- B-splines

Motivation

For computational concerns, use control points, \mathbf{p}^F and \mathbf{p}^O , to determine the warp.

Introduce *log*-likelihood to measure dissimilarity between \tilde{F} and O . This is different from measuring via a forecast verification score!

$$\log p(O|F, \mathbf{p}^F, \mathbf{p}^O) = h(\tilde{F}, O) \quad (1)$$

where choice of error likelihood h depends on the forecast variable.

Methodology

Must penalize non-physical warps!

Introduce a smoothness prior for the warps

Behavior determined by the control points. Assume \mathbf{p}^O are fixed and apriori *known*, in order to reduce the prior on the warping function to $p(\mathbf{p}^F | \mathbf{p}^O)$.

$$p(\mathbf{p}^F | O, F, \mathbf{p}^O) = \log p(O | F, \mathbf{p}^F, \mathbf{p}^O) p(\mathbf{p}^F | \mathbf{p}^O) \quad (2)$$

where it is assumed that \mathbf{p}^F are conditionally independent of F given \mathbf{p}^O .

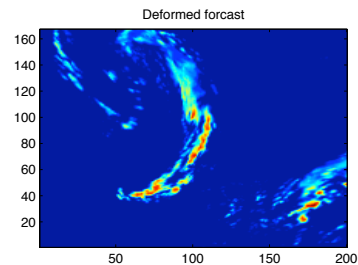
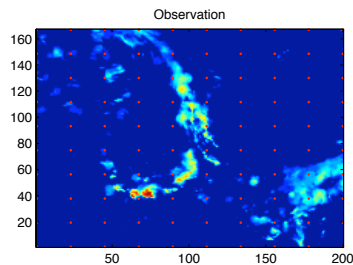
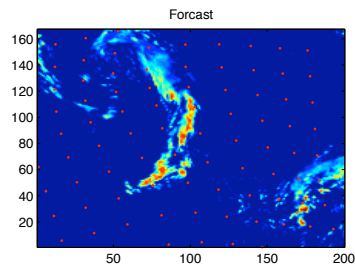
Methodology

Estimation

To find the optimal deformation (based on \mathbf{p}^F and \mathbf{p}^O), maximize the likelihood given by (2). From (1) and (2), we get

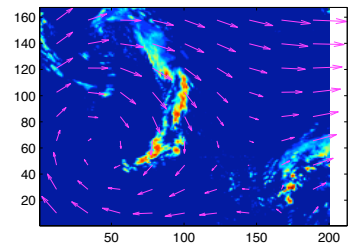
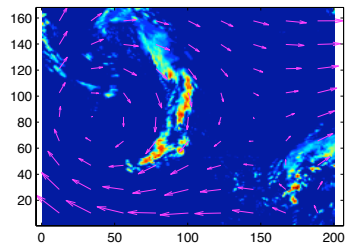
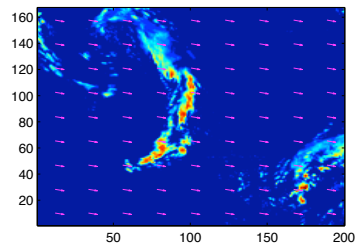
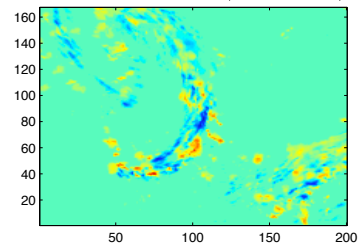
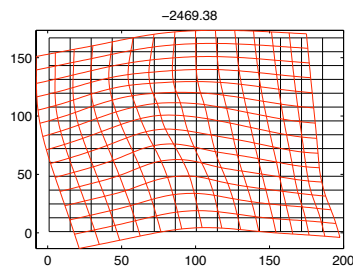
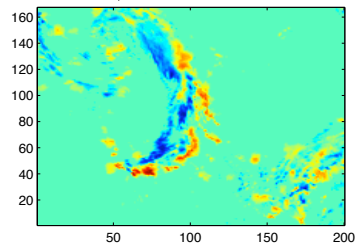
$$\begin{aligned}\ell(\mathbf{p}^F|O, F, \mathbf{p}^O) &= \log p(O|F, \mathbf{p}^F, \mathbf{p}^O) + \log p(\mathbf{p}^F|\mathbf{p}^O) \\ &= h(\tilde{F}, O) + \log p(\mathbf{p}^F|\mathbf{p}^O).\end{aligned}$$

ICP Test Cases



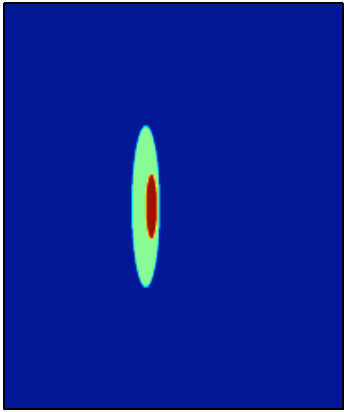
$$\text{MSE}(\text{before}) = 17,508$$

$$\text{MSE}(\text{after}) = 9,316$$

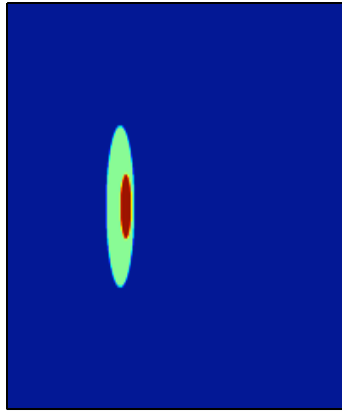


$$\frac{17,508 - 9,316}{17,508} \approx 47\%$$

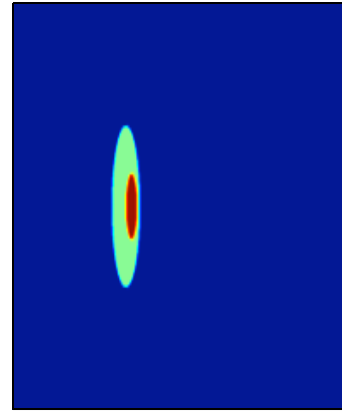
Forecast



Observation

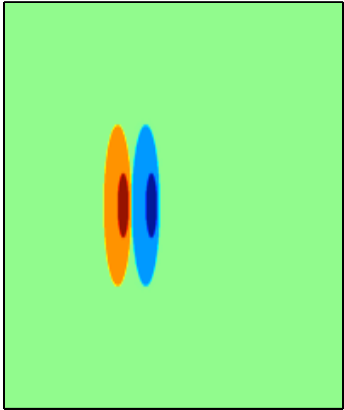
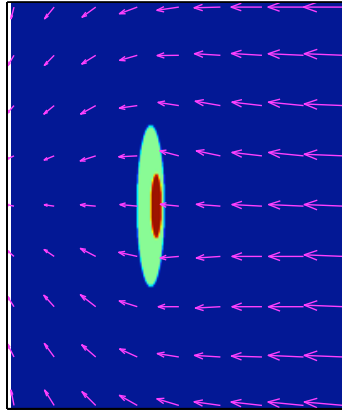


Deformed forecast



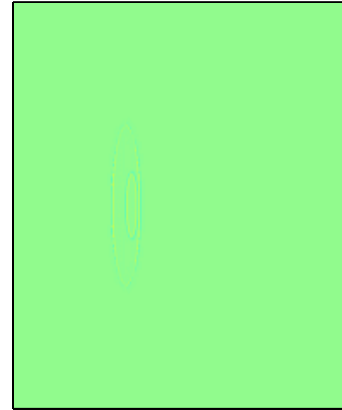
$\approx 99.8\%$ reduction in MSE.

MSE 184.71

Warp $-3.64\text{e-}002$ 

x: -16.0 y: 0.0
s_x: 0.848 s_y: 0.949

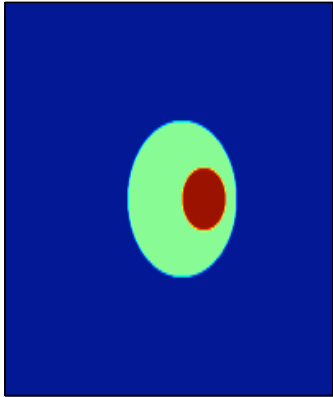
MSE 0.31



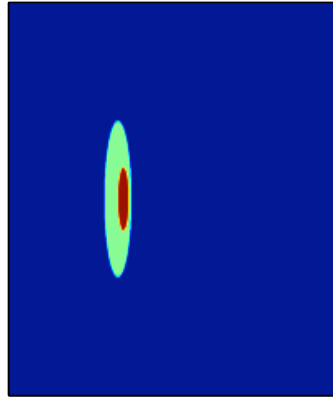
Gemoetric 1; 50 pts too far to the east

$3 \cdot (-16.0) = -48 \equiv$ Moves forecast 48 grid points to the west;
negligible re-scaling and nonlinear movement.

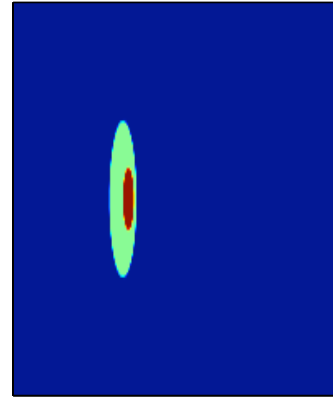
Forecast



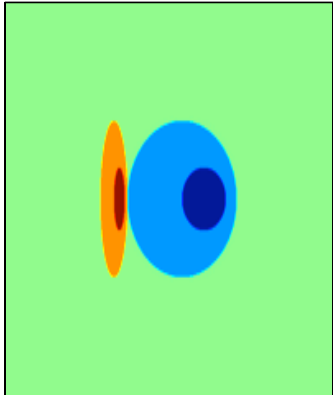
Observation



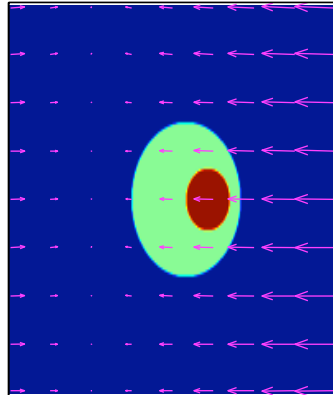
Deformed forecast



MSE 471.32

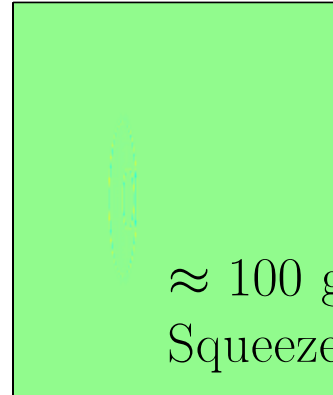


Warp $-3.39e-003$



$x: -33.3$ $y: -0.1$
 $s_x: 0.252$ $s_y: 1.029$

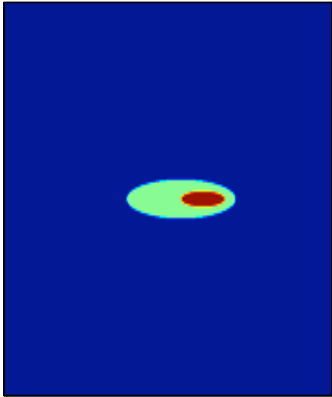
MSE 0.27



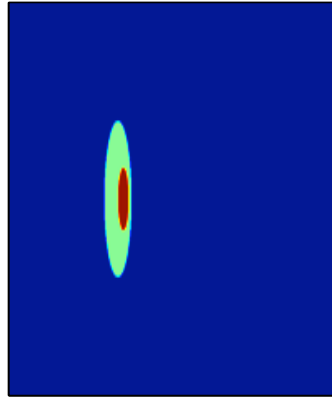
≈ 100 grid points west
 Squeezes horizontally.

Geometric 3; 125 grid points too far east and larger spatial coverage

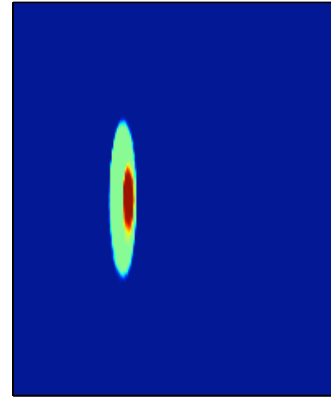
Forecast



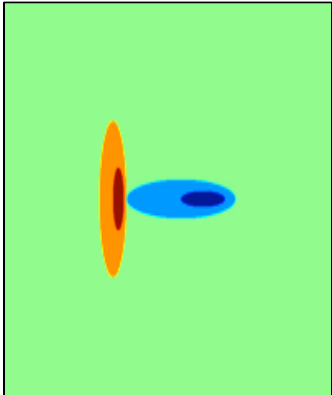
Observation



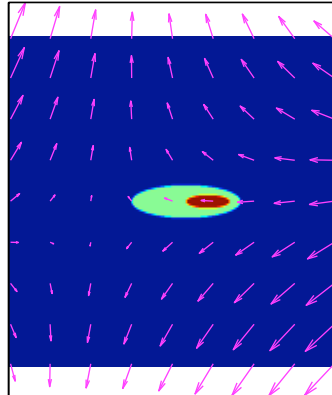
Deformed forecast



MSE 184.93

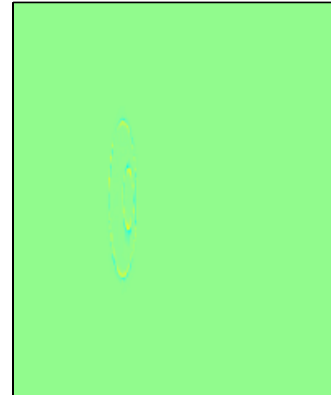


Warp $-1.88e-001$



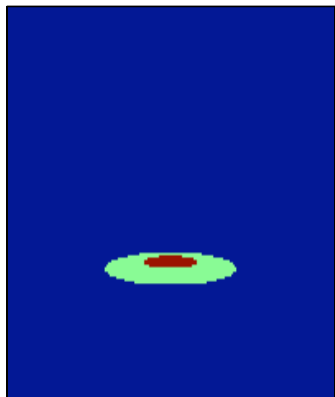
x: -31.2 y: 20.5
s_x: 0.267 s_y: 2.524

MSE 0.47

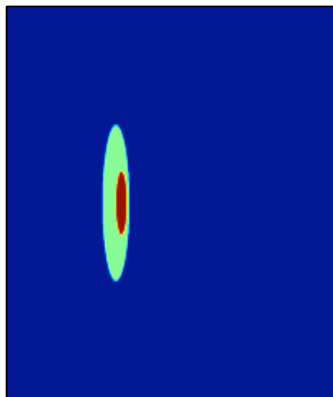


Geometric 4; 125 pts too far east and incorrect orientation

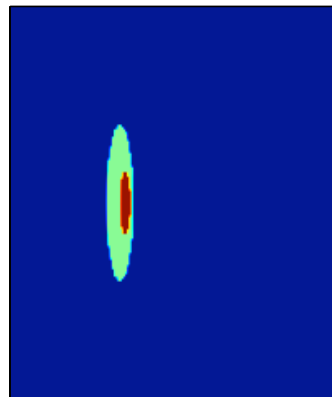
Forecast



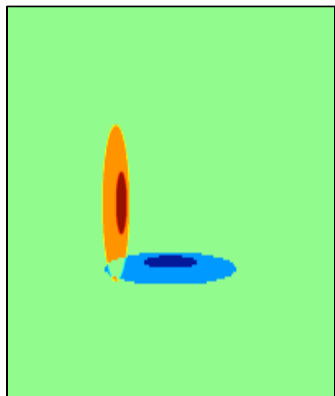
Observation



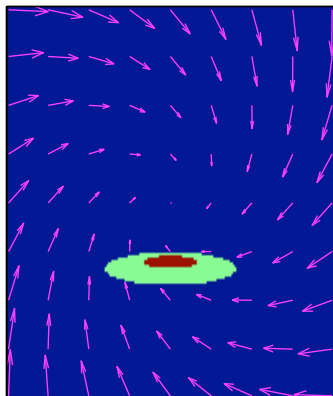
Deformed forecast



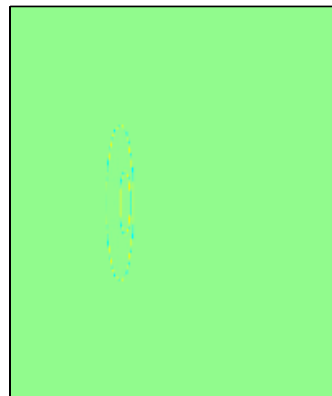
RMS 176.75



Warp $-4.35e-002$



RMS 0.82



x: -10.1 y: 0.9
s_x: 1.116 s_y: 0.781

True Rotation

Ranking of multiple forecasts: A proposed statistic

$$\text{IWS}_j = c_{1j}D_j + c_{2j}(1 - \eta_j) + c_{3j}\text{AMP}_j$$

- $j = 1, \dots, J$ indexes the forecasts being compared,
- D is the (normalized) average displacement of points,
- η represents the reduction in RMSE,
- AMP is the standardized RMSE before deformation, and
- the coefficients, $c_{.j}$ are user-specified weights that can depend on the values of each component (e.g., if D is very large, might want to ignore the first two components).

ICP perturbed cases

Perturbed *real* cases have identical shape, but displaced, and in one case (**prt006**) the amplitude has been everywhere multiplied by 1.5 mm, and another (**prt007**) has it everywhere reduced by 1.27 mm. These last two have the same spatial displacements as **prt003**, and otherwise, the x and y displacements each double with case number, beginning with 3 pts to the right and 5 pts down for case **prt001**.

IWS rank by case results:

prt001	prt002	prt003	prt004	prt005	prt006	prt007
1	2	3	5	6	7	4

Discussion, Ongoing and Future Work

- A fine line between rotations vs. re-scaling, but for real cases, does not seem to be an issue.
- Control points:
Fewer mean faster computation, but less intricate warps.
- Statistical model will allow for parametric confidence intervals.
- Could be applied to most any field
(e.g., wind vector fields, temperature, etc.)
- Extendable to multiple dimensions (time, vertical, etc.)
- Gives information about types of error:
Vector field describing the deformation has potential to give a lot of information, but a few simple statistics also yield very useful results.

That's all ...

Thank you.

Questions?

References from slides on next slide.

Test cases taken from the Spatial forecast Verification
Inter-Comparison Project (ICP)

<http://www.ral.ucar.edu/projects/icp>

References

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